Plumbing Engineering Design Handbook

A Plumbing Engineer's Guide to System Design and Specifications

VOLUME ONE

Fundamentals of Plumbing Engineering

ASPE
American Society of Plumbing Engineers™

6400 Shafer Court, Suite 350
Rosemont, IL 60018

American Society of Plumbing Engineers

Plumbing Engineering Design Handbook

51 Chapters in 4 Volumes

(The chapters and subjects listed for these volume are subject to modification, adjustment, and change. The contents shown for each volume are proposed and may not represent the final contents of the volume. A final listing of included chapters for each volume will appear in the actual publication.)

VOLUME 1: FUNDAMENTALS OF PLUMBING ENGINEERING

VOLUME 2: PLUMBING SYSTEMS

VOLUME 3: SPECIAL PLUMBING SYSTEMS

VOLUME 4: PLUMBING COMPONENTS AND EQUIPMENT

ASPE American Society of Plumbing Engineers

6400 Shafer Court, Suite 350, Rosemont, IL 60018
(847) 296-0002 • Fax: (847) 296-2963
info@aspe.org • www.aspe.org

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Plumbing Engineering Design Handbook

Volume 1: Fundamentals of Plumbing Engineering

CONTRIBUTORS

CHAPTER 1:
Formulas, Symbols, and Terminology
Jose Francisco DeHoyos, CPD
David J. Fruchtman, PE

CHAPTER 2:
Standards for Plumbing Materials and Equipment
Kurt Bramstedt
Samuel C. McLeod
Mark R. Penoyar, CPMP, MCP
Karl E. Yrjanainen, PE, CPD

CHAPTER 3:
Specifications
Paul L. Baker, PE, CDP, LEED AP BD+C
Anthony J. Curiale, CPD, LEED AP, FASPE

CHAPTER 4:
Plumbing Cost Estimation
R. David Eagan, CPD, CPE
Steven Skattebo, PE
Karl E. Yrjanainen, PE, CPD

CHAPTER 5:
Job Preparation, Drawings, and Field Checklists
Paul L. Baker, PE, CDP, LEED AP BD+C
Anthony J. Curiale, CPD, LEED AP, FASPE

CHAPTER 6:
Plumbing for People with Disabilities
Thura Zin, CPD, GPD

CHAPTER 7:
Energy and Resource Conservation in Plumbing Systems
Jeffrey L. Cordell, II, CPD, GPD
David E. DeBord, CPD, GPD, LEED AP BD+C, ARCSA AP, CFPS, FASPE

CHAPTER 8:
Corrosion
Victor L. Hines, Jr., CPD, LEED AP
Douglas J. Nelson, PE, GPD
Lance MacNevin, P.Eng.
Stephen F. Ziga, CPD, SET, CFPS

CHAPTER 9:
Seismic Protection of Plumbing Systems
Keo, Uykheang
Robert P. Woodward, PE

CHAPTER 10:
Acoustics in Plumbing
Michael D. Curtright, CPD, LEED AP
Stephen F. Ziga, CPD, SET, CFPS

CHAPTER 11:
Basics of Value Engineering
Rob Westphal, PE, CPD, LEED AP

CHAPTER 12:
Ensuring High-Quality Plumbing Installations
Anthony Albergo
Robert Bernstein, CPD
Kurt Bramstedt

CHAPTER 13:
Existing Building Job Preparation and Condition Survey
Paul L. Baker, PE, CDP, LEED AP BD+C
Larisa Miro, CPD

CHAPTER 14:
Building Information Modeling
Timothy M. Goodale, CPD
Kevin L. McGlothlin

Editor: Gretchen Pienta | Graphic Designer: Nadine Saucedo
2016–2018 ASPE Vice President, Technical: David E. DeBord, CPD, GPD, LEED AP BD+C, ARCSA AP, CFPS, FASPE

About ASPE

The American Society of Plumbing Engineers (ASPE), founded in 1964, is the international organization for professionals skilled in the design and specification of plumbing systems. ASPE is dedicated to the advancement of the science of plumbing engineering, to the professional growth and advancement of its members, and to the health, welfare, and safety of the public.

The Society disseminates technical data and information, sponsors activities that facilitate interaction with fellow professionals, and, through research and education programs, expands the base of knowledge of the plumbing engineering industry. ASPE members are leaders in innovative plumbing design, effective materials and energy use, and the application of advanced techniques from around the world.

Worldwide Membership — Spanning the globe, ASPE members are located in the United States, Canada, the Caribbean, Asia, the Middle East, Mexico, South America, the South Pacific, Australia, and Europe. They represent an extensive network of experienced engineers, designers, contractors, educators, code officials, and manufacturers interested in furthering their careers, their profession, and the industry. ASPE represents its members and promotes the profession among all segments of the construction industry.

ASPE Membership Communication — All members belong to ASPE worldwide and have the opportunity to belong to and participate in one of the state, provincial, or local chapters throughout the United States and Canada. ASPE chapters provide the major communication link and the first line of services and programs for the individual member. Communication with the membership is enhanced through the Society's official publication, *Plumbing Engineer,* and the e-newsletter *ASPE Pipeline*.

Technical Publications — The Society maintains a comprehensive publishing program, spearheaded by the profession's basic reference text, the *Plumbing Engineering Design Handbook,* which encompasses almost 50 chapters in four volumes and provides comprehensive details of the accepted practices and design criteria used in the field of plumbing engineering. ASPE's published library of professional technical manuals and handbooks also includes *Advanced Plumbing Technology, Plumbineering Dictionary, Fire Protection Systems, Illustrated Plumbing Codes Design Handbook, Plumbing Engineering and Design Handbook of Tables, Pharmaceutical Facilities Plumbing Systems, Engineered Plumbing Design, Practical Plumbing Engineering,* and *Domestic Water Heating Design Manual*.

Convention and Technical Symposium — The Society hosts the ASPE Convention & Exposition in even-numbered years and the ASPE Technical Symposium in odd-numbered years to provide opportunities for plumbing engineers and designers to improve their skills, learn original concepts, and make important networking contacts to help them stay abreast of current trends and technologies. The ASPE Convention & Exposition includes the largest tradeshow in the industry dedicated exclusively to plumbing engineering and design products, equipment, and services. Everything from pipes to pumps to fixtures, from compressors to computers to consulting services is on display, giving engineers and specifiers the opportunity to view the newest and most innovative products, services, and equipment available.

Certified in Plumbing Design — ASPE sponsors an international certification program for engineers and designers of plumbing systems, which carries the designation Certified in Plumbing Design, or CPD. The certification program provides the profession, the plumbing industry, and the general public with a single, comprehensive qualification of professional competence for engineers and designers of plumbing systems. Created to provide a single, uniform national credential in the field of engineered plumbing systems, the CPD program is not in any way connected to state-regulated Professional Engineer (PE) registration.

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CHAPTER 1

Formulas, Symbols, and Terminology

For the convenience of plumbing engineers, following are some of the basic formulas commonly referred to and utilized in plumbing engineering and design. It is extremely important to convert values to the proper units whenever using these equations.

Take note that gravitational acceleration and gravitational constant have the same numerical value, but the units are not the same. These terms can be left out of equations with no effect on the numerical value. However, the units will not be dimensionally correct and do not cancel out.

Due to the English system of measurement utilizing pounds to indicate mass and force, pounds-mass (lbm) and pounds-force (lbf) are used to distinguish between the two. This is not an issue for the International System of Units (SI).

FORMULAS COMMONLY USED IN PLUMBING ENGINEERING

Hydraulic Radius

Usually referred to as the hydraulic mean depth of flow, hydraulic radius (R) is the ratio of the cross-sectional area of flow to the wetted perimeter of pipe surface.

Equation 1-1

$$R = \frac{\text{Area of flow}}{\text{Wetted perimeter}}$$

For half-full (HF) and full-flow (FF) conditions, the hydraulic radii can be represented as:

Equation 1-1A

$$R_{HF} = R_{FF} = \frac{D}{4}$$

where

D = Diameter of pipe, ft (m)

R_{HF} = Hydraulic radius, half-full condition, ft (m)

R_{FF} = Hydraulic radius, full-flow condition, ft (m)

Manning Formula

The Manning Formula is used to determine the velocity (V) of uniform flow in sloping drains. (Uniform flow is defined as the flow that is achieved in open channels of constant shape and size and uniform slope.) Note that the slope of the water surface is equal to the slope of the channel, and the flows in such open channels do not depend on the pressure applied to the water but on the gravitational force induced by the slope of the drain and the height of the water in that drain.

Equation 1-2

$$V = \frac{1.486\, R^{2/3}\, S^{1/2}}{n} \qquad \left[V = \frac{1.00\, R^{2/3}\, S^{1/2}}{n} \right]$$

where

V = Velocity of flow, feet per second (ft/s) (meters per second [m/s])
n = Coefficient representing roughness of pipe surface, degree of fouling, and pipe diameter
R = Hydraulic radius, ft (m)
S = Hydraulic slope of surface of flow, ft/ft (m/m)

The hydraulic radius can be calculated using Equation 1-1. The roughness coefficient and several values for the hydraulic radii are given in *Marks' Standard Handbook for Mechanical Engineers*.

Rate of Flow

Equation 1-3 is used to determine the amount of water passing through a pipe. This quantity of water, for a given time, depends on the cross-sectional area of the pipe and the velocity of the water.

Equation 1-3

$$Q = AV$$

where

Q = Flow rate of water, ft^3/s (m^3/s)
A = Cross-sectional area of pipe, ft^2 (m^2)
V = Flow velocity of water, ft/s (m/s)

Therefore, substituting Equation 1-3 in Equation 1-2, the Manning Formula can be represented as follows:

Equation 1-3A

$$Q = \frac{1.486\, AR^{2/3}\, S^{1/2}}{n} \qquad \left[Q = \frac{1.000\, AR^{2/3}\, S^{1/2}}{n} \right]$$

Water Flow in Pipes

Two types of water flow exist: laminar and turbulent. Each type is characterized by the Reynolds number, a dimensionless quantity. The physical characteristics of the water, the velocity of the flow, and the internal diameter of the pipe are factors for consideration, and the Reynolds number is represented as shown in Equation 1-4:

Equation 1-4

$$Re = \frac{VD\rho}{\mu g_c}$$

where

Re = Reynolds number, dimensionless
V = Velocity of flow, ft/s (m/s)
D = Diameter of pipe, ft (m)
ρ = Density, lbm/ft^3 (kg/m^3)
μ = Absolute viscosity of fluid, $lb\text{-}s/ft^2$ (m^2/s)
g_c = Gravitational constant, 32.2 $lbm\text{-}ft/lbf\text{-}s^2$

Values of viscosity are tabulated in the *ASHRAE Handbook—Fundamentals*. In laminar flow, the fluid particles move in layers in straight parallel paths, the viscosity of the fluid is dominant, and its upper limit is represented by Re = 2,000. In turbulent flow, the fluid particles move in a haphazard fashion in all directions, the path of an individual fluid particle is not possible to trace, and Re is more than 4,000. Flows with a Reynolds number between 2,000 and 4,000 are classified as critical flows. The Reynolds number is necessary to calculate friction coefficients, which, in turn, are used to determine pressure losses.

Friction Head Loss

Whenever flow occurs, a continuous pressure loss exists along the piping in the direction of flow, and this head loss is affected by the density of the fluid, its temperature, the pipe roughness, the length of the run, and the fluid velocity. The friction head loss is represented by the Darcy-Weisbach equation:

Equation 1-5

$$h = \frac{fLV^2}{2gD}$$

where

h = Friction head loss, ft (m)
f = Friction coefficient, dimensionless
L = Length of pipe, ft (m)
V = Velocity of flow, ft/s (m/s)
g = Gravitational acceleration, 32.2 ft/s^2 (9.8 m/s^2)
D = Internal diameter of pipe, ft (m)

The static head is the pressure (P) exerted at any point by the height of the substance above that point. To convert from feet (m) of head to pounds per square inch (psi) (kPa or kg/m^2), the following relationship is used:

Equation 1-5A

$$P = \frac{\gamma gh}{144}$$

where

P = Pressure, lbf/in^2 (kPa)
γ = Specific weight of substance, lbf/ft^3 (N/m^3)
h = Static head, ft (m)

Therefore, Equation 1-5 may be represented as:

Equation 1-5B

$$P = \frac{g\gamma fLV^2}{288gD}$$

To convert pressure in meters of head to pressure in kilopascals, use the following:

Equation 1-5C

$$kPa = 9.81 \text{ (m head)}$$

To calculate the head loss due to friction, the Hazen-Williams formula is used:

Equation 1-5D

$$h = 0.002083L\left(\frac{100}{C}\right)^{1.85}\left(\frac{q^{1.85}}{d^{4.8655}}\right)$$

where

h = Head loss due to friction, ft of liquid
C = Roughness constant
q = Flow rate, gallons per minute (gpm) (l/s)
d = Actual inside diameter of pipe, in. (mm)
L = Length of pipe, ft (m)

Values for f and C are tabulated in *Marks' Standard Handbook for Mechanical Engineers*.

Potential Energy

Potential energy (PE) is defined as the energy of a body due to its elevation above a given level and is expressed as:

Equation 1-6

$$PE = Wh = mgh/g_c$$
$$(PE = Wh)$$

where

PE = Potential energy, ft-lbf (J)
W = Weight of body, lbf (N)
m = Mass of body, lbm (kg)
h = Height above level, ft (m)
g = Gravitational acceleration, 32.2 ft/s^2 (9.8 m/s^2)
g_c = Gravitational constant, 32.2 lbm-ft/lbf-s^2

Kinetic Energy

Kinetic energy (KE) is the energy of a body due to its motion and is expressed as:

Equation 1-7

$$KE = \frac{mV^2}{2g} = \frac{WV^2}{2g_c}$$

where

KE = Kinetic energy, ft-lbf (J)
m = Mass of body, lbm (kg)
V = Velocity, ft/s (m/s)
W = Weight of body, lbf (kg)
g = Gravitational acceleration, 32.2 ft/s^2 (9.8 m/s^2)
g_c = Gravitational constant, 32.2 lbm-ft/lbf-s^2

Flow at Outlet

Flow at outlet can be determined by using the following relationship:

Equation 1-8

$$Q = 20\ C_d d^2 P^{1/2}$$

where

Q = Flow at outlet, gpm (l/s)
C_d = Discharge coefficient
d = Inside diameter of outlet, in. (mm)
P = Flow pressure, lbf/in^2 (kPa)

The discharge coefficient (C_d) may be obtained from *Marks' Standard Handbook for Mechanical Engineers*.

Length of Vent Piping

The length of vent piping can be determined by combining the Darcy-Weisbach equation (Equation 1-5) and the flow equation:

Equation 1-9

$$L = \frac{2{,}226d^5}{fQ^2}$$

where

L = Length of pipe, ft (m)
d = Diameter of pipe, in. (mm)
f = Friction coefficient, dimensionless
Q = Rate of flow, gpm (l/s)

Stacks

Terminal velocity in stacks is calculated by:

Equation 1-10A

$$V_T = 3\left(\frac{Q}{d}\right)^{2/5}$$

where

V_T = Terminal velocity in stack, ft/s (m/s)
Q = Rate of flow, gpm (l/s)
d = Diameter of stack, in. (mm)

Terminal length in stacks is calculated by:

Equation 1-10B

$$L_T = 0.052\, V_T^2$$

where

L_T = Terminal length below the point of flow entry, ft (m)

Stack capacity is calculated by:

Equation 1-10C

$$Q = 27.8\, r^{5/3}\, d^{8/3}$$

where

Q = Maximum permissible flow rate in the stack, gpm (l/s)
r = Ratio of the cross-sectional area of the sheet of water to the cross-sectional area of the stack
d = Diameter of stack, in. (mm)

Flow Rate in Fixture Drains

The flow rate in a fixture drain should equal the flow rate at the fixture outlet and is expressed as:

Equation 1-11

$$Q = 13.17\, d^2 H^{1/2}$$

where

Q = Discharge flow rate, gpm (l/s)
d = Diameter of outlet orifice, in. (mm)
H = Mean vertical height of the water surface above the point of the outlet orifice, ft (m)

Pipe Expansion and Contraction

All pipes that are subject to temperature changes expand and contract. Piping expands with an increase in temperature and contracts with a decrease in temperature. The rate of change in length due to temperature is referred to as the expansion coefficient. The changes in length can be calculated by using the following relation:

Equation 1-12

$$D_L = C_E\, L_1\, D_T$$

where

D_L = Length differential, length of expansion, inches (m)
C_E = Coefficient of expansion of material, in/in°F (m/m°C) (see Table 1-1)
L_1 = Initial length of pipe, inches (m)
D_T = Temperature differential, (final T – initial T), °F (°C)

Table 1-1 Mean Expansion Coefficient 10^{-6} (in./in.°F, m/m°C)

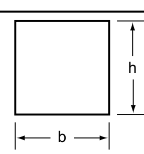
Material	Expansion Coefficients	
	10^{-6} in./in.°F	10^{-6} m/m°C
Carbon steel	6.5	11.7
Cast iron	5.9	10.6
Copper	9.3	16.8
Stainless steel	9.9	17.8
HDPE	67.0	120.0
CPVC	44.0	79.0
PVC	28.0	50.4

Notes: Adjust coefficient to expanded form for equation (i.e., 10^{-6} in./in.°F for copper pipe (9.3) = 0.0000093 in./in.°F). Verify exact material properties with the manufacturer.

Formulas for Areas and Volumes

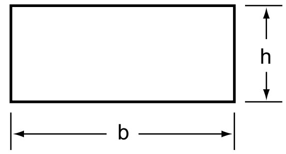
Equation 1-13A, Square

$$A = bh$$



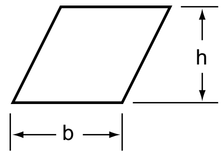
Equation 1-13B, Rectangle

$$A = bh$$



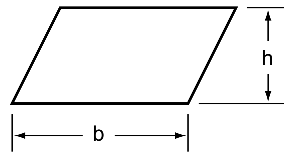
Equation 1-13C, Rhombus

$$A = bh$$



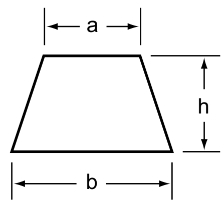
Equation 1-13D, Rhomboid

$$A = bh$$



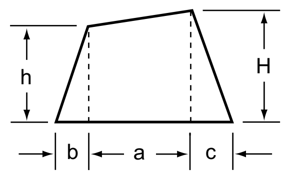
Equation 1-13E, Trapezoid

$$A = \frac{h(a + b)}{2}$$



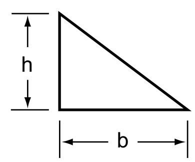
Equation 1-13F, Trapezium

$$A = \frac{(H + h)a + bh + cH}{2}$$



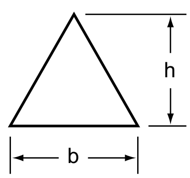
Equation 1-13G, Right-Angle Triangle

$$A = \frac{bh}{2}$$



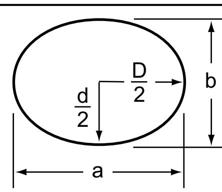
Equation 1-13H, Isosceles Triangle

$$A = \frac{bh}{2}$$



Equation 1-13I, Ellipse

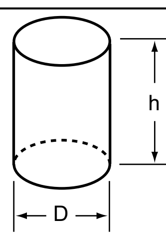
$$A = \pi ab$$



Equation 1-13J, Cylinder

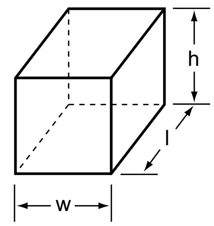
$$A = \pi Dh$$

$$V = \pi R^2 h$$



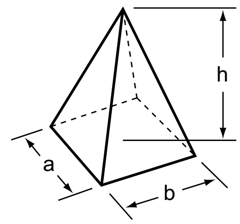
Equation 1-13K, Cube or Rectangular Solid

$$V = whl$$



Equation 1-13L, Pyramid

$$V = \frac{abh}{3}$$



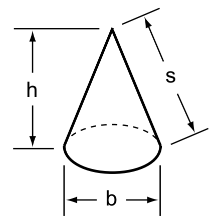
Equation 1-13M, Cone

$$A = \frac{\pi Ds}{2} \qquad V = \frac{\pi R^2 h}{3}$$

where

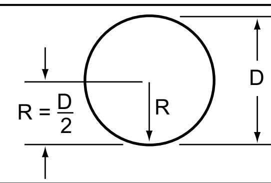
$D = b$

$R = b/2$



Equation 1-13N, Circle

$$C = 2\pi R$$

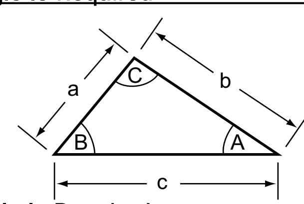


Equation 1-13O, Circle

$$A = \pi R^2$$

Equation 1-13P, Triangle, Where Two Angles Are Known and Third Angle Is Required

$$A = 180° - (B + C)$$



Equation 1-13Q, Triangle, Where Three Sides Are Known and Any Angle Is Required

$$\cos A = \frac{b^2 + c^2 - a^2}{2bc}$$

Equation 1-13R, Triangle, Where Two Sides and Included Angle Are Known and Third Side Is Required

$$c = (a^2 + b^2 - 2ab \cos C)^{1/2}$$

Equation 1-13S, Triangle, Where Two Sides and Included Angle Are Known and Third Angle Is Required

$$\tan A = \frac{a \sin C}{b - a \cos C}$$

Equation 1-13T, Triangle, Where Two Sides and Excluded Angle Are Known and Third Side Is Required

$$c = b \cos A \pm (a^2 - b^2 \sin^2 A)^{1/2}$$

Equation 1-13U, Triangle, Where One Side and Adjacent Angles Are Known and Adjacent Side Is Required

$$c = \frac{a \sin C}{\sin A}$$

Flow Rate in Outlet

Equation 1-11 showed that the flow rate (Q) in the outlet should be equal to the flow rate in the fixture drain. The maximum discharge rate is expressed as:

Equation 1-14

$$Q_D = c_D Q_I$$

where

Q_D = Actual discharge quantity, gpm (l/s)
c_D = Discharge coefficient
Q_I = Ideal discharge quantity, gpm (l/s)

The discharge coefficient (c_D) may be obtained from *Marks' Standard Handbook for Mechanical Engineers*.

Gravity Circulation

Gravity circulation is used to prevent foul odors and the growth of slime and fungi in sanitary systems. The circulation is induced by the pressure difference between the outdoor air and the air in the vent piping. This pressure difference is due to the difference in temperature (T) and density (ρ) between the two and the height (h) of the air column in the vent piping. The gravity circulation is determined by using the following formula:

Equation 1-15

$$P = 0.1925\,(\gamma_O - \gamma_I)\,H_s$$

where

P = Natural draft pressure, in. (mm)
γ_O = Specific weight of outside air, lbf/ft^3 (N/m^3)
γ_I = Specific weight of air in pipe, lbf/ft^3 (N/m^3)
H_s = Height of air column in stack, ft (m)

The outside and inside air densities (ρ_O and ρ_I) may be obtained from *ASHRAE Handbook—Fundamentals*.

Velocity Head

When the water in a piping system is at rest, it has potential energy (PE). When the water in a piping system is flowing, it has kinetic energy (KE). For the water to flow, some of the potential energy must be converted to kinetic energy. The decrease in potential energy (static head) is referred to as the velocity head and is expressed as:

Equation 1-16

$$H = \frac{V^2}{2g}$$

where

H = Height of the fall, ft (m)
V = Velocity at any moment, ft/s (m/s)
g = Gravitational acceleration, 32.2 ft/s^2 (9.8 m/s^2)

Bernoulli's Equation

Since energy cannot be created or destroyed, Bernoulli developed a theorem to express this energy conservation. It is represented by the following equation:

Equation 1-17

$$E_T = \frac{Zg}{g_c} + \frac{P}{\rho} + \frac{V^2}{2g_c} \qquad [\, E_T = Zg + \frac{P}{\rho} + \frac{V^2}{2} \,]$$

where

E_T = Total energy, ft-lbf/lbm (J/kg)
Z = Height of point above datum, ft (m)
P = Pressure, lbf/ft^2 (kPa)
ρ = Density, lbm/ft^3 (N/m^3)
V = Velocity, ft/s (m/s)
g = Gravitational acceleration, 32.2 ft/s^2 (9.8 m/s^2)
g_c = Gravitational constant, 32.2 lbm-ft/lbf-s^2

For two points in the system, Equation 1-17 can be expressed as:

Equation 1-17A

$$\frac{Z_1 g}{g_c} + P_{1/\rho} + \frac{V_1^2}{2g_c} = \frac{Z_2 g}{g_c} + \frac{P_2}{\rho} + \frac{V_2^2}{2g_c}$$

Subscripts 1 and 2 represent points in the system.

Friction Head

When water flows in a pipe, friction is produced by the rubbing of water particles against each other and against the walls of the pipe. This causes a pressure loss in the line of flow, called the friction head, which is expressed by using Bernoulli's equation.

Equation 1-18

$$H_f = (Z_1 + H_1 + \frac{V_1^2}{2g_c}) - (Z_2 + H_2 + \frac{V_2^2}{2g_c})$$

where

H_f = Friction head, ft (m)
Z = Height of point, ft (m)
H = P/ρ = Static head or height of liquid column, ft (m)
V = Velocity at outlet, ft/s (m/s)
g_c = Gravitational constant, 32.2 lbm-ft/lbf-s^2

Subscripts 1 and 2 represent points in the system.

Flow from Outlets

The velocity of flow from outlets can be expressed by the following:

Equation 1-19

$$V = C_D (2gH)^{1/2}$$

where

V = Velocity at outlet, ft/s (m/s)
C_D = Coefficient of discharge (usually 0.67)
g = Gravitational acceleration, 32.2 ft/s^2 (9.8 m/s^2)
H = Static head or height of liquid column, ft (m)

Hydraulic Shock

The magnitude of the pressure wave can be expressed by the following relationship:

Equation 1-20

$$P = \frac{\gamma a d_V}{144g}$$

where

P = Pressure in excess of flow pressure, lb/in^2 (kPa)
γ = Specific weight of liquid, lbf/ft^3 (N/m^3)
a = Velocity of propagation of elastic vibration in the pipe, ft/s (m/s)
d_V = Change in flow velocity, ft/s (m/s)
g = Gravitational acceleration, 32.2 ft/s^2 (9.8 m/s^2)

The velocity of propagation of elastic vibration in the pipe (a) can be defined as:

Equation 1-20A

$$a = \frac{4{,}660}{(1 + KB)^{1/2}}$$

where

a = Propagation velocity, ft/s (m/s)
4,660 = Velocity of sound in water, ft/s (m/s)
K = Ratio of modulus of elasticity of fluid to modulus of elasticity of pipe
B = Ratio of pipe diameter to wall thickness

The values for γ, K, and B are given or can be calculated from *ASHRAE Handbook—Fundamentals*.

The time interval required for the pressure wave to travel back and forth in the pipe can be expressed as:

Equation 1-20B

$$t = \frac{2L}{a}$$

where

t = Time interval, s
L = Length of pipe from point of closure to point of relief, ft (m)

Pump Affinity Laws

Affinity laws describe the relationships between the capacity, head, brake horsepower, speed, and impeller diameter of a given pump.

The first law states the performance data of a constant impeller diameter with a change in speed.

Equation 1-21A

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \text{ and } \frac{H_1}{H_2} = \frac{N_1^2}{N_2^2} \text{ and } \frac{BHP_1}{BHP_2} = \frac{N_1^3}{N_2^3} \text{ or}$$

$$\frac{N_1}{N_2} = \frac{Q_1}{Q_2} = \left(\frac{H_1}{H_2}\right)^{1/2} = \left(\frac{BHP_1}{BHP_2}\right)^{1/3}$$

where

Q = Capacity, gpm (m^3/h)
N = Speed, revolutions per minute (rpm) (r/s)
H = Head, ft (m)
BHP = Brake horsepower, watts (W)

The second law assumes the performance data of constant speed with a change in impeller diameter.

Equation 1-21B

$$\frac{Q_1}{Q_2} = \frac{D_1}{D_2} \text{ and } \frac{H_1}{H_2} = \frac{D_1^2}{D_2^2} \text{ and } \frac{BHP_1}{BHP_2} = \frac{D_1^3}{D_2^3} \text{ or}$$

$$\frac{D_1}{D_2} = \frac{Q_1}{Q_2} = \left(\frac{H_1}{H_2}\right)^{1/2} = \left(\frac{BHP_1}{BHP_2}\right)^{1/3}$$

where

D = Impeller diameter, in. (mm)

Pump Efficiency

The efficiency of a pump is represented by the following equation:

Equation 1-22

$$Ep = \frac{WHP}{BHP}$$

where

Ep = Pump efficiency as a decimal equivalent
WHP = Water horsepower = ft Hd x gpm x (8.33 lb/gal) x (HP/33,000 ft-lb/min)
BHP = Brake horsepower input to pump

From Equation 1-22, the brake horsepower can be represented as:

Equation 1-22A

$$BHP = \frac{WHP}{Ep} \quad \text{or} \quad \frac{\text{ft Hd} \times \text{gpm}}{3{,}960 \times Ep}$$

Rational Method of Storm Design

The rational method calculates the peak stormwater runoff.

Equation 1-23

$$Q = CIA$$

where

Q = Runoff, ft^3/s (m^3/s)
C = Runoff coefficient (surface roughness in drained area)
I = Rainfall intensity, in./h (mm/h)
A = Drainage area, acres (m^2)

Spitzglass Formula

The Spitzglass formula is used to size gas piping in systems operating at a pressure of less than 1 psi.

Equation 1-24

$$Q = 3{,}550 \left(\frac{d^5}{1 + 3.6/d + 0.03d} \right)^{1/2} \left(\frac{h}{SL} \right)^{1/2}$$

where

Q = Flow rate, ft^3/h (m^3/h)
d = Diameter of pipe, in. (mm)
h = Pressure drop over length, inches of water column (in. wc)
S = Specific gravity
L = Equivalent length of pipe, ft (m)

Weymouth Formula

The Weymouth formula is used to size gas piping in systems operating at a pressure exceeding 1 psi.

Equation 1-25

$$Q = 28.05 \left[\frac{(P_1^2 - P_2^2)\, d^{16/3}}{SL} \right]^{1/2}$$

where

Q = Flow rate, ft^3/h (m^3/h)
P_1 = Initial gas pressure, psi
P_2 = Final gas pressure, psi
d = Diameter of pipe, in. (mm)
S = Specific gravity
L = Equivalent length of pipe, mi (km)

Slope

The slope of a pipe is represented by the following formula:

Equation 1-26

$$s = \frac{h}{L} \qquad h = L \times s \qquad L = \frac{h}{s}$$

where

s = Slope, in./ft (mm/m)
h = Fall, in. (mm)
L = Length, ft (m)

Discharge from Rectangular Weir with End Contractions (Francis Formula)

Equation 1-27

$$Q = 3.33(L - 0.2H)H^{1.5}$$

where

Q = Rate of flow, ft^3/s (m^3/s)
L = Length of weir opening, ft (m)—should be longer than 2H
H = Head of water, ft (m)

Note: The distance on either side of the weir should be at least 3H.

Heat Loss Formula

Equation 1-28

$$q = \frac{T_p - T_a}{\frac{1}{\pi D_1 h_i} + \frac{\ln(D_2/D_1)}{2\pi k} + \frac{1}{\pi D_2 h_{co}} + \frac{1}{\pi D_2 h_o}}$$

where

q = Heat loss per unit length of pipe, Btuh x ft (W/m)
T_p = Maintenance temperature desired, °F (°C)
T_a = Design ambient temperature, °F (°C)
D_1 = Inside diameter of the insulation, ft (m)
h_i = Inside air contact coefficient from pipe to inside insulation surface, Btuh x ft^2 x °F (W/m^2 x °C)
D_2 = Outside diameter of the insulation, ft (m)
k = Thermal conductivity of insulation evaluated at its mean temperature, Btuh x ft^2 x °F (W/m^2 x °C)
h_{co} = Inside air contact coefficient of weather barrier, Btuh x ft^2 x °F (W/m^2 x °C)
h_o = Outside air film coefficient from weather barrier to ambient, Btuh x ft^2 x °F (W/m^2 x °C)

SYMBOLS

The standardized plumbing- and piping-related symbols in Tables 1-2 and 1-3 and the abbreviations in Table 1-4 have been tabulated by the American Society of Plumbing Engineers for use in the design and preparation of drawings. Users of these symbols are cautioned that some governmental agencies, industry groups, and other clients may have a different list of symbols that are required for their projects.

Table 1-2 Standard Plumbing Drawing Symbols

Symbol	Description	Abbreviation
———— SD ————	Storm drain, rainwater drain	SD, ST
—— —— SSD —— ——	Subsoil drain, footing drain	SSD
———— SS ————	Soil, waste, or sanitary sewer	S, W, SAN, SS
———— SW ————	Stormwater	
———— SWO ————	Stormwater overflow	
— — — — — — — — — — —	Vent	V
———— AW ————	Acid waste	AW
— — — — — AV — — — — —	Acid vent	AV
———— D ————	Indirect drain	D
———— PD ————	Pump discharge line	PD
———— – ————	Cold water	CW
———— – – ————	Hot water supply (140°F)[a]	HW
———— – – – ————	Hot water recirculating (140°F)[a]	HWR
———— TW ————	Tempered water (temp. °F)[b]	TEMP. HW, TW
———— TWR ————	Tempered water recirculating (temp. °F)[b]	TEMP. HWR, TWR
———— DWS ————	(Chilled) drinking water supply	DWS
———— DWR ————	(Chilled) drinking water recirculating	DWR
———— SCW ————	Soft cold water	SCW
———— CD ————	Condensate drain	CD
———— DI ————	Distilled water	DI
———— DE ————	Deionized water	DE
———— RO ————	Reverse osmosis water	RO
———— CWS ————	Chilled water supply	CWS
———— CWR ————	Chilled water return	CWR
———— LS ————	Lawn sprinkler supply	LS
———— F ————	Fire protection water supply	F
———— G ————	Gas: low-pressure	G
———— MG ————	Gas: medium-pressure	MG
———— HG ————	Gas: high-pressure	HG
— — — — — GV — — — — —	Gas vent	GV
———— FOS ————	Fuel oil supply	FOS
———— FOR ————	Fuel oil return	FOR
— — — — — FOV — — — — —	Fuel oil vent	FOV
———— LO ————	Lubricating oil	LO
— — — — — LOV — — — — —	Lubricating oil vent	LOV
———— WO ————	Waste oil	WO
— — — — — WOV — — — — —	Waste oil vent	WOV
———— O_2 ————	Oxygen	O_2
———— LO_2 ————	Liquid oxygen	LO_2
———— A ————	Compressed air[c]	A
———— X#A ————	Compressed air: X#[c]	X#A
———— MA ————	Medical compressed air	MA
———— LA ————	Laboratory compressed air	LA
———— HPCA ————	High-pressure compressed air	HPCA
———— HHWS ————	(Heating) hot water supply	HHWS

Table 1-2 Standard Plumbing Drawing Symbols (continued)

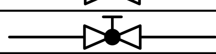
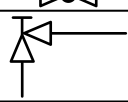
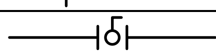
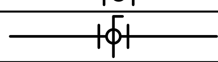
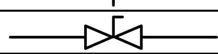
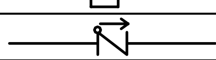
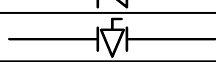
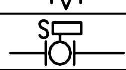
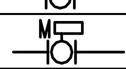
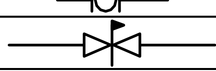
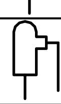
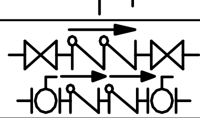
Symbol	Description	Abbreviation
——— HHWR ———	(Heating) hot water return	HHWR
——— VAC ———	Vacuum	VAC
——— NPCW ———	Nonpotable cold water	NPCW
——— NPHW ———	Nonpotable hot water	NPHW
——— NPHWR ———	Nonpotable hot water return	NPHWR
——— MV ———	Medical vacuum	MV
——— SV ———	Surgical vacuum	SV
——— LV ———	Laboratory vacuum	LV
——— N_2 ———	Nitrogen	N_2
——— N_2O ———	Nitrous oxide	N_2O
——— CO_2 ———	Carbon dioxide	CO_2
——— WVC ———	Wet vacuum cleaning	WVC
——— DVC ———	Dry vacuum cleaning	DVC
——— LPS ———	Low-pressure steam supply	LPS
— — — — — LPC — — — — —	Low-pressure condensate	LPC
——— MPS ———	Medium-pressure steam supply	MPS
— — — — — MPC — — — — —	Medium-pressure condensate	MPC
——— HPS ———	High-pressure steam supply	HPS
— — — — — HPC — — — — —	High-pressure condensate	HPC
— — — — — ATV — — — — —	Atmospheric vent (steam or hot vapor)	ATV
	Gate valve	GV
	Globe valve	GLV
	Angle valve	AV
	Ball valve	BV
	Butterfly valve	BFV
	Gas cock, gas stop	
	Balancing valve (specify type)	BLV
	Check valve	CV
	Plug valve	PV
	Solenoid valve	
	Motor-operated valve (specify type)	
	Pressure-reducing valve	PRV
	Pressure-relief valve	RV
	Temperature pressure-relief valve	TPV
	Backflow preventer, large assembly (top), small assembly (bottom)	RZBP
	Hose bibb	HB

Table 1-2 Standard Plumbing Drawing Symbols (continued)

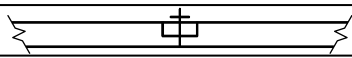
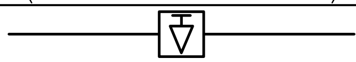
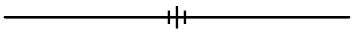
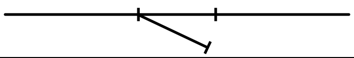
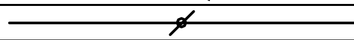
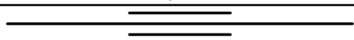
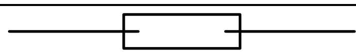
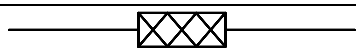
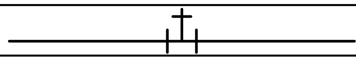
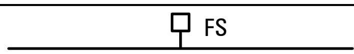
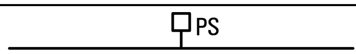
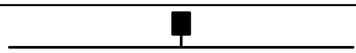
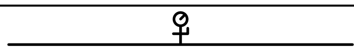
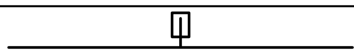
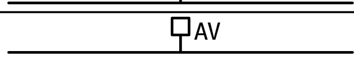
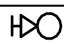
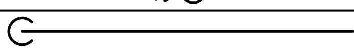
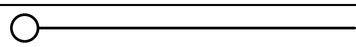
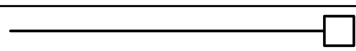
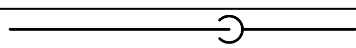
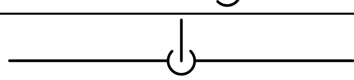
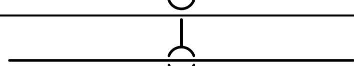
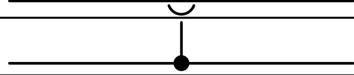
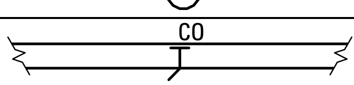
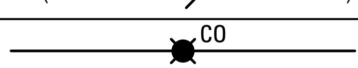
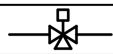
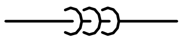
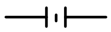
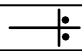
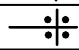
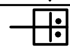
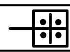
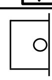
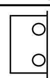
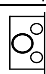
Symbol	Description	Abbreviation
	Recessed-box hose bibb or wall hydrant	WH
	Valve in yard box (valve type symbol as required for valve use)	YB
	Union (screwed)	
	Union (flanged)	
	Strainer (specify type)	
	Pipe anchor	PA
	Pipe guide	
	Expansion joint	EJ
	Flexible connector	FC
	Tee	
	Concentric reducer	
	Eccentric reducer	
	Aquastat	
	Flow switch	FS
	Pressure switch	PS
	Water hammer arrester	WHA
	Pressure gauge with gauge cock	PG
	Thermometer (specify type)	
	Automatic air vent	AAV
	Valve in riser (type as specified or noted)	
	Riser down (elbow)	
	Riser up (elbow)	
	Air chamber	AC
	Rise or drop	
	Branch, top connection	
	Branch, bottom connection	
	Branch, side connection	
	Cap on end of pipe	
	Cleanout plug	CO
	Floor cleanout	FCO
	Wall cleanout	WCO
	Yard cleanout or cleanout to grade	CO
	Drain (all types) (specify)	D
	Pitch down or up in direction of arrow	
	Flow in direction of arrow	

Table 1-2 Standard Plumbing Drawing Symbols (continued)

Symbol	Description	Abbreviation
	Point of connection	POC
	Outlet (specify type)	
	Steam trap (all types)	
	Floor drain with p-trap	FD
	Thermostatic mixing valve	TMV
	Pipe change in elevation	
	Dielectric union	
	Non-freeze CW wall hydrant	
	Non-freeze CW & HW wall hydrant	
	Non-freeze CW wall hydrant in box	
	Non-freeze CW & HW wall hydrant in box	
	Plumbing service box with one water supply	PSB
	Plumbing service box with dual-temperature water supply	PSB
	Plumbing service box with dual-temperature water supply and open drain inlet	PSB

a Hot water (140°F) and hot water return (140°F). Use for normal hot water distribution system, usually but not necessarily (140°F). Change temperature designation if required.
b Hot water (temp. °F) and hot water return (temp. °F). Use for any domestic hot water system (e.g., tempered or sanitizing) required in addition to the normal system (see note "a" above). Insert system supply temperature where "temp." is indicated.
c Compressed air and compressed air X#. Use pressure designations (X#) when compressed air is to be distributed at more than one pressure.

Table 1-3 Standard Fire Protection Piping Symbols

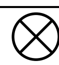
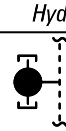
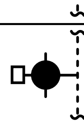
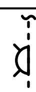
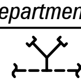
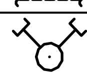
Referent (Synonym)	Symbol	Comments
Water Supply and Distribution Symbols		
Mains, Pipe		
Riser		
Hydrants		
Public hydrant, two hose outlets		Indicate size,[a] type of thread, or connection
Public hydrant, two hose outlets and pumper connection		Indicate size,[a] type of thread, or connection
Wall hydrant, two hose outlets		Indicate size,[a] type of thread, or connection
Fire Department Connections		
Siamese fire department connection		Specify type, size, and angle
Freestanding Siamese fire department connection		Sidewalk or pit type, specify size

Table 1-3 Standard Fire Protection Piping Symbols (continued)

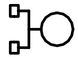
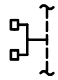
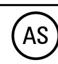
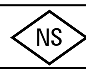
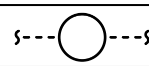
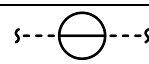
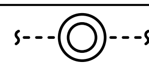
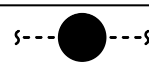
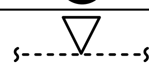
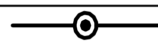
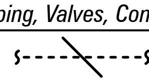
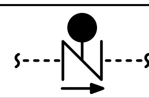
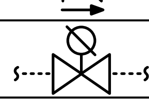
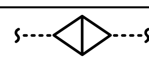
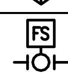
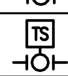
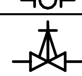
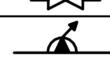
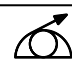
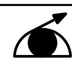
Fire Pump Test Connections		
Fire pump		Freestanding; specify number and sizes of outlets
Test header		Wall
Symbols for Control Panels		
Control panel		Basic shape
(a)		Fire alarm control panel
Symbols for Fire Extinguishing Systems		
Symbols for Various Types of Extinguishing Systems[b]		
Supplementary Symbols		
Fully sprinklered space		
Partially sprinklered space		
Nonsprinklered space		
Symbols for Fire Sprinkler Heads		
Upright sprinkler[c]		
Pendant sprinkler[c, d]		
Upright sprinkler, nippled up[c]		
Pendent sprinkler, on drop nipple[c, d]		
Sidewall sprinkler[c]		
Pendant concealed sprinkler head		
Symbols for Piping, Valves, Control Devices, and Hangers[e]		
Pipe hanger		This symbol is a diagonal stroke imposed on the pipe that it supports
Alarm check valve		Specify size, direction of flow
Dry pipe valve		Specify size
Deluge valve		Specify size and type
Preaction valve		Specify size and type
Flow sensor		
Tamper switch		
OS&Y (Outside screw and yoke valve)		
Carbon dioxide nozzle		

Table 1-3 Standard Fire Protection Piping Symbols (continued)

Referent (Synonym)	Symbol	Comments
Symbols for Portable Fire Extinguishers		
Portable fire extinguisher		Portable fire extinguisher
Symbols for Firefighting Equipment		
Hose station, dry standpipe		
Hose station, changed standpipe		

Source: National Fire Protection Association (NFPA), Standard 170
a Symbol element can be utilized in any combination to fit the type of hydrant.
b These symbols are intended for use in identifying the type of system installed to protect an area within a building.
c Temperature rating of sprinkler and other characteristics can be shown via legends where a limited number of an individual type of sprinkler is called for by the design.
d Can notate "DP" on drawing and/or in specifications where dry pendent sprinklers are employed.
e See also NFPA Standard 170, Section 5-4, for related symbols.

Table 1-4 Commonly Used Plumbing Abbreviations

The standardized plumbing and piping abbreviations in Table 1-4 have been tabulated by the American Society of Plumbing Engineers for use in the design and preparation of drawings. Users of these abbreviations are cautioned that some governmental agencies, industry groups, and clients may have a list of preferences that are required for their projects. All abbreviations should be applied with a consideration for drafting and clarity if drawings are to be reduced.

Term	Abbreviation	Term	Abbreviation
Above finished floor	AFF	Compressed Gas Association	CGA
Above finished roof	AFR	Check valve	cv
Above grade	AG	Chemical and Petroleum Industry	CPI
Absolute	abs	Cleanout	co
Acid vent stack through roof	AVTR	Cleanout deck plate	codp
American Gas Association	AGA	Cold water	cw
American Institute of Steel Construction	AISC	Compressed air	ca
American National Standards Institute	ANSI	Cubic feet	ft^3
American Petroleum Institute	API	Cubic feet per minute	cfm
American Society of Mechanical Engineers	ASME	Cubic feet per second	cfs
American Society of Plumbing Engineers	ASPE	Current good manufacturing practice	cGMP
American Society of Sanitary Engineering	ASSE	Degree	deg. or °
Area drain	ad	Degrees Celsius	°C
Alternating current	ac	Degrees Fahrenheit	°F
American National Standards Institute	ANSI	Degrees Kelvin	ºK
American Society of Heating, Refrigerating, and Air-Conditioning Engineers	ASHRAE	Double check valve	dcv
American Society of Testing Materials	ASTM	Department of Transportation	DOT
Ampere	amp	Deutsches Institut fur Normung	DIN
American Water Works Association	AWWA	Diameter	dia.
Angle valve	av	Diameter, inside	ID
Backflow preventer	bfp	Diameter, outside	OD
Ball valve	bv	Difference or delta	Δ
Bathtub	bt	Direct current	dc
Brake horsepower	bhp	Distilled water	dw
British thermal unit	Btu	Dimensional, nominal (size in metric)	DN
Butterfly valve	bfv	Double detector check	DDC
Cast iron	CI	Down	dn
Canadian Standards Association	CSA	Drop manhole	DMH
Centers for Disease Control	CDC	Drinking fountain	df

Table 1-4 Commonly Used Plumbing Abbreviations (continued)

Term	Abbreviation	Term	Abbreviation
Drainage fixture unit	dfu	Medical air	MA
Drainage inlet	DI	Medical oxygen	MO
Drawing	dwg	Medical vacuum	MV
Elevation	elev.	Million gallons per day	mgd
Fats, oils, and grease	FOG	Miles per hour	mph
Feet per minute	fpm	Minimum	min.
Feet per second	fps	Material safety and data sheet	msds
Fire extinguisher	fe	National Bureau of Standards (now NIST)	NBS
Fire hose rack	fhr	National Electrical Manufacturers Association	NEMA
Fire hose valve	fhv	National Fire Protection Association	NFPA
Fixture unit	fu	National Plumbing Code	NPC
Foot or feet	ft	National pipe thread	npt
Foot-pound	ft-lb	Natural gas	ng
Foot head	ft.hd.	National Oceanic and Atmospheric Administration	NOAA
Gallons	gal	Nominal pipe size	nps
Gallons per day	gpd	Normally closed	n c
Gallons per minute	gpm	Normally open	n o
Gallons per hour	gph	Normal temperature and pressure	ntp
Gallons per year	gpy	Not in contract	n i c
Good manufacturing practice	GMP	Not to scale	nts
Hands-off automatic	HOA	Number	no.
Head	hd	Occupational Safety and Health Administration	OSHA
Horsepower	hp	Original equipment manufacturer	oem
Hose bibb	hb	On center	oc
Heater	htr	Outside diameter	od
Hot water	hw	Ounce	oz
Hot water return	hwr	Oxygen	o
Heating, ventilating, and air-conditioning	HVAC	Parts per million	ppm
Hertz	Hz	Piping and instrumentation diagram	P & ID
Inches	in.	Plug valve	pv
Inches per hour	in./hr	Plumbing service box	PSB
Inch-pounds	ip	Post indicator valve	piv
Inside diameter	id	Pounds	lb
Instrument air	IA	Pounds per cubic foot	lb/ft^3
Invert elevation	ie	Pounds per square foot	psf
Industrial risk insurers	IRI	Pounds per square inch	psi
International Association of Plumbing and Mechanical Officials	IAPMO	Pounds per square inch, absolute	psia
International Code Council	ICC	Pounds per square inch, gauge	psig
International Plumbing Code	IPC	Pressure reducing valve	prv
Iron body bronze mounted	ibbm	Pressure relief valve	pv
Iron pipe size	ips	psi absolute	psia
Kilowatt	kW	psi gage	psig
Kilowatt hour	kWh	Rankine	°R
Kitchen sink	ks	Reduced pressure zone	rpz
Laundry tray	lt	Revolutions per minute	rpm
Lavatory	lav	Revolutions per second	rps
Leader	l	Relative humidity	rh
Linear feet	lin ft	Roof drain	rd
Liquefied petroleum gas	lpg	Root main square	rms
Manhole	mh	Sanitary fixture units	sfu
Mechanical equipment room	mer	Shower	sh

Table 1-4 Commonly Used Plumbing Abbreviations (continued)

Term	Abbreviation	Term	Abbreviation
Sillcock	sc	Typical	typ
Soil	s	Ultraviolet	UV
Specific gravity	sg	Uniform Plumbing Code	UPC
Standard dimensional ratio	sdr	Urinal	ur
Standard	std	Vacuum	vac
Service sink	ss	Vacuum breaker	VB
Steam working pressure	swp	Vent	v
Sprinkler	spkr	Vent through roof	VTR
Square feet	SQ	Volatile organic compound	voc
Systeme International d'Unites	SI	Wall hydrant	wh
Temperature and pressure relief valve	tprv	Waste	w
Tempered water	tw	Water closet	wc
Testable double detector check	TDDC	Water fixture units	wfu
That is	i.e.	Water, oil, and gas	WOG
Thousand cubic feet	Mcf	Water working pressure	wwp
Thousand pounds	kip	Yard hydrant	yh
Thermostatic mixing valve	tmv	Zone control valve	zcv
Top elevation	te		

PLUMBING TERMINOLOGY

Abrasion The withstanding of any material to rubbing, scratching, or wearing away.

Absolute pressure The total pressure equal to that measured from an absolute vacuum. It equals the sum of gauge pressure plus barometric atmospheric pressure. It is expressed in pounds per square inch (psia) or kilopascals per square meter (kPa/m^2).

Absolute temperature Temperature measured from absolute zero.

Absolute zero The point at which any substance has no molecular motion and no heat. It is equivalent to -459.72°F or -273.18°C.

Absorption The soaking up of a gas or liquid into a solid substance.

Access door A panel that can be opened and used to provide easy approach to concealed valves or equipment.

Access to That which enables a fixture, device, or appliance to be easily reached.

Accuracy The degree of agreement between a measured value and the true value of a quantity or concern.

Accessible That which enables direct approach, either with or without the removing or moving of any panel, door, or similar obstruction. Regarding physically challenged individuals, a plumbing fixture, site, building, facility, or portion thereof that can be approached, entered, and/or used.

Accumulation The amount a pressure, temperature, liquid level, or differential pressure deviates higher from a set value.

Accumulator A container in which fluid is stored under pressure as a source of power.

Acid A fluid with a pH lower than 7.0.

Acid vent A pipe venting an acid-waste system.

Acid waste A pipe that conveys liquid waste matter having a pH of less than 7.0.

Activated sludge Sewage sediment, rich in destructive bacteria, that can be used to break down fresh sewage quickly.

Actuator A movable component of a valve that when operated causes the closure element to move.

Actual capacity With reference to inlet conditions, the volume rate of air compressed and delivered at the discharge point.

Adapter fitting Any fitting that mates or connects two pipes or fittings of different size, material, or design.

Adhesive A substance capable of holding two or more objects together by attaching to their surfaces.

Adiabatic compression Air compression that allows an increase of temperature in the air.

Adsorption The surface retention or adhesion of a gas on the surface of a solid.

Administrative authority Also called the authority having jurisdiction (AHJ), the individual official, board, department, entity, or agency established and authorized by a state, county, city, or other political subdivision created by law to administer and enforce the provisions of a particular code as adapted or amended.

Aeration An artificial method of bringing a liquid into direct contact with air.

Aerobic Living or active only in the presence of free oxygen.

Aerosol A small vapor particle suspended in air.

Aftercooler A device used to lower the temperature of a gas after the compression process.

Aging The effect of exposing material to a specific environment for an extended period of time.

Air-admittance valve A one-way valve designed to open and allow air to enter a drainage system when negative pressures are present without extending to the outside air and then positively close by gravity.

Air chamber A device, either made up of fittings or manufactured, installed on a piping system for the purpose of attenuating a pressure surge resulting from water hammer.

Air, compressed Air at any pressure greater than atmospheric pressure.

Air, free Air subject only to ambient atmospheric conditions.

Air gap The unobstructed vertical distance between the end of a pipe and the flood level of a plumbing fixture or receptacle.

Air lock Sometimes called vapor lock, a condition in which a gas is entrapped between two liquid surfaces in a conduit causing a stoppage or impediment.

Air, standard Air having a temperature of 60°F (15.6°C), with a pressure of 14.70 psia (101.4 kPa) and 0 percent humidity. These figures may be different outside the United States.

Air test A test using compressed air applied to a plumbing system for the purpose of determining a leak.

Alarm Any audible or visible signal indicating the existence of any condition or operation outside a preset normal.

Alarm check valve A check valve, equipped with a signaling device, that will annunciate a remote alarm when a sprinkler head is discharging.

Alkali A fluid with a pH of 7.0 or higher.

Alloy A substance composed of two or more metals or a metal and nonmetal intimately united, usually fused together and dissolving in each other when molten.

Alloy pipe A metallic pipe composed of two or more metals.

Ambient temperature The average or mean temperature of the surrounding air where a reading is taken.

American standard pipe thread A type of screw thread commonly used on pipe and fittings.

Amplifier A device that magnifies the input signal using power other than that from the signal itself.

Amplitude A measurement of the distance between the highest to the lowest excursion of a variable or physical motion.

Anaerobic (re: bacteria) Living or active in the absence of free oxygen.

Analysis Separation and measurements of component parts.

Anchor A device used to fasten or secure pipes to a building or structure.

Angle of bend In a pipe, the angle between radial lines from the beginning and end of the bend to the center.

Angle stop Common term for right-angle valves used to control water supplies to plumbing fixtures.

Angle valve A device, usually of the globe type, in which the inlet and outlet are at right angles.

Anion A negatively charged atom attracted to the negative electrode.

Anneal A procedure for preventing or removing stress within a material through controlled heating and/or cooling.

Antisiphon A term used to describe any device that eliminates siphonic action.

Approach A term, expressed in degrees, indicating how close the outlet temperature of a fluid being heated in a heat exchanger comes to the temperature of the heating medium.

Approved Accepted or acceptable under an applicable specification or standard stated or cited for the proposed use under the procedures and authority of the administrative authority.

Approved testing agency An organization established for purposes of testing products to approved standards and acceptable to the administrative authority.

Aquifer A water-bearing underground formation or stratum capable of storing water suitable for development.

Area drain A receptacle designed to collect surface or rainwater from a determined or calculated open area.

Areaway An enclosed excavated area below grade adjacent to a building open to the weather.

Asphyxiant gas A gas with little or no toxicity, but which could induce unconsciousness or death by replacing air, thus depriving an organism of oxygen.

Aspirator A fitting or device supplied with water or other fluid under positive pressure that passes through an integral orifice or "constriction," causing a vacuum.

Asynchronous An event that occurs at an arbitrary time without synchronization to a referenced clock.

Atmospheric vacuum breaker A mechanical device consisting of a check valve that opens to the atmosphere when the pressure in the piping drops to atmospheric.

Atomic weight The relative weight of an atom of an element compared to carbon 12.

Authority having jurisdiction (AHJ) The organization, office, or individual responsible for approving equipment, materials, installation, or procedure.

Autoignition The temperature at which a material will ignite and sustain combustion in the absence of a spark or flame.

Availability of a sewer The closeness of a public sewer to a building based on code requirements, generally 500 ft (151 m) or less.

Backfill Material used to replace excavated material for piping installed in an earthen trench.

Backflow 1. The flow of water or other liquids, mixtures, or substances into the distributing pipes of a potable supply from any source other than that intended. 2. The reversal of flow in drainage systems.

Backflow connection A arrangement where backflow can occur.

Backflow preventer A device or means to prevent backflow into the potable water system.

Backing ring A metal strip used to prevent melted metal from the welding process from entering a pipe in the process of making a butt-welded joint.

Backpressure Negative pressure created by any means in a potable water distribution system that causes a potential backflow.

Backsiphonage The flowing back of potentially contaminated or polluted water into the potable water supply piping due to a negative pressure in the potable water supply pipe.

Backup A general sanitary condition where wastewater flows back into a fixture or compartment.

Backwater valve A check valve assembly on the sanitary drainage piping that allows effluent to flow in only one direction.

Baffle plate A tray or partition placed in process equipment or tanks to direct or change the direction of flow.

Ball check valve A check valve that uses a spherical or ball-shaped closure member allowing flow in only one direction.

Ball joint A connection utilizing a ball in a cuplike shell that allows movement in any direction other than along the axis of the pipes.

Ball valve A type of quarter-turn valve that uses a spherical closure member.

Barrier free A condition where no obstruction exists to prevent access by physically challenged individuals.

Base 1. The lowest point of a stack of vertical pipe. 2. A liquid with a pH of 7.0 or higher.

Bathroom group Several plumbing fixtures located together on the same level, generally a water closet, lavatory, and shower or bathtub.

Battery of fixtures Any group of two or more adjacent fixtures.

Bedding Any material in direct contact with a pipe that is under and up to its centerline.

Bell Commonly called a hub, that portion of a pipe that is sufficiently enlarged to receive the mating spigot end of another pipe for the purpose of making a joint.

Bell-and-spigot joint Commonly called a hub-and-spigot joint for cast-iron soil pipe, a joint in which the spigot is inserted into the hub and the joint is then made tight by caulking or by a gasket.

Black pipe Steel pipe that has not been galvanized.

Blank flange A solid plate flange used to seal off the end of a pipe.

Boiling point The temperature of a liquid where the internal vapor pressure is equal to the pressure on the surface of the liquid.

Boiler blowoff An outlet on a boiler to permit the emptying or discharge of sediment.

Bonnet That part of a valve connecting the valve actuator to the valve body; in some valves, it may also contain the stem packing.

Booster water heater A secondary water heating system used to heat water to a higher temperature than that of the primary heater.

Branch Any part of a piping system other than a main, riser, or stack.

Branch interval A length of soil or waste stack corresponding, in general, to a story height, but in no case less than 8 ft (2.4 m) within which the horizontal branches from one floor or story of a building are connected to the soil stack.

Branch tee A tee having one side branch.

Branch vent A vent connecting one or more individual vents to a vent stack or stack vent.

Brazing The joining of two pipes using a filler metal that has a melting point more than 1,000°F (538 °C).

Brazing ends The ends of a pipe, valve, or fitting that are prepared for brazing.

British thermal unit (Btu) The amount of heat required to raise the temperature of 1 pound (0.45 kg) of water 1°F (0.565°C).

Bronze-mounted Where internal water contact parts of valves known as trim materials (stem, disc, seat rings, etc.) are made of bronze.

Btuh Abbreviation for British thermal units per hour.

Bubble tight A valve seat that does not allow visible bubbles to appear when the valve is closed.

Building A structure having walls and a roof designed and used for housing, shelter, enclosure, or support of people, animals, and property.

Building drain Often called a house drain, the lowest piping of a drainage system that receives the discharge from soil, waste, and other drainage pipes inside the walls of a building and conveys it outside the building to a distance from 2 to 5 ft (0.70 to 1.70 m). This drain could be sanitary only, stormwater only, or combined stormwater and sanitary.

Building sewer Also called a house sewer, that part of the horizontal piping of a drainage system that extends from the end of the building drain outside the building and conveys the wastewater to a public sewer, private sewer, individual sewage-disposal system, or other approved point of disposal.

Building subdrain That portion of a drainage system below the building sewer that cannot drain by gravity.

Building trap Commonly called a house trap, a device, fitting, or assembly of fittings installed in the house drain to prevent the circulation of air between the house drain and the house sewer. It is usually installed as a running trap.

Bull head tee A tee in which the branch is larger than the run.

Burr A roughness of extra metal protruding from a pipe, usually caused by pipe cutting.

Burst pressure The maximum design pressure, usually four times normal operating pressure, applied to a piping assembly without causing rupture.

Bushing A pipe fitting that is solid plate with a hole in the center.

Butterfly valve A valve deriving its name from the wing-like action of the disc, which operates at right angles to the flow.

Butt weld A joint made with the two pipes ends or edges brought together and melted at the junction.

Bypass A pipeline with valves intended for diverting flow in a different direction or around a piece of equipment.

Bypass valve A device used to divert the flow past the part of the system through which it normally passes.

Calibration Comparison of the graduation of an instrument with a standard of known accuracy to eliminate variation.

Canopy A small roof protecting a window or entrance.

Capacity 1. The maximum or minimum flow obtainable under given conditions of media, temperature, pressure, velocity, etc. 2. The volume of media that may be stored in a container or receptacle.

Capillary The action by which a liquid is drawn into a void, primarily observed during soldering.

Catch basin A drainage structure used to collect stormwater only to enter a drainage system.

Cathodic protection The control of electrolytic corrosion by the application of an electric current in such a way that the structure is made to act as the cathode instead of the anode of an electrolytic cell.

Caulking A method of sealing a space tight against the passage of water or gas by means of applying a substance to adjacent surfaces.

Cavitation The formation of bubbles in a liquid because of a partial vacuum, which damages adjacent parts when these bubbles revert back to a liquid.

Cement joint The union of two fittings by the insertion of material, accomplished mechanically or chemically.

Cesspool Sometimes called a leaching cesspool, an excavation in the ground that receives the discharge of a drainage system and retains the organic matter and solids discharged but permit the liquids to seep through the bottom and sides.

Chainwheel A method of operating a valve by means of a chain-driven wheel.

Channel A trough through which any media may flow.

Chase A recess in a wall or a space in which pipes can be run.

Check valve A device designed to allow a fluid to pass through in one direction only.

Chemical waste system Piping that conveys corrosive or harmful industrial, chemical, or processed wastes to a separate drainage system.

Circuit The directed route taken by a flow of media from one point to another.

Circuit vent A branch vent that serves two or more traps and extends from in front of the last fixture to the connection with the vent stack.

Cistern A covered tank used for storing water, placed underground in many cases.

City water The potable water supply provided by a public utility.

Cleanout An opening or fitting in a pipe that can be removed for the purpose of cleaning or examining the interior of the pipe.

Clean room A particle-controlled area in which filtered air is supplied to maintain a specified level of cleanliness.

Clear water waste Clear wastewater drainage from equipment, rooms, and other areas that does not contain contaminants considered harmful.

Close nipple A short piece of pipe used to connect various fittings.

Coalescing The impingement of small-diameter aerosols that causes them to merge.

Cock Often used nomenclature for a faucet.

Code Regulations, subsequent amendments thereto, and any emergency rules that the department having jurisdiction may lawfully adopt.

Coefficient of expansion The numerical value that describes the increase in unit length and area of volume as a result of heat.

Cold flow The deformation of a material attributed to the pressure or forces acting at ambient temperatures.

Coliform Organisms considered to be in the coli aerogenes group.

Combination fixture A fixture that combines one sink and tray or a two- or three-compartment sink and/or tray in one unit.

Combined waste and vent system A specially designed system of waste piping, embodying the horizontal wet venting of one or more sinks, floor sinks, or floor drains by means of a common waste and vent pipe, adequately sized to provide the free movement of air above the flow line of the drain.

Combustible liquid Any liquid with a closed-cup flash point at or above 37.8°C (100°F), classified as follows: Class II liquid: a flash point at or above 37.8°C (100°F) and below 60°C (140°F); Class IIIA liquid: a flash point at or above 60°C (140°F) and below 93°C (200°F); Class IIIB liquid: a flash point at or above 93°C (200°F).

Combustion efficiency The rated percentage of heat produced compared to the actual heat transferred to the medium being heated.

Common vent A vent that connects at the junction of two fixture drains and serves as a vent for both fixtures.

Compressor A mechanical device used to increase the pressure of air or gas.

Condensate Molecules that separate from a gas upon cooling.

Condensate pipe A pipe that conveys liquid that is reduced from a vapor or a gas.

Conductivity The ability of a substance to conduct heat or electricity.

Conductor The piping conveying stormwater from a building to a point of disposal.

Conduit A pipe or channel for conveying media.

Connected load The total number of fixtures, equipment, or devices attached to a system.

Confluent vent A vent serving more than one fixture vent or stack vent.

Construction documents All drawings, specifications, and other written papers prepared or assembled for the purpose of describing the design, location, and physical characteristics necessary for obtaining permits and building a facility.

Contamination A degradation of quality in any material that creates a hazard to public health.

Contaminator A medium or condition that spoils the nature or quality of another medium.

Continuous vent A vertical vent that is a continuation of the drain to which it connects.

Continuous waste A drain from two or three fixtures connected to a single trap.

Control A manual or automatic device that regulates a machine or process.

Controller A cabinet containing the motor starter, circuit breaker, disconnect switch, and other control devices for the control of electric motors and internal combustion-engine-driven fire pumps.

Corporation cock A stopcock screwed into the street water main to supply the house service connection.

Corrosive The ability of a chemical compound or material to attack, eat away, and damage materials or human beings.

Coupling A pipe fitting with female threads used only to connect two pipes in a straight line.

Creep The elongation of a material due to heat or stress.

Critical level A reference point on a backflow prevention device or vacuum breaker that determines the minimum elevation above the flood level rim of a fixture or receptacle at which the device may be installed. When a backflow prevention device does not bear critical-level marking, the bottom of the vacuum breaker or combination valve or the bottom of any such approved device shall constitute the critical level.

Critical point The transition point at which a liquid and gas state merge into one another.

Cross A pipe fitting with four branches each at 90 degrees to each other.

Cross-connection Any physical connection or arrangement between two otherwise separated piping systems—one of which contains potable water and the other of which contains a liquid or another substance of unknown or questionable safety—whereby flow may occur from one system to the other, the direction of flow depending on the pressure differential between the two systems.

Crossover A pipe fitting with a double offset, or shaped like the letter U with the ends turned out, used to pass the flow of one pipe past another when the pipes are in the same plane.

Cross valve A valve fitted on a transverse pipe so as to open communication between two parallel pipes.

Crown The upper part of a trap where the direction of flow is changed from upward to horizontal.

Crown vent A vent pipe connected at the topmost point of a trap.

Cryogenic The field of low temperature.

Curb box An enclosure or chamber located at the curb that contains a shutoff valve on the supply line for gas or water to a building.

Curb inlet A drainage structure that allows stormwater to enter a drainage system from an opening in a road.

Curb valve A valve in a public location that controls the supply of water to a building.

Dampen 1. To check or reduce. 2. To deaden vibration.

Dead end A pipe, 2 ft (0.70 m) or more, terminated by means of a plug, cap, or other fitting that closes off the end of a pipe, which contains water, air, or a mixture of both that is not circulating in the piping system.

Deep seal trap A trap with a longer water seal than that required by code.

Deliquescent A material that changes state in the presence of water.

Demand Estimated flow or use expected under specific operating conditions.

Density The ratio of the weight of a substance to its volume.

Desiccant A material that easily adsorbs water vapor.

Design point The specific point in a piping network where a pipe size is calculated.

Detector, smoke A listed device for sensing the visible or invisible products of combustion.

Developed length The length along the centerline of pipe and fittings.

Dewpoint The temperature at which water in the air will start to condense on a surface.

Diameter The nominal inside diameter of a pipe as commercially designated unless otherwise noted.

Diaphragm A flexible disc that is used as a closure member in some valves.

Dielectric fitting A fitting having insulating parts or material that prohibits the flow of electric current.

Differential The variance between two target values.

Dissociation A separation of compounds dissolved in water into ions.

Diversity factor A percent of estimated usage compared to the connected load.

Digestion A process in which biochemical decomposition of organic matter takes place, resulting in the formation of simple organic and mineral substances.

Disc A closure member in some types of valves that closes off the flow.

Dishwasher An appliance for washing dishes, glassware, flatware, and utensils.

Displacement The volume or weight of a fluid, displaced by a floating body.

Disposal A motor-driven appliance that reduces food and other waste by grinding so it can flow through the drainage system.

Dissolved gases Gases that form ion components between molecules of a fluid or other substance.

Diversity factor A usage percent applied to the water flow rate that lowers the connected load, used because not all fixtures will discharge simultaneously.

Domestic sewage Liquid and waterborne wastes derived from ordinary living processes that are free of industrial wastes and of such a character as to permit satisfactory disposal without special treatment into the public sewer or by means of a private sewage disposal system.

Domestic water Water primarily indented for direct human use, such as that supplied to plumbing fixtures.

Dosing tank A watertight tank in a septic system placed between the septic tank and the distribution box and equipped with a pump or automatic siphon designed to discharge sewage intermittently to a disposal field so that rest periods may be provided between discharges.

Double check valve or double check assembly A backflow prevention device designed to protect the water supply from contamination that incorporates two check valves assembled in series.

Double disc When two wedges acting as a closure member in a gate valve are in contact with the seating faces.

Double offset Two changes of direction installed in succession, or series, in continuous pipe.

Double-ported valve A valve having two ports to overcome line pressure imbalance.

Double-sweep tee A tee made with easy (long-radius) curves between the body and branch.

Down Any piping running to a lower level.

Downspout A pipe that carries rainwater from a roof to its ultimate point of disposal.

Downstream A location in the direction of flow from a referenced point.

Drain Any pipe that carries wastewater or waterborne wastes in a building drainage system.

Drain field The area containing a piping arrangement from a septic tank for the purpose of disposing unwanted liquid waste into the soil.

Drain tile Subsoil drainage system used to protect foundations, underground floor levels, and/or structures from leakage or seepage trough of water due to hydrostatic pressure or ground saturation due to stormwater.

Drainage fitting A type of fitting used in drainage systems with a wide radius that allows a smooth flow of wastewater with minimum obstructions.

Drainage system The piping within a public or private premises that conveys sewage, rainwater, or other liquid wastes to an approved point of disposal immediately outside the building.

Drainage fixture unit (dfu) A measure of the probable discharge of a fixture or device into a drainage system.

Drift The deviation between actual values over time and a predetermined value.

Droop The amount a pressure, temperature, liquid level, or differential pressure deviates lower than a set value.

Drop Piping running to a lower elevation within the same floor level.

Drop elbow A small elbow having wings cast on each side, which have countersunk holes so they may be fastened by wood screws to a ceiling, wall, or framing timbers.

Drop manhole A drainage structure installed at the junction of two sewers when one is 2 ft (0.66 m) above the other.

Drop tee A tee having wings of the same type as the drop elbow.

Dry-bulb temperature The temperature of air as measured by an ordinary thermometer.

Dry-pipe valve A valve used with a dry-pipe fire protection sprinkler system that separates water and air. When a sprinkler head fuses, this valve opens, allowing water to flow to the sprinkler head.

Dry-weather flow Drainage collected during periods of no rain that contains little or no groundwater by infiltration and no stormwater at the time of collection.

Dry well A pit belowground having porous walls that allow liquid contents to seep into surrounding earth.

Dual fuel A device that is capable of using more than one heating medium to supply heat.

Dual vent See *common vent.*

Duration The concentration of a rainstorm, used in the design of a stormwater drainage system.

Durham system A soil or waste system in which all piping is of threaded pipe, tubing, or other material of rigid construction, and recessed draining fittings corresponding to the type of piping are used.

Durion Brand name for a high-silicon alloy that is resistant to practically all corrosive wastes, with a silicon content of approximately 14.5 percent and acid resistant throughout the entire thickness of the metal.

Duty cycle The length of time a particular device is in operation.

Dwelling A habitable unit with a potable water supply and integral or closely adjacent toilet facilities, intended for people and used for living.

DWV Abbreviation for drain, waste, and vent.

Earth load The vertical weight of earth or backfill over a buried pipe.

Eccentric fittings Fittings where the openings on either end are offset.

Effective opening The minimum cross-sectional area at the point of water-supply discharge, measured or expressed in terms of the diameter of a circle or, if the opening is not circular, the diameter of a circle of equivalent cross-sectional area, applicable to an air gap.

Effluent Any substance entering or carried in a drainage system.

Ejector pit A tank or pit located below the normal grade of a gravity system that receives sanitary waste and must be emptied by mechanical means.

Ejector pump A mechanical device for removing sanitary waste containing solids from an ejector pit.

Elastic limit The greatest stress that a material can withstand without permanent deformation after the release of the stress.

Elastomer A rubber-like substance that when stretched to at least two times its length will return to its original shape upon release.

Elbow A fitting that makes a 90-degree angle (unless otherwise specified) between adjacent pipes.

Electrolysis The process of producing chemical changes by passage of an electric current through an electrolyte (as in a cell), where the ions present carry the current by migrating to the electrodes where they may form new substances (as in the deposition of metals or the liberation of gases).

Electrolyte A dissolved impurity of water.

Elutriation A process of sludge conditioning in which certain constituents are removed by successive decontaminations with freshwater or plant effluent, thereby reducing the demand for conditioning chemicals.

End connection A method of connecting the parts of a piping system (e.g., threaded, flanged, butt-weld, socket-weld).

Engineered plumbing system A plumbing system designed by use of modern engineering design criteria.

Equivalent run The measured length of pipe with an additional length to compensate for the friction lost to pipe flow, fittings, and valves.

Erosion The gradual destruction of metal or other material by the abrasive or electromechanical action of liquids, gases, solids, or mixtures of these materials.

Evapotranspiration The loss of water from soil by both evaporation and transpiration from the plants growing thereon.

Existing work A plumbing system regulated by code, or any part thereof, that was installed prior to the effective date of an applicable code.

Exfiltration A liquid leaking out of a sewer.

Expansion joint A joint whose primary purpose is to absorb expansion.

Expansion loop A piping arrangement with sufficient length to absorb longitudinal thermal expansion due to heat without undue stress.

Extra heavy Piping material, usually cast iron, that is thicker than standard pipe.

Faucet A mechanical device used to supply water to a plumbing fixture or shut it off.

Face-to-face dimensions The dimensions from the face of the inlet port to the face of the outlet port of a valve or fitting.

Female thread The internal thread in pipe fittings, valves, etc., for making screwed connections.

Filter A device through which fluid is passed to separate contaminants from it.

Filter element or media A porous device that performs the process of filtration or filtering.

Fire alarm system A functionally related group of devices that, when automatically or manually activated, sounds an audible or visual warning either on or off the protected premises, signaling a fire.

Fire department connection An inlet connection that receives pumped water from fire department equipment to supply a building's fire sprinkler or standpipe system, most commonly made of a brass body with several 2½-inch hose inlets, a check valve for inlet flow only, an automatic drip connection to prevent leftover water from freezing, and escutcheons with integrated or separate labels indicating what system is being served. FDCs can be exposed (mounted on an exterior building wall), flush-mount (mounted on an interior building connection with inlets on the exterior wall), or freestanding (post-mounted outside the building).

Fire hazard Any thing or act that increases, or will cause an increase of, the hazard or menace of fire to a degree greater than what is customarily recognized as normal or that will obstruct, delay, hinder, or interfere with the operations of the fire department or the egress of occupants in the event of a fire.

Fire hydrant A dedicated piping connection used to supply water for fire department use.

Fire line A system of pipes and equipment used exclusively for extinguishing fires.

Fire pump An approved pump with a driver, controls, and accessories used to supply water for fire protection service.

Fire pump types

- **Can pump** A vertical-shaft, turbine-type pump in a can (suction vessel) for installation in a pipeline to raise water pressure.
- **Centrifugal pump** A pump in which the pressure is developed principally by the action of centrifugal force.
- **End-suction pump** A single-suction pump with its suction nozzle on the opposite side of the casing from the stuffing box and the face of the suction nozzle perpendicular to the longitudinal axis of the shaft.
- **Excess pressure pump** A low-flow, high-head pump for sprinkler systems not being supplied from a fire pump that pressurizes the sprinkler system so the loss of water supply pressure will not cause a false alarm.
- **Horizontal pump** A pump with the shaft normally in a horizontal position.
- **Horizontal split-case pump** A centrifugal pump characterized by a housing that is split parallel to the shaft.
- **Inline pump** A centrifugal pump in which the drive unit is supported by the pump, with its suction and discharge flanges on approximately the same centerline.
- **Pressure maintenance (jockey) pump** A pump with controls and accessories used to maintain pressure in a fire protection system without the operation of the fire pump.
- **Vertical shaft turbine pump** A centrifugal pump with one or more impellers discharging into one or more bowls and a vertical educator or column pipe used to connect the bowls to the discharge head on which the pump driver is mounted.

Fitting A device used to connect pipes or change the direction of straight runs of pipe.

Fitting, compression A fitting designed to join pipe or tubing by means of pressure or friction.

Fitting, flange A fitting that utilizes a radially extending collar for sealing and connection.

Fixture branch A pipe, not considered a main, connecting several fixtures.

Fixture carrier A device designed to support a plumbing fixture.

Fixture drain The drain from the trap of a fixture to the junction of that drain with any other drain pipe.

Fixture supply A water supply pipe connecting to a fixture from a branch or main.

Fixture unit, drainage (dfu) A numeric value representing the probable rate of drainage discharge into a drainage system by various types of plumbing fixtures or equipment.

Fixture unit, water (wfu) A numeric value representing the probable rate of water supply used by various types of plumbing fixtures or equipment.

Flammable Capable of being ignited.

Flammable gas Any substance that exists in the gaseous state at normal atmospheric temperature and pressure and is capable of being ignited and burned when mixed with the proper proportion of air, oxygen, or other oxidizers.

Flammable liquid A liquid that has a closed-cup flash point below 37.8°C (100°F) and a maximum vapor pressure of 2,068 mm Hg (40 psi absolute) at 37.8°C (100°F).

Flange A ring-shaped plate on the end of a pipe at right angles to the end of the pipe and provided with holes for bolts to allow the pipe to be fastened to a similarly equipped adjoining pipe.

Flange end A valve or fitting having plain-faced, raised-face, large male-and female, large tongue-and-groove, small tongue-and-groove, or ring-joint flanges for joining to other piping elements.

Flange faces A pipe flange in which the entire surface of the flange is faced straight across and uses either a full-face or ring gasket.

Flashing Any waterproof material fitted over a surface where water is expected to run.

Flash point The temperature at which a fluid gives off flammable vapor in sufficient concentration to form an ignitable mixture.

Float valve A valve that is operated by means of a bulb or ball floating on the surface of a liquid within a tank. The rising and falling action operates a lever, which opens and closes the valve.

Flooded The condition when liquid rises to the flood level rim of a fixture.

Flood level rim The top edge of a receptacle or fixture from which water overflows.

Flow pressure The pressure in a water supply pipe near the water outlet while the faucet or water outlet is fully open and flowing.

Flotation A buoyant force that causes a buried tank to rise.

Flue An enclosed passage, primarily vertical, for the removal of the gaseous products of combustion to the exterior.

Flush tank An atmospheric receptacle holding water integrated with a water closet designed to discharge a predetermined quantity of water to flush a water closet.

Flush valve A pressurized device that supplies a predetermined quantity of water to water closets and other similar fixtures and is closed by direct pressure or other mechanical means. Also called flushometer valve.

Flushing-type floor drain A floor drain that is equipped with an integral water supply, enabling flushing of the drain receptor and trap.

Flux A paste used to aid the flowing characteristics and to prevent oxidation of brazed or soldered joints.

Footing The lowest part of a foundation wall or column resting on the bearing soil, rock, or piling that transmits the superimposed load to the bearing material.

Footing drain A special pipe installed at or below a footing to remove accumulated groundwater or rainwater.

Foot valve A check valve installed at the base of a pump suction pipe to maintain prime by preventing pumped liquid from draining away from the pump.

Force main A pumped sewer under pressure.

Fouling factor A percent reduction used in water heating devices to account for obstructions in the heating coils.

French drain A drain consisting of an underground passage made by filling a trench with loose stones and covering it with earth. Also called rubble drain.

Fresh-air inlet A vent line connected with the building drain upstream of the house trap and extending to the outer air, which provides air circulation between the house drain and the public sewer.

Friction factor A quantity that relates to the head loss of a fluid's velocity while the fluid is flowing through a specific length and diameter of pipe.

Frostproof A device containing water that will not freeze at a low temperature.

Galvanic action An interchange of atoms carrying an electric charge between materials. The anode metal with the higher electrode potential corrodes; the cathode is protected.

Galvanizing A process where the surface of iron or steel piping or plate is covered with a layer of zinc.

Generally accepted standard A document referred to in criteria or code and accepted by the administrative authority.

Grade 1. The surface of the ground or the slope or fall of a line of pipe in reference to a horizontal plane. 2. In drainage systems, the fall in a fraction of an inch or percentage slope per foot (mm/m) length of pipe. 3. The quality of a material.

Grating A device that allows stormwater to enter the top of a drainage structure while preventing the entrance of debris.

Gravel A course material of sizes ¾ inch to 3 inches.

Graywater Domestic wastewater that is untreated and does not contain serious contaminants, including waste from lavatories, bathtubs, showers, clothes washers, and laundry tubs but not waste from water closets, kitchen sinks, and dishwashers.

Grease interceptor A plumbing appurtenance that is installed in a sanitary drainage system to intercept oily and greasy wastes from a wastewater discharge and is capable of intercepting free-floating fats and oils.

Grease-laden waste Effluent discharge that is produced from food processing, food preparation, or other sources where grease, fats, and oils enter automatic dishwater pre-rinse stations, sinks, or other appurtenances.

Grinder pump A solids-handling pump that grinds sewage solids to a fine slurry, rather than passing through entire spherical solids.

Groundwater Water found at or below grade extending down to an impervious layer.

Guide (piping) A device used to allow axial pipe movement only.

Guide (document) A document that is advisory or informative in nature and contains only nonmandatory provisions, thus is not suitable for adoption into law.

Gutter An open horizontal channel that carries stormwater away from a roof surface.

Halon 1301 A colorless, odorless, electrically nonconductive gas for extinguishing fires that is no longer used due to environmental considerations.

Hanger A device used to suspend pipes or equipment within a building or structure.

Haunch The portion of a buried pipe below the centerline.

Hazardous chemical A chemical with one or more of the hazard ratings as defined in NFPA 704: *Standard System for the Identification of the Hazards of Materials for Emergency Response*. (For the hazard ratings of many chemicals, see *Fire Protection Guide to Hazardous Materials* by NFPA.)

Head A unit of measure representing the relative energy of a static or flowing fluid.

Header A pipe that does not diminish in size.

Head loss The energy loss of a fluid as it passes through a flow passage. Also called pressure drop.

Heat exchanger A device specifically designed and constructed to efficiently transfer heat energy from a hot fluid to a cooler fluid.

Heat tracing A continuous or intermittent application of heat to a pipe or vessel to replace the heat lost to ambient air.

Heat transfer The movement of heat energy.

Horizontal A pipe or fitting that makes an angle of less than 45 degrees with the horizontal.

Hose bibb A faucet installed on the outside wall of a building for the supply of potable water.

Hot water Water at a temperature higher than ambient established by generally accepted practice or code as being suitable for a specific application (e.g., water at a temperature greater than or equal to 110°F [43°C] as defined in the International Plumbing Code).

House drain A house sewer.

House trap A building trap.

Hub-and-spigot A joint made with an enlarged diameter or hub at one end and a spigot at the other end, tightened by oakum and lead or by a neoprene gasket caulked or inserted in the hub around the spigot. Generally referred to as a caulked joint.

Hub drain 1. A drainage receptacle with a raised rim and without a strainer or grate. 2. A floor drain incapable of receiving surface drainage (commonly used for equipment condensation drainage).

Hubless Soil piping with plain ends, with a joint consisting of a stainless steel or cast-iron clamp and neoprene gasket assembly.

Humidity The percent of water vapor in the air compared to the saturated amount of water vapor possible at the temperature when measured. Often called relative humidity.

Hydrant A valve or faucet for drawing water from a pipe in large quantities, usually used in reference to a fire department water supply.

Hydraulically remote Furthest from the source of supply in terms of total pressure lost through the entire system.

Immiscible A liquid incapable of being dissolved in water.

Impeller A rotating part of a pump that imparts velocity to the liquid by centrifugal force.

Impurity Any physical, chemical, or biological substance found in water that makes it unsuitable for the purpose intended or as a source of potable water.

Indirect waste A discharge to the drainage system or receptacle through an air gap as a method to avoid cross-connections.

Individual vent A pipe that is installed to vent only one fixture trap and connects with the vent system above the fixture served or terminates in the open air.

Induced siphonage Loss of liquid from a fixture trap due to the pressure differential between the inlet and outlet of a trap, often caused by the discharge of another fixture.

Industrial waste All liquid or waterborne waste from industrial or commercial processes that has properties other than domestic sewage.

Inert A gas that does not react with other materials at ordinary temperatures and pressures.

Infiltration Liquid leaking into a sewer.

Inflow Surface water flowing into a catch basin, manhole, or other collection device.

Inlet filter A device in compressed air service that cleans air entering a compressor.

Inorganic A chemical substance of mineral origin.

Input The amount required for proper operation of any device.

Instantaneous water heater A water heater designed to heat water only upon demand.

Instrument air 1. An alternative for nitrogen intended for the powering of medical devices unrelated to human respiration (e.g., surgical tools, ceiling arms). It is a medical support gas that falls under the general requirements for medical gases. 2. Air intended for powering industrial equipment and devices, cleaning, service, and maintenance.

Interceptor A device that separates, retains, and allows removal of any specific material suspended in a waste stream, while permitting acceptable liquids to flow freely into a drainage system.

Invert The lowest point on the interior of a horizontal pipe.

Ion An atom or group of atoms that has an electrical charge.

Isobaric process The compressing of air under constant pressure.

Isochoric process The compressing of air under constant volume.

Isothermal process The compressing of air under constant temperature.

Labeled Equipment, products, or materials bearing a label of a listing agency.

Laboratory outlet A small faucet in a bench used for dispensing water or gas in laboratories.

Lateral sewer A drainage pipe that does not receive sewage from any other common sewer except house connections.

Leaching well See dry well.

Leader Piping containing only stormwater.

Liquid waste The discharge from any fixture, appliance, or appurtenance in connection with a plumbing system that does not receive fecal matter.

Listed Equipment, products, or materials approved by a third-party testing organization and acceptable to the authority having jurisdiction.

Listing agency An agency accepted by the administrative authority to list or label certain models of a product and maintain a periodic inspection program on the current production of listed models to indicate that the products have been tested, comply with generally accepted standards, and are safe for use in a specified manner.

Load factor The percentage of the total connected fixture unit flow that is likely to occur at any point in a drainage system, representing the ratio of the probable load to the connected load and determined by the average rates of flow of the various kinds of fixtures, average frequency of use, duration of flow during one use, and number of fixtures installed.

Loop vent A vent serving two or more traps and extending from the front of the last fixture to a stack vent.

Main The principal artery of a system of continuous piping to which branches may be connected.

Main vent A vent header to which vent stacks are connected.

Malleable Capable of being extended or shaped. Most metals are malleable.

Manhole A drainage structure used for allowing access into a sewer, allowing water to enter a sewer, or allowing easy connection when placed at the junction of sewers.

Manifold (medical) A device used to connect the outlets of one or more gas cylinders to the central piping system for that specific gas.

Manifold (plumbing) A multi-opening header to which one or more branch lines connect.

Master plumber An individual who is licensed and authorized to install and assume responsibility for contractual agreements pertaining to plumbing and to secure any required permits.

Maximum probable demand The most connected devices that may be expected to be in use at any one time.

Medical air Pharmaceutical air used for life support, supplied from cylinders, bulk containers, or medical air compressors or reconstituted from oxygen USP and oil-free, dry nitrogen NF.

Medical gas alarm system One of four distinct types of alarms in Category 1 and Category 2 medical gas systems—master alarms, area alarms, local alarms, and Category 3 alarms—as recognized by NFPA 99: *Healthcare Facilities Code*.

> **Area alarm system** A warning system within an area of use that provides continuous visible and audible surveillance of Category 1 and Category 2 medical gas and vacuum systems, typically located in treatment areas at or near the nurses' station to monitor and report on conditions for the benefit of the staff in that area.
>
> **Category 3 alarm system** A warning system within an area of use that provides continuous visible and audible surveillance of Category 3 medical gas systems, commonly used in a medical gas system with low risk to the patient, such as in a dental office.
>
> **Local alarm system** A warning system that provides continuous visible and audible surveillance of medical gas and vacuum system source equipment at the equipment site, placed on or very near the source equipment they monitor.
>
> **Master alarm system** A warning system that monitors the operation and condition of the source of supply, the reserve source (if any), and the pressure in the main lines of each medical gas and vacuum piping system, used to indicate the condition of the sources of supply (which may be remote) at locations that are attended whenever the building is occupied and where the staff who will act to correct any failures will see the alarm.

Medical gas system An assembly of equipment and piping used to distribute nonflammable medical gases such as oxygen, nitrous oxide, compressed air, carbon dioxide, and helium for direct patient application from central supply systems, with pressure and operating controls, alarm warning systems, related components, and piping networks extending to station outlet valves at patient use points.

Medical support gas Nitrogen or instrument air falling under the general requirements for medical gases used for any medical support purpose (e.g., to remove excess moisture from instruments before further processing or to operate medical-surgical tools, air-driven booms, pendants, or similar applications) and not respired as part of any treatment.

Medical-surgical vacuum A method used to provide a source of drainage, aspiration, and suction to remove body fluids from patients.

Medical-surgical vacuum system A system consisting of central vacuum-producing equipment with pressure and operating controls, shutoff valves, alarm warning systems, gauges, and a network of piping extending to and terminating with suitable stations inlets at locations where patient suction may be required.

Mist An aerosol suspended in air composed of liquid particles.

Monitoring Observation, sampling, or testing at designated locations.

Negative pressure Pressure less than atmospheric.

Nonpotable water Water not safe for drinking, personal, or culinary use.

Normal pressure The design or expected force per unit area at any point of a system.

Occupancy The purpose for which a building, structure, or portion thereof is utilized or occupied.

Occupancy classification A classification that designates the combustibility of the contents in an area, used for fire suppression system design.

> **Light hazard** Occupancies with a low quantity of combustibles with low heat release (e.g., churches, hospitals, museums, offices).
>
> **Ordinary hazard 1** Occupancies with a moderate quantity of combustibles with moderate heat release and 8-foot stockpiles (e.g., mechanical rooms, restaurant kitchens, laundry facilities).

Ordinary hazard 2 Occupancies with a moderate quantity of combustibles with moderate heat release and 12-foot stockpiles (e.g., stages, large library stack rooms, repair garages).

Extra hazard 1 Occupancies with a high quantity of combustibles with high heat release and no flammable or combustible liquids (e.g., aircraft hangers, saw mills).

Extra hazard 2 Occupancies with a high quantity of combustibles with high heat release and flammable and combustible liquids (e.g., plastics processing, flammable liquids spraying).

Offset A combination of fittings that takes a pipe out of line and places it parallel to the original pipe.

Open air Free air outside any structure.

Open site drain A floor drainage receptacle without a strainer or grate capable of receiving surface drainage, commonly used in mechanical rooms for equipment pressure and temperature relief valve discharge spillage.

Outfall sewer A sewer receiving the sewage from a collection system and carrying it to the point of final discharge or treatment. It usually is the largest sewer of an entire system.

Output The actual amount of available material necessary to perform the intended function of a device.

Overflow roof drain A redundant (emergency) roof drain installed in roofs with parapet walls that entraps rainwater and removes it from the surface of the roof into a leader, discharging above grade. See also secondary roof drain.

Oxidant A nonflammable gas that will support combustion.

Peak load The maximum design flow rate calculated by multiplying the connected load with the diversity factor.

Percolation Also called infiltration, the rate that a liquid will flow deeper into a soil.

Pitch The amount of downward slope or grade given to horizontal piping and expressed in inches per foot (mm/m) on a horizontally projected run of pipe.

Plumbing The practice, materials, and fixtures used in the installation, maintenance, extension, and alteration of all piping, fixtures, appliances, and plumbing appurtenances within or adjacent to any structure in connection with sanitary or liquid waste drainage, storm drainage facilities, venting systems, public or private water supply systems, and natural and other gases to their connection with any point of supply, public disposal, or other acceptable terminal. It does not include any fire, product, or process work.

Plumbing appliance Any one of a special class of plumbing fixtures intended to perform a special function, including fixtures having operation and control dependent on one or more energized components, such as motors, controls, heating elements, or pressure- or temperature-sensing elements.

Plumbing appurtenance A manufactured device, prefabricated assembly, or on-the-job assembly of components that is adjunct with the basic piping system and plumbing fixtures.

Plumbing engineering The application of scientific principles to the design, installation, and operation of efficient, economical, ecological, energy-conserving, and plumbing code-compliant systems for the transport and distribution of liquids and gases.

Plumbing fixture An installed receptacle, device, or appliance other than a trap that dispenses potable hot and cold water and discharges the waste into the plumbing drainage system of a facility.

Plumbing inspector Any person who, under the authority of the department having jurisdiction, is authorized to inspect plumbing and drainage systems as defined in the code for the municipality and complies with the laws of licensing and/or registration of the state, city, or county.

Plumbing service box Wall-recessed or surface-mounted box containing valve(s) with connections for water supply and drainage, open inlet, or both. (Commonly used for clothes washing machine connections and as a point of water supply connection for dishwashers, refrigerators, humidifiers, brewage machines, coffee machines, and ice makes, etc.)

Plumbing systems All potable water supply and distribution piping, plumbing fixtures and traps, drainage and vent pipe, and natural gas systems including their respective joints, connections, devices, receptacles, and appurtenances within the property lines of the premises, including additional components in the system such as potable water-treating or water-using equipment, fuel gas piping, water heaters, and vents.

Polymer A chemical compound or mixture of compounds of high molecular weight formed by the polymerization of monomers.

Pore The space between particles of soil.

Potable water Water of sufficient purity suitable for human use and meeting the quality standards and regulations of the public health authority having jurisdiction.

Precipitation Water directly discharged from the clouds as snow, rain, hail, or sleet.

Pressure rating The estimated maximum force per unit area that a medium in a pipe can exert continuously with a high degree of certainty that failure of the pipe would not occur.

Private sewage disposal system A system not connected to any public sewer or point of disposal that discharges effluent into a tank that reduces the sewage to a liquid and discharges this liquid into a subsurface disposal field, one or more seepage pits, a combination of subsurface disposal field and seepage pit, or other such facilities as may be permitted under the procedures set forth in a code.

Private sewer A sewer that is privately owned and not directly operated by public authority.

Private use Plumbing fixtures in residences and apartments, private bathrooms in hotels and hospitals, and restrooms in commercial establishments containing restricted-use single fixtures or groups of single fixtures and similar installations, where the fixtures are intended for the use of a family or an individual.

Public sewer A common sewer directly operated by the public authority.

Public use Toilet rooms and bathrooms used by employees, occupants, visitors, or patrons in or about any premises, and locked toilet rooms or bathrooms to which several occupants or employees on the premises possess keys and have access.

Putrefaction Biological decomposition of organic matter with the production of ill-smelling products, usually occurring when there is a deficiency of oxygen.

Rainfall intensity Commonly called the rate of rainfall, the amount of rain measured in inches per hour (mm/hour).

Raw sewage Untreated sewage.

Raw water Nonpotable water used as the intake to any device or process, generally used to describe water supply from a natural source such as a river, lake, or stream.

Receptor A plumbing fixture or device of such material, shape, and capacity that it will adequately receive the discharge from indirect waste pipes and so constructed and located that it can be readily cleaned.

Recovery rate The amount of water capable of being heated to the design temperature per unit of time.

Reduced pressure zone backflow preventer A backflow prevention device consisting of two independently acting check valves separated by an intermediate chamber, intended to discharge water that backflows into the chamber.

Reducer A pipe fitting larger at one end than at the other used to connect pipes of different diameters.

Reflecting pool A water basin used for decorative purposes.

Registered design professional An individual who is registered or licensed to practice professional architecture or engineering as defined by the statutory requirements of the professional registration laws of the state or jurisdiction in which the project is to be constructed.

Regulator A device intended to reduce a variable inlet pressure to a constant outlet pressure under variable flow conditions.

Relief vent A vent designed to equalize the pressure of air between drainage and vent systems or to act as an auxiliary vent.

Residual pressure Water pressure less than static pressure that varies with flow rate.

Resistivity A measurement of the resistance of a substance to the passage of an electrical current.

Return offset A double offset installed to return a pipe to its original alignment.

Return period The amount of time that must elapse to produce the most severe design storm. Also called frequency.

Revent pipe That part of a vent pipe line that connects directly with an individual waste pipe or group of waste pipes, underneath or at the back of the fixture, and extending either to the main or branch vent pipe. Also known as individual vent.

Rim An unobstructed open edge of a fixture.

Riprap A rough stone of various sizes placed irregularly to prevent scouring or erosion by water or debris.

Riser A vertical water supply pipe that extends one full story or more to convey water to branches, fixtures, or the fire suppression system above or below grade

Roof drain A drain installed to remove water collecting on the surface of a roof and discharge it into the leader.

Roughing in The installation of all parts of a plumbing system that can be completed prior to the installation of fixtures, including drainage, water supply, and vent piping and the necessary fixture supports.

Runout A horizontal drainage line connected to a vertical line at its lowest level.

Sand filter A water treatment device for removing solid or colloidal material using sand as the filter medium.

Sanitary 1. When used for plumbing, any drainage system that carries human waste. 2. When used for pharmaceutical purposes, a system that is clean or sterile.

Sanitary sewer A conduit or pipe carrying sanitary sewage.

Schedule A system of iron pipe sizes that provides for standardized outside diameters and wall thicknesses.

Scupper An opening in a parapet wall above the roof line serving as an overflow.

Secondary roof drain A redundant (emergency) roof drain installed in roofs with parapet walls that entraps rainwater and removes it from the surface of the roof into a leader, discharging above grade. See also overflow roof drain.

Seepage pit An excavation in the ground that receives the discharge of a septic tank and is designed to permit effluent from the tank to seep through its bottom and sides.

Self-extinguishing The ability of a material to resist burning when the source of heat has been removed.

Septic tank A watertight receptor that receives the discharge of a drainage system, or part thereof, designed and constructed to digest organic matter over a period of detention and then discharge the wastewater into the soil.

Service factor A percent number used to reduce the strength value used to obtain an engineered stress.

Service hot water Hot water for other than potable use, intended for commercial or industrial purposes.

Sewage Any liquid waste containing animal, vegetable, or chemical wastes in suspension or solution.

Sewage ejector A device used to lift sewage by entraining it in a high-velocity jet or stream of air or water.

Siamese connection A multiple water connection in the form of a wye on the outside of a building that combines flow from two or more lines into a single pipe supplying water into the building, used for fire department purposes.

Sidewall area A vertical surface that contributes runoff to the stormwater drainage system.

Sill cock Water outlet with a threaded end, attached to the exterior of a building structure, normally used as a hose connection (also known as wall hydrant).

Slip joint A fitting used in drainage systems, usually from a fixture, where one pipe slides into another.

Sludge The accumulated waste solids of sewage deposited in tanks, beds, or basins, mixed with water to form a semi-liquid mass.

Soil pipe Any pipe that conveys the discharge of human or animal bodily waste.

Soldering The joining of two pipes using a filler metal that has a melting point less than 1,000°F (538°C).

Special waste Waste that requires some special method of handling, such as the use of indirect waste piping and receptors, corrosion-resistant piping, sand, oil, or grease interceptors, condensers, or other pretreatment.

Specific gravity The ratio of the weight of one substance to another standard of equal volume. For gas, the standard is air (1), and the standard for liquids and solids is water (1).

Spring line The centerline of a buried pipe.

Sprinkler system An integrated system of underground and overhead piping designed in accordance with fire-protection engineering standards, including one or more automatic water supplies, which is activated by heat from a fire and discharges water over the fire area.

Sprinkler system, special type A special-purpose fire-suppression system employing departures from the requirements of standards, such as special water supplies and reduced pipe sizing, installed in accordance with its listing.

Sprinkler types

Concealed sprinkler A recessed sprinkler with cover plates.

Corrosion-resistant sprinkler A sprinkler with a special coating or plating to be used in an atmosphere that would corrode an uncoated sprinkler.

Dry pendent sprinkler A sprinkler for use in a pendent position in a dry-pipe or wet-pipe system with the seal in a heated area.

Dry upright sprinkler A sprinkler designed to be installed in an upright position on a wet-pipe system to extend into an unheated area with a seal in a heated area.

Early suppression fast response (ESFR) sprinkler A sprinkler designed to be fast response and listed for its capability to provide fire suppression of a specific high-challenge fire hazard.

Extended-coverage sprinkler A sprinkler (pendent or sidewall) with special extended, directional discharge patterns.

Flush sprinkler A sprinkler in which all or part of the body, including the shank thread, is mounted above the lower plane of the ceiling.

Intermediate-level sprinkler A sprinkler equipped with integral shields to protect its operating elements from the discharge of sprinklers installed at higher elevations.

Large-drop sprinkler A listed sprinkler characterized by a K factor between 11.0 and 11.5, large drops of such size and velocity as to enable effective penetration of a high-velocity fire plume, and a proven ability to meet the penetration, cooling, and distribution criteria prescribed in the large-drop sprinkler examination requirements.

Nozzle A device for use in applications requiring special discharge patterns, directional spray, fine spray, or other unusual discharge characteristics.

Old-style/conventional sprinkler A sprinkler that directs 40 to 60 percent of the total water initially in a downward direction and designed to be installed with a deflector either upright or pendent.

Open sprinkler A sprinkler from which the actuating elements (fusible links) have been removed.

Ornamental sprinkler A sprinkler that has been painted or plated by the manufacturer.

Pendent sprinkler A sprinkler designed to be installed in such a way that the water stream is directed downward against the deflector. (Note the spelling of the word pendent—a convention adopted by the fire protection industry.)

Quick response early suppression (QRES) sprinkler A quick response sprinkler that complies with the extended protection areas as defined by NFPA and tested by the manufacturer.

Quick-response (QR) A type of sprinkler that is both a fast-response and a spray sprinkler.

Recessed sprinkler A sprinkler in which all or a part of the body, other than the shank thread, is mounted within a recessed housing.

Residential sprinkler A sprinkler that has been specifically listed for use in residential occupancies.

Sidewall sprinkler A sprinkler having special deflectors that are designed to discharge most of the water away from a nearby wall in a pattern resembling a quarter of a sphere, with a small portion of the discharge directed at the wall behind the sprinkler.

Special sprinkler A sprinkler that has been tested and listed as having special limitations.

Upright sprinkler A sprinkler designed to be installed in such a way that the water spray is directed upward against the deflector.

Stack The vertical main pipe of a system of soil, waste, or vent piping extending through one or more stories.

Stack vent The extension of a soil waste stack above the highest horizontal drain connected to the stack extending to the outside air.

Stack venting A method of venting a fixture or fixtures through a soil or waste stack.

Standard A generally accepted document, published by a recognized authority, that is referenced by inclusion in codes and requires conformance.

Standard dimensional ratio Regarding plastic pipe, the diameter of the pipe divided by the wall thickness.

Standard temperature and pressure Conforming to the temperature and pressure requirements of the authority having jurisdiction.

Standpipe A vertical pipe generally used for the distribution of water for fire extinguishing.

Standpipe system An arrangement of piping, valves, hose connections, and allied equipment with a connection to a water supply installed in a building or structure in such a manner that water can be discharged in streams or spray patterns through attached hoses and nozzles, for the purpose of extinguishing a fire and protecting a building or structure and its contents as well as its occupants.

Standpipe system class of service

- **Class I** For use by fire departments and those trained in handling heavy fire streams (2½-inch hose).
- **Class II** For use primarily by the building occupants until the arrival of the fire department (1½-inch hose).
- **Class III** For use either by fire departments and those trained in handling heavy hose streams (2½-inch hose) or by the building occupants (1½-inch hose).

Standpipe system types

- **Dry standpipe** A system having no permanent water supply, arranged through the use of approved devices to admit water to the system automatically by the opening of a hose valve.
- **Wet standpipe** A system with an open supply valve and pressurized water in the system at all times.

Stop valve Commonly called an angle stop, a valve used to control the water supply, usually to a single fixture.

Storm sewer A sewer used for conveying only rainwater, snow, ice, or other natural precipitation.

Stormwater Rainwater, snow, ice, or other natural precipitation from site or roof surfaces.

Strain Change in the shape or size of a body produced by the action of stress.

Stratification A condition found inside water heating tanks where water remains in layers depending on temperature instead of mixing.

Street pressure The pressure available in a public water main.

Stress Reactions within a body resisting external forces acting on it.

Subsoil drain A drain that receives only subsurface or seepage water and conveys it to an approved place of disposal.

Suds pressure zone The portion of a waste stack where the formation of soap suds could create pressure higher than atmospheric pressure.

Sump A tank or pit located below the normal grade of a gravity system that receives clear liquid waste and must be emptied by mechanical means.

Sump pump A mechanical device for removing clear liquid waste from a sump.

Super flush When many flush valves are used at one time in stadiums and places of assembly, typically done to test the system.

Supervisory (tamper) switch A device attached to the handle of a valve that, when the valve is operated, annunciates a trouble signal at a remote location.

Support A device for supporting and securing pipe, fixtures, and equipment to walls, ceilings, floors, or structural members.

Swimming pool A structure, basin, or tank containing water for swimming, diving, or recreation.

Tee A fitting where a straight run of pipe has a connection at a right angle to the run.

Temperature A measure of heat.

- **Degree Celsius (formally Centigrade) (C)** An incremental value in metric units (SI) where the freezing point of water (0°C) and the boiling point of water (100°C) are divided into 100 divisions.
- **Degree Fahrenheit (F)** An incremental value in English (IP) units, where the freezing point of water (32°F) and the boiling point of water (212°F) are divided into 180 divisions.

Degree Kelvin (K) A value in degrees Celsius based on a starting temperature of absolute zero, -273.15°C, created for laboratory use.

Degree Rankine (R) A value in degrees Fahrenheit based on a starting temperature of absolute zero, -459.67°F.

Tempered water Hot and cold water mixed to obtain an intermediate temperature, generally from 80°F to 100°F (29°C to 43°C).

Tepid A moderate, lukewarm water temperature, between 60°F and 100°F (16°C and 38°C).

Thermal efficiency A ratio of the energy output from a system to the energy input to the system.

Third-party certified Certification obtained by the manufacturer indicating that the function and performance characteristics of a product or material have been determined by testing and ongoing surveillance by an approved third-party certification agency.

Thrust block A heavy, solid material placed at a fitting of an underground water pipe on undisturbed soil, used to resist the force generated by flowing water on the fitting.

Torr The suggested international standard term to replace millimeters of mercury.

Toxic The ability of a substance to produce injurious or lethal effects on a susceptible site.

Trailer park sewer The part of the horizontal piping of a drainage system that begins 2 ft (0.6 m) downstream from the last trailer site connection, receives the discharge of the trailer site, and conveys it to a public sewer, private sewer, individual sewage disposal system, or other approved point of disposal.

Trap A fitting or device designed and constructed to provide, when properly vented, a liquid seal that will prevent the back-passage of air without significantly affecting the flow of sewage or wastewater through it.

Trap primer A device or system of piping to maintain a water seal in a trap.

Trap seal The maximum vertical depth of liquid that a trap will retain, measured between the crown weir and the top of the dip of the trap.

Triple point The temperature and pressure for a pure substance where the three phases (liquid, solid, and gas) exist in equilibrium.

Tube pull The room necessary to remove either heating tube bundle from a water heater.

Turbidity A measure of the number of suspended particles in a liquid.

Turbulence Any deviation from parallel flow in a pipe.

Underground piping Pipe buried below grade.

Unsanitary A condition that is contrary to sanitary principles or that is injurious to health.

Upstream A location in the direction of flow before reaching a referenced point.

Vacuum Any pressure less than that exerted by the atmosphere.

Vacuum breaker, atmospheric A vacuum breaker not designed to be subject to static line pressure.

Vacuum breaker, pressure A vacuum breaker designed to operate under static line pressure.

Vacuum relief valve A device used to prevent excessive vacuum in a pressure vessel.

Valve A fitting whose primary function is to control flow inside a pipe by means of a movable closure member.

Vapor pressure The pressure characteristics at any given temperature of a vapor in equilibrium with its liquid.

Velocity Flow rate measured in feet per second (m/sec).

Vent, loop Any vent connecting a horizontal branch or fixture drain with the stack vent of the originating waste or soil stack.

Vent stack A vertical vent pipe installed primarily for the purpose of providing circulation of air to and from any part of the drainage system.

Vertical pipe Any pipe or fitting installed in a vertical position or that makes an angle of not more than 45 degrees with the vertical.

Vitrified clay Fired and glazed earthenware.

Wall hydrant A faucet on the exterior of a building for the purpose of supplying water.

Waste The discharge from any fixture, appliance, area, or appurtenance that does not contain fecal matter.

Waste anesthetic gas disposal (WAGD) The process of capturing and carrying away gases vented from a patient's breathing circuit during the normal operation of gas anesthesia or analgesia equipment.

Waste pipe The discharge pipe from any fixture, appliance, or appurtenance in connection with the plumbing system that does not contain fecal matter.

Water-conditioning or treating device A device that conditions or treats a water supply to change its chemical content or remove suspended solids by filtration.

Water-distributing pipe Any pipe that conveys potable water.

Water hammer A surge pressure resulting from a sudden start or stop of water.

Water hammer arrester A device, other than an air chamber, designed to protect against excessive surge pressure.

Water main The water supply pipe for public or community use, normally under the jurisdiction of the municipality or water company.

Water riser A water supply pipe that extends vertically one full story or more to convey water to branches or fixtures.

Water seal The depth of water in a fixture trap that prevents the passage of noxious odors but allows the free flow of wastewater.

Water service pipe The pipe from the water main or other source of water supply to the building served.

Water softener Piped tank filter system or chemical plant that is used to filter or treat water to reduce or remove chemicals (usually calcium and magnesium ions) that cause hardness.

Water supply system The building supply pipe, water-distributing pipes, and necessary connecting pipes, fittings, control valves, and all appurtenances carrying or supplying potable water in, or adjacent to, a building or premises.

Wet vent A vent that also serves as a drain.

Yoke vent A pipe connecting upward from a soil or waste stack to a vent stack for the purpose of preventing pressure changes in the stacks.

RESOURCES

- Baumeister, Theodore and Lionel S. Marks, *Marks' Standard Handbook for Mechanical Engineers,* McGraw-Hill
- *ASHRAE Handbook—Fundamentals,* American Society of Heating, Refrigerating, and Air-Conditioning Engineers
- *Pumps and Pump Systems,* American Society of Plumbing Engineers
- Steele, Alfred, *Engineered Plumbing Design II,* American Society of Plumbing Engineers
- NFPA 99: *Healthcare Facilities Code,* National Fire Protection Association

APPENDIX 1-A: PLUMBING ACRONYMS

ADA: Americans with Disabilities Act
AGA: American Gas Association
AHJ: Authority having jurisdiction
ANSI: American National Standards Institute
ARCSA: American Rainwater Catchment Systems Association
ASHRAE: American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASME: American Society of Mechanical Engineers
ASPE: American Society of Plumbing Engineers
ASSE: American Society of Sanitary Engineering or American Society of Safety Engineers
ASTM: American Society for Testing and Materials
AWWA: American Water Works Association
AWS : American Welding Society
CDA: Copper Development Association
CGPM: General Conference on Weights and Measures, from the French term *Conference Generale de Poids et Measures*
CIPH: Canadian Institute of Plumbing & Heating
CISPI: Cast Iron Soil Pipe Institute
CSA: Canadian Standards Association
CS: Commercial standards
DWV: Drain, waste, and vent
FM: Factory Mutual
FS: Federal specifications
IA: Irrigation Association
IAPMO: International Association of Plumbing and Mechanical Officials
ICC: International Code Council
LEED: Leadership in Energy and Environmental Design
MSS: Manufacturers Standardization Society of the Valve and Fittings Industry Inc.
NBS: National Building Specification (UK)
NFPA: National Fire Protection Association
NIST: National Institute of Standards and Technology (formerly the National Bureau of Standards)
NSF: National Sanitation Foundation
PDI: Plumbing and Drainage Institute
PMI: Plumbing Manufacturers International
UL: Underwriters Laboratory
USGBC: United States Green Building Council
WPC: World Plumbing Council
WQA: Water Quality Association

APPENDIX 1-B: PLASTIC PIPING ACRONYMS

Following is a list of commonly used and available plastic pipe and elastomer materials from various sources. The names in parentheses are trade names patented by various manufacturers. Elastomers, indicated by (E), are listed only for reference.

ABS: Acrylonitrile butadiene styrene
BR: Butadiene (E)
CA: Cellulose acetate
CAB: Cellulose acetate butyrate (Celcon)
CAP: Cellulose acetate propionate
CIIR: Chlorinated isobutene isoprene (E)
CMC: Carboxymethyl cellulose
CN: Cellulose nitrate
CP: Cellulose propionate
CPE: Chlorinated polyethylene (E)
CPVC: Chlorinated polyvinyl chloride
CR: Chloroprene rubber (Neoprene) (E)
CS: Casein
CSP: Chlorine sulphonyl polyethylene (Hypalon) (E)
ECTFE: Ethylenechlorotrifluoroethylene
EP: Epoxide, epoxy
EPDM: Ethylene propylene-diene monomer (E)
FPM: Fluorine rubber (E)
EPM: Ethylene propylene terpolymer (E)
FPM: Flurine rubber (Viton) (E)
HDPE: High-density polyethylene
IIR: Isobutene isoprene (butyl) rubber (E)
IR: Polyisopryne (E)
PA: Polyamide
PAEK: Polyaryl etherketone
PB: Polybutylene
PC: Polycarbonate
PCTFE: Polychlorotrifluoroethylene (Halar)
PDAP: Polydiallyl phthalate
PE: Polyethylene
PEEK: Polyether etherketone
PEX: Cross-linked polyethylene
PF: Phenol formaldehyde
PFA: Perfuoroalkoxy
PIB: Polyisobutylene
PP: Polypropylene
PPS: Polyphenylene sulfide
PS: Polysulfone
PTFE: Polytetrafluoroethylene (Teflon)
PVC: Polyvinyl chloride
PVDC: Polyvinylidene chloride
PVDF: Polyvinylidene fluoride
PVFM: Polyvinyl formal
PVK: Polyvinyl carbazol
SBR: Styrene butadiene (E)

APPENDIX 1-C: RECOMMENDED PRACTICE FOR CONVERSION TO THE INTERNATIONAL SYSTEM OF UNITS

The International System of Units was developed by the General Conference of Weights and Measures, an international treaty organization, and has been officially abbreviated SI from the French term *Système International d'Unités.* The SI system of units is a preferred international measurement system that evolved from earlier decimal metric systems.

When President Ford signed the Metric Conversion Act (Public Law 94-168) on December 23, 1975, a metric system in the United States was declared, and a United States Metric Board was established to coordinate the national voluntary conversion effort to the metric system. The Metric Conversion Act specifically defines the metric system of measurement to be used as the International System of Units (SI), established by the General Conference of Weights and Measures and as interpreted and modified by the Secretary of Commerce.

The recommended practice section that follows outlines a selection of SI units, including multiples and submultiples, for use in plumbing design and related fields of science and engineering. It is intended to provide the technical basis for a comprehensive and authoritative standard guide for SI units to be used in plumbing design and related fields of science and engineering.

The section also is intended to provide the basic concepts and practices for the conversion of units given in several systems of measurement to the SI system. Rules and recommendations are detailed for the presentation of SI units and their corresponding symbols and numerical values used in conjunction with the SI system.

A selection of conversion factors to SI units for use in plumbing design and related fields of science and engineering is also given. It should be noted that the SI units, rules, and recommendations listed herein comply with those provisions set forth in IEEE/ASTM SI 10: *American National Standard for Metric Practice.*

Terminology and Abbreviations

For uniformity in the interpretation of the provisions set forth in this recommended practice section, the following definitions and abbreviations will apply.

Accuracy The degree of conformity of a measured or calculated value to some recognized standard or specified value.

Approximate value A quantity that is nearly, but not exactly, correct or accurate.

CGPM Acronym for the General Conference on Weights and Measures, from the French term *Conference Generale de Poids et Measures.*

Coherent unit system A system in which relations between units contain as numerical factor only the number 1 (or unity). All derived units have a unity relationship to the constituent base or supplementary units.

Deviation The variation from a specified dimension or design requirement, defining the upper and lower limits.

Digit One of the 10 Arabic numerals (0 to 9).

Dimension A geometric element in a design or the magnitude of such a quantity.

Feature An individual characteristic of a component or part.

Nominal value A value assigned for the purpose of convenient designation, existing in name only.

Precision The degree of mutual agreement between individual measurements, namely repeatability and reproducibility.

Significant digit Any digit necessary to define a value or quantity.

Tolerance The total range of variation permitted; the upper and lower limits between which a dimension must be maintained.

Unit The reference value of a given quantity as defined by CGPM.

Types of Conversion

Exact These conversions denote the precise (or direct) conversion to the SI unit value, accurate to a number of decimal places.

Soft These conversions denote the conversion to the SI unit value in the software only. The materials and products remain unchanged, and minimal rounding off to the nearest integer is usually applied.

Hard These conversions denote that the product or material characteristics are physically changed from existing values to preferred SI unit values.

SI Units and Symbols

The International System of Units has three types of units, as follows.

Base Units

These units are used for independent quantities. There are seven base units:

Quantity	Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Current (electric)	ampere	A
Temperature (thermodynamic)	Kelvin	K
Substance (amount)	mole	mol
Intensity (luminous)	candela	cd

Supplementary Units

These units are used to denote angles. There are two supplementary units:

Quantity	Unit	Symbol
Plane angle	radian	rad
Solid angle	steradian	sr

Derived Units

These units are defined in terms of their derivation from base and supplementary units. Derived units are classified in two categories: (1) derived units with special names and symbols and (2) derived units with generic or complex names, expressed in terms of a base unit, two or more base units, base units and/or derived units with special names, or supplementary units and base and/or derived units.

Quantity	Unit	Symbol
Frequency	hertz	Hz
Force	newton	N
Pressure, stress	pascal	Pa
Energy, work, heat (quantity)	joule	J
Power	watt	W
Electricity (quantity)	coulomb	C
Electric potential, electromotive force	volt	V
Electric capacitance	farad	F
Electric resistance	ohm	Ω
Magnetic flux	weber	Wb
Illuminance	lux	lx
Electric inductance	henry	H
Conductance	siemens	S
Magnetic flux density	tesla	T
Luminous flux	lumen	lm

The following are classified as derived units with generic or complex names, expressed in various terms:

Quantity	Unit	Symbol
Linear acceleration	meter per second squared	m/s^2
Angular acceleration	radian per second squared	rad/s^2
Area	meter squared	m^2
Density	kilogram per cubic meter	kg/m^3
Electric charge density	coulomb per cubic meter	C/m^3
Electric permittivity	farad per meter	F/m
Electric permeability	henry per meter	H/m
Electric resistivity	ohm-meter	$\Omega \cdot m$
Entropy	joule per kelvin	J/K
Luminance	candela per meter squared	cd/m^2
Magnetic field strength	ampere per meter	A/m
Mass per unit length	kilogram per meter	kg/m
Mass per unit area	kilogram per meter squared	kg/m^2
Mass flow rate	kilogram per second	kg/s
Moment of inertia	kilogram-meter squared	$kg \cdot m^2$
Momentum	kilogram-meter per second	$kg \cdot m/s$
Torque	newton-meter	$N \cdot m$
Specific heat	joule per kg per kelvin	$J/kg \cdot K$
Thermal conductivity	watt per meter per kelvin	$W/m \cdot K$
Linear velocity	meter per second	m/s
Angular velocity	radian per second	rad/s
Dynamic viscosity	pascal-second	$Pa \cdot s$
Kinematic viscosity	meter squared per second	m^2/s
Volume, capacity	cubic meter	m^3
Volume flow rate	cubic meter per second	m^3/s
Specific volume	cubic meter per kilogram	m^3/kg

Non-SI Units and Symbols for Use With the SI System

Several non-SI units are traditional and acceptable for use in the SI system of units due to their significance in specific and general applications. These units are as follows:

Quantity	Unit	Symbol
Area	hectare	ha
Energy	kilowatt-hour	kW•h
Mass	metric ton	t
Temperature	degree Celsius	C
Time	minute, hour, year	min, h, y (respectively)
Velocity	kilometer per hour	km/h
Volume	liter	l

SI Unit Prefixes and Symbols

The SI unit system is based on multiples and submultiples. The following prefixes and corresponding symbols are accepted for use with SI units.

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^{24}	yotta	Y	10^{-1}	deci[a]	d
10^{21}	zetta	Z	10^{-2}	centi[a]	c
10^{18}	exa	E	10^{-3}	milli	m
10^{15}	peta	P	10^{-6}	micro	μ
10^{12}	tera	T	10^{-9}	nano	n
10^{9}	giga	G	10^{-12}	pico	p
10^{6}	mega	M	10^{-15}	femto	f
10^{3}	kilo	k	10^{-18}	atto	a
10^{2}	hecto[a]	h	10^{-21}	zepto	z
10^{1}	deka[a]	da	10^{-24}	yocto	y
a Use of these prefixes should be avoided whenever possible.					

SI Units Style and Use

- Multiples and submultiples of SI units are to be formed by adding the appropriate SI prefixes to such units.
- Except for the kilogram, SI prefixes are not to be used in the denominator of compound numbers.
- Double prefixes are not to be used.
- Except for yotta (Y), zetta (Z), exa (E), peta (P), tera (T), giga (G), and mega (M), SI prefixes are not capitalized.
- The use of units from other systems of measurement is to be avoided.
- Except when the SI unit is derived from a proper name, the symbol for SI units is not capitalized.
- SI unit symbols are always denoted in singular form.
- Except at the end of a sentence, periods are not used after SI unit symbols.
- Digits are placed in groups of three numbers, separated by a space to the left and to the right of the decimal point. In the case of four digits, spacing is optional.
- A center dot indicates multiplication, and a slash indicates division (to the left of the slash is the numerator and to the right of the slash is the denominator).
- When equations are used, such equations are to be restated using SI terms.
- All units are to be denoted by either their symbols or their names written in full. Mixed use of symbols and names is not allowed.

SI Unit Conversion Factors

To convert from other systems of measurement to SI values, the following conversion factors are to be used. (For additional conversion equivalents not shown herein, refer to IEEE/ASTM SI 10). (See also Table 1-C1.)

Acceleration, Linear

foot per second squared = 0.3048 m/s²
m/s² = 3.28 ft/s²
inch per second squared = 0.0254 m/s²
m/s² = 39.37 in/s²

Area

acre = 4,046.9 m²
m² = 0.0000247 acre
foot squared = 0.0929 m²
m² = 10.76 ft²
inch squared = 0.000645 m² = 645.16 mm²
m² = 1,550.39 in.²
mile squared = 2,589,988 m² = 2.59 km²
km² = 0.39 mi²
yard squared = 0.836 m²
m² = 1.2 yd²

Bending Movement (Torque)

pound-force-inch = 0.113 N•m
N•m = 8.85 lbf-in
pound-force-foot = 1.356 N•m
N•m = 0.74 lbf-ft

Bending Movement (Torque) per Unit Length

pound-force-inch per inch = 4.448 N•m/m
N•m/m = 0.225 lbf-in/in
pound-force-foot per inch = 53.379 N•m/m
N•m/m = 0.019 lbf-ft/in

Electricity and Magnetism

ampere = 1A
ampere-hour = 3,600C
coulomb = 1C
farad = 1F
henry = 1H

ohm = 1Ω
volt = 1V

Energy (work)
British thermal unit (Btu) = 1,055 J
J = 0.000948 Btu
foot-pound-force = 1.356 J
J = 0.74 ft-lbf
kilowatt-hour = 3,600,000 J
J = 0.000000278 kWh

Energy per Unit Area per Unit Time
Btu per foot squared-second = 11,349 W/m^2
W/m^2 = 0.000088 Btu/ft^2-s

Force
ounce-force = 0.287 N
N = 3.48 ozf
pound-force = 4.448 N
N = 0.23 lbf
kilogram-force = 9.807 N
N = 0.1 kgf

Force per Unit Length
pound-force per inch = 175.1 N/m
N/m = 0.0057 lbf/in
pound-force per foot = 14.594 N/m
N/m = 0.069 lbf/ft

Heat
Btu-inch per second-foot squared-F = 519.2 W/m•K
W/m•K = 0.002 Btu-in./s-ft^{2}F
Btu-inch per hour-foot squared-F = 0.144 W/m•K
W/m•K = 6.94 Btu-in./h-ft^{2}F
Btu per foot squared = 11,357 J/m^2
J/m^2 = 0.000088 Btu/ft^2
Btu per hour-foot squared-F = 5.678 W/m^2•K
W/m^2•K = 0.176 Btuh-ft^{2}F
Btu per pound-mass = 2,326 J/kg
J/kg = 0.00043 Btu/lbm
Btu per pound-mass-F = 4,186.8 J/kg•K
J/kg•K = 0.000239 Btu/lbm F
F-hour-foot squared per Btu = 0.176 K•m^2/W
K•m^2/W = 5.68 F-h-ft^2/Btu

Length
inch = 0.0254 m
m = 39.37 in
foot = 0.3048 m
m = 3.28 ft
yard = 0.914 m
m = 1.1 yd
mile = 1,609.3 m and 1.6093 km
m = 0.000621 mi

Light (illuminance)
footcandle = 10.764 lx
lx = 0.093 ftcd

Mass
ounce-mass = 0.028 kg
kg = 35.7 ozm
pound-mass = 0.454 kg
kg = 2.2 lbm

Mass per Unit Area
pound-mass per foot squared = 4.882 kg/m^2
kg/m^2 = 0.205 lbm/ft^2

Mass per Unit Length
pound-mass per foot = 1.488 kg/m
kg/m = 0.67 lbm/ft

Mass per Unit Time (flow)
pound-mass per hour = 0.0076 kg/s
kg/s = 131.58 lbm/h

Mass per Unit Volume (density)
pound-mass per cubic foot = 16.019 kg/m^3
kg/m^3 = 0.062 lbm/ft^3
pound-mass per cubic inch = 27,680 kg/m^3
kg/m^3 = 0.000036 lbm/in.^{3}
pound-mass per gallon = 119.8 kg/m^3
kg/m^3 = 0.008347 lbm/gal

Moment of Inertia
pound-foot squared = 0.042 kg•m^2
kg•m^2 = 23.8 lb-ft^2

Plane Angle
degree = 17.453 mrad
mrad = 0.057 deg
minute = 290.89 μrad
μrad = 0.00344 min
second = 4.848 μrad
μrad = 0.206 s

Power
Btu per hour = 0.293 W
W = 3.41 Btuh
foot-pound-force per hour = 0.38 mW
mW = 2.63 ft-lbf/h
horsepower = 745.7 W
W = 0.00134 hp

Pressure (stress), Force per Unit Area
inches water column = 25.4 mm water
mm water = 0.0394 in. wc
atmosphere = 101.325 kPa
kPa = 0.009869 atm
inch of mercury (at 60°F) = 3.3769 kPa
kPa = 0.296 in. Hg
inch of water (at 60°F) = 248.8 Pa
Pa = 0.004 in. H_2O
pound-force per foot squared = 47.88 Pa
Pa = 0.02 lbf/ft^2
pound-force per inch squared = 6.8948 kPa
kPa = 0.145 lbf/in.^{2} (psi)
pounds per square inch = 0.0703 kg/cm^3
kg/cm^3 = 14.22 psi
pounds per square inch = 0.069 bars
bars = 14.50 psi

Temperature Equivalent
$t_k = (t_f + 459.67)/1.8$

$t_f = 1.8\ t_k - 459.67$
$t_c = (t_f - 32)/1.8$ (see Table 1-C2)
$t_f = 1.8\ t_c + 32$ (see Table 1-C2)

Velocity (length per unit time)

foot per hour = 0.085 mm/s
mm/s = 11.76 ft/h
foot per minute = 5.08 mm/s
mm/s = 0.197 ft/min
foot per second = 0.3048 m/s
m/s = 3.28 ft/s
inch per second = 0.0254 m/s
m/s = 39.37 in./s
mile per hour = 0.447 m/s
m/s = 2.24 mi/h

Volume

cubic foot = 0.028 m^3 = 28.317 l
m^3 = 35.71 ft^3
cubic inch = 16,378 ml
ml = 0.061 in.^{3}
gallon = 3.785 l
l = 0.264 gal
ounce = 29.574 ml
ml = 0.034 oz
pint = 473.18 ml
ml = 0.002 pt
quart = 946.35 ml
ml = 0.001 qt
acre-foot = 1,233.49 m^3
m3 = 0.00081 acre-ft

Volume per Unit Time (flow)

cubic foot per minute = 0.472 l/s
l/s = 2.12 ft^3/min
cubic inch per minute = 0.273 ml/s
ml/s = 3.66 in.^{3}/min
gallon per minute = 0.063 l/s
l/s = 15.87 gal/min
cubic feet per hour = 0.0283 m^3/h
m^3/h = 35.31 ft^3/h (cfh)
cubic feet per hour = 0.007866 l/s
l/s = 127.13 cfh

Table 1-C1 Conversion to SI Units

Multiply	By	To Obtain
acre	0.4047	ha
atmosphere (standard)	101.325[a]	kPa
bar	100[a]	kPa
barrel (42 US gal, petroleum)	159 0.159	L m^3
Btu (International Table)	1.055	kJ
Btu/ft^2	11.36	kJ/m^2
Btu/ft^3	37.3	kJ/m^3
Btu/gal	279	kJ/m^3
Btu · ft/h · ft^2 · °F	1.731	W/(m · K)
Btu · in/h · ft^2 · °F (thermal conductivity, k)	0.1442	W/(m · K)
Btu/h	0.2931	W
Btu/h · ft^2	3.155	W/m^2
Btu/h · ft^2 · °F (overall heat transfer coefficient, U)	5.678	W/(m^2 · K)
Btu/lbm	2.326[a]	kJ/kg
Btu/lbm · °F (specific heat, cp)	4.186	kJ/(kg · K)
bushel	0.03524	m^3
calorie, gram	4.1868	J
calorie, kilogram (kilocalorie)	4.1868	kJ
centipoise (dynamic viscosity, μ)	1.00[a]	mPa · s
centistokes (kinematic viscosity, v)	1.00[a]	mm^2/s
clo	0.155	m^2 · K/W
dyne/cm^2	0.100[a]	Pa
To Obtain	**By**	**Divide**

Multiply	By	To Obtain
EDR hot water (150 Btu/h)	44.0	W
EDR steam (240 Btu/h)	70.3	W
EER	0.293	COP
ft	0.3048[a] 304.8[a]	m mm
ft/min, fpm	0.00508[a]	m/s
ft/s, fps	0.3048[a]	m/s
ft of water	2.99	kPa
ft of water per 100 ft pipe	0.0981	kPa/m
ft^2	0.09290	m^2
ft^2 · h · °F/Btu (thermal resistance, R)	0.176	m^2 · K/W
ft^2/s (kinematic viscosity, v)	92.900	mm^2/s
ft^3	28.32 0.02832	L m^3
ft^3/min, cfm	0.4719	l/s
ft^3/s, cfs	28.32	l/s
ft · lbf (torque or moment)	1.356	N · m
ft · lbf (work)	1.356	J
ft · lbf/lb (specific energy)	2.99	J/kg
ft · lbf/min (power)	0.0226	W
footcandle	10.76	lx
gallon (US, 231 in.^{3})	3.7854[a]	L
gph	1.05	ml/s
gpm	0.0631	l/s
gpm/ft^2	0.6791	L/(s · m^2)
To Obtain	**By**	**Divide**

Table 1-C1 Conversion to SI Units

Multiply	By	To Obtain
gpm/ton refrigeration	0.0179	ml/J
grain (1⁄7000 lb)	0.0648	g
gr/gal	17.1	g/m^3
gr/lb	0.143	g/kg
horsepower (boiler) (33,470 Btu/h)	9.81	kW
horsepower (550 ft · lb_f/s)	0.746	kW
inch	25.4[a]	mm
in. of mercury (60°F)	3.377	kPa
in. of water (60°F)	249	Pa
in./100 ft, thermal expansion	0.833	mm/m
in. · lb_f (torque or moment)	113	mN · m
$in.^2$	645	mm^2
$in.^3$ (volume)	16.4	ml
$in.^3$/min (SCIM)	0.273	ml/s
$in.^3$ (section modulus)	16,400	mm^3
$in.^4$ (section moment)	416,200	mm^4
km/h	0.278	m/s
kWh	3.60[a]	MJ
kW/1000 cfm	2.12	kJ/m^3
kilopond (kg force)	9.81	N
kip (1,000 lb_f)	4.45	kN
kip/$in.^2$ (ksi)	6.895	MPa
lb_m (mass)	0.4536 453.6	kg g
lb_f (force, thrust)	4.45	N
lb_m/ft (uniform load)	1.49	kg/m
lb_m/ft · h (dynamic viscosity, μ)	0.413	mPa · s
lb_m/ft · s (dynamic viscosity, μ)	1490	mPa · s
lb_f · s/ft^2 (dynamic viscosity, μ)	47.88	Pa · s
lb/h	0.126	g/s
lb/min	0.00756	kg/s
lb/h [steam at 212°F (100°C)]	0.284	kW
lb_f/ft^2	47.9	Pa
lb_m/ft^2	4.88	kg/m^2
lb_m/ft^3 (density, ρ)	16.0	kg/m^3
lb_m/gallon	120	kg/m^3
To Obtain	**By**	**Divide**

Multiply	By	To Obtain
litre	0.001[a]	m^3
met	58.15	W/m^2
micron (μm) of mercury (60°F)	133	mPa
mile	1.609	km
mile, nautical	1.852[a]	km
mph	1.609 0.447	km/h m/s
millibar	0.100[a]	kPa
mm of mercury (60°F)	0.133	kPa
mm of water (60°F)	9.80	Pa
ounce (mass, avoirdupois)	28.35	g
ounce (force, thrust)	0.278	N
ounce (liquid, US)	29.6	ml
ounce inch (torque, moment)	7.06	mN · m
ounce (avoirdupois) per gallon	7.49	kg/m^3
perm (permeance)	57.45	ng/(s·m^2·Pa)
perm inch (permeability)	1.46	ng/(s · m · Pa)
pint (liquid, US)	473	ml
ppm (by mass)	1.00[a]	mg/kg
psi	6.895	kPa
quad (1,015 Btu)	1.055	EJ
quart (liquid, U.S.)	0.946	L
square (100 ft^2)	9.29	m^2
tablespoon (approx.)	15	ml
teaspoon (approx.)	5	ml
therm (U.S.)	105.5	MJ
ton, long (2,240 lb)	1.016	Mg
ton, short (2,000 lb)	0.907	Mg; t (tonne)
ton, refrigeration (12,000 Btuh)	3.517	kW
ton (1 mm Hg at 0°C)	133	Pa
watt per square foot	10.76	W/m^2
yd	0.9144[a]	m
yd^2	0.836	m^2
yd^3	0.7646	m^3
To Obtain	**By**	**Divide**

Notes: 1. Units are U.S. values unless noted otherwise. 2. Litre is a special name for the cubic decimetre. 1 l = dm^3 and 1 ml = 1 cm^3.

a Conversion factor is exact.

Table 1-C2 Temperature Conversion Chart, °F – °C

The numbers in the center column refer to the known temperature, in either °F or °C, to be converted to the other scale. If converting from °F to °C, the number in the center column represents the known temperature, in °F, and its equivalent temperature, in °C, will be found in the left column. If converting from °C to °F, the number in the center represents the known temperature, in °C, and its equivalent temperature, in °F, will be found in the right column.

	Known Temperature	
°C	(°F or °C)	°F
–59	–74	–101
–58	–73	–99
–58	–72	–98
–57	–71	–96
–57	–70	–94
–56	–69	–92
–56	–68	–90
–55	–67	–89
–54	–66	–87
–54	–65	–85
–53	–64	–83
–53	–63	–81
–52	–62	–80
–52	–61	–78
–51	–60	–76
–51	–59	–74
–50	–58	–72
–49	–57	–71
–49	–56	–69
–48	–55	–67
–48	–54	–65
–47	–53	–63
–47	–52	–62
–46	–51	–60
–45.6	–50	–58.0
–45.0	–49	–56.2
–44.4	–48	–54.4
–43.9	–47	–52.6
–43.3	–46	–50.8
–42.8	–45	–49.0
–42.2	–44	–47.2
–41.7	–43	–45.4
–41.1	–42	–43.6
–40.6	–41	–41.8
–40.0	–40	–40.0
–39.4	–39	–38.2
–38.9	–38	–36.4
–38.3	–37	–34.6
–37.8	–36	–32.8
–37.2	–35	–31.0
–36.7	–34	–29.2
–36.1	–33	–27.4
–35.5	–32	–25.6
–35.0	–31	–23.8
–34.4	–30	–22.0
–33.9	–29	–20.2
–33.3	–28	–18.4
–32.8	–27	–16.6
–32.2	–26	–14.8
–31.6	–25	–13.0
–31.1	–24	–11.2
–30.5	–23	–9.4
–30.0	–22	–7.6
–29.4	–21	–5.8
–28.9	–20	–4.0

	Known Temperature	
°C	(°F or °C)	°F
–28.3	–19	–2.2
–27.7	–18	–0.4
–27.2	–17	1.4
–26.6	–16	3.2
–26.1	–15	5.0
–25.5	–14	6.8
–25.0	–13	8.6
–24.4	–12	10.4
–23.8	–11	12.2
–23.3	–10	14.0
–22.7	–9	15.8
–22.2	–8	17.6
–21.6	–7	19.4
–21.1	–6	21.2
–20.5	–5	23.0
–20.0	–4	24.8
–19.4	–3	26.6
–18.8	–2	28.4
–18.3	–1	30.2
–17.8	0	32.0
–17.2	1	33.8
–16.7	2	35.6
–16.1	3	37.4
–15.6	4	39.2
–15.0	5	41.0
–14.4	6	42.8
–13.9	7	44.6
–13.3	8	46.4
–12.8	9	48.2
–12.2	10	50.0
–11.7	11	51.8
–11.1	12	53.6
–10.6	13	55.4
–10.0	14	57.2
–9.4	15	59.0
–8.9	16	60.8
–8.3	17	62.6
–7.8	18	64.4
–7.2	19	66.2
–6.7	20	68.0
–6.1	21	69.8
–5.6	22	71.6
–5.0	23	73.4
–4.4	24	75.2
–3.9	25	77.0
–3.3	26	78.8
–2.8	27	80.6
–2.2	28	82.4
–1.7	29	84.2
–1.1	30	86.0
–0.6	31	87.8
0	32	89.6
0.6	33	91.4
1.1	34	93.2
1.7	35	95.0

	Known Temperature	
°C	(°F or °C)	°F
2.2	36	96.8
2.8	37	98.6
3.3	38	100.4
3.9	39	102.2
4.4	40	104.0
5.0	41	105.8
5.6	42	107.6
6.1	43	109.4
6.7	44	111.2
7.2	45	113.0
7.8	46	114.8
8.3	47	116.6
8.9	48	118.4
9.4	49	120.2
10.0	50	122.0
10.6	51	123.8
11.1	52	125.6
11.7	53	127.4
12.2	54	129.2
12.8	55	131.0
13.3	56	132.8
13.9	57	134.6
14.4	58	136.4
15.0	59	138.2
15.6	60	140.0
16.1	61	141.8
16.7	62	143.6
17.2	63	145.4
17.8	64	147.2
18.3	65	149.0
18.9	66	150.8
19.4	67	152.6
20.0	68	154.4
20.6	69	156.2
21.1	70	158.0
21.7	71	159.8
22.2	72	161.6
22.8	73	163.4
23.3	74	165.2
23.9	75	167.0
24.4	76	168.8
25.0	77	170.6
25.6	78	172.4
26.1	79	174.2
26.7	80	176.0
27.2	81	177.8
27.8	82	179.6
28.3	83	181.4
28.9	84	183.2
29.4	85	185.0
30.0	86	186.8
30.6	87	188.6
31.1	88	190.4
31.7	89	192.2
32.2	90	194.0

	Known Temperature	
°C	(°F or °C)	°F
32.8	91	195.8
33.3	92	197.6
33.9	93	199.4
34.4	94	201.2
35.0	95	203.0
35.6	96	204.8
36.1	97	206.6
36.7	98	208.4
37.2	99	210.2
37.8	100	212.0
43	110	230
49	120	248
54	130	266
60	140	284
66	150	302
71	160	320
77	170	338
82	180	356
88	190	374
93	200	392
99	210	410
100	212	414
104	220	428
110	230	446
116	240	464
121	250	482
127	260	500
132	270	518
138	280	536
143	290	554
149	300	572
154	310	590
160	320	608
166	330	626
171	340	644
177	350	662
182	360	680
188	370	698
193	380	716
199	390	734
204	400	752
210	410	770
216	420	788
221	430	806
227	440	824
232	450	842
238	460	860
243	470	878
249	480	896
254	490	914
260	500	932

CHAPTER 2

Standards for Plumbing Materials and Equipment

Codes and standards often cross paths to the point that it can be difficult to understand the difference between a code and a standard. A code typically regulates a broad part of construction, whereas a standard regulates a very specific area or product. Codes often include installation and approval requirements, and they typically reference standards for specific material, product, or design requirements. State, provincial, and local jurisdictions adopt codes to regulate construction. A standard only becomes a legally enforceable document when it is referenced in the adopted code.

Sometimes a standard becomes a code. A good example is the National Fuel Gas Code. As the name implies, the document is a code that regulates the installation of fuel gas systems. However, the National Fuel Gas Code is a National Fire Protection Association (NFPA) standard (NFPA 54).

A code review is necessary to determine the appropriate standards for the jurisdiction in which the designer is working. In the United States, the codes developed by the International Code Council (ICC) and the International Association of Plumbing and Mechanical Officials (IAPMO) are generally used. The responsibility to enforce the code falls on the authority having jurisdiction (AHJ), but the responsibility to comply with the code falls on the architects, engineers, designers, and contractors working on the project. It is important to note that codes and standards list the minimum requirements for compliance, but good design practice typically calls for a design that well exceeds the minimum.

Keep in mind that some clients, especially governmental agencies, may have design standards of their own that also must be followed in addition to the code requirements, so be sure to inquire about this early in the design process.

Standards are continually updated. As a result, soon after this book is published, the list of standards will be out of date. Whenever using or referencing a standard, it is appropriate to check with the standards developing organization (SDO) to identify the latest edition of that standard.

It should be noted that the American National Standards Institute (ANSI) approves many standards as American National Standards (ANS). ANSI is the organization in the United States that oversees the development of national consensus standards. ANSI does not develop standards; it regulates (as an oversight body) the organizations that develop standards, such as the American Society of Mechanical Engineers (ASME) and American Society of Plumbing Engineers (ASPE).

Standards are identified by the acronym of the standards developing organization. When a standard has been approved as an ANS, the identification sometimes also includes ANSI, such as ASME/ANSI B16: *Standards for Pipes and Fittings*. For ease of use, ANSI has not been included in the tables in this chapter, except for the few remaining standards that do not have another developing organization.

Most standards are developed through a consensus process, including all ANSI and CSA Group (Canadian Standards Association) standards. The consensus process requires the committee that is writing the standard to be balanced among the various interest groups. For example, for a material standard, producers (manufacturers), users (engineers), and general-interest representatives would be on the committee. The consensus process also requires standards to be made available for review by the public, and the committee must attempt to resolve all comments. As a result of the consensus process, standards are developed through fair and open procedures that result in a higher-caliber product.

Although most standards are country-specific, a trend toward consolidation to make cross-border design and installation more efficient has been occurring in the industry. Thus, many standards carry the acronym of two or more SDOs of different nationalities, such as ASME A112.19.2/CSA B45.1: *Ceramic Plumbing Fixtures.* Underwriters Laboratories (UL) and Underwriters Laboratories of Canada (ULC) standards are published by both UL and ULC and reflect the requirements of both the United States and Canada. For those who frequently work out of state or province, the governing codes can be found at the U.S. Department of Energy and Underwriters Laboratories of Canada.

This chapter lists standards by category (Table 2-1) and by standards developing organization (Table 2-2). Not every standard currently in existence is listed. Some SDOs also publish guidelines as well as standards. Guidelines provide information and guidance in certain areas and are intended for the use of designers, installers, owners, operators, users, maintenance personnel, and equipment manufacturers. Table 2-3 identifies some guidelines for use by design and construction professionals.

Table 2-1 Standards by Category

Aboveground Sanitary (or Storm) Drainage and Vent Pipe	
Acrylonitrile butadiene styrene (ABS) plastic pipe	ASTM D2661, ASTM F628, CSA B181.1
Brass pipe	ASTM B43
Cast iron pipe	ASTM A74, ASTM A888, CISPI 301, CAN/CSA B70
Coextruded composite ABS or PVC DWV pipe	ASTM F1488
Copper or copper alloy pipe	ASTM B42, ASTM B302
Copper or copper alloy tubing	ASTM B75, ASTM B88, ASTM B251, ASTM B306
Galvanized steel pipe	ASTM A53
Glass pipe	ASTM C1053
Polyolefin pipe	CAN/CSA B181.2
Polyvinyl chloride (PVC) plastic pipe (type DWV)	ASTM D2665, ASTM D2949, ASTM F891, CAN/CSA B181.2, ASTM F1488
Stainless steel drainage systems (types 304 and 316L)	ASME A112.3
Backflow Preventers	
Air gap	ASME A112.1.2, ASME A112.1.3
Backflow preventer with intermediate atmospheric vents	ASSE 1012, CAN/CSA B64.3
Ballcock	ASSE 1002
Carbonated beverage dispenser backflow preventer	ASSE 1022
Double-check backflow prevention assembly	ASSE 1015, ASSE 1048, AWWA C510
Dual check valve-type backflow preventer	ASSE 1024
Faucet and fixture fitting backflow devices	ASME A112.18.3
Hose connection backflow preventer	ASSE 1052
Hose connection vacuum breaker	ASSE 1011, ASSE 1019, CAN/CSA B64.2.2
Laboratory faucet backflow preventer	ASSE 1035, CSA B64.7
Pipe-applied atmospheric-type vacuum breaker	ASSE 1001, CAN/CSA B64.1.1
Pressure vacuum breaker assembly	ASSE 1020, ASSE 1056
Reduced pressure principle backflow preventer	ASSE 1013, ASSE 1047, AWWA C511, CAN/CSA B64.4
Building Storm Sewer Pipe	
ABS plastic pipe	ASTM D2661, ASTM D2751, ASTM F628, ASTM D2680
Asbestos-cement pipe	ASTM C428
Cast iron pipe	ASTM A74, ASTM A888, CISPI 301
Concrete pipe	ASTM C14, ASTM C76, CSA A257.1, CAN/CSA A257.2
Copper or copper alloy tubing	ASTM B75, ASTM B88, ASTM B251, ASTM B306

Table 2-1 Standards by Category	
PVC plastic pipe	ASTM D2665, ASTM D3034, ASTM F891, CSA B182.2, CAN/CSA B182.4
Stainless steel drainage systems (type 316L)	ASME A112.3.1
Vitrified clay pipe	ASTM C4, ASTM C700
Fire Protection	
Combustibility test	ASTM E136
Fire pumps	NFPA 20
Fire-resistance rating test	ASTM E119
Flame spread and smoke developed	ASTM E84
One- and two-family dwelling sprinkler design	NFPA 13D
Residential sprinkler design	NFPA 13R
Sprinkler design	NFPA 13
Standpipe systems	NFPA 14
Through-penetration fire test	ASTM E814
Gas Piping	
Aluminum	ASTM B210, ASTM B211, ASTM B241
Copper and copper alloy tubing	ASTM B88, ASTM B280
Corrugated stainless steel tubing	ANSI LC-1
Plastic pipe (underground only)	ASTM D2513
Steel pipe	ASTM A53, ASTM A106
Joints and Connections	
ABS solvent cement	ASTM D2235, CSA B181.1
ABS and PVC building drain/sewer transition	ASTM D3138
Brazed filler metal	AWS A5.8
Cast iron hubless coupling	ASTM C1277, CISPI 310
Chlorinated polyvinyl chloride (CPVC) solvent cement	ASTM F493
Elastomeric seal	ASTM C425, ASTM C443, ASTM C477, ASTM C564, ASTM C1440, ASTM D1869, CAN/CSA A257.3, CAN/CSA B602
Pipe thread	ASME B1.20.1
PVC primer	ASTM F656
PVC solvent cement	ASTM D2564, CSA B137.3, CSA B181.2
Solder filler metal	ASTM B32
Solder flux	ASTM B813
Miscellaneous	
Air-admittance valves	ASSE 1049, ASSE 1050, ASSE 1051
Backwater valves	ASME A112.14.1, CSA B181.1, CSA B181.2
Category II, III, and IV vent systems	UL 1738, ULC 5636
Disinfecting methods	AWWA 651, AWWA 652
Drinking water material protection	NSF 61
Factory-built chimneys	UL 103
Grease traps and interceptors	ASME A112.14.3, ASME A112.14.4, PDI G101
Masonry chimney liner	ULC S635, ULC S640, UL 1777
Pipe hangers	MSS SP-58, MSS SP-69
Plastic pipe quality control	NSF 14
Type B vents	UL 441, ULC S605

Table 2-1 Standards by Category

Type L vents	UL 641, ULC 5609
Water hammer arresters	ASSE 1010, PDI WH201
Water heaters	ANSI Z21.10.1, ANSI Z21.10.3, UL 732, UL 1261
Pipe Nipples	
Brass, copper, and chromium plated	ASTM B687
Steel	ASTM A733
Plumbing Fixtures	
Bathtubs	ASME A112.19.1, ASME A112.19.4, ASME A112.19.7, ASME A112.19.9, ANSI Z124.1, CSA B45.2, CSA B45.3, CSA B45.5
Bidets	ASME A112.19.2, ASME A112.19.9, CSA B45.1
Dishwashing machines	ASSE 1004, ASSE 1006, NSF 3
Drinking fountains	ASME A112.19.1, ASME A112.19.2, ASME A112.19.9
Emergency shower and eyewash stations	ISEA Z358.1
Faucet and fixture fittings	ASME A112.18.1, CSA B125
Fixture waste fittings	ASME A112.18.2
Floor drains	ASME A112.3.1, ASME A112.6.3, CSA B79
Food waste grinders	ASSE 1008, ASSE 1009
Lavatories	ASME A112.19.1, ASME A112.19.2, ASME A112.19.3, ASME A112.19.4, ASME A112.19.9, ANSI Z124.3, CSA B45.1, CSA B45.2, CSA B45.3, CSA B45.4
Pressure-balancing valves	ASSE 1016, ASSE 1066
Roof drains	ASME A112.3.1, ASME A112.6.4
Showers	ASME A112.19.9, ANSI Z124.2, CSA B45.5
Sinks	ASME A112.19.1, ASME A112.19.2, ASME A112.19.3, ASME A112.19.4, ASME A112.19.9, ASME A112.19.12, ANSI Z124.6, CSA B45.1, CSA B45.2, CSA B45.3, CSA B45.4
Thermostatic mixing valves	ASSE 1016, ASSE 1017
Urinals	ASME A112.19.2, ANSI Z124.4, CSA B45.1, CSA B45.5
Wall carriers	ASME A112.6.1, ASME A112.6.2
Water closets	ASME A112.19.2, ANSI Z124.4, CSA B45.1, CSA B45.4, CSA B45.5
Sanitary Drainage Pipe Fittings	
ABS plastic	ASTM D2661, ASTM D3311, CSA B181.1
Cast iron	ASME B16.4, ASME B16.12, ASTM A74, ASTM A888, CISPI 301
Copper or copper alloy	ASME B16.15, ASME B16.18, ASME B16.22, ASME B16.23, ASME B16.26, ASME B16.29, ASME B16.32
Glass	ASTM C1053
Gray iron and ductile iron	AWWA C110
Malleable iron	ASME B16.3
PVC plastic	ASTM D2665, ASTM D3311
Stainless steel drainage systems	ASME A112.3.1
Steel	ASME B16.9, ASME B16.11, ASME B16.28
Sanitary Sewer Pipe	
ABS plastic pipe	ASTM D2661, ASTM D2751, ASTM F628
Asbestos-cement pipe	ASTM C428
Cast iron pipe	ASTM A74, ASTM A888, CISPI 301
Coextruded composite ABS or PVC DWV pipe	ASTM F1488

Table 2-1 Standards by Category

Concrete pipe	ASTM C14, ASTM C76, CSA A257.1, CAN/CSA A257.2
Copper or copper alloy tubing	ASTM B75, ASTM B88, ASTM B251
PVC plastic pipe	ASTM D2665, ASTM D2949, ASTM D3034, ASTM F891, CSA B182.2, CAN/CSA B182.4
Stainless steel drainage systems (type 316L)	ASME A112.3.1
Vitrified clay pipe	ASTM C4, ASTM C700
Subsoil Drainage Pipe	
Asbestos-cement pipe	ASTM C508
Cast iron pipe	ASTM A74, ASTM A888, CISPI 301
Polyethylene (PE) plastic pipe	ASTM F667
PVC plastic pipe	ASTM D2729, ASTM F891, CSA B182.2, CAN/CSA B182.4
Stainless steel drainage systems (type 316L)	ASME A112.3.1
Vitrified clay pipe	ASTM C4, ASTM C700
Underground Building Sanitary (or Storm) Drainage and Vent Pipe	
ABS plastic pipe	ASTM D2661, ASTM F628, CSA B181.1
Asbestos-cement pipe	ASTM C428
Cast iron pipe	ASTM A74, ASTM A888, CISPI 301
Coextruded composite ABS or PVC DWV pipe	ASTM F1488
Copper or copper alloy tubing	ASTM B75, ASTM B 88, ASTM B251, ASTM B306
Polyolefin pipe	CAN/CSA B181.2
PVC plastic pipe (type DWV)	ASTM D2665, ASTM D2949, ASTM F891, CAN/CSA B181.2
Stainless steel drainage systems (type 316L)	ASME A112.3.1
Water Distribution Piping (Aboveground)	
Brass pipe	ASTM B43
CPVC plastic pipe and tubing	ASTM D2846, ASTM F441, ASTM F442, CSA B137.6
Copper or copper alloy pipe	ASTM B42, ASTM B302
Copper or copper alloy tubing	ASTM B75, ASTM B88, ASTM B251, ASTM B447
Cross-linked polyethylene (PEX) plastic tubing	ASTM F877, CAN/CSA B137.5
Cross-linked polyethylene/aluminum/ cross-linked polyethylene (PEX-AL-PEX) pipe	ASTM F1281, CAN/CSA B137.10
Galvanized steel pipe	ASTM A53
Polybutylene (PB) plastic pipe and tubing	ASTM D3309, CAN/CSA B137.8
Polyethylene of raised temperature (PERT) tubing	ASTM F2769
Water Pipe Fittings	
ABS plastic	ASTM D2468
Cast iron	ASME B16.4, ASME B16.12
CPVC plastic	ASTM F437, ASTM F438, ASTM F439
Copper or copper alloy	ASME B16.15, ASME B16.18, ASME B16.22, ASME B16.23, ASME B16.26, ASME B16.29, ASME B16.32, ASME B16.50, ASTM B16.51
Gray iron and ductile iron	ASME B16.4, AWWA C110, AWWA C153
Malleable iron	ASME B16.3
PE plastic	ASTM D2609, ASTM D2683, ASTM D3261, ASTM F1055, CSA B137.1
Fittings for PEX tubing	ASTM F1807, ASSE 1061, ASTM F877, ASTM F1960, ASTM F1961, ASTM F2080, ASTM F2159, ASTM F2735, CSA B137.5
Fittings for PERT tubing	ASTM F1807, ASTM F2098, ASTM F2159, ASTM F2735, ASTM F2769

Table 2-1 Standards by Category	
PVC plastic	ASTM D2464, ASTM D2466, ASTM D2467, ASTM F1970, CAN/CSA B137.2
Steel	ASME B16.9, ASME B16.11, ASME B16.28
Water Service Piping (Underground)	
ABS plastic pipe	ASTM D1527, ASTM D2282
Asbestos-cement pipe	ASTM C296
Brass pipe	ASTM B43
Copper or copper alloy pipe	ASTM B42, ASTM B302
Copper or copper alloy tubing	ASTM B75, ASTM B88, ASTM B251, ASTM B447
CPVC plastic pipe	ASTM D2846, ASTM F441, ASTM F442, CSA B137.6
Ductile iron water pipe	AWWA C115, AWWA C151
Galvanized steel pipe	ASTM A53
PEX plastic tubing	ASTM F876, ASTM F877, CAN/CSA B137.5
PEX-AL-PEX pipe	ASTM F1281, CAN/CSA B137.10
PB plastic pipe and tubing	ASTM D2662, ASTM D2666, ASTM D3309, CSA B137.8
PE plastic pipe	ASTM D2239, CAN/CSA B137.1
PE plastic tubing	ASTM D2737, CSA B137.1
Polyethylene of raised temperature (PERT) tubing	ASTM F2769
Polyethylene/aluminum/polyethylene (PE-AL-PE) pipe	ASTM F1282, CAN/CSA B137.9
PVC plastic pipe	ASTM D1785, ASTM D2241, ASTM D2672, CAN/CSA B137.3

Table 2-2 Standards by Standards Developing Organization	
ANSI (American National Standards Institute, ansi.org)	
LC-1	Fuel Gas Piping Systems Using Corrugated Stainless Steel Tubing
Z4.3	Minimum Requirements for Nonsewered Waste-Disposal Systems
Z21.8	Installation of Domestic Gas Conversion Burners
Z21.10.1/CSA 4.1	Gas Water Heaters Volume 1, Storage Water Heaters with Input Ratings of 75,000 Btu per Hour or Less
Z21.10.3/CSA 4.3	Gas Water Heaters Volume 3, Storage Water Heaters with Input Ratings Above 75,000 Btu per hour, Circulating and Instantaneous
Z21.13/CSA 4.9	Gas-Fired, Low-Pressure Steam and Hot Water Boilers
Z21.15/CSA 9.1	Manually Operated Gas Valves for Appliances, Appliance Connector Valves, and Hose End Valves
Z21.19/CSA 1.4	Refrigerators Using Gas Fuel
Z21.22/CSA 4.4	Relief Valves for Hot Water Supply Systems
Z21.40.1	Gas-Fired, Heat-Activated Air-Conditioning and Heat Pump Appliances
Z21.40.2	Gas-Fired, Work-Activated Air-Conditioning and Heat Pump Appliances (Internal Combustion)
Z21.42	Gas-Fired Illuminating Appliances
Z21.50/CSA 2.22	Vented Gas Fireplaces
Z21.56/CSA 4.7	Gas-Fired Pool Heaters
Z21.61	Gas-Fired Toilets
Z21.69/CSA 6.16	Connectors for Movable Gas Appliances
Z21.83	Fuel Cell Power Plants
Z21.84	Manually Lighted, Natural Gas Decorative Gas Appliances for Installation in Solid-Fuel-Burning Fireplaces
Z21.88/CSA 2.33	Vented Gas Fireplace Heaters
Z83.11/CSA 1.8	Gas Food Service Equipment
Z124.1.2	Plastic Bathtub and Shower Units

Table 2-2 Standards by Standards Developing Organization

Z124.2	Plastic Shower Units
Z124.3	Plastic Lavatories
Z124.4	Plastic Water Closet Bowls and Tanks
Z124.5	Plastic Toilet (Water Closet) Seats
Z124.6	Plastic Sinks
Z124.7	Prefabricated Plastic Spa Shells
Z124.9	Plastic Urinal Fixtures
AHRI (Air-Conditioning, Heating, and Refrigeration Institute, ahrinet.org)	
700	Specification for Fluorocarbon Refrigerants
1300	Performance Rating of Commercial Heat Pump Water Heaters
550/590	Performance Rating of Water-Chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle
ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ashrae.org)	
15	Safety Code for Mechanical Refrigeration
34	Designation and Safety Classification of Refrigerants
90.1	Energy Standard for Buildings Except Low-Rise Residential Buildings
90.2	Energy Efficient Design of Low-Rise Residential Buildings
100	Energy Conservation in Existing Buildings
118.1	Method of Testing for Rating Commercial Gas, Electric, and Oil Service Water Heating Equipment
118.2	Method of Testing for Rating Residential Water Heaters
124	Methods of Testing for Rating Combination Space-Heating and Water-Heating Appliances
137	Methods of Testing for Efficiency of Space-Conditioning/Water-Heating Appliances that Include a Desuperheater Water Heater
146	Method of Testing and Rating Pool Heaters
188	Legionellosis: Risk Management for Building Water Systems
189.1	Standard for the Design of High-Performance Green Buildings
ASME International (American Society of Mechanical Engineers, asme.org)	
A112.1.2	Air Gaps in Plumbing Systems
A112.1.3	Air Gap Fittings for Use with Plumbing Fixtures, Appliances, and Appurtenances
A112.3.1	Stainless Steel Drainage Systems for Sanitary DWV, Storm, and Vacuum Applications, Above and Below Ground
A112.3.4/CSA B45.9	Macerating Toilet Systems and Related Components
A112.4.1	Water Heater Relief Valve Drain Tubes
A112.4.2/CSA B45.16	Water Closet Personal Hygiene Devices
A112.4.3	Plastic Fittings for Connecting Water Closets to the Sanitary Drainage System
A112.4.7	Point-of-Use and Branch Water Submetering Systems
A112.6.1M	Support for Off-the-Floor Plumbing Fixtures for Public Use
A112.6.2	Framing-Affixed Supports for Off-the-Floor Water Closets with Concealed Tanks
A112.6.3	Floor and Trench Drains
A112.6.4	Roof, Deck, and Balcony Drains
A112.6.7	Enameled and Epoxy-Coated Cast Iron and PVC Plastic Sanitary Floor Sinks
A112.6.9	Siphonic Roof Drains
A112.14.1	Backwater Valves
A112.14.3	Grease Interceptors
A112.14.4	Grease Removal Devices
A112.18.1/CSA B125.1	Plumbing Supply Fittings

Table 2-2 Standards by Standards Developing Organization

A112.18.2/CSA B125.2	Plumbing Fixture Waste Fittings
A112.18.3M	Performance Requirements for Backflow Devices and Systems in Plumbing Fixture Fittings
A112.18.6	Flexible Water Connectors
A112.18.7	Deck-Mounted Bath/Shower Transfer Valves with Integral Backflow Protection
A112.19.1M	Enameled Cast Iron Plumbing Fixtures
A112.19.2M	Vitreous China Plumbing Fixtures
A112.19.3/CSA B45.4	Stainless Steel Plumbing Fixtures
A112.19.4M	Porcelain Enameled Formed Steel Plumbing Fixtures
A112.19.5/CSA B45.15	Trim for Water Closet Bowls, Tanks, and Urinals
A112.19.6	Hydraulic Performance Requirements for Water Closets and Urinals
A112.19.7/CSA B45.10	Hydromassage Bathtub Appliances
A112.19.8	Suction Fittings for Use in Swimming Pools, Wading Pools, Spas, and Hot Tubs
A112.19.9M	Non-Vitreous Ceramic Plumbing Fixtures
A112.19.12	Wall-Mounted, Pedestal-Mounted, Adjustable, Elevated, Tilting, and Pivoting Lavatory and Sink, and Shampoo Bowl Carrier and Drain Waste Systems
A112.19.13	Electrohydraulic Water Closets
A112.19.14	Six-Liter Water Closets Equipped with a Dual-Flushing Device
A112.19.15	Bathtub/Whirlpool Bathtubs with Pressure-Sealed Doors
A112.19.17	Manufactured Safety Vacuum Release Systems (SVRS) for Residential and Commercial Swimming Pool, Spa, Hot Tub, Wading Pool Suction Systems
A112.19.19	Vitreous China Nonwater Urinals
A112.6.3	Floor and Trench Drains
A112.36.2M	Cleanouts
B1.20.1	Pipe Threads, General Purpose (inch)
B16.1	Gray Iron Pipe Flanges and Flanged Fittings: Classes 25, 125, and 250
B16.3	Malleable Iron Threaded Fittings: Classes 150 and 300
B16.4	Gray Iron Threaded Fittings: Classes 125 and 250
B16.5	Pipe Flanges and Flanged Fittings
B16.9	Factory-Made Wrought Steel Buttwelding Fittings
B16.11	Forged Steel Fittings, Socket-Welding and Threaded
B16.12	Cast Iron Threaded Drainage Fittings
B16.15	Cast Bronze Threaded Fittings: Classes 125 and 250
B16.18	Cast Copper Alloy Solder Joint Pressure Fittings
B16.20	Metallic Gaskets for Pipe Flanges: Ring-Joint, Spiral-Wound, and Jacketed
B16.22	Wrought Copper and Copper Alloy Solder Joint Pressure Fittings
B16.23	Cast Copper Alloy Solder Joint Drainage Fittings—DWV
B16.24	Cast Copper Alloy Pipe Flanges and Flanged Fittings: Classes 150, 300, 400, 600, 900, 1,500, and 2,500
B16.26	Cast Copper Alloy Fittings for Flared Copper Tubes
B16.28	Wrought Steel Buttwelding Short Radius Elbows and Returns
B16.29	Wrought Copper and Wrought Copper Alloy Solder Joint Drainage Fittings—DWV
B16.33	Manually Operated Metallic Gas Valves for Use in Gas Piping Systems up to 125 psig (Sizes ½ through 2)
B16.50	Wrought Copper and Copper Alloy Braze-Joint Pressure Fittings
B31.3	Power and Process Piping Package
B36.10M	Welded and Seamless Wrought Steel Pipe

Table 2-2 Standards by Standards Developing Organization	
BPVC	Boiler and Pressure Vessel Code
CSD-1	Controls and Safety Devices for Automatically Fired Boilers
ASPE (American Society of Plumbing Engineers, aspe.org)	
45	Siphonic Roof Drainage
ARCSA/ASPE 63	Rainwater Catchment Systems
ARCSA/ASPE 78	Stormwater Harvesting System Design for Direct End-Use Applications
WQA/ASPE S-801	Sustainable Management
WQA/ASPE/NSF S-802	Sustainable Media Products for Water Treatment
WQA/ASPE/NSF S-803	Sustainable Drinking Water Treatment Systems
ASSE International (American Society of Sanitary Engineering, asse-plumbing.org)	
1001	Atmospheric Type Vacuum Breakers
1002/ASME A112.1002/ CSA B125.12	Anti-Siphon Fill Valves for Gravity Water Closet Tanks
1003	Water Pressure Reducing Valves for Domestic Water Distribution Systems
1004	Backflow Prevention Requirements for Commercial Dishwashing Machines
1006	Residential Use Dishwashers
1007	Home Laundry Equipment
1008	Plumbing Aspects of Residential Food Waste Grinders
1009	Commercial Food Grinder Units
1010	Water Hammer Arresters
1011	Hose Connection Vacuum Breakers
1012	Backflow Preventer with Intermediate Atmospheric Vent
1013	Reduced-Pressure Principle Backflow Preventers and Reduced-Pressure Principle Fire Protection Backflow Preventers
1014	Backflow Prevention Devices for Handheld Showers
1015	Double-Check Backflow Prevention Assemblies and Double-Check Fire Protection Backflow Prevention Assemblies
1016/ASME A112.1016/ CSA B125.16	Automatic Compensating Valves for Individual Showers and Tub/Shower Combinations
1017	Temperature Actuated Mixing Valves for Hot Water Distribution Systems
1018	Trap Seal Primer Valves—Potable Water Supplied
1019	Vacuum Breaker Wall Hydrants—Freeze Resistant Automatic Draining Type
1020	Pressure Vacuum Breaker Assembly
1021	Drain Air Gaps for Domestic Dishwasher Applications
1022	Backflow Preventer for Beverage Dispensing Equipment
1023	Hot Water Dispensers, Household Storage Type, Electrical
1024	Dual-Check Backflow Preventers
1030	Positive Air Pressure Attenuators for Sanitary Drainage Systems
1032	Dual-Check Valve-Type Backflow Preventer for Carbonated Beverage Dispensers—Post-Mix Type
1035	Laboratory Faucet Backflow Preventers
1037/ASME A112.1037/ CSA B125.37	Pressurized Flushing Devices (Flushometers) for Plumbing Fixtures
1044	Trap Seal Primer Devices—Drainage Types and Electronic Design Types
1047	Reduced-Pressure Detector Fire Protection Backflow Prevention Assemblies
1048	Double-Check Detector Fire Protection Backflow Prevention Assemblies
1049	Performance Requirements for Individual Branch Type Air Admittance Valves for Chemical Waste Systems

Table 2-2 Standards by Standards Developing Organization

1050	Stack Air-Admittance Valves for Sanitary Drainage Systems
1051	Individual and Branch-Type Air-Admittance Valves for Sanitary Drainage Systems
1052	Hose Connection Backflow Preventers
1053	Dual-Check Backflow Preventer Wall Hydrants—Freeze-Resistant Type
1055	Chemical Dispensing Systems
1056	Spill-Resistant Vacuum Breakers
1057	Freeze-Resistant Sanitary Yard Hydrants with Backflow Protection
1060	Outdoor Enclosures for Fluid-Conveying Components
1061	Removable and Non-Removable Push-Fit Fittings
1062	Temperature-Actuated, Flow Reduction (TAFR) Valves for Individual Fixture Fittings
1063	Air Valve and Vent Intake Preventers
1064	Backflow Prevention Assembly Field Test Kits
1066	Individual Pressure Balancing Inline Valves for Individual Fixture Fittings
1069	Automatic Temperature Control Mixing Valves
1070/ASME A112.1070/ CSA B125.70	Water Temperature Limiting Devices
1071	Temperature-Actuated Mixing Valves for Plumbed Emergency Equipment
1072	Barrier-Type Floor Drain Trap Seal Protection Devices
1079	Dielectric Pipe Unions
5000	Professional Qualifications Standard for Backflow Prevention Assemblies Testers, Repairers, and Surveyors
6000	Professional Qualifications Standard for Medical Gas Systems Personnel
7000	Professional Qualifications Standard for Plumbing-Based Residential Fire Protection Systems Installers and Inspectors
ASTM International (American Society for Testing and Materials, astm.org)	
A53/A53M	Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless
A74	Specification for Cast Iron Soil Pipe and Fittings
A106/A106M	Specification for Seamless Carbon Steel Pipe for High-Temperature Service
A126	Specification for Gray Iron Castings for Valves, Flanges, and Pipe Fittings
A254	Specification for Copper-Brazed Steel Tubing
A312/A312M	Specification for Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes
A420/A420M	Specification for Piping Fittings of Wrought Carbon Steel and Alloy Steel for Low-Temperature Service
A733	Specification for Welded and Seamless Carbon Steel and Austenitic Stainless Steel Pipe Nipples
A778	Specification for Welded, Unannealed Austenitic Stainless Steel Tubular Products
A888	Specification for Hubless Cast Iron Soil Pipe and Fittings for Sanitary and Storm Drain, Waste, and Vent Piping Applications
B32	Specification for Solder Metal
B42	Specification for Seamless Copper Pipe, Standard Sizes
B43	Specification for Seamless Red Brass Pipe, Standard Sizes
B68/B68M	Specification for Seamless Copper Tube, Bright Annealed
B75/B75M	Specification for Seamless Copper Tube
B88/B88M	Specification for Seamless Copper Water Tube
B135/B135M	Specification for Seamless Brass Tube
B152/B152M	Specification for Copper Sheet, Strip, Plate, and Rolled Bar
B210/B210M	Specification for Aluminum and Aluminum-Alloy Drawn Seamless Tubes
B211/B211M	Specification for Aluminum and Aluminum-Alloy Bar, Rod, and Wire

Table 2-2 Standards by Standards Developing Organization

B241/B241M	Specification for Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube
B251/B251M	Specification for General Requirements for Wrought Seamless Copper and Copper-Alloy Tube
B280	Specification for Seamless Copper Tube for Air-Conditioning and Refrigeration Field Service
B302	Specification for Threadless Copper Pipe, Standard Sizes
B306	Specification for Copper Drainage Tube (DWV)
B447	Specification for Welded Copper Tube
B687	Specification for Brass, Copper, and Chromium-Plated Pipe Nipples
B813	Specification for Liquid and Paste Fluxes for Soldering of Copper and Copper Alloy Tube
B828	Practice for Making Capillary Joints by Soldering of Copper and Copper Alloy Tube and Fittings
C4	Specification for Clay Drain Tile and Perforated Clay Drain Tile
C14/C14M	Specification for Nonreinforced Concrete Sewer, Storm Drain, and Culvert Pipe
C76/C76M	Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe
C296/C296M	Specification for Asbestos-Cement Pressure Pipe
C411	Test Method for Hot-Surface Performance of High-Temperature Thermal Insulation
C425	Specification for Compression Joints for Vitrified Clay Pipe and Fittings
C428/C248M	Specification for Asbestos-Cement Nonpressure Sewer Pipe
C443/C443M	Specification for Joints for Concrete Pipe and Manholes, Using Rubber Gaskets
C508/C508M	Specification for Asbestos-Cement Underdrain Pipe
C564	Specification for Rubber Gaskets for Cast Iron Soil Pipe and Fittings
C700	Specification for Vitrified Clay Pipe, Extra Strength, Standard Strength, and Perforated
C913	Specification for Precast Concrete Water and Wastewater Structures
C1053	Specification for Borosilicate Glass Pipe and Fittings for Drain, Waste, and Vent (DWV) Applications
C1173	Specification for Flexible Transition Couplings for Underground Piping Systems
C1277	Specification for Shielded Coupling Joining Hubless Cast Iron Soil Pipe and Fittings
C1440	Specification for Thermoplastic Elastomeric (TPE) Gasket Materials for Drain, Waste, and Vent (DWV), Sewer, Sanitary, and Storm Plumbing Systems
C1460	Specification for Shielded Transition Couplings for Use with Dissimilar DWV Pipe and Fittings Aboveground
C 1461	Specification for Mechanical Couplings Using Thermoplastic Elastomeric (TPE) Gaskets for Joining Drain, Waste, and Vent (DWV) Sewer, Sanitary and Storm Plumbing Systems for Above- and Belowground Use
D1527	Specification for Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe, Schedules 40 and 80
D1785	Specification for Poly (Vinyl Chloride) (PVC) Plastic Pipe, Schedules 40, 80, and 120
D1869	Specification for Rubber Rings for Asbestos-Cement Pipe
D2235	Specification for Solvent Cement for Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe and Fittings
D2239	Specification for Polyethylene (PE) Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameter
D2241	Specification for Poly (Vinyl Chloride) (PVC) Pressure-Rated Pipe (SDR Series)
D2464	Specification for Threaded Poly (Vinyl Chloride) (PVC) Plastic Pipe Fittings, Schedule 80
D2466	Specification for Poly (Vinyl Chloride) (PVC) Plastic Pipe Fittings, Schedule 40
D2467	Specification for Poly (Vinyl Chloride) (PVC) Plastic Pipe Fittings, Schedule 80
D2513	Specification for Thermoplastic Gas Pressure Pipe, Tubing, and Fittings
D2564	Specification for Solvent Cements for Poly (Vinyl Chloride) (PVC) Plastic Piping Systems
D2609	Specification for Plastic Insert Fittings for Polyethylene (PE) Plastic Pipe
D2657	Standard Practice for Heat Fusion Joining of Polyolefin Pipe and Fittings
D2661	Specification for Acrylonitrile-Butadiene-Styrene (ABS) Schedule 40 Plastic Drain, Waste, and Vent Pipe and Fittings
D2665	Specification for Poly (Vinyl Chloride) (PVC) Plastic Drain, Waste, and Vent Pipe and Fittings

Table 2-2 Standards by Standards Developing Organization	
D2672	Specification for Joints for IPS PVC Pipe Using Solvent Cement
D2683	Specification for Socket-Type Polyethylene Fittings for Outside Diameter-Controlled Polyethylene Pipe and Tubing
D2729	Specification for Poly (Vinyl Chloride) (PVC) Sewer Pipe and Fittings
D2737	Specification for Polyethylene (PE) Plastic Tubing
D2751	Specification for Acrylonitrile-Butadiene-Styrene (ABS) Sewer Pipe and Fittings
D2846/D2846M	Specification for Chlorinated Poly (Vinyl Chloride) (CPVC) Plastic Hot and Cold Water Distribution Systems
D2855	Standard Practice for Making Solvent-Cemented Joints with Poly (Vinyl Chloride) (PVC) Pipe and Fittings
D2949	Specification for 3.25-in. Outside Diameter Poly (Vinyl Chloride) (PVC) Plastic Drain, Waste, and Vent Pipe and Fittings
D2996	Specification for Filament-Wound “Fiberglass” (Glass Fiber Reinforced Thermosetting Resin) Pipe
D3034	Specification for Type PSM Poly (Vinyl Chloride) (PVC) Sewer Pipe and Fittings
D3035	Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Controlled Outside Diameter
D3139	Specification for Joints for Plastic Pressure Pipes Using Flexible Elastomeric Seals
D3212	Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals
D3311	Specification for Drain, Waste, and Vent (DWV) Plastic Fittings Patterns
D3350	Specification for Polyethylene Plastics Pipe and Fittings Materials
D4068	Specification for Chlorinated Polyethylene (CPE) Sheeting for Concealed Water-Containment Membrane
D4551	Specification for Poly (Vinyl Chloride) (PVC) Plastic Flexible Concealed Water-Containment Membrane
E84	Test Method for Surface Burning Characteristics of Building Materials
E119	Test Method for Fire Tests of Building Construction and Materials
E136	Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C
E814	Test Method for Fire Tests of Penetration Firestop Systems
F405	Specification for Corrugated Polyethylene (PE) Pipe and Fittings
F409	Specification for Thermoplastic Accessible and Replaceable Plastic Tube and Tubular Fittings
F437	Specification for Threaded Chlorinated Poly (Vinyl Chloride) (CPVC) Plastic Pipe Fittings, Schedule 80
F438	Specification for Socket-Type Chlorinated Poly (Vinyl Chloride) (CPVC) Plastic Pipe Fittings, Schedule 40
F439	Specification for Socket-Type Chlorinated Poly (Vinyl Chloride) (CPVC) Plastic Pipe Fittings, Schedule 80
F441/F441M	Specification for Chlorinated Poly (Vinyl Chloride) (CPVC) Plastic Pipe, Schedules 40 and 80
F442/F442M	Specification for Chlorinated Poly (Vinyl Chloride) (CPVC) Plastic Pipe (SDR-PR)
F477	Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe
F493	Specification for Solvent Cements for Chlorinated Poly (Vinyl Chloride) (CPVC) Plastic Pipe and Fittings
F628	Specification for Acrylonitrile-Butadiene-Styrene (ABS) Schedule 40 Plastic Drain, Waste, and Vent Pipe with a Cellular Core
F656	Specification for Primers for Use in Solvent Cement Joints of Poly (Vinyl Chloride) (PVC) Plastic Pipe and Fittings
F714	Specification for Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter
F876	Specification for Crosslinked Polyethylene (PEX) Tubing
F877	Specification for Crosslinked Polyethylene (PEX) Plastic Hot and Cold Water Distribution Systems
F891	Specification for Coextruded Poly (Vinyl Chloride) (PVC) Plastic Pipe with a Cellular Core
F1055	Specification for Electrofusion-Type Polyethylene Fittings for Outside Diameter-Controlled Polyethylene Pipe and Tubing
F1281	Specification for Crosslinked Polyethylene/Aluminum/Cross-Linked Polyethylene (PEX-AL-PEX) Pressure Pipe
F1282	Specification for Polyethylene/Aluminum/Polyethylene (PE-AL-PE) Composite Pressure Pipe
F1488	Specification for Coextruded Composite Pipe
F1807	Specification for Metal Insert Fittings Utilizing a Copper Crimp Ring for SDR9 Crosslinked Polyethylene (PEX) Tubing

Table 2-2 Standards by Standards Developing Organization	
F1866	Specification for Poly (Vinyl Chloride) (PVC) Plastic Schedule 40 Drainage and DWV Fabricated Fittings
F1960	Specification for Cold Expansion Fittings with PEX Reinforcing Rings for Use with Crosslinked Polyethylene (PEX) Tubing
F1974	Specification for Metal Insert Fittings for Polyethylene/Aluminum/Polyethylene and Crosslinked Polyethylene/ Aluminum/Crosslinked Polyethylene Composite Pressure Pipe
F2080	Specification for Cold-Expansion Fittings with Metal Compression Sleeves for Crosslinked Polyethylene (PEX) Pipe
AWS (American Welding Society, aws.org)	
A5.8	Specifications for Filler Metals for Brazing and Braze Welding
AWWA (American Water Works Association, awwa.org)	
C104/ANSI A21.4	Cement-Mortar Lining for Ductile Iron Pipe and Fittings for Water
C110	Ductile Iron and Gray Iron Fittings for Water
C111	Rubber Gasket Joints for Ductile Iron Pressure Pipe and Fittings
C115	Flanged Ductile Iron Pipe with Threaded Flanges
C151	Ductile Iron Pipe, Centrifugally Cast, for Water
C153	Ductile Iron Compact Fittings for Water Service
C510	Double-Check Valve Backflow Prevention Assembly
C511	Reduced-Pressure Principle Backflow Prevention Assembly
C651	Disinfecting Water Mains
C652	Disinfection of Water-Storage Facilities
C901	Polyethylene (PE) Pressure Pipe and Tubing ½ inch (13 mm) Through 3 inch (76 mm) for Water Service
C904	Cross-Linked Polyethylene (PEX) Pressure Pipe ½ inch (13 mm) Through 3 inch (76 mm) for Water Service
CISPI (Cast Iron Soil Pipe Institute, cispi.org)	
301	Specification for Hubless Cast Iron Soil Pipe and Fittings for Sanitary and Storm Drain, Waste, and Vent Piping Applications
310	Specification for Coupling for Use in Connection with Hubless Cast Iron Soil Pipe and Fittings for Sanitary and Storm Drain, Waste, and Vent Piping Applications
CGA (Compressed Gas Association, cganet.com)	
S-1.1	Pressure Relief Device Standards, Part 1: Cylinders for Compressed Gases
S-1.2	Pressure Relief Device Standards, Part 2: Cargo and Portable Tanks for Compressed Gases
S-1.3	Pressure Relief Device Standards, Part 3: Stationary Storage Containers for Compressed Gases
CSA Group (Canadian Standards Association, csagroup.org)	
A257	Concrete Pipe and Manhole Sections
A257.1	Non-reinforced Circular Concrete Culvert, Storm Drain, Sewer Pipe, and Fittings
A257.2	Reinforced Circular Concrete Culvert, Storm Drain, Sewer Pipe, and Fittings
A257.3	Joints for Circular Concrete Sewer and Culvert Pipe, Manhole Sections, and Fittings Using Rubber Gaskets
B45.1	Ceramic Plumbing Fixtures
B45.2	Enamelled Cast-Iron Plumbing Fixtures
B45.3	Porcelain-Enamelled Steel Plumbing Fixtures
B45.4	Stainless Steel Plumbing Fixtures
B45.5/IAPMO Z124	Plastic Plumbing Fixtures
B64	Backflow Preventers and Vacuum Breakers
B70	Cast Iron Soil Pipe, Fittings and Means of Joining
B79	Commercial and Residential Drains and Cleanouts
B125.3	Plumbing Fittings
B137	Thermoplastic Pressure Piping Compendium

Table 2-2 Standards by Standards Developing Organization	
B137.1	Polyethylene Pipe, Tubing, and Fittings for Cold Water Pressure Service
B137.2	PVC Injected Moulded Gasketed Fittings for Pressure Applications
B137.3	Rigid Polyvinyl Chloride (PVC) Pipe for Pressure Applications
B137.5	Crosslinked Polyethylene (PEX) Tubing Systems for Pressure Applications
B137.6	CPVC Pipe, Tubing, and Fittings for Hot and Cold Water Distribution Systems
B137.8	Polybutylene (PB) Piping for Pressure Applications
B137.9	Polyethylene/Aluminum/Polyethylene Composite Pressure Pipe Systems
B137.10	Crosslinked Polyethylene/Aluminum/Crosslinked Polyethylene Composite Pressure Pipe Systems
B181.1	ABS Drain, Waste and Vent Pipe and Pipe Fittings
B181.2	PVC Drain, Waste and Vent Pipe and Pipe Fittings
B182.2	PVC Sewer Pipe and Fittings (PSM Type)
B182.4	Profile PVC Sewer Pipe and Fittings
B149	Natural Gas and Propane Installation Code
B139	Installation Code for Oil-Burning Equipment
B602	Mechanical Couplings for Drain, Waste, and Vent Pipe and Sewer Pipe
B1800	Plastic Nonpressure Pipe Compendium
ISEA (International Safety Equipment Association, safetyequipment.org)	
Z358.1	Emergency Eyewash and Shower Equipment
MSS (Manufacturers Standardization Society of the Valve and Fittings Industry, msshq.org)	
SP-6	Standard Finishes for Contact Faces of Pipe Flanges and Connecting-End Flanges of Valves and Fittings
SP-58	Pipe Hangers and Supports—Materials, Design, Manufacture, Selection, Application, and Installation
SP-70	Gray Iron Gate Valves, Flanged and Threaded Ends
SP-72	Ball Valves with Flanged or Buttwelding Ends for General Service
SP-80	Bronze Gate, Globe, Angle, and Check Valves
NFPA (National Fire Protection Association, nfpa.org)	
1	Fire Code
13	Installation of Sprinkler Systems
13D	Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes
13R	Installation of Sprinkler Systems in Residential Occupancies Up to and Including Four Stories in Height
14	Installation of Standpipes and Hose Systems
20	Installation of Stationary Pumps for Fire Protection
24	Installation of Private Fire Service Mains and Their Appurtenances
25	Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems
30	Flammable and Combustible Liquids Code
31	Installation of Oil-Burning Equipment
37	Installation and Use of Stationary Combustion Engines and Gas Turbines
45	Fire Protection for Laboratories Using Chemicals
50	Bulk Oxygen Systems at Consumer Sites
51	Design and Installation of Oxygen-Fuel Gas Systems for Welding, Cutting, and Allied Processes
54	National Fuel Gas Code
58	Liquefied Petroleum Gas Code
69	Explosion Prevention Systems
70	National Electrical Code
72	National Fire Alarm Code

Table 2-2 Standards by Standards Developing Organization

85	Boiler and Combustion Systems Hazards Code
88A	Parking Structures
96	Ventilation Control and Fire Protection of Commercial Cooking Operations
99	Health Care Facilities Code
101	Life Safety Code
211	Chimneys, Fireplaces, Vents, and Solid Fuel-Burning Appliances
704	Identification of the Hazards of Materials for Emergency Response
853	Installation of Stationary Fuel Cell Power Systems
5000	Building Construction and Safety Code
NSF (National Sanitation Foundation, nsf.org)	
3	Commercial Warewashing Equipment
14	Plastic Piping System Components and Related Materials
18	Manual Food and Beverage Dispensing Equipment
40	Residential Wastewater Treatment Systems
41	Non-Liquid Saturated Treatment Systems
42	Drinking Water Treatment Units—Aesthetic Effects
44	Residential Cation Exchange Water Softeners
53	Drinking Water Treatment Units—Health Effects
58	Reverse Osmosis Drinking Water Treatment Systems
61	Drinking Water System Components—Health Effects
62	Drinking Water Distillation Systems
PDI (Plumbing and Drainage Institute, pdionline.org)	
G101	Testing and Rating Procedure for Grease Interceptors
G102	Testing and Certification for Grease Interceptors with FOG-Sensing and Alarm Devices
WH201	Water Hammer Arresters
UL (Underwriters Laboratories, ul.com)	
17	Vent or Chimney Connector Dampers for Oil-Fired Appliances
70	Septic Tanks, Bituminous Coated Metal
103	Factory-Built Chimneys, Residential Type and Building Heating Appliance
127	Factory-Built Fireplaces for Residential-Type and Building Heating Appliances
174	Household Electric Storage Tank Water Heaters
343	Pumps for Oil-Burning Appliances
391	Solid-Fuel and Combination-Fuel Central and Supplementary Furnaces
441	Gas Vents
536	Flexible Metallic Hose
641	Type L Low-Temperature Venting Systems
710	Exhaust Hoods for Commercial Cooking Equipment
726	Oil-Fired Boiler Assemblies
727	Oil-Fired Central Furnaces
729	Oil-Fired Floor Furnaces
730	Oil-Fired Wall Furnaces
731	Oil-Fired Unit Heaters
732	Oil-Fired Storage Tank Water Heaters
834	Heating, Water Supply, and Power Boilers—Electric

Table 2-2 Standards by Standards Developing Organization

896	Oil-Burning Stoves
959	Medium Heat Appliance Factory-Built Chimneys
1261	Electric Water Heaters for Pools and Tubs
1453	Electronic Booster and Commercial Storage Tank Water Heaters
1738	Venting Systems for Gas-Burning Appliances, Categories II, III, and IV
1820	Fire Test of Pneumatic Tubing for Flame and Smoke Characteristics
1887	Fire Tests of Plastic Sprinkler Pipe for Flame and Smoke Characteristics
U.S. Department of Transportation (dot.gov)	
49 CFR	Parts 192.281(e) and 192.283 (b) Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards Parts 100–180 Hazardous Materials Regulations

Table 2-3 Guidelines by Standards Developing Organization

ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ashrae.org)	
Guideline 0	The Commissioning Process
Guideline 12	Minimizing the Risk of Legionellosis Associated with Building Water Systems
Guideline 32	Sustainable High-Performance Operations and Maintenance

Specifications

Plumbing drawings, plumbing specifications, general conditions, special conditions, and the addenda comprise the documents that make up the contract between the owner and the contractor. None of these items can stand alone—the drawings cannot serve as a contract without the specifications and vice versa. The plumbing designer must, therefore, be familiar with specification writing. If others prepare the specifications, then the plumbing designer must coordinate the drawings with the project specifications.

When writing specifications, the language used must be clear, precise, and exact to convey the information required. The essence of a well-written specification includes clarity, brevity, accuracy, and completeness.

Specification writers should follow established, uniform practices that will ensure good communication between the designer and all other segments of the construction industry. The result will be a set of documents that will allow an engineer in one part of the country to converse with a supplier or contractor in another location, and the language in the specifications will be clear to all parties.

DEFINITION OF TERMS

It is necessary to understand the terms that are used in these documents so one term, and only that one term, is used for any one part of the documents.

Bid The price submitted to the owner by the contractor to perform the work per the contract documents.

Bidder The person or firm that has met the requirements set forth in the general conditions to submit a price in writing to the owner to do the work per the contract documents.

Bidding documents Construction documents issued to bidders before the owner/contractor agreement has been signed.

Bidding requirements The explanation of the procedures to follow when preparing and submitting a bid; also used to attract potential bidders.

Construction contract documents More often referred to as the contract documents, these describe the proposed construction, or the work that will result from construction. Many times these documents are erroneously referred to as the plans and specifications. It should be noted that many times these documents do not include plans or specifications. Instead of using the term *plans* when referring to the graphic documents, the term *drawings* should be used. Many times the term *specifications* is expanded to generally refer to all written documents. The correct term when describing all of the documents, with the exception of the drawings, is *project manual*.

Contract documents The legally enforceable requirements that become part of the contract when the agreement is signed.

Contractor The successful bidder after award of the contract.

Furnish To supply and deliver to a project site, ready for unloading, unpacking, assembly, installation, and similar operations.

Install To perform operations at a project site such as unloading, temporarily storing, unpacking, assembling, erecting, placing, anchoring, applying, working to dimension, finishing, curing, protecting, cleaning, and similar operations.

May This term is used in specifications to indicate non-mandatory recommendations or permissions.

Provide To furnish and install, complete and ready for the intended use.

Shall This term is used in specifications to indicate a mandatory requirement that can be verified.

Should This term is used in specifications to indicate non-mandatory design criteria or preference.

Will This term is used in specifications to indicate a statement of fact.

Work Performing services, furnishing labor, and supplying and incorporating materials and equipment during construction.

The Contractor

The word *contractor* is often used in the contract documents incorrectly, so it is important to understand how the construction contract will be delivered. In many instances, the project will be delivered by a general contractor. In some states, the project will be delivered by multiple prime contractors, and in others projects are delivered by different types of prime contractors such as the general construction contractor, plumbing and fire protection contractor, mechanical contractor, and electrical contractor. Similarly, the owner may decide to have several prime contractors install different portions of the work on site. Indiscriminately using the term *plumbing contractor* when there is only supposed to be a general contractor may create an issue of somebody thinking that another contractor is supposed to deliver that work.

Words that would be better to use are *plumbing trade, fire protection trade, automatic control subcontractor, Division 22,* etc.

Theoretically, the point behind dividing the work among different divisions and sections of the contract with a single prime contractor is so all parties look in the same locations for different parts and pieces of the work. The purpose of dividing the work among different divisions and sections is not for the designer to determine how the work will be divided between subcontractors and suppliers.

If there are multiple prime contractors, then it is important for the work to be divided between the various contractors. For instance, who will furnish the starters and VFDs? The bidding contractors need to know if these devices will be furnished by the electrical contractor or the plumbing contractor. What about access panels in hard ceilings? What happens in a renovation project when the work will primarily happen in one area, but the plumbing contractor needs to run a new water line for 300 feet through an existing facility? Who is going to pay to have the walls repaired and painted? These are questions that need to be answered, and division of the work between the contractors is important.

One final thought has to do with when the client wants to pre-purchase equipment to expedite the work or potentially have greater control over what equipment is used on the project. Say the plumbing engineer is working on a large compressed air plant. The pre-purchase specification not only should cover the normal three-part aspect of furnishing the equipment, but also should include specifications about what the contractor is supposed to do to install the equipment and how much assistance the vendor is to provide during delivery and startup. What startup reports must be included? How many hours of instruction are necessary?

Approved Equal

The standardized specifications from the major specification suppliers do not include definitions of the words *approved equal*. Later in this chapter is a discussion of open and closed specifications. Clients often require designers or engineers to include more than one supplier that can provide each type of product used on the project. Most products are competitive among suppliers but are not identical. For instance, flushometers are not identical between manufacturers, but the engineer might wish to include three brand-name manufacturers for the products.

Following is an example of how to establish products that the contractor can purchase for the project. It would be defined in the Common Work Results for Plumbing section of the specifications. These definitions could also be included in Section 016000–Product Requirements.

"Materials and equipment are specified to provide a level of quality and performance as a part of these Specifications.

"Where the Specification requires the installation of a product by a reference standard (for example, ASTM B88 Type L pipe), the contractor may install any product meeting the reference standard's requirements and which is produced by any domestic manufacturer.

"Where the Specification requires the installation of a particular manufacturer's model or an approved equal by several other listed manufacturers, the contractor shall provide the particular product specified or a comparable item with all the specified characteristics and accessories that is manufactured by one of the other listed manufacturers.

"Bidders wishing to obtain approval on manufacturers other than those specified by name must submit their request to the Architect not less than ten (10) days before the bid opening. Approval by the Architect will be in the form of an Addendum to the Specification; the Addendum will indicate that the additional manufacturer or manufacturers are approved as equal to those specified so far as the requirements of the project are concerned.

"Where the Specification requires the installation of a particular manufacturer's model or an approved equal with no other manufacturers listed, the contractor shall provide the particular product specified or a comparable item with all the specified characteristics and accessories that is manufactured by a reputable manufacturer and meets the approval of the Architect and the Owner and Engineer. These items are often generic in nature.

"Where the Specification requires the installation of a particular manufacturer's model without an approved equal, the contractor shall provide the product specified. There is no option, and no substitutions will be permitted."

PROJECT MANUAL

The project manual consists of the following documents, but not the drawings.

- Pre-bid information advises prospective bidders about the proposed project. The pre-bid information for private work can be sent directly to certain bidders by the architect, engineer, or owner, and the bid is restricted to those bidders. This method is usually referred to as bid by invitation. Pre-bid information for public work is required by law to be advertised for a predetermined period in the immediate area where the work will be done. The exact length of time is set forth by local ordinances governing public notices.
- Instructions to bidders are written to inform prospective bidders how to prepare their bid so all bids are in the same format and can be easily and fairly compared.
- Bid forms are prepared by the architect or engineer to provide uniform bid submittals by the bidders and to facilitate the comparison and evaluation of the bids received.
- Bonds and certificates are the legal documents that bind a third party into the contract as a surety that the bidder and the owner will perform as agreed or that the contractor and subcontractors will perform as agreed. The types of bonds and certificates commonly used are:
    - Bid bond: Ensures that the bidder will enter into a contract with the owner or the contractor if the bidder is selected during the bidding phase.
    - Performance bond: Ensures that, once a contract has been signed, the work will be completed in compliance with the contract documents.
    - Labor and materials payment bond: Ensures that workers on the project will be paid in full and that all suppliers that have provided materials for the project will be paid in full prior to the project closeout.
    - Guaranty bond: Guarantees that the contractor will be paid in full for all work performed to construct the project.
    - Certificates: Certificates of insurance, or proof of insurance from the contractors and/or subcontractors, as well as certificates of compliance with applicable codes, laws, and regulations.
- The agreement is the written document signed by the owner and the contractor, or by the contractor and a subcontractor or a material supplier, that is the legal instrument binding these parties to the contract. The agreement defines the relationships as well as the obligations between the signing parties.

- General conditions are the general clauses that establish how the project is to be administered. These clauses contain provisions that are common practice in the United States. The American Institute of Architects (AIA) has developed Document A201: *General Conditions of the Contract for Construction*. A printed copy of this document is usually included in the project manual and referenced by the other documents that are included in the manual. Other general conditions documents are available from organizations such as the National Society of Professional Engineers (NSPE), American Council of Engineering Companies (ACEC), American Society of Civil Engineers (ASCE), and Construction Specifications Institute (CSI).
- Supplementary conditions are the clauses that modify or supplement the general conditions as needed to provide for requirements that are specific to the project. They consist of modifications and/or substitutions such as insurance requirements and prevailing wage rates. It is important to remember that these are not standardized documents and must be prepared based on the requirements of the specific project.
- Specifications describe the required materials and equipment, the level of quality required for installation and equipment, and the methods by which the materials and equipment are assembled, installed, and interface within the project as a whole. The specifications also set the administrative requirements for the contract. All items pertaining to the work under the contract should be included in the specifications.
- Addenda are the written or graphic documents that are issued prior to the bid to clarify, revise, add to, or delete information in the original bid documents or in previous addenda. It should be noted that while an addendum is typically issued prior to the bid opening, AIA A201 permits the issuance of an addendum any time up to the execution of the contract, which allows for the negotiated adjustment of a selected bid after the bid opening. In contrast, a similar document by the Engineers Joint Contract Documents Committee (EJCDC) restricts the issuance of addenda to before the bid opening.
- Modifications are the written or graphic documents that are issued after the construction agreement has been signed to allow for additions to, deletions from, or modifications of the work that is to be performed. These changes are accomplished by the use of change orders, construction change directives, work change directives, field orders, architect's supplemental instructions (ASI), and written amendments to the construction agreement. These changes or modifications can be issued any time during the contract period.

Each of the documents listed above is a separate piece, but when grouped together, they are collectively referred to as the front-end documents. Although the specifications document usually comprises the bulk of the project manual, it is only one of the required documents. If the project is primarily plumbing, then the plumbing engineer/designer may be responsible for preparing the entire project manual.

SPECIFICATIONS

Originally all documentation for a given project was placed in the drawings, but as the amount of information increased to where it would not fit on the drawings, another way was needed to present this information. Thus, designers started compiling all of the notes that would not fit on the drawings and over time added more information, product requirements, contractual provisions, and construction methods and systems. Known as the project specifications, this information is used to define the qualitative requirements for the products, materials, and workmanship that will be used to construct a given project.

As the popularity of the specification grew among design professionals, so did the problems this new idea created—especially the lack of universal guidelines to ensure uniform documents. Designers wrote specifications using their own style according to what they thought was important. Even the specifications that came from large firms lacked consistency between documents. Materials, methods, or items that were related were not grouped together in a logical manner but were scattered throughout the document. This practice made it very easy to overlook important and costly items when the contractor tried to prepare a specific bid. Also, coordination among the various trades and the contractor was difficult at best.

Specifications can be generated in many ways. They can be produced by the designer as part of the design process or by a specific individual within the firm who is employed full time for writing project specifications. Large firms may even have a full-time specifications department.

To develop a specification, the designer must have as much information as possible that pertains to the section that is to be written. This includes any reference materials that describe products and methods of construction to be included within the specification section. The project information would include the drawings prepared by the designer, the project's scope of work, and any applicable laws and/or building codes. Information for the products can be obtained from a variety of sources, including previous project specifications, owner requirements, manufacturer's literature, handbooks, reference standards, governmental agencies, trade associations, technical and professional societies, commercially prepared guide specifications, and personal experience.

It is a bad idea to edit previous specifications to use for a new project, as they may or may not contain the required language, the standards cited may have changed, the products specified may not be available, or the codes and/or laws may have changed since those specifications were written.

Once the needed information has been gathered, the designer must decide what type of format will be used as the basis of the specifications to be written. Depending on the size of the project or the project phase, the designer may choose a short, abbreviated format such as CSI's UniFormat. For larger, more complex projects, the designer may choose the full format as found in CSI's MasterFormat. Specification formats are also developed by EJCDC, AIA, and NSPE, as well as various governmental agencies such as the U.S. Army Corps of Engineers and NASA. The designer needs to become knowledgeable of the different specifications that are available to decide which format is best suited for the phase of the project being designed. The architect may be responsible for choosing the specification format, so determine this before proceeding.

UniFormat

UniFormat is a specification system that was developed during the early 1970s, and its format is systems based. This format is used mostly during the schematic phase as well as for preliminary or budgetary cost estimates. CSI and Construction Specifications Canada (CSC) recommend the use of UniFormat to organize project data during the preliminary project phases.

UniFormat is divided into eight broad sections:

1. Substructure
2. Shell
3. Interiors
4. Services
5. Equipment and Furnishings
6. Other Building Construction
7. Sitework
8. General

For more information and the subcategories that are found within each of the eight categories of this format, refer to Appendix 3-A.

One of the best features of UniFormat is that each category or subcategory can be easily expanded as more information is accumulated during the design process. As more information is added, the specification will provide the estimator with valuable information to prepare an informed preliminary cost estimate.

Once the project progresses from the preliminary or schematic phase to the design development, or DD, phase, more detailed information is required that UniFormat is not designed to handle. At this stage of the project, outline specifications are usually introduced to organize the required information. In some projects, use of the outline specification may be required as part of the agreement between the owner and the architect/engineer (A/E). Refer to AIA Document B101: *Standard Form of Agreement Between Owner and Architect* for additional information.

Drawings that are prepared during the design development phase contain more detail, both general and specific, than the schematic phase drawings.

MasterFormat

At this point, some designers organize their outline specifications using CSI's MasterFormat because this format can be used from the design development phase to the construction documents (CD) phase.

MasterFormat was created in the 1960s and later became the industry standard in both the United States and Canada. At the core of the system were five-digit numbers with titles that organized construction and/or project data into an easily understood sequence.

The numbers and titles were organized into six groups: Introductory Information, Bidding Requirements, Contracting Requirements, Facilities and Spaces, Systems and Assemblies, and Construction Products and Activities. While they were not specifications, the first five groups were usually included in the project manual as Division 0. The last group—Construction Products and Activities—contained 16 divisions comprising the construction specifications.

On December 31, 2009, CSI officially ended its support of the 16-division format, also known as MasterFormat 95, though some in the construction industry continue to use it. For a more detailed listing of the discontinued format beyond what is shown in Appendix 3-B, refer to CSI's website (csiresources.org) or contact the CSI chapter in your area.

Significant changes were made to MasterFormat when it was transformed from 16 divisions to 49 divisions. The original six groups were condensed into two groups: the Procurement and Contracting Requirements Group and the Specifications Group. The Procurement and Contracting Requirements Group contains the first five groups of MasterFormat 95 and is still known as the front-end documents. The Specifications Group is divided into five subgroups that are further divided into 49 divisions. The subgroups and the divisions contained within each are as follows:

- General Requirements, Division 01
- Facility Construction, Divisions 02–19
- Facility Services, Divisions 20–29
- Site and Infrastructure, Divisions 30–39
- Process Equipment, Divisions 40–49

Refer to Appendix 3-C for a complete list of the divisions that are contained within each subgroup along with a short description of the changes.

In addition to increasing the number of divisions from 16 to 49, the original five-digit numbering system was increased to a six-digit numbering system. For example, Concrete Reinforcement, which was 03200 in the old system, became 03 20 00. The addition of the extra digit increased the number of possible subjects tenfold.

Another change was the relocation of items from one division to another. For example, Plumbing was moved from Division 15 to Division 22, while HVAC was moved from Division 15 to Division 23. Division 15 is now reserved for future expansion. Fire Suppression, previously located in Division 13, was relocated to Division 21. See Appendix 3-D for a complete listing of the numbers and titles for Division 21–Fire Suppression and Appendix 3-E for a complete listing of the numbers and titles for Division 22–Plumbing.

Also included in the new document are sections for facility operations and maintenance, repairs, and commissioning. These sections are located within each division instead of being located in a separate division. These changes can be seen in Appendix 3-E as Section 22 01 00–Operation and Maintenance of Plumbing and Section 22 08 00–Commissioning of Plumbing.

MasterFormat provides a standardized numbering system and the section titles to be used in the project manual, but it does not address how information should be organized. CSI and CSC publish another format—SectionFormat/PageFormat—that provides a uniform standard for arranging specification text using a three-part format as well as a framework for formatting and designating sections. The three parts are Part I–General, Part II–Products, and Part III–Execution, and this organization system helps develop specification sections that provide answers to the following questions:

- How does the work that is defined in the section relate to the work that is defined for the rest of the project?

- What materials and/or products are to be used to complete the work under this section?
- How are these materials and/or products to be incorporated into the work under this section and the project as a whole?

Appendix 3-F contains the shell outline developed by AIA that conforms to this system. The order in which the parts are used within each section is fixed, providing a consistent format throughout all sections and thereby simplifying the designer's job by making it easier to locate information.

MasterFormat and SectionFormat/PageFormat, when used together, will help produce specifications that are clear, complete, accurate, and coordinated, allowing the information to flow from the divisions to the sections to the parts and vice versa.

SPECIFICATION METHODS

Specifications are written using one of the following methods of specifying products, materials, or workmanship:

- Descriptive specification
- Performance specification
- Reference standard specification
- Proprietary specification

Descriptive Specifications

A descriptive specification consists of a detailed written description of the required properties of a product, material, or piece of equipment and the workmanship required for its proper installation. It is important to remember that proprietary or brand names of manufactured products shall not be used in descriptive specifications and that the burden of performance is assumed by the specifier. This method of specifying, while once widely used, has declined in popularity because writing a descriptive specification is very tedious and time-consuming. Descriptive specifications are used when the use of proprietary names is prohibited by law (such as with federally funded projects) or it is not possible to write a reference standard specification due to a lack of reference standards.

To write a descriptive specification, the specifier needs to adhere to certain basic steps:

- Research available products that will be included in the section.
- Research the critical features that will be required in the section, and analyze and compare these requirements with the products that are available.
- Review the features that are required and determine those features that are best described by the specification and those features that would be best shown on the drawings.
- Describe those features that are considered to be critical and the minimum acceptable requirements that must be met by the products to be supplied.

The designer should take care not to select and specify unique features from different products and manufacturers (i.e., pick features from one product and combine them with features from other products). This could create a descriptive specification of a particular product that does not exist. Unnecessary features and minutely detailed requirements should also be avoided.

Performance Specifications

A performance specification includes a statement of the required results with the criteria that the specifier is requiring to verify compliance. Criteria for verifying compliance include measurement, test evaluation, or other means as required by the designer to ensure that the standards of performance have been met. All desired end results the specifier wants must be spelled out completely, but the performance specification should not contain unnecessary limitations on the methods for achieving the required results. An incomplete performance specification will result in the designer losing control over the quality of materials, equipment, and workmanship that will go into the project.

When the performance specification is the primary method of design and contracting, specialized contract documents will be required that are far more complex and often will involve a variety of participants in the contract proceedings.

Reference Standard Specifications

A reference standard specification involves the use of a nationally or internationally recognized standard to specify a product, materials, or workmanship instead of writing a detailed description. A standard is a set of requirements developed by a recognized authority, such as a trade association, professional society, or governmental organization, using a consensus process. Standards usually are authored by a committee that includes architects, engineers, scientists, technicians, manufacturers, and product users who are very knowledgeable about a particular subject area.

The reference-based standards commonly used when writing a specification are:

- Basic material standards
- Product standards
- Design standards
- Workmanship standards
- Test method standards

An example of a basic material standard is ASTM B88: *Standard Specification for Seamless Copper Water Tube,* of a product standard is ASME B16.22: *Wrought Copper and Copper Alloy Solder-Joint Pressure Fittings,* of a design standard is ASPE 45: *Siphonic Roof Drainage,* of a workmanship standard is ASTM B828: *Standard Practice for Making Capillary Joints by Soldering of Copper and Copper Alloy Tube and Fittings,* and of a test standard is ASTM E53: *Standard Test Method for Determination of Copper in Unalloyed Copper by Gravimetry.*

When referring to a standard in a specification, it is not necessary to include the entire text of the standard. The specifier can simply use the standard's number and/or title. The most common form is to cite the standard's sponsoring organization and the number, such as ASTM B88-02. The last two digits are the date the standard was written or last revised. A lowercase "a" after the date indicates an amendment to the standard. These cited standards become part of the specification just as if the standard's entire text were included.

When using a reference standard specification, the designer should thoroughly familiarize himself with the standards he plans to use and how to incorporate these standards into the document correctly, as well as how to enforce the requirements of the standard once it has been included. Some standards may contain requirements of which the designer is unaware, and many standards meet only the minimum requirements; thus, their inclusion in the specification may cause myriad problems during enforcement of the contract conditions. Also, indiscriminate use of standards within the specification can result in duplication, contradiction, and general chaos for the designer, contractor, and owner.

Due to the possible conflicts between the language of the written standard and the general conditions of the contract, the designer should include a clause in the supplementary conditions stating that the contract conditions shall govern over the requirements of the cited reference standards. Another clause should be included stating that the more stringent requirement shall apply should a conflict or discrepancy arise between a reference standard and another cited reference and the specifications. Once the standard has been specified, it becomes necessary for the designer to be able to enforce its requirements once the project begins. The most common means to ensure compliance with a material, product, design, or testing standard is to check the shop drawings and other submittals, including manufacturer literature, samples, and test reports. Making regular site visits can help ensure compliance with workmanship standards.

Proprietary Specifications

The last method of specifying is the proprietary specification, which identifies each product to be used by the manufacturer's name, brand name of the product, model number, type designation, and/or unique characteristics. A specification is considered proprietary if the product to be specified is available from a single source.

The proprietary specification has advantages and disadvantages. Advantages include closer control in the selection of products, more detailed and complete drawings due to the more precise information from the product suppliers, shorter specifications that result in less production time, the removal of product pricing as a major variable, and a simplified bidding process. Disadvantages to the use of this method include the elimination or narrowing of the competition. Also, the contractor might be forced to work with a product with which they have little or no prior experience, which could result in poor performance by the contractor. A last disadvantage is the potential to specify a product that is no longer available.

The two types of proprietary specifications are open and closed. The difference between them is how substitutions of the specified products are addressed. An open specification typically allows substitution with products that can be shown to be equal to the specified item, while the closed specification does not allow any substitutions.

The closed proprietary specification allows the design to be completed with a higher level of detail while reducing the variables, thus promoting more accurate bids. It will not protect against a supplier of a specified product taking an unfair advantage of their proprietary position and increasing the price. In many cases where only one manufacturer is acceptable, the client will require a single source bid request to be submitted by the architect or engineer during design. These requests typically must be accompanied by a business case justification.

The closed proprietary specification can list one product or multiple products as the designer sees fit without allowing substitutions, and the designer can control product selection using the instructions found in Section 012500–Substitution Procedures and Section 016000–Product Requirements (or Section 01630 under the old 16-division format) if Division 01 is included in the front-end documents.

Under a closed proprietary specification, when only a single product is specified, the substitution of another product is not allowed, and the bids submitted must be based on the specified product only. When products by several different manufacturers are specified, the substitution of other products by unlisted manufacturers will not be permitted; the bids submitted should be based only on the products specified. The successful bidder is usually required to submit a list of the product or products that they intend to use within a specified time following the bid for approval prior to purchase and installation.

In many cases, the client will allow closed proprietary specifications if three or more acceptable manufacturers are named. If three products are named and competition is achieved in the bid process, the designer must make sure the products specified are equal and acceptable for the purpose for which they are being specified.

The open proprietary specification specifies or names products or materials in the same manner as the closed specification. The difference is that alternatives for the specified products or materials also are listed. The bidder must bid on the specified items and may also provide prices for the alternative items specified. These prices are usually included on the bid form in the spaces provided. To clarify the bidding process, the designer could include instructions to the bidder such as the following: "When the product is specified to only one manufacturer, substitution of products will not be permitted. If alternates to the base bid are requested, then the bidder may submit bids for the alternative items. These bid prices shall include the amount required to incorporate the alternate products into the project. Requests for additional monies for alternate products or materials shall not be considered after the agreement has been executed." Open proprietary specifications remove the problem of overpricing, which is common in sole-source product or material bids, by allowing for the selection of alternate items and price quotations for those items.

The major problem with the use of proprietary specifications is the attempts made by some bidders to introduce products or materials that are of inferior quality to those originally specified. This problem is the greatest when the bidder is allowed to specify substitutions after the award of the contract, which leads to the practice known as bid shopping. This practice is unfair to those who submitted bids originally, and pressure can be put on the designer to accept these substitutions of inferior products. The designer must maintain control over the bidding process by including requirements similar to the following into the specifications:

- All substitution requests are to be in writing from the bidders only, and any requests from manufacturers and suppliers will not be considered.
- The submission of substitution requests by the bidder shall be made at a minimum of 10 days prior to the bid opening.
- All requests for substitutions shall be submitted with the request for approval.
- Submissions without supporting documentation shall not be considered.

The designer shall review all submissions and issue notification of any accepted substitutions to all bidders by addendum. The period between the deadline for requests and the addendum is at the discretion of the designer, but should not be less than three days to allow proper examination of the submitted materials.

The federal government and other public authorities forbid the use of the proprietary or other exclusionary specifications except under special conditions.

CREATING THE SPECIFICATION SECTION

Under Section Format, a specification section is divided into three parts: Part 1–General, Part 2–Products, and Part 3–Execution.

Part 1–General includes the scope, necessary references to the related work, codes and standards that will be in force during the project, performance requirements, qualifications for both manufacturers and workmanship, required submittals (including the format required for submission), any samples required for examination by the designer, required information on product manufacturing and shipping schedules, receiving and storage requirements, special warranties, spare parts to be included with the package, and any other information considered to be necessary.

Part 2–Products includes those products that are to be used on the project that are part of the work described by this specification section. These products should be described as accurately, completely, and briefly as possible to give the user the facts needed in least amount of text. Any descriptions of these products should be to describe the product that is to be used and to present any pertinent data that is required for the use of that product.

Part 3–Execution contains the detailed instructions of how the products listed in Part 2 are to be used or installed into the work being performed. Information on any testing that is to be performed must include instructions on who pays for the testing as well as what tests and how many are required. Instructions for coordination among the various trades, the acceptance of the substrate, and any required tolerances for installations shall also be included in this section. Contractor or supplier operation and maintenance training instructions are also included.

Refer to Appendix 3-F, Section Shell Outline, for additional information.

Beginning at the top, the first item to be completed is the section number. The section number is a six-digit number corresponding to the MasterFormat system. Following the section number is the section title. The designer should keep this to a maximum of one line, approximately six to eight words. Then comes Part 1–General, Part 2–Products, and Part 3–Execution. The section number is usually either level two or level three. Level four section numbers are becoming more common, while level one section numbers are being phased out.

Part 1–General

Section 1.1 Summary

This section includes the description of the work that is to be performed, a list of any products that are to be furnished but not installed, and products that are not furnished but are to be installed under this section, sometimes referred to as owner furnished, contractor installed (OFCI). The next item found in Part 1 is the list of related sections, where other sections in the specifications containing requirements that relate to this particular section are listed. Some designers choose to omit this part because during last-minute changes, it often is not updated, resulting in a confusing, flawed document.

Also found in the summary are allowances, unit prices, and alternates. An allowance is a predetermined monetary amount agreed to by both the designer and the owner to be inserted into the bid for certain items such as artwork, furniture, or even plumbing fixtures. A unit price is a fixed bid price amount for an item such as a water closet, lavatory, or 4-inch cast iron pipe. An alternate is a defined portion of the work that is priced separately and provides an option for the owner to select the final scope of work. Alternates usually allow choices among the products to be used or for portions of the work to be added or deleted from the project.

It may be useful to outline all of the systems incorporated in this subsection of the specification. For instance, in Section 221116–Domestic Water Piping, the designer may have several piping systems that might use the piping systems described in this section, including nonpotable water, rainwater collection, etc.

Section 1.2 References

Here, the reference standards that have been cited in this section are listed alphabetically. Standards are usually written in the following manner: standard number, standard title, standard society or agency, and date of the last revision—for example, ASME B16.22: *Wrought Copper and Copper Alloy Solder-Joint Pressure Fittings,* American Society of Mechanical Engineers (ASME), 2013. When multiple references by the same organization are listed, those references are arranged in ascending numerical order.

Section 1.3 Definition

Any special definitions required to explain the work or products used are listed alphabetically.

Section 1.4 System Description

The system description is used by some designers and omitted by others. This is usually a brief but accurate description of how this specification section fits into the work.

Section 1.5 System Performance Criteria

This subsection should include the standardized pressures and temperatures the designer expects the systems described to experience. It forces him to think about the products he is specifying. For example, what is the gas pressure? What if the street water pressure is 130 pounds per square inch gauge (psig)? What if the domestic hot water design temperature is 160°F? What are the seismic bracing requirements?

Section 1.6 Submittals

This portion of Part 1 is probably one of the most important because it governs the submittals. It tells what is required for all products that will be used in the project. The designer must decide what information will be submitted for review and approval. On some government projects, the submittal process will be under governmental control, not the designer's control. MasterSpec now includes three categories of submittals: action submittals, informational submittals, and closeout submittals.

The information required for the submittal can include the following:

Action Submittals

- Product data as prepared by the manufacturer or third-party organization
- Shop drawings from either the manufacturer or the contractor
- Coordination drawings
- Piping connection diagrams from the manufacturer or the contractor
- Power and control wiring diagrams from the manufacturer or the contractor
- Product certifications from manufacturers that these products have been tested and comply with the appropriate standards

Informational Submittals

- Test reports from an independent (or third-party) test laboratory certifying those products
- Qualification data for manufacturers, firms, or individuals as requested
- Qualification data for persons or firms responsible for delegated design

Closeout Submittals

- Maintenance data for the materials and products used for inclusion in the operation and maintenance (O&M) manuals for the owner (if required)

What is the difference between action submittals, informational submittals, and closeout submittals?

- Action submittals require an architect's action, including returning the reviewed submittal to the contractor. Ultimately the submittal must be approved for the contractor to rely on it to build the project. This approval puts the construction players on notice that the architect has reviewed the document and found that it complies with the design intent.

- Informational submittals, however, imply inaction by architects. The submittal is often simply a file of information for record. Some observers believe that the architect still has a responsibility to review informational submittals to ensure that the submittal actually reflects what is required for the project. Simply filing an erroneous or incorrect submittal without any review could subject the architect to unexpected liability if something goes wrong. For example, consider explaining to a jury that you never looked at the design calculations to confirm that the correct design loads were used for the structural computations because it was just an informational submittal.
- Closeout submittals are submittals that must be provided to the owner before final payment is made to the contractor.

Section 1.7 Quality Assurance

This is the quality control for the project. In this section the designer can include what he or she feels is needed to ensure that the project is correctly completed. Included in this section are manufacturer and installer qualifications, typically a set number of years of experience. The typical experience for manufacturers is five years minimum, and for installers it is three years minimum. Also, requirements for supervision and licensure can be included—for example, "All work required by this specification section shall be performed by licensed, experienced tradesmen working under the direct supervision of a licensed, experienced supervisor with a minimum of 10 years of experience. No unsupervised work by unlicensed workers shall be permitted." Requirements for testing laboratories, welding and welder certifications, compliance with UL standards, compliance with NFPA 70 (National Electrical Code), ASME compliance, and others are also included within this section.

Section 1.8 Delivery, Storage, and Handling

This section deals with the delivery, storage, and handling of materials and equipment until installation, including instructions on the shipping and handling of materials and equipment from the manufacturer to the jobsite as well as lifting and rigging instructions, storage requirements, and coordination between shipping schedules, delivery dates, and installation dates.

Section 1.9 Project Conditions

Site condition disclaimers and disclaimers for field measurements direct the contractor to verify all measurements prior to starting work. This section is optional at the discretion of the designer. Provide information here if there are special instructions concerning utility system shutdowns and what approvals are necessary.

Section 1.10 Sequence and Scheduling

This section is used to coordinate the various portions of the project and can cross trades. Since it is the responsibility of the general contractor, not the plumbing designer, to schedule and coordinate work that is under contract, this section is usually omitted.

Section 1.11 Warranty

The designer lists any special warranties required or any warranty conditions that are different from the contractor's standard warranty. If the products specified normally include standard warranties extending beyond the first year, this is where this information would be included.

Section 1.12 Maintenance

This section contains any special maintenance requirements for the equipment installed.

Section 1.13 Extra Materials

This section lists any necessary extra materials such as valve repair kits, faucet repair parts, extra belts, handles, lubricants, or seals. Items and quantities required to be supplied to the owner by the contractor are also listed.

Part 2–Products

This section deals with the products, materials, equipment, and manufacturers that will be included in the work.

Section 2.1 Manufacturers (Refer to Appendix 3-F Paragraph 2.1 for "Paragraphs A, B, C, and D")

Under paragraph A, the contractor may supply products by any manufacturer that he feels are compliant with the specification section covering that portion of the work. Most of the time the products to be supplied comply with the specifications, but sometimes they do not.

Paragraph B states that the designer decides which manufacturers of a particular product to be used will be permitted and which will not. Under this paragraph, the contractor is given a list of approved manufacturers from which to choose. The designer must research both the products and manufacturers to make sure the products meet or exceed the standards set forth by that section of the specification. For example, a listing for a water closet would be:

Water closet, floor outlet, flushometer

Manufacturer A

Manufacturer B

Manufacturer C

Manufacturer D

Substitutions

Under this arrangement, the contractor must supply a water closet made by one of the four manufacturers listed. With the use of a substitution option, the designer may elect to allow the substitution of a water closet by a non-listed manufacturer as long as it is proven to be equal to the others. Many designers feel that allowing no substitutions levels the bidding field and takes away the problems of a bidder getting a lower bid by using a substandard product. Under this method, the decision can be made about the product as well as the manufacturer. Only one of these methods should be used—either an open specification in paragraph A or a closed specification in paragraph B. The same is true for paragraphs C and D. As stated earlier, the closed method gives the designer more control over the quality of the products being included in the project.

Sections 2.2, 2.3, and 2.4

These are similar to Section 2.1. In Section 2.3 the materials that will be used are specified using either a descriptive specification or a performance specification.

Sections 2.5, 2.6, 2.7, 2.8, and 2.9

These are not usually included in plumbing specifications. However, that does not mean they cannot be used if the designer feels they are needed.

Part 3–Execution

Section 3.1 Examination

This section is concerned with the installation of the products and materials for the project. The first part involves the instructions to the contractor to examine the sites, plans, existing or constructed walls, and floors and ceilings that must be installed. The contractor should also be instructed in this section to not proceed with the work until all unsatisfactory items have been corrected.

Sections 3.2 through 3.5

These sections deal with the general and specific installation requirements of the products and/or materials being used. Often included, but not mandatory by CSI standards, is a section on connections (shown as Section 3.5). In this section, connection requirements for OFCI (or GFCI on government projects) are found. A good example of this is a commercial kitchen where the kitchen equipment supplier sets the equipment, but the plumber connects it to the utilities.

Also, if a piece of equipment that is assembled on site appears to be complicated, this is where the designer could include a requirement to provide the services of a factory-authorized service technician to supervise the assembly.

Section 3.6 Field Quality Control

In this section, the designer deals with system flushing and pressure and leak testing, as well as what standard(s) must be met. Also included is what remedy must be made if the tests prove that the products and/or materials are not compliant with the standards set forth in the specification section.

Section 3.7 Adjusting and Cleaning

A section that covers the adjustment, cleaning, and calibration of the products included in the project is well advised. One of the most common requirements is the cleaning and disinfection of the potable water system. Another is balancing the water flow through the hot water recirculation loops, adjusting the sensitivity of sensor faucets and flushometers, and adjusting thermostatic mixing valves.

Section 3.8 Commissioning

Commissioning, or placing the building into service for the owner to use, should address items such as:

- Equipment startup by factory-authorized service technicians
- Testing and adjusting of controls and safeties with the replacement of all malfunctioning parts
- Providing adequate training to the owner's maintenance staff with regard to the startup and shutdown of the equipment, troubleshooting, servicing, and maintenance
- Reviewing the data in the O&M manuals with the maintenance staff

USING MASTER SPECIFICATIONS

Very few plumbing specifications today are written as an original document, or from scratch. In most cases, project specifications are created using an office-prepared master specification or commercially prepared specifications that have been published by various industry organizations, such as AIA's MasterSpec or the Construction Sciences Research Foundation's SpecText. The use of a master specification to prepare a project specification is certainly more cost-efficient than starting from scratch with each new project.

One of the best features of the master specification programs is the periodic updates, with new sections being added and obsolete sections being deleted. Also in these updates, the reference standards that are included in each section are updated to the latest version. For any specifier who has spent several hours researching these standards, this feature is worth the price of the program.

These programs have evolved into interactive systems that contain checklists or interactive input dialogue for the specifier to utilize. Also, many programs interface with BIM and CAD systems to extract the data to produce the specifications, estimates, and life-cycle analysis reports.

CONCLUSION

Writing effective specifications requires broad experience as a plumbing designer. In most engineering offices, specifications are prepared by the project engineer or team leader or under their supervision. The designer must remember that the essence of plumbing specifications is communication among the people involved with both the design and the construction of the project. Plumbing specifiers must develop skills to communicate the project requirements in a clear, concise, and easy-to-understand manner.

The one thing that has not changed in specification writing and never will is the amount of time that is allotted by project managers to complete the specifications. The amount of time given is never enough.

Like most plumbing engineering, specification writing is learned on the job. This is because university-level courses in specification writing are rare. Classes may be available as continuing education programs offered by CSI at both the national and local level. Interested parties should contact their local CSI chapter for more information about what is available.

Plumbing designers who have at least five years of specification writing experience can demonstrate their proficiency and understanding by taking the Certified Construction Specifier (CCS) examination that is given by CSI.

In this world of continually changing workplaces and corporate restructuring, the plumbing designer who demonstrates the ability to produce a clear, concise set of specification documents is a valuable asset to project design teams.

APPENDIX 3-A: CSI UNIFORMAT UNIFORM CLASSIFICATIONS

A. Substructure

A10 Foundations
A20 Basement Construction

B. Shell

B10 Superstructure
B20 Exterior Closure
B30 Roofing

C. Interiors

C10 Interior Construction
C20 Stairways
C30 Interior Finishes

D. Services

D10 Conveying Systems
D20 Plumbing Systems
D30 Heating, Ventilation, and Air-Conditioning (HVAC) Systems
D40 Fire Protection Systems
D50 Electrical Systems

E. Equipment and Furnishings

E10 Equipment
E20 Furnishings

F. Other Building Construction

F10 Special Construction
F20 Selective Demolition

G. Building Sitework

G10 Site Preparation
G20 Site Improvements
G30 Site Mechanical Utilities
G40 Site Electrical Utilities
G50 Other Site Construction

Z. General

Z10 General Requirements
Z20 Bidding Requirements, Contract Forms, and Conditions
Z90 Project Cost Estimate

APPENDIX 3-B: CSI MASTERFORMAT LEVEL TWO SECTION TITLES

(Note: This Appendix is retained for those designers who still use this format. The 16-division format is no longer supported by CSI.)

Division 1 General Requirements

01100 Summary of Work
01200 Price and Payment Procedures
01300 Administrative Requirements
01400 Quality Procedures
01500 Temporary Facilities and Controls
01600 Product Requirements
01700 Execution Requirements
01800 Facility Operation

01900 Facility Decommissioning

Division 2 Site Construction

02050 Basic Site Materials and Methods
02100 Site Remediation
02200 Site Preparation
02300 Earthwork
02400 Tunneling, Boring, and Jacking
02450 Foundation and Load Bearing Elements
02500 Utility Services
02600 Drainage and Containment
02700 Bases, Ballasts, Pavements, and Appurtenances
02800 Site Improvements and Amenities
02900 Planting
02950 Site Restoration and Rehabilitation

Division 3 Concrete

03050 Basic Concrete Materials and Methods
03100 Concrete Forms and Accessories
03200 Concrete Reinforcement
03300 Cast-in-Place Concrete
03400 Precast Concrete
03500 Cementitious Decks and Underlayment
03600 Grouts
03700 Mass Concrete
03900 Concrete Restoration and Cleaning

Division 4 Masonry

04050 Basic Masonry Materials and Methods
04200 Masonry Units
04400 Stone
04500 Refractories
04600 Corrosion-Resistant Masonry
04700 Simulated Masonry
04800 Masonry Assemblies
04900 Masonry Restoration and Cleaning

Division 5 Metals

05050 Basic Metal Materials and Methods
05100 Structural Metal Framing
05200 Metal Joists
05300 Metal Deck
05400 Cold-Formed Metal Framing
05500 Metal Fabrications
05600 Hydraulic Fabrications
05650 Railroad Track and Accessories
05700 Ornamental Metal
05800 Expansion Control
05900 Metal Restoration and Cleaning

Division 6 Wood and Plastics

06050	Basic Wood and Plastic Materials and Methods
06100	Rough Carpentry
06200	Finish Carpentry
06400	Architectural Woodwork
06500	Structural Plastics
06600	Plastic Fabrications
06900	Wood and Plastic Restoration and Cleaning

Division 7 Thermal and Moisture Protection

07050	Basic Thermal and Moisture Protection Materials and Methods
07100	Dampproofing and Waterproofing
07200	Thermal Protection
07300	Shingles, Roof Tiles, and Roof Coverings
07400	Roofing and Siding Tiles
07500	Membrane Roofing
07600	Flashing and Sheet Metal
07700	Roof Specialties and Accessories
07800	Fire and Smoke Protection
07900	Joint Sealers

Division 8 Doors and Windows

08050	Basic Doors and Windows Materials and Methods
08100	Metal Doors and Frames
08200	Wood and Plastic Doors
08300	Specialty Doors
08400	Entrances and Storefronts
08500	Windows
08600	Skylights
08700	Hardware
08800	Glazing
08900	Glazed Curtain Wall

Division 9 Finishes

09050	Basic Finishes Materials and Methods
09100	Metal Support Assemblies
09200	Plaster and Gypsum Board
09300	Tile
09400	Terrazzo
09500	Ceilings
09600	Flooring
09700	Wall Finishes
09800	Acoustical Treatment
09900	Paints and Coatings

Division 10 Specialties

10100	Visual Display Boards
10150	Compartments and Cubicles
10200	Louvers and Vents
10240	Grilles and Screens

10250 Service Walls
10260 Wall and Corner Guards
10270 Access Flooring
10290 Pest Control
10300 Fireplaces and Stoves
10340 Manufactured Exterior Specialties
10350 Flag Poles
10400 Identification Devices
10450 Pedestrian Control Devices
10500 Lockers
10520 Fire Protection Specialties
10530 Protective Covers
10550 Postal Specialties
10600 Partitions
10670 Storage Shelving
10700 Exterior Protection
10750 Telephone Specialties
10800 Toilet, Bath, and Laundry Accessories
10880 Scales
10900 Wardrobe and Closet Specialties

Division 11 Equipment

11010 Maintenance Equipment
11020 Security and Vault Equipment
11030 Teller and Service Equipment
11040 Ecclesiastical Equipment
11050 Library Equipment
11060 Theater and Stage Equipment
11070 Instrumental Equipment
11080 Registration Equipment
11090 Check Room Equipment
11100 Mercantile Equipment
11110 Commercial Laundry and Dry-Cleaning Equipment
11120 Vending Equipment
11130 Audio/Visual Equipment
11140 Vehicle Service Equipment
11150 Parking Control Equipment
11160 Loading Dock Equipment
11170 Solid Waste Handling Equipment
11190 Detention Equipment
11200 Water Supply and Treatment Equipment
11280 Hydraulic Gates and Valves
11300 Fluid Waste Treatment and Disposal Equipment
11400 Foodservice Equipment
11450 Residential Equipment
11460 Unit Kitchens
11470 Darkroom Equipment

11480	Athletic, Recreational, and Therapeutic Equipment
11500	Industrial and Process Equipment
11600	Laboratory Equipment
11650	Planetarium Equipment
11660	Observatory Equipment
11680	Office Equipment
11700	Medical Equipment
11780	Mortuary Equipment
11850	Navigation Equipment
11870	Agricultural Equipment
11900	Exhibit Equipment

Division 12 Furnishings

12050	Fabrics
12100	Art
12300	Manufactured Casework
12400	Furnishings and Accessories
12500	Furniture
12600	Multiple Seating
12700	Systems Furniture
12800	Interior Plants and Planters
12900	Furnishings Restoration and Repair

Division 13 Special Construction

13010	Air-Supported Structures
13020	Building Modules
13030	Special-Purpose Rooms
13080	Sound, Vibration, and Seismic Control
13090	Radiation Protection
13100	Lightning Protection
13110	Cathodic Protection
13120	Pre-Engineered Structures
13150	Swimming Pools
13160	Aquariums
13165	Aquatic Park Facilities
13170	Tubs and Pools
13175	Ice Rinks
13185	Kennels and Animal Shelters
13190	Site Constructed Incinerators
13200	Storage Tanks
13220	Filter Underdrains and Media
13230	Digester Covers and Appurtenances
13240	Oxygenation Systems
13260	Sludge Conditioning Systems
13280	Hazardous Material Remediation
13400	Measurement and Control Instrumentation
13500	Recording Instrumentation
13550	Transportation Control Instrumentation

13600 Solar and Wind Energy Equipment
13700 Security Access and Surveillance
13800 Building Automation and Control
13850 Detection and Alarm
13900 Fire Suppression

Division 14 Conveying Systems

14100 Dumbwaiters
14200 Elevators
14300 Escalators and Moving Walks
14400 Lifts
14500 Material Handling
14600 Hoists and Cranes
14700 Turntables
14800 Scaffolding
14900 Transportation

Division 15 Mechanical

15050 Basic Mechanical Materials and Methods
15100 Building Services Piping
15200 Process Piping
15300 Fire Protection Piping (See 13900)
15400 Plumbing Fixtures and Equipment
15500 Heat Generation Equipment
15600 Refrigeration Equipment
15700 Heating, Ventilation, and Air-Conditioning Equipment
15800 Air Distribution
15900 HVAC Instrumentation and Control
15950 Testing, Adjusting, and Balancing

Division 16 Electrical

16050 Basic Electrical Materials and Methods
16100 Wiring Methods
16200 Electrical Power
16300 Transmission and Distribution
16400 Low Voltage Distribution
16500 Lighting
16700 Communications
16800 Sound and Video

APPENDIX 3-C: CSI MASTERFORMAT DIVISIONS

Procurement and Contracting Documents Group

Division 00—Procurement and Contracting Requirements: This division is essentially the same in scope as it was in the previous formats.

Specifications Group

General Requirements Subgroup

Division 01—General Requirements: The area for performance requirements was added to allow for the writing of performance requirements for the elements that are found in more than one work section such as building envelope, structure, etc. This feature allows the specifier to include a mixture of broad performance specifications and descriptive specifications in the project manual.

Facility Construction Subgroup

Division 02—Existing Conditions: Division 2 is restricted to construction tasks that relate to the items at the site when the project commences, such as selective demolition, subsurface and other investigations, surveying, and site decontamination and/or remediation. (All site construction as well as heavy civil and infrastructure items including pavement and utilities are in the Site and Infrastructure Subgroup.)

Division 03—Concrete: This division is essentially as it was under MasterFormat95.

Division 04—Masonry: This division is essentially as it was under MasterFormat95.

Division 05—Metals: This division is essentially as it was under MasterFormat95.

Division 06—Wood, Plastics, and Composites: This division is essentially as it was under MasterFormat95, but also includes expanded areas for plastics and other composite materials.

Division 07—Thermal and Moisture Protection: This division is essentially as it was under MasterFormat95.

Division 08—Openings: This section was called Doors and Windows under MasterFormat95 but was renamed to include other openings such as louvers and grilles.

Division 09—Finishes: This division is essentially as it was under MasterFormat95.

Division 10—Specialties: This division is essentially as it was under MasterFormat95.

Division 11—Equipment: This division is essentially as it was under MasterFormat95, with the exception that equipment related to process engineering was relocated to the Process Equipment Subgroup and equipment related to infrastructure was relocated to the Site and Infrastructure Subgroup.

Division 12—Furnishings: This division is essentially as it was under MasterFormat95.

Division 13—Special Construction: This division is essentially as it was under MasterFormat95 except that special construction related to process engineering was relocated to the Process Equipment Subgroup. Security, building automation, detection, and alarms as well as fire suppression were relocated to the Facility Services Subgroup.

Division 14—Conveying Equipment: This division was renamed, and process-related material handling equipment was relocated to the Process Equipment Subgroup.

Division 15—Reserved for Future Expansion: This division was divided and relocated to Division 22—Plumbing and Division 23—Heating, Ventilation, and Air-Conditioning in the Facility Services Subgroup.

Division 16—Reserved for Future Expansion: This division was divided and relocated to Division 26—Electrical and Division 27—Communications in the Facility Services Subgroup.

Facility Services Subgroup

Division 21—Fire Suppression: This division contains the fire suppression sections relocated from Division 13 in previous formats.

Division 22—Plumbing: This division contains the plumbing sections relocated from Division 15 in previous formats.

Division 23—Heating, Ventilation, and Air Conditioning: This division contains the HVAC sections from Division 15 in previous formats.

Division 25—Integrated Automation: This division contains the expanded integrated automation sections that were relocated from Division 13 in previous formats.

Division 26—Electrical: This division contains the electrical and lighting sections relocated from Division 16 in previous formats.

Division 27—Communications: This division contains the expanded communications sections relocated from Division 16 in previous formats.

Division 28—Electronic Safety and Security: This division contains the expanded electronic safety and security sections relocated from Division 13 in previous formats.

Site and Infrastructure Subgroup

Division 31—Earthwork: This division contains site construction sections, predominately below grade, that were relocated from Division 02 in previous formats.

Division 32—Exterior Improvements: This division contains site construction sections, predominately above grade, that were relocated from Division 02 in previous formats.

Division 33—Utilities: This division includes utility sections with expansions that were relocated from Division 02 in previous formats.

Division 34—Transportation: This division contains transportation sections with expansions relocated from the various divisions in previous formats.

Division 35—Waterway and Marine: This division includes expanded waterway and other marine sections from Division 02 and other divisions in previous formats.

Process Equipment Subgroup

Division 41—Material Processing and Handling Equipment: This division includes equipment for the processing and conditioning of raw materials, material handling equipment for bulk materials as well as discrete units, manufacturing equipment and machinery, and test equipment and packaging/shipping systems.

Division 42—Process Heating, Cooling, and Drying Equipment: This division contains equipment for process heating, cooling, and drying of materials, liquids, gases, and manufactured items and/or materials.

Division 43—Process Gas and Liquid Handling, Purification, and Storage Equipment: This division includes equipment for handling the purification and storage of process liquids, gases, and slurries including atmospheric tanks as well as pressure vessels.

Division 44—Pollution Control Equipment: This division includes equipment for controlling the emission of contaminants from manufacturing processes and the treatment of air, soil, and water contaminants.

Division 45—Industry-Specific Manufacturing Equipment: In this division, the owner can specify equipment that is used only within a single industry. (All industries currently identified in the North American Industry Classification System [NAICS] are allocated space within this division.)

Division 46—Solid Waste Equipment: Not defined at this time.

Division 48—Electrical Power Generation: This division includes plants and equipment for the generation and control of electrical power from fossil fuel, nuclear energy, hydroelectric, wind, solar energy, geothermal energy, electrochemical energy, and fuel cells.

APPENDIX 3-D: MASTERFORMAT FACILITY CONSTRUCTION SUBGROUP, DIVISION 21

This appendix is based on MasterFormat 2016 as published by CSI.

Division 21—Fire Suppression

21 00 00—Fire Suppression
- 21 01 00—Operation and Maintenance of Fire Suppression
  - 21 01 10—Operation and Maintenance of Water-Based Fire-Suppression Systems
  - 21 01 20—Operation and Maintenance of Fire-Extinguishing Systems
  - 21 01 30—Operation and Maintenance of Fire-Suppression Equipment
- 21 05 00—Common Work Results for Fire Suppression
  - 21 05 05—Selective Demolition for Fire Suppression
  - 21 05 13—Common Motor Requirements for Fire-Suppression Equipment
  - 21 05 16—Expansion Fittings and Loops for Fire-Suppression Piping
  - 21 05 17—Sleeves and Sleeve Seals for Fire-Suppression Piping
  - 21 05 19—Meters and Gages for Fire-Suppression Systems
  - 21 05 23—General-Duty Valves for Water-Based Fire-Suppression Piping
  - 21 05 29—Hangers and Supports for Fire-Suppression Piping and Equipment
  - 21 05 33—Heat Tracing for Fire-Suppression Piping
  - 21 05 48—Vibration and Seismic Controls for Fire-Suppression Piping and Equipment

21 05 48.13—Vibration Controls for Fire-Suppression Piping and Equipment
21 05 53—Identification for Fire-Suppression Piping and Equipment
21 06 00—Schedules for Fire Suppression
21 06 10—Schedules for Water-Based Fire-Suppression Systems
21 06 20—Schedules for Fire-Extinguishing Systems
21 06 30—Schedules for Fire-Suppression Equipment
21 07 00—Fire Suppression Systems Insulation
21 07 16—Fire-Suppression Equipment Insulation
21 07 19—Fire-Suppression Piping Insulation
21 08 00—Commissioning of Fire Suppression
21 09 00—Instrumentation and Control for Fire-Suppression Systems
21 10 00—Water-Based Fire-Suppression Systems
21 11 00—Facility Fire-Suppression Water-Service Piping
21 11 16—Facility Fire Hydrants
21 11 19—Fire-Department Connections
21 12 00—Fire-Suppression Standpipes
21 12 13—Fire-Suppression Hoses and Nozzles
21 12 16—Fire-Suppression Hose Reels
21 12 19—Fire-Suppression Hose Racks
21 12 23—Fire-Suppression Hose Valves
21 13 00—Fire-Suppression Sprinkler Systems
21 13 13—Wet-Pipe Sprinkler Systems
21 13 16—Dry-Pipe Sprinkler Systems
21 13 19—Preaction Sprinkler Systems
21 13 23—Combined Dry-Pipe and Preaction Sprinkler Systems
21 13 26—Deluge Fire-Suppression Sprinkler Systems
21 13 29—Water Spray Fixed Systems
21 13 36—Antifreeze Sprinkler Systems
21 13 39—Foam-Water Systems
21 16 00—Fire-Suppression Pressure Maintenance Pumps
21 20 00—Fire-Extinguishing Systems
21 21 00—Carbon-Dioxide Fire-Extinguishing Systems
21 21 13—Carbon-Dioxide Fire-Extinguishing Piping
21 21 13.13—High-Pressure, Carbon-Dioxide Fire-Extinguishing Systems
21 21 13.16—Low-Pressure, Carbon-Dioxide Fire-Extinguishing Systems
21 21 16—Carbon-Dioxide Fire-Extinguishing Equipment
21 22 00—Clean-Agent Fire-Extinguishing Systems
21 22 13—Clean-Agent Fire-Extinguishing Piping
21 22 16—Clean-Agent Fire-Extinguishing Equipment
21 23 00—Wet-Chemical Fire-Extinguishing Systems
21 23 13—Wet-Chemical Fire-Extinguishing Piping
21 23 16—Wet-Chemical Fire-Extinguishing Equipment
21 24 00—Dry-Chemical Fire-Extinguishing Systems
21 24 13—Dry-Chemical Fire-Extinguishing Piping
21 24 16—Dry-Chemical Fire-Extinguishing Equipment
21 30 00—Fire Pumps

21 31 00—Centrifugal Fire Pumps
21 31 13—Electric-Drive, Centrifugal Fire Pumps
21 31 16—Diesel-Drive, Centrifugal Fire Pumps
21 32 00—Vertical-Turbine Fire Pumps
21 32 13—Electric-Drive, Vertical-Turbine Fire Pumps
21 32 16—Diesel-Drive, Vertical-Turbine Fire Pumps
21 33 00—Positive-Displacement Fire Pumps
21 33 13—Electric-Drive, Positive-Displacement Fire Pumps
21 33 16—Diesel-Drive, Positive-Displacement Fire Pumps
21 34 00—Fire Pump Accessories
21 34 13—Pressure Maintenance Pumps
21 40 00—Fire-Suppression Water Storage
21 41 00—Storage Tanks for Fire-Suppression Water
21 41 13—Pressurized Storage Tanks for Fire-Suppression Water
21 41 16—Elevated Storage Tanks for Fire-Suppression Water
21 41 19—Roof-Mounted Storage Tanks for Fire-Suppression Water
21 41 23—Ground Suction Storage Tanks for Fire-Suppression Water
21 41 26—Underground Storage Tanks for Fire-Suppression Water
21 41 29—Storage Tanks for Fire-Suppression Water Additives

APPENDIX 3-E: MASTERFORMAT FACILITY CONSTRUCTION SUBGROUP, DIVISION 22

This appendix is based on MasterFormat 2016 as published by CSI.

Division 22—Plumbing

22 00 00—Plumbing
22 01 00—Operation and Maintenance of Plumbing
22 01 10—Operation and Maintenance of Plumbing Piping and Pumps
22 01 10.16—Video Piping Inspections
22 01 10.51—Plumbing Piping Cleaning
22 01 10.61—Plumbing Piping Repairs
22 01 10.62—Plumbing Piping Relining
22 01 30—Operation and Maintenance of Plumbing Equipment
22 01 40—Operation and Maintenance of Plumbing Fixtures
22 01 50—Operation and Maintenance of Pool and Fountain Plumbing Systems
22 01 60—Operation and Maintenance of Laboratory and Healthcare Systems
22 05 00—Common Work Results for Plumbing
22 05 05—Selective Demolition for Plumbing
22 05 13—Common Motor Requirements for Plumbing Equipment
22 05 16—Expansion Fittings and Loops for Plumbing Piping
22 05 17—Sleeves and Sleeve Seals for Plumbing Piping
22 05 19—Meters and Gages for Plumbing Piping
22 05 23—General-Duty Valves for Plumbing Piping
22 05 29—Hangers and Supports for Plumbing Piping and Equipment
22 05 33—Heat Tracing for Plumbing Piping
22 05 48—Vibration and Seismic Controls for Plumbing Piping and Equipment
22 05 48.13—Vibration Controls for Plumbing Piping and Equipment

- 22 05 53—Identification for Plumbing Piping and Equipment
- 22 05 73—Facility Drainage Manholes
- 22 05 76—Facility Drainage Piping Cleanouts

22 06 00—Schedules for Plumbing
- 22 06 10—Schedules for Plumbing Piping and Pumps
  - 22 06 10.13—Plumbing Pump Schedule
- 22 06 12—Schedules for Facility Potable Water Storage
- 22 06 15—Schedules for General Service Compressed-Air Equipment
- 22 06 30—Schedules for Plumbing Equipment
  - 22 06 30.13—Domestic Water Heater Schedule
- 22 06 40—Schedules for Plumbing Fixtures
  - 22 06 40.13—Plumbing Fixture Schedule
- 22 06 50—Schedules for Pool and Fountain Plumbing Systems
- 22 06 60—Schedules for Laboratory and Healthcare Systems

22 07 00—Plumbing Insulation
- 22 07 16—Plumbing Equipment Insulation
- 22 07 19—Plumbing Piping Insulation

22 08 00—Commissioning of Plumbing

22 09 00—Instrumentation and Control for Plumbing
- 22 09 63—Medical Gas Alarms

22 10 00—Plumbing Piping

22 11 00—Facility Water Distribution
- 22 11 13—Facility Water Distribution Piping
- 22 11 16—Domestic Water Piping
- 22 11 17—Gray-Water Piping
- 22 11 19—Domestic Water Piping Specialties
- 22 11 23—Domestic Water Pumps
  - 22 11 23.13—Domestic-Water Packaged Booster Pumps
  - 22 11 23.23—Domestic-Water In-Line Pumps
  - 22 11 23.26—Close-Coupled, Horizontally Mounted, In-Line Centrifugal Domestic-Water Pumps
  - 22 11 23.29—Close-Coupled, Vertically Mounted, In-Line Centrifugal Domestic-Water Pumps
  - 22 11 23.33—Separately Coupled, In-Line Centrifugal Domestic-Water Pumps
  - 22 11 23.36—Separately Coupled, Horizontally Mounted, In-Line Centrifugal Domestic-Water Pumps
  - 22 11 23.43—Domestic-Water, Base-Mounted Pumps
- 22 11 63—Gray-Water Pumps

22 12 00—Facility Potable-Water Storage Tanks
- 22 12 13—Facility Roof-Mounted, Potable-Water Storage Tanks
- 22 12 16—Facility Elevated, Potable-Water Storage Tanks
- 22 12 19—Facility Ground-Mounted, Potable-Water Storage Tanks
- 22 12 21—Facility Underground Potable-Water Storage Tanks
- 22 12 23—Facility Indoor Potable-Water Storage Tanks
  - 22 12 23.13—Facility Steel, Indoor Potable-Water Storage Pressure Tanks
  - 22 12 23.16—Facility Steel, Indoor Potable-Water Storage Non-Pressure Tanks
  - 22 12 23.23—Facility Plastic, Indoor Potable-Water Storage Pressure Tanks
  - 22 12 23.26—Facility Plastic, Indoor Potable-Water Storage Non-Pressure Tanks

22 13 00—Facility Sanitary Sewerage

- 22 13 13—Facility Sanitary Sewers
- 22 13 16—Sanitary Waste and Vent Piping
- 22 13 19—Sanitary Waste Piping Specialties
  - 22 13 19.13—Sanitary Drains
  - 22 13 19.23—Fats, Oils, and Grease Disposal Systems
  - 22 13 19.26—Grease Removal Devices
  - 22 13 19.33—Backwater Valves
  - 22 13 19.36—Air-Admittance Valves
- 22 13 23—Sanitary Waste Interceptors
- 22 13 26—Sanitary Waste Separators
- 22 13 29—Sanitary Sewerage Pumps
  - 22 13 29.13—Wet-Pit-Mounted, Vertical Sewerage Pumps
  - 22 13 29.16—Submersible Sewerage Pumps
  - 22 13 29.23—Sewerage Pump Reverse-Flow Assemblies
  - 22 13 29.33—Sewerage Pump Basins and Pits
- 22 13 33—Packaged, Submersible Sewerage Pump Units
- 22 13 36—Packaged, Wastewater Pump Units
- 22 13 43—Facility Packaged Sewage Pumping Stations
  - 22 13 43.13—Facility Dry-Well Packaged Sewage Pumping Stations
  - 22 13 43.16—Facility Wet-Well Packaged Sewage Pumping Stations
- 22 13 63—Facility Gray Water Tanks

22 14 00—Facility Storm Drainage

- 22 14 13—Facility Storm Drainage Piping
- 22 14 16—Rainwater Leaders
- 22 14 19—Sump Pump Discharge Piping
- 22 14 23—Storm Drainage Piping Specialties
- 22 14 26—Facility Storm Drains
  - 22 14 26.13—Roof Drains
  - 22 14 26.16—Facility Area Drains
  - 22 14 26.19—Facility Trench Drains
- 22 14 29—Sump Pumps
  - 22 14 29.13—Wet-Pit-Mounted, Vertical Sump Pumps
  - 22 14 29.16—Submersible Sump Pumps
  - 22 14 29.19—Sump-Pump Basins and Pits
- 22 14 33—Packaged, Pedestal Drainage Pump Units
- 22 14 36—Packaged, Submersible, Drainage Pump Units
- 22 14 53—Rainwater Storage Tanks
- 22 14 63—Facility Storm-Water Retention Tanks

22 15 00—General Service Compressed-Air Systems

- 22 15 13—General Service Compressed-Air Piping
- 22 15 16—General Service Compressed-Air Valves
- 22 15 19—General Service Packaged Air Compressors and Receivers
  - 22 15 19.13—General Service Packaged Reciprocating Air Compressors
  - 22 15 19.16—General Service Packaged Liquid-Ring Air Compressors
  - 22 15 19.19—General Service Packaged Rotary-Screw Air Compressors
  - 22 15 19.23—General Service Packaged Sliding-Vane Air Compressors

22 30 00—Plumbing Equipment
22 31 00—Domestic Water Softeners
  22 31 13—Residential Domestic Water Softeners
  22 31 16—Commercial Domestic Water Softeners
22 32 00—Domestic Water Filtration Equipment
  22 32 13—Domestic-Water Bag-Type Filters
  22 32 16—Domestic-Water Freestanding Cartridge Filters
  22 32 19—Domestic-Water Off-Floor Cartridge Filters
  22 32 23—Domestic-Water Carbon Filters
  22 32 26—Domestic-Water Sand Filters
    22 32 26.13—Domestic-Water Circulating Sand Filters
    22 32 26.16—Domestic-Water Multimedia Sand Filters
    22 32 26.19—Domestic-Water Greensand Filters
22 33 00—Electric Domestic Water Heaters
  22 33 13—Instantaneous Electric Domestic Water Heaters
    22 33 13.13—Flow-Control, Instantaneous Electric Domestic Water Heaters
    22 33 13.16—Thermostat-Control, Instantaneous Electric Domestic Water Heaters
  22 33 30—Residential, Electric Domestic Water Heaters
    22 33 30.13—Residential, Small-Capacity Electric Domestic Water Heaters
    22 33 30.16—Residential, Storage Electric Domestic Water Heaters
    22 33 30.23—Residential, Collector-to-Tank, Solar-Electric Domestic Water Heaters
    22 33 30.26—Residential, Collector-to-Tank, Heat-Exchanger-Coil, Solar-Electric Domestic Water Heaters
  22 33 33—Light-Commercial Electric Domestic Water Heaters
  22 33 36—Commercial Domestic Water Electric Booster Heaters
    22 33 36.13—Commercial Domestic Water Electric Booster Heaters
    22 33 36.16—Commercial Storage Electric Domestic Water Heaters
22 34 00—Fuel-Fired Domestic Water Heaters
  22 34 13—Instantaneous, Tankless, Gas Domestic Water Heaters
  22 34 30—Residential Gas Domestic Water Heaters
    22 34 30.13—Residential, Atmospheric, Gas Domestic Water Heaters
    22 34 30.16—Residential, Direct-Vent, Gas Domestic Water Heaters
    22 34 30.19—Residential, Power-Vent, Gas Domestic Water Heaters
  22 34 36—Commercial Gas Domestic Water Heaters
    22 34 36.13—Commercial, Atmospheric, Gas Domestic Water Heaters
    22 34 36.16—Commercial, Power-Burner, Gas Domestic Water Heaters
    22 34 36.19—Commercial, Power-Vent, Gas Domestic Water Heaters
    22 34 36.23—Commercial, High-Efficiency, Gas Domestic Water Heaters
    22 34 36.26—Commercial, Coil-Type, Finned-Tube, Gas Domestic Water Heaters
    22 34 36.29—Commercial, Grid-Type, Finned-Tube, Gas Domestic Water Heaters
  22 34 46—Oil-Fired Domestic Water Heaters
    22 34 46.13—Large-Capacity, Oil-Fired Domestic Water Heaters
  22 34 56—Dual-Fuel-Fired Domestic Water Heaters
22 35 00—Domestic Water Heat Exchangers
  22 35 13—Instantaneous Domestic Water Heat Exchangers
    22 35 13.13—Heating-Fluid-in-Coil, Instantaneous Domestic Water Heat Exchangers
    22 35 13.16—Domestic-Water-in-Coil, Instantaneous Domestic Water Heat Exchangers

22 35 13.19—Heating-Fluid-in-U-Tube-Coil, Instantaneous Domestic Water Heat Exchangers
22 35 23—Circulating, Domestic Water Heat Exchangers
22 35 23.13—Circulating, Compact Domestic Water Heat Exchangers
22 35 23.16—Circulating, Storage Domestic Water Heat Exchangers
22 35 29—Noncirculating, Domestic Water Heat Exchangers
22 35 29.13—Noncirculating, Compact Domestic Water Heat Exchangers
22 35 29.16—Noncirculating, Storage Domestic Water Heat Exchangers
22 35 36—Domestic Water Brazed-Plate Heat Exchangers
22 35 39—Domestic Water Frame-and-Plate Heat Exchangers
22 35 43—Domestic Water Heat Reclaimers
22 36 00—Domestic Water Preheaters
22 36 13—Solar Domestic Water Preheaters
22 36 23—Geothermal Domestic Water Preheaters
22 40 00—Plumbing Fixtures
22 41 00—Residential Plumbing Fixtures
22 41 13—Residential Water Closets, Urinals, and Bidets
22 41 13.13—Residential Water Closets
22 41 13.16—Residential Urinals
22 41 13.19—Residential Bidets
22 41 16—Residential Lavatories and Sinks
22 41 16.13—Residential Lavatories
22 41 16.16—Residential Sinks
22 41 19—Residential Bathtubs
22 41 23—Residential Showers
22 41 26—Residential Disposers
22 41 36—Residential Laundry Trays
22 41 39—Residential Faucets, Supplies, and Trim
22 42 00—Commercial Plumbing Fixtures
22 42 13—Commercial Water Closets, Urinals, and Bidets
22 42 13.13—Commercial Water Closets
22 42 13.16—Commercial Urinals
22 42 16—Commercial Lavatories and Sinks
22 42 16.13—Commercial Lavatories
22 42 16.16—Commercial Sinks
22 42 19—Commercial Bathtubs
22 42 23—Commercial Showers
22 42 26—Commercial Disposers
22 42 29—Shampoo Bowls
22 42 33—Wash Fountains
22 42 36—Commercial Laundry Trays
22 42 39—Commercial Faucets, Supplies, and Trim
22 42 43—Flushometers
22 43 00—Healthcare Plumbing Fixtures
22 43 13—Healthcare Water Closets
22 43 16—Healthcare Sinks
22 43 19—Healthcare Bathtubs

- 22 43 23—Healthcare Showers
- 22 43 39—Healthcare Faucets
- 22 43 43—Healthcare Plumbing Fixture Flushometers

22 45 00—Emergency Plumbing Fixtures

- 22 45 13—Emergency Showers
- 22 45 16—Eyewash Equipment
- 22 45 19—Self-Contained Eyewash Equipment
- 22 45 23—Personal Eyewash Equipment
- 22 45 26—Eye/Face Wash Equipment
- 22 45 29—Hand-Held Emergency Drench Hoses
- 22 45 33—Combination Emergency Fixture Units
- 22 45 36—Emergency Fixture Water-Tempering Equipment

22 46 00—Security Plumbing Fixtures

- 22 46 13—Security Water Closets and Urinals
  - 22 46 13.13—Security Water Closets
  - 22 46 13.16—Security Urinals
- 22 46 16—Security Lavatories and Sinks
  - 22 46 16.13—Security Lavatories
  - 22 46 16.16—Security Sinks
- 22 46 19—Security Showers
- 22 46 39—Security Faucets, Supplies, and Trim
- 22 46 43—Security Plumbing Fixture Flushometers
- 22 46 53—Security Plumbing Fixture Supports

22 47 00—Drinking Fountains and Water Coolers

- 22 47 13—Drinking Fountains
- 22 47 16—Pressure Water Coolers
- 22 47 19—Water-Station Water Coolers
- 22 47 23—Remote Water Coolers

22 50 00—Pool and Fountain Plumbing Systems

22 51 00—Swimming Pool Plumbing Systems

- 22 51 13—Swimming Pool Piping
- 22 51 16—Swimming Pool Pumps
- 22 51 19—Swimming Pool Water Treatment Equipment
- 22 51 23—Swimming Pool Equipment Controls

22 52 00—Fountain Plumbing Systems

- 22 52 13—Fountain Piping
- 22 52 16—Fountain Pumps
- 22 52 19—Fountain Water Treatment Equipment
- 22 52 23—Fountain Equipment Controls

22 60 00—Gas and Vacuum Systems for Laboratory and Healthcare Facilities

22 61 00—Compressed-Air Systems for Laboratory and Healthcare Facilities

- 22 61 13—Compressed-Air Piping for Laboratory and Healthcare Facilities
  - 22 61 13.53—Laboratory Compressed-Air Piping
  - 22 61 13.70—Healthcare Compressed-Air Piping
  - 22 61 13.74—Dental Compressed-Air Piping
- 22 61 19—Compressed-Air Equipment for Laboratory and Healthcare Facilities

22 61 19.53—Laboratory Compressed-Air Equipment
22 61 19.70—Healthcare Compressed-Air Equipment
22 61 19.74—Dental Compressed-Air Equipment
22 62 00—Vacuum Systems for Laboratory and Healthcare Facilities
22 62 13—Vacuum Piping for Laboratory and Healthcare Facilities
22 62 13.53—Laboratory Vacuum Piping
22 62 13.70—Healthcare, Surgical Vacuum Piping
22 62 13.74—Dental Vacuum Piping
22 62 19—Vacuum Equipment for Laboratory and Healthcare Facilities
22 62 19.53—Laboratory Vacuum Equipment
22 62 19.70—Healthcare Vacuum Equipment
22 62 19.74—Dental Vacuum and Evacuation Equipment
22 62 23—Waste Anesthesia-Gas Piping
22 63 00—Gas Systems for Laboratory and Healthcare Facilities
22 63 13—Gas Piping for Laboratory and Healthcare Facilities
22 63 13.53—Laboratory Gas Piping
22 63 13.70—Healthcare Gas Piping
22 63 19—Gas Storage Tanks for Laboratory and Healthcare Facilities
22 63 19.53—Laboratory Gas Storage Tanks
22 63 19.70—Healthcare Gas Storage Tanks
22 66 00—Chemical-Waste Systems for Laboratory and Healthcare Facilities
22 66 53—Laboratory Chemical-Waste and Vent Piping
22 66 70—Healthcare Chemical-Waste and Vent Piping
22 66 83—Chemical-Waste Tanks
22 66 83.13—Chemical-Waste Dilution Tanks
22 66 83.16—Chemical-Waste Neutralization Tanks
22 67 00—Processed Water Systems for Laboratory and Healthcare Facilities
22 67 13—Processed Water Piping for Laboratory and Healthcare Facilities
22 67 13.13—Distilled-Water Piping
22 67 13.16—Reverse-Osmosis Water Piping
22 67 13.19—Deionized-Water Piping
22 67 19—Processed Water Equipment for Laboratory and Healthcare Facilities
22 67 19.13—Distilled-Water Equipment
22 67 19.16—Reverse-Osmosis Water Equipment
22 67 19.19—Deionized-Water Equipment

APPENDIX 3-F: SECTION SHELL OUTLINE

This shell outline has been developed by the American Institute of Architects (AIA) .

SECTION XXXXXX

Part 1–General

1.1 Summary

A. This section includes [description of the essential unit of work included in this section].
B. Products furnished but not installed under this section include [description].
C. Products installed but not furnished under this section include [description].
D. Systems covered under this section of the specification

E. Related Sections: The following sections contain requirements that relate to this section.
   1. Division [#] Section [Title] for [Description of Work].
   2. Division [#] Section [Title] for [Description of Work].
   3. Division [#] Section [Title] for [Description of Work].
   4. Division [#] Section [Title] for [Description of Work].

F. Allowances

G. Unit Prices

H. Unit Prices

1.2 References

1.3 Definitions

1.4 System Description

1.5 System Performance Requirements

A. Performance Requirements: Provide [system] complying with requirements specified.

B. Normal Operating Pressure for [System] System: Up to [#] psig maximum. Temperature limits: [#] to [#] deg F.

C. Structural Performance: Hangers and supports for plumbing piping and equipment shall withstand the effects of gravity loads and stresses within limits and under conditions indicated according to ASCE/SEI 7.

D. This project is Risk Category [#} which results in seismic design category [#], which …

1.6 Submittals

A. General: Submit the following:

B. Product data for each type of [products] specified, including details of construction relative to materials, dimensions of individual components, profiles, and finishes.

C. Product data for the following products:
   1. [Product]
   2. [Product]
   3. [Product]
   4. [Product]

D. Shop drawings from manufacturer detailing equipment assemblies and indicating dimensions, weights, loadings, required clearances, methods of field assembly, components, utility requirements, and location and size of each field connection.

E. Include setting drawings, templates, and directions for installation of the anchor bolts and other anchorages to be installed as unit of work of other sections.

F. Coordination drawings for [unit of work].

G. Coordination plans for reflected ceiling plans drawn accurately to scale and coordinating penetrations and ceiling-mounted items including sprinklers, diffusers, grilles, light fixtures, speakers, and access panels.

H. Power and control wiring diagrams from manufacturer for electrically operated equipment.

I. Wiring diagrams detailing wiring for power, signal, and control systems, differentiating between manufacturer and field-installed wiring.

J. Material certificates signed by the manufacturer certifying that each material item complies with requirements, in lieu of laboratory test reports, when permitted by the Architect.

K. Material certificates signed by manufacturers of [products] certifying that their products comply with the requirements.

L. Welder certificates signed by the contractor certifying that welders comply with requirements of the "quality assurance" article.

M. Qualifications data for firms and persons specified in the "quality assurance" article to demonstrate their capabilities and experience. Include list of all similar projects with project name, addresses, name(s) of architect(s) and owner(s), plus any other information specified.

N. Test reports from and based on tests performed by qualified, independent testing laboratory evidencing compliance of [product] with requirements based on comprehensive testing.

O. Maintenance data for [materials and products] for inclusion into operating and maintenance (O&M) manuals.

1.7 Quality Assurance

A. Installer Qualifications: Engage an experienced installer who has successfully completed [unit of work] similar in material, design, and extent to that indicated for the project.

B. Installer's Field Supervision: Require the installer to maintain an experienced full-time supervisor who will be on the jobsite during times that [unit of work] is in progress.

C. Testing Laboratory Qualifications: Demonstrate the required experience and capability to conduct the indicated testing without delaying progress of the work based on evaluation of the laboratory submitted criteria conforming to ASTM E 699.

D. Qualify welding process and welding operators in accordance with ASME Boiler and Pressure Vessel Code, Section IX, "Welding and Brazing Qualifications."

E. Regulatory Requirements: Fabricate and stamp [product] to comply with [code].

F. Regulatory Requirements: Comply with the following codes.

1. [Itemize codes in the form of separate subparagraphs under the above.

G. UL Standard: Provide [products] complying with the UL [designation, title].

H. Electrical Component Standard: Provide components complying with NFPA 70: National Electrical Code and listed and labeled by UL where available.

I. UL and NEMA Compliance: Provide [components] required as part of [product or system] which are listed and labeled by UL and comply with applicable NEMA standards.

J. ASME Compliance: Fabricate and stamp [product] to comply with ASME Boiler and Pressure Vessel Code, Section VIII, Division 1.

K. Single Source Responsibility: Obtain [system] components from single source having the responsibility and accountability to answer and resolve any problems regarding proper installation, compatibility, performance, and acceptance.

L. Manufacturer and Product Selection: The drawings indicate sizes, profiles, and dimensional requirements of [product or system]. A [product or system] having equal performance characteristics with deviations from indicated dimensions and profiles may be considered, provided the deviations do not change the design concept or intended performance. The burden of proof of equality rests on the proposer of the change.

1.8 Delivery, Storage, and Handling

A. Deliver materials and equipment to the site in such quantities and at such times to ensure continuity of installation. Store them at the site to prevent any cracking, distortion, staining, and other physical damage and so that markings are visible.

B. Lift and support equipment only at designated lifting or supporting points as shown on the final shop drawings.

C. Deliver [product] as a factory-assembled unit with the protective crating (packaging) and covering undamaged and in place.

D. Store [products] on elevated platforms, etc. in a dry location.

E. Coordinate delivery of [product] in sufficient time to allow movement into the building.

1.9 Project Conditions

A. Site Information: Data on indicated subsurface conditions are not intended as representations or warranties of accuracy or continuity of these conditions [between soil borings]. It is expressly understood that the owner and engineer will not be responsible for any interpretations or conclusions drawn there from by the contractor. The data is made available for the convenience of the contractor and is not guaranteed to represent conditions that may be encountered.

B. Field Measurements: Verify dimensions by field measurements. Verify that the [system, product, or equipment] may be installed in compliance with the original design and referenced standards.

1.10 Sequencing and Scheduling

A. Coordinate the size and location of the concrete equipment pads. Cast anchor bolt inserts into the pad. Concrete reinforcement and formwork requirements are specified in Division 3.

B. Coordinate the installation of roof penetrations Roof specialties are specified in Division 7.

1.11 Warranty

A. Special Project Warranty: Submit written warranty, executed by the manufacturer agreeing to repair or replace [product], which fails in materials or workmanship within the specified warranty period. This warranty shall be in addition to and not limit other rights the owner may have against the contractor under the contract documents.

1. The minimum warranty period shall be one (1) year following the date of substantial completion.

1.12 Maintenance

1.13 Extra Materials

A. Deliver extra materials to owner. Furnish extra materials described below matching the products installed and packaged with a protective covering for storage and identified with labels clearly describing the contents.

Part 2–Products

2.1 Manufacturers

A. Available Manufacturers: Subject to compliance with requirements, manufacturers offering products that may be incorporated in the work include, but are not limited to, the following:

B. Manufacturers: Subject to compliance with requirements, provide products by one of the following:

1. [Name of Product]
   a. [Manufacturer's Name]
   b. [Manufacturer's Name]
   c. [Manufacturer's Name]
2. [Name of Product]
   a. [Manufacturer's Name]
   b. [Manufacturer's Name]
   c. [Manufacturer's Name]
3. [Name of Product]
   a. [Manufacturer's Name]
   b. [Manufacturer's Name]
   c. [Manufacturer's Name]
4. [Name of Product]
   a. [Manufacturer's Name]
   b. [Manufacturer's Name]
   c. [Manufacturer's Name]

C. Available Products: Subject to compliance with requirements, products that may be incorporated in the work include, but are not limited to the following:

D. Products: Subject to compliance with the requirements, provide one of the following:

2.2 Materials [Product Name]

A. [Material or Product Name]: [Nonproprietary description of the material] complying with [standard designation] (for type, grade, etc.).

B. [Material or Product Name]: [Nonproprietary description of the material] complying with [standard designation] (for type, grade, etc.).

C. [Material or Product Name]: [Standard designation], [type, grade, etc. as applicable to the referenced standard].

D. [Material or Product Name]: [Standard designation], [type, grade, etc. as applicable to the referenced standard].

2.3 Materials, General [Product, General]

A. [Description] Standard: Provide [product or material] that complies with [standard designation].

B. [Description] Standard: Provide [product or material] that complies with [standard designation].

C. [Kind of Performance] Characteristics: [Insert requirements for kind of performance involved and type of test method as applicable unless the requirements are included under Part 1 Article ("System Description").]

D. [Kind of Performance] Characteristics: [Insert requirements for kind of performance involved and type of test method as applicable unless the requirements are included under Part 1 Article ("System Description").]

2.4 Equipment [Name of Manufactured Unit]

A. [Equipment or Unit Name]: [Nonproprietary description of ….] complying with [standard designation] (for type, grade, etc.).

B. [Equipment or Unit Name]: [Nonproprietary description of ….] complying with [standard designation] (for type, grade, etc.).

C. [Equipment, Unit, or Product Name]: [standard description] (type, grade, etc. as applicable to the referenced standard).

D. [Equipment, Unit, or Product Name]: [standard description] (type, grade, etc. as applicable to the referenced standard).

2.5 Components

A. [Component Name]: [Nonproprietary description of ….] complying with [standard designation] (for type, grade, etc.).

B. [Component Name]: [Nonproprietary description of ….] complying with [standard designation] (for type, grade, etc.).

2.6 Accessories

A. Manufacturer's standard factory finish

2.7 Mixes

2.8 Fabrication

2.9 Source of Quality Control

Part 3–Execution

3.1 Examination

A. Examine [substrates] [areas] [land] [conditions] [with installer present] for compliance with the requirements for [maximum moisture content], installation tolerances, [other specific conditions], and other conditions affecting the performance of [unit of work of this section]. Do not proceed with installation until the unsatisfactory conditions have been corrected.

3.2 Preparation

A. Protection:

3.3 Installation, General [Application, General]

A. [Description] Standard: Install [name of product, material or system] to comply with [standard designation].

3.4 Installation {of [Name]} {Application of [Name]}

A. Install [name of unit of work] level and plumb in accordance with the manufacturer's written instructions, rough-in drawings, the original design, and the referenced standards.

3.5 Connections (not a CSI article but useful for Division 15 or 22)

A. Piping installation requirements are found in other specification sections. The drawings indicate the general arrangement of the piping, fittings, and specialties. The following are specific connection requirements:

B. Install piping adjacent to equipment to allow servicing and maintenance.

3.6 Field Quality Control

A. Testing Laboratory: Owner will employ and pay an independent testing laboratory to perform field quality control testing.

B. Testing Laboratory: Provide the services of an independent testing laboratory experienced in the testing of [unit of work] and acceptable to the engineer to perform field quality control testing.

C. Extent and Testing Methodology: Arrange for testing of completed [unit of work] in successive stages in areas of extent described below; do not proceed with [unit of work] of the next area until the test results for the previously completed work verify compliance with the requirements.

D. Testing laboratory shall report test results promptly and in writing to the contractor and engineer.

E. Repair or replace [unit of work] within the areas where the test results indicate [unit of work] does not comply with the requirements.

F. Manufacturer's Field Service: Provide the services of a factory-authorized service representative to supervise the field assembly of components, the installation of [products] including piping and electrical connections, and to report the results in writing.

3.7 Adjusting [Cleaning] [Adjusting and Cleaning]

3.8 Commissioning (not a CSI article but useful)

A. Startup Services, General: Provide services of a factory-authorized service representative to provide startup service and to demonstrate and train owner's maintenance personnel as specified below.

B. Test and adjust controls. Replace damaged or malfunctioning controls and equipment.

C. Train owner's maintenance personnel on procedures and schedules that are related to startup and shutdown, troubleshooting, servicing, and preventative maintenance.

D. Review the data in the operation and maintenance (O & M) manuals. Refer to Division 1, Section ["Project Closeouts"] ["Operating and Maintenance Manuals"].

E. Schedule training with the owner through the Architect [Engineer] with at least seven (7) days' notice.

3.9 Protection

3.10 Schedules

A. Schedule the types of piping materials that are acceptable for the different systems described based on size and application.

B. Schedule the types of insulation that are to be used for each system based on size. Include specifications for acceptable materials, wall thickness, standard service jacket, and special final PVC or metal jacket.

CHAPTER 4

Plumbing Cost Estimation

Plumbing systems contribute to a significant portion of building construction, and controlling their costs helps control the total cost of construction. This chapter discusses the fundamentals of cost estimation and several approaches peculiar to plumbing and related systems including plumbing fixtures, sanitary and storm drainage, water supply systems, natural gas distribution, fire sprinkler systems, medical gas systems, site irrigation, compressed air systems, and various fluid distribution systems such as foodservice, pharmaceutical, and industrial pipe systems.

Plumbing cost estimation applies to a fully designed project, changes to a project during construction, or a project in its early design.

Fundamentally, any cost estimation applies known information, called a database, to a proposed project to obtain an approximate cost of the project. The approximation is more accurate if the database is similar to the proposed project and any differences are recognized and appropriately adjusted. An engineer with sufficient experience with similar projects is able to apply that historical information to a given project and adjust it where the project is slightly different. Generally, parts of a project are proportional to quantities such as lengths, weights, volumes, or areas, but other factors may affect the estimate such as difficult access, varied labor rates and jurisdictions, tax rates, new work vs. renovation, occupied vs. unoccupied buildings, grade of material, and varied local regulations. For example, hanging a pipe at a very high elevation (e.g., 20 feet) costs more than hanging a pipe at a typical elevation (e.g., 10 feet).

A simple cost estimate applies a known unit cost of material to the quantity required in a project. For example, an estimator may apply $20 per foot of pipe to 200 feet required in a project to arrive at $4,000 for the pipe, or in an early stage, such as schematic design, an estimator may apply $2 per square foot for fire sprinklers to 100,000 square feet. Similarly, in a preliminary design, an estimator may apply $4,000 per plumbing fixture, which includes a rough-in cost, but will recognize later that not all fixtures cost the same.

A more elaborate estimate gets its accuracy by breaking the parts of construction into many parts, generally by pipe diameter and pipe material. Thus, the cost estimate is not merely proportional, but it is proportional for each part that has a quantity. Estimators also split the cost of materials from the cost of labor. Lastly, the estimator adds costs that do not vary much between projects—the so-called fixed costs.

A further elaboration recognizes labor crews of various wage rates and productivity. For example, a crew of three plumbers, each with a different labor rate and productivity rate, has a certain overall productivity rate for a given pipe diameter and material. Another elaboration recognizes a slower productivity rate for labor working beyond eight-hour days or 40-hour weeks.

Regarding rounding up or down, the common engineering practice of rounding to three significant digits should be practiced in cost estimating. However, calculated money is often left rounded to the penny or dollar. To maintain accuracy in cost estimating, drastic rounding up to a number that looks presentable, such as $851 rounded to $900, should be avoided except for the final grand total.

COST COMPONENTS

Plumbing construction costs can be broken down into the following components:

- Materials
- Equipment (rented or owned)
- Labor
- Subcontracts
- Other miscellaneous costs such as per diem, permits, trucking expenses, etc.

Materials include fixtures, appurtenances, and commodity items such as pipe, fittings, valves, pipe supports, sleeves, access panels, low-voltage wiring, firestopping, insulation, drains, cleanouts, and fixture carriers. An estimator may also include purchased services as materials since a purchase order is written. The services may include material handling, equipment rental, surveyors, insulators, firestopping installers, medical gas certifiers, laboratory services, waste handlers, and waste reclaimers.

Plumbing appurtenances may include water heaters, water treatment devices, and medical plants but also may include accessories such as interceptors, pumps, alarms, water meters, backflow preventers, pressure vessels, and sump pumps.

Estimators enter labor costs in terms of labor hours. For example, two hours of labor for a portion of a project may be one plumber working two hours or two plumbers working one hour each. If the hourly labor rate is the same for both plumbers, the estimated labor cost is the same, so quantifying the number of plumbers in the estimating effort is not necessary.

The following parts of a labor rate are applied to the gross wage rate to reflect an hourly labor rate of construction:

- Social Security and Medicare taxes that employers pay
- Workman's compensation insurance premiums
- Unemployment taxes
- Health insurance premiums
- Holiday and vacation pay
- Retirement costs

The estimated cost of labor will be the labor rate multiplied by the estimated time to provide the work.

An adjustment to the sum of costs is called a markup, which is universally understood to be overhead and profit, including:

- Correction factors, or adjustments to labor and material costs to compensate for productivity, project size, or availability of resources
- Sales tax, which is applied only to materials and sometimes to rented equipment but not to the entire project

If the conditions of the project match the unit costs of a database and sales taxes do not apply, then the markup ranges from 1.10 to 1.12 to reflect a 10 to 12 percent overhead for the plumbing contractor. The final installed cost may include an additional overhead for the general contractor, which ranges from 6 to 15 percent. If the design of the project is incomplete, then a 15 percent contingency may be considered plus the 10 to 12 percent overhead. Assuming a 15 percent contingency and a 10 percent overhead for the plumbing contractor, the markup becomes $1.15 \times 1.10 = 1.265$. The geography factor (location of the jobsite) ranges from 0.87 to 1.10 for most of North America. This factor is used to account for geographic differences in productivity and labor rates. Sales taxes also vary regionally and by how they are applied. The size of a job causes the largest range of factors and is discussed later in this chapter. To summarize, a job's markup on its sum of costs may be 1.10 for geography, 1.02 for job size, 1.15 for contingencies, 1.06 for sales tax, and 1.12 for plumbing contractor overhead, resulting in a total markup factor of 1.53.

Some estimators prefer to consider each markup factor separately. The amount for each markup is then added to the sum of costs as separate line items. The overhead may be derived before or after adding the sales tax, depending on local practice.

It should be noted how markups are considered for estimates for alternative materials or changes during construction. The same markup should be applied to the base cost and to the alternate cost. If an alternate is presented without the markup, it may erroneously appear to be more attractive over the base cost.

TAKE-OFF ESTIMATING METHOD

To estimate a completed design, the database of unit costs is used plus a small contingency, but typically a more liberal contingency is used for estimating a schematic or design development document package.

Mathematically, the estimating process involves multiplying the quantity by the unit cost (or unit of labor) and adding that subtotal to other subtotals. Then, appropriate percentages are applied to appropriate subtotals (e.g., material plus 8 percent sales tax or labor plus 45 percent labor burden), and then the subtotals are added. Markups (i.e., overhead and profit) are added to this subtotal, and the result is the estimate, or the selling price. The labor database may be developed over time, may be obtained using a vendor's estimating software program, or may be created from tables in this chapter. The material database may be a vendor's price sheet adjusted by a contractor's discount. Calculations generally are set up with tabular sheets, an ordinary spreadsheet program, or a vendor's software program.

With material costs treated apart from labor, Equation 4-1 can be used to create a tabular take-off sheet for estimating a category of plumbing work. Equation 4-2 joins each category into a final estimate. A category is each size of pipe for each pipe material. A category for trench work is considered where applicable using separate categories for each depth involved. The last category will handle the fixtures, trim, appurtenances, and accessories.

Equation 4-1

$$E_1 = (QMd) + (HLw)$$

where

E_1 = Estimate of one category of construction
Q = Quantity of each material on a specific job
M = Price of each material, typically taken from a vendor's catalog
d = A multiplier, such as 0.65, to represent a contractor's discount
H = Quantity of each labor activity (may be equal to Q)
L = Time for a single worker to do each type of activity
w = A multiplier to represent the hourly cost for such a worker including taxes, insurance costs, and benefits

Equation 4-2

$$E_t = \text{Sum}\ (E_1, E_2, E_3 \ldots E_n)\ m + O$$

where

E_1 = Estimate of one category of construction
E_2, E_3 = Estimate of other categories of construction
n = Total number of categories
m = Total markup, a product of factors such as geography, job size, contingency, sales tax, and contractor overhead
O = Sum of fixed costs
E_t = Total of construction estimate

One method to create a tabular take-off sheet for piping is shown in Table 4-1. The material quantity (Q) is in the second column. The product of the second column and the fifth column will create the labor quantity—in this case, the quantity of pipe joints. This table reflects that some fittings have two joints, while others have three. The time accounted for preparing the hangers and joints covers the labor for installing the pipe. With building information modeling (BIM), the quantity information can be inserted without the tedium of manually counting every item. It is important to note that with BIM takeoffs, they are dependent on the level of development that is included in the model being used for the take-off. Appropriate factors should be included for incomplete models to develop an accurate material take-off and project cost.

Various work situations can be adjusted. For example, Table 4-1 shows an extra 10 percent adjustment to reflect work on a scissors lift. If piping is at two different elevations, then two separate sheets are tabulated.

Each category of construction is tabulated in a similar manner, and the tabulation sheets are added together. If necessary, premium labor rates are applied for nonstandard work-week hours. Overtime labor rates are adjusted further to reflect a lower productivity of longer workdays.

Table 4-1 Piping Take-Off Sample Using 1-in. Copper Type L, 50/50 Solder

Item	Quantity	Unit Material Cost	Total Material Cost	Number of Joints	Unit Labor Hours	Total Labor Hours
Pipe, ft	237	$2.05	$486			
Couplings	24	1.56	37	2	0.25	12
Elbows	19	1.78	34	2	0.25	9.5
Tees	5	4.03	20	3	0.25	3.8
Ball valves	2	31.80	64	2	0.25	1
Hangers (ring type)	46	3.48	160		0.50	23
Subtotal			$801	Subtotal		49.3
– Material deduction discount (35% = $280)			$521	+ Elevated work adjustment (10%)		54.2
				x Wage rate ($110/hr)		$5,962
Total (materials subtotal + labor subtotal) = $6,483						

Table 4-2 Hours to Excavate 100 ft (30.5 m) of Trench

Depth, ft	Width, in.	Volume, yd^3/ft	All Work by Hand			Mechanical		Chain Trencher[a]	Final Hand Grading[b]
			Sandy	Medium	Hard	Modest Length	Long Length		
1	18	6	7	11	16	1	1	2	3
1½	18	8	11	17	24	2	1	3	3
2	18	11	14	22	32	2	1	3	3
2½	18	14	18	28	40	3	2	4	4
3	24	22	21	34	48	3	2	4	4
3½	24	26	25	40	56	3	2	–	4
4	24	30	28	44	64	4	3	–	4
4½	24	33	32	50	72	4	3	–	4
5	24	37	48	76	105	6	5	–	4
5½	24	41	53	84	116	6	5	–	4
6	48	89	57	90	124	7	6	–	4
6½	48	96	62	100	138	7	6	–	6
7	48	104	91	130	208	8	7	–	6
7½	48	111	100	143	228	8	7	–	6
8	48	118	106	150	240	9	7	–	6
8½	48	126	113	160	256	9	8	–	6
9	48	133	120	170	272	10	9	–	6
10	48	148	134	188	300	11	10	–	8
11	48	163	148	208	332	12	11	–	8
12	48	178	163	228	364	13	12	–	8
13	48	192	275	455	675	14	13	–	8
14	48	207	303	500	751	16	14	–	8

Conversion factors: 1 in. = 25.4 mm, 1 ft = 0.3048 m, 1 yd^3 = 0.7646 m^3, 1 ft^3 = 0.037 yd^3

a Chain trencher refers to a gasoline-driven trenching machine, which digs a maximum of 10 in. wide x 3-1/3 ft deep.

b Add hand grading for mechanical trenching only if required.

PRODUCTIVITY RATES

Tables 4-2 through 4-8 provide common labor units. Table 4-9 provides some adjustments for various job conditions. The information is derived from the Plumbing-Heating-Cooling Contractors Association (PHCC) and is based on surveys solicited of 150 plumbing contractors from all areas of the United States.

Notice the cost difference between hand trenching and machine trenching in Table 4-2. For example, a 3-foot (0.91-m) deep trench that is 100 feet (30.5 m) long takes two or three hours by machine and up to 48 man hours by hand. Four hours of additional time is applied to the machine method if hand grading is required. For hand work, the volume should be adjusted to reflect a typical 24-inch (609.6-mm) trench width for excavation and backfill volumes. For exterior work or other clear spaces that accommodate larger machinery, hours may be reduced more substantially than indicated. Saw-cutting may be faster than shown in Table 4-3 if space allows for larger equipment. Breaking pavement with heavier pneumatics or removing whole pieces of cut concrete can reduce the times shown in Table 4-4.

Table 4-5 shows that the time to hand backfill (17 hours) and mechanically backfill (one hour) a 3-foot (0.91-m) deep trench that is 100 feet (30.5 m) long is 18 hours total. The same table shows that

Table 4-3 Time to Saw Cut 100 ft (30.5 m) of Concrete Trench

Depth, in. (mm)	Hours
3 (75)	5
4 (100)	6
5 (125)	7

Table 4-4 Time to Break 100 ft (30.5 m) of Pavement

Method	Material	Width	Hours
Pneumatic hand tool	Concrete	24 in. (600 mm)	10

Table 4-5 Hours to Backfill 100 ft (30.5 m) of Trench

Depth, ft	Volume, yd³	All Work by Hand			Pipe Bedding by Hand		Mechanical Backfill[a]	Mechanical Compaction
		Sandy	Medium	Hard	3-in. dia. pipe	4–10-in. dia. pipe		
1	6	5	6	7	8	12	0.3	–
1½	8	7	8	11	8	12	0.4	0.5
2	11	9	11	15	8	12	0.5	0.5
2½	14	11	14	20	8	12	0.6	0.5
3	23	14	17	24	8	12	0.8	1
3½	26	16	20	28	8	12	0.9	1
4	30	18	22	29	8	12	1	1
4½	33	20	25	33	8	12	2	1
5	37	31	38	50	8	12	2	1
5½	41	34	42	55	8	12	2	1
6	89	36	45	59	8	12	2	2
6½	96	40	49	63	8	12	3	2
7	104	42	52	68	8	12	3	2
7½	111	46	57	74	8	12	3	2
8	118	48	60	78	8	12	3	3
8½	126	51	64	83	8	12	3	4
9	133	55	68	89	8	12	4	4
10	144	60	75	98	8	12	4	5
11	164	67	83	108	8	12	5	b
12	178	73	91	119	8	12	5	b
13	192	80	99	130	8	12	6	b
14	207	88	110	143	8	12	6	b

Conversion factors: 1 in. = 25.4 mm, 1 ft = 0.3048 m, 1 yd³ = 0.7646 m³, 1 ft³ = 0.037 yd³
a Must add for standby hand laborer.
b Call equipment company for hours to compact backfill.

Table 4-6 Time to Complete 100 Joints

Method	Size (diameter), in. (mm)													
	½ (12)	¾ (19)	1 (25)	1¼ (32)	1½ (38)	2 (50)	2½ (63)	3 (75)	4 (100)	5 (125)	6 (150)	8 (200)	10 (250)	12 (300)
	Hours													
Screw thread	25	27	30	36	38	40	90	95	100	145	150	200		
50/50 solder	20	21	25	27	30	32	63	75	85	123	127			
DWV solder				33	36	39	76	90	102	148	153	204		
Brazed	26	27	33	35	39	42	82	96	111	160	165			
Groove steel			30	36	38	40	72	76	80	116	120	160	184	208
Groove copper			30	36	38	40	72	76	80	116	120	160	184	208
Plastic[a]	20	21	25	26	27	28	40	50	60	98	101	136	162	216
Hub and caulk[b]						50		55	60	65	70	120	130	150
Hub and gasket[b]						45		45	50	55	60	100	110	125
Hubless					30	30		35	40	45	50	80	90	100
Water main, mechanical joint[c]								60	62		70	72	80	82
Water main, compression[c]								47	48		50	52	54	56

a Solvent joint. For heat fusion, multiply value by 1.5.
b Hub-and-spigot, service-weight cast iron pipe. For extra heavy, multiply value by 1.02.
c Labor for 300 ft (90 m) minimum. Add crane cost.

Table 4-7 Time to Install 100 Pipe Hangers

Hanger Type	Size (diameter), in. (mm)												
	¾ (19)	1 (25)	1¼ (32)	1½ (38)	2 (50)	2½ (63)	3 (75)	4 (100)	5 (125)	6 (150)	8 (200)	10 (250)	12 (300)
	Hours												
Ring	50	50	50	50	50	60	60	70	70	80	100	100	100
Roller						140	140	160	160	180	220	220	220

Table 4-8 Time to Install Fixtures

Fixture	Type	Hours
Bathtub		3
Drinking fountain	Wall mount	2
Lavatory	Wall mount	2
Lavatory	Counter	2.5
Mop basin		2
Shower	Built-up stall	1
Sink	Single compartment	2
Sink	Double compartment	2.5
Service sink		3
Urinal	Wall mount	2.8
Urinal	Stall	3.8
Water closet	Floor mount	1.8
Water closet	Wall mount	2.7

the time to do it by machine (mechanical backfill and mechanical compaction) is 1.8 hours. Notice in Table 4-6 that completing a single 4-inch (100-mm) threaded joint takes the most time (one hour), and completing a single hubless joint takes the least (0.4 hour). (Not shown are joining methods and materials such as press fit, CPVC, and PEX.)

Example 4-1

Using Tables 4-2 and 4-5, estimate the cost to excavate and backfill a 5-foot (1.52-m) deep trench that is 210 feet (64 m) long by machine (long length method). Final hand grading will be required, the pipe will be 4 inches (100 mm), and spoils will be used for backfilling.

Solution: Select the required unit labor and apply it to the trench length. Add the equipment rental charge (or ownership hourly rate). Table 4-10 shows the take-off tabulated solution.

Example 4-2

Using Tables 4-2 and 4-5, estimate the cost to excavate and backfill the following trench sizes by machine (modest length method): 120 feet (36.6 m) of 3 feet (0.9 m) average depth, 130 feet (39.6 m) of 2 feet (0.6 m) average depth, and a variety of trenches totaling 250 feet (76.2) of 18 inches (457.2 mm) average depth. Excavated material will be dumped off site and replaced with new fill. Final hand grading will be required, and the pipe will be 4 inches (100 mm).

Solution: Determine the various required unit labor and apply it to the various trench lengths. Add the equipment rental charge (or ownership hourly rate). Add the cost of hauling excavated material and delivering backfill material. Since excavated material increases in volume by the excavation process, appropriately adjust the volume to account for this swelling (assume 15 percent). Table 4-11 shows the tabulated solution for each step.

Table 4-9 Adjustments from Standard Conditions

Activity	Condition	Multiplier
Overhead piping	8-ft (2.5-m) ladder	1.00
	10-ft (3-m) ladder	1.03
	Powered lift	1.10
Crawl space or tunnel	3 ft (1 m) high	1.50
Trench piping	3 ft (1 m) deep	1.00
	5 ft (1.5 m) deep	1.10
	Deeper	1.30
Distribution of material	Distance from stock:	
	100 ft (30 m)	1.00
	300 ft (90 m)	1.03
	500 ft (150 m)	1.04
	1,000 ft (300 m)	1.05
Equipment room piping		1.20
Laboratory		1.10
Foodservice		1.10

OTHER ESTIMATING METHODS

Counting fixtures and major accessories and applying time-proven costs per fixture can arrive at an estimated total cost. Piping and material costs are included in the per-fixture cost, and the particular level of trim and the quality level of the specific project can be comparable to those of the database. For example, if the project requires cast brass faucets, caulked cast iron piping, and extra valves on the supply distribution, then apply a per-fixture cost that is derived from a project that used similar materials.

The advantage of the per-fixture method is that it can be performed without a piping layout. A disadvantage is that it fails to distinguish between projects with fixtures that are concentrated in a few areas and projects with fixtures that are spread around a building.

Table 4-10 Solution to Example 4-1

Item	Length, ft (m)	Unit Hours	Total Hours
Mechanical excavation	210 (64)	0.05	10.5
Hand grading	210 (64)	0.04	8.4
Pipe bedding by hand	210 (64)	0.12	25.2
Mechanical backfill	210 (64)	0.02	4.2
Standby hand laborer (use mechanical backfill rate)	210 (64)	0.02	4.2
Mechanical compaction	210 (64)	0.01	2.1
Total labor hours			54.6
Costs			**Total costs**
Total labor cost ($110/hr x 54.6 hrs)			$6,006
Machine cost ($300/hr x 16.8 hrs)			$5,040
Total cost			$11,046

Another less precise estimating method is the square foot (m^2) method, which is usually used at the early stages of a project, concept, or schematic stage. This method provides a reasonable cost estimate even with little project information. It is determined simply by multiplying the building area by a per-area cost. The per-area cost must be selected carefully to reflect not only the level of trim, quality of the particular project, and concentration of fixtures, but also the intensity of fixtures. For example, a medical office building usually has a higher number of fixtures per building area than an ordinary office building. Regulations and probable demand vary with the different types of occupancies and will influence infrastructure requirements.

Internet search engines provide an option to obtain equipment prices, which may be helpful for comparing alternatives. However, the price in a search result will not realistically reflect a purchase price. A contractor's discount will likely bring about a lower price than the retail price that could be obtained on the Internet.

More precise estimating methods are now available through computer programs, hardware peripherals, and BIM. While the value of using an appropriate database has been emphasized, the ability to enter precise counts and lengths is now being offered by numerous vendors. The value of accurate data entry helps avoid costly errors and speeds up the estimating process. Some peripherals allow the user to overlay scaled drawings on a digitizing pad, so pipes are picked at each end and the software accounts for the length. Other software works with electronic versions of the drawing, and the user highlights each pipe as they enter key information, such as pipe diameters.

Table 4-11 Solution to Example 4-2

Item	Length, ft (m)	Unit Hours	Total Hours	Volume, yd³ (m³)
1.5-ft (450-mm) deep trenches				
Mechanical excavation	250 (76)	0.02	5	
Hand grading	250 (76)	0.03	7.5	
Pipe bedding by hand	250 (76)	0.12	30	
Mechanical backfill	250 (76)	0.004	1	
Standby hand laborer (use mechanical backfill rate)	250 (76)	0.004	1	
Mechanical compaction	250 (76)	0.005	1.25	
Hours			45.75	
Cubic yards (m³)	250 (76)			20.83 (15.93)
2-ft (610-mm) deep trenches				
Mechanical excavation	130 (40)	0.02	2.6	
Hand grading	130 (40)	0.03	3.9	
Pipe bedding by hand	130 (40)	0.12	15.6	
Mechanical backfill	130 (40)	0.005	0.65	
Standby hand laborer (use mechanical backfill rate)	130 (40)	0.005	0.65	
Mechanical compaction	130 (40)	0.005	0.65	
Hours			24.05	
Cubic yards (m³)	130 (40)			14.44 (11.04)
3-ft (915-mm) deep trenches				
Mechanical excavation	120 (37)	0.03	3.6	
Hand grading	120 (37)	0.04	4.8	
Pipe bedding by hand	120 (37)	0.12	14.4	
Mechanical backfill	120 (37)	0.008	0.96	
Standby hand laborer (use mechanical backfill rate)	120 (37)	0.008	0.96	
Mechanical compaction	120 (37)	0.01	1.2	
Hours			25.9	
Cubic yards (m³)	120 (37)			26.7 (20.4)
Total cubic yards (m³)				61.9 (47.4)
Adjusted cubic yards (m³)—swelling, add 15%				71.2 (54.5)
Total labor hours			95.7	
Total machine hours			16.9	
Total labor cost at $110/hour = $10,527 Machine cost at $180/hour = $3,044 Haul excavated material at $9/cubic yard ($12/m³) = $641 Fill material cost at $12 /cubic yard ($15/m³) = $855 Total = $15,066				

BIM provides a more accurate tabulation of pipes, pipe fittings, valves, fixtures, and other parts of the plumbing system. Through schedules created in BIM and imported to a spreadsheet or other software, pipe lengths and fitting counts can be obtained with great precision.

When the counts and lengths of materials are accurately and quickly gathered, a more precise cost estimate can be determined. However, an estimating program should address current needs without being too complicated. The vendor of the program should be experienced with plumbing in building construction and should offer upgrades as the estimating technology evolves.

OTHER COST FACTORS

Most cost estimating assumes certain conditions in establishing the estimator's database. Among such assumptions are the level of work quality, standard work hours, general crew productivity, size of the project, allotment of a reasonable timeframe, new plumbing or alterations of existing plumbing systems, geographic location of the project, season and weather, contractor management, collective bargaining agreements, utility availability, and general business conditions. The size of a job usually affects unit costs, and larger projects typically exhibit lower unit costs due to economies of scale. The location of a job affects shipping costs as well as the market for skilled labor.

For repair work and alterations, consider slower work productivity because of limited physical access, material-handling restrictions, more precise cutting to match existing systems, efforts to protect existing finishes, nonstandard work hours, unexpected delays, unplanned piping offsets, and unfavorable economies of scale.

For cost estimating changes to an ongoing construction project, other cost factors may be necessary even though they were not applied to the original estimate. For example, a change in the project may need to occur out of the planned sequence, the timeframe may be constricted, or the plumbing change may now be within a finished space.

RECONCILING ESTIMATES

Since cost estimating involves the matching of specific project information with a database of known construction costs, variations from the database will affect the cost estimate, and an appropriate adjustment must be used to arrive at an accurate estimate. The amount of the adjustment involves many factors, from geography to job size. The estimator's experience determines the best adjustment, while the estimator's careful examination of the specific project provides the needed information to match with established unit costs.

In many projects, two separate cost estimates are done. Usually the construction manager does an estimate during different points during the design, and either the design firm or the owner hires a separate estimating consultant for a parallel estimate. Then, either the designer/engineer reviews and reconciles the estimates for accuracy or a meeting is held among all parties to reconcile the two estimates. This assures the owner that the cost is accurate and nothing was missed in the estimate.

Since the design becomes more precise as the project progresses, the accuracy of estimates at the different stages of design may vary. Early estimates are sometimes identified to have an accuracy expressed as a percentage of the cost. For instance, at the schematic stage, the estimate has a ±15 percent accuracy, and as the design progresses to the CD level, the accuracy improves since the drawings show more detail to get a more accurate material take-off.

In conclusion, seasoned judgment and a tedious review of the project documents will yield an accurate prediction of plumbing costs.

Job Preparation, Drawings, and Field Checklists

Project management may be defined as the effort to direct and control the success of a project. It is not project engineering, but it is enhanced by a knowledge of engineering. Directing and controlling a project can be achieved by planning, organizing, and leading resources and observing milestones through the final design. The end result, at a minimum, is an adequate design provided on time and within budget.

Resources, standards, risk assessments, field work, and communication play a role in sound project management. While other work in an engineering firm includes marketing, information technology, finances, contracted services such as various insurance policies, and employment issues, project management focuses on engineering tools, policies, project staffing, communication, and specific requirements for a project. Good managers know their clients, track the progress of their projects, identify and limit project risks, and rein back any creeping of the project beyond its original scope and budget.

PROJECT MANAGEMENT

Good management practices include recognizing engineering resources, the general nature of plumbing engineering projects, and the management of specific projects. Resources include a qualified staff, copies of regulatory information and product literature, internal engineering standards, and various engineering tools such as communication devices and computers, computer peripherals, and appropriate software.

Qualifications of a project's staff include their education, experience, and demonstrated talent. Shortfalls in talent will require greater supervisory efforts when managing the details of a project. The benefits of a strong staff include the ability to extend their reach into projects greater than their past efforts, but this should not extend by more than 30 percent, whether measured by cost, project square area, or other relevant criteria.

Successful management does not require the latest or most powerful computers, but computers should not be more than five years old, unsupported by their vendors, or lack an Internet connection. Other tools include measuring devices, reference books, cameras, communication devices, and a means of transportation.

Other resources include up-to-date regulatory codes and their reference standards. At minimum, an office should have the local plumbing code and other building codes, ASPE *Plumbing Engineering Design Handbooks,* ANSI/ASHRAE/IES 90.1: *Energy Standard for Buildings Except Low-Rise Residential Buildings* and/or ANSI/ASHRAE 90.2: *Energy Efficient Design of Low-Rise Residential Buildings,* standards for pipe materials, and knowledge of the local water, sewer, and gas utility service requirements. It should be noted that the 2015 International Energy Conservation Code (IECC) has introduced significant creep into the plumbing engineering environment with its reduction in the distances allowed between circulated water mains and their connections to public lavatory faucets. The IECC also continues to regulate the insulation thicknesses for domestic hot water piping.

Many offices no longer have product literature; this data is now found on the Internet and in electronic format from previous projects. It is always a good idea to review referenced product data on the Internet to determine if the equipment or fixtures are still the same. An office also should have a guide written by experienced engineers in the office that reflects their combined knowledge on sound practices and a uniform level of design requirements. Helpful information in such a guide could include wall thicknesses to enclose various pipe sizes, tables with heat loss data for hot water pipes to assist in calculating circulation return flow rates, commonly used fixtures and equipment, rules of thumb for checking designs, recommended drawing notes and details, and copies of tables from codes and standards.

Lastly, resources should be available to account for an engineer's time spent on a project, including a method for tracking expenses.

Management includes assigning staff for each project, based on experience, availability in their schedule, and/or the level of risk involved for a particular project. Higher risk may require a more mature staff member, whether that risk involves high loss potential, a remote project location, limited field information, or a tight project schedule.

Many projects no longer fall exclusively under full engineering services. A project may be limited to a schematic level, with or without preparing an opinion of probable cost. In other projects, only scope documents are needed, which do not require pipes shown on the drawings and the specification is just a brief narrative with little distinction between fixture types. Some projects include basis-of-design information so an engineering design can be provided by others. The information may include limits to flow velocities or water heater recovery rates for a given unit such as a bed count. Any of these project types may or may not require reviewing project submittals or the plumbing work in the field during construction.

Managing staff for various projects is much like dealing with marbles on a Chinese checkers game board. As only one marble can fit in a hole, too many projects assigned to one engineer can choke up productivity, despite their talent or motivation. A balance of the workload among the staff and an awareness of bottlenecks or milestones can help avoid excessive pressure and consequential errors. In addition, having an awareness of project peculiarities might help avert design consequences that may cause the major parts to be designed two and three times, which can disturb a project's schedule and other work.

Management also includes tracking project team members from other design firms to maintain communication and adapt to staff changes. A project manager will maintain a list of project team members and up-to-date contact information.

GUIDELINES FOR PRELIMINARY DESIGN

The following items can be part of a set of guidelines for a project manager to control and direct plumbing projects.

- During a project's initial discovery phase, identify relevant codes and standards, including local amendments and revision dates. Verify insurance company requirements. Relevant issues include:
    - Energy and water conservation
    - Hot water production and maintenance
    - Cross-connection control
    - Interceptors and solid waste control
    - Clear water disposal
    - Rainfall rates
    - Secondary drainage
    - Stormwater management
    - Fire sprinklers and standpipes and occupancy class
    - Fuel gas code
    - Medical gases and other healthcare matters
    - Wastes other than domestic
    - Local Environmental Protection Agency (EPA) restrictions on boiler and water heater sizes
- Identify the date, time, method, and format of document deliveries: type and version of a computer-aided design (CAD) program, building information modeling (BIM) requirements, hard-copy plots, and PDFs. Identify and set up an upload/download website or designated e-mail address.

- Coordinate requirements with the plumbing code official and the fire suppression authority having jurisdiction (AHJ). Contact the water, sewer, and gas utilities and establish connection requirements.
- If likely to be relevant for the project, identify certain information such as geographic elevation, humidity issues, hurricane issues, and seismic matters.
- Identify phasing issues and whether there will be concurrent occupancy.
- Review surveys and other documents for the size, location, and depth of sanitary and storm sewers, water mains, and gas mains along with any site obstructions and interferences. Coordinate with the project's civil engineer if he is included on the project team.
- Obtain the water flow and pressure data (static and residual) at a given elevation. Determine if a fire pump and a domestic booster pump are required. Select and size the pumps as needed.
- For building alterations or additions, check if the existing plumbing accessories and piping are adequate. Accessories include water heaters, water treatment equipment, pumps, compressors, backflow preventers, and interceptors. Identify energy sources: gas, propane, electric, steam, or hydronic.
- Determine if water treatment is required. Review the water purveyor's annual water quality report. Obtain a water quality analysis. Determine if water softeners are used elsewhere on the site. Select and size any necessary treatment equipment.
- Determine if unusual occupancy-related plumbing requirements exist.
- Within the limits of the code, determine the architect's preferred method of cleanout design.
- Coordinate electrical voltages and phases for motors and controls with the electrical engineer.
- Coordinate gas pressure requirements for water heaters and other equipment with the gas utility. Identify the gas pressure in the existing building if the existing system will be extended.
- Determine the need for other systems, such as compressed air, vacuum, deionized water, acid waste, fuel oil, and steam.
- Identify major water and drain users such as cooling towers, reverse osmosis equipment, and process users.
- If the building will have a kitchen or include special appliances, obtain a design development submission from the foodservice consultant or the building's special equipment consultant, or review previously completed projects of similar magnitude and scope.
- Identify the water service entrance scheme, including meters, backflow preventers, water softeners, domestic water heaters, and central thermostatic mixing valves.
- Review the locations of electrical rooms, data communication rooms, and noise-sensitive rooms with pipe routings and with noisy mechanical rooms.
- Review the geotechnical report to determine requirements for subsurface drainage or the need to compensate for expansive soil or rock.
- If this is a campus, determine if sub-metering is required for each of the utilities being installed.
- If campus utilities will be used, determine if they are available year-round. Determine the water temperatures and steam pressures throughout the year, as the campus may "reset" temperatures and pressures to lower values in the summer.
- Select fixtures and fixture trim including faucets, shutoff valves, flush valves, carriers, strainers, drains, traps, and wall flanges. Send fixture cut sheets to the architect. Include dimensioned drawings of fixtures and fixture trim.
- Select sprinkler head designs, including escutcheons or covers, finish type, and color. Send sprinkler head cut sheets to the architect.
- Coordinate with the HVAC designer as to which discipline will handle air-conditioning coil condensate drainage piping.
- Review the cost and time estimates against recent project developments.

- If required, determine possible green building strategies, including water and energy conservation, water reuse, sustainable technologies, project commissioning, and certification. Chart the progress toward LEED certification if desired by the owner. (Note, these are not always base-bid services.)
- Review the plumbing construction budget compared to the initial project scope.
- Review internal hours and other costs against the fee and the progress in a project.

GUIDELINES FOR CONSTRUCTION DOCUMENTS

The following items can be part of a set of guidelines for a project manager to control the preparation of drawings, specifications, and other construction documents.

- Review the elevation of storm and sanitary sewers to determine if gravity flow is feasible. Ensure that storm and sanitary drain pipes do not conflict. Consider backwater valves where appropriate.
- Review utility regulations and provide required water service devices. Provide an approved backflow preventer on the service and where required at equipment connection points. Provide pressure-reducing valves for domestic water systems where the static pressure exceeds 80 pounds per square inch (psi) (550 kPa).
- Review fire suppression standards and local requirements, including standpipe classes and occupancy classifications. Determine the water demand, including the flow at the required residual pressure. Provide water service with an approved backflow preventer or other approved cross-connection control. Select the appropriate type of sprinkler system.
- Coordinate the fire department connection location and fire hydrant requirements with the architect, site civil engineer, and landscape designer.
- Review the code-minimum rainfall rate and whether a higher rate should be considered. Size roof drains, conductors, and the storm drain system accordingly. Review secondary drainage requirements and coordinate them with the architect and structural engineer.
- Determine the size and extent of subsoil drainage based on soil reports and wall structural requirements. Determine if expansive soil or rock will be a problem.
- Review stormwater management issues. Review clear-water disposal restrictions.
- Send the electrical control and power requirements for plumbing and fire suppression equipment to the electrical engineer. These requirements may include power for pumps, air compressors, water heaters, water coolers, heat tracing, solenoids, high water alarms, medical gas alarms and manifolds, fire sprinkler switches, and fire alarm bells. Among the various pumps, consider fire pumps, domestic boosters, circulation pumps, vacuum pumps, sump pumps, and sewage ejectors.
- Evaluate hot water demand requirements. Select and size the water heater(s), mixing valve(s), and circulation pump(s). Provide a hot water system with a circulating return unless the distance between the heater and the farthest fixture is relatively short. Coordinate non-circulated pipe length requirements with the energy code and local water conservation requirements.
- Review local energy code requirements and determine the type and extent of circulation pipe lengths.
- Determine combustion air requirements for atmospheric gas-fired water heaters.
- Address scald hazard concerns and pathological hazards (Legionella pneumophila) within the hot water system.
- Determine water treatment requirements. Select and size equipment for the anticipated occupancy demand and client preferences.
- Review the pipe material selection for each part of the plumbing system from supply systems to drain systems. Consider purity requirements, corrosion issues, fluid temperature and pressure, joining methods, hanger spacing, code issues, and physical protection.
- Review pipe insulation requirements thermally and acoustically. Coordinate with the energy code.
- Review any noise and vibration concerns regarding the piping systems and plumbing equipment, such as water hammer and noise from rotary vacuum pumps and similar equipment.

- Consider building expansion requirements and design concerns that affect tenant occupancy changes.
- Arrange plumbing piping logically while considering obstructions, occupancy restrictions, accessibility, control, noise-sensitive rooms, future expansion, designer's preferences, and economics. In general, run piping clear of structural beams. Where necessary and in consultation with the structural engineer, penetrate through the web of steel beams and the middle third of wood or concrete beams. Keep piping out of elevator shafts, electric and data communication rooms, and similar restricted areas, as well as stairs and exit discharge corridors. Size piping for the required supply and drainage fixture units.
- Provide pipe expansion loops or expansion joints where required.
- Provide valves on distribution branches, on branches off supply risers, and at the base of supply risers. Provide drain valves with hose threads at the base of risers and in the low portions of piping.
- Provide hose bibbs around the building, in mechanical rooms, and adjacent to roof-mounted equipment. Select frost-proof hose bibbs if required. Review the landscape irrigation connection points where required.
- Note piping elevation changes on the plans. Pipes rising within a story should be noted as "rise." Pipes rising to another story should be noted as "up." Pipes dropping to another story should be noted as "down." Pipes at the ceiling should be noted as "at ceiling" when exposed and "above ceiling" when concealed. Pipes under the floor, other than obvious fixture drain pipes, should be noted as "below floor," "at ceiling below," or "above ceiling below."
- Select the location and spacing of cleanouts.
- Locate fire standpipes and hose connections.
- Locate alarm panels and motor controllers.
- Locate roof leaders, main stacks, and supply risers. Coordinate wall thicknesses, beam clearances, and footing clearances with the architect and structural engineer.
- Coordinate structural penetrations and housekeeping pads with the architect and structural engineer. Review the weight of the water heater, tanks, boilers, softeners, and other heavy equipment with the structural engineer.
- Finalize fixtures and fixture trim including faucets, shutoff valves, flush valves, carriers, strainers, drains, traps, and wall flanges. Send fixture cut sheets to the architect. Include dimensioned drawings of fixtures and fixture trim.
- Review the selection of architect- or interior designer-specified fixtures for compliance with applicable codes and standards and advise the specifier of non-compliances.
- Finalize sprinkler head designs, including escutcheons or covers, finish type, and color. Send sprinkler head cut sheets to the architect.
- Determine medical gas outlet adapter types, shutoff valve box locations, and alarm panel layouts. Send equipment cut sheets to the architect. Include dimensioned drawings and option selections.
- Review the plans for mop basin, drinking fountain, and floor drain requirements.
- Provide floor drains for public toilet rooms, at least one floor drain at the lowest floor level of the building, and in pits such as elevator pits.
- Review and coordinate the water supply connection and drain requirements for:
    - Backflow preventers (adequate drain for relief port)
    - Beverage machines
    - Boilers
    - Chillers
    - Compressors
    - Cooling towers
    - Cooling coils (drain only)
    - Emergency eyewash/shower
    - Evaporative coolers
    - Fire sprinklers and fire pumps

  - Food service areas, including dishwashers, walk-in refrigerators and freezers, steam kettles, and scullery sinks
  - High-efficiency burners (drain only, coordinate who provides neutralization kits)
  - Humidifiers
  - Ice machines
  - Laboratory equipment and casework
  - Laundries
  - Pressure relief valves (drain only)
  - Sterilizers
  - Vacuum pumps
  - Other equipment
- Review and coordinate natural gas connections for water heaters, mechanical HVAC equipment, foodservice equipment, and other equipment as required. Select or specify gas pressure regulators.
- Select the size and design of floor drains, floor sinks, trench drains, and receptors to meet requirements. If required, segregate clear-water wastes from sanitary wastes. Connect the clear-water system to the storm drain system or another disposal point as permitted. Verify load rating requirements for drain grates and cleanout covers.
- Identify infrequently used drains and provide them with trap primers or other means of trap seal protection as allowed by code.
- Offset roof drains and vent terminals 12 to 18 inches (0.3 to 0.5 m) from parapet walls, roof openings, and other roofing elements.
- Review canopies and porte-cocheres for adequate drainage.
- Provide cross-connection control for potable water supply connections to equipment, fixtures, and accessories as required. In particular, provide air gaps or approved backflow preventers for connections to boilers and sprinkler supplies. Provide air gaps for relief ports of backflow preventers, pressure relief valves, and fixture faucet outlets.
- Provide interceptors as required, including subsoil receivers, exterior pavement catch basins, garage catch basins, grease interceptors, oil and sand interceptors, laundry interceptors, plaster interceptors, acid and caustic dilution or neutralization basins, and special industrial treatment systems.
- Coordinate any building automation system (BAS) interface requirements with the HVAC engineer.

MODELS, GRAPHICS, AND DOCUMENTS

A graphical presentation of a plumbing design can be prepared with conventional drawings, by 2-D or 3-D CAD, or through BIM. The latter presentation is the most content-rich.

The quality of CAD or BIM can be controlled through internal standards and policies. Establish such standards through collaboration with the client and staff to reach a consensus. Review drawings through readers and by making plots and use a checklist in a quality control process.

Similarly, review specifications by using a checklist.

QUALITY CONTROL

The quality of a set of documents can be improved by employing checklists. Where issues are uncovered in a project that warrant changing internal standards, other projects may be affected and require changes.

Note checked items with your initials. Label N/A where a matter is not applicable.

Drawing Plans

_____ Is it evident that the architectural backgrounds are current?

_____ Does the title block have the correct format, the proper date, and proper nouns spelled correctly?

_____ Are the drawings legible and of sufficient scale?

_____ Does the drawing contain a graphic scale?

_____ Are arrangements coordinated so the drawing sheet index matches the final set of drawing sheets?
_____ Are more recent requirements coordinated with the architect, electrical engineer, HVAC engineer, and structural engineer?
_____ Do pipes clear structural members, high ceilings, skylights, and clerestories?
_____ Do all pipes show sizes? Are fixture units shown? Are invert elevations shown?
_____ Are valves and cleanouts accessible?
_____ Are all fixtures connected to supply, waste, and vent piping?
_____ Do toilet rooms have floor drains where required? Lowest level, elevator pit, and other pits?
_____ Is piping kept out of elevator shafts, electric and data communication rooms, similar restricted areas, stairs, and exit discharge corridors?
_____ Are pipes clear of ductwork?
_____ Are stacks, conductors, and risers within interior partitions or shafts?
_____ Are pipe sizes and equipment sizes sufficient?
_____ Are ceiling spaces and similar concealed spaces prone to freezing?
_____ Is cutting and patching addressed clearly?
_____ Do roof drain locations coordinate with architectural requirements?
_____ Are drawing notes complete and edited for the specific job?
_____ Are plumbing vents sufficiently separated from air intakes and operable windows?
_____ Are medical gas alarm panels and shutoff valve boxes clear of obstructions such as carts and not blocked by doors? Are valve boxes located along exit paths and "blocked" by a wall?
_____ Is the mechanical room coordinated and well laid out with sufficient access to service equipment, including equipment removal? Are equipment connections and drains coordinated?
_____ Does the direction of the north arrow agree with the architect's plans?

Drawing Risers and Details

_____ Are risers legible? Are references, such as drawing references, room numbers, and fixture tags, clearly presented? Are fixture traps oriented correctly?
_____ Are all vents properly connected? Are vent stacks, relief vents, and yoke vents shown where required?
_____ Are pipe sizes consistent between risers and plans?
_____ Are details shown for accessible fixtures, interceptors, backflow preventers, water heaters, water treatment systems, sump pumps, and sewage ejectors?
_____ Are pipe supports, sleeves, and firestopping systems properly detailed? Are fire and smoke walls designated on the floor plans?
_____ Is the water service design properly detailed and coordinated with the utility?
_____ Is the natural gas service design properly detailed and coordinated with the utility?
_____ Does the fire riser design meet utility purveyor and insurance company requirements?
_____ Are detail references coordinated with the plans?

Schedules and Specifications

_____ Are arrangements coordinated so the project manual's table of contents matches the final sections of the plumbing specification?
_____ Is the inclusion of fixtures and equipment consistent in both the drawings and the specifications?
_____ Are fixtures and equipment consistently referenced on plans, risers, schedules, and specifications?
_____ Are pumps selected for proper flow and head? Has a calculation been prepared for each pump?
_____ Is voltage and other electric data consistent in schedules with the equipment supplier and the electrical engineer?
_____ Does the schedule of supply and drainage fixture units show the original total, removed total, and new total?

____ Is a water supply uniform pressure calculation or other sizing method included? Is the street pressure correct? Is the controlling fixture pressure correct? Is the maximum length accurate?
____ Do faucets and flush valves meet water-conservation requirements? Does the fixture trim meet requirements for handle design, strainer design, and spout height? Is the vendor selection accepted by the client?
____ Are legends, symbols, and abbreviations included and consistent with what is shown on the drawings?

CONTRACT ADMINISTRATION

Administration of a contract refers to the contract between a builder, an architect, and a building owner. A plumbing engineer generally administers the plumbing, fire suppression, and medical gas portions of this contract and acts as an agent for the architect. Hence, a plumbing subcontractor's requests for information (RFIs) are forwarded to the plumbing engineer through the general contractor and the architect. Similarly, documents showing actual material intended to be employed in the work, called shop drawings or submittals, are forwarded to the plumbing engineer through the general contractor and architect.

Administration also includes providing aid or guidance during bidding, preparing document addenda, creating change order documents, making field observations during construction, and issuing field reports (punch lists). It is important for the plumbing engineer to understand that he is generally only responsible for ensuring general conformance to the plans and specifications. The contractor remains ultimately responsible for final conformance.

Submittals

- All submittals should be reviewed, corrections noted, and stamped with the contractor's seal prior to being submitted to the architect or engineer.
- Ensure substitutions are made in accordance with contract requirements.
- Review each submittal and note deficiencies for the contractor to correct.
- Verify compliance of each item not only with the construction documents (drawings, schedules, and specifications), but also with the latest changes to the construction documents.
- Review product capacity, type, application, warranty, pressure rating, and other relevant criteria against the construction documents and project requirements. Obtain wiring diagrams, performance curves, and required clearances for proper operation and maintenance.
- Review types of plumbing materials, including valves, hangers, pipe, and pipe fittings, against the construction documents and project requirements.
- Review each fixture trim item, including angle stops, traps, toilet seats, and wall carriers.
- Review fixture and fixture trim items specified by the architect or others after the specifying party has reviewed them first for compliance with project requirements. The plumbing engineer should review them for compliance with codes and standards.
- Check for indication of a product listing where required.
- Check for domestic manufacturers where this is a requirement of the client.
- Review installation instructions if included. If not included, insist on it.
- At project closure, review operation and maintenance manuals and as-built drawings. Request clarifications if necessary. Create record drawings by adapting up-to-date construction drawings with as-built information.

FIELD OBSERVATION

Field visits may be broken down into three phases: underground, rough-in, and final. Important items to observe when visiting a jobsite are listed as follows and should be in reference to the requirements of the construction documents. The plumbing engineer is generally not responsible for making exhaustive field observations and measurements to ensure that the work conforms to the plans and specifications; however, if problems are observed, bring them to the attention of the architect after coordinating with the Engineer of Record for the project.

Observed items may be noted with initials. Label N/A where not applicable. Add a list of comments regarding deficiencies. Take pictures for the record and to include with the report.

Building Drain

____ General alignment and conformity to plans
____ Workmanship of joints; general compactness of soil below and around pipe
____ General slope of piping
____ Spacing and accessibility of cleanouts
____ Vent connections
____ Branch to the building drain not connected near the base of the stack or a conductor
____ Pipe sleeves and waterstopping
____ Pipe sizes and invert elevations
____ Sumps and underground tanks properly ballasted
____ Workmanship, specified size, invert elevations, and rim elevations of manholes, sumps, receivers, grease interceptors, sand and oil interceptors, trench drains, and other structures
____ Trap primer connections
____ Temporary terminations covered or capped to prevent the entry of debris
____ Acid waste and vent piping and acid dilution tank

Water and Gas Services

____ Compliance with water service requirements, including service location, pipe depth, thrust blocks, and shutoff valves
____ Compliance with natural gas service requirements such as service location and shutoff valves
____ Tracer wires installed on PE and other plastic piping

Above Grade Rough-In

____ Compliance with water service requirements such as location, shutoff valves, meters, meter registers, pressure-reducing valves, bypasses, backflow preventers, pressure gauges, and testing ports
____ Compliance with natural gas service requirements such as location, shutoff valves, meters, meter registers, pressure-reducing valves, vent ports, and bypasses
____ Piping at booster pumps, water heaters, and water treatment devices
____ Fire suppression system piping
____ Medical gas system piping, valves, outlets, panels, and source equipment such as cryogenic systems, high-pressure manifolds, emergency connection panel, vacuum pumps, and air compressors, as well as attendant dewpoint and carbon monoxide monitors, air dryers, and inlet, discharge, or relief piping to the exterior
____ Medical vacuum producer exhaust located away from fresh air intakes
____ Medical air compressor air intakes located in open air space and away from plumbing vent and HVAC exhaust fans
____ Function of sump pumps, subsoil receivers, and sewage ejectors
____ General alignment, arrangement, and size of piping in conformity to plans
____ Waste and vent piping sloped in the proper direction
____ Workmanship of joints
____ Installation of pipe supports, expansion joints or expansion loops, and pipe swing joints
____ Fixture carriers
____ Location of valves
____ Clearances around pipes within sleeves

_____ Spacing and accessibility of cleanouts
_____ Firestopping at fire-rated walls, fire-rated floors, and other locations as required
_____ Vent connections close enough to the trap to avoid air lock, above flood level, and vertical where required
_____ Branch to stack offset not connected near the upstream end of the offset
_____ Pipe labeling, valve tags, and valve schedule
_____ Installation of pipe insulation including covers over valves and fittings
_____ Adequacy of cooling coil condensate drains, combustion condensate drains, relief valve drains, and indirect waste pipes—properly supported with an air break or air gap as required
_____ Adequacy of floor slope to floor drains and floor sinks; rims of indirect waste receptors elevated to prevent the entrance of debris
_____ Adequacy of roof slope to roof drains; rims of roof drains submerged to prevent water buildup. Dams on overflow drains installed on the correct drains and of adequate size to operate when required.
_____ Installation of small interceptors
_____ Vent terminals properly flashed, located away from air intakes, and away from operable windows
_____ Motor controllers, magnetic and manual
_____ Connection of plumbing to other building equipment including boilers, chillers, cooling towers, air handlers or fan coils, foodservice, medical, laundry, and similar equipment—arrangement of piping, valves, cross-connection control, and drainage

Final

_____ Adequacy and delivery of hot water within designated time limits at remote fixtures
_____ Americans with Disabilities Act (ADA) accessibility requirements
_____ Fixture support
_____ Water closet bowl type and seat design
_____ Flush valve performance
_____ Strainers and traps
_____ Faucet handles, outlet flow rating, spout design
_____ Fixture supply stop location
_____ Fixture mixing valve location and temperature setting
_____ Mop basin accessories
_____ Caulking at fixtures
_____ Sensitivity of sensor faucets and flushometers
_____ All pressure testing, flushing, and disinfection complete
_____ Access panels for valves and cleanouts
_____ Cross-connection control type, application, installation, approval, product listing, and drainage
_____ Sprinkler heads and standpipe hose connections
_____ Medical gas valves, outlets, and panels
_____ Owner equipment manuals
_____ Record drawings
_____ Training and commissioning

CONCLUSION

Managing projects efficiently can be facilitated by using practices that ensure predictable control from initial discovery to the preparation of budgets, reports, and construction documents and through contract administration. These practices can include internal standards, guidelines, and checklists, which generally are refined throughout the history of an engineering office.

CHAPTER 6

Plumbing for People with Disabilities

Plumbing engineers must be prepared to provide adequate facilities for people with disabilities, whether or not the requirements for these facilities are covered specifically in the local jurisdiction's applicable code. Most U.S. plumbing codes today include some type of provision for people with disabilities. Also, the Americans with Disabilities Act (ADA) includes plumbing provisions. The plumbing engineer must determine which codes are applicable to the project he or she is designing and incorporate any provisions these codes require, in addition to any ADA requirements.

This chapter presents background information on past and current legislation affecting plumbing for people with disabilities and design requirements for compliance with ICC A117.1–2017: *Standard for Accessible and Usable Buildings and Facilities,* which was first published by the American National Standards Institute (ANSI) in 1961, and the ADA Accessibility Guidelines (ADAAG).

This chapter is based on U.S. codes only. Plumbing designers who have projects located outside the United States should use this chapter as a starting point and then check with the local authority having jurisdiction (AHJ) to ensure compliance.

LEGISLATION

In 1969, Public Law 90-480, known as the Architectural Barriers Act of 1968, was signed by President Lyndon B. Johnson. The main thrust of this legislation was that any building constructed, in whole or in part, with federal funds must be made accessible to, and usable by, the physically challenged. Public Law 93-112, the Rehabilitation Act, passed in 1973, gave states and the federal government broad authority to establish services for the disabled.

At the same time, state and municipal governments began issuing their own ordinances regarding architectural barriers. Currently, almost every state has adopted some legislation covering this subject; however, major differences can be found from one ordinance to another. While the original legislation applied to government-owned or government-financed structures, now the requirements generally apply to all public accommodations.

Americans with Disabilities Act

ADA was enacted by Congress and signed by President George Bush on July 26, 1990. ADA prohibits discrimination based on physical or mental disabilities in private places of employment and public accommodations, in addition to requiring transportation systems and communication systems to facilitate access by the disabled. ADA is modeled, to a considerable extent, on the Rehabilitation Act of 1973, which applies to federal grantees and contractors.

ADA is essentially civil rights legislation, but its implementation has had a major impact on the construction industry. To clarify construction requirements, the attorney general's office commissioned the U.S. Access Board to prepare architectural guidelines to ensure that the construction industry understood what was required to comply with the act. The Board used much of the completed how-to data that was available from A117.1 and where-to data from the ongoing scoping work being done by the Board for the Coordination of Model Codes (BCMC), its governmental experiences, and public comments to produce the guidelines commonly referred to as ADAAG.

After incorporating public comments, the act became effective on January 26, 1992 and applied to all construction with application for permit after that date. This final rule preempted state and local laws affecting entities subject to ADA, to the extent that those laws directly conflicted with the statutory requirements of the act. For state and local accessibility codes or ordinances to be certified, the attorney general's office required that they meet or exceed the requirements of ADA. It was hoped that, with such a certified code enforced by local inspectors, compliance with ADA would not be decided in the courts.

Design professionals must continue to review ADA in its entirety, and forthcoming revisions, as well as state and local codes for application to their projects. The Department of Justice (DOJ) revised the Americans with Disabilities Act of 1990 in September 2010, with accessibility standards called the 2010 ADA Standards for Accessible Design. Compliance with these revised standards for all construction projects with application for permit was required after March 15, 2012. Approval of ADA-type plumbing fixtures is the responsibility of the fixture manufacturer. The design professional and/or the specifying professional must also verify and approve that the submitted ADA plumbing fixtures meet the intent of the requirements of the latest ADA standard.

There are still a number of concerns regarding whether the established standards properly address the specific needs of children and the elderly. Children cannot necessarily reach fixtures set at established heights for people with disabilities. Also, the elderly may have trouble accessing fixtures set low to meet the established height requirements for people with disabilities.

DESIGN REQUIREMENTS

Although plumbing is only a small portion of the overall effort to create a totally barrier-free environment, it is one of the most important areas to be dealt with by engineers and design professionals. Listed below are the various classifications of disabilities:

- Non-ambulatory disabilities: Those that confine individuals to wheelchairs
- Semi-ambulatory disabilities: Those that necessitate individuals to require the aid of braces, crutches, walkers, or some other type of device to walk
- Sight disabilities: Total blindness and other types of impairment affecting an individual's sight
- Hearing disabilities: Total deafness and other types of impairment affecting an individual's hearing
- Coordination disabilities: Those caused by palsy due to cerebral, spinal, or peripheral nerve injury
- Aging disabilities: Those brought on by the natural process of aging, reducing mobility, flexibility, coordination, and perceptiveness in individuals

(Note: To some extent, various national standards—such as the U.S. Department of Housing and Urban Development (HUD) Minimum Property Standards—differentiate the elderly from people with disabilities.)

The disabilities classifications that affect the plumbing engineer the most, in terms of design, are the non-ambulatory and the semi-ambulatory groups. Adequate plumbing facilities must be provided for these individuals. The architect is responsible for analyzing the needs of a person confined to a wheelchair and those forced to use walking aids such as crutches and braces. However, the plumbing designer should become familiar with the characteristics of the wheelchair and various associated types of equipment. The specifications in these guidelines are based on adult dimensions and anthropometrics. An illustration of a typical wheelchair design is shown in Figure 6-1.

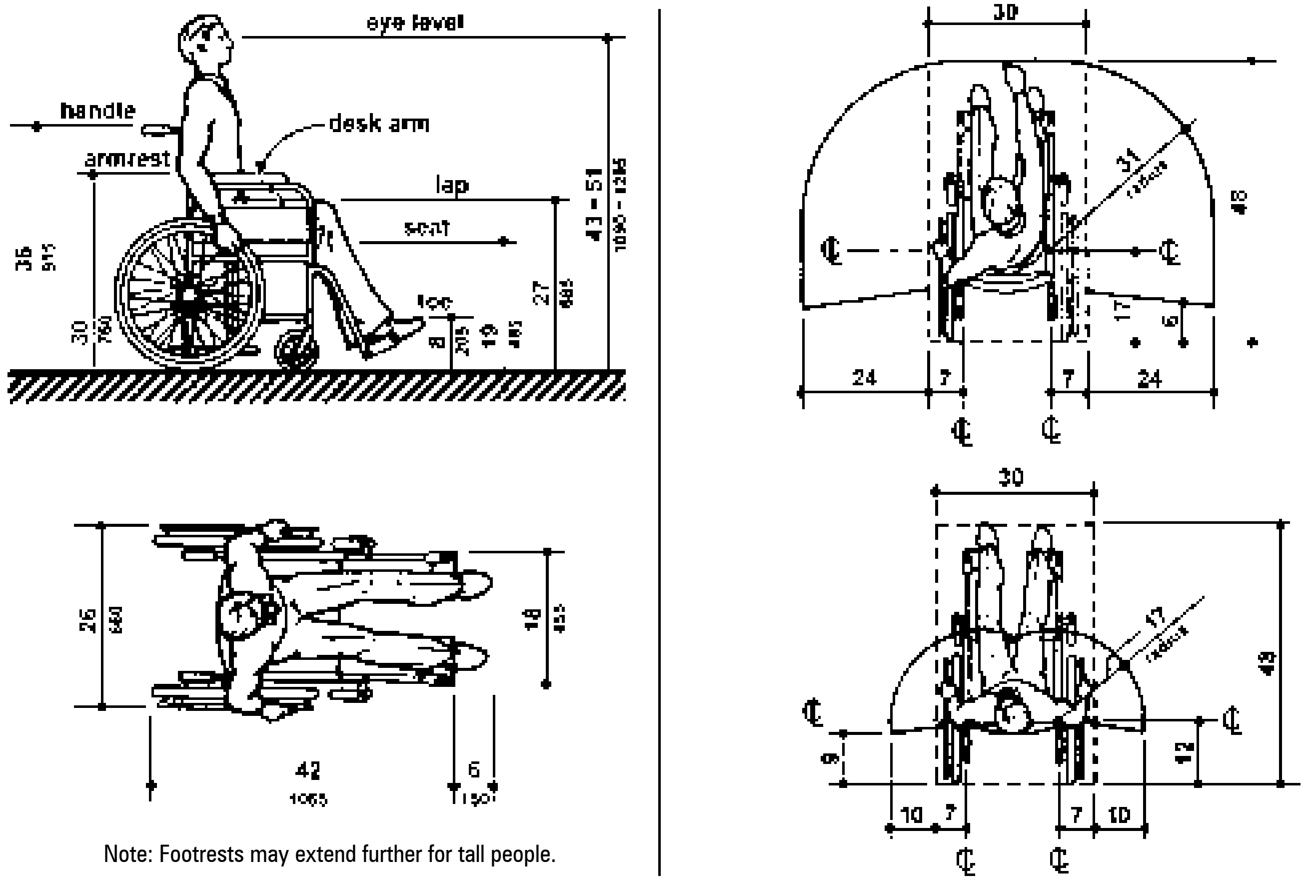
In addition to the dimensions of the wheelchair, the plumbing engineer must take into consideration how wheelchairs are employed and how the person in a wheelchair utilizes plumbing fixtures.

Clear Floor or Ground Space for Wheelchairs

The minimum clear floor or ground space required to accommodate a single, stationary wheelchair and occupant is 48 inches long by 30 inches wide (1,220 x 760 mm) for existing buildings and 52 inches long by 30 inches wide

Figure 6-1 Dimensions of Adult-Sized Wheelchairs

Note: U.S. customary units are above or to the left of the line, and SI units are below or to the right of the line.



Note: Footrests may extend further for tall people.

Graphic Conventions for Figure 6-1	
Convention	**Description**
	Typical dimension line showing U.S. customary units (inches) above the line and SI units (mm) below
8/230	Dimensions for short distances indicated on extended line
9/230 36/915	Dimension line showing alternate dimensions required
	Direction of approach
max	Maximum
min	Minimum
– – – – – – – – – – –	Boundary of clear floor area
———— – ———— – ℄	Centerline
Note: Dimensions that are not marked "minumum" or "maximum" are absolute, unless indicated otherwise in text or captions.	

(1,320 x 760 mm) minimum in new buildings (see Figure 6-2). The minimum clear floor or ground space for wheelchairs may be positioned for forward or parallel approach to an object (see Figure 6-3). Clear floor or ground space for wheelchairs may be part of the knee space required under some objects. One full, unobstructed side of the clear floor or ground space for a wheelchair shall adjoin another wheelchair clear floor space. If a clear floor space is located in an alcove or otherwise confined on all or part of three sides, additional maneuvering clearances shall be provided as shown in Figure 6-4.

Figure 6-2 Minimum Clear Floor Space for Wheelchairs

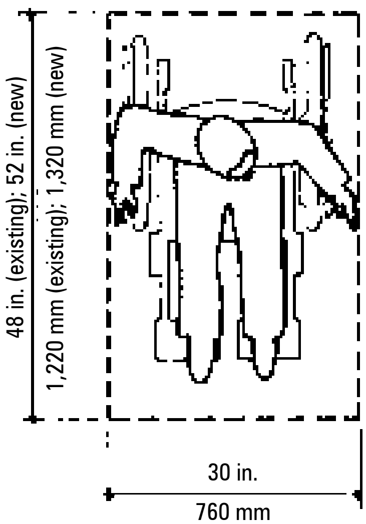


Figure 6-3 Wheelchair Approaches

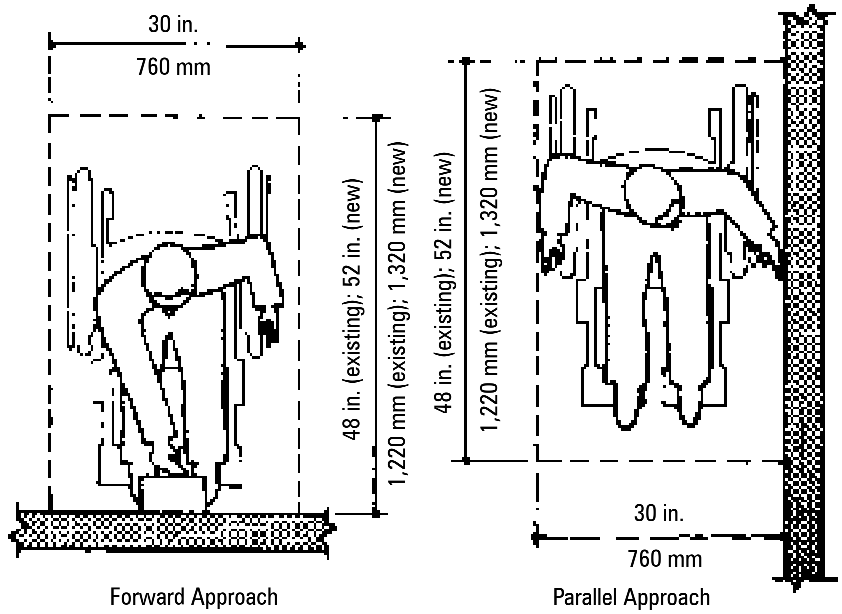
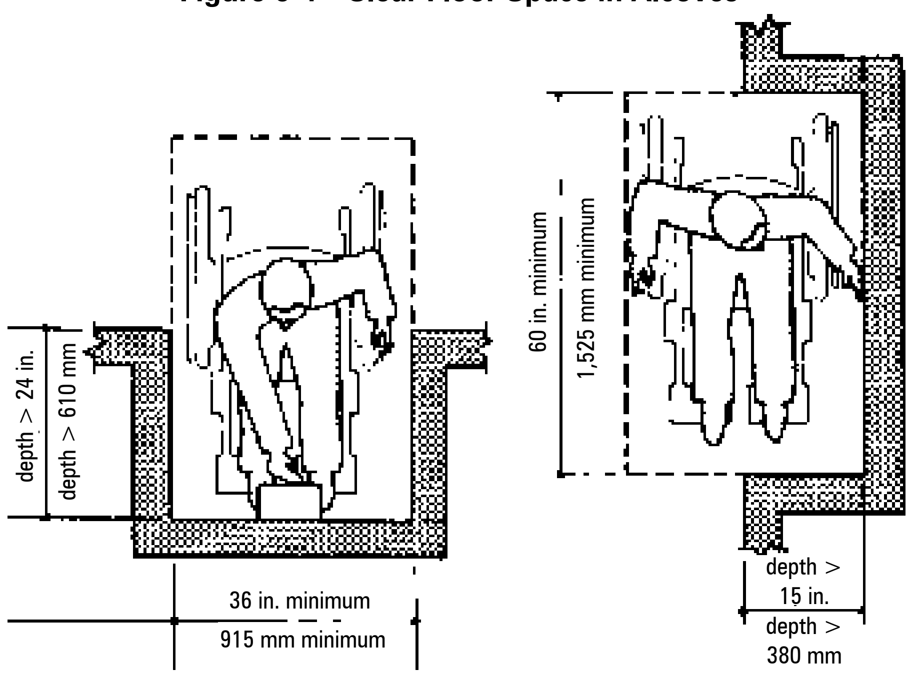


Figure 6-4 Clear Floor Space in Alcoves



Forward Reach

If the clear floor space only allows forward approach to an object, the maximum high forward reach allowed shall be 48 inches (1,220 mm) (see Figure 6-5). The minimum low forward reach is 15 inches (380 mm). If the high forward reach is over an obstruction, the reach shall be as shown in Figure 6-6.

Side Reach

If the clear floor space allows parallel approach to an object by a person in a wheelchair and the edge of the clear floor space is no more than 10 inches (255 mm) from the object, the maximum high side reach allowed shall be 48 inches (1,220 mm), and the low side reach shall be 15 inches (380 mm) minimum (see Figure 6-7). If the side reach is over an obstruction that is 10 inches (255 mm) deep or less, the high side reach allowed is 48 inches (1,220 mm) maximum. If the obstruction is more than 10 inches deep, the side reach shall be as shown in Figure 6-8. The height of the obstruction shall not be more than 34 inches (865 mm).

Drinking Fountains and Water Coolers for Wheelchair Access

Clear floor or ground space shall be centered on the drinking fountain and the dimensions shall comply with Figures 6-2, 6-3, and 6-4. Knee and toe space complying with A117.1 Section 306 also shall be provided.

The spout shall be located 36 inches (915 mm) maximum above the floor or 30 inches (760 mm) maximum for units for use by children. For drinking fountains for adult use, the spout shall be located at least 15 inches (380 mm)

Figure 6-5 Unobstructed Forward Reach

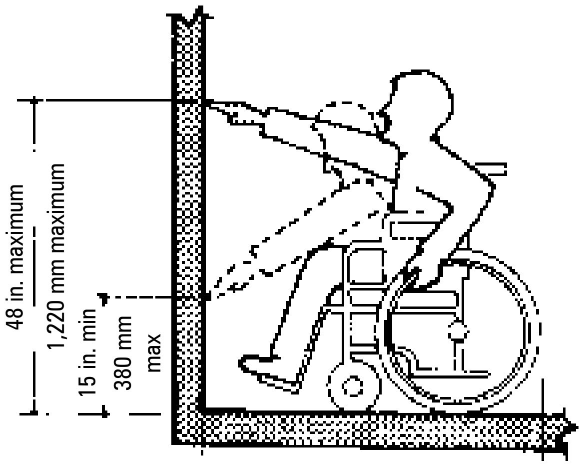
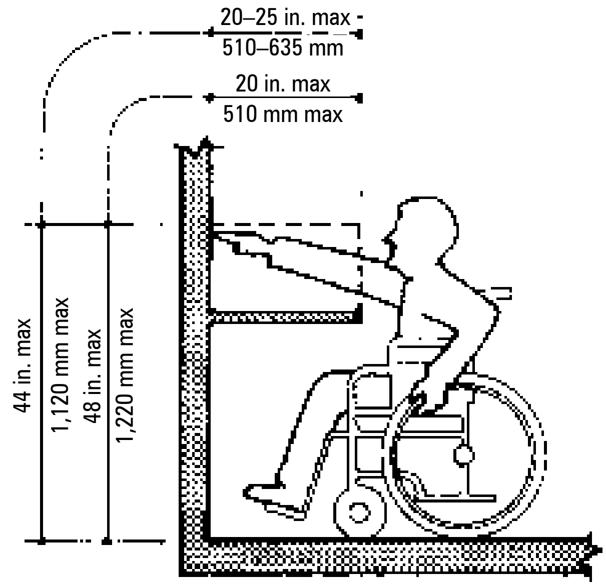


Figure 6-6 High Forward Reach Over an Obstruction



from the vertical support and no more than 5 inches (125 mm) from the front edge of the unit, including bumpers. If the drinking fountain is for children's use, the spout shall be 3.5 inches (90 mm) maximum from the front edge of the unit, including bumpers. The water flow from the spout shall be 4 inches (100 mm) high minimum to allow the insertion of a cup or glass under the flow of water. For spouts less than 3 inches (75 mm) from the front of the unit, the angle of the water stream shall be 30 degrees maximum. For spouts between 3 and 5 inches (75 mm and 125 mm) from the front of the unit, the angle of the water stream shall be 15 degrees maximum (see Figure 6-9).

Note: The easiest way for someone confined to a wheelchair to use a drinking fountain is to approach it from the side and lean to the side to reach the spout. Therefore, the plumbing engineer should specify a fountain or cooler with a spout located as close to the front edge and as low as possible. Self-contained units are available that can be mounted so spout heights of 33 to 34 inches (839 to 864 mm) can be obtained without interfering with the required leg clearances.

Parallel approach units are more difficult to use than the cantilevered type and should be avoided if possible. If used, the spout should be mounted as close to 30 inches (762 mm) in front of the unit as the fountain will permit.

It is desirable to provide some water coolers or fountains with spout heights of approximately 42 inches (1,067 mm) to serve semi-ambulatory users who can have difficulty bending to lower elevations.

Drinking fountains must be provided not only for wheelchair-bound individuals but also for back-disabled individuals. Where only one fountain is required by code, it must be an accessible bi-level unit, or two separate accessible units mounted at different heights must be provided. Where more than one fountain is required by code, 50 percent of them must be installed for wheelchair-bound individuals.

Figure 6-7 Unobstructed Side Reach

Note: The low side reach is the minimum.

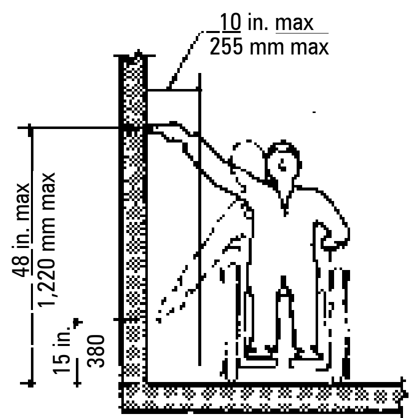
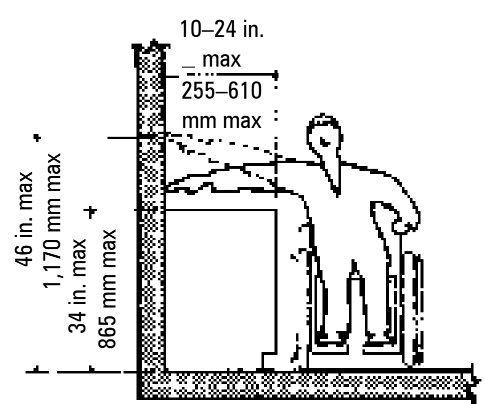


Figure 6-8 Obstructed High Side Reach

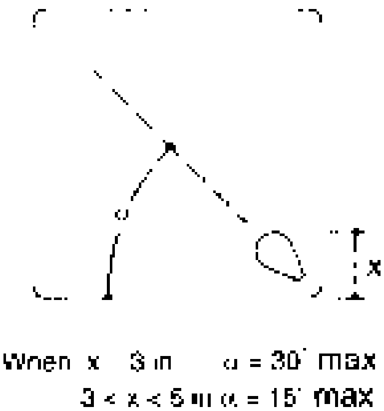


Toilet and Bathing Rooms

When a door opens into a bathroom, sufficient maneuvering space (60 inches [1,525 mm] diameter minimum) should be provided within the room for a person using a wheelchair to enter, close the door, use the fixtures, reopen the door, and exit without undue difficulty. The wheelchair maneuvering space overlaps the required clear floor space at fixtures and extends under the lavatory 19 inches (480 mm) maximum because knee space is provided. However, because toe or knee space is not available at the toilet, the wheelchair maneuvering space is clear of the toilet.

The bottom edge of a mirror above a lavatory or counter shall be mounted 40 inches (1,015 mm) maximum above the floor. The bottom edge of mirrors not located above lavatories or countertops shall be mounted 35 inches (890 mm) maximum above the floor. If mirrors are to be used by both ambulatory people and wheelchair users, then they should be 74 inches (1,880 mm) high minimum at their top-most edge. A single full-length mirror accommodates all people, including children.

Figure 6-9 Horizontal Angle of Water Stream for Drinking Fountains



Where provided, a fold-down shelf shall be located between 40 inches minimum and 48 inches maximum (1,015 and 1,220 mm) above the floor.

The design and location of floor drains should not impede the use of plumbing fixtures.

Water Closets

Water closets shall be positioned with a wall or partition to the rear and to one side. In an ambulatory-accessible toilet compartment, the centerline of the water closet shall be located 17 inches (430 mm) to 19 inches (485 mm) from the side wall or partition. The centerline of other water closets shall be 16 inches (405 mm) to 18 inches (455 mm) from the side wall or partition. Water closets should be arranged for a left-hand or right-hand approach.

Clearance around water closets shall be 60 inches (1,524 mm) minimum from the side wall and 56 inches (1,420 mm) minimum from the rear wall. The clearance shall overlap only the fixture, grab bars, paper dispenser, sanitary napkin receptacle, shelf, coat hook, accessible routes, clear floor space, and wheelchair turning space.

Water closet seats shall be between 17 inches (430 mm) and 19 inches (485 mm) above the floor. Seats shall not return automatically to a lifted position.

Toilet Compartments

Grab bars shall be provided in public toilet rooms on the rear wall and on the side wall closest to the water closet. The side wall grab bar shall be 42 inches (1,065 mm) long minimum, installed 12 inches (305 mm) maximum from the rear wall, and extending 54 inches (1,370 mm) minimum from the rear wall. The rear wall grab bar shall be 36 inches (915 mm) long minimum and extend 42 inches (1,065 mm) minimum from the side, but be no more than 6 inches (150 mm) maximum from the side wall. If the wall space does not permit a length of 36 inches (915 mm), the rear grab bar shall be 24 inches (610 mm) long minimum, centered on the water closet. If the AHJ requires flush controls for flush valves to be located in a position that conflicts with the location of the rear grab bar, it may be split or shifted to the open side of the toilet area.

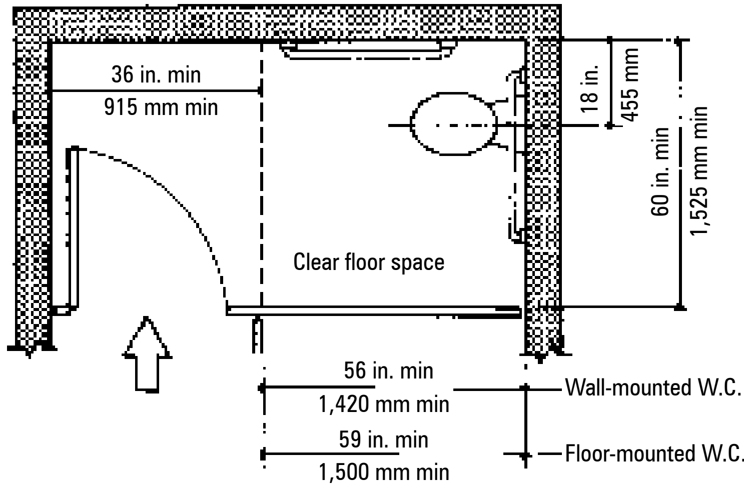
Flush controls shall be hand operated or automatic and located on the open side of the toilet—except in ambulatory-accessible compartments, the controls may be located on either side of the toilet.

If located above the grab bar, the outlet of a toilet paper dispenser shall be in an area between 24 and 36 inches (610 and 915 mm) from the rear wall, and if located below the grab bar, the outlet shall be no more than 48 inches (1,220 mm) above the floor.

Coat hooks in toilet compartments shall be 48 inches (1,220 mm) maximum above the floor, and shelves shall be between 40 inches (1,015 mm) and 48 inches (1,220 mm) above the floor.

Wheelchair-accessible compartments shall be 60 inches (1,525 mm) wide minimum and 56 inches (1,420 mm) deep minimum for wall-hung water closets and 59 inches (1,500 mm) deep minimum for floor-mounted water closets, mea-

Figure 6-10 Wheelchair Accessible Toilet Stall — Door Swing In



sured perpendicular to the rear wall. The 60-inch (1,524-mm) wide wheelchair-accessible compartment is preferred and should be designed. In the design of alterations to existing structures, it may not be possible to create the preferred compartment by combining two existing compartments, or physical conditions may not permit the full 60-inch (1,525-mm) width. In these cases, the authority having jurisdiction may permit a narrower compartment. In no case should a width of less than 48 inches (1,220 mm) be used.

Compartments shall be designed for either left-hand or right-hand approach. Doors for wheelchair-accessible compartments shall be self-closing and shall be located in the front partition or in the side wall or partition farthest from the water closet (see Figure 6-10 for dimensions). In wheelchair-accessible compartments, the front partition and at least one side partition shall provide a toe clearance of 12 inches (305 mm) minimum above the floor and extend 8 inches (205 mm) deep beyond the side of the partition (or 9 inches [230 mm] and 6 inches [150 mm] respectively according to ADAAG). Front partition toe clearance is not required if the compartment has a wall-hung water closet and is more than 64 inches (1,625 mm) deep (ADAAG: 62 inches [1,575 mm] deep) or has a floor-mounted water closet and is more than 67 inches (1,700 mm) deep (ADAAG: 65 inches [1,650 mm] deep). Side partition toe clearance is not required if the compartment is more than 68 inches (1,725 mm) wide (66 inches [1,675 mm] for ADAAG).

Ambulatory-accessible compartments shall be 60 inches (1,525 mm) deep and 35 to 37 inches (890 to 940 mm) wide. This narrower width presumes the use of grab bars on either or both sides of the compartment. The door shall be self-closing.

According to ADAAG, where six or more compartments are provided in a toilet room, one must be a 60-inch (1,524-mm) wheelchair-accessible compartment, and one must be a 36-inch (915-mm) ambulatory compartment. The flush valve handles should not exceed 44 inches (1,118 mm) above the floor. The handles in standard accessible stalls must be at the wide side of the stall, which means, depending on how the stall is configured, that the handle must be on either the right or left side of the flush valve.

Water Closets and Toilet Compartments for Children's Use

For water closets and toilet compartments primarily for children's use, all of the requirements above shall apply except for the following changes. The centerline of the water closet shall be between 12 inches (305 mm) and 18 inches (455 mm) from the side wall or partition. The top of the seat shall be between 11 inches (280 mm) and 17 inches (430 mm) above the floor. Flush controls shall be installed 36 inches (915 mm) maximum above the floor. Toilet paper dispensers shall be located between 24 and 42 inches (610 and 1,065 mm) from the rear wall. The dispenser outlet shall be between 14 inches (355 mm) and 19 inches (485 mm) above the floor. Dispensers shall not control delivery or prohibit continuous paper flow.

Urinals

Stall-type and wall-hung urinals shall be installed with the rim 17 inches (430 mm) maximum above the floor and shall be 13.5 inches (345 mm) deep minimum from the outer face of the rim to the wall.

A clear floor space of 30 by 48 inches (760 mm by 1,220 mm) shall be provided in front of a urinal to allow forward approach. Flush controls shall be hand operated or automatic and should not be mounted more than 44 inches (1,120 mm) above the floor.

Lavatories and Sinks

A clear floor space of 30 by 48 inches (760 by 1,220 mm) positioned for forward approach shall be provided for accessible lavatories and sinks. A parallel approach is permitted to kitchen sinks and wet bar sinks without a cooktop or range.

For sinks used primarily by children ages six through 12, a knee clearance of 24 inches (610 mm) minimum above the floor shall be permitted if the rim or counter surface is 31 inches (785 mm) maximum above the floor. A parallel approach may be used for lavatories and sinks used by children five years old and younger.

Lavatories and sinks shall be no more than 34 inches (865 mm) above the floor, measured to the fixture rim or counter surface, whichever is higher.

If hand-operated metering faucets are installed, they shall remain open for at least 10 seconds. Built-in lavatories in countertops should be placed as close as possible to the front edge of the countertop to minimize the reach to the faucet. Single-lever faucets are preferred, but where aesthetics or fear of vandalism precludes their use, conventional quarter-turn handles are a good choice. Avoid faucets that require finger dexterity for grasping or twisting.

Both hot and cold water supply tubes, as well as drain pipes that are in the vicinity of the designated clear floor space under the fixture, must be concealed or insulated to protect wheelchair users who have no functioning sensory nerves. Insulation is not required on pipes beyond possible contact.

Bathtubs

Clearance shall be provided in front of accessible bathtubs extending the length of the bathtub and 30 inches (760 mm) minimum deep. A permanent or removable in-tub seat shall be provided at the head end of the bathtub, and grab bars shall be provided. If a permanent seat is installed, the clearance shall extend at least 12 inches (380 mm) beyond the wall at the head end. Controls shall be between the bathtub rim and the grab bar and between the open side of the bathtub and the midpoint of its width. No obstructions should prohibit entry into the bathtub or transfer onto the seat. See Figure 6-11 for bathtub installation dimensions.

A handheld showerhead controlled by an on/off diverter and a non-positive shutoff with a 59-inch (1,500-mm) long hose shall be provided.

Bathtubs (including the showerhead) shall not deliver water greater than 120°F (49°C). Due to the probable lack of maneuverability of the user, it is recommended that the plumbing engineer specify a temperature- and/or pressure-balancing, water-blending valve with temperature limit stops.

Showers

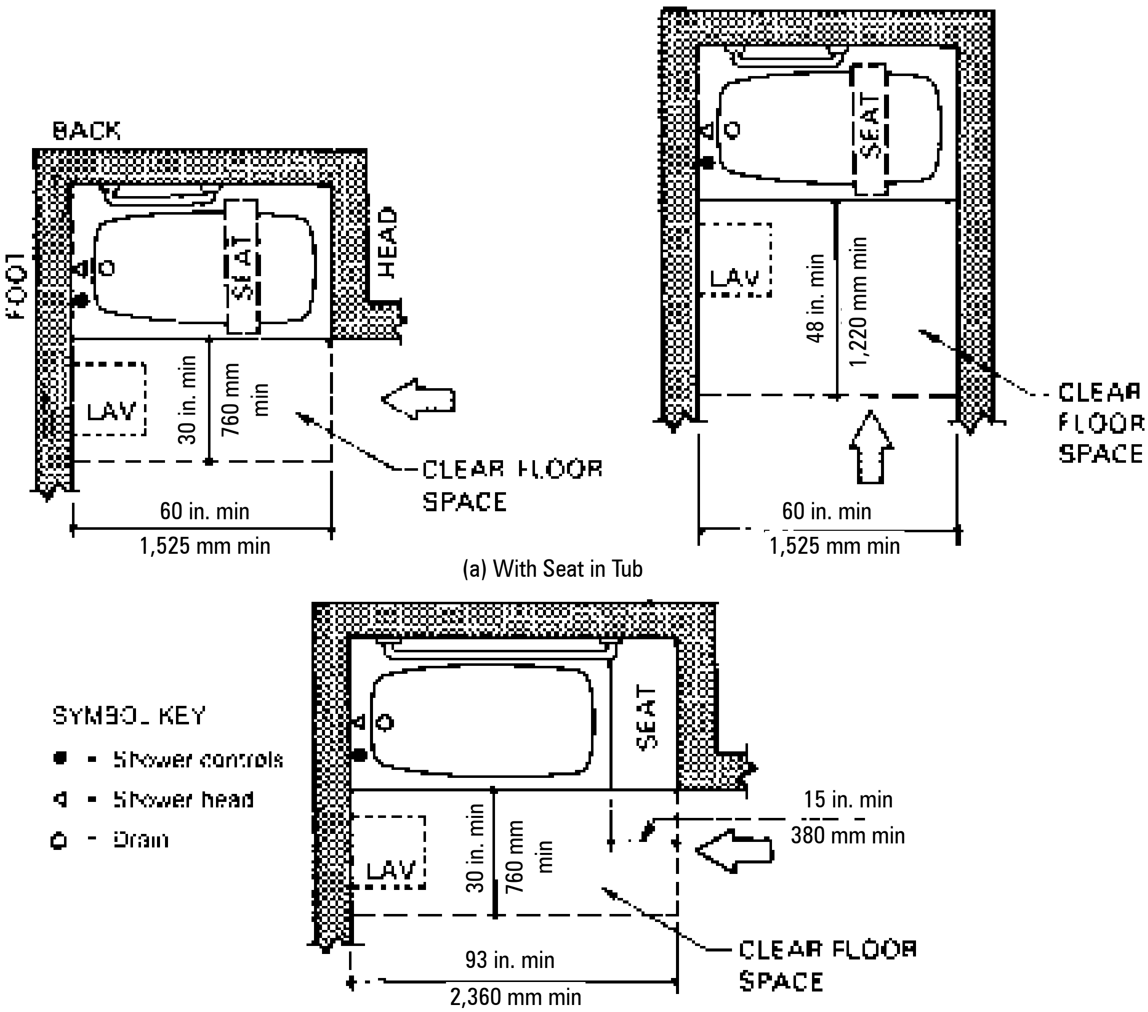
A handheld showerhead controlled by an on/off diverter and a non-positive shutoff with a 59-inch (1,500-mm) long hose shall be provided in all accessible showers. Showers shall not deliver water greater than 120°F (49°C).

Transfer-Type Shower

Transfer-type shower compartments provide additional safety to people who have difficulty maintaining balance because all grab bars and walls are within easy reach. Seated people use the walls of these showers for back support. This type of shower has been designated a transfer-type compartment to indicate that wheelchair users can transfer from their chair to the required seat. These dimensions will allow a person of average size to reach and operate the controls without difficulty, while providing reasonable knee space for larger users. A transfer-type shower is also intended to serve persons without disabilities, so a folding seat would provide more space for a standing person.

Transfer-type shower compartments shall be 36 by 36 inches (915 by 915 mm) and have a minimum 36-inch (915-mm) wide entry. The clearance in front of the compartment shall be at least 48 inches (1,220 mm) long and 36 inches (915 mm) deep for existing buildings and 52 inches (1,320 mm) long and 36 inches (915 mm) deep for new buildings. The threshold shall be 0.5 inch (13 mm) high maximum and shall be beveled, rounded, or vertical. A threshold 2 inches (51 mm) high maximum shall be permitted in transfer-type shower compartments in existing facilities where the 0.5-inch (13-mm) provision would disturb the structural reinforcement of the floor slab. Grab bars shall be provided.

Figure 6-11 Clear Floor Space at Bathtubs



(a) With Seat in Tub

(b) With Seat at Head of Tub

The controls and hand shower unit shall be installed on the control wall opposite the seat at a height between 38 and 48 inches (965 and 1,220 mm) above the compartment floor and shall be located no more than 15 inches (380 mm) from the centerline of the control wall toward the shower entry.

Standard Roll-In Shower

Roll-in shower compartments shall be 60 inches (1,524 mm) wide by 30 inches (760 mm) deep minimum and have a minimum 60-inch (1,524-mm) wide entry. The clearance in front of the entry shall be 60 inches (1,524 mm) wide by 30 inches (760 mm) deep minimum. The threshold shall be 0.5 inch (13 mm) high maximum.

Where a seat is provided, grab bars shall be provided on the back and side wall opposite the seat. Where a seat is not provided, grab bars shall be provided on all three shower enclosure walls. Grab bars shall not be provided above the seat. Grab bars shall extend 6 inches (150 mm) maximum from the adjacent wall.

The controls and hand shower unit shall be located above the grab bar on the back wall between 38 and 48 inches (965 and 1,220 mm) above the compartment floor and shall be located 16 to 27 inches (405 to 685 mm) from the end wall behind the seat.

Alternate Roll-In Shower

Alternate roll-in shower compartments shall be 60 inches (1,524 mm) wide and 36 inches (915 mm) deep minimum. A minimum 36-inch (915-mm) wide entry shall be provided at one end of the long side of the compartment. The threshold shall be 0.5 inch (13 mm) high maximum.

A folding seat shall be provided on a seat wall that is 24 to 26 inches (610 to 915 mm) long and opposite the back wall. Grab bars shall be installed on the back wall and the side wall farthest from the entry at 6 inches (150 mm) maximum from adjacent walls and shall not be installed above the seat.

The controls and hand shower unit shall be located between 38 and 48 inches (965 and 1,220 mm) above the compartment floor. If a seat is provided, the controls and hand shower unit may be located on the adjacent wall, 16 to 27 inches (405 to 685 mm) maximum from the seat wall, or they may be located on the back wall 15 inches (380 mm) maximum, left or right, of the centerline of the seat.

Grab Bars

Many people with disabilities rely heavily on grab bars to maintain balance and prevent serious falls. Many people brace their forearms between supports and walls to give them more leverage and stability in maintaining balance or for lifting. Circular grab bars in toilet and bathing facilities shall be between 1.25 and 2 inches (32 and 51 mm). Grab bars with other shapes shall be permitted, provided they have a perimeter dimension between 4 and 4.8 inches (100 and 120 mm) and have a cross-section dimension of 2 inches (51 mm).

The grab bar shall be 1.5 inches (38 mm) from the wall. This clearance helps prevent injuries from arms slipping through the opening while providing a space for gripping. The space between the grab bar and objects below and at the ends shall be at least 1.5 inches (38 mm), and the space between the grab bar and projecting objects above shall be at least 12 inches (305 mm). However, the space between grab bars and shower controls, shower fittings, and other grab bars above can be 1.5 inches (38 mm) minimum.

Grab bars shall be mounted horizontally between 33 and 36 inches (840 and 915 mm) above the floor. For water closets primarily for children's use, grab bars shall be installed horizontally between 18 and 27 inches (455 and 685 mm) above the floor or vertically with the bottom of the bar located between 21 and 30 inches (535 and 760 mm) above the floor. Grab bars that are wall mounted do not affect the measurement of the required clear floor space where the space below the grab bar is clear and does not present a knee space encroachment.

Grab bars shall have rounded edges and be free of sharp or abrasive elements, and they shall not rotate within their fittings. Allowable bending, shear, and tension stresses shall not be exceeded for materials used where a vertical or horizontal force of 250 pounds (113.5 kg) is applied at any point on the grab bar, fastener-mounting device, or supporting structure.

Seats

Bathtub Seats

The top of a bathtub seat shall be between 17 and 19 inches (430 and 485 mm) above the bathroom floor. Removable in-tub seats shall be between 15 and 16 inches (380 and 405 mm) deep, and permanent seats shall be at least 15 inches (380 mm) deep.

Shower Seats

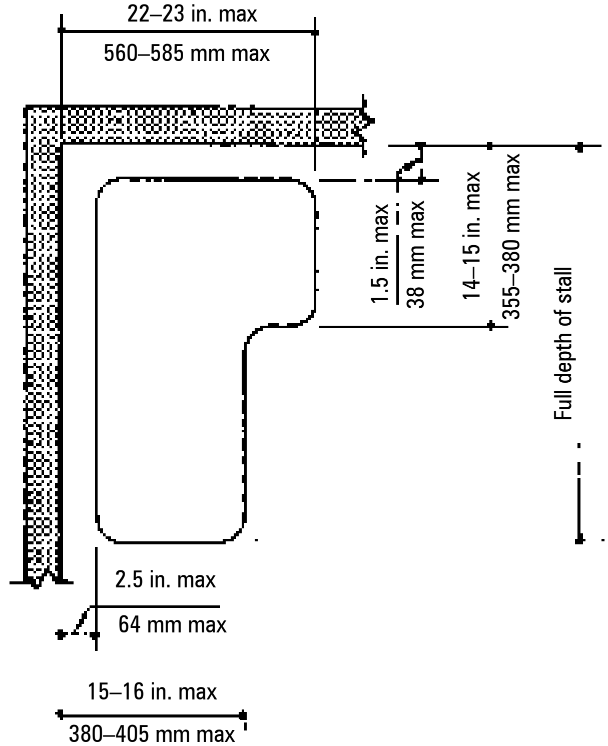
The top of a shower seat shall be between 17 and 19 inches (430 and 485 mm) above the bathroom floor. In a transfer-type shower, the seat shall extend from the back wall to a point within 3 inches (75 mm) of the compartment entry. In a roll-in type shower, the seat shall extend from the control wall to a point within 3 inches (75 mm) of the compartment entry. See Figure 6-12 for seat dimensions. The seat in a shower is required to be nearly the full depth of the compartment. It should be as close to the front edge of the seat wall as possible to minimize the distance between the seat and the wheelchair to facilitate transfer. The seat wall must be free of grab bars to allow a person to slide onto the seat, and a portion of the adjacent back wall must be without a grab bar so the person's back can be placed against the wall for support.

Allowable bending, shear, and tension stresses shall not be exceeded for materials used where a vertical or horizontal force of 250 pounds (113.5 kg) is applied at any point on the seat, fastener-mounting device, or supporting structure.

Washing Machines and Clothes Dryers

A clear floor space shall be positioned for parallel approach and be centered on the appliance for top-loading machines and be offset no more than 24 inches (610 mm) from the centerline of front-loading machines. The door to top-loading machines shall be no more than 36 inches (915 mm) above the floor. The bottom of the door to front-loading machines shall be between 15 and 36 inches (380 and 915 mm) above the floor.

Figure 6-12 L-Shaped Shower Seat Design



RESOURCES

- ICC A117.1 (2017): *Standard for Accessible and Usable Buildings and Facilities*
- Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities

ACKNOWLEDGEMENT

ASPE thanks the International Code Council for providing a copy of ICC A117.1 (2017) for use in updating this chapter.

CHAPTER 7

Energy and Resource Conservation in Plumbing Systems

It is imperative to understand that there is embedded energy and embedded water in everything. This is important to remember when considering any type of energy- and/or water-reduction methods. It takes both of these resources to deliver either of these commodities, but hopefully, when one is reduced, the other is reduced as well. However, sometimes an effort to decrease the consumption of either of these resources produces an increase on the other side. Designing systems to achieve a positive effect on both sides is not a question of "does this method work?" but more a question of "is this the appropriate application?"

Prior to the 1973–1974 OPEC oil embargo, energy was considered inexhaustible and expendable, but as energy costs increased, society turned its attention toward energy conservation. The Energy Policy and Conservation Act (EPCA) of 1975 was the first major piece of legislation that addressed federal energy management. Additional laws soon followed, including the Resource Conservation and Recovery Act of 1976, National Energy Conservation Policy Act of 1978, Federal Energy Management Improvement Act (FEMIA) of 1988, Energy Policy Act (EPAct) of 1992, and the Energy Policy Act (EPAct) of 2005, which expanded on the previous legislation.

Along with the federal government, other sectors of society made strides to reduce energy consumption. The automotive industry, which was heavily impacted by the oil embargo, was quick to adapt by producing smaller, lighter, more fuel-efficient cars. The construction market also made strides by adopting model energy codes, efficiency standards, and alternate fuel sources. A green movement has spread across the globe, pushing for the implementation of efficient and sustainable technologies.

Just as important as energy conservation is other resource conservation. Obviously, a resource greatly affected by plumbing system design is water. Water use in the United States has more than doubled in the past half-century, from approximately 180 billion gallons per day in 1950 to more than 400 billion gallons per day in 2005. Because of increases in population and demand, at least 36 states are projecting water shortages. Data shows that homes use more than half of the publicly supplied water in the United States, which is significantly more than is used by either business or industry. A family of four can use up to approximately 400 gallons of water every day. Those amounts used can increase depending on location; for example, the arid Western United States has some of the highest per capita residential water use because of landscape irrigation.

Water conservation is an easy, cheap, and safe way to reduce energy and water footprints. That being said, it is important to note that conservation alone is not enough to guarantee sufficient water supplies when the need is greatest, but it should be considered an important part of any strategic water plan.

Water is often referred to as "the oil of the 21st Century" by experts and authorities around the world. Although water covers approximately 70 percent of the Earth's surface, less than 1 percent of that water is actually readily available for human use, let alone human consumption. Globally, humans have tripled their water consumption in the last 50 years, according to the U.S. Environmental Protection Agency (EPA). The problem of trying to manage the supply and availability of water is one of the most critical natural resource issues facing the United States as well as the rest of the world. The populations of the world must find ways to share this precious resource and support the growing demands for agricultural, domestic, commercial, industrial, and environmental needs.

Another aspect of water conservation is using wastewater and rainwater and the different treatment technologies available to satisfy specific end-user needs. Australia, Belgium, Bermuda, Germany, India, and some other countries are requiring all new developments in certain areas to be equipped with rainwater harvesting systems to preserve declining groundwater supplies. These regulations were made in response to the imbalance of population demand and available water supplies. Some U.S. housing developments are even incorporating rainwater harvesting in their low-impact development designs as a means to reduce municipal water demand and deter stormwater runoff. Furthermore, some states and localities have restricted or prevented development in areas with insufficient drinking water supplies. For instance, in March 2007, the Arizona Senate approved a bill that would allow counties and cities in rural Arizona to restrict housing developments without "long-term" water supplies.

This chapter is intended to provide a plumbing engineer with design techniques that conserve both energy and water and to assist them in selecting energy- and water-efficient equipment and systems. Where the recommendations set forth in this chapter do not meet the minimum provisions of the local code, the code shall apply.

DESIGN TECHNIQUES FOR DOMESTIC HOT WATER SYSTEM ENERGY CONSERVATION

One of the highest energy-consuming plumbing systems is domestic hot water, often consuming 2 to 4 percent of the total energy used in an office building and 8 to 25 percent in residential properties. This plumbing system has a great need for energy-conservation measures. The gas utilities have been given quotas to reduce their therm usage by government standards, and monetary penalties are forcing the gas utilities to offer rebates and other incentives to customers that install high-efficiency water heating equipment.

Each American uses an average of 125 gallons of water per day at home, and it is important to note that by reducing hot water use, both energy and water are conserved. For example, if one in every 10 homes in the United States were to install low-flow faucets or faucet accessories in their bathrooms, 6 billion gallons of water and more than $50 million in energy costs to supply, heat, and treat that water could be saved.

Hot water use can vary from handwashing, showering, and janitorial needs to cooking, dishwashing, and laundering needs. Design techniques that can be employed to conserve energy when heating water follow. However, it is important to review the building type and how energy reductions can be implemented. In certain types of buildings (e.g., hospitals), sometimes the measures that can be taken are limited.

Eliminate Leaks

One of the first and easiest actions to take to conserve energy and water resources is by repairing leaking fixtures, appliances, and hot water piping. A leaky faucet dripping 120 times a minute will waste close to 700 gallons of water a year. (Assuming that there are 90,840 drops of water in 1 gallon, two drops per second is equivalent to 692 gallons per year.) That doesn't sound like so much, but what if there were 10 million leaky faucets in the U.S.? That would be 7 billion gallons lost per year.

One major city recently estimated that up to 65 million gallons of water per day was lost from leaky mains. After being sued by surrounding states for taking more than their share of the water source, the city started an extensive program of water main replacement.

Reduce Domestic Hot Water Temperature

Many domestic water heating systems are designed to deliver 140°F (60°C) water based on the anticipated needs of kitchen and janitorial uses, though water for human contact typically is delivered between 105°F (41°C) and 110°F (43°C). Many energy codes and standards for new buildings require the domestic hot water system to be set at 110°F to 120°F (49°C). (It is important to note that setting a water heater below 127°F (53°C) may allow Legionella bacteria to grow inside the domestic hot water tank.) Often, 105°F water is produced by blending 140°F hot water with cold water. This reduces the amount of hot water required, but it may not decrease the energy used to heat the water.

Distributing 140°F water definitely increases energy use due to higher heat loss values, but within certain parameters, mixing theoretically is using the same British thermal units per hour (Btuh) because the result is the same quantity of water delivered at the same temperature. (This presumes the presence of thermostatic mixing valves and other temperature controls at the outlets.)

The temperature, after mixing two or more volumes (or flows) of water, is calculated using the following equation:

Equation 7-1

$$t_m = \frac{Q_1 \times t_1 + Q_2 \times t_2}{Q_1 + Q_2}$$

where

t_m = Temperature of mixture
t_1 = Temperature of flow Q_1
t_2 = Temperature of flow Q_2
Q_1 = Cold water, gallons per minute (gpm) (l/s)
Q_2 = Hot water, gpm (l/s)

Example 7-1

What is the temperature of 45 gpm (2.84 l/s) of 155°F (68.5°C) water mixed with 55 gpm (3.47 l/s) of 75°F (23.9°C) water?

$$\frac{45 \times 155 + 55 \times 75}{45 + 55} = 111°F \qquad \left[\frac{2.84 \times 68.5 + 3.47 \times 23.9}{2.84 + 3.47} = 44°C \right]$$

The ratio (percentage) of hot water required to be mixed with cold water to provide a mixed water requirement is determined using the following equation:

Equation 7-2

$$\text{Ratio HW} = \frac{t_m - t_1}{t_2 - t_1}$$

Example 7-2

How much hot water is required to provide 80 gallons per hour (gph) (0.084 l/s) of 110°F (43°C) mixed water with 155°F (68.5°C) hot water and 75°F (23.9°C) cold water?

$$\frac{110 - 75}{155 - 75} = 0.44 \text{ or } 44\% \text{ hot water}$$

80 gph x 0.44 = 35 gph of 155°F hot water

[0.084 l/s x 0.44 = 0.037 l/s of 68.5°C hot water]

How much hot water is required to provide 80 gph (0.084 l/s) of 110°F (43°C) mixed water with 125°F (51.5°C) hot water and 75°F (23.9°C) cold water?

$$\frac{110 - 75}{125 - 75} = 0.70 \text{ or } 70\% \text{ hot water}$$

80 gph × 0.70 = 56 gph of 125°F hot water

[0.084 l/s × 0.70 = 0.059 l/s of 51.5°C hot water]

Reduce Fixture Flow Rates

The EPAct of 1992 set maximum water usage rates for specific fixtures, such as 1.6 gallons per flush (gpf) for water closets. Many water closet manufacturers now offer dual-flush fixtures that allow for two separate flushes—one rate for flushing solids and a lower rate for flushing liquids—further contributing to water savings. Reduced flow rates result in less water needing to be pumped and heated as well as smaller pipe sizes (therefore, less heat loss from piping), which saves energy as well.

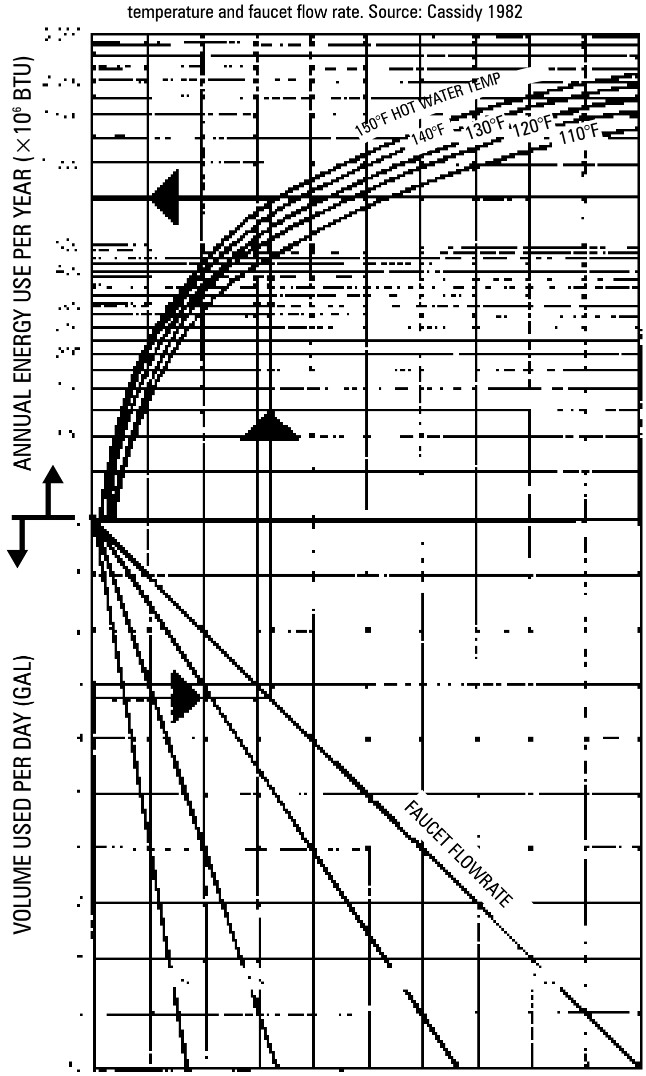
Fixture flow rates vary depending on the supply fitting design and water pressure. Manufacturers' test results have shown that flows for lavatories and showers can be quite high, making them prime candidates for fixture flow reduction, such as by providing automatic flow-control fittings. On lavatories, the type of faucet and spout usually dictates the location of these fittings. In showers, the type of head and arm determines the fitting location. After being fitted with a flow-control device, reduced flow rates of 1 gpm or less in lavatories and 2.5 gpm or less in showers can be accomplished.

The installation of flow-control devices has saved millions of gallons of water per year throughout the country. For example, a faucet using 3.25 gallons of 150°F hot water per day with a 100 percent faucet flow rate equates to an annual energy use of 774,000 Btu per year (3.25 gal × 8.33 lb/gal × 110°FΔT × 260 days). A 50 percent flow rate reduces the water use by 1.63 gallons per day (gpd) and energy use by 387,000 Btu per year. This reduction in water demand translates into water the local utility company does not have to pump, the purification plant does not have to handle and process, and the waste treatment plant does not have to treat.

Figure 7-1 provides a way to translate fixture flow rate to annual consumption and is useful in determining the most energy-efficient design flow rate. By varying the percent of hot water at the fixture, annual energy consumption can be predicted. Figure 7-1 can also be used as a design tool to predict anticipated utility costs and payback for fixture replacement.

Figure 7-1 Energy Savings from Reduced Faucet Flow Rates

Chart allows user to estimate domestic hot water heating use in terms of water temperature and faucet flow rate. Source: Cassidy 1982



Apply Economical Thermal Insulation

Economical thermal insulation is the amount of insulation that annually produces the lowest sum of energy lost versus the annual cost of insulation. In addition to conserving energy by retarding heat loss, insulation provides additional benefits such as protection against burns, noise reduction, and condensation control. The North American Insulation Manufacturers Association (NAIMA) offers software called 3E Plus, which calculates the thermal performance of both insulated and uninsulated piping, ducts, and equipment; translates Btu losses into actual dollars; and calculates greenhouse gas emissions and reductions.

The International Energy Conservation Code requires automatic-circulating hot water system piping to be insulated with 1 inch (25 mm) of insulation having a conductivity not exceeding 0.27 Btu per inch/h/ft^2 °F (1.53 W per 25 mm/m^2 K).

Energy savings can be determined by the following formula:

Equation 7-3

$$S = g \times L$$

where

S = Energy savings, Btuh (kJ/h)

g = Factors taken from Table 7-1 or 7-2 at a particular ΔT, Btuh/ft (kJ/h/m)

L = System length, ft (m)

Hot water pipes should be continuously insulated from the heater to the end use. Cold water lines, at a minimum, should be insulated near the water heater tank to minimize convective losses.

Limit Water Heater and Circulation Pump Operation

Buildings with large hot water distribution systems use circulating loops to ensure that hot water is available to all fixtures within a timely manner. By limiting the number of hours the pumps and water heaters are operating, substantial savings can be realized.

Table 7-1 Energy Savings Chart for Steel Hot Water Pipes and Tanks

ΔT, °F (°C)	Pipe Size, in. (mm)							Hot Water Tanks, Btuh/ft² (kJh/m²)	
	½ (12.7)	¾ (19.1)	1 (25.4)	1¼ (31.8)	1½ (38.1)	2 (50.8)	2½ (63.5)	With Insulation	Without Insulation
40 (4.4)	14 (48.44)	17 (58.8)	21 (72.7)	26 (90.0)	29 (100.3)	35 (121.1)	42 (145.3)	6 (68.1)	57 (647.3)
45 (7.2)	16 (55.36)	20 (69.2)	24 (83.0)	30 (103.8)	33 (114.2)	41 (141.9)	48 (166.1)	6 (68.1)	65 (738.2)
50 (10.0)	18 (62.28)	22 (76.1)	27 (93.4)	34 (117.6)	38 (131.5)	47 (162.6)	55 (190.3)	7 (79.5)	73 (829.1)
55 (12.8)	20 (69.20)	25 (86.5)	31 (107.3)	38 (131.5)	42 (145.3)	52 (179.9)	62 (214.5)	7 (79.5)	83 (942.6)
60 (13.6)	23 (79.58)	28 (96.9)	35 (121.1)	42 (145.3)	48 (166.1)	58 (200.7)	69 (238.7)	9 (102.2)	92 (1044.8)
65 (18.3)	25 (86.50)	31 (107.3)	38 (131.5)	47 (162.6)	53 (183.4)	65 (224.9)	77 (266.4)	9 (102.2)	102 (1158.4)
70 (21.1)	28 (96.88)	34 (117.6)	42 (145.3)	52 (179.9)	58 (200.7)	71 (245.7)	84 (290.6)	10 (113.6)	112 (1272.0)
75 (23.9)	30 (103.8)	36 (124.6)	46 (159.2)	56 (193.8)	64 (221.4)	78 (269.9)	91 (314.9)	11 (124.9)	122 (1385.6)
80 (26.7)	33 (114.2)	41 (141.9)	50 (173.0)	61 (211.1)	69 (238.7)	84 (290.6)	99 (342.5)	11 (124.9)	132 (1499.1)
85 (28.4)	36 (124.6)	44 (152.2)	54 (186.8)	67 (231.8)	74 (256.0)	91 (314.9)	107 (370.2)	12 (136.3)	142 (1612.7)
90 (32.2)	38 (131.5)	47 (162.6)	58 (200.7)	72 (249.1)	80 (276.8)	98 (339.1)	116 (401.4)	12 (136.3)	154 (1749.0)
95 (35.0)	42 (145.3)	51 (176.5)	62 (214.5)	77 (266.4)	86 (297.6)	105 (363.3)	124 (429.0)	14 (159.0)	164 (1862.5)
100 (37.8)	45 (155.7)	54 (186.8)	66 (228.4)	82 (283.7)	93 (321.8)	113 (391.0)	133 (460.2)	14 (159.0)	175 (1987.5)
105 (38.0)	47 (162.6)	58 (200.7)	72 (249.1)	87 (301.0)	98 (339.1)	120 (415.2)	141 (487.9)	15 (170.4)	187 (2123.8)
110 (43.0)	51 (176.5)	62 (214.5)	75 (259.5)	93 (321.8)	104 (359.8)	128 (442.9)	150 (519.0)	16 (181.7)	198 (2248.7)
115 (46.0)	54 (186.8)	65 (224.9)	80 (276.8)	98 (339.1)	110 (380.6)	135 (467.1)	159 (550.1)	16 (181.7)	210 (2385.0)
120 (49.0)	56 (193.8)	69 (238.7)	85 (294.1)	104 (359.8)	117 (404.8)	143 (494.8)	169 (584.7)	17 (193.1)	222 (2521.3)

Source: San Diego Gas & Electric Co.
Notes: 1. Savings are in Btuh/linear ft. (kJh/linear m), unless otherwise indicated.
2. Figures are based on an assumption of 1 in. (25.4 mm) of insulation.
3. $\Delta T = t_o - t_a$ where t_o = Hot water circulating temperature and t_a = Air temperature surrounding piping system.

Table 7-2 Energy Savings Chart for Copper Hot Water Pipes

ΔT, °F (°C)	Pipe Size, in. (mm)							
	½ (12.7)	¾ (19.1)	1 (25.4)	1¼ (31.8)	1½ (38.1)	2 (50.8)	2½ (63.5)	3 (76.2)
40 (4.4)	8 (27.68)	12 (41.5)	14 (48.4)	17 (58.8)	20 (69.2)	25 (86.5)	30 (103.8)	35 (121.1)
45 (7.2)	10 (34.6)	13 (45.0)	16 (55.5)	20 (69.2)	23 (79.6)	29 (100.3)	35 (121.1)	40 (138.4)
50 (10.0)	12 (41.5)	15 (51.9)	19 (65.7)	23 (79.6)	26 (90.0)	33 (114.2)	40 (138.4)	46 (159.2)
55 (12.8)	13 (45.0)	17 (58.8)	21 (72.7)	26 (90.0)	30 (103.8)	38 (131.5)	45 (155.7)	52 (179.9)
60 (13.6)	15 (51.9)	20 (69.2)	24 (83.0)	29 (100.3)	34 (117.6)	42 (145.3)	51 (176.5)	58 (200.7)
65 (18.3)	16 (55.4)	21 (72.7)	27 (93.4)	32 (110.7)	37 (128.0)	47 (162.6)	56 (193.8)	65 (224.9)
70 (21.1)	18 (62.3)	24 (83.0)	30 (103.8)	35 (121.1)	41 (141.9)	52 (180.0)	62 (214.5)	71 (245.7)
75 (23.9)	20 (69.2)	26 (90.0)	33 (114.2)	39 (134.9)	44 (152.2)	56 (193.8)	67 (231.8)	76 (263.0)
80 (26.7)	21 (72.7)	28 (96.7)	35 (121.1)	42 (145.3)	49 (169.5)	61 (211.1)	73 (252.6)	85 (294.1)
85 (29.4)	22 (76.1)	31 (107.3)	38 (131.5)	45 (155.7)	53 (183.4)	66 (228.4)	79 (273.3)	92 (318.3)
90 (32.2)	24 (83.0)	33 (114.2)	41 (141.9)	49 (169.5)	57 (197.2)	71 (245.7)	85 (294.1)	99 (342.5)
95 (35.0)	26 (90.0)	36 (124.6)	44 (152.2)	53 (183.4)	61 (211.1)	76 (263.0)	91 (314.9)	106 (366.7)
100 (37.8)	28 (96.7)	38 (131.5)	48 (166.1)	57 (197.2)	65 (224.9)	82 (283.7)	98 (339.1)	113 (391.0)
105 (38.0)	30 (103.8)	41 (141.9)	51 (176.5)	60 (207.6)	70 (242.2)	87 (301.0)	104 (359.8)	121 (418.7)
110 (43.0)	32 (110.7)	43 (148.8)	54 (186.8)	65 (224.9)	74 (256.0)	93 (321.8)	111 (384.1)	128 (442.9)
115 (46.0)	34 (117.6)	46 (159.2)	57 (197.2)	68 (235.3)	78 (269.9)	98 (339.1)	118 (408.3)	136 (470.6)
120 (49.0)	36 (124.6)	49 (169.5)	61 (211.1)	72 (249.1)	83 (287.2)	104 (359.8)	125 (432.5)	144 (498.2)

Source: San Diego Gas & Electric Co.
Notes: 1. Savings are in Btuh/linear ft (kJh/linear m).
2. Figures are based on an assumption of 1 in. (25.4 mm) of insulation.
3. $\Delta T = t_o - t_a$ where t_o = Hot water circulating temperature and t_a = Air temperature surrounding piping system.

An automatic thermostatic control should be installed to cycle the pump on and off in response to the temperature of the water returning to the water heater through the recirculation piping. The minimum differential, or deadband, of the control shall 5–10°F (-15 to -12°C).

Time clocks can be used to control hot water circulating pumps. The energy saved when using time clocks can be calculated as follows:

Equation 7-4

$$\text{Motor kilowatts (kW)} \times \text{Off hours} \times \text{Electric rate (\$/kWh)} = \text{Total savings (\$)}$$

Another alternative to hot water recirculation is heat tracing the distribution and supply piping. This method eliminates the need for hot water recirculation lines and the associated pumps. (This is not allowed under all codes.)

Upgrade to More Efficient Equipment

Equipment specifications need to be examined to ensure that only water heating equipment meeting minimum energy standards is approved for installation. The following factors contribute to the efficiency of gas-fired water heaters and need to be taken into consideration when selecting this equipment: combustion equipment and its adjustment, tank insulation, heat exchanger effectiveness, firing rate, modulation or turndown of the heater, and night setback. In many systems, a night setback option can be included in the controls. This allows the end user to lower the temperature set point to save energy.

Locate Water Heaters Near Points of Use

Many water heaters are installed in central locations, requiring long supply and return piping runs to reach plumbing fixtures. Moving these heaters near the most frequent points of use can minimize piping heat losses. Heaters are getting smaller to allow modular systems to be installed. This allows the engineer to locate the water heater closer to the point of use, which saves piping and recirculation costs.

Additionally, water heaters today offer several venting options, allowing for the installation of these units in areas that traditionally were not considered in the past.

DOMESTIC WATER HEATING EQUIPMENT

Many different means of generating hot water are available. Each has advantages and disadvantages, and it is the plumbing engineer's responsibility to determine which technology is best suited for an application. The recovery efficiency and standby losses of water heating equipment should comply with the latest codes and regulations. State energy codes also mandate the use of energy-efficient equipment and should be checked prior to preparing the specifications. As well as evaluating what type of water heating equipment to use, also be sure to "right size" the equipment. Regardless of the type of equipment used, any oversized (or undersized for that matter) piece of equipment could be wasteful of energy.

Following are several water heating technologies.

Storage Water Heaters

Tank-type water heaters are self-contained units that heat and store water within the same storage tank. Insulation is added around the exterior of the tank to prevent heat from escaping. Because the tank maintains a stored water temperature, there is an associated standby energy loss. Most storage water heater manufacturers comply with ASHRAE energy-efficiency standards, which keeps this standby loss to a minimum. Compared to tankless water heaters, storage water heaters have the advantage of using energy (gas or electricity) at a relatively slow rate, storing the heat for later use. During low demands, the water heater may not even need to fire.

Electric Storage Water Heaters

The heating element for electric tank-type water heaters is immersed directly into the water, allowing energy to transfer from the element to the water fast and efficiently. These heaters can be used for many applications ranging from commercial and industrial to booster heaters for dishwashing needs.

Gas-Fired Storage Water Heaters

A gas-fired tank-type water heater uses natural gas or propane to heat stored water. These units range in efficiency from 81–96 percent.

Split Systems

A split system consists of a separate heater and storage tank. The heated water is transferred to the separate storage tank where it is maintained at the desired temperature. This allows the engineer to design a system that matches the Btu and storage requirements for the building and also allows for redundancy at any level desired. This scenario can be used for both standard heaters and tankless applications.

Condensing Storage Water Heaters

Several manufacturers offer condensing water heaters in both a tank-type and split system design. These heaters are rated up to 96 percent thermal efficiency. To take advantage of the condensing capability of this type of heater, the system design should send the cold water from the building water supply directly into the heater. The lower the water supply temperature into the heater, the more efficient the heater can be. Another advantage of condensing heaters is the ability to turn down, or modulate, the heater; 5:1 and even 10:1 turndowns are available today. For example, a 10:1 turndown on a 1-million-Btu heater will be able to fire anywhere between 100,000 and 1 million Btu to meet the current hot water demand.

The advantages of condensing water heaters follow:

- The lower the heater can be modulated, the more efficient it runs.
- With modulation, the heater cycles less, increasing the components' longevity.
- It matches the desired temperature closely, so temperature fluctuations are reduced.

Note: The condensate generated from a condensing unit needs to be drained, but care must be taken to account for its acidic nature. With a pH as low as 5, the condensate may need to be diluted until it reaches an acceptable pH range or drained to a neutralization tank. Most manufacturers of these units supply these tanks to match the heater size.

Tankless Water Heaters

Tankless water heaters heat the water as it flows through the device (demand based) and retain only minimal amounts of water internally, including what is in the heat exchanger coil. Tankless water heaters often have minimum flow requirements before the heater is activated, and this can result in a gap between the cold water temperature and the coolest warm water temperature that can be achieved with a hot and cold water mix.

Electric Tankless Heaters

Electric tankless water heaters consume large amounts of energy when operating, which has relegated their use to remote areas with low fixture counts and infrequent use. They usually are installed near the point of use to minimize pipe heat loss.

Gas-Fired Tankless Heaters

These heaters can be found in commercial, industrial, and residential applications. They are typically direct-vent exhaust and carry a very high rate of efficiency.

Condensing Tankless Heaters

Refer back to condensing storage-type heaters for an explanation of condensing tankless products.

Steam-Fired Water Heaters

Steam-fired water heaters generate hot water through the use of a heat exchanger. They are used in hospitals, industrial plants, restaurants, apartment houses, laundries, universities, and hotels, among other applications. They can be combined in parallel to meet high flow requirements while requiring less space than comparable tank-type units. The installation of a mixing valve is recommended to ensure that steam does not enter the hot water system in the event of a heat exchanger breach. Many authorities having jurisdiction (AHJs) require a dual-wall heat exchanger on steam-fired units. The annular space between the two heat exchanger walls is vented to the atmosphere, preventing the possibility of cross-contamination.

Direct-Fired Water Heaters

These heaters are used in applications where several hundred gallons of hot water are needed per minute. These units use a direct exchange between the water and the combustion products produced by the burner assembly. This process eliminates standby losses and can achieve operating efficiencies in excess of 98 percent.

ALTERNATIVE RESOURCES

As the consumption of fossil fuels increases, so does the need to develop alternative fuel sources. One of these sources is solar energy. Energy captured from sunlight can be converted to power to heat domestic water. Other forms of alternative energy are geothermal and solid wastes, which have been used to heat water while reducing the load placed on mainstream resources. The designer may choose to use alternative energy sources for all or part of the hot water system. This helps meet restrictions placed on domestic water heating systems by energy codes in many parts of the country.

Solar Energy

One of the most cost-effective ways to include renewable technologies in a building is by incorporating solar hot water. A typical residential solar water heating system reduces the need for conventional water heating by about two-thirds. It minimizes the expense of electricity or fossil fuel to heat the water and reduces the associated environmental impacts. Most solar water heating systems for buildings have two main parts: a solar collector and a storage tank. The most common collector used in solar hot water systems is the flat-plate collector.

Solar water heaters use the sun to heat either water or a heat-transfer fluid in the collector. Heated water then is held in the storage tank ready for use, with a conventional system providing additional heating as necessary. The tank can be a modified standard water heater, but it is usually larger and very well insulated. Solar water heating systems can be either active or passive, but the most common are active systems. Active solar water heaters rely on electric pumps and controllers to circulate water or other heat-transfer fluids through the collectors.

The three types of solar water heating systems are direct circulation, indirect circulation, and passive.

Direct-Circulation Systems

Direct-circulation systems use pumps to circulate pressurized potable water directly through the collectors. These systems are appropriate in areas that do not freeze for long periods and do not have hard or acidic water. These systems are not approved by the Solar Rating & Certification Corporation (SRCC) if they use recirculation freeze protection (circulating warm tank water during freeze conditions) because that requires electrical power for the protection to be effective.

Indirect-Circulation Systems

Indirect-circulation systems pump heat-transfer fluids through collectors. Heat exchangers transfer the heat from the fluid to the potable water. Some indirect systems have overheat protection, which is a means to protect the collector and the glycol fluid from becoming super-heated when the load is low and the intensity of the incoming solar radiation is high. The two most common indirect systems are:

- Antifreeze: The heat-transfer fluid is usually a glycol-water mixture with the glycol concentration depending on the expected minimum temperature. The glycol is usually food-grade propylene glycol because it is nontoxic.
- Drainback: This system uses pumps to circulate water through the collectors. The water in the collector loop drains into a reservoir tank when the pumps stop. This makes drainback systems a good choice in colder climates. Drainback systems must be carefully installed to ensure that the piping always slopes downward, so the water will completely drain from the piping. This can be difficult to achieve in some circumstances.

Passive Systems

Passive solar water systems rely on gravity and the tendency for water to naturally circulate as it is heated. Because they contain no electrical components, passive systems are generally more reliable, easier to maintain, and possibly have a longer work life than active systems. The two most popular types of passive systems follow:

- Integral-collector storage systems consist of one or more storage tanks placed in an insulated box with a glazed side facing the sun. These solar collectors are suited for areas where temperatures rarely go below freezing, and they work well in households with predominantly morning draws because they lose most of the collected energy overnight.

- Thermosyphon systems are an economical and reliable choice, especially in new homes. These systems rely on the natural convection of warm water rising to circulate water through the collectors and to the tank (located above the collectors). As water in the solar collectors heats, it becomes lighter and rises naturally into the tank above. Meanwhile, the cooler water flows down the pipes to the bottom of the collectors, enhancing the circulation. Some manufacturers place the storage tank in the house's attic, concealing it from view. An indirect thermosyphon (that uses a glycol fluid in the collector loop) can be installed in freeze-prone climates if the piping in the unconditioned space is adequately protected.

Solid-Waste Disposal Energy

Solid-waste collection and disposal systems produce various gases during decomposition. One of these is methane, which can be recovered and burned to produce heat. A second source of methane is leachate evaporation systems in landfill closures. Lastly, solid-waste incineration systems constructed to stringent pollution-control rules and regulations are another source of methane. These systems potentially can provide large volumes of steam and/or domestic hot water.

The use of these alternate energy sources should be within reasonable proximity to the resource. Typical applications include industrial plants with large volumes of burnable materials such as trash, paper, scrap wood, and plastics. A solid-waste incinerator system typically consists of a waste-disposal plant with a conveyor, loading system, boiler, ash-disposal equipment, heat exchanger, insulated piping, circulating pump, and controls.

Geothermal Energy

Geothermal energy is heat from the Earth. In states where this form of energy is believed to be available at reasonable depths, the U.S. Department of Energy (DOE) is supporting various state energy commissions in their funding of geothermal assessment programs. The temperature of the available liquid or gas (created when water flows through heated, permeable rock) and the cost of retrieval dictate the viability of geothermal energy. Some geothermal energy uses include steam for the generation of electricity, building domestic hot water systems with a minimum temperature of 150°F (66°C), and space and water heating needs for industrial parks.

Three prime areas of concern must be addressed when planning and developing geothermal energy systems:

- Competitive institutional processes
- Adequate temperature and flow rate
- Thermal loads to make the system economically viable

A geothermal energy system typically consists of production and disposal wells, two water-to-water heat exchangers (typically plate-and-frame or shell-and-tube type), one for operation while the other is being cleaned of deposits, insulated piping, a circulating pump, and a control system. The plumbing engineer should consult with the state energy department or the Geothermal Resources Council for information on applying this alternate energy source.

Heat Recovery

Heat recovery is the capture and reuse of energy that normally would be lost from a facility. It can be in the form of a liquid or a gas. Common waste heat sources are:

- Heat rejected from air-conditioning and commercial refrigeration processes
- Heat reclaimed from steam condensate
- Heat generated by cogeneration plants
- Heat pumps and heat reclamation systems
- Heat from wastewater such as showers

When considering heat recovery, it is important to determine if the hot water demand justifies the equipment and maintenance costs and if the heat recovered is sufficient to serve as a heat source. Facilities that typically have the proper blend of demand and waste heat are hospitals, military bases, and industrial facilities.

Air-Conditioning and Commercial Refrigeration

Systems with air- or water-cooled or evaporative condensers reject heat from air-conditioning and refrigeration systems that can be reclaimed. Within the refrigerant cycle is a condenser that rejects heat while an evaporator creates a cooling effect. For example, for every 1 Btuh of cooling effect produced by a 40°F evaporator, a 105°F condensing unit rejects 1.15 Btuh of heat. Systems with an air-cooled or evaporative condenser can be supplemented with a heat exchanger in the compressor's hot gas discharge line to capture the rejected heat (see Figure 7-2).

Systems with water-cooled condensers can be supplemented with a heat exchanger in the hot water return line from the condenser to the cooling tower (see Figure 7-3). System efficiency can be improved by providing a storage tank with a tube bundle (see Figure 7-4). An advantage of the system shown in Figure 7-4 is that simultaneous use of the domestic water and refrigeration systems does not need to occur for heat recovery. Another advantage of the system shown in Figure 7-4 is that when an insufficient amount of heat is rejected, a backup water heater can be used to bring the water in the storage tank to the proper design temperature. The backup heater can operate on fossil fuel, electricity, or steam or may be fitted with a tube bundle utilizing hot water.

Steam Condensate

When steam is used as a source for space heating, water heating, or process work, steam condensate generally is produced. The heat content of the condensate can be captured and reused for heating with the use of a heat exchanger. Laundries are a prime example of facilities where heat reclaimed from steam condensate can be put to use in heat recovery. It is essential to select a system with adequate storage to compensate for fluctuations in the condensate and domestic water flow. When deciding whether to capture and reuse steam condensate, remember that energy will not be saved if the boiler used to raise the temperature of the returned condensate is less efficient than the primary water heater.

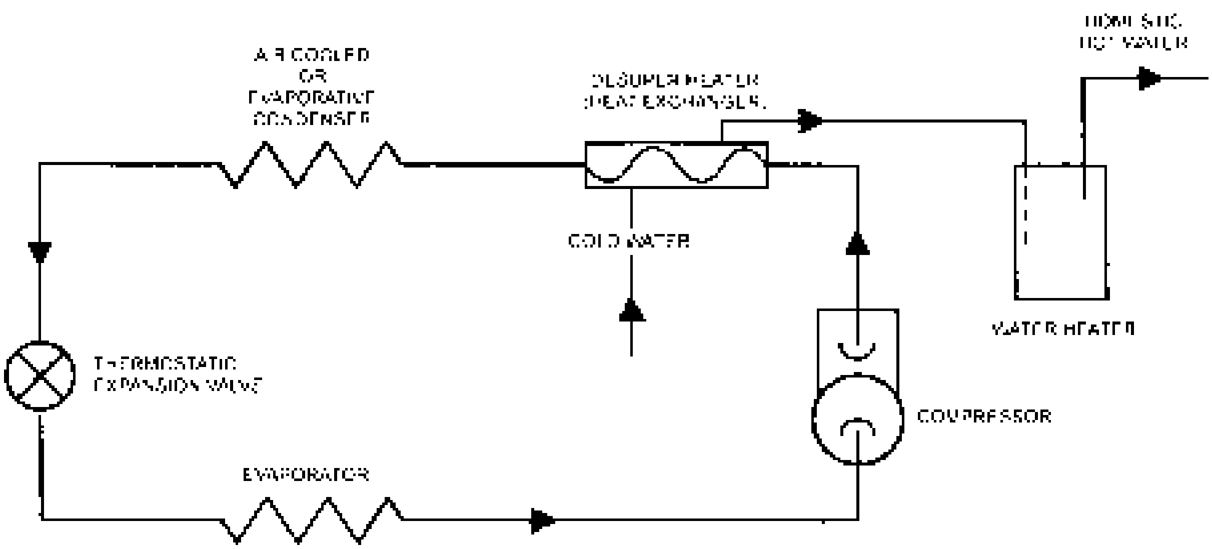
Cogeneration Plants

The heat produced as a by-product of generating electricity from reciprocating engines or gas turbines can be reclaimed from the cooling systems and exhaust gases by using a waste heat boiler and heat exchanger. The heat then can be used to produce steam or medium-temperature water. To be economically viable, most systems must have a year-round thermal heat load. Reheating makeup water and maintaining the temperature in a domestic hot water system are excellent ways to obtain high overall thermal efficiencies.

Heat Pumps

In buildings where computer rooms are continuously generating heat and industrial plants are producing waste heat, heat pumps can be used to transfer this heat to the domestic hot water systems, resulting in energy conservation. This system extracts heat from a warm environment directly, either through a heat exchanger or a cooling coil. Either direct-expansion or chilled-water heat pumps can be used to transfer the heat through the refrigeration process from the surrounding air to a water storage tank.

Figure 7-2 Refrigeration Waste Heat Recovery



Drainline Heat Reclaim Systems

It has been estimated that 80–90 percent of all hot water energy is wasted. The U.S. DOE estimates this amount of energy to be 235 billion kWh a year. One method of recouping some of this energy is using a drainline heat reclaim system (see Figure 7-5). This device can be a passive or active piece of equipment installed in the wastewater drainline of a building. Passive devices use a copper coil wrapped around a vertical portion of a waste line. Domestic water is fed through the copper coil to the hot water heater. As hot water is drained, heat is transferred from the drainline to the incoming domestic water. It has been estimated that these exchangers have an operating efficiency of up to 60

Figure 7-3 Condenser Water Heat Recovery

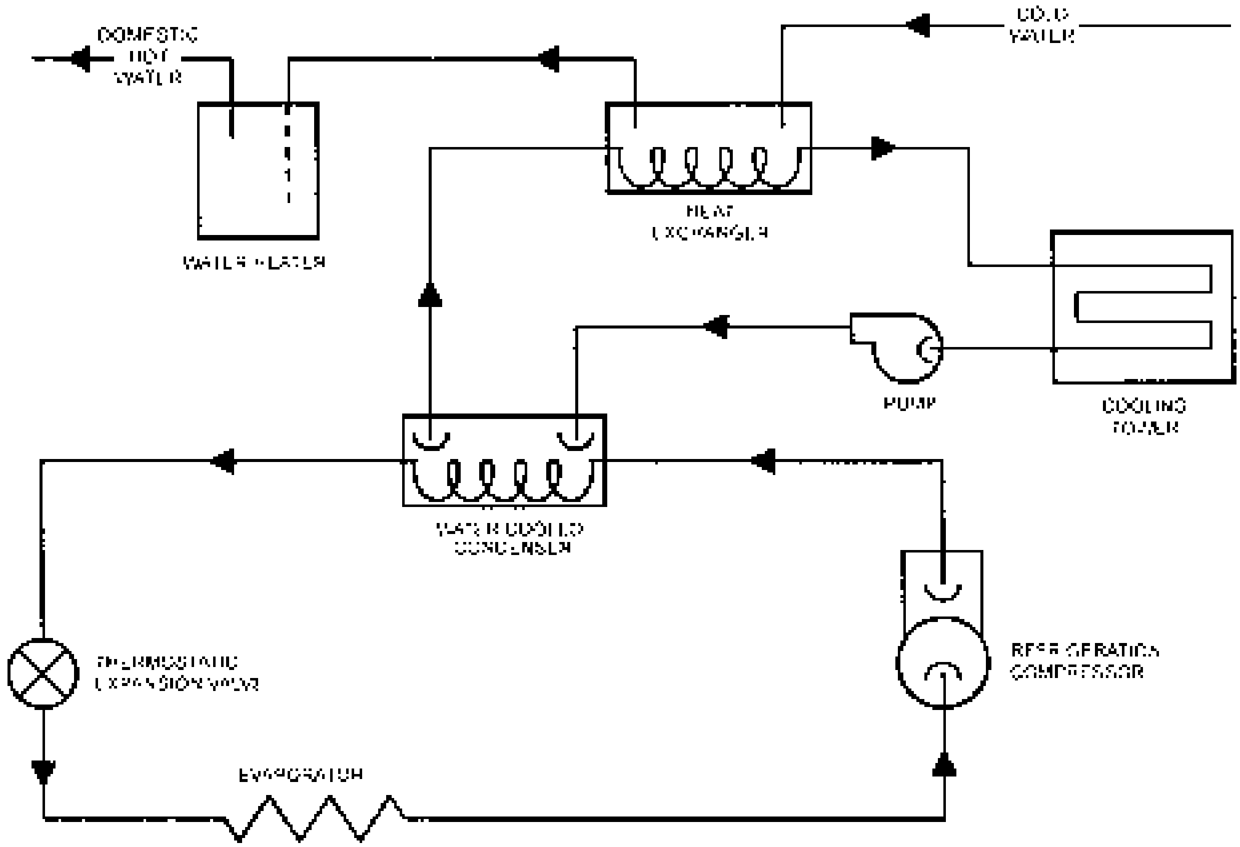


Figure 7-4 Condenser Water Heat Recovery with Storage Tank

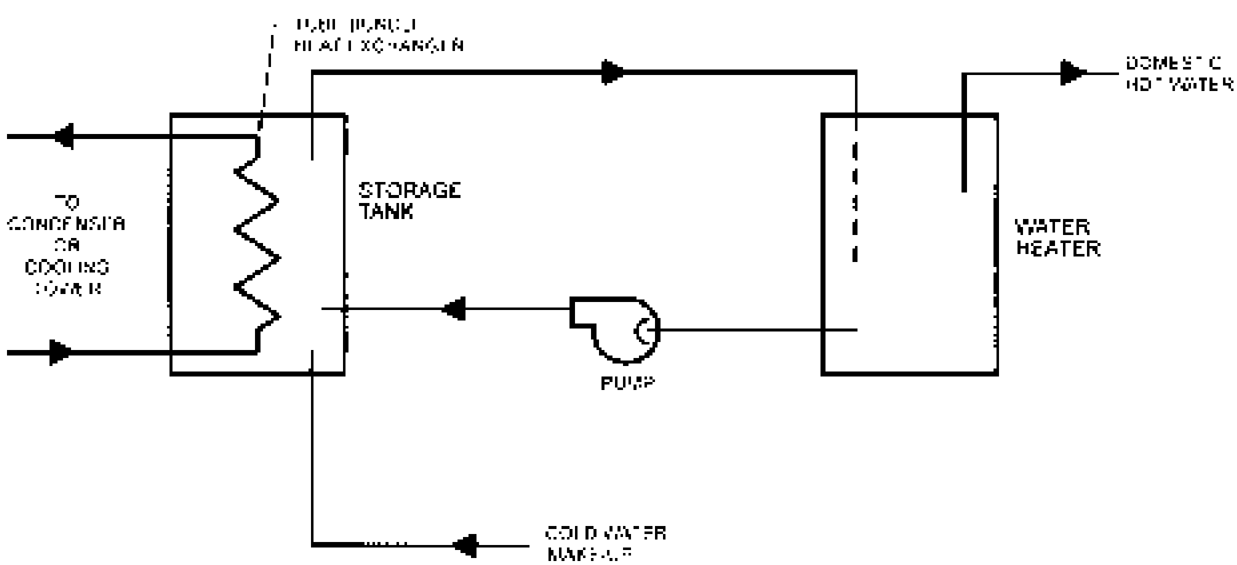


Figure 7-5 Wastewater Heat Recovery

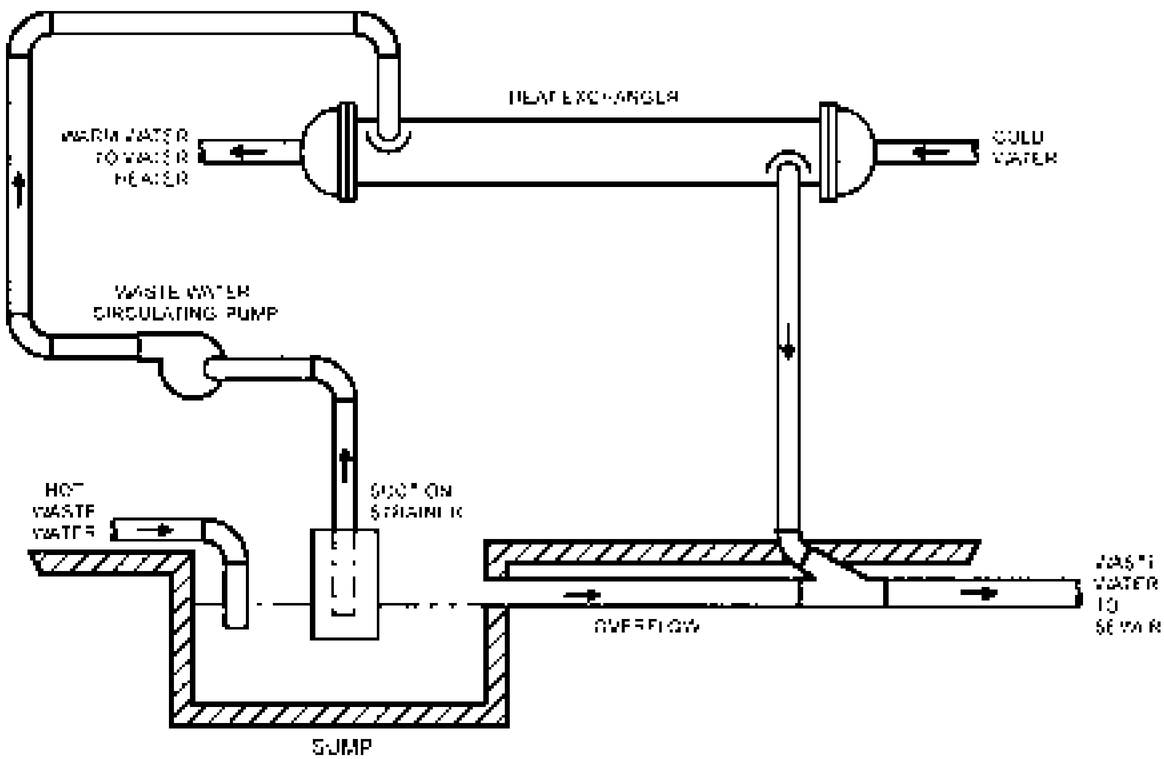
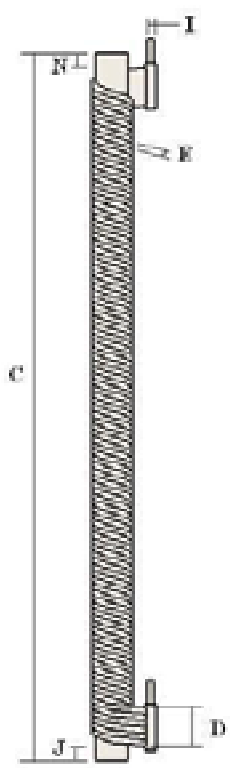


Figure 7-6 Simple Wastewater Heat Recovery System

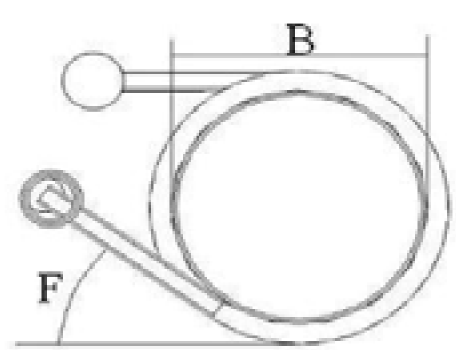


NOMENCLATURE

A	Commercial (C) / Residential (R) / Industrial (I) / Custom (X)
B	Nominal Inner Pipe Diameter [inches]
C	Inner Pipe Length [inches]
D	# of coils in each wrap
E	Coil tube, nominal size (eights of an inch)
F	% Overwrap, from parallel, +/- 2%
G	Inlet Stubbie Orientation (U/D/B – Up/Down/Both)
H	Outlet Stubbie Orientation (U/D – Up/Down/Both)
I	Stubbie - Nominal Size - See List
J	Approximate Lower Collar Length
N	Approximate Upper Collar Length

TUBE CODES (E,I)

Code	Nominal Size
2	1/4"
3	3/8"
4	1/2"
6	3/4"
8	1"



NOTE:
For 4" units the minimum wall cavity required dimensions are: 4.75" by 7.5"
For 3" units the minimum wall cavity required dimensions are: 3.75" by 7.5"

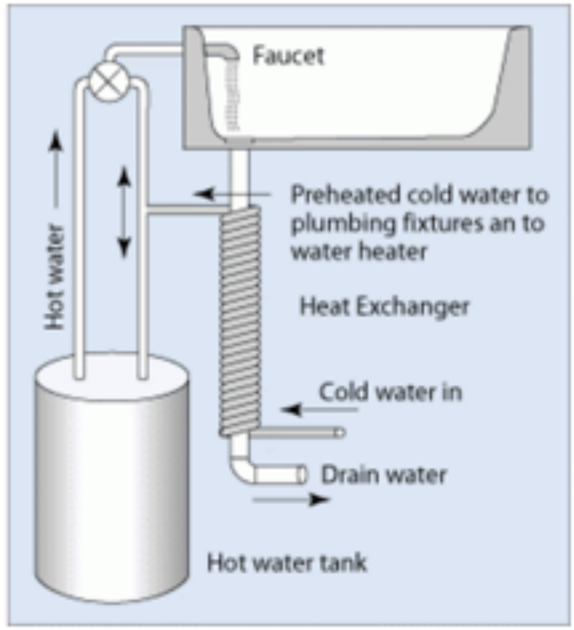
percent and can raise the incoming water temperature by as much as 36°F. Active systems utilize a wastewater circulating pump in conjunction with the heat exchanger.

A simpler way to recover wastewater heat, which may be applicable to some projects, is illustrated in Figure 7-6. This system directs the cold water supply to the shower through a series of tubing wrapped around the waste piping from the same shower or group of showers, which results in a pre-heating of the supply cold water to the shower, in turn reducing the amount of hot water needed to achieve the desired hot water temperature out of the shower.

Figure 7-7 is another version that sends the pre-heated water to the water heater as well as the fixture. Remember that pre-heating the cold water to the heater may interfere with the unit operating in the condensing mode and therefore lower its efficiency. All methods require thought and balance.

Another option could consist of multi-strategic approach.

Figure 7-7 Drain Water Heat Recovery System



CREATING A WATER MANAGEMENT PROGRAM

Conserving water benefits both the building owner and the local municipality. The owner saves by having lower utility costs, while the municipality saves resources by having to treat and circulate less water and wastewater. To realize these savings, the plumbing engineer must provide designs that reduce water consumption without compromising a fixture's operation.

For a water management program to be successful in renovation projects, it is important to first establish the building's current water consumption. The U.S. DOE has developed eight steps to make a successful water management plan:

1. Gather information.
2. Conduct a comprehensive facility survey.
3. Explore and evaluate water management options.
4. Conduct a life-cycle cost analysis and explore financing options.
5. Develop a water management plan and work schedule.
6. Inform building occupants about water management.
7. Implement the water management plan.
8. Monitor the water management plan.

For more information, refer to *Greening Federal Facilities* by the U.S. DOE.

Water Quality Effects on Water Management

Water quality has a dramatic effect on all water systems. If water quality is not maintained in a public, local, or household water system, the following can be projected:

- Lower flow rates through fixtures such as showerheads and sinks that were designed for set flow rates of "water at a certain quality" to work properly. These lower flow rates can cause consumers to keep fixtures running longer.
- Reduced efficiency for equipment such as pumps and water heaters. For example, a water heater working within its hardness or total dissolved solids (TDS) level will last three times longer than a heater having to heat high-TDS water.

These are considerations for water equipment that have been overlooked in the past, but they need to be considered due to the water supply available today.

Design Techniques for Water Management

Some design techniques previously mentioned are eliminating faucet and pipe leaks and reducing fixture flow rates. Other methods of unique water management are using alternate sources of fresh or reclaimed water.

Eliminate Faucet and Pipe Leaks

Similar to hot water conservation, this is one of the easiest and first actions that should be taken. Leaks in both the cold and hot water piping should be repaired, as well as any leaking faucets. This will reduce the amount of water being wasted and prevent more expensive repairs later.

Reduce Fixture Flow Rates

Replacing old plumbing fixtures can save huge quantities of water. The standards established for water consumption by the EPAct restrict showerheads to 2.5 gpm (9.5 L/m), urinals to 1 gpf (3.8 Lpf), faucets to 2.2 gpm (8.3 L/m) at 60 psi (410 kPa), and toilets to 1.6 gpf (6 Lpf) at 80 psi (550 kPa). Older models can be retrofitted by adjusting the flush valve, but a specific amount of water needs to be delivered per flush. Such tampering could also cause malfunction. Even if the valve does not fail, the fixture could fail to perform as intended. Fixtures need to be engineered to work at these flow rates. It is important to note that a flush valve water closet and a flush tank water closet both discharge about 25–26 gpm. It is also important to understand that regardless of the gpf, they still flush the same peak flow rate. The difference is in the total discharge time (i.e., less time = less gpf).

Use Alternate Sources of Fresh Water

Rainwater harvesting is the collection, storage, treatment, and use of rainwater for nonpotable and potable uses. A rainwater harvesting system typically starts with a catchment area that collects rainwater, usually a building's roof. To prevent potential contaminants and pollutants from entering the system's storage tank, a wash system is installed that diverts the initial portion of the rainfall away from the storage tank while cleaning the catchment area. Vortex-style filters also are available to continuously filter out sediment, leaves, and other debris. A screen usually is installed in the catchment area to also help keep out debris.

Piping routes the collected rainwater to a storage tank, which can be located indoors, outdoors, aboveground, or underground. It is important to provide a lid on the storage tank to keep light out to discourage algae growth. Water typically is delivered to the building through the use of a nonpotable water booster pump system, and final water treatment may be needed depending on the application and quality of water collected.

Use Reclaimed Water and Graywater

Reclaimed water and graywater collection systems can be used to reduce the amount of domestic water consumed by a building. Graywater typically is collected from showers, tubs, lavatories, washing machines, and drinking fountains. It contains a minimal amount of contamination and is reused in certain landscape applications such as the subsurface irrigation of lawns, flowers, trees, and shrubs, but it should not be used for vegetable gardens because of the potential absorption of cleaning and washing chemicals.

Similar to rainwater harvesting, graywater is collected, stored, and filtered prior to use. A graywater storage container should be fitted with overflow protection that is connected to the sanitary sewer system in the event the amount of water collected is more than the amount of water being consumed, a distribution pipe becomes clogged, or the collected water is not used in a timely manner.

Wastewater treatment plants are constructed to provide reclaimed or recycled water to buildings through a second municipal water system where two water lines enter a building. One line is used to deliver potable water for domestic use, and a second provides treated wastewater that can be used for nonpotable applications such as landscape irrigation, cooling tower makeup, toilet flushing, and fire protection.

Water Management Equipment

The goal of effective water management is to reduce water consumption without compromising the performance of equipment and fixtures. Replacing or retrofitting water closets, urinals, showerheads, and faucets with low-flow versions can considerably lower a building's water consumption.

Water Closets

Americans flush about 4.8 billion gallons (18.2 billion liters) of water down toilets each day, according to the U.S. EPA, but the simple act of replacing old, inefficient toilets with low-flow toilets can save millions of gallons. For example, in 2013, the New York City Department of Environmental Protection implemented a Toilet Replacement Program to incentivize residential building owners to replace older toilets (3.5 gpf or above) with high-efficiency models (1.28 gpf or less). It is estimated that the program saved 30 million gallons of water each day citywide.

Most toilets sold today consume 1.28 gpf (5 Lpf), but dual-flush and high-efficiency models are gaining popularity. In tank-type water closets, most commonly used in residential applications, water is drained by gravity. A low-cost method of conserving water in these models is using a refill diverter. When a tank-type water closet is flushed, water starts to refill the tank as it is emptying. The time elapsed between the open and closed position of the flapper allows excess water to flow through the bowl, into the bowl, and consequently to the drain. While refilling the tank, this water is wasted. A diverter keeps this water in the tank, saving 0.25 gallon on high-efficiency models.

Some specialty water closets are pressure-assisted tank type, dual flush, and composting. Pressure-assisted tank-type water closets can be used in applications where gravity tank-type water closets are desired, but there are concerns about flushing performance. When additional water conservation is desired, dual-flush water closets can be used. These have two flush settings: one for normal operation to flush solids and a second, reduced amount for liquids, saving approximately 1 gpf. Composting systems are high-capital ventures that require a lot of space and typically are used in unique locations where no water supply exists. They are popular choices in parks and camping facilities and are gaining acceptance in other areas of the world for mainstream use in households.

The high-efficiency toilet (HET) is defined as a fixture that flushes with 20 percent less water than the 1.6-gpf toilet. This includes dual-flush technology. Toilets that flush 1 gpf are also available.

Urinals

Urinals consume 1 gpf, but water conservation methods can go beyond this level. Flush valves that consume as low as 1 pint per flush have been employed with success. Waterless urinals that do not consume any water also are being used. Waterless urinals utilize a specially designed trap insert that prevent odors from passing through the urinal trap. Traps can be mechanical or filled with a liquid sealant. The lighter-than-water sealant floats on top of the urine collected in the U-bend. The cartridge and/or sealant must be replaced periodically. A waterless urinal could save anywhere between 15,000 and 45,000 gallons (approximately between 56,800 and 170,000 liters) of water per urinal per year. Waterless urinals can be installed in high-traffic facilities and in situations where providing a water supply may be difficult or where water conservation is desired. An alternative would be to install 1-pint urinals (0.125 gpf).

Showerheads

The 1992 EPAct set the maximum flow rates for showerheads and faucets at 2.5 gpm. Prior to this act, showerhead flow rates were between 3 and 7 gpm. Water-conserving showerheads incorporate a more narrow spray jet and introduce a greater volume of air when compared to conventional heads. The use of flow restrictors in conventional showerheads is not recommended because they typically restrict the showerhead too much, providing poor water pressure from the head. 1.5 gpm is the current best solution for most applications.

Faucets

Faucets manufactured after 1993 provide no more than 2.5 gpm at 80 psig, meeting the requirements of the 1992 EPAct. This was later revised to 2.2 gpm for private lavatory faucets and to the 0.5 gpm that was already required by ANSI/ASME for commercial lavatory faucets. 0.35 gpm is often used for commercial lavatories and sometimes residential sinks. Replacing the faucet's tip with an aerator, which mixes air into the faucet's discharge and reduces its flow rate to 2.5 gpm, can retrofit older faucets, which consume between 3 and 5 gpm.

With manual valve faucets, replacing the screw-in tip of the faucet is all that typically is necessary to reduce water use. While faucet aerators that mix air into the water stream are commonly used in residential faucets, they are specifically prohibited in healthcare facilities because they can harbor germs and pathogens. Instead, these facilities use nonaerating, low-flow faucet tips (including those providing a smooth, laminar stream of water). Choose 2.2- to

2.5-gpm (8.3- to 9.5-L/m) devices for kitchens. In washrooms, 0.5- to 1.25-gpm (1.9- to 4.7-L/m) models often prove adequate for personal washing purposes.

Metered (metered valve or electronic sensor) faucets deliver a preset amount of water and then shut off. For water management purposes, the preset amount of water can be reduced by adjusting the flow valve. The Americans with Disabilities Act requires a 10-second minimum on-cycle time. To maximize water savings, choose the lowest water use models—typically 0.5 gpm (1.9 L/m) or 0.35 gpm (1.3 L/m).

GLOSSARY

British thermal unit (Btu) A heat unit equal to the amount of heat required to raise 1 pound of water 1 degree Fahrenheit.

Coefficient of performance (COP) The ratio of the rate of heat removal to the rate of energy input, in consistent units, generally relating to a refrigeration system under designated operating conditions.

Condenser A heat exchanger that removes heat from a vapor, changing it to its liquid state.

Delta T (ΔT) Temperature differential.

Domestic water heating Supply of hot water for domestic or commercial purposes other than comfort heating.

Domestic water heating demand The maximum design rate of energy withdrawal from a domestic water heating system in a specified period of time.

Efficiency, thermal (overall system) The ratio of useful energy at the point of ultimate use to the energy input.

Energy The force required for doing work.

Energy, non-depletable Energy derived from incoming solar radiation and phenomena resulting therefrom, including wind, waves, tides, and lake or pond thermal differences, and energy derived from the internal heat of the Earth (geothermal)—including nocturnal thermal exchanges.

Energy, recovered A by-product of energy used in a primary system that otherwise would be wasted from an energy utilization system.

Heat, latent The quantity of heat required to effect a change in state.

Heat, sensible Heat that results in a temperature change but not a change in state.

Life-cycle cost The cost of equipment over its entire life, including operating and maintenance costs.

Makeup Water supplied to a system to replace that lost by blowdown, leakage, evaporation, etc.

Solar energy source Source of chemical, thermal, or electrical energy derived from the conversion of incident solar radiation.

System An arrangement of components (including controls, accessories, interconnecting means, and terminal elements) by which energy is transformed to perform a specific function.

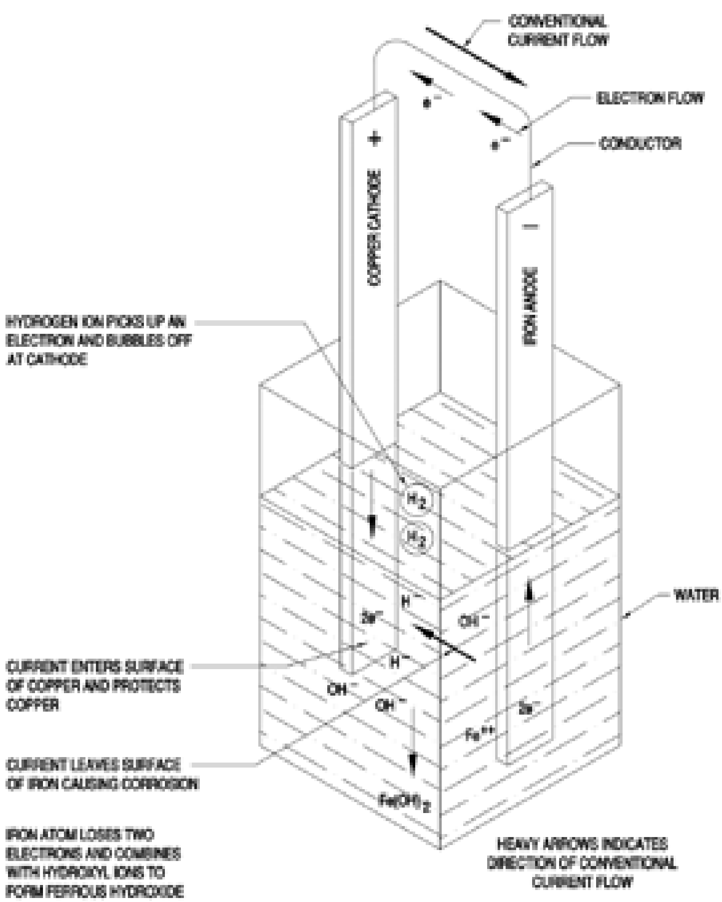
Terminal element The means by which the transformed energy from a system is ultimately delivered.

Corrosion

Corrosion is the degradation of a material by its environment. In the case of metals, corrosion is an electrochemical reaction between a metal and its environment. For iron piping, the iron reacts with oxygen to form iron oxide, or rust, which is the basic constituent of the magnetic iron ore (hematite) from which the iron was refined. The many processes necessary to produce iron or steel pipe—from refining through rolling, stamping, and fabricating to the finished product—all impart large amounts of energy to the iron. The iron in a finished pipe is in a highly energized state and reacts readily with oxygen in the environment to form rust. Corrosion results from a flow of direct current through an electrolyte (soil or water) from one location on the metal surface to another location on the metal surface. The current flow is caused by a voltage difference between the two locations.

This chapter covers the fundamentals of corrosion as they relate to a building's utility systems, essentially dealing with piping materials for the conveyance of fluids, both liquid and gas. These pipes are installed either below- or aboveground, thus making the external environment of the pipe earth or air, respectively. The internal environment is the fluid conveyed inside the pipe. Many environmental conditions may affect the performance of any given piping material.

Figure 8-1 Basic Corrosion Cell



FUNDAMENTAL CORROSION CELL

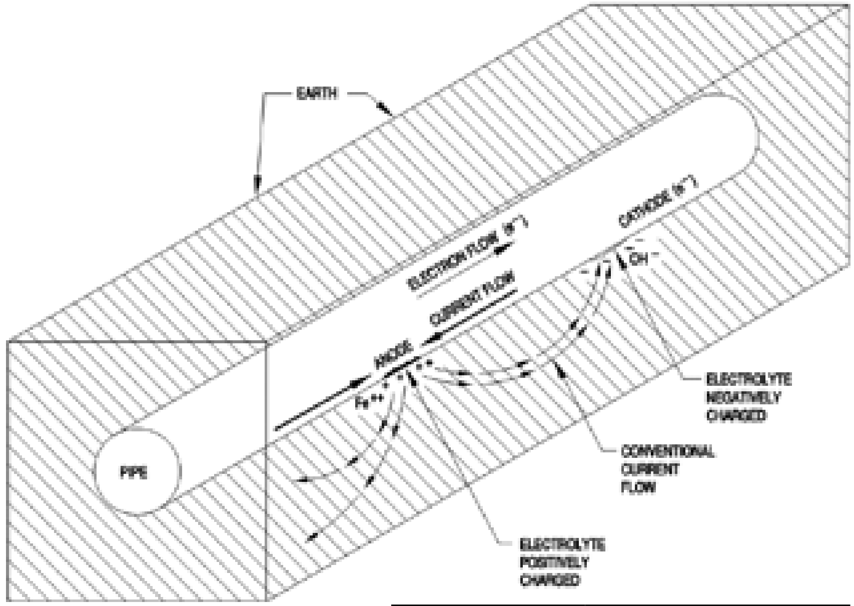
Corrosion is, in effect, similar to a dry cell battery. For corrosion to occur, four elements must be present: an electrolyte, an anode, a cathode, and a return circuit. The electrolyte is an ionized material, such as earth or water, capable of conducting an electric current.

Figure 8-1 shows the actual corrosion cell. Figure 8-2 (practical case) shows the current flows associated with corrosion. The current flows through the electrolyte from the anode to the cathode. It returns to the anode through the return circuit. Corrosion occurs wherever the current leaves the metal and enters the electrolyte. The point where the current leaves the metal is the anode. Corrosion, therefore, occurs at the anode. The current is then picked up at the cathode. No corrosion occurs here, as the cathode is protected against corrosion (the basis of cathodic protection). Polarization (hydrogen film buildup) occurs at the cathode. The flow of the current is caused by a potential (voltage) difference between the anode and the cathode.

Electrochemical Equivalents

Dissimilar metals, when coupled together in a suitable environment, will corrode according to Faraday's law—that is, 26.8 ampere-hours (A-h), or 96,500 coulombs (C), are required to remove 1 gram-equivalent of the metal. At this rate of attack, the amount of metal that is removed by a current of 1 A flowing for one year is shown in Table 8-1.

Figure 8-2 Basic Cell Applied to an Underground Structure



COMMON FORMS OF CORROSION

Corrosion occurs in a number of common forms.

Uniform Attack

Uniform attack (Figure 8-3) is the most common form of corrosion and is characterized by a general dissolving of the metal wall. The material and its corrosion products are readily dissolved in the corrosive media.

Pitting Corrosion

Pitting corrosion (Figure 8-4) is usually the result of the localized breakdown of a protective film or layer of corrosion products. Anodic areas form at the breaks in the film, and cathodic areas form at the unbroken portions of the film. The result is localized, concentrated corrosion, which forms deep pits.

Table 8-1 Electrochemical Metal Losses of Some Common Metals

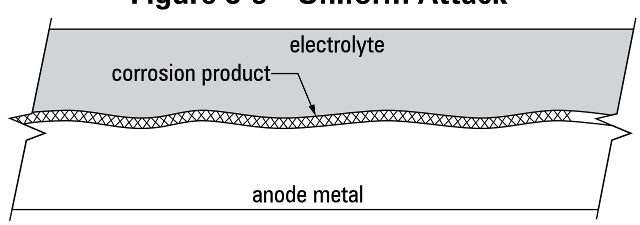
Metal	Loss, lb/A-yr (kg/C)[a]
Iron (Fe2+)	20.1 (72.4)
Aluminum (Al3+)	6.5 (23.4)
Lead (Pb2+)	74.5 (268.3)
Copper (Cu2+)	45.0 (162.0)
Zinc (Zn2+)	23.6 (85.0)
Magnesium (Mg2+)	8.8 (31.7)
Nickel (Ni2+)	21.1 (76.0)
Tin (Sn+)	42.0 (151.2)
Silver (Ag+)	77.6 (279.4)
Carbon (C4+)	2.2 (7.9)

a A = Ampere; C = Coulomb, the amount of electric charge transported in 1 second by a steady current of 1 ampere

Galvanic Corrosion

Galvanic corrosion (Figure 8-5) occurs when two dissimilar metals are in contact with an electrolyte. The example shown is iron and copper in a salt solution, with the iron being the anode corroding toward the copper cathode. The driving force of this corrosion is the difference in cell potential, or electromotive force, of the metals, which drives the electrons from one metal to the other.

Figure 8-3 Uniform Attack



Concentration Cell Attack

Concentration cell attack (Figure 8-6) is caused by differences in the concentration of a solution, such as differences in oxygen concentration or metal-ion concentration. These can occur in crevices, as shown in the example, or under mounds of dirt, corrosion products, or contamination on the

Figure 8-4 Pitting Corrosion

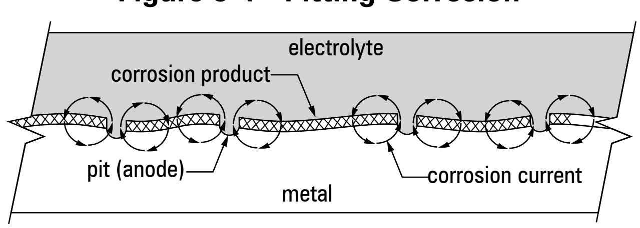


Figure 8-5 Galvanic Corrosion

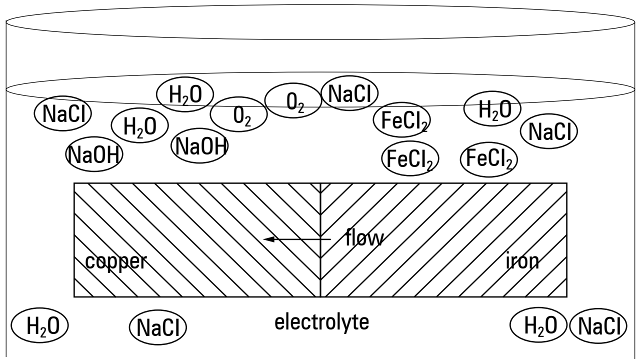


Figure 8-6 Concentration Cells

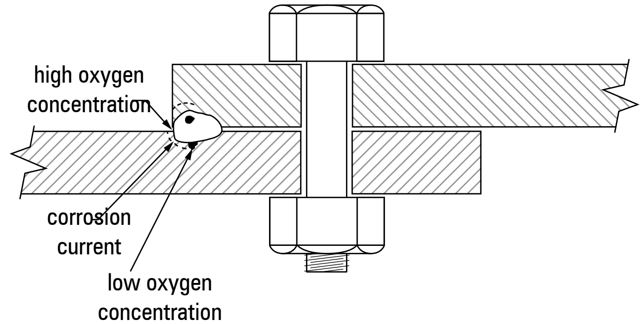


Figure 8-7 Impingement Attack

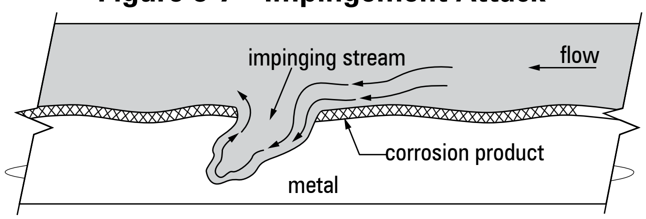
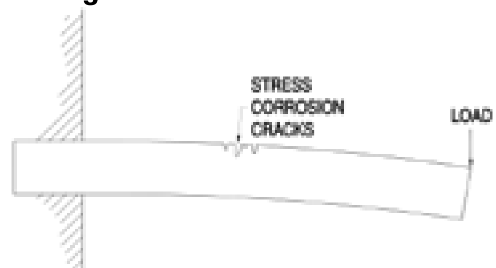


Figure 8-8 Stress Corrosion



metal surface. The area of low oxygen or metal-ion concentration becomes anodic to areas of higher concentration.

Crevice corrosion is a form of concentration cell attack.

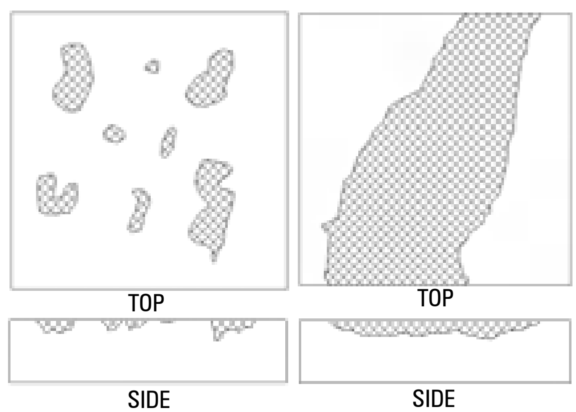
Impingement Attack

Impingement attack, or erosion corrosion (Figure 8-7), is the result of turbulent fluid at high velocity breaking through protective or corrosion films on a metal surface. The corrosion usually forms in a definite direction.

Stress Corrosion Cracking

Stress corrosion cracking (Figure 8-8) results from placing highly stressed parts in corrosive environments. Corrosion causes concentration of the stress, which eventually exceeds the yield strength of the material, and cracking occurs.

Figure 8-9 Plug-Type Dezincification (left) and Layer-Type Dezincification (right)



Selective Attack

Selective attack, or leaching (Figure 8-9), is the corrosive destruction of one element of an alloy. Examples are dezincification of brass and graphitization of cast iron.

Stray Current

Stray current corrosion (Figure 8-10) is caused by the effects of a direct current source such as a cathodic protection rectifier. A protective current may be picked up on a pipeline or structure that is not part of the protected system. This current follows to the other structure and at some point leaves the other structure and travels through the electrolyte (soil or water) back to the protected structure. This causes severe corrosion at the point of current discharge.

Figure 8-10 Stray Current Corrosion

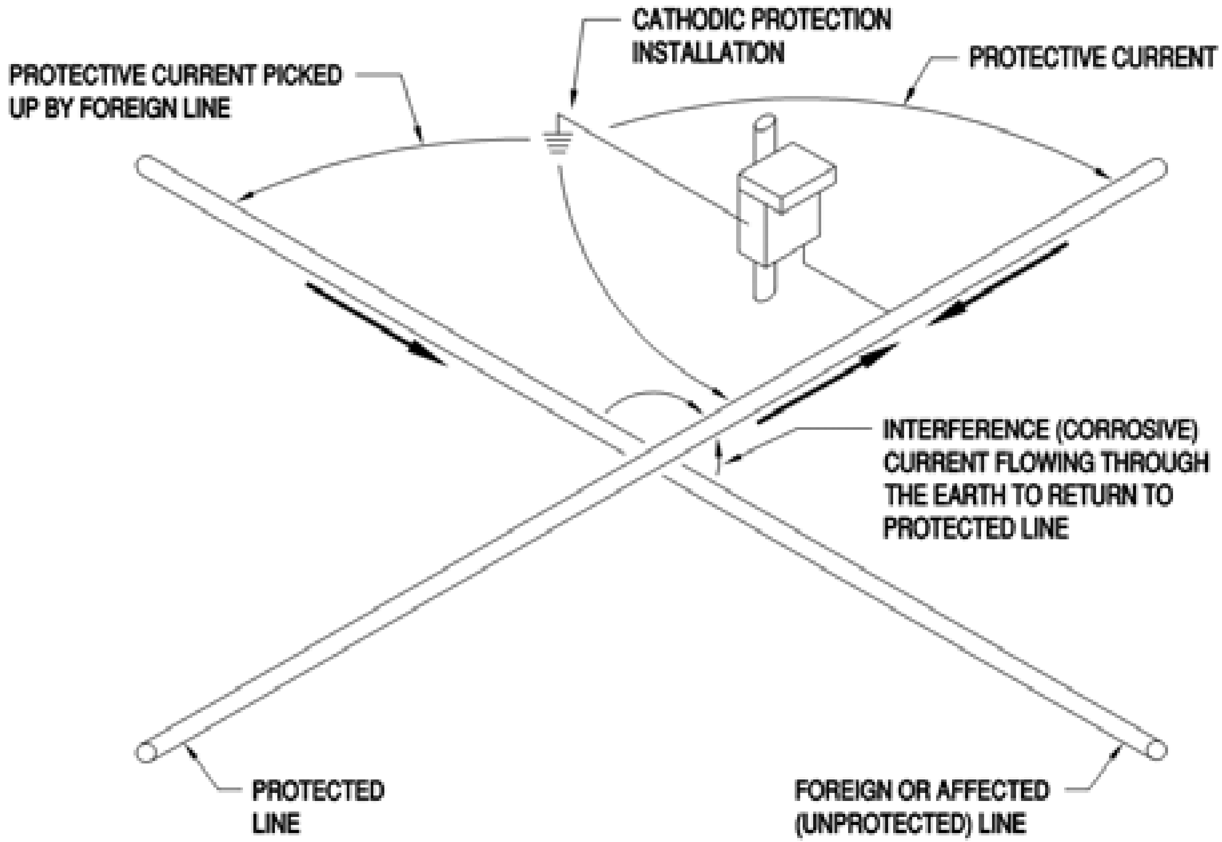
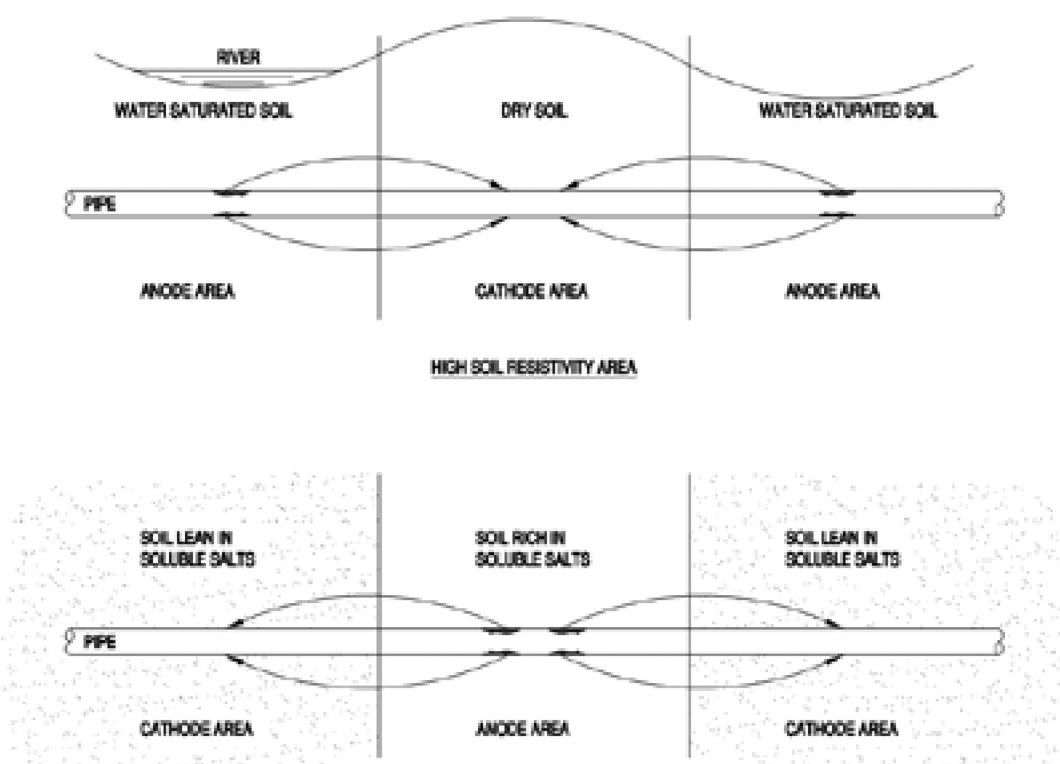


Figure 8-11 Corrosion by Differential Environmental Conditions



Corrosion by Differential Environmental Conditions

Examples of differential environmental cells are shown in Figure 8-11. It should be noted that variations in moisture content, the availability of oxygen, change in soil resistivity, or variations of all three may occur in some cases. As in all corrosion phenomena, changes or variations in the environment are a contributing factor.

THE GALVANIC SERIES

The galvanic series of metals in seawater, listed in Table 8-2, is useful in predicting the effects of coupling various metals. Actual tests at different temperatures and in different environments may yield slightly different results. Metals that are far apart in the series have a greater potential for galvanic corrosion than do metals in the same group or metals near each other in the series. Metals listed above other metals in the series are generally anodic (corrode) to metals listed below them. The relative area of the metals in the couple must be considered along with the polarization characteristic of each metal. To avoid corrosion, a large anode area with a small cathode area is favorable.

Table 8-2 Standard Galvanic Series of Common Metals in Seawater

Anodic End (most corrodible)
Magnesium
Magnesium alloys
Zinc
Galvanized steel
Aluminum 5052H
Aluminum 3004
Aluminum 3003
Aluminum 1100
Aluminum 6053
Alcad aluminum alloys
Cadmium
Aluminum 2017
Aluminum 2024
Low-carbon steel
Wrought iron
Cast iron
Ni-resist
Type 410 stainless steel (active)
50Sn-50Pb solder
Type 304 stainless steel (active)
Type 316 stainless steel (active)
Lead
Tin
Muntz metal (C28000)
Manganese bronze (C67500)
Naval brass (C46400)
Nickel (active)
Inconel (active)
Cartridge brass (C26000)
Admiralty metal (C44300)
Aluminum bronze (C61400)
Red brass (C23000)
Copper (C11000)
Silicon bronze (C65100)
Copper nickel, 30% (C71500)
Nickel (passive)
Inconel (passive)
Monel
Type 304 stainless steel (passive)
Type 316 stainless steel (passive)
Brazing filler metals (silver-copper-zinc alloys)
Silver
Gold
Platinum
Cathodic End

ELECTROMOTIVE FORCE SERIES

An electromotive force is defined as a force that tends to cause a movement of electrical current through a conductor. Table 8-3, known as the electromotive force series, lists the metals in their electromotive force order and defines their potential with respect to a saturated copper-copper sulfite half-cell. This list is arranged according to standard electrode potentials, with positive potentials (greater than 1) for elements that are cathodic to a standard hydrogen electrode and negative potentials (less than 1) for elements that are anodic to a standard hydrogen electrode.

In most cases, any metal in this series will displace the more positive metal from a solution and thus corrode to protect the more positive metal. There are exceptions to this rule because of the effect of ion concentrations in a solution and because of the different environments found in practice. This exception usually applies to metals close together in the series, which may suffer reversals of potential. Metals far apart in the series will behave as expected; the more negative will corrode to the more positive.

In an electrochemical reaction, the atoms of an element are changed to ions. If an atom loses one or more electrons (e-), it becomes an ion that is positively charged and is called a cation (example: Fe2+). An atom that takes on one or more electrons also becomes an ion, but it is negatively charged and is called an anion (example: OH-). The charges coincide with the valence of the elements.

The arrangement of a list of metals and alloys according to their relative potentials in a given environment is a galvanic series. By definition, a different series could be developed for each environment.

FACTORS AFFECTING THE RATE OF CORROSION

The rate of corrosion is directly proportional to the amount of current leaving the anode surface. This current is related to both the potential (voltage) between the anode and cathode and the circuit resistance. Voltage, resistance, and current are governed by Ohm's law, shown in Equation 8-1.

Equation 8-1

$$I = \frac{E}{R}$$

where:
I = Current, A or mA
E = Voltage, V or mV
R = Resistance, ohm (Ω)

Essentially, Ohm's law states that current is directly proportional to the voltage and inversely proportional to the resistance.

Effect of the Metal Itself

For a given current flow, the rate of corrosion of a metal depends on Faraday's law, shown in Equation 8-2.

Equation 8-2

$$w = KIt$$

where:
w = Weight loss
K = Electrochemical equivalent
I = Current
t = Time

For practical purposes, the weight loss typically is expressed in pounds per ampere year (kilograms per coulomb). Loss rates for some common metals are given in Table 8-1. For example, if 1 ampere is discharged from a steel pipeline over a period of one year, 20 pounds (6.1 kilograms) of steel will be lost.

Corrosion of metals in aqueous solutions also is influenced by the following factors: acidity, oxygen content, film formation, temperature, velocity, and homogeneity of the metal and the electrolyte. These factors are discussed below, since they are factors that can be measured or detected by suitable instruments.

Acidity

The acidity of a solution represents the concentration of hydrogen ions, or the pH. In general, low pH (acid) solutions are more corrosive than neutral (7.0 pH) or high pH (alkaline) solutions. Iron and steel, for example, suffer accelerated corrosion in solutions where the pH is 4.5 or less. Exceptions to this rule are amphoteric materials such as aluminum and lead, which corrode more rapidly in alkaline solutions.

Table 8-3 Electromotive Force Series

Metal	Potential of Metal
Magnesium (galvomag alloy)[a]	1.75
Magnesium (H-I alloy)[a]	1.55
Zinc	1.10
Aluminum	1.01
Cast iron	0.68
Carbon steel	0.68
Stainless steel type 430 (17% Cr)[b]	0.64
Ni-resist cast iron (20% Ni)	0.61
Stainless steel type 304 (18% Cr, 8% Ni)[b]	0.60
Stainless steel type 410 (13% Cr)[b]	0.59
Ni-resist cast iron (30% Ni)	0.56
Ni-resist cast iron (20% Ni+Cu)	0.53
Naval rolled brass	0.47
Yellow brass	0.43
Copper	0.43
Red brass	0.40
Bronze	0.38
Admiralty brass	0.36
90:10 Cu-Ni+ (0.8% Fe)	0.35
70:30 Cu-Ni+ (0.06% Fe)	0.34
70:30 Cu-Ni+ (0.47% Fe)	0.32
Stainless steel type 430 (17% Cr)[b]	0.29
Nickel	0.27
Stainless steel type 316 (18% Cr, 12% Ni, 3% Mo)[b]	0.25
Inconel	0.24
Stainless steel type 410 (13% Cr)[b]	0.22
Titanium (commercial)	0.22
Silver	0.20
Titanium (high purity)	0.20
Stainless steel type 304 (18% Cr, 8% Ni)[b]	0.15
Hastelloy C	0.15
Monel	0.15
Stainless steel type 316 (18% Cr, 12% Ni, 3% Mo)[b]	0.12

Note: Based on potential measurements in sea water, velocity of flow 13 ft/s (3.96 m/s), temperature 77°F (25°C).
a Based on data provided by the Dow Chemical Co.
b The stainless steels, as a class, exhibited erratic potentials depending on the incidence of pitting and corrosion in the crevices formed around the specimen supports. The values listed represent the extremes observed and, due to their erratic nature, should not be considered as establishing an invariable potential relation among the alloys that are covered.

Oxygen Content

The oxygen content of aqueous solutions causes corrosion by reacting with hydrogen at the metal surface to depolarize the cathode, resulting in the exposure of additional metal. Iron and steel corrode at a rate proportional to the oxygen content. Most natural waters originating from rivers, lakes, and streams are saturated with oxygen. The reduction of oxygen is part of the corrosion process in most of the corrosion found in practice. The possibility of corrosion being influenced by atmospheric oxygen should not be overlooked in design work.

Film Formation

Corrosion and its progress often are controlled by the corrosion products formed on the metal surface. The ability of these films to protect metal depends on how they form when the metal is originally exposed to the environment. Thin, hard, dense, tightly adherent films afford protection, whereas thick, porous, loose films allow corrosion to proceed without providing any protection. As an example, the iron oxide film that usually forms on iron pipe in contact with water is porous and easily washed away to expose more metal to corrosion. The effective use of corrosion inhibitors in many cases depends on the type of film they form on the surface to be protected.

Temperature

The effect of temperature on corrosion is complex because of its influence on other corrosion factors. Temperature can determine oxygen solubility, the content of dissolved gases, and the nature of protective film formation, thereby resulting in variations in the corrosion rate. Generally, in aqueous solutions, higher temperatures increase corrosion rates. In domestic hot water systems, for example, corrosion rates double for each 10°F (6°C) rise above 140°F (60°C) water temperature. Temperature also can reverse potentials, such as in the case of zinc-coated iron at approximately 160°F (71°C) water temperature, when the zinc coating can become cathodic to the iron surface, accelerating the corrosion of iron.

Velocity

In many cases, velocity of the solution controls the rate of corrosion. Increasing velocity usually increases corrosion rates. The more rapid movement of the solution causes corrosion chemicals, including oxygen, to be brought into contact with the metal surface at an increased rate, and corrosion products or protective films are carried away from the surface at a faster rate.

Another important effect of high velocity is that turbulence can result in local differential oxygen cells or metal-ion concentration cells, causing severe local attack. High velocities also tend to remove protective films, causing rapid corrosion of the metal surfaces.

Homogeneity

The homogeneity of the metal and of the electrolyte is extremely important to corrosion rates. In general, nonhomogeneous metals or electrolytes cause local attack or pitting, which occurs at concentrated areas and is, therefore, more serious than the general overall corrosion of a material. Examples include concentration cells, galvanic cells, microstructural differences, and differences in temperature and velocity.

CORROSION CONTROL

Corrosion control is the regulation, control, or prevention of a corrosion reaction for a specific goal. This may be accomplished through any one or a combination of the following methods: material selection, design to reduce corrosion, passivation, coating, cathodic protection, and inhibitors (water treatment).

Material Selection

Material selection is the most common method of preventing corrosion. Corrosion resistance, along with other important properties, must be considered in selecting a material for any given environment. When a material is to be specified, the following steps should be used:

1. Determine the application requirements.
2. Evaluate possible material choices that meet the requirements.
3. Specify the most economical method.

Factors to be considered include:

- Material cost
- Corrosion-resistance data
- Ability to be formed or joined by welding or soldering
- Fabricating characteristics (bending, stamping, cutting, etc.)
- Mechanical properties (tensile and yield strength, impact resistance, hardness, ductility, etc.)
- Availability of material
- Electrical or thermal properties
- Compatibility with other materials in the system
- Specific properties, such as nuclear radiation absorption and low- or high-temperature properties

Initial cost is an important consideration, but the life cost as applied to the system as a whole is more important. For example, if an inexpensive part must be replaced periodically, the cost of downtime and labor to install it may make the inexpensive part the most expensive part when all factors are considered.

Design to Reduce Corrosion

Corrosion can be eliminated or substantially reduced by incorporating some basic design suggestions. The following design suggestions can minimize corrosive attack.

- Provide dielectric insulation between dissimilar metals, when dissimilar metals such as copper and steel are connected together (e.g., at a water heater). In a pipeline, for example, dielectric insulation should be installed to prevent contact between the two metals. Without such insulation, the metal higher in the galvanic series (steel) will suffer accelerated corrosion because of the galvanic cell between copper and steel. When designing systems requiring dissimilar metals, the need for dielectric insulation should be investigated.
- Avoid surface damage or marking. Areas on surfaces that have been damaged or marked can initiate corrosion. These areas usually become anodic to the adjacent untouched areas and can lead to failures. The designer should consider this when machining or fabrication is needed so unnecessary damage does not occur.
- Do not use excessive welding or soldering heat. Areas that are heated excessively during welding or soldering can result in changes to a metal's microstructure. Large grain growth can result in accelerated corrosion. The grain growth changes the physical properties of the metal and results in non-homogeneity of the metal wall. Designs can minimize this effect by using heavier wall thicknesses in areas to be welded.
- Crevices should be avoided. Concentration cells usually form in crevices and can cause premature failures. Regardless of the amount of force applied in bolting two plates together, it is not possible to prevent the gradual penetration of liquid into the crevice between the plates. This forms concentration cells where the fluid in the crevices is depleted and forms anodic areas. The most practical way of avoiding crevices is to use welded connections in place of mechanical fasteners.
- Avoid heat or chemicals near metal walls.
- Prevent the condensation of moisture from the air on cold metal surfaces. The cold metal surface should be thermally insulated if possible.
- Install beams, angles, etc. so they drain easily and cannot collect moisture, or provide drain holes.

Passivation

Passivation is the accelerated formation of a protective coating on metal pipe (primarily stainless steel) by contact with a chemical specifically developed for this purpose. A thin protective film is formed when reacting and bonding to the metal. This occurs at the point of potential metal loss (corrosion).

Passivation prevents corrosion in the remaining pits left from free machining and the residual that gets trapped therein. Sulfides and iron particles act as initiation sites to corrosion. This is not a scale removal method; thus, surface cutting tool contaminants need to be removed prior to the passivation process. The use of citric acid for passivation is an alternate to using nitric acid in the stainless steel industry. Due to it being safe, organic, and easy to use, citric acid has gained popularity.

Care must be taken to ensure the balance of time, temperature, and concentrations to avoid flash attack, which is caused by contaminated passivating solutions containing high levels of chlorides. Flash attack causes a heavily etched, dark surface rather than an oxide film to occur. Passivating solutions should be free of contaminants to prevent oxide film formation.

New methods are being discovered and tested to protect other material surfaces such as aluminum. Periodic testing after passivation ensures that the metal surfaces are maintained.

Coating

Materials exposed to the atmosphere that do not have the ability to form natural protective coatings, such as nickel and aluminum, are best protected by the application of an artificial protective coating. The coating is applied to keep the corroding material from the surface at all times.

One of the most important considerations in coating application is surface preparation. The surface must be properly cleaned and free of scale, rust, grease, and dirt to allow the coating to bond properly to the surface. The best coating in the world will give unsatisfactory results if the surface is poorly prepared. The surface may require pickling, sandblasting, scratch brushing, or flame cleaning to properly prepare it for the application of a coating.

The actual coating that is applied depends on the application and may be either metallic (such as galvanizing) or nonmetallic organic (such as vinyl or epoxy). The coating may actually be a coating system, such as primer, intermediate coat (to bond the primer and top coat), and finish or top coat. Coating manufacturers' literature should be consulted regarding coating performance, surface preparatory application, and handling of coated surfaces.

For atmospheric exposure, coatings alone are relied on to provide protection in many applications. Coatings by themselves, however, are not considered adequate for corrosion control of buried or submerged structures because there is no such thing as a perfect coating. All coatings have inherent holes or holidays. Often the coating is damaged during installation or adjacent construction. Concentrated corrosion at coating breaks often causes failures sooner on coated structures than on bare ones. In stray current areas, severe damage occurs frequently on coated pipe because of the high density of the discharge current at coating faults.

The most important function of coating is in its relation to cathodic protection. Cathodic protection current requirements, and hence operating costs, are proportional to the amount of bare surface exposed to the soil. When structures are coated, it is necessary to protect only the small areas of coating faults. Careful applications of coating and careful handling of coated structures lead to maximum coating effectiveness, thus minimizing protective current requirements and costs. Also, lower current usage generally means less chance of stray current effects on other structures.

Cathodic Protection

Cathodic protection is an effective tool to control corrosion of metallic structures, such as water lines and tanks buried or immersed in a continuous electrolyte, by making the metal structure the cathode and applying direct current from an anode source. By making the entire structure the cathode, all anode areas from the local corrosion cells are eliminated, and direct current is prevented from leaving the structure, thereby stopping further corrosion.

The most common sacrificial anode is made of magnesium. Magnesium has the highest natural potential of the metals listed in the electromotive series and, therefore, has the greatest current-producing capacity of the series. Zinc anodes sometimes are used in very low-resistivity soils where current-producing capacity such as that of magnesium is not required.

The two proven methods of applying cathodic protection are with galvanic anodes and impressed current systems. The basic difference between the two types of protection is as follows: The galvanic anode system depends on the voltage difference generated between the anode material and the structure material to cause a flow of DC to the structure. The impressed current system utilizes an AC/DC rectifier to provide current to relatively inert anodes and can be adjusted to provide the necessary voltage to drive the required current to the structure's surfaces. The choice of the proper system depends on a number of factors. Each has its advantages, which are discussed below.

Galvanic Anodes

Galvanic anodes are used most advantageously on coated structures in low soil resistivity where current requirements are low. Some advantages of using galvanic anodes are as follows:

- Relatively low installation cost
- No external power source required
- Does not require much maintenance
- Does not adversely affect foreign structures
- Can be installed with pipe, minimizing right-of-way cost

Some disadvantages of using galvanic anodes are as follows:

- Low driving voltage (approximately 0.15 V)
- Current output limited by soil resistivity
- Not applicable for large current requirements

The galvanic anode system of an active metal anode, such as magnesium or zinc, is placed in the electrolyte (soil or water) near the structure and connected to it with a wire. This is illustrated in Figures 8-12 and 8-13. Cathodic protection is achieved by current flow due to the potential difference between the anode (metal) and the cathode (structure). A corrosion cell or battery is created, and current flows from the corroding anode material through the soil to the cathode or protected structure. Hence, the galvanic anode is caused deliberately to waste itself to prevent corrosion of the protected structure. Because the galvanic anode system relies on the difference in voltage between two metals, which in most cases is limited to 1 V or less, the current generated by the anodes is usually low (approximately 0.1 to 0.5 A per anode).

Galvanic anode systems usually are used for structures having small current requirements, such as well-coated, small-diameter pipes, water heaters, sewage lift stations, some offshore structures, and structures in congested areas where currents must be kept low to avoid detrimental effects on other structures. Galvanic anodes may be installed in banks at specific locations. They are, however, usually distributed around protected structures because of their limited current output.

As an example, considering a pipe-to-soil potential of 0.85 V as protection for a steel pipeline, the driving potential for zinc anodes is 0.25 V and for magnesium

Figure 8-12 Cathodic Protection by the Sacrificial Anode Method

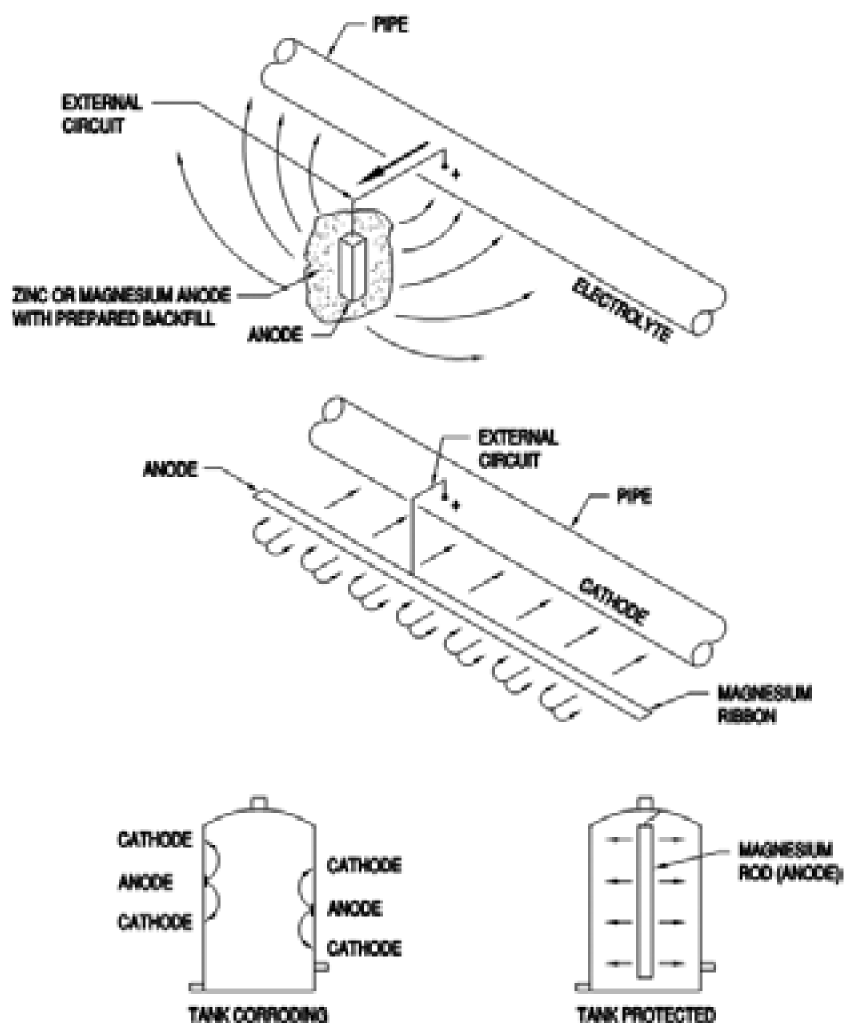
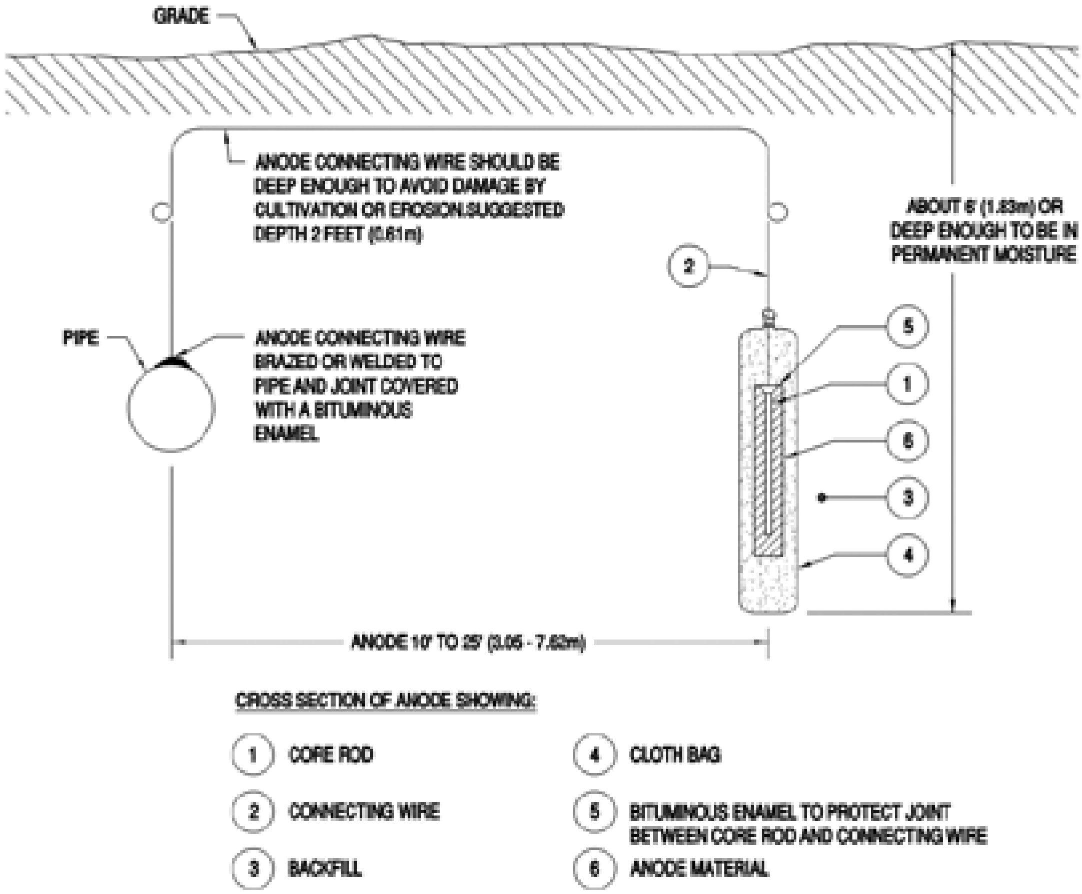


Figure 8-13 Typical Sacrificial Anode Installation



is 500 A-h/lb (1,795 C/kg). The actual life of anodes of a given weight at a known current output can be calculated using the following formulas:

Equation 8-3

$$LM = \frac{57.08 \times w}{i}$$

Equation 8-4

$$LZ = \frac{38.2 \times w}{i}$$

where:

LM = Life of magnesium anode, years
LZ = Life of zinc anode, years
w = Weight of anode, lb (kg)
i = Output of anode, mA

The controlling factor for the current output of zinc and magnesium anodes is soil resistivity. When soil resistivity is known or determined, then the current output of variously sized anodes for either magnesium or zinc can be estimated as follows:

Equation 8-5

$$iM = \frac{150{,}000 \times f}{p}$$

Equation 8-6

$$iZ = \frac{150{,}000 \times f \times 0.27}{p}$$

where:

iM = Current output of magnesium, mA
iZ = Current output of zinc, mA
p = Soil resistivity, Ω-cm
f = Anode size factor

The cost of galvanic cathodic protection generally favors the use of zinc anodes over magnesium at soil resistances less than 1,500 ohm-cm and the use of magnesium at soil resistances more than 1,500 ohm-cm.

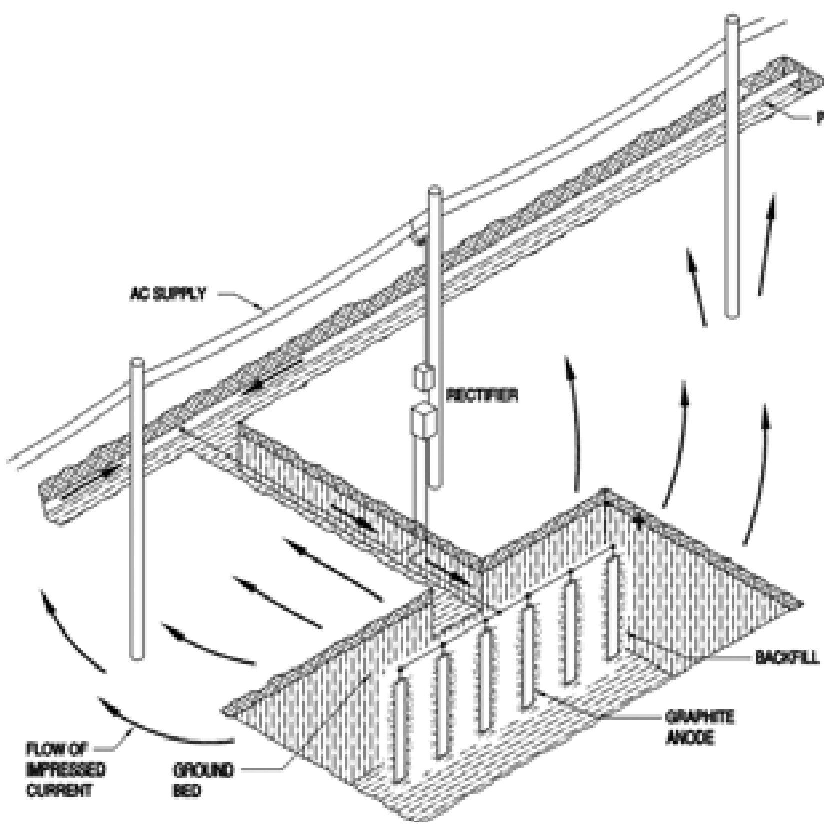
Impressed Current

The impressed current system, illustrated in Figure 8-14, differs substantially from the galvanic anode system in that it is externally powered, usually by an AC/DC rectifier, which allows great freedom in adjusting the current output. Current requirements of several hundred amperes can be handled by impressed current systems. The impressed current system usually consists of graphite or high-silicon iron anodes connected to an AC/DC rectifier, which, in turn, is wired to the structure being protected. The current output is determined by adjusting the rectifier voltage to provide current as required. The system is not limited by potential difference between metals, and voltage can be adjusted to provide an adequate driving force to emit the necessary current. Impressed current systems are used for structures having large current requirements, such as bare pipe, tank farms, large-diameter cross-country pipelines, cast iron water lines, and many offshore facilities.

Impressed current cathodic protection has the following advantages:

- Large current output
- Voltage adjustment over a wide range
- Can be used with a high soil resistivity environment

Figure 8-14 Cathodic Protection by the Impressed Current Method



- Can protect uncoated structures
- Can be used to protect larger structures

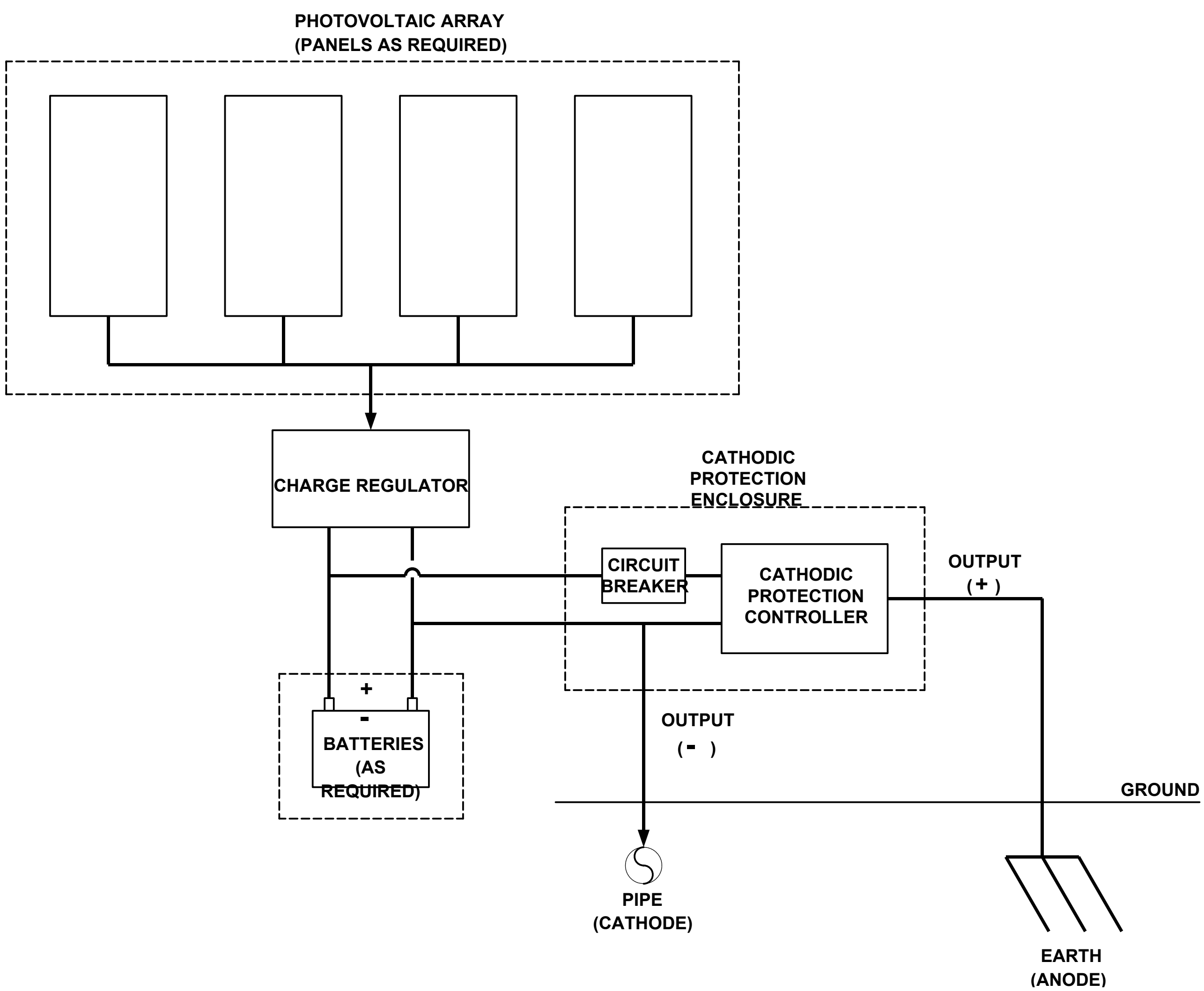
Impressed current cathodic protection has the following disadvantages:

- Higher installation and maintenance costs
- Power costs
- Can cause adverse effects (stray current) with foreign structures

Solar-powered photovoltaic systems for cathodic protection are now available at a reasonable cost due to advances in the technology. A system consists of solar photovoltaic panels, a charge controller, high capacity batteries, a cathodic protection control unit, and a DC array combiner box as illustrated in Figure 8-15. The system needs to be designed for the particular location, and system performance is modeled taking into account the working temperature, voltage, battery efficiency, system losses, and derating factors. Batteries need to be incorporated in these systems to store the excess electrical energy generated by the photovoltaic array during the day to provide power at night or periods of low sunlight. The batteries' capacity is calculated to provide enough power for normal day-to-day operation at the worst time of the year plus a reserve capacity for periods of bad weather. The main advantage of this type of system is the use of solar power, which may work well for remote locations.

When designing impressed current cathodic protection systems, the engineer must determine the type and condition of the structure. Obtaining knowledge of the presence or lack of coating, size of the structure, electrical continuity, and location is a necessary first step. Next, the availability of power and ease of installing the ground bed must be

Figure 8-15 Cathodic Protection by the Impressed Current Method Using Solar Power



determined. It also is generally necessary to perform a current requirement test utilizing a portable DC generator or storage batteries, which defines an apparent direct current requirement to protect the structure. Tests to determine any adverse effects also should be conducted on foreign structures at this time. Any current drained to foreign structures should be added to the current requirements.

After the total current requirement is known, the ground bed is designed so the circuit resistance is relatively low. The actual ground bed design depends on soil resistivity. A number of empirical formulas are available to determine the number of parallel anodes required for a certain circuit resistance.

Cathodic Protection Criteria

Criteria for determining adequate cathodic protection have been established by NACE International. These criteria are based on measuring structure-to-electrode potentials with a copper-sulfate reference electrode.

Cathodic protection serves its purpose best, and is by far the most economical, when it is properly coordinated with the other methods of corrosion control, especially coating. In general, the least expensive, easiest to maintain, and most practical system is to apply a good-quality coating to a new structure and then use cathodic protection to eliminate corrosion at the inevitable breaks in the coating. The reason for this is that it takes more current and anodes to protect bare metal than it does to protect coated metal. The amount of protective current required is proportional to the area of metal exposed to the electrolyte.

In addition to using coatings, it is necessary to ensure continuity of the structures to provide protection of the whole structure. This also prevents undesirable accelerated stray current corrosion to the parts of the structure that are not electrically continuous. Therefore, all non-continuous joints, such as mechanical, push-on, or screwed joints in pipelines, must be bonded. All tanks in a tank farm or piles on a wharf must be bonded to ensure electrical continuity.

Other important components used in effective cathodic protection systems are dielectric insulation and test stations. Dielectric insulation sometimes is used to isolate underground protected structures from aboveground structures to reduce the amount of cathodic protection current required. Care must be taken to avoid short-circuiting (bypassing) the insulation, or protection can be destroyed. Test stations are wires attached to the underground structure (pipeline or tank) to provide electrical contact for the purpose of determining protection effectiveness. Test stations also are used to make bonds or connections between structures when required to mitigate stray current effects.

Costs of Cathodic Protection

Corrosion of underground, ferrous metal structures can be economically controlled by cathodic protection. Cathodic protection costs are added to the initial investment since they are a capital expense. To be economically sound, the spending of the funds must yield a fair return over the expected life of the facility.

Protecting a new facility requires an initial increase of perhaps 10 percent in capital investment. Payout time is usually 10 to 15 years; thereafter, appreciable savings accrue due to this investment, which prevents or reduces the frequency of leaks. Effective corrosion control through the application of cathodic protection reduces the leak frequency for a structure to a minimum with minimal cost.

Cathodic protection systems must be properly maintained. Rectifier outputs must be checked monthly. Changes or additions to the protected structure must be considered to see if changes or additions to the cathodic protection system are required. Annual inspections by a corrosion engineer are required to ensure that all malfunctions are corrected and that cathodic protection continues unhampered.

Inhibitors (Water Treatment)

Plant utility services such as boiler feed water, condensate, refrigerants, and cooling water require the addition of inhibitors or water treatment. Boiler feed water must be treated to maintain proper pH control, dissolved solid levels, and oxygen content. Condensate requires treatment to control corrosion by oxygen and carbon dioxide. Brine refrigerants and cooling water in closed-loop circulating systems require proper inhibitors to prevent corrosion.

Water treatment may consist of a simple adjustment of water hardness to produce a naturally forming carbonate films, which, if properly adjusted, will form to a controlled thickness just sufficient to prevent corrosion by keeping water from contacting the metal surface. In cooling water, where hardness control is not practical, inhibitors or film-forming compounds may be required.

Sodium silicate and sodium hexametaphosphate are examples of film-forming additives in potable water treatment. A tight, thin, continuous film of silica (water glass) or phosphate adheres to the metal surface, preventing pipe contact with the water. (Phosphate additives to potable water are limited or prohibited in some jurisdictions.)

In closed-loop cooling systems and systems involving heat-exchange surfaces, it may not be possible to use film-forming treatment because of the detrimental effects on heat transfer. In these cases, inhibitors are used. These control corrosion by increasing polarization of the anodic or cathodic surfaces and are called anodic or cathodic inhibitors respectively. The anodic or cathodic surfaces are covered, preventing completion of the corrosion cell by eliminating either the anode or cathode.

When water treatment or inhibitors are used, a testing program must be established to ensure that proper additive levels are maintained. In some cases, continuous monitoring is required. Also, environmental considerations in local areas must be determined before additives are used or before any treated water is discharged to the sanitary sewer or storm drainage system.

EROSION/CORROSION OF COPPER PIPING SYSTEMS

While copper is well known for its excellent resistance to corrosion, several things can damage copper piping systems. One of the more common causes of damage to a copper piping system is erosion/corrosion.

Erosion/corrosion is a mechanically induced failure, which may be caused by any or all of the following conditions:

- Water at high velocity: An undersized piping system or an oversized circulating pump may cause high water velocity. The installation of a smaller capacity pump or a throttling bypass on the existing pump should help lower the velocity of the water in the system. The recommended velocity for cold water in a copper tube system is 5–8 feet per second (fps). The recommended maximum velocity for hot water in a copper tube system is 4–5 feet per second.
- Numerous, abrupt changes in direction in the piping system: Where structural conditions cause numerous directional changes, long-radius (1.5 x diameter) fittings should be used to minimize the interruption of laminar flow.
- Lack of reaming of the tube ends: Burrs left on the interior diameter of the tube can interrupt laminar flow, resulting in localized high water velocity and cavitation. In the area immediately downstream of the unreamed tube ends, the local flow pressure can be drastically reduced due to the sharp burr in the flow stream. This decrease in local flow pressure allows air bubbles entrained in the water to escape and scour the tube/fitting wall, creating pits that eventually lead to failure.
- Protrusions in the flow stream: These can be caused by excessive lumps of solder/brazing material, improperly fabricated tees (a branch protruding into the run of pipe), etc. These protrusions can also interrupt laminar flow, resulting in localized high water velocity and cavitation.
- Excessive water temperature: Heating the water above 140°F (60°C) can accelerate the process of erosion/corrosion. To avoid “cold” hot water concerns, insulation can be added to the hot water supply lines.
- Excessive amounts of dissolved gases, vapors, or suspended solids in the water conveyed: At high velocities these gases, vapors, or solids can impinge on the metal surface, causing erosion/corrosion.

Short of visual inspection of the interior tube surfaces, there is no sure way to determine if a system is being affected by erosion/corrosion. However, in some cases noise is created in the system, especially in the area of joints, pumps, valves, and components. This noise is generally characterized as sounding like gravel bouncing through the line.

Upon visual examination of interior tube surfaces, areas of severe horseshoe-shaped pitting usually characterize damage due to erosion/corrosion. These pits are generally undercut, with the deepest section of the pit occurring at its upstream end with the horseshoe opening in the direction of flow. In cases where prolonged damage has occurred, distinct horseshoe-shaped pits may no longer be distinguishable, giving way to entire areas of the tube wall that have been worn away. These areas are generally clean, free of corrosion products, and may have a rippled appearance.

Although it is virtually impossible to rehabilitate a piping system that is experiencing erosion/corrosion-related failures, short of replacing joints and affected areas, a number of recommendations can be made to mitigate the erosion/corrosion of copper tube systems. The water flow rates should be measured in the affected sections of the system and, if necessary, reduced to ensure that they do not routinely exceed 5–8 fps in cold water systems and 4–5 fps in hot water systems. References such as the Copper Development Association's *Copper Tube Handbook* provide basic information regarding desirable flow rates.

The water chemistry in the affected system should also be checked for excessive amounts of suspended gases, vapors, and solids. Also, system temperature should be monitored to ensure that temperature spikes are not occurring. As the temperature of the water in the system approaches the boiling point of water, localized areas of low pressure in the piping system may allow the water to flash into steam, greatly increasing the possibility of erosion/corrosion.

Finally, plumbing technicians must use industry standard workmanship when installing copper tube systems. Cut tube ends must be properly reamed/deburred prior to soldering. Adhering to the general guidelines for tube installation, joint preparation, and soldering presented in the *Copper Tube Handbook* and ASTM B828: *Standard Practice for Making Capillary Joints by Soldering of Copper and Copper Alloy Tube and Fittings* should eliminate many of the erosion/corrosion concerns associated with improper workmanship. This condition is not specific to copper tube, but can affect other materials as well. However, when erosion/corrosion does occur in copper tube, it is readily identifiable by the distinctive horseshoe-shaped pitting throughout the inside of the tubes.

CORROSION OF MIXED-METAL FIRE SPRINKLER SYSTEMS

The capability of mixed metals specifically to resist galvanic corrosion is sometimes questioned. The concern expressed focuses primarily on composite systems where copper tube branch lines and cross mains are used in connection with steel pipe feed mains, risers, and standpipes. Other areas of concern are the use of steel band or ring hangers to support copper tube, the practice of threading copper tube through steel sleeves for wall penetrations, and the potential for galvanic corrosion between copper tube and metal building studs in interior wall partitions. Frequently, the erroneous assumption is made that copper components corrode preferentially. This is not accurate. Should galvanic corrosion occur, the steel or cast iron components are normally attacked. The protection of the ferrous materials via dielectric separation, protective insulating tape, sleeves, or grommets must be evaluated. The beneficial results achieved versus the attendant increased costs of such protective measures must also be evaluated.

A standard galvanic series (a practical simplification of the electrochemical series of the elements) provides a first approximation of galvanic corrosion potential and is a starting point for understanding the problem. In a standard galvanic series, the common metals are ranked from the most active (anodic) to the least active (cathodic). Generally, when two dissimilar metals are coupled in the presence of an electrolyte (such as water), the potential for accelerated corrosion of the more active metal in the couple increases in proportion to the position of the metals in the standard galvanic series.

Using the standard galvanic series for common metals in seawater (refer back to Table 8-2), aluminum, which is ranked second in activity to magnesium, would exhibit a greater potential for galvanic corrosion when in direct contact with copper, which is ranked in the lower third of the series, than iron (steel), which is ranked in the middle third of the series.

The amount or severity of galvanic corrosion, however, cannot be predicted simply on the basis of the relative ranking of the two metals forming the couple in a standard galvanic series. The rate and extent of corrosion potential also depend on:

- The electrical resistance of the joint between the metals
- The conductivity of the electrolyte
- The relative areas or masses of the anodic metal with respect to the cathodic metal
- The polarization of the anodic metal through the buildup of adherent surface films

Considering each of these factors in the context of an automatic fire sprinkler system, the following can be interpreted:

- Black steel pipe is anodic with respect to copper tube. However, the close proximity of the two metals in the standard galvanic series indicates that the corrosion potential is only moderate.
- Where the transition from copper tube to steel pipe employs a standard gasketed flanged fitting, the electrical resistance of the joint increases, while the potential for corrosion decreases.

The use of threaded transitional fittings of either wrought or cast copper alloy is also appropriate when joining copper tube and steel pipe conductors. The pipe dope or tape sealant, which is normally applied to the threads, tends to increase the joint's electrical resistance, further decreasing the corrosion potential.

In a wet pipe sprinkler system, the standing water condition tends to reduce the aggressive character of the electrolyte (conductivity of the water) as the corrosive elements in the water react with the pipe or tube to form superficial surface films. This is unlike the situation encountered in domestic and process water distribution systems, where intermittent flow tends to replenish the strength of the electrolyte.

In dry pipe sprinkler systems, particularly where positive drainage is not ensured, the potential for galvanic corrosion may increase slightly in those portions of the system where water collects in the presence of a copper-steel couple, which acts as a catch basin.

The relative masses of the metals in contact have a significant impact on the galvanic corrosion potential. When the mass of the copper is small in comparison to the mass of the steel, the corrosion potential is relatively low. For example, no special precautions are taken when installing bronze sprinkler heads in either cast iron or malleable iron fittings. Bronze-bodied valves are frequently installed in steel pipe sprinkler systems without exercising special protective measures. In large iron-bodied valves, bronze seats, wedges, and stems are commonly employed.

Since economics tend to dictate the use of smaller-diameter, lighter-weight copper tube branch lines and cross-mains in conjunction with steel pipe feed mains and risers, the mass or area of the steel pipe portions of the system tends to be relatively large in comparison to the copper tube portion of the system, thus reducing the potential for significant corrosion.

Polarization of the anodic metal through the buildup of adherent surface films is probably not a factor.

In essence, when all factors are weighed, the potential for significant corrosion of steel pipe in a composite copper/steel pipe fire sprinkler system is relatively low, and the requirement for dielectric separation usually is not warranted, unless the mass of the steel is small in comparison to the mass of the copper and intermittent water flow is permitted within the system, thus replenishing the electrolyte. Routine inspection, testing, and flushing, or other infrequent maintenance that introduces fresh electrolytes into the system, are not a significant factor. The inherent corrosion-resistant properties of the copper metals indicate that system flushing of all-copper systems need not be completed on the same frequency as normally required for the flushing of corrosive scale and rust from all-steel systems.

Copper fire sprinkler systems are frequently concealed within the interior stud wall partitions. When metal building studs are employed, the copper tube is normally threaded through an opening in the web of the metal stud. A common field practice permits the tube to rest on the edge of the web opening, thereby eliminating the need for additional hangers. Since the water within the fire sprinkler system is stagnant, it will assume the ambient temperature found within the wall partition, with the result that condensation will not collect on the outside surface of the copper tube. Without the presence of moisture at the point of contact between the copper tube and the metal building stud, galvanic corrosion should not occur. The requirement for protective insulating sleeves or grommets, or the application of tape or other insulating material at the point of contact, may not be warranted in this instance. Care should be exercised, however, to ensure that the copper tube is not abraded when it is threaded through punched or drilled openings in the metal building stud during installation of the fire sprinkler system.

Similarly, the use of steel band or ring hangers, either plain or cadmium plated, for the support of copper tube and steel sleeves (for wall penetrations) that are in contact with copper tube will normally prove satisfactory, except in those instances where the contact surfaces are frequently or continuously moist. Laundries, dye houses, piers, and wharves are a few examples of locations where plain steel hangers should not be employed in conjunction with copper tube. Plain steel sleeves should not be employed in conjunction with copper tube to penetrate foundation walls or any other walls where the presence of moisture could be expected to occur unless a suitable insulating material is installed to minimize or prevent corrosion of the steel component.

Economics and modern building practices and techniques have spurred the rapid growth of copper tube and fitting use in fire sprinkler system installations where copper tube and steel pipe are joined or the two metals are placed in direct contact. No cases of galvanic corrosion in these systems have been reported, and none are anticipated where all factors have been considered and rational judgments are made.

While it is acknowledged that significant galvanic corrosion potential will not occur simply by the contact or joining of copper and steel materials, reasonable care must be exercised in determining the desirability of isolating the contact surfaces for each individual application. A blanket requirement to insulate the contact surfaces would place unnecessary additional costs on the fire sprinkler system installation and in most typical applications would afford negligible additional protection.

MICROBIOLOGICALLY INFLUENCED CORROSION

The deterioration of metallic materials by the activities of various microorganisms (microbes), hereinafter referred to as microbiologically influenced corrosion (MIC), is a ubiquitous problem that occurs in freshwater, brackish water, and seawater environments. MIC can have a wide range of short-term to long-term deleterious effects on water wells; these include, but are not limited to, dramatically reducing the useful life of the water well casing and screen and causing a marked increase in the cost to operate a well due to its effects (i.e., lowered specific capacity, reduced well efficiency, and higher power consumption). MIC can result in pitting, crevice corrosion, selective dealloying, stress corrosion cracking, and underdeposit corrosion. MIC can occur in other locations than wells where proper environmental conditions exist.

MIC is an interesting and complex topic that has been the subject of many studies regarding its occurrence, treatment, and effects. Much useful information is available on MIC in a wide variety of professional publications, texts, and the Internet. The following provides a brief, concise overview of MIC. Those who require a detailed explanation of MIC are encouraged to seek out pertinent information from any of the references listed herein and others.

Mechanism

MIC occurs as microbes grow and metabolize in either aerobic or anaerobic conditions. Microbes that rely on oxygen are referred to as aerobic; those that can live in environments with little or no oxygen are anaerobic. Table 8-4 presents a brief list of some microbes that are associated with MIC. As microbes go about their existence, they regularly produce gelatinous slimes, metabolites (e.g., organic acids, sulfates, and sulfide) that lead to aggressive environments for metals, and microhabitats suitable for the proliferation of other bacteria species (e.g., sulfate-reducing bacteria). Microbes also participate in corrosive electrochemical reactions that can start or speed up electrode reaction.

MIC affects metallic surfaces in a unique manner. Whereas general corrosion affects an entire surface, MIC is localized. The microbes initiate the process with a search for a suitable place for habitation. They seek out irregularities on the surface of the well casing and/or screen where they can attach themselves. Once in residence, they begin their

Table 8-4 Bacteria Known to Cause MIC

Genus of Species	pH	Temperature Range, °C	Oxygen Requirement	Metals Affected
Desulfovibrio	4–8	10–40	Anaerobic	Iron, steel, stainless steels, aluminum, zinc, and copper alloys
Desulfotomaculum	6–8	10–40 (some 45–75)	Anaerobic	Iron and steel, stainless steels
Desulfomonas		10–40	Anaerobic	Iron and steel
Thiobacillus thioxidans	0.5–8	10–40	Aerobic	Iron and steel, copper alloys
Thiobacillus ferrooxidans	1–7	10–40	Aerobic	Iron and steel
Gallionella	7–10	20–40	Aerobic	Iron and steel
Sphaerotilus	7–10	20–40	Aerobic	Iron and steel

Source: Modified from D.A. Jones, 1995

life-cycle activity and generate by-products such as sticky polymers, which retain various organic and inorganic materials. These by-products are important to the development of rounded to irregularly shaped nodules, and beneath each nodule is a pit. The nodule serves as the habitat for the microbe community. In a typical nodule found in an aerobic environment, microbes live within its exterior layer where they consume oxygen in the water. As they do so, they reduce the oxygen level within the outer layer of the nodule. This activity creates an environment that allows the underlying anaerobic bacteria to survive and thrive. When a nodule is developed, it creates conditions that are chemically dissimilar to the surface material to which it is attached. This is the beginning of accelerated corrosion. As the microbe community continues to live and develop within the nodule, its by-products eventually lower the pH to acidic levels, which in turn increases the corrosive conditions within the underlying crevice on the metallic surface (i.e., well casing and/or screen).

The acidic conditions actually promote the growth and development of other acid-producing bacteria whose own acid by-products further reduce the pH to even lower levels. The continuance of the MIC mechanism eventually leads to the existence of a nodule over a mature pit. At this point, pH may be less than 4, and live bacteria may exist only in the outer layer of the nodule. In fact, the bacteria could be eliminated, yet traditional electrochemical corrosion would continue. Hence, this form of corrosion is referred to as microbiologically "influenced" corrosion.

MIC has the potential to seriously impact the efficiency and structural integrity of water wells. Therefore, it is imperative to correctly diagnose and treat such problems as soon as possible to interrupt and curtail the development process of the microbe community. Therefore, one must first identify the type of microbial community in the well and then develop an appropriate course of treatment. Many diagnostic and treatment methods are available that can be implemented.

CORROSION IN PLASTICS

Whereas corrosion in metals is largely an electrochemical process, plastics may be susceptible to types of chemical attack such chemical solvation, direct chemical attack, and stress-cracking induced failure. Such attacks can lead to softening of the material, loss of density, loss of strength, embrittlement, swelling, or a breakdown in polymeric chains.

Many different plastic families are used for plumbing pipe, fittings, and valves, including vinyls, olefins, fluorinated, ABS, sulfones, and others. Each of these plastics has different attributes and varying resistances to the conditions that will cause a breakdown in polymeric chains or other forms of failure.

In addition to the pipe and fittings materials, many plumbing components have seats, seals, O-rings, coupling gaskets, and other elastomers that must be considered.

The rate of chemical attack on a plastic piping system shares several factors that could cause problems with metals, yet plastics are unaffected by other forms of corrosion (MIC, dezincification, erosion corrosion, and galvanic corrosion for example). At the same time, plastics can be more severely affected by pressure, excessive temperature, exposure to solvents and surfactants, etc. than their metallic counterparts.

Some of the factors to consider when selecting a suitable plastic for a particular application include the following:

pH

pH is not a predictor of failure or corrosion in plastics. Many plastics can easily transport mild or moderately strong acids or bases, while other chemicals with a neutral pH of 7 would cause rapid degradation of a given plastic. In general, the range of pH values found in plumbing systems is of no concern to plastic piping materials that are approved in codes for plumbing. Any system subjected to chemicals should be selected after researching all of the design conditions.

Chemical Content (Internal and Environmental)

Aside from pH, many other chemical attributes or combinations of exposures can cause chemical attack in plastics. For example, the presence of surfactants can make otherwise moderate amounts of a chemical agent detrimental to certain plastic materials. Construction compounds used outside of a piping system may attack certain plastic materials.

Examples include pipe dopes, leak-detection fluids, some types of spray foam insulation, termiticides, mold retardants, and firestopping compounds. Whereas some types of plastics are practically immune to these listed construction materials, others have specific limitations of exposure.

Presence of Oxidizing Agents

The chlorine and chloramine disinfectants used in normal drinking water in the United States and Canada are not normally a problem for the plastic materials usually used in plumbing systems, but in areas with high residual values or plumbing systems that see high levels of oxidizers (bleach, for example), some plastics are more adversely affected than others. Materials such as PEX, PE-RT, PP-R, and HDPE each have specific test methods used to evaluate their resistance to these disinfectants, and the specific product standards set mandatory minimum performance levels and categorize resistance to disinfectants with respect to operating temperatures and pressures.

Temperature

Excessive temperature has a strong influence on chemical attack of plastics. Dependent on the material, plastics lose strength at temperatures above 73°F; the rate of reduction in strength depends on the plastic material, and in pressurized systems, the ability to withstand required operating pressures also must be taken into account. As a general rule, as temperatures increase, corrosion is accelerated in plastics.

Pressure

By their nature, thermoplastic materials have a lower tensile strength and stiffness than their metal counterparts. To achieve a given strength (or ability to handle a given pressure), plastic pipes normally have thicker walls than the corresponding metallic they might replace. Plastic pipe dimensions are based on dimensional ratios (e.g., SDR 9), so each diameter of a given pipe material will withstand the same hoop stress and carry the same pressure rating. Excessive operating pressure increases stress on plastics, which can accelerate the effects of chemical attack.

Velocity

Whereas erosion corrosion is rarely an issue in plastics, the potential effect of excessive velocity in plastic systems is the sudden surge pressure that can occur with the operation of fast-closing valves and the resulting water hammer effect. Olefin plastics have excellent cyclic fatigue strength and can withstand thousands of such cycles with no degradation. In fact, the inherent flexibility of most plastic materials allows them to absorb and reduce peak surge pressures in the system. Chemical attack may reduce material flexibility and the ability to handle the high bursts of pressure associated with high velocities in plumbing systems.

Stress

Stress in its many forms is a large influencer on failure in plastics. ESC (environmental stress corrosion, or cracking) is somewhat different from polymer degradation in that stress cracking does not break polymer bonds. Instead, it breaks the secondary linkages between polymers. These are broken when the mechanical stresses cause minute cracks in the polymer, which may propagate rapidly in some materials.

Also, the chemical resistance of a particular plastic generally decreases with increasing applied stress.

Excessive stress can be caused by many factors, from overtightening a plastic threaded fitting or flange or by not making proper allowance for longitudinal expansion and contraction in a plastic piping system—a common occurrence as plastics generally expand and contract at a much greater rate than their metallic counterparts.

Effects of Solvents on Plastics

Although the term "solvent" can apply to a wide range of liquid chemicals that may allow materials to dissolve within them, each type of plastic material has its own unique resistance to solvents. Vinyls (e.g., PVC, CPVC) are typically joined using solvent cements that are developed, tested, and approved specifically for those materials, whereas olefins are generally immune to exposure to those solvent cement materials.

Depending on the plastic, detrimental effects can range from mild to a moderately bad effect to total breakdown and failure.

For More Information

For more information on the effects of chemicals on plastic piping, see TR-19/2007: *Chemical Resistance of Thermoplastics Piping Materials,* published by the Plastics Pipe Institute, Inc.

GLOSSARY

Active The state in which a metal is in the process of corroding.

Active potential The capability of a metal corroding based on a transfer of electrical current.

Aeration cell An oxygen concentration cell—an electrolytic cell resulting from differences in the quantity of dissolved oxygen at two points.

Amphoteric corrosion Corrosion usually caused by a chemical reaction resulting from a concentration of alkaline products formed by the electrochemical process. Amphoteric materials are those materials that are subject to attack from both acidic and alkaline environments. Aluminum and lead, commonly used in construction, are subject to amphoteric corrosion in highly alkaline environments. The use of cathodic protection in highly alkaline environments, therefore, intensifies the formation of alkaline by-products.

Anaerobic Free of air or uncombined oxygen.

Anion A negatively charged ion of an electrolyte that migrates toward the anode under the influence of a potential gradient.

Anode Negative in relation to the electrochemical process. The electrode at which oxidation or corrosion occurs.

Anodic protection An appreciable reduction in corrosion by making a metal an anode and maintaining this highly polarized condition with very little current flow.

Cathode Positive in relation to the electrochemical process. The electrode where reduction (and practically no corrosion) occurs.

Cathodic The electrolyte of an electrolytic cell adjacent to the cathode.

Cathodic corrosion An unusual condition in which corrosion is accelerated at the cathode because cathodic reaction creates an alkaline condition corrosive to certain metals, such as aluminum, zinc, and lead.

Cathodic protection Reduction or elimination of corrosion by making the metal a cathode by means of an impressed direct current or attachment to a sacrificial anode.

Cation A positively charged ion of an electrolyte that migrates toward the cathode under the influence of a potential gradient.

Caustic embrittlement Weakening of a metal resulting from contact with an alkaline solution.

Cavitation Formation and sudden collapse of vapor bubbles in a liquid, usually resulting from local low pressures, such as on the trailing edge of an impeller. This condition develops momentary high local pressure, which can mechanically destroy a portion of the surface on which the bubbles collapse.

Cavitation corrosion Corrosion damage resulting from cavitation and corrosion in which metal corrodes and pressure develops from collapse of the cavity and removes the corrosion product, exposing bare metal to repeated corrosion.

Cell A circuit consisting of an anode and a cathode in electrical contact in a solid or liquid electrolyte.

Concentration cell A cell involving an electrolyte and two identical electrodes, with the potential resulting from differences in the chemistry of the environments adjacent to the two electrodes.

Concentration polarization That portion of the polarization of an electrolytic cell produced by concentration changes resulting from passage of electric current through the electrolyte.

Contact corrosion Corrosion of a metal at an area where contact is made with a usually nonmetallic material.

Corrosion Degradation of a metal by a chemical or electrochemical reaction with its environment.

Corrosion fatigue Reduction of fatigue durability by a corrosive environment.

Corrosion fatigue limit The maximum repeated stress endured by a metal without failure in a stated number of stress applications under defined conditions of corrosion and stressing.

Corrosion mitigation The reduction of metal loss or damage through use of protective methods and devices.

Corrosion prevention The halting or elimination of metal damage through use of corrosion-resisting materials, protective methods, and protective devices.

Corrosion potential The potential that a corroding metal exhibits under specific conditions of concentration, time, temperature, aeration, velocity, etc.

Couple A cell developed in an electrolyte resulting from electrical contact between two dissimilar metals.

Cracking Separation in a brittle manner along a single or branched path.

Crevice corrosion Localized corrosion resulting from the formation of a concentration cell in a crack formed between a metal and a nonmetal or between two metal surfaces.

Deactivation Process of the prior removal of active corrosion constituents, usually oxygen, from a corrosive liquid by controlled corrosion of expendable metal or by other chemical means.

Dealloying The selective leaching or corrosion of a specific constituent from an alloy.

Decomposition potential (or voltage) The practical minimum potential difference necessary to decompose the electrolyte of a cell at a continuous rate.

Depolarization The elimination or reduction of polarization by physical or chemical means, resulting in increased corrosion.

Deposit attack (deposition corrosion) Pitting corrosion resulting from accumulations on a metal surface that cause concentration cells.

Differential aeration cell An oxygen concentration cell resulting from a potential difference caused by different amounts of oxygen dissolved at two locations.

Drainage Conduction of current (positive electricity) from an underground metallic structure by means of a metallic conductor.

Electrode A metal in contact with an electrolyte that serves as a site where an electrical current enters the metal or leaves the metal to enter the solution.

Electrolyte An ionic conductor (usually in aqueous solution).

Electromotive force series A list of elements arranged according to their standard electrode potentials, the sign being positive for elements having potentials that are cathodic to hydrogen and negative for elements having potentials that are anodic to hydrogen. (This convention of sign, historically and currently used in European literature, has been adopted by the Electrochemical Society and the National Institute of Standards and Technology; it is employed in this publication. The opposite convention of Gilbert N. Lewis has been adopted by the American Chemical Society.)

Electronegative potential A potential corresponding in sign to those of the active or anodic members of the electromotive force series. Because of the existing confusion of sign in the literature, it is suggested that "anodic potential" be used whenever "electronegative potential" is implied. (See *electromotive force series*.)

Electropositive potential A potential corresponding in sign to potentials of the noble or cathodic members of the electromotive force series. It is suggested that "cathodic potential" be used whenever "electropositive potential" is implied. (See *electromotive force series*.)

Flash attack A heavily etched, dark surface resulting from contaminated passivating solutions with high chloride levels.

Forced drainage Drainage applied to underground metallic structures by means of an applied electromotive force or sacrificial anode.

Galvanic cell A cell consisting of two dissimilar conductors in contact with an electrolyte or two singular conductors in contact with dissimilar electrolytes. More generally, a galvanic cell converts energy liberated by a spontaneous chemical reaction directly into electrical energy.

Galvanic corrosion Corrosion that is increased because of the current caused by a galvanic cell (sometimes called couple action).

Galvanic series A list of metals arranged according to their relative corrosion potential in some specific environment; seawater often is used.

General corrosion Corrosion in a uniform manner.

Graphitization (graphitic corrosion) Corrosion of gray cast iron in which the metallic constituents are converted to corrosion products, leaving the graphite flakes intact. Graphitization also is used in a metallurgical sense to mean the decomposition of iron carbide to form iron and graphite.

Hydrogen embrittlement A weakening of a metal by the entrance of hydrogen into the metal through, for example, pickling or cathodic polarization.

Hydrogen overvoltage A higher-than-expected difference in potential associated with the liberation of hydrogen gas.

Impingement attack Localized erosion/corrosion caused by turbulence or impinged flow at certain points.

Inhibitor A substance that, when added in small amounts to water, acid, or other liquids, sharply reduces corrosion.

Ion An electrically charged atom or group of atoms known as radicals.

Microbiologically influenced corrosion (MIC) The deterioration of metallic materials by the activities of various microorganisms (microbes).

Natural drainage Drainage from an underground metallic structure to a more negative structure, such as the negative bus of a trolley substation.

Noble potential A potential substantially cathodic compared to the standard hydrogen potential.

Open-circuit potential The measured potential of a cell during which no significant current flows in the external circuit.

Overvoltage The difference between the potential of an electrode at which a reaction is actively taking place and another electrode is at equilibrium for the same reaction.

Oxidation Loss of electrons, as when a metal goes from the metallic state to the corroded state. Thus, when a metal reacts with oxygen, sulfur, etc. to form a compound as oxide, sulfide, etc., it is oxidized.

Oxygen concentration cell A galvanic cell caused by a difference in oxygen concentration at two points on a metal surface.

Passive The state of a metal when its behavior is much more noble (resists corrosion) than its position in the electromotive force series would predict. This is a surface phenomenon.

pH A measure of the acidity or alkalinity of a solution (from 0 to 14). A value of 7 is neutral; low numbers (0–6) are acidic, and large numbers (8–14) are alkaline.

Pitting Localized light corrosion resulting in deep penetration at a small number of points.

Polarization The shift in electrode potential resulting from the effects of current flow, measured with respect to the zero-flow (reversible) potential, i.e., the counter-electromotive force caused by the products formed or concentration changes in the electrode.

Protective potential A term sometimes used in cathodic protection to define the minimum potential required to suppress corrosion. For steel in seawater, this is claimed to be about 0.85 V as measured against a saturated calomel cell.

Remote electrode (remote earth) Any location away from the structure at which the potential gradient of the structure to earth is constant. The potential of a structure-to-earth will change rapidly near the structure, and if remote earth is reached, there will be little or no variation in the voltage.

Resistivity The specific opposition of a material. Measured in ohms (Ω) to the flow of electricity.

Rusting Corrosion of iron or an iron-base alloy to form a reddish-brown product that is primarily hydrated ferric oxide.

Stray current corrosion Corrosion that is caused by stray currents from some external source.

Stress corrosion/stress-accelerated corrosion Corrosion that is accelerated by stress.

Stress corrosion cracking Cracking that results from stress corrosion.

Tuberculation Localized corrosion at scattered locations resulting in knob-like mounds.

Under-film corrosion Corrosion that occurs under lacquers and similar organic films in the form of randomly distributed hairlines (most common) or spots.

Weld decay Corrosion, notably at specific zones away from a weld.

Seismic Protection of Plumbing Equipment

Every structure is designed for vertical, or gravity, loads. In the case of pipes, gravity loads include the weight of the pipe and its contents, and the direction of the loading is downward. Seismic loads are the lateral forces exerted on a structure during an earthquake, and earthquake forces can be in any direction. The ordinary supports designed for gravity loads generally compensate for vertical loads during an earthquake. Therefore, the primary emphasis in seismic design is on lateral, or horizontal, forces.

Study of seismic risk maps (see Figure 9-1 on the next page) indicates that the potential for damaging earthquake motion is far more pervasive than commonly known. Complete seismic design requirements, including the construction of nonstructural elements, are in effect in only a small fraction of the areas that could be rated as having a high or moderate risk. Nonstructural components and elements such as piping, water heaters, pumps, tanks, boilers, ductwork, and conduit are partitioned into two categories: attached to a building and not attached to a building. Seismic design requirements for nonstructural elements, except for heavy cladding panels, are seldom enforced even in California, which is considered the innovator in state building code requirements related to seismic movement. However, nonstructural damage resulting from small earthquakes shows that the major advancements in building structural design by themselves may not have produced an acceptable level of overall seismic protection.

Now that the potential for collapse or other direct, life-endangering structural behavior is quite small, at least for modern structures designed and built in accordance with current seismic codes, attention has shifted to nonstructural life-safety hazards, continued functionality, and economic issues. The cost of an interruption in a building's ability to function, which could cause a loss of rent, disruption of normal business affairs, or curtailment of production, is coming more into focus.

The primary codes governing the seismic laws are found in the International Building Code (Chapter 16). However, this code refers to ASCE/SEI 7: *Minimum Design Loads for Buildings and Other Structures*. This book subdivides the issues as follows:

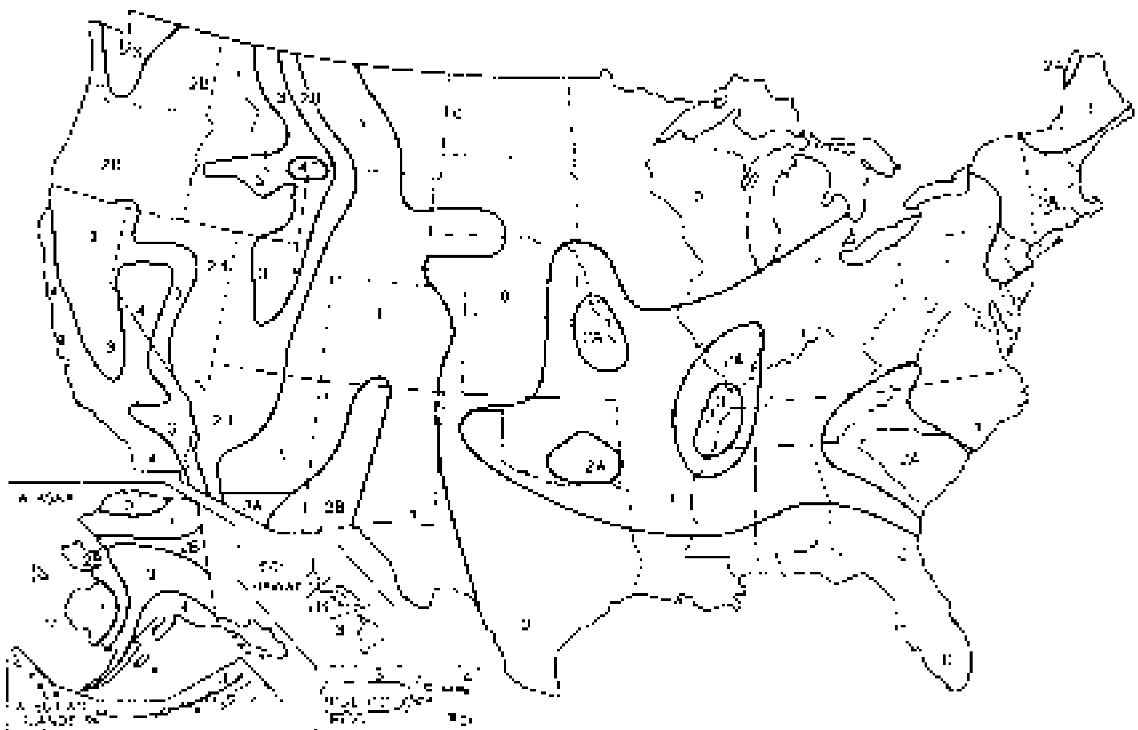
- Chapter 12: Building Structures
- Chapter 13: Nonstructural Components
- Chapter 15: Non-Building Structures
- Chapter 17: Seismically Isolated Structures
- Chapter 18: Structures with Damping Systems

Chapters 13 and 15 are most relevant to the plumbing engineer. Nonstructural components include mechanical, electrical, and architectural elements. If the components are not attached to the building or on slab, then they can be considered non-building structures. The level of hazard to the building is defined as maximum considered earthquake (MCE) ground motion. The acceleration from this motion times the effective mass of the component is the effective seismic force acted on the mass.

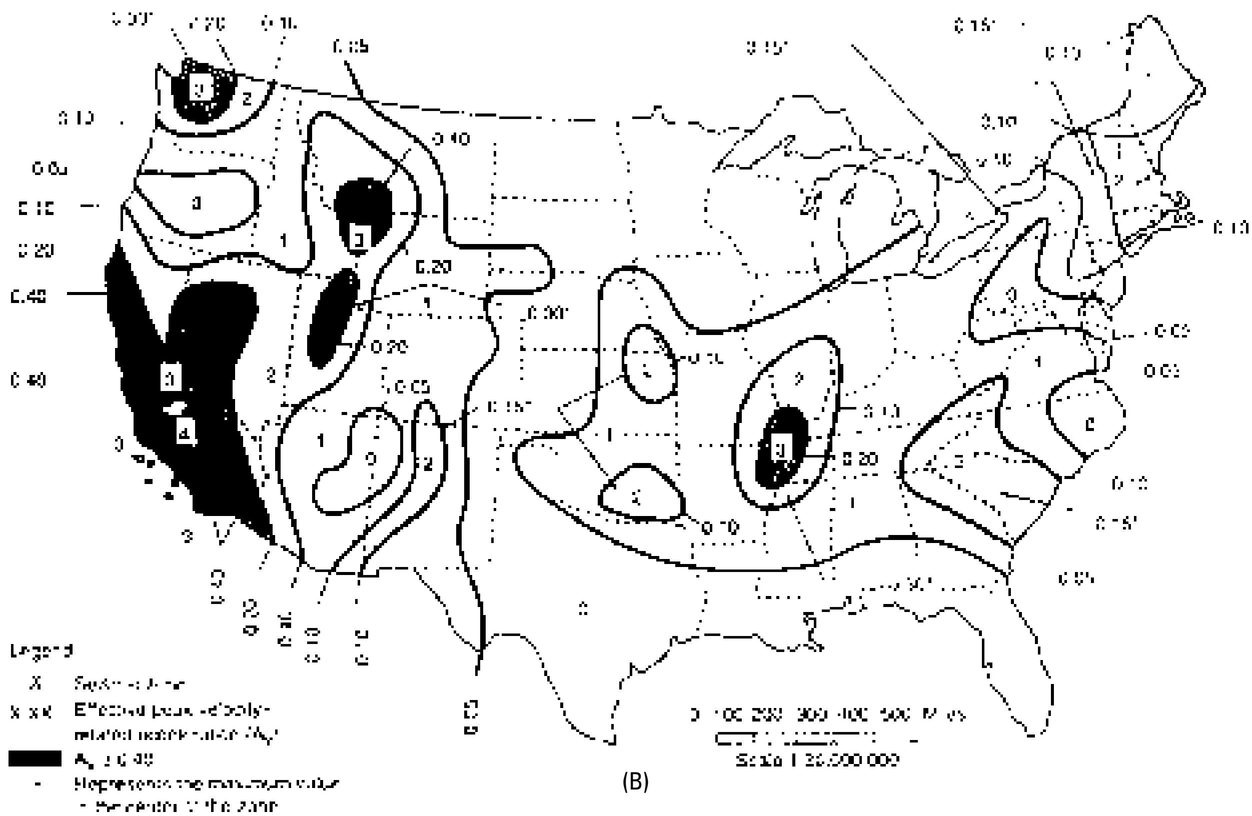
The costs of seismic protection of plumbing components and equipment range from small, such as those to anchor small tanks, to a considerable percentage of installation costs, such as those for complete pipe-bracing systems. Beyond

Figure 9-1 (A) Seismic Zone Map of the United States; (B) Map of Seismic Zones and Effective, Peak-Velocity-Related Acceleration (Av) for Contiguous 48 States

Note: Linear interpolation between contours is acceptable.



(A)



(B)

protection of life, the purpose or cost/benefit relationship of seismic protection must be clearly understood before the appropriate response to the risk can be made. The design professional responsible for any given element or system in a building is in the best position to provide that response. Seldom, however, can rational seismic protection be supplied solely by a single discipline. Building systems are interdependent in both design and function, and good seismic protection, like good overall building design, is best provided by employing a cooperative, interdisciplinary approach.

This chapter is intended to provide a basic understanding of the mechanisms of seismic damage and the particular vulnerabilities of plumbing systems and equipment. The design professional should sufficiently understand the problem to select the appropriate seismic protection in any situation based on a ranking of the susceptibility of damage and a knowledge of the scope of mitigation techniques. The seismic protection techniques currently in use for buildings are described in general. Although specific seismic protection details for some situations are discussed, it is suggested that structural design assistance be obtained from a professional of that discipline. Care should be taken in the design of seismic control systems. Proper design may require assistance from an engineer experienced in these systems. In all cases, the current local building code requirements for seismic movement should be consulted and used as the minimum standard. The detailed analysis and design techniques used for nuclear power plants and other heavy industrial applications, while similar in nature to those discussed here, are considered inappropriate for most buildings and are beyond the scope of this chapter. References are given throughout the text for additional study in specific areas of interest.

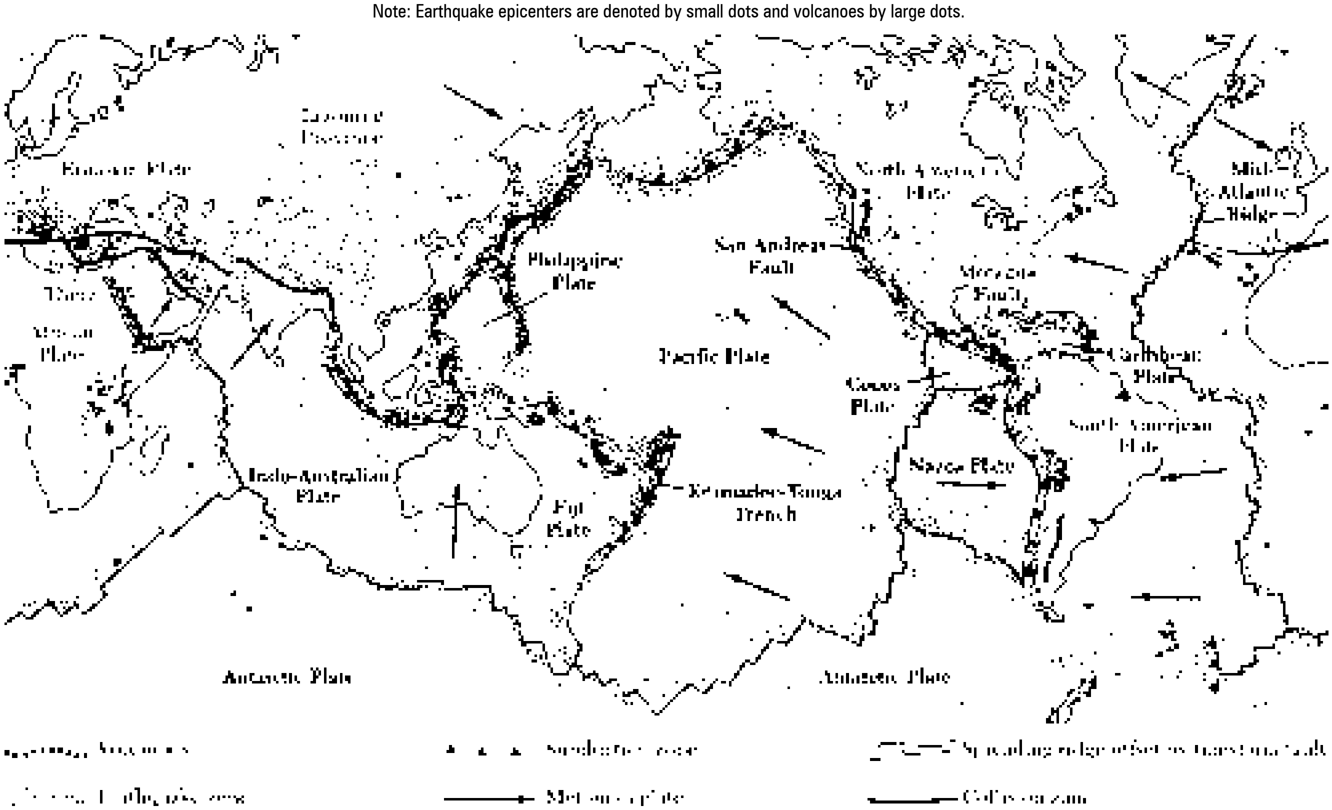
CAUSES AND EFFECTS OF EARTHQUAKES

Plate Tectonics and Faults

All seismic activity on the Earth's surface, including earthquakes and volcanoes, is caused by the relative movement of pieces of the Earth's crust. Ten of the largest pieces, called plates, and their prevailing motions are shown in Figure 9-2. The edges of these plates make up the world's primary fault systems, along which 90 percent of all earthquakes occur. The balance of earthquakes occurs on countless additional, smaller faults that lie within plate boundaries. The

Figure 9-2 World Map Showing the Relation Between the Major Tectonic Plates and Recent Earthquakes and Volcanoes

Note: Earthquake epicenters are denoted by small dots and volcanoes by large dots.



causes and exact mechanisms of these intra-plate earthquakes, which affect much of the middle and eastern United States, are not well understood.

The relative movement at plate boundaries is often a sliding action, such as occurs along the San Andreas Fault along the west coast of North America. The plates also can converge, when one plate slides beneath another, or diverge, when molten rock from below rises to fill the voids that gradually form. Although overall plate movement is extremely slow, properly measured only in a geologic time frame, the local relative movement directly at the fault can occur either gradually (creep) or suddenly, when tremendous energy is released into the surrounding mass.

The most common mechanism used to describe earthquakes is the elastic rebound theory, wherein a length of fault that is locked together by friction is strained to its capacity by the continuing plate movement, and both sides spring back to their original positions (see Figure 9-3). According to the elastic rebound theory, a fault is incapable of movement until strain has built up in the rocks on either side. As this strain accumulates, the earth's crust gradually shifts (at a rate of about 2 inches a year along the San Andreas Fault). Rocks become distorted but hold their original positions. When the accumulated stress finally overcomes the resistance of the rocks, the earth snaps back into an unrestrained position. The "fling" of the rocks past each other creates the shock waves we know as earthquakes. Waves in a variety of patterns emanate from this fault movement and spread in every direction. The two types of waves produced by an earthquake are P, or primary, waves and S, or secondary, waves. These waves change throughout the duration of a earthquake. Add them to one another, and the result is extremely complicated wave motions and vibrations.

At any site away from the fault, the three-dimensional movement of the surface, which is caused by combinations of direct, reflected, and refracted waves, is known simply as ground shaking. Energy content, or the intensity of the ground shaking, decreases with distance from the causative fault, although because certain structures can be tuned into the motion, this is not always apparent. The horizontal, vertical, and rotational forces on structures are unpredictable in direction, strength, and duration. The structural load is proportional to the intensity of shaking and to the weight of the supported elements.

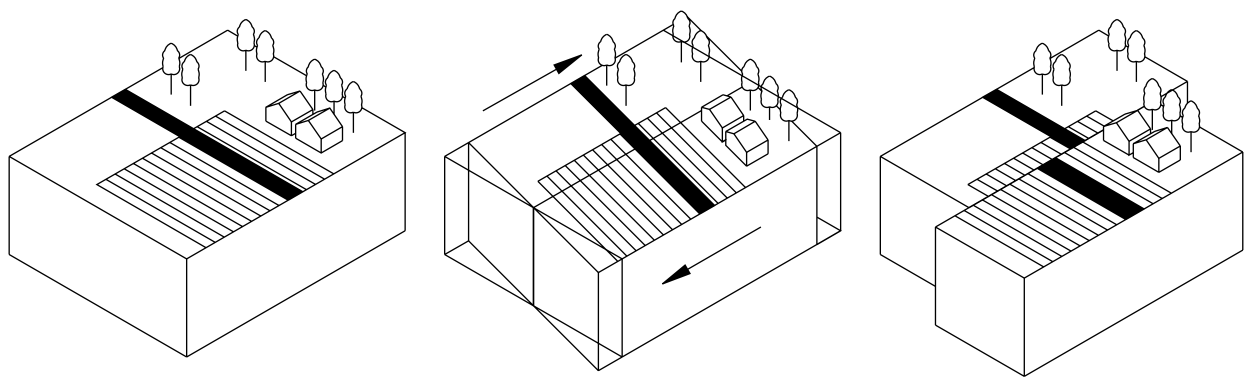
By combining knowledge of known fault locations with historical and instrumented ground motion records, seismologists can construct maps showing zones of varying expected ground motion. Figure 9-1 shows an example of such maps, which were used to develop design criteria zoning for a national seismic code.

Damage from Earthquakes

Four separate phenomena created by earthquakes can cause damage:

- Surface fault slip (ground rupture)
- Wave action in water created by seismic movement (called tsunamis in open bodies of water and seiches in closed bodies of water)
- Ground shaking
- Ground failure (landslides and liquefaction—i.e., a sudden change to liquid characteristics in certain sands caused by increased pore water pressure)

Figure 9-3 Elastic Rebound Theory of Earthquake Movement



It is accepted that buildings and their contents are not designed to withstand ground rupture caused by seismic events. Protection from this is obtained by avoiding potentially dangerous sites, but that is not always possible. Underground piping can be damaged severely by either fault rupture or ground failure, and frequently pipelines must cross areas with these potential problems. Seismic design for underground systems in these cases consists of special provisions for the considerable distortion expected in the ground or redundant systems and valving, such that local damage can be accepted without serious consequences.

EARTHQUAKE MEASUREMENT AND SEISMIC DESIGN

Ground Shaking and Dynamic Response

The primary thrust of seismic design, as it relates to buildings, is to protect against the effects of ground shaking. Although recently there has been concern that surface waves may damage structures by pure distortion, virtually all design is done assuming the entire ground surface beneath a structure moves as a unit, producing a shaking or random motion for which the unidirectional components can be studied mathematically and the effects on structures can be analyzed using structural dynamics and modeling. The movement of the ground mass under a building during an earthquake is measured and recorded using the normal parameters of motion, displacement, velocity, and acceleration. Two orthogonal plan components and one vertical component are used to completely describe the motion. The effect of each orthogonal plan component on the structure under design is considered separately.

The amplitudes of displacement, velocity, and acceleration at any moment are, of course, related, as each measures the change in the other over time. Given the record of how one parameter has changed over time (time history), the other two can be calculated. However, due to the direct relationship of force to acceleration (F-Ma) and also because acceleration is easiest to instrumentally measure, acceleration has become the standard measurement parameter. The characteristically spiked and jagged shape of the acceleration time history (called an accelerogram, as shown in Figure 9-4) is recognized universally as being associated with earthquakes.

Figure 9-4 Earthquake Ground Accelerations in Epicentral Regions

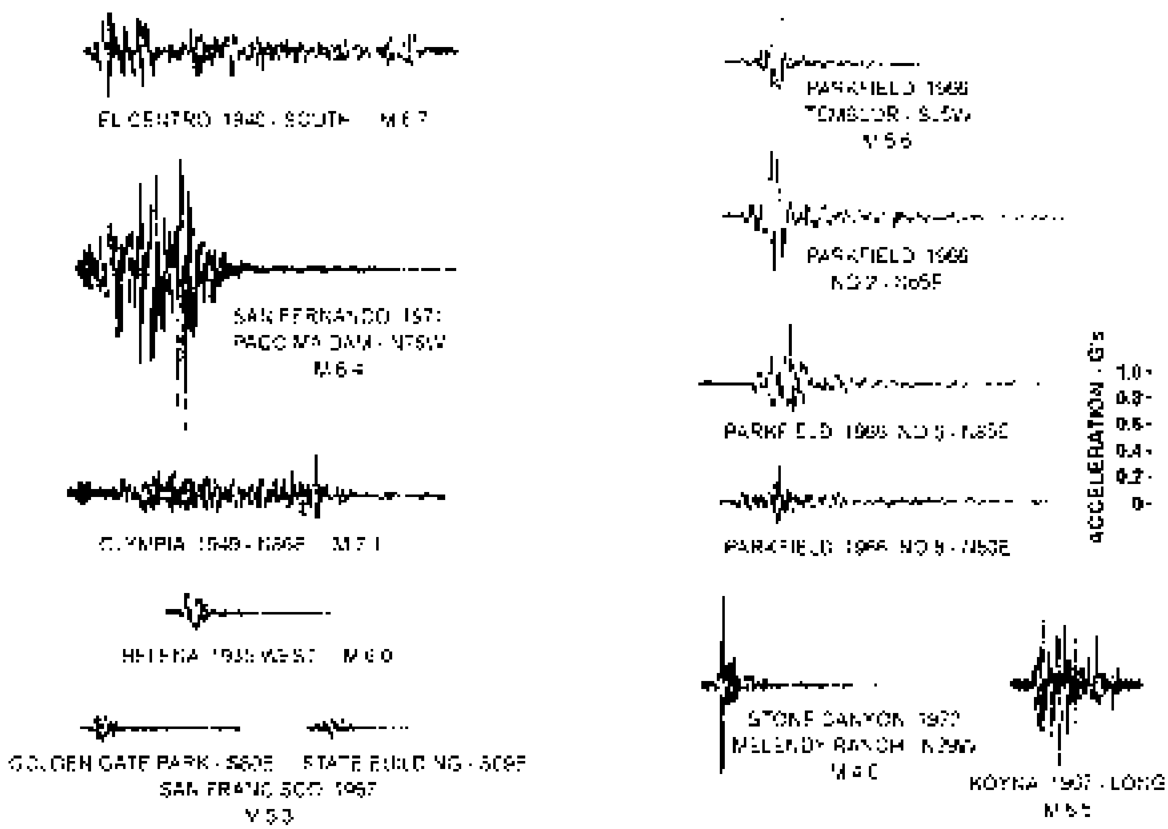
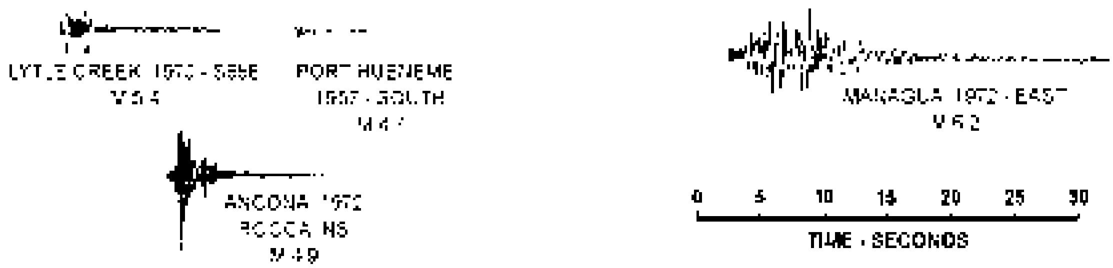


Figure 9-4 Earthquake Ground Accelerations in Epicentral Regions (continued)



The basic physics of seismic systems are relatively simple (Hooke's law). When any nonrigid structure, such as the pendulum or cart and spring of Figure 9-5(A), is subjected to a time history of base motion, the movement (D) of the mass (M) can be measured over time, and this record of motions becomes the dynamic response (K), which is different than the input motion because of the inertial lag of the mass behind the base and the resultant energy stored by distorting the connecting structure. Thus, the dynamic response to any input motion depends on the size of the mass and the stiffness of the supporting structure.

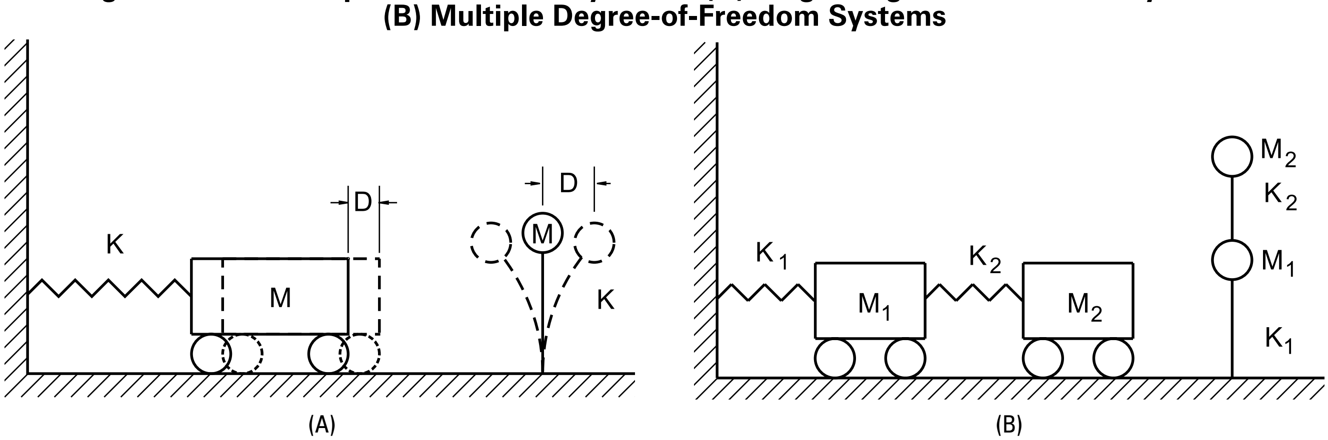
The Response Spectrum

Because of the difficulty of measuring all of the variations of distortion in a normal structure at each moment of time, a shorthand measure of maximum response often is used. The maximum response of a series of simple pendulums (single degree-of-freedom system) to a given time history of motion is calculated, and the resulting set of maximums is known as a response spectrum (see Figure 9-6). The response parameter could be displacement, velocity, or acceleration, although acceleration is used most often. The variation in the dynamic characteristics of each pendulum in the infinite set is measured by the natural period of vibration. The natural period of any system is dependent on stiffness and mass and measures the length of one complete cycle of free (natural) vibration. Frequency, or the inverse of the period, also often is used in place of the period.

If the input motion (or forcing function) for a structure is of constant frequency and matches the natural frequency, resonance occurs, and the response is theoretically infinite. Damping that occurs to some degree in all real systems prevents infinite response, and the amplitude of the actual response is proportional to the damping present. Damping normally is measured as a percentage of the amount of damping that would create zero response; that is, the pendulum when set in motion would return to its at-rest position. The damping in most structures is between 2 and 10 percent. For any input motion, the response depends on the amount of damping present; therefore, responses (and response spectra) often are presented as families of similar curves, each corresponding to a different damping value (refer to Figure 9-6).

By the response spectrum technique, the maximum single response to a given base motion of a structure with a known period and damping can be predicted. It must be remembered that the response spectrum eliminates the time

Figure 9-5 Undamped Mechanical Systems: (A) Single Degree-of-Freedom Systems; (B) Multiple Degree-of-Freedom Systems

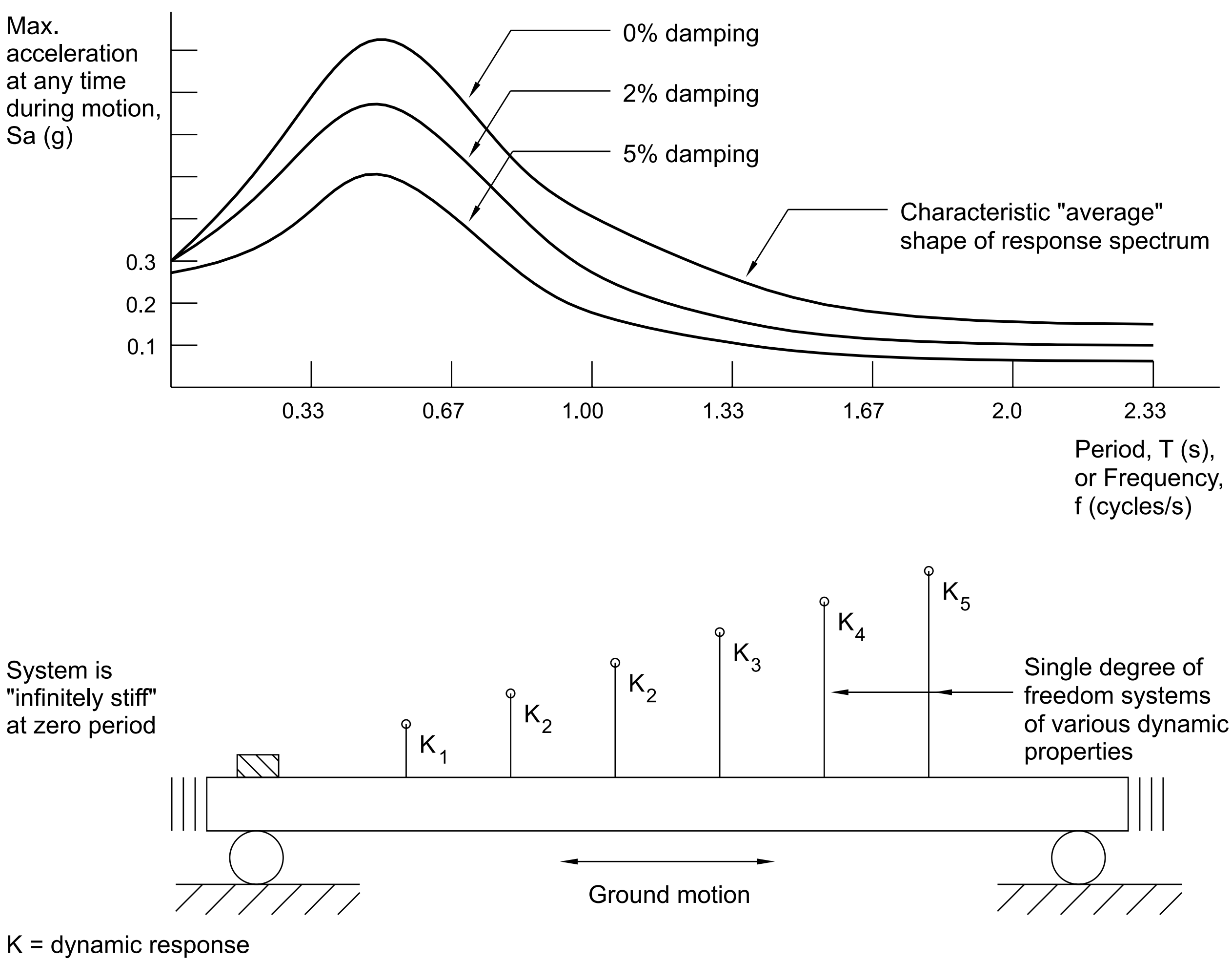


element from consideration because the maximums plotted for each period are likely to have occurred at different times during the time history. Every ground motion has its own distinct response spectrum, which shows on a gross basis which vibratory frequencies were predominant in motion. Since ground motions vary not only between earthquakes but also between sites during the same earthquake, an infinite variety of response spectra must be considered possible. Fortunately, the characteristics of wave transmission and the physical properties of soil place upper bounds on spectral shapes. Using statistical analysis of many motions and curve-fitting techniques, it is possible to create a design spectrum of energy stored by distorting the connecting structure. The spectrum that is theoretically most appropriate for a dynamic response to any input motion depends on the region or even the given site.

With such a design spectrum for acceleration, measured in units of the acceleration of gravity (e.g., the maximum horizontal force in a single degree of freedom), systems can be closely approximated using the ordinate as a percentage of the system.

Just as the response of a structure on the ground can be calculated by considering the ground motion time history, the response of a system on any floor of a building can be calculated similarly if the time history of the floor motion is known. Using computers, it is possible to calculate such floor motions in structures using base ground motion as input. Response spectra then can be calculated for each floor that would be appropriate for building contents or equipment. The vibratory response of a building is generally far more coherent than rock or soil, as the motion of floors is focused into the natural periods of the building. Therefore, floor response spectra often are highly peaked around one or two frequencies, so responses nearer to theoretical resonance are more likely than they are on the ground. Responses 25 times greater than input acceleration can be calculated in such circumstances where response spectra for ground mo-

Figure 9-6 Response Spectrum



tion usually show response multiples of 25. However, these extreme responses are unlikely and are not considered in design due to the many non-linearities in real structures and the low possibility of near-perfect resonance.

The response of multiple degree-of-freedom systems, see Figure 9-5(B), cannot be calculated simply from a response spectrum, but spectra often are used to quickly approximate the upper limit of the total lateral force on the system. A pseudodynamic elastic analysis can be done on any system using response spectra to obtain a close approximation of maximum forces or distortions. These analyses typically are done by an experienced engineer using a computer, as they can be labor intensive if performed manually.

LEARNING FROM PAST EARTHQUAKES

The Great San Francisco Earthquake

On April 18, 1906, one of the most significant earthquakes struck California at 5:12 a.m. The 1906 San Francisco earthquake ranks among the most important earthquakes of all time. It caused massive devastation to several cities including Santa Rosa, San Jose, and Santa Cruz. Buildings collapsed, gas lines ruptured, and a catastrophic fire spread throughout the city of San Francisco.

This pre-plate tectonics theory event perplexed the scientific community of the time for its magnitude, rupture length, and horizontal displacements. In the aftermath, existing seismic building codes were revised and made more stringent, and several municipalities adopted seismic provisions. Furthermore, engineers realized the importance of both a building and its nonstructural components to withstand lateral and vertical movements during a seismic event to protect the health, safety, and welfare of the public.

Damage to Plumbing Equipment

Damage to plumbing equipment or systems in earthquakes occurs in two ways:

- Failure due to forces on the element resulting from dynamic response to ground or floor shaking. The most common example is the sliding or overturning of tanks.
- Failure due to forced distortions on the element caused by the differential movement of two or more supports. This can occur at underground utility entrances to buildings, at building expansion or seismic joints, or, on rare occasions, even between floors due to inter-story drift.

All earthquakes can create major water service disruptions. Water systems can collapse or be severely damaged. The potable water supply may be at risk as a result of underground water main breaks, backsiphonage, or backflow.

An obvious method of determining failure modes and isolation elements susceptible to damage is to study the experience of past earthquakes. Particularly useful are the following summaries. (Concerning piping, it should be pointed out that both reports indicate that damage was light on an overall basis. The scattered damage found was as described below.)

A summary of the damage resulting from the 1964 Great Alaskan earthquake follows:

- Most pipe failures occurred at fittings. Most brazed or soldered joints were undamaged, many screwed joints failed, and a few caulked joints were pulled apart or twisted.
- Failures in screwed joints often occurred where long, unbraced horizontal runs of pipe joined short vertical risers or were connected to equipment. Small branch lines that were clamped tightly to the building were torn from large horizontal mains if these were unbraced and allowed to sway.
- Joints were loosened or pulled apart in long horizontal runs of unbraced cast iron pipe, and hangers were bent, shifted, or broken.
- Pipes crossing seismic joints were damaged if provisions were not made for the relative movements between structural units of buildings.
- Thermal expansion loops and joints were damaged when pipes were not properly guided.
- Fire sprinkler piping was practically undamaged because it was provided with lateral bracing.

- Sand filter, water softener, domestic hot water, hot water expansion, and cold water storage tanks shifted, toppled, or rolled over when they were not firmly anchored to buildings.
- Hundreds of small gas-fired and electric domestic water heaters fell over. Many of the legs on which heaters stood collapsed, and vent connectors were damaged.
- Some plumbing fixtures were damaged by falling debris.
- Vertical plumbing stacks in tall buildings were practically undamaged.

The damage resulting from the 1971 San Fernando earthquake follows:

- Unanchored heavy equipment and tanks moved and damaged the connected piping.
- Heavy equipment installed with vibration isolation mounts moved excessively, often destroyed the isolators, and damaged the connected piping.
- Cast iron supports for heavy cast iron boilers failed.
- Pipes failed at threaded connections to screwed fittings. Some cast iron fittings were fractured.
- Pipes were damaged when crossing separations between buildings.
- Screwed pipe legs under heavy tanks failed, and angle iron legs were deformed.
- Plumbing fixtures were loosened from mounts, and enamel was chipped.
- Domestic water heater legs bent or collapsed.

Recommendations

The overall recommendations applicable to plumbing equipment from the Alaska report, made primarily as a response to observed damage, are worth relating.

- Pipelines should be tied to only one structural system. Where structural systems change and relative deflections are anticipated, movable joints should be installed in the piping to allow for the same amount of movement.
- Suspended piping systems should have consistent freedom throughout; for example, branch lines should not be anchored to structural elements if the main line is allowed to sway.
- If the piping system is allowed to sway, movable joints should be installed at equipment connections.
- Pipes leading to thermal expansion loops or flexible pipe connections should be guided to confine the degree of pipe movement.
- Whenever possible, pipes should not cross seismic joints. Where they must cross seismic joints, appropriate allowance for differential movements must be provided. The crossing should be made at the lowest floor possible, and all pipe deflections and stresses induced by the deflections should be carefully evaluated. National Fire Protection Association (NFPA) standards for earthquake protection for fire sprinkler systems should be referred to for successful, field-tested installation details that are applicable to any piping system. The latest revision to FM Global's Data Sheet 2-8: *Earthquake Protection for Water-Based Fire Protection Systems* is also valuable as a reference guide.
- Supports for tanks and heavy equipment should be designed to withstand earthquake forces and should be anchored to the floor or otherwise secured.
- Suspended tanks should be strapped to their hanger systems and provided with lateral bracing.
- Pipe sleeves through walls or floors should be large enough to allow for the anticipated movement of the pipes and ducts.
- Domestic water heaters should be provided with legs that can withstand earthquake forces, and the legs should be anchored to the floor and/or strapped to a structurally sound wall.
- Earthquake-sensitive shutoff valves on gas service lines should be provided where maximum protection from gas leaks is required.
- Vibrating and noisy equipment should, if possible, be located far from critical occupancies, so the equipment can be anchored to the structure, and vibration isolation is not required.

- Avoid mounting heavy mechanical equipment on the top or upper floors of tall buildings unless all vibration-isolation mounts and supports are carefully analyzed for earthquake-resistant design.
- When equipment and the attached piping must be isolated from the structure by vibration isolators, constraints should be used.
- Provide means to protect the water supply against backflow or backsiphonage. The local codes should be used as minimum safeguards.

SEISMIC PROTECTION TECHNIQUES FOR EQUIPMENT

Assuming that the building in which the piping systems are supported is designed to perform safely in response to earthquake forces, the piping systems must be designed to resist the seismic forces through the strength of the building attachments.

The design professional must consider local, state, and federal seismic requirements, as applicable, in the area of consideration. Only those engineers with seismic experience should design the supports required for seismic zones. Close coordination with the structural engineer is required to ensure that the structural system properly supports the mechanical systems and equipment.

Seismic protection of equipment in buildings, as controlled by the design professional, consists of preventing excessive movement that would either damage the equipment directly or break the connected services. Equipment certification is required in the International Building Code for equipment with an importance factor of 1.5. Importance factors vary from 1.0 (basic commercial building) to 1.5 (hospitals). Piping systems with an importance factor of 1.5 must be completely designed and detailed on the plans, including supports and restraints.

Other than meeting the requirements set forth in the International Building Code, the ability of the equipment housing or working parts to withstand earthquake vibration generally is not considered for one or more of the following reasons:

- Such failure would not endanger life.
- Continued functioning is not always required.
- Most equipment will experience transportation shocks or working vibrations that are similar to earthquake motions, and the housing and internal parts therefore are considered adequate.
- The design professional has little control over the manufacturing process. Competitively priced equipment specially qualified to resist earthquake motion is not available.
- Because of a lack of performance data for equipment that is anchored, the extent of the problem is unknown.

Movement to be prevented is essentially overturning and sliding, although these effects can take place with a variety of characteristics:

- Overturning (moment): Overturn of equipment; failure in tension or compression of perimeter legs, vibration isolators, hangers, or their supports; excessive foundation rotation
- Sliding (shear): Sliding of floor-mounted equipment; swinging of hung equipment; excessive sideways failure of legs, stands, tank mounts, vibration isolators, or other supports. (Although these failures often are described as local overturning of the support structure, they are categorized as a shear or sliding failure because they are caused by the straight lateral movement of the equipment rather than the tendency to overturn.)

The prevention of overturning and sliding effects is best discussed by considering the categories of mounting equipment, such as fixed or vibration isolated and floor mounted or hung.

Fixed, Floor-Mounted Equipment

This group includes tanks, water heaters, boilers, and other equipment that can rest directly on the floor. Although anchoring the base of such equipment to the floor is obvious, simple, and inexpensive, it often is omitted. Universal base anchorage of equipment undoubtedly would be the single largest improvement and would yield the largest cost/benefit ratio in the entire field of seismic protection of plumbing equipment. This anchoring is almost always to concrete and is accomplished by cast-in-place anchor bolts or other inserts or by drilled or shot-in concrete anchors. The connection to the equipment base depends on the configuration and may require angles or other hardware to supplement the manufactured base. For elements that have a high center of gravity, it may be most efficient to prevent overturning by bracing at the top, diagonally down to the floor, to the structure above, or to adjacent structural walls. Vertical steel beams, or strongbacks, also can be added on either side of tall equipment to span from floor to floor. A vertical slip joint connection should be placed at the top of such beams to avoid unexpected interaction between the floor structures.

Tanks supported on cast iron legs or threaded pipes have proven to be particularly susceptible to support failure. These types of legs should be avoided or should have supplemental bracing.

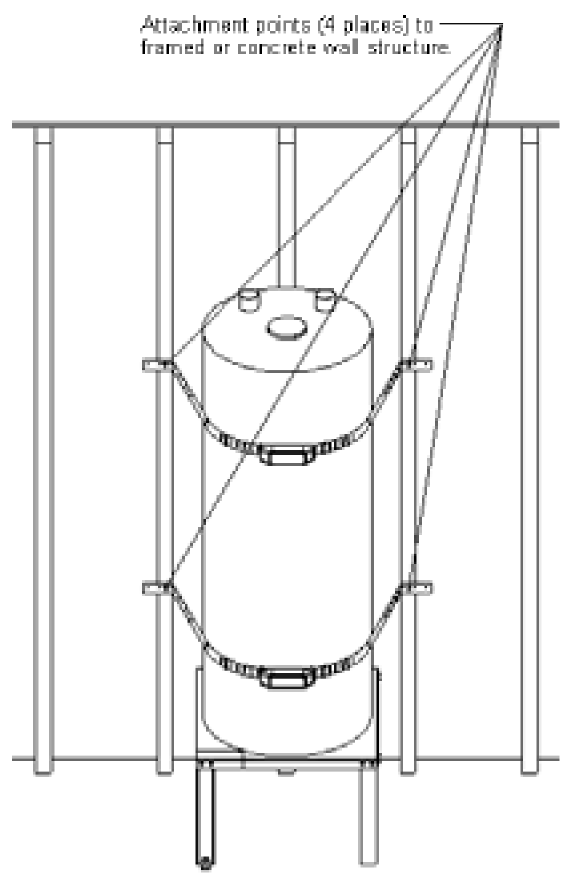
The horizontal earthquake loads from equipment mounted on or within concrete stands or steel frames should be braced from the equipment through the support structure and out the base. Concrete tank saddles often are not attached to the tank, are of inadequate strength (particularly in the longitudinal direction), are not anchored to the floor foundation, or have inadequate provisions for earthquake-generated forces in the floor or foundation. Steel equipment frames often have similar problems, some of which can be solved by diagonal bracing between the legs.

Domestic water heaters require special attention for several reasons. Most water heaters are tall and slender, thus providing a high center of gravity. In a seismic event, the tendency is for the water heater to tip over. The small feet that support many water heaters have been known to collapse under the stress of seismic motion, potentially further throwing the unit off balance. Many units are elevated on small platforms and can dance right off the edge if unbraced. The resulting excessive movement or tipping of the water heater can rupture the water piping and fuel gas piping, potentially resulting in fire or water damage or even complete destruction of a home that might otherwise have been relatively untouched by the earthquake. Thus, the point to anchoring a water heater is to protect life and property by preventing the fire or water damage that can result if the unit gets thrown about or tipped over. Anchoring the unit to a wall or other secure structure is an inexpensive and usually uncomplicated bit of insurance. At the same time, it is advisable to replace rigid fuel gas and water connectors with flexible ones to minimize the risk of even a small tremor breaking a line.

Although usually thought of as an earthquake issue, protection of the water heater is also a good idea as a general home security measure. Other natural events, such as hurricanes or tornadoes, can cause structures to move, and even a careless late-night parking bump could be enough to start a garage fire. In the event of any kind of natural disaster or civil defense situation, the water heater is a significant source of critical fresh water that is well worth protecting.

Code requirements for bracing or anchoring water heaters have been in place since the early 1980s. Initially, the Uniform Plumbing Code (UPC) supplied no specifics as to how to accomplish this or how many anchors to use. Later, the UPC was revised to require two points of anchorage in the upper and lower thirds of the heater, which remains true today (UPC Section 508.2). Both the UPC and the International Plumbing Code (IPC) specify that a water heater shall be strapped within the upper third and lower third of its vertical dimensions. The UPC additionally requires that at the lower point, a minimum distance of 4 inches (101.6 mm) shall be maintained above the controls with the strapping. The IPC and the International Mechanical Code (IMC) point to the International Residential Code (IRC) for this directive. Because of the availability of low-cost pre-manufactured kits, this approach is becoming universal wherever water heater bracing is required. Some pre-manufactured kits have straps that wrap completely around the

Figure 9-7 Domestic Water Heater Seismic Restraints Installed



water heater, while others go from one side to the other. (See Figure 9-7 for an example of a water heater with dual seismic straps in the 180-degree configuration.)

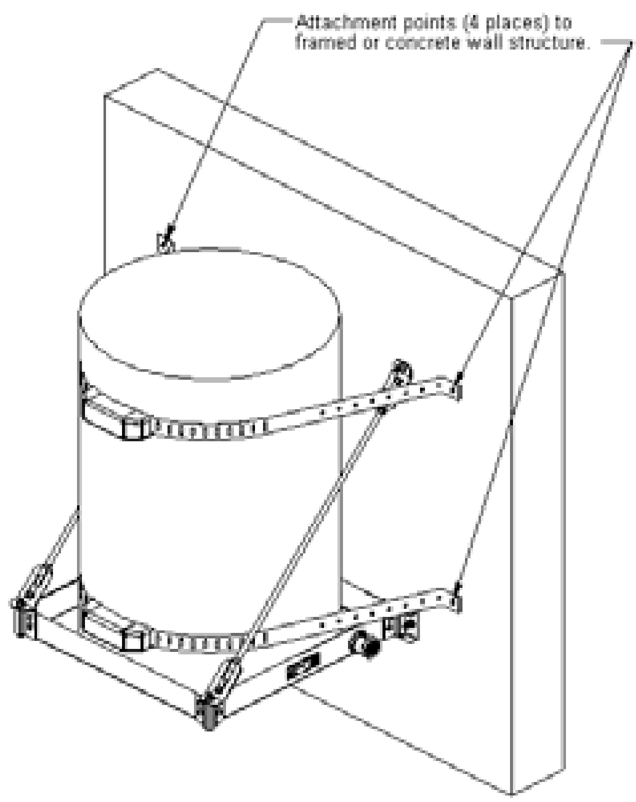
Regardless of the plumbing code, structural engineering calculations and details may be required for any plumbing equipment or piping. The calculations depend on all factors related to the seismic behavior, soil, type of building, location of the equipment relative to the ground level, and type of attachments. The attachment detail becomes more critical when the forces are being transferred back to the building.

The following plumbing nonstructural components are exempt from seismic calculations (ASCE/SEI 7-10 Section 13.1.4):

- All plumbing components in Seismic Design Categories B and C with an importance factor of 1.0
- All plumbing components in Seismic Design Categories D, E, and F with an importance factor of 1.0 and either:
  1. Flexible connections between the components and associated elements, or
  2. Components mounted less than 4 feet (1.2 m) above floor level and weighing less than 400 pounds (181.4 kg)
- All plumbing components (suspended) in Seismic Design Categories D, E, and F with an importance factor of 1.0 and either:
  1. Flexible connections between the components and associated elements, or
  2. Components weighing 20 pounds (9.1 kg) or less or, for distribution systems, weighing 5 pounds per foot (7.4 kg/m) or less

Figure 9-8 Suspended Equipment Platform with Seismic Restraints

Figure 9-9 Wall-Hung Equipment Platform/Drain Pan with Seismic Restraints



Fixed Suspended Equipment

The most common element in this group is the suspended tank. Seldom are these heavy elements laterally braced. The best solution is to install the tank tightly against the structural member above, thus eliminating the need for bracing. However, even these tanks should be secured to the suspension system to prevent slipping. Where the element is suspended below the supporting member, cross-bracing should be installed in all directions to provide lateral stability. Where a tank is suspended near a structural wall, struts to the wall may prove to be simpler and more effective than diagonal bracing. Due to the fact that these pieces of equipment are often above ceilings or in other overhead locations, this becomes a life-safety issue. See Figures 9-8 and 9-9 for examples of pre-manufactured suspended equipment support platforms engineered for this purpose.

Vibration-Isolated Floor-Mounted Equipment

This group includes units containing internal moving parts, such as pumps, motors, compressors, and engines. The codes only address damping and isolation to buildings. Manufacturers have provided seismically braced attachments to address vibrations, isolations, and damping. The effect of these attachments becomes extremely crucial in transferring noise and seismic forces. Although these devices reduce the impact of the forces to the structure, the full forces calculated are used in evaluating the attachments, beams, and structural members.

The entire concept of vibratory isolation by flotation on a non-transmitting material (spring, neoprene, cork, etc.), although necessary for equipment-operating movement, is at cross-purposes with seismic anchorage. The isolation material generally has poor lateral force-carrying capacity in itself, and the housing devices are prone to overturning. Therefore, it is necessary to either supplement conventional isolators with separate snubbing devices (see Figure 9-10) or install specially designed isolators that have built-in restraints and overturning resistance (see Figure 9-11).

Isolators with minimal lateral force resistance used in exterior applications to resist wind are usually inadequate for large seismic forces and also commonly are made of brittle cast iron. The possibility of complete isolator unloading and the ensuing tension forces due to overturning or vertical acceleration must be considered. Manufacturers' ratings of lateral loads for isolators should be examined carefully, because often the capacity is limited by the anchorage of the isolators themselves, which typically is unspecified.

Figure 9-10A Three-Dimensional Cylinder Snubber

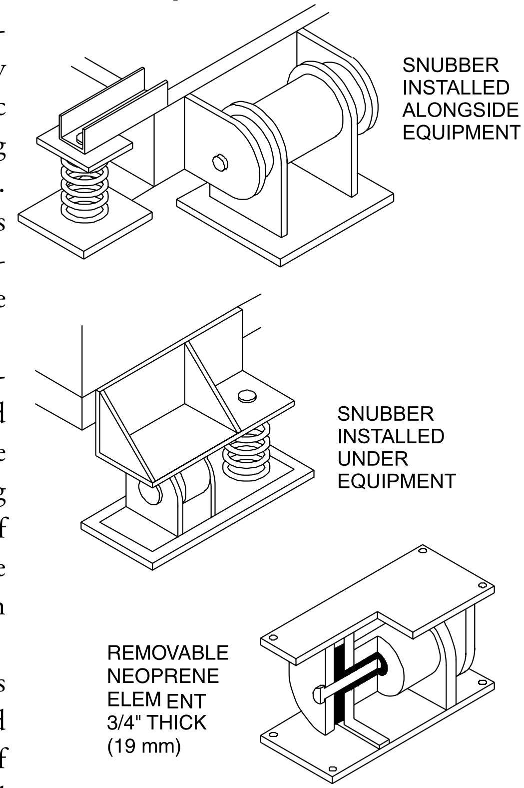
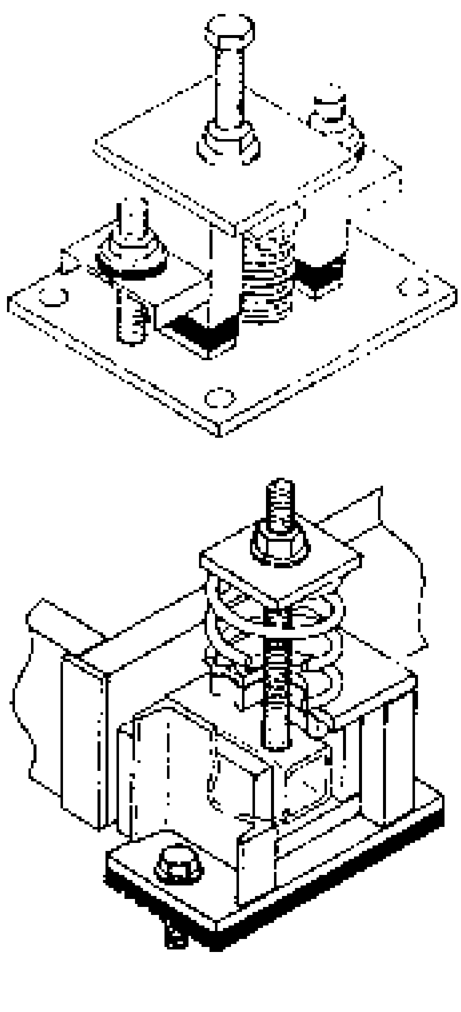


Figure 9-11 Isolators with Built-In Seismic Restraint



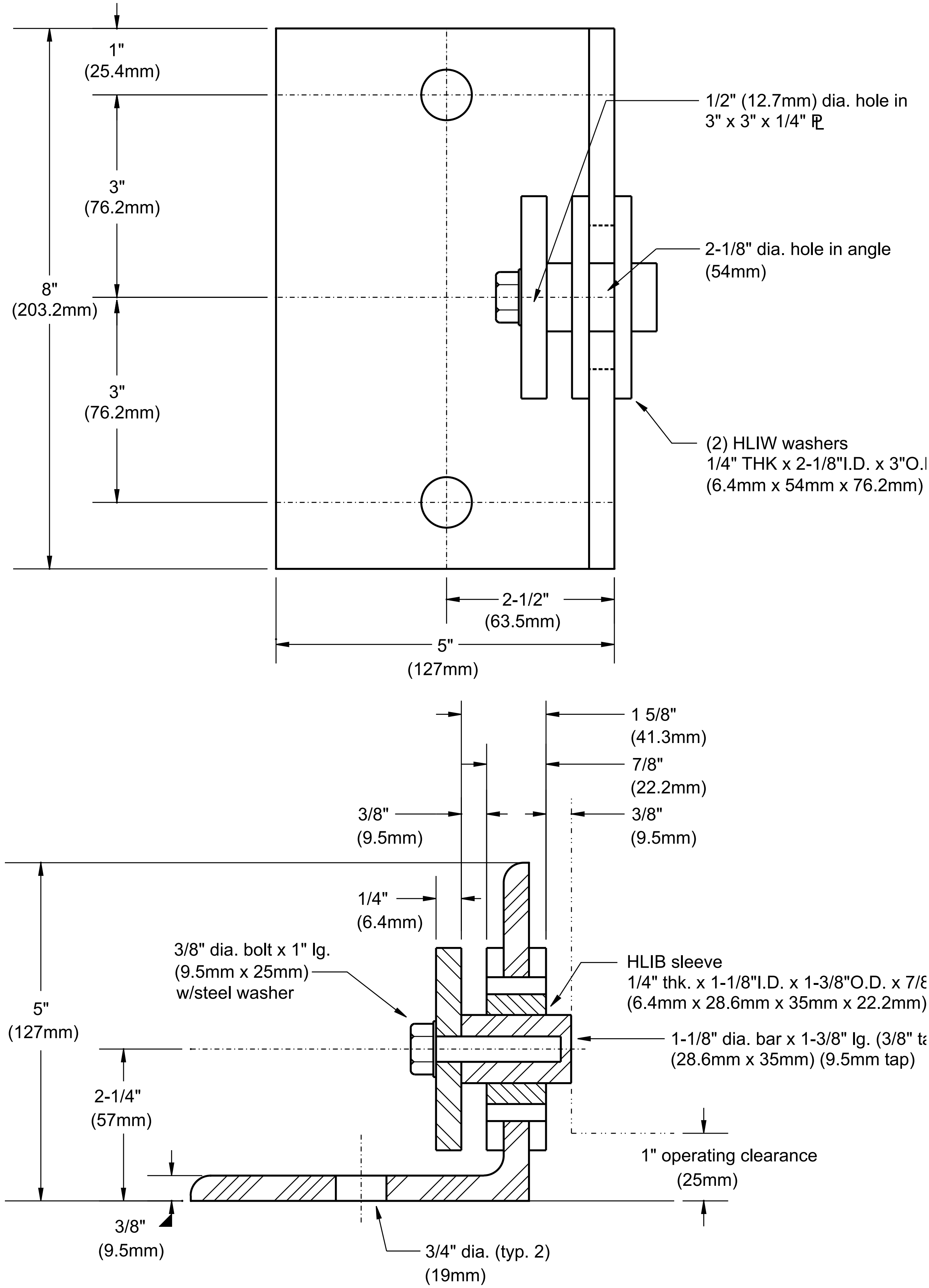
The containment surfaces in these devices must be hard connections to the piece of equipment or its base to avoid vibratory short-circuits. Because this requirement for complete operational clearance allows a small, ¼-inch (6.3-mm) movement before restraint begins, resilient pads are added to ease the shock load that could be caused by impact.

Because of the stored energy in isolation springs, it is more efficient to anchor the assembly, as restraint is built into the isolator rather than being a separate unit. In retrofit applications or occasionally due to dimensional limitations, separate snubbers are preferable. Snubbers that restrain in three dimensions are preferred because that feature minimizes the number required. Although some rubber-in-shear isolators are intended to resist loads in several directions, little data indicates their adequacy to resist the concurrent large-amplitude dynamic loading that could occur in an earthquake. Unless such isolators are considered for real earthquake loading (as opposed to code requirements) with a suitable safety factor, additional snubbing is recommended. Rubber-in-shear isolators with metal housing are more likely to have the overload capacity that may be needed to resist seismic loading, but unless they are specifically tested and rated for this loading, ultimate capacities should be compared with expected real seismic loads.

Vibration-Isolated Suspended Equipment

This is by far the most difficult type of equipment to restrain, particularly if only a small movement can be tolerated. The best method is to place an independent, laterally stable frame around the equipment with proper operating gaps padded with resilient material, similar to a snubber. However, this frame and its support system can be elaborate and awkward. An alternate

Figure 9-10B Three-Directional Angle Snubbers



method is to provide a self-contained, laterally stable, suspended platform upon which conventional seismic isolators or snubbers can be mounted.

Smaller equipment bolted or welded directly to the structure doesn't need restraints, but the bolts or welds must be designed for seismic loads. However, equipment suspended close to the structure does require restraints. Isolators within hangers always should be installed tight against the supporting structural member. When hanger rods are used to lower the unit, cross-bracing or diagonal bracing should be installed.

Cable that is installed taut, but allowed to sag under its own weight, allows vibration isolation to function. Additional slack is not required and should not be allowed. The use of neoprene grommets or bushings is not required. The cable sag and flexibility provide adequate cushioning.

SEISMIC PROTECTION TECHNIQUES FOR PIPING SYSTEMS

Typically, piping suspended by hangers less than 12 inches (305 mm) in length, as measured from the top of the pipe to the bottom of the support where the hanger is attached, does not require bracing (ASCE/SEI 7-10 Section 13.6.8, Exception 1). Seismic calculations are not required when high-deformability piping is used having provisions to avoid impact with its surroundings and meeting one of the following requirements:

- Seismic Design Categories D, E, and F, with an importance factor greater than 1.0 and pipe size equal to or less than 1 inch (25.4 mm)
- Seismic Design Category C, with an importance factor greater than 1.0 and pipe size equal to or less than 2 inches (50.8 mm)
- Seismic Design Categories D, E, and F, with an importance factor of 1.0 and pipe size less than 3 inches

(Refer to NFPA 13: *Standard for the Installation of Sprinkler Systems* for sprinkler pipe bracing.)

The following piping also shall be braced:

- Fuel oil, gas, medical gas, and compressed air piping of 1-inch (25.4-mm) nominal diameter and larger
- Piping in boiler rooms, mechanical rooms, and refrigeration mechanical rooms of 1¼-inch (31.75-mm) nominal diameter and larger

Conventionally installed piping systems have survived earthquakes with minimal damage. Fitting failures generally occur at or near equipment connectors where equipment is allowed to move or where a main is forced to move and small branches connected to the main are clamped to the structural elements. In theory, a few well-placed pipe restraints in the problem areas could provide adequate seismic protection. In practice, however, the exact configuration of piping is seldom known to the designer, and even if it was, the key brace locations are not easy to determine. Often, partial restraint in the wrong location is worse than no restraint at all. The correct practice is to provide complete restraint when seismic protection of piping systems is advisable. This restraint can be applied throughout the system or in local, well-defined areas such as mechanical or service rooms.

Although many variables must be considered when restraining pipe against seismic movement, the techniques to do so are simple and similar to those used for hanging equipment. Fixing pipe directly to structural slabs, beams, columns, or walls is the simplest method. Note that the seismic forces are considered the same in both directions. Therefore, the bracing calculated must be considered and detailed in both directions. Many codes and guidelines consider hangers of less than 12 inches (304.8 mm) as being equivalent to direct attachment. For pipes suspended more than 12 inches (304.8 mm), diagonal braces to the structure above or horizontal struts to an adjacent structure commonly are installed at vertical hanger locations. Vertical suspension hardware usually is incorporated into braces, both for efficiency and because it is readily available.

Connection to the pipe at transverse braces is accomplished by bearing the pipe or insulation on the pipe clamp or hanger. Attachment to the pipe at longitudinal brace points is not as simple. For small loads, tight-fitting clamps (such as riser clamps) dependent on friction often are used. For larger loadings, details commonly used for anchor points in high-temperature systems with welded or brazed direct connections to the piping may be necessary. Welding should be done by certified welders in accordance with AWS D1.1: *Structural Welding Code—Steel* and shall use either the shielded or submerged arc method.

Transverse bracing shall be based on the structural engineering calculations. However, certain minimum bracings must be established. Traverse bracing shall be spaced a maximum of 40 feet (12.2 m), except that fuel oil and gas piping shall be at 20-foot (6.1-m) maximum spacing. Longitudinal bracing shall be at 80-foot (24.4-m) maximum spacing, except that fuel oil and gas piping shall be at 40-foot (12.2-m) maximum spacing.

Pipe Layout Parameters

The many parameters that must be considered before the exact details and layout of a pipe bracing system can be completed are shown schematically in Figure 9-12. These parameters are discussed in more detail below.

Weight of Pipe and Contents

Since the motion being restrained is a dynamic response, the forces that must be resisted in each brace are proportional to the tributary weight.

Location of Pipe

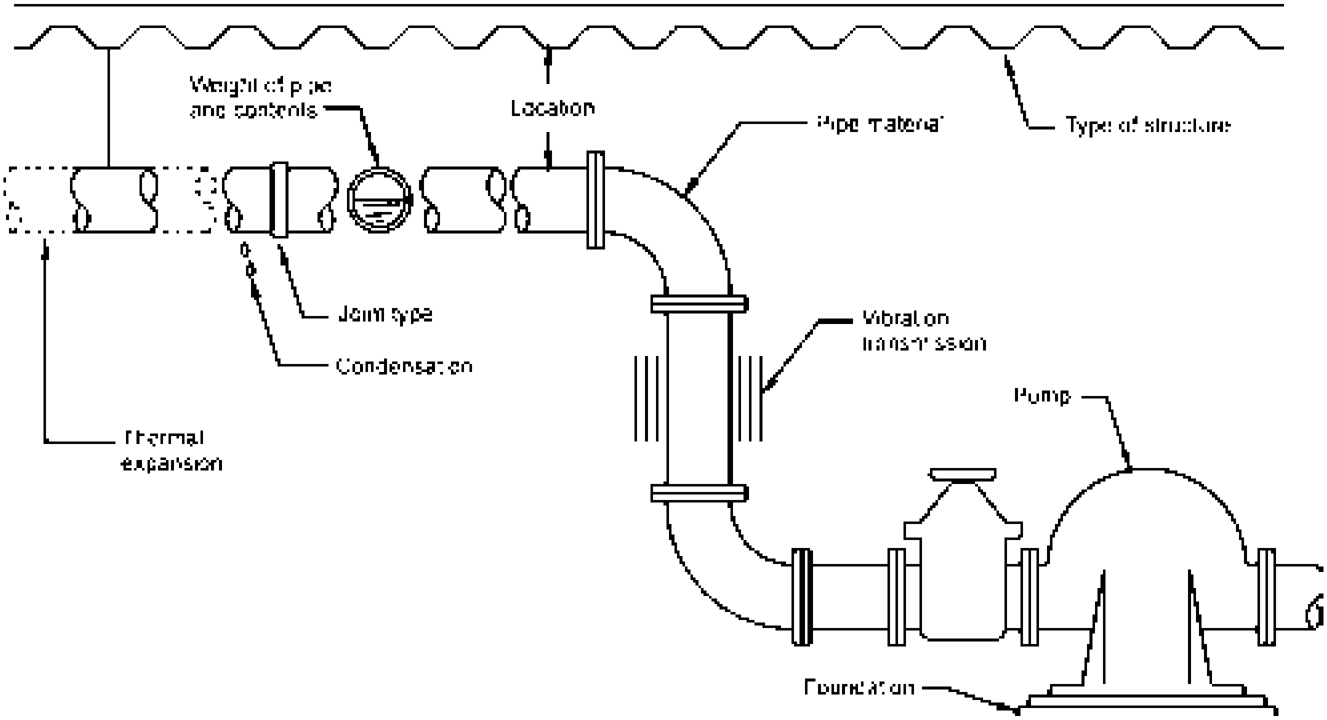
The strength of structural members, particularly compression members, is sensitive to length, so a pipe that must run far from a structural support may require more or longer braces. In boiler service rooms, a horizontal grid of structural beams sometimes is placed at an intermediate height to facilitate the bracing of pipes. The relative position of the equipment or pipes with respect to the floor is critical.

Type of Structure

The types of structures are subdivided into the following framing categories that act as seismic force-resisting systems:

- Bearing wall systems
- Building frame systems
- Moment-resisting frame systems
- Dual systems with special moment frames capable of resisting at least 25 percent of prescribed seismic forces
- Dual systems with intermediate moment frames capable of resisting at least 25 percent of prescribed seismic forces

Figure 9-12 Parameters to Be Considered for Pipe Bracing



- Shear wall-frame interactive systems with ordinary reinforced-concrete moment frames and ordinary reinforced-concrete shear walls
- Cantilevered column systems detailed to conform to the requirements
- Steel systems not specifically detailed for seismic resistance, excluding cantilever column systems

The connection of hangers and braces to the different types of structures is an important factor in determining a bracing system. For instance, many light roof-deck systems cannot accept point loads except at beam locations; pipe locations and brace layout are thereby severely limited unless costly cross beams are placed at every brace. Other roof and floor systems have significant limitations on the magnitude of point loads, which limits brace spacing.

It is often unacceptable to drill or shoot anchors into the underneath of pre-stressed concrete floors. Limitations on depth and location also exist in the bottom flange of steel or reinforced concrete beams and in the bottom chord of joists. Many steel floor-deck styles have down flutes of 1½ inch (38.1 mm) or less in width, and the strength of drilled or shot-in anchors installed in these locations is questionable.

In buildings with structures that employ interstitial space, the capacity to brace pipe to either the top or the bottom of the space may be available, which greatly increases bracing layout flexibility.

Piping Material

The strength and ductility of the material affect brace spacing. The stiffness affects dynamic response and therefore loading. Flexible piping reduces the transmission of the forces into the building.

Joint Type

The joint has proven to be the piping system element most likely to be damaged during earthquakes. Threaded and bell-and-spigot joints are particularly susceptible. The joint type also determines, in conjunction with the pipe material, the length of the span between braces. Brazed and soldered joints perform acceptably. Most no-hub joints, however, have virtually no stiffness; thus, effective bracing of such systems is nearly impossible. Mechanical joints exhibit the most complex behavior, with spring-like flexibility (when pressurized) within a certain rotation and then rigidity. In addition, the behavior of such systems under earthquake conditions, which cause the axial loadings necessary to transmit forces to longitudinal braces, is unknown.

At a minimum, cast iron, glass pipe, and any other pipe joined with a shield-and-clamp assembly where the top of the pipe exceeds 12 inches (304.8 mm) from the supporting structure shall be braced on each side of a change in direction of 90 degrees or more. Riser joints shall be braced or stabilized between floors. For hubless pipe-riser joints unsupported between floors, additional bracing is required. All vertical pipe risers shall be laterally supported with a riser clamp at each floor.

In most engineered buildings where seismic concerns are greatly emphasized, all pipe connections near the building frame system are flexible piping.

Vibration

Traditionally, unbraced pipe systems seldom cause vibration transmission problems because of their inherent flexibility. Many engineers are concerned that completely braced, tight piping systems could cause unpredictable sound and vibration problems. Vibration isolation assists in reducing the seismic loading; however, it does not decrease the design loading of the attachments.

Temperature Movement

Pipe anchors and guides used in high-temperature piping systems must be considered and integrated into a seismic bracing system. A misplaced longitudinal brace can become an unwanted anchor and cause severe damage. Thermal forces at anchor points, unless released after the system is operational, are additive to tributary seismic forces. Potential interference between seismic and thermal support systems is particularly high near pipe bends where a transverse brace can become an anchor for the perpendicular pipe run.

Condensation

The need to thermally insulate high-temperature and chilled water lines from hanging hardware makes longitudinal brace attachment difficult. In some configurations of short runs with bends, transverse braces can be utilized near elbows to brace the system in both directions. Friction connections, using wax-impregnated oak or calcium-silicate sleeves as insulators, have been used.

Piping Bracing Methods

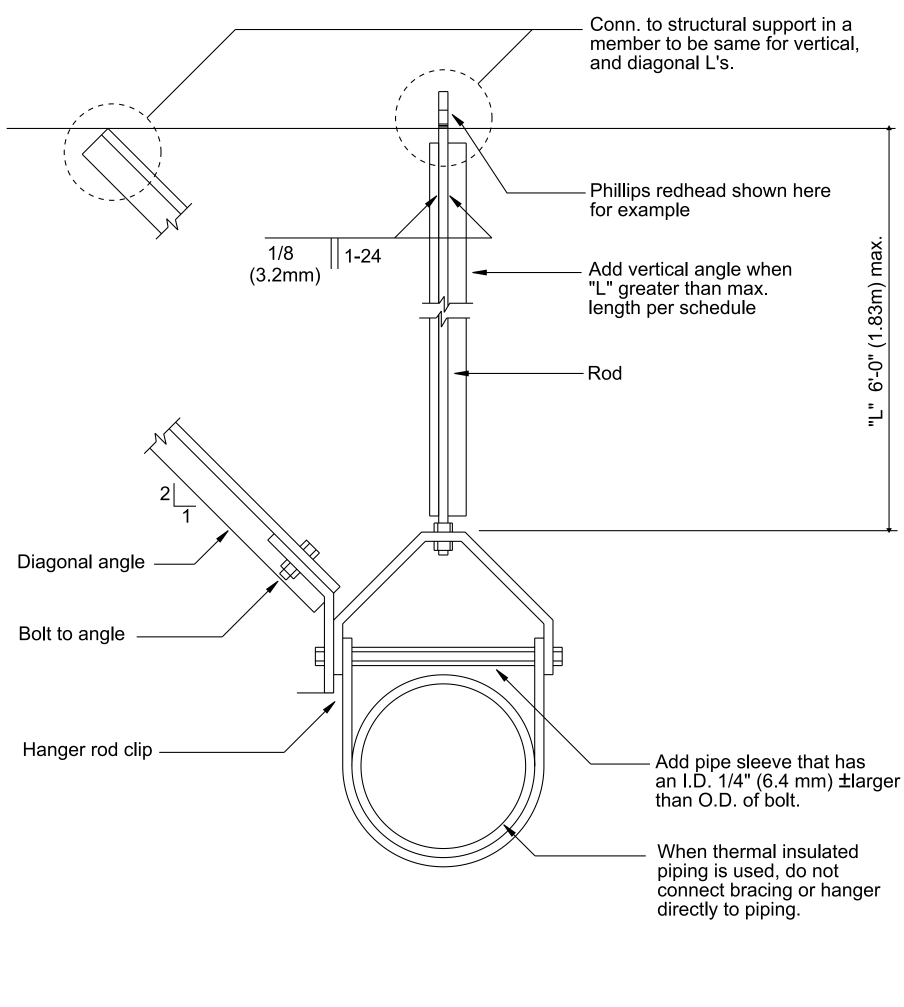
Several bracing systems have been developed that contain some realistic and safe details governing a wide range of loading conditions and configurations. For example, SMACNA (Sheet Metal and Air-Conditioning Contractors' National Association) has prepared some guidelines on bracing systems for use by engineers, architects, contractors, and approving authorities. Some of these details for the construction of seismic restraints are seen in Figures 9-13 and 9-14. These guidelines utilize three pipe-bracing methods: structural angle, structural channel, and aircraft cable. In addition, several manufacturers have developed their own seismic bracing methods (see Figures 9-15 and 9-16). Whatever method is used, the adequacy of the supporting structure should be determined by properly applying acceptable engineering procedures.

Pipe risers seldom pose a problem because they typically are clamped at each floor, and movement due to temperature changes is routinely considered. Very large or stiff configurations, which could be affected by inter-story drift, or situations where long, free-hanging horizontal runs could be inadvertently braced by a riser are possible exceptions. The effect of mid-span couplings with less strength or rigidity than the pipe itself also must be considered.

The techniques for handling the possible differential movement at locations of utility entrances to buildings or at building expansion joints are well developed because of the similarity to the non-seismic problems of settlement, temperature movement, and wind drift. Expansion loops or combinations of mechanically flexible joints commonly are employed. For threaded piping, flexibility may be provided by the installation of swing joints. For manufactured

Figure 9-13A Typical Pipe Bracing

Source: SMACNA



ball joints, the length of the piping offset should be calculated using a seismic drift of 0.015 foot per foot of height above the base where seismic separation occurs. The primary consideration in seismic applications is to recognize the possibility of repeated, large differential movements.

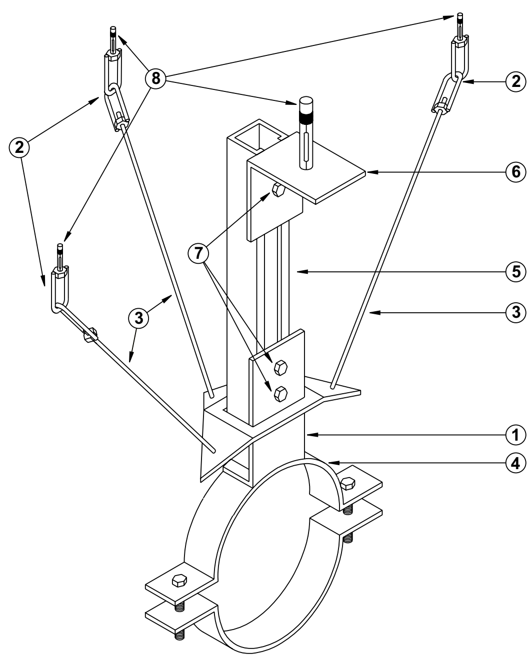
CODE REQUIREMENTS

The process of seismic design for buildings has had a reasonably long time to mature. Beginning in the 1920s, after engineers observed heavy building damage from earthquakes, they began to consider lateral forces on buildings in this country and Japan. Today's procedures are based on analytical results as well as considerable design experience and observed performance in earthquakes of varying characteristics. Accelerations calculated for the seismic design forces are based on maximum considered earthquakes as the foundation for the most severe earthquakes considered by the codes. The lateral forces for buildings specified in most codes are much lower than could be calculated from structural dynamics for a variety of reasons, including:

- Observed acceptable performance at low design levels
- Expected ductile action of building systems (ability to continue withstanding force and distortion after yielding)
- Redundancy of resisting elements in most systems
- High damping as distortions increase, which creates a self-limiting characteristic on response

Figure 9-13B Tension 360 Pipe Bracing

Source: SMACNA



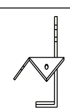
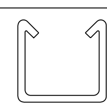
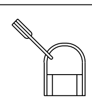
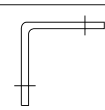
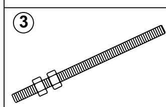
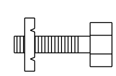
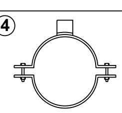
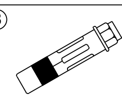
1 	Triangle Plate 1/4" Plate 1/4"X1-1/4" Flat Bar	5 	1-1/4"x1-1/4"x12 Ga. Channel Length Varies (Not Included)
2 	1/2" Flexible Connector	6 	1/4" Angle Clip
3 	1/2" All-Thread Rod (Not Included) Length Varies With Nylon Lock Nut	7 	1/4" Dia Mach. Bolt with Clamp Nut 30 Ft # Torque
4 	Pipe Hanger Size and Type Can Vary	8 	Phillips Sleeve Anchor

Figure 9-13C Superstrut

Source: SMACNA

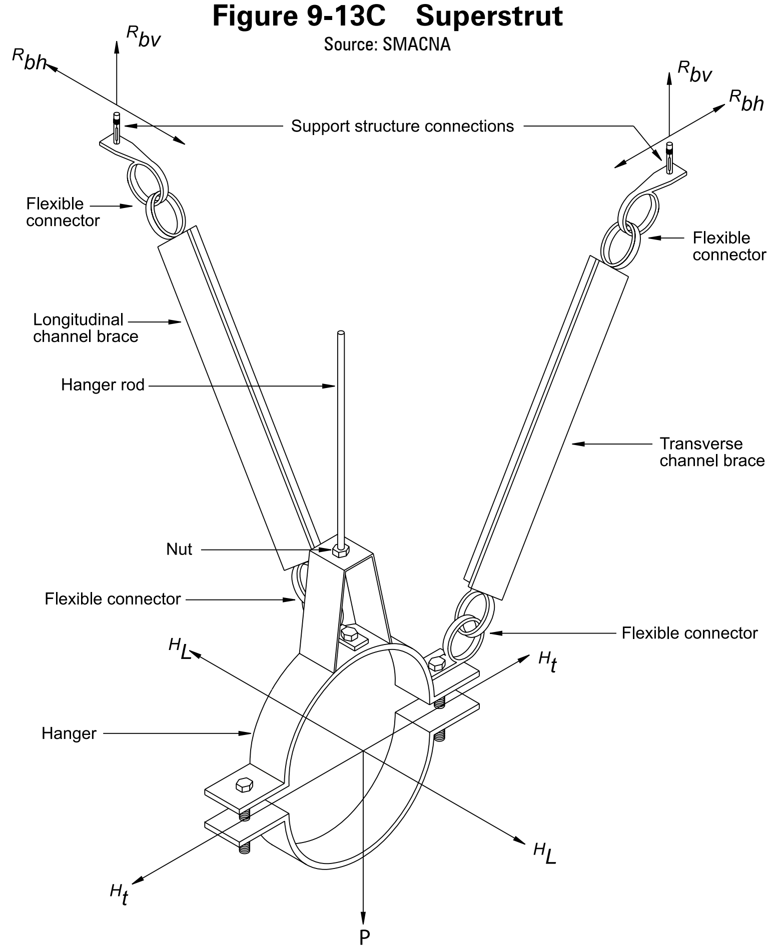
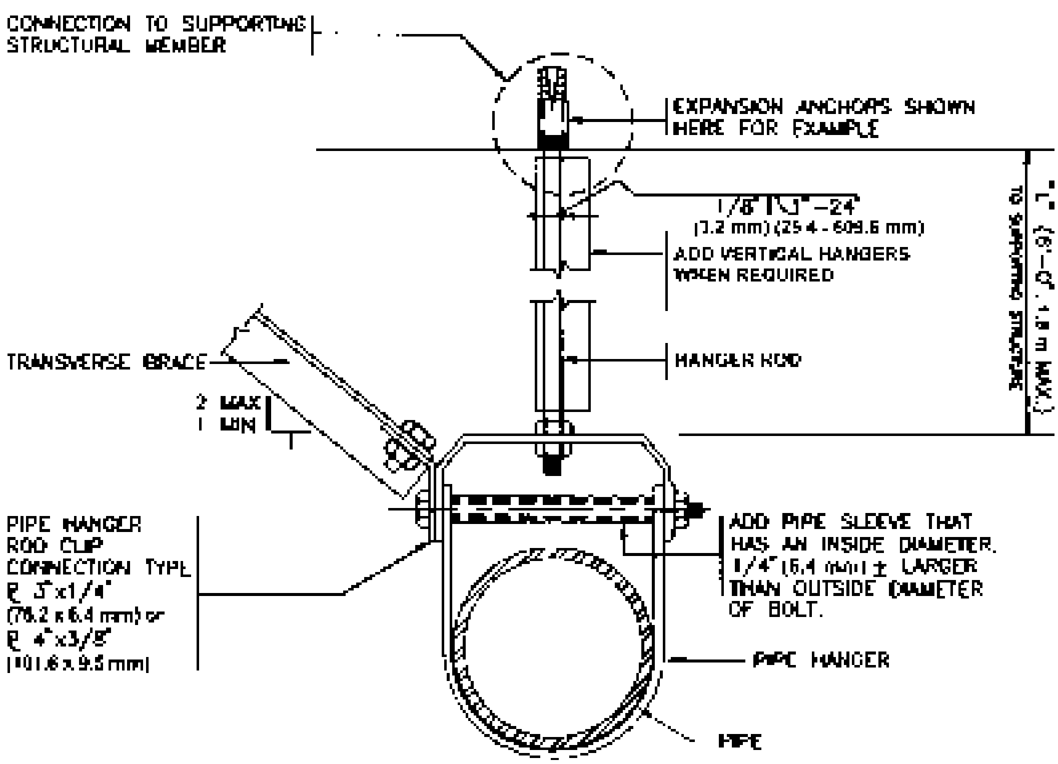


Figure 9-14A Transverse Bracing for Pipes

Source: SMACNA



- Less-than-perfect compliance of the foundation to the ground motion
- Economic restraints on building codes

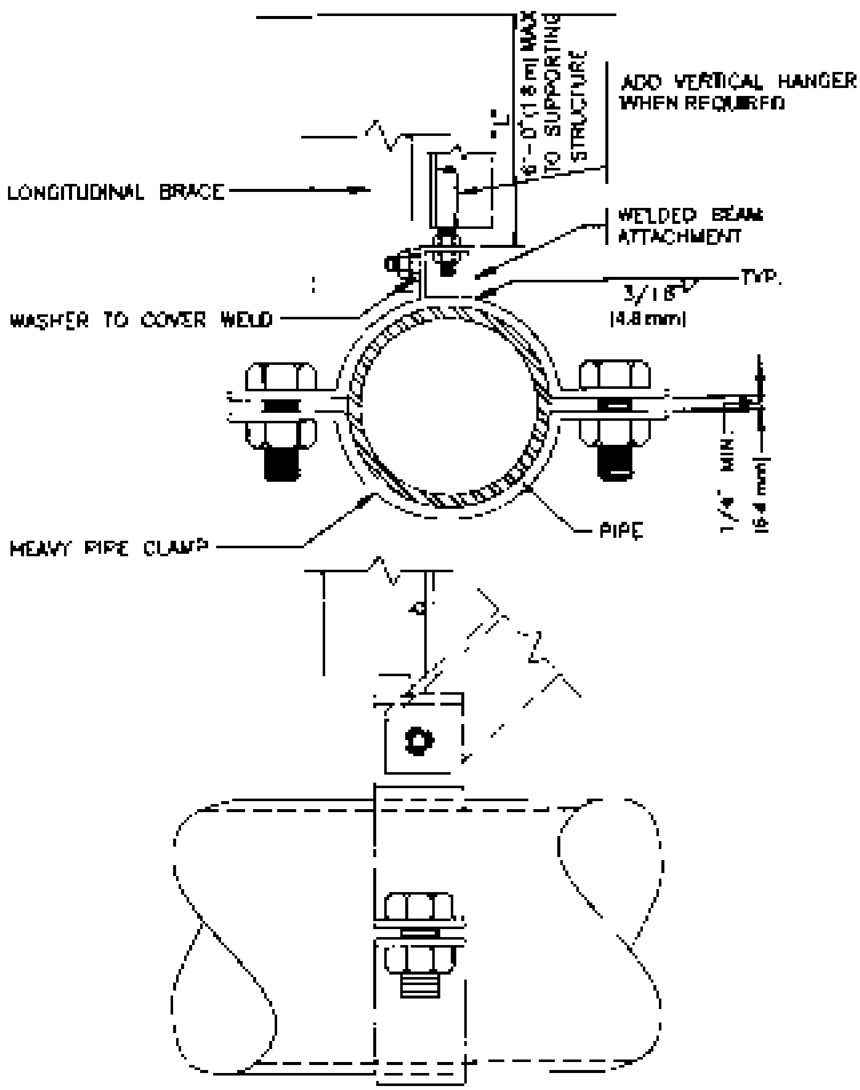
The fact that the actual response of a building during an earthquake could be three or four times that represented by code forces must be understood and considered in good seismic design. Traditionally, this was done by rule of thumb and good judgment to ensure that structural yielding is not sudden or does not produce a collapsed mechanism. More recently, the response of many distinguished buildings to real earthquake input with site-specific data is being considered more specifically than using computer analysis.

Design of seismic protection for nonstructural elements, including plumbing components and equipment, has neither the tradition nor a large number of in-place tests by actual earthquakes to enable much refinement of design force capability or design technique. Unfortunately, few of the effects listed above that mitigate the low force level for structures apply to plumbing or piping. Equipment and piping systems are generally simple and have low damping, and their lateral force-resisting systems are usually non-redundant. It is imperative, therefore, when designing seismic protection for these elements to recognize whether the force levels being utilized are arbitrarily low for design or realistic predictions of actual response. Even when predictions of actual response are used, earthquake forces are considered

Figure 9-14B Longitudinal Bracing for Pipes

Note: Movement due to temperature has been neglected in this example.

Source: SMACNA



sufficiently unpredictable when friction is not allowed as a means of anchorage. Often, less-than-full dead load is used to both simulate vertical accelerations and provide a further safety factor against overturning or swinging action.

All current building codes require most structures and portions of structures to be designed for a horizontal force based on a certain percentage of their weight. Each code may vary in the method of determining this percentage, based on factors including the seismic zone, importance of the structure, and type of construction.

It is difficult to consider specific code requirements out of context. The code documents themselves should be consulted for specific usage. Most codes currently in use, or being developed, can be discussed generally by considering the following:

- International Building Code
- California Building Standards Code (California Code of Regulations, Title 24)
- ASCE/SEI 7
- *Seismic Design for Buildings,* U.S. Department of Defense
- *Tentative Provisions for the Development of Seismic Regulations for Buildings,* Applied Technology Council

The Lateral Force

All of these codes require consideration of a lateral force that must be placed at the center of gravity of the element. The lateral force, or equivalent static force, is calculated using some or all of the following parameters.

Figure 9-14C Strut Bracing for Pipes

Source: SMACNA

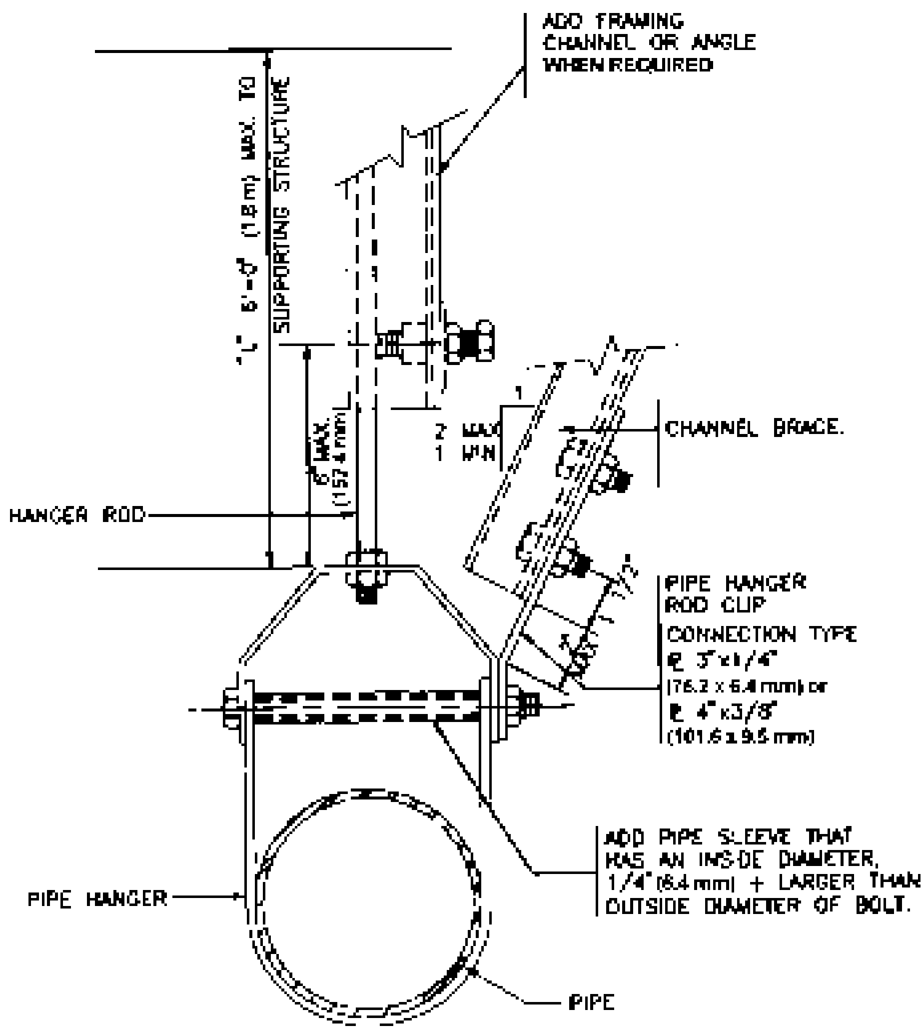


Figure 9-14D Alternate Attachment to Hanger for Pipe Bracing

Source: SMACNA

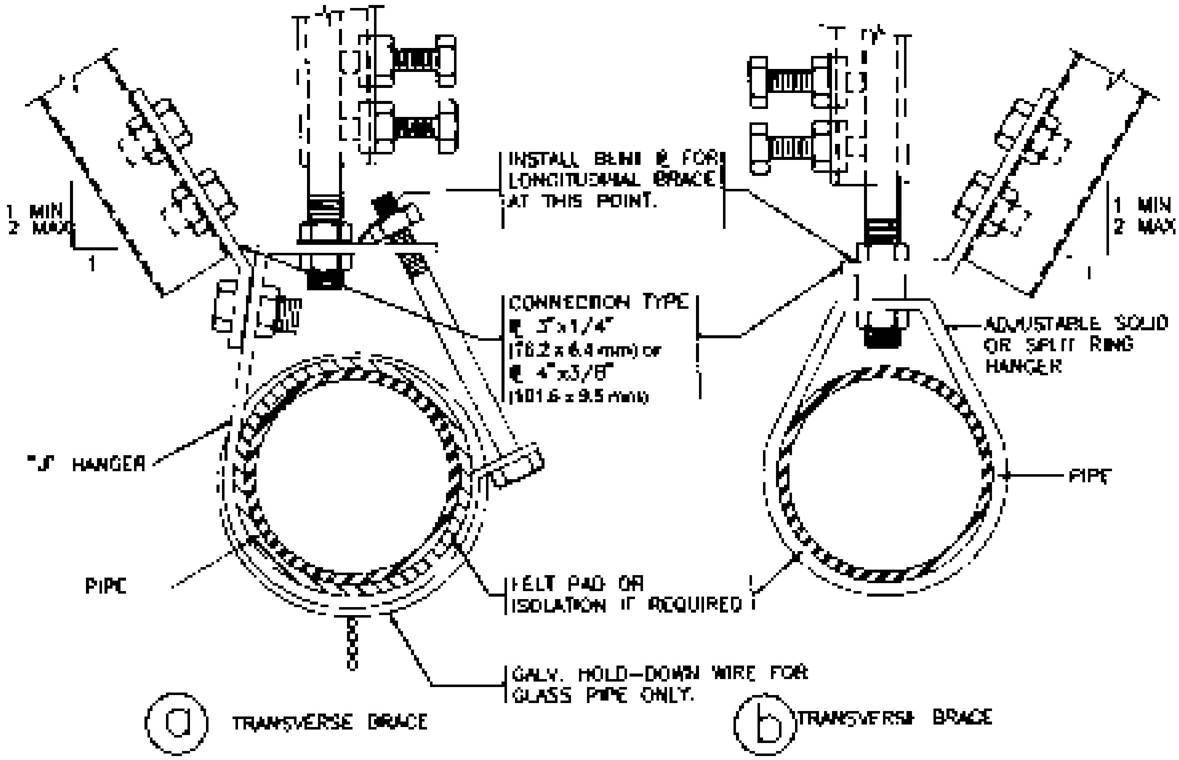
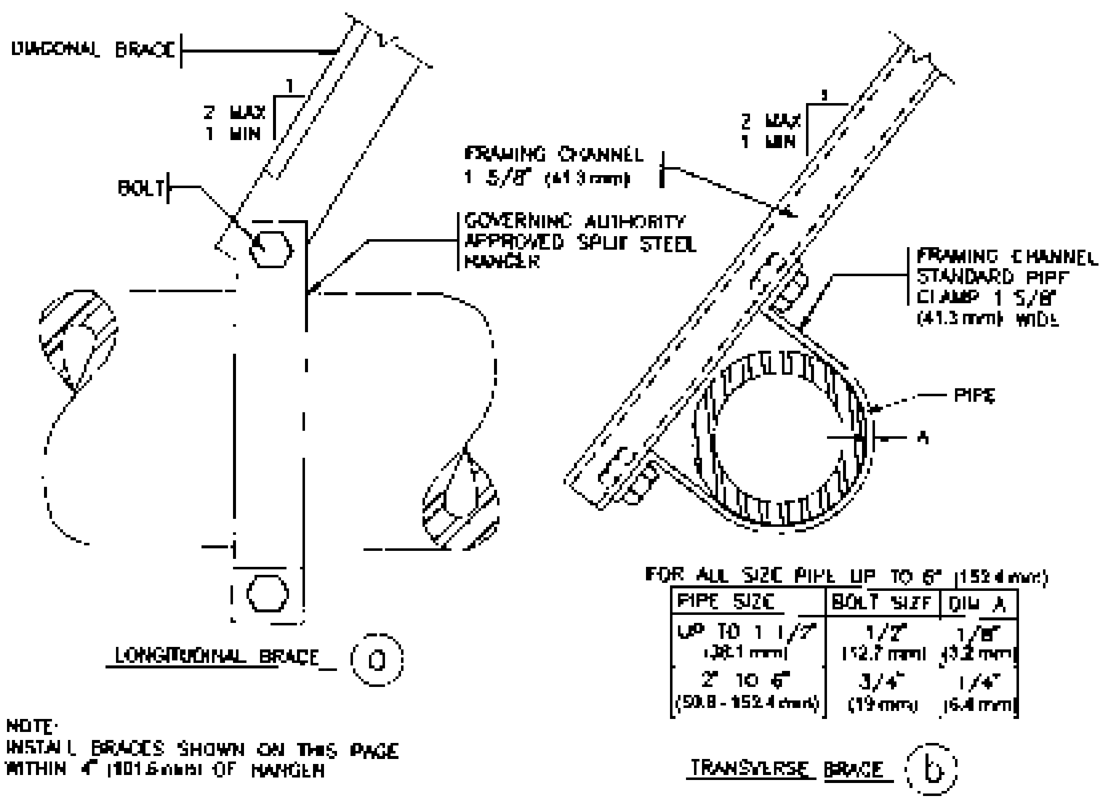


Figure 9-14(E) Alternate Bracing for Pipes

Source: SMACNA



FOR ALL SIZE PIPE UP TO 6" (152.4 mm)

PIPE SIZE	BOLT SIZE	DIM A
UP TO 1 1/2" (38.1 mm)	1/2" (12.7 mm)	1/8" (3.2 mm)
2" TO 6" (50.8 - 152.4 mm)	3/4" (19 mm)	1/4" (6.4 mm)

NOTE:
INSTALL BRACES SHOWN ON THIS PAGE WITHIN 4" (101.6 mm) OF HANGER

Figure 9-14F Strut Bracing for Pipe Trapeze

Source: SMACNA

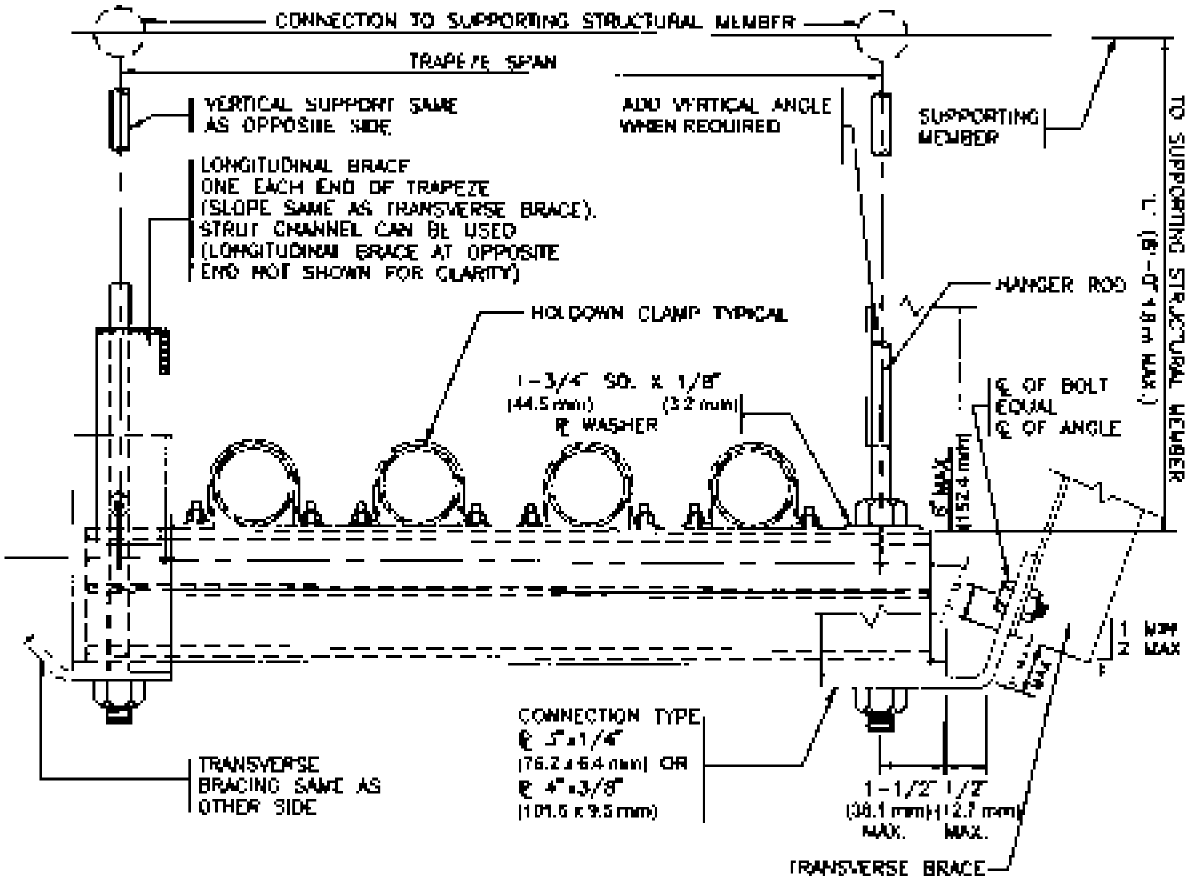
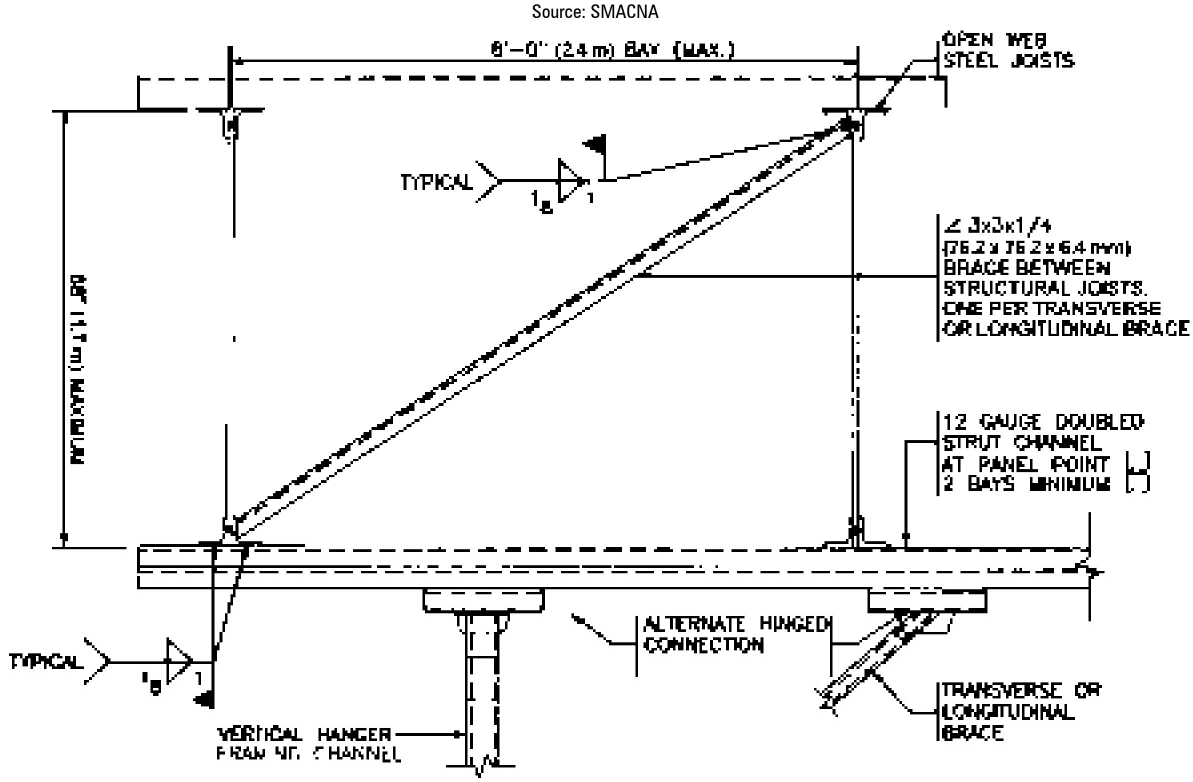


Figure 9-14H Connections to Open-Web Steel Joists

Source: SMACNA



Zone

The zone category (refer back to Figure 9-1) affects the lateral force calculated by considering the size and frequency of potential earthquakes in the region. Zones vary from no earthquakes (Zone 0) to a majority of California (Zone 4).

Soil

The effect of specific site soils on ground motion must be considered. Soil types are divided based on three characteristics: soil shear wave velocity, standard penetration resistance, and soil undrained shear strength. The types of soils are:

A: Hard rock
B: Rock
C: Very dense soil and soft rock
D: Stiff soil profile
E: Soft soil profile or near liquefaction
F: Full liquefaction

Site Coefficient

The site coefficient considers the basic response of the element to ground motion and is affected by sub-parameters, which could include location within the building and possible resonance with the structure. Given the exact latitude and longitude of the location, U.S. Geological Survey data can provide all of the parameters based on exact location with respect to all fault lines occurring within the vicinity. All parameters are site specific, and the data provided includes a site coefficient based on the maximum considered earthquake for short (less than 0.04 second) and long (less than 1 second) periods, as well as the accelerations for corresponding periods.

Figure 9-14G Connections to Steel Beams

Source: SMACNA

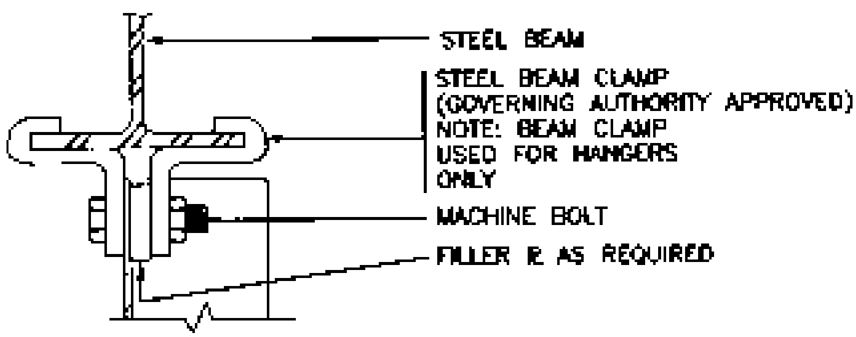


Figure 9-14(I) Connections to Steel

Source: SMACNA

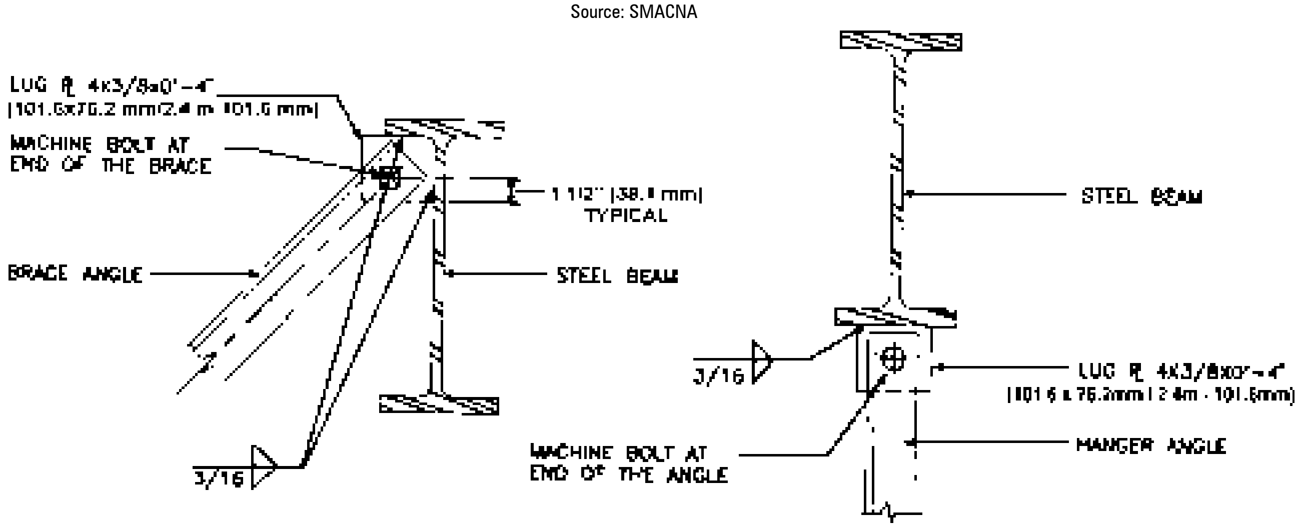


Figure 9-14J Hanger Rod Connections

Source: SMACNA

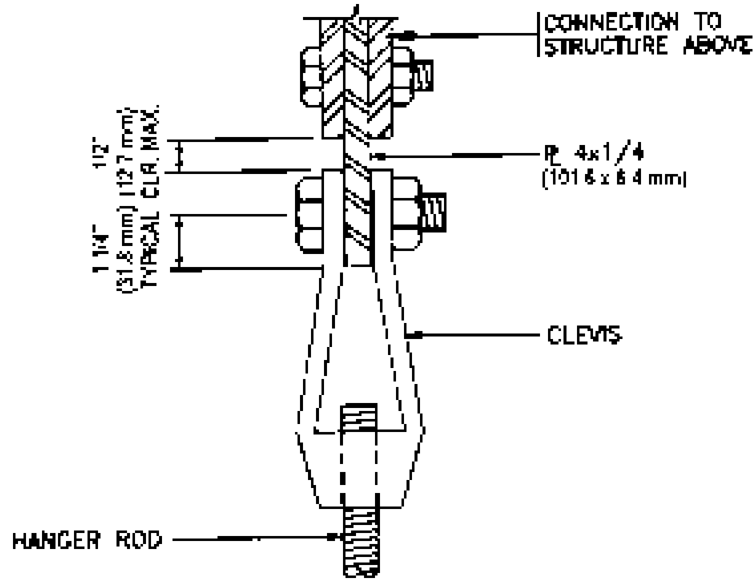


Figure 9-14K Hubless Cast-Iron Pipe

Source: SMACNA

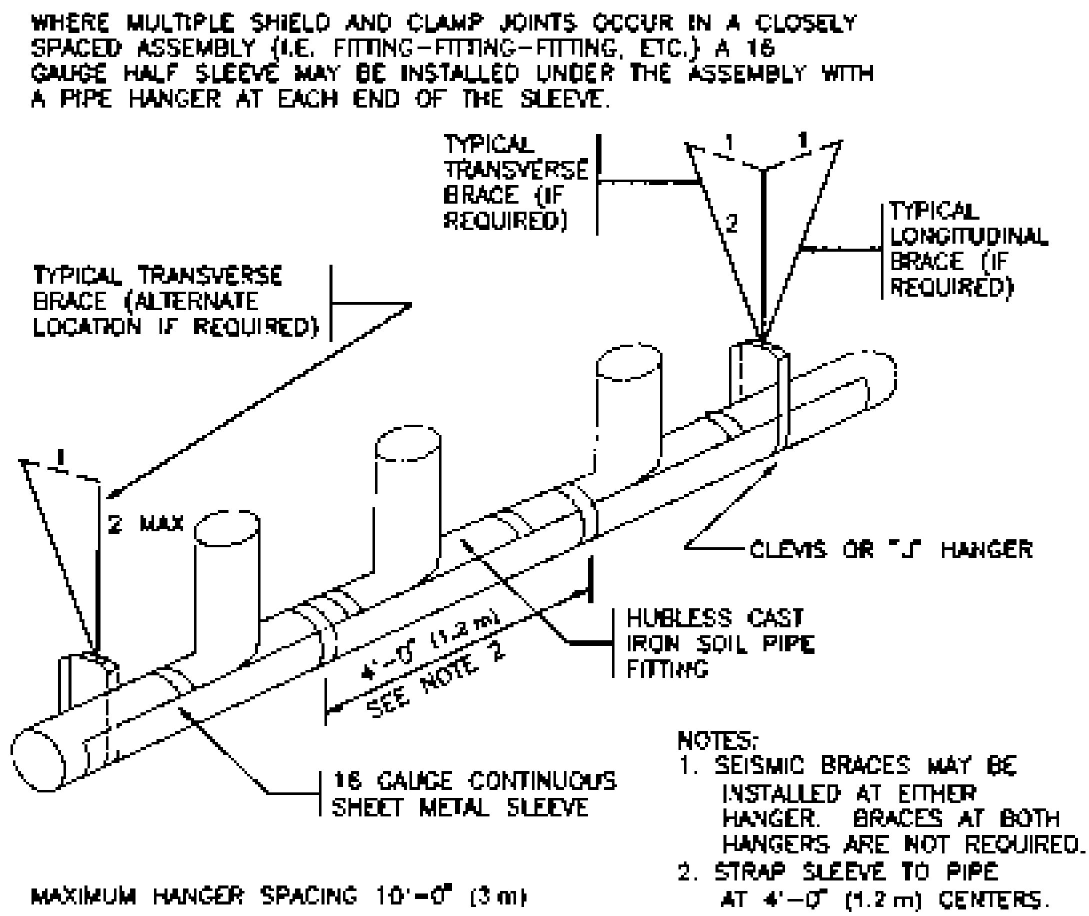
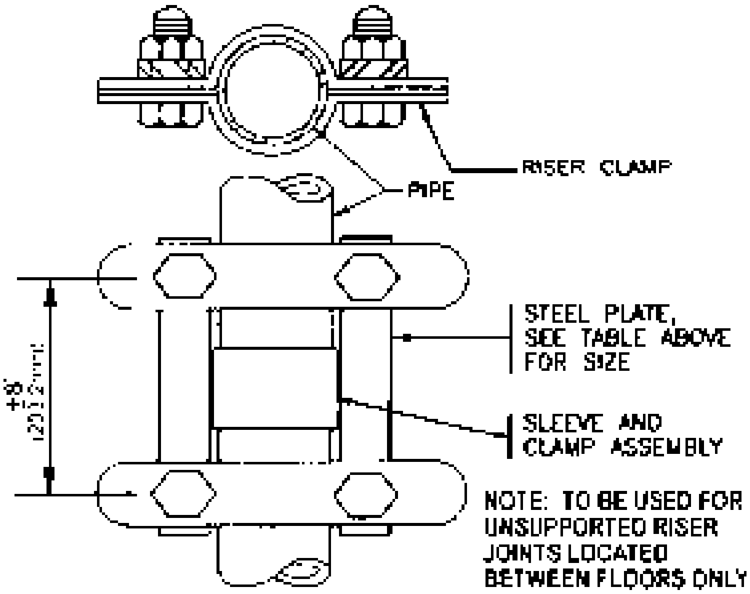


Figure 9-14L Riser Bracing for Hubless Pipes

Source: SMACNA



PIPE SIZE	PLATE SIZE	BOLT SIZE
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
5" (152.4mm)	[illegible]	[illegible]
8" (203.2mm)	[illegible]	[illegible]

Figure 9-14M Connections for Pipes on Trapeze

Source: SMACNA

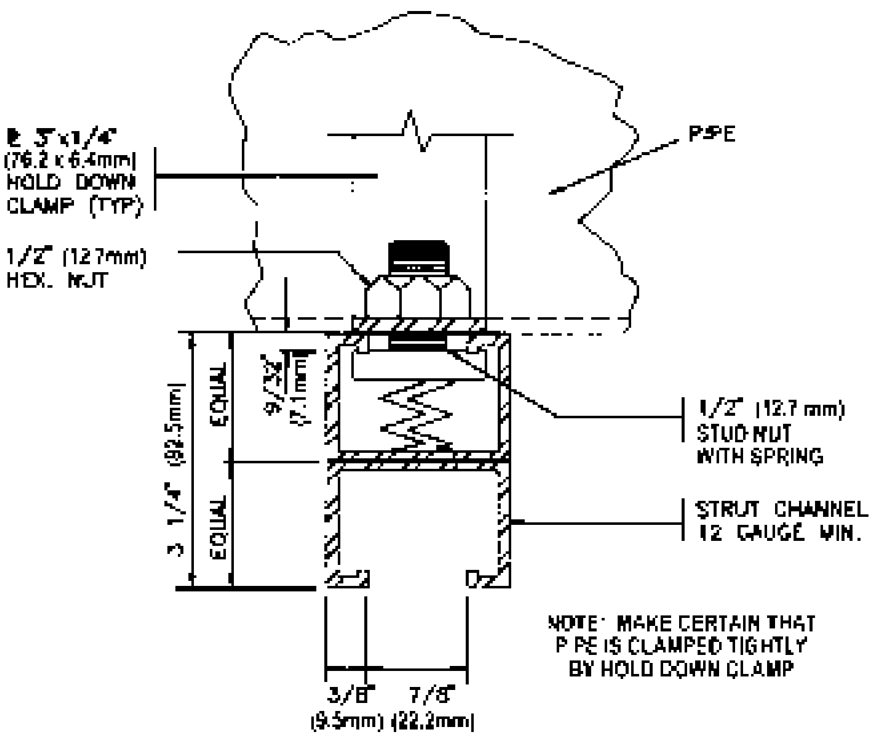


Figure 9-15 Sway Bracing, 0.5 G Force

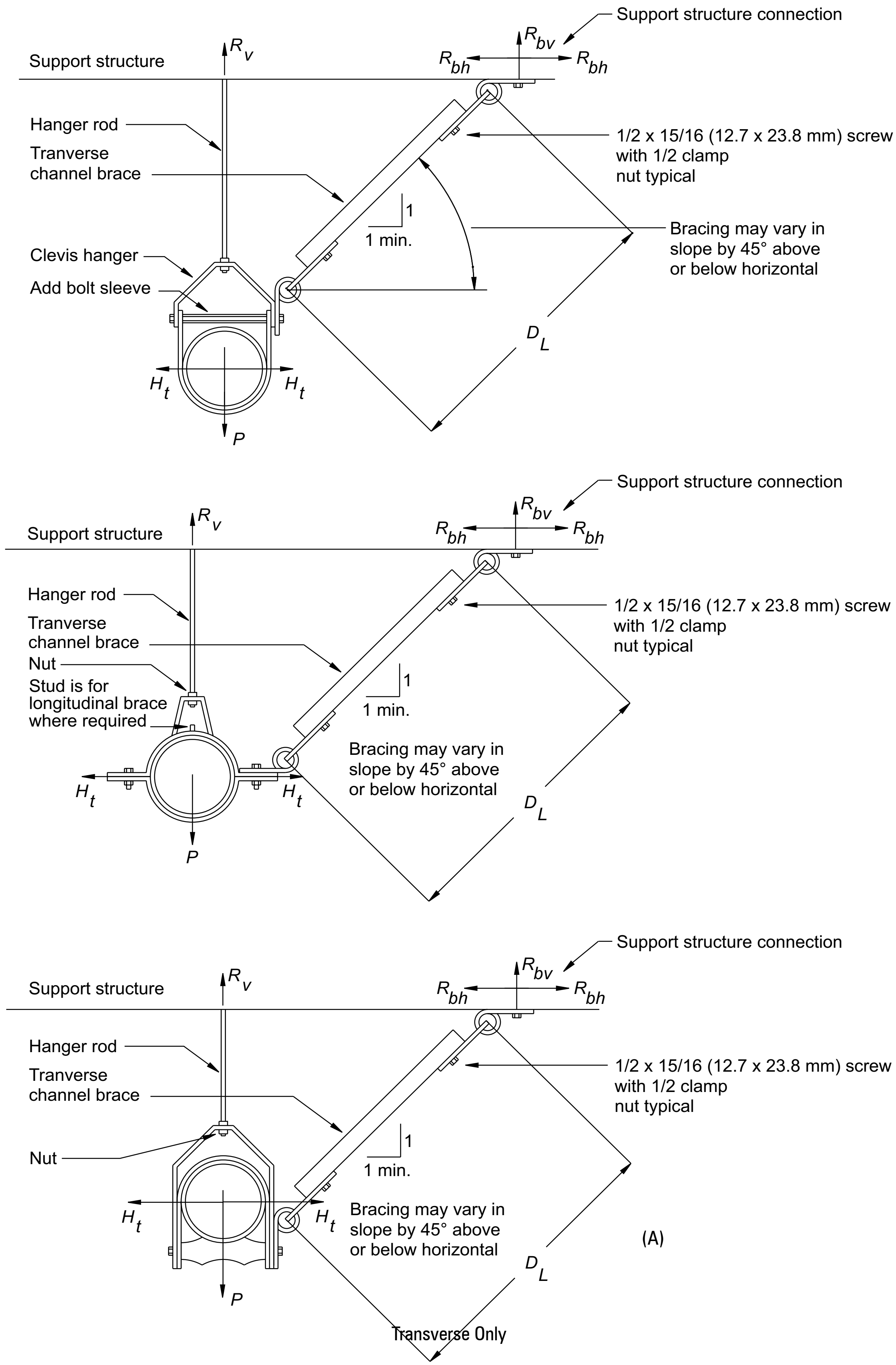
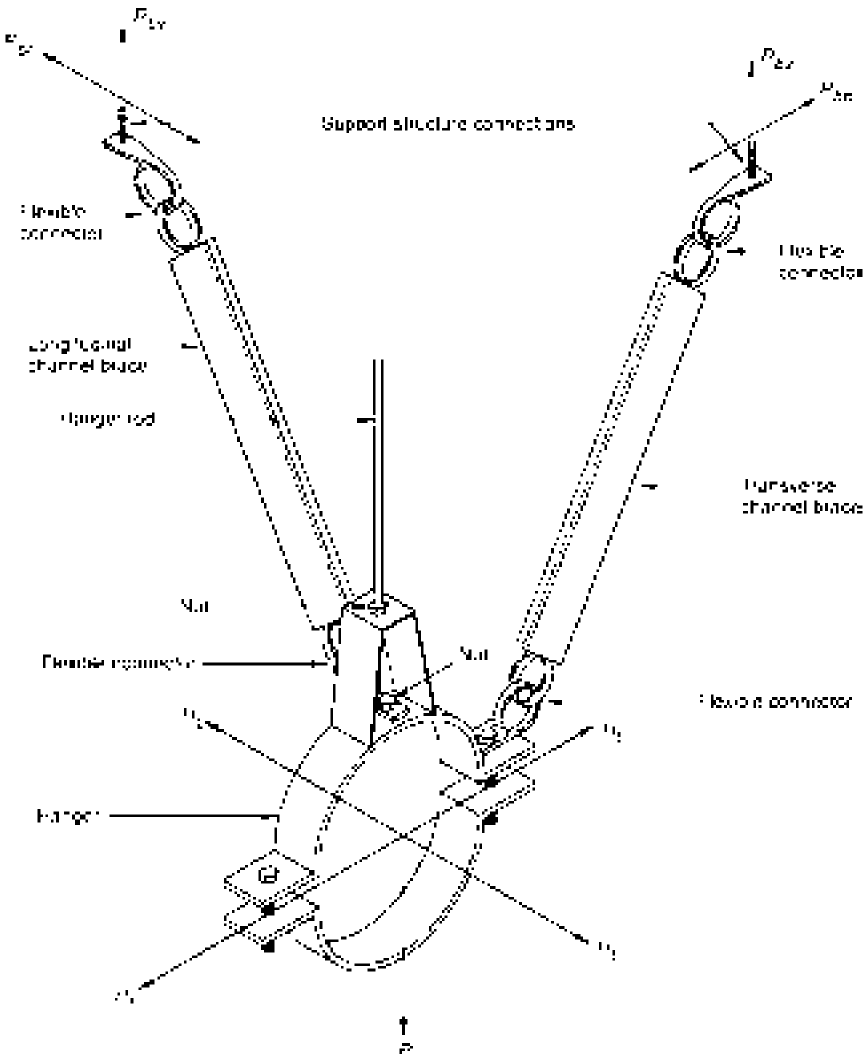
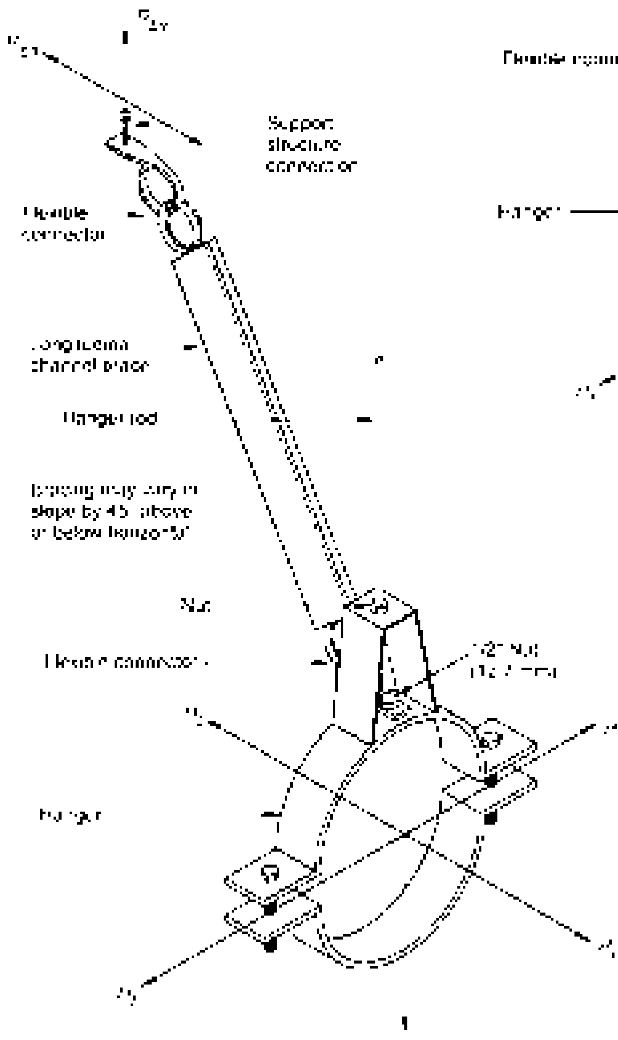


Figure 9-15 Sway Bracing, 0.5 G Force (continued)



(B)

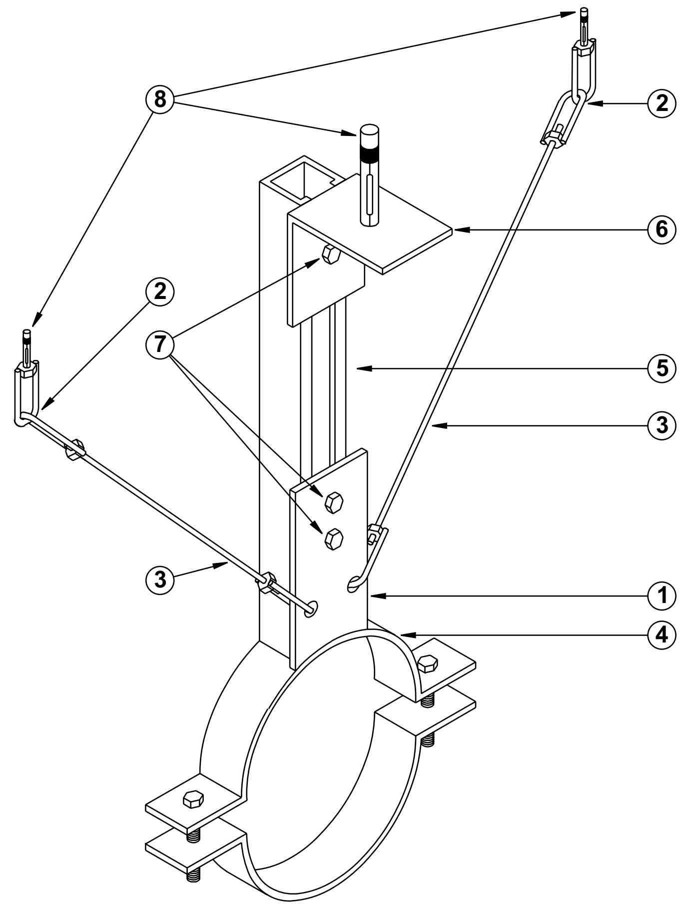
Longitudinal and Transverse



(C)

Longitudinal Only

Figure 9-16A Lateral Sway Bracing



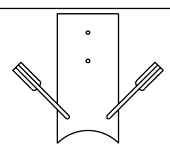
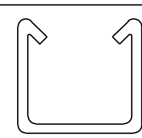
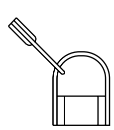
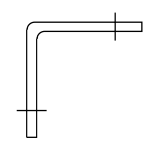
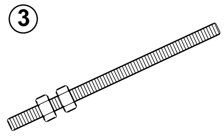
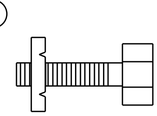
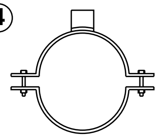
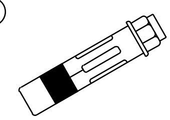
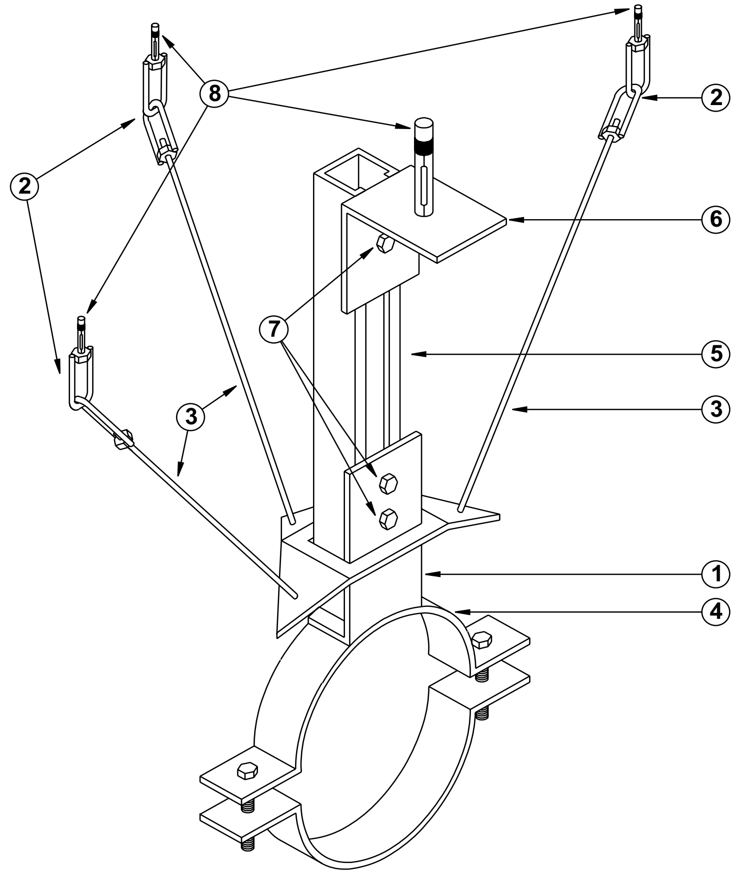
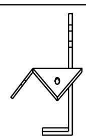
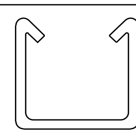
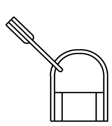
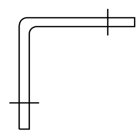
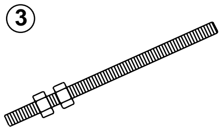
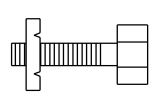
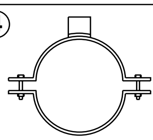
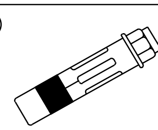
1 	Brace Plates Type Thickness Links 1 3/8" (9.5mm) 1/2" (12.7mm) 2 1/2" (12.7mm) 5/8" (15.8mm)	5 	Strut Type 1 1-5/8"(41.3mm)x1-5/8"(41.3mm)x12 Ga 2 1-5/8"(41.3mm)x1-5/8"(41.3mm)x12 Ga
2 	Connectors Type Diameter 1 1/2" (12.7mm) 2 5/8" (15.8mm)	6 	Angle Clip Type Thickness Hole Dia. 1 3/8" (9.5mm) 9/16" (14.3mm) 2 1/2" (12.7mm) 11/16" (17.5mm)
3 	All-Thread Rod & Nylock Nuts Type Diameter 1 1/2" (12.7mm) 2 5/8" (15.8mm) (4 Tension Rods Required)	7 	Bolts & Clamping Nut Type Diameter 1 1/2" (12.7mm) 2 5/8" (15.8mm)
4 	Pipe Clamp Model Selection per pipe Clamp & Accessory Detail	8 	Drilled Sleeve Anchor

Figure 9-16B Lateral and Longitudinal Sway Bracing



① 	Brace Plates Type Thickness 1 3/8" (9.5mm) 2 1/2" (12.7mm)	⑤ 	Strut 1-5/8"(41.3mm) x 1-5/8"(41.3mm) x 12 Ga Length Varies
② 	Connectors Type Diameter 1 1/2" (12.7mm) 2 5/8" (15.8mm)	⑥ 	Angle Clip Type Thickness Hole Dia. 1 3/8" (9.5mm) 9/16" (14.3mm) 2 1/2" (12.7mm) 11/16" (17.5mm)
③ 	All-Thread Rod & Nylock Nuts Type Diameter 1 1/2" (12.7mm) 2 5/8" (15.8mm)	⑦ 	Bolts & Clamping Nut Type Diameter 1 1/2" (12.7mm) 2 5/8" (15.8mm)
④ 	Pipe Clamp Model Selection per pipe Clamp & Accessory Detail	⑧ 	Drilled Sleeve Anchor

Importance Factor

The importance factor is a measure of the desirability of protection for a specific element. The importance factor ranges from 1.0 for ordinary buildings to 1.5 for hospitals and police stations.

Element Weight

All codes require calculation of a lateral force that is a percentage of the element weight. The tributary weight that the lateral forces encounter is the whole or partial weight of the equipment or element depending on its position within the building.

Amplification Factor

The amplification factor is defined by the natural period, damping ratio, and mass of the equipment and the structure. This amplifies certain critical connections and allows a higher level of bonding of the equipment and the building.

Response Factor

Determined by driven frequency (equipment motors) and natural frequency, the response factor depends on the rigidity and flexibility of the connection. This becomes critical in the case of non-building structures such as tanks, billboards, and other equipment that are totally self-supporting. When the fundamental period of the structure, T, is less than 0.06 second, then the structure is considered rigid. The response factor increases as the connection becomes more flexible.

Sprinkler Systems: NFPA 13

Because of the potential for fire immediately after earthquakes, sprinkler piping has long received special attention. The reference standard for the installation of sprinkler piping, NFPA 13, often is cited as containing prototype seismic bracing for piping systems. In fact, in those cases observed, sprinkler piping has performed well. In addition to bracing, good earthquake performance by sprinkler piping is also due to other factors, such as limited pipe size, the use of steel pipe, coherent layouts, and conservative suspension (for vertical loads).

Use of NFPA 13 guidelines for pipe bracing is not discouraged, but it should not be considered a panacea for all piping systems. Other organizations, such as FM Global, have developed guidelines for properties insured by them and in many cases are more restrictive.

For reference, Table 9-1 provides the weights of steel pipe filled with water for determining horizontal loads, Table 9-2 provides load information for the spacing of sway bracing, and Table 9-3 provides maximum horizontal loads for sway bracing.

ANALYSIS TECHNIQUES

Determination of Seismic Forces

As discussed in the previous section, one of the most common methods of defining seismic forces is by use of code equivalents of dynamic earthquake forces. The following formula can be used to determine the loading.

Equation 9-1

$$F_p = 0.4\, a_p S_{DS} W_p (1 + 2\, z/h)/(R_p/I_p)$$

where:

F_p = Lateral (seismic) force applied at element center of gravity (Must be within the maximum value of $1.6 S_{DS} W_p I_p$ and the minimum value of $0.30 S_{DS} W_p I_p$.)

S_{DS} = Coefficient considering the parameters discussed above. The final percentage of the element weight often is described in units of g, the acceleration of gravity (e.g., 0.5 g). This is equivalent to specifying a percentage of the weight; thus, 0.5 = 50 percent of W.

W_p = Weight tributary to anchorage (pipe and contents)

I_p = Importance factor, ranging from 1.0 to 1.5 (Section 13.1.3 of ASCE 7-10)

h = Height of the building roof from ground level

z = Vertical distance from ground level to equipment location. Height in structure of point of anchorage of the component with respect to the base. Where components at or below the ground level, z shall be taken as 0. The value of z/h cannot exceed 1.0.

Table 9-1 Piping Weights for Determining Horizontal Load

Schedule 40 Pipe, in. (mm)	Weight of Water-Filled Pipe, lb/ft (kg/m)	One-Half Weight of Water-Filled Pipe, lb/ft (kg/m)
1 (25.4)	2.05 (0.28)	1.03 (0.14)
1¼ (31.8)	2.93 (0.40)	1.47 (0.20)
1½[a] (38.1)	3.61 (0.50)	1.81 (0.25)
2(50.8)	5.13 (0.70)	2.57 (0.35)
2½ (63.5)	7.89 (1.08)	3.95 (0.54)
3 (76.2)	10.82 (1.48)	5.41 (0.74)
3½ (88.9)	13.48 (1.85)	6.74 (0.92)
4 (101.6)	16.40 (2.25)	8.20 (1.12)
5 (127)	23.47 (3.22)	11.74 (1.61)
6 (152.4)	31.69 (4.35)	15.85 (2.17)
8[b] (203.2)	47.70 (6.54)	23.85 (3.27)
Schedule 10 Pipe, in. (mm)	**Weight of Water-Filled Pipe, lb/ft (kg/m)**	**One-Half Weight of Water-Filled Pipe, lb/ft (kg/m)**
1 (25.4)	1.81 (0.25)	0.91 (0.12)
1¼ (31.8)	2.52 (0.35)	1.26 (0.17)
1½ (38.1)	3.04 (0.42)	1.52 (0.21)
2[a] (50.8)	4.22 (0.58)	2.11 (0.29)
2½ (63.5)	5.89 (0.81)	2.95 (0.40)
3 (76.2)	7.94 (1.09)	3.97 (0.54)
3½ (88.9)	9.78 (1.34)	4.89 (0.67)
4 (101.6)	11.78 (1.62)	5.89 (0.81)
5 (127)	17.30 (2.37)	8.65 (1.19)
6 (152.4)	23.03 (3.16)	11.52 (1.58)
8 (203.2)	40.08 (5.50)	20.04 (2.75)

a Maximum pipe size within 12" of the roof framing that does not require seismic bracing calculations
b Schedule 30

Table 9-2 Assigned Load Table for Lateral and Longitudinal Sway Bracing[a]

Spacing of Lateral Braces, ft (m)	Spacing of Longitudinal Braces, ft (m)	Assigned Load for Pipe Size to Be Braced, lb (kg)						
		2	2½	3	4	5	6	9
10 (3.0)	20 (6.0)	380 (171.0)	395 (177.8)	410 (184.5)	435 (195.8)	470 (211.5)	655 (294.8)	915 (411.8)
20 (6.0)	40 (12.2)	760 (342.0)	785 (353.3)	815 (366.8)	870 (391.5)	940 (423.0)	1,305 (587.3)	1,830 (823.5)
25 (7.6)	50 (15.2)	950 (427.5)	980 (441.0)	1,020 (459.0)	1,090 (490.5)	1,175 (528.8)	1,630 (733.5)	2,290 (1030.5)
30 (9.1)	60 (18.3)	1,140 (513.0)	1,180 (531.0)	1,225 (551.3)	1,305 (587.3)	1,410 (634.5)	1,960 (882.0)	2,745 (1235.3)
40 (12.2)	80 (24.4)	1,515 (681.8)	1,570 (706.5)	1,630 (733.5)	1,740 (783.0)	1,880 846.0)	2,610 (1174.5)	3,660 (1647.0)
50 (15.2)		1,895 (852.8)	1,965 (884.3)	2,035 (915.8)	2,175 (978.8)	2,350 (1057.5)	3,260 (1467.0)	4,575 (2058.8)

Note: Table is based on half the weight of a water-filled pipe.
a Minimum required bracing. All connections for these pipes must be verified with full Professional Engineer's structural engineering calculations.

R_p = Component response modification factor, varying from 1 to 12 (Select appropriate value from Table 13.5-1 or 13.6-1 of ASCE 7-10)
a_p = Component amplification factor that varies from 1 to 2.5 (select appropriate value from Table 13.5-1 or 13.6-1)

Since F_p is a representation of vibratory response, it can be applied in a plus or minus sense.

In piping systems, since vertical supports are placed more frequently than lateral braces, W_p is greater than the dead load supported at that point. This mismatching of F_p and available dead load often causes uplift on the pipe, which should be taken into consideration.

The loading (F_p) also can be calculated using a response spectrum determined for the appropriate floor or by modeling the equipment or piping as part of the structure and, by computer, inputting an appropriate time history of motion at the base. In practice, these techniques are seldom used, except in buildings of extreme importance or when the mass of the equipment becomes a significant percentage of the total building mass. (10 percent is sometimes used as the limit.) Where the weight of a nonstructural component is greater than or equal to 25 percent of the effective

Table 9-3 Maximum Horizontal Loads for Sway Bracing[a]

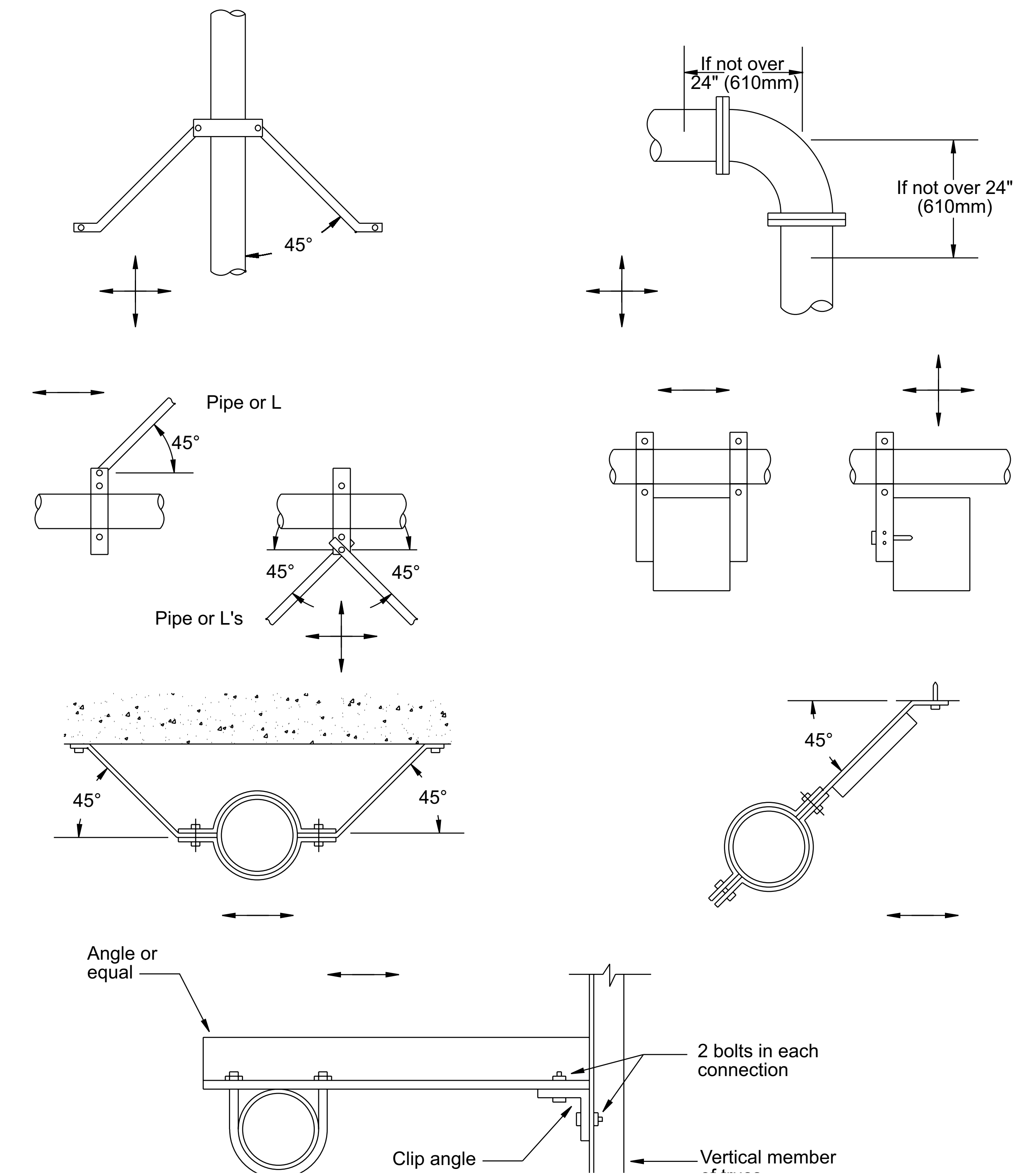
Shape and Size, in. (mm)		Least Radius of Gyration	Maximum Length for 1/r = 200	Maximum Horizontal Load, lb (kg) 30-44° Angle from Vertical	45-59° Angle from Vertical	60-90° Angle from Vertical
Pipe (Schedule 40)		**= $(\sqrt{r_0^2 + r_1^2})/2$**				
1	(25.4)	0.42	7 ft 0 in (2.1 m)	1,767 (801.5)	2,500 (1,134.0)	3,061 (1,388.4)
1¼	(31.8)	0.54	9 ft 0 in (2.7 m)	2,393 (1,085.4)	3,385 (1,535.4)	4,145 (1,880.1)
1½	(38.1)	0.623	10 ft 4 in (3.1 m)	2,858 (1,296.4)	4,043 (1,833.9)	4,955 (2,241.5)
2	(50.8)	0.787	13 ft 1 in (4.0 m)	3,828 (1,736.3)	5,414 (2,455.7)	6,630 (3,007.3)
Pipe (Schedule 10)		**= $(\sqrt{r_0^2 + r_1^2})/2$**				
1	(25.4)	0.43	7 ft 2 in (2.2 m)	1,477 (670.0)	2,090 (948.0)	2,559 (1,160.7)
1¼	(31.8)	0.55	9 ft 2 in (2.8 m)	1,900 (861.8)	2,687 (1,218.8)	3,291 (1,492.8)
1½	(38.1)	0.634	10 ft 7 in (3.2 m)	2,194 (995.2)	3,103 (1,407.5)	3,800 (1,723.6)
2	(50.8)	0.802	13 ft 4 in (4.1 m)	2,771 (1,256.9)	3,926 (1,780.8)	4,803 (2,178.6)
Angles						
1½ x 1½ x ¼	(38.1 x 38.1 x 6.4)	0.292	4 ft 10 in (1.5 m)	2,461 (1,116.3)	3,481 (1,578.9)	4,263 (1,933.7)
2 x 2 x ¼	(50.8 x 50.8 x 6.4)	0.391	6 ft 6 in (2 m)	3,356 (1,522.2)	4,746 (2,152.7)	5,813 (2,636.7)
2½ x 2 x ¼	(63.5 x 50.8 x 6.4)	0.424	7 ft 0 in (2.1 m)	3,792 (1,720.0)	5,363 (2,432.6)	6,569 (2,979.6)
2½ x 2½ x ¼	(63.5 x 63.5 x 6.4)	0.491	8 ft 2 in (2.5 m)	4,257 (1,930.9)	6,021 (2,731.1)	7,374 (3,344.8)
3 x 2½ x ¼	(76.2 x 63.5 x 6.4)	0.528	8 ft 10 in (2.7 m)	4,687 (2,126.0)	6,628 (3,006.4)	8,118 (3,682.2)
3 x 3 x ¼	(76.2 x 76.2 x 6.4)	0.592	9 ft 10 in (3 m)	5,152 (2,336.9)	7,286 (3,304.9)	8,923 (4,047.4)
Rods		**= r/2**				
⅜	(9.5)	0.094	1 ft 6 in (0.5 m)	395 (179.2)	559 (253.6)	685 (310.7)
½	(12.7)	0.125	2 ft 6 in (0.8 m)	702 (318.4)	993 (450.4)	1,217 (552.0)
⅝	(15.9)	0.156	2 ft 7 in (0.8 m)	1,087 (493.1)	1,537 (697.2)	1,883 (854.1)
¾	(19.1)	0.188	3 ft 1 in (0.9 m)	1,580 (716.7)	2,235 (1,013.8)	2,737 (1,241.5)
⅞	(22.2)	0.219	3 ft 7 in (1.1 m)	2,151 (975.7)	3,043 (1,380.3)	3,726 (1,690.1)
Flats	(where h is smaller of two side dimensions)	**= 0.29 h**				
1½ x ¼	(38.1 x 6.4)	0.0725	1 ft 2 in (0.4 m)	1,118 (507.1)	1,581 (717.1)	1,936 (878.2)
2 x ¼	(50.8 x 6.4)	0.0725	1 ft 2 in (0.4 m)	1,789 (811.5)	2,530 (1,147.6)	3,098 (1,405.2)
2 x ⅜	(50.8 x 9.5)	0.109	1 ft 9 in (0.5 m)	2,683 (1,217.0)	3,795 (1,721.4)	4,648 (2,108.3)
Pipe (Schedule 40)		**= $(\sqrt{r_0^2 + r_1^2})/2$**				
1	(25.4)	0.42	3 ft 6 in (1.1 m)	7,068 (3,206.0)	9,996 (4,534.1)	12,242 (5,552.8)
1¼	(31.8)	0.54	4 ft 6 in (1.4 m)	9,567 (4,339.5)	13,530 (6,137.1)	16,570 (7,516.0)
1½	(38.1)	0.623	5 ft 2 in (1.6 m)	11,441 (5,189.5)	16,181 (7,339.5)	19,817 (8,988.8)
2	(50.8)	0.787	6 ft 6 in (2 m)	15,377 (6,974.9)	21,746 (9,863.8)	26,634 (12,080.9)
Pipe (Schedule 10)		**= $(\sqrt{r_0^2 + r_1^2})/2$**				
1	(25.4)	0.43	3 ft 7 in (1.1 m)	5,910 (2,680.7)	8,359 (3,791.6)	10,237 (4,643.4)
1¼	(31.8)	0.55	4 ft 7 in (1.4 m)	7,600 (3,447.3)	10,749 (4,875.6)	13,164 (5,971.1)
1½	(38.1)	0.634	5 ft 3 in (1.6 m)	8,777 (3,981.2)	12,412 (5,630.0)	15,202 (6,895.5)
2	(50.8)	0.802	6 ft 8 in (2 m)	11,105 (5,037.1)	15,705 (7,123.6)	19,235 (8,724.8)
Rods		**= r/2**				
⅜	(9.5)	0.094	0 ft 9 in (0.2 m)	1,580 (716.7)	2,234 (1,013.3)	2,737 (1,241.5)
½	(12.7)	0.125	1 ft 0 in (0.3 m)	2,809 (1,274.1)	3,972 (1,801.7)	4,865 (2,206.7)
⅝	(15.9)	0.156	1 ft 3 in (0.4 m)	4,390 (1,991.3)	6,209 (2,816.3)	7,605 (3,449.6)
¾	(19.1)	0.188	1 ft 6 in (0.5 m)	6,322 (2,867.6)	8,941 (4,055.5)	10,951 (4,967.3)
⅞	(22.2)	0.219	1 ft 9 in (0.5 m)	8,675 (3,934.9)	12,169 (5,519.7)	14,904 (6,760.3)
Pipe (Schedule 40)		**= $(\sqrt{r_0^2 + r_1^2})/2$**	**1/r = 300**			
1	(25.4)	0.42	10 ft 6 in (3.2 m)	786 (356.5)	1,111 (503.9)	1,360 (616.9)
1¼	(31.8)	0.54	13 ft 6 in (4.1 m)	1,063 (482.2)	1,503 (681.7)	1,841 (835.1)
1½	(38.1)	0.623	15 ft 7 in (4.7 m)	1,272 (577.0)	1,798 (815.5)	2,202 (998.8)
2	(50.8)	0.787	19 ft 8 in (6 m)	1,666 (755.7)	2,355 (1,068.2)	2,885 (1,308.6)
Pipe (Schedule 10)		**= $(\sqrt{r_0^2 + r_1^2})/2$**				
1	(25.4)	0.43	10 ft 9 in (3.3 m)	656 (297.8)	928 (420.9)	1,137 (515.7)
1¼	(31.8)	0.55	13 ft 9 in (4.2 m)	844 (383.2)	1,194 (541.6)	1,463 (663.6)
1½	(38.1)	0.634	15 ft 10 in (4.8 m)	975 (442.3)	1,379 (625.5)	1,194 (541.6)
2	(50.8)	0.802	20 ft 0 in (6.1 m)	1,234 (559.7)	1,745 (791.5)	2,137 (969.3)
Rods		**= r/2**				
⅜	(9.5)	0.094	2 ft 4 in (0.7 m)	176 (79.8)	248 (112.5)	304 (137.9)
½	(12.7)	0.125	3 ft 1 in (0.9 m)	312 (141.5)	441 (200.0)	540 (244.9)
⅝	(15.9)	0.156	3 ft 11 in (1.2 m)	488 (221.4)	690 (313.0)	845 (383.3)
¾	(19.1)	0.188	4 ft 8 in (1.4 m)	702 (318.4)	993 (450.4)	1,217 (552.0)
⅞	(22.2)	0.219	5 ft 6 in (1.7 m)	956 (433.6)	1,352 (613.3)	1,656 (751.1)

a Minimum required bracing. All connections for these pipes must be verified with full Professional Engineer's structural engineering calculations.

seismic weight, W, it shall be designed for a non-building structure in accordance with Section 15.3.2 of ASCE 7-10. The effective seismic weight is the dead load as defined in Section 3.1 of ASCE 7-10.

The generalized loadings that must be considered in the design of seismic restraints, F_p, uplift loading, shear loading (sliding), and W are shown schematically in Figure 9-17.

Figure 9-17 Acceptable Types of Sway Bracing



For non-building structures such as independent cooling towers, tanks, etc., the following formula can be used for weights of non-building structures greater than or equal to 25 percent of the combined effective seismic weights.

Equation 9-2

$$F_p = 0.8S_1W_p/(R/I)$$

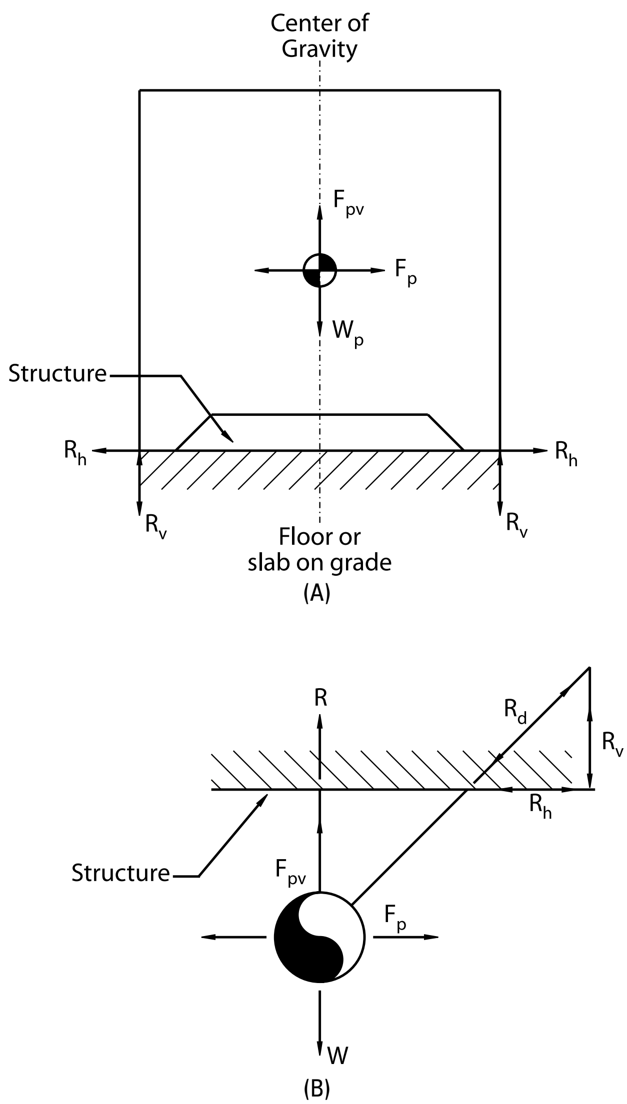
where:
- F_p = Lateral (seismic) force applied at element center of gravity (Cannot be less than 0.03 W_p.)
- S_1 = Spectral response acceleration, at mapped maximum considered earthquake at 1 second with 5 percent damped
- R = Response modification coefficient as noted in tabulation
- I = Importance factor
- W_p = Weight tributary

Determination of Anchorage Forces

In most cases, anchorage or reaction forces, R_h and R_v (see Figure 9-18A), created by the loading described above, are calculated by simple moment diagrams. Although trivial for a professional familiar with statistics, calculations to find all maximums become numerous when the center of gravity is off one or both plan centerline axes or if the base support is non-symmetrical.

In typical pipe braces (see Figure 9-18B), it is important to note that R, the gravity force in the hanger rod, is affected significantly by the addition of the brace and is not equal to W, as indicated previously. Dealing with these loads is a huge problem. A tension rod hanger commonly goes into compression in such a situation. Cable restraints do not have this problem.

Figure 9-18 Forces for Seismic Design (A) Equipment; (B) Piping



COMPUTER ANALYSIS OF PIPING SYSTEMS

Computer programs have been used to analyze piping systems for stress for some time. These programs initially were developed to consider thermal stresses and anchor point load, but software now can consider seismic and settlement loading, spring or damping supports, snubbers (similar to equipment snubbers), differing materials, and non-rigid couplings. The seismic loading can be determined by using a full-time history, as a response spectrum, or equivalent static forces. The time history has the inherent problem of requiring a search of each time increment for worst-case stresses and brace loadings. The computer time and man-hours required are seldom justified.

In fact, for seismic loading alone, computer analysis is almost never performed because brace loadings easily can be determined by tributary length methods, and rule-of-thumb pipe spans (brace spacing) are contained in several publications (see NFPA 13, *Seismic Restraint Manual: Guidelines for Mechanical Systems,* and *Seismic Design for Buildings*). Computer analysis may be appropriate, however, when it is necessary to combine seismic loading with several of the following considerations:

- Temperature changes and anchorage
- Nonlinear support conditions (springs, snubbers, etc.)
- Complex geometry
- Several loading conditions
- Piping materials other than steel or copper
- Joints or couplings that are significantly more flexible or weaker than the pipe itself

Because of the variety of computer programs available and because many have proprietary restrictions, specific programs are not listed here.

Loads in Structures

It is always important to identify unusual equipment and piping loads during the first stages of project design to ensure that the structural system being developed is adequate. Consideration of seismic effects makes this coordination even more important because seismic forces produce unusual reactions. During an earthquake, horizontal forces must be taken into the structure, and vertical load effects are intensified due to vertical accelerations and overturning movements. These reactions must be acceptable to the structure locally (at the point of connection) and globally (by the system as a whole).

If the structural system is properly designed for the appropriate weights of equipment and piping, seismic reactions will seldom cause problems to the overall system. However, local problems are not uncommon. Most floors are required by code to withstand a 2,000-pound concentrated load, so this is a reasonable load to consider acceptable without special provisions. However, seismic reactions to structures can easily exceed this figure. For example:

- A longitudinal brace carrying a tributary load of 80 feet of 8-inch steel pipe filled with water generates reactions of this magnitude.
- Transverse or longitudinal braces on trapezes often have larger reactions.
- A 4,000-pound tank on legs also could yield such a concentrated load.

In addition, possible limitations on attachment methods due to structure type could reduce the effective maximum allowable concentration.

Roof structures have no code-specified concentrated load requirement and often are the source of problems, particularly concerning piping systems, because of the random nature of hanger and brace locations. Many roof-decking systems cannot accept concentrations greater than 50 pounds without spreaders or strengthening beams. Such limitations should be considered in both the selection of a structural system and the equipment and piping layout.

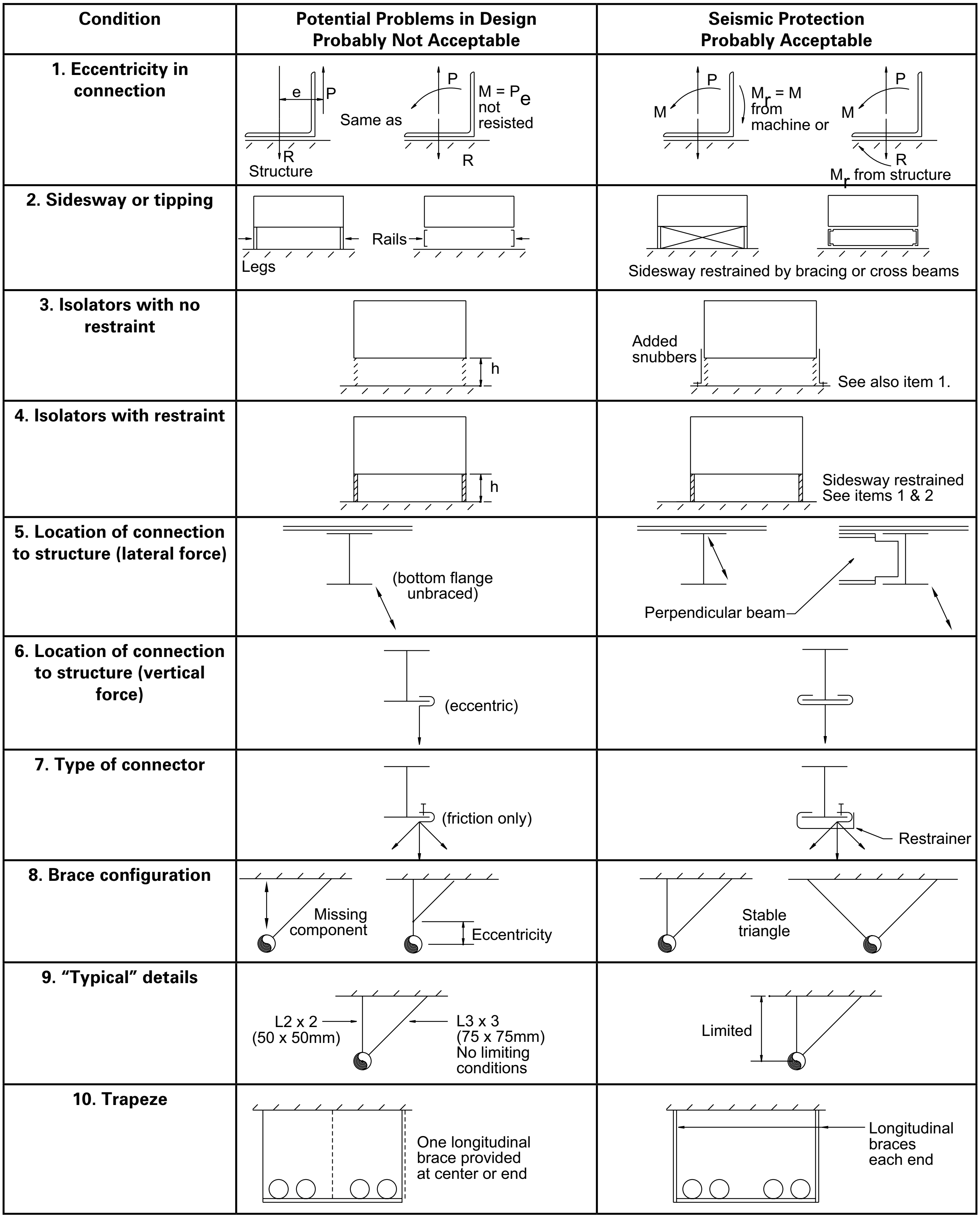
If equipment anchorage or pipe bracing is specified to be contractor supplied, attachment load limitations or other structural criteria should be given. Compliance with such criteria should be checked to ensure that the structure is not being damaged or overloaded.

POTENTIAL PROBLEMS

It would be impractical to cover the details of structural design for seismic anchorage and bracing in this chapter. The engineer can get design information and techniques from standard textbooks and design manuals or, preferably, obtain help from a professional experienced in seismic and/or structural design. Simple, typical details are seldom appropriate, and all-encompassing seismic protection systems quickly become complex. Certain common situations that have the potential to create problems can be identified, however. These are shown schematically in Figure 9-19 and discussed below.

Condition 1 in Figure 9-19 occurs frequently in making attachments to concrete. Often an angle is used, as indicated. The seismic force, P, enters the connector eccentric to the reaction, R, by the distance e; this is equivalent to a concentric force plus the moment P_e. For the connector to perform as designed, this moment must be resisted by the connection of the angle either to the machine or to the concrete. To use the machine to provide this moment, the machine base must be adequate, and the connection from the angle to the base must be greatly increased over that

Figure 9-19 Potential Problems in Equipment Anchorage or Pipe Bracing



required merely for P. Taking this moment into the concrete significantly increases the tension in the anchorage, R, which is known as prying action. The appropriate solution must be decided on a case-by-case basis, but eccentricities in connections should not be ignored.

Legs 18 inches (0.5 m) or longer on supporting tanks or machines clearly create a sideways problem and commonly are cross-braced. However, shorter legs or even rails often have no strength or stiffness in their weak direction, as shown in Condition 2, and also should be restrained against base failure.

Conditions 3 and 4 point out that spring isolators typically create a significant height, h, through which lateral forces must be transmitted. This height, in turn, creates conditions similar to the problems shown in 1 and 2 and must be treated in the same manner.

Condition 5 is meant to indicate that the bottom flange of a steel beam seldom can resist a horizontal force; diagonal braces, which often are connected to bottom flanges, create such a horizontal force. This condition can be rectified by attaching the diagonal brace near the top flange or adding a stabilizing element to the bottom flange.

Condition 6 depicts a typical beam connection device (beam clamp), which slips over one flange. Although this is often acceptable, significant stresses can be introduced into the beam if the load is large or the beam is small. Considering the variability and potential overload characteristics of seismic forces, this condition should be avoided. Condition 7 also shows a connector in common use, which is acceptable in a non-seismic environment but should be secured in place as shown under dynamic conditions.

Most pipe bracing systems utilize bracing members in pure tension or compression for stiffness and efficiency. This truss-type action is possible only when bracing configurations make up completed triangles, as shown on the right under Condition 8. The brace configuration on the far left is technically unstable, and the eccentric condition shown produces moment in the vertical support.

As previously indicated, typical details must be designed and presented carefully to prevent their misuse. Condition 9 shows the most common deficiency: a lack of limiting conditions.

Condition 10 shows a situation often seen in the field where interferences may prevent the placement of longitudinal braces at the ends of a trapeze and either one is simply left out or two are replaced by one in the middle. Both of these substitutions can cause an undesirable twist of the trapeze and subsequent pipe damage. All field revisions to bracing schemes should be checked for adequacy.

Other potential problems that occur less frequently include the incompatibility of piping systems with the differential movement of the structure and the inadvertent self-bracing of piping through short, stiff service connections or branches that penetrate the structure. If the possibility of either is apparent, pipe stresses should be checked or the self-bracing restraint should be eliminated.

A few problems associated with making a connection to a structure were discussed above, in relation to Figure 9-19. When connecting to structural steel, in addition to manufactured clip devices, bolting and welding are also used. Holes for bolting should never be placed in structural steel without the approval of the structural engineer responsible for the design. Field welding should consider the effects of elevated temperatures on loaded structural members.

The preferred method of connecting to concrete is through embedments, but this is seldom practical. Since the location of required anchorages or braces often is not known when concrete is poured, the use of drilled-in or shot-in anchors is prevalent for this purpose. Although these anchors are extremely useful and necessary connecting devices, their adequacy has many sensitivities, and they should be applied with thorough understanding and caution. The following items should be considered in the design or installation of drilled or shot-in anchors.

- Manufacturers often list ultimate (failure) values in their literature. Normally, factors of safety of 4 or 5 are applied to these values for design.
- Combined shear and tension should be considered in the design. A conservative approach commonly used is the following equation.

Equation 9-3

$$(T/T_a) + (V/V_a) < 1$$

where:

T = Tension, lbf/in^2

T_a = Allowable tension, lbf/in^2

V = Shear, lbf/in^2

V_a = Allowable shear, lbf/in^2

Edge distances are important because of the expansive nature of these anchors. Six diameters typically are required.

Review the embedments required for design values. Embedment is defined as full penetration of the bolt/nail with at least 8 diameters of the bolt/nail. For example, a ½-inch (12.7-mm) lag bolt will require 4 inches (101.6 mm) of full penetration of that bolt. If such distances are not available, then this is considered a shallow penetration, and the value of R, the response modification coefficient, shall be reduced. It is difficult to install an expansion bolt more than ½ inch (12.7 mm) in diameter in a typical floor system of 2½-inch (63.5-mm) concrete over steel decking.

Bolt sizes more than ¼ inch (6.35 mm) in diameter have embedments sufficient to penetrate the reinforcing envelope. Thus, bolts should not be placed in columns, the bottom flange of beams, or the bottom chord of joists. Bolts in slabs or walls are less critical, but the possibility of special and critical reinforcing bars being cut should be considered. The critical nature of each strand of tendon in pre-stressed concrete, as well as the stored energy, generally dictates a complete prohibition of these anchors.

Installation technique has been shown to be extremely important in developing design strength. Field testing of a certain percentage of anchors should be considered.

ADDITIONAL CONSIDERATIONS

Seismic anchorage and bracing, like all construction, should be thoroughly reviewed in the field. Considering the lack of construction tradition, the likelihood of field changes or interferences, and other potential problems (discussed above), seismic work should be more clearly controlled, inspected, and tested than normal construction.

Another result of the relative newness of seismic protection of equipment and piping is the lack of performance data for the design and detailing techniques now being used. Essentially no field data is available to ensure that present assumptions, although scientifically logical and accurate, will actually provide the desired protection. Will firm anchorage of equipment damage the internal workings? Will the base cabinet or framework (which is seldom checked) of equipment be severely damaged by the anchorage? The present requirements are largely the result of observations of damage to structures in actual earthquakes over 75 years.

The net result of current standards in seismic protection can only be positive. The fine-tuning of scope, force levels, and detailing techniques must wait for additional, full-scale testing in real earthquakes.

GLOSSARY

Acceleration 1. Change from one speed or velocity to another. 2. The rate at which the velocity of a body changes with time commonly measured in "g" (an acceleration of 32 ft/sec/sec or 980 cm/sec/sec = gravity constant on earth).

Accelerogram The graphical output from an accelerograph or seismograph showing acceleration as a function of time.

Accelerograph Also known as a seismograph or an accelerometer, an instrument that records ground acceleration during an earthquake.

Amplitude Deviation from mean of the centerline of a wave.

Anchor A device, such as an expansion bolt, for connecting pipe-bracing members to the structure of a building.

Attachment See *positive attachment.*

Bracing Metal channels, cables, or hanger angles that prevent pipes from breaking away from the structure during an earthquake. See also *longitudinal bracing* and *transverse bracing.* Together, these resist lateral loads from any direction.

Center of mass Also known as center of gravity, the unique point where the weighted relative position of the distributed mass sums to zero.

Creep (along a fault) Slow movement along a fault due to ongoing tectonic deformation.

Crust/lithosphere The outermost major layer of the Earth, ranging from 10 to 80 kilometers in thickness. It is made up of crustal rocks, sediment, and basalt. The general composition is silicon-aluminum-iron.

Damping The rate at which natural vibration decays as a result of the absorption of energy.

Deflection The displacement of a building element due to the application of external force.

Ductility Ability to withstand inelastic strain without fracturing.

Duration The period of time within which ground acceleration occurs.

Dynamic 1. The branch of mechanics concerned with the forces that cause motions of bodies. 2. The property of a building when it is in motion.

Dynamic properties of piping The tendency of pipes to change in weight and size because of the movement and temperature of fluids in them. This does not refer to movement due to seismic forces.

Eccentric Not having a common center; not concentric.

Epicenter The point of the Earth's surface directly above the focus or hypocenter of an earthquake.

Equipment For the purposes of this chapter, the mechanical devices associated with pipes that have significant weight. Examples include pumps, tanks, and electric motors.

Essential facilities Buildings that must remain safe and usable for emergency purposes after an earthquake to preserve the health and safety of the general public. Examples include hospitals, emergency shelters, and fire stations.

Fault A fracture or crack in the Earth's crust across which relative displacement has occurred.

Frequency 1. The number of wave peaks or cycles per second. 2. The inverse of period.

Fundamental or natural period 1. The elapsed time, in seconds, of a single cycle of oscillation. 2. The inverse of frequency.

Gas pipe For the purposes of this chapter, any pipe that carries fuel gas, fuel oil, medical gas, vacuum, or compressed air.

Hooke's law In mechanics and physics, an approximation stating that the extension of a spring is in direct proportion with the load applied to it. Mathematically, Hooke's law states that $F= kx$, where x is the displacement of the spring's end from its equilibrium position (meters), F is the restoring force exerted by the spring on that end (N or $kg{\cdot}m/s_2$), and k is a constant called the rate or spring constant (N/m or kg/s_2).

Hypocenter/focus The point below the epicenter at which an earthquake rupture starts.

Inelastic Non-recoverable deformation of an element.

Inertial forces The product of mass times acceleration ($F = ma$).

Input motion The seismic forces applied to a building or structure.

Intensity A subjective measure describing the severity of an earthquake in terms of its effects on persons, structures, and the Earth's surface, depicted as a Roman numeral based on the Modified Mercalli (MM) version ranging from MM-I (not felt) through MM-XII (nearly total damage).

Landslide Movement or land disturbance on a hillside where material slides down a slope.

Lateral force A force acting on a pipe in the horizontal plane. This force can be in any direction.

Longitudinal bracing Bracing that prevents a pipe from moving in the direction of its run.

Longitudinal force A lateral force that happens to be in the same direction as the pipe.

Magnitude A measure of the relative size of an earthquake describing the amount of energy released. See *Richter scale.*

Mass The property of a body that causes it to have weight in a gravitational field.

Natural or fundamental frequency The frequency at which a particular object or system vibrates when pushed by a single force or impulse and not influenced by other external forces or by damping.

Nonstructural components Components not intended primarily for the structural support of the building.

OSHPD Office of Statewide Health Planning and Development (California).

Oscillation Regular periodic variation in value about a mean.

Period 1. The elapsed time in seconds of a single cycle of oscillation. 2. The time interval required for one full cycle of a wave. 3. The inverse of frequency.

Plate tectonics The theory supported by a wide range of evidence that considers the Earth's crust and upper mantle to be composed of several large, thick, relatively rigid plates that move relative to one another. This theory studies plate formation, movement, interaction, and destruction.

Positive attachment A mechanical device designed to resist seismic forces that connects a nonstructural element, such as a pipe, to a structural element, such as a beam. Bolts and screws are examples of positive attachments. Glue and friction due to gravity do not create positive attachments.

Resonance A vibration of large amplitude produced by a relatively small vibration near the same frequency of vibration as the natural frequency of the resonating system.

Response spectrum Maximum response of a site plotted against increasing periods.

Richter scale Developed in 1935 by Charles F. Richter of the California Institute of Technology, a device that compares the size of earthquakes by describing the amount of energy released.

Rigidity 1. The physical property of being stiff and resisting bending. 2. The relative stiffness of a structure or element. 3. In numerical terms, equal to the reciprocal of displacement caused by a unit force.

Seiche A wave on the surface of water in an enclosed or semi-enclosed basin caused by atmospheric or seismic disturbances.

Seismic Subject to or caused by an earthquake or earth vibration. Seismic loads on a structure are caused by wave movements in the Earth during an earthquake.

Spectra A plot indicating maximum earthquake response with respect to the natural period or frequency of the structure or element. Response can show acceleration, velocity, displacement, shear, or other properties of response.

Stability 1. The strength to stand or endure. 2. Resistance to displacement or overturning.

Stiffness A measure of deflection or of staying in alignment within a certain stress.

Strength 1. Power to resist force. 2. A measure of load bearing without exceeding a certain stress.

Stress 1. The deformation caused in a body by such a force. 2. Internal resistance within a material opposing a force to deform it.

Transverse bracing Bracing that prevents a pipe from moving from side to side.

Tsunami A sea wave produced by submarine earth movement or volcanic eruption.

Velocity 1. The rate of change of position along a straight line with respect to time 2. The derivative of position with respect to time measured in centimeters/second.

Vibration 1. A periodic motion that repeats itself after a definite interval of time. 2. The periodic motion of the particles of an elastic body or medium in alternately opposite directions from the position of equilibrium when that equilibrium has been disturbed

Wave "P" 1. The primary or compressional wave. 2. The fastest waves traveling away from a seismic event through the Earth's crust, which shake the ground back and forth in the same direction and the opposite direction as the direction the wave is moving.

Wave "S" Secondary or shear wave, which shakes the ground back and forth perpendicular to the direction the wave is moving.

RESOURCES

- ASCE/SEI 7-10: *Minimum Design Loads for Buildings and Other Structures,* American Society of Civil Engineers
- ATC-3: *Tentative Provisions for the Development of Seismic Regulation for Buildings,* Applied Technology Council
- "Nonstructural damage. The San Fernando, California, Earthquake of February 9, 1971," National Oceanic and Atmospheric Administration

- "Nonstructural Damage to Buildings. The Great Alaska Earthquake of 1964: Engineering," National Academy of Sciences
- California Building Standards Code (California Code of Regulations, Title 24)
- *Guidelines for Seismic Restraints of Mechanical Systems,* Sheet Metal Industry Fund
- *Automatic Sprinkler Systems Handbook*, National Fire Protection Association
- NFPA 13: *Standard for the Installation of Sprinkler Systems*, National Fire Protection Association
- *Seismic Restraint Manual: Guidelines for Mechanical Systems*, Sheet Metal and Air Conditioning Contractors' National Association
- *Seismic Design for Buildings,* U.S. Department of Defense
- *Design Guidelines. Earthquake Resistance of Buildings, Vol. 1,* U.S. General Services Administration Public Buildings Service
- *Earthquake-Resistant Design Requirements Handbook* (H-08-8), U.S. Veterans Administration
- *Installation Handbook for Seismic Support of Water Heaters and Similar Equipment*, Chip O'Neil, Hubbard Enterprises/HOLDRITE

Acoustics in Plumbing Systems

Plumbing system noise is a common irritant to building owners and tenants. Three main factors contribute to this problem: 1) lack of awareness on the part of owners/developers and design teams regarding the application of specific products and practical installation solutions; 2) lack of contractor awareness and training regarding the application of specific solutions; and 3) design teams fearful of uncertain solutions and seemingly uncontrollable expenses. On many high-end projects, building design teams and contractors have faced litigation as a result of insufficient or poorly installed attempts at plumbing noise mitigation.

Luckily, much advancement has been made regarding the issue of plumbing noise mitigation. Resources are available from a product and service standpoint that can help the engineering community find application solutions, plumbing installation detail drawings, and third-party laboratory test data to recognized International Organization for Standardization (ISO) standards.

To a building occupant or perspective buyer, the perceived quality of a building is based on numerous observations. A building deemed excessively noisy will likely be viewed as low quality. In cases where building occupants are dissatisfied with the comfort of a building, one of the common complaints includes noise from adjoining tenants. Noise through floor and ceiling systems and noise through walls are the main issue. The noise sources and solutions vary widely. Issues can be very difficult and costly to remedy, especially after the fact. A quiet building does not usually happen accidentally, and steps to ensure success must be planned from the early stages of design and specification. Attention to acoustics and the successful implementation of effective noise control are added value.

Plumbing system noise mitigation is inconsistently addressed in many buildings, although it can be one of the most intrusive and difficult sounds to mitigate. Varying levels of plumbing noise are expected and tolerated without complaint by many people. Noise generated within a tenant's or owner's own space and resulting from their use of plumbing fixtures is often tolerated. Conversely, intrusive plumbing noise from an adjoining space that results in sleep disturbance or interruption or even in some cases where it is simply identifiable may be regarded as annoying. In multifamily residential buildings, plumbing noise is a significant source of complaint.

NOISE

Noise issues within a building fall into one of two categories: airborne noise and structure-borne noise. Airborne noise sources include voices, amplified music, televisions, and radios. The ability of a construction (such as a door, wall, or window) to reduce airborne noise passing through it is quantified by the metric transmission loss, which is usually measured over a number of different frequency bands that are used to generate a single-figure Sound Transmission Class (STC) rating. The higher the STC, the better the system is at isolating airborne noise. However, the use of STC ratings is generally not recommended for noise from plumbing and other building systems because the frequency content of this noise is dissimilar to that of the human voice.

Structure-borne noise is produced when part of the building fabric transmits vibration, which is subsequently heard as radiated noise. Examples are footsteps on hard floor surfaces like tile or bare timber, banging doors, scraping furniture, and plumbing noise. Controlling structure-borne noise is usually achieved through vibration isolation.

CONTRIBUTING FACTORS

Plumbing systems generate both airborne and structure-borne noise. Following are the four main categories comprising a building's plumbing system and how these systems create noise.

Drainage Systems

This category includes sanitary waste piping receiving drainage from plumbing fixtures and appliances, as well as rain leader/roof drain piping receiving drainage from roof drains, deck drains, and similar receptacles.

Drainage piping is manufactured in a variety of materials that radiate airborne and structure-borne noise at varying levels. The most common pipe and fitting materials used in these systems within buildings include Schedule 40 PVC or ABS plastic DWV, type DWV copper, several weight classifications of hub-and-spigot cast iron, standard weight hub-less cast iron, and tubular thin-wall PVC, ABS, or chrome-plated brass (used in the fixture outlet connection/p-trap location under sinks and similar fixtures).

Drainage piping receiving gravity flow includes roof drains, rain leaders, deck drains, condensate drains, and sanitary drains receiving flow from typical plumbing fixtures such as sinks, wash basins, water closets, bathtubs, and showers. Drainage piping receiving liquids intermittently and under pressure includes the discharge from laundry washers, dishwashers, funnel drains in mechanical rooms, floor sinks in commercial foodservice establishments, and similar indirect waste receptacles. In each of these cases, the density and wall thickness of the pipe and fittings have a direct bearing on the amount of both airborne and structure-borne noise generated. The thicker, more dense, and more highly damped the pipe's wall construction, the quieter is its performance.

In a gravity system, drainage liquid traveling vertically adheres to the walls of the pipe and travels in a spiral motion. In this mode, very little noise is generated. The flow of the pipe's contents generates the most noise when liquids and solids hit fittings at changes in direction within the piping system, especially when a vertical stack hits a horizontal pipe. It is most noticeable in plastic drainage systems. This should be a consideration when engineering a single-stack DWV system with the required aerators, offsets, and deaerators.

Drainage piping also generates noise, especially in thermoplastic systems, when it experiences thermal expansion and contraction due to temperature changes. (PVC and ABS pipe expand and contract at approximately five to eight times the rate of cast iron pipe.) The pipe can be heard creaking or squeaking as it moves and rubs against various building components, especially if the penetrations in the wall and ceiling framing are cut or drilled to a size that results in a tight fit. An example of this is when a roof drain system within the warmth of a building receives cold rainwater. In this case, the piping contracts as the rainwater lowers the pipe's temperature. After the rainwater stops flowing, the pipe warms up and expands once again. As this occurs, structure-borne noise transmits to the interior of the building through various contact points throughout the system, such as floor, wall, and ceiling penetrations and at various support or hanger locations. While accommodations for expansion and contraction should be engineered into thermoplastic systems, airborne and structure-borne noise still may persist.

Water Distribution Systems

Water distribution systems include domestic/potable water piping delivering water under pressure to plumbing fixtures and appliances throughout a building, nonpotable water piping delivering water under pressure to systems such as irrigation and mechanical equipment, and industrial water, process piping, and HVAC piping delivering water under pressure to various equipment components within a building.

Water piping/tubing is constructed from a variety of materials that radiate airborne and structure-borne noise at varying levels. The most common pipe and fitting materials used in these systems within buildings include copper (types M, L, or K), CPVC (CTS and Schedule 80), PEX, PVC Schedule 40 or 80, Schedule 40 galvanized steel, Schedule 10 stainless, corrugated, or smooth-wall chrome-plated brass (for fixture connections), and braided stainless steel (at fixture and equipment supply connections).

A common cause of noise generation in a water system is simply the flow of water due to the operation of a fixture or faucet. In this scenario, several factors contribute to increased levels of noise generation: water pressure, flow velocities, undersized tubing, turbulence caused by changes in direction, and obstructions in valves and equipment. The largest contributing factor is direct contact between the water system's tubing and the building's various components.

Another common noise generator is water hammer, which results when water moving at a high velocity stops suddenly. This occurs when valves are closed quickly, producing a shock wave in the system that causes the pipes to vibrate. Some of the items in a common plumbing system that cause this problem are laundry washing machines, icemakers, and dishwashers, each of which have electric solenoid, or fast-closing, valves. Other common contributors include flush valves on urinals and water closets in commercial buildings.

Another noise source in pressurized water systems is similar to that described in the drainage section. When water tubing experiences thermal expansion and contraction due to temperature changes, water piping can be heard creaking or squeaking at contact points with various building components and support points. This is especially pronounced in thermoplastic water systems such as CPVC, which expands and contracts at a much higher rate than metallic tubing. (CPVC tubing expands and contracts at nearly four times the rate of copper tubing.)

Fixtures, Faucets, Appliances, and Appurtenances

Fixtures are manufactured using a wide variety of materials including vitreous china, plastic, cultured marble, fiberglass, stainless steel, cast iron, enameled steel, nonvitreous ceramic, terrazzo, and various composite materials. Each material contributes to both airborne and structure-borne noise differently. A thin steel fixture can sound like a drum being struck when it is hit with a flow of water. When fixtures are in direct contact with building components, such as is often the case with a bathtub or shower pan, they generate not only airborne noise, but a high level of structure-borne noise as well.

Faucets typically are constructed of brass (with a variety of plated finishes), stainless steel, plastic, or cast metals. The wall thickness of these items contributes to the level of noise generation, as does the degree of direct contact with the fixture they serve or the building itself, such as a hard surface countertop or ceramic tile tub deck. The level of noise generating turbulence emitted from faucets varies greatly depending on the level of attention each manufacturer has given to this issue.

Appliances vary widely in their ability to control the noise each one emits. The cost of an appliance often relates to a manufacturer's published operating noise level.

Valves, Pumps, and Equipment

Valves emit varying levels of noise depending on the amount of friction and turbulence they generate. Globe valves, for instance, are very noisy because they are designed in such a way that turbulence is very high. Alternatively, full-port ball valves generate less noise than standard port due to reduced water velocity.

Pumps often generate high levels of structure-borne noise if they are in direct contact with building components or are piped incorrectly, resulting in turbulence and cavitation.

Equipment generates noise and vibration over a wide frequency range. Equipment noise control and vibration isolation have been handled by plumbing and mechanical engineers for many years and are better controlled than many of the other components of a plumbing or piping system.

MITIGATING NOISE FROM DRAINAGE SYSTEMS

A number of common approaches can be used to mitigate unwanted noise from drainage systems.

A very common and effective method of controlling noise generated from drain, waste, and vent systems is to use cast iron pipe and fittings rather than thermoplastic or copper pipe and fittings. The density of the cast iron, as well as the neoprene couplings, has effective dampening properties. Often, a hybrid DWV system is specified consisting of cast iron drainage piping and thermoplastic vents. Ideally, the choice of cast iron rather than thermoplastic or copper also should be applied to the selection of drainage system components such as roof drains, deck drains, and floor drains. When mounting roof drain bodies on wood sheathing or pan decking, isolate the drain body and under-deck clamps from direct contact with the sheathing with the use of ¼-inch (6.35-mm) neoprene rubber padding. This should be addressed within the body of the specification and/or in plumbing installation detail drawings.

To minimize noise and vibration transferred to the building, the contact between the piping and the building's components (drywall, studs, joists, floor structure, etc.) should be broken (see Figures 10-1, 10-2, and 10-3). This often is accomplished by the use of various types of isolating materials such as felt or rubber when passing through studs, joists, hangers, etc. The use of engineered laboratory-tested products specifically designed for this purpose makes this task fast, easy, and affordable when compared to makeshift or field-devised attempts to isolate these pipelines from contact with building components. All contact points should be isolated; failure to achieve this for even a small percentage of contact points can result in a noise issue. This requirement should be clearly expressed within the project specifications and installation detail pages.

When pipes pass through floors, noise transfer often is minimized with the use of various types of rubber or neoprene pads placed under the ears of riser clamps. On very large and heavy riser pipes, the use of spring-loaded riser isolators is effective. Numerous manufacturers provide these types of isolation pads in various thicknesses ranging from ¼ to ¾ inch (6.35 to 19.05 mm) and even thicker. These typically are made of rubber or neoprene, which is often more resistant to chemicals than rubber. Others are also available with steel bearing plates, which help evenly distribute the weight across the surface of the pad. Use only lab-tested and proven materials.

Additionally, piping must be isolated from contact with the edges of the floor penetration, whether wood, concrete, or metal pan decking. This typically is done with the use of acoustical sealant within the annular space surrounding the piping. When the floor system caries a fire rating, the sealant used must meet or exceed the required rating. Failure to eliminate contact in the annular space can negate any attempt at effective vibration isolation. Clearly express this requirement within the project specification and installation detail pages. (See Figures 10-4 and 10-5.)

A number of methods can be used to reduce noise from piping to support hangers and thus to the supporting structure. One method is the use of spring or rubber-isolated hanger rod attachments at the structure above. Another method is by isolating the noise transfer by installing felt, rubber, or neoprene material within the hanger (between the pipe and the hanger). When applying isolation lining

Figure 10-1 Pipe Isolation Through Framing Member

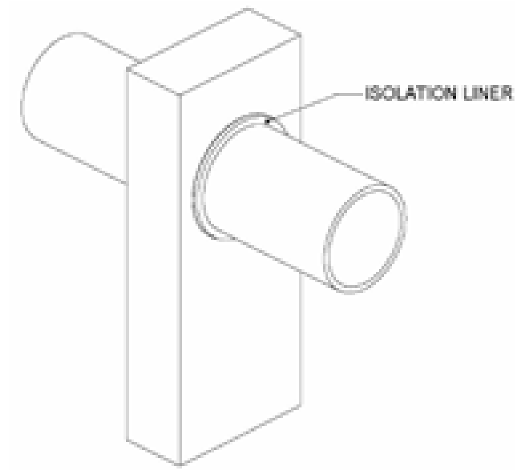


Figure 10-2 Resilient Pipe Isolation

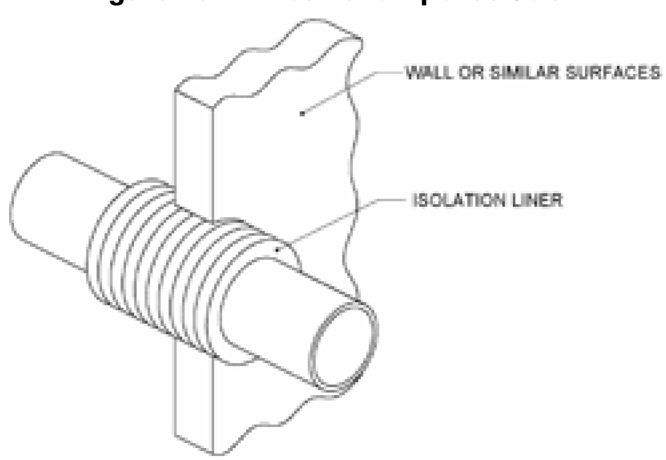


Figure 10-3 Vertical Mid-Span Support

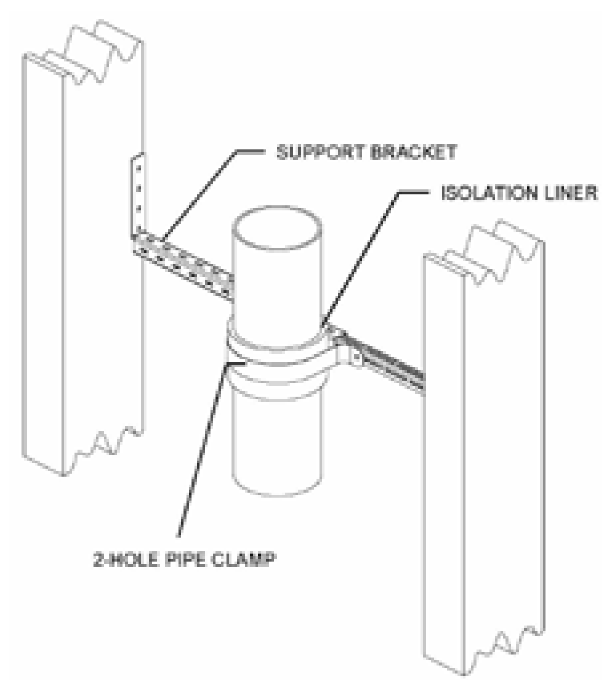


Figure 10-4 Riser Clamp Isolation

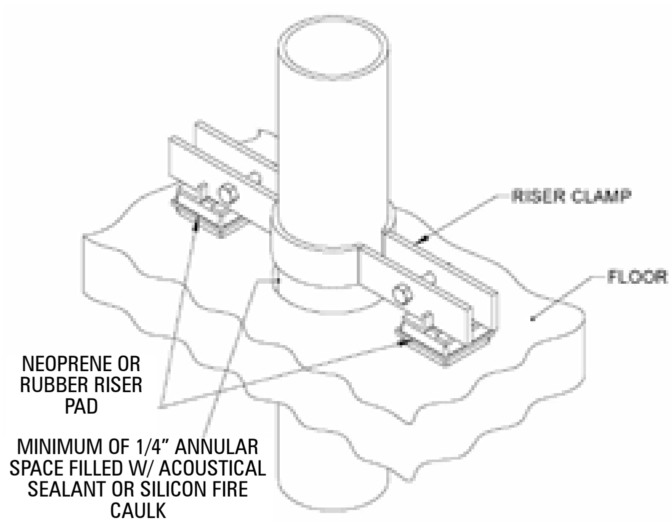


Figure 10-5 Vertical Cast Iron Stacks and Water Risers

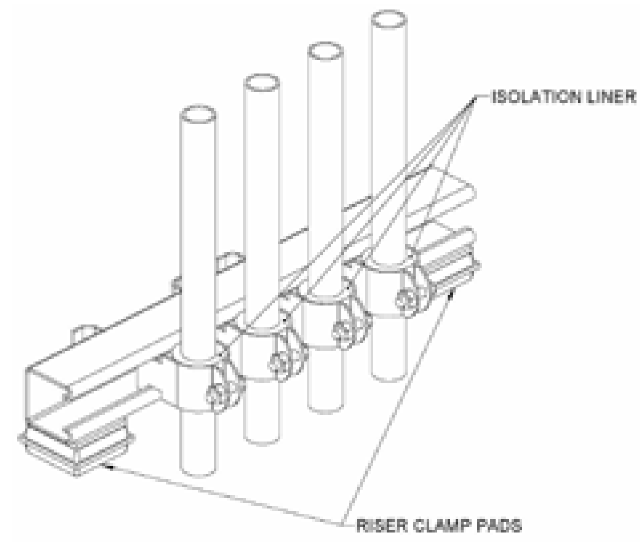


Figure 10-6 Suspended Waste, Vent, or Other Piping

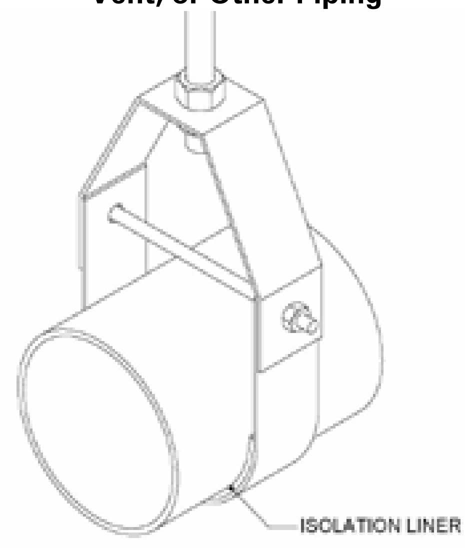
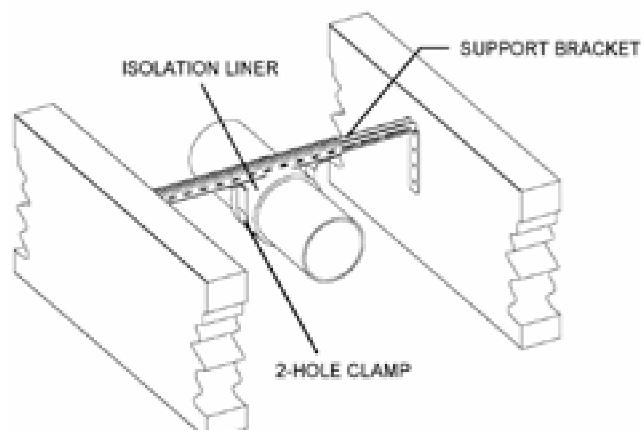


Figure 10-7 Horizontal Joist Bay Support

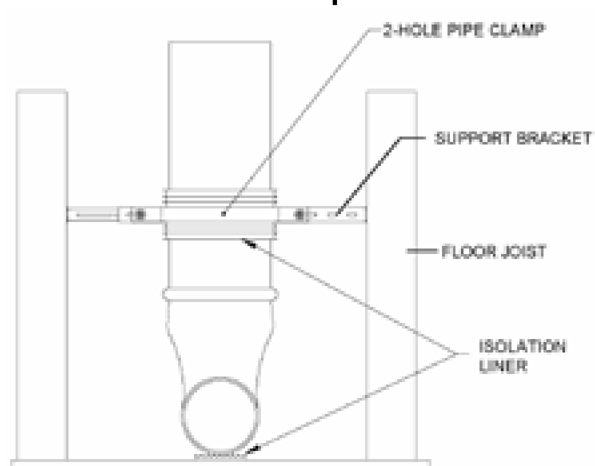


between the hanger and the piping, use only materials engineered and tested for this application. As a caution, some pipe support products contain plasticizers such as plasticized vinyl, which may have a detrimental effect on the drainage piping (e.g., CPVC lab drainage materials).

When drainage and vent piping are being supported at mid-story or mid-span locations, care must be taken to isolate the piping from contact with the support brace as well as the pipe clamp used to attach the pipe to the bracket itself through the use of rubber felt or neoprene materials engineered and tested to be effective in this application (see Figures 10-6, 10-7, and 10-8).

In seismic regions, be sure to avoid the use of rigid seismic/sway bracing methods. Use systems that include aircraft cable

Figure 10-8 Isolation of Toilet Fixture Waste Pipe



and accessories designed to allow minimal movement. These help avoid short-circuiting of vibration transfer to the building. Several manufacturers provide these types of materials and performance data. Clearly express these requirements in the project specifications and detail pages.

Another noise isolation method involves the addition of some form of lagging to the outside of the piping to minimize airborne noise. Lagging is done by wrapping the piping with foam rubber or fiberglass insulation and surrounding the insulation with a layer of dense, limp material such as vinyl impregnated with an inert metal or other dense material. Commercially manufactured and tested products ranging from adhesive wraps to sound baffles are available. They often list their tested NRC (Noise Reduction Coefficient). For example, an NRC of 0.85 indicates that the product has been proven to reduce noise by 85 percent. Unfortunately, in some cases, makeshift methods are employed, such as attaching carpet padding or similar scrap materials poorly held in place with wire tie, bailing wire, duct tape, or similar methods.

When attempting to reduce airborne noise, dense materials work best. Use only materials and methods with tested and proven results. Various insulation manufacturers provide test data to indicate the level of noise reduction to be expected in this application. Specifically disallow makeshift attempts on the jobsite, such as taping or wire-tying carpet padding around piping.

MITIGATING NOISE IN WATER DISTRIBUTION SYSTEMS

Three main factors affect the noise in water distribution systems: water pressure, water velocity, and the number and type of constrictions and fittings. Water piping noise is usually transmitted as structure-borne vibration eventually radiating from lightweight surfaces.

The choice of water tubing materials can have some effect on water distribution system noise. For instance, some independent laboratory tests have shown that plastic tubing is up to four times quieter than copper tube, despite its often thicker pipe wall, smaller internal diameter, and higher fluid velocities. However, local building and plumbing code requirements may dictate which material types are allowed.

Very similar to drainage piping, steps should be taken to break any direct contact between the water piping system and the building's components. Some contractors use plastic isolators to break this contact, and others wrap tubing with some kind of felt or install a rubber isolator. The use of tested and proven pipe isolators and clamps for through-stud situations and surface-mounted attachments is critical. Specifications and plumbing detail drawings should clearly disallow makeshift, field-devised attempts at isolating water lines from structure contact. Specify products with proven performance that are compatible with the piping material. (See Figures 10-9, 10-10, 10-11, and 10-12.)

As with drainage systems, when passing through floors, steps should be taken to isolate noise transfer to the wood, metal, or concrete floor system by placing rubber or neoprene pads under the ears of riser clamps. Additionally, the piping must be isolated from contact with the edges of the floor penetration with the use of acoustical sealant within the annular space surrounding the piping. (See Figures 10-13 and 10-14.)

Another important factor is the isolation of water piping from hangers and other support systems. In the case of hangers, this often is accomplished by the use of either a spring-isolated hanger attachment point at the supporting structure or a hanger lining of felt or a rubber/neoprene material to break the connection between the hanger and the water tube. As a caution, some pipe support products contain plasticizers such as plasticized vinyl, which may have a detrimental effect on the water piping material (e.g., CPVC materials). Pipe insulation that runs continuous through the hanger or support is another effective method of isolating the pipe from the support.

All chilled, condenser, domestic, and hot water equipment, including the heat exchanger and the hot water storage tank, should be isolated from the following:

- All piping in the equipment room
- All piping outside of the equipment room within 50 feet (15.24 m) of the connected pump
- All piping more than 2 inches (50.8 mm) in diameter (nominal size) and any piping suspended below or near a noise-sensitive area

Figure 10-9 Isolation Through Wall Stud or Other Wood Framing Member

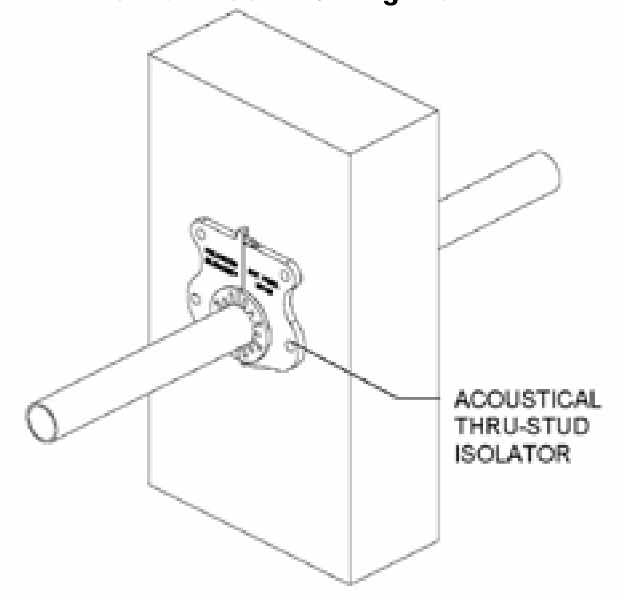


Figure 10-10 Surface-Mounted Pipe Clamp

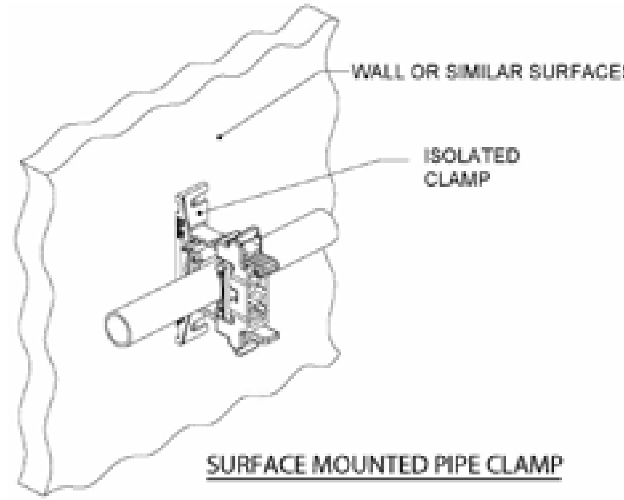


Figure 10-11 Horizontal/Vertical Piping Isolation

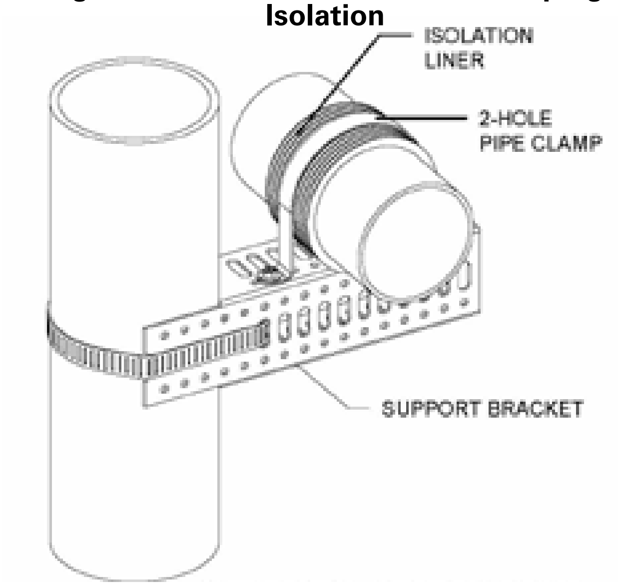


Figure 10-12 Horizontal/Vertical Piping Isolation

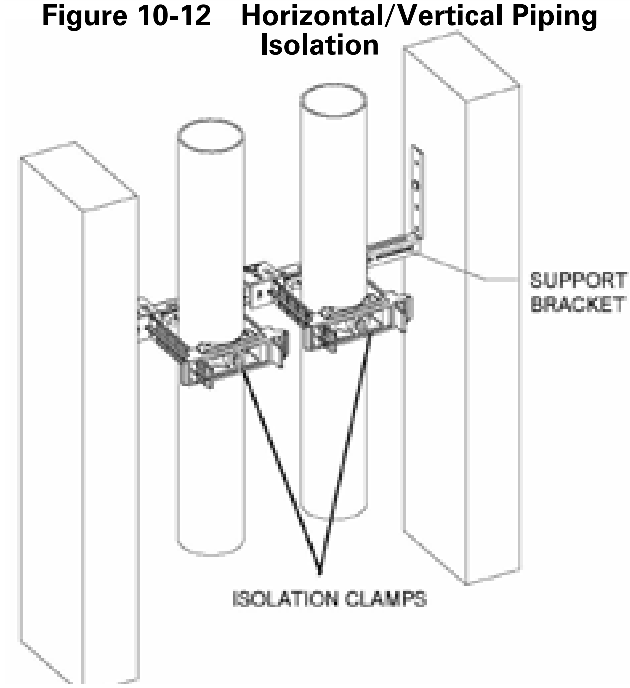


Figure 10-13 Riser Clamp Isolation

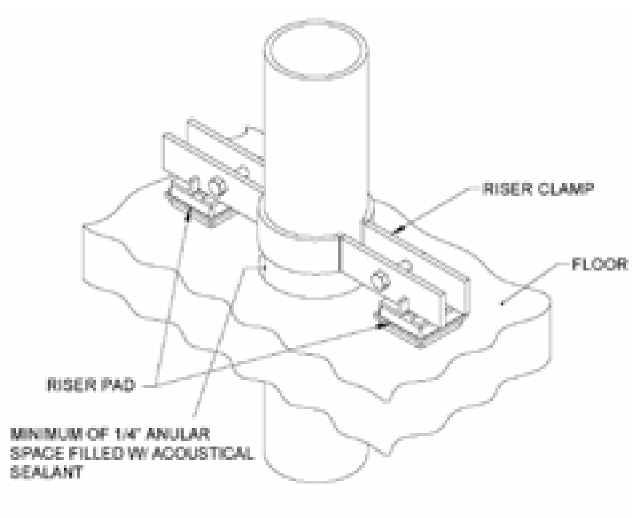
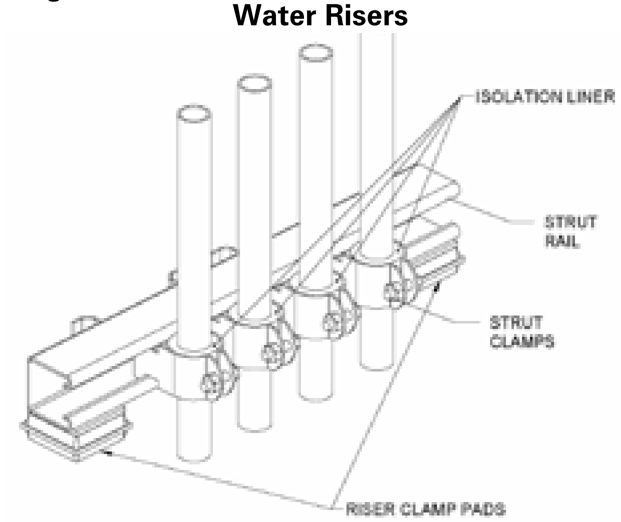


Figure 10-14 Vertical Cast Iron Stacks and Water Risers



Supports should be of a pre-compressed type to prevent a load transfer to the equipment when the piping systems are filled. The first three vibration isolators from the equipment should provide the same deflection of the pump isolators with a maximum deflection of 2 inches (50.8 mm); the remaining hangers should be spring or combination spring and rubber with ¾-inch (19.05-mm) deflection. All piping connected to plumbing equipment should be resiliently supported or connected.

When water tubing is supported by a mid-span or mid-story brace attached to the building's structure, steps must be taken to keep the tubing from contacting the support brace or the clamp that holds the tube to the support by the use of an effective isolating material, such as felt, rubber, or neoprene. Use only materials tested and proven to be effective in this application and approved for use with the pipe material. (See Figures 10-15 through 10-20.)

In seismic regions, avoid the use of rigid bracing methods. Instead, use systems that include aircraft cable and accessories designed to allow minimal movement, which aids in avoiding short-circuiting of vibration transfer to the building.

Another common step taken is the addition of pipe insulation or lagging to the outside of the tubing to help minimize airborne noise transfer. To effectively isolate airborne noise, dense materials are always best. Use materials tested and proven to be effective for this purpose.

A practice that is growing in use is the routing of PEX domestic water within the structural slab (see Figure 10-21). This is more common in structures with post-tensioned concrete slabs and occupancies such as hotels and apartments. The installation eliminates noise from water flow within the living space.

Another common source of water system noise is water hammer, which occurs when valves are closed quickly, producing a shock wave in the system and causing the pipes to vibrate. Reducing pressure and velocity and avoiding quick-closing valves helps reduce water hammer. Air-filled stubs referred to as air chambers can be used, but they are effective only for a very short time, and their presence in specifications has drastically decreased in recent years.

An effective solution is the use of shock arrestors or water hammer arrestors, which are sealed, pre-charged mechanical devices similar to spring-loaded shock absorbers. These should be introduced in the piping near appliances or equipment with fast-closing valves, such as washing machines, and act as cushions to reduce the shock. Both the Uniform Plumbing Code (UPC) and the International Plumbing Code (IPC) require water hammer arrestors to be installed at the location of quick-acting or quick-closing valves such as found in dishwashers, clothes washers, and icemakers. The IPC specifically requires that these devices shall conform to ASSE 1010: *Performance Requirements for Water Hammer Arresters*. Another reference standard is PDI WH 201: *Water Hammer Arresters Standard*.

Figure 10-15 Suspended Waste, Water, or Other Piping

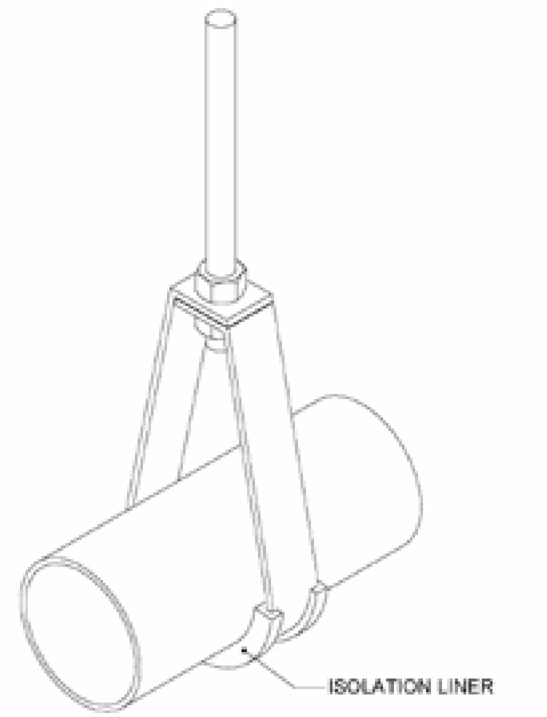


Figure 10-16 Suspended Horizontal Overhead

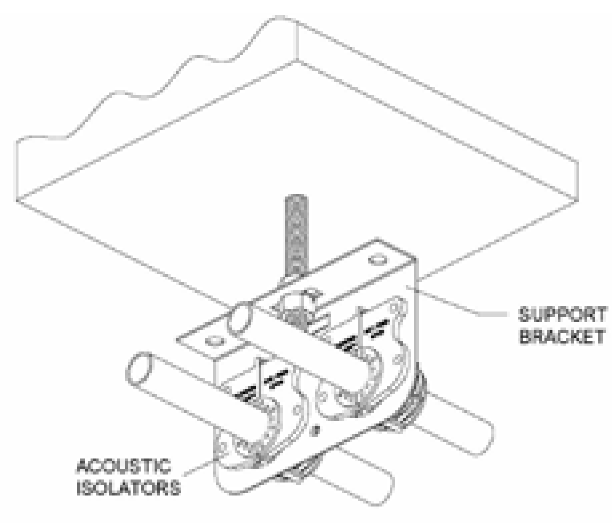


Figure 10-17 Horizontal Overhead

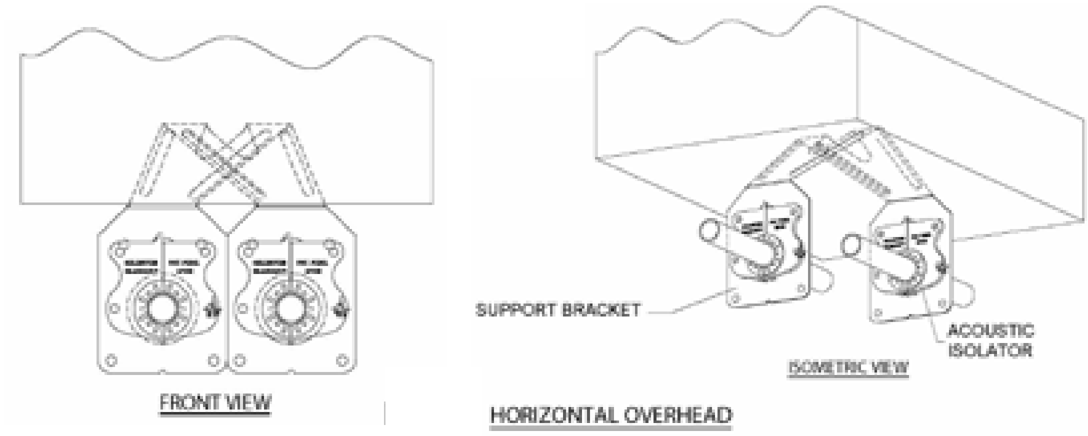


Figure 10-18 Water, Vent, Waste

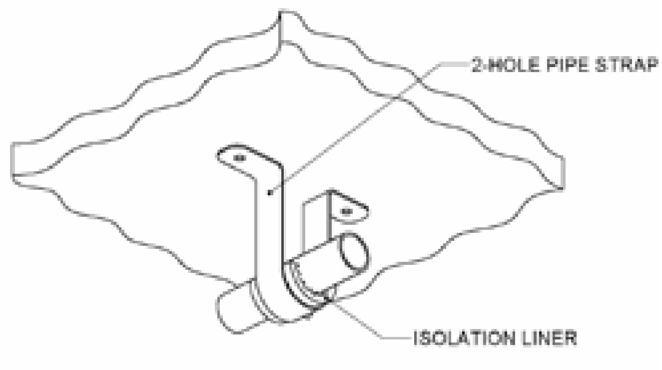


Figure 10-20 Horizontal Joist Bay Support

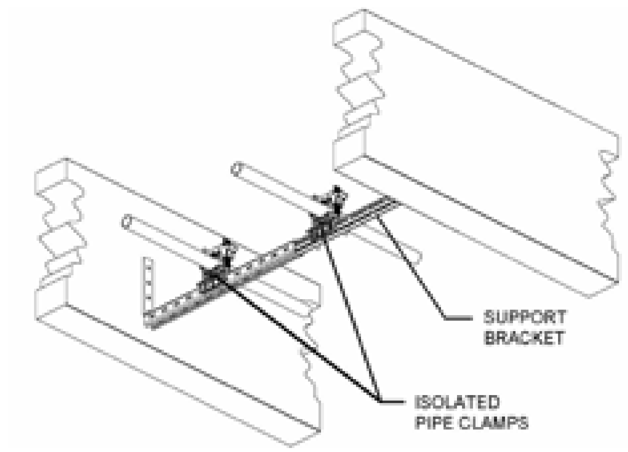


Figure 10-19 Overhead Trapeze Piping

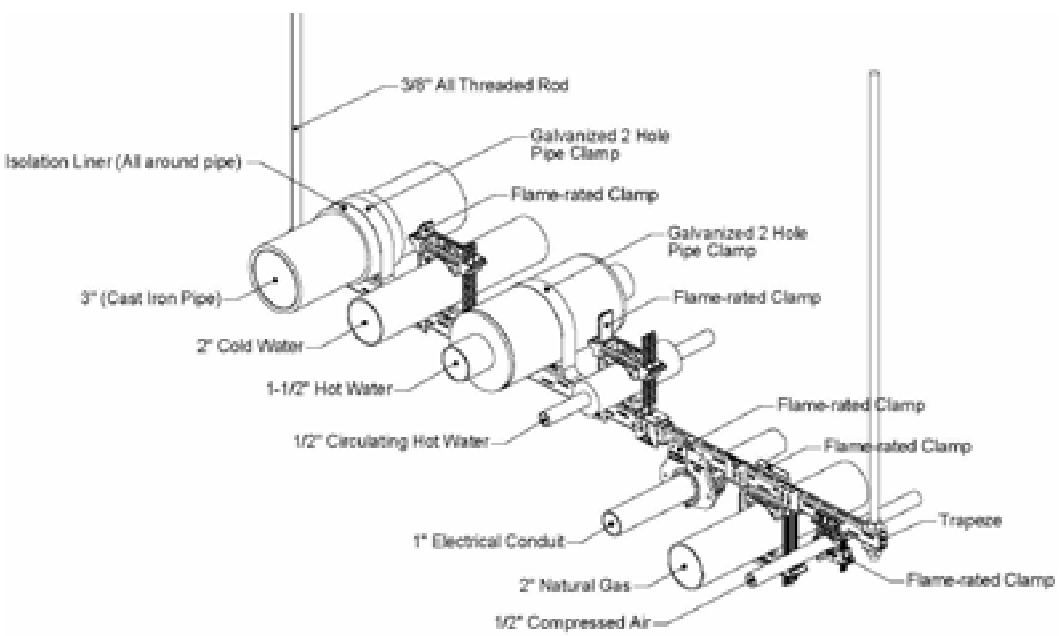


Figure 10-21 In-Slab PEX Installation
Source: Figure courtesy of Uponor.

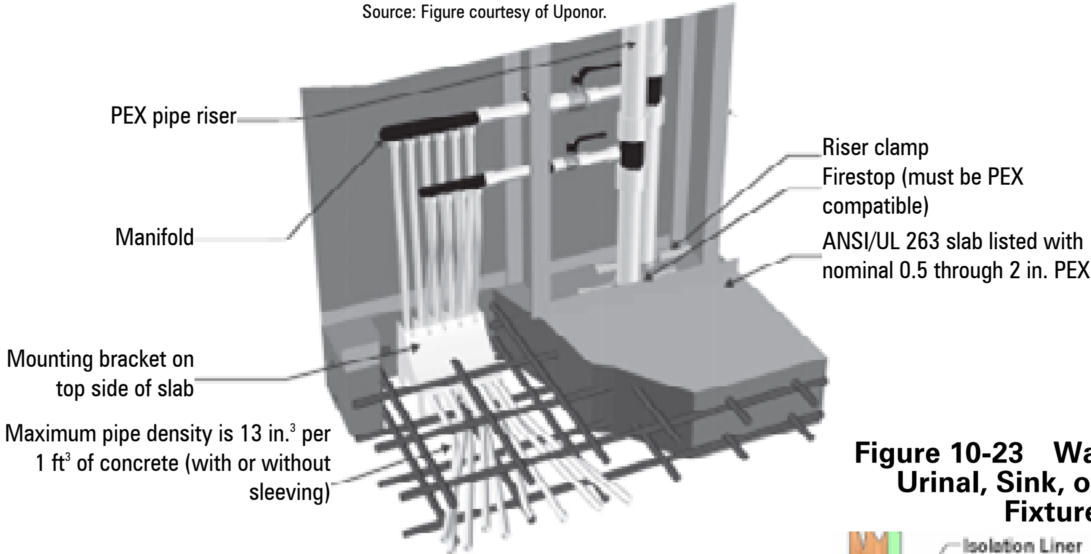


Figure 10-23 Wall-Mounted Urinal, Sink, or Similar Fixture

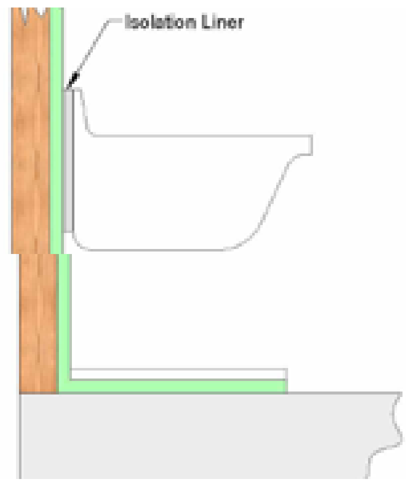


Figure 10-22 Wall-Hung Water Closet or Similar

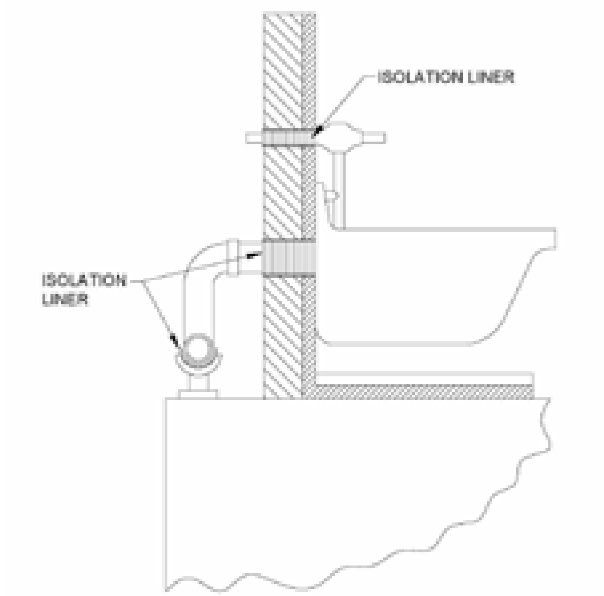


Figure 10-24 Sink Isolation Detail

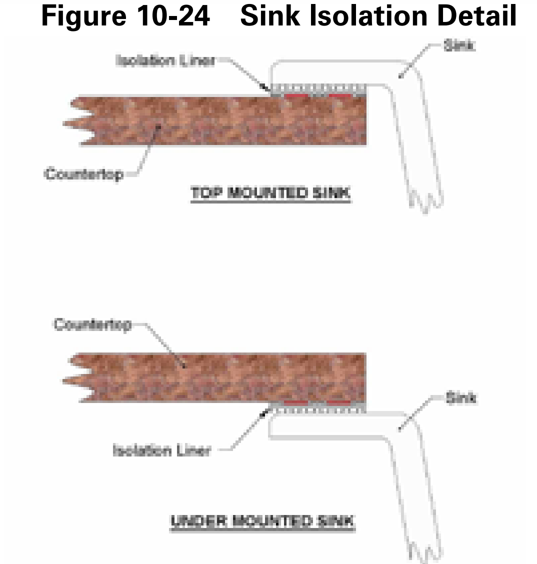
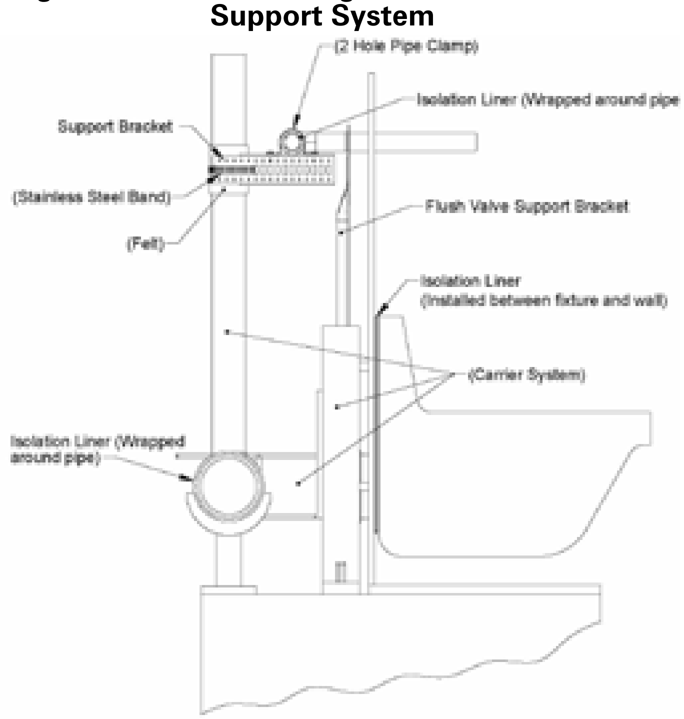


Figure 10-25 Wall-Hung Fixture with Carrier Support System



MITIGATING NOISE FROM FIXTURES

While addressing noise sources involving various piping systems within a building, it is important to not overlook fixture and faucet selection. Fixtures, faucets, and appliances can be chosen based on third-party test data regarding their inherent sound qualities. ISO 3822 sets out a test method and uniform rating system for evaluating noise emissions from plumbing fixtures. Other methods to reduce noise from fixtures and faucets are as follows.

One common way to ensure that fixtures will be quieter than others is by choosing those made of materials that are heavier and better damped, such as vitreous china, terrazzo, or cast iron rather than thin-gauge stainless, enameled steel, or fiberglass. As an example, when choosing a kitchen sink, consider various factors that determine how much noise will result under normal operation. A stainless steel sink without the addition of a dense damping sound pad applied to the bottom of the bowl will experience a loud drumming sound when water hits the bowl, resulting in both airborne and structure-borne noise. Additionally, if the faucet is in direct contact with the upper surface of the sink or the countertop, devoid of a gasket, putty, or similar isolation, it will transfer noise generated from the operation of water running through the faucet itself. Instead, consider choosing a cast iron sink combined with a faucet made of heavy gauge metal and rubber isolation gaskets at both the base of the faucet and the attachment points under the ledge of the sink. Another example is to use flush tank-type toilets rather than flushometer valve or pressure-assisted water closets. Flush tank toilets are much quieter, and some are nearly silent. (See Figures 10-22 through 10-31.)

Water supply connections between the wall and the faucet constructed by rigid supply tubing will produce more noise than those made with flexible or braided supply lines. Flexible tubing made of corrugated stainless steel or braided nylon will perform better than chrome or rigid brass supply lines. (See Figure 10-32, in the case of a clothes washer.)

It is important to keep wall surface materials from contacting fixture supply stub-outs or escutcheons positioned behind angle stops. Provide rubber or dense foam isolation spacers behind the escutcheons so that a slight void is provided. Fill the void space around each escutcheon with an acoustical caulking compound, and use acoustical caulk or ¼-inch (6.35-mm) felt within the annular space between the stub-out pipe and the wall surface material.

Figure 10-26 Typical Floor-Mounted Toilet Flange

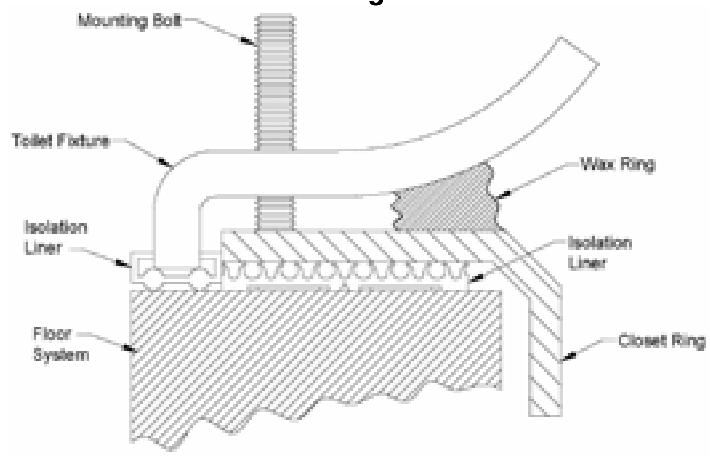


Figure 10-27 Floor-Mounted Bathtub or Shower Isolation

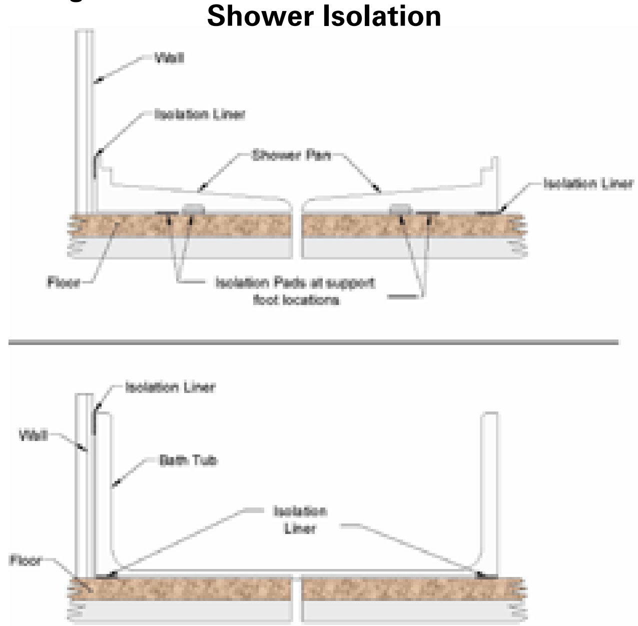
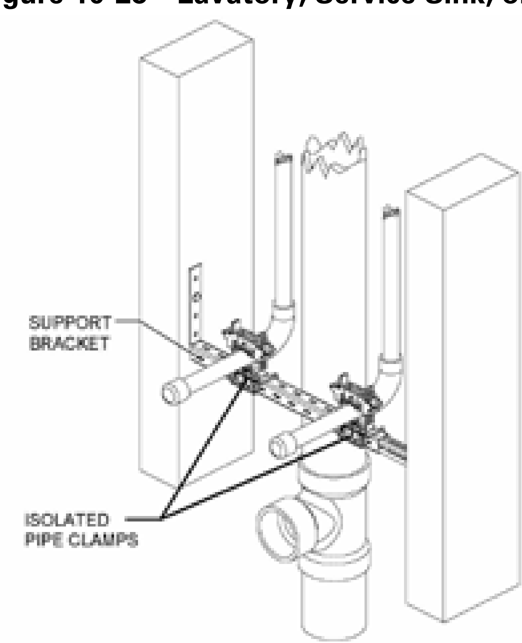


Figure 10-28 Lavatory, Service Sink, or Sink



Tub and shower mixing valves and associated parts such as showerheads and tub spouts should be treated much the same as the water distribution system to which they are connected. Tub and shower fixtures and faucets are among the worst culprits regarding unwanted noise generation.

The attachment points between the supports within the wall at the showerhead fitting, tub spout fitting, and supply lines feeding the diverter valve must be isolated from hard contact. Use only tested and proven isolating materials specifically engineered to accomplish this.

The showerhead arm and the sub-spout supply lines must be kept from contact with the wall surface as well. Provide a ¼-inch (6.35-mm) clear annular space around both pipe supply locations, and fill this space with a flexible caulking

Figure 10-29 Icemaker Box

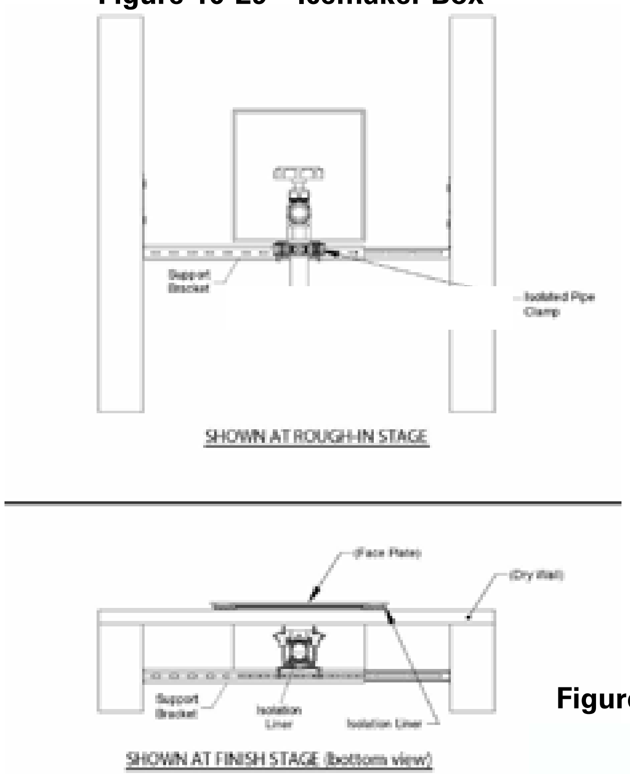


Figure 10-30 Laundry Outlet Box

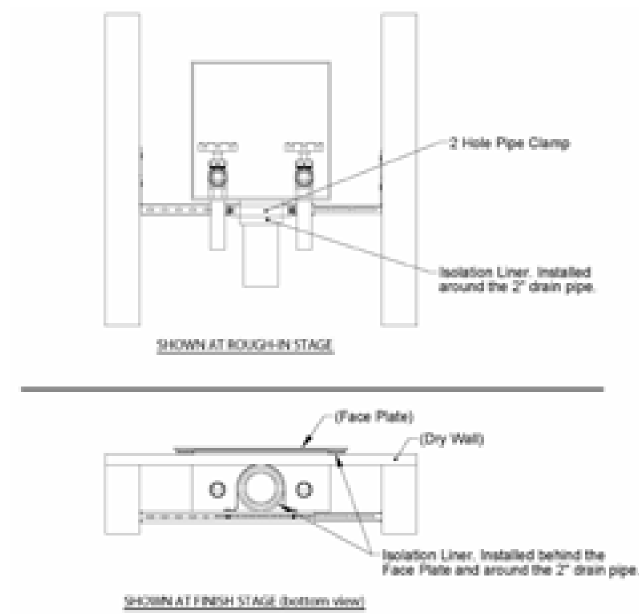


Figure 10-31 Hot Water Tank Rough-In

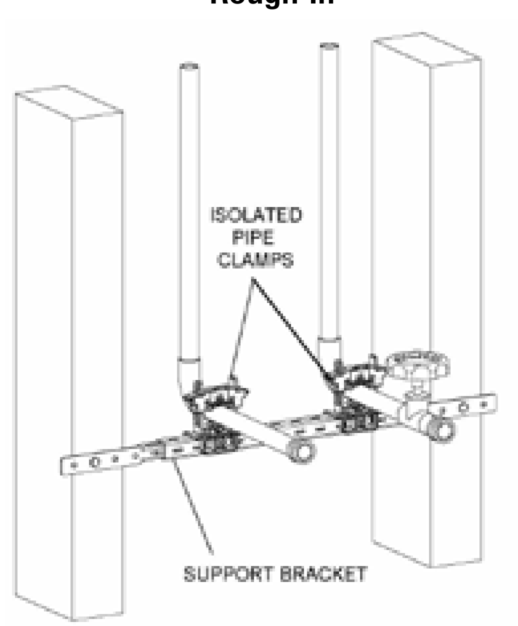
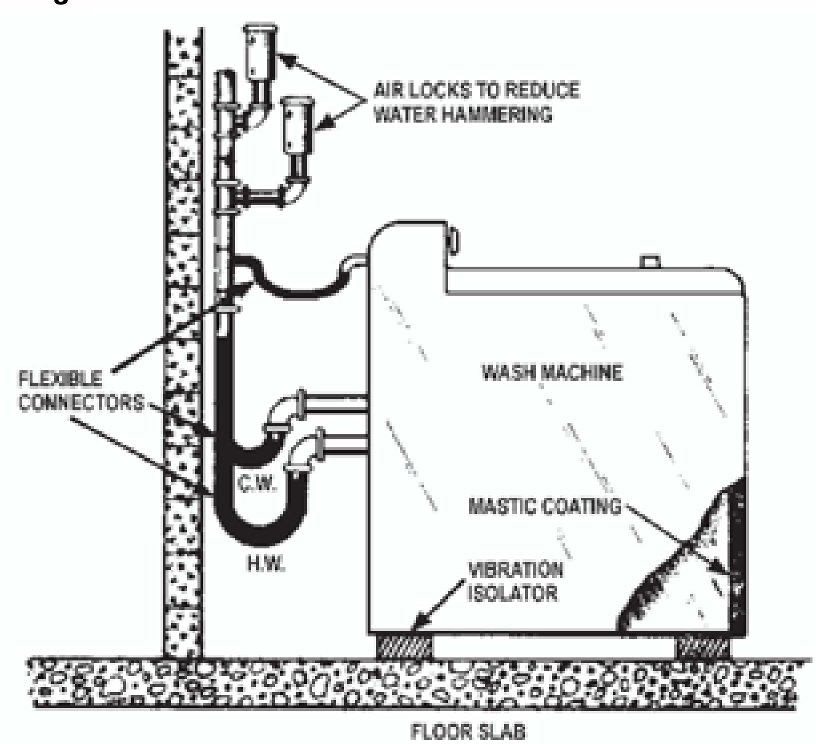


Figure 10-32 Flexible Connections for Clothes Washer



compound. Clearly define these isolation requirements within the specification as well as on plumbing installation detail drawings.

Additional noise and vibration isolation can be provided at tub and/or shower locations by selecting fixtures made of dense materials such as cast iron, as well as by eliminating direct contact with the floor sheathing and the wall framing surrounding the edges of the tub or shower. This should be accomplished by the use of a rubber or neoprene liner and ¼-inch (6.35-mm) rubber pads between heavy contact points and the building structure. Provide clear specification language and plumbing detail drawings to the installing contractor. (See Figures 10-33 through 10-36.)

Figure 10-33 Typical Bathtub Spout

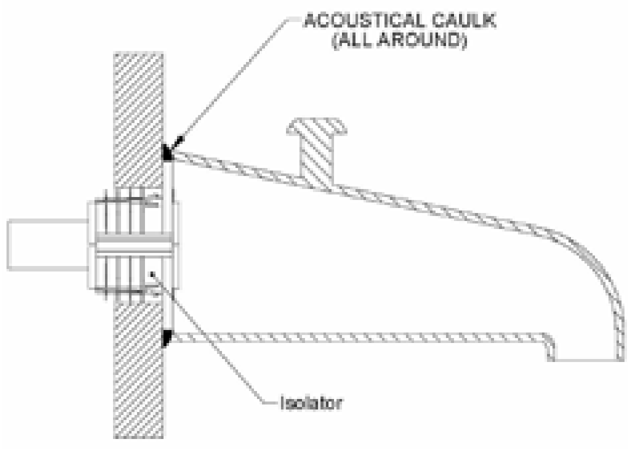
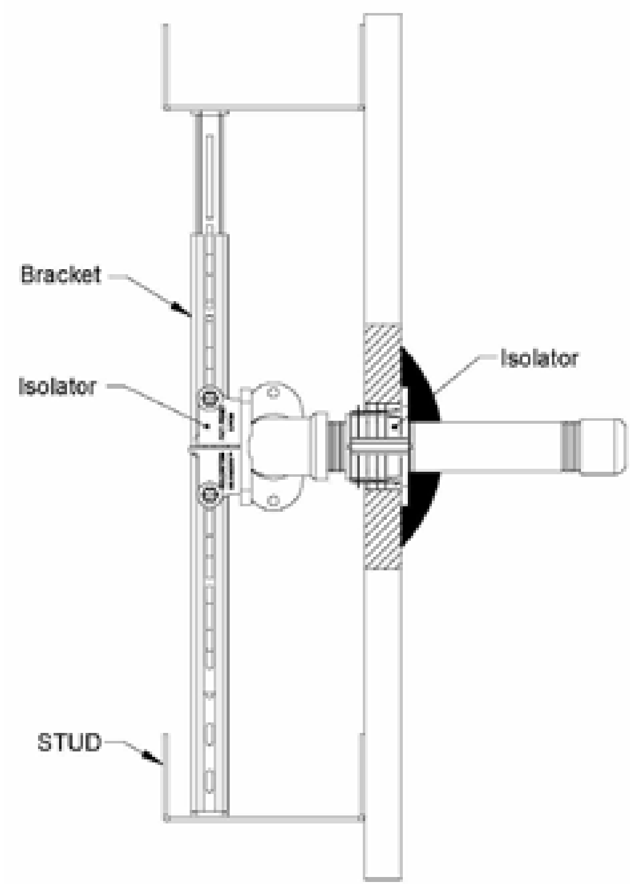


Figure 10-34 Showerhead Isolation



MITIGATING NOISE FROM VALVES, PUMPS, AND OTHER EQUIPMENT

Valves, pumps, and other equipment are common contributors of noise in a plumbing system. Most valve manufacturers provide flow and turbulence data to assist in the choice of valves. Typically, the quietest valves are those with smooth waterways such as full-way ball valves and full-way gate valves. Specify appropriate valves with this in mind.

Pumps can be extremely loud and must be isolated in several ways. Rubber or spring isolators commonly are used when mounting pumps on floors. Concrete bases with spring isolators or neoprene pads are preferred for all floor-mounted pumps. Select the appropriate rubber or spring isolator based on third-party testing and load data provided by various manufacturers.

When connecting the piping system to pumps and equipment, especially ones that generate a great deal of vibration, pay special attention to the use of flexible connectors and effective hanger isolation. Select and specify flexible connectors that are appropriate for the pipe system's material and fluid content. Various manufacturers can provide the necessary data on which to base decisions. Table 10-1 contains the recommended static deflections for the selection of pump vibration-isolation devices.

Vibration-control devices generally consist of steel springs, air springs, rubber isolators, slabs of fibrous (or other resilient) materials, isolation hangers, flexible pipe connectors, concrete inertia bases, or any combination of these items.

Steel springs are available for typical required static deflections to 4 inches (101.6 mm). These devices generally are used as vibration isolators that must carry heavy loads where more isolation performance is desired than rubber or glass fiber provides or where environmental conditions make other materials unsuitable. The basic types of steel spring mountings are housed-spring mountings, open-spring mountings, and restrained-spring mountings. Because steel springs have little inherent damping and can amplify

Table 10-1 Recommended Isolator Types and Static Deflections for Pumps

Pump Type	Power Range, hp (kW)	Speed, rpm	Slab on Grade			Indicated Floor Span, ft (m): Up to 20 ft (6 m)			20–30 ft (6–9 m)			30–40 ft (9–12 m)		
			Base Type[a]	Isolator Type[b]	Minimum Deflection, in. (mm)	Base Type[a]	Isolator Type[b]	Minimum Deflection, in. (mm)	Base Type[a]	Isolator Type[b]	Minimum Deflection, in. (mm)	Base Type[a]	Isolator Type[b]	Minimum Deflection, in. (mm)
Close-coupled	≤7.5 (≤5.5)	All	B	2	0.25 (6)	C	3	0.75 (19)	C	3	0.75 (19)	C	3	0.75 (19)
	≥10 (≥7.5)	All	C	3	0.75 (19)	C	3	0.75 (19)	C	3	1.50 (38)	C	3	1.50 (38)
Inline	5–25 (4–18.5)	All	A	3	0.75 (19)	A	3	1.50 (38)	A	3	1.50 (38)	A	3	1.50 (38)
	≥30 (≥22)	All	A	3	1.50 (38)	A	3	1.50 (38)	A	3	1.50 (38)	A	3	2.50 (64)
End-suction and double-suction/ split case	≤40 (≤30)	All	C	3	0.75 (19)	C	3	0.75 (19)	C	3	1.50 (38)	C	3	1.50 (38)
	50–125 (37–90)	All	C	3	0.75 (19)	C	3	0.75 (19)	C	3	1.50 (38)	C	3	2.50 (64)
	≥150 (≥110)	All	C	3	0.75 (19)	C	3	1.50 (38)	C	3	2.50 (64)	C	3	3.50 (89)
Packaged pump systems	All	All	A	3	0.75 (19)	A	3	0.75 (19)	A	3	1.50 (38)	C	3	2.50 (64)

[a]Base Type: A = No base; isolators attached directly to equipment; B = Structural steel rails or base; C = Concrete inertia base
[b]Isolator Type: 1 = Neoprene or rubber pad (not used); 2 = Neoprene or rubber mount/floor isolator or hanger; 3 = Spring floor isolator or hanger
Source: ASHRAE 2011 *HVAC Applications Handbook,* Chapter 48: Noise and Vibration Control

vibration at resonance frequencies, all steel-spring mountings should be used in series with pads of rubber, fibrous, or other resilient materials to interrupt any possible vibration-transmission paths.

Air springs are employed when deflections of 6 inches (152.4 mm) or more are required. By varying the air pressure in the bladder, air springs are capable of carrying a wide range of loads. The shape, rather than the pressure, determines the spring's frequency. Air springs have the advantage of virtually no transmission of high-frequency noise. They have the disadvantage of higher cost, higher maintenance, higher failure rates, and low damping.

Rubber or neoprene isolators generally are used where deflections of 0.3 inch (7.62 mm) or less are required. These devices can be molded in a wide variety of forms designed for several combinations of stiffness in the various directions. The stiffness of a rubber or neoprene isolator depends on many factors, including the elastic modules of the material used, which vary with the temperature and frequency and are usually a characteristic of a durometer number, measured at room temperature. Materials in excess of 60 durometers are usually ineffective as vibration isolators. Rubber or neoprene isolating devices can be relatively light, strong, and inexpensive; however, their stiffness can vary considerably with the temperature. They are effective primarily against high-frequency disturbances with very limited performance at low frequencies.

Pre-compressed glass-fiber pads generally are used where deflections of ¼ inch (6.35 mm) or less are required. They are available in a variety of densities and fiber diameters. Although glass-fiber pads usually are specified in terms of their densities, the stiffness of the pads supplied by different manufacturers may differ greatly, even for pads of the same density.

Sponge-rubber vibration-isolation materials are commercially available in many variations and degrees of stiffness. The stiffness of such a material usually increases rapidly with increasing load and frequency. This material is rarely used in manufactured isolators, but often is used in jobsite-fabricated installations.

Concrete base devices are usually masses of concrete, poured with steel channel, weld-in reinforcing bars, and other inserts for equipment hold-down and vibration-isolator brackets. These devices maintain the alignment of the component parts; minimize the effects of unequal weight distribution; reduce the effects of the reaction forces, such as when a vibration-isolating device is applied to a pump; lower the center of gravity of the isolated system, thereby increasing its stability; and reduce motion. Concrete bases can be employed with spring isolators, rubber vibration isolators, and neoprene pads. Industry practice is to make the base in a rectangular configuration approximately 6 inches (152.4 mm) larger in each dimension than the equipment being supported. The base depth needs not exceed 12 inches (304.8 mm) unless specifically required for mass, rigidity, or component alignment. A concrete base should weigh at least as much as the items being isolated. (Preferably, the base should weigh twice as much as the items.) The plumbing designer should utilize the services of a structural engineer when designing a concrete base.

When providing vibration isolation for any plumbing system or component, the engineer must consider and treat all possible vibration-transmission paths that may bypass (short-circuit or bridge) the primary vibration isolator. Flexible connectors commonly are used in pipe connecting isolated and un-isolated plumbing components. Flexible pipe connectors usually are used to provide flexibility of the pipe and permit the vibration isolators to function properly, to protect the plumbing equipment from strains due to the misalignment and expansion or contraction of the piping, and to attenuate the transmission of noise and vibration along the piping system. Most commercially available flexible pipe connectors are not designed primarily for noise reduction. For noise control, resilient pipe isolators should be utilized. (See Figures 10-37 through 10-44.)

Grooved flexible mechanical couplings are a great alternative to U-shaped expansion loops, offsets, braided expansion joints, and rubber bellows. These couplings are often easier and faster to install and accommodate deflection and linear movement within the design capability of the coupling, all the while doing this within the product's free range of motion. This means that imparted deflections can be accommodated in smaller spaces, with low stress on the components. (See Figure 10-45.)

Note that sometimes the simplest solution may involve relocating the equipment to a less sensitive location. Many electric water coolers incorporate a small chiller, which generates noise on an intermittent basis as the compressor cycles. A potential approach for reducing the noise output of a water cooler to sensitive spaces is to ensure that it is not installed near the space in question or in a sensitive wall. If the location of the cooler cannot be moved, consider using a remote chiller to move the primary noise source as far from the receiver as possible. Locating centralized equipment in a dedicated equipment room far from acoustically sensitive spaces often provides better energy efficiency in addition to increased noise reduction.

Figure 10-35 Bathtub/Shower Rough-In

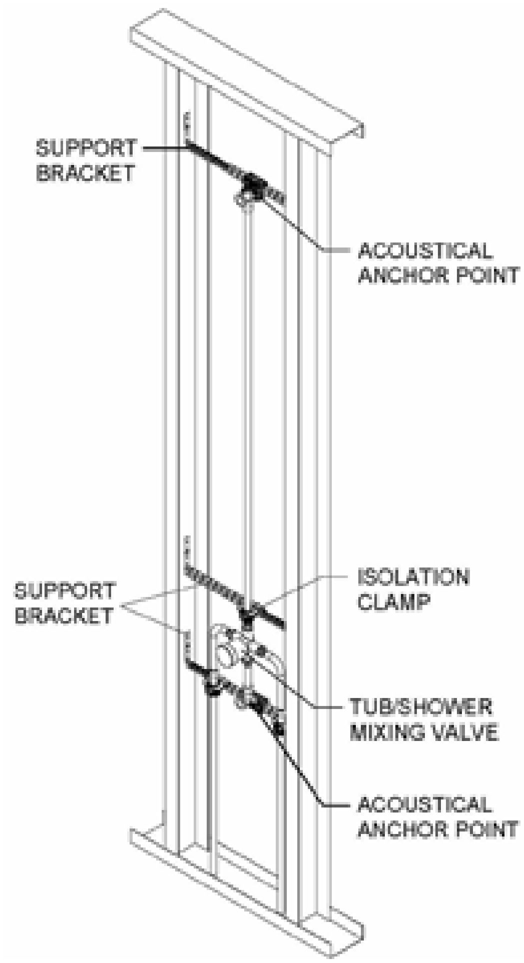
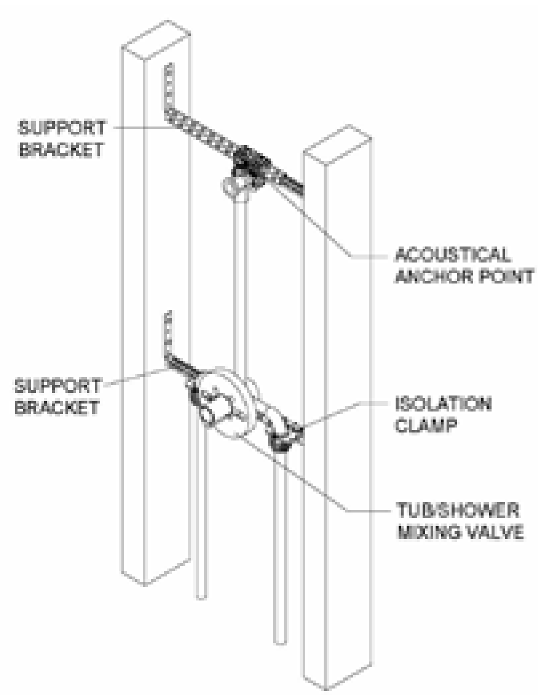


Figure 10-36 Shower Rough-In



BENEFITS OF EARLY INVOLVEMENT IN DESIGN AND THROUGHOUT CONSTRUCTION

Once the engineer has a clear understanding of the owner's requirements regarding the level of noise abatement expected for a particular project, a plan of attack can be formulated. While this chapter covers acoustics in plumbing systems, it is apparent that the building layout must also be carefully considered. Coordination with the project architect and the plumbing/mechanical design team should occur early in the design stage. For some projects, an acoustical consulting firm may be an essential addition to the project team. These specialists, or acousticians, are typically members of the Acoustical Society of America and/or the Institute of Noise Control Engineering.

Figure 10-37 Neoprene Hanger Isolator

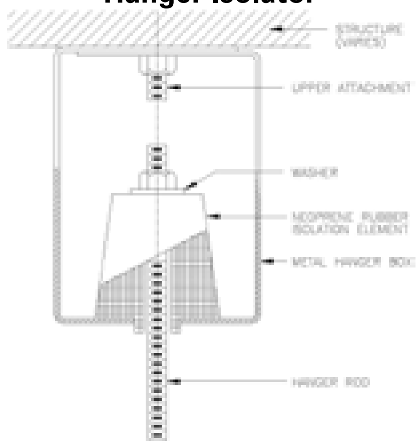


Figure 10-38 Sump Pumps

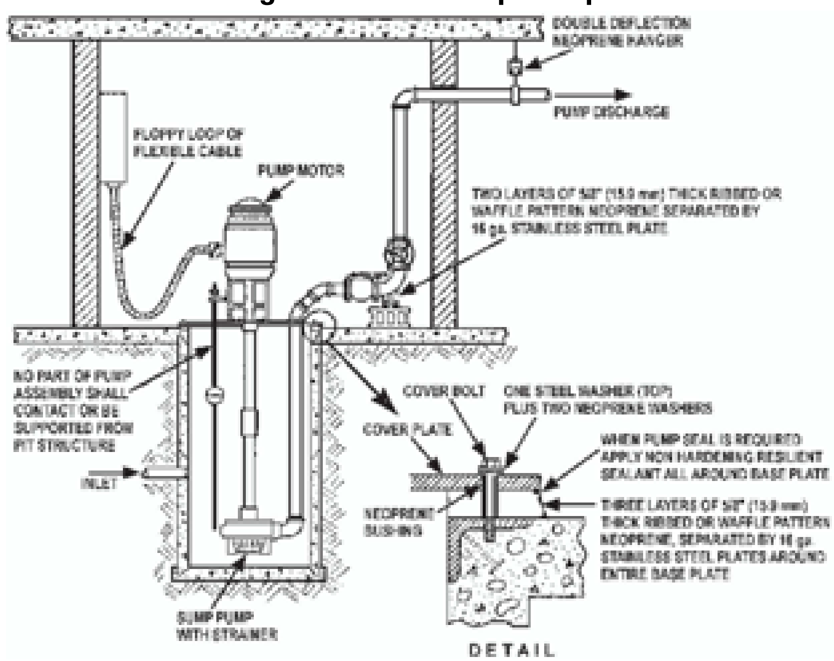


Figure 10-39 Neoprene Mount, Double Deflection

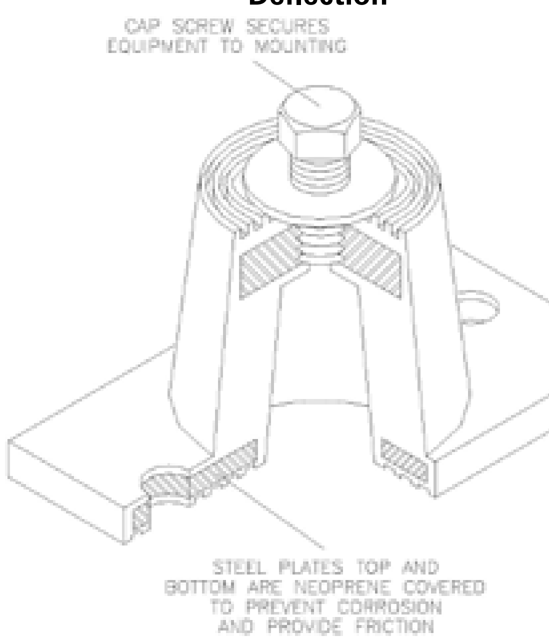


Figure 10-40 Spring-Mount Isolator

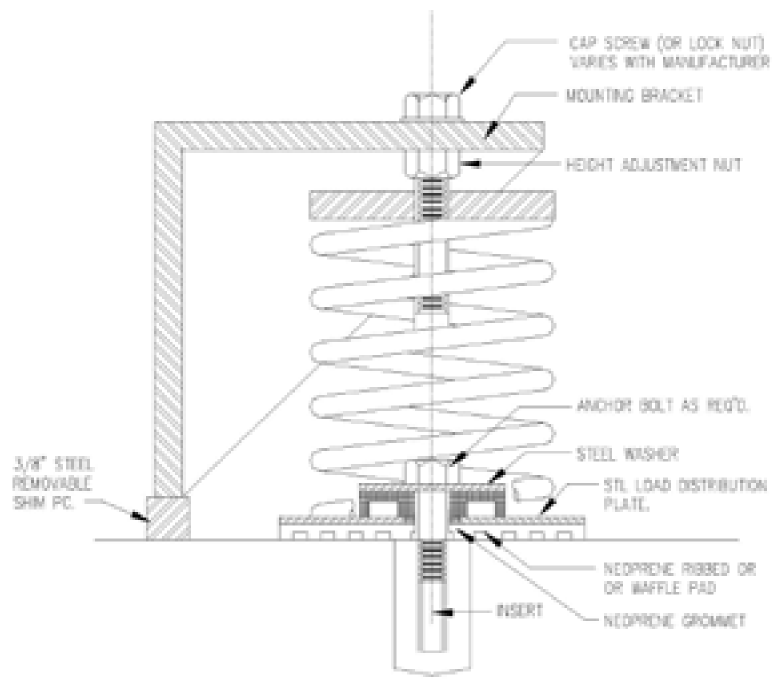


Figure 10-41 Neoprene Pad Isolator

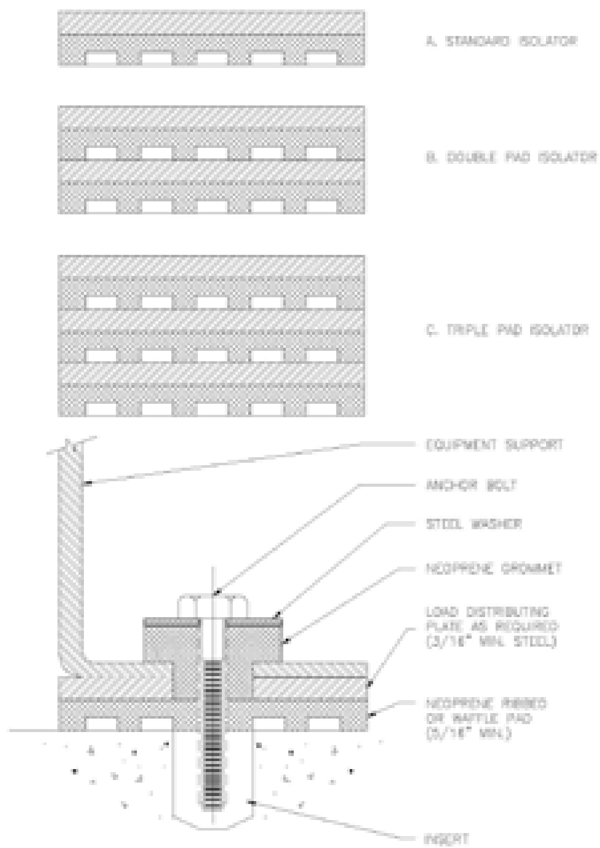


Figure 10-42 General Mounting Detail for End-Suction, Close-Coupled Pump

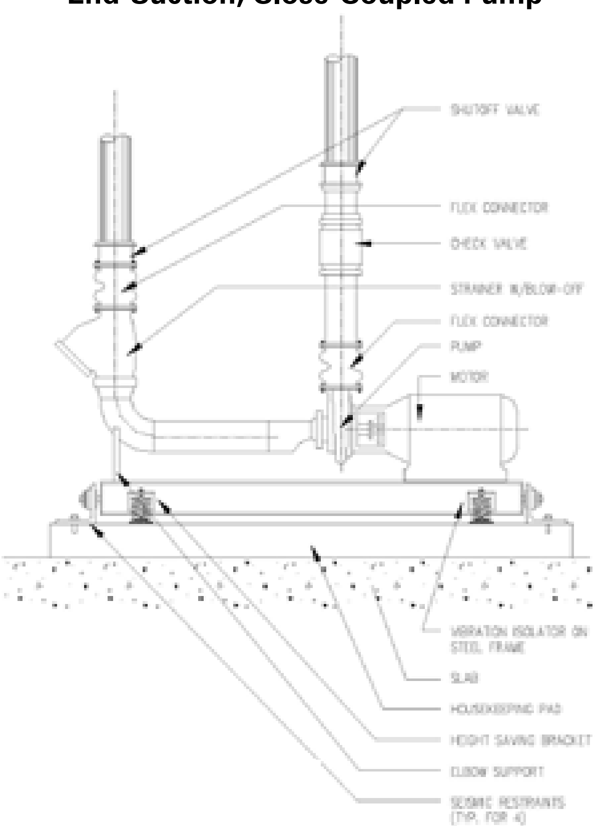


Figure 10-43 Examples of Flex Connectors

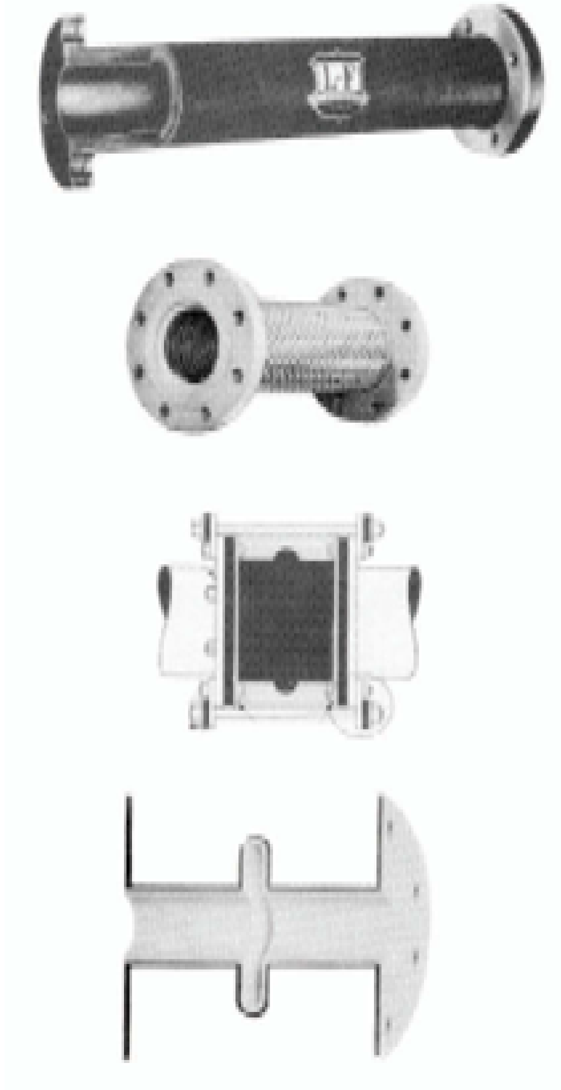
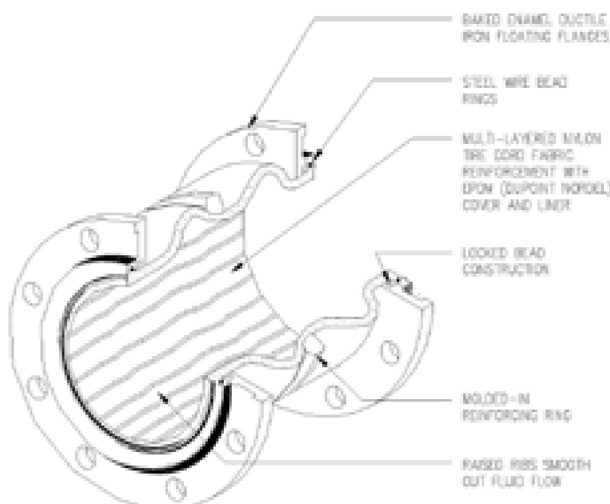


Figure 10-44 Flex Connector Detail



Party and Plumbing Walls

Ideally, plumbing walls should not be located near quiet rooms. Party walls should be constructed to minimize sound transfer from one tenant to another or from common areas to tenant spaces and vice versa. Consider designs and configurations including increased physical separation (air space) between walls, staggered studs, dense insulation within wall cavities, multiple layers of sheetrock, and a variety of resilient channel configurations.

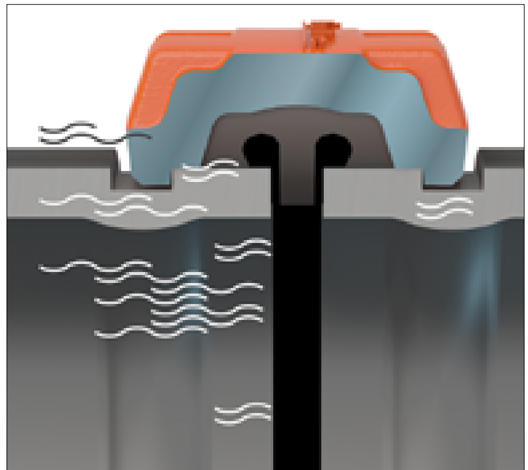
Floor and Ceiling System Construction and Configuration

Avoid routing plumbing system piping in ceiling spaces that are positioned above sensitive areas such as bedrooms. Minimize the use of hard floor surfaces where possible. Soft floor coverings help minimize the transfer of noise generated by plumbing fixtures and appliances between occupant levels of a building.

If pipes must be installed in the walls and ceilings of acoustically sensitive rooms, provide noise reduction as appropriate with sound-absorbing materials. Pipes should be decoupled from lightweight walls through the use of vibration-isolating clamps or other materials.

Figure 10-45 Attenuation Through the Use of Flexible Grooved End Couplings

Source: Reprinted with the permission of Victaulic.



Noise and vibration attenuation – by isolating the transference of vibration at each joint.

Documenting Construction Requirements and Observing Installation

After building-related design issues are resolved, the acoustical engineer or other responsible entity should draft the needed documents and establish means and methods that will be required of the plumbing or mechanical contractor. These documents typically include a project-specific plumbing noise and vibration specification, which establishes submittal requirements and procedures and specifies the acoustical materials and methods required for the project, and plumbing installation detail drawings, which establish how quality control will be monitored throughout construction.

On-site inspection during the building process often reveals errors that can be corrected easily and early. Waiting too long to visit the site can result in concealed errors that cannot be easily uncovered or repaired in a finished building.

Acoustical testing in a partially completed building can be helpful to prevent repeated errors and allow for timely correction.

RESOURCES

- ISO 3822: *Acoustics -- Laboratory tests on noise emission from appliances and equipment used in water supply installations -- Part 1: Method of measurement*
- *Sound & Vibration Magazine*
- UPC Section 609.10
- IPC Section 604.9
- *ASHRAE HVAC Applications Handbook,* Chapter 48: Noise and Vibration Control
- *Noise and Vibration Control,* Leo L. Beranek, McGraw-Hill
- *Handbook of Acoustical Measurements and Noise Control,* Cyril M. Harris, McGraw-Hill
- *Noise and Vibration Control in Buildings,* Robert S. Jones, McGraw-Hill
- *Noise Control in Building Services,* Alan Fry, Sound Research Laboratories
- ASTM E413: *Classification for Rating Sound Insulation*
- ASTM E90: *Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements*

CHAPTER 11

Basics of Value Engineering

Value engineering's intended definition is simply to apply a systematic and planned analysis to engineering and design applications to obtain some desired result. In a perfect situation, this result would be improved performance at a minimal total cost. However, all too often value engineering is synonymous with cutting application engineering and design, including the substitution of products and services, with the intended end result of reduced costs by any and all means. This is not the intended result of value engineering. There is enormous value in performing some form of in-house value engineering in the design process.

WHAT IS VALUE ENGINEERING?

From a historical perspective, the concept of value engineering began in 1947 when the General Electric Company instituted a value-analysis approach to purchasing. The concept was nothing more than applying a systematic analysis to what was being purchased to determine how to get the best for the least cost. This systematic analysis approach evolved and began to be employed in all aspects of business—from products and services to manufacturing, software engineering, and general business management.

In its original incarnation, value engineering was envisioned to be an analysis approach that provided for cost controls to be instituted at any point in a project or product's life-cycle. The only standard or constant was emphasizing the reduction or elimination of costs. However, the first law of such analysis was the requirement that any and all cost reductions maintain the engineered or design standards, quality, and reliability of the project or product to which they were being applied. In fact, SAVE International calls value engineering "a powerful problem-solving tool that can reduce costs while maintaining or improving performance and quality requirements." The key to this definition is that the objective of value engineering is to not diminish, devalue, or degrade the quality or effectiveness of the engineering or design of the project or product. Therefore, reductions in cost are not to be made to degrade or cheapen a project's quality, effectiveness, or reliability.

A similar definition used by the U.S. Army Corps of Engineers as part of its procurement process describes value engineering as "an organized study of functions to satisfy the user's needs, with a quality product at the lowest life-cycle cost through applied creativity. The study is conducted by a multidisciplinary team that provides an independent look at the project. Value engineering is directed at reducing cost, while maintaining or improving quality, maintainability, performance, and reliability." The government's definition also adds, "emphasis is placed on preserving unique and important ecological, aesthetic, and cultural values of our national heritage in accord with the general environmental objectives of the Corps of Engineers."

Many terms have been used over the years to describe the concept of value engineering, including value analysis, value control, value assurance, and value management. All have the same basic objectives: reduce costs, increase productivity, and improve quality.

What is the purpose of value engineering? It is to provide a means to systematically analyze a project and control its total costs. It is designed to analyze a function of a project and determine the best value or the best relationship between its worth and its cost. For a facilities construction project, the best value is a finished project that will consistently perform its required basic function and has the lowest total cost. Therefore, construction of a facility can yield maximum value when value engineering is incorporated into the project. This is accomplished by providing and developing alternatives that produce the desired results and maintain the quality and reliability of the project utilizing the most efficient and effective mix of resources at the least cost.

It would seem that implementing value engineering is fairly simple. First, however, the team must have some perspective about where, how, and why value engineering will be applied. For the plumbing engineer, the most typical application is the creation of a building. In this regard, at least three major aspects of costs will be of concern to the overall development, engineering, and construction team: development costs, engineering and design costs, and construction costs. Within these three areas, all related costs associated with the creation of a building are lumped, such as property acquisition, inspections, licenses and permits, buildout, and finishing.

Value engineering can be introduced at any point in the construction or life-cycle of a project; however, it is best to start the process of value engineering prior to filing the project to obtain building department approvals. For maximum efficiency and to ensure maximum value, value engineering must be integrated from the beginning and continue throughout a project's life-cycle. In this regard, it is important that the concept of a team be immediately integrated into all aspects and phases of the project, for this team will be ultimately responsible for the finished project and its final total cost.

As with any project, three major components comprise the cost cycle: materials, labor, and administration and operations (typically described as overhead). The team must constantly monitor and evaluate all aspects of the project, including any changes and modifications that may affect the quality, life expectancy or life-cycle, maintenance cycles, and reliability of each aspect of the project, from development through engineering, design, and construction. Interestingly, although labor is a major component for each area of a building's creation, it is not often subject to any in-depth analysis in value engineering. Instead, the main effort of value engineering is directed at the cost and value of things—the cost of the elements of construction, the functionality of each element, and the materials and products being utilized.

THE INTENT OF VALUE ENGINEERING

In 1965, the U.S. Department of Defense conducted a study to evaluate cost-saving opportunities that could accrue from the use of value engineering. The study examined a number of projects and analyzed 415 project changes that were considered successful value changes. The study found that only a limited number of factors could achieve more than 95 percent of cost savings. These factors were excessive cost, additional design effort, advances in technology, and the questioning of specifications.

The study (see Table 11-1) revealed that no single factor was ever dominant in the implementation of value engineering. It was rare for the implementation of a change to be the result of a bad design. Trying to second guess a design looking for deficiencies provided little value because the majority of designs performed as expected. It was discovered that many designs did not always provide maximum value due to excessive costs, over-specifying, and the lack of value for the project.

What Is Value?

For the purposes of value engineering, value does not simply equate to cost reduction. It can be described as the lowest cost to provide the necessary and required products, functions, or services at a chosen time, in a needed place, and with the requisite quality.

For engineering purposes, value can be defined best by the following formula:

$$\text{Value} = \frac{\text{Worth}}{\text{Cost}}$$

Table 11-1 Qualitative Results from the Implementation of Value Engineering

Reason for Change	Percent Total Savings Achieved	Definition of Change
Advances in technology	23	Incorporation of new materials, components, techniques, or processes not available at the time of the previous design effort
Additional design effort	15	Application of additional skills, ideas, and information available but not utilized during previous design effort
Change in user's needs	12	User's modification or redefinition of mission, function, or application of item
Feedback from test/use	4	Design modifications based on user tests or field experience suggesting that specified parameters governing previous design were unrealistic or exaggerated
Questioning specifications	18	User's specifications were examined, questioned, and determined to be inappropriate, out-of-date, or over-specified.
Design deficiencies	4	Prior design proved inadequate in use (e.g., was characterized by inadequate performance, excessive failure rates, or technical deficiency).
Excessive cost	22	Prior design proved technically adequate, but subsequent cost analysis revealed excessive cost.
Other	2	

Source: Directorate of Value Engineering, Office of the Assistant Director of Defense as taken from "Value Engineering Theory & Practice in Industry," Thomas R. King, 2000, Lawrence D. Miles Foundation, Washington, D.C.

In this formula, when value is equal to or greater than 1 (V = 1), it is understood that there is equality of value. As an example, consider the specification of a vacuum pump. The pump is vital to the function of the design. If the pump costs $1,000 and is indeed worth $1,000, then there is equality of value (good value). If the pump is only worth $800 and costs $1,000, then there is imperfect value (poor value). If the pump is worth $1,200 and costs $1,000, then there is increased value (outstanding value).

This brings up the concept of cost and worth. Cost seems straightforward: It's what you pay for a product or service. What is worth? For value engineering purposes, worth is the concept of the value of a function, product, or system. Alternately stated, worth is the least cost to provide the function, product, or service. The concept of value and worth are amorphous; they are not easily measured or defined.

A number of basic questions were developed as part of the concept of value engineering to help determine value and worth. It is important to note that these questions relate to the general nature of value engineering and are relevant for all types of engineering, from construction to manufacturing. They have been modified below to be more specific to construction.

- Are the products, systems, or materials necessary for the functionality of the project, and do they contribute value to the project?
- Are the costs of the products, systems, or materials in proportion to their usefulness within the project?
- Do the designed or specified products, systems, or materials need all of the designated features?
- Will other available products, systems, or materials accomplish the intended use or purpose and provide better performance?
- Are the exact products, systems, or materials available for less?
- Will other available products, systems, or materials accomplish the intended use or purpose at a lower cost?
- Will other available products, systems, or materials accomplish the intended use and purpose with an equal performance?
- Can another dependable supplier provide the products, systems, or materials for less?
- Does the total cost of the products, systems, or materials include all materials, reasonable labor, and overhead?
- Are the products, systems, or materials the proper ones considering the quantity available or manufactured or the quantity that is needed and will be used?

ELEMENTS OF VALUE ENGINEERING

In the world and vernacular of value engineering, a value engineering analysis incorporates a VEJP (value engineering job plan). Because this analysis is in itself an engineering project, the job plan is divided into phases, and the number of phases can vary (see Table 11-2).

It doesn't really matter how many phases are in a VEJP. What is vital is that the engineer is comfortable with all of the phases of the plan and understands the various techniques for each phase's evaluation and analysis and that the plan provides a systematic and consistent approach for implementing the project.

Table 11-2 Value Engineering Job Plan Examples, Job Plan Phases by Noted Practitioners

Miles	Fowler	King	Parker	Mudge	International
Information	Preparation	Information	Information	General	Information
Analysis	Information	Function analysis	Function	Information	Function analysis
Creativity	Analysis	Creative	Creative	Function	Creative
Judgment	Creativity	Evaluation	Judicial	Creation	Evaluation
Development	Synthesis	Implementation	Development	Evaluation	Development
Development		Presentation	Investigation	Presentation	
Presentation		Implementation	Recommendation		
Follow-up		Follow-up			

Source: SAVE International

The following introduction to value engineering integrates the six general phases listed by SAVE International with the five phases from Lawrence E. Mills (considered the father of value engineering) and incorporates the various implementation techniques within each phase.

Phase One: Information

This phase addresses three questions: What is it? What does it do? What does it cost? In practice, this phase describes the project and collects the necessary information, both critical components for the remainder of the value engineering project. Actually, gathering information is pretty straightforward. The hard part is making sure that the information gathered is factual, accurate, unbiased, untainted by opinion, and contains no assumptions.

As every plumbing engineer knows, the hardest part of the project is collecting accurate and factual information. A project can be engineered and designed only according to the quality of the information used. Likewise, value engineering is only as good and accurate as the quality and accuracy of the data and information collected and used throughout the process.

For the plumbing design portion of a facility, the value engineer must follow the design engineer's thinking and collect and assemble the same information used by the design engineer (see Table 11-3). This means detailing every product and design element.

Table 11-3 Information Gathering

ABC Project — Plumbing Design
Project description documents
Original client directions/specifications
Architectural drawings
Engineering drawings
Detail drawings
Materials list
Details of materials examined/considered
Material line information
Product list
Details of products examined/considered
Product line information
Vendor information

Value engineering worksheets come in many variations, but typically they include the basic information form that describes the project and related data such as in Figure 11-1. Additional information forms include each detail of the project or design.

The next phase of the information collection process is to understand the background and purpose of the complete project and each of its elements. This requires developing the right questions or a checklist of items that need to be collected, understood, and used for the remainder of the engineering process. Figure 11-2 is a sample of such a checklist.

As the value engineer collects this information, he needs to keep a detailed record of information sources and types of actions needed or taken. This record provides the forensic trail that will back up the final conclusions. It tracks each stage of the information collection process and provides a reference and source record for the analysis and recommendations. A sample of a source record form is shown in Figure 11-3.

With all of the information and data that has been collected, the engineer still must make a qualitative determination of its value. The following questions can help make that determination.

- Does the information support the definition, specifications, or requirements of the project?

- Does the information seem to be factual and valid for the project or detail being analyzed?
- Is all of the information current and up to date?
- Does the information form an integrated whole? Does each item support the other items?
- Are there any conflicts within the information collected?
- Does the information conform to the expectations of the investigator?
- Is any information suspect? Does some of the information seem to be inaccurate or nonrepresentative of the project or detail?
- Does additional information need to be collected?
- Do the relationships or associations between the information sets require further exploration?
- Is there reason to suspect that any of the information is biased?
- If the information causes concern or creates a restraint to the analysis, can it be verified by more than one source?

Figure 11-1 Sample Value Engineering Worksheet

Value Engineering Consultants
Project Information

Reference Number ____________________ Date ____________________

Name of Project ____

Project Element ____________________ Project Detail ____________________

Detail Name ____

Description ____

____

Detail Location ____

Description ____

____

Detail Number ____________________

Materials List Number ____________________

Product List Number ____________________

Pertinent Information ____

____

Figure 11-1 Sample Value Engineering Worksheet (continued)

Value Engineering Consultants
Project Information

Reference Number ____________ **Date** ____________

Name of Project: ____________

Project Location: ____________
Address ____________
City ____________ State ____________ Zip ____________
Telephone ____________ Fax ____________ e-mail ____________

Owners: ____________
Address ____________
City ____________ State ____________ Zip ____________
Telephone ____________ Fax ____________ e-mail ____________

Developer: ____________
Address ____________
City ____________ State ____________ Zip ____________
Telephone ____________ Fax ____________ e-mail ____________

Architect ____________
Address ____________
City ____________ State ____________ Zip ____________
Telephone ____________ Fax ____________ e-mail ____________

Engineers:
Structural ____________
Address ____________
City ____________ State ____________ Zip ____________
Telephone ____________ Fax ____________ e-mail ____________

Electrical ____________
Address ____________
City ____________ State ____________ Zip ____________
Telephone ____________ Fax ____________ e-mail ____________

Plumbing ____________
Address ____________
City ____________ State ____________ Zip ____________
Telephone ____________ Fax ____________ e-mail ____________

HVAC ____________
Address ____________
City ____________ State ____________ Zip ____________
Telephone ____________ Fax ____________ e-mail ____________

Communications ____________
Address ____________
City ____________ State ____________ Zip ____________
Telephone ____________ Fax ____________ e-mail ____________

Other: ____________
Address ____________
City ____________ State ____________ Zip ____________
Telephone ____________ Fax ____________ e-mail ____________

Figure 11-1 Sample Value Engineering Worksheet (continued)

Value Engineering Consultants
Project Information

Reference Number ________________ **Date** ________________

Contractors:

Structural ____________________
Address ____________________
City ________ State ________ Zip ________
Telephone ________ Fax ________ e-mail ________

Electrical ____________________
Address ____________________
City ________ State ________ Zip ________
Telephone ________ Fax ________ e-mail ________

Plumbing ____________________
Address ____________________
City ________ State ________ Zip ________
Telephone ________ Fax ________ e-mail ________

HVAC ____________________
Address ____________________
City ________ State ________ Zip ________
Telephone ________ Fax ________ e-mail ________

Communications ____________________
Address ____________________
City ________ State ________ Zip ________
Telephone ________ Fax ________ e-mail ________

Other: ____________________
Address ____________________
City ________ State ________ Zip ________
Telephone ________ Fax ________ e-mail ________

Suppliers:

Structural ____________________
Address ____________________
City ________ State ________ Zip ________
Telephone ________ Fax ________ e-mail ________

Electrical ____________________
Address ____________________
City ________ State ________ Zip ________
Telephone ________ Fax ________ e-mail ________

Plumbing ____________________
Address ____________________
City ________ State ________ Zip ________
Telephone ________ Fax ________ e-mail ________

HVAC ____________________
Address ____________________
City ________ State ________ Zip ________
Telephone ________ Fax ________ e-mail ________

Communications ____________________
Address ____________________
City ________ State ________ Zip ________
Telephone ________ Fax ________ e-mail ________

Other: ____________________
Address ____________________
City ________ State ________ Zip ________
Telephone ________ Fax ________ e-mail ________

Figure 11-2 Sample Value Engineering Checklist

Value Engineering Consultants
Project Information Checklist

Reference Number______________________ **Date**______________________

Project Details

1. Detailed Specifications established by user/owner: ______________________
2. Detailed Requirements established by user/owner: ______________________
3. Project Considerations:
   A. Environmental Conditions (before, during, after): ______________________
   B. Physical Space Limitations: ______________________
   C. Desired/Required:
      a. Reliability: ______________________
      b. Serviceability: ______________________
      c. Maintainability: ______________________
      d. Operability: ______________________
4. Prior Experiences/Concerns
   A. History of projects: ______________________
   B. Operation of projects: ______________________
   C. Maintenance of projects: ______________________
5. Anticipated Marke:
   A. Requirements: ______________________
   B. Expected Percentage of Total Market: ______________________
   C. Market Expected to Serve: ______________________
6. Anticipated Life
   A. Of original Built Project: ______________________
   B. Total Life with Rehab: ______________________
7. Project Competitors: ______________________
8. What Liscensing or Permits Need to be Considered: ______________________
9. What are Desired:
   A. Physical requirements: ______________________
   B. Performance Requirements: ______________________
   C. Workmanship Requirements: ______________________
10. Is This Project to be Part of a Larger Project: ______________________
11. What New Developments, Technology, State-of-the-Art Engineering/Design/Materials are Contemplated: ______________________
12. Are There Any Special Processes or Uses for the Project: ______________________
13. Who Is Responsible for Overseeing Purchasing for Overall Project: ______________________
14. Who Is Responsible for Overseeing Contractors for Overall Project: ______________________
15. Anticipated Project Milestones for:
   A. Changes/Modifications: ______________________
   B. Improvements: ______________________

Figure 11-2 Sample Value Engineering Checklist (continued)

Value Engineering Consultants
Project Information Checklist

Reference Number ____________________ **Date** ____________________

Detail/Product/Material Specifations

Detail/Product/Material Description: ____________________

1. Detailed Specifications established by user/owner: ____________________
2. Detailed Requirements established by user/owner: ____________________
3. Detail/Product/Material Considerations
   - A. Environmental Conditions (before, during, after): ____________________
   - B. Physical Space Limitations: ____________________
   - C. Desired/Required:
     - a. Reliability: ____________________
     - b. Serviceability: ____________________
     - c. Maintainability: ____________________
     - d. Operability: ____________________
     - e. Special Features: ____________________
4. Prior Experiences/Concerns With This Detail/Product/Material
   - A. History of Detail/Product/Material: ____________________
   - B. Operation of Detail/Product/Material: ____________________
   - C. Maintenance of Detail/Product/Material: ____________________
   - D. Reasons for Replancement Needs of Detail/Product/Material: ____________________
   - E. Operating Life of Detail/Product/Material: ____________________
5. Anticipated General Market for This Detail/Product/Material
   - A. Requirements: ____________________
   - B. Expected Percentage of Total Market: ____________________
   - C. Market Expected to Serve: ____________________
6. Anticipated Life of Detail/Product/Material: ____________________
7. Detail/Product/Material Competitors: ____________________
8. Are There Any Liscensing or Use Limitations That Need to be Considered: ____________________
9. For the Detail/Product/Material What Are Desired (consider weight, dimensions, tolerances, shock and vibration, facility environment, operation environment, life, performance, appearance.
   - A. Physical Requirements: ____________________
   - B. Performance Requirements: ____________________
   - C. Workmanship Requirements: ____________________
10. Is This Detail/Product/Material to be Part of a Larger Detail/Product/Material: ____________________
11. Is This Detail/Product/Material to be Used in Quantity? If So, Explain: ____________________
12. What New Developments, Technology, State-of-the-Art Engineering/Design/Materials are Contemplated for the Detail/Product/Material: ____________________
13. Are There Any Special Processes or Uses for the Detail/Product/Material: ____________________
14. How Many Suppliers/Manufacturers/ Sources Are There for the Detail/Product/Material: ____________________
15. Who Are the Suppliers/Manufacturers/ Sources for the Detail/Product/Material: ____________________

Figure 11-3 Sample Source Record Form

Value Engineering Consultants
Project Information Checklist

Reference Number________________ Date________________

Information/Data Collector: ________________________________

Source of Information/Data	Information/Data Received	Action Taken

Determine and Collect Costs

Collection of the costs related to the project, detail, or material being analyzed is the next step in the information collection phase. Cost determination quickly can become complex and overwhelming. Suffice to say, the smaller the design element of a project, such as stand-alone products like a pump or water heater, the easier it will be to come to grips with a cost determination. The total value engineering of a facility involves determining costs for all aspects of the development, engineering, design, construction, and commissioning of the project.

For the value engineer, these costs are a measurement tool for the other information that has been collected and a determinant of the economic impact of the item under consideration, and thus a measure for the level of effort that should be applied.

The two primary elements of establishing the cost of a design, product, or material are the material cost and the labor cost. At this juncture, a cost is not the same as an acquisition price. Cost determination becomes complicated by economic forces applied throughout the project life-cycle. There are project costs, development costs, product, assembly, and material costs, labor costs, overhead costs, and, of course, a markup for profit.

All of the costs associated with a project need to be determined. Furthermore, they need to be segregated into actual and estimated, and a record must be kept of the original source of the information.

What Is Cost?

Value engineering focuses primarily on the term *cost*. However, as noted earlier, cost can mean different things to different people and for different reasons. The first important law is that, in most instances, cost and price are not synonymous. Consider cost to be the valuation of labor, time, and other resources used to achieve the end result. A price is a fixed sum for a given item or service that results in the transfer of ownership of the product or service. The difference between cost and price is often nothing more than perception—for instance, whether you are the buyer or the seller. For example, the cost of the product for the seller is included in the price to the buyer. On the other hand, the price to the buyer may be the cost, and additional value will be added to determine a new and different price.

In value engineering, the primary element is cost. Of course, to complicate matters, there are product and producer costs and total cost to a user. For most facility projects, both of these cost structures will be part of the analysis.

Three costs are involved with any project, design, or material: major or prime costs, overhead costs, and the cost of goods. The best way to describe this is with a simple diagram (see Figure 11-4).

In the facility business there may be myriad levels of purchasers, from the owner to the developer to the architect to the engineer to the contractor. Therefore, the cost structure actually becomes a pyramid of costs and prices with different users along each link in the project chain. Figure 11-5 gives a generalization of the cost makeup for each user at the different stages of the facility project process.

A wide variety of costs goes into each element and aspect of a facility. These costs are divided into ongoing costs and one-

Figure 11-5 Cost Makeup for Users

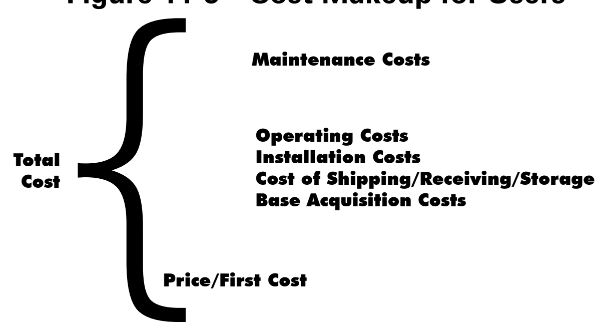
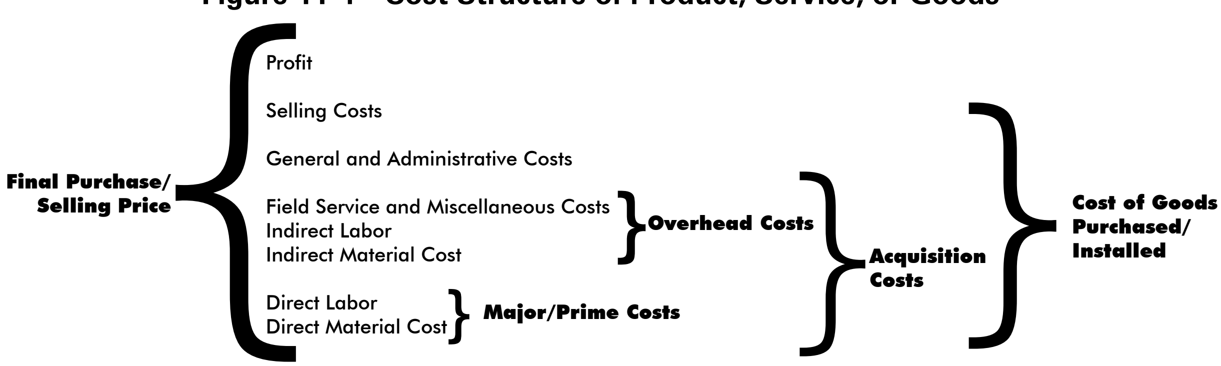


Figure 11-4 Cost Structure of Product, Service, or Goods



time costs. Ongoing costs are those that occur throughout the life of the project. The owner has one set of ongoing costs, while each product, service, or material provider has its own ongoing cost structure. Likewise, there are one-time costs for all of these providers. Table 11-4 offers an example of the differing cost elements that not only comprise the cost of a total project, but also are considered at each stage of the project process.

With all of the costs collected and detailed, the analysis can proceed. The next step is to relate all of the costs to each other, define relationships, and establish which of the costs are related to the specifications for the project and which are imposed requirements. Costs associated with specifications are those imposed by the owner, developer, or user of the facility. These costs can be connected to the land, construction limitations, or user-defined needs. Required costs are those that different vendors, project managers, and contractors impose on the project due to their experience and knowledge. They are the expert costs that form the basis for the creation of the facility.

The value engineer's job is to discover and understand all of these different potential costs. Then, as part of the analysis, the engineer must differentiate between costs that are real (those based on specifications, available information, and condition) and those that are imaginary (skewed by bias, attitudes, habits, lack of information, old technology, lack of ideas and creativity, and temporary conditions).

Table 11-4 Cost Breakdown Checklist

Ongoing Costs	One-Time Costs
Labor	Labor
Administration, management, and operations	Engineering
Ongoing staffing	Design
Technical support	Drafting and review
Field services	Production planning and engineering
Quality control	Procurement
Administrative support	Development
Documentation (in-house)	Testing and review
Inspections	Field engineering
Purchase orders and paperwork	Training
Reports: producing, receiving, and sending	Administrative support services
Documentations	Documentation
Certifications	Licensing, permits, and inspections
Training	Purchase orders and paperwork
Product/Services/Materials	Reports: producing, receiving, and sending
Basic materials	Documentation
Subcontracts	Handbooks and user manuals
Intercompany effort	Certifications and inspections
Administration and operations (i.e., reproduction)	***Product/Services/Materials***
Indirect supplies, services, and materials	Products, supplies, and materials
Other and General	Special tools
Travel	Special equipment (i.e., test equipment)
Equipment rental	Administration and operations (i.e., reproduction)
Contracted services	Change orders, modifications, and corrections
Shipping and freight	***Other and General***
	Travel
	Equipment rental
	Contracted services
	Shipping and freight
	Disposition of equipment and materials

Value engineering has come about because users inevitably overestimate their needs and have unrealistic expectations. This is compounded by those involved in a facility project who often over-engineer and over-design at the beginning of the project due to the unrealistic expectations and overestimates of the owner or user. The value engineer must bring expectations, estimates, and reality into focus.

The Pareto Principle

Vilfredo Pareto developed an economic theory regarding the distribution of wealth. This principle has found its way into many disciplines of engineering—especially value engineering, where the principle is better known as the 80/20 rule. In its original form, Pareto stated that 80 percent of all wealth is held by just 20 percent of all people. This 80/20 principle has been applied to everything from manufacturing to construction to engineering principles. In this chapter's context, it states that 80 percent of a facility's costs are associated with just 20 percent of its components. It is very useful when examining the resources available for a project and focusing on those that will provide the largest economic benefit and result in the highest level of return for the expended effort.

Phase Two: Analysis and Function Analysis

The questions "What does it do?" and "What is it supposed to do?" continue to be addressed in this phase and concisely sum up this concept. In this phase, the engineer needs to identify the functions of the project. The analysis and function phase often is considered the heart of value engineering because in this phase, the engineer has a methodology to reestablish the original project or element needs into simple, workable expressions.

For example, in value engineering the accepted definitions for function are that which makes a product work or sell and that which satisfies the needs or requirements of the user. However, it is not that simple.

The difficulty in this phase is the translation and giving of substance to the words used for project or element specifications and requirements. An engineering discipline has taken these words, brought them to life, and provided a visual interpretation. The value engineer now must examine those same words and provide a structured evaluation and analysis of them, which results in a functional analysis and/or definitions.

Rules of a Functional Analysis

Three rules are generally accepted for conducting a functional analysis or creating functional definitions.

Rule 1: The expression of all functions must be accomplished using two words: an active verb and a descriptive or measurable noun. Table 11-5 offers a sample listing of verbs and nouns typically used in value engineering functional definitions. Rule 1 is based on the adage that less is more. If you cannot provide a definition of a function in two words, either you do not have enough information about the project or element or the item has not yet been defined in its simplest form. By being limited to two words, you will be able to describe the simplest element of the project in a manner that reduces the potential for miscommunication or misunderstanding.

Table 11-5 Function Definition Verbs and Nouns

Active Verbs	Measurable Nouns
Desirable Apply, amplify, attract, change, collect, conduct, control, create, emit, enclose, establish, filter, hold, induce, impede, insulate, interrupt, modulate, prevent, protect, rectify, reduce, repel, shield, support, transmit ***Less Desirable*** Provide	***Desirable*** Contamination, current, density, energy, flow, fluid, force, friction, heat, insulation, light, liquid, load, oxidation, protection, radiation, torque, voltage, weight ***Less Desirable*** Article, circuit, component, damage, device, part, repair, table, wire
Passive Verbs	**Non-measurable Nouns**
Desirable Create, decrease, establish, improve, increase	***Desirable*** Appearance, beauty, convenience, costs, exchange, features, style ***Less Desirable*** Effect, form, loops, symmetry

Rule 2: All functional definitions can be divided into one of two levels of importance: work or appearance or selling. Work functions are expressed in action verbs and descriptive or measurable nouns that establish a quantitative statement for the item. Appearance or sell functions are expressed in passive verbs and in general or non-measurable nouns that describe a qualitative statement for the item. Rule 2 provides meaning to the descriptive terms of rule 1. The definitions here are designed to amplify the meanings of the function under consideration. If the function cannot be described with action or active verbs, the functionality of the element is questionable. If there is no action, then nothing is being accomplished; thus, the function has no end result or usefulness. By using measurable nouns, the evaluating engineer can establish a cost-to-function relationship. These nouns provide a quantitative measure to the function and, therefore, provide a measurable level of usefulness for the function.

Why have appearance or sell factors if they do not provide any quantifiable or measurable attribute? First, having appearance or sell factors involved in the function that can be separated out helps in the assignment of some proportionate amount of the element's cost. Second, by identifying these function descriptors, the engineer is providing a further description of the specifications and requirements of the function. This helps the owner in the final decision process regarding the function. While the value engineer may find an equal element at a lower cost, the non-quantifiable part of the requirements may be an overriding consideration. For instance, while a basic white porcelain bowl may be less expensive, the use of a special color porcelain bowl may be an important and overriding appearance or selling requirement.

Rule 3: All functional definitions also can be divided into one of two descriptive uses: basic or secondary. A basic function is one that describes the primary purpose for a product, system, or material. Secondary functions are all other functions of the product, system, or material that do not directly accomplish the primary purpose, but support

Figure 11-6 Sample Functional Analysis Form

Value Engineering Consultants
Functional Definition and Analysis

Reference Number ______________ Date ______________

Detail/Product/Material Specification: Pencil

Function: Make Marks

Description (e.g., part number): ______________

Qty	Item Description	FUNCTIONS * VERB	NOUN	B	S	W	AP SL	Cost per Function (Estimate)	Label Function V = Vital E = Essential N = Nice to Have	Notes/ Comments
1	Eraser	Remove	Marks		X	X				
1	Band	Secure	Eraser		X					
		Improve	Appearance		X					
1	Body	Support	Lead	X						
		Transmit	Force	X						
		Accommodate	Grip							
		Display	Info							
1	Paint	Protect	Wood							
		Improve	Appearance		X					
1	Lead	Make	Marks	X						

Note: B - Basic
S - Secondary
W - Work
AP/SL - Appearance/Self

the primary purpose or are the result of a specific engineering or design approach. In functional analysis, the secondary functions are the ones that can be combined, modified, or eliminated. This rule further enhances the ability to assign a relative importance to the function. For a majority of projects, products, or materials, only one basic function can be derived. In those rare cases when more than one basic function is stated, usually it is just a restatement of the original basic function. Secondary functions tend to fall into two categories: specific and dependent. Specific functionality requires a specific action to be accomplished. Dependent functionality refers to functions that require some prior action before they can be performed. Secondary functions can exist because they are part of the specifications or requirements or because they are inherent to the engineering or design approach used.

Function Definitions

With all of the rules in place and understood, the value engineer begins the function analysis. Figure 11-6 shows a sample of the type of form that helps in this phase. The form is straightforward and, given all of the definitions and explanations supplied, should be self-evident. The most important part of this phase is to define the function or the element under analysis and create its functional definitions.

Figure 11-6 Sample Functional Analysis Form (continued)

Example 1: Expansion Chamber

Qty	Item Description	FUNCTIONS *						Cost per Function (Estimate)	Label Function V = Vital E = Essential N = Nice to Have	Notes/ Comments
		VERB	NOUN	B	S	W	AP SL			
1	Expansion Tank	Contain	Liquid	X						
		Provide	Pressure	X						

Example 2: Wall Box

Qty	Item Description	FUNCTIONS *						Cost per Function (Estimate)	Label Function V = Vital E = Essential N = Nice to Have	Notes/ Comments
		VERB	NOUN	B	S	W	AP SL			
1	Wall Box	Confine	Material	X						
		Store	Material		X					
		Protect	Inside		X					
		Protect	Material	X						
		Prevent	Loss		X					
		Enhance	Appearance		X					
		Establish	Privacy		X					

The pencil form in Figure 11-6 is considered one of the quintessential examples in value engineering analysis for explaining the use of two-word definitions. The pencil is an everyday object that requires a successive and seemingly unnecessary number of items to define it and all of its elements. However, this remains the crux of the value engineering definition phase. The expansion tank form in Figure 11-6 provides an example that could be used to evaluate a product used in plumbing engineering. However, as should be obvious, in both examples the emphasis of the value engineering is in the manufacture of the item and is not related to its role in a construction project.

Only a portion of the form in Figure 11-6 is filled out at this early stage of the analysis process. At a minimum and if necessary, the function and its elements are defined. At this stage, only basic and secondary indicators are marked. The remaining portion of the form will become part of the evaluation phase.

FAST

A second approach is an adjunct to, and works in tandem with, functional definition analysis. This approach is known as FAST, which stands for Functional Analysis System Technique. The FAST process is essentially a diagramming process. With diagramming, a visual representation is created that highlights the functions of a product, system, or material and the interrelations between them.

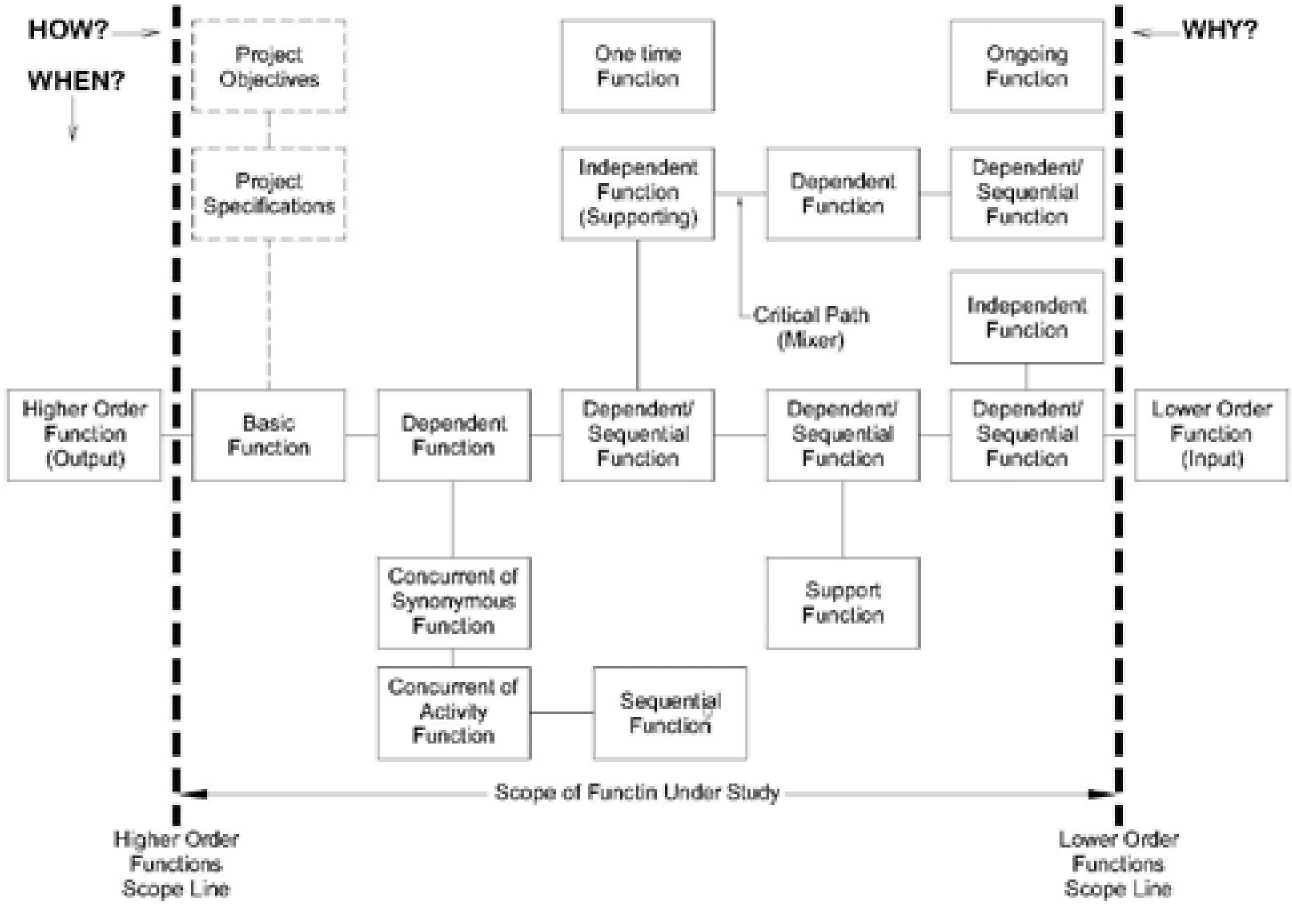
A basic FAST model diagram is shown in Figure 11-7. The FAST model is a building process that will:

- Help avoid a random listing of functions. Functional analysis requires the use of verb-noun definitions. The FAST diagram helps sort out the functions and show interrelationships.
- Help find any missing functions.
- Aid in identifying the basic function and understanding the secondary functions.
- Provide visualization and a better understanding of the product, system, or material under study.
- Result in a team consensus in defining the product, system, or material under study.
- Provide a test of the functions utilizing system analysis and determinate logic.
- Demonstrate that the team approach has fully analyzed the elements.

The parts of FAST shown in Figure 11-7 are as follows.

- Scope lines: The two vertical dotted lines provide a boundary to the function under study. That part of the function is of concern.
- Highest order function: The object or output side of the basic function under study is referred to as the highest order function. Additional functions to the left of another on the critical path are higher order functions.
- Lower order function: Functions to the right of another function on the critical path are a lower order function. This doesn't imply a relative importance or ranking of these functions. Rather, the lower functions are those necessary to successfully perform the basic or higher order function.
- Basic function: This is the function under study, which cannot change.
- Objectives and specifications: These are the parameters and requirements that must be achieved for the function to perform as needed in its operational place in the project. Objectives and specifications are not themselves functions; they influence the selection of lower order functions.
- Critical path functions: Any function that is on the how or why logic path is a critical path function. If the function is on the why path, it is considered a major critical path. Otherwise, like the independent supporting functions or the dependent functions, it becomes a minor critical path item. Supporting functions tend to be of secondary value and exist to meet the performance requirements specified in the objectives and specifications.
- Dependent or sequential functions: To exist, functions to the right of the basic function are dependent on the functions to their left and require one to be completed before they enter as a performance requirement.
- Independent functions: These functions are above or below the critical path line and are necessary to satisfy the when question in relationship to the main or basic function.
- Independent (supporting) functions: These functions do not depend on another function as does a dependent or sequential function. However, they still are considered secondary functions to the basic function and the major critical path.

Figure 11-7 Basic FAST Model Diagram



- Function: The end event or purpose of the product, system, or material under analysis. It first must be expressed in a verb-noun form.
- Activity: The method selected to perform a function.

For engineers familiar with systems-type diagramming, it would appear that the FAST diagram is backward. As an example, consider the position of the why part of the function. For systems analysis, it is on the left, but for FAST, the how function is in the left position and dominates the analysis. In this position, all of the functions and activities to the right are dependent on the basic function or moving toward the why of the function.

Figure 11-8 diagrams the how, why, and when relationship, relates it to the FAST diagram, and shows a simple how functional relationship.

As it turns out, in the team environment the FAST model, while a means to an end, is not the vital part of this process. The vital part is the dialogue and discussions between the team members as the model is formulated and built. The process of identification—functions, questions, justifications, and relationships—is the key to the structure of the function analysis and provides the team with a methodology to produce a desired result. In fact, once the model is created, its only purpose remains as an explanatory, rationale, and communication to the decision-makers and other engineering disciplines.

It would seem to be intuitive that the next step should be evaluation and cost determination, but in value engineering the next phase is creativity.

Phase Three: Creativity

The creative process evaluates the project with an emphasis on the following question: What else will do the job? The creative part of the value engineering process is best summed by the trite expression, "Start with a clean sheet of pa-

Figure 11-8 Simple How Functional Relationship

Value Engineering Consultants
Functional Definition and Analysis

Reference Number ____________________ Date ____________________

Detail/Product/Material Specification: Pencil

Function: Make Marks

Description (e.g., part number): ____________________

Qty	Item Description	FUNCTIONS *						Cost per Function (Estimate)	Label Function V = Vital E = Essential N = Nice to Have	Notes/ Comments
		VERB	NOUN	B	S	W	AP SL			
1	Eraser	Remove	Marks		X	X				
1	Band	Secure	Eraser		X					
		Improve	Appearance		X					
1	Body	Support	Lead	X						
		Transmit	Force	X						
		Accommodate	Grip							
		Display	Info							
1	Paint	Protect	Wood							
		Improve	Appearance		X					
1	Lead	Make	Marks	X						

Note: B - Basic
S - Secondary
W - Work
AP/SL - Appearance/Self

per." Again, this phase requires a team approach to engineering disciplines. In the creativity phase, the team needs to separate itself from all of the previous phases. The team needs to leave the drawings, information, forms, and models behind and find a fresh environment in which to reassemble. In this creativity environment, the two-word, verb-noun functions describe a single product, system, or material being analyzed.

Creative Thinking Personified

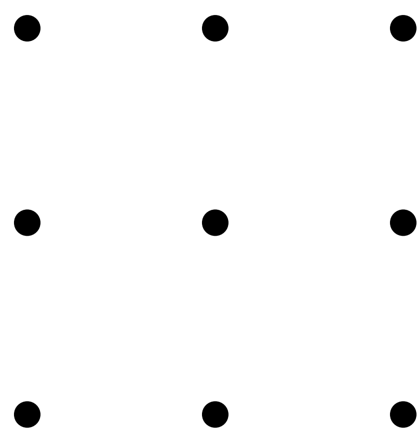
Positive creative thinking can be described by the invention of the cotton gin. Eli Whitney was trying to find a way to remove seed from raw cotton. One afternoon, on a walk, he noticed a cat trying to catch a chicken through a wire fence. The cat's claw would stick through the fence whenever a chicken came close, but all that came through the fence on the cat's claw was feathers. This observation provided the creative incentive. Whitney conceived the concept of pulling the cotton (feathers) though a comb (fence). It was a subtle difference to all thinking that went before. Instead of trying to remove seeds from the cotton by pulling on the seeds, Whitney's solution was to pull the cotton away from the seeds.

Inflexibility

An illustration of inflexible thinking is an innovation that to this day remains a worldwide standard despite its outmoded purpose: the computer keyboard configured in the QWERTY style. This style was an innovation of Christopher Sholes, who invented the typewriter. Due to the mechanics of the typewriter and the fact that gravity was the engine to move the keys back into position, Sholes found that fast typists quickly created key jambs as they stroked faster than the keys could clear each other and return to rest. Through persistence and experimentation, he developed a keyboard layout that separated the most often used letter keys and thereby slowed down the typing process. Today, that same slow-down mentality continues with the modern computer keyboard, despite other layouts such as the Dvorak Simplified Keyboard, which produces faster results. Ingrained habit is hard to overcome.

Roadblocks to Creativity

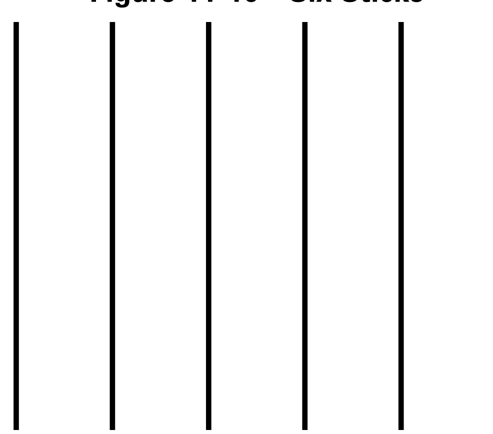
Figure 11-9 Nine Dots



Creativity takes work, hard work. Of course, as an alternative to providing the creativity phase in value engineering, the engineer can fall back on one of the following top 10 reasons why value engineering should not be used at this time, adapted from *Value Management* by the U.S. General Services Administration.

1. It isn't in the budget.
2. We don't have the time.
3. Let's form a committee.
4. Has anyone else tried it on this type of project?
5. Why change it? It's always worked perfectly before.
6. We tried that before.
7. The developers will never buy into it.
8. You're years ahead of your time.
9. Let's shelve it for the time being.
10. It is against company policy.

Figure 11-10 Six Sticks



Divergent Thinking

Creativity in value engineering is best described as speculation and brainstorming. An all-too-often overused and trite phrase "thinking outside the box" is an attempt to describe divergent thinking.

What is outside-the-box thinking? One example is the nine dots (see Figure 11-9). First, draw nine dots in the form of a square on a piece of paper as shown. Next, without lifting your pencil from the paper, draw four straight, connected lines that go through all nine dots. You may not backtrack on a line, and each line must go through each dot only once. See the end of this chapter for the solution.

Another example is the six sticks (see Figure 11-10). Use six sticks (toothpicks, straightened paperclips, matchsticks, etc.) of equal length and arrange the sticks to make four equilateral triangles. The ends of each stick must touch each other. As engineers, we all know that an equilateral triangle has three sides of the same length. See the end of this chapter for the solution.

Finding Solutions

In this phase, the team is not trying to find solutions, only ideas. The brainstorming or speculative process consists of two techniques: unassisted creativity and assisted creativity.

With unassisted creativity, one team member takes the creativity worksheet (see Figure 11-11) and is assigned one two-word definition for one of the functions. The individual lists every possible idea he or she has regarding that function, such as "create seal." Once the individual has put down their ideas, the worksheet is moved to another team member who then adds his own ideas. The sheet is passed to each team member in turn.

Figure 11-11 Creativity Worksheet

Value Engineering Consultants
Creativity Worksheet

Reference Number__________ Date__________

Function ____________________

1.	31.	61.
2.	32.	62.
3.	33.	63.
4.	34.	64.
5.	35.	65.
6.	36.	66.
7.	37.	67.
8.	38.	68.
9.	39.	69.
10.	40.	70.
11.	41.	71.
12.	42.	72.
13.	43.	73.
14.	44.	74.
15.	45.	75.
16.	46.	76.
17.	47.	77.
18.	48.	78.
19.	49.	79.
20.	50.	80.
21.	51.	81.
22.	52.	82.
23.	53.	83.
24.	54.	84.
25.	55.	85.
26.	56.	86.
27.	57.	87.
28.	58.	88.
29.	59.	89.
30.	60.	90.

The second step, assisted creativity, is nothing more than a group exercise in which each participant hitchhikes on each other's ideas to create yet another new idea. To get started, the team splits into three parts: one group has the worksheet for one of the two-word function definitions, one group has a set of idea generators, or checklists to help the thinking, and the third group has reference sources such as a dictionary and thesaurus. As one sub-team reads the list, the second finds new words and ideas using the alphabet concept (take a word and think of another word with a different starting letter) and the dictionary, while the third works the checklists, continually questioning all of the thought processes. Two sample checklists are shown in Table 11-6A and Table 11-6B.

Table 11-6A Creativity Checklist	Table 11-6B Creativity Checklist
How much of this is the result of custom, tradition, or opinions? Why does it have this shape? How would I design it if I had to build it in my home workshop? What if this were turned inside out? Reversed? Upside down? What if this were larger? Higher? Wider? Thicker? Lower? Longer? What else can it be made to do? Suppose this were left out? How can it be done piecemeal? How can it appeal to the senses? How about extra value? Can this be multiplied? What if this were blown up? What if this were carried to extremes? How can this be made more compact? Would this be better symmetrical or asymmetrical? In what form could this be: liquid, powder, paste, or solid? Rod, tube, triangle, cube, or sphere? Can motion be added to it? Will it be better standing still? What other layout might be better? Can cause and effect be reversed? Is one possibly the other? Should it be put on the other end or in the middle? Should it slide instead of rotate? Demonstrate or describe it by what it isn't. Has a search been made of the patent literature? Trade journals? Could a vendor supply this for less? How could this be made easier to use? Can it be made safer? How could this be changed for quicker assembly? What other materials would do this job? What is similar to this but costs less? Why? What if it were made lighter or faster? What motion or power is wasted? Could the package be used for something afterward? If all specifications could be forgotten, how else could the basic function be accomplished? Could these be made to meet specifications? How do competitors solve problems similar to this?	***1. Can the dimensions be changed?*** Border, converge, deeper, delineate, encircle, intervene, invert (reverse), larger, longer, make slanted or parallel, more shallow, place horizontally, shorter, smaller, stand vertically, stratify, thicker, thinner, use crosswise ***2. Can the quantity be changed?*** Add something, combine with something, complete, fractionate, join something, less, more ***3. Can the order be changed?*** Arrangement, assembly or disassembly, beginning, focus, precedence ***4. Can the time element be changed?*** Alternated, anticipated, chronologized, faster, longer, perpetuated, recurrence, renewed, shorter, slower, synchronized ***5. Can the cause or effect be changed?*** Altered, counteracted, destroyed, energized, influenced, louder, softer, strengthened, stimulated ***6. Can there be a change in character?*** Add color, altered, change color, cheaper, interchanged, more expensive, resilient, reversed, stabilized, stronger, substituted, weaker, uniformity ***7. Can the form be changed?*** Accidents avoided, conformation, curved, damage avoided, delays avoided, harder, irregular, notched, regular, rougher, smoother, something added, softer, straight, symmetrical, theft avoided ***8. Can the motion be changed?*** Admitted, animated, agitated, attracted, barred, deviated, directed, lifted, lowered, oscillated, repelled, rotated, slowed, speeded, stilled ***9. Can the state or condition be changed?*** Abraded, coagulated, colder, disposable, drier, effervesced, elasticized, harden, heavier, hotter, incorporated, insulated, lighter, liquefied, lubricated, open or closed, parted, preformed, pulverized, resistant, soften, solidified, vaporized, wetter ***10. Can the use be adapted to a new market?*** Children, elderly, foreigners, men, physically challenged

During this process, a strong individual's habit of being judgmental must be abated. To do this, the group should decide beforehand how to indicate that someone is being judgmental and thus can modify the behavior (e.g., slapping the table with a palm).

The three sub-teams switch roles from time to time until they reach the point of stagnation and agree that they are finished. The team by now has created a unique creative list of new and old ideas for each function under study. A possible result of this team effort for the two-word function "create seal" is shown in Figure 11-12.

After the creative process, it becomes time for the evaluation phase.

Phase Four: Evaluation

The evaluation phase is a continuation of the creativity phase. It deals with a combination of appraisal, judgment, and selection to the qualitative and quantitative criteria and ideas developed for each function. In this phase, the team goes from divergent thinking to convergent thinking. Divergent thinking is problem identification and fact finding, and convergent thinking is a mixing of appraisal, evaluation, judgment, selection, development, and implementation.

This phase results in workable and meritorious alternatives. The introduction of appraisal, evaluation, and judgment eliminates or reduces unnecessary costs and creates a preferred recommendation or course of action. However, in this phase it is easy to impart a cost-reduction spiral that does not result in value engineering, but in simple cost

Figure 11-12 Sample Creativity Worksheet

Value Engineering Consultants
Creativity Worksheet

Reference Number ____________ Date ____________

Function: Create Seal

1. PAINT	31. SPIGOT	61.
2. RUBBER	32. LABYRINTH	62.
3. RING	33. WATER	63.
4. FLUID	34. BIMETAL	64.
5. DRIED BLOOD	35. CORK	65.
6. VARNISH	36. FLANGE	66.
7. GLUE	37. PAPER	67.
8. PLASTIC	38. ROD	68.
9. EPOXY	39. FOAM PLASTIC	69.
10. WAX	40. STOPPER	70.
11. PITCH	41.	71.
12. CHROME	42.	72.
13. WELD	43.	73.
14. RIVET	44.	74.
15. FIT	45.	75.
16. WASHER	46.	76.
17. SOAP	47.	77.
18. GASKET	48.	78.
19. LEATHER	49.	79.
20. GREASE	50.	80.
21. AIR	51.	81.
22. HEAT	52.	82.
23. FREEZE	53.	83.
24. COMPRESS	54.	84.
25. EXPAND	55.	85.
26. BRAZE	56.	86.
27. PLATE	57.	87.
28. SOLDER	58.	88.
29. GLASS	59.	89.
30. VACUUM	60.	90.

reductions for budgetary reasons. It also is easy to degrade the product, system, or material by reducing its quality, reliability, or maintainability.

Although the evaluation phase is shown as distinct from the development and investigation phase, in many cases the two phases often overlap. The value engineering team must decide how many phases are needed and what to do when.

Refining, Combining, and Evaluating by Comparison

Idea generation is a dynamic process that doesn't really ever stop. The creative thought process is an ongoing series of judgments and evaluations. In the evaluation phase, ideas that seem unusable may be combined with other ideas to create a better solution. Some ideas will stand out as preferred solutions, while others may be found to be lacking information. No idea should be discarded out of hand, for whatever reason. All ideas have some merit, which is not always immediately obvious.

To get started, the team should use a worksheet to list the advantages and disadvantages of each function or idea that is an offshoot of a function. Figure 11-13 shows a sample of such a worksheet. The essence of this step is to be sure that no good ideas are overlooked and that no efforts are misdirected. As the functions and ideas are refined, combined, and evaluated, it is important to be evaluating the time required to develop alternatives versus any potential gain. The gain is, of course, improvements in quality, maintainability, and reliability, as well as cost advantages. Similarly, any immediately perceived disadvantages may, with a little thought and creativity, be turned into advantages.

Cost Analysis and Evaluation

This step also is integrated into the development and investigation phase. In this initial evaluation step, a new worksheet is used to first draw a sketch of the function item being evaluated and then prepare a basic cost basis. Figure 11-14 shows the basic worksheets with the information included.

In the sketch step, all that is needed is a simple freehand drawing that incorporates all of the essential items. With this parameter clearly defined and set, fewer tangential discussions and considerations will occur.

Using the simple concept of the wall box, in this phase the requirement may be for an off-the-shelf unit supplied out of a catalogue. In the next phase, development and investigation, the team will be expanded, and a second review and evaluation will be made that integrates advantages and disadvantages and cost savings.

In this evaluation phase, everything from quantity purchases to custom-designed and manufactured items should be taken into account. The value engineering team is establishing the first benchmarks of the functional and cost analysis, examining any secondary functions that should or can be considered, and ensuring that all of the project's parameters have been met. The team must answer many questions:

- Are all of the specifications and requirements being met?
- Does the plan account for all of the two-word function definitions?
- Are all functions and needs being met?
- Can any duplication of effort or definitions be eliminated, thus reducing costs?

Incorporating the Functional Definitions

In the information phase, the functional definitions worksheet was initialized. The evaluation phase provides the information necessary to complete the final four sections of the worksheet: the work vs. appearance evaluation, estimated cost, importance valuation of each element, and any notes or comments. The first step is to evaluate and compare the functional relationships and create a numerical weighting of the functions. This numerical weighting will provide a basis for determining value or the functions' levels of importance, as well as the magnitude of importance. To create a numerical evaluation, a functional evaluation worksheet will be utilized as shown in Figure 11-15.

To start, use the function definition and analysis worksheet (Figure 11-15A) for the detail, product, or material. Continuing the wall box example, the worksheet identifies eight functions for the wall box and lists them in order. This simply provides a list order for the items with appropriate alphabetic identification.

Comparison of Functions

The value engineering team must know and compare each function with every other function. Starting with the function delineated as A, or "confine materials," it is compared to function B, "store materials." "Confine materials"

Figure 11-13 Sample Idea and Function Evaluation Form

Value Engineering Consultants
Idea and Fuction Evaluation

Reference Number ____________ Date ____________

Team: ____________

Detail/Production/Material Specification: ____________

Function: Wall Box: Confine and Secure Material

Description (e.g., part number): ____________

IDEA FROM FUNCTIONAL DEVELOPMENT	ADVANTAGES	DISADVANTAGES
Provide 2' by 2' 10 gauge polished aluminum wall box to confine and secure on/off regulator valve for hot water for each fixture in each bathroom.	1. Secures and Hides Valves	1. Hides Valves
	2. Provides Protection of Material.	2. Not Easily visible in Emergency
	3. Gives Better Appearance than Plain View	3. Requires identification on outside of box
	4. Quality Look and finish.	4. Requires Secure latching Mechanism.
		5. Requires access to latch key or opening mechanism
		6. Additional cost to install.

Plan(s)/Action(s) on Idea(s)

Figure 11-14 Sample Functional Development Sketch Form

Value Engineering Consultants
Functional Development Sketch

Reference Number ____________ **Date** ____________

Team: ____________

Detail/Production/Material Specification: ____________

Function: Wall Box

Description (e.g., part number): Standard Wall Box:
ABC Manufacturer
Model Number 123456-A
Size 2' X 2'

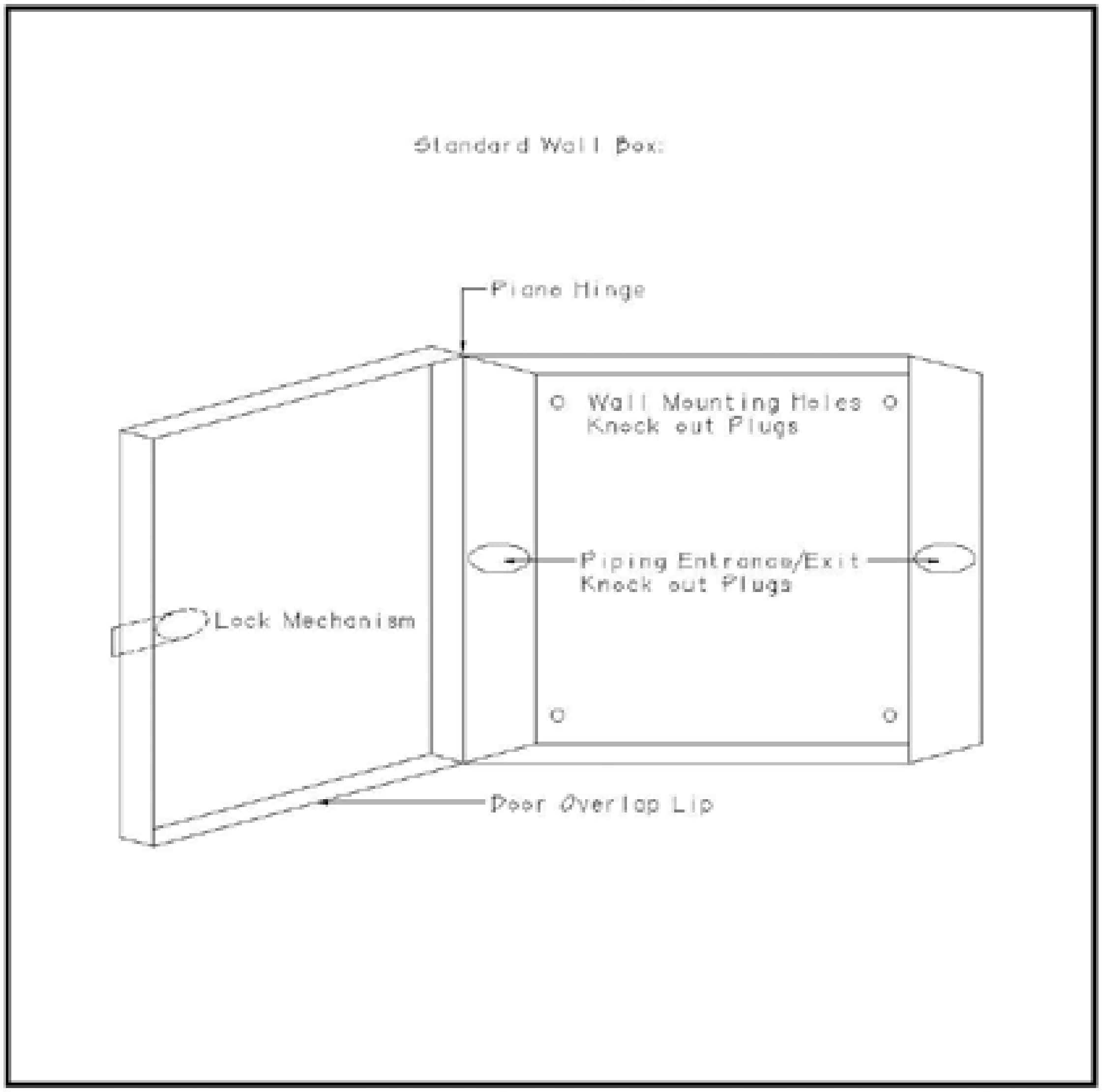


Figure 11-14 Sample Functional Development Sketch Form (continued)

Value Engineering Consultants
Functional Development
Idea Development and Estimated Cost

Reference Number ____________ Date ____________

Team: ____________

Detail/Production/Material Specification: ____________

Function: Wall Box

Description (e.g., part number): Standard Wall Box:
ABC Manufacturer
Model Number 123456-A
Size 2" X 2"

FUNCTION	CREATIVE IDEA(S) & DEVELOPMENT	ESTIMATED COST	CUMULATIVE ESTIMATED COST
Standard Wall Box	Standard ABC Manufacturer Catalogue Wall Box	$12.75	$12.75
		TOTAL	$12.75

Cost Summary

Material & Material Burden	$ ____________
Direct Labor	$ ____________
Direct Labor Burden	$ ____________

Figure 11-15A Example Functional Evaluation

Value Engineering Consultants
Functional Evaluation - Part 1

Reference Number________________ Date________________

Detail/Production/Material Specification: Wall Box

Function: ________________

Description (e.g., part number): ________________

EVALUATION SUMMARY

LIST ORDER	FUNCTIONS	WEIGHT
A	Confine Material	
B	Store Material	
C	Protect Material	
D	Protect Material	
E	Prevent Loss	
F	Enhance Appearance	
G	Establish Privacy	
H		
I		
J		
K		
L		
M		
N		
O		
P		
Q		
R		
S		
T		
U		
V		
W		
X		
Y		
Z		

Figure 11-15B Example Functional Evaluation

Value Engineering Consultants
Functional Evaluation - Part 2

Reference Number ______________________ Date ______________________

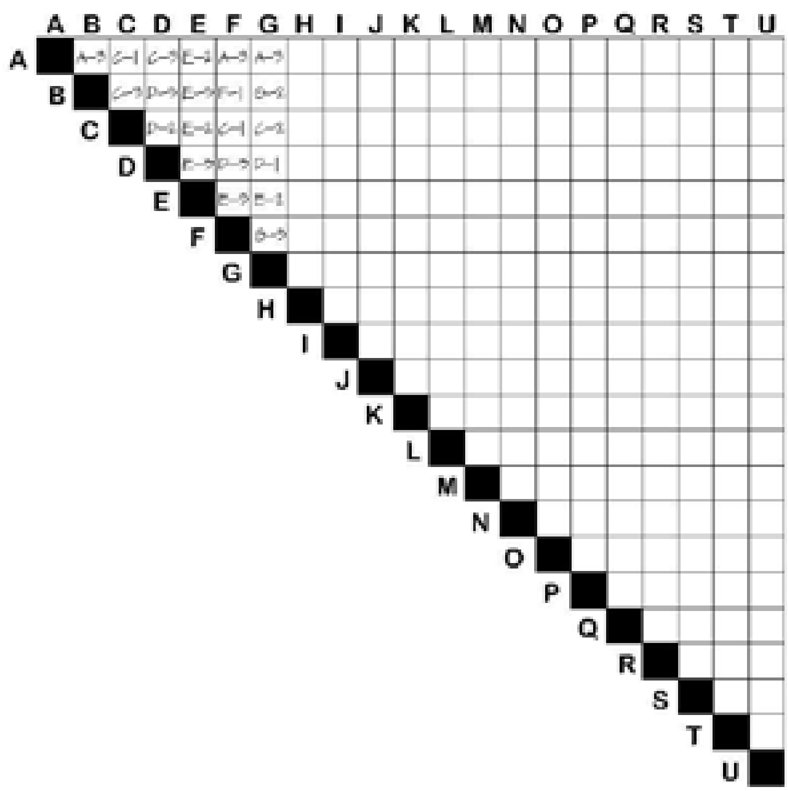
Detail/Production/Material Specification: Wall Box

Function: ______________________

Description (e.g., part number): ______________________

Numerical Evaluation

Weight Factors
- 1 = Nice to Have - Minor Importance
- 2 = Essential - Medium Importance
- 3 = Vital - Major Importance



is determined to be more important than "store materials" and thus is accorded a listing of A in the A line under the B listing in Part 2 of the worksheet (Figure 11-15B).

At the same time that the relative importance is being determined, the magnitude of the importance also must be established. The numerical weights provided in Part 2 are used to establish this importance difference. As seen, "confine materials" is rated to be of major importance when compared to "store materials."

Each of the remaining functions are evaluated and analyzed in a similar manner in relationship to all of the functions below it, as shown in Figure 11-15B.

With the evaluation and analysis complete, Figure 11-15C shows that the functions in order of importance are:

- Prevent loss: 15
- Protect inside: 10
- Confine materials: 9
- Protect materials: 9
- Establish privacy: 5
- Enhance appearance: 1
- Store materials: 0

From this analysis, the value engineering team would declare the "prevent loss" function to be the basic function. The final weighted list shows the relative importance of each of the functions to each other and to the project.

With this information, the function definition and analysis worksheet can be completed as shown in Figure 11-16. Note that the basic and secondary functions have been redefined based on the evaluation, and the team can now determine which of the elements are vital, essential, or just nice to have.

This analysis would continue to examine each of the system functions in relationship to the others and would, in turn, create a weighted evaluation of each of the separate products, systems, or materials for the overall project being examined.

The Pencil: Another Look

An alternative evaluation and analysis could be constructed by establishing idea criteria using a qualitative approach. In this method, each of the items of the function can be evaluated in the reverse of the function definitions, using prescriptive connotations for expressing value. In this instance, the listing order might look like Figure 11-17A, the evaluation worksheet Part 2 like Figure 11-17B, and the completed evaluation worksheet Part 1 like Figure 11-17C.

This alternate analysis can be conducted by the original value engineering team, or it can wait until the next phase, development and investigation, and be conducted with an expanded value engineering team.

Phase Five: Development and Investigation

The evaluation phase is continued here as the value engineering team brings in other team members to provide additional creativity and energy to the process. All of the functional development worksheets are prepared for review by the advanced team. In Figure 11-18, the idea evaluation worksheet is recreated with only the ideas of the function development listed.

Once again, the team sets down rules to follow similar to those that went before. In this phase, additional team members might include the manufacturer, contractor, or owner representative. This phase can provide an intense critique of the function or idea under discussion. This value-added group reestablishes advantages and disadvantages, with the original value engineering team providing input based on their initial worksheet.

Second Creativity, Evaluation, and Cost Analysis

In this phase, the larger team again performs creativity and evaluation. As seen in Figures 11-19A and 11-19B, the sketch can be significantly modified, and a new, secondary approach to the idea development phase can result in a different evaluation that could result in significant cost savings.

As seen in Figure 11-19, in this development and investigative phase the emphasis is on alternatives to a catalogue box and a new brainstorming session with different expertise and viewpoints.

Figure 11-15C Example Functional Evaluation

Value Engineering Consultants
Functional Evaluation - Part 1

Reference Number ______________________ **Date** ______________________

Detail/Production/Material Specification: Wall Box

Function: ______________________

Description (e.g., part number): ______________________

EVALUATION SUMMARY

LIST ORDER	FUNCTIONS		WEIGHT
A	Confine	Material	9
B	Store	Material	0
C	Protect	Material	10
D	Protect	Material	9
E	Prevent	Loss	15
F	Enhance	Appearance	1
G	Establish	Privacy	5
H			
I			
J			
K			
L			
M			
N			
O			
P			
Q			
R			
S			
T			
U			
V			
W			
X			
Y			
Z			

Figure 11-16 Example Functional Analysis

Value Engineering Consultants
Functional Definition and Analysis

Reference Number ______________________ Date ______________________

Detail/Product/Material Specification: ______________________

Function: ______________________

Description (e.g., part number): ______________________

Qty	Item Description	FUNCTIONS * VERB	NOUN	B	S	W	AP SL	Cost per Function (Estimate)	Label Function V = Vital E = Essential N = Nice to Have	Notes/ Comments
1	Wall Box	CONFINE	Material	X		X			E	
		STORE	Material		X		X		N	
		PROTECT	Inside	X		X			E	
		PROTECT	Material		X	X			E	
		PREVENT	Loss	X		X		[illegible]	V	See Costing Material Above
		ENHANCE	Appearance		X		X		N	
		ESTABLISH	Privacy		X		X		N	

Note: B - Basic
S - Secondary
W - Work
AP/SL - Appearance/Self

Figure 11-17A Example Functional Evaluation

Value Engineering Consultants
Functional Evaluation - Part 1

Reference Number ____________________ Date ____________________

Detail/Production/Material Specification: PENCIL

Function: MAKE MARK

Description (e.g., part number): ____________________

EVALUATION SUMMARY

LIST ORDER	FUNCTIONS	WEIGHT
A	Eliminate Paint	
B	Reduce Length of Lead	
C	Remove Eraser	
D	Stain Wood in Lieu of Paint	
E	Make Body out of Plastic	
F		
G		
H		
I		
J		
K		
L		
M		
N		
O		
P		
Q		
R		
S		
T		
U		
V		
W		
X		
Y		
Z		

Figure 11-17B Example Functional Evaluation

Value Engineering Consultants
Functional Evaluation - Part 2

Reference Number ______________ Date ______________

Detail/Production/Material Specification: PENCIL

Function: MAKE MARK

Description (e.g., part number): ______________

Numerical Evaluation

Weight Factors
1 = Nice to Have - Minor Importance
2 = Essential - Medium Importance
3 = Vital - Major Importance

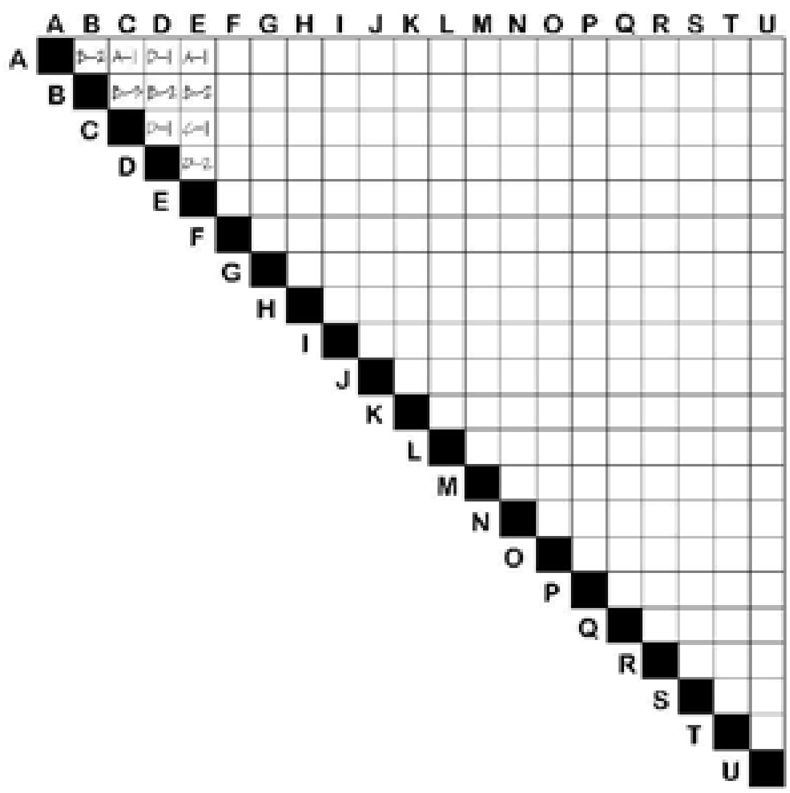


Figure 11-17C Example Functional Evaluation

Value Engineering Consultants
Functional Evaluation - Part 1

Reference Number ______________ Date ______________

Detail/Production/Material Specification: PENCIL
Function: MAKE MARK
Description (e.g., part number): ______________

EVALUATION SUMMARY

LIST ORDER	FUNCTIONS	WEIGHT
A	Eliminate Paint	2
B	Reduce Length of Lead	9
C	Remove Eraser	1
D	Stain Wood in Lieu of Paint	5
E	Make Body out of Plastic	0
F		
G		
H		
I		
J		
K		
L		
M		
N		
O		
P		
Q		
R		
S		
T		
U		
V		
W		
X		
Y		
Z		

Figure 11-18 Example Idea and Function Evaluation

Value Engineering Consultants
Idea and Fuction Evaluation

Reference Number ____________ Date ____________

Team: ____________

Detail/Production/Material Specification: ____________

Function: Wall Box: Confine and Secure Material

Description (e.g., part number): ____________

IDEA FROM FUNCTIONAL DEVELOPMENT	ADVANTAGES	DISADVANTAGES
Provide 2' by 2' 10 gauge polished aluminum wall box to confine and secure on/off regulator valve for hot water for each fixture in each bathroom		

Plan(s)/Action(s) on Idea(s)

Figure 11-19A Example Functional Evaluation Sketch

Value Engineering Consultants
Functional Development Sketch

Reference Number ____________ **Date** ____________

Team: ____________

Detail/Production/Material Specification: ____________

Function: Wall Box

Description (e.g., part number): Standard Wall Box: ABC Manufacturer Model Number 123456-A Size 2' X 2'

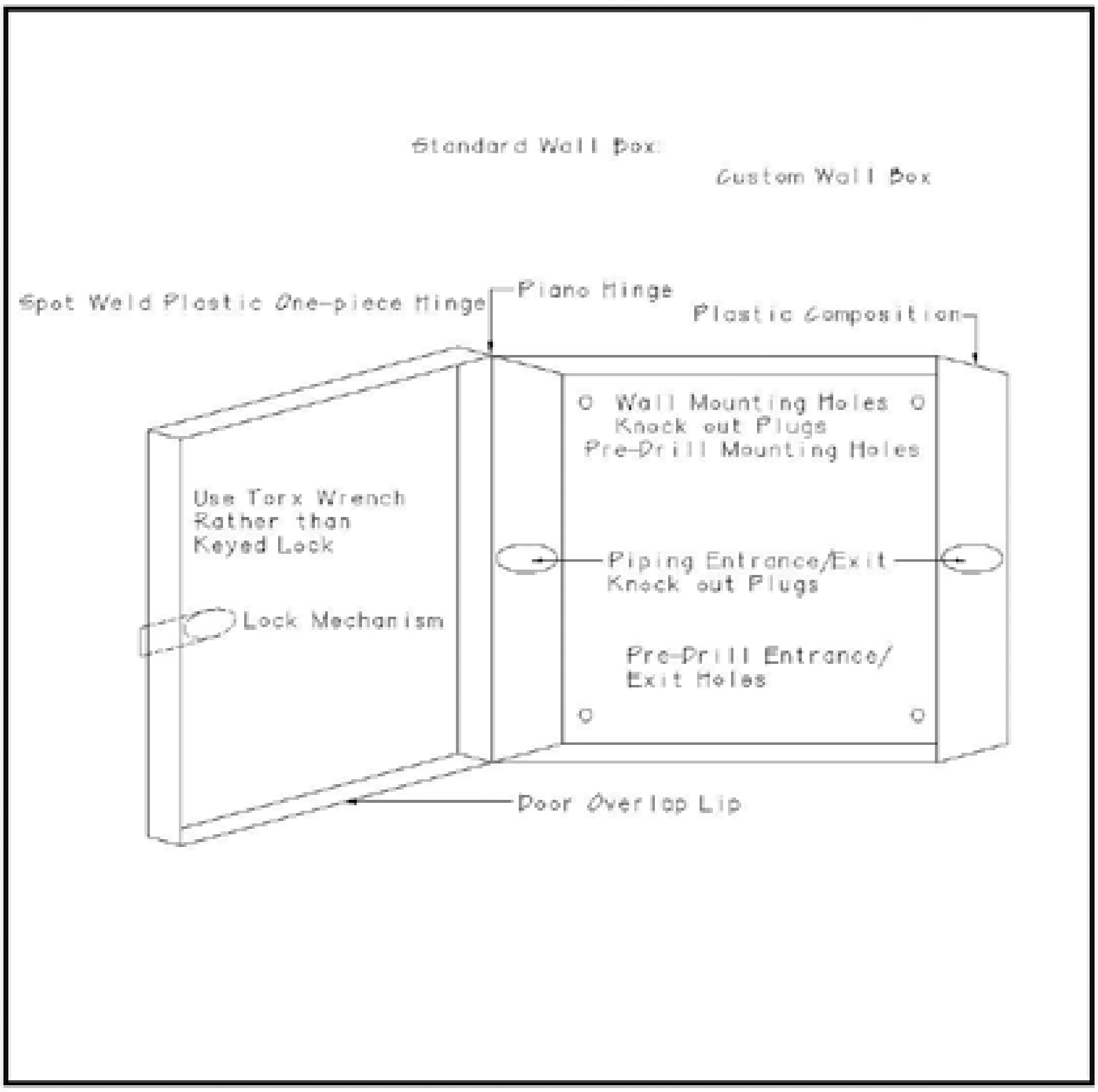


Figure 11-19B Example Functional Evaluation Sketch

Value Engineering Consultants
Functional Development
Idea Development and Estimated Cost

Reference Number ____________ **Date** ____________

Team: ____________

Detail/Production/Material Specification: ____________

Function: Wall Box

Description (e.g., part number): Standard Wall Box:
ABC Manufacturer
Model Number 123456-A
Size 2' X 2'

FUNCTION	CREATIVE IDEA(S) & DEVELOPMENT	ESTIMATED COST	CUMULATIVE ESTIMATED COST	
Standard Wall Box	Standard ABC Manufacturer Catalogue Wall Box	$2.75	$2.75	
	Custom Box			
	Plastic Composition	$5.95		$5.95
	Plastic Composition – Vacuum Molded	$5.12	$5.12	
	Spot Weld Single Hinge	$.75		$6.70
	Use Two Hinges instead of one hinge	$0.75	$5.86	
	Pre-cut holes	$.75		$7.45
	Drill Pipe Entrance/Exit on Site	$.25	$5.60	
	Drill Mounting Holes on Site	$0.75	$6.35	
		TOTAL	$6.35	$7.45

Cost Summary

Material & Material Burden $ ____________

Direct Labor $ ____________

Direct Labor Burden $ ____________

Final Alternatives

With additional idea evaluation, cost estimate worksheets, and possible sketches, the expanded value engineering team is ready to redevelop the idea. The team again establishes the advantages and disadvantages using the Figure 11-18 worksheet. At this stage, the engineering disciplines, contractors, and even the owner help in the final development and investigation to determine the best outcome.

With a workable and best-cost idea developed, the final step is to use construction supplies and industry standards to confirm the ability to meet the final engineering and design.

The Gut Feel Index

This is what engineers have developed from the original Delphi method of evaluation. The Delphi method attempts to achieve a consensus opinion within a group using questionnaires regarding future events and technical expertise. The Gut Feel Index (GFI) is similar, but it uses the intuitive qualification of each developed idea using the technical expertise of the individuals. Each team member scores each idea on a scale of 1 to 10 based on its technical merits and economic expectations. Low technical requirements, low costs, and low risks get the highest mark. High rankings by any individual are further explained to the other group members so all understand the rationale behind the rankings. The average of the scores is then computed. A GFI of less than 2 is excluded automatically.

Finally, a Risk Guide is used to make the final determination about each idea. Table 11-7 depicts a sample Risk Guide. In this approach, the Risk 1 level can be implemented or accepted without much concern. All other categories will require further investigation.

Table 11-7 Risk Guide

Rank	Risk Description	GFI Range
1	Recommendation/idea has low risk, good payback, minimal cost or investment risk, and change will not be owner or client sensitive.	7.5–10
2	Recommendation/idea has some technical risk, payback and/or cost/investment is not fully defined, and change will not be sensitive to the owner/client.	6–7.4
3	Recommendation/idea is a new approach, needs some additional technical engineering/design work, cost/investment is not expected to be excessive, but change is a new approach to owner or client.	4.5–5.9
4	Recommendation/idea is a whole different technical concept with attendant risks and unknown cost/investment requirements, and it will be unknown to owner/client.	2–4.4

Final Cost Analysis

One of the major elements of value engineering is the final cost analysis that is done for the recommendations and alternatives. Cost considerations are an important element of the value engineering process. Up to this point, the process has relied on creative techniques, brainstorming, functional analysis, and comparative analysis. The concentration has been on the technical side of the equation.

However, the result of value analysis must also incorporate the cost analysis side of value engineering. Interestingly, in many value engineering projects, a comparative cost analysis is not often conducted. A cost analysis looks at life-cycle costing, break-even analysis, and comparative cost analysis. For purposes of this basic overview, the details and in-depth review of the various cost-analysis methodologies are not included.

Are We There Yet?

The evaluation phase was intended to provide visibility to all ideas and to flush out any constraints while offering alternative solutions. This phase, while seeming to repeat some of the evaluation phase, is the final organization and analysis phase. In this phase the value engineering team prepares its final recommendations prior to presenting them to the client.

The value engineering process reviewed here has used, depended on, and recommended the use of standardized worksheets. One major disadvantage to this approach is the attempt to find a standardized process that is all-encompassing for all situations and projects. Since that is not possible, why have the worksheets been included? Their primary purpose is as a tool to help provide structure to the process and offer a presentation format. All of the worksheets help form a picture of the value engineering process and provide illustrative detail to support the final recommendations.

The end result must show the depth of the engineering and analysis—that the proposal is not just a suggestion or a best guess, but is based on engineering discipline.

The value engineering team can use one more checklist of questions to support the value engineering process.

- Does the proposed solution or alternative satisfy all of the original requirements and specifications?
- Do any issues or ideas remain unresolved prior to final recommendations?
- Are all reliability requirements and specifications met by the alternatives?
- Are all of the recommendations and alternatives compatible with all other systems, processes, and materials?
- Do the recommendations or alternatives create any health or safety concerns?
- Do the recommendations and alternatives meet the operational and maintainability requirements of the project or system?
- Can the recommendations or alternatives be implemented within the guidelines of the applicable codes and regulations?
- Are the recommendations or alternatives in line with the schedule and costs of the original engineering and design?
- Do the recommendations and alternatives support the client's requirements, specifications, and goals?

Everything is now in place and ready for the final step.

Phase Six: Recommendation and Presentation

This phase is the culmination of all previous phases. Will the value engineering team's recommendations and alternatives be accepted or rejected? In the end, it all boils down to salesmanship. The recommendations and alternatives, no matter how they are couched, will be seen as an attack, repudiation, or rejection of another engineer's work. People react in different ways, but in the engineering profession you can count on a few things occurring.

First, because it is human nature, change, no matter how slight or how right, will be resisted. Overcoming resistance requires patience and proof. This requires the value engineering team to have all of their worksheets for all aspects and phases of the process available for critical review.

Second, all recommendations and alternatives must be based on the same technical basis as the original specification. Some people may not require in-depth detail to be convinced, while others are never satisfied with whatever is provided. To prevail, the value engineering team needs to present the facts. This must be accomplished in the same deliberate manner that was followed throughout the value engineering process. When prepared with the worksheets and a written analysis, the presentation can account for every requirement and specification and trace the path of the analysis from the beginning to the end with a clear understanding of the final recommendations.

The worksheets used throughout the value engineering process will prove invaluable. They paint a picture for all to see and provide a concise and complete visual explanation of the end result, along with compelling and irrefutable conclusions.

Present Costs

The whole exercise for value engineering is to provide cost savings on the total project. The presentation of exacting support details results in a successful and fully accepted modification. Because value engineering is a team approach and depends on a team recommendation, an agreed-to consensus result is the one most sought after by everyone involved.

Present Recommendation

The final step is to present a team recommendation. A recommendation worksheet is shown in Figure 11-20. This worksheet summarizes all of the support worksheets and spells out the findings and recommendations.

The final presentation should be both a written report of findings and a verbal description. Both need to be clear and concise, and the presentation should be confident and positive. The basic strategies for a successful presentation follow.

- Explain the why's: Provide the facts, detail the modifications or changes, and describe and acknowledge any risks.
- List the benefits: It's important to concentrate on the benefits that will accrue because of the value engineering process. However, be sure to not exaggerate or oversell the results.

Figure 11-20 Sample Cost/Improvement Recommendation Form

Value Engineering Consultants
Team Cost/Improvement Recommendation

Reference Number ______________________ Date ______________________

Team: ______________________

Detail/Production/Material Specification: ______________________

Function: ______________________

Description (e.g., part number): ______________________

____

____

Team Members: ______________________

____

Original Design/Sketch	Recommended Design/Sketch

Expected Savings: ______________________

Life Cycle Costs: ______________________

Explanation of Savings or Cost Reduction(s): ______________________

____

____

FINDINGS AND RECOMMENDATIONS:

____

____

____

____

____

____

____

EXPLANATION FOR:

☐ APPROVAL ☐ REFECTION

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- Make it participatory: Be sure to involve the audience in the discussion and presentation. Incorporate audience suggestions. Involvement is ownership.
- Answer questions before they are asked: Be ready for the negativity of some individuals.
- Be prepared: Avoid surprises by being prepared, and don't let emotions interfere with the presentation.
- Acknowledge difficulties or unknowns: Don't gloss over an obvious problem or a void in the presentation. Acknowledge the unknown and provide an interpretation or at least some alternative response.
- Repeat, repeat, repeat: Repetition is the road to understanding. However, in repeating, be sure you are prepared with alternative road directions and maps. Repeating the same words over and over will not make the material understood or embraced any easier.

IS IT VALUE ENGINEERING?

In the construction industry, the emphasis is constantly on the cost side of the equation. All too often the quality of the engineering and design are attacked under the guise of value engineering. As should be clear by this point, true value engineering can be an expensive undertaking, which is why value engineering invokes the Pareto principle: Only 20 percent of the product, project, or system produces 80 percent of the savings. A value engineering analysis is of value for this 20 percent.

Unfortunately, most so-called value engineering is simply the misappropriation of a term that connotes structured and scientific analysis to the evaluation of a product, system, or material. In reality, it is nothing more than simple cost cutting or cost reductions for the sake of savings alone. This is not value engineering. The proper term for what often passes for value engineering is *cost reductions* or, if an analytical name must be used, *cost fitting*.

Cost Fitting

Cost fitting is where engineers, designers, and the like are left out of the process, and the designs and mechanicals are turned over to a "value engineer," often nothing more than a contractor seeking the bid for the project. In this iteration of cost fitting, the pseudo value engineer (PVE) offers replacement products or designs that can be installed for less money or to meet the budgetary needs of the project. The quality of the engineering or design is of no concern in cost fitting. One problem with cost fitting is that an alternative to anyone's choice of a product or design element can always be found. The PVE, knowing this, can offer cost savings over the design engineer's original work. All too often, the cost savings result in increased profits for the PVE as he garners the business with an on-budget bid—only to use inferior or less-desirable products, systems, or materials with greater markups for the supplier.

Level the Playing Field

One option open to engineers is to include in their contracts clauses that provide or require true value engineering to be performed on their designs. The role of the engineer is not to inhibit good value engineering of a project. As already shown, value engineering is a discipline that, when properly applied, results in cost savings without any sacrifice in the quality of the design. The example in Figure 11-21 is not intended to be exact legal language or offered as an instant contract addition. Rather, it is provided as a concept for ensuring that proper value engineering is implemented on the engineer's design and mechanicals.

THE DÉJA VU OF THE SCIENCE OF VALUE ENGINEERING

Does the science of value engineering seem very familiar? It should, because it contains many of the same elements followed in plumbing engineering and design. In fact, the elements described just as easily could be applied to a plumbing design project. The elements and techniques of value engineering are similar to most other engineering disciplines. Thus, if the plumbing engineer is already doing all of this, why does it need to be done again?

For the project's owner, developer, or manager, it is an issue of perception. Each of the engineering and design disciplines used throughout a construction project are open to suspect and suspicion. Engineers and designers often are seen as engineering artists: those who create an enduring engineering work of art under the guise of quality of design. A lasting engineered product that includes redundancies most likely includes the most up-to-date and state-of-the-art products and materials available on the market—therefore, by inference, the most expensive products and materials. The perception is that the engineering artist over-engineers the project. The engineer is suspected of using materials and products that have a longer life-cycle cost than actually is necessary to provide an extra measure of safety, longevity, and quality of design.

This quality of design is perceived by those financing the project to result in a more costly enterprise than necessary, while still providing the safety and longevity desired. Thus enters the discipline of value engineering. This engineering step at each stage of a project is perceived to be nothing more than an oversight function protecting the economic interests of the owner and ensuring the quality of the design at the best possible cost. It is not intended to be cost reductions simply for the sake of cost reduction.

What the engineer often sees as being the end result of value engineering and why many object to its use is the misconception that lower costs equate directly with reduced quality. The plumbing engineer needs to remain flexible and open to the integration of other disciplines' ideas and concepts. Value engineering is not a methodology designed to undermine the engineering, design, or specifications of a project, and it is not intended to outsmart or out-think the engineer. Value engineering is not intended or designed to reduce quality, safety, professionalism, or creativity. It is an analysis to identify and stop waste, thus lowering costs while maintaining quality.

Value engineering, when performed properly, does not affect performance and does not result in trade-offs to reliability, quality, or maintainability. This is the crux of the conundrum inherent in the discipline. Value engineering is only as good as the process followed and the experience of the engineers and is subject to various obvious and hidden agendas by numerous parties involved. Moreover, many value-engineered changes are nothing more than owner-mandated cost reductions disguised as value engineering.

Despite its negative connotation, the concept needs to be looked at as an adjunct to a project's engineering, and engineers need to embrace the concept and use it effectively within their disciplines.

Figure 11-21 Example of Value Engineering Change Proposal Contract Clause

1. INTENT AND OBJECTIVES—This clause applies to any cost reduction proposal (hereafter referred to as a Value Engineering Change Proposal or VECP) initiated and developed by the Contractor for the purpose of changing any requirement of this contract. This clause does not, however, apply to any such proposal unless it is identified by the Contractor, at the time of its submission to the Owner, as a proposal submitted pursuant to this clause.

   1.1 VECPs contemplated are those that would result in net savings to the Owner by providing either: (1) a decrease in the cost of performance of this contract, or; (2) a reduction in the cost of ownership (hereafter referred to as collateral costs) of the work provided by this contract, regardless of acquisition costs. VECPs must result in savings without impairing any required functions and characteristics such as service life, reliability, economy of operation, ease of maintenance, standardized features, esthetics, fire protection features, and safety features presently required by this contract. However, nothing herein precludes the submittal of VECPs where the Contractor considers that the required functions and characteristics could be combined, reduced, or eliminated as being nonessential or excessive for the function served by the work involved.

2. SUBCONTRACTOR INCLUSION—The Contractor shall include the provisions of this clause, with the pre-determined sharing arrangements contained herein, in all subcontracts in excess of $25,000, and any other sub-contracts which, in the judgment of the Contractor, is of such nature as to offer reasonable likelihood of value engineering cost reductions. At the option of the first-tier Subcontractor, this clause may be included in lower tier subcontracts. The Contractor shall encourage submission of VECPs from Sub-contractors; however, it is not mandatory that VECPs be submitted, nor is it mandatory that the Contractor accept and/or transmit to the Owner VECPs proposed by his Subcontractors.

3. DATA REQUIREMENTS—As a minimum, the following information shall be submitted by the Contractor with each VECP:

   3.1 A description of the difference between the existing contract requirement and the proposed change, and the comparative advantages and disadvantages of each; including justification where function or characteristic of a work item is being reduced;

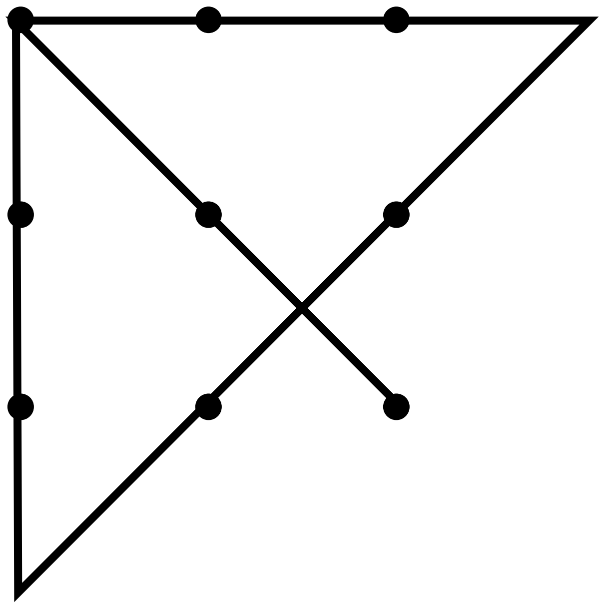
   3.2 Separate detailed cost estimates for both the existing contract requirement and the proposed change, and an estimate of the change in contract price, including consideration of the costs of development and implementation of the VECP and the sharing arrangement set forth in this clause;

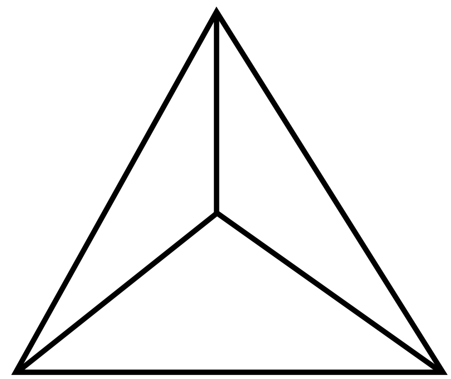
   3.3 An estimate of the effects the VECP would have on collateral costs to the Owner, including an estimate of the sharing that the Contractor requests be paid by the Owner upon approval of the VECP;

   3.4 Architectural, engineering, or other analysis in sufficient detail to identify and describe each requirement of the contract, which must be changed if the VECP is accepted, with recommendation as to how to accomplish each such change and its effect on unchanged work.

SOLUTION TO NINE DOTS AND SIX STICKS

The solution to the nine dots calls for thinking outside the box. The solution to the six sticks calls for thinking off the two-dimensional surface of a table and into three dimensions. The solution shown is as viewed from above. It's a pyramid shape. The base is, of course, one of the equilateral triangles.





CHAPTER 12

Ensuring High-Quality Plumbing Installations

One of a plumbing engineer's responsibilities to his or her clients is to ensure high-quality plumbing installations. Luckily, the plumbing engineer has a number of tools available such as plans, schedules, specifications, site inspections, and commissioning procedures.

COST AS IT RELATES TO QUALITY

A common perception is that high quality equates to high price. However, paying more for something doesn't always mean receiving a better product or installation.

The quality of a plumbing system may well depend on the client's intentions for the building. For example, in the case of a long-term building owner who is comparing one pumping system to another, a cost vs. benefit analysis is performed. If one pump costs 20 percent more than another pump but is guaranteed to last 50 percent longer, is quieter, and is built with higher-quality components, the choice is quite clear.

Other decisions regarding product choices and installation methodologies may not be quite so clear at first glance. A large part of the plumbing design addresses issues such as means and methods of installation, local codes, local climate, etc. These are the less obvious areas of an engineer's influence on the overall outcome of a plumbing system's quality. How can the engineer better ensure quality for the building's owner? How can this be done without imposing undue cost burdens on either the building owner or the installing contractors? As the old saying goes, "The devil is in the details." Many of these details, especially regarding the means and methods of installation, are addressed in this chapter.

CLEAR AND SPECIFIC DIRECTION FOR THE CONSTRUCTION TEAM

Regarding the means and methods of installation for a building's plumbing systems, most specifications include vague language such as "installations shall be performed by qualified mechanics," "the installing contractor shall have a minimum of five years of plumbing contracting experience," "plumbing installations shall be performed in a professional and workmanlike manner," or "product must be installed to a particular standard or per manufacturer's installation instructions." While these statements have value, they fall far short of ensuring the desired level of quality expected by a conscientious engineer or building owner. Some engineers are under the impression that the plumbing codes address this issue, but in reality the codes also fall short of doing so. For example, one of the model plumbing codes makes only these two statements regarding workmanship: "All design, construction, and workmanship shall be in conformity with accepted engineering practices and shall be of such character as to ensure the results sought to be obtained by this code." "All piping, equipment, appurtenances, and devices shall be installed in a workmanlike manner in conformity with the provisions and intent of the code." Again, while the intent is noble, the necessary detail is lacking, and many design professionals may fail to know all portions of the code or applicable standards.

What one contractor or installer considers to be a workmanlike installation may be considered poor, weak, or unprofessional by the next person. To eliminate subjectivity, plumbing engineers need to provide very specific language within the body of the specification documents as well as include specific installation detail drawings that complement

Figure 12-1 Makeshift Attempt to Support a Water Heater (left) vs. an Engineered Solution (right)

the specifications or refer to applicable manufacturing standards, which include installation instructions. Figure 12-1 shows an example of a plumbing field installation of a water heater. The installation on the left may have appeared to comply with the code at the time of installation, but it was obviously of poor quality and prone to failure. Most project specifications do not contain specific language or installation detail drawings that would have disallowed this method of water heater support installation. When left to their own imagination and without specific direction, an installer may resort to inappropriate, makeshift, and sometimes dangerous means and methods to accomplish the installation at hand. The installation on the right side of Figure 12-1 is a workmanlike and engineered solution to support a water heater stand in a non-seismic region of the country (as evidenced by the lack of seismic restraints around the water heater).

Figures 12-2, 12-3, and 12-4 show examples of appropriate specification language, an installation detail drawing, and a product submittal sheet. The engineer can use the information from the submittal sheet to develop the detail and provide a description in the specifications. These forms of direction, if enforced, help ensure that a high-quality, engineered application solution is installed rather than a makeshift, field-devised, and possibly dangerous method. It is important to remember that specifications and details need to be made project specific to provide accountability to the installing contractor.

Figure 12-2 Sample Specification Language

3.3 EQUIPMENT SUPPORTS

Engineered, factory-fabricated, galvanized steel supports are to be used when suspending equipment from overhead structures or when supporting equipment above the floor.

1. Water heaters placed on a stand, to elevate them above the floor, shall be installed using a manufactured galvanized steel stand, engineered to meet the intended weight load. Use the "Brand X" series from "Manufacturer A" or Owner approved equal.

Figure 12-3 Sample Installation Detail Drawing

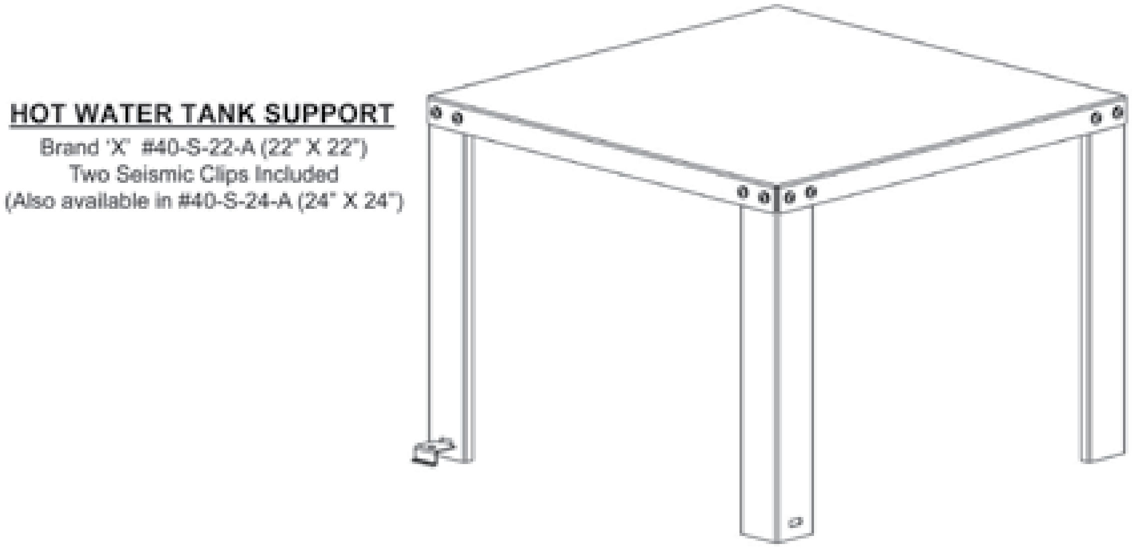
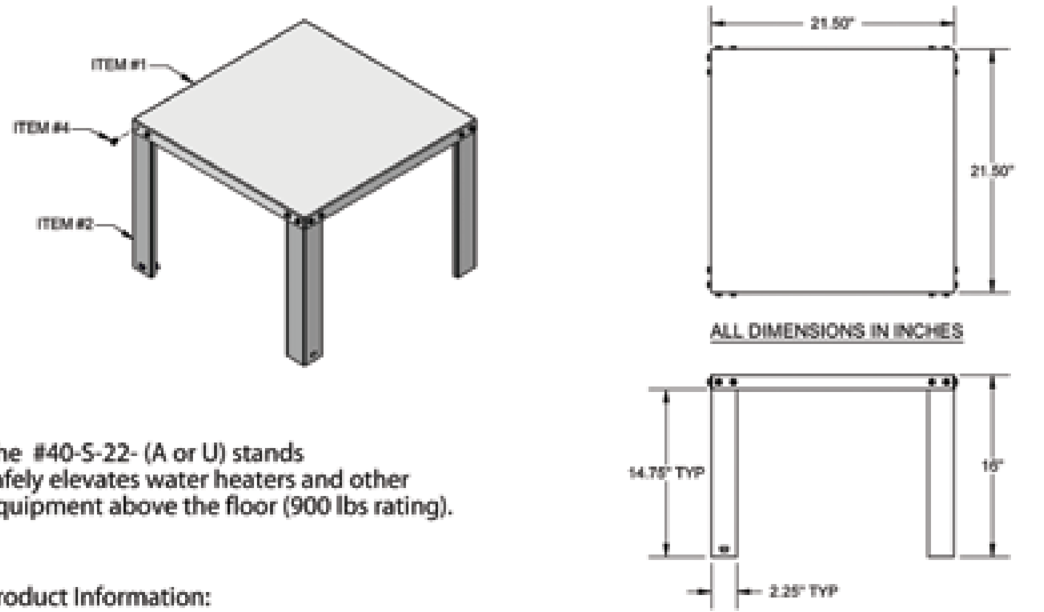


Figure 12-4 Sample Product Spec Sheet



The #40-S-22- (A or U) stands safely elevates water heaters and other equipment above the floor (900 lbs rating).

Product Information:

- Material:
  - Item #1: Top, 14 gage CRS, galvanized
  - Item #2: Leg, 16 gage CRS, galvanized, 4 places
  - Item #3: Safety Clip, 14 gage CRS, galvanized, 2 places
  - Item #4: Screw, PH, Sems, #1/4 X 1/2"L (w / external starwasher), 16 places
  - Item #5: Lag Bolt, #1/4 X 2-1/2"L, self-drilling, 2 places
  - (items #3 and #5 included with product)
- Engineered and lab tested to meet Uniform Plumbing Code (UPC) and International Plumbing Code (IPC) requirements, including elevation of water heater's ignition source 18" above the floor
- Holds up to 900 pounds capacity (up to 65 gallon tank)
- Weight: 17-1/2 pounds without packaging
- Available in asembled and unassembled configurations

Product Submittal	
Job Name:	
Date:	
Part Number:	Qty:
Architect / Owner:	
Contractor:	
Notes:	

COMBATING MAKESHIFT, FIELD-DEVISED METHODS OF INSTALLATION

In most cases when poor installations are evident on a jobsite, they are a result of bad habits, dishonesty, or a lack of knowledge and direction. In addition, they may be the result of a design professional who refuses to refer to appropriate industry standards or who writes a very generic specification. Bad habits are hard to break, and even conscientious laborers may choose to ignore concise directions and rely on past practices, good or bad. When this occurs, it is especially important for the project's documents to be in good order.

If the project plans and specifications are not clear, little can be done to force a contractor to comply with the supposed intent of the design. Anything left up to personal interpretation on the part of the installing contractor may result in an outcome that is less than expected by the design team and the building owner. This situation is especially true in the case of a plan and spec project. Anything regarding material choices or means and methods of installation that is not clearly spelled out in the plans or specs provides the contractor with grounds to issue a change order and be paid extra to make changes or additions to the work. Specified products must be known to be available and consistent with the authority having jurisdiction (AHJ), or the specification risks being disregarded.

Piping System Support and Protection

In most cases, plumbing codes and piping manufacturers have requirements regarding the methods of support. The most stringent requirements must be specified or scheduled as a minimum. The engineer may choose to augment these requirements with additional details and specifications to ensure a quality installation. When specific pipe support requirements are not followed, then the installation may look like some of the examples shown. Figure 12-5 shows a half-hearted attempt to support a PVC condensate drain outlet. Figure 12-6 shows an attempt to support hot and cold water supply lines for a sink. The scrap piece of wood used, with its split and broken pieces, probably will not provide long-lasting support.

Figure 12-5 Condensate Drain Stub-Out (Poor)

Figure 12-6 Sink Rough-In (Poor)

Figure 12-7 shows a water supply rough-in for a floor-mounted toilet in a high-end hotel project. The outcome will not be what the design team intended. The water piping will be loose, loud, and crooked. In addition, several of the solder joints will likely fail due to the lack of appropriate support, which causes undue strain on the joints. Figure 12-8 shows a better toilet rough-in installation, although a quality installation would have more than one point of connection between the bracket and the studs.

Figure 12-9 shows an attempt to support a showerhead outlet. The scrap metal framing stud has been cut, notched, and bent to the point that no real support is provided, which will result in a loud and very loose showerhead installation. A quality installation would not use the stud as the support and instead would include an engineered bracket that works around the obstruction.

Some who view these pictures may think that these are extreme examples. However, consider the fact that each of these installations was approved by the plumbing foreman, signed off on by the plumbing inspector, and then covered up by sheetrock to become a permanent installation. Why were these installations allowed? The plumbing codes did not specifically disallow this work, and the project specification documents for these projects did not specifically disallow

Figure 12-7 Toilet Rough-In (Poor)

Figure 12-8 Toilet Rough-In (Engineered)

Figure 12-9 Showerhead Rough-In (Poor)

Figure 12-10 Poor Attempt at Dissimilar Metal Isolation

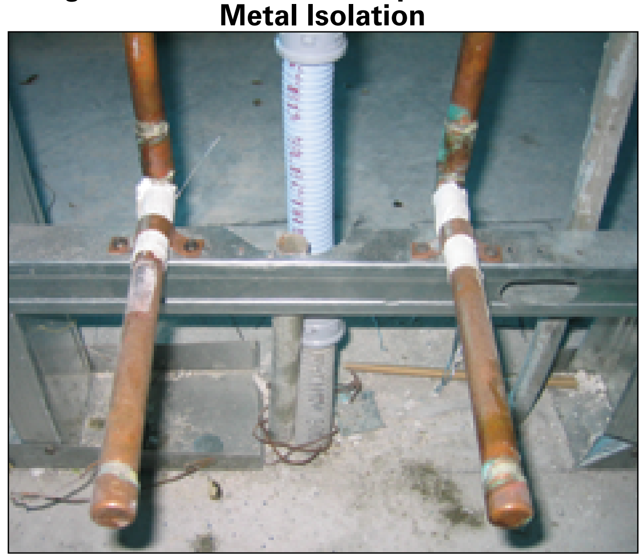
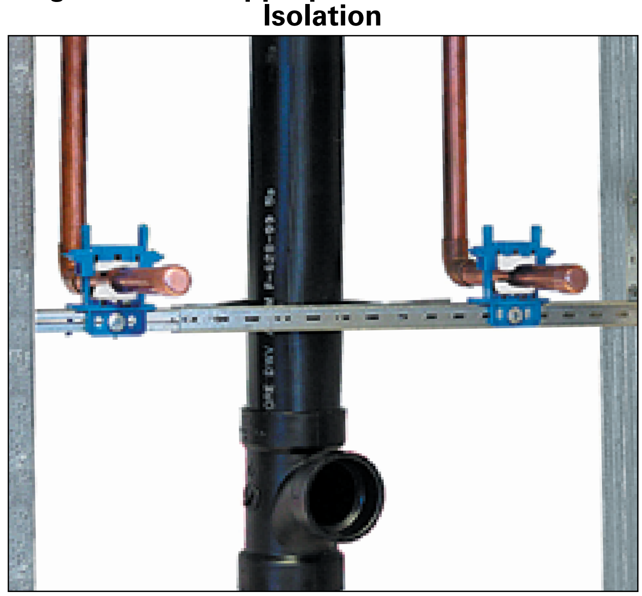


Figure 12-11 Appropriate Dissimilar Metal Isolation



these methods of support. The real question for engineers is: Do your project specifications and/or installation detail drawings specifically disallow these plumbing support methods? If not, these very same methods may be used on other projects as well. The end result can be controlled very easily by spelling out the requirements during the design phase of the project.

Abrasion, Corrosion, and Joint Failure Issues

Other problems can result from poor-quality installation practices. Piping and tubing can be damaged easily if not protected from potential harm from adjacent building components. In Figure 12-10, notice the attempt to isolate copper tubing from contact with a dissimilar metal. In this case, a galvanized scrap of framing stud material was used as a support member. The installer wrapped white paper from the outside of fiberglass insulation around the tubing and then secured the stub-outs in position with copper tube straps for spa tub water supplies. Figure 12-11 shows an appropriate installation method for the isolation of dissimilar metals.

Figure 12-12 Dissimilar Metal Contact with Wire Tie

Figure 12-13 Appropriate Dissimilar Metal Isolation

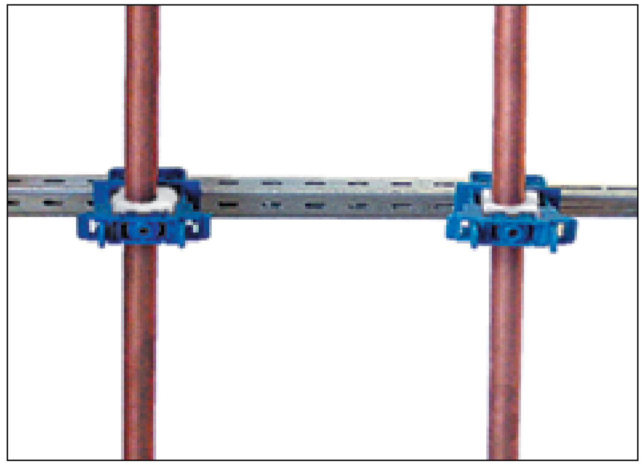


Figure 12-14 Makeshift Suspended Equipment Platform

Figure 12-15 Engineered Suspended Equipment Platform

In Figure 12-12, wire tie is used to fasten water tubing to a horizontal vent pipe in a plumbing wall. This obviously is not going to provide adequate support and will pose a problem with dissimilar metal contact. In this case, evidence of galvanic corrosion is already beginning to occur. Figure 12-13 shows the correct installation.

Equipment Support Safety Issues

A wide variety of equipment is installed as part of a plumbing system, especially in commercial installations. Many of these are floor mounted and have clear direction as to the installation required by the manufacturer or simply are addressed in very well-known ways. A floor-mounted pump in a mechanical room sitting on a housekeeping pad with spring-isolated mounts is a common installation, and most plumbing or mechanical specifications and detail drawings have addressed this thoroughly for decades.

Yet plumbing engineers must watch out for uncommon equipment installations that may pose serious consequences if installed improperly. An example of this is a water heater that needs to be suspended above the floor. The plumbing or mechanical engineer must be diligent in addressing the details of such an installation. Failing to do so could result in more than an unsightly installation—it also could be a safety hazard both in the short term and throughout the life of the building. In Figure 12-14, notice a suspended water heater over a bathroom ceiling in a commercial office building. The suspended platform was built from a piece of ¾-inch-thick plywood and suspended with various hardware components. What is its safe load rating? It doesn't have one. Figures 12-15 and 12-16 show engineered and load-rated installation methods for installations of this sort. Whether it be a piece of equipment suspended from the structure above or one mounted to a wall, do not leave it up to the installing contractor to determine the safe and appropriate solution. Specify it clearly in the project documents by requiring installation to be done to appropriate industry standards or manufacturer's installation guidelines. The specifications should include various options to allow for efficient adjustment to changes in the field.

Figure 12-16 Engineered Wall-Hung Equipment Platform

Other Safety Considerations

The safety of a building's tenants must be a top concern for any design engineer. The issue previously discussed relating to overhead equipment is just one example of the need to exercise reasonable control over the outcome of a plumbing or mechanical installation.

Support of overhead piping is another area that must be carefully addressed. Care must be taken to ensure that appropriate hangers and building attachment methods are well defined within the project's specification documents. Serious injuries and property damage have resulted when piping was hung with insufficient materials. Make sure to strictly disallow makeshift types of pipe and tubing support in the design.

Other issues regarding safety also must be considered. One obvious one is addressed in Chapter 9, in which the issue of earthquake protection is covered.

Another life-safety issue relates to plenum-rated areas within a building. Many times, as a result of value engineering, return-air ducting is removed, creating a return-air plenum above the ceiling. When a plenum environment exists within a building, be sure to clearly specify that materials used in these spaces must meet the appropriate standards, such as ASTM E84: *Standard Test Method for Surface Burning Characteristics of Building Materials*. Contractors and plumbing inspectors often are not aware of the type of materials appropriate for use in these areas. Do not assume that they understand this issue, and clearly specify exact directions in the construction documents. Also, it is important for the design professional to only accept standards such as ASTM E84 that are accepted and referenced in the local codes. Standards from outside the appropriate jurisdiction should never be referenced.

REGIONAL LOCATION AND CLIMATE CONSIDERATIONS

Codes are often general in their language and fail to thoroughly address issues such as weather conditions. Practices that are common in Southern California are not appropriate in Montana, for instance. While water lines are run very shallow in the ground or even aboveground in Southern California, they need to be buried several feet belowground in Montana. Freeze protection extends to many elements within a plumbing system and should be carefully reviewed, especially if an engineer is performing work outside of his familiar geographical region.

Regional location and climate affect numerous issues in addition to freeze protection, such as condensation, elevation, rainfall, snowfall, salt-laden air, earthquakes, tornadoes, and hurricanes. These should be considered carefully, and necessary adjustments should be applied to the many components of a building's plumbing and piping systems and equipment. In addition, the design professional must include in their specifications information regarding the burial depth limits for piping installed at specific depths.

ENGINEERED, COST-EFFECTIVE APPLICATION SOLUTIONS READILY AVAILABLE TO CONTRACTORS

The plumbing industry doesn't evolve very quickly, but changes do take place. Just consider the wide variety of pipe material types, faucet and valve types, seismic system component variations, equipment and fixture variations, and the ever-changing codes that are available today. That being said, it is important for engineers to keep their eyes open for changes regarding approved materials, acceptable methods of installation, and other variations that previously may have been taken for granted.

Great advancements have been made that have resulted in products that provide application solutions previously unavailable. Sophisticated packaged pump systems, advancements in hanger designs, advanced grease interceptors, seismic restraint mechanisms, drainage systems, and pipe testing systems are just a few of the innovations. As a result, many common installation tasks that previously required installers to create field-devised solutions have been replaced with engineered and tested product solutions. As an engineer, be alert to these changes and the beneficial options in today's market.

Plumbing engineers may be unaware that their plumbing specifications and documents are not up to date and may even still include materials and methods now considered to be dangerous. For example, most specification language and detail drawings in existence show a welded steel frame that must be fabricated by a metal shop or on a jobsite and installed where needed, without any weight load certification or test data. However, products for this application are readily available to the marketplace. It is important for the engineer to be active in the industry, attend local industry meetings, and, if needed, contact industry sources for an expert opinion. An engineer can't be expected to know everything available, but it is wise to learn about positive changes in the marketplace. They often make both the engineer's and the installing contractor's job easier, faster, and more profitable than before.

THE BUILDING OWNER'S BEST INTERESTS

Building owners and contractors often see things differently. The design of the plumbing system should reflect this by taking the necessary steps to ensure that the construction document regulating the installation materials and techniques of the contractor leave little if anything to the imagination. Otherwise, what may happen will be similar to what happens when a design team is challenged to cut costs through value engineering. Every contractor wants to be as profitable as possible on each job they install, but it is important that they provide the same value and quality when value engineering. Value engineering does not mean just reducing installed cost and improving the contractor's profit. Keep their position in mind when deciding which aspects of a plumbing system to leave undefined and to the discretion of the installer.

TAKE PRETTY TO THE BANK

A wise contractor once said, "You can take pretty to the bank." He meant that a good-looking installation builds and maintains a good reputation with all those who see it. This applies to inspectors, other contractors, and building owners. Good-looking installations retain and attract good customers.

One example of a simple way to improve the appearance of the plumbing system is addressed in Figures 12-17 and 12-18. Figure 12-17 shows a rough-in for a sink in a commercial building with the use of makeshift, field-devised support components creatively assembled by a plumber. Figure 12-18 shows the rough-in of a sink with the use of an engineered product that is easy, quick, and reliably repeatable.

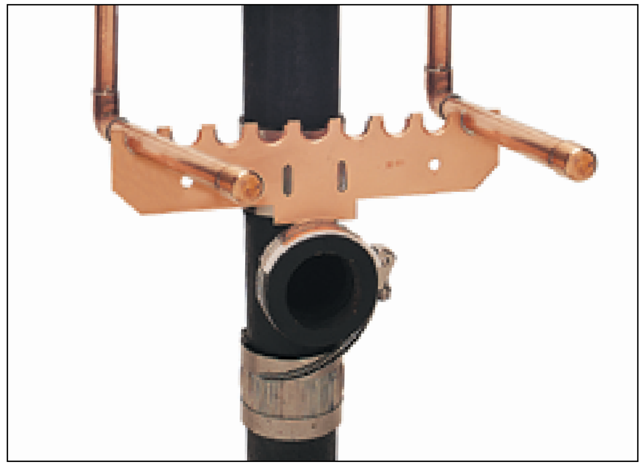
The concept of "taking pretty to the bank" regarding plumbing engineering documents is similar. How? When plans and specifications are incomplete or based on outdated information, they reflect poorly on the design team as a whole. On the other hand, when the documents are clear and complete, they reflect very well on the team and, by extension, the owner.

BUILDING OCCUPANT SATISFACTION IS AT STAKE

When a building is constructed, it is done so with the intent of satisfying the needs of the targeted occupants. If the finished product fails to accomplish this goal, the results for the owner can be financially devastating. In many cases, a building owner puts a great deal of trust in the design team to help accomplish the desired outcome. Many elements come into play regarding the satisfaction of the targeted end user.

Figure 12-17 Makeshift Lavatory Rough-In

Figure 12-18 Engineered Lavatory Rough-In



Over the past several years, the two most occurring hot spots regarding tenant dissatisfaction within a building have related to moisture problems and noise. Moisture problems, including issues such as roof leaks, window or glazing leaks or condensation, and mechanical or plumbing system leaks, can result in the related issues of property damage, mold, or mildew. Wet or humid climates contribute to many of these problems. In the design and specification of the plumbing system, be sure to address the issues that can add to these problems. As an example, be sure to specify the appropriate amount and type of pipe insulation to prevent damaging condensation. Also, to avoid leaks within water piping systems, drainage systems, and all pressurized piping systems, be sure to specify that all of these systems must be tested to reasonable pressures and have such tests witnessed by an owner's representative in addition to any requirements by the plumbing or mechanical inspectors.

Regarding noise disturbance within a building, in most mechanical specifications attention is given to noise and vibration, but usually only as they relate to the larger components of the mechanical system. Rarely have specifications addressed noise in plumbing systems to the extent of the entire system, including small water lines and drain lines. In some areas of the country, especially on the West Coast, litigation has forced building owners and design teams to address plumbing noise throughout the building to avoid dissatisfied occupants. Sadly enough, the point has been driven home due to the fact that many lawsuits were filed and successfully prosecuted based on occupant discontent with loud buildings. Most multifamily buildings in Southern California and Washington now include some level of acoustical plumbing system noise isolation. Some of the major hotel chains are slowly adopting this requirement, and the trend appears to be growing. As a plumbing engineer, be aware of the issue and the available solutions regarding this situation. (For more detail, see Chapter 10.)

Sustainable construction practices and LEED certification are obviously high on the radar of many building owners as well as perspective building tenants. Although the subject is too involved to develop in this chapter, be sure to address sustainability to the degree deemed necessary for each project.

PERCEIVED CONFLICT BETWEEN LOW COST AND HIGH QUALITY

In many areas of plumbing system design and construction, choices made to increase the quality of a system may result in added costs. Makeshift means and methods of installation may be viewed as inexpensive, but they actually may increase costs. These makeshift methods are typically slower, less likely to be repeatable, and often more dangerous to execute. One example is specifying hangers for suspended piping. This is an area where an increased upfront cost can often lead to decreased overall cost, as more hangers tend to reduce hours spent installing the actual piping. Another example is the use of carrier-mounted brackets to support flush valve stub-outs, where the product leads to labor savings in the layout portion of the installation as well as by replacing a field-devised support method

Additionally, when correct application solutions are employed widely on a project, they will increase worker productivity and can result in benefits to the project's schedule, as well as reduce crew sizes.

ENSURING QUALITY

As noted, the construction specifications need to be clear, concise, and complete at the beginning of the project, or the installing contractors will make their own determination as to what are appropriate means and methods of installation. These decisions often are based on the minimum requirements of the local codes. As the engineer of record representing the best interests of the owner, make sure that the necessary details are in place. In the construction specifications, clarify which products are required and the recognized standards the products need to meet. Clearly disallow makeshift, field-devised methods of installation that may compromise the quality outcome of the project. Include clear installation plumbing detail drawings, and make sure that a clear submittal process is in place (see Figure 12-19 as an example). All details and specifications should be tailored to the specific project as needed. Directions that do not apply to a piping system, do not apply to a region, or contradict local codes are likely to be ignored and will cast doubt on the applicability of other details and specifications.

In addition, even the best specifications and details will not create a high-quality installation if the plumbing contractor disregards them. A plumbing system that is reworked and adjusted to conform with the specifications is rarely the equal of a system installed properly the first time.

If appropriate for your project, include pre-construction meetings with pertinent members of the construction team. This will give the project members an improved form of communication to begin the job. It also is wise to require a mock-up of typical installations to be repeated multiple times to be created prior to actual construction. This often is done with typical hotel rooms or apartments. A mock-up that is created during the early stages of a project is an excellent way to ensure that the intent of the design is followed.

The next challenge is to ensure that the intent of the specification is upheld throughout the construction phase of the project. This is best accomplished by the use of contractors known to have a history of quality installations, as well as through on-site job inspections by the engineer or an appointed and competent representative. Take advantage of reputable manufacturers who are happy to provide complimentary technical and application/installation training and support to both engineers and contractors.

Commissioning the Plumbing System

Building commissioning is a great way to ensure high-quality plumbing installations. Commissioning is the process of verifying that all buildings, systems, and assemblies are properly designed, installed, operated, and maintained to meet the requirements set forth by the building owner. Commissioning offers an owner a sense of protection that their facility will operate as intended. Commissioning also provides a reduction in operating costs, energy optimization, O&M staff education, and building system documentation. The commissioning process is performed by a qualified Certified Commissioning Authority (CxA) who will follow the predetermined commissioning plan as agreed on by the CxA and the building owner.

A plumbing engineer or designer will probably be required to partake in the commissioning process on some level. Commissioning for new construction will begin as early as the kickoff meeting and conclude as late as one or two years after project completion. The CxA will want to look through the plumbing design to develop construction checklists and functional tests for the contractor to perform. The CxA will not review the documents for compliance or performance. Plumbing systems that may be commissioned include but are not limited to:

- Domestic water: cold, hot, and recirculated hot water piping
- Water heating equipment
- Natural gas piping
- Booster pumps
- Medical gas piping
- Medical gas equipment
- Heat tracing
- Water treatment devices
- Sump pumps

Figure 12-19 Sample Plumbing Detail Page

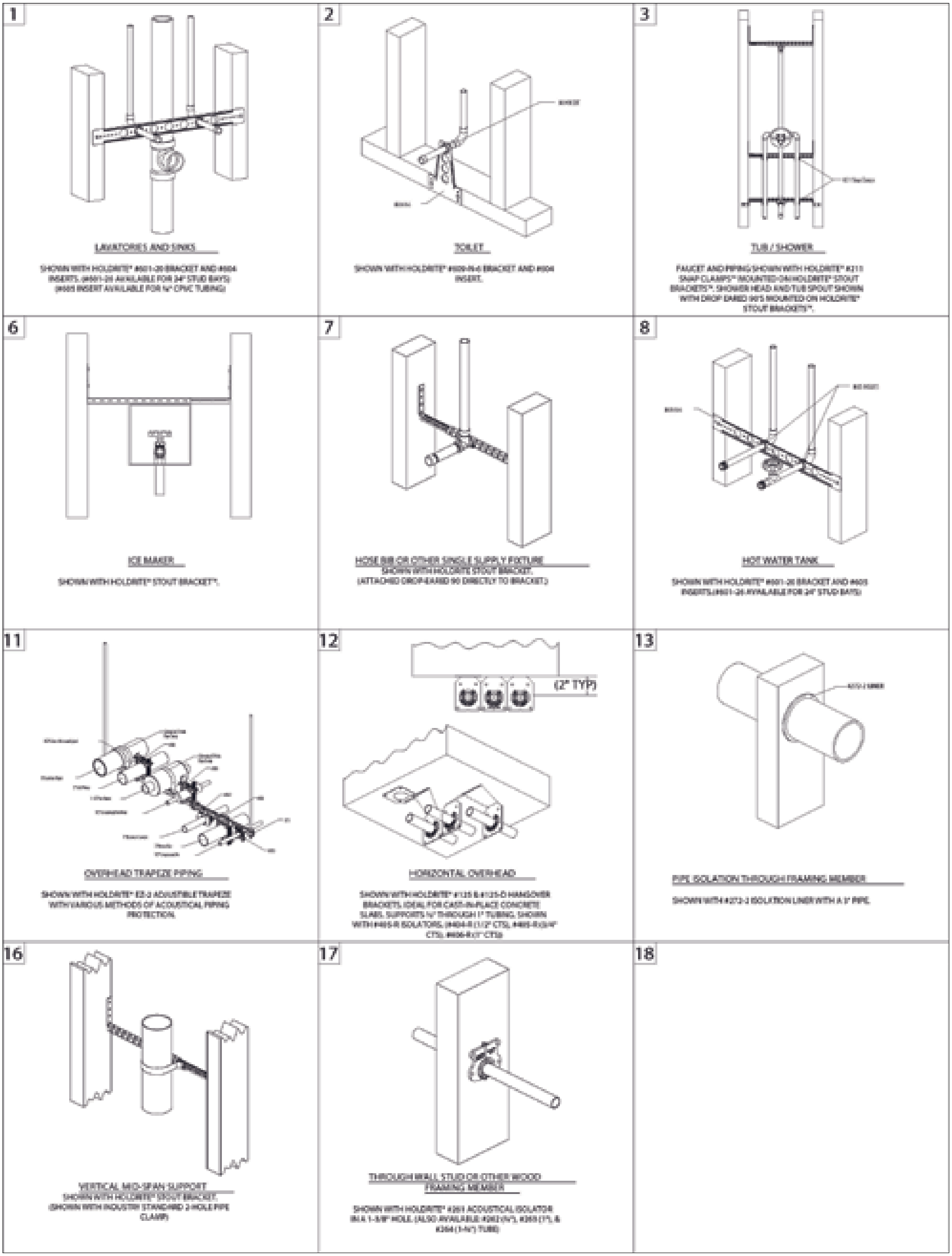
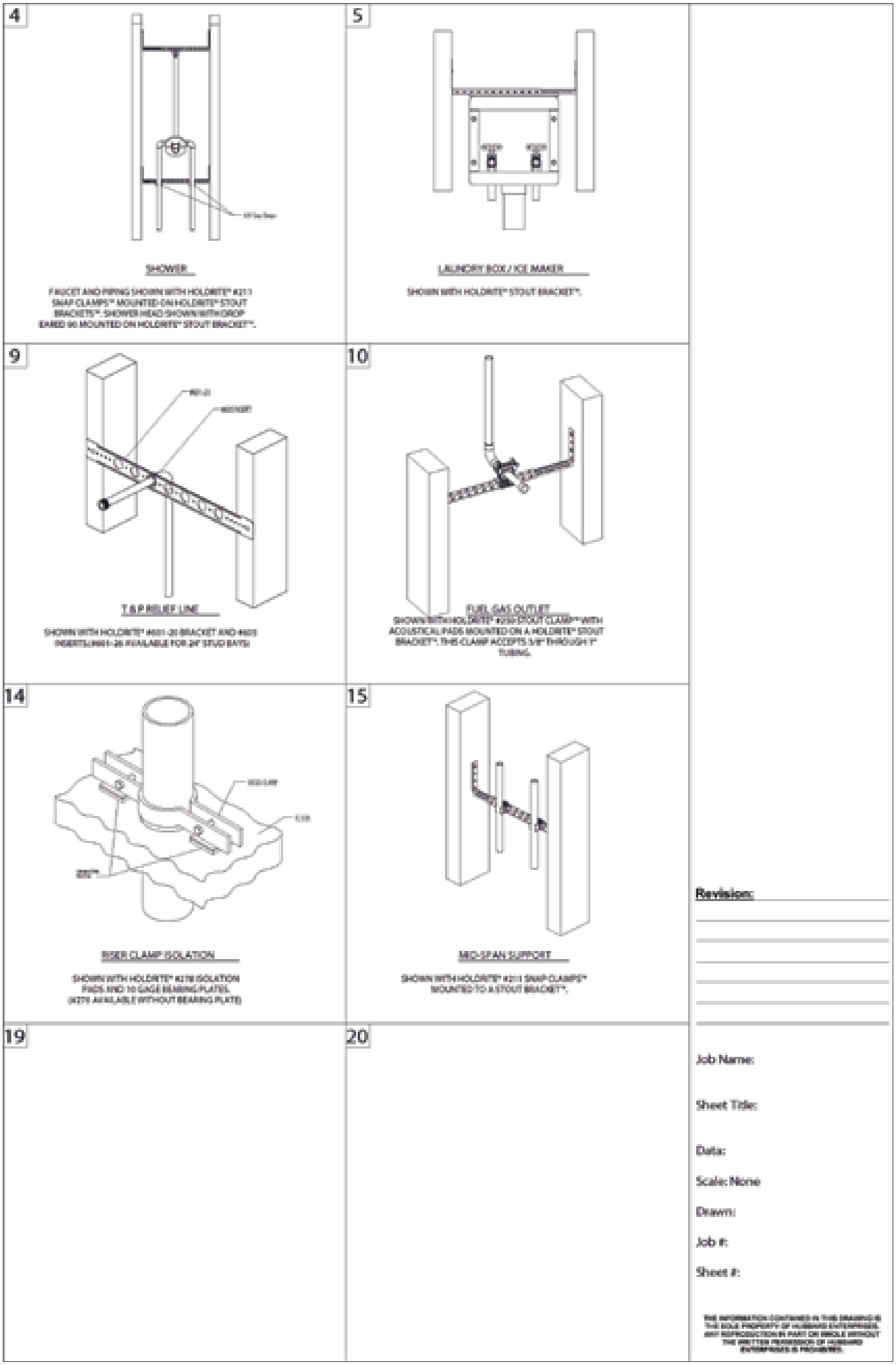


Figure 12-19 Sample Plumbing Detail Page (continued)



- Plumbing fixtures
- Compressed air
- Fire protection

The CxA should be independent from the design to create an unbiased presence on the project. When everyone works together, the commissioning process can be a huge benefit to the owner and everyone involved with the project.

CONCLUSION

Plumbing tradespeople are typically very visual people. They are, by nature, also very creative, but without direction, their creativity may not serve the building owner well. Quality means different things to different people. The design professional carries the weighty responsibility of directing the construction team throughout the course of the project.

As discussed, high quality does not have to translate into high costs. High quality is simply a matter of choice. The plumbing engineer must do his or her part in ensuring that clients receive high-quality plumbing installations that will last for the life of the building.

Existing Building Job Preparation and Condition Survey

This chapter includes two sections: a survey of a commercial building with a proposed alteration and a condition survey for a client who wants an assessment of the condition of an existing commercial building. Fire protection and the building structure itself are outside the scope of this discussion.

Job preparation concerning any construction project is covered in Chapter 5. This chapter is intended to augment any additional work necessary for the design phase and concentrates only on the existing building.

SURVEY IN EXISTING BUILDINGS FOR PROPOSED NEW WORK

Engineers often are asked to revise, alter, or add to an existing building. The scope of such work requires frequent site visits to examine the existing facility and its equipment. Except for extremely small jobs, additions generally are independent projects separate from the original building.

New additions may affect plumbing work in the existing building, which might be based on an older code. This may require the existing building to be brought up to the current code, which must be ascertained very early in the project by contacting the various authorities having jurisdiction (AHJs) and examining the local code.

Additions and alterations present their own unique set of problems. The engineer is presented with an existing facility that has its own operating characteristics, some of which may require various methods of obtaining the information needed to prepare the project documents.

General Design Considerations

Before beginning work, the engineer must gather the necessary information about the existing building to determine how the new scope of work may affect it. Although numerous methods could be used, a procedures checklist such as the following ensures that the pertinent plumbing items have been observed.

- Obtain from the architect a complete set of the new work plans, including fixture types, preliminary specifications for new work, and locations of all new equipment.
- Obtain from the architect or the owner a complete set of the existing architectural and plumbing drawings along with the date of construction, if available, of the areas in which the new work is anticipated.
- Obtain, if possible, the name of the architect and plumbing engineer who designed the original building.
- Obtain, if possible, the name of the plumbing contractor who installed the plumbing work.
- Obtain the name of the custodian, operating engineer, or similarly titled individual who is responsible for the present building's plumbing equipment and system operation. His input is necessary to discover any existing problems and to learn how the new work will interface with the existing systems. He can also aid the engineer in determining where existing valves are located and where chases are available to route new work.
- Make certain that the latest site survey of the new project is available, including all existing utilities. This should include aboveground obstacles such as boulders, large caliber trees, or small buildings that might affect the

routing of new underground utilities. All information regarding the existing utilities should be shown on the site survey and verified with the utility companies. Call 811 if you will be responsible for site utilities.

- Determine what, if any, provisions should be made for anticipated future expansion.
- If taking over a job from another designer, do not assume that the latest existing building documents and site plans have been obtained. If you will be responsible for the work, ensure that this has been done on your own.
- Conduct a code search to establish all of the codes and standards applicable to the new project. A code search for the plumbing code in effect at the time of construction of the original project also is necessary.
- Determine to what extent the operating engineer wants to use the same equipment and plumbing fixture manufacturers in the new building as presently used in the existing building.
- Find out about any plumbing service contracts.
- Find out if the building's plumbing systems have any existing operational or maintenance issues, such as water hammer, sewer gas smell, delay in hot water service to fixtures, or inadequate water pressure.
- Identify the type and coverage area of fire suppression systems. Learn about the extent of all life-safety systems (if applicable).
- Obtain, in particular, the date and possibly a copy of the original building's plumbing code. Determine if any existing plumbing work must be upgraded based on the scope of the new work.
- Obtain the names and contact information of the plumbing and fire department AHJs, as well as the names of the examiner, inspector, and all other individuals who will approve or inspect the new work.
- Obtain the names of all local utility providers (water, sewage, and gas) and health departments. All requirements of the various other departments should be carefully investigated and discussed with the respective individuals to avoid any miscommunication.
- Obtain any special requirements for the new building from the fire department and the owner's insurance company.

Considerations for the New Work in Existing Buildings

The following discussion concerns only how the plumbing work in the existing building may affect new work. For the actual preparation of the new work, refer to Chapter 5. This guide will help the engineer use the information obtained to design the new work. It is not necessary to proceed in the order given. Rather, use this list as a reference to identify and conduct the work as expeditiously as possible.

- Find the location of existing water services. If new (or multiple) services are necessary, how will the connections be made? Who is responsible for the new connections? Where will the new connections be run to avoid interference with existing elements?
- Arrange for a new water meter room with enough space for all of the required equipment. Provide adequate drains to remove water from a backflow preventer, if necessary. Determine the size and arrangement of the inlet service, water meter, backflow preventer, gauges, valves, water treatment, etc. Note the pressure on gauges. Consider if pressure-reducing valves or booster pumps are necessary. Ask operating personnel about any complaints regarding the water service in the existing building.
- If there are no gauges, obtain the static and residual pressure directly from the utility company, in writing. For smaller projects, take water pressure readings in the building near the water service entrance.
- Determine the size, location, and incoming delivery pressure of the natural gas service. How will new gas lines be routed to new appliances/equipment? The utility company may have historical peak usage profiles for large customers.
- Using the new drawings, identify the quantity and type of new equipment and fixtures. Calculate the size of the new water main needed to serve the new work and the size of the new main drain. Also calculate the hot water demand, and determine the size, type, and arrangement of the water heater(s) and circulators. Obtain the original calculations used to size the systems in the existing building if possible.

- If the new work is not concentrated in one place, each existing area must be researched to determine if the existing branch is large enough for the new work. If not, new piping will be required and will need to be run as expeditiously as possible.
- If water service, natural gas service, or sewer demands are expected to increase significantly, contact these utility companies to determine if their systems will support the increased demand.
- Determine the final location(s) of the new mechanical room(s). Confirm that the existing water-heating plant is sufficient for the new hot water demand.
- Determine if sump and/or ejector pumps are necessary or if they currently exist. Determine their locations, and calculate the sizes of the respective basins and the clearance height necessary to maintain the pumps.
- Determine the primary and secondary roof drain requirements. If the discharge will be above grade, select the location.
- Select the new location of the natural gas service, its size, meter, and arrangement. Is an outdoor location acceptable or is a meter room necessary? Will it fit into existing areas?
- Find out if chilled drinking water will be necessary.
- Find out if water softening or water filtration systems will be required for any fixtures. Is there existing water softening equipment or are water softeners used? Obtain water quality data from the owner's chemical treatment specialist or obtain a sample from a neighbor.
- Determine the extent of fire protection requirements. Will dry pipe or preaction fire suppression systems be required?
- If a kitchen is included, discover if grease interceptors need to be provided. Are lint traps required? Do any underground elements require service access? Have any had a service issue in the past? Also, consider if special fire suppression systems are required. In what condition is the existing equipment? How frequently does it require service?
- Find out if the client wants to install the most water-efficient or energy-efficient equipment. Should waterless urinals be considered?
- If new underground (underslab) sanitary waste lines are to be connected to existing sanitary lines within the building, determine the invert elevation of the existing line at the proposed connection point.
- If new underground (underslab) sanitary waste lines are to be connected to existing sanitary lines outside the building, confirm that the invert elevation of the existing line is suitable for connection. Will new waste pass under the perimeter slab structure?

CONDITION SURVEY

Even before a facility is occupied for the first time, its systems and components have started to deteriorate from their new condition. Over time and with use, that deterioration increases exponentially. Over the life of a facility, this deterioration results in repeated repair cycles until repair of the equipment is no longer economically feasible. When a facility changes hands or occupancies, it is necessary for the new owner to determine if the facility is suitable and how well the building will be expected to meet the needs of the new owner.

A physical condition survey of a building can assure the new owner that any problems with a building are identified. A survey and assessment of the physical condition of an existing property, performed by qualified consultants, can minimize the risk of any client being surprised by problems that could have been identified prior to the client's purchase investment. A physical condition survey also may be necessary for the correction of a specific set of problems.

The purpose of the survey is to prepare a report that briefly describes the central building systems, to observe the exposed and accessible equipment and piping, and to discuss the physical condition of all plumbing work in general terms based on observation.

The scope of the survey generally is limited to a visual inspection. Only exposed equipment and piping are typically evaluated. Insulated piping is not disturbed, and ceiling access doors are not opened. The external appearance of all piping and equipment is the sole basis of evaluation. Obvious code deficiencies should be noted. (Note: This description may be altered based on the actual contract between the consultant and the client. If the client wants specific tests to be conducted, this needs to be made clear in the owner's proposal request or in the engineer's proposal. For instance, sometimes the due diligence report requires some above-ceiling inspection and an estimation of pipe insulation thickness and pipe condition.)

Several of the subjects in the following sections and checklists may not be necessary or desired by the engineer or client. They are listed only to make this chapter as complete as possible.

The following checklists should be used as a guide to observe, identify, and recommend corrective action, as well as potential costs. They are dependent on time and contract constraints. They are not intended for a special-purpose building such as a healthcare, industrial, or pharmaceutical facility. The list should be modified by any constraints of the contract between the consultant and client.

Note: If the following sections or checklists are used as a basis of contract, the words "will" or "should" should be replaced with the word "shall."

General Requirements for the Entire Building

- Obtain the plumbing code under which the building was designed. Determine the code compliance of the building, equipment, and piping systems. Conduct a code search of all other existing authorities. Are any special provisions required by the client's insurance carrier (e.g., FM or IRI)?
- If necessary, contact the AHJ and obtain (in writing if possible) explanations of any nonconforming code deficiencies and solutions to variations.
- Document possible code violations to correct existing building deficiencies.
- Request an owner-provided asbestos abatement report for buildings constructed prior to 1978. Recommend that the owner solicit and obtain other necessary specialty assessments covering Americans with Disabilities Act (ADA) compliance, mold remediation, and other biological/environmental issues.

Format for the Condition Report

The format found in Figure 13-1 is suggested. It is intended to be reasonably complete and can be revised as necessary.

Abbreviations

In some cases, due to lack of space, a series of abbreviations (see Figure 13-2) may be necessary to reduce the amount of information required in a deficiency report. This same series of numbers also could be used to establish a computer code that accomplishes the same purpose.

Checklist for the Preparation of a Contract

When a contract between an engineer and a client is prepared, the following wording is helpful.

Function of Survey

- The function of the condition survey is only to assess the condition of the exposed equipment and components.
- Code compliance with existing plumbing and fire protection systems is for the current code only.
- If special agency design criteria are to be used, they are only for the current edition.
- Photographs can be taken where necessary to clarify deficiencies.
- Recommendations are prepared only for the deficiencies noted.
- The priority of corrective action will be given.
- The engineer may recommend additional tests or studies to ascertain actual condition or function.
- The engineer will provide estimated costs for the correction of deficiencies.
- The engineer may make recommendations for upgrading systems to meet current engineering standards or codes.

Conditions and Qualifications

- The architect or client should furnish a list of all codes and standards to be used.
- The client should furnish an assessment of the facility by his insurance company.
- System design parameters are not mentioned.
- The engineer does not perform any design or redesign functions.
- The engineer is not responsible for hidden damage revealed during progress of the work.
- If modifications to existing systems are requested, this is considered extra work.
- The architect or client should furnish all existing plans and specifications.
- Insulation is not to be disturbed.
- The engineer indicates the presence of suspected insulation containing asbestos when observed. It is strongly recommended that additional tests be conducted by a third party.

Figure 13-1 Suggested Format for Condition Report

INTRODUCTION

The first part should contain the following information:

1. The purpose and scope of the survey
2. A statement of a problem or problems specific to the subject building, if any
3. A brief physical description of the building, including:
   a. Physical description of the building, such as the size, number of stories, type of construction, energy sources, etc.
   b. History of the building, such as date of initial construction, history of major alterations, repair history, and listing if this is considered a historical building
   c. Usage, both past and present
   d. A maintenance overview
4. The boundaries of the building site, showing all property lines and streets, both past and present
5. Planned future usage of the building
6. Repair, upgrading, or replacement of any system(s) or equipment that has been done
7. Any existing maintenance contracts and their purpose
8. A summary of additional abbreviations and definitions if necessary

EXECUTIVE SUMMARY

This section is intended to provide the client with a brief overview of the building condition, problems, and costs.

1. Discuss findings of the survey.
2. Provide general recommendations.
3. Provide a maintenance overview. This may include staffing for the basic mechanical systems.
4. Discuss in general terms the estimates by discipline.
5. Immediately note if any dangerous or priority conditions exist, or if a situation exists that might be a threat to life safety.

OBSERVATIONS AND CONCLUSIONS OF OBSERVED PLUMBING EQUIPMENT

1. Domestic water system
   a. Location, size, and arrangement of water service and distribution, including:
      - Services: Number and location, pressure available, metering, backflow prevention, treatment
      - House tanks: Number and location. Are the water level controls reliable and functioning?
      - House pumps: Number and location and pump rating. How are they controlled? What is the condition of the shaft bearings and seals?
      - Condition of pressure-boosting system, if provided, and controls. Is there excessive vibration or cycling?
      - Are there any water treatment facilities, such as softeners?

Figure 13-1 Suggested Format for Condition Report (continued)

b. Condition of system valves, strainers, piping and insulation, supports, and accessibility. Check the visible piping hangers, sway bracing, pipe joints, valves, and the piping itself for any deficiencies, particularly at the points of possible connections. Are there valve tags and a tag chart?

c. System pressure at service entrance and at remote fixtures

d. Condition of plumbing fixtures, water hammer arrestors, hose bibbs, etc. Are pressure-reducing valves installed? Check the condition and spot check pressures.
- Verify the age and gallons per flush or gallons per use.
- Check the flow in gallons per minute of a sampling of fixtures.
- Verify the amount of time it takes to get hot water to remote fixtures.

e. Provisions for pipe expansion and condition of expansion joints

f. Presence of drip pans

g. Check the condition of the existing hot water generator and circulator. If the building is working, check the water temperature at the generator, a few remote fixtures, and the recirculation line at the generator. This should include the following:
- Number and type of heaters
- Location of heaters
- Input rating in British thermal units per hour
- Condensing/non-condensing
- Storage or tankless
- Any maintenance problems
- Location and operability of safety valves, thermometers, and water temperature and mixing valves

h. Spot check the piping and tank insulation. If the building was built before 1978, asbestos insulation may be present. Pay particular attention to the piping and equipment in the mechanical room.

i. Is there any sweating or indication of leakage from piping, walls, or ceilings?

j. Are there any obvious cross-connections?

k. Does the client wish to have the engineer review the sewer and water charges for discrepancies?

l. Does there appear to be an excessive use of water?

m. Have any unscheduled outages occurred in the past 12 months? Also, indicate which equipment requires frequent maintenance and repair.

2. Drainage systems

a. Point of discharge for sanitary and storm systems. Will die tracing be necessary to find the point of discharge? Will the height of manholes above grade prevent the entrance of water?

b. Condition of sanitary and waste systems including sump pumps and sewage ejector pumps and controls
- Number and location
- Manufacturer and model/size
- Motor speed in revolutions per minute
- Motor horsepower
- Emergency power
- How are they controlled?
- What is the condition of the shaft bearings and seals?

c. Condition of piping, cleanouts, fixture traps, plumbing fixtures, etc.

d. Condition of stormwater systems including roof drains, poor drainage, grates, and secondary drainage system. This includes the secondary system's point of discharge.

e. Condition and presence of grease traps and check valves

f. Poor floor drainage or drains not properly located. Trap primer provisions.

Figure 13-1 Suggested Format for Condition Report (continued)

g. Condition of the elevator sump pit. Is the pit clean? Are the pump and controls operating?
h. Conditions of ladder access in manholes

3. Fire suppression and fire safety systems
   a. Service: Number of services, pressures available, meter types and locations
   b. Condition of the fire pump, sprinkler system piping, alarms, and valves
   c. Condition of hose racks, hose, and hose valves
   d. Condition of sprinklers, such as being painted, in a poor location, or corroded
   e. Obvious areas where sprinklers are missing
   f. Condition and location of fire extinguishers
   g. Condition and location of smoke and heat detection systems
   h. Special systems such as those for computer rooms and kitchens
   i. Condition and location of fire pump test header and fire department connection
   j. Emergency power
4. Fuel gas system
   a. Condition of natural gas system, including meter, meter arrangement, and location
   b. What is the heating value of the gas and the existing gas pressure?
   c. Condition of the gas-using equipment
5. Other building systems
   a. Equipment connections to emergency generators
   b. Condition of chilled drinking water system, if any, including tanks, pumps, and insulated piping
   c. Is any piping exposed to freezing temperatures?
   d. Plumbing connections for the following:
      - Boiler water makeup
      - Chilled water system makeup
      - Cooling tower makeup
      - Backflow provisions and back-siphonage protection
   e. What is the condition of any water-softening treatment systems? Are maintenance logs available for inspection?
   f. Access to the roof
   g. Access to fall protection restraints
   h. Signs at locations where confined space entry would be obtained

RECOMMENDATIONS

Based on the observations and conclusions, recommendations should be made to correct defects by subject and system. If a serious problem is discovered, it should be brought to the attention of the client immediately, first by direct contact and secondly via written correspondence.

COST ESTIMATES

The estimated costs of all of the observed deficiencies should be prepared by priority, subject, and system. Potentially, energy and water cost savings should be evaluated for using water-efficient fixtures or alternate water-heating methods or improving controls for water pressure booster systems.

Figure 13-2 Proposed Abbreviations for Reports

CONDITION

1—Excellent
2—Good
3—Fair
4—Poor
5—Unserviceable
6—Minimal wear indicated
7—Moderate wear indicated
8—Extreme wear indicated

DEFICIENCY

1—Inadequate
2—Excessive
3—Loose
4—Broken
5—Dirty
6—Noisy
7—Misaligned
8—Leaks
9—Corroded
10—Vibration
11—Plugged
12—Shut off
13—Disassembled
14—Disconnected
15—Missing
16—Obsolete
17—Inoperable
18—Code violation
19—Overage/beyond normal useful life
20—Improperly set or misadjusted
21—Not properly supported
22—Untreated
23—Reduced

ACTION

1—Repair
2—Replace
3—Reassemble
4—Lubricate
5—Install
6—Water treatment required
7—Exercise
8—Clean
9—Rod out
10—Test or investigation required
11—Adjust correctly
12—Add additional supports
13—Apply protective coating

PRIORITY

1—Urgent, might be an immediate threat to life safety
2—Urgent, might be a threat to property
3—Urgent, imminent possibility of failure
4—At next scheduled maintenance or one year
5—Within a five-year period

Building Information Modeling

The engineering field has become a highly competitive market, and the designs that plumbing engineering professionals are required to supply are quickly evolving. The design of plumbing systems is becoming more visible, and engineers are asked to provide not only stamped construction documents, but also 3D models to help contractors bid more accurately. Thus, an engineer who does not familiarize him- or herself with building information modeling (BIM) technologies will be left out of future projects. However, the concept of BIM goes beyond three-dimensional models of building systems and integrates all aspects of a building's components from design and construction through the building's life-cycle (4D, 5D, and 6D, see the "Definitions and Terms" section below). BIM is intended to be used by all members of the design team, contractors and subcontractors, and the building owner and facility personnel to manage costs, construction, and operations.

Numerous resources and software providers are available to plumbing engineers, many of which are proprietary. This chapter takes a generalized overview of BIM to introduce its basic concepts.

DEFINITIONS AND TERMS

2D Hand drawings or CAD drawings represented in two dimensions: length x width or X, Y coordinates.

3D Drawings that are represented in three dimensions: length x width x height or X, Y, Z coordinates.

4D The relation of time to a project concerning phasing or scheduling.

5D The relation of cost estimation and automated quantity takeoffs to a project.

6D The relation of life-cycle management to a project for the owner's or facility management's use.

Building information modeling (BIM) A process involving the production and management of digital representations of the physical and functional characteristics of a building's design, construction, costs, maintenance, and management. The building information models become shared knowledge resources to support collaboration about a building from the earliest stages of conceptualization, to design and construction, throughout the life of the building, and to eventual demolition.

buildingSMART alliance An organization formed within the National Institute of Building Sciences to promote open interoperability and full life-cycle implementation of building information modeling as well as to develop national standards including the National BIM Standard–United States (NBIMS–US).

Construction Operations Building Information Exchange (COBie) An information exchange specification for the life-cycle capture and delivery of information created during design, construction, and commissioning, which is passed directly to the building operator to be put into the owner's facility management program.

Constructability model A BIM model used to simulate the actual components of a building in 3D, created as the building would be built, used primarily for MEP model coordination, 4D simulations, and 5D estimating or quantity takeoffs.

Design model A BIM model developed by a segment of the design team (architectural, mechanical, structural, plumbing, electrical) from which the automated construction documents are derived, along with automated schedules, details, and client presentations.

Industry Foundation Classes (IFC) A data model developed by the buildingSMART alliance that makes it possible to hold and exchange data between different proprietary software applications to facilitate interoperability in the building industry. It is a neutral format of open BIM.

Integrated project delivery (IPD) A project delivery approach that integrates people, systems, business structures, and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication, and construction.

Level of detail (LOD) Developed by the American Institute of Architects (AIA), five steps through which a BIM element can logically progress from the lowest level of conceptual approximation to the highest level of representational precision.

LOD 100 Essentially the equivalent of conceptual design, consisting of overall building massing.

LOD 200 Similar to schematic design or design development, consisting of generalized systems or assemblies with approximate quantities, sizes, shapes, locations, and orientations.

LOD 300 Models suitable for the generation of traditional construction documents and shop drawings.

LOD 400 Models suitable for fabrication and assembly, typically originating from the trade contractor or fabricator.

LOD 500 A final representation of the project as it has been constructed; the as-built conditions. This model is suitable for facility maintenance and operations.

Open BIM A unified method of collaboration for design, construction, and building operations based on open standards and workflow. Open BIM is an initiative of the buildingSMART alliance and several leading software vendors using the open buildingSMART data model (IFC).

Virtual design and construction The management of integrated multidisciplinary performance models of design-construction projects, including the building, work processes, and organization of the design, construction, and operation teams.

FROM THEORY TO PRACTICE

One of the biggest drawbacks to BIM is the lack of comprehensive implementation and knowledge. For instance, a plumbing engineer working on an Army Corps of Engineers project may be required to provide BIM information that interacts with COBie (Construction Operations Building Information Exchange). Typically this information is gathered during the construction phase due to commissioning practices being implemented by the owner, but if this information is required during design, then the plumbing engineering professional is required to input information into an IFC (Industry Foundation Classes) format that can be used to translate the design product information from the model into a database for facilities management software. The theory is that gathering all of this information upfront will ultimately help the building owner construct and operate the building more efficiently, when in practice most owners do not have any idea what to do with this information when they receive it.

At the time of the writing of this chapter, plumbing BIM software is lacking in a few areas that affect plumbing design the most. One of those key areas is pipe sizing. If a third-party software developer understood the true value of the relationships between flow, friction, pressure loss, total dynamic head, and static and residual pressure with the total length of run of pipe and was able to correlate that with a current plumbing code, they would be able to develop a very productive piece of software. In practice, while great advances have been made in the various software packages, plumbing models still fall well short of their counterparts. Plumbing designers can help combat this problem by creating troubleshooting lists as they run into problems to keep track of solutions and workarounds for other designers to reference.

The BIM process can save time and money, but this is possible only if the plumbing designer is efficient at using the BIM software that is required for the project. One of the biggest setbacks that an engineering firm can face when using BIM is underestimating the importance of proper training and funding for the end user. When BIM projects start growing in size, so does the data, resulting in performance issues with the computer system running the software. Users must know how to properly assess and take the proper measures to keep the production of a project on track. If the computer system is not set up to at least the minimum specifications required by the software vendor, then the owner has already started on a path of failure.

QUESTIONS THAT MUST BE ANSWERED

A few productive tools can be used to produce building information models, and plumbing designers, engineers, and contractors must be aware of them to ask educated questions of vendors about their products. The following discussion references design building information models and construction building information models, but different products take different approaches to meet the definition of BIM.

When choosing a BIM software product, an individual or company should ask the following questions:

- What is the goal to be accomplished?
- Will the product be able to help create an effective source of income?
- Will the models need to contain element-type information for future use with facilities management software?
- Will this model be shared with contractors?
- What is the timeframe of training and education vs. production?

What Is the Goal to Be Accomplished?

This should be the first question ever raised; instead, most decisions about new software are a knee-jerk reaction to an industrial or economic change or forecast. Many companies jump on the BIM bandwagon without understanding their needs or the level of training and implementation required.

To effectively answer this question, start by looking at the definition of BIM. Do not just look at the blanket response, but how the definition affects the company's projects or designs. For example, engineering firms will need software that is effective for designing plumbing or mechanical piping systems. Contractors will need software that works with cost estimating software and can be used for fabricating parts and assemblies. Numerous solutions for various needs are available.

Will the Product Be Able to Help Create an Effective Source of Income?

The answer to the first question will help answer this question. In our current economic climate, projects are being won or lost because of the ability to meet owners' demands for more quality at an equal or discounted price. Thus, obtaining real-world information on returns on investment from other companies using the software being considered is essential. The calculation should include any network and hardware requirements and training costs. Staging expectations can go a long way toward producing a manageable and profitable solution.

Keep in mind that each LOD that is required has a certain cost impact on producing a BIM model. LOD 100 models can be produced easily and quickly using 3D sketching software. LOD 300 models require more time and more complex software. LOD 400 models will increase time and labor even further and require more collaboration. LOD 500 models can cost as much as two times more than LOD 300 models to produce due to the level of complexity required.

Will the Models Need to Contain Element-Type Information for Future Use with Facilities Management Software?

After considering the company's needs and price point, it is time to find out what the clients expect. For instance, designers seldom request piping to be shown in double lines unless the design is for a congested area or the budget could allow for such detail. With the advancement of facilities management software, this request will become more relevant. Some BIM software packages are better tooled for facilities management than others. If this must be a consideration for client projects, it is in the company's best interest to ask this question early to avoid completion issues.

Will This Model Be Shared with Contractors?

As more and more contractors begin to embrace and incorporate BIM, plumbing engineers have to ask themselves if their building information model will be shared with the contractor once the design is completed. Even though this is not a requirement on most projects, it is slowly becoming the industry norm. With the time and money savings that can be realized with digital coordination/cost estimating and the increased accuracy that a three-dimensional model can provide, the contractor is more likely to request a BIM file for coordination than they are a two-dimensional electronic file. The engineer's response to this request does not have to be the same for every project, but it can have an impact on the level of detail and coordination that a plumbing designer will need to place in the model during their design.

For instance, a small restroom building with few plumbing systems could be field coordinated easily and estimated with a simple cost-per-square-foot number. A project like this may only need to reach LOD 200 or 300. On the other hand, a 200,000-square-foot K–12 school building with several plumbing systems will be much more difficult to estimate based on cost per square foot, and the time it would take to field coordinate the installation could delay the project substantially. The contractor can utilize an accurate and complete model to obtain a more accurate cost estimate and to streamline the coordination process, but the plumbing designer would have to take more care in laying out systems. This model would include more LOD 400 elements such as correct fitting types, correct pipe slopes, and purposeful valve placements. Knowing which level of detail to assign to which projects can help an engineer be more successful when implementing BIM early on as well as making it more profitable once established.

What Is the Timeframe of Training and Education vs. Production?

The answer to this last question can have a big impact on engineering job losses for plumbing designers. Using BIM for MEP requires a different take on the current engineering business method. If BIM is to be implemented, it will require the retooling of details and templates, the creation of 3D content, and a commitment to these fundamental changes. Training a small team can be very beneficial and cost-effective, but if the team is not comprised of self-motivated, quick-learning, and positive-thinking personnel with the ability to teach others what they have learned, the initiative is doomed for failure. The company will spend more time and money fueling this losing cause than it would training the entire staff and outsourcing the development of templates, details, and content.

When selecting an online training method or training consultant, ask for references. When talking to the referenced company, find out how long it took to be profitable using the BIM software or if they tracked ROI. Ask about template, detail, and content development. This will help establish benchmarks for a company. Use these benchmarks as success markers for company trainees. Keeping a positive mindset will go a long way in motivating designers. Do not project unreal schedules when starting a process such as retooling design workflows. With proper planning and preparation, a company will be able to succeed in the BIM arena.

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