Star JR Calculator User Manual

Metric Version

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1. INTRODUCTION

The use of mechanical restraints for containing thrust forces has grown steadily in the later part of the 20th century. As more and more buried pressure systems used mechanical restraints instead of thrust blocks for thrust restraint, the greater the demand grew for design tools that calculate the restrained length. The *Star JR Calculator* is the latest offering in this field. When using mechanical restraints, one must determine the length of pipe that must be restrained near a fitting in order to contain the unbalanced thrust forces generated at changes in direction or changes in size. Programs such as the *Star JR Calculator* have greatly automated this design calculation. This *User Manual* is broken into following sections:

- Section 2 provides guidance on entering the input the program needs in order to calculate the restrained length.
- Section 3 gives details on the underlying theory for mechanical thrust restraint.
- Section 4 gives specifics for common fitting configurations where a restrained length calculation may be needed.
- Section 5 is a list of references.
- Section 6 contains Appendix A, which discusses the Unified Soil Classification System.
- Section 7 has Appendix B, which details standard trench types.

2. PROGRAM HELP

Program's Main Screen

The program's main screen is shown to the left. The main screen has been subdivided into five areas with colored rectangles.

- In the red rectangle is a field into which the user may enter a unique identifier for the location for which the calculation is being run.
- In the green rectangle is a hot link that pulls up this *User Manual*.
- Calculation inputs are inside the blue rectangle.
- Clicking the RUN CALCULATION button in the purple rectangle prompts the program to run the restrained length calculation based on the inputs entered.
- The output (the restrained length) appears inside the orange rectangle after the RUN CALCULATION button is clicked. If any inputs are changed, the calculated length disappears. This

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<td>will avoid the possibility of printing a calculation sheet where the output does not match the inputs.</td>
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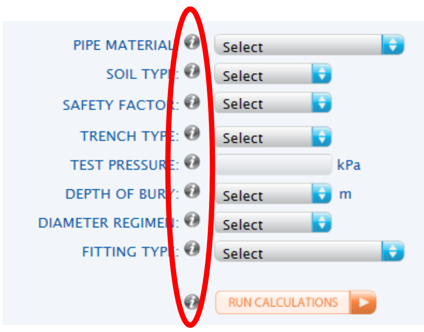
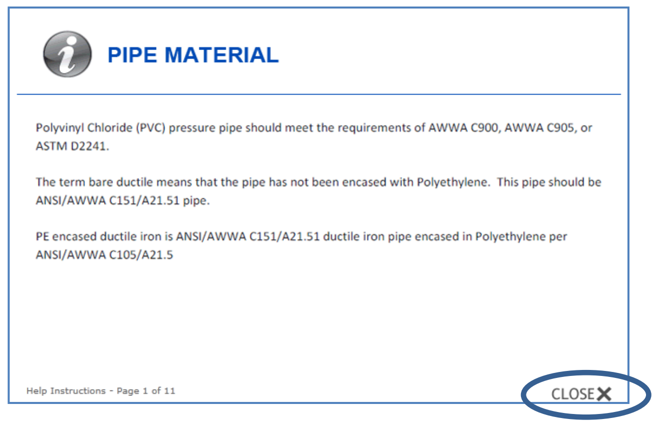
<td>

Context Sensitive Help</td>
<td>Context sensitive help is available by clicking any of the  shown in the red ellipse. If the question mark next to PIPE MATERIAL is clicked, a help page similar to the one shown below appears. Click the CLOSE button in the lower right to return to the main calculation screen.

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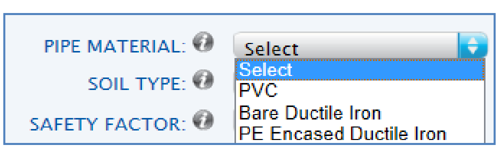
<td>

Pull Down Menu for Pipe Material</td>
<td>When the pull down menu next to pipe material is clicked, the user is given three options.

The first option is PVC. PVC pressure pipe should meet the requirements of AWWA C900, AWWA C905, or ASTM D2241.

The second option is Bare Ductile Iron. This is ductile iron pipe that has not been encased with Polyethylene. This pipe should be ANSI/AWWA C151/A21.51 pipe.

The third and last option is PE Encased Ductile Iron. This is ANSI/AWWA C151/A21.51 ductile iron pipe that has been encased in Polyethylene per ANSI/AWWA C105/A21.5</td>
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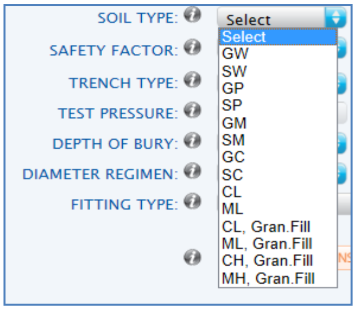
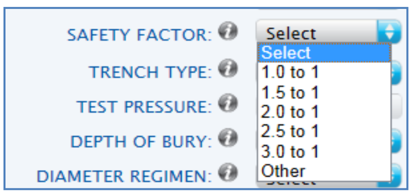
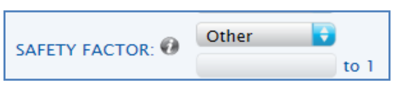


Pull Down Menu for Soil Type

When the pull down menu next to SOIL TYPE is clicked, the user is given fourteen types of soil to choose from. Please see Appendix A of this *User Manual* for details on how these soils are classified.



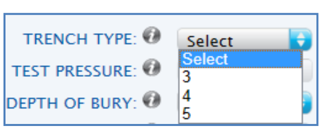
Pull Down Menu for Safety Factor



User Defined Safety Factor

When the pull down menu next to SAFETY FACTOR is clicked, the user is given five pre-defined options and a user defined option. (This is shown in the upper screen shot on the left.) If the desired safety factor is one of the pre-defined options, select it. If a different safety factor is desired, click Other. After Other is clicked, a field appears below the SAFETY FACTOR pull down menu. Enter the user defined safety factor in that field, as shown in the lower screen shot to the left. The program requires user defined safety factors to be between 1 and 5.

A safety factor of 1.5 is typically used for the restrained length calculation for ductile iron and PVC. (Note: This is a different value than the safety factor used for rating the pressure capability of the restraints and fittings.)



Pull Down Menu for Trench Type

When the pull down menu next to TRENCH TYPE is clicked, three options appear. Refer to Appendix B for details on these trench types. Trench Types 1 and 2 are not recommended in the area delineated by the restrained length.

Input Field for Test Pressure

The test pressure is user defined and is inputted through a field rather than a pull down menu. The pressure must be a whole number between one and 2400 kPa. The pressure entered should be the highest pressure that the system is expected to experience.

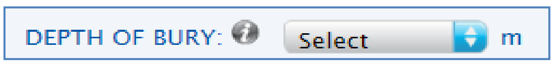
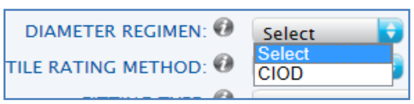
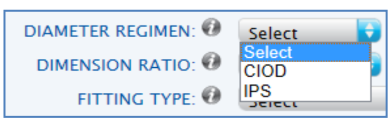
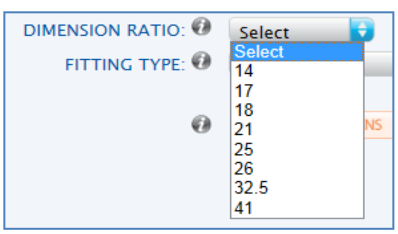
	It is the designer's responsibility to recommend a test pressure appropriate for the piping system. The *Star JR Calculator* does not evaluate whether or not the test pressure entered is appropriate for the pipe material and class of pipe entered.
 **Pull Down Menu for Depth of Bury**	When the pull down menu for DEPTH OF BURY is clicked, 20 different burial depths appear. The depth of bury ranges from 0.5 to 10.0 meters in half meter increments. The depth of bury is measured from the top of the pipe. For reducers, depth of bury is to the higher of the two pipes entering the reducer. For vertical offsets, depth of bury is to the top of the pipe entering the upper fitting.
 **Pull Down Menu for Diameter Regimen When Ductile Iron is the Pipe Material**  **Pull Down Menu for Diameter Regimen When PVC is the Pipe Material**	For ductile iron pipe, the program only allows one diameter regimen – CIOD. (See the upper screen shot on the left.) For PVC pipe, the user may select either CIOD or IPS. (See the lower screen shot on the left.) Table 2-1 below lists the actual outside diameter for the corresponding nominal diameter for the two diameter regimens coded into the program.

Table 2-1. Actual Outside Diameters for CIOD and IPS Diameter Regimens

Nominal Diameter (mm)	CIOD Diameter Regimen (mm)	IPS Diameter Regimen (mm)
75	100.58	88.90
100	121.92	114.30
150	175.26	168.28
200	229.87	219.08
250	281.94	273.05
300	335.28	323.85
350	388.62	355.60
400	441.96	406.40
450	495.30	457.20
500	548.64	508.00
600	655.32	609.60
750	812.80	762.00
900	972.82	914.400
1,050	1,130.3	NA
1,200	1,290.32	NA



Dimension Ratio Pull Down Menu for PVC

When PVC is selected as the pipe material, a DIMENSION RATIO pull down menu appears. To precisely calculate the weight of the pipe and the fluid in the pipe, one needs to know both the diameter regimen and dimension ratio for PVC.

The program lists the available dimension ratios found in three standards: AWWA C900, AWWA C905, and ASTM D2241. It is the user's responsibility to confirm that the dimension ratio entered is available for the diameter and diameter regimen combination under consideration. Please refer to the appropriate PVC pressure pipe standard for details.

When ductile iron is selected as the pipe material, a DUCTILE RATING pull down menu appears. The AWWA C151 standard for ductile iron has two different rating

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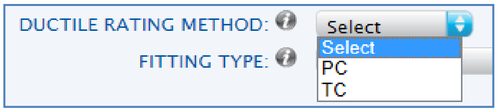
<td>

Ductile Rating Method Pull Down Menu When Ductile Iron is the Pipe Material</td>
<td>methods. Table 1 of AWWA C151-09 describes Pressure Class pipe. Table 3 of AWWA C151-09 details Special Thickness Classes. The footnote to Table 3 notes that Special Thickness Classes were referred to as Standard Thickness Classes in the 1986 edition of the standard. Select PC for Pressure Class ductile iron. Select TC for Special Thickness Class ductile iron. The rating method and corresponding TC or PC are needed to precisely calculate the weight of the pipe and the fluid in the pipe.</td>
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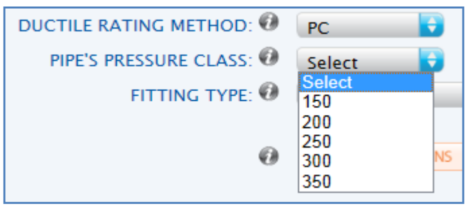
<td>

Pressure Class Pull Down Menu for Ductile Iron Pipe</td>
<td>When ductile iron is selected as the pipe material and PC is selected as the rating method, a PIPE'S PRESSURE CLASS pull down menu appears. The AWWA C151 standard covers five pressure classes (PCs). However, not every PC is available in each diameter. If a PC is selected that is not listed in the AWWA C151 standard for that diameter, the program will notify the user with a message at the bottom of the main screen.</td>
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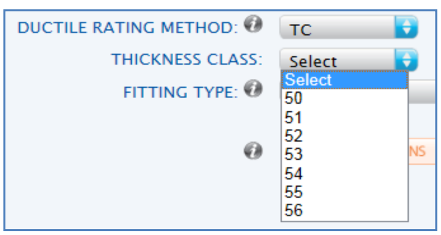
<td>

Thickness Class Pull Down Menu for Ductile Iron Pipe</td>
<td>When ductile iron is selected as the pipe material and TC is selected as the rating method, a THICKNESS CLASS pull down menu appears. The AWWA C151 standard has seven special thickness classes (TCs) specified. However, not every TC is available in each diameter. If a TC is selected that is not listed in the AWWA C151 standard for that diameter, the program will notify the user with a message at the bottom of the main screen.</td>
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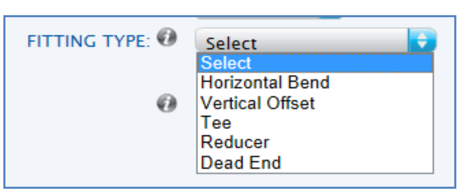
<td>

Pull Down Menu for Fitting Type</td>
<td>When the FITTING TYPE pull down menu is clicked, five configurations appear. Refer to the following sections for a discussion on each configuration.

Section 3 for horizontal bends.
Section 4.1 for vertical offsets.
Section 4.4 for tees.
Section 4.3 for reducers.
Section 4.2 for dead ends.
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3. THRUST RESTRAINT THEORY

This section reviews thrust restraint theory. First, the building blocks are introduced in Subsection 3.1. The remaining subsections address these building blocks individually. Subsection 3.2 looks at the unbalanced thrust force. Subsections 3.3 through 3.5 examine how that unbalanced thrust force is resisted. This is accomplished through friction (Subsection 3.3), adhesion resistance (Subsection 3.4), and passive soil pressure (Subsection 3.6). The friction forces and adhesion resistance are combined in Subsection 3.5. Subsection 3.7 reassembles the thrust restraint building blocks into an equation for calculating the restrained length.

3.1 Pipe / Soil Interaction at a Horizontal Bend

An early study is used to introduce the mechanisms at work. In 1970, Kennedy and Wickstrom completed a model study on thrust restraint that they conducted for US Pipe and Foundry. The study involved restrained, small diameter pipe that was installed in sand in a soil box. Two horizontal bend angles were examined: a 45-degree bend and a 90-degree bend. Figure 3-1 shows the position before pressurization in gray and the approximate position after pressurization. The unbalanced thrust force (indicated by the red arrow) causes the fitting to move in the direction shown. This thrust force also causes bending, rotation, and movement in the pipe legs joined to the fitting. That movement is resisted by soil friction (shown by the orange arrows) and passive resistance (shown by the gray arrows). If the soil is cohesive, adhesion forces also resist the piping system's movement. The adhesive forces are shown by the orange arrows as well.

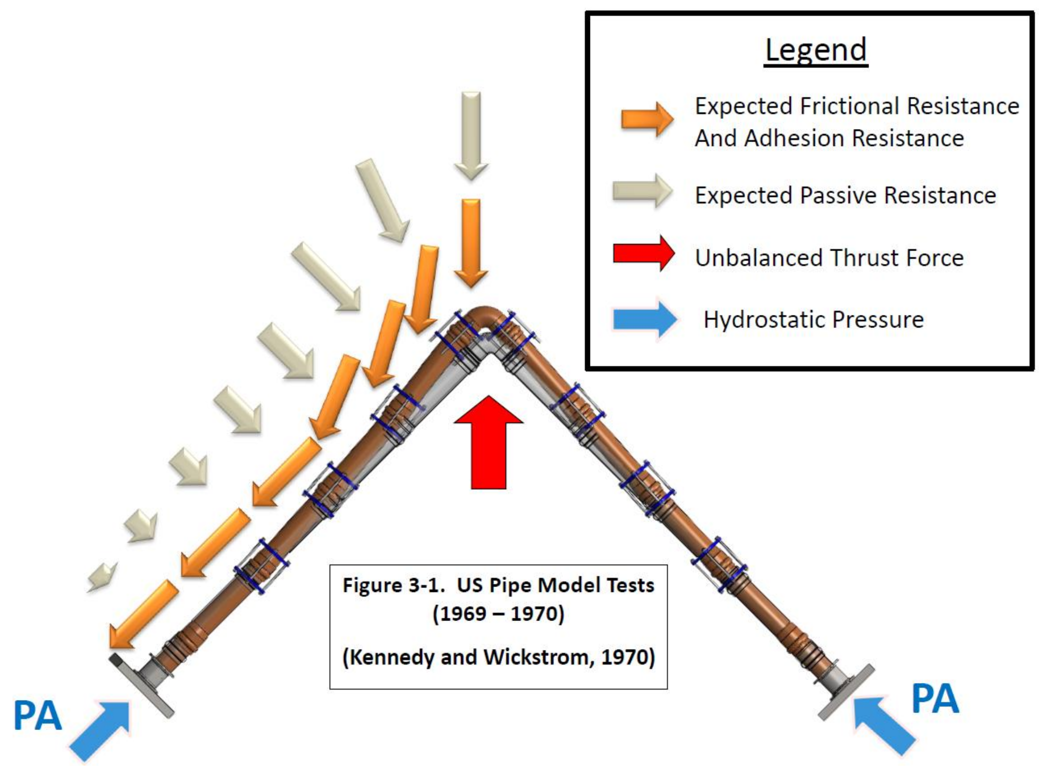

Figure 3-1. US Pipe Model Tests (1969 – 1970)

(Kennedy and Wickstrom, 1970)

3.2 Thrust Force

Figure 3-2 is a simpler version of Figure 3-1. Figure 3-2 is a vector diagram that shows the derivation of the thrust force, T, for a horizontal bend. Each leg has a hydrostatic force of PA. That force has been projected to the fitting's point of inflection. The horizontal and vertical components of the hydrostatic force are shown with the dashed arrows. The horizontal component of PA [Cos(Δ/2)] for each leg are equal and opposite; therefore, they cancel each other out. The vertical component of the hydrostatic force for each leg is PA [Sin(Δ/2)]. The resultant thrust force, T, is shown in green; and it is the sum of the two vertical components. (Note: The cross sectional area, A, is calculated using the pipe's outside diameter.)

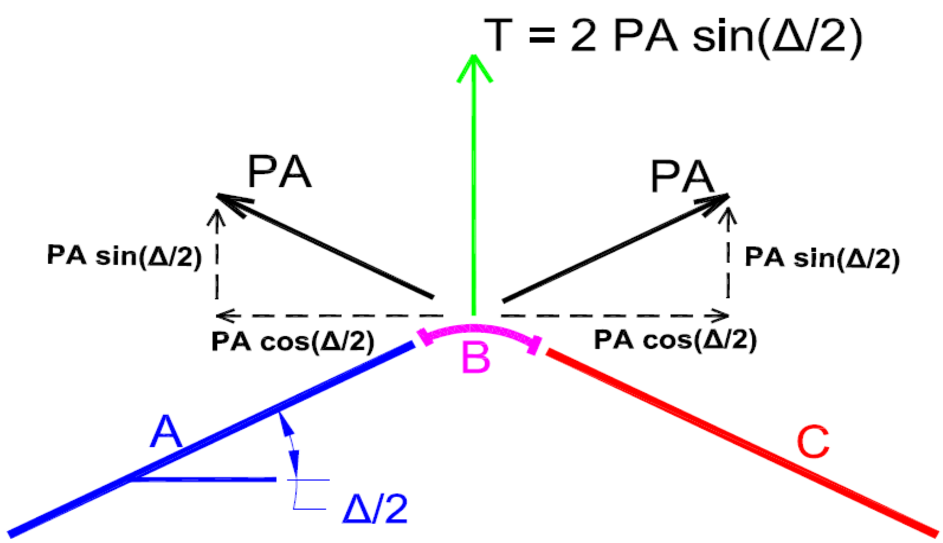

Figure 3-2. Vector Diagram of Thrust Forces at a Horizontal Bend

3.3 Frictional Resistance

Friction is one of the mechanisms resisting the unbalanced thrust force. To calculate the friction, one first determines the normal force (Subsection 3.3.1) and then multiplies it by the coefficient of friction (Subsection 3.3.2).

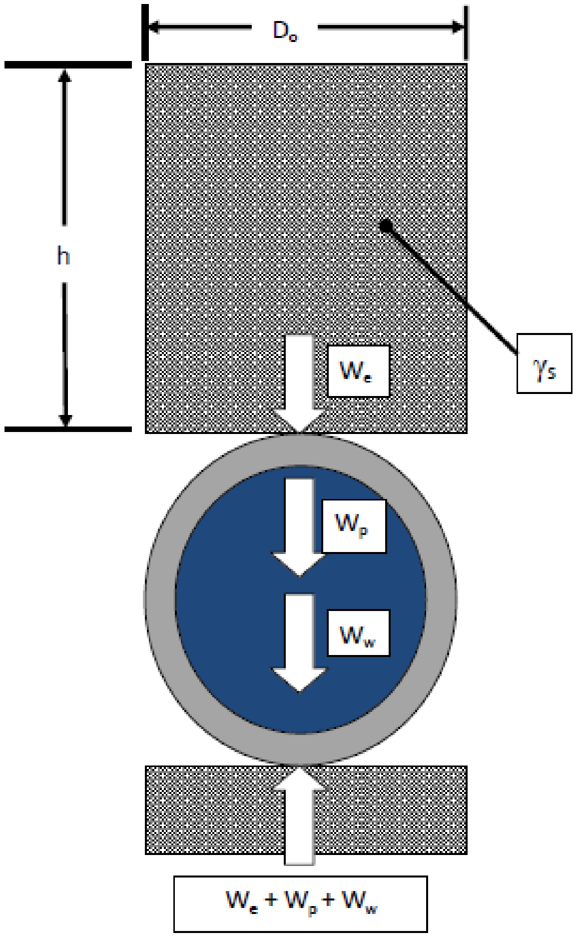

Figure 3-3. Weights Considered When Calculating The Normal Force

3.3.1 Normal Force. The normal force is determined by summing the weights shown in Figure 3-3. Those weights are

- the earth load (W_e) in kN/m,
- the weight of the water (or other fluid) in the pipe (W_w) in kN/m, and
- the weight of the pipe (W_p) in kN/m.

The total normal force in plf from the backfill, weight of water, and pipe is given as W in Equation (3-1).

$$W = 2W_e + W_w + W_p \qquad \textbf{(3-1)}$$

Use Equation (3-2) to calculate the earth load.

$$W_e = h\,\gamma_s\,D_o \qquad \textbf{(3-2)}$$

Where:

W_e is the earth load in kN/m
h is the height of cover in m
γ_s is the unit weight of soil in kN/m^3. (Refer to Table 3-1.)
D_o is the pipe outside diameter in m.

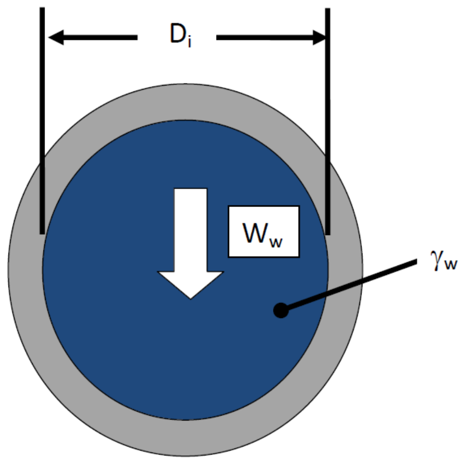

Figure 3-4. Weight of Fluid Inside the Pipe

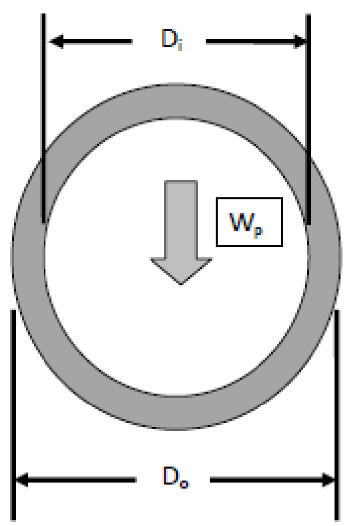

Figure 3-5. Weight of the Pipe

Table 3-1. Unit Weight of Soil Used by Soil Group

Soil Group*	Unit Weight of Soil, γ_s (kN/m^3)
GW, SW	17.3
GP, SP	17.3
GM, SM	17.3
GC, SC	15.7
CL	15.7
ML	15.7
CL / Granular Embedment	15.7
ML /Granular Embedment	15.7
CH / Granular Embedment	15.7
MH / Granular Embedment	15.7

* Appendix A gives details on soil classification

Use Equation (3-3) to calculate the weight of water (or other fluid). (Refer to Figure 3-4.)

$$W_w = \gamma_w (\pi/4) D_i^{\,2} \qquad \textbf{(3-3)}$$

Where:

W_w is the weight of fluid inside the pipe in kN/m.
γ_w is the unit weight of fluid inside the pipe in kN/m^3. For water, it is 9.8 kN/m^3.
D_i is the pipe inside diameter in m.

The *Star JR Calculator* assumes that the fluid being transported has the unit weight of water. Typically, wastewater is assumed to have the same unit weight as water.

The last item for computing the normal force is the weight of the pipe in pounds per linear foot. *Star's JR Calculator* is unique in that it gathers more pipe data for determining the pipe's weight than other calculators.

- *PVC.* For PVC, the program asks for the diameter regimen of the pipe (IPS or CIOD) and the dimension ratio.
- *DI.* For ductile iron, the program asks which rating method is being used (thickness class or pressure class) and the corresponding PC or TC.

With this pipe data, the program computes a weight specific for the combination of pipe data entered. This gives the *Star JR Calculator* greater accuracy compared to programs that assume a typical weight for each diameter for a particular pipe material. Table 3-2 shows that the difference between the heaviest pipe available for a particular diameter compared to the lightest can be significant.

Table 3-2. Pipe Weight Comparisons

Diameter and Pipe Material	Heaviest	Lightest
1,200mm Ductile Iron	PC350 weighs 4.93 kN/m	PC150 weighs 3.25 kN/m
600mm PVC	DR18 with a CIOD weighs 1.0 kN/m	DR41 with an IPS OD weighs 0.4 kN/m

For ductile iron pipe, the *Star JR Calculator* uses the weight per linear foot listed in the AWWA C151 standard. For PVC pipe, Equation (3-4) is used. (Refer to Figure 3-5.)

$$W_p = \rho_{pvc}\,\gamma_w\,(\pi/4)\,[D_o^2 - D_i^2] \qquad \textbf{(3-4)}$$

Where:

W_p is the weight of the pipe in kN/m
ρ_{pvc} is the specific gravity for PVC. The program uses 1.4.
γ_w is the unit weight of water, which is 9.8 kN/m^3
D_o is the pipe outside diameter in m
D_i is the pipe inside diameter in m

3.3.2 Coefficient of Friction. The other variable needed for calculating the friction force is the coefficient of friction, μ_{ps}. The value of μ_{ps} is determined using Equation (3-5), which is based on empirical work done by Potyondy (1961).

$$\mu_{ps} = \mathrm{Tan}(f_\phi \phi) \qquad \textbf{(3-5)}$$

Where:

μ_{ps} is the friction coefficient between the pipe and the soil
f_ϕ is the ratio of the pipe-soil interface friction angle to soil friction angle. (Refer to Table 3-3.)
ϕ is the internal friction angle of the soil in degrees. (Refer to Table 3-3.)

Table 3-3. Soil Properties Used for Calculating the Coefficient of Friction

Soil Group*	f_ϕ		ϕ
	DI	PVC	(Degrees)
GW, SW	1.0	0.7	36
GP, SP	1.0	0.7	31
GM, SM	1.0	0.7	30
GC, SC	1.0	0.7	25
CL	1.0	0.7	20
ML	1.0	0.7	29
CL / Granular Embedment	1.0	0.7	31
ML / Granular Embedment	1.0	0.7	31
CH / Granular Embedment	1.0	0.7	31
MH / Granular Embedment	1.0	0.7	31

* Appendix A gives details on soil classification

3.3.3 Magnitude of Friction Force. Now that the inputs have been determined, the magnitude of the frictional resistance may be calculated using Equation (3-6).

$$F_{sf} = \mu_{ps} W \qquad \textbf{(3-6)}$$

Where:

F_{sf} is the frictional force in kN/m
μ_{ps} is the friction coefficient between the pipe and the soil
W is the total normal force from the weight of the backfill, pipe, and water in kN/m

3.4 Adhesion Resistance

In the previous subsection, it was noted that the coefficient of friction was calculated using the approach first proposed by Potyondy. When using this approach, one also accounts for the adhesion resistance (F_{sa}) exhibited by cohesive soils as follows:

$$F_{sa} = A_p f_c C_s \qquad \textbf{(3-7)}$$

Where:

F_{sa} is the adhesion resistance in kN/m
A_p is the surface area of the pipe in m^2 / m
f_c is the ratio of the pipe-soil adhesion to soil adhesion
C_s is the soil cohesion in kN/m^2

When determining the surface area of the pipe, one uses either half of the circumference (Figure 3-6a) or the entire circumference (Figure 3-6b). For horizontal bends, vertical offsets, and runs of tees, half of the circumference is used; see Equation (3-8a). For branches of tees, reducers, and dead ends, the entire circumference is used; see Equation (3-8b).

$$A_{p\text{-}hc} = (\pi/2)\, D_o \qquad \textbf{(3-8a)}$$

or

$$A_{p\text{-}ec} = \pi\, D_o \qquad \textbf{(3-8b)}$$

Where:

$A_{p\text{-}hc}$ is the surface area of the pipe in m^2 / m based on half of the circumference
$A_{p\text{-}ec}$ is the surface area of the pipe in m^2 / m based on the entire circumference

Table 3-4. Soil Properties Used for Calculating the Adhesion Resistance

Soil Group*	f_c		C_s (kPa)
	DI	PVC	
GW, SW	0	0	0
GP, SP	0	0	0
GM, SM	0	0	0
GC, SC	0.4	0.2	10.8
CL	0.5	0.3	12.0
ML	0	0	0
CL / Granular Embedment	0	0	0
ML / Granular Embedment	0	0	0
CH / Granular Embedment	0	0	0
MH / Granular Embedment	0	0	0

* Appendix A gives details on soil classification

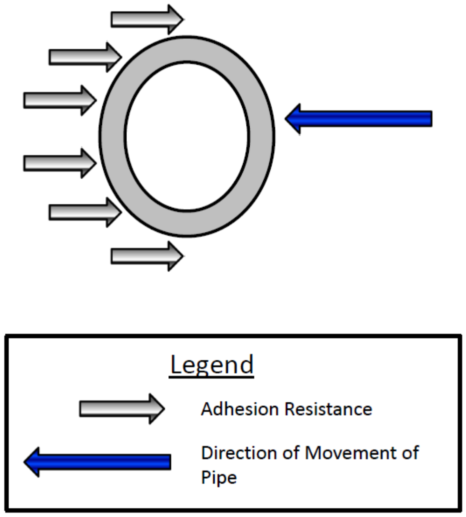

Figure 3-6a. Only half of the circumference is used for runs of tees, horizontal bends, and vertical offsets.

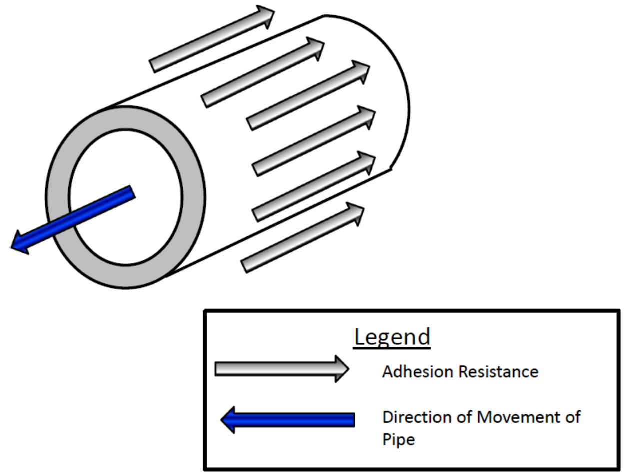

Figure 3-6b. The entire circumference is used for branches of tees, reducers, and dead ends.

Figure 3-6. Surface area of pipe for adhesion resistance

3.5 Total Pipe/Soil Resistance

The total resistance between the pipe and the soil (F_s) is given in Equation (3-9).

$$F_s = F_{sf} + F_{sa} \qquad \textbf{(3-9)}$$

Where:

F_s is the total resistance between the pipe and the soil in kN/m and as given by Potyondy.
F_{sf} and F_{sa} have been defined previously

If the pipe is ductile iron, and if it encased in polyethylene (PE), Equation (3-10) should be used instead of Equation (3-9). Equation (3-10) estimates the force at which the ductile iron pipe slips inside the PE encasement.

$$F_s = 0.249\ W \qquad \textbf{(3-10)}$$

Where:

W is calculated using Equation (3-1). Refer to Subsection 3.3.1.

3.6 Passive Resistance

The last item to consider is lateral resistance, R_s. The unbalanced thrust force (T) causes the fitting to move in the direction of that force. When the fitting moves in the embedment material, it develops the passive soil pressure, which is estimated using Rankine's passive pressure theory as follows:

$$\sigma_p = \gamma_s H_c N_\phi + 2 C_s \sqrt{N_\phi} \qquad \textbf{(3-11)}$$

Where:

σ_p is the passive soil pressure in kPa
γ_s is the unit weight of soil in kN/m^3. See Table 3-5.
H_c is the height of cover from the centerline of the pipe in m
N_ϕ is $\mathrm{Tan}^2(45 + \phi/2)$
ϕ is the internal friction angle of the soil in degrees. See Table 3-5.
C_s is the soil cohesion in kPa. See Table 3-5.

Table 3-5. Soil Properties Used for Calculating the Passive Resistance

Soil Group*	Unit Weight of Soil, γ_s (kN/m^3)	C_s (kPa)	ϕ (Degrees)
GW, SW	17.3	0	36
GP, SP	17.3	0	31
GM, SM	17.3	0	30
GC, SC	15.7	10.8	25
CL	15.7	12.0	20
ML	15.7	0	29
CL / Granular Embedment	15.7	0	31
ML / Granular Embedment	15.7	0	31
CH / Granular Embedment	15.7	0	31
MH / Granular Embedment	15.7	0	31

* Appendix A gives details on soil classification

The lateral resistance generated from the passive soil pressure is denoted as R_s and is calculated using Equation (3-12).

$$R_s = K_n \sigma_p D_o \qquad \textbf{(3-12)}$$

Where:

R_s is the lateral bearing resistance in kN/m

K_n is a trench compaction modifier. See Table 6.
σ_p is the passive soil pressure in kPa
D_o is the outside diameter of the pipe in m

Table 3-6. Trench Compaction Modifiers, K_n

Soil Group*	K_n for Trench Type 3**	K_n for Trench Type 4**	K_n for Trench Type 5**
GW, SW	0.6	0.85	1.00
GP, SP	0.6	0.85	1.00
GM, SM	0.6	0.85	1.00
GC, SC	0.6	0.85	1.00
CL	0.6	0.85	1.00
ML	0.6	0.85	1.00
CL / Granular Embedment	0.6	0.85	1.00
ML / Granular Embedment	0.6	0.85	1.00
CH / Granular Embedment	0.4	0.6	0.85
MH / Granular Embedment	0.4	0.6	0.85

* Appendix A gives details on soil classification
** Appendix B reviews AWWA trench types

3.7 Restrained Length for a Horizontal Bend

Having reviewed the thrust restraint building blocks, it is now time to reassemble them into a restrained length formula. Refer to the free body diagram in Figure 3-7 while this is accomplished. Bearing resistance and frictional resistance (which include adhesion resistance for cohesive soils) act to oppose the unbalance thrust force, T. In Figure 3-7, only the vertical components of the friction resistance and bearing resistance are assumed to be effective. The horizontal components of these distributed forces cancel one another out. These distributed forces are projected onto the length L Cos (Δ /2) . Restating, the unbalanced thrust force of 2PA Sin(Δ / 2) is opposed by (F_s + 0.5 R_s) [L_r Cos (Δ /2)]. When one solves for L_r and adds a factor of safety (S_f), Equation (3-13) is the result. (Note: The pipe's outside diameter is used when calculating the cross sectional area, A.)

$$L_r = \frac{S_f \, PA \, [\mathrm{Tan}\,(\Delta/2)]}{F_S + 0.5\, R_S} \qquad \textbf{(3-13)}$$

Where

L_r is the restrained length in m
S_f is the safety factor. 1.5 is typically used.
The other terms have been defined previously

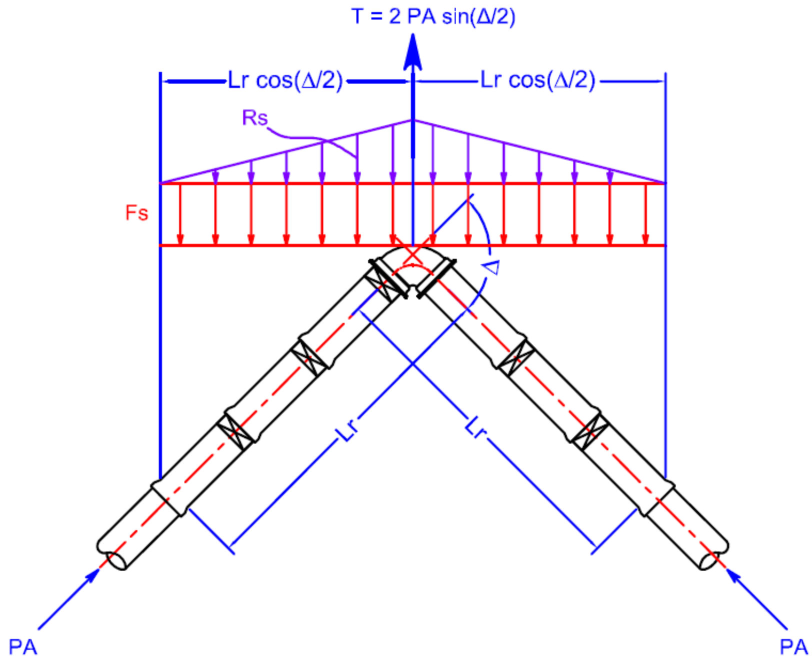

Figure 3-7. Free Body Diagram for a Horizontal Bend

4. RESTRAINED LENGTH EQUATIONS

Subsection 3.7 analyzed the restrained length required for a horizontal bend. In this section, the restrained length needed for other applications is reviewed. Those applications are vertical offsets (Subsection 4.1), Dead Ends (Subsection 4.2), Reducers (Subsection 4.3), and Tees (Subsection 4.4).

4.1 Vertical Offsets

A vertical offset is shown in Figure 4-1. It consists of a vertical down bend (within the blue circle) and a vertical up bend (inside the green circle). The thrust forces for both are calculated the same way. The formula is indicated in Figure 3-2. The resisting forces, however, differ between the two.

Down Bend: One accounts for the total pipe/soil resistance as given in Equation (3-9) but not the passive resistance. Therefore, the unbalanced thrust force of 2PA Sin(Δ / 2) is opposed by (F_f) [$L_{r(upper)}$ Cos (Δ /2)]. When one solves for $L_{r(upper)}$ and adds a factor of safety (S_f), Equation (4-1) is the result. (Note: The pipe's outside diameter is used when calculating the cross sectional area, A.)

$$L_{r(upper)} = \frac{S_f\, PA\, [\mathrm{Tan}\, (\Delta/2)]}{F_s} \qquad \textbf{(4-1)}$$

These terms have been defined in Section 3.

Up Bend: In the up bend, one accounts for the total pipe/soil resistance and the passive resistance as given in Equation (3-12). The restrained length for the low side of the offset ($L_{r(lower)}$) is the same as that for a horizontal bend. See Equation (3-13).

Passive Resistance: For the up bend, the direction of the unbalanced thrust force is up and into the backfill. One should not rely on the passive resistance of this recently disturbed soil. For the down bend, however, the unbalanced thrust force is directed down and into the trench bottom, where one may confidently rely on the soils' passive resistance.

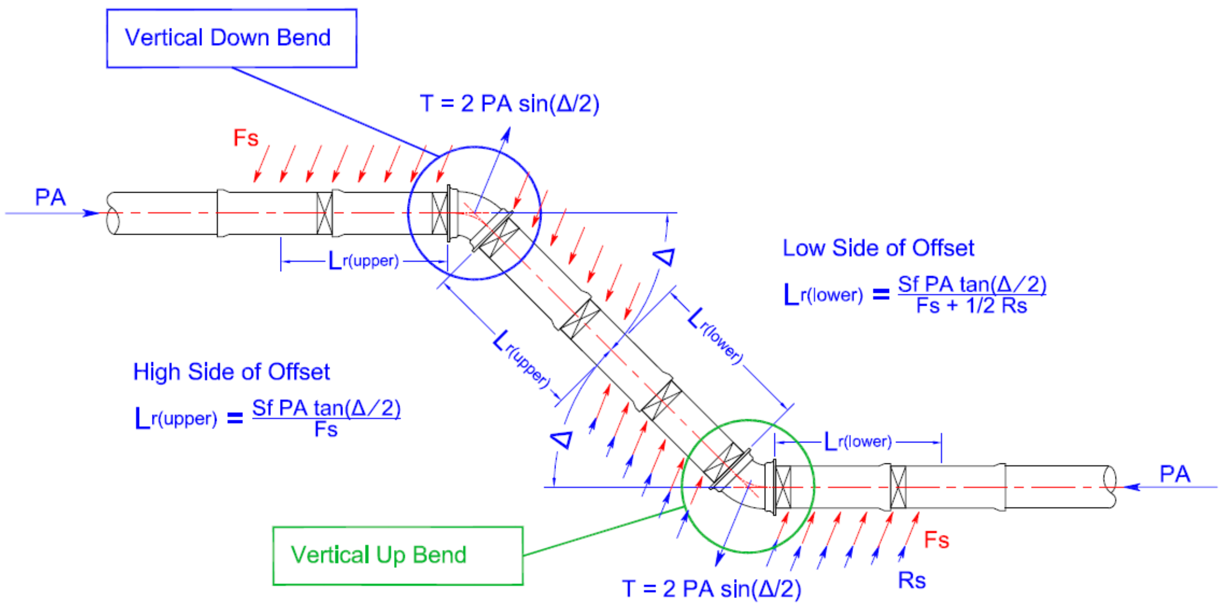

Figure 4-1. Vertical Offset

4.2 Dead Ends

A dead end is shown in Figure 4-2. In a dead end, the pipe is attempting to move longitudinally in the direction of the unbalanced thrust force, T. This is unlike a horizontal bend, where there is lateral movement near the near the elbow. As a result, the surface area used for calculating the adhesive resistance is the full circumference as given in Equation (3-8b). This must be kept in mind when calculating the total pipe/soil resistance per Equation (3-9). Any passive resistance that may be generated by the movement of the end cap is neglected when calculating the restrained length.

The pipe/soil resistance ($L_r F_s$) opposes the unbalanced thrust force, which for dead ends is PA. Solving for L_r and adding a safety factor results in Equation (4-2).

$$L_r = S_f\, PA \div F_s \qquad \textbf{(4-2)}$$

Where

L_r is the restrained length in meters
S_f is the factor of safety. 1.5 is typically used.
P is the largest pressure that the pipeline is expected to experience in kPa
A is the cross sectional area in square meters based on the pipe's outside diameter.
F_s is given in Equation (3-9)

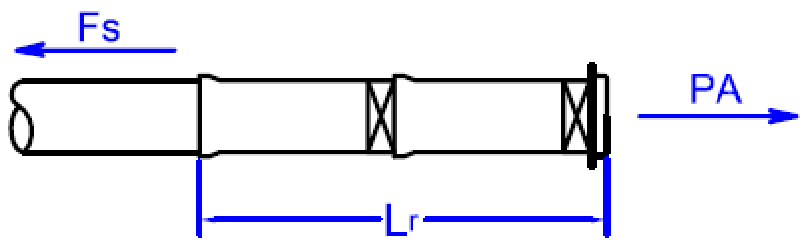

Figure 4-2. Dead End

4.3 Reducers

The restrained length calculation for a reducer is similar to that of a dead end. The passive soil resistance is considered negligible, and the unbalanced thrust force is opposed only by the pipe/soil resistance. The unbalanced thrust force generated at a reducer is illustrated in Figure 4-3.

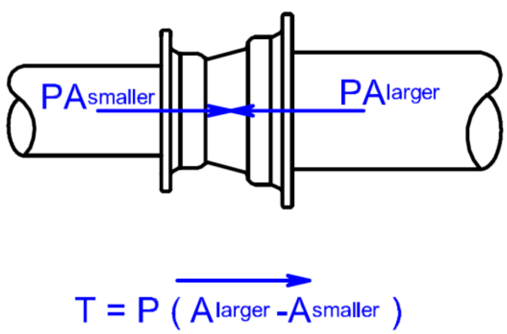

Figure 4-3. Unbalanced Thrust Force for a Reducer

The unbalanced thrust force at a reducer is the pressure times the difference between the two cross sectional areas. See Equation (4-3).

$$T = P\,(A_{larger} - A_{smaller}) \quad \textbf{(4-3)}$$

Where:

T is the unbalanced thrust force in kN
P is the largest pressure that the pipeline is expected to experience in kPa
A_{larger} is the cross sectional area of the larger pipe in square meters. Use the larger pipe's outside diameter when calculating the cross sectional area.
$A_{smaller}$ is the cross sectional area of the smaller pipe in square meters. Use the smaller pipe's outside diameter when calculating the cross sectional area.

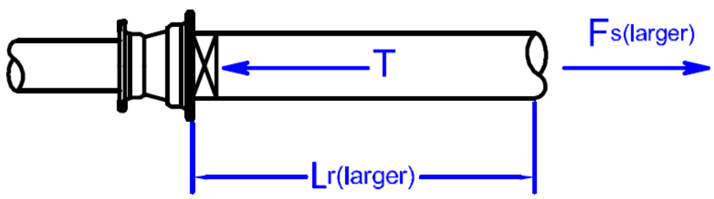

Figure 4-4. Restrained Length for Reducers

In most situations, the reducer is restrained to the larger pipe for a distance $L_{r(larger)}$ as shown in Figure 4-4. Equation (4-5) is used to calculate the restrained length, $L_{r(larger)}$.

$$L_{r(larger)} = [S_f\ P(A_{larger} - A_{smaller})] \div F_{s(larger)} \quad \textbf{(4-4)}$$

Note: $F_{s(larger)}$ is calculated using the larger pipe's outside diameter and height of cover. Refer to Equation (3-9).
The other terms in Equation (4-4) have been defined previously.

For ductile iron pipe, it may not be necessary to restrain the larger pipe for a distance $L_{r(larger)}$. To see if this is the case, first calculate $L_{r(smaller)}$ using Equation (4-5). $L_{r(smaller)}$ is dimensioned in Figure 4-5.

$$L_{r(smaller)} = [S_f\ P(A_{larger} - A_{smaller})] \div F_{s(smaller)} \quad \textbf{(4-5)}$$

Note: $F_{s(smaller)}$ is calculated using the smaller pipe's outside diameter and height of cover. Refer to Equation (3-9).
The other terms in Equation (4-5) have been defined previously.

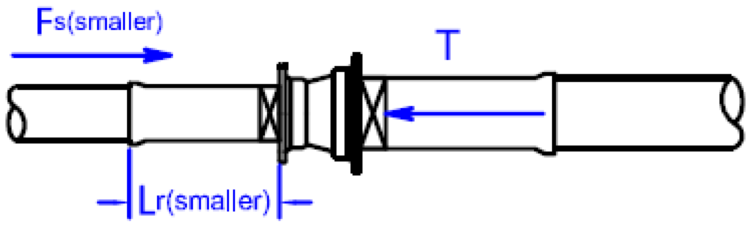

Figure 4-5. Checking To See If Restraint for Reducer Is Provided By Smaller Pipe

If there are no sleeves, valves, or fittings a distance $L_{r(smaller)}$ on the smaller pipe, restraint on the larger pipe may not be needed. For this to be the case, one of two criteria must be met:

- *Criterion One:* No pipe joints are present within the area dimensioned by $L_{r(smaller)}$.
- *Criterion Two.* The pipe manufacturer allows the spigot to be bottomed out in the bell. And, all pipe joints falling in the area dimensioned by $L_{r(smaller)}$ are bottomed out.

4.4 Tees

A tee is shown in Figure 4-6. The run is oriented horizontally, and the branch is oriented vertically.

Thrust Force: The thrust forces in the run are equal and opposite and cancel one another. That is not the case for the branch. There, the thrust force generated by the branch is unbalanced. The thrust force for a tee is given in Equation (4-6).

$$T = P\ A_{branch} \qquad \textbf{(4-6)}$$

Where:

T is the unbalanced thrust force in kN
P is the largest pressure that the pipeline is expected to experience in kPa
A_{branch} is the cross sectional area of the branch in square meters and based on the pipe's outside diameter.

Run: To calculate the restrained length $L_{r(branch)}$, one must first specify a minimum restrained length of pipe connected to the run, $L_{r(run)}$, as dimensioned in Figure 4-6. The soil a distance of $L_{r(run)}$ on either side of the tee opposes the unbalanced thrust force of the branch with passive resistance and pipe/soil resistance. For the passive resistance, use Equation (3-12). For pipe/soil resistance, use Equation (3-9). Only half the circumference should be used for the surface area when calculating the adhesive resistance portion of Equation (3-9). In other words, use Equation (3-8a) for the surface area. An $L_{r(run)}$ of three meters is typical. For larger diameters, $L_{r(run)}$ may be as long as six meters.

Branch: Having specified a minimum $L_{r(run)}$, the restrained length for the branch can now be calculated. In addition to the passive resistance and pipe/soil resistance behind the tee, there is also pipe/soil resistance along the branch. As with the run, the pipe/soil resistance is calculated using Equation (3-9). However, the surface area used for the adhesive portion of the equation will now be based on the branch's full circumference because it moves longitudinally rather than laterally. Use Equation (3-8b) to calculate the branch's surface area. To summarize, a thrust force of P A_{branch} is attempting to push the tee off the branch piping. The thrust force is resisted by the soil behind the tee and the embedment around the branch piping. The magnitude of the resistance behind the tee is $L_{r(run)}R_{s(run)}$. The magnitude of the resistance along the branch is $L_{r(branch)}$ $F_{s(branch)}$. Adding a safety factor and solving for $L_{r(branch)}$ results in Equation (4-7).

$$L_{r(branch)} = \frac{S_f\left[\,(PA_{branch})-\left(L_{r(run)}R_{s(run)}\right)\right]}{F_{s(branch)}} \qquad \textbf{(4-7)}$$

These terms have been defined previously.

Equation (4-7) may produce a negative number. This indicates that the soil support behind the tee is sufficient for resisting the thrust force generated. To avoid confusion, the *Star JR Calculator* rounds $L_{r(branch)}$ values less than 0.5m up to 0.5m.

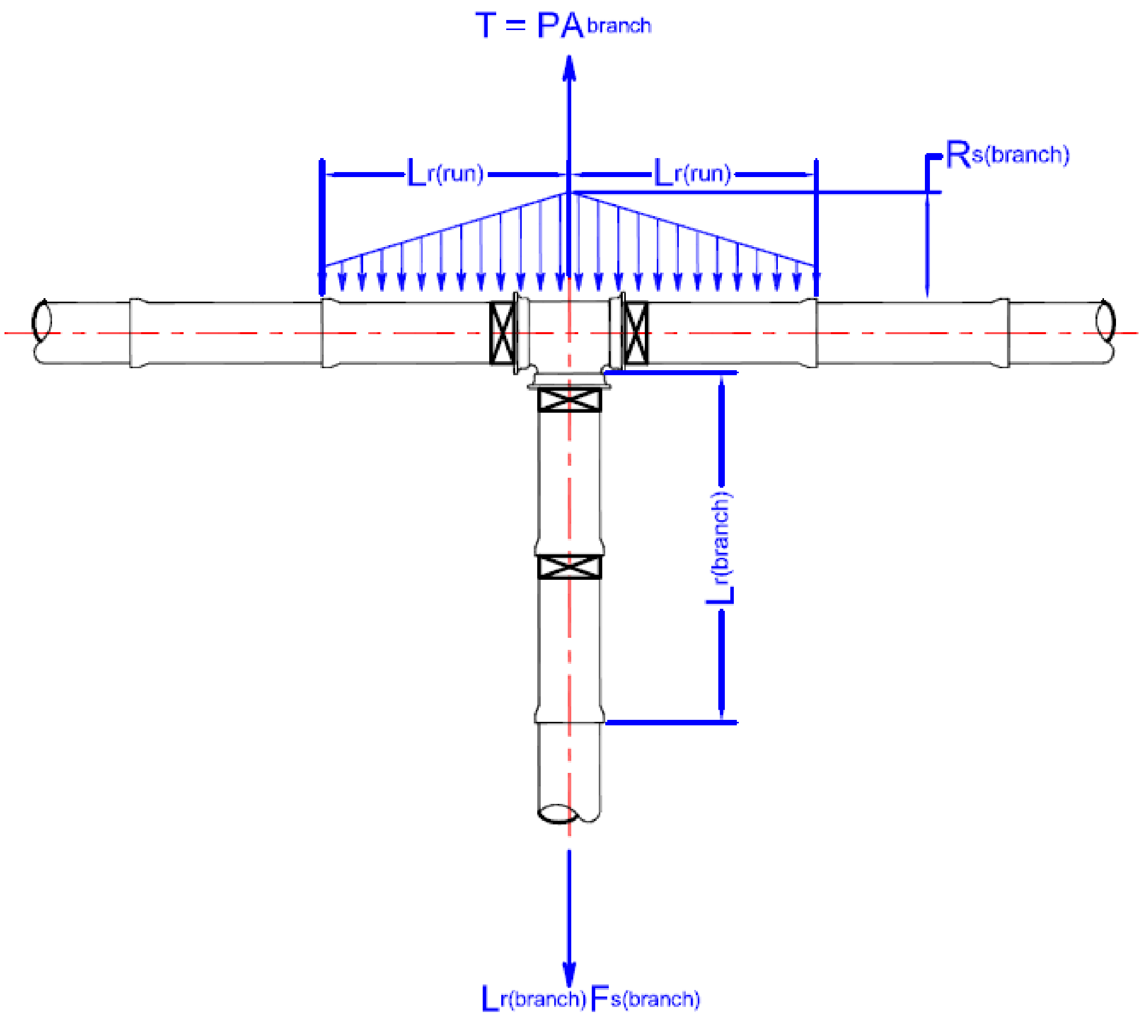

Figure 4-6. Tee

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6. APPENDIX A, SOIL CLASSIFICATION INFORMATION

ASTM D2487 defines GW, GP, GM, GC, SW, SP, SM, SC, ML, and CL as shown in Table A-1. See ASTM D2487 for additional details. Refer to Figure A-1 for the discussion on CL / Granular Fill, ML / Granular Fill, CH / Granular Fill, and MH / Granular Fill.

Table A-1, ASTM D2487 Unified Soil Classification System

Major Divisions			Soil Symbol	Typical Names
Coarse Grained Soils. More than 50% retained n the number 200 sieve.	Gravels 50% or more of coarse fraction retrained Number 4 sieve.	Clean Gravels	GW	Well-graded gravels and gravel-sand mixtures with little or no fines.
			GP	Poorly graded gravels and gravel-sand mixtures with little or no fines.
		Gravels with Fines	GM	Silty gravels, gravel-sand-silt mixtures.
			GC	Clayey gravels, gravel-sand-clay mixtures.
	Sands. More than 50% of the coarse fraction passes the Number 4 sieve.	Clean Sands	SW	Well-graded sands and gravelly sands with little or no fines.
			SP	Poorly-graded sands and gravelly sands with little or no fines.
		Sands with Fines	SM	Silty sands, sand-silt mixtures
			SC	Clayey sands, sand-clay mixtures.
Fine Grained Soils. 50% or more passes no. 200 sieve.	Silts and Clays. Liquid Limit is 50% or less.		ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands.
			CL	Inorganics clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.

The program has soil types for CL / Granular Fill, ML / Granular Fill, CH / Granular Fill, and MH / Granular Fill. In these cases, the granular material is the pipe embedment material as shown in Figure A-1. CL, ML, CH, and MH describe the native material.

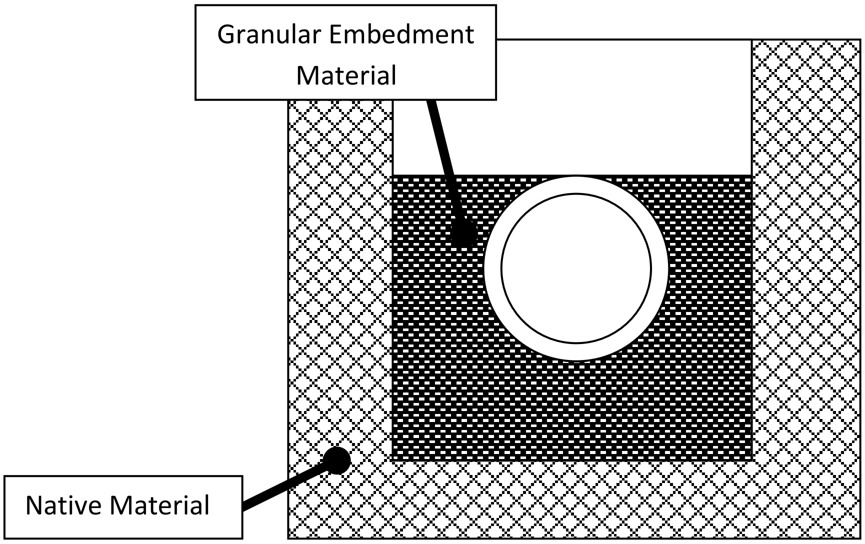
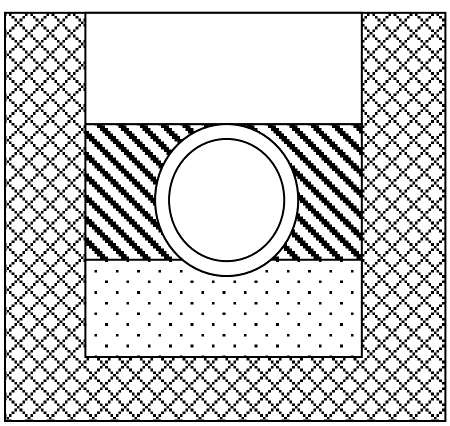


Figure A-1, Combined Soil Types

7. APPENDIX B, TRENCH TYPES

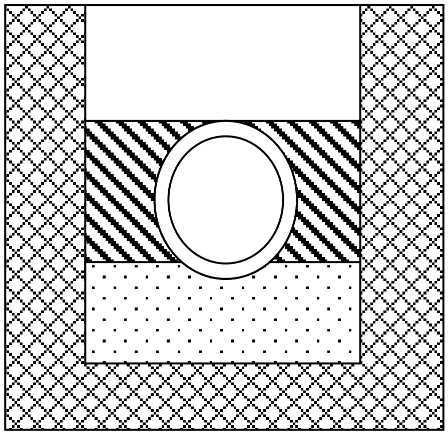
Trench Types 3, 4, or 5 are recommended for embedding pipe that falls within the restrained length. Trench Types 1 and 2 are not recommended within the restrained length. Additional details are available in AWWA C605. Cross sections of the trenches are provided in the following figures:

- See Figure B-1 for a Type 3 trench.
- See Figure B-2 for a Type 4 trench.
- See Figure B-3 for a Type 5 trench.



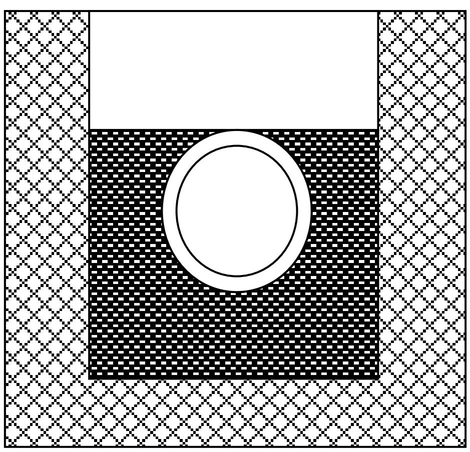
Notes from AWWA C605 for a Type 3 Trench: Pipe bedded in 100mm minimum of loose soil. Embedment lightly consolidated to top of the pipe.

Figure B-1, Type 3 Trench
Per AWWA C605



Notes from AWWA C605 for a Type 4 Trench: Pipe bedded in sand, gravel, or crushed stone to a depth of 1/8 pipe diameter, 100mm minimum. Embedment compacted to top of pipe. (Approximately 80 percent Standard Proctor, AASHTO T-99)

Figure B-2, Type 4 Trench
Per AWWA C605



Notes from AWWA C605 for a Type 5 Trench: Pipe embedded in compacted granular material to the centerline of the pipe, 100mm minimum under the pipe. Compacted granular or select material to top of pipe. (Approximately 90 percent Standard Proctor, AASHTO T-99)

Figure B-3, Type 5 Trench
Per AWWA C605