Resistance to Ring Bending – Pipe Stiffness (PS), Ring Stiffness Constant (RSC) and Flexibility Factor (FF)

for

Buried Gravity Flow Pipes

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Foreword

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The purpose of this technical note is to provide general information on resistance to ring bending for buried, gravity flow pipes.

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RESISTANCE TO RING BENDING FOR BURIED GRAVITY FLOW PIPES

Various measures have been used to characterize the resistance to ring bending of pipe. In the U.S., these measures include:

- Flexibility Factor (FF) as defined in AASHTO Bridge Design Specification Section 18,
- Pipe Stiffness (PS) as defined in ASTM D 2412, and
- Ring Stiffness Constant (RSC) as defined in ASTM F 894.

These measures characterize the pipe's resistance to ring deflection when subjected to a short-term parallel plate load. The purpose of PPI Technical Note-19 is to advise on the applicability of these measures for comparing and classifying plastic pipes.

The first commonly used measure for pipe deflection resistance was "pipe stiffness" (PS). Designers found it easy to assign a minimum PS value in their specifications for plastic pipes. However, for larger diameter pipes, the validity of PS as a product specification requirement has been questioned because:

(1) It was discovered that given the same handling and installation forces smaller diameter pipes require much higher "pipe stiffness" for proper installation than do larger diameter pipes.

(2) It was found that there was a trade-off between pipe material strain capacity and "pipe stiffness". Pipes made from strain-limited plastics such as glass-reinforced thermoset resin required greater stiffness to resist localized deflections than that required for pipes made from thermoplastic materials having high strain capacity.

HANDLING AND INSTALLATION

Pipe intended for buried applications must have sufficient resistance to deflection from shipping, handling, and storage loads as well as loads applied during installation. The most significant of these loads is the force exerted on the pipe during mechanical compaction of the soil. This force can cause the pipe to undergo deformations that are exacerbated by soil loads during the subsequent placement of backfill. The force exerted on the pipe during backfill compaction can be treated as a backfill compaction load that is primarily a function of the compaction method and soil type, but is relatively independent of the pipe's diameter.

When pipes of equal PS but different diameters are subject to equal backfill compaction loads, the deflection response in percent is a function of its diameter. For a given backfill compaction load, the deflection of a pipe can be calculated from the PS equation:

$$PS = \frac{F}{\Delta Y} = \frac{EI}{.149\left(\frac{D_m}{2}\right)^3} \tag{1}$$

$$\Delta Y = \frac{F}{PS} \tag{2}$$

Where:	PS	=	Pipe Stiffness (lbs/in^2)
	F	=	Load (lbs/lineal-in)
	ΔY	=	Pipe Deflection (in)
	E	=	Pipe Material Modulus of Elasticity (lbs/in^2)
	I	=	Pipe wall Cross-Section Moment of Inertia (in^4/in)
	D_m	=	Pipe Mean Diameter (in)

By definition, pipes of various diameters that experience the same parallel plate load (e.g., 50 lbs/lineal-in) and experience the same absolute deflection (e.g., 1”) have a PS of 50 psi. However, when deflection is calculated as a percentage of the initial diameter, a 1” deflection in a small pipe is a significantly larger percentage deflection than the same 1” deflection in a larger pipe (for 12” pipe, 1” deflection equals 8.3 %; for 60” pipe, 1” deflection equals 1.7%). Since control of deflection as a percent of pipe diameter is a common evaluation criterion, the conclusion can be drawn that PS is not a particularly useful measure for classifying pipes of different diameters with regard to installation forces.

The above discussion leads to the conclusion that any workable minimum requirement for resistance to ring bending deflection has to be diameter weighted. This can be accomplished by "weighting" the PS equation by multiplying both sides of Eq. 1 by the mean diameter of the pipe. When terms are rearranged, the result is Eq. 3.

$$\frac{F}{\frac{\Delta Y}{D_m}} = \frac{8EI}{.149(D_m)^2} \qquad (3)$$

If the load in Eq. 3 is expressed in lbs/lineal-ft instead of lbs/lineal-in and if deflection is expressed in percent, Eq. 3 becomes the mathematical expression for “ring stiffness constant”, RSC:

$$RSC = \frac{F}{\frac{\Delta Y}{D_m}}\left(\frac{12}{100}\right) = \frac{6.44EI}{(D_m)^2} \qquad (4)$$

Where: RSC = Ring Stiffness Constant.

When pipes of different diameter but equal RSC are subjected to the same parallel plate loads, an equivalent percent deflection results. The AASHTO flexibility factor, FF, is simply the inverse of RSC multiplied by a constant. Therefore, FF and RSC produce equal deflection responses and can be used to classify pipes for handling and installation capacity.

What minimum value of RSC is necessary to provide sufficient resistance to handling and installation forces? ASTM F 894 for example anticipates up to 3 percent out-of-roundness for pipe prior to earthloading. Therefore, the pipe should be able to withstand normal handling and installation loads, such as the force transmitted to the pipe due to machine compaction of the embedment, without exceeding 3 percent out-of-roundness. (This is not to be confused with the deflection limit applied to deflections due to backfill and live loads.) Field measurements reported by Petroff [1] show that RSC 40 HDPE pipes possess sufficient stiffness to resist normal handling and installation loads and remain round within 3 percent when installed in accordance with ASTM D 2321.

It should be noted that the ASTM test methods for RSC and PS differ. RSC tests are conducted at 2 in/min load rate versus 0.5 in/min for PS, and RSC is measured at 3 percent deflection where PS is measured at 5 percent. Therefore, when the expression in Eq. 4 is used to convert from RSC to PS, the F/ΔY value in Eq. 4 should be multiplied by an empirical factor that varies for the material. For HDPE, the empirical factor is about 0.8.

In summary, as pipe diameter increases, less resistance to ring bending is required for the same handling and installation capacity. Useful measures that compare handling and installation capacity without regard to pipe size include AASHTO flexibility factor, FF, and ring stiffness constant, RSC. Pipe stiffness, PS, however, is sensitive to pipe size, and is not useful for comparing the handling and installation capacities of larger and smaller pipes.

STRAIN CAPACITY

When subjected to earth loads, strain in the pipe wall results from ring bending and ring thrust deformations. If the pipe material has a low tolerance for strain, it is usually necessary to limit strain by limiting pipe deformation.

There are two levels of deformation in buried pipe. One is elliptical deflection due to uniform earth load; the other is a second order deformation from uneven loads around the pipe circumference such as point loads that cause localized deviation from an elliptical shape. Second order deformations are generally small but may induce high strains, and they are directly proportional to the pipe's resistance to ring bending. Second-order deformations are of little consequence with strain-tolerant pipes such as HDPE because of the high strain capacity. In an eight-year study of pipes made using pressure-rated HDPE material, Janson reports that for practical design purposes such as for gravity sewers, there does not appear to be an upper limit on design strain [2]. This essentially means that a design for pipes made from pressure-rated grades of HDPE does not need to address strains from second order deformations when overall deflection and buckling are controlled.

BURIED PIPE PERFORMANCE

Buried pipe must possess sufficient stiffness to mobilize backfill soil resistance and resist buckling. Deflection must be limited to a value that will not disrupt flow or cause joint leakage. Extensive field experience with high DR stress-rated HDPE pipes and stress-rated HDPE, profile wall pipes speaks to the capability of low stiffness pipes to perform under soil loads.

Flexible pipe deflection depends on the combined contribution of pipe ring bending stiffness and embedment soil stiffness (E'), but primarily on embedment soil stiffness. Considerable testing and field measurements have established that for low stiffness pipes, deflection is almost exclusively controlled by the embedment soil surrounding the pipe. This is true for any flexible pipe, whether metal or plastic. Spangler's Iowa formula can be used to demonstrate that the soil's contribution to resisting deflection is much more significant than the pipe's contribution. Although Spangler’s Iowa formula was developed using pipes of 25-psi stiffness and higher, considerable field experience has demonstrated its applicability to low stiffness pipes [3]. For example when pipes of 46 psi PS and 4.6 psi PS are installed with embedment having normal soil stiffness (E'), there is little difference in either pipe’s deflection. On the other hand, when pipe is not installed properly, a low embedment soil E' results in excessive deflection for both 46 psi and 4.6 psi pipes.. It can be shown mathematically that a 46 psi pipe supplies a stiffness to the soil/pipe system equivalent to a soil with an E' of 112 psi, which offers little resistance to deflection. Therefore, embedment soil placement (installation quality), not pipe stiffness controls deflection.

The principle of soil embedment controlling deflection has been illustrated over and over again in field tests and numerous soil box demonstrations. Publications by Chua and Lytton [4], Watkins et al [5], Gaube and Muller [6], Taprogge [7], Janson and Molin [8], Selig [9], and Gabriel [10] all speak to the fact that the pipe's stiffness makes only a minimal contribution to deflection resistance.

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APPENDIX

APPROXIMATE PIPE STIFFNESS (PS) FOR SOLID-WALL HDPE DR PIPE

It is occasionally convenient to know PS values for solid-wall OD-controlled HDPE pipes made to common dimension ratios (DR's). The table below was developed using Eq. 1, and assumes pipe having average outside diameter, minimum wall thickness, and made using HDPE material having 110,000 psi short-term modulus of elasticity. For the same material, pipes having the same DR have the same PS regardless of diameter.

DR	7	7.3	9	11	13.5	15.5	17	21	26	32.5
PS, psi	2278.6	1968.3	961.3	492.2	252	161.4	120.2	61.5	31.5	15.7