

PIPE DEFLECTION

The performance of flexible pipe in its ability to support load is typically assessed by measuring the deflection from its initial shape. This measurement alone, being simple to obtain in both laboratory and field installations, allows a measurable quantity to be compared with design calculated values. This deflection characteristic typically controls the design limitation on flexible pipe as currently produced and helps to identify structural problems associated with other performance criteria.

Pipe deflection has been, and continues to be a controversial subject and some pipe manufacturers and engineers have ignored deflection as part of the design procedure.

Such exclusion of deflection analyses stemmed from metal pipe using riveted seams and those seams typically controlled the design rather than deflection. Pipe produced today, however, is not controlled by riveted seam strength and, in many instances, use thinner materials.

The structural design for deflection must be considered in the evaluation of anticipated flexible pipe performance, not only for deflection alone, but also for the assessment of strain limitations and pipe buckling capacity. In addition, excessive deflection can reduce the hydraulics, restrict mechanical means of pipe cleaning and cause leakage where flexible elastomeric seals are utilized.

The most commonly used equation for the prediction of deflection is the empirical equation as developed by Spangler⁽¹⁾ and has been further modified by Watkins to become the Modified Iowa Equation⁽²⁾.

The equation predicts the horizontal diameter change in a flexible pipe.

$$\Delta X = \frac{KW_c r^3 D_L}{EI + .061er^3}$$

(1)

or

$$\Delta X = \frac{KW_c D_L}{\frac{EI}{r^3} + .061E'}$$

(2)

D_L = Deflection Lag Factor - Typical range 1.25 to 2.25, 1.5 is a commonly listed value (for wet conditions, these values should be doubled).

W_C = Vertical load per unit of pipe length (lb/Lin.in. of pipe). Prism load with earth density @ 140 lbs/ft³.

K = Bedding Constant, depends on bedding angle, i.e., a 90 deg. effective bedding angle has a bedding constant of 0.096.

ΔX = Horizontal Deflection

$\frac{EI}{r^3}$ = Pipe Stiffness Term Where:

E = Modulus of Elasticity, psi

I = Moment of Inertia of Wall Cross Section per Unit Length of Pipe, in⁴/Lin.

r = Mean Radius of Pipe, in.

.061 E' = Soil Stiffness Term Where:

E' = Modulus of Soil Reaction.

See Information Series 202 for additional information for Pipe Stiffness.

It is important to recognize the factors associated with the use of this equation for thermoplastic pipe, such as:

1. The development was for much stiffer corrugated metal pipe having a constant stiffness as a function of time.
2. Modulus of Soil Reaction is subject to change along the length of the line due to installation variables.
3. Vertical deflection is not equal to horizontal deflection.
4. Construction - Induced deflection during installation caused by high compaction effort could be greater than load induced deflection and is not considered by the equation.

Deflection is controlled by:

1. Stiffness of the pipe
2. Variations in pipe wall thickness or profile (Quality Control)
3. Stiffness of the Soil Embedment
4. Stiffness of the Native Soil
5. Type of Shoring System Used
6. Water Table
7. Techniques of the Contractor
8. Pipe Handling
9. Compaction Control
10. Inspection
11. Temperature

The use of the Modified Iowa equation to predict performance has a basic premise that the pipe deflection approximates an elliptical response and the vertical deflection is approximately equal to the calculated horizontal deflection. To properly evaluate this equation for low stiffness pipe or high soil stiffness the resulting answers must be corrected.

If the pipe deflects a small increment into an elliptical shape, then ΔX may be considered as equal to Δy . However, the formula that was derived from tests performed on Corrugated Metal Pipe is now being adopted by flexible plastic pipe producers without applying proper correction factors for vertical to horizontal deflections and without correcting for the combined effect of insitu and backfill soil conditions. These subjects have been discussed in length by:

CARLSTROM, B.I., from a paper entitled "Calculation of Circumferential Deflections and Flexural Strains in Underground GRP Pipes Used for Non-Pressure Applications", from European Conference, 1982, Basel, Switzerland.

and

SCHROCK, B.J., Plastic Pipe Seminar, San Diego, CA 1985.

and these theories have been incorporated in the Rinker Materials Computer Program (FLEXP PIPE) for the design of Flexible Pipe.

Copies of these discussions and computer programs are available upon request.

As stated in WPCF Manual No. 37, "It is recommended as a practical measure that the value of EI should never be less than about 10 to 15 percent of the term $0.061 E' r^3$."

The accuracy in terms of percent deflection as a function of the soil modulus ranges from $\pm 2\%$ for dumped backfill to 0.5% for high compacted backfill, proctor > 90%, and relative density > 70%. These percentage variations should be added to the deflection calculations to account for variations in the backfill. That is, for a predicted deflection of 3%, and a $\pm 2\%$ variation, the actual deflection would be between 1% and 5%. The lag factor should be included in deflection calculations to account for time dependent soil consolidation, with a minimum design recommended value of 1.5. Modulus of Soil Reaction (E') has been discussed by Amster Howard of the United States Bureau of Reclamation (USBR) in the paper entitled, "Modulus of Soil Reaction (E') Values for Buried Flexible Pipe", and by

LEONHARDT, G., Belastungsannahmen
bei erdverlegten GFK - Rohren,
AVK, Freudenstadt 4 Okt. 1978.

For pipe stiffness, long-term mechanical properties are to be used for a theoretical prediction of deflection.

Particular attention should be given to the soil condition along the entire length of the proposed pipeline. *Minimum trench widths should be determined as a function of the insitu soil and backfill material, using the following criteria for flexible pipe in vertical trench installations:

4 in. thru 54 in.

Trench Type	Minimum Clearance
1	0.5* (W - O.D.)
2	1.0* (O.D.)
3	2.0* (O.D.)

W is minimum width of excavation.
OD is maximum pipe outside diameter.

60 in. thru 108 in.

Trench Type	Minimum Clearance
1	18 in.
2	1.0* (O.D.)
3	2.0* (O.D.)

*Reference from Training Manual No. 7, USBR, Pipe Bedding & Backfill

Trench type is determined by comparing the strength of the insitu trench wall against that of compacted soil in resisting lateral pipe deflections:

Type 1 - Trench Wall > Compacted Soil

Type 2 - Trench Wall = Compacted Soil

Type 3 - Trench Wall < Compacted Soil

It is important to recognize that a rigid pipe may be installed in a properly designed trench for flexible pipe. However, a flexible pipe may not necessarily be installed in a trench designed for a rigid pipe.

Because a flexible pipe does not have the inherent strength to properly support loads, the success of a flexible pipe installation is typically 95 to 99% dependent on the contractor and the degree of provided inspection.

SPECIFICATION SUGGESTIONS

1. Specify maximum allowable deflection of 3%, using a nine (9) point mandrel, at least 30 days after completed, and also prior to project acceptance by owner. Maximum long-term deflection shall not exceed 5% using long-term pipe stiffness data.
2. Compaction testing of pipe embedment materials.
3. Rerounders shall not be utilized for correcting excess deflection. Pipe shall be removed and reinstalled.
4. Calculations submitted by the pipe supplier shall confirm the ability of the proposed pipe strength to perform as a soil-structure system and shall evaluate potential modes of failure, direct thrust, deflection, strain and buckling.