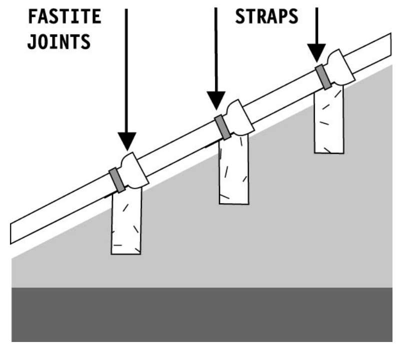
# Engineering Data

# Engineering Data

Ductile iron pipe can be laid on normal slopes without any special construction techniques. Once the pipeline exceeds a certain angle, the pipe will tend to slide down the slope. As a general rule, the designer should consider potential problems when the slope exceeds 25% for underground pipelines and 20% for aboveground pipelines.




Once the slope of the pipeline approaches these values, the designer should pay particular attention to the need for special restraint or anchor requirements. For pipelines on piers aboveground, suitable restraint can be obtained by strapping each pipe length behind the bell to the anchor block and laying the pipe with the sockets pointing uphill. A gap of 12mm between the spigot and bottom of the socket should be provided to allow for expansion and contraction. In underground pipelines with steep slopes, it is normal for the pipe to be furnished with restrained joints and laid either uphill or downhill.

**HYDROSTATIC PRESSURE TEST** All newly laid pipe or any valved section thereof should be subjected to hydrostatic pressure of at least 1.5 times the working pressure at the point of testing.

**TEST PRESSURES SHOULD MEET THE FOLLOWING CRITERIA:**

- be no less than 1.25 times the working pressure at the highest point along the test section
- exceed no pipe, fitting, or thrust-restraint design pressures
- be at least 2 hours in duration
- vary by no more than ± 5 psi (34.5 kPa) for the duration of the test
- exceed no more than twice the rated pressure of the valves or hydrants when the pressure boundary of the test section includes closed metal seated valves or hydrants
  - — valves should not be operated in either direction at differential pressure exceeding the rated pressure
  - — hydrants in a test section should only be tested with the main valve of the hydrant closed
- not exceed the rated pressure of the valves when the pressure boundary of the test section includes closed, resilient seated gate valves, or rubber-seated butterfly valves

Each valved section of pipe should be slowly filled. The specified test pressure, based on the elevation of the lowest point of the line or section under test and corrected to the elevation of the test gauge, is applied by means of a pump connected to the pipe. Valves should not be operated in either the opening or closing direction at differential pressures above the rated pressure. It is good practice to allow the system to stabilize at the test pressure before conducting the leakage test.

Before applying the specified test pressure, air must be completely expelled from the section of the piping being tested. If permanent air vents are not located at all high points, corporation stops shall be installed at such points so that the air can be expelled as the system is filled with water. After all the air has been expelled, the corporation stops are closed and the test pressure applied. At the conclusion of the pressure test, the corporation stops should be removed and plugged or left in place as required by the specifications.

Any exposed pipe, fittings, valves, hydrants, and joints should be carefully examined during the pressure test. Any damaged or defective pipe, fittings, valves, or hydrants discovered as the result of the pressure test should be repaired with sound material and the test repeated until satisfactory results are obtained.

## TESTING ALLOWANCE

The testing allowance is defined as the quantity of water that must be supplied (make-up water) to any installed pipeline, or valved section thereof, to maintain pressure within 5 psi 34.5 kPa of the specified test pressure after the air in the pipeline has been expelled and the pipe has been filled with water. The testing allowance is not measured by a drop in pressure in a test section over a period of time. No pipe installation should be accepted if the amount of make-up water is greater than that determined using the following formula:

$$T = \frac{LD\sqrt{P}}{715{,}317}$$

T = testing allowance, (L/h)
L = length of pipe tested (m)
D = nominal diameter of the pipe (mm)
P = average test pressure (kPa)

When testing against closed metal seated valves, an additional amount of make-up water per closed valve of 1.2 mL/h/mm of nominal valve size is allowed. When hydrants are in the test section, the test should be made against the main valve in the hydrant. Acceptance of an installation is determined on the basis of the testing allowance. If any test shows an amount of make-up water greater than that allowed, the installer is responsible for locating and repairing any leaks, as necessary, until the test result is within the specified allowance. All visible leaks must be repaired regardless of the amount of leakage.

Please note that the following section is an adaptation of the Ductile Iron Pipe Research Association (DIPRA) “Thrust Restraint Design for Ductile Iron Pipe” brochure. Explanations of formulas, as well as design theory and practical considerations, are presented in the DIPRA brochure. For a copy of the brochure, contact **ACIPCO**.

**THRUST BLOCKS** One of the most common methods of providing resistance to thrust forces is the use of thrust blocks. Figure 1 depicts a typical bearing thrust block on a horizontal bend. Resistance is provided by transferring the thrust force to the soil through the larger bearing area of the block such that the resultant pressure against the soil does not exceed the horizontal bearing strength of the soil. Design of thrust blocks consists of determining the appropriate bearing area of the block for a particular set of conditions. The parameters involved in the design include pipe size, design pressure, angle of the bend (or configuration of the fitting involved), and the horizontal bearing strength of the soil.

The following are general criteria for bearing block design.

- Bearing surface should, where possible, be placed against undisturbed soil. Where it is not possible, the fill between the bearing surface and undisturbed soil must be compacted to at least 90% Standard Proctor Density.

- Block height (h) should be equal to or less than one-half the total depth to the bottom of the block, ($H_t$), but not less than the pipe diameter (D’).

- Block height (h) should be chosen such that the calculated block width (b) varies between one and two times the height.

The required bearing block area is $A_b = hb = \dfrac{T}{S_b}$

Then, for a horizontal bend, $b = \dfrac{2\, S_f\, PA \sin(\Theta/2)}{h\, S_b}$

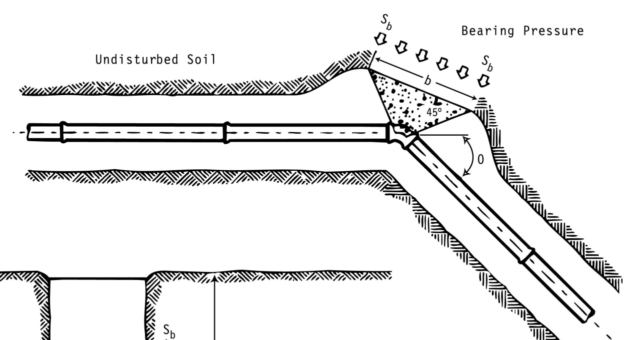
Where:
$S_f$ = safety factor (usually 1.5 for thrust block design)
P = maximum system pressure (kg/cm$^2$)
A = cross-section area of the pipe (cm$^2$)
$\Theta$ = angle of the bend (°)
$S_b$ = bearing strength of the soil (kg/m$^2$)
T = thrust force (kg)
b = block width (m)
h = block height (m)

| SOIL | BEARING STRENGTH $S_b$ (kg/m$^2$) |
|---|---|
| Muck | 0 |
| Soft Clay | 4800 |
| Silt | 7300 |
| Sandy Silt | 14,600 |
| Sand | 19,400 |
| Sandy Clay | 29,200 |
| Hard Clay | 48,800 |

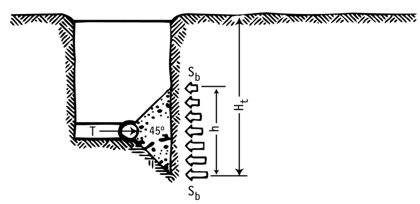
**TABLE 1. HORIZONTAL BEARING STRENGTHS.** Although the bearing strength values have been used successfully in the design of thrust blocks and are considered to be conservative, their accuracy is totally dependent on accurate soil identification and evaluation. The ultimate responsibility for selecting the proper bearing strength of a particular soil type must rest with the design engineer.

A similar approach may be used to design bearing blocks to resist the thrust forces at tees, dead ends, etc. Typical values for conservative horizontal bearing strengths of various soil types are listed in Table 1.

In lieu of the values for soil bearing strength shown in Table 1, a designer might choose to use calculated Rankine passive pressure ($P_p$) or other determination of soil bearing strength based on actual soil properties.




An alternative method of providing thrust restraint is the use of restrained joints. A restrained joint is a special push-on type joint that is designed to provide longitudinal restraint. Restrained joint systems function in a manner similar to thrust blocks, insofar as the reaction of the entire restrained unit of piping with the soil balances the thrust forces.




**RESTRAINED JOINTS** The thrust force must be restrained or balanced by the reaction of the restrained pipe unit with the surrounding soil. The source of the restraining forces is twofold. First, the static friction between the pipe unit and the soil, and second, the restraint provided by the pipe as it bears against the sidefill soil along each leg of the bend. Both of these forces are presumed to be functions of the restrained length L on each side of the bend, and they are presumed to act in the direction opposing the thrust force (i.e., directly opposing impending movement of the bend).

Values of soil cohesion ($C_s$) and internal friction angle of the soil (ø) must be known or conservatively estimated for the soil at a particular installation. The values $f_c$ and $f_ø$ are related to soil types and pipe material. Table 3 presents conservative values of these parameters for ductile iron pipe in seven general classifications of saturated soils.

A static frictional force acting on a body is equal in magnitude to the applied force up to a maximum value. In the conventional analysis, the maximum static friction is proportional to the normal force between the surfaces which provide the friction. The constant of proportionality, in this case called the coefficient of friction, depends upon the nature of the surfaces. Potyondy's empirical work indicates that for friction between pipe and soils, the force is also dependent upon the cohesion of the soil.

Thus $F_s = A_pC + W \tan \delta$ where $A_p$ is the surface area of the pipe exterior in m²/m, C is the pipe cohesion in kg/m², and $\delta$ is the pipe friction angle in degrees. The term $\delta$ is defined by the equation $\delta = f_\phi \phi$. The unit normal force W is given by $W = 2W_e + W_p + W_w$, where the earth load ($W_e$) is taken as the prism load on the pipe in kg/m. It is defined by the equation $W_e = \wp HD'$, where $\wp$ is the soil density in kg²/m³ and H is the depth of covers in meters. The earth load is doubled to account for the forces acting on both the top and the bottom of the pipe. The unit weight of the pipe and water ($W_p + W_w$) is given in Table 2. The pipe cohesion (C) is defined by the formula $C = f_c \bullet C_s$.

Then $$Fs = \frac{\pi D'C}{2} + (2W_e + W_p + W_w) \tan \delta$$

The maximum unit lateral resistance, $R_s$, at the bend is limited so as not to exceed a rectangular distribution of the Rankine passive soil pressure $P_p$, which is generally less than the ultimate capacity of the soil to resist pipe movement.

The passive soil pressure for a particular soil is given by the Rankine formula: $P_p = \wp H_c N_\phi + 2 C_s \sqrt{N_\phi}$

Where:
$P_p$ = passive soil pressure (kg/m²)
$\wp$ = soil density (kg/m³)
$H_c$ = depth of cover to center line of pipe (m)
$N_\phi = \tan^2 (45° + \phi/2)$
$C_s$ = soil cohesion (kg/m²)

As discussed above, the full Rankine passive soil pressure, $P_p$, can be developed with insignificant movement in well-compacted soils. For some of the standard Laying Conditions for ductile iron pipe, the design value of passive soil pressure should be modified by a factor $K_n$ to ensure that excessive movement will not occur. Therefore, $R_s = K_n P_p D'$.

Empirically determined values for $K_n$ can be found in Table 3.

In this context, the value chosen for $K_n$ depends on the compaction achieved in the trench, the backfill materials, and the undisturbed earth. Thus, for a horizontal bend, the equation is:

$$L = \frac{S_f PA \tan(\Theta/2)}{Fs + \frac{K_n P_p D'}{2}}$$

Extraordinary installations might result in lesser loads and frictional resistance on the pipes than that calculated by these equations. When such conditions exist, this must be provided for in the design.

# THRUST RESTRAINT CALCULATIONS USING DIPRA DESIGN

| NOMINAL PIPE DIAMETER (mm) | H (m) | CLASS A OR B SOIL TYPE 3 LAYING CONDITION | | SILT 2 CLASS C SOIL TYPE 2 LAYING CONDITION | |
|---|---|---|---|---|---|
| | | CALCULATED RESTRAINT WITHOUT POLYWRAP(m) | CALCULATED RESTRAINT WITH POLYWRAP(m) | CALCULATED RESTRAINT WITHOUT POLYWRAP(m) | CALCULATED RESTRAINT WITH POLYWRAP(m) |
| 100 | 0.8 | 3.7 | 4.3 | 6.8 | 8 |
| 100 | 1 | 3 | 3.5 | 5.5 | 6.5 |
| 100 | 1.5 | 2.1 | 2.4 | 3.8 | 4.4 |
| 100 | 2 | 1.6 | 1.8 | 2.9 | 3.3 |
| 100 | 2.5 | 1.3 | 1.4 | 2.3 | 2.7 |
| 100 | 3 | 1.1 | 1.2 | 1.9 | 2.3 |
| 150 | 0.8 | 5.3 | 6 | 9.6 | 11.2 |
| 150 | 1 | 4.3 | 4.9 | 7.8 | 9.2 |
| 150 | 1.5 | 2.9 | 3.3 | 5.4 | 6.3 |
| 150 | 2 | 2.2 | 2.5 | 4.1 | 4.8 |
| 150 | 2.5 | 1.8 | 2.1 | 3.3 | 3.8 |
| 150 | 3 | 1.5 | 1.7 | 2.8 | 3.2 |
| 200 | 0.8 | 6.7 | 7.6 | 12.2 | 14.3 |
| 200 | 1 | 5.5 | 6.3 | 10 | 11.7 |
| 200 | 1.5 | 3.8 | 4.3 | 6.9 | 8.1 |
| 200 | 2 | 2.9 | 3.3 | 5.3 | 6.2 |
| 200 | 2.5 | 2.3 | 2.7 | 4.3 | 5 |
| 200 | 3 | 2 | 2.2 | 3.6 | 4.2 |
| 250 | 0.8 | 8.1 | 9.2 | 14.7 | 17.2 |
| 250 | 1 | 6.7 | 7.6 | 12.1 | 14.2 |
| 250 | 1.5 | 4.6 | 5.2 | 8.4 | 9.8 |
| 250 | 2 | 3.5 | 4 | 6.4 | 7.5 |
| 250 | 2.5 | 2.9 | 3.2 | 5.2 | 6.1 |
| 250 | 3 | 2.4 | 2.7 | 4.4 | 5.1 |
| 300 | 0.8 | 9.4 | 10.7 | 17.1 | 20 |
| 300 | 1 | 7.8 | 8.8 | 14.2 | 16.5 |
| 300 | 1.5 | 5.4 | 6.2 | 9.9 | 11.5 |
| 300 | 2 | 4.2 | 4.7 | 7.6 | 8.9 |
| 300 | 2.5 | 3.4 | 3.8 | 6.2 | 7.2 |
| 300 | 3 | 2.8 | 3.2 | 5.2 | 6.1 |
| 350 | 0.8 | 10.7 | 12.1 | 19.4 | 22.6 |
| 350 | 1 | 8.8 | 10 | 16.1 | 18.8 |
| 350 | 1.5 | 6.2 | 7 | 11.3 | 13.2 |
| 350 | 2 | 4.8 | 5.4 | 8.7 | 10.2 |
| 350 | 2.5 | 3.9 | 4.4 | 7.1 | 8.3 |
| 350 | 3 | 3.3 | 3.7 | 6 | 7 |
| 400 | 0.8 | 11.8 | 13.4 | 21.5 | 25.1 |
| 400 | 1 | 9.9 | 11.2 | 18 | 20.9 |
| 400 | 1.5 | 6.9 | 7.9 | 12.7 | 14.8 |
| 400 | 2 | 5.4 | 6.1 | 9.8 | 11.4 |
| 400 | 2.5 | 4.4 | 5 | 8 | 9.3 |
| 400 | 3 | 3.7 | 4.2 | 6.7 | 7.8 |
| 450 | 0.8 | 13 | 14.7 | 23.6 | 27.5 |
| 450 | 1 | 10.8 | 12.3 | 19.7 | 23 |
| 450 | 1.5 | 7.7 | 8.7 | 14 | 16.3 |
| 450 | 2 | 5.9 | 6.7 | 10.8 | 12.6 |
| 450 | 2.5 | 4.8 | 5.5 | 8.8 | 10.3 |
| 450 | 3 | 4.1 | 4.6 | 7.5 | 8.7 |
| 500 | 0.8 | 14.1 | 15.9 | 25.6 | 29.8 |
| 500 | 1 | 11.8 | 13.4 | 21.5 | 25 |
| 500 | 1.5 | 8.4 | 9.5 | 15.3 | 17.8 |
| 500 | 2 | 6.5 | 7.4 | 11.9 | 13.9 |
| 500 | 2.5 | 5.3 | 6 | 9.7 | 11.3 |
| 500 | 3 | 4.5 | 5.1 | 8.2 | 9.6 |
| 600 | 0.8 | 16.1 | 18.2 | 29.4 | 34.1 |
| 600 | 1 | 13.6 | 15.4 | 24.8 | 28.8 |
| 600 | 1.5 | 9.8 | 11.1 | 17.8 | 20.8 |
| 600 | 2 | 7.6 | 8.7 | 13.9 | 16.2 |
| 600 | 2.5 | 6.3 | 7.1 | 11.4 | 13.3 |
| 600 | 3 | 5.3 | 6 | 9.7 | 11.3 |
| 700 | 0.8 | 18 | 20.3 | 32.8 | 38.1 |
| 700 | 1 | 15.3 | 17.3 | 27.9 | 32.4 |

# THRUST RESTRAINT CALCULATIONS USING DIPRA DESIGN (CONTINUED)

| NOMINAL PIPE DIAME-TER (mm) | H (m) | CLASS A OR B SOIL TYPE 3 LAYING CONDITION | | SILT 2 CLASS C SOIL TYPE 2 LAYING CONDITION | |
|---|---|---|---|---|---|
| | | CALCULATED RESTRAINT WITHOUT POLYWRAP(m) | CALCULATED RESTRAINT WITH POLYWRAP(m) | CALCULATED RESTRAINT WITHOUT POLYWRAP(m) | CALCULATED RESTRAINT WITH POLYWRAP(m) |
| 700 | 1.5 | 11.1 | 12.6 | 20.2 | 23.5 |
| 700 | 2 | 8.7 | 9.9 | 15.9 | 18.5 |
| 700 | 2.5 | 7.2 | 8.1 | 13.1 | 15.2 |
| 700 | 3 | 6.1 | 6.9 | 11.1 | 13 |
| 800 | 0.8 | 19.8 | 22.3 | 36 | 41.8 |
| 800 | 1 | 16.9 | 19.1 | 30.8 | 35.7 |
| 800 | 1.5 | 12.4 | 14 | 22.5 | 26.2 |
| 800 | 2 | 9.8 | 11 | 17.8 | 20.7 |
| 800 | 2.5 | 8.1 | 9.1 | 14.7 | 17.1 |
| 800 | 3 | 6.9 | 7.8 | 12.5 | 14.6 |
| 900 | 0.8 | 21.4 | 24.1 | 39 | 45.2 |
| 900 | 1 | 18.4 | 20.7 | 33.5 | 38.8 |
| 900 | 1.5 | 13.6 | 15.3 | 24.7 | 28.7 |
| 900 | 2 | 10.8 | 12.2 | 19.6 | 22.8 |
| 900 | 2.5 | 8.9 | 10.1 | 16.3 | 18.9 |
| 900 | 3 | 7.6 | 8.6 | 13.9 | 16.2 |
| 1000 | 0.8 | 22.9 | 25.8 | 41.8 | 48.3 |
| 1000 | 1 | 19.8 | 22.3 | 36 | 41.8 |
| 1000 | 1.5 | 14.7 | 16.6 | 26.8 | 31.2 |
| 1000 | 2 | 11.7 | 13.2 | 21.4 | 24.8 |
| 1000 | 2.5 | 9.7 | 11 | 17.8 | 20.7 |
| 1000 | 3 | 8.3 | 9.4 | 15.2 | 17.7 |
| 1200 | 0.8 | 25.7 | 28.8 | 46.8 | 54 |
| 1200 | 1 | 22.3 | 25.1 | 40.7 | 47.1 |
| 1200 | 1.5 | 16.9 | 19 | 30.8 | 35.7 |
| 1200 | 2 | 13.5 | 15.3 | 24.7 | 28.7 |
| 1200 | 2.5 | 11.3 | 12.8 | 20.7 | 24 |
| 1200 | 3 | 9.7 | 11 | 17.7 | 20.6 |
| 1400 | 0.8 | 28.1 | 31.4 | 51.1 | 59 |
| 1400 | 1 | 24.6 | 27.6 | 44.8 | 51.8 |
| 1400 | 1.5 | 18.8 | 21.2 | 34.3 | 39.8 |
| 1400 | 2 | 15.2 | 17.2 | 27.8 | 32.2 |
| 1400 | 2.5 | 12.8 | 14.5 | 23.4 | 27.2 |
| 1400 | 3 | 11 | 12.5 | 20.2 | 23.4 |
| 1500 | 0.8 | 29.1 | 32.6 | 53.1 | 61.2 |
| 1500 | 1 | 25.7 | 28.8 | 46.7 | 54 |
| 1500 | 1.5 | 19.8 | 22.2 | 36 | 41.7 |
| 1500 | 2 | 16.1 | 18.1 | 29.3 | 34 |
| 1500 | 2.5 | 13.5 | 15.3 | 24.7 | 28.7 |
| 1500 | 3 | 11.7 | 13.2 | 21.3 | 24.8 |
| 1600 | 0.8 | 30.2 | 33.8 | 54.9 | 63.3 |
| 1600 | 1 | 26.7 | 29.9 | 48.6 | 56.1 |
| 1600 | 1.5 | 20.6 | 23.2 | 37.6 | 43.6 |
| 1600 | 2 | 16.8 | 19 | 30.7 | 35.6 |
| 1600 | 2.5 | 14.2 | 16.1 | 25.9 | 30.1 |
| 1600 | 3 | 12.3 | 13.9 | 22.5 | 26.1 |

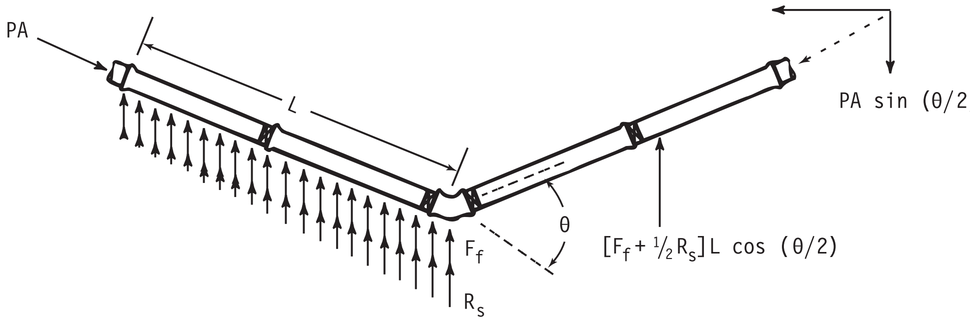
Above information is based upon the following:
10 bar maximum system pressure
90° horizontal bend: multiply by the following coefficients for other horizontal bends:

45° –0.414; 22.5° – 0.199; 11.25° – 0.098

Class K9 pipe weight.
Additionally, pipe must be bedded in at least 100mm of loose material.
H = depth of cover

## POLYETHYLENE ENCASEMENT

Limited experimental data suggest that the frictional resistance term ($F_S$) should be multiplied by a factor of 0.70 for pipe encased in polyethylene film.



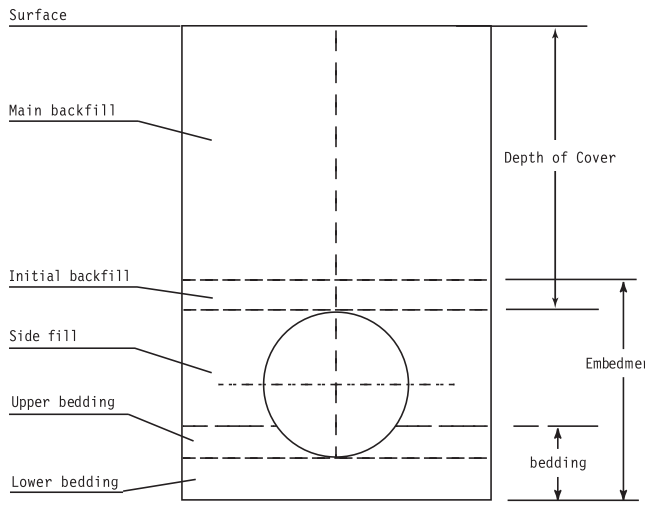

Horizontal Bend
$F_f = F_S$ ; For standard asphaltic coated pipe.

$F_f = 0.7\ F_S$ ; For polyethylene encased pipe.

| DIMENSIONS AND UNIT WEIGHTS OF PIPE AND WATER | | | | | | |
|---|---|---|---|---|---|---|
| NOMINAL PIPE SIZE (mm) | CLASS | PIPE OUTSIDE DIAMETER, D' (m) | CROSS-SECTION AREA OF PIPE, A ($cm^2$) | Wp (kg/m) | Ww (kg/m) | Wp + Ww (kg/m) |
| 100 | K9 | 0.119 | 110 | 16 | 7 | 23 |
| 150 | K9 | 0.171 | 227 | 24 | 18 | 42 |
| 200 | K9 | 0.222 | 386 | 33 | 33 | 66 |
| 250 | K9 | 0.274 | 589 | 42 | 51 | 93 |
| 300 | K9 | 0.326 | 835 | 54 | 73 | 127 |
| 350 | K9 | 0.378 | 1122 | 67 | 98 | 165 |
| 400 | K9 | 0.43 | 1446 | 80 | 128 | 208 |
| 450 | K9 | 0.482 | 1810 | 95 | 161 | 256 |
| 500 | K9 | 0.533 | 2222 | 110 | 199 | 309 |
| 600 | K9 | 0.634 | 3166 | 144 | 287 | 431 |
| 700 | K9 | 0.738 | 4277 | 183 | 390 | 573 |
| 800 | K9 | 0.844 | 5582 | 228 | 512 | 740 |
| 900 | K9 | 0.945 | 7012 | 274 | 647 | 921 |
| 1000 | K9 | 1.048 | 8625 | 326 | 799 | 1125 |
| 1200 | K9 | 1.256 | 12368 | 446 | 1155 | 1601 |
| 1400 | K9 | 1.463 | 16791 | 580 | 1604 | 2184 |
| 1500 | K9 | 1.567 | 19241 | 661 | 1840 | 2501 |
| 1600 | K9 | 1.667 | 21849 | 743 | 2094 | 2837 |

TABLE 2.

# LAYING CONDITIONS




Laying Conditions
Trench Type 2: Embedment with very light compaction, greater than 75% standard Proctor density.
Trench Type 3: Embedment with light compaction, greater than 80% standard Proctor density.
Trench Type 4: Embedment with medium compaction, greater than 85% standard proctor density.
Trench type 5: Embedment with high compaction, greater than 90% standard Proctor density.
NOTE: A layer of loose soil at least 100mm deep should be used as lower bedding for all trench conditions.

| SOIL DESIGNATION | | SOIL DESCRIPTION | f (°) | $f_f$ | $C_s$ (kg/m$^2$) | $f_c$ | g (kg/m$^3$) | $K_n$ LAYING CONDITION | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 2 | 3 | 4&5 |
| CLAY 1 | D | CLAY OF MEDIUM TO LOW PLASTICITY, LL<50, <25% COARSE PARTICLES [CL & CL-ML] | 0 | 0 | 1465 | .80 | 1440 | .40 | .60 | .85 |
| SILT 1 | D | SILTS OF MEDIUM TO LOW PLASTICITY, LL<50, <25% COARSE PARTICLES [ML & ML-CL] | 29 | .75 | 0 | 0 | 1440 | .40 | .60 | .85 |
| CLAY 2 | C | CLAY OF MEDIUM TO LOW PLASTICITY WITH SAND OR GRAVEL, LL<50, 25-50% COARSE PARTI-CLES [CL] | 0 | 0 | 1465 | .80 | 1440 | .60 | .85 | 1.0 |
| SILT 2 | C | SILT OF MEDIUM TO LOW PLASTICITY WITH SAND OR GRAVEL, LL<50, 25-50% COARSE PARTICLES [ML] | 29 | .75 | 0 | 0 | 1440 | .60 | .85 | 1.0 |
| GOOD SAND | A & B | CLEAN SAND, >95% COARSE PARTICLES [SW & SP] | 36 | .80 | 0 | 0 | 1600 | .60 | .85 | 1.0 |

## TABLE 3.

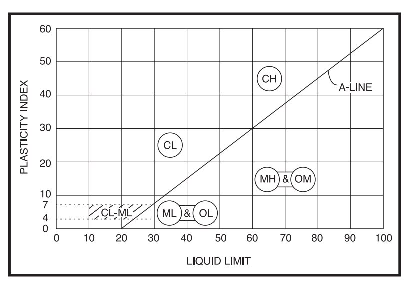
Suggested values for soil parameters and reduction constant, $K_n$. Definition "coarse particles" – held on No. 200 sieve.
See table 4 for more detailed soil descriptions.
NOTE: For conservatism, values for ℘ shown in table 3 and used in this procedure are lower than the soil weight values used to calculate earth loads in ANSI/AWWA C150/A21.50. All other values in table 3 assume saturated soil conditions and were also selected as such for conservatism.

# SOIL CLASSIFICATION CHART
# ASTM STANDARD D2487

| MAJOR DIVISIONS | | | GROUP SYMBOLS | TYPICAL NAMES | CLASSIFICATION CRITERIA | | |
|---|---|---|---|---|---|---|---|
| COARSE-GRAINED SOILS MORE THAN 50% RETAINED ON NO. 200 SIEVE | GRAVELS 50% OR MORE OF COARSE FRACTION RETAINED ON NO.4 SIEVE | CLEAN GRAVELS | GW | Well-graded gravels and gravel-sand mixtures, little or no fines | CLASSIFICATION ON BASIS OF PERCENTAGE OF FINES<br>LESS THAN 5% PASS NO. 200 SIEVE GW, GP, SW, SP<br>MORE THAN 12% PASS NO. 200 SIEVE GM, GC, SM, SC<br>5% TO 12% PASS NO. 200 SIEVE BORDERLINE CLASSIFICATION REQUIRING USE OF DUAL SYMBOLS | $C_u = D_{60}/D_{10}$ Greater than 4<br>$C_z = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3 | |
| | | | GP | Poorly graded gravels and gravel-sand mixtures, little or no fines | | Not meeting both criteria for GW | |
| | | GRAVELS WITH FINES | GM | Silty gravels, gravel-sand-silt mixtures | | Atterberg limits plot below "A" line or plasticity index less than 4 | Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols. |
| | | | GC | Clayey gravels, gravel-sand-clay mixtures | | Atterberg limits plot above "A" line or plasticity index less than 7 | |
| | SANDS MORE THAN 50% OF COARSE FRACTION PASSES NO.4 SIEVE | CLEAN SANDS | SW | Well-graded sands and gravelly sands, little or no fines | | $C_u = D_{60}/D_{10}$ Greater than 6<br>$C_z = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3 | |
| | | | SP | Poorly graded sands and gravelly sands, little or no fines | | Not meeting both criteria for SW | |
| | | SANDS WITH FINES | SM | Silty sands, sand-silt mixtures | | Atterberg limits plot below "A" line or plasticity index less than 4 | Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols. |
| | | | SC | Clayey sands, sand-clay mixtures | | Atterberg limits plot above "A" line & plasticity index greater than 7 | |
| FINE-GRAINED SOILS 50% OR MORE PASSES NO. 200 SIEVE | SILTS AND CLAY LIQUID LIMIT 50% OR LESS | | ML | Inorganic silts, very fine sands, rock flour, silty or clayey fine sands | | | |
| | | | CL | Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays | | | |
| | | | OL | Organic silts and organic silty clays of low plasticity | | | |
| | SILTS AND CLAY LIQUID LIMIT GREATER THAN 50% | | MH | Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts | | | |
| | | | CH | Inorganic clays of high plasticity, fat clays | | | |
| | | | OH | Organic clays of medium to high plasticity | | | |
| HIGHLY ORGANIC SOILS | | | PT | Peat, muck, and other highly organic soils | | | |

**PLASTICITY CHART**
For classification of fine-grained soils and fine fraction of coarse-grained soils.
Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols.
Equation of A-line:

$$PI = 0.73 (LL-20)$$




## TABLE 4.

Based on the material passing the 3-in. (75-mm) sieve.
Reprinted, with permission, from the Annual Book of ASTM Standards, copyright the American Society for Testing and Materials, Philadelphia, Pennsylvania.

## LENGTH EQUIVALENTS

| MEASURE | INCHES | FEET | MILES | MILLIMETERS | CENTIMETERS | METERS | KILOMETERS |
|---|---|---|---|---|---|---|---|
| INCHES | 1 | 0.0833 | - | 25.4 | 2.54 | 0.0254 | - |
| FEET | 12 | 1 | - | 304.8 | 30.48 | 0.3048 | - |
| MILES | 63,360 | 5,280 | 1 | - | - | 1,609.344 | 1.609344 |
| MILLIMETERS | 0.03937 | 0.003281 | - | 1 | 0.1 | 0.001 | - |
| CENTIMETERS | 0.3937 | 0.032808 | - | 10 | 1 | 0.01 | - |
| METERS | 39.3701 | 3.28084 | - | 1,000 | 100 | 1 | 0.001 |
| KILOMETERS | 39,370 | 3,280.8 | 0.62137 | - | 100,000 | 1,000 | 1 |

## AREA EQUIVALENTS

| MEASURE | SQUARE INCHES | SQUARE FEET | ACRES | SQUARE MILLIMETERS | SQUARE CENTIMETERS | SQUARE METERS |
|---|---|---|---|---|---|---|
| SQUARE INCHES | 1 | 0.006944 | - | 645.16 | 6.4516 | 0.00064516 |
| SQUARE FEET | 144 | 1 | - | 92,903.04 | 929.0304 | 0.09290 |
| ACRES | - | 43,560 | 1 | - | - | 4,046.8564 |
| SQUARE MILLIMETERS | 0.00155 | - | - | 1 | 0.01 | - |
| SQUARE CENTIMETERS | 0.1550 | 0.001076 | - | 100 | 1 | 0.0001 |
| SQUARE METERS | 1,550.0031 | 10.76391 | 0.000247 | - | 10,000 | 1 |

## WEIGHT AND VOLUME EQUIVALENTS OF WATER

| MEASURE | U.S. GALLONS | IMPERIAL GALLONS | CUBIC INCHES | CUBIC FEET | CUBIC METERS | LITERS | POUNDS |
|---|---|---|---|---|---|---|---|
| U.S. GALLONS | 1.0 | 0.833 | 231.0 | 0.1337 | 0.00378 | 3.785 | 8.33 |
| IMPERIAL GALLONS | 1.20 | 1.0 | 277.41 | 0.1605 | 0.00455 | 4.546 | 10.0 |
| CUBIC INCHES | 0.004329 | 0.003607 | 1.0 | 0.00057 | 0.000016 | – | 0.0361 |
| CUBIC FEET | 7.48 | 6.232 | 1,728.0 | 1.0 | 0.0283 | 28.317 | 62.425 |
| CUBIC METERS | 284.17 | 220.05 | – | 35.314 | 1.0 | 1,000 | 2,204.5 |
| LITERS | 0.26417 | 0.220 | 61.023 | 0.0353 | 0.001 | 1.0 | 2.205 |
| POUNDS | 0.12 | 0.1 | 27.68 | 0.016 | – | 0.454 | 1.0 |

## PRESSURE AND HEAD EQUIVALENTS OF WATER

| MEASURE | POUNDS /SQ INCH | POUNDS /SQ FOOT | ATMO- SPHERE | KILOGRAMS /SQ CM | INCHES WATER | FEET WATER | INCHES MERCURY | MILLIMETERS MERCURY | BAR |
|---|---|---|---|---|---|---|---|---|---|
| POUNDS /SQ INCH | 1 | 144.0 | 0.068046 | 0.070307 | 27.7276 | 2.3106 | 2.0360 | 51.7150 | 0.06895 |
| POUNDS /SQ FOOT | 0.006945 | 1 | 0.000473 | 0.000488 | 0.1926 | 0.01605 | 0.0141139 | 0.35913 | 0.000479 |
| ATMOSPHERE | 14.696 | 2,116.22 | 1 | 1.0332 | 407.484 | 33.9570 | 29.921 | 760.0 | 1.01325 |
| KILOGRAMS /SQ CM | 14.2233 | 2,048.16 | 0.96784 | 1 | 394.27 | 32.864 | 28.959 | 735.558 | 0.9807 |
| INCHES OF WATER | 0.03607 | 5.184 | 0.002454 | 0.00254 | 1 | 0.08333 | 0.0734 | 1.865 | 0.00249 |
| FEET OF WATER | 0.43278 | 62.3205 | 0.029449 | 0.03043 | 12.0 | 1 | 0.8811 | 22.381 | 0.02964 |
| INCHES OF MERCURY | 0.49115 | 70.726 | 0.033421 | 0.03453 | 13.617 | 1.1349 | 1 | 25.40 | 0.03386 |
| MILLIMETERS MERCURY | 0.019337 | 2.7845 | 0.0013158 | 0.0013595 | 0.5361 | 0.04468 | 0.03937 | 1 | 0.001333 |
| BAR | 14.5036 | 2,068.55 | 0.98692 | 1.0197 | 402.1 | 33.51 | 29.53 | 750.0 | 1 |

## FLOW RATE EQUIVALENTS OF WATER

| MEASURE | US GALLONS PER MINUTE | IMPERIAL GAL. PER MINUTE | US MILLION GAL. PER DAY | CUBIC FEET PER SECOND | CUBIC METER PER HOUR | LITERS PER SECOND | BARRELS PER MINUTE | BARRELS PER DAY |
|---|---|---|---|---|---|---|---|---|
| US GALLONS PER MINUTE | 1 | 0.8327 | 0.00144 | 0.00223 | 0.02271 | 0.0631 | 0.0238 | 34.286 |
| IMPERIAL GAL PER MINUTE | 1,201 | 1 | 0.00173 | 0.002676 | 0.2727 | 0.0758 | 0.02859 | 41.176 |
| US MILLION GAL PER DAY | 694.4 | 578.25 | 1 | 1.547 | 157.7 | 43.8 | 16.53 | 23,810 |
| CUBIC FEET PER SECOND | 448.83 | 373.7 | 0.646 | 1 | 101.9 | 28.32 | 10.686 | 15,388 |
| CUBIC METER PER SECOND | 15,850 | 13,199 | 22.83 | 35.315 | 3,600 | 1,000 | 377.4 | 543,447 |
| CUBIC METER PER MINUTE | 264.2 | 220 | 0.3804 | 0.5883 | 60.0 | 16.667 | 6.290 | 9,058 |
| CUBIC METER PER HOUR | 4.403 | 3.67 | 0.00634 | 0.00982 | 1 | 0.2778 | 0.1048 | 151 |
| LITERS PER SECOND | 15.85 | 13.20 | 0.0228 | 0.0353 | 3.60 | 1 | 0.3773 | 543.3 |
| LITERS PER MINUTE | 0.2642 | 0.220 | 0.000380 | 0.000589 | 0.060 | 0.0167 | 0.00629 | 9.055 |
| BARRELS (42 GAL) PER MINUTE | 42 | 34.97 | 0.0605 | 0.09357 | 9.5256 | 2.65 | 1 | 1,440 |
| BARRELS (42 GAL) PER DAY | 0.0292 | 0.0243 | 0.000042 | 0.000065 | 0.00662 | 0.00184 | 0.00069 | 1 |

# DECIMAL AND METRIC EQUIVALENT OF FRACTIONS

| INCHES | DECIMAL OF AN INCH | MILLIMETERS | INCHES | DECIMAL OF AN INCH | MILLIMETERS |
|---|---|---|---|---|---|
| 1/64 | .015625 | 0.396875 | 7/16 | .4375 | 11.112500 |
| 1/32 | .03125 | 0.793750 | 29/64 | .453125 | 11.509375 |
| 3/64 | .046875 | 1.190625 | 15/32 | .46875 | 11.906250 |
| 1/20 | .05 | 1.270003 | 31/64 | .484375 | 12.303125 |
| 1/16 | .0625 | 1.597500 | 1/2 | .5 | 12.700000 |
| 1/13 | .0769 | 1.953850 | 33/64 | .515625 | 13.096875 |
| 5/64 | .078125 | 1.984375 | 17/32 | .53125 | 13.493750 |
| 1/12 | .0833 | 2.116671 | 35/64 | .546875 | 13.890652 |
| 1/11 | .0909 | 2.309095 | 9/16 | .5625 | 14.287500 |
| 3/32 | .09375 | 2.381250 | 37/64 | .578125 | 14.684375 |
| 1/10 | .10 | 2.540005 | 19/32 | .59375 | 15.081250 |
| 7/64 | .109375 | 2.778125 | 39/64 | .609375 | 15.478125 |
| 1/9 | .111 | 2.822228 | 5/8 | .625 | 15.875000 |
| 1/8 | .125 | 3.175000 | 41/64 | .640625 | 16.271875 |
| 9/64 | .140625 | 3.571875 | 21/32 | .65625 | 16.668750 |
| 1/7 | .1429 | 3.628579 | 43/64 | .671875 | 17.065625 |
| 5/32 | .15625 | 3.968750 | 11/16 | .6875 | 17.462500 |
| 1/6 | .1667 | 4.233342 | 45/64 | .703125 | 17.859375 |
| 11/64 | .171875 | 4.365625 | 23/32 | .71875 | 18.256250 |
| 3/16 | .1875 | 4.762500 | 47/64 | .734375 | 18.653125 |
| 1/5 | .2 | 5.080000 | 3/4 | .75 | 19.050000 |
| 13/64 | .203125 | 5.159375 | 49/64 | .765625 | 19.446875 |
| 7/32 | .21875 | 5.556250 | 25/32 | .78125 | 19.843750 |
| 15/64 | .234375 | 5.953125 | 51/64 | .796875 | 20.240625 |
| 1/4 | .25 | 6.350000 | 13/16 | .8125 | 20.637500 |
| 17/64 | .265625 | 6.746875 | 53/64 | .828125 | 21.034375 |
| 9/32 | .28125 | 7.143750 | 27/32 | .84375 | 21.431250 |
| 19/64 | .296875 | 7.540625 | 56/64 | .859375 | 21.828125 |
| 5/16 | .3125 | 7.937500 | 7/8 | .875 | 22.335000 |
| 21/64 | .328125 | 8.334375 | 57/64 | .890625 | 22.621875 |
| 1/3 | .333 | 8.466683 | 29/32 | .90625 | 23.018750 |
| 11/32 | .34375 | 8.731250 | 59/64 | .921875 | 23.415625 |
| 23/64 | .359375 | 9.128125 | 15/16 | .9375 | 23.812500 |
| 3/8 | .375 | 9.525000 | 61/64 | .953125 | 24.209375 |
| 25/64 | .390625 | 9.921875 | 31/32 | .96875 | 24.606350 |
| 13/32 | .40625 | 10.318750 | 63/64 | .984375 | 25.003125 |
| 27/64 | .421875 | 10.715625 | 1 | 1 | 25.400050 |

## FLOW OF WATER IN DUCTILE IRON PIPE

The carrying capacity of a given pipeline is limited by its internal resistance to the flow of water. This resistance to flow causes a loss of head or drop in pressure as the water moves through the line. The amount of head loss depends on (1) the velocity of the water, (2) the roughness of the interior surface of the pipe, (3) the internal diameter, and (4) the length of the line. These factors have been related in the widely used Hazen-Williams formula for computing head losses, pipe sizes and carrying capacities in distribution lines. This formula is as follows:

$Q = 0.278 \times C \times D^{2.63} \times S^{0.54}$

in which:

Q = flow of water through the pipe in cubic meters per second
C = factor depending on the roughness of the interior surface
D = pipe diameter, in meters
S = hydraulic slope or head loss in meter per meter of pipe

The factor C is well known as the Hazen-Williams "C" or flow coefficient C," and its value must be estimated in flow calculations. Numerous tests have shown that cement-lined pipe installed many years ago maintains a "C" of approximately 140 to 150 even in tuberculating waters. The quality of more recent, high-speed **ACIPCO** cement linings and the availability of even larger pipe sizes may justify the use of the higher values for C, particularly in intermediate and larger pipe sizes.

## LINEAR EXPANSION OF DUCTILE IRON PIPE

The coefficient of linear expansion of ductile iron may be taken as 1.12E-05 per degree Celsius. The expansion or contraction in mm that will take place in a line of given length with various temperature changes is shown in the following table:

| Temp Differ-ence C | Length of Line in meters | | | | |
|---|---|---|---|---|---|
| | 6m | 250m | 500m | 750m | 1000m |
| | Expansion or Contraction in mm | | | | |
| 5 | 0.33 | 13.95 | 27.90 | 41.85 | 55.80 |
| 10 | 0.67 | 27.90 | 55.80 | 83.70 | 111.60 |
| 15 | 1.00 | 41.85 | 83.70 | 125.55 | 167.40 |
| 20 | 1.34 | 55.80 | 111.60 | 167.40 | 223.20 |
| 25 | 1.67 | 69.75 | 139.50 | 209.25 | 279.00 |
| 30 | 2.01 | 83.70 | 167.40 | 251.10 | 334.80 |
| 35 | 2.34 | 97.65 | 195.30 | 292.95 | 390.60 |
| 40 | 2.68 | 111.60 | 223.20 | 334.80 | 446.40 |
| 45 | 3.01 | 125.55 | 251.10 | 376.65 | 502.20 |
| 50 | 3.35 | 139.50 | 279.00 | 418.50 | 558.00 |
| 55 | 3.68 | 153.45 | 306.90 | 460.35 | 613.80 |
| 60 | 4.02 | 167.40 | 334.80 | 502.20 | 669.60 |
| 65 | 4.35 | 181.35 | 362.70 | 544.05 | 725.40 |
| 70 | 4.69 | 195.30 | 390.60 | 585.90 | 781.20 |
| 80 | 5.36 | 223.20 | 446.40 | 669.60 | 892.80 |
| 90 | 6.03 | 251.10 | 502.20 | 753.30 | 1004.40 |
| 100 | 6.70 | 279.00 | 558.00 | 837.00 | 1116.00 |

# FLOW OF WATER IN DUCTILE IRON PIPE
# HAZEN-WILLIAMS C=145*

| Flow in Liters per Second | 100mm Class K9 Pipe | | 150mm Class K9 Pipe | | 200mm Class K9 Pipe | | 250mm Class K9 Pipe | | 300mm Class K9 Pipe | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Velocity in meters per sec. | Loss of Head (m) | Velocity in meters per sec. | Loss of Head (m) | Velocity in meters per sec. | Loss of Head (m) | Velocity in meters per sec. | Loss of Head (m) | Velocity in meters per sec. | Loss of Head (m) |
| 1 | 0.13 | 0.22 | | | | | | | | |
| 2 | 0.26 | 0.81 | | | | | | | | |
| 3 | 0.38 | 1.71 | 0.17 | 0.22 | | | | | | |
| 4 | 0.51 | 2.91 | 0.22 | 0.38 | | | | | | |
| 5 | 0.64 | 4.39 | 0.28 | 0.58 | 0.15 | 0.14 | | | | |
| 10 | 1.28 | 15.84 | 0.56 | 2.08 | 0.31 | 0.50 | 0.20 | 0.17 | | |
| 15 | 1.92 | 33.53 | 0.83 | 4.41 | 0.46 | 1.05 | 0.30 | 0.35 | 0.20 | 0.14 |
| 20 | 2.56 | 57.10 | 1.11 | 7.52 | 0.62 | 1.80 | 0.39 | 0.60 | 0.27 | 0.25 |
| 25 | 3.20 | 86.28 | 1.39 | 11.36 | 0.77 | 2.71 | 0.49 | 0.91 | 0.34 | 0.37 |
| 30 | | | 1.67 | 15.91 | 0.93 | 3.80 | 0.59 | 1.27 | 0.41 | 0.52 |
| 40 | | | 2.22 | 27.10 | 1.23 | 6.47 | 0.79 | 2.17 | 0.55 | 0.89 |
| 50 | | | 2.78 | 40.94 | 1.54 | 9.78 | 0.98 | 3.28 | 0.68 | 1.34 |
| 60 | | | 3.33 | 57.37 | 1.85 | 13.70 | 1.18 | 4.59 | 0.82 | 1.88 |
| 70 | | | | | 2.16 | 18.23 | 1.38 | 6.11 | 0.95 | 2.50 |
| 80 | | | | | 2.47 | 23.33 | 1.57 | 7.82 | 1.09 | 3.20 |
| 90 | | | | | 2.78 | 29.02 | 1.77 | 9.72 | 1.23 | 3.98 |
| 100 | | | | | 3.08 | 35.26 | 1.97 | 11.82 | 1.36 | 4.84 |
| 120 | | | | | | | 2.36 | 16.55 | 1.64 | 6.78 |
| 140 | | | | | | | 2.75 | 22.02 | 1.91 | 9.02 |
| 160 | | | | | | | 3.15 | 28.19 | 2.18 | 11.55 |
| 180 | | | | | | | | | 2.45 | 14.36 |
| 200 | | | | | | | | | 2.73 | 17.45 |
| 250 | | | | | | | | | 3.41 | 26.37 |
| 300 | | | | | | | | | 4.09 | 36.95 |

Loss of Head shown is per 1,000m of pipeline.
Table is based on minimum class, cement-lined Ductile Iron Pipe.

| Flow in Liters per Second | 350mm Class K9 Pipe | | 400mm Class K9 Pipe | | 450mm Class K8 Pipe | | 500mm Class K8 Pipe | | 600mm Class K7 Pipe | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Velocity in meters per sec. | Loss of Head (m) | Velocity in meters per sec. | Loss of Head (m) | Velocity in meters per sec. | Loss of Head (m) | Velocity in meters per sec. | Loss of Head (m) | Velocity in meters per sec. | Loss of Head (m) |
| 20 | 0.20 | 0.12 | | | | | | | | |
| 30 | 0.31 | 0.26 | 0.24 | 0.14 | | | | | | |
| 40 | 0.41 | 0.44 | 0.31 | 0.23 | 0.25 | 0.13 | 0.20 | 0.08 | | |
| 50 | 0.51 | 0.67 | 0.39 | 0.35 | 0.31 | 0.19 | 0.25 | 0.12 | | |
| 60 | 0.61 | 0.94 | 0.47 | 0.49 | 0.37 | 0.27 | 0.30 | 0.16 | 0.21 | 0.07 |
| 70 | 0.72 | 1.25 | 0.55 | 0.65 | 0.43 | 0.36 | 0.35 | 0.22 | 0.24 | 0.09 |
| 80 | 0.82 | 1.60 | 0.63 | 0.84 | 0.49 | 0.46 | 0.40 | 0.28 | 0.27 | 0.11 |
| 90 | 0.92 | 1.99 | 0.71 | 1.04 | 0.55 | 0.58 | 0.45 | 0.34 | 0.31 | 0.14 |
| 100 | 1.02 | 2.41 | 0.78 | 1.26 | 0.62 | 0.70 | 0.50 | 0.42 | 0.34 | 0.17 |
| 120 | 1.23 | 3.38 | 0.94 | 1.77 | 0.74 | 0.98 | 0.60 | 0.58 | 0.41 | 0.24 |
| 140 | 1.43 | 4.50 | 1.10 | 2.35 | 0.86 | 1.30 | 0.70 | 0.78 | 0.48 | 0.31 |
| 160 | 1.64 | 5.76 | 1.26 | 3.01 | 0.98 | 1.67 | 0.80 | 0.99 | 0.55 | 0.40 |
| 180 | 1.84 | 7.16 | 1.41 | 3.75 | 1.11 | 2.08 | 0.90 | 1.24 | 0.62 | 0.50 |
| 200 | 2.05 | 8.70 | 1.57 | 4.55 | 1.23 | 2.52 | 0.99 | 1.50 | 0.69 | 0.61 |
| 250 | 2.56 | 13.15 | 1.96 | 6.88 | 1.54 | 3.81 | 1.24 | 2.27 | 0.86 | 0.92 |
| 300 | 3.07 | 18.42 | 2.35 | 9.64 | 1.85 | 5.34 | 1.49 | 3.18 | 1.03 | 1.28 |
| 350 | | | 2.75 | 12.82 | 2.15 | 7.10 | 1.74 | 4.23 | 1.20 | 1.71 |
| 400 | | | 3.14 | 16.41 | 2.46 | 9.09 | 1.99 | 5.41 | 1.37 | 2.19 |
| 450 | | | | | 2.77 | 11.31 | 2.24 | 6.73 | 1.54 | 2.72 |
| 500 | | | | | 3.08 | 13.74 | 2.49 | 8.18 | 1.71 | 3.30 |
| 600 | | | | | | | 2.98 | 11.46 | 2.06 | 4.63 |
| 700 | | | | | | | | | 2.40 | 6.16 |
| 800 | | | | | | | | | 2.74 | 7.88 |
| 900 | | | | | | | | | 3.08 | 9.80 |
| 1000 | | | | | | | | | 3.43 | 11.91 |

Loss of Head shown is per 1,000m of pipeline.
Table is based on minimum class, cement-lined Ductile Iron Pipe.

* The Hazen-Williams flow coefficient shown is a representative value for long term service of cement mortar lined ductile iron pipe. Values of C=140 to C=155 have been used by various manufacturers as a long term Hazen-Williams coefficient, depending on pipe diameter and lining smoothness.
The design of systems outside common water velocities, i.e. 0.5m/s to 1.5m/s, may involve special design considerations (for example, the generation of substantial surge pressures as a result of valve closure or other water column effects, sedimentation at extremely low velocities, etc.)

# FLOW OF WATER IN DUCTILE IRON PIPE
# HAZEN-WILLIAMS C=145*

| Flow in Liters per Second | 700mm Class K7 | | 800mm Class K7 | | 900mm Class K7 Pipe | | 1000mm Class K7 | | 1200mm Class K7 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Velocity in meters per sec. | Loss of Head (m) | Velocity in meters per sec. | Loss of Head (m) | Velocity in meters per sec. | Loss of Head (m) | Velocity in meters per sec. | Loss of Head (m) | Velocity in meters per sec. | Loss of Head (m) |
| 100 | 0.25 | 0.08 | | | | | | | | |
| 150 | 0.38 | 0.17 | 0.29 | 0.09 | 0.23 | 0.05 | | | | |
| 200 | 0.51 | 0.29 | 0.39 | 0.15 | 0.31 | 0.08 | 0.25 | 0.05 | | |
| 250 | 0.63 | 0.44 | 0.48 | 0.23 | 0.38 | 0.13 | 0.31 | 0.08 | 0.21 | 0.03 |
| 300 | 0.76 | 0.61 | 0.58 | 0.32 | 0.46 | 0.18 | 0.37 | 0.11 | 0.26 | 0.04 |
| 350 | 0.89 | 0.82 | 0.68 | 0.42 | 0.53 | 0.24 | 0.43 | 0.14 | 0.30 | 0.06 |
| 400 | 1.01 | 1.05 | 0.77 | 0.54 | 0.61 | 0.31 | 0.49 | 0.18 | 0.34 | 0.07 |
| 450 | 1.14 | 1.30 | 0.87 | 0.67 | 0.69 | 0.38 | 0.56 | 0.23 | 0.39 | 0.09 |
| 500 | 1.27 | 1.58 | 0.97 | 0.82 | 0.76 | 0.46 | 0.62 | 0.28 | 0.43 | 0.11 |
| 600 | 1.52 | 2.22 | 1.16 | 1.15 | 0.92 | 0.65 | 0.74 | 0.39 | 0.51 | 0.16 |
| 700 | 1.77 | 2.95 | 1.35 | 1.53 | 1.07 | 0.86 | 0.87 | 0.52 | 0.60 | 0.21 |
| 800 | 2.03 | 3.77 | 1.55 | 1.96 | 1.22 | 1.10 | 0.99 | 0.66 | 0.69 | 0.27 |
| 900 | 2.28 | 4.69 | 1.74 | 2.43 | 1.37 | 1.37 | 1.11 | 0.82 | 0.77 | 0.34 |
| 1000 | 2.53 | 5.70 | 1.93 | 2.96 | 1.53 | 1.66 | 1.24 | 1.00 | 0.86 | 0.41 |
| 1200 | 3.04 | 7.99 | 2.32 | 4.14 | 1.83 | 2.33 | 1.48 | 1.40 | 1.03 | 0.57 |
| 1400 | | | 2.70 | 5.51 | 2.14 | 3.10 | 1.73 | 1.86 | 1.20 | 0.76 |
| 1600 | | | 3.09 | 7.05 | 2.44 | 3.97 | 1.98 | 2.38 | 1.37 | 0.97 |
| 1800 | | | | | 2.75 | 4.94 | 2.22 | 2.96 | 1.54 | 1.21 |
| 2000 | | | | | 3.05 | 6.00 | 2.47 | 3.59 | 1.71 | 1.47 |
| 2200 | | | | | | | 2.72 | 4.29 | 1.88 | 1.76 |
| 2400 | | | | | | | 2.97 | 5.03 | 2.06 | 2.06 |
| 2600 | | | | | | | 3.21 | 5.84 | 2.23 | 2.39 |
| 2800 | | | | | | | | | 2.40 | 2.74 |
| 3000 | | | | | | | | | 2.57 | 3.12 |
| 3500 | | | | | | | | | 3.00 | 4.15 |
| 4000 | | | | | | | | | 3.43 | 5.31 |

Loss of Head shown is per 1,000m of pipeline.
Table is based on minimum class, cement-lined Ductile Iron Pipe.

| Flow in Liters per Second | 1400mm Class K7 | | 1500mm Class K7 | | 1600mm Class K7 | |
|---|---|---|---|---|---|---|
| | Velocity in meters per sec. | Loss of Head (m) | Velocity in meters per sec. | Loss of Head (m) | Velocity in meters per sec. | Loss of Head (m) |
| 400 | 0.25 | 0.04 | 0.22 | 0.03 | | |
| 500 | 0.32 | 0.05 | 0.28 | 0.04 | 0.24 | 0.03 |
| 600 | 0.38 | 0.08 | 0.33 | 0.05 | 0.29 | 0.04 |
| 700 | 0.44 | 0.10 | 0.39 | 0.07 | 0.34 | 0.05 |
| 800 | 0.51 | 0.13 | 0.44 | 0.09 | 0.39 | 0.07 |
| 900 | 0.57 | 0.16 | 0.50 | 0.12 | 0.44 | 0.08 |
| 1000 | 0.63 | 0.20 | 0.55 | 0.14 | 0.48 | 0.10 |
| 1200 | 0.76 | 0.28 | 0.66 | 0.20 | 0.58 | 0.14 |
| 1400 | 0.89 | 0.37 | 0.77 | 0.26 | 0.68 | 0.19 |
| 1600 | 1.01 | 0.47 | 0.88 | 0.33 | 0.78 | 0.24 |
| 1800 | 1.14 | 0.58 | 0.99 | 0.42 | 0.87 | 0.30 |
| 2000 | 1.27 | 0.71 | 1.10 | 0.51 | 0.97 | 0.37 |
| 2500 | 1.58 | 1.07 | 1.38 | 0.76 | 1.21 | 0.56 |
| 3000 | 1.90 | 1.50 | 1.66 | 1.07 | 1.45 | 0.78 |
| 3500 | 2.22 | 1.99 | 1.93 | 1.42 | 1.70 | 1.04 |
| 4000 | 2.54 | 2.55 | 2.21 | 1.82 | 1.94 | 1.33 |
| 4500 | 2.85 | 3.17 | 2.48 | 2.26 | 2.18 | 1.65 |
| 5000 | 3.17 | 3.85 | 2.76 | 2.75 | 2.42 | 2.01 |
| 5500 | | | 3.03 | 3.28 | 2.67 | 2.40 |
| 6000 | | | | | 2.91 | 2.81 |
| 6500 | | | | | 3.15 | 3.26 |
| 7000 | | | | | 3.39 | 3.74 |

Loss of Head shown is per 1,000m of pipeline.
Table is based on minimum class, cement-lined Ductile Iron Pipe.

* The Hazen-Williams flow coefficient shown is a representative value for long term service of cement mortar lined ductile iron pipe. Values of C=140 to C=155 have been used by various manufacturers as a long term Hazen-Williams coefficient, depending on pipe diameter and lining smoothness.

The design of systems outside common water velocities, i.e. 0.5m/s to 1.5m/s, may involve special design considerations (for example, the generation of substantial surge pressures as a result of valve closure or other water column effects, sedimentation at extremely low velocities, etc.)

## DIAMETERS, CIRCUMFERENCES, AREAS AND VOLUMES FOR MINIMUM STANDARD CLASSES OF DUCTILE IRON CEMENT-LINED PIPE

| Nominal Size mm | Outside Diameter mm | Inside Diameter mm | O.D. Area sq. m | I.D. Area sq. m | O.D. Circum-ference mm | I.D. Circum-ference mm | Volume Liters per meter | Volume Liters per 6m nom. Length |
|---|---|---|---|---|---|---|---|---|
| 100 | 118 | 99.8 | 0.0109 | 0.0078 | 370.71 | 313.53 | 7.82 | 46.94 |
| 150 | 170 | 151.4 | 0.0227 | 0.0180 | 534.07 | 475.64 | 18.00 | 108.02 |
| 200 | 222 | 203.2 | 0.0387 | 0.0324 | 697.43 | 638.37 | 32.43 | 194.58 |
| 250 | 274 | 254.4 | 0.0590 | 0.0508 | 860.80 | 799.22 | 50.83 | 304.98 |
| 300 | 326 | 305.6 | 0.0835 | 0.0733 | 1024.16 | 960.07 | 73.35 | 440.10 |
| 350 | 378 | 356.6 | 0.1122 | 0.0999 | 1187.52 | 1120.29 | 99.87 | 599.24 |
| 400 | 429 | 402.8 | 0.1445 | 0.1274 | 1347.74 | 1265.43 | 127.43 | 764.57 |
| 450 | 480 | 454.8 | 0.1810 | 0.1625 | 1507.96 | 1428.80 | 162.45 | 974.72 |
| 500 | 532 | 506.0 | 0.2223 | 0.2011 | 1671.33 | 1589.65 | 201.09 | 1206.54 |
| 600 | 635 | 609.6 | 0.3167 | 0.2919 | 1994.91 | 1915.11 | 291.86 | 1751.18 |
| 700 | 738 | 709.2 | 0.4278 | 0.3950 | 2318.50 | 2228.02 | 395.03 | 2370.17 |
| 800 | 842 | 811.8 | 0.5568 | 0.5176 | 2645.22 | 2550.34 | 517.59 | 3105.56 |
| 900 | 945 | 913.4 | 0.7014 | 0.6553 | 2968.81 | 2869.53 | 655.26 | 3931.54 |
| 1000 | 1048 | 1015.0 | 0.8626 | 0.8091 | 3292.39 | 3188.72 | 809.14 | 4854.82 |
| 1200 | 1255 | 1219.2 | 1.2370 | 1.1675 | 3942.70 | 3830.23 | 1167.45 | 7004.72 |
| 1400 | 1462 | 1417.4 | 1.6787 | 1.5779 | 4593.01 | 4452.89 | 1577.88 | 9467.30 |
| 1500 | 1565 | 1519.0 | 1.9236 | 1.8122 | 4916.59 | 4772.08 | 1812.20 | 10873.18 |
| 1600 | 1668 | 1620.6 | 2.1852 | 2.0627 | 5240.18 | 5091.27 | 2062.73 | 12376.36 |

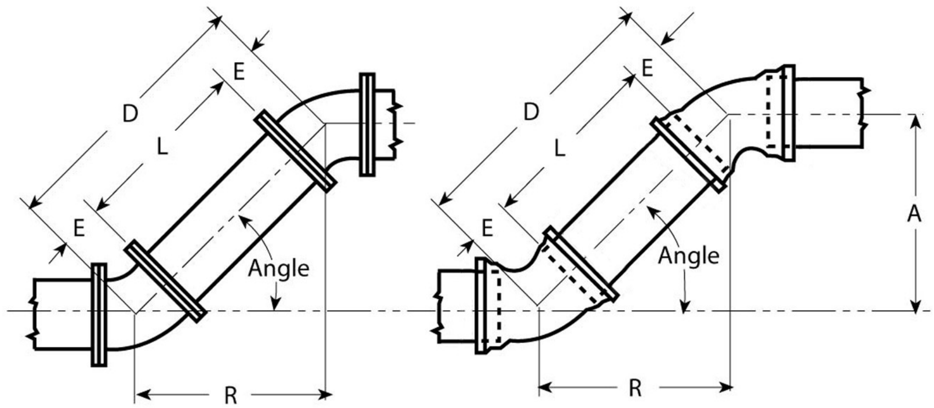
## WEIGHTS FOR PIPELINE DESIGN WEIGHT OF DUCTILE IRON PIPE AND CONTAINED WATER

| Size mm | Weight - kg per meter | | | Size mm | Weight - kg per meter | | |
|---|---|---|---|---|---|---|---|
| | Pipe | Water | Total | | Pipe | Water | Total |
| 100 | 15.9 | 7.8 | 23.7 | 600 | 114.1 | 291.9 | 406.0 |
| 150 | 23.7 | 18.0 | 41.7 | 700 | 145.6 | 395.0 | 540.6 |
| 200 | 32.1 | 32.4 | 64.5 | 800 | 179.7 | 517.6 | 697.3 |
| 250 | 42.2 | 50.8 | 93.0 | 900 | 216.2 | 655.3 | 871.5 |
| 300 | 53.5 | 73.3 | 126.8 | 1000 | 257.4 | 809.1 | 1066.5 |
| 350 | 66.3 | 99.9 | 166.2 | 1200 | 353.3 | 1167.5 | 1520.8 |
| 400 | 80.2 | 127.4 | 207.6 | 1400 | 459.4 | 1577.9 | 2037.3 |
| 450 | 84.9 | 162.5 | 247.4 | 1500 | 524.6 | 1812.2 | 2336.8 |
| 500 | 99 | 201.1 | 300.1 | 1600 | 591.2 | 2062.7 | 2653.9 |

These weights are based on minimum classes of Ductile Iron Fastite Pipe with minimum thickness standard cement lining as specified in ISO 4179 and on weight of water of 1,000 kg/m$^3$. The inside diameters are given in above table.

Ductile Iron = 7,063 kg/m$^3$

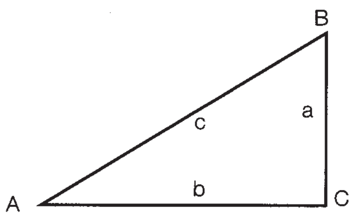
## PIPE LENGTH CALCULATIONS:
## CALCULATIONS OF PIPE LENGTHS FOR OFFSET CONNECTIONS




| Angle | D Equals | R Equals | L Equals | |
|---|---|---|---|---|
| | | | Flg Pipe | FST Pipe |
| 45° | A x 1.41 | A x 1.00 | D - (2 x E) | D - (2 x E) or D - (E + S) |
| 22 1/2° | A x 2.61 | A x 2.41 | D - (2 x E) | D - (2 x E) or D - (E + S) |
| 11 1/4° | A x 5.13 | A x 5.03 | D - (2 x E) | D - (2 x E) or D - (E + S) |
| 5 5/8° | A x 10.20 | A x 10.15 | D - (2 x E) | D - (2 x E) or D - (E + S) |

Allowance in flange joint (usually 3mm for gasket) and in Fastite joint (usually 6mm) should be taken into account in determination of required pipe length. Likewise, extension of restrained joints subjected to thrust load in installation and/or service should be considered as well.

## Solution of Right Triangle




$a^2 + b^2 = c^2$

$\text{Sin A} = \frac{a}{c}$

$\text{Cos A} = \frac{b}{c}$

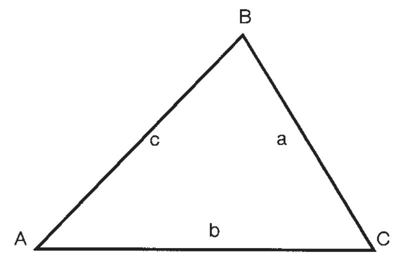
$\text{Tan A} = \frac{a}{b}$

$\text{Cot A} = \frac{b}{a}$

$\text{Sec A} = \frac{c}{b}$

$\text{Csc A} = \frac{c}{a}$

## Solution of Oblique Triangle




$A + B + C = 180°$

Law of Sines

$\frac{a}{\text{Sin A}} = \frac{b}{\text{Sin B}} = \frac{c}{\text{Sin C}}$

Law of Cosines:

$c^2 = a^2 + b^2 - 2ab \text{ Cos C}$

Law of Tangents

$\frac{a + b}{a - b} = \frac{\text{Tan } 1/2\,(A+B)}{\text{Tan } 1/2\,(A-B)}$

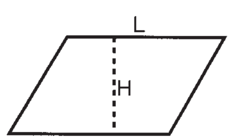
## Plane Figures

A = Area

C = Circumference

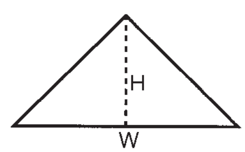
$\pi = 3.1415926536$

### Parallelogram



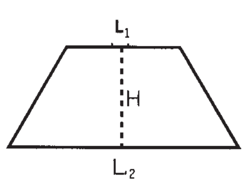

$A = H \times L$

### Triangle



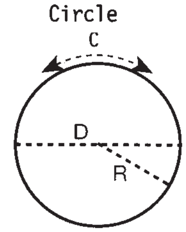

$A = 1/2\ WH$

### Trapezoid




$A = 1/2\ H(L_1 + L_2)$

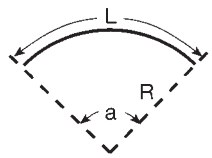
### Circle




$C = \pi D$

$A = 1/4\ \pi D^2$

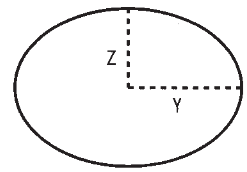
### Segment of a Circle




$A = \pi R^2 \times a \div 360$

$L = 2\pi R \times a \div 360$

### Ellipse



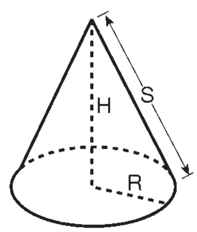

$A = \pi ZY$

$C = 2\pi \sqrt{1/2(Z^2 + Y^2)}$ (approximate formula)

## Solid Figures

A = Surface Area V = Volume

### Cone

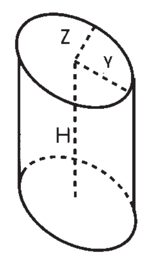



$A = \pi R (S + R)$

$A_1 = \pi RS$ (Lateral Area)

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

### Elliptical Tank

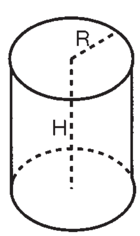



$A = 2\pi ZY + 2\pi H \sqrt{1/2(Z^2 + Y^2)}$

$V = \pi ZYH$

$A_1 = 2\pi H \sqrt{1/2(Z^2 + Y^2)}$ (Lateral Area)

### Cylinder

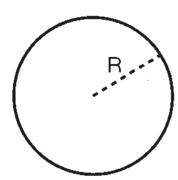



$A = 2\pi R (H + R)$

$A_1 = 2\pi RH$ (Lateral Area)

$V = \pi R^2 H$

### Sphere

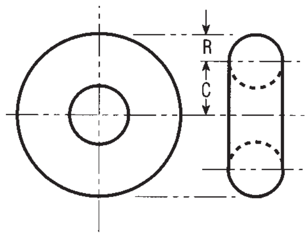



$A = 4\pi R^2$

$V = \frac{4}{3}\pi R^3$

# MATHEMATICAL FORMULAS

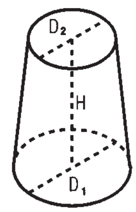
Torus




$A = 4\pi^2 CR$

$V = 2\pi^2 CR^2$

Frustum of Cone




$V = \frac{1}{12} \pi H \left[ (D_1^2 + D_2^2) + (D_1 X D_2) \right]$