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EXTERNAL LOAD DESIGN OF PVC PIPE

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GENERAL

The use of PVC pipe is becoming more widespread every year. Pipe sizes range from 1/2" to 27" with a variety of wall thicknesses available. When selecting the wall thickness for a particular project, most emphasis is placed on the effects of internal pressures, but in some cases, particularly for low pressure applications, the effects of external loads may be more important. This paper addresses the types and magnitudes of external loads that a designer must consider in determining if the proposed design is adequate.

Because PVC is a petroleum based product, costs are influenced by the world oil prices. To keep prices down, pipe manufacturers are constantly trying to find the minimum wall thickness that will meet a particular need. Because all flexible pipes depend on the support of the surrounding soil envelope to give much of the resistance to deflection, construction techniques and materials become increasingly important as wall thicknesses get thinner.

PVC is a unique material in that failure from external loads can occur in two different ways: 1) A sudden loading that exceeds the pipe strength may cause permanent deflection or buckling; or 2) a long term load may cause a gradual, permanent change in shape (called creep) of the pipe that will eventually overstress the pipe. The magnitude of the load causing long term failure may be smaller than the load causing sudden failure. Generally, pipes that are buried less than 4 feet deep are affected more by sudden loadings than by the long term loads.

In most typical farm installations, the contractor uses the dirt excavated from the trench as backfill around the pipe and he does a minimum amount of compaction in order to keep his costs low. So the problem for the designer is to select wall thicknesses and depth of soil cover for SCS projects that will be economical and yet have adequate strength to resist loading failure for the typical installation conditions that can be expected to occur. In this process, the danger is that unexpected loads or pressures will be applied to that product and failure will result. Consequently, it is essential that the designer properly evaluate the types and sizes of loads that can be expected at any particular job site in order to find a safe and economical pipe to meet the farmer's needs.

The plastic pipe industry and researchers generally recommend that designers should not allow deflections to exceed 5 percent of the vertical height. While actual

failure of the pipe will not occur until deflections exceed 10 percent, designing to 5 percent will provide a safety factor against unexpected loads and other unpredictable conditions that may occur.

DESIGN PROCEDURE

DEAD LOADS. Dead loads are defined as the weight of permanent loadings that will affect the pipe, such as the earth load and buildings or other permanent structures constructed over the pipe.

In most SCS projects, the design dead load will be the weight of the soil directly over the pipe. In this case, the following equation can be used to find the magnitude of the load on the pipe.

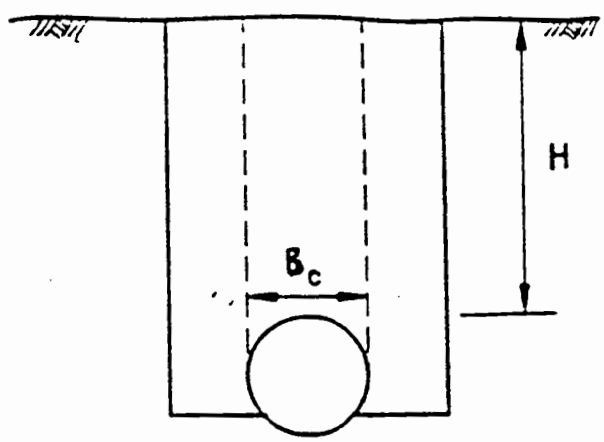
$$W_d = (w)(H)(B_c)$$

where: W_d = dead load (lbs/ft.)

w = Unit weight of soil (lbs/cu.ft.)

H = Height of fill over pipe (ft.)

B_c = Outside diameter of the pipe (ft.)



DEAD LOAD

Figure 1

LIVE LOADS Live loads are defined as temporary loads that may affect the pipe only for a short period of time. The most common live loads are vehicle weights caused by farm equipment and trucks traveling over the pipe. The effect of live loads on the pipe decreases as the depth of soil increases between the ground surface and the top of the pipe. A dramatic change in loading occurs as the depth of cover goes from 1 foot to 4 feet. As depths increase beyond 5 feet, the effect of live load is less significant and the dead load becomes more important.

Recommended design live loads at ground surface for SCS projects are as follows. The maximum load of a single wheel caused by normal field equipment operating over a pipe line is 10,000 pounds. A loaded farm truck with dual wheels on a single rear axle exerts a load of 12,000 pounds on each set of duals (designated H15). A truck with two rear axles can exert a load of 16,000 pounds on each rear corner, which is considered to be a point load as it crosses the pipe (designated H20).

A second part of the live load is often referred to as the impact forces. As a vehicle travels over the pipe, there is often an increase in the weight exerted on the pipe because of the changes in momentum of the vehicle. For example, applying the brakes, accelerating or changing direction over the pipe can cause an increase in loading on the pipe. Backfill that is either mounded or depressed over the pipe can cause significant impact forces when a vehicle crosses the pipe.

Obviously, impact will be greater for shallow depths of cover over the pipe. A term, I_f, called the impact factor, is commonly used to account for the effects of impact in design equations. Recommended impact factors for pipes where the live loads will be crossing at speeds over 20 miles per hour, is 1.2 for depths of cover between 2′ and 3′, and 1.0 for cover over 3 feet. For slower speeds and where no mounding or depressions exist over the pipe, the impact factor can be reduced to 1.0 at 2.5′ of cover.

The basic equation for determining the effects of live load on a flexible pipe is as follows:

$$W_L = \frac{0.48(I_f)(P)(B_c)}{2.67\ (H^2)}$$

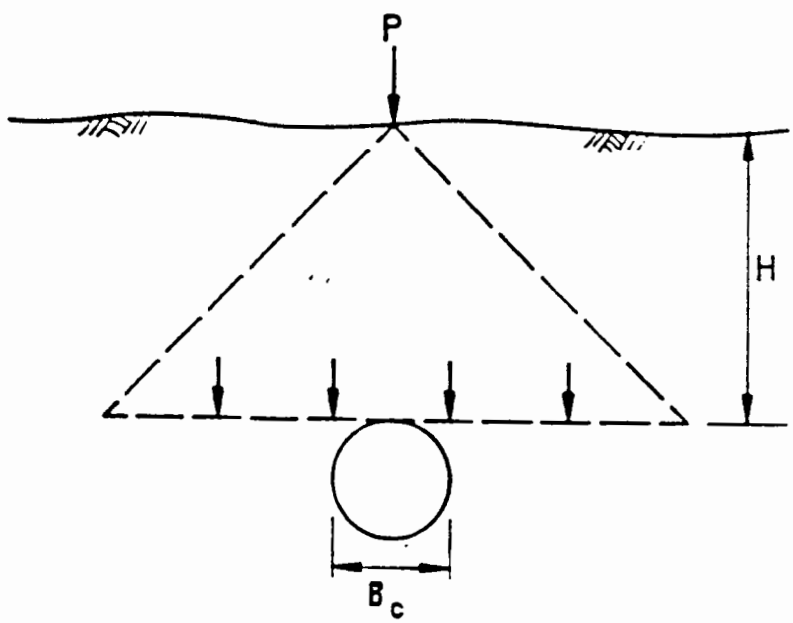
where: W_L = Live load on pipe (lbs/ft.)

I_f = Impact Factor

P = Live load at ground surface (lbs.)

H = Height of fill over pipe (ft.)

B_c = Outside diameter of pipe (ft.)



LIVE LOAD

Figure 2

PIPE DEFLECTION The Modified Iowa Formula is generally used to determine the amount of deflection that can be expected when the loads are known. The equation is expressed as follows.

$$\text{Delta Y} = \frac{1.1(D_L)(k)(W_c)(r^3)}{(E)(I) + 0.061(E')(r^3)}$$

where: Delta Y = Amount of deflection in vertical direction (in.) (See Figure 3)

D_L = Lag Factor

k = Bedding Constant

W_c = Total load on pipe (#/lin.in.) = $(W_d + W_L)/12$

r = radius of pipe (in.)

E = Modulus of elasticity of pipe (psi)

I = Moment of inertia of pipe wall cross section (in^4/lin.in.) = $t^3/12$; where t = pipe wall thickness (in.)

E′ = Modulus of soil reaction (psi)

Several factors in the equation need some explanation to be understood by the designer.

The lag factor (D_L) is used to account for the gradual change in shape caused by long term loadings as described in the first section of this paper. Typically, this value ranges between 1.0 and 1.5. Where the pipe is buried less than 4 feet deep, a value of 1.2 is recommended. For depths greater than 5 feet, 1.5 should be used.

The bedding constant, k, is the means to evaluate the nature of the surface that the pipe is placed upon. It ranges from 0.10 for a flat bottom trench with little support under the haunches, to 0.20 for a trench that has been carefully shaped to fit the bottom one/third of the pipe. For normal SCS work, a value of 0.1 should be used.

The modulus of elasticity (E) of the pipe is a measure of the flexibility and strength of the material. It is usually considered to be 400,000 for Class 12454-B and C,

Designation PVC 1120 and 1220, which are the types used in most agricultural pipelines. For Class 14333-D, Designation PVC 2110, 2112, or 2116, a value of 320,000 is recommended.

The modulus of soil reaction, E′, is a measure of the type of backfill around the pipe and the amount of effort used to place and compact it. The Bureau of Reclamation has evaluated over 1,000 installations and prepared Table 1 which is widely used as a guide in selecting the modulus of soil reaction.

Table 1

Average Values* of Modulus of Soil Reaction (E′) (For initial flexible pipe deflection)

Soil Type/Primary Pipe Zone Backfill Material (Unified Classification System)†	*E′* for Degree of Compaction of Bedding, *psi (MPa)*		
	Slight <85% Proctor <40% rel. den.	Moderate 85–95% Proctor 40–70% rel. den.	High >95% Proctor >70% rel. den.
Fine-grained soils (LL>50)‡/Soils with medium to high plasticity CH, MH, CH-MH	Soils in this category require special engineering analysis to determine required density, moisture content, compactive effort.		
Fine-grained soils (LL<50)/Soils with medium to no plasticity CL, ML, ML-CL, CL-CH, ML-MH, with less than 25% coarse-grained particles	200 (1.4)	400 (2.8)	1000 (6.9)
Fine-grained soils (LL<50)/Soils with medium to no plasticity CL, ML, ML-CL, CL-CH, ML-MH, with more than 25% coarse-grained particles Coarse-grained soils with fines/GM, GC, SM, SC§ containing more than 12% fines	400 (2.8)	1000 (6.9)	2000 (13.8)
Coarse-grained soils with little or no fines/GW, GP, SW, SP§ containing less than 12% fines	1000 (6.9)	2000 (13.8)	3000 (20.7)
Crushed rock		3000 (20.7)	
Accuracy in terms of difference between predicted and actual average percent deflection	±2%	±1%	±0.5%

*As determined by the US Bureau of Reclamation.
†Refer to Table 6-2.
‡LL = Liquid limit.
§Or any borderline soil beginning with one of these symbols (i.e., GM-GC, GC-SC).

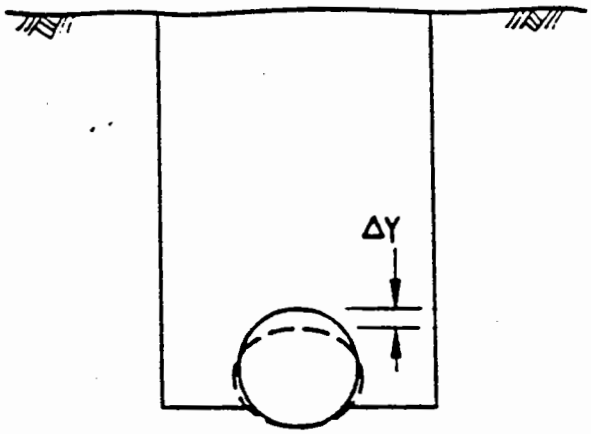
NOTES:
1. Values applicable only for fill less than 50 ft (15 m).
2. For use in predicting initial deflections only, appropriate Deflection Lag Factor must be applied for long-term deflections.
3. Percent Proctor based on laboratory maximum dry density from test standards using about 12 500 ft·lbf/ft^3 (598 000 J/m^3) (Method D698, AASHTO T-99).

The terms "fine-grained" and "coarse-grained" in Table 1 are based on the percentage of particles passing the #200 sieve. If more than 50% of a sample of soil passes through this sieve, then it is termed "fine-grained". Fine-grained soils with medium to no plasticity are probably the most common soil group in Idaho and include most silts and silt loams. Coarse-grained soils with fines are typically sandy loams and loamy sands.

To use Table 1 may require a determination at the 12% or 25% level of coarse or fine grained soils. Finding this additional break-down of particle percentages is a little more difficult. If a published soil survey exists for the site in question, the typical gradations of each soil type can be found in there. If not, check with an Engineer, a soil scientist, or estimate as carefully as possible from a close examination of the soil sample.

Soils with a liquid limit (LL) greater than 50 usually have a high clay content and a low load-carrying capacity. It also indicates a soil with high cohesion.

The columns in Table 1 describing the degree of compaction should be evaluated by the following criteria. "Dumped" indicates that the backfill is pushed or dumped into the trench in large quantities with no attempt at layering or compaction. On the other extreme, "high" compaction would apply when the contractor puts the material under and around the pipe in thin layers (less than 6 inches thick), and uses hand or machine compaction methods on each layer to ensure uniform soil densities all the way around the pipe. The finished densities would be equivalent to that of the undisturbed soil adjacent to the trench. The intermediate conditions, "slight" and "moderate" indicate increasing levels of care in placing and compacting the supporting soils around the pipe.



PIPE DEFLECTION

Figure 3

EXAMPLE PROBLEM

Given: Pipe is Class 12454-B, Type 1120.
Size is 12"dia., IPS, with SDR = 64.
Pipe will be installed across a farmers field where double-axled trucks will be hauling potatoes, and 18-wheelers will haul grain.
Minimum cover over the pipe will be 30 Inches.
Soil is non-plastic loam, w/35% sands size parts.

Find: Pipe Deflection in inches and in percent of pipe diameter and compare with an allowable deflection of 5%.

a. Determine the Dead Load.

$w = 110$ #/cu.ft.
$H = 2.5$ ft.
$B_c = 12.75/12 = 1.0625$ ft.

$$W_d = (w)(H)(B_c) = (110)(2.5)(1.0625)$$

$$= 292.2 \text{ \#/ft.}$$

b. Find Live Load

$I_f = 1.0$ (Trucks will be going very slow)
$P = 16{,}000$ #

$$W_L = \frac{0.48(I_f)(P)(B_c)}{(H^2)}$$

$$= \frac{0.48(1.0)(16{,}000)(1.0625)}{(2.5^2)}$$

$$= 1{,}306 \text{ \#/ft.}$$

c. Determine amount of deflection

$D_L = 1.2$
$K = 0.1$
$W_c = (292 + 1{,}306)/12 = 133$ #/lin.in.
$r = 12.75/2 = 6.275$ inches
$E = 400{,}000$
$t = 0.1992$ in. (From 12.75/64)
$I = 0.1992^3/12 = 0.000659$ in^4
$E' = 400$ psi (From Table 1, Slight compaction)

$$\text{Delta Y} = \frac{1.1(D_L)(k)(W_c)(r^3)}{(E)(I) + 0.061(E')(r^3)}$$

$$= \frac{1.1(1.2)(0.1)(133)(6.275^3)}{(400{,}000)(.000659) + 0.061(400)(6.275^3)}$$

$$= \frac{4{,}337.8}{263.6 + 6028.8} = 0.689 \text{ inches}$$

% Defl. = 0.689(100)/12.75 = 5.4% > 5% Too High

Alternative 1: Install the pipe with 3 feet of cover.

a. Determine Dead Load

$$W_d = (110)(3.0)(1.0625) = 350.6 \text{ \#/ft.}$$

b. Determine Live Load

$$W_L = \frac{0.48(1.0)(16{,}000)(1.0625)}{3.0^2} = 906.7 \text{ \#/ft.}$$

c. Determine Amount of Deflection

$$\text{Delta Y} = \frac{1.1(1.2)(0.1)(104.7)(6.275^3)}{263.6 + 6028.8} = 0.543''$$

% Deflection = 0.543(100)/12.75 = 4.3% < 5% OK

Alternative 2: Improve compaction to E′ = 1,000

$$\text{Delta Y} = \frac{4{,}337.8}{263.6 + 0.061(1{,}000)(6.275^3)} = 0.283 \text{ In.}$$

% Deflection = 0.283(100)/12.75 = 2.2% < 5% OK

Either alternative will reduce the deflection to a safe level.