American Society of Plumbing Engineers

Plumbing Engineering Design Handbook

A Plumbing Engineer's Guide to System Design and Specifications

Volume 1

Fundamentals of Plumbing Engineering

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1

Formulas, Symbols, and Terminology

For the convenience of plumbing engineers, following are some of the basic formulae commonly referred to and utilized in plumbing engineering and design. It is extremely important to convert to values of 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. This term is frequently left out of equations with no effect to 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). Equations listed in parenthesis are used to represent equations that are unit-system specific to SI units and differ when using English units.

FORMULAE COMMONLY USED IN PLUMBING ENGINEERING

The Manning Formula

The Manning Formula is used for determining the velocity (V) of uniform flow (defined as the flow that is achieved in open channels of constant shape and size and uniform slope) in sloping drains. Note that the slope of the water surface is equal to the slope of the channel, and that 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 1-1

$$V = \frac{1.486\, R^{2/3}\, S^{1/2}}{n}$$

Equation 1-1a (metric)

$$V = \frac{1.00\, R^{2/3}\, S^{1/2}}{n}$$

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 (R) can be calculated using Equation 1-3. The roughness coefficient (n) and several values for the hydraulic radii are given in Baumeister and Marks's *Standard Handbook for Mechanical Engineers*.[1]

Rate of Flow

Equation 1-2 is used for determining 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 1-2

$$Q = AV$$

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

Equation 1-2a

$$Q = \frac{1.486\, AR^{2/3}\, S^{1/2}}{n}$$

Equation 1-2b (metric)

$$Q = \frac{1.000\, AR^{2/3}\, S^{1/2}}{n}$$

Hydraulic Radius (R)

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

Equation 1-3

R = Area of flow/Wetted perimeter

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

Equation 1-3a

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

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)

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:

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 (kilograms [kg]/m^3)
μ = Absolute viscosity of fluid, lb-s/ft^2 (m^2/s)
g_c = Gravitational constant, 32.2 lbm-ft/lbf-s^2

Values of viscosity are tabulated in the *ASHRAE Handbook of Fundamentals*.[2] 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 Re between 2,000 and 4,000 are classified as critical flows. Re 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 Darcy's Friction Formula:

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 (kilopascals [kPa] or kg/m^2), the following relationship is used:

Equation 1-5a

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

where

P = Pressure, lbf/in2 (kPa)
γ = Specific weight of substance, lbf/ft3 (N/m3)
h = Static head, ft (m)

Therefore, Equation 1-5 may be represented as:

Equation 1-5b

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

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 friction loss, the Hazen-Williams Formula is used:

Equation 1-5d

$$h = 0.002082L\left(\frac{100}{C}\right)^{1.85}\left(\frac{q^{1.8}}{d^{4.8655}}\right)$$

where

h = Pressure drop, pounds per square inch [psi] (kPa)
C = Friction factor for Hazen-Williams
q = Flow rate, gallons per minute (gpm) (liters per second [L/s])
d = Actual inside diameter of pipe, in. (mm)
L = Length of pipe, ft (m)
f = Friction factor

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

Potential Energy

Potential energy 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 (joules [J])
W = Weight of body, lbf (newtons [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 (KE)

Kinetic energy 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 Baumeister and Marks's *Handbook for Mechanical Engineers*.

Length of Vent Piping

Length of vent piping can be determined by combining Darcy's Friction Formula (Equation 1-5) and the flow equation:

Equation 1-9

$$L = \frac{2226d^5}{fQ^2}$$

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 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 stack, gpm (L/s)
r = Ratio of cross-sectional area of the sheet of water to cross-sectional area of stack
d = Diameter of stack, in. (mm)

Flow Rate in Fixture Drain

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 water surface above the point of 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

$$L_2 - L_1 = C_E L_1\ (T_2 - T_1)$$

where

L_2 = Final length of pipe, ft (m)
L_1 = Initial length of pipe, ft (m)
C_E = Coefficient of expansion of material (A material's expansion coefficient may be obtained from the *ASHRAE Handbook of Fundamentals*.)
T_2 = Final temperature, °F (°C)
T_1 = Initial temperature, °F (°C)

Formulae for Areas and Volumes, in ft^2 (m^2) and ft^3 (m^3) Respectively

Equation 1-13a, Square (See Figure 1-1.)

$A = bh$

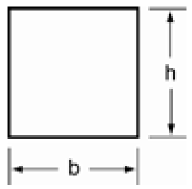


Figure 1-1 Square

Equation 1-13b, Rectangle (See Figure 1-2.)

$A = bh$

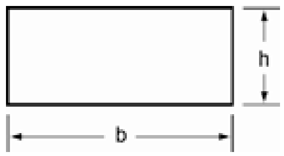


Figure 1-2 Rectangle

Equation 1-13c, Rhombus (See Figure 1-3.)

$A = bh$

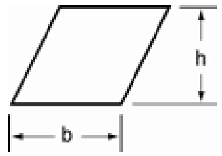


Figure 1-3 Rhombus

Equation 1-13d, Rhomboid (See Figure 1-4.)

$$A = bh$$

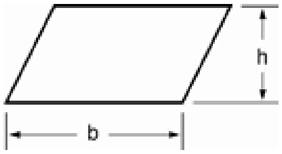


Figure 1-4 Rhomboid

Equation 1-13e, Trapezoid (See Figure 1-5.)

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

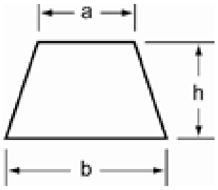


Figure 1-5 Trapezoid

Equation 1-13f, Trapezium (See Figure 1-6.)

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

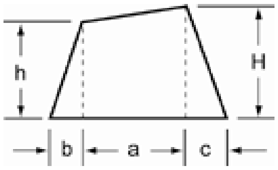


Figure 1-6 Trapezium

Equation 1-13g, Right-angle triangle (See Figure 1-7.)

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

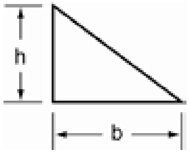


Figure 1-7 Right-Angle Triangle

Equation 1-13h, Isosceles triangle (See Figure 1-8.)

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

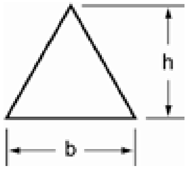


Figure 1-8 Isoceles Triangle

Equation 1-13i, Ellipse (See Figure 1-9.)

$$A = \pi ab$$

where

$a = D$

$b = d$

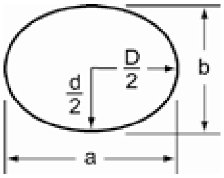


Figure 1-9 Ellipse

Equation 1-13j, Cylinder (See Figure 1-10.)

$$A = \pi Dh$$

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

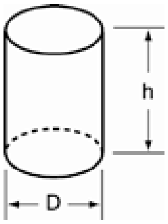


Figure 1-10 Cylinder

Equation 1-13k, Cube or rectangular solid (See Figure 1-11.)

$$V = whl$$

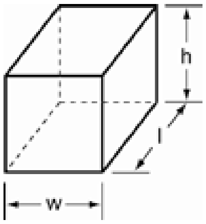


Figure 1-11 Cube or Rectangular Solid

Equation 1-13l, Pyramid (See Figure 1-12.)

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

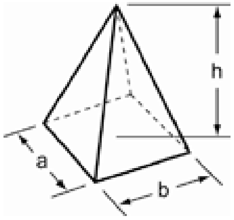


Figure 1-12 Pyramid

Equation 1-13m, Cone (See Figure 1-13.)

$$A = \frac{\pi Ds}{2}$$

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

where

$D = b$

$R = \frac{b}{2}$

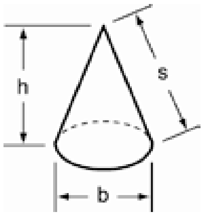


Figure 1-13 Cone

Equation 1-13n, Circle (See Figure 1-14.)

$$C = 2\pi R$$

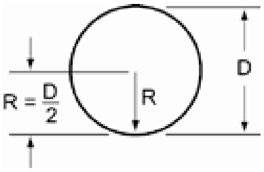


Figure 1-14 Circle

Equation 1-13o, Circle (See Figure 1-14.)

$$A = \pi R2$$

Equation 1-13p, Triangle[3] (See Figure 1-15.)

Known: 2 angles

Required: Third angle

Solution: $A = 180° - (B + C)$

Equation 1-13q, Triangle[3] (See Figure 1-15.)

Known: 3 sides

Required: Any angle

Solution: $\cos A = \dfrac{b^2 + c^2 - a^2}{2bc}$

Equation 1-13r, Triangle[3] (See Figure 1-15.)

Known: 2 sides and included angle

Required: Third side

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

Equation 1-13s, Triangle[3] (See Figure 1-15.)

Known: 2 sides and included angle

Required: Third angle

Solution: $\tan A = \dfrac{a \sin C}{b - a \cos C}$

Equation 1-13t, Triangle[3] (See Figure 1-15.)

Known: 2 sides and excluded angle

Required: Third side

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

Equation 1-13u, Triangle[3] (See Figure 1-15.)

Known: 1 side and adjacent angles

Required: Adjacent side

Solution: $c = \dfrac{a \sin C}{\sin A}$

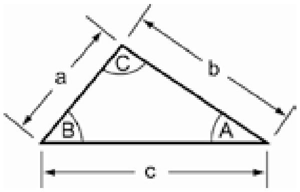


Figure 1-15 Triangle

Flow Rate in Outlet

With Equation 1-11, we determined 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 coefficients (c_D) may be obtained from Baumeister and Marks's *Handbook for Mechanical Engineers*.

Gravity Circulation

This principle is used to keep the sanitary system free of foul odors and the growth of slime and fungi. 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 the *ASHRAE Handbook of Fundamentals*.

Velocity Head (h)

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 (h) 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

$$E_T = \frac{Zg}{g_c} + \frac{P}{\rho} + \frac{V^2}{2g_c}$$

$$\left(E_T = Zg + \frac{P}{\rho} + \frac{V^2}{2}\right)$$

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 $lbm\text{-}ft/lbf\text{-}s^2$

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 (h_f)

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

$$h_f = (Z_1 + h_1 + v_1^2/2g_c) - (Z_2 + h_2 + V_2^2/2g_c)$$

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 = Gravitational acceleration, 32.2 ft/s^2 (9.8 m/s^2)
g_c = Gravitational constant, 32.2 lbm ft/lbf s^2

Subscripts 1 and 2 represent points in the system.

Flow from Outlets

This velocity 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

$$P = \frac{\gamma\, a dV}{144g}$$

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)
dV = 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 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 specific weights (γ), K, and B are given or can be calculated from the *ASHRAE Handbook of 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 among the capacity, head, brake horsepower, speed, and impeller diameter of a given pump.

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

Equation 1-21a

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

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

where

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 change in diameter of the impeller.

Equation 1-21b

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

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

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 derived from:

$$\text{WHP} = \text{ft Hd} \times \frac{\text{gal}}{\text{min}} \times \frac{8.33\text{ lb}}{\text{gal}} \times \frac{\text{HP}}{33{,}000\text{ ft-lb/min}}$$

BHP = Brake horsepower input to pump

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

Equation 1-22a

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

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

Rational Method of Storm Design

This calculates the peak storm water runoff.

Equation 1-23

$$Q = CIA$$

where

Q = Runoff, ft³/s (m³/s)

C = Runoff coefficient (surface roughness in drained area)

I = Rainfall intensity, in./h (mm/h)

A = Drainage area, acres (m²)

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

$$Q = 3550\left(\frac{d^5}{1 + {}^{3.6}\!/\!{}_{d} + 0.03d}\right)^{1/2}\left(\frac{h}{SL}\right)^{1/2}$$

where

Q = Flow rate, f^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 = Length of pipe, ft (m)

Weymouth Formula

The Weymouth Formula is used to size gas piping in systems operating at a pressure in excess of 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 = Length of pipe, mi (km)

Slope

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

Equation 1-26

$$s = \frac{h}{l}$$

$$h = l \times s$$

$$l = \frac{h}{s}$$

where

s = Slope, in./ft (mm/m)

h = Fall, in. (mm)

l = Length, ft (m)

Discharge from Rectangular Weir with End Contractions

Equation 1-27

$$Q = 1494.6\ (L - 0.2H)H^{1.5}$$

where

Q = Rate of flow, ft^3/s (m^3/s)

L = Length of weir opening, ft (Should be longer than 2H.)

H = Head of water, ft (m)

a = Should be at least 3H. (Refer to *Plumbing Engineering Design Handbook, Volume 2,* Chapter 4: "Storm Drainage Systems" Table 4-5 for diagram.)

Heat Loss Formula

Equation 1-28

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

where

q = Heat loss per unit length of pipe, Btuh × 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 × ft² × °F (W/m² × °C)

D_2 = Outside diameter of the insulation, ft (m)

k = Thermal conductivity of the insulation evaluated at its mean temperature, Btuh × ft × °F (W/m² × °C)

h_{co} = Inside air contact coefficient of weather barrier, Btuh × ft² × °F (W/m² × °C)

h_o = Outside air film coefficient from weather barrier to ambient, Btuh × ft² × °F (W/m² × °C)

SYMBOLS

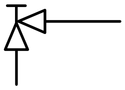
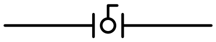
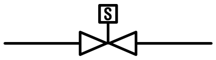
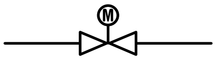
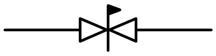
The standardized plumbing and piping-related symbols in Tables 1-1 and 1-2 and the abbreviations in Table 1-3 have been tabulated by the American Society of Plumbing Engineers for use in the design and preparation of drawings. Users of these symbols are cautioned that some governmental agencies, industry groups, and other clients may have a list of symbols that are required for their projects. All symbols should be applied with a consideration for drafting and clarity if drawings are to be reduced.

Table 1-1 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
— — — — — — — — — — —	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

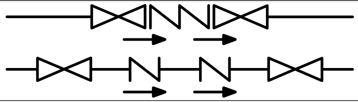
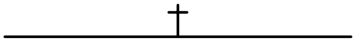
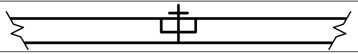
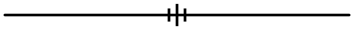
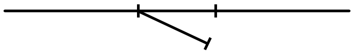
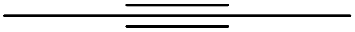
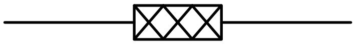
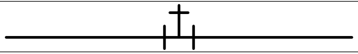
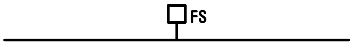
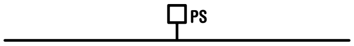
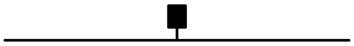
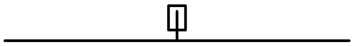
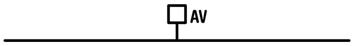
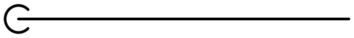
(CONTINUED)

Table 1-1 Standard Plumbing Drawing Symbols

Symbol	Description	Abbreviation
——— HPCA ———	High-pressure compressed air	HPCA
——— HHWS ———	(Heating) hot water supply	HHWS
——— 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

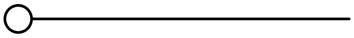
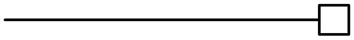
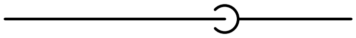
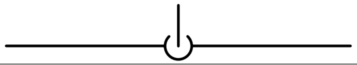
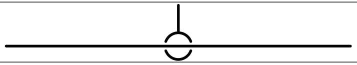
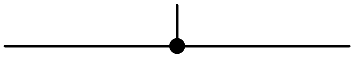
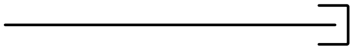
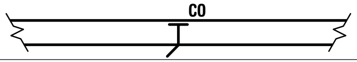
(CONTINUED)

Table 1-1 Standard Plumbing Drawing Symbols

Symbol	Description	Abbreviation
	Pressure-relief valve	RV
	Temperature pressure-relief valve	TPV
	Backflow preventer	RZBP
	Hose bibb	HB
	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)	

(CONTINUED)

Table 1-1 Standard Plumbing Drawing Symbols

Symbol	Description	Abbreviation
	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	
	Point of connection	POC
	Outlet (specify type)	
	Steam trap (all types)	
	Floor drain with p-trap	FD

[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 1-2 Standard Fire Protection Piping Symbols

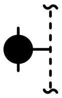
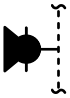
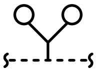
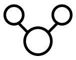
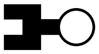
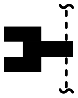
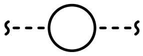
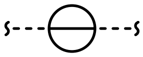
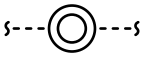
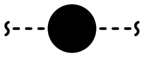
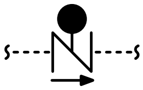
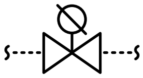
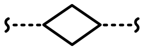
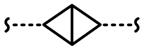
Referent (Synonym)	Symbol	Comments
Water supply and distribution symbols		
Mains, pipe		
Riser		
Hydrants		
Public hydrant, two hose outlets		Indicate size,[a] type of thread, or connection
Public hydrant, two hose outlets and pumper connection		Indicate size,[a] type of thread, or connection
Wall hydrant, 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
Fire pumps		
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 system		
Symbols for various types of extinguishing systems[b]		
Supplementary symbols		
Fully sprinklered space		
Partially sprinklered space		
Nonsprinklered space		

Table 1-2 Standard Fire-Protection Piping Symbols (continued)

Referent (Synonym)	Symbol	Comments
Symbols for fire sprinkler heads		
Upright sprinkler[c]		
Pendent sprinkler[c, d]		
Upright sprinkler, nippled up[c]		
Pendent sprinkler, on drop nipple[c, d]		
Sidewall sprinkler[c]		
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
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 1-3 Commonly Used Plumbing Abbreviations

The standardized plumbing and piping abbreviations in Table 1-3 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 clients may have a list of preferences that are required for their projects. All symbols should be applied with a consideration for drafting and clarity if drawings are to be reduced.

Term	Abbreviation
Above finished floor	aff
Absolute	abs
American Gas Association	AGA
American Institute of Steel Construction	AISC
American National Standards Association	ANSI
American Petroleum Institute	API
American Society of Mechanical Engineers	ASME
American Society of Plumbing Engineers	ASPE
American Society of Sanitary Engineering	ASSE
Area drain	ad
Alternating current	ac
American National Standards Institute	ANSI
American Society of Heating, Refrigerating, and Air-conditioning Engineers	ASHRAE
American Society of Testing Materials	ASTM
Ampere	amp
American Water Works Association	AWWA
Angle valve	av
Backflow preventer	bfp
Ball valve	bv
Bathtub	bt
Brake horsepower	bhp
British thermal unit	Btu
Butterfly valve	bfv
Cast iron	CI
Canadian Standards Association	CSA
Centers for Disease Control	CDC
Celsius	°C
Compressed Gas Association	CGA
Check valve	cv
Chemical and Petroleum Industry	CPI
Cleanout	co
Cleanout deck plate	codp
Cold water	cw
Compressed air	ca
Cubic feet	ft^3
Cubic feet per minute	cfm
Cubic feet per second	cfs
Current good manufacturing practice	cGMP
Double check valve	dcv
Degree	deg. or °
Diameter	dia.
Department of Transportation	DOT
Deutsches Institut fur Normung	DIN
Diameter, inside	ID
Diameter, outside	OD

(CONTINUED)

Term	Abbreviation
Difference or delta	Δ
Direct current	dc
Distilled water	dw
Dimensional, nominal (size in metric)	DN
Down	dn
Drop manhole	DMH
Drinking fountain	df
Drainage fixture unit	dfu
Drainage inlet	DI
Drawing	dwg
Elevation	elev.
Fahrenheit	°F
Feet per minute	fpm
Feet per second	fps
Fire extinguisher	fe
Fire hose rack	fhr
Fire hose valve	fhv
Fixture unit	fu
Foot or feet	ft
Foot-pound	ft-lb
Foot head	ft.hd.
Gallons	gal
Gallons per day	gpd
Gallons per minute	gpm
Gallons per hour	gph
Good manufacturing practice	GMP
Hands-off automatic	HOA
Head	hd
Horsepower	hp
Hose bibb	hb
Heater	htr
Hot water	hw
Hot water return	hwr
Heating, ventilating, and air-conditioning	HVAC
Hertz	Hz
Inches	in
Inches per hour	in./hr
Inch-pounds	ip
Inside diameter	id
Invert elevation	ie
Industrial risk insurers	IRI
International Plumbing Code	IPC
Iron body bronze mounted	ibbm
Iron pipe size	ips
Kelvin	ºK
Kilowatt	kW

(CONTINUED)

Table 1-3 Commonly Used Plumbing Abbreviations (continued)

Term	Abbreviation
Kilowatt hour	kWh
Kitchen sink	ks
Laundry tray	lt
Lavatory	lav
Leader	l
Linear feet	lin ft
Liquefied petroleum gas	lpg
Manhole	mh
Mechanical equipment room	mer
Million gallons per day	mgd
Miles per hour	mph
Minimum	min.
Material safety and data sheet	msds
National Bureau of Standards	NBS
National Electrical Manufacturers Association	NEMA
National Fire Protection Association	NFPA
National Plumbing Code	NPC
National pipe thread	npt
Natural gas	ng
National Oceanic and Atmospheric Administration	NOAA
Nominal pipe size	nps
Normally closed	n c
Normally open	n o
Normal temperature and pressure	ntp
Not in contract	n i c
Not to scale	nts
Number	no.
Occupational Safety and Health Administration	OSHA
Original equipment manufacturer	oem
On center	oc
Outside diameter	od
Ounce	oz
Oxygen	o
Parts per million	ppm
Piping and instrumentation diagram	P & ID
Plug valve	pv
Post indicator valve	piv
Pounds	lb
Pounds per cubic foot	lb/ft^3
Pounds per square foot	psf
Pounds per square inch	psi
Pounds per square inch, absolute	psia
Pounds per square inch, gauge	psig
Pressure Reducing Valve	prv
Pressure relief valve	pv
psi absolute	psia
psi gage	psig
Rankine	°R
Reduced pressure zone	rpz
Revolutions per minute	rpm
Revolutions per second	rps
Relative humidity	rh
Roof drain	rd
Root main square	rms
Sanitary fixture units	sfu
Shower	sh
Sillcock	sc
Soil	s
Specific gravity	sg
Standard dimensional ratio	sdr
Standard	std
Service sink	ss
Steam working pressure	swp
Sprinkler	spkr
Systeme International d'Unites	SI
Temperature and pressure relief valve	tprv
Tempered water	tw
That is	i.e.
Thousand cubic feet	Mcf
Thousand pounds	kip
Top elevation	te
Thermostatic mixing valve	tmv
Typical	typ
Ultraviolet	UV
Universal Plumbing Code	UPC
Urinal	ur
Vacuum	vac
Vent	v
Volatile organic compound	voc
Wall hydrant	wh
Waste	w
Water closet	wc
Water fixture units	wfu
Water, oil, and gas	WOG
Water working pressure	wwp
Yard hydrant	yh
Zone control valve	zcv

(CONTINUED)

PLUMBING TERMINOLOGY[4]

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 This is 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 a true value of a quantity or concern.

Accessible That which enables direct approach, either with or without the removing or moving 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 more quickly.

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

Actual capacity The volume rate of air compressed and delivered at the discharge point referred to inlet conditions.

Adapter fitting Any fitting that serves to mate or connect to each other two pipes or fittings different in size, material, or design.

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

Adiabatic compression Air compressed 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, 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 and air into direct contact with one another.

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

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, standard Air having a temperature of 60°F (15.6°C), with a pressure of 14.70 psia (101.4 kPa) and 0.0 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 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 the 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 highest to 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 the 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 (or approaches) 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 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 Used to replace excavated material for piping installed in an earthen trench.

Backflow 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. In drainage systems, it is the reversal of flow.

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 the potable water distribution system which 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 spherical closure member.

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

Base The lowest point of a stack of vertical pipe. Another definition is 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, the spigot is inserted into the hub. 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 emptying or discharge of sediment.

Bonnet That part of a valve that connects 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 with a vent stack or stack vent.

Brazing The joining of two pipes using a filler metal holding the pipes together that has a melting point more than 1,000°F.

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

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

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

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

Building sewer Called the house sewer, it is that part of the horizontal piping of a drainage system that extends from the end of the building drain outside the building and conveys it 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, it is a device, fitting, or assembly of fittings installed in the house drain to prevent 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 for storm water 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 that cause damage to adjacent parts when these bubbles revert back to a liquid.

Cement joint The union of two fittings by the insertion of material. Sometimes this joint is accomplished mechanically, sometimes 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 That 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 connection with the vent stack.

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

City water A term used for 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 do not contain contaminants considered harmful by the authorities.

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

Coalescing A term used to describe the impingement of small diameter aerosols that causes them to merge.

Cock Often used nomenclature for a faucet.

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

Coefficient of expansion The numerical value that describes the increase in unit length, 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 free movement of air above the flow line of the drain.

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 for increasing the pressure of air or gas.

Condensate Molecules that separate from a gas upon cooling.

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

Conductor The piping conveying storm water located inside the 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 any facility.

Contamination A degradation of quality in any material that creates any 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 Any manual or automatic device for the regulation of a machine or process.

Controller The cabinet containing motor starter(s), circuit breaker(s), disconnect switch(s), 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 the fixture or receptacle served 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 states merge into one another.

Cross A pipe fitting with four branches each at 90° 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 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 Refers to 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 and provides protection.

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

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

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 the pipe.

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.

Department having jurisdiction See *administrative authority*.

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 Listed device for sensing visible or invisible products of combustion.

Developed length The length along the center line of the 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 term used to indicate a percent of estimated usage compared to the connected load.

Digestion A term used in the sewage treatment process where 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 actually 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 for reducing food and other waste by grinding so that 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, lowering the connected load to account for because not all fixtures will be used simultaneity.

Domestic sewage The 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. This is done so that rest periods may be provided between discharges.

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

Down Term referring to any piping running to a lower level.

Downspout The pipe containing rainwater from the roof, located outside of the building, to its ultimate point of disposal.

Downstream Term referring to 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.

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

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

Drainage fixture unit (dfu) A measure of 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 deviating lower from a set value.

Drop Term referring to piping running to a lower elevation within the same floor level.

Drop elbow A small elbow having wings cast on each side, the wings having 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 storm water at the time of collection.

Dry well A pit below ground having porous walls allowing 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 A term used in the design of a storm water drainage system to indicate the concentration of a rainstorm.

Durham system A term used to describe soil or waste systems where all piping is of threaded pipe, tubing, or other such material of rigid construction, and where 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. The silicon content is approximately 14.5 percent, and the acid resistance is in 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. (This is applicable to an air gap.)

Effluent The general term used to describe any substance entering or carried in a drainage system.

Ejector pit A tank or pit located below the normal grade of the 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 an angle between adjacent pipes. The angle is 90° unless another angle is specified.

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 reference to the method of connecting the parts of a piping system, e.g., threaded, flanged, butt-weld, socket-weld.

Engineered plumbing system Plumbing systems 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 Loss of water from the 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 Description of piping material, usually cast-iron, indicating piping 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 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, will sound an audible or visual warning either on or off the protected premises, signaling a fire.

Fire department connection A piping connection on the outside of a building for fire department use to supplement in supplying water for standpipes and sprinkler systems without having to go inside.

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 by persons in the public service regularly engaged in preventing, suppressing, or extinguishing fire; or that will obstruct, delay, hinder, or interfere with the operations of the fire department or the egress of occupants in the event of fire.

Fire hydrant A dedicated piping connection on the site 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 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 having its suction nozzle on the opposite side of the casing from the stuffing box and having the face of the suction nozzle perpendicular to the longitudinal axis of the shaft.
- ***Excess pressure pump*** UL-listed and/or FM-approved, low-flow, high-head pump for sprinkler systems not being supplied from a fire pump. The pump pressurizes the sprinkler system so that the loss of water supply pressure will not cause a false alarm.
- ***Fire pump*** UL-listed and/or FM-approved pump with driver, controls, and accessories used for fire protection service. Fire pumps are of the centrifugal or turbine type and usually have an electric-motor or diesel-engine driver.
- ***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, having its suction and discharge flanges on approximately the same center line.
- ***Pressure maintenance (jockey) pump*** Pump with controls and accessories used to maintain pressure in a fire protection system without the operation of the fire pump. Does not have to be a listed 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 bowl(s) to the discharge head on which the pump driver is mounted.

Fitting Used to connect pipes to one another 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 the fixture from a branch or main.

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

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

Flammable Gases or solids, when in the presence of air at normal temperature and pressure, form a mixture or are a material capable of burning.

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 fastening the pipe to a similarly equipped adjoining pipe. The resulting joint is a flanged joint.

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

Flange faces Pipe flanges that have the entire surface of the flange faced straight across and use either a full-face or ring gasket.

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

Flash point The lower 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 the water supply pipe near the water outlet while the faucet or water outlet is fully open and flowing.

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

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

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. Also see *flushometer valve*.

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.

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

Flushometer 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 see *flush valve*.

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.

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

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

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 with earth. Also known as rubble drain.

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

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

Frostproof A designation given to any 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 is accepted by the administrative authority.

Grade The surface of the ground or the slope or fall of a line of pipe in reference to a horizontal plane. In drainage, it is expressed as the fall in a fraction of an inch or percentage slope per foot or (mm/m) length of pipe. It is sometimes used to indicate the quality of a material.

Grating A device that allows storm water 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.

Grease interceptor An automatic or manual device used to separate and retain grease.

Grease trap An automatic or manual device used to separate and retain grease replacing a fixture trap.

Grinder pump A special class of 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 A device used to allow axial pipe movement only.

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

Halon 1301 Halon 1301 (bromtrifluoromethane CBrF3) is a colorless, odorless, electrically nonconductive gas for extinguishing fires that is no longer used due to environmental considerations.

Hangers A device used to suspend pipes or equipment within the building or structure.

Haunch The portion of a buried pipe below the centerline.

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

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

Heat transfer The movement of heat energy.

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

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

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

Header A pipe that does not diminish in size.

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

Hot water Water at a temperature higher than ambient established by generally accepted practice or code as being suitable for a specific application.

House drain A commonly used term for a house sewer.

House trap A commonly used term for a building trap.

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

Hubless Soil piping with plain ends. The joint is made tight with a stainless steel or cast-iron clamp and neoprene gasket assembly.

Humidity Often called relative humidity, this is a method of determining the percent of water vapor in the air compared to the saturated amount of water vapor possible at the temperature when measured.

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

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

Immiscible A liquid found to be 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 making 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 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 Gases that do not react with other materials at ordinary temperatures and pressures.

Infiltration A 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.

Interceptor A device designed and installed to separate and retain certain matter from waste streams.

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.

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 Term referring to the lowest point on the interior of a horizontal pipe.

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

Isobaric process A term used in the compressing of air that does so under constant pressure.

Isochoric process A term used in the compressing of air that does so under constant volume.

Isothermal process A term used in the compressing of air that does so under constant temperature.

Labeled Term describing equipment or materials bearing a label of a listing agency.

Laboratory outlet An 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 Another name for piping containing only storm water.

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

Listed Term describing equipment and materials included in a list published by an organization acceptable to the authority having jurisdiction and concerned (a listing agency).

Listing agency An agency accepted by the administrative authority that lists or labels certain models of a product and maintains a periodic inspection program on the current production of listed models for the purpose intended. It makes available a published report of its listing, including information indicating that the products have been tested, comply with generally accepted standards, and are found 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 the drainage system. The load factor represents the ratio of the probable load to the connected load and is 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 placed at a junction of sewers to allow easy connection.

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. The journeyman plumber is allowed to install plumbing only under the authority of a master plumber.

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

Mist An aerosol suspended in air composed of liquid particles.

Monitor Observation, sampling, or testing at designated locations.

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.

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.

Outfall sewers Sewers receiving the sewage from a collection system and carrying it to the point of final discharge or treatment. They are usually the largest sewers 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 entrap rainwater and remove the water 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 or 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 A special class of plumbing fixture that is intended to perform a special plumbing function.

Plumbing appurtenances A manufactured device, prefabricated assembly, or on-the-job assembly of component parts that is an adjunct to the basic piping system and plumbing fixtures. An appurtenance demands no additional water supply, nor does it add any discharge load to a fixture or the drainage system. It is presumed to perform some useful function in the operation, maintenance, servicing, economy, or safety of the plumbing system.

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 Installed receptacles, devices, or appliances other than a trap that dispense potable hot and cold water and discharge the wastes 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 complying with the laws of licensing and/or registration of the state, city, or county.

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. Additional components in the system include potable water-treating or water-using equipment, fuel gas piping, water heaters, and vents for same.

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

Polytrophic process A generalized term in compressing air used to allow pressure, temperature, and volume to occur.

Pool A swimming pool is a basin used for swimming that will accommodate all possible uses determined by the owner, architect, or pool consultant or as a plunge or other bath designed to accommodate more than one bather at a time.

Pore The space between particles of a soil.

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

Precipitation Water directly discharged from the clouds as snow, rain, hail, and 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 Applies to 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 public authority.

Public use Applies to 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 takes place when there is a deficiency of oxygen.

Rainfall intensity Commonly called the rate of rainfall, it is 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.

Reducer A pipe fitting larger at one end than at the other.

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.

Reflecting pool A water basin used for decorative purposes.

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

Relief vent A vent designed to equalize 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 the pipe to its original alignment.

Return period A commonly used term to describe frequency. This is the statical amount of time that must elapse to produce the most severe design storm.

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 protection 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. This includes drainage, water supply and vent piping, and the necessary fixture supports.

Runout A commonly used term for a horizontal drainage line connected to a vertical line at its lowest level.

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

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

Sanitary When used for plumbing, it denotes any drainage system that carries human waste. When used for pharmaceutical purposes, it denotes 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 thickness.

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 entrap rain water and remove the water 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 that is designed to permit effluent from the tank to seep through its bottom and sides.

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

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

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

Sewage ejector A mechanical device or pump for lifting sewage.

Siamese A multiple water connection in the form of a wye on the outside of a building used for fire department purposes, permitting water to be supplied to a building, combining of flow from two or more lines into a single pipe.

Sidewall area Vertical surfaces that contribute runoff to the storm water drainage system.

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 semiliquid 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 holding the pipes together that has a melting point less than 1,000°F.

Special wastes Wastes that require 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 facilities.

Specific gravity The ratio of 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. The installation includes one or more automatic water supplies. The portion of the sprinkler system aboveground is a network of specially sized or hydraulically designed piping installed in a building, structure, or area, generally overhead, and to which sprinklers are attached in a systematic pattern. The valve controlling each system riser is located in the system riser or its supply piping. Each sprinkler system riser includes a device for actuating an alarm when the system is in operation. The system is activated by heat from a fire and discharges water over the fire area.

Sprinkler system classification

Automatic sprinkler system types

1. Wet-pipe systems
2. Dry-pipe systems
3. Pre-action systems
4. Deluge systems
5. Combined dry-pipe and preaction systems

Sprinkler systems, special types Special-purpose systems employing departures from the requirements of standards, such as special water supplies and reduced pipe sizing, shall be installed in accordance with their listings.

Occupancy classification Relates to sprinkler installations and their water supplies only, not intended to be a general classification of occupancy hazards.

1. *Extra hazard occupancies* Occupancies or portions of other occupancies where quantity and combustibility of contents is very high, and flammable and combustible liquids, dust, lint, or other materials are present, introducing the probability of rapidly developing fires with high rates of heat release. Extra hazard occupancies involve a wide range of variables that may produce severe fires. The following shall be used to evaluate the severity of extra hazard occupancies:

   - A. *Extra hazard group 1* Includes occupancies with little or no flammable or combustible liquids.
   - B. *Extra hazard group 2* Includes occupancies with moderate to substantial amounts of flammable or combustible liquids or where shielding of combustibles is extensive.
2. *Ordinary hazard occupancies*
   - A. *Ordinary hazard group 1* Occupancies or portions of other occupancies where combustibility is low, quantity of combustibles does not exceed 8 ft (2.4 m), and fires with moderate rates of heat release are expected.
   - B. *Ordinary hazard group 2* Occupancies or portions of other occupancies where quantity and combustibility of contents are moderate to high, stockpiles do not exceed 12 ft (3.7 m), and fires with moderate to high rates of heat release are expected.
3. *Light hazard occupancies* Occupancies or portions of other occupancies where the quantity and/or combustibility of contents is low and fires with relatively low rates of heat release are expected.

Sprinkler types

Concealed sprinklers Recessed sprinklers with cover plates.

Corrosion-resistant sprinklers Sprinklers with special coatings or platings to be used in an atmosphere that would corrode an uncoated sprinkler.

Dry, pendent sprinklers Sprinklers for use in a pendent position in a dry-pipe or wet-pipe system with the seal in a heated area.

Dry, upright sprinklers Sprinklers 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.

Extended-coverage sidewall sprinklers Sprinklers with special extended, directional, discharge patterns.

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

Intermediate-level sprinklers Sprinklers equipped with integral shields to protect their operating elements from the discharge of sprinklers installed at high elevations.

Large-drop sprinklers Listed sprinklers that are characterized by a K factor between 11.0 and 11.5 and a proven ability to meet the prescribed penetration, cooling, and distribution criteria prescribed in the large-drop sprinkler examination requirements. The deflector/discharge characteristics of the large-drop sprinkler generate large drops of such size and velocity as to enable effective penetration of a high-velocity fire plume.

Nozzles Devices for use in applications requiring special discharge patterns, directional spray, fine spray, or other unusual discharge characteristics.

Open sprinklers Sprinklers from which the actuating elements (fusible links) have been removed.

Ornamental sprinklers Sprinklers that have been painted or plated by the manufacturer.

Pendent sprinklers Sprinklers 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 sprinklers A type of sprinkler that is both a fast-response and a spray sprinkler.

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

Residential sprinklers Sprinklers that have been specifically listed for use in residential occupancies.

Sidewall sprinklers Sprinklers 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 sprinklers Sprinklers that have been tested and listed as having special limitations.

Upright sprinklers Sprinklers 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 the soil or waste stack.

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

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

Standard dimensional ratio A term used for plastic pipe where the diameter of a pipe is divided by the wall thickness.

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 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 hose and nozzles, for the purpose of extinguishing a fire and so protecting a building or structure and its contents as well as its occupants. This is accomplished by systems or by pumps, tanks, and other equipment necessary to provide an adequate supply of water to the hose connections.

Standpipe system class of service

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

Standpipe system types

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

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

Storm sewer A sewer used for conveying rainwater, snow, or ice, except for sewage and industrial waste.

Storm water Rainwater, snow, or ice from site or roof surfaces, except for sewage and industrial waste.

Strain Change of 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.

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

Street pressure A water piping system supplied from a public water main that uses only the pressure available in the main.

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

Suds pressure zone That 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 the 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 A term used in stadiums and places of assembly to indicate many flush valves used at one time.

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.

Supports Devices 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 tee is a fitting where a straight run of pipe has a connection at right angle to the run.

Temperature

- ***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. Each division is called a degree F.
- ***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. Each division is called a degree C.
- ***Degree Rankine (R)*** A value in °F based on a starting temperature of absolute zero, -459.67°F
- ***Degree Kelvin (K)*** Created for laboratory use. A value in °C based on a starting temperature of absolute zero, -273.15°C.

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

Thermal efficiency Ratio of the energy output from the system to energy input to the system.

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 That 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 Piping buried below grade.

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

Upstream Term referring to a location in the direction of flow before reaching a referenced point.

Vacuum Any pressure less than that exerted by the atmosphere.

Vacuum breaker An atmospheric vacuum breaker is not designed to be subject to static line pressure. A pressure vacuum breaker is designed to operate under static line pressure.

Vacuum relief valve A device 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/second (IP units) or meters per second (SI units).

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 potable water.

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

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 provide protection 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 free flow of waste water.

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

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

PLUMBING ACRONYMS

AGA	American Gas Association
AHJ	Authority having jurisdiction
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-conditioning Engineers
ASME	American Society of Mechanical Engineers
ASPE	American Society of Plumbing Engineers
ASPERF	American Society of Plumbing Engineers Research Foundation
ASSE	American Society of Sanitary Engineering or American Society of Safety Engineers
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
CDA	Copper Development Association
CGPM	General Conference on Weights and Measures, from the French term Conference Generale de Poids et Measures.
CISPI	Cast Iron Soil Pipe Institute
CS	Commercial standards
DWV	Drain, waste, and vent; a name for copper or plastic tubing used for drain, waste, or venting pipe
FM	Factory Mutual
FS	Federal specifications
LEED	Leadership in Energy and Environmental Design
MSS	Manufacturers Standardization Society of the Valve and Fittings Industry Inc.
NFPA	National Fire Protection Association
NSF	National Sanitation Foundation
PDI	Plumbing and Drainage Institute
UL	Underwriters Laboratory
USGBC	United States Green Building Council

PLASTIC PIPING ACRONYMS

The 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)

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 the American national standard for use of the International System: IEEE/ASTM SI 10 (2002): *Modern Metric System*.

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[5]

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 sq.	m/s^2
Angular acceleration	radian per second sq.	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	Ω·m
Entropy	joule per kelvin	J/K
Luminance	candela per meter sq.	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 sq.	kg/m^2
Mass flow rate	kilogram per second	kg/s
Moment of inertia	kilogram-meter sq.	kg·m^2
Momentum	kilogram-meter per sec.	kg·m/s
Torque	newton-meter	N·m
Specific heat	joule per kg per kelvin	J/kg·K
Thermal conductivity	watt per meter per kelvin	W/m·K
Linear velocity	meter per second	m/s
Angular velocity	radian per second	rad/s
Dynamic viscosity	pascal-second	Pa·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
10^{24}	Yotta	Y
10^{21}	Zetta	Z
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto[a]	h
10^{1}	deka[a]	da
10^{-1}	deci[a]	d
10^{-2}	centi[a]	c
10^{-3}	milli	m
10^{-6}	micro	µ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a
10^{-21}	zepto	z
10^{-24}	yocto	y

[a] Use of these prefixes should be avoided whenever possible.

SI Units Style and Use

1. Multiples and submultiples of SI units are to be formed by adding the appropriate SI prefixes to such units.
2. Except for the kilogram, SI prefixes are not to be used in the denominator of compound numbers.
3. Double prefixes are not to be used.
4. Except for exa (E), peta (P), teca (T), giga (G), and mega (M), SI prefixes are not capitalized.
5. The use of units from other systems of measurement is to be avoided.
6. Except when the SI unit is derived from a proper name, the symbol for SI units is not capitalized.
7. SI unit symbols are always denoted in singular form.

8. Except at the end of a sentence, periods are not used after SI unit symbols.
9. 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.
10. 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).
11. When equations are used, such equations are to be restated using SI terms.
12. All units are to be denoted by either their symbols or their names written in full. Mixed use of symbols are 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).

Acceleration, linear

foot per second squared = 0.3048 m/s^2
m/s^2 = 3.28 ft/s^2

inch per second squared = 0.0254 m/s^2
m/s^2 = 39.37 in/s^2

Area

acre = 4046.9 m^2
m^2 = 0.0000247 acre

foot squared = 0.0929 m^2
m^2 = 10.76 ft^2

inch squared = 0.000645 m^2 = 645.16 mm^2
m^2 = 1550.39 in^2

mile squared = 2 589 988 m^2 = 1.59
km^2 = 0.39 mi^2

yard squared = 0.836 m^2
m^2 = 1.2 yd^2

Bending movement (torque)

pound-force-inch = 0.113 N·m
N·m = 8.85 lb$_f$-in

pound-force-foot = 1.356 N·m
N·m = 0.74 lb$_f$-ft

Bending movement (torque) per unit length

pound-force-inch per inch = 4.448 N·m/m
N·m/m = 0.225 lb$_f$-in/in

pound-force-foot per inch = 53.379 N·m/m
N·m/m = 0.019 lb$_f$-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-lb$_f$

kilowatt-hour = 3,600,000 J
J = 0.000000278 kW-h

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 oz$_f$

pound-force = 4.448 N
N = 0.23 lb$_f$

kilogram-force = 9.807 N
N = 0.1 kg$_f$

Force per unit length

pound-force per inch = 175.1 N/m
N/m = 0.0057 lb$_f$/in

pound-force per foot = 14.594 N/m
N/m = 0.069 lb$_f$/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/lb$_m$

Btu per pound-mass-F = 4,186.8 J/kg·K
J/kg·K = 0.000239 Btu/lb$_m$ 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

m = 0.000621 mi

Light (illuminance)

footcandle = 10.764 lx
lx = 0.093 ftcd

Mass

ounce-mass = 0.028 kg
kg = 35.7 oz_m

pound-mass = 0.454 kg
kg = 2.2 lb_m

Mass per unit area

pound-mass per foot squared = 4.882 kg/m^2
kg/m^2 = 0.205 lb_m/ft^2

Mass per unit length

pound-mass per foot = 1.488 kg/m
kg/m = 0.67 lb_m/ft

Mass per unit time (flow)

pound-mass per hour = 0.0076 kg/s
kg/s = 131.58 lb_m/h

Mass per unit volume (density)

pound-mass per cubic foot = 16.019 kg/m^3
kg/m^3 = 0.062 lb_m/ft^3

pound-mass per cubic inch = 27,680 kg/m^3
kg/m^3 = 0.000036 lb_m/in^3

pound-mass per gallon = 119.8 kg/m^3
kg/m^3 = 0.008347 lb_m/gal

Moment of inertia

pound-foot squared = 0.042 $kg{\cdot}m^2$
$kg{\cdot}m^2$ = 23.8 $lb\text{-}ft^2$

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 $ft\text{-}lb_f/h$

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 lb_f/ft^2

pound-force per inch squared = 6.8948 kPa
kPa = 0.145 lb_f/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

$t_k = (t_f + 459.67)/1.8$
$t_f = 1.8\ t_k - 459.67$

$t_c = (t_f - 32)/1.8$
$t_f = 1.8\ t_c + 32$

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
m^3 = 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 1-4 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 Temp.	
°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
–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
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
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

Table 1-5 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/lb$_m$	2.326[a]	kJ/kg
Btu/lb$_m$ · °F (specific heat, c_p)	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
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 · lb$_f$ (torque or moment)	1.356	N · m
ft · lb$_f$ (work)	1.356	J
ft · lb$_f$/lb (specific energy)	2.99	J/kg
ft · lb$_f$/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)
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 (1000 lb$_f$)	4.45	kN
kip/in^2 (ksi)	6.895	MPa
litre	0.001[a]	m^3
met	58.15	W/m^2
To Obtain	**By**	**Divide**

(CONTINUED)

Table 1-5 Conversion to SI Units (continued)

Multiply	By	To Obtain
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
pound		
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
ppm (by mass)	1.00[a]	mg/kg
psi	6.895	kPa
quad (10^{15} Btu)	1.055	EJ
quart (liquid, US)	0.946	L
square (100 ft^2)	9.29	m^2
tablespoon (approx.)	15	mL
teaspoon (approx.)	5	mL
therm (US)	105.5	MJ
ton, long (2240 lb)	1.016	Mg
ton, short (2000 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 US 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.

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3. Chan, Wen-Yung W., and Milton Meckler. 1983. *Pumps and Pump Systems*. Sherman Oaks, Calif.: American Society of Plumbing Engineers.
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2

Standards for Plumbing Materials and Equipment

A plumbing engineer's life is surrounded by codes and standards. This chapter lists the majority of codes and standards used and referenced by the profession.

Codes and standards often cross paths to the point that it is 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, material, and approval requirements. Codes rely on standards and normally reference standards for specific materials or installation requirements. State, provincial, and local jurisdictions adopt codes to regulate construction. The standard only becomes a legally enforceable document when it is referenced in the adopted code. A code review is necessary to determine the appropriate standard.

Sometimes a standard crosses the line and 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 an National Fire Protection Association (NFPA) standard, NFPA 54. Another document that regulates fuel gas systems is the International Fuel Gas Code. This document is a code and does not have a standard designation.

Codes and standards are continually updated. As a result, as soon as this book is published, the list of standards is out of date. To identify the specific edition of a standard, the date is located in the numerical designation of the standard. Whenever using a standard, it is appropriate to check with the standard-promulgating organization to identify the latest edition of that standard.

This chapter is separated into three tables: codes and standards listed by category (Tables 2-1 and 2-2) and a complete list of standards by standard-writing organization (Table 2-3). The first table identifies the codes based on their category. The second table identifies standards by category. For example, the heading of "Water Distribution Piping (Aboveground)" lists the standards for each given material approved for such use. In these two tables, only the standard acronym and number are identified. Not every standard is listed.

In the third table, the standard designation and full title appear. The standards are listed in alphabetical numerical order for each standard-promulgating agency. It should be noted that the American National Standards Institute (ANSI) accredits many standards as American national standards. 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 organization) the agencies that promulgate standards, such as the American Society of Mechanical Engineers (ASME).

ANSI identifies the standard by the acronym of the standard-promulgating agency. For example, the vitreous china fixture standard may be written as ANSI/ASME A112.19.2; however, both ANSI and ASME also identify the same standard as ASME A112.19.2. For ease of identification, "ANSI" has not been included in the table for ANSI-accredited standards. The only listings of ANSI standards are the few remaining standards that do not have another acronym from a promulgating agency. A typical example is ANSI LC-1, which regulates corrugated stainless steel tubing.

Most standards are developed through a consensus process. This would include all ANSI, American Society of Testing and Materials (ASTM), and Canadian Standards Association (CSA) standards. A consensus process requires the standards committee to be balanced among the various interest groups. For example, material standards have manufacturers (producers), users (engineers), and general-interest representatives on the committee. The consensus process also requires all negative comments to be resolved. As a result of the consensus process, standards are of a higher caliber, developed through a fair and open process.

The Canadian affiliate of Underwriters Laboratories (UL) is Underwriters Laboratories of Canada. Products can bear UL, ULC, cUL, or other variations of the certification logo, which largely depends on where the product is to be marketed. Acceptance of the product in a particular region is governed by the applicable code. UL/ULC standards are copublished by both UL and Underwriters Laboratories of Canada 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 at Underwriters Laboratories of Canada.

Table 2-1 Codes Listed by Category

Boiler codes	ASME BPVC, IAPMO UMC, ICC IMC, CSA
Building codes	ICC IBC, NFPA 5000, CCC
Energy codes	ASHRAE 90.1, ASHRAE 90.2, ICC IECC
Fuel gas codes	IAPMO UPC, ICC IFGC, NFPA 54, NFPA 58, CAN/CSA
Mechanical codes	IAPMO UMC, ICC IMC
Plumbing codes	IAPMO UPC, ICC IPC, PHCC-NA NSPC

Table 2-2 Standards Listed 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
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
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

continued

Table 2-2 Standards Listed by Category (contintued)

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
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 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 S-635, S-640, UL 1777
Pipe hangers	MSS SP-58, MSS SP-69
Plastic pipe quality control	NSF 14
Type B vents	UL 441, ULC S605
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
Bidet	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, ARI 1010
Emergency shower and eyewash stations	ISEA Z358.1
Faucets and fixture fitting	ASME A112.18.1, CSA B125
Fixture waste fittings	ASME A112.18.2

continued

Table 2-2 Standards Listed by Category (contintued)

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, 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 D3311, ASTM D2665
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
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 F405
PVC plastic pipe	ASTM D2729, ASTM F891, CSA B182.2, CSA 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

continued

Table 2-2 Standards Listed by Category (contintued)

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
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 B16.18, ASME B16.22, ASME B16.23, ASME B16.26, ASME B16.29, ASME B16.32
Gray iron and ductile iron	AWWA C110, AWWA C153
Malleable iron	ASME B16.3
PE plastic	ASTM D2609
PEX tubing	ASTM F1807
PVC plastic	ASTM D2464, ASTM D2466, ASTM D2467, 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, CSA 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/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 2-3 Complete List of Standards by Standard-writing Organization

ANSI (American National Standards Institute, ansi.org)	
LC-1	Fuel Gas Piping Systems Using Corrugated Stainless Steel Tubing
Z4.3	Sanitation—Nonsewered Waste-disposal Systems—Minimum Requirements
Z21.8	Installation of Domestic Gas Conversion Burners
Z21.10.1	Gas Water Heaters Volume 1, Storage Water Heaters with Input Ratings of 75,000 Btu per Hour or Less

continued

Table 2-3 Complete List of Standards by Standard-writing Organization (continuted)

Z21.10.3	Gas Water Heaters Volume 3, Storage Water Heaters with Input Ratings Above 75,000 Btu per hour, Circulating and Instantaneous
Z21.13	Gas-fired, Low-pressure Steam and Hot Water Boilers
Z21.15	Manually Operated Gas Valves for Appliances, Appliance Connector Valves, and Hose End Valves
Z21.19	Refrigerators Using Gas Fuel
Z21.22	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	Vented Gas Fireplaces
Z21.56	Gas-fired Pool Heaters
Z21.61	Gas-fired Toilets
Z21.69	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	Vented Gas Fireplace Heaters
Z83.11	Gas Food Service Equipment
Z124.1	Plastic Bathtub and Shower Units
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
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
ASME (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 Belowground
A112.3.4	Macerating Toilet Systems and Related Components
A112.4.1	Water Heater Relief Valve Drain Tubes
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

continued

Table 2-3 Complete List of Standards by Standard-writing Organization (continuted)

A112.6.2	Framing-Affixed Supports for Off-the-Floor Water Closets with Concealed Tanks
A112.6.3	Floor Drains
A112.6.4	Roof, Deck, and Balcony Drains
A112.6.7	Enameled and Epoxy-coated Cast Iron and PVC Plastic Sanitary Floor Sinks
A112.14.1	Backwater Valves
A112.14.3	Grease Interceptors
A112.14.4	Grease Removal Devices
A112.18.1	Plumbing Fixture Fittings
A112.18.2	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	Stainless Steel Plumbing Fixtures
A112.19.4M	Porcelain Enameled Formed Steel Plumbing Fixtures
A112.19.5	Trim for Water Closet Bowls, Tanks, and Urinals
A112.19.6	Hydraulic Performance Requirements for Water Closets and Urinals
A112.19.7	Whirlpool 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
A112.6.3	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 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
B16.29	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

continued

Table 2-3 Complete List of Standards by Standard-writing Organization (continuted)

B31.3	Power and Process Piping Package
B36.10M	Welded and Seamless Wrought Steel Pipe
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
ASSE (American Society of Sanitary Engineering, asse-plumbing.org)	
1001	Atmospheric Type Vacuum Breakers
1002	Anti-siphon Fill Valves for Water Closet Tanks
1003	Water Pressure Reducing Valves
1004	Backflow Prevention Requirements for Commercial Dishwashing Machines
1006	Residential Use Dishwashers
1007	Home Laundry Equipment
1008	Plumbing Aspects of Residential Food Waste Disposer Units
1009	Commercial Food Waste 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	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
1032	Dual-check Valve-type Backflow Preventer for Carbonated Beverage Dispensers—Post-mix Type
1035	Laboratory Faucet Backflow Preventers
1037	Pressurized Flushing Devices (Flushometers) for Plumbing Fixtures
1043	Cast Iron Sovent Sanitary Drainage Systems
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
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

continued

Table 2-3 Complete List of Standards by Standard-writing Organization (continuted)

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	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 ande Inspectors
ASTM (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	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	Specification for Seamless Copper Tube, Bright Annealed
B75	Specification for Seamless Copper Tube
B88	Specification for Seamless Copper Water Tube
B135	Specification for Seamless Brass Tube
B152/B152M	Specification for Copper Sheet, Strip, Plate, and Rolled Bar
B 210	Specification for Aluminum and Aluminum-alloy Drawn Seamless Tubes
B211	Specification for Aluminum and Aluminum-alloy Bar, Rod, and Wire
B241/B241M	Specification for Aluminum and Aluminum-alloy Seamless Pipe and Seamless Extruded Tube
B251	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	Specification for Nonreinforced Concrete Sewer, Storm Drain, and Culvert Pipe
C76	Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe
C296	Specification for Asbestos-cement Pressure Pipe
C411	Test Method for Hot-surface Performance of High-temperature Thermal Insulation

continued

Table 2-3 Complete List of Standards by Standard-writing Organization (continuted)

C425	Specification for Compression Joints for Vitrified Clay Pipe and Fittings
C428	Specification for Asbestos-cement Nonpressure Sewer Pipe
C443	Specification for Joints for Concrete Pipe and Manholes, Using Rubber Gaskets
C508	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)
D2447	Specification for Polyethylene (PE) Plastic Pipe, Schedules 40 and 80, Based on Outside Diameter
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
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
D3309	Specification for Polybutylene (PB) Plastic Hot and Cold Water Distribution Systems
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

continued

Table 2-3 Complete List of Standards by Standard-writing Organization (continuted)

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
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	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
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

continued

Table 2-3 Complete List of Standards by Standard-writing Organization (continuted)

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 **(Canadian Standards Association, csa-international.org)**	
B45	Plumbing Fixtures
B64	Backflow Preventers and Vacuum Breakers
B79	Commercial and Residential Drains and Cleanouts
B125	Plumbing Fittings
B137	Thermoplastic Pressure Piping Compendium
B1800	Plastic Nonpressure Pipe Compendium
A257	Concrete Pipe and Manhole Sections
CAN/CSA B182.4	Profile PVC Sewer Pipe and Fittings
B602	Mechanical Couplings for Drain, Waste, and Vent Pipe and Sewer Pipe
B149	Natural Gas and Propane Installation Code
B139	Installation Code for Oil-burning Equipment
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
IAPMO **(International Association of Plumbing and Mechanical Officials, iapmo.org)**	
UMC	Uniform Mechanical Code
UPC	Uniform Plumbing Code
USEC	Uniform Solar Energy Code
USPC	Uniform Swimming Pool, Spa, and Hot Tub Code
ICC **(International Code Council, iccsafe.org)**	
IBC	International Building Code
ICC EC	ICC Electrical Code
IEBC	International Existing Building Code
IECC	International Energy Conservation Code
IFC	International Fire Code
IFGC	International Fuel Gas Code
IMC	International Mechanical Code
IPC	International Plumbing Code
IPSDC	International Private Sewage Disposal Code
IRC	International Residential Code
ISEA **(International Safety Equipment Association, safetyequipment.org)**	
Z358.1	Emergency Eyewash and Shower Equipment
MSS **(Manufacturers Standardization Society of the Valve and Fittings Industry, mss-hq.com)**	
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, and Manufacture
SP-69	Pipe Hangers and Supports—Selection and Application
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

continued

Table 2-3 Complete List of Standards by Standard-writing Organization (continuted)

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
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
85	Boiler and Combustion Systems Hazards Code
88A	Parking Structures
96	Ventilation Control and Fire Protection of Commercial Cooking Operations
99	Healthcare Facilities
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

continued

Table 2-3 Complete List of Standards by Standard-writing Organization (continuted)

PHCC (Plumbing-Heating-Cooling Contractors Association, phccweb.org)	
NSPC	National Standard Plumbing Code
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—with Revisions Through March 1999
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
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

3 Specifications

Plumbing drawings, plumbing specifications, general conditions, special conditions, and the addenda comprise the contract 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. Therefore, the plumbing designer must be familiar with specification writing. If others prepare the specifications, then the plumbing designer must be able to coordinate the drawings with the project's specifications.

When writing specifications, the language used must be clear, precise, and exact to convey to the reader the information required. The essence of a well-written specification is clarity, brevity, correctness, 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 is a set of documents that allows an engineer in one part of the country to converse with a supplier or contractor in another location, with the language and meanings in the specifications the same to all parties.

CONSTRUCTION CONTRACT DOCUMENTS

The Construction Specifications Institute (CSI) developed and implemented a set of documents known as the *Manual of Practice* that has been used nationwide for about 40 years.

This document is intended to provide an ordered, logical, simple, and flexible format for the specification writer to use in the preparation of the specifications. One of the principles of this format, which is known as MasterFormat, is to establish a standard location for specific information, and that information is stated only at that location. This allows the reader to retrieve the information required in the least amount of time. It is essential that the plumbing specification writer be familiar with and understand all the components that constitute the *Manual of Practice* to write clear, concise specifications.

DEFINITION OF TERMS

It is necessary to define some of the terms that are used in these documents, so that 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 as per the contract documents.

Bidder A person or firm that meets the requirements as set forth in the General Conditions to submit a price in writing to the owner to do the work as per the contract documents.

Contractor The successful bidder after the award of the contract.

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

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

Contract documents The legally enforceable requirements that become part of the contract when the agreement is signed.

Construction contract documents More often referred to as the "contract documents," these describe the proposed construction, which is referred to as the "work" that will result from construction. These documents often are erroneously referred to as the "plans and specifications," but it should be noted that many times neither plans nor specifications can be found in these documents. Instead of the use of 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."

Work The performing of services, furnishing of labor, and supplying and incorporating materials and equipment into the construction.

PROJECT MANUAL

The project manual is an accurate and descriptive term to describe the collection of documents other than the drawings. This manual consists of the following documents:

1. Pre-bid information advises those prospective bidders about the proposed project. The architect, engineer, or owner invites these bidders, and the bid is restricted to those bidders invited. This method usually is referred to as "bid by invitation." Pre-bid information for public work is required by law to be advertised in all newspapers of general subscription in the immediate area where the work is to be bid, as well as on the owner's website or other Internet venues, for a predetermined period. (The exact length of time for publication is set forth by local ordinances governing public notices.)
2. Instructions to bidders are written to inform the prospective bidders how to prepare their bid so that all bids are in the same format and can be compared easily and fairly after the bid opening.
3. 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.
4. 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. They also could be used to ensure that the contractor and subcontractors will perform as agreed. The types of bonds commonly used are:
    a. 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.
    b. Performance bond: Ensures that the work, once a contract has been signed, will be completed in compliance with the contract documents.
    c. Labor and materials payment bond: Ensures that workers on this 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.
    d. Guaranty bond: Guarantees that the contractor will be paid in full for all work performed to construct the project.
    e. Certificates: These include 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.
5. 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.
6. 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 usually in included in the project manual and referenced by 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 CSI.
7. Supplementary conditions are the clauses that modify or supplement the general conditions as needed to provide for requirements that are specific to that project. They consist of modifications and or substitutions such as insurance requirements, prevailing wage rates, etc. It is important to remember that these are not a standardized document like AIA A201 and must be prepared based on the requirements of each specific project.
8. 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 contract should be included in the specifications. The plumbing drawings graphically illustrate the scope of the design, equipment location, routing of piping, quantity of the materials required, and interface with the other trades involved.
9. 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 bidding documents or in previous addenda, It should be noted that while an addendum typically is issued prior to the bid opening, AIA A201 allows for the issuance of an addendum any time up to the execution of the contract. This feature 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.

10. 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 above-listed documents is a separate document, but when grouped together, they are referred to collectively 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 or designer may be responsible for the preparation of the entire project manual.

SPECIFICATIONS

Originally, all documentation for a given project could be found in the drawings, but as the amount of required information increased, another way was needed to present it. Over time, all of the notes that would not fit on the drawings, including additional information, product requirements, contractual provisions, and construction methods and systems, became known as the project's specifications and were used to define the qualitative requirements for 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. Primarily, no universal guidelines ensured a uniform document. Each designer wrote specifications using their own style according to what they thought was important. Even specifications from large firms lacked consistency between documents. Materials, methods, or items that were related often were not grouped in a logical manner. This practice caused great difficulty when the contractor tried to prepare a specific bid because it very easy to overlook important and costly items. Also, coordination between the various trades and the contractor was difficult at best. Last-minute changes were extremely difficult to accomplish.

Writing Specifications

Specifications can be generated in many ways. They may 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.

The designer must have as much information as possible that pertains to the section to be written. This includes any reference materials that describe products and methods of construction detailed within the specification. The project information includes the drawing set as prepared by the designer, project notebook, project scope of work, and any applicable laws and/or building codes. Information for products can be obtained through a variety of sources, including previous project specifications, manufacturer's information, handbooks or pamphlets for the various trade associations, information from the manufacturer's representatives, reference standards from national standards organizations, governmental agencies, and trade associations, technical and professional societies, commercially prepared guide specifications, information obtained from the trades or contractors, and personal experience.

Never edit previous specifications for use in a new project, as they 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 first written.

Once the needed information has been gathered, the designer must decide what type of format will be used as the basis of the specification. Depending on the size of the project or the project phase for which the specification is being prepared, the designer may choose a short, abbreviated format such as Uniformat as developed by CSI. For large, complex projects, the designer may choose the full format as is found in MasterFormat, also developed by CSI.

In addition to Uniformat and MasterFormat, specifications also are developed by EJCDC, AIA, NSPE, and various governmental agencies such as the U.S. Army Corps of Engineers (USACOE), the armed services, NASA, etc.

The designer must be knowledgeable of the different specifications that are available so he can decide which specification is best suited for the phase of the project being designed.

UNIFORMAT

Uniformat is a systems-based format used for the most part during the schematic phase as well as the preliminary or "budgetary" cost estimates. Both CSI and Construction Specifications Canada (CSC) recommend Uniformat for the organization of project data during 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. Site Work
8. General

For more information and the subcategories that are found within each of the eight categories of this format, refer to Appendix 3-A1. Additional information on Uniformat may be obtained from CSI's publication *Manual of Practice*.

One of the best features of Uniformat is that each category or subcategory can be easily expanded as more information is accumulated during the ongoing design process, which helps the estimator prepare an informed preliminary cost estimate.

Once the project progresses from the preliminary or schematic phase, where Uniformat provides the necessary information, 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 usually are introduced to organize the required information. In some projects, the 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 B141: *Standard Form of Agreement Between Owner and Architect* and EJCDC Document 1910-1: *Standard Form of Agreement Between Owner and Architect for Professional Services* for additional information.

MASTERFORMAT

Drawings that are prepared during the design development phase contain more detail, both general and specific, than the schematic phase drawings. At this point, some designers organize their outline specifications around CSI's MasterFormat because this format can be used from the design development phase through the construction documents (CD) phase.

MasterFormat is a list of divisions, numbers, and titles that has become the industry standard in both the United States and Canada. The core of this system is the five-digit numbers and titles that arrange construction/project data into an organized order of sequence. With this universal standardized system, the placement and retrieval of information is greatly facilitated, and communication throughout construction is greatly improved.

In MasterFormat, group numbers and titles are organized under these headings: introductory information, bidding requirements, contracting requirements, facilities and spaces, systems and assemblies, and construction products and activities (divisions 1–16). The first five groups, while they are not specifications, usually are included in the project manual. The last group forms the construction specifications.

Under MasterFormat are four levels of detail. Level one consists of the titles for the 16 divisions (see Appendix 3-A2). Level two titles (or sections) are referred to as "broad scope," as they provide the widest scope in describing the work to be performed or the products to be utilized (see Appendix 3-A3). Level three titles sometimes are referred to as "medium scope," since they cover work that is more limited in scope than that under the level two titles. Level three further divides the titles listed under level two to add a more definitive scope (see Appendix 3-A4). The titles found under level four are the most limited in scope and often are referred to as "narrow scope." These titles cover the elements of the work that are very specific (see Appendix 3-A5).

As you proceed from level one to level four, the titles (or sections) become more narrow or specialized. For example, using the specification for nitrogen piping, level one is 15000-Mechanical; level two is 15200-Process piping; level three is 15210-Process air and gas piping; and level four is 15215-Nitrogen piping.

MASTERFORMAT 2004—AN OVERVIEW

Since being updated in 1995, CSI's MasterFormat was the staple of the architectural and engineering community. However, while it was very effective, this document began to show some problems with respect to supporting the entire construction industry, and it had very limited room for any future expansion. In 2001, a 17-member task force known as the MasterFormat Expansion Task Team (MFETT) was formed by CSI to address the format's problems. Three years and many drafts later, the revised document known as MasterFormat 2004 was ready and introduced on CSI's website (csinet.org).

Many changes were made in the organization of this document, the most significant of which is the reduction of the six groups to two groups: Procurement and Contracting Requirements and Specifications. The Procurement and Contracting Requirements group, known by the more familiar term "front-end documents," contains the bidding information, project forms, contract conditions, etc. Essentially, this is the same material, just with a new name and different location.

The Specifications group contains the administrative and technical requirements that govern a project. This group is divided into five subgroups, which are divided further into a total of 49 divisions. The five subgroups comprising the Specifications group are:

1. General Requirements: Division 01
2. Facility Construction: Divisions 02–19
3. Facility Services: Divisions 20-29

4. Site and Infrastructure: Divisions 30–39
5. Process Equipment: Divisions 40–49

Appendix 3-C1 contains a complete list of the subgroups and divisions and a short description of any changes.

The original numbering system consisted of a five-digit number that organized the information throughout the 16 divisions. The new system utilizes a six-digit number that consists of three pairs of two-digit numbers. For example, 03200 found in MasterFormat 1995 was replaced by 03 20 00 (the new number for Concrete Reinforcement). Level four numbers have been removed. However, recommendations for their use have been included in the supporting documents should the specifier choose to do so. It should be noted that each level has two digits, and this alone allows 10 times as many subjects as was possible under the old five-digit format.

Another change is the relocation of certain items from one division to other divisions. Plumbing items have been relocated to Division 22: Plumbing, and HVAC items have been moved to Division 23: Heating, Ventilation, and Air-conditioning. Fire Suppression items that were located in Division 13 have been relocated to Division 21: Fire Suppression. (Refer to Appendix 3-C2 for a listing of the sections found in Division 21. For a more detailed breakdown of the subjects listed in this division, refer to Appendix 3-C3. Appendix 3-C4 contains a listing of the sections found in Division 22, while Appendix 3-C5 contains a more detailed breakdown of the sections and subjects.)

In conclusion, the changes discussed above and any others made to MasterFormat 2004 were made to facilitate its use in the architectural and engineering fields for years to come. As when anything changes, there will be those who love, hate, use, or ignore the new. However, MasterFormat 2004 deserves a chance.

SectionFormat

While MasterFormat standardizes the titles to be used in the project manual, it does not address the way in which the information will be organized. This need for standardization within a section prompted the development of SectionFormat, which provides organization, a uniform appearance, and completeness that is consistent from one section to the next.

A good specification section provides the answer to the following three questions:

1. How does the work that is defined in the section relate to the work that is defined for the rest of the project?
2. What materials and/or products are to be used to complete the work under this section?
3. How are these materials and/or products to be incorporated into the work under this section and the project as a whole?

The answers to these questions are grouped into three parts that form the outline for a given section. These parts are Part I: General, Part II: Products, and Part III: Execution. Refer to Appendix 3-B1 for the shell outline that has been developed by AIA that conforms to CSI's *Manual of Practice*. The order in which these parts are used within a section is fixed in both name and order, providing a consistent format throughout all sections. This, in turn, simplifies the designer's job and makes finding information by the reader much easier.

MasterFormat and SectionFormat when used together will produce specifications that are clear, complete, accurate, and coordinated. This allows the information to flow from the divisions to the sections to the parts and vice versa.

MASTERFORMAT 2004 IN TEN EASY LESSONS

1. MasterFormat is a list of standardized numbers and titles for organizing bidding and contract requirements, specifications, drawing notes, cost data, and building operations by work results.
2. It does not establish design disciplines, trade jurisdictions, or product classifications
3. It has been proven through more than 40 years of use.
4. Revision was necessary to allow for new materials and technologies, increased use of databases, project life-cycle issues, expansion to non-building types of construction, and flexibility for future developments.

What Has Changed?

5. The highest levels of organization are groups, subgroups, and divisions.
   - The number of divisions increased from 16 to 34 active division (plus 15 reserved for expansion).
   - For continuity, Divisions 03 through 14 (building construction work) remain basically the same.
   - New divisions allow more flexibility for specifying civil, process, and other engineering work.
6. Section numbers and titles are assigned for thousands of common work results.
   - Numbers generally include three pairs of numbers (six digits), with each pair defining a level of specificity.
   - An optional fourth pair of numbers (Level 4) is used when greater specificity is required.

Table 3-1 Changes Between 1995 and 2004 Versions of MasterFormat

Scope (Old Terms)	Levels	MasterFormat 1995	MasterFormat 2004
Division	Level 1	11234	11 22 33
Broad Scope	Level 2	11234	11 22 33
Medium Scope	Level 3	11234	11 22 33
Narrow Scope (if required)	Level 4	11234	11 22 33 44
User Defined (if required)	Level 5	Not Used	11 22 33 44 55ABC

- Additional numbers and letters can be added (Level 5) for user-assigned numbers.
- Spaces between pairs are optional and should be made word processing "hard space" functions.
- Titles are work results when practical, such as "Painting" not "Paints" and "Lighting" not "Luminaries" (see Table 3-1.)

7. Unassigned section numbers can be user defined. To avoid conflicts in the future, numbers in reserved divisions should not be used.

Why and How Should I Adopt the New Standard?

8. The benefits of early adoption are:
    - Facility owners and managers can create a database for use throughout the entire building life cycle.
    - Designers and consultants can be an industry leader, meet the standard of practice, and have better document organization.
    - Builders can be ready for jobs using MasterFormat 2004, which would improve organization of cost databases.
    - Suppliers and sales representatives can provide a service to customers by helping them during transition.
    - Individuals can distinguish themselves as authorities and advance their careers as a trainer or consultant.
9. Time and costs are less if implementation is done strategically. Educate your staff, consultants, and clients. Change documents as you use them, with the most frequently used documents first or all at once. Hire a consultant if necessary. Lagging behind the industry will decrease your efficiency and competitiveness as the rest of the industry converts.
10. MasterFormat 2004 numbers and titles can be downloaded without charge. Major master specifications, cost estimating databases, construction reporting services, and product directories are making the transition. The U.S. Department of Defense and other government agencies have adopted MasterFormat 2004, AIA supports the change, and liaisons are being forged with other organizations. A slide show, training as a CSI MasterFormat Accredited Instructor, and other resources are available.

METHODS OF SPECIFICATION

Specifications are written using one of the following four methods of specifying products, materials, or workmanship:

1. Descriptive specifications
2. Performance specifications
3. Reference standard specifications
4. Proprietary specifications

Descriptive Specification

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. When writing this type of specification, it is important to remember that proprietary or brand names of manufactured products are not to be used and that the burden of performance is assumed by the specifier. This method of specifying was once widely used, but as projects became more complex, its use declined because writing this type of specification is tedious and time consuming.

Descriptive specifications are appropriate when the use of proprietary names is prohibited by law (such as with federally funded projects) or when 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:

1. Research available products that will be included in the section.
2. Research the critical features that will be required in the section, and analyze and compare these requirements with the products that are available.
3. 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.

4. Describe those features that are considered to be critical and that are the minimum acceptable requirements.
5. Ensure that these requirements can be met by the products to be supplied.

The designer should take care in selecting and specifying unique features from different products and manufacturers (picking features from one product and combining it with others, etc). This could create a descriptive specification of a particular product that does not exist. When this happens, the designer must spend additional time rewriting this useless description. Avoid any unnecessary features and minutely detailed requirements.

Performance Specification

A performance specification is a statement or statements of the required results with the criteria the specifier has required to verify compliance. It should not contain unnecessary limitations on the methods for achieving the required results. All desired end results the specifier wants must be spelled out completely. 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. Criteria for verifying compliance includes measurement, test evaluation, or other means as required by the designer to ensure that the standards of performance have been met.

Using the performance specification, it should be remembered that only essential restrictions should be placed on the system. Limitations on the means should be avoided. When performance specifications are the primary method of design and contracting procedure, specialized contract documents will be required, as the contract documents are complex and often involve a variety of participants in the contract proceedings.

Reference Standard Specification

The reference standard specification is the use of a nationally or internationally recognized standard to specify a product, materials, or workmanship instead of writing a detailed description. A standard generally is defined as a requirement by a recognized authority, custom, or general consensus. These standards usually are published by trade associations, professional societies, standards organizations, and governmental and institutional organizations. They usually are authored by a committee that includes architects, engineers, scientists, technicians, manufacturers, and product users who are very knowledgeable about that particular subject area.

The six types of reference-based standards commonly used when writing a specification are:

1. Basic material standards
2. Product standards
3. Design standards
4. Workmanship standards
5. Test method standards
6. Codes

When a designer wants to refer to or cite a standard, it is not necessary to include the entire text of the referenced standard in the body of the specification. The desired standard can be included into the document by referring to its number, title, or other designation. The most common form is to cite it with the initials of the sponsoring organization, the number of the standard, and the date, such as ASPE 45 (2007). These cited standards become part of the document just as surely as if the standard's entire text were included.

When using the reference standard, the designer needs to remember certain things. First, there are bad reference standards as well as good ones. Next, indiscriminate use of standards within the document can result in duplication, contradiction, and general chaos for the designer, contractor, and owner. Finally, some standards may contain hidden choices that the designer does not know exist, and their inclusion in the document may cause myriad problems with the enforcement of the contract conditions. These standards often only meet the minimum requirements.

Before writing a reference-based specification, the designer should become thoroughly familiar 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.

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 of the contract stating that the contract conditions shall govern over the requirements of the cited reference standards. Another statement should declare that should a conflict or discrepancy arise between the reference standard and another cited reference and the specifications, the more stringent requirement shall apply. Once the standard has been specified, it becomes necessary for the designer to be able to enforce the requirements of that particular standard once the project begins. The most common means to ensure compliance of the standard is to check the shop drawings and other submittals including manufacturer's literature, samples, test reports, and regular site visits to ensure compliance of the workmanship standards.

Proprietary Specifications

The last method of specifying is the use of the proprietary specification. This method identifies the products to be used by the manufacturer's name, the brand name of a given product, the model number, type designation, or unique characteristics. A specification is considered proprietary if the product to be specified is available from a single source.

The use of this type of specification has both advantages and disadvantages. Advantages include allowing for closer control in the selection of the product, having more detailed and complete drawings due to the more precise information from the product supplier, having shorter specifications, which results in less production time, allowing for removal of product pricing as a major variable, and narrowing of the competition, which will simplify the bidding process. Disadvantages to the use of this method include the elimination or narrowing of the competition, preferential treatment that might be shown for one product over another, and resentment that might be directed back to the designer. It also may force contractors to work with a product with which they have little or no prior experience, which could result in poor performance.

The two types of proprietary specifications are open and closed. The difference between them is how substitutions are handled. Open specifications usually allow the substitution of products, while closed specifications usually do not allow any substitutions or allow only a limited number of choices.

The closed proprietary specification allows the design to be completed with a high level of detail and few variables, thus promoting more accurate bids. It does not, however, protect against a supplier of a specified product taking an unfair advantage of his proprietary position and increasing the price. The designer can control product selection through the use of instructions found in Section 01630: Product Substitution Procedures. Under a closed proprietary specification, when only a single product is named, the substitution of another product is not allowed. Bids submitted must be based on this product only. When multiple products are specified by naming several manufacturers, the bids submitted must be based on one of the products specified. The successful bidder usually is required to submit a list of the products that they intend to use within a specified time following the bid for approval prior to purchase and installation.

The open proprietary specification names products or materials in the same manner as a closed specification. The difference is that alternatives for the specified products or materials also are listed. The bidder must bid on the specified items, but also may provide prices for the alternative items. To clarify the bidding process, the designer might include instructions such as the following: "When the product is specified to only one manufacturer, substitution of products will not be allowed. 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 product into the project. Requests for additional monies for alternate products or materials shall not be considered after the agreement has been executed." The open proprietary specification removes the problem of overpricing, which is common in sole-source product or material bids. It also allows for the selection of alternate items and price quotations for those items.

A major problem with proprietary specifications is when bidders introduce products or materials of inferior quality to those which were specified originally. This problem is the greatest when the bidder is allowed to specify substitutions after the award of the contract because it leads to the practice known as "bid shopping." This is unfair to those who submitted bids originally and puts pressure on the designer to accept these substitutions of inferior product. To prevent this situation, the designer must maintain control over the bidding process by including requirements similar to the following into the specifications:

1. All substitution requests are to be in writing from the bidders only, and any requests from manufacturers and suppliers will not be considered.

2. A definite deadline should be set at a minimum of 10 days prior to the bid opening for the submission of substitution requests by the bidder.

3. All requests for substitutions shall be submitted with the request for approval. Submissions without supporting documentation shall not be considered.

4. The designer shall review all submissions and issue notification of any accepted substitutions to all bidders by addendum. The time 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 SectionFormat as discussed earlier, a specification section is divided into three parts: General, Products, and Execution.

Part 1: General includes the scope, any necessary references to the related work, codes and standards that are to be in force during the project, qualifications for both manufacturers and workmanship, required submittals including the format required for submission of the submittals, any samples required for examination by the designer, required information on product manufacturing and shipping schedules, receiving and storage requirements, and any other information found 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, above all, briefly as possible to give the reader the facts needed in the least amount of text. Any descriptions of these products shall detail the product to be used and present any pertinent data that is required for the use of that product. Installation instructions and similar information should not be included in this part of the specification.

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. Each product that is listed in Part 2 should have information as to its use in Part 3. Any testing that is to be performed (including who pays for the testing and the number required), instructions for the coordination between the various trades, the acceptance of the substrate, and any required tolerances for installations also shall be included in this section.

(Refer to Appendix 3-B1: Section Shell Outline for additional information.)

Beginning at the top, the first item to be completed is the five-digit section number. This number may refer to any level from level two to level five depending on how specific the designer wants to be. (Level four section numbers are becoming more common while level one section numbers are being phased out.) Following the section number is the section title, which the designer should keep to a maximum of one line. Then comes Part 1: General, Part 2: Products, and Part 3: Execution.

Part 1

Section 1.1: Summary In this section is a description of the work to be performed, a list of any products to be furnished but not installed, and products that are not furnished but are to be installed (sometimes referred to as "owner furnished, contractor installed"). The next item found in the summary is a list of related sections in the specifications. Some designers choose to omit this part because it often fails to get updated during last-minute changes, 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 or lavatory. 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 the 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.

Section 1.2: References It is here that any cited reference standards are listed alphabetically. When there are multiple references by the same organization, those references are arranged in ascending numerical order.

Section 1.3: Definition After the references, 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 The system performance requirements give the performance criteria, if required, for this work. This section usually is omitted unless a performance specification is desired.

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 should be submitted for review and approval. (On some government projects, the submittal process is under governmental control, not the designer's.) The information required for the submittal can include product data as prepared by the manufacturer or third-party organization, shop drawings from either the manufacturer or the contractor, coordination drawings, wiring or piping diagrams from the manufacturer or contractor, product certification from manufacturers that products have been tested and are compliant with the appropriate standard cited, test reports from an independent (or third-party) test laboratory certifying the products, qualification data for manufacturers, firms, or individuals as requested in Section 1.7: Quality Assurance, and maintenance data for the materials and products used for inclusion in the operation and maintenance (O&M) manuals for the owner (if required).

Section 1.7: Quality Assurance In this section, the designer can include what is needed to ensure that the project is completed correctly. Included in this section are required manufacturer and installer qualifications, such as the level of experience. Requirements for supervision and licensure, testing laboratories, certifications, and compliance with regulatory standards also are included within this section.

Section 1.8: Delivery, Storage, and Handling This section deals with how materials and equipment are delivered to the jobsite and how they are stored on site until installation, including instructions on shipping and handling of materials or 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 the start of work. This section is optional at the decision of the designer.

Section 1.10: Sequence and Scheduling This section coordinates the various portions of the project and can cross trades. It is optional as well because it is up to the general contractor, not the plumbing designer, to schedule and coordinate work.

Section 1.11: Warranty Here the designer lists any special warranties required or any warranty conditions that are different from the manufacturer's standard warranty.

Section 1.12: Maintenance This section contains any special maintenance requirements for the equipment installed.

Section 1.13: Extra Materials This contains a list of extra materials such as valve repair kits, faucet repair parts, extra belts, handles, lubricants, or seals, as well as the quantity required to be supplied to the owner by the contractor.

Part 2

This section deals with the products, materials, and equipment, as well as the manufacturers that will be included in the work.

Section 2.1: Manufacturers Under paragraph A, the contractor may supply products by any manufacturer that he feels is compliant with the specification section covering that portion of the work. Paragraph B states that the designer decides which manufacturers of a particular product will be allowed and which will not. Under this paragraph, the contractor is given a list of approved manufacturers. The designer must research both the products and manufacturers to ensure that 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:

1. Water closet, floor outlet, flushometer
   a. American Standard
   b. Eljer
   c. Kohler
   d. Toto
   e. Substitutions

Under this arrangement, the contractor would have to supply the water closet by one of the four manufacturers listed. With the use of a substitution option, the designer may elect to allow substitutions 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 substandard products.

Only one of these methods should be used—specify the manufacturer or product with either an open specification as seen in paragraph A or a closed specification as seen in paragraph B. As stated earlier in this chapter, the closed method gives the designer more control over the quality of the products being used.

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

Section 3.1: Examination This section is concerned with the installation of the products and materials. The first part involves the instructions to the contractor to examine the site, plans, existing or constructed walls, floors, and ceilings that must be installed. The contractor also should be instructed 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). It is in this section that connection requirements for owner furnished, contractor installed (often seen as OFCI or GFCI on government projects) are found. A good example of this would be in the case of a commercial kitchen where the kitchen equipment supplier sets the equipment, but the plumber connects them to the utilities.

Section 3.6: Field Quality Control In this section, the designer deals with testing laboratory services (including who pays for it), what tests are to be made, and 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 standard set forth in the specification section. Also, this is where the designer could put a requirement to provide the services of a factory-authorized service technician to supervise the assembly of a piece of equipment on site.

Section 3.7: Adjusting and Cleaning This section covers the adjustment, cleaning, and calibration of the products included in the project. One of the most common requirements would be the cleaning and disinfection of the potable water system.

Section 3.8: Commissioning This section was not mandated by the 1995 MasterFormat, but it is gaining in use as part of MasterFormat 2004. Items that should be addressed include:

- 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, and servicing and maintenance
- Reviewing the data in the O&M manuals with the maintenance staff

USE OF COMPUTERS IN PRODUCING SPECIFICATIONS

Very few plumbing specifications today are written from scratch. In most cases, project specifications are created using an office-prepared master specification or by using a set of commercially prepared specifications that have been published by various industry organizations such as Masterspec or 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.

Fortunately for specification writers, computers have aided in the writing of specifications in the form of computerized or computer-assisted specification programs. Now, specifications that might have required an entire file cabinet for storage can be reduced to one or two CD-ROMs or a jump drive. The specification programs that have evolved over the past years have merged word processing, data storage, and acquisition programs. One of the best features of the new master specification programs is the periodic updates, with new sections being added and obsolete sections being deleted. Also in these updates, any reference standards that are included in each section are updated to the latest version. For any specifier who has spent several hours searching these standards, this feature is worth the price of the program.

These programs have evolved beyond just specialized word processing programs to interactive programs that contain checklists or input dialogue. Also, programs are being written and developed that will interface with the CAD systems to produce specifications and even estimates.

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. The designer must remember that the essence of plumbing specifications is communication among the people involved with the project. Plumbing specifiers must develop the skills to communicate the project requirements in a clear, concise manner.

The one thing that probably has changed the least in specification writing is the amount of time that is allotted by the 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 (actually almost nonexistent). 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 chapters for more information about available courses.

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. Successful completion of this exam will earn the designer the title of Certified Construction Specifier (CCS). A growing number of plumbing engineers can include CCS after CPD or PE when citing their professional credentials.

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.

RESOURCES

1. *Construction Specifications Institute (CSI) Manual of Practice—Construction Documents Fundamentals and Formats Module*, 1996, Alexandria, VA.
2. Construction Specifications Institute (CSI), 1995 MasterFormat, Alexandria, VA.
3. Hall, Dennis, 2003, "An Inside Look at the MasterFormat 2004 Update." BSD Linkline: Spring 2004, *Building Systems Design.* Atlanta, GA.
4. Construction Specifications Institute (CSI), 2004 MasterFormat Divisions 21 and 22, Alexandria, VA.
5. Construction Specifications Institute (CSI) 2003, Summer. MasterFormat 2004, Alexandria, VA.

APPENDIX 3-A1

CSI UNIFORMAT, UNIFORM CLASSIFICATION (1995 Edition)

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 Plumbing Utilities
G40	Site Heating, Ventilation, and Air-conditioning (HVAC) Utilities
G50	Site Electrical Utilities
G60	Other Site Construction

Z. General

Z10	General Requirements
Z20	Bidding Requirements, Contract Forms, and Conditions
Z90	Project Cost Estimate

APPENDIX 3-A2

CSI MASTERFORMAT, LEVEL ONE DIVISION TITLES (1995 Edition)

01000	Division 1: General Requirements
02000	Division 2: Site Construction
03000	Division 3: Concrete
04000	Division 4: Masonry
05000	Division 5: Metals
06000	Division 6: Wood and Plastics
07000	Division 7: Thermal and Moisture Protection
08000	Division 8: Doors and Windows
09000	Division 9: Finishes
10000	Division 10: Specialties
11000	Division 11: Equipment
12000	Division 12: Furnishings
13000	Division 13: Special Construction
14000	Division 14: Conveying Systems
15000	Division 15: Mechanical
16000	Division 16: Electrical

APPENDIX 3-A3

CSI MASTERFORMAT, LEVEL TWO SECTION TITLES (1995 Edition)

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	Concrete Materials and Methods
03100	Concrete Forms and Accessories
03200	Concrete Reinforcement
03300	Cast-in-Place Concrete
03400	Pre-cast Concrete
03500	Cementitous 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	Damp-proofing 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	Grills 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
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	Food Service Equipment
11450	Residential Equipment
11460	Unit Kitchens
11470	Dark Room 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
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-A4

CSI MASTERFORMAT, LEVEL THREE SECTION TITLES (Selected Sections) (1995 Edition)

13900	**Fire Suppression**
13920	Basic Fire Suppression Materials and Methods
13930	Wet-pipe Fire Suppression Sprinklers
13935	Dry-pipe Fire Suppression Sprinklers
13940	Preaction Fire Suppression Sprinklers
13945	Combination Dry-pipe and Preaction Fire Sprinkler Systems
13950	Deluge Fire Suppression Sprinklers
13955	Foam Fire Extinguishing
13960	Carbon Dioxide Fire Extinguishing
13965	Alternative Fire Extinguishing Systems
13970	Dry Chemical Fire Extinguishing
13975	Standpipes and Hoses
15100	**Building Services Piping**
15105	Pipes and Tubes
15110	Valves
15120	Piping Specialties
15130	Pumps
15140	Domestic Water Piping
15150	Sanitary Waste and Vent Piping
15160	Storm Drainage Piping
15170	Swimming Pool and Fountain Piping
15180	Heating and Cooling Piping
15190	Fuel Piping
15200	**Process Piping**
15210	Process Air and Gas Piping
15220	Process Water and Waste Piping
15230	Industrial Process Piping
15400	**Plumbing Fixtures and Equipment**
15410	Plumbing Fixtures
15440	Plumbing Pumps
15450	Potable Water Storage Tanks
15460	Domestic Water-conditioning Equipment
15470	Domestic Water Filtration Equipment
15480	Domestic Water Heaters
15490	Pool and Fountain Equipment

APPENDIX 3-A5 CSI MASTERFORMAT, LEVEL FOUR SECTION TITLES (Sections Selected from Division 15; Section 200) (1995 Edition)

15200	**Process Piping**
15210	Process Air and Gas Piping
15211	Air Compressors
15212	Compressed Air Piping
15213	Gas Equipment
15214	Gas Piping
15215	Nitrogen Piping

15216	Nitrous Oxide Piping
15217	Oxygen Piping
15218	Vacuum Pumps
15219	Vacuum Piping
15220	**Process Water and Waste Piping**
15221	Deionized Water Piping
15223	Distilled Water Piping
15225	Laboratory Acid Waste and Vent Piping
15227	Process Piping Interceptors
15229	Reverse Osmosis Water Piping
15230	**Industrial Process Piping**
15231	Dry Product Piping
15232	Fluid Product Piping

APPENDIX 3-B1
SECTION SHELL OUTLINE

This shell outline has been developed by the American Institute of Architects (AIA) conforming to the Construction Specifications Institute's *Manual of Practice*.

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. 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].

E. Allowances

F.Unit Prices

1.2 REFERENCES

1.3 DEFINITIONS

1.4 SYSTEM DESCRIPTION

1.5 SYSTEM PERFORMANCE REQUIREMENTS

A. Performance Requirements: Provide [system] complying with performance requirements specified.

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. 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 job site 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.

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 are listed and labeled by UL where available.

I.UL and NEMA Compliance: Provide [components] required as part of [product or system] that 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] that fails in materials or workmanship within the specified warranty period. This warranty shall be in addition to and not limitation of other rights the owner may have against the contractor under the contract documents.

   1. The 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 which 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:

E. Manufacturer: 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 the [standard designation] [for type, grade, etc.].

B. [Material or Product Name]: [Standard designation], [type, grade, etc. as applicable to the referenced standard].

2.3 MATERIALS, GENERAL [PRODUCTS, GENERAL]

A. [Description] Standard: Provide [product or material] which complies with [standard designation].

B. [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, 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.).

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

APPENDIX 3-C1

CSI MASTERFORMAT DIVISIONS (2004 Edition)

Procurement and Contracting Documents Group

DIVISION 00 – PROCUREMENT and CONTRACTING REQUIREMENTS: *This division is essentially the same in scope as it was in MasterFormat95.*

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 new feature will allow 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 now restricted to the "existing conditions," that is, construction tasks that relate to the items at the site when the project commences—selective demolition, subsurface and other investigations, surveying, site decontamination, and/or remediation to mention a few. (All site construction as well as heavy civil and infrastructure items including pavement and utilities was relocated to 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 Doors and Windows under MasterFormat95 and remains essentially unchanged, but was renamed to include the addition of 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 the same, 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 alarm as well as fire suppression were relocated to the Facility Services subgroup.*

DIVISION 14 – CONVEYING EQUIPMENT: *This division was renamed with process-related material-handling equipment relocated to the Process Equipment subgroup.*

DIVISION 15 – RESERVED FOR FUTURE EXPANSION: *This division has been assigned for any future expansion, and Division 15 was separated and relocated to Division 22 and Division 23 in the Facility Services subgroup.*

DIVISION 16 – RESERVED FOR FUTURE EXPANSION: *This division has been assigned for any future expansion and Division 16 was separated and relocated to Division 26 and Division 27 in the Facility Services Subgroup.*

DIVISION 17 – RESERVED FOR FUTURE EXPANSION

DIVISION 18 – RESERVED FOR FUTURE EXPANSION

DIVISION 19 – RESERVED FOR FUTURE EXPANSION

Facility Services Subgroup

DIVISION 20 – RESERVED

DIVISION 21 – FIRE SUPPRESSION: *This division contains the Fire Suppression sections relocated from Division 13 in MasterFormat95.*

DIVISION 22 – PLUMBING: *This division contains the Plumbing sections relocated from Division 15 in MasterFormat95.*

DIVISION 23 – HEATING, VENTILATION and AIR-CONDITIONING: *This division contains the Heating, Ventilation, and Air-conditioning Sections from Division 15 in MasterFormat95.*

DIVISION 24 – RESERVED

DIVISION 25 – INTEGRATED AUTOMATION: *This division contains the expanded integrated automation sections that were relocated from Division 13 in MasterFormat95.*

DIVISION 26 – ELECTRICAL: *This division contains the Electrical and Lighting sections relocated from Division 16 in MasterFormat95.*

DIVISION 27 – COMMUNICATIONS: *This division contains the expanded Communications sections relocated from Division 16 in MasterFormat95.*

DIVISION 28 – ELECTRONIC SAFETY and SECURITY: *This division contains the expanded Electronic Safety and Security sections relocated from Division 13 in MasterFormat95.*

DIVISION 29 – RESERVED

Site and Infrastructure Subgroup

DIVISION 30 – RESERVED FOR FUTURE EXPANSION

DIVISION 31 – EARTHWORK: S*ite Construction sections, predominately below grade, that were relocated from Division 02 in MasterFormat95.*

DIVISION 32 – EXTERIOR IMPROVEMENTS: *Site Construction sections, predominately above grade, that were relocated from Division 02 in MasterFormat95.*

DIVISION 33 – UTILITIES: *Utility sections with expansions that were relocated from Division 02 in MasterFormat95.*

DIVISION 34 – TRANSPORTATION: *Transportation sections with expansions relocated from the various divisions in MasterFormat95.*

DIVISION 35 – WATERWAY and MARINE: *Expanded waterway and other marine sections from Division 02 and other divisions in MasterFormat95.*

DIVISION 36 – RESERVED FOR FUTURE EXPANSION

DIVISION 37 –
RESERVED FOR FUTURE EXPANSION

DIVISION 38 –
RESERVED FOR FUTURE EXPANSION

DIVISION 39 –
RESERVED FOR FUTURE EXPANSION

Process Equipment Subgroup

DIVISION 40 –
RESERVED FOR FUTURE EXPANSION

DIVISION 41 – MATERIAL PROCESSING and HANDLING EQUIPMENT: *Equipment for the processing and conditioning of raw materials; material-handling equipment for bulk materials as well as discrete units; manufacturing equipment and machinery; test equipment and packaging/shipping systems.*

DIVISION 42 – PROCESSING HEATING, COOLING and DRYING EQUIPMENT: *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: *Equipment for handling purification and storage of process liquids, gases, and slurries including atmospheric tanks as well as pressure vessels.*

DIVISION 44 – POLLUTION CONTROL EQUIPMENT: *Equipment for controlling emission of contaminants from manufacturing processes and treatment of air, soil, and water contaminants.*

DIVISION 45 – INDUSTRY SPECIFIC MANUFACTURING EQUIPMENT: *A division in which the owners 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 47 –
RESERVED FOR FUTURE EXPANSION

DIVISION 48 – ELECTRICAL POWER GENERATION: *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.*

DIVISION 49 –
RESERVED FOR FUTURE EXPANSION

APPENDIX 3-C2

MASTERFORMAT 2004 FACILITY CONSTRUCTION SUBGROUP

Division 21 Fire Suppression

21 00 00	**Fire Suppression**
21 01 00	Operation and Maintenance of Fire Suppression
21 02 00	Reserved
21 03 00	Reserved
21 04 00	Reserved
21 05 00	Common Work Results for Fire Suppression
21 06 00	Schedules for Fire Suppression
21 07 00	Fire Suppression Systems Insulation
21 08 00	Commissioning of Fire Suppression Systems
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 12 00	Fire Suppression Standpipes
21 13 00	Fire Suppression Sprinkler Systems
21 14 00	Reserved
21 15 00	Reserved
21 16 00	Reserved
21 17 00	Reserved
21 18 00	Reserved
21 19 00	Reserved
21 20 00	**Fire Extinguishing Systems**
21 21 00	Carbon Dioxide Fire Extinguishing Systems
21 22 00	Clean Agent Fire Extinguishing Systems
21 23 00	Wet Chemical Fire Extinguishing Systems
21 24 00	Dry Chemical Fire Extinguishing Systems
21 25 00	Reserved
21 26 00	Reserved
21 27 00	Reserved
21 28 00	Reserved
21 29 00	Reserved
21 30 00	**Fire Pumps**
21 31 00	Centrifugal Fire Pumps
21 32 00	Vertical Turbine Fire Pumps
21 33 00	Positive Displacement Fire Pumps
21 34 00	Reserved
21 35 00	Reserved
21 36 00	Reserved
21 37 00	Reserved
21 38 00	Reserved
21 39 00	Reserved
21 40 00	**Fire Suppression Water Storage**
21 41 00	Storage Tanks for Fire Suppression Water
21 42 00	Reserved

21 43 00	Reserved
21 44 00	Reserved
21 45 00	Reserved
21 46 00	Reserved
21 47 00	Reserved
21 48 00	Reserved
21 49 00	Reserved
21 50 00	**Reserved**
21 60 00	**Reserved**
21 70 00	**Reserved**
21 80 00	**Reserved**
21 90 00	**Reserved**

APPENDIX 3-C3

MASTERFORMAT 2004 FACILITY CONSTRUCTION SUBGROUP

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 02 00	**Reserved**
21 03 00	**Reserved**
21 04 00	**Reserved**
21 05 00	**Common Work Results 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 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 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 10	Fire Suppression Equipment Insulation
21 07 20	Fire Suppression Piping Insulation
21 08 00	**Commissioning of Fire Suppression Systems**
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 12 26	Fire Suppression Valve and Hose Cabinets
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 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 14 00	**Reserved**
21 15 00	**Reserved**
21 16 00	**Reserved**
21 17 00	**Reserved**
21 18 00	**Reserved**
21 19 00	**Reserved**
21 20 00	**Fire Extinguishing Systems**
21 21 00	**Carbon Dioxide Fire Extinguishing Systems**
21 21 13	Carbon Dioxide Fire Extinguishing Piping
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 25 00	**Reserved**
21 26 00	**Reserved**
21 27 00	**Reserved**
21 28 00	**Reserved**
21 29 00	**Reserved**
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 10	Electric Drive, Positive Displacement Fire Pumps
21 33 16	Diesel Drive, Positive Displacement Fire Pumps
21 34 00	**Reserved**
21 35 00	**Reserved**
21 36 00	**Reserved**
21 37 00	**Reserved**
21 38 00	**Reserved**
21 39 00	**Reserved**
21 40 00	**Fire Suppression Water Storage**
21 41 10	**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
21 42 00	**Reserved**
21 43 00	**Reserved**
21 44 00	**Reserved**
21 45 00	**Reserved**
21 46 00	Reserved
21 47 00	Reserved
21 48 00	**Reserved**
21 49 00	**Reserved**
21 50 00	**Reserved**
21 60 00	**Reserved**
21 70 00	**Reserved**
21 80 00	**Reserved**
21 90 00	**Reserved**

APPENDIX 3-C4

MASTERFORMAT 2004 FACILITY CONSTRUCTION SUBGROUP

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 20	Reserved
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 01 70	Reserved
22 01 80	Reserved
22 01 90	Reserved
22 02 00	**Reserved**
22 03 00	**Reserved**
22 04 00	**Reserved**
22 05 00	**Common Work Results for Plumbing**
22 05 13	Common Motor Requirements for Plumbing Equipment
22 05 16	Expansion Fittings and Loops 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 53	Identification for Plumbing Piping and Equipment
22 05 73	Facility Drainage Manholes
22 05 76	Facility Drainage Cleanouts
22 06 00	**Schedules for Plumbing**
22 06 10	Schedules for Plumbing Piping and Pumps
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 40	Schedules for Plumbing Fixtures

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 of Plumbing**
22 10 00	**Plumbing Piping and Pumps**
22 11 00	**Facility Water Distribution**
22 11 13	Facility Water Distribution Piping
22 11 16	Domestic Water Piping
22 11 19	Domestic Water Piping Specialties
22 11 23	Domestic 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 23	Facility Indoor Potable Water Storage 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 23	Sanitary Waste Interceptors
22 13 26	Sanitary Waste Separators
22 13 29	Sanitary Sewerage Pumps
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 53	Facility Septic 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 29	Sump Pumps
22 14 33	Packaged, Pedestal, Drainage Pump Units
22 14 36	Packaged, Submersible, Drainage Pump Units
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 16 00	**Reserved**
22 17 00	**Reserved**
22 18 00	**Reserved**
22 19 00	**Reserved**
22 20 00	**Reserved**
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-free Standing 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 33 00	**Electric Domestic Water Heaters**
22 33 13	Instantaneous Electric Domestic Water Heaters
22 33 30	Residential, Electric Domestic Water Heaters
22 33 33	Light Commercial Electric Domestic Water Heaters
22 33 36	Commercial Domestic Water Electric Booster 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 36	Commercial Gas Domestic Water Heaters
22 34 46	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 23	Circulating Domestic Water Heat Exchangers
22 35 29	Noncirculating Domestic Water Heat Exchangers
22 35 36	Domestic Water Brazed Plate Heat Exchangers
22 35 39	Domestic Water Plate and Frame Heat Exchangers
22 35 43	Domestic Water Heat Reclaimers
22 36 00	**Reserved**
22 37 00	**Reserved**
22 38 00	**Reserved**
22 39 00	**Reserved**
22 40 00	**Plumbing Fixtures**
22 41 00	**Residential Plumbing Fixtures**
22 41 13	Residential Water Closets, Urinals, and Bidets

22 41 16	Residential Lavatories and Sinks
22 41 19	Residential Bathtubs
22 41 23	Residential Shower Receptors and Basins
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 16	Commercial Lavatories and Sinks
22 42 19	Commercial Bathtubs
22 42 23	Commercial Shower Receptors and Basins
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 and Showers
22 43 23	Healthcare Shower Receptors and Basins
22 43 26	Healthcare Faucets
22 43 43	Healthcare Plumbing Fixture Flushometers
22 44 00	**Reserved**
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 Units
22 46 00	**Security Plumbing Fixtures**
22 46 13	Security Water Closets and Urinals
22 46 16	Security Lavatories and Sinks
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 48 00	**Reserved**
22 49 00	**Reserved**
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 53 00	**Reserved**
22 54 00	**Reserved**
22 55 00	**Reserved**
22 56 00	**Reserved**
22 57 00	**Reserved**
22 58 00	**Reserved**
22 59 00	**Reserved**
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 19	Compressed Air Equipment for Laboratory and Healthcare Facilities
22 62 00	**Vacuum Systems for Laboratory and Healthcare Facilities**
22 62 13	Vacuum Piping for Laboratory and Healthcare Facilities
22 62 19	Vacuum Equipment for Laboratory and Healthcare Facilities
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 19	Gas Storage Tanks for Laboratory and Healthcare Facilities
22 64 00	**Reserved**
22 65 00	**Reserved**
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 67 00	**Processed Water Systems for Laboratory and Healthcare Facilities**
22 67 13	Processed Water Piping for Laboratory and Healthcare Facilities
22 67 19	Processed Water Equipment for Laboratory and Healthcare Facilities
22 68 00	**Reserved**

22 69 00	**Reserved**
22 70 00	**Reserved**
22 80 00	**Reserved**
22 90 00	**Reserved**

APPENDIX 3-C5

MasterFormat 2004 Facility Construction Subgroup

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 20	Reserved
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 01 70	Reserved
22 01 80	Reserved
22 01 90	Reserved
22 02 00	**Reserved**
22 03 00	**Reserved**
22 04 00	**Reserved**
22 05 00	**Common Work Results for Plumbing**
22 05 13	Common Motor Requirements for Plumbing Equipment
22 05 16	Expansion Fittings and Loops 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 53	Identification for Plumbing Piping and Equipment
22 05 73	Facility Drainage Manholes
22 05 76	Facility Drainage 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 of Plumbing**
22 10 00	**Plumbing Piping and Pumps**
22 11 00	**Facility Water Distribution**
22 11 13	Facility Water Distribution Piping
22 11 16	Domestic 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 Close-coupled, Inline, Seal-less Centrifugal Domestic Water Pumps
	22 11 23.26 Close-coupled, Horizontally Mounted, Inline, Centrifugal Domestic Water Pumps
	22 11 23.29 Close-coupled, Vertically Mounted, Inline, Centrifugal Domestic Water Pumps
	22 11 23.33 Separately Coupled, Inline, Centrifugal Domestic Water Pumps
	22 11 23.36 Separately Coupled, Horizontally Mounted, Inline, Centrifugal Domestic 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 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 53	Facility Septic 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 23.23	Gas/Oil Disposal Systems
	22 14 23.26	Gas/Oil Removal Devices
	22 14 23.33	Backwater Valves
	22 14 23.36	Air-admittance Valves
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 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 16 00	**Reserved**	
22 17 00	**Reserved**	
22 18 00	**Reserved**	
22 19 00	**Reserved**	
22 20 00	**Reserved**	
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 Green Sand 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 Controlled, 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 Exchanger
22 35 13.16	Domestic Water in Coil, Instantaneous Domestic Water Heat Exchanger
22 35 13.19	Heating Fluid in a U-Tube Coil, Instantaneous Domestic Water Heat Exchanger
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 Plate and Frame Heat Exchangers
22 35 43	Domestic Water Heat Reclaimers
22 36 00	**Reserved**
22 37 00	**Reserved**
22 38 00	**Reserved**
22 39 00	**Reserved**
22 40 00	**Plumbing Fixtures**
22 41 00	**Residential Plumbing Fixtures**
22 41 13	Residential Water Closets, Urinals, and Bidets
22 41 16	Residential Lavatories and Sinks
22 41 19	Residential Bathtubs
22 41 23	Residential Shower Receptors and Basins
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 16	Commercial Lavatories and Sinks
22 42 19	Commercial Bathtubs

22 42 23 Commercial Shower Receptors and Basins
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 and Showers
22 43 23 Healthcare Shower Receptors and Basins
22 43 26 Healthcare Faucets
22 43 43 Healthcare Plumbing Fixture Flushometers

22 44 00 Reserved

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 Handheld Emergency Drench Hoses
22 45 33 Combination Emergency Fixture Units
22 45 36 Emergency Fixture Water Tempering Units

22 46 00 Security Plumbing Fixtures
22 46 13 Security Water Closets and Urinals
22 46 16 Security Lavatories and Sinks
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 Chillers

22 48 00 Reserved

22 49 00 Reserved

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 53 00 Reserved

22 54 00 Reserved

22 55 00 Reserved

22 56 00 Reserved

22 57 00 Reserved

22 58 00 Reserved

22 59 00 Reserved

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 64 00 Reserved

22 65 00 Reserved

22 66 00 Chemical Waste Systems for Laboratory and Healthcare Facilities

22 66 53 Laboratory Chemical Waste and Vent Piping
22 66 70 Health Care 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

22 68 00 Reserved

22 69 00 Reserved

22 70 00 Reserved

22 80 00 Reserved

22 90 00 Reserved

APPENDIX 3-C6

MASTERFORMAT 2004 FACILITY CONSTRUCTION SUBGROUP

23 00 00 Heating, Ventilation, and Air-conditioning
23 10 00 Facility Fuel Systems
23 11 13 Facility Fuel Oil Piping
23 11 16 Facility Gasoline Piping
23 11 23 Facility Natural Gas Piping
23 11 26 Facility Liquefied Petroleum Gas Piping
23 12 00 Facility Fuel Pumps
23 12 13 Facility Fuel Oil Pumps
23 12 16 Facility Gasoline Dispensing Pumps
23 13 00 Facility Fuel Storage Tanks
23 13 13 Facility Underground Fuel Oil Storage Tanks
- 23 13 13.13 Double-wall Steel, Underground Fuel Oil, Storage Tanks
- 23 13 13.16 Composite Steel, Underground Fuel Oil, Storage Tanks
- 23 13 13.19 Jacketed Steel, Underground Fuel Oil, Storage Tanks
- 23 13 13.23 Glass Fiber Reinforced Plastic, Underground Fuel Oil, Storage Tanks
- 23 13 13.33 Fuel Oil Storage Tank Pumps

23 13 13 Facility Aboveground Fuel Oil, Storage Tanks
- 23 13 13.13 Vertical Steel, Aboveground Fuel Oil, Storage Tanks
- 23 13 13.16 Horizontal Steel, Aboveground Fuel Oil, Storage Tanks
- 23 13 13.19 Containment Dike, Steel, Aboveground Fuel Oil, Storage Tanks
- 23 13 13.23 Insulated, Steel, Aboveground Fuel Oil, Storage Tanks
- 23 13 13.33 Concrete Vaulted, Steel, Aboveground Fuel Oil, Storage Tanks

4

Plumbing Cost Estimation

Cost estimating involves matching the specific information of a project with a database of known construction costs to predict the cost of the project. When the project varies from the assumptions of the database, the predicted cost is adjusted appropriately. Specific project information generally is identified as groups of repeated activities. The database is a compilation of the costs for each activity, which are called the unit costs. Quantities of each activity are multiplied by the unit costs and added for a sum of the costs. Often, the quantity of material is separated from the hours of labor. Multipliers then are applied to this sum, and the number is rounded up.

Mathematically, the process is multiplying two vectors, called a dot product, and then multiplying this dot product by a scalar. The first vector is the quantity of activities. The second vector is the cost of each activity. A database may be developed over time or may be obtained with a vendor's estimating software program. The calculations generally are set up with tabular sheets, an ordinary spreadsheet program, or a vendor's program.

The database of unit costs is usually different for projects that have a completed design than for projects that are in the schematic phase. For estimating design development, where final sizes are not known, approximate sizes are estimated, and the same database that is used on final projects is applied, but a more liberal contingency factor is used.

Plumbing construction costs can be broken down into these categories:

- Materials
- Preparation
- Fixtures
- Accessories

Materials include pipe, fittings, valves, pipe supports, sleeves, low-voltage wiring, fire stopping, insulation, identity, drains, cleanouts, fixture carriers, sprinkler heads, medical gas outlets, and similar commodity items as well as general material handling. Preparation includes demolition work, excavation and backfill, cutting and patching, and survey and marking. Accessories include interceptors, pumps, alarms, water meters, backflow preventers, pressure vessels, water heaters, and water treatment equipment.

Cost estimating is broken down into two convenient sets of sums. Material costs are estimated separately from labor costs. Thus, we have the following formulae to create a tabular take-off sheet for manual estimating or writing a spreadsheet.

Equation 4-1

$$E1 = (Q)\ (M)\ d + (H)\ (L)\ w$$

where

Q=Quantity vector of each material on a specific job

M=Price vector 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 vector of each labor activity (may be equal to Q)

L=Time vector for a single worker to do each type of activity

w=A multiplier to represent the hourly cost for such a worker including all taxes, insurance costs, and benefits

Equation 4-2

$$Et = \text{Sum}\ (E1, E2, E3\ldots En)\ m + O$$

where

E1, 2, 3… = Estimate of one category of construction

m=Product of factors such as geography, job size, contingency, sales tax, and contractor overhead

O=A sum of fixed costs such as permits, equipment mobilization, bonds, chlorination, certification, recordkeeping costs, equipment rental, and submittal preparation

The product of factors, m, often is called a markup. If the conditions of the project match the database and sales tax does not apply, then m ranges from 1.10 to 1.12 to reflect a 10 to 12 percent overhead for the plumbing contractor. The final installed cost will include the additional overhead of the general contractor ranging from 6 to 15 percent. If geography and job size are ideal, but the design is incomplete, then a 15 percent contingency may be considered as well as the 10 percent overhead. Thus, m = 1.15 × 1.10 = 1.265. The geography factor ranges from 0.87 to 1.10 for most of North America. Sales tax varies regionally and by how it is applied. The size of a job causes the largest range of factors and is discussed later in this chapter. Thus, a job's markup on its sum of costs for geography, job size, contingency, sales tax, and plumbing contractor overhead may be 1.12, 1.00, 1.02, 1.06, and 1.10 respectively, resulting in m = 1.33.

Some estimators prefer to consider each markup factor separately in terms of the amount of additional costs for each factor. Thus, in the last example, 12 percent of the sum of costs is derived to give the added cost for geography. Then the geography factor is added to the sum of costs. The 2 percent contingency is derived from this last sum. Then the 6 percent sales tax is similarly derived. The overhead may be derived before or after adding the sales tax, depending on local practice.

It should be noted in how markups are considered for estimates for alternative materials or construction methods. The same markup should be applied to the original cost and to the alternate cost. If an alternate is presented without the markup, it may erroneously appear to be attractive over the original. Conversely, beware of an alternate that includes the markup while it is compared to the original that is part of a larger estimate. The original will not have the markup included if it is only a line item because the markup is applied later in the estimate. Hence, the alternate may not appear attractive, even though it is.

LABOR COSTS

The following parts of a labor rate are applied to the gross wage rate to reflect a labor cost of construction:

- Social Security and Medicare taxes that employers pay
- Workman's compensation insurance premium
- Unemployment tax
- Health insurance premium
- Holiday and vacation pay
- Retirement cost

The estimated cost of labor will be the labor rate multiplied by the estimated time to complete the work.

TAKE-OFF ESTIMATING METHOD

The take-off method requires measuring the length of each size and type of pipe using scaled drawings. In addition, the method requires counting all fittings, valves, fixtures, accessories, and other materials. This tedious process then is combined with known material costs and expected productivity and labor rates to obtain the sum of costs. The method has an established record of providing accurate cost estimates.

One method to create the tabular take-off sheet is shown in Table 4-1. The material quantity vector 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. Various work situations can be adjusted. Table 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 before being adjusted by the markup, m, to give the final estimate. If necessary, premium labor rates are applied for nonstandard work-week hours. Overtime labor rates are adjusted further to reflect lower productivity for longer workdays.

Another method of take-off estimation reflects the fact that construction con-

Table 4-1 Piping Take-off Sample

1-in. [25-mm] copper L , 50/50 solder						
ft [m] of pipe	237 [72.2]	$2.05	$486			
Couplings	24	1.56	$ 37	2	0.25	12 hr
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			49.2 hr
Deduct discount			$280			
Elevated work adjustment			(10%)			54.2 hr
Wage rate ($/hr per person)						$55/hr
Subtotal (materials and installation)			$520			$2,980
Total						$3,500

sists of crews of varying skills and labor rates. The database shows productivity of certain sizes of crews. For example, one plumber and one apprentice, each with their own wage, can install so many feet of 3-in. [75-mm] PVC pipe per day.

PRODUCTIVITY RATES

Tables 4-2 through 4-8 provide labor units for estimating a plumbing project. Table 4-9 provides some modifiers for various job conditions. The information was derived from the Plumbing-Heating-Cooling Contractors Association (PHCC) 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-ft [0.91-m] deep trench 100 ft [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-in. 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. Sawcutting 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 sawcut concrete can reduce the times shown in Table 4-4.

Table 4-5 shows that the time for one laborer to hand backfill and mechanically hand tamper medium backfill in a 3-ft [0.91-m] deep trench 100 ft [30.5 m] long is 17 hours. The same table shows that the time to do it by machine is 1.8 hours. However, 12 additional hours are required for hand tamping the first layer of a 4-in. [100-mm] pipe and 0.8 hour of labor to assist the backfilling. If certain types of fill material are used, such as ¾ to 1 in. [19 to 25 mm] stone, compacting the fill is not required.

Notice in Table 4-6 that completing a single 4-in. [100-mm] threaded joint takes the most time (one hour) and completing a single hubless joint takes the least (0.4 hour). Joining methods and materials not shown but growing in the market include press fit, CPVC, and PEX.

Example 4-1

Using Tables 4-2 and 4-5, estimate the cost to excavate and backfill a 5-ft [1.52-m] deep trench 210 ft [64 m] long by machine. Final hand grading will be required, the pipe will be 4 in. [100 mm], and spoils will be backfilled.

Solution: Select the required unit labor and apply it to the trench length. Add equipment rental charge

Table 4-2 Hours to Excavate 100 ft [30.5 m] of Trench

Depth (ft)	Width (in)	Volume (yd³)	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 yd³ = 0.7646 m³, 1 ft³ = 0.037 yd³

[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.

Table 4-3 To Sawcut 100 ft [30.5 m] of Concrete Trench

Depth			
Inches	3	4	5
mm	75	100	125
Hours	5	6	7

Table 4-4 To Break 100 ft [30.5 m] of Pavement

Method	Pavement	Width	Hours
Hand Pneumatic	Concrete	24 in. [600 mm]	10

(or ownership hourly rate). Table 4-10 shows the take-off tabulation.

Example 4-2

Using Tables 4-2 and 4-5, estimate the cost to excavate and backfill trenches, by machine, 120 ft of 3-ft average depth, 130 ft of 2-ft average depth, and a variety of trenches totaling 250 ft of 18-in. average depth. Excavated material will be dumped off site and replaced by new fill. Final hand grading will be required, and the pipe will be 4 in. [100 mm].

Solution: Determine the various required unit labor and apply it to the various trench lengths. Add equipment rental charge (or ownership hourly rate). Add hauling cost of excavated material and delivery of backfill material. Since excavated material increases in volume by the excavation process, appropriately adjust the volume to account for this swelling. Table 4-11 shows the take-off tabulation for each step.

OTHER ESTIMATING METHODS

A less precise estimating method is to count fixtures and major accessories and apply time-proven costs per fixture or accessory to arrive at the total cost. Piping and material costs are included in the per-fixture cost, and the particular level of trim and quality level of the specific project should be comparable with those of the database. For example, if the project requires cast brass faucets, caulked cast iron piping, and frequent valves on the supply distribution, then apply a per-fixture cost that is derived from a project that used similar materials.

Table 4-5 Hours to Backfill 100 ft [30.5 m] of Trench

Depth (ft)	Volume (yd^3)	All Work by Hand			Pipe Bedding		Mechanical Backfill[a]	Mechanical Compaction
		Sandy	Medium	Hard	3″ dia	4-10″ dia		
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 yd^3 = 0.7646 m^3, 1 ft^3 = 0.037 yd^3

[a] Must add for standby hand laborer.

[b] Call equipment company for hours to compact backfill.

Table 4-6 Hours to Complete 100 Joints

Method	Size														Note
Inch	**½**	**¾**	**1**	**1¼**	**1½**	**2**	**2½**	**3**	**4**	**5**	**6**	**8**	**10**	**12**	
mm	**12**	**19**	**25**	**32**	**38**	**50**	**63**	**75**	**100**	**125**	**150**	**200**	**250**	**300**	
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	20	21	25	26	27	28	40	50	60	98	101	136	162	216	1
Hub and caulk						50		55	60	65	70	120	130	150	2
Hub and gasket						45		45	50	55	60	100	110	125	2
Hubless					30	30		35	40	45	50	80	90	100	
Water main, mechanical joint								60	62		70	72	80	82	3
Water main, compression								47	48		50	52	54	56	3

Note 1: Solvent joint. For heat fusion, multiply value by 1.5.

Note 2: Hub-and-spigot, service-weight cast iron pipe. For extra heavy, multiply value by 1.02.

Note 3: Labor for 300 ft [90 m] minimum. Add crane cost.

Table 4-7 Hours to Install 100 Pipe Hangers

Type	Size												
Inch	**¾**	**1**	**1¼**	**1½**	**2**	**2½**	**3**	**4**	**5**	**6**	**8**	**10**	**12**
mm	**19**	**25**	**32**	**38**	**50**	**63**	**75**	**100**	**125**	**150**	**200**	**250**	**300**
Ring	50	50	50	50	50	60	60	70	70	80	100	100	100
Roller						140	140	160	160	180	220	220	220

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.

Another less precise estimating method is the square foot [m^2] method. 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 or spread-out distribution of fixtures, but also the intensity of fixtures. For example, a medical office usually has a higher number of fixtures per building area than an ordinary office building. Regulations and probable demand vary with different types of occupancy and will influence infrastructure requirements.

More precise estimating methods are now available through computer programs and certain types of hardware peripherals While the value of using an appropriate database has been emphasized, entering precise counts and lengths is now being addressed by several 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 over a digitizing pad so that pipes are picked at each end and the software accounts for its length. Other software works with electronic versions of the drawing, and the user highlights each pipe as he enters key information, such as pipe diameter. When the counts and lengths of materials are accurately and quickly gathered, a more precise cost estimate is determined. However, an estimating program should address current needs without being too complicated. The vendor of the program should be experienced with 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 level of work quality, standard work hours, general crew productivity, size of a project,

Table 4-8 Hours to Install Fixtures

Fixture	Type	Time
Bathtub		3.0
Drinking fountain	Wall mount	2.0
Lavatory	Wall mount	2.0
Lavatory	Counter	2.5
Mop basin		2.0
Shower	Built-up stall	1.0
Sink	Single compartment	2.0
Sink	Double compartment	2.5
Service sink		3.0
Urinal	Wall mount	2.8
Urinal	Stall	3.8
Water closet	Floor mount	1.8
Water cooler	Wall mount	2.7

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] 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
Food service		1.10

Table 4-10 Solution to Example 4-1

Item	Length, ft [m]	Unit Hours	Total hours
Excavate	210 [64]	0.05	10.5
Hand grading	210 [64]	0.04	8.4
Pipe bedding	210 [64]	0.12	25.2
Backfill	210 [64]	0.02	4.2
Added labor	210 [64]	0.02	4.2
Compaction	210 [64]	0.01	2.1
Total labor hours			54.6
Labor rate [$/hr per person]			$55/hr
Total labor cost [$55/hr x 54.6 hrs]			$3,003
Total machine hours			17
Machine cost [$120/hr x 17 hrs]			$2,040
Total cost			$5,043

allotment of a reasonable time frame, new plumbing or alteration of existing plumbing, geographic location of the project, weather, season of the year, contractor management, collective bargaining agreements, utility availability, and general business conditions. The size of a job favors larger projects because of 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.

Table 4-11 Solution to Example 4-2

Item	Length, ft [m]	Unit Hours	Hours	Volume
1.5-ft [450-mm] deep trenches				
Excavate	250 [76]	0.02	5	
Hand grading	250 [76]	0.03	7.5	
Pipe bedding	250 [76]	0.12	30	
Backfill	250 [76]	0.004	1	
Added labor	250 [76]	0.004	1	
Compaction	250 [76]	0.005	1.25	
Hours			47.8	
Cubic yards [m^3]	250 [76]	0.09 [0.07]		22.5 [17.2]
2-ft [610-mm] deep trenches				
Excavate	130 [40]	0.02	2.6	
Hand grading	130 [40]	0.03	3.9	
Pipe bedding	130 [40]	0.12	15.6	
Backfill	130 [40]	0.005	0.65	
Added labor	130 [40]	0.005	0.65	
Compaction	130 [40]	0.005	0.65	
Hours			24.1	
Cubic yards [m^3]	130 [40]	0.12 [0.09]		15.6 [11.9]
3-ft [915-mm] deep trenches				
Excavate	120 [37]	0.03	3.6	
Hand grading	120 [37]	0.04	4.8	
Pipe bedding	120 [37]	0.12	14.4	
Backfill	120 [37]	0.008	0.96	
Added labor	120 [37]	0.008	0.96	
Compaction	120 [37]	0.01	1.2	
Hours			25.9	
Cubic yards [m^3]	120 [37]	0.27 [0.21]		32.4 [24.8]
Total labor hours			95.7	
Cubic yards [m^3]				70.5 [53.9]
Adjusted cubic yards [m^3]				81.1 [67.3]
Labor rate			$55/hour	
Total labor cost			**$5,265**	
Total machine hours			16.9	
Machine cost at $120/hour			$2,029	
Haul excavated material at $6/cubic yard [$8 m^3]			$487	
Fill material cost at $8 cubic yard [$10 m^3]			$649	
Total			**$8,430**	

For cost estimating changes to an ongoing construction project, other cost factors may be necessary even though they may not have applied for the original estimate. For example, the size may be smaller and out of a planned sequence, the time frame may be constricted, or the plumbing change is now within a finished space.

In conclusion, since cost estimating involves the matching of specific project information with a database of known construction costs, variations from the database affect the cost estimate, and an appropriate adjustment is used to arrive at an accurate estimate. The amount of 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 gives the needed information to match with established unit costs. Hence, seasoned judgment with tedious review of the project documents yields a precise and accurate prediction of plumbing costs.

5

Job Preparation, Drawings, and Field Reports

A significant portion of time spent on a project is devoted to communication. While good design practices and accurate engineering analyses are important, they will be of little benefit if communication fails to reach the receiver. Hence, effective means are required to ensure that information is faithfully passed among the design team, contractors, and building owner. In the proper preparation of plumbing documents for a construction project, the general expectations of the project are established, including the work scope, regulatory requirements, specification formats, drawing title blocks, and design team directory.

Drawings are prepared as the means to graphically communicate the design. Specifications are prepared to communicate detail requirements of the design. Then, as construction proceeds and the engineer observes progress of the plumbing work, the engineer provides feedback to the plumbing contractor. To assist in providing thorough communication, engineering offices frequently use lists to prepare quality documents and make field observations.

JOB PREPARATION GUIDELINES

1. Identify relevant codes and standards, including local amendments and dates of issue. Relevant issues include:
    - Energy and water conservation
    - Hot water production and maintenance
    - Cross-connection control
    - Interceptors
    - Clear water disposal
    - Rainfall rates
    - Secondary drainage
    - Storm water management
    - Fire sprinklers and standpipes and occupancy class
    - Fuel gas code
    - Medical gases and other healthcare matters
2. Establish a directory of project team members. Organize project schedule with staff.
3. Identify date, time, method, and format of document deliveries: type and version of a CAD program, BIM requirements, hard-copy plots, PDFs, and e-mail or upload/download to a designated website.
4. Contact the plumbing code official and the fire suppression authority having jurisdiction (AHJ). Contact water, sewer, and gas utilities and establish connection requirements.
5. If likely to be relevant for the project, identify certain information such as geographic elevation, humidity issues, hurricane issues, and seismic matters.
6. Identify phasing issues and whether there will be concurrent occupancy.
7. Review survey and other documents for size, location, and depth of sanitary and storm sewers, water mains, and gas mains along with any site obstructions and interferences.
8. 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 pumps as required.
9. 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.
10. Determine if water treatment is required. Obtain a water quality analysis. Select and size any necessary treatment equipment.
11. Determine if unusual occupancy-related plumbing requirements exist.
12. Within the limits of the code, determine the architect's preferred method of cleanout design.
13. Coordinate electrical voltages and phases for motors and controls with the electrical engineer.
14. Coordinate gas pressure requirements for water heaters and other equipment with the gas utility.

15. Determine the need for other systems, such as compressed air, vacuum, deionized water, acid waste, fuel oil, and steam.
16. Review the cost estimate and time estimate against recent project developments.
17. If required, determine possible green building strategies, including water and energy conservation, water reuse, sustainable technologies, project commissioning, and certification. Chart progress toward USGBC certification.

PLUMBING DRAWING GUIDELINES

1. Review 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.
2. Review utility regulations and provide water service requirements. 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 kilopascals [kPa]).
3. Review fire suppression standards and local requirements, including class of standpipes and classification of occupancy. Determine water demand, including flow at required residual pressure. Provide service with an approved backflow preventer or other approved cross-connection control. Select a wet, dry, or antifreeze type sprinkler system.
4. Coordinate the fire department connection location and fire hydrant requirements with the architect, site civil engineer, and landscape designer.
5. Review the code-minimum rainfall rate and whether a higher rate should be considered. Size roof drains, conductors, and storm drain system accordingly. Review secondary drainage requirements and coordinate them with the architect.
6. Determine the size and extent of subsoil drainage based on soil reports and wall structural requirements.
7. Review storm water management issues. Review clear water disposal restrictions.
8. Send electrical control and power requirements of plumbing and fire suppression equipment to the electrical engineer. These requirements may include 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.
9. Evaluate hot water demand requirements. Select and size the water heater, mixing valve, and circulation pump. Provide a hot water system with a circulating return unless the distance between the heater and the farthest fixture is relatively short.
10. Determine combustion air requirements for atmospheric gas-fired water heaters.
11. Address scald hazard concerns and pathological hazards (Legionella pneumophila) within the hot water system.
12. Determine water treatment requirements. Select and size equipment for anticipated occupancy demand and client preferences.
13. Review selection of pipe material for each part of the plumbing system from supply systems to drain systems. Consider purity requirements, corrosion issues, fluid temperature, fluid pressure, joining methods, hanger spacing, code issues, and physical protection.
14. Review pipe insulation requirements thermally and acoustically.
15. Review noise and vibration considerations of piping systems and plumbing equipment. Review water hammer requirements. Review noise concerns from rotary vacuum pumps and similar equipment.
16. Consider building expansion requirements and design concerns that affect tenant occupancy changes.
17. Arrange plumbing piping logically while considering obstructions, occupancy restrictions, accessibility, control, future expansion, designer's preferences, and economics. In general, run piping clear of structural beams. Where necessary 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 rooms, as well as stairs and exit discharge corridors. Size piping for the required supply and drainage fixture units.
18. Provide pipe expansion loops or expansion joints where required.

19. 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.
20. Provide hose bibbs around the building. Select frostproof hose bibbs if required. Review the landscape irrigation connection point where required.
21. Note piping elevation changes on 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 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."
22. Select the location and spacing of cleanouts.
23. Locate fire standpipes and hose connections.
24. Locate alarm panels and motor controllers.
25. Locate roof leaders, main stacks, and supply risers. Coordinate wall thicknesses, beam clearances, and footing clearances with the architect and structural engineer.
26. Coordinate structural penetrations and housekeeping pads with the architect and structural engineer. Review the weight of the water heater and other equipment with the structural engineer.
27. 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.
28. Select sprinkler head designs, including escutcheons or covers, finish type, and color. Send sprinkler head cut sheets to the architect.
29. Determine medical gas outlet adaptor types, shutoff valve box locations, and alarm panel layouts. Send equipment cut sheets to the architect. Include dimensioned drawings and selection of options.
30. Review plans for mop basin, drinking fountain, and floor drain requirements.
31. 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.
32. Review and coordinate 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
    - 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)
    - Humidifiers
    - Ice machines
    - Laboratory equipment
    - Laundries
    - Pressure relief valves (drain only)
    - Sterilizers
    - Vacuum pumps
    - Other equipment
33. Review and coordinate natural gas connections for water heaters, food service equipment, and other equipment as required.
34. Select the size and design of floor drains and receptors to meet requirements. If required, segregate clear water wastes from sanitary wastes. Connect clear water system to the storm drain system or another disposal point as permitted.
35. Identify infrequently used drains and provide them with trap primers.
36. Offset roof drains and vent terminals 12 to 18 in. (0.3 to 0.5 m) away from parapet walls, roof openings, and other roofing elements.
37. Review canopies and porte-cocheres for adequate drainage.
38. 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 to sprinkler supplies. Provide air gaps for relief ports of backflow preventers, for pressure relief valves, and generally for fixture faucet outlets.
39. 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.

DOCUMENT CHECKLIST

Modify this checklist to suit client requirements and the policy of your firm. Note checked items with your initials. Label NA where not applicable.

Drawing Plans

1. ____ Is it evident that the architectural backgrounds are current?
2. ____ Does the title block have correct format, proper date, and proper nouns spelled correctly?
3. ____ Are the drawings legible and of sufficient scale?
4. ____ Are arrangements coordinated so that the drawing sheet index matches the final set of drawing sheets?
5. ____ Are more recent requirements coordinated with the architect, electrical engineer, HVAC engineer, and structural engineer?
6. ____ Do pipes clear structural members, high ceilings, skylights, and clerestories?
7. ____ Do all pipes show sizes? Are fixture units shown? Are invert elevations shown?
8. ____ Are valves and cleanouts accessible?
9. ____ Are all fixtures connected to supply, waste, and vent piping?
10. ____ Do toilet rooms have floor drains where required? Lowest level, elevator pit, and other pits?
11. ____ Is piping kept out of elevator shafts, electric and data communication rooms, similar restricted rooms, stairs, and exit discharge corridors?
12. ____ Are pipes clear of ductwork?
13. ____ Are stacks, conductors, and risers within interior partitions or shafts?
14. ____ Is size sufficient?
15. ____ Are ceiling spaces and similar concealed spaces prone to freezing?
16. ____ Is cutting and patching addressed clearly?
17. ____ Do roof drain locations coordinate with architectural requirements?
18. ____ Are drawing notes complete and edited for the specific job?
19. ____ Are plumbing vents sufficiently separated from air intakes and operable windows?
20. ____ Are medical gas alarm panels and shutoff valve boxes clear of obstructions such as carts and doors?
21. ____ Is the mechanical room coordinated and well laid out with sufficient access to service equipment, including equipment removal? Are equipment connections and drains coordinated?
22. ____ Does the direction of the north arrow agree with the architect's plans?

Drawing Risers and Details

1. ____ Are risers legible? Are references, such as drawing references, room numbers, and fixture tags, clearly presented? Are fixture traps oriented correctly?
2. ____ Are all vents properly connected? Are vent stacks, relief vents, and yoke vents shown where required?
3. ____ Are pipe sizes consistent between risers and plans?
4. ____ Are details shown for accessible fixtures, interceptors, backflow preventers, water heaters, water treatment systems, sump pumps, and sewage ejectors?
5. ____ Are pipe supports, sleeves, and fire stopping systems properly detailed?
6. ____ Is the water service design properly detailed and coordinated with the utility?
7. ____ Does the fire riser design meet requirements?
8. ____ Are detail references coordinated with the plans?

Schedules and Specifications

1. ____ Are arrangements coordinated so that the project manual table of contents matches the final sections of the plumbing specification?
2. ____ Is the inclusion of fixtures and equipment consistent in both the drawings and the specifications?

3. ____ Are fixtures and equipment consistently referenced on plans, risers, schedules, and specifications?

4. ____ Are pumps selected for proper flow and head?

5 ____ Is voltage and other electric data consistent in schedules, with the equipment supplier and the electrical engineer?

6. ____ Does the schedule of supply and drainage fixture units show the original total, removed total, and new total?

7. ____ 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?

8. ____ 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?

9. ____ Are legends, symbols, and abbreviations included?

FIELD CHECKLIST

Field visits can 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 requirements of the construction documents. Note observed items with your initials. Label NA where not applicable. Add comments regarding deficiencies.

Building Drains

1. ____ General alignment and conformity to plans

2. ____ Workmanship of joints, general compactness of soil below and around pipe

3. ____ General slope of piping

4. ____ Spacing and accessibility of cleanouts

5. ____ Vent connections

6. ____ Branch to building drain not connected near base of stack or conductor

7. ____ Pipe sleeves and waterstopping

8. ____ Pipe sizes and invert elevations

9. ____ Manholes, sumps, receivers, grease interceptors, sand and oil interceptors, trench drains, and other structures: workmanship, specified size, invert elevations, and rim elevations

10. ____ Trap primer connections

11. ____ Temporary terminations covered or capped to prevent the entry of any debris

12. ____ Acid waste and vent piping and acid dilution tank

Water and Gas Services

1. ____ Compliance with water service requirements, including service location, pipe depth, thrust blocks, and shutoff valves

2. ____ Compliance with natural gas service requirements such as service location and shutoff valves

Above Grade Rough-in

1. ____ Compliance with water service requirements such as location, shutoff valves, meters, meter registers, pressure-reducing valves, bypasses, backflow preventers, pressure gauges, and testing ports

2. ____ Compliance with natural gas service requirements such as location, shutoff valves, meters, meter registers, pressure-reducing valves, vent ports, and bypasses

3. ____ Piping at booster pumps, water heaters, and water treatment devices

4. ____ Fire suppression system piping

5. ____ 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 dew point and carbon monoxide monitors, air dryers, and inlet, discharge, or relief piping to the exterior

6. ____ Adequacy of sump pumps, subsoil receivers, and sewage ejectors

7. ____ General alignment, arrangement, and size of piping in conformity to plans

8. ____ Workmanship of joints

9. ____ Installation of pipe supports, expansion joints or expansion loops, and pipe swing joints

10. ____ Location of valves

11. ____ Clearances around pipes within sleeves
12. ____ Spacing and accessibility of cleanouts
13. ____ Firestopping at fire-rated walls, fire-rated floors, and other locations as required
14. ____ Vent connections: close enough to trap to avoid air lock, above flood level, and vertical where required
15. ____ Branch to stack offset not connected near upstream end of offset
16. ____ Pipe labeling, valve tags, and valve schedule
17. ____ Installation of pipe insulation including covers over valves and fittings.
18. ____ Adequacy of cooling coil condensate drains, combustion condensate drains, relief valve drains, and indirect waste pipes: properly supported and air break or air gap as required
19. ____ Adequacy of floor slope to floor drains and floor sinks; rims of indirect waste receptors elevated to prevent entrance of debris
20. ____ Installation of small interceptors
21. ____ Vent terminals properly flashed, located away from air intakes, and away from operable windows
22. ____ Motor controllers: magnetic and manual
23. ____ Connection of plumbing to other building equipment including boilers, chillers, cooling towers, air handlers or fan coils, food service, medical, laundry and similar equipment: arrangement of piping, valves, cross-connection control, and drainage.

Final

1. ____ Adequacy of hot water at remote fixture
2. ____ ADA accessibility requirements
3. ____ Fixture support
4. ____ Water closet bowl type and seat design
5. ____ Flush valve performance
6. ____ Strainers and traps
7. ____ Faucet handles, outlet flow rating, spout design
8. ____ Fixture supply stop location
9. ____ Fixture mixing valve location and temperature setting
10. ____ Mop basin accessories
11. ____ Caulking at fixture
12. ____ Access panels for valves and cleanouts
13. ____ Cross-connection control type, application, installation, approval, product listing, and drainage
14. ____ Sprinkler heads and standpipe hose connections
15. ____ Medical gas valves, outlets, and panels
16. ____ Owner equipment manuals
17. ____ Record drawings
18. ____ Training and commissioning

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 ANSI A117.1: *Accessible and Usable Buildings and Facilities* and the Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities (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 beginning and then check with the local authority having jurisdiction (AHJ) to ensure compliance.

BACKGROUND

Many design and construction features of facilities cause problems for individuals with physical impairments. These architectural barriers make it difficult for people with disabilities to participate in educational, employment, and recreational activities.

In 1959, various groups vitally interested in the problem of accessibility were invited to participate in a general conference on this issue. The attendees recommended the initiation of a standards-development project to study the issue and prepare a national document.

In 1961, the American Standards Association (now the American National Standards Institute) issued ASA A117.1: *American Standard Specifications for Making Buildings and Facilities Usable by the Physically Handicapped*. The U.S. Department of Housing and Urban Development (HUD), along with the National Easter Seal Society and the President's Committee on Employment of the Handicapped (the original co-secretariat of the A117 standards committee), sponsored two years of research and development to revise the A117.1 standard in 1974. This work (extended to include residential environments) resulted in the 1980 version of this standard. The scope of ANSI A117.1 (1980) was greatly expanded. Curb ramps, accessible bathrooms and kitchens, and other elements of housing were included in the standard; an appendix was added to assist the designer in understanding the standard's minimum requirements; and more illustrations were incorporated.

The standard was upgraded again in 1985, in compliance with ANSI standard practice, which requires a review every five years at the minimum. The standard, issued as ANSI A117.1 (1986), further reinforced the concept that the standard is basically a resource for design specifications and leaves application criteria such as where, when, and to what extent such specifications will apply to the enforcing agency. Clarification of this how-to function of ANSI A117.1 (1986) facilitated its referencing in building codes and federal design standards—a major step toward achieving uniformity in design specifications.

The technical data contained in ANSI A117.1 (1986) was expanded greatly to incorporate additional elevator and plumbing data, as well as, for the first time, specifications for alarm and communications systems for use by individuals with visual or hearing impairments.

The technical data contained in the 1986 issue has been used as the basis of most state and local codes, as well as Uniform Federal Accessibility Standard (UFAS) and U.S. Architectural and Transportation Barriers Compliance Board (ATBCB) requirements.

As part of an ongoing review process, the A117.1 committee was reconvened in 1989 with the intention of reissuing the standard in 1990. The magnitude of the changes, in both technical data and format, resulted in a delay in publication of the standard until December 15, 1992. This standard was the most comprehensive to date, and the involvement from disability advocates and interested parties was remarkable. The 1992 standard is referenced in several model codes and has resulted in improved accessibility in many regards.

In 1995, the A117.1 committee was called again and charged with the task of reviewing the standard for changes. The makeup of the committee had grown to include many disability advocacy groups, model code representatives, and associations—including the American Society of Plumbing Engineers (ASPE)—and design professionals. The committee worked for more than three years, through three public reviews, examining more than 1,000 proposed changes, during 23 days of meetings, to produce the 1998 ANSI A117.1 standard. The 1998 standard was developed to work in harmony with federal accessibility laws, including the Fair Housing Accessibility Guidelines and ADAAG.

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, known as the Rehabilitation Act, was passed by the federal government in 1973.

At the same time, state and municipal governments also began issuing their own ordinances regarding architectural barriers. These legislative acts usually were modified versions of the ANSI A117.1 document. Currently, almost every state has adopted some legislation covering this subject; however, there are major differences 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. ATBCB to prepare architectural guidelines to ensure that the construction industry understood what was required to comply with the act. The ATBCB, which is represented on the A117.1 committee, 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 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 final rule was issued on July 26, 1991, in the federal register (28 CFR Part 36) as "Nondiscrimination on the Basis of Disability by Public Accommodations and in Commercial Facilities." The act became effective on January 26, 1992, and applies 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 conflict with the statutory requirements of the act. The attorney general's office established as a procedure for the certification of state and local accessibility codes or ordinances 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.

In 1994, the ATBCB commissioned a new committee to make recommendations for an improved document to replace the current ADAAG. This committee met for more than two years to review proposed changes to the document and remove the ambiguities that had been a cause of contention to designers as well as code-enforcement officials. This new committee included 22 members representing advocacy groups (American Council of the Blind, Disability Rights Education and Defense Fund, Eastern Paralyzed Veterans Association, Maryland Association of the Deaf, and World Institute on Disability), code-enforcement officials (Virginia Building and Code Officials Association, Texas Department of Licensing and Regulation, Southern Building Code Congress International, National Fire Protection Association, National Conference of States on Building Codes and Standards, International Conference of Building Officials, Council of American Building Officials, and Building Officials and Code Administrators International), and designers (American Institute of Architects and American Society of Interior Designers. The document that came from this committee's work was presented to the ATBCB on October 10, 1996.

Design professionals must continue to review the ADA in its entirety, and forthcoming revisions, as well as state and local codes for application to their projects. Some states require preapproval of accessible plumbing fixtures. Approval of fixtures is the responsibility of the fixture manufacturers, but the specifier must specify and approve only those fixtures that have received approval.

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

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.

The following 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 in order 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, which reduces mobility, flexibility, coordination, and perceptiveness in individuals

(Note: To some extent, various national standards—such as HUD's Minimum Property Standards—differentiate the elderly from "people with disabilities.")

The disability 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. At the present time, many variations in wheelchair design are available on the market. 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. (Refer to Table 6-1 for graphic conventions.)

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.

The following information on fixture requirements for the use of people with disabilities is based on the recommended design criteria contained in ANSI A117.1. For convenient reference to the ANSI A117.1 text, the corresponding ANSI article numbers have been used (e.g., 601.1 and 602.5). Illustrations, in most cases, are the same as or similar to those in ANSI A117.1. Therefore, A117.1 figure numbers (such as Figure B4.15.2.1 and Figure B4.20.3.1) have been included with the *Plumbing Engineering Design Handbook* figure numbers.

Explanatory notes have been added after the recommendations for each fixture, where deemed of value. Differences between A117.1 and ADAAG, other than of an editorial nature, also are noted.

CLEAR FLOOR OR GROUND SPACE FOR WHEELCHAIRS

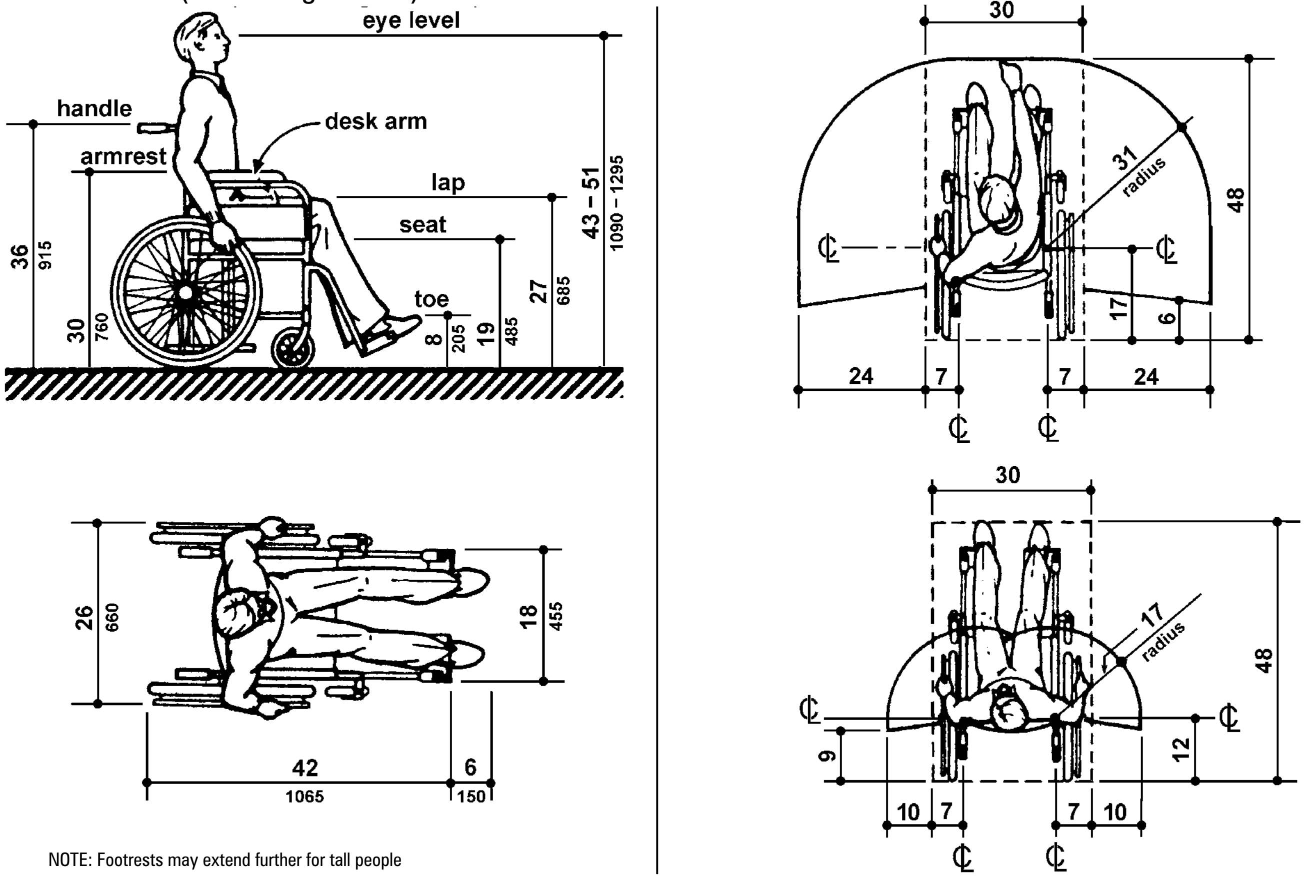
The minimum clear floor or ground space required to accommodate a single, stationary wheelchair and occupant is 30–48 in. (760–1,220 mm). (See Figure 6-2-B4.2.4.1.) The minimum clear floor or ground space for wheelchairs may be positioned for forward or parallel approach to an object (see Figure 6-3-B4.2.4.2). 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

Table 6-1 Graphic Conventions

Convention	Description
36 915	Typical dimension line showing US customary units (in in.) above the line and SI units (in mm) below.
9 230	Dimensions for short distances indicated on extended line.
9 36 230 915	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.

US Customary units above line (or to left of line) and SI units below line (or to the right of line)



NOTE: Footrests may extend further for tall people

Figure 6-1 Dimensions of Adult-Sized Wheelchairs

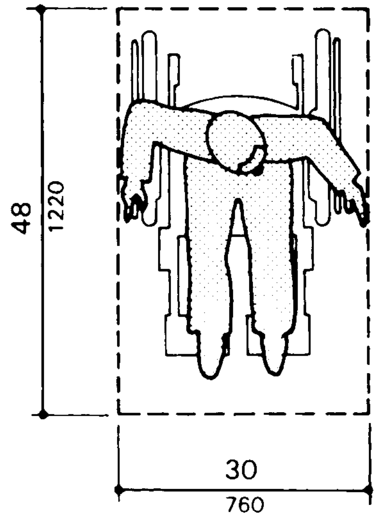


Figure 6-2 Clear Floor Space for Wheelchairs

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confined on all or part of three sides, additional maneuvering clearances shall be provided as shown in Figure 6-4-B4.2.4.4.

Forward Reach

If the clear floor space only allows forward approach to an object, the maximum high forward reach allowed shall be 48 in. (1,220 mm). (See Figure 6-5-B4.2.5.1.) The minimum low forward reach is 15 in. (380 mm). If the high forward reach is over an obstruction, reach and clearances shall be as shown in Figure 6-6-B4.2.5.2.

Side Reach

If the clear floor space allows parallel approach by a person in a wheelchair, the maximum high side reach allowed shall be 48 in. (1,220 mm), and the low side reach shall be 15 in. (380 mm). (See Figure 6-7-B4.2.6.1). If the side reach is over an obstruction, the reach and clearances shall be as shown in Figure 6-8-B4.2.6.2.

PLUMBING ELEMENTS AND FACILITIES[1]

601 General

601.1 Scope Plumbing elements and facilities required to be accessible by scoping provisions adopted by the administrative authority shall comply with the applicable provisions of this chapter.

602 Drinking Fountains and Water Coolers

602.1 General Accessible fixed drinking fountains and water coolers shall comply with 602.

602.2 Clear floor or ground space A clear floor or ground space complying with 305 shall be provided.[2]

> *602.2.1 Forward approach* Where a forward approach is provided, the clear floor or ground space shall be centered on the unit and shall include knee and toe clearance complying with 306.[2]
>
> *602.2.2 Parallel approach* Where a parallel approach is provided, the clear floor or ground space shall be centered on the unit.

602.3 Operable parts Operable parts shall comply with 309.[2]

602.4 Spout height Spout outlets shall be 36 in. (915 mm) maximum above the floor or ground. See Figure 6-9(a)-B4.15.2.1A.

602.5 Spout location Units with a parallel approach shall have the spout 3½ in. (89 mm) maximum from the front edge of the unit, including bumpers. Units with a forward approach shall have the spout 15 in. (380 mm) minimum from the vertical support and 5 in. (125 mm) maximum from the front edge of the unit, including bumpers.

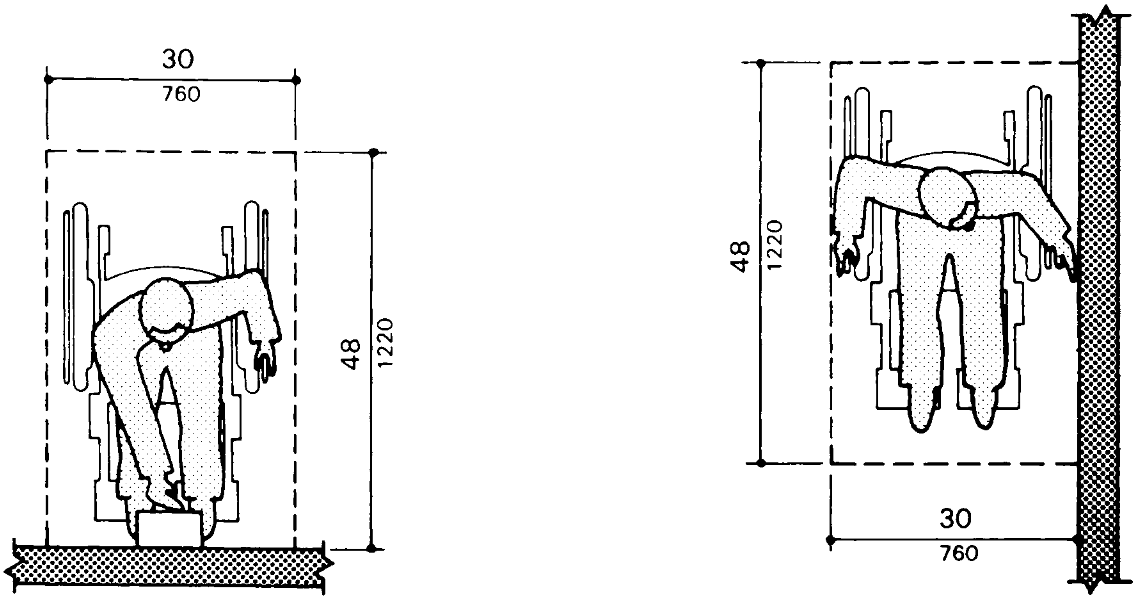
602.6 Water flow The spout shall provide a flow of water 4 in. (100 mm) high minimum to allow the insertion of a cup or glass under the flow of water. The angle of the water stream from spouts within 3 in. (75 mm) of the front of the unit shall be 30 degrees maximum. The angle of the water stream from spouts between 3 in. (75 mm) and 5 in. (125 mm) from the front of the unit shall be 15 degrees maximum. The angle of the water stream shall be measured horizontally, relative to the front face of the unit. See Figure 6-10-B4.15.2.3.

602.7 Protruding objects Units shall comply with 307.[2]

Drinking fountain note:
The easiest way for someone in 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 that spout heights of 33 to 34 in. (839 to 864 mm) can be obtained, without interfering with 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 in. (762 mm) as the fountain will permit.

It is desirable to provide some water coolers or fountains with spout heights of approximately 42 in.



(a) Forward Approach

(b) Parallel Approach

Figure 6-3 Wheelchair Approaches

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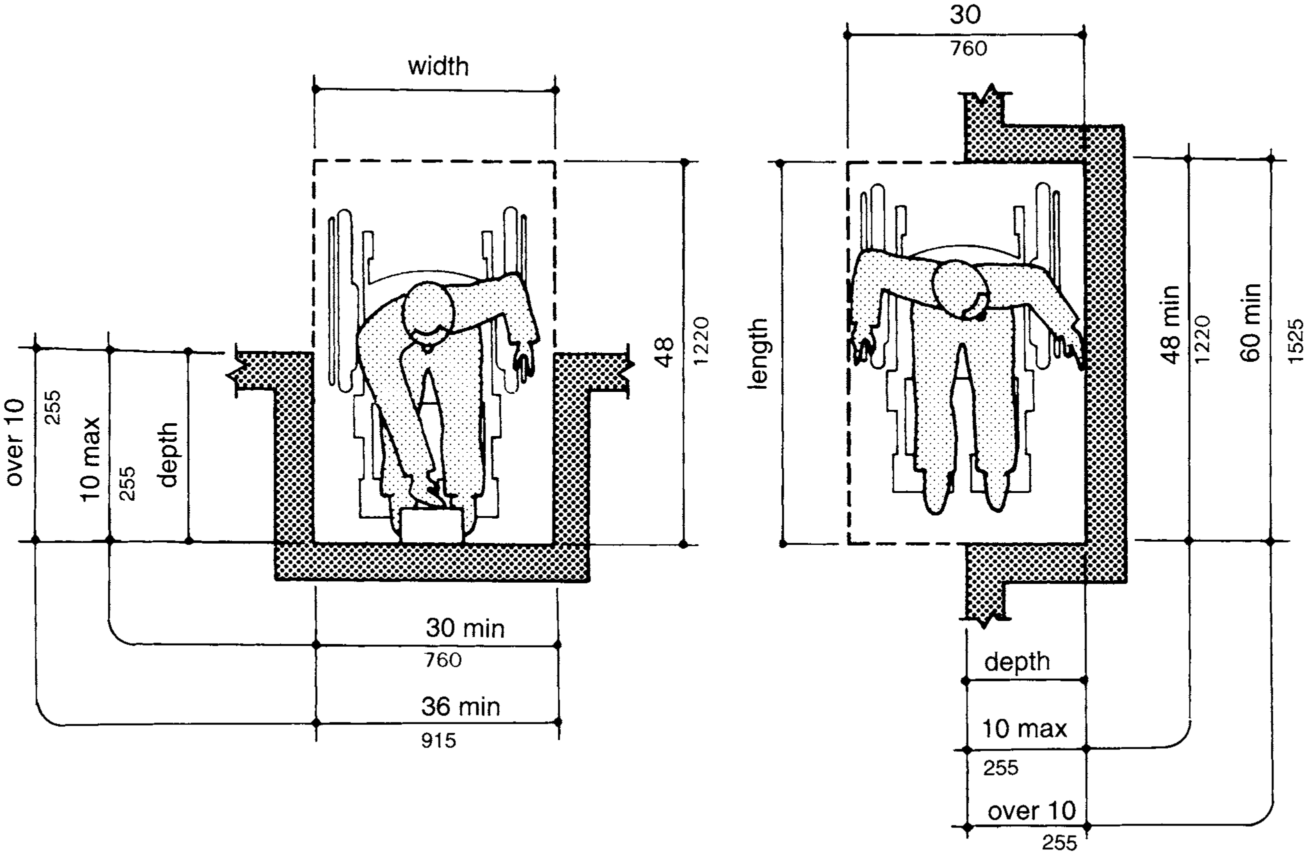

Figure 6-4 Clear Floor Space in Alcoves

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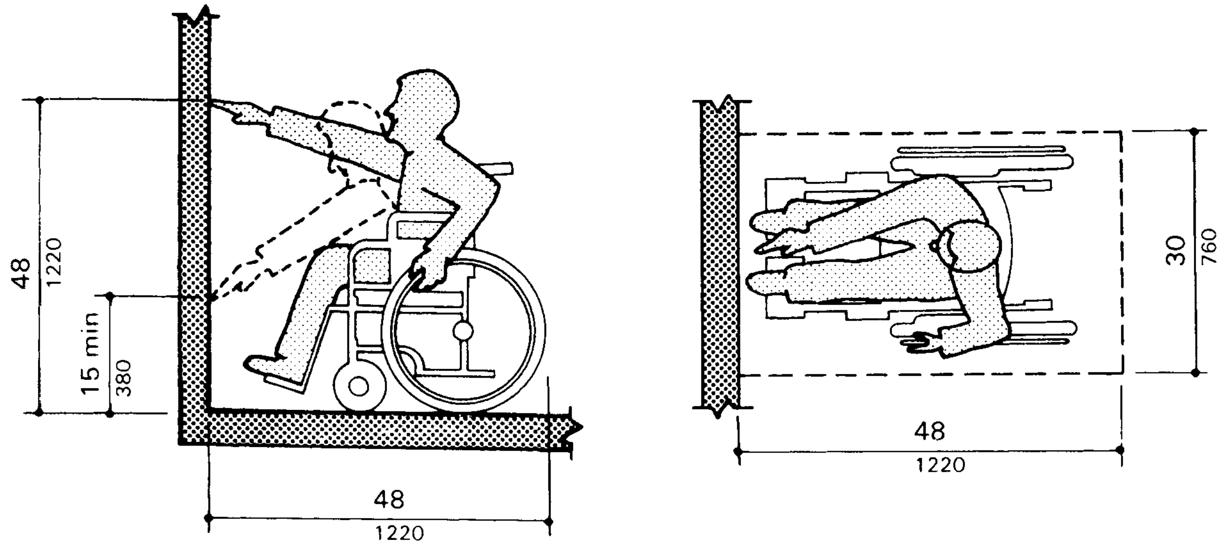

Figure 6-5 Unobstructed Forward Reach Limit

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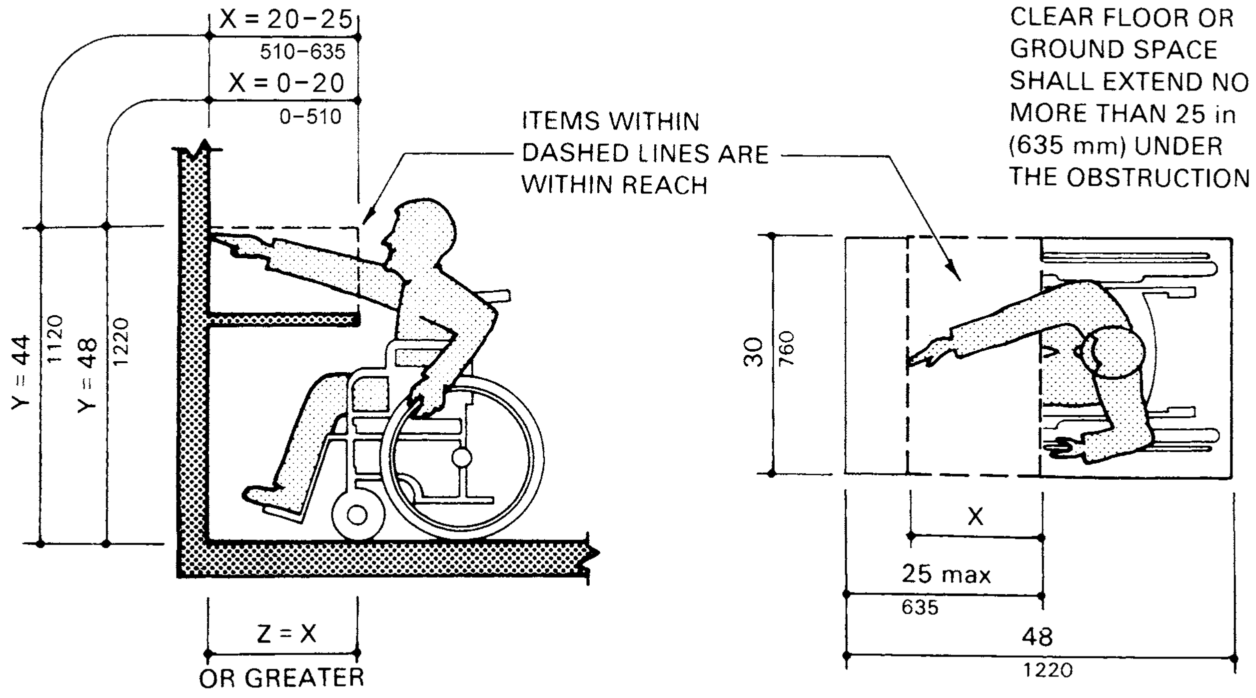

ITEMS WITHIN DASHED LINES ARE WITHIN REACH

CLEAR FLOOR OR GROUND SPACE SHALL EXTEND NO MORE THAN 25 in (635 mm) UNDER THE OBSTRUCTION

Figure 6-6 Forward Reach Over an Obstruction

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Note: X = Reach depth, Y = Reach height, Z = Clear knee space.

Z is the clear space below the obstruction, which shall be at least as deep as the reach distance, X.

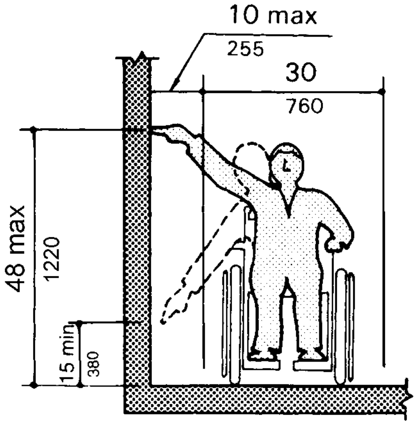

Figure 6-7 Unobstructed Side Reach Limit

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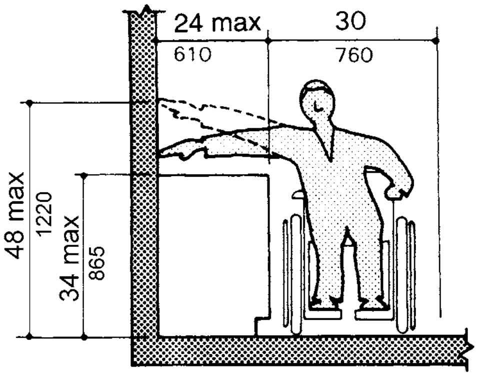

Figure 6-8 Obstructed Side Reach Limit

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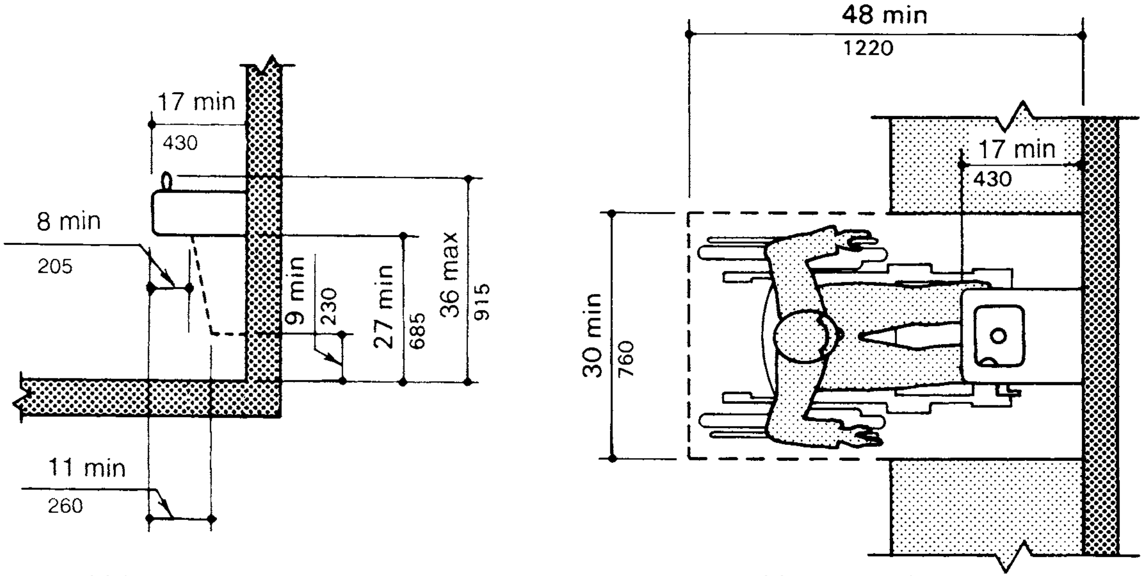

(a) Spout Height and Leg Clearance

(b) Clear Floor Space

Figure 6-9 Cantilevered Drinking Fountains and Water Coolers

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Note: Figure 6-9a only: Equipment permitted within dashed lines if mounted below apron.

(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 (ADAAG Section 4.1.3, item no. 10, and Appendix A4.15.2). 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.

603 Toilet and Bathing Rooms

603.1 General Accessible toilet and bathing rooms shall comply with 603.

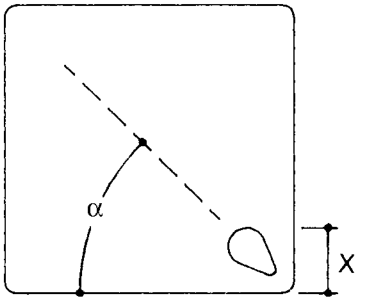
603.2 Clearances

603.2.1 Wheelchair turning space A wheelchair turning space complying with 304 shall be provided within the room.[2]

603.2.2 Overlap Clear floor or ground spaces, clearances at fixtures, and wheelchair turning spaces shall be permitted to overlap.

603.2.3 Doors Doors shall not swing into the clear floor or ground space or clearance for any fixture.

EXCEPTION: Where the room is for individual use and a clear floor or ground space complying with 305.3 is provided within the room beyond the arc of the door swing.[2]



When: x = 3 in α = 30° max
3 < x < 5 in α = 15° max

Figure 6-10 Horizontal Angle of Water Stream — Plan View

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603.3 Mirrors Mirrors shall be mounted with the bottom edge of the reflecting surface 40 in. (1,015 mm) maximum above the floor or ground. See Figure 6-11-B4.20.3.1.

603.4 Coat hooks and shelves Coat hooks provided within toilet rooms shall accommodate a forward reach or side reach complying with 308.[2] Where provided, a fold-down shelf shall be 40 in. (1,015 mm) minimum and 48 in. (1,220 mm) maximum above the floor or ground.

Toilet and bathing rooms note:
When a door opens into a bathroom, sufficient maneuvering space is 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 in. (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. Design and location of floor drains should not impede the use of plumbing fixtures.

Medical cabinets or other methods for storing medical and personal care items are very useful to people with disabilities. Shelves, drawers, and floor-mounted cabinets should be within the reach ranges of a physically challenged person.

If mirrors are to be used by both ambulatory people and wheelchair users, then they should be 74 in. (1,880 mm) high minimum at their top-most edge and 40 in. (1,015 mm) maximum at their lowest edge. A single full-length mirror accommodates all people, including children.

604 Water Closets and Toilet Compartments

604.1 General Accessible water closets and toilet compartments shall comply with 604.

604.2 Location The water closet shall be positioned with a wall or partition to the rear and to one side. The centerline of the water closet shall be 16 in. (405 mm) minimum to 18 in. (455 mm) maximum from the side wall or partition, except that the water closet shall be centered in the ambulatory accessible compartment specified in 604.8.2. See Figure 6-12-B4.18.4.

604.3 Clearance

604.3.1 Size Clearance around the water closet shall be 60 in. (1,524 mm) minimum, measured perpendicular from the side wall, and 56 in. (1,420 mm) minimum, measured perpendicular from the rear wall. No other fixtures or obstructions shall be within the water closet clearance. See Figure 6-13-B4.18.3.1.

604.3.2 Overlap The clearance around the water closet shall be permitted to overlap the fixture, associated grab bars, tissue dispensers, accessible routes and clear floor or ground space or clearances at other fixtures and the wheelchair turning space. Clear floor space shall comply with Figure 6-14-B4.17.2.

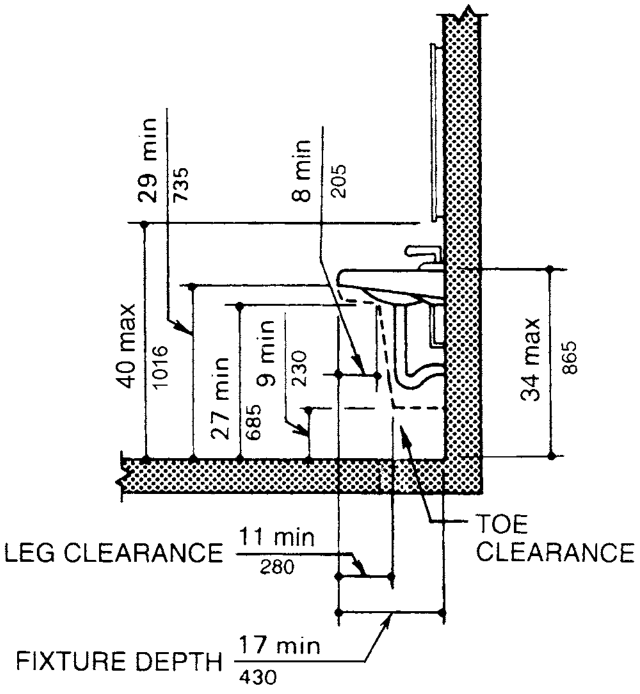

Figure 6-11 Leg Clearances

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Note: Dashed line indicates dimensional clearance of optional, under-fixture enclosure.

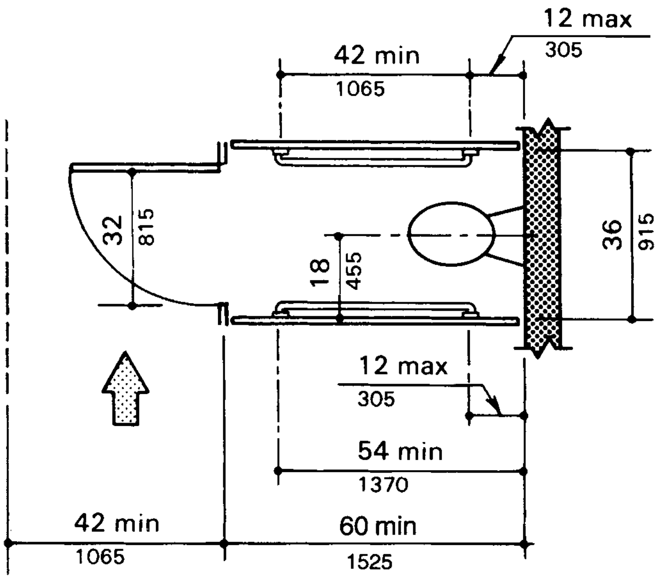

Figure 6-12 Ambulatory Accessible Stall

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604.4 Height The top of water closet seats shall be 17 in. (430 mm) minimum and 19 in. (485 mm) maximum above the floor or ground. Seats shall not return automatically to a lifted position. See Figure 6-15-B4.17.3.

604.5 Grab bars Grab bars for water closets shall comply with 609. Grab bars shall be provided on the rear wall and on the side wall closest to the water closet.

604.5.1 Side wall Side wall grab bar shall be 42 in. (1,065 mm) long minimum, 12 in. (305 mm) maximum from the rear wall and extending 54 in. (1,370 mm) minimum from the rear wall. See Figure 6-15-B4.17.3.

604.5.2 Rear wall The rear wall grab bar shall be 24 in. (610 mm) long minimum, centered on the water closet. Where space permits, the bar shall be 36 in. (915 mm) long minimum, with the additional length provided on the transfer side of the water closet. See Figure 6-16-B4.17.4.

604.6 Flush controls Flush controls shall be hand operated or automatic. Hand-operated flush controls shall comply with 309.[2]

604.7 Dispensers Toilet paper dispensers shall comply with 309.4 and shall be 7 in. (180 mm) minimum and 9 in. (230 mm) maximum in front of the water closet.[2] The outlet of the dispenser shall be 15 in. (380 mm) minimum and 48 in. (1,220 mm) maximum above the floor or ground. There shall be a clearance of 1½ in. (38 mm) minimum below and 12 in. (305 mm) minimum above the grab bar. Dispensers shall not be of a type that control delivery or that do not allow continuous paper flow.

604.8 Toilet compartments Accessible toilet compartments shall comply with 604.8.1 through 604.8.5. Compartments containing more than one plumbing fixture shall comply with 603. Water closets in accessible toilet compartments shall comply with 604.1 through 604.7.

604.8.1 Wheelchair accessible compartments

604.8.1.1 Size Wheelchair accessible compartments shall be 60 in. (1,524 mm) wide minimum measured perpendicular to the side wall, and 56 in. (1,420 mm) deep minimum for wall-hung water closets and 59 in. (1,500 mm) deep minimum for floor-mounted water closets, measured perpendicular to the rear wall. See Figure 6-13-B4.18.3.1.

604.8.1.2 Doors Compartment doors shall not swing into the minimum required compartment area. See Figure 6-17-B4.18.3.2.

604.8.1.3 Approach Compartment arrangements shall be permitted for left-hand or right-hand approach to the water closet.

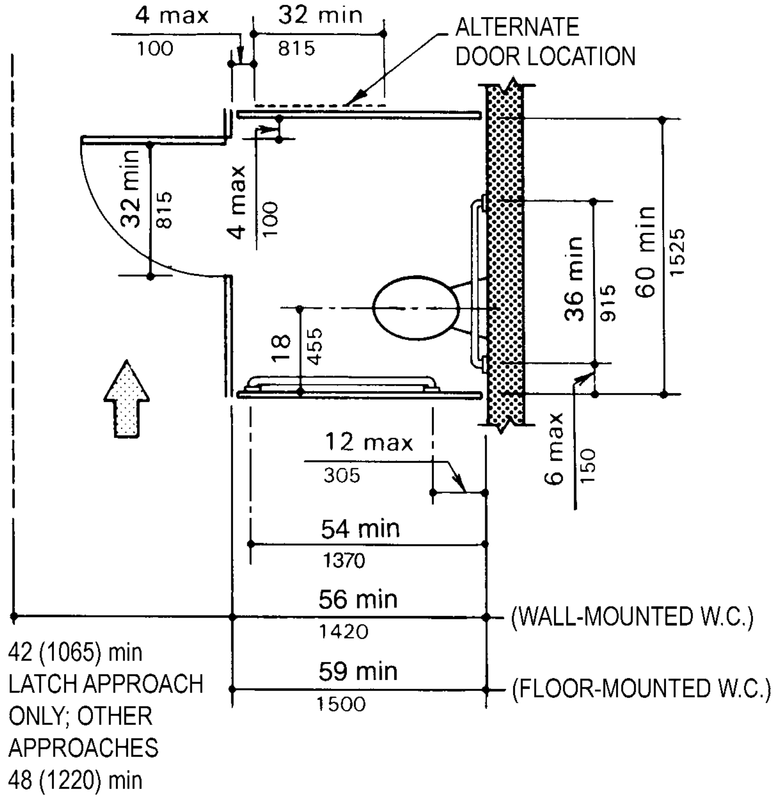

Figure 6-13 Wheelchair Accessible Toilet Stalls — Door Swing Out

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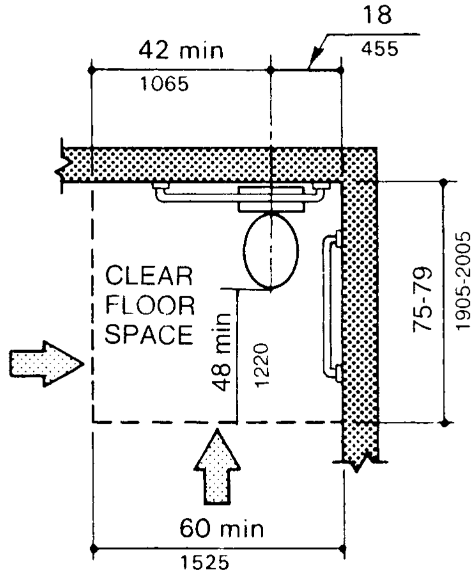

Figure 6-14 Clear Floor Space at Water Closets

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604.8.1.4 Toe clearance In wheelchair-accessible compartments, the front partition and at least one side partition shall provide a toe clearance complying with 306.2 and extending 6 in. (150 mm) deep beyond the compartment-side face of the partition, exclusive of partition support members.[2] Toe clearance at the front of the partition is not required in a compartment greater than 62 in. (1,575 mm) deep with a wall-hung water closet or 65 in. (1,650 mm) deep with a floor-mounted water closet. Toe clearance at the side partition is not required in a compartment greater than 66 in. (1,675 mm) wide.

604.8.2 Ambulatory-accessible compartments Ambulatory-accessible compartments shall be 60 in. (1,524 mm) deep minimum and 36 in. (915 mm) wide. Compartment doors shall not swing into the minimum required compartment area. See Figure 6-12-B4.18.4.

604.8.3 Doors Toilet compartment doors shall comply with 404, except that if the approach is to the latch side of the compartment door, the clearance between the door side of the compartment and any obstruction shall be 42 in. (1,065 mm) minimum. The door shall be hinged 4 in. (100 mm) maximum from the adjacent wall or partition farthest from the water closet. The door shall be self-closing. A door pull complying with 404.2.7 shall be placed on both sides of the door near the latch.[2]

604.8.4 Grab bars Grab bars shall comply with 609.

604.8.4.1 Wheelchair-accessible compartments A side-wall grab bar complying with 604.5.1 shall be provided on the wall closest to the water closet, and a rear-wall grab bar complying with 604.5.2 shall be provided. See Figure 6-13-B4.18.3.1.

604.8.4.2 Ambulatory-accessible compartments A side-wall grab bar complying with 604.5.1 shall be provided on both sides of the compartment. See Figure 6-12-B4.18.4.

604.8.5 Coat hooks and shelves Coat hooks provided within toilet compartments shall be 48 in. (1,220 mm) maximum above the floor or ground. Where provided, a fold-down shelf shall be 40 in. (1015 mm) minimum and 48 in. (1220 mm) maximum above the floor or ground.

Water closets and toilet compartments note:
The centerline requirement for water closets has been adjusted to allow a range of 16 to 18 in. (407 to 457 mm) from the centerline of the fixture to the side

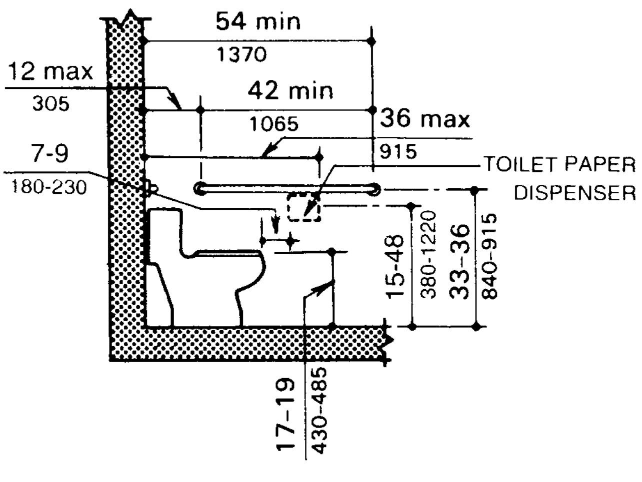

Figure 6-15 Water Closet — Side View

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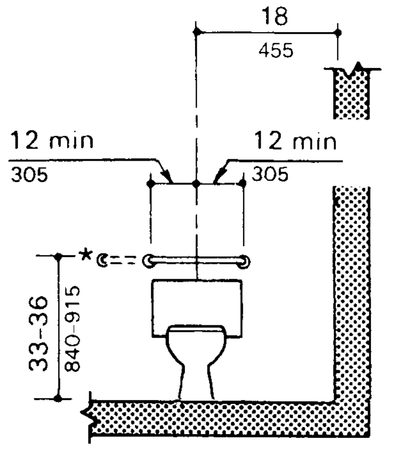

* Where space permits, extend grab bar on transfer side.

Figure 6-16 Water Closet — Front View

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wall, eliminating the fixed 18 in. (457 mm) dimensional requirement. Code enforcement officials in the field have successfully argued this change on the merits of allowing some flexibility. The greater or lesser accessibility of a water closet installed 16 in. (407 mm) from the side wall to the centerline of the toilet versus a water closet installed 18 in. (457 mm) from the side wall has yet to be answered to a majority of either committee.

The toilet seat height of 17 to 19 in. (432 to 483 mm) in public areas is intended to minimize the difference between the seat and the standard wheelchair seat height to aid the transfer process, without elevating the toilet seat to the point that stability problems are created.

The 60 in. (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 in. (1,524 mm) width. In these cases, the authority having jurisdiction may permit a narrower compartment. In no case should a width of less than 48 in. (1,220 mm) be used.

The needs of a semi-ambulatory user are best served by a narrower, 36-in. (915-mm) maximum compartment which premises use of grab bars on either or both sides of the compartment.

ADAAG note:

ADAAG has an exception to the height requirement of water closets and grab bars for water closets located in a toilet room for a single occupant, accessed only through a private office and not for common or public use. Where six or more compartments are provided in a toilet room, one must be a 60-in.(1,524-mm) wheelchair-accessible compartment, and one must be a 36-in. (915-mm) ambulatory compartment.

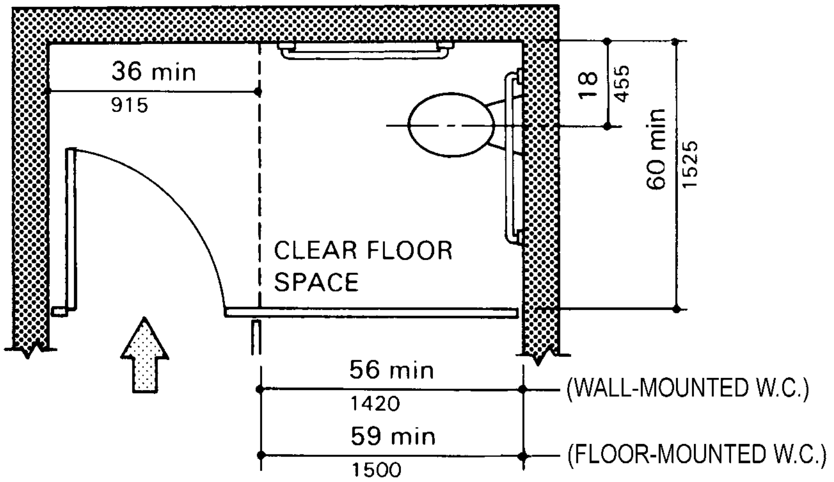

Figure 6-17 Wheelchair Accessible Toilet Stalls — Door Swing In

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The flush valve handles should not exceed 44 in. (1,118 mm) above the floor. The handles in standard accessible stalls must be at the wide side of the stall (ADAAG Section 4.16.5). This means, depending on how the stall is configured, the handle must be on either the right or left side of the flush valve. This does not apply to tank-type units, although several manufacturers have developed a right-hand operator.

605 Urinals

605.1 General Accessible urinals shall comply with 605.

605.2 Height Urinals shall be of the stall type or shall be of the wall-hung type with the rim at 17 in. (430 mm) maximum above the floor or ground.

605.3 Clear floor or ground space A clear floor or ground space complying with 305 positioned for forward approach shall be provided.[2]

605.4 Flush controls Flush controls shall be hand operated or automatic. Hand-operated flush controls shall comply with 309.[2]

Urinal note:

It should be understood that the referenced urinal is not intended to be used by a wheelchair occupant for the normal urination process. It is intended for the drainage of bladder bags, a function normally performed in a water closet compartment, if available. Where an accessible urinal is required, it can serve as a child's urinal. Urinals must be provided with an elongated rim (ADAAG Section 4.18.2). Although ADAAG does not define what constitutes an elongated urinal, the Department of Justice deferred to ANSI, which defines these fixtures as having a lip that protrudes a minimum of 14 in. (356 mm) from the wall. Flush valve handles should not exceed 48 in. (1,220 mm) above the floor.

606 Lavatories and Sinks

606.1 General Accessible lavatories and sinks shall comply with 606.

606.2 Clear floor or ground space A clear floor or ground space complying with 305.3, positioned for forward approach, shall be provided. Knee and toe clearance complying with 306 shall be provided.[2] See Figure 6-18-B4.20.3.2.

EXCEPTIONS: 1) A parallel approach shall be permitted to a kitchen sink in a space where a cooktop or conventional range is not provided. 2) The dip of the overflow shall not be considered in determining knee and toe clearances.

606.3 Height and clearances The front of lavatories and sinks shall be 34 in. (865 mm) maximum above the floor or ground, measured to the higher of the fixture rim or counter surface.

606.4 Faucets Faucets shall comply with 309.[2] Hand-operated, self-closing faucets shall remain open for 10 seconds minimum.

606.5 Bowl depth Sinks shall be 6½ in. (165 mm) deep maximum. Multiple-compartment sinks shall have at least one compartment complying with this requirement.

606.6 Exposed pipes and surfaces Water supply and drain pipes under lavatories and sinks shall be insulated or otherwise configured to protect against contact. See Figure 6-11-B4.20.3.1. There shall be no sharp or abrasive surfaces under lavatories and sinks.

Lavatories and sinks note:
Conventional slab-type lavatories are available to meet the dimensional requirements of A117.1, since the dip of the overflow can be ignored.

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 pipes, 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.

607 Bathtubs

607.1 General Accessible bathtubs shall comply with 607.

607.2 Clearance Clearance in front of bathtubs shall extend the length of the bathtub and shall be 30 in. (760 mm) wide minimum. A lavatory complying with 606 shall be permitted at the foot end of the clearance. See Figure 6-19-B4.21.2. Where a permanent seat is provided at the head end of the bathtub, the clearance shall extend a minimum of 15 in. (380 mm) beyond the wall at the head end of the bathtub.

607.3 Seat A permanent seat at the head end of the bathtub or a removable in-tub seat shall be provided. Seats shall comply with 610.

607.4 Grab bars Grab bars shall comply with 607.4 and 609.

607.4.1 Bathtubs with permanent seats For bathtubs with permanent seats, grab bars complying with 607.4.1.1 and 607.4.1.2 shall be provided.

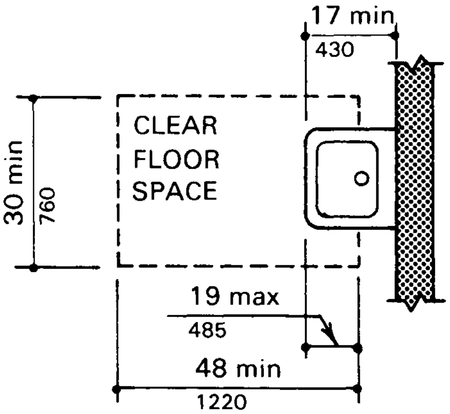

Figure 6-18 Clear Floor Space at Lavatories and Sinks

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607.4.1.1 Back wall Two grab bars shall be provided on the back wall, one complying with 609.4 and the other 9 in. (230 mm) above the rim of the bathtub. Each grab bar shall be 15 in. (380 mm) maximum from the head-end wall and 12 in. (305 mm) maximum from the foot-end wall.

607.4.1.2 Foot-end wall A grab bar 24 in. (610 mm) long minimum shall be provided on the foot-end wall at the front edge of the bathtub.

607.4.2 Bathtubs without permanent seats For bathtubs without permanent seats, grab bars complying with 607.4.2.1 through 607.4.2.3 shall be provided.

607.4.2.1 Back wall Two grab bars shall be provided on the back wall, one complying with 609.4 and the other 9 in. (230 mm) above the rim of the bathtub. Each grab bar shall be 24 in. (610 mm) long minimum and shall be 24 in. (610 mm) maximum from the head-end wall and 12 in. (305 mm) maximum from the foot-end wall.

607.4.2.2 Foot-end wall A grab bar 24 in. (610 mm) long minimum shall be provided on the foot-end wall at the front edge of the bathtub.

607.4.2.3 Head-end wall A grab bar 12 in. (305 mm) long minimum shall be provided on the head-end wall at the front edge of the bathtub.

607.5 Controls Controls, other than drain stoppers, shall be on an end wall. Controls shall be between the bathtub rim and grab bar, and between the open side of the bathtub and the midpoint of the width of the bathtub. Controls shall comply with 309.4.[2] See Figure 6-20-B4.21.4.

607.6 Shower unit A shower spray unit shall be provided, with a hose 59 in. (1,500 mm) long minimum, that can be used as a fixed showerhead and as a hand-held shower. If an adjustable-height showerhead on a vertical bar is used, the bar shall not obstruct the use of grab bars.

607.7 Bathtub enclosures Bathtub enclosures shall not obstruct controls or transfer from wheelchairs onto bathtub seats or into bathtubs. Bathtub enclosures shall not have tracks on the rim of the bathtub.

Bathtub note:
A fixed seat at the head of the tub adds safety and convenience for transfer purposes, as does the 17 to 19 in. (432 to 483 mm) rim height. The rim height that is more in line with the tub seat does not require the use of a deeper tub; it is better to use a tub with a deeper apron or use a tile filler.

Due to the probable lack of maneuverability of the user, it is recommended that the plumbing engineer specify a temperature- and/or pressure-balanced, water-blending valve with temperature-limit stops.

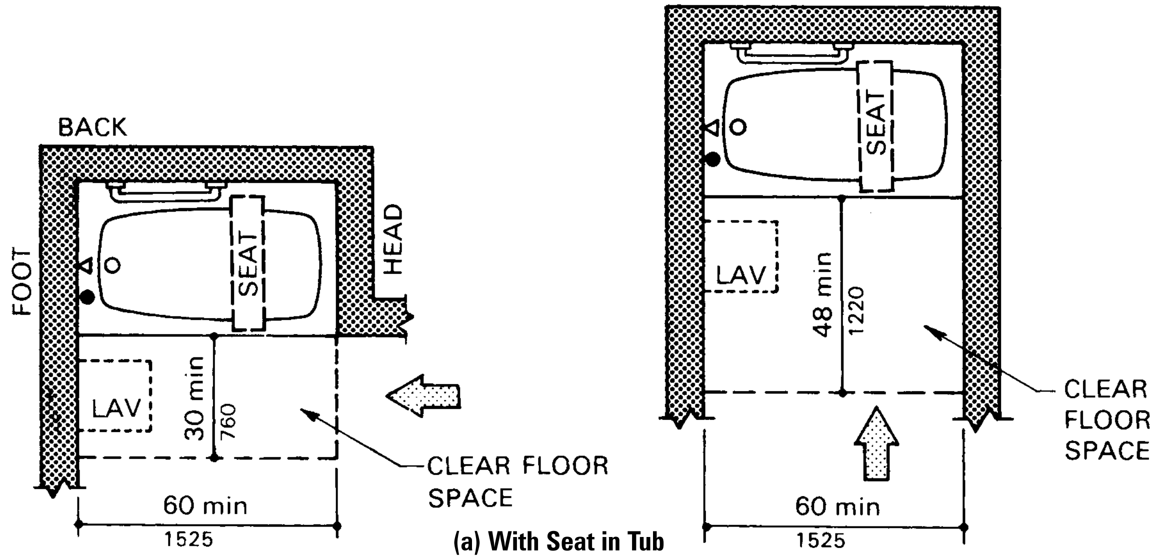
608 Shower Compartments

608.1 General Accessible shower compartments shall comply with 608.

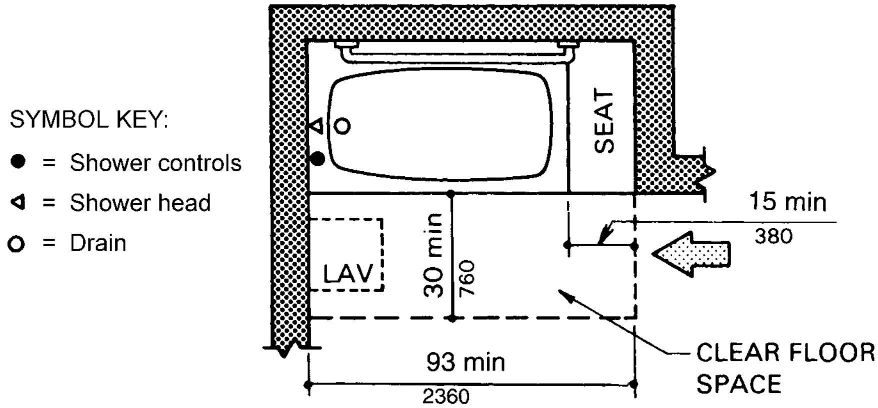
608.2 Size and clearances

608.2.1 Transfer-type shower compartments Transfer-type shower compartments shall be 36 in. (915 mm) wide by 36 in. (915 mm) deep inside finished dimension, measured at the centerpoint of opposing sides, and shall have a minimum 36 in. (915 mm) wide entry on the face of the shower compartment. The clearance in front of the compartment shall be 48 in. (1,220 mm) long minimum measured from the control wall and 36 in. (915 mm) wide minimum. See Figure 6-21-B4.22.2.1.

608.2.2 Standard roll-in type shower compartments Roll-in type shower compartments shall be 30 in. (760 mm) wide minimum by 60 in. (1,524 mm)



(a) With Seat in Tub



(b) With Seat at Head of Tub

Figure 6-19 Clear Floor Space at Bathtubs

Source: CABO/ANSI A117.1-1992, Reprinted with permission deep minimum, clear inside dimension, measured at the centerpoint of opposing sides and shall have a minimum 60 in. (1,220 mm) wide entry on the face of the shower. A 30 in. (760 mm) wide minimum by 60 in. (1,524 mm) long minimum clearance shall be provided adjacent to the open face of the shower compartment. A lavatory complying with 606 shall be permitted at the end of the clear space, opposite the shower-compartment side where shower controls are positioned. See Figure 6-22-B4.22.2.2.

608.2.3 Alternate roll-in type shower compartments Alternate roll-in shower compartments shall be 36 in. (915 mm) wide and 60 in. (1,524 mm) deep minimum. A 36 in. (915 mm) wide minimum entry shall be provided at one end of the long side of the compartment. The shower unit and controls shall be mounted on the end wall farthest from the compartment entry.

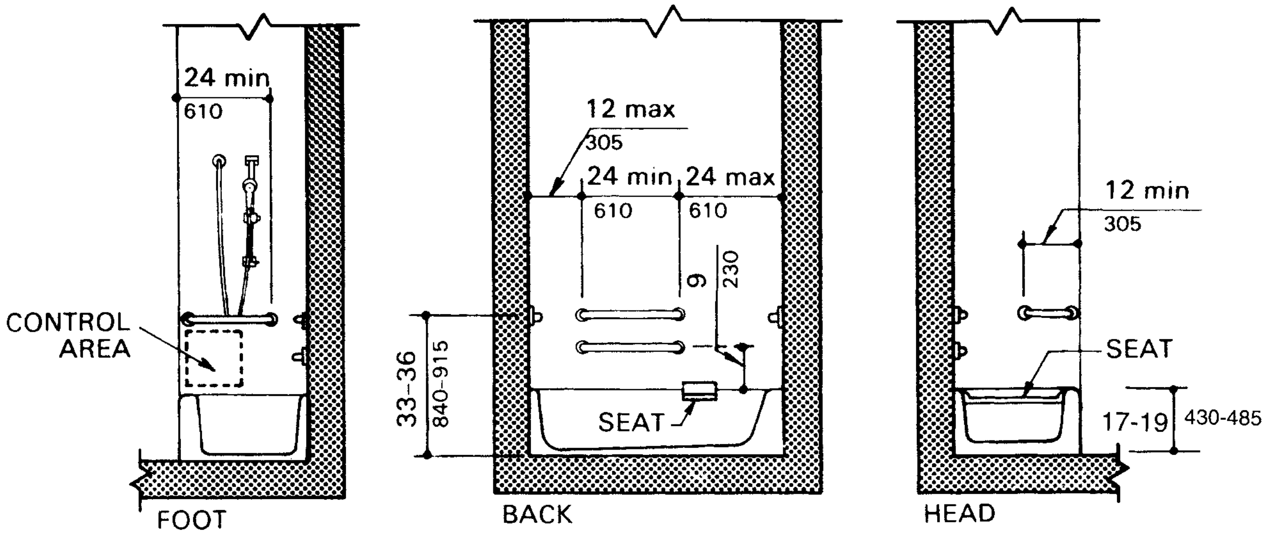
608.3 Grab bars Grab bars shall comply with 608.3 and 609 and shall be provided.

608.3.1 Transfer-type showers Grab bars shall be provided across the control wall and on the back wall to a point 18 in. (455 mm) from the control wall. See Figure 6-23(a)-B4.22.4A.

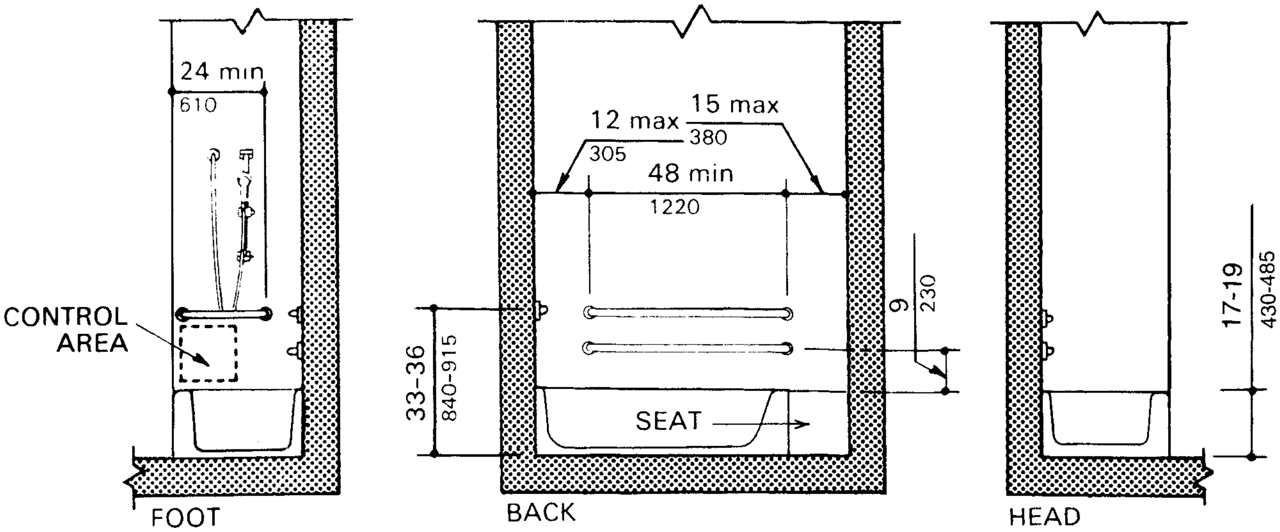
608.3.2 Roll-in type showers Grab bars shall be provided on the three walls of the shower. See Figure 6-23(b)-B4.22.4B. Grab bars shall be 6 in. (150 mm) maximum from the adjacent wall.

EXCEPTION: Where a seat is provided in a roll-in shower, grab bars shall not extend over the seat at the control wall and shall not be behind the seat.

In alternate roll-in type showers, grab bars shall not be required on the sidewall opposite the control wall and shall not be behind the seat.



(a) Without Permanent Seat in Tub



(b) With Permanent Seat at Head of Tub

Figure 6-20 Bathtub Accessories

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608.4 Seats An attachable or integral seat shall be provided in transfer-type shower compartments. Seats shall comply with 610.

608.5 Controls Shower or bathtub/shower facilities shall deliver water that is thermal-shock protected to 120°F (49°C) maximum. Faucets and controls shall comply with 309.4.2 Controls in roll-in showers shall be above the grab bar but no higher than 48 in. (1,220 mm) above the shower floor. See Figure 6-23(b)-B4.22.4B. In transfer type shower compartments, controls, faucets, and the shower unit shall be on the side wall opposite the seat 38 in. (965 mm) minimum and 48 in. (1,220 mm) maximum above the shower floor. See Figure 6-23(a)-B4.22.4A.

608.6 Shower unit A shower spray unit shall be provided, with a hose 59 in. (1,500 mm) long minimum, that can be used as a fixed showerhead and as a hand-held shower. In transfer-type showers, the controls and shower unit shall be on the control wall within 15 in. (380 mm), left or right, of the centerline of the seat. In roll-in type showers, shower spray units mounted on the back wall shall be 27 in. (685 mm) maximum from the side wall. If an adjustable-height shower head mounted on a vertical bar is used, the bar shall not obstruct the use of grab bars.

608.7 Thresholds Shower compartment thresholds shall be ½ in. (13 mm) high maximum and shall comply with 303.[2]

608.8 Shower enclosures Shower compartment enclosures for shower compartments shall not obstruct controls or obstruct transfer from wheelchairs onto shower seats.

Shower compartments note:
The recommended shower compartments are for independent use by an individual. Compartments between the two recommended sizes do not effectively serve people with disabilities who wish to use a shower without assistance.

Transfer-type shower compartments that are 36 in. by 36 in. (915 mm by 915 mm) 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.

The shower compartment with inside finish dimensions of 36 in. by 36 in. (915 mm by 915 mm) 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. Temperature may be limited to 105 to 110°F (40.5 to 43°C), depending on local code requirements.

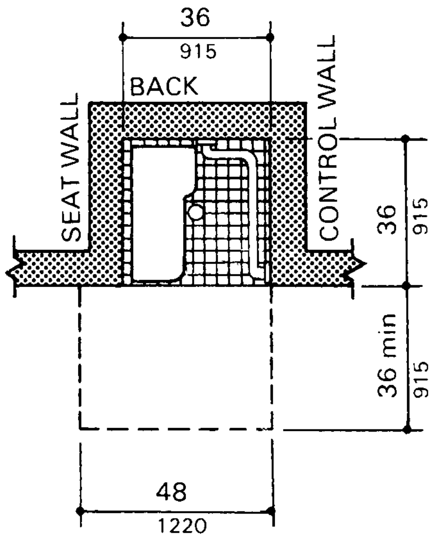

Figure 6-21 Transfer Type Shower Stall
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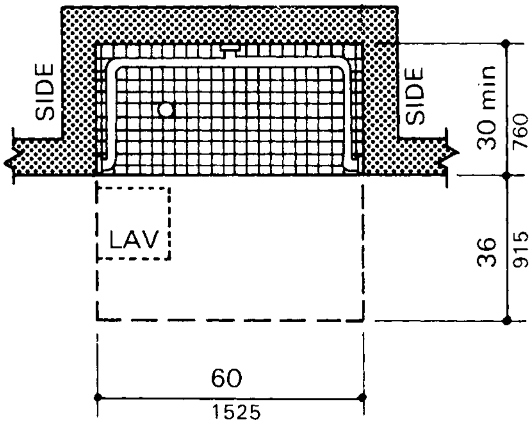

Figure 6-22 Roll-in Type Shower Stall
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609 Grab Bars

609.1 General Grab bars in accessible toilet or bathing facilities shall comply with 609.

609.2 Size Grab bars shall have a circular cross section with a diameter of 1¼ in. (32 mm) minimum and 2 in. (51 mm) maximum or shall provide equivalent grasp ability complying with 505.7.1.[2]

609.2.1 Noncircular cross sections Grab bars with other shapes shall be permitted, provided they have a perimeter dimension of 4 in. (100 mm) minimum and 4.8 in. (160 mm) maximum and edges having an 8-in. (3.2-mm) minimum radius.

609.3 Spacing The space between the wall and the grab bar shall be 1½ in. (38 mm). The space between the grab bar and objects below and at the ends shall be 1½ in. (38 mm) minimum. The space between the grab bar and projecting objects above shall be 15 in. (355 mm) minimum. See Figure 6-24-B4.24.2.1.

EXCEPTION: The space between the grab bars and shower controls, shower fittings, and other grab bars above shall be 1½ in. (38 mm) minimum.

609.4 Position of grab bars Grab bars shall be mounted in a horizontal position, 33 in. (840 mm) minimum and 36 in. (915 mm) maximum above the floor.

EXCEPTION: Height of grab bars on the back wall of a bathtub shall comply with 607.4.1.1 and 607.4.2.1.

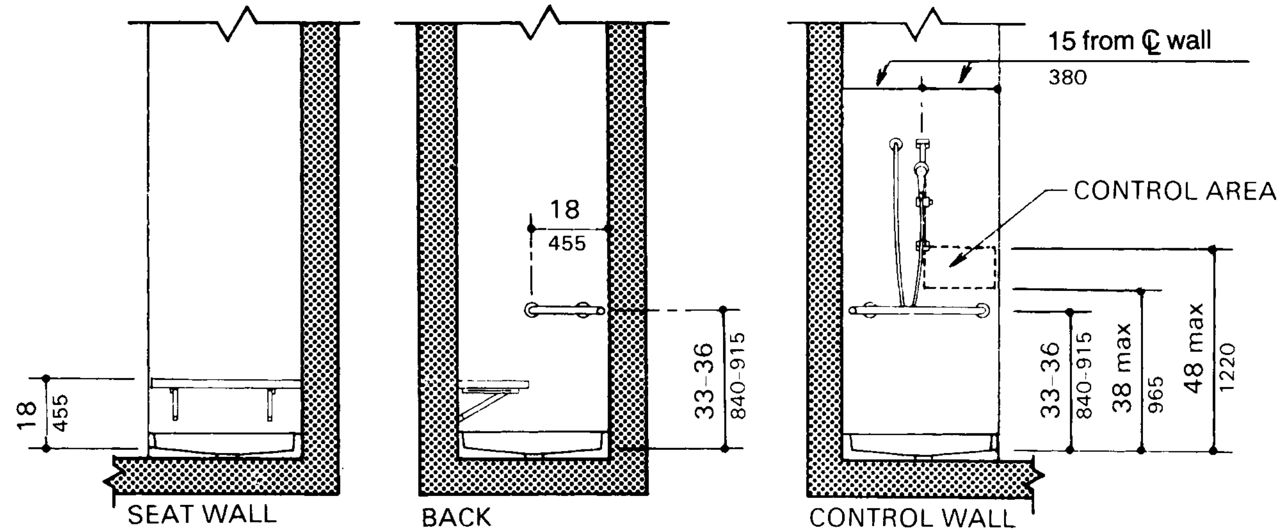
609.5 Surface hazards Grab bars and any wall or other surfaces adjacent to grab bars shall be free of sharp or abrasive elements. Edges shall have a radius of 8 in. (3 mm) minimum.

609.6 Fittings Grab bars shall not rotate within their fittings.

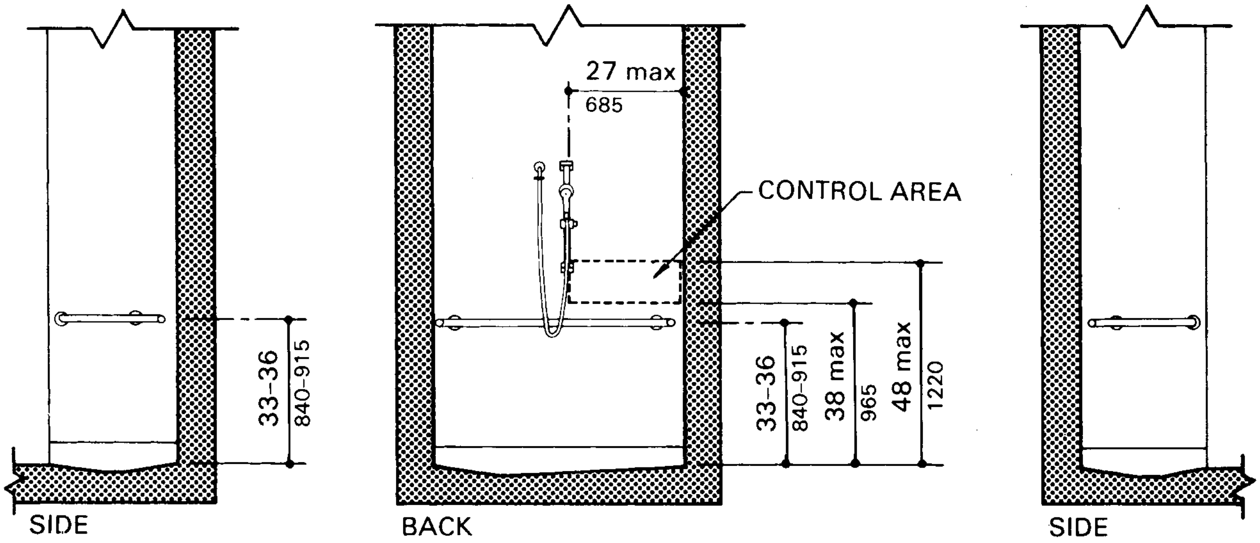
609.7 Installation Grab bars shall be installed in any manner that provides a gripping surface at the locations specified in this standard and that does not obstruct the clear floor space.

609.8 Structural strength Allowable stresses in bending, shear, and tension 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.

Grab bars note:
Many people with disabilities rely heavily on grab bars to maintain balance and prevent serious falls. Many people brace their forearms between supports



(a) 36 × 36-in (915 × 915-mm) Stall



(b) 30 × 60-in (760 × 1525-mm) Stall

Figure 6-23 Grab Bars at Shower Stalls

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Note: Figure 6-23b: Shower head and control area may be on back wall (as shown) or on either side wall.

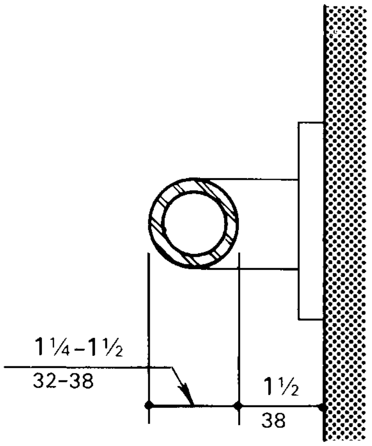

Figure 6-24 Size and Spacing of Grab Bars

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and walls to give them more leverage and stability in maintaining balance or for lifting. The grab bars clearance of 1½ in. (38 mm) required in this standard is a safety clearance to prevent injuries from arms slipping through the opening. This clearance also provides a minimum space for gripping.

Grab bars that are wall mounted do not affect the measurement of required clear floor space where the space below the grab bar is clear and does not present a knee space encroachment.

610 Seats

610.1 General Seats in accessible bathtubs and shower compartments shall comply with 610.

610.2 Bathtub seats A removable in-tub seat shall be 15 in. (380 mm) minimum and 16 in. (405 mm) deep maximum, and shall be capable of secure placement. A permanent seat shall be 15 in. (380 mm) deep minimum and be positioned at the head end of the bathtub. The top of the seat shall be 17 in. (430 mm) minimum and 19 in. (485 mm) maximum above the bathroom floor.

610.3 Shower compartment seats Where a seat is provided in a roll-in shower compartment, it shall be a folding type and shall be on the wall adjacent to the controls. Seats shall be L-shaped or rectangular. The top of the seat shall be 17 in. (430 mm) minimum and 19 in. (485 mm) maximum above the bathroom floor. In a transfer-type shower, the seat shall extend from the back wall to a point within 3 in. (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 in. (75 mm) of the minimum required seat wall width.

610.3.1 Rectangular seats The rear edge of a rectangular seat shall be 2½ in. (64 mm) maximum from the seat wall, and the front edge 15 in. (380 mm) minimum and 16 in. (405 mm) maximum from the seat wall. In a transfer-type shower, the side edge of a rectangular seat shall be 1½ in. (38 mm) maximum. In a roll-in type shower, the side edge of a rectangular seat shall be 1½ in. (38 mm) maximum from the control wall.

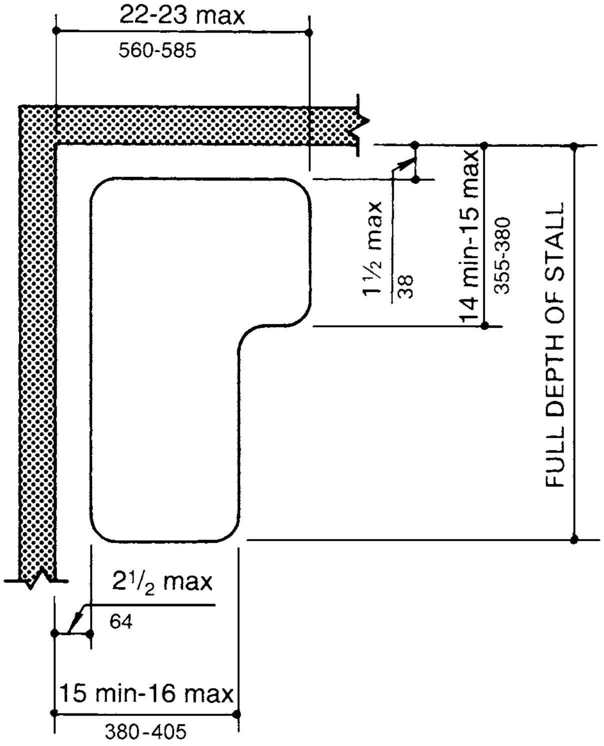

Figure 6-25 Shower Seat Design

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610.3.2 L-shaped seats The rear edge of an L-shaped seat shall be 2½ in. (64 mm) maximum from the seat wall, and the front edge 15 in. (380 mm) minimum and 16 in. (405 mm) maximum from the seat wall. The rear edge of the L portion of the seat shall be 1½ in. (38 mm) maximum from the wall and the front edge shall be 14 in. (355 mm) minimum and 15 in. (380 mm) maximum from the wall. The end of the L shall be 22 in. (560 mm) minimum and 23 in. (585 mm) maximum from the main seat wall. See Figure 6-25-B4.22.3.

610.4 Structural strength Allowable stresses in bending, shear, and tension shall not be exceeded for materials used where a vertical or horizontal force of 250 lb (113.5 kg) is applied at any point on the seat, fastener mounting device, or supporting structure.

Seats note:
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 so as to facilitate a 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 walls for support.

611 Laundry Equipment

611.2 Clear floor or ground space A clear floor or ground space complying with 305 positioned for parallel approach shall be provided. The clear floor or ground space shall be centered on the appliance.[2]

611.3 Operable parts Operable parts, including doors, lint screens, detergent and bleach compartments, shall comply with 309.[2]

611.4 Height Top-loading machines shall have the door to the laundry compartment 34 in. (865 mm) maximum above the floor or ground. Front-loading machines shall have the bottom of the opening to the laundry compartment 15 in. (380 mm) minimum and 34 in. (865 mm) maximum above the floor or ground.

REFERENCES

1. ADAAG Review Federal Advisory Committee. September 30, 1996. *Recommendations for a new ADAAG.*
2. ANSI A117.1: *Accessible and usable buildings and facilities.*

7

Energy and Resource Conservation in Plumbing Systems

Prior to the 1973–1974 OPEC oil embargo, energy was considered inexhaustible and expendable. As energy costs grew, 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, and the most recent 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 nation, pushing for the implementation of efficient and sustainable technologies.

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 percent in residential properties. This plumbing system has a great need for energy-conservation measures.

Just as important as energy conservation is 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 a day in 2000. Because of increases in population and demand, at least 36 states are projecting water shortages by 2013.

Each American uses an average of 100 gallons of water a 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, it could save 6 billion gallons of water and more than $50 million in the energy costs to supply, heat, and treat that water.

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

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.

Eliminate Leaks

One of the first and easiest actions to take to conserve energy and resources is by repairing leaking fixtures, appliances, and hot water piping.

Reduce Domestic Hot Water Temperature

Many domestic water-heating systems are designed to deliver 140°F water based on the anticipated needs of kitchen and janitorial uses, though water for human contact typically is delivered between 110 °F and 105°F. Often, 105°F water is produced by blending 140°F hot water with cold water. While this reduces the amount of hot water required, it does not decrease the energy used to heat the water. Many energy codes and standards for new buildings require the domestic hot water system to be set at 110°F. (It is important to note that setting a water heater below 120°F may allow Legionella bacteria to grow inside the domestic hot water tank.)

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) (liters per second [L/s])
Q_2 = Hot water, gpm (lpm)

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?

$$\frac{45 \times 155 + 55 \times 75}{45 + 55} = 111°F$$

In SI units:

$$\left(\frac{2.84 \times 68.5 + 3.47 \times 23.9}{2.84 + 3.47} = 44°C\right)$$

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?

$$\frac{110 - 75}{155 - 75} = 0.44 \text{ or } 44\% \text{ hot water}$$

$$80 \text{ gph x } 0.44 = 35 \text{ gph of } 155°F \text{ hot water}$$

$$(0.084 \text{ L/s x } 0.44 = 0.037 \text{ L/s of } 68.5°C \text{ hot water})$$

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?

$$\frac{110 - 75}{125 - 75} = 0.70 \text{ or } 70\% \text{ hot water}$$

$$80 \text{ gph} \times 0.70 = 56 \text{ gph of } 125°F \text{ hot water}$$

$$(0.084 \text{ L/s} \times 0.70 = 0.059 \text{ L/s of } 51.5°C \text{ hot water})$$

As shown, the reduction in domestic water temperature in itself does not necessarily result in a reduction in energy input related to the water consumed.

Reduce Fixture Flow Rates

The EPAct of 1992 set maximum water usages for specific fixtures (e.g., 1.6 gallons per flush [gpf] for water closets). Reduced flow rates result in less water needing to be pumped and heated, smaller pipe sizes, and less heat loss from piping, consequently saving energy. 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. Providing automatic flow-control fittings can reduce fixture flow rates. 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 usually are seen in lavatories and 2.5 gpm or less in showers.

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 be used as a design tool for many purposes, some of which are to predict energy consumption, anticipated utility costs, and payback calculations for fixture replacement.

Manufacturers of flow-control devices describe in greater detail their design and installation requirements. The installation of this water-conserving device has resulted in the savings of millions of gallons of water per year throughout the country. 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.

Example 7-3

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 British thermal units (Btu) per year (3.25 gal × 8.33 lb/gal × 110°FΔT × 260 days). A 50 percent flow rate reduces energy use to 387,000 Btu per year.

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, reduction of noise, and control of condensation. The North American Insulation Manufacturers Association (NAIMA) has developed 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 emission and reductions.

The International Energy Conservation Code requires automatic-circulating hot water system piping to be insulated with 1 in. of insulation having a conductivity not exceeding 0.27 Btu per inch/h × ft^2.

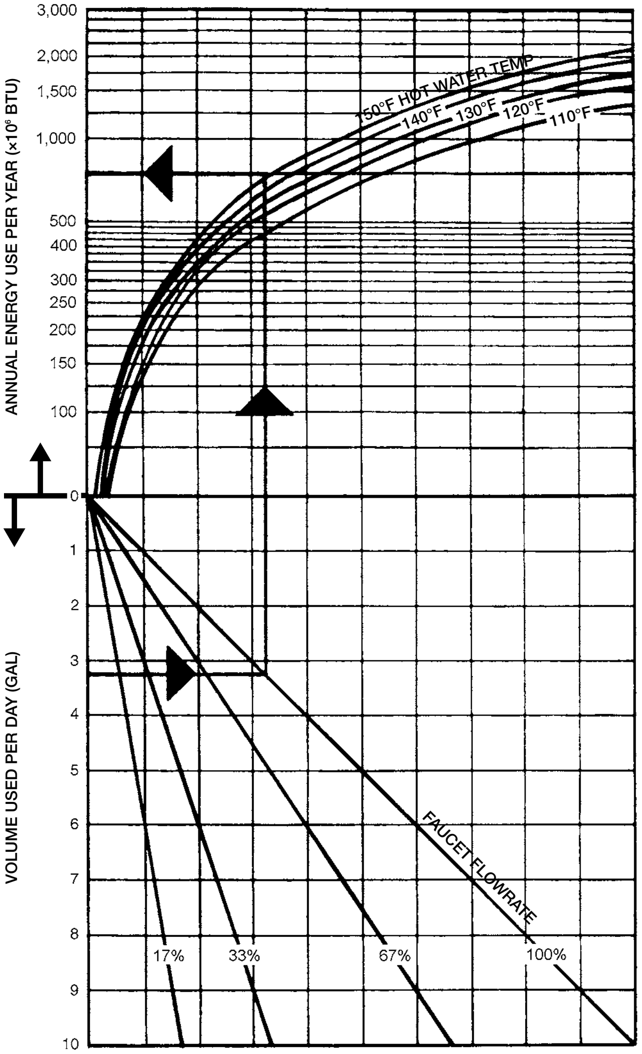

Chart allows user to estimate domestic hot water heating use in terms of water temperature and faucet flow rate.

Source: Cassidy 1982.

Figure 7-1 Energy Savings from Reduced Faucet Flow Rates

Energy savings, in Btu, can be determined by the following formula:

Equation 7-3

$$S = g \times L$$

where

S=Energy savings, Btu per hour (Btuh) (kilojoules per hour [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, while cold water lines 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 hours of operation of these pumps and water heaters, substantial savings can be realized.

An automatic thermostatic control should be installed to cycle the pump on and off in response to the temperature of water returning to the water heater through the recirculation piping. The minimum differential, or deadband, of the control shall not be less than 20°F.

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

Motor kilowatts (kW) × off hours
× electric rate ($/kWh) = total savings ($)

Consume Off-peak Power

One of a plumbing engineer's responsibilities is to size the domestic water heating equipment to meet the needs of the building's occupants in the most energy-efficient manner. While using off-peak power to heat and circulate water does not change the amount of Btu required, it does allow the building's owner and tenants to benefit from lower utility costs. Power companies encourage their commercial customers to purchase power during off-peak hours in hopes of flattening or evening out the demand on their generating equipment. Some utility companies not only offer lower rates for electricity purchased during off-peak and semi-peak periods, but in many instances also have no customer demand charges. The plumbing engineer can obtain electric rate schedules from the utility serving the site and observe the off-peak periods to program the operation of domestic water heating equipment. Typically, the highest demand for hot water takes place when electrical costs are at their peak. To account for this, the hot water system can maintain the heated water at an elevated temperature, which is blended to achieve the desired temperature levels, saving the system from having to operate during the day. Depending on the difference in electrical rates, an off-peak powered hot water system generally pays (in a few years) for the additional equipment required, including the effects of equipment heat losses during periods of standby.

Upgrade to More Efficient Equipment

Equipment specifications need to be examined to ensure that only hot 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

Table 7-1 Energy Savings Chart for Steel Hot Water Pipes and Tanks

ΔT °F (°C)	Pipe Size, in. (mm)							Hot Water Tanks, Btu/h/ft^2 (kJ/h/m^2)	
	½ (12.7)	¾ (19.1)	1 (25.4)	1¼ (31.8)	1½ (38.1)	2 (50.8)	2½ (63.5)	with Insulation	with out 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 Btu/h/linear ft. (kJ/h/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 Btu/h/linear ft (kJ/h/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.

Table 7-3 The Effect of Stopping Circulation

Operating Temperature, °F (°C)	Piping Insulation Thickness, in. (mm)	Energy Conserved, Btu/yr (kJ/yr)
140 (60)	½ (12.7)	1428×10^{6} (1506.5×10^{6})
125 (51.5)	½ (12.7)	1153×10^{6} (1216×10^{6})
110 (43)	½ (12.7)	824×10^{6} (869.3×10^{6})
140 (60)	1 (25.4)	934×10^{6} (985.4×10^{6})
125 (51.5)	1 (25.4)	714×10^{6} (753.3×10^{6})
110 (43)	1 (25.4)	522×10^{6} (550.7×10^{6})

consideration when selecting this equipment: combustion equipment and its adjustment, tank insulation, heat exchanger effectiveness, firing rate, pickup and demand, and standby stack losses.

Water Heater Location

Many hot 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 loss.

DOMESTIC HOT WATER HEATING EQUIPMENT

There are many different means of generating hot water. Each has its own 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 for the manufacturer. State energy codes also mandate the use of energy-efficient equipment and should be checked by the plumbing engineer prior to the preparation of specifications.

Listed below are several hot 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 tanks maintain a stored water temperature, there is an associated standby energy loss. Compared to tankless heaters, storage water heaters have the advantage of using energy (gas or electricity) at a relatively slow rate, storing the heat for later use.

Electric 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. They can be used for many applications ranging from commercial and industrial to booster heaters for dishwashing needs.

Gas Fired A gas-fired tank-type water heater uses natural gas or propane to heat stored water.

Tankless Water Heaters

These water heaters heat the water as the water flows through the device (demand based) and do not retain any water internally, except for 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 Electric tankless water heaters consume large amounts of energy when operating. This 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 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 Condensing gas water heaters recover the heat created by the combustion gases. The recovered heat is referred to as the latent heat of vaporization and is directed back into the water, increasing the unit's efficiency. A condensing water heater operates at approximately 95 percent efficiency compared to 80–85 percent for a noncondensing water heater. 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 rating of approximately 5, the condensate must be either diluted until it reaches an acceptable pH range or drained to a neutralization tank.

Steam Fired Steam-fired tankless 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.

Direct Fired 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 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 resources 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. Following are the three types of active solar water heating systems:

1. 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 and Certification Corp. (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.
2. 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 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 that the water will completely drain from the piping. This can be difficult to achieve in some circumstances.
3. Passive solar water heaters 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. They are also good in households with significant daytime and evening hot water needs, but they do not 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 collector). As water in the solar collector heats, it becomes lighter and rises naturally into the tank above. Meanwhile, the cooler water flows down the pipes to the bottom of the collector, enhancing the circulation. Some manufacturers place the storage tank in the house's attic, concealing it from view. Indirect thermosyphons (that use 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 conveyer, 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, and space and water heating needs for industrial parks.

Three prime areas of concern must be addressed when planning and developing geothermal energy:

1. Competitive institutional processes
2. Adequate temperature and flow rate
3. Thermal loads to make the system economically viable

A geothermal energy system typically consists of production and disposal wells, water-to-water heat exchangers (usually shell-and-tube type and two are required—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 office (Department of Energy or the Geothermal Resources Council) for resource information to apply this high-capital, low operating cost, alternate energy source.

Heat Recovery

Heat recovery is the capture and reuse of energy that normally would be lost from a facility. It could 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

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 condensor can be supplemented with a heat exchanger in the compressor's hot gas discharge line to capture the rejected heat. (Refer to 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. (Refer to Figure 7-3.) System efficiency can be improved by providing a storage tank with a tube bundle. (Refer to 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 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 temperature in a domestic hot water system are excellent ways to maintain high overall thermal efficiencies.

Heat Pumps In today's 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. Either direct-expansion or chilled-water heat pumps can be used to transfer heat through the refrigeration process from the surrounding air to a water storage tank. The mechanics of this system are to extract heat from a warm environment directly, either through a heat exchanger or cooling coil.

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. 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

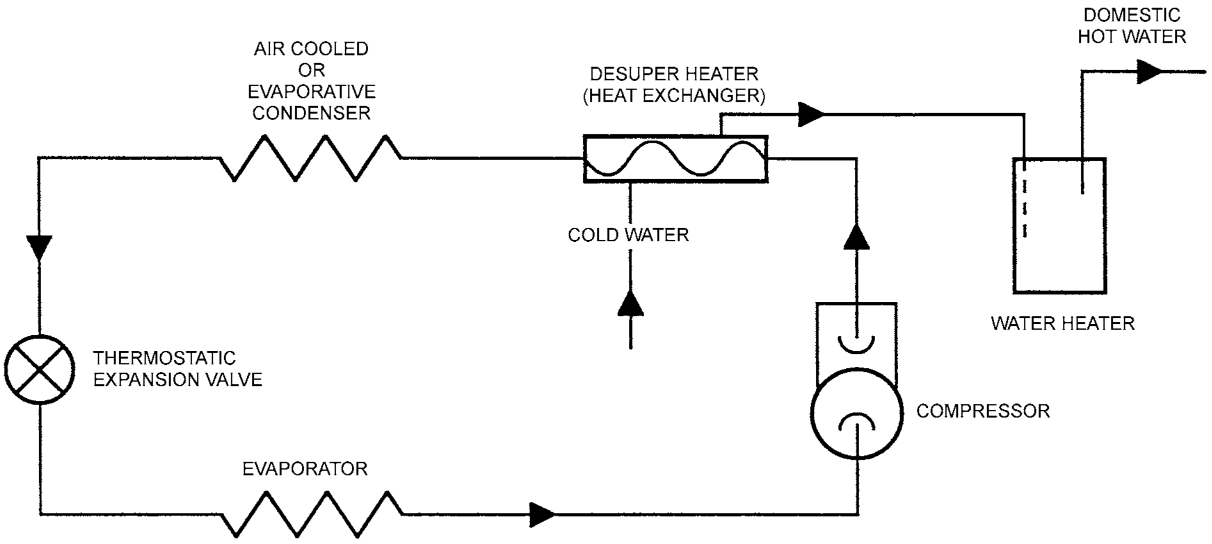

Figure 7-2 Refrigeration Waste Heat Recovery

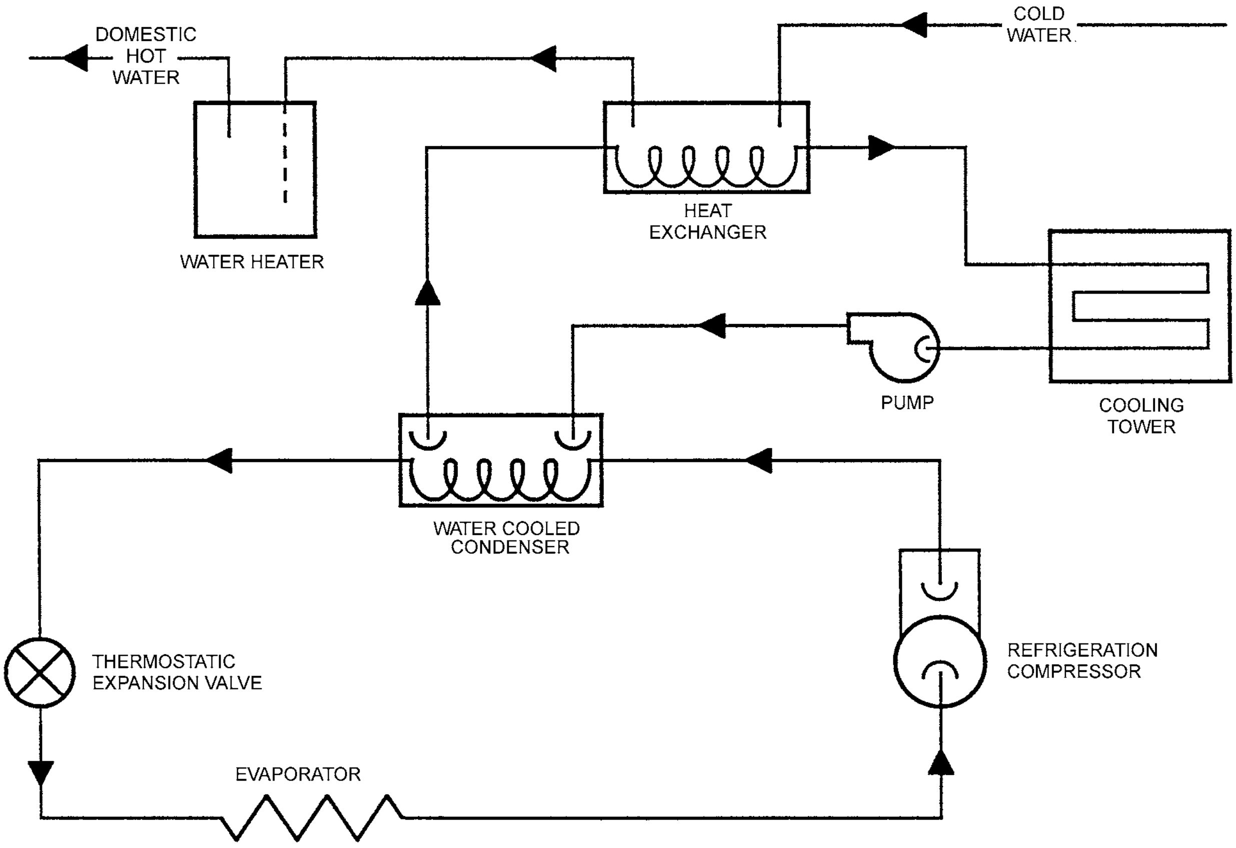

Figure 7-3 Condenser Water Heat Recovery

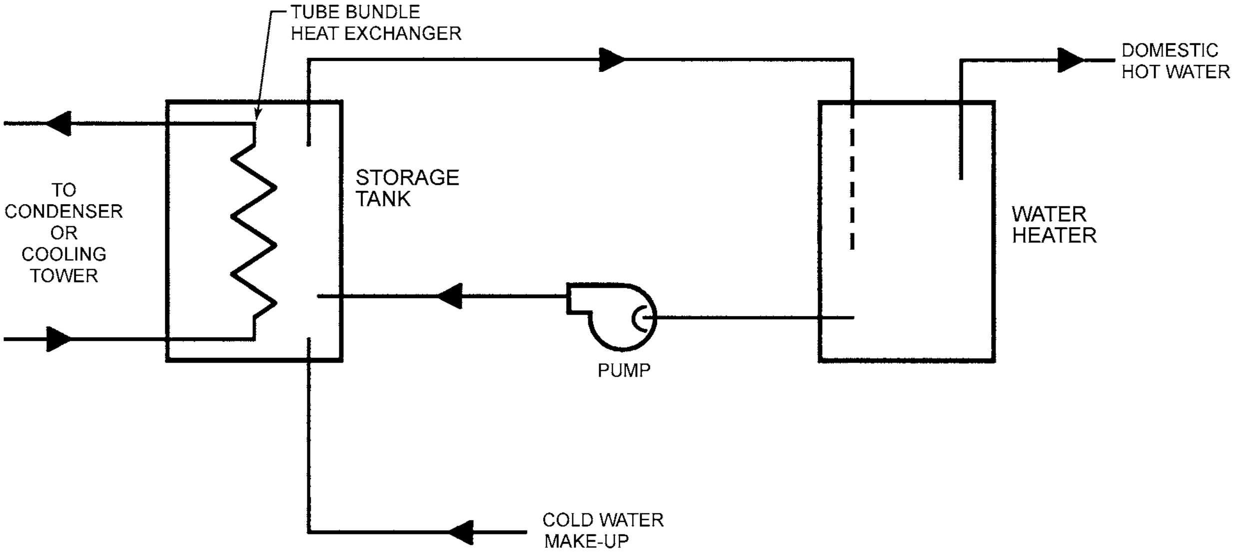

Figure 7-4 Condenser Water Heat Recovery with Storage Tank

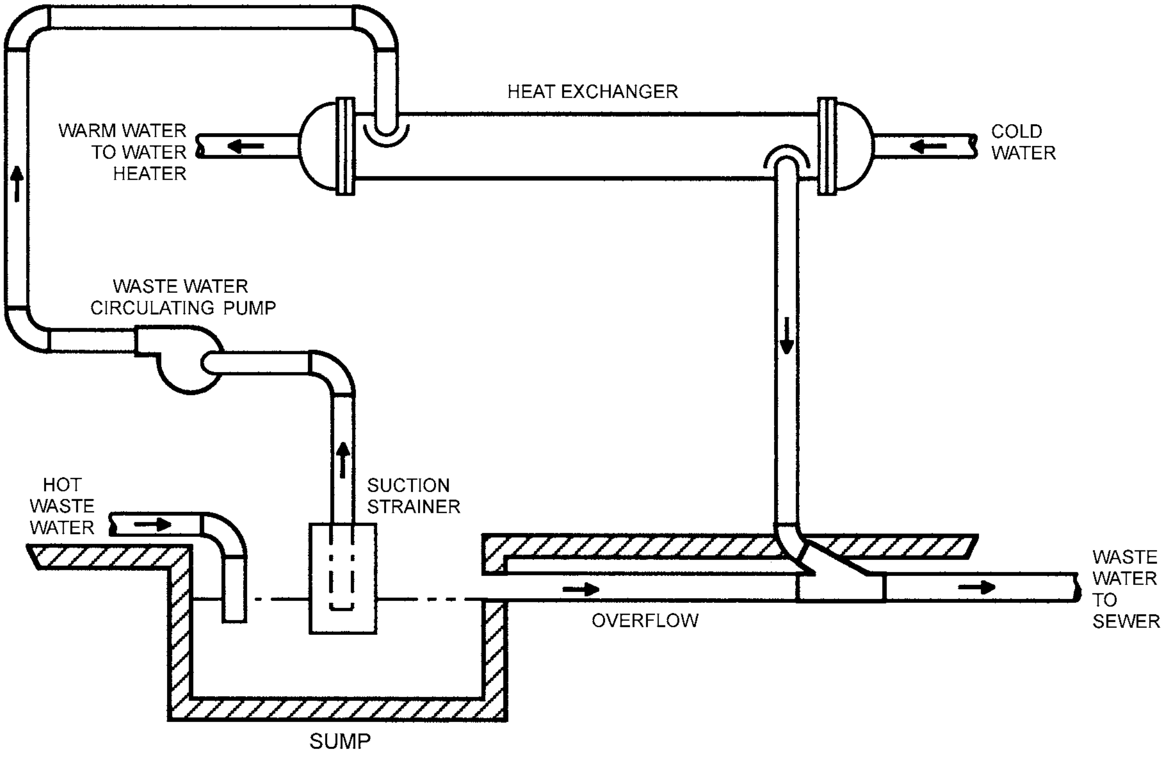

Figure 7-5 Wastewater Heat Recovery

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 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. This system is shown in Figure 7-5.

DESIGN TECHNIQUES FOR WATER MANAGEMENT

Conserving water benefits both the building's 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 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 the U.S. DOE's *Greening Federal Facilities Guide*.

Some design techniques previously mentioned are:

- Eliminate faucet and pipe leaks
- Reduce fixture flow rates

Other methods of unique water management are:

- Alternate sources of freshwater
- Reclaimed and graywater

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 avoid 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 lpm), urinals to 1 gpf (3.8 lpf), faucets to 2.2 gpm (8.3 lpm) at 60 psi (410 kPa), and toilets to 1.6 gpf (6 lpf) at 80 psi (550 kPa).

Alternate Sources of Fresh Water

Rainwater harvesting is the collection, storage, treatment, and use of rainwater. Harvested water can be used for irrigation, nonpotable, and potable uses. A rainwater harvesting system typically starts with a catch area that collects rainwater, usually on a building's roof. To ensure that potential contaminants and pollutants do not enter 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 catch area. A screen usually is installed in the catch area to 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 domestic water booster pump system, and final water treatment may be needed depending on the application and quality of water collected.

Reclaimed 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 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 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. Environmental Protection Agency. According to the Plumbing Foundation, replacing all existing toilets with 1.6-gpf (6-lpf) ultra-low-flow models would save almost 5,500 gallons (25,000 liters) of water per person each year. A widespread toilet replacement program in New York City apartment buildings found an average 29 percent reduction in total water use for the buildings studied. The entire program, in which 1.3 million toilets were replaced, is estimated to be saving 60–80 million gallons (230–300 million liters) per day.

Ultra-low-flow water closets consume 1.6 gpf (6 lpf) and are available in three different classifications:

1. Tank type
2. Flush valve
3. Specialty

While the problems associated with ultra-low-flow toilets when they first became available have been corrected, some low-cost models continue to exhibit poor performance.

Tank Type Water is drained from this water closet by gravity and is most commonly used in residential applications. Prior to ultra-low-flow models, these fixtures consumed 3.5 gpf. A low-cost method of conserving water in these earlier models and in today's ultra-low-flow version 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 ½ to 1 gallon when installed on older toilets and ¼ gallon on ultra-low-flow models.

Flush Valve Flush valve water closets use the building's water pressure to exert a force when operating. They typically require 25 to 40 pounds per square inch gauge (psig) to operate and are most commonly used in commercial buildings. Older models can be retrofitted by adjusting the flush valve, but care must be taken to not overly constrain the valve, which could cause it to malfunction. Early closure devices also can be used to cause the flush valve to stop the flow of water sooner than normal, limiting the amount of water discharged.

Specialty 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 it is desired to use a gravity tank-type water closet, but there is concern about flushing performance. When water conservation beyond ultra-low-flow 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. Composting toilets are gaining acceptance in other areas of the world for mainstream use in households.

High-efficiency Toilets (HET) The HET is defined as a fixture that flushes at 20 percent below the 1.6 gpf ultra-low-flow toilet. This includes dual-flush technology.

Urinals

Ultra-low-flow 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.

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.

Faucets

Faucets manufactured after 1993 consume no more than 2.5 gpm at 80 psig, meeting the requirements of the 1992 EPAct. 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 health 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-lpm) devices for kitchens. In washrooms, 0.5- to 1.25-gpm (1.9- to 4.7-lpm) 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 lpm).

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 the 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.

RESOURCES

1. Cassidy, Victor M. 1982. "Energy saving and the plumbing system." *Specifying Engineering* (February).
2. San Diego Gas & Electric Company. Commercial Energy Conservation Manual.

8

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 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.

FUNDAMENTAL CORROSION CELL

Corrosion is, in effect, similar to a dry cell battery. For corrosion to occur, there must be four elements: electrolyte, anode, 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:

1. Current flows through electrolyte from the anode to the cathode. It returns to the anode through the return circuit.
2. Corrosion occurs wherever current leaves the metal and enters the electrolyte. The point where current leaves the metal is called the anode. Corrosion, therefore, occurs at the anode.
3. Current is 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.
4. 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.

Table 8-1 Electrochemical Metal Losses of Some Common Metals

Metal	Loss, lb/A-yr (kg/C)[a]
Iron (Fe^{2+})	20.1 (72.4)
Aluminum (Al^{3+})	6.5 (23.4)
Lead (Pb^{2+})	74.5 (268.3)
Copper (Cu^{2+})	45.0 (162.0)
Zinc (Zn^{2+})	23.6 (85.0)
Magnesium (Mg^{2+})	8.8 (31.7)
Nickel (Ni^{2+})	21.1 (76.0)
Tin (Sn^{+})	42.0 (151.2)
Silver (Ag^{+})	77.6 (279.4)
Carbon (C^{4+})	2.2 (7.9)

[a] A = Ampere; C = Coulomb, the amount of electric charge transported in one second by a steady current of 1 ampere

COMMON FORMS OF CORROSION

Corrosion occurs in a number of common forms as follows:

Uniform attack (Figure 8-3): Uniform attack 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 (Figure 8-4): Pitting corrosion 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 portion of the film. The result is localized, concentrated corrosion, which forms deep pits.

Galvanic corrosion (Figure 8-5): Galvanic corrosion 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 shown in Table 8-3, which drives the electrons from one metal to the other.

Concentration cell attack (Figure 8-6): Concentration cell attack is caused by differences in the concentration of a solution, such as differences in oxygen concentration

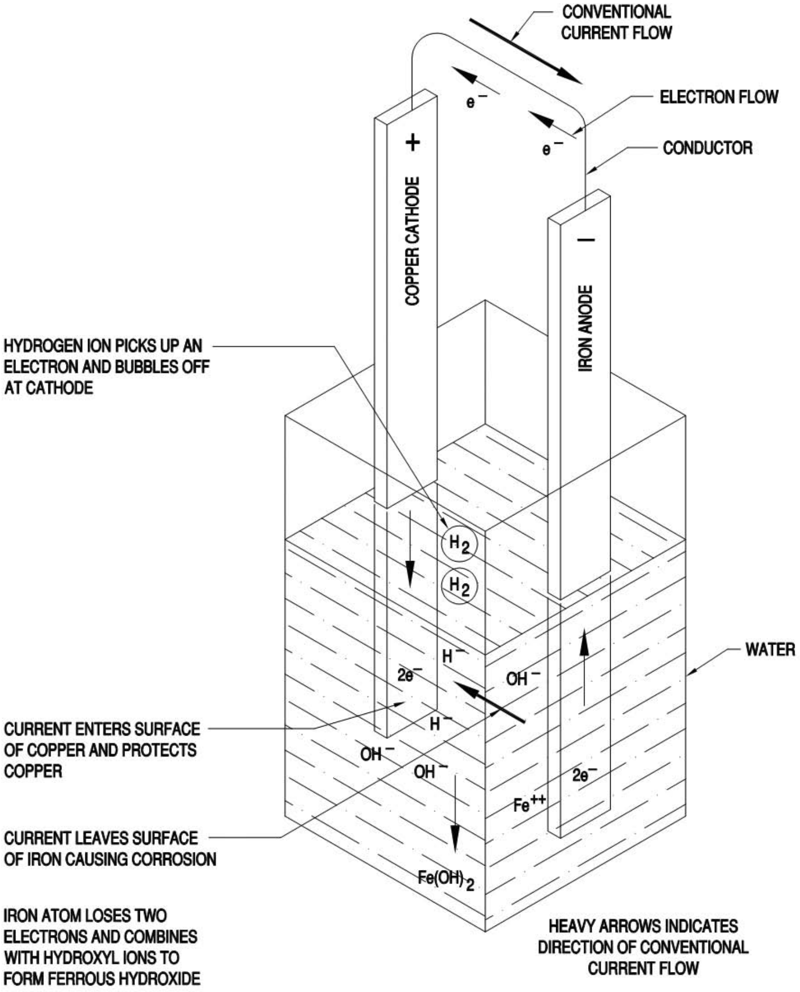

Figure 8-1 Basic Corrosion Cell

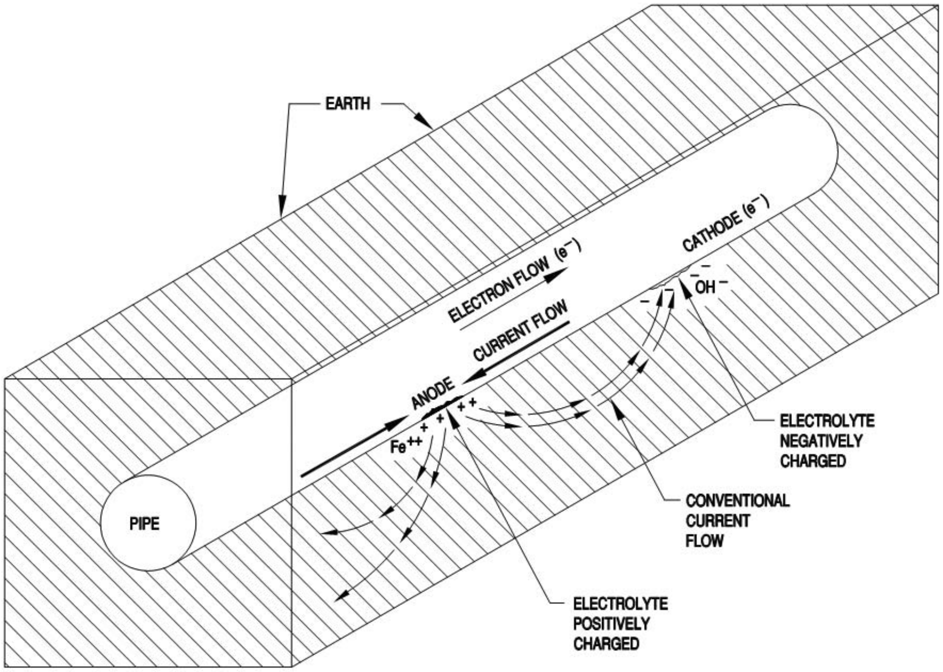

Figure 8-2 Basic Cell Applied to an Underground Structure

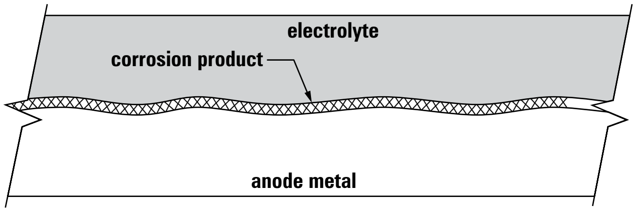

Figure 8-3 Uniform Attack

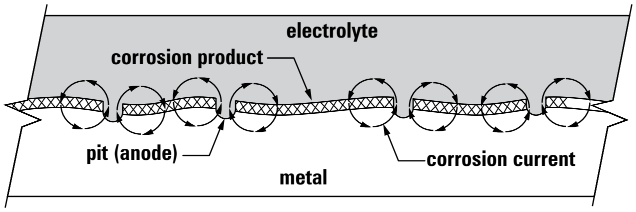

Figure 8-4 Pitting Corrosion

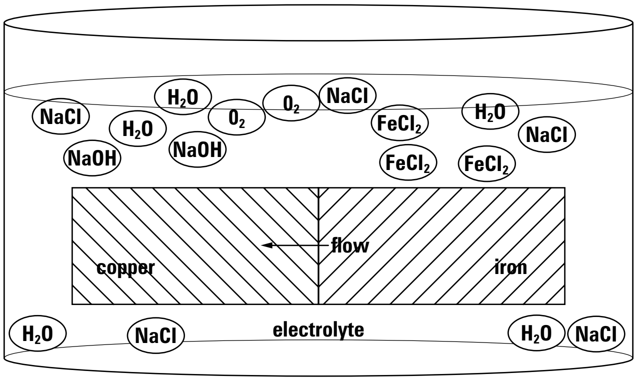

Figure 8-5 Galvanic Corrosion

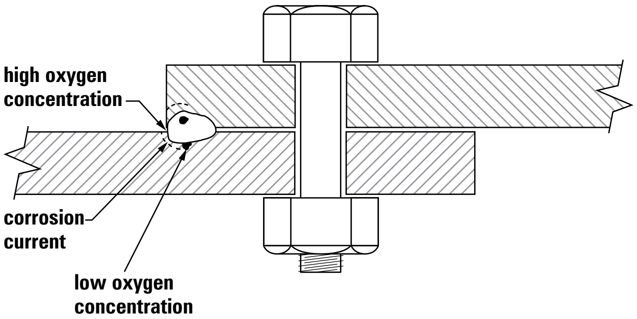

Figure 8-6 Concentration Cells

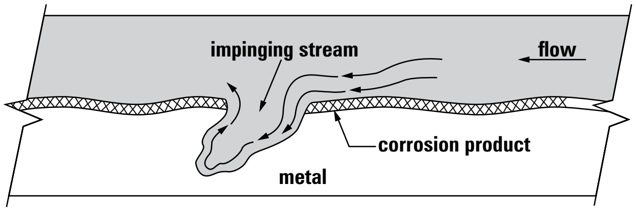

Figure 8-7 Impingement Attack

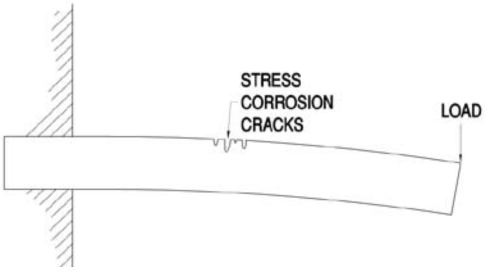

Figure 8-8 Stress Corrosion

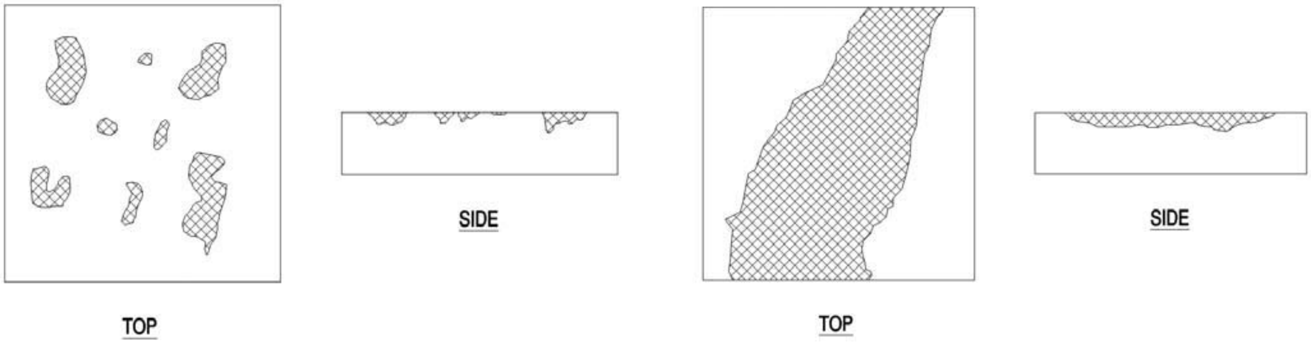

Figure 8-9 (A) Plug-zType Dezincification. (B) Layer-Type Dezincification

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 metal surface. The area of low oxygen or metal-ion concentration becomes anodic to areas of higher concentration.

Crevice corrosion: This is a form of concentration cell attack (see previous listing).

Impingement attack (Figure 8-7): Impingement attack, or erosion corrosion, is the result of turbulent fluid at high velocity breaking through protective or corrosion films on a metal surface. There usually is a definite direction to the corrosion formed.

Stress corrosion cracking (Figure 8-8): Stress corrosion cracking 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.

Selective attack (Figure 8-9): Selective attack, or leaching, is the corrosive destruction of one element

Table 8-2 Galvanic Series of Metals

Corroded end (anodic)
Magnesium
Magnesium alloys
Zinc
Aluminum 1100
Cadmium
Aluminum 2017 & 2024
Steel or iron
Cast iron
Chromium-iron (active)
Ni-resist irons
18-8 SS (active)
18-8-3 SS (active)
Lead-tin solders
Lead
Tin
Nickel (active)
Inconel (active)
Hastelloy C (active)
Brasses
Copper
Bronzes
Copper-nickel alloys
Monel
Silver solder
Nickel (passive)
Inconel (passive)
Chromium-iron (passive)
18-8 SS (passive)
18-8-3 SS (passive)
Hastelloy C (passive)
Silver
Titanium
Graphite
Gold
Platinum
Protected end (cathode)

of an alloy. Examples are dezincification of brass and graphitization of cast iron.

Stray current (Figure 8-10): Stray current corrosion is caused by the effects of a direct current source such as a cathodic protection rectifier. 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.

Corrosion by differential environmental conditions (Figure 8-11): Examples of differential environmental cells are shown in Figure 8-11. It should be noted that variations in moisture content, 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.

Table 8-3 Electromotive Force Series

Metal	Potential of Metals
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.

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.

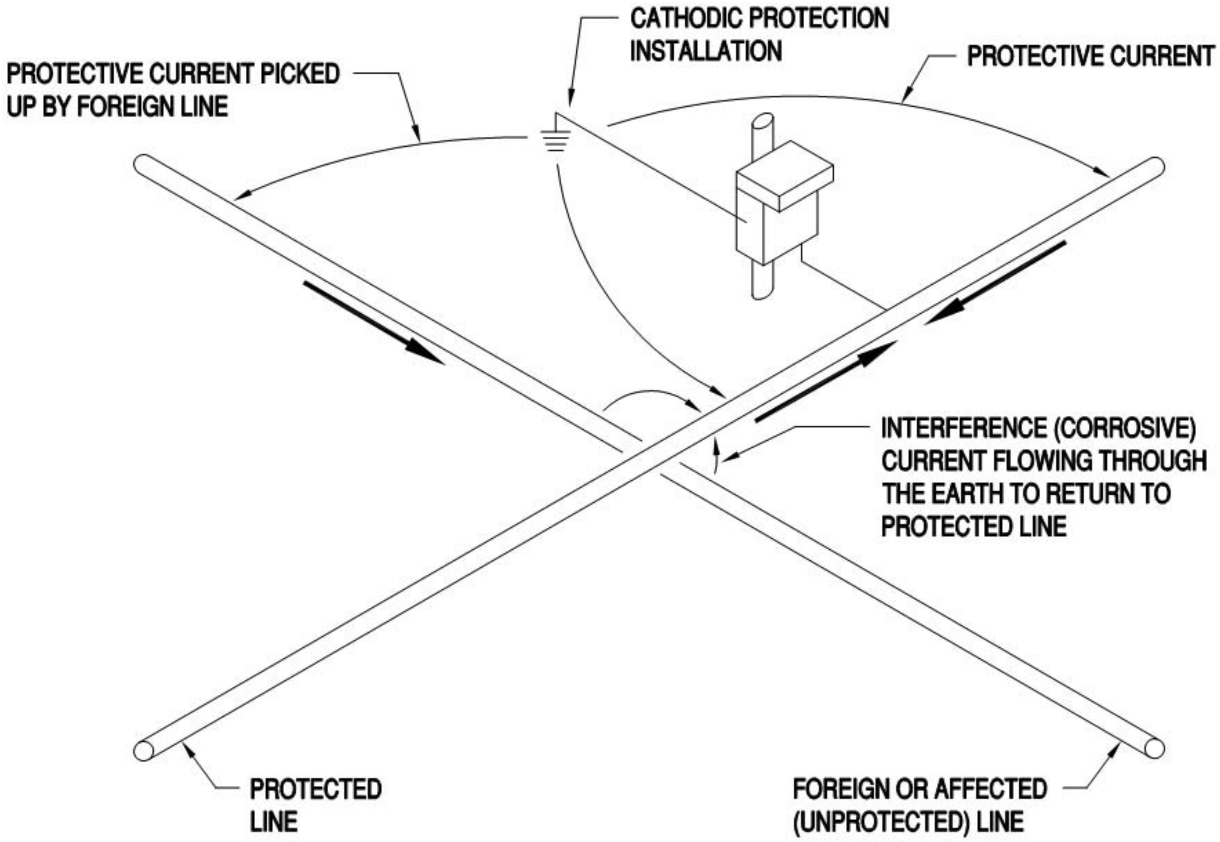

Figure 8-10 Stray Current Corrosion

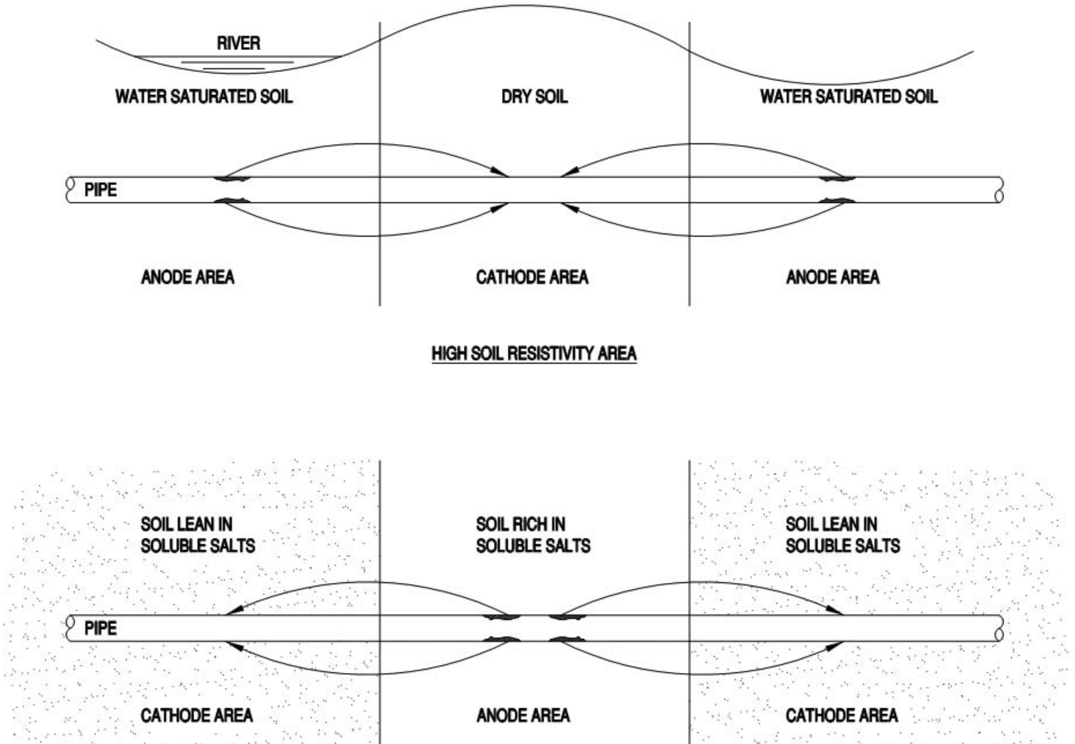

Figure 8-11 Corrosion by Differential Environmental Conditions

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 1.0) for elements that are cathodic to a standard hydrogen electrode and negative potentials (less than 1.0) 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: Fe^{2+}). 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:

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:

Equation 8-2

$$w = KIt$$

where:

w = Weight loss
K = Electrochemical equivalent
I = Current
t = Time

Table 8-4 Corrosion Rates for Common Metals

Metal	Loss Rate, lb/A-yr (kg/C)[a]
Iron or steel	20 (6.1)
Lead	74 (22.5)
Copper	45 (162.0)
Zinc	23 (7.0)
Aluminum	6.5 (23.4)
Carbon	2.2 (7.9)

[a] A = Ampere; C = Coulomb, the amount of electric charge transported in one second by a steady current of 1 ampere

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 8-4. 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 or steel, for example, suffers accelerated corrosion in solutions where the pH is 4.5 or less. Exceptions to this rule are amphoteric materials such as aluminum or lead, which corrode more rapidly in alkaline solutions.

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 or steel corrodes at a rate proportional to the oxygen content. Most natural waters originating from rivers, lakes, or streams are saturated with oxygen. Reduction of oxygen is a 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 it forms 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, content of dissolved gases, and 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. 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 factors:

- Materials selection
- Design to reduce corrosion
- Passivation
- Coating
- Cathodic protection
- Inhibitors (water treatment)

Materials Selection

Materials 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 in the system design. The following five design suggestions can minimize corrosive attack:

1. 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 of 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.

2. 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 there is a need for machining or fabrication so that unnecessary damage does not occur.
3. 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 nonhomogeneity of the metal wall. Designs can minimize this effect by using heavier wall thicknesses in areas to be welded.
4. 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 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 design welded connections in place of mechanical fasteners.
5. Other design suggestions include the following: Corrosion can be minimized if heat or chemicals near metal walls are avoided. Condensation of moisture from the air on cold metal surfaces can cause extensive corrosion if not prevented. The cold metal surface should be thermally insulated if possible. Any beams, angles, etc., should be installed so they drain easily and cannot collect moisture, or drain holes must be provided.

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. It is not a scale removal method; thus, surface cutting tool contaminates 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. A heavily etched, dark surface rather than an oxide film occurs. Passivating solutions should be free of contaminants to prevent this from happening.

New methods are being discovered and tested to protect other material surfaces such as aluminum. Periodic testing after passivation ensures that the metal surfaces is 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 artificial protective coatings. 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 application of a coating.

The actual coating that is applied depends on the application and may be either a metallic (such as galvanizing) or nonmetallic organic (such as vinyl or epoxy) coating. The coating may actually be a coating system, such as primer, intermediate coat (to bond 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 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.

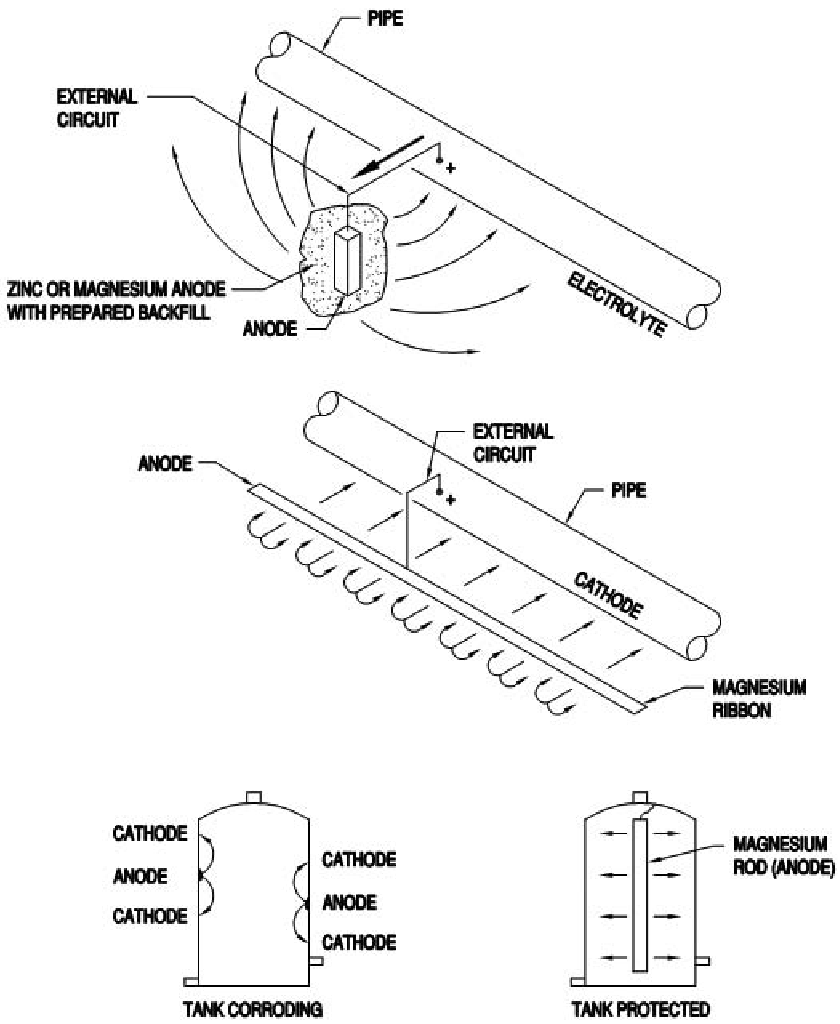

Figure 8-12 Cathodic Protection by the Sacrificial Anode Method

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 DC 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, 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 current 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. 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 galvanic anodes are its relatively low installation cost, no required external power source, low maintenance requirements, no adverse effects on foreign structures, and can be installed with pipe, minimizing right-of-way cost.

Some disadvantages of galvanic anodes are as follows:

- Driving voltage is low (approximately 0.15 V).
- Current output is limited by soil resistivity.
- It's 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

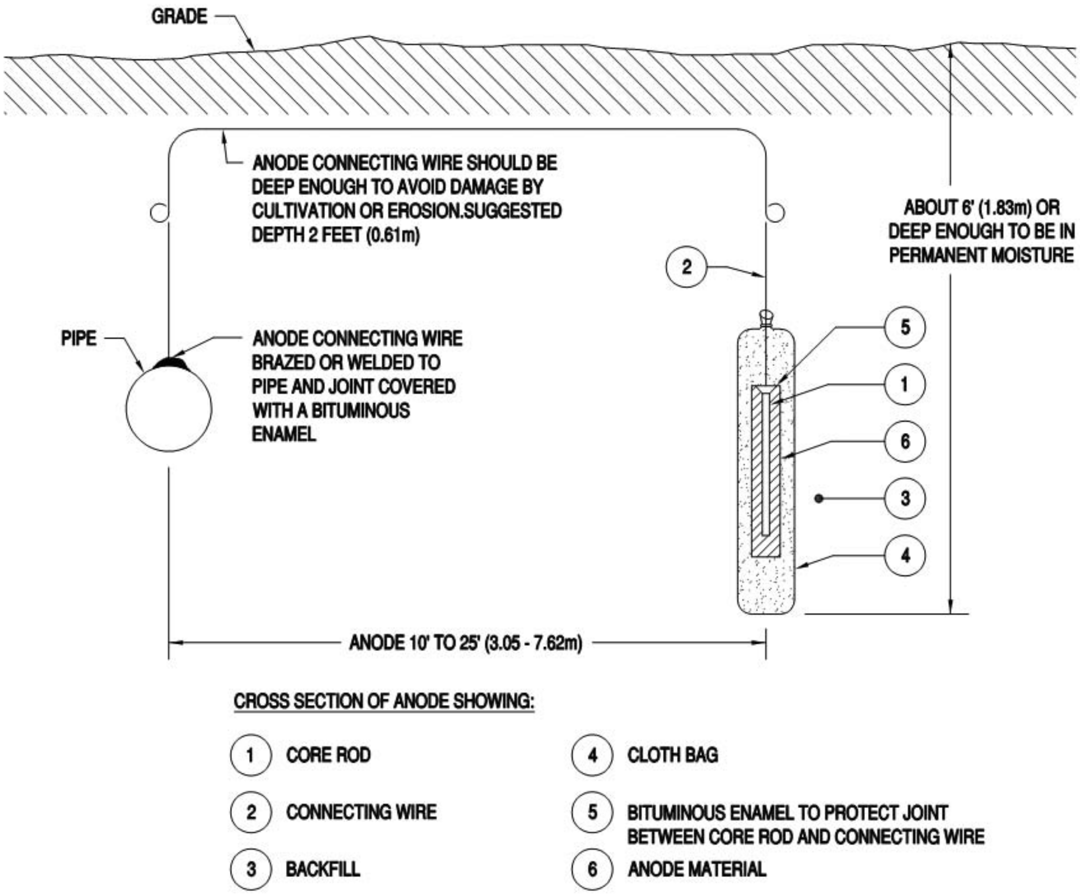

Figure 8-13 Typical Sacrificial Anode Installation

two metals, which in most cases is limited to 1.0 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 of zinc anodes is 0.25 V and for magnesium 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 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:

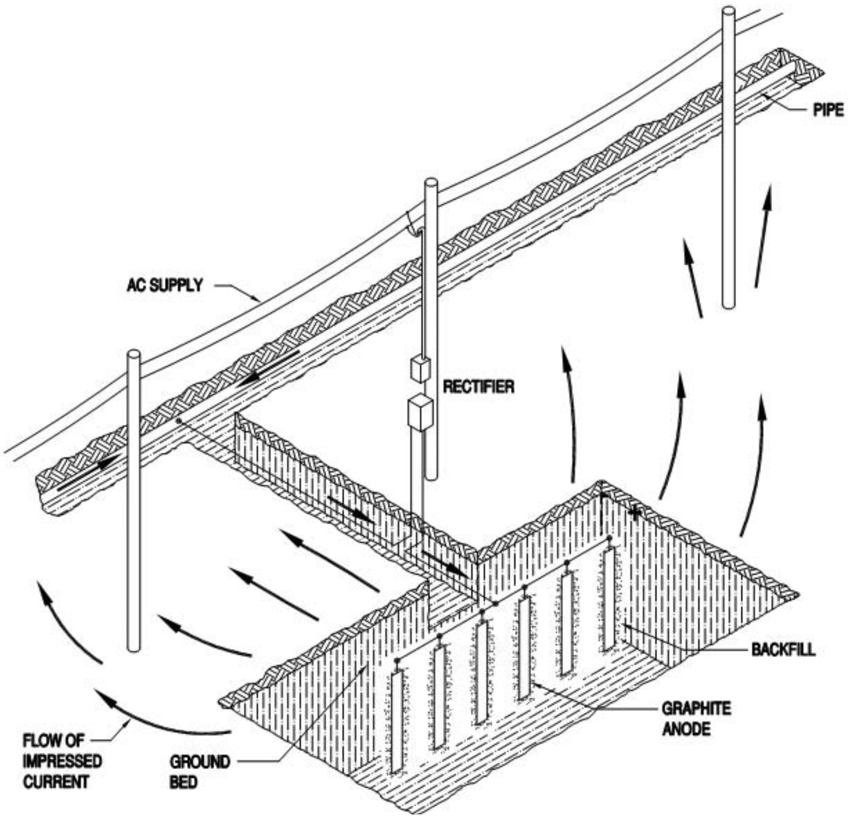

Figure 8-14 Cathodic Protection by the Impressed Current Method

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 adjustment of 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. Current output is determined by adjustment of 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
- 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

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 structure, electrical continuity, and location is a necessary first step. Next, the availability of power and ease of installing the ground bed are required. After all of the above are satisfactorily done, it is generally necessary to perform a current-requirement test utilizing a portable DC generator or storage batteries. This defines an apparent DC 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 that the circuit resistance is relatively low. 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 the National Association of Corrosion Engineers (NACE). These criteria are based on measuring structure-to-electrode potentials with a copper-sulfate reference electrode. The criteria are listed for various metals, such as steel, cast iron, aluminum, and copper, and may be found in NACE Standard RP-01.

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 much 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 noncontinuous 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 the minimum with minimum 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 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 naturally forming carbonate films. This carbonate film, 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 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 elimination of 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.

CORROSION IN PLASTICS

Plastic materials corrode by processes different than metallic materials. Physicochemical processes rather than electrochemical reactions are responsible for the degradation of plastics. Plastic materials are attacked by swelling, dissolution and bond (joint) rupture due to chemical reaction (oxidation), heat, and radiation (sunlight). These reactions can occur singly or in combination.

The traditional method of expressing the rate of corrosion as weight loss cannot be used for plastic materials. Other evaluation methods such as change in hardness, tensile properties, losses or gains in dimensions, elongation, and appearance changes determine the corrosion effect on a plastic material. The effects of various environments on plastic materials are tabulated for each specific plastic material, as shown on Table 8-5. The designer must evaluate plastic materials against the chemical environment inside and outside of the material.

Table 8-5 Chemical Resistance for Common Plastics[a]

Chemical Name	Pipe Material		
	ABS	PVC	CPVC
Acetone	NR	NR	NR
Beer	120	140	180
Chlorox bleach solution, 5.5%CL2	NR	NR	NR
Citric acid, 10%	160	140	180
Detergents	73	140	NR
Distilled water	160	140	180
Ethylene glycol, up to 50%	170	140	180
Plating solutions, nickel	INC	140	180
Propylene glycol, up to 25%	73	140	180
Seawater	160	140	180
Soaps	160	140	180
Water	160	140	180

NR = Not recommended

INC = Incomplete data

[a] Based on data from Charlotte Pipe and Foundry, Plastics Technical and Installation Manual, January 2008

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 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 DC current or attachment to a sacrificial anode.

Cathodic The electrolyte of an electrolytic cell adjacent to the cathode.

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, 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 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 The process of prior removal of the 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 Bureau of Standards; it is employed in this publication. The opposite convention of G. 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 the 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.

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 seven (7) is neutral; low numbers (0–6) are acidic, 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) Remote earth is 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.

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9

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 horizontal forces exerted on a structure during an earthquake. 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 (Figures 9-1 and 9-2) indicates that the potential for damaging earthquake motion is far more pervasive than commonly known. Complete seismic design requirements, including 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 (piping, water heaters, pumps, tanks, boilers, ductwork, conduit, etc.) 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

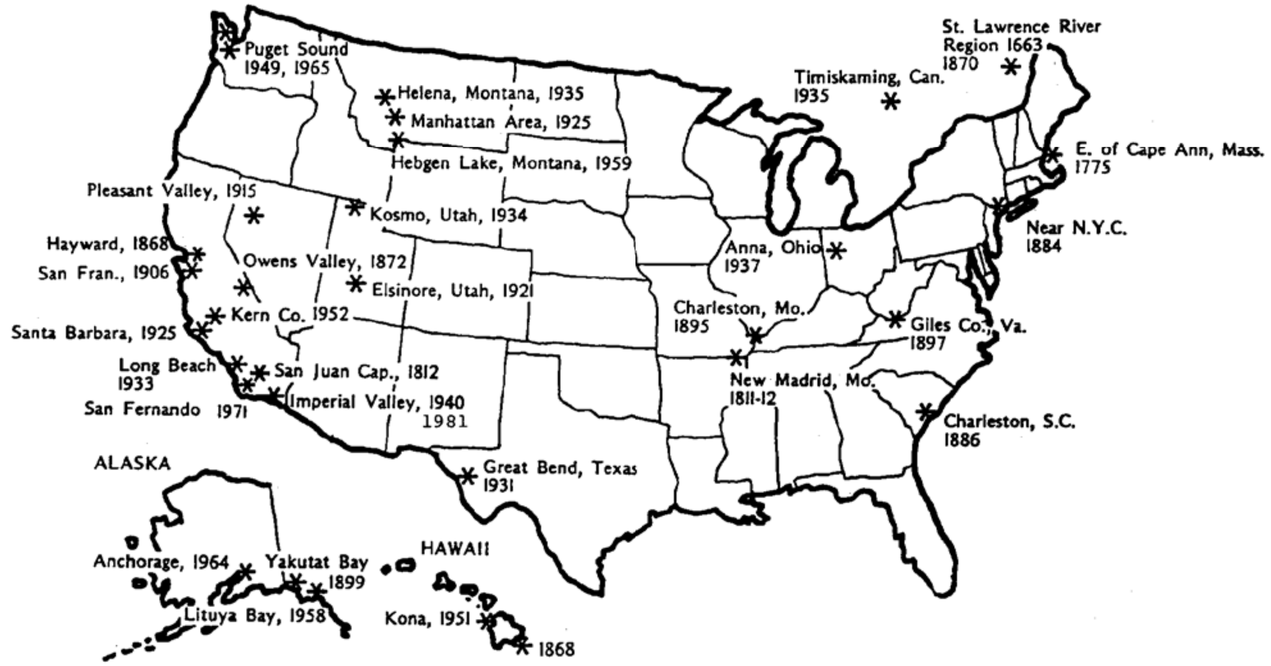
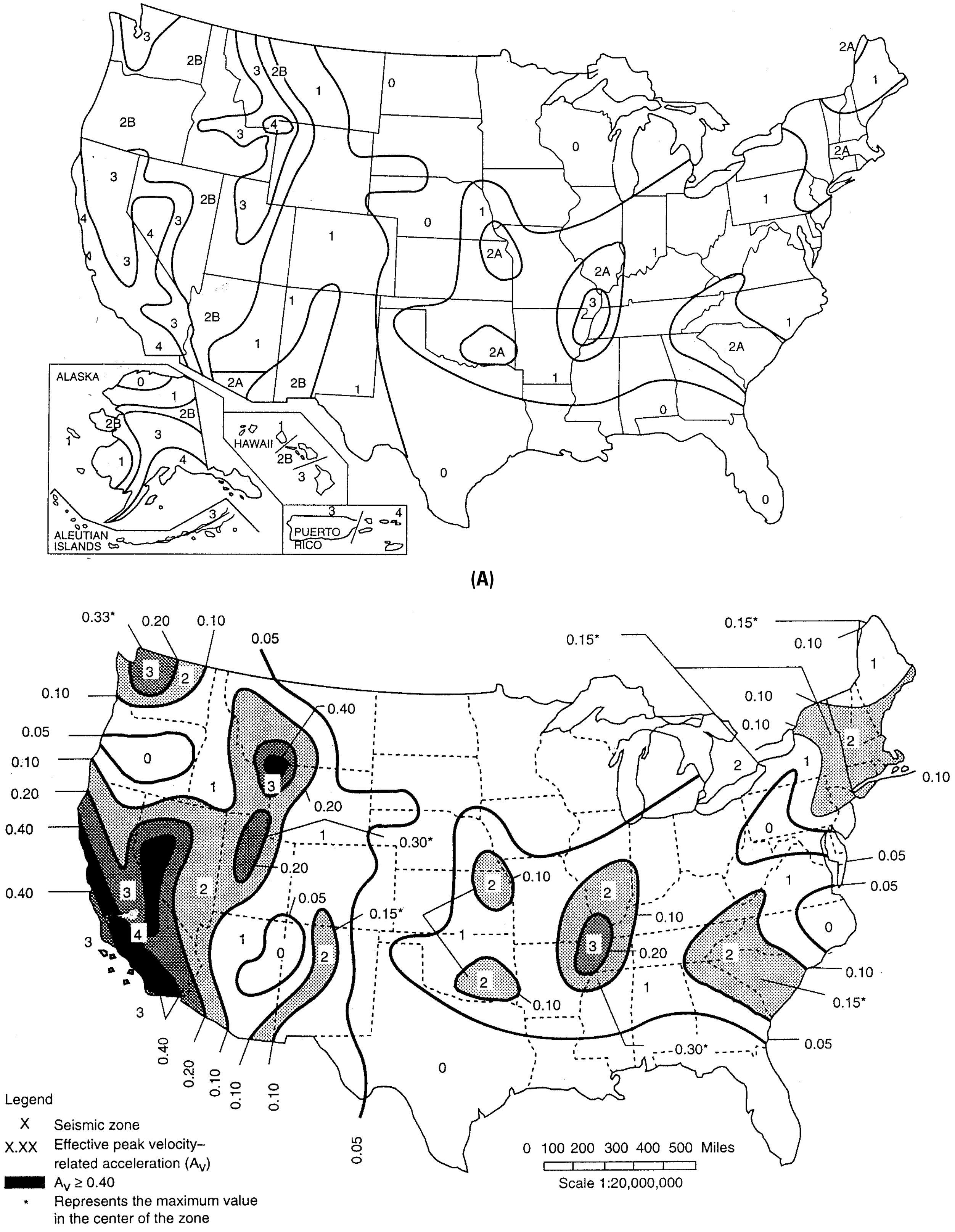


Figure 9-1 Significant Earthquakes in the United States



(A)

(B)

Figure 9-2 (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.

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 American Society of Civil Engineers (ASCE) 7: *Minimum Design Loads for Buildings and Other Structures*. This book subdivides the issues as follows:

- Chapter 12: Buildings
- Chapter 15: Non-building Structures
- Chapter 13: Nonstructural Components
- 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 the equipment 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 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 damage susceptibility 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

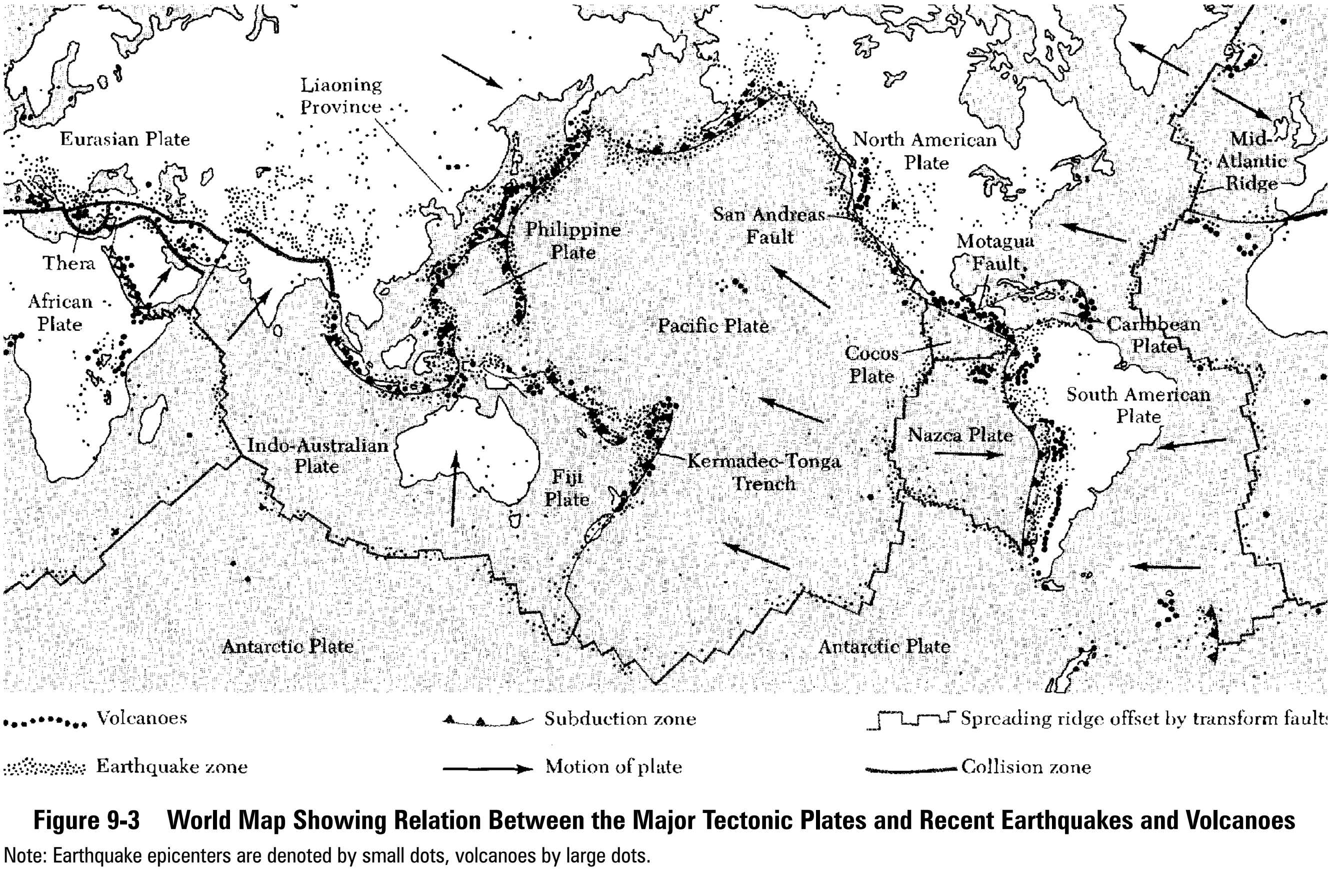


Figure 9-3 World Map Showing Relation Between the Major Tectonic Plates and Recent Earthquakes and Volcanoes

Note: Earthquake epicenters are denoted by small dots, volcanoes by large dots.

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 9-3. 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 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 9-4). Waves in a variety of patterns emanate from this fault movement and spread in every direction. The two types of waves produced by the earthquake are P, or primary, waves and S, or secondary, waves. These waves change throughout the duration of the earthquake, add to one another, and result in 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 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 9-2 shows such maps, which were used to develop design criteria zoning for a national seismic code.

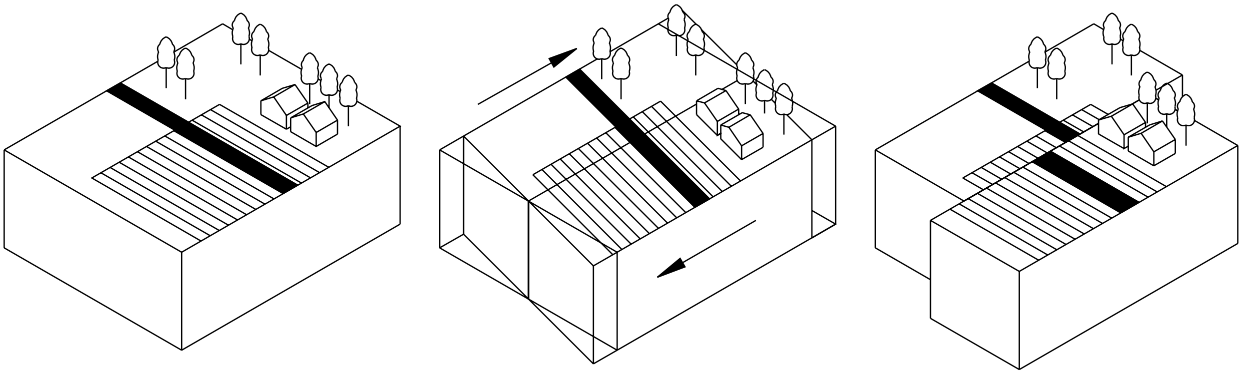


Figure 9-4 Elastic Rebound Theory of Earthquake Movement

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.

Damage from Earthquakes

Four separate phenomena created by earthquakes can cause damage:

1. Surface fault slip (ground rupture)
2. Wave action in water created by seismic movement (called tsunamis in open bodies of water and seiches in closed bodies of water)
3. Ground shaking
4. Ground failure, such as a sudden change to liquid characteristics in certain sands caused by increased pore water pressure called liquefaction and landslides

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. 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

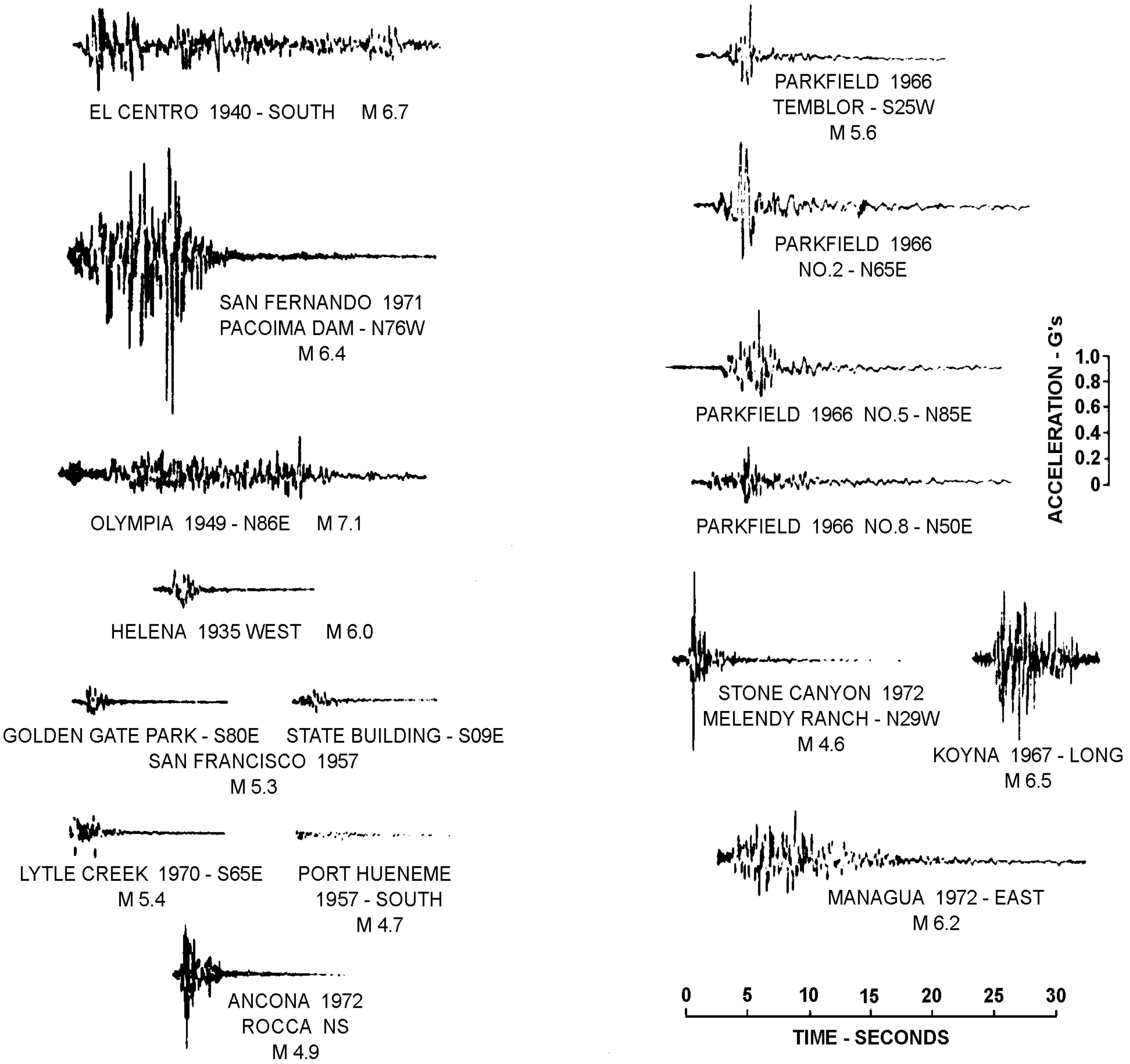


Figure 9-5 Earthquake Ground Accelerations in Epicentral Regions

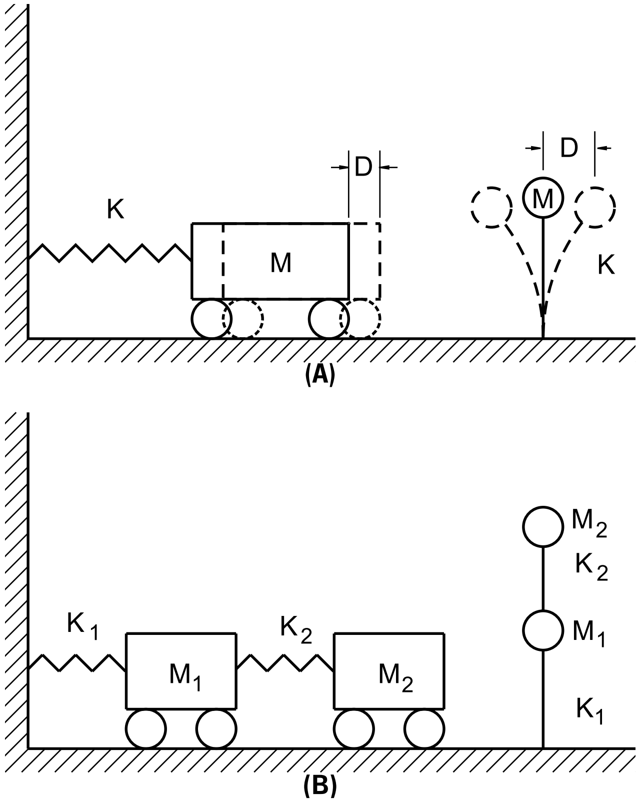


Figure 9-6 Undamped Mechanical Systems (A) Single-Degree-of-Freedom Systems (B) Multiple-Degree-of-Freedom Systems

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 amplitude 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 accellerogram, as shown in Figure 9-5) is recognized universally as being associated with earthquakes.

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 9-6(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). The dynamic response 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 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 9-7). The response parameter could be displacement, velocity, or acceleration, although acceleration is used most often. The variation in 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 9-7.)

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 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

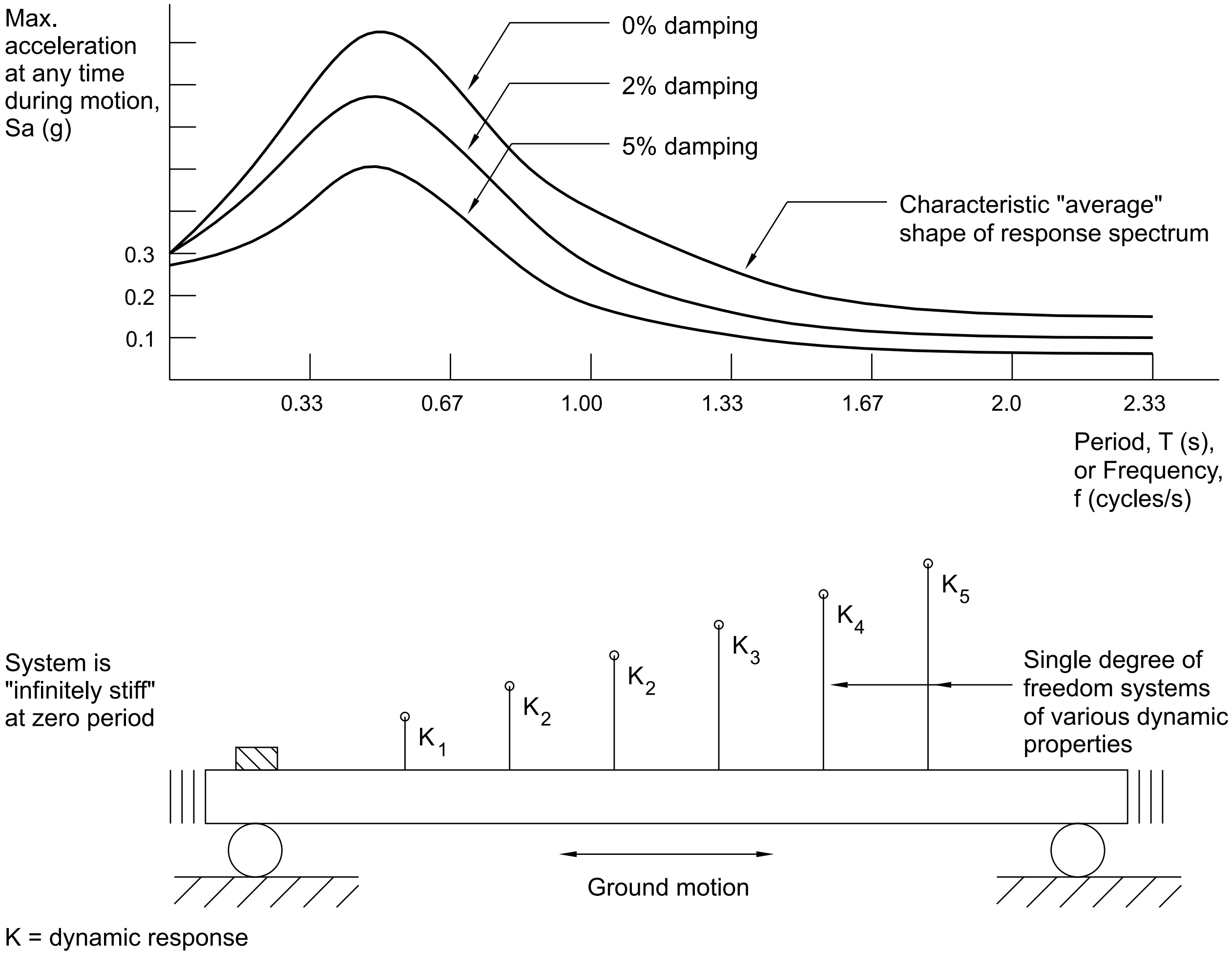


Figure 9-7 Response Spectrum

not only between earthquakes but also between sites during the same earthquake, an infinite variety of response spectra must be considered possible. Fortunately, characteristics of wave transmission and 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 consideration of 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 the 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 motion 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 multi degree-of-freedom systems, see Figure 9-6(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

Damage to Plumbing Equipment

Damage to plumbing equipment or systems in earthquakes occurs in two ways:

1. 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.
2. Failure due to forced distortions on the element caused by 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.

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.)

1964 Alaska Earthquake Damage Summary

- 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 the 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 tanks, 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.

1971 San Fernando Earthquake Damage Summary

- 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. Standards of the National Fire Protection Association (NFPA) for earthquake pro-

tection to 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 Data Sheet 2-8 for sprinkler 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.

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:

1. Overturning (moment)
    A. Overturn of equipment
    B. Failure in tension or compression of perimeter legs, vibration isolators, hangers, or their supports
    C. Excessive foundation rotation
2. Sliding (shear)
    A. Sliding of floor-mounted equipment
    B. Swinging of hung equipment
    C. 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.

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 is configuration dependent 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 resist 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 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 to 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 fire or water damage that can result if the unit gets thrown about or tipped over.

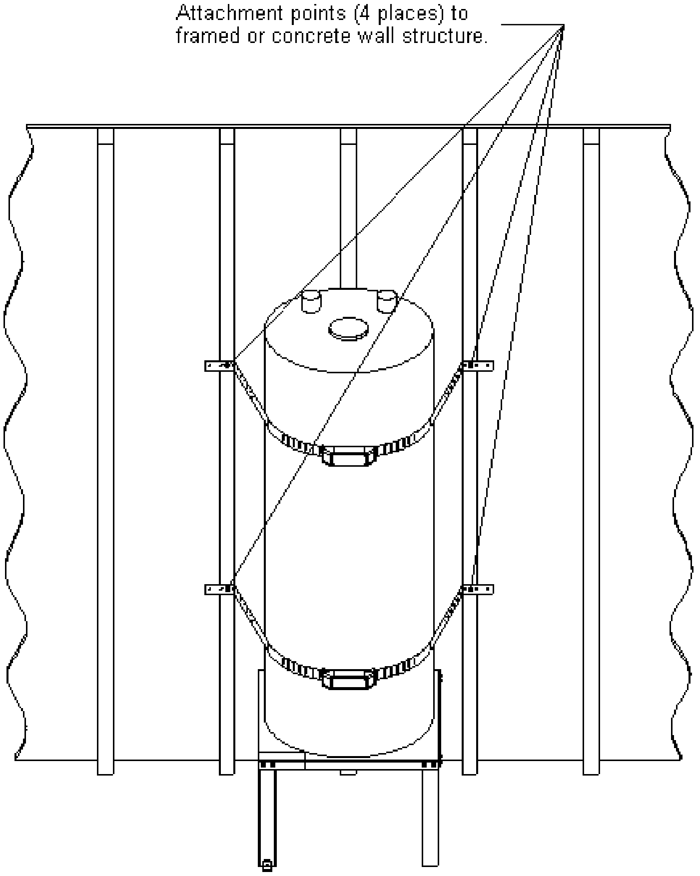


Figure 9-8 Domestic Water Heater Seismic Restraints Installed

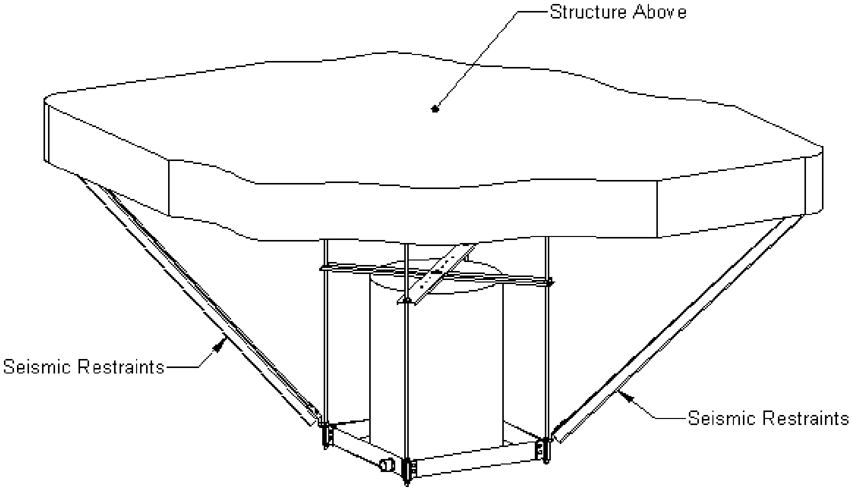


Figure 9-9 Suspended Equipment Platform with Seismic Restraints

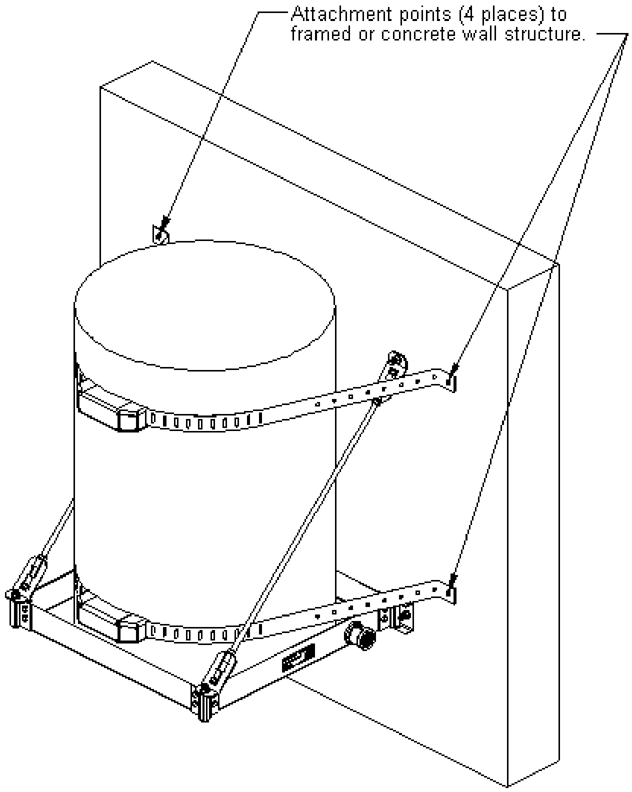
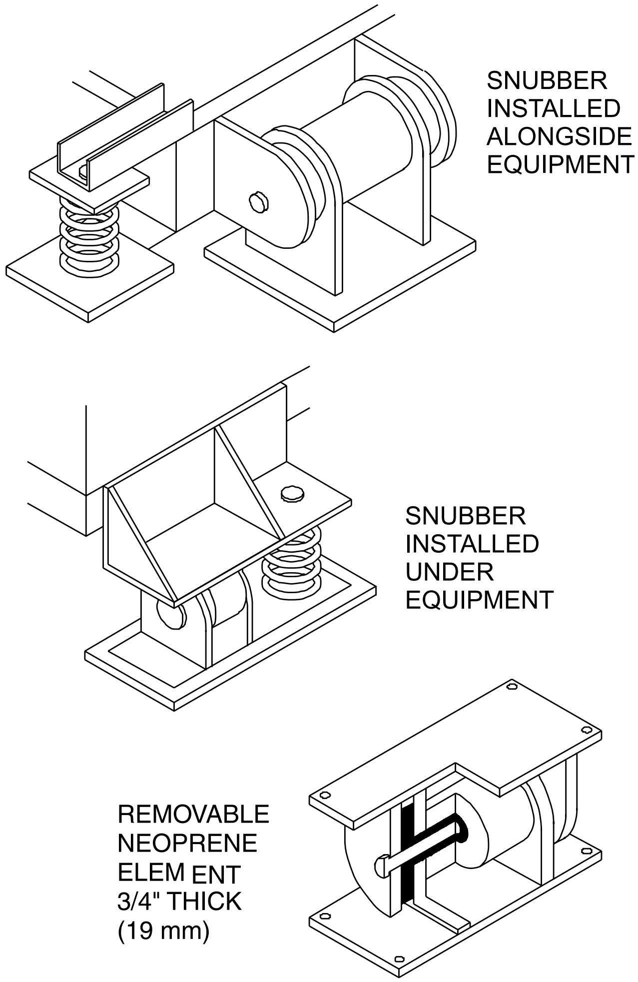


Figure 9-10 Wall Hung Equipment Platform/Drain Pan with Seismic Restraints



(A)

Figure 9-11 (A) Three-Dimensional Cylinder Snubber

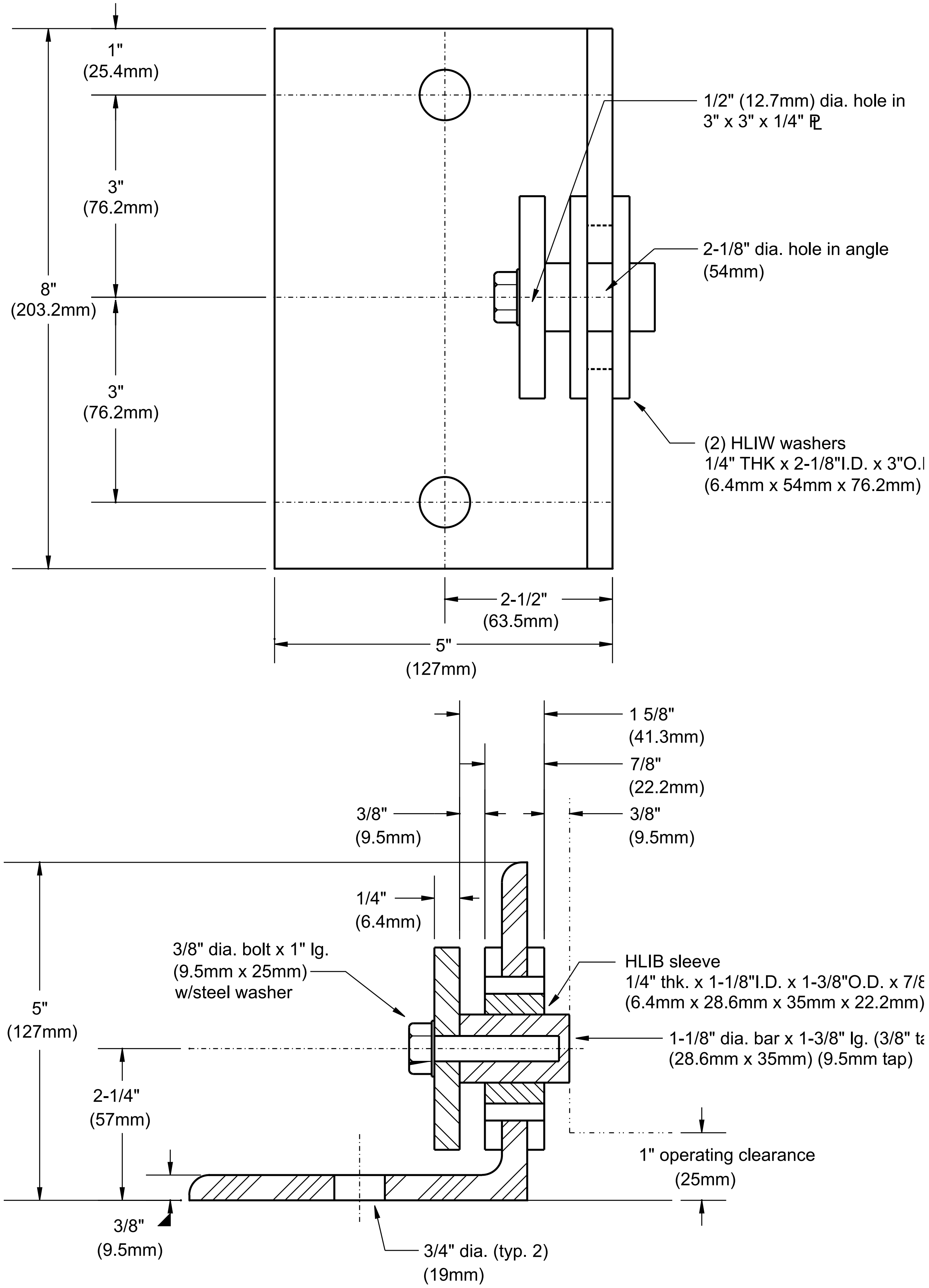
Anchoring the unit to a wall or other secure structure is an inexpensive and usually uncomplicated bit of insurance. At the same time, it is advisable to replace rigid fuel gas and water connectors with flexible ones to minimize the risk of even a small tremor breaking a line.

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 tornados, 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 of 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 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 water heater, while others go from one side to the other, and no uniform legislative or code requirement specifies either type. (See Figure 9-8 for an example of a water heater with dual seismic straps in the 180° 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



(B)

Figure 9-11 (B) Three-Directional Angle Snubbers 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 Section 13.1.4):

1. All plumbing components in Seismic Design Category B and in Seismic Design Category C with an importance factor of 1.0
2. All plumbing components in Seismic Design Categories D, E, and F with an importance factor of 1.0 and either:
   A. Flexible connections between the components and associated elements
   B. Components mounted less than 4 feet above floor level and weigh less than 400 pounds
3. All plumbing components (suspended) in Seismic Design Categories D, E, and F with an importance factor of 1.0 and either:
   A. Flexible connections between the components and associated elements
   B. Components weighing 20 pounds or less or, for distribution systems, weighting 5 pounds per foot or less

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 9-9 and 9-10 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.

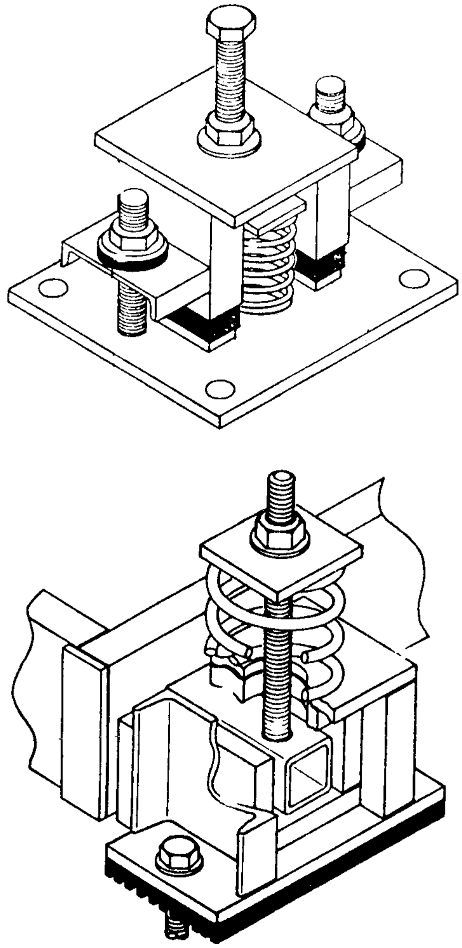


Figure 9-12 Isolators with Built-In Seismic Restraint

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 (Figure 9-11) or to install specially designed isolators that have built-in restraints and overturning resistance (Figure 9-12).

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.

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 to -inch 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. Once snubbers are decided on, those that restrain in three dimensions are preferred because that 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 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. Use of neoprene grommets or bushings is not required. The cable sag and cable 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 Section 13.6.8, Exception 1). Seismic calculations are not required when high-deformability piping is used having provisions to avoid impact with surroundings and meeting one of the following requirements:

1. 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
2. Seismic Design Category C, with an importance factor greater than 1.0 and pipe size equal to or less than 2 inches
3. 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:

1. Fuel oil, gas, medical gas, and compressed air piping 1-inch nominal diameter and larger
2. Piping in boiler rooms, mechanical rooms, and refrigeration mechanical rooms 1¼-inch 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. 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

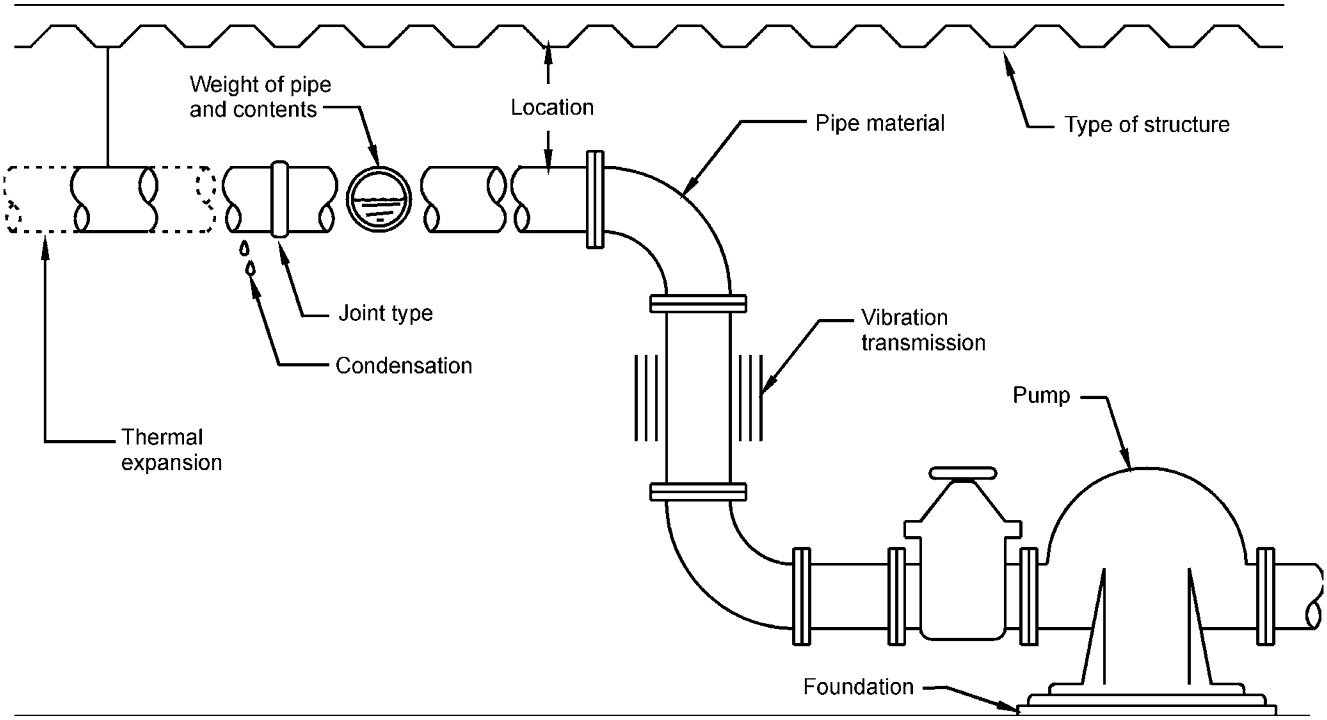


Figure 9-13 Parameters to be Considered for Pipe Bracing

and guidelines consider hangers of less than 12 inches as being equivalent to direct attachment. For pipes suspended more than 12 inches, 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 American Welding Society (AWS) D 1.1 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, except that fuel oil and gas piping shall be at 20-foot maximum spacing. Longitudinal bracing shall be at 80-foot maximum spacing, except that fuel oil and gas piping shall be at 40-foot 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 9-13. 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 bracing of pipes. Relative position of the equipment or pipes with respect to the floor is critical.

Type of Structure The types of structures are subdivided into different framing categories that act as seismic force-resisting systems:

1. Bearing wall systems
2. Building frame systems
3. Moment-resisting frame systems
4. Dual systems with special moment frames capable of resisting at least 25 percent of prescribed seismic forces

5. Dual systems with intermediate moment frames capable of resisting at least 25 percent of prescribed seismic forces
6. Shear wall-frame interactive systems with ordinary reinforced concrete moment frames and ordinary reinforced concrete shear walls
7. Cantilevered column systems detailed to conform to the requirements
8. 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 limit brace spacing.

It is often unacceptable to have anchors drilled or shot into the underneath of prestressed 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 1½ inch or less in width; the strength of drilled or shot-in anchors installed in these locations is questionable.

The structures of buildings that employ interstitial space may have the capacity to brace pipe to either the top or the bottom of the space, 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 axial loadings necessary to transmit forces to longitudinal braces, is unknown.

As 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 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.

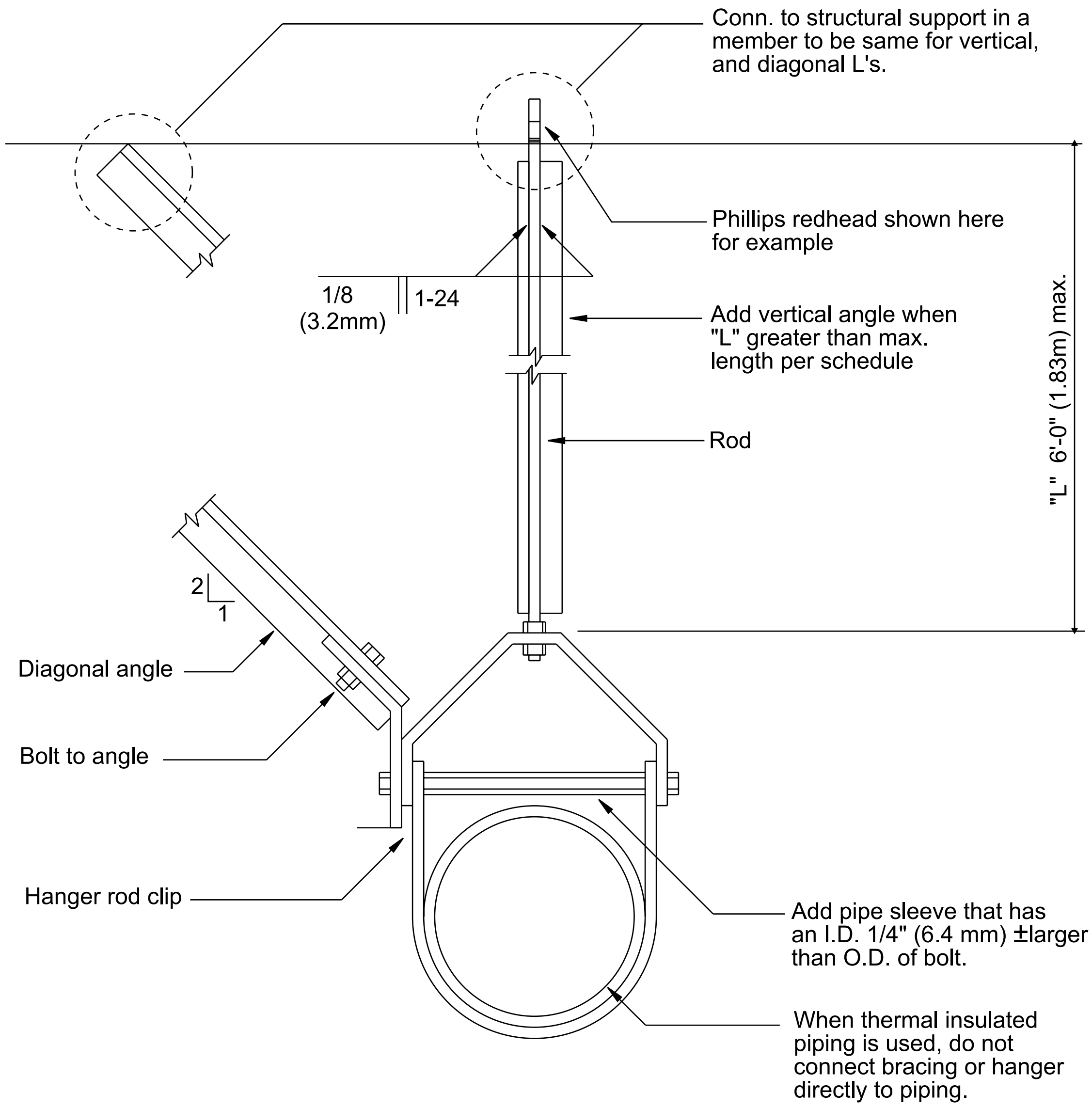
Piping Bracing Methods

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) and the Plumbing and Piping Industry Council have prepared some guidelines on bracing systems for use by engineers, architects, contractors, and approving authorities. Some of these details for construction of seismic restraints are seen in Figures 9-14 and 9-15.

These guidelines utilize three pipe-bracing methods:

1. The structural angle
2. The structural channel
3. The aircraft cable method (Figure 9-12)

In addition, several manufacturers have developed their own seismic bracing methods (see Figures 9-16 and 9-17). Whatever method is used, one should determine the adequacy of the supporting structure by properly applying acceptable engineering procedures.



(A)

Figure 9-14 (A) Typical Pipe Bracing

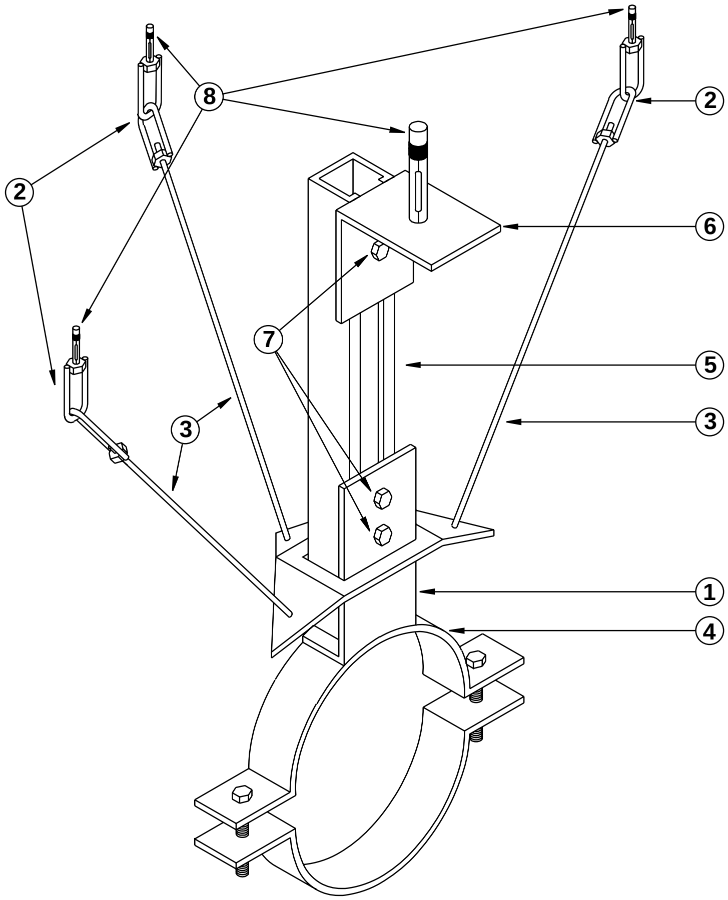
Source: SMACNA

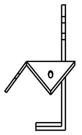
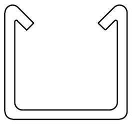
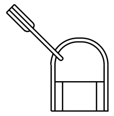
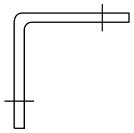
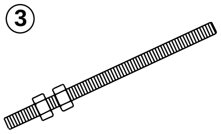
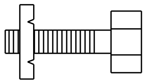
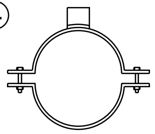
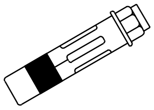
Pipe risers seldom pose a problem because they typically are clamped at each floor, and movement due to temperature changes is routinely considered. Very large or stiff configurations, which could be affected by inter-story drift, or situations where long, free-hanging horizontal runs could be inadvertently 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 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 ball joints, the length of 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

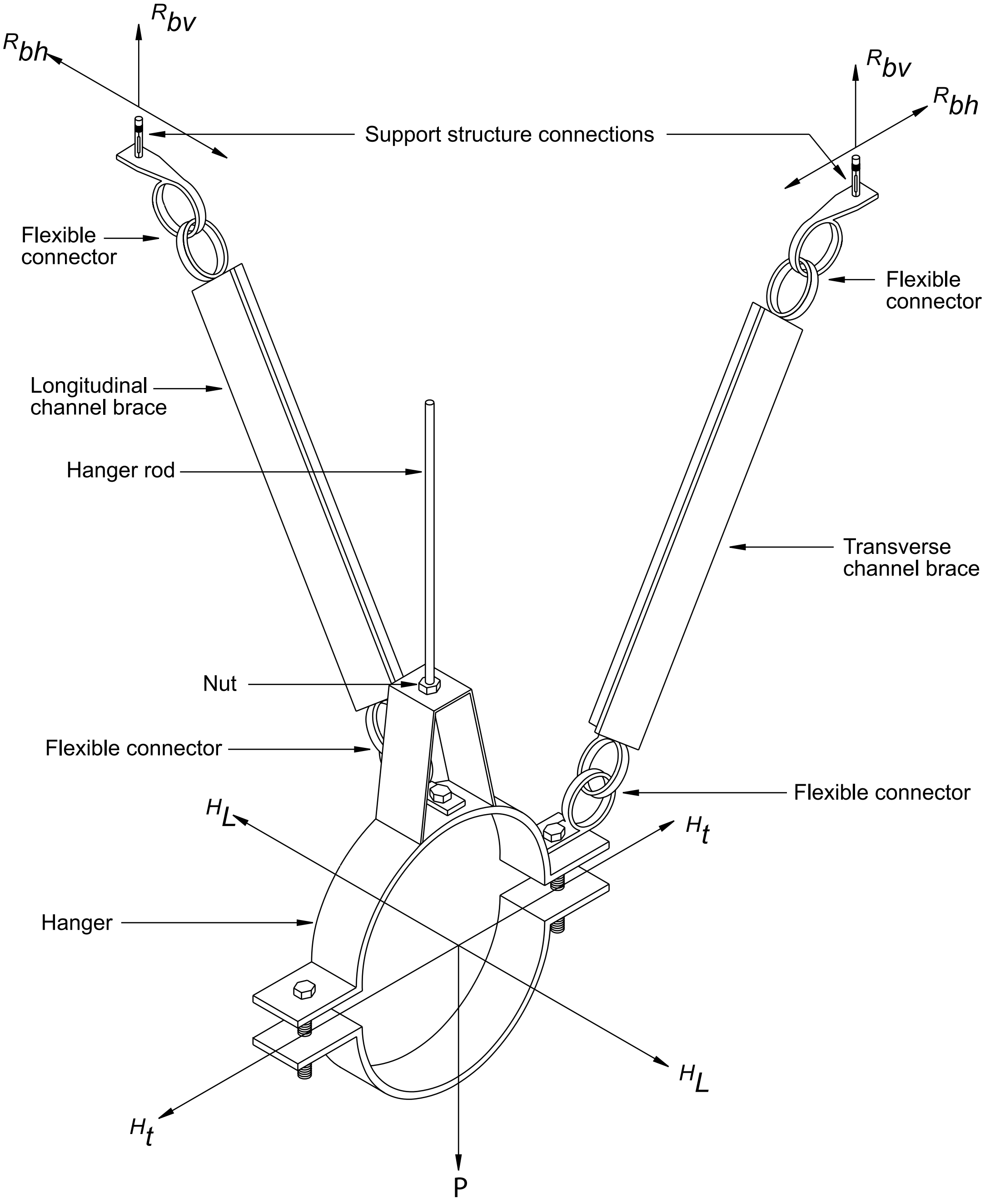
The process of the seismic design for buildings has had a reasonably long time to mature. Beginning in the 1920s, after engineers observed heavy building damage from earthquakes, they began to consider



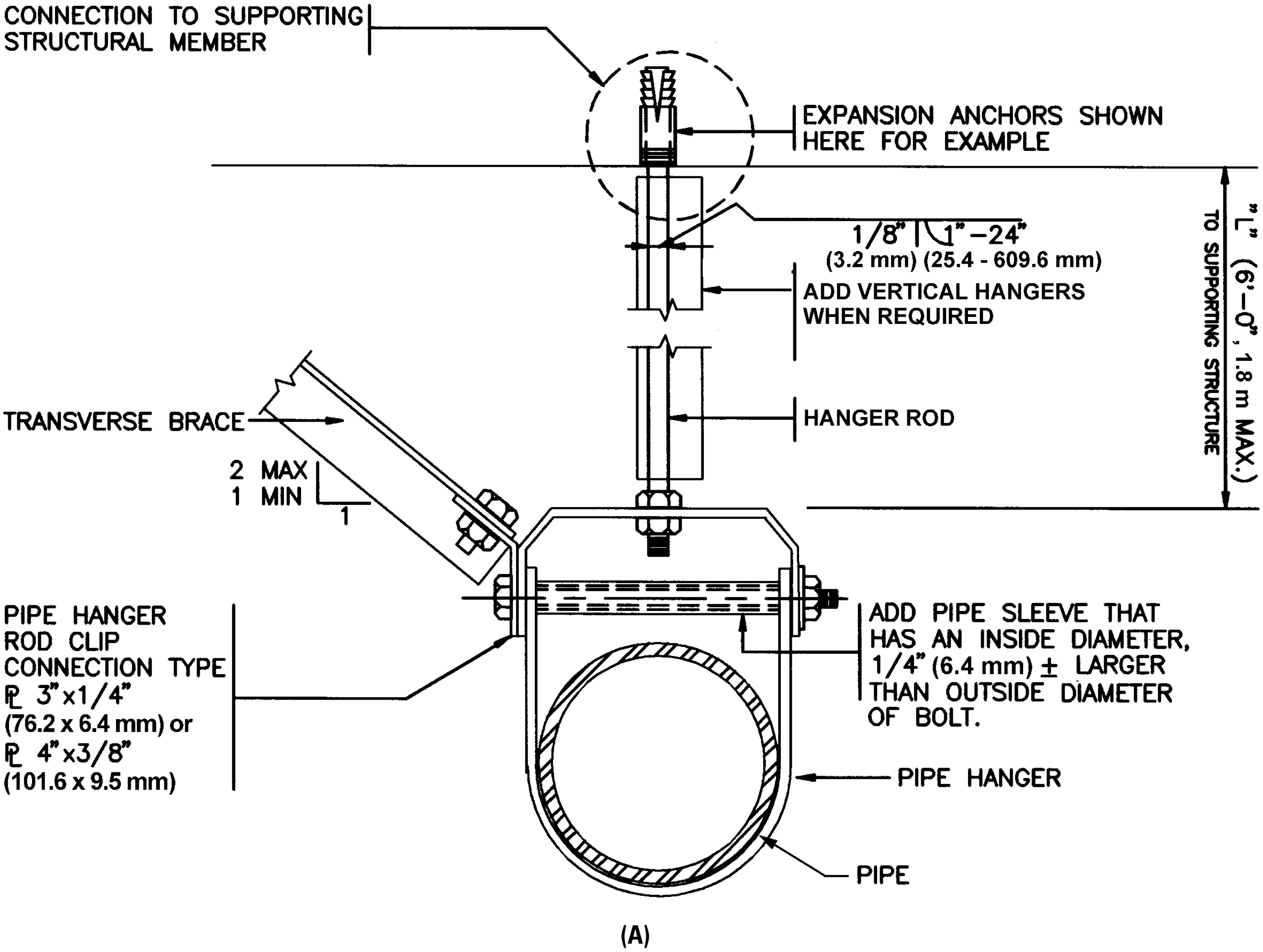
① 	Triangle Plate 1/4" Plate 1/4"X1-1/4" Flat Bar	⑤ 	1-1/4"x1-1/4"x12 Ga. Channel Length Varies (Not Included)
② 	1/2" Flexible Connector	⑥ 	1/4" Angle Clip
③ 	1/2" All-Thread Rod (Not Included) Length Varies With Nylon Lock Nut	⑦ 	1/4" Dia Mach. Bolt with Clamp Nut 30 Ft # Torque
④ 	Pipe Hanger Size and Type Can Vary	⑧ 	Phillips Sleeve Anchor

(B)

Figure 9-14 (B) Tension 360 Pipe Bracing



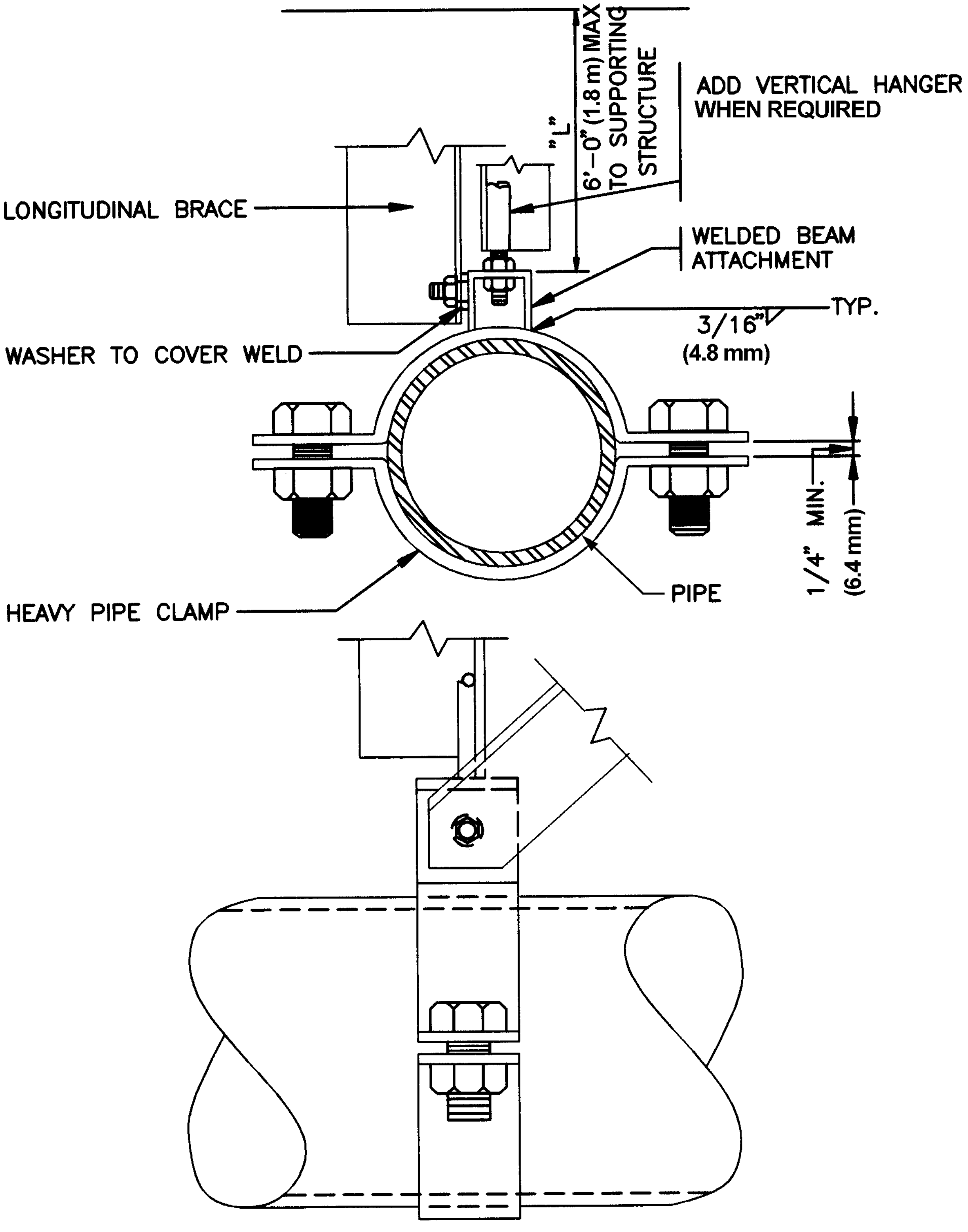
(C)
Figure 9-14 (C) Superstrut



(A)

Figure 9-15 (A) Transverse Bracing for Pipes

Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.

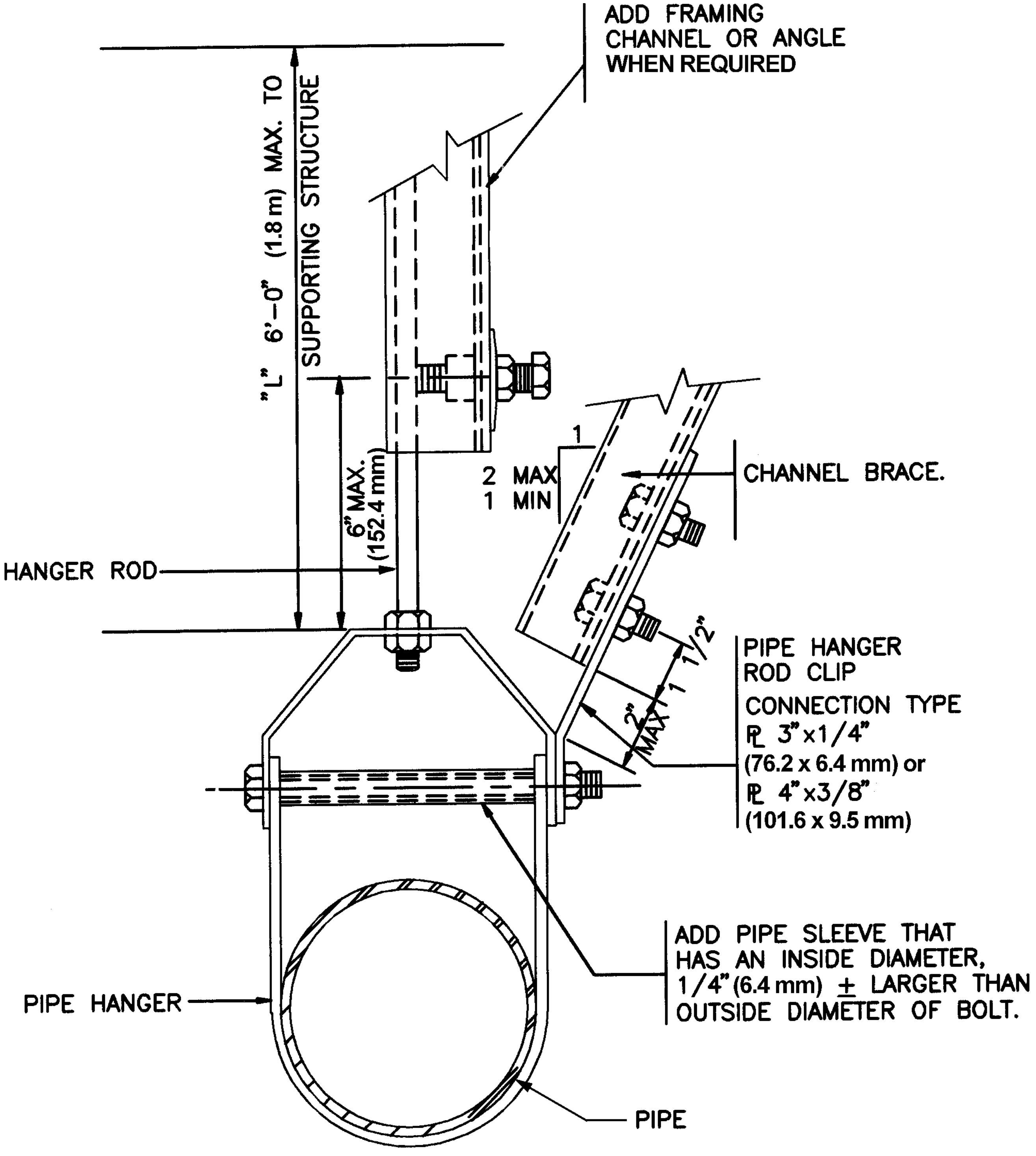


(B)

Figure 9-15 (B) Longitudinal Bracing for Pipes

Note: Movement due to temperature has been neglected in this example.

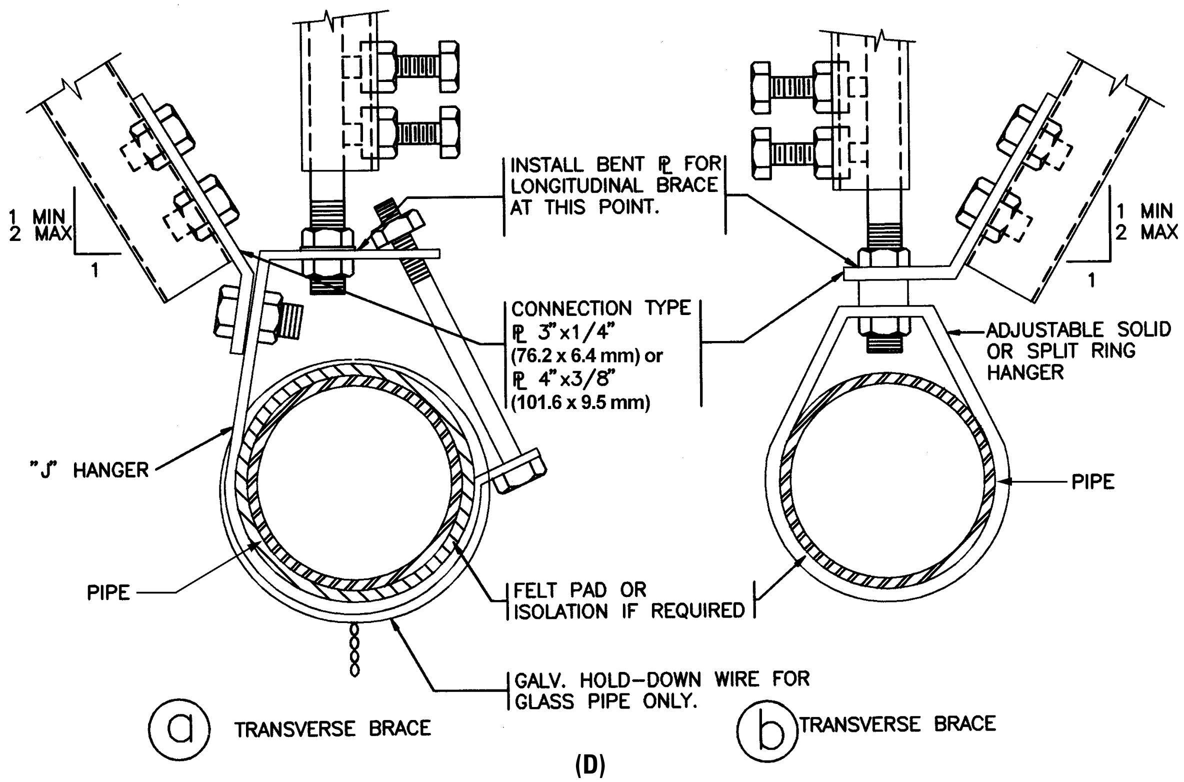
Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.



(C)

Figure 9-15 (C) Strut Bracing for Pipes

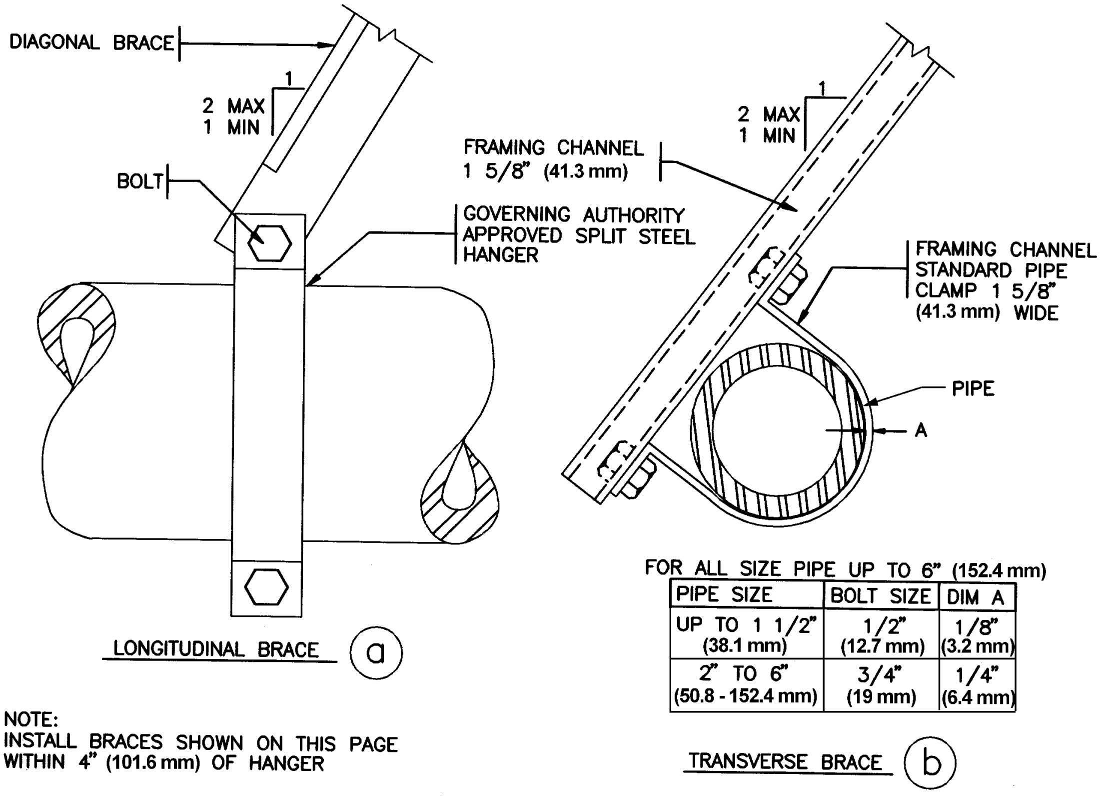
Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.



(D)

Figure 9-15 (D) Alternate Attachment to Hanger for Pipe Bracing

Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.



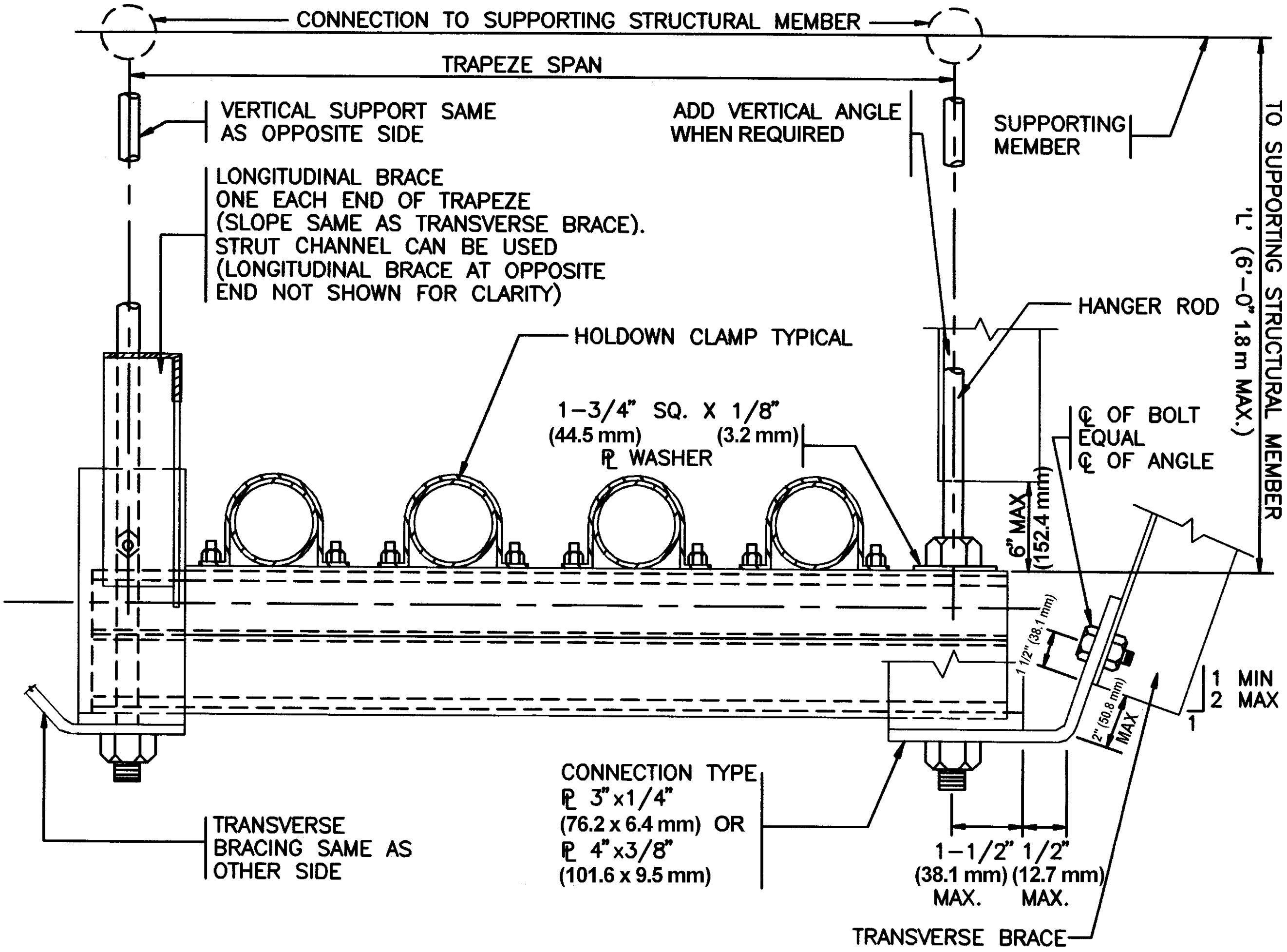
FOR ALL SIZE PIPE UP TO 6" (152.4 mm)

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)

(E)

Figure 9-15 (E) Alternate Bracing for Pipes

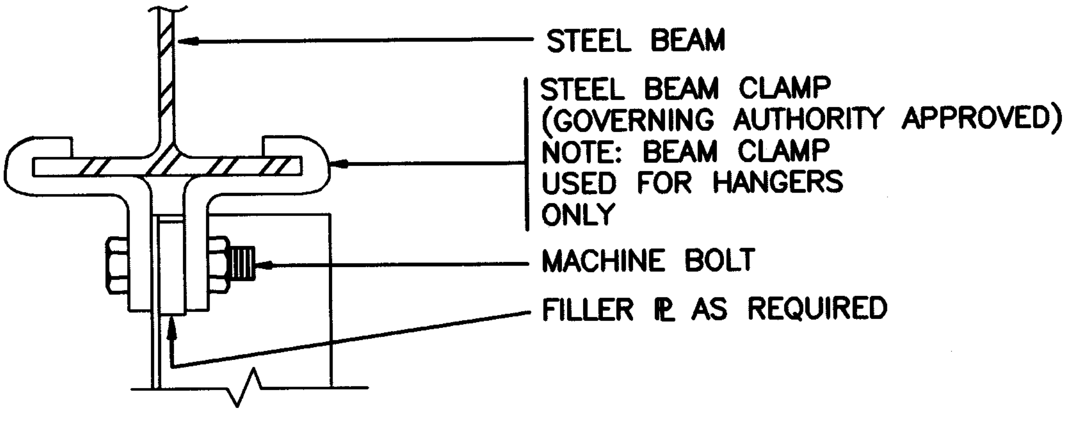
Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.



(F)

Figure 9-15 (F) Strut Bracing for Pipe Trapeze

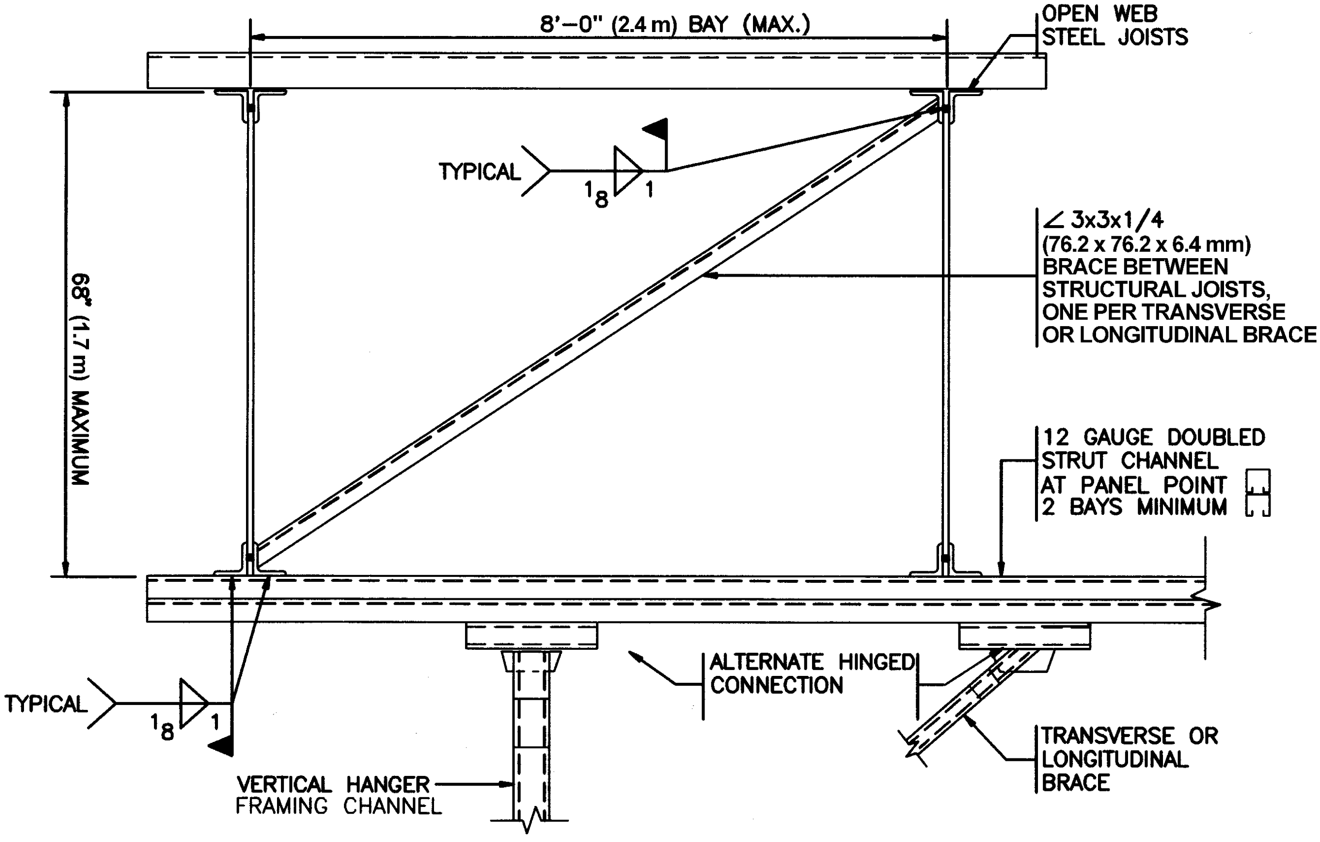
Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.



(G)

Figure 9-15 (G) Connections to Steel Beams

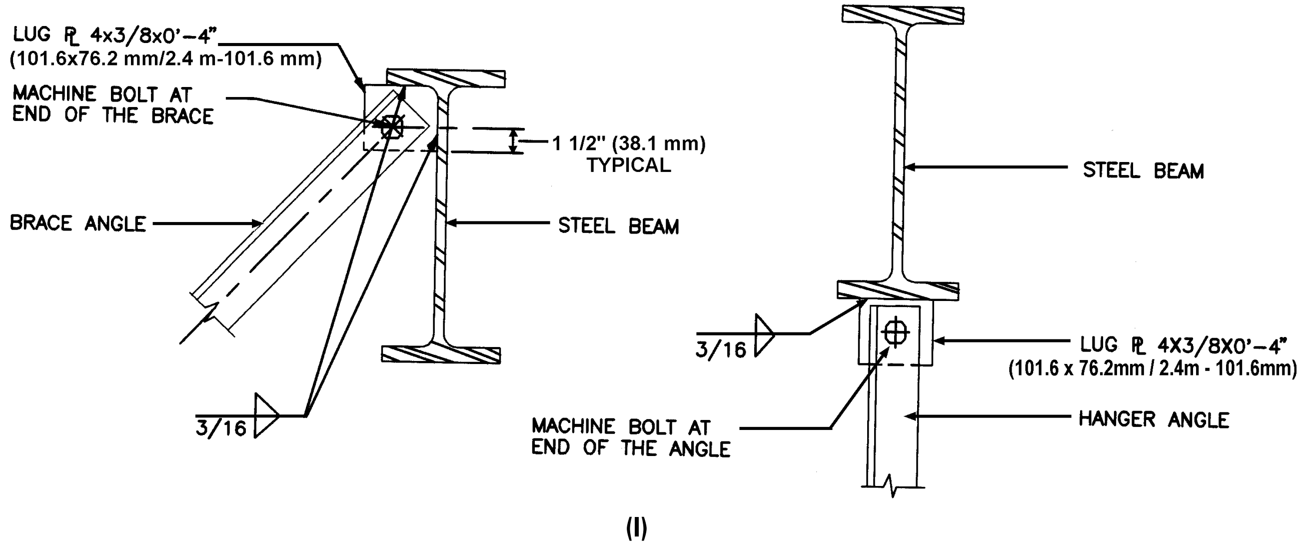
Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.



(H)

Figure 9-15 (H) Connections to Open-Web Steel Joists

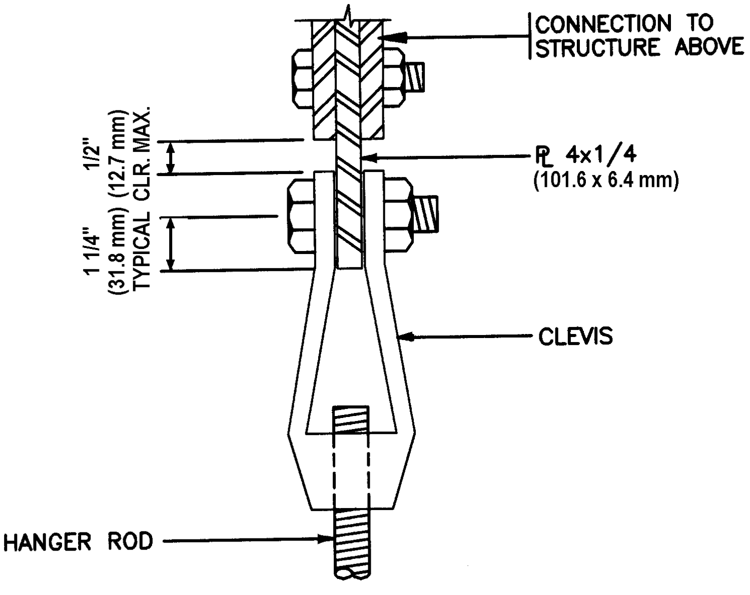
Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.



(I)

Figure 9-15 (I) Connections to Steel

Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.

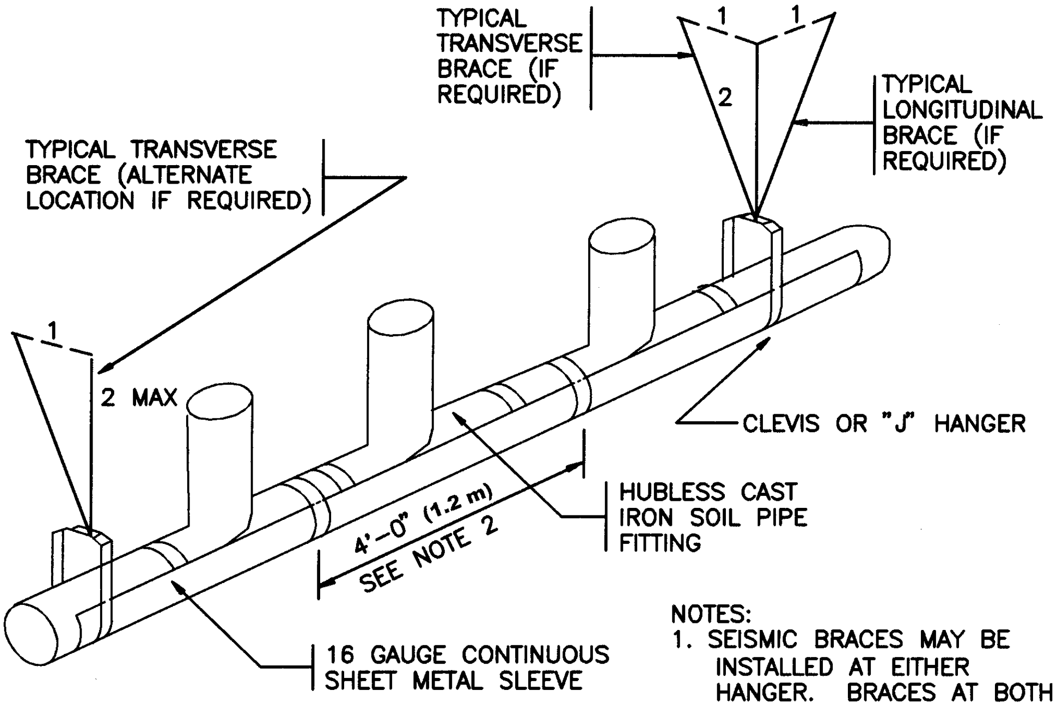


(J)

Figure 9-15 (J) Hanger Rod Connections

Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.

WHERE MULTIPLE SHIELD AND CLAMP JOINTS OCCUR IN A CLOSELY SPACED ASSEMBLY (I.E. FITTING–FITTING–FITTING, ETC.) A 16 GAUGE HALF SLEEVE MAY BE INSTALLED UNDER THE ASSEMBLY WITH A PIPE HANGER AT EACH END OF THE SLEEVE.



NOTES:

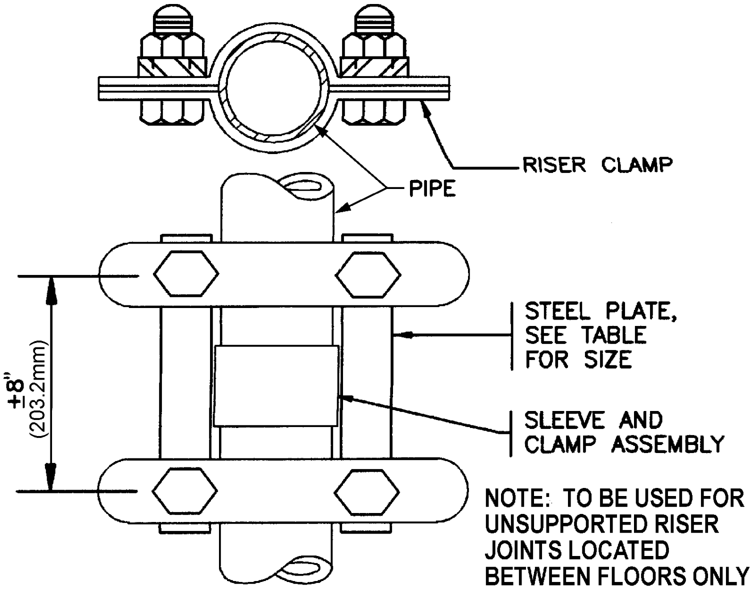
1. SEISMIC BRACES MAY BE INSTALLED AT EITHER HANGER. BRACES AT BOTH HANGERS ARE NOT REQUIRED.
2. STRAP SLEEVE TO PIPE AT 4'–0" (1.2 m) CENTERS.

MAXIMUM HANGER SPACING 10'–0" (3 m)

(K)

Figure 9-15 (K) Hubless Cast-Iron Pipe

Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.



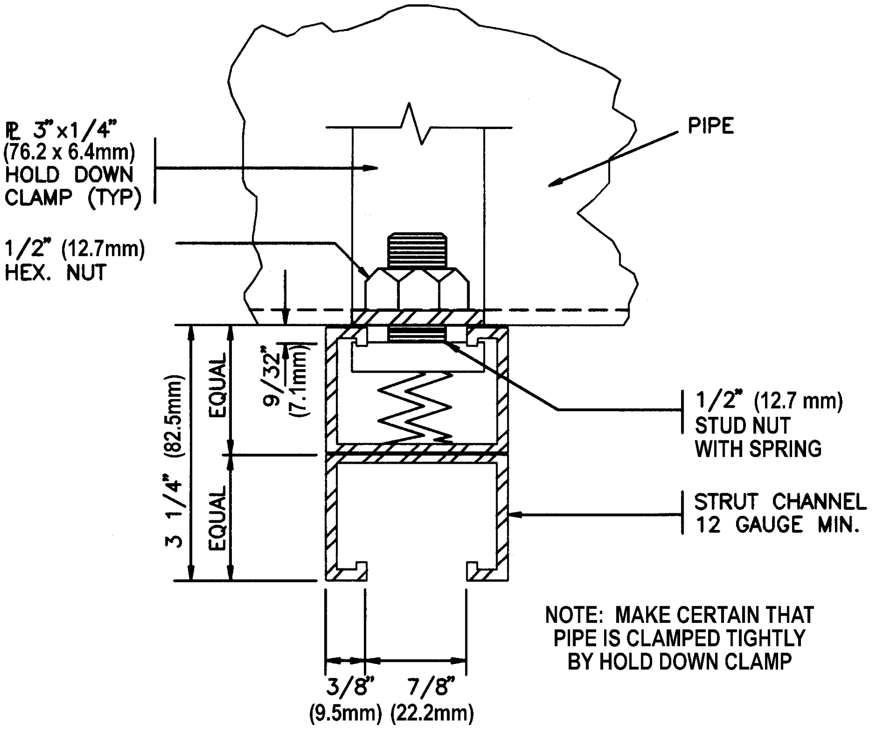
NOTE: TO BE USED FOR UNSUPPORTED RISER JOINTS LOCATED BETWEEN FLOORS ONLY

PIPE SIZE	PLATE SIZE	BOLT SIZE
Up To 2" (50.8mm)"	¼" x 1¼" (6.4 x 31.8mm)	¼" (6.4mm)
2½" to 3" (63.5 - 76.2mm)	¼" x 1¼" (6.4 x 31.8mm)	⅜" (9.5mm)
4" and 5" (101.6 & 127mm)	¼" x 1¼" (6.4 x 31.8mm)	½" (12.7mm)
6" (152.4mm)	⅜" x 1½" (9.5 x 38.1mm)	½" (12.7mm)
8" (203.2mm)	⅜" x 1½" (9.5 x 38.1mm)	⅝" (15.9mm)

(L)

Figure 9-15 (L) Riser Bracing for Hubless Pipes

Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.

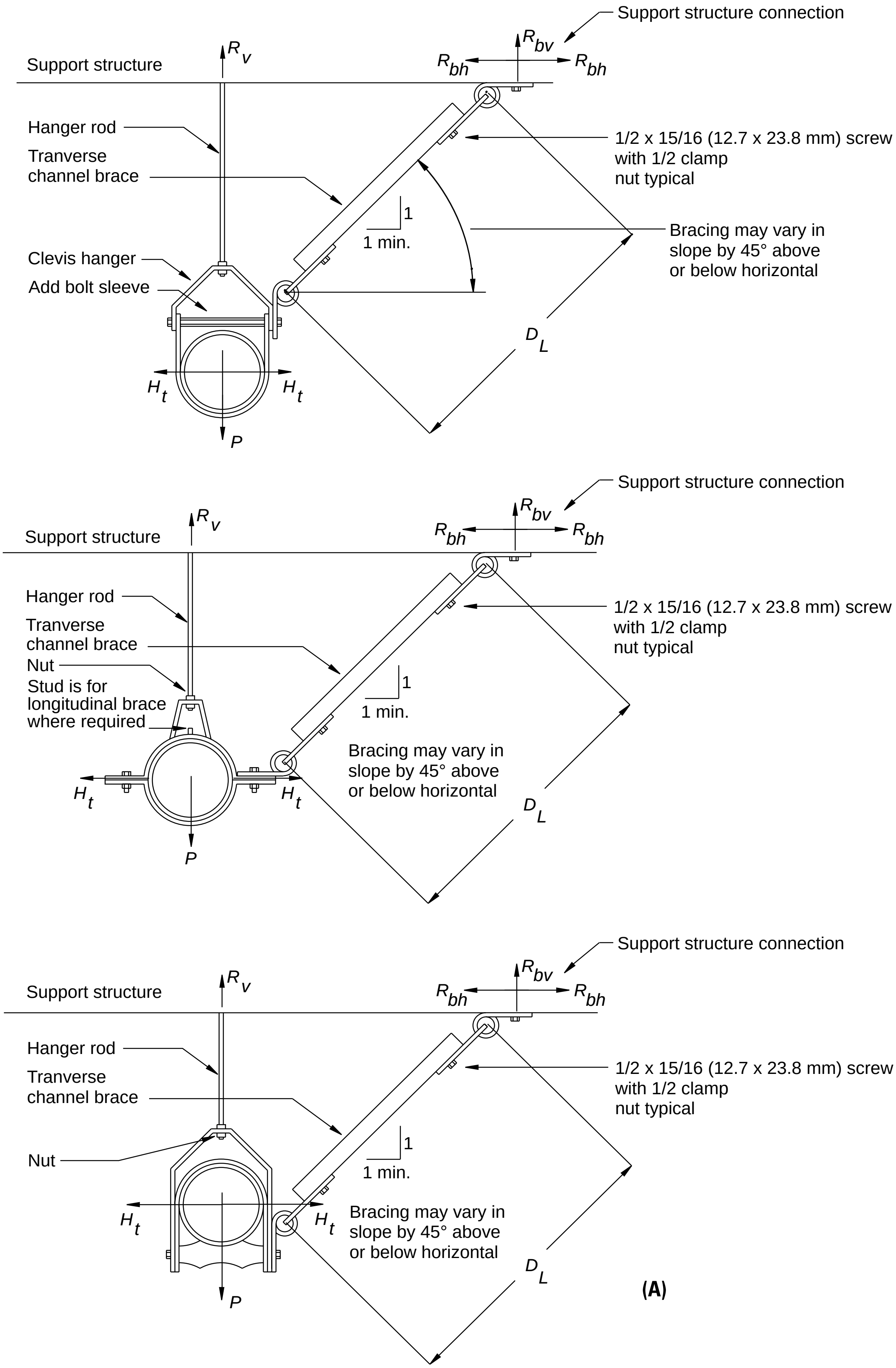


NOTE: MAKE CERTAIN THAT PIPE IS CLAMPED TIGHTLY BY HOLD DOWN CLAMP

(M)

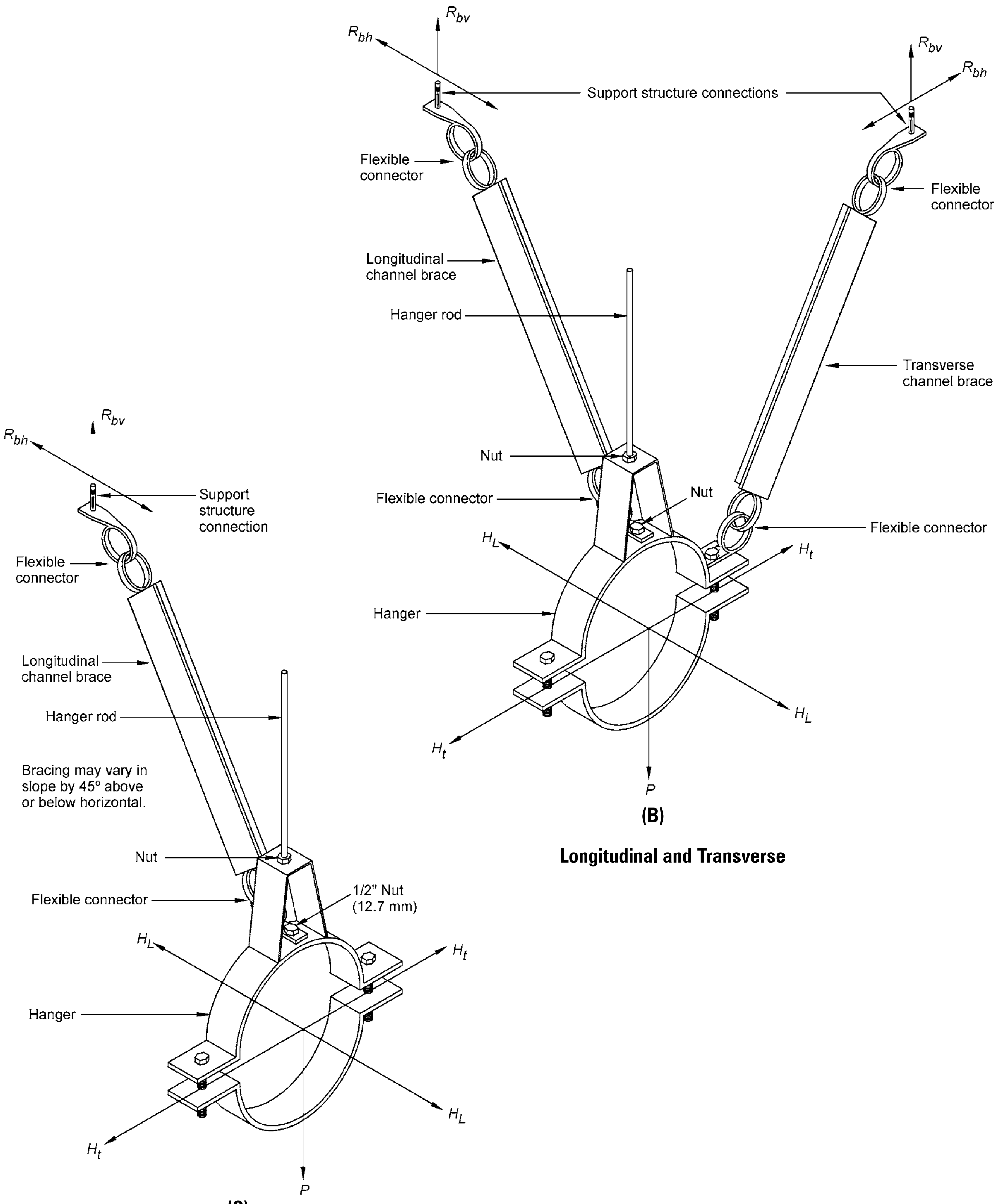
Figure 9-15 (M) Connections for Pipes on Trapeze

Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.



Transverse Only

Figure 9-16 Sway Bracing, 0.5 G Force



(B)

Longitudinal and Transverse

(C)

Longitudinal Only

Figure 9-16 Sway Bracing, 0.5 G Force (continued) 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. Acceleration calculated for the seismic design forces are based on maximum considered earthquakes as the foundation for most severe earthquakes considered by the codes. 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 to withstand force and distort after yielding)
- Redundancy of resisting elements in most systems
- High damping as distortions increase, which creates a self-limiting characteristic on response
- 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 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 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 its 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:

1. International Building Code
2. California Code of Regulations, Title 24: California Building Standards Code
3. ASCE/SEI 7: *Minimum Design Loads for Buildings and Other Structures*
4. *Tri-Services Manual: Seismic Design for Buildings,* U.S. Department of Defense
5. *Tentative Provisions for the Development of Seismic Regulations for Buildings,* Applied Technology Council

The Lateral Force

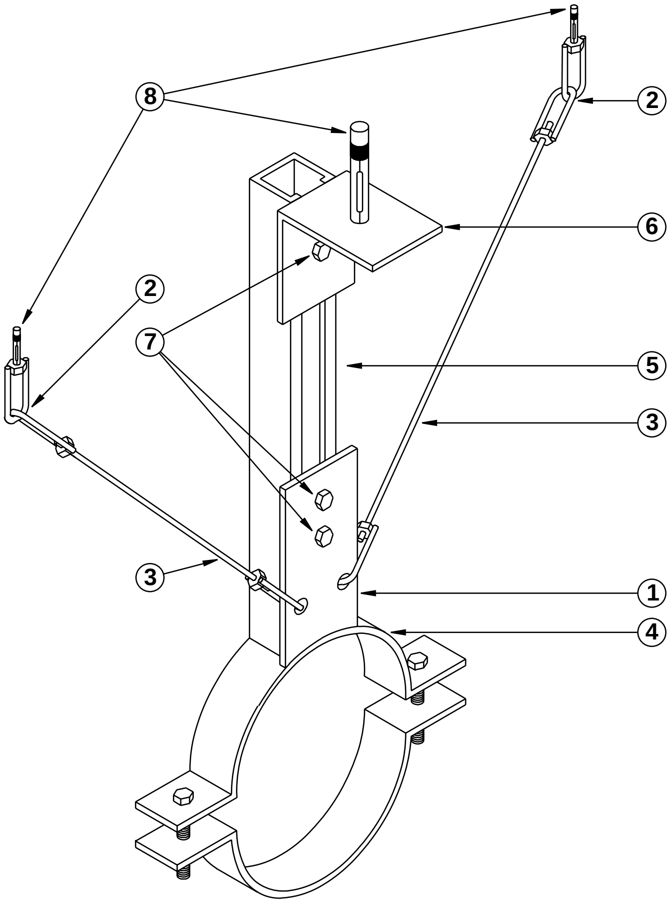
All of these codes require consideration of a lateral force that must be placed at the center of gravity of the element. The lateral force, or equivalent static force, is calculated using some or all of the following parameters:

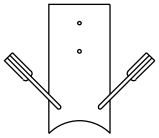
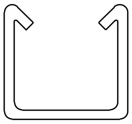
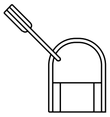
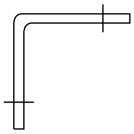
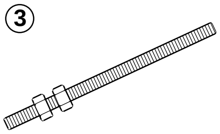
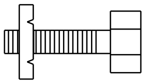
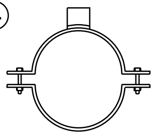
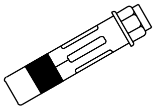
Zone Similar to Figure 9-2, the zone category affects the lateral force calculated by considering the size and frequency of potential earthquakes in the region. Zones vary from no earthquake (Zone 0) to a majority of California (Zone 4).

Soils 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

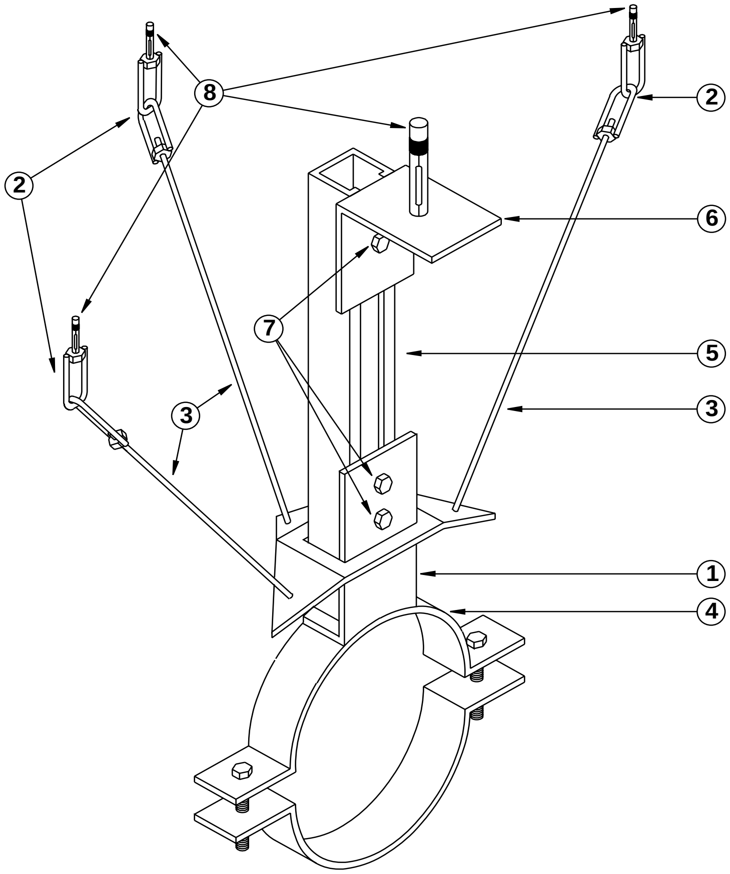
Site Coefficient This considers the basic response of the element to ground motion and is affected by sub-parameters, which could include location within the building and possible resonance with the structure. Given the exact latitude and longitude of the location, U.S. Geological Survey data can provide all the parameters based on exact location with respect to all fault

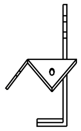
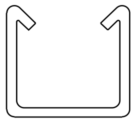
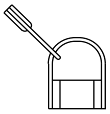
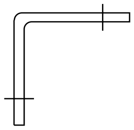
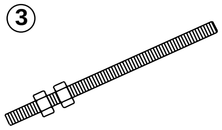
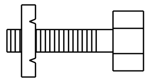
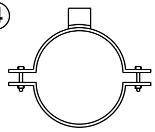
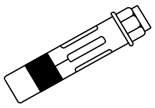


① 	Brace Plates Type Thickness Links 1 3/8" (9.5mm) 1/2" (12.7mm) 2 1/2" (12.7mm) 5/8" (15.8mm)	⑤ 	Strut Type 1 1-5/8"(41.3mm)x1-5/8"(41.3mm)x12 Ga 2 1-5/8"(41.3mm)x1-5/8"(41.3mm)x12 Ga
② 	Connectors Type Diameter 1 1/2" (12.7mm) 2 5/8" (15.8mm)	⑥ 	Angle Clip Type Thickness Hole Dia. 1 3/8" (9.5mm) 9/16" (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

(A)

Figure 9-17 (A) Lateral 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

(B)

Figure 9-17 (B) Lateral and Longitudinal Sway Bracing lines occurring within the vicinity. All parameters are site specific, and the data provided includes site coefficient based on 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.

Importance Factor This is a measure of the desirability of protection for a specific element. The importance factor is 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 This 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, response factor depends on the rigidity and flexibility of the connection. This becomes critical in the case of non-building structures (i.e., tanks, billboards, etc.) 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. The bracing guidelines followed for some time in seismically active areas are actually contained in Appendix A of NFPA 13. However, good earthquake performance by sprinkler piping is also due to other factors, such as limited pipe size, 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 Factory Mutual (FM), have developed guidelines for properties insured by them and in many cases are more restrictive.

For reference, the following three tables provide good information for the engineer. 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.

Table 9-1 Piping Weights for Determining Horizontal Load

Schedule 40 Pipe, in. (mm)	Weight of Water-filled Pipe, lb/ft (kg/m)	½ 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)**	**½ 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

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 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.

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)		$= \frac{\sqrt{r_0^2 + r_1^2}}{2}$								
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)		$= \frac{\sqrt{r_0^2 + r_1^2}}{2}$								
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		$= \frac{r}{2}$								
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		= 0.29 h (where h is smaller of two side dimensions)								
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)		$= \frac{\sqrt{r_0^2 + r_1^2}}{2}$								
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)		$= \frac{\sqrt{r_0^2 + r_1^2}}{2}$								
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		$= \frac{r}{2}$								
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)

(CONTINUED)

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	
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)		$= \frac{\sqrt{r_0^2 + r_1^2}}{2}$	1/r = 300							
1	(25.4)	0.42	10 ft 6 in	(3.2 m)	786	(356.5)	1111	(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)		$= \frac{\sqrt{r_0^2 + r_1^2}}{2}$								
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		$= \frac{r}{2}$								
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.

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 $1.6S_{DS}W_pI_p$ and the minimum value of $0.30S_{DS}W_pI_p$.)

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)

h = Height of the building roof from ground level

z = Vertical distance from ground level to equipment location

R_p = Component response modification factor (varying from 1 to 12)

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.)

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 9-18.

For non-building structures such as independent cooling towers, tanks, etc., the following formula can be used:

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 (Figure 9-19(A)), 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 nonsymmetrical.

In typical pipe braces (Figure 9-19(B)), 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.

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; *Guidelines for*

Seismic Restraints of Mechanical Systems, Sheet Metal Industry Fund; and the U.S. Deptartment of Defense *Tri-Services Manual*). 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. Piping analysis programs are available at most computer service bureaus, many universities, and national computer program clearinghouses.

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, not only must horizontal forces be taken into the structure, but also 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 both in the selection of a structural system and in 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

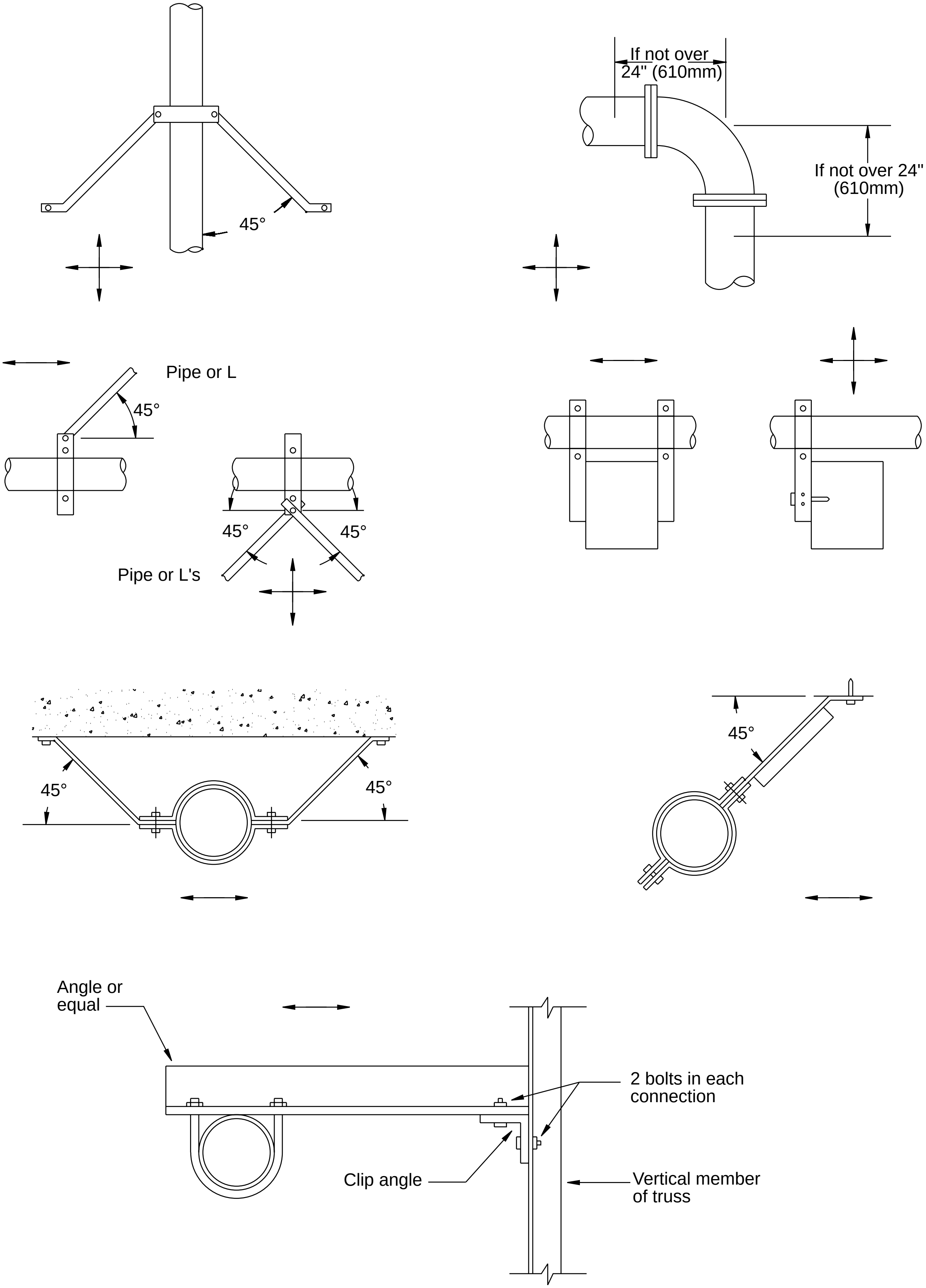


Figure 9-18 Acceptable Types of Sway Bracing

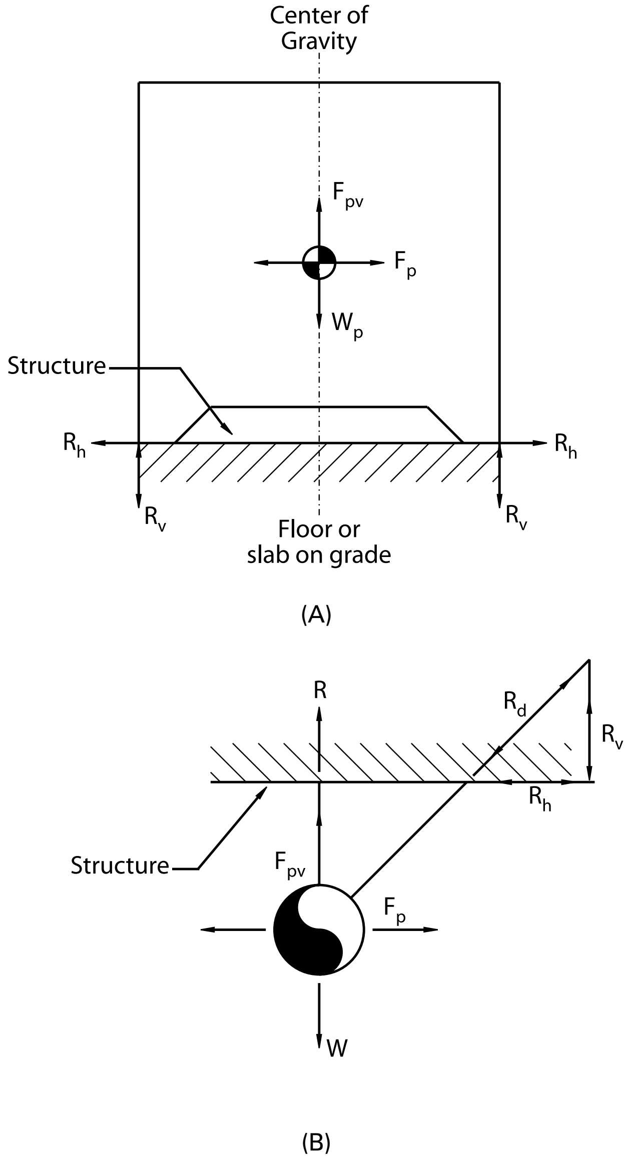


Figure 9-19 Forces for Seismic Design (A) Equipment; (B) Piping

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 9-20 and discussed below.

Condition 1 in Figure 9-20 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 angle to base must be greatly increased over that 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 connection should not be ignored.

Legs 18 inches 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 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 which 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.

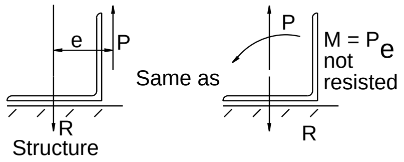
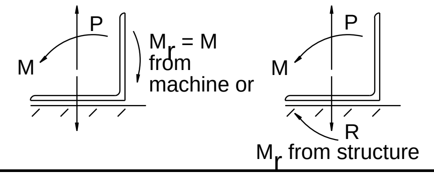
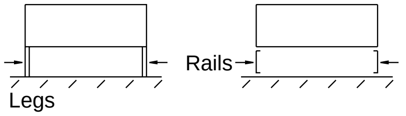
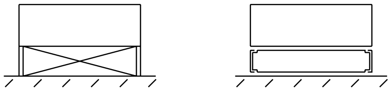
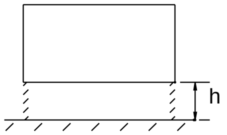
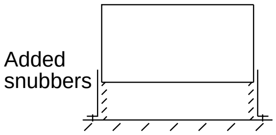
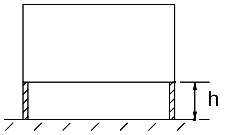
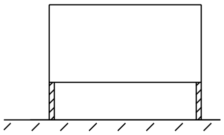
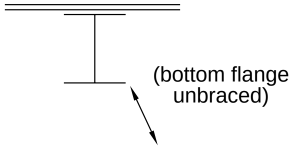
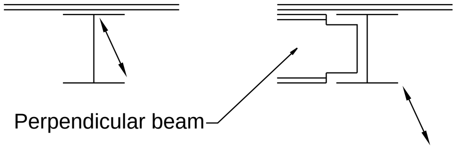
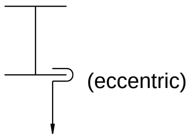
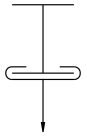
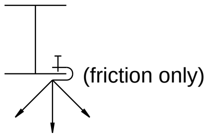
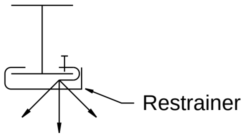
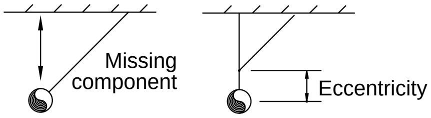
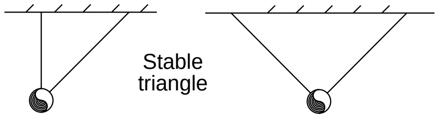
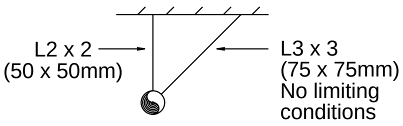
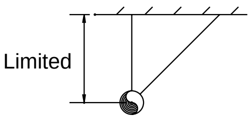
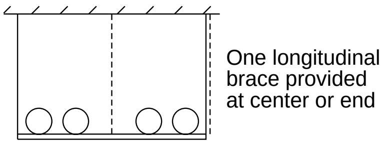
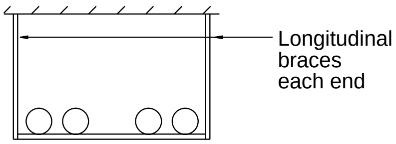
Condition	Potential Problems in Design Probably *Not* Acceptable	Seismic Protection Probably Acceptable
1. Eccentricity in connection		
2. Sidesway or tipping		Sidesway restrained by bracing or cross beams
3. Isolators with no restraint		 See also item 1.
4. Isolators with restraint		Sidesway restrained See items 1 & 2
5. Location of connection to structure (lateral force)		
6. Location of connection to structure (vertical force)		
7. Type of connector		
8. Brace configuration		
9. "Typical" details		
10. Trapeze		

Figure 9-20 Potential Problems in Equipment Anchorage or Pipe Bracing

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 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 incompatibility of piping systems with differential movement of the structure (drift) and 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 eliminated.

A few problems associated with making a connection to a structure were discussed above, in relation to 9-20. 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 eight diameters of the said bolt/nail. For example, a ½-inch lag bolt will require 4 inches of full penetration of that bolt. If such distances are not available, then this is considered a shallow penetration, and the value of R, response modification coefficient, shall be reduced. It is difficult to install an expansion bolt more than ½ inch in diameter in a typical floor system of 2½-inch concrete over steel decking.
- Bolt sizes more than ¼ inch 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. Considerable failure data was collected in Anchorage and San Fernando, but 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 cause damage to the internal workings? Will the base cabinet or framework (which is seldom checked) of equipment be severely damaged by the anchorage? In contrast, 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

Anchor A device, such as an expansion bolt, for connecting pipe-bracing members into 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.

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.

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.

Equipment For the purposes of this chapter, equipment refers to the mechanical devices associated with pipes that have significant weight. Examples include pumps, tanks, and electric motors.

Gas pipe For the purposes of this chapter, gas pipe is any pipe that carries fuel gas, fuel oil, medical gas, vacuum, or compressed air.

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.

OSHPD Office of Statewide Health Planning and Development (California).

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.

Seismic Related to an earthquake. Seismic loads on a structure are caused by wave movements in the earth during an earthquake.

Transverse bracing Bracing that prevents a pipe from moving from side to side.

RESOURCES

1. ASCE 7: *Minimum Design Loads for Buildings and Other Structures.* American Society of Civil Engineers.
2. ATC-3: *Tentative Provisions for the Development of Seismic Regulation for Buildings.* Applied Technology Council, U.S. Department of Commerce, National Bureau of Standards.
3. Ayres, J. M., and T. Y. Sun. "Nonstructural damage." *The San Fernando, California, Earthquake of February 9, 1971.* National Oceanic and Atmospheric Administration.
4. Ayres, J. M., T. Y. Sun, and F. R. Brown. "Nonstructural Damage to Buildings." *The Great Alaska Earthquake of 1964: Engineering.* National Academy of Sciences.
5. California Code of Regulations, Title 24: California Building Standards Code.
6. Hillman, Biddison, and Loevenguth. *Guidelines for Seismic Restraints of Mechanical Systems.* Los Angeles: Sheet Metal Industry Fund.
7. Hodnott, Robert M. *Automatic Sprinkler Systems Handbook.* National Fire Protection Association.
8. *Uniform Building Code.* International Conference of Building Officials.
9. NFPA 13: *Standard for the Installation of Sprinkler Systems.* National Fire Protection Association.

10 *Seismic Restraint Manual: Guidelines for Mechanical Systems.* Sheet Metal and Air Conditioning Contractors' National Association.

11. *Guidelines for Seismic Restraint of Mechanical Systems.* Sheet Metal Industry Fund of Los Angeles, Calif., and Plumbing and Piping Industry Council Inc.
12. "Seismic Design for Buildings." *Tri-Services Manual.* U.S. Department of Defense.
13. "Design Guidelines." *Earthquake Resistance of Buildings, Vol. 1.* U.S. General Services Administration Public Buildings Service.
14. *Earthquake-resistant Design Requirements Handbook* (H-08-8). U.S. Veterans Administration.
15. O'Neil, Chip. *Installation Handbook for Seismic Support of Water Heaters and Similar Equipment.* Hubbard Enterprises/HOLDRITE.

10

Acoustics in Plumbing Systems

Plumbing system noise is a common irritant to building owners and tenants. Three main factors often contribute to this problem: 1) Lack of awareness on the part of owners/developers and design teams regarding application of specific products and practical installation solutions; 2) lack of contractor awareness and training regarding 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.

In the past few years, much advancement has been made regarding the issue of plumbing noise mitigation. Resources are now available from a product and service standpoint that can assist the engineering community with identification of application solutions, plumbing installation detail drawings, and third-party laboratory test data to recognized ISO standards. If commonly implemented, a holistic approach to this issue ultimately will contribute to a marketplace more acceptable to plumbing systems that include noise and vibration solution components.

In the eyes of a building occupant or a perspective buyer, the perceived quality of a building is based on numerous observations. A building that seems noisy likely is 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 usually the culprits. The noise sources and solutions are widely varied. Some of the solutions are very difficult and costly to remedy, especially after the fact. Most engineers and architects would agree that a quiet building does not happen accidentally and that taking steps to ensure success must be planned from the early stages of specification and building design.

Some noise issues have been addressed quite successfully through common methods for many years, such as advancements in floor systems and a variety of party wall configurations. However, one area of noise mitigation that continues to be addressed with inconsistent levels of success is plumbing system noise. Plumbing noise is one of the most intrusive and difficult sounds to mitigate. It is this issue and related solutions that this chapter addresses, including:

1. Why plumbing system noise is difficult to remedy
2. Identification of common sources of plumbing system noise
3. A review of common attempts to mitigate plumbing system noise
4. Proven acoustical materials, techniques, and resources
5. Steps the engineer can take to ensure success on the job

In many people's eyes, varying levels of plumbing noise are expected and tolerated without complaint. Most often, the noise generated within a tenant's own space and resulting from one's own use of plumbing fixtures is tolerated. On the other hand, when plumbing noise is a result of an adjoining space and results in sleep disturbance or interruption of peace and quiet, it quickly becomes an annoyance. In multifamily settings, it is a main reason that tenants complain to their neighbors, move, or, even worse, decide to sue the builder.

Most noise issues within a building relate to either airborne noise or structure-borne noise. Airborne noise typically comes from common sound sources such as voices, televisions, and radios. The noise performance of a building system is called the Sound Transmission Class (STC). The higher the STC, the better the system is at isolating airborne noise. An STC rating of 45 means that the element reduces the sound passing through it by 45 decibels (dB). (See Table 10-1.) Mass is required to solve airborne noise.

Structure-borne noise, also referred to as impact noise, is produced when part of the building fabric is directly or indirectly impacted. Energy passes through the building structure and creates noise in nearby rooms. Examples are heavy footsteps (particularly on bare timber

Table 10-1 Decibel Reduction Effect on Subjective Sound Perception

Reduction in Decibel	%	Reduction in Sounds/Energy Subjective Perception
3	50	Barely perceptible
4–5	70	Significant
6	75	Sound appears to be reduced by about 1/4
7–9	87	Major reduction
10	90	Sound appears to be less than half original

Table 10-2 Impact Insulation Classes

IIC	
45	People walking around are clearly audible
50	People walking around are audible and noticeable
55	People walking around audible but acceptable
62	Walking heard as low frequency thump
70	Heavy walking heard as low frequency thump

or hard floor surfaces like tile), banging doors, scraping furniture, vibrations from loud music, and plumbing noise. The Impact Insulation Class (IIC, see Table 10-2) is used to rate the impact noise insulation of floors. Solving structure-borne noise is the complete opposite of solving airborne noise: It is not so much the function of mass as it is the function of isolation and vibration breaks.

Various building codes such as the Uniform Building Code (UBC) and International Building Code (IBC) contain requirements for sound isolation between dwelling units in Group R occupancy projects (including apartments and condominiums). However, these criteria are not universally enforced. The codes require walls and floor/ceiling assemblies to have both an STC and IIC rating of 50 (if tested in a laboratory) or 45 (if tested in the field). The field test evaluates the dwelling's actual construction and includes all sound paths. (Note: Even if a particular municipality has not adopted this part of the code, it typically is recognized as an industry minimum standard.)

THE OVERALL MARKET IMPRESSION OF THE PROBLEM

Plumbing system noise mitigation often is considered by engineers, building owners, and contractors to be a complicated, labor-intensive, and expensive problem to resolve. Thus, the issue of controlling plumbing noise unfortunately is viewed as economically unfeasible. Because many engineers and contractors are in a quandary as to best materials and best practices and are often in disagreement as to what is considered fair market value to perform the this work, many building owners/developers shy away from including plumbing acoustics in the project's scope of work.

The fact of the matter is that it does not have to be difficult or expensive. Recent advancements regarding the availability of products and support services now make the mitigation of plumbing system noise easier, more effective, and more affordable than ever before.

A WIDE VARIETY OF CONTRIBUTING FACTORS

The fact that plumbing systems generate both airborne and structure-borne noise makes the problem fairly complex. 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 at varying rates and volumes, as well as rain leader/roof drain piping receiving drainage from roof drains, deck drains, and similar receptacles at varying rates and volumes.

Drainage piping is manufactured with a variety of materials that each 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 cast iron (usually no hub), 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, toilets, bathtubs and showers. Drainage piping receiving liquids intermittently and under pressure include discharge from laundry washers, dishwashers, and funnel drains in mechanical rooms, floor sinks in commercial food service establishments, and similar indirect waste receptacles. In each of these cases, the density and wall thickness of the pipe and fittings has a direct bearing on the amount of both airborne and structure-borne noise generated. The thicker and more dense the pipe's wall construction, the quieter is its performance.

In a gravity system, drainage liquid traveling vertically adheres to the outside 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.

Drainage piping also generates noise, especially in plastic systems, when it experiences thermal expansion and contraction due to temperature changes. (PVC and ABS pipe expands and contracts 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 would be 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.

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 each delivering water under pressure to various equipment components within a building.

Water piping/tubing is constructed from a variety of materials that each 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, PEX, PVC Schedule 40 or 80 (typically in nonpotable water systems), galvanized or black iron, Schedule 10, 40, or 80 (typically nonpotable), corrugated or smooth wall chrome-plated brass (for fixture connections), and braided stainless steel (at fixture and equipment supply connections).

A common cause for 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, ice makers, 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 plastic water systems such as CPVC, which expands and contracts at a much higher rate than metallic tubing. (CPVC tubing expands/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, non-vitreous 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 well as 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 levels.

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.

Pumps are often very loud, especially if they are in direct contact with building components or are piped incorrectly, resulting in turbulence and cavitation.

Equipment generates noise in a wide variety of frequencies through vibration. Equipment noise isolation has been handled by plumbing and mechanical consultants for many years and is an area that is probably less of a mystery to most engineers than many of the other components of a plumbing or piping system.

MITIGATING NOISE FROM DRAINAGE SYSTEMS

Regarding drainage systems, both engineers and plumbing contractors can take several common approaches to mitigate unwanted noise.

One 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 plastic or copper pipe and fittings. Ideally, the choice of cast iron rather than plastic 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 neoprene rubber padding. Engineers should address these items within the body of the specification and/or in plumbing installation detail drawings.

To minimize the amount of noise and vibration transferred to the building, it is wise to break the contact between the piping and the building's components (drywall, studs, joists, floor structure, etc., 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 and ISO 3822 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. Be careful to isolate each and every possible contact point. Inconsistent success in even a small percentage of contact points can result in an overall failed attempt. Clearly express this requirement 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 popular and effective. Numerous manufacturers provide these types of isolation pads in various thicknesses ranging from ¼ inch to ¾ inch and even thicker. These often are made of rubber or neoprene (neoprene being the more chemically resistant). 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, the 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 negates any attempts at effective noise isolation. Clearly express this requirement within the project specification and installation detail pages. (See Figures 10-4 and 10-5.)

Regarding the isolation of noise transferred from piping to support hangers and thus to the supporting structure, a couple common methods can be used. 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 between the hanger and the piping, use only materials engineered and tested for this application.

When drainage and vent piping is 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.

In seismic regions, be sure to avoid the use of rigid seismic/sway bracing methods. Use systems that include aircraft cable and accessories designed to allow minimal movement. These aid in avoiding 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. (See Figures 10-6, 10-7, and 10-8.)

Another noise isolation method involves the addition of some form of insulation to the outside of the piping to minimize the airborne noise. This often is done by wrapping the piping with foam rubber or fiberglass insulation. 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 block 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 almost always is transmitted as structure-borne vibration and eventually radiates from lightweight surfaces in many different places.

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 that copper tube. 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 a 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. Use of tested and proven pipe isolators and clamps for

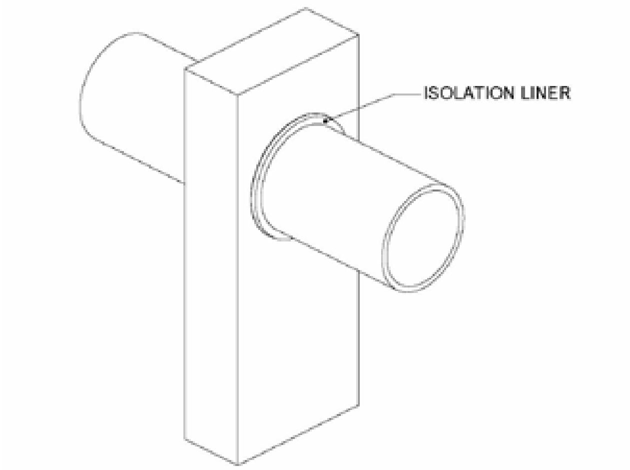


Figure 10-1 Pipe Isolation Through Framing Member

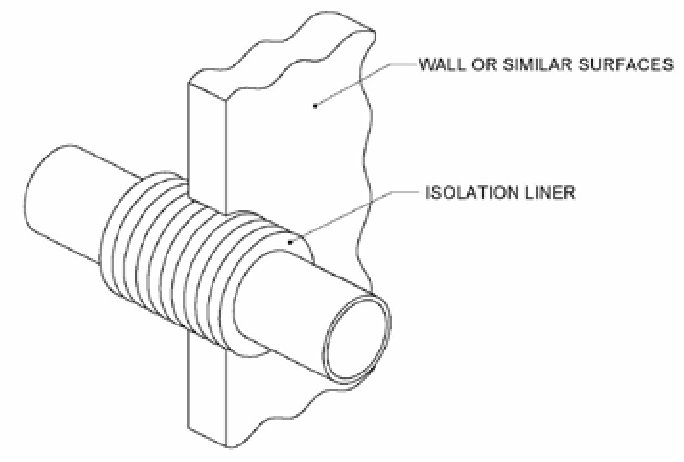


Figure 10-2 Resilient Pipe Isolation

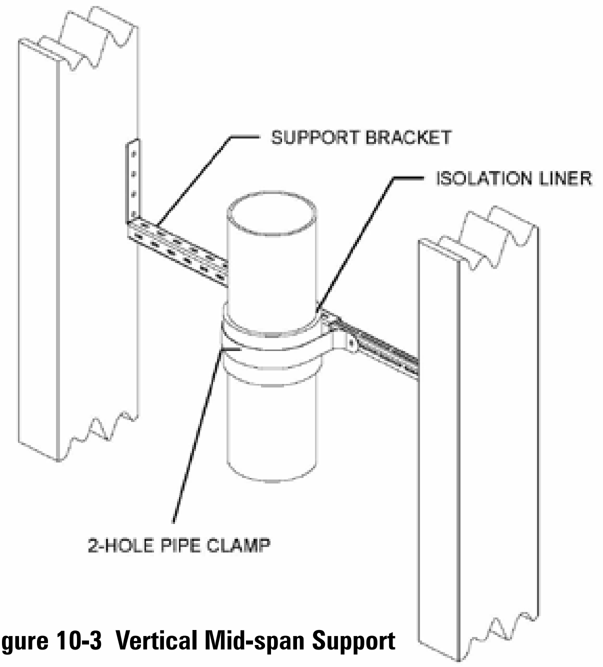


Figure 10-3 Vertical Mid-span Support

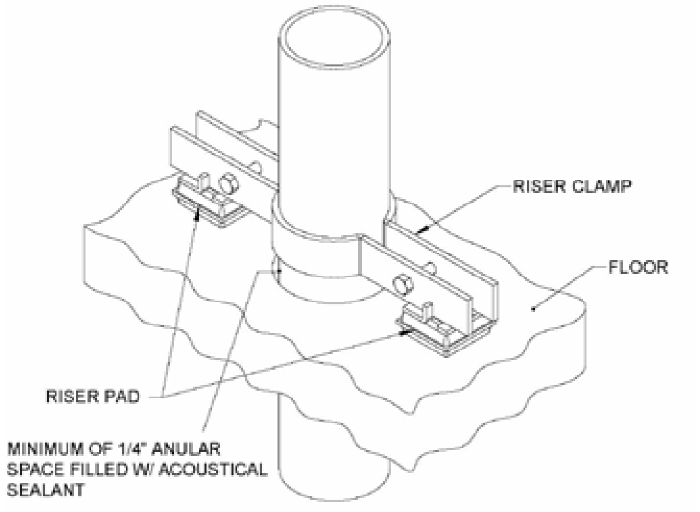


Figure 10-4 Riser Clamp Isolation

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. (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 rubber/neoprene material to break the connection between the hanger and the water tube.

All chilled, condenser, domestic, and hot water equipment, including the heat exchanger and the hot water storage tank, should be isolated from the following:

1. All piping in the equipment room
2. All piping outside of the equipment room within 50 feet of the connected pump
3. All piping more than 2 inches in diameter (nominal size) and any piping suspended below or near a noise-sensitive area

Supports should be a pre-compressed type to prevent a load transfer to the equipment when the piping systems are filled. Vibration isolators should provide one-half the deflection of the pump isolators or 0.75 inch deflection, whichever is larger. All

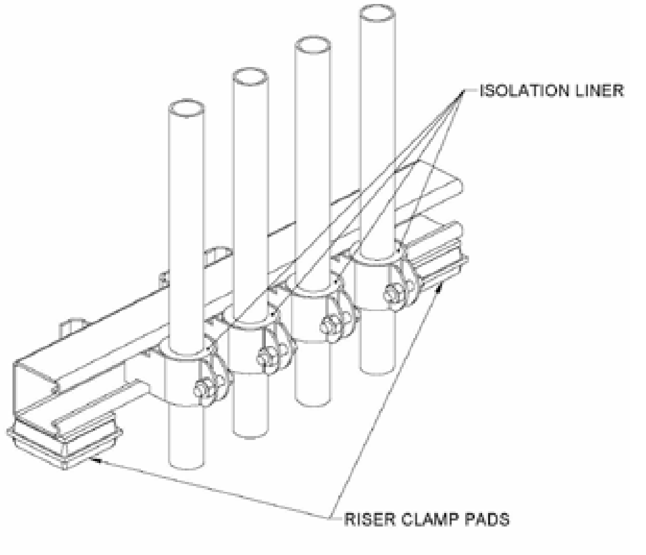


Figure 10-5 Vertical Cast Iron Stacks and Water Risers

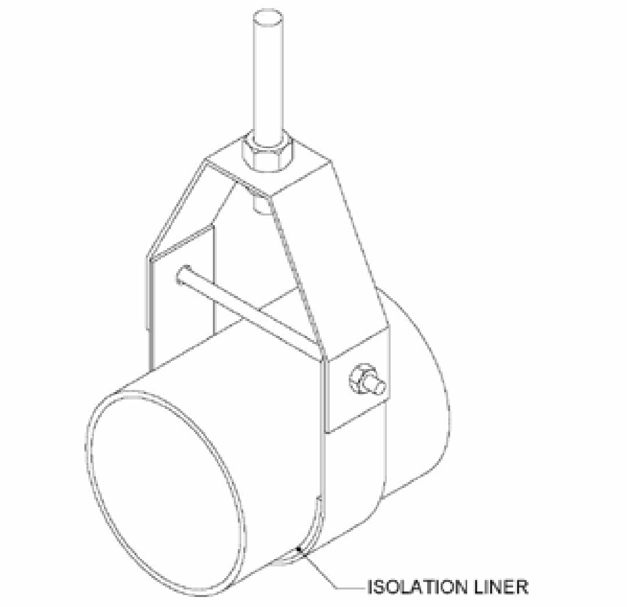


Figure 10-6 Suspended Waste, Vent, or Other Piping

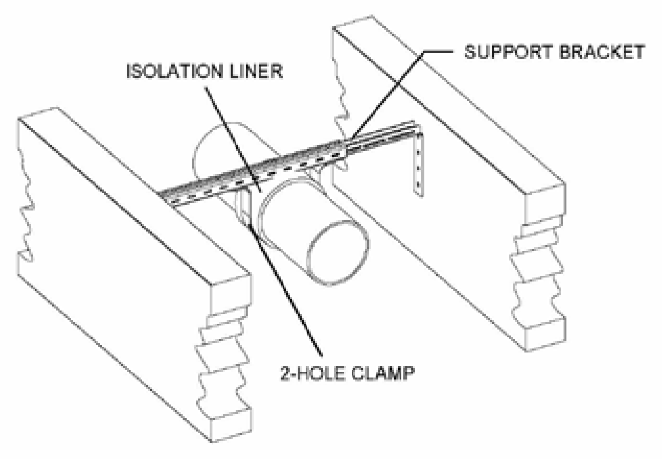


Figure 10-7 Horizontal Joist Bay Support

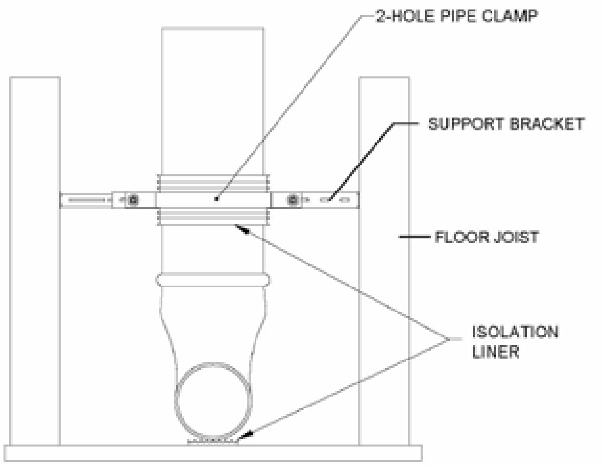


Figure 10-8 Isolation of Toilet Fixture Waste Pipe

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. (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 isolated against airborne noise, dense materials are always best. Use materials tested and proven to be effective for this purpose.

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.

A better solution is the use of shock arrestors or water hammer arrestors, which are 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. They act as cushions to reduce the shock. Both the Uniform Plumbing Code (UPC) and the

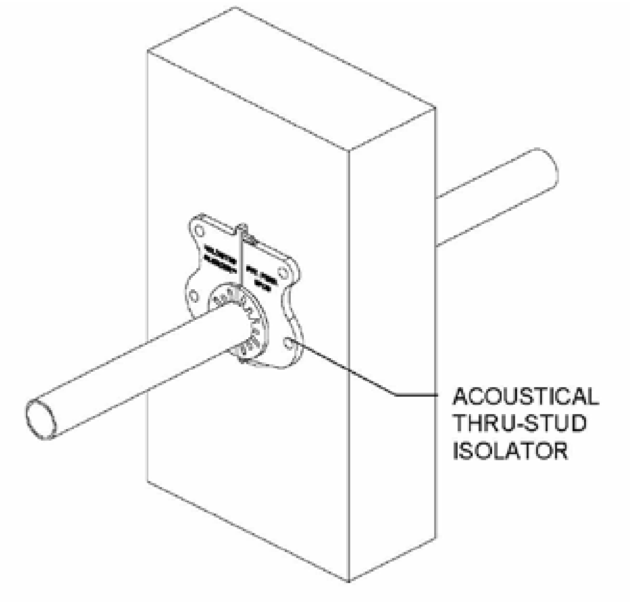


Figure 10-9 Through Wall Stud or Other Wood Framing Member

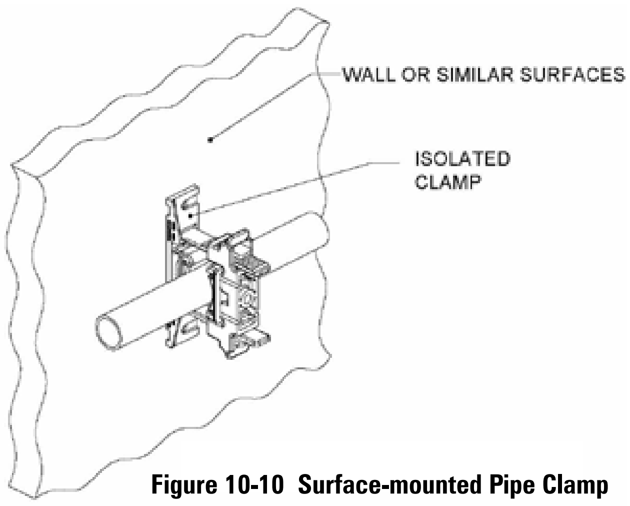


Figure 10-10 Surface-mounted Pipe Clamp

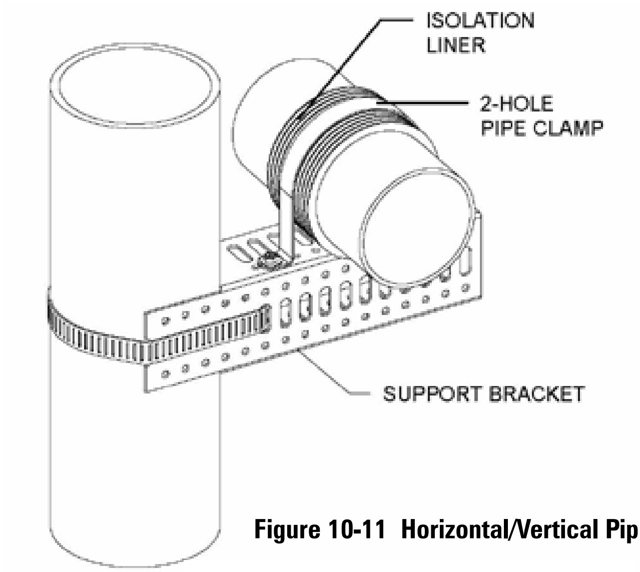


Figure 10-11 Horizontal/Vertical Piping

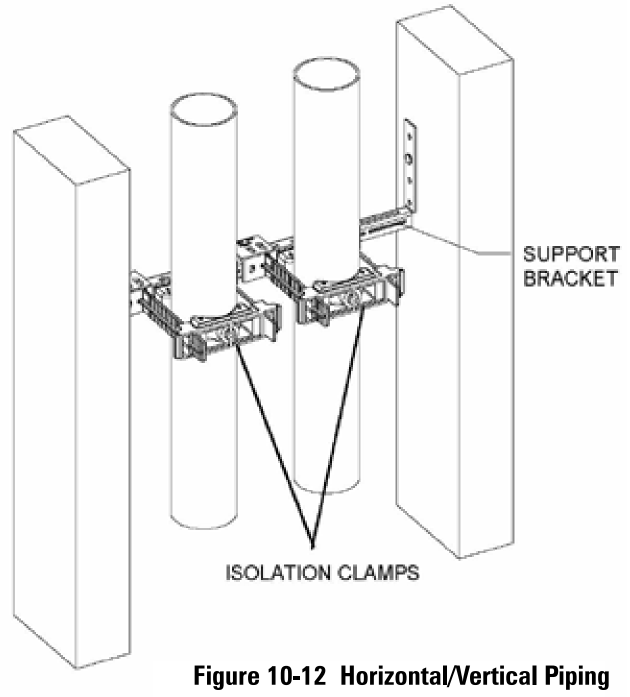


Figure 10-12 Horizontal/Vertical Piping

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, laundry washers, and ice makers. IPC specifically requires that these devices shall conform to ASSE 1010: *Performance Requirements for Water Hammer Arrestors*.

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: *Laboratory Tests on Noise Emission from Appliances and Equipment Used in Water Supply Installations* 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 the fixtures will be quieter than others is by choosing those made of materials that absorb sound, such as vitreous china or cast iron rather than thin-gauge stainless or enameled steel. 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 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.

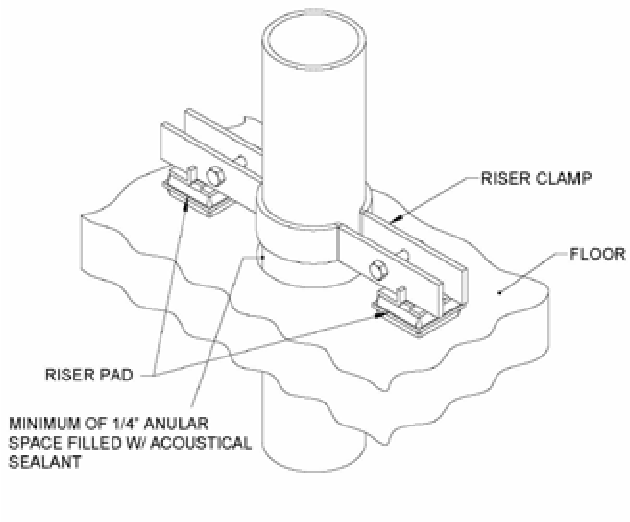


Figure 10-13 Riser Clamp Isolation

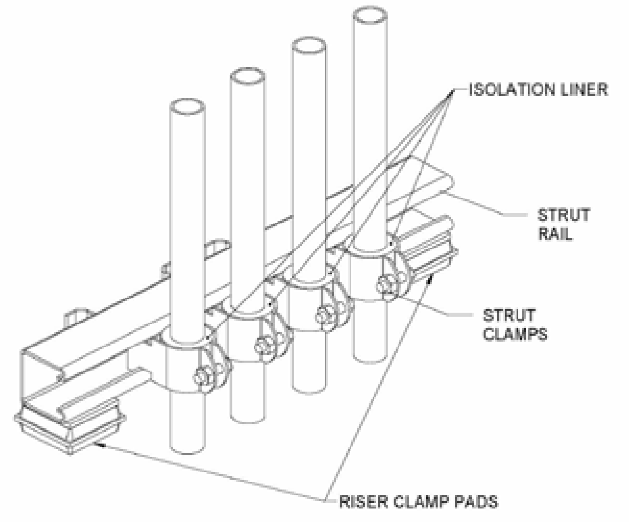


Figure 10-14 Vertical Cast Iron Stacks and Water Risers

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 toilets. Flush tank-type toilets are much quieter, and some are nearly silent. (See Figures 10-21 through 10-32.)

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 10-33, in the case of a laundry 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 acoustical caulking compound, and use acoustical caulk or ¼-inch felt within the annular space between the stub-out pipe and the wall surface material.

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 clear annular space around both pipe supply locations, and fill this space with flexible caulking 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 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 rubber or neoprene liner and ¼-inch rubber pads between heavy contact points and the building structure. Provide clear specification language and plumbing detail drawings to the installing contractor. (See Figures 10-34 through 10-37.)

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

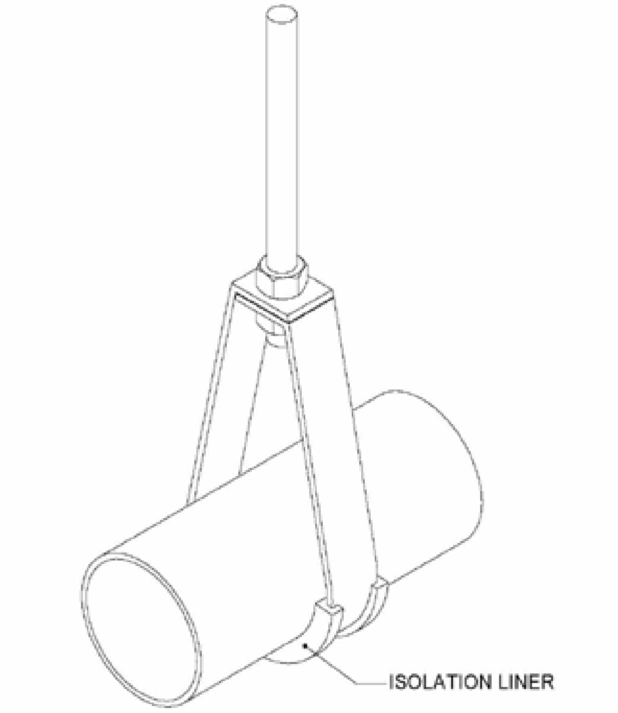


Figure 10-15 Suspended Waste, Water, or Other Piping

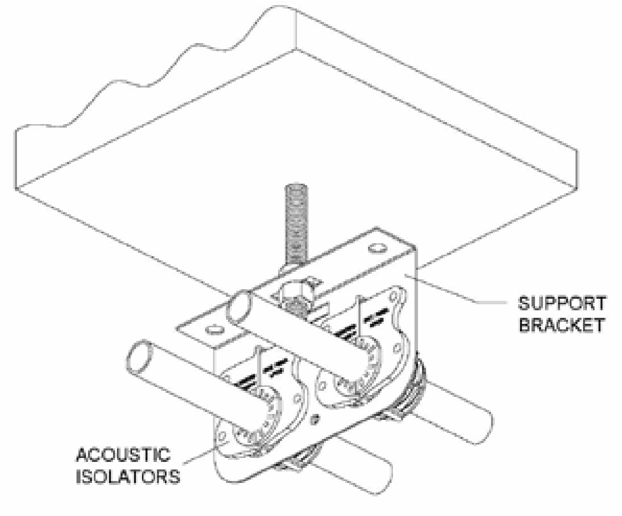


Figure 10-16 Suspended Horizontal Overhead

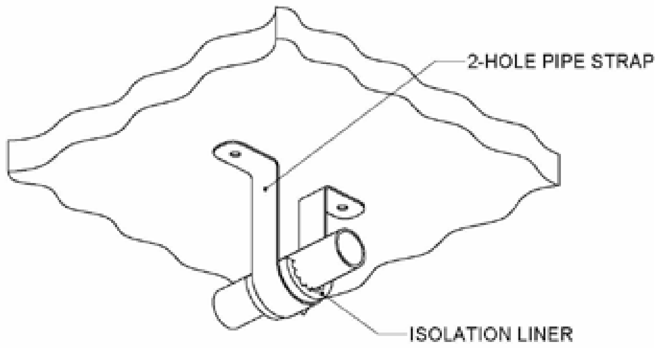


Figure 10-18 Water, Vent, Waste

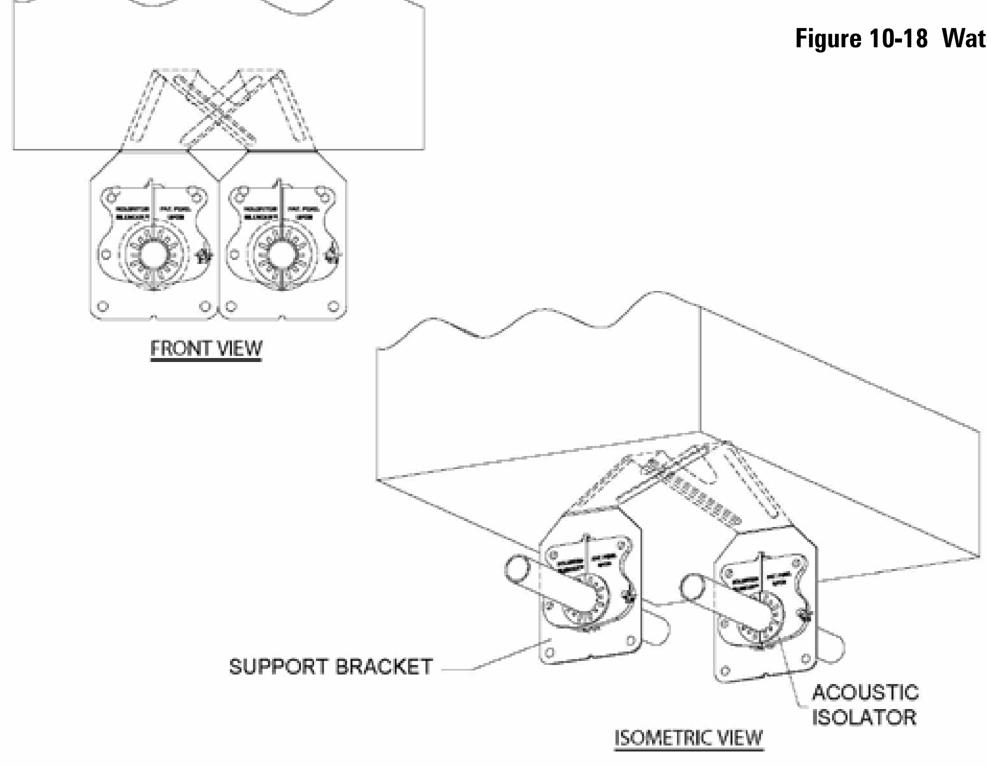


Figure 10-17 Horizontal Overhead

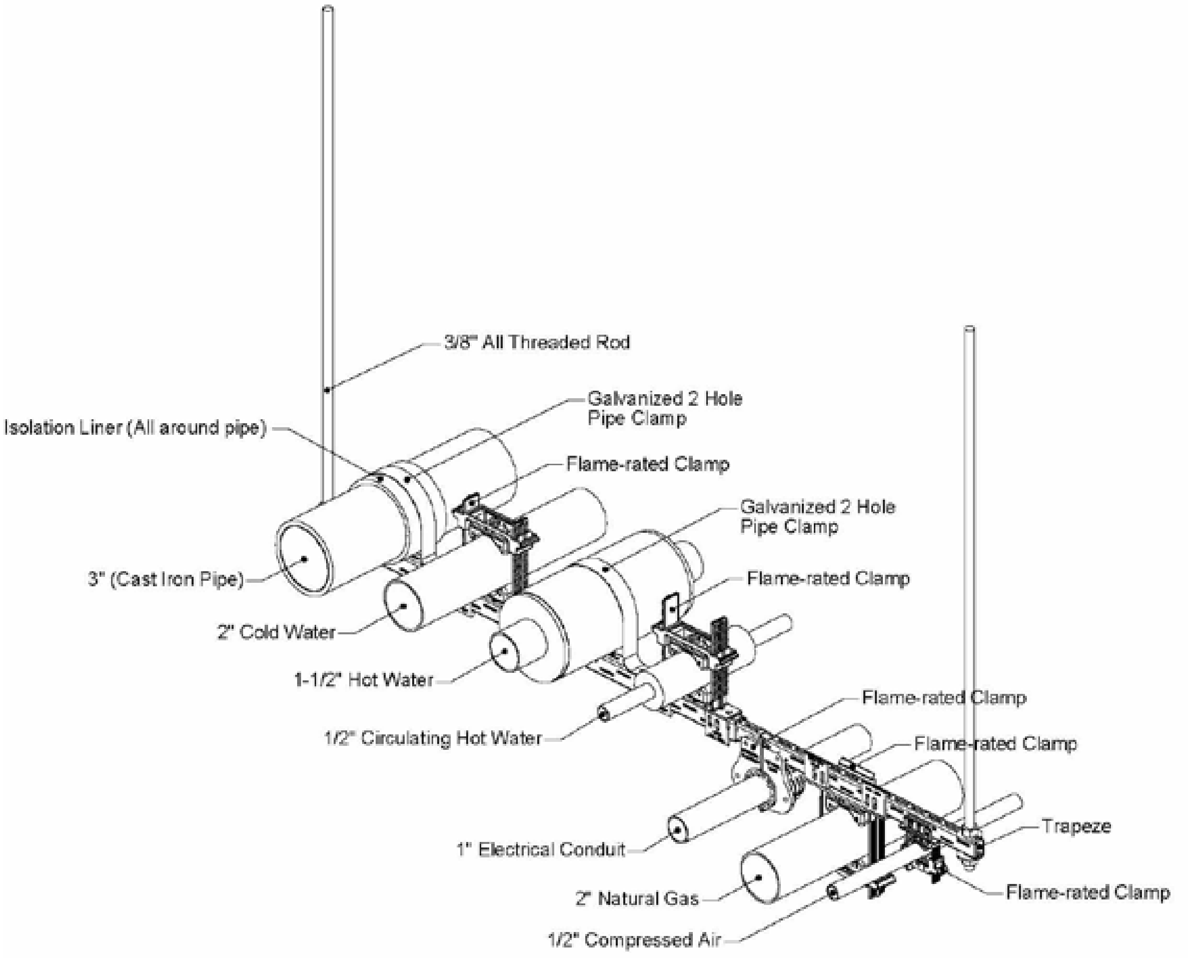


Figure 10-19 Overhead Trapeze Piping

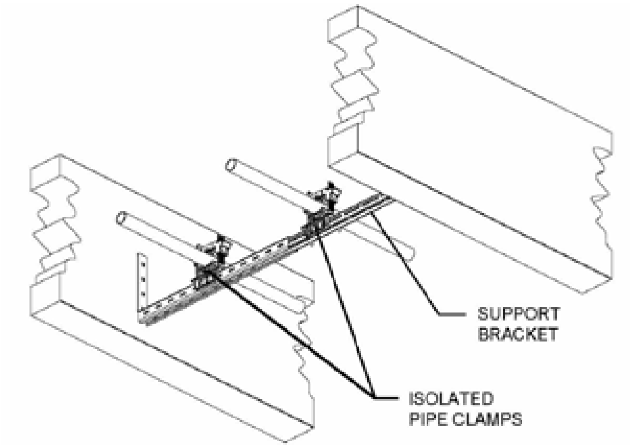


Figure 10-20 Horizontal Joist Bay Support

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 10-3 contains the recommended static deflection for the selection of pump vibration-isolation devices.

Vibration-control devices generally consist of steel springs, air springs, rubber isolators, concrete housekeeping pads or 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 almost any desired deflection. 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. They are available for deflection only up through 4 inches. The basic types of steel spring mountings are housed-spring mountings, open-spring mountings, and restrained-spring

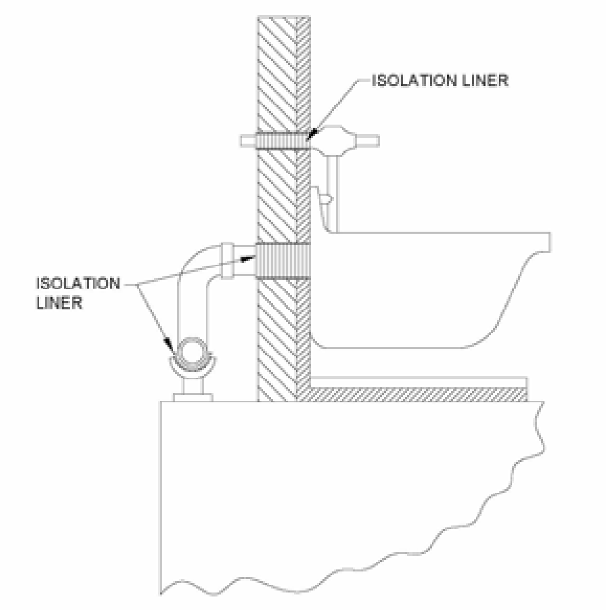


Figure 10-21 Wall-hung Water Closet or Similar

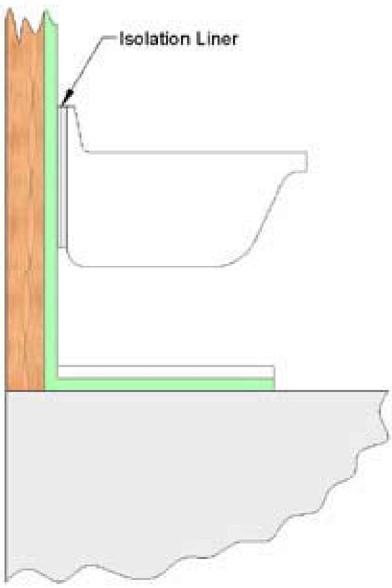


Figure 10-22 Wall-mounted Urinal, Sink, or Similar Fixture

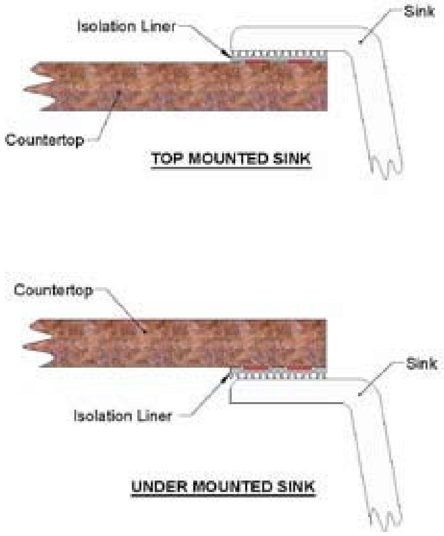


Figure 10-23 Sink Isolation Detail

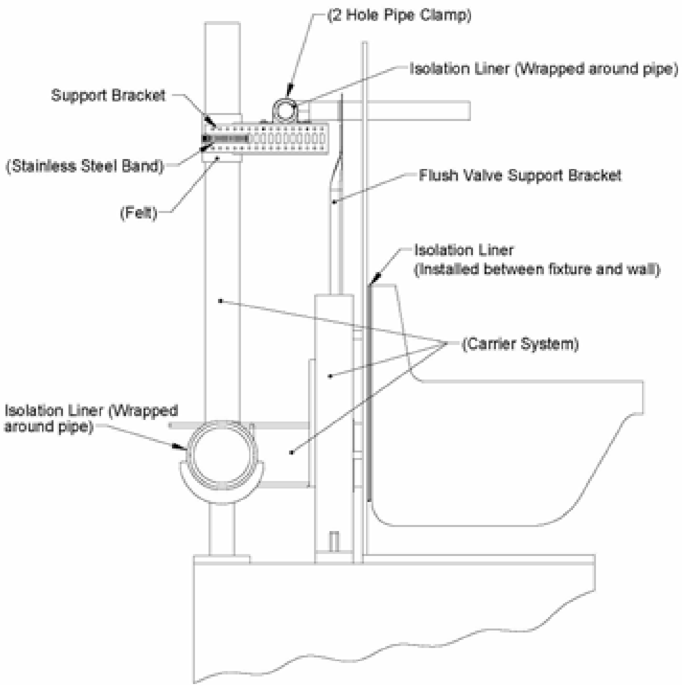


Figure 10-24 Wall-hung Fixture with Carrier Support System

mountings. Because steel springs have little inherent damping and can increase their resonance in the audio frequency range, 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, as steel springs, are available for almost any desired deflection where 6 inches or more is required. By varying the air pressure in the bladder, air springs are capable of carrying a wide range of loads. The shapes, rather than the pressure, determine the spring frequency. Air springs have the advantage of virtually no transmission of high-frequency noise. They have the disadvantage of higher cost, higher maintenance, failure rates, and low damping.

Rubber isolators generally are used where deflections of 0.3 inch 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 isolator depends on many factors, including the elastic modules of the material used. The elastic modules of the material vary with the temperature and frequency and are usually a characteristic of a durometer number, measured at room temperature. Materials in excess of 70 durometers are usually ineffective as vibration

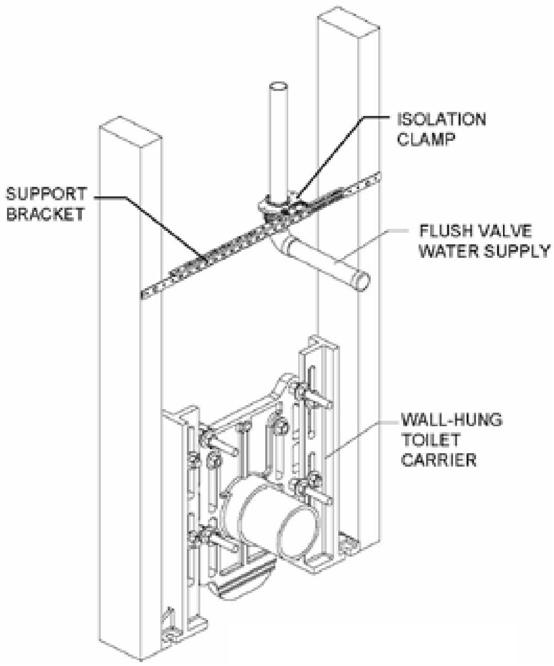


Figure 10-25 Flush Valve Support

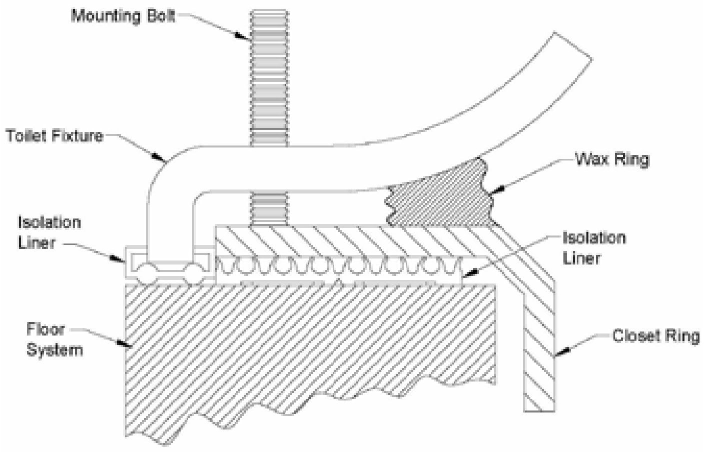


Figure 10-26 Typical Floor-mounted Toilet Flange

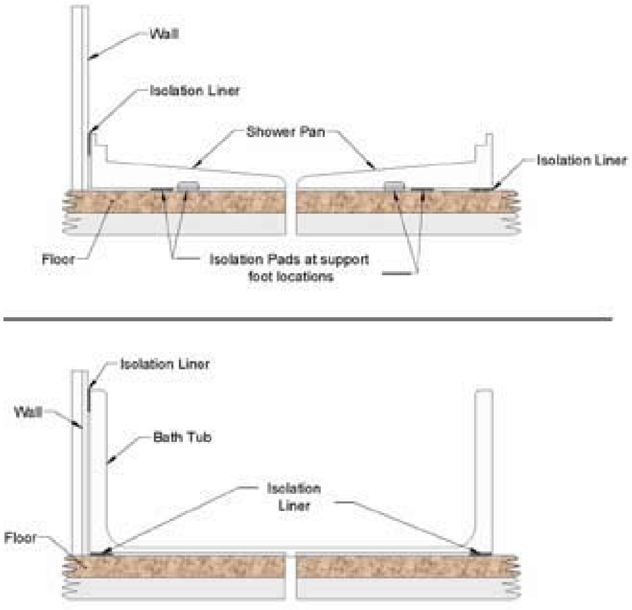


Figure 10-27 Floor-mounted Bathtub or Shower Isolation

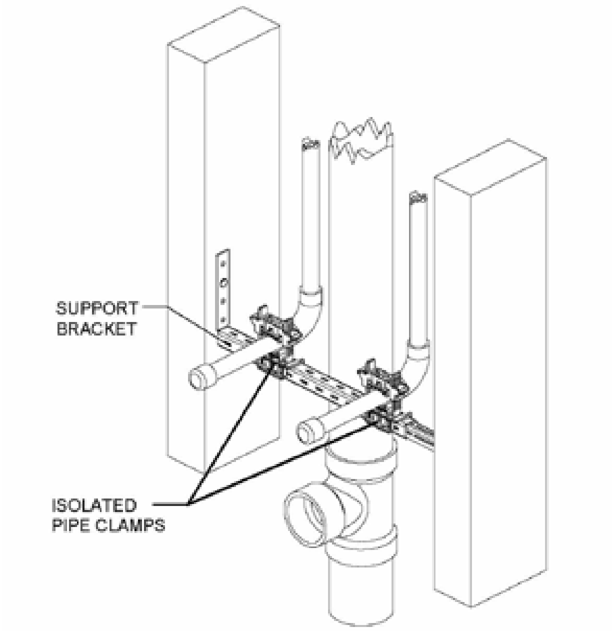


Figure 10-28 Lavatory or Sink

isolators. Rubber 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 0.25 inch 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 rarely is used in manufac-

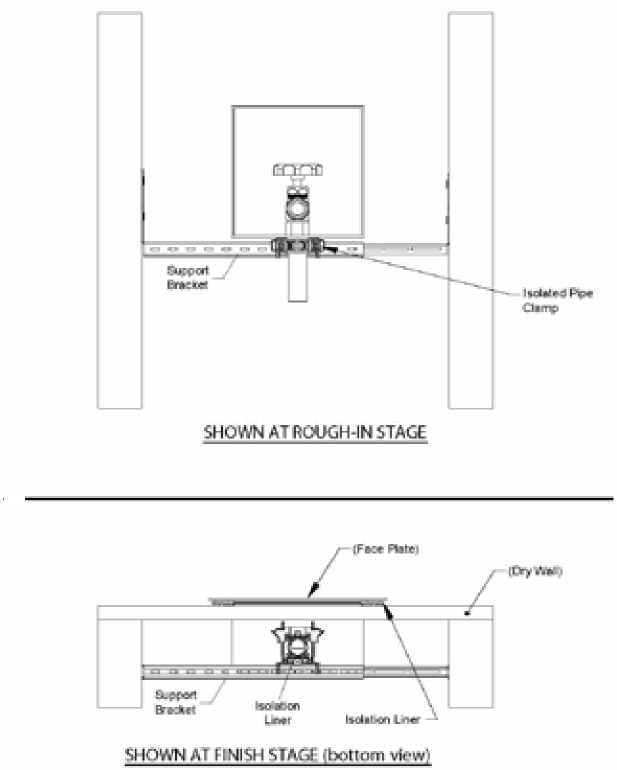


Figure 10-29 Icemaker Box

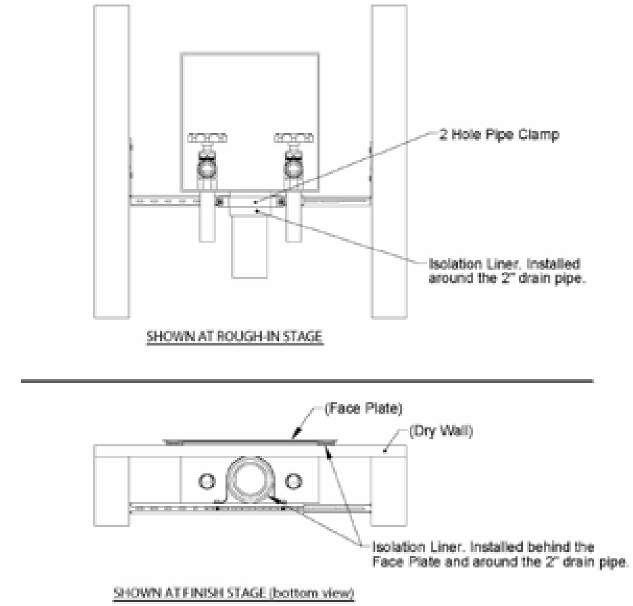


Figure 10-30 Laundry Outlet Box

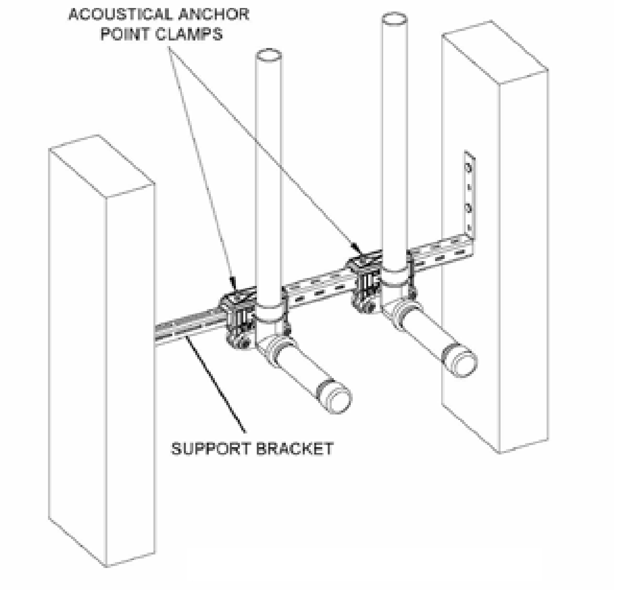


Figure 10-32 Mop/Service Sink Rough-in

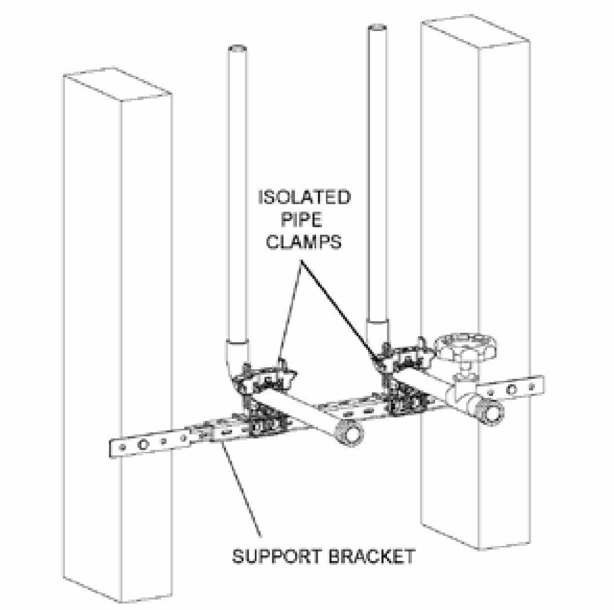


Figure 10-31 Hot Water Tank Rough-in

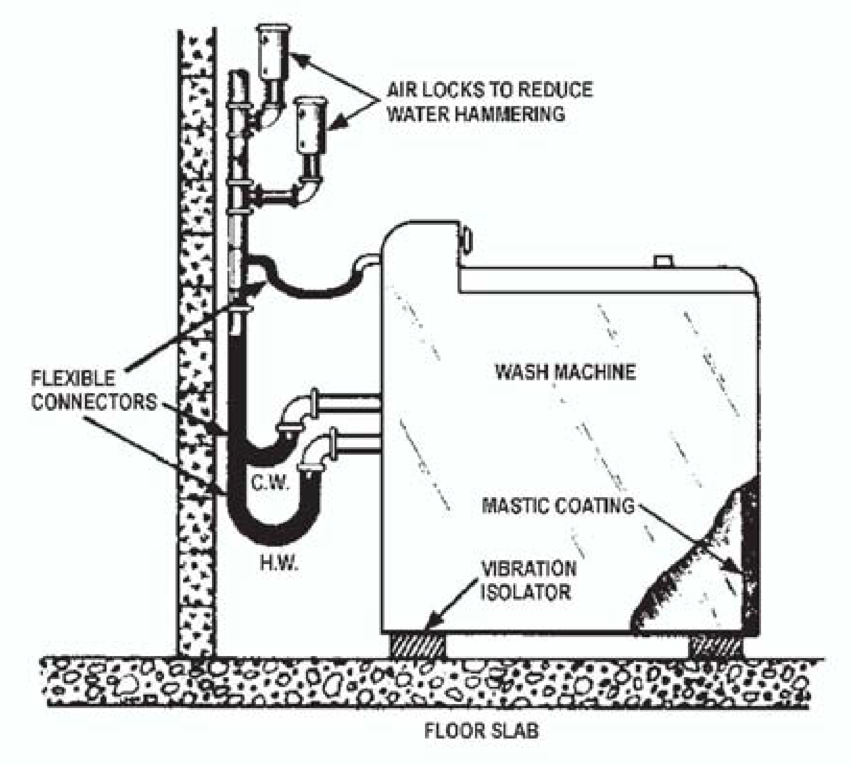


Figure 10-33 Flexible Connections for Clothes Washer

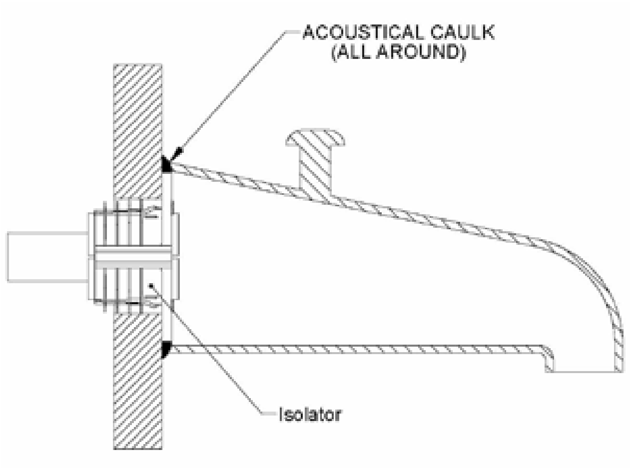


Figure 10-34 Typical Bathtub Spout

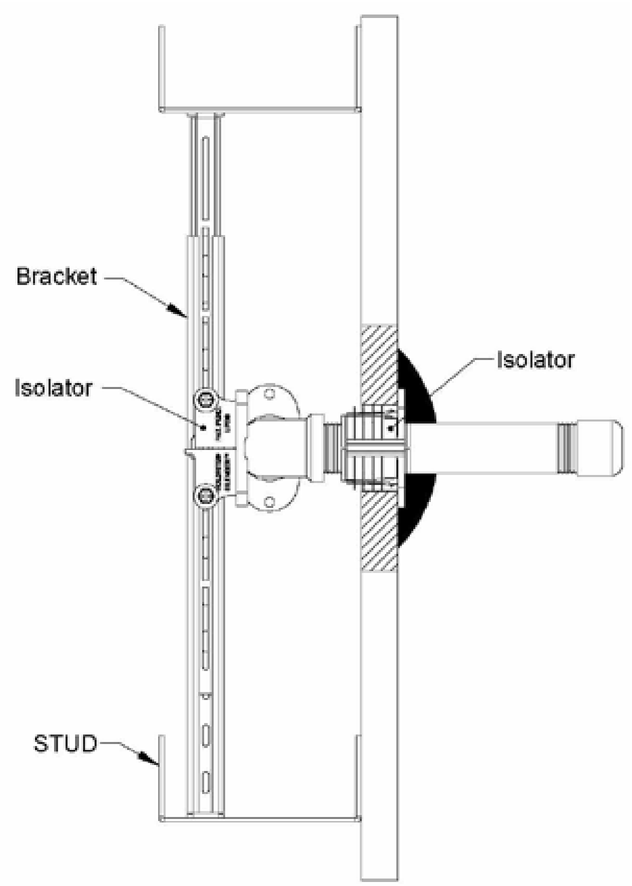


Figure 10-35 Showerhead Isolation

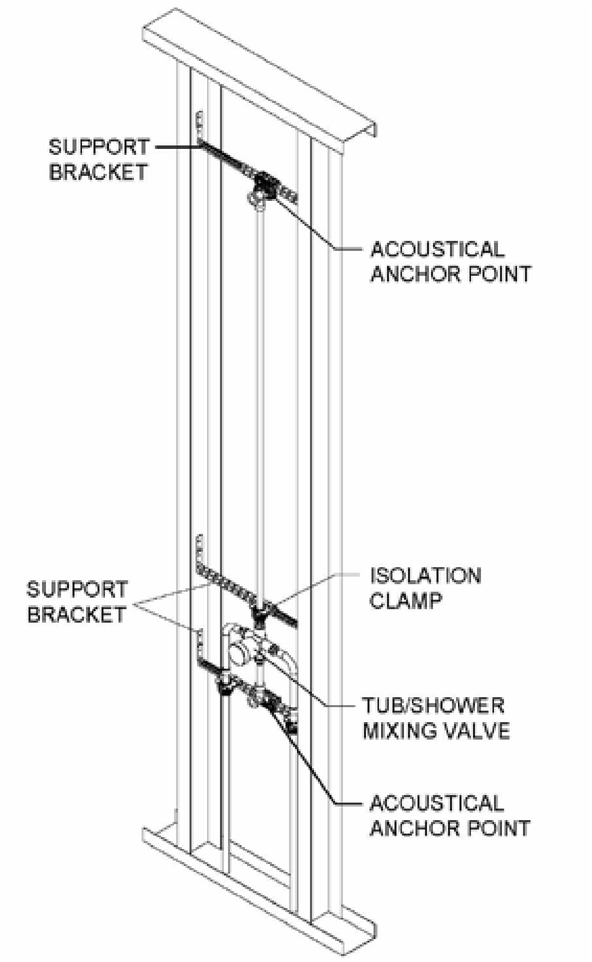


Figure 10-36 Bathtub/Shower Rough-in

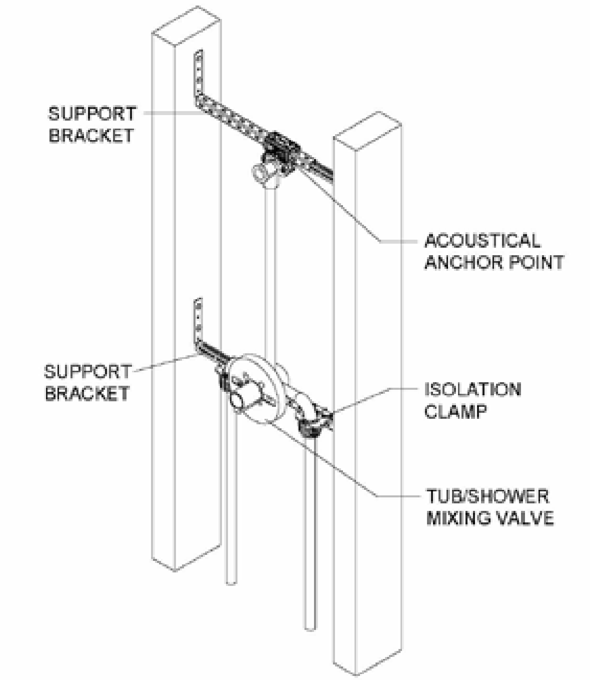


Figure 10-37 Shower Rough-in

tured 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. Industrial practice is to make the base in a rectangular configuration approximately 6 inches larger in each dimension than the equipment being supported. The base depth needs not exceed 12 inches 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 the 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 the 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 10-38 through 10-45.)

POSITIVE ENGINEERING INFLUENCE OVER BOTH DESIGN AND 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. Though this chapter focused on the subject of acoustics in plumbing systems, it is obvious that attention must be given to a few elements in the building itself to set the stage for success. These items must be addressed with the project architect and the plumbing/me-

Table 10-3 Recommended Static Deflection for Pump Vibration-Isolation Devices

Equipment Location	Power Range, HP (kW)	Speed, RPM	Indicated Floor Span, in. (mm)		
			30 ft (9.1 m)	40 ft (12.2 m)	50 ft (15.2 m)
Slab on grade	Up to 7.5 (5.6)	1800	¾ (19.1)	¾ (19.1)	¾ (19.1)
		3600	¼ (6.4)	¼ (6.4)	¼ (6.4)
	Over 7.5 (5.6)	1800	1 (25.4)	1 (25.4)	1 (25.4)
		3600	¾ (19.1)	¾ (19.1)	¾ (19.1)
	50-125 (37.3-93.2)	1800	1½ (38.1)	1½ (38.1)	1½ (38.1)
		3600	1 (25.4)	1 (25.4)	1 (25.4)
Upper floor above noncritical areas	Up to 7.5 (5.6)	1800	¾ (19.1)	¾ (19.1)	1½ (38.1)
		3600	¾ (19.1)	¾ (19.1)	1 (25.4)
	Over 7.5 (5.6)	1800	1 (25.4)	1½ (38.1)	2 (50.8)
		3600	¾ (19.1)	1 (25.4)	1½ (38.1)
	50-125 (37.3-93.2)	1800	1½ (38.1)	2 (50.8)	2½ (63.5)
		3600	1 (25.4)	1½ (38.1)	2 (50.8)
Upper floor above critical areas	Up to 7.5 (5.6)	1800	1 (25.4)	1½ (38.1)	2 (50.8)
		3600	¾ (19.1)	1 (25.4)	1½ (38.1)
	Over 7.5 (5.6)	1800	1½ (38.1)	2 (50.8)	3 (76.2)
		3600	1 (25.4)	1½ (38.1)	2 (50.8)
	50-125 (37.3-93.2)	1800	2 (50.8)	3 (76.2)	4 (101.6)
		3600	1½ (38.1)	2 (50.8)	3 (76.2)

chanical design team early in the design stage. In some cases, it may be wise to consider hiring an acoustical consulting firm with a proven track record of success. These specialists, or acousticians, are typically members of the Acoustical Society of America and/or the Institute of Noise Control Engineering.

Influence the Design and Location of Party and Plumbing Walls

Ideally, encourage the architect to locate plumbing walls away from quiet rooms. As an example, do not position a bathroom or kitchen plumbing wall next to or above a bedroom or adjoining tenant party wall.

Party walls should be constructed to minimize sound transfer from one tenant to another or from common areas to tenant spaces and visa versa. Multiple designs and configurations are available to accomplish this, including physical separation (air space) between walls, staggered studs, dense insulation within wall cavities, multiple layers of sheetrock, and a variety of resilient channel configurations.

Influence Floor and Ceiling System Construction and Configuration

Floor and ceiling systems built with attention to minimizing noise transfer also can contribute to the level of success with plumbing system noise mitigation. Be sure that a proven, effective system is used.

Avoid routing plumbing system piping in ceiling spaces that are positioned above sensitive areas such as bedrooms. Also, avoid hard floor surfaces where possible. Soft floor coverings help minimize noise transfer between occupant levels. This aids in minimizing the transfer of airborne noise generated by plumbing fixtures and appliances from one level of a building to another.

In situations where pipes absolutely must be installed in sensitive walls and ceilings, care must be taken to provide noise reduction with sound-absorbing materials.

Once these building-related design issues are resolved, the acoustical engineer can 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 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 early in the process. All too often these errors are concealed and cannot be easily uncovered or repaired in a finished building.

Acoustical testing in a partially completed building is an additional step that can be taken to ensure that errors are not needlessly repeated and to give the opportunity for correction.

ACCOMPLISHING EFFECTIVE NOISE MITIGATION IS EASIER THAN EVER

The engineer does not have to perform all of these tasks alone. Thanks to increasing marketplace availability of tested and proven products along with manufacturers' support services, the engineer has willing and capable partners. Figures 10-46 and 10-47 show examples of complimentary

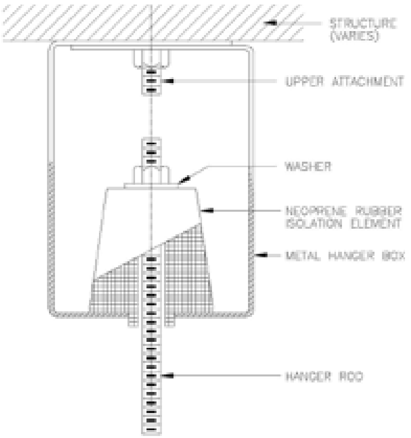


Figure 10-38 Neoprene Hanger Isolator

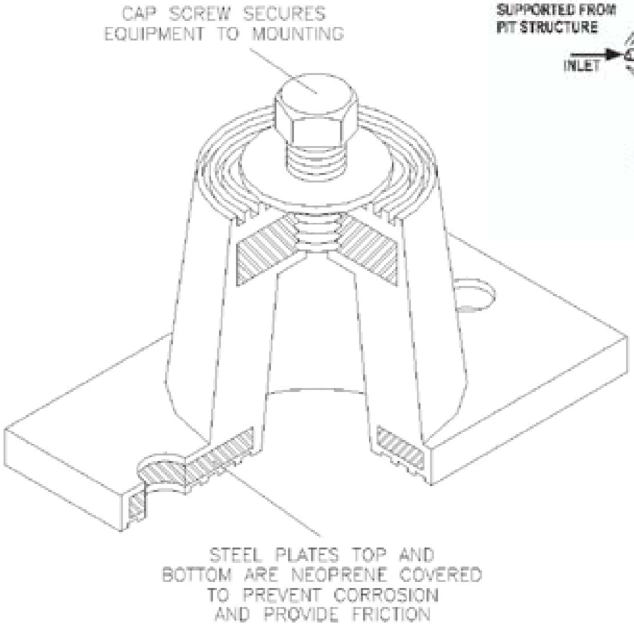


Figure 10-40 Neoprene Mount, Double Deflection

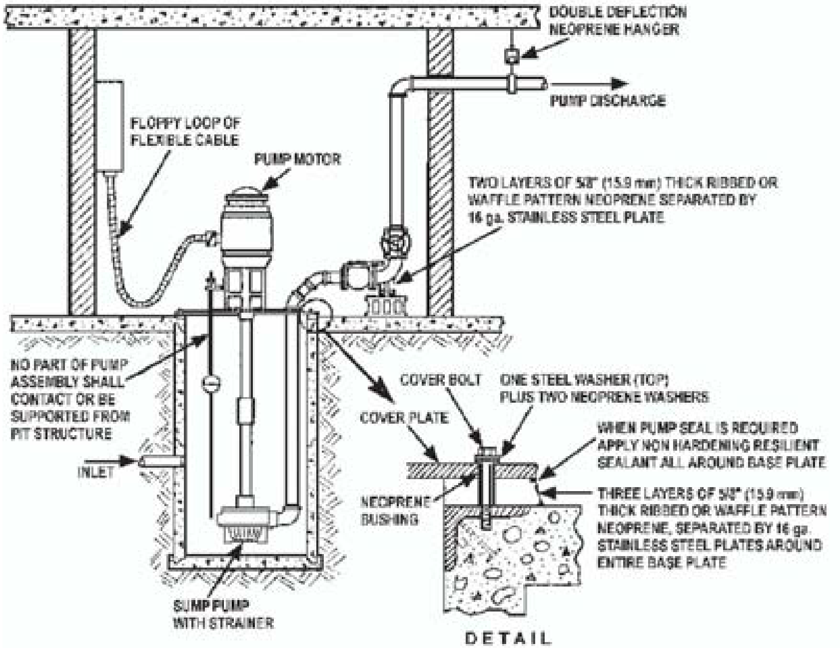


Figure 10-39 Sump Pumps

support documentation provided by reputable manufacturers.

Engineers and acoustical consultants now can easily and confidently do their part in providing a comprehensive and holistic solution for the mitigation of plumbing system noise for their clients' buildings. The owner's concerns regarding high costs and legal exposure can be dispelled. The contractor's concerns regarding time-consuming, confusing, and expensive materials and methods also can be put to rest. Necessary materials can be purchased through normal plumbing wholesale channels throughout the United States and much of Canada, rather than a long list of specialty suppliers, as historically required by most plumbing noise and vibration specifications in years past. When contractors are confident that plans and specifications point them in a clear and understandable direction as to what is expected, the results will be quality installations, protection against litigation, and reasonable contract pricing. Ultimately, happy building owners and building occupants will be the result.

Low installed-cost acoustical application solutions are the result of the successful specification inclusion and implementation of products that help the contractor to be efficient and consistent with each installation. The elimination of random unproven and makeshift methods of installation with an insistence on engineered solutions at the jobsite level results in fast, simple, and easily duplicated installations and a win-win for all parties concerned.

The availability of a clear, concise, and affordable solution to plumbing system noise provides up-sell opportunities for buyers interested in an improved quality of life in a quiet environment. One study recently showed that currently about 30 percent of homebuilders offer sound-attenuating interior walls as standard pre-priced upgrades for prospective buyers. Another opportunity involves green building projects. More and more sustainable projects are including specification requirements relating to a peaceful environment. Noise both from indoor and outdoor sources add to stress and discomfort for a building's occupants.

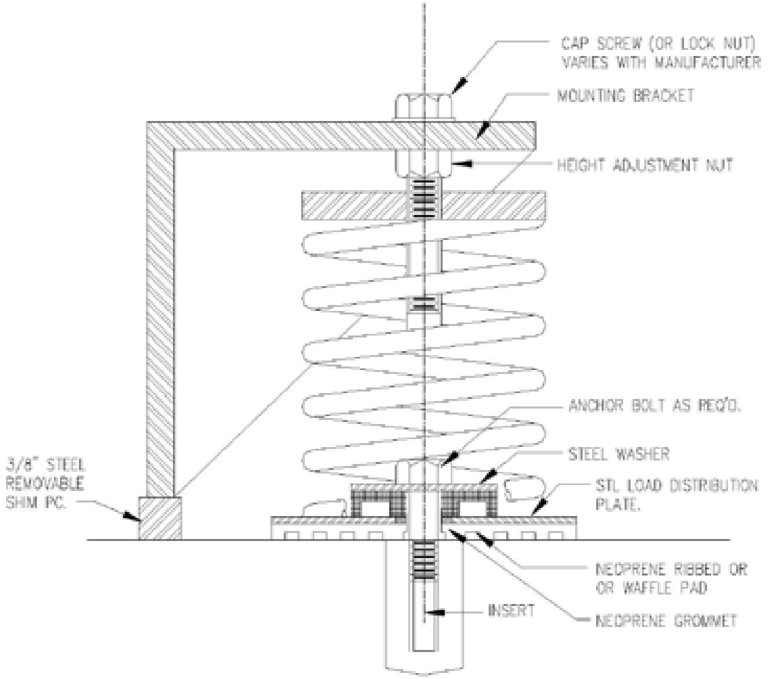


Figure 10-41 Spring-mount Isolator

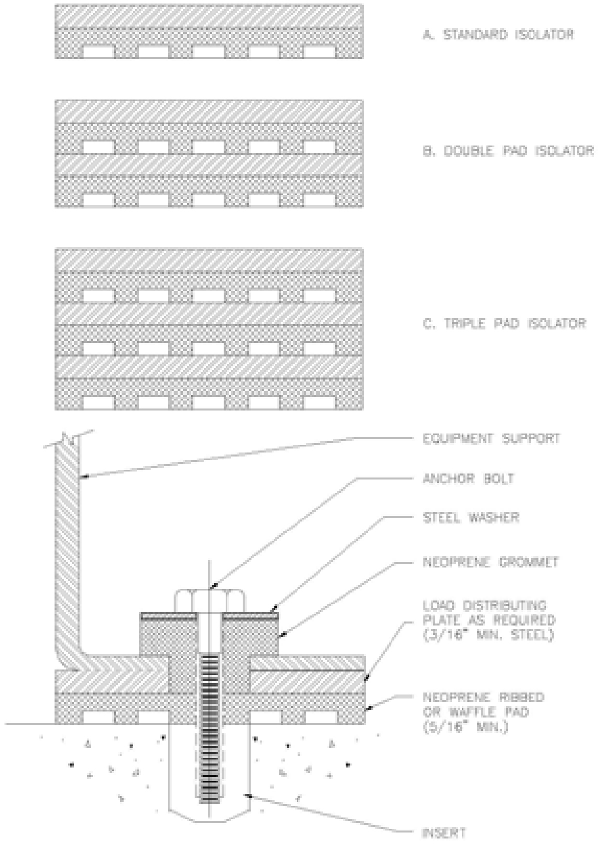


Figure 10-42 Neoprene Pad Isolator

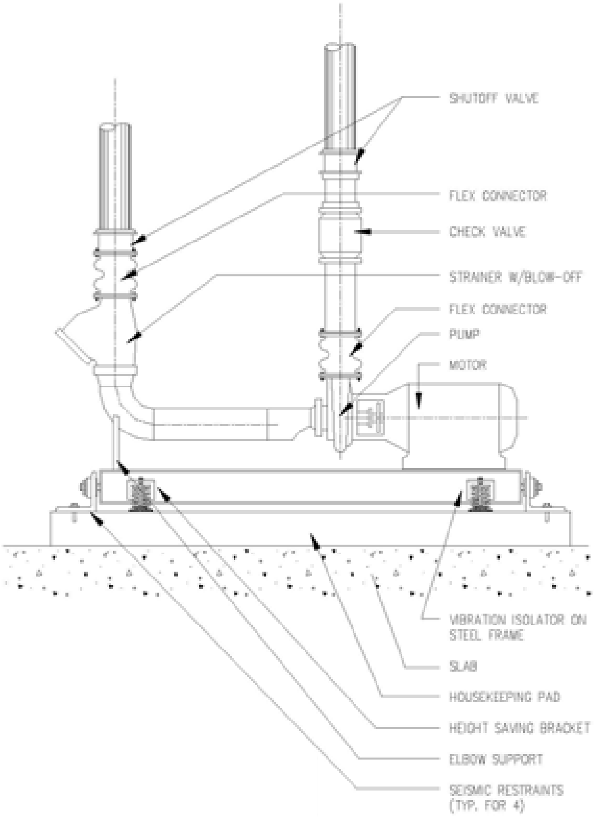


Figure 10-43 General Mounting Detail for End-suction, Close-coupled Pump

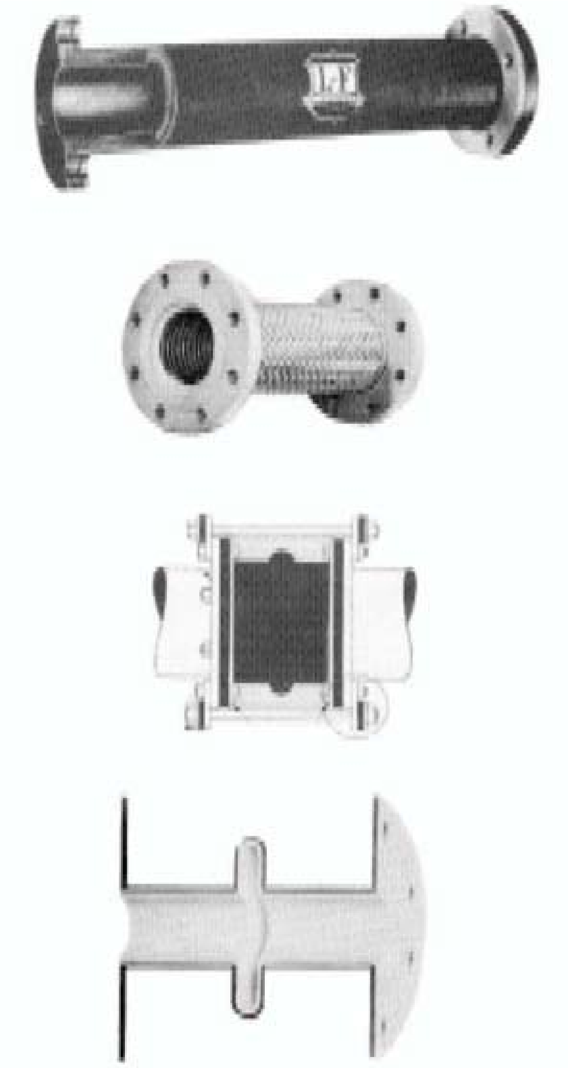


Figure 10-44 Examples of Flex Connectors

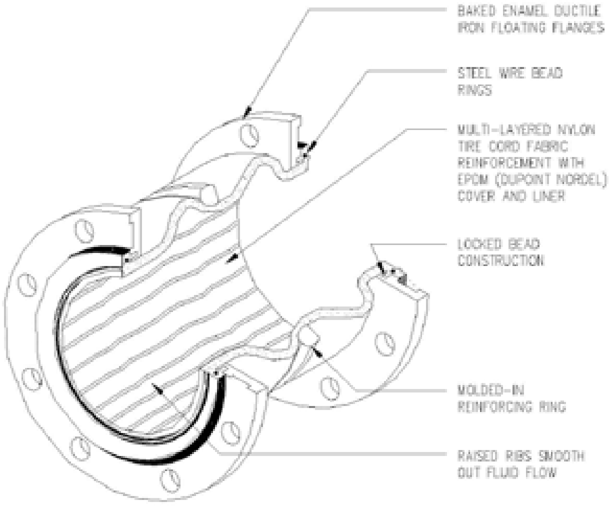


Figure 10-45 Flex Connector Detail

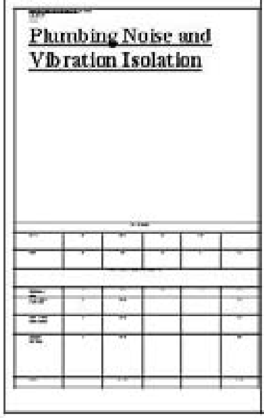
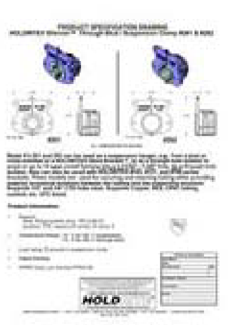
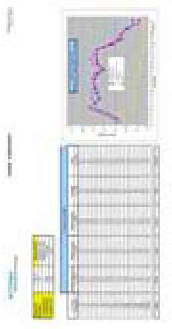
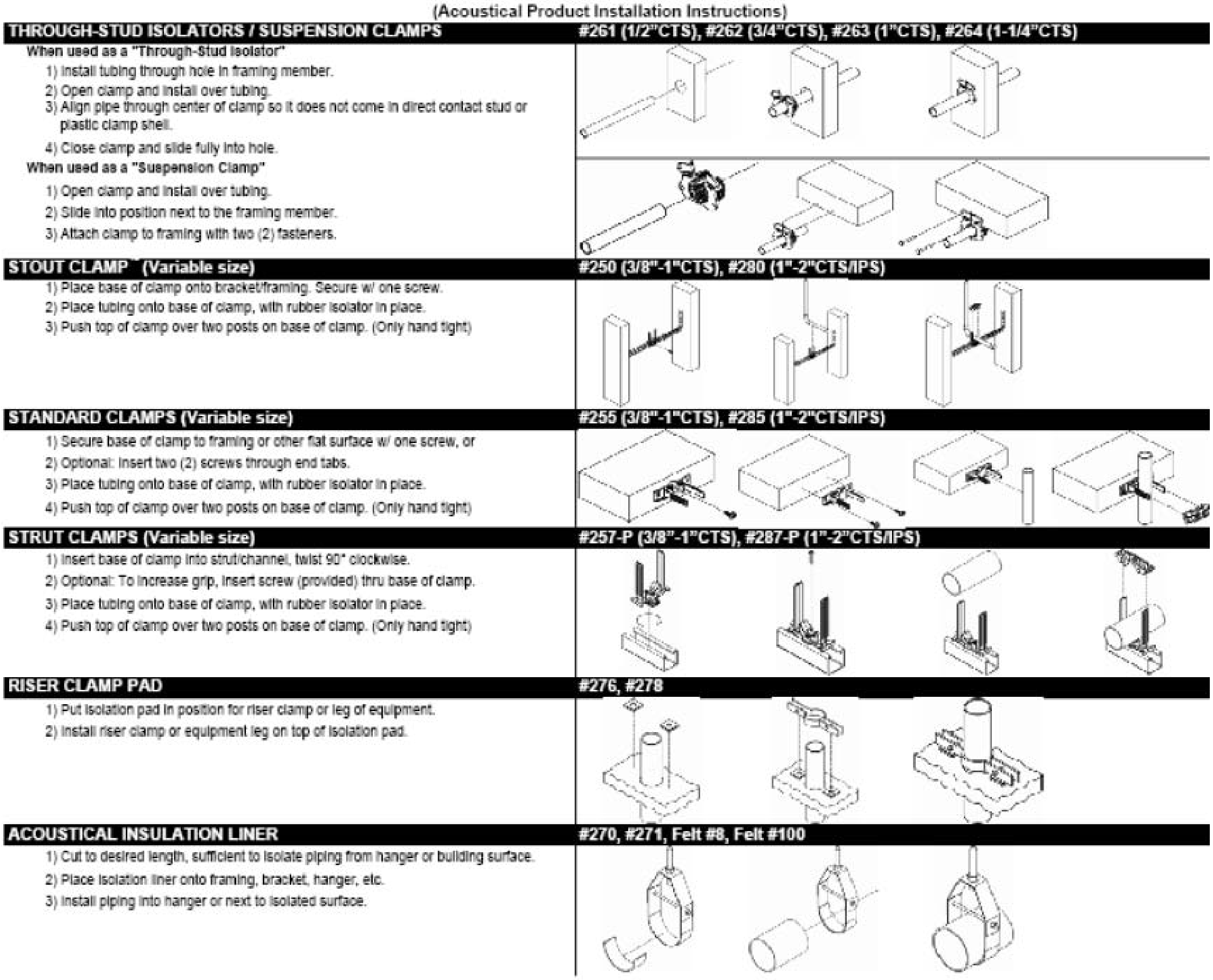
Spec Writing Assistance	Product Spec Sheets	Certified Laboratory Test Data	Application Installation	Plumbing Installation Detail Page
 Plumbing Noise and Vibration Isolation				

Figure 10-46 Sample Specification Sheets



(Acoustical Product Installation Instructions)

THROUGH-STUD ISOLATORS / SUSPENSION CLAMPS **#261 (1/2"CTS), #262 (3/4"CTS), #263 (1"CTS), #264 (1-1/4"CTS)**

When used as a "Through-Stud Isolator"

1) Install tubing through hole in framing member.
2) Open clamp and install over tubing.
3) Align pipe through center of clamp so it does not come in direct contact stud or plastic clamp shell.
4) Close clamp and slide fully into hole.

When used as a "Suspension Clamp"

1) Open clamp and install over tubing.
2) Slide into position next to the framing member.
3) Attach clamp to framing with two (2) fasteners.

STOUT CLAMP ˜ (Variable size) **#250 (3/8"-1"CTS), #280 (1"-2"CTS/IPS)**

1) Place base of clamp onto bracket/framing. Secure w/ one screw.
2) Place tubing onto base of clamp, with rubber isolator in place.
3) Push top of clamp over two posts on base of clamp. (Only hand tight)

STANDARD CLAMPS (Variable size) **#255 (3/8"-1"CTS), #285 (1"-2"CTS/IPS)**

1) Secure base of clamp to framing or other flat surface w/ one screw, or
2) Optional: Insert two (2) screws through end tabs.
3) Place tubing onto base of clamp, with rubber isolator in place.
4) Push top of clamp over two posts on base of clamp. (Only hand tight)

STRUT CLAMPS (Variable size) **#257-P (3/8"-1"CTS), #287-P (1"-2"CTS/IPS)**

1) Insert base of clamp into strut/channel, twist 90° clockwise.
2) Optional: To increase grip, insert screw (provided) thru base of clamp.
3) Place tubing onto base of clamp, with rubber isolator in place.
4) Push top of clamp over two posts on base of clamp. (Only hand tight)

RISER CLAMP PAD **#276, #278**

1) Put isolation pad in position for riser clamp or leg of equipment.
2) Install riser clamp or equipment leg on top of isolation pad.

ACOUSTICAL INSULATION LINER **#270, #271, Felt #8, Felt #100**

1) Cut to desired length, sufficient to isolate piping from hanger or building surface.
2) Place isolation liner onto framing, bracket, hanger, etc.
3) Install piping into hanger or next to isolated surface.

Figure 10-47 Sample Installation Instruction Sheet

REFERENCES

1. ISO 3822: *Laboratory Tests of Noise Emissions from Appliances and Equipment used in Water Supply Installations*. International Organization for Standardization
2. PPI TR-21: *Thermal Expansion and Contraction in Plastic Piping Systems.* Plastic Pipe Institute.
3. Engineering Resource Binder. Hubbard Enterprises-HOLDRITE.
4. *FlowGuard Gold Connection.* Issue 13, 1Q 2005.
5. "Plumbing Appliance Noise Measurements," *Sound and Vibration.*
6. UPC Section 609.10. International Association of Plumbing and Mechanical Officials.
7. IPC Section 604.9. International Code Council.

11

Basics of Value Engineering

Value engineering, or VE—the term alone often chills a design engineer, during any part of a construction project. 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 the definition synonymous with the term value engineering is 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.

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 and 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 it was being applied. In fact, the Society of American Value Engineers (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. federal government 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."

A lot of terms have been used over the years to describe this concept, including value analysis, value control, value assurance, and value management—all tend to be synonymous terms for value engineering. All have the same basic objectives: reduce costs, increase productivity, and improve quality.

What is the purpose of value engineering? It provides a means to systematically analyze a project and control its total costs. It is designed to analyze the functions of a project and determine the best value or the best relationship between its worth and its cost. For a facilities construction project, 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: just control and/or reduce costs. First, however, the team must have some perspective about where, how, and why value engineering will be applied. For the plumbing engineer and designer, the most typical application is the creation of a building.

Figure 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, 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, DC.

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, finishing, etc.

In the end, one person or entity is concerned with the total picture in the creation of a building: the owner or developer. 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 it is this team that needs to ultimately be 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 of 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 Figure 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 perform 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?

Value means different things to different people. Thus, there is no one perfect definition of value. For purposes of value engineering, value does not simply equate to cost reduction. Values also include economic, moral, social, and political ideals. In terms of value engineering, it is the economic value that most conforms to what is being measured or evaluated. Value, then, can be described as the lowest cost to provide the necessary and required products, functions, or services at the chosen time to its needed place with the requisite quality.

For engineering purposes, value can be defined best by the following formula:

$$\text{Value} = \frac{\text{Worth}}{\text{Cost}}$$

Figure 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		Development	Evaluation	Development
Development		Presentation	Investigation	Presentation	
Presentation					
Follow-up		Follow-up			

Source: Society of American Value Engineers, International

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 pretty straightforward: It's what you pay for the product or service. What is worth? For value engineering purposes, worth is the concept of the value of a function, product, system, etc., or, alternately stated, worth is the least cost to provide the function, product, or service. Still confused? It's no wonder. 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.

1. Are the products, systems, and materials necessary for the functionality of the project, and do they contribute value to the project?
2. Are the costs of the products, systems, or materials in proportion to their usefulness within the project?
3. Do the designed or specified products, systems, or materials need all the designated features?
4. Will other available products, systems, or materials accomplish the intended use or purpose and provide better performance?
5. Are the exact products, systems, or materials available for less?
6. Will other available products, systems, or materials accomplish the intended use or purpose at a lower cost?
7. Will other available products, systems, or materials accomplish the intended use and purpose with an equal performance?
8. Can another dependable supplier provide the products, systems, or materials for less?
9. Does the total cost of the products, systems, or materials include all materials, reasonable labor, and overhead?
10. 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. The number of phases can vary (see Figure 11-2). It all depends on what expert you have learned from, what books you've read, and what direct experience you have had in conducting value engineering projects.

It doesn't really matter how many phases are in a VEJP. What is vital is that the engineer is comfortable with all 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 implementation of the project.

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?" and "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.

Figure 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

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 engineer's thinking and collect and assemble the same information used by the engineer (see Figure 11-3). This means detailing every product and design element.

VE worksheets come in many variations, but typically they include the basic information form that describes the project and related data such as in Figure 11-4A. Additional information forms such as Figure 11-4B 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 11-5 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 11-6.

With all 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:

1. Does the information support the definition, specifications, or requirements of the project?
2. Does the information seem to be factual and valid for the project or detail being analyzed?
3. Is all the information current and up to date?
4. Does the information form an integrated whole? Does each item support the other items?
5. Are there any conflicts within the information collected?
6. Does the information conform to the expectations of the investigator?
7. Is any information suspect? Does some of the information seem to be inaccurate or nonrepresentative of the project or detail?
8. Does additional information need to be collected?
9. Do the relationships or associations between the information sets require further exploration?
10. Is there reason to suspect that any of the information is biased?
11. If the information causes concern or creates a restraint to the analysis, can it be verified by more than one source?

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 a stand-alone product, 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.)

There are two primary elements of establishing the cost of a design, product, or material: 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 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 for the information.

What Is Cost? Value engineering is big 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 (i.e., 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

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 ______________________________

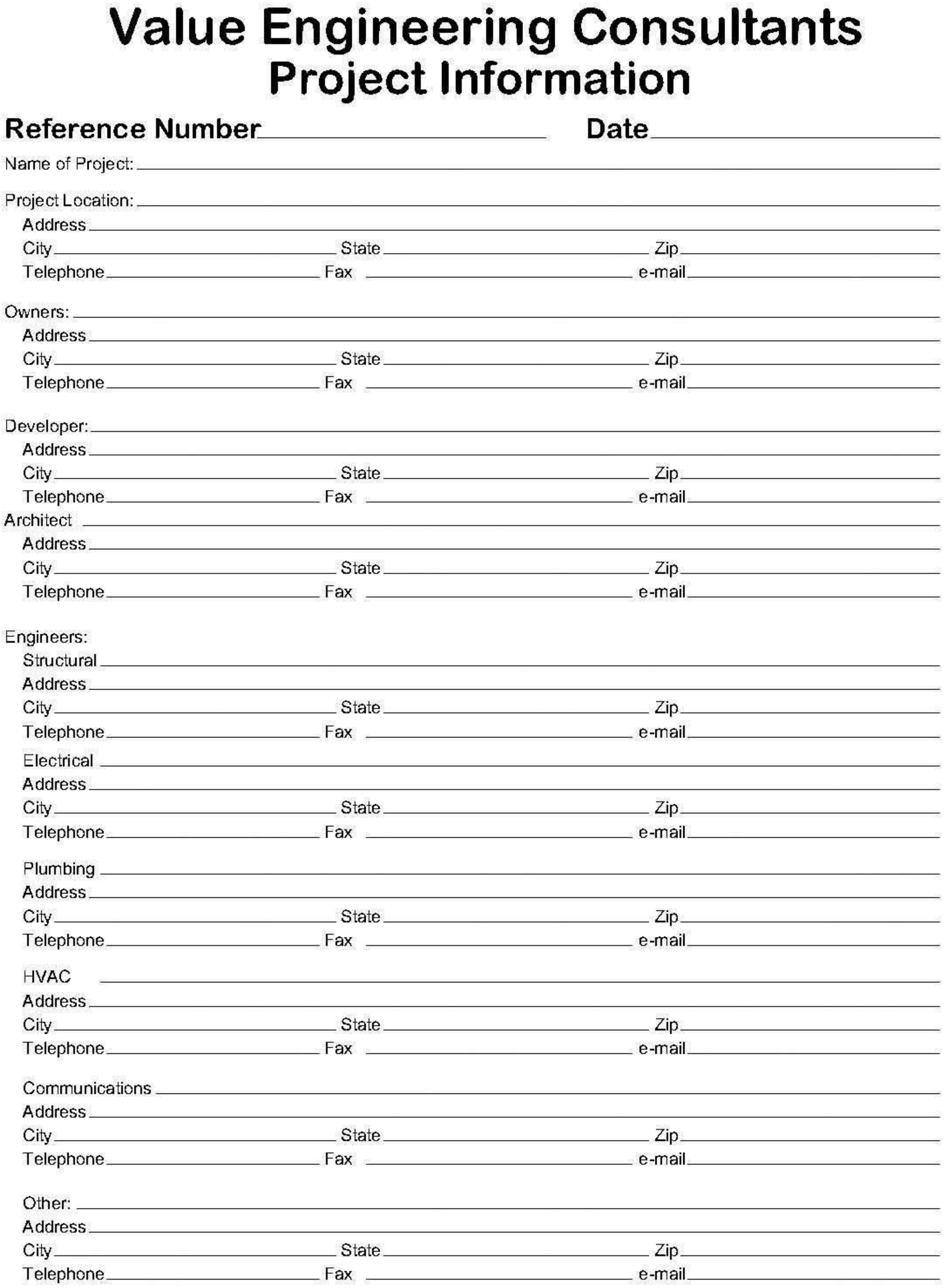
Pertinent Information ____

____

____

____

Figure 11-4 Sample Value Engineering Worksheet



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 ________

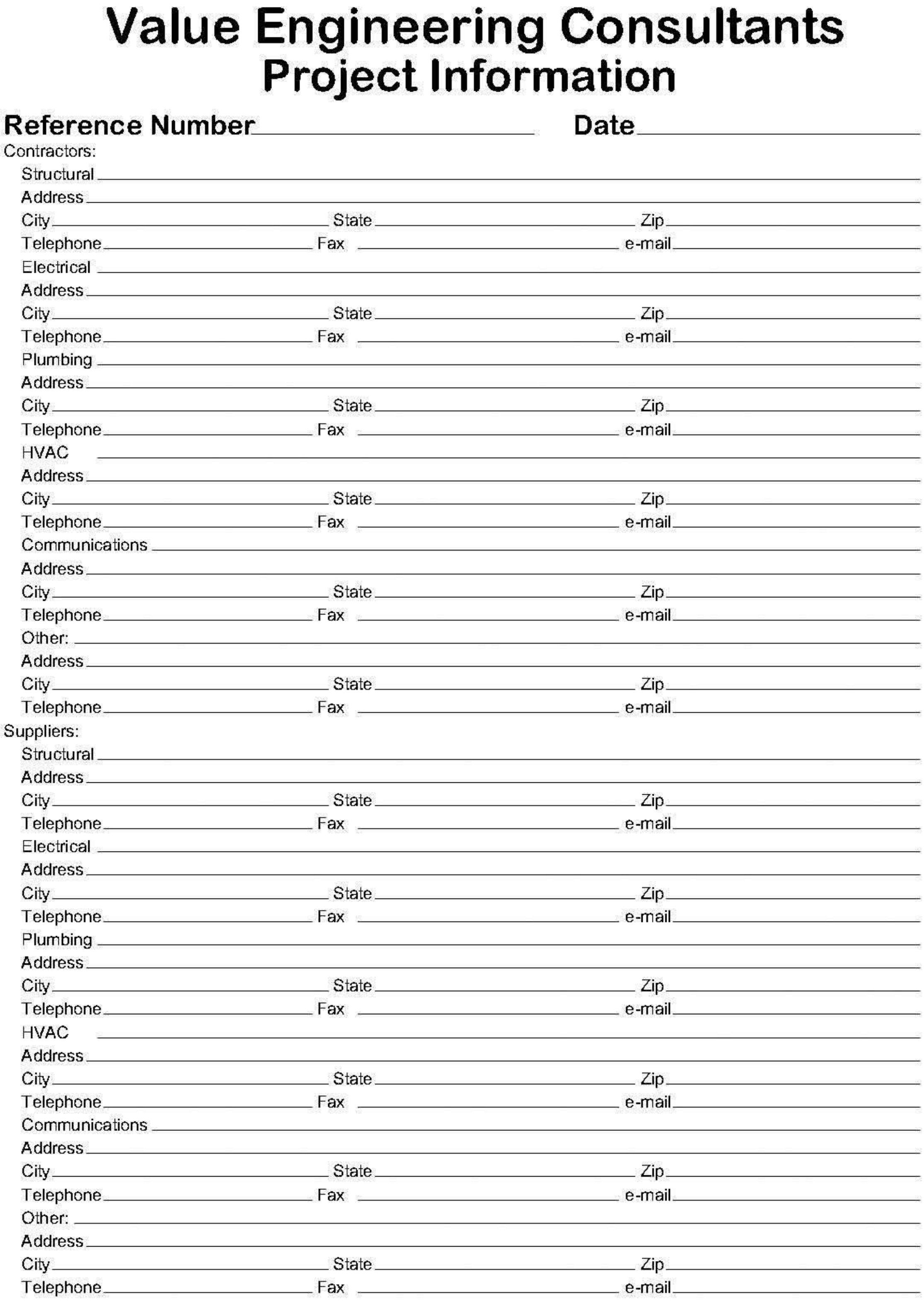
Plumbing ________
Address ________
City ________ State ________ Zip ________
Telephone ________ Fax ________ e-mail ________

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 11-4 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 11-4 Sample Value Engineering Worksheet (Continued)

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 (berore, 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 Market
    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 11-5 Sample Value Engineering Checklist

Value Engineering Consultants
Project Information Checklist

Reference Number **Date**

Detail/Product/Material Specifations

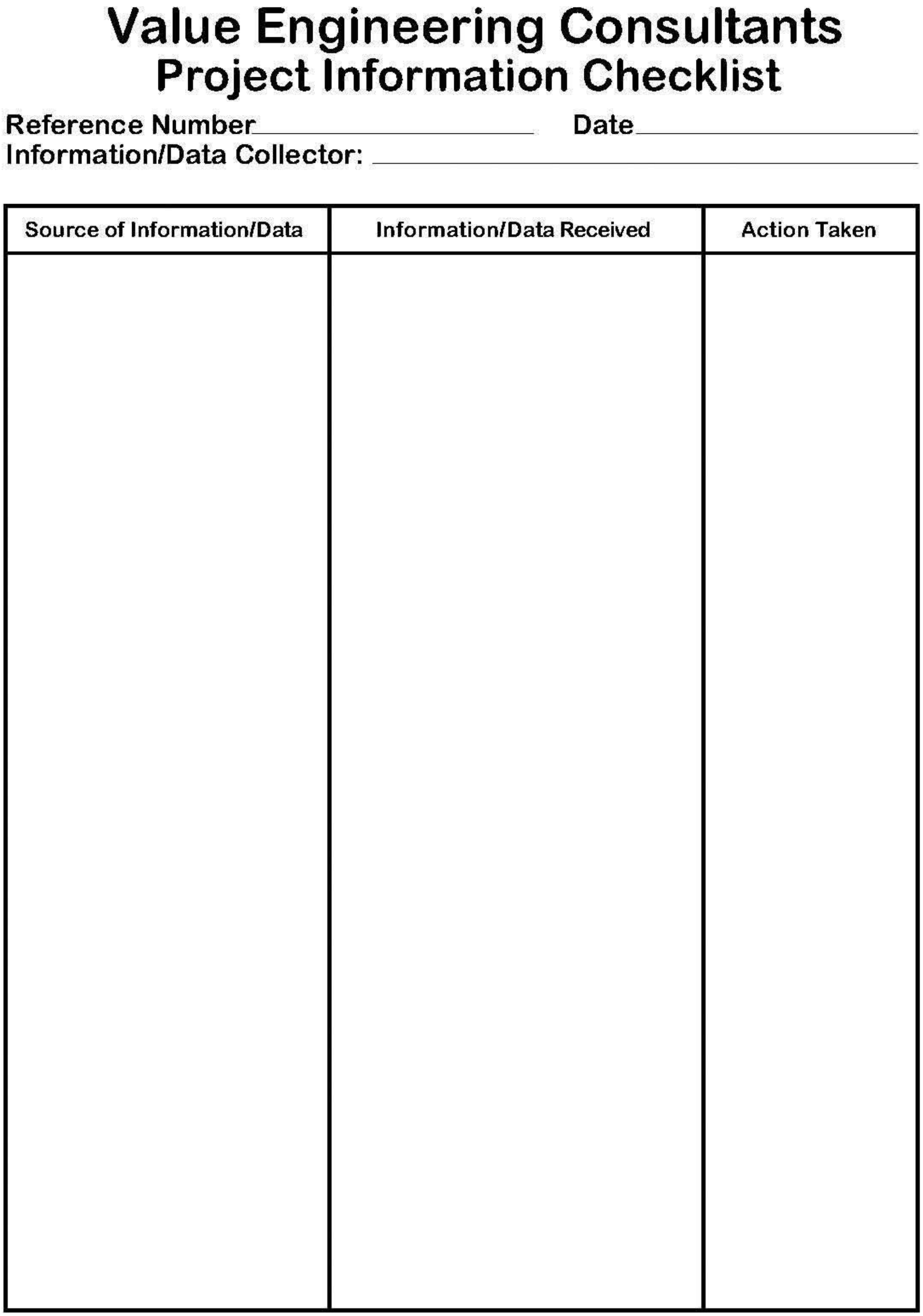
Detail/Product/Material Description:

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 Replacement 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 11-5 Sample Value Engineering Checklist (Continued)



Value Engineering Consultants
Project Information Checklist

Reference Number__________________ Date__________________
Information/Data Collector: ________________________________

Source of Information/Data	Information/Data Received	Action Taken

Figure 11-6 Sample Source Record Form

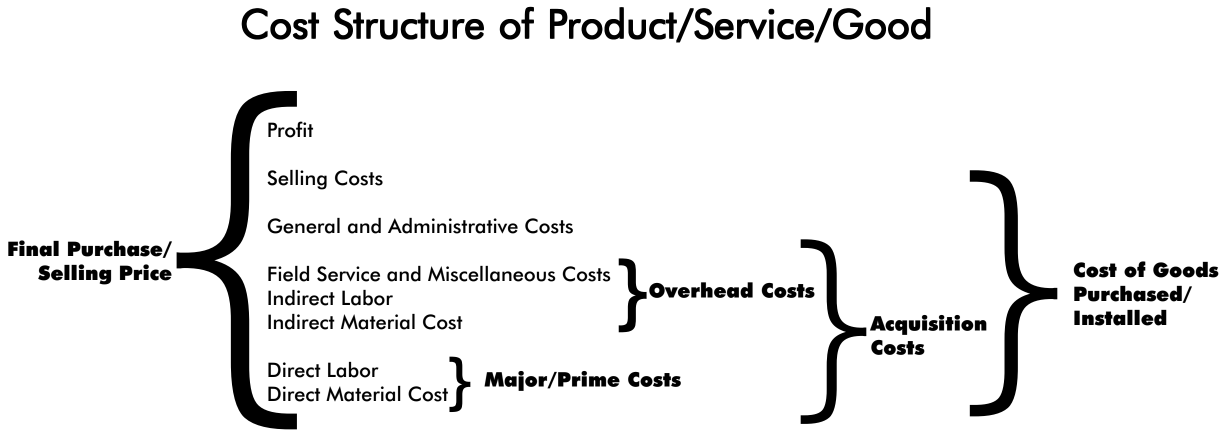


Figure 11-7 Cost Structure of Product, Service, or Goods

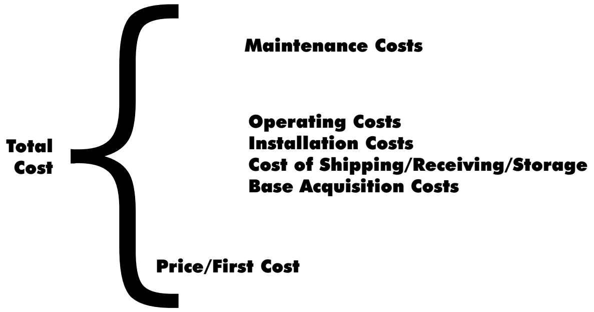


Figure 11-8 Cost Makeup for Users

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 are going to 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 11-7).

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 11-8 gives a generalization of the cost makeup for each user at the different stages of the facility project process.

A wide variety of costs go into each element and aspect of a facility. These costs are divided into ongoing costs and one-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. Figure 11-9 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.

Figure 11-9 Cost Breakdown Checklist

Ongoing Costs	One-time Costs
Labor Administration, management, and operations Ongoing staffing Technical support Field services Quality control Administrative support Documentation (in-house) Inspections Purchase orders and paperwork Reports: producing, receiving, and sending Documentations Certifications Training **Product/Services/ Materials** Basic materials Subcontracts Intercompany effort Administration and operations (i.e., reproduction) Indirect supplies, services, and materials **Other and General** Travel Equipment rental Contracted services Shipping and freight	Labor Engineering Design Drafting and review Production planning and engineering Procurement Development Testing and review Field engineering Training Administrative support services Documentation Licensing, permits, and inspections Purchase orders and paperwork Reports: producing, receiving, and sending Documentation Handbooks and user manuals Certifications and inspections **Product/Services/Materials** Products, supplies, and materials Special tools Special equipment (i.e., test equipment) Administration and operations (i.e., reproduction) Change orders, modifications, and corrections **Other and General** Travel Equipment rental Contracted services Shipping and freight Disposition of equipment and materials

With all 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 specifications for the project or design and which are imposed requirements. Costs associated with specifications are those imposed by the

Figure 11-10 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

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 these different potential costs. Then, as part of the analysis, the engineer must differentiate between costs that are real— based on specifications, available information, and conditions—and those that are imaginary (skewed by bias, attitudes, habits, lack of information, old technology, lack of ideas and creativity, and temporary conditions).

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 a 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, and 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.

Is it true? The principle is stated as the theory of the Law of Inverse Proportions and is actually a concept. 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 it is in this phase that the engineer has a methodology to reestablish the original project or element needs into simply 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.

If it were only 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 to them, which results in a functional analysis and/or definitions.

Rules of Function Analysis Three rules are generally accepted for conducting functional analysis or creating functional definitions:

1. The expression of all functions must be accomplished using two words; one must be an active verb, and the other a descriptive or measurable noun. Figure 11-10 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.

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, then, 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 elements 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 nonquantifiable part of the requirements may be an overriding consideration. (For instance, color: 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.)

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 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 are those functions that require some prior action before it 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 the rules in place and understood, the value engineer begins the function analysis. Figure 11-11 shows a sample of the type of form that helps in this phase. The form is straightforward and, given all 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.

Example 3 in Figure 11-11 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. Example 4 in Figure 11-11 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 11-11 is filled out at this early stage of the analysis process. At a minimum, the function is defined, and, if necessary, its elements. At this stage, only basic and secondary indicators are marked. The remaining portion of the form will become part of the evaluation phase.

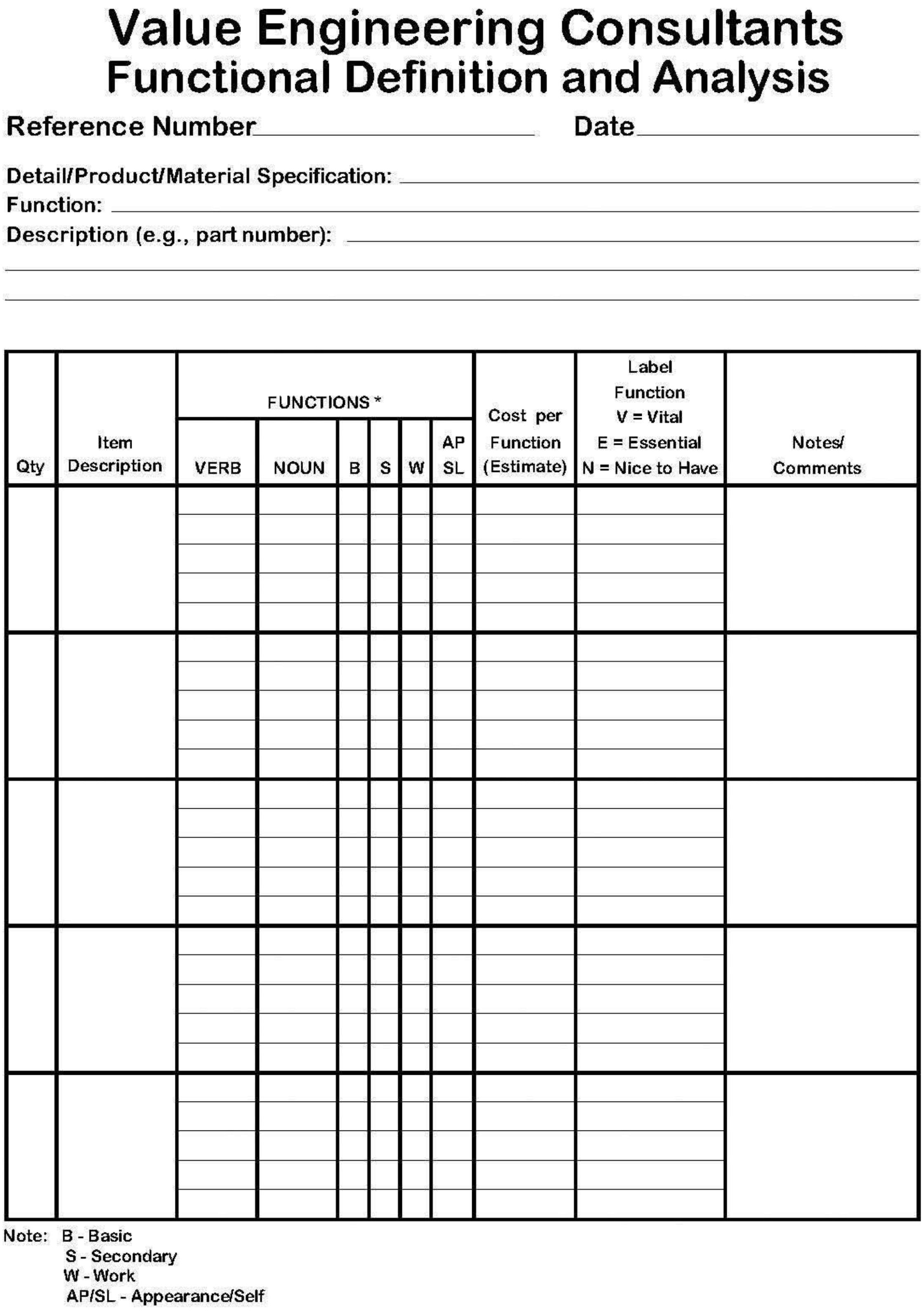
FAST A second approach is an adjunct to, and works in tandem with, function definitional analysis. This approach is known as FAST, which stands for Functional Analysis System Technique. The FAST process is essentially a diagramming process. With diagramming, a visual representation is created that highlights the functions of a product, system, or material and the interrelations between them.

A basic FAST model diagram is shown in Figure 11-12. 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 a visualization and 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 11-12 are:

1. Scope lines: The two vertical dotted lines provide a boundary to the function under study. That part of the function is of concern.



Value Engineering Consultants
Functional Definition and Analysis

Reference Number____________________ Date____________________

Detail/Product/Material Specification: ____________________

Function: ____________________

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			

Note: B - Basic
S - Secondary
W - Work
AP/SL - Appearance/Self

Figure 11-11 Sample Functional Analysis Form

Example 1: Expansion Chamber

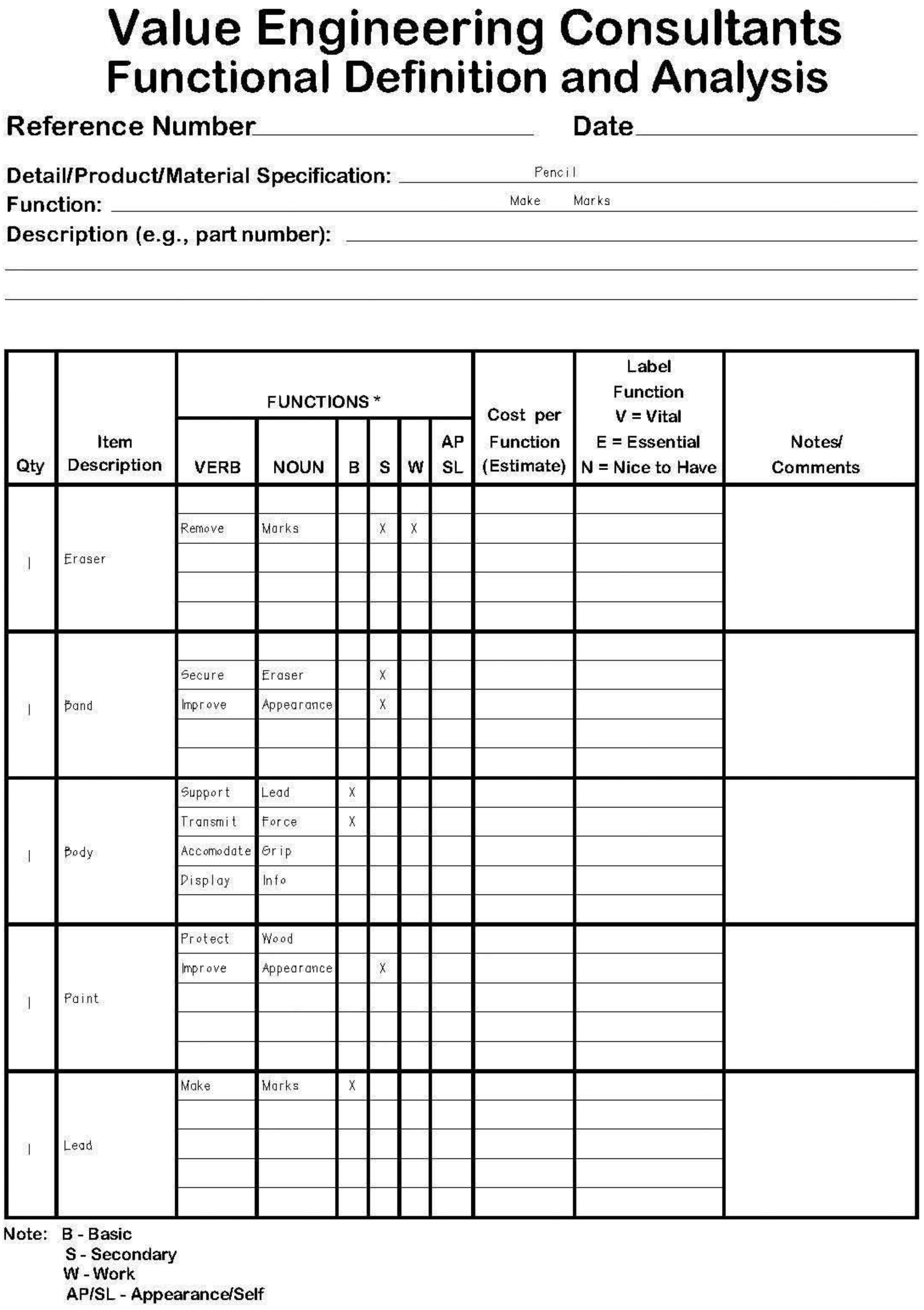
Qty	Item Description	FUNCTIONS *						Cost per Function (Estimate)	Label Function V = Vital E = Essential N = Nice to Have	Notes/ Comments
		VERB	NOUN	B	S	W	AP SL			
1	Expansion Tank	Contain	Liquid	X						
		Provide	Pressure	X						

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					

Figure 11-11 Sample Functional Analysis Form (Continued)

2. 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.
3. 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 to these functions. Rather, the lower functions are those necessary to successfully perform the basic or higher order function.
4. Basic function: This is the function under study, which cannot change.
5. 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.
6. 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.
7. Dependent or sequential functions: To exist, functions to the right of the basic function are dependent on the functions to their left and



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						
		Accomodate	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

Figure 11-11 Sample Functional Analysis Form (Continued)

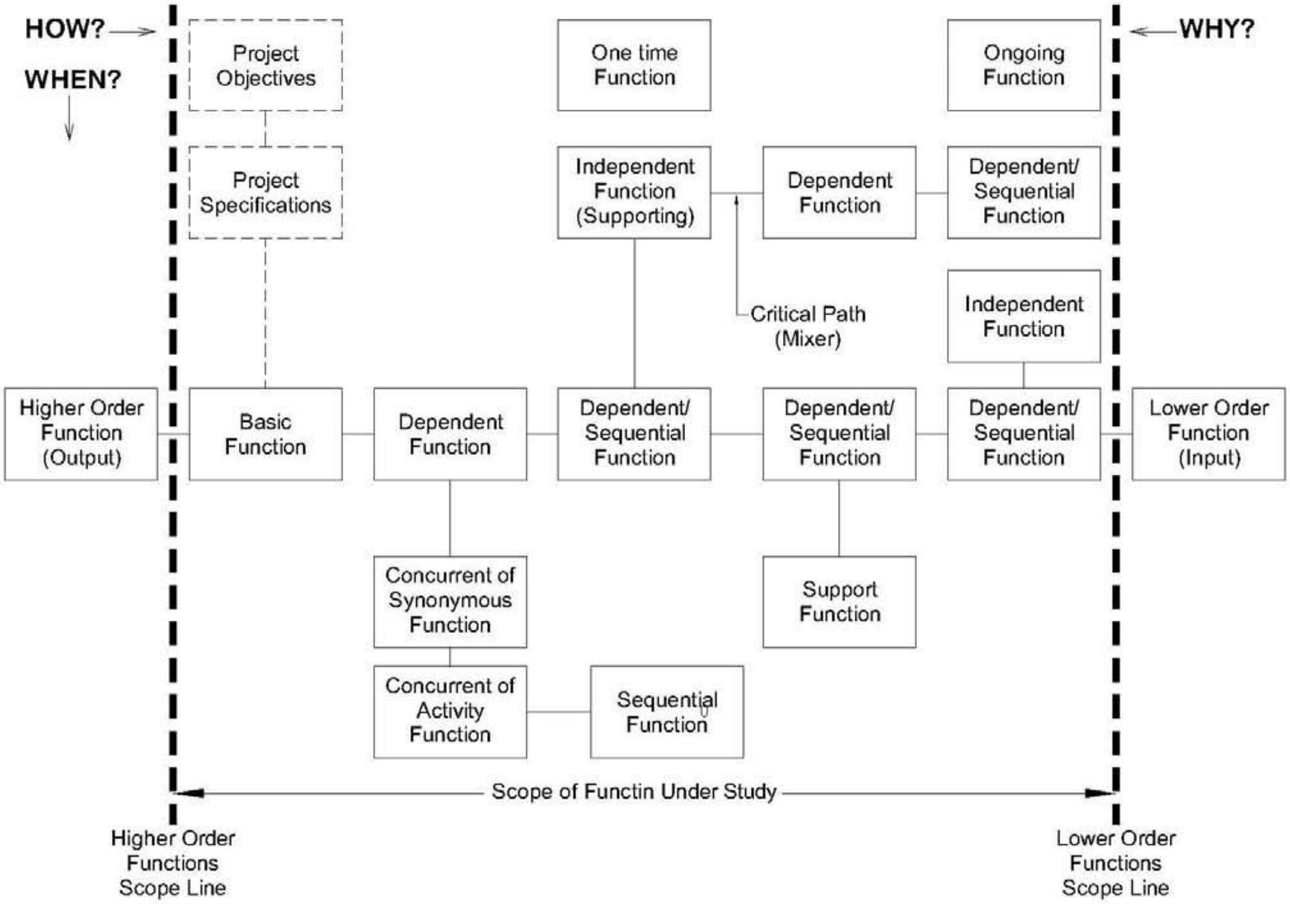


Figure 11-12 Basic FAST Model Diagram

require one to be completed before they enter as a performance requirement.

8. 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.
9. 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.
10. Function: The end event or purpose of the product, system, or material under analysis. It first must be expressed in a verb–noun form.
11. Activity: The method selected to perform a function.

For engineers familiar with systems-type diagramming, it would appear that the FAST diagram is backwards. 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 the functions and activities to the right are dependent on the basic function or moving toward the why of the function.

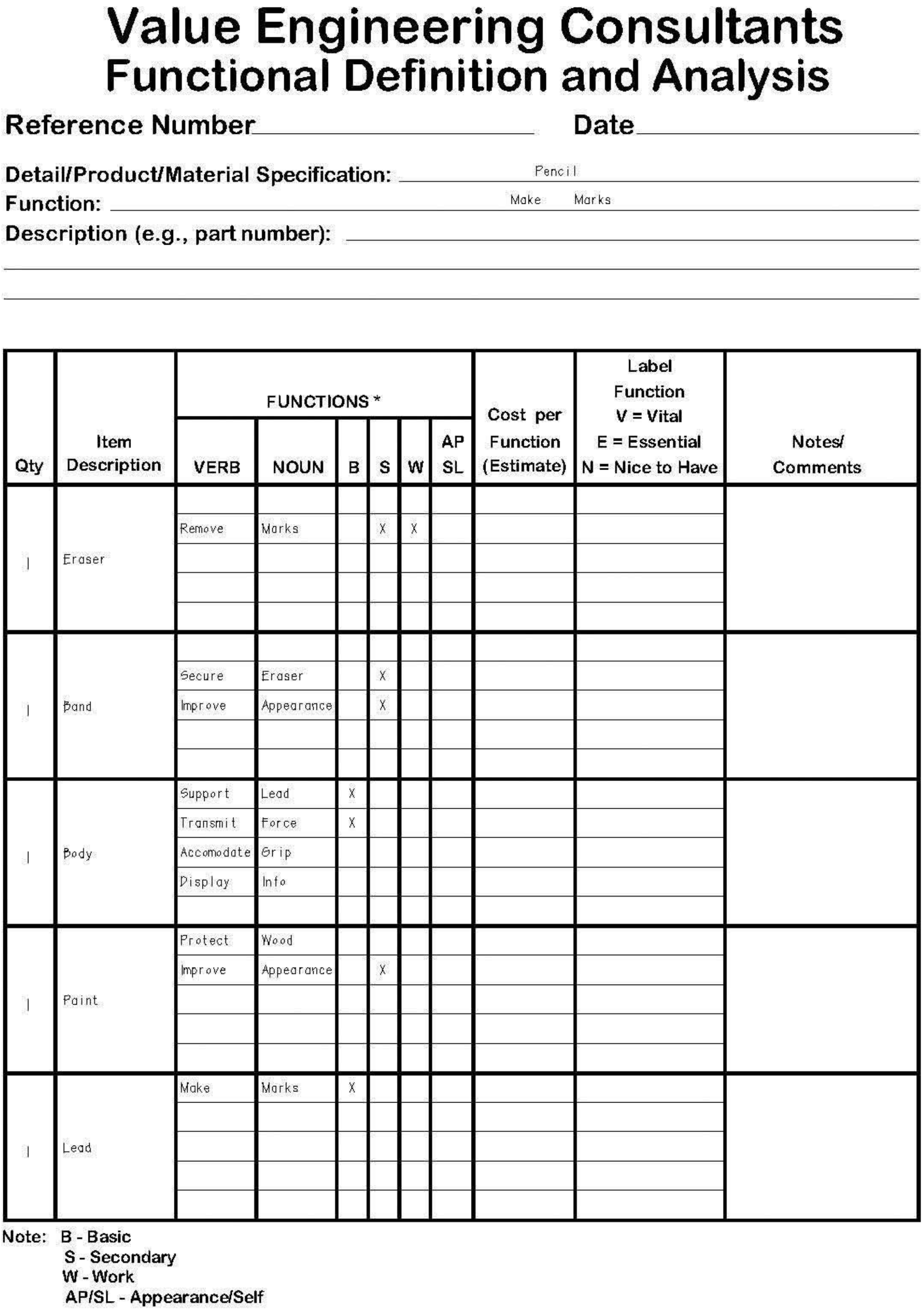
Figure 11-13 diagrams the how, why, and when relationship, relates it to the FAST diagram, and shows a simple how functional relationship.

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, 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 “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



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						
		Accomodate	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

Figure 11-13 Simple How Functional Relationship paper." Again, this phase requires a team approach to engineering disciplines. In the creativity phase, the team needs to unstructure and 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 only information permitted are the two-word, verb-noun functions that 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 the 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 just the opposite inflexible thinking is of an innovation made to an invention 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 the Dvorak and American Standard system of keyboard layout that produces a faster result. Ingrained habit is hard to overcome.

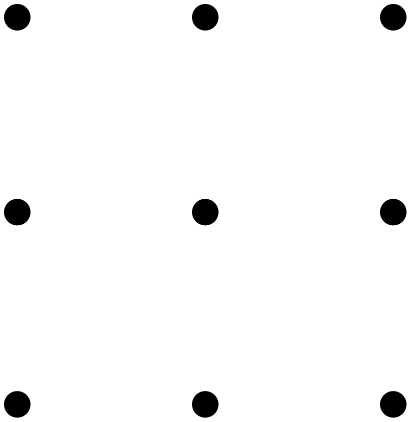
Roadblocks to Creativity Creativity takes work, hard work. Of course, as an alternative to providing the creativity phase in value engineering, the engineer can fall back on one of the top 10 reasons why value engineering should not be used at this time:

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's against company policy.

(Adapted from *Value Management,* General Services Administration, Washington, D.C.)

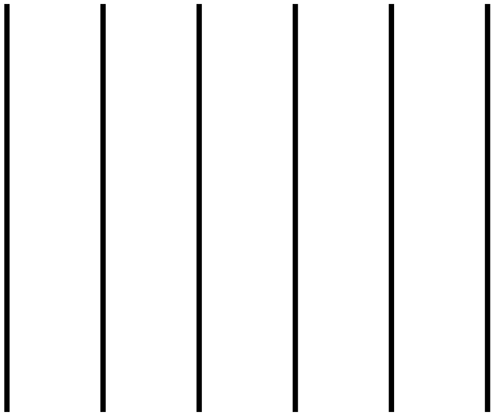
Divergent Thinking Creativity in value engineering is best described as speculation and brainstorming. An all-too-often overused and trite phrase "thinking outside the box" is an attempt to describe divergent thinking.

What is outside-the-box thinking? One example is the Nine Dots. First, draw nine dots in the form of a square on a piece of paper as shown.

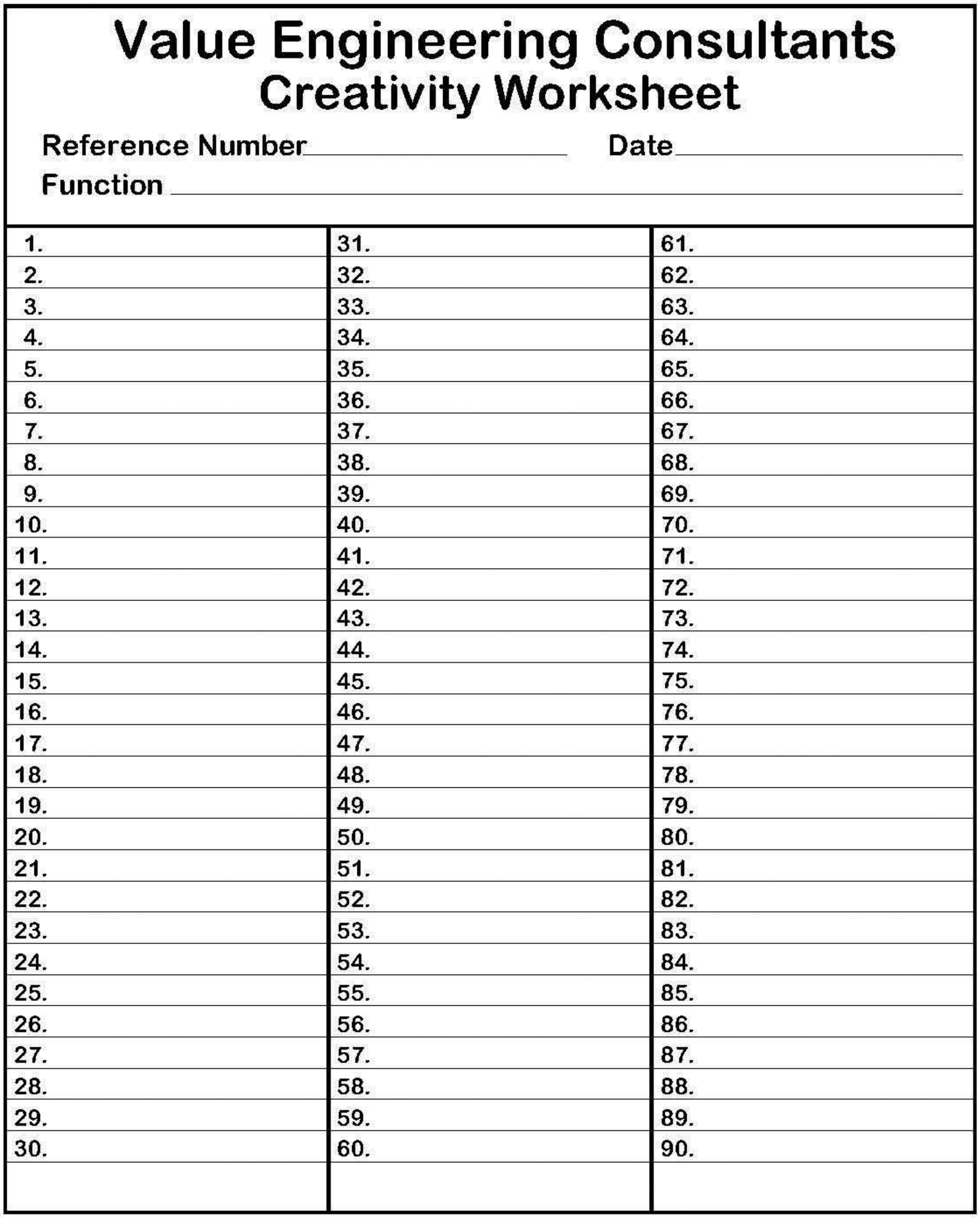


Next, without lifting your pencil from the paper, draw four straight, connected lines that go through all nine dots. You may not backtrack on a line, and each line must go through each dot only once. (See the end of this chapter for the solution.)

Another example is the six sticks. Use six sticks (toothpicks, straightened paperclips, matchsticks, etc.) of equal length as shown below.



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



Value Engineering Consultants
Creativity Worksheet

Reference Number____________________ Date____________________

Function ____

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Figure 11-14 Creativity Worksheet

Figure 11-15a 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, tri¬angle, 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 afterwards?
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?

Figure 11-15b Creativity Checklist

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 automatic electric blanket, 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

has three sides of the same length. See the end of this chapter for the solution.)

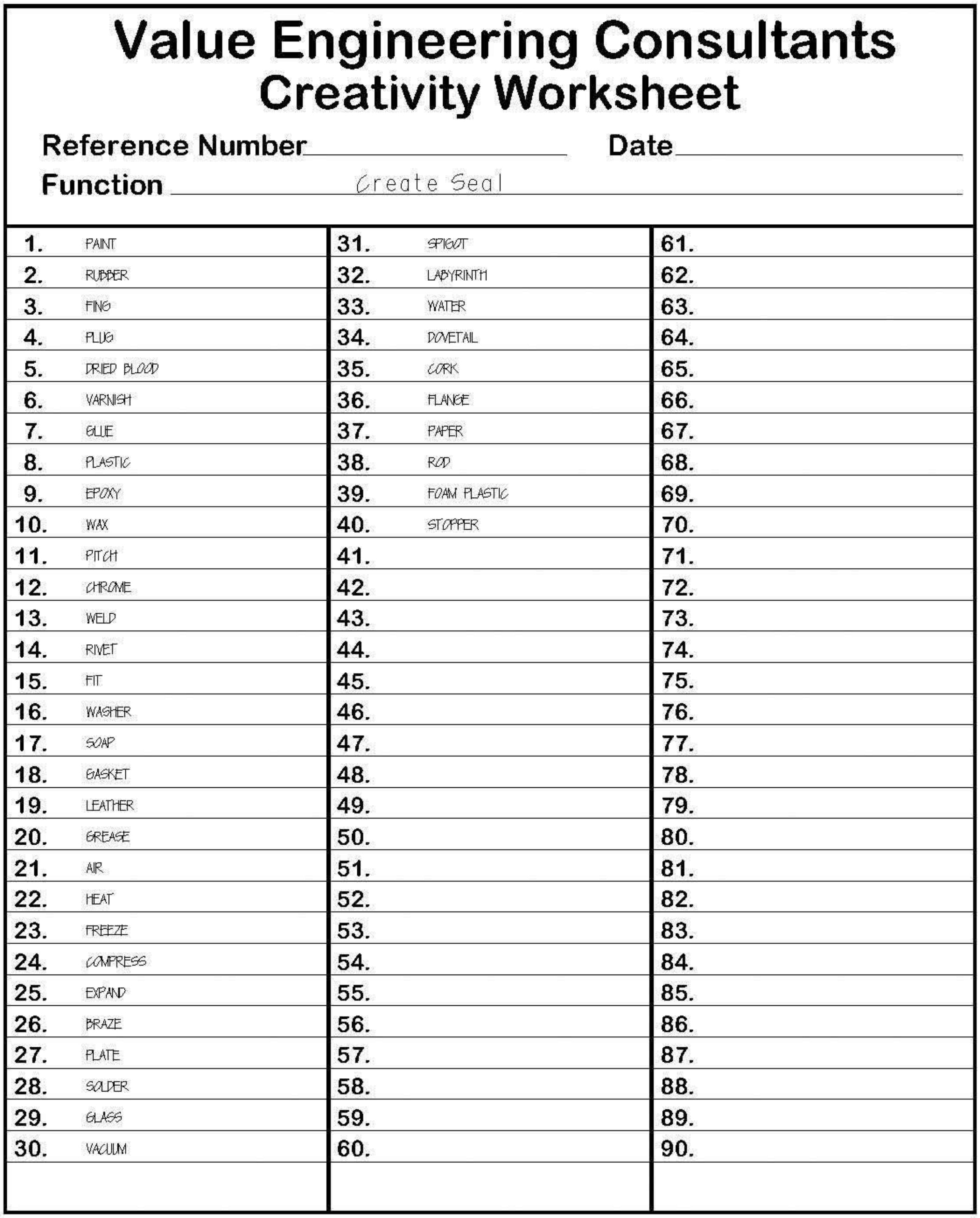
Finding Solutions In this phase, the team is not trying to find solutions, only ideas. To help this process, the leader has some help; a simple paper and pencil. Of course, a form can be created from this idea (see Figure 11-14). The brainstorming or speculative process consists of two techniques: unassisted creativity and assisted creativity.

With unassisted creativity, one team member takes the creativity worksheet and is assigned one two-word definition for one of the functions. The individual lists every possible idea she has regarding that function, such as "create seal." Once the individual has put down her 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.

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 of the alphabet) and the dictionary, while the third works the checklists, continually questioning all the thought processes. Two sample checklists are shown in Figure 11-15A and Figure 11-15B.

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



Value Engineering Consultants
Creativity Worksheet

Reference Number ____________ Date ____________

Function Create Seal

1. PAINT
2. RUBBER
3. FING
4. PLUG
5. DRIED BLOOD
6. VARNISH
7. GLUE
8. PLASTIC
9. EPOXY
10. WAX
11. PITCH
12. CHROME
13. WELD
14. RIVET
15. FIT
16. WASHER
17. SOAP
18. GASKET
19. LEATHER
20. GREASE
21. AIR
22. HEAT
23. FREEZE
24. COMPRESS
25. EXPAND
26. BRAZE
27. PLATE
28. SOLDER
29. GLASS
30. VACUUM
31. SPIGOT
32. LABYRINTH
33. WATER
34. DOVETAIL
35. CORK
36. FLANGE
37. PAPER
38. ROD
39. FOAM PLASTIC
40. STOPPER
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Figure 11-16 Sample Creativity Worksheet

12

Ensuring High-quality Plumbing Installations

A common perception is that high quality equates high price. Is this true regarding the level of a plumbing system's quality? When comparing a high-quality pump to a low-quality pump, it may be true. When comparing type M copper tubing to type L copper tubing, it definitely is true.

On the other hand, sometimes it is not true. Why not? The actual cost of a plumbing system must be viewed through various dimensions and from various points of view. For example, a building owner planning to possess a building over the long term views costs differently that an owner who plans to flip a building in a couple of years and turn a quick profit. 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 methodology may not be quite so clear at first glance. The responsibility of the plumbing engineer goes far beyond specifying which pump or which piping materials for use in a particular building. A large part of the plumbing specification addresses issues such as means and methods of installation, local codes, local climate, ADA requirements, 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's 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," or "plumbing installations shall be performed in a processional and workmanlike manner." While these statements have value, they fall far short of ensuring the desired level of quality expected by a contentious 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.

What one contractor or installer interprets to be a workmanlike installation may be considered poor, weak, and un-workmanlike by the next person. How can the engineer of record for a particular project remedy this situation to ensure that the client receives the quality of plumbing system desired? Providing very specific language within the body of the specification documents and including specific installation detail drawings are the best ways to accomplish this goal. Figure 12-1 shows an example of a plumbing field installation of a water heater. In the picture on the left, the installation may have appeared to comply with the code at the time of installation, but it was obviously of poor quality and was 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

Figure 12-1 A Makeshift Attempt to Support a Water Heater versus an Engineered Solution

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.

hand. On the right side of the picture is a workmanlike and engineered solution for support of 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 specification sheet that provide direction for this water heater stand installation. These forms of direction, if enforced, help ensure that a high-quality engineered application solution is installed rather than a makeshift, field-devised, possibly dangerous method.

PREVALENCE OF MAKESHIFT, FIELD-DEVISED METHODS OF INSTALLATION

In most cases when poor installations result on a jobsite, they are a result of bad habits or a lack of knowledge and direction. Bad habits are hard to break, and even conscientious tradespeople may choose to ignore 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 specifications and other documents are not clear and concise, little can be done to force a contractor to comply with the supposed intent of the design for the project without additional financial compensation. 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 not clearly spelled out in the plans or the specs provides the contractor with grounds to issue a change order and

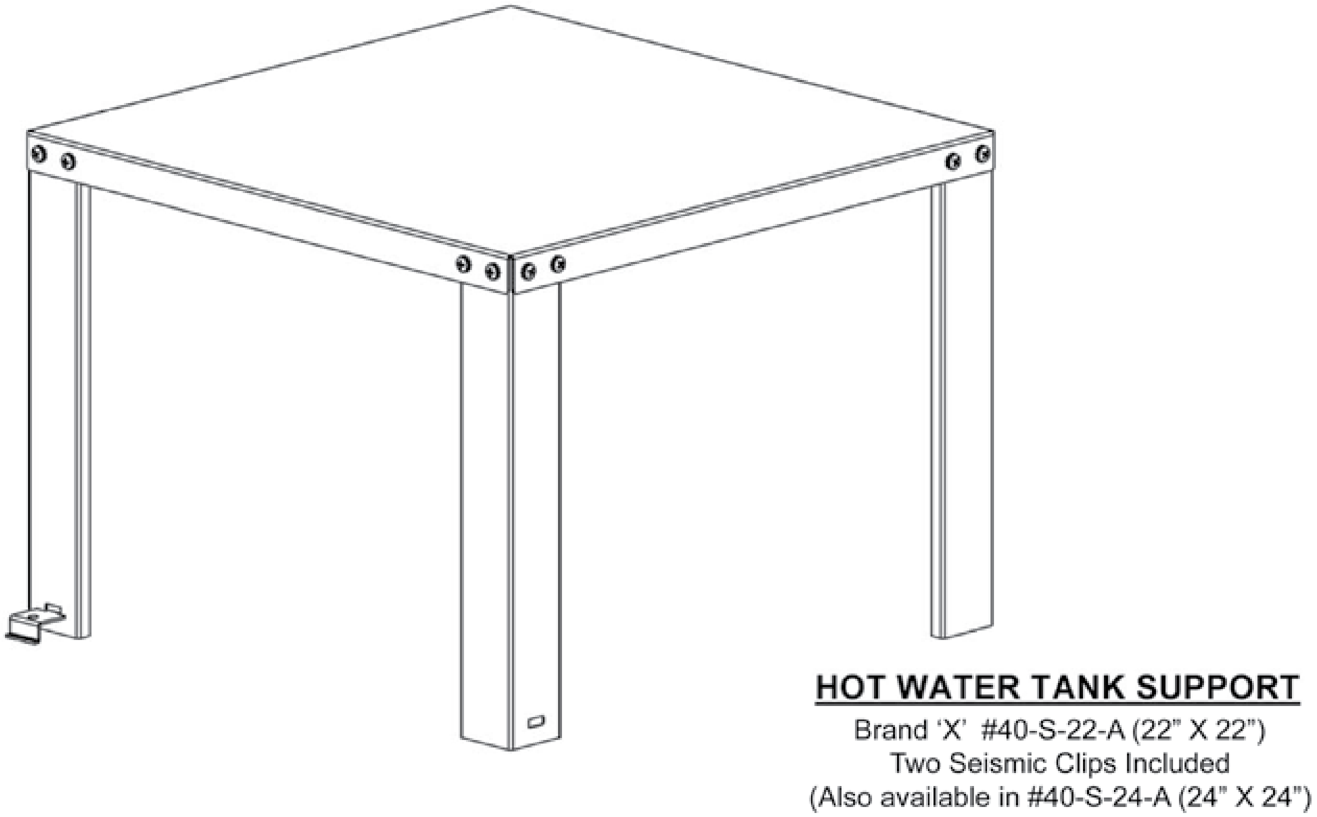


Figure 12-3 Sample Installation Detail Drawing

be paid extra to make changes or additions to the original installation.

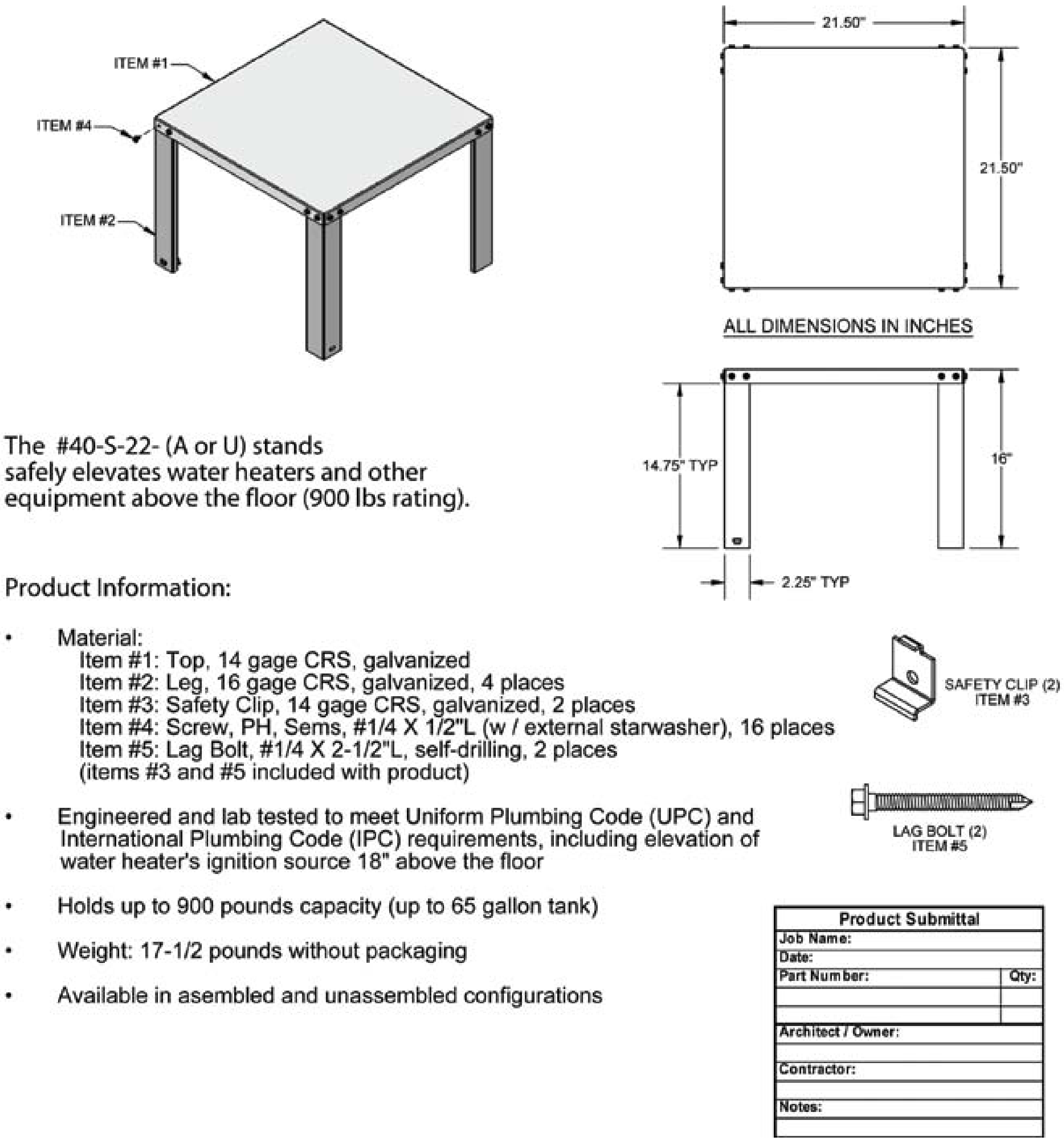
Water Piping Support and Protection

Most plumbing codes require water piping to be supported at least every floor vertically. Non-metallic water lines require additional supports at mid-story locations every 32 inches to 48 inches on vertical runs. Horizontally, various types of water tubing must be supported every 32 inches to 72 inches depending on the manufacturer's requirements and other standards. In most cases, plumbing codes and tubing manufacturer's specifications are silent regarding the methods of support that are appropriate. The methods employed to accomplish these support requirements typically are left to the installer. As a result, 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 12-7 shows a water supply rough-in for a floor-mounted toilet in a very 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, there is a good chance that several of the solder joints will fail, due to lack of appropriate support causing undue strain of the joints. Figure 12-8 shows a quality toilet rough-in installation.

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. Figure 12-10 shows a quality installation.

Some who view these pictures may think that these are extreme examples. However, consider the fact that the installations were approved by the plumbing foremen, signed off by the plumbing inspector, and then covered up by sheetrock to become permanent installations. Why were these installations allowed? The plumbing codes did not specifically disallow this work, nor did the project specification documents for these projects specifically disallow these methods of pipe support. The real question for engineers reading this information 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 your projects as well. The end result can be controlled very easily by spelling out the requirements during the design phase of the project.



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:

Figure 12-4 Sample Product Spec Sheet

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 12-11, notice the attempt to isolate copper tubing from contact with 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 12-12 shows the appropriate installation.

In Figure 12-13, 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 12-14 shows the correct installation.

Figure 12-5 Condensate Drain Stub-out (Poor)

Figure 12-6 Sink Rough-in (Poor)

Figure 12-7 Toilet Rough-in (Poor)

Figure 12-8 Toilet Rough-in (Engineered)

Figure 12-9 Shower Head Rough-in (Poor)

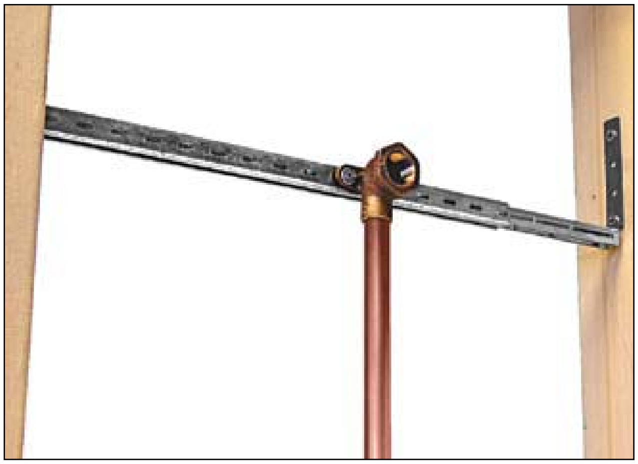


Figure 12-10 Shower Head Rough-in (Engineered)

Figure 12-11 Poor Attempt at Dissimilar Metal Isolation

Figure 12-12 Appropriate Dissimilar Metal Isolation

Figure 12-13 Dissimilar Metal Contact with Tie Wire

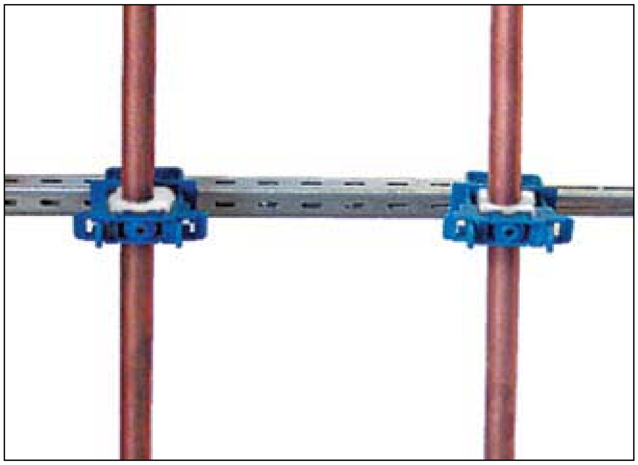


Figure 12-14 Appropriate Dissimilar Metal Isolation

PROPER EQUIPMENT SUPPORTS ARE A MATTER OF BOTH LONGEVITY AND SAFETY

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 12-15, 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? There isn't one. Figures 12-16 and 12-17 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 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.

SAFETY CONSIDERATIONS

The safety of a building's tenants must be a top concern for any design engineer. The issue previ-

Figure 12-15 Makeshift Suspended Equipment Platform

Figure 12-16 Engineered Suspended Equipment Platform

Figure 12-17 Engineered Wall-hung Equipment Platform

Figure 12-18 Makeshift Lavatory Rough-in

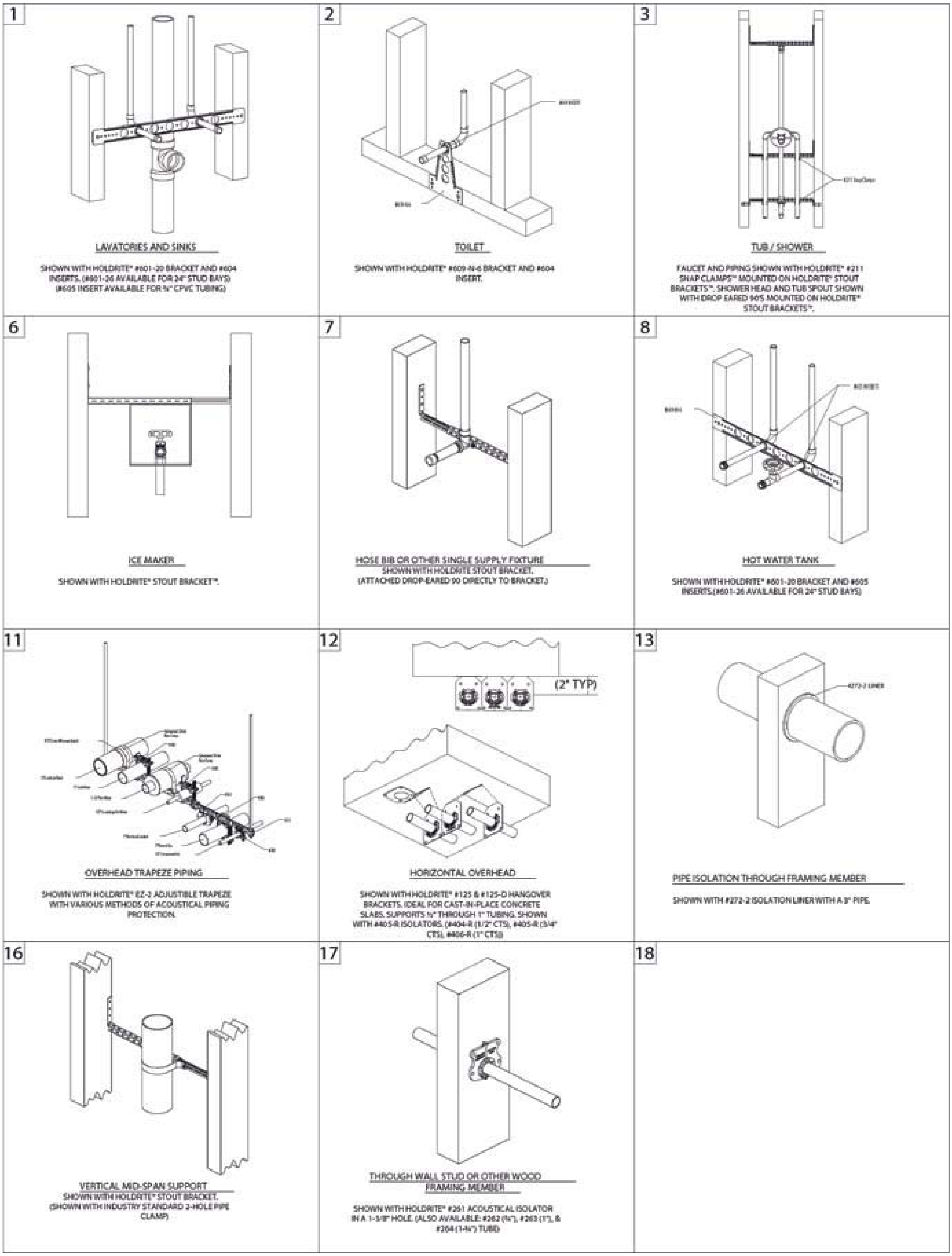
Figure 12-19 Engineered Lavatory Rough-in

ously 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 such as wire tie and plumber's tape. Make sure to strictly disallow these and other makeshift types of pipe and tubing support on your design projects.

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



LAVATORIES AND SINKS

SHOWN WITH HOLDRITE® #601-20 BRACKET AND #604 INSERTS. (#601-26 AVAILABLE FOR 24" STUD BAYS) (#605 INSERT AVAILABLE FOR ¾" CPVC TUBING)

TOILET

SHOWN WITH HOLDRITE® #609-N-6 BRACKET AND #604 INSERT.

TUB / SHOWER

FAUCET AND PIPING SHOWN WITH HOLDRITE® #211 SNAP CLAMPS™ MOUNTED ON HOLDRITE® STOUT BRACKETS™. SHOWER HEAD AND TUB SPOUT SHOWN WITH DROP EARED 90'S MOUNTED ON HOLDRITE® STOUT BRACKETS™.

ICE MAKER

SHOWN WITH HOLDRITE® STOUT BRACKET™.

HOSE BIB OR OTHER SINGLE SUPPLY FIXTURE

SHOWN WITH HOLDRITE STOUT BRACKET. (ATTACHED DROP-EARED 90 DIRECTLY TO BRACKET.)

HOT WATER TANK

SHOWN WITH HOLDRITE® #601-20 BRACKET AND #605 INSERTS.(#601-26 AVAILABLE FOR 24" STUD BAYS)

OVERHEAD TRAPEZE PIPING

SHOWN WITH HOLDRITE® EZ-2 ADJUSTIBLE TRAPEZE WITH VARIOUS METHODS OF ACOUSTICAL PIPING PROTECTION.

HORIZONTAL OVERHEAD

SHOWN WITH HOLDRITE® #125 & #125-D HANGOVER BRACKETS. IDEAL FOR CAST-IN-PLACE CONCRETE SLABS. SUPPORTS ½" THROUGH 1" TUBING. SHOWN WITH #405-R ISOLATORS. (#404-R (1/2" CTS), #405-R (3/4" CTS), #406-R (1" CTS))

PIPE ISOLATION THROUGH FRAMING MEMBER

SHOWN WITH #272-2 ISOLATION LINER WITH A 3" PIPE.

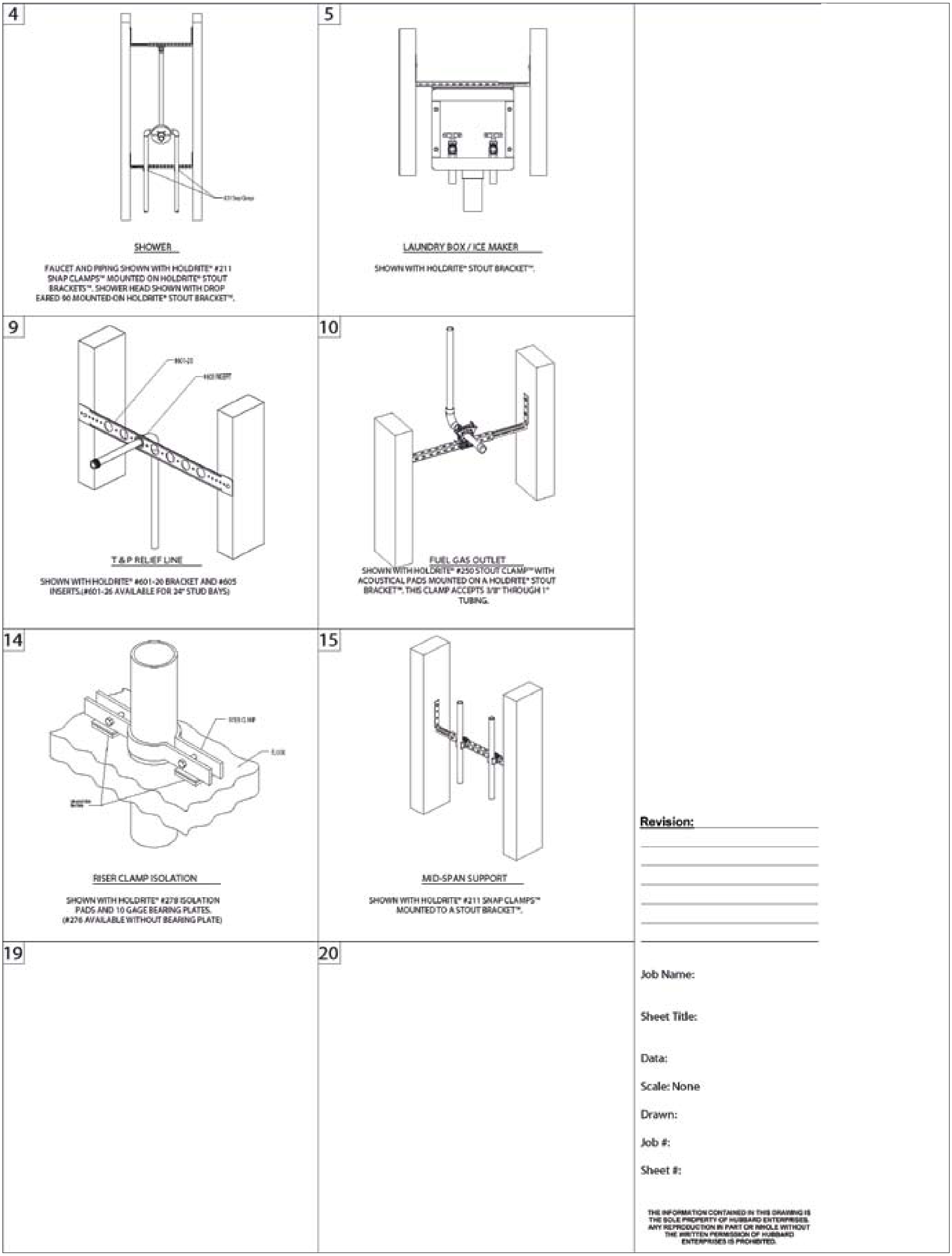
VERTICAL MID-SPAN SUPPORT

SHOWN WITH HOLDRITE® STOUT BRACKET. (SHOWN WITH INDUSTRY STANDARD 2-HOLE PIPE CLAMP)

THROUGH WALL STUD OR OTHER WOOD FRAMING MEMBER

SHOWN WITH HOLDRITE® #261 ACOUSTICAL ISOLATOR IN A 1-5/8" HOLE. (ALSO AVAILABLE: #262 (¾"), #263 (1"), & #264 (1-¼") TUBE)

Figure 12-20 Sample Plumbing Detail Page



SHOWER

FAUCET AND PIPING SHOWN WITH HOLDRITE® #211 SNAP CLAMPS™ MOUNTED ON HOLDRITE® STOUT BRACKETS™. SHOWER HEAD SHOWN WITH DROP EARED 90 MOUNTED ON HOLDRITE® STOUT BRACKET™.

LAUNDRY BOX / ICE MAKER

SHOWN WITH HOLDRITE® STOUT BRACKET™.

T & P RELIEF LINE

SHOWN WITH HOLDRITE® #601-20 BRACKET AND #605 INSERTS.(#601-26 AVAILABLE FOR 24" STUD BAYS)

FUEL GAS OUTLET

SHOWN WITH HOLDRITE® #250 STOUT CLAMP™ WITH ACOUSTICAL PADS MOUNTED ON A HOLDRITE® STOUT BRACKET™. THIS CLAMP ACCEPTS 3/8" THROUGH 1" TUBING.

RISER CLAMP ISOLATION

SHOWN WITH HOLDRITE® #278 ISOLATION PADS AND 10 GAGE BEARING PLATES. (#276 AVAILABLE WITHOUT BEARING PLATE)

MID-SPAN SUPPORT

SHOWN WITH HOLDRITE® #211 SNAP CLAMPS™ MOUNTED TO A STOUT BRACKET™.

Revision:

Job Name:

Sheet Title:

Data:

Scale: None

Drawn:

Job #:

Sheet #:

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Figure 12-20 Sample Plumbing Detail Page (continued) 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, and clearly specify it in your construction documents.

REGIONAL LOCATION AND CLIMATE CONSIDERATION

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, tornados, 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.

ENGINEERED, COST-EFFECTIVE APPLICATION SOLUTIONS READILY AVAILABLE TO CONTRACTORS

The plumbing industry doesn't evolve very quickly, but changes do take place. Many feel that the plumbing industry has been undergoing change at a faster rate in the past few years than at any time in the lives of those of us in the business today. Just consider the wide variety of pipe material types, faucet and valve types, seismic system component variations, equipment and fixture variations, and a mixed bag of widely varied codes with which to work. 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.

One trap some engineers fall into is thinking that plumbing materials and methodology have remained fairly unchanged. Some of the plumbing specification documents in use today have failed to keep up with the times and even include materials and methods considered by many to be dangerous, or at least outdated. In reality, 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, pipe testing systems are just a few of the innovations. As a result, many common installation tasks that previously required installers to create a field-devised solution 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.

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. 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.

IN THE BUILDING OWNERS' BEST INTERESTS

Building owners and contractors often see things differently. Many contractors think in the short term: the end of the project or the end of the warranty. On the other hand, a building owner looks much more long range, including maintenance and repair considerations. The design of the plumbing system should reflect this by taking the needed 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. Put yourself in their position when deciding which aspects of a plumbing system you leave undefined and left 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 12-18 and 12-19. Figure 12-18 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 12-19 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" as regards plumbing engineering documents is similar. How? When a set of plans and specifications is incomplete or based on outdated information, it fails to reflect well 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.

Over the past several years, the two most occurring hot spots regarding tenant dissatisfaction with a building relate 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.)

Green building 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. Most people agree that it is much more than a fad or a temporary trend and will continue to affect the professional engineer going forward. Many components of a building's plumbing and piping systems are involved in this endeavor, and these building systems can have a very positive impact in achieving the goals associated with the various levels of LEED certification.

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. How can this be? Makeshift methods are typically slower, less likely to be repeatable, and are often times more dangerous to execute. As an example, Figures 12-18 and 12-19 show two methods of supporting the rough-in of the water supply tubing for a lavatory sink. The assembly shown in Figure 12-18 is accomplished by the use of random materials gathered on a jobsite, possibly even scraps. It may be perceived to be less expensive, until you take into account the fact that it took 30 minutes for the plumber to collect the parts and assemble it. In the case of Figure 12-19, the plumber used a manufactured and engineered product meeting the requirements of IAPMO PS 42-96, a recognized standard for pipe support systems. The product cost the contractor about $3, but took just one minute to install. The installation will be consistent every time and is fast and safe. Does improved quality need to equate to increased expense? No. In many metropolitan areas of the country, the cost to employ a plumber can easily be $60 per hour or more. In the example discussed in Figure 12-18, the labor component alone will cost the contractor $30, plus whatever random materials were consumed. 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.

Provide Comprehensive Specification Documents that Ensure Quality

Obviously, unless the project documents are clear and complete at the beginning of the project, 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 project specification documents, 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 12-20 as an example).

If appropriate for your project, include preconstruction meetings with pertinent members of the construction team. It also is wise to require a mock-up of critical areas of the building to be created prior to actual construction. This often is done with typical bathroom and kitchen areas. 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 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.

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. Do your part in ensuring that your clients receive high-quality plumbing installations that will last for the life of the building.

13

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 to know the condition of the existing mechanical work in a 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 design and concentrates only on the existing building.

SURVEY IN EXISTING BUILDING FOR PROPOSED NEW WORK

Engineers often are called on to revise, alter, or add onto 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 and mechanical work in the existing building that was 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 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 necessary 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 mechanical work may affect the new project. Although numerous methods could be used, a procedures checklist 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 location of all types of new equipment.
- Obtain from the architect a complete set of the existing architectural and mechanical 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 mechanical engineer who designed the original building.
- Obtain, if possible, the name of the mechanical 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 mechanical 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 also can aid the engineer in determining where existing valves are located.
- Make certain that the latest site survey of the new project is available, including all existing utilities. This shall include aboveground obstacles such as boulders or small buildings that might affect the routing of new underground utilities. All information regarding the existing utilities shall be shown and verified with the utility companies.
- Determine what, if any, provisions shall 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 manufacturers in the new building as presently used in the existing building.
- Find out about any mechanical service contracts.
- Learn about the extent of all life safety systems.

Basic Documents Concerning the Existing Building

- Obtain, in particular, the date and possibly a copy of the original building plumbing code. Determine if any existing plumbing work must be upgraded based on the scope of the new work.
- Obtain the names of and contact the plumbing and fire department authorities having jurisdiction, 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 the local utility providers (water, sewage, and gas) and health departments. All requirements of the various other departments shall be carefully investigated and discussed with the respective individuals to avoid any miscommunication.
- Obtain from the fire department any special requirements for the new building.

CONTRACT DRAWING PREPARATION

Considerations for the New Work in Existing Buildings

The following discussion concerns only how the mechanical work in the existing building may affect any new work. For the actual preparation for 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.

1. Find the location of existing water services on the site plan and verify their locations. If new (or multiple) services are necessary for the new work, how will the connections be made, who is responsible for the actual connections, and from where will they be run to avoid any interference? Will curb valves be required?
2. Arrange for a new water meter with enough space for all equipment. Provide adequate drains to remove water from a backflow preventer, if necessary. Determine the size and arrangement of the inlet service (meter, backflow preventer, gauges, valves, water treatment, etc). Note the pressure on gauges. Are pressure-reducing valves necessary? Ask operating personnel about any complaints about the water service in the existing building.
3. If there are no gauges, obtain the static and residual pressure directly from the utility company, in writing.
4. Using the new drawings, count the number 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 house drain. Also calculate the hot water demand, and determine the size, type, and arrangement of the water heater. Obtain the original calculations regarding the sizing of systems in the existing building if possible.
5. If the new work is not concentrated in one place, each existing area must be searched to determine if the existing branch is large enough for the new work. If not, new piping shall be required and run as expeditiously as possible.
6. Determine the final location of the new mechanical room. Calculate the size and type of the water heaters and circulators. Select the space required for the new water meter and ancillary equipment. As a general rule, it is best to provide new heaters because the existing heaters rarely are large enough to supply both the existing fixtures and the new work. Arrange for boiler makeup and cooling tower makeup.
7. Determine the location of the new house trap and fresh air inlet. Some codes do not require either. Inquire about any public sewer problems.
8. Determine if sump and/or ejector pumps are necessary. Determine their locations, and calculate the sizes of the respective basins and height necessary to maintain the pumps.
9. Determine the primary and secondary roof drain requirements. If the discharge is to be above grade, select the location.
10. 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?
11. Will chilled drinking water be necessary?
12. Determine the extent of fire protection requirements.
13. If a kitchen is included, do grease traps need to be provided?
14. Does the client wish to install the most energy-efficient equipment?

CONDITION SURVEY

Even before a facility is occupied for the first time, its systems and components have started to deteriorate from their once like-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 meets 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. It also may be necessary for the correction of a specific set of problems.

The purpose of the survey is to prepare a report briefly describing the central building systems, observe the exposed and accessible equipment and piping, and discuss the observed physical condition of all mechanical 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 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 shall be noted. (Note: This description may be altered based on the actual contract between the consultant and the client. If the client wishes specific tests to be conducted, this shall be made clear.)

Several of the following subjects 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 shall 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 hospital, industrial, or pharmaceutical facility. The list shall be modified by any constraints of the contract between the consultant and client.

General Requirements for the Entire Building

- Obtain the plumbing code under which the building was designed. Determine code compliance of the building, equipment, and piping systems. Conduct a code search of all other existing authorities.
- If necessary, contact the authority having jurisdiction, and obtain in writing explanations of any nonconforming code deficiencies and solutions to variations.
- Explain in detail code violations to correct existing building deficiencies.
- If the building was constructed before 1978, asbestos could be a problem. A special consultant may be necessary to conduct an asbestos survey.
- Are adequate provisions for the disabled provided?
- If necessary to obtain additional information required to make critical decisions, the engineer shall recommend the services of special consultants. The client then can contract with these consultants directly.

Format for the Condition Report

The following format is suggested. It is intended to be reasonably complete and can be revised as necessary.

Introduction The first part should contain the following information:

1. The purpose and scope of the survey
2. A statement of a problem 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 an historical building
    c. Usage, both past and present
    d. A maintenance overview
4. The boundaries of the building, showing all property lines and streets, both past and present
5. Usage of the building, including past, present, and planned future use
6. Repair, upgrading, and replacement of any system 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 estimates by discipline.
5. Immediately note if any dangerous or priority condition exists, 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. This shall include:
      - House tanks: Number and location. Are the water level controls reliable and functioning?
      - House pumps: Number and location. How are they controlled? What is the condition of the shaft bearings and seals?
      - Are other pressure-increasing methods adequate?

   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.
   e. Condition of pressure boosting system, if provided, and controls. Is there excessive vibration or cycling?
   f. Provisions for pipe expansion and condition of expansion joints
   g. Presence of drip pans
   h. 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 shall include the following:
      - Number and type of heaters
      - Location of heaters
      - Any maintenance problems
      - Location and operability of safety valves and thermometers

   i. 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.
   j. Is there any sweating or indication of leakage from piping, walls, or ceiling?
   k. Are there any obvious cross-connections?
   l. Does the client wish to have the engineer review the sewer and water charges for discrepancies?
   m. Does there appear to be an excessive use of water?
   n. Have there been any unscheduled outages in the past 12 months? Also indicate which equipment requires frequent maintenance and repair.
   o. Are there any water treatment facilities, such as softeners?
2. Drainage systems
   a. Condition of sanitary and waste systems including sump pumps and sewage ejector pumps and controls
      - Number and location
      - How are they controlled?
      - What is the condition of the shaft bearings and seals?

   b. Condition of piping, cleanouts, fixture traps, plumbing fixtures, etc.
   c. Condition of storm water systems including roof drains, poor drainage, grates, and secondary drainage system. This includes the secondary system's point of discharge.
   d. Condition and presence of grease traps and check valves
   e. Point of discharge for sanitary and storm system. Will die tracing be necessary to find the point of discharge? Will the height of manholes above grade prevent the entrance of water?
   f. Poor floor drainage or drains not properly located
   g. Condition of the elevator sump pit. Is the pit clean? Are the pump and controls operating?
3. Fire suppression and life safety systems

   a. Condition of fire pump, sprinkler system piping, alarms, and valves
   b. Condition of hose racks, hose, and hose valves
   c. Condition of sprinklers, such as being painted, poor location, or corrosion
   d. Obvious areas where sprinklers are missing
   e. Condition and location of fire extinguishers
   f. Condition and location of smoke and heat detection systems
   g. Special systems such as those for computer rooms and kitchens
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 connection 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. The plumbing connections for the following:
   - Boiler water 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?

Recommendations Based on the observations and conclusions, recommendations shall be made to correct defects by subject and system. If a serious problem is discovered, it shall 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.

PROPOSED ABBREVIATIONS

In some cases, due to lack of space, a series of abbreviations 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.

Condition

1—Excellent
2—Good
3—Fair
4—Poor
5—Unserviceable
6—Little 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
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

CHECKLIST FOR THE PREPARATION OF A CONTRACT

When a contract between an engineer and client is prepared, the following checklist is helpful.

Function of Survey

- The function of the condition survey is only for the exposed equipment and components.
- Code compliance of existing plumbing and fire protection systems are 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 deficiencies noted.
- The priority of corrective action is given.
- The engineer recommends additional tests or studies to ascertain condition or function.
- The engineer provides estimated costs for correction of deficiencies.
- The engineer recommends upgrading systems to meet current engineering standards or code.

Conditions and Qualifications

- The architect furnishes a list of all codes and standards to be used.
- The architect provides, develops, and prints film.
- 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 modification to existing systems is requested, this is considered extra work.
- The architect furnishes 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.

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