DESIGN METHODS FOR REINFORCED CONCRETE PIPE

Traditionally, there are two methods of structural designs that have been used for designing buried concrete pipe, these being the **Indirect Design** method and the **Direct Design** method. While the direct design procedures have been used for over 40 years and have long been included in detail in Section 17 of the AASHTO Standard Specifications for Highway Bridges, most engineers and designers are more familiar with the indirect method when specifying concrete pipe.

By definition, Direct Design is designing specifically for the field condition anticipated loads and the resulting moments, thrust and shear caused by such loadings. Indirect Design (D-Load concept) is designing for a concentrated test load that is determined by the relationship of field calculated moment to the test moment for the same load. This relationship is called a bedding factor.

The bending moment in a 3-edge bearing test is expressed as:

$$M_{3EB} = 0.159 \text{ Load } (D + E)$$

The controlling bending moment in field is expressed as:

$$M_F = M_{FI} - 0.375\, tN_{FI} - 0.125\, N_{FI}\, C$$

By using the field load in the M_{3EB} equation, which is equal to 2 times the thrust at the side of the pipe, the test moment is calculated.

The bedding factor is then determined by dividing M_{3EB} by M_F.

In the above equations, the terms are:

N_{FS} = Field thrust at side

N_{FI} = Field thrust at invert

M_{FI} = Field moment at invert

t = Wall thickness

D = Pipe inside diameter

C = Concrete cover ℄ of steel

The direct design procedure, in the past, applied the forces acting on the pipe using the "Paris" or "Olander" force distribution. In recent years, based on a 20-year in-depth study of pipe-soil interaction, a modified soil pressure distribution has been developed as a function of soil type and compaction. These soil pressure configurations are called the Heger distribution, and are referred to as Type I through Type IV, depending on pipe bedding, soil type, and compaction level. All four types have been incorporated into ASCE, AASHTO and ACPA standards. A significant point relative to the Heger distribution is that the difficulty in obtaining specified soil compaction under the haunches of the pipe has been recognized in the soil pressure distribution by conservatively assuming all installations will have voids and soft inclusion in the haunch area.

DIRECT DESIGN PROCEDURE

1. Establish the pipe diameter and wall thickness.

2. Select the Standard Installation to be used, Type I, II, III or IV.

3. Determine the vertical earth and live load forces acting on the pipe.

4. For the type of installation selected, determine the moments, thrusts and shears due to the applied loads. For each type installation design coefficients have been developed for the determination of the critical moments, thrusts and shears. Such coefficients are presented in the Concrete Pipe Technology Handbook, published by the American Concrete Pipe Association.

5. The structural design of the pipe is performed using established reinforced concrete design principles. Such design will include five performance modes:

   - Flexural
   - Diagonal tension
   - Radial tension
   - Concrete compression
   - Service load crack control

INDIRECT DESIGN PROCEDURE

1. Establish the pipe diameter and wall thickness.

2. Select the Standard Installation to be used, Type I, II, III or IV.

3. Determine the vertical earth load and live load forces acting on the pipe.

4. Select the earth load and live load bedding factors for the selected installation (the live load bedding factor can not be greater than the earth load bedding factor). These bedding factors are presented in the ACPA publication Design Data 40 and in AASHTO Standard Specifications for Highway Bridges.

5. Divide the earth load and live load by their respective bedding factors and by the pipe diameter to determine the required D-Load strength. This D-Load is the service load condition.

In comparing Indirect Design (D-Load) with Direct Design, one recognizes in the 3-edge bearing test (D-Load) the maximum moment and shear is at the same location which is not the case in the field. Also, in view of the concentrated load and reaction that exists in the indirect (D-Load) design test, failure modes can exist that are not typical for the Direct Design pipe, which often require special steel reinforcing assemblies that are unnecessary in the field.

While either of these methods can be used with reliability, the direct design method is best suited for the larger diameters of pipe and high load installations.