

# Do You Really Know the Difference Between Rigid and Flexible Pipe?

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So, tell me...what's the difference between rigid and flexible pipe? I encounter this question many times, especially at industry trade shows or Concrete Pipe University seminars. When teaching classes on the basics of concrete pipe design, I have often been asked for the design criteria that differentiate a rigid and a flexible pipe. There is no easy answer to this question.

A rigid pipe is less installation sensitive than flexible pipe products. With rigid concrete pipe, a large portion of the soil-pipe structure is contained within the pipe itself, thereby relying less on the portion of the structure provided by the soil. This is not to say that you don't need to perform a proper design for whatever product you use. Concrete pipe does, however, lend itself to design of a sufficient soil-pipe structure regardless of the existing soil conditions.

There are several different pipe options, and all have their own unique design method. AASHTO splits them into three sections of its Bridge Design Code:

- Section 12.7 covers, "Metal Pipe, Pipe Arch, and Arch Structures"
- Section 12.10 covers "Reinforced Concrete Pipe", and,
- Section 12.12 covers "Thermoplastic Pipes".

The interaction between a buried pipe and the soil is extremely important. By classifying pipe materials into three distinct categories, you do not always get a good understanding of the differences between a rigid pipe and a flexible pipe, including the pipe's dependence on the soil. How would you classify a pipe as being rigid, where it works with the active pressure of the soil? And when would you classify a conduit as a flexible pipe that uses the passive pressure of soil?

In the U.S., you sometimes hear that if a pipe can deflect more than 2 percent it should be considered a flexible pipe. But outside of deflection, there is not much clarification on the issue. Other countries take a slightly different approach. In Australia and New Zealand the stiffness of the pipe is related to the stiffness of the soil surrounding it. In Europe the settlement of the top of the pipe is related to the settlement of the surrounding soil. These aspects are addressed before design of the pipe is commenced.

The US method has an advantage because the designer immediately references the chapter that deals with the chosen pipe material, rather than performing preliminary calculations. However, one disadvantage is that the designer does not fully see the roles that the soil and the pipe play in the completed structure.

In Australian/New Zealand Standard Commentary AS/NZS 2566.1, Supplement 1, to AS/NZS 2566.1, "Buried Flexible Pipelines", the engineer multiplies the soil modulus ( $E'$ ) in MPa units by 7,500 and compares it to the long-term ring bending stiffness  $S_{DL}$  of the pipe. If  $S_{DL}$  is less than  $7,500 \times E'$ , then a flexible pipe design is appropriate. If  $S_{DL}$  is greater than  $7,500E'$  then a rigid pipe design is appropriate.

For information purposes, we can compare reinforced concrete, corrugated metal, and high-density polyethylene pipes, 36 inch in diameter, using the pipe properties provided in the tables at the end of Chapter 12 of the AASHTO LRFD Bridge Design Specifications. The long-term ring bending stiffness per AS/NZS 2566.1 is:  $S_{DL} = (EI/D^3)10^6$ . Our soil assumption will be a good granular material with an  $E'$  of 2,000 psi, or 13.8 MPa. Our values are:

$$7500E' = 103,500 \text{ MPa} \quad \begin{array}{l} \text{Reinforced Concrete Pipe } S_{DL} = 2,102,085 \text{ MPa} \\ \text{Corrugated Metal Pipe } S_{DL} = 15,610 \text{ MPa} \\ \text{High-Density Polyethylene Pipe } S_{DL} = 2,977 \text{ MPa} \end{array}$$

As anticipated, the concrete pipe value is much higher than  $7,500E'$ , and is therefore classified as a rigid pipe. The CMP and HDPE pipe values are lower than  $7,500E'$  and are therefore classified as flexible pipe. Notice just how much more "flexible" a high-density polyethylene pipe is compared to a corrugated

metal pipe.

In Europe, a somewhat similar, although more elaborate, check on the pipe's dependency of the soil is made before design of the pipe. Unlike the Australian/New Zealand Standards, which are separate for rigid and flexible pipe, the latest draft of the European Standard, JWG 1/TG 1 N 210 E, Preliminary Draft, "Piping Systems – Structural Design of Buried Pipelines", covers all buried drainage pipe under one standard. One of the first steps in the design process is to determine the "deformation ratio" of the pipe and soil. The deformation ratio, ( $\alpha$ ), is defined using the ratio between the vertical deflections of both the pipe and the soil to the side of the pipe under the same loading conditions. The deformation criterion is documented as follows:

$\alpha \leq 0.05$	Rigid Pipe
$0.05 < \alpha < 1.0$	Semi-Flexible Pipe
$\alpha \geq 1.0$	Flexible Pipe

The pipe is subsequently designed in accordance with its deformation criterion. The deformation ratio is a relatively complex calculation involving the pipe stiffness, soil stiffness, bedding angle, and lateral soil pressure ratio. If the deformation ratios were calculated using the same properties previously used for the Australian/New Zealand check, the following results would be obtained:

Reinforced Concrete Pipe - $\alpha = 0.042$	$< 0.05$
Corrugated Metal Pipe - $\alpha = 5.3$	$> 1.0$
High-Density Polyethylene Pipe - $\alpha = 28.96$	$> 1.0$

Once again the results are as expected. Proportionally, the results are very similar to those obtained using the less elaborate Australian/New Zealand method. Concrete pipe is verified as a rigid pipe, and once again the HDPE pipe is a more flexible pipe than CMP by a factor of approximately 5. It may take more effort to perform the initial evaluation, but the information does provide insight into a pipe's soil dependency.

In the U S, the pipe designs are kept separate in AASHTO, although recent developments in the design section for thermoplastic pipe would lend itself to a similar preliminary investigation. The 2001 Interim of the AASHTO LRFD Bridge Design Specifications includes the use of a hoop stiffness factor ( $S_H$ ) in Section 12.12 for thermoplastic pipe. While this factor is used to analyze the soil load on a thermoplastic pipe, it could easily be incorporated into a rigid/flexible pipe differentiator. Similar to the rigid/flexible comparison methods used in Australia/New Zealand and Europe, the hoop stiffness factor is a function of the pipe properties and soil stiffness. The hoop stiffness is defined as follows:

$$S_H := \frac{\phi_s \cdot M_s \cdot R}{E \cdot A}$$

where:

- $S_H$  = hoop stiffness factor (dimensionless)
- $\phi_s$  = resistance factor for soil stiffness ( $\phi_s = 0.90$ )
- $M_s$  = constrained soil modulus (MPa)
- $R$  = radius to centroid of culvert wall (mm)
- $E$  = long-term modulus of elasticity (MPa)
- $A$  = wall area (mm<sup>2</sup>/mm)

The higher the hoop stiffness value, the more reliant the pipe-soil structure is on the soil. The hoop stiffness factor is subsequently used to determine the soil load on the pipe via a vertical arching factor (VAF) (factor that is multiplied by the soil prism load above the pipe). The equation for VAF being:

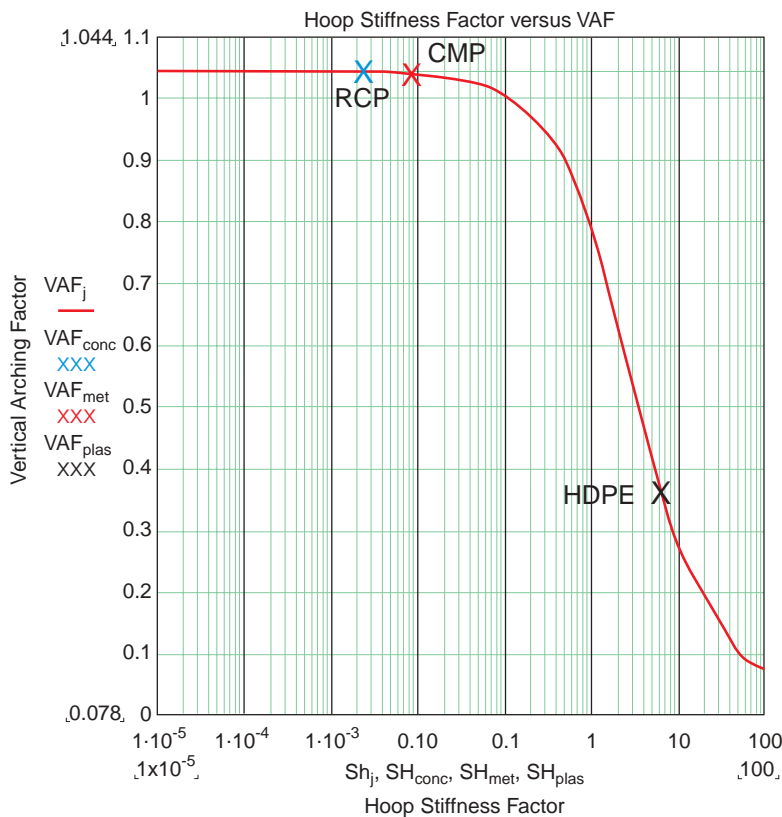
$$VAF := 0.76 - 0.71 \cdot \left( \frac{S_H - 1.17}{S_H - 2.92} \right)$$

If you were to graph this equation, it would look like the curve in Figure 1.

By inputting the same pipe values we used for the prior examples, we obtain hoop stiffness values of:

- Reinforced Concrete Pipe –  $S_H = .0023$
- Corrugated Metal Pipe –  $S_H = .0081$
- High-Density Polyethylene Pipe –  $S_H = 6.18$

These values have been plotted on Figure 1. It is easy to see that the relationships are significantly different with this method, largely as a result of the equation being dependent on pipe wall area as opposed to pipe wall moment of inertia. The RCP and CMP values are much closer when using the  $S_H$  value,



**Figure 1**

and the CMP and HDPE values are much farther apart. There is definitely an increase in the hoop stiffness value with dependence of the pipe on the soil surrounding it. The hoop stiffness factor is used for thermoplastic pipe design only. The development of the vertical arching factor based on the assumptions of a weightless, homogenous, isotropic, and linearly elastic soil medium limit its use as a final design tool. That is not to say that the hoop stiffness value may not be sufficient for use as an identifier of soil dependence.

Unfortunately, the curve for the vertical arching factor using  $S_H$  was developed for the lower modulus plastic pipe materials, and underestimates the load on a stronger pipe. Therefore, the upper range of the curve flattens out too quickly to accurately apply to concrete pipe. The curve flattens out at a VAF value of 1.044, while we know that concrete pipe VAFs are in the range of 1.35 to 1.45. We could take the existing curve, however, and decide that when a point is not “riding the curve”, it is the rigid/flexible dividing line. The hoop stiffness value in that case would be approximately  $S_H = .0025$ .

This would be a good place for the US to start, but a complete differentiator for rigid versus flexible pipe would have to involve pipe wall area (as applied in AASHTO’s hoop stiffness factor) as well as the pipe wall moment of inertia (as applied by our counterparts overseas). This would incorporate both hoop compression and bending deflection of the pipe in relationship with the surrounding soil.

Do we really have use for such a rigid/flexible pipe differentiator? This question will have a better answer as new and innovative materials are developed, and composites of existing materials such as concrete are developed with alternative reinforcing schemes.

As a leading voice in the applied science of buried drainage structures, the ACPA must keep abreast, and build new knowledge of the roles that the soil and pipe (of all materials) play in the soil-pipe structure. In the future, a measure of the rigidity or flexibility of a pipe may become a routine design requirement. ☺

1. Australian/New Zealand Standard, “Buried Flexible Pipelines, Part 1: Structural Design – Commentary (Supplement to AS/NZS 2566.1:1998)
2. Preliminary Draft of “Piping Systems – Structural Design of Buried Pipelines”, JWG 1/TG 1 N 210 E, November 2001
3. AASHTO LRFD Bridge Design Specifications, Second Edition, and 1999,2000, and 2001 interims