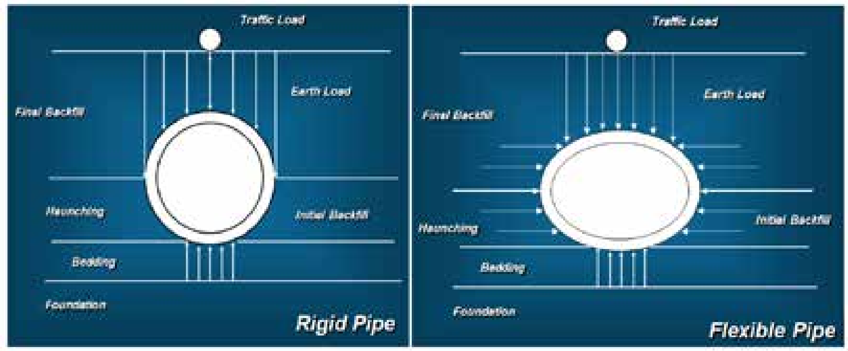
Flexible and Rigid Pipe Installation Review and Discussion

American Concrete Pipe Association
www.concretepipe.org

An educational document from the American Concrete Pipe Association for users and specifiers

The Installation Nature of Pipes:

Flexible pipes respond to load differently than rigid pipes as shown in the picture to the right. Flexible pipe require a very strong, well compacted side fill, because the pipe will shorten vertically with applied vertical load thereby deflecting the sides of the pipe outward horizontally engaging the side-fill soils in two ways:



1. As a column that is assumed to be stiffer than the pipe and carries some of the vertical load and;
2. As a bearing surface for the sides of the pipe to resist the horizontal deflection of the pipe counter-acting the deflecting forces within the pipe.

Rigid pipe deflects vertically, but to a much lesser degree and relies very little on the horizontal support given by the side-fill soils.

Installation Envelope Variations:

When rigid or flexible pipe is installed, the surrounding soil envelope can be characterized in one of three ways:

1. **Embankment:** The pipe is installed at or near the existing grade and the soil surrounding the pipe is placed as fill for a large distance on either side of the pipe. (Fig 1)
2. **Wide Trench:** The pipe is installed in an excavated trench that is relatively wide such that load on pipe is similar to an embankment condition (Fig 2).
3. **Narrow Trench:** The pipe is installed in an excavated trench that is relatively narrow, such that the vertical load on the concrete pipe is reduced by the friction that develops between the soil prism above the pipe and the undisturbed trench walls (Fig 4). Note that increased horizontal pressure at the sides of the pipe is not developed in a Narrow Trench since the vertical pressure on the soil columns to either side of the pipe is reduced by the friction on the trench walls. Since the soil is stiffer than the plastic pipe, using a narrow trench with flexible pipe can cause vertical deflection or "squaring" of the pipe.

Figure 1 Positive Projecting Embankment

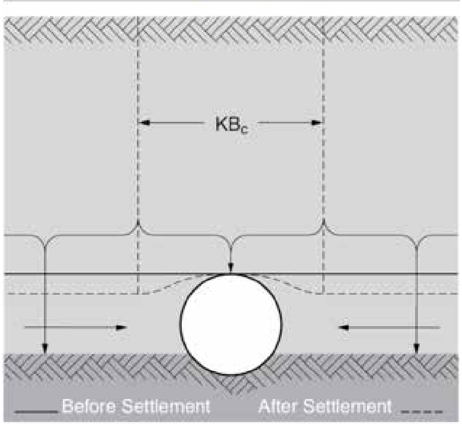


Figure 2 Wide Trench Condition

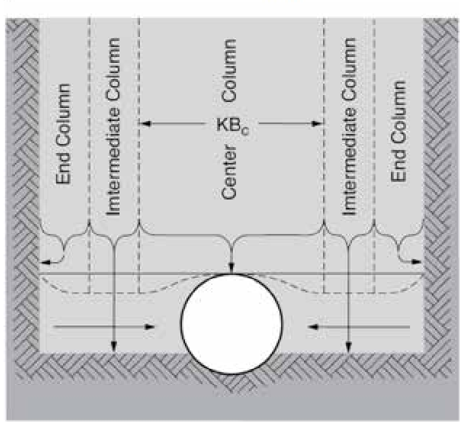
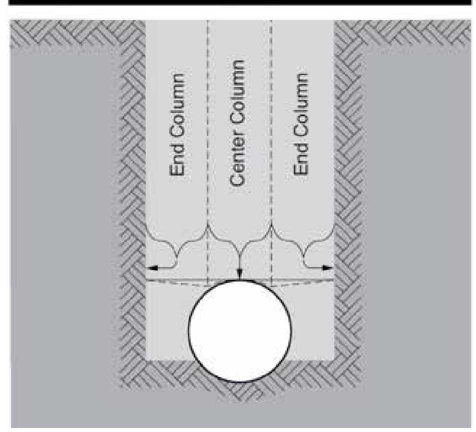


Figure 4 Trench Condition



Installed pipe load discussion:

For Embankment and Wide Trench installations, the vertical load on the flexible or rigid pipe will not benefit from the friction between the soil prism and the excavated trench because both sections are settling at or near the same rate without an undisturbed section close enough to develop beneficial friction. For Rigid pipe, settlement of the side fill soils is usually more than the soil prism over the pipe thus the vertical load on the pipe increases as the side fill soils settle due to downward drag on the soil prism above the pipe. In addition, lateral support develops on either side of the pipe as the soil settles, as shown by the horizontal arrows in Fig 1 and Fig 2. For Rigid pipe design, the Vertical Arching Factor accounts for this **increase** in load as shown in Table 12.10.2.1-3 from the AASHTO LRFD code. Note that the VAF is 3 to 4 times larger than the HAF for rigid pipe. Conservatively, rigid pipe designs and fill height tables are based on the assumption of the worst case Embankment installation.

Table 12.10.2.1-3—Coefficients for Use with Figure 12.10.2.1-1

	Installation Type			
	1	2	3	4
VAF	1.35	1.40	1.40	1.45
HAF	0.45	0.40	0.37	0.30

For Flexible pipe, the embankment and wide trench installation conditions have a very different net effect on the pipe. The underlying assumption for flexible pipe designs is that the side-fill soils will develop as columns that are stiffer than the flexible pipe and will carry a portion of the vertical load on the pipe via soil arching. The relative vertical stiffness of the pipe, as compared to the assumed stiffness of the soil columns, is termed the Hoop-Stiffness ratio (SH), as is discussed in the Commentary of Section 12.12.3 of the AASHTO LRFD code shown to the right. The resulting VAF for flexible pipe is calculated by the following equation:

$$VAF = 0.76 - 0.71\left(\frac{S_H - 1.17}{S_H + 2.92}\right) \quad (12.12.3.5\text{-}3)$$

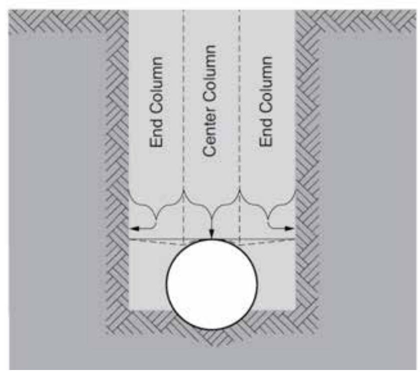
The use of the vertical arching factor is based on the behavior, demonstrated by Burns and Richard (1964), that pipe with high hoop-stiffness ratios (S_H, ratio of soil stiffness to pipe hoop stiffness) carry substantially less load than the weight of the prism of soil directly over the pipe. This behavior was demonstrated experimentally by Hashash and Selig (1990) and analytically by Moore (1995). McGrath (1999) developed the simplified form of the equation presented in this Section.

The *VAF* approach is only developed for the embankment load case. No guidance is currently available to predict the reduced loads on pipe in trench conditions. The only trench load theory proposed for flexible pipe was that by Spangler, which does not have good guidance on selection of input parameters. It is conservative to use the *VAF* approach as presented for embankments.

Depending on the quality and level of compaction of the soils placed in the side fill areas and the relative overburden pressure, the VAF can vary from as low as 0.2 (for well compacted granular soils with high overburden pressure) to as high as 1.0 (for poorly compacted clays with low overburden pressure). The reason for this is found by comparing the stiffness of the soil to the stiffness of the pipe which is significantly less, which is variable and dependent on overburden pressure. This means, **for an embankment condition where vertical soil columns are developed and the horizontal strength of the side-fill soils is developed, a flexible pipe will be subjected to somewhere from 20% to 100% of the soil prism load directly above the flexible pipe**. Currently, the plastic pipe industry is promoting that it is less precarious to assume that (similar to rigid pipe design) the embankment condition is a conservative assumption for flexible pipe - even if installed in a narrow trench.

For Narrow Trench installations, the soil prism load on a rigid pipe will be reduced by the friction that develops on the side walls of the undisturbed trench, because the fill above the pipe settles downward over time. For AASHTO rigid pipe designs, this benefit is typically ignored and the more conservative embankment condition is assumed. The VAF for Rigid pipe designs will typically be from 1.35 to 1.45 and never less than 1.0 given the assumption that the side-fill soil is not required to develop columns that must support the soil prism above the pipe.

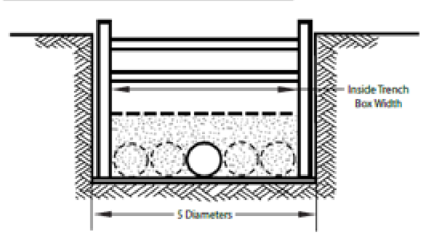
Figure 4 Trench Condition



For flexible pipe installed in Narrow Trench installations, research has not directly addressed the flexible pipe system design to verify that the assumption stated in the commentary above is accurate - "It is conservative to use the VAF approach as presented for embankments." Depending on the materials used in a trench installation, as well as the width of the trench, lateral support for the pipe, and the relative column strength of the side-fill, soils may not develop to the same extent as assumed when a flexible pipe is installed in an embankment. The vertical load on the side-fill soils is reduced, which then reduces the stiffness of the soil columns as well as the lateral resistance that can be developed in the side-fill soils. **In this condition, the VAF may likely be higher than assumed by equation 12.12.3.5-3 to the point that it may be more than 1.0. this means that the flexible pipe may actually see an increase to the soil prism load directly above the pipe compared to the assumed embankment condition, which is not accounted for in current designs**. This question was raised by Dr. A. Moser in the book, *Buried Pipe Design 2nd Edition* on page 27: "Also, a true trench condition may or may not result in significant load reductions on flexible conduit since a reduction depends upon the direction of the frictional forces in the soil." Dr. Moser goes on to clarify that side support is critical on page 29: "However, since a flexible pipe develops a large percentage of its load-carrying capacity from passive side support, this support must be provided, or the pipe will tend to deflect until the sides of the pipe are being supported by the sides of the tunnel" (in this discussion, tunnel refers to trench). Since a trench box is nearly always required, narrow trenches are extremely difficult to install without disturbing the compacted side fill which reduces the passive side support, thereby reducing the strength of the installed pipe system.

Until appropriate research is completed to verify the use of embankment VAF as the conservative assumption for all Flexible pipe installations, **it is recommended that trench installations not be allowed or at a minimum not receive the benefit from a VAF less than 1.0 in LRFD calculations. Minimum trench widths should be established to ensure that the installed pipe system meets the assumptions of an embankment**. A recommendation for this minimum trench width is shown in one manufacturer's documentation as 5 times the OD of the flexible pipe.

Plastic Pipe Trench Box Detail



"If it is necessary for a trench box to be dragged through a trench, do not raise the box more than 24" above the work surface. Another alternative for when the box will be dragged is to use a well-graded granular backfill material at least two diameters on either side of the pipe and compact it to a minimum of 90% standard Proctor density before moving the box." *ADS Technical Note, TN 5.01, March 2009*

Failure to adhere to these trench box requirements or other HDPE manufacturer recommended procedures could void the product's warranty, increase the project's risk of failure, and jeopardize your professional liability.