FLEXIBLE PIPE DESIGN

In the late 1920's and 1930's, Professor Spangler, of Iowa State University, developed a rational design procedure to predict the deflection of an installed flexible conduit. This design procedure calculated the horizontal deformation of the conduit as a function of the vertical load, the bedding support provided, and soil pressures acting laterally to resist the horizontal movement of the pipe. Based on the assumption the pipe was sufficiently rigid, the deformed shape would be that of an ellipse, he determined the vertical deflection would be approximately equal to the horizontal. Since his original work, the soil term of his initial equation was modified to obtain what is referred to as the Modified Spangler Equation:

$$\Delta x = \Delta y = \frac{D_L w k r^3}{EI + .061 E' r^3}$$

or

$$\Delta x = \Delta y = \frac{D_L w k}{EI / r^3 + .061 E'}$$

Subsequent to Spangler's research and world-wide acceptance of the modified equation, major changes have been made to the structural integrity of many flexible pipe products, such as substantially reduced section properties, and the use of materials whose physical properties change (decrease) as a function of time or temperature or both, resulting in deformations that are non-elliptical in shape (i.e., the vertical deflection is not equal to the horizontal deflection), and may increase with time.

In discussing the trends toward very flexible pipe installed in stiff soils with Professor Spangler, while he did not quantify any limits for using his equation, he did say a more flexible pipe would probably not deform elliptically and would likely have a much greater vertical deflection.

Also, in discussing with him the minimum ratio of the pipe and soil factors stated in the ASCE MOP No. 37/WPCF MOP No. 9, he confirmed he believed that ratio to be reasonable (i.e., "EI should never be less than about 10 to 15 percent of the term 0.061 $E'r^3$"), advising the greatest problem with pipe installation is the quality of the installation (compaction of the backfill under the haunches and around the pipe) independent of detailed specification requirements.

Recent trends in flexible pipe designs proposed by some manufacturers have ignored the long established guidelines suggested by the late Professor Spangler, but continue to use his equation in their attempt to substantiate adequacy of their proposed product.

In reviewing the modified Spangler equation, it is most obvious one could use very small values (approaching zero) for the EI/r^3) to the soil stiffness factor (.061E') ratio decreases, the shape of the deformed pipe changes toward rectangularization. The vertical deformation (Δ y) is significantly increased, no longer approximating the horizontal deformation Δ x. Consequently, the vertical deformation, as predicted by the modified Spangler equation, must be corrected for the pipe to soil stiffness ratio.

A correction factor, developed using the ATV system from Germany, presented in Figure 1, can be used to correct the Spangler predicted deflection (shape change) as a function of $EI/E'r^3$.

Basically, this correction factor takes into consideration differing amounts of restraint at the sides of a flexible pipe can result in different deformations as a function of the amount of restraint and flexibility of the product being restrained.

Another factor typically not considered in the design of flexible pipe is the relationship of the backfill material modulus to the insitu soil modulus. Many designers only use the soil modulus of the backfill material independent of softness or firmness of the adjacent material, or the width of the placed backfill. This relationship addressed by Leonhardt (1 and Fig. 2) recognizes a narrow band of firm material adjacent to a soft material does not provide the same restraint as a wide band of firm material and vice versa. He refers to this as the combined soil modulus which considers the affect of the width of the side fill soil placed, as well as the stiffness of both the backfill and insitu material.

A third factor, typically overlooked in flexible pipe design, is the strain that occurs increases as a function of the decrease in the pipe to soil stiffness ratio as deformations (flattening of the crown or invert) occur. These deformations, smaller radii of curvature as the shape changes towards rectangularization, result in a corresponding increase in strain. This factor (D_f), as evaluated by Carlstrom, (2) is shown in figure 3.

$$\text{Strain} = D_f \left(\frac{t}{D}\right)\left(\frac{\Delta y}{D}\right)$$

This paper is not intended to re-invent any of the concepts or factors addressed in the preceding discussion; it is a brief consolidation of design principles and factors available for design and analysis of flexible pipe systems and to advise that a computer program is available which incorporates the above mentioned correction factors such that the user can readily assess the potential performance of the flexible pipe being considered. The basic design procedure is in accord with the ASCE MOP No. 37/WPCF MOP No. 9; the AASHTO design criteria as presented in sections 12 and 18; the ATV pipe to soil stiffness factors for deflection, the combined effect of the backfill and the insitu soil in determining the effective soil modulus, and strain adjustments as a function of shape changes occurring with variation in the pipe to soil relationships.

The program input is user friendly, asking the user specific questions for entry of the data, as well as offering some guidelines.

Required input data includes the following:

Type of material: PVC, Steel, Aluminum, HDPE, etc.

Pipe diameter and wall thickness
Wall area - if available
Design deflection
Buckling safety factor
Fill height over pipe
Height of water over pipe
Pipe stiffness or section property information
Maximum distance from C.G. of wall to wall surface
Deflection lag factor
Bedding factor
Insitu soil modulus
Backfill soil modulus
Width of backfill

Program output includes:

Pipe diameter
Wall thickness from input
Wall area
Pipe material

Pipe stiffness initial
Pipe stiffness long term

Minimum required stiffness for handling

Combined soil modulus

Fill height
Weight of earth
Live load
Total load

Minimum wall area for thrust

Allowable design deflection
Initial deflection
Long-term deflection
Deformation factor
Long-term strain

Minimum pipe stiffness for buckling resistance

Percent supporting strength installation dependent
Percent supporting strength pipe dependent

The program then provides options to run different fill heights, to analyze different pipe stiffnesses, to make an entirely new run, or to analyze the run and calculate the minimum pipe stiffness for the design deflection.

This program is available to sewer, drain and culvert designers, at no charge, from Rinker Materials on receipt of a written request.

REFERENCES

1. LEONHARDT, G., Belaslungsannakmen
   beu erdverkegten GFK - Rohren,
   AVK, Freudenstadt 4 Okt. 1978.

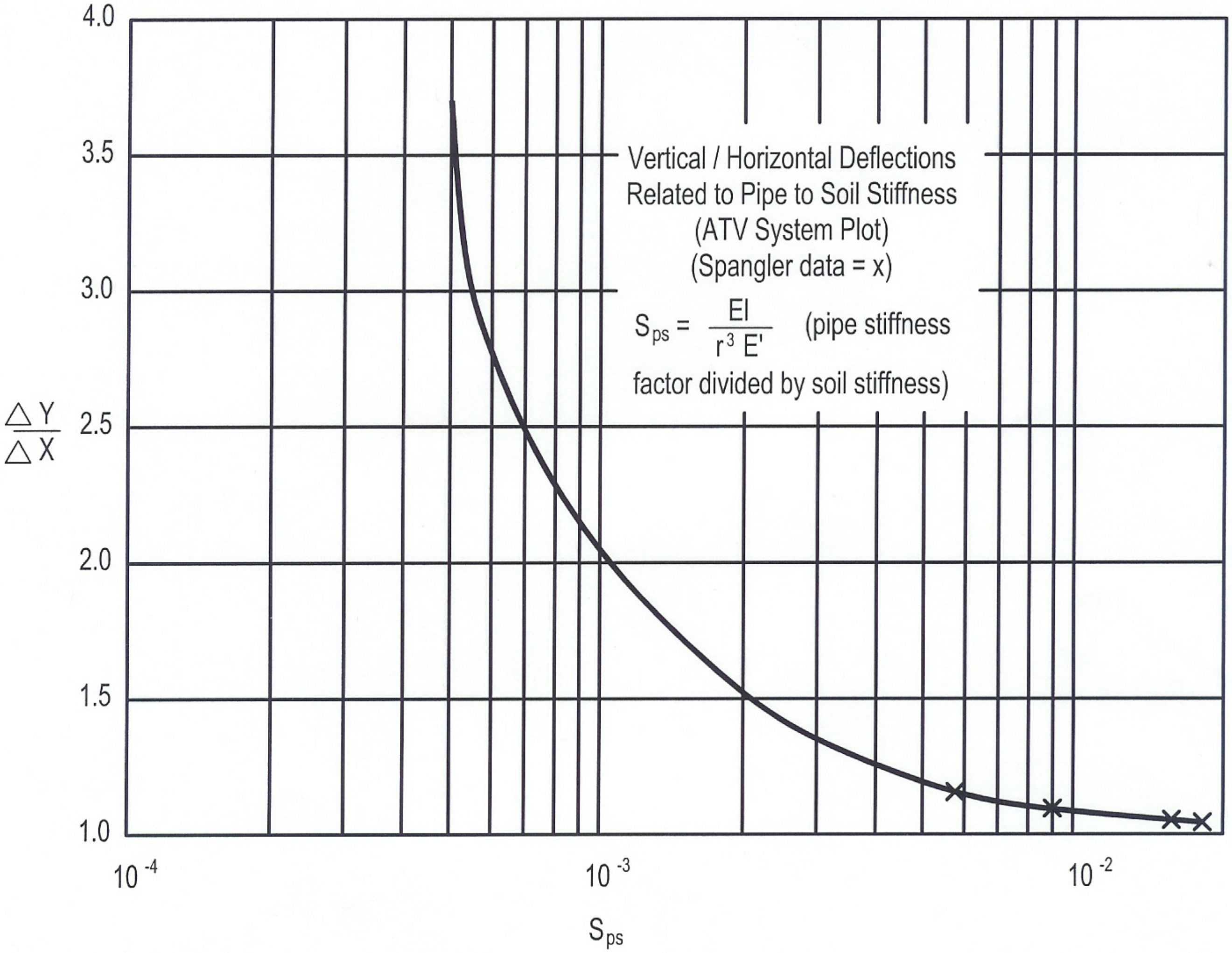
2. CARLSTROM, B.I., from a paper entitled "Calculation of Circumferential
   Deflections and Flexural Strains in Underground GRP Pipes Used for Non-Pressure Applications", from Europipe Conference, 1982, Basel, Switzerland.

Figure 1. SCHROCK, B.J., Plastic Pipe Seminar - San Diego, CA 1985

Figure 2. LENHARDT, G., See Ref. (1).

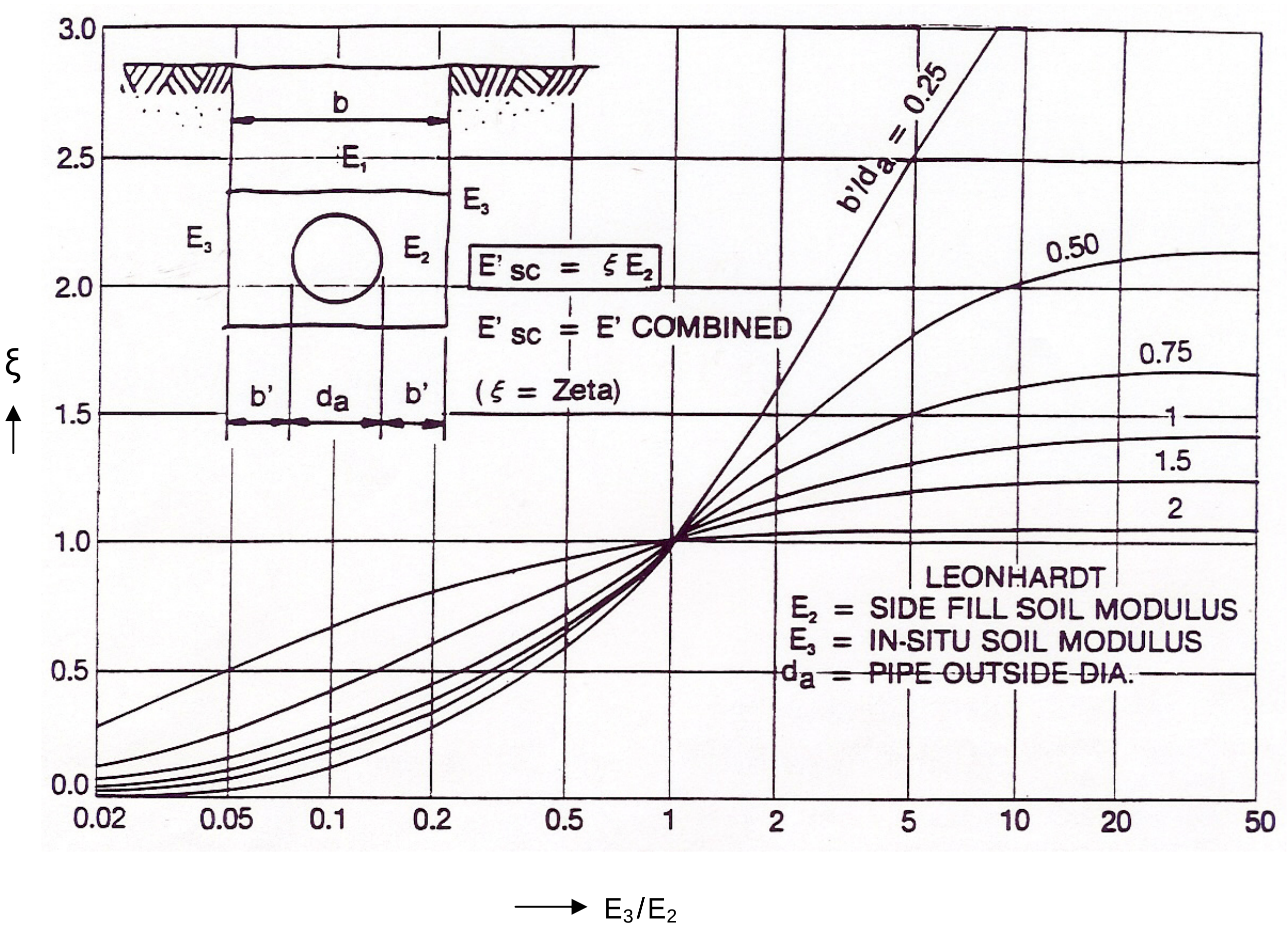
Figure 3. CARLSTROM, B.I., See Ref. (2).

Figure 1



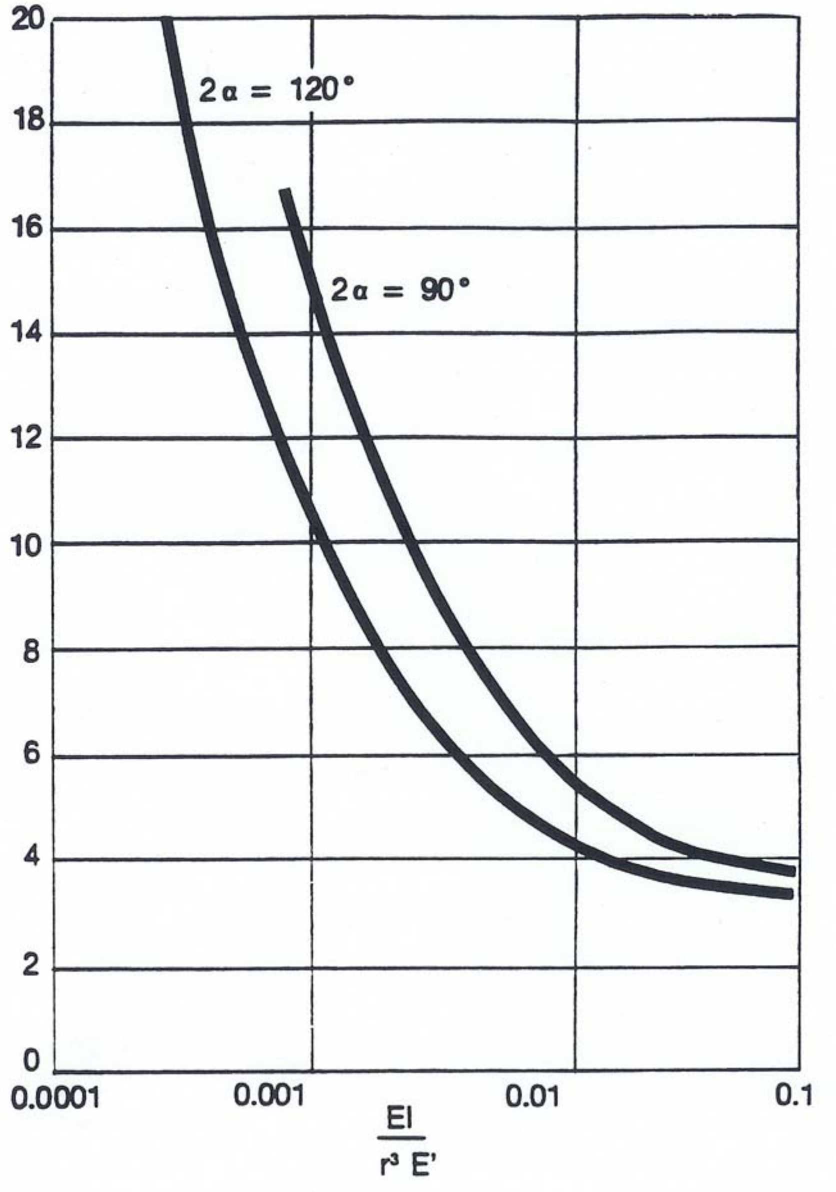
B J. Schrock's Correction Factors

Figure 2



Correction Factors for In-Situ and Backfill Soil Combinations

Figure 3



Carlstrom Deformation Factors for Two Bedding Angles.