United States Department of Agriculture
Soil Conservation Service
P.O. Box 2890
Washington, D.C.
20013

**TR-77A**

May 24, 1993

TECHNICAL RELEASE NO. 77
210-VI
AMENDMENT 1

SUBJECT: ENG - DESIGN AND INSTALLATION of FLEXIBLE CONDUITS -- PLASTIC PIPE

Purpose. To distribute revisions to Technical Release No. 77.

Effective Date. Effective upon receipt.

Amendment 1, Technical Release No. 77A, (TR-77A) corrects some omissions and typographical errors contained in the August 1990 version of TR-77.

Filing Instructions. Replace pages iii, 7, 8, 11, 12, 15, 16, 19, 20, 21, 22, 31, 32, 35, 36, 41, 42, 57, 58, 89, 90, and 99 with the enclosed amended pages.

Distribution. The distribution being made is that established for TR-77. Additional copies may be obtained by ordering TR-77A from the Consolidated Forms and Distribution Center, 3222 Hubbard Road, Landover, Maryland 20785.

Edgar H. Nelson for
ROBERT R. SHAW
Deputy Chief for Technology

Enclosure

DIST: TR-77

## Figures



## Tables

## System flow requirements

In designing any plastic pipe system, pressure losses caused by fittings, pipe friction, changes in alignment and elevation, or similar problems, are all considered when the system is expected to operate under pressure.

### Selection based on pressurized flow

The pipe selection process may need to be repeated to find a pipe that has the right combination of diameter, flow capacity and velocity, and an acceptable pressure drop. The Hazen and Williams formula may be used to determine the pressure loss caused by friction.

The Hazen and Williams formula

$$\Delta P_{100} = \frac{452 Q_g^{1.85}}{C^{1.85} d^{4.86}} \qquad (3)$$

Where:

$\Delta P_{100}$ = Friction pressure loss, in pounds per square inch per 100 feet of pipe
$Q_g$ = Rate of flow, U.S. gallons per minute
$C$ = Pipe coefficient (Hazen and Williams)
$d$ = Pipe internal diameter, inches

The coefficient C is essentially a friction factor. "C" values vary for plastic pipe from 150 for ABS and PVC to 155 for PE.

### Fitting pressure drop

Listed below in Table 2 are various common piping system components and the associated pressure loss through the fitting expressed as an equivalent length of straight pipe in terms of diameters. The inside diameter (in inches) multiplied by the equivalent length diameters gives the equivalent length (in feet) of pipe. This equivalent length of pipe is added to the total footage of the piping system when calculating the total system pressure drop.

These equivalent lengths were developed from an average of published data and thus should be considered an approximation suitable for most installations.

**Table 2.** ***Equivalent length of fittings***

| Fabricated Fitting | Equivalent Length in Feet |
|---|---|
| Running Tee | 1.667 d * |
| Branch Tee | 4.167 d |
| 90° Fab, Ell | 2.500 d |
| 60° Fab, Ell | 2.083 d |
| 45° Fab, Ell | 1.500 d |
| 45° Fab, Wye | 5.000 d |
| Conventional Globe Valve (Full Open) | 29.167 d |
| Conventional Angle Valve (Full Open) | 15.000 d |
| Conventional Wedge Gate Valve (Full Open) | 1.250 d |
| Butterfly Valve (Full Open) | 3.333 d |
| Conventional Swing Check Valve | 8.333 d |

*d = inside diameter in inches

## Design precautions

After appropriate pipe sizes, based upon flow requirements, have been selected the designer should consider the following before proceeding with the remaining design steps:

The system pressure drop (including fittings and transients) should not exceed the pressure rating of the pipe selected.

The pump pressure should exceed the system pressure drop, but should not exceed the pressure rating or pressure class of the pipe selected.

## Pipe flow

Pipe flow systems are typified by irrigation pipelines, as well as water and slurry pipelines. Some may operate with full flow and some may operate partially full.

**Full flow.** Four things are required to select and size a pipe for a full flow system: (1) flow-rate requirements, (2) the elevation change of the pipeline, (3) the pipe roughness, and (4) a selection of an appropriate pipe inside diameter.

Based upon a full flow situation, the flow rate can be calculated from the Manning's equation as follows:

$$Q = \frac{1.486}{n} A r^{2/3} S^{1/2} \qquad (4)$$

Where:

$Q$ = Flow in CFS
$r$ = Hydraulic radius, ft
$S$ = Friction slope, ft/ft
$A$ = Cross sectional area of pipe I.D., $ft^2$
$n$ = Roughness coefficient

**Partial flow.** A gravity pipeline at the same energy slope will carry more liquid when flowing 85 percent to 95 percent full than when 100 percent full. This is recognized as the effect of reduced friction because of the liquid's contact with less pipe wall surface. The discharge rate of partial flow pipelines can be calculated by using Manning's equation. Table 3 illustrates the changes in velocity and flow capacity when compared to full flow.

Instantaneous surge pressures are shock waves known as "water hammer." The pressure wave caused by water hammer races back and forth in the pipe getting progressively weaker with each hammer. The magnitude of the pressure change caused by a water hammer shock wave depends upon the elastic properties of the pipe and liquid as well as upon the magnitude and rapidity of the shock wave's velocity change. The maximum surge pressure results when the time required to change a flowstream velocity a given amount is equal to or less than $2L/V_w$ such that:

$$T \leq \frac{2L}{V_w} \qquad (7)$$

Where:

$L$ = Length of pipeline, ft
$V_w$ = Velocity of the pressure, ft/sec
$T$ = Time, sec

$$V_w = 12\sqrt{\frac{KE}{\frac{\gamma}{g}\left[E + K\left(\frac{d}{t}\right)\right]}} \qquad (8)$$

Where:

$K$ = Bulk modulus of the liquid, psi
= 300,000 psi for water
$E$ = Modulus of elasticity of pipe material, psi
$\gamma$ = Unit weight of fluid, lb/ft$^3$
g = Acceleration due to gravity (5)
= 32.2 ft/sec/sec

The pressure change caused by water hammer is:

$$\Delta P = \frac{\gamma V_w \Delta V}{144g} \qquad (9)$$

Where:

$\Delta P$ = Change in pressure, psi
$\Delta V$ = Change in velocity, ft/sec occurring within critical time $2L/V_w$.
$\gamma$, $g$ and $V_w$ are as above.

The following example illustrates the use of these equations.

**Example:**
**Water is flowing in a 6 inch PE pipeline with an *SDR* of 21 at a velocity of 10 ft/sec. Determine the maximum pressure increase when a valve is closed in a time equal to or less than $2L/V_w$.**

Where:

$SDR = 21 \qquad K = 300{,}000\,psi \qquad E = 100{,}000\,psi \qquad d=5.972$

$$V_w = 12\sqrt{\frac{(300{,}000)\,(100{,}000)}{\frac{62.4}{32.2}\left[100{,}000 + 300{,}000\left(\frac{5.972}{0.315}\right)\right]}} = 620.622\,ft/sec \qquad (8)$$

$$\Delta V = 10 - 0 = 10\,ft/sec$$

$$\Delta P = [(62.4/32.2)(620.622)(10)] \div 144 = 83.52\ psi$$

The use of 100,000 psi for the modulus of elasticity for PE pipe is justified by the short-term duration of the pressure surges and the rapidity with which the surges are dampened. Because the long-term modulus on which allowable operating pressures are based is only a fraction of the short-term modulus, occasional total overpressure caused by pressure surges up to 2.5 times rated pressure can be tolerated safely. The changes in pressure can be minimized by using a valve closure time greater than $2L/V_w$. Because the magnitude of the surge is basically a function of the rate of velocity change, particular attention should be given to the final portion of valve closure. This is the time during maximum change in velocity of the flowing liquid. The actual increase in pressure caused by valve closure is difficult to determine. A closure time of 10 times $2L/V_w$ for a gate valve that has linear closure characteristics should reduce the pressure surge to the range of 10 to 20 percent of the surge caused by closure in a time equal to or less than $2L/V_w$.

In general, good system design will eliminate quick opening/closing valves on anything but very small or very short lines. The design engineer should use judgement with regard to the addition of surge pressures to operating pressures when selecting pipe SDR's. The following rules of thumb may help:

> Occasional shock pressures can be accommodated within the design safety factor. Because of the short time duration of the surge pressure, occasional shock wave surge pressures to 2.5 times the SDR pressure rating at 73.4 °F are usually allowable.
>
> If surge pressure or water hammer is expected, maximize the time required to shut off a valve or reduce flow. A valve shutting period 6-10 times longer than the time period $2L/V_w$ is suggested to minimize surge pressures by gradually slowing the fluid flowstream.

Any system with a velocity in excess of 2 ft/sec should be examined for overpressurization caused by water hammer.

Pipe coupled with slip joints having elastomeric seals that have sufficient latitude for movement does not require any special precautions to handle thermal expansion and contraction because these dimensional changes are taken up by movement in each joint.

## Aboveground piping

Aboveground piping generally undergoes larger and more frequent temperature changes than underground piping because of atmospheric temperature changes and the greater temperature differentials of the materials being conveyed. Pipe supports should permit longitudinal movement of the pipe.

If runs in excess of 20 ft are required, flexural offsets or loops should be provided. To not exceed the maximum allowable strain in the piping, the developed length that should be provided in the offset or loop can be calculated from the equation.

$$y = \frac{F L^3}{3 E I} \tag{11}$$

Where:

$y$ = maximum deflection at the end of a cantilever beam, in
$F$ = force at end, lb
$L$ = length of pipe subjected to flexural stress, in
$E$ = flexural modulus of elasticity, psi
$I$ = moment of inertia, $in^4$

The following symbols are also used in this section:

$D$ = average outside diameter, in
$R_o$ = outside radius, in
$R_i$ = inside radius, in
$t$ = wall thickness, in
$M$ = bending moment = FL, lb-in
$\varepsilon$ = strain
$f$ = fiber stress $\frac{M}{Z}$, psi
$Z$ = section modulus, $in^3$

Note, also, that $y$ is the maximum expansion or contraction to be accommodated (in).

For pipes in which the wall thickness is large with respect to the outside diameter, (SDR $\leq$ 20)

$$I = \frac{\pi}{4}\left(R_o^{\,4} - R_i^{\,4}\right) \tag{12}$$

$$Z = \frac{\pi}{4}\left(\frac{R_o^{\,4} - R_i^{\,4}}{R_o}\right) \tag{13}$$

When the wall thickness is not large with respect to the outside diameter (which is the case for most plastic pipes) these equations can be expressed as:

$$I = \pi R_o^{\,3} t \tag{12a}$$

$$Z = \pi R_o^{\,2} t \tag{13a}$$

Therefore, for most plastic piping

$$I = \frac{\pi D^3 t}{8} \tag{12b}$$

$$Z = \frac{\pi D^2 t}{4} \tag{13b}$$

$$f = \frac{4F\ L}{\pi D^2 t} \tag{14}$$

$$F = \frac{\pi D^2 f\ (t)}{4L} \tag{15}$$

Substituting in equation (11)

$$y = \frac{2f\ L^2}{3E\ D} \tag{11a}$$

$$L = \left(\frac{3EDy}{2f}\right)^{\frac{1}{2}} \tag{11b}$$

$$L = \left(\frac{3Dy}{2\varepsilon}\right)^{\frac{1}{2}} \tag{11c}$$

Equation (11b) is used when the maximum allowable stress is fixed and equation (11c) when the maximum allowable strain is fixed. When equation (11b) is used, the flexural modulus of elasticity must be known. In cases where the modulus of the specific compound is not available, the following approximate average values are usually adequate:

| Compound | Flexural modulus (psi) |
|---|---|
| PVC 1120 | 400,000 |
| PVC 2110 | 320,000 |
| ABS 1210 | 240,000 |
| ABS 1316 | 340,000 |
| PE 2306 | 90,000 |
| PE 3306 | 120,000 |

Strength relationships for pipe materials are in the appropriate ASTM specification. The ASCE Manual No. 63 contains a detailed discussion of strength parameters to be used in plastic pipe design. Some of the factors are:

1. Hydrostatic Design Basis (HDB) = Hydrostatic Design Stress x Service Factor (Safety Factor)

2. Creep Factor

$$\overline{CF} = \frac{E_o}{E_{10}} \tag{16}$$

3. Strength in Creep (constant stress)

$$\varepsilon_c = \frac{HDB}{E_o}, \% \tag{17}$$

4. Strength in Relaxation (constant strain)

$$\varepsilon_R = \frac{HDB}{E_o} \overline{CF}, \% \tag{18}$$

**Safety factors.** As with all designs, safety factors are included to account for variations from assumed conditions. These factors are in the form of capacity reduction factors and load factors.

*Capacity reduction factors* account for variations in materials, ultraviolet exposure, scratches, variation of cross section, and other strength-reducing problems. Capacity reduction factors currently recommended are:

| | |
|---|---|
| For pipe stiffness for buckling, $\phi''$ | = 0.75 |
| For pipe strength, $\phi$ | = 0.80 |
| For modulus of soil reaction, $\phi'$ | = 0.50 |

*Load factors* are used to account for overloads, surges, impacts, and other load variations that cannot be predicted accurately. Load factors, $\overline{LF}$, currently recommended for use in SCS work are:

Vehicle load factor = 1.8 maximum, 0.0 minimum

Earth load factor = 1.5 maximum, 0.80 minimum

Groundwater load factor = 1.0 (in most SCS designs, the designer should be able to estimate maximum groundwater accurately)

Installation load factor = 1.0

Vacuum load factor = 1.2

Internal pressure load factor = 2.0

**Loads.** The prism load theory is used to determine the soil load above the pipe. This will yield a conservative soil load because, as the flexible pipe deflects with any load increase, some of the prism load is transferred into the sidewalls of the trench, thus reducing the load transmitted to the pipe. The soil load in this analysis is the total weight of soil above the outside diameter of the pipe per unit of length. The earth pressure without a load factor is represented by

$$P_s = \frac{\gamma_s h}{144}, \; lbs/in^2 \qquad (21)$$

When groundwater is above the top of the pipe, the earth pressure, $P_s$, may be reduced for buoyancy by the factor $C_w$.

$$C_w = 1 - \frac{h_w}{3h} \qquad (19)$$

Where h = height of the soil above the top of the pipe and $h_w$=height of water above the top of the pipe. When adjusted for load factors

$$P_{su} = P_s \, \overline{LF} \text{ (maximum)} \qquad (22)$$

$$P'_{su} = P_s \, \overline{LF} \text{ (minimum)} \qquad (23)$$

The effect of wheel loads varies with depth. The Boussinesq theory was used to verify the equations given in SCS West Technical Note Number 1, "External Loads on Rigid Pipe Conduits," September 1982. The equations for wheel loads, excluding impact factor and load factors are:

$$\text{if } D-t < 2.67h(12) \qquad (24)$$

$$P_{wh} = \frac{0.48 P_{wL}\left(\frac{D-t}{12}\right)^2}{2.67h^3 (D-t)12}\left[\frac{2.67h}{\frac{D-t}{12}} - 0.5\right]$$

$$\text{if } D-t \geq 2.67h(12) \qquad (25)$$

$$P_{wh} = \frac{0.64 P_{wL}}{h(D-t)\,12}$$

Wheel loads multiplied by an impact factor accounts for the reduction of the effect of wheel loads with depth.

$$\text{Impact factor, } \overline{IF} = \frac{\text{wheel load}}{\text{wheel load + soil load}} + 1 \qquad (20)$$

Including impact factor the equations become:

$$P_w = P_{wh}(IF) \qquad (26)$$

and adjusted for load factors

$$P_{wu} = P_w(LF) \text{ maximum} \qquad (27)$$

$$P'_{wu} = 0 \text{ minimum} \quad \text{(no wheel load)} \qquad (28)$$

**Deflection.** One of the limiting criteria of design is deflection expressed in percent or inches of vertical deflection divided by the mean diameter in inches. The average deflection may be calculated and an installation deflection is added to obtain the maximum deflection. For SCS work, acceptable limits are 3% for short-term deflection and 5% for long-term deflection. Short-term deflection is that deflection that occurs during construction. The deflection limits were established primarily to prevent joint leakage and to permit cleanout by pulling a plug through the pipe rather than for reasons of structural distress.

The Modified Iowa Formula is the basis for determination of the average deflection created by the earth load.

$$\frac{\Delta_s}{2R_m} = \frac{K_b P_e D_L}{0.149\,\overline{PS_o} + 0.061E'} \qquad (29)$$

$K_b$ is the bedding constant and varies from 0.083 for pipe bedded to the springline to 0.110 for pipe that has zero bedding angle. Unless otherwise known, a value of $K_b = 0.10$ may be used.

$P_e$ is the earth load in psi above the pipe.

$D_L$ is the deflection lag factor. A value of 1.0 is recommended for initial or short term deflections and 1.5 for the long term deflections. The deflection lag factor was recommended by Spangler to account for the increase in load caused by the consolidation of the soil at the sides of the pipe, which is a function of time.

$\overline{PS_o}$ is the pipe stiffness computed from the equation

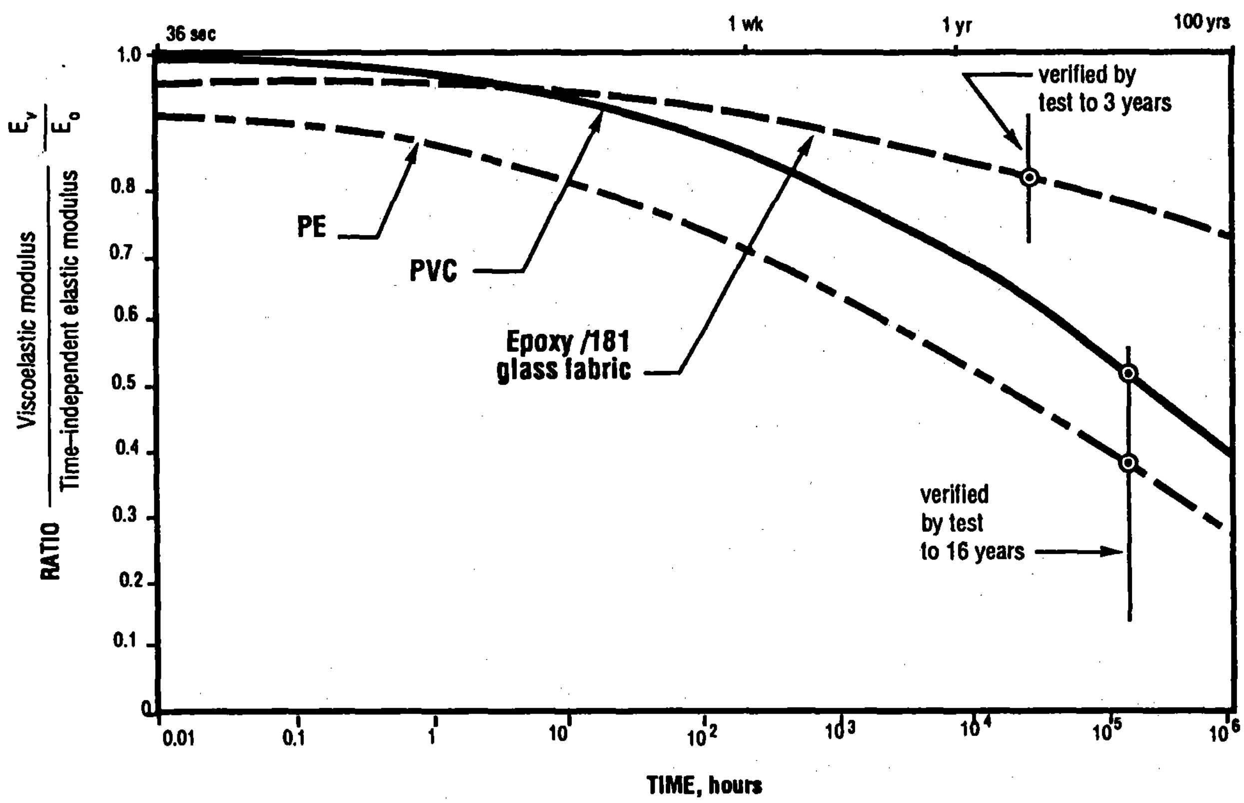
$$\overline{PS_o} = 4.47\frac{E_o}{(DR-1)^3} \qquad (30)$$

for OD-controlled pipe.

Equation (29) is based upon the assumption that the pipe deforms to an elliptical shape. When $\overline{PS_o}$ is less than 34 (approx.) and the embedment materials are very stiff, Equation (29) is not valid as the pipe deforms to an odd configuration (nearly square).

$E_o$ is used for all computations of deflection, no matter whether the short- term or long-term deflection value is desired. For the purposes of this discussion, long-term is defined as 10 years in the United States and 50 years in Europe. Figure 1 shows the ratio of the decrease of the $E_o$ value with time for the thermoplastics polyethylene and polyvinyl chloride.

**Figure 1.** ***Variation in viscoelastic modulus with time***




The question arises "Why not use a different E value when comparing deflection for a 10-year-old pipe than the value used for a new pipe?" The following discussion is this author's rationale for using only $E_o$ to calculate deflection.

Many technical articles were studied in the preparation of this Technical Release(TR). Most articles report that properly installed thermoplastic pipe did not deflect any significant amount after completion of loading or at least by the end of the first year following installation. The $E_l$ is approximately 0.70 $E_o$. In the Iowa equation the $E$ value has a small effect on deflection, therefore a 30% reduction of $E$ would be insignificant in the deflection computation.

Another consideration is the effects of the pipe-soil relationship and the value of the pipe $E$. In other words, at what point in the aging of the pipe does the sidewall support and arching effect of the soil become the major factor in the computation of deflection? Currently the Iowa equation assumes the pipe-soil relationship is fully developed upon completion of fill for granular and low plastic soils. There is no data available for use with highly plastic soils that may creep when a load is applied or shrink significantly when dried. One could write an equation for the variation of $E$ with time and

# Sample Problem

Design a 6-inch PVC perforated pipe to be installed in a coarse aggregate filter system under a dam. The maximum elevation of the seepage water is expected to be 2.0 feet above the pipe invert and the pipe flows full. The specifications require the coarse filter to have a density of 90%. The SML report shows the earthfill to have a moist density of 132.0 lbs/ft$^3$ at an optimum moisture of 15%. The maximum height of the gravel filter is 4.0 ft above the pipe invert and the maximum height of the earthfill above the pipe invert is 30 ft. A check of local suppliers indicated schedule 40 pipe meeting ASTM D 1785; PVC 1120 SDR 17 and SDR 21 meeting ASTM D 2241; and PVC pipe meeting ASTM F 758 are all locally available.

## Problem

Design pipe system that will permit the contractor to select the pipe. Determine the fill height that the contractor may begin traversing the pipe with construction equipment.

## Procedure

| Known data | Comments and information |
|---|---|
| **Earthfill:** | |
| 1. $\gamma_m$ = 132 lb/ft$^3$ = 0.91667 psi per ft of height<br>2. Fill height = h = 30 ft - 0.5 ft = 29.5 ft<br>3. Optimum water content = 15% | *See assumption 1. under filter material which permitted the filter height to be included in the soil height.* |
| **Filter material:** | |
| 1. For this problem assume filter material has same unit weight @ 90% density as earth fill does @ 100% density<br>2. Height of filter = 4.0 ft<br>3. Height of groundwater = 2.0 - 0.5 = 1.5 ft<br>4. Modulus of Soil Reaction, E' = 2000 psi | From table 4, coarse grained soil with little or no fines. |

| Known data | | | | | Comments and Information |
|---|---|---|---|---|---|

## Pipe properties

| | ASTM D 1785 | ASTM D 2241 | ASTM D 2241 | ASTM F 758 | Comments and Information |
|---|---|---|---|---|---|
| | Sch 40 | SDR 21 | SDR 17 | PS 46 | |
| Cell class | 12454B | 12454B | 12454B | 12454C | From ASTM spec shown |
| Designation | PVC 1120 | PVC 1120 | PVC 1120 | —— | From ASTM spec shown |
| $E_0$ | 400,000 | 400,000 | 400,000 | 400,000 | Table 1 ASTM D 1784 |
| Wall t | 0.280 | 0.316 | 0.390 | 0.180 | From ASTM spec shown |
| D | 6.625 | 6.625 | 6.625 | 6.275 | From ASTM spec shown |
| Mean D | 6.345 | 6.309 | 6.6235 | 6.095 | Calculate (D – t) |
| d | 6.065 | 5.993 | 5.845 | 5.915 | Calculate (D – 2t) |
| $\overline{CF}$ | 2.0 | 2.0 | 2.0 | 2.0 | Industry standard |
| $\overline{PS_0}$ | 154 | 225 | 437 | 46 | From ASTM or calculate see below |
| $\overline{PS_{10}}$ | 77 | 112.5 | 218.5 | 23 | Calculate see below |
| ø | 0.80 | 0.80 | 0.80 | 0.80 | Recommended factors, may change with research and experience. |
| ø" | 0.75 | 0.75 | 0.75 | 0.75 | |
| $\varepsilon_C$ | 1.0 | 1.0 | 1.0 | 1.0 | See page 19 |
| $\varepsilon_{Cu}$ | 0.8 | 0.8 | 0.8 | 0.8 | Reduced ultimate strain in creep. 80% of $\varepsilon_C$ |
| $\varepsilon_R$ | use 2 for non-perforated pipe<br>use 3 for perforated pipe | | | | Recommended by SNTC for ultimate strain in relaxation. |
| $\varepsilon_{Ru}$ | use 1.6 for non-perforated pipe<br>use 2.4 for perforated pipe | | | | |

| Known data | Comments and Information |
|---|---|
| **E. Vacuum load**<br>Should not occur in a perforated pipe drain system. | |
| **F. Internal pressure**<br>Internal pressure should not develop in a properly sized and installed open drain system | |
| **2. Maximum long term deflection:** | |
| **A. Earth load**<br>Max load occurs when groundwater is below pipe invert. $D_L = 1.5$, Assume $K_b = 0.10$ | |
| $\frac{\Delta_s}{2R_m} = \frac{D_L K_b P_s}{0.149\ \overline{PS_o} + 0.061\ E'}$ | Eq (29) |
| **Pipe ASTM D 1785 Sch 40**<br>$\frac{\Delta_s}{2R_m} = \frac{1.5\,(0.10)(27.04)}{0.149\,(154) + 0.061(2000)} = 0.028 = 2.8\%$ | |
| **Pipe ASTM D 2241 SDR 21**<br>$\frac{\Delta_s}{2R_m} = \frac{1.5\,(0.10)\,(27.04)}{0.149\,(225) + 0.061(2000)} = 0.026 = 2.6\%$ | |
| **Pipe ASTM D 2241 SDR 17**<br>$\frac{\Delta_s}{2R_m} = \frac{1.5(0.10)(27.04)}{0.149\,(437) + 0.061\,(2000)} = 0.022 = 2.2\%$ | |
| **Pipe ASTM F758 PS46**<br>$\frac{\Delta_s}{2R_m} = \frac{1.5(0.10)(27.04)}{0.149\,(46) + 0.061\,(2000)} = 0.031 = 3.1\%$ | |

| Known data | Comments and Information |
|---|---|
| **B. Wheel load** | |
| $D_L = 1.0, \; n_w = 0.50, \; K_b = 0.10$ | See narrative page 24 |
| $\frac{\Delta_w}{2R_m} = \frac{D_L K_b P_w}{0.149\,\overline{PS_O} + 0.061\,E'\,n_w}$ | Eq (29a) |
| Obviously deflections caused by wheel loading at design depth are too small to consider. | |
| **C. Installation deflection** | Use Table 5 |
| Must calculate pipe stiffness. Embedment material and density is from specifications. | |
| **Pipe ASTM D 1785 Sch 40** | |
| $\overline{PS_O} = 154$ | |
| From table 5 $\frac{\Delta_i}{2R_m} = 2\%$ | |
| **Pipe ASTM D 2241 SDR 21** | |
| $\overline{PS_O} = 225$ | |
| From table 5 $\frac{\Delta_i}{2R_m} = 2\%$ | |
| **Pipe ASTM D 2241 SDR 17** | |
| $\overline{PS_O} = 437$ | |
| From table 5 $\frac{\Delta_i}{2R_m} = 2\%$ | |
| **Pipe ASTM F 758 PS 46** | |
| $\overline{PS_O} = 46$ | |
| From table 5 $\frac{\Delta_i}{2R_m} = 3\%$ | |

| Known data | Comments and Information |
|---|---|
| **Pipe ASTM D 1785 Sch 40**<br>$\frac{2.3\,(0.978)}{2.4} - \frac{0.06}{0.80} = 0.862$ | < 1 Design OK |
| **Pipe ASTM D 2241 SDR 21**<br>$\frac{2.3\,(1.055)}{2.4} - \frac{0.06}{0.80} = 0.937$ | < 1 Design OK |
| **Pipe ASTM D 2241 SDR 17**<br>$\frac{2.3\,(1.176)}{2.4} - \frac{0.046}{0.80} = 1.069$ | > 1 Design not valid |
| The Sch 40 and the SDR 21 meet the design requirements. Can the design be revised to make the SDR 17 acceptable? Yes, there are several options open to the designer:<br><br>1. Design again using E' = 3000 psi. If the new design passes specifications must be written to include embedment material and density that will result in an E' of 3000 psi.<br><br>2. Design the perforations to be installed at some point other than the maximum strain points (invert, crown, or springline).<br><br>This designer chooses to try option 2.<br><br>Use the equation for strain when perforations are located at some angle, θ, from the vertical or horizontal axis through the center of the pipe. | |
| Try θ = 10° $C_m = 0.2349$ | Moment Coeff. from Table 6 |
| **Use equation:**<br>$\overline{PF}\ \varepsilon_{bsu} = 10 \frac{t}{R_m} C_m \overline{MF} \frac{\Delta_y}{2R_m} \overline{LF}\ \overline{PF}$ | Eq (31) |
| **Ring Bending Strain @ 10°:**<br><br>**A. Earth**<br>$\overline{PF}\ \varepsilon_{bsu} = 10 \left(\frac{0.390}{3.117}\right) (0.2349)\,(0.75)\,(2.168\%)\,(1.5)\,(2.3)$<br>$\overline{PF}\ \varepsilon_{bsu} = 1.648$ | |

| Known data | Comments and information |
|---|---|
| **B. Installation** | |
| $\overline{PF}\ \varepsilon_{biu} = 8.56 \left(\frac{0.390}{3.117}\right) (0.2349)(0.75)(2.0\%)(1.0)(2.3)$ | |
| $\overline{PF}\ \varepsilon_{biu} = 0.8678$ | |
| **C. Total Ring Bending Strain @ 10°** | |
| $\overline{PF}\ \varepsilon_{bu} = \overline{PF}\ \varepsilon_{bsu} + \overline{PF}\ \varepsilon_{biu}$ | Eq (34) |
| $\overline{PF}\ \varepsilon_{bu} = 1.648 + 0.868 = 2.516$ | |
| **Ring Compression Strain @ 10°** | |
| **A. Earth:** | |
| $\varepsilon_{csu} = \frac{(3.312)(40.56)}{0.390\ (400{,}000)} = 0.086$ | Maximum Compression |
| $\varepsilon'_{csu} = \frac{(3.312)(21.63)}{0.390\ (400{,}000)} = 0.046$ | Minimum Compression |
| **Check strength index using the interaction equations.** | |
| Revised maximum compression @ 10° : | |
| Because the strength index check for compression was acceptable at the critical points, there is no reason to check again. | |
| Revised maximum tension @ 10° : | |
| $\frac{\overline{PF}\ (\varepsilon_{bu})}{\varepsilon_{Ru}} - \frac{\varepsilon'_{csu}}{\varepsilon_{Cu}} \leq 1$ | Eq (41) |
| $\frac{2.516}{2.4} - \frac{0.046}{0.80} = 0.991$ | <1 Design OK |
| These computations indicate the SDR 17 is satisfactory but the perforations must be installed between 10° to 80° from the vertical line through the center of the pipe. Some tolerance for construction must be allowed. This designer would specify 22.5° to 67.5° | |

# Installation Guidelines

When installing a buried plastic pipe, the objectives are to minimize pipe deflections induced by, or resulting from, the installation process, and to provide a firm, stable permanent support for the pipe when the installation is subjected to loads. This section deals with factors that are especially critical in obtaining such an installation.

## Terminology

Terminology that describes buried pipe installations varies among regions of the country and also among various specifying authorities. The terminology that follows is used throughout this report. A general arrangement of the pipe embedment system describing the terminology is shown in figure 2.

**Foundation.** A foundation is an imported material used under the bedding. It may be required when trench bottom instability, rock, or excess water is encountered.

**Embedment System.** The embedment system, which also may be the drainage envelope for perforated underdrains, includes bedding, haunching, and initial backfill.

**Bedding.** Bedding is the portion of the embedment that is prepared and in place before installing the pipe. Where *in-situ* soil conditions and drainage characteristics permit, the *in-situ* trench bottom may serve as bedding. Bedding may or may not contain a groove conforming to the pipe curvature, depending on installation requirements.

**Haunching.** This is a layer of embedment material that extends from the top of the bedding to the springline of the pipe.

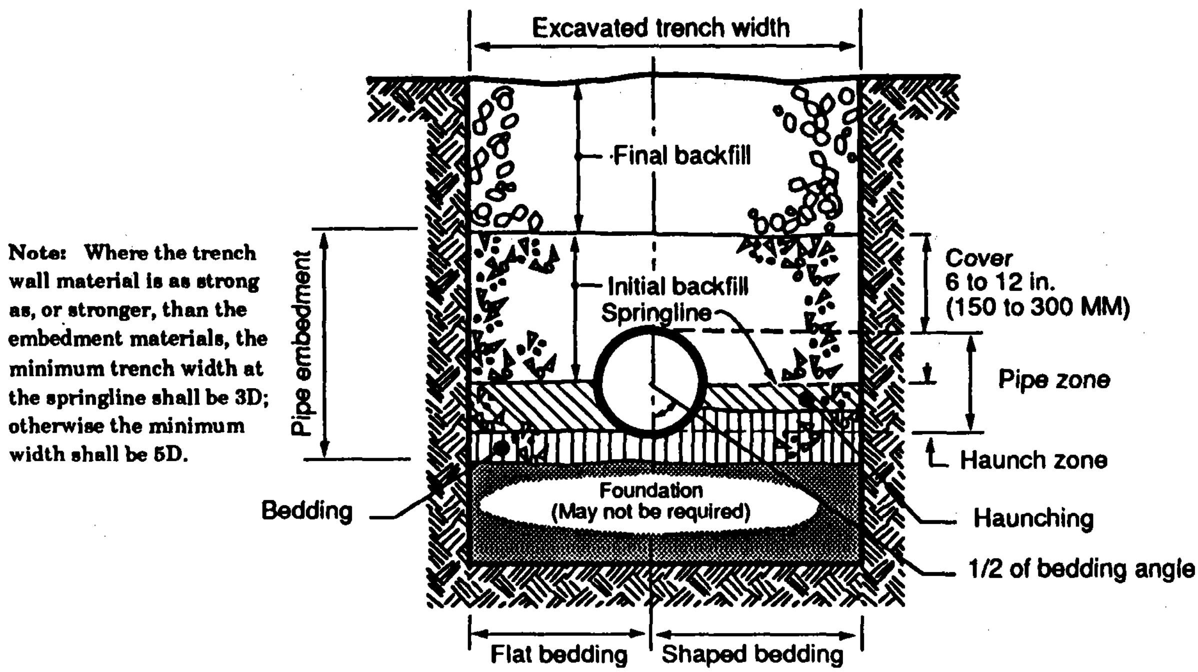
**Haunch Zone.** This zone is defined as the area between the invert and the springline of the pipe (haunches).

**Initial Backfill.** Initial backfill is the portion of the embedment system that extends from the top of the haunching to 150 to 300 mm (6 to 12 in) above the crown of the pipe.

**Final Backfill.** Final backfill is that portion of the installation that lies between the top of the initial backfill and the top of the trench.

**Pipe Zone.** This zone lies adjacent to the pipe over its full height.

**Figure 2.** ***Pipe embedment system terminology***




# Pipe-Embedment System

The objectives that must be achieved in the installation of a flexible buried plastic pipe for drainage are as follows:

1. The line and grade of a drainage piping system should be constructed to provide the gravity flow requirements anticipated in design.

2. The cross section of the installed pipe should be within specified deflection limits immediately after construction and remain reasonably circular for the indefinite future. This means that distortion built in during installation, or caused by construction, service traffic, or earth loadings, should remain within tolerable limits. Overdeflection is an indication of excessive strain in the pipe wall; it may restrict cleaning devices and cause gasketed joints to leak.

3. When buried pipe is used for underdrains, the embedment system also serves as a drainage envelope, and must permit free drainage for the design life of the installation. This means that the envelope must be designed and constructed to allow passage of water with minimum transport of fines into or through the pipe-envelope system. Movement of fines from the *in-situ* trench may clog the envelope. Movement of fines into the pipe through perforations can clog the pipe or cause loss of structural support by embedment materials.

An acceptable installation results from the proper choice of materials and construction techniques that recognize the factors that contribute to both successful and unsuccessful installation performance.

COMPUTATION SHEET
SCS ENG 523A
Rev. 6-69

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

| | | | | |
|---|---|---|---|---|
| STATE SNTC | | PROJECT Design of Flexible Pipe | | |
| BY MNL | DATE 3-88 | CHECKED BY SRW | DATE | JOB NO. |
| SUBJECT Derivation of Equation & Coefficient in Strain Computations | | | | SHEET 7 OF 7 |

in the deflection equation solve for E:

$$E = 0.09988 \frac{W R_m^4}{\Delta_p I}$$

Substitute values into the equation for strain:

$$\varepsilon = \frac{Mc}{EI} = \frac{\frac{1}{4} W R_m^2 \left(\frac{t}{2}\right)}{\left(\frac{0.09988 W R_m^4}{\Delta_p I}\right) I}$$

reduce terms:

$$\varepsilon = \frac{\frac{1}{8} t}{\frac{0.09988 R_m^2}{\Delta_p}} = \frac{1.25\, t\, \Delta_p}{R_m^2} = 1.25 \frac{t}{R_m} \frac{\Delta_p}{R_m}$$

Deflection is usually reported as a ratio to the mean diameter, therefore must multiply numerator and denominator by 2.

$$\varepsilon = 2.50 \frac{t}{R_m} \frac{\Delta_p}{2 R_m}$$

**or if all terms are a ratio of the mean diameter**

$$\varepsilon = 5.00 \frac{t}{D_m} \frac{\Delta_p}{D_m}$$

A similiar analysis was done for the point loading condition and the only change from the strain equation above was the coefficient. It changed from 5.00 to 4.28. Published research shows the coefficient to be as high as 10. A decision was made to use 5.00 as the coefficient when computing the bending strain from the soil and wheel loads and to use 4.28 as the coefficient when computing the bending strain that may develop from tthe installation.

# 9. Calculate Buckling Resistance

**Check both procedures**

## Modified AWWA formula

$$P_{cr} = 0.77 \sqrt{\left(\frac{1 - \frac{\Delta}{2R_m}}{\left(1 + \frac{\Delta}{2R_m}\right)^2}\right)^3 Cw\, B'\, E'\, \phi\, \overline{PS_{10}}\, \phi'}$$

$$C_w = 1 - \frac{h_w}{3h}$$

*If* $0 < \frac{h\,(12)}{2R_o} < 5$

*then* $B' = \left(0.015 + 0.041 \frac{h}{2R_o}\right)$

*If* $5 < \frac{h\,(12)}{2R_o} < 80$

*then* $B' = \left(0.150 + 0.014 \frac{h}{2R_o}\right)$

**Buckling resistance**

$$\frac{P_{bu} + P_{gu} + P_{vu} + P_{wu}}{P_{cr}}$$

**Is the value ≤ 1.0**

- **YES** → All requirements have been met.
- **NO** → Return to 2. Select another pipe / Return to 1. Change embedment material

## Check buckling under hydrostatic loads

$$P'_{cr} = 0.5\, C_a\, \overline{PS_{10}}\, \phi'\, \phi''$$

$C_a$ = 2 to 3 for soft soils but may be up to 6 for rigid encasement

**Buckling resistance**

$$\frac{P_{gu} + P_{vu}}{P'_{cr}}$$

**Is the value ≤ 1.0**

- **YES** → All requirements have been met.
- **NO** → Return to 2. Select another pipe / Return to 1. Change embankment material

**All requirements have been met. The design is complete.**