Welcome to FHWA-IP-83-6-Structural Design Manual for Improved Inlets & Culverts.

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Chapter 1 : FHWA-IP-83-6

Introduction

1.1 Objective

This Manual provides structural design methods for inlets having specific configurations that improve hydraulic flow in culverts. Hydraulic design methods for obtaining these inlet configurations are given in Hydraulic Engineering Circular No. 13 (HEC No. 13), "Hydraulic Design of Improved Inlets for Culverts" (1), first published in 1972 by the Federal Highway Administration (FHWA). HEC No. 13 contains a series of charts and tables for determining the improvement in hydraulic performance obtained with beveled headwalls, falls and side or slope tapered inlets.

Design methods and typical details for the component structures found in improved inlets, such as wing walls, headwalls, aprons and the inlet itself, are also presented in this Manual. These methods cover inlets to reinforced concrete pipe, reinforced concrete box sections and corrugated metal pipe. They also apply to the design of culvert barrels, themselves, for each of the above type conduits.

1.2 Scope

The Manual is based on a review of the current state of the art for the design of culverts and inlet structures. This review included published technical literature, industry sources and state transportation agencies. Existing practices were reviewed for accuracy, complexity, design time and applicability to improved inlet design. Those methods that reflect current practice and best account for the structural behavior of improved inlets are included in this Manual. Existing methods were selected wherever possible. New methods were developed only where there were gaps in existing design methods.

The principal design methods covered in this Manual are for the inlet itself; however, since headwalls, wingwalls and aprons are also important to the proper hydraulic function of an improved inlet, design information is also included for these components.

The Manual includes both hand and computer methods for analysis and design. The computer programs were written for a large computer, but the hand methods are readily programmable for hand-held calculators.

Hand analysis and design methods are provided for:

- One and two cell reinforced concrete box culverts
- Reinforced concrete pipe culverts
- Corrugated metal pipe culverts
Computer analysis and design methods are provided for:

- One cell reinforced concrete box culverts
- Reinforced concrete pipe culverts

General design approaches, design criteria and typical details for wingwalls, headwalls and circular to square transition sections are also presented in the Manual.

### 1.3 Types and Geometry of Improved Inlets

The five basic combinations of geometry to improve the hydraulic capacity of inlets are listed below. Typical plans, details and reinforcing arrangements of improved inlets are included in Appendix G, and typical designs are included in Appendix E.

#### 1.3.1 Beveled Headwall

A bevel can be characterized as a large chamfer that is used to decrease flow contraction at the inlet. A bevel is shown schematically in Figure 1-1, in conjunction with other features described below. A bevel is not needed on the sides for wingwalls flared between 30° and 60°. A beveled headwall is a geometrical feature of the headwall and does not require unique structural design. Reinforced concrete pipe sections are generally precast, and can have a bevel formed at the time of manufacture, or in the case of pipe with bell and spigot joints, tests have shown that the bell will improve hydraulic capacity much the same as a bevel. Corrugated metal pipe can have bevels cast as a part of the reinforced concrete headwall. Typically, a bevel should be used at the face of all culvert entrances.
1.3.2 Beveled Headwall with Fall

A fall is a depression in front of the entrance to a non-tapered culvert or, as shown in Figure 1-1, in front of a side tapered inlet. A fall is used to increase the head at the throat section. Structurally a fall apron represents a slab on grade, and should be designed as such.

1.3.3 Side Tapered Inlet

A side-tapered inlet is a pipe or box section with an enlarged face area, with transition to the culvert barrel accomplished by tapering the side wall (Figure 1-1). A bevel is generally provided at the top and sides of the face of a side tapered inlet, except as noted earlier.
For simplicity of analysis and design, a side-tapered inlet may be considered to behave structurally as a series of typical non-tapered culverts of varying span and load. The span becomes shorter as the sides of the structure taper from the face section to the throat culvert. Because of these differing influences, the reinforcing design may be governed at the face, throat or some intermediate section. As a minimum, designs should be completed for the faces, throat, and middle sections. Typically, inlet structures are relatively short, and the most conservative combination of these designs can be selected for the entire structure. For longer structures where the use of two designs may be economical, either the face or mid-length design, whichever gives the greater requirement, may be used in the outer half of the structure. For longer structures it may be necessary and/or economical to obtain designs at additional intermediate locations along the inlet. Equations for locating side tapered inlets with embankments, and determining heights of fill for design are included in Appendix F.

Additional geometry required to define a side tapered pipe inlet is shown in Figure 1-2. These inlets taper from a pseudo-elliptical shape at the face to a circular section at the throat. The face sections are not true ellipses, but are defined geometrically using the same principles as the precast concrete "elliptical" sections defined in ASTM C507 (AASHTO M207). For simplicity, this shape will be called elliptical in this Manual. The elliptical sections are formed by intersecting top, bottom and side circular segments with different radii and centers, and can be defined by four parameters as shown, the radii \( r_1 \) and \( r_2 \) and the offset distances \( u \) and \( v \).

One method of defining the geometry of an inlet along its length in terms of the taper, \( T \), the coordinate \( z \), the ratio \( u/v \), and the diameter at the throat, \( D_j \), is shown in Figure 1-2. The \( u/v \) ratio can be selected by the designer and will typically vary from 0 to 1. A ratio near 1.0 will produce top and bottom sections that are rounded, while a value near zero will produce very flat top and bottom sections. A ratio of \( u/v \approx 0.5 \) is used for the horizontal elliptical pipe in ASTM C507 (AASHTO M207). Any consistent geometry that produces the desired face section may be used by the designer. The angle \( \theta \), is defined as the angle from the vertical, measured about the center of rotation of the radius of the circular segment being considered. Thus, the point of reference for \( \theta \) varies for each of the four circular segments, as well as along the longitudinal axis of the inlet.

### 1.3.4 Side Tapered Inlet with Fall

The hydraulic capacity of a side tapered inlet can be increased further by incorporating a fall, as described above, in front of the inlet. This is shown in Figure 1-1.
1.3.5 Slope Tapered Inlet

A slope tapered inlet is a side tapered inlet, with a fall incorporated into the tapered portion of the structure, as shown in Figure 1-3. Structural design of a slope tapered inlet can be completed in the same manner as a side tapered inlet, except that the bend section, where segments L₂ and L₃ intersect (Figure 1-3) rather than the midlength is typically the critical section for structural design. Thus, for slope tapered inlets the face, bend and throat sections must be investigated to determine the critical sections for design. As for side tapered inlets, additional sections should be investigated in longer structures. Only box sections are normally used for slope tapered inlets, since the structure is generally cast-in-place. When it is cost effective to use a slope tapered inlet with a pipe culvert, a circular to square transition section can be provided. (See Section 6.1). Equations for locating slope tapered culverts within embankments and for determining heights of fill at various sections are presented in Appendix F.
Figure 1-2. Additional Geometry for Side Tapered Pipe Inlets
1.4 Appurtenant Structures

Other structures that may be required at the entrance to culverts, besides the culvert barrel itself and the inlet, include headwalls, wingwalls, apron slabs and circular to square transition sections. Design of these structures is discussed briefly in Chapter 6. Typical details are provided in Appendix G.
Inlet structures are subjected to the same loading conditions as are ordinary culvert structures. These are culvert weight, internal fluid weight, earth load and vehicle loads.

### 2.1 Culvert Weight

The total weight of a reinforced concrete culvert per unit length, $W_p$, at a given section can be obtained from tables in the American Concrete Pipe Association (ACPA) Pipe Design Handbook (2), or from the following simplified equations for approximate total weight of structure in lbs per ft. These equations apply when $D_j$, $B_j$, $h$, $r_1$, $r_2$, $u$, $v$, $H_H$, $H_V$, $T_S$, $T_T$ and $T_B$ are in inches, and the concrete unit weight is 150 lbs per cu. ft.

**Circular:**

\[ W_p = 3.3 \ h \ (D_j + h) \]  

**Elliptical (Figure 1-2):**

\[ W_p = 4.2 \left( \frac{r_2 + \frac{h}{2}}{2} \right) \arctan \left( \frac{u}{v} \right) + \left( \frac{r_1 + \frac{h}{2}}{2} \right) \left[ 1.57 - \arctan \left( \frac{u}{v} \right) \right] \]  

**Box Sections**

\[ W_p = 1.04 \left( B_i + 2T_S \right) \left( T_T + T_B \right) + 2 \left( D_i T_S + H_H H_V \right) \]

The weight of corrugated metal structures is small relative to the earth load, and is generally neglected in design.

### 2.2 Fluid Loads

The weight of fluid per unit length, $W_f$, inside a culvert filled with fluid can be calculated from the following simplified equations for approximate total weight of water in lbs per ft. These equations apply when $D_j$, $B_j$, $r_1$, $r_2$, $u$ and $v$ are in inches, and the fluid unit weight is 62.5 lbs per cu. ft. (This unit weight is slightly higher than the normal unit weight of clean water to account for any increases due to dissolved matter.)

**Circular:**

\[ W_f = 0.34 \ D_i^2 \]

**Elliptical:**

\[ W_f = 0.87 \left( r_2^2 \arctan \left( \frac{u}{v} \right) + r_1^2 \left[ 1.57 - \arctan \left( \frac{u}{v} \right) \right] - uv \right) \]

**Box Sections**

\[ W_f = 0.43 \left( B_i \times D_i \right) \]
2.3 Earth Loads

Earth load in Ibs/ft is determined by multiplying the weight of the earth prism load above the extremities of the inlet by a soil-structure interaction factor, $F_e$. The following equation applies when $B_o$ is in inches, $H_e$ is in feet and $\gamma_s$ is in Ibs/cu. ft.

$$W_e = F_e \gamma_s B_o H_e / 12$$

Equation 2.7a

For pipe under deep fill, the earth load due to the backfill between the springline and crown is generally ignored, and Equation 2.7a can be used, to compute the total load. However, for pipe inlets, which are under relatively low heights of fill, this load makes up a substantial part of the total load, and Equation 2.7b is more appropriate. Units are the same as for Equation 2.7a, $D_o$ is in inches.

$$W_e = F_e \gamma_s B_o \left( H_e + D_o / 72 \right) / 12$$

Equation 2.7b

$F_e$ represents the ratio of the earth load on the culvert to the earth prism load, and may be determined by the Marston-Spangler theory of earth loads on pipe (2, 3) or the approximations presented below may be used.

Equations that may be used to locate culverts within embankments and determine the height of fill over design sections are presented in Appendix F.

2.3.1 Soil Structure Interaction Factor for Rigid Culverts

When rigid conduits are installed with compacted sidefill they are subject to less load than when the sidefill is loosely installed. This is because the compacted sidefill is relatively stiff and can carry more load, resulting in less "negative arching" of the earth load onto the culvert. Other factors which affect the load on a conduit include trench width, if applicable, burial depth to span ratio and soil type. Since inlet structures are generally short relative to the culvert barrel, and since they are typically under very low fill heights, it is recommended that conservative values be used for the soil structure interaction factor. Suggested values are 1.2 for sections installed with compacted sidefill, and 1.5 for sections installed with loose sidefill.

For box culverts, 1981 AASHTO Standard Specifications for Highway Bridges (4) (abbreviated as AASHTO in the following text) allow the use of $F_e = 1.0$, but some recently completed soil structure interaction studies (5) indicate that this may be unconservative. Use of the above values is recommended for both reinforced concrete pipe and box sections.

2.3.2 Flexible Culverts

For flexible metal culverts, AASHTO allows $F_e$ to be taken equal to 1.0 for both trench and embankment installations; however, like box culverts, current research indicates that flexible metal culverts carry a load that is greater than the earth prism load. Estimates of the actual $F_e$ are as high as 1.3 (6).
2.3.3 Other Installations

Various methods may be used to reduce the loads on culverts in embankment and trench installations, including negative projection and induced trench (2, 3). The loads for such installations may also be determined by accepted methods based on tests, soil-structure interaction analyses (generally by finite element methods), or previous experience. However, these installation methods generally are used only for deep burial conditions and thus are not relevant to inlet designs.

2.4 Construction Loads

Inlet structures included in this manual will not normally be subjected to highway loads, but may be loaded by miscellaneous construction or maintenance equipment, such as bulldozers and mowing machines. A uniformly distributed load equal to at least 240 lbs/sq. ft. is recommended for this condition. This is the equivalent of 2 ft. of 120 lbs per cu. ft. earth. This minimum surcharge is recommended only to account for random unanticipated loads. Any significant expected loads should be specifically considered in design.

2.5 Distribution of Earth Pressures on Culvert

2.5.1 Rigid Culverts

Earth pressures are distributed around various rigid culvert types as shown in Figure 2-1.

\[ p_t = p_b = F_e \gamma_s H_e \]  \hspace{1cm} \text{Equation 2.8}

\[ p_s = \alpha \gamma_s \left( H_e + \gamma_e \right) \]  \hspace{1cm} \text{Equation 2.9a}

or approximately

\[ p_s = \alpha \gamma_s \left( H_e + \frac{D_0}{2} \right) \]  \hspace{1cm} \text{Equation 2.9b}
For box culverts, earth pressures are assumed uniformly distributed over the top and bottom of the culvert, and with linear variation with depth along the sides, as shown in Figure 2-1. Sometimes, especially for simplified hand analysis, the lateral pressure is assumed uniform over the culvert height. A lateral pressure coefficient, $\alpha = 0.25$, is recommended in AASHTO for rigid culverts. However, because of variations in installation conditions a more rational and conservative design is obtained by designing for maximum stress resultants produced by the range of $\alpha$ values between 0.25 and 0.50.

Suggested pressure distributions for circular and elliptical rigid pipe are presented in Figures 2-1b and 2-1c. These distributions consist of a radially applied earth pressure over a specified load angle, $\beta_1$, at the top of the pipe, and a radially applied bedding pressure over a specified bedding angle, $\beta_2$, at the bottom of the pipe. This pressure distribution is based on the work of Olander (7). Olander proposed that the load and bedding angles always add up to 360 degrees; however, this results in increased lateral pressure on the

\[ p_t = p_0 \cos \frac{2\pi}{\beta_1} (\pi - \theta) \]  
\[ p_b = p_1 \cos \frac{2\pi \theta}{\beta_2} \]

\( p_t \) and \( p_b \) from Equation 2.10 and Equation 2.11 above

See Notations sections for definition of $\theta$ for elliptical sections.
sides of the pipe as the bedding angle, $\beta_2$, decreases. This is not consistent with expected behavior, and results in unconservative designs for narrow bedding angles. In view of this, the load angle should be limited to a maximum of 240 degrees. This limitation should apply even in cases where the bedding and load angles do not add up to 360 degrees, as is shown in Figure 2-1b.

The same system for distribution of earth pressure can also be used for elliptical pipe, as shown in Figure 2-1c. The earth pressure is always applied normal to the curved segments that make up the elliptical section, that is, radial to the center of curvature of the particular segment.

### 2.5.2 Flexible Culverts

The distribution of earth pressure on a flexible metal culvert tends to be a fairly uniform radial pressure, since the pipe readily deforms under load, and can mobilize earth pressures at the sides to help resist vertical loads. No pressure distribution is shown here, however, since metal culvert design is done by semi-empirical methods and typically a specific pressure distribution need not be assumed by the designer.

Go to Chapter 3
Given the load and distributions of Chapter 2, any method of elastic structural analysis may be sued to determine the moments, thrusts, and shears at critical locations in the structure. The structural analysis and design of culverts can be completed very efficiently by computer. Computer programs are presented in Chapter 5 for analysis and design of reinforced concrete single cell box culverts, and circular and elliptical pipe culverts. The method discussed below are appropriate for hand analysis, or are readily programmable for a hand-held calculator.

None of the computer or hand analysis methods presented in this manual account for effects of variation in wall stiffness caused by cracking. This is consistent with current general reinforced concrete design practice. The reduction in stiffness produced by cracking becomes more significant when soil-structure interaction is considered, using finite element models of the pipe-soil system. Models that account for such changes in stiffness have developed and correlated with test results, but currently these are only being used for research on the behavior of buried conduits.

### 3.1 Reinforced Concrete Box Sections

The first step in box section design is to select trail wall haunch dimensions. Typically haunches are at an angle of 45°, and the dimensions are taken equal to the top slab thickness. After these dimensions are estimated, the section can then be analyzed as a rigid frame, and moment distribution is often used for this purpose. A simplified moment distribution was developed by AREA (8) for box culverts under railroads. Modifications of these equations are reproduced in Table 3-1 and Table 3-2 for one and two cell box culverts respectively. This analysis is based on the following assumptions.

- The lateral pressure is assumed to be uniform, rather than to vary with depth.
- The top and bottom slabs are assumed to be of equal thickness, as are the side walls.
- Only boxes with "Standard" haunches or without haunches can be considered. Standard haunches have horizontal and vertical dimensions equal to the top slab thickness.
- The section is assumed doubly symmetrical, thus separate moments and shears are not calculated for the top and bottom slabs, since these are nearly identical.

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</tbody>
</table>
### Design Pressures

\[ p_{v} = \gamma_s H_e F_e + \gamma_o T_T + 2 \gamma_f D'T_S / B' \]

**Equation 3.1**

\[ p_{s,\text{max}} = \alpha_{\text{max}} \gamma_s H_e' \]

**Equation 3.2**

\[ p_{s,\text{min}} = \alpha_{\text{min}} \gamma_s H_e' - \gamma_f \frac{(D'-T_T)^2}{2D'} \]

**Equation 3.3**

### Design Constants

\[ G_1 = \frac{T_T^3 D'}{T_S^3 B'} \]

**Equation 3.4**
\[ G_2 = \frac{9H^5}{D'B'^3T_S^3} \left( 1 - \frac{T_T}{D'} \right) \]

Equation 3.5

\[ G_3 = \frac{2H^3}{B'} \left( \frac{1}{T_T^2} + \frac{T_T}{T_S^3} \right) \]

For boxes with no haunches \((H_H = H_V = 0)\)
\[ G_2 = G_3 = G_4 = 0 \]

Equation 3.6

\[ G_4 = \frac{6H_H}{B'} \left( 1.02 - \frac{3T_T}{B'} + \frac{T_T^3}{T_S} \right) \]

Equation 3.7

### Design Moments

\[
\begin{align*}
\begin{bmatrix} M_{o \text{ max}} \\ M_{o \text{ min}} \end{bmatrix} &= -\frac{p_v B'^2}{12} \left( \frac{1 - 1.5 G_3 + 0.5 G_4}{1 + G_1 - G_3} \right) - \left\{ \frac{p_{s \text{ max}}}{p_{s \text{ min}}} \right\}^{*} \left[ \frac{D'^2}{12} \left( \frac{G_1 - G_2}{1 + G_1 - G_3} \right) \right] \\
\end{align*}
\]

Equation 3.8

Moment at origin:

\[ M_{b}(x) = \begin{cases} 
M_{o \text{ max}} & \\
M_{o \text{ min}} & 
\end{cases} + 0.5 p_v x (B' - x) \]

Equation 3.9

Moment in top and bottom slab:

\[ M_{s}(y) = \begin{cases} 
M_{o \text{ max}} & \\
M_{o \text{ min}} & 
\end{cases}^{*} + \left\{ \frac{p_{s \text{ max}}}{p_{s \text{ min}}} \right\}^{*} 0.5 y (D' - y) \]

Equation 3.10

Moment in sidewall:

### Design Shears

\[ V_b(x) = p_v \left( \frac{B'}{2} - x \right) \]

Equation 3.11

Shear in top and bottom slab:

\[ V_s(y) = p_{s \text{ max}} \left( \frac{D'}{2} - y \right) \]

Equation 3.12

Shear in sidewall:
Thrusts in bottom slab:

\[
\begin{align*}
\left\{ \begin{array}{c}
N_{b \text{ max}} \\
N_{b \text{ min}}
\end{array} \right\} &= \left\{ \begin{array}{c}
p_{s \text{ max}} \\
p_{s \text{ min}}
\end{array} \right\} \cdot \frac{D'}{2}
\end{align*}
\]

Thrust in sidewall:

\[N_s = \frac{p_v B'}{2}\]

*Use \(p_{\text{max}}\) or \(p_{\text{min}}\) as follows:

- Locations 8, 9, and 10 only use \(p_{\text{max}}\).
- Locations 11, 12, and 13 check both \(p_{\text{max}}\) and \(p_{\text{min}}\) for the governing case.
- Locations 14 and 15 only use \(p_{\text{min}}\).

Notes:

1. Analysis is for boxes with standard haunches (\(H_H = H_V = T_T\)).
2. Equations may be used to analyze box sections with no haunches by setting \(G_2 = G_3 = G_4 = 0.0\).
3. See Equation 4.22 for determination of \(x_{dc}\).
4. If \(M_8\) is negative use \(A_{s \text{ min}}\) for the sidewall inside reinforcing, and do not check shear at Section 9.

<table>
<thead>
<tr>
<th>Design Force in Two Cell Box Culverts</th>
</tr>
</thead>
</table>

| Flexure Design Sections: 6, 11, 12, 15, 18 |
| Shear Design Sections: Method 1: 10, 17 |
| Method 2: 9, 16, 17 |

<table>
<thead>
<tr>
<th>Design Pressures</th>
</tr>
</thead>
</table>

\[p_v = \gamma_s H e F_e + \gamma_c T_T + \frac{\gamma_c D' (T_s + 0.5 T_c)}{B'}\]  
Equation 3.15

\[p_{s \text{ max}} = \alpha_{\text{max}} v_s H e\]  
Equation 3.16
\[ p_s \min = \alpha_{\min} \gamma_s H_e - \gamma_f \frac{(D' - T_T)^2}{2D'} \]  
\[ \text{Equation 3.17} \]

**Geometry Constants**

\[
F_1 = \frac{B'^2}{T^2} \left( \frac{B'}{3T} - 1 \right) + \frac{3}{2} \left( \frac{B'}{T} - 1 \right)
\]
\[ \text{Equation 3.18} \]

\[
F_2 = \frac{1}{T^3} \left( \frac{D'}{2} + B' \right) - \frac{3}{T^2}
\]
\[ \text{Equation 3.19} \]

\[
F_3 = \frac{B'}{T^2} \left( \frac{B'}{2T} + 1 \right)
\]

For boxes with standard haunches  
\[ \text{Equation 3.20} \]

\[
F_4 = \frac{B'^3}{T^3} - \frac{4B'^2}{T^2} + \frac{9B'}{T} - 9
\]
\[ \text{Equation 3.21} \]

\[
F_5 = \frac{D'}{2T^3} - \frac{9}{T^2} + \frac{9}{D'T} - \frac{9}{D'T^2} + \frac{3B'}{T^3}
\]
\[ \text{Equation 3.22} \]

\[
F_6 = \frac{T^3D'}{T_s B'}
\]

For boxes without haunches  
\[ \text{Equation 3.23} \]

**Design Moments**

Moments at Origin:

\[
\begin{cases}
M_{0 \ max} \\
M_{0 \ min}
\end{cases} = M_{ov} + \begin{cases}
M_{0s \ max} \\
M_{0s \ min}
\end{cases}
\]
\[ \text{Equation 3.24} \]

Boxes with standard haunches and uniform wall thickness (\(H_H=H_V=T_T=T_S=T_B\)):

\[
M_{ov} = -\frac{P_v}{8} \left( \frac{B'F_4F_3 - 4F_1^2}{F_2F_1 - F_3^2} \right)
\]
\[ \text{Equation 3.25a} \]

\[
\begin{cases}
M_{0s \ max} \\
M_{0s \ min}
\end{cases} = \begin{cases}
P_{s \ max} \\
P_{s \ min}
\end{cases} \times \frac{D'^2}{8} \left( \frac{F_5F_1 - 3F_3^2}{3(F_2F_1 - F_3^2)} - 1 \right)
\]
\[ \text{Equation 3.26a} \]

Boxes without haunches (\(H_H=H_V=0, \ T_T=T_B \neq T_S\)):

\[
M_{ov} = \frac{P_vB'^2}{12} \left( \frac{1}{1 + 2F_b} \right)
\]
\[ \text{Equation 3.25b} \]

\[
\begin{cases}
M_{0s \ max} \\
M_{0s \ min}
\end{cases} = -\begin{cases}
P_{s \ max} \\
P_{s \ min}
\end{cases} \times \frac{D'^2}{6} \left( \frac{F_3}{1 + F_b} \right)
\]
\[ \text{Equation 3.26b} \]
### Design Shears

#### Shear on bottom slab:

\[
V_{b}(x) = N_{s,\text{min}} + p_{v} x
\]

**Equation 3.29**

#### Shear in sideline:

\[
V_{s}(y) = p_{s,\text{max}} \left( \frac{D'}{2} - y \right)
\]

**Equation 3.30**

### Design Thrusts

#### Thrust in bottom slab:

\[
\begin{align*}
N_{b,\text{max}} &= \frac{p_{s,\text{max}} D'}{2} \\
N_{b,\text{min}} &= \frac{p_{s,\text{min}} D'}{2}
\end{align*}
\]

**Equation 3.31**

#### Thrust in side slab, boxes with haunches:

\[
\begin{align*}
N_{b,\text{max}} &= \frac{0.5p_{v}F_{1} + M_{0}F_{2}}{F_{3}} \\
N_{b,\text{min}} &= \frac{M_{0s,\text{max}}}{F_{3}} \frac{F_{3}}{F_{1}}
\end{align*}
\]

**Equation 3.32a**

#### Thrust in side slab, boxes without haunches:

\[
\begin{align*}
N_{b,\text{max}} &= \frac{p_{v}B' \left( \frac{2 + 3F_{6}}{1 + 2F_{6}} \right)}{4} + \frac{p_{s,\text{max}}}{p_{s,\text{min}}} \frac{D'^{2}}{4B'} \left( \frac{F_{6}}{1 + 2F_{6}} \right)
\end{align*}
\]

**Equation 3.32b**

*Use \( p_{s,\text{max}} \) or \( p_{s,\text{min}} \) as follows:

- Locations 8, 9 and 10 use \( p_{s,\text{max}} \) only.
- Locations 11, 12 and 13 check both \( p_{s,\text{max}} \) and \( p_{s,\text{min}} \) for governing case.
- Locations 14 and 15 use \( p_{s,\text{min}} \) only.

### Notes:

1. For boxes with standard haunches and all walls of the same thickness \( H_{H}=H_{V}=T_{L}=T_{S}=T_{B} \) use **Equation 3.25a**, **Equation 3.26a** and **Equation 3.32a**.
2. For boxes with no haunches and side walls with the amw or different thickness than the top and bottom slabs \( H_{H}=H_{V}=0 \) and \( T_{L}=T_{B} \neq T_{S} \) use **Equation 3.25b**, **Equation 3.26b**, and **Equation 3.32b**.
3. See **Equation 4.22** for determination of \( x_{dc} \).
4. If \( M_{0} \) is negative, use \( A_{s,\text{min}} \) for sidewall inside reinforcing, and do not check shear at **Section 9**.
5. Geometry constants \( F_{1} \) through \( F_{5} \) are not required for boxes without haunches.
The equations cover the load cases of earth, dead and internal fluid loads. Any one of these cases can be dropped by setting the appropriate unit weight (soil, concrete or fluid) to zero when computing the design pressures \( p_v \) and \( p_s \).

The equations provide moments, shears and thrusts at design sections. These design forces can then be used in the design equations presented in Chapter 4 to size the reinforcing based on the assumed geometry.

### 3.2 Rigid Pipe Sections

Using the coefficients presented in Figures 3-1 through 3-6, the following equations may be used to determine moments, thrusts and shears in the pipe due to earth, pipe and internal fluid loads:

\[
M = (c_{m1} W_e + c_{m2} W_p + C_{m3} W_f) \frac{B'}{2} \quad \text{Equation 3.33}
\]

\[
N = c_{n1} W_e + c_{n2} W_p + c_{n3} W_f \quad \text{Equation 3.34}
\]

\[
V = c_{v1} W_e + c_{v2} W_p + c_{v3} W_f \quad \text{Equation 3.35}
\]

Figure 3-1 provides coefficients for earth load analysis of circular pipe with 3 loading conditions \( \beta_1 = 90^\circ, 120^\circ \) and \( 180^\circ \). In all cases, \( \beta_2 = 360^\circ - \beta_1 \). These load conditions are normally referenced by the bedding angle, \( \beta_2 \). The \( 120^\circ \) and \( 90^\circ \) bedding cases correspond approximately with the traditional Class B and Class C bedding conditions (2, 3). These coefficients should only be used when the sidefill is compacted during installation. Compacting the sidefill allows the development of the beneficial lateral pressures assumed in the analysis. If the sidefills are not compacted (this is not recommended), then a new analysis should be completed using the computer program described in Section 5.2 with reduced load angles, \( \beta_1 \).

Figure 3-2, Figure 3-3, and Figure 3-4 provide coefficients for earth load analysis of elliptical pipe having various ratios of span to rise \( (B'/D') \) and offset distances \( (u/v) \). Coefficients for two bedding conditions are provided, corresponding to traditional Class B and Class C bedding conditions (2). These coefficients also should only be used for pipe installed with compacted sidefill. Coefficients for other \( B'/D' \) and \( u/v \) ratios may be obtained by interpolation between coefficients for the given ratios.
Figure 3-1. Coefficients for M, N, and V due to Earth Load on Circular Pipe
Figure 3-2. Coefficients for M, N, and V due to Earth Load on Elliptical Pipe with U/V = 0.1
Figure 3-3. Coefficients of M, N and V due to Earth Load on Elliptical Pipe with U/V = 0.5
Figure 3-4. Coefficients of M, N and V due to Earth Load on Elliptical Pipe with U/V = 1.0
Figure 3-5. Coefficients or M, N and V due to Pipe Weight on Narrow Support
Figure 3-6. Coefficients or M, N and V due to Water Load on Circular Pipe

Figure 3-5 provides coefficients for dead load analysis of circular pipe. These coefficients represent a
narrow bedding condition, since concrete pipe are generally installed on a flat bedding. Figure 3-6 provides coefficients for water load analysis of circular pipe. The coefficients in Figure 3-5 and Figure 3-6 can also be used to approximate the moments, thrusts and shears in elliptical pipe of equal span for these two less critical types of load.

3.3 Flexible Pipe Sections

Flexible pipe culverts are typically designed by semi-empirical methods which have been in use for many years. Design by these methods does not include a structural analysis per se, since the analysis is generally implicit in the design equations. The current AASHTO design/analysis methods for corrugated metal pipe are presented in Appendix A.

For large or unusual structures, including inlets, most manufacturers offer special modifications to corrugated metal culverts to improve the structural behavior. These modifications are usually proprietary, and designers should consult with the manufacturers before completing detailed designs.

Go to Chapter 4
Structural design of reinforced concrete culvert and inlet structures is quite different than design for corrugated metal structures. For reinforced concrete inlets, the designer typically selects a trial wall thickness and then sizes the reinforcing to meet the design requirements. For precast structures the trial wall thickness is normally limited to standard wall thicknesses established in material specifications such as ASTM C76, C655 and C789 (AASHTO M170, M242 and M259). For corrugated metal structures, the designer typically selects a standard wall thickness and corrugation type that provide the required ring compression and seam strength, and the required stiffness to resist buckling and installation loads.

The design approach suggested herein is to treat inlet structures, that have varying cross sections, as a series of slices that behave as typical culvert sections. Representative slices along the length of the inlet are selected for design. The face and throat sections and one or more additional slices are usually included. For reinforced concrete structures, either the reinforcement design for the maximum condition is used for the entire inlet, or several bands of reinforcement whose requirements are interpolated from the several "slice" designs are used for the actual structure. For corrugated metal structures, the structure requirements are usually based on the maximum condition. This approach is illustrated in the example problems in Appendix D. Special considerations required for slope tapered inlets (Figure 1-3) are discussed in Section 4.1.6.

4.1 Reinforced Concrete Design

The method for the design of reinforced concrete pipe and box sections presented below was recently adopted by the American Concrete Pipe Association and has been recommended by the AASHTO Rigid Culvert Liaison Committee for adoption by the AASHTO Bridge Committee. This design method provides a set of equations for sizing the main circumferential reinforcing in a buried reinforced concrete culvert. For additional criteria, such as temperature reinforcing in monolithic structures, the designer should refer to the appropriate sections of AASHTO (4).

Typically, the design process involves a determination of reinforcement area for strength and crack control at various governing locations in a slice and checks for shear strength and certain reinforcement limits.

The number and location of sections at which designers must size and reinforce and check shear strength will vary with the shape of the cross section and the reinforcing scheme used. Figure 4-1. shows typical reinforcing schemes for precast and cast-in-place one cell box sections. The design sections for these schemes are shown in Figure 4-2. For flexural design of
box sections with typical geometry and load conditions. Locations 1, 8, and 15 will be positive moment design locations (tension on inside) and locations 4, 5, 11, and 12 will be negative moment design locations. Shear design is by two methods; one is relatively simple, and requires checking locations 3, 6, 10 and 13 which are located at a distance \( d_{vd} \) from the tip of haunches. The second method is slightly more complex and requires checking locations 2, 7, 9, and 14 which are where the \( M/Vd \) ratio 3.0 and locations 3, 6, 10 and 13 which are located at a distance \( vd \) from the tip of haunches. The design methods will be discussed in subsequent sections. Typical reinforcing schemes and design locations for two cell box sections are shown in Figure 4-3.

A typical reinforcing layout and typical design sections for pipe are shown in Figure 4-4. Pipes have three flexure design locations and two shear design locations. Figure 4-4 is also applicable to elliptical sections.
Figure 4-1. Typical Reinforcing Layout for Single Cell Box Culverts

Note: Reinforcing Designations Correspond to Those Used in ASTM C789 and C850
### Flexure Design Locations:

<table>
<thead>
<tr>
<th>Steel Area</th>
<th>Precast</th>
<th>Cast-In-Place</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{s1}$</td>
<td>4, 5, 11, 12</td>
<td>5, 11, 12</td>
</tr>
<tr>
<td>$A_{s2}$</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$A_{s3}$</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>$A_{s4}$</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>$A_{s8}$</td>
<td>-</td>
<td>4</td>
</tr>
</tbody>
</table>

### Shear Design Locations:

- Method 1: 3, 6, 10, 13
- Method 2: 2, 3, 6, 7, 9, 10, 13, 14

*Note: For method 2 shear design, any distributed load within a distance $d/2$ from the tip of the haunch is neglected. Thus the shear strengths at locations 4, 5, 11 and 12 are compared to the shear forces at locations 3, 6, 10, and 13 respectively.*

**Figure 4-2. Locations of Critical Sections for Shear and Flexure Design in Single Cell Box Sections**
Figure 4-3. Typical Reinforcing Layout and Location of Design Sections for Shear and Flexure Design of Two Cell Box Culverts
Figure 4-4. Typical Reinforcing Layout and Locations of Critical Sections for Shear and Flexure Design in Pipe Sections

Flexure Design Locations:
1, 5 Maximum Positive Moment Locations At Invert & Crown.
3 Maximum Negative Moment Location Near Springline.

Shear Design Locations:
2,4 Locations Near Invert and Crown Where $M/V_{d} = 3.0$

Notes:
1. Reinforcing in Crown ($A_{sc}$) will be the same as that used at the invert unless mat, quadrant or other special reinforcing arrangements are used.
2. Design Locations are the same for elliptical sections.
4.1.1 Limit States Design Criteria

The concept of limit states design has been used in buried pipe engineering practice, although it generally is not formally defined as such. In this design approach, the structure is proportioned to satisfy the following limits of structural behavior:

- Minimum ultimate strength equal to strength required for expected service loading times a load factor
- Control of crack width at expected service load to maintain suitable protection of reinforcement from corrosion, and in some cases, to limit infiltration or exfiltration of fluids.

In addition, provisions are incorporated to account for a reduction of ultimate strength and service load performance that may result from variations in dimensions and nominal strength properties within manufacturing tolerances allowed in standard product specifications, or design codes.

Moments, thrusts and shears at critical points in the pipe or box section, caused by the design loads and pressure distribution, are determined by elastic analysis. In this analysis, the section stiffness is usually assumed constant, but it may be varied with stress level, loosed on experimentally determined stiffness of crooked sections at the crown, invert and springlines in computer analysis methods. Ultimate moments, thrusts and shears required for design are determined by multiplying calculated moments, thrusts, and shears (service conditions) by a load factor \( L_f \) as follows:

\[
M_u = L_f M \\
N_u = L_f N \\
V_u = L_f V
\]

Equations 4.1, 4.2, 4.3

**Load Factors for Ultimate Strength**: The minimum load factors given below are appropriate when the design bedding is selected near the poorest extreme of the expected installation, and when the design earth load is conservatively estimated using the Morston-Spongler method \((2, 3)\) for culvert or trench installations. Alternatively, these minimum load factors may be applied when the weight of earth on the buried section and the earth pressure distribution are determined by a soil-structure interaction analysis in which soil properties are selected at the lower end of their expected practical range. Also, the suggested load factors are intended to be used in conjunction with the strength reduction factors given below.

The 1981 AASHTO Bridge Specifications \((4)\) specify use of a minimum load factor of 1.3 for all loads, multiplied by \( \beta \) coefficients of 1.0 for dead and earth load and 1.67 for live load plus impact. Thus the effective load factors are 1.3 for earth and dead load and \(1.3 \times 1.67 = 2.2\) for live loads. These load factors are applied to the moments, thrusts and shears resulting from the loads determined in Chapter 2.

**Strength Reduction Factors**: Strength reduction factors, \( \phi \), provide “for the possibility that small adverse
variations in material strengths, workmanship, and dimensions, while individually within acceptable tolerances and limits of good practice, may combine to result in understrength” (4). Table 4-1 presents the maximum $\phi$ factors given in the 1981 AASHTO Bridge Specification.

<table>
<thead>
<tr>
<th>Table 4-1. Strength Reduction Factors in Current AASHTO Standard Specifications for Highway Bridges (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Box Culverts</strong></td>
</tr>
<tr>
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<tr>
<td>Flexure</td>
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<tr>
<td>Shear</td>
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</table>

- Section 1.15.7b.
- Section 1.5.30
- Currently recommended by AASHTO Rigid Culvert Liaison Committee for adoption by AASHTO Bridge Committee.
- The use of a strength reduction factor equal to 1.0 is contrary to the philosophy of ultimate strength design; however, it has been justified by the Rigid Culvert Committee on the basis that precast sections are a manufactured product, and are subject to better quality control than are cast-in-place structures. Because welded wire fabric, the reinforcing normally used in precast box and pipe sections, can develop its ultimate strength before failing in flexure, the use of $\phi = 1.0$ with the yield strength still provides a margin for variations equal to the ratio of the yield strength to the ultimate strength. If hot rolled reinforcing is used in a precast structure, or if any unusual conditions exist, a strength reduction factor of 0.9, instead of 1.0, should be used in flexural calculations.

4.1.2 Design of Reinforcement for Flexural Strength

Design for flexural strength is required at sections of maximum moment, as shown in Figure 4-2, Figure 4-3 and Figure 4-4.

(a) Reinforcement for Flexural Strength, $A_s$

$$A_s f_y = g \phi_f d - N_u - \sqrt{g[\phi_f (\phi_f d)^2 - N_u (2 \phi_f d - h) - 2M_u]}$$  
Equation 4.4

$$g = 0.85 b f_{o}$$  
Equation 4.5

$d$ may be approximated as

$$d = 0.96 h - t_b$$  
Equation 4.6
(b) Minimum Reinforcement

For precast or cast-in-place box sections: \[ \text{min. } A_s = 0.002 \, bh \]  
Equation 4.7

For precast pipe sections:
- For inside face of pipe: \[ \text{min. } A_s = \frac{(B_i + h)^2}{65,000} \]  
Equation 4.8
- For outside face of pipe: \[ \text{min. } A_s = 0.75 \frac{(B_i + h)^2}{65,000} \]  
Equation 4.9
- For elliptical reinforcement in circular pipe: \[ \text{min. } A_s = 2.0 \frac{(B_i + h)^2}{65,000} \]  
Equation 4.10
- For pipe 33 inch diameter and smaller with a single cage of reinforcement in the middle third of the pipe wall: \[ \text{min. } A_s = 2.0 \frac{(B_i + h)^2}{65,000} \]  
Equation 4.11

In no case shall the minimum reinforcement in precast pipe be less than 0.07 square inches per linear foot.

(c) Maximum Flexural Reinforcement Without Stirrups

(1) Limited by radial tension (inside reinforcing of curved members only):

\[ \text{max. inside } A_{sfy} = 1.33 b \, r_s \sqrt{f_{c}' \, F_{rp}} \]  
Equation 4.12

Where \( r_s \) is the radius of the inside reinforcement = \( \frac{D_i + 2t_b}{2} \) for circular pipe.

The term \( F_{rp} \) is a factor used to reflect the variations that local materials and manufacturing processes can have on the tensile strength (and therefore the radial tension strength) of concrete in precast concrete pipe. Experience within the precast concrete pipe industry has shown that such variations are significant. \( F_{rp} \) may be determined with Equation 4.13 below when a manufacturer has a sufficient amount of test data on pipe with large amounts of reinforcing (greater than \( A_s \) by Equation 4.12) to determine a statistically valid test strength, \( D_{lut} \), using the criteria in ASTM C655 (AASHTO M242) "Standard Specification for Reinforced Concrete D-Load Culvert, Storm Drain and Sewer Pipe."

\[ F_{rp} = \frac{\left( D_{lut} + 9 W_p / D_i \right)}{1230 \, r_s \, d \sqrt{f_{c}'}} D_i \left( D_i + h \right) \]  
Equation 4.13

Once determined, \( F_{rp} \) may be applied to other pipe built by the same process and with the same materials. If Equation 4.13 yields values of \( F_{rp} \) less than 1.0, a value of 1.0 may still be used if a review of test results shows that the failure mode was diagonal tension, and not radial tension.
If max. inside $A_s$ is less than $A_s$ required for flexure, use a greater $d$ to reduce the required $A_s$, or use radial stirrups, as specified later.

(2) Limited by concrete compression:

$$\max A_s f_y = \frac{5.5 \times 10^4 \phi f_y d}{(87,000 + f_y)} - 0.75N_u$$  
Equation 4.14

where:

$$g' = \left(0.85 - 0.05 \left[\frac{f_c' - 4000}{1000}\right]\right) b f_c'$$  
Equation 4.15

$$0.65 b f_c' < g' < 0.85 b f_c'$$

If max $A_s$ is less than $A_s$ required for flexure, use a greater $d$ to reduce the required $A_s$, or the member must be designed as a compression member subjected to combined axial load and bending. This design should be by conventional ultimate strength methods, meeting the requirements of the AASHTO Bridge Specification, Section 1.5.11. Stirrups provided for diagonal or radial tension may be used to meet the lateral tie requirements of this section if they are anchored to the compression reinforcement, as well as to the tension reinforcement.

### 4.1.3 Crack Control Check

Check flexural reinforcement for adequate crack width control at service loads.

Crack Width Control Factor:

$$F_{cr} = \frac{B'}{30,000 \phi f_y d A_s} \left[ M + N \left( \frac{d - h}{2} \right) \right] - C_1 b h^2 \sqrt{f_c'}$$  
Equation 4.16

where:

$F_{cr}$ = crack control factor, see note c.
\[ e = \frac{M + d - h}{N} \]  
Equation 4.17

Note: If \( e/d \) is less than 1.15, crack control will not govern and Equation 4.16 should not be used.

\[ j = 0.74 + 0.1 \frac{e}{d} \]  
Equation 4.18

Note: If \( e/d > 1.6 \), use \( j = 0.90 \).

\[ i = \frac{1}{1 - \frac{jd}{e}} \]  
Equation 4.19

\( B_1 \) and \( C_1 \) are crack control coefficients that define performance of different reinforcements in 0.01 in. crack strength tests of reinforced concrete sections. Crack control coefficients \( B_1 \) and \( C_1 \) for the type reinforcements noted below are:

**Type Reinforcement (RTYPE)**

<table>
<thead>
<tr>
<th>Type Reinforcement (RTYPE)</th>
<th>( B_1 )</th>
<th>( C_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Smooth wire or plain bars</td>
<td>( \sqrt[3]{\frac{0.5t^2_s s_t}{n}} )</td>
<td>1.0</td>
</tr>
<tr>
<td>2. Welded smooth wire fabric, 8 in. max. spacing of longitudinals</td>
<td>1.0</td>
<td>1.5</td>
</tr>
<tr>
<td>3. Welded deformed wire fabric, deformed wire, deformed bars, or any reinforcement with stirrups anchored thereto</td>
<td>( \sqrt[3]{\frac{0.5t^2_s s_t}{n}} )</td>
<td>1.9</td>
</tr>
</tbody>
</table>

**Notes:**

a. Use \( n = 1 \) when the inner and the outer cages are each a single layer.

b. Use \( n = 2 \) when the inner and the outer cages are each made up from multiple layers.

c. For type 2 reinforcement having \( \left( t_b s_t \right) / n > 3.0 \), also check \( F_{cr} \) using coefficients \( B_1 \) and \( C_1 \) for type 3 reinforcement, and use the larger value for \( F_{cr} \).

c. \( F_{cr} \) is a crack control factor related to the limit for the average maximum crack width that is needed to satisfy performance requirements at service load. When \( F_{cr} = 1.0 \), the average maximum crack width is 0.01 inch for a reinforcement area \( A_s \). If a limiting value of less than 1.0 is specified for \( F_{cr} \), the probability of an 0.01 inch crack is reduced. No data is available to correlate values of \( F_{cr} \) with specific crack widths other...
If the calculated $F_{cr}$ is greater than the limiting $F_{cr}$, increase $A_s$ by the ratio: calculated $F_{cr}$/limiting $F_{cr}$, or decrease the reinforcing spacing.

### 4.1.4 Shear Strength Check

**Method 1**: This method is given in Section 1.5.35 G of the AASHTO Bridge Specification for shear strength of box sections (4). Under uniform load, the ultimate concrete strength, $\phi V_c$ must be greater than the ultimate shear force, $V_u$, computed at a distance $\phi vd$ from the face of a support, or from the tip of a haunch with inclination of 45 degrees or greater with horizontal:

$$\phi_v V_o = 3 \phi_v \sqrt{f_c} b d$$  
Equation 4.20

$$V_u \leq \phi_v V_c$$  
Equation 4.21

Current research (9) indicates that this method may be unconservative in some conditions, most importantly, in the top and bottom slab, near the center wall of two cell box culverts. Thus, Method 2 should also be checked.

**Method 2**: Method 2 is based on research sponsored by the American Concrete Pipe Association (9), and is more complex than Method 1, but it reflects the behavior of reinforced concrete sections under combined shear, thrust and moment with greater accuracy than Method 1, or the current provisions in the reinforced concrete design section of the AASHTO Bridge Specification.

Determine $V_u$ at the critical shear strength location in the pipe or box. For buried pipe, this occurs where the ratio $M/V\phi vd = 3.0$, and for boxes, it occurs either where $M/V\phi vd = 3.0$ or at the face of supports (or tip of haunch). Distributed load within a distance $\phi vd$ from the face of a support may be neglected in calculating $V_u$, but should be included in calculating the ratio $M/V\phi vd$. 
Figure 4-5. Critical Shear Location in Circular Pipe for Olander (7) Earth Pressure Distribution

(a) For pipe, the location where $M/V\phi_v d = 3.0$ varies with bedding and load pressure distributions. For
the distributions shown in Figure 2-1b, it varies between about 10 degrees and 30 degrees from the invert. For the Olander bedding conditions (Figure 2-1b), the location where \( M/V_\phi vd = 3.0 \) in a circular pipe can be determined from Figure 4-5, based on the parameter \( rm/\phi vd \). For noncircular pipe or other loading conditions, the critical location must be determined by inspection of the moment and shear diagrams.

(b) For box sections, the location where \( M_u/V_u \phi vd = 3.0 \) is at \( x_{dc} \) from the point of maximum positive moment, determined as follows:

\[
x_{dc} = 3 \left[ \sqrt{(\phi_v d)^2 + \frac{2M_c}{g w}} - \phi_v d \right]
\]

Equation 4.22

where
- \( x_{dc} \) is the distance from the point of maximum positive moment (mid-span for equal end moments) to the point of critical shear
- \( w \) is the uniformly distributed load on the section, use \( p_s \) or \( p_v \) as appropriate
- \( M_c \) is the maximum positive moment on span

This equation can be nondimensionalized by dividing all terms by the mean span of the section being considered. Figure 4-6 is a plot of the variation of \( x_{dc}/l \) with \( l/\phi vd \) for several typical values of \( c_m \), where

\[
c_m = \frac{2M_c}{Wl^2}
\]

Equation 4.23

At sections where \( M/V_\phi vd \geq 3.0 \), shear is governed by the basic shear strength, \( V_b \), calculated as

\[
\phi_v V_b = (1.1 + 6.3p) \sqrt{f'_c \phi_v bd} \left[ \frac{F_d F_{vp}}{F_c F_N} \right]
\]

Equation 4.24

where:
- \( p = \frac{A_s}{\phi_v bd} \leq 0.02 \)
- \( \max. f'_c = 7000 \text{psi} \)
\[ F_d = 0.8 + \frac{1.6}{d} \leq 1.25 \]

\[ F_c = 1 \] for straight members

Equation 4.27
Equation 4.28
Figure 4-6. Location of Critical Shear Section for Straight Members with Uniformly Distributed Load

\[
F_c = 1 + \frac{d}{2r_m} \quad \text{when moment produces tension on the inside of a pipe} \quad \text{Equation 4.27b}
\]

\[
F_c = 1 - \frac{d}{2r_m} \quad \text{when moment produces tension on the outside of a pipe} \quad \text{Equation 4.27c}
\]

\[
F_N = 1.0 - 0.12 \frac{N_u}{V_u} \geq 0.75 \quad \text{Equation 4.28}
\]

The term \( F_{vp} \) is a factor used to reflect the variations that local materials and manufacturing processes can have on the tensile strength (and therefore diagonal tension strength) of concrete in precast concrete pipe. Experience within the precast concrete pipe industry has shown that such variations are significant. \( F_{vp} \) may be determined with Equation 4.29 below when a manufacturer has a sufficient amount of test data on pipe that fail in diagonal tension to determine a statistically valid test strength, \( D_{lt} \), using the criteria in ASTM C655 *AASHTO M242) "Specifications for Reinforced Concrete D-Load Culvert, Storm Drain and Sewer Pipe."

\[
F_{vp} = \frac{F_c \left(D_{lt} + 1.1W_p / D_i \right) D_i}{293F_d (1.1 + 63p) d / \sqrt{f_c}} \quad \text{Equation 4.29}
\]

Once determined, \( F_{vp} \) may be applied to other pipe built by the same process and with the same materials. \( F_{vp} = 1.0 \) gives predicted 3-edge bearing test strengths in reasonably good agreement with pipe industry experience, as reflected in the pipe designs for Class 4 strengths given in ASTM C76, "Standard Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe." Thus, it is appropriate to use \( F_{vp} = 1.0 \) for pipe manufactured by most combinations of process and local materials. Available 3-edge bearing test data show minimum values of \( F_{vp} \) of about 0.9 for poor quality materials and/or processes, as well as possible increases up to about 1.1, or more, with some combinations of high quality materials and manufacturing process. For tapered inlet structures, \( F_{vp} = 0.9 \) is recommended in the absence of test data.

If \( \phi_v V_b < V_u \), either use stirrups, as specified in Section 4.1.5 below, or if \( M / V \phi_v d < 3.0 \), calculate the general shear strength, as given below.
Shear strength will be greater than $V_b$ when $M/V_\phi d < 3.0$ at critical sections at the face of supports or, for members under concentrated load, at the edge of the load application point. The increased shear strength when $M/V_\phi d < 3.0$, termed the general shear strength, $V_c$, is:

$$\phi V_c = \frac{4\phi V_b}{(M/V_\phi d + 3.0)} \leq \frac{4.5\sqrt{f_c} b d \phi v}{F_N} \quad \text{Equation 4.30}$$

If $M/V_\phi d \geq 3.0$, use $M/V_\phi d = 3.0$ in Equation 4.30. $V_c$ shall be determined based on $M/V_\phi d$ at the face of supports in restrained end flexural members and at the edges of concentrated loads. Distributed load within a distance $\phi v d$ from the face of a support may be neglected in calculating $V_u$, but should be included for determining $M/V_\phi d$.

### 4.1.5 Stirrups

Stirrups are used for increased radial tension and/or shear strength.

(a) Maximum Circumferential Spacing of Stirrups:

For boxes, max. $s = 0.60 \phi v d$ \quad \text{Equation 4.31a}

For pipe, max. $s = 0.75 \phi v d$ \quad \text{Equation 4.31b}

(b) Maximum Longitudinal Spacing and Anchorage Requirements for Stirrups

Longitudinal spacing of stirrups shall equal $s_t$. Stirrups shall be anchored around each inner reinforcement wire or bar, and the anchorage at each end shall develop the ultimate strength, $f_v$, used for design of the stirrups. Also, $f_v$ shall not be greater than $f_y$ for the stirrup material.

(c) Radial Tension Stirrups (curved members only):

$$A_{tr} = 1.15(M_u - 0.45N_u \phi v d) $$

$$f_v f_s \phi v d \quad \text{Equation 4.32}$$

(d) Shear Stirrups (also resist radial tension):
Equation 4.33

\[ A_{vt} = \frac{1.1S}{f_v \phi_v d} \left[ V_u F_c - \phi_v V_c \right] + A_{vt} \]

\[ V_c \leq 2 \sqrt{f_c^* b \phi_v d} \]

Vc is determined in Equation 4.30 except use \( A_{vt} = 0 \) for straight members.

(e) Extent of Stirrups:

Stirrups should be used wherever the radial tension strength limits and/or wherever shear strength limits are exceeded.

(f) Computer Design of Stirrups:

The computer program to design reinforced concrete pipe that is described in Chapter 5 includes design of stirrups. The output gives a stirrup design factor (Sdf) which may be used to size stirrups as follows:

\[ A_v = \frac{S_{df} S}{f_v} \]

Equation 4.34

This format allows the designer to select the most suitable stirrup effective ultimate strength and spacing.

4.1.6 Special Design Considerations for Slope Tapered Inlets

Slope tapered inlets are designed in the same manner as ordinary culverts, or side tapered inlets, except that the steeper slope of the section, \( S_f \), must be taken into account. The recommended design procedure for precast inlets is to analyze the section and design the reinforcing based on earth loads applied normal to the section, as shown in Figure 4-7a; however, since it is usually easier to build cast-in-place inlets with the main sidewall reinforcing (ASI) vertical, the reinforcing spacing and area must be adjusted to provide the necessary area. This is accomplished, as shown in Figure 4-7b, by using the transverse spacing assumed for the analysis as the horizontal spacing, and by modifying the area of sidewall outside reinforcing by

\[ A_{s1}' = \frac{A_{s1}}{\sqrt{\left(1/ S_f^2 + 1\right)}} \]

Equation 4.35
A consequence of installing the main reinforcing at an angle to the applied forces is the creation of secondary stress resultants in the wall in the longitudinal direction. These stress resultants are relatively small and sufficient flexural resistance is usually developed if the minimum flexural reinforcing is provided in the longitudinal direction, as shown in Figure 4-7b.
4.2 Corrugated Metal Pipe Design Method

The AASHTO design method for corrugated metal structures has been successfully used for many years, and is reproduced in Appendix A. As noted in Chapter 3, many manufacturers provide proprietary modifications to large or unusual corrugated metal culverts, and should be consulted prior to completion of detailed designs.

The use of side tapered corrugated metal inlets requires the design of horizontal elliptical sections. The current AASHTO Bridge Specifications provide for the design of horizontal ellipses only under Section 1.9.6. Long-span structures are set apart from typical corrugated metal pipe in that:

- "Special features", such as longitudinal or circumferential stiffeners, are required to control deformations in the top arc of the structure.
- The design criteria for buckling and handling do not apply.

The concept of special features was introduced by the corrugated metal pipe industry to help stiffen long-span structures without using heavier corrugated metal plate, on the theory that the extra stiffness provided by the special features allows the use of lighter corrugated metal plate, since the combined stiffness of the plate and special feature may be used in design. Thus, for such structures, the corrugated metal plate alone need not meet the handling and buckling criteria. This approach results in more economical structures for large spans.

The concept of special features also applies to side tapered corrugated metal inlets; however, it is not practical to provide special features for small inlets, and thus a special condition exists. The recommended approach for these structures is that either special features must be provided, or the handling and buckling criteria must be met by the corrugated metal section alone. This is not specifically allowed by the AASHTO Bridge Specification, but is within the design philosophy of the code.
Computer programs that make the analysis and design of concrete culvert and inlet sections both simple and cost effective are described in this Chapter. Use of the computer methods allows the engineer to make a more complete evaluation of various culvert configurations for a given installation.

5.1 Box Sections

The design program for buried reinforced concrete box sections provides a comprehensive structural analysis and design method that may be used to design any single cell rectangular box section with or without haunches. For tapered inlet design, the program may be used to design cross sections at various locations along the longitudinal axis that the designer may then assemble into a single design. This program is modeled after a similar program that was used to develop ASTM Specification C789 (AASHTO M259) "Precast Reinforced Concrete Box Sections for Culverts, Storm Drains and Sewers". This section gives a general description of the program. Specific information needed to use the program is given in Appendix B. A program listing is provided in Appendix H.

5.1.1 Input Variables

The following parameters are input variables in the program:

- **Culvert geometry** - span, rise, wall thicknesses, and haunch dimensions.
- **Loading data** - depth of fill, density of fill, lateral pressure coefficients, soil-structure interaction factor, depth of internal fluid, and density of fluid.
- **Material properties** - reinforcing tensile yield strength, concrete compressive strength, and concrete density.
- **Design data** - load factors, concrete cover over reinforcement, wire diameter, wire spacing, type of reinforcing used, layers of reinforcing used, capacity reduction factor, and limiting crack control factor.

The only parameters that must be specified are the span, rise, and depth of fill. If no values are input for the remaining parameters, then the computer will use standard default values. Default values are listed in Appendix B (Table B-1) for all the input parameters.
5.1.2 Loadings

The program analyzes the five loading cases shown in Figure 5-1. The loading cases are separated into two groups; permanent dead loads (Cases 1, 2 and 3) that are always considered present and additional dead loads (Cases 4 and 5) that are considered present only when they tend to increase the design force under consideration. The two foot surcharge load (Section 2.4) is added to the height of fill, and is therefore considered as a permanent dead load.

Earth pressures are assumed distributed uniformly across the width of the section and vary linearly with depth. Soil reactions are assumed to be uniformly distributed across the base of the culvert.

5.1.3 Structural Analysis

To determine the design moments, thrusts, and shears, the program employs the stiffness matrix method of analysis. Box culverts are idealized as 4 member frames of unit width. For a given frame, member stiffness matrices are assembled into a global stiffness matrix; a joint load matrix is assembled, and conventional methods of matrix analysis are employed. For simplicity, the fixed end force terms and flexibility coefficients for a member with linearly varying haunches are determined by numerical integration. The trapezoidal rule with 50 integration points is used and a sufficiently high degree of accuracy is obtained.

5.1.4 Design of Reinforcing

The program incorporates the design method entitled "Design Method for Reinforced Concrete Pipe and Box Sections", developed by Simpson Gumpertz & Heger Inc. for the American Concrete Pipe Association (9). This method is presented in Chapter 4. For a given trial wall thickness and haunch arrangements the design procedure consists of determining the required steel reinforcement based on flexural strength and checking limits based on crack control, concrete compressive strength, and diagonal tension strength. If the limits are exceeded, the designer may choose to increase the amount of steel reinforcement, add stirrups for diagonal tension, or change the wall thicknesses and haunch geometry as required to provide a satisfactory design.
The following limitations apply to the use of the program to design box sections:

- Only transverse reinforcement areas are computed.
Anchorage lengths must be calculated and added to the theoretical cut-off lengths determined by the program.

The program does not design wall thicknesses (these must be input by the user).

The program does not design shear reinforcement, but prints a message when shear reinforcement is required.

These limitations are included to allow the structural designer the maximum possible flexibility in selecting reinforcing, i.e. type (hot rolled reinforcing bar or smooth or deformed welded wire fabric), size and spacing.

The maximum forces at the design sections (Figure 4-2) are determined by taking the forces due to the permanent dead load cases, and adding to them the forces due to the additional dead load cases, if they increase the maximum force. Five steel areas designated as AS1, AS2, AS3, AS4 and AS8 in Figure 4-1 are sized based on the maximum governing moment at each section. The area AS1 is the maximum of the steel areas required to resist moments at locations 5, 11 and 12 in Figure 4-2. Areas AS2, AS3, AS4 and AS8 are designed to resist moments at locations 1, 15, 8 and 4, respectively. The steel areas determined for flexural strength requirements are then checked for crack control. The program then checks shear by both Methods 1 and 2 (Section 4.1.4) at the locations shown in Figure 4-2. The more conservative criteria is used as the limiting shear capacity.

For the reinforcing scheme for precast box sections (Figure 4-1a), the theoretical cutoff lengths, $\zeta_d$ for AS1 in the top and the bottom slab are calculated from the assumption of uniformly distributed load across the width of the section. The point where the negative moment envelope is zero is computed from the minimum midspan moment. Informative messages are printed when excessive concrete compression governs the design or when stirrups are required due to excessive shear stresses.

5.1.5 Input/Output Description

The amount of data required for the program is very flexible because much of the data is optional. Input for a particular box culvert may range from a minimum of 3 cards to a maximum of 16 cards depending on the amount of optional input data required by the designer. The type of data to be supplied on each card is specified in Appendix B. A program with minimum data would require only a title card, data card 1 specifying the span, rise and depth of fill, and data card 15 indicating the end of the input data.

The amount of output can be controlled by the user, as described in Appendix B. The minimum amount of output that will be printed is an echo print of the input data and a one page summary of the design. An example design summary sheet is included in Appendix B. Additional available output includes maps of major input arrays, displacements, end forces, moments, thrusts and shears at critical sections, and shear and flexure design tables.
5.2 Circular and Elliptical Pipe Sections

The program for buried reinforced concrete pipe has the capability to analyze and design circular, and horizontal elliptical pipe. Information needed to use the program is presented in Appendix C.

5.2.1 Input Variables and Dimensional Limitations

The following parameters are input variables in the program:

- **Pipe Geometry**
  - diameter for circular pipe, or radius 1, radius 2, horizontal offset, and vertical offset for elliptical pipe, and wall thickness (see Figure 1-2)

- **Loading Data**
  - depth of fill over crown of pipe, density of fill, bedding angle, load angle, soil structure interaction factor, depth of internal fluid and fluid density

- **Material Properties**
  - reinforcing tensile yield strength, concrete compressive strength and concrete density

- **Design Data**
  - load factors, concrete cover over inner and outer reinforcement, wire diameters, wire spacing, reinforcing type, layers of reinforcing, capacity reduction factor, crack control factor, shear process factor and radial tension process factor

The pipe geometry and height of fill are the only required input parameters. Default values are assumed for any optional data not specified by the user. Appendix C (Table C-1) lists all the input parameters and their associated default values.

The program has the following limitations:

- The specified load angle must be between 180° and 300°.
- The specified bedding angle must be between 10° and 180°.
- The sum of the bedding and load angles must be less than or equal to 360°.
- Only circumferential reinforcement is designed.
- Wall thicknesses must be selected by the designer.
- Internal pressure is not a design case.

5.2.2 Loadings

The program analyzes the three load cases shown in Figure 5-2. Load cases 1 and 2 are considered as permanent dead load, and load case 3 is considered additional dead load and is used in design only if it increases the design force under consideration. The two foot surcharge load suggested in Section 2.4 should be added to the height of fill input into the program.
5.2.3 Structural Analysis

Due to symmetry, it is only necessary to analyze one half of the pipe section. The pipe is modeled as a 36 member plane frame with boundary supports at the crown and invert. Each member spans 5 degrees and is located at middepth of the pipe wall. For each member of the frame, a member stiffness matrix is formed, and then transformed into a global coordinate system. The loads on the pipe are calculated as pressures applied normal and tangential to each of the 36 members. These pressures are converted into nodal pressures that act radially and tangentially to the pipe. Loads of each joint are assembled into a joint load matrix, and a solution is obtained by a recursion algorithm from which member end forces are obtained at each joint. Analysis is completed separately for each load condition.
5.2.4 Design of Reinforcing

Forces or moments for ultimate strength design are determined by summing the stress resultants obtained from the analyses for dead load, and earth load, and fluid load, (if the latter increases the force under consideration), and multiplying the resultant by the appropriate load factor.

The design procedure consists of determining reinforcement areas based on bending moment and axial compression at locations of maximum moment, and checking for radial tension strength, crack control, excessive concrete compression and diagonal tension strength. If necessary, the reinforcement areas are increased to meet these other requirements. The design procedure is the same as used for box sections (See Chapter 4).

Reinforcing is designed at three locations; inside crown, inside invert and outside springline (See Figure 4-4). These areas are designated $A_{sc}$, $A_{si}$ and $A_{so}$, respectively. Critical shear locations are determined by locating the points where $M_u/V_u \phi_V d$ equals 3.0 (See Chapter 4). Shear forces are calculated at each of these points and compared to the maximum shear strength. When the applied shear exceeds the shear strength, stirrups are designed by outputting a stirrup design factor ($S_{df}$). This is then used to determine stirrup area by the following equation:

$$A_v = \frac{S_{df} (S)}{f_v}$$  

Equation 5.1

This allows the designer to select a desirable stirrup spacing and to vary $f_v$ depending upon the developable strength of the stirrup type used. The stirrup reinforcing strength, $f_v$, is based on either the yield strength of the stirrup material, or the developable strength of the stirrup anchorage, whichever is less.

5.2.5 Input/Output Description

The amount of data required for the program is very flexible because much of the data is optional. For an elliptical pipe, the number of data cards required may range from 5 cards to 14 cards. For circular pipe design, one less card is required. The type of data to be specified on each card and format is described in Appendix C. The first card for every design is a problem identification card which may be used to describe the structure being...
designed. The remaining cards are data cards. Data cards 1 through 3 are required cards that specify the pipe geometry and height of fill. Data cards 4 through 12 specify the loading data, material strengths, and design criteria to be used. A data card over 12 indicates that the end of the data stream has been reached. For elliptical pipe, a design with a minimum amount of data would require a title card, data cards 1 through 3 specifying the culvert geometry and height of fill, and a data card with code greater than 12, indicating the end of the data stream. For circular pipe, data card 2 is not required.

The amount of output can be controlled by the user, as described in Appendix C. The minimum amount of information that will be printed is an echo print of the input data and a one page summary of the design. Additional available output includes stiffness matrices, displacements, moments, thrusts and shears at each node point and a table of design forces.

Go to Chapter 6
In order to integrate an improved inlet into a culvert system, several appurtenant structures may be required. These structures, which include circular to square transition sections, wingwalls, headwalls and aprons also require the attention of a structural engineer. The design of these structures is governed by the AASHTO Bridge Specifications (4), as is the design of inlets. Design requirements of these structures are discussed below. Typical suggested details are included in Appendix G. Suggested designs for several of these structures are presented in Appendix E.

### 6.1 Circular to Square Transition

In some instances it is desirable to use a cast-in-place box inlet with a circular culvert barrel. This requires the use of a transition section that meets the following criteria:

- The cross section must provide a smooth transition from a square to a circular shape. The rise and span of the square end should be equal to the diameter of the circular section.
- The length of the transition section must be at least one half the diameter of the circular section.

The outside of the transition section is not restricted by any hydraulic requirements; thus structural, and construction considerations should be used to determine the shape. Typically, for cast-in-place structures the simplest method is to make the outside square, and maintain the box section reinforcing arrangement throughout the length of the section. This simplifies the form work for the outside and allows the use of the same reinforcing layout throughout the length of the section, avoiding the need to bend each bar to a different shape. A suggested geometry and reinforcing diagram is shown in Figure 6-1 and Appendix G.

Reinforcing for transition sections can be sized by designing for the loads at the square end of the section according to the design method of Chapter 4 and then using that reinforcing throughout the length of the structure.

Typically, the transition section will be a cast-in-place structure up against a precast pipe section. It is important that the backfill be well compacted (95% of maximum AASHTO T99) around both structures to preclude significant longitudinal discontinuity stresses due to the differing stiffnesses of the two structures.
6.2 Wingwalls and Headwalls

At the opening of an improved inlet it is common to use a headwall and wingwalls to hold the toe of the embankment back from the entrance, protecting it from erosion (Figure 1-1). The headwall is a retaining wall with an opening for the culvert. It derives support from attachment to the culvert, and is subject to less lateral soil pressure than a retaining wall of equal size since the culvert replaces much of the backfill. The Wingwalls are retaining walls placed at either side of the headwall, usually at an angle (Figure 1-1).
6.2.1 Wingwalls

Wingwalls are designed as retaining walls and pose no unusual problems for the engineer. The methods of design and construction of retaining walls vary widely, and it is not possible to cover all of these in this Manual. There are a number of soil mechanics texts (10, 11, 12) that explain in detail the analysis of retaining walls; also, in 1967 the FHWA published "Typical Plans for Retaining Walls" (13) which gives typical designs for cantilever and counterfort type retaining walls. For the purpose of demonstrating typical details, one of the drawings from this document was revised and reproduced in Appendix G. The revisions made were to change the steel areas to reflect the use of reinforcing with a yield stress of 60,000 psi, which is the most common type in current use. The loading diagram and typical reinforcing layout for this drawing are shown in Figure 6-2.

The designs are based on working stress methods given in Section 1.5 of the AASHTO Bridge Specification (4).

For large culverts, the headwalls and wingwalls should always be separated by a structural expansion joint. For smaller structures, this expansion joint may be omitted at the discretion of the designer.

6.2.2 Headwalls

Headwalls are similar in appearance to wingwalls but behave much differently because of the culvert opening. The presence of the culvert greatly reduces the lateral pressure on the wall, and since the headwall is normally secured to the culvert barrel, the lateral forces do not normally need to be carried to the foot of the wall. Thus, for this case, only a small amount of reinforcing as shown in the typical details in Appendix G need be placed in the wall. If the headwall is not anchored to the inlet, culvert or the wing walls, then the headwall must be designed to span horizontally across the width of the inlet, and vertical edge must be provided on each side of the inlet, cantilevering from the foundation.

Skewed Headwalls: A special design case for a headwall occurs when the face of a culvert is skewed relative to the barrel (Figure 6-3). This requires special design for the headwall, and the portion of the culvert which is not a closed rectangle. The headwall is designed as a vertical beam to support the loads on the edge portion of the culvert slab that is beyond the closed rectangular sections of the culvert. This produces a triangular distribution of load from the culvert slab to be supported by the vertical beam action of the headwall. Transverse reinforcing in the culvert is sized as required in the closed rectangular sections, and in the area of the skew, this reinforcing is cut off at the skew face of the headwall beam. In addition, U-bars are provided at the skew edge, as shown in Figure 6-3. Skewed headwalls are not recommended for normal installations. The best hydraulic performance is received
from a headwall that is perpendicular to the barrel.

Figure 6-2. Loading Diagram and Typical Reinforcing Layout for Cantilever Type Retaining Wall

6.3 Apron Slabs

Apron slabs are slabs on grade in front of the culvert face section. They are primarily used to protect against erosion, and to hold the slope of fall sections. Apron slabs should be treated as
Figure 6-3. Skewed Headwall Detail

Go to Appendix A
1.9.1 General

(A) Scope
The specifications of this section are intended for the structural design of corrugated metal structures. It must be recognized that a buried flexible structure is a composite structure made up of the metal ring and the soil envelope; and both materials play a vital part in the structural design of flexible metal structures.

(B) Service Lead Design
This is a working stress method, as traditionally used for culvert design.

(C) Load Factor Design
This is an alternate method of design based on ultimate strength principles.

(D) Loads
Design load, P., shall be the pressure acting on the structure. For earth pressures see Article 1.2.2(A). For live load see Articles 1.2.3-1.2.9, 1.2.12 and 1.3.3, except that the words "When the depth of fill is 2 feet (0.610m) or more" in paragraph 1 of Art.1.3.3 need not be considered. For loading combinations see Article 1.2.22.

(E) Design
(1) The thrust in the wall must be checked by three criteria. Each considers the mutual function of the metal wall and the soil envelope surrounding it. The criteria are:
   (a) Wall area
   (b) Buckling stress
   (c) Seam strength (structures with longitudinal seams)

(2) Thrust in the wall is:

\[ T = P \times S/2 \]
Where

\[
\begin{align*}
P &= \text{Design load, Ibs/sq.ft. (N/m}^2) \\
S &= \text{Diameter or Span, ft. (m)} \\
T &= \text{Thrust, Ibs/ft. (N/m)}
\end{align*}
\]

(3) Handling and installation strength.

Handling and installation strength must be sufficient to withstand impact forces when shipping and placing the pipe.

(4) Minimum cover

Height of cover over the structure must be sufficient to prevent damage to the buried structure. A minimum of 2 feet (.610m) is suggested.

(F) Materials

The materials shall conform to the AASHTO specifications referenced herein.

(G) Soil Design

(1) Soil parameters

The performance of a flexible culvert is dependent on soil structure interaction and soil stiffness. The following must be considered:

(a) Soils

(1) The type and anticipated behavior of the foundation soil must be considered; i.e., stability for bedding and settlement under load.

(2) The type, compacted density and strength properties of the soil envelope immediately adjacent to the pipe must be established. Dimensions of culvert soil envelope recommended criteria for lateral limits are as follows:

Trench width 2 ft. (.610m) minimum each side of culvert. This recommended limit should be modified as necessary to account for variables such as poor in situ soils.

Embankment installations one diameter or span each side of culvert. The minimum upper limit of the soil envelope is one foot (.305m) above the culvert. Good side fill is considered to be a granular material with little or no plasticity and free of organic material, i.e., AASHTO classification groups A-1, A-2 and A-3 and compacted to a minimum 90 percent of standard density based on AASHTO Specifications T99 (ASTM D 698).

(3) The density of the embankment material above the pipe must be determined. See Article 1.2.2(A).

(2) Pipe arch design

Corner pressures must be accounted for in the design of the corner backfill. Corner pressure is considered to be approximately equal to thrust divided by the radius of the pipe arch corner. The soil envelope around the corners of pipe arches must be capable of supporting this pressure.
(3) Arch design

(a) Special design considerations may be applicable. A buried flexible structure may raise two important considerations. First is that it is undesirable to make the metal arch relatively unyielding or fixed compared to the adjacent sidefill. The use of massive footings or piles to prevent any settlement of the arch is generally not recommended. Where poor materials are encountered consideration should be given to removing some or all of this poor material and replacing it with acceptable material. The footing should be designed to provide uniform longitudinal settlement, of acceptable magnitude from a functional aspect. Providing for the arch to settle will protect it from possible drag down forces caused by the consolidation of the adjacent sidefill.

The second consideration is bearing pressure of soils under footings. Recognition must be given to the effect of depth of the base of footing and the direction of the footing reaction from the arch.

Footing reactions for the metal arch are considered to act tangential to the metal plate at its point of connection to the footing. The value of the reaction is the thrust in the metal arch plate at the footing.

(b) Invert slabs and/or other appropriate alternates shall be provided when scour is anticipated.

(H) Abrasive or Corrosive Conditions

Extra metal thickness, or coatings, may be required for resistance to corrosion and/or abrasion.

For a highly abrasive condition, a special design may be required.

(I) Minimum Spacing

When multiple lines of pipes or pipe arches greater than 48 inches (1.219m) in diameter or span are used, they shall be spaced so that the sides of the pipe shall be no closer than one-half diameter or three feet (.914m), whichever is less, to permit adequate compaction of backfill material. For diameters up to and including 48 inches (1.219m), the minimum clear spacing shall be not less than two feet (.610m).

(J) End Treatment

Protection of end slopes may require special consideration where backwater conditions may occur, or where erosion and uplift could be a problem. Culvert ends constitute a major run-off-the-road hazard if not properly designed. Safety treatment such as structurally adequate grating that conforms to the embankment slope, extension of culvert length beyond the point of hazard, or provision of guard rail are among the alternatives to be considered.

End walls on skewed alignment require a special design.

(K) Construction and Installation

The construction and installation shall conform to Section 23, Division II.
1.9.2 Service Load Design

(A) Wall Area

\[
A = \frac{T_s}{f_a}
\]

where

- \(A\) = Required wall area, in\(^2\)/ft \(\text{Im}^2/\text{m}\)
- \(T_s\) = Thrust, Service Load, lbs/ft (N/m)
- \(f_a\) = Allowable stress-specified minimum yield point, psi (MPa), divided by safety factor (\(f_y/\text{SF}\))

(B) Buckling

Corrugations with the required wall area, \(A\), shall be checked for possible buckling.

If allowable buckling stress, \(f_{cr}/\text{SF}\), is less than \(f_a\), required area must be recalculated using \(f_{cr}/\text{SF}\) in lieu of \(f_a\).

Formulae for buckling are:

\[
\text{If } S < \frac{r}{k} \sqrt{\frac{24E_m}{f_u}} \quad \text{then } f_{cr} = f_u - \frac{f_u^2}{48E_m} \left(\frac{kS}{r}\right)^2
\]

\[
\text{If } S > \frac{r}{k} \sqrt{\frac{24E_m}{f_u}} \quad \text{then } f_{cr} = \frac{12E_m}{(kS/r)^2}
\]

Where

- \(f_u\) = Specified minimum tensile strength, psi (MPa)
- \(f_{cr}\) = Critical buckling stress, psi (MPa)
- \(k\) = Soil stiffness factor = 0.22
- \(S\) = Diameter or span, inches (m)
- \(r\) = Radius of gyration of corrugation, in. (m)
- \(E_m\) = Modulus of elasticity of metal, psi (MPa)

(C) Seam Strength

For pipe fabricated with longitudinal seams (riveted, spot-welded, bolted), the seam strength shall be sufficient to develop the thrust in the pipe wall.

The required seam strength shall be:

\[
SS = T_s \times (\text{SF})
\]

Where

- \(SS\) = Required seam strength in pounds per foot (N/m)
- \(T_s\) = Thrust in pipe wall, lbs/ft (N/m)
- \(\text{SF}\) = Safety Factor

(D) Handling and Installation Strength
Handling and installation rigidity is measured by a Flexibility Factor, FF, determined by the formula

$$\text{FF} = \frac{s^2}{\text{E}_m I}$$

Where

- FF = Flexibility Factor, inches per pound (m/N)
- s = Pipe diameter or maximum span, inches (m)
- E_m = Modulus of elasticity of the pipe material, psi (MPa)
- I = Moment of inertia per unit length of cross section of the pipe wall, inches to the 4th power per inch (m^4/m).

1.9.3 Load Factor Design

(A) Wall Area

$$A = \frac{T_L}{\phi \text{f}_y}$$

Where

- A = Area of pipe wall, in²/ft (m²/m)
- T_L = Thrust, load factor, lbs/ft (N/m)
- f_y = Specified minimum yield point, psi (MPa)
- \(\phi\) = Capacity modification factor

(B) Buckling

If for is less than \(f_y\) then A must be recalculated using \(f_{cr}\) in lieu of \(f_y\).

If \(s < \frac{r}{k} \sqrt{\frac{24 \text{E}_m}{f_u}}\) then \(f_{cr} = f_u - \frac{f_u^2}{48 \text{E}_m \left(\frac{kS}{r}\right)^2}\)

If \(s > \frac{r}{k} \sqrt{\frac{24 \text{E}_m}{f_u}}\) then \(f_{cr} = \frac{12 \text{E}_m}{(kS/r)^2}\)

Where

- \(f_u\) = Specified minimum metal strength, psi (MPa)
- \(f_{cr}\) = Critical buckling stress, psi (MPa)
- k = Soil stiffness factor = 0.22
- s = Pipe diameter or span, inches (m)
- r = Radius of gyration of corrugation, inches (m)
- E_m = Modulus of elasticity of metal, psi (MPa)

(C) Seam Strength

For pipe fabricated with longitudinal seams (riveted, spot-welded, bolted), the seam strength shall be sufficient to develop the thrust in the pipe wall. The required seam strength shall be:
\[
SS = \frac{T_L}{\phi}
\]

Where
- \(SS\) = Required seam strength in pounds/ft (N/m)
- \(T_L\) = Thrust multiplied by applicable factor, in pounds/lin. ft. (N/m)
- \(\phi\) = Capacity modification factor

(D) Handling and Installation Strength

Handling rigidity is measured by a Flexibility Factor, \(FF\), determined by the formula

\[FF = \frac{S^2}{Eml}\]

Where
- \(FF\) = Flexibility Factor, inches per pound (m/N)
- \(s\) = Pipe diameter of maximum span, inches (m)
- \(Em\) = Modulus of elasticity of the pipe material, psi (MPa)
- \(l\) = Moment of inertia per unit length of cross section of the pipe wall, inches to the 4th power per inch (m^4/m).

1.9.4 Corrugated Metal Pipe

(A) General

(1) Corrugated metal pipe and pipe-arches may be of riveted, welded or lock seam fabrication with annular or helical corrugations.

The specifications are:

<table>
<thead>
<tr>
<th>Material</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>AASHTO M190, M196</td>
</tr>
<tr>
<td>Steel</td>
<td>AASHTO M36, M245, M190</td>
</tr>
</tbody>
</table>

(2) Service load design safety factor, \(SF\):

- Seam strength = 3.0
- Wall area = 2.0
- Buckling = 2.0

(3) Load factor design capacity modification factor, \(\phi\). Helical pipe with lock seam or fully welded seam

\[\phi = 1.00\]

Annular pipe with spot welded, riveted or bolted seam

\[\phi = 0.67\]

(4) Flexibility factor

(a) For steel conduits, \(FF\) should generally not exceed the following values:

\(\frac{1}{4}\)" (6.4mm) and \(\frac{1}{2}\)" (12.7mm) depth corrugation \(FF = 4.3 \times 10^{-2}\)
1" (25.4mm) depth corrugation FF = 3.3 X 10^{-2}

(b) For aluminum conduits, FF should generally not exceed the following values:

\(\frac{1}{4}" (6.4\text{mm})\) and \(\frac{1}{2}"(12.7\text{mm})\) depth corrugation FF = 9.5 X 10^{-2}

\(1" (25.4\text{mm})\) depth corrugation FF = 6 X 10^{-2}

(5) Minimum Cover

The minimum cover for design loads shall be Span/8 but not less than 12 inches (.305 m). (The minimum cover shall be measured from the top of rigid pavement or the bottom of flexible pavement).

For construction requirements see Article 2.23.10.

(B) Seam Strength

(1) Minimum Longitudinal Seam Strength

<table>
<thead>
<tr>
<th>Thickness (inches) (mm)</th>
<th>Rivet Size (inches) (mm)</th>
<th>Single Rivets (Kips/ft) (kN/m)</th>
<th>Double Rivets (Kips/ft) (kN/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.064(1.63) 0.079(2.01)</td>
<td>5/16(7.9) 5/16(7.9)</td>
<td>16.7(244) 18.2(266)</td>
<td>21.6(315) 29.8(435)</td>
</tr>
<tr>
<td>0.109(2.77) 0.138(3.51)</td>
<td>3/8(9.5) 3/8(9.5)</td>
<td>23.4(342) 24.5(358)</td>
<td>46.8(685) 49.0(715)</td>
</tr>
<tr>
<td>0.168(4.27)</td>
<td>25.6(374)</td>
<td>51.3(748)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thickness (inches) (mm)</th>
<th>Rivet Size (inches) (mm)</th>
<th>Single Rivets (Kips/ft) (kN/m)</th>
<th>Double Rivets (Kips/ft) (kN/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.064(1.63) 0.079(2.01)</td>
<td>3/8(9.5) 3/8(9.5)</td>
<td>9.0(131) 9.0(131)</td>
<td>14.0(204) 18.0(263)</td>
</tr>
<tr>
<td>0.109(2.77) 0.138(3.51)</td>
<td>1/2(12.7) 1/2(12.7)</td>
<td>15.6(228) 16.2(236)</td>
<td>31.5(460) 33.0(482)</td>
</tr>
<tr>
<td>0.168(4.27)</td>
<td>16.8(245)</td>
<td>34.0(496)</td>
<td></td>
</tr>
</tbody>
</table>

For 2 X 1/2(50.8 X 12.7) and 2-2/3 X 1/2 (67.8 X 12.7mm) Corrugated Aluminum Pipe Riveted:

<table>
<thead>
<tr>
<th>Thickness (inches) (mm)</th>
<th>Rivet Size (inches) (mm)</th>
<th>Single Rivets (Kips/ft) (kN/m)</th>
<th>Double Rivets (Kips/ft) (kN/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.060(1.5) 0.075(1.9)</td>
<td>5/16(7.9) 5/16(7.9)</td>
<td>9.0(131) 9.0(131)</td>
<td>14.0(204) 18.0(263)</td>
</tr>
<tr>
<td>0.105(2.7) 0.135(3.4)</td>
<td>3/8(9.5) 3/8(9.5)</td>
<td>15.6(228) 16.2(236)</td>
<td>31.5(460) 33.0(482)</td>
</tr>
<tr>
<td>0.164(4.2)</td>
<td>16.8(245)</td>
<td>34.0(496)</td>
<td></td>
</tr>
</tbody>
</table>

For 3 X 1 (76.2 X 25.4mm) Corrugated Aluminum Pipe Riveted:

<table>
<thead>
<tr>
<th>Thickness (inches) (mm)</th>
<th>Rivet Size (inches) (mm)</th>
<th>Single Rivets (Kips/ft) (kN/m)</th>
<th>Double Rivets (Kips/ft) (kN/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.060(1.5) 0.075(1.9)</td>
<td>3/8(9.5) 3/8(9.5)</td>
<td>16.5(239) 20.5(297)</td>
<td>28.0(406) 42.0(608)</td>
</tr>
<tr>
<td>0.105(2.7) 0.135(3.4)</td>
<td>1/2(12.7) 1/2(12.7)</td>
<td>42.0(608) 54.5(790)</td>
<td>43.5(631)</td>
</tr>
</tbody>
</table>

For 6 X 1 (152.4 x 25.4mm) Corrugated Aluminum Pipe Riveted:

<table>
<thead>
<tr>
<th>Thickness (inches) (mm)</th>
<th>Rivet Size (inches) (mm)</th>
<th>Single Rivets (Kips/ft) (kN/m)</th>
<th>Double Rivets (Kips/ft) (kN/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.060(1.5) 0.075(1.9)</td>
<td>1/2(12.7) 1/2(12.7)</td>
<td>16.0(232) 19.9(288)</td>
<td>27.9(405) 35.9(520)</td>
</tr>
<tr>
<td>0.105(2.7) 0.135(3.4)</td>
<td>1/2(12.7) 1/2(12.7)</td>
<td>16.0(232) 19.9(288)</td>
<td>27.9(405) 35.9(520)</td>
</tr>
</tbody>
</table>
### (C) Section Properties

#### (1) Steel conduits

<table>
<thead>
<tr>
<th>Thickness (inches)</th>
<th>1-1/2 X 1/4 (38.2 X 6.4mm), Corrugation</th>
<th>2-2/3 X 1/2 (67.8 X 12.7mm) Corrugation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(mm)</td>
<td>( A_s ) (sq.in/ft) (mm²/m)</td>
<td>( r ) (in.) (mm)</td>
</tr>
<tr>
<td>0.028 (.71)</td>
<td>0.304 (643.5)</td>
<td>0.0816 (2.07)</td>
</tr>
<tr>
<td>0.034 (.86)</td>
<td>0.380 (804.3)</td>
<td>0.0824 (2.09)</td>
</tr>
<tr>
<td>0.040 (1.02)</td>
<td>0.456 (965.2)</td>
<td>0.0832 (2.11)</td>
</tr>
<tr>
<td>0.052 (1.32)</td>
<td>0.608 (1286.9)</td>
<td>0.0832 (2.11)</td>
</tr>
<tr>
<td>0.064 (1.63)</td>
<td>0.761 (1610.8)</td>
<td>0.0832 (2.11)</td>
</tr>
<tr>
<td>0.079 (2.01)</td>
<td>0.950 (2101.3)</td>
<td>0.0846 (2.15)</td>
</tr>
<tr>
<td>0.109 (2.77)</td>
<td>1.331 (2817.3)</td>
<td>0.0879 (2.23)</td>
</tr>
<tr>
<td>0.138 (3.51)</td>
<td>1.712 (3623.7)</td>
<td>0.0919 (2.33)</td>
</tr>
<tr>
<td>0.168 (4.27)</td>
<td>2.098 (4440.8)</td>
<td>0.0967 (2.46)</td>
</tr>
</tbody>
</table>

#### (2) Aluminum conduits

<table>
<thead>
<tr>
<th>Thickness (inches)</th>
<th>1-1/2 X 1/4 (38.2 X 6.4mm), Corrugation</th>
<th>2-2/3 X 1/2 (67.8 X 12.7mm) Corrugation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(mm)</td>
<td>( A_s ) (sq.in/ft) (mm²/m)</td>
<td>( r ) (in.) (mm)</td>
</tr>
<tr>
<td>0.048 (1.22)</td>
<td>0.608 (1286.9)</td>
<td>0.0824 (2.09)</td>
</tr>
<tr>
<td>0.060 (1.52)</td>
<td>0.761 (1610.8)</td>
<td>0.0832 (2.11)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thickness (inches)</th>
<th>3 X 1 (76.2 X 25.4mm) Corrugation</th>
<th>5 x 1 (127 X 25.4mm) Corrugation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(mm)</td>
<td>( A_s ) (sq.in/ft) (mm²/m)</td>
<td>( r ) (in.) (mm)</td>
</tr>
<tr>
<td>0.064 (1.63)</td>
<td>0.890 (1883.8)</td>
<td>0.3417 (8.68)</td>
</tr>
<tr>
<td>0.079 (2.01)</td>
<td>1.113 (2355.9)</td>
<td>0.3427 (8.70)</td>
</tr>
<tr>
<td>0.109 (2.77)</td>
<td>1.560 (3302.0)</td>
<td>0.3488 (8.86)</td>
</tr>
<tr>
<td>0.138 (3.51)</td>
<td>2.008 (4250.3)</td>
<td>0.3472 (8.82)</td>
</tr>
<tr>
<td>0.168 (4.27)</td>
<td>2.458 (5202.8)</td>
<td>0.3499 (8.95)</td>
</tr>
</tbody>
</table>
(D) Chemical and Mechanical Requirements

(1) Aluminum Corrugated Metal Pipe and Pipe-Arch Material requirements

<table>
<thead>
<tr>
<th>Minimum Tensile Strength psi (MPa)</th>
<th>Minimum Yield Point psi (MPa)</th>
<th>Mod. of Elast. psi (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>31,000 (213.737)</td>
<td>24,000 (165.474)</td>
<td>10 X 10^6 (68947)</td>
</tr>
</tbody>
</table>

(2) Steel Corrugated Metal Pipe and Pipe-Arch Material requirements

<table>
<thead>
<tr>
<th>Minimum Tensile Strength psi (MPa)</th>
<th>Minimum Yield Point psi (MPa)</th>
<th>Mod. of Elast. psi (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45,000 (310.264)</td>
<td>33,000 (227.527)</td>
<td>29 X 10^6 (199948)</td>
</tr>
</tbody>
</table>

(E) Smooth Lined Pipe

Corrugated metal pipe composed of a smooth liner and corrugated shell attached integrally at helical seams spaced not more than 30 inches (.762 m) apart may be designed in accordance with Article 1.9.1 on the same basis as a standard corrugated metal pipe having the same corrugations as the shell and a weight per foot (m) equal to the sum of the weights per foot (m) of liner and helically corrugated shell. The shell shall be limited to corrugations having a maximum pitch of 3 inches (76.2mm) and a thickness of not less than 60 percent of the total thickness of the equivalent standard pipe.
1.9.5 Structural Plate Pipe Structures

(A) General

(1) Structural plate pipe, pipe arches, and arches shall be bolted with annular corrugations only.

The specifications are:

<table>
<thead>
<tr>
<th>Material</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>AASHTO M219</td>
</tr>
<tr>
<td>Steel</td>
<td>AASHTO M167</td>
</tr>
</tbody>
</table>

(2) Service load design

- **Seam strength = 3.0**
- **Wall area = 2.0**
- **Buckling = 2.0**

(3) Load factor design

- **Capacity modification factor, \( \phi \)**
  \[ \phi = 0.67 \]

(4) Flexibility factor

(a) For steel conduits, FF should generally not exceed the following values:

- **6" X 2" (152.4 X 50.8mm) corrugation FF = 2.0 X 10^-2 (Pipe)**
- **6" X 2" (152.4 X 50.8mm) corrugation FF = 3.0 X 10^-2 (Pipe-arch)**
- **6" X 2" (152.4 X 50.8mm) corrugation FF = 3.0 X 10^-2 (Arch)**

(b) For aluminum conduits, FF should generally not exceed the following values:

- **9" X 2½" (228.6 X 63.5mm) corrugation FF = 2.5 X 10^-2 (Pipe)**
- **9" X 2½" (228.6 X 63.5mm) corrugation FF = 3.6 X 10^-2 (Pipe-arch)**
- **9" X 2½" (228.6 X 63.5mm) corrugation FF = 7.2 X 10^-2 (Arch)**

(5) Minimum cover

The minimum cover for design loads shall be Span/8 but not less than 12 inches (.305m). (The minimum cover shall be measured from the top of rigid pavement or the bottom of flexible pavement.) For Construction requirements see Article 2.23.10.

(B) Seam Strength

<p>| Minimum Longitudinal Seam Strengths 6 X 2 (152.4 X 50.8mm) Steel Structure Plate Pipe |
|-----------------------------------------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Thickness (inches) (mm)</th>
<th>Bolt Size (inch) (mm)</th>
<th>4 Bolts/ft(.305) (Kips/ft) (kN/m)</th>
<th>6 Bolts/ft(.305) (Kips/ft) (kN/m)</th>
<th>8 Bolts/ft(.305) (Kips/ft) (kN/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.109(2.77)</td>
<td>3/4(19.1)</td>
<td>43.0(627.8)</td>
<td>62.0(905.2)</td>
<td>93.0(1357.8)</td>
</tr>
<tr>
<td>0.138(3.51)</td>
<td>3/4(19.1)</td>
<td>43.0(627.8)</td>
<td>62.0(905.2)</td>
<td>93.0(1357.8)</td>
</tr>
<tr>
<td>0.168(4.27)</td>
<td>3/4(19.1)</td>
<td>43.0(627.8)</td>
<td>62.0(905.2)</td>
<td>93.0(1357.8)</td>
</tr>
<tr>
<td>0.188(4.78)</td>
<td>3/4(19.1)</td>
<td>43.0(627.8)</td>
<td>62.0(905.2)</td>
<td>93.0(1357.8)</td>
</tr>
<tr>
<td>0.218(5.54)</td>
<td>3/4(19.1)</td>
<td>112.0(1635.2)</td>
<td>132.0(1927.2)</td>
<td>180(2628.0)</td>
</tr>
<tr>
<td>0.249(6.32)</td>
<td>3/4(19.1)</td>
<td>112.0(1635.2)</td>
<td>132.0(1927.2)</td>
<td>180(2628.0)</td>
</tr>
<tr>
<td>0.280(7.11)</td>
<td>3/4(19.1)</td>
<td>144.0(2102.4)</td>
<td>180(2628.0)</td>
<td>194(2832.4)</td>
</tr>
</tbody>
</table>
### 9 X 2-½ (2228.6 X 63.5mm) Aluminum Structural Plate Pipe

<table>
<thead>
<tr>
<th>Thickness (inches) (mm)</th>
<th>Bolt Size (inch) (mm)</th>
<th>Steel Bolts 5-½ Bolts Per ft(.305) (Kips/ft) (kN/m)</th>
<th>Aluminum Bolts 5-½ Bolts Per ft(.305) (Kips/ft) (kN/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10(2.54)</td>
<td>3/4(19.1)</td>
<td>28.0(408.8)</td>
<td>26.4(385.4)</td>
</tr>
<tr>
<td>0.125(3.18)</td>
<td>3/4(19.1)</td>
<td>41.0(598.6)</td>
<td>34.8(508.1)</td>
</tr>
<tr>
<td>0.15(3.81)</td>
<td>3/4(19.1)</td>
<td>54.1(789.9)</td>
<td>44.4(648.2)</td>
</tr>
<tr>
<td>0.175(4.45)</td>
<td>3/4(19.1)</td>
<td>63.7(930.0)</td>
<td>52.8(770.9)</td>
</tr>
<tr>
<td>0.200(5.08)</td>
<td>3/4(19.1)</td>
<td>73.4(1071.6)</td>
<td>52.8(770.9)</td>
</tr>
<tr>
<td>0.225(5.72)</td>
<td>3/4(19.1)</td>
<td>83.2(1214.7)</td>
<td>52.8(770.9)</td>
</tr>
<tr>
<td>0.250(6.35)</td>
<td>3/4(19.1)</td>
<td>93.1(1359.3)</td>
<td>52.8(770.9)</td>
</tr>
</tbody>
</table>

### (C) Section Properties

(1) Steel conduits

### 6" X 2" (152.4 X 50.8mm) Corrugations

<table>
<thead>
<tr>
<th>Thickness (inches) (mm)</th>
<th>(A_s) (sp.in/ft mm²/m)</th>
<th>r (in.) (mm)</th>
<th>1 X 10⁻³ (in.⁴/in) (mm⁴/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.109(2.77)</td>
<td>1.556(3293.5)</td>
<td>0.682(17.32)</td>
<td>60.411(989713)</td>
</tr>
<tr>
<td>0.138(3.51)</td>
<td>2.003(4139.7)</td>
<td>0.684(17.37)</td>
<td>78.175(1280741)</td>
</tr>
<tr>
<td>0.168(4.17)</td>
<td>2.449(5183.7)</td>
<td>0.686(17.42)</td>
<td>96.163(1575438)</td>
</tr>
<tr>
<td>0.188(4.78)</td>
<td>2.739(5797.6)</td>
<td>0.688(17.48)</td>
<td>108.000(1769364)</td>
</tr>
<tr>
<td>0.21(5.54)</td>
<td>3.199(6771.2)</td>
<td>0.690(17.53)</td>
<td>126.922(2079363)</td>
</tr>
<tr>
<td>0.249(6.32)</td>
<td>3.650(7725.8)</td>
<td>0.692(17.58)</td>
<td>146.172(2394735)</td>
</tr>
<tr>
<td>0.280(7.11)</td>
<td>4.119(8718.6)</td>
<td>0.695(17.65)</td>
<td>165.836(2716891)</td>
</tr>
</tbody>
</table>

### 9" X 2-½" (228.6 X 63.5mm) Corrugations

<table>
<thead>
<tr>
<th>Thickness (inches) (mm)</th>
<th>(A_s) (sp.in/ft mm²/m)</th>
<th>r (in.) (mm)</th>
<th>1 X 10⁻³ (in.⁴/in) (mm⁴/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.100(2.54)</td>
<td>1.404(2971.8)</td>
<td>0.8438(21.49)</td>
<td>83.065(136054)</td>
</tr>
<tr>
<td>0.125(3.18)</td>
<td>1.750(3704.2)</td>
<td>0.8444(21.45)</td>
<td>103.991(1703685)</td>
</tr>
<tr>
<td>0.150(3.81)</td>
<td>2.100(4445.0)</td>
<td>0.8449(21.46)</td>
<td>124.883(2045958)</td>
</tr>
<tr>
<td>0.175(4.45)</td>
<td>2.449(5183.72)</td>
<td>0.8454(21.47)</td>
<td>145.895(2390198)</td>
</tr>
<tr>
<td>0.200(5.08)</td>
<td>2.799(5924.6)</td>
<td>0.8460(21.49)</td>
<td>166.959(2735289)</td>
</tr>
<tr>
<td>0.225(5.72)</td>
<td>3.149(6665.4)</td>
<td>0.8468(21.51)</td>
<td>188.179(3082937)</td>
</tr>
<tr>
<td>0.250(6.35)</td>
<td>3.501(7410.5)</td>
<td>0.8473(21.52)</td>
<td>209.434(3431157)</td>
</tr>
</tbody>
</table>

### (D) Chemical and Mechanical Properties

(1) Aluminum—Structural plate pipe, pipe-arch, and arch

Material requirement—AASHTO M 167

### Mechanical Properties for Design

<table>
<thead>
<tr>
<th>Thickness (inches) (mm)</th>
<th>Minimum Tensile Strength psi(MPa)</th>
<th>Minimum Yield point psi(MPa)</th>
<th>Mod. of Elast. psi(MPa)</th>
</tr>
</thead>
</table>
(2) Steel—Structural plate pipe, Pipe-arch, and arch

Material requirements—AASHTO M 167

<table>
<thead>
<tr>
<th>Material</th>
<th>Minimum Tensile Strength psi (MPa)</th>
<th>Minimum Yield point psi (MPa)</th>
<th>Mod. of Elast. psi (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>45,000 (310.264)</td>
<td>33,000 (227.527)</td>
<td>29 X 10^6 (199948)</td>
</tr>
</tbody>
</table>

(E) Structural Plate Arches

The design of structural plate arches should be based on retios of a rise to span of 0.3 minimum.

1.9.6 Long Span Structural Plate Structures

(A) General

Long Span structural plate structures are short span bridges defined as:

(1) Structural Plate Structures (pipe, pipe-arch, and arch) which exceed maximum sizes imposed by 1.9.5.

(2) Special shapes of any size which involve a relatively large radius of curvature in crown or side plates. Vertical ellipses, horizontal ellipses, underpasses, low profile arches, high profile arches, and inverted pear shapes are the terms describing these special shapes.

Wall Strength and Chemical and Mechanical Properties shall be in accordance with Article 1.9.5. The construction and installation shall conform to Section 23, Division II.

(B) Design

Long span structures shall be designed in accordance with Art. 1.9.1, 1.9.2 or 1.9.3 and 1.9.5. Requirements for buckling and flexibility factor do not apply. Substitute twice the top arc radius for the span in the formulae for thrust. Long span structures shall include acceptable special features. Minimum requirements are detailed in Table 1.

(2) Acceptable special features

(a) Continuous longitudinal structural stiffeners connected to the corrugated plates at each side of the top arc. Stiffeners may be metal or reinforced concrete or combination thereof.

(b) Reinforcing ribs formed from structural shapes curved to conform to the curvature of the plates, fastened to the structure as required to insure integral action with the corrugated plates, and spaced at such intervals as necessary to increase the moment of inertia of the section to that required by the design.

(3) Design for deflection
Soil design and placement requirements for long span structures limit deflection satisfactorily. However, construction procedures must be such that severe deformations do not occur during construction.

(4) Soil design

Granular type soils shall be used as structure backfill (the envelope next to the metal structure). The order of preference of acceptable structure backfill materials is as follows:

(a) Well graded sand and gravel; sharp, rough or angular if possible.
(b) Uniform sand or gravel.
(c) Approved stabilized soil shall be used only under direct supervision of a competent, experienced soils engineer. Plastic soils shall not be used.

The structure backfill material shall conform to one of the following soil classifications from AASHTO Specification M 145, Table 2: For height of fill less than 12 feet (3.658m), A-1, A-3, A-2-4 and A-2-5; for height of fill of 12 feet (3.658m) and more, A-1, A-3. Structure backfill shall be placed and compacted to not less than 90 percent density per AASHTO T 180.

The extent of the select structural backfill about the barrel is dependent on the quality of the adjacent embankment. For ordinary installations, with good quality, well compacted embankment or in situ soil adjacent to the structure backfill, a width of structural backfill six feet (1.829m) beyond the structure is sufficient. The structure backfill shall also extend to an elevation two (.610m) to four feet (1.219m) over the structure.

It is not necessary to excavate native soil at the sides if the quality of the native soil is already as good as the proposed compacted side-fill. The soil over the top shall also be select and shall be carefully and densely compacted.

(C) Structural Plate Shapes
(D) End Treatment

When headwalls are not used, special attention may be necessary at the ends of the structure. Severe bevels and skew are not recommended. For hydraulic structures, additional reinforcement of the end is recommended to secure the metal edges at inlet and outlet against hydraulic forces. Reinforced concrete or structural steel collars, or tension tiebacks or anchors in soil, partial headwalls and cut off walls below invert elevation are some of the methods which can be used. Square ends may have side plates beveled up to a maximum 2:1 slope. Skew ends up to 15° with no bevel, are permissible. When this is done on spans over 20 feet (6.096m) the cut edge must be reinforced with reinforced concrete or structural steel collar. When full head walls are used and they are skewed, the offset portion of the metal structure shall be supported by the headwall. A special headwall shall be designed for skews exceeding 15°. The maximum skew shall be limited to 35°.

(E) Multiple Structures

Care must be exercised on the design of multiple, closely spaced structures to control unbalanced loading. Fills should be kept level over the series of structures when possible. Significant roadway grades across the series of structures require checking stability of the flexible structures under the resultant unbalanced loading.
Table A-1. Minimum Requirements for Long Span Structures with Acceptable Special Features

<table>
<thead>
<tr>
<th>I. Top Arc</th>
<th>Top Radius in ft (m)</th>
<th>Top Radius in ft (m)</th>
<th>Top Radius in ft (m)</th>
<th>Top Radius in ft (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Thickness (mm)</td>
<td>23-25 (7.010-7.620)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 X 2 Corrugated Steel Plates (152.4 X 50.8)</td>
<td>.109&quot; (2.77)</td>
<td>.138&quot; (3.51)</td>
<td>.168&quot; (4.27)</td>
<td>.218&quot; (5.54)</td>
</tr>
<tr>
<td></td>
<td>(2.77)</td>
<td>(3.51)</td>
<td>(4.27)</td>
<td>(5.54)</td>
</tr>
<tr>
<td></td>
<td>.294&quot; (6.32)</td>
<td>.294&quot; (6.32)</td>
<td>.294&quot; (6.32)</td>
<td>.294&quot; (6.32)</td>
</tr>
</tbody>
</table>

II Minimum Cover in ft. (m)

<table>
<thead>
<tr>
<th>Steel Thickness in in.(mm)</th>
<th>Top Radius in ft (m)</th>
<th>Top Radius in ft (m)</th>
<th>Top Radius in ft (m)</th>
<th>Top Radius in ft (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>.019 (2.77)</td>
<td>2.5 (.762)</td>
<td>2.5 (.762)</td>
<td>2.5 (.762)</td>
<td>2.5 (.762)</td>
</tr>
<tr>
<td>.138 (3.51)</td>
<td>2.5 (.762)</td>
<td>2.5 (.762)</td>
<td>2.5 (.762)</td>
<td>2.5 (.762)</td>
</tr>
<tr>
<td>.168 (4.27)</td>
<td>2.5 (.762)</td>
<td>2.5 (.762)</td>
<td>2.5 (.762)</td>
<td>2.5 (.762)</td>
</tr>
<tr>
<td>.188 (4.78)</td>
<td>2.5 (.762)</td>
<td>2.5 (.762)</td>
<td>2.5 (.762)</td>
<td>2.5 (.762)</td>
</tr>
<tr>
<td>.218 (5.54)</td>
<td>2.0 (.762)</td>
<td>2.0 (.762)</td>
<td>2.0 (.762)</td>
<td>2.0 (.762)</td>
</tr>
<tr>
<td>.294 (6.32)</td>
<td>2.0 (.762)</td>
<td>2.0 (.762)</td>
<td>2.0 (.762)</td>
<td>2.0 (.762)</td>
</tr>
<tr>
<td>.280 (7.11)</td>
<td>2.0 (.762)</td>
<td>2.0 (.762)</td>
<td>2.0 (.762)</td>
<td>2.0 (.762)</td>
</tr>
</tbody>
</table>

III. Geometric Limits

A. Maximum Plate Radius-25 Ft. (7.620m)
B. Maximum Central Angle of Top Arc = 80°
C. Minimum Ration, Top Arc Radius to Side Arc Radius = 2
D. Maximum Ratio, Top Arc Radius to Side Arc Radius = 5*

*Note: Sharp radii generate high soil bearing pressures. Avoid high ratios when significant heights of fill are involved.

IV. Special Designs

- Structures not described herein shall be regarded as special designs.
- When reinforcing ribs are used the moment of inertia of the composite section shall be equal to or greater than the moment of inertia of the minimum plate thickness shown.

Section 23 - Construction and Installation of Soil Metal Plate Structure Interaction System

2.23.1 General

This item shall consist of furnishing corrugated metal or structural plate pipe, pipe-arches and arches conforming to these specifications and of the sizes and dimensions required on the plans, and installing such structures at the places designated on the plans or by the Engineer, and in conformity with the lines and grades established by the Engineer. Pipe shall be either circular or elongated as specified or shown on the plans.
The thickness of plates or sheets shall be as determined in Art. 1.9.2, Division I, and the radius of curvature shall be as shown on the plans. Each plate or sheet shall be curved to one or more circular arcs.

The plates at longitudinal and circumferential seams of structural plates shall be connected by bolts. Joints shall be staggered so that not more than three plates come together at any one point.

### 2.23.2 Forming and Punching of Corrugated Structural Plates and Sheets for Pipe

**A) Structural Plate Pipe**

Structural plates of steel shall conform to the requirements of AASHTO M 167 and aluminum to the requirements of AASHTO M 219.

Plates shall be formed to provide lap joints. The bolt holes shall be so punched that all plates having like dimensions, curvature, and the same number of bolts per foot (m) of seam shall be interchangeable. Each plate shall be curved to the proper radius so that the cross-sectional dimensions of the finished structure will be as indicated on the drawings or as specified.

Unless otherwise specified, bolt holes along those edges of the plates that form longitudinal seams in the finished structure shall be in two rows. Bolt holes along those edges of the plates that form circumferential seams in the finished structure shall provide for a bolt spacing of not more than 12 in. (0.305m). The minimum distance from center of hole to edge of the plate shall be not less than 1-3/4 times the diameter of the bolt. The diameter of the bolt holes in the longitudinal seams shall not exceed the diameter of the bolt by more than 1/8 inch (3.2mm).

Plates for forming skewed or sloped ends shall be cut so as to give the angle of skew or slope specified. Burned edges shall be free from oxide and burn and shall present a workmanlike finish. Legible identification numerals shall be placed on each plate to designate its proper position in the finished structure.

**B) Corrugated Metal Pipe**

Corrugated steel pipe shall conform to the requirements of AASHTO M 36 and aluminum to the requirements of AASHTO M 196.

Punching and forming of sheets shall conform to AASHTO M 36.

**C) Elongation**

If elongated structural plate or corrugated metal pipe is specified or called for on the plans, the plates or pipes shall be formed so that the finished pipe is elliptical in shape with the vertical diameter approximately five percent greater than the nominal diameter of the pipe. Pipe-arches shall not be elongated. Elongated pipes shall be installed with the longer axis vertical.

### 2.23.3 Assembly

**A) General**

Corrugated metal pipe, and structural plate pipe shall be assembled in accordance with the manufacturer's instructions. All pipe shall be unloaded and handled with reasonable care. Pipe or plates shall not be rolled or dragged over gravel or rock and shall be prevented from striking rock or other
Corrugated metal pipe shall be placed on the bed starting at downstream end with the inside circumferential laps pointing downstream.

Bituminous coated pipe and paved invert pipe shall be installed in a similar manner to corrugated metal pipe with special care in handling to avoid damage to coatings. Paved invert pipe shall be installed with the invert pavement placed and centered on the bottom.

Structural plate pipe, pipe arches, and arches shall be installed in accordance with the plans and detailed erection instructions. Bolted longitudinal seams shall be well fitted with the lapping plates parallel to each other. The applied bolt torque for 3/4" (19.1 mm) diameter high strength steel bolts shall be a minimum of 100 ft.-lbs. (135.58Nm) and a maximum of 300 ft. lbs. (406.74Nm); for 3/4" (19.1mm) diameter aluminum bolts, the applied bolt torque shall be a minimum of 100 ft.-lbs. (135.58Nm) and a maximum of 150 ft. lbs. (203.37Nm). There is no structural requirement for residual torque; the important factor is the seam fit-up.

Joints for corrugated metal culvert and drainage pipe shall meet the following performance requirements:

(1) Field Joints

Transverse field joints shall be of such design that the successive connection of pipe sections will form a continuous line free from appreciable irregularities in the flow line. In addition, the joints shall meet the general performance requirements described in items (1) through (3). Suitable transverse field joints, which satisfy the requirements for one or more of the subsequently defined joint performance categories, can be obtained with the following types of connecting bands furnished with the suitable band-end fastening devices.

(a) Corrugated bands
(b) Bands with projections
(c) Flat bands
(d) Bands of special design that engage factory reformed ends of corrugated pipe.

Other equally effective types of field joints may be used with the approval of the Engineer.

(2) Joint Types

Applications may require either "Standard" or "Special" joints. Standard joints are for pipe not subject to large soil movements or disjointing forces, these joints are satisfactory for ordinary installations, where simple slip type joints are typically used. Special joints are for more adverse requirements such as the need to withstand soil movements or resist disjointing forces. Special designs must be considered for unusual conditions as in poor foundation conditions. Down drain joints are required to resist longitudinal hydraulic forces. Examples of this are steep slopes and sharp curves.

(3) Soil Conditions

The requirements of the joints are dependent upon the soil conditions at the construction site. Pipe backfill which is not subject to piping action is classified as "Nonerodible." Such backfill typically includes granular soil (with grain sizes equivalent to coarse sand, small gravel, or larger) and cohesive clays.
Backfill that is subject to piping action, and would tend either to infiltrate the pipe or to be easily washed by exfiltration of water from the pipe, is classified as "Erodible." Such backfill typically includes fine sands, and silts.

Special joints are required when poor soil conditions are encountered such as when the backfill or foundation material is characterized by large soft spots or voids. If construction in such soil is unavoidable, this condition can only be tolerated for relatively low fill heights, since the pipe must span the soft spots and support imposed loads. Backfills of organic silt, which are typically semifluid during installation, are included in this classification.

(4) Joint Properties

The requirements for joint properties are divided into the six categories shown on Table 2.23.3. Properties are defined and requirements are given in the following Paragraphs (a) through (l). The values for various types of pipe can be determined by a rational analysis or a suitable test.

(a) Shear Strength
The shear strength required of the joint is expressed as a percent of the calculated shear strength of the pipe on a transverse cross section remote from the joint.

(b) Moment Strength
The moment strength required of the joint is expressed as a percent of the calculated moment capacity of the pipe on a transverse cross section remote from the joint. In lieu of the required moment strength, the pipe joint may be furnished with an allowable slip as defined in Paragraph (4)(c).

(c) Allowable Slip
The allowable slip is the maximum slip that a pipe can withstand without disjointing, divided by a factor of safety.

(d) Soiltightness
Soiltightness refers to openings in the joint through which soil may infiltrate. Soiltightness is influenced by the size of the opening (maximum dimension normal to the direction that the soil may infiltrate) and the length of the channel (length of the path along which the soil may infiltrate). No opening may exceed 1 inch (.025m). In addition, for all categories, if the size of the opening exceeds 1/8 inch (.003m), the length of the channel must be at least four times the size of the opening. Furthermore, for non-erodible, erodible, or poor soils, the ratio of D85 soil size to size of opening must be greater than 0.3 for medium to fine sand or 0.2 for uniform sand; these ratios need not be met for cohesive backfills where the plasticity index exceeds 12. As a general guideline, a backfill material containing a high percentage of fine grained soils requires investigation for the specific type of joint to be used to guard against soil infiltration.

(e) Watertightness
Watertightness may be specified for joints of any category where needed to satisfy other criteria. The leakage rate shall be measured with the pipe in place or at an approved test facility.

(B) Assembly of Long-Span Structures

Long-span structures covered in Article 1.9.10 may require deviation from the normal good practice of loose bolt assembly. Unless held in shape by cables, struts, or backfill, longitudinal seams should be tightened when the plates are hung. Care should be taken to properly align plates circumferentially and
to avoid permanent distortion from specified shape. This may require temporary shoring. The variation before backfill shall not exceed 2 percent of the span or rise, whichever is greater, but in no case shall exceed 5 inches (.127m). The rise of arches with a ratio of top to side radii of three or more should not deviate from the specified dimensions by more than 1 percent of the span.

### 2.23.4 Bedding

When, in the opinion of the Engineer, the natural soil does not provide a suitable bedding, a bedding blanket conforming to Figure 2.23A shall be provided. Bedding shall be uniform for the full length of the pipe.

Bedding of long-span structures with invert plates exceeding 12 ft. (3.658m) in radius requires a preshaped excavation or bedding blanket for a minimum width of 10 ft. (3.048m) or half the top radius of the structure, whichever is less. This preshaping may be a simple "v" shape fine graded in the soil in accordance with Figure 2.23E.

<table>
<thead>
<tr>
<th>Soil Condition</th>
<th>Non-Erodible</th>
<th>Erodible</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard</td>
<td>Positive</td>
<td></td>
</tr>
<tr>
<td>Shear Moment(^1)</td>
<td>2%</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>0-42&quot; Dia (0-1.066 m)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>48&quot;-84&quot; Dia (1.219-2.134 m)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Tensile</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-42&quot; Dia (0-1.066 m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>48&quot;-84&quot; Dia (1.219-2.134 m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slip</td>
<td>NA</td>
<td>0.3 or 0.2</td>
<td>0.3 or 0.2</td>
</tr>
<tr>
<td>Soil tightness(^2)</td>
<td>See Paragraph (A)(4)(e)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Watertightness</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1\(^{\text{See Paragraph (4)(b)}}\)
2\(^{\text{Minimum ratio of D}_{85}\text{ soil size of opening 0.3 for medium to fine sand and 0.2 for uniform sand. Structural plate pipe, pipe-arches, and arches shall be installed in accordance with the plans and detailed erection instructions.}}\)

### 2.23.5 Pipe Foundation

The foundation material under the pipe shall be investigated for its ability to support the load. If rock strata or boulders are closer than 12 inches (.305m) under the pipe, the rock or boulders shall be removed and replaced with suitable granular material as shown in Figure 2.23B. Where, in the opinion of the Engineer, the natural foundation soil is such as to require stabilization, such material shall be replaced by a layer of suitable granular material as shown in Figure 2.23C. Where an unsuitable material (peat, muck, etc.) is encountered at or below invert elevation during excavation, the necessary subsurface exploration and analysis shall be made and corrective treatment shall be as directed by the Engineer.

For shapes such as pipe arches, horizontal ellipses or underpasses, where relatively large radius inverts are joined by relatively small radius corners or sides, the corrective treatment shall provide for principal support of the structure at the adjoining corner or side plates and insure proper settlement of those high pressure zones relative to the low pressure zone under the invert, as shown in Figure 2.23F. This allows the invert to settle uniformly.
2.23.6 Fill Requirements

(A) Sidefill

Sidefill material within one pipe diameter of the sides of pipe and not less than one foot (.305m) over the pipe shall be fine readily compactible soil or granular fill material. Sidefill beyond these limits may be regular embankment fill. Job-excavated soil used as backfill shall not contain stones retained on a 3-inch (76.2mm) ring, frozen lumps, chunks of highly plastic clay, or other objectionable material. Sidefill material shall be noncorrosive.

Sidefill material shall be placed as shown in Figure 2.23D, in layers not exceeding 6 inches (.152m) in compacted thickness at near optimum moisture content by engineer-approved equipment to the density required for superimposed embankment fill. Other approved compacting equipment may be used for sidefill more than 3 feet (.914m) from sides of pipe. The sidefill shall be placed and compacted with care under the haunches of the pipe and shall be brought up evenly and simultaneously on both sides of the pipe to not less than 1 foot (.305m) above the top for the full length of the pipe. Fill above this elevation may be material for embankment fill. The width of trench shall be kept to the minimum width required for placing pipe, placing adequate bedding and sidefill, and safe working conditions. Ponding or jetting of sidefill will not be permitted except upon written permission by the Engineer.

(B) Backfill For Long-Span Structures

While basic backfill requirements for long-span structural-plate structures are similar to those for smaller structures, their size is such that excellent control of soil placement and compaction must be maintained. Because these structures are especially designed to fully mobilize soil-structure interaction, a large portion of their full strength is not realized until backfill (sidefill and overfill) is in place. Of particular importance is control of structure shape. Equipment and construction procedures used shall be such that excessive structure distortion will not occur. Structure shape shall be checked regularly during backfilling to verify acceptability of the construction methods used. Magnitude of allowable shape changes will be specified by the manufacturer (fabricator of long-span structures). The manufacturer shall provide a qualified construction inspector to aid the Engineer during all structure backfilling. The Inspector shall advise the Engineer on the acceptability of all backfill material and methods and the proper monitoring of the shape. Structure backfill material shall be placed in horizontal uniform layers not exceeding 8 inches (.203m) in thickness after compaction and shall be brought up uniformly on both sides of the structure. Each layer shall be compacted to a density not less than 90 percent per AASHTO T 180. The structure backfill shall be constructed to the minimum lines and grades shown on the plans, keeping it at or below the level of adjacent soil. Permissible exceptions to required structure backfill density are: the area under the invert, the 12 inch to 18 inch (.305 to .457 m) width of soil immediately adjacent to the large radius side plates of high profile arches and inverted pear shapes, and the lower portion of the first horizontal lift of overfill carried ahead of and under heavy construction earth movers initially crossing the structure.

2.23.7 Bracing

Temporary bracing shall be installed and shall remain in place as required to protect workmen during construction.

For long-span structures which require temporary bracing to handle backfilling loads, the bracing shall not be removed until the fill is completed or to a height over the crown equal to 1/4 the span.
2.23.8 Camber

The invert grade of the pipe shall be cambered, when required, by an amount sufficient to prevent the development of a sag or back slope in the flow line as the foundation under the pipe settles under the weight of embankment. The amount of camber shall be based on consideration of the flow-line gradient, height of fill, compressive characteristics of the supporting soil, and depth of supporting soil stratum to rock.

When specified on the plans, long-span structures shall be vertically elongated approximately 2 percent during installation to provide for compression of the backfill under higher fills.

2.23.9 Arch Substructures and Headwalls

Substructures and headwalls shall be designed in accordance with the requirements of Division I.

Each side of each arch shall rest in a groove formed into the masonry or shall rest on a galvanized angle or channel securely anchored to or embedded in the substructure. Where the span of the arch is greater than 15 feet (4.572m) or the skew angle is more than 20 degrees, a metal bearing surface, having a width of at least equal to the depth of the corrugation, shall be provided for all arches.

Metal bearings may be either rolled structural or cold formed galvanized angles or channels, not less than 3/16 inch (4.8mm) in thickness with the horizontal leg securely anchored to the substructure on a maximum of 24 inch (.610m) centers. When the metal bearing is not embedded in a groove in the substructure, one vertical leg should be punched to allow bolting to the bottom row of plates.

Where an invert slab is provided which is not integral with the arch footing, the invert slab shall be continuously reinforced.

When backfilling arches before headwalls are placed, the first material shall be placed midway between the ends of the arch, forming as narrow a ramp as possible until the top of the arch is reached. The ramp shall be built evenly from both sides and the backfilling material shall be thoroughly compacted as it is placed. After the two ramps have been built to depth specified to the top of the arch, the remainder of the backfill shall be deposited from the top of the arch both ways from the center to the ends, and as evenly as possible on both sides of the arch.

If the headwalls are built before the arch is backfilled, the filling material shall first be placed adjacent to one headwall, until the top of the arch is reached, after which the fill shall be dumped from the top of the arch toward the other headwall, with care being taken to deposit the material evenly on both sides of the arch.

In multiple installations the procedure above specified shall be followed, but extreme care shall be used to bring the backfill up evenly on each side of each arch so that unequal pressure will be avoided.

In all cases the filling material shall be thoroughly but not excessively tamped. Puddling the backfill will not be permitted.
Figure 223 Pipe Bedding, Foundation & Sidefill

(A.) BEDDING

Nominal Pipe D

Existing ground

Bedding blanket of suitable granular material

1' (254 mm) min for 1/2" (12.7 mm)
depth corrugations
2' (508 mm) min for 1" (254 mm)
depth corrugations
3' (762 mm) for 2" or 2 1/2" (508 or 635 mm) depth corrugations

(B.) ROCK FOUNDATION

Normal Pipe D

Suitable granular material uniformly compacted

6' (152 mm)
6' (152 mm)

2' (610 mm)

3D

Max of D+4' (D in m +1.219 m)

Suitable granular material uniformly compacted.

(C.) YIELDING FOUNDATION

D

2D minimum D

12' (3.658 m)

maximum

Side fill

Existing ground

6' (152 mm) compacted layers to density specified for adjacent embankment.

(D.) SIDEFILL
2.23.10 Cover over Pipe during Construction

All pipe shall be protected by sufficient cover before permitting heavy construction equipment to pass over them during construction.

2.23.11 Workmanship and Inspection

In addition to compliance with the details of construction, the completed structure shall show careful finished workmanship in all particulars. Structures on which the speller coating has been bruised or broken either in the shop or in shipping, or which shows defective workmanship, shall be rejected.
unless repaired to the satisfaction of the Engineer. The following defects are specified as constituting poor workmanship and the presence of any or all of them in any individual culvert plate or in general in any shipment shall constitute sufficient cause for rejection unless repaired:

1. Uneven laps.
2. Elliptical shaping (unless specified).
3. Variation from specified alignment.
4. Ragged edges.
5. Loose, unevenly lined or spaced bolts.
6. Illegible brand.
7. Bruised, scaled, or broken speller coating.
8. Dents or bends in the metal itself.

---

### 2.23.12 Method of Measurement

Corrugated metal and structural plate pipe, pipe-arches or arches shall be measured in linear feet (m) installed in place, completed, and accepted. The number of linear feet (m) shall be the average of the top and bottom centerline lengths for pipe, the bottom centerline length for pipe-arches, and the average of springing line lengths for arches.

---

### 2.23.13 Basis of Payment

The lengths, determined as herein given shall be paid for at the contract unit prices per linear foot (m) bid for corrugated metal and structural plate pipe, pipe-arch or arches of the several sizes, as the case may be, which prices and payments shall constitute full compensation for furnishing, handling, erecting, and installing the pipe, pipe-arches or arches and for all materials, labor, equipment, tools, and incidentals necessary to complete this item, but for arches shall not constitute payment for concrete or masonry headwalls and foundations, or for excavation.

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Go to Appendix B
Appendix B: FHWA-IP-83-6
Users Manual - Improved Inlet Box Section Program, Boxcar

This Appendix provides the information needed to use the computer program BOXCAR (BOX section Concrete And Reinforcing design) to design reinforcing for one cell box section inlets. The program is sufficiently general that it may also be used to design box sections for general applications, except that surface applied wheel loads are not included. For a general description of the program and method of analysis, see Section 5.1. For information on the loads and design methods see Chapter 2, Chapter 3, and Chapter 4.

B.1 Input Data

FIRST CARD: Format (19A4, A3, 11)

Problem Identification Card Columns 1 through 79 are read and echo printed in the output. These columns can be used for job identification. An integer from 0 to 3 in card column 80 controls the amount of output to be printed. For a description of the available output, see Section B.2.

REMAINING CARDS: Format (12, 4A4, A2, 6F10.3)

Data The first field (12) is an input code that internally identifies the type of data being input. The second field (4A4, A2) is a comment field which is used to identify the data on each card and is echo printed in the output. The remaining fields (6F10.3) are data items. Table B-1 describes the specific input data and format required for each card and default values for each parameter. If default values are used for all the parameters on any given card, then that card may be omitted.

<table>
<thead>
<tr>
<th>Card Columns</th>
<th>Coce (Note 1)</th>
<th>Description (Note 2)</th>
<th>Nome of Variables</th>
<th>Units</th>
<th>Default Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Format</td>
<td>12</td>
<td>4A4, A2</td>
<td>6F10.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Required Data</td>
<td>01</td>
<td>Inside Span</td>
<td>Inside Rise</td>
<td>Depth of Fill</td>
<td>( S_i )</td>
</tr>
<tr>
<td>---------------</td>
<td>----</td>
<td>-------------</td>
<td>-------------</td>
<td>--------------</td>
<td>----------</td>
</tr>
<tr>
<td>02</td>
<td>Top Slab Thickness</td>
<td>Bottom Slab Thickness</td>
<td>Side Wall Thickness</td>
<td>( T_T )</td>
<td>( T_B )</td>
</tr>
<tr>
<td>03</td>
<td>Horizontal Haunch Dim.</td>
<td>Vertical Haunch Dim.</td>
<td>( H_H )</td>
<td>( H_V )</td>
<td>in.</td>
</tr>
<tr>
<td>04</td>
<td>Soil unit weight</td>
<td>Concrete unit weight</td>
<td>Fluid unit weight</td>
<td>( \gamma_s )</td>
<td>( \gamma_c )</td>
</tr>
<tr>
<td>05</td>
<td>Lateral Soil Pressure (Min.)</td>
<td>Lateral Soil Pressure (Max.)</td>
<td>Soil Structure Int. Factor</td>
<td>Flag for Side Load</td>
<td>( \alpha_{\text{min}} ) (Note3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( \alpha_{\text{max}} ) None</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( F_e ) None</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( F_{\text{Flg}} ) None</td>
</tr>
<tr>
<td>06</td>
<td>Load Factor</td>
<td>Flexure Cap. Red. Factor</td>
<td>Shear Capacity Red. Factor</td>
<td>( L_f )</td>
<td>( \phi_f )</td>
</tr>
<tr>
<td>07</td>
<td>Depth of Fluid</td>
<td>( D_f )</td>
<td>in.</td>
<td>( D_i )</td>
<td></td>
</tr>
<tr>
<td>08</td>
<td>Steel Yield Stress</td>
<td>Concrete Compressive Strength</td>
<td>( f_y )</td>
<td>( f'_{c} )</td>
<td>ksi</td>
</tr>
<tr>
<td>09</td>
<td>Concrete Covers</td>
<td>Top - Outside</td>
<td>Side - Outside</td>
<td>Bottom - Outside</td>
<td>( t_{bl} )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Top- Inside</td>
<td>Bottom - Inside</td>
<td>Side- Inside</td>
<td>( t_{b4} )</td>
</tr>
<tr>
<td>10</td>
<td>Limiting Crack Width Factor</td>
<td>( F_{\text{cr}} )</td>
<td>None</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Number of Layers of Steel Reinforcing</td>
<td>Reinforcing Type</td>
<td>NLAY</td>
<td>RTYPE(Note 8)</td>
<td>None</td>
</tr>
</tbody>
</table>
### Wire Diameters

<table>
<thead>
<tr>
<th>12</th>
<th>Wire Diameters</th>
<th>SDATA(1-3)</th>
<th>in.</th>
<th>0.08T(Note6)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AS1 - Outside Steel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>AS2 - Inside Steel - Top</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>AS3 - Inside Steel - Bottom</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>AS4 - Inside Steel - Side</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SDATA(4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SDATA(5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SDATA(6)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Wire Spacing

<table>
<thead>
<tr>
<th>13</th>
<th>Wire Spacing</th>
<th>SDATA (7-9)</th>
<th>in.</th>
<th>2.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AS1 - Outside Steel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>AS2 - Inside Steel - Top</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>AS3 - Inside Steel - Bottom</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>AS4 - Inside Steel - Side</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SDATA (10)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SDATA (11)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SDATA (12)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Required</th>
<th>Over 13</th>
<th>End of Data</th>
</tr>
</thead>
</table>

### NOTES

1. The input cards do not need to be numerically ordered by code number; however, a code number greater than 13 must be the final data card.
2. The data punched in this field is arbitrary; it is echo printed in the output and may be helpful to the user for identification of the data in card columns 21-80.
3. \( \alpha \) min. defaults to 0.25 if input less than 0.
4. If FLG = 0, the initial side load (Load Case 3) is considered as 'permanent' dead load. If FLG \( \neq 0 \), the initial side load is considered as an additional dead load.
5. If the designer wishes to change any item on an optional data card from the default value, then all the items on that card must be given, even if the default values are desired.
6. For span < 7.0 ft \( T = \text{span}/12 + I \)
   For span > 7.0 ft \( T = \text{span}/12 \)
7. If the soil structure interaction factor is input as less than 0.75, it will default to 1.2.
8. RTYPE = 1 for smooth reinforcing with longitudinals spaced greater than 8 in.
   = 2 for smooth reinforcing with longitudinals spaced less than or equal to 8 in.
   = 3 for deformed reinforcing.

### B.2 Output

Column 80 of the problem identification card is the "DEBUG" parameter that controls the amount of output to be printed. An integer from 0 to 3 is specified in this column with each increasing number providing more output, as listed below. Table B-2 shows sample output, in the order that it is printed.

- **DEBUG = 0**
  - Echo print of input data
  - Summary table for design
B.2.1 Debug = 0

Echo print of input data: The program prints the data cards as they are read to allow the designer to check the input and to identify the design (Table B-2a).

Summary Table for Design: This table presents all important design parameters for the box section. If stirrups are required at a certain location, the stirrup design must be done by hand in accordance with Section 4.1.5. A row of stars (*** ) under the steel area column shows that steel design at that location is governed by concrete compression (Section 4.1.3) and the member must be designed with a thicker section, or designed as a compression member according to AASHTO ultimate strength design methods. (Table B-2j).

B.2.2 Debug = 1

Listing of BDATA, IBDATA, SDATA, ISDATA arrays: All of the input data and some additional parameters that are calculated from input data are stored in two arrays, BDATA, and SDATA. Maps of these arrays are presented in Tables B-3 and B-4 respectively. When these arrays are listed in the output, two parallel arrays, IBDATA and ISDATA are also output. These parallel arrays contain flags which indicate whether the items in the BDATA or SDATA arrays were input, assumed, or in no value is present (Table B-2b & c).

Moments, Thrusts, and Shears at Design Sections: This table presents the forces at the 15 design locations in the box section (Figure B-1). Under the service load category, two types of loads are shown, Group 1 and Group 2. Group 1 loads are considered permanent loads, including dead load, vertical soil load and the minimum lateral load case (unless FLG at 0, see Table B-1, Note 4) and are always included in the calculation of ultimate forces. Group 2 loads are considered "additional" loads and are only included in the calculation of ultimate forces if they increase the magnitude of the Group I forces. Additional loads are normally fluid load and the additional lateral soil load ($\alpha_{\text{max}} - \alpha_{\text{min}}$) The ultimate loads are found by adding Group I and Group 2 forces to obtain the "worst case" and multiplying by the appropriate load factor (Table B-2f).
The sign convention on the forces is as follows: positive thrust is tensile, positive shear decreases the moment from the A to the B end of the member and positive moment causes tension on the inside steel.

The zero moment top and bottom distances represent the maximum distance from the A end (Figure B-2) of the member to the point of zero moment in the member.

Table B-2. Sample Output from Box Culvert Design Program

a. Echo Print of Input Data

```
10.5 X 6 BOX TEST RUN WITH 4 FEET OF COVER
1 SPAN,RISE,BURIAL 10.500 6.000 4.000
2 TT,TS 8.000 8.000 8.000
3 HH,HV 8.000 8.000
4 FACTORS 1.300 0.900 0.850
5 TOTALS 60.000 3.000
6 CONCRETE COVERS 2.000 2.000 2.000 1.000 1.000 1.000
7 REINFORCING 1.000 3.000
8 END OF DATA
```

b. Listing of BDATA Array
c. Listing of SDATA Array

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>DATA</th>
<th>SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>INSIDE SPAN (IN)</td>
<td>0.126000E 03</td>
<td>INPUT</td>
</tr>
<tr>
<td>INSIDE BGE</td>
<td>0.720000E 02</td>
<td>INPUT</td>
</tr>
<tr>
<td>TOP SLABTRK (IN)</td>
<td>0.800000E 01</td>
<td>INPUT</td>
</tr>
<tr>
<td>BOT SLABTHK (IN)</td>
<td>0.800000E 01</td>
<td>INPUT</td>
</tr>
<tr>
<td>SIDE WALL T (IN)</td>
<td>0.800000E 01</td>
<td>INPUT</td>
</tr>
<tr>
<td>CONC UNIT WT KC</td>
<td>0.864000E 04</td>
<td>ASSUMED</td>
</tr>
<tr>
<td>SOIL UNIT WT KC</td>
<td>0.694444E 04</td>
<td>ASSUMED</td>
</tr>
<tr>
<td>FLUID UNIT WT KC</td>
<td>0.361700E 04</td>
<td>ASSUMED</td>
</tr>
<tr>
<td>FLEX CAPRED FACT</td>
<td>0.900000E 00</td>
<td>INPUT</td>
</tr>
<tr>
<td>BURIAL DEPTH IN</td>
<td>0.480000E 02</td>
<td>INPUT</td>
</tr>
<tr>
<td>HORIZ HAUNCH IN</td>
<td>0.800000E 01</td>
<td>INPUT</td>
</tr>
<tr>
<td>VERT HAUNCH IN</td>
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d. Joint Displacement Table
### e. Member End Forces Table

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### f. Design Forces Table
## g. Flexure Design Table

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### MEMBER THREAT
- **TOP**: 2.977
- **SIDE**: 4.833
- **BUT**: 1.209

### ZERO MOMENT TOP: 25.61222  
### ZERO MOMENT BOTTOM: 21.78448

---

***NOTE: ALL UNITS ARE KIPS AND INCHES***
### h. Method 1 Shear Design Table

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### Shear Design Table - Method 2

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**j. Design Summary Sheet**
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### Loading Data

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<td></td>
<td>0.900</td>
</tr>
<tr>
<td>Strength Reduction Factor - Diagonal Tension</td>
<td></td>
<td>0.650</td>
</tr>
<tr>
<td>Limiting Crack Width Factor</td>
<td></td>
<td>1.000</td>
</tr>
</tbody>
</table>

### Material Properties

<table>
<thead>
<tr>
<th>Material</th>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>Minimum Specified Yield Stress, ksi</td>
<td>60.000</td>
</tr>
<tr>
<td>Concrete</td>
<td>Specified Compressive Strength, ksi</td>
<td>3.000</td>
</tr>
<tr>
<td>Reinforcing Type</td>
<td></td>
<td>3.000</td>
</tr>
</tbody>
</table>

### Concrete Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Slab Thickness, in.</td>
<td></td>
<td>8.000</td>
</tr>
<tr>
<td>Bottom Slab Thickness, in.</td>
<td></td>
<td>8.000</td>
</tr>
<tr>
<td>Side Wall Thickness, in.</td>
<td></td>
<td>8.000</td>
</tr>
<tr>
<td>Horizontal Haunch Dimension, in.</td>
<td></td>
<td>8.000</td>
</tr>
<tr>
<td>Vertical Haunch Dimension, in.</td>
<td></td>
<td>8.000</td>
</tr>
<tr>
<td>Concrete Cover Over Steel, in.</td>
<td></td>
<td>2.000</td>
</tr>
<tr>
<td>Top Slab - Outside Face</td>
<td></td>
<td>0.247</td>
</tr>
<tr>
<td>Side Wall - Outside Face</td>
<td></td>
<td>0.192</td>
</tr>
<tr>
<td>Bottom Slab - Outside Face</td>
<td></td>
<td>0.192</td>
</tr>
<tr>
<td>Top Slab - Inside Face</td>
<td></td>
<td>0.271</td>
</tr>
<tr>
<td>Side Wall - Inside Face</td>
<td></td>
<td>0.248</td>
</tr>
<tr>
<td>Bottom Slab - Inside Face</td>
<td></td>
<td>0.192</td>
</tr>
</tbody>
</table>

### Reinforcing Steel Data

<table>
<thead>
<tr>
<th>Location</th>
<th>Area (sq. in.)</th>
<th>Stirrups Per Ft Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Slab - Inside Face</td>
<td>0.247</td>
<td>No</td>
</tr>
<tr>
<td>Top Slab - Outside Face</td>
<td>0.192</td>
<td>No</td>
</tr>
<tr>
<td>Bottom Slab - Inside Face</td>
<td>0.271</td>
<td>No</td>
</tr>
<tr>
<td>Side Wall - Outside Face</td>
<td>0.248</td>
<td>No</td>
</tr>
<tr>
<td>Side Wall - Inside Face</td>
<td>0.192</td>
<td>No</td>
</tr>
</tbody>
</table>

### Program Assumed Value

The side wall outside face steel is bent at the culvert corners and extended into the outside face of the top and bottom slabs. The theoretical cut-off lengths measured from the bend point are 21.7 and 23.4 in., respectively. Anchorage lengths must be added.
<table>
<thead>
<tr>
<th>Index of BNDAT (Note 1)</th>
<th>Notation</th>
<th>Computer Code</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Design Method</td>
<td></td>
<td>inside span of box section</td>
<td>in.</td>
</tr>
<tr>
<td></td>
<td>T&lt;sub&gt;s&lt;/sub&gt;</td>
<td>SPAN</td>
<td>inside rise of box section in.</td>
<td>in.</td>
</tr>
<tr>
<td></td>
<td>R&lt;sub&gt;i&lt;/sub&gt;</td>
<td>RISE</td>
<td>thickness of top slab in.</td>
<td>in.</td>
</tr>
<tr>
<td></td>
<td>T&lt;sub&gt;T&lt;/sub&gt;</td>
<td>TT</td>
<td>thickness of bottom slab</td>
<td>in.</td>
</tr>
<tr>
<td></td>
<td>T&lt;sub&gt;B&lt;/sub&gt;</td>
<td>TB</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T&lt;sub&gt;S&lt;/sub&gt;</td>
<td>TS</td>
<td>thickness of side wall</td>
<td>in.</td>
</tr>
<tr>
<td></td>
<td>γ&lt;sub&gt;c&lt;/sub&gt;</td>
<td>GAMAC</td>
<td>unit weight of concrete</td>
<td>kips/in.³</td>
</tr>
<tr>
<td></td>
<td>γ&lt;sub&gt;s&lt;/sub&gt;</td>
<td>GAMAS</td>
<td>unit weight of soil</td>
<td>kips/in.³</td>
</tr>
<tr>
<td></td>
<td>γ&lt;sub&gt;f&lt;/sub&gt;</td>
<td>GAMAF</td>
<td>unit weight of fluid in box</td>
<td>kips/in.³</td>
</tr>
<tr>
<td></td>
<td>φ&lt;sub&gt;f&lt;/sub&gt;</td>
<td>POF</td>
<td>capacity reduction factor for flexure</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>H&lt;sub&gt;e&lt;/sub&gt;</td>
<td>H</td>
<td>depth of fill</td>
<td>in.</td>
</tr>
<tr>
<td></td>
<td>H&lt;sub&gt;H&lt;/sub&gt;</td>
<td>HH</td>
<td>horizontal width of haunch</td>
<td>in.</td>
</tr>
<tr>
<td></td>
<td>H&lt;sub&gt;v&lt;/sub&gt;</td>
<td>HV</td>
<td>vertical height of haunch</td>
<td>in.</td>
</tr>
<tr>
<td></td>
<td>φ&lt;sub&gt;v&lt;/sub&gt;</td>
<td>POV</td>
<td>capacity reduction factor for shear</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>α&lt;sub&gt;min&lt;/sub&gt;</td>
<td>ZETA</td>
<td>lateral soil pressure coefficient</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>F&lt;sub&gt;e&lt;/sub&gt;</td>
<td>BETA</td>
<td>soil structure interaction factor</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>d&lt;sub&gt;f&lt;/sub&gt;</td>
<td>DF</td>
<td>depth of fluid</td>
<td>in.</td>
</tr>
<tr>
<td></td>
<td>E&lt;sub&gt;c&lt;/sub&gt;</td>
<td>EC</td>
<td>modulus of elasticity of concrete</td>
<td>ksi</td>
</tr>
<tr>
<td></td>
<td>E&lt;sub&gt;s&lt;/sub&gt;</td>
<td>ES</td>
<td>modulus of elasticity of steel</td>
<td>ksi</td>
</tr>
<tr>
<td></td>
<td>f&lt;sub&gt;y&lt;/sub&gt;</td>
<td>FY</td>
<td>specified yield strength of reinforcing</td>
<td>ksi</td>
</tr>
<tr>
<td></td>
<td>f&lt;sub&gt;c&lt;/sub&gt;'</td>
<td>FCP</td>
<td>specified compressive strength of concrete</td>
<td>ksi</td>
</tr>
<tr>
<td></td>
<td>L&lt;sub&gt;fmv&lt;/sub&gt;</td>
<td>FLMV</td>
<td>load factor for moment &amp; shear</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>L&lt;sub&gt;fn&lt;/sub&gt;</td>
<td>FLN</td>
<td>load factor for thrust</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>FCR</td>
<td>FCR</td>
<td>factor for crack control</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>NLAY</td>
<td>NLAY</td>
<td>relative to I for 0.01 &quot; crack</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>RTYPE</td>
<td>RTYPE</td>
<td>number of layers of circumferential reinforcing</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>t&lt;sub&gt;b1&lt;/sub&gt;</td>
<td>CT (1)</td>
<td>type of reinforcing steel</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>t&lt;sub&gt;b2&lt;/sub&gt;</td>
<td>CT (2)</td>
<td>concrete cover over top slab outside steel (ASI)</td>
<td>in.</td>
</tr>
<tr>
<td></td>
<td>t&lt;sub&gt;b3&lt;/sub&gt;</td>
<td>CT (3)</td>
<td>concrete cover over side wall outside steel (ASI)</td>
<td>in.</td>
</tr>
<tr>
<td></td>
<td>t&lt;sub&gt;b4&lt;/sub&gt;</td>
<td>CT (4)</td>
<td>concrete cover over bottom slab outside steel (ASI)</td>
<td>in.</td>
</tr>
<tr>
<td></td>
<td>t&lt;sub&gt;b5&lt;/sub&gt;</td>
<td>CT (5)</td>
<td>concrete cover over top slab inside steel (AS2)</td>
<td>in.</td>
</tr>
<tr>
<td></td>
<td>t&lt;sub&gt;b6&lt;/sub&gt;</td>
<td>CT (6)</td>
<td>concrete cover over bottom slab inside steel (AS3)</td>
<td>in.</td>
</tr>
<tr>
<td></td>
<td>t&lt;sub&gt;b7&lt;/sub&gt;</td>
<td>CT (6)</td>
<td>concrete cover over side wall inside steel (AS4)</td>
<td>in.</td>
</tr>
</tbody>
</table>

Notes:
1. Some index numbers are not listed here because those slots in the array were not used.
<table>
<thead>
<tr>
<th>Index of SDATA (Note 1)</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Wire diameter:</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>- outside steel top slab</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>- outside steel side wall</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>- outside steel bottom slab</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>- inside steel top slab</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>- inside steel bottom slab</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>- inside steel side wall</td>
</tr>
<tr>
<td></td>
<td><strong>Wire Spacing:</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>- outside steel top slab</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>- outside steel side wall</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>- outside steel bottom slab</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>- inside steel top slab</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>- inside steel bottom slab</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>- inside steel side wall</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>- length of outside steel in top slab</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>- length of outside steel in bottom slab</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td><strong>Lateral soil pressure ratio (Note 2)</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Depth of steel reinforcing:</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>- outside steel top slab</td>
</tr>
<tr>
<td></td>
<td>31</td>
<td>- outside steel side wall</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>- outside steel bottom slab</td>
</tr>
<tr>
<td></td>
<td>33</td>
<td>- inside steel top slab</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>- inside steel bottom slab</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>- inside steel side wall</td>
</tr>
</tbody>
</table>

1. Some index numbers are not listed here because those slots in the array were not used.
2. Lateral soil pressure ratio $= (\alpha_{\text{max}} - \alpha_{\text{min}})/\alpha_{\text{min}}$. 

---

| Output Note | Description |
|-------------|-------------|-------------|
|             |             |             |
**B.2.3 Debug = 2**

**Summary Table for Flexural Design:** This table presents all the information required to design steel reinforcing based on flexure, minimum steel, maximum steel and crack control. AS1 is taken as the maximum of the steel areas required at Sections 5, 11, and 12. AS2, AS3, AS4 and AS8 are the steel areas required at Sections 1, 15, 8 and 4 respectively. The table also lists the governing design criteria at each section (Table B-2g). See Table B-5 for a description of the governing mode output notes.

**Summary Table for Shear Design:** This table presents all the information used to evaluate the diagonal tension strength. Design Sections 3, 6, 10 and 13 are for shear design by Method 1. Design Sections 3, 6, 10 and 13 are for shear design by Method 2 at d from the tip of the haunch and design Sections 2, 7, 9 and 14 are for shear design by Method 2 where M/VIVd = 3.0. The program always checks shear design by both methods, and uses the most conservative (Table B-2h & i).
**Note:** For method 2 shear design, any distributed load within a distance $\phi vd$ from the tip of the haunch is neglected. Thus the shear strengths at locations 4, 5, 11 and 12 are compared to the shear forces at locations 3, 6, 10, and 13 respectively.

Figure B-1. Locations of Critical Sections for Shear and Flexure Design in Single Call Box Sections

### B.2.4 Debug = 3

**Displacement Matrix:** This table presents the joint displacements for each load condition in a global coordinate system, as shown in Figure B-2. These displacements are based on an elastic analysis of an uncracked concrete section, and are not estimates of expected field displacements. They are used only for consistency checks (Table B-2d).

**Member End Forces:** This table presents the equivalent member end forces used in application of the direct stiffness method. These forces are in the local coordinate system with the local x-axis along the member and positive from end A to end B. (Figure B-2). The local y-axis is always positive towards the inside of the box section and the moment follows the right-hand rule from x to y for sign (Table B-2e).
Figure B-2. Frame Model Used for Computer Analysis of Box Sections

Notes:

1. Member directions are taken clockwise. Thus end A of member 1 is at node 1 and end A of member 3 is at node 3.

2. Rotations are positive counterclockwise.
This Appendix provides the necessary information to use the computer program PIPECAR (PIPE culvert Concrete And Reinforcing design) to design reinforcing for circular and elliptical reinforced concrete pipe. For a general description of the program and the method of analysis used, see Section 5.2. For information on the loads and design methods see Chapter 2, Chapter 3, and Chapter 4.

C.1 Input Data

FIRST CARD: Format (1 9A4, A3, 1 1),

Problem Identification: Card Columns 1 through 79 are read and are echo printed in the output. An integer from 0 to 3 in card column 80 controls the amount of output printed. For a description of the available output, see Section C.2.

REMAINING CARDS: Format (12, 4A4, A2, 4F10.3)

Data: The first field (Columns 1 and 2) is an input code that internally identifies the type of data read on each card. The second field (Columns 3 through 20) is a comment field which may be used by the designer to identify the information being input on each card. The remaining fields (4F10.3) are for input data. Table C-1 describes the input data and format for each card, and default values for each parameter. If default values are used for all the items on any given card, then that card may be omitted.

<table>
<thead>
<tr>
<th>Card Column</th>
<th>Code (Note 1)</th>
<th>Description (Note 2)</th>
<th>Name of Variable</th>
<th>Units</th>
<th>Default Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>01(1)</td>
<td>01</td>
<td>inside Diameter or Side Radius</td>
<td>B_i or r_1</td>
<td>in.</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>02</td>
<td>Crown/Invert Radius</td>
<td>r_2</td>
<td>in.</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>03</td>
<td>Depth of Fill</td>
<td>H_e</td>
<td>ft.</td>
<td>None</td>
</tr>
<tr>
<td>02(1)</td>
<td>01</td>
<td>Horizontal Offset</td>
<td>u</td>
<td>in.</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>02</td>
<td>Vertical Offset</td>
<td>v</td>
<td>in.</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>03</td>
<td>Thickness</td>
<td>h</td>
<td>in.</td>
<td>None</td>
</tr>
<tr>
<td>04(1)</td>
<td>01</td>
<td>Bedding Angle</td>
<td>β_2</td>
<td>Degrees</td>
<td>90 (Note 4)</td>
</tr>
<tr>
<td></td>
<td>02</td>
<td>Load Angle</td>
<td>β_1</td>
<td>Degrees</td>
<td>270 (Note 4)</td>
</tr>
<tr>
<td></td>
<td>03</td>
<td>Soil Structure Int. Factor</td>
<td>F_e</td>
<td>None</td>
<td>1.2 (Note 6)</td>
</tr>
<tr>
<td>Optional Data (Note 5)</td>
<td>05</td>
<td>Soil Unit Weight Concrete Unit Weight Fluid Unit Weight</td>
<td>$\gamma_s$</td>
<td>$\gamma_c$</td>
<td>$\gamma_f$</td>
</tr>
<tr>
<td>------------------------</td>
<td>----</td>
<td>---------------------------------------------------------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>06</td>
<td></td>
<td>Depth of Fluid</td>
<td>$d_f$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>07</td>
<td></td>
<td>Steel Yield Stress Concrete Compressive Stress</td>
<td>$f_y$</td>
<td>$f'_c$</td>
<td></td>
</tr>
<tr>
<td>08</td>
<td></td>
<td>Outside Concrete Cover Inside Concrete Cover</td>
<td>$t_{bo}$</td>
<td>$t_{bi}$</td>
<td></td>
</tr>
<tr>
<td>09</td>
<td></td>
<td>Load Factor Flexure Cap Red Factor Shear Cap Red Factor</td>
<td>$L_f$</td>
<td>$\phi_f$</td>
<td>$\phi_v$</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>Inside Wire Diameter Outside Wire Diameter Reinforcing Type Number of Layers of Circumferential Reinforcing</td>
<td>$d_{in}$</td>
<td>$d_{out}$</td>
<td>RTYPE (Note 7)</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>Inside Wire Spacing Outside Wire Spacing</td>
<td>$S_{in}$</td>
<td>$S_{out}$</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>Limiting Crack Width Factor Radial Tension Process Factor Shear Process Factor</td>
<td>$F_{cr}$</td>
<td>$F_{rp}$</td>
<td>$F_{vp}$</td>
</tr>
</tbody>
</table>

Required OVER 12 End of Data

NOTES
1. The input cards do not need to be ordered by code number; however, a code number greater than 12 must be the final data card.
2. The data punched in this field is arbitrary; it will be echo printed in the output and is helpful to the user for identification of the data in card columns 21-61.
3. Since the program can design either circular or elliptical pipe shapes, there are different input criteria for each shape. For circular pipe, $B$ should be specified as the inside diameter of the pipe, radius 2 must be blank or 0., and the card with Code = 02 should not be used. For elliptical pipe, $r$ and $r'$ must be specified on the card with Code = 01 and the offset distances $u$ and $v$ must be specified on the card with Code = 02. Note that for $r > r'$, a horizontal ellipse will be designed, $r_1 > r_2$, would define a vertical ellipse, but this is not operational at this time.
4. The load Angle ($\beta_1$) must be between 180° and 300° and the bedding angle ($\beta_2$) must be between 60° and 180°. If $\beta_1 + \beta_2 > 360$ then the program will set $\beta_2 = 360 - \beta_1$. If the designer wishes to change any item on an optional data card from the default value, then all the items on that card must be given, even if the default values are used.
5. The soil structure interaction factor is input less than 0.75 it will default to 1.2.
6. RTYPE = 1 for smooth reinforcing with longitudinals spaced greater than 8 in.,
   = 2 for smooth reinforcing with longitudinals spaced greater than or equal to 8 in.,
   = 3 for deformed reinforcing.

C.2 Output

Column 80 of the problem identification card is the "DEBUG" parameter that controls the amount of output to be printed. An integer from 0 to 3 is specified in this column with each increasing number providing more output, as listed below. Table C-2 shows sample output, in the order that it is printed.

DEBUG = 0
- Echo print of input data
- Summary table for design
C.2.1 Debug = 0

Echo print of input data: The program prints the data cards as they are read to allow the designer to check the input and to identify the design (Table C-2a).

Summary Table for Design: This table (Table C-2j) presents all important design parameters for the pipe section. If stirrups are required at a certain location, the stirrup design factor is output. A row of stars (*** ) under the steel area column shows that steel design at that location was governed by concrete compression (Section 4.1.2) and the member must be designed with a thicker section, or designed as a compression member according to AASHTO ultimate strength design methods.

Table C-2. Sample Output from Pipe Culvert Design Program

```
a. Echo Print of Input Data

09576/SIDE TAPERED RCP TEST RUN 16/41-THROAT RUND 8/4/82

1
THICKNESS  6

3
THICKNESS  8

SCIL STRUCTURE INTERACTION FACTOR MODIFIED

# ALL INFORMATION PRESENTED IS FOR REVIEW, APPROVAL, INTERPRETATION
# AND APPLICATION BY A REGISTERED ENGINEER.

b. Listing of BDATA Array
```
### c. Pipe Geometry

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Data</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPRING RADIUS (IN)</td>
<td>42.000</td>
<td>INPUT</td>
</tr>
<tr>
<td>CROWN RADIUS (IN)</td>
<td>42.000</td>
<td>INPUT</td>
</tr>
<tr>
<td>HEIGHT OF FILL (FT)</td>
<td>7.500</td>
<td>INPUT</td>
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<td></td>
</tr>
<tr>
<td>34</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

**Additional Information:**
- **Pipe Weight:** 2.408 Kips/foot
- **Soil Weight:** 1.667 Kips/foot
- **Fluid Weight:** 2.408 Kips/foot

**e. Joint Displacement Table**
<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>160.30-97-2.31960-86 8.89735-63</td>
<td>8.81680-84 8.78980-84 8.63120-84</td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>160.30-97-2.31960-86 8.89735-63</td>
<td>8.81680-84 8.78980-84 8.63120-84</td>
<td></td>
</tr>
</tbody>
</table>

**f. Moments, Thrusts and Shears at Joints**
### Table of Ultimate Forces

<table>
<thead>
<tr>
<th>Design Location</th>
<th>Moment</th>
<th>Thrust</th>
<th>Shear</th>
<th>In. Kips/foot</th>
<th>Kips/foot</th>
<th>Kips/foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>131.769</td>
<td>3.93</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>17.92</td>
<td>84.968</td>
<td>5.744</td>
<td>4.711</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>75.90</td>
<td>-84.901</td>
<td>8.297</td>
<td>0.170</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>148.88</td>
<td>37.725</td>
<td>5.997</td>
<td>2.092</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>180.00</td>
<td>65.546</td>
<td>4.424</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Flexure Design Table

<table>
<thead>
<tr>
<th>Design Location</th>
<th>Design Values</th>
<th>Governing Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0</td>
<td>6.313</td>
<td>0.119</td>
</tr>
<tr>
<td>75.73</td>
<td>8.359</td>
<td>0.741</td>
</tr>
<tr>
<td>150.00</td>
<td>1.350</td>
<td>0.624</td>
</tr>
</tbody>
</table>
i. Shear Design Table

<table>
<thead>
<tr>
<th>DESIGN LOCATION DEG FROM INVERT</th>
<th>REQUIRED REINFORCING SQ.IN./FT</th>
<th>STEEL RATIO 0.0</th>
<th>STIRUP FACTOR 0.0</th>
<th>STIRUP EXTENT 0.0</th>
<th>GOVERNING MODE DOESNOTGOVRN</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.92</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>DOESNOTGOVRN</td>
</tr>
<tr>
<td>148.88</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>DOESNOTGOVRN</td>
</tr>
</tbody>
</table>

j. Summary Table for Design

**8-INCH DIAMETER REINFORCED CONCRETE CIRCULAR PIPE**

### Installation Data

| HEIGHT OF FILL ABOVE CROWN, FT. | 1.50 |
| UNIT WEIGHT, PCF.               | 120.00 |
| SOIL-STRUCTURE INTERACTION COEFFICIENT | 1.20 |
| REOVAL ANGLE, DEGREES | 90.00 |
| LOAD ANGLE, DEGREES | 270.00 |

### Material Properties

| STEEL - MINIMUM SPECIFIED YIELD STRESS, PSI | 65000.0 |
| REINFORCING TYPE | 2.0 |
| % OF LAYERS OF REINFORCING | 1.0 |
| CONCRETE - SPECIFIED COMpressive STRESS, PSI | 5000.0 |

### Loading Data

| LOAD FACTOR - MOMENT AND SHEAR | 1.50 |
| LOAD FACTOR - THRUST | 1.50 |
| STRENGTH REDUCTION FACTOR - FLEXURE | 0.90 |
| STRENGTH REDUCTION FACTOR - DIAGONAL TENSION | 0.90 |
| LIMITING CRACK WIDTH FACTOR | 1.00 |

### Pipe Data

| WALL THICKNESS, IN. | 6.00 |
| INSIDE CONCRETE COVER OVER STEEL, IN. | 1.30 |
| OUTSIDE CONCRETE COVER OVER STEEL, IN. | 1.06 |

### Fluid Data

| FLUID DENSITY, PCF. | 62.50 |
| DEPTH OF FLUID, INCHES ABOVE INVERT | 84.00 |

### Reinforcing Steel Data

| INVERT - INSIDE REINFORCING, SQ.IN./FT. | 0.311 |
| SPRINGLINE - OUTSIDE REINFORCING, SQ.IN./FT. | 0.139 |
| CROWN - INSIDE REINFORCING, SQ.IN./FT. | 0.130 |
Listing of BDATA and IBDATA arrays: All of the input data and some additional parameters which are calculated from input data are stored in the BDATA array. A map of this array is presented in Table C-3. When this array is listed in the output, a parallel array, IBDATA is also output. This parallel array contains flags which indicate whether the items in the BDATA array were input, assumed, or if no value is present (Table C-2b).

Table of Ultimate Forces: This table (Table C-2g) lists the ultimate moments, thrusts and shears at each of the five design locations (Figure C-1) in the pipe. These are the forces used to complete the reinforcing design.

Flexure Design Table: This table (Table C-2h) lists the reinforcing requirements for flexure and crack control, and the index value for radial tension. Also listed is the governing design, the steel ratio produced by that design and stirrup requirements if the radial tension index was greater than 1.0. The governing mode is also listed. The output notes under governing mode are described more fully in Table C-4.

Shear Design Table: This table (Table C-2i) summarizes the design calculations for shear strength. The values listed are the circumferential reinforcing area required to produce the required shear strength, the steel ratio produced by that reinforcing and any stirrup requirements if the circumferential reinforcing required to meet the shear requirements is greater than that needed to meet the flexure or crack requirements.

Pipe Geometry: This table (Table C-2c) lists the coordinates and angle from vertical (a) and the lengths and unit sines and cosines of each member. The pipe model is shown in Figure C-2.

Loads Applied at Each Joint: This table (Table C-2d) lists the radial and tangential pressure at each joint due to earth, fluid and dead load. The units are kips per circumferential inch per longitudinal foot.

Pipe, Soil and Fluid Weights: The total applied loads on the pipe for each load condition. Units are kips per foot (Table C-2d).

Moments, Thrusts and Shears at Joints: This table (Table C-2f) lists the service load moment thrust and shear at each joint. The forces are listed separately for the three load conditions.

Joint Displacements: This table (Table C-2e) lists the displacements for each joint due to each load condition. The displacements are in a global coordinate system, with positive x and y displacements as shown in Figure C-2 and rotations positive counterclockwise from the y to the x axis.
Figure C-1. Typical Reinforcing Layout and Locations of Critical Sections for Shear and Flexure Design in Pipe Sections

Flexure Design Locations:
1, 5 Maximum positive moment locations at invert and crown.
3 Maximum negative moment location near springline.

Shear Design Locations:
2, 4 Locations near invert and crown where \( M/V_d \), \( d = 3.0 \)

Notes:
1. Reinforcing in crown \( (A_{sc}) \) will be the same as that used at the invert unless mat, quadrant, or other special reinforcing arrangements are used.
2. Design locations are the same for elliptical sections.

Table C-3. Map of BDATA Array

<table>
<thead>
<tr>
<th>Index of BDATA</th>
<th>Notation</th>
<th>Design Method</th>
<th>Computer Code</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( r_1 )</td>
<td>( r_1 )</td>
<td>RADI 1</td>
<td>inside radius, side</td>
<td>in.</td>
</tr>
<tr>
<td>2</td>
<td>( r_2 )</td>
<td>( r_2 )</td>
<td>RADI 2</td>
<td>inside radius, crown &amp; invert</td>
<td>in.</td>
</tr>
<tr>
<td>3</td>
<td>( H_e )</td>
<td>( H_e )</td>
<td>H</td>
<td>depth of fill</td>
<td>ft.</td>
</tr>
<tr>
<td>4</td>
<td>( u )</td>
<td>( u )</td>
<td>U</td>
<td>horizontal offset distance</td>
<td>in.</td>
</tr>
<tr>
<td>5</td>
<td>( v )</td>
<td>( v )</td>
<td>V</td>
<td>vertical offset distance</td>
<td>in.</td>
</tr>
<tr>
<td>Column 1</td>
<td>Column 2</td>
<td>Column 3</td>
<td>Column 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>----------</td>
<td>----------</td>
<td>----------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>h</td>
<td>T_H</td>
<td>wall thickness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>b_2</td>
<td>BETA</td>
<td>bedding angle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>F_e</td>
<td>HH</td>
<td>soil structure int. factor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>g_s</td>
<td>GAMAS</td>
<td>soil unit weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>g_c</td>
<td>GAMAC</td>
<td>concrete unit weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>g_f</td>
<td>GAMAF</td>
<td>fluid unit weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>d_f</td>
<td>DF</td>
<td>depth of internal fluid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>f_y</td>
<td>FY</td>
<td>reinforcing yield strength</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>f_c</td>
<td>FCP</td>
<td>concrete compressive strength</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>t_bo</td>
<td>COUT</td>
<td>cover over outside reinforcing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>t_b_i</td>
<td>CIN</td>
<td>cover over inside reinforcing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>L_mnv</td>
<td>FLMV</td>
<td>load factor, moment, shear</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>L_f_n</td>
<td>FLN</td>
<td>load factor, thrust</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>w_d_i</td>
<td>DIN</td>
<td>diameter of inside reinforcing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>w_d_o</td>
<td>DOUT</td>
<td>diameter of outside reinforcing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>RTYPE</td>
<td>RTYPE</td>
<td>reinforcing type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>n</td>
<td>NLAY</td>
<td>number of layers of reinforcing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>S_i</td>
<td>SPIN</td>
<td>spacing of inside reinforcing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>S_o</td>
<td>SPOUT</td>
<td>spacing of outside reinforcing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>θ_i</td>
<td>PO</td>
<td>strength reduction factor, flexure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>F_cr</td>
<td>FCR</td>
<td>crack width factor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>E_s</td>
<td>EST</td>
<td>modulus of elasticity - steel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>E_c</td>
<td>ECON</td>
<td>modulus of elasticity - concrete</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>r_m_1</td>
<td>RADMI</td>
<td>mean radius, side</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>r_m_20</td>
<td>RADM2</td>
<td>mean radius, crown, invert</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>D_eq</td>
<td>EQUID</td>
<td>equivalent circular diameter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>β_1</td>
<td>BETAS</td>
<td>load angle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>φ_d</td>
<td>POD</td>
<td>strength reduction factor, diagonal tension</td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>F_r_f</td>
<td>FRP</td>
<td>radial tension strength process factor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>F_v</td>
<td>FVP</td>
<td>diagonal tension strength process factor</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table C-4. Description of Governing Mode Output Notes**

<table>
<thead>
<tr>
<th>Output Note</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLEXURE</td>
<td>Steel area based on ultimate flexural strength requirements.</td>
</tr>
<tr>
<td>MIN STEEL</td>
<td>Steel area based on minimum steel requirements.</td>
</tr>
<tr>
<td>CRACK</td>
<td>Steel based on crack requirements at service load.</td>
</tr>
<tr>
<td>RADTEN + FLEX</td>
<td>Steel area based on ultimate flexural strength requirements, but stirrups are required to meet radial tension requirements.</td>
</tr>
<tr>
<td>RADTEN + CR</td>
<td>Steel area based on crack requirements but stirrups required to meet radial tension requirements.</td>
</tr>
<tr>
<td>DT NOSTIRUPS</td>
<td>Diagonal tension strength is exceeded based on steel required for flexure or crack. Stirrups may be used, or the circumferential steel may be increased to the amount shown.</td>
</tr>
<tr>
<td>DT + STIRRUPS</td>
<td>Diagonal tension strength is exceeded based on steel required for flexure or crack. Stirrups must be used.</td>
</tr>
<tr>
<td>MAXCONCOMPR</td>
<td>Design by usual methods is not possible due to maximum concrete compression. Section must be designed as a compression member, or reanalyzed with a different wall thickness or installation conditions.</td>
</tr>
</tbody>
</table>
Figure C-2. Frame Model Used for Computer Analysis of Circular an Elliptical Pipe

Note: For Circular Pipe
\[ u = v = 0 \text{ and } r_1 = r_2 \]
D.1 Side Tapered Box Section Inlet Design Example

D.1.1 Problem:
Determine the reinforcing requirements for a cast-in-place side tapered box inlet. For geometry use the results of Example No. 1 in Reference 1.

D.1.2 Design Data
Note: Add 2' surcharge for miscellaneous unanticipated loads.
He @ Face

\[ = 2' + 2' = 4' \]

He' @ Face

\[ = H_e + \frac{D_i}{2} + \frac{8}{12} = 7.67' \]

Say 8'-0"

---

**Given Data**

<table>
<thead>
<tr>
<th></th>
<th>Face</th>
<th>Throat</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B_i )</td>
<td>10.5 ft</td>
<td>7.0 ft</td>
</tr>
<tr>
<td>( D_i )</td>
<td>6.0 ft</td>
<td>6.0 ft</td>
</tr>
<tr>
<td>( T_T ), ( T_B ), ( T_S )</td>
<td>8 in. *</td>
<td></td>
</tr>
<tr>
<td>( H_T ), ( H_V )</td>
<td>8 in.</td>
<td></td>
</tr>
<tr>
<td>( \gamma_s )</td>
<td>120 pcf</td>
<td></td>
</tr>
<tr>
<td>( \gamma_c )</td>
<td>150 pcf</td>
<td></td>
</tr>
<tr>
<td>( \gamma_f )</td>
<td>62.5 pcf</td>
<td></td>
</tr>
<tr>
<td>( \alpha_{\text{min.}} )</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>( \alpha_{\text{max.}} )</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>( \phi_f )</td>
<td>0.90</td>
<td></td>
</tr>
<tr>
<td>( \phi_v )</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td>( F_{cr} )</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>( f' )</td>
<td>60.0 ksi</td>
<td></td>
</tr>
<tr>
<td>( f_c )</td>
<td>3.0 ksi</td>
<td></td>
</tr>
<tr>
<td>( t_{bo} )</td>
<td>2.0 in.</td>
<td></td>
</tr>
<tr>
<td>( t_{bi} )</td>
<td>1.0 in.</td>
<td></td>
</tr>
<tr>
<td>( L_f )</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>( R ) Type</td>
<td>3 = Def. bar</td>
<td></td>
</tr>
<tr>
<td>( F_{vp} )</td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Add 2' surcharge for miscellaneous unanticipated loads.

* Estimated wall thickness = \( T = \frac{B_i}{12} + 1 = \frac{84}{12} + 1 = 8" \)
He @ Throat
\[ = 4 + L_1 \left( \frac{1}{S_e} + S_o \right) = 4 + 7 \left( \frac{1}{2} = 0.029 \right) = 7.7' \]
Say 8'-0"

He' @ Throat
\[ = 7.7' + 3.67' = 11.37' \]
Say 11'-6"

He @ Midlength
\[ = 4 + \frac{7}{2} \left( \frac{1}{2} + 0.029 \right) = 5.85' \]
Say 6'-0"

B_i @ Midlength
\[ = \frac{10.5 + 7}{2} = 8.75' \]

He @ Midlength
\[ = 6 + 3.67 = 9.67' \]
Say 10'-0"

---

D.1.3 Calculate Soil Pressure

Throat
\[ \rho_v = \gamma_s H_e F_e = \gamma_c T_T = 2 \gamma_c D' T_S / B' \]  
Eq. 31

\[ D' = 6 + 8 / 12 = 6.67'; B' = 7 + 8 / 12 = 7.67' \]

\[ \rho_v = (120)(8)(1.2) + (150)(8/12) + (2)(150)(6.67)(8/12) / 7.67' = 1,426 \text{ psf} \]
= 118.8 lb/in/ft

\[ \rho_{\text{max}} = \alpha_{\text{max}} \gamma_s H'_e = (0.5)(120)(11.5) = 690 \text{ psf} \]
= 57.5 lb/in/ft

\[ \rho_{\text{min}} = \alpha_{\text{max}} \gamma_s H'_e - \gamma_f \left( \frac{D' - T_T}{2R'} \right)^2 \]  
Eq. 3.3

\[ = (0.25)(120)(11.5) - 62.5 \left( \frac{6.67 - 8}{12} \right)^2 \]
\[ = 176 \text{ psf} \]
\[ = 14.7 \text{ lb/in/ft} \]

Face
\[ D' = 6 + 8 / 12 = 6.67'; B' = 10.5 + 8 / 12 = 11.17' \]

\[ \rho_v = (120)(4)(1.2) + (150)(8/12) + (2)(150)(6.67)(8/12) / 11.17 = 795 \text{ psf} \]
= 66.3 lb/in/ft

Eq. 3.1
\[ P_{\text{max.}} = (0.5)(120)(8) = 480 \text{ psf} = 40 \text{ lb.in/ft} \quad \text{Eq. 3.2} \]
\[ P_{\text{min.}} = (0.25)(120)(8) \cdot \frac{(6.67 - \frac{8}{12})^2}{(2)(6.67)} = 71 \text{ psf} \quad \text{Eq. 3.3} \]

**Midlength**

\[ D' = 6 + \frac{8}{12} = 6.67'; B' = 8.75 + \frac{8}{12} = 9.42' \]
\[ P_v = (120)(6)(1.2) + (150)(8/12) + \frac{(2)(150)(6.67)(8/12)}{9.42} = 1,106 \text{ psf} \]
\[ = 92.1 \text{ lb/in/ft} \quad \text{Eq. 3.1} \]
\[ P_{\text{max.}} = (0.5)(120)(10) = 600 \text{ psf} = 50 \text{ lb.in/ft} \quad \text{Eq. 3.2} \]
\[ P_{\text{min.}} = (0.25)(120)(10) - \frac{(6.25)(6.67 - \frac{8}{12})^2}{(2)(6.67)} = 131 \text{ psf} \quad \text{Eq. 3.3} \]

---

### D.1.4 Calculate Moments, Thrusts & Shears @ Design Sections

Using the following equations, calculate the moments, thrusts, and shears at design locations shown on Fig. 4-2.

**Moment in bottom slab:**
\[ M_b(x) = \begin{cases} M_{\text{max}} \\ M_{\text{min}} \end{cases} + 0.5P_v \times (B' - x) \quad \text{Eq. 3.9} \]

**Moment in sidewall:**
\[ M_z(y) = \begin{cases} M_{\text{max}} \\ M_{\text{min}} \end{cases} + \begin{cases} P_{\text{max}} \\ P_{\text{min}} \end{cases} \times 0.5y(D' - y) \quad \text{Eq. 3.10} \]

where:
\[
\begin{align*}
\begin{cases}
M_{o \text{ max}} \\
M_{o \text{ min}}
\end{cases}
= - \frac{p_v B'^2}{12} \left( 1 - 1.5G_3 + 0.5G_4 \right) - \frac{p_{s \text{ max}}}{p_{s \text{ min}}} \left[ \frac{D'^2}{12} \left( \frac{G_1 - G_2}{1 + G_1 - G_3} \right) \right]
\end{align*}
\]
Eq. 3.8

\[
G_1 = \frac{T'_T D'}{T'_S B'}
\]
Eq. 3.4

\[
G_2 = \frac{9H'_H}{D'B'T'_S} \left( 1 - \frac{T'_T}{D'} \right)
\]
Eq. 3.5

\[
G_3 = \frac{2H'_H}{B'} \left( 1 - \frac{T'_T}{T'_S} \right)
\]
Eq. 3.6

\[
G_4 = \frac{6H'_H}{B'} \left( 1.02 - \frac{3T'_T}{B'} + \frac{T'_S}{T'_S} \right)
\]
Eq. 3.7

* Use \( \frac{M_{o \text{ max}}}{M_{o \text{ min}}} \) or \( \frac{M_{o \text{ min}}}{M_{o \text{ min}}} \) as follows:

Location 8, 9, and 10, use \( P_{s \text{ max}} \) only

Locations 11, 12, and 13 check both \( P_{s \text{ max}} \) and \( P_{s \text{ min}} \) for governing case.

Locations 14 and 15 use \( P_{s \text{ min}} \) only.

**Design Shears**

Shear in bottom slab:

\[
V_b (x) = p_v (B'/2 - x)
\]
Eq. 3.11

Shear in sidewall:

\[
V_s (y) = p_{s \text{ max}} \cdot (D'/2 - y)
\]
Eq. 3.12
Thrust in bottom slab:
\[
\begin{bmatrix}
N_{b, \text{max}} \\
N_{b, \text{min}}
\end{bmatrix} = \begin{bmatrix}
p_{s, \text{max}} \\
p_{s, \text{min}}
\end{bmatrix} \cdot \frac{D'}{2}
\]
Eq. 3.13

Thrust in sidewall:
\[N_s = \frac{p_v B'}{2}\]
Eq. 3.14

**Throat - Design Moments**

\[G_1 = \frac{(8/12)^3 (6.67)}{(8/12)^3 (7.67)} = 0.870\]
Eq. 3.4

\[G_2 = \frac{(9)(8/12)^5}{(6.67)(7.67)(8/12)^3 (1- \frac{8/12}{6.67})} = 0.70\]
Eq. 3.5

\[G_3 = \frac{(2)(8/12)^3}{7.67} \left( \frac{1}{(8/12)^2} + \frac{8/12}{(8/12)^3} \right) = 0.348\]
Eq. 3.6

\[G_4 = \frac{(6)(8/12)}{7.67} \left( 1.02 - \frac{3(8/12)}{7.67} + \frac{(8/12)^3}{(8/12)^3} \right) = 0.917\]
Eq. 3.7

\[M_0 = \frac{-118.8(92)^2}{12} \left( 1 - \frac{(1.5)(0.348) + (0.5)(0.917)}{1+0.870-0.348} \right) - \begin{bmatrix} P_{s, \text{max}} \\ P_{s, \text{min}} \end{bmatrix} \left[ \frac{(80)^2}{12} \left( \frac{0.87-0.070}{1+0.870-0.348} \right) \right] \]
Eq. 3.8

\[= -51558.9 - \begin{bmatrix} P_{s, \text{max}} \\ P_{s, \text{min}} \end{bmatrix} (280.33)\]
Eq. 3.8

\[M_{o, \text{max.}} = -51558.9 - (57.5)(280.33) = -67680 \text{ in-lb/ft}\]

\[M_{o, \text{min.}} = -51558.9 - (14.7)(280.33) = -55680 \text{ in-lb/ft}\]
Throat - Design Moments

<table>
<thead>
<tr>
<th>Design Location</th>
<th>Coordinat</th>
<th>Moment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>x (in)</td>
<td>y (in)</td>
</tr>
<tr>
<td>8</td>
<td>-</td>
<td>40.00</td>
</tr>
<tr>
<td>11</td>
<td>-</td>
<td>12.00</td>
</tr>
<tr>
<td>12</td>
<td>12.00</td>
<td>-</td>
</tr>
<tr>
<td>15</td>
<td>46.00</td>
<td>-</td>
</tr>
</tbody>
</table>

Sidewall moment Eq. 3.10

Bottom slab moment Eq. 3.9

Throat - Design Shears

\[ d_{\text{inner}} = (0.96(8)-1) = 6.68 \text{ in} \]
\[ d_{\text{outer}} = (0.96(8)-2) = 5.68 \text{ in} \]
\[ \phi_v d_{\text{inner}} = 0.85 (6.86) = 5.68 \text{ in} \]
\[ \phi_v d_{\text{outer}} = 0.85 (5.86) = 4.83 \text{ in} \]
\[ x_{dc} = 3 \left[ \sqrt{\left(\phi_v d\right)^2 + \frac{2M_u}{V_u \phi_v d}} \right] \]
\[ \frac{M_u}{V_u \phi_v d} = 3.0 \]

Eq. 4.22

@Design Location 9

\[ M_8 < 0 \text{ do not investigate} \]

@ Design Location 14 (positive moment region)

\[ x_{dc} = 3 \left[ \sqrt{\left(5.68\right)^2 + \frac{2(70010)}{9(118.8)}} - 5.68 \right] = 21.29 \text{ in} \]
\[ x_{\text{coord@14}} = 46.00 - 21.29 = 24.71 \text{ in} \]

Throat - Design Shears

<table>
<thead>
<tr>
<th>Design Location</th>
<th>Coordinat</th>
<th>Design Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>x (in)</td>
<td>y (in)</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Shear in sidewall
Eq. 3.12
### Throat - Design Thrusts

\[ N_{b_{\text{max.}}} = (5.75) \left( \frac{(6.67)(12)}{2} \right) = 2300 \text{ lb/ft} \quad \text{Eq. 3.13} \]

\[ N_{b_{\text{min.}}} = (14.7) \left( \frac{(6.67)(12)}{2} \right) = 590 \text{ lb/ft} \]

\[ N_s = \frac{(118.8)(7.67)(12)}{2} = 5470 \text{ lb/ft} \quad \text{Eq. 3.14} \]

### Face - Design Moments

\[ G_1 = \frac{(8/12)^3 (6.67)}{(8/12)^3 (11.17)} = 0.597 \quad \text{Eq. 3.4} \]

\[ G_2 = \frac{(9)(8/12)^5}{(6.67)(11.17)(8/12)^3} \left( 1 - \frac{8/12}{6.67} \right) = 0.048 \quad \text{Eq. 3.5} \]

\[ G_3 = \frac{(2)(8/12)^3}{11.17} \left( 1 - \frac{8/12}{(8/12)^2} + \frac{8/12}{(8/12)^3} \right) = 0.239 \quad \text{Eq. 3.6} \]

\[ G_4 = \frac{(6)(8/12)}{11.17} \left( 1.02 - \frac{(3)(8/12)}{11.17} + \frac{(8/12)^3}{(8/12)^3} \right) = 0.659 \quad \text{Eq. 3.7} \]
\[ M_o = \frac{(\frac{-66.3}{12})(134)^2}{1+0.597-0.239} \left( 1-\frac{(1.5)(0.239)+(0.5)(0.659)}{1+0.597-0.239} \right) \left[ \frac{P_{s_{\text{max}}}}{P_{s_{\text{min}}}} \right] \left[ (30)^2 \left( \frac{0.597-0.048}{1+0.597-0.239} \right) \right] \]

\[ = 70935.1 - \frac{P_{s_{\text{max}}}}{P_{s_{\text{min}}}} \times 215.61 \]

Eq. 3.8

\[ M_{o_{\text{max}}} = -70935.1 - (40)(215.6) = -79560 \text{ in-lb/ft} \]

\[ M_{o_{\text{min}}} = -70935.1 - (5.9)(215.6) = -72210 \text{ in-lb/ft} \]

**Face - Design Moments**

<table>
<thead>
<tr>
<th>Design Location</th>
<th>Coordinat</th>
<th>Moment for</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>x (in)</td>
<td>y (in)</td>
</tr>
<tr>
<td>8</td>
<td>-</td>
<td>40.00</td>
</tr>
<tr>
<td>11</td>
<td>-</td>
<td>12.00</td>
</tr>
<tr>
<td>12</td>
<td>12.00</td>
<td>-</td>
</tr>
<tr>
<td>15</td>
<td>67.00</td>
<td>-</td>
</tr>
</tbody>
</table>

| Sidewall moment Eq. 3.10
| Bottom slab moment Eq. 3.9

@ Design Location 9

\[ M_8 < 0 \text{ do not investigate} \]

@ Design Location 14 (positive moment region)

\[ x_{dc} = 3 \left[ \sqrt{(5.68)^2 + \frac{(2)(76600)}{(9)(66.3)}} - 5.68 \right] = 33.96 \text{ in} \]

\[ x_{\text{coord}@14} = 67.00 - 33.96 = 33.04 \text{ in} \]

<table>
<thead>
<tr>
<th>Design Location</th>
<th>Coordinat</th>
<th>Design Shear (lbs/ft)</th>
</tr>
</thead>
</table>
|                 | x (in)    | y (in)               | \begin{tabular}{c} \text{Shear in sidewall} \\
|                 | 9         | 10                   | 11                   |
|                 | 12        | 13                   | 14                   |
|                 | -         | 16.83                | 12.00                |
|                 | -         | -                    | -                    |
|                 | 12.00     | -                    | -                    |
|                 | 16.83     | -                    | -                    |
|                 | 33.04     | -                    | -                    |
|                 | 930       | 1120                 | -                    |
|                 | 3650      | 3330                 | 2250                 |
|                 | \text{Shear in bottom slab} \\
|                 | Eq. 3.11   | Eq. 3.11              | Eq. 3.11              |
Face - Design Thrusts

\[ N_{b_{\text{max.}}} = (40) (80/2) = 1600 \text{ lb/ft} \quad \text{Eq. 3.13} \]
\[ N_{b_{\text{min.}}} = (5.9) (80/2) = 240 \text{ lb/ft} \quad \text{Eq. 3.13} \]
\[ N_s = (66.3) (134)/2 = 4440 \text{ lb/ft} \quad \text{Eq. 3.14} \]

Mid-Length - Design Moments

\[ G_1 = \frac{(8/12)^3 (6.67)}{(8/12)^3 (9.42)} = 0.708 \quad \text{Eq. 3.4} \]
\[ G_2 = \frac{(9)(8/12)^5}{(6.67)(9.42)(8/12)^3} \left(1 - \frac{8/12}{6.67}\right) = 0.057 \quad \text{Eq. 3.5} \]
\[ G_3 = \frac{(2)(8/12)^3}{9.42} \left(1 - \frac{1}{(8/12)^2} + \frac{8/12}{(8/12)^3}\right) = 0.283 \quad \text{Eq. 3.6} \]
\[ G_4 = \frac{(6)(8/12)}{9.42} \left[1.02 - \frac{(3)(8/12)}{9.42} + \frac{(8/12)^3}{(8/12)^3}\right] = 0.708 \quad \text{Eq. 3.7} \]
\[ M_o = \frac{(-92.1)(113)^2}{12} \left[1 - (1.5)(0.283) + (0.5)(0.708)\right] - \frac{P_{s_{\text{max.}}}}{P_{s_{\text{min.}}}} \left[\frac{(80)^2}{12} \left(1 + 0.708 - 0.283\right)\right] \]
\[ = -65988.1 - \left\{\frac{P_{s_{\text{max.}}}}{P_{s_{\text{min.}}}} \right\} 243.65 \quad \text{Eq. 3.8} \]

\[ M_{o_{\text{max.}}} = -78170 \text{ in-lb/ft} \]
\[ M_{o_{\text{min.}}} = -68640 \text{ in-lb/ft} \]
<table>
<thead>
<tr>
<th></th>
<th></th>
<th>( P_{\text{min.}} ) (in-lb/ft)</th>
<th>( P_{\text{max.}} ) (in-lb/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>11</td>
<td>40.00</td>
<td>-64190</td>
</tr>
<tr>
<td>12</td>
<td>15</td>
<td>12.00</td>
<td>+78360</td>
</tr>
</tbody>
</table>

\( \text{Sidwall moment} \)  
\( \text{Eq. 3.10} \)

<table>
<thead>
<tr>
<th></th>
<th>( x ) Coordinate</th>
<th>( y ) Coordinate</th>
<th>Design Shear (lbs/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td></td>
<td></td>
<td>No Check ( M_8 &lt; 0 )</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>12.00</td>
<td>16.83</td>
<td>4100</td>
</tr>
<tr>
<td>13</td>
<td>16.83</td>
<td>-</td>
<td>3650</td>
</tr>
<tr>
<td>14</td>
<td>28.90</td>
<td>-</td>
<td>2540</td>
</tr>
</tbody>
</table>

\( \text{Shear in sidewall} \)  
\( \text{Eq. 3.12} \)

\( \text{Shear in bottom slab} \)  
\( \text{Eq. 3.11} \)

**Mid-length Design Shears**

@ Design Location 9

\( M_8 < 0 \) do not investigate

@ Design Location 14 (positive moment region)

\[
\begin{align*}
 x_{\text{dc}} &= 3 \left[ \frac{(2)(78360)^2}{(9)(92.1)} - 5.68 \right] = 27.59 \text{ in} \\
 x_{\text{coord@14}} &= 56.50 - 27.59 = 28.91 \text{ in}
\end{align*}
\]

**Midlength Design Thrusts**

\[
 N_{\text{bmax.}} = 50 \left( \frac{(6.67)(12)}{2} \right) = 2000 \text{ lb/ft}
\]  
\( \text{Eq. 3.13} \)
\[ N_{b_{\text{min.}}} = (10.9)(40) = 440 \text{ lb/ft} \quad \text{Eq. 3.13} \]
\[ N_s = \frac{(9.2)(9.42)(12)}{2} = 5200 \text{ lb/ft} \quad \text{Eq. 3.14} \]

### Summary of Design Moments, Thrusts And Shears

<table>
<thead>
<tr>
<th>Section</th>
<th>Design Location</th>
<th>Service Load Forces</th>
<th>Ultimate Load Forces*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M (in-lb/ft)</td>
<td>N (lb/ft)</td>
<td>V (lb/ft)</td>
</tr>
<tr>
<td>Throat</td>
<td>8 9</td>
<td>-21630</td>
<td></td>
</tr>
<tr>
<td></td>
<td>**</td>
<td>**</td>
<td>1330</td>
</tr>
<tr>
<td></td>
<td>10 11</td>
<td>-9680</td>
<td>5470</td>
</tr>
<tr>
<td></td>
<td>12 13</td>
<td>-10360</td>
<td>5470</td>
</tr>
<tr>
<td></td>
<td>14 15</td>
<td>70010</td>
<td>590</td>
</tr>
</tbody>
</table>

** M_8 < 0 - No Flexure Design Required  
M_8 < 0 - No shear Design Required

| face          | 8 9             | -47560              |                       |               |             |             |
|               | **              | **                  | 1330                  | -64580        | 7110        | 2090        |
|               | 10 11           | -69800              | 4400                  | 1120          | -13820      | 2990        |
|               | 12 13           | -31030              | 1600                  | 3650          | -40340      | 2080        |
|               | 14 15           | 76600               | 240                   | 99580         | 310         | 2930        |

** M_8 < 0 - No Flexure Design Required  
M_8 < 0 - No shear Design Required

| Mid- Length   | 8 9             | -38170              |                       |               |             |             |
|               | **              | **                  | 1330                  | -64580        | 7110        | 2090        |
D.1.5 Reinforcing Design

**Flexure**

\[
A_s = \left( g_{\phi} \frac{d-N_u}{\sqrt{g_{\phi}^2-(2\phi d-h)-2M_u}} \right) \frac{1}{f_y}
\]

Eq. 4.4

\[
g = 0.85 \, b'c = (0.85)(12)(3000) = 30600
\]

Eq. 4.5

\[
d = 0.96 \, h - t_b
\]

Eq. 4.6

\[
d = (0.96)(8) - 1 = 6.68'' \text{ To inner steel (positive moment)}
\]

\[
d = (0.96)(8) - 2 = 5.68'' \text{ To outer steel (negative moment)}
\]

\[
f_f = 0.90
\]

\[
g' = 0.85 \times 0.05 \left( \frac{3000-4000}{10000} \right) \, b'c
\]

Eq. 4.15

\[
g' = 0.85 \times 0.05 \left( \frac{3000-4000}{10000} \right) (12)(3000) = 32400
\]

\[
g' = 0.85 \times 0.05 \left( \frac{3000-4000}{10000} \right) (12)(3000) = 32400
\]

\[
(0.85)(12)(3000) = 30600 < 32400 \text{ use } g' = 30600
\]

\[
\min A_s = 0.002 \, b \, h
\]

\[
= (0.002)(12)(8) = 0.192 \text{ in}^2/\text{ft}
\]

Eq. 4.7

*Load factor x service load force - Eq. 4.1, 4.2, and 4.3.

** Force at this location not required for calculations.
Flexure

<table>
<thead>
<tr>
<th>Section</th>
<th>Design Location</th>
<th>$M_u$ (in.-lb/ft)</th>
<th>$N_u$ (lb/ft)</th>
<th>$f_d$ (in.)</th>
<th>$A_s$ (in.²/ft)</th>
<th>$\text{min.} A_s$ (in.²/ft)</th>
<th>$\text{max.} A_s$ (in.²)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Throat</strong></td>
<td>8 (+M) M8 &lt; 0 - Use min. $A_s$</td>
<td>0.192*</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 (-M)</td>
<td>-64580</td>
<td>7110</td>
<td>5.112</td>
<td>0.13</td>
<td>0.192*</td>
<td>0.887</td>
<td></td>
</tr>
<tr>
<td>12 (-M)</td>
<td>-13820</td>
<td>2990</td>
<td>5.112</td>
<td>0.007</td>
<td>0.192*</td>
<td>0.938</td>
<td></td>
</tr>
<tr>
<td>15 (+M)</td>
<td>+91010</td>
<td>770</td>
<td>6.012</td>
<td>0.256*</td>
<td>0.192</td>
<td>1.138</td>
<td></td>
</tr>
<tr>
<td><strong>Face</strong></td>
<td>8 (+M) M8 &lt; 0 - Use min. $A_s$</td>
<td>0.192*</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 (-M)</td>
<td>-90740</td>
<td>5720</td>
<td>5.112</td>
<td>0.243*</td>
<td>0.192</td>
<td>0.904</td>
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</tr>
<tr>
<td>12 (-M)</td>
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<td>0.192</td>
<td>0.949</td>
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</tr>
<tr>
<td>15 (+M)</td>
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<td>310</td>
<td>6.012</td>
<td>0.286*</td>
<td>0.192</td>
<td>1.143</td>
<td></td>
</tr>
<tr>
<td><strong>Mid Length</strong></td>
<td>8 (+M) M8 &lt; 0 - Use min. $A_s$</td>
<td>0.192*</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 (-M)</td>
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<td>5.112</td>
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<td>0.192</td>
<td>0.891</td>
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<tr>
<td>12 (-M)</td>
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<td>2600</td>
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<td>0.192</td>
<td>0.943</td>
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</tr>
<tr>
<td>15 (+M)</td>
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<td>570</td>
<td>6.012</td>
<td>0.291*</td>
<td>0.192</td>
<td>1.143</td>
<td></td>
</tr>
</tbody>
</table>

* Governs design at this location.

Crack Width Control Check

\[
F_{cr} = \frac{E_1}{(30000)(\phi_f)(A_s)} \left[ \frac{M+N(d-h/2)}{j i} - C_1 b h^2 \sqrt{f_y} \right] \quad \text{Eq. 4.16}
\]

\[
e = \frac{M}{N} + d - \frac{h}{2} \quad \text{Eq. 4.17}
\]

\[
j = 0.74 + 0.1 \frac{e}{d} \text{ where } j \leq 0.90 \quad \text{Eq. 4.18}
\]

\[
i = \frac{1}{1 - \frac{d}{e}} \quad \text{Eq. 4.19}
\]

For Reinforcement Type 3 (RTYPE = 3)

\[
= 3 \sqrt{\frac{0.5(t_b)^2(s_f)}{n}} \text{ and } D_1 = 1.9
\]

Crack Width Control Check

Conservatively assume circumferential reinforcement spacing = 12 in. (S 6)
\[ n = 1 \text{ (inner and outer cages are each a single layer)} \]

\[ B_l = \sqrt[3]{\frac{0.5(1)^2 (12)}{n}} = 1.82 \text{ (for tension on inside)} \]

\[ B_l = \sqrt[3]{\frac{0.5(2)^2 (12)}{n}} = 2.88 \text{ (for tension on outside)} \]

<table>
<thead>
<tr>
<th>Sect.</th>
<th>Design Location</th>
<th>( M ) (in.-lb/ft)</th>
<th>( N ) (lb/ft)</th>
<th>( d ) (in.)</th>
<th>( B_l )</th>
<th>( e ) (in.)</th>
<th>( e/d )</th>
<th>( j )</th>
<th>( i )</th>
<th>( A_{s\text{flex}} ) (in (^2/ft ))</th>
<th>( F_{cr} )</th>
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<tbody>
<tr>
<td>Throat</td>
<td>8</td>
<td>-21630</td>
<td>M8 &lt; 0 - No Check Required</td>
<td></td>
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<tr>
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<td>1.91</td>
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<tr>
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<td>1.03</td>
<td>0.291</td>
<td>0.20</td>
</tr>
</tbody>
</table>

* \( e/d < 1.15; \) therefore, crack control will not govern.
Since \( F_{cr} < 1.0 \) at all sections, flexure reinforcement will govern design at all locations.

**Calculate Shear Strength**

**Method 1 - Locations 10 and 13**

\[
\phi V_c = 3 \phi v \sqrt{f_{c}^*} b d \quad \text{Eq. 4.20}
\]

Use \( d = 5.68 \) (conservative) @ throat & midlength section

\[
\phi V_c = (3)(0.85) \sqrt{3000}(12)(5.68) = 9520 \text{ lbs/ft}
\]

\[
V_u \leq \phi V_c \quad \text{Eq. 4.21}
\]

<table>
<thead>
<tr>
<th>Section</th>
<th>Design Location</th>
<th>( V_u ) (lbs/ft)</th>
<th>( fV_c ) (lbs/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throat</td>
<td>10</td>
<td>1730</td>
<td>9520</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>4370</td>
<td>9520</td>
</tr>
</tbody>
</table>
fVc > Vu; therefore, shear does not govern design.

Method 2 - Locations 9, 10, 13 and 14

For M/(VfVd) > 3.0

\[ \phi V_b = (1.1 + 6.3\phi) \sqrt{f'_{cv}} \phi_v b d \left( \frac{F_d F_{vp}}{F_cv F_N} \right) \]  
Eq. 4.24

\[ r = \frac{A_s}{\phi_v b d} \]  
Eq. 4.25

\[ F_d = 0.8 + 1.6/d \leq 1.25 \]  
Eq. 4.26

\[ F_c = 1 \]  
Eq. 4.27a

Calculate Shear Strength - Method 2

\[ F_N = 1.0 - 0.12 \frac{N_u}{V_u} \geq 0.75 \]  
Eq. 4.28

For M/(Vϕd) < 3.0

\[ \phi V_c = \frac{4\phi_v V_b}{\left( \frac{M}{V \phi_v d} \right)} \leq \frac{4.5 \sqrt{f'_{cv} b d \phi_v}}{F_N} \]  
Eq. 4.30

<table>
<thead>
<tr>
<th>Section</th>
<th>Design Location</th>
<th>Mu (in.-lb/ft)</th>
<th>Nu (lb/ft)</th>
<th>Vu (lb/ft)</th>
<th>d (in.)</th>
<th>As (in.²/ft)</th>
<th>r</th>
<th>M/Vu φv d</th>
<th>Fd</th>
<th>Fn</th>
<th>fVb (lb/ft)</th>
<th>4vC (lb/ft)</th>
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<td></td>
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</tr>
</tbody>
</table>

* $M/V_{\phi d} > 3.0$, use 3.0

* Shear strength ($\phi V_b$) at tip of haunch (Sections 11, 12) is compared to shear force ($V_u$) at $\phi_d$ from tip of haunch (10, 13).

$\phi V_b > V_u$ at all sections; therefore, shear will not govern design.

Box Section Design Example.
**Installation Data**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Height of Fill Over Culvert, ft</td>
<td>4.000</td>
</tr>
<tr>
<td>Unit Weight, PCF</td>
<td>120.000</td>
</tr>
<tr>
<td>Minimum Lateral Soil Pressure Coefficient</td>
<td>0.250</td>
</tr>
<tr>
<td>Maximum Lateral Soil Pressure Coefficient</td>
<td>0.500</td>
</tr>
<tr>
<td>Soil - Structure Interaction Coefficient</td>
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**Loading Data**

<table>
<thead>
<tr>
<th>Type</th>
<th>Factor</th>
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<tbody>
<tr>
<td>Load Factor - Weight and Shear</td>
<td>1.300</td>
</tr>
<tr>
<td>Load Factor - Thrust</td>
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</table>

**Material Properties**

<table>
<thead>
<tr>
<th>Material</th>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>Minimum Specified Yield Stress, KSI</td>
<td>60,000</td>
</tr>
<tr>
<td>Concrete</td>
<td>Specified Compressive Strength, KSI</td>
<td>3,000</td>
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</table>

**Culvert Data**

<table>
<thead>
<tr>
<th>Component</th>
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<tbody>
<tr>
<td>Top Slab Thickness, in.</td>
<td>8.000</td>
</tr>
<tr>
<td>Bottom Slab Thickness, in.</td>
<td>8.000</td>
</tr>
<tr>
<td>Side Wall Thickness, in.</td>
<td>8.000</td>
</tr>
<tr>
<td>Horizontal Haunch Dimension, in.</td>
<td>8.000</td>
</tr>
<tr>
<td>Vertical Haunch Dimension, in.</td>
<td>8.000</td>
</tr>
<tr>
<td>Concrete Cover Over Steel, in.</td>
<td>8.000</td>
</tr>
<tr>
<td>Top Slab - Outside Face</td>
<td>2.000</td>
</tr>
<tr>
<td>Side Wall - Outside Face</td>
<td>2.000</td>
</tr>
<tr>
<td>Bottom Slab - Outside Face</td>
<td>2.000</td>
</tr>
<tr>
<td>Top Slab - Inside Face</td>
<td>1.000</td>
</tr>
<tr>
<td>Bottom Slab - Inside Face</td>
<td>1.000</td>
</tr>
<tr>
<td>Side Wall - Inside Face</td>
<td>1.000</td>
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</table>

**Reinforcing Steel Data**

<table>
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<tr>
<th>Location</th>
<th>Area</th>
<th>Min. Wire</th>
<th>Location</th>
<th>Area</th>
<th>Min. Wire</th>
<th>Location</th>
<th>Area</th>
<th>Min. Wire</th>
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<tbody>
<tr>
<td>Top Slab - Inside Face</td>
<td>0.247</td>
<td>2.0*</td>
<td>Top Slab - Outside Face</td>
<td>0.192</td>
<td>2.0*</td>
<td>Bottom Slab - Inside Face</td>
<td>0.271</td>
<td>2.0*</td>
</tr>
<tr>
<td>Top Slab - Inside Face</td>
<td>0.247</td>
<td>2.0*</td>
<td></td>
<td></td>
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<td>Side Wall - Outside Face</td>
<td>0.192</td>
<td>2.0*</td>
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<tr>
<td>Top Slab - Inside Face</td>
<td>0.247</td>
<td>2.0*</td>
<td></td>
<td></td>
<td></td>
<td>Side Wall - Inside Face</td>
<td>0.192</td>
<td>2.0*</td>
</tr>
</tbody>
</table>

*Program Assigned Value

The side wall outside face steel is bent at the culvert corners and extended into the outside face of the top and bottom slabs. The theoretical cut-off lengths measured from the bend point are 21.7 and 23.4 in. respectively. Anchorage lengths must be added.
### Installation Data

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Height of Fill Over Culvert, ft</td>
<td>6.000</td>
</tr>
<tr>
<td>Lait Weight,pcf</td>
<td>120.000</td>
</tr>
<tr>
<td>Minimum Lateral Soil Pressure Coefficient</td>
<td>0.250</td>
</tr>
<tr>
<td>Maximum Lateral Soil Pressure Coefficient</td>
<td>0.500</td>
</tr>
<tr>
<td>Soil - Structure Interaction Coefficient</td>
<td>1.200</td>
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</tbody>
</table>

### Leading Data

<table>
<thead>
<tr>
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<th>Value</th>
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</thead>
<tbody>
<tr>
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<td>1.500</td>
</tr>
<tr>
<td>Load Factor - Thrust</td>
<td>1.300</td>
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### Material Properties

<table>
<thead>
<tr>
<th>Material</th>
<th>Property</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Steel</td>
<td>Minimum Specified Yield Stress, ksi</td>
<td>60.000</td>
</tr>
<tr>
<td>Concrete</td>
<td>Specified Compressive Strength, ksi</td>
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### Concrete Data

<table>
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</tr>
<tr>
<td>Bottom Slab Thickness, in.</td>
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</tr>
<tr>
<td>Side Wall Thickness, in.</td>
<td>8.000</td>
</tr>
<tr>
<td>Horizontal Haunch Dimension, in.</td>
<td>8.000</td>
</tr>
<tr>
<td>Vertical Haunch Dimension, in.</td>
<td>8.000</td>
</tr>
<tr>
<td>Concrete Cover Over Steel, in.</td>
<td>2.000</td>
</tr>
<tr>
<td>Top Slab - Outside Face</td>
<td>2.000</td>
</tr>
<tr>
<td>Side Wall - Outside Face</td>
<td>2.000</td>
</tr>
<tr>
<td>Bottom Slab - Outside Face</td>
<td>2.000</td>
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<tr>
<td>Top Slab - Inside Face</td>
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<td>Bottom Slab - Inside Face</td>
<td>1.000</td>
</tr>
<tr>
<td>Side Wall - Inside Face</td>
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### Reinforcing Steel Data

<table>
<thead>
<tr>
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<th>Area, in²</th>
<th>Wire, per ft</th>
<th>Space, in</th>
<th>Stirrups Required</th>
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<tr>
<td>Side Wall - Inside Face</td>
<td>0.147</td>
<td>2.00</td>
<td>2.00</td>
<td>No</td>
</tr>
</tbody>
</table>

**Program Assigned Value**

The side wall outside face steel is bent at the culvert corners and extended into the outside face of the top and bottom slabs. The theoretical cut-off lengths measured from the bend point are 18.5 and 19.7 in. respectively. Anchorage lengths must be added.
**INSTALLATION DATA**

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of Fill Over Culvert, ft</td>
<td>8.000</td>
</tr>
<tr>
<td>Unit Weight,pcf</td>
<td>120.000</td>
</tr>
<tr>
<td>Minimum Lateral Soil Pressure Coefficient</td>
<td>0.250</td>
</tr>
<tr>
<td>Maximum Lateral Soil Pressure Coefficient</td>
<td>0.500</td>
</tr>
<tr>
<td>Soil - Structure Interaction Coefficient</td>
<td>1.200</td>
</tr>
</tbody>
</table>

**LOADING DATA**

| Load Factor - Moment and Shear | 1.300 |
| Load Factor - Thrust | 1.300 |

**MATERIAL PROPERTIES**

<table>
<thead>
<tr>
<th>Material</th>
<th>Minimum Specified Yield Stress,ksi</th>
<th>Specified Compressive Strength, ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>60.000</td>
<td>30.000</td>
</tr>
<tr>
<td>Concrete</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CONCRETE DATA**

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Slab Thickness, in.</td>
<td>8.000</td>
</tr>
<tr>
<td>Bottom Slab Thickness, in.</td>
<td>8.000</td>
</tr>
<tr>
<td>Side Wall Thickness, in.</td>
<td>8.000</td>
</tr>
<tr>
<td>Horizontal Haunch Dimension, in.</td>
<td>8.000</td>
</tr>
<tr>
<td>Vertical Haunch Dimension, in.</td>
<td>8.000</td>
</tr>
<tr>
<td>Concrete Cover Over Steel, in.</td>
<td>2.000</td>
</tr>
<tr>
<td>Top Slab - Outside Face</td>
<td>2.000</td>
</tr>
<tr>
<td>Side Wall - Outside Face</td>
<td>2.000</td>
</tr>
<tr>
<td>Bottom Slab - Outside Face</td>
<td>2.000</td>
</tr>
<tr>
<td>Top Slab - Inside Face</td>
<td>1.000</td>
</tr>
<tr>
<td>Bottom Slab - Inside Face</td>
<td>1.000</td>
</tr>
<tr>
<td>Side Wall - Inside Face</td>
<td>1.000</td>
</tr>
</tbody>
</table>

**REINFORCING STEEL DATA**

<table>
<thead>
<tr>
<th>Location</th>
<th>Min Area, in.</th>
<th>Max Spacings, in.</th>
<th>Stirrups Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Slab - Inside Face</td>
<td>0.222</td>
<td>2.5*</td>
<td>NO</td>
</tr>
<tr>
<td>Top Slab - Outside Face</td>
<td>0.192</td>
<td>2.0*</td>
<td>NO</td>
</tr>
<tr>
<td>Bottom Slab - Inside Face</td>
<td>0.239</td>
<td>2.0*</td>
<td>NO</td>
</tr>
<tr>
<td>Side Wall - Outside Face</td>
<td>0.192</td>
<td>2.0*</td>
<td>NO</td>
</tr>
<tr>
<td>Side Wall - Inside Face</td>
<td>0.192</td>
<td>2.0*</td>
<td>NO</td>
</tr>
</tbody>
</table>

*Program Assigned Value*

The side wall outside face steel is bent at the culvert corners and extended into the outside face of the top and bottom slabs. The theoretical cut-off lengths measured from the bend point are 15.7 and 16.6 in., respectively. Anchorage lengths must be added.
D.1.6 Summary of Design Example D.1

Compare hand and computer designs for throat face and midlength sections.

<table>
<thead>
<tr>
<th>Location</th>
<th>Designation*</th>
<th>Required Steel Area, in.^2/ft</th>
<th>Hand</th>
<th>Hand</th>
<th>Hand</th>
<th>Hand</th>
<th>Hand</th>
<th>Hand</th>
<th>Hand</th>
<th>Hand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Throat</td>
<td></td>
<td>Face</td>
<td></td>
<td>Mid-Length</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top slab - inside</td>
<td>AS2</td>
<td>0.256</td>
<td>0.222</td>
<td>0.286</td>
<td>0.247</td>
<td>0.291</td>
<td>0.256</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top slab - outside</td>
<td>AS8</td>
<td>0.192</td>
<td>0.192</td>
<td>0.192</td>
<td>0.192</td>
<td>0.192</td>
<td>0.192</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom slab - inside</td>
<td>AS3</td>
<td>0.256</td>
<td>0.239</td>
<td>0.286</td>
<td>0.271</td>
<td>0.291</td>
<td>0.276</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sidewall - outside</td>
<td>ASI</td>
<td>0.192</td>
<td>0.192</td>
<td>0.243</td>
<td>0.248</td>
<td>0.203</td>
<td>0.210</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sidewall - inside</td>
<td>AS4</td>
<td>0.192</td>
<td>0.192</td>
<td>0.192</td>
<td>0.192</td>
<td>0.192</td>
<td>0.192</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Also refer to Figure 4-1.

**Conclusion:** Since structure is relatively short, it is probably most efficient to use a single design by selecting the most conservative combination of areas from the individual designs.

<table>
<thead>
<tr>
<th>Location</th>
<th>Designation*</th>
<th>Required Area, in.^2/ft</th>
<th>Hand</th>
<th>Hand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top slab - inside</td>
<td>AS2</td>
<td>0.291</td>
<td>0.256</td>
<td></td>
</tr>
<tr>
<td>Top slab - outside</td>
<td>AS8</td>
<td>0.192</td>
<td>0.192</td>
<td></td>
</tr>
<tr>
<td>Bottom slab - inside</td>
<td>AS3</td>
<td>0.291</td>
<td>0.276</td>
<td>Mid-Length</td>
</tr>
<tr>
<td>Sidewall - outside</td>
<td>ASI</td>
<td>0.243</td>
<td>0.248</td>
<td>Face</td>
</tr>
<tr>
<td>Sidewall - inside</td>
<td>AS4</td>
<td>0.192</td>
<td>0.192</td>
<td>All Sections</td>
</tr>
</tbody>
</table>

D.2 Side Tapered Reinforced Concrete Pipe

D.2.1 Problem:

Determine the reinforcing requirements for a side tapered pipe inlet. For geometry, use the results of Example No. 2-A in Reference 1.

D.2.2 Design Data
Note: Add 2' surcharge for miscellaneous unanticipated loads

RTYPE = 2, smooth WWF

\[ F_e = 1.2 \]
\[ t = 4.1 \]
\[ n = 1 \]

**Given Data**

- \( \gamma_s = 120 \text{ pcf} \)
- \( \gamma_c = 150 \text{ pcf} \)
- \( \gamma_f = 62.5 \text{ pcf} \)
- \( \phi_f = 0.9 \)
- \( \phi_v = 0.9 \)
- \( F_{cr} = 1.0 \)
- \( F_{vp} = 1.0 \)
- \( F_{rp} = 1.0 \)
- \( f_c' = 5000 \text{ psi} \)
- \( f_y = 65000 \text{ psi} \)
- \( t_{bo}, t_{bi} = 1 \text{ in.} \)

**Class C Bedding Angle:**
- Circular - 90°
- Elliptical - 0.5 \( B' \)
Assume $h = 8'$ (B wall @ throat)

$H_e @ Face = 2' + 2' = 4'$

$H_e @ Midlength Section = 4' + \frac{L_1}{2} \left( \frac{1}{S_e} + S_0 \right) = 4 + \frac{6}{2} \left( \frac{1}{2} + 0.05 \right) = 5.65'$ Say 6'-0"

$H_e @ Throat = 4 + 6 \left( \frac{1}{2} + 0.005 \right) = 7.3'$ Say 7'-6"

Culvert Geometry

Assume: $u/v = 0.5 = k_1$, Typ. for HE pipe

Taper = 4.0

Throat: $D_i = 84''$

$r_m = 84/2 + 8/2 = 46''$

Face:

$$r_1 = \frac{z/T}{1 + 1/k_1 - \sqrt{1 + 1/k_1^2}} + \frac{D_i}{2} = \frac{72/4 \left( 1/0.5 - \sqrt{1 + 1/0.5^2} \right)}{1 + 1/0.5 - \sqrt{1 + 1/0.5^2}} + \frac{84}{2} = 36.44''$$

$$u = \frac{z}{T} + \frac{D_i}{2} - r_1 = \frac{72}{4} + \frac{84}{2} - 36.44 = 23.56''$$

$$v = \frac{u}{k_1} = \frac{23.56}{0.5} = 47.12''$$
See Figure 1-2.

Midlength:

\[
\frac{r_1}{2} = \frac{36/4}{1 + 1/0.5 - \sqrt{1 + 1/0.5^2}} \left( 1/0.5 - \sqrt{1 + 1/0.5^2} \right) + \frac{84}{2} = 39.22''
\]

\[
u = \frac{36}{4} + \frac{84}{2} = 39.22''
\]

\[
v = \frac{11.78}{0.5} = 23.56''
\]

\[
r_2 = \frac{84}{2} + 23.56'' = 65.56''
\]

**D.2.3 Calculate Applied Loads**

**Throat** (Circular Section)

Earth Load \(W_e\)

\[
w_e = F_e \gamma_s B_0 (H_e + R_0/6)
\]

\[
R_0 = B_0 = D_i + 2h = 100\ \text{in}
\]

\[
= (1.2)(120)(100/12) \left( 7.5 + \frac{100}{(12)(6)} \right) = 10670 \text{ lb/ft}
\]

Dead Load \(W_p\)

\[
W_p = 3.3 (h)(D_i + h) = (3.3)(8)(84 + 8) = 2430 \text{ lb/ft}
\]

Internal Fluid Load \(W_f\)
\[ W_f = 0.34 \, D_i^2 = (0.34)(84)^2 = 2400 \, \text{lb/ft} \quad \text{Eq. 2.4} \]

**Face (Elliptical Section)**

**Earth Load** \( W_e \)

\[ B_0 = 2 \, (h + r_1 + u) = 2 \, (8 + 36.44 + 23.56) = 136 \, \text{in.} \]

\[ R_0 = 100 \, \text{in.} \]

\[ W_e = (1.2)(120) \left( \frac{136}{12} \right) \left( 4 + \frac{100}{12}(6) \right) = 8790 \, \text{lb/ft} \quad \text{Eq. 2.7b} \]

**Dead Load** \( W_p \)

\[ W_p = 4.2h \left[ (r_2 + \frac{h}{2}) \arctan\left( \frac{u}{v} \right) + (r_1 + \frac{h}{2})(1.57 - \arctan\left( \frac{u}{v} \right)) \right] \quad \text{Eq. 2.2} \]

\[ = 4.2(8) \left[ (89.12 + \frac{8}{2}) \arctan(0.5) + (36.44 + \frac{8}{2})(1.57 - \arctan(0.5)) \right] \]

\[ = 2950 \, \text{lb/ft} \]

**Internal Fluid Load** \( W_f \)

\[ W_f = 0.87 \left[ \frac{r_2^2}{2} \arctan\left( \frac{u}{v} \right) + r_1^2(1.57 - \arctan\left( \frac{u}{v} \right)) - u \, v \right] \quad \text{Eq. 2.5} \]

\[ = 0.87 \left[ (89.12^2) \arctan(0.5) + 36.44^2(1.57 - \arctan(0.5)) - (23.56)(47.12) \right] \]

\[ = 3520 \, \text{lb/ft} \]

**Midlength**

**Earth Load** \( W_e \)

\[ B_0 = 2 \, (8 + 39.22 + 11.78) = 118 \, \text{in.} \]

\[ R_0 = 100 \, \text{in.} \]
We = \((1.2)(120)(118/12)\left(\frac{600}{12}\right)\) = 10460 lb/ft \[\text{Eq. 2.7b}\]

Dead Load \(W_p\)

\[W_p = (4.2)(8) [(65.56 + 8/2) \arctan (0.5) + (39.22 + 8/2)(1.57 - \arctan (0.5))]\]

= 2690 lb/ft \[\text{Eq. 2.2}\]

Internal Fluid Load \(W_f\)

\[W_f = 0.87 [(65.56^2) \arctan (0.5) + 39.22^2 (1.57 - \arctan (0.5)) - (11.78)(23.56)]\]

= 2970 lb/ft \[\text{Eq. 2.5}\]

---

**D.2.4 Calculate Moments, Thrusts & Shears @ Design Sections**

Using the following equations, calculate the moments, thrusts, and shears at design locations 1 through 5 shown on Figure 4-4.

\[M = (C_{m1} W_e + C_{m2} W_p + C_{m3} W_f) \frac{B'}{2}\]  \[\text{Eq. 3.33}\]

\[N = C_{n1} W_e + C_{n2} W_p + C_{n3} W_f\]  \[\text{Eq. 3.34}\]

\[V = C_{v1} W_e + C_{v2} W_p + C_{v3} W_f\]  \[\text{Eq. 3.35}\]

\[M_u = L_f M\]  \[\text{Eq. 4.1}\]

\[N_u = L_f N\]  \[\text{Eq. 4.2}\]

\[V_u = L_f V\]  \[\text{Eq. 4.3}\]

**Throat - Design Locations (Figure 4-4)**

**Design Location**

1  I @ invert \(\theta_1 = 0^\circ\)

2  near invert where \(M/Vd = 3.0\) (Figure 4-5)
   \(r = 46''\)
   \(f_v d \sim f_v (0.96 h - t_b) = 0.9 [(0.96)(8) - 1] = 6.01\) \(\theta_2 = 19^\circ\)  \[\text{Eq. 4.6}\]

3  maximum negative moment based on earth load only (Figure 3-1) \(\theta_3 = 75^\circ\)
4 near crown where $M/Vd = 3.0$ (Figure 4-5) $\theta_4 = 149^\circ$
5 crown $\theta_5 = 180^\circ$

**Throat**

<table>
<thead>
<tr>
<th>Design Location</th>
<th>$c_{m1}$ Fig. 3-1</th>
<th>$c_{m2}$ Fig. 3-5</th>
<th>$c_{m3}$ Fig. 3-6</th>
<th>$M$ (in.-lb/ft)</th>
<th>$M_u$ (in.-lb/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 = 0°</td>
<td>0.13</td>
<td>0.20</td>
<td>0.12</td>
<td>99410</td>
<td>129230</td>
</tr>
<tr>
<td>2 = 19°</td>
<td>0.09</td>
<td>0.10</td>
<td>0.08</td>
<td>64180</td>
<td>83440</td>
</tr>
<tr>
<td>3 = 75°</td>
<td>-0.09</td>
<td>-0.10</td>
<td>-0.09</td>
<td>-65290</td>
<td>-84870</td>
</tr>
<tr>
<td>4 = 149°</td>
<td>0.04</td>
<td>0.05</td>
<td>0.04</td>
<td>29640</td>
<td>38530</td>
</tr>
<tr>
<td>5 = 180°</td>
<td>0.07</td>
<td>0.08</td>
<td>0.07</td>
<td>51030</td>
<td>66340</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Design Location</th>
<th>$c_{n1}$ Fig. 3-1</th>
<th>$c_{n2}$ Fig. 3-5</th>
<th>$c_{n3}$ Fig. 3-6</th>
<th>$N$ (lb/ft)</th>
<th>$N_u$ (lb/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 = 0°</td>
<td>0.32</td>
<td>0.12</td>
<td>-0.28</td>
<td>3030</td>
<td>3940</td>
</tr>
<tr>
<td>2 = 19°</td>
<td>0.36</td>
<td>0.22</td>
<td>-0.24</td>
<td>3800</td>
<td>4940</td>
</tr>
<tr>
<td>3 = 75°</td>
<td>0.53</td>
<td>0.30</td>
<td>-0.07</td>
<td>6220</td>
<td>8080</td>
</tr>
<tr>
<td>4 = 149°</td>
<td>0.41</td>
<td>-0.02</td>
<td>-0.19</td>
<td>3870</td>
<td>5030</td>
</tr>
<tr>
<td>5 = 180°</td>
<td>0.38</td>
<td>-0.09</td>
<td>-0.22</td>
<td>3310</td>
<td>4300</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Design Location</th>
<th>$c_{v1}$ Fig. 3-1</th>
<th>$c_{v2}$ Fig. 3-5</th>
<th>$c_{v3}$ Fig. 3-6</th>
<th>$V$ (lb/ft)</th>
<th>$V_u$ (lb/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 = 0°</td>
<td>- - Not Applicable - -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 = 19°</td>
<td>0.21</td>
<td>0.40</td>
<td>0.20</td>
<td>3690</td>
<td>4800</td>
</tr>
<tr>
<td>3 = 75°</td>
<td>- - Not Applicable - -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 = 149°</td>
<td>-0.10</td>
<td>-0.11</td>
<td>-0.11</td>
<td>-1600</td>
<td>-2080</td>
</tr>
<tr>
<td>5 = 180°</td>
<td>- - Not Applicable - -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Face - Design Locations (Figure 4-4)**

**Flexure Design Location**
1 @ invert $\theta_1 = 0^\circ$
3 maximum negative moment based on earth load only (Figure 3-3) $\theta_3 = 80^\circ$
Shear Design Location
2 and 4 where $M/V_d = 3.0$

From Eqs. 3.33 and 3.35, using earth load only

$$\frac{M}{\phi V_d} = \frac{C_{m1} W_e B'}{2 C_{v1} W_e d \phi_v} = 3$$

$$B'/D' = \frac{120 + 8}{84 + 8} = 1.39$$

$$\frac{C_{m1}}{C_{v1}} = \frac{(3)(2)(d)(\phi)}{B'} = \frac{(3)(2)(6.68)(0.9)}{120 + 8} = 0.282$$

### Critical Shear Location

<table>
<thead>
<tr>
<th>Location</th>
<th>q</th>
<th>$C_{m1}$ Fig. 3-3</th>
<th>$C_{v1}$ Fig. 3-3</th>
<th>$C_{m1}/C_{v1}$</th>
<th>$M/V_d=3$ @ $13^\circ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>10°</td>
<td>0.13</td>
<td>0.30</td>
<td>0.433</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15°</td>
<td>0.08</td>
<td>0.37</td>
<td>0.216</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20°</td>
<td>0.03</td>
<td>0.40</td>
<td>0.075</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>160°</td>
<td>0.05</td>
<td>-0.20</td>
<td>-0.25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>165°</td>
<td>0.07</td>
<td>-0.15</td>
<td>-0.467</td>
<td>M/V_d=3 @ 161°</td>
</tr>
</tbody>
</table>

### Design Moments

<table>
<thead>
<tr>
<th>Design Location</th>
<th>$c_{m1}$ Fig. 3-3</th>
<th>$c_{m2}$ Fig. 3-5</th>
<th>$c_{m3}$ Fig. 3-6</th>
<th>$M$ (in.-lb/ft)</th>
<th>$M_u$ (in.-lb/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 = 0°</td>
<td>0.17</td>
<td>0.20</td>
<td>0.12</td>
<td>160430</td>
<td>208560</td>
</tr>
<tr>
<td>2 = 13°</td>
<td>0.10</td>
<td>0.13</td>
<td>0.10</td>
<td>103330</td>
<td>134330</td>
</tr>
<tr>
<td>3 = 80°</td>
<td>-0.12</td>
<td>-0.10</td>
<td>-0.08</td>
<td>-104410</td>
<td>-135730</td>
</tr>
<tr>
<td>4 = 161°</td>
<td>0.05</td>
<td>0.07</td>
<td>0.06</td>
<td>54860</td>
<td>71320</td>
</tr>
<tr>
<td>5 = 180°</td>
<td>0.10</td>
<td>0.08</td>
<td>0.07</td>
<td>87130</td>
<td>113270</td>
</tr>
</tbody>
</table>

### Design Thrusts

<table>
<thead>
<tr>
<th>Design Location</th>
<th>$c_{n1}$ Fig. 3-3</th>
<th>$c_{n2}$ Fig. 3-5</th>
<th>$c_{n3}$ Fig. 3-6</th>
<th>$N$ (lb/ft)</th>
<th>$N_u$ (lb/ft)</th>
</tr>
</thead>
</table>
### Design Shears

<table>
<thead>
<tr>
<th>Design Location</th>
<th>$C_{v1}$ Fig. 3-1</th>
<th>$C_{v2}$ Fig. 3-5</th>
<th>$C_{v3}$ Fig. 3-6</th>
<th>$V$ (in.-lb/ft)</th>
<th>$V_u$ (in.-lb/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 = 0°</td>
<td>0.27</td>
<td>0.12</td>
<td>-0.28</td>
<td>1740</td>
<td>2260</td>
</tr>
<tr>
<td>2 = 13°</td>
<td>0.32</td>
<td>0.18</td>
<td>-0.25</td>
<td>2460</td>
<td>3200</td>
</tr>
<tr>
<td>3 = 80°</td>
<td>0.55</td>
<td>0.29</td>
<td>-0.07</td>
<td>5440</td>
<td>7080</td>
</tr>
<tr>
<td>4 = 161°</td>
<td>0.31</td>
<td>-0.05</td>
<td>-0.21</td>
<td>1840</td>
<td>2390</td>
</tr>
<tr>
<td>5 = 180°</td>
<td>0.29</td>
<td>-0.08</td>
<td>-0.22</td>
<td>1540</td>
<td>2000</td>
</tr>
</tbody>
</table>

### Midlength - Design Locations (Figure 4-4)

**Flexure**

- $B'/D' = 110/92 = 1.20$
- $\theta_1 = 0°$
- $\theta_3 = 78°$
- $\theta_5 = 180°$

**Shear**

$$C_{m1} = \frac{(3)(2)(d)(\phi)}{B'} = \frac{(3)(2)(6,68)(0.9)}{110} = 0.382$$

### Critical Shear Location

<table>
<thead>
<tr>
<th>Location</th>
<th>$q$</th>
<th>$C_{m1}$ Fig. 3-3</th>
<th>$C_{v1}$ Fig. 3-3</th>
<th>$C_{m1}/C_{v1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>$10°$</td>
<td>0.13</td>
<td>0.26</td>
<td>0.500</td>
</tr>
<tr>
<td></td>
<td>$15°$</td>
<td>0.10</td>
<td>0.35</td>
<td>0.286</td>
</tr>
<tr>
<td>4</td>
<td>$160°$</td>
<td>0.05</td>
<td>-0.17</td>
<td>-0.294</td>
</tr>
<tr>
<td></td>
<td>$165°$</td>
<td>0.07</td>
<td>-0.13</td>
<td>-0.538</td>
</tr>
</tbody>
</table>

**Midlength (Continued)**

**Design Moments**
### Design Thrusts

<table>
<thead>
<tr>
<th>Design Location</th>
<th>$C_{n1}$ Fig. 3-3</th>
<th>$C_{n2}$ Fig. 3-5</th>
<th>$C_{n3}$ Fig. 3-6</th>
<th>$N$ (lb/ft)</th>
<th>$N_u$ (lb/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 = 0°</td>
<td>0.28</td>
<td>0.12</td>
<td>-0.28</td>
<td>2420</td>
<td>3150</td>
</tr>
<tr>
<td>2 = 14°</td>
<td>0.33</td>
<td>0.19</td>
<td>-0.25</td>
<td>3220</td>
<td>4190</td>
</tr>
<tr>
<td>3 = 78°</td>
<td>0.56</td>
<td>0.30</td>
<td>-0.07</td>
<td>6460</td>
<td>8390</td>
</tr>
<tr>
<td>4 = 161°</td>
<td>0.33</td>
<td>-0.06</td>
<td>-0.21</td>
<td>2670</td>
<td>3470</td>
</tr>
<tr>
<td>5 = 180°</td>
<td>0.31</td>
<td>-0.08</td>
<td>-0.22</td>
<td>2370</td>
<td>3090</td>
</tr>
</tbody>
</table>

### Design Shears

<table>
<thead>
<tr>
<th>Design Location</th>
<th>$C_{v1}$ Fig. 3-1</th>
<th>$C_{v2}$ Fig. 3-5</th>
<th>$C_{v3}$ Fig. 3-6</th>
<th>$V$ (in.-lb/ft)</th>
<th>$V_u$ (in.-lb/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 = 0°</td>
<td></td>
<td></td>
<td></td>
<td>4740</td>
<td>6160</td>
</tr>
<tr>
<td>2 = 14°</td>
<td>0.30</td>
<td>0.43</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 = 78°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 = 161°</td>
<td></td>
<td></td>
<td></td>
<td>-1920</td>
<td>-2490</td>
</tr>
<tr>
<td>5 = 180°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### D.2.5 Reinforcing Design

**Flexure**

$$A_s = \left\{ g \phi_f d - N_u - \sqrt{g^2 (\phi_f d)^2 - N_u (2 \phi_f d - h) - 2 M_u} \right\} \frac{1}{f_y}$$  \hspace{1cm} Eq. 4.4

- $g = 0.085 b f'_c = (0.085)(12)(5000) = 51000 \text{ lb/in.}$  \hspace{1cm} Eq. 4.5
- $\phi_f d = (6.68)(0.9) = 6.01$
\[ A_s = \frac{(51000)(0.601) - N_u - \sqrt{51000(51000)(6.01)^2 - N_u ((2)(6.01) - 8) - 2M_u}}{65000} \]
\[ = 4.717 - \frac{N_u}{65000} - 0.003474\sqrt{1843351.3 - 4.024N_u - 2M_u} \]

**Minimum Steel**

**Inside**

\[ A_{smin.} = \frac{(B_i + h)^2}{65000} \]

Throat: \( A_{smin.} = \frac{(84 + 8)^2}{65000} = 0.130 \text{ in}^2/\text{ft} \)

Face: \( A_{smin.} = \frac{(120 + 8)^2}{65000} = 0.252 \text{ in}^2/\text{ft} \)

Midlength: \( A_{smin.} = \frac{(102 + 8)^2}{65000} = 0.186 \text{ in}^2/\text{ft} \)

**Outside**

\[ A_{smin.} = 0.75 \frac{(B_i + h)^2}{65000} \]

Throat: \( A_{smin.} = (0.75)(0.130) = 0.098 \text{ in}^2/\text{ft} \)

Face: \( A_{smin.} = (0.75)(0.252) = 0.189 \text{ in}^2/\text{ft} \)

Midlength: \( A_{smin.} = (0.75)(0.186) = 0.140 \text{ in}^2/\text{ft} \)

**Maximum Steel**

\[ A_{smax.} = \left( \frac{(5.5 \times 10^4) \phi_1 d}{(87000 + f_y)} - 0.75 N_u \right) \frac{1}{f_y} \]

Eq. 4.14
\[ g' = \left[ 0.85 - 0.05 \left( \frac{(f'c - 4000)}{1000} \right) \right] b f'c \quad \text{Eq. 4.15} \]

\[ g' = \left[ 0.85 - 0.05 \left( \frac{(5000 - 4000)}{1000} \right) \right] (12)(5000) = 48000 \]

\[(0.65)(12)(5000) < 48000 < (0.85)(12)(5000) \quad \text{o.k.} \]

\[ A_{\text{smax.}} = \left( \frac{5.5 \times 10^4)(48000)(0.9)(6.68)}{87000 + 65000} - 0.75 N_u \right) \frac{1}{65000} = 1.606 - \frac{N_u}{86670} \]

<table>
<thead>
<tr>
<th>Flexural Reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Section</strong></td>
</tr>
<tr>
<td>Throat</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Face</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Mid-</td>
</tr>
<tr>
<td>Length</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

**0.01 Inch Crack Width Control**

\[ F_{cr} = \frac{B_i}{(30000)(f'c)(A_s)} \left[ M + N (d - h/2) \right] - C_1 b h^2 \sqrt{f'c} \quad \text{Eq. 4.16} \]

\[ e = \frac{M}{N} + d - \frac{h}{2} \quad \text{Eq. 4.17} \]

\[ j = 0.74 + 0.1 \frac{e}{d} \leq 0.9 \quad \text{Eq. 4.18} \]

\[ i = \frac{1}{1 - \frac{d}{e}} \quad \text{Eq. 4.19} \]
B1  For Type 2 reinforcing - smooth WWF

C1

<table>
<thead>
<tr>
<th>Section</th>
<th>Design Location</th>
<th>M (in.-lb/ft)</th>
<th>N (lb/ft)</th>
<th>e (in.)</th>
<th>j</th>
<th>i</th>
<th>Asflex (in.²/ft)</th>
<th>Fcr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throat</td>
<td>1</td>
<td>99410</td>
<td>3030</td>
<td>35.49</td>
<td>0.90</td>
<td>1.20</td>
<td>0.304</td>
<td>0.324</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>65290</td>
<td>6220</td>
<td>13.18</td>
<td>0.90</td>
<td>1.84</td>
<td>0.142</td>
<td>&lt; 0</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>51030</td>
<td>3310</td>
<td>18.10</td>
<td>0.90</td>
<td>1.50</td>
<td>0.130</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>Face</td>
<td>1</td>
<td>160430</td>
<td>1740</td>
<td>94.88</td>
<td>0.90</td>
<td>1.07</td>
<td>0.546</td>
<td>0.918</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>104410</td>
<td>5440</td>
<td>21.87</td>
<td>0.90</td>
<td>1.38</td>
<td>0.292</td>
<td>0.274</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>87130</td>
<td>1540</td>
<td>59.26</td>
<td>0.90</td>
<td>1.11</td>
<td>0.280</td>
<td>0.191</td>
</tr>
<tr>
<td>Mid-Length</td>
<td>1</td>
<td>142720</td>
<td>2420</td>
<td>61.66</td>
<td>0.90</td>
<td>1.11</td>
<td>0.471</td>
<td>0.803</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>96900</td>
<td>6460</td>
<td>17.68</td>
<td>0.90</td>
<td>1.52</td>
<td>0.252</td>
<td>0.050</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>75050</td>
<td>2370</td>
<td>34.35</td>
<td>0.90</td>
<td>1.21</td>
<td>0.226</td>
<td>&lt; 0</td>
</tr>
</tbody>
</table>

In all cases the crack control factor ($F_{cr}$) is less than 1.0; therefore, the flexural reinforcement will govern the design.

**Shear** (Method 2 for Pipe)

$$\phi_c V_b = (1.1 + 6.3\phi_c) \sqrt{f'_c} \frac{\phi_c}{b'd} \left( \frac{F_d F_{vd}}{F_c F_N} \right)$$  \hspace{1cm} \text{Eq. 4.24}

$$r = \frac{A_s}{\phi_c b'd} \leq 0.02 = \frac{A_s}{(0.9)(12)(6.68)} = 72.14$$  \hspace{1cm} \text{Eq. 4.25}

$$F_c = 1 + \frac{d}{2r_m} \text{ @ design locations 2 & 4 moment produces tension on inside of pipe}$$  \hspace{1cm} \text{Eq. 4.27b}

**Throat:**

$$F_c = 1 + \frac{6.68}{(42+2)(2)} = 1.073$$

$r_m$ depends upon whether the design section is in the $r_1$ or $r_2$

**Face:**

segment. $\arctan \frac{u}{v} = 26.6° > 14°$ & ($180° - 160°$); therefore, $r_m$ is located in segment $r_2$
Face:

\[ F_c = 1 + \frac{6.68}{2(89.12 + 4)} = 1.036 \]

Midlength:

\[ F_c = 1 + \frac{6.68}{2(65.56 + 4)} = 1.048 \]

\[ F_N = 1.0 - 0.12 \frac{N_u}{V_u} \geq 0.75 \quad \text{Eq. 4.28} \]

<table>
<thead>
<tr>
<th>Section</th>
<th>Design Location</th>
<th>( N_u )</th>
<th>( V_u )</th>
<th>( A_s )</th>
<th>( r )</th>
<th>FN</th>
<th>( V_b )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(lb/ft)</td>
<td>(lb/ft)</td>
<td>(in.²/ft)</td>
<td></td>
<td></td>
<td>(lb/ft)</td>
</tr>
<tr>
<td>Throat</td>
<td>2</td>
<td>4940</td>
<td>4800</td>
<td>0.304</td>
<td>0.0042</td>
<td>0.877</td>
<td>7690</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5030</td>
<td>2080</td>
<td>0.130</td>
<td>0.0018</td>
<td>0.750</td>
<td>8000</td>
</tr>
<tr>
<td>Face</td>
<td>2</td>
<td>3200</td>
<td>6220</td>
<td>0.546</td>
<td>0.0076</td>
<td>0.938</td>
<td>8620</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>2390</td>
<td>2730</td>
<td>0.280</td>
<td>0.0039</td>
<td>0.895</td>
<td>7700</td>
</tr>
<tr>
<td>Mid- Length</td>
<td>2</td>
<td>4190</td>
<td>6160</td>
<td>0.471</td>
<td>0.0065</td>
<td>0.918</td>
<td>8320</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>3470</td>
<td>2490</td>
<td>0.226</td>
<td>0.0031</td>
<td>0.833</td>
<td>7870</td>
</tr>
</tbody>
</table>

\( \phi V_b > V_u \); therefore, shear does not govern design.

RCP Pipe Design Example (Cont.)
### Installation Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of Fill Above Crown, FT.</td>
<td>4.00</td>
</tr>
<tr>
<td>Unit Weight, PCF</td>
<td>120.00</td>
</tr>
<tr>
<td>Soil-Structure Interaction Coefficient</td>
<td>1.20</td>
</tr>
<tr>
<td>Bedding Angle, Degrees</td>
<td>88.00</td>
</tr>
<tr>
<td>Load Angle, Degrees</td>
<td>272.00</td>
</tr>
</tbody>
</table>

### Material Properties

<table>
<thead>
<tr>
<th>Material</th>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel - Minimum Specified Yield Stress, PSI</td>
<td></td>
<td>65000</td>
</tr>
<tr>
<td>Reinforcing Type</td>
<td></td>
<td>2.00</td>
</tr>
<tr>
<td>No. of Layers of Reinforcing</td>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td>Concrete - Specified Compressive Stress, PSI</td>
<td></td>
<td>5000</td>
</tr>
</tbody>
</table>

### Loading Data

<table>
<thead>
<tr>
<th>Load Factor</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moment and Shear</td>
<td>1.30</td>
</tr>
<tr>
<td>Thrust</td>
<td>1.30</td>
</tr>
<tr>
<td>Strength Reduction Factor - Flexure</td>
<td>0.90</td>
</tr>
<tr>
<td>Strength Reduction Factor - Diagonal Tension</td>
<td>0.90</td>
</tr>
<tr>
<td>Crack Width Reduction Factor</td>
<td>1.00</td>
</tr>
</tbody>
</table>

### Pipe Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius 1, in.</td>
<td>36.44</td>
</tr>
<tr>
<td>Radius 2, in.</td>
<td>89.12</td>
</tr>
<tr>
<td>Wall Thickness, in.</td>
<td>8.00</td>
</tr>
<tr>
<td>Inside Concrete Cover Over Steel, in.</td>
<td>1.00</td>
</tr>
<tr>
<td>Outside Concrete Cover Over Steel, in.</td>
<td>1.00</td>
</tr>
</tbody>
</table>

### Fluid Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid Density, PCF</td>
<td>62.50</td>
</tr>
<tr>
<td>Depth of Fluid, Inches Above Invert</td>
<td>84.00</td>
</tr>
</tbody>
</table>

### Reinforcing Steel Data

<table>
<thead>
<tr>
<th>Location</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invert - Inside Reinforcing, sq. in./ft.</td>
<td>0.558</td>
</tr>
<tr>
<td>Springline - Outside Reinforcing, sq. in./ft.</td>
<td>0.291</td>
</tr>
<tr>
<td>Crown - Inside Reinforcing, sq. in./ft.</td>
<td>0.257</td>
</tr>
</tbody>
</table>
102.0 INCH SPAN X 84.0 INCH RISE REINFORCED ELLIPTICAL CONCRETE PIPE

**INSTALLATION DATA**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of fill above crown, ft.</td>
<td>6.00</td>
</tr>
<tr>
<td>Unit weight,pcf</td>
<td>120.00</td>
</tr>
<tr>
<td>Soil-structure interaction coefficient</td>
<td>1.20</td>
</tr>
<tr>
<td>Bedding angle, degrees</td>
<td>80.00</td>
</tr>
<tr>
<td>Load angle, degrees</td>
<td>280.00</td>
</tr>
</tbody>
</table>

**MATERIAL PROPERTIES**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel - minimum specified yield stress, psi</td>
<td>65000</td>
</tr>
<tr>
<td>Reinforcing type</td>
<td>2</td>
</tr>
<tr>
<td>No. of layers of reinforcing</td>
<td>1</td>
</tr>
<tr>
<td>Concrete - specified compressive stress, psi</td>
<td>5000</td>
</tr>
</tbody>
</table>

**LOADING DATA**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load factor - moment and shear</td>
<td>1.50</td>
</tr>
<tr>
<td>Load factor - thrust</td>
<td>1.50</td>
</tr>
<tr>
<td>Strength reduction factor - flexure</td>
<td>0.90</td>
</tr>
<tr>
<td>Strength reduction factor - diagonal tension</td>
<td>0.90</td>
</tr>
<tr>
<td>Crack width reduction factor</td>
<td>1.00</td>
</tr>
</tbody>
</table>

**PIPE DATA**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius 1, in.</td>
<td>39.22</td>
</tr>
<tr>
<td>Radius 2, in.</td>
<td>65.56</td>
</tr>
<tr>
<td>Wall thickness, in.</td>
<td>8.00</td>
</tr>
<tr>
<td>Inside concrete cover over steel, in.</td>
<td>1.30</td>
</tr>
<tr>
<td>Outside concrete cover over steel, in.</td>
<td>1.00</td>
</tr>
</tbody>
</table>

**FLUID DATA**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid density,pcf</td>
<td>62.50</td>
</tr>
<tr>
<td>Depth of fluid, inches above invert</td>
<td>84.00</td>
</tr>
</tbody>
</table>

**REINFORCING STEEL DATA**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invert - inside reinforcing, sq.in./ft.</td>
<td>0.479</td>
</tr>
<tr>
<td>Springline - outside reinforcing, sq.in./ft.</td>
<td>0.223</td>
</tr>
<tr>
<td>Crown - inside reinforcing, sq.in./ft.</td>
<td>0.209</td>
</tr>
<tr>
<td><strong>INSTALLATION DATA</strong></td>
<td></td>
</tr>
<tr>
<td>-----------------------</td>
<td></td>
</tr>
<tr>
<td>HEIGHT OF FILL ABOVE CROWN, FT.</td>
<td>7.50</td>
</tr>
<tr>
<td>UNIT WEIGHT, PCF</td>
<td>120.00</td>
</tr>
<tr>
<td>SOIL-STRUCTURE INTERACTION COEFFICIENT</td>
<td>1.20</td>
</tr>
<tr>
<td>BEDDING ANGLE, DEGREES</td>
<td>90.00</td>
</tr>
<tr>
<td>LOAD ANGLE, DEGREES</td>
<td>27.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>MATERIAL PROPERTIES</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>STEEL - MINIMUM SPECIFIED YIELD STRESS, PSI</td>
</tr>
<tr>
<td>REINFORCING TYPE</td>
</tr>
<tr>
<td>% OF LAYERS OF REINFORCING</td>
</tr>
<tr>
<td>CONCRETE - SPECIFIED COMpressive STRESS, PSI</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>LOADING DATA</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>LOAD FACTOR - MOMENT AND SHEAR</td>
</tr>
<tr>
<td>LOAD FACTOR - THRUST</td>
</tr>
<tr>
<td>STRENGTH REDUCTION FACTOR - FLEXURE</td>
</tr>
<tr>
<td>STRENGTH REDUCTION FACTOR - DIAGONAL TENSION</td>
</tr>
<tr>
<td>CRACK WIDTH REDUCTION FACTOR</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>PIPE DATA</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>WALL THICKNESS, IN.</td>
</tr>
<tr>
<td>INSIDE CONCRETE COVER OVER STEEL, IN.</td>
</tr>
<tr>
<td>OUTSIDE CONCRETE COVER OVER STEEL, IN.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>FLUID DATA</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>FLUID DENSITY, PCF</td>
</tr>
<tr>
<td>DEPTH OF FLUID, INCHES ABOVE INVERT</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>REINFORCING STEEL DATA</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>INVERT - INSIDE REINFORCING, SQ. IN./FT.</td>
</tr>
<tr>
<td>SPRINGLINE - OUTSIDE REINFORCING, SQ. IN./FT.</td>
</tr>
<tr>
<td>CROWN - INSIDE REINFORCING, SQ. IN./FT.</td>
</tr>
</tbody>
</table>
D.2.6 Summary - Design Example D.2

Compare hand and computer designs for face, midlength & throat.

<table>
<thead>
<tr>
<th>Required Steel Areas, in.²/ft</th>
<th>Face</th>
<th>Midlength</th>
<th>Throat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hand</td>
<td>Computer</td>
<td>Hand</td>
</tr>
<tr>
<td>Invert - inside</td>
<td>0.546</td>
<td>0.558</td>
<td>0.471</td>
</tr>
<tr>
<td>Springline - outside</td>
<td>0.292</td>
<td>0.291</td>
<td>0.252</td>
</tr>
<tr>
<td>Crown - inside</td>
<td>0.280</td>
<td>0.257</td>
<td>0.226</td>
</tr>
</tbody>
</table>

**Conclusion:** Design of the face section governs the design of the entire section.

D.3 Side Tapered Corrugated Metal Inlet Design Example

D.3.1 Problem:

Determine the gage and corrugation required for a side tapered corrugated steel inlet meeting the geometry requirements of Example No. 2-B in Reference 1.

D.3.2 Design Data:
Steel Corrugated Pipe:

\[ f_u = 45,000 \text{ psi} \]
\[ f_y = 33,000 \text{ psi} \]
\[ E = 29 \times 10^6 \text{ psi} \]

Fill Heights:

Face:
\[ H_e = 2' + 2' = 4.0' \]

Midlength:
\[ H_e = 4 + \frac{30}{12} \left( \frac{1}{S_e} + S_o \right) \]
\[ = 4 + \frac{30}{12} \left( \frac{1}{2} + 0.05 \right) \]
\[ = 5.38' \quad \text{Say 5.5'} \]

Throat:
\[ H_e = 4 + \frac{60}{12} \left( \frac{1}{S_e} + S_o \right) \]
\[ = 4 + 5 \left( \frac{1}{2} + 0.05 \right) \]
\[ = 6.75' \quad \text{Say 7.0'} \]
Note: Add 2'-0" surcharge for miscellaneous unanticipated loads.

Culvert Geometry

Assume $u/v = 0.5 = k_1$

$D_i = 78''$

$L_1 = 60''$

$r_1(z) = \frac{z}{T} \left( \frac{1}{k_1} - \sqrt{1 + 1/k_1^2} \right) + \frac{D_i}{2}$

$= \frac{z/4}{1 + 1/0.5 - \sqrt{1 + 1/0.5^2}} + \frac{78}{2} = 39.0 - 0.0773 z$

$u(z) = \frac{z}{T} + \frac{D_i}{2} - r_1(z) = 0.3273 z$

$v(z) = \frac{u(z)}{k_1} = 0.6546 z$

$r_2(z) = \frac{D_i}{2} + v(z) = 39 + 0.6546 z$

Span = $2(r_1 + u)$
D.3.3 Calculate Applied Loads:

Earth Load - \( W_e = F_e \gamma_s B_o (H_e + R_o/6) \)

- Neglect corrugation depth; therefore, \( B_o = B_i \), \( R_o = R_i \)
- \( F_e = 1.0 \) (flexible culvert)

\( W_e = 1.0 \times (120) B_o (H_e + 78/12.6) = 120 \cdot \text{span} (H_e + 1.08) \)

<table>
<thead>
<tr>
<th>Location</th>
<th>( z )</th>
<th>( f_1 )</th>
<th>( u )</th>
<th>( v )</th>
<th>( f_2 )</th>
<th>Span</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face</td>
<td>60</td>
<td>34.36</td>
<td>19.64</td>
<td>39.28</td>
<td>78.28</td>
<td>108</td>
</tr>
<tr>
<td>Midlength</td>
<td>30</td>
<td>36.68</td>
<td>9.82</td>
<td>19.64</td>
<td>58.64</td>
<td>93</td>
</tr>
<tr>
<td>Throat</td>
<td>0</td>
<td>39</td>
<td>0</td>
<td>0</td>
<td>39</td>
<td>78</td>
</tr>
</tbody>
</table>

D.3.4 Metal Ring Design

Use service load design method: AASHTO - Interim Specifications Bridges (1981), Section 1.9.2.

Thrust

\[
T = \frac{\sqrt{W_e}}{2}
\]

Required cross-sectional wall area:

\[
A = T \left( \frac{SF}{f_y} \right) = \frac{W_e (SF)}{Sf_y}
\]

\( Sf = 2 \)

\( f_y = 33000 \) psi

Required sectional wall area:
<table>
<thead>
<tr>
<th>Location</th>
<th>$2 \times r_2$ (in.)</th>
<th>$I_{\text{req}}$ (in$^4$/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face</td>
<td>156.6</td>
<td>25.6 x 10$^{-3}$</td>
</tr>
<tr>
<td>Midlength</td>
<td>117.3</td>
<td>14.4 x 10$^{-3}$</td>
</tr>
<tr>
<td>Throat</td>
<td>78</td>
<td>6.36 x 10$^{-3}$</td>
</tr>
</tbody>
</table>

Select a corrugation for steel conduit that meet the required area and moment of inertia calculated. 

Choose a 3 x 1 corrugation with the following properties:

<table>
<thead>
<tr>
<th>Location</th>
<th>S (in)</th>
<th>Corr.</th>
<th>$t$ (in.$^2$/ft)</th>
<th>$A$ (in$^2$/ft)</th>
<th>1</th>
<th>$r$ (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face</td>
<td>108</td>
<td>3 x 1</td>
<td>0.168</td>
<td>2.46</td>
<td>25.09 x 10$^{-3}$*</td>
<td>0.3490</td>
</tr>
<tr>
<td>Midlength</td>
<td>93</td>
<td>3 x 1</td>
<td>0.109</td>
<td>1.56</td>
<td>15.46 x 10$^{-3}$</td>
<td>0.3488</td>
</tr>
<tr>
<td>Throat</td>
<td>78</td>
<td>3 x 1</td>
<td>0.064</td>
<td>0.89</td>
<td>8.66 x 10$^{-3}$</td>
<td>0.3410</td>
</tr>
</tbody>
</table>

* 2% less than required for handling, but since the face will be stiffened by the head wall, this is acceptable.

**Wall Buckling**

If the computed buckling stress divided by the required safety factor is less than the service load steel stress, $f_a$, the required wall area must be recalculated using $f_{cr}/SF$ in lieu of $f_a$.

$$r < \frac{1}{k} \sqrt{\frac{24E}{f_u}}$$

Then $f_{cr} = f_u - \frac{f_u^2}{48E} \left( \frac{kS}{r} \right)^2$
If $S > \frac{r}{k} \sqrt{\frac{24E}{f_u}}$, then $f_{cr} = \frac{12E}{(kS)^2} \left(\frac{r}{r}\right)$

$r$ = radius of gyration

$k$ = soil stiffness factor

For granular backfill with 90% min. standard density, use $k = 0.22$.

For all sections, $r \approx 0.34$.

\[
\frac{r}{k} \sqrt{\frac{24E}{f_u}} \approx \frac{0.34}{0.22} \sqrt{\frac{24 \times 29 \times 10^6}{45000}} = 192 \text{ in.}
\]

Use $2 \times r^2$ in place of span in calculating buckling capacity. Since $2 \times r^2$ is less than 192 in. in all cases, use:

\[
\frac{f_{cr}}{Sf} = \left[ f_u - \frac{f_u^2}{48E} \left(\frac{kS}{r}\right)^2 \right] \frac{1}{2}
\]

\[
= 22500 - \frac{45000^2 (0.22)^2}{(2)48(29 \times 10^6)} \left(\frac{2r^2}{r}\right)^2
\]

\[
= 22500 - 0.0352 \left(\frac{2r^2}{r}\right)^2
\]

<table>
<thead>
<tr>
<th>Location</th>
<th>$(2r^2)/r$</th>
<th>$f_{cr}/SF$ (psi)</th>
<th>$f_a=T/A$ (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face</td>
<td>460.6</td>
<td>15032</td>
<td>1115</td>
</tr>
<tr>
<td>Midlength</td>
<td>345</td>
<td>18310</td>
<td>1962</td>
</tr>
<tr>
<td>Throat</td>
<td>228.3</td>
<td>20665</td>
<td>3540</td>
</tr>
</tbody>
</table>

Since $f_{cr}/SF > f_a$, buckling does not govern.

**Seam Strength**

\[(SS) = T \times SF \quad SF = 3\]
<table>
<thead>
<tr>
<th>Location</th>
<th>T (lb/ft)</th>
<th>SS (k/ft)</th>
<th>t</th>
<th>Double rivets (k/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face</td>
<td>2743</td>
<td>8.23</td>
<td>0.168</td>
<td>70.7</td>
</tr>
<tr>
<td>Midlength</td>
<td>3060</td>
<td>9.18</td>
<td>0.109</td>
<td>53.0</td>
</tr>
<tr>
<td>Throat</td>
<td>3151</td>
<td>9.45</td>
<td>0.064</td>
<td>28.7</td>
</tr>
</tbody>
</table>

**Summary**

Use a 3 x 1 corrugated steel pipe with the following properties:

<table>
<thead>
<tr>
<th>Location</th>
<th>S (in)</th>
<th>Corr.</th>
<th>t (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face</td>
<td>108</td>
<td>3 x 1</td>
<td>0.168</td>
</tr>
<tr>
<td>Midlength</td>
<td>93</td>
<td>3 x 1</td>
<td>0.109</td>
</tr>
<tr>
<td>Throat</td>
<td>78</td>
<td>3 x 1</td>
<td>0.064</td>
</tr>
</tbody>
</table>

Since this is a relatively short structure, use a 3 x 1 corrugation with t = 0.168 in. throughout.

*Go to Appendix E*
The following tables present designs for various types of improved inlets and appurtenant structures based on the design methods in this manual, and the example standard plans presented in Appendix G.

**Tables E-1 through E-5** present designs for reinforced concrete box section inlets. The following geometric and design parameters are assumed for these designs:

- Slope of earth embankment above box, \( S_e = 2:1 \).
- Fall slope, \( S_f = 2:1 \), where applicable.
- Culvert slope, \( S = 0.03 \), except for Tables E-4 and E-5 where \( S = 0.06 \).
- Sidewall Taper, \( T = 4:1 \), except for one cell slope tapered sections (Tables E-3 and E-4) where \( T = 6:1 \).
- All box sections have 45° haunches with dimensions equal to the top slab thickness, i.e. \( HH = HV = TT \).
- Reinforcing strength, \( f_y = 60,000 \) psi.
- Concrete strength, \( f_c' = 3,000 \) psi.
- Cover over reinforcing \( t_b = 2 \) in. clear, except for bottom reinforcing of bottom slab where \( t_b = 3 \) in. clear.
- The heights of fill at the face and throat section are shown for each design. In addition to the fill shown, a two-foot surcharge load is included for each design. All soil is assumed to have a unit weight of 120 pcf. A soil structure interaction coefficient of 1.2 is applied to the earth load.
- Two conditions of lateral soil pressure were considered, equal to 0.25 and 0.50 times the vertical soil pressure. The worst case at each design section was chosen for design.

**Table E-6** presents designs for side tapered reinforced concrete pipe inlets. The following geometry and design parameters are assumed for these designs:

- Slope of earth embankment above pipe, \( S_e = 2:1 \).
- Culvert slope, \( S = 0.03 \).
- Sidewall taper, \( T = 4:1 \).
- Reinforcing strength, \( f_y = 65,000 \) psi.
- Concrete strength, \( f_c' = 5,000 \) psi.
- Cover over reinforcing, \( t_b = 1 \) in. clear, inside and outside.
- The heights of fill at the face (\( H_f \)) and throat (\( H_t \)) are shown for each design. In addition to the fill shown, a two foot surcharge load is included in each design. All soil is assumed to have a unit weight of 120 pcf. A soil structure interaction factor of 1.2 is applied to all earth load.

**Table E-7** presents designs for side tapered corrugated metal pipe inlets. The slopes, tapers, heights of fill and soil unit weight are all the same as for the corresponding reinforced concrete pipe inlets.

**Figure E-1, Figure E-2, and Figure E-3** present algorithms for sizing headwalls for cast-in-place concrete, precast concrete and corrugated metal inlets. Following are **Tables E-8, E-9, E-10** and **E-11** presenting
headwall designs for one cell and two cell box, concrete pipe and corrugated metal pipe, respectively. 

Figure E-4, Figure E-5, and Figure E-6 show typical designs of skewed headwalls for a concrete box section, precast concrete pipe and a corrugated metal pipe, respectively. 

Table E-12 shows apron designs for several sizes of culvert opening, and Table E-13 shows designs for two sizes of square to circular transition sections. 

<table>
<thead>
<tr>
<th>Span x Rise at Throat</th>
<th>5x5</th>
<th>6x6</th>
<th>7x7</th>
<th>8x8</th>
<th>9x9</th>
<th>10x10</th>
<th>12x12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B₁(Throat)</td>
<td>5'-0&quot;</td>
<td>6'-0&quot;</td>
<td>7'-0&quot;</td>
<td>8'-0&quot;</td>
<td>9'-0&quot;</td>
<td>10'-0&quot;</td>
<td>12'-0&quot;</td>
</tr>
<tr>
<td>D₁</td>
<td>5-0</td>
<td>6-0</td>
<td>7-0</td>
<td>8-0</td>
<td>9-0</td>
<td>10-0</td>
<td>12-0</td>
</tr>
<tr>
<td>Bf</td>
<td>7-6</td>
<td>9-0</td>
<td>10-6</td>
<td>12-0</td>
<td>13-6</td>
<td>15-0</td>
<td>18-0</td>
</tr>
<tr>
<td>L₁</td>
<td>5-0</td>
<td>6-0</td>
<td>7-0</td>
<td>8-0</td>
<td>9-0</td>
<td>10-0</td>
<td>12-0</td>
</tr>
<tr>
<td>T₁</td>
<td>0-8</td>
<td>0-8</td>
<td>0-8</td>
<td>0-8</td>
<td>0-9</td>
<td>0-10</td>
<td>1-0</td>
</tr>
<tr>
<td>Tₛ</td>
<td>0-8</td>
<td>0-8</td>
<td>0-8</td>
<td>0-8</td>
<td>0-9</td>
<td>0-10</td>
<td>1-0</td>
</tr>
<tr>
<td>Tₐ</td>
<td>0-9</td>
<td>0-9</td>
<td>0-9</td>
<td>0-9</td>
<td>0-10</td>
<td>0-11</td>
<td>1-1</td>
</tr>
<tr>
<td>Hf</td>
<td>1-0</td>
<td>1-0</td>
<td>1-0</td>
<td>1-0</td>
<td>1-2</td>
<td>1-3</td>
<td>1-6</td>
</tr>
<tr>
<td>H₁</td>
<td>3-8</td>
<td>4-2</td>
<td>4-9</td>
<td>5-3</td>
<td>5-11</td>
<td>6-7</td>
<td>7-10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bar Designation</th>
<th>Required Reinforcement Area (in.²/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>0.20</td>
</tr>
<tr>
<td>1B</td>
<td>0.20</td>
</tr>
<tr>
<td>2A</td>
<td>0.20</td>
</tr>
<tr>
<td>3A</td>
<td>0.20</td>
</tr>
<tr>
<td>4A</td>
<td>0.20</td>
</tr>
<tr>
<td>4B</td>
<td>0.20</td>
</tr>
<tr>
<td>8A</td>
<td>0.20</td>
</tr>
<tr>
<td>Long. 1</td>
<td>0.13</td>
</tr>
</tbody>
</table>

* See Appendix G, Sheet 1.

** Numbers in parentheses indicate maximum bar spacing (in.) as limited by crack control Otherwise maximum spacing is 3 times slob thickness or 18 in., whichever is less.

Other Design Parameters
Embankment slope, Sₑ = 2:1
Culvert barrel slope, S = 0.03:1
Taper, T = 4: 1
Reinforcing yield strength, fₚ = 60,000 psi
Concrete compressive strength, f'ₚ = 3,000 psi
Haunch dimensions, Hₑ = Hᵥ = T₁

<table>
<thead>
<tr>
<th>Reinforcing YIELD Strength, fₚ = 60,000 psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Compressive Strength, f'ₚ = 3,000 psi</td>
</tr>
<tr>
<td>Haunch Dimensions, Hₑ = Hᵥ = T₁</td>
</tr>
</tbody>
</table>
### Table E-2
Reinforcing Requirements - Two Cell Side Tapered Box Inlets

<table>
<thead>
<tr>
<th>Span x Rise at Throat</th>
<th>5x5</th>
<th>6x6</th>
<th>7x7</th>
<th>8x8</th>
<th>9x9</th>
<th>10x10</th>
<th>12x12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B_{i}(Throat)</td>
<td>5'-0&quot;</td>
<td>6'-0&quot;</td>
<td>7'-0&quot;</td>
<td>8'-10&quot;</td>
<td>9'-0&quot;</td>
<td>10'-10&quot;</td>
<td>12'-0&quot;</td>
</tr>
<tr>
<td>D_{i}</td>
<td>5-0</td>
<td>6-0</td>
<td>7-0</td>
<td>8-0</td>
<td>9-0</td>
<td>10-0</td>
<td>12-0</td>
</tr>
<tr>
<td>B_{i}/2</td>
<td>7-6</td>
<td>9-0</td>
<td>10-6</td>
<td>12-0</td>
<td>13-6</td>
<td>15-0</td>
<td>18-0</td>
</tr>
<tr>
<td>L_{1}</td>
<td>10-0</td>
<td>12-0</td>
<td>14-0</td>
<td>16-0</td>
<td>18-0</td>
<td>20-0</td>
<td>24-0</td>
</tr>
<tr>
<td>T_{T}</td>
<td>0-8</td>
<td>0-8</td>
<td>0-8</td>
<td>0-9</td>
<td>0-10</td>
<td>1-0</td>
<td>1-4</td>
</tr>
<tr>
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<td>NR</td>
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<td>0.61(9'-0&quot;)</td>
<td>0.84(10'-0&quot;)</td>
<td>1.11(12'-0&quot;)</td>
<td>1.26(16'-0&quot;)</td>
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<tr>
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<td>NR</td>
<td>NR</td>
<td>0.49(8'-10&quot;)</td>
<td>0.61(9'-0&quot;)</td>
<td>0.84(10'-0&quot;)</td>
<td>1.11(12'-0&quot;)</td>
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</table>

* See Appendix G. Sheet 1.

** Numbers in parentheses indicate maximum bar spacing (in.) as limited by crack control. Otherwise maximum spacing is 3 times slob thickness or 18 in., whichever is less.

Other Design Parameters:
- Embankment slope, S_e = 2:1
- Culvert barrel slope, S = 0.03:1
- Taper, T = 4:1
- Reinforcing yield strength, f_y = 60,000 psi
- Concrete compressive strength, f_c = 3,000 psi
- Haunch dimensions, H_H = H_Y = T_T
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<th>5x5</th>
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<td>5'-0&quot;</td>
<td>5'-0&quot;</td>
<td>7'-0&quot;</td>
<td>7'-0&quot;</td>
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<td>Required Reinforcement Area (in.$^2$/ft)</td>
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<td>0.35</td>
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<td>0.68(4)**</td>
<td>0.80(4)**</td>
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</table>

* See Appendix G. Sheet 3.

** Numbers in parentheses indicate maximum bar spacing (in.) as limited by crack control. Otherwise maximum spacing is 3 times slob thickness or 18 in., whichever is less.

** Other Design Parameters

- Embankment slope, $S_e = 2:1$
- Culvert barrel slope, $S = 0.03:1$
- Reinforcing yield strength, $f_y = 60,000$ psi
- Concrete compressive strength, $f_{cc} = 3,000$ psi
- Haunch dimensions, $H_t = H_v = T_T$

** Other Design Parameters**

- Embankment slope, $S_e = 2:1$
- Culvert barrel slope, $S = 0.03:1$
- Reinforcing yield strength, $f_y = 60,000$ psi
- Concrete compressive strength, $f_{cc} = 3,000$ psi
- Haunch dimensions, $H_t = H_v = T_T$
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<th>9'-0&quot;</th>
<th>9'-0&quot;</th>
<th>9'-0&quot;</th>
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<td>1-4</td>
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<tr>
<td>1B</td>
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<tr>
<td>2A</td>
<td>0.88(4)**</td>
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<td>3A</td>
<td>0.99(4)**</td>
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<tr>
<td>4A</td>
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* See Appendix G. Sheet 3.

** Numbers in parentheses indicate maximum bar spacing (in.) as limited by crack control. Otherwise maximum spacing is 3 times slob thickness or 18 in., whichever is less.

** Other Design Parameters **

- Embankment slope, Sₑ = 2:1
- Culvert barrel slope, S = 0.03:1
- Taper, T = 6:1
- Reinforcing yield strength, fᵧ = 60,000 psi
- Concrete compressive strength, f'c = 3,000 psi
- Haunch dimensions, Hₑ = Hᵥ = Tₜ

Table E-4

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<th>6x6</th>
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<th>8x8</th>
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<tbody>
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<td>6</td>
<td>2</td>
<td>4</td>
<td>6</td>
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<table>
<thead>
<tr>
<th>Dimension*</th>
<th>Inlet Geometry (ft-in.)</th>
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</thead>
</table>

Inlet Geometry (ft-in.)
### Other Design Parameters

- **Embankment slope,** $S_e = 2:1$
- **Culvert barrel slope,** $S = 0.06:1$
- **Taper,** $T = 6:1$
- **Reinforcing yield strength,** $f_y = 60,000$ psi
- **Concrete compressive strength,** $f'_c = 3,000$ psi
- **Haunch dimensions,** $H_H = H_V = T_T$

### Reinforcing Requirements - One Cell Slope Tapered Box Inlets

<table>
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<tr>
<th>Span x Rise at Throat</th>
<th>8x8</th>
<th>10x10</th>
<th>10x10</th>
<th>10x10</th>
<th>10x10</th>
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<tbody>
<tr>
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<th>Inlet Geometry (ft-in.)</th>
<th>B_H(Throat)</th>
<th>D_L</th>
<th>B_F</th>
<th>L_1</th>
<th>L_2</th>
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<tr>
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</table>

**Fall**
- **TT**
- **TS**
- **TB**
- **Hf**
- **Ht**

**Numbers in parentheses indicate maximum bar spacing (in.) as limited by crack control. Otherwise maximum spacing is 3 times slab thickness or 18 in., whichever is less.**

* See Appendix G. Sheet 3.
<table>
<thead>
<tr>
<th>Bar Designation</th>
<th>Required Reinforcement Area (in.²/ft)</th>
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<tbody>
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<td>0.38</td>
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<tr>
<td>1B</td>
<td>0.38</td>
</tr>
<tr>
<td>2A</td>
<td>0.90(4)**</td>
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<td>3A</td>
<td>1.04(4)**</td>
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<td>4A</td>
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<tr>
<td>8A</td>
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<tr>
<td>Long. 1</td>
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<tr>
<td>1.20(4)**</td>
<td>0.92(4)**</td>
</tr>
<tr>
<td>1.40(4)**</td>
<td>0.29</td>
</tr>
<tr>
<td>0.24</td>
<td>0.29</td>
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<td>0.36</td>
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<td>0.13</td>
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<tr>
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<td>0.34</td>
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<tr>
<td>0.42</td>
<td>0.29</td>
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<tr>
<td>1.09(4)**</td>
<td>0.34</td>
</tr>
<tr>
<td>0.74</td>
<td>0.24</td>
</tr>
<tr>
<td>1.20(4)**</td>
<td>0.34</td>
</tr>
<tr>
<td>1.40(4)**</td>
<td>0.39</td>
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<tr>
<td>1.04(4)**</td>
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<td>1.25(8)**</td>
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<tr>
<td>0.29</td>
<td>0.39</td>
</tr>
<tr>
<td>1.10(12)**</td>
<td>0.44</td>
</tr>
<tr>
<td>0.39</td>
<td>0.39</td>
</tr>
<tr>
<td>1.33(12)**</td>
<td>0.44</td>
</tr>
</tbody>
</table>

* See Appendix G, Sheet 3.

** Numbers in parentheses indicate maximum bar spacing (in.) as limited by crack control. Otherwise maximum spacing is 3 times slob thickness or 18 in., whichever is less.

Other Design Parameters

- Embankment slope, $S_e = 2:1$
- Culvert barrel slope, $S = 0.06:1$
- Taper, $T = 6:1$
- Reinforcing yield strength, $f_y = 60,000$ psi
- Concrete compressive strength, $f'_c = 3,000$ psi
- Haunch dimensions, $H_L = H_V = T_T$

Reinforcing Requirements - One Cell Slope Tapered Box Inlets

<table>
<thead>
<tr>
<th>Span x Rise at Throat</th>
<th>12x12</th>
<th>12x12</th>
<th>12x12</th>
<th>12x12</th>
<th>12x12</th>
<th>12x12</th>
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</thead>
<tbody>
<tr>
<td>Fall (ft)</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Dimension*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B_i$(Throat)</td>
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<td>12'-0&quot;</td>
<td>12'-0&quot;</td>
<td>12'-0&quot;</td>
<td>12'-0&quot;</td>
<td>12'-0&quot;</td>
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<td>12-0</td>
<td>12-0</td>
<td>12-0</td>
<td>12-0</td>
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<tr>
<td>$B_T$</td>
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<td>18-0</td>
<td>18-0</td>
<td>18-0</td>
<td>18-0</td>
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<tr>
<td>$L_1$</td>
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<td>18-1</td>
<td>22-1</td>
<td>26-1</td>
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<tr>
<td>$L_3$</td>
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<td>6-0</td>
<td>6-0</td>
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<tr>
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<td>3-2</td>
<td>3-2</td>
<td>3-2</td>
<td>3-2</td>
</tr>
<tr>
<td>Fall</td>
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<td>4-0</td>
<td>6-0</td>
<td>8-0</td>
<td>10-0</td>
<td>12-0</td>
</tr>
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<td>1-4</td>
<td>1-6</td>
<td>1-8</td>
<td>1-10</td>
<td>2-0</td>
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<td>1-8</td>
<td>1-10</td>
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<td>1-11</td>
<td>2-1</td>
</tr>
<tr>
<td>$H_F$</td>
<td>1-6</td>
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<td>1-7</td>
<td>1-8</td>
<td>1-9</td>
<td>1-11</td>
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<tr>
<td>$H_L$</td>
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<td>19-0</td>
<td>23-1</td>
<td>27-3</td>
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</table>

Bar Designation

<table>
<thead>
<tr>
<th>Required Reinforcement Area (in.²/ft)</th>
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</thead>
<tbody>
<tr>
<td>1A</td>
</tr>
<tr>
<td>1B</td>
</tr>
<tr>
<td>2A</td>
</tr>
<tr>
<td>3A</td>
</tr>
<tr>
<td>4A</td>
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<tr>
<td>4B</td>
</tr>
<tr>
<td>8A</td>
</tr>
<tr>
<td>Long. 1</td>
</tr>
<tr>
<td>Long. 2</td>
</tr>
<tr>
<td>0.50</td>
</tr>
<tr>
<td>0.97(4)**</td>
</tr>
<tr>
<td>1.20(4)**</td>
</tr>
<tr>
<td>0.39</td>
</tr>
<tr>
<td>0.39</td>
</tr>
<tr>
<td>0.13</td>
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<td>0.13</td>
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<tr>
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<td>0.48</td>
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<td>0.44</td>
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<td>0.48</td>
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<td>0.48</td>
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<td>0.44</td>
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<td>0.44</td>
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</tbody>
</table>

* See Appendix G, Sheet 3.

** Numbers in parentheses indicate maximum bar spacing (in.) as limited by crack control. Otherwise maximum spacing is 3 times slob thickness or 18 in., whichever is less.
Other Design Parameters
Embankment slope, Se = 2:1
Culvert barrel slope, S = 0.03:1
Taper, T = 6:1
Reinforcing yield strength, fy = 60,000 psi
Concrete compressive strength, fc' = 3,000 psi
Haunch dimensions, HH = HV = TT

<table>
<thead>
<tr>
<th>Table E-5</th>
<th>Reinforcing Requirements - Two Cell Slope Tapered Box Inlets</th>
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<tbody>
<tr>
<td><strong>Span x Rise at Throat</strong></td>
<td><strong>6x6</strong></td>
</tr>
<tr>
<td><strong>Fall (ft)</strong></td>
<td>2</td>
</tr>
<tr>
<td><strong>Dimension</strong>*</td>
<td><strong>Inlet Geometry (ft-in.)</strong></td>
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<tr>
<td>Bi</td>
<td>6'-0&quot;</td>
</tr>
<tr>
<td>Di</td>
<td>6-0</td>
</tr>
<tr>
<td>Bi</td>
<td>18-0</td>
</tr>
<tr>
<td>L1</td>
<td>12-0</td>
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<tr>
<td>L2</td>
<td>4-6</td>
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<td>L3</td>
<td>7-6</td>
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<tr>
<td>LB</td>
<td>1-7</td>
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<tr>
<td>Fall</td>
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<tr>
<td>TT</td>
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<tr>
<td>TS</td>
<td>0-8</td>
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<td>TB</td>
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<td>TC</td>
<td>0-8</td>
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<td>Hf</td>
<td>1-0</td>
</tr>
<tr>
<td>Ht</td>
<td>9-8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Bar Designation</strong></th>
<th><strong>Required Reinforcement Area (in.²/ft)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>0.20</td>
</tr>
<tr>
<td>1B</td>
<td>0.20</td>
</tr>
<tr>
<td>2A</td>
<td>0.23</td>
</tr>
<tr>
<td>3A</td>
<td>0.23</td>
</tr>
<tr>
<td>4A</td>
<td>0.20</td>
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<tr>
<td>4B</td>
<td>0.20</td>
</tr>
<tr>
<td>8A</td>
<td>0.20</td>
</tr>
<tr>
<td>8B</td>
<td>0.38(8'-0&quot;)</td>
</tr>
<tr>
<td>8C(Length)</td>
<td>0.38(8'-0&quot;)</td>
</tr>
<tr>
<td>8D(Length)</td>
<td>0.13</td>
</tr>
<tr>
<td>Long. 1</td>
<td>0.20</td>
</tr>
<tr>
<td>Long. 2</td>
<td>0.20</td>
</tr>
<tr>
<td>8A</td>
<td>0.20</td>
</tr>
<tr>
<td>8B</td>
<td>0.38(8'-0&quot;)</td>
</tr>
<tr>
<td>8C(Length)</td>
<td>0.38(8'-0&quot;)</td>
</tr>
<tr>
<td>8D(Length)</td>
<td>0.13</td>
</tr>
<tr>
<td>Long. 1</td>
<td>0.20</td>
</tr>
<tr>
<td>Long. 2</td>
<td>0.20</td>
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</tbody>
</table>
Other Design Parameters

Embankment slope, $S_e = 2:1$
Culvert barrel slope, $S = 0.04:1$
Taper, $T = 4:1$

Reinforcing yield strength, $f_y = 60,000$ psi
Concrete compressive strength, $f_c = 3,000$ psi
Haunch dimensions, $H_H = H_V = T_T$

### Reinforcing Requirements - Two Cell Slope Tapered Box Inlets

<table>
<thead>
<tr>
<th>Span x Rise at Throat</th>
<th>10x10</th>
<th>10x10</th>
<th>10x10</th>
<th>12x12</th>
<th>12x12</th>
<th>12x12</th>
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</thead>
<tbody>
<tr>
<td>Fall (ft)</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Dimension*</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>$B_i$</td>
<td>10'-0&quot;</td>
<td>10'-0&quot;</td>
<td>10'-0&quot;</td>
<td>12'-0&quot;</td>
<td>12'-0&quot;</td>
<td>12'-0&quot;</td>
</tr>
<tr>
<td>$D_i$</td>
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<td>10-0</td>
<td>10-0</td>
<td>12-0</td>
<td>12-0</td>
<td>12-0</td>
</tr>
<tr>
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<td>30-0</td>
<td>30-0</td>
<td>36-0</td>
<td>36-0</td>
<td>36-0</td>
</tr>
<tr>
<td>$L_1$</td>
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<td>20-0</td>
<td>20-0</td>
<td>24-0</td>
<td>24-0</td>
<td>24-0</td>
</tr>
<tr>
<td>$L_2$</td>
<td>4-6</td>
<td>9-0</td>
<td>13-7</td>
<td>4-5</td>
<td>9-0</td>
<td>13-6</td>
</tr>
<tr>
<td>$L_3$</td>
<td>15-6</td>
<td>11-0</td>
<td>6-5</td>
<td>19-7</td>
<td>15-0</td>
<td>10-6</td>
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<td>2-8</td>
<td>3-2</td>
<td>3-2</td>
<td>3-2</td>
</tr>
<tr>
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<td>6-0</td>
<td>2-0</td>
<td>4-0</td>
<td>6-0</td>
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<td>1-9</td>
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<td>1-8</td>
<td>1-8</td>
</tr>
<tr>
<td>$H_f$</td>
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<td>1-3</td>
<td>1-6</td>
<td>1-6</td>
<td>1-6</td>
</tr>
<tr>
<td>$H_t$</td>
<td>14-5</td>
<td>16-5</td>
<td>18-5</td>
<td>16-11</td>
<td>18-11</td>
<td>20-11</td>
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<table>
<thead>
<tr>
<th>Bar Designation</th>
<th>Required Reinforcement Area (in.$^2$/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>0.39</td>
</tr>
<tr>
<td>1B</td>
<td>0.39</td>
</tr>
<tr>
<td>2A</td>
<td>0.39</td>
</tr>
<tr>
<td>3A</td>
<td>0.42</td>
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<tr>
<td>4A</td>
<td>0.39</td>
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<td>4B</td>
<td>0.39</td>
</tr>
<tr>
<td>8A</td>
<td>0.39</td>
</tr>
<tr>
<td>8B</td>
<td>0.39</td>
</tr>
<tr>
<td>8C(Length)</td>
<td>0.16(12'-0&quot;)</td>
</tr>
<tr>
<td>8D(Length)</td>
<td>0.16(12'-0&quot;)</td>
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<td>Long. 1</td>
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<tr>
<td>Long. 2</td>
<td>0.39</td>
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</table>

* See Appendix G, Sheet 3.

** Numbers in parentheses indicate maximum bar spacing (in.) as limited by crack control. Otherwise maximum spacing is 3 times slob thickness or 18 in., whichever is less.
### Table E-6

**Reinforcing Requirements - Side Tapered Reinforced Concrete Pipe Inlets**

<table>
<thead>
<tr>
<th>Dimension at Throat</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
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<tbody>
<tr>
<td></td>
<td>Di</td>
<td>Bf</td>
<td>Di</td>
<td>Bf</td>
<td>Di</td>
</tr>
<tr>
<td>D_i</td>
<td>4'-0&quot;</td>
<td>6'-0&quot;</td>
<td>8'-0&quot;</td>
<td>10'-0&quot;</td>
<td>12'-0&quot;</td>
</tr>
<tr>
<td>B_f</td>
<td>6-0</td>
<td>9-0</td>
<td>12-0</td>
<td>15-0</td>
<td>18-8</td>
</tr>
<tr>
<td>r_1@Face</td>
<td>1-8</td>
<td>2-6</td>
<td>3-4</td>
<td>4-2</td>
<td>5-0</td>
</tr>
<tr>
<td>r_2@Face</td>
<td>4-7</td>
<td>6-11</td>
<td>9-2</td>
<td>11-6</td>
<td>13-10¼</td>
</tr>
<tr>
<td>u@Face</td>
<td>1-3</td>
<td>1-11</td>
<td>2-7</td>
<td>3-3½</td>
<td>3-11</td>
</tr>
<tr>
<td>v@Face</td>
<td>2-7</td>
<td>3-11</td>
<td>5-2</td>
<td>6-6</td>
<td>7-10¼</td>
</tr>
<tr>
<td>L_1</td>
<td>4-0</td>
<td>6-0</td>
<td>8-0</td>
<td>10-0</td>
<td>12-0</td>
</tr>
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<td>h</td>
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<td>0-6</td>
<td>0-8</td>
<td>0-10</td>
<td>1-0</td>
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<td>1-6</td>
</tr>
<tr>
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<td>4-2</td>
<td>5-3</td>
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<td>7-10</td>
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<td>Bar Designation</td>
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<td>0.59</td>
<td>0.82</td>
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</tbody>
</table>

*See Appendix G, Sheet 5.*

**Other Design Parameters**

- Embankment slope, $S_e = 2:1$
- Culvert barrel slope, $S = 0.03:1$
- Taper, $T = 4:1$
- Reinforcing yield strength, $f_y = 65,000$ psi
- Concrete compressive strength, $f'_c = 5,000$ psi

### Table E-7

**Corrugation Requirements - Side Tapered Metal Pipe Inlets**

<table>
<thead>
<tr>
<th>Diameter at Throat</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Di</td>
<td>Bf</td>
<td>Di</td>
<td>Bf</td>
<td>Di</td>
</tr>
<tr>
<td>D_i</td>
<td>4'-0&quot;</td>
<td>6'-0&quot;</td>
<td>8'-0&quot;</td>
<td>10'-0&quot;</td>
<td>12'-0&quot;</td>
</tr>
<tr>
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<td>9-0</td>
<td>12-0</td>
<td>15-0</td>
<td>18-8</td>
</tr>
<tr>
<td>r_1@Face</td>
<td>1-8</td>
<td>2-6</td>
<td>3-4</td>
<td>4-2</td>
<td>5-0</td>
</tr>
<tr>
<td>r_2@Face</td>
<td>4-7</td>
<td>6-11</td>
<td>9-2</td>
<td>11-6</td>
<td>13-10¼</td>
</tr>
<tr>
<td>u@Face</td>
<td>1-3 11/16</td>
<td>1-11 9/16</td>
<td>2-7 7/16</td>
<td>3-3/4</td>
<td>3-11 1/8</td>
</tr>
<tr>
<td>--------</td>
<td>-----------</td>
<td>-----------</td>
<td>----------</td>
<td>-------</td>
<td>----------</td>
</tr>
<tr>
<td>v@Face</td>
<td>2-7 7/16</td>
<td>3-11 1/8</td>
<td>5-2 13/16</td>
<td>6-6 9/8</td>
<td>7-10 7/8</td>
</tr>
<tr>
<td>L₁</td>
<td>4-0</td>
<td>6-0</td>
<td>8-0</td>
<td>10-0</td>
<td>12-0</td>
</tr>
<tr>
<td>Hᵗ</td>
<td>1-0</td>
<td>1-2</td>
<td>1-6</td>
<td>1-11</td>
<td>2-3</td>
</tr>
<tr>
<td>Hᵗ</td>
<td>3-2</td>
<td>4-4</td>
<td>5-9</td>
<td>7-2</td>
<td>8-7</td>
</tr>
</tbody>
</table>

**Design Without Special Features (in.)**

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<th>Corrugation Thickness</th>
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<th>6x2</th>
<th>6x2</th>
<th>6x2</th>
<th>-</th>
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<tbody>
<tr>
<td>Thickness</td>
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<td>0.109</td>
<td>0.168</td>
<td>0.249</td>
<td>-</td>
</tr>
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</table>

**Design With Special Features**

*See Appendix G. Sheet 6.*

** As per the AASHTO Bridge Specification Section 1.9.6

Other Design Parameters

<table>
<thead>
<tr>
<th>Embankment slope, Sₑ = 2:1</th>
<th>Corrugated metal, fᵧ = 33,000 psi, fᵤ = 45,000 psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Culvert barrel slope, S = 0.03:1</td>
<td>Taper, T = 4:1</td>
</tr>
</tbody>
</table>
Figure E-1. Headwall Dimensions for Cast-In-Place Reinforced Concrete Structures.

**a. Wingwall Flare Angles Less Than or Equal to 45°**

\[ T_H = \frac{B_f}{12} \geq 12" \]
\[ t_w = 14 + \frac{B_f}{24} \]
\[ t_f = \frac{B_f}{12} \sin F \geq 12 \sin F \]
\[ t_s = t_f \sin F + t_w \cos F - T_S \]
\[ d_s = T_H + t_f \cos F - t_w \sin F \]

**b. Wingwall Flare Angles Greater Than 45°**

\[ T_H = \frac{B_f}{12} \geq 12 \]
\[ t_s = \frac{B_f}{24} \geq 6 \]
\[ t_f = T_S + t_s - d_t - \frac{T_H}{\tan F} \sin F \]
\[ t_w = \frac{T_H + t_f \cos F}{\sin F} \]
Figure E-2. Headwall Dimensions for Precast Concrete Culverts

a. Wingwall Flare Angles Less Than 60°

\[
T_H = \frac{B_f}{12} \geq \frac{B_f}{24} + 8 \geq 12
\]

\[
t_w = \frac{B_f}{24}
\]

\[
t_f = \frac{B_f}{12} + T_S \sin F \geq (12 + T_S) \sin F
\]

\[
t_s = d_t + t_f \sin F + t_w \cos F - T_s
\]

\[
d_s = T_H + t_f \cos F - t_w \sin F
\]

b. Wingwall Flare Angles Greater Than or Equal to 60°

\[
T_H = \frac{B_f}{12} \geq 12
\]

\[
t_f = \frac{B_f}{12} + T_S \geq 12 + d_t
\]

\[
t_w = \frac{T_H + t_f \cos F}{\sin F}
\]

\[
t_s = t_w \cos F + t_f \sin F + d_t
\]
Figure E-3. Headwall Dimensions for Corrugated Metal Pipe

\[
T_H = \frac{B_f}{24} + \frac{d_t}{\tan B} \geq 8 + \frac{d_t}{\tan B} \geq 12''
\]

\[
t_w = \frac{B_f}{24}
\]

\[
t_f = \frac{B_f \sin F}{12} > 12 \sin F
\]

\[
t_s = d_t + t_f \sin F + t_w \cos F
\]

\[
d_s = T_H + t_f \cos F - t_w \sin F
\]

a. Wingwall Flare Angles Less Than 60°

\[
T_H = \frac{B_f}{24} + \frac{d_t}{\tan B} \geq 8 + \frac{d_t}{\tan B} \geq 12''
\]

\[
t_f = \frac{B_f}{12} \geq 12 - d_t \geq 6''
\]

\[
t_s = t_w \cos F + t_f \sin F + d_t
\]

\[
t_w = \frac{T_H + t_f \cos F}{\sin F}
\]

b. Wingwall Flare Angles Greater Than or Equal to 60°

Table E-8

| Box Section Headwall Designs - 45° Wingwall Flare Angle |
### Table E-9

#### Box Section Headwall Designs - 60° Wingwall Flare Angle

<table>
<thead>
<tr>
<th>(ft x ft.)</th>
<th>Headwall Opening Span x Rise</th>
<th>TT (in.)</th>
<th>TS (in.)</th>
<th>TH (in.)</th>
<th>t_W (in.)</th>
<th>t_S (in.)</th>
<th>t_f (in.)</th>
<th>d_s (in.)</th>
<th>d_h (in.)</th>
<th>d_t (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0 x 5.0</td>
<td>8.0</td>
<td>8.0</td>
<td>12.0</td>
<td>16.5</td>
<td>9.7</td>
<td>8.5</td>
<td>6.3</td>
<td>8.0</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>6.0 x 6.0</td>
<td>8.0</td>
<td>8.0</td>
<td>12.0</td>
<td>17.0</td>
<td>10.0</td>
<td>8.5</td>
<td>6.0</td>
<td>8.0</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>7.0 x 7.0</td>
<td>8.0</td>
<td>8.0</td>
<td>12.0</td>
<td>17.5</td>
<td>10.4</td>
<td>8.5</td>
<td>5.6</td>
<td>8.0</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>8.0 x 8.0</td>
<td>8.0</td>
<td>8.0</td>
<td>12.0</td>
<td>18.0</td>
<td>10.7</td>
<td>8.5</td>
<td>5.3</td>
<td>8.0</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>9.0 x 9.0</td>
<td>9.0</td>
<td>9.0</td>
<td>12.0</td>
<td>18.5</td>
<td>10.1</td>
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<td>4.9</td>
<td>9.0</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>10.0 x 10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>12.0</td>
<td>19.0</td>
<td>9.4</td>
<td>8.5</td>
<td>4.6</td>
<td>10.0</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>12.0 x 12.0</td>
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<td>12.0</td>
<td>12.0</td>
<td>20.0</td>
<td>8.1</td>
<td>8.5</td>
<td>3.9</td>
<td>12.0</td>
<td>6.0</td>
<td></td>
</tr>
</tbody>
</table>

1. Above designs are based on 45° bevel angle and 60° flare angle. See Figure E-1 for other angles.
2. See Sheet 7, Appendix G for key to dimensions and reinforcing requirements.
3. Designs are applicable to one and two cell box sections.

### Table E-10

#### Reinforced Concrete Pipe Headwall Designs - 45° Wingwall Flare Angle

<table>
<thead>
<tr>
<th>Headwall Opening Diameter</th>
<th>h (in.)</th>
<th>T_H (in.)</th>
<th>t_W (in.)</th>
<th>t_S (in.)</th>
<th>t_f (in.)</th>
<th>d_s (in.)</th>
<th>d_h (in.)</th>
<th>d_t (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(ft)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4.0</td>
<td>12.0</td>
<td>16.0</td>
<td>17.7</td>
<td>11.3</td>
<td>8.7</td>
<td>12.0</td>
<td>2.4</td>
</tr>
<tr>
<td>6</td>
<td>6.0</td>
<td>12.0</td>
<td>17.0</td>
<td>18.6</td>
<td>12.7</td>
<td>9.0</td>
<td>12.0</td>
<td>3.6</td>
</tr>
<tr>
<td>8</td>
<td>8.0</td>
<td>12.0</td>
<td>18.0</td>
<td>19.5</td>
<td>14.1</td>
<td>9.3</td>
<td>12.0</td>
<td>4.8</td>
</tr>
<tr>
<td>10</td>
<td>10.0</td>
<td>13.0</td>
<td>19.0</td>
<td>20.4</td>
<td>15.6</td>
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<tr>
<td>12</td>
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<td>21.3</td>
<td>17.0</td>
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</tr>
<tr>
<td>14</td>
<td>14.0</td>
<td>15.0</td>
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<td>19.8</td>
<td>14.2</td>
<td>14.0</td>
<td>8.4</td>
</tr>
</tbody>
</table>

1. Above designs are based on 45 degree bevel angle and 45 degree wingwall angle. See Figure E-2 for dimensions for other angles.
2. See Sheet 8, Appendix G for key to dimensions and other requirements.

### Table E-11

#### Corrugated Metal Pipe Headwall Designs - 45° Wingwall Flare Angle
<table>
<thead>
<tr>
<th>Headwall Opening Diameter (ft)</th>
<th>$T_H$ (in.)</th>
<th>$t_w$ (in.)</th>
<th>$t_s$ (in.)</th>
<th>$t_f$ (in.)</th>
<th>$d_s$ (in.)</th>
<th>$d_h$ (in.)</th>
<th>$d_t$ (in.)</th>
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</thead>
<tbody>
<tr>
<td>4</td>
<td>12.0</td>
<td>16.0</td>
<td>19.3</td>
<td>8.5</td>
<td>6.7</td>
<td>8.0</td>
<td>2.0</td>
</tr>
<tr>
<td>6</td>
<td>12.0</td>
<td>17.0</td>
<td>21.0</td>
<td>8.5</td>
<td>6.0</td>
<td>8.0</td>
<td>3.0</td>
</tr>
<tr>
<td>8</td>
<td>12.0</td>
<td>18.0</td>
<td>22.7</td>
<td>8.5</td>
<td>5.3</td>
<td>8.0</td>
<td>4.0</td>
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<tr>
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<td>12.0</td>
<td>19.0</td>
<td>24.4</td>
<td>8.5</td>
<td>4.6</td>
<td>10.0</td>
<td>5.0</td>
</tr>
<tr>
<td>12</td>
<td>12.0</td>
<td>20.0</td>
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<td>3.9</td>
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<td>6.0</td>
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<tr>
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<td>22.0</td>
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<td>16.0</td>
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<tr>
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<td>37.0</td>
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<td>16.0</td>
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<td>31.6</td>
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<td>8.4</td>
<td>16.0</td>
<td>8.0</td>
</tr>
</tbody>
</table>

1. Above designs are based on 45 degree vevel angle and 45 degree wingwoll angle. See Figure E-2 for dimensions for other angles.
2. See Sheet 8, Appendix G for key to dimensions and other requirements.

Notes:
1. Dimensions as shown use reinforcing as for typical non-skewed headwall. See App. G., Sheet 7.
2. Foundation and cutoff wall to be designed based on local conditions.
b. **Section A-A**

Figure E-4. Skewed Headwall for 8 X 8 Box Section

Headwall Skew = 30°

---

**Notes:**

1. Dimensions as shown, use reinforcing as for typical non-skewed headwall. See Appendix G, Sheet 8.

2. Foundation and cutoff wall to be designed based on local conditions.
b. Section A-A

Figure E-5. Skewed Headwall for 72" Reinforced Concrete Pipe

Notes:

1. Dimensions as shown, use reinforcing as for typical non-skewed headwall. See Appendix G, Sheet 8.

2. Foundation and cutoff wall to be designed based on local conditions.
**Table E-12**

**Apron Designs - 30° Wingwalls, S_f = 2:1**

<table>
<thead>
<tr>
<th>B_f (ft)</th>
<th>D_i (ft)</th>
<th>S</th>
<th>Fall (ft)</th>
<th>L_b (ft-in.)</th>
<th>L_F (ft-in.)</th>
<th>W_p (ft-in.)</th>
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</thead>
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<td></td>
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<td>3-0</td>
<td>7-10</td>
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</tr>
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<td>3-0</td>
<td>11-10</td>
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<td>3-0</td>
<td>15-10</td>
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</tr>
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<td>3-0</td>
<td>19-10</td>
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<td>14.0</td>
<td>0.03</td>
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<td>7-0</td>
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<td>6-0</td>
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**Table E-13**

**Reinforcing Requirements - Square to Circular Transition Sections**

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<th>8</th>
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<td></td>
</tr>
<tr>
<td>Fill Over Transition (ft)</td>
<td>4 to 10</td>
<td>8</td>
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<tr>
<td>--------------------------</td>
<td>---------</td>
<td>----</td>
</tr>
<tr>
<td>Bar Designation</td>
<td>Required Reinforcement Area (in.²/ft)</td>
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<tr>
<td>IA</td>
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<td>0.20</td>
</tr>
<tr>
<td>IB</td>
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<td>0.20</td>
</tr>
<tr>
<td>8A</td>
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<tr>
<td>Long. 1</td>
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<td>0.13</td>
</tr>
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</table>

Go to Appendix F
Appendix F : FHWA-IP-83-6
Derivation of Equations for Locating Culverts

Go to Appendix G

F.1 Derive Equations to Determine Elevations of Critical Points and Lengths of Critical Sections for Slope Tapered Inlets

F.1.1 Definition of Terms

Assume the following parameters are known:

- Slopes: Stream bed ($S_0$), Fall ($S_f$), Embankment ($S_e$),
- Lengths: $L_1, L_2, L_3, L_T$ and vertical "Fall"
- Elevations: Points $E_E, E_O$
- Barrel Diameter: $D_i$

Determine the following variables:

- Slopes: Barrel ($S$)
- Lengths: $L_E, L_O, L, L_B$
- Elevations: $E_F, E_T, E_B, E_S$
F.1.2 Determine the Lengths $L_E$ & $L_O$

$T_H$: selected by designer

$D_{Hi}, D_{Ho} = D_i/12$, (or as selected by designer, 12 in/min.)

$D_{Vi} = D_i \sqrt{\frac{1}{S_f^2} + 1}$

$D_{Vo} = D_i \sqrt{S_f^2 + 1} \approx D_i$ (0.5% error for $S = 0.10$)

by similar triangles:

\[
\frac{(L_E + T_H)}{(D_{Vi} + D_{Hi}) - S_0 L_E} = S_e
\]

$L_E + S_e S_0 L_E = S_e (D_{Vi} + D_{Hi}) - T_H$

\[
L_E = \frac{S_e (D_{Vi} + D_{Hi}) - T_H}{1 + S_e S_0}
\]

Equation F.1

by similar calculations:

\[
L_O = \frac{S_8 (D_{Vo} + D_{Ho}) - T_H}{1 + S_8 S_0}
\]

Equation F.2

$L = L_T - L_O - L_E$

Equation F.3

F.1.3 Determine $L_B$
\[ \theta = \frac{1}{2} \left( \arctan \frac{l}{S_f} - \arctan S \right) \]

\[ L_B' = D_i \tan \theta \]

\[ L_B'' = S(D_i) \quad \text{Note: See Eq. F.9 for determination of } S. \]

\[ L_B = \frac{L_B'' + L_B'}{\sqrt{S^2 + 1}} \]

Substituting:

\[ L_B = \frac{D_i \left\{ \tan \left[ \frac{1}{2} \left( \arctan \frac{l}{S_f} - \arctan S \right) \right] + S \right\}}{\sqrt{1 + S^2}} \]

**Eq. F.4**

---

**F.1.4 Determine Elevations** $D_F$, $E_B$, $E_T$, $E_s$

\[ E_l.E_F = (E_l.E_E) - S_o L_E \quad \text{Equation F.5} \]
\[ E_l.E_T = (E_l.E_F) - \text{Fall} \quad \text{Equation F.6} \]
\[ E_l.E_{BF} = (E_l.E_T) + S(L_3 + L_B) \quad \text{Equation F.7} \]
El.ES = El.EO + S₀LE
\[ E = E_T - E_S \]
\[ L = (L_E + L_I + L_O) \]

**F.1.5 Determine Slope of Barrel S**

\[ S = \frac{E_E - E_S}{L_T - (L_E + L_I + L_O)} \]

**F.1.6 Determine Height of Fill over Inlet at Face, Hf, and along Length, H(x), Where x Is Horizontal Distance from Face Culvert**

Hf varies with site conditions and height of headwall, and must include any surcharge loads being considered.

\[ H(x) = H_f + x(1/S_f + 1/S_e), \quad 0 < x < L_2 \]

\[ H(x) = H_f + L_2(1/S_f + 1/S_e) + (x - L_2)(1/S_e + S), \quad L_2 < x < L_1 \]

**F.2 Derive Equations to Determine Elevations of Critical Points and Lengths of Critical Sections for Side Tapered Inlets with Fall**

**F.2.1 Definition of Terms**
Assume the following parameters are known:

- Slopes: Stream bed ($S_o$), Fall ($S_f$), Embankment ($S_e$)
- Lengths: $L_I$, $L_T$, and vertical "Fall"
- Elevations: Points $E_E$, $E_0$

Determine the following variables:

- Slopes: Barrel ($S$)
- Elevations: $E_C$, $E_B$, $E_F$, $E_T$
F.2.2 Determine Lengths

\[ T_H: \text{Selected by designer} \]

\[ D_H = D_i / 12, \text{ (or selected by designer, 12 in. min.)} \]

\[ D_V = D_i \sqrt{S^2 + 1} \approx D_i \text{ (0.5% error for } S = 0.10) \]

\[ L_B = D_i / 2 \text{ minimum, selected by designer} \]

\[ L_O = \frac{S_e (D_{Vo} + D_{Ho}) - T_H}{1 - S_e S_o} \]

For inlet location without Fall:

\[ L_E' = \frac{1}{1 + S_e S_o} \left[ S_e (D_V + D_H) - T_H \right] \quad \text{Eq. F.11} \]
Due to the increased number of variables, the remaining parameters are most easily determined by an iterative process.

a. Estimate barrel slope $S$

$$S = \frac{(L_T - L_O - L'_E) S_o - \text{Fall}}{L_T - (L_O + L_B + L_1)}$$  \hspace{1cm} \text{Equation F.12}

b. Determine remaining lengths

$$L_1 = \left[ \text{Fall} - L_1 S + \left(D_v + D_h\left(\frac{s^2}{s^2} + 1\right)\right) S_o \right]$$  \hspace{1cm} \text{Equation F.13}

$$L_C = L'_E - L_B - L_i - \frac{S_f [\text{Fall} - S(L_1 + L_B) + S_o (L_i + L_B)]}{1 - S_o S_f}$$ \hspace{1cm} \text{Equation F.14}

$$\text{Fall}' = \text{Fall} + S_o (L'_E - L_C)$$  \hspace{1cm} \text{Equation F.15}

$$L_F = [\text{Fall}' - S (L_B + L_1)] S_f$$  \hspace{1cm} \text{Equation F.16}

$$L_E = L_B + L_C + L_F$$  \hspace{1cm} \text{Equation F.17}

Note: $L_E$ and/or $L_C$ may be negative indicating that the points $E_F$ and/or $E_C$ are located outside the toe of the embankment (to the left of point $E_E$ in the figure on Section F.2.1)

$$L = L_T - (L_O + L_E)$$ \hspace{1cm} \text{Equation F.18}

c. Check result, calculate $\Delta$

$$\Delta = S_o (L_T - L_O - L_C) - S (L_B + L_1) - L_F/S_f$$  \hspace{1cm} \text{Equation F.19}

d. if $\Delta > 0.01$, calculate a new $S$

$$S = \frac{SL + \Delta}{L}$$  \hspace{1cm} \text{Equation F.20}

Repay steps b and c. This iteration will normally close with one additional cycle. See Example

---

**F.2.3 Determine Elevations**

El. $E_C = \text{El.} E_E - S_o L_C$  \hspace{1cm} \text{Equation F.21}

El. $E_B = \text{El.} E_C - L_F/S_f$  \hspace{1cm} \text{Equation F.22}

El. $E_F = \text{El.} E_B - S L_B$  \hspace{1cm} \text{Equation F.23}

El. $E_T = \text{El.} E_F - S L_B$  \hspace{1cm} \text{Equation F.24}

El. $E_S = \text{El.} E_O - S L_O$  \hspace{1cm} \text{Equation F.25}
F.2.4 Determine Height of Fill over Inlet at Face ($H_f$) and along Length $H(x)$ Where $x$ Is the Horizontal Distance from the Face of the Culvert

$H_f$ varies with site conditions and height of headwall. Must include any surcharge loads being considered.  

$$H(x) = H_f + x(S + 1/S_e)$$  
Equation F.26

F.2.5 Example - Side Tapered Inlet with Fall

a. Given

- $D_i = B_i = 4.0$ ft  
- $S_o = 0.05$  
- $E_i, E_E = 17.5$ ft
- $L_T = 350$ ft  
- $S_e = 2$  
- $E_i, E_O = 0.0$ ft
- $L_I = 4.0$ ft  
- $S_f = 2$
- Fall = 1.5 $D_i = 6.0$ ft

b. Designer selected parameters

$$D_V \approx D_i = 4.0 \text{ ft}$$

$$D_H = \frac{D_i}{12} = \frac{4.0}{12} = 0.33 \text{ ft} \Rightarrow \text{Use 1.0 ft min.}$$

$$T_H = 1.0 \text{ ft (for simplicity)}$$

$$L_B = \frac{D_i}{2} = 2.0 \text{ ft}$$

c. Determine remaining variables

$$L_O = \frac{1}{1 - S_e S_o} \left[ S_e (D_V + D_H) - T_H \right]$$

$$= \frac{1}{1 - 2(0.05)} \left[ 2(4.0 + 1.0) - 1.0 \right] = 10.0 \text{ ft}$$

$$L'_E = \frac{1}{1 + S_e S_o} \left[ S_e (D_V + D_H) - T_H \right]$$
\[
S = 1 + 2(0.05) \left[ 2(4 + 1) - 1 \right] = 8.18 \text{ ft}
\]
\[
S \approx \frac{(L_T - L_O - L_E') S_o - \text{Fall}}{L_T - (L_O + L_B + L_I)} = \frac{(350 - 10 - 8.18) 0.05 - 6.0}{350 - (10 + 2 + 4)} = 0.0317
\]
\[
L_{ii} = \left[ \frac{\text{Fall} - L_I S + (D_V + D_H)(\sqrt{S_o^2 + 1} - \sqrt{S_o^2 + 1})}{S_o} \right] S_e
\]
\[
= \left[ 6.0 - 4.0(0.0317) + (4 + 1)(\sqrt{0.05^2 + 1} - \sqrt{0.0317^2 + 1}) \right] 2 = 11.75 \text{ ft}
\]
\[
L_C = L_{E} - L_B - L_{i} + S_f \left[ \frac{\text{Fall} - S (L_I + L_B) + S_o (L_i + L_B)}{1 - S_o S_f} \right]
\]
\[
= 8.18 - 2 - 11.75 - 2 \left[ \frac{6 - 0.0317 (4+2) + 0.05 (11.75+2)}{1 - (0.05) 2} \right] = -20.01 \text{ ft}
\]
\[
\text{Fall'} = \text{Fall} + S_o (L_{E'} - L_C) = 7.41 \text{ ft}
\]
\[
L_{F} = \left[ \frac{\text{Fall'} - S(L_B + L_I)}{S_f} \right] S_f = \left[ \frac{7.41 - 0.0317 (2 + 4)}{2} \right] 2 = 14.44 \text{ ft}
\]
\[
L_E = L_B + L_C + L_F = 2 + (-20.01) + 14.44 = -3.57 \text{ ft}
\]
\[
L = L_T - (L_E + L_O) = 350.0 - (-3.57 + 10.0) = 343.57 \text{ ft}
\]
d. Check \( \Delta \)
\[
\Delta = 0.05 \left[ 350 - 10 - (-20.01) \right] - 0.0317 (343.57 + 2) - \frac{14.44}{2} = -0.174
\]
e. \( \Delta > 0.01 \); therefore, recalculate \( S \) and lengths \( L_F, L_E, L_C, L \)
\[
S = \frac{SL + \Delta}{L} = \frac{0.0317 (343.57) + (-0.174)}{343.57} = 0.0312
\]
\[
L_{i} = \left[ 6 - 4(0.0312) + (4 + 1)(\sqrt{0.05^2 + 1} - \sqrt{0.0312^2 + 1}) \right] 2 = 11.76 \text{ ft}
\]
\[
L_C = 8.18 - 2 - 11.76 - 2 \left[ \frac{6.0 - 0.0312 (4+2) + 0.05 (11.76+2)}{1 - 0.05 (2)} \right] = -20.03 \text{ ft}
\]
Fall' = 6.0 + 0.05 \left[ 8.18 - (-20.03) \right] = 7.41 \text{ ft}

L_F = 7.41 - 0.0312 (2 + 4) \times 2 = 14.45

L_E = 2 + (-20.03) + 14.45 = -3.58

L = 350 - (-3.58 + 10) = 343.58

\text{f. Check } \Delta

\Delta = 0.05 \times 350 - 10 - (-20.03) - 0.0312 (343.58 + 2) - \frac{14.45}{2} = -0.006

\Delta < 0.01, \quad \text{Okay}

g. Determine elevations

El. E_C = El. E_E - S_o L_C = 17.5 - (0.05)(-20.03) = 18.50 \text{ ft}

El. E_B = El. E_C - L_F / S_f = 18.50 - 14.45 / 2 = 11.28 \text{ ft}

El. E_F = El. E_B - S L_B = 11.28 - 0.0312(2) = 11.22 \text{ ft}

El. E_T = El. E_F - S L_T = 11.22 - 0.0312(4) = 11.10 \text{ ft}

h. Determine height of fill

\approx 1 \text{ ft at headwall} + 2.0 \text{ ft surcharge}

H_f = 1 + 2 = 3.0 \text{ ft}

H_{throat} = 3 + 4 \left( 0.0313 + \frac{1}{2} \right) = 5.13 \text{ ft}

i. Summary Sketch
F.3 Derive Equations to Determine Elevation of Critical Points and Lengths of Critical Sections for Side Tapered Inlets without Fall

Note: This case is a simplification of Case B. All the necessary equations have been derived previously, and are assembled here for simplicity.
$T_H$: Selected by designer

\[ D_H = \frac{D_i}{T^2}, \text{(or as selected by the designer, 12 in. min.)} \]

\[ D_V = D_i \sqrt{S^2 + 1} \approx D_i \]

\[ L_E = \frac{1}{1 + S_e S_o} \left[ S_e (D_V + D_H) - T_H \right] \]

\[ L_O = \frac{1}{1 - S_e S_o} \left[ S_e (D_V + D_H) - T_H \right] \]

\[ L = L_T - L_E - L_O \]

\[ E_{F} = E_{E} - L_E S \]

\[ E_{T} = E_{F} - L_T S \]

$H_f$ varies with site conditions and height of headwall. Must include any surcharge being considered.

\[ H(x) = H_f + x \left( S + \frac{1}{S_e} \right) \]
Appendix G: FHWA-IP-83-6

Typical Details for Improved Inlets

Go to Appendix H

Sheet 1. Typical Reinforcing Layout - Side Tapered Single Cell Box Inlets
Sheet 2. Typical Reinforcing Layout - Side Tapered Two Cell Box Inlets
Sheet 3. Typical Reinforcing Layout - Slope Tapered Single Cell Box Inlets
Sheet 4. Typical Reinforcing Layout - Slope Tapered Two Cell Box Inlets
Sheet 5. Typical Reinforcing Layout - Side Tapered Reinforced Concrete Pipe Inlets
Sheet 6. Side Tapered Corrugated Metal Inlet
Sheet 7. Headwall Details for Box Inlets
Sheet 8. Headwall Details for Pipe Inlets
Sheet 9. Cantilever Wingwall Designs
Sheet 10. Miscellaneous Improved Inlet Details

Go to Appendix H
Program BOXCAR

V 6 LEVEL 21 MAIN DATE = R2251 183509

PROGRAM BOXCAR

ANALYSIS AND DESIGN PROGRAM FOR ONE CELL REINF. CONCRETE BOX SECTIONS

SUBMITTED TO FEDERAL HIGHWAY ADMINISTRATION - AUGUST 1982
DEVELOPED FOR FHWA PROJECT NO. DOT-FH-11-9692
BY SIMPSON GUMPERTZ AND HEGEN INC. 1696 MASSACHUSETTS AVENUE
CAMBRIDGE, MASSACHUSETTS 02138

EXAMPLE STANDARD PLANS FOR IMPROVED INLETS

THIS IS THE MAIN PROGRAM, IT SEQUENTIALLY CALLS THE VARIOUS
SUBROUTINES NEEDED TO COMPLETE THE ANALYSIS AND DESIGN OF THE
ONE CELL BOX.

REAL*4 ULOAD(12,5)
REAL*4 LY,KK(4,5),KAD(4,3,3),KAB(4,3,3),KBA(4,3,3),KPB(4,3,3)
INTEGER ISDATA(35),IPDATA(35)
INTEGER ICON(6)

COMMON/SCALE/SPAN,RISE,TT,TR,TS,SAMAC,GAMAC,GAMAF,PC,H,H,H,H,H,0,1
COMMON/ETA,BETA,DF,W,EC,FS,FY,FCP,FLMV,FLN,02,03,MLAY,RTYPE,04,05,
COMMON/RARRAY/V(12,5),W1(4,5),W2(4,5),A(4,5),B(4,5),C(4,5),
COMMON/ARRAY/UM(4,25),V(50,4)

COMMON/RARRAY/TMER,KAD,KAB,KBA,KBB

COMMON/ANAL/YLOAD,STIFF(12,12),FIXMO(4,5,4),DM(6),DV(6),DP(6),
COMMON/ISCALE/NOLC,ISUB,IR,IS,ITAPE,IPATH,ICYC,ININT

COMMON/IARRAY/EMB(4,2)

COMMON/RARRAY/MOM(20,5),V(20,5),P(3,5),FSLA(4,5),FYLA(4,5)
1,BMA(4,5),FSLB(4,5),FSLB(4,5),EMB(4,5),EMD(20,5),EDV(20,5),
2,GRV1(20),GRV1(20),GPI(3),GRVNG(20),GRI2NG(20),GRV2PL(20)
3,GRPM2PL(20),GRIPL(3),GRPM2NG(3),FMIN(3),FMIN(20),FM1IA(20),
4,FMAX(3),FMAX(29),FMAX(29),FMAX(29),ZMOM1,ZMUMB,XL(20)

COMMON/IFLAGS/IPDATA,ISDATA,ICON
*END OF COMMON*

IV 6 LEVEL 21

C
INTERNAL UNITS ARE KIPS AND INCHES

C
IR=5
I0=6
4 IPATH=1
1 CALL RREAD(ISTOP)
   GO TO 12,5,1,ISTOP
2 CALL INIT
   IF(IPATH.LE.0)GO TO 4
   CALL DESIGN
   IF(IPATH.LE.0)GO TO 4
   CALL OUTPUT
   GO TO 1
3 CONTINUE
   END

IV 6 LEVEL 21

SUBROUTINE RREAD(ISTOP)

C
THIS ROUTINE READS ALL THE INPUT IN A SPECIFIED FORMAT AND
TRANSFERS THE DATA INTO THE BOATA AND SDATA ARRAYS. THE EXECUTION OF RREAD
IS CONTROLLED BY THE CODE VARIABLE ON THE INPUT CARDS. A CODE
GREATER THAN 13 SIGNALS THE END OF THE INPUT DATA. RREAD REPRINTS
THE INPUT CARDS AS IT READS THEM AS A CHECK FOR THE USER.

C
INTEGER ISDATA(35),IRDATA(35)
COMMON /FLAGS/ IBDATA,ISDATA
COMMON /SCALE/ BOATA(35),SDATA(35)
COMMON/VSCALE/NIT,NOLD,IDBUG,IR,IW,ITAPE,IPATH,ICYC,NINT
DIMENSION TEXT(5),OT(6)
DTYPE(18),LAT(15)
DATA LAT/3,3,3,3,1,2,6,1,2,1,2,1,2,1,2,

C
C
WRITE(IW,99)
99 FORMAT(*1*)
READ(IN,1022,END=995) (BOATA(I),I=1,20),IDBUG
1022 FORMAT(1X,19A4,A3,11)
WRITE(IW,1021) (BOATA(I),I=1,20),IDBUG
1021 FORMAT(1X,19A4,A3,11)
DO 5 I=1,35
SDATA(I)=0
ISDATA(I)=0
RDATA(I)=0
5 ISDATA(I)=0
SLEN=1
SLEN2=SLEN*SLEN
SLEN3=SLEN2*SLEN
SDL=1000.
1 READ IR,1000,END=995) KDE,(TEXT(I),I=1,5),(D(I),I=1,6)
1000 FORMAT(I2,4A4,A2,6F10.2)
   IF (K=2) GO TO 999
   K=LAT(KDE)
   WRITE(IW,2000) KDE,(TEXT(I),I=1,5),(D(I),I=1,K)
2000 FORMAT(1X,12,4A4,A2,6F10.3)
C CONTINUE
GO TO (10,20,30,40,50,60,70,80,90,100,110,120,130)*KODE
C
C SPAN, RISE, AND DEPTH OF FILL, KODE=1
10 CONTINUE
BDATA(1)=D(1)*SLEN
BDATA(2)=D(2)*SLEN
BDATA(10)=D(3)*SLEN
IBDATA(1)=1
IBDATA(2)=1

IV G LEVEL 21 RREAD DATE = 82251 18/35/09

IBDATA(10)=1
GO TO 1

C
C SLAB THICKNESSES, TT, TP, TS, KODE=2
20 CONTINUE
BDATA(3)=D(1)
BDATA(4)=D(2)
BDATA(5)=D(3)
GO 21 IF=3
IF (BDATA(1)) 21,21,23
23 IBDATA(1)=1
21 CONTINUE
GO TO 1

C
C MAXIMUM GEOMETRY, HH, HV, KODE=3
30 CONTINUE
IF (D(1)EQ.0.0) D(1)=D(2)
IF (D(2)EQ.0.0) D(2)=D(1)
BDATA(11)=D(1)
BDATA(12)=D(1)
IBDATA(11)=1
IBDATA(12)=1
GO TO 1

C
C DENSITIES, GAMAS, GAMAC, GAMAF, KODE=4
40 CONTINUE
47 BDATA(7)=D(1)/SLEN3/SLD
IBDATA(7)=1
42 BDATA(6)=D(2)/SLEN3/SLD
IBDATA(6)=1
44 BDATA(5)=D(3)/SLEN3/SLD
IBDATA(5)=1
GO TO 1

C
C MINIMUM LATERAL SOIL COEFFICIENT (ZETA), MAXIMUM LATERAL SOIL
C COEFFICIENT (CONVERTED TO RAT IN BDATA(25)), SOIL-STRUCTURE
C INTERACTION COEFFICIENT (BETA), FLAG FOR PERMANENT SIDE LOAD
50 CONTINUE
IF (D(1)) 51,57,52
51 IBDATA(14)=-1
BDATA(14)=0.30
GO TO 53
57 BDATA(14)=D(2)
D(4)=1
GO TO 53
52 BDATA(14)=D(1)
IBDATA(14)=1
53 IF (D(1)EQ.0.0) GO TO 56
SDATA(25) = O(2)/O(1) - 1.0
56 ISDATA(25) = 1
  IF ( D(14) .NE. 0.0 ) IPODATA(14) = 2
  IF ( D(13) .LT. 5.0 ) 54, 55, 55
54 IPODATA(15) = 1.0
  IPODATA(15) = -1
  GO TO 1
55 IPODATA(15) = O(1)
  IBDATA(15) = 1
  GO TO 1

C LOAD FACTOR, CAPACITY RED. FACTORS KODE=6

60 CONTINUE
  RDATA(22) = O(1)
  RDATA(23) = O(1)
  RDATA(24) = D(2)
  RDATA(25) = O(1)
  IBDATA(22) = 1
  IBDATA(23) = 1
  IBDATA(24) = 1
  IBDATA(25) = 1
  GO TO 1

C DEPTH OF FLUID KODE=7
70 CONTINUE
  RDATA(16) = D(1)
  IBDATA(16) = 1
  GO TO 1

C MATERIAL STRENGTHS, FY, FCP KODE=8
80 CONTINUE
  IF ( D(11) .EQ. 0.0 ) GO TO 81
  RDATA(20) = D(1)
  IBDATA(20) = 1
81 IF ( D(2) .EQ. 0.0 ) GO TO 1
  RDATA(21) = O(2)
  IBDATA(21) = 1
  GO TO 1

C CONCRETE COVER KODE=9
90 CONTINUE
  DO 95 I = 1, 6
    IF ( D(I) ) 95, 95, 92
92 RDATA(29+I) = D(I)
    IBDATA(29+I) = 1
95 CONTINUE
  GO TO 1
C CRACK FACTOR

100 CONTINUE
RDATA(24)=D(1)
IRDATA(24)=1
GO TO 1

C REINFORCING TYPE AND NUMBER OF LAYERS

110 CONTINUE
RDATA(25)=D(1)
RDATA(26)=D(2)
IRDATA(25)=1
IRDATA(26)=1
GO TO 1

C WIRE DIAMETERS

120 CONTINUE
DO 121 I=5,6
IF (C(I-2)) 121,121,122
122 SDATA(I)=D(I-2)
IRDATA(I)=1
121 CONTINUE
IF (ISDATA(3) .NE. 1) GO TO 1
ISDATA(1)=1
ISDATA(2)=1
SDATA(1)=D(1)
SDATA(2)=D(1)
GO TO 1

C WIRE SPACING

130 CONTINUE
DO 135 I=9,12
IF (D(I-8)) 135,135,135
133 SDATA(I)=D(I-8)
IRDATA(I)=1
135 CONTINUE
IF (ISDATA(9) .NE. 1) GO TO 1
ISDATA(7)=1
ISDATA(8)=1
SDATA(7)=D(1)
SDATA(8)=D(1)
GO TO 1

C END OF DATA

999 CONTINUE
WRITE(*,2000) KODE,(TEXT(I),I=1,5)
994 CONTINUE

IV G LEVEL 21

ISTOP=1
GO TO 996
995 ISTOP=2
996 CONTINUE
RETURN
END
SUBROUTINE INIT

THIS SUBROUTINE FILLS OUT THE R DATA AND SDATA ARRAYS WHERE
NEEDED, IT CALCULATES VALUES FROM INPUT AND INSERTS THEM INTO
THE APPROPRIATE ARRAY.

INIT ASSIGNS DEFAULT VALUES ON THE FOLLOWING BASIS:
    IRDATA(*) .OR. ISDATA(*) = 1 - VALUE HAS BEEN INPUT NO VALUE NEEDED
    IFDATA(*) .OR. ISDATA(*) = 0 - VALUE HAS NOT BEEN INPUT, DEFAULT VALUE
    GIVEN TO BDATA(*) OR SDATA(*); IRDATA(*) OR IFDATA(*) IS THEN
    SET EQUAL TO -1.

THIS ROUTINE ALSO CHECKS FOR ERROR CONDITIONS IN THE INPUT DATA
AND PRINTS THE BDATA AND SDATA ARRAYS FOR AN IDELG VALUE GREATER
THAN 0.3.

INTEGER ISDATA(35), IRDATA(35)
COMMON /IFLAGS/ IRDATA, ISDATA
COMMON /PScale/ BDATA(35), SDATA(35)
COMMON /I1SCALE/ NCOL, IDBUG, IV, ITAPE, IPATH, ICYC, IINT
COMMON /ARRAY/MEMB(4,2)
COMMON /ARRAY/ FILE(160), PMEMB(4,25)
EQUIVALENCE (BDATA(1)),
EQUIVALENCE (RDATA(1), SPAN), (RDATA(2), RISE)
EQUIVALENCE (TT, RDATA(3)), (TB, RDATA(4)), (TS, RDATA(5)), (Hi, 
1 RDATA(11)), (Mv, RDATA(12))
DIMENSION ASSUME(35)

DIMENSION SOURCE(8)
DATA SOURCE/4MINPU, 4HT, 4HND, 4HVALUE, 4HASSU, 4HMED, 4H FL,
1 4HPP, 1
REAL B, SCRIPT(75), TTEXT(75)
DATA SCRIPT/8HINSIDE S, BFPAN (IN), 8HINSIDE R, 8HISE (IN),
1 8HTOP SLAF, 8HTH (IN), 8HTMOT SLAF, 8HTHK (IN), 8HINSIDE WAL,
1 8HL T (IN), 8HCONEC UNI, 8HT WT KCI, 8HSOIL UNI, 8HT WT KCL,
1 8HFLUID UNI, 8HT WT KCI, 8HFLEX CAP, 8HRED FACT, 8HBURIAL D,
1 8HEFTM IN, 8HMORIZ HA, 8HNANCH IN, 8HVERT HA, 8FMACH IN,
1 8HEM, 8CNPRED HA, 8HMPHRED, 8HMPHEQ, 8HMPHA, 8HMMFAC, 8HMPHAD,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
1 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC, 8HMPB, 8HMPFAC,
IF (IDATA(1) .EQ. 0) GO TO 100
IF ((RISE/12.*LT.2.) .OR. (RISE/12.*GT.29.)) GO TO 102
DO 4 I=1,4
MEMB(1+,1)=1
5 MEMB(1+,2)=1+1
MEMB(1+,3)=1
THICK =FILDAT(IFX(SPAN/12.+5))
ASSUME(3)=THICK+1.
IF (SPAN*GT.89.) ASSUME(3)=THICK
THICK=ASSUME(3)
ASSUME(4)=THICK
ASSUME(5)=THICK
ASSUME(6)=0.*R68F=04.
ASSUME(7)=0.*6544494E=04
ASSUME(8)=0.*3617F=04
ASSUME(9)=0.*90
C ASSUME(10) IS THE DEPTH OF FILL = FATAL ERROR IF OMITTED
ASSUME(11)=THICK
ASSUME(12)=THICK
ASSUME(13)=0.*9
ASSUME(14)=0.*25
ASSUME(15)=1.*2
ASSUME(16)=RISE
ASSUME(20)=65*
ASSUME(21)=5.*
ASSUME(22)=1.*3
ASSUME(23)=ASSUME(22)
ASSUME(24)=1.*C
ASSUME(25)=1.*0
ASSUME(27)=2.*
ASSUME(30)=1.*
ASSUME(31)=1.*
ASSUME(32)=1.*
ASSUME(33)=1.*
ASSUME(34)=1.*

ASSUME(15)=1.
DO 10 I=3*16
IF (IBDATA(I)) 10,9,16
9 IBDATA(I)=1
IBDATA(I)=ASSUME(I)
10 CONTINUE
DO 20 I=20*24
IF (IBDATA(I)) 20,19,20
19 IBDATA(I)=1
IBDATA(I)=ASSUME(I)
20 CONTINUE
DO 22 I=26*27
IF (IBDATA(I)) 22,21,22
21 IBDATA(I)=1
IBDATA(I)=ASSUME(I)
22 CONTINUE
DO 24 I=30*35
IF (IBDATA(I)) 24,23,24
23 IBDATA(I)=1
IBDATA(I)=ASSUME(I)
24 CONTINUE
IBDATA(19)=29000.
IBDATA(18)=(IBDATA(6)+1728000.*1.5*33.*SQRT(IBDATA(21)+1000.))/1000.
IBDATA(19)=-1
IBDATA(18)=-1
C C INITIALIZE PMEMB(I,J)
GO TO 81
80 CONTINUE
Q1=0.
92=0.
GO TO 82
81 IF ((HM.EQ.0.) .OR. (HV.EQ.0.)) GC TO 80
Q1=HM/HV/2.
Q2=HV*TS/HH/2.
82 D1=TS+HM+Q1*TT
D2=TT+HV+Q2
D3=TB+HV+Q2
D4=TS+HM+Q1*TB
PMEMB(1,1)=D2
PMEMB(1,2)=D1
PMEMB(3,1)=D3
PMEMB(4,1)=D4
PMEMB(1,2)=D2
PMEMB(2,2)=D4
PMEMB(3,2)=D3
PMEMB(4,2)=D1
PMEMB(1,3)=TT
PMEMB(2,3)=TS
PMEMB(3,3)=TB
PMEMB(4,3)=TS
Q1=SPAN+TS
Q2=RISE+(TT+TB)/2.
PMEMB(1,4)=Q1
PMEMB(2,4)=Q2
PMEMB(3,4)=Q1
PMEMB(4,4)=Q2
PMEMB(1,5)=HH+TS/2.
PMEMB(2,5)=HV+TT/2.
PMEMB(3,5)=HH+TS/2.
PMEMB(4,5)=HV+TT/2.
PMEMB(1,6)=HH+TS/2.
PMEMB(2,6)=HV+TR/2.
PMEMB(3,6)=HH+TS/2.
PMEMB(4,6)=HV+TT/2
GO TO 149
144 CONTINUE
WRITE(IW,999)
WRITE(IW,1000)
1000 FORMAT(' SPAN, RISE, AND DEPTH OF FILL MUST BE GIVEN.*)
WRITE(IW,1010)
IPATH=-1
GO TO 150
102 CONTINUE
SPAN=SPAN/12.
WRITE(IW,999)
WRITE(IW,1001) SPAN
1001 FORMAT(' PERMITTED RANGE OF SPANS IS 3 FT TO 20 FT. SPAN GIVEN AS 19DEC 7: 1*F3C8.3)
WRITE(IW,1010)
IPATH=-1
GO TO 150
102 CONTINUE
WRITE(IW,999)
RISE=RISE/12.
WRITE(IW,1002) RISE
1002 FORMAT(' PERMITTED RANGE OF RISES IS 2 FT TO 20 FT. RISE GIVEN AS 1*F3C8.3)
WRITE(IW,1010)
IPATH=-1
999 FORMAT(' *** INPUT ERROR ***)
1012 FORMAT(' EXECUTING FOR THIS PROBLEM HAS BEEN TERMINATED.*')
GO TO 150
149 CONTINUE
B=AKAY1(TT+TB+TS)
ASSUME(1)=0.08*TT
ASSUME(2)=0.08*PP
ASSUME(3)=0.08*RR
ASSUME(4)=0.08*TT
ASSUME(5)=0.08*PB
ASSUME(6)=0.08*TS
DO 31 I=7,12
ASSUME(1)=2*
31 CONTINUE
DO 33 I=1,12
IF ( ISDATA(I) ) 34,32,33
32 ISDATA(I)=-1
ISDATA(I+25)=-1
SDATA(I)=ASSUME(I)
IF (I .GT. 6) GO TO 33
34 CONTINUE
A=TT
IF ( I .GT. 2 .OR. 1 .EQ. 6 ) A=TS
IF ( I .GT. 5 .OR. 1 .EQ. 5 ) A=TB
SDATA(29)=A-RDATA(29)-SDATA(1)/2.
IF ( ISDATA(I+29) .NE. -1 ) ISDATA(I+29)=1
33 CONTINUE
IF ( ISDATA(25) .EQ. 0. ) GO TO 994
60 TO 996
994 SDATA(25) = 0.5/50DATA(14) - 1
ISDATA(25)=-1
WRITE(6,4050)
4050 FORMAT(///,3X,69(1H4),//,3X,1H4,67X,1H4,///,3X,1H4,1X,
1*ALL INFORMATION PRESENTED IS FOR REVIEW, APPROVAL, INTERPRETATION
2 ** AND APPLICATION BY A REGISTERED ENGINEER**,25X,1H4,//,
33X,1H4,67X,1H4,///,3X,69(1H4))
996 IF ( IDBUG.EQ.0 ) GO TO 901
WRITE(6,993) DEBUG
993 FORMAT(1H1,///,15H,MAP OF DDATA AND SDATA ARRAYS**,// )
WRITE(6,3031) DEBUG
3031 FORMAT(*0*,T12,*PARAMETER*,T28,*DATA*,T37,*SOURCE*,T73,
1 *PARAMETER*,T93,*DATA*,T102,*SOURCE* )
DO 900 1=1,35
900 JF = 1 * 2 - 1
KF = 1 * 2
IF ( ISDATA(I) ) 702, 701, 700
700 J = 1
IF ( ISDATA(I) .EQ. 2 ) J = 7
GO TO 703
701 J = 2
GO TO 703
702 J = 5
703 IF ( ISDATA(I) ) 706,705,704
IV 6
LEVEL 21
INIT
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704 N = 1
GO TO 707
705 N = 2
GO TO 707
706 N = 5
707 J1 = J+ 1
N1 = N + 1
WRITE(*,3000)(I=SCRIPT(K),K=JF*KF),(BDATA(I),SOURCE(K),K=J+J1)
1 WRITE(*,2300),(I=JF*KF),(SLDATA(I),SOURCE(K),K=N,N1)
3000 FORMAT(*,12,3X,2A8,-E12.5,2X,2A4,T65,E12.5,2X,2A4)
900 CONTINUE
901 CONTINUE
150 CONTINUE
RETURN
END

IV 6
LEVEL 21
DESIGN
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SUBROUTINE DESIGN
C
C THIS SUBROUTINE SEQUENTIALLY CALLS OTHER SUBROUTINES IN ORDER TO
C COMPLETE THE ANALYSIS AND DESIGN OF THE ONE CELL BOX.
A PRINTOUT OF THE X, Y, DEFLECTIONS AND ROTATIONS FOR EACH MEMBER
AND LOADING CASE IS AVAILABLE WITH AN IDBUG VALUE GREATER THAN 2.
C
COMMON/ARRAY/UR(12,5),FLG(100),PHM(4,25)
COMMON/RSCALE/SAN,RISE,IT,TR,TS,GAAC,GAAM,GAQF,P0,H,MH,MV,G,
1 ZETA,BETA,DF,Q1,EC,ES,FY,FCP,FLMV,FLN,Q2,Q3,NLAY,RTYPE,Q4,Q5,
2 CY(SY,SDATA(F5)
COMMON/ANAL/B(12,5),G(12,12),FIXM0(4,5,30),DM(6),D(6),DP(6)
1AS(6),SKM(11,6)
COMMON/VSCALE/NIT,NCLD,IDBUG,IR,ITAPE,IPATH,ICYC,NINT

ICYC=0
1 CONTINUE
DO 2 I=1,4
CALL GENJS(I)
2 CONTINUE
C
CALL GSTIF
C
CALL GENLD
C
CALL MATMP(ST,9,P,5,U(12))
C
EXPAND DISPLACEMENT MATRIX FOR REACTION COMPONENTS
DO 10 J=1,5
U(12+J)=U(5+J)
U(10+J)=U(8+J)
U(9+J)=U(7+J)
U(7+J)=0
U(8+J)=0
U(11+J)=0
10 CONTINUE
IF (IDBUG.LT.3) GO TO 12
WRITE(*,99)
99 FORMAT(*,200)
1200 FORMAT(*,T99,"DISPLACEMENT MATRIX - INCHES AND RADIAN",
2 T49,",T54,":

C3
DO 11 J = 1, 4
   JA = J*3-2
   JB = J*3-1
   JC = 3*J
   WRITE(6,1002) J, (U(JA*K), K=1,5)
   WRITE(6,1003) (U(JB*K), K=1,5)
1002 FORMAT(T5,11*T10,9*X, T13,5(E10,4.2X))
1003 FORMAT(T10,9*Y, T13,5(E10,4.2X))
1004 FORMAT(TA, *ROT* T13,5(E10,4.2X))
11 CONTINUE
12 CONTINUE
C
CALL ENDO
CALL SIMSPN
CALL FMXKN
IF (IPATH .LE. 0) RETURN
C
CALL DESCK
RETURN
END
SUBROUTINE GENUS(*)
C GENERATES FLEXIBILITY COEFFICIENTS FROM ONE CELL FOX GEOMETRY.
C FOR MEMBERS WITH LINEARLY VARYING WALLACHES THESE COEFFICIENTS ARE
C DETERMINED BY NUMERICAL INTEGRATION.
C
THE INTEGRATION POINTS ARE X=0.0 AT EQUALLY INTERVALS
REAL*4 M(50),M2(50),M3(50),M4(50),M5(50),M6(50)
REAL*4 INER(4,50)
COMMON /SCALE/ BDATA(35)
COMMON /ARRAY/ FIL(160),PMEMB(4,25),XX(50,4),INER
COMMON /ISCALE/ N
N=50
EQUIVALENCE (BDATA(11),XX),(BDATA(12),HV),(BDATA(18),EC)
DA=PMEMB(M+1)
DB=PMEMB(M+2)
DC=PMEMB(M+3)
SP=PMEMB(M+4)
AL =PMEMB(M+5)
ALB=PMEMB(M+6)
Y1=AL
Y2=SP-ALB
CA=(DA-DC)/AL
CB=(CA-DC)/ALB
IF ((HH.EQ.0).OR.(HV.EQ.0)) GO TO 5
DX1=AL/5.
DX2=(SP-ALB)/39.
DX3=ALB/5.
GO TO 6
5 DX1=SP/49.
DX2=DX1
DX3=DX1
6 X=DX1
DC 10 I=1,6
X=X+DX1
D=DA-CA+X
INER(M,1)=D*D*EC
XX(I,M)=X
10 CONTINUE
DC 11 I=7,45
X=X+DX2
D=DC
INER(M,1)=D*D*EC
XX(I,M)=X
11 CONTINUE
DC 12 I=46,50
X=X+DX3
D=DC*CB=(X-X2)
}
IV G LEVEL 21

FUNCTION TRAP(MOM,N,S,M)

USES THE TRAPEZOIDAL RULE WITH 50 INTEGRATION POINTS TO OBTAIN
THE FLEXIBILITY COEFFICIENTS

THIS IS THE 2ND VERSION OF THIS PROGRAM
THE INTEGRATION POINTS ARE N Q T AT EQUAL INTERVALS

REAL M,* INER(4,50)*MOM(1)
COMMOM /HARRAY/ FL(26,2)*X(50,4),INER
K=N+1
H=S/K
TRAP=0.
DO I=1,K
TRAP=TRAP+(MCM(I)/INER(M,I)*MOM(I+1)/INER(M+I+1))*
1 *(X(I+1)*M)-X(I,M))
1 CONTINUE
TRAP=0.5*TRAP
RETURN
END
SUBROUTINE GSTIF

generates stiffness matrix
flexibility coefficients are inverted and assembled to obtain
stiffness matrix.

1 ZETA/BETA/DEF/1/EC/ES/FLY/FCP/FLMV/FLM/02/03/NLAY/RYPE/64/05.
2 C(6), SDATA(25).
COMMON/ARRAY/YU(12+), W1(4+5), W2(4+5), A(4+5), B(4+5), C(4+5).
1 PMEMB(4+25), X(504).
COMMON/ANAL/FIL(600), STIF(12,12).
COMMON/ISCALE/NIT, NIND, NBUG, IR, IM, ITAPE, IPATH, ICYC, NINT.
DIMENSION F(3+5), AK(5,5), UN(5,5).

DO 8 I = 1, 12
 DO 8 H = 1, 12
 8 STIF(I,H) = 0.
DO 10 I = 1, 4
 10 CONTINUE

generate script F
DO 6 J = 2, 5
 F(J,J) = 3.
 F(1,J) = 0.
 AK(I,J) = 0.
 AK(J,J) = 0.
6 CONTINUE
 F(3,3) = PMEMB(1,7)
 F(2,3) = PMEMB(1,8)
 F(1,3) = F(2,3)
 F(2,2) = F(2,3)
 DC = PMEMB(1,3) * 12.
 SP = PMEMB(1,4).
 F(1,1) = SP / DC / EC.

invert F to get AK
DELTAF = F(2,2) * F(3,3) - F(2,3) * F(3,2).
 AK(1,1) = 1 / F(1,1)
 AK(2,2) = F(3,3) / DELTA
 AK(1,3) = F(1,2) / DELTA
 AK(2,3) = F(2,3) / DELTA
 AK(3,2) = AK(2,3)
 CALL ASSEMB(I, AK).

10 CONTINUE

remove reaction components
DO 12 J = 1, 12
 STIF(7,J) = STIF(9,J).
 STIF(8,J) = STIF(10,J).

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```
STIF(9,J)=STIF(12,J)
12 CONTINUE
   DO 13 I=1,12
   STIF(I,7)=STIF(I,9)
   STIF(I,8)=STIF(I,10)
   STIF(I,9)=STIF(I,12)
13 CONTINUE
   CALL CROUT(STIF,9,12)
   RETURN
END
```

IV & LEVEL 21

```
SUBROUTINE ASSEM(M,AKY)
C
C     ASSEMBLES THE MEMBER STIFFNESS MATRICES INTO A GLOBAL STIFFNESS
C     MATRIX
C
C
REAL *4 KAA(4,3,3), KAP(4,3,3)*, KBA(4,3,3), KBP(4,3,3)
COMMON /ARRAY/FIL(160), CMEMB(4,25), FIL1(400), KAA, KAP, KBA, KBP
COMMON /ICSCALE/IT, NCDO, IDPUG, IR, IW, ITAPIE, IPTM, CYC, NINT
COMMON /ANAL/FILE(6C), STIF(12,12)
DIMENSION D(3,3), AK(3,3)

JTA=MEMB(M,1)
JTB=MEMB(M,2)
SP=PMEMB(M,4)
IRAA=3*(JTA-1)
IRPB=3*(JTB-1)
C........FORM KBA
   DO 1 I=1,3
      DO 1 J=1,3
1 D(I,J)=-2*K(I,J)
   DO 11 I=1,4
      DO 11 J=1,4
11 D(I,J)=D(I,J)+SP*M(I,J)
   DO 25 E=1,3
      DO 25 F=1,3
25 KPA(M,E,J)=D(I,J)
   IF (M+NEF+1) THEN CALL ROTS(M,D)
      DO 9 I=1,3
      TROW=IRAA+1
      DO 9 J=1,3
9 ICOL=IRPB+J
      STIF(ICOL+TROW)=STIF(ICOL+ICOL)+C(J+I)
   C
   C........FORM KAP
      DO 3 I=1,3
      DO 3 J=1,3
3 D(I,J)=KPA(M+J,E)
      DO 13 I=1,3
      DO 13 J=1,3
13 KAP(M,E,J)=D(I,J)
      IF (M+NEF+1) THEN CALL ROTS(M,D)
         DO 6 I=1,3
         TROW=IRAA+1
         DO 6 J=1,3
6 ICOL=IRPB+J
         STIF(ICOL+TROW)=STIF(ICOL+ICOL)+D(I,J)
```

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C

C.... Form KBB
DO 5 I=1,3
DO 5 J=1,3
5 D(I,J)= AK(I,J)
DO 23 I=1,3
DO 23 J=1,3
23 KBB(M+1,J)=D(I,J)
IF ( M+NE+1) CALL ROTS(M,D)
DO 4 I=1,3
IROW=IRBB+I
DO 4 J=1,3
ICOL=IRPB+J
4 STIF(IROW,ICOL)=STIF(IROW,ICOL)+D(I,J)

C

C.... Form KAA
DO 7 I=1,3
DO 7 J=1,3
7 D(I,J)= AK(I,J)
DO 17 I=1,3
17 D(I,3)=D(I,3)+SP*D(I,2)
DO 27 J=1,3
27 D(3,J)=D(3,J)+SP*D(2,J)
DO 30 I=1,3
DO 30 J=1,3
30 KAA(M+1,J)=D(I,J)
IF ( M+NE+1) CALL ROTS(M,D)
DO 2 I=1,3
IROW=IRAA+I
DO 2 J=1,3
ICOL=IRAA+J
2 STIF(IROW,ICOL)=STIF(IROW,ICOL)+D(I,J)

C

C.... Member matrices are now in the global stiffness matrix
C

RETURN
END
SUBROUTINE ROTS(M,D)

DIMENSION D(3,3)

1 RETURN

2 F=1.
   GO TO 5

3 D(2,3)=-D(2,3)
   D(3,2)=-D(3,2)
   GO TO 1

4 F=-1.

5 D(1,3)=F*D(2,3)
   D(3,1)=F*D(3,2)
   T=D(2,2)
   D(2,2)=D(1,1)
   D(1,1)=T
   D(2,3)=0.
   D(3,2)=0.
   GO TO 1

END
SUBROUTINE CROUT(A,N,NF)

C INVERTS STIFFNESS MATRIX

DIMENSION A(2)
R=A(1)
JA=1
DO 1 J=2,N
JAA=JA+N
1 A(JAA)=A(JAA)/R
J0=0
DO 2 J=2,N
J1=J+1
J0=J0+N
J0=J+J0
2 DO 3 I=J,N
S=1.
IA=I-NF
DO 4 K=1,J1
IA=IA+N
KA=J0+K
4 S=S+A(IA)*A(KA)
JA=J0+I
3 A(JA)=A(JA)-S
IF (J-N) .LT. 7,2,2
7 J2=J+1
10=JC
DO 5 I=J2,N
S=0.
IO=IO+N
JA=J-NF
5 DO 6 K=1,J1
JA=JA+N
KA=K+IO
6 S=S+A(JA)*A(KA)+S
IB=J+IO
5 A(IP)=A(IP)+S/A(IP)
2 CONTINUE
RETURN
END
SUBROUTINE GENLD
C
C GENERATES JOINT LOAD MATRIX
C
REAL*4, DIMENSION(50) :: MOM
REAL*4, DIMENSION(12,5) :: LOAD
COMMON/SCALE/SPAN,PISE,TT,TB,TS,GAMAC,GAMAS,GAMAF,PC,H,HH,HV,Q,
1 ZETA,BETA,DF,O1,EC,ES,FY,FCP,FLM,FLN,Q2,Q3,NLAY,RTYPE,Q4,Q5,
2 CI(6),ISCATA(35)
COMMON/RARRAY/U(12*5),W1(4*5),W2(4*5),A(4*5),R(4*5),C(4*5),
1 PMEMB(4*25),V(50,4)
COMMON /ISCALE/AMIT,NOLC,IDEBUG,TR,IW,ITAPE,IPATH,ICYC,NINT
COMMON/ANAL/JLOAD,STIF(12,12),FIXMO(4,5,4)
INTEGER*2, IBDATA(35), ISDATA(35)
COMMON /IFLAGS/ IBDATA, ISDATA
C
DO 250 I=1,4
DO 250 J=1,5
DO 250 K=1,4
250 FIXMO(I,J,K)=0.
DO 211 I=1,4
DO 201 J=1,5
10 W1(I,J)=0.
20 W2(I,J)=0.
A(I,J)=0.
P(I,J)=0.
L(I,J)=0.
201 CONTINUE
DO 215 I=1,12
DO 215 J=1,5
215 JLOAD(I,J)=0.
DO 1700 L=1,4
GO TO (1,2,30,40,L)
C
C CONCRETE: DEAD LOAD - LOADING CONDITION 1
10 CONTINUE
G=GAMAC*12.
WT=TT*G
PS=(TS*PMEMB(2,4)+HM*HV)*G
WR=TW*G
SP=PMEMB(1,4)
WR=WT+WR+2.*PS/SP
PS = PS/2.
W=WR-WB
W1(1,1)=WT
W1(3,1)=W
W2(1,1)=WT
W2(3,1)=W
IV G LEVEL 21  GFMLO  DATE = 82251  18/55/09

B(1,1)=SP
B(3,1)=SP
DO 11 M=1,3+2
CALL MOMENT(W1(M+L),W2(M+L),A(M+L),B(M+L),C(M+L),X(1,M),MOM+VA+1
VB+NI)
CALL FXEDMO(MOM,FMB,FMBA+M)
CALL FLLOD(M+L+VA+VB+FMB+FMBA)
11 CONTINUE
DO 12 I=1,4
K=(I-1)*3+2
JLOAD(K,1)=JLOAD(K,1)+PS
12 CONTINUE
GO TO 1000

C
C VERTICAL SOIL PRESSURE - LOADING CONDITION 2
C
20 CONTINUE
WT=BETA*1+GAMAS*12.
SP=P*EMPH(1,4)
P=WT+TS/2.
DO 21 M=1,3+2
W1(M+2)=WT
W2(M+2)=WT
B(M+2)=SP
CALL MOMENT(W1(M+L),W2(M+L),A(M+L),B(M+L),C(M+L),X(1,M),MOM+VA+1
VB+NI)
CALL FXEDMO(MOM,FMB,FMBA+M)
CALL FLLOD(M+L+VA+VB+FMB+FMBA)
21 CONTINUE
JLOAD(2*2)=JLOAD(2*2)+P
JLOAD(5*2)=JLOAD(5*2)+P
JLOAD(8*2)=JLOAD(8*2)+F
JLOAD(11*2)=JLOAD(11*2)+P
GO TO 1000

C
C HORIZONTAL SOIL PRESSURE - LOADING CONDITION 3
C
30 CONTINUE
G=GAMAS*ZETA*12
WST=G*M
WSB=G*(H+RISE+TT+TB)
SP=PHMEM(2,4)
W1(2*3)=WST
W1(4*3)=WSB
W2(2*3)=WSR
W2(4*3)=WST
B(2*3)=SP
B(4*3)=SP
DO 31 M=2,9+2
CALL MOMENT(W1(M+L),W2(M+L),A(M+L),B(M+L),C(M+L),X(1,M),MOM+VA+1
VB+NI)
31 CONTINUE

190CT73
1 VB, NIT
   CALL VXEDM0 (MOM, FMAB, FMBA, M)
   CALL FLLO (M, YL, VA, VB, FMAB, FMBA)

31 CONTINUE
   PT = WST * TT / 2
   PB = WSB + TR / 2
   JLOAD (1, 3) = JLOAD (1, 3) * PT
   JLOAD (4, 3) = JLOAD (4, 3) * PT
   JLOAD (7, 3) = JLOAD (7, 3) * PR
   JLOAD (10, 3) = JLOAD (10, 3) * PB

C ADDITIONAL LATERAL SOIL PRESSURE
   W1 (2, 5) = WST * SDATA (25)
   W1 (4, 5) = WSB * SDATA (25)
   W2 (2, 5) = WSB * SDATA (25)
   W2 (4, 5) = WSB * SDATA (25)
   B1 (2, 5) = SP
   B1 (4, 5) = SP
   DO 35 M = 2, 142
      CALL MOMENT (W1 (M, 5), W2 (M, 5), A (M, 5), B (M, 5), C (M, 5))
      CALL FXEDM0 (MOM, FMAB, FMBA, M)
      CALL FLLO (M, YL, VA, VB, FMAB, FMBA)

35 CONTINUE
   JLOAD (1, 5) = JLOAD (1, 5) * PT * SDATA (25)
   JLOAD (4, 5) = JLOAD (4, 5) * PT * SDATA (25)
   JLOAD (7, 5) = JLOAD (7, 5) * PB * SDATA (25)
   JLOAD (10, 5) = JLOAD (10, 5) * PB * SDATA (25)
   GO TO 40

C C INTERNAL WATER LOAD - LOADING CONDITION 4

40 CONTINUE
   WSB = GMAF * DF * 12
   SP = PMEMB (2, 4)
   W1 = WSB * SPAN / (SPAN + TS)
   W = WR + WSB
   S2 = TR / 2
   S1 = SP + S2 - DP
   S3 = TS / 2
   W1 (2, 4) = W
   W2 (2, 4) = WSB
   A (2, 4) = S1
   B (2, 4) = DF
   C (2, 4) = S2
   W1 (5, 4) = W
   W2 (5, 4) = W
   A (3, 4) = S3
   B (3, 4) = SPAN
   C (3, 4) = S3
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W1(4*4) = WSR
W2(4*4) = C*
A(4*4) = S2
R(4*4) = DF
C(4*4) = S1
P = WP*TS
JLOAD(8*4) = JLOAD(8*4)*P
JLOAD(11*4) = JLOAD(11*4)*P
DD 41 M = 2*4
CALL MOMENT(W1(M,L), W2(M,L), A(M,L), P(M,L), C(M,L), X(1*M), MOM, VA, 1 VR, NIT)
CALL FEXEDMO(MOM, FMAB, FMBA, M)
CALL FLD(M*L, VA, VB, FMAB, FMBA)
41 CONTINUE

C
1000 CONTINUE
1010 DO 1003 J = 1, 5
JLOAD(7*J) = JLOAD(9*J)
JLOAD(8*J) = JLOAD(10*J)
JLOAD(9*J) = JLOAD(12*J)
1003 CONTINUE
RETURN
END
SUBROUTINE MOMENT(W1,W2,A,B,C,X,MOM,VA,VB,N)

C GENERATES MEMBER MOMENTS AND SHEARS

REAL*4 MOM(1:N),X(1)
COMMON /ISCALE/MITNOLD,IDBUG,IR,ITAPE,IPAT

1 CONTINUE
IF ( W1.EQ.0. .AND. W2.EQ.0. ) GO TO 101
QM=W1+W2
QP=W1+W2
C S=A*B*C

C COMPUTE B-BAR,VA,AND VB
IF (QP ) 9,10,9

10 BBAR=B/2.
GO TO 11
9 BBAR=(W1+B+2.*QM+B/3.)/QP
!
11 VA=QP*B*(B+C-BBAR)/2.*S
VB=QP*B*(A+BBAR)/2.*S

C GENERATE MOMENTS
DO 100 I=1,N
Y=X(I)
IF (Y.LE.A) GO TO 3
IF (Y.GE.A+B) GO TO 2
XP=Y-A
WX=W1*XP+QM*XP*XP/2./B
XPBAR=(W1*XP+2.*QM*XP*XP/3./B)/(2.*W1+QM*XP/B)
MOM(I)=VA*Y-WX*(XP-XPBAR)
GO TO 100
2 MOM(I)=VB*(S-Y)
GO TO 100
3 MOM(I)=VA*Y
100 CONTINUE
GO TO 110

101 CONTINUE
DO 102 I=1,N
102 MOM(I)=0.
VA=0.
VB=0.
110 CONTINUE
RETURN
END
SUBROUTINE FXEDMO(M, FMAB, FMBA, M)
C
C GENERATES MEMBER FIXED END MOMENTS.
C
COMMON /ARRAY/ F(160), PMEM(4, 25), X(50, 4)
REAL *4 J5, J6, MOM(1)
DIMENSION A(50)
COMMON /ISCALE/ NIT
DO 1 I = 1, NIT
A(I) = MOM(I) * X(I, M)
1 CONTINUE
J4 = PMEM(10)
J5 = PMEM(11)
S = PMEM(M + 4)
J6 = PMEM(M + 12)
C1 = S * TRAP(A, NIT, S, M)
DO 2 I = 1, NIT
A(I) = MOM(I) * (S - X(I, M))
2 CONTINUE
C2 = S * TRAP(A, NIT, S, M)
D = -J5 * J6 * J4 * J6
FMAB = (-J5 * C1 + J6 * C2) / D
FMBA = (-J4 * C1 + J5 * C2) / D
RETURN
END
SUBROUTINE FLLD(M,L,VA,VB,FMAB,FMBA)
C
C ASSEMBLES MEMBER FIXED END MOMENTS AND SHEARS INTO JOINT LOAD
C MATRIX.
C
REAL*4 JLOAD(12,5)
COMMON/ANAL/JLOAD,STIF(12,12),FIXMO(4,5,4)
COMMON /ARRAY/FIL(16L),PMEMB(4,25)
COMMON /SCALE/AIT,NOLD,IDBUG,IP*4,ITAPE,IPAT*,ICYC,MINT
DIMENSION JSUB(4,4),SV(4)
DATA ISUB/2,5,3,6,4,7,6,9,8,11,9,12,10,12,3/
DATA SV/-1.,1.,1.,1./
V=(FMAB+FMBA)/PMEMB(M,4)
IF (IDBUG.LT.5) GO TO 1
1 CONTINUE
VA=VA+V
VB=VB-V
FIXMO(M,L,1)=FMAB
FIXMO(M,L,2)=FMBA
FIXMO(M,L,3)=VA
FIXMO(M,L,4)=VB
I1=ISUB(1,M)
I2=ISUB(2,M)
I3=ISUB(3,M)
I4=ISUB(4,M)
S=SV(M)
JLOAD(I1,L)=JLOAD(I1,L)+S*VA
JLOAD(I2,L)=JLOAD(I2,L)+S*VB
JLOAD(I3,L)=JLOAD(I3,L)-FMAB
JLOAD(I4,L)=JLOAD(I4,L)-FMBA
RETURN
END
SUBROUTINE MAIMP(A,N,NF,M,D,NF)
DIMENSION A(2),B(2),C(2)

C C multiplies inverted stiffness matrix by load matrix to get displacements
C FOR EACH LOAD CONDITION.
C
DOUBLE PRECISION A,B,C,D,S
C=A(1)
JB=1-NF
DO 10 J=1,M
JB=JB+N

! D(JB)=P(JB)/C
IA=1
DO 21 I=2,N
II=I-1
IA=IA+1+N
C=A(IA)
JR=-NF
DO 21 J=1,M
S=0.
JA=1-NF
JB=JB+N
DO 22 K=1,II
JA=JA+N
KB=K+JB

22 S=S+A(JA)*C(KB)
IR=I+JB

21 D(IR)=(P(IR)+S)/C
DO 170 I=2,N
IF=N*1-I
IP1=IP+1
IA=(TP-1)*NF+IP
IH=-NF
DO 170 J=1,M
S=0.
IR=IP+N
KA=IA
DO 162 K=IP1,N
KA=KA+N
KB=K+JB
162 S=S+A(KA)*D(KB)
KB=IP+IR
100 D(KB)=D(KB)-S
RETURN
END
SUBROUTINE ENDFO

C DETERMINES MEMBER END FORCES PRINTS MEMBER END FORCES TABLE
C FOR IDBUG EQUAL TO 3

C REAL*4 ALOAD(12,5)
C REAL INER(4,5), KAA(4,3,2), KAB(4,3,2), KBA(4,3,2), KBP(4,3,3)

C REAL SCALAR COMMON
C COMMON/RSCALE/SPAN, PISE, TT, TR, TS, GAMAC, GAMAS, GAMAF, PD, HH, HV, Q,
C 1 ZETA, B1A, DF, Q1, EC, ES, FY, FCP, FLMV, FLN, Q2, Q3, Mlay, RTYPE, Q4, Q5,
C 2 CT(F), SDATA(35)

C REAL COMMON ARRAYS
C COMMON/HARRAY/U(12,5), W1(4,5), W2(4,5), A(4,5), F(4,5), C(4,5),
C 1 PMEMB(4,25) X(50,4)
C COMMON/HARRAY/INER, KAA, KAB, KBA, KBP
C COMMON/ANAL/ULOAD */STIF(12,12), FIXMO(4,5), 4

C COMMON/HARRAY/AMOM(20,5), W(20,5), P(3,5), FLA(4,5), FYLA(4,5)
C 1 BM(4,5), FXL(4,5), FLP(4,5), BMB(4,5), ENDM(20,5), ENDO(20,5),
C 2 GRM(20), GR1(20), GR2(20), GR2(20), GR2N(20), GR2NL(20),
C 3 GR2PL(20), GR2PL(20), GR2PL(20), GR2PL(20), GR2PL(20), GR2PL(20),
C 4 FPMAX(3), FVMAY(20), FMMAY(20), ZMOMT, ZMOMP, XL(20)

C COMMON SCALAR COMMON
C COMMON/SSCALE/IT, NOLD, IDBUG, IR, IW, ITAPE, IPATH, ICYC, NINT

C INTEGER COMMON ARRAYS
C COMMON/IARRAY/PMEMB(4,2)

C SCRATCH
C DIMENSION D(3,3), UA(3), UB(3), FB(3)
C IF ( IDBUG .EQ. 3 ) WRITE(IW,1099)

1099 FORMAT(F14,16,2X,END FORCES KIPS AND INCH-KIPS*)
C 1 T4, A-END, T93, R-END, /, 14X, ALOAD, 9X,
C 1 *FLA, 11X *FLA*
C 1 11X, RMA, 11X, FXL*, 11X, FY*, 11X, EMB*, /, 14X, CASE, 8X,
C 2 *FX, 9X, FY, 9X, MOMENT, 15X, FX, 9X, FY, 9X,
C 3 *MOMENT *
C DO 1 M=1,4
C DO 1 N=1,5
C FLA(M,N)=0.0
C FLYA(M,N)=0.0
C FXLB(M,N)=0.0
C FLYB(M,N)=0.0
C SAA(M,N)=0.0
BM(M,N)=0
1 CONTINUE
DO 10 M=1,4
JTA = MEMB(M,1)
JTB = MEMB(M,2)
K = 3*(JTA-1)+1
L = 3*(JTB-1)+1
DO 5 N=1,5
GO TO (10,11,12,13)*M
10 UA(1) = U(K,N)
UA(2) = U(K+1,N)
UA(3) = U(K+2,N)
UB(1) = U(L,N)
UB(2) = U(L+1,N)
UB(3) = U(L+2,N)
GO TO 14
11 UA(1) = -U(K+1,N)
UA(2) = U(K,N)
UA(3) = U(K+2,N)
UB(1) = -U(L+1,N)
UB(2) = U(L,N)
UB(3) = U(L+2,N)
GO TO 14
12 UA(1) = -U(K,N)
UA(2) = -U(K+1,N)
UA(3) = U(K+2,N)
UB(1) = -U(L,N)
UB(2) = -U(L+1,N)
UB(3) = U(L+2,N)
GO TO 14
13 UA(1) = U(K+1,N)
UA(2) = -U(K,N)
UA(3) = U(K+2,N)
UB(1) = U(L+1,N)
UB(2) = -U(L,N)
UB(3) = U(L+2,N)
14 CONTINUE
DO 2 J=1,3
2 D(I,J) = KRA(M,I,J)
CALL SOLVE(FB,UA,D)
DO 3 I=1,3
3 D(I,J) = KRB(M,I,J)
CALL SOLVE(UA,UB,D)
DO 4 I=1,3
4 FB(I) = FB(I)+UA(I)
FXLB(M,N) = FB(1)
FYLM(N,N) = FB(2)
MMA(M,N) = FB(3)

DO 250 M=1,N
DO 250 N=1,N
FXLM(N,M) = FXLM(N,M)*FXMO(M,N,3)
FMN(M,N) = FMN(M,N)*FMNO(M,N,1)
FYLM(N,M) = FYLM(N,M)*FMNO(M,N,4)
MAMB(M,N) = FMN(M,N)*FMNO(M,N,2)

C DEBUG OUTPUT
C
IF ( IDBUG .LT. 3 ) GO TO 1102
WRITE (*,1100) M,N,FXLM(N,M),FMX(M,N),FMN(M,N),FXMO(M,N),FMN(M,N)
1100 FORMAT(* MEMBER*,8I5,2F15.5,5X,3F15.5)
1102 CONTINUE
C
250 CONTINUE
260 CONTINUE
RETURN
END

SUBROUTINE SOLVE(DU,DF,AK)
C
C MULTIPLIES 3X3 MATRIX BY 3X1 MATRIX.
C
DIMENSION DU(3),DF(3),AK(3,3)
DO 1 I=1,3
DU(I) = 0.
DO 1 K=1,3
1 DU(I) = DU(I) + AK(I,K)*DF(K)
RETURN
END
SUBROUTINE SIMSPN

GIVEN THE MEMBER END FORCES AND THE LOADING VALUES
THE SERVICE LOAD FORCES ARE CALCULATED AT THE CRITICAL DESIGN SECTIONS

COMMON/RSCALE/SPAN*RISE,TT,TB,TS*,GAMAC,GAMAS,GAMAF,PLH,H,H,H,HV
1 ZETA,BETA,DF,01,EC,ES,FY,FCP,FLMV,FLN,02,03,NLAY,RTYPE,04,05
2 CT(6),SDATA(35)

COMMON/RARRAY/W1(12,5),W1(4,5),W2(4,5),A(4,5),E(4,5),C(4,5),
1 PMEMB(4,25),X(50,4)

COMMON/ARRAY/MEMB(4,2)

COMMON/HARRAY/ANOM(20,5),V(20,5),P(3,5),FXLA(4,5),FYLA(4,5)
1 *AMA(4,5),FXLB(4,5),FYLB(4,5),BMP(4,5),ENDM(20,5),EADV(20,5),
2 GRM(20),GRV(20),GRP1(3),GRV2NG(20),GRM2NG(20),GRV2PL(20)
3 *GRM2PL(20),GRP2PL(3),GRP2NG(3),FPMIN(3),FVMIN(20),FMMIN(20),
4 FPMAX(3),FVMAX(20),FMMAX(20),ZMOMT,ZMOMB,XL(2)

COMMON/IFLAGS/ISDATA(35),ISDATA(35),ICON(6)

COMMON/SCALE/NT,NOLD,IDRUG,IR,IN,ITAPL,IPATH,ICYC,MINT

DIMENSION TM(5),TV(5)

ENDM0(BMOM,CMOM,X,SP)=-BMOM*(1*-X/SP)+CMOM*X/SP
ENDSPR(BMOM,CMOM,X,SP)=(BMOM+CMOM)/SP

INITIALIZE DATA
USE MINIMUM D FOR SETTING DESIGN SECTION LOCATIONS

TOP SLAB

D = AMIN1(SDATA(31),SDATA(33))
D=D*POV
XL(1)=(SPAN+TS)/2.
XL(2)=0.*D
XL(3) = TS/2.* HH + D
XL(4)=TS/2.*HH

MEMBER 2 = SIDE WALL
D = AMIN1(SDATA(31),SDATA(35))
D=D*POV
XL(5) = TB/2.* HV
XL(6)= XL(5) + D
XL(7)=D*0.
\[ XL(8) = \text{RISE}/2 \times (1 + TB)/4 \times \]
\[ XL(9) = 0.0 \]

C MEMBER 4 - SIDE WALL
\[ XL(10) = XL(6) \]
\[ XL(11) = XL(5) \]

C BOTTOM SLAB
\[ D = \text{MIN}(SDATA(32), SDATA(34)) \]
\[ D = D \times P0V \]
\[ XL(12) = TS/2 \times \text{SPAN-HH} \]
\[ XL(13) = XL(12) - D \]
\[ XL(14) = 0.0 \]
\[ XL(15) = (\text{SPAN+TS})/2 \]

C
\[ \text{DO 11 I = 1, 5} \]
\[ TV(I) = 0.0 \]
\[ TM(I) = 0.0 \]
\[ \text{DO 11 J = 1, 20} \]
\[ \text{ENDM(J, I) = 0.0} \]
\[ \text{ENDV(J, I) = 0.0} \]
\[ AMCM(J, I) = 0.0 \]
\[ V(J, I) = 0.0 \]

11 CONTINUE
C
\[ \text{DO 200 M = 1, 4} \]
\[ \text{GO TO (190, 20, 36, 40), M} \]

C MEMBER 1
\[ 10 \]
\[ I1 = 1 \]
\[ I2 = 3 \]
\[ I4 = 4 \]
\[ \text{GO TO 60} \]

C MEMBER 2
\[ 20 \]
\[ I1 = 8 \]
\[ I2 = 6 \]
\[ I4 = 5 \]
\[ \text{GO TO 60} \]

C MEMBER 3
\[ 30 \]
\[ I1 = 15 \]
\[ I2 = 13 \]
\[ I4 = 12 \]
\[ \text{GO TO 60} \]

C MEMBER 4
\[ 40 \]
\[ I1 = 0 \]
\[ I2 = 10 \]
\[ I4 = 11 \]

60 CONTINUE
C
\[ I1 = \text{CENTER SPAN MOMENT} \]
C \[ I2 = PHI*D FROM HAUNCH, SHEAR AND MOMENT \]
I4 = TIP OF HAUNCH, SHEAR AND MOMENT

DO 100 LOCN=1,5
1 CONTINUE

IF ( I1.EQ. 0 ) GO TO 45
ENOM(I1,LOCN) = ENOMO(BMA(M,LOCN),BMB(M,LOCN),XL(I1),PMEMB(M,4))
45 IF ( M.EQ. 1 .AND. LOCN .GE. 3 ) GO TO 100
IF ( M.EQ. 2 .AND. LOCN .LT. 3 ) GO TO 100
IF ( M.EQ. 2 .AND. LOCN .EQ. 3 ) GO TO 100
IF ( M.EQ. 3 .AND. LOCN .EQ. 5 ) GO TO 100
IF ( M.EQ. 4 .AND. LOCN .LT. 3 ) GO TO 100

MOMENT FOR CENTER SPAN POINTS 1, 8, 15

IF ( I1 .EQ. 0 ) GO TO 46
CALL MOMENT(W1(M,LOCN),W2(M,LOCN),A(M,LOCN),B(M,LOCN),C(M,LOCN),XL(I1),AMOM(I1,LOCN),DUM,DUM,1)
46 CONTINUE

MOMENT AT POINTS 3, 6, 10, 13

CALL MOMENT(W1(M,LOCN),W2(M,LOCN),A(M,LOCN),B(M,LOCN),C(M,LOCN),XL(I2),AMOM(I2,LOCN),RL,RR,1)

IF ( XL(I2) .LE. A(M,LOCN) ) V(I2,LOCN) = RL
IF ( XL(I2) .GT. A(M,LOCN) .AND. XL(I2) .LT. A(M,LOCN) ) B(M,LOCN))
2 V(I2,LOCN) = RL - W1(M,LOCN) + (XL(I2) - A(M,LOCN)) - (W2(M,LOCN) - W1(M,LOCN)) % 2/2 * B(M,LOCN)
3 IF ( XL(I2) .GE. A(M,LOCN) + B(M,LOCN) ) V(I2,LOCN) = RR

MOMENT AT THE HAUNCHES POINTS 4, 5, 11, 12

CALL MOMENT(W1(M,LOCN),W2(M,LOCN),A(M,LOCN),B(M,LOCN),C(M,LOCN),XL(I4),AMOM(I4,LOCN),DUM,DUM,1)

IF ( XL(I4) .LE. A(M,LOCN) ) V(I4,LOCN) = RL
IF ( XL(I4) .GT. A(M,LOCN) .AND. XL(I4) .LT. A(M,LOCN) )
V(I4, LDCN) = RL - W1(M, LDCN) * (XL(I4) - A(M, LDCN)) - W2(M, LDCN) - W1(M, LDCN) * (XL(I4) - A(M, LDCN)) * 2 / 2. * (R, LDCN)

IF (XL(I4) - GE - A(M, LDCN) + B(M, LDCN)) V(I4, LDCN) = -RR

160 CONTINUE
200 CONTINUE

STORE AXIAL FORCES

DO 210 I = 1, 5
   P(I, 1) = FYLR(I, 1)
   P(2, 1) = FYLB(I, 4, 1)
   P(3, 1) = FXLB(3, 1)
DO 210 J = 1, 20
   V(J, 1) = V(J, 1) + ENDV(J, 1)
   AMOK(J, 1) = AMOK(J, 1) + ENDM(J, 1)
210 CONTINUE

FIND XD IN TOP AND BOTTOM SLABS AND
CALCULATE M * V AT XD AWAY FROM CENTERSSPAN

N = 2
IF (IPDATA(14) * NE. 2) N = 3
DMT = D, 0
DME = D, 0
WT = T, 0
WB = T, 0
DO 350 I = 1, N
   WT = WT + W1(I, 1)
   WB = WB + W1(3, 1)
   DMT = DMT + AMOM(15, 1)
   DME = DME + AMOM(15, 4)
350 CONTINUE

XL(14) = 3, 0 * (SORT(T(3) + P0V)**2 + 2 * DMB / 9 * W0B - SDATA(34) * P0V)
XL(2) = 3, 0 * (SORT(T(3) + P0V)**2 + 2 * DMT / 9 * W0T - SDATA(33) * P0V)
XL(2) = (SPAN + TS) / 2 * XL(2)
XL(14) = (SPAN + TS) / 2 * XL(14)

TOP

IF (XL(2) * LE. 0) GO TO 320
M = 1
J = 2
320 CONTINUE
DO 327 LDCN = 1, 5

IW & LEVEL 21
CALL MOMENT(W1(M,LDCN)+W2(M,LDCN)+A(M,LDCN)+B(M,LDCN)+
       C(M,LDCN)+XL(J)+AOM(J,LDCN)+B(L,RR+1)

C

IF (XL(J) = LE, A(M,LDCN)) V(J,LDCN)=RL
IF (XL(J) = GT, A(M,LDCN)) AND XL(J) = LT, A(M,LDCN)+
       B(M,LDCN))

2

V(J,LDCN)=RL-W1(M,LDCN)*(XL(J)-A(M,LDCN))-(W2(M,LDCN)
       -W1(M,LDCN))*(XL(J)-A(M,LDCN))*2/2.*B(M,LDCN)

3

IF (XL(J) = GE, A(M,LDCN)+B(M,LDCN)) V(J,LDCN)=RR

4

AMOM(J,LDCN)=AMOM(J,LDCN)+ENDM0B(BMA(M,LDCN)+BMB(M,LDCN)+XL(J),
       PMEMB(M,4))
V(J,LDCN)=V(J,LDCN)+ENDSHR(BMA(M,LDCN)+BMB(M,LDCN)+XL(J),
       PMEMB(M,4))

5

327 CONTINUE
IF (M <= 1) GO TO 340

C

BOTTOM SLAB

C

320 IF (XL(14) = GE, SPAN+TS/2., = HH) GO TO 340
M=3
J=14
GO TO 322

C

340 CONTINUE

C

FIND LOCATION OF MOMENT IN TOP AND BOTTOM SLABS

C

DMT = DMT + AMOM(1,31)*IARSEN - 3) + AMOM(1,5)
DMB = DMB+AMOM(15,3)*IABS(N - 3) + AMOM(15,5)
IF (DMT = LE, 6.0) GO TO 75

2

ZMOMT=(SPAN+TS)/2.-SQR(2.*DMT/WT)

75

IF (DMB = LE, 7.6) GO TO 76
ZMOMB=(SPAN+TS)/2.*SQR(2.*DMB/WT)

76 CONTINUE

C

FIND WHERE M/VD=3.0 IN THE SIDE WALL

C

IF (AMOM(8,1)+AMOM(8,2)+AMOM(8,3)+AMOM(8,5)+LT, 0.0)
1
D=AMIA1(SOATA(31),SCATA(35))
D=D*D
X=TE/2.*HV = D + PMEMB(4,9)/200.0 + RISE
L=6
TEMP1 = (AMOM(6,1)+AMOM(6,2)+AMOM(6,3)+AMOM(6,5))/(V(6,1)+V(6,2)+

1 V(6,3)+V(6,5))

75 L=L+1
IF (L = EQ, 8) L=9
50 CONTINUE
IV G LEVEL 21
SIMSPN
DATE = 82/251
18/35/09

\[ x = \text{PMEMB}(4,4)/200, \]
\[
  \text{TEMP} = \text{TEMP1}
\]
IF (L EQ 10) GO TO 505
IF (L LE 8 AND X LE \((\text{RISE}+\text{TR})/2\)) L = 9
IF (X LT T6/2 + MW + D) GO TO 490
TV1 = 0.0
TM1 = 0.0
DO 450 K = 1, 5
CALL R/H/B(R, 4, K), A(4, K), B(4, K), C(4, K), X, TM(K), RL, RK

1 IF (X LE A(4, K)) TV(K) = RL
IF (X GT A(4, K) AND X LT A(4, K) + B(4, K))

2 \[
  TV(K) = \frac{(X - A(4, K)) - (W1(4, K) - W2(4, K)) - W1(4, K)}{2}
\]
IF (X GT A(4, K) + B(4, K)) TV(K) = -AP
TV(K) = TV(K) + ENDSHR(RMA(4, K), RMB(4, K), X, PMEMB(4, 4))
TM(K) = TM(K) + ENDSHR(RMA(4, K), RMB(4, K), X, PMEMB(4, 4))
IF (K EQ 4) GO TO 450
TM1 = TM1 + TM(K)
TV1 = TV1 + TV(K)
450 CONTINUE
D = SDATA(35) * POV
IF (TM1 LT 0.0) GO TO 50
TEMP1 = 3.0 - APS(TM1 / TV1 / D)
IF (ABS(TEMP1) GT 0.0) GO TO 485
IF (ABS(TEMP1) LT APS(TEMP1)) GO TO 70
485 DO 475 J = 1, 5
V(L+J) = TV(J)
AMOM(L+J) = TM(J)
475 CONTINUE
XL(L) = X
IF (TEMP1 LT TEMP GT 0.0) GO TO 50
GO TO 70
490 CONTINUE
DO 495 I = 1, 5
V(L, I) = 0.0
AMOM(L, I) = 0.0
495 CONTINUE
XL(L) = 0.0
505 CONTINUE
IF (T0 + MW + LT > 3) GO TO 506
WRITE (IV*509)
509 FORMAT (1H1)
WRITE (IV*510)
510 FORMAT (/*140*"SERVICE MOMENTS AND SHEARS FOR EACH LUAU ",
1*CONDITION*/*/5X*125(1H-),/*6X,*DESIGN*/*5X,*DIST* FROM*/*T35,*MOME
2*/*T15*KIPS/FT,/*T100*"SHEAR(KIPS/FT)"/*5X,*SECTION*/*6X,*A-ENCLN* 
3)*/*T25,45(1H-),17X,*44(1H-),/*T26,*LC-19,*6X,*LC-29,*6X,*LC-39,*6X, 

*/5X,125(1H-),/*6X,*DESIGN*/*5X,*DIST* FROM*/*T35,*MOME
2*/T15*KIPS/FT,/*T100*"SHEAR(KIPS/FT)"/*5X,*SECTION*/*6X,*A-ENCLN* 
3)*/*T25,45(1H-),17X,*44(1H-),/*T26,*LC-19,*6X,*LC-29,*6X,*LC-39,*6X,
C SUBROUTINE FMXM

C DETERMINES THE MINIMUM AND MAXIMUM DESIGN FORCES AND RESULTING
C ULTIMATE FORCES AT THE CRITICAL DESIGN LOCATIONS.

C REAL *4, JLOAD (12, 5)
C REAL *4, INER (4, 5), KAA (4, 3, 3), KAB (4, 3, 3), KBA (4, 3, 3), KBR (4, 3, 3)

C COMMON / RSCALE, SPAN, RISE, TT, TB, TS, GAMAC, GAMAS, GAMA F, PO, H, HH, HV, Q0
C 1 ZETA, BETA, DF, Q1, ECC, ES, FY, FC, FFMV, FLMV, 02, 03, NLAY, RTYPE, Q4, Q5
C 2 CT (6), SDATA (35)
C COMMON / RARRAY, U (12, 5), V (12, 5), W (12, 5), A (4, 5), P (4, 5), C (4, 5)
C 1 PMEM (4, 25), X (504)
C COMMON / RARRAY, INER, KAA, KAB, KBA, KBR

C COMMON / ANAL / JLOAD, STIF (12, 12), FIXMO (4, 9, 4), BM (4), DV (6), DP (6)
C 1 AS (6), SRATD (6)
C COMMON / SCALE / NOLD, I0DBG, IF, IN, ITAPE, IPATH, ICYC, NINT
C COMMON / IARRAY / MEMB (4, 2)

C COMMON / HARRAY / ADIM (20, 5), V (20, 5), P (3, 5), FXL A (4, 5), FYL A (4, 5)
C 1, 9MA (4, 5), FXLF (9, 5), FYLF (4, 5), BMB (4, 5), E NDM (20, 5), E NDV (20, 5)
C 2 GM (20), GRV1 (20), GPR1 (13), GRV2NG (20), GRM2NG (20), GRV2PL (20)
C 3 GRM2P (2), GPR2PL (3), GRP2NG (3), FPMIN (3), FVMIN (20), FMNIM (20)
C 4 FMMAX (3), FVMAX (20), FMMAX (20), ZMCHT, ZMCNB, XLI (20)

C COMMON / IFLAGS / I0DATA (35), I0DATA (35), ICON (6)
C DIMENSION SIDE (3)
C DATA SIDE = 'TOP', 'SIDE', 'BOT'

C IS = 3
C COEF = 0.0

DO 100 LT = 1, 20
  GKM1 (LT) = 0.0
  GRVK (LT) = 0.0
  GPR2PL (LT) = 0.0
  GRV2PL (LT) = 0.0
  GRM2NG (LT) = 0.0
  GRM2PL (LT) = 0.0
  IF (LT .GE. 3) GO TO 100
  GPR1 (LT) = 0.0
  GPR2PL (LT) = 0.0
  GRV2NG (LT) = 0.0

100 CONTINUE
I4=4
102 CONTINUE
DO 1 I = 1, 15
GRM1(I) = AMOM(I, 1) + AMOM(I, 2) + AMOM(I, 3) + COEFS
GVR1(I) = V(I, 1) + V(I, 2) + V(I, 3) + COEFS
DO 1 K = I + 5
GRM2(K) = GRM2PL(I) + (1.0 + SIGN(1.0, AMOM(I, K))) / 2.0 + AMOM(I, K)
GVR2(K) = GVR2PL(I) + (1.0 + SIGN(1.0, V(I, K))) / 2.0 + V(I, K)
1 CONTINUE
DO 3 I = 1, 3
GRR1(I) = P(I, 1) * P(I, 2) * P(I, 3) + COEFS
DO 3 K = I + 5
GRR2(K) = GRR2PL(I) + (1.0 + SIGN(1.0, P(I, K))) / 2.0 + P(I, K)
3 CONTINUE
DO 5 K = I + 15
FVMIN(K) = GRV1(K) + GRV2NG(K) + FLMV
FMMIN(K) = GRM1(K) + GRM2NG(K) + FLMV
FVMAX(K) = GRV1(K) + GRV2PL(K) + FLMV
FMMAX(K) = GRM1(K) + GRM2PL(K) + FLMV
IF (FVMIN(K) GT 0.0) FMMIN(K) = 0.0
IF (FVMAX(K) GT 0.0) FMMAX(K) = 0.0
IF (FMMAX(K) LT 0.0) FMMAX(K) = 0.0
IF (FVMIN(K) LT 0.0) FMMIN(K) = 0.0
IF (K .GT. 3) GO TO 5
FPMIN(K) = GRR1(K) + GRR2NG(K) + FLN
FPMAX(K) = GRR1(K) + GRR2PL(K) + FLN
5 CONTINUE
C C SPECIAL SHEAR DESIGN SECTIONS
DO 2 J = 6, 7, 1
FVMIN(J) = (GRM1(J) + GRM2PL(J)) + FLMV
FVMAX(J) = (GRM1(J) + GRM2PL(J)) + FLMV
IF (FVMIN(J) GT 0.0) FMMIN(J) = 0.0
IF (FVMAX(J) LT 0.0) FMMAX(J) = 0.0
K = J + 3
FVMIN(K) = (GRM1(K) + GRM2PL(K)) + FLMV
FMMAX(K) = (GRM1(K) + GRM2PL(K)) + FLMV
IF (FVMIN(K) GT 0.0) FMMIN(K) = 0.0
IF (FMMAX(K) LT 0.0) FMMAX(K) = 0.0
2 CONTINUE
IF (FMMIN(J) .NE. 0.0) GO TO 1498
IF (FMMIN(15) .NE. 0.0) GO TO 1498
C C DEBUG OUTPUT
C
1498 CONTINUE
WRITE(IW,1101)
1101 FORMAT("1. F33. SERVICE LOADS",9T0, "ULTIMATE LOADS", 6T13,
1 56.1H = ), T79, 34. (1H = ), 6. SECTION", T20, " GROUP 1", 5G,
2 " GROUP 2")
WRITE(IW,1103)
1103 FORMAT(6T13, " M Om e n t", 5T3, " Shear", 3T5, " H Plus", 14E,
1 " V Plus", 5T5, " M Neg", 6T6, " V Neg", 7T9, " F Max", 8T8,
1 " F V Max", 9T9, " F Min", 10G3, " F V Min")
WRITE(IW,1102)(I, GRM1(I), CRV1(I), GRM2PL(I), GRV2PL(I), GRM2NG(I),
1 GRV2NG(I), F MAX(I), FV MAX(I), FMIN(I), FVMIN(I), I=1,15)
1102 FORMAT(5T4, I2, T10, 6F10.3, T75, 9F10.3)
WRITE(IW,1105)
WRITE(IW,1106) (SIDE(I), GRP1(I), GRP2PL(I), GRP2NG(I), FMAX(I),
1 FMIN(I), I=1,3)
IF (FM MIN(I) .NE. 0.0) GO TO 1500
IF (FM MIN(15).NE. 0.0) GO TO 1501
GO TO 1502
1500 J=1
GO TO 1504
1501 J=3
1504 IPATH = 0
WRITE(IW,1503) SIDE(J)
1503 FORMAT("### ONE NEGATIVE MOMENT EXISTS IN MIDSPAN OF **44** SLARCH.",/
1. THE DESIGN SUBROUTINE IS NOT EQUIPPED TO ADEQUATELY**,/
2. HANDLE SUCH A CASE AND THE REINFORCING DESIGN SHOULD**,/
3. BE COMPLETED BY HAND USING THE MOMENTS, THRUSTS, AND ***,/
4. SHEARS GIVEN ABOVE")
GO TO 1203
1502 CONTINUE
2XMOBC=SPAN*TS-ZMOMR
WRITE(IW,1104) 2XMOFT, 2XMOBC
1104 FORMAT("0 ZERO MOMENT TOP **F15.5**, T5G, **ZER0 MOMENT BOTTOM**, F15.5,/
1."O INCHES FROM CENTERLINE OF SIDEWALL",//
1."*0** NOTE: ALL UNITS ARE KIPS AND INCHES **1"...)
1 T79. F MAX**, T99. F VM IN")
1106 FORMAT(T3. A4, 2X, F10.3, 11X, F10.3, 10X, F10.3, 10X, 4X, F10.3,
1 10X, F10.3)
1203 CONTINUE
RETURN
END
SUBROUTINE DESCK

CALCULATES THE REQUIRED STEEL AREA AT THE FLEXURE DESIGN
LOCATIONS BASED ON THE FOLLOWING:
- FLEXURE:
  * MINIMUM STEEL FOR FLEXURE
  * LIMITING CONCRETE COMPRESSION
  * 0.01" CRACK AT SERVICE LOADS
- IT CHECKS FOR DIAGONAL TENSION SHEAR AT THE APPROPRIATE DESIGN
LOCATIONS USING METHODS 1(AASHTO) AND 2
- A PRINTOUT OF THE FLEXURE DESIGN TABLE, SHEAR DESIGN TABLE METHOD 1
  AND SHEAR DESIGN TABLE METHOD 2 ARE AVAILABLE WITH AN IOBUG VALUE
  GREATER THAN 1.

REAL*4, LOAD(12,5)
REAL*4, TME(4,50), MAA(4,3,3), KAP(4,3,3), KBA(4,3,3), KFB(4,3,3)
COMMON/RSCALE.SPAN.RISE.ITT.TP.TS.GAMAC.GAMAS.GAMAT.PCF.H.HH.HHV.
1 PTV,
1 VTA.CHETA.DF.Q1.CE.ES.FY.FCP.FLMV.FLM.FCR.Q3.NLAY.RTYPE.Q4.Q5.
2 C6(6).SCATA(35)
COMMON/RARRAY/U1(12,5), W1(4,5), W2(4,5), A(4,5), P(4,5), C(4,5),
1 PMEMB(4,25), Y(56,4)
COMMON/RARRAY/RNER, KAA.KAB.KBA.KBB
COMMON/ANAL/LOAD.STIF(12,12), FIXMO(4,5,4), OM(6), DV(6), DP(6),
1 AS(6), SRATIO(6)
COMMON/ISCALE/NIT,NOLC,INBUG,IR,IN.PAPE,IPATH,ICYC,MINT
COMMON/IARRAY/MEMB(4,21)
COMMON/HARRAY/MOM(20,5), V(20,5), P(3,5), FXL(4,5), FYL(4,5)
1 BMAB(4,5), FXLB(4,5), FYLB(4,5), RMR(4,5), ENDM(20,5), FNDV(20,5),
2 GRM1(20), GRV1(20), GRP1(3), GRV2NG(20), GRM2NG(20), GRV2PL(20)
3 GRM2PL(20), GRP2PL(3), GRP2NG(3), FPMIN(3), FVMIN(20), FMIN(20),
4 FMX(3), FVMAX(20), FMX(20), ZMONT.ZMOMB.ZX(20)
COMMON/IFLAGS/IRDATA(35), ISDATA(35), ICCN(6)
REAL MUNU.MNU.MNO.NLAY.NO
INTEGER AASHTO(4), CHECK(8)
DIMENSION INDEX(8), QS(6), SIDE(3), SH(8,10), POINT(6), GOVERN(15),
1 PRINT(18), Z(4,6), CRACK(6), AMIN(6), AMAX(6), AREAFL(6)
DIMENSION INDEX2(48)
DATA INDEX /24579111214/ SIDE/
1" BOTH/1 POINT/4 5:11:12 1 15 8 /
2 GOVERN/ FL/HEXUR.4HE 4H MIN/4H ST/HEEL 4HCRAC.


3 4HMK 4HHTP 4HMAX 4HCON 4HCOMP /
DATA INDEX2 / 3 4 6 7 9 10 13 14 /
DATA AASHTO/ 3 5 10 13 / CHECK/ 30 33 31 35 31 35 32 34 /
1 YES / YES / NO / NO / *
*
C
FIND DESIGN VALUES FOR EACH REINFORCING MEMBER
DC 71 L=1 8
DO 71 M=1 10
SH(L,M)=0 0
71 CONTINUE
C
AS1
DM(1)=-FMIN(4)
DP(1)=ABS(FMIN(1))
DM(2)=AMAX1(-FMIN(5),-FMIN(11))
DP(2)=ABS(FMIN(2))
DM(3)=-FMIN(12)
DP(3)=ARS(FMIN(3))
C
AS 2
DM(4)=FMAX(1)
DP(4)=ARS(FMAX(1))
C
AS 3
DM(5)=FMAX(15)
DP(5)=ARS(FMAX(3))
C
AS 4
DM(6)=FMAX(8)
DP(6)=ARS(FMAX(2))
C
DS(1)=T1
DS(2)=T2
DS(3)=T8
DS(4)=T1
DS(5)=T8
DS(6)=T8
C
FYPST=F Y*1000
FCPPST=FCP*1000
BL=0 85-0 05*(FCP-4)
IF (BL .GT. 0 85) BL=0 85
IF (BL .LT. 0 65) BL=0 65
DO 10 I=1 6
FLAY=0 0
CD1=0 0
ICON(1)=1
FIND STEEL AREA FOR FLEXURE

PHIDF=SDATA(29*I)*PGF
E=10.2*FCPSI
FLEX =EO*PHIDF**2 - DP(I)**1000.*((2.*PHIDF-DS(I)) - 1.*PD0.3*DM(I))
IF (FLEX .LT. 0.0) AS(I) = 1.0E15
IF (FLEX .GE. 0.0) AS(I) = (EO*PHIDF - DP(I)**1000.0 - 1.*PD0.*FLEX) / FYPSI
SRATIO(I) = AS(I)/12./PHIDF
AREAFL(I) = AS(I)

MINIMUM STEEL AREA FOR FLEXURE

AMIN(I) = 0.024*DS(I)
IF (AS(I) .GT. 0.024*DS(I)) GO TO 2
AS(I) = DS(I) * 0.024
SRATIO(I) = AS(I)/12./PHIDF
ICON(I) = 2
2 AREAMFL = 6.*6E5*B1*FCPSI*PHIDF/FYPSI/(FYPSI*27000.)
1 -(750.*DP(I)/FYPSI)
AMAX(I) = AREAMFL
IF (ASCI) .LT. AREAMFL) GO TO 3
WRITE(I=1011) POI47(I),CM(I),DP(I),AS(I),AREAMFL
1001 FORMAT(I=1011) / *DESIGN NOT POSSIBLE AT SECTION */
2.*TO EXCESSIVE CONCRETE COMPRESSION*/
3.*DM = *F10.3, *IN.*KIPS/FT*
4.*F10.3, *SQ,IN./FT.*
5.*MAXIMUM STEEL AREA = *F10.3*
AS(I) = 1.0E15
SRATIO(I) = 1.0E15
ICON(I) = 4
GO TO 10
3 CONTINUE

STEEL AREA BASED ON 0.01 INCH CRACK

K=PTYP*0.5
GO TO (1000,2000,3000), K
1000 CC=1.0
B2=(0.5*CT(I)**2*SDATA(6+1)/NLAY)**(1./3.)
GO TO 142
2000 CC=1.5
B2=1.0
FLAY=CT(I)**2*SDATA(6+1)/NLAY
GO TO 140
3000 GO TO 140
GO TO 140
GO TO 140
CC=1.9
B2 = (0.5 * CT(I) * 2 * SDATA(6+1)) / NLAY + (1.3) 

140 CONTINUE 
MU = DM(I) / FLMV * 1000. 
NC = DP(I) / FLN * 1000. 
E = MD/NO * SDATA(29+1) - DS(I) / 2. 
IF (E / SDATA(29+1) * LT. 1 + 15) G0 TC 13 
AJ = 0.74 + 0.1 * E / SDATA(29+1) 
IF (AJ * GT. 0.9) AJ = 0.9 
AP = 1.0 / I1 * AJ * SDATA(29+1) / E) 

7 CONTINUE 
R2 = (R2 / NO * (SDATA(29+1) = DS(I) / E)) / AJ / AP 
R1 = CO * 12 * DS(I) / 2 * SORT(FCPPSI) 
AREA01 = (R2 - R1) * R2 / 30000. * PHIDF / FCR 
IF (CO1 .EQ. 1) GO TO 9 
IF (FLAY .LT. 3) GO TO 11 
CO1 = 1. 

9 CO = 1.09 
B2 = (0.5 * FLAY) * (1.3) 
AREA012 = AREA01 
GO TO 7 

5 IF (ARE012 .GT. AREA01) AREA01 = ARE012 

11 CONTINUE 
CRACK(I) = AREA01 / AS(I) 
IF (CRACK(I) .LE. 1.0) GO TO 13 
TCON(I) = 3 
AS(I) = AREA01 
SRATIO(I) = AS(I) / 12. * PHIDF 

13 CONTINUE 

15 CONTINUE 
IF (IDBUE .LT. 2) GO TO 164 
DO 2007 I = 1 + 6 
PRINT(3*I-2) = GOVERN(TCON(I) * 3 - 2) 
PRINT(3*I-1) = GOVERN(TCON(I) * 3 - 1) 
PRINT(3*I) = GOVERN(TCON(I) * 3) 

2007 CONTINUE 
WRITE(*,2005) (POINT(I), I = 1, 6), (DM(I), I = 1, 6), (DP(I), I = 1, 6), 
1 (SDATA(29+I), I = 1, 6), (AREAFL(I), I = 1, 6), (AMIN(I), I = 1, 6), 
2 (AMAX(I), I = 1, 6), (CRACK(I), I = 1, 6), (AS(I), I = 1, 6) 

2005 FORMAT(*, T50,*6, *** FLEXURE DESIGN TABLE ***,* /, 
1 *REINFORCING* T2B 12 AS 8 12 T32 12 AS 12 12 T73 12 AS 2 12 T88 12 AS 3 12 T103 12, 
2 *AS 4 12 T40 23( ***) */ * /, *DESIGN SECTION* T29, 6 4 11 X */, 
3 *ULTIMATE MOMENT* T20, 6 15 5 */ */*, IN.KIPS/FT */ */ 
4 *ULTIMATE THRUST* T20, 6 15 5 */ */*, KIPS/FT */ */ 
5 *DEPTH TC STEEL* T20, 6 15 5 */ */*, IN */ */ 
6 *O STEEL AREAS(FLEX)* T20, 6 15 5 */ */*, SG IN/FT */ */ 
7 *O MIN. FLEX STEEL* T20, 6 15 5 */ */*, SG IN/FT */ */ 
8 *O MAX. FLEX STEEL* T20, 6 15 5 */ */*, SG IN/FT */ */ 
9 *0CRACK INDEX* T20, 6 15 5 */ */*,
GOVERNING STEEL, T20, 6F15.5, /" SQR, IN. /" FT, /"
WRITE (1H4, 2999) (PRINT(I), I=1, 18)
2999 FORMAT(* GOVERNING MODE, T26, 6(344, 3X), /" *1 *1 *)
164 CONTINUE
IF (AS(2) GT. AS(3)) GO TO 25
AS(2) = AS(3)
ICON(2) = ICON(3)
SRATIO(2) = SRATIO(3)
25 CONTINUE
DO 30 I = 3, 5
AS(I) = AS(I + 1)
SRATIO(I) = SRATIO(I + 1)
ICON(I) = ICON(I + 1)
30 CONTINUE

DIAGONAL TENSION CHECK

FCPS1 = FCPPSI
IF (FCPS1 GT. 7000.) FCPS1 = 7000.

AASHTO SHEAR CHECK - METHOD 1

DO 60 I = 1, 4
N1 = 3
Z1(I, 5) = NO
O = AMIN1(SDATA(CHECK(2*I-1)), SDATA(CHECK(2*I)))
IF (FMMIN(AASHTO(I)) GT. 0.0) GO TO 61
O = SDATA(CHECK(2*I))
N1 = 1
61 IF (FMAX(AASHTO(I)) LT. 0.0) GO TO 62
O = SDATA(CHECK(2*I-1))
N1 = 2
62 CONTINUE
PHIDV = O * POV
VU = AMAX1(FMAX(AASHTO(I)) - FMMIN(AASHTO(I)))
IF (VU LT. 0.036 * SQRT(FCPS1) * PHIDV) GO TO 65
WRITE (IW, 9501) AASHTO(I), SIDE(N1)
ISDATA(25+I) = 1
Z1(I, 5) = YES
65 CONTINUE
Z1(I+1) = VU
Z1(I+2) = 0.036 * SQRT(FCPS1) * PHIDV
Z1(I, 3) = Z1(I+1) / Z1(I+2)
Z1(I, 4) = O
60 CONTINUE

DO 432 I = 1, 5
432 SRATIO(I) = SRATIO(I) * POV / POV
CONTINUE
DO 1500 I = 1, 3
RHO1 = RATIO(2)
MU = ARS(FPMAX(1))
C
IF (I-2) .LT. 2100*31) ?
C
TOP SLAB
C
1100 CONTINUE
N = 1
K1 = 2
RHO2 = RATIO(1)
RHO2 = RATIO(3)
DIN = SDATA(33)
DOUT = SDATA(30)
GO TO 4000
C
SIDE WALL
C
2100 CONTINUE
N = 3
K1 = 6
RHO2 = RATIO(5)
DIN = SDATA(35)
DOUT = SDATA(31)
GO TO 4000
C
BOTTOM SLAB
C
3100 CONTINUE
N = 7
K1 = 8
RHO2 = RATIO(4)
DIN = SDATA(34)
DOUT = SDATA(32)
C
4000 CONTINUE
DO 2500 K = N, K1
   VU = AMAX1(FVMAX(INDEX(K)), FVMIN(INDEX(K)))
   VU2 = AMAX1(FVMAX(INDEX2(K)), FVMIN(INDEX2(K)))
   IF (VU .EQ. 0.0) GO TO 2500
   IF ((FPMAX(INDEX(K)) + FMIN(INDEX(K))) .LT. 5000, 6000, 7000
C
5000 RHO = RHO1
   MU = FMIN(INDEX(K))
   D = DOUT
   N1 = 2
GO TO 2000

C

6000  RH0=AMINI(RH01,RH02)
      MU=FMX(MAX(INDEX(K)))
      D=AMXI(DIN, DOUT)
      'I-1=3
      GO TO 8000

C

7000  RH0=RH02
      MU=FMX(MAX(INDEX(K)))
      D=CIM
      'I=1

C

8000  CONTINUE
      SH(K+1)=ABS(MU/VU/D/POV)
      SH(K+2)=VU2
      SH(K+3)=NU
      SH(K+4)=RH0
      SH(K+5)=D
      IF ( RH0 GT 0.02 ) RH0=0.02
      FO=0.2*1.6/D
      IF ( FO GT 1.25 ) FO=1.25
      FN=0.5*NU/VU/6.0*SORT(0.25*(NU/VU/6.0)**2)
      IF (SN GT 0.75) FN=0.75
      AMVC=ABS(MU/VU/D/POV)
      IF (AMXC GT 3.1) AMVC=3.1
      VC=(1.3*6.5*RH0)*SORT(FCPSI)*POV*D*12.*FD/FN*
      1.4/(AMVC+1.)
      IF (VC GT 4.5*SORT(FCPSI)*POV*12.*D) VC=4.5*SORT(FCPSI)*POV*12.*D
      RDT=VU2*100.0/VC
      SH(K+6)=XL(INDEX(K))
      SH(K+7)=FN
      SH(K+8)=VC/1001.0
      SH(K+9)=RDT
      IF ( RDT LE 1.0 ) GO TO 2500
      ASINC=0.69*VU/FN+(AMVC+1.)*/FD/SORT(FCPSI)-0.2095*D*POV
      SH(K+10)=ASINC
      IF ( ASINC/12./POV/D GT 0.02 ) GO TO 950A
      WRITE(14,9501) INDEX(K),SIDEK(1)
      9501  FORMAT('/T30,*0(1H9),/T30,*0(1H4X,*0(1H9),/T30,*0(2X,*0(W20X,*0(W12X,*0(W12X,12X,’WARNING:*1 21X,*0(1H9),/T30,*0(1H4X,*0(1H9),/T30,*0(2X,*0(W20X,*0(W12X,*0(W12X,**STIRRUPS ARE REQUIRED ON **SIDE STEEL**
      3 21X,**T30,*0(1H4X,*0(1H9),/T30,*0(2X,*0(W20X,*0(W12X,*0(W12X,**STIRRUPS ARE REQUIRED ON **SIDE STEEL**
      ISDATA(15*K)=1
      SH(K+10)=1.0E15
      GO TO 2500

950A  IF ( MU LT 0.0 ) GO TO 2001
      IF (I-2) 1003, 1002, 1006
C    BOTTOM SLAB
1006 CONTINUE
   IF (ASINC .LT. AS(4)) GO TO 2500
   AS(4) = ASINC
   ICON(4) = 4
   SRATIO(4) = ASINC / 12. / D / FOV
   GO TO 2500
C    SIDE WALL
1002 CONTINUE
   IF (ASINC .LT. AS(5)) GO TO 2500
   AS(5) = ASINC
   ICON(5) = 4
   SRATIO(5) = ASINC / 12. / D / FOV
   GO TO 2500
C    TOP SLAB
1003 CONTINUE
   IF (ASINC .LT. AS(3)) GO TO 2500
   AS(3) = ASINC
   ICON(3) = 4
   SRATIO(3) = ASINC / 12. / D / FOV
   GO TO 2500
C
2001 CONTINUE
   IF (1. .GE. 1.) GO TO 2003
   IF (ASINC .LT. AS(2)) GO TO 2500
   AS(2) = ASINC
   ICON(2) = 4
   SRATIO(2) = ASINC / 12. / D / FOV
   GO TO 2500
2003 IF (ASINC .LT. AS(1)) GO TO 2500
   AS(1) = ASINC
   ICON(1) = 4
   SRATIO(1) = ASINC / 12. / D / FOV
2500 CONTINUE
1500 CONTINUE
C  SDATA(19) = ZMOMT + TS/2. - CT(1) - SDATA(1)/2.
C  SDATA(20) = SPAN - ZMOMP + 1.5*TS - CT(3) - SDATA(3)/2.
C
C  IF (IDRUG .LT. 2) GO TO 174
   WRITE(14,2008) (AASHTC(K), K=1,4), (ZI(I,J), I=1,4, J=1,5)
2008 FORMAT(/'**** SHEAR DESIGN TABLE - METHOD 1 ****'/,
     1'DESIGN SECTION',T32,'(#12,24X)',I2,'/','* ALL SECTIONS ARE AT D*/,
     2' FROM THE HAUNCH*/,'ULTIMATE SHEAR', T26,'(F1C,3,16X)*/,)
SUPPLEMENTARY OUTPUT

C ORGANIZES AND PRINTS OUT A ONE CELL BOX DESIGN SUMMARY SHEET.
C THE PRINT OUT INCLUDES THE FOLLOWING:
C INSTALLATION DATA
C LOADING DATA
C MATERIAL PROPERTIES
C CONCRETE DATA
C REINFORCING STEEL DATA
C THE OUTPUT IS AVAILABLE WITH ALL IDEBUG VALUES.

COMMON /IFLAGS/, IRODATA, ISDATA
COMMON /ISCALE/, ITPLOD, IDEBUG, IR, IPTAPE, IPATH, ICYC, IINT
INTEGER ISDATA(35), IRCATA(35)
COMMON /RSCALE/, RDATA(35), SDATA(35)
REAL ILOAD(12,5)
COMMON /ANAL/, ILOAD, STIF(12,12), FIXM0(4,5,4), DR(4,4), D1(6,6)
I ARRAY, SPATT(6)
EQUIVALENCE (ISF, RDATA(1))
DIMENSION STAF(5,2), ISB(5), STIRR(2)
DATA STIRR /* NO */ */ YES */
DATA ISB73, 1, 4, 2, 5/
T=1, UC-06
C=11
U=1, 50, 100
CSTAN=RDATA(1), C+T
CRISE=RDATA(2), C+T
C=BDATA(10), C+T
C=BDATA(1), C+T
C=BDATA(14), C+T
C=BDATA(12), C+T
ALPHA = 1+BDATA(25)*HDATA(14)
IF ( IRDATA(14), 50, 12 ) C2FTA=0.
DO 30 I=1, 5
K=ISF(I)
STAF(I,1)=AS(I)
30 CONTINUE
STAF(1,2) = STIRR(MAX(ISDATA(14), ISDATA(15), ISDATA(26)) + 1)
STAF(2,2) = STAP(1,2)
STAF(3,2) = STIRR(MAX(ISDATA(20), ISDATA(21), ISDATA(29)) + 1)
STAF(4,2) = STIRR(MAX(ISDATA(16), ISDATA(19), ISDATA(27))
1 ISDATA(28), ISDATA(47), ISDATA(17), ISDATA(18)) + 1)
STAF(5,2) = STAP(4,2)

WRITE(1,4) OSPAN ORISE
WRITE(IW,4)
WRITE(IW,97)
WRITE(IW,5) UH OGAMAS OZETA ALPHA BDATA(15)

IV & LEVEL 21 OUTPUT DATE = 82251 18/35/09

WRITE(IW,6)
WRITE(IW,97)
WRITE(IW,7) BDATA(22), BDATA(23), BDATA(9), BDATA(13), BDATA(24)

WRITE(IW,2)
WRITE(IW,97)
WRITE(IW,5) BDATA(20), BDATA(21), BDATA(27)

WRITE(IW,8)
WRITE(IW,97)
WRITE(IW,9) (BDATA(I), I=3,5) (BDATA(I), I=11,12)
1 (BDATA(I), I=30,35)

WRITE(IW,10)
WRITE(IW,97)
WRITE(IW,11)
WRITE(IW,12) (STAF(I,J), J=1,2, I=1,5)

WRITE(IW,13) SDATA(19), SDATA(20)

C........ FORMATS

97 FORMAT(T10,72******)

1 FORMAT(*1, 10.4, 1.0 FT, SPAN X, 1.0 FT, RISE REINFORCED CONCRETE HEADER BOX SECTION
B117) /T10,72(******)

4 FORMAT(/T11,14 INSTALLATION DATA*)

5 FORMAT(T12,4 HEIGHT OF FILL OVER CULVERT, FT, T70, F12.3,/
1 T12, UNIT WEIGHT, PCF, T70, F12.3,/
2 T12, *MINIMUM LATERAL SOIL PRESSURE COEFFICIENT, T70, F12.3,/
3 T12, *MAXIMUM LATERAL SOIL PRESSURE COEFFICIENT, T70, F12.3,/
4 T12, SOIL - STRUCTURE INTERACTION COEFFICIENT, T70, F12.3

6 FORMAT(/T15, 15 LOADING DATA*)

7 FORMAT(T12, *LOAD FACTOR - MOMENT AND SHEAR, T70, F12.3,/
1 T12, *LOAD FACTOR - THRUST, T70, F12.3,/
2 T12, *STRENGTH REDUCTION FACTOR - FLEXURE, T70, F12.3,/
3 T12, *STRENGTH REDUCTION FACTOR - DIAGONAL TENSION, T70, F12.3,/
4 T12, *LIMITING CRACK WIDTH FACTOR, T70, F12.3

2 FORMAT(*1, MATERIAL PROPERTIES*)
Go to Part II, Program Pipecar
Program PIPECAR

COMMON/ISCALE/IDRUG/IPATH
COMMON/IFLAG/IBDATA(35)
COMMON/PRESS/ULPR(37),ULPT(37),SLPR(37),SLPT(37),FLPT(37)
COMMON/CORD/XY(37),X(37),Y(37),A(37),R(37)
COMMON/AREA/A(37),B(37),BS
COMMON/RSCALE/IBDATA(35)
COMMON/STRA/AREA1(5),SRATIO(5),SGOV(5),AREADT(5),STEXT(5),
ISTFL(5)
COMMON/DESIGN/CA(5),DV(5),DP(5),VLCC(5)
COMMON/PROP/SDT(37),CO(37),ALEN(37)
COMMON/CST/K1(3,3,36),K2(3,3,36),K12(3,3,36)
COMMON/LOAD/F1(3,3,36),F2(3,3,36)
COMMON/DISP/UI(3,3,37)
COMMON/PVM/PVM1(3,3,36),PVM2(3,3,36)
COMMON/REACTION/R(3,3,2)
DOUBLE PRECISION K1, K2, K12, F1, F2, PVM1, PVM2,
DOUBLE PRECISION UN,R

2000 CONTINUE
IPATH=u
CALL READ
IF (IPATH .GT. 0) GO TO 3000
IF (IPATH .LT. 0) GO TO 1000
CALL INIT
IF (IPATH .LT. 0) GO TO 1000
CALL GEOMET
CALL LOADS
CALL STIFF
CALL LDMATR(INP,IMPT,ILP)
IV G LEVEL 21    MAIN    DATE = 10/25/71    1/8/44/55

CALL READ

CALL RECP

CALL DLOAD

CALL POSID

CALL LLOAD

CALL LFID

CALL PRID

CALL FLID

CALL PRINT

1000 CONTINUE

GO TO 2000

2000 CONTINUE

STOP

END

IV G LEVEL 21    READ    DATE = 10/25/71    1/8/44/55

SUBROUTINE READ

C
C THIS SUBROUTINE READS ALL THE INPUT IN A SPECIFIED FORMAT AND
C TRANSFERS THE DATA INTO THE DATA ARRAY. THE EXECUTION OF READ
C IS CONTROLLED BY THE CODE VARIABLE ON THE INPUT CARDS. A CODE
C GREATER THAN 12 SIGNALS THE END OF THE INPUT DATA, READ REPRINTS
C THE INPUT CARDS AS IT READS THEM AS A CHECK FOR THE USER.
C
COMMON/1,FLAG,IPDATA(35)
COMMON/2,SCALE,DATA(35)
COMMON/4,SCALE,ID,PATH
DIMENSION TEXT(1),PAT(1),LAT(12),CSCPTR(4)
DATA LAT /4,2,1,3,4,1,2,3,1,4,2,3/

C
C TABDATA = VALUE NOT READ
C
C = 1 VALUE WAS READ
C
C = 0 VALUE WAS DEFAULTED
C
C WIRE DIAMETERS ARE NOT DEFAULTED

DO 5 I=1,35

IPDATA(I) = 0

5 CONTINUE

WRITE (6,99)

99 FORMAT (1,1)

READ(5,1220,END=993) (HCDATA(I), I=1,20), IDBUG

1220 FORMAT (19A4, 13+1)
IV G LEVEL 21

READ DATE = 82251 18/4/55

CONTINUE
IF(D(2) .EQ. 0, 2) GO TO 15
WRITE(6,1002) KODE, (TEXT(I), I=1,E), (0(I), I=1,K)
DATA(1)=D(1)
GO TO 1

15 CONTINUE
WRITE(6,1001) KODE, (TEXT(I), I=1,K), (0(I), I=1,K)
DATA(4)=D(1)/2
DATA(2)=D(1)/2
DATA(3)=D(3)
DATA(1)=1
DATA(3)=1
DATA(2)=-1
DATA(1)=0.00001
DATA(5)=0.00001
DATA(4)=-1
DATA(5)=-1
GO TO 1

C
C UNIV.
C
C
24 CONTINUE
WRITE(6,1003) KODE, (TEXT(I), I=1,K), (0(I), I=1,K)
DATA(1)=D(1)
DATA(2)=D(2)
DATA(1)=1
DATA(3)=-1
DATA(2)=1
GO TO 1

C SLAB THICKNESS
C
30 CONTINUE
WRITE(6,1004) KODE, (TEXT(I), I=1,K), (0(I), I=1,K)
DATA(6)=D(1)
DATA(1)=1
GO TO 1

C BENDING ANGLE, LOAD ANGLE, SOIL-STRUCTURE INTERACTION COEFFICIENT, KODE=4
C
40 CONTINUE
WRITE(6,1015) KODE, (TEXT(I), I=1,K), (0(I), I=1,K)
DATA(7)=D(1)
DATA(1)=1
DATA(3)=D(2)
DATA(1)=1
DATA(3)=D(3)
IV 0 LEVEL 21 READ DATE = 82251 18/4/55

IBDATA(1)=1
GO TO 1

C DENSITIES: GAMAS, GAMAC, GAMAFA KODE=5

C CONTINUE
WRITE (6,1506) KODE, (TEXT(I), I=1,5), (D(I), I=1+K)
IBDATA(9)=D(1)
IBDATA(10)=D(2)
IBDATA(11)=D(3)
IBDATA(12)=1
IBDATA(13)=1
IBDATA(14)=1
IBDATA(15)=1
GO TO 1

C FLUID PARAMETERS KODE=6

C CONTINUE
WRITE (6,1507) KODE, (TEXT(I), I=1,5), (D(I), I=1+K)
IBDATA(12)=D(1)
IBDATA(12)=1
GO TO 1

C MATERIAL STRENGTH: F(Y), F(CF) KODE=7

C CONTINUE
WRITE (6,1508) KODE, (TEXT(I), I=1,5), (D(I), I=1+K)
IF (D(1) .EQ. 0.) GO TO 71
IBDATA(13)=D(1)
IBDATA(13)=1
71 IF (D(2) .EQ. 0.) GO TO 1
IBDATA(14)=D(2)
IBDATA(14)=1
GO TO 1

C CONCRETE COVER KODE=8

C CONTINUE
WRITE (6,1509) KODE, (TEXT(I), I=1,5), (D(I), I=1+K)
IBDATA(15)=D(1)
IBDATA(15)=1
IBDATA(16)=D(2)
IBDATA(16)=1
GO TO 1

C LOAD FACTORS, CAP. RED. FACTORS KODE=9

C CONTINUE

01290
01300
01320
01330
01331
01340
01350
01360
01370
01380
01390
01400
01420
01430
01431
01440
01450
01460
01480
01490
01491
01500
01501
01520
01530
01540
01550
01560
01580
01590
01591
01600
01610
01620
01630
01640
01670
IVS LEVEL 21

DATE = 8/25/55

100 CONTINUE
READ(6,111) CODE, TEXT(I), I=1,5, D(I), I=1,100
IF (CODE.EQ.15) GO TO 105
DATA(4) = D(1)
DATA(19) = 1
GO TO 1
105 IF (D(2) .EQ. 2.) GO TO 106
DATA(18) = D(1)
DATA(22) = D(2)
DATA(27) = 1
106 IF (D(2) .EQ. 3.) GO TO 107
DATA(21) = D(2)
DATA(24) = D(4)
DATA(29) = 1
107 IF (D(4) .EQ. 2.) GO TO 1
DATA(22) = D(4)
DATA(26) = 1
GO TO 1

C

C WIRE DIAMETERS, TYPE, LAYERS

C

C

C WIRE SPACING

C

C

C DESIGN FACTORS: FCR, FRP, FVP

C

C

C CONTINUE
READ(6,113) CODE, TEXT(I), I=1,5, D(I), I=1,100
DATA(26) = D(1)
DATA(34) = D(2)
DATA(35) = D(3)
DATA(26) = 1
DATA(34) = 1
C   FORMAT STATEMENTS FOR INPUT VALUES
C
10 FORMAT (2F15.3, 1F14.4, 2F10.3, 1F10.7, 1F11.5, 1F10.7)
101 FORMAT (5X,I12, 2F15.3, 1F14.4, 2F10.3, 1F10.7, 1F11.5, 1F10.7)
102 FORMAT (5X,2F15.3, 1F14.4, 2F10.3, 1F10.7, 1F11.5, 1F10.7)
103 FORMAT (5X,2F15.3, 1F14.4, 2F10.3, 1F10.7, 1F11.5, 1F10.7)
104 FORMAT (5X,2F15.3, 1F14.4, 2F10.3, 1F10.7, 1F11.5, 1F10.7)
105 FORMAT (5X,2F15.3, 1F14.4, 2F10.3, 1F10.7, 1F11.5, 1F10.7)
106 FORMAT (5X,2F15.3, 1F14.4, 2F10.3, 1F10.7, 1F11.5, 1F10.7)
107 FORMAT (5X,2F15.3, 1F14.4, 2F10.3, 1F10.7, 1F11.5, 1F10.7)
108 FORMAT (5X,2F15.3, 1F14.4, 2F10.3, 1F10.7, 1F11.5, 1F10.7)
109 FORMAT (5X,2F15.3, 1F14.4, 2F10.3, 1F10.7, 1F11.5, 1F10.7)
110 FORMAT (5X,2F15.3, 1F14.4, 2F10.3, 1F10.7, 1F11.5, 1F10.7)
111 FORMAT (5X,2F15.3, 1F14.4, 2F10.3, 1F10.7, 1F11.5, 1F10.7)
112 FORMAT (5X,2F15.3, 1F14.4, 2F10.3, 1F10.7, 1F11.5, 1F10.7)
113 FORMAT (5X,2F15.3, 1F14.4, 2F10.3, 1F10.7, 1F11.5, 1F10.7)
114 FORMAT (5X,2F15.3, 1F14.4, 2F10.3, 1F10.7, 1F11.5, 1F10.7)

C  CONTINUE  RETURN  END
C END OF DATA, EXECUTION TERMINATED
C
995 CONTINUE
RETURN
END
IVC LEVEL 21          INIT          DATE = 82251          18/44/55

103 IF (IBDATA(6) .EQ. 0) GO TO 206
    WRITE (6,500)
    WRITE (6,1104)

206 CONTINUE

104 IF (IBDATA(7) .NE. 0) GO TO 22
    DATA(7) = 0.0
    DATA(7) = -1
    GO TO 225
225 IF (DATA(7) .LT. 30.) 330. 94, 94
    IF (DATA(7) .LT. 180.) DATA(7) = 180.
    DATA(7) = -1

205 CONTINUE

104 FORMAT (24H0, REDDING ANGLE MODIFIED )
    IF (DATA(7) .LT. 30.) DATA(7) = 30.
    IF (DATA(7) .GT. 180.) DATA(7) = 180.

104 CHECK REDDING AND LOAD ANGLES

204 CONTINUE

104 IF (IBDATA(32) .NE. 0.00) GO TO 20
    DATA(32) = 360. - DATA(7)
    DATA(32) = -1
    GO TO 274
274 CONTINUE

104 IF (DATA(32) .LT. 180.) GO TO 206
    DATA(32) = 180.0
    DATA(32) = -1
    WRITE (6,500)
    WRITE (6,1105)
206 CONTINUE

104 IF ((DATA(7) + DATA(32)) .LE. 360.) GO TO 254
    WRITE (6,500)
    WRITE (6,1104)
    WRITE (6,1105)

1104 FORMAT (38H0, REDDING AND LOAD ANGLES INCONSISTENT ,/ ,/)
1105 FORMAT (21H0, LOAD ANGLE MODIFIED )

204 CONTINUE

C CHECK SOIL STRUCTURE INTERACTION FACTOR

C IF (IBDATA(8) .GE. 0.75) GO TO 776
    DATA(8) = 1.2
    DATA(8) = -1
    WRITE (6,777)
DO NOT ASSUME PIPE DIAMETERS

DO 10 I = 7, 9
IF (IBDATA(1) .EQ. 0) IRDATA(I) = 0
CONTINUE
10 CONTINUE

DO 13 I = 9, 12
IF (IBDATA(I) .EQ. 0 .OR. 1) IRDATA(I) = 0
CONTINUE
13 CONTINUE

12 CONTINUE

CALCULATE FS, EC, MEAN RADII, EQUIVALENT DIAMETER
BDATA(27)=29000.0
BDATA(28)=(BDATA(10))*1.533*SORT(BDATA(14)*1000.0)/1000.
UVROT=UBDATA(1)/BDATA(5)
BDATA(31)=SORT(2.*(BDATA(1)+2.*ATAN(UVROT))+BDATA(1)*2.*(PI/2-
1ATAN(UVROT)))+BDATA(4)*BDATA(5))/PI.*2.
I1DATA(27)=-1
I1DATA(28)=-1
I1DATA(29)=-1
I1DATA(30)=-1
I1DATA(31)=-1
BDATA(25)=BDATA(1)+BDATA(6)/2
BDATA(35)=BDATA(2)+BDATA(6)/2
IF (BDATA(12) .LE. (2.*(BDATA(2)-BDATA(5)))) GC TO 101
WRITE(6,102)
102 FORMAT(45HC DEPTH OF FLUID TOO LARGE, SET TO FULL DEPTH)
BDATA(12)=ASSUME(12)
101 CONTINUE
GO TO 145
100 CONTINUE
WRITE(6,500)
WRITE(6,1000)
1000 FORMAT(22HC RADIUS MUST BE GIVEN.)
WRITE(6,1100)
IPATH=-1
GO TO 150
115 WRITE(6,500)
WRITE(6,1100)
1100 FORMAT(29HC GEOMETRY MUST BE CONSISTENT)
WRITE(6,1100)
IPATH=-1
GO TO 150
210 CONTINUE
WRITE(6,500)
WRITE(6,2000)
2000 FORMAT (25HC THICKNESS MUST BE GIVEN)
WRITE(6,1100)
IPATH=-1
GO TO 150
250 FORMAT(23HC *** INPUT ERROR ****)
1100 FORMAT (95HC EXECUTION OF THIS PIPE HAS BEEN TERMINATED)
149 CONTINUE
C CHECK FOR NUMBER OF LAYERS OF WIRE
IF (BDATA(22) .GT. 2.) BDATA(22)=2.
WRITE(6,4050)
4050 FORMAT(///32X,69(1*F*14),/32X,1H4,67X,1H4,/,32X,1H4,1X*).
* ALL INFORMATION PRESENTED IS FOR REVIEW, APPROVAL, INTERPRETATION
IV G LEVEL 21 INIT DATE = 8/25/51 18/4/55

2 ** */ 32X** AND APPLICATION BY A REGISTERED ENGINEER.*/ 25X* 1H*/ 2
32X* 1H** 67X* 1H** */ 32X* 69(1H*)
IF ( IDMUG .LT. 1 ) GO TO 150
WRITE(6* 4051)

4051 FORMAT(1H1)
IF (BDATA(1) .EQ. BDATA(2)) GO TO 6000
WRITE(6* 4002)
GO TO 6001

6000 WRITE(6* 6003)
6002 FORMAT(// 5X* 120(1H*)*/ 10X* 28HELIPTICAL PIPE ANALYSIS AND+
1H DESIGN/** 5X* 120(1H*)
6003 FORMAT(// 5X* 126(1H*)*/ 10X* 29HCIRCULAR PIPE ANALYSIS AND DE+
1H SIGNAL*/ 5X* 120(1H*)
6001 CONTINUE
WRITE(6* 5000)

5000 FORMAT(//T30** MAP OF BDATA ARRAY**, //24X* 9HPARAMETER, 12X*,
1 *DATA*, 8X*, SOURCE*, **)
DO 5006 I=1,35
IF (IBDATA(I)) 5001, 5002, 5003

5001 J=1
N=2
GO TO 5004

5002 J=3
N=4
GO TO 5004

5003 J=5
N=6
5004 KF = 5+1
JF = JF* +
WRITE(6* 5005) 1*(SCRIPT(LF)* LF=JF* KF)* BDATA(1:), SOURCE(J), SOURCE(K)

5005 FORMAT(15X* 12* 2X* 5A4+3X, F10.3, 4X* 2A4)
5006 CONTINUE
150 CONTINUE
RETURN
END
SUPROUTINE GEOMET

CALCULATES COORDINATES OF THE NODES, AND THE LENGTH AND DIRECTIONAL
SINES AND COSINES OF MEMBERS FOR CIRCULAR AND ELLIPTICAL
PIPE.
A PRINTOUT OF THIS INFORMATION IS AVAILABLE WITH AN IDBUG VALUE
GREATER THAN 1

COMMON/RSCALE/RADI1,RADI2,HU7,THBETA,HH,GMAS,GAMAC,GAMAF,DF-
IFY,FCP,COUT,CIN,FLMV,FLN,DOUT,DOUT,RTYPE,NLAY,SPIN,SPOUT,PO,FCR,EST
1,ECOM,RADM1,SE9M2,SE9D,RITAS,P00,
COMMON/CORDO/X(37),Y(37),A(37),B(37),BS
COMMON/Application/SI(37),CO(37),ALEN(37)
COMMON/RSCALE/IDBUG,IPATH
DIMENSION DEG(37)

M=0
PI=3.1415926535897
IF(P ETA NE.180.) GO TO 200
P=179.99*PI/180.0
BS=179.99*PI/180.
M=2
CONTINUE
200
IF (RITAS .EQ. 180.) BS = 180.0*PI/180.
RETA=RITA+PI/180.
RITAS=RITAS+PI/180.

GENERATE COORDINATES

P 2 = ATAN(U/V)
DO 350 I=1,37
DEG(I) = (I-1) * 5.00000
A(I)=(I-1)*PI/36
IF(A(I)*.GT.(PI-P2)) GO TO 700
IF (A(I) .GT. P2) GO TO 600
X(I)=RADM1*SIN(A(I))
Y(I)=-RADM1*CCS(A(I))+V
GO TO 500
600
CONTINUE
X(I)=RADM1*SIN(A(I))+U
Y(I)=-RADM1*CCS(A(I))
500
CONTINUE
IF (M .GE. 1) GO TO 750
IF (ABS(X(I)/Y(I)) .LE. (BETA+0.0017)/2.) GC TO 800
200 = A(I)=1
M=1
LE. 3.14247
IF (RITAS .EQ. 180.) M = 2
IF (BETA+RETAS) .LT. 6.28144) GO TO 750
BS=2
M=2
GO TO 800
750 IF (M .EQ. 2) GO TO 800
IF(-ATAN(X(I)/Y(I)) .LT.(6.2815-RETAS)/2.) GO TO 800
PS=2.*A(I)
M=2
GO TO 800
790 CONTINUE
X(I)=RADM2*Sin(A(I))
C
C X(I)=RADM2*Sin(A(I))
C
Y(I)=-RADM2*Cos(A(I))-V
C
C Y(I)=-RADM2*Cos(A(I))-V
C
890 CONTINUE
IF(I .EQ. 1) GO TO 300
ALEN(I-1)=(X(I)*X(I-1)+Y(I-1)*Y(I-1))**0.5
SI(I-1)=(X(I)-X(I-1))/ALEN(I-1)
CO(I-1)=(Y(I)-Y(I-1))/ALEN(I-1)
300 CONTINUE
IF (IMBUG .LT. 2) GO TO 1300
WRITE(6,99)
99 FORMAT(1H1)
WRITE(6,1000)
WRITE(6,1400)
WRITE(6,1200)(1,DEG(I),X(I),Y(I),ALEN(I),A(I),SI(I),CO(I),
I=1,37)
1100 CONTINUE
1900 FORMAT(5X,8HGEOMETRY,/6X*11-5X*8HDEG FROM\5X*4HX(I),12X,
14HX(I-1)+12X*7AHLEN(I),12X*4HA(I),13X,5HSI(I),12X*5HC0(I))
1200 FORMAT(37(5X*12-6X,F4.0,1X,F12.3,5X,4F12.3,5X,F12.3,/) )
1400 FORMAT(4X,8HHORIZONTAL,5X,1PHINCHES FROM CENTER,13X,
16PHICHES,11X,THRADIANS )
1300 CONTINUE
RETURN
END
C*************************************************
C*************************************************
SUBROUTINE LOADS
C
C CALCULATES THE NORMAL AND TANGENTIAL PRESSURES(KIPS/IN/FT) ON EACH
C JOINT DUE TO PIPE SOIL AND FLUID LOADS. POSITIVE RADIAL PRESSURE IS
C ASSUMED TO BE ACTING TOWARD THE CENTER AND POSITIVE TANGENTIAL
C PRESSURE IS ASSUMED TO BE CLOCKWISE.
C A PRINTOUT OF THIS INFORMATION ALONG WITH A SUMMARY OF
C THE TOTAL APPLIED PIPE, SOIL AND FLUID LOADS IS AVAILABLE
C WITH AN IDBUG VALUE GREATER THAN 1.
C
COMMON/RSCALE/RADI1,RADI2,HH,UT,ETA,HH,GAMAS,GAMAG,GAMAF,DF,
IFY,FCP,COUT,CFM,FLMV,FLN,DIN,DOUT,TYPE,WLAY,SPIN,SFCUT,PD,FCR,EST
1,ECON,RAIM1,RAIN2,EGUID,RETAS,POD
COMMON/COORD/X(37),Y(37),A(37),L(37),R(37)
COMMON/PROP/SII(37),CC(37),ALEN(37)
COMMON/ISCALC/IDBUG,1,PATH
COMMON/IFLAG/I DATA(35)
COMMON/PRESS/OLPR(37),DLPT(37),SLPR(37),SLPT(37),FLPR(37),
1,FLPT(37)
DIMENSION D(37)
DIMENSION Q(37),PREACT(37),T(37),S(37)
REAL L,LF
C
C SET FLUID LEVEL TO NEAREST JOINT
C
IF(I DATA(12).EQ.1) GO TO 850
FS=Y(37)-TH/2.
GO TO 950
850 DO 1000 J=1,37
FS=Y(J)+TH/2.*COS(A(J))
IF(FS+6E6*(5F*Y(J)+TH/2.)) GO TO 950
1000 CONTINUE
C
950 CONTINUE
B2=0.0
A4=0.0
B7=0.0
B8=0.0
PM=0.0
M5=1.0
B6=1.0
F1=1.0
PI=3.1415926535897
C
C TOTAL SOIL LOAD
C
W=GAMAS*HH*(TH+RADI1+L1)*(H*(RADI2-V+TH)/36)/6000.
R3=RAD1
IF (EQUID. GT. 7.0) R3=(EQUID*TH1/2)

C GLANDER SOIL PRESSURE DISTRIBUTION

C C=SIN((PI/8-B-1.)*B/2.)*2./((PI/B+1.))
D=SIN((PI/B+1.)*B/2.)*2./((PI/B+1.))
PINV=W/2.*R3/(C*D)
E=PI-PS/2.
A9=PI-PS/2.
E=SIN((PI/2.+A9-1.)*A9)/2.*((PI/2.+A9-1.)
F=SIN((PI/2.+A9-1.)*A9)/2.*((PI/2.+A9+1.)
PTOP=W/2.*R3/IE+F)
DO 100 I=1,37
DEG(I)=(I-1)*5.00000
IF (I.EQ.37) GO TO 225
IF (I.EQ.1) GO TO 225
GO TO 250
225 CONTINUE

DEAD LOAD

C DLPR = DEAD LOAD - NORMAL PRESSURE

C DLPT = DEAD LOAD - TANGENTIAL PRESSURE

C DLPR(I)=TH*GAMAC/144000.*0
DLPR(37)=-DLPR(1)
DLT(I)=7.0
DLPT(37)=0.0
GO TO 101
250 CONTINUE
L=((Y(I+1)-X(I-1))**2+(Y(I+1)-Y(I-1))**2)**0.5
CA=(Y(I+1)-X(I-1))/L
SA=(Y(I+1)-Y(I-1))/L
DLPR(I)=DLPR(I)+CA
DLPT(I)=DLPT(37)+SA
101 CONTINUE

C PW=TH*GAMAC*ALEN(I)*2.*144000.*PW

SOIL LOAD

C SLPR = SOIL - NORMAL PRESSURE

C SLPT = SOIL - TANGENTIAL PRESSURE

C SLPT(I)=0.0
IF (A1(I) .GT. B/2.) GO TO 300
SLPR(I)=PINV*COS(PI/B+A(I))
GO TO 350
300 CONTINUE
IF (A1(I) .GT. BS/2.) GO TO 310
SLPR(I)=0.0
GO TO 350
310 SLPR(I)=PTOP*SIN(0.5*(A1(I)-BS/2.)*(PI/A9))
IV G LEVEL 21 LOADS DATE = 87251 18/44/55

350 CONTINUE
Q(I)=SLPR(I)*COS(A(I))
IF (I.EQ.1) GO TO 200
IF(A(I) .LT. 8/2.) GO TO 400
B2=(Q(I)+Q(I-1))/2.*ALEN(I-1)+B2
GO TO 200
400 CONTINUE
B4=(Q(I)+Q(I-1))/2.*ALEN(I-1)+B4
200 CONTINUE
C
C FLPR = FLUID NORMAL PRESSURE
04970
C FLPT = FLUID TANGENTIAL PRESSURE
04972
C
FLPR(I)=(FS-(Y(I)+TH/2.*COS(A(I))))*GAMAF/19480.0*0*(-1.0)
IF (FLPR(I) .LE. 0.0) FLPR(I)=0.0
FLPT(I)=0.0
PREACT(I)=0.0
T(I)=FLPR(I)+COS(A(I))
LF=RI2/RAD12
IF(A(I) .LT. (PI-ATAN(U/V))) GO TO 107
IF(A(I) .GT. ATAN(U/V)) LF=RI1/RAD1
107 CONTINUE
FLPR(I)=FLPR(I)*LF
B7=(T(I)+T(I-1))/2.*ALEN(I-1)*LF+B7
100 CONTINUE
C
C ADJUST SOIL AND FLUID PRESSURES FOR BALANCE
05082
C
IF (W .LE. 0.0) GO TO 550
65=W2/W+2.*
F6=W4*(-2.*W)/W
550 PROT=P7/P3/(C+D)
DO 560 U=1,37
1E (A(U) .LT. (B/2.)) GO TO 600
SLPR(U)=SLPR(U)/B5
PREACT(U)=PROT*(COS(A(U)+PI/8))
S(U)=PREACT(U)*COS(A(U))
GO TO 700
600 CONTINUE
SLPR(U)=SLPR(U)/B6
700 CONTINUE
IF (J .EQ. 1) GO TO 500
IF (AJ .LT. B/2.1 GO TO 500
B8=(S(J)+S(J-1))/2.*ALEN(J-1)+B8
500 CONTINUE
IF (F7 .NE. 0.0) F1=-B8/B7
DO 1300 K=1,37
FLPR(K)=FLPR(K)+PREACT(K)/F1
1300 CONTINUE

1300 CONTINUE
   IF (IDBUG.LT.2) GO TO 3000

C PRINT LOADS TABLE
C
99 WRITE(*,99)
99 FORMAT(1H1)
WRITE(*,1400)
1400 FORMAT(//,5X,36MLoads at Each Joint, Kips/In/Foot 1)
WRITE(*,1500)
1500 FORMAT(3X,4HDEAD,2X,4H SOIL,2X,(4HFLUID))
WRITE(*,1550)
1550 FORMAT(12X,4H DEG FROM, 5X, 24 (1H=), 9X, 24 (1H=), 9X, 72 (1H=))
WRITE(*,1600)
1600 FORMAT(6X,1HI,5X,1HVERTICAL,8X,6H RADIAL,9X,4HTANG,2(14X,6H RADIAL,1)
9X,4HTANG))
WRITE(*,1700) (1,DEG(I),DLPR(I),DLPT(I),SLPR(I),SLPT(I),FPRM(I),
1FLPT(I),I=1,37)
1700 FORMAT(5X,12X,4X,F4.0,4X,F12.6,3X,F12.6,6X,F12.6,3X,F12.6,6X).
1F12.6,3X,F12.6)
3000 CONTINUE
   IF (IDBUG.LT.1) GO TO 4000
WRITE(*,1800) PW
1800 FORMAT(//,14HO PIPE WEIGHT=*,F9.3,10H KIPS/FOOT )
WRITE(*,1900) W
1900 FORMAT(//,14H SOIL WEIGHT=*,F9.3,10H KIPS/FOOT )
BPMP = -2.0*E7
WRITE(*,2000) BPMP
2000 FORMAT(//,15H FLUID WEIGHT=*,F9.3,10H KIPS/FOOT )
4000 CONTINUE
RETURN
END
IV G LEVEL 21  STIFF  DATE = 8/251  18/44/55

**SUBROUTINE STIFF**

**C**

**C** CALCULATES MEMBER STIFFNESS SUBMATRICES

**C**

COMMON/PROP/SI(I7), CO(I7), ALEN(37)  05630
COMMON/SCALE/DUM(5), TH, DUMM(21), ECON, D(2)  05640
COMMON/SCALE/DUM, IPUG, JPATH  05650
COMMON/VCONST/K1(3,3,36), K2(3,3,36), K12(3,3,36)  05660

**DOUBLE PRECISION** K1, K2, K12, MI  05680

**C**

AREA = 12. * TH  05700
M1 = TH ** 5  05710
C0 1: C 1 = 1.36  05720
C1 = ECON / ALEN(1)  05730
C2 = "1 / ALEN(1) ** 2  05740
A1 = C1 * C0(I) * 2 * AREA + 12. * SI(I) * C2  05750
A2 = C1 * C0(I) * 2 * AREA + 12. * CO(I) * 2 * C2  05760
A3 = C1 * SI(I) * CO(I) * (AREA - 12. * C2)  05770
A4 = 0. * SI(I) * ECON * C2  05780
A5 = A4 * SI(I) * CO(I)  05790
A6 = 0. * "1 * C1  05800
K1(1,1,I) = A1  05810
K2(1,1,I) = A1  05820
K12(1,1,I) = -A1  05830
K1(1,2,I) = A3  05840
K2(1,2,I) = A3  05850
K12(1,2,I) = A3  05860
K1(2,1,I) = A3  05870
K2(2,1,I) = A3  05880
K12(2,1,I) = -A3  05890
K1(1,3,I) = -A4  05900
K1(3,1,I) = -A4  05910
K12(1,3,I) = -A4  05920
K12(3,1,I) = -A4  05930
K1(2,3,I) = A5  05940
K1(3,2,I) = A5  05950
K12(2,3,I) = A5  05960
K12(3,2,I) = A5  05970
K1(3,3,I) = A6  05980
K2(3,3,I) = A6  05990
K12(3,3,I) = 0.5 * A6  06000
K2(1,3,I) = A4  06010
K2(3,1,I) = A4  06020
K12(3,1,I) = A4  06030

**IV G LEVEL 21  STIFF  DATE = 8/251  18/44/55**

100 CONTINUE

200 CONTINUE

RETURN

END
SUBROUTINE LDMATR(P, PT, K)

FOR EACH LOADING CONDITION, LDMATR GENERATES THE LOAD MATRICES
FOR EACH JOINT FROM THE MEMBER PROPERTIES AND THE RADIAL AND
TANGENTIAL PRESSURES. THE LDMATR VALUES, REPRESENT THE REACTIONS,
AT EACH END OF A MEMBER DUE TO THE APPLIED LOADS.

DIMENSION P(37), PT(37)
COMMON/PROP/SI(37), CO(37), ALEN(37)
COMMON/LUAD/F1(1, 5, 56), F2(3, 3, 36)
DOUBLE PRECISION F1, F2, C1, C2

DO 100 T=1, 36
   C1 = SI(T) * ALEN(T)
   C2 = CO(T) * ALEN(T)
   F1(T, K) = C1 / (-2.0) * (7.0 * P(T) + 3.0 * P(T+1)) - C2 / 8.0 * (3.0 * PT(T) +
   PT(T+1))
   F1(2, K) = C2 / 20.0 * (7.0 * F1(T) + 5.0 * P(T+1)) - C1 / 8.0 * (3.0 * PT(T) +
   PT(T+1))
   F1(3, K) = ALEN(T) * PT(T) / 20.0 * (3.0 * P(T) + 2.0 * P(T+1))
   F2(1, K) = C1 / (-20.0) * (3.0 * P(T) + 7.0 * P(T+1)) - C2 / 8.0 * (PT(T) +
   PT(T+1))
   F2(2, K) = C2 / 20.0 * (3.0 * P(T) + 7.0 * P(T+1)) - C1 / 8.0 * (PT(T) + 3.0 * PT(T+1))
   F2(3, K) = ALEN(T) * PT(T) / 20.0 * (2.0 * P(T) + 3.0 * P(T+1)) * (-1.0)

100 CONTINUE

RETURN

END
SUBROUTINE RECUR

C Assumes that joint 1('INVERT) is fixed and joint 7('GROWN) only
C deflects in the Y-direction. Given these boundary conditions and
C the load and stiffness matrices the deflection at joint 37 is
C calculated and all other joint X, Y deflections and rotations
C are solved recursively.
C A printout of this information is available with an IDBUG value
C equal to 3.
C
COMMON/1SCALE, IDBUG, 1PATH
COMMON/CONST/F1(3, 3, 36), K2(3, 3, 36), K12(3, 3, 36)
COMMON/LOAD/F1(3, 3, 36), F2(3, 3, 36)
COMMON/DISP/UN(3, 3, 37)
DOUBLE PRECISION K1, K2, K12, F1, F2, K12T(3, 3)
DOUBLE PRECISION UNP(3, 3, 37), O(3, 3, 37), D(3), A(3, 3), B(3, 3),
1(3, 3)

C
DO 100 I = 1, 3
  DO 10 J = 1, 3
    A(I, J) = K2(I, J + 1) + K1(I, J + 2)
    C(I, J) = F2(I, J + 1) + F1(I, J + 2)
  10 CONTINUE
CALL MATINV(A, P)
CALL MATMPPY(E, K12(1, 1, 2), P(1, 1, 2))
CALL MATMPPY(F, C, G(1, 1, 2))
DO 20 L = 1, 3
  DO 20 J = 1, 3
    K12T(J, 1) = K12(I, J, L - 1)
  20 CONTINUE
CALL MATMPPY(K12T, P(1, 1, L - 1), A)
DO 40 I = 1, 3
  DO 40 J = 1, 3
    A(I, J) = K2(I, J + L - 1) - A(I, J) + K1(I, J, L)
  40 CONTINUE
CALL MATINV(A, B)
CALL MATMPPY(K12T, G(1, 1, L - 1), C)
DO 500 I = 1, 3
  DO 500 J = 1, 3
    C(I, J) = F2(I, J + L - 1) - C(I, J) + F1(I, J, L)
  500 CONTINUE
CALL MATMPPY(F, C, G(1, 1, L))
IF (IL = ED. 360) GO TO 600
CALL MATMPPY(F, K12(1, 1, L), P(1, 1, L))
GO TO 200
600 CONTINUE
D11 = K12 (1 + 2 * L)
D(2) = K12 (2 + 2 * L)
D(3) = K12 (3 + 2 * L)
CALL MAT1C0 (D + P (1, 1, 36))

200 CONTINUE
DO 700 K = 1, 36
UN(1 + K) = 0.000
UN(2 + K) = 0.000
UN(3 + K) = 0.000
UN(1 + K) = P (1 + K) * UN(2 + K) * UN(3 + K)
UN(2 + K) = P (2 + K) * UN(2 + K) * UN(3 + K)
UN(3 + K) = P (3 + K) * UN(2 + K) * UN(3 + K)
700 CONTINUE

1000 CONTINUE
CALL MAT1PY (P (1 + 1, L) * UN (1 + 1, L + 1) + A)
DC ABC 1 = 1, 3
DO 800 J = 1, 3
UN (1 + J) = 0 (1 + J) - A (J)
800 CONTINUE

A00 CONTINUE
L = 1 + 1
IF (L .GE. 2) GO TO 1000
IF (UNBUG .LT. 3) GO TO 2500
C
C WRITES DISPLACEMENTS
C
WRITE (6, 99)
FORMAT (1H1)
WRITE (6, 2001)
WRITE (6, 2001)
WRITE (6, 2001)
DC 1200 L = 1 + 35
L1TMP = L + 1
L2TMP = L + 2
WRITE (6, 2100) L1TMP, L2TMP
DO 1200 I = 1 + 3
GO TO (11, 12, 13) +
11 WRITE (6, 11) (UN (I + J) + J = 1 + 3) * (UN (I + J + L + 1) + J = 1 + 3) * (UN (I + J + L + 2) + J = 1 + 3)
13 = 1 + 3
GO TO 1200
12 WRITE (6, 12) (UN (I + 1, J) + J = 1 + 3) * (UN (I + J + L + 1) + J = 1 + 3) * (UN (I + J + L + 2) + J = 1 + 3)
13 = 1 + 3
GO TO 1200
07052
07061
IV G LEVEL 21
RECUR 12/34/24

GO TO 1200

15 WRITE(6,3) (UN(I+J*3),I=1,3) + (UN(I+J*3+1),J=1,3) + (UN(I+J*3+2),J=1,3)
1+J=1+J

1200 CONTINUE

WRITE(6,2003) (UN(I+J*3),J=1,3),I=1,3

2003 FORMAT((4X,8H ELEMENT, 8X*2H37+/, 2X*, 8X*3X, 3(12,5,2X),/,
12X*, 3X, 3(F12,5,2X),/*, 1X*, 3X, 3(F12,5,2X))

2000 FORMAT(/S51%22HDIPLACEMENTS, INCHES ,/) 07170

2001 FORMAT(23X,7HLOADING, 32X,7HLOADING, 31X,7HLOADING)


2100 FORMAT(6X,8H ELEMENT, 8X*12, 3AX*12) 07180

1 FORMAT(2X*, 5X, 5X, 5E12, 5, 5X, 5E12, 5, 5X)

2 FORMAT(2X*, 5X, 5X, 5E12, 5, 5X, 5E12, 5, 5X)

3 FORMAT(1X*, 5X, 5X, 5E12, 5, 5X, 5E12, 5, 5X)

2500 CONTINUE

RETURN

END

IV G LEVEL 21
REACT 12/34/24

SURROGATE REACT

C CALCULATES THE MOMENTS, THRUSTS AND SHEARS AT JOINT 1 (INVERT) AND
C JOINT 37 (CROWN)

C C

COMMON/REACTIV/R(3,3,2)
COMMON/DESIGN/DH(5),DP(5),DV(5),VLOC(5)
COMMON/CONST/K1(3,3,36),K2(3,3,36),K12(3,3,36)
COMMON/DISP/UN(3,3,37)
COMMON/LOAD/F1(3,3,36),F2(3,3,36)
COMMON/ISCALE/0,DEBUG,IPATH
DOUBLE PRECISION K1, K2, K12, F1, F2, UN
DOUBLE PRECISION R(3,3), B(3,3), C(3,3)

CALL MATMUL(K12(1,1,1),UN(1,1,2),B) 0846C
DO 100 I=1,3
DO 100 J=1,3
R(J,J+1)=B(J,J+1)-F1(I,J+1)
100 CONTINUE

DO 200 I=1,3,2
T(I+1)=K12(I+1,1,36)
T(I+2)=K12(I+2,1,36)
T(I,1)=K12(I,1,36)
T(I,1)=0.000
T(I,2)=0.000
T(I,3)=0.000
T(I,2)=0.000
T(I,3)=0.000
T(I,3)=0.000
CALL MATMUL(T,UN(1,1,36),C) 0856C
DO 300 J=1,3
R(I,J+2)=C(I,J)+F2(I,J+2,36)*K2(1,2,36)*UN(2,J+3)
300 CONTINUE

200 CONTINUE

DM(1)=R(3,1,1)+R(3,2,1)
DP(1)=R(1,1,1)+R(1,2,1)
IF (DAABS(DM(1))^R(3,3,1),LT, ABS(DM(1))) GO TO 700
DM(1)=DM(1)-R(3,3,1)
DP(1)=DP(1)+R(1,3,1)
700 EXIT

0713A 0713B 0713C 0713D 0713E 0713F 0714A 0714B 07150 07151 07170 07171 07180 08370 08380 08390 08400 08410 08420 0846C 0847C 0848C 0849C 0850C 0851C 0852C 0853C 0854C 0856C 0857C 0858C 0859C 0860C 0861C 0862C 0864C 0865C 0866C
IVG LEVEL 21  FEACT  DATE = 82252  12/34/24

AC1 CONTINUE
RETURN
END

IVG LEVEL 21  TEHMPO  DATE = 82252  12/34/24

SUBROUTINE TEHMPO

C  CALCULATES THE INTERNAL THRUSTS, SPEARS AND MOMENTS AT EACH END OF ECH MEMBER
C  PVM1 REPRESENTS THE FORCES AT THE LEFT END OF A MEMPER
C  PVM2 REPRESENTS THE FORCES AT THE RIGHT END OF A MEMBER
C  PVM*(X,Y,Z) X REFERS TO THE P, V OR M FOR X=1,2,3 RESPECTIVELY
C  Y REFERS TO THE LOAD CONDITIONS
C  Z REFERS TO THE ELEMENT
C  A PRINTOUT OF THE SERVICE LOAD FORCES IS AVAILABLE WITH AN IDHUG VALUE GREATER THAN 1
C
C COMMON/PROP/S1(37),G0(37),ALEN(37)
COMMON/LOAD/F1(3*3,36),F2(3*3,36)
COMMON/SCALE/IORDUG,IENTRY
COMMON/CONST/K1K2K12T(3,3,3),K21K31K32T(3,3,3)
COMMON/DISP/UN(3,3,37)
COMMON/PVM/PVM1(3,3,36),PVM2(3,3,36)
DOUBLE PRECISION K1K2K12T(3,3,3),PVM1, PVM2, UN,F1,F2
DOUBLE PRECISION T(3,3),UN(3,3),G(3,3),S(3,3),M(3,3)
COMMON/REAC/REAC(3,2)
DOUBLE PRECISION A(9),REAC

IF (IDHUG *LT* 2) GO TO 2
WRITE(*,99)
99 FORMAT(1H1)
WRITE(*,600)
2 CONTINUE
DEG = 3.0
DO 200 I=1,9
T(1,1)=G0(I)
T(1,2)=S1(I)
T(1,3)=0.000
T2(I)= -ST(I)
T2(2)=S0(I)
T2(3)=5.000
T3(I)=9.000
T3(2)=5.000
T3(3)=1.000
DO 300 L=1,3
DO 300 M=1,3
K12T(M,L) = K12(L,M)*I
300 CONTINUE
CALL MATMPY(K1(1,1:1),UN(1,1:1)*C)
CALL MATMPY(K12(1,1:1),UN(1,1:1)*E)
CALL MATMPY(K12T(1,1),UN(1,1,1))
CALL MATMPY(K22(1,1,1),UN(1,1,1,1))

IV G LEVEL 21
THSHMD
DATE = 07/252
12/34/24

DO 400 J=1,3
DO 400 K=1,3
G(J,K) = D(J,K) + F1(J,K,I) + E(J,K)
W(J,K) = R(J,K) + F2(J,K,I) + S(J,K)
400 CONTINUE
CALL MATMPY(T,G,PVM1(1,1,1))
CALL MATMPY(T,W,PVM2(1,1,1))
IF (IDBUG .LT. 2) GO TO 200

C WRITE THRUSTS SHEARS AND MOMENTS
C
IF (I .EQ. 1) GO TO 201
J3 = 0
DO 203 J1 = 1,3
    DO 203 J2 = 1,3
        J3 = J3 + 1
        A(J3) = (PVM1(J2,J1,1)-PVM2(J2,J1,1,1))/2.0000000
 203 CONTINUE
DEG = (T-1)*500000
WRITE(6,204) I,DEG(A(J5),J5=1,9)
GO TO 200

201 WRITE(6,204) I,DEG(REAC(J6+1,1)+J6=1,3),(REAC(J6+2,1)+J6=1,3),
                 (REAC(J6+3,1)+J6=1,3)
240 CONTINUE
IF (IDBUG .LT. 2) GO TO 1200
I=37
DEG = 180.0
WRITE(6,204) I,DEG,(REAC(J6+1,2)+J6=1,3),(REAC(J6+2,2)+J6=1,3),
                 (REAC(J6+3,2)+J6=1,3)  
600 FORMAT(//T36,service load thrust(kips/ft), shear(kips/ft),
                *moment(in-kips/ft),/T36,dead load*t71,soil load*t105,
                2*fluid load/*t12,*deg, from*5x30(1H-1),5x30(1H-1),
                3*joint*t12,*vepertical*t30,2*(kx9,tx9,kx9,tx9,14x),
                4*(kx9,tx9,14x)
204 FORMAT(2*X,T12,F4.0,T24,23F10.4,5X),3F10.4)
1200 CONTINUE
RETURN
END
SUBROUTINE MATINV(A,B,E)
C
C INVERTS 3 x 3 MATRIX
C
DOUBLE PRECISION A(3,3), B(3,3), DELTA
C
DELTA=A(1,1)*A(2,2)*A(3,3)-A(1,2)*A(2,3)*A(3,1)+A(1,3)*A(2,1)-C
1A(3,2)*A(1,3)*A(2,1)-A(3,1)*A(2,2)*A(1,3)+A(3,3)*A(1,2)-A(3,2)*A
1(1,3)*A(2,1)-A(3,1)*A(2,2)*A(1,3)+A(3,3)*A(1,2)
C
B(1,1)= (A(2,2)*A(3,3)-A(2,3)*A(3,2))/DELTA
B(1,2)=- (A(1,2)*A(3,3)-A(1,3)*A(3,2))/DELTA
B(1,3)= (A(1,2)*A(2,3)-A(1,3)*A(2,3))/DELTA
B(2,1)= (A(2,3)*A(3,1)-A(3,1)*A(3,3))/DELTA
B(2,2)= (A(1,1)*A(3,3)-A(1,3)*A(3,3))/DELTA
B(2,3)= (A(1,1)*A(2,3)-A(1,3)*A(2,3))/DELTA
B(3,1)= (A(1,3)*A(2,2)-A(1,2)*A(2,3))/DELTA
B(3,2)= (A(1,3)*A(3,2)-A(1,2)*A(3,3))/DELTA
B(3,3)= (A(1,3)*A(2,2)-A(1,2)*A(2,3))/DELTA
RETURN
END

SUBROUTINE MATMIP(A,P,C)
C
C GENERATES MATRIX MULTIPLICATION
C
DOUBLE PRECISION A(3,3), B(3,3), C(3,3)
C
DO 10 I=1,3
DO 10 J=1,3
C(J+J)=P(J,J)
DO 10 K=1,3
C(J+J)=C(J+J)+A(J,K)*P(K,J)
10 CONTINUE
RETURN
END

SUBROUTINE MATXCO(X,A,Y)
C
C MULTIPLIES 3X3 MATRIX BY 3X1 MATRIX
C
DOUBLE PRECISION X(3),A(3,3), Y(3)
C
DO 10 I=1,3
Y(I)=X(I,D)
DO 10 K=1,3
Y(I)=Y(I)+A(I,K)*X(K)
10 CONTINUE
RETURN
END
SUBROUTINE PVMAX

LOCATES AND CALCULATES THE THRUSTS, SHEARS AND MOMENTS AT THE 5 CRITICAL DESIGN SECTIONS. THE PROCEDURE FOR FINDING THE EXACT LOCATION OF M/ZVD=3.0 ASSUMES LINEAR SHEAR AND QUADRATIC MOMENT DISTRIBUTION ON A MEMBER.

LOAD FACTORS ARE THEN USED TO CONVERT DESIGN FORCES TO ULTIMATE FORCES.

COMMON/PVM/PVM1(3,3,36),PVM2(3,3,36)
COMMON/RSCALE/RAD1,RAD2,H,Us,V,TH,BETA,H,GAAMAS,GAAC,GMAC,GMIF,DF,
1Fy=FCP,POTU,CIN,FLMV,FLND,DOUT,PRTYPE,NLAY,SPIN,SPOUT,PO,FRC,
1EST,ECO,Y,RAIM,PRAM,EGQD,BETAS,POD,
COMMON/PROP/SI(37),CO(37),ALEN(37)
COMMON/COORD/X(37),Y(37),A(37),R(37)
COMMON/DESIGN/DM(5),OP(5),OV(5),VLOC(5)
COMMON/DEBUG,IPATH
DOUBLE PRECISION PVM1,PVM2
REAL MMAX

L IS INDEX FOR LOCATIONS AT WHICH DESIGN WILL BE CHECKED
L=2
SEARCH FOR MEMBER NEAR INVERT WHERE M/ZVD=3

W=0
DO 300 I=2,36

G=PVM1(1,2+I),PVM1(3,2+I)
C=(PVM1(2+I),PVM1(2+2+I),PVM2(2+1+I)-PVM2(2+2+I-I-1))
F=0.5*(PVM1(1,2+I),PVM1(2+2+I),PVM2(1+1+I-I)-PVM2(1+2+I-I-I))
IF(DABS(C+(C1-3+1)-PVM2(2+3+I-1-I))/2,LT,ABS(C)) GO TO 400

C=C*(PVM1(2+3+I)-PVM2(2+3+I-1-I))/2
G=G*(PVM1(1,3+1)-PVM1(1,3+I-1))

300 CONTINUE

D=PDM*(TH,CIN,DIN/2)
IF (DIN,=EQ,0.0) D=D-PDM=0.04*TH
IF (G,=LT,0.0) GO TO 350
D=PDM*(TH-COUT,DOUT/2)
IF (DOUT,=EQ,0.0) D=D-PDM=0.04*TH

350 IF (ABS(G/C/D),LE,3.0) GO TO 200

G1=G
C1=C
F1=F

300 CONTINUE

200 CONTINUE

J=1-1
J1=1
J2=J

2000 CONTINUE
VUNIT=(C-C1)/AI INT(J)
Q=3.0*D*VUNIT+C1
YL=1.0-G*SQRT(2.0*G*By-2.0*VUNIT*(3.0*D*VUNIT*C1-G1))/VUNIT
OM(L)=G1-C1*YL-0.5*VUNIT*XL*YL
DP(L)=F1+(F-F1)*XL/ALength(J)
DV(L)=C1*VUNIT*YL
VLOC(L)=A(J2)+0.87266*XL/ALength(J)*J1
IF (L.EQ.4) GO TO 2100

C C SEARCH FOR LOCATION OF MAX NEG MOMENT
C
MMAX=0.0
DO 1000 I=10,28
S=PMV1(3*I+1)+PMV1(3*I+2)
IF (ABS(S+PMV1(3*I+1)) .LT. ABS(S)) GO TO 1000
IF (ABS(S) .LT. ABS(MMAX)) GO TO 1000
MMAX=S
GO TO 1300
1000 CONTINUE
IF (ABS(S+PMV1(3*I+1)) .LT. ABS(MMAX)) GO TO 1000
MMAX=S+PMV1(3*I+1)

1300 CONTINUE
OM(3)=G
DV(3)=PMV1(2*I+1)+PMV1(2*I+2)+PMV1(2*I+1)+PMV2(2*I+1)/2
DP(3)=PMV1(2*I+1)+PMV1(2*I+2)+PMV1(2*I+1)+PMV2(2*I+1)/2
VLOC(3)=A(I)
IF (ABS(DM(3)+PMV1(3*I)) .LT. ABS(DM(3))) GO TO 1000
DM(3)=PMV1(3*I)+DM(3)
DP(3)=PMV1(3*I)+PMV1(3*I)+PMV1(3*I)+PMV2(3*I+1)/2+DP(3)
DV(3)=PMV1(2*I+1)+PMV2(2*I+1)/2+DV(3)

1000 CONTINUE
C C SEARCH FOR MEMBER NEAR CROWN WHERE W/VD=3
C
I=36
1400 CONTINUE
G=PMV1(3*I+1)+PMV1(3*I+2)
C=(PMV1(2*I+1)+PMV1(2*I+2)+PMV1(2*I+1)+PMV2(2*I+1)+PMV2(2*I+1))/2
F=0.5*(PMV1(2*I+1)+PMV1(2*I+2)+PMV1(2*I+1)+PMV2(2*I+1)+PMV2(2*I+1))/2
IF (ABS(C*PMV1(2*I+1)+PMV2(2*I+1)/2) .LT. ABS(C)) GO TO 1500
C=C+(PMV1(2*I+1)+PMV2(2*I+1)/2)
G=G+PMV1(3*I+1)
F=F+0.5*(PMV1(1*I)+PMV2(1*I+1))/2

1500 CONTINUE
D=POD*(TH-C1N-C1N/2.)
IF (DIN .LE. G .AND. D .GT. 9.34 * TH) D = D - PEC * (D - 9.34 * TH)
If (G .GT. 0.0) GO TO 1450
D = PEC * (TH - COUT - COUT / 2.0)
IF (DOUT .EQ. D .AND. C .GT. 0) D = C - PCD * 9.34 * TH
1450 CONTINUE
C = APSIC(C)
IF (ABS(G/C/D) .LE. 3.0) GO TO 1600
G1 = G
C1 = C
F1 = F
I = I - 1
GO TO 1450
1600 CONTINUE
L = *
J = 1
J1 = - 1
J2 = J + 1
GO TO 2000
2100 CONTINUE
VLOC(1) = A(1)
VLOC(5) = A(37)
DO 2400 J = 1, 5
DM(J) = DM(J) * FLMV
DV(J) = DV(J) * FLMV
DP(J) = DP(J) * FLMV
2400 CONTINUE
RETURN
END
SUBROUTINE DESIGN

CALCULATES THE REQUIRED STEEL AREAS AT DESIGN LOCATIONS 1, 3 AND 5
BASED ON THE FOLLOWING: FLEXURE
  MINIMUM STEEL FOR FLEXURE
  LIMITING CONCRETE COMPRESSION
  U**O.999 CRACK AT SERVICE LOADS
IT CHECKS FOR RADIAL TENSION AT DESIGN LOCATIONS 1 AND 5 AND
IF REQUIRED CALCULATES THE CIRCUMFERENTIAL EXTENT AND MAXIMUM
SPACING OF STIRRUPS.
IT ALSO CHECKS THE DIAGONAL TENSION SHEAR AT DESIGN LOCATIONS 2
AND 4 AND IF REQUIRED, CALCULATES THE CIRCUMFERENTIAL EXTENT AND
MAXIMUM SPACING OF STIRRUPS.
ALL THE CALCULATED STEEL AREAS ARE PASSED TO THE PRINT SUBROUTINE
THROUGH THE COMMON BLOCK STLAR
A PRINTOUT OF THE ULTIMATE FORCES AT EACH DESIGN SECTION, ALONG
WITH FLEXURE AND SHEAR DESIGN TABLES ARE AVAILABLE WITH AN IDBUC
VALUE GREATER THAN 0.

COMMON/RSCALE/RADI1,RADI2,H,U,V,TH,PETA,HM,GAMAS,GAMAC,GAMAF,DF, 10060
  F,Y,FCP,COUT,CIN,FLMV,FLDV,CIN,DOUT,RTYPE,SLAY,SPIN,SPOUT,PO,FCR,EST  10070
  1.EDCM,DRAM1,RADM2,EQUD,PETAS,POD,FRP,FVP
COMMON/SCALE/IDBUG/IPATH  10040
COMMON/PVM/PVM1(3,3,36),PVM2(3,3,36)  10050
COMMON/DESIGN/DM(5),DP(5),DV(5),VLQR(5)  10100
COMMON/STLAR/AREA1(5),SRATI0(5),S60V(5),AREADT(5),STEAT(5)  10110
1STSPA(5)

DOUBLE PRECISION PVM1, PVM2

AREA1(1) = INSIDE STEEL AT INVERT  10130
AREA1(2) = M/VD=3 NEAR INVERT  10140
  TAKE MAX OF (1) AND (2) FOR INSIDE STEEL AT INVERT.
AREA1(3) = OUTSIDE STEEL  10150
AREA1(4) = M/VD=3 NEAR CROWN  10160
AREA1(5) = INSIDE STEEL AT CROWN  10170
  TAKE MAX OF (4) AND (5) FOR INSIDE STEEL AT CROWN  10180

COMMON/COORD/X(37),Y(37),A(37),R
REAL J(37),N(37),M1(37),MPSI,SLAY,MRAD,NRAD
DIMENSION AREA(5),AREAC(5),RDT(5),CRIND(5)
DIMENSION RLOC(9),GOVERN(27),RAD(2),DA(2)  10200

DATA RAD/RAD1*,RAD2*,/STAG/STAG1*,STAG2*,/RLCC/STAG3*,STAG4* HRT  10230
12H*, 4HSPR*,4HNL*,2H*4HCR*,4H**2H /  10240
DATA GOVERN/GOVERN*,4HOT6*,4HDRK*,4HFLX*,4HURE*,4H*,4HMIN*,  10250
14HSTEE*,4H*,4H0*,4H*,4HC*,4HDRD*,4HEA*,4HFLX*,4HARD*,  10260
14HENV*,4H*,4H*,4HOSTI*,4HRU*,4HOT*,4HT*,4HTIR*,4HUPS*,4HM*,  10270
14HMC*,4HTM*,  10271
DO 901 I=1,5
AREA1(I)=0.0
AREAF(I)=0.0
AREAC(I)=0.0
ROT(I)=0.0
SRATIO(I)=0.0
AREADT(I)=0.0
STEXT(I)=0.0
SGOV(I)=0.0

CONTINUE
w = ATAN(1.0/V)
B1=0.85*0.05*(FCPSI=4.0)
IF (w *GT* 0.85) B1=0.85
IF (w *LT* 0.65) B1=0.65
FCPSI=FPSI*1000
FPSI=F*1000
PI=3.1415926535897
SPMM=(RADMO+U)*2.0

DO 1 L=1,5+2
CASN=1.0
CO1=0.0
FLAY=0.0
DIAM=DIN
IF (L .EQ. 3) DIAM=DOUT
M1=ABS(DM(L))
N1=DP(L)
M1PSI=M1*1000
N1PSI=N1*1000
DH=0.04*TH
IF (DIAM *GT* 0.0) DH=DIAM/2.0
CM=CIN
IF (L .EQ. 3) CM=COUT
D=PI*(TH-CM-DH)
Q=10.2*FCPSI

REQUITRED STEEL FOR FLEXURE
IF(Q*(Q+D-D-N1PSI*(2.0*D-TH)-2.0*M1PSI) *LT* 0.0) GO TO 1111
AREA1(L)=(Q*D-N1PSI-SQRT(Q*(Q+D-D-N1PSI*(2.0*D-TH)-2.0*M1PSI))

AREAF(L)=AREAF(L)
SRATIO(L)=AREA1(L)/(12.0*D)
SGOV(L)=1.0
MINIMUM STEEL AREA FOR FLEXURE

IF (L .EQ. 3) CASMN=0.75
IF (AREA1(L) .GT. CASMN*SPMN**2/65000) GO TO 2
AREA1(L)=CASMN*SPMN**2/65000
APRAT(L)=AREA1(L)
SRATIO(L)=AREA1(L)/(12.*D)
SGOV(L)=2.*

CHECK CONCRETE COMPRESSION

AREAF=5.55E+4*12.*B1*FCPPS1*D/
1(FYPSI*(187000.*FYPSI))=0.75*N1PSI/FYPSI
IF (AREA1(L) .LT. AREAF) GO TO 3

IF (F1*9.5*112*9.5*195) FORMAT(//,1H0,95(1H*))/
17H DESIGN NOT POSSIBLE AT POINT ,11,
12H EXCESSIVE CONCRETE COMPRESSIVE M1=,F1*2.9
195H MAXIMUM STEEL AREA=,F1*3.11H SQ. IN./FT.

IF (F6.3*115*195) AREA1(L)=1.0E26
AREAF(L)=AREA1(L)
RDT(L)=1.0E26
SRATIO(L)=1.0E26
SGOV(L)=0.0
GO TO 1

CHECK RADIAL TENSION AT CROWN AND INVERT

IF (L .EQ. 3) GO TO 990
RADTE=1(M1PSI-0.45*N1PSI*D)/12./D/(RAD12+CIM)/1.2/SQRT(FCPPS1)*FRP
RDT(L)=RADTE
IF (RDT(L) .LE. 1.) GO TO 990
SGOV(L)=4.
K=L/2.*0.75
WRITE(6,850) RLOC(2*K-1),RLOC(2*K-3),RLOC(2*K-5),RAD(2),RAD(2)

SIZE RADIAL TENSION STIRRUPS

AREAT(L)=1.0*(M1PSI-0.45*N1PSI*D)/(D*F1RAD2+CIM))

EXTENT OF RADIAL TENSION STIRRUPS

K=2
IF (L .EQ. 5) K=36
CONTINUE
MRAD=(PV1(3,4*K)+PV1(3,2*K))*FLMV*1000.
NRAD=0.5*(PV1(1,4*K)+PV1(1,2*K))-PV2(1,1*K)-PV2(1,2*K)=1)*FLMV*1000.
IF(L washer*K=1.0)
GO TO 71
MRAD=MRAD*(3.3*PV1(1,3*K)-PV2(1,2*K)=1))]*FLMV*1000.
CONTINUE
RADST=RAD1*VCIN
IF(A(K) GT W)RADST=RAD1*VCIN
RADIAN=(MRAD-C.35*MRAD*D)/((12.*0*(RADST+1.2*SCRT(FCFPSI)))
IF(RADIAN LT 1.0) GO TO 73
K=K+1
IF(L washer*K=5)*K=K-2
GO TO 672
CONTINUE
IF(L washer*K=5)*L=3*K-1
STSPA(L) = 0.7*W
IF(A(K) LT W) GO TO 874
STEXT(L) = (RADM2*W+RADM1*(A(K)-W))*2.
GO TO 990
CONTINUE
STEXT(L) = 2.*RADM2*A(K)
CONTINUE
SIM=SPIN
IF(L washer*3)*SIM=SPOUT
ITMP = IFIX(RTYPE)
GO TO (1000+2000+3000)+ITMP
CONTINUE
GO TO 140
00150 C0=1.0
B2=(C0.5*SIM**2*SIM/NLAY)**(1./3.)*
GO TO 140
2000 C0=1.5
B2=1.0
FLAY=SIM**2*SIM/NLAY
GO TO 140
3000 C0=1.9
B2=(0.5*SIM**2*SIM/NLAY)**(1./3.)*
140 MO=1/FLMV
NO=NPSI/FLMV
D=D/PO
E=4/NO+D-TH/2.
IF(E/D) LT 1.15) GO TO 1
619 J=0.74+0.1*E/D
IF(J G 0.50) J=0.90
P=1./((1.-J*D/E))
IV G LEVEL 21

CONTINUE

\[ c1 = \left( L \cdot S \cdot ( \frac{S}{2} - Th/2) \right) + \frac{E2}{(30000 + \Delta F \cdot D \cdot FCR)} \]

\[ p1 = c1 \cdot B \cdot 12 \cdot T2 \cdot 2 \cdot 2 \cdot S \cdot Q \cdot ( F \cdot P ) / ( 30000 \cdot FCR \cdot D \cdot P ) \]

\[ AREX = 0 \cdot 1 = 0 \cdot 1 \]

IF( C1 .EQ. 1. ) GO TO 625

IF( FLAY .LT. 3. ) GO TO 650

C1 = 1

C2 = 1.9

P2 = C2 \cdot S \cdot FLAY \cdot ( 1 + F )

AREX = AREX \cdot 1

GO TO 625

IF( AREX12 .GT. AREX01 ) AREX01 = AREX12

CONTINUE

CRACK = AREA11 / AREA1(L)

CRACK = CRACK

AREX1(L) = AREA1

SERVICE LOAD CRACK CONTROL INDEX LIMIT

IF( CRACK .LE. 1. ) GO TO 1

IF( SGOV(L) .EQ. 4. ) GO TO 666

SGOV(L) = 3.4

GO TO 667

CONTINUE

SGOV(L) = 3.4

CONTINUE

STELL AREA IS DETERMINED BY CRACK CONTROL

AREA1(L) = AREA1

SRATIO(L) = AREA1(L) / (12 \cdot C \cdot P)

CONTINUE

EVALUATE DIAGONAL TENSION SHEAR

DO 410 K = 2, 4, 2

\[ \Delta X = 0 \]

\[ \Delta Y = 0 \]

\[ \Delta \theta = 0 \]

\[ M1 = \text{ARS}(OM(K)) \]

\[ N1 = \text{DP}(K) \]

\[ VU = \text{ARS}(DV(K)) \]

IF( K = 4 ) GO TO 1051

SRAT = SRATIO(K) \cdot PO / POD

IF( SGOV(K) .LT. 8. ) GO TO 1952

\[ SGOV(K) = 8.0 \]

\[ AREA1(K) = 1 \cdot BE26 \]

\[ SRATIO(K) = 1.0 \cdot BE26 \]
GO TO 810
1051 SRAT=SRATIO(5)*PD/POD
   IF(SGOV(5) .LT. 0) GO TO 1052
   SGOV(K) = 0.0
   AREA(K)=1.0E26
   SRATIO(K)=1.0E26
1052 CONTINUE
   IF (SRAT .GT. 0.02) SRAT=0.02
   MIPSI=M1*1000.
   NIPSI=N1*1000.
   VUPSI=VU*1000.
   DH=D*0.01*TH
   IF (DG+DT .LT. 0) DH=CIN/2.
   D=D-TH-CIN-DH
   FD=1.0 * D/0.1
   IF (FD .GT. 1.25) FD=1.25
   FDN=F*0.5*(N1/6*VU)+SQRT((0.25*(N1/6*VU)**2))
   IF (FDN .LT. 0.75) FDN=0.75
   K=RADM1
   IF (VLOC(K) .LT. W) R=RADM2
   IF (VLOC(K) .LT. PI-W) R=RADM2
   RADST=R+CIN+TH/2.
   IF (FCPPSI .GT. 7000.) FCPPSI=7000.
   FC=1.0+0.02/R
   VC=1.0+6.0*SRAT*SQRT(FCPPSI)*PD/12.0*D*FD*VFP/(FC*FN)
   RDTIN=VUPSI/VC
   IF (KUTIN .LE. 1) GO TO 8
   AREA1(K)=0.1587*FC*FN*VUPSI/(FD*VFP*SQRT(FCPPSI))-0.220952*POD*0
   SGOV(K)=6.
   SRATIO(K)=AREA1(K)/(12.*D*POD)
   IF (SRATIO(K) .LT. 0.02) GO TO 9050
   SGOV(K)=7.
   AREA1(K)=1.0E26
   SRATIO(K)=1.0E26
9050 CONTINUE
   IF (K .EQ. 4) GO TO 9
   WRITE(6,850)RLOC(1),RLOC(2),RLOC(3),DA6(1),CA6(2)
   GO TO 6
9   WRITE(6,850)RLOC(7),RLOC(8),RLOC(9),DA6(1),CA6(2)
6   STIND=2.
   CONTINUE
   C
   CSTIRRUP DESIGN
   C
   IF (STIND .EQ. 0) GO TO 830
   C
   CSTIRRUP DESIGN FOR RADIAL TENSION
   C
AREVRT=1.1*(M1PSI-0.45*N1PSI*D*POD)/(POD*D*RACST)

C

CSTIRRUP DESIGN FOR DIAGONAL TENSION

C

IF ( VC > (.05+SQRT(FCPPSI))*.12+POD*D) VC = 2*SQRT(FCPPSI)
1*12.5*POD*D
AREVDT = 1.1/(POD*D)*MVPSI+FC-POD*VC+AREVRT

880 CONTINUE
AREAUT(K) = AREVDT
N = LCC*1000000
12281

5000 CONTINUE

V1 = (5*(PVM1(1)*V1*N-PVM1(2,2)*N-PVM2(1,1)*N=1)-PVM2(2,2,2,2=N-1))#FLMV
M1 = (PVM1(3,1)*N-PVM1(3,2,2)*N)#FLMV
N1 = (5*(PVM1(0,1)*N-PVM1(1,2,2)*N=1)-PVM2(1,1,1=N-1))#FLMV
IF (DARS(V1)*(0.5*(PVM1(2,3)*N-PVM2(2,3,3,3=N-1))#FLMV).LT. ABS(V1))
1 GO TO 4000
V1 = V1 + (0.5*(PVM2(N=2,3)*N-PVM2(N=2,3,3,3=N-1))#FLMV)
M1 = M1 + PVM1(3,3,3,3=N)#FLMV
N1 = N1 + (0.5*(PVM1(1,3)*N-PVM2(1,1,1,1=N-1))#FLMV)

4000 CONTINUE

DH = DCUT
CM = COUT
IF (M1 LT 0.0) GO TO 6600
CM = CM
DH = DI1

6600 CONTINUE

V1 = ABS(V1)
M1PSI = APS(M1+150000)
N1PSI = N1+150000
V1PSI = V1+150000
IF (DH . LT 0.0) DH = 0.0 + TH
DTH = CM + DH/2
FU = ?*80 + 1.67/D
IF (FD . GT .1.25) FD = 1.25
FN = 0.5 - (N1/V1)**100000
IF (FN . LT .0.75) FN = 0.75
R = RADM1
IF (A(N) LT W) R = RADM2
IF (A(N) . GT . PI-W) R = RADM2
FC = 1.0 + D/2 + R
SRAT = SRATIO(1)*P0/POD
IF (L.GT.4) SRAT = SRATIO(5)*P0/POD
IF (M1 . GT . 0.0) GO TO 6601
FC = 1.0 + D/(2.*R)
SRAT = SRATIO(3)*P0/POD

6601 CONTINUE

VC = (V1 + 63.0*SRAT)*SQRT(FCPPSI)*POD*D*12.*FD*FVP/(FC*FN)
1*4./(M1PSI/(V1PSI*P0*D+1))
IF (AREAC(L) .GE. 0) GO TO 719
AREAC(L) = 0
CRIND(L) = 0
718 CONTINUE
719 WRITE (6,720) VLCTM, AREAF(L), AREAC(L), CRIND(L), ROT(L), AREAI(L),
1SRATIO(L), AREADT(L), STEXT(L), (GOVERN(LF), LF=JF,KF)
11X,F2.1,2X,F9.1,3X,3A4)
701 CONTINUE
WRITE (6,711)
711 FORMAT (/6X, 'SHEAR DESIGN TABLE'/, 1X, '1H-'/,
25X, 'GOVERNING', 4X, 'LOCATION', 5X, 'REINFORCING', 5X, 'RATIO', 6X,
4*IN', 5X, 'INVERT')
DO 702 L=2,4,2
JF=KF-2
VLCTM=VLOC(L)=180.*/PI
WRITE (6,721) VLCTM, AREAI(L), SRATIO(L), AREADT(L), STEXT(L),
1(GOVERN(LF), LF=JF,KF)
721 FORMAT (/5X,F6.2,8X,F7.3,6X,F6.4,4X,F8.1,3X,F9.1,4X,3A4)
702 CONTINUE
950 CONTINUE
END
SUBROUTINE PRINT

ORGANIZES AND PRINTS OUT A PIPE DESIGN SUMMARY SHEET FROM DATA
ACCUMULATED IN THE COMMON BLOCKS StellarCALCULATED STEEL AREAS FROM
SUBROUTINE DESIGN) AND SCALE (DATA ARRAY GENERATED IN SUBROUTINES
READ AND INIT)

THE PRINTOUT INCLUDES THE FOLLOWING:

INSTALLATION DATA
MATERIAL PROPERTIES
LOADING DATA
PIPE DATA
FLUID DATA
REINFORCING DATA

THE OUTPUT IS AVAILABLE WITH ALL ICBUR VALUES.

COMMON/RSCALE/RAD11/RAD2/H1/UL/H1/TH/BETA/MM/AMAS/AMAC/GMAS/DF,
1FY/FCP/COUT/CIN/FLMV/FLN/DIN/DOUT/RTYPE/NLAY/SPIN/SPOUT/P5/FCR
1EST/ECON/RAD1/RAD2/EQUID/Betas/P00
COMMON/STLAP/AREA1(5)/SRAT(5)/SGOV(5)/AREAOT(5)/STEXT(5)
1STPA(5)
INTEGER RTYPE,P

SET UP DESIGN TABLES

WRITE(6,99)
599 FORMAT(1H1)
IF (RAD11*EQ. RAD2) GO TO 10
SPAN=2*(U+RAD11)
RISE=2*(RAD2-V)
WRITE(6,100) SPAN,RISE
100 FORMAT(1H0*F5.1)*12HINCH SPAN X *F5.1*45HINCH PISe REINFORCED ELLIP
ICAL CONCRETE PIPE */71(1H*)
GO TO 2F
2F READMP = RAD11*2.
WRITE(6,2000) RDLMP
2000 FORMAT(1H0*F5.1)*1.4HINCH DIAMETER REINFORCED CONCRETE CIRCULAR PIPE
*/71(1H*)
20 CONTINUE
WRITE(6,6000)
6000 FORMAT(1H0*/*3AH INSTALLATION DATA */71(1H*))
BMP= BETA+180.*3.1415926536
BMP= BETA+180.*3.1415926536
WRITE(6,7000)BMP,AMAS/MM/RMMP/RTMPS
7000 FORMAT(5X*31H HEIGHT OF FILL ABOVE CROWN FT.*29X*F6.2*/5X*16HUNIT
WEIGHT* DCF*44Y*F6.2*/5X*
138HSOIL=STRUCTURE INTRATION COEFFICIENT */22Y*F6.2*/
1/X5Y*2X-REDUCING ANGLE, DEGREES */38Y*F6.2*/
2/X5Y*2C+LOAD ANGLE, DEGREES */48Y*F6.2/
WRITE(6,7001) STEXTM, AREDTX, STSPAM
116MINCHES AT INVENT, /* 5X21STIRRUP DESIGN FACTOR
12H; AV=SDF*SPACING/(STIRRUP YIELD) */ 5X*F6*1.66
15X, 31MAXIMUM STIRRUP SPACING, INCHES, 25X, F6.1
GO TO 103
101 IF (SGOV(2) .LT. 7.) GO TO 102
WRITE(6,6001) ASINV, ASSPR, ASCRN
WRITE(6,7001) STEXTM, AREDTX, STSPAM
GO TO 103
102 IF (SGOV(2) .GT. 6.) GO TO 108
WRITE(6,6001) ASINV, ASSPR, ASCRN
WRITE(6,7001) STEXTM, AREDTX, STSPAM
ASINV=AREA1(2)
103 CREXM = AMAX1(STEXT(4)*0.5, STEXT(5)*0.5, STEXT(6))
CRASTM = AMAX1(STEXT(4), STEXT(5))
CRSTSP = STSPAM(4)
IF (STSPAM(5) .GT. 0.) CRSTSP=MIN1(STSPAM(4), STSPAM(5))
IF (SGOV(5) .LT. 4.) GO TO 124
IF (SGOV(5) .GT. 8.) GO TO 110
WRITE(6,8001) CREXM, CRASTM, CRSTSP
8001 FORMAT(5X, 2HSTIRRUPS REQUIRED OVER *F6.0, *2X, *)
115MINCHES AT CROWN, 5X21STIRRUP DESIGN FACTOR
12H; AV=SDF*SPACING/(STIRRUP YIELD) */ *X*F6.1, 15X
15X31MAXIMUM STIRRUP SPACING, INCHES, 25X, F6.1
GO TO 110
104 IF (SGOV(4) .LT. 7.) GO TO 105
WRITE(6,8001) CREXM, CRASTM, CRSTSP
GO TO 110
105 IF (SGOV(4) .GT. 6.) GO TO 106
WRITE(6,8001) CREXM, CRASTM, CRSTSP
ASCRN=AREA1(4)
IF (SGOV(1) .LT. 4.) GO TO 109
IF (SGOV(2) .LT. 6.) GO TO 109
WRITE(6,9001)
WRITE(6,6001) ASINV, ASSPR, ASCRN
GO TO 110
109 WRITE(6,9002)
9002 FORMAT(5X, 2HSTIRRUPS REQUIRED WITHOUT CROWN STIRRUPS, */)
WRITE(6,6001) ASINV, ASSPR, ASCRN
IF (SGOV(2) .LT. 8.) GO TO 110
WRITE(6,7001) STEXTM, AREDTX, STSPAM
GO TO 110
106 IF (SGOV(1) .LT. 8.) GO TO 110
107 WRITE(6,9001)
106 WRITE(6,6001) ASINV, ASSPR, ASCRN
9001 FORMAT(5X, 2HSTIRRUPS REQUIRED WITHOUT STIRRUPS, *)
WRITE(6,6001) ASINV, ASSPR, ASCRN
GO TO 110
108 CONTINUE
WRITE(6,6001) ASINV, ASSPR, ASCRN
END
Sheet #1: Typical Reinforcing Layout - Side Tapered Single Cell Box Inlets

- **Typical Plan**
  - Go to Appendix G
  - Go to Sheet #2

- **Typical Section - Single Cell Box Inlets**

- **Circumferential Reinforcing Dimensions**

- **U.S. DEPARTMENT OF TRANSPORTATION**
  **FEDERAL HIGHWAY ADMINISTRATION**
  **WASHINGTON, D.C.**

- **Example Standard Plans For Improved Inlets**

- **Typical Reinforcing Layout Side Tapered Single Cell Box Inlets**
  - Go to Appendix G
### Sheet #9: Cantilever Wingwall Designs

#### Wall Dimensions

<table>
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#### Notes
1. The design presented here is based on the Federal Highway Administration's "Standard Cantilever Wingwall Design Manual," 1961. The design may be used as a basis for designing similar structures, but it should be verified by tests. The designer or contractor is responsible for all testing and verification. The owner of the structure or project should be made aware of the material specifications and testing requirements.
2. **U.S. DEPARTMENT OF TRANSPORTATION** Federal Highway Administration

#### Example Standard Plans For Improved Inlets

**CANTILEVER WINGWALL DESIGNS**

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**Sheet #10**

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**Appendix G**
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Table 3-2. Design Force in Two Cell Box Culverts
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Table A-1. Minimum Requirements for Long Span Structures with Acceptable Special Features
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Equation 3.8
Equation 3.9
Equation 3.10
Equation 3.11
Equation 3.12
Equation 3.13
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7. **Author(s)**
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14. **Sponsoring Agency Code**

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    FHWA Co-COTR:
    Robert Wood, HRT-10
    Philip Thompson, HNG-31
    Claude Napier, HNG-32

16. **Abstract**
    This manual provides structural design methods for culverts and for improved inlets. Manual methods for structural analysis are included with a complete design procedure and example problems for both circular and box culverts. These manual methods are supplemented by computer programs which are contained in the Appendices. Example standard plans have been prepared for headwalls, wingwalls, side tapered, and slope tapered culverts for both single and two cell inlets. Tables of example designs are provided for each standard plan to illustrate a range of design parameters.

17. **Key Words**
    Culverts, Improved Inlets, Structural Design, Computer Program

18. **Distribution Statement**
    No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia, 22161.
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Symbols:

$F_c$ factor for effect of curvature on shear strength in curved sections

$F_{cr}$ factor for adjusting crack control relative to average maximum crack width of 0.01 in. when $F_{cr} = 1.0$

$F_d$ factor for crack depth effect resulting in increase in diagonal tension (shear) strength with decreasing $d$.

$F_e$ soil-structure interaction factor that relates actual load on culvert to weight of column of earth directly over culvert

$F_N$ coefficient for effect of thrust on shear strength

$F_{rp}$ coefficient for effect of local materials and manufacturing process on radial tension strength of concrete in precast concrete pipe

$F_{vp}$ coefficient for effect of local materials and manufacturing process on the diagonal tension strength of concrete in precast concrete pipe

$F_1, F_2 ...$ coefficients used in hand analysis of two cell box culverts

$f'_c$ design compressive strength of concrete, lbs/in.$^2$

$f_v$ design ultimate stress in stirrup, lbs/in.$^2$; may be governed by maximum anchorage force that can be developed between stirrup and each inner reinforcement wire or bar, or by yield strength $f_y$, whichever is less

$f_y$ specified tensile yield strength of reinforcement, lbs/in.$^2$

$G_1, G_2 ...$ coefficients used in hand analysis of one cell box culverts

$g, g'$ factor in equations for area of reinforcement for ultimate flexure

$H_e$ height of fill over top of buried culvert, ft
$H_e$  
height of fill over horizontal centerline of buried culvert, ft

$H_h$  
horizontal haunch dimension, in.

$H_v$  
vertical haunch dimension, in.

$h$  
overall thickness of member (wall thickness), in.

$i$  
coefficient for effect of axial force at service load stress

$j$  
coefficient for moment arm at service load stress

$K_1$  
ratio of offset distances for elliptical pipe section ($u/v$)

$L_B$  
horizontal distance from throat section to invert of bend section in a slope tapered inlet, ft (Figure 1-3)

$L_f$  
load factor used to multiply calculated design forces under service conditions to get ultimate forces

$L_1$  
overall length of improved inlet, ft (Figures 1-1 and 1-3)

$L_2$  
length of fall section of slope tapered inlet, ft (Figure 1-3)

$L_3$  
length of bend section of slope tapered inlet, ft (Figure 1-3)

$l$  
span length used in the determination of the critical shear location for uniformly distributed loads, in.

$l_d$  
development length of reinforcing bar, in.

$M$  
moment acting on cross section of width $b$, service load conditions, in.-lbs  
taken as absolute value in design equations, always +

$M_{lb}$  
moment in bottom slab of box section acting on section of width $b$, service load conditions, in.-lbs
Maximum midspan moment acting on cross section of width \( b \), in.-lbf

Moment at corner of box section acting on section of width \( b \), service load conditions, in.-lbf

Moment in side wall of box section acting on section of width \( b \), service load conditions, in.-lbf

Ultimate moment acting on cross section of width \( b \), in.-lbf

Axial thrust acting on cross section of width \( b \), service load condition (+ when compressive, - when tensile), lbs

Axial thrust acting on cross section of width \( b \), of top, side or bottom slab, respectively, service load condition (+ when compressive, - when tensile), lbs

Ultimate axial thrust acting on cross section of width \( b \), lbs

Number of layers of reinforcement in a cage (1 or 2) utile (ductile)

Ratio of area of tension reinforcement to area of concrete section, Eq. 4.25

Soil pressure at bottom of pipe or box section that reacts soil, fluid, and dead load, lbs/in./section width \( b \)

Fluid pressure acting on inside of pipe, lb/in./section width \( b \)

Soil pressure at invert of pipe section, lb/in./section width \( b \)

Soil pressure at crown of pipe section, lb/in./section width \( b \)

Lateral soil pressure on box section, lbs/in./section width \( b \)

Soil pressure at top of pipe or box section, lb/in./section width \( b \)
\( p_v \) vertical pressure applied to box section, lb/in./section width \( b \), load

\( r_m \) radial distance to centerline of pipe wall, in.

\( r_s \) radius to inside reinforcement, in.

\( r_l \) radius to inside of side section of elliptical pipe, in. (Figure 1-2)

\( r_2 \) radius to inside top and bottom section of elliptical pipe, in. (Figure 1-2)

\( S \) slope of culvert barrel, ft/ft

\( S_{df} \) stirrup design factor used in Equation 4.34 lb/in./section width \( b \)

\( S_f \) slope of fall, ft/ft

\( S_0 \) slope of natural channel, ft/ft

\( s \) circumferential spacing of shear or radial tension stirrup reinforcement, in.

\( s_{2} \) spacing (longitudinal) of circumferential reinforcement, in.

\( T \) taper of side wall of improved inlet (Figure 1-1)

\( T_{B}, T_{S}, T_{T} \) thickness of bottom, side and top slabs of box culvert, respectively, in.

\( T_c \) thickness of centerwall of two-span box section, in.

\( t_b \) clear cover distance from tension face of reinforcing to tension face of concrete, in.

\( u \) horizontal offset distance from center of elliptical pipe to center of rotation of radius \( r_l \), in. (Figure 1-2)

\( V \) shear force acting on cross section of width \( b \), service load condition, lbs (taken as absolute value in design equations, always +).
$V_b$ basic shear strength of cross-section of width $b$, where $M/V \phi_y d < 3.0$, lbs

$V_c$ general shear strength of cross-section of width $b$, where $M/V \phi_y d < 3.0$, lbs

- $x$

$V_u$ ultimate shear force acting on cross section of width $b$, lbs

$v$ vertical offset distance from center of elliptical pipe to center of rotation of radius $r_2$, in. (Figure 1-2)

$W$ width of weir crest, ft

$W_e$ total weight of earth on unit length of buried structure, lbs/ft

$W_f$ total weight of fluid inside unit length of buried structure, lbs/ft

$W_p$ weight of unit length of structure, lbs/ft

$w$ uniformly distributed load used in the determination of the critical shear location, lbs/in./section width $b$

$x$ horizontal coordinate, in.

$x_{dc}$ distance from point of maximum midspan moment to point where $M/V \phi_y d = 3.0$, in.

$y$ vertical coordinate, in.

$y_e$ vertical coordinate from top of box section (Figure 2-1), in.

$z$ longitudinal coordinate, in.

$Z_{mt}$, $Z_{mb}$ distance from bend point in top and bottom slab reinforcing, respectively, to point of zero moment, in.
\[ \alpha_{\text{max}}, \alpha_{\text{min}} \] ratio of lateral to vertical soil pressure on box culvert

\[ \beta \] AASHTO coefficient used to compute design loads

\[ \beta_1 \] angle over which earth load is applied to buried pipe, degrees

\[ \beta_2 \] bedding angle over which soil support is provided to pipe to resist applied loads, degrees.

\[ \gamma_c \] unit weight of concrete, lb/ft\(^3\)

\[ \gamma_f \] unit weight of internal fluid, lbs/ft\(^3\)

\[ \gamma_s \] unit weight of soil, lbs/ft\(^3\)

\[ \theta \] angle from vertical to a design section, degrees; in circular pipe, this is the angle from the invert; in elliptical pipe, this is the angle from a vertical line through the center of rotation of \( r_1 \) or \( r_2 \)

\[ \phi_f \] flexure strength reduction factor for variability in material strengths or manufacturing tolerances

\[ \phi_v \] shear strength reduction factor for variability in material strengths or manufacturing tolerances
References


2. Design Handbook - Concrete Pipe, American Concrete Pipe Association, Vienna, VA, 1980


