Structural Design Manual for Improved Inlets & Culverts

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

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Chapter 1 : FHWA-IP-83-6

Introduction

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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.

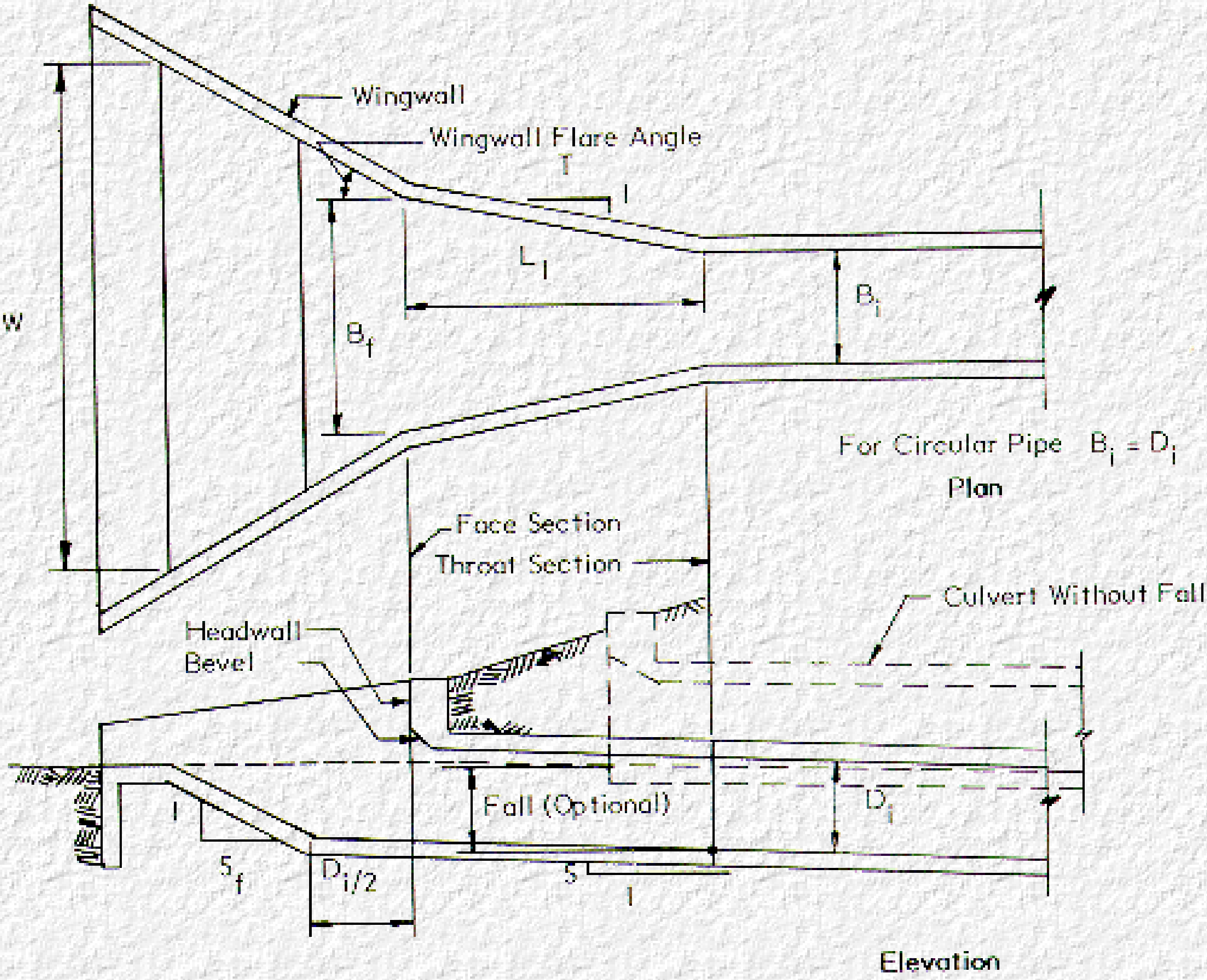


Figure 1-1. Side Tapered Box Section or Pipe Inlet Geometry

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 r1, and r2 and the offset distances u and v.

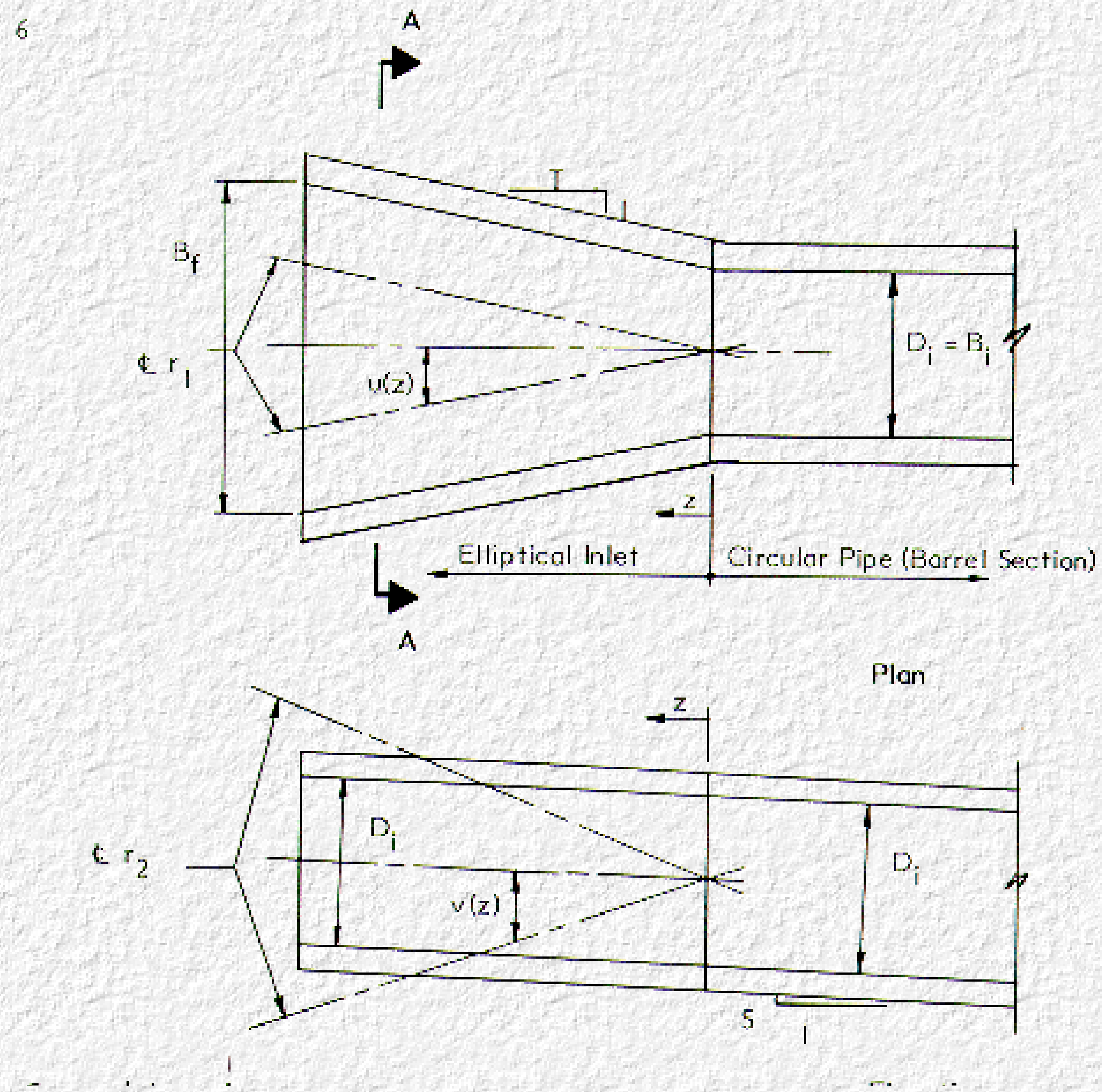
One method of defining the geometry of an inlet along its length in terms of the taper, T. the coordinate z, the ratio u/v, and the diameter at the throat, D_j, is shown in Figure 1-2. The u/v ratio can be selected by the designer and will typically vary from 0 to 1. A ratio near 1.0 will produce top 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 θ, 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 θ varies for each of the four circular segments, as well as along the longitudinal axis of the inlet.

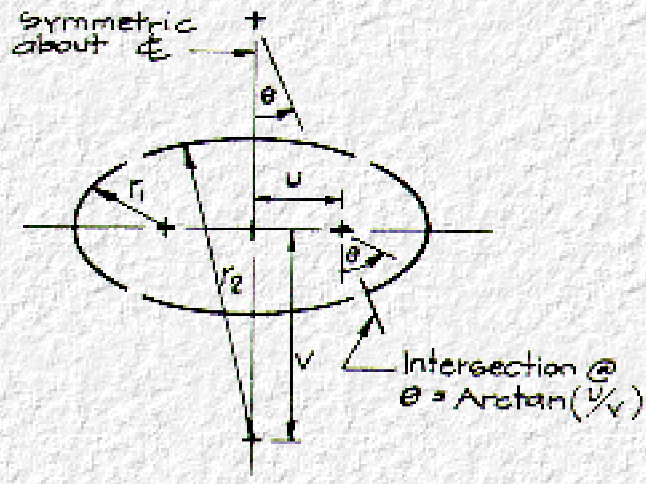
1.3.4 Side Tapered Inlet with Fall

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 L_2 and L_3 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.





Section A-A

Elevation

$$K_1 = \frac{u}{v} \text{ (ratio is constant)}$$

$$r_1(z) = \frac{\frac{z}{T}\left[\frac{1}{K_1} - \sqrt{1 + \left(\frac{1}{K_1}\right)^2}\right]}{1 + \frac{1}{K_1} - \sqrt{1 + \left(\frac{1}{K_1}\right)^2}} + \frac{D_i}{2}$$

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

$$v(z) = \frac{u(z)}{K_1}$$

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

Figure 1-2. Additional Geometry for Side Tapered Pipe Inlets

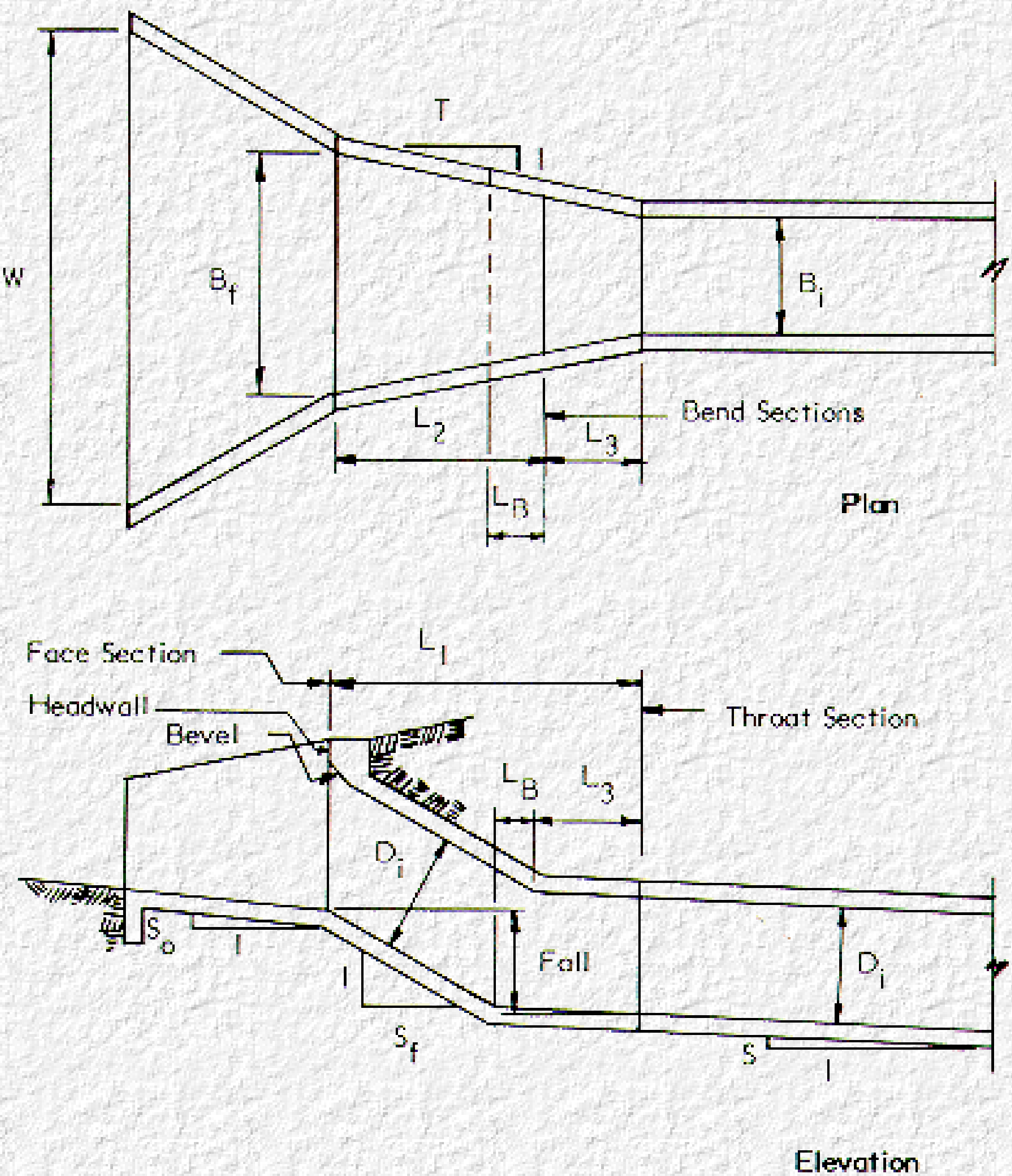


Figure 1-3. Slope Tapered Box Section Inlets

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.

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Chapter 2 : FHWA-IP-83-6
Loads on Inlet Structures

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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:	$W_p = 3.3\,h\,(D_i + h)$	Equation 2.1
Elliptical (Figure 1-2):	$W_p = 4.2\left\{\left(r_2 + \frac{h}{2}\right)\arctan\left(\frac{u}{v}\right) + \left(r_1 + \frac{h}{2}\right)\left[1.57 - \arctan\left(\frac{u}{v}\right)\right]\right\}$	Equation 2.2
Box Sections	$W_p = 1.04\left[(B_i + 2T_s)(T_T + T_B) + 2(D_i T_s + H_H H_V)\right]$	Equation 2.3

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:	$W_f = 0.34\,D_i^2$	Equation 2.4
Elliptical:	$W_f = 0.87\left\{r_2^2 \arctan\left(\frac{u}{v}\right) + r_1^2\left[1.57 - \arctan\left(\frac{u}{v}\right)\right] - uv\right\}$	Equation 2.5
Box Sections	$W_f = 0.43\,(B_i \times D_i)$	Equation 2.6

2.3 Earth Loads

Earth load in lbs/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 γ_s is in lbs/cu. ft.

$$W_e = F_e \gamma_s B_o H_e / 12 \quad \text{Equation 2.7a}$$

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.

$$W_e = F_e \gamma_s B_o \left(H_e + D_o / 72\right) / 12 \quad \text{Equation 2.7b}$$

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.

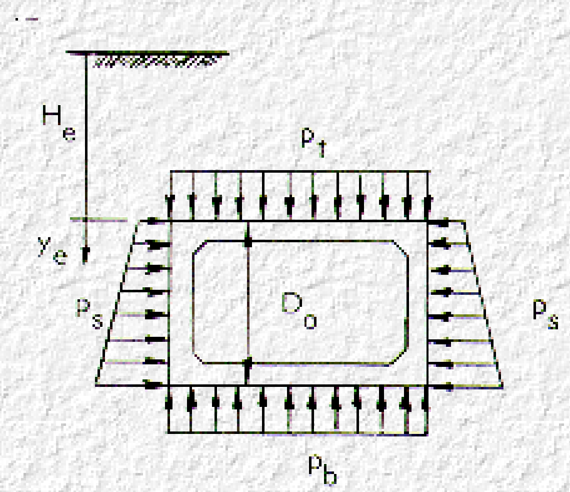
2.4 Construction Loads

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.



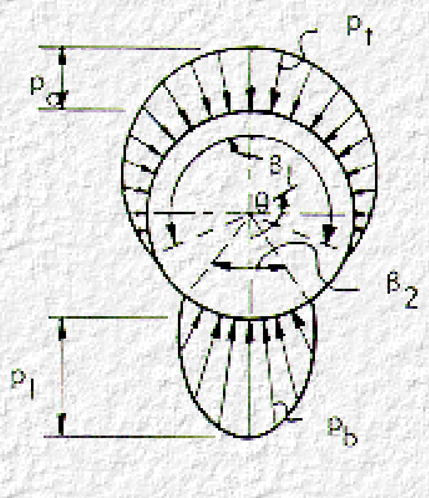
a. Box Culverts

$$p_t = p_b = F_e \gamma_s H_e \qquad \text{Equation 2.8}$$

$$p_s = \alpha \gamma_s (H_e + y_e) \qquad \text{Equation 2.9a}$$

or approximately

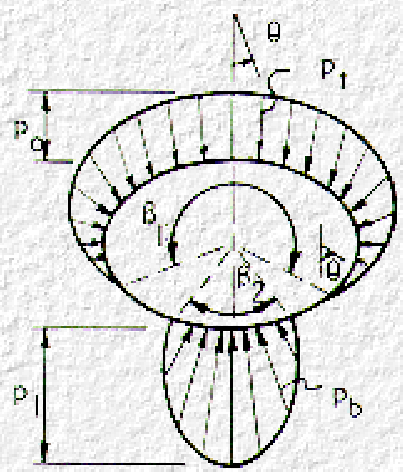
$$p_s = \alpha \gamma_s \left(H_e + \frac{D_o}{2} \right) \qquad \text{Equation 2.9b}$$



b. Circular Sections

$$p_t = p_o \cos\frac{2\pi}{\beta_1}(\pi-\theta) \qquad \text{Equation 2.10}$$

$$p_b = p_1 \cos\frac{2\pi\theta}{\beta_2} \qquad \text{Equation 2.11}$$



c. Elliptical Sections

p_t and p_b from Equation 2.10 and Equation 2.11 above

See Notations sections for definition of θ for elliptical sections.

Figure 2-1. Distribution of Earth Pressure on Culverts

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 a 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, β_1, at the top of the pipe, and a radially applied bedding pressure over a specified bedding angle, β_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 sides of the pipe as the bedding angle, β_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.

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Manual Methods for Structural Analysis

Go to Chapter 4

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.

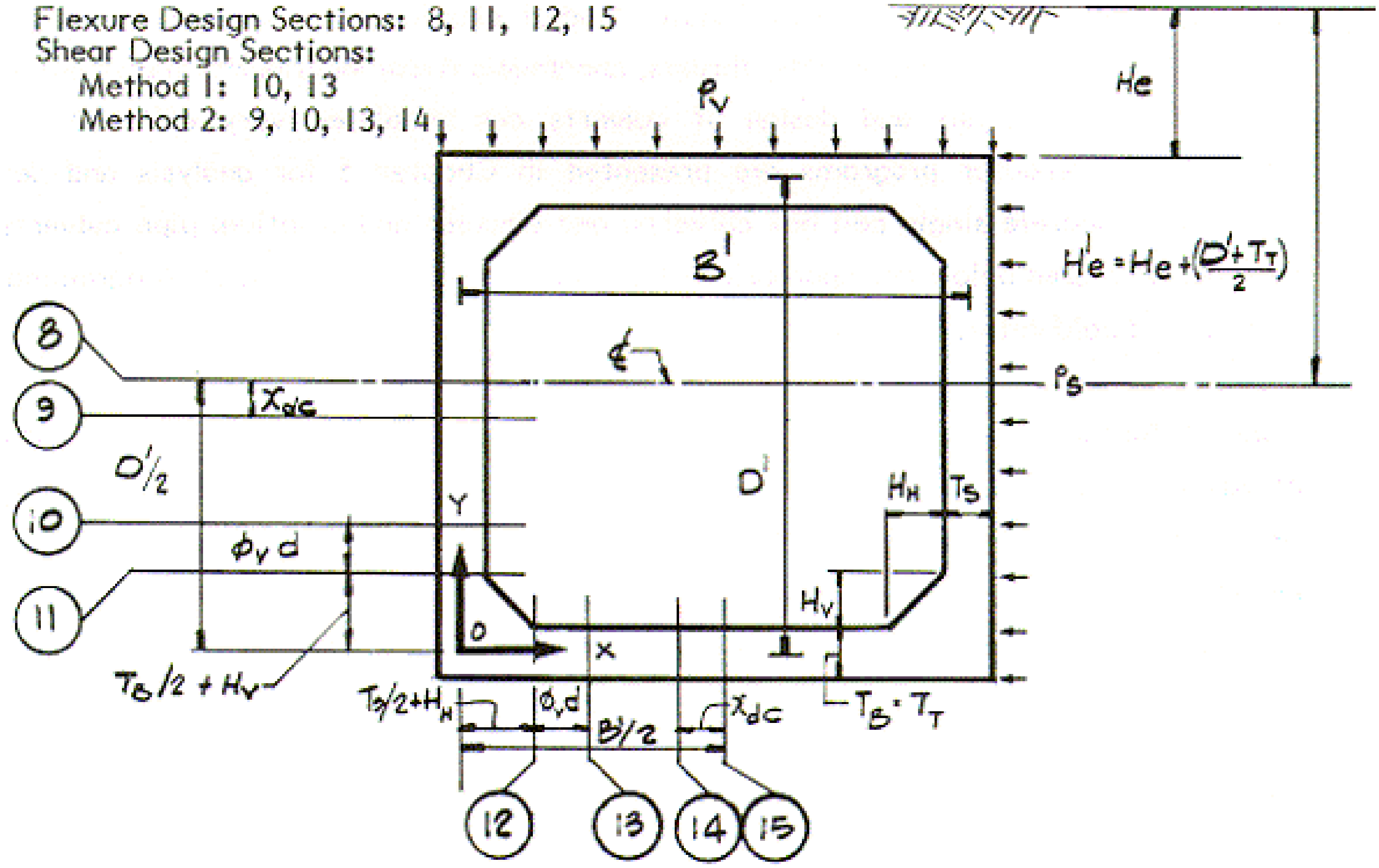
None of the computer or hand analysis methods presented in this manual account for effects of variation in wall stiffness caused by cracking. This is consistent with current general reinforced concrete design practice. The reduction in stiffness produced by cracking becomes more significant when soil-structure 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.

Table 3-1. Design Forces in Single Cell Box Culverts



Design Pressures

$p_v = \gamma_s H_e F_e + \gamma_c T_T + 2\gamma_c D' T_S / B'$	Equation 3.1
$p_{s\,max} = \alpha_{max} \gamma_s H'_e$	Equation 3.2
$p_{s\,min} = \alpha_{min} \gamma_s H'_e - \gamma_f \dfrac{(D' - T_T)^2}{2D'}$	Equation 3.3

Design Constants

$G_1 = \dfrac{T_T^3 D'}{T_S^3 B'}$	Equation 3.4

$G_2 = \frac{9H_H^5}{D'B'T_S^3}\left(1 - \frac{T_T}{D'}\right)$	For boxes with no haunches($H_H = H_V = 0$) $G_2 = G_3 = G_4 = 0$	Equation 3.5
$G_3 = \frac{2H_H^3}{B'}\left(\frac{1}{T_T^2} + \frac{T_T}{T_S^3}\right)$		Equation 3.6
$G_4 = \frac{6H_H}{B'}\left(1.02 - \frac{3T_T}{B'} + \frac{T_T^3}{T_S^3}\right)$		Equation 3.7
Design Moments		
Moment @ origin: $\begin{Bmatrix} M_{o\,max} \\ M_{o\,min} \end{Bmatrix} = -\frac{p_v B'^2}{12}\left(\frac{1 - 1.5G_3 + 0.5G_4}{1 + G_1 - G_3}\right) - \begin{Bmatrix} p_{s\,max} \\ p_{s\,min} \end{Bmatrix}^* \left[\frac{D'^2}{12}\left(\frac{G_1 - G_2}{1 + G_1 - G_3}\right)\right]$		Equation 3.8
Moment in top amd bottom slab:	$M_b(x) = \begin{Bmatrix} M_{o\,max} \\ M_{o\,min} \end{Bmatrix}^* + 0.5p_v x(B'-x)$	Equation 3.9
Moment in sidewall:	$M_s(y) = \begin{Bmatrix} M_{o\,max} \\ M_{o\,min} \end{Bmatrix}^* + \begin{Bmatrix} p_{s\,max} \\ p_{s\,min} \end{Bmatrix}^* 0.5y(D'-y)$	Equation 3.10
Design Shears		
Shear in top and bottom slab:	$V_b(x) = p_v\left(\frac{B'}{2} - x\right)$	Equation 3.11
Shear in widewall:	$V_s(y) = p_{s\,max}\left(\frac{D'}{2} - y\right)$	Equation 3.12
Design Thrusts		

Thrusts in bottom slab:	$\begin{Bmatrix} N_{b\,max} \\ N_{b\,min} \end{Bmatrix} = \begin{Bmatrix} p_{s\,max} \\ p_{s\,min} \end{Bmatrix}^{*} \dfrac{D'}{2}$	Equation 3.13
Thrust in sidewall:	$N_s = \dfrac{p_v B'}{2}$	Equation 3.14

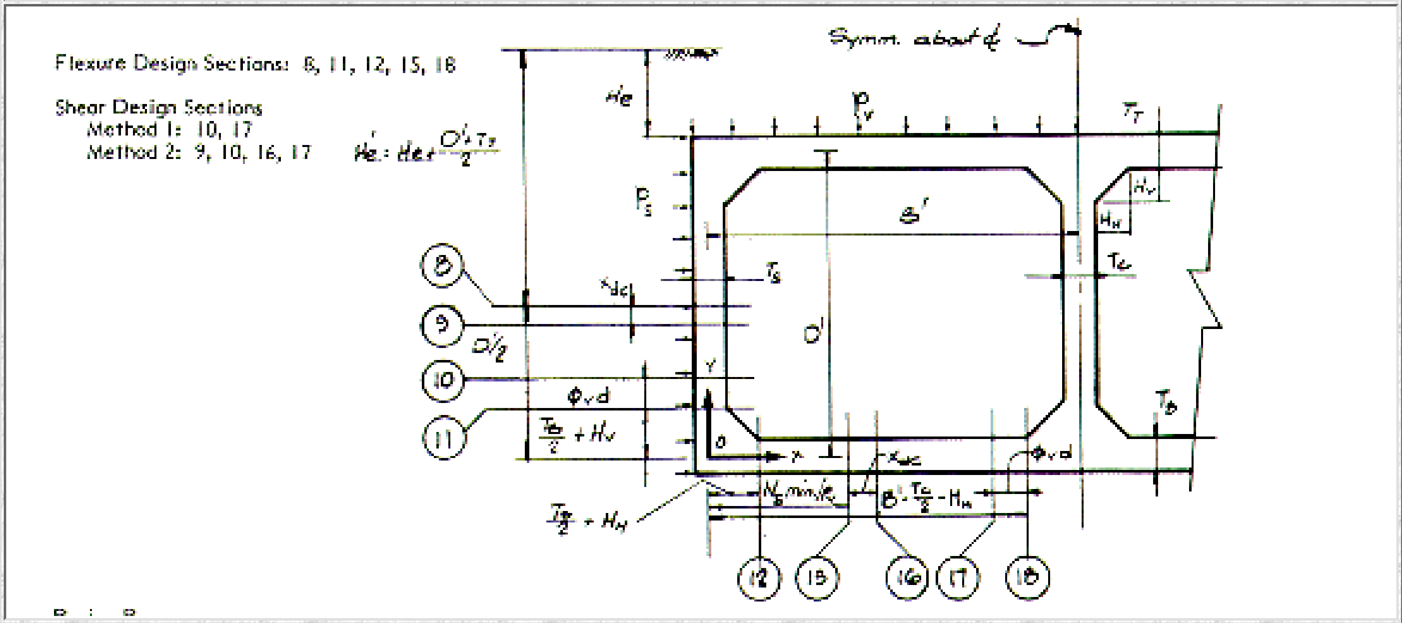
*Use p_{smax} or p_{smin} as follows:

- Locations 8, 9 and 10 use p_{smax} only.
- Locations 11, 12 and 13 check both p_{smax} and p_{smin} for governing case.
- Locatioins 14 and 15 use p_{smin} only.

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 $A_{s\,min}$ for sidewall inside reinforcing, and do not check shear at Section 9.

Table 3-2. Design Force in Two Cell Box Culverts



Design Pressures

$p_v = \gamma_s H_e F_e + \gamma_c T_T + \dfrac{\gamma_c D'(T_s + 0.5T_c)}{B'}$	Equation 3.15
$p_{s\,max} = \alpha_{max} \gamma_s H'_e$	Equation 3.16

$p_{s\,min} = \alpha_{min}\gamma_s H'_e - \gamma_f \dfrac{(D'-T_T)^2}{2D'}$		Equation 3.17
Geometry Constants		
$F_1 = \dfrac{B'^2}{T^2}\left(\dfrac{B'}{3T}-1\right)+\dfrac{3}{2}\left(\dfrac{B'}{T}-1\right)$	For boxes with standard haunches	Equation 3.18
$F_2 = \dfrac{1}{T^3}\left(\dfrac{D'}{2}+B'\right)-\dfrac{3}{T^2}$		Equation 3.19
$F_3 = \dfrac{B'}{T^2}\left(\dfrac{B'}{2T}+1\right)$		Equation 3.20
$F_4 = \dfrac{B'^3}{T^3}-\dfrac{4B'^2}{T^2}+\dfrac{9B'}{T}-9$		Equation 3.21
$F_5 = \dfrac{D'}{2T^3}-\dfrac{9}{T^2}+\dfrac{9}{D'T}-\dfrac{9}{D'^2}+\dfrac{3B'}{T^3}$		Equation 3.22
$F_6 = \dfrac{T_T^3 D'}{T_S^3 B'}$	For boxes without haunches	Equation 3.23
Design Moments		
Moments at Origin:		
$\left\{\begin{matrix} M_{o\,max} \\ M_{o\,min} \end{matrix}\right\} = M_{ov} + \left\{\begin{matrix} M_{os\,max} \\ M_{os\,min} \end{matrix}\right\}$		Equation 3.24
Boxes with standard haunches and uniform wall thickness ($H_H=H_V=T_T=T_S=T_B$):		
$M_{ov} = -\dfrac{P_v}{8}\left(\dfrac{B'F_4F_3-4F_1^2}{F_2F_1-F_3^2}\right)$		Equation 3.25a
$\left\{\begin{matrix} M_{os\,max} \\ M_{os\,min} \end{matrix}\right\} = \left\{\begin{matrix} P_{s\,max} \\ P_{s\,min} \end{matrix}\right\}^* \dfrac{D'^2}{8}\left(\dfrac{F_5F_1-3F_3^2}{3(F_2F_1-F_3^2)}-1\right)$		Equation 3.26a
Boxes without haunches ($H_H=H_V=0$, $T_T=T_B \neq T_S$):		
$M_{ov} = \dfrac{P_v B'^2}{12}\left(\dfrac{1}{1+2F_6}\right)$		Equation 3.25b
$\left\{\begin{matrix} M_{os\,max} \\ M_{os\,min} \end{matrix}\right\} = -\left\{\begin{matrix} P_{s\,max} \\ P_{s\,min} \end{matrix}\right\}^* \dfrac{D'^2}{6}\left(\dfrac{F_3}{1+F_6}\right)$		Equation 3.26b

Moment on bottom slab:	
$M_b(x) = \begin{Bmatrix} M_{o\,max} \\ M_{o\,min} \end{Bmatrix}^* - 0.5 p_v x^2 + \begin{Bmatrix} N_{s\,max} \\ N_{s\,min} \end{Bmatrix}^* x$	Equation 3.27
Moment in sidewall:	
$M_s(y) = \begin{Bmatrix} M_{o\,max} \\ M_{o\,min} \end{Bmatrix}^* + \begin{Bmatrix} P_{s\,max} \\ P_{s\,min} \end{Bmatrix}^* 0.5y(D'-y)$	Equation 3.28
Design Shears	
Shear on bottom slab:	
$V_b(x) = N_{s\,min} + p_v x$	Equation 3.29
Shear in sidewall:	
$V_s(y) = p_{s\,max}\left(\frac{D'}{2} - y\right)$	Equation 3.30
Design Thrusts	
Thrust in bottom slab:	
$\begin{Bmatrix} N_{b\,max} \\ N_{b\,min} \end{Bmatrix} = \begin{Bmatrix} p_{s\,max} \\ p_{s\,min} \end{Bmatrix} \frac{D'}{2}$	Equation 3.31
Thrust in side slab; boxes with haunches:	
$\begin{Bmatrix} N_{b\,max} \\ N_{b\,min} \end{Bmatrix} = \frac{0.5 p_v F_1 + M_{ov} F_2}{F_3} - \begin{Bmatrix} M_{os\,max} \\ M_{os\,min} \end{Bmatrix}^* \frac{F_3}{F_1}$	Equation 3.32a
Thrust in side slab, boxes without haunches:	
$\begin{Bmatrix} N_{b\,max} \\ N_{b\,min} \end{Bmatrix} = \frac{p_v B'}{4}\left(\frac{2+3F_6}{1+2F_6}\right) + \begin{Bmatrix} p_{s\,max} \\ p_{s\,min} \end{Bmatrix} \frac{D'^2}{4B'}\left(\frac{F_6}{1+2F_6}\right)$	Equation 3.32b

*Use p_{smax} or p_{smin} as follows:

- Locations 8, 9 and 10 use p_{smax} only.
- Locations 11, 12 and 13 check both p_{smax} and p_{smin} for governing case.
- Locations 14 and 15 use p_{smin} only.

Notes:

1. For boxes with standard haunches and all walls of the same thickness ($H_H=H_V=T_T=T_S=T_B$) 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 $T_T=T_B \neq T_S$) use Equation 3.25b, Equation 3.26b, and Equation 3.32b.
3. See Equation 4.22 for determination of x_{dc}.
4. If M_8 is negative, use A_{smin} for sidewall inside reinforcing, and do not check shear at Section 9.
5. Geometry constants F1 through F5 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:

$$M = (c_{m1} W_e + c_{m2} W_p + C_{m3} W_f) B'/2 \qquad \text{Equation 3.33}$$

$$N = c_{n1} W_e + c_{n2} W_p + c_{n3} W_f \qquad \text{Equation 3.34}$$

$$V = c_{v1} W_e + c_{v2} W_p + c_{v3} W_f \qquad \text{Equation 3.35}$$

Figure 3-1 provides coefficients for earth load analysis of circular pipe with 3 loading conditions β_1 = 90°, 120° and 180°. In all cases, β_2 = 360° - β_1. These load conditions are normally referenced by the bedding angle, β_2. The 120° and 90° 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, β_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.

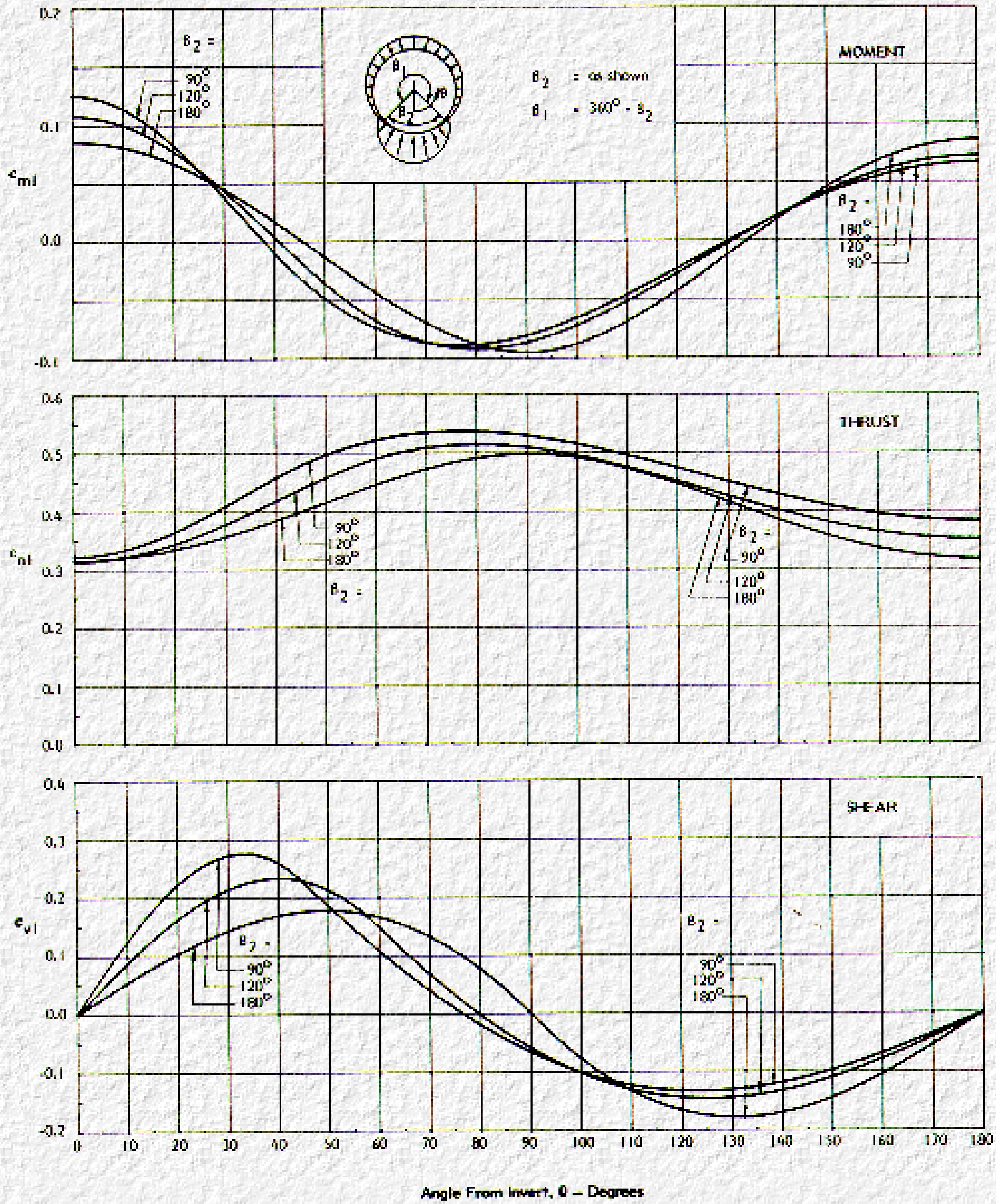


Figure 3-1. Coefficients for M, N, and V due to Earth Load on Circular Pipe

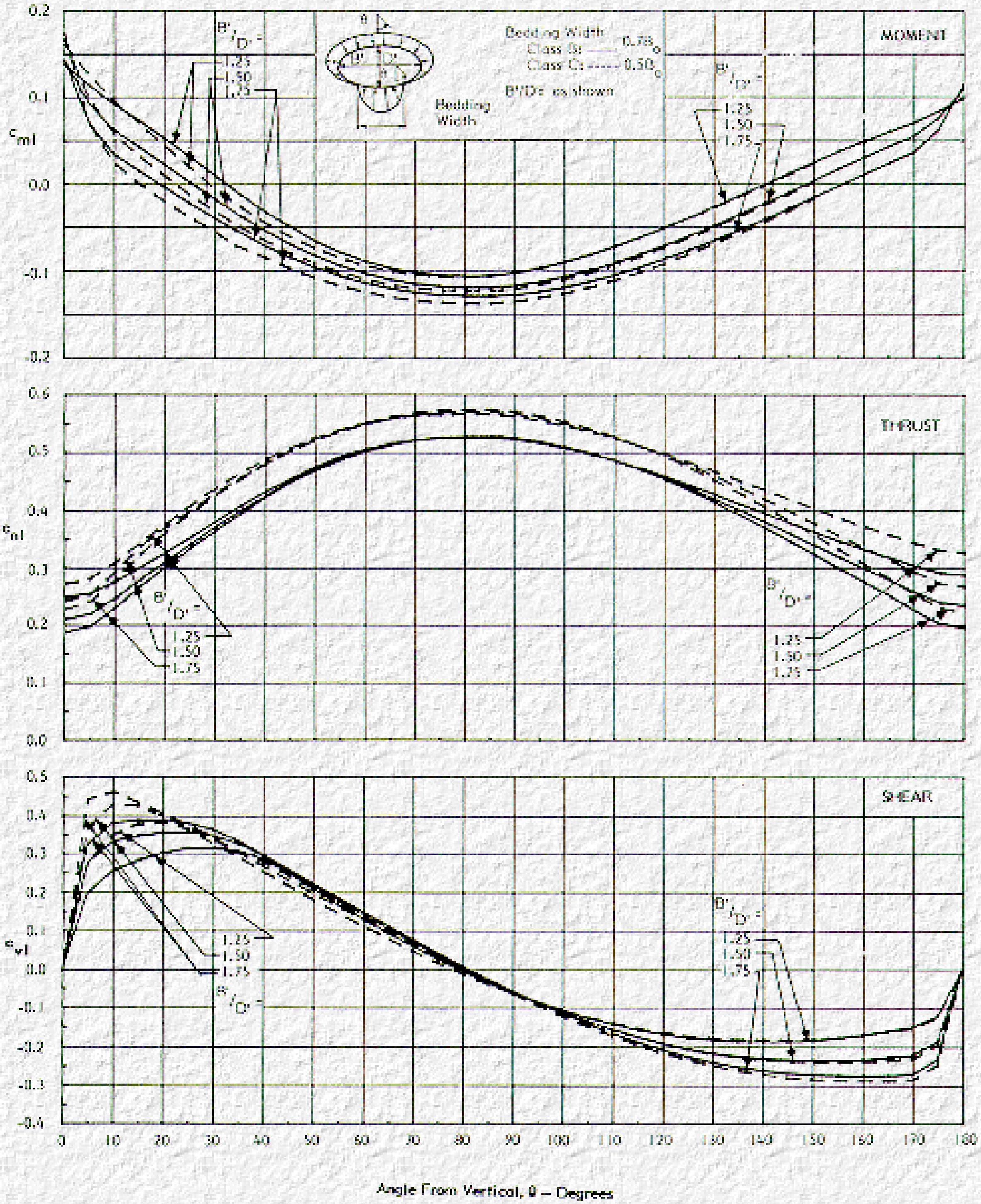


Figure 3-2. Coefficients for M, N, and V due to Earth Load on Elliptical Pipe with U/V = 0.1

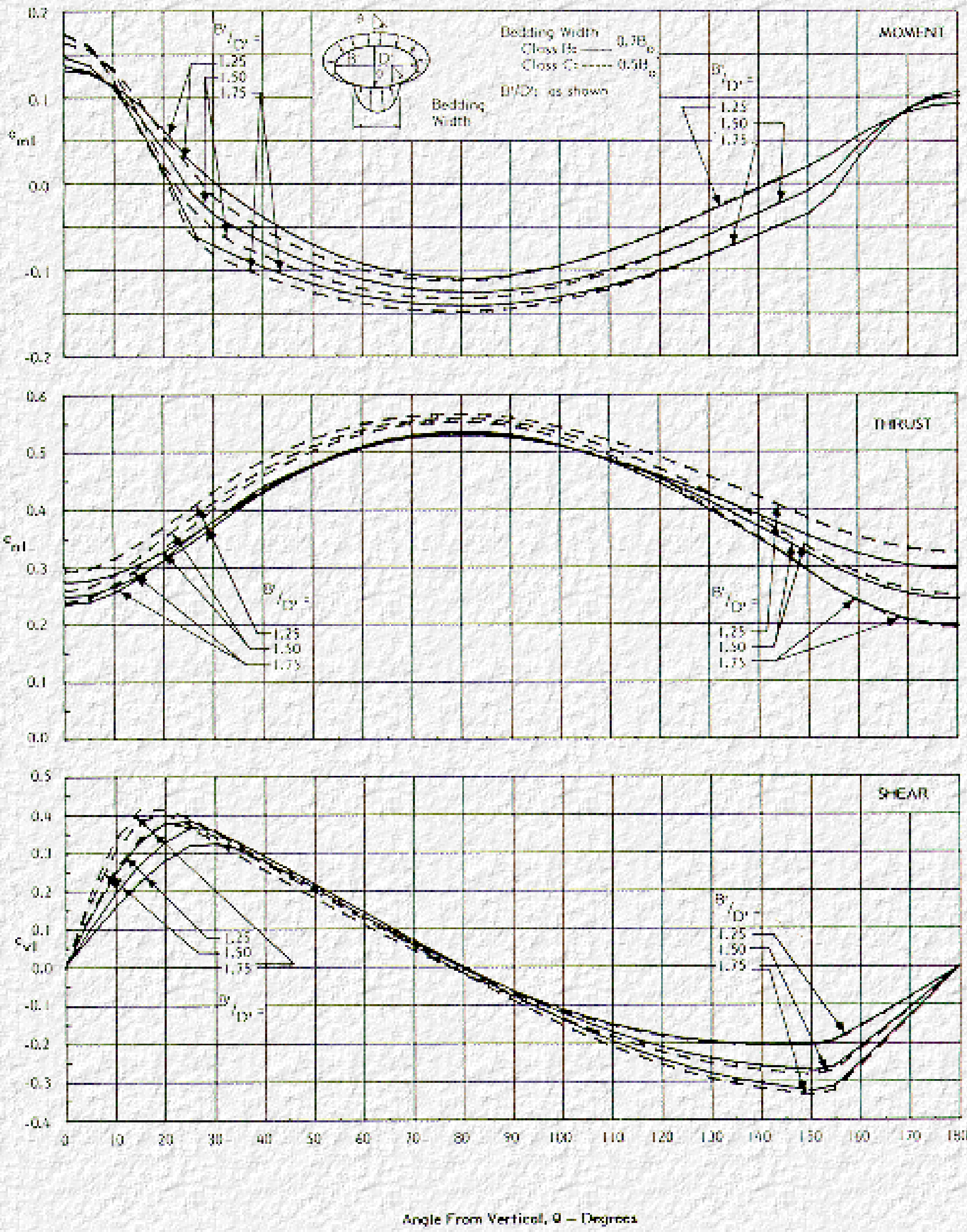


Figure 3-3. Coefficients or M, N and V due to Earth Load on Elliptical Pipe with U/V = 0.5

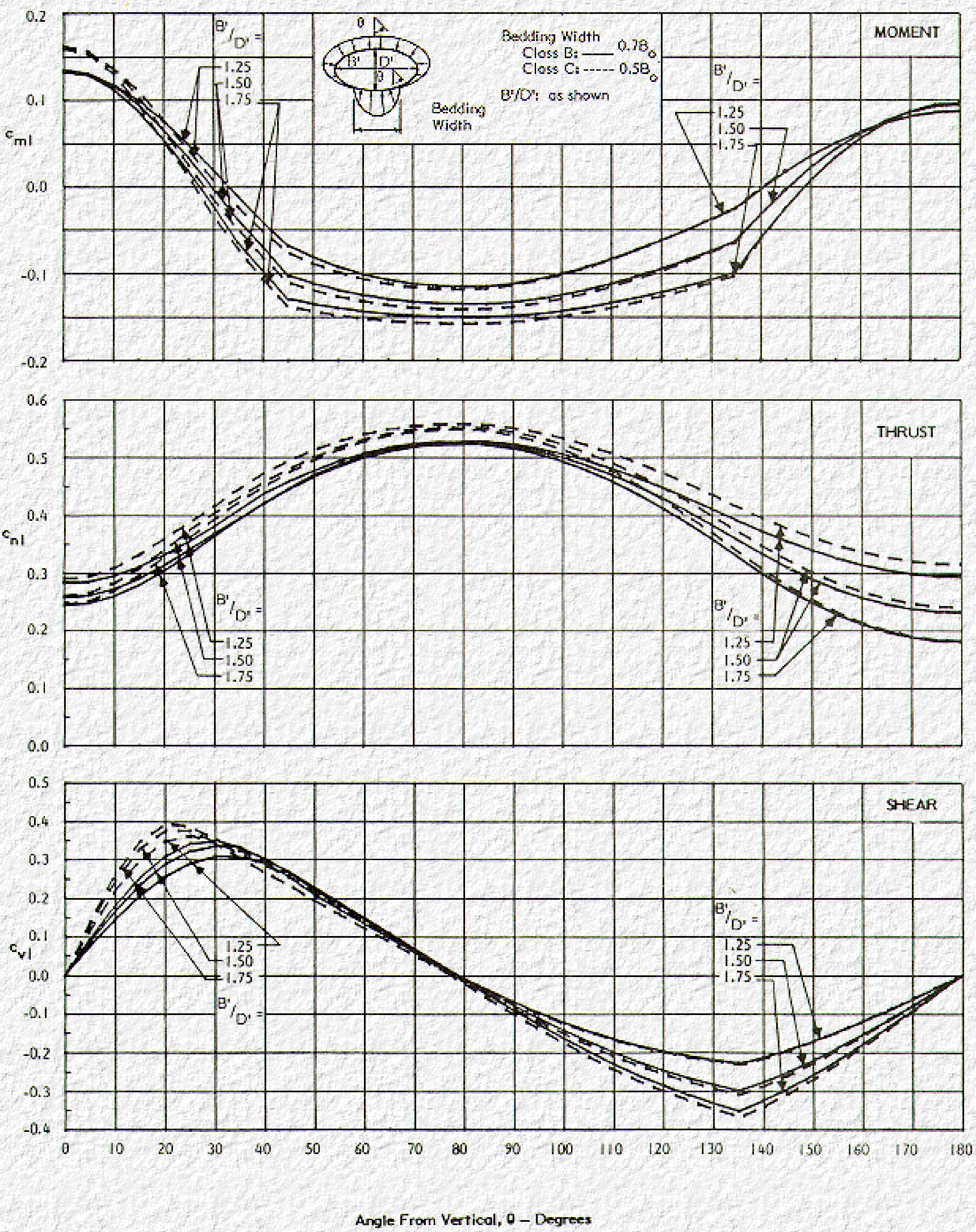


Figure 3-4. Coefficients or M, N and V due to Earth Load on Elliptical Pipe with U/V = 1.0

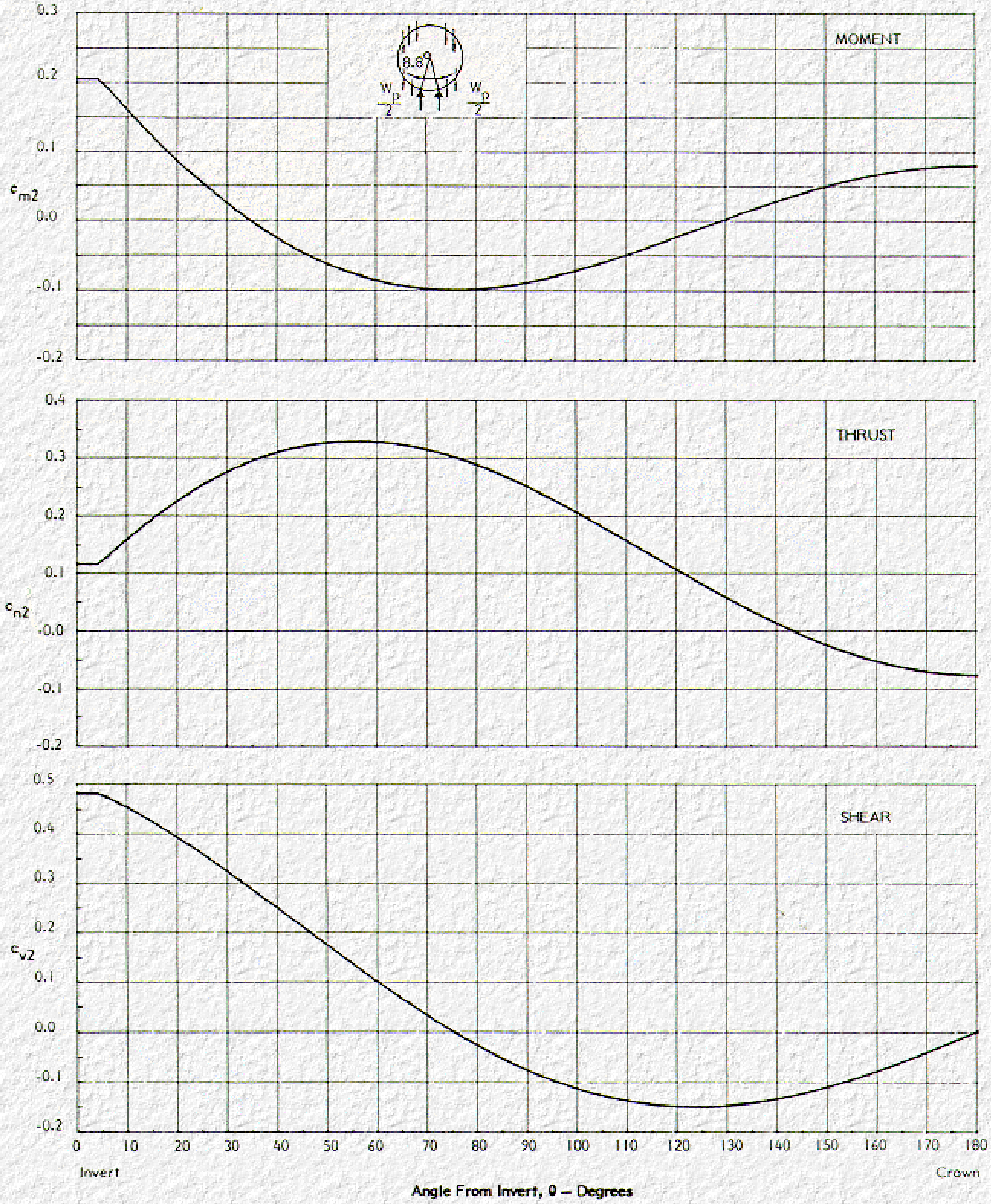


Figure 3-5. Coefficients or M, N and V due to Pipe Weight on Narrow Support

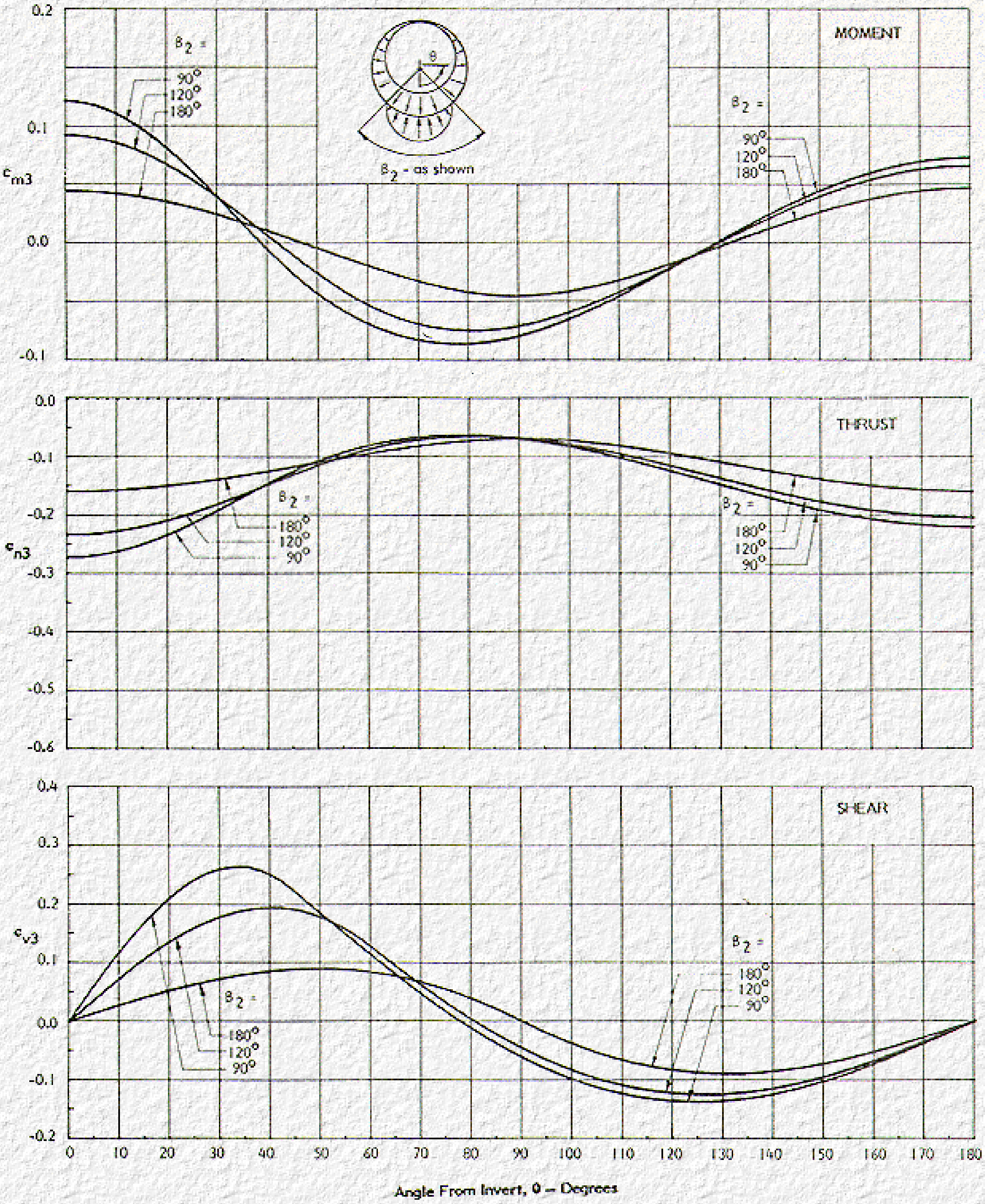


Figure 3-6. Coefficients or M, N and V due to Water Load on Circular Pipe

[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.

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Structural Design of Inlet Structures

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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.

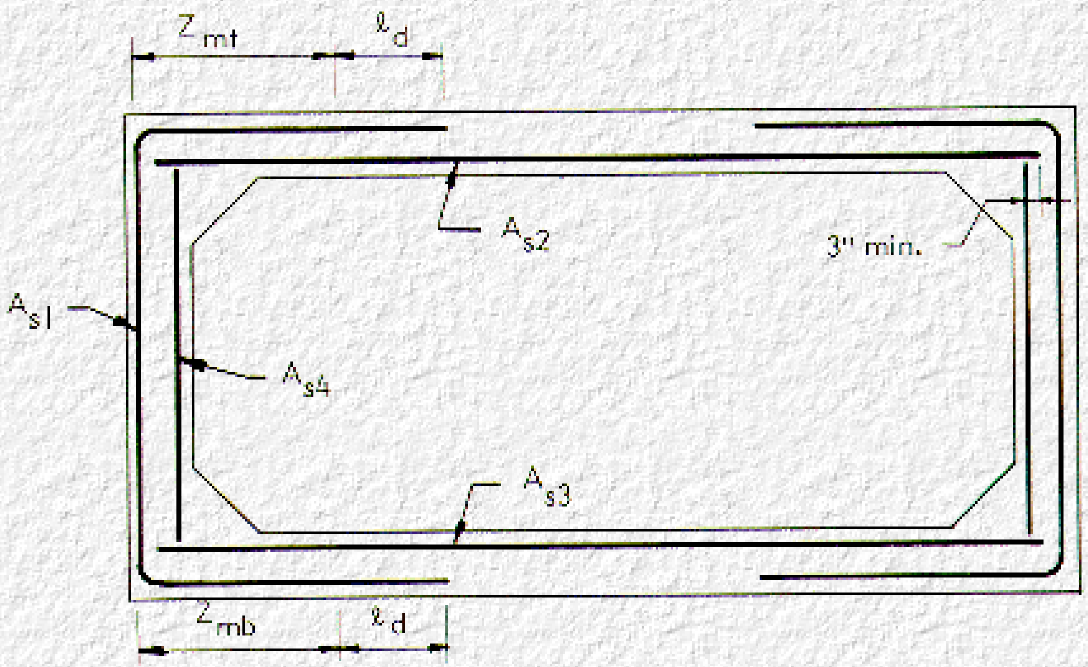
4.1 Reinforced Concrete Design

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).

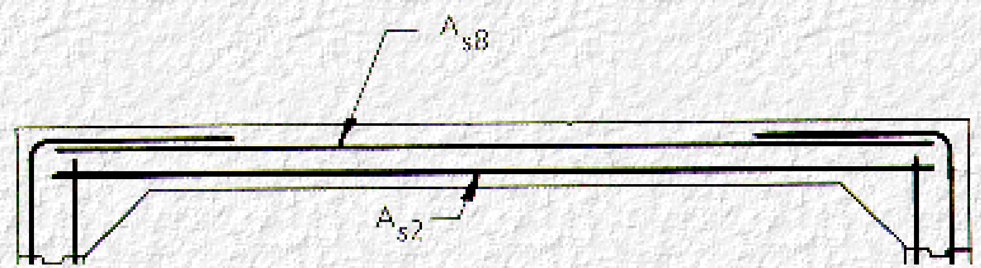
Typically, the design process involves a determination of reinforcement area for strength and crack control at various governing locations in a slice and checks for shear strength and certain reinforcement limits.

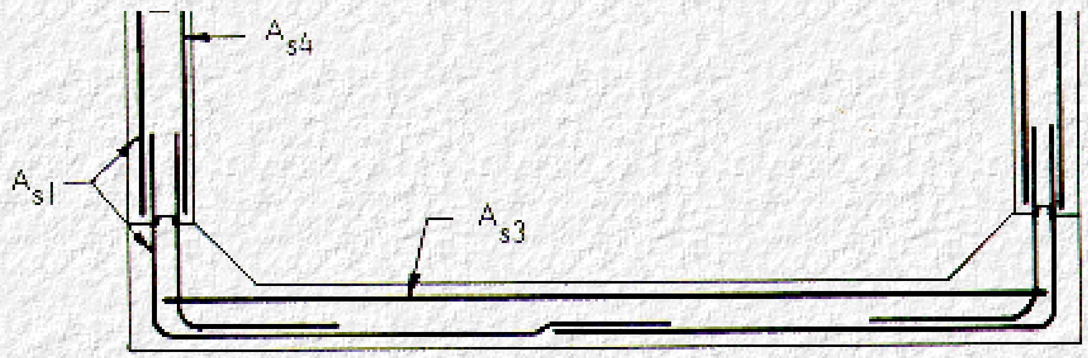
The number and location of sections at which designers must size and reinforce and check shear strength will vary with the shape of the cross section and the reinforcing scheme used. Figure 4-1. shows typical reinforcing schemes for precast and cast-in-place one cell box sections. The design sections 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 dvd 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.



a. Precast box sections

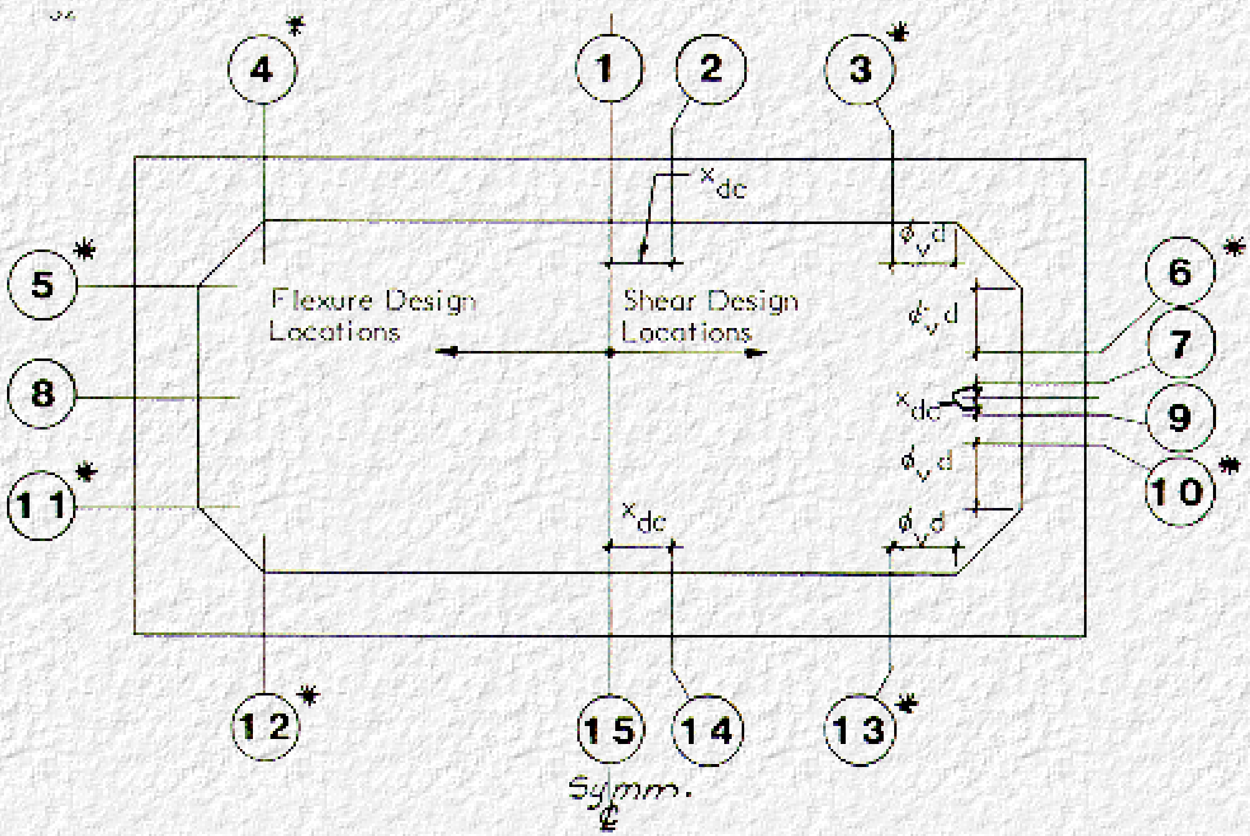




b. Cast-in-place box sections

Note: Reinforcing Designations Correspond To Those Used In ASTM C789 And C850

Figure 4-1. Typical Reinforcing Layout for Single Cell Box Culverts



Flexure Design Locations:

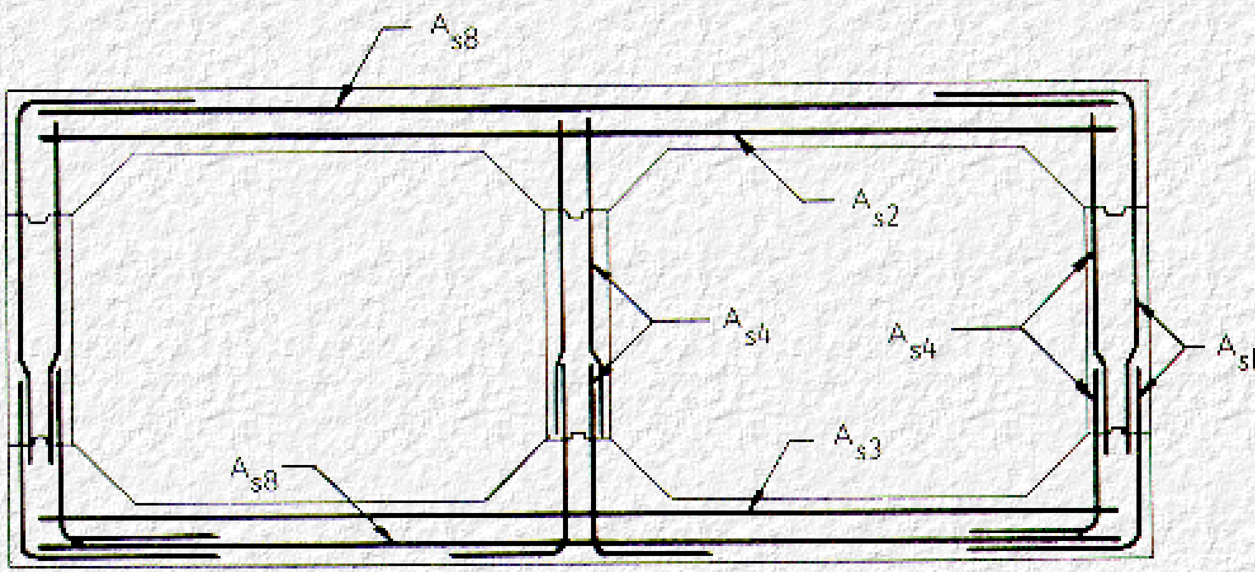
Steel Area	Precast	Cast-In-Place
A_{s1}	4, 5, 11, 12	5, 11, 12
A_{s2}	1	1
A_{s3}	15	15
A_{s4}	8	8
A_{s8}	-	4

Shear Design Locations:

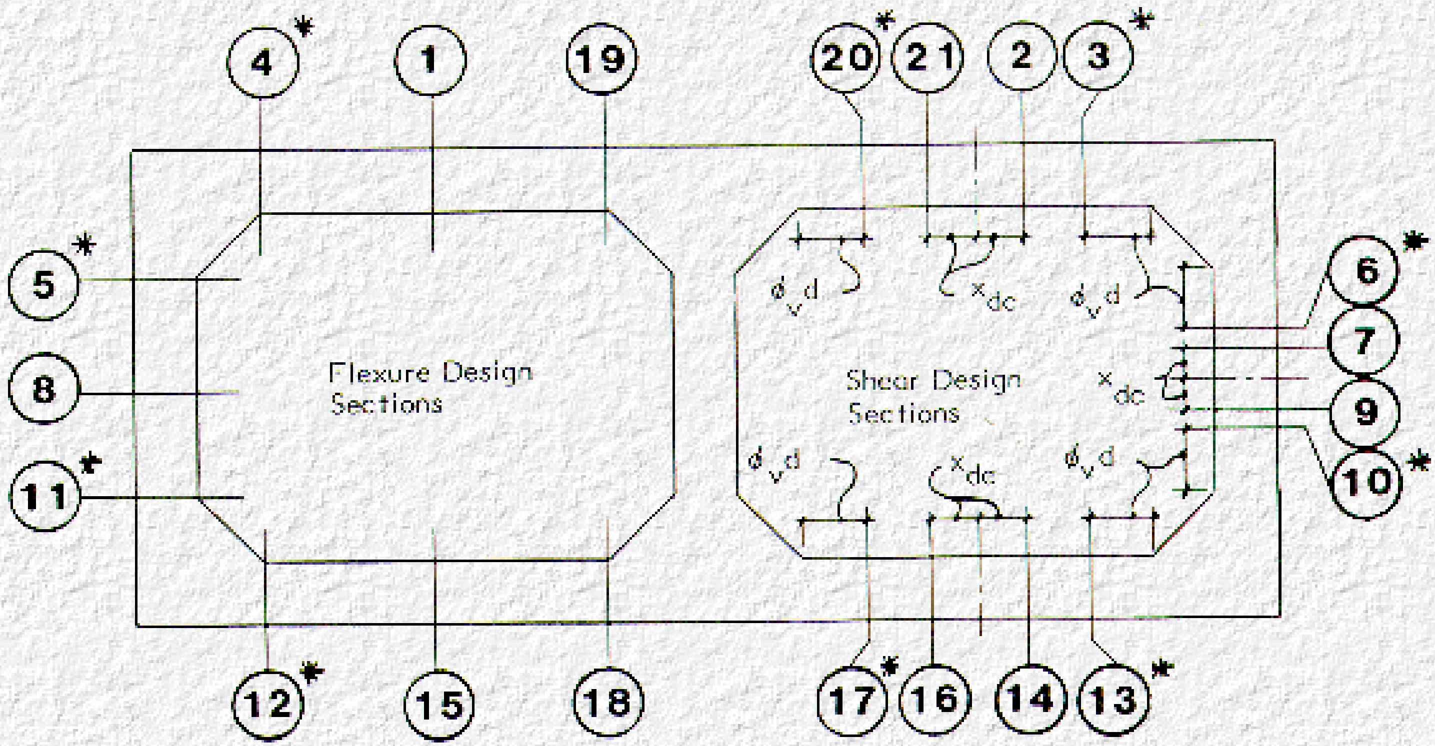
Method 1: 3, 6, 10, 13
Method 2: 2, 3, 6, 7, 9, 10, 13, 14

*Note: For method 2 shear design, any distributed load within a distance $\phi_v d$ 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



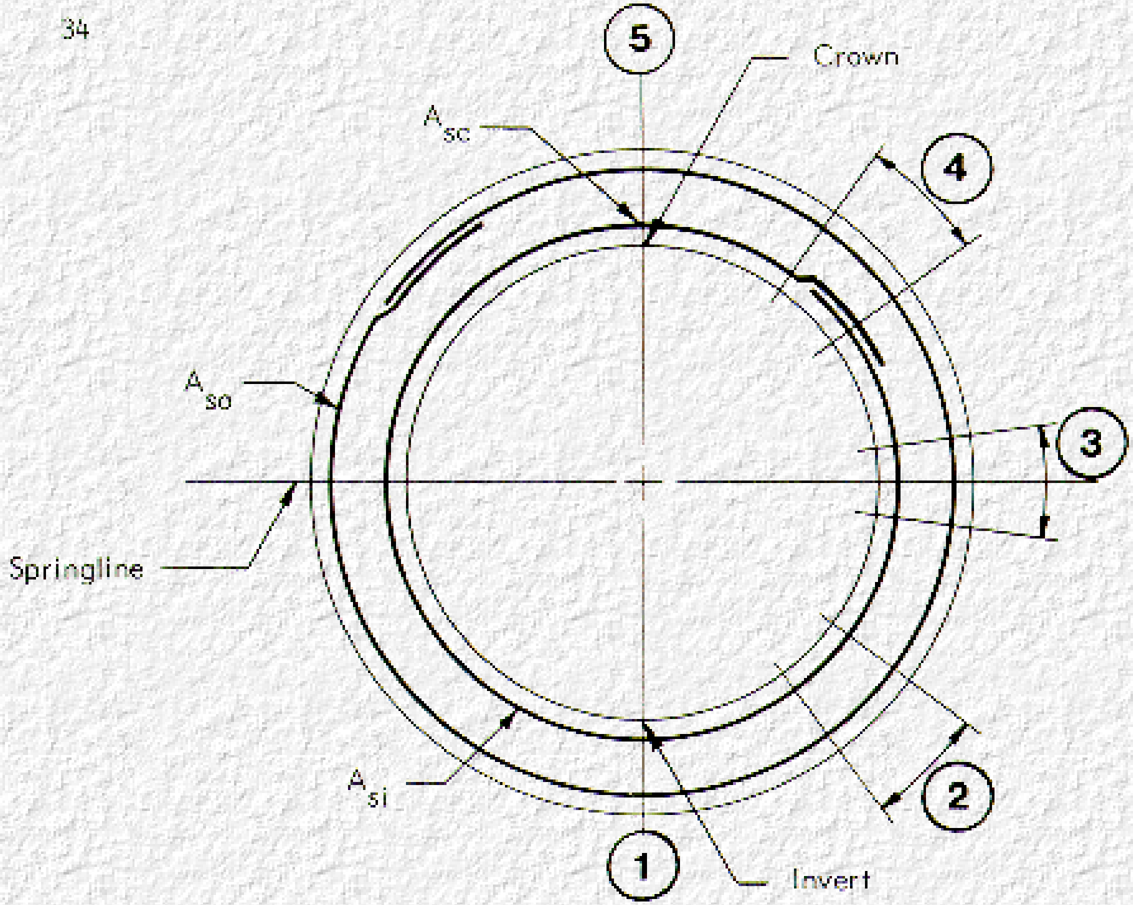
a. Typical reinforcing layout: cast-in-place two cell box culvert



*See note, Figure 4-2

b. Design locations: two cell box culverts

Figure 4-3. Typical Reinforcing Layout and Location of Design Sections for Shear and Flexure Design of Two Cell Box Culverts



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 $M/V\phi_v d = 3.0$

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.

Figure 4-4. Typical Reinforcing Layout and Locations of Critical Sections for Shear and Flexure Design in Pipe 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 crocked 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:

$$M_u = L_f M \qquad \text{Equation 4.1}$$

$$N_u = L_f N \qquad \text{Equation 4.2}$$

$$Vu = L_f V \qquad \text{Equation 4.3}$$

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 β 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 x 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, ϕ, 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 ϕ factors given in the 1981 AASHTO Bridge Specification.

Table 4-1. Strength Reduction Factors in Current AASHTO Standard Specifications for Highway Bridges (4)

	Box Culverts		Pipe Culverts
	Precast (a)	Cast-in-Place (b)	Precast (c)
Flexure	1.0 (d)	0.9	1.0 (d)
Shear	0.9	0.85	0.9

. Section 1.15.7b.

b. Section 1.5.30

c. Currently recommended by AASHTO Rigid Culvert Liaison Committee for adoption by AASHTO Bridge Committee.

d. 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 ϕ = 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 Flexurol 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

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

$$g = 0.85bf'_c \qquad \text{Equation 4.5}$$

d may be approximated as

$$d = 0.96h - t_b \qquad \text{Equation 4.6}$$

(b) Minimum Reinforcement

For precast or cast-in-place box sections:	min. $A_s = 0.002\ bh$	Equation 4.7
For precast pipe sections:		
For inside face of pipe:	min. $A_s = (B_i + h)^2/65{,}000$	Equation 4.8
For outside face of pipe:	min. $A_s = 0\ 75\ (B_i + h)^2/65{,}000$	Equation 4.9
For elliptical reinforcement in circular pipe	min. $A_s = 2.0\ (B_i + h)^2/65{,}000$	Equation 4.10
For pipe 33 inch diameter and smaller with a single cage of reinforcement in the middle third of the pipe wall:	min. $A_s = 2.0\ (B_i + h)^2/65{,}000$	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):

$$\text{max. inside } A_s f_y = 1.33 b\, r_s \sqrt{f'_c}\, F_{rp} \qquad \text{Equation 4.12}$$

Where r_s is the radius of the inside reinforcement = $(D_i + 2t_b)/2$ 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, DL_{ut}, using the criteria in ASTM C655 (AASHTO M242) "Standard Specification for Reinforced Concrete D-Load Culvert, Storm Drain and Sewer Pipe."

$$F_{rp} = \frac{\left(DL_{ut} + 9W_p / D_i\right)}{1230\, r_s d \sqrt{f_c'}} D_i \left(D_i + h\right) \qquad \text{Equation 4.13}$$

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:

$$\max A_s f_y = \frac{5.5\times10^4 g'\phi_f d}{(87{,}000+f_y)} - 0.75N_u \qquad \text{Equation 4.14}$$

where:

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

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

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:

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

where:

F_{cr} = crack control factor, see note c.

e	=	$\frac{M}{N} + d - \frac{h}{2}$	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 e/d	Equation 4.18

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

i	=	$\dfrac{1}{1 - \dfrac{jd}{e}}$	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_l and C_l for the type reinforcements noted below are:

Type Reinforcement (RTYPE)	B_1	C_1
1. Smooth wire or plain bars	$\sqrt[3]{\dfrac{0.5t_b^2 s_\ell}{n}}$	1.0
2. Welded smooth wire fabric, 8 in.max. spacing of longitudinals	1.0	1.5
3. Welded deformed wire fabric, deformed wire, deformed bars, or any reinforcement with stirrups anchored thereto	$\sqrt[3]{\dfrac{0.5t_b^2 s_\ell}{n}}$	1.9

Notes:

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

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

b. For type 2 reinforcement having $\left(t_b^2\ s_\ell\right)/n > 3.0$, 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 than 0.01 inches at $F_{cr} = 1.0$.

If the calculated F_{cr} is greater than the limiting F_{cr}, increase A_s by the ratio: calculated Fcr/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, $\phi_v V_c$ must be greater than the ultimate shear force, V_u, computed at a distance $\phi_v d$ from the face of a support, or from the tip of a haunch with inclination of 45 degrees or greater with horizontal:

$$\phi_v V_c = 3\phi_v \sqrt{f'_c}\, bd \qquad \text{Equation 4.20}$$

$$V_u \le \phi_v V_c \qquad \text{Equation 4.21}$$

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 $M/V\phi_v d = 3.0$, and for boxes, it occurs either where $M/V\phi_v d = 3.0$ or at the face of supports (or tip of haunch). 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 in calculating the ratio $M/V\phi_v d$.

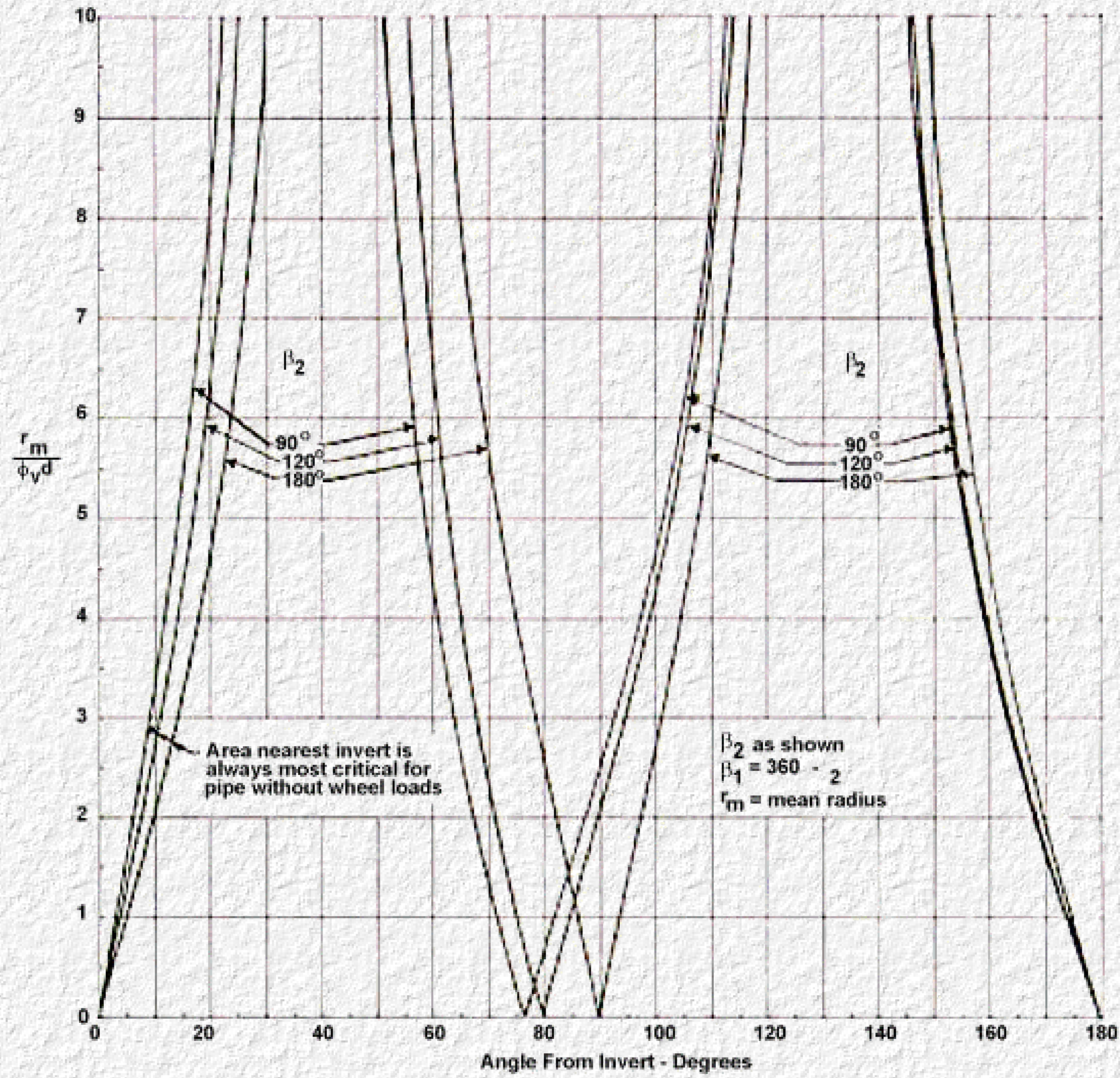


Figure 4-5. Critical Shear Location in Circular Pipe for Olander (7) Earth Pressure Distribution

(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 $M/V\phi_V d$ = 3.0 in a circular pipe can be determined from Figure 4-5, based on the parameter rm/¢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 $M_u/V_u\phi_V d$ = 3.0 is at x_{dc} from the point of maximum positive moment, determined as follows:

$$x_{dc} = 3\left[\sqrt{(\phi_v d)^2 + \frac{2M_c}{9w}} - \phi_v d\right] \qquad \text{Equation 4.22}$$

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 $l/\phi_v d$ for several typical values of c_m, where

$$c_m = \frac{2M_c}{w\ell^2} \qquad \text{Equation 4.23}$$

At sections where $M/V\phi_v d \geq 3.0$, shear is governed by the basic shear strength, V_b, calculated as

$$\phi_v V_b = (1.1 + 63p)\sqrt{f'_c \phi_v bd}\left[\frac{F_d F_{vp}}{F_c F_N}\right] \qquad \text{Equation 4.24}$$

where:

$$p = \frac{A_s}{\phi_v bd} \leq 0.02 \qquad \text{Equation 4.25}$$

max. f'_c = 7000psi Equation 4.26

$F_d = 0.8+1.6/d \leq 1.25$ Equation 4.27

$F_c = 1$ for straight members Equation 4.28

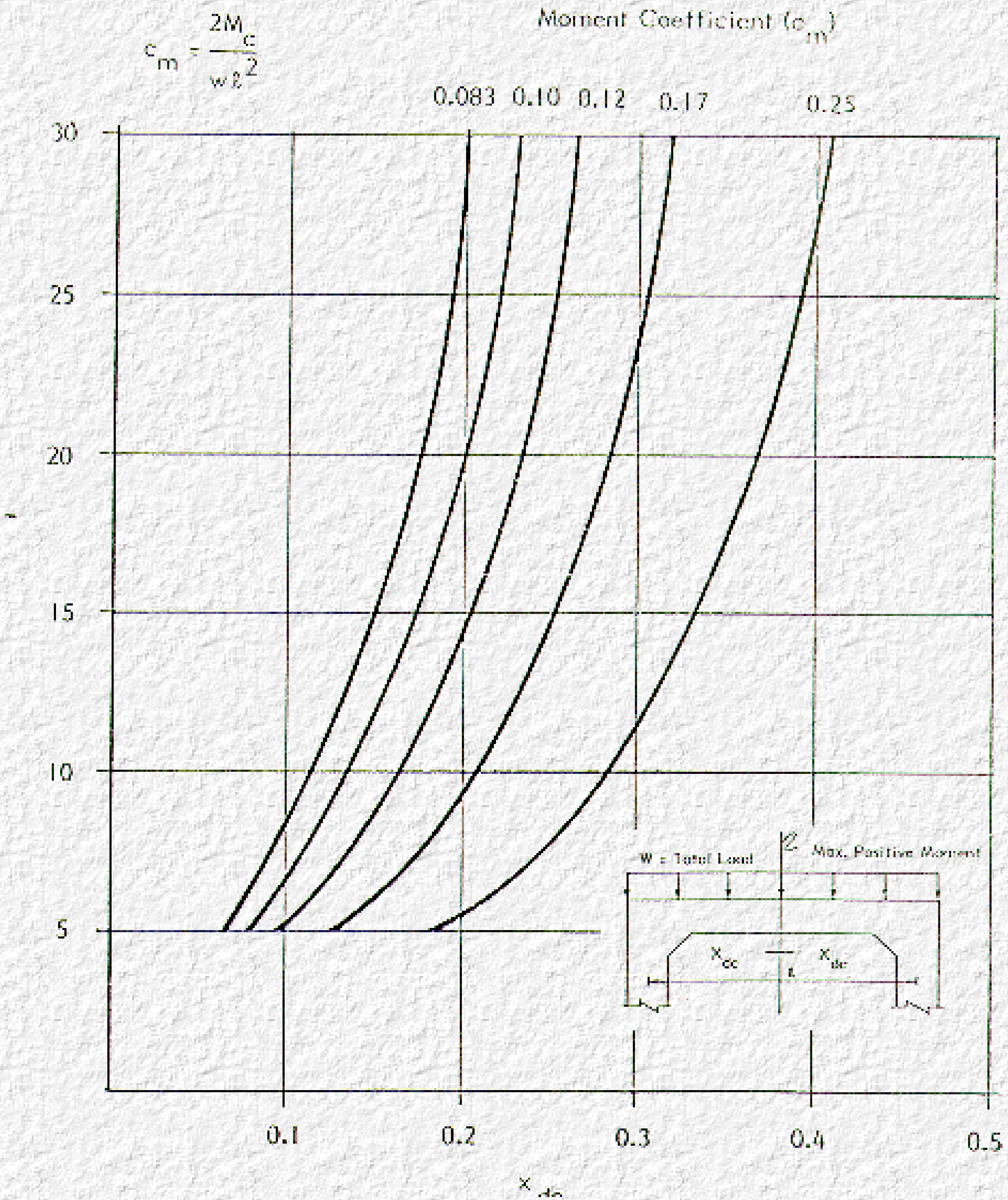


Figure 4-6. Location of Critical Shear Section for Straight Members with Uniformly Distributed Load

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

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

$$F_N = 1.0 - 0.12\frac{N_u}{V_u} \geq 0.75$$ 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, DL_{ut}, using the criteria in ASTM C655 *AASHTO M242) "Specifications for Reinforced Concrete D-Load Culvert, Storm Drain and Sewer Pipe."

$$F_{vp} = \frac{F_c\left(DL_{ut} + 11W_p / D_i\right)D_i}{293F_d(1.1 + 63p)d\sqrt{f_c'}}$$ 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 shaer strength, as given below.

Shear strength will be greater than V_b when $M/V\phi_v d < 3.0$ 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 $M/V\phi_v d < 3.0$, termed the general shear strength, V_c, is:

$$\phi_v V_c = \frac{4\phi_v V_b}{(M/V\phi_v d + 1)} \leq \frac{4.5\sqrt{f'_c}\, bd\phi_v}{F_N} \qquad \text{Equation 4.30}$$

If $M/V\phi_v d \geq 3.0$, use $M/V\phi_v d = 3.0$ in Equation 4.30. V_c shall be determined based on $M/V\phi_v d$ 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 $M/V\phi_v d$.

4.1.5 Stirrups

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

(a) Maximum Circumferential Spacing of Stirrups:

For boxes, max. $s = 0.60\ \phi_v d$ Equation 4.31a

For pipe, max. $s = 0.75\ \phi_v d$ Equation 4.31b

(b) Maximum Longitudinal Spacing and Anchorage Requirements for Stirrups

Longitudinal spacing of stirrups shall equal s_l. 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):

$$A_{vr} = \frac{1.1s(M_u - 0.45N_u\phi_v d)}{f_v r_s \phi_v d} \qquad \text{Equation 4.32}$$

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

$$A_{vr} = \frac{1.1s}{f_v \phi_v d}\left[V_u F_c - \phi_v V_c\right] + A_{vr}$$ Equation 4.33

Vc is determined in Equation 4.30 except use $V_c \leq 2\sqrt{f'_c}\, b \phi_v d$

$A_{vr} = 0$ 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

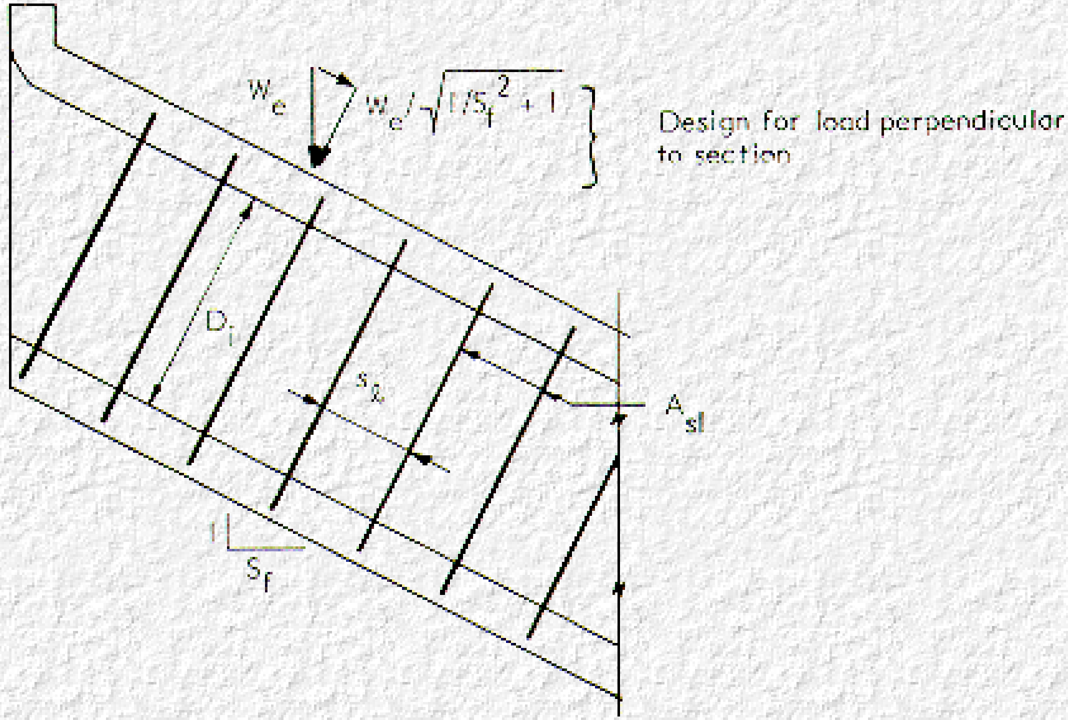
This format allows the designer to select the most suitable stirrup effective ultimate strength and spacing.

4.1.6 Special Design Considerations for Slope Tapered Inlets

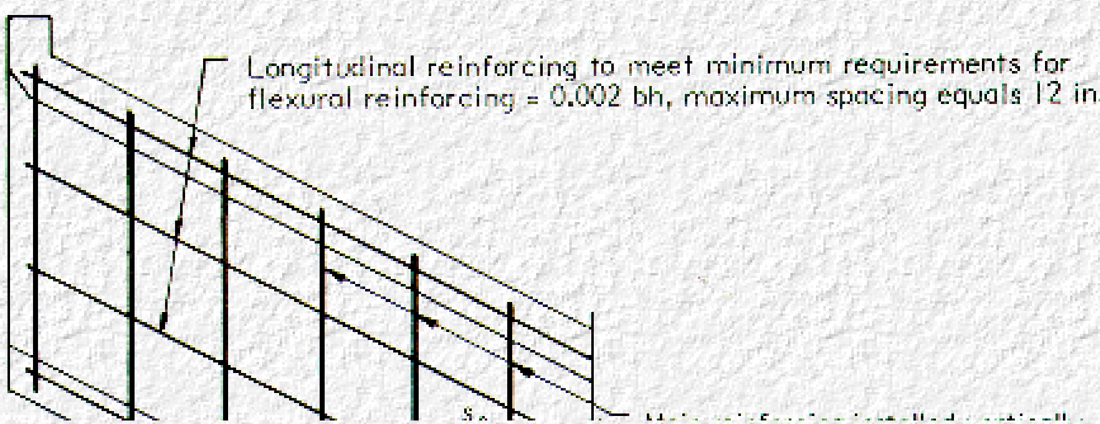
Slope tapered inlets are designed in the same manner as ordinary culverts, or side tapered inlets, except that the steeper slope of the section, S_f, must be taken into account. The recommended design procedure for precast inlets is to analyze the section and design the reinforcing based on earth loads 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 (ASl) 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

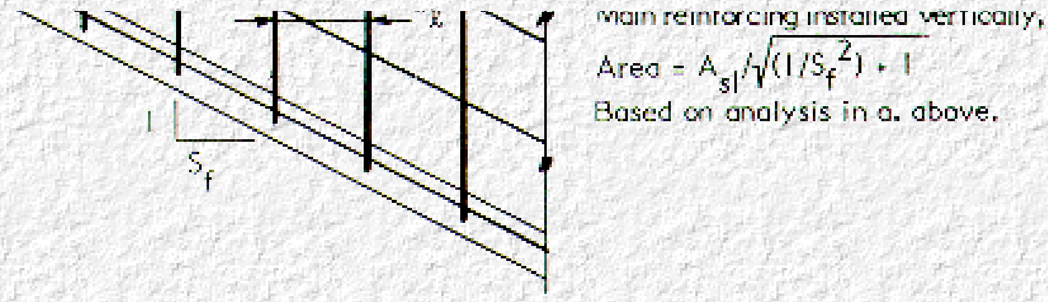
$$A_{s1}' = \frac{A_{s1}}{\sqrt{\left(1/S_f^2 + 1\right)}}$$ Equation 4.35

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](#).



a. **Dimensions, loads and reinforcement area, A_{sl} based on analysis for loads transverse to slope of slope tapered inlet.**





b. Reinforcing requirements when main reinforcing is installed vertically, and transverse reinforcing is parallel to slope.

Figure 4-7. Design Considerations for Slope Tapered Inlets

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.

Go to Chapter 5

Chapter 5 : FHWA-IP-83-6

Computerized Analysis and Design of Reinforced Concrete Sections

Go to Chapter 6

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.

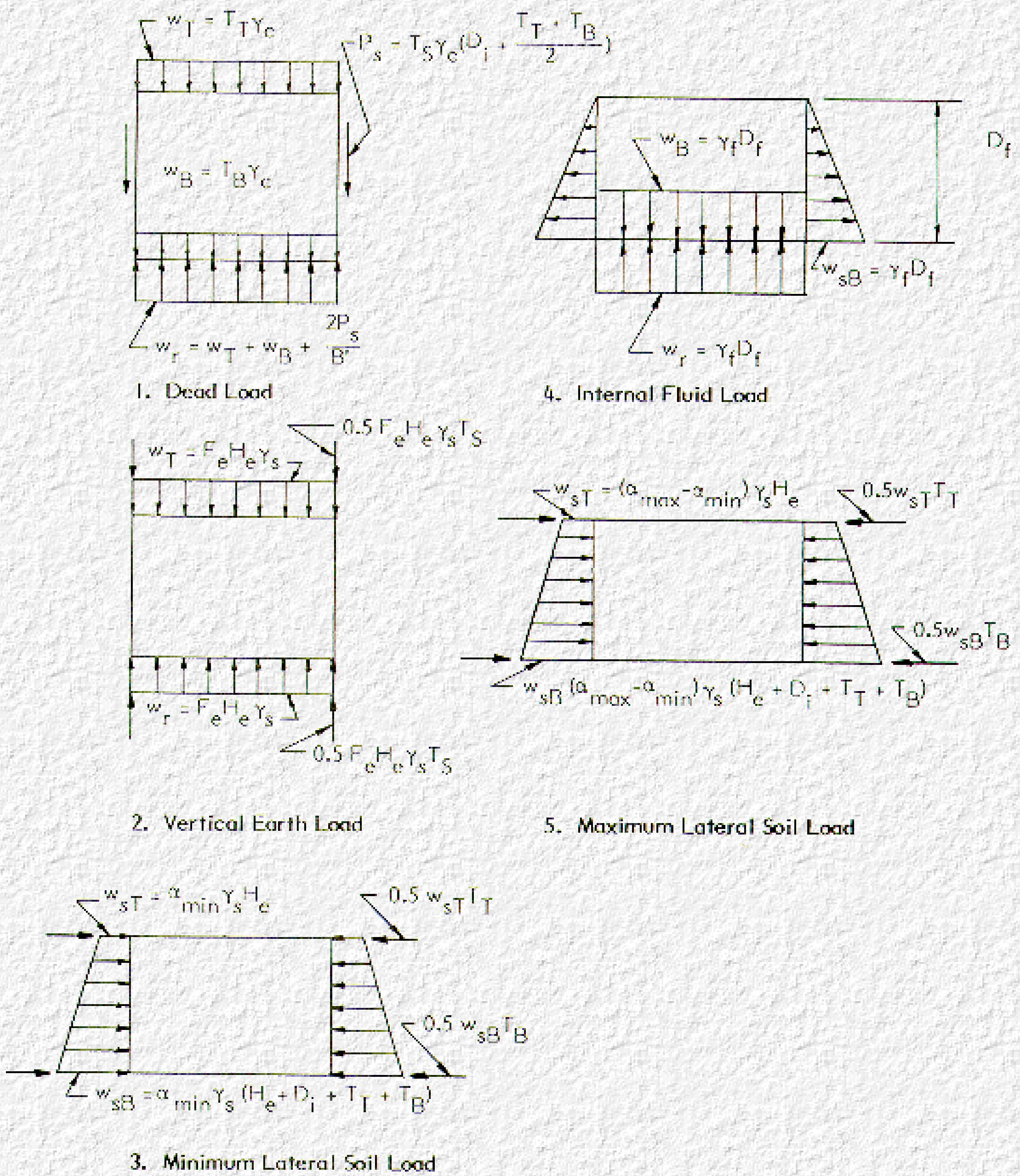


Figure 5-1. Single Cell Box Section Loading Cases

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 al low 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, ℓ_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:

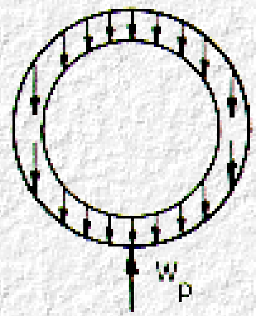
- The specified load angle must be between 180° and 300°.
- The specified bedding angle must be between 10° and 180°.
- The sum of the bedding and load angles must be less than or equal to 360°.
- Only circumferential reinforcement is designed.
- Wall thicknesses must be selected by the designer.
- Internal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

5.2.2 Loadings

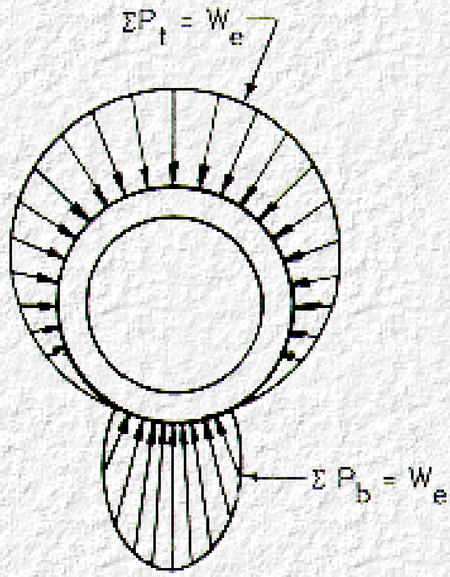
The program analyzes the three load cases shown in Figure 5-2. Load cases 1 and 2 are considered as permanent dead load, and load case 3 is considered additional dead load and is used in design only if it increases the design force under consideration. The two foot surcharge load suggested in Section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

5.2.3 Structural Analysis

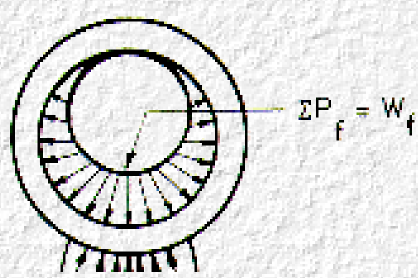
Due to symmetry, it is only necessary to analyze one half of the pipe section. The pipe is modeled as a 36 member plane frame with boundary supports at the crown and invert. Each member spans 5 degrees and is located at middepth of the pipe wall. For each member of the frame, a member stiffness matrix 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.

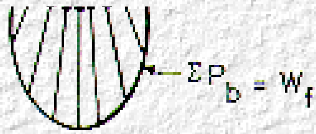


1. Pipe Weight



2. Soil Weight





3. Internal Fluid Load

Figure 5-2. Pipe Section Load Cases

Note: These load cases also apply to elliptical sections.

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:

$$A_v = \frac{S_{df}(s)}{f_v} \qquad \text{Equation 5.1}$$

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

Chapter 6 : FHWA-IP-83-6

Design of Appurtenant Structures

Go to Appendix A

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.

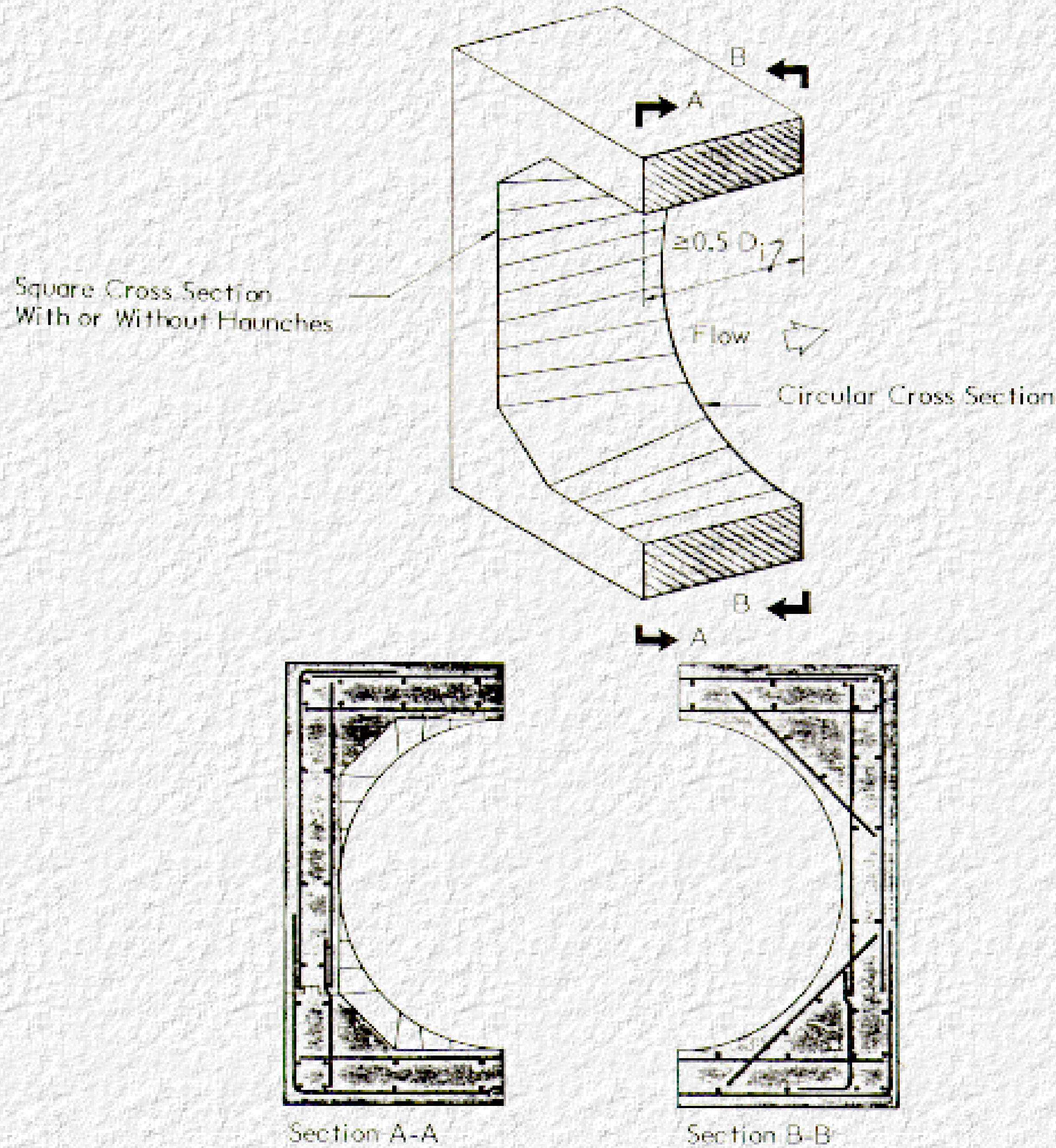


Figure 6-1. Circular to Square Transition Section

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.

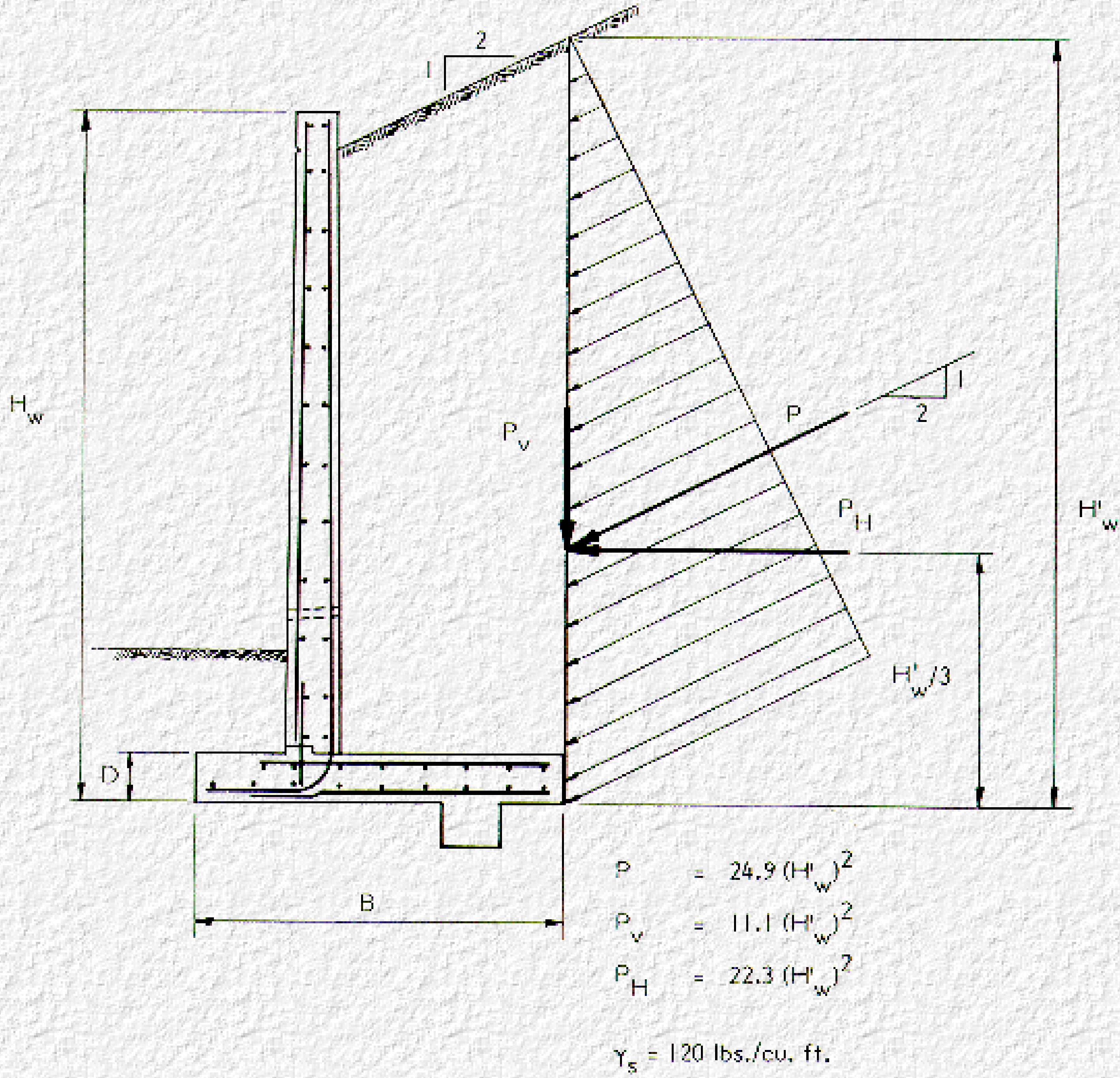


Figure 6-2. Loading Diagram and Typical Reinforcing Layout for Cantilever Type Retaining Wall

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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 slabs on grade for design purposes.

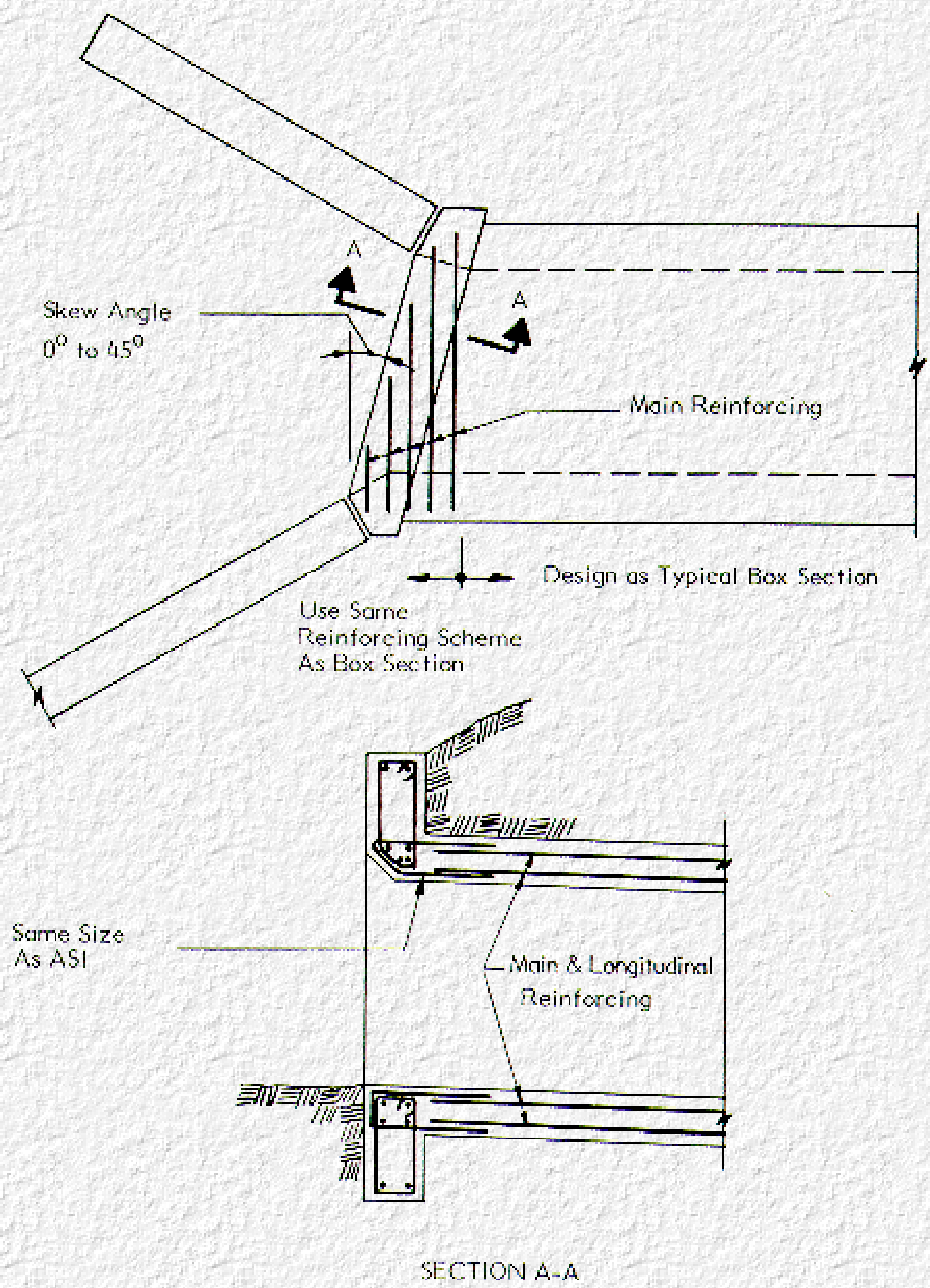

Figure 6-3. Skewed Headwall Detail

Go to Appendix A

Appendix A : FHWA-IP-83-6
Structural Design of Inlet Structures

Go to Appendix B

AASHTO Standard Specifications for Highway Bridges - 1977, and 1978, 1979, 1980 and 1981 Interim Specifications

Section 1.9 *Soil Corrugated Metal Structure Interaction Systems (pages 240-249E)*

Section 2.23 *Construction and Installation of Soil Metal Plate Structure Interaction Systems (pages 430-440)*

Section 9 - Soil Corrugated Metal Structure Interaction Systems

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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

P = Design load, Ibs/sq.ft. (N/m^2)
S = Diameter or Span, ft. (m)
T = Thrust, Ibs/ft. (N/m)

(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 envelopeCgeneral recommended criteria for lateral limits are as follows:

Trench widthC2 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 installationsCone 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 41.219m), 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

$$A = T_s/f_a$$

where

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

(B) Buckling

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

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

Formulae for buckling are:

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

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

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:

$$SS = T_s\ (SF)$$

Where

SS = Required seam strength in pounds per foot (N/m)
T_s = Thrust in pipe wall, Ibs/ft (N/m)
SF = Safety Factor

(D) Handling and Installation Strength

Handling and installation rigidity is measured by a Flexibility Factor, FF, determined by the formula

$$FF = s^2/E_mI$$

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

$$A = T_L/\phi f_y$$

Where

A = Area of pipe wall, in^2/ft (m^2/m)
T_L = Thrust, load factor, Ibs/ft (N/m)
f_y = Specified minimum yield point, psi (MPa)
ϕ = 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.

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

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

Where

f_u = Specified minimum metal strength, psi (MPa)
f_c, = 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)
ϕ = Capacity modification factor

(D) Handling and Installation Strength

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

$$FF = S^2/E_m l$$

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)
I = Moment of inertia per unit length of cross section of the pipe wall, inches to the 4th power per inch (m^4/m).

1.9.4 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:

Aluminum	Steel
AASHTO M190, M196	AASHTO M36, M245, M190

(2) Service load designCsafety factor, SF:

Seam strength = 3.0
Wall area = 2.0
Buckling = 2.0

(3) Load factor designCcapacity modification factor, ϕ. 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:

¼" (6.4mm) and ½" (12.7mm) depth corrugation FF = 4.3×10^{-2}

1 " (25.4mm) depth corrugation FF = 3.3 X 10^{-2}

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

¼" (6.4mm) and ½"(12.7mm) depth corrugation FF = 9.5 X 10^{-2}

1" (25.4mm) 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

2 X 1/2150.8 X 12.71 and 2-2/3 X 1/2 (67.8 X 12.7 mm) Corugated Steel Pipe Riveted or Spot Welded				3 X 1 (76.2 X 25.4 mm) Corrugated Steel Pipe Riveted or Spot Welded		
Thickness (inches) (mm)	Rivet Size (inches) (mm)	Single Rivets (Kips/ft) (kN/m)	Double Rivets (Kips/ft) (kN/m)	Thickness (inches) (mm)	Rivet Size (inches) (mm)	Double Rivets (Kips/ft) (kN/m)
0.064(1.63)	5/16(7.9)	16.7(244)	21.6(315)	0.064(1.63)	3/8(9.5)	28.7(419)
0.079(2.01)	5/16(7.9)	18.2(266)	29.8(435)	0.079(2.01)	3/8(9.5)	35.7(521)
0.109(2.77)	3/8(9.5)	23.4(342)	46.8(685)	0.109(2.77)	7/16(11.1)	53.0(773)
0.138(3.51)	3/8(9.5)	24.5(358)	49.0(715)	0.138(3.51)	7/16(11.1)	63.7(930)
0.168(4.27)	3/8(9.5)	25.6(374)	51.3(748)	0.168(4.27)	7/16(11.1)	70.7(1033)

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

3 X 1 (76.2 X 25.4mm) Corrugated Aluminum Pipe Riveted			6 X 1 (152.4 x 25.4mm) Corrugated Aluminum Pipe Riveted		
Thickness (inches) (mm)	Rivet Size (inches) (mm)	Double Rivets (Kips/ft) (kN/m)	Thickness (inches) (mm)	Rivet Size (inches) (mm)	Double Rivets (Kips/ft) (kN/m)
0.060(1.5)	3/8(9.5)	16.5(239)	0.060(1.5)	1/2(12.7)	16.0(232)
0.075(1.9)	3/8(9.5)	20.5(297)	0.075(1.9)	1/2(12.7)	19.9(288)
0.105(2.7)	1/2(12.7)	28.0(406)	0.105(2.7)	1/2(12.7)	27.9(405)
0.135(3.4)	1/2(12.7)	42.0(608)	0.135(3.4)	1/2(12.7)	35.9(520)
0.164(4.2)	1/2(12.7)	54.5(790)	0.167(4.2)	1/2(12.7)	43.5(631)

(C) Section Properties

(1) Steel conduits

	1-1/2 X 1/4 (38.2 X 6.4mm), Corrugation			2-2/3 X 1/2 (67.8 x 12.7mm) Corrugation		
Thickness (inches) (mm)	A_s (sq.in/ft) (mm^2/m)	r (in.) (mm)	I X 10^{-3} (in^4/in) (mm^4/mm)	A_s (sq.in/ft) (mm^2/m)	r (in.) (mm)	I X 10^{-3} (in^4/in) (mm^4/mm)
0.028 (.71)	0.304 (643.5)					
0.034 (.86)	0.380 (804.3)					
0.040 (1.02)	0.456 (965.2)	0.0816 (2.07)	0.253 (4144.9)	0.465 (984.3)	0.1702 (4.32)	1.121 (18365.3)
0.052 (1.32)	0.608 (1286.9)	0.0824 (2.09)	0.344 (5635.8)	0.619 (1310.2)	0.1707 (4.34)	1.500 (24574.5)
0.064 (1.63)	0.761 (1610.8)	0.0832 (2.11)	0.439 (7192.1)	0.775 (1640.4)	0.1712 (4.35)	1.892 (30996.6)
0.079 (2.01)	0.950 (2010.8)	0.0846 (2.15)	0.567 (9289.2)	0.968 (2048.9)	0.1721 (4.37)	2.392 (39188.1)
0.109 (2.77)	1.331 (2817.3)	0.0879 (2.23)	0.857 (14040.2)	1.356 (2870.2)	0.1741 (4.42)	3.425 (56111.8)
0.138 (3.51)	1.712 (3623.7)	0.0919 (2.33)	1.205 (19741.5)	1.744 (3691.5)	0.1766 (4.49)	4.533 (74264.1)
0.168 (4.27)	2.098 (4440.8)	0.0967 (2.46)	1.635 (26786.2)	2.133 (4514.9)	0.1795 (4.56)	5.725 (93792.7)

	3 X 1 (76.2 X 25.4mm) Corrugation			5 x 1 (127 X 25.4mm) Corrugation		
Thickness (inches) (mm)	A_s (sq.in/ft) (mm^2/m)	r (in.) (mm)	I X 10^{-3} (in^4/in) (mm^4/mm)	A_s (sq.in/ft) (mm^2/m)	r (in.) (mm)	I X 10^{-3} (in^4/in) (mm^4/mm)
0.064 (1.63)	0.890 (1883.8)	0.3417 (8.68)	8.659 (141860)	0.794 (1680.6)	0.3657 (9.29)	8.850 (144990)
0.079 (2.01)	1.113 (2355.9)	0.3427 (8.70)	10.883 (178296)	0.992 (2099.7)	0.3663 (9.30)	11.092 (181720)
0.109 (2.77)	1.560 (3302.0)	0.3488 (8.86)	15.459 (253265)	1.390 (2942.2)	0.3677 (9.34)	15.650 (256394)
0.138 (3.51)	2.008 (4250.3)	0.3472 (8.82)	20.183 (330658)	1.788 (3784.6)	0.3693 (9.38)	20.317 (332853)
0.168 (4.27)	2.458 (5202.8)	0.3499 (8.89)	25.091 (411065)	2.186 (4627.0)	0.3711 (9.43)	25.092 (411082)

(2) Aluminum conduits

	1-1/2 X 1/4 (38.2 X 6.4mm) Corrugation			2-2/3 X 1/2 (67.8 X 12.7mm) Corrugation		
Thickness (inches) (mm)	A_s (sq.in/ft) (mm^2/m)	r (in.) (mm)	I X 10^{-3} (in^4/in) (mm^4/mm)	A_s (sq.in/ft) (mm^2/m)	r (in.) (mm)	I X 10^{-3} (in^4/in) (mm^4/mm)
0.048 (1.22)	0.608 (1286.9)	0.0824 (2.09)	0.344 (5635.8)			
0.060 (1.52)	0.761 (1610.8)	0.0832 (2.11)	0.349 (5717.7)	0.775 (1640.4)	0.1712 (4.35)	1.892 (30996.6)

				0.968 (2048.9) 1.356 (2870.2) 1.745 (3693.6) 2.130 (4508.5)	0.1721 (4.37) 0.1 741 (4.42) 0.1766 (4.49) 0.1795 (4.56)	2.392 (39188.1) 3.425 (5611.8) 4.533 (74264.1) 5.725 (93792.7)

	3 X 1 (76.2 X 25.4mm) Corrugation			6 X 1 (52.4 X 25.4mm)			
Thickness (inches) (mm)	A_s (sq.in/ft) (mm^2/m)	r (in.) (mm)	I X 10^{-3} (in^4/in) (mm^4/mm)	A_s (sq.in/ft) (mm^2/m)	Effective Area (sq.in/ft) (mm^2/m)	r (in.) (mm)	I X 10^{-3} (in^4/in) (mm^4/mm)
0.060 (1.52) 0.075 (1.91) 0. I05	0.890 (1883.8) 1.118 (2366.4) 1.560	0.3417 (8.68) 0.3427 (8.70) 0.3488	8.659 (141860) 10.883 (178296) 15.459	0.775 (1640.4) 0.968 (2048.9) 1.356	0.387 (819.2) 0.484 (1024.5) 0.678	0.3629 (9.22) 0.3630 (9.22) 0.3636	8.505 (139337) 10.631 (174168) 14.340
(2.67) 0.135 (3.43) 0.164 (4.17)	(3302.0) 2.088 (4419.6) 2.458 (5202.8)	(8.86) 0.3472 (8.82) 0.3499 (8.89)	(253265) 20.183 (330658) 25.091 (411065)	(2870.2) 1.744 (3691.5) 2.133 (4514.9)	(1435.1) 0.872 (1845.7) 1.066 (2256.4)	(9.24) 0.3646 (9.26) 0.3656 (9.29)	(234932) 19.319 (316503) 23.760 (389260)

(D) Chemical and Mechanical Requirements

(1) AluminumCCorrugated Metal Pipe and Pipe-Arch Material requirementsCAASHTO M 197

Mechanical properties for design

Minimum Tensile Strength psi (MPa)	Minimum Yield Point psi (MPa)	Mod. of Elast. psi (MPa)
31,000(213.737)	24,000(165.474)	10 X 10^6(68947)

(2) SteelCCorrugated Metal Pipe and Pipe-Arch Material requirementsCAASHTO

M 218
M 246

Mechanical properties for design

Minimum Tensile Strength psi (MPa)	Minimum Yield Point psi (MPa)	Mod. of Elast. psi (MPa)
45,000(310.264)	33,000(227.527)	29 X 10^6(199948)

(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:

Aluminum	Steel
AASHTO M219	AASHTO M167

(2) Service load designCsafety factor, SF

Seam strength = 3.0
Wall area = 2.0
Buckling = 2.0

(3) Load factor designCcapacity modification factor,ϕ

$$\phi = 0.67$$

(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} (Pipearch)
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 thebottom of flexible pavement.) For Construction requirements see Article 2.23.10.

(B) Seam Stregth

Minimum Longitudinal Seam Strengths
6 X 2 (152.4 X 50.8mm) Steel Structure Plate Pipe

Thickness (inches) (mm)	Bolt Size (inch) (mm)	4 Bolts/ft(.305) (Kips/ft) (kN/m)	6 Bolts/ft(.305) (Kips/ft) (kN/m)	8 Bolts/ft(.305) (Kips/ft) (kN/m)
0.109(2.77)	3/4(19.1)	43.0(627.8)		
0.138(3.51)	3/4(19.1)	62.0(905.2)		
0.168(4.27)	3/4(19.1)	81.0(1182.6)		
0.188(4.78)	3/4(19.1)	93.0(1357.8)		
0.218(5.54)	3/4(19.1)	112.0(1635.2)		
0.249(6.32)	3/4(19.1)	132.0(1927.2)		
0.280(7.11)	3/4(19.1)	144.0(2102.4)	180(2628.0)	194(2832.4)

9 X 2-½ (2228.6 X 63.5mm) Aluminum Structural Plate Pipe			
Thickness (inches) (mm)	Bolt Size (inch) (mm)	Steel Bolts 5-½ Bolts Per ft(.305) (Kips/ft) (kN/m)	Aluminum Bolts 5-½ Bolts Per ft(.305) (Kips/ft) (kN/m)
0.10(2.54) 0.125(3.18) 0.15(3.81 0.175(4.45) 0.200(5.08) 0.225(5.72) 0.250(6.35)	3/4(19.1) 3/4(19.1) 3/4(19.1) 3/4(19.1) 3/4(19.1) 3/4(19.1) 3/4(19.1)	28.0(408.8) 41.0(598.6) 54.1(789.9) 63.7(930.0) 73.4(1071.6) 83.2(1214.7) 93.1(1359.3)	26.4(385.4) 34.8(508.1) 44.4(648.2) 52.8(770.9) 52.8(770.9) 52.8(770.9) 52.8(770.9)

(C)Section Properties

(1) Stell conduits

6" X 2" (152.4 X 50.8mm) Corrugations			
Thickness (inches) (mm)	A_s (sp.in/ft) mm^2/m)	r (in.) (mm)	1 X 10^{-3} ($in.^4/in$) (mm^4/mm)
0.109(2.77) 0.138(3.51) 0.168(4.17) 0.188(4.78) 0.21(5.54) 0.249(6.32) 0.280(7.11)	1.556(3293.5) 2.003(4139.7) 2.449(5183.7) 2.739(5797.6) 3.199(6771.2) 3.650(7725.8) 4.119(8718.6)	0.682(17.32) 0.684(17.37) 0.686(17.42) 0.688(17.48) 0.690(17.53) 0.692(17.58) 0.695(17.65)	60.411(989713) 78.175(1280741) 96.163(1575438) 108.000(1769364) 126.922(2079363) 146.172(2394735) 165.836(2716891)

9" X 2-½" (228.6 X 63.5mm) Corrugations			
Thickness (inches) (mm)	A_s (sp.in/ft) mm^2/m)	r (in.) (mm)	1 X 10^{-3} ($in.^4/in$) (mm^4/mm)
0.100(2.54) 0.125(3.18) 0.150(3.81) 0.175(4.45) 0.200(5.08) 0.225(5.72) 0.250(6.35)	1.404(2971.8) 1.750(3704.2) 2.100(4445.0) 2.449(5183.72) 2.799(5924.6) 3.149(6665.4) 3.501(7410.5)	0.8438(21.49 0.8444(21.45) 0.8449(21.46) 0.8454(21.47) 0.8460(21.49) 0.8468(21.51) 0.8473(21.52)	83.065(136054) 103.991(1703685) 124.883(2045958) 145.895(2390198) 166.959(2735289) 188.179(3082937) 209.434(3431157)

(D) Chemical and Mechanical Properties

(1) Aluminum—Structural plate pipe, pipe-arch, and arch
Material requirement—AASHTO M 167

Mechanical Properties for Design			
Thickness (inches) (mm)	Minimum Tensile Strength psi(MPa)	Minimum Yield point psi(MPa)	Mod. of Elast. psi(MPa)

0.100 to 0.175 (2.54 to 4.45) 0.176 to 0.250 (4.47 to 6.35)	35,000 (241.316) 34,00 (234.421)	24,000 (165.474) 24,000 (165.474)	10 X 10^6 (68947) 10 X 10^6 (68947)

(2) Steel—Structural plate pipe, Pipe-arch, and arch
Material requirements—AASHTO M 167

Mechanical Properties for Design		
Minimum Tensile Strength psi(MPa)	Minimum Yield point psi(MPa)	Mod. of Elast. psi(MPa)
45,000 (310.264)	33,000 (227.527)	29 X 10^6 (199948)

(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 masimum 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

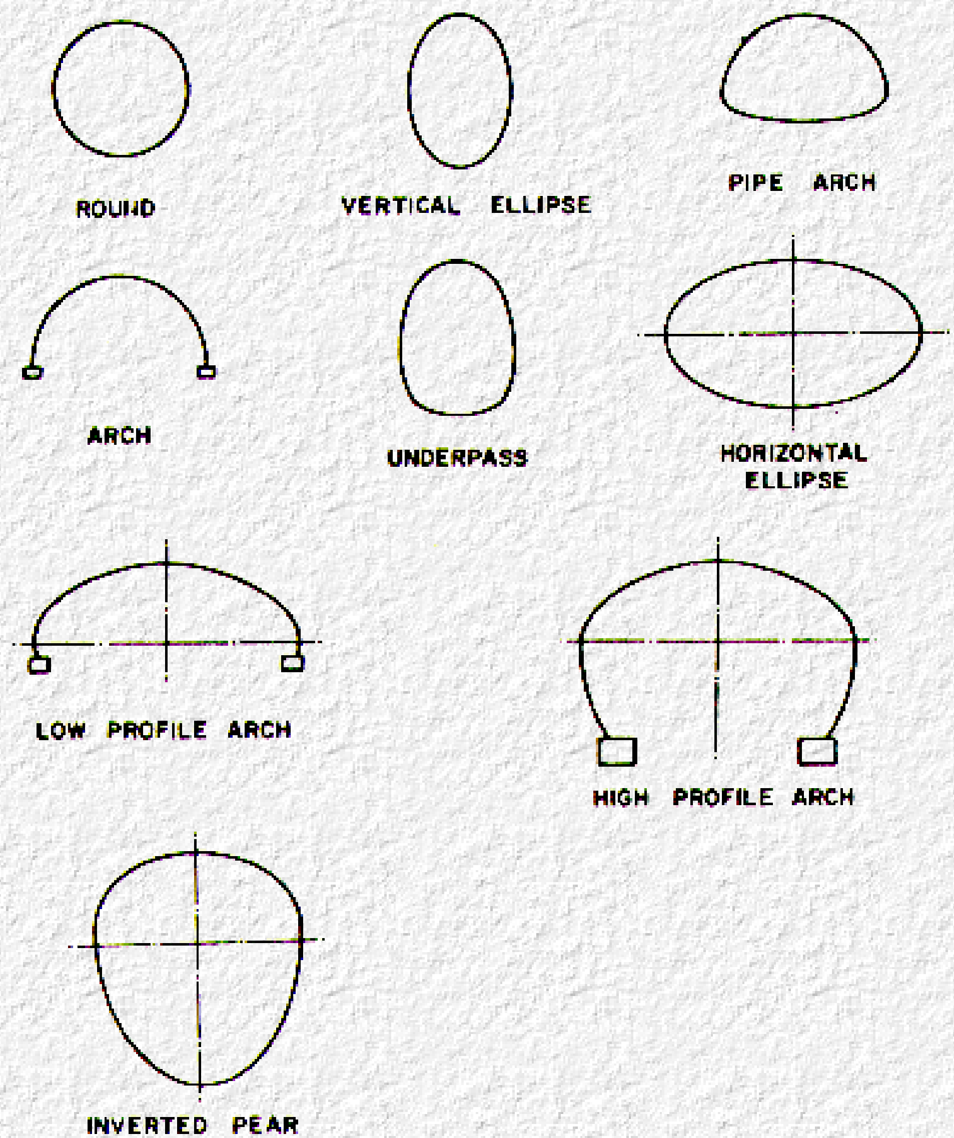


Figure A-1.9.6

(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

I. Top Arc	Top Radius in ft (m)				
	15 (4.572)	17-20 (4.572-5.182)	20-23 (6.096-6.096)	20-23 (6.096-7.010)	23-25 (7.010-7.620)
Minimum Thickness (mm) 6 X 2 Corugated Steel Plates (152.4 X 50.8)	.109" (2.77)	.138" (3.51)	.168" (4.27)	.218" (5.54)	.294" (6.32)
II Minimum Cover in ft. (m)					
	Top Radius in ft. (m)				
Steel Thickness[1] in in.(mm)	15 (4.572)	15-17 (4.572-5.182)	20-23 (6.096-6.096)	20-23 (6.096-7.010)	23-25 (7.010-7.620)
.019 (2.77) .138 (3.51) .168 (4.27) .188 (4.78) .218 (5.54) .294 (6.32) .280 (7.11)	2.5 (.762) 2.5 (.762) 2.5 (.762) 2.5 (.762) 2.0 (.762) 2.0 (.762) 2.0 (.762)	3.0 (.914) 3.0 (.914) 3.0 (.914) 2.5 (.914) 2.0 (.914) 2.0 (.914)	3.0 (.914) 3.0 (.914) 2.5 (.762) 2.5 (.762)	3.0 (9.14) 3.0 (.914) 3.0 (.914)	4.0 (1.219) 4.0 (1.219)
III. Geometric Limits					
A. Maximum Plate Radius-25 Ft. (7.620m) B. Maximum Central Angle of Top Arc = 80º 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.					
1. *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 bum 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 hard objects during placement in trench or on bedding.

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 (I). The values for various types of pipe can be determined by a rational analysis or a suitable test.

(a) Shear StrengthCThe 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 StrengthCThe 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 SlipCThe allowable slip is the maximum slip that a pipe can withstand without disjointing, divided by a factor of safety.

(d) SoiltightnessCSoil tightness 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 D_{85} 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) WatertightnessCWatertightness 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 A-2.23.3 Categories of Pipe Joints

	Non-Erodible		Erodible		Poor
Soil Condition	**Standard**	**Positive**	**Standard**	**Positive**	**Standard**
Shear	2%	10%	10%	10%	25%
Moment[1]	0	10	0	10	10
Tensile 0-42" Dia (0-1.066 m)	0	5000 lbs (22.24 kN)		5000 lbs (22.24 kN)	5000 lbs (22.24 kN)
48"-84" Dia (1.219-2.134 m)		10,000 lbs (44.48 kN)		10,000 lbs (44.48 kN)	10,000 lbs (44.48 kN)
Slip		1 in.(.025 m)		1 in.(.025 m)	
Soiltightness[2]	NA	NA	0.3 or 0.2	0.3 or 0.2	0.3 or 0.2
Watertightness	See Paragraph (A)(4)(e)				

[1] See Paragraph (4)(b)

[2]Minimumb ration of D_{85} 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.

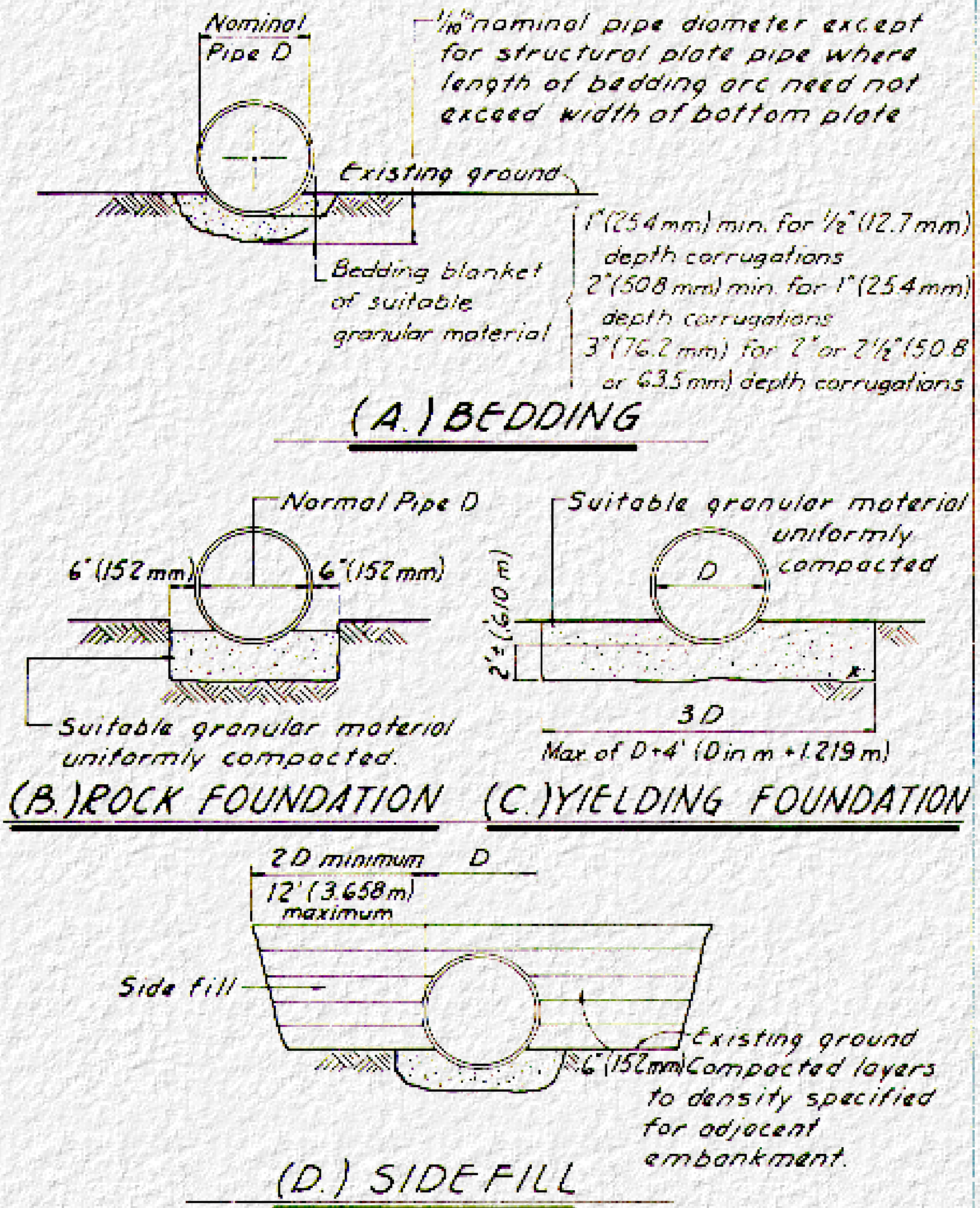
When backfilling arches before headwalls are placed, the first material shall be placed midway between the ends of the arch, forming as narrow a ramp as possible until the top of the arch is reached. The ramp shall be built evenly from both sides and the backfilling material shall be thoroughly compacted 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 2.23 Pipe Bedding, Foundation & Sidefill



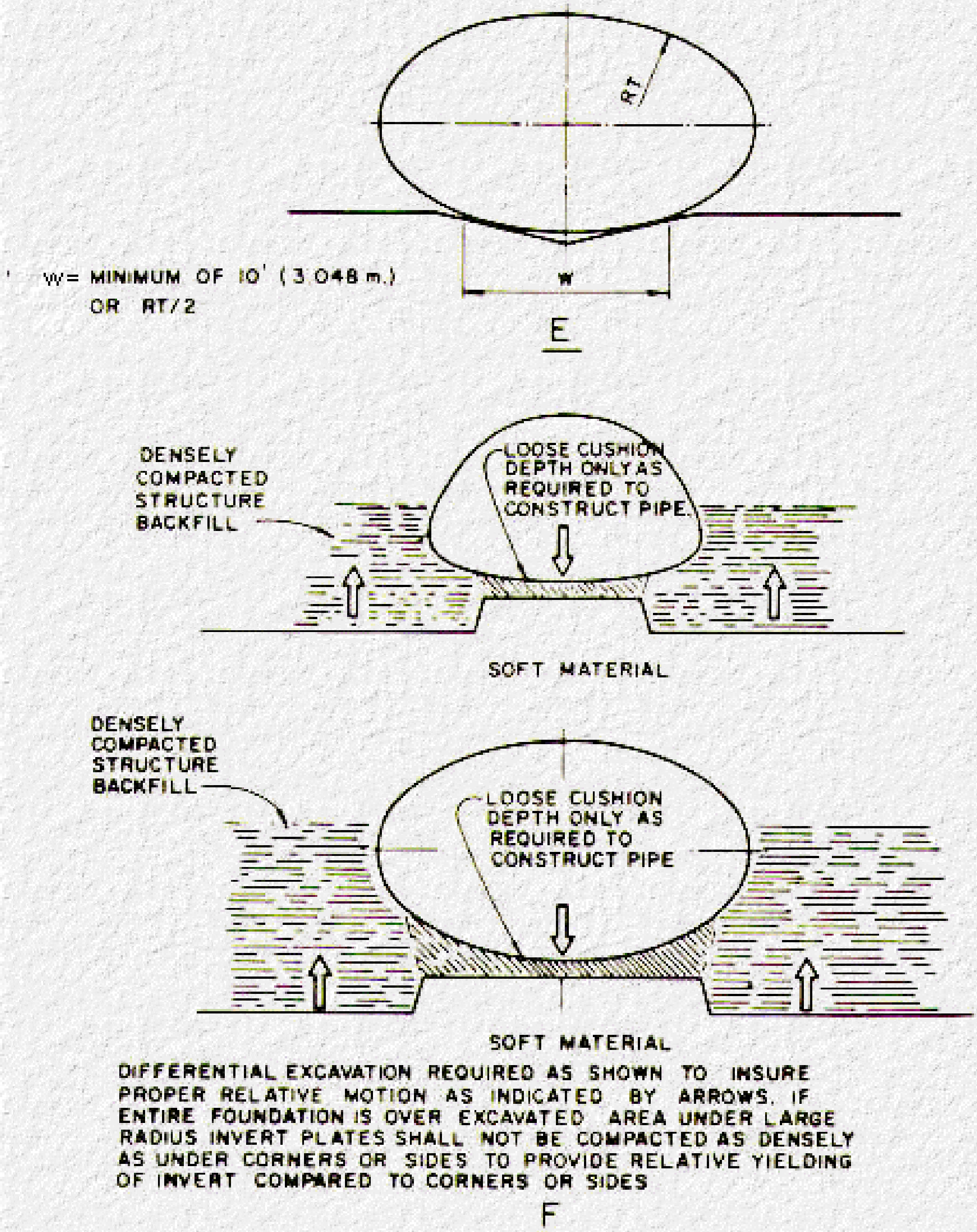


Figure A-2.23

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.

Go to Appendix B

Appendix B : FHWA-IP-83-6

Users Manual - Improved Inlet Box Section Program, Boxcar

Go to Appendix C

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 B-1. Format for Data Input, Boxcar

	Coce (Note 1)	Description (Note 2)	Nome of Variables	Units	Default Value
Card Columns	1-2	3-20	21-80		
Format	12	4A4, A2	6F10.3		

Required Data	01	Inside Span Inside Rise Depth of Fill	S_i D_i h	ft ft ft	None None None
Optional Data (Note 5)	02	Top Slab Thickness Bottom Slab Thickness Side Wall Thickness	T_T T_B T_S	in. in. in.	T(Note 6) T(Note 6) T(Note 6)
	03	Horizontal Haunch Dim. Vertical Haunch Dim.	H_H H_V	in. in.	T(Note 6) T(Note 6)
	04	Soil unit weight Concrete unit weight Fluid unit weight	γ_s γ_c γ_f	pcf pcf pcf	120. 150. 62.5
	05	Lateral Soil Pressure (Min.) Lateral Soil Pressure (Max.) Soil Structure Int. Factor Flag for Side Load	α_{min} (Note3) α_{max} None Fe Flg	None None None None	0.25 0.5 1.2 (Note 7) 0 (Note 4)
	06	Load Factor Flexure Cap. Red. Factor Shear Capacity Red. Factor	L_f ϕ_f ϕ_v	None None None	1.3 0.9 0.9
	07	Depth of Fluid	D_f	in.	D_i
	08	Steel Yield Stress Concrete Compressive Strength	f_y f'_c	ksi ksi	65 5.
	09	Concrete Covers Top - Outside Side - Outside Bottom - Outside	t_{bl} t_{b2} t_{b3}	in. in. in.	1. 1. 1.
		Top- Inside Bottom - Inside Side- Inside	t_{b4} t_{b5} t_{b6}	in. in. in.	1. 1. 1.
	10	Limiting Crack Width Factor	F_{cr}	None	1.0
	11	Number of Layers of Steel Reinforcing Reinforcing Type	NLAY RTYPE(Note 8)	None None	I 2

	12	Wire Diameters ASI - Outside Steel AS2 - Inside Steel - Top AS3 - Inside Steel - Bottom AS4 - Inside Steel - Side	SDATA(1-3) SDATA(4) SDATA(5) SDATA(6)	in. in. in. in.	0.08T(Note6) 0.08T(Note6) 0.08T(Note6) 0.08T(Note6)
	13	Wire Spacing AS I - Outside Steel AS 2 - Inside Steel - Top AS 3 - Inside Steel - Bottom AS 4 - Inside Steel - Side	SDATA (7-9) SDATA (10) SDATA (11) SDATA (12)	in. in. in. in.	2. 2. 2. 2.
Required	Over 13	End of Data			

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. α 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 ≠ 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 = span/12 + I
   For span > 7.0 ft T = span/12
7. If the soil structure interaction factor is input as less than 0.75, it will default to 1.2.
8. RTYPE = I 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 O 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

DEBUG = I
- Output from debug = 0
- Listing of BDATA, IBDATA, SDATA, and ISDATA arrays
- Moments, thrusts and shears at design sections

DEBUG = 2
- Output from debug = I
- Summary table for flexural design
- Summary table for shear design

DEBUG = 3
- Output from debug = 2
- Displacement matrix
- Member end forces

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 (α_{max} -α_{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                                          3
  1 SPAN,RISE,BURIAL      10.500     6.000     4.000
  2 TT,TB,TS               8.000     8.000     8.000
  3 HH,HV                  8.000     8.000
  6 FACTORS                1.300     0.900     0.850
  8 STRENGTH              60.000     3.000
  9 CONCRETE COVERS        2.000     2.000     2.000     1.000     1.000     1.000
 11 REINFORCING            1.000     3.000
 99 END OF DATA


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

b. Listing of BDATA Array

	PARAMETER	DATA	SOURCE
1	INSIDE SPAN (IN)	0.12600E 03	INPUT
2	INSIDE RISE (IN)	0.72000E 02	INPUT
3	TOP SLABTHK (IN)	0.80000E 01	INPUT
4	BOT SLABTHK (IN)	0.80000E 01	INPUT
5	SIDE WALL T (IN)	0.80000E 01	INPUT
6	CONC UNIT WT KCI	0.86800E-04	ASSUMED
7	SOIL UNIT WT KCI	0.69444E-04	ASSUMED
8	FLUID UNT WT KCI	0.36170E-04	ASSUMED
9	FLEX CAPRED FACT	0.90000E 00	INPUT
10	BURIAL DEPTH IN	0.48000E 02	INPUT
11	HORIZ HAUNCH IN	0.80000E 01	INPUT
12	VERT HAUNCH IN	0.80000E 01	INPUT
13	SHEAR CAP RED FR	0.85000E 00	INPUT
14	LAT SOILPRESS CO	0.25000E 00	ASSUMED
15	SOIL-STR INT COF	0.12000E 01	ASSUMED
16	FLUID DEPTH (IN)	0.72000E 02	ASSUMED
17	***EMPTY********	0.0	NO VALUE
18	CONCRETE E (KSI)	0.33202E 04	ASSUMED
19	STEEL E (KSI)	0.29000E 05	ASSUMED
20	STEEL STR (KSI)	0.60000E 02	INPUT
21	CONCRETE STR KSI	0.30000E 01	INPUT
22	LOAD FACTOR M,V	0.13000E 01	INPUT
23	LOAD FACTOR P	0.13000E 01	INPUT
24	.01 CRACK FACTOR	0.10000E 01	ASSUMED
25	***EMPTY********	0.0	NO VALUE
26	# LAYERSOF REINF	0.10000E 01	INPUT
27	REINFORCING TYPE	0.30000E 01	INPUT
28	***EMPTY********	0.0	NO VALUE
29	***EMPTY********	0.0	NO VALUE
30	TOP OUT CVR (IN)	0.20000E 01	INPUT
31	SIDE OUT CVR IN	0.20000E 01	INPUT
32	BOT OUT CVR (IN)	0.20000E 01	INPUT
33	TOP INS CVR (IN)	0.20000E 01	INPUT
34	BOT INS CVR (IN)	0.20000E 01	INPUT
35	SIDE INS CVR IN	0.20000E 01	INPUT

c. Listing of SDATA Array

	PARAMATER	DATA	SOURCE
1	WIRE DIA OUT TOP	0.64000E 00	ASSUMED
2	WIRE DIA OUT SDE	0.64000E 00	ASSUMED
3	WIRE DIA OUT BOT	0.64000E 00	ASSUMED
4	WIRE DIA INS TOP	0.64000E 00	ASSUMED
5	WIRE DIA INS BOT	0.64000E 00	ASSUMED
6	WIRE DIA INS SDE	0.64000E 00	ASSUMED
7	WIRE SPA OUT TOP	0.20000E 01	ASSUMED
8	WIRE SPA OUT SDE	0.20000E 01	ASSUMED
9	WIRE SPA OUT BOT	0.20000E 01	ASSUMED
10	WIRE SPA INS TOP	0.20000E 01	ASSUMED
11	WIRE SPA INS BOT	0.20000E 01	ASSUMED
12	WIRE SPA INS SDE	0.20000E 01	ASSUMED
13	***EMPTY********	0.0	NO VALUE
14	***EMPTY********	0.0	NO VALUE
15	***EMPTY********	0.0	NO VALUE
16	***EMPTY********	0.0	NO VALUE
17	***EMPTY********	0.0	NO VALUE
18	***EMPTY********	0.0	NO VALUE
19	TOP STEEL LTH IN	0.0	NO VALUE
20	BOT STEEL LTH IN	0.0	NO VALUE
21	***EMPTY********	0.0	NO VALUE
22	***EMPTY********	0.0	NO VALUE
23	***EMPTY********	0.0	NO VALUE
24	***EMPTY********	0.0	NO VALUE
25	LAT SOIL RATIO	0.10000E 01	ASSUMED
26	***EMPTY********	0.0	NO VALUE
27	***EMPTY********	0.0	NO VALUE
28	***EMPTY********	0.0	NO VALUE
29	***EMPTY********	0.0	NO VALUE
30	D OUT TOP (IN)	0.56800E 01	ASSUMED
31	D OUT SIDE (IN)	0.56800E 01	ASSUMED
32	D OUT BOTT (IN)	0.56800E 01	ASSUMED
33	D IN TOP (IN)	0.66800E 01	ASSUMED
34	D IN BOTT (IN)	0.66800E 01	ASSUMED
35	D IN SIDE (IN)	0.66800E 01	ASSUMED

d. Joint Displacement Table

DISPLACEMENT MATRIX - INCHES AND RADIANS

NODE		LOAD CASE 1	2	3	4	5
1	X	-.7381E-07	0.4472E-07	0.3545E-03	-.2365E-03	0.3545E-03
	Y	-.2321E-03	-.8554E-03	-.8731E-10	0.2910E-10	-.8731E-10
	ROT	-.2441E-03	-.9650E-03	0.1409E-03	-.9546E-04	0.1409E-03
2	X	0.8566E-04	0.4472E-07	0.6811E-04	-.8808E-04	0.6811E-04
	Y	-.2321E-03	-.8554E-03	0.1110E-09	-.3638E-10	0.1110E-09
	ROT	0.2441E-03	0.9651E-03	-.1409E-03	0.9546E-04	-.1409E-03
3	X	0.0	0.0	0.0	0.0	0.0
	Y	0.0	0.0	0.0	0.0	0.0
	ROT	-.3110E-03	-.9650E-03	0.1497E-03	-.1012E-03	0.1497E-03
4	X	0.8573E-04	0.0	0.4227E-03	-.3246E-03	0.4227E-03
	Y	0.0	0.0	0.0	0.0	0.0
	ROT	0.3110E-03	0.9651E-03	-.1497E-03	0.1012E-03	-.1497E-03

e. Member End Forces Table

END FORCES, KIPS AND INCH-KIPS

		LOAD CASE	A-END FXLA FX	FYLA FY	BMA MOMENT	B-END FXLB FX	FYLB FY	BMB MOMENT
MEMBER	1	1	-0.20393	0.55830	6.80739	0.20393	0.55830	-6.80741
MEMBER	1	2	0.0	3.21599	52.03101	0.0	3.21599	-52.03099
MEMBER	1	3	0.68124	0.00000	4.09291	-0.68124	-0.00000	-4.09286
MEMBER	1	4	-0.35298	-0.00000	-2.77264	0.35298	0.00000	2.77263
MEMBER	1	5	0.68124	0.00000	4.09291	-0.68124	-0.00000	-4.09286
MEMBER	2	1	0.92494	-0.20393	6.80739	-0.92494	0.20393	-23.12146
MEMBER	2	2	3.40799	0.0	52.03087	-3.40799	0.0	-52.03087
MEMBER	2	3	-0.00000	0.64125	4.09288	0.00000	0.89209	-4.34883
MEMBER	2	4	0.00000	-0.35298	-2.77264	-0.00000	-0.77205	6.03486
MEMBER	2	5	-0.00000	0.64125	4.09288	0.00000	0.89209	-4.34883
MEMBER	3	1	0.20393	1.29158	23.12151	-0.20393	1.29158	-23.12149
MEMBER	3	2	0.0	3.21599	52.03094	0.0	3.21599	-52.03105
MEMBER	3	3	1.00542	0.00000	4.34880	-1.00542	-0.00000	-4.34872
MEMBER	3	4	-0.77205	-0.11754	-6.03487	0.77205	0.11754	6.03482
MEMBER	3	5	1.00542	0.00000	4.34882	-1.00542	-0.00000	-4.34872
MEMBER	4	1	0.92494	0.20393	23.12140	-0.92494	-0.20393	-6.80731
MEMBER	4	2	3.40799	0.0	52.03088	-3.40799	0.0	-52.03088
MEMBER	4	3	0.00000	0.89209	4.34877	-0.00000	0.64125	-4.09292
MEMBER	4	4	-0.00000	-0.77205	-6.03485	0.00000	-0.35298	2.77265
MEMBER	4	5	0.00000	0.89209	4.34877	-0.00000	0.64125	-4.09292

f. Design Forces Table

SECTION	GROUP 1 MOMENT	GROUP 1 SHEAR	GROUP 2 MPLUS	GROUP 2 VPLUS	GROUP 2 MNEG	GROUP 2 VNEG	ULTIMATE LOADS FMMAX	ULTIMATE LOADS FVMAX	ULTIMATE LOADS FMMIN	ULTIMATE LOADS FVMIN
	SERVICE LOADS									
1	63.507	0.0	2.773	0.0	-4.093	0.0	86.164	0.0	0.0	0.0
2	30.217	1.937	2.773	0.000	-4.093	-0.000	42.886	2.518	0.0	0.0
3	-7.394	2.826	2.773	0.000	-4.093	-0.000	0.0	3.674	-14.933	0.0
4	-21.696	3.098	2.773	0.000	-4.093	-0.000	0.0	4.028	-33.525	0.0
5	-58.469	0.301	2.816	0.505	-1.426	-0.339	0.0	1.047	-77.864	-0.050
6	-57.170	0.237	5.100	0.441	-3.015	-0.317	0.0	0.880	-67.691	-0.105
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	-55.883	0.0	11.112	0.0	-7.972	0.0	0.0	0.0	-83.011	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	-64.887	2.652	6.834	0.448	-4.539	-0.407	0.0	1.429	-75.470	0.0
11	-68.323	0.773	4.382	0.569	-2.267	-0.536	0.0	1.743	-91.766	0.0
12	-30.254	-3.700	4.684	0.103	-4.349	0.0	0.0	0.0	-44.984	-4.810
13	-13.174	-3.375	4.210	0.094	-4.349	0.0	0.0	0.0	-22.779	-4.388
14	35.585	-2.198	2.858	0.961	-4.349	0.0	49.976	0.0	0.0	-2.858
15	71.503	0.0	1.862	0.0	-4.349	0.0	95.374	0.0	0.0	0.0

MEMBER	THRUST	NPLUS	NNEG	FNMAX	FNMIN
TOP	-0.477	2.353	-0.681	-0.162	-1.506
SIDE	-4.333	0.000	-0.000	-5.633	-5.633
BOT	-1.209	0.772	-1.005	-0.568	-2.879

ZERO MOMENT TOP 20.01222 ZERO MOMENT BOTTOM 21.70448

INCHES FROM CENTERLINE OF SIDEWALL

***NOTE: ALL UNITS ARE KIPS AND INCHES

g. Flexure Design Table

REINFORCING	AS 8	AS 1		AS 2	AS 3	AS 4
DESIGN SECTION	4	5;11	12	1	15	8
ULTIMATE MOMENT IN.KIPS/FT	33.52519	91.76640	44.98412	86.36403	95.37399	0.0
ULTIMATE THRUST KIPS/FT	1.50613	5.63281	2.87919	0.16163	0.56848	5.63281
DEPTH TO STEEL IN.	5.68000	5.68000	5.68000	6.68000	6.68000	6.68000
STEEL AREAS(FLEX) SQ.IN./FT	0.09230	0.24817	0.11416	0.24726	0.27092	-0.06230
MIN. FLEX STEEL SQ.IN./FT	0.19200	0.19200	0.19200	0.19200	0.19200	0.19200
MAX. FLEX STEEL SQ.IN./FT	0.95663	0.90804	0.93946	1.14517	1.14008	1.07678
CRACK INDEX	-3.00214	-0.75134	-2.69128	-0.15112	-0.00054	0.0
GOVERNING STEEL SQ.IN./FT	0.19200	0.24817	0.19200	0.24726	0.27092	0.19200
GOVERNING MODE	MIN. STEEL	FLEXURE	MIN. STEEL	FLEXURE	FLEXURE	MIN. STEEL

h. Method 1 Shear Design Table

*** SHEAR DESIGN TABLE - METHOD 1 ***

DESIGN SECTION ALL SECTIONS ARE AT D FROM THE HAUNCH	3	6	10	13
ULTIMATE SHEAR KIPS/FT	3.674	0.860	1.429	4.388
ALLOWABLE SHEAR KIPS/FT	9.520	9.520	9.520	9.520
DIAGONAL TENSION INDEX LIMIT	0.385953	0.092464	0.160132	0.460939
DEPTH TO STEEL IN.	5.68000	5.68000	5.68000	5.68000
STIRRUPS REQUIRED?	NO	NO	NO	NO

i. Method 2 Shear Design Table

****** SHEAR DESIGN TABLE - METHOD 2 ******

DESIGN SECTION	2	4	5	7	9	11	12	14
M/(V*PHI*D)	3.000	1.724	15.400	0.0	0.0	10.902	1.937	3.080
ULTIMATE SHEAR KIPS/FT	2.510	3.674	0.880	0.0	0.0	1.429	4.380	2.858
ULTIMATE THRUST KIPS/FT	0.162	0.162	5.633	0.0	0.0	5.633	0.568	0.568
STEEL RATIO	0.003629	0.003334	0.004283	0.0	0.0	0.004283	0.004283	0.003976
DEPTH TO STEEL IN.	6.68000	5.68000	5.68000	0.0	0.0	5.68000	5.68000	6.68000
DISTANCE FROM A-END, IN.	32.621	12.000	12.000	0.0	0.0	12.000	122.000	99.676
THRUST FACTOR (FN)	0.989414	0.993356	0.750000	0.0	0.0	0.750000	0.980691	0.967945
DIAGONAL TENSION STRENGTH, KIPS/FT	5.209	6.641	6.269	0.0	0.0	6.269	6.530	5.413
ULTIMATE SHEAR/ ALLOWABLE SHEAR	0.483287	0.553274	0.140403	0.0	0.0	0.227970	0.671977	0.527999
NEW STEEL AREA DUE TO DIAGONAL TENSION SQ.IN./FT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

j. Design Summary Sheet

10.5 FT. SPAN X 6.0 FT. RISE REINFORCED CONCRETE BOX SECTION

INSTALLATION DATA

HEIGHT OF FILL OVER CULVERT, FT	4.000
UNIT WEIGHT, PCF	120.000
MINIMUM LATERAL SOIL PRESSURE COEFFICIENT	0.250
MAXIMUM LATERAL SOIL PRESSURE COEFFICIENT	0.500
SOIL - STRUCTURE INTERACTION COEFFICIENT	1.200

LOADING DATA

LOAD FACTOR - MOMENT AND SHEAR	1.300
LOAD FACTOR - THRUST	1.300
STRENGTH REDUCTION FACTOR-FLEXURE	0.900
STRENGTH REDUCTION FACTOR-DIAGONAL TENSION	0.850
LIMITING CRACK WIDTH FACTOR	1.000

MATERIAL PROPERTIES

STEEL - MINIMUM SPECIFIED YIELD STRESS, KSI	60.000
CONCRETE - SPECIFIED COMPRESSIVE STRENGTH, KSI	3.000
REINFORCING TYPE	3.000

CONCRETE DATA

TOP SLAB THICKNESS, IN.	8.000
BOTTOM SLAB THICKNESS, IN.	8.000
SIDE WALL THICKNESS, IN.	8.000
HORIZONTAL HAUNCH DIMENSION, IN.	8.000
VERTICAL HAUNCH DIMENSION, IN.	8.000
CONCRETE COVER OVER STEEL, IN.	
TOP SLAB - OUTSIDE FACE	2.000
SIDE WALL - OUTSIDE FACE	2.000
BOTTOM SLAB - OUTSIDE FACE	2.000
TOP SLAB - INSIDE FACE	1.000
BOTTOM SLAB - INSIDE FACE	1.000
SIDE WALL - INSIDE FACE	1.000

REINFORCING STEEL DATA

LOCATION	AREA SQ. IN. PER FT	STIRRUPS REQUIRED?
TOP SLAB - INSIDE FACE	0.247	NO
TOP SLAB - OUTSIDE FACE	0.192	NO
BOTTOM SLAB - INSIDE FACE	0.271	NO
SIDE WALL - OUTSIDE FACE	0.248	NO
SIDE WALL - INSIDE FACE	0.192	NO

*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.

Table B-3. Map of BDATA Array

Index of BNDAT (Note 1)	Notation		Description	Units
	Design Method	Computer Code		
1	S_i	SPAN	inside span of box section	in.
2	R_i	RISE	inside rise of box section in.	in.
3	T_T	TT	thickness of top slab in.	in.
4	T_B	TB	thickness of bottom slab	in.
5	T_S	TS	thickness of side wall	in.
6	γ_c	GAMAC	unit weight of concrete	kips/in.^{3}
7	γ_s	GAMAS	unit weight of soil	kips/in.^{3}
8	γ_f	GAMAF	unit weight of fluid in box	kips/in.^{3}
9	ϕ_f	POF	capacity reduction factor for flexure	none
10	H_e	H	depth of fill	in.
11	H_H	HH	horizontal width of haunch	in.
12	H_v	HV	vertical height of haunch	in.
13	ϕ_v	POV	capacity reduction factor for shear	none
14	α_{min}	ZETA	lateral soil pressure coefficient	none
15	F_e	BETA	soil structure interaction factor	none
16	d_f	DF	depth of fluid	in.
18	E_c	EC	modulus of elasticity of concrete	ksi
19	E_s	ES	modulus of elasticity of steel	ksi
20	f_y	FY	specified yield strength of reinforcing	ksi
21	f'_c	FCP	specified compressive strength of concrete	ksi
22	L_{fmv}	FLMV	load factor for moment & shear	none
23	L_{fn}	FLN	oad factor for thrust	none
24	FCR	FCR	factor for crack control relative to I for 0.01 " crack	none
26	NLAY	NLAY	number of layers of circumferential reinforcing	none
27	RTYPE	RTYPE	type of reinforcing steel	none
30	t_{bI}	CT (I)	concrete cover over top slab outside steel (ASI)	in.
31	t_{b2}	CT (2)	concrete cover over side wall outside steel (ASI)	in.
32	t_{b3}	CT (3)	concrete cover over bottom slab outside steel (ASI)	in.
33	t_{b4}	CT (4)	concrete cover over top slab inside steel (AS2)	in.
34	t_{b5}	CT (5)	concrete cover over bottom slab inside steel (AS3)	in.
35	t_{b6}	CT (6)	concrete cover over side wall inside steel (AS4)	in.

Notes:
1. Some index numbers are not listed here because those slots in the array were not used.

Table B-4. Map of SDATA Array

Index of SDATA (Note 1)	Description	Units
	Wire diameter:	
I	- outside steel top slab	in.
2	- outside steel side wall	in.
3	- outside steel bottom slab	in.
4	- inside steel top slab	in.
5	- inside steel bottom slab	in.
6	- inside steel side wall	in.
	Wire Spacing:	
7	- outside steel top slab	in.
8	- outside steel side wall	in.
9	- outside steel bottom slab	in.
10	- inside steel top slab	in.
11	- inside steel bottom slab	in.
12	- inside steel side wall	in.
19	- length of outside steel in top slab	in.
20	- length of outside steel in bottom slab	in.
25	Lateral soil pressure ratio (Note 2)	none
	Depth of steel reinforcing:	
30	- outside steel top slab	in.
31	- outside steel side wall	in.
32	- outside steel bottom slab	in.
33	- inside steel top slab	in.
34	- inside steel bottom slab	in.
35	- inside steel side wall	in.

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

Table B-5. Description of Governing Mode Output Notes

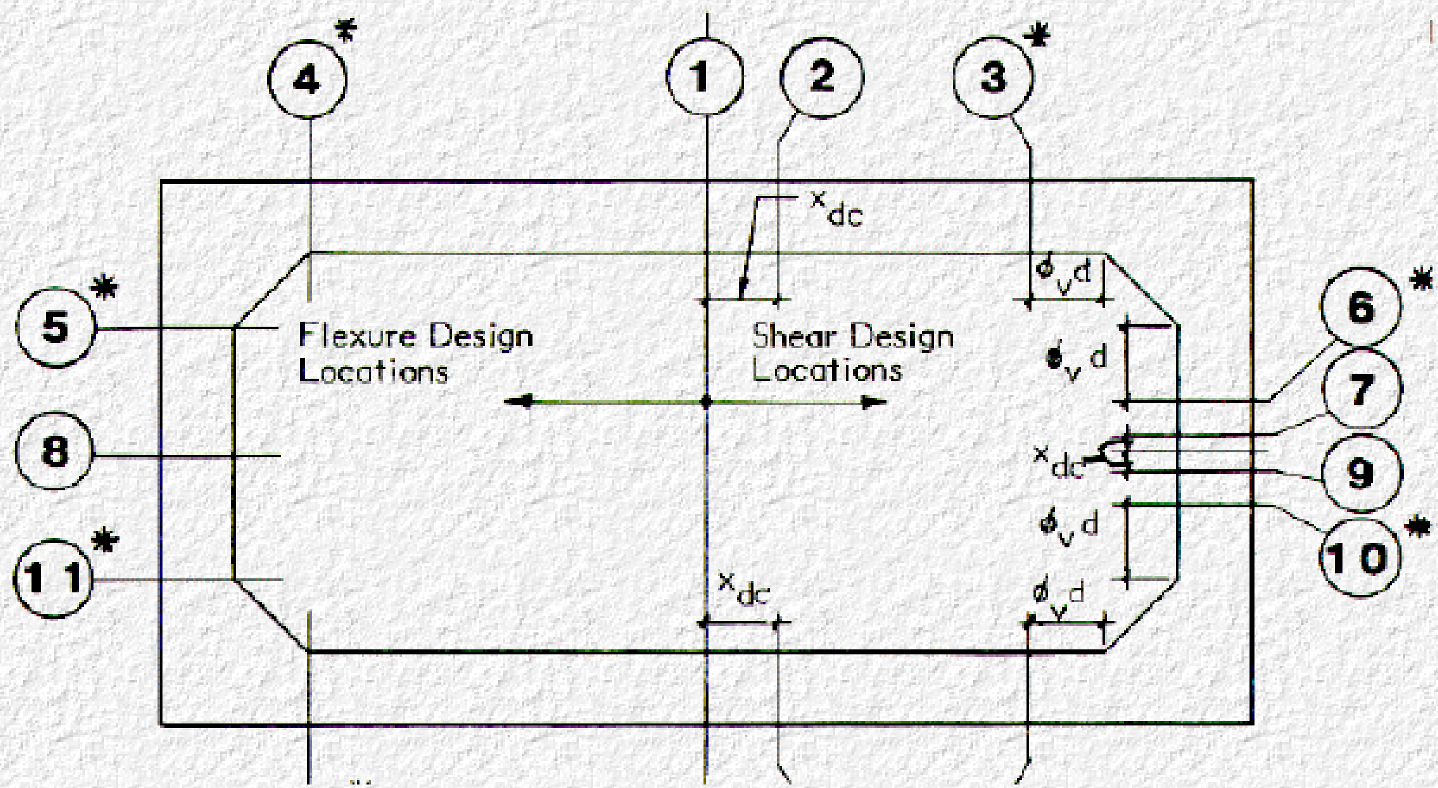
Output Note	Description

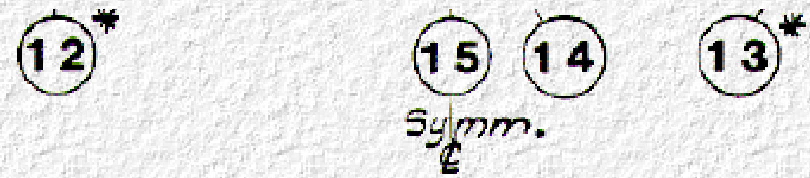
FLEXURE	Steel area based on ultimate flexural strength requirements.
MIN STEEL	Steel area based on minimum steel requirements.
CRACK WIDTH	Steel based on crock requirements at service load.
MAXCONCOMPR	Design by usual methods is not possible due to maximum concrete compression. Section must be designed as a compression member, or reanalyzed with a different wall thickness or installation conditions.

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).





Flexure Design Locations:

Steel Area	Precast	Cast-In-Place
A_{s1}	4, 5, 11, 12	5, 11, 12
A_{s2}	1	1
A_{s3}	15	15
A_{s4}	8	8
A_{s8}	-	4

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 $\phi_v d$ 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.

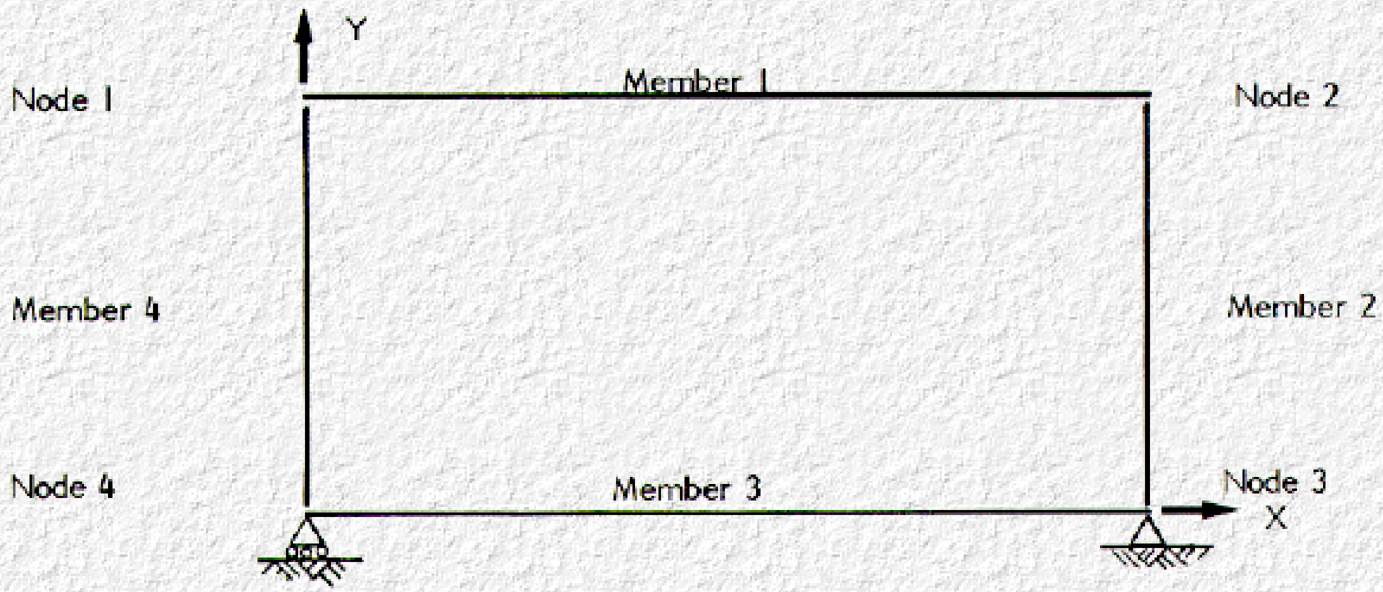
Figure B-1. Locations of Critical Sections for Shear and Flexure Design in Single Call Box Sections

---

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).



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.

Figure B-2. Frame Model Used for Computer Analysis of Box Sections

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Go to Appendix C

Appendix C : FHWA-IP-83-6

Users Manual - Pipe Design Program, Pipecar

Go to Appendix D

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 (l 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 C-1. Format for Data Input

	Code (Note 1)	Description (Note 2)	Name of Variable	Units	Default Values
Card Column	1-2	3-20	21-60		
Format	12	4A4, A2	4F10.3		
Required Data	01 (Note 3)	inside Diameter or Side Radius Crown/lnvert Radius Depth of Fill	B_i or r_1 r_2 H_e	in. in. ft.	None None None
	02 (Note 3)	Horizontal Offset Vertical Offset	u v	in. in.	None None
	03	Thickness	h	in.	None
	04	Bedding Angle Load Angle Soil Structure Int. Factor	β_2 β_1 F_e	Degrees Degrees None	90 (Note 4) 270 (Note 4) 1.2 (Note 6)

Optional Data (Note 5)	05	Soil Unit Weight Concrete Unit Weight Fluid Unit Weight	γ_s γ_c γ_f	pcf pcf pcf	120. 150. 62.5
	06	Depth of Fluid	d_f	in.	Dj
	07	Steel Yield Stress Concrete Compressive Stress	f_y f'_c	ksi ksi	65. 5.
	08	Outside Concrete Cover Inside Concrete Cover	t_{bo} t_{bi}	in. in.	1.0 1.0
	09	Load Factor Flexure Cap Red Factor Shear Cap Red Factor	L_f ϕ_f ϕ_v	None None None	1.3 0.9 0.9
	10	Inside Wire Diameter Outside Wire Diameter Reinforcing Type Number of Layers of Circumferential Reinforcing	d_{in} d_{out} RTYPE (Note7) NLAY	in. in. None None	0.08h 0.08h 2. 1.
	11	Inside Wire Spacing Outside Wire Spacing	$s\ell_{in.}$ $s\ell_{out}$	in. in.	2. 2.
	12	Limiting Crack Width Factor Radial Tension Process Factor Shear Process Factor	F_{cr} F_{rp} F_{vp}	None None None	1.0 1.0 1.0
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 mush be specified on the card with Code = 02. Note that for r > r, a horizontal ellipse will be designed, r1 > r2, would define a vertical ellipse, but this is not operational at this time.
4. The load Angle (β_1) must be between 180° and 300° and the bedding angle (β_2) must be between 60° and 180 . If ~ 1 +~2 > 360 then the program will set 02 = 360 - 0 1. 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 used.
6. If the soil structure interaction factor is input less than 0.75 it will default to 1.2.
7. RTYPE = I 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

DEBUG = 1

- Output from debug = 0
- Listing of BDATA and I BDATA arrays
- Table of ultimate forces
- Flexure design table
- Shear design table

DEBUG = 2

- Output from debug = I
- Pipe geometry
- Loads applied at each joint
- Pipe, soil, and fluid weights
- Service load moments, thrusts, and shears at each joint

DEBUG = 3

- Output from debug = 2
- Displacements

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  10X7-THROAT-RUND 8/4/82                    3
     1                        INSDDIAP(IN)     84.000                   DPTHFILL(FT)      7.500
     3                        THICKNES(IN)      8.000
        SOIL STRUCTURE INTERACTION FACTOR MODIFIED

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

b. Listing of BDATA Array

MAP OF BDATA ARRAY

	PARAMETER	DATA	SOURCE
1	SPRING RADIUS (IN)	42.000	INPUT
2	CROWN RADIUS (IN)	42.000	ASSUMED
3	HEIGHT OF FILL (FT)	7.500	INPUT
4	HORIZ OFFSET (IN)	0.000	ASSUMED
5	VERTICAL OFFSET (IN)	0.000	ASSUMED
6	WALL THICKNESS (IN)	6.000	INPUT
7	BEDDING ANGLE (DEG)	90.000	ASSUMED
8	SOIL-STRUC INT COEFF	1.200	ASSUMED
9	SOIL UNIT WT(LB/FT3)	120.000	ASSUMED
10	CONC UNIT WT(LB/FT3)	150.000	ASSUMED
11	FLUID UNT WT(LB/FT3)	62.500	ASSUMED
12	DEPTH OF FLUID (IN)	84.000	ASSUMED
13	TENSTRGTH STEEL(KSI)	65.000	ASSUMED
14	COMPSTRGTH CONC(KSI)	5.000	ASSUMED
15	CONCOV:OUT STEEL(IN)	1.000	ASSUMED
16	CONCOV:IN STEEL (IN)	1.000	ASSUMED
17	LOAD FACTOR: MOM,SHR	1.300	ASSUMED
18	LOAD FACTOR: THRUST	1.300	ASSUMED
19	INSIDE WIRE DIAM(IN)	0.0	NO VALUE
20	OUTSIDE WIREDIAM(IN)	0.0	NO VALUE
21	TYPE OF REINFORCING	2.000	ASSUMED
22	# LAYERS CIRCUM REIN	1.000	ASSUMED
23	SPCG INSD WIRES (IN)	2.000	ASSUMED
24	SPCG OUTSD WIRES(IN)	2.000	ASSUMED
25	CAP RED FACTOR FLEX	0.900	ASSUMED
26	CRACK FACTOR	1.000	ASSUMED
27	MODLS ELAS:STL (KSI)	29000.000	ASSUMED
28	MODLS ELAS:CONC(KSI)	4286.824	ASSUMED
29	MEAN RAD:SPRGLN (IN)	46.000	ASSUMED
30	MEAN RAD:CRWNIVT(IN)	46.000	ASSUMED
31	EQIV CIRC DIAM (IN)	84.000	ASSUMED
32	LOAD ANGLE (DEG)	270.000	ASSUMED
33	CAP RED FACTOR SHEAR	0.900	ASSUMED
34	RAD TENS PROC FACTOR	1.000	ASSUMED
35	SHEAR PROCESS FACTOR	1.000	ASSUMED

c. Pipe Geometry

GEOMETRY

I JOINT	DEG FROM VERTICAL	X(I) INCHES FROM CENTER	Y(I)	ALEN(I) INCHES	A(I) RADIANS	SI(I)	CO(I)
1	0.	0.0	-46.000	4.013	0.0	0.044	0.999
2	5.	4.009	-45.825	4.013	0.087	0.131	0.991
3	10.	7.988	-45.301	4.013	0.175	0.216	0.976
4	15.	11.906	-44.433	4.013	0.262	0.301	0.954
5	20.	15.733	-43.226	4.013	0.349	0.383	0.924
6	25.	19.440	-41.690	4.013	0.436	0.462	0.887
7	30.	23.000	-39.837	4.013	0.524	0.537	0.843
8	35.	26.384	-37.681	4.013	0.611	0.609	0.793
9	40.	29.568	-35.238	4.013	0.698	0.676	0.737
10	45.	32.527	-32.527	4.013	0.785	0.737	0.676
11	50.	35.238	-29.568	4.013	0.873	0.793	0.609
12	55.	37.681	-26.385	4.013	0.960	0.843	0.537
13	60.	39.837	-23.000	4.013	1.047	0.887	0.462
14	65.	41.690	-19.440	4.013	1.134	0.924	0.383
15	70.	43.226	-15.733	4.013	1.222	0.954	0.301
16	75.	44.433	-11.906	4.013	1.309	0.976	0.216
17	80.	45.301	-7.988	4.013	1.396	0.991	0.131
18	85.	45.825	-4.009	4.013	1.484	0.999	0.044
19	90.	46.000	-0.000	4.013	1.571	0.999	-0.044
20	95.	45.825	4.009	4.013	1.658	0.991	-0.131
21	100.	45.301	7.988	4.013	1.745	0.976	-0.216
22	105.	44.433	11.906	4.013	1.833	0.954	-0.301
23	110.	43.226	15.733	4.013	1.920	0.924	-0.383
24	115.	41.690	19.440	4.013	2.007	0.887	-0.462
25	120.	39.837	23.000	4.013	2.094	0.843	-0.537
26	125.	37.681	26.384	4.013	2.182	0.793	-0.609
27	130.	35.238	29.568	4.013	2.269	0.737	-0.676
28	135.	32.527	32.527	4.013	2.356	0.676	-0.737
29	140.	29.568	35.238	4.013	2.443	0.609	-0.793
30	145.	26.385	37.681	4.013	2.531	0.537	-0.843
31	150.	23.000	39.837	4.013	2.618	0.462	-0.887
32	155.	19.440	41.690	4.013	2.705	0.383	-0.924
33	160.	15.733	43.226	4.013	2.793	0.301	-0.954
34	165.	11.906	44.433	4.013	2.880	0.216	-0.976
35	170.	7.988	45.301	4.013	2.967	0.131	-0.991
36	175.	4.009	45.825	4.013	3.054	0.044	-0.999
37	180.	0.000	46.000	0.0	3.142	0.0	0.0

d. Joint Pressure

		LOADS AT EACH JOINT, KIPS/IN/FOOT					
		DEAD		SOIL		FLUID	
I	DEG FROM VERTICAL	RADIAL	TANG	RADIAL	TANG	RADIAL	TANG
1	0.	-0.008333	0.0	0.249577	0.0	0.022972	0.0
2	5.	-0.008302	0.000726	0.245785	0.0	0.022181	0.0
3	10.	-0.008207	0.001447	0.234526	0.0	0.019832	0.0
4	15.	-0.008049	0.002157	0.216140	0.0	0.016002	0.0
5	20.	-0.007831	0.002850	0.191187	0.0	0.010813	0.0
6	25.	-0.007553	0.003522	0.160425	0.0	0.004435	0.0
7	30.	-0.007217	0.004167	0.124789	0.0	-0.002928	0.0
8	35.	-0.006826	0.004780	0.085361	0.0	-0.011036	0.0
9	40.	-0.006384	0.005357	0.043339	0.0	-0.019625	0.0
10	45.	-0.005893	0.005893	0.000000	0.0	-0.028413	0.0
11	50.	-0.005357	0.006384	0.008044	0.0	-0.027343	0.0
12	55.	-0.004780	0.006826	0.016060	0.0	-0.026191	0.0
13	60.	-0.004167	0.007217	0.024122	0.0	-0.024966	0.0
14	65.	-0.003522	0.007553	0.031953	0.0	-0.023678	0.0
15	70.	-0.002850	0.007831	0.039676	0.0	-0.022337	0.0
16	75.	-0.002157	0.008049	0.047314	0.0	-0.020952	0.0
17	80.	-0.001447	0.008207	0.054793	0.0	-0.019534	0.0
18	85.	-0.000726	0.008302	0.062086	0.0	-0.018095	0.0
19	90.	0.0	0.008333	0.069169	0.0	-0.016644	0.0
20	95.	0.000726	0.008302	0.076017	0.0	-0.015193	0.0
21	100.	0.001447	0.008207	0.082609	0.0	-0.013754	0.0
22	105.	0.002157	0.008049	0.088921	0.0	-0.012336	0.0
23	110.	0.002850	0.007831	0.094933	0.0	-0.010951	0.0
24	115.	0.003522	0.007553	0.100623	0.0	-0.009610	0.0
25	120.	0.004167	0.007217	0.105972	0.0	-0.008322	0.0
26	125.	0.004780	0.006826	0.110963	0.0	-0.007097	0.0
27	130.	0.005357	0.006384	0.115579	0.0	-0.005945	0.0
28	135.	0.005893	0.005893	0.119805	0.0	-0.004875	0.0
29	140.	0.006384	0.005357	0.123623	0.0	-0.003894	0.0
30	145.	0.006826	0.004780	0.127023	0.0	-0.003010	0.0
31	150.	0.007217	0.004167	0.129994	0.0	-0.002230	0.0
32	155.	0.007553	0.003522	0.132526	0.0	-0.001559	0.0
33	160.	0.007831	0.002850	0.134608	0.0	-0.001004	0.0
34	165.	0.008049	0.002157	0.136236	0.0	-0.000567	0.0
35	170.	0.008207	0.001447	0.137402	0.0	-0.000253	0.0
36	175.	0.008302	0.000726	0.138103	0.0	-0.000063	0.0
37	180.	0.008333	0.0	0.138337	0.0	0.0	0.0

PIPE WEIGHT= 2.400 KIPS/FOOT

SOIL WEIGHT= 10.667 KIPS/FOOT

FLUID WEIGHT= 2.400 KIPS/FOOT

e. Joint Daplacement Table

DISPLACEMENTS, INCHES

	LOADING 1	2	3	LOADING 1	2	3	LOADING 1	2	3
ELEMENT	1			2			3		
X	0.0	0.0	0.0	0.36183D-05	-0.24396D-04	0.83926D-05	0.31063D-04	0.28198D-04	0.33172D-04
Y	0.0	0.0	0.0	-0.91191D-04	-0.22724D-03	-0.47930D-04	-0.34028D-03	-0.89386D-03	-0.18879D-03
ROT	0.0	0.0	0.0	-0.44001D-04	-0.11219D-03	-0.23976D-04	-0.79586D-04	-0.21938D-03	-0.46989D-04
ELEMENT	4			5			6		
X	0.10267D-03	0.22676D-03	0.69107D-04	0.24621D-03	0.62589D-03	0.18782D-03	0.44769D-03	0.12561D-02	0.33656D-03
Y	-0.73954D-03	-0.19559D-02	-0.41368D-03	-0.11623D-02	-0.33444D-02	-0.70801D-03	-0.16634D-02	-0.49714D-02	-0.10535D-02
ROT	-0.13721D-03	-0.31680D-03	-0.68021D-04	-0.12739D-03	-0.40821D-03	-0.86159D-04	-0.14069D-03	-0.46612D-03	-0.10064D-03
ELEMENT	7			8			9		
X	0.71027D-03	0.21285D-02	0.53742D-03	0.10254D-02	0.32248D-02	0.78708D-03	0.13803D-02	0.45853D-02	0.10772D-02
Y	-0.21913D-02	-0.67378D-02	-0.14292D-02	-0.26886D-02	-0.85419D-02	-0.18134D-02	-0.31628D-02	-0.10288D-01	-0.21855D-02
ROT	-0.14769D-03	-0.51197D-03	-0.11091D-03	-0.14903D-03	-0.53633D-03	-0.11664D-03	-0.14535D-03	-0.53905D-03	-0.11776D-03
ELEMENT	10			11			12		
X	0.17569D-02	0.59167D-02	0.13952D-02	0.21435D-02	0.73696D-02	0.17260D-02	0.25198D-02	0.88068D-02	0.20531D-02
Y	-0.35869D-02	-0.11895D-01	-0.25280D-02	-0.39496D-02	-0.13382D-01	-0.28274D-02	-0.42491D-02	-0.14471D-01	-0.30755D-02
ROT	-0.13731D-03	-0.52131D-03	-0.11447D-03	-0.12557D-03	-0.48568D-03	-0.10729D-03	-0.11082D-03	-0.43533D-03	-0.96824D-04
ELEMENT	13			14			15		
X	0.28583D-02	0.10149D-01	0.23683D-02	0.31551D-02	0.11329D-01	0.26327D-02	0.33928D-02	0.12299D-01	0.28574D-02
Y	-0.44724D-02	-0.15391D-01	-0.32689D-02	-0.46355D-02	-0.16068D-01	-0.34088D-02	-0.47421D-02	-0.16527D-01	-0.35001D-02
ROT	-0.92685D-04	-0.37340D-03	-0.83722D-04	-0.74820D-04	-0.30289D-03	-0.68602D-04	-0.54836D-04	-0.22661D-03	-0.52066D-04
ELEMENT	16			17			18		
X	0.35613D-02	0.12989D-01	0.30240D-02	0.36540D-02	0.13397D-01	0.31256D-02	0.36683D-02	0.13499D-01	0.31585D-02
Y	-0.48028D-02	-0.16807D-01	-0.35511D-02	-0.48305D-02	-0.16955D-01	-0.35721D-02	-0.48389D-02	-0.17026D-01	-0.35750D-02
ROT	-0.34417D-04	-0.14728D-03	-0.34686D-04	-0.13812D-04	-0.67899D-04	-0.17808D-04	0.61727D-05	0.11685D-04	0.48949D-06
ELEMENT	19			20			21		
X	0.36246D-02	0.13299D-01	0.31226D-02	0.34661D-02	0.12812D-01	0.30218D-02	0.32663D-02	0.12069D-01	0.28599D-02
Y	-0.48423D-02	-0.17073D-01	-0.35719D-02	-0.48538D-02	-0.17150D-01	-0.35746D-02	-0.48855D-02	-0.17303D-01	-0.35940D-02
ROT	0.25176D-04	0.86559D-04	0.17328D-04	0.42786D-04	0.15638D-03	0.33105D-04	0.58646D-04	0.21943D-03	0.47463D-04
ELEMENT	22			23			24		
X	0.30094D-02	0.11110D-01	0.26482D-02	0.27109D-02	0.99847D-02	0.23964D-02	0.23833D-02	0.87468D-02	0.21167D-02
Y	-0.49471D-02	-0.17570D-01	-0.36388D-02	-0.50454D-02	-0.17980D-01	-0.37158D-02	-0.51847D-02	-0.18549D-01	-0.38270D-02
ROT	0.72454D-04	0.27447D-03	0.60297D-04	0.83966D-04	0.32049D-03	0.70756D-04	0.92996D-04	0.35673D-03	0.79247D-04
ELEMENT	25			26			27		
X	0.20413D-02	0.74561D-02	0.18216D-02	0.16989D-02	0.61523D-02	0.15237D-02	0.13698D-02	0.49037D-02	0.12348D-02
Y	-0.53659D-02	-0.19281D-01	-0.39794D-02	-0.55866D-02	-0.20166D-01	-0.41656D-02	-0.58417D-02	-0.21184D-01	-0.43831D-02
ROT	0.99417D-04	0.38268D-03	0.85432D-04	0.10314D-03	0.39808D-03	0.89238D-04	0.10422D-03	0.40289D-03	0.90616D-04
ELEMENT	28			29			30		
X	0.10631D-02	0.37469D-02	0.96511D-03	0.79021D-03	0.27243D-02	0.72426D-03	0.55705D-03	0.18558D-02	0.51539D-03
Y	-0.61234D-02	-0.22366D-01	-0.46253D-02	-0.64220D-02	-0.23491D-01	-0.48835D-02	-0.67259D-02	-0.24696D-01	-0.51476D-02
ROT	0.10264D-03	0.39738D-03	0.89617D-04	0.98915D-04	0.38171D-03	0.86311D-04	0.91993D-04	0.35670D-03	0.80824D-04
ELEMENT	31			32			33		
X	0.36736D-03	0.11581D-02	0.34517D-03	0.22197D-03	0.63449D-03	0.21359D-03	0.11876D-03	0.27663D-03	0.11902D-03
Y	-0.70228D-02	-0.25872D-01	-0.54066D-02	-0.73003D-02	-0.26970D-01	-0.56495D-02	-0.75468D-02	-0.27943D-01	-0.58653D-02
ROT	0.82268D-04	0.32504D-03	0.73326D-04	0.72573D-04	0.28166D-03	0.64026D-04	0.60188D-04	0.23563D-03	0.53170D-04
ELEMENT	34			35			36		
X	0.52974D-04	0.65718D-04	0.57378D-04	0.17469D-04	-0.26262D-04	0.22478D-04	0.32462D-05	-0.34679D-04	0.63775D-05
Y	-0.77584D-02	-0.28749D-01	-0.60445D-02	-0.79029D-02	-0.29352D-01	-0.61787D-02	-0.79973D-02	-0.29724D-01	-0.62618D-02
ROT	0.46391D-04	0.18013D-03	0.41832D-04	0.31552D-04	0.12245D-03	0.27910D-04	0.15949D-04	0.61940D-04	0.14123D-04
ELEMENT	37								
X	0.0	0.0	0.0						
Y	-0.80293D-02	-0.29851D-01	-0.62980D-02						
ROT	0.0	0.0	0.0						

f. Moments, Thrusts and Shears at Joints

SERVICE LOAD THRUST(KIPS/FT), SHEAR(KIPS/FT), MOMENT(IN.KIPS/FT)

JOINT	LEG. FROM VERTICAL	DEAD LOAD N	DEAD LOAD V	DEAD LOAD M	SOIL LOAD N	SOIL LOAD V	SOIL LOAD M	FLUID LOAD N	FLUID LOAD V	FLUID LOAD M
1	0.	0.1902	1.2027	26.4381	3.5193	-0.6002	61.7218	-0.6454	-0.0150	13.2007
2	5.	0.2911	1.1472	21.7164	3.5459	0.6855	60.3391	-0.6397	0.1317	12.9456
3	10.	0.3842	1.0846	17.2305	3.6341	1.3357	56.2613	-0.6221	0.2711	12.1522
4	15.	0.4686	1.0148	13.0136	3.7761	1.9164	49.7907	-0.5934	0.3960	10.8064
5	20.	0.5439	0.9387	9.1066	3.9644	2.3958	41.0016	-0.5539	0.4999	8.9988
6	25.	0.6095	0.8575	5.4769	4.1089	2.7453	30.6232	-0.5069	0.5768	6.8254
7	30.	0.6652	0.7722	2.2027	4.4371	2.9410	19.1446	-0.4545	0.6218	4.4059
8	35.	0.7129	0.6839	-0.7722	4.6949	2.9639	7.2217	-0.3998	0.6311	1.8764
9	40.	0.7463	0.5978	-3.2883	4.9466	2.8012	-4.4240	-0.3460	0.6021	-0.6143
10	45.	0.7716	0.5029	-5.4904	5.1758	2.4462	-15.0315	-0.2964	0.5338	-2.9098
11	50.	0.7869	0.4123	-7.3272	5.3700	2.0019	-23.9626	-0.2536	0.4459	-4.8780
12	55.	0.7925	0.3230	-8.8027	5.5261	1.5745	-31.1439	-0.2184	0.3591	-6.4954
13	60.	0.7888	0.2360	-9.9242	5.6458	1.1672	-36.6495	-0.1908	0.2744	-7.7684
14	65.	0.7761	0.1522	-10.7012	5.7309	0.7827	-40.5591	-0.1704	0.1925	-8.7053
15	70.	0.7550	0.0776	-11.1502	5.7836	0.4236	-42.9761	-0.1574	0.1145	-9.3213
16	75.	0.7262	-0.0021	-11.2883	5.8861	0.0921	-44.0035	-0.1502	0.0410	-9.6324
17	80.	0.6904	-0.0712	-11.1372	5.8010	-0.2098	-43.7573	-0.1496	-0.0271	-9.6587
18	85.	0.6483	-0.1340	-10.7207	5.7708	-0.4805	-42.3598	-0.1547	-0.0893	-9.4228
19	90.	0.6008	-0.1901	-10.0653	5.7185	-0.7188	-39.9390	-0.1649	-0.1451	-8.9496
20	95.	0.5487	-0.2388	-9.1992	5.6468	-0.9237	-36.6271	-0.1797	-0.1939	-8.2661
21	100.	0.4929	-0.2799	-8.1527	5.5586	-1.0947	-32.5606	-0.1985	-0.2355	-7.4010
22	105.	0.4344	-0.3131	-6.9566	5.4573	-1.2315	-27.8753	-0.2205	-0.2695	-6.3838
23	110.	0.3741	-0.3384	-5.6476	5.3451	-1.3342	-22.7077	-0.2452	-0.2959	-5.2448
24	115.	0.3129	-0.3556	-4.2434	5.2255	-1.4033	-17.1948	-0.2718	-0.3146	-4.0153
25	120.	0.2519	-0.3648	-2.7911	5.1014	-1.4397	-11.4705	-0.2998	-0.3256	-2.7260
26	125.	0.1918	-0.3663	-1.3180	4.9755	-1.4444	-5.6653	-0.3284	-0.3291	-1.4088
27	130.	0.1335	-0.3601	0.1454	4.8505	-1.4188	0.0370	-0.3570	-0.3254	-0.0906
28	135.	0.0780	-0.3468	1.5694	4.7269	-1.3648	5.6988	-0.3849	-0.3147	1.1976
29	140.	0.0261	-0.3267	2.9269	4.6133	-1.2842	11.0328	-0.4116	-0.2975	2.4305
30	145.	-0.0216	-0.3004	4.1899	4.5057	-1.1795	15.9991	-0.4366	-0.2743	3.5812
31	150.	-0.0644	-0.2685	5.3356	4.4082	-1.0529	20.4823	-0.4593	-0.2457	4.6279
32	155.	-0.1017	-0.2316	6.3428	4.3227	-0.9074	24.4274	-0.4795	-0.2124	5.5498
33	160.	-0.1329	-0.1905	7.1928	4.2505	-0.7457	27.7537	-0.4962	-0.1749	6.3291
34	165.	-0.1576	-0.1459	7.8704	4.1930	-0.5709	30.4921	-0.5097	-0.1341	6.9519
35	170.	-0.1755	-0.0987	8.3624	4.1512	-0.3862	32.3267	-0.5195	-0.0908	7.4033
36	175.	-0.1864	-0.0498	8.6616	4.1258	-0.1948	33.4959	-0.5255	-0.0459	7.6785
37	180.	-0.1902	0.0	8.7619	4.1213	0.0	33.8877	-0.5280	0.0	7.7707

g. Table of Ultimate Forces

TABLE OF ULTIMATE FORCES

DESIGN LOCATION DEG FROM INVERT	MOMENT IN.KIPS/FOOT	THRUST KIPS/FOOT	SHEAR KIPS/FOOT
0.0	131.769	3.983	0.0
17.92	84.968	5.744	4.711
75.00	-84.401	8.297	0.170
148.88	37.725	5.097	2.092
180.00	65.546	4.424	0.0

h. Flexure Design Table

FLEXURE DESIGN TABLE

DESIGN LOCATION DEG FROM INVERT	DESIGN VALUES: REINFORCING FLEXURE SQ.IN./FT	REINFORCING CRACK CONTROL SQ.IN./FT	CRACK INDEX	RADIAL TENSION INDEX	GOVERNING DESIGN: AREA SQ.IN./FT	STEEL RATIO	STIRRUP FACTOR	STIRRUP EXTENT IN.	GOVERNING MODE
0.0	0.311	0.110	0.353	0.460	0.311	0.0043	0.0	0.0	FLEXURE
75.00	0.139	0.0	0.0	0.0	0.139	0.0019	0.0	0.0	FLEXURE
180.00	0.130	0.0	0.0	0.204	0.130	0.0018	0.0	0.0	MIN STEEL

i. Shear Design Table

SHEAR DESIGN TABLE

DESIGN LOCATION DEG FROM INVERT	REQUIRED REINFORCING SQ.IN./FT	STEEL RATIO	STIRRUP FACTOR	STIRRUP EXTENT IN.	GOVERNING MODE
17.92	0.0	0.0	0.0	0.0	DOESNOTGOVRN
148.88	0.0	0.0	0.0	0.0	DOESNOTGOVRN

j. Summary Table for Design

84.0INCH DIAMETER REINFORCED CONCRETE CIRCULAR PIPE

I N S T A L L A T I O N D A T A	
HEIGHT OF FILL ABOVE CROWN, FT.	7.50
UNIT WEIGHT, PCF	120.00
SOIL-STRUCTURE INTERACTION COEFFICIENT	1.20
BEDDING ANGLE, DEGREES	90.00
LOAD ANGLE, DEGREES	270.00

M A T E R I A L P R O P E R T I E S	
STEEL - MINIMUM SPECIFIED YIELD STRESS, PSI	65000.
REINFORCING TYPE	2.
NO. OF LAYERS OF REINFORCING	1.
CONCRETE - SPECIFIED COMPRESSIVE STRESS, PSI	5000.

L O A D I N G D A T A	
LOAD FACTOR - MOMENT AND SHEAR	1.30
LOAD FACTOR - THRUST	1.30
STRENGTH REDUCTION FACTOR-FLEXURE	0.90
STRENGTH REDUCTION FACTOR-DIAGONAL TENSION	0.90
LIMITING CRACK WIDTH FACTOR	1.00

P I P E D A T A	
WALL THICKNESS, IN.	8.00
INSIDE CONCRETE COVER OVER STEEL, IN.	1.00
OUTSIDE CONCRETE COVER OVER STEEL, IN.	1.00

F L U I D D A T A	
FLUID DENSITY, PCF.	62.50
DEPTH OF FLUID,INCHES ABOVE INVERT	84.00

R E I N F O R C I N G S T E E L D A T A	
INVERT- INSIDE REINFORCING, SQ.IN./FT.	0.311
SPRINGLINE- OUTSIDE REINFORCING, SQ.IN./FT.	0.139
CROWN- INSIDE REINFORCING, SQ.IN./FT.	0.130

C.2.2 Debug = 1

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.

C.2.3 Debug = 2

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.

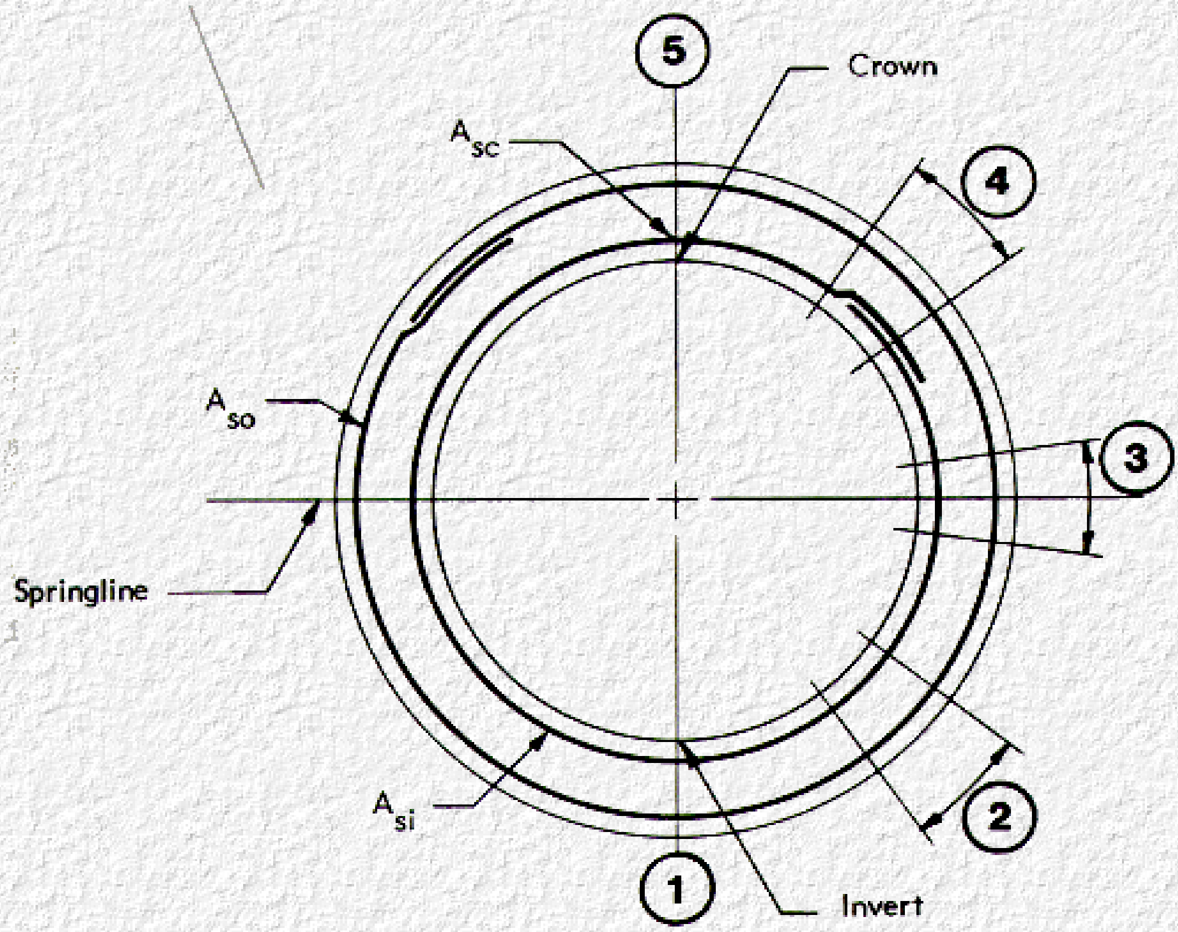
Loads Applied at Each Joint: This table (Table C-2d) lists the radial and tangential pressure at each joint due to earth, fluid and dead load. The units are kips per circumferential inch per longitudinal foot.

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.

C.2.4 Debug = 3

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.



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 $M/V\phi_v d = 3.0$

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.

Figure C-1. Typical Reinforcing Layout and Locations of Critical Sections for Shear and Flexure Design in Pipe Setions

Table C-3. Map of BDATA Array

Index of BDATA	Notation		Description	Units
	Design Method	Computer Code		
1	r_I	RADI I	inside radius, side	in.
2	r_2	RADI 2	inside radius, crown & invert	in.
3	H_e	H	depth of fill	ft.
4	u	U	horizontal offset distance	in.
5	v	V	vertical offset distance	in.

6	h	T_H	wall thickness	in.
7	b_2	BETA	bedding angle	degrees
8	F_e	HH	soil structure int. factor	none
9	g_s	GAMAS	soil unit weight	lb/ft^3
10	g_c	GAMAC	concrete unit weight	lb/ft^3
11	g_f	GAMAF	fluid unit weight	lb/ft^3
12	d_f	DF	depth of internal fluid	in.
13	f_y	FY	reinforcing yield strength	kips/in.^{2}
14	f'_c	FCP	concrete compressive strength	kips/in.
15	t_{bo}	COUT	cover over outside reinforcing	in.
16	t_{bi}	CIN	cover over inside reinforcing	in.
17	L_{fmv}	FLMV	load factor, moment, shear	none
18	L_{fn}	FLN	load factor, thrust	none
19	wd_i	DIN	diameter of inside reinforcing	in.
20	wd_o	DOUT	diameter of outside reinforcing	in.
21	RTYPE	RTYPE	reinforcing type	none
22	n	NLAY	number of layers of reinforcing	none
23	$S_{\ell i}$	SPIN	spacing of inside reinforcing	in.
24	$S_{\ell o}$	SPOUT	spacing of outside reinforcing	in.
25	ϕ_f	PO	strength reduction factor, flexure	none
26	F_{cr}	FCR	crack width factor	none
27	E_s	EST	modulus of elasticity - steel	kips/in.^{2}
28	E_c	ECON	modulus of elasticity - concrete	kips/in.
29	r_{m1}	RADMI	mean radius, side	in.
30	r_{m2o}	RADM2	mean radius, crown, invert	in.
31	D_{eq}	EQUID	equivalent circular diameter	in.
32	β_1	BETAS	load angle	degrees
33	ϕ_d	POD	strength reduction factor, diagonal tension	none
34	F_{rp}	FRP	radial tension strength process factor	none
35	F_v	FVP	diagonal tension strength process factor	none

Table C-4. Description of Governing Mode Output Notes

Output Note	Description
FLEXURE	Steel area based on ultimate flexural strength requirements.
MIN STEEL	Steel area based on minimum steel requirements.
CRACK	Steel based on crack requirements at service load.
RADTEN + FLEX	Steel area based on ultimate flexural strength requirements, but stirrups are required to meet radial tension requirements.
RADTEN + CR	Steel area based on crack requirements but stirrups required to meet radial tension requirements.
DT NOSTIRUPS	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.
DT + STIRRUPS	Diagonal tension strength is exceeded based on steel required for flexure or crack. Stirrups must be used.
MAXCONCOMPR	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.

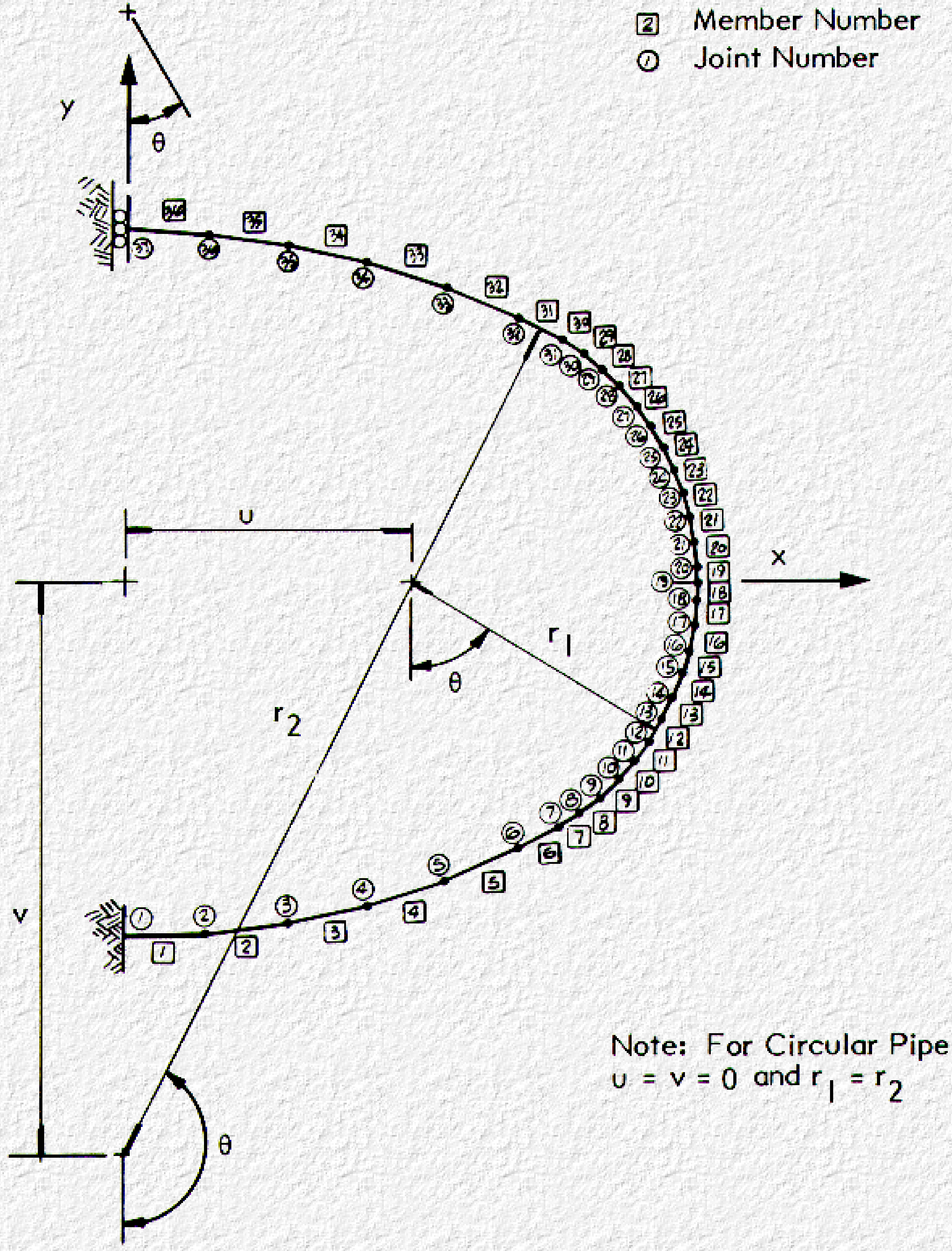


Figure C-2. Frame Model Used for Computer Analysis of Circular an Elliptical Pipe

Go to Appendix D

Appendix D : FHWA-IP-83-6

Design Examples

[Go to Appendix E]

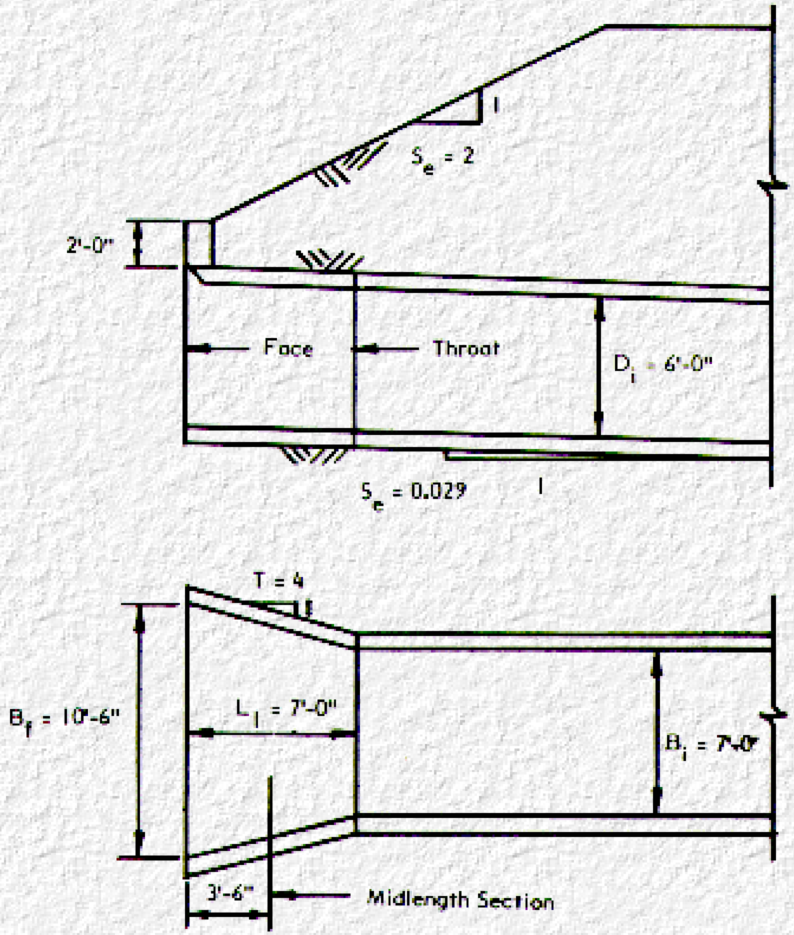
D.1 Side Tapered Box Section Inlet Design Example

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.



Given Data		
	Face	Throat
B_i	10.5 ft	7.0 ft
D_i	6.0 ft	6.0 ft
T_T, T_B, T_S	8 in. *	
H_H, H_V	8 in.	
γ_s	120 pcf	
γ_c	150 pcf	
γ_f	62.5 pcf	
$\alpha_{min.}$	0.25	
$\alpha_{max.}$	0.50	
ϕ_f	0.90	
ϕ_v	0.85	
F_{cr}	1.0	
f_y	60.0 ksi	
f'_c	3.0 ksi	
t_{bo}	2.0 in.	
t_{bi}	1.0 in.	
L_f	1.3	
R Type	3 = Def. bar	
F_{vp}	1.0	

Note: Add 2' surcharge for miscellaneous unanticipated loads.

* Estimated wall thickness = $T = \frac{B_i}{12} + 1 = \frac{84}{12} + 1 = 8"$

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

H_e' @ Face $=H_e+D_i/2+T_T=4+6/2+8/12=7.67'$ Say 8'-0"

H_e @ Throat	$=4+L_1\,(1/S_e+S_o)=4+7\,(½=0.029)=7.7'$	Say 8'-0"
H_e' @ Throat	$=7.7'+3.67'=11.37'$	Say 11'-6"
H_e @ Midlength	$=4+7/2(½+0.029)=5.85'$	Say 6'-0"
B_i @ Midlength	$=\dfrac{10.5+7}{2}=8.75'$	
H_e @ Midlength	$=6+3.67=9.67'$	Say 10'-0"

D.1.3 Calculate Soil Pressure

Throat

p_v $=\gamma_s H_e F_e=\gamma_c T_T=2\gamma_c D'\,T_S/B'$ Eq.31

D' $=6+8/12=6.67'$; $B'=7+8/12=7.67'$

p_v $=(120)(8)(1.2)+(150)(8/12)+(2)(150)(6.67)(8/12)/7.67'$ =1,426 psf =118.8 lb/in/ft

$p_{smax.}$ $=\alpha_{max.}\,\gamma_s H'_e=(0.5)(120)(11.5)=690$ psf =57.5 lb/in/ft Eq. 3.2

$p_{smin.}$ $=\alpha_{max.}\,\gamma_s H'_e-\gamma_f\,\dfrac{(D'-T_T)^2}{2R'}$ Eq. 3.3

$$= (0.25)(120)(11.5)-62.5\,\frac{(6.67-\frac{8}{12})^2}{(2)(6.67)} = 176 \text{ psf}$$

= 14.7 lb/in/ft

Face

D' $=6+8/12=6.67'$; $B'=10.5+8/12=11.17'$

p_v $=(120)(4)(1.2)+(150)(8/12)+(2)(150)(6.67)(8/12)/11.17=795$ psf =66.3 lb/in/ft Eq. 3.1

$p_{smax.}$ =(0.5)(120)(8)=480 psf =40 lb.in/ft Eq. 3.2

$p_{smin.}$ $=(0.25)(120)(8) - 62.5\,\dfrac{(6.67-\frac{8}{12})^2}{(2)(6.67)}$ =71 psf Eq. 3.3

=5.9 lb/in/ft

Midlength

D' =6+8/12=6.67'; B'=8.75+8/12=9.42'

p_v =(120)(6)(1.2) +(150)(8/12)+
(2)(150)(6.67)(8/12)/9.42=1,106 psf Eq. 3.1
=92.1 lb/in/ft

$p_{smax.}$ =(0.5)(120)(10)=600 psf =50 lb.in/ft Eq. 3.2

$p_{smin.}$ $=(0.25)(120)(10) - \dfrac{(62.5)(6.67-\frac{8}{12})^2}{(2)(6.67)}$ =131 psf Eq. 3.3

=10.9 lb/in/ft

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: $M_b(x) = \begin{Bmatrix} M_{o\ max} \\ M_{o\ min} \end{Bmatrix}^* + 0.5p_v x(B'-x)$ Eq. 3.9

Moment in sidewall: $M_s(y) = \begin{Bmatrix} M_{o\ max} \\ M_{o\ min} \end{Bmatrix}^* + \begin{Bmatrix} p_{s\ max} \\ p_{s\ min} \end{Bmatrix}^* 0.5y(D'-y)$ Eq. 3.10

where:

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

$$G_1 = \frac{T_T^3 D'}{T_S^3 B'} \quad \text{Eq. 3.4}$$

$$G_2 = \frac{9H_H^5}{D'B'T_S^3}\left(1-\frac{T_T}{D'}\right) \quad \text{Eq. 3.5}$$

$$G_3 = \frac{2H_H^3}{B'}\left(\frac{1}{T_T^2}+\frac{T_T}{T_S^3}\right) \quad \text{Eq. 3.6}$$

$$G_4 = \frac{6H_H}{B'}\left(1.02-\frac{3T_T}{B'}+\frac{T_T^3}{T_S^3}\right) \quad \text{Eq. 3.7}$$

* Use $\dfrac{M_{omax.}}{M_{smin.}}$ or $\dfrac{M_{omin.}}{M_{smin.}}$ as follows:

Location 8, 9, and 10, use P_{smax} only

Locations 11, 12, and 13 check both $P_{smax.}$ and $P_{smin.}$ for governing case.

Locations 14 and 15 use $p_{smin.}$ only.

Design Shears

Shear in bottom slab:

$V_b\,(x) = p_V(B'/2 - x)$ Eq. 3.11

Shear in sidewall:

$V_s\,(y) = p_{smax.}\,(D'/2 - y)$ Eq. 3.12

Design Thrusts

Thrust in bottom slab:

$$\begin{Bmatrix} N_{b\,max} \\ N_{b\,min} \end{Bmatrix} = \begin{Bmatrix} p_{s\,max} \\ p_{s\,min} \end{Bmatrix}^{*} \frac{D'}{2} \qquad \text{Eq. 3.13}$$

Thrust in sidewall:

$$N_s = \frac{p_v B'}{2} \qquad \text{Eq. 3.14}$$

Throat - Design Moments

$$G_1 = \frac{(8/12)^3 (6.67)}{(8/12)^3 (7.67)} = 0.870 \qquad \text{Eq. 3.4}$$

$$G_2 = \frac{(9)(8/12)^5}{(6.67)(7.67)(8/12)^3}\left(1 - \frac{8/12}{6.67}\right) = 0.70 \qquad \text{Eq. 3.5}$$

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

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

$$M_o = \frac{(-118.8)(92)^2}{12}\left(\frac{1-(1.5)(0.348)+(0.5)(0.917)}{1+0.870-0.348}\right) - \begin{Bmatrix} P_{smax.} \\ P_{smin.} \end{Bmatrix}\left[\frac{(80)^2}{12}\left(\frac{0.87-0.070}{1+0.870-0.348}\right)\right] \qquad \text{Eq. 3.8}$$

$$= -51558.9 - \begin{Bmatrix} P_{smax.} \\ P_{smin.} \end{Bmatrix} 280.33 \qquad \text{Eq. 3.8}$$

$M_{omax.}$ = -51558.9-(57.5)(280.33)= -67680 in-lb/ft

$M_{omin.}$ = -51558.9-(14.7)(280.33)= -55680 in-lb/ft

Throat - Design Moments

Design Location	Coordinat x (in)	y (in)	Moment $p_{smin.}$ (in-lb/ft)	$p_{smax.}$ (in-lb/ft)	
8 11	- -	40.00 12.00	- -49680	-21630 -44210	Sidewall moment Eq. 3.10
12 15	12.00 46.00	- -	1370 70010	-10630 -	Bottom slab moment Eq. 3.9

Throat - Design Shears

d_{inner} = (0.96(8)-1) = 6.68 in

d_{outer} =(0.96(8)-2) = 5.68 in

$\phi_v d_{inner}$ = 0.85 (6.86) =5.68 in

$\phi_v d_{outer}$ = 0.85 (5.86) = 4.83 in

$$x_{dc} = 3\left[\sqrt{(\phi_v d)^2 + \frac{2M_c}{9w}} - \phi_v d\right] @ \frac{M_u}{V_u \phi_v d} = 3.0$$ Eq. 4.22

@Design Location 9

$M_8 < 0$ do not investigate

@ Design Location 14 (positive moment region)

$$x_{dc} = 3\left[\sqrt{(5.68)^2 + \frac{(2)(70010)}{(9)(118.8)}} - 5.68\right] = 21.29\,\text{in}$$

$x_{coord@14}$ = 46.00 - 21.29 = 24.71 in

Throat - Design Shears

Design Location	Coordinat x (in)	y (in)	Design Shear (lbs/ft)	
9 10 11	No Check $M_8 < 0$			Shear in sidewall Eq. 3.12

	- -	16.83 12.00	1330 1610	
12 13 14	12.00 17.86 24.71	- - -	4040 3360 2530	Shear in bottom slab Eq. 3.11

Throat - Design Thrusts

$N_{bmax.}$ $=(5.75)\left(\frac{(6.67)(12)}{2}\right)$ =2300 lb/ft Eq. 3.13

$N_{bmin.}$ $=(14.7)\left(\frac{(6.67)(12)}{2}\right)$ =590 lb/ft

N_s $= \frac{(118.8)(7.67)(12)}{2}$ =5470 lb/ft Eq. 3.14

Face - Design Moments

G_1 $= \frac{(8/12)^3(6.67)}{(8/12)^3(11.17)} = 0.597$ Eq. 3.4

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

G_3 $= \frac{(2)(8/12)^3}{11.17}\left(\frac{1}{(8/12)^2}+\frac{8/12}{(8/12)^3}\right) = 0.239$ Eq. 3.6

G_4 $= \frac{(6)(8/12)}{11.17}\left(1.02-\frac{(3)(8/12)}{11.17}+\frac{(8/12)^3}{(8/12)^3}\right) = 0.659$ Eq. 3.7

$$M_o = \frac{(-66.3)(134)^2}{12}\left(\frac{1-(1.5)(0.239)+(0.5)(0.659)}{1+0.597-0.239}\right)-\begin{Bmatrix}P_{smax.}\\P_{smin.}\end{Bmatrix}\left[\frac{(80)^2}{2}\left(\frac{0.597-0.048}{1+0.597-0.239}\right)\right]$$

$$= 70935.1-\begin{Bmatrix}P_{smax}\\P_{smin}\end{Bmatrix}215.61 \qquad \text{Eq. 3.8}$$

$M_{omax.}$ = -70935.1-(40)(215.6)= -79560 in-lb/ft

$M_{omin.}$ = -70935.1-(5.9)(215.6)= -72210 in-lb/ft

Face - Design Moments

Design Location	Coordinat x (in)	y (in)	Moment for $p_{smin.}$ (in-lb/ft)	$p_{smax.}$ (in-lb/ft)	
8 11	- -	40.00 12.00	- -69800	-47560 -63240	Sidewall moment Eq. 3.10
12 15	12.00 67.00	- -	-23680 +76600	-31030 -	Bottom slab moment Eq. 3.9

@Design Location 9

$M_8 < 0$ do not investigate

@ Design Location 14 (positive moment region)

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

$x_{coord@14}$ = 67.00 - 33.96 = 33.04 in

Design Location	Coordinat x (in)	y (in)	Design Shear (lbs/ft)	
9 10 11	No Check $M_8 < 0$ - -	 16.83 12.00	 930 1120	Shear in sidewall Eq. 3.12
12 13 14	12.00 16.83 33.04	- - -	3650 3330 2250	Shear in bottom slab Eq. 3.11

Face - Design Thrusts

$N_{bmax.}$	$=(40)(80/2) = 1600$ lb/ft	Eq. 3.13
$N_{bmin.}$	$=(5.9)(80/2) = 240$ lb/ft	Eq. 3.13
N_s	$=(66.3)(134)/2 = 4440$ lb/ft	Eq. 3.14

Mid-Length - Design Moments

$$G_1 = \frac{(8/12)^3(6.67)}{(8/12)^3(9.42)} = 0.708 \qquad \text{Eq. 3.4}$$

$$G_2 = \frac{(9)(8/12)^5}{(6.67)(9.42)(8/12)^3}\left(1-\frac{8/12}{6.67}\right) = 0.057 \qquad \text{Eq. 3.5}$$

$$G_3 = \frac{(2)(8/12)^3}{9.42}\left(\frac{1}{(8/12)^2}+\frac{8/12}{(8/12)^3}\right) = 0.283 \qquad \text{Eq. 3.6}$$

$$G_4 = \frac{(6)(8/12)}{9.42}\left(1.02-\frac{(3)(8/12)}{9.42}+\frac{(8/12)^3}{(8/12)^3}\right) = 0.768 \qquad \text{Eq. 3.7}$$

$$M_o = \frac{(-92.1)(113)^2}{12}\left(\frac{1-(1.5)(0.283)+(0.5)(0.768)}{1+0.708-0.283}\right) - \begin{Bmatrix} P_{smax.} \\ P_{smin.} \end{Bmatrix}\left[\frac{(80)^2}{12}\left(\frac{0.708-0.057}{1+0.708-0.283}\right)\right]$$

$$= -65988.1 - \begin{Bmatrix} P_{smax.} \\ P_{smin.} \end{Bmatrix} 243.65 \qquad \text{Eq. 3.8}$$

$M_{omax.}$ = -78170 in-lb/ft

$M_{omin.}$ = -68640 in-lb/ft

Design Location	y Coordinate	Moment for

	(in)	$p_{smin.}$ (in-lb/ft)	$p_{smax.}$ (in-lb/ft)	
8 11	40.00 12.00	- -64190	-38170 -57770	Sidwall moment Eq. 3.10
	x Coordinate			
12 15	12.00 56.50	-12830 +78360	-22360 -	bottom slab moment Eq. 3.9

Mid-length Design Shears

@Design Location 9

$M_8 < 0$ do not investigate

@ Design Location 14 (positive moment region)

$$x_{dc} = 3\left[\sqrt{(5.68)^2 + \frac{(2)(78360)}{(9)(92.1)}} - 5.68\right] = 27.59\,\text{in}$$

$$x_{coord@14} = 56.50 - 27.59 = 28.91 \text{ in}$$

Design Location	Coordinat x (in)	y (in)	Design Shear (lbs/ft)	
9 10 11	No Check $M_8 < 0$ - -	 16.83 12.00	 116. 1400	Shear in sidewall Eq. 3.12
12 13 14	12.00 16.83 28.90	- - -	4100 3650 2540	Shear in bottom slab Eq. 3.11

Midlength Design Thrusts

$$N_{bmax.} = (50)\left(\frac{(6.67)(12)}{2}\right) = 2000 \text{ lb/ft} \qquad \text{Eq. 3.13}$$

$N_{bmin.}$ $= (10.9)(40) = 440$ lb/ft Eq. 3.13

$$N_s = \frac{(92.1)(9.42)(12)}{2} = 5200 \text{ lb/ft} \quad \text{Eq. 3.14}$$

Summary of Design Moments, Thrusts And Shears

Section	Design Location	Service Load Forces			Ultimate Load Forces*		
		M (in-lb/ft)	N (lb/ft)	V (lb/ft)	M_u (in-lb/ft)	N_u (lb/ft)	V_u (lb/ft)
Throat	8	-21630		$M_8 < 0$ - No Flexure Design Required			
	9			$M_8 < 0$ - No shear Design Required			
	10	**	**	1330	-	-	1730
	11	-49680	5470	1610	-64580	7110	2090
	12	-10630	2300	4040	-13820	2990	5250
	13	**	**	3360	-	-	4370
	14	**	590	2530	-	770	3290
	15	70010	590	**	91010	770	-
face	8	-47560		$M_8 < 0$ - No Flexure Design Required			
	9			$M_8 < 0$ - No shear Design Required			
	10	**	**	930	-	-	1210
	11	-69800	4400	1120	-90740	5720	1460
	12	-31030	1600	3650	-40340	2080	4750
	13	**	**	3330	-	-	4330
	14	**	240	2250	-	310	2930
	15	76600	240	**	99580	310	-
Mid-Length	8	-38170		$M_8 < 0$ - No Flexure Design Required			
	9			$M_8 < 0$ - No shear Design Required			

	10	**	**	1160	-	-	1510
	11	-64190	5200	1400	-83450	6760	1820
	12	-22360	2000	4100	-29070	2600	5330
	13	**	**	3650	-	-	4750
	14	**	440	2540	-	570	3300
	15	78360	440	**	101870	570	-

** Load factor x service load force - Eq. 4.1, 4.2, and 4.3.*
*** Force at this location not required for calculations.*

D.1.5 Reinforcing Design

Flexure

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

g = 0.85 bf'_c =(0.85)(12)(3000)=30600 Eq. 4.5

d = 0.96 h -t_b Eq.4.6

=(0.96)(8) - 1= 6.68" To inner steel (positive moment)
=(0.96)(8) - 2= 5.68" To outer steel (negative momet)

f_f = 0.90

max A_s $$= \left(\frac{(5.5\times10^4)(g')(\phi_f)(d)}{(87000+f_y)} - 0.75N_u\right)\frac{1}{f_y}$$ Eq. 4.14

g' $$= \left[0.85 - 0.05\left(\frac{(3000-4000)}{10000}\right)\right]$$ bf'_c Eq. 4.15

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

(0.85)(12)(3000) = 30600 < 32400 use g' = 30600

minA_s = 0.002 b h
=(0.002)(12)(8) = 0.192 in^2/ft Eq. 4.7

Flexure

Section	Design Location	M_u (in.-lb/ft)	N_u (lb/ft)	$f_r d$ (in.)	A_s (in.²/ft)	min.A_s (in.²/ft)	max.A_s (in.²)
Throat	8 (+M)	M8 < 0 - Use min.A_s				0.192*	-
	11 (-M)	-64580	7110	5.112	0.13	0 0.192*	0.887
	12 (-M)	-13820	2990	5.112	0.007	0 0.192*	0.938
	15 (+M)	+91010	770	6.012	0.256*	0 0.192	1.138
Face	8 (+M)	M8 < 0 - Use min.A_s				0 0.192*	-
	11 (-M)	-90740	5720	5.112	0.243*	0 0.192	0.904
	12 (-M)	-40340	2080	5.112	0.108	0 0.192*	0.949
	15 (+M)	+99580	310	6.012	0.286*	0 0.192	1.143
Mid Length	8 (+M)	M8 < 0 - Use min.A_s				0 0.192*	-
	11 (-M)	-83450	6760	5.112	0.203*	0 0.192	0.891
	12 (-M)	-29070	2600	5.112	0.063	0 0.192*	0.943
	15(+M)	+101870	570	6.012	0.291*	0 0.192	1.140
** Governs design at this location.*							

Crack Width Control Check

$$F_{cr} = \frac{B_1}{(30000)(\phi_f)(A_s)}\left[\frac{M+N(d-h/2)}{ji} - C_1 b h^2\sqrt{f'_c}\right] \quad \text{Eq. 4.16}$$

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

j @ 0.74 + 0.1 e/d where j ≤ 0.90 Eq. 4.18

$$i = \frac{1}{1-\frac{jd}{e}} \quad \text{Eq. 4.19}$$

For Reinforcement Type 3 (RTYPE = 3)

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

Crack Width Control Check

Conservatively assume circumferential reinforcement spacing = 12 in. (S_ℓ)

n = I (inner and outer cages are each a single layer)

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

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

Sect.	Design Location	M (in.-lb/ft)	N (lb/ft)	d (in.)	B_l	e (in.)	e/d	j	i	A_{sflex} (in ^{2}/ft)	F_{cr}
Throat	8	-21630	M8 < 0 - No Check Required								
	11	-49680	5470	5.68	2.88	10.76	1.89	0.90	1.91	0.192	< 0
	12	10630	2300	5.68	2.88	6.30	1.11	-	-	0.192	*
	15	+70010	590	6.68	1.82	121.34	18.16	0.90	1.05	0.256	< 0
Face	8	-47560	M8 < 0 - No Check Required								
	11	-69800	4400	5.68	2.88	17.54	3.09	0.90	1.41	0.243	< 0
	12	-31030	1600	5.68	2.88	21.07	3.71	0.90	1.32	0.192	< 0
	15	+76600	240	6.68	1.82	321.85	48.18	0.90	1.02	0.286	0.15
Mid Length	8	-38170	M8 < 0 - No Check Required								
	11	-64190	5200	5.68	2.88	14.02	2.47	0.90	1.57	0.203	< 0
	12	-22360	2000	5.68	2.88	12.86	2.26	0.90	1.66	0.192	< 0
	15	+78360	440	6.68	1.82	180.77	27.06	0.90	1.03	0.291	0.20

** 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

ϕV_c $= 3\phi_v \sqrt{f'_c}\, b\, d$ Eq. 4.20

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

$= (3)(0.85)\ \sqrt{3000}\ (12)(5.68) = 9520$ lbs/ft

V_u $\leq \phi V_c$ Eq. 4.21

Section	Design Location	V_u (lbs/ft)	fV_c (lbs/ft)
Throat	10	1730	9520
	13	4370	9520

Face	10 13	1210 4330	9520 9520
Mid Length	10 13	1510 4750	9520 9520

$fV_c > V_u$; therefore, shear does not govern design.

<u>Method 2 - Locations 9, 10, 13 and 14</u>

For M/(VfVd) > 3.0

$$\phi V_b = (1.1 + 63\rho)\sqrt{f'_c}\,\phi_v b\, d\left(\frac{F_d F_{vp}}{F_c F_N}\right) \qquad \text{Eq. 4.24}$$

$$r \quad \frac{A_s}{\phi_v b\, d} \qquad \text{Eq. 4.25}$$

$$F_d = 0.8 + 1.6/d \leq 1.25 \qquad \text{Eq. 4.26}$$

$$F_c = 1 \qquad \text{Eq. 4.27a}$$

Calculate Shear Strength - <u>Method 2</u>

$$F_N = 1.0 - 0.12\,\frac{N_u}{V_u} \geq 0.75 \qquad \text{Eq. 4.28}$$

For $M/(v\phi_v d) < 3.0$

$$\phi V_c = \frac{4\phi_v V_b}{\left(\frac{M}{V\phi_v d}\right)} \leq \frac{4.5\sqrt{f'_c}\,b\, d\phi_v}{F_N} \qquad \text{Eq. 4.30}$$

Section	Design Location	M_u (in.-ib/ft)	N_u (ib/ft)	V_u (ib/ft)	d (in.)	A_s (in.2/ft)	r	$\frac{M}{V_u \phi_v d}$	F_d	F_N	$f_v V_b$ lb/ft)	4v c (lb/ft)
Throat	9	No Check - M8 < 0										
	10 11*	- -64580	- 7110	1730 2090	5.68	0.192	0.0033	6.400+	1.082	0.750	5990	5990
	12 13*	-13820 -	2990 -	5250 4370	5.68	0.192	0.0033	0.545	1.082	0.932	12480	12480

	14	-	770	3290	6.68	0.256	0.0038	3.000	1.040	0.972	5350	5350
Face	9	No Check - M8 < 0										
	10 11*	- -90740	- 5720	1210 1460	5.68	0.243	0.0042	12.873^{+}	1.082	0.750	6250	6250
	12 13*	-40340 -	2080 -	4750 4330	5.68	0.192	0.0033	1.759	1.082	0.947	4740	6870
	14	-	310	2930	6.68	0.286	0.0042	3.00	1.040	0.987	5370	5370
Mid Length	9											
	10 11*	- -83450	- 6760	1510 1820	5.68	0.203	0.0035	9.497^{+}	1.082	0.750	6050	6050
	12 13*	-29070 -	2600 -	5330 4750	5.68	0.192	0.0033	1.130	1.082	0.941	4770	8960
	14	-	570	3300	6.68	0.291	0.0043	3.00	1.040	0.979	5440	5440

$^{+}$ *$M/V\phi_v d > 3.0$, use 3.0*

** Shear strength (ϕV_b) at tip of haunch (Sections 11, 12) is cornpared to shear force (V_u) at $\phi_v d$ from tip of haunch (10, 13).*

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

Box Section Design Example.

10.5 FT. SPAN X 6.9 FT. RISE REINFORCED CONCRETE CULVERT

****

I N S T A L L A T I O N   D A T A

HEIGHT OF FILL OVER CULVERT, FT	4.000
UNIT WEIGHT, PCF	120.000
MINIMUM LATERAL SOIL PRESSURE COEFFICIENT	0.250
MAXIMUM LATERAL SOIL PRESSURE COEFFICIENT	0.500
SOIL - STRUCTURE INTERACTION COEFFICIENT	1.200

L O A D I N G   D A T A

LOAD FACTOR - MOMENT AND SHEAR	1.300
LOAD FACTOR - THRUST	1.300

M A T E R I A L   P R O P E R T I E S

STEEL - MINIMUM SPECIFIED YIELD STRESS, KSI	60.000
CONCRETE - SPECIFIED COMPRESSIVE STRENGTH, KSI	3.000

C O N C R E T E   D A T A

TOP SLAB THICKNESS, IN.	8.000
BOTTOM SLAB THICKNESS, IN.	8.000
SIDE WALL THICKNESS, IN.	8.000
HORIZONTAL HAUNCH DIMENSION, IN.	8.000
VERTICAL HAUNCH DIMENSION, IN.	8.000
CONCRETE COVER OVER STEEL, IN.	
TOP SLAB - OUTSIDE FACE	2.000
SIDE WALL - OUTSIDE FACE	2.000
BOTTOM SLAB - OUTSIDE FACE	2.000
TOP SLAB - INSIDE FACE	1.000
BOTTOM SLAB - INSIDE FACE	1.000
SIDE WALL - INSIDE FACE	1.000

R E I N F O R C I N G   S T E E L   D A T A

LOCATION	AREA SQ. IN. PER FT	MIN WIRE SPAC'G IN.	STIRRUPS REQUIRED?
TOP SLAB - INSIDE FACE	0.247	2.0*	NO
TOP SLAB - OUTSIDE FACE	0.192	2.0*	NO
BOTTOM SLAB - INSIDE FACE	0.271	2.0*	NO
SIDE WALL - OUTSIDE FACE	0.248	2.0*	NO
SIDE WALL - INSIDE FACE	0.192	2.0*	NO

*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.

8.8 FT. SPAN X 6.0 FT. RISE REINFORCED CONCRETE CULVERT

I N S T A L L A T I O N   D A T A

HEIGHT OF FILL OVER CULVERT,FT	6.000
UNIT WEIGHT, PCF	120.000
MINIMUM LATERAL SOIL PRESSURE COEFFICIENT	0.250
MAXIMUM LATERAL SOIL PRESSURE COEFFICIENT	0.500
SOIL - STRUCTURE INTERACTION COEFFICIENT	1.200

L O A D I N G   D A T A

LOAD FACTOR - MOMENT AND SHEAR	1.300
LOAD FACTOR - THRUST	1.300

M A T E R I A L   P R O P E R T I E S

STEEL - MINIMUM SPECIFIED YIELD STRESS, KSI	60.000
CONCRETE - SPECIFIED COMPRESSIVE STRENGTH, KSI	3.200

C O N C R E T E   D A T A

TOP SLAB THICKNESS, IN.	8.000
BOTTOM SLAB THICKNESS, IN.	8.000
SIDE WALL THICKNESS, IN.	8.000
HORIZONTAL HAUNCH DIMENSION, IN.	8.000
VERTICAL HAUNCH DIMENSION, IN.	8.000
CONCRETE COVER OVER STEEL, IN.	
TOP SLAB - OUTSIDE FACE	2.000
SIDE WALL - OUTSIDE FACE	2.000
BOTTOM SLAB - OUTSIDE FACE	2.000
TOP SLAB - INSIDE FACE	1.000
BOTTOM SLAB - INSIDE FACE	1.000
SIDE WALL - INSIDE FACE	1.000

R E I N F O R C I N G   S T E E L   D A T A

LOCATION	AREA SQ. IN. PER FT	MIN WIRE SPAC'G IN.	STIRRUPS REQUIRED?
TOP SLAB - INSIDE FACE	0.256	2.0*	NO
TOP SLAB - OUTSIDE FACE	0.192	2.0*	NO
BOTTOM SLAB - INSIDE FACE	0.276	2.0*	NO
SIDE WALL - OUTSIDE FACE	0.219	2.0*	NO
SIDE WALL - INSIDE FACE	0.192	2.0*	NO

*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.

7.0 FT. SPAN X 6.0 FT. RISE REINFORCED CONCRETE CULVERT

****

I N S T A L L A T I O N   D A T A

HEIGHT OF FILL OVER CULVERT,FT	8.000
UNIT WEIGHT, PCF	120.000
MINIMUM LATERAL SOIL PRESSURE COEFFICIENT	0.250
MAXIMUM LATERAL SOIL PRESSURE COEFFICIENT	0.500
SOIL - STRUCTURE INTERACTION COEFFICIENT	1.200

L O A D I N G   D A T A

LOAD FACTOR - MOMENT AND SHEAR	1.300
LOAD FACTOR - THRUST	1.300

M A T E R I A L   P R O P E R T I E S

STEEL - MINIMUM SPECIFIED YIELD STRESS, KSI	60.000
CONCRETE - SPECIFIED COMPRESSIVE STRENGTH, KSI	3.000

C O N C R E T E   D A T A

TOP SLAB THICKNESS, IN.	8.000
BOTTOM SLAB THICKNESS, IN.	8.000
SIDE WALL THICKNESS, IN.	8.000
HORIZONTAL HAUNCH DIMENSION, IN.	8.000
VERTICAL HAUNCH DIMENSION, IN.	8.000
CONCRETE COVER OVER STEEL, IN.	
TOP SLAB - OUTSIDE FACE	2.000
SIDE WALL - OUTSIDE FACE	2.000
BOTTOM SLAB - OUTSIDE FACE	2.000
TOP SLAB - INSIDE FACE	1.000
BOTTOM SLAB - INSIDE FACE	1.000
SIDE WALL - INSIDE FACE	1.000

R E I N F O R C I N G   S T E E L   D A T A

LOCATION	AREA SQ. IN. PER FT	MIN WIRE SPAC'G IN.	STIRRUPS REQUIRED?
TOP SLAB - INSIDE FACE	0.222	2.0*	NO
TOP SLAB - OUTSIDE FACE	0.192	2.0*	NO
BOTTOM SLAB - INSIDE FACE	0.239	2.0*	NO
SIDE WALL - OUTSIDE FACE	0.192	2.0*	NO
SIDE WALL - INSIDE FACE	0.192	2.0*	NO

*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.

Location	Desig-nation*	Required Steel Area, in.^{2}/ft					
		Throat		Face		Mid-Length	
		Hand	Computer	Hand	Computer	Hand	Computer
Top slab - inside	AS2	0.256	0.222	0.286	0.247	0.291	0.256
Top slab - outside	AS8	0.192	0.192	0.192	0.192	0.192	0.192
Bottom slab - inside	AS3	0.256	0.239	0.286	0.271	0.291	0.276
Sidewall - outside	ASI	0.192	0.192	0.243	0.248	0.203	0.210
Sidewall - inside	AS4	0.192	0.192	0.192	0.192	0.192	0.192
* *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.

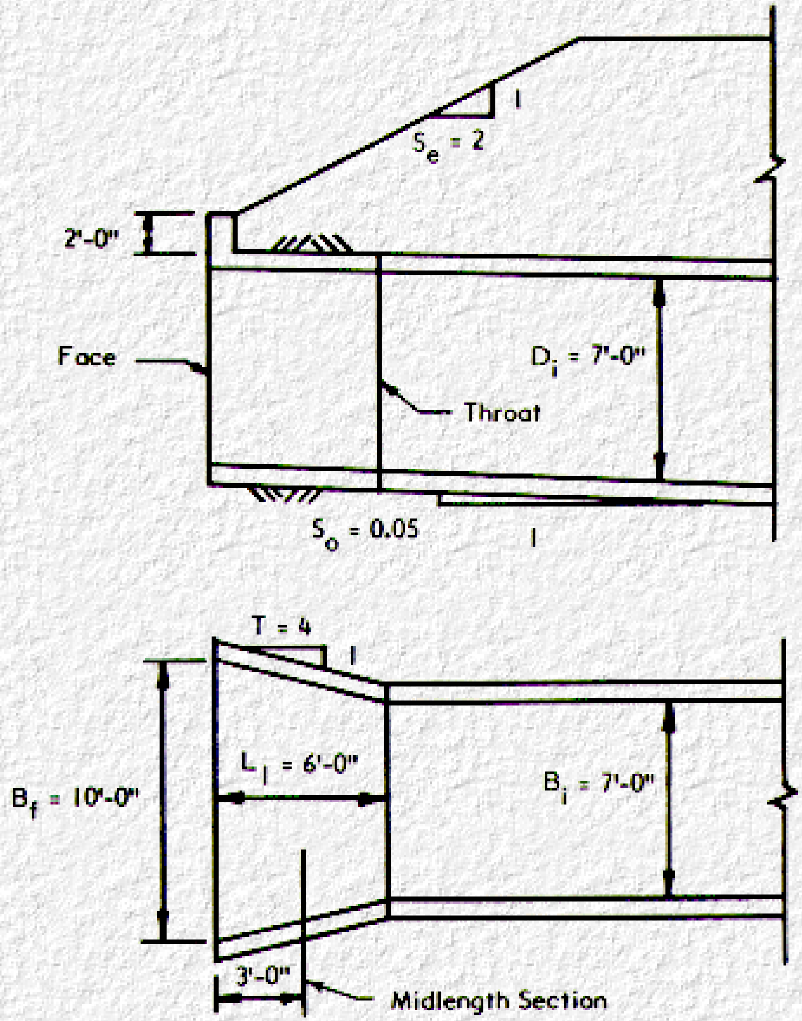
Location	Desig-nation*	Required Area, in.^{2}/ft		Governed at
		Hand	Computer	
Top slab - inside	AS2	0.291	0.256	Mid-Length
Top slab - outside	AS8	0.192	0.192	All Sections
Bottom slab - inside	AS3	0.291	0.276	Mid-Length
Sidewall - outside	ASI	0.243	0.248	Face
Sidewall - inside	AS4	0.192	0.192	All Sections

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



Given Data

γ_s	=	120 pcf
γ_c	=	150 pcf
γ_f	=	62.5 pcf
ϕ_f	=	0.9
ϕ_v	=	0.9
F_{cr}	=	1.0
F_{vp}	=	1.0
F_{rp}	=	1.0
f'_c	=	5000 psi
f_y	=	65000 psi
t_{bo}, t_{bi}	=	1 in.

Class C Bedding Angle:

Circular - 90^o

Elliptical - 0.5 B'

Note: Add 2' surcharge for miscellaneous unanticipated loads

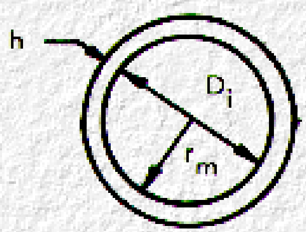
RTYPE = 2, smooth WWF
$F_e = 1.2$
t = 4.1
n = 1

Assume h =8' (B wall @ throat)
H_e @ Face = 2' + 2' =4'

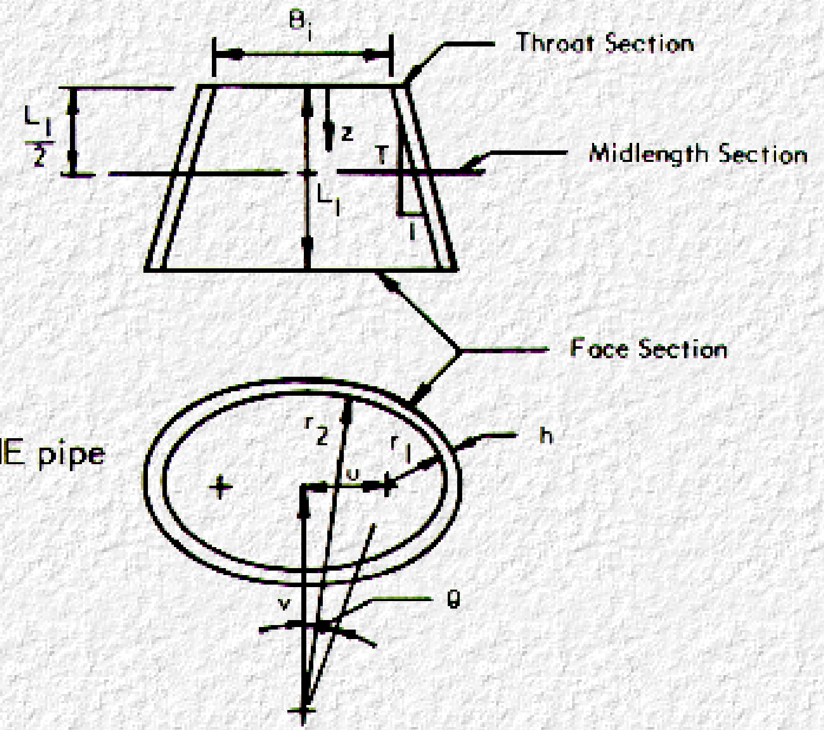
H_e @ Midlength Section = 4' + $L_1/2$ (1/S_e + So) = 4 +
6/2 (½ + 0.05) = 5.65'   Say 6'-0"

H_e @ Throat = 4 + 6(½ + 0.005) = 7.3'   Say 7'-6"

Culvert Geometry



Throat Section



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

Taper = 4.0

<u>Throat:</u> D_i = 84"

r_m = 84/2 + 8/2 = 46"

<u>Face:</u>

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

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

$$v = \frac{u}{k_1} = \frac{23.56}{0.5} = 47.12''$$

$$r_2 = \frac{D_i}{2} + v = \frac{84}{2} + 47.12" = 89.12"$$

See Figure 1-2.

Midlength:

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

$$u = \frac{36}{4} + \frac{84}{2} - 39.22 = 11.78"$$

$$v = \frac{11.78}{0.5} = 23.56"$$

$$r_2 = \frac{84}{2} + 23.56" = 65.56"$$

D.2.3 Calculate Applied Loads

Throat (Circular Section)

Earth Load W_e

$w_e = F_e \gamma_s B_o (H_e + R_o/6)$ Eq 2.7b

$R_o = B_o = D_i + 2h = 100$ in

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

Dead Load W_p

$W_p = 3.3\,(h)(D_i + h) = (3.3)(8)(84 + 8) = 2430$ lb/ft Eq. 2.1

Internal Fluid Load W_f

W_f $= 0.34\, D_i^2 = (0.34)(84)2 = 2400$ lb/ft Eq. 2.4

Face (Elliptical Section)

Earth Load We

B_o $= 2\,(h + r_1 + u) = 2\,(8 + 36.44 + 23.56) = 136$ in.

R_o $= 100$ in.

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

Dead Load W_p

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

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

$= 2950$ ib/ft

Internal Fluid Load W_f

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

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

$= 3520$ lb/ft

Midlength

Earth Load W_e

B_o $= 2\,(8 + 39.22 + 11.78) = 118$ in.

R_o $= 100$ in.

W_e = (1.2)(120)(118/12) $\left(6 + \frac{100}{(12)(6)}\right)$ = 104601b/ft 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 Ib/ft 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 Ib/ft 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 I through 5 shown on Figure 4-4.

M	$= (C_{m1} W_e + C_{m2} W_p + C_{m3} W_f)$ B'/2	Eq. 3.33
N	$= C_{n1} W_e + C_{n2} W_p + C_{n3} W_f$	Eq. 3.34
V	$= C_{v1} W_e + C_{v2} W_p + C_{v3} W_f$	Eq. 3.35
M_u	$= L_f M$	Eq.4.1
N_u	$= L_f N$	Eq. 4.2
V_u	$= L_f V$	Eq. 4.3

Throat - Design Locations (Figure 4-4)

Design Location

1 I @ invert $\theta_1 = 0°$

2 near invert where M/Vd = 3.0 (Figure 4-5)
r = 46"
$f_v d \simeq f_v (0.96\ h - t_b)$ = 0 9 [(0.96)(8) - 1] = 6.01 $\theta_2 = 19°$ Eq.4.6

3 maximum negative moment based on
earth load only (Figure 3-1) $\theta_3 = 75°$

4 near crown where M/Vd = 3.0 (Figure 4-5) θ_4 =149°

5 crown θ_5 =180°

Throat

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

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

Design Shears					
Design Location	c_{v1} Fig. 3-1	C_{v2} Fig. 3-5	C_{v3} Fig. 3-6	V (lb/ft)	V_u (lb/ft)
I = 0°	- - Not Applicable - -				
2 = 19°	0.21	0.40	0.20	3690	4800
3 = 75°	- - Not Applicable - -				
4 = 149°	-0.10	-0.11	-0.11	-1600	-2080
5 = 180°	- - Not Applicable - -				

Face - Design Locations (Figure 4-4)

<u>Flexure Design Location</u>

1 @ invert θ_1 = 0°

3 maximum negative moment based on earth load only (Figure 3-3) θ_3 = 80°

5 crown $\theta_5 = 180°$

<u>Shear Design Location</u>

2 and 4 where $M/\phi Vd = 3.0$

From Eqs. 3.33 and 3.35, using earth load only

$$\frac{M}{\phi Vd} = \frac{C_{m1} W_e B'}{2 C_{v1} W_e d \phi_v} = 3 \qquad B'/D' = \frac{120+8}{84+8} = 1.39$$

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

Critical Shear Location					
Location	q	C_{m1} Fig. 3-3	C_{v1} Fig. 3-3	C_{m1}/C_{v1}	
2	10° 15° 20°	0.13 0.08 0.03	0.30 0.37 0.40	0.433 0.216 0.075	M/Vd=3 @ 13°
4	160° 165°	0.05 0.07	-0.20 -0.15	-0.25 -0.467	M/Vd=3 @ 161°

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

Design Thrusts					
Design Location	c_{n1} Fig. 3-3	C_{n2} Fig. 3-5	C_{n3} Fig. 3-6	N (lb/ft)	N_u (lb/ft)

1 = 0° 2 = 13° 3 = 80° 4 = 161° 5 = 180°	0.27 0.32 0.55 0.31 0.29	0.12 0.18 0.29 -0.05 -0.08	-0.28 -0.25 -0.07 -0.21 -0.22	1740 2460 5440 1840 1540	2260 3200 7080 2390 2000

Design Shears					
Design Location	c_{v1} Fig. 3-1	C_{v2} Fig. 3-5	C_{v3} Fig. 3-6	V (in.-lb/ft)	V_u (in.-lb/ft)
I = 0°	- - Not Applicable - -				
2 = 13°	0.34	0.43	0.15	4790	6220
3 = 80°	- - Not Applicable - -				
4 = 161°	-0.18	-0.08	-0.08	-2100	-2730
5 = 180°	- - Not Applicable - -				

Midlength - Design Locations (Figure 4-4)

Flexure	B'/D' = 110/92 = 1.20	
1	@ invert	$\theta_1 = 0°$
3	maximum negative moment based on earth load only (Fig. 3-3)	$\theta_3 = 78°$
5	crown	$\theta_5 = 180°$
	2 and 4: where M/fVd = 3.0	

Shear

$$\frac{C_{m1}}{C_{v1}} = \frac{(3)(2)(d)(\phi)}{B'} = \frac{(3)(2)(6.68)(0.9)}{110} = 0.382$$

Critical Shear Location					
Location	q	C_{m1} Fig. 3-3	C_{v1} Fig. 3-3	C_{m1}/C_{v1}	
2	10° 15°	0.13 0.10	0.26 0.35	0.500 0.286	$M/\phi Vd=3$ $\theta_2=14°$
4	160° 165°	0.05 0.07	-0.17 -0.13	-0.294 -0.538	$M/\phi Vd=3$ $\theta_4=161°$

Midlength (Continued)

Design Moments

Design Location	c_{m1} Fig. 3-3	C_{m2} Fig. 3-5	C_{m3} Fig. 3-6	M (in.-lb/ft)	M_u (in.-lb/ft)
1 = 0°	0.16	0.21	0.12	142720	185540
2 = 14°	0.10	0.13	0.10	93100	121030
3 = 78°	-0.12	-0.10	-0.08	-96900	-125970
4 = 161°	0.06	0.07	0.06	54680	71080
5 = 180°	0.09	0.08	0.07	75050	97560

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

Design Shears					
Design Location	c_{v1} Fig. 3-1	C_{v2} Fig. 3-5	C_{v3} Fig. 3-6	V (in.-lb/ft)	V_u (in.-lb/ft)
I = 0°	- - Not Applicable - -				
2 = 14°	0.30	0.43	0.15	4740	6160
3 = 78°	- - Not Applicable - -				
4 = 161°	-0.14	-0.08	-0.08	-1920	-2490
5 = 180°	- - Not Applicable - -				

D.2.5 Reinforcing Design

Flexure

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

g - 0.085 b f'_c = (0.085)(12)(5000) = 51000 lb/in. Eq. 4.5

$\phi_f d$ = (6.68)(0.9) = 6.01

$$A_s = \frac{(51000)(0.601) - N_u - \sqrt{51000\left[(51000)(6.01)^2 - N_u\left((2)(6.01) - 8\right) - 2M_u\right]}}{65000}$$

$$= 4.717 - \frac{N_u}{65000} - 0.003474\sqrt{1843351.3 - 4.024\,N_u - 2M_u}$$

Minimum Steel

Inside

$A_{smin.}$ $$\frac{(B_i + h)^2}{65000}$$ Eq. 4.8

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

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

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

Outside

$A_{smin.}$ $$= 0.75\,\frac{(B_i + h)^2}{65000}$$ Eq. 4.9

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

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

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

Maximum Steel

$$A_{smax.} = \left(\frac{(5.5 \times 10^4)g'\phi_f d}{(87000 + f_y)} - 0.75\,N_u\right)\frac{1}{f_y}$$ Eq. 4.14

$$g' = \left[0.85 - 0.05\left(\frac{(f'_c - 4000)}{1000}\right)\right] b\, f'_c \qquad \text{Eq. 4.15}$$

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

(0.65)(12)(5000) < 48000 < (0.85)(12)(5000) o.k.

$$A_{smax.} = \left(\frac{(5.5\times10^{4})(48000)(0.9)(6.68)}{87000+65000} - 0.75\,N_u\right)\frac{1}{65000} = 1.606 - \frac{N_u}{86670}$$

Flexural Reinforcement						
Section	**Design Location**	**M_u (in.-lb/ft)**	**N_u (lb/ft)**	**A_s (in.^{2}/ft)**	**$A_{smin.}$ (in.^{2}/ft)**	**$A_{smax.}$ (in.^{2}/ft)**
Throat	1 3 5	129230 84870 66340	3940 8080 4300	0.304 0.142 0.130	0.130 0.098 0.130	1.561 1.513 1.556
Face	1 3 5	208560 135730 113270	2260 7080 2000	0.546 0.292 0.280	0.252 0.189 0.252	1.580 1.524 1.583
Mid-Length	1 3 5	185540 125970 97560	3150 8390 3090	0.471 0.252 0.226	0.186 0.140 0.186	1.570 1.509 1.570

0.01 Inch Crack Width Control

$$F_{cr} = \frac{B_i}{(30000)(\phi_f)(A_s)}\left[\frac{M+N(d-h/2)}{j\,i} - C_1 b\, h^2 \sqrt{f'_c}\right] \qquad \text{Eq. 4.16}$$

$$e = \frac{M}{N} + d - \frac{h}{2} \qquad \text{Eq. 4.17}$$

$$j = 0.74 + 0.1\, e/d \le 0.9 \qquad \text{Eq.4.18}$$

$$i = \frac{1}{1 - \frac{j\,d}{e}} \qquad \text{Eq. 4.19}$$

B_1
C_1 For Type 2 reinforcing - smooth WWF

Crack Control Reinforcement								
Section	Design Location	M (in.-lb/ft)	N (lb/ft)	e (in.)	j	i	A_{sflex} (in.^{2}/ft)	F_{cr}
Throat	1 3 5	99410 65290 51030	3030 6220 3310	35.49 13.18 18.10	0.90 0.90 0.90	1.20 1.84 1.50	0.304 0.142 0.130	0.324 < 0 < 0
Face	1 3 5	160430 104410 87130	1740 5440 1540	94.88 21.87 59.26	0.90 0.90 0.90	1.07 1.38 1.11	0.546 0.292 0.280	0.918 0.274 0.191
Mid-Length	1 3 5	142720 96900 75050	2420 6460 2370	61.66 17.68 34.35	0.90 0.90 0.90	1.11 1.52 1.21	0.471 0.252 0.226	0.803 0.050 < 0

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)

$\phi_c V_b$ $$= (1.1 + 63\rho)\sqrt{f'_c}\ \phi_v b\, d\left(\frac{F_d F_{vp}}{F_c F_N}\right)$$ Eq. 4.24

r $$\frac{A_s}{\phi_v b\, d} \le 0.02 = \frac{A_s}{(0.9)(12)(6.68)} = \frac{A_s}{72.14}$$ Eq. 4.25

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

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

Face: r_m depends upon whether the design section is in the r_1 or r_2 segment. arctan 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:

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

$$F_N = 1.0 - 0.12\frac{N_u}{V_u} \geq 0.75 \qquad \text{Eq. 4.28}$$

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

$\phi_v V_b > V_u$; therefore, shear does not govern design.

120.0INCH SPAN X 84.0INCH RISE REINFORCED ELLIPTICAL CONCRETE PIPE

INSTALLATION DATA

HEIGHT OF FILL ABOVE CROWN, FT.	4.00
UNIT WEIGHT, PCF	120.00
SOIL-STRUCTURE INTERACTION COEFFICIENT	1.20
BEDDING ANGLE, DEGREES	88.00
LOAD ANGLE, DEGREES	272.00

MATERIAL PROPERTIES

STEEL - MINIMUM SPECIFIED YIELD STRESS, PSI	65000.
REINFORCING TYPE	2.
NO. OF LAYERS OF REINFORCING	1.
CONCRETE - SPECIFIED COMPRESSIVE STRESS, PSI	5000.

LOADING DATA

LOAD FACTOR - MOMENT AND SHEAR	1.30
LOAD FACTOR - THRUST	1.30
STRENGTH REDUCTION FACTOR-FLEXURE	0.90
STRENGTH REDUCTION FACTOR-DIAGONAL TENSION	0.90
CRACK WIDTH REDUCTION FACTOR	1.00

PIPE DATA

RADIUS 1, IN.	36.44
RADIUS 2, IN.	89.12
WALL THICKNESS, IN.	8.00
INSIDE CONCRETE COVER OVER STEEL, IN.	1.00
OUTSIDE CONCRETE COVER OVER STEEL, IN.	1.00

FLUID DATA

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

REINFORCING STEEL DATA

INVERT- INSIDE REINFORCING, SQ.IN./FT.	0.558
SPRINGLINE- OUTSIDE REINFORCING, SQ.IN./FT.	0.291
CROWN- INSIDE REINFORCING, SQ.IN./FT.	0.257

102.0INCH SPAN X 84.0INCH RISE REINFORCED ELLIPTICAL CONCRETE PIPE

****

I N S T A L L A T I O N   D A T A

HEIGHT OF FILL ABOVE CROWN, FT.	6.00
UNIT WEIGHT, PCF	120.00
SOIL-STRUCTURE INTERACTION COEFFICIENT	1.20
BEDDING ANGLE, DEGREES	80.00
LOAD ANGLE, DEGREES	280.00

M A T E R I A L   P R O P E R T I E S

STEEL - MINIMUM SPECIFIED YIELD STRESS, PSI	65000.
REINFORCING TYPE	2.
NO. OF LAYERS OF REINFORCING	1.
CONCRETE - SPECIFIED COMPRESSIVE STRESS, PSI	5000.

L O A D I N G   D A T A

LOAD FACTOR - MOMENT AND SHEAR	1.30
LOAD FACTOR - THRUST	1.30
STRENGTH REDUCTION FACTOR-FLEXURE	0.90
STRENGTH REDUCTION FACTOR-DIAGONAL TENSION	0.90
CRACK WIDTH REDUCTION FACTOR	1.00

P I P E   D A T A

RADIUS 1, IN.	39.22
RADIUS 2, IN.	65.56
WALL THICKNESS, IN.	8.00
INSIDE CONCRETE COVER OVER STEEL, IN.	1.00
OUTSIDE CONCRETE COVER OVER STEEL, IN.	1.00

F L U I D   D A T A

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

R E I N F O R C I N G   S T E E L   D A T A

INVERT- INSIDE REINFORCING, SQ.IN./FT.	0.479
SPRINGLINE- OUTSIDE REINFORCING, SQ.IN./FT.	0.223
CROWN- INSIDE REINFORCING, SQ.IN./FT.	0.209

84.0INCH DIAMETER REINFORCED CONCRETE CIRCULAR PIPE

****

I N S T A L L A T I O N   D A T A

HEIGHT OF FILL ABOVE CROWN, FT.	7.50
UNIT WEIGHT, PCF	120.00
SOIL-STRUCTURE INTERACTION COEFFICIENT	1.20
BEDDING ANGLE, DEGREES	90.00
LOAD ANGLE, DEGREES	270.00

M A T E R I A L   P R O P E R T I E S

STEEL - MINIMUM SPECIFIED YIELD STRESS, PSI	65000.
REINFORCING TYPE	2.
NO. OF LAYERS OF REINFORCING	1.
CONCRETE - SPECIFIED COMPRESSIVE STRESS, PSI	5000.

L O A D I N G   D A T A

LOAD FACTOR - MOMENT AND SHEAR	1.30
LOAD FACTOR - THRUST	1.30
STRENGTH REDUCTION FACTOR-FLEXURE	0.90
STRENGTH REDUCTION FACTOR-DIAGONAL TENSION	0.90
CRACK WIDTH REDUCTION FACTOR	1.00

P I P E   D A T A

WALL THICKNESS, IN.	8.00
INSIDE CONCRETE COVER OVER STEEL, IN.	1.00
OUTSIDE CONCRETE COVER OVER STEEL, IN.	1.00

F L U I D   D A T A

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

R E I N F O R C I N G   S T E E L   D A T A

INVERT- INSIDE REINFORCING, SQ.IN./FT.	0.311
SPRINGLINE- OUTSIDE REINFORCING, SQ.IN./FT.	0.139
CROWN- INSIDE REINFORCING, SQ.IN./FT.	0.130

D.2.6 Summary - Design Example D.2

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

Required Steel Areas, in.^{2}/ft						
	Face		Midlength		Throat	
	Hand	Computer	Hand	Computer	Hand	Computer
Invert - inside	0.546	0.558	0.471	0.479	0.304	0.311
Springline - outside	0.292	0.291	0.252	0.223	0.142	0.139
Crown - inside	0.280	0.257	0.226	0.209	0.130	0.130

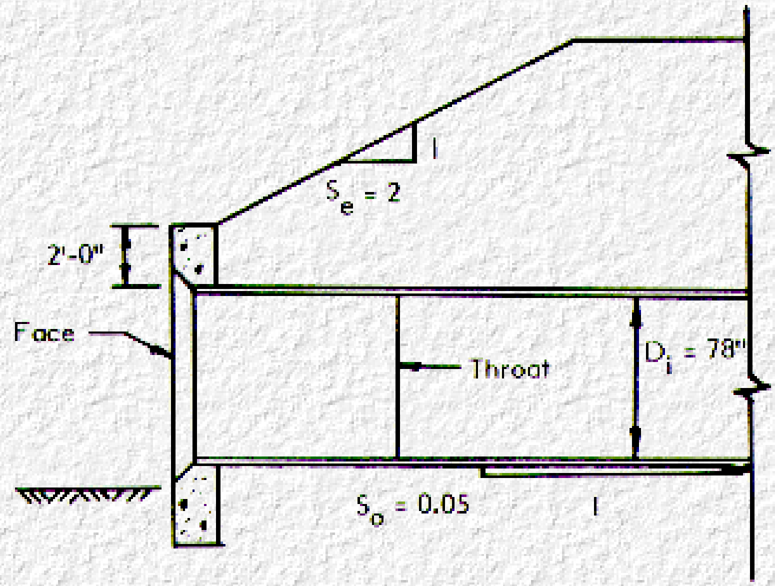
Conclusion: Design of the face section governs the design of the entire section.

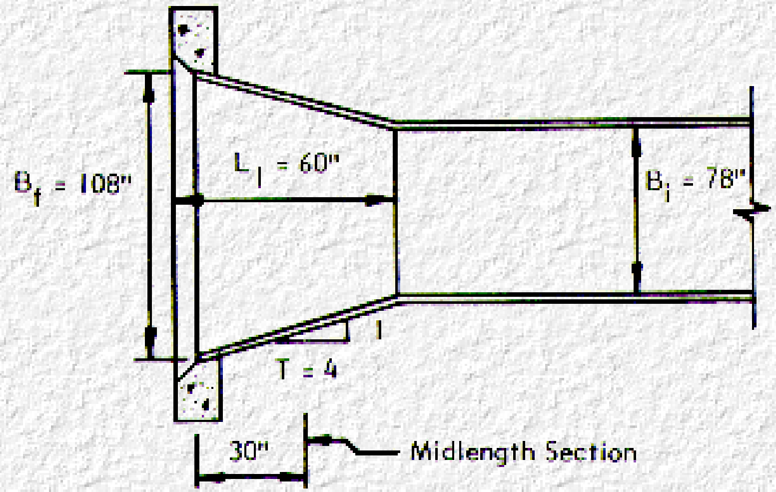
D.3 Side Tapered Corrugated Metal Inlet Design Example

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:

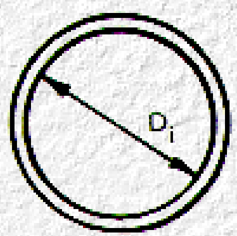
$$H_e = 4 + \frac{30}{12}\left(\frac{1}{S_e} + S_o\right)$$
$$= 4 + \frac{30}{12}\left(\frac{1}{2} + 0.05\right)$$
$$= 5.38' \qquad \text{Say } 5.5'$$

Throat:

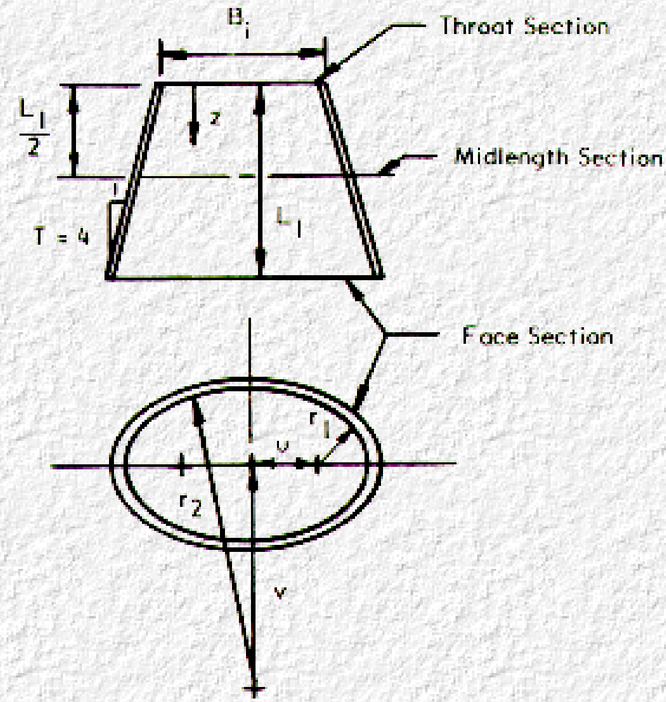
$$H_e = 4 + \frac{60}{12}\left(\frac{1}{S_e} + S_o\right)$$
$$= 4 + 5\left(\frac{1}{2} + 0.05\right)$$
$$= 6.75' \qquad \text{Say } 7.0'$$

Note: Add 2'-0" surcharge for miscellaneous unanticipated loads.

Culvert Geometry



Throat Section



Assume $u/v = 0.5 = k_1$

$$D_i = 78"$$

$$L_1 = 60"$$

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

$$= \frac{z/4 \left(1/0.5 - \sqrt{1 + 1/0.5^2}\right)}{1 + 1/0.5 - \sqrt{1 + 1/0.5^2}} + \frac{78}{2} = 39.0 - 0.0773\,z$$

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

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

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

$$\text{Span} = 2(r_1 + u)$$

Location	z	r_1	u	v	r_2	Span
Face Midlength Throat	60 30 0	34.36 36.68 39	19.64 9.82 0	39.28 19.64 0	78.28 58.64 39	108 93 78

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 (flixible culvert)

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

Location	Span (ft)	H_e (ft)	W_e (lb/ft)
Face Midlength Throat	9.0 7.75 6.5	4.0 5.5 7.0	5486 6120 6302

D.3.4 Metal Ring Design

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

Thrust

$$T = \frac{W_e}{2}$$

Required cross-sectional wall area:

$$A = T\frac{(SF)}{f_y} = \frac{W_e(SF)}{sf_y}$$

Sf = 2
f_y = 33000 psi

Required sectional wall area:

Location	W_e (lb/ft)	T (lb/ft)	Area ($in.^2/ft$)

Face Midlength Throat	5486 6120 6302	2743 3060 3151	0.166 0.186 0.191

Flexibility:

$$(FF) = \frac{S^2}{E1} \qquad 1 = \frac{S^2}{E(FF)}$$

E = 29×10^6 psi

S = span - use 2 times r_2 for non-circular shape.

Assume a 1" depth corrugation; therefore, (FF) = 0.033 (AASHTO, Section 1.9.4).

Location	$2 \times r_2$ (in.)	1_{req} (in^4/ft)
Face Midlength Throat	156.6 117.3 78	25.6×10^{-3} 14.4×10^{-3} 6.36×10^{-3}

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:

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

If S $< \frac{r}{k}\sqrt{\frac{24E}{f_u}}$ 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 $f_{cr} = \frac{12E}{\left(\frac{kS}{r}\right)^2}$

r = radius of gyration

k = soil stiffness factor
For granular backfill with 90% min. standard density, use k = 0.22.

For all sections, r $\simeq$ 0.34.

$$\frac{r}{k}\sqrt{\frac{24E}{f_u}} \approx \frac{0.34}{0.22}\sqrt{\frac{(24)29\times10^6}{45000}} = 192\,\text{in.}$$

Use 2 x r_2 in place of span in calculating buckling capacity. Since 2 x r_2 is less than 192 in. in all cases, use:

$$\frac{f_{cr}}{Sf} = \left[f_u - \frac{f_u^2}{48E}\left(\frac{kS}{r}\right)^2\right]\frac{1}{2}$$

$$= 22500 - \frac{45000^2(0.22)^2}{(2)48(29\times10^6)}\left(\frac{2r_2}{r}\right)^2$$

$$= 22500 - 0.0352\left(\frac{2r_2}{r}\right)^2$$

Location	$(2r_2)/r$	f_{cr}/SF (psi)	$f_a=T/A$ (psi)
Face	460.6	15032	1115
Midlength	345	18310	1962
Throat	228.3	20665	3540

Since $f_{cr}/SF > f_a$ buckling does not govern.

Seam Strength

(SS) = T (SF) SF = 3

Location	T (lb/ft)	SS (k/ft)	t	Double rivets (k/ft)
Face Midlength Throat	2743 3060 3151	8.23 9.18 9.45	0.168 0.109 0.064	70.7 53.0 28.7

Summary

Use a 3 x 1 corrugated steel pipe with the following properties:

Location	S (in)	Corr.	t (in)
Face Midlength Throat	108 93 78	3 x 1 3 x 1 3 x 1	0.168 0.109 0.064

Since this is a relatively short structure, use a 3 x 1 corrugation with t = 0.168 in. throughout.

Go to Appendix E

Appendix E : FHWA-IP-83-6

Improved Inlet Example Designs

Go to Appendix F

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 = I 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 E-1

Reinforcing Requirements - One Cell Side Tapered Box Inlets

Span x Rise at Throat	5x5	6x6	7x7	8x8	9x9	10x10	12x12
Dimension*	**Inlet Geometry (ft-in.)**						
B_i(Throat)	5'-0"	6'-0"	7'-0"	8'-0"	9'-0"	10'-0"	12'-0"
D_i	5-0	6-0	7-0	8-0	9-0	10-0	12-0
B_f	7-6	9-0	10-6	12-0	13-6	15-0	18-0
L_1	5-0	6-0	7-0	8-0	9-0	10-0	12-0
T_T	0-8	0-8	0-8	0-8	0-9	0-10	1 -0
T_S	0-8	0-8	0-8	0-8	0-9	0-10	1-0
T_B	0-9	0-9	0-9	0-9	0-10	0-11	1-1
H_f	1-0	1-0	1-0	1-0	1-2	1-3	1-6
H_t	3-8	4-2	4-9	5-3	5-11	6-7	7-10
Bar Designation	**Required Reinforcement Area (in.^{2}/ft)**						
1A	0.20	0.20	0.20	0.27	0.31	0.36	0.46
1B	0.20	0.20	0.20	0.27	0.31	0.36	0.46
2A	0.20	0.20	0.27	0.38(12)**	0.45(4)**	0.52(4)**	0.77(4)**
3A	0.20	0.21	0.31	0.43(12)**	0.51(4)**	0.62(4)**	1.04(4)**
4A	0.20	0.20	0.20	0.20	0.22	0.24	0.29
4B	0.20	0.20	0.20	0.20	0.22	0.24	0.29
8A	0.20	0.20	0.20	0.20	0.22	0.24	0.29
Long. 1	0.13	0.13	0.13	0.13	0.13	0.13	0.13

** 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: I

Reinforcing yield strength, f_y = 60,000 psi
Concrete compressive strength, f'_c = 3,000 psi
Haunch dimensions, $H_H = H_V = T_T$

Table E-2							
Reinforcing Requirements - Two Cell Side Tapered Box Inlets							
Span x Rise at Throat	**5x5**	**6x6**	**7x7**	**8x8**	**9x9**	**10x10**	**12x12**
Dimension*	**Inlet Geometry (ft-in.)**						
B_i(Throat) D_i $B_f/2$ L_1 T_T	5'-0" 5-0 7-6 10-0 0-8	6'-0" 6-0 9-0 12-0 0-8	7'-0" 7-0 10-6 14-0 0-8	8'-10" 8-0 12-0 16-0 0-9	9'-0" 9-0 13-6 18-0 0-10	10'-10" 10-0 15-0 20-0 1-0	12'-0" 12-0 18-0 24-0 1-4
T_S T_B T_C H_f H_t	0-8 0-9 0-8 1-0 6-4	0-8 0-9 0-8 1-0 7-4	0-8 0-9 0-8 1-0 8-5	0-9 0-10 0-9 1-0 9-6	0-10 0-11 0-10 1-2 10-8	1-0 1-1 1-0 1-3 11-10	1-4 1-5 1-4 1-6 14-3
Bar Designation	**Required Reinforcement Area (in.^{2}/ft)**						
1A 1B 2A 3A 4A	0.20 0.20 0.20 0.20 0.20	0.20 0.20 0.20 0.20 0.20	0.20 0.20 0.26 0.26 0.20	0.22 0.22 0.32 0.32 0.22	0.24 0.24 0.39 0.39 0.24	0.29 0.29 0.42 0.42 0.29	0.39 0.39 0.51 0.51 0.39
4B 8A 8B 8C (Length) 8D (Length) Long. 1	0.20 0.20 0.20 NR NR 0.13	0.20 0.25 0.25 NR NR 0.13	0.20 0.20 0.20 0.49(8'-10") 0.49(8'-10") 0.13	0.22 0.40 0.40 0.61(9'-0") 0.61(9'-0") 0.13	0.24 0.60 0.60 0.84(10'-0") 0.84(10'-0") 0.13	0.29 0.55 0.55 1.11(12'-0") 1.11(12'-0") 0.13	0.39 0.63 0.63 1.26(16'-0") 1.26(16'-0") 0.13

** 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: I

Reinforcing yield strength, f_y = 60,000 psi
Concrete compressive strength, f'_c = 3,000 psi
Haunch dimensions, $H_H = H_V = T_T$

Table E-3

Reinforcing Requirements - One Cell Slope Tapered Box Inlets						
Span x Rise at Throat	**5x5**	**5x5**	**5x5**	**7x7**	**7x7**	**7x7**
Fall (ft)	**2**	**4**	**6**	**2**	**4**	**6**
Dimension*	**Inlet Geometry (ft-in.)**					
B_i(Throat)	5'-0"	5'-0"	5'-0"	7'-0"	7'-0"	7'-0"
D_i	5-0	5-0	5-0	7-0	7-0	7-0
B_f	7-6	8-10	10-2	10-6	11-4	12-8
L_1	7-6	11-6	15-6	10-6	12-11	16-11
L_2	5-0	9-0	13-0	5-4	9-5	13-5
L_3	2-6	2-6	2-6	5-2	3-6	3-6
L_B	1-3	1-3	1-3	1-9	1-9	1-9
Fall	2-0	4-0	6-0	2-0	4-0	6-0
T_T	0-8	0-8	0-8	0-8	0-8	0-9
T_S	0-8	0-8	0-8	0-8	0-8	0-9
T_B	0-9	0-9	0-9	0-9	0-9	0-10
H_f	1-0	1-0	1-0	1-0	1-0	1-1
H_t	7-4	11-4	15-4	12-3	12-3	16-4
Bar Designation	**Required Reinforcement Area (in.^{2}/ft)**					
1A	0.20	0.20	0.20	0.26	0.31	0.33
1B	0.20	0.20	0.20	0.26	0.31	0.33
2A	0.20	0.27	0.35	0.46(12)**	0.68(4)**	0.80(4)**
3A	0.20	0.28	0.36	0.60(12)**	0.78(4)**	0.88(4)**
4A	0.20	0.20	0.20	0.20	0.20	0.22
4B	0.20	0.20	0.20	0.20	0.20	0.22
8A	0.20	0.20	0.20	0.20	0.20	0.22
Long. 1	0.13	0.13	0.13	0.13	0.13	0.13
Long. 2	0.20	0.20	0.20	0.20	0.20	0.22

** 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

Taper, T = 6: I

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						
Span x Rise at Throat	**7x7**	**9x9**	**9x9**	**9x9**	**9x9**	**9x9**
Fall (ft)	**8**	**2**	**4**	**6**	**8**	**10**
Dimension*	**Inlet Geometry (ft-in.)**					

B_i(Throat)	7'-0"	9'-0"	9'-0"	9'-0"	9'-0"	9'-0"
D_i	7-0	9-0	9-0	9-0	9-0	9-0
B_f	14-0	13-6	13-9	15-1	16-5	17-9
L_1	20-11	13-6	14-4	18-4	22-4	26-4
L_2	17-5	5-8	9-10	13-10	17-10	21-10
L_3	3-6	7-10	4-6	4-6	4-6	4-6
L_B	1-9	2-3	2-3	2-3	2-3	2-3
Fall	8-0	2-0	4-0	6-0	8-0	10-0
T_T	0-10	0-9	0-10	1-0	1-2	1-4
T_S	0-10	0-9	0-10	1-0	1-2	1-4
T_B	0-11	0-10	0-11	1-1	1-3	1-5
H_f	1-2	1-2	1-2	1-3	1-4	1-6
H_t	20-6	10-11	13-5	17-6	21-7	25-9
Bar Designation	**Required Reinforcement Area (in.^{2}/ft)**					
1A	0.33	0.57	0.42	0.40	0.37	0.39
1B	0.33	0.57	0.42	0.40	0.37	0.39
2A	0.88(4)**	1.05(4)**	1.06(4)**	0.96(4)**	1.06(8)**	1.02(12)**
3A	0.99(4)**	1.21(4)**	1.20(4)**	1.09(4)**	1.20(8)**	1.21(12)**
4A	0.24	0.22	0.24	0.29	0.34	0.39
4B	0.24	0.22	0.24	0.29	0.34	0.39
8A	0.24	0.28	0.24	0.29	0.34	0.39
Long. 1	0.13	0.13	0.13	0.13	0.13	0.13
Long. 2	0.24	0.22	0.24	0.29	0.34	0.39

** 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

Taper, T = 6: I

Reinforcing yield strength, f_y = 60,000 psi
Concrete compressive strength, f'_c = 3,000 psi
Haunch dimensions, $H_H = H_V = T_T$

Table E-4						
Reinforcing Requirements - One Cell Slope Tapered Box Inlets						
Span x Rise at Throat	**6x6**	**6x6**	**6x6**	**8x8**	**8x8**	**8x8**
Fall (ft)	**2**	**4**	**6**	**2**	**4**	**6**
Dimension*	**Inlet Geometry (ft-in.)**					

B_i(Throat)	6'-0"	6'-0"	6'-0"	8'-0"	8'-0"	8'-0"
D_i	6-0	6-0	6-0	8-0	8-0	8-0
B_f	9-0	10-0	11-4	12-0	12-5	13-9
L_1	9-0	12-0	16-0	12-0	13-4	17-4
L_2	4-11	9-0	13-0	5-0	9-4	13-4
L_3	4-1	3-0	3-0	7-0	4-0	4-0
L_B	1-7	1-7	1-7	2-1	2-1	2-1
Fall	2-0	4-0	6-0	2-0	4-0	6-0
T_T	0-8	0-8	0-8	0-8	0-8	0-10
T_S	0-8	0-8	0-8	0-8	0-8	0-10
T_B	0-9	0-9	0-9	0-9	0-9	0-11
H_f	1-0	1-0	1-0	1-0	1-0	1-2
H_t	8-2	11-9	15-9	9-11	12-8	16-9
Bar Designation	**Required Reinforcement Area (in.^{2}/ft)**					
1A	0.20	0.20	0.26	0.39	0.55	0.39
1B	0.20	0.20	0.26	0.39	0.55	0.39
2A	0.29	0.39	0.55(4)**	0.79(4)**	1.21(4)**	1.00(4)**
3A	0.31	0.42	0.62(4)**	0.93(4)**	1.34(4)**	1.12(4)**
4A	0.20	0.20	0.20	0.20	0.20	0.24
4B	0.20	0.20	0.20	0.20	0.20	0.24
8A	0.20	0.20	0.20	0.20	0.35	0.24
Long. 1	0.13	0.13	0.13	0.13	0.13	0.13
Long. 2	0.20	0.20	0.20	0.20	0.20	0.24

** 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: I

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

Span x Rise at Throat	8x8	10x10	10x10	10x10	10x10	10x10
Fall (ft)	**8**	**2**	**4**	**6**	**8**	**10**
Dimension*	**Inlet Geometry (ft-in.)**					
B_i(Throat)	8'-0"	10'-0"	10'-0"	10'-0"	10'-0"	10'-0"
D_i	8-0	10-0	10-0	10-0	10-0	10-0
B_f	15-2	15-0	15-0	16-3	17-7	18-11
L_1	21-5	15-0	15-0	18-9	22-9	26-9
L_2	17-5	5-2	9-8	13-9	17-9	21-9
L_3	4-0	9-10	5-4	5-0	5-0	5-0
L_B	2-1	2-8	2-8	2-8	2-8	2-8
Fall	8-0	2-0	4-0	6-0	8-0	10-0
T_T	1-0	0-10	1-0	1-2	1-4	1-6
T_S	1-0	0-10	1-0	1-2	1-4	1-6
T_B	1-1	0-11	1-1	1-3	1-5	1-7
H_f	1-3	1-3	1-3	1-4	1-6	1-7
H_t	20-10	11-11	13-11	17-11	22-0	26-2

Bar Designation	Required Reinforcement Area ($in.^2/ft$)					
1A	0.38	0.74	0.42	0.40	0.39	0.44
1B	0.38	0.74	0.42	0.40	0.39	0.44
2A	0.90(4)**	1.20(4)**	0.92(4)**	0.88(4)**	1.04(8)**	1.10(12)**
3A	1.04(4)**	1.40(4)**	1.09(4)**	1.11(4)**	1.25(8)**	1.33(12)**
4A	0.29	0.24	0.29	0.34	0.39	0.44
4B	0.29	0.24	0.29	0.34	0.39	0.44
8A	0.29	0.36	0.29	0.34	0.39	0.44
Long. 1	0.13	0.13	0.13	0.13	0.13	0.13
Long. 2	0.29	0.24	0.29	0.34	0.39	0.44

* *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: I

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

Span x Rise at Throat	12x12	12x12	12x12	12x12	12x12	12x12
Fall (ft)	**2**	**4**	**6**	**8**	**10**	**12**
Dimension*	**Inlet Geometry (ft-in.)**					
B_i(Throat)	12'-0"	12'-0"	12'-0"	12'-0"	12'-0"	12'-0"
D_i	12-0	12-0	12-0	12-0	12-0	12-0
B_f	18-0	18-0	18-8	20-0	21-4	22-8
L_1	18-0	18-0	20-1	24-1	28-1	32-1
L_2	5-3	9-10	14-1	18-1	22-1	26-1
L_3	12-9	8-2	6-0	6-0	6-0	6-0
L_B	3-2	3-2	3-2	3-2	3-2	3-2
Fall	2-0	4-0	6-0	8-0	10-0	12-0
T_T	1-2	1-4	1-6	1-8	1-10	2-0
T_S	1-2	1-4	1-6	1-8	1-10	2-0
T_B	1-3	1-5	1-7	1-9	1-11	2-1
H_f	1-6	1-6	1-7	1-8	1-9	1-11
H_t	13-11	15-11	19-0	23-1	27-3	31-4
Bar Designation	**Required Reinforcement Area ($in.^2/ft$)**					
1A	0.57	0.50	0.45	0.48	0.53	0.58
1B	0.57	0.50	0.45	0.48	0.53	0.58
2A	1.04(4)**	0.97(4)**	1.10(8)**	1.20(8)**	1.38(12)**	1.50
3A	1.30(4)**	1.20(4)**	1.36(8)**	1.53(8)**	1.70(12)**	1.83
4A	0.34	0.39	0.44	0.48	0.53	0.58
4B	0.34	0.39	0.44	0.48	0.53	0.58
8A	0.34	0.39	0.44	0.48	0.53	0.58
Long. 1	0.13	0.13	0.13	0.13	0.13	0.13
Long. 2	0.34	0.39	0.44	0.48	0.53	0.58

* *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

Taper, T = 6: I

Reinforcing yield strength, f_y = 60,000 psi
Concrete compressive strength, f'_c = 3,000 psi
Haunch dimensions, $H_H = H_V = T_T$

Table E-5

Reinforcing Requirements - Two Cell Slope Tapered Box Inlets

Span x Rise at Throat	6x6	6x6	6x6	8x8	8x8	8x8
Fall (ft)	**2**	**4**	**6**	**2**	**4**	**6**
Dimension*	**Inlet Geometry (ft-in.)**					
B_i	6'-0"	6'-0"	6'-0"	8'-0"	8'-0"	8'-0"
D_i	6-0	6-0	6-0	8-0	8-0	8-0
B_f	18-0	18-0	20-0	24-0	24-0	24-8
L_1	12-0	12-0	16-0	16-0	16-0	14-5
L_2	4-6	9-0	13-0	4-6	8-0	13-5
L_3	7-6	3-0	3-0	11-6	7-0	4-0
L_B	1-7	1-7	1-7	2-1	2-1	2-1
Fall	2-0	4-0	6-0	2-0	4-0	6-0
T_T	0-8	0-8	0-10	1-0	1-0	1-0
T_S	0-8	0-8	0-10	1-0	1-0	1-0
T_B	0-9	0-9	0-11	1-1	1-1	1-1
T_C	0-8	0-8	0-10	1-0	1-0	1-0
H_f	1-0	1-0	1-0	1-0	1-0	1-0
H_t	9-8	11-9	15-9	11-11	13-11	16-8
Bar Designation	**Required Reinforcement Area (in.^{2}/ft)**					
1A	0.20	0.20	0.24	0.29	0.29	0.29
1B	0.20	0.20	0.24	0.29	0.29	0.29
2A	0.23	0.25	0.24	0.29	0.32	0.36
3A	0.23	0.25	0.24	0.29	0.32	0.36
4A	0.20	0.20	0.24	0.29	0.29	0.29
4B	0.20	0.20	0.24	0.29	0.29	0.29
8A	0.20	0.23	0.24	0.29	0.29	0.34
8B	0.20	0.23	0.24	0.29	0.29	0.34
8C(Length)	0.38(8'-0")	0.46(8'-0")	0.14(8'-0")	0.20(9'-0")	0.53(9'-0")	0.69(9'-0")
8D(Length)	0.38(8'-0")	0.46(8'-0")	0.14(8'-0")	0.20(9'-0")	0.53(9'-0")	0.69(9'-0")
Long. 1	0.13	0.13	0.13	0.13	0.13	0.13
Long. 2	0.20	0.20	0.24	0.29	0.29	0.29

* 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 = 4: I	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

Span x Rise at Throat	10x10	10x10	10x10	12x12	12x12	12x12
Fall (ft)	**2**	**4**	**6**	**2**	**4**	**6**
Dimension*	**Inlet Geometry (ft-in.)**					
B_i	10'-0"	10'-0"	10'-0"	12'-0"	12'-0"	12'-0"
D_i	10-0	10-0	10-0	12-0	12-0	12-0
B_f	30-0	30-0	30-0	36-0	36-0	36-0
L_1	20-0	20-0	20-0	24-0	24-0	24-0
L_2	4-6	9-0	13-7	4-5	9-0	13-6
L_3	15-6	11-0	6-5	19-7	15-0	10-6
L_B	2-8	2-8	2-8	3-2	3-2	3-2
Fall	2-0	4-0	6-0	2-0	4-0	6-0
T_T	1-4	1-4	1-4	1-8	1-8	1-8
T_S	1-4	1-4	1-4	1-8	1-8	1-8
T_B	1-5	1-5	1-5	1-9	1-9	1-9
T_C	1-4	1-4	1-4	1-8	1-8	1-8
H_f	1-3	1-3	1-3	1-6	1-6	1-6
H_t	14-5	16-5	18-5	16-11	18-11	20-11
Bar Designation	**Required Reinforcement Area (in.^{2}/ft)**					
1A	0.39	0.39	0.39	0.48	0.48	0.48
1B	0.39	0.39	0.39	0.48	0.48	0.48
2A	0.39	0.42	0.45	0.48	0.53	0.59
3A	0.39	0.42	0.45	0.48	0.53	0.59
4A	0.39	0.39	0.39	0.48	0.48	0.48
4B	0.39	0.39	0.39	0.48	0.48	0.48
8A	0.39	0.39	0.41	0.48	0.48	0.59
8B	0.39	0.39	0.41	0.48	0.48	0.59
8C(Length)	0.16(12'-0")	0.68(12'-0")	0.83(12'-0")	0.23(14'-0")	0.95(14'-0")	1.19(14'-0")
8D(Length)	0.16(12'-0")	0.68(12'-0")	0.83(12'-0")	0.23(14'-0")	0.95(14'-0")	1.19(14'-0")
Long. 1	0.13	0.13	0.13	0.13	0.13	0.13
Long. 2	0.39	0.39	0.39	0.48	0.48	0.48

* 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 = 0.04:1 Taper, T = 4: I	Reinforcing yield strength, f_y = 60,000 psi Concrete compressive strength, f'_c = 3,000 psi Haunch dimensions, $H_H = H_V = T_T$

Table E-6					
Reinforcing Requirements - Side Tapered Reinforced Concrete Pipe Inlets					
Diameter at Throat	**4**	**6**	**8**	**10**	**12**
Dimension*	**Inlet Geometry (ft-in.)**				
D_i B_f	4'-0" 6-0	6'-0" 9-0	8'-0" 12-0	10'-0" 15-0	12'-0" 18-8
r_1@Face	1-8 $\frac{5}{16}$	2-6 $\frac{7}{16}$	3-4 $\frac{9}{16}$	4-2 $\frac{3}{4}$	5-0 $\frac{7}{8}$
r_2@Face	4-7 $\frac{7}{16}$	6-11 $\frac{1}{8}$	9-2 $\frac{13}{16}$	11-6 $\frac{9}{16}$	13-10¼
u@Face	1-3 $\frac{11}{16}$	1-11 $\frac{9}{16}$	2-7 $\frac{7}{16}$	3-3¼	3-11 $\frac{1}{8}$
v@Face	2-7 $\frac{7}{16}$	3-11 $\frac{1}{8}$	5-2 $\frac{13}{16}$	6-6 $\frac{9}{16}$	7-10¼
L_1 h H_f H_t	4-0 0-4 1-0 3-2	6-0 0-6 1-0 4-2	8-0 0-8 1-0 5-3	10-0 0-10 1-3 6-7	12-0 1-0 1-6 7-10
Bar Designation	**Required Reinforcement Area (in.^{2}/ft)**				
A_{si} A_{sc} A_{so}	0.29 0.14 0.17	0.49 0.23 0.27	0.81 0.36 0.41	1.27 0.56 0.59	1.84 0.80 0.82

* *See Appendix G. Sheet 5.*

Other Design Parameters

Embankment slope, S_e = 2:1
Culvert barrel slope, S = 0.03:1

Taper, T = 4: I

Reinforcing yield strength, f_y = 65,000 psi
Concrete compressive strength, f'_c = 5,000 psi

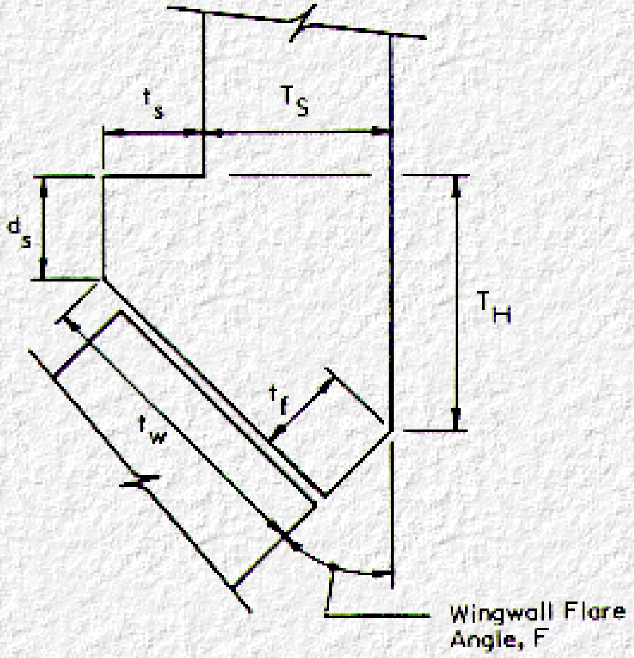
Table E-7					
Corrugation Requirements - Side Tapered Metal Pipe Inlets					
Diameter at Throat	**4**	**6**	**8**	**10**	**12**
Dimension*	**Inlet Geometry (ft-in.)**				
D_i B_f	4'-0" 6-0	6'-0" 9-0	8'-0" 12-0	10'-0" 15-0	12'-0" 18-8
r_1@Face	1-8 $\frac{5}{16}$	2-6 $\frac{7}{16}$	3-4 $\frac{9}{16}$	4-2 $\frac{3}{4}$	5-0 $\frac{7}{8}$
r_2@Face	4-7 $\frac{7}{16}$	6-11 $\frac{1}{8}$	9-2 $\frac{13}{16}$	11-6 $\frac{9}{16}$	13-10¼

u@Face	1-3 $\frac{11}{16}$	1-11 $\frac{9}{16}$	2-7 $\frac{7}{16}$	3-3¼	3-11 $\frac{1}{8}$
v@Face	2-7 $\frac{7}{16}$	3-11 $\frac{1}{8}$	5-2 $\frac{13}{16}$	6-6 $\frac{9}{16}$	7-10¼
L_1 H_f H_t	4-0 1-0 3-2	6-0 1-2 4-4	8-0 1-6 5-9	10-0 1-11 7-2	12-0 2-3 8-7
Design Without Special Features (in.)					
Corrugation Thickness	3x1 0.109	6x2 0.109	6x2 0.168	6x2 0.249	-
Design With Special Features (in.)**					
Corrugation Thickness	-	-	6x2 0.109	6x2 0.109	6x2 0.109

** See Appendix G. Sheet 6.*

*** As per the AASHTO Bridge Specification Section 1.9.6*

Other Design Parameters Embankment slope, S_e = 2:1 Culvert barrel slope, S = 0.03:1	Corrugated metal,, f_y = 33,000 psi, f_u = 45,000 psi Taper, T = 4: I



$$T_H = \frac{B_f}{12} \geq 12''$$

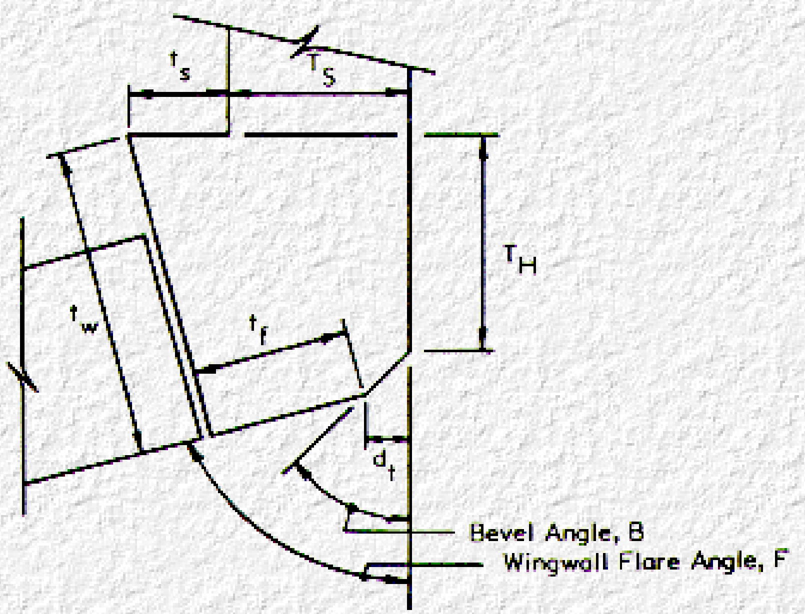
$$t_w = 14 + \frac{B_f}{24}$$

$$t_f = \frac{B_f}{12} \sin F \geq 12 \sin F$$

$$t_s = t_f \sin F + t_w \cos F - T_S$$

$$d_s = T_H + t_f \cos F - t_w \sin F$$

a. Wingwall Flare Angles Less Than or Equal to 45°



$$T_H = \frac{B_f}{12} \geq 12$$

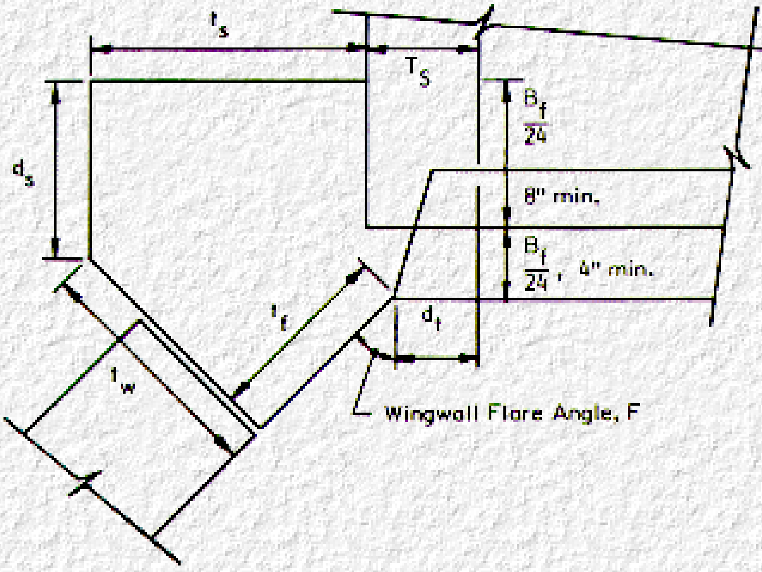
$$t_s = \frac{B_f}{24} \geq 6$$

$$t_f = T_S + t_s - d_t - \frac{T_H}{\tan F} \sin F$$

$$t_w = \frac{T_H + t_f \cos F}{\sin F}$$

b. Wingwall Flare Angles Greater Than 45°

Figure E-1. Headwall Dimensions for Cast-In-Place Reinforced Concrete Structures.



$$T_H = \frac{B_f}{12} \geq \frac{B_f}{24} + 8 \geq 12$$

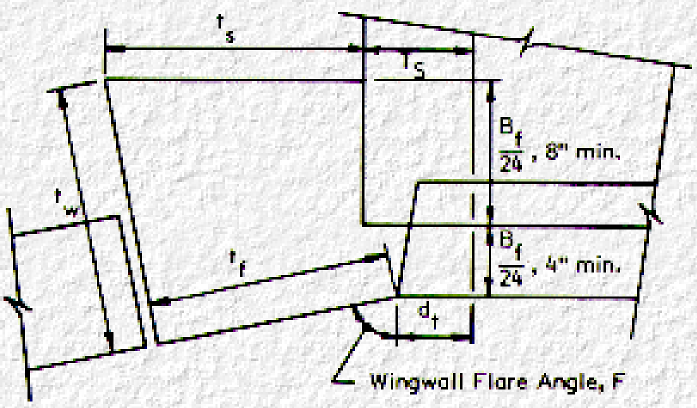
$$t_w = 14 + \frac{B_f}{24}$$

$$t_f = \frac{B_f}{12} + T_S \sin F \geq (12 + T_S) \sin F$$

$$t_s = d_t + t_f \sin F + t_w \cos F - T_S$$

$$d_s = T_H + t_f \cos F - t_w \sin F$$

a. Wingwall Flare Angles Less Than 60°



$$T_H = \frac{B_f}{12} \geq 12$$

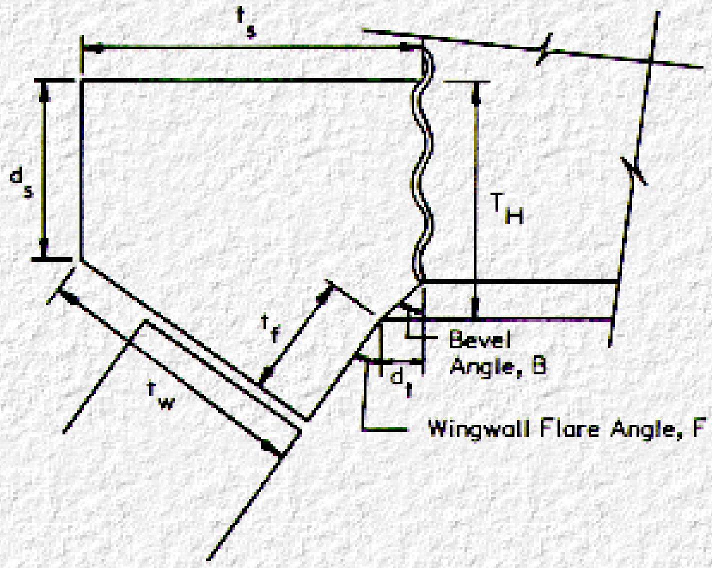
$$t_f = \frac{B_f}{12} + T_S \geq 12 + d_t$$

$$t_w = \frac{T_H + t_f \cos F}{\sin F}$$

$$t_s = t_w \cos F + t_f \sin F + d_t$$

b. Wingwall Flare Angles Greater Than or Equal to 60°

Figure E-2. Headwall Dimensions for Precast Concrete Culverts



$$T_H = \frac{B_f}{24} + \frac{d_t}{\tan B} \geq 8 + \frac{d_t}{\tan B} \geq 12''$$

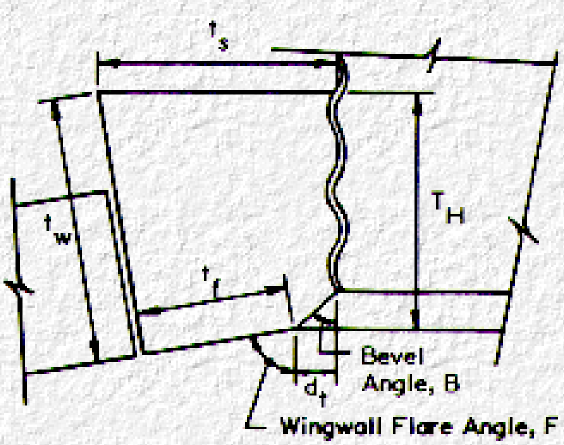
$$t_w = 14 + \frac{B_f}{24}$$

$$t_f = \frac{B_f \sin F}{12} > 12 \sin F$$

$$t_s = d_t + t_f \sin F + t_w \cos F$$

$$d_s = T_H + t_f \cos F - t_w \sin F$$

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°

Figure E-3. Headwall Dimensions for Corrugated Metal Pipe

Table E-8
Box Section Headwall Designs - 45° Wingwall Flare Angle

Headwall Opening Span x Rise	T_T	T_S	T_H	t_w	t_s	t_f	d_s	d_h	d_t
(ft x ft.)	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)
5.0 x 5.0	8.0	8.0	12.0	16.5	9.7	8.5	6.3	8.0	2.5
6.0 x 6.0	8.0	8.0	12.0	17.0	10.0	8.5	6.0	8.0	3.0
7.0 x 7.0	8.0	8.0	12.0	17.5	10.4	8.5	5.6	8.0	3.5
8.0 x 8.0	8.0	8.0	12.0	18.0	10.7	8.5	5.3	8.0	4.0
9.0 x 9.0	9.0	9.0	12.0	18.5	10.1	8.5	4.9	9.0	4.5
10.0 x 10.0	10.0	10.0	12.0	19.0	9.4	8.5	4.6	10.0	5.0
12.0 x 12.0	12.0	12.0	12.0	20.0	8.1	8.5	3.9	12.0	6.0

1. Above designs ore based on 45° bevel angle and 45° flare angle. See Figure E-1 for other angles.
2. See Sheet 7, Appendix G for key to dimensions and reinforcing requirements.
3. Designs ore applicable to one and two cell box sections.

Table E-9

Box Section Headwall Designs - 60° Wingwall Flare Angle

Headwall Opening Span x Rise	T_T	T_S	T_H	t_w	t_s	t_f	d_h	d_t
(ft x ft.)	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)
5.0 x 5.0	8.0	8.0	12.0	16.1	6.0	4.0	8.0	2.5
6.0 x 6.0	8.0	8.0	12.0	15.9	6.0	3.5	8.0	3.0
7.0 x 7.0	8.0	8.0	12.0	15.6	6.0	3.1	8.0	3.5
8.0 x 8.0	8.0	8.0	12.0	15.4	6.0	2.7	8.0	4.0
9.0 x 9.0	9.0	9.0	12.0	15.6	6.0	3.1	9.0	4.5
10.0x 10.0	10.0	10.0	12.0	15.9	6.0	3.5	10.0	5.0
12.0x 12.0	12.0	12.0	12.0	16.4	6.0	4.4	12.0	6.0

1. Above designs are based on 45° bevel angle and 60° wingwall anglw. See Figure E-1 for other angles.
2. See Sheet 7, Appendix G for key to dimensions and reinforcing requirements.
3. Designs ore applicable to one and two cell box sections.

Table E-10

Reinforced Concrete Pipe Headwall Designs - 45° Wingwall Flare Angle

Headwall Opening Diameter	h	T_H	t_w	t_s	t_f	d_s	d_h	d_t
(ft)	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)
4	4.0	12.0	16.0	17.7	11.3	8.7	12.0	2.4
6	6.0	12.0	17.0	18.6	12.7	9.0	12.0	3.6
8	8.0	12.0	18.0	19.5	14.1	9.3	12.0	4.8
10	10.0	13.0	19.0	20.4	15.6	10.6	12.0	6.0
12	12.0	14.0	20.0	21.3	17.0	11.9	12.0	7.2
14	14.0	15.0	21.0	23.3	19.8	14.2	14.0	8.4

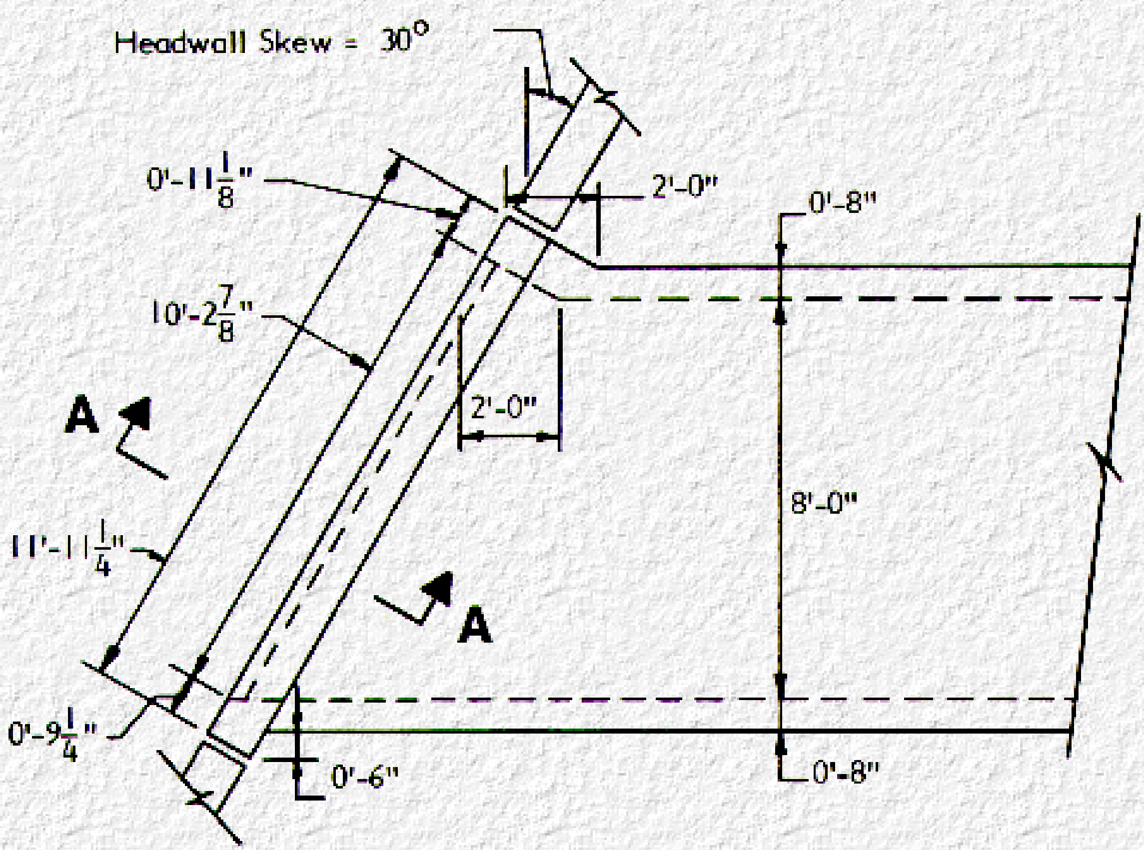
1. Above designs are based on 45 degree bevel angle and 45 degree wingwall angle. See Figure E-2 for dimensions for other angles.
2. See Sheet 8, Appendix G for key to dimensions and other requirements.

Table E-11

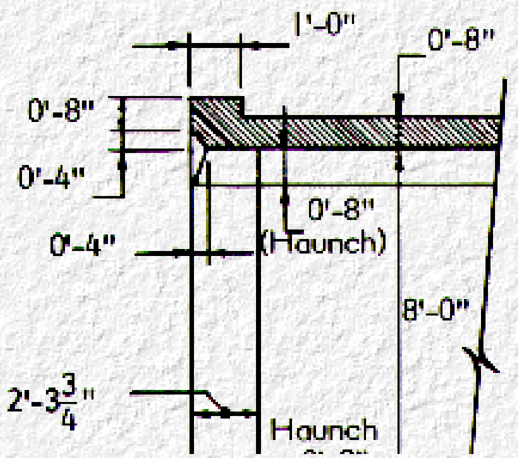
Corrugated Metal Pipe Headwall Designs - 45° Wingwall Flare Angle

Headwall Opening Diameter	T_H	t_w	t_s	t_f	d_s	d_h	d_t
(ft)	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)
4 6 8 10 12 14 16 20	12.0 12.0 12.0 12.0 12.0 16.0 20.0	16.0 17.0 18.0 19.0 20.0 22.0 24.0	19.3 21.0 22.7 24.4 26.2 31.6 37.0	8.5 8.5 8.5 8.5 8.5 11.3 14.1	6.7 6.0 5.3 4.6 3.9 8.4 13.0	8.0 8.0 8.0 10.0 12.0 16.0 20.0	2.0 3.0 4.0 5.0 6.0 8.0 10.0

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.



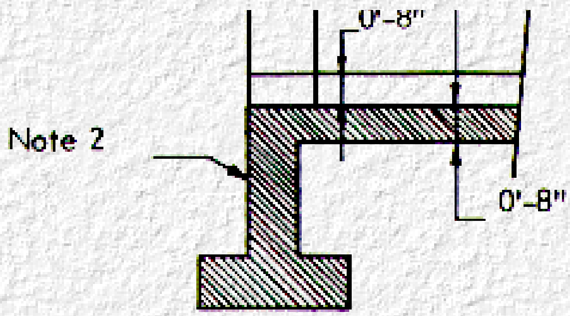
a. **Plan**



Notes:

1. Dimensions as shown use reinforcing as for typical non-skewed headwall. See App. G., Sheet 7.

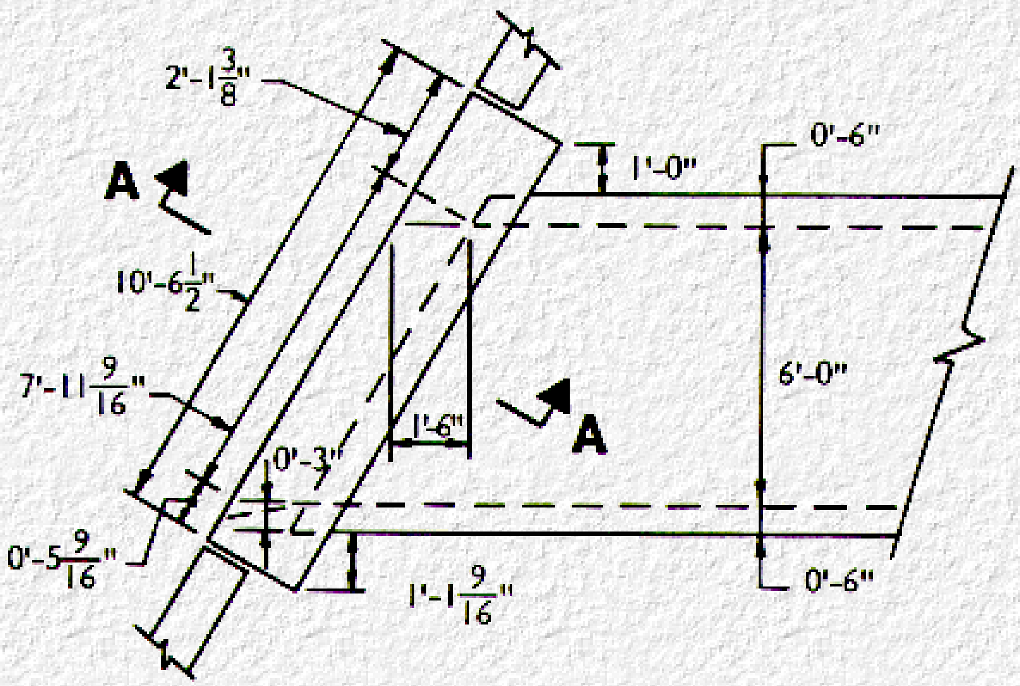
2. Foundation and cutoff wall to be designed based on local conditions.



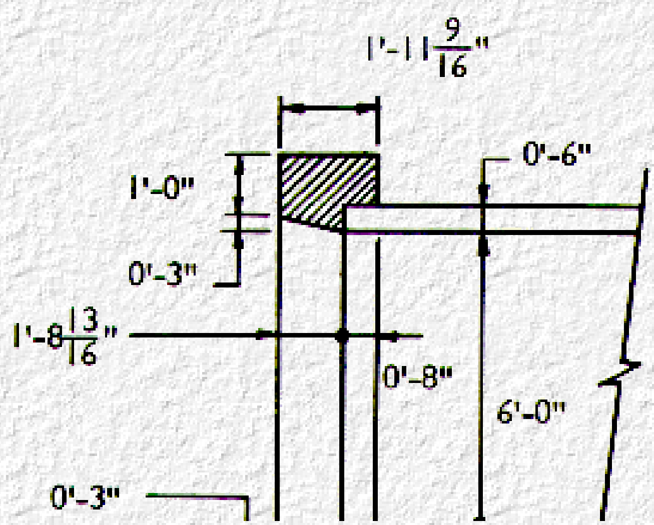
b. Section A-A

Figure E-4. Skewed Headwall for 8 X 8 Box Section

Headwall Skew = 30°

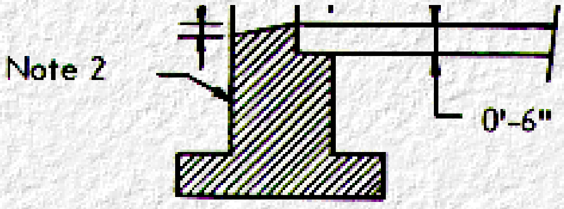


a. Plan



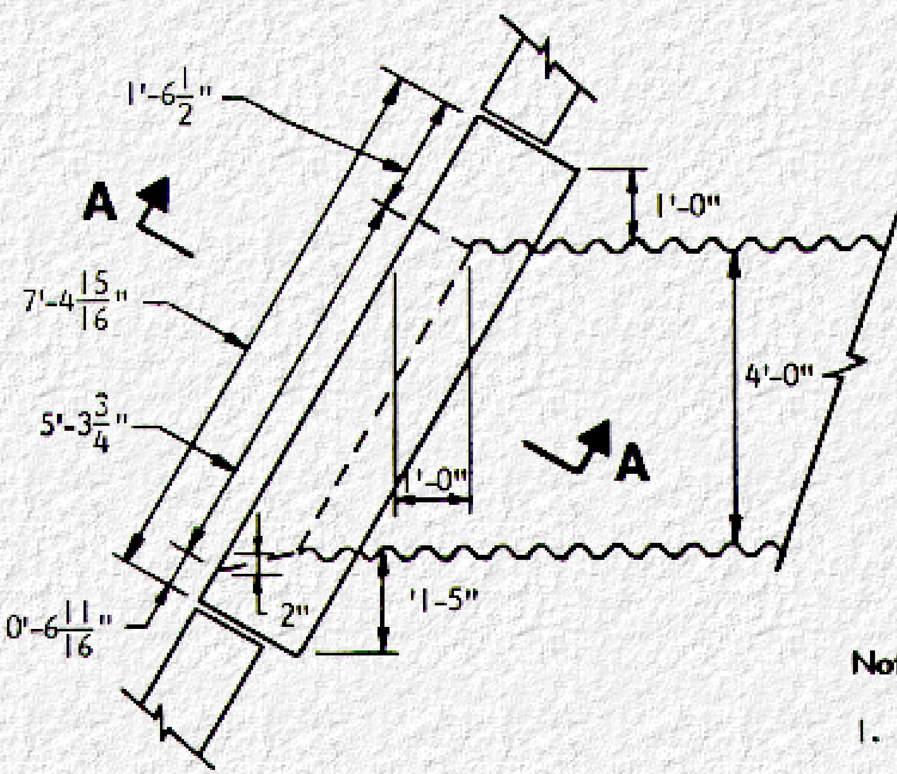
Notes:

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

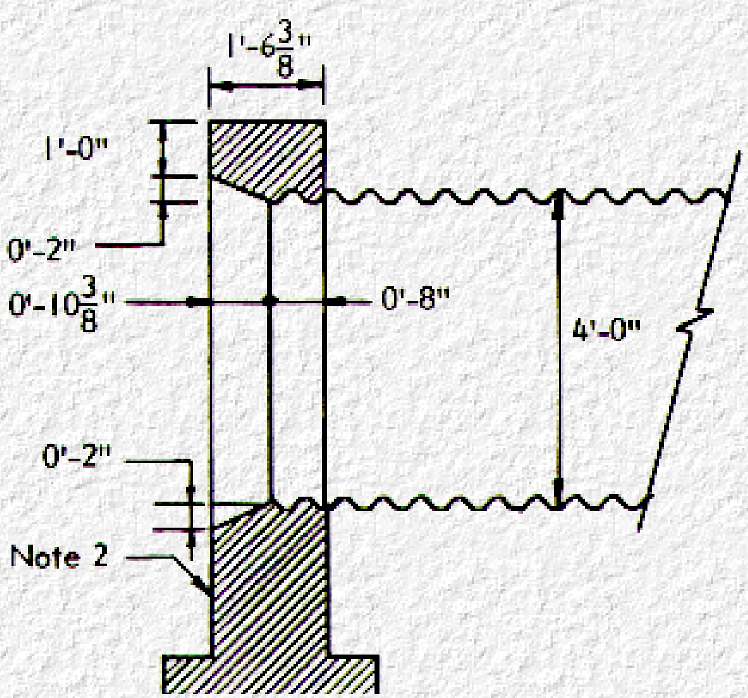


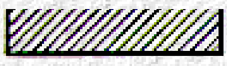
a. Plan

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-6. Skewed Headwall for 48" Corrugated Metal Pipe

Table E-12						
Apron Designs - 30° Wingwalls, S_f = 2:1						
B_f	D_i	S	Fall	L_b	L_F	W_p
(ft)	(ft)		(ft)	(ft-in.)	(ft-in.)	(ft-in.)
6.0	6.0	0.03	2 4 6 8 10	3-0 3-0 3-0 3-0 3-0	3-10 7-10 11-10 15-10 19-10	13-11 18-6 23-1 27-9 32-4
14.0	14.0	0.03	2 4 6 8 10	7-0 7-0 7-0 7-0 7-0	3-7 7-7 11-7 15-7 19-7	26-3 30-10 35-5 40-1 44-8
10.0	10.0	0.06	2 4 6 8 10	5-0 5-0 5-0 5-0 5-0	3-5 7-5 11-5 15-5 19-5	19-8 24-4 28-11 33-7 38-2
18.0	12.0	0.06	2 4 6 8 10	6-0 6-0 6-0 6-0 6-0	3-3 7-3 11-3 15-3 19-3	28-9 33-4 37-11 42-7 47-2

Table E-13		
Reinforcing Requirements - Square to Circular Transition Sections		
Diameter @ Throat (ft)	4	8

Fill Over Transition (ft)	4 to 10	8	10	12	14
Bar Designation	**Required Reinforcement Area (in.^{2}/ft)**				
IA	0.20	0.20	0.22	0.26	0.30
IB	0.20	0.20	0.22	0.26	0.30
2A	0.20	0.37	0.46(4)	0.61(4)	0.85
3A	0.20	0.42	0.50(4)	0.73(4)	0.97
4A	0.20	0.20	0.20	0.20	0.20
8A	0.20	0.20	0.20	0.20	0.20
Long. 1	0.13	0.13	0.13	0.13	0.13

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

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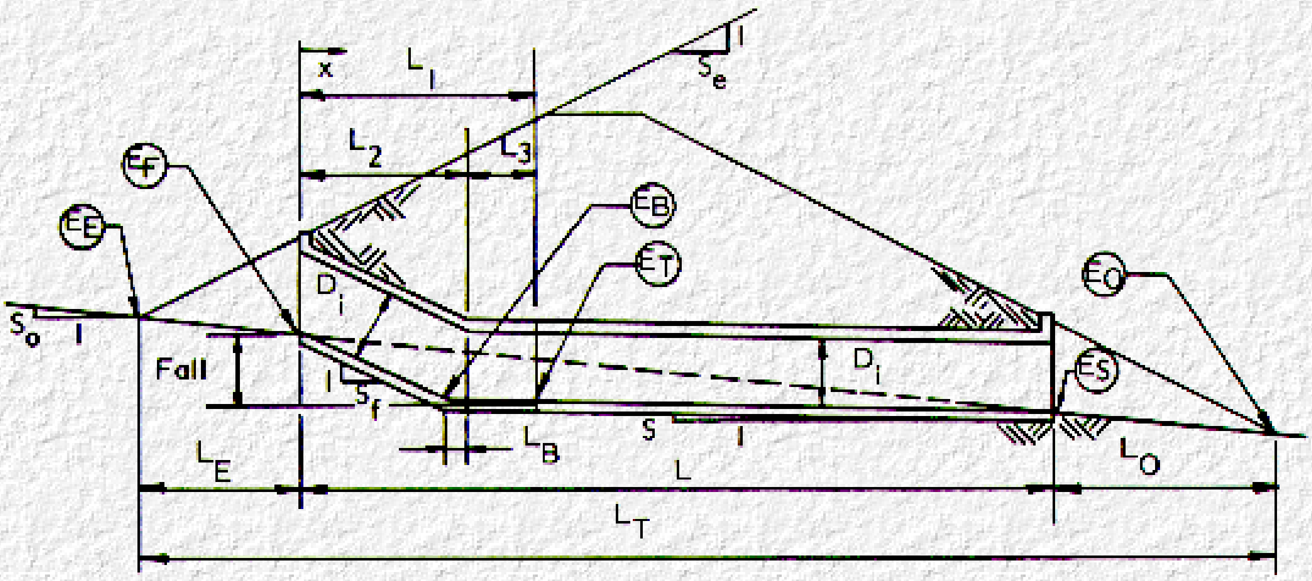
F.1.1 Definition of Terms



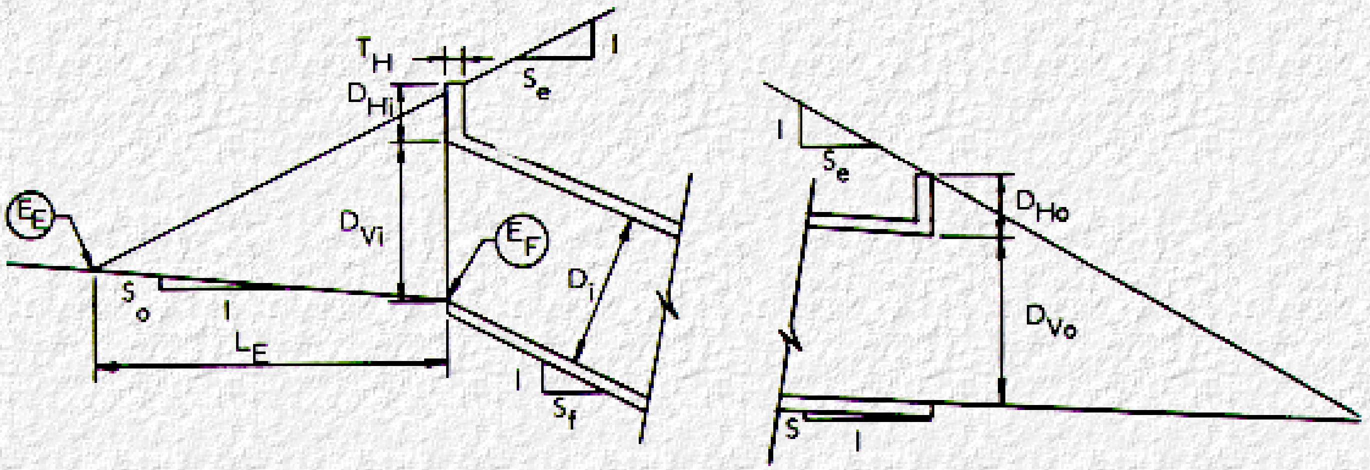
Assume the following parameters are known:

> Slopes: Stream bed (S_o), 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 followin 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.)

$$D_{Vi} = D_i \sqrt{\frac{1}{S_f^2} + 1}$$

$$D_{Vo} = D_i \sqrt{S^2 + 1} \approx D_i \text{ (0.5\% error for } S = 0.10)$$

by similar triagles:

$$\frac{(L_E + T_H)}{(D_{Vi} + D_{Hi}) - S_o L_E} = S_e$$

$L_E + S_e S_o L_E = S_e (D_{Vi} + D_{Hi}) - T_H$

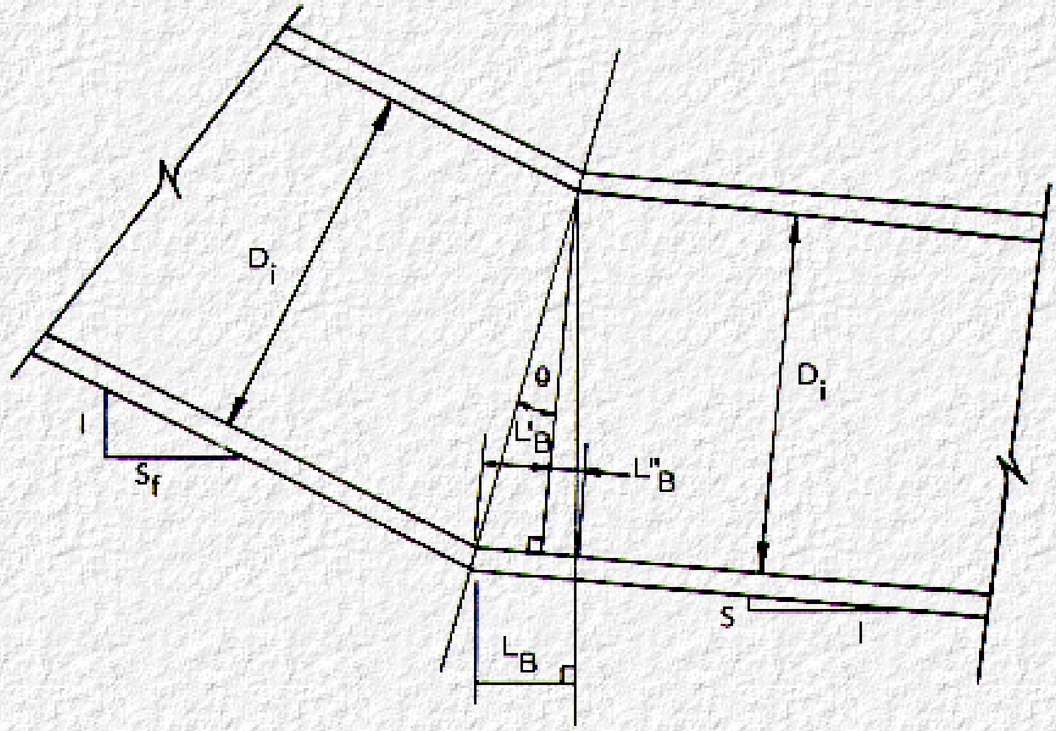
$$L_E = \frac{S_e (D_{Vi} + D_{Hi}) - T_H}{1 + S_e S_o} \qquad \text{Equation F.1}$$

by similar calculations:

$$L_O = \frac{S_e (D_{Vo} + D_{Ho}) - T_H}{1 + S_e S_o} \qquad \text{Equation F.2}$$

$$L = L_T - L_O - L_E \qquad \text{Equation F.3}$$

F.1.3 Determine L_B



$$\theta = \frac{1}{2}\left(\arctan\frac{1}{S_f} - \arctan S\right)$$

$$L'_B = D_i(\tan\theta)$$

$$L''_B = S(D_i)$$ Note: See Eq. F.9 for determination of S.

$$L_B = \frac{L''_B + L'_B}{\sqrt{S^2+1}}$$

Substituting:

$$L_B = \frac{D_i\left\{\tan\left[\frac{1}{2}\left(\arctan\frac{1}{S_f} - \arctan S\right)\right] + S\right\}}{\sqrt{1+S^2}}$$ Eq. F.4

F.1.4 Determine Elevations D_F, E_B, E_T, E_S

$El.E_F = (El.E_E) - S_oL_E$ Equation F.5

$El.E_T = (El.E_F) - Fall$ Equation F.6

$El.E_{BF} = (El.E_T) + S(L_3 + L_B)$ Equation F.7

$El.E_S = El.E_O + S_oL_E$ Equation F.8

F.1.5 Determine Slope of Barrel S

$$S = \frac{El.E_T - El.E_S}{L_T - (L_E + L_I + L_O)}$$ Equation F.9

F.1.6 Determine Height of Fill over Inlet at Face, H_f, and along Length, H(x), Where x Is Horizontal Distance from Face Culvert

H_f varies with site coditions and height of headwall, and must include any surcharge loads being considered.

$H(x) = H_f + x(1/S_f + 1/S_e), 0< x < L_2$ Equation F.10a

$H(x) = H_f + L_2(1/S_f + 1/S_e) + (x - L_2)(1/S_e + S), L_2< x < L_1$ Equation F.10b

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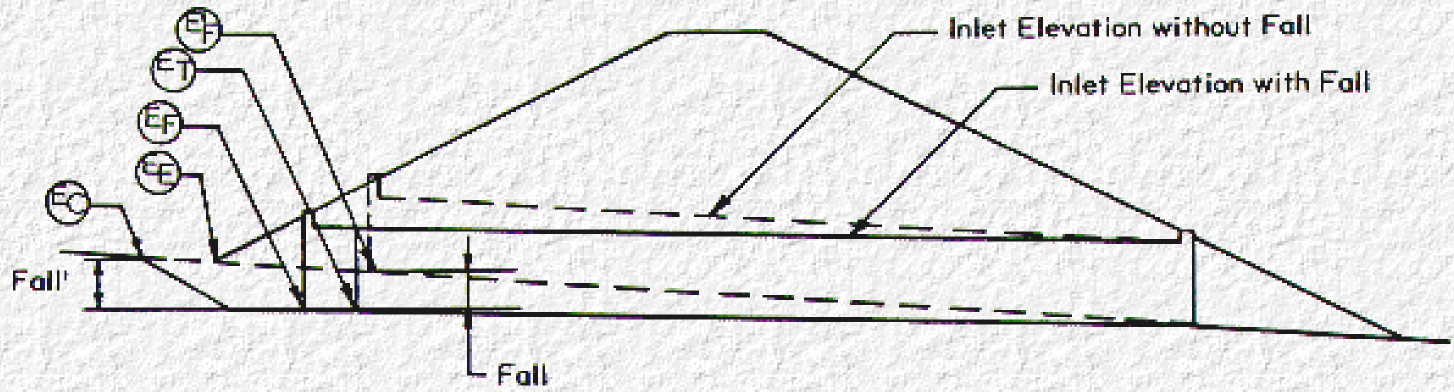
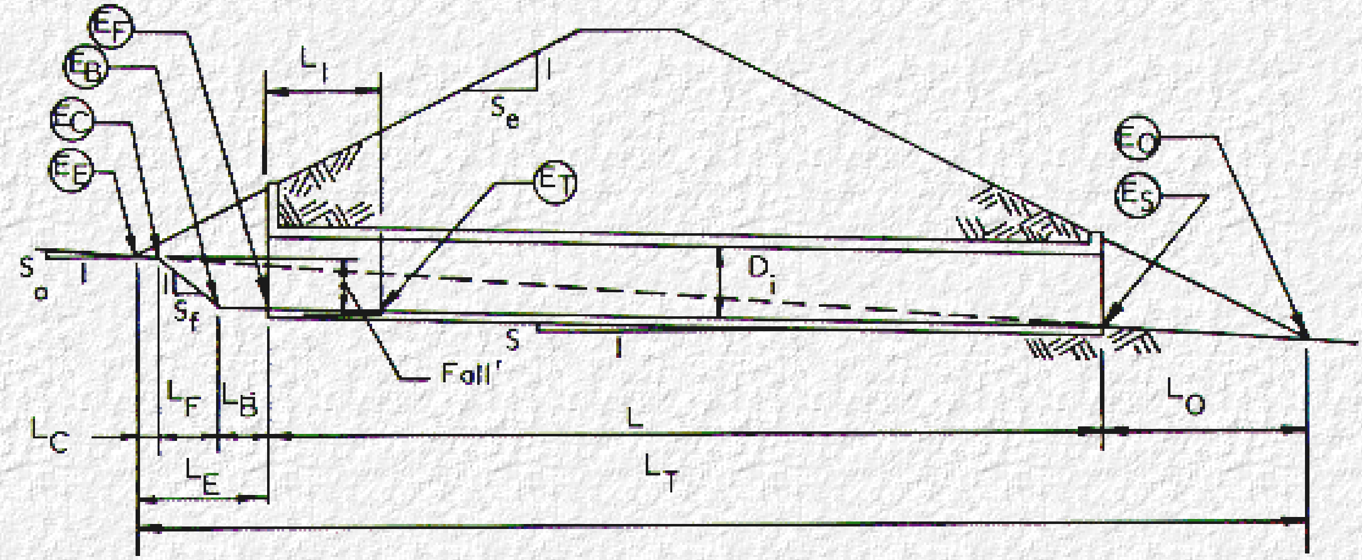
F.2 Derive Equations to Determine Elevations of Critical Points and Lengths of Critical Sections for Side Tapered Inlets with Fall

---

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_O

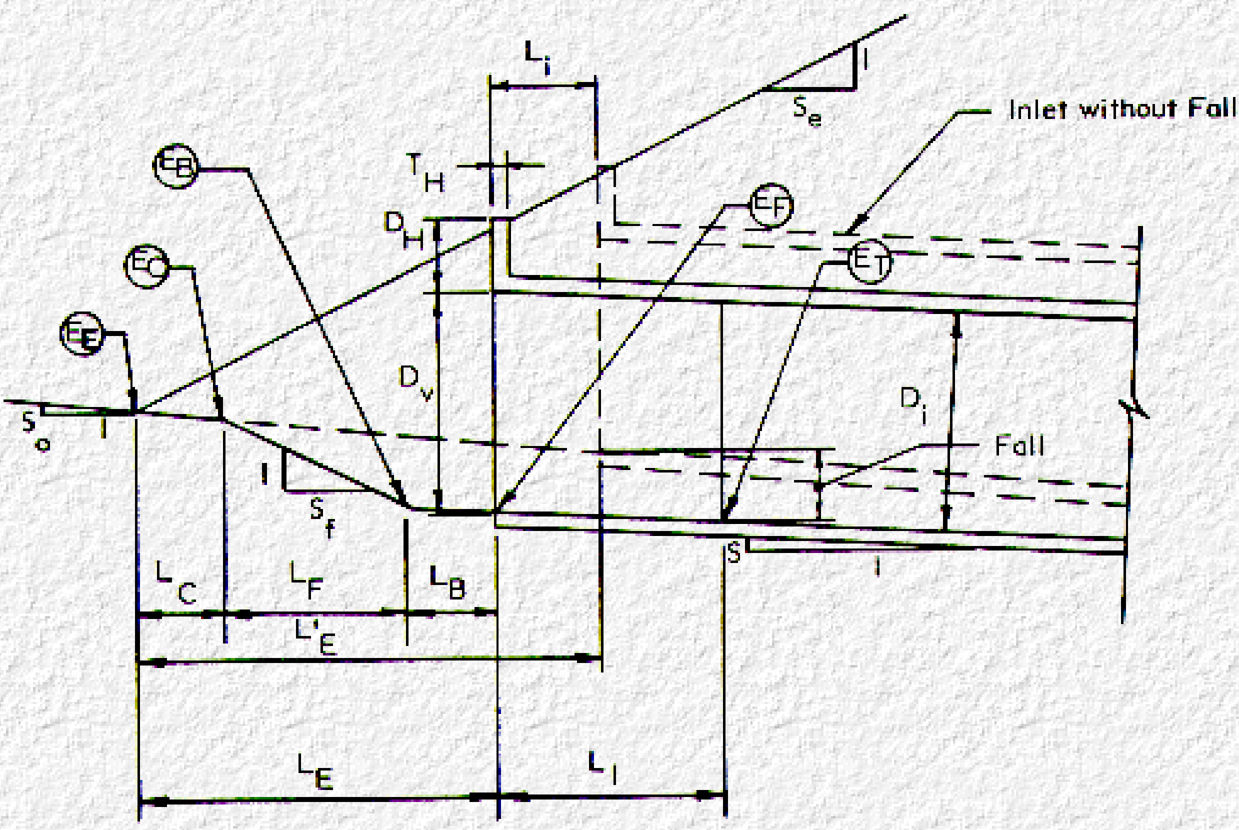
Determine the following variables:

Slopes: Barrel (S)

Lengths: L_C, L_F, L_B, L, L_O

Elevations: E_C, E_B, E_F, E_T

F.2.2 Determine Lengths



T_H: Selected by designer

$D_H = D_i/12$, (or selected by designer, 12 in. min.)

$D_V = D_i\sqrt{S^2 + 1} \approx D_i$ (0.5% error for $S = 0.10$)

$L_B = D_i/2$ 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:

$$L'_E = \frac{1}{1 + S_e\,S_o}\left[S_e\,(D_V + D_H) - T_H\right] \qquad \text{Eq. F.11}$$

Due to the increased number of variables, the remaining parameters are most easily determined by an iterative process.

a. Estimate barrel slope S

$$S \approx \frac{(L_T - L_o - L'_E)\, S_o - Fall}{L_T - (L_o + L_B + L_1)}$$ Equation F.12

b. Determine remaining lengths

$$L_i = \left[Fall - L_1 S + (D_v + D_H)\left(\sqrt{s_o^2 + 1} - \sqrt{s^2 + 1}\right)\right] S_e$$ Equation F.13

$$L_C = L'_E - L_B - L_i - \frac{S_f\left[Fall - S(L_1 + L_B) + S_o(L_i + L_B)\right]}{1 - S_o S_f}$$ Equation F.14

$Fall' = Fall + S_o\,(L'_E - L_c)$ Equation F.15
$L_F = [Fall' - S\,(L_B + L_1)]\, S_f$ Equation F.16
$L_E = L_B + L_C + L_F$ 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)

$L = L_T - (L_O + L_E)$ Equation F.18

c. Check result, calculate Δ

$\Delta = S_o(L_T - L_O - L_C) - S\,(L + L_B) - L_F/S_f$ Equation F.19

d. if $\Delta > 0.01$, calculate a new S

$$S = \frac{SL + \Delta}{L}$$ Equation F.20

Repay steps b and c. This iteration will normally close with one additional cycle. See Example

---

F.2.3 Determine Elevations

$El.\ E_C = El.E_E - S_o L_C$ Equation F.21

$El.\ E_B = El.E_C - L_F/S_f$ Equation F.22

$El.\ E_F = El.E_B - SL_B$ Equation F.23

$El.\ E_T = El.E_F - SL_1$ Equation F.24

$El.\ E_S = El.E_O - SL_O$ 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.

$$H(x) = H_f + x(S + 1/S_e) \qquad \text{Equation F.26}$$

F.2.5 Example - Side Tapered Inlet with Fall

a. Given

$D_i = B_i$	=	4.0 ft	S_o	=	0.05	El. E_E	=	17.5 ft
L_T	=	350 ft	S_e	=	2	El. 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

$$D_V \approx D_i = 4.0 \text{ ft}$$

$$D_H = \frac{D_i}{12} = \frac{4.0}{12} = 0.33 \text{ ft} \Rightarrow \quad \text{Use 1.0 ft min.}$$

$$T_H = 1.0 \text{ ft (for simplicity)}$$

$$L_B = \frac{D_i}{2} = 2.0 \text{ ft}$$

c. Determine remaining variables

$$L_O = \frac{1}{1 - S_e S_o}\left[S_e(D_V + D_H) - T_H\right]$$

$$= \frac{1}{1 - 2(0.05)}\left[2(4.0 + 1.0) - 1.0\right] = 10.0 \text{ ft}$$

$$L'_E = \frac{1}{1 + S_e S_o}\left[S_e (D_V + D_H) - T_H\right]$$

$$= \frac{\cdot}{1 + 2(0.05)} \left[2(4 + 1) - 1 \right] = 8.18 \text{ ft}$$

$$S \approx \frac{(L_T - L_O - L'_E)\ S_o - \text{Fall}}{L_T - (L_O + L_B + L_I)} = \frac{(350 - 10 - 8.18)\ 0.05 - 6.0}{350 - (10 + 2 + 4)} = 0.0317$$

$$L_i = \left[\text{Fall} - L_I\, S + (D_V + D_H)\left(\sqrt{S_o^{\,2} + 1} - \sqrt{S^2 + 1}\right) \right] S_e$$

$$= \left[6.0 - 4.0(0.0317) + (4 + 1)\left(\sqrt{0.05^2 + 1} - \sqrt{0.0317^2 + 1}\right) \right] 2 = 11.75 \text{ ft}$$

$$L_C = L'_E - L_B - L_i - \frac{S_f \left[\text{Fall} - S\,(L_I + L_B) + S_o\,(L_i + L_B) \right]}{1 - S_o\, S_f}$$

$$= 8.18 - 2 - 11.75 - \frac{2 \left[6 - 0.0317\,(4{+}2) + 0.05\,(11.75{+}2) \right]}{1 - (0.05)\,2} = -20.01 \text{ ft}$$

$$\text{Fall}' = \text{Fall} + S_o\,(L'_E - L_C) = 7.41 \text{ ft}$$

$$L_F = \left[\text{Fall}' - S(L_B + L_I) \right] S_f = \left[7.41 - 0.0317\,(2 + 4) \right]\ 2 = 14.44 \text{ ft}$$

$$L_E = L_B + L_C + L_F = 2 + (-20.01) + 14.44 = -3.57 \text{ ft}$$

$$L = L_T - (L_E + L_O) = 350.0 - (-3.57 + 10.0) = 343.57 \text{ ft}$$

d. Check Δ

$$\Delta = 0.05 \left[350 - 10 - (-20.01) \right] - 0.0317\,(343.57 + 2) - \frac{14.44}{2} = -0.174$$

e. $\Delta > 0.01$; therefore, recalculate S and lengths L_F, L_E, L_C, L

$$S = \frac{SL + \Delta}{L} = \frac{0.0317\,(343.57) + (-0.174)}{(343.57)} = 0.0312$$

$$L_i = \left[6 - 4(0.0312) + (4 + 1)\left(\sqrt{0.05^2 + 1} - \sqrt{0.0312^2 + 1} \right) \right] 2 = 11.76 \text{ ft}$$

$$L_C = 8.18 - 2 - 11.76 - \frac{2\ \ 6.0 - -0.0312(4{+}2) + 0.05(11.76{+}2)}{1 - 0.05\,(2)} = -20.03 \text{ ft}$$

$$\text{Fall}' = 6.0 + 0.05\left[8.18 - (-20.03)\right] = 7.41 \text{ ft}$$

$$L_F = 7.41 - 0.0312(2 + 4) \quad 2 = 14.45$$

$$L_E = 2 + (-20.03) + 14.45 = -3.58$$

$$L = 350 - (-3.58 + 10) = 343.58$$

f. Check Δ

$$\Delta = 0.05 \quad 350 - 10 - (-20.03) \quad - 0.0312\,(343.58 + 2) - \frac{14.45}{2} = -0.006$$

$\Delta < 0.01$, Okay

g. Determine elevations

$$\text{El. } E_C = \text{El. } E_E - S_o L_C = 17.5 - (0.05)(-20.03) = 18.50 \text{ ft}$$

$$\text{El. } E_B = \text{El. } E_C - L_F/S_f = 18.50 - 14.45/2 = 11.28 \text{ ft}$$

$$\text{El. } E_F = \text{El. } E_B - S\,L_B = 11.28 - 0.0312(2) = 11.22 \text{ ft}$$

$$\text{El. } E_T = \text{El. } E_F - S\,L_I = 11.22 - 0.0312(4) = 11.10 \text{ ft}$$

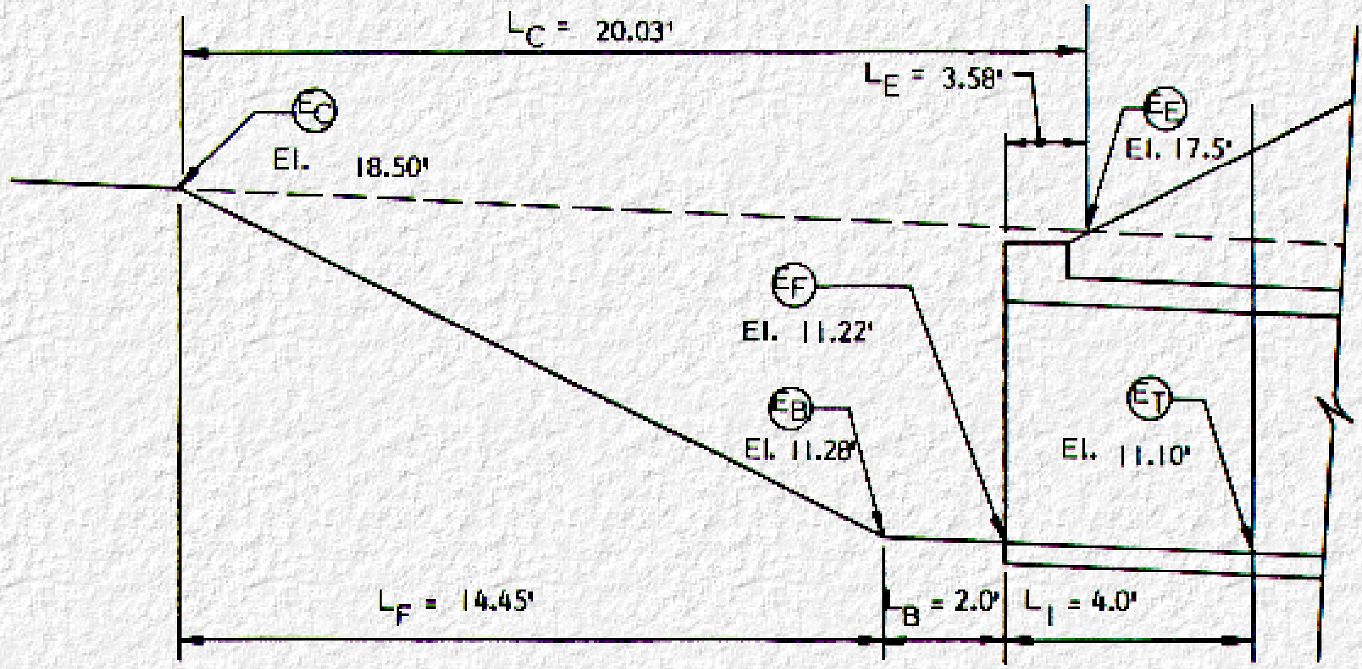
h. Determine height of fill

$\approx$ 1 ft at headwall + 2.0 ft surcharge

$$H_f = 1 + 2 = 3.0 \text{ ft}$$

$$H_{throat} = 3 + 4\,(0.0313 + \tfrac{1}{2}) = 5.13 \text{ ft}$$

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

$$D_H = \frac{D_i}{12}, \text{ (or as selected by the designer, 12 in. min.)}$$

$$D_V = D_i\sqrt{S^2 + 1} \approx D_i$$

$$L_E = \frac{1}{1 + S_e S_o}\left[S_e(D_V + D_H) - T_H\right]$$

$$L_O = \frac{1}{1 - S_e S_o}\left[S_e(D_V + D_H) - T_H\right]$$

$$L = L_T - L_E - L_O$$

$$El.\ E_F = El.\ E_E - L_E\ S$$

$$El.\ E_T = El.\ E_F - L_I\ S$$

H_f varies with site conditions and height of headwall. Must include any surcharge being considered.

$$H(x) = H_f + x\,(S + \frac{1}{S_e})$$

Go to Appendix G

Appendix G : FHWA-IP-83-6

Typical Details for Improved Inlets

Go to Appendix H

Go to Appendix H

Appendix H : FHWA-IP-83-6

Computer Program Listings
Part I

[Go to Part II, Program Pipecar]

Program BOXCAR

```
.V G LEVEL  21                     MAIN               DATE = 82251          18/35/09

      C
      C
      C        PROGRAM BOXCAR
      C
      C        ANALYSIS AND DESIGN PROGRAM FOR ONE CELL REINF. CONCRETE BOX SECTIONS
      C
      C        SUBMITTED TO FEDERAL HIGHWAY ADMINISTRATION  -  AUGUST 1982
      C        DEVELOPED FOR FHWA PROJECT NO. DOT-FH-11-9692
      C     BY SIMPSON GUMPERTZ AND HEGER INC.  1696 MASSACHUSETTS AVENUE
      C                                         CAMBRIGE,MASSACHUSETTS 02138
      C        EXAMPLE STANDARD PLANS FOR IMPROVED INLETS
      C
      C     THIS IS THE MAIN PROGRAM. IT SEQUENTIALLY CALLS THE VARIOUS
      C     SUBROUTINES NEEDED TO COMPLETE THE ANALYSIS AND DESIGN OF THE
      C     ONE CELL BOX.
      C
      C
            REAL*4 JLOAD(12,5)
            REAL*4 INER(4,5),KAA(4,3,3),KAB(4,3,3),KBA(4,3,3),KBB(4,3,3)
            INTEGER ISDATA(35),IBDATA(35)
            INTEGER ICON(6)
      C
            COMMON/RSCALE/SPAN,RISE,TT,TB,TS,GAMAC,GAMAS,GAMAF,PC,H,HH,HV,Q,
           1 ZETA,BETA,DF,Q1,EC,FS,FY,FCP,FLMV,FLN,Q2,Q3,NLAY,RTYPE,Q4,Q5,
           2 CT(6),SDATA(35)
      C
            COMMON/RARRAY/U(12,5),W1(4,5),W2(4,5),A(4,5),B(4,5),C(4,5),
           1 PMEMB(4,25),X(50,4)
      C
            COMMON/RARRAY/INER,KAA,KAB,KBA,KBB
      C
            COMMON/ANAL/JLOAD,STIF(12,12),FIXMO(4,5,4),DM(6),DV(6),DP(6),
           1 AS(5),SRATIO(6)
      C
            COMMON/ISCALE/NIT,NOLD,IDBUG,IR,IW,ITAPE,IPATH,ICYC,NINT
      C
            COMMON/IARRAY/MEMB(4,2)
      C
            COMMON/HARRAY/AMOM(20,5),V(20,5),P(3,5),FXLA(4,5),FYLA(4,5)
           1 ,BMA(4,5),FXLB(4,5),FYLB(4,5),BMB(4,5),ENDM(20,5),ENDV(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),FMMIN(20),
           4 FPMAX(3),FVMAX(20),FMMAX(20),ZMOMT,ZMOMB,XL(20)
      C
            COMMON/IFLAGS/IBDATA,ISDATA,ICON
      C
```

```
C      ***********************END OF COMMON ******************************
C

IV G LEVEL  21                    MAIN                DATE = 82251          18/35/09

      C      INTERNAL UNITS ARE KIPS,AND INCHES
      C
             IR=5
             IW=6
           4 IPATH=1
           1 CALL RREAD(ISTOP)
             GO TO (2,5),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
           5 CONTINUE
             END

V G LEVEL  21                    RREAD               DATE = 82251          18/35/09

          SUBROUTINE RREAD(ISTOP)
    C
    C   THIS ROUTINE READS ALL THE INPUT IN A SPECIFIED FORMAT AND
    C   TRANSFERS THE DATA INTO THE BDATA AND SDATA ARRAYS. THE EXECUTION OF RREAD
    C   IS CONTROLLED BY THE KODE VARIABLE ON THE INPUT CARDS. A KODE
    C   GREATER THAN 13 SIGNALS THE END OF THE INPUT DATA. RREAD REPRINTS
    C   THE INPUT CARDS AS IT READS THEM AS A CHECK FOR THE USER.
    C
          INTEGER ISDATA(35),IBDATA(35)
          COMMON /IFLAGS/ IBDATA,ISDATA
          COMMON /RSCALE/ BDATA(35),SDATA(35)
          COMMON/ISCALE/NIT,NOLD,IDBUG,IR,IW,ITAPE,IPATH,ICYC,NINT
          DIMENSION TEXT(5),D(6)
          DIMENSION LAT(15)
          DATA LAT/3,3,2,3,4,3,1,2,6,1,2,4,4/
    C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
    C
          WRITE(IW,99)
       99 FORMAT('1')
          READ(IR,1020,END=995)  (BDATA(I),I=1,20),IDBUG
     1020 FORMAT(19A4,A3,I1)
          WRITE(IW,1021) (BDATA(I),I=1,20), IDBUG
     1021 FORMAT(1X,19A4,A3,I1 )
          DO 5 I=1,35
          SDATA(I)=0.
          ISDATA(I)=0
          BDATA(I)=0.
        5 IBDATA(I)=0
          SLEN=12.
          SLEN2=SLEN*SLEN
          SLEN3=SLEN2*SLEN
          SLD=1000.
        1 READ( IR,1000,END=995)  KODE,(TEXT(I),I=1,5),(D(I),I=1,6)
     1000 FORMAT(I2,4A4,A2,6F10.3)
          IF ( KODE.GT.13)  GO TO 999
          K=LAT(KODE)
          WRITE(IW,2000)              KODE,(TEXT(I),I=1,5),(D(I),I=1,K)
     2000 FORMAT(1X,I2,4A4,A2,6F10.3)
        6 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
```



```
      IBDATA(10)=1
      GO TO 1
C
C     SLAB THICKNESSES,TT,TB,TS, KODE=2
   20 CONTINUE
      BDATA(3)=D(1)
      BDATA(4)=D(2)
      BDATA(5)=D(3)
      DO 21 I=3,5
      IF (BDATA(I))  21,21,23
   23 IBDATA(I)=1
   21 CONTINUE
      GO TO 1
C
C     HAUNCH GEOMETRY,HH,HV, KODE=3
   30 CONTINUE
      IF ( D(1).EQ.0.) D(1)=D(2)
      IF ( D(2).EQ.0.) D(2)=D(1)
      BDATA(11)=D(1)
      BDATA(12)=D(2)
      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(8)=D(3)/SLEN3/SLD
      IBDATA(8)=1
      GO TO 1
C
C     MINIMUM LATERAL SOIL COEFFICIENT (ZETA), MAXIMUM LATERAL SOIL
C     COEFFICIENT (CONVERTED TO RAT IN SDATA(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)=0.50
      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)=D(2)/D(1) - 1.0
   56 ISDATA(25) = 1
      IF ( D(4).NE.0.) IBDATA(14)=2
      IF ( D(3)-.5 )  54,55,55
   54 BDATA(15)=1.2
      IBDATA(15)=-1
      GO TO 1
   55 BDATA(15)=D(3)
      IBDATA(15)=1
      GO TO 1
C
C     LOAD FACTOR, CAPACITY RED. FACTORS                    KODE=6
C
   60 CONTINUE
      BDATA(22)=D(1)
      BDATA(23)=D(1)
      BDATA(9)=D(2)
      BDATA(13)=D(3)
      IBDATA(22)=1
      IBDATA(23)=1
      IBDATA(9)=1
      IBDATA(13)=1
      GO TO 1
C
C     DEPTH OF FLUID.  KODE=7
   70 CONTINUE
      BDATA(16)=D(1)
      IBDATA(16)=1
      GO TO 1
C
C     MATERIAL STRENGTHS, FY,FCP,  KODE=8
   80 CONTINUE
      IF ( D(1).EQ.0.)   GO TO 81
      BDATA(20)=D(1)
      IBDATA(20)=1
   81 IF ( D(2).EQ.0.)    GO TO 1
      BDATA(21)=D(2)
      IBDATA(21)=1
      GO TO 1
C
C     CONCRETE COVER, KODE=9
   90 CONTINUE
      DO 95 I=1,6
      IF ( D(I))95,95,92
   92 BDATA(29+I)=D(I)
      IBDATA(29+I)=1
   95 CONTINUE
      GO TO 1
```

```
C
C    CRACK FACTOR                                   KODE=10
C
  100 CONTINUE
      BDATA(24)=D(1)
      IBDATA(24)=1
      GO TO 1
C
C     REINFORCING TYPE AND NUMBER OF LAYERS
  110 CONTINUE
      BDATA(26)=D(1)
      BDATA(27)=D(2)
      IBDATA(26)=1
      IBDATA(27)=1
      GO TO 1
C
C     WIRE DIAMETERS KODE=12
  120 CONTINUE
      DO 121 I=3,6
      IF (D(I-2)) 121,121,122
  122 SDATA(I)=D(I-2)
      ISDATA(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
C     WIRE SPACING, KODE=13
  130 CONTINUE
      DO 135 I=9,12
      IF (D(I-8)) 135,135,133
  133 SDATA(I)=D(I-8)
      ISDATA(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
C     END OF DATA, KODE.GT.13
  999 CONTINUE
      WRITE(IW,2000)  KODE,(TEXT(I),I=1,5)
  994 CONTINUE
```



```
      ISTOP=1
      GO TO 996
  995 ISTOP=2
  996 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE INIT
C
C   THIS SUBROUTINE FILLS OUT THE B DATA AND SDATA ARRAYS.WHERE
C   NEEDED, IT CALCULATES VALUES FROM INPUT AND INSERTS THEM INTO
C   THE APPROPRIATE ARRAY.
C   INIT ASSIGNS DEFAULT VALUES ON THE FOLLOWING BASIS:
C     IBDATA(*)OR ISDATA(*)=1 -VALUE HAS BEEN INPUT NO VALUE NEEDED
C   IBDATA(*)OR ISDATA(*)=0-VALUE HAS NOT BEEN INPUT, DEFAULT VALUE
C     GIVEN TO BDATA(*) OR  SDATA(*); IBDATA(*) OR IBDATA(*) IS THEN
C   SET EQUAL TO -1.
C   THIS ROUTINE ALSO CHECKS FOR ERROR CONDITIONS IN THE INPUT DATA
C   AND PRINTS THE BDATA AND SDATA ARRAYS FOR AN IDBUG VALUE GREATER
C   THAN 0.
C
C
      INTEGER ISDATA(35),IBDATA(35)
      COMMON /IFLAGS/ IBDATA,ISDATA
      COMMON /RSCALE/ BDATA(35),SDATA(35)
      COMMON /ISCALE/NIT,NOLD,IDBUG,IR,IW,ITAPE,IPATH,ICYC,NINT
      COMMON /IARRAY/MEMB(4,2)
      COMMON /RARRAY/ FIL(160),PMEMB(4,25)
      EQUIVALENCE(H,BDATA(19))
      EQUIVALENCE (BDATA(1),SPAN),(BDATA(2),RISE)
      EQUIVALENCE(TT,BDATA(3)),(TB,BDATA(4)),(TS,BDATA(5)),(HH,
     1 BDATA(11)),(HV,BDATA(12))
      DIMENSION ASSUME(35)
C
      DIMENSION SOURCE(8)
      DATA SOURCE/4HINPU,4HT    ,4HNO V,4HALUE,4HASSU,4HMED ,4H  FL,
     1 4HAG        /
      REAL*8 SCRIPT(75), TTEXT(75)
      DATA SCRIPT/8HINSIDE S,8HPAN (IN),8HINSIDE R,8HISE (IN),
     1 8HTOP SLAB,8HTHK (IN),8HBOT SLAB,8HTHK (IN),8HSIDE WAL,
     1 8HL T (IN),8HCONC UNI,8HT WT KCI,8HSOIL UNI,8HT WT KCI,
     1 8HFLUID UN,8HT WT KCI,8HFLEX CAP,8HRED FACT,8HBURIAL D,
     1 8HEPTH  IN,8HHORIZ HA,8HUNCH  IN,8HVERT HAU,8HNCH   IN,
     1 8HSHEAR CA,8HP RED FR,8HLAT SOIL,8HPRESS CC,8HSOIL-STR,
     1 8H INT COF,8HFLUID DE,8HPTH (IN),8H***EMPTY,8H********,
     1 8HCONCRETE,8H E (KSI),8HSTEEL E ,8H (KSI)  ,8HSTEEL ST,
     1 8HR  (KSI),8HCONCRETE,8H STR KSI,8HLOAD FAC,8HTOR M,V ,
     18HLOAD FAC,8HTOR  P  ,8H.01 CRAC,8HK FACTOR,8H***EMPTY,
     1 8H********,8H# LAYERS,8HOF REINF,8HREINFORC,8HING TYPE,
     1 8H***EMPTY,8H********,8H***EMPTY,8H********,8HTOP OUT ,
     1 8HCVR (IN),8HSIDE OUT,8H CVR IN ,8HBOT OUT ,8HCVR (IN),
     1 8HTOP INS ,8HCVR (IN),8HBOT INS ,8HCVR (IN),8HSIDE INS,
     1 8H CVR IN
      DATA TTEXT/8HWIRE DIA,8H OUT TOP,8HWIRE DIA,8H OUT SDE,8HWIRE DIA,
     1 8H OUT BOT,8HWIRE DIA,8H INS TOP,8HWIRE DIA,8H INS BOT,
```

```
     1 8HWIRE DIA,8H INS SDE,8HWIRE SPA,8H OUT TOP,8HWIRE SPA,
     1 8H OUT SDE,8HWIRE SPA,8H OUT BOT,8HWIRE SPA,8H INS TOP,
     2 8HWIRE SPA,8H INS BOT,8HWIRE SPA,8H INS SDE,8H***EMPTY,
     1 8H********,8H***EMPTY,8H********,8H***EMPTY,8H********,
     1 8H***EMPTY,8H********,8H***EMPTY,8H********,8H***EMPTY,
     1 8H********,8HTOP STEE,8HL LTH IN,8HBOT STEE,8HL LTH IN,
     1 8H***EMPTY,8H********,8H***EMPTY,8H********,8H***EMPTY,
     1 8H********,8H***EMPTY,8H********,8H  LAT SC,8HIL RATIO,
     1 8H***EMPTY,8H********,8H***EMPTY,8H********,8H***EMPTY,
     1 8H********,8H***EMPTY,8H********,8HD OUT TO,8HP  (IN) ,
     1 8HD OUT ST,8HDE  (IN),8HD OUT BO,8HTT  (IN),8HD IN TOP,
     1 8H  (IN)  ,8HD IN BOT,8HT  (IN) ,8HD IN SID,8HE  (IN) /
C
      IF(IFDATA(1).EQ.0)  GO TO 100
      IF ((RISE/12..LT.2.).OR.(RISE/12..GT.20.)) GO TO 102
      DO 5 I=1,4
      MEMB(I,1)=I
    5 MEMB(I,2)=I+1
      MEMB(4,2)=1
      THICK    =FLOAT(IFIX(SPAN/12.+.5))
      ASSUME(3)=THICK+1.
      IF ( SPAN.GT.84.)  ASSUME(3)=THICK
      THICK=ASSUME(3)
      ASSUME(4)=THICK
      ASSUME(5)=THICK
      ASSUME(6)=0.868E-04
      ASSUME(7)=0.69444444E-04
      ASSUME(8)=0.3617E-04
      ASSUME(9)=0.90
C     ASSUME(10) IS THE DEPTH OF FILL- FATAL ERROR IF ONMITTED
      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)=1.0
      ASSUME(26)=1.00
      ASSUME(27)=2.
      ASSUME(30)=1.
      ASSUME(31)=1.
      ASSUME(32)=1.
      ASSUME(33)=1.
      ASSUME(34)=1.
```

```
      ASSUME(35)=1.
      DO 10 I=3,16
      IF (IBDATA(I)   ) 10,9,10
    9 IBDATA(I)=-1
      BDATA(I)=ASSUME(I)
   10 CONTINUE
      DO 20 I=20,24
      IF ( IBDATA(I) )  20,19,20
   19 IBDATA(I)=-1
      BDATA(I)=ASSUME(I)
   20 CONTINUE
      DO 22 I=26,27
      IF ( IBDATA(I) )  22,21,22
   21 IBDATA(I)=-1
      BDATA(I)=ASSUME(I)
   22 CONTINUE
        DO 24 I=30,35
      IF (IBDATA(I)) 24,23,24
   23 IBDATA(I)=-1
      BDATA(I)=ASSUME(I)
   24 CONTINUE
      BDATA(19)=29000.
      BDATA(18)=(BDATA(6)*1728000.)**1.5*33.*SQRT(BDATA(21)*1000.)/
     1   1000.
      IBDATA(19)=-1
      IBDATA(18)=-1
C
C     INITIALIZE PMEMB(I,J)
      GO TO 81
   80 CONTINUE
      Q1=0.
      Q2=0.
      GO TO 82
   81 IF ((HH.EQ.0.).OR.(HV.EQ.0.))  GO TO 80
      Q1=HH/HV/2.
      Q2=HV*TS/HH/2.
   82 D1=TS+HH+Q1*TT
      D2=TT+HV+Q2
      D3=TB+HV+Q2
      D4=TS+HH+Q1*TB
      PMEMB(1,1)=D2
      PMEMB(2,1)=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+TB/2.
      PMEMB(1,6)=HH+TS/2.
      PMEMB(2,6)=HV+TB/2.
      PMEMB(3,6)=HH+TS/2.
      PMEMB(4,6)=HV+TT/2.
      GO TO 149
  100 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
  101 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 AS19DEC 7
     1 ',F20.3)
      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,F20.3)
      WRITE(IW,1010)
      IPATH=-1
  999 FORMAT(' *** INPUT ERROR ***')
 1010 FORMAT(     ' EXECUTION FOR THIS PROBLEM HAS BEEN TERMINATED.')
      GO TO 150
  149 CONTINUE
      B=AMAX1(TT,TB,TS)
```

```
      ASSUME(1)=0.08*TT
      ASSUME(2)=0.08*B
      ASSUME(3)=0.08*B
      ASSUME(4)=0.08*TT
      ASSUME(5)=0.08*TB
      ASSUME(6)=0.08*TS
      DO 31 I=7,12
      ASSUME(I)=2.
   31 CONTINUE
      DO 33 I=1,12
      IF ( ISDATA(I) )  34,32,34
   32 ISDATA(I)=-1
      ISDATA(I+29)=-1
      SDATA(I)=ASSUME(I)
      IF (I .GT.6) GO TO 33
   34 CONTINUE
      A=TT
      IF (I .EQ. 2 .OR. I .EQ.6 ) A=TS
      IF (I .EQ. 3 .OR. I .EQ. 5 ) A=TB
      SDATA(29+I)=A-BDATA(29+I)-SDATA(I)/2.
      IF (ISDATA(I+29) .NE. -1)  ISDATA(I+29)=1
   33 CONTINUE
      IF ( ISDATA(25) .EQ. 0.) GO TO 994
      GO TO 996
  994 SDATA(25) = 0.5/BDATA(14) - 1
      ISDATA(25)=-1
      WRITE(IW,4050)
 4050 FORMAT(/////,3X,69(1H*),/,3X,1H*,67X,1H*,/,3X,1H*,1X,
     1'ALL INFORMATION PRESENTED IS FOR REVIEW, APPROVAL, INTERPRETATION
     2 *',/,3X,'* AND APPLICATION BY A REGISTERED ENGINEER.',25X,1H*,/,
     33X,1H*,67X,1H*,/,3X,69(1H*))
  996 IF ( IDBUG.EQ.0)  GO TO 901
      WRITE(IW,99)                                                      DEBUG
   99 FORMAT(1H1,////,T43,'MAP OF BDATA AND SDATA ARRAYS',// )
      WRITE(IW,3001)                                                    DEBUG
 3001 FORMAT('0',T10,'PARAMETER',T28,'DATA',T37,'SOURCE',T73,
     1 'PARAMATER',T93,'DATA',T102,'SOURCE'    )
      DO 900 I=1,35                                                     DEBUG
      JF = I * 2 - 1
      KF = I * 2
      IF (IBDATA(I)) 702, 701, 700
  700 J = 1
      IF (IBDATA(I) .EQ. 2 ) J = 7
      GO TO 703
  701 J = 3
      GO TO 703
  702  J = 5
  703 IF (ISDATA(I)) 706,705,704
```

```
  704 N = 1
      GO TO 707
  705 N = 3
      GO TO 707
  706 N = 5
  707 J1 = J+ 1
      N1 = N + 1
      WRITE(IW,3000)I,(SCRIPT(K),K=JF,KF),BDATA(I),(SOURCE(K),K=J,J1),
     1  I,(TTEXT(K),K=JF,KF),SDATA(I),(SOURCE(K),K=N,N1)
 3000 FORMAT(' ',I2,3X,2A8,E12.5,2X,2A4,T65,I2,3X,2A8,E12.5,2X,2A4)
  900 CONTINUE                                                          DEBUG
  901 CONTINUE
  150 CONTINUE
      RETURN
      END
```



```
      SUBROUTINE DESIGN
C
C     THIS SUBROUTINE SEQUENTIALLY CALLS OTHER SUBROUTINES IN ORDER TO
C     COMPLETE THE ANALYSIS AND DESIGN OF THE ONE CELL BOX.
C     A PRINTOUT OF THE X,Y DEFLECTIONS AND ROTATIONS FOR EACH MEMBER
C     AND LOADING CASE IS AVAILABLE WITH AN IDBUG VALUE GREATER THAN 2.
C
      COMMON/RARRAY/U(12,5),FIL(100),PMEMB(4,25)
      COMMON/RSCALE/SPAN,RISE,TT,TB,TS,GAMAC,GAMAS,GAMAF,PO,H,HH,HV,Q,
     1 ZETA,BETA,DF,Q1,EC,ES,FY,FCP,FLMV,FLN,Q2,Q3,NLAY,RTYPE,Q4,Q5,
     2 CT(6),SDATA(35)
      COMMON/ANAL/P(12,5),STIF(12,12),FIXMO(4,5,4),DM(6),DV(6),DP(6),
     1AS(6),SRATIO(6)
      COMMON /ISCALE/NIT,NCLD,IDBUG,IR,IW,ITAPE,IPATH,ICYC,NINT
C
      ICYC=0
    1 CONTINUE
      DO 2 I=1,4
      CALL GENJS(I)
    2 CONTINUE
C
      CALL GSTIF
C
      CALL GENLD
C
      CALL MATMP(STIF,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(IW,99)
   99 FORMAT('1',///  )
      WRITE(IW,1000)
 1000 FORMAT('0',T29,'DISPLACEMENT MATRIX - INCHES AND RADIANS',
     1 //,T38,'LOAD CASE',/ ,T2,' NODE ',T18,'1',T30,'2',T42,'3',T54,
     2 '4',T66,'5'  )
```

```
      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)
```



```
         WRITE(6,1004)   (U(JC,K),K=1,5)
 1002 FORMAT(T5,I1,T10,'X',T13,5(F10.4,2X))
 1003 FORMAT(T10,'Y',T13,5(E10.4,2X))
 1004 FORMAT(T8, 'ROT',T13,5(E10.4,2X))
   11 CONTINUE
   12 CONTINUE
C
      CALL ENDFO
      CALL SIMSPN
      CALL FMXMN
      IF (IPATH .LE. 0 ) RETURN
C
      CALL DESCK
      RETURN
      END
```

```
      SUBROUTINE GENJS(M)
C
C     GENERATES FLEXIBILITY COEFICIENTS FROM ONE CELL BOX GEOMETRY.
C     FOR MEMBERS WITH LINEARLY VARYING HAUNCHES THESE COEFFICIENTS ARE
C     DETERMINED BY NUMERICAL INTEGRATION.
C
C       THE INTEGRATION POINTS ARE  N O T  AT EQUAL INTERVALS
      REAL*4 M1(50),M2(50),M3(50),M4(50),M5(50),M6(50)
      REAL*4 INER(4,50)
      COMMON /RSCALE/ BDATA(35)
      COMMON /RARRAY/ FIL(160),PMEMB(4,25),XX(50,4),INER
      COMMON /ISCALE/ N
      N=50
      EQUIVALENCE (BDATA(11),HH),(BDATA(12),HV),(BDATA(18),EC)
      DA=PMEMB(M,1)
      DB=PMEMB(M,2)
      DC=PMEMB(M,3)
      SP=PMEMB(M,4)
      ALA=PMEMB(M,5)
      ALB=PMEMB(M,6)
      X1=ALA
      X2=SP-ALB
      CA=(DA-DC)/ALA
      CB=(DB-DC)/ALB
      IF ((HH.EQ.0.).OR.(HV.EQ.0.))  GO TO 5
      DX1=ALA/5.
      DX2=(SP-ALA-ALB)/39.
      DX3=ALB/5.
      GO TO 6
    5 DX1=SP/49.
      DX2=DX1
      DX3=DX1
    6 X=-DX1
      DO 10 I=1,6
      X=X+DX1
      D=DA-CA*X
      INER(M,I)=D*D*D*EC
      XX(I,M)=X
   10 CONTINUE
      DO 11 I=7,45
      X=X+DX2
      D=DC
      INER(M,I)=D*D*D*EC
      XX(I,M)=X
   11 CONTINUE
      DO 12 I=46,50
      X=X+DX3
      D=DC+CB*(X-X2)
```

```
      INER(M,I)=D*D*D*EC
      XX(I,M)=X
   12 CONTINUE
      DO 20 I=1,N
      X=XX(I,M)
      D=SP-X
      M1(I)=1.
      M2(I)=D
      M3(I)=X
      M4(I)=D*D
      M5(I)=D*X
      M6(I)=X*X
   20 CONTINUE
      PMEMB(M,7)=TRAP(M1,N,SP,M)
      PMEMB(M,8)=TRAP(M2,N,SP,M)
      PMEMB(M,9)=TRAP(M3,N,SP,M)
      PMEMB(M,10)=TRAP(M4,N,SP,M)
      PMEMB(M,11)=TRAP(M5,N,SP,M)
      PMEMB(M,12)=TRAP(M6,N,SP,M)
      RETURN
        END
```



```
      FUNCTION TRAP(MOM,N,S,M)
C
C   USES THE TRAPEZOIDAL RULE WITH 50 INTEGRATION POINTS TO OBTAIN
C   THE FLEXIBILITY COEFFICIENTS
C
C     THIS IS THE 2ND VERSION OF THIS PROGRAM
C     THE INTEGRATION POINTS ARE  N O T  AT EQUAL INTERVALS
      REAL*4 INER(4,50),MOM(1)
      COMMON /HARRAY/ FL(260),X(50,4),INER
      K=N-1
      H=S/K
      TRAP=0.
      DO 1 I=1,K
      TRAP=TRAP+(MOM(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
C
C     GENERATES STIFFNESS MATRIX
C     FLEXIBILITY COEFFICIENTS ARE INVERTED AND ASSEMBLED TO OBTAIN
C     STIFFNESS MATRIX
C
C
      COMMON/RSCALE/SPAN,RISE,TT,TB,TS,GAMAC,GAMAS,GAMAF,PO,H,HH,HV,D,
     1 ZETA,BETA,DF,W1,EC,ES,FY,FCP,FLMV,FLN,Q2,Q3,NLAY,RTYPE,Q4,Q5,
     2 CT(6),SDATA(35)
      COMMON/RARRAY/U(12,5),W1(4,5),W2(4,5),A(4,5),B(4,5),C(4,5),
     1 PMEMB(4,25),X(50,4)
      COMMON /ANAL/FIL(60) ,STIF(12,12)
      COMMON /ISCALE/NIT,NOLD,IDBUG,IR,IW,ITAPE,IPATH,ICYC,NINT
      DIMENSION F(3,3),AK(3,3),UM(3,3)
C
      DO 8 I=1,12
      DO 8 J=1,12
    8 STIF(I,J)=0.
      DO 10 I=1,4
C     GENERATE SCRIPT F
      DO 6 J=2,3
      F(J,1)=0.
      F(1,J)= 0.
      AK(1,J)=0.
      AK(J,1)=0.
    6 CONTINUE
      F(3,3)=PMEMB(I,7)
      F(2,3)=PMEMB(I,8)
      F(2,2)=PMEMB(I,10)
      F(3,2)=F(2,3)
      DC=PMEMB(I,3)*12.
      SP=PMEMB(I,4)
      F(1,1)=SP/DC/EC
C     INVERT F TO GET AK
      DELTA=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(3,3)=F(2,2)/DELTA
      AK(2,3)=-F(2,3)/DELTA
      AK(3,2)=AK(2,3)
      CALL ASSEM(I,AK)
   10 CONTINUE
C
C     REMOVE REACTION COMPONENTS
      DO 12 J=1,12
      STIF(7,J)=STIF(9,J)
      STIF(8,J)=STIF(10,J)
```

```
      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
```



```
      SUBROUTINE ASSEM(M,AK)
C
C   ASSEMBLES THE MEMBER STIFFNESS MATRICES INTO A GLOBAL STIFFNESS
C   MATRIX
C
C
      REAL*4 KAA(4,3,3),KAB(4,3,3),KBA(4,3,3),KBB(4,3,3)
      COMMON /RARRAY/FIL(160),PMEMB(4,25),FIL1(400),KAA,KAB,KBA,KBB
      COMMON /IARRAY/MEMB(4,2)
      COMMON /ISCALE/NIT,NOLD,IDBUG,IR,IW,ITAPE,IPATH,ICYC,NINT
      COMMON /ANAL/ FIL2(60) ,STIF(12,12)
      DIMENSION D(3,3),AK(3,3)
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      JTA=MEMB(M,1)
      JTB=MEMB(M,2)
      SP=PMEMB(M,4)
      IRAA=3*(JTA-1)
      IRBB=3*(JTB-1)
C.....FORM KBA
      DO 1 I=1,3
      DO 1 J=1,3
    1 D(I,J)=-AK(I,J)
      DO 11 I=1,3
   11 D(I,3)=D(I,3)+SP*D(I,2)
      DO 26 I=1,3
      DO 26 J=1,3
   26 KBA(M,I,J)=D(I,J)
      IF ( M.NE.1)  CALL ROTS(M,D)
      DO 8 I=1,3
      IROW=IRAA+I
      DO 8 J=1,3
      ICOL=IRBB+J
    8 STIF(ICOL,IROW)=STIF(ICOL,IROW)+D(J,I)
C
C.....FORM KAB
      DO 3 I=1,3
      DO 3 J=1,3
    3 D(I,J)=KBA(M,J,I)
      DO 13 I=1,3
      DO 13 J=1,3
   13 KAB(M,I,J)=D(I,J)
      IF ( M.NE.1)  CALL ROTS(M,D)
      DO 6 I=1,3
      IROW=IRAA+I
      DO 6 J=1,3
      ICOL=IRBB+J
    6 STIF(IROW,ICOL)=STIF(IROW,ICOL)+D(I,J)
```

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,I,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=IRBB+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,I,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)
C
C     CHANGES MEMBER STIFFNESS MATRICES FROM LOCAL COORDINATE SYSTEM TO
C     GLOBAL COORDINATE SYSTEM
C
      DIMENSION D(3,3)
      GO TO (1,2,3,4),M
    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
C   INVERTS STIFFNESS MATRIX
C
      DIMENSION A(2)
      B=A(1)
      JAA=1
      DO 1 J=2,N
      JAA=JAA+NF
    1 A(JAA) = A(JAA)/B
      JO = 0
      DO 2 J=2,N
      J1=J-1
      JO=JO+NF
      JB=J+JO
      DO 3 I=J,N
      S=0.
      IA=I-NF
      DO 4 K=1,J1
      IA = IA+NF
      KA=JO+K
    4 S=S+A(IA)*A(KA)
      JA=JO+I
    3 A(JA)=A(JA )-S
      IF (J-N) 7,2,2
    7 J2=J+1
      IO=JO
      DO 5 I=J2,N
      S=0.
      IO=IO+NF
      JA=J-NF
      DO 6 K=1,J1
      JA = JA+NF
      KA =K+IO
    6 S=A(JA)*A(KA)+S
      IB=J+IO
    5 A(IB)=(A(IB)-S)/A(JB)
    2 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE GENLD
C
C   GENERATES JOINT LOAD MATRIX
C
      REAL*4 MOM(50)
      REAL*4 JLOAD(12,5)
      COMMON/RSCALE/SPAN,RISE,TT,TB,TS,GAMAC,GAMAS,GAMAF,PC,H,HH,HV,Q,
     1 ZETA,BETA,DF,Q1,EC,ES,FY,FCP,FLMV,FLN,Q2,Q3,NLAY,RTYPE,Q4,Q5,
     2 CT(6),SDATA(35)
      COMMON/RARRAY/U(12,5),W1(4,5),W2(4,5),A(4,5),B(4,5),C(4,5),
     1 PMEMB(4,25),X(50,4)
      COMMON /ISCALE/NIT,NOLD,IDBUG,IR,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 201 I=1,4
      DO 201 J=1,5
      W1(I,J)=0.
      W2(I,J)=0.
      A(I,J)=0.
      B(I,J)=0.
      C(I,J)=0.
  201 CONTINUE
      DO 215 I=1,12
      DO 215 J=1,5
  215 JLOAD(I,J)=0.
      DO 1000 L=1,4
      GO TO (10,20,30,40 ),L
C
C     CONCRETE DEAD LOAD - LOADING CONDITION 1
   10 CONTINUE
      G=GAMAC*12.
      WT=TT*G
      PS=(TS*PMEMB(2,4)+HH*HV)*G
      WB=TB*G
      SP=PMEMB(1,4)
      WR=WT+WB+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
```

```
      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(I,M),MOM,VA,
     1 VB,NIT)
      CALL FXEDMO(MOM,FMAB,FMBA,M)
      CALL FLLD(M,L,VA,VB,FMAB,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
   20 CONTINUE
      WT=BETA*H*GAMAS*12.
      SP=PMEMB(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,NIT)
      CALL FXEDMO(MOM,FMAB,FMBA,M)
      CALL FLLD(M,L,VA,VB,FMAB,FMBA)
   21 CONTINUE
      JLOAD(2,2)=JLOAD(2,2)-P
      JLOAD(5,2)=JLOAD(5,2)-P
      JLOAD(8,2)=JLOAD(8,2)+P
      JLOAD(11,2)=JLOAD(11,2)+P
      GO TO 1000
C
C     HORIZONTAL SOIL PRESSURE - LOADING CONDITION 3
   30 CONTINUE
      G=GAMAS*ZETA*12                                                   19OCT73
      WST=G*H
      WSB=G*(H+RISE+TT+TB)
      SP=PMEMB(2,4)
      W1(2,3)=WST
      W1(4,3)=WSB
      W2(2,3)=WSB
      W2(4,3)=WST
      B(2,3)=SP
      B(4,3)=SP
      DO 31 M=2,4,2
      CALL MOMENT(W1(M,L),W2(M,L),A(M,L),B(M,L),C(M,L),X(1,M),MOM,VA,
```

```
     1 VB,NIT)
      CALL FXEDMO(MOM,FMAB,FMBA,M)
      CALL FLLD(M,L,VA,VB,FMAB,FMBA)
   31 CONTINUE
      PT=WST*TT/2.
      PB=WSB*TB/2.
      JLOAD(1,3)=JLOAD(1,3)+PT
      JLOAD(4,3)=JLOAD(4,3)-PT
      JLOAD(7,3)=JLOAD(7,3)-PB
      JLOAD(10,3)=JLOAD(10,3)+PB
C ADDITIONAL LATERAL SOIL PRESSURE                                        2-12-76
      W1(2, 5)=WST*SDATA(25)
      W1(4, 5)=WSB*SDATA(25)
      W2(2, 5)=WSB*SDATA(25)
      W2(4, 5)=WST*SDATA(25)
      B(2, 5)=SP
      B(4, 5)=SP
      DO 33 M=2,4,2                                                       2-12-76
      CALL MOMENT(W1(M,5),W2(M,5),A(M,5),B(M,5),C(M,5),
     B        X(1,M),MOM,VA,VB,NIT)                                      2-12-76
      CALL FXEDMO (MOM,FMAB,FMBA,M)                                       2-12-76
      CALL FLLD (M,5,VA,VB,FMAB,FMBA)
   33 CONTINUE                                                            2-12-76
      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 1000
C
C     INTERNAL WATER LOAD - LOADING CONDITION 4
   40 CONTINUE
      WSB=GAMAF*DF*12.
      SP=PKEMB(2,4)
      WR=WSB*SPAN/(SPAN+TS)
      W=WR-WSB
      S2=TB/2.
      S1=SP-S2-DF
      S3=TS/2.
      W1(2,4)=0.
      W2(2,4)=-WSB
      A(2,4)=S1
      B(2,4)=DF
      C(2,4)=S2
      W1(3,4)=W
      W2(3,4)=W
      A(3,4)=S3
      B(3,4)=SPAN
      C(3,4)=S3
```

```
      W1(4,4)=-WSB
      W2(4,4)=0.
      A(4,4)=S2
      B(4,4)=DF
      C(4,4)=S1
      P=WB*TS
      JLOAD( 8,4)=JLOAD( 8,4)+P
      JLOAD(11,4)=JLOAD(11,4)+P
      DO 41 M=2,4
      CALL MOMENT(W1(M,L),W2(M,L),A(M,L),B(M,L),C(M,L),X(1,M),MOM,VA,
     1 VB,NIT)
      CALL FXEDMO(MOM,FMAB,FMBA,M)
      CALL FLLD(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
C   GENERATES MEMBER MOMENTS AND SHEARS
C
C
      REAL*4 MOM(1),X(1)
      COMMON /ISCALE/NIT,NOLD,IDBUG,IR,IW,ITAPE,IPATH
    1 CONTINUE
      IF ( W1.EQ.0. .AND. W2.EQ.0. )  GO TO 101
      QM=W2-W1
      QP=W1+W2
      S=A+B+C
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
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(MOM,FMAB,FMBA,M)
C
C    GENERATES MEMBER FIXED END MOMENTS.
C
      COMMON /RARRAY/ FIL(160),PMEMB(4,25), X(50,4)
      REAL*4 J4,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=PMEMB(M,10)
      J5=PMEMB(M,11)
      S= PMEMB(M,4)
      J6=PMEMB(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*J5+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
C     ASSEMBLES MEMBER FIXED END MOMENTS AND SHEARS INTO JOINT LOAD MATRIX.
C
      REAL*4 JLOAD(12,5)
      COMMON/ANAL/JLOAD,STIF(12,12),FIXMO(4,5,4)
      COMMON /RARRAY/ FIL(160),PMEMB(4,25)
      COMMON /ISCALE/NIT,NOLD,IDBUG,IP,IW,ITAPE,IPATH,ICYC,NINT
      DIMENSION ISUB(4,4),SV(4)
      DATA ISUB/2,5,3,6,4,7,6,9,8,11,9,12,10,1,12,3/
      DATA SV/-1.,-1.,1.,1./
      V=(FMAB+FMBA)/PMEMB(M,4)
      IF ( IDBUG.LT.3)  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 MATMP(A,N,B,M,D,NF)
      DIMENSION A(2),B(2),D(2)
C
C  MULTIPLIES INVERTED STIFFNESS MATRIX BY LOAD MATRIX TO GET DISPLACEMENTS
C  FOR EACH LOAD CONDITION.
C
C     DOUBLE PRECISION A,B,C,D,S
      C=A(1)
      JB=1-NF
      DO 10 J=1,M
      JB=JB+NF
   10 D(JB)=B(JB)/C
      IA=1
      DO 21 I=2,N
      II=I-1
      IA=IA+1+NF
      C=A(IA)
      JB=-NF
      DO 21 J=1,M
      S=0.
      JA=1-NF
      JB=JB+NF
      DO 22 K=1,II
      JA = JA+NF
      KB=K+JB
   22 S=S+A(JA)*D(KB)
      IB=I+JB
   21 D(IB)=(B(IB)-S)/C
      DO 100 I=2,N
      IP=N+1-I
      IP1=IP+1
      IA=(IP-1)*NF+IP
      IB=-NF
      DO 100 J=1,M
      S=0.
      IB=IB+NF
      KA=IA
      DO 102 K=IP1,N
      KA=KA+NF
      KB=K+IB
  102 S=S+A(KA)*D(KB)
      KB=IP+IB
  100 D(KB)=D(KB)-S
      RETURN
      END
```

```
      SUBROUTINE ENDFO
C
C   DETERMINES MEMBER END FORCES PRINTS MEMBER END FORCES TABLE
C   FOR IDBUG EQUAL TO 3
C
      REAL*4 JLOAD(12,5)
      REAL INER(4,5),KAA(4,3,3),KAB(4,3,3),KBA(4,3,3),KBB(4,3,3)
C
C     REAL SCALAR COMMON
      COMMON/RSCALE/SPAN,RISE,TT,TB,TS,GAMAC,GAMAS,GAMAF,PD,H,HH,HV,Q,
     1 ZETA,BETA,DF,Q1,EC,ES,FY,FCP,FLMV,FLN,Q2,Q3,NLAY,RTYPE,Q4,Q5,
     2 CT(6),SDATA(35)
C
C     REAL COMMON ARRAYS
      COMMON/RARRAY/U(12,5),W1(4,5),W2(4,5),A(4,5),B(4,5),C(4,5),
     1 PMEMB(4,25),X(50,4)
      COMMON/RARRAY/INER,KAA,KAB,KBA,KBB
      COMMON /ANAL/ JLOAD    ,STIF(12,12),FIXMO(4,5,4)
C
      COMMON/HARRAY/AMOM(20,5),V(20,5),P(3,5),FXLA(4,5),FYLA(4,5)
     1 ,BMA(4,5),FXLB(4,5),FYLB(4,5),BMB(4,5),ENDM(20,5),ENDV(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),FMMIN(20),
     4 FPMAX(3),FVMAX(20),FMMAX(20),ZMOMT,ZMOMB,XL(20)
C
C
C     INTEGER SCALAR COMMON
      COMMON /ISCALE/NIT,NOLD,IDBUG,IR,IW,ITAPE,IPATH,ICYC,NINT
C
C     INTEGER COMMON ARRAYS
      COMMON /IARRAY/MEMB(4,2)                                          COMMON
C
C    SCRATCH
      DIMENSION D(3,3),UA(3),UB(3),FB(3)
      IF ( IDBUG .GE. 3 ) WRITE(IW,1099)
 1099 FORMAT('1',T50,'END FORCES. KIPS AND INCH-KIPS',/
     1 T43,'A-END',T93,'B-END',/,14X,'LOAD',9X,
     1 'FXLA',11X,'FYLA',
     1 11X,'BMA',17X,'FXLB',11X,'FYLB',11X,'BMB',/,14X,'CASE',8X,
     2 '  FX  ',9X,'  FY ',9X,'MOMENT',15X,'  FX  ',9X,'  FY ',9X,
     3  'MOMENT'
      DO 1 M=1,4
      DO 1 N=1,5
      FXLA(M,N)=0.0
      FYLA(M,N)=0.0
      FXLB(M,N)=0.0
      FYLB(M,N)=0.0
       BMA(M,N)=0.0
```

```
          BMB(M,N)=0.0
    1     CONTINUE
          DO 100 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 I=1,3
          DO 2 J=1,3
    2     D(I,J) = KBA(M,I,J)
          CALL SOLVE(FB,UA,D)
          DO 3 I=1,3
          DO 3 J=1,3
    3     D(I,J) = KBB(M,I,J)
          CALL SOLVE(UA,UB,D)
          DO 4 I=1,3
    4     FB(I) = FB(I)+UA(I)
    C
```

```
      FXLB(M,N) = FB(1)
      FYLB(M,N) = FB(2)
       BMB(M,N) = FB(3)
C
      FXLA(M,N) =-FB(1)
      FYLA(M,N) =-FB(2)
       BMA(M,N) =-FB(2)*PMEMB(M,4)-FB(3)
5     CONTINUE
100   CONTINUE
C
      DO 200 M=1,4
      DO 250 N=1,5
      FYLA(M,N) = FYLA(M,N)+FIXMO(M,N,3)
       BMA(M,N) =  BMA(M,N)+FIXMO(M,N,1)
      FYLB(M,N) = FYLB(M,N)+FIXMO(M,N,4)
       BMB(M,N) =  BMB(M,N)+FIXMO(M,N,2)
C
C   DEBUG OUTPUT
C
      IF( IDBUG .LT. 3 ) GO TO 1102
      WRITE(IW,1100) M,N,FXLA(M,N),FYLA(M,N),BMA(M,N),FXLB(M,N),
     1 FYLB(M,N),BMB(M,N)
 1100 FORMAT(' MEMBER',2I5,3F15.5,5X,3F15.5)
1102  CONTINUE
C
250   CONTINUE
200   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
C
C   GIVEN THE MEMBER END FORCES AND THE LOADING VALUES
C   THE SERVICE LOAD FORCES ARE CALCULATED AT THE CRITICAL DESIGN SECTIONS
C
C
      COMMON/RSCALE/SPAN,RISE,TT,TB,TS,GAMAC,GAMAS,GAMAF,PC,H,HH,HV,
     1                                                             POV,
     1 ZETA,BETA,DF,Q1,EC,ES,FY,FCP,FLMV,FLN,Q2,Q3,NLAY,RTYPE,Q4,Q5,
     2 CT(6),SDATA(35)
C
      COMMON/RARRAY/U(12,5),W1(4,5),W2(4,5),A(4,5),B(4,5),C(4,5),
     1 PMEMB(4,25),XX(50,4)
C
      COMMON/IARRAY/MEMB(4,2)
C
      COMMON/MARRAY/AMOM(20,5),V(20,5),P(3,5),FXLA(4,5),FYLA(4,5)
     1 ,BMA(4,5),FXLB(4,5),FYLB(4,5),BMB(4,5),ENDM(20,5),ENDV(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),FMMIN(20),
     4 FPMAX(3),FVMAX(20),FMMAX(20),ZMOMT,ZMOMB,XL(20)
C
      COMMON/IFLAGS/IBDATA(35),ISDATA(35),ICON(6)
C
      COMMON/ISCALE/NIT,NCLD,IDBUG,IR,IW,ITAPE,IPATH,ICYC,KINT
C
      DIMENSION TM(5),TV(5)
C
      ENDMO(BMOM,CMOM,X,SP)=-BMOM*(1.-X/SP)+CMOM*X/SP
      ENDSHR(BMOM,CMOM,X,SP)=(BMOM+CMOM)/SP
C
C                 INITIALIZE DATA
C     USE MINIMUM D FOR SETTING DESIGN SECTION LOCATIONS
C
C     TOP SLAB
C
      D = AMIN1(SDATA(31),SDATA(33))
      D=D*POV
      XL(1)=(SPAN+TS)/2.
      XL(2)=0.0
      XL(3) = TS/2. + HH + D
      XL(4)=TS/2.+HH
C     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)=0.0
```

```
      XL(8) =RISE/2.+(TT+TB)/4.
      XL(9) =0.0
C     MEMBER 4 - SIDE WALL
      XL(10) = XL(6)
      XL(11) = XL(5)
C     BOTTOM SLAB
      D= AMIN1(SDATA(32),SDATA(34) )
      D=D*POV
      XL(12)=TS/2.+SPAN-HH
      XL(13) = XL(12) - D
      XL(14)=0.0
      XL(15)=(SPAN+TS)/2.
C
      DO 11 I=1,5
      TV(I)=0.0
      TM(I)=0.0
      DO 11 J=1,20
        ENDM(J,I)=0.0
        ENDV(J,I)=0.0
        AMOM(J,I)=0.0
        V(J,I)=0.0
   11 CONTINUE
C
      DO 200 M=1,4
        GO TO (10,20,30,40),M
C         MEMBER 1
   10   I1=1
        I2=3
      I4=4
      GO TO 60
C     MEMBER 2
 20   I1=8
      I2=6
      I4=5
      GO TO 60
C         MEMBER 3
 30   I1=15
      I2=13
      I4=12
      GO TO 60
C         MEMBER 4
 40   I1=0
      I2=10
      I4=11
   60 CONTINUE
C
C     I1 = CENTER SPAN MOMENT
C     I2 = PHI*D FROM HAUNCH, SHEAR AND MOMENT
```

```
C       I4 = TIP OF HAUNCH, SHEAR AND MOMENT
C
          DO 100 LDCN=1,5
        IF ( I1.EQ. 0 ) GO TO 45
            ENDM(I1,LDCN)=ENDMO(BMA(M,LDCN),BMB(M,LDCN),XL(I1),
     1                                                        PMEMB(M,4))
   45       CONTINUE
            ENDM(I2,LDCN)=ENDMO(BMA(M,LDCN),BMB(M,LDCN),XL(I2),
     1                                                        PMEMB(M,4))
            ENDV(I2,LDCN)=ENDSHR(BMA(M,LDCN),BMB(M,LDCN),XL(I2),
     1                                                        PMEMB(M,4))
            ENDM(I4,LDCN)=ENDMO(BMA(M,LDCN),BMB(M,LDCN),XL(I4),
     1                                                        PMEMB(M,4))
            ENDV(I4,LDCN)=ENDSHR(BMA(M,LDCN),BMB(M,LDCN),XL(I4),
     1                                                        PMEMB(M,4))
C
            IF (M .EQ. 1 .AND. LDCN .GE. 3) GO TO 100
          IF (M .EQ. 2 .AND. LDCN .LT. 3 ) GO TO 100
            IF (M .EQ. 3 .AND. LDCN .EQ. 3) GO TO 100
            IF (M .EQ. 3 .AND. LDCN .EQ. 5) GO TO 100
            IF (M .EQ. 4 .AND. LDCN .LT. 3) GO TO 100
C
C               MOMENT FOR CENTER SPAN POINTS 1, 8, 15
C
          IF ( I1 .EQ. 0 ) GO TO 46
            CALL MOMENT(W1(M,LDCN),W2(M,LDCN),A(M,LDCN),B(M,LDCN),
     1      C(M,LDCN),XL(I1),AMOM(I1,LDCN),DUM,DUM,1)
   46     CONTINUE
C
C               MOMENT AT POINTS 3, 6, 10, 13
C
            CALL MOMENT(W1(M,LDCN),W2(M,LDCN),A(M,LDCN),B(M,LDCN),
     1      C(M,LDCN),XL(I2),AMOM(I2,LDCN),RL,RR,1)
C
            IF (XL(I2) .LE. A(M,LDCN)) V(I2,LDCN)=RL
            IF (XL(I2) .GT. A(M,LDCN) .AND. XL(I2) .LT. A(M,LDCN)+
     1                                                        B(M,LDCN))
     2      V(I2,LDCN)=RL-W1(M,LDCN)*(XL(I2)-A(M,LDCN))-(W2(M,LDCN)
     3                 -W1(M,LDCN))*(XL(I2)-A(M,LDCN))**2/2./B(M,LDCN)
            IF (XL(I2) .GE. A(M,LDCN)+B(M,LDCN)) V(I2,LDCN)=-RR
C
C               MOMENT AT THE HAUNCHES; POINTS 4, 5, 11, 12
C
            CALL MOMENT(W1(M,LDCN),W2(M,LDCN),A(M,LDCN),B(M,LDCN),
     1      C(M,LDCN),XL(I4),AMOM(I4,LDCN),DUM,DUM,1)
C
            IF (XL(I4) .LE. A(M,LDCN)) V(I4,LDCN)=RL
            IF (XL(I4) .GT. A(M,LDCN) .AND. XL(I4) .LT. A(M,LDCN)+
```

```
     1                                                          B(M,LDCN))
     2       V(I4,LDCN)=RL-W1(M,LDCN)*(XL(I4)-A(M,LDCN))-(W2(M,LDCN)
     3                 -W1(M,LDCN))*(XL(I4)-A(M,LDCN))**2/2./B(M,LDCN)
             IF (XL(I4) .GE. A(M,LDCN)+B(M,LDCN)) V(I4,LDCN)=-RR
C
  100        CONTINUE
  200        CONTINUE
C
C                  STORE AXIAL FORCES
           DO 210 I=1,5
             P(1,I)=FXLB(1,I)
             P(2,I)=FXLB(4,I)
             P(3,I)=FXLB(3,I)
           DO 210 J=1,29
             V(J,I)=V(J,I)+ENDV(J,I)
             AMOM(J,I)=AMOM(J,I)+ENDM(J,I)
 210         CONTINUE
C
C                  FIND XD IN TOP AND BOTTOM SLABS AND
C                  CALCULATE M,V AT XD AWAY FROM CENTERSPAN
C
         N=2
         IF ( IBDATA(14) .NE. 2 ) N=3
         DMT=0.0
         DMB=0.0
         WT=0.0
         WB=0.0
         DO 300 I=1,N
           WT=WT+W1(1,I)
           WB=WB+W1(3,I)
           DMB=DMB+AMOM(15,I)
           DMT=DMT+AMOM(1,I)
 300         CONTINUE
           WT=WT+W1(1,4)
           DMB=DMB+AMOM(15,4)
           DMT=DMT+AMOM(1,4)
         XL(14)=3.0*(SQRT((SDATA(34)*POV)**2+2.*DMB/9./WB)-SDATA(34)*POV)
         XL(2)=3.0*(SQRT((SDATA(33)*POV)**2+2.*DMT/9./WT)-SDATA(33)*POV)
         XL(2)=(SPAN+TS)/2.-XL(2)
         XL(14)=(SPAN+TS)/2.+XL(14)
C
C          TOP
C
         IF ( XL(2) .LE. 0 ) GO TO 320
         M=1
         J=2
  322    CONTINUE
         DO 327 LDCN=1,5
```

```
            CALL MOMENT(W1(M,LDCN),W2(M,LDCN),A(M,LDCN),B(M,LDCN),
     1      C(M,LDCN),XL(J ),AMOM(J ,LDCN),RL,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)+
     1                                                       B(M,LDCN))
     2      V(J ,LDCN)=RL-W1(M,LDCN)*(XL(J )-A(M,LDCN))-(W2(M,LDCN)
     3                 -W1(M,LDCN))*(XL(J )-A(M,LDCN))**2/2./B(M,LDCN)
            IF (XL(J ) .GE. A(M,LDCN)+B(M,LDCN)) V(J ,LDCN)=-RR
C
          AMOM(J,LDCN)=AMOM(J,LDCN)+ENDMO(BMA(M,LDCN),BMB(M,LDCN),XL(J),
     1                                                       PMEMB(M,4))
          V(J,LDCN)=V(J,LDCN)+ENDSHR(BMA(M,LDCN),BMB(M,LDCN),XL(J),
     1                                                       PMEMB(M,4))
  327 CONTINUE
      IF ( M .NE. 1 ) GO TO 340
C
C           BOTTOM SLAB
C
  320 IF ( XL(14) .GE. SPAN+TS/2.-HH ) GO TO 340
      M=3
      J=14
      GO TO 322
  340 CONTINUE
C
C         FIND LOCATION OF 0 MOMENT IN TOP AND BOTTOM SLABS
C
          DMT = DMT + AMOM(1,3)*IABS(N - 3) + AMOM(1,5)
          DMB = DMB+AMOM(15,3)*IABS(N - 3) + AMOM(15,5)
          IF ( DMT .LE. 0.0 ) GO TO 75
          ZMOMT = (SPAN + TS)/2.- SQRT(2.*DMT/WT)
   75     IF(DMB .LE. 0.0 ) GO TO 76
          ZMOMB=(SPAN+TS)/2. + SQRT(2.*DMB/WB)
   76     CONTINUE
C
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                          GO TO 505
      D = AMIN1(SDATA(31),SDATA(35))
      D=D*POV
      X=TB/2. + HV + D + PMEMB(4,4)/200.0+ RISE
      L=6
      TEMPI =-(AMOM(6,1)+AMOM(6,2)+AMOM(6,3)+AMOM(6,5))/(V(6,1)+V(6,2)+
     I V(6,3)+V(6,5))
   76 L=L+1
      IF ( L .EQ. 8 ) L=9
   50 CONTINUE
```

```
      X=X-PMEMB(4,4)/200.
        TEMP=TEMP1
      IF ( L .EQ. 10) GO TO 505
      IF(L.LE. 8 .AND. X.LE.(RISE+TB)/2.) L=9
      IF (X .LT. TB/2.+HV+ D ) GO TO 490
        TV1=0.0
        TM1=0.0
        DO 450 K=1,5
        CALL MOMENT(W1(4,K),W2(4,K),A(4,K),B(4,K),C(4,K),X,TM(K),RL,RR
     1                                                              ,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))
     1     TV(K)=RL-W1(4,K)*(X-A(4,K))-(W2(4,K)-W1(4,K))*(X-A(4,K))**2
     2           /2./B(4,K)
        IF (X .GT. A(4,K)+B(4,K) ) TV(K)=-RR
        TV(K)=TV(K)+ENDSHR(BMA(4,K),BMB(4,K),X,PMEMB(4,4))
        TM(K)=TM(K)+ ENDMO(BMA(4,K),BMB(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)*PDV
      IF ( TM1 .LT. 0.0 ) GO TO 50
      TEMP1 = 3.0 - ABS(TM1/TV1/D)
      IF (TEMP1 * TEMP .GT. 0.0 ) GO TO 485
      IF ( ABS(TEMP) .LT. ABS(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 * TEMP .GT. 0.0 ) GO TO 50
      GO TO 70
 490  CONTINUE
      DO 495 I=1,5
      V(L,I) = 0.0
      AMOM(L,1) = 0.0
 495  CONTINUE
      XL(L) = 0.0
 505  CONTINUE
      IF ( IDBUG .LT. 3 )  GO TO 506
      WRITE (IW,509)
509   FORMAT (1H1)
      WRITE (IW,510)
510   FORMAT (//,T40,'SERVICE MOMENTS AND SHEARS FOR EACH LOAD ',
     1'CONDITION',/,5X,125(1H-),//,6X,'DESIGN',5X,'DIST. FROM',T35,'MOME
     2NT(IN.KIPS/FT)',T100,'SHEAR(KIPS/FT)',/,5X,'SECTION',6X,'A-END(IN.
     3)',T25,45(1H-),17X,44(1H-),//,T26,'LC-1',6X,'LC-2',6X,'LC-3',6X,
```

```
     4'LC-4',6X,'LC-5',16X,'LC-1',6X,'LC-2',6X,'LC-3',6X,'LC-4',6X,
     5'LC-5')
      DO 507 I=1,15
      WRITE(IW,508) I,XL(I),(AMOM(L,I),L=1,5),(V(L,I),L=1,5)
  508 FORMAT (5X,I5,F10.2,5(F10.2),10X,5(F10.2))
  507 CONTINUE
  506 CONTINUE
      RETURN
      END
```



```
      SUBROUTINE FMXMN
C
C   DETERMINES THE MINIMUM AND MAXIMUM DESIGN FORCES AND RESULTING
C   ULTIMATE FORCES AT THE CRITICAL DESIGN LOCATIONS.
C
      REAL*4 JLOAD(12,5)
      REAL*4 INER(4,50),KAA(4,3,3),KAB(4,3,3),KBA(4,3,3),KBB(4,3,3)
C
      COMMON/RSCALE/SPAN,RISE,TT,TB,TS,GAMAC,GAMAS,GAMAF,P0,H,HH,HV,Q,
     1 ZETA,BETA,DF,Q1,EC,ES,FY,FCP,FLMV,FLN,Q2,Q3,NLAY,RTYPE,Q4,Q5,
     2 CT(6),SDATA(35)
      COMMON/RARRAY/U(12,5),W1(4,5),W2(4,5),A(4,5),B(4,5),C(4,5),
     1 PMEMB(4,25),X(50,4)
      COMMON/RARRAY/INER,KAA,KAB,KBA,KBB
C
      COMMON/ANAL/JLOAD,STIF(12,12),FIXMO(4,5,4),DM(6),DV(6),DP(6),
     1 AS(6),SRATIO(6)
C
      COMMON/ISCALE/NIT,NOLD,IDBUG,IR,IW,ITAPE,IPATH,ICYC,NINT
C
      COMMON/IARRAY/MEMB(4,2)
C
      COMMON/HARRAY/AMOM(20,5),V(20,5),P(3,5),FXLA(4,5),FYLA(4,5)
     1 ,BMA(4,5),FXLB(4,5),FYLB(4,5),BMB(4,5),ENDM(20,5),ENDV(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),FMMIN(20),
     4 FPMAX(3),FVMAX(20),FMMAX(20),ZMOMT,ZMOMB,XL(20)
C
      COMMON/IFLAGS/IBDATA(35),ISDATA(35),ICON(6)
      DIMENSION SIDE(3)
      DATA SIDE/'TOP','SIDE','BOT' /
C
      I4=3
      COEF3=0.0
      DO 100 L=1,20
        GRM1(L)=0.0
        GRV1(L)=0.0
        GRM2PL(L)=0.0
        GRV2PL(L)=0.0
        GRM2NG(L)=0.0
        GRV2NG(L)=0.0
        IF (L .GT. 3) GO TO 100
        GRP1(L)=0.0
        GRP2PL(L)=0.0
        GRP2NG(L)=0.0
  100   CONTINUE
```

```
         IF (IBDATA(14) .EQ. 2) GO TO 102
           COEF3=1.0
```



```
         I4=4
  102    CONTINUE
         DO 1 I = 1, 15
           GRM1(I)=AMOM(I,1)+AMOM(I,2)+AMOM(I,3)*COEF3
           GRV1(I)=V(I,1)+V(I,2)+V(I,3)*COEF3
           DO 1 K=I4,5
             GRM2PL(I)=GRM2PL(I)+(1.+SIGN(1.,AMOM(I,K)))/2.*AMOM(I,K)
             GRM2NG(I)=GRM2NG(I)+(1.-SIGN(1.,AMOM(I,K)))/2.*AMOM(I,K)
             GRV2PL(I)=GRV2PL(I)+(1.+SIGN(1.,V(I,K)))/2.*V(I,K)
             GRV2NG(I)=GRV2NG(I)+(1.-SIGN(1.,V(I,K)))/2.*V(I,K)
    1        CONTINUE
         DO 3 I=1,3
           GRP1(I)=P(I,1)+P(I,2)+P(I,3)*COEF3
           DO 3 K=I4,5
             GRP2PL(I)=GRP2PL(I)+(1.+SIGN(1.,P(I,K)))/2.*P(I,K)
             GRP2NG(I)=GRP2NG(I)+(1.-SIGN(1.,P(I,K)))/2.*P(I,K)
    3    CONTINUE
         DO 5 K=1,15
             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 (FMMIN(K) .GT. 0.0) FMMIN(K)=0.0
             IF (FVMIN(K) .GT. 0.0) FVMIN(K)=0.0
             IF (FMMAX(K) .LT. 0.0) FMMAX(K)=0.0
             IF (FVMAX(K) .LT. 0.0) FVMAX(K)=0.0
             IF ( K .GT. 3 ) GO TO 5
             FPMIN(K)=(GRP1(K)+GRP2NG(K))*FLN
             FPMAX(K)=(GRP1(K)+GRP2PL(K))*FLN
    5    CONTINUE
C
C     SPECIAL SHEAR DESIGN SECTIONS
         DO 2 J = 6,7,1
           FMMIN(J)=(GRM1(J) + GRM2PL(J))*FLMV
             FMMAX(J)=(GRM1(J)+GRM2PL(J))*FLMV
             IF (FMMIN(J) .GT. 0.0) FMMIN(J)=0.0
             IF (FMMAX(J) .LT. 0.0) FMMAX(J)=0.0
         K = J+3
           FMMIN(K)=(GRM1(K) + GRM2PL(K))*FLMV
             FMMAX(K)=(GRM1(K)+GRM2PL(K))*FLMV
             IF (FMMIN(K) .GT. 0.0) FMMIN(K)=0.0
             IF (FMMAX(K) .LT. 0.0) FMMAX(K)=0.0
    2    CONTINUE
         IF ( FMMIN(1) .NE. 0.0 ) GO TO 1498
         IF ( FMMIN(15).NE. 0.0 ) GO TO 1498
C
C
C    DEBUG OUTPUT
```

```
C
      IF(IDBUG.LT.1) GO TO 1203
 1498 CONTINUE
      WRITE(IW,1101)
 1101 FORMAT('1',T33,'SERVICE LOADS',T90,'ULTIMATE LOADS',/,T13,
     1 56(1H-),T79,34(1H-) ,/,' SECTION',T20,'GROUP 1',T50,
     2 'GROUP 2'    )
      WRITE(IW,1103)
 1103 FORMAT(T13,'MOMENT',T25,'SHEAR',T35,'MPLUS',T45,'VPLUS',T56,
     2 'MNEG',T66,'VNEG',T79,'FMMAX',T89,'FVMAX',T99,'FMMIN',T109
     3 ,'FVMIN')
      WRITE(IW,1102)(I,GRM1(I),GRV1(I),GRM2PL(I),GRV2PL(I),GRM2NG(I),
     1 GRV2NG(I),FMMAX(I),FVMAX(I),FMMIN(I),FVMIN(I),I=1,15)
 1102 FORMAT(T4,I2,T10,6F10.3,T75,4F10.3)
      WRITE(IW,1105)
      WRITE(IW,1106) (SIDE(I),GRP1(I),GRP2PL(I),GRP2NG(I),FPMAX(I),
     1 FPMIN(I), I=1,3)
      IF ( FMMIN(1) .NE. 0.0 ) GO TO 1500
      IF ( FMMIN(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(///,'0NEGATIVE MOMENT EXISTS IN MIDSPAN OF ',A4,'SLAB.',/,
     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
      ZMOMBC=SPAN+TS-ZMOMB
      WRITE(IW,1104) ZMOMT,ZMOMBC
 1104 FORMAT('0 ZERO MOMENT TOP ',F15.5,T50,'ZERO MOMENT BOTTOM',F15.5,/
     1,'0 INCHES FROM CENTERLINE OF SIDEWALL',//
     1/,'0***NOTE: ALL UNITS ARE KIPS AND INCHES',/,'1'   )
 1105 FORMAT('0 MEMBER',T13,'THRUST',T35,'NPLUS',T56,'NNEG',
     2 T79,'FNMAX',T99,'FNMIN')
 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
C
C   CALCULATES THE REQUIRED STEEL AREA AT THE FLEXURE DESIGN
C   LOCATIONS BASED ON THE FOLLOWING:  FLEXURE
C                                      MINIMUM STEEL FOR FLEXURE
C                                      LIMITING CONCRETE COMPRESSION
C                                      0.01" CRACK AT SERVICE LOADS
C   IT CHECKS FOR DIAGONAL TENSION SHEAR AT THE APPROPRIATE DESIGN
C   LOCATIONS USING METHODS 1(AASHTO) AND 2
C   A PRINTOUT OF THE FLEXURE DESIGN TABLE, SHEAR DESIGN TABLE METHOD 1
C   AND SHEAR DESIGN TABLE METHOD 2 ARE AVAILABLE WITH AN IDBUG VALUE
C   GREATER THAN 1.
C
      REAL*4 JLOAD(12,5)
      REAL*4 INER(4,50),KAA(4,3,3),KAB(4,3,3),KBA(4,3,3),KBB(4,3,3)
C
      COMMON/RSCALE/SPAN,RISE,TT,TB,TS,GAMAC,GAMAS,GAMAF,PCF,H,HH,HV,
     1 PDV,
     1 ZETA,BETA,DF,Q1,EC,ES,FY,FCP,FLMV,FLN,FCR,Q3,NLAY,RTYPE,Q4,Q5,
     2 CT(6),SDATA(35)
C
      COMMON/RARRAY/U(12,5),W1(4,5),W2(4,5),A(4,5),B(4,5),C(4,5),
     1 PMEMB(4,25),Y(56,4)
      COMMON/RARRAY/INER,KAA,KAB,KBA,KBB
C
      COMMON/ANAL/JLOAD,STIF(12,12),FIXMO(4,5,4),DM(6),DV(6),DP(6),
     1 AS(6),SRATIO(6)
C
      COMMON/ISCALE/NIT,NOLC,IDBUG,IR,IW,ITAPE,IPATH,ICYC,NINT
C
      COMMON/IARRAY/MEMB(4,2)
C
      COMMON/HARRAY/AMOM(20,5),V(20,5),P(3,5),FXLA(4,5),FYLA(4,5)
     1 ,BMA(4,5),FXLB(4,5),FYLB(4,5),BMB(4,5),ENDM(20,5),ENDV(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),FMMIN(20),
     4 FPMAX(3),FVMAX(20),FMMAX(20),ZMOMT,ZMOMB,XL(20)
C
      COMMON/IFLAGS/IBDATA(35),ISDATA(35),ICON(6)
C
      REAL MU,NU,M0,ND,NLAY,NO
      INTEGER AASHTO(4),CHECK(8)
      DIMENSION INDEX(8),DS(6),SIDE(3),SH(8,10),POINT(6),GOVERN(15),
     1 PRINT(18),Z1(4,6),CRACK(6),AMIN(6),AMAX(6),AREAFL(6)
      DIMENSION INDEX2(8)
      DATA INDEX /2,4,5,7,9,11,12,14/,SIDE/'  IN',' OUT',
     1 'BOTH'/,POINT/'4   ','5:11','12  ','1   ','15  ','8   '/
     2 ,GOVERN/'  FL',4HEXUR,4HE   ,4H MIN,4H. ST,4HEEL ,4HCRAC,
```

```
     3 4HK WI,4HDTH ,4HMAX ,4HCON ,4HCOMP  /
      DATA INDEX2/2,3,6,7,9,10,13,14/
      DATA AASHTO/3,6,10,13 /,CHECK/30,33,31,35,31,35,32,34/,
     1 YES/' YES'/,NO/' NO ' /
C
C          FIND DESIGN VALUES FOR EACH REINFORCING MEMBER
      DO 71 L=1,8
      DO 71 M=1,10
      SH(L,M)=0.0
   71 CONTINUE
C
C          AS1
      DM(1)=-FMMIN(4)
      DP(1)=ABS(FPMIN(1))
      DM(2)=AMAX1(-FMMIN(5),-FMMIN(11))
      DP(2)=ABS(FPMIN(2))
      DM(3)=-FMMIN(12)
      DP(3)=ABS(FPMIN(3))
C
C          AS 2
      DM(4)=FMMAX(1)
      DP(4)=ABS(FPMAX(1))
C
C          AS 3
      DM(5)=FMMAX(15)
      DP(5)=ABS(FPMAX(3))
C
C          AS 4
      DM(6)=FMMAX(8)
      DP(6)=ABS(FPMAX(2))
C
      DS(1)=TT
      DS(2)=TS
      DS(3)=TB
      DS(4)=TT
      DS(5)=TB
      DS(6)=TS
C
      FYPSI=FY*1000.
      FCPPSI=FCP*1000.
      B1=0.85-0.05*(FCP-4.)
      IF (B1 .GT. 0.85) B1=0.85
      IF (B1 .LT. 0.65) B1=0.65
      DO 10 I=1,6
      FLAY=0.0
      CB1=0.0
        ICON(I)=1
C
```

```
C          FIND STEEL AREA FOR FLEXURE
C
        PHIDF=SDATA(29+I)*POF
        E0=10.2*FCPPSI
        FLEX =E0*PHIDF**2 - DP(I)*1000.*(2.*PHIDF-DS(I)) -
       1   2000.0*DM(I)
        IF (FLEX .LT. 0.0 ) AS(I) = 1.0E15
        IF (FLEX .GE. 0.0) AS(I)=(E0*PHIDF - DP(I)*1000.0 -
       1    SQRT(E0*FLEX) ) / FYPSI
           SRATIO(I)=AS(I)/12./PHIDF
           AREAFL(I)=AS(I)
C
C          MINIMUM STEEL AREA FOR FLEXURE
C
        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     AREAMF=6.6E5*B1*FCPPSI*PHIDF/FYPSI/(FYPSI+87000.)
       1         -(750.*DP(I)/FYPSI)
           AMAX(I)=AREAMF
           IF (AS(I) .LT. AREAMF) GO TO 3
        WRITE(IW,1001) POINT(I),DM(I),DP(I),AS(I),AREAMF
 1001 FORMAT(1X,90('*'),/,'  DESIGN NOT POSSIBLE AT SECTION ',A4,' DUE'
      2,' TO EXCESSIVE CONCRETE COMPRESSION'/'  DM=',F10.3,' IN.KIPS/FT'
      3 ,5X,'DP= ',F10.3,' KIPS/FT.',/,T5,'REQUIRED STEEL AREA = ',
      4F10.3,' SQ.IN./FT.',10X,'MAXIMUM STEEL AREA = ',F10.3,
      5 ' SQ.IN./FT.',/,1X,90('*') ,///)
        AS(I) = 1.0E15
        SRATIO(I) = 1.0E15
        ICON(I) =4
             GO TO 10
     3     CONTINUE
C
C          STEEL AREA BASED ON 0.01 INCH CRACK
C
           K=PTYPE+0.5
           GO TO (1000,2000,3000), K
 1000      C0=1.0
           B2=(0.5*CT(I)**2*SDATA(6+I)/NLAY)**(1./3.)
           GO TO 140
 2000      C0=1.5
           B2=1.0
           FLAY=CT(I)**2*SDATA(6+I)/NLAY
C
           GO TO 140
 3000      C0=1.9
```

```
         B2=(0.5*CT(I)**2*SDATA(6+I)/NLAY)**(1./3.)
  140    CONTINUE
         MB=DM(I)/FLMV*1000.
         NC=DP(I)/FLN*1000.
         E=MD/ND+SDATA(29+I)-DS(I)/2.
         IF (E/SDATA(29+I) .LT. 1.15) GC TC 13
         AJ=0.74+0.1*E/SDATA(29+I)
         IF (AJ .GT. 0.9 ) AJ=0.9
         AP=1./(1.-AJ*SDATA(29+I)/E)
    7    CONTINUE
       R2 = (MC + ND*(SDATA(29+I)-DS(I)/2.))/AJ/AP
       R1 = C0*12.*DS(I)**2*SQRT(FCPPSI)
       AREA01 = (R2-R1)*B2/30000./PHIDF/FCR
         IF ( C01 .EQ. 1 ) GO TO 9
         IF ( FLAY .LT. 3 ) GO TO 11
          C01=1.
       C0=1.9
         B2=(0.5*FLAY)**(1./3.)
         ARE012=AREA01
         GO TO 7
    9    IF ( ARE012 .GT. AREA01 ) AREA01=ARE012
   11    CONTINUE
         CRACK(I)=AREA01/AS(I)
         IF ( CRACK(I) .LE. 1. ) GO TO 13
           ICON(I)=3
           AS(I)=AREA01
           SRATIO(I)=AS(I)/12./PHIDF
   13    CONTINUE
   10  CONTINUE
       IF(IDBUG.LT.2) GO TO 164
       DO 2007 I=1,6
       PRINT(3*I-2) = GOVERN(ICON(I)*3-2)
       PRINT(3*I-1) = GOVERN(ICON(I)*3-1)
       PRINT(3*I) = GOVERN(ICON(I)*3)
  2007 CONTINUE
       WRITE(IW,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('0',T50,'*******  FLEXURE DESIGN TABLE  *******',/,
      1'0REINFORCING',T28,'AS B',T52,'AS 1',T73,'AS 2',T88,'AS 3',T103,
      2 'AS 4',/,T40,23('-'),/,'0DESIGN SECTION',T29,6(A4,11X),/,
      3 '0ULTIMATE MOMENT',T20,6F15.5,/,'     IN.KIPS/FT',/,
      4 '0ULTIMATE THRUST',T20,6F15.5,/,'     KIPS/FT',/,
      5 '0DEPTH TC STEEL',T20,6F15.5,/,'       IN.',/,
      6 '0STEEL AREAS(FLEX)',T20,6F15.5,/,'  SQ.IN./FT',/,
      7 '0MIN. FLEX STEEL',T20,6F15.5,/,'     SQ.IN./FT',/,
      8 '0MAX. FLEX STEEL',T20,6F15.5,/,'     SQ.IN./FT',/,
      9 '0CRACK INDEX',T20,6F15.5,/,/,
```

```
      1 '0GOVERNING STEEL',T20,6F15.5,/,'     SQ.IN./FT',/)
        WRITE (IW,2099) (PRINT(I),I=1,18)
   2099 FORMAT(' GOVERNING MODE',T26,6(3A4,3X),/,'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
C
C          DIAGONAL TENSION CHECK
C
        FCPSI=FCPPSI
        IF ( FCPPSI .GT. 7000.) FCPSI=7000.0
C
C          AASHTO SHEAR CHECK - METHOD 1
C
        DO 60 I=1,4
          N1 = 3
          Z1(I,5) = NO
          D = AMIN1(SDATA(CHECK(2*I-1)),SDATA(CHECK(2*I)) )
          IF (FMMIN(AASHTO(I)).NE. 0.0 ) GO TO 61
          D = SDATA(CHECK(2*I))
          N1 = 1
     61   IF (FMMAX(AASHTO(I)).NE. 0.0 ) GO TO 62
          D = SDATA(CHECK(2*I-1))
          N1 = 2
     62   CONTINUE
        PHIDV = D* PDV
          VU =AMAX1(FVMAX(AASHTO(I)),-FVMIN(AASHTO(I)))
          IF ( VU .LT. 0.036 * SQRT(FCPSI) * 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(FCPSI) * PHIDV
          Z1(I,3) = Z1(I,1) / Z1(I,2)
          Z1(I,4)= D
     60 CONTINUE
C
        DO 432 I=1,5
    432 SRATIO(I)=SRATIO(I)*PDF/PDV
```

```
      CONTINUE
      DO 1500 I=1,3
      RHO1=SRATIO(2)
      MU=ABS(FPMAX(I))
C
      IF (I-2) 1100,2100,3100
C
C         TOP SLAB
C
 1100 CONTINUE
      N = 1
      K1=2
      RHO1=SRATIO(1)
      RHO2=SRATIO(3)
      DIN=SDATA(33)
      DOUT=SDATA(30)
      GO TO 4000
C
C         SIDE WALL
C
 2100 CONTINUE
      N = 3
      K1 = 6
      RHO2=SRATIO(5)
      DIN=SDATA(35)
      DOUT=SDATA(31)
      GO TO 4000
C
C         BOTTOM SLAB
C
 3100 CONTINUE
      N = 7
      K1 = 8
      RHO2=SRATIO(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 (FMMAX(INDEX(K))+FMMIN(INDEX(K)) ) 5000, 6000, 7000
C
 5000   RHO=RHO1
      MU=FMMIN(INDEX(K))
        D=DOUT
        N1=2
```

```
          GO TO 8000
C
 6005     RHO=AMIN1(RHO1,RHO2)
          MU=FMMAX(INDEX(K))
          D=AMIN1(DIN,DOUT)
          N1=3
          GO TO 8000
C
 7000     RHO=RHO2
          MU=FMMAX(INDEX(K))
          D=DIN
          N1=1
C
 8000     CONTINUE
        SH(K,1)=ABS(MU/VU/D/POV)
        SH(K,2)=VU2
        SH(K,3)=NU
        SH(K,4)=RHO
        SH(K,5)=D
          IF ( RHO .GT. 0.02 ) RHO=0.02
          FD=0.8+1.6/D
          IF ( FD .GT. 1.25 ) FD=1.25
          FN=0.5-NU/VU/6.0+SQRT(0.25+(NU/VU/6.0)**2)
        IF(FN.LT.0.75) FN=0.75
        AMVD=ABS(MU/VU/D/POV)
        IF(AMVD.GT.3.0) AMVD=3.0
        VC = (1.1+63.0*RHO) * SQRT(FCPSI) * POV *D *12.*FD/FN*
     1                                                    4./(AMVD+1.)
        IF(VC .GT. 4.5*SQRT(FCPSI)*POV*12.*D) VC=4.5*SQRT(FCPSI)*POV*12.*D
        ROT = VU2*1000.0/VC
        SH(K,6)= XL(INDEX(K))
        SH(K,7)=FN
        SH(K,8)=VC/1000.0
        SH(K,9)=ROT
          IF ( ROT .LE. 1.0 ) GO TO 2500
        ASINC=3.968*VU2*FN*(AMVD+1.)/FD/SQRT(FCPSI)-0.2095*D*POV
        SH(K,10)=ASINC
        IF ( ASINC/12./POV/D .LT. 0.02 )  GO TO 9500
           WRITE(IW,9501) INDEX(K),SIDE(N1)
 9501 FORMAT(//T30,50(1H*),/,T30,'*',48X,'*',/,T30,'*',20X,'WARNING',
     1  21X,'*',/,T30,'*',9X,'DESIGN NOT POSSIBLE AT SECTION ',I2,6X,
     2  '*',/,T30,'*',6X,'STIRRUPS ARE REQUIRED ON ',A4,'SIDE STEEL',
     3 3X,'*',/,T30,50('*')   )
        ISDATA(13+K)=1
        SH(K,10) = 1.0E15
          GO TO 2500
 9500     IF ( MU .LT. 0.0 ) GO TO 2001
          IF (I-2) 1003,1002,1006
```

```
      C
      C         BOTTOM SLAB
       1006 CONTINUE
            IF(ASINC .LT. AS(4) ) GO TO 2500
            AS(4)=ASINC
            ICON(4)=4
            SRATIO(4)=ASINC/12./D/PCV
            GO TO 2500
      C
      C         SIDE WALL
       1002 CONTINUE
            IF(ASINC .LT. AS(5)) GO TO 2500
            AS(5)=ASINC
            ICON(5)=4
            SRATIO(5)=ASINC/12./D/PCV
            GO TO 2500
      C
      C         TOP SLAB
       1003 CONTINUE
            IF(ASINC.LT.AS(3)) GO TO 2500
            AS(3)=ASINC
            ICON(3)=4
            SRATIO(3)=ASINC/12./D/PCV
            GO TO 2500
      C
       2001 CONTINUE
            IF(I.EQ.1) GO TO 2003
            IF(ASINC.LT.AS(2)) GO TO 2500
            AS(2)=ASINC
            ICON(2)=4
            SRATIO(2)=ASINC/12./D/PCV
            GO TO 2500
       2003 IF(ASINC.LT.AS(1)) GO TO 2500
            AS(1)=ASINC
            ICON(1)=4
            SRATIO(1)=ASINC/12./D/PCV
       2500 CONTINUE
       1500 CONTINUE
      C
            SDATA(19) = ZMOMT + TS/2. - CT(1) - SDATA(1)/2.
            SDATA(20) = SPAN - ZMOMB + 1.5*TS - CT(3) - SDATA(3)/2.
      C
      C
            IF(IDBUG.LT.2) GO TO 174
            WRITE(IW,2008) (AASHTC(K),K=1,4),((Z1(I,J),I=1,4),J=1,5)
       2008 FORMAT(//,T46,'***    SHEAR DESIGN TABLE - METHOD 1    ***',/,
           1 '0DESIGN SECTION',T32,3(I2,24X),I2,/,' ALL SECTIONS ARE AT D',/,
           2 ' FROM THE HAUNCH',/,'0ULTIMATE SHEAR',T26,4(F10.3,16X),/,
```

```
      3 *      KIPS/FT*,/,*0ALLOWABLE SHEAR*,T26,4(F10.3,16X),/,
      3 *      KIPS/FT*,/,*0DIAGONAL TENSION*,T29,3(F10.6,16X),F10.6,/,
      4 * INDEX LIMIT*,/,*0DEPTH TO STEEL*,T28,4(F10.5,16X),/,
      5 *      IN.*,/,*0STIRRUPS REQUIRED?*,T31,3(A4,22X),A4    )
      WRITE(IW,2036) (INDEX(K),K=1, 8),((SH(K,I),K=1, 8),I=1,10)
 2036 FORMAT(*0*,/,T46,*******  SHEAR DESIGN TABLE - METHOD 2 *******,/,
     1 *0DESIGN SECTION*,T26,8(I2,11X),/,/,/,
     2 *0M/(V*PHI*D)*,T20,8(F10.3,3X),/,/,
     3 *0ULTIMATE SHEAR*,T20,8(F10.3, 3X),/,*      KIPS/FT*,/,
     4 *0ULTIMATE THRUST*,T20,8(F10.3,3X),/,*      KIPS/FT*,/,
     5 *0STEEL RATIO*,T23,8(F10.6,3X),/,
     6 *0DEPTH TO STEEL*,T22,8(F10.5,3X),/,/,7X,*IN.*,/,
     7 *0DISTANCE FROM*,T20,8(F10.3,3X),/,*  A-END,  IN.*,/,
     8 *0THRUST FACTOR (FN)*,T23,8(F10.6,3X),/,
     9 *0DIAGONAL TENSION*,T20,8(F10.3,3X),/,*  STRENGTH,  KIPS/FT*,/,
     1 *0ULTIMATE SHEAR/ *,T23,8(F10.6,3X),/,* ALLOWABLE SHEAR*,/,
     2 *0NEW STEEL AREA DUE*,T23,8(F10.6,3X),/,* TO DIAGONAL TENSION*,/
     3 *    SQ.IN./FT*   )
  174 RETURN
      END
```



```
      SUBROUTINE OUTPUT
C
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 IDBUG VALUES.
C
      COMMON /IFLAGS/ IBDATA,ISDATA
      COMMON /ISCALE/NIT,NOLD,IDBUG,IR,IW,ITAPE,IPATH,ICYC,NINT
      INTEGER ISDATA(35),IBDATA(35)
      COMMON/RSCALE/BDATA(35),SDATA(35)
      REAL JLOAD(12,5)
      COMMON/ANAL/JLOAD,STIF(12,12),FIXMO(4,5,4),DM(6),DV(6),DP(6),
     1 AS(6),SRATIO(6)
      EQUIVALENCE (SPAN,BDATA(1))
      DIMENSION STAB(5,2),ISB(5),STIRR(2)
      DATA STIRR  /* NO *,**YES* /
      DATA ISB/3,1,4,2,5/
      T=1.0E-06
      C=12.
      D=1.728E6
      OSPAN=BDATA(1)/C+T
      ORISE=BDATA(2)/C+T
      OH=BDATA(10)/C+T
      OGAMAS=BDATA(7)*D+T
      OZETA=BDATA(14)
      ALPHA = (1+SDATA(25))*BDATA(14)
      IF ( IBDATA(14).EQ.2) OZETA=0.
      DO 30 I=1,5
      K=ISB(I)
      STAB(I,1)=AS(K)
   30 CONTINUE
```

```
      STAB(1,2)= STIRR(MAX0(ISDATA(14),ISDATA(15),ISDATA(26))+ 1 )
      STAB(2,2)= STAB(1,2)
      STAB(3,2)= STIRR(MAX0(ISDATA(20),ISDATA(21),ISDATA(29))+1)
      STAB(4,2)= STIRR(MAX0(ISDATA(16),ISDATA(19),ISDATA(27),
     1 ISDATA(28),ISDATA(17),ISDATA(18))+1)
      STAB(5,2)= STAB(4,2)
C
      WRITE(IW,1)  OSPAN,ORISE
C
      WRITE(IW,4)
      WRITE(IW,97)
      WRITE(IW,5) OH,OGAMAS,OZETA,ALPHA,BDATA(15)
```



```
C
      WRITE(IW,6)
      WRITE(IW,97)
      WRITE(IW,7)  BDATA(22),BDATA(23),BDATA(9),BDATA(13),BDATA(24)
C
      WRITE(IW,2)
      WRITE(IW,97)
      WRITE(IW,3) BDATA(20),BDATA(21),BDATA(27)
C
      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)
C
      WRITE(IW,10)
      WRITE(IW,97)
      WRITE(IW,11)
      WRITE(IW,12) ((STAB(I,J),J=1,2),I=1,5)
C
      WRITE(IW,13) SDATA(19),SDATA(20)
C
C..... F O R M A T S
C
   97 FORMAT(T10,72('-'))
C.....
    1 FORMAT('1',T10,F4.1,' FT. SPAN X ',F4.1,' FT. RISE REINFORCED CONC
     1RETE BOX SECTION'/T10,72('*'))
C.....
    4 FORMAT( /T10,'I N S T A L L A T I O N   D A T A')
C.....
    5 FORMAT(T12,'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 )
C.....
    6 FORMAT( /T10,'L O A D I N G   D A T A')
C.....
    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)
C.....
    2 FORMAT( /T10,'M A T E R I A L   P R O P E R T I E S')
```

```
C.....
    3 FORMAT(T12,'STEEL - MINIMUM SPECIFIED YIELD STRESS, KSI',T70,
     1 F12.3/T12,'CONCRETE - SPECIFIED COMPRESSIVE STRENGTH, KSI',
```



```
     2 T70,F12.3,/,
     3 T12,'REINFORCING TYPE',T70,F12.3)
C.....
    8 FORMAT( /T10,'C O N C R E T E   D A T A')
C.....
    9 FORMAT(
     1 T12,'TOP SLAB THICKNESS, IN.',T70,F12.3/
     2 T12,'BOTTOM SLAB THICKNESS, IN.',T70,F12.3/
     3 T12, 'SIDE WALL THICKNESS, IN.',T70,F12.3,/,
     4 T12,'HORIZONTAL HAUNCH DIMENSION, IN.',T70,F12.3/
     5 T12,'VERTICAL HAUNCH DIMENSION, IN.',T70,F12.3,/ ,
     6 T12,'CONCRETE COVER CVER STEEL, IN. ',T70,/,
     1 T18,'TOP SLAB - OUTSIDE FACE',T70,F12.3,/,
     9 T18,'SIDE WALL - OUTSIDE FACE',T70,F12.3,/,
     2 T18,'BOTTOM SLAB - OUTSIDE FACE',T70,F12.3 , /,
     7 T18,'TOP SLAB - INSIDE FACE',T70,F12.3,/,
     8 T18,'BOTTOM SLAB - INSIDE FACE',T70,F12.3,/,
     1 T18,'SIDE WALL - INSIDE FACE',T70,F12.3  )
C.....
   10 FORMAT( /T10,'R E I N F O R C I N G   S T E E L   D A T A')
C.....
   11 FORMAT(T12,35X,'AREA',19X,/,T12,12X,'LOCATION',14X,'SQ. IN.',6X,
     1'STIRRUPS',/,T12,34X,'PER FT',7X,'REQUIRED?',/,T12,70(1H-)  )
C.....
   12 FORMAT(T12,'   TOP SLAB     - INSIDE  FACE',
     1 6X,F5.3,10X,A4/
     1 T12,'   TOP SLAB     - OUTSIDE FACE',
     1 6X,F5.3,10X,A4/
     2 T12,'   BOTTOM SLAB - INSIDE  FACE',
     3 6X,F5.3,10X,A4/
     4 T12,'   SIDE WALL    - OUTSIDE FACE',
     5 6X,F5.3,10X,A4/
     6 T12,'   SIDE WALL    - INSIDE  FACE',
     7 6X,F5.3,10X,A4/
     8 T12,70('-'))
C.....
   13 FORMAT(T12,'    *PROGRAM ASSIGNED VALUE'//
     1 T12,'THE SIDE WALL OUTSIDE FACE STEEL IS BENT AT THE CULVERT CORN
     2ERS AND'/ T12,'EXTENDED INTO THE OUTSIDE FACE OF THE TOP AND BOTTO
     3M SLABS.  THE'/T12, 'THEORETICAL CUT-OFF LENGTHS MEASURED FROM',
     4 ' THE BEND POINT ARE',F5.1,/T12,'AND',F5.1,' IN. RESPECTIVELY. ',
     6 'ANCHORAGE LENGTHS MUST BE ADDED.')
C.....
      RETURN
      END
```

Go to Part II, Program Pipecar

Program PIPECAR

```
IV G LEVEL  21                    MAIN                    DATE = 82251            18/44/55

      C
      C
      C      PROGRAM PIPECAR
      C
      C      ANALYSIS AND DESIGN PROGRAM FOR REINFORCED CONCRETE PIPE
      C
      C      SUBMITTED TO FEDERAL HIGHWAY ADMINISTRATION  -  AUGUST 1982
      C      DEVELOPED FOR FHWA PROJECT NO. DOT-FH-11-9692
      C    BY SIMPSON GUMPERTZ AND HEGER INC.   1696 MASSACHUSETTS AVENUE
      C                                         CAMBRIGE,MASSACHUSETTS 02138
      C      EXAMPLE STANDARD PLANS FOR IMPROVED INLETS
      C
      C      THIS IS THE MAIN PROGRAM. IT SEQUENTIALLY CALLS THE VARIOUS
      C      SUBROUTINES NEEDED TO COMPLETE THE ANALYSIS AND DESIGN OF
      C      THE PIPE
      C
            COMMON/ISCALE/IDBUG,IPATH
            COMMON/IFLAG/IBDATA(35)
            COMMON/PRESS/DLPR(37),DLPT(37),SLPR(37),SLPT(37),FLPR(37)
           1,FLPT(37)
            COMMON/COORD/X(37),Y(37),A(37),B,BS
            COMMON/RSCALE/BDATA(35)
            COMMON/STLAR/AREAI(5),SRATIO(5),SGOV(5),AREADT(5),STEXT(5),
           1STSPA(5)
            COMMON/DESIGN/DM(5),DV(5),DP(5),VLCC(5)
            COMMON/PROP/SI(37),CD(37),ALEN(37)
            COMMON/CONST/K1(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)
            COMMON/PVM/PVM1(3,3,36),PVM2(3,3,36)
            COMMON/REACTI/R(3,3,2)
            DOUBLE PRECISION K1, K2, K12, F1, F2, PVM1, PVM2
            DOUBLE PRECISION UN,R
      C
      2000  CONTINUE
            IPATH=0
            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(DLPR,DLPT,1)
```

```
      CALL LDMATR(SLPR,SLPT,2)
      CALL LDMATR(FLPR,FLPT,3)
      CALL RECUR
```



```
      CALL REACT
      CALL THSHMG
      CALL PVGMAX
      CALL DESGN
      CALL PRINT
 1000 CONTINUE
      GO TO 2000
 3000 CONTINUE
      STOP
      END
```



```
      SUBROUTINE READ
C
C   THIS SUBROUTINE READS ALL THE INPUT IN A SPECIFIED FORMAT AND
C   TRANSFERS THE DATA INTO THE RDATA ARRAY. THE EXECUTION OF READ
C   IS CONTROLLED BY THE KODE VARIABLE ON THE INPUT CARDS. A KODE
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/IFLAG/IRDATA(35)
      COMMON/RSCALE/RDATA(35)
      COMMON/ISCALE/IDBUG,IPATH
      DIMENSION TEXT(5),D(6),LAT(12),DSCPTR(6)
      DATA LAT /3,2,1,3,3,1,2,2,3,4,2,3/
C   * * * * * * * * * * * * * * * * * * * * * *
C   IRDATA =   VALUE NOT READ
C          =+1 VALUE WAS READ
C          =-1 VALUE WAS DEFAULTED
C   WIRE DIAMETERS ARE NOT DEFAULTED
C
      DO 5 I=1,35
      RDATA(I)=0.0
      IRDATA(I)=0
5     CONTINUE
      WRITE (6,99)
 99   FORMAT(1H1)
      READ(5,1020,END=993)  (RDATA(I), I=1,20), IDBUG
 1020 FORMAT ( 19A4, A3,I1
C
C   IDBUG CONTROLS PRINT
C    IDBUG =0-------INPUT ARRAY AND TOTAL LOADS AND FINAL DESIGN
C          =1-------ABOVE + REACTIONS AND DESIGN FORCES
C          =2-------ABOVE + GEOMETRY,MOMENTS,THRUSTS AND SHEARS
C          =3-------ABOVE + STIFFNESS MATRICES AND JOINT
C                   DISPLACEMENTS
C
3     WRITE (6,1021)         (RDATA(I),I=1,20),IDBUG
1021  FORMAT (1X,20A4,I2)
1     READ (5,1000)  KODE, (TEXT(I), I=1,5), (D(I), I=1,6)
      IF ( KODE .GT. 12 ) GO TO 995
4     K=LAT(KODE)
      GO TO (10,20,30,40,50,60,70,80,90,100,110,120), KODE
C
C  RADIUS1, RADIUS2, DEPTH OF FILL        KODE=1
C
```

```
 10     CONTINUE                                                        0093C
        IF(D(2) .EQ. 0.0) GO TO 15                                      00931
        WRITE(6,1002) KODE,(TEXT(I),I=1,5),(D(I),I=1,K)                 00932
        BDATA(1)=D(1)                                                   00951
```



```
        BDATA(2)=D(2)                                                   00960
        BDATA(3)=D(3)                                                   00970
        IBDATA(1)=1
        IBDATA(2)=1
        IBDATA(3)=1
        GO TO 1                                                         00990
 15     CONTINUE                                                        01000
        WRITE(6,1001) KODE,(TEXT(I),I=1,5),D(I),D(3)                    01001
        BDATA(1)=D(1)/2
        BDATA(2)=D(1)/2
        BDATA(3)=D(3)                                                   01020
        IBDATA(1)=1
        IBDATA(3)=1
        IBDATA(2)=-1                                                    01040
        BDATA(4)=0.000001
        BDATA(5)=0.000001
        IBDATA(4)=-1
        IBDATA(5)=-1
        GO TO 1                                                         01070
C
C  U,V,                              KODE=2
C
 20     CONTINUE                                                        01100
        WRITE(6,1003) KODE,(TEXT(I),I=1,5),(D(I),I=1,K)                 01101
        BDATA(4)=D(1)                                                   01110
        BDATA(5)=D(2)                                                   01120
        IBDATA(4)=1
        IBDATA(5)=1
 25     CONTINUE                                                        01150
        GO TO 1                                                         01160
C
C  SLAB THICKNESS                    KODE=3                             01180
C
 30     CONTINUE                                                        0119C
        WRITE(6,1004) KODE,(TEXT(I),I=1,5),(D(I),I=1,K)                 01191
        BDATA(6)=D(1)                                                   0120C
        IBDATA(6)=1                                                     0121C
        GO TO 1                                                         0122C
C
C  BEDDING ANGLE, LOAD ANGLE, SOIL-STRUCTURE INTERACTION COEFFICIENT, KODE=4
C
 40     CONTINUE                                                        0125C
        WRITE(6,1005) KODE,(TEXT(I),I=1,5),(D(I),I=1,K)                 01251
        BDATA(7)=D(1)                                                   0126C
        IBDATA(7)=1                                                     0127C
        BDATA(32)=D(2)
        IBDATA(32)=1
        BDATA(8)=D(3)
```

```
      IBDATA(8)=1
      GO TO 1
C
C  DENSITIES: GAMAS, GAMAC, GAMAF      KODE=5
C
50    CONTINUE
      WRITE(6,1006) KODE,(TEXT(I),I=1,5),(D(I),I=1,K)
      BDATA(9)=D(1)
      BDATA(10)=D(2)
      BDATA(11)=D(3)
      IBDATA(9)=1
      IBDATA(10)=1
      IBDATA(11)=1
      GO TO 1
C
C  FLUID PARAMETERS                 KODE=6
C
60    CONTINUE
      WRITE(6,1007) KODE,(TEXT(I),I=1,5),(D(I),I=1,K)
      BDATA(12)=D(1)
      IBDATA(12)=1
      GO TO 1
C
C  MATERIAL STRENGTHS F(Y),F(CP)         KODE=7
C
70    CONTINUE
      WRITE(6,1008) KODE,(TEXT(I),I=1,5),(D(I),I=1,K)
      IF (D(1) .EQ. 0.) GO TO 71
      BDATA(13)=D(1)
      IBDATA(13)=1
71    IF (D(2) .EQ. 0.) GO TO 1
      BDATA(14)=D(2)
      IBDATA(14)=1
      GO TO 1
C
C CONCRETE COVER                        KODE=8
C
80    CONTINUE
      WRITE(6,1009) KODE,(TEXT(I),I=1,5),(D(I),I=1,K)
      BDATA(15)=D(1)
      IBDATA(15)=1
      BDATA(16)=D(2)
      IBDATA(16)=1
      GO TO 1
C
C  LOAD FACTORS, CAP. RED. FACTORS    KODE=9
C
90    CONTINUE
```

```
      WRITE(6,1010) KODE,(TEXT(I),I=1,5),(D(I),I=1,K)
      BDATA(17)=D(1)
      BDATA(25)=D(2)
      BDATA(33)=D(3)
      IBDATA(17)=1
      IBDATA(25)=1
      IBDATA(33)=1
      GO TO 1
C
C  WIRE DIAMETERS,TYPE,LAYERS              KODE=10
C
100   CONTINUE
      WRITE(6,1011) KODE,(TEXT(I),I=1,5),(D(I),I=1,K)
      IF (D(1) .EQ. 0.0 ) GO TO 105
      BDATA(19)=D(1)
      IBDATA(19)=1
105   IF(D(2) .EQ. 0.) GO TO 106
      BDATA(20)=D(2)
      IBDATA(20)=1
106   IF (D(3) .EQ. 0.0) GO TO 107
      BDATA(21)=D(3)
      IBDATA(21)=1
107   IF (D(4) .EQ. 0.0) GO TO 1
      BDATA(22)=D(4)
      IBDATA(22)=1
      GO TO 1
C
C  WIRE SPACING                              KODE=11
C
110   CONTINUE
      WRITE(6,1012) KODE,(TEXT(I),I=1,5),(D(I),I=1,K)
      IF (D(1) .EQ. 0.0 ) GO TO 115
      BDATA(23)=D(1)
      IBDATA(23)=1
115   IF (D(2) .EQ. 0.0 ) GO TO 1
      BDATA(24)=D(2)
      IBDATA(24)=1
      GO TO 1
C
C  DESIGN FACTORS :  FCR,FRP,FVP      KODE=12
C
120   CONTINUE
      WRITE(6,1013) KODE,(TEXT(I),I=1,5),(D(I),I=1,K)
      BDATA(26)=D(1)
      BDATA(34)=D(2)
      BDATA(35)=D(3)
      IBDATA(26)=1
      IBDATA(34)=1
```

```
       IPDATA(35)=1
       GO TO 1                                                          02080
C
C  END OF DATA,  MODE AT 12                                             02100
C
993    CONTINUE                                                         02110
       IPATH=1                                                          02120
       WRITE(6,1014)                                                    02129
C
C   FORMAT STATEMENTS FOR INPUT VALUES
C
 1000 FORMAT (I2, 4A4, A2, 6F10.3 )
1001  FORMAT(5X,I2,3X,5A4,3X,12HINSDDIAM(IN),1X,F10.3,                  02131
     126X,12HDPTHFILL(FT),1X,F10.3)                                     02132
1002  FORMAT(5X,I2,3X,5A4,3X,12HRADIUS 1(IN),1X,F10.3,2X,               02133
     112HRADIUS 2(IN),1X,F10.3,2X,12HDPTHFILL(FT),1X,F10.3)             02134
1003  FORMAT(5X,I2,3X,5A4,3X,12HHORIZ CS(IN),1X,F10.3,2X,               02135
     112HVERT  OS(IN),1X,F10.3)
1004  FORMAT(5X,I2,3X,5A4,3X,12HTHICKNES(IN),1X,F10.3)                  02137
1005  FORMAT(5X,I2,3X,5A4,3X,12HBED. ANGLE  ,1X,F10.3,2X,               02138
     112HLOAD ANGLE  ,1X,F10.3,2X,12HSL-SH INT CO,1X,F10.3    )
1006  FORMAT(5X,I2,3X,5A4,3X,12HSOIL (#/FT3),1X,F10.3,2X,               02140
     112HCONC (#/FT3),1X,F10.3,2X,12HFLUID(#/FT3),1X,F10.3)             02141
1007  FORMAT(5X,I2,3X,5A4,3X,12HDPTHFLUD(IN),1X,F10.3)                  02142
1008  FORMAT(5X,I2,3X,5A4,3X,12HFY      (KSI),1X,F10.3,2X,              02143
     112HFCP     (KSI),1X,F10.3)                                        02144
1009  FORMAT(5X,I2,3X,5A4,3X,12HOUTSDCOV(IN),1X,F10.3,2X,               02145
     112HINSDCOV (IN),1X,F10.3)                                         02146
 1010 FORMAT(5X,I2,3X,5A4,3X,'LOAD FACTOR  ',1X,F10.3,2X,
     1'PHI FLEXURE ',1X,F10.3,2X,'PHI SHEAR   ',1X,F10.3)
1011  FORMAT(5X,I2,3X,5A4,3X,12HINSID WIRDIA,1X,F10.3,2X,               02149
     112HOUTSD WIRDIA,1X,F10.3,2X,12HREINFG TYPE ,1X,F10.3,2X,          02150
     112H# OF LAYERS ,1X,F10.3)                                         02151
1012  FORMAT(5X,I2,3X,5A4,3X,12HINSIDWIRSPCG,1X,F10.3,2X,               02152
     112HOUTSDWIRSPCG,1X,F10.3)                                         02153
 1013 FORMAT(5X,I2,3X,5A4,3X,12HPHI FLEX    ,1X,F10.3,2X,
     112HFRP         ,1X,F10.3,2X,12HFVP         ,1X,F10.3)
 1014 FORMAT(//,35H0 END OF DATA. EXECUTION TERMINATED  )
995   CONTINUE                                                          02157
      RETURN                                                            02160
      END                                                               02170
```

```
       IRDATA(35)=1
       GO TO 1                                                          02080
C
C  END OF DATA,  MODE AT 12                                             02100
C
993    CONTINUE                                                         02110
       IPATH=1                                                          02120
       WRITE(6,1014)                                                    02129
C
C   FORMAT STATEMENTS FOR INPUT VALUES
C
 1000 FORMAT (I2, 4A4, A2, 6F10.3 )
1001   FORMAT(5X,I2,3X,5A4,3X,12HINSDDIAM(IN),1X,F10.3,                 02131
      126X,12HDPTHFILL(FT),1X,F10.3)                                    02132
1002   FORMAT(5X,I2,3X,5A4,3X,12HRADIUS 1(IN),1X,F10.3,2X,              02133
      112HRADIUS 2(IN),1X,F10.3,2X,12HDPTHFILL(FT),1X,F10.3)            02134
1003   FORMAT(5X,I2,3X,5A4,3X,12HHORIZ CS(IN),1X,F10.3,2X,              02135
      112HVERT  OS(IN),1X,F10.3)
1004   FORMAT(5X,I2,3X,5A4,3X,12HTHICKNES(IN),1X,F10.3)                 02137
1005   FORMAT(5X,I2,3X,5A4,3X,12HBED. ANGLE  ,1X,F10.3,2X,              02138
      112HLOAD ANGLE  ,1X,F10.3,2X,12HSL-S! INT CO,1X,F10.3    )
1006   FORMAT(5X,I2,3X,5A4,3X,12HSOIL (#/FT3),1X,F10.3,2X,              02140
      112HCONC (#/FT3),1X,F10.3,2X,12HFLUID(#/FT3),1X,F10.3)            02141
1007   FORMAT(5X,I2,3X,5A4,3X,12HDPTHFLUD(IN),1X,F10.3)                 02142
1008   FORMAT(5X,I2,3X,5A4,3X,12HFY      (KSI),1X,F10.3,2X,             02143
      112HFCP     (KSI),1X,F10.3)                                       02144
1009   FORMAT(5X,I2,3X,5A4,3X,12HOUTSDCOV(IN),1X,F10.3,2X,              02145
      112HINSDCOV (IN),1X,F10.3)                                        02146
 1010 FORMAT(5X,I2,3X,5A4,3X,'LOAD FACTOR  ',1X,F10.3,2X,
      1'PHI FLEXURE ',1X,F10.3,2X,'PHI SHEAR   ',1X,F10.3)
1011   FORMAT(5X,I2,3X,5A4,3X,12HINSID WIRDIA,1X,F10.3,2X,              02149
      112HOUTSD WIRDIA,1X,F10.3,2X,12HREINFG TYPE ,1X,F10.3,2X,         02150
      112H# OF LAYERS ,1X,F10.3)                                        02151
1012   FORMAT(5X,I2,3X,5A4,3X,12HINSIDWIRSPCG,1X,F10.3,2X,              02152
      112HOUTSDWIRSPCG,1X,F10.3)                                        02153
 1013 FORMAT(5X,I2,3X,5A4,3X,12HPHI FLEX     ,1X,F10.3,2X,
      112HFRP          ,1X,F10.3,2X,12HFVP         ,1X,F10.3)
 1014 FORMAT(//,35H0 END OF DATA. EXECUTION TERMINATED  )
995    CONTINUE                                                         02157
       RETURN                                                           02160
       END                                                              02170
```

```
     1.GT. 0.0005) GO TO 103                                          02490
      IF (IBDATA(6) .EQ. 0) GO TO 200                                 02530
C
C   CHECK BEDDING ANGLE                                               02510
C
      IF (IBDATA(7) .NE. 0) GO TO 22
      BDATA(7) = 90.0
      IBDATA(7) = -1
      GO TO 205
   22 IF (BDATA(7)-30. )300, 94, 94                                   02550
 94   IF (BDATA(7) - 180.0 ) 205 , 205, 300
  300 WRITE(6,500)
      WRITE(6,1106)
 1106 FORMAT(24H0 BEDDING ANGLE MODIFIED    )
      IF ( BDATA(7) .LT. 30. ) BDATA(7) = 30.
      IF(BDATA(7) .GT. 180. ) BDATA(7) = 180.
      IBDATA(7) = -1
  205 CONTINUE
C
C   CHECK BEDDING AND LOAD ANGLES
C
      IF( BDATA(32) .NE. 0.00 ) GO TO 20
      BDATA(32) = 360. - BDATA(7)
      IBDATA(32)=-1
      GO TO 204
 20   CONTINUE
      IF ( BDATA(32) .GE. 180.   ) GO TO 206
      BDATA(32) = 180.0
      IBDATA(32) = -1
      WRITE(6,500)
      WRITE(6,1105)
  206 CONTINUE
      IF ((BDATA(7)+BDATA(32)) .LE. 360.) GO TO 204
      WRITE (6,500)
      WRITE (6,1104)
      WRITE(6,1105)
 1104 FORMAT(38H0 BEDDING AND LOAD ANGLES INCONSISTENT ,/,/)
 1105 FORMAT(21H0 LOAD ANGLE MODIFIED )
      BDATA(32)=360.0-BDATA(7)
      IBDATA(32)=-1
 204  CONTINUE
C
C     CHECK SOIL STRUCTURE INTERACTION FACTOR
C
      IF(BDATA(8) .GE. 0.75) GO TO 776
      BDATA(8)=1.2
      IBDATA(8)=-1
      WRITE(6,777)
```

```
   777 FORMAT(10X,'SOIL STRUCTURE INTERACTION FACTOR MODIFIED')
   776 CONTINUE
C
C    SET DEFAULT VALUES
C    INDEX OF ASSUME REFERS TO POSITION IN RSCALE COMMON
C
95      CONTINUE
        ASSUME(7)=90.0
        ASSUME(8)=1.2
        ASSUME(9)=120.0
        ASSUME(10)=150.0
        ASSUME(11)=62.5
        ASSUME(12)=2.*(BDATA(2)-BDATA(5))
        ASSUME(13)=65.0
        ASSUME(14)=5.0
        ASSUME(15)=1.0
        ASSUME(16)=1.0
        ASSUME(17)=1.3
        ASSUME(19)=ASSUME(17)
C
C     DO NOT ASSUME WIRE DIAMETERS
C
        ASSUME(21)=2.
        ASSUME(22)=1.
        ASSUME(23)=2.0
        ASSUME(24)=2.0
        ASSUME(25)=0.90
        ASSUME(26)=1.00
        ASSUME(33)=0.9
        ASSUME(34)=1.0
        ASSUME(35)=1.0
        BDATA(18)=BDATA(17)
        IBDATA(18)=IBDATA(17)
        DO 10 I=7,26
        IF (IBDATA(I)) 10,9,10
9       IBDATA(I)=-1
        BDATA(I)=ASSUME(I)
        IF (BDATA(I) .EQ. 0.0) IBDATA(I)=0
10      CONTINUE
        DO 13 I=33,35
        IF(IBDATA(I))  13,14,13
 14     IBDATA(I)=-1
        BDATA(I)=ASSUME(I)
 13     CONTINUE
  12    CONTINUE
C
C    CALCULATE ES, EC, MEAN RADII, EQUIVALENT DIAMETER
C
```

```
      BDATA(27)=29000.0
      BDATA(28)=(BDATA(16))**1.5*33.*SQRT(BDATA(14)*1000.)/1000.
      UVRAT=BDATA(4)/BDATA(5)
      BDATA(31)=SQRT(2.*(BDATA(2)**2*ATAN(UVRAT)+BDATA(1)**2*(PI/2-
     1ATAN(UVRAT))-BDATA(4)*BDATA(5))/PI)*2.
      IBDATA(27)=-1
      IBDATA(28)=-1
      IBDATA(29)=-1
      IBDATA(30)=-1
      IBDATA(31)=-1
      BDATA(29)=BDATA(1)+BDATA(6)/2
      BDATA(30)=BDATA(2)+BDATA(6)/2
      IF (BDATA(12) .LE. (2.*(BDATA(2)-BDATA(5)))) GO TO 101
      WRITE(6,102)
  102 FORMAT(45H0 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(22H0 RADII MUST BE GIVEN.)
      WRITE(6,1100)
      IPATH=-1
      GO TO 150
  103 WRITE(6,500)
      WRITE(6,1103)
 1103 FORMAT(29H0 GEOMETRY MUST BE CONSISTENT )
      WRITE(6,1100)
      IPATH=-1
      GO TO 150
  200 CONTINUE
      WRITE(6,500)
      WRITE(6,2000)
 2000 FORMAT (25H0 THICKNESS MUST BE GIVEN )
      WRITE(6,1100)
      IPATH=-1
      GO TO 150
  500 FORMAT(23H0 *** INPUT ERROR ***  )
 1100 FORMAT( 45H0 EXECUTION OF THIS PIPE HAS BEEN TERMINATED  )
  149 CONTINUE
C
C   CHECK FOR NUMBER OF LAYERS OF WIRE
C
      IF (BDATA(22) .GT. 2.) BDATA(22)=2.
      WRITE(6,4050)
 4050 FORMAT(/////,32X,69(1H*),/,32X,1H*,67X,1H*,/,32X,1H*,1X,
     1*ALL INFORMATION PRESENTED IS FOR REVIEW, APPROVAL, INTERPRETATION
```

```
      2 '*',/,32X,'* AND APPLICATION BY A REGISTERED ENGINEER.',25X,1H*,/,
      332X,1H*,67X,1H*,/,32X,69(1H*))
       IF ( IDBUG .LT. 1 ) GO TO 150
       WRITE(6,4051)
 4051  FORMAT(1H1)
       IF(BDATA(1) .EQ. BDATA(2)) GO TO 6000                                03360
       WRITE(6,6002)                                                        03361
       GO TO 6001                                                           03362
6000   WRITE(6,6003)                                                        03363
6002   FORMAT(///,5X,120(1H*),/,10X,28HELLIPTICAL PIPE ANALYSIS AND,        03364
      17H DESIGN,/,5X,120(1H*))                                             03365
6003   FORMAT(///,5X,120(1H*),/,10X,29HCIRCULAR PIPE ANALYSIS AND DE,
      14HSIGN,/,5X,120(1H*))
6001   CONTINUE                                                             03368
       WRITE(6,5000)                                                        03370
 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                                         03400
5001   J=1
       N=2
       GO TO 5004                                                           03440
5002   J=3
       N = 4
       GO TO 5004                                                           03420
5003   J=5
       N = 6
5004   KF = 5*I                                                             03452
       JF = KF-4                                                            03453
       WRITE(6,5005) I,(SCRIPT(LF),LF=JF,KF),BDATA(I),SOURCE(J),SOURCE(N)
5005   FORMAT(15X,I2,2X,5A4,3X,F10.3,4X,2A4)                                03470
5006   CONTINUE                                                             03480
150    CONTINUE                                                             03490
       RETURN                                                               03500
       END                                                                  03510
```

```
      SUBROUTINE GEOMET                                                 03550
C
C  CALCULATES COORDINATES OF THE NODES, AND THE LENGTH AND DIRECTIONAL
C  SINES AND COSINES OF MEMBERS FOR CIRCULAR AND ELLIPTICAL             03553
C  PIPE.                                                                03554
C  A PRINTOUT OF THIS INFORMATION IS AVAILABLE WITH AN IDBUG VALUE
C  GREATER THAN 1
C
C
      COMMON/RSCALE/RADI1, RADI2,H,U,V,TH,BETA,HH,GAMAS,GAMAC,GAMAF,DF, 03560
     1FY,FCP,COUT,CIN,FLMV,FLN,DIN,DOUT,RTYPE,NLAY,SPIN,SPOUT,PD,FCR,EST 03570
     1,ECON,RADM1,RADM2,EQUID,BETAS,PDD
      COMMON/COORD/X(37),Y(37),A(37),B,BS
      COMMON/PROP/SI(37),CO(37),ALEN(37)                                03600
      COMMON/ISCALE/IDBUG,IPATH                                         03610
      DIMENSION DEG(37)
C
      M=0                                                               03640
      PI=3.1415926535897                                                04450
      IF(BETA .NE. 180.) GO TO 200                                      03660
      B=179.9*PI/180.0
      BS=~~180.1~~*PI/180.
      M=2
                                179.9
200   CONTINUE                                                          03700
      IF (BETAS .EQ. 180. ) BS = ~~180.1~~*PI/180.
      BETA=BETA*PI/180.                                                 03710
      BETAS=BETAS*PI/180.
C
C                           GENERATE COORDINATES                        03720
C
      P2 = ATAN(U/V)
      DO 300 I=1,37                                                     03750
      DEG(I) = (I-1) * 5.00000
      A(I)=(I-1)*PI/36                                                  03760
      IF(A(I) .GT. (PI-P2)) GO TO 700                                   03780
      IF (A(I) .GT. P2) GO TO 600                                       03790
      X(I)=RADM2*SIN(A(I))                                              03800
      Y(I)=-RADM2*COS(A(I))+V                                           03810
      GO TO 500                                                         03820
600   CONTINUE                                                          03830
      X(I)=RADM1*SIN(A(I))+U                                            03840
      Y(I)=-RADM1*COS(A(I))                                             03850
500   CONTINUE                                                          03860
      IF (M .GE. 1) GO TO 750
      IF (-ATAN(X(I)/Y(I)) .LE. (BETA+0.0017)/2.) GO TO 800
      B=2.*A(I-1)                                                       03890
      M=1                                                               03900
                  .LE. 3.14247
      IF ( BETAS ~~.EQ. 180.~~ ) M = 2
```

```
      IF ((BETA+BETAS) .LT. 6.28144) GO TO 750
      BS=B
      M=2
      GO TO 800
 750  IF ( M .EQ. 2 ) GO TO 800
      IF(-ATAN(X(I)/Y(I)) .LE.(6.2815-BETAS)/2.) GO TO 800
      BS=2.*A(I)
      M=2
      GO TO 800
 700  CONTINUE
      X(I)=RADM2*SIN(A(I))
C
C X(I)=RADM3*SIN(A(I))
C
      Y(I)=-RADM2*COS(A(I))-V
C
C Y(I)=-RADM3*COS(A(I))-VP
C
 800  CONTINUE
      IF(I .EQ. 1) GO TO 300
      ALEN(I-1)=((X(I)-X(I-1))**2+(Y(I)-Y(I-1))**2)**0.5
      SI(I-1)=(Y(I)-Y(I-1))/ALEN(I-1)
      CO(I-1)=(X(I)-X(I-1))/ALEN(I-1)
 300  CONTINUE
      IF (IDBUG .LT. 2) GO TO 1300
      WRITE(6,99)
  99  FORMAT(1H1)
      WRITE(6,1000)
      WRITE(6,1400)
      WRITE(6,1200)(I,DEG(I),X(I),Y(I),ALEN(I),A(I),SI(I),CO(I),
     1  I=1,37  )
 1100 CONTINUE
 1000 FORMAT(//,5*X,8HGEOMETRY,/,6X,1HI,5X,8HDEG FROM,5X,4HX(I),12X,
     1 4HY(I),12X,7HALEN(I),12X,4HA(I),13X,5HSI(I),12X,5HCO(I))
 1200 FORMAT(37(5X,I2,6X,F4.0,1X,F12.3,5X,4(F12.3,5X),F12.3,/)  )
 1400 FORMAT(4X,5HJOINT,4X,8HVERTICAL,5X,18HINCHES FROM CENTER,13X,
     1 6HINCHES,11X,7HRADIANS   )
 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,H,U,V,TH,BETA,HH,GAMAS,GAMAC,GAMAF,DF,
     1FY,FCP,COUT,CIN,FLMV,FLN,DIN,DOUT,RTYPE,NLAY,SPIN,SPOUT,PD,FCR,EST
     1,ECON,RADMI,RADM2,EQUID,BETAS,POD
      COMMON/COORD/X(37),Y(37),A(37),B,BS
      COMMON/PROP/SI(37),CD(37),ALEN(37)
      COMMON/ISCALE/IDBUG,IPATH
      COMMON/IFLAG/IBDATA(35)
      COMMON/PRESS/DLPR(37),DLPT(37),SLPR(37),SLPT(37),FLPR(37),
     1FLPT(37)
      DIMENSION DEG(37)
      DIMENSIONR(37),Q(37),PREACT(37),T(37),S(37)
      REAL L,LF
C
C   SET FLUID LEVEL TO NEAREST JOINT
C
      IF(IBDATA(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 .GE.(DF+Y(1)+TH/2.)) GO TO 950
1000  CONTINUE
950   CONTINUE
      B2=0.0
      B4=0.0
      B7=0.0
      B8=0.0
      PW=0.0
      B5=1.0
      B6=1.0
      F1=1.0
      PI=3.1415926535897
C
C   TOTAL SOIL LOAD
C
      W=GAMAS*HH*(TH+RADI1+U)*(H+(RADI2-V+TH)/36)/6000.
```

```
      R3=RADM1                                                          04470
      IF (EQUID .NE. 0.0) R3=(EQUID+TH)/2.                              04480
C
C    OLANDER SOIL PRESSURE DISTRIBUTION                                 04482
C
      C=SIN((PI/B-1.)*B/2.)/2./(PI/B-1.)                                04490
      D=SIN((PI/B+1.)*B/2.)/2./(PI/B+1.)                                04500
      PINV=W/2./R3/(C+D)                                                04510
      A9=PI-BS/2.
      E=SIN((PI/2./A9-1.)*A9)/2./(PI/2./A9-1.)                          04530
      F=SIN((PI/2./A9+1.)*A9)/2./(PI/2./A9+1.)                          04540
      PTOP=W/2./R3/(E+F)                                                04550
      DO 100 I=1,37                                                     04570
      DEG(I) = (I-1) * 5.00000
      IF (I .EQ. 1) GO TO 225                                           04580
      IF (I .EQ. 37) GO TO 101                                          04590
      GO TO 250                                                         04600
225   CONTINUE                                                          04610
C                                                DEAD LOAD              04630
C    DLPR = DEAD LOAD - NORMAL PRESSURE                                 04641
C    DLPT = DEAD LOAD - TANGENTIAL PRESSURE                             04642
C
      DLPR(1)=-TH*GAMAC/144000.0                                        04650
      DLPR(37)=-DLPR(1)                                                 04660
      DLPT(1)=0.0
      DLPT(37)=0.0
      GO TO 101                                                         04680
250   CONTINUE                                                          04690
      L=((X(I+1)-X(I-1))**2+(Y(I+1)-Y(I-1))**2)**0.5                    04700
      CA=(X(I+1)-X(I-1))/L                                              04710
      SA=(Y(I+1)-Y(I-1))/L                                              04720
      DLPR(I)=DLPR(1)*CA                                                04730
      DLPT(I)=DLPR(37)*SA                                               04740
101   CONTINUE                                                          04750
      PW=TH*GAMAC*ALEN(I)*2./144000.+PW                                 04760
C                                                SOIL LOAD              04780
C    SLPR = SOIL - NORMAL PRESSURE                                      04791
C    SLPT = SOIL - TANGENTIAL PRESSURE                                  04792
C
      SLPT(I)=0.0                                                       04800
      IF (A(I) .GT. (B/2.)) GO TO 300                                   04810
      SLPR(I)=PINV*COS(PI/B*A(I))                                       04820
      GO TO 350                                                         04830
300   CONTINUE                                                          04840
      IF ( A(I) .GT. BS/2. ) GO TO 310
      SLPR(I)=0.0
      GO TO 350
 310  SLPR(I)=PTOP*SIN(0.5*(A(I)-BS/2.)*(PI/A9))
```

```
  350   CONTINUE
        Q(I)=SLPR(I)*COS(A(I))
        IF (I .EQ. 1) GO TO 200
        IF(A(I) .GT. B/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                                                 FLUID LOAD
  C   FLPR = FLUID NORMAL PRESSURE
  C   FLPT = FLUID TANGENTIAL PRESSURE
  C
        FLPR(I)=(FS-(Y(I)+TH/2.*COS(A(I))))*GAMAF/144000.0*(-1.0)
        IF (FLPR(I) .GT. 0.0) FLPR(I)=0.0
        FLPT(I)=0.0
        PREACT(I) = 0.0
        T(I)=FLPR(I)*COS(A(I))
        LF = RADI2/RADM2
        IF(A(I) .GT. (PI-ATAN(U/V))) GO TO 107
        IF(A(I) .GT.  ATAN(U/V)) LF=RADI1/RADM1
  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
  C
        IF (W .EQ. 0.0) GO TO 550
        B5=B2/W*2.
        B6=B4*(-2.0)/W
  550   PROT=-B7/R3/(C+D)
        DO 500 J=1,37
        IF (A(J) .GT. (B/2.)) GO TO 600
        SLPR(J)=SLPR(J)/B5
        PREACT(J)=PROT*(COS(A(J)*PI/B))
        S(J)=PREACT(J)*COS(A(J))
        GO TO 700
  600   CONTINUE
        SLPR(J)=SLPR(J)/B6
  700   CONTINUE
        IF (J .EQ. 1)GO TO 500
        IF (A(J) .GT. B/2.) GO TO 500
        B8=(S(J)+S(J-1))/2.*ALEN(J-1)+B8
  500   CONTINUE
        IF (B7 .NE. 0) F1=-B8/B7
        DO 1300 K=1,37
        FLPR(K)=FLPR(K)+PREACT(K)/F1
```

```
 1300  CONTINUE
       IF (IOBUG .LT. 2) GO TO 3000
 C
 C    PRINT LOADS TABLE
 C
       WRITE(6,99)
  99   FORMAT(1H1)
       WRITE(6,1400)
 1400  FORMAT(///,57X,36HLOADS AT EACH JOINT, KIPS/IN/FOOT    )
       WRITE(6,1500)
  1500 FORMAT(37X,4HDEAD,28X,4HSOIL,28X,5HFLUID)
       WRITE(6,1550)
 1550  FORMAT(12X,8HDEG FROM,5X,24(1H-),9X,24(1H-),9X,24(1H-) )
       WRITE(6,1600)
  1600 FORMAT(6X,1HI,5X,8HVERTICAL,8X,6HRADIAL,9X,4HTANG,2(14X,6HRADIAL,
      1   9X,4HTANG ) )
       WRITE(6,1700)(I,DEG(I),DLPR(I),DLPT(I),SLPR(I),SLPT(I),FLPR(I),
      1FLPT(I), I=1,37)
  1700 FORMAT(5X,I2,7X,F4.0,4X,F12.6,3X,F12.6,6X,F12.6,3X,F12.6,6X,
      1F12.6,3X,F12.6)
 3000  CONTINUE
       IF (IOBUG .LT. 1 ) GO TO 4000
       WRITE(6,1800) PW
  1800 FORMAT(///,14H0 PIPE WEIGHT=,F9.3,10H KIPS/FOOT    )
       WRITE(6,1900) W
  1900 FORMAT(/,14H0 SOIL WEIGHT=,F9.3,10H KIPS/FOOT )
       B7TMP = -2.0*B7
       WRITE(6,2000) B7TMP
  2000 FORMAT(/,15H0 FLUID WEIGHT=,F9.3,10H KIPS/FOOT   )
 4000  CONTINUE
       RETURN
       END
```

```
      SUBROUTINE STIFF
C
C  CALCULATES MEMBER STIFFNESS SUBMATRICES
C
      COMMON/PROP/SI(37),CO(37),ALEN(37)
      COMMON/RSCALE/DUM(5),TH,DUMM(21),ECON,D(2)
      COMMON/ISCALE/IDPUS,IPATH
      COMMON/CONST/K1(3,3,36),K2(3,3,36),K12(3,3,36)
      DOUBLE PRECISION K1, K2, K12, MI
C
      AREA=12.*TH
      MI=TH**3
      DO 100 I=1,36
      C1=ECON/ALEN(I)
      C2=MI/ALEN(I)**2
      A1=C1*(CO(I)**2*AREA+12.*SI(I)**2*C2)
      A2=C1*(SI(I)**2*AREA+12.*CO(I)**2*C2)
      A3=C1*SI(I)*CO(I)*(AREA-12.*C2)
      A4=6.*SI(I)*ECON*C2
      A5=A4/SI(I)*CO(I)
      A6=4.*MI*C1
      K1(1,1,I)=A1
      K2(1,1,I)=A1
      K12(1,1,I)=-A1
      K1(1,2,I)=A3
      K1(2,1,I)=A3
      K2(1,2,I)=A3
      K2(2,1,I)=A3
      K12(1,2,I)=-A3
      K12(2,1,I)=-A3
      K1(1,3,I)=-A4
      K1(3,1,I)=-A4
      K12(1,3,I)=-A4
      K1(2,2,I)=A2
      K2(2,2,I)=A2
      K12(2,2,I)=-A2
      K1(2,3,I)=A5
      K1(3,2,I)=A5
      K12(2,3,I)=A5
      K2(2,3,I)=-A5
      K2(3,2,I)=-A5
      K12(3,2,I)=-A5
      K1(3,3,I)=A6
      K2(3,3,I)=A6
      K12(3,3,I)=0.5*A6
      K2(1,3,I)=A4
      K2(3,1,I)=A4
      K12(3,1,I)=A4
```



```
  100 CONTINUE
  200 CONTINUE
      RETURN
      END
```

```
          SUBROUTINE LDMATR(P,PT,K)                                           06180
C
C     FOR EACH LOADING CONDITION, LDMATR GENERATES THE LOAD MATRICES
C     FOR EACH JOINT FROM THE MEMBER PROPERTIES AND THE RADIAL AND
C     TANGENTIAL PRESSURES. THE LDMATR VALUES, REPRESENT THE REACTIONS.
C     AT EACH END OF A MEMBER DUE TO THE APPLIED LOADS
C
C
          DIMENSION P(37),PT(37)                                              06190
          COMMON/PROP/SI(37),CO(37),ALEN(37)                                  06200
          COMMON/LOAD/F1(3,3,36),F2(3,3,36)                                   06210
          DOUBLE PRECISION F1, F2, C1, C2
C
          DO 100 I=1,36                                                       06230
          C1=SI(I)*ALEN(I)                                                    06240
          C2=CO(I)*ALEN(I)                                                    06250
          F1(1,K,I)=C1/(-20.)*(7.*P(I)+3.*P(I+1))-C2/8.*(3.*PT(I)+            06270
         1PT(I+1))                                                            06280
          F1(2,K,I)=C2/20.*(7.*P(I)+3.*P(I+1))-C1/8.*(3.*PT(I)+PT(I+1))       06290
          F1(3,K,I)=ALEN(I)**2/60.*(3.*P(I)+2.*P(I+1))                        06300
          F2(1,K,I)=C1/(-20.)*(3.*P(I)+7.*P(I+1))-C2/8.*(PT(I)+               06310
         13.*PT(I+1))                                                         06320
          F2(2,K,I)=C2/20.*(3.*P(I)+7.*P(I+1))-C1/8.*(PT(I)+3.*PT(I+1))       06330
          F2(3,K,I)=ALEN(I)**2/60.0*(2.*P(I)+3.*P(I+1))*(-1.0)                06340
  100     CONTINUE                                                            06350
          RETURN                                                              06360
          END                                                                 06370
```

```
      SUBROUTINE RECUR
C
C   ASSUMES THAT JOINT 1(INVERT) IS FIXED AND JOINT 37(CROWN) 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
C
      COMMON/ISCALE/IDBUG,IPATH
      COMMON/CONST/K1(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 UN, P(3,3,37),Q(3,3,37),D(3),A(3,3),B(3,3),
     1C(3,3)
C
      DO 100 I=1,3
      DO 100 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)
100   CONTINUE
      CALL MATINV(A,B)
      CALL MATMPY(B,K12(1,1,2),P(1,1,2))
      CALL MATMPY(B,C,Q(1,1,2))
      DO 200 L=3,36
      DO 300 I=1,3
      DO 300 J=1,3
      K12T(J,I)=K12(I,J,L-1)
300   CONTINUE
      CALL MATMPY(K12T,P(1,1,L-1),A)
      DO 400 I=1,3
      DO 400 J=1,3
      A(I,J) = K2(I,J,L-1) - A(I,J) + K1(I,J,L)
400   CONTINUE
      CALL MATINV(A,B)
      CALL MATMPY(K12T,Q(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 MATMPY(B,C,Q(1,1,L))
      IF (L .EQ. 36)GO TO 600
      CALL MATMPY(B,K12(1,1,L),P(1,1,L))
      GO TO 200
600   CONTINUE
```

```
      D(1)=K12(1,2,L)
      D(2)=K12(2,2,L)
      D(3)=K12(3,2,L)
      CALL MATXCO(D,B,P(1,1,36))
 200  CONTINUE
      DO 700 K=1,3
      UN(1,K,37)=0.0D0
      UN(3,K,37)=0.0D0
      UN(2,K,37)=(K2(2,1,36)*Q(1,K,36) - K2(2,3,36)*Q(3,K,36) +
     1            K2(2,2,36)*Q(2,K,36) + F2(2,K,36) ) /
     2            (K2(2,1,36)*P(1,1,36) - K2(2,3,36)*P(3,1,36) +
     3            K2(2,2,36)*(1.0D0 + P(2,1,36) )  )
      UN(1,K,1)=0.0D0
      UN(2,K,1)=0.0D0
      UN(3,K,1)=0.0D0
      UN(1,K,36)=-P(1,1,36)*UN(2,K,37)+Q(1,K,36)
      UN(2,K,36)=-P(2,1,36)*UN(2,K,37)+Q(2,K,36)
      UN(3,K,36)=-P(3,1,36)*UN(2,K,37)+Q(3,K,36)
 700  CONTINUE
      L=35
 1000 CONTINUE
      CALL MATMPY(P(1,1,L),UN(1,1,L+1),A)
      DO 800 I=1,3
      DO 800 J=1,3
      UN(I,J,L)=Q(I,J,L)-A(I,J)
 800  CONTINUE
      L=L-1
      IF(L .GE. 2) GO TO 1000
      IF(IDBUG .LT. 3) GO TO 2500
C
C   WRITES DISPLACEMENTS
C
      WRITE(6,99)
  99  FORMAT(1H1)
      WRITE(6,2000)
      WRITE(6,2001)
      WRITE(6,2002)
      DO 1200 L=1,35,3
      L1TMP = L+1
      L2TMP = L+2
      WRITE(6,2100)L,L1TMP,L2TMP
      DO 1230 I=1,3
      GO TO (11,12,13),I
 11   WRITE(6,1) (UN(I,J,L),J=1,3),(UN(I,J,L+1),J=1,3),(UN(I,J,L+2)
     1,J=1,3)
      GO TO 1230
 12   WRITE(6,2)(UN(I,J,L),J=1,3),(UN(I,J,L+1),J=1,3),(UN(I,J,L+2)
     1,J=1,3)
```

```
      GO TO 1200
 15   WRITE(6,3)(UN(I,J,L),J=1,3),(UN(I,J,L+1),J=1,3),(UN(I,J,L+2)
     1,J=1,3)
 1200 CONTINUE
      WRITE(6,2003) ((UN(I,J,37),J=1,3),I=1,3)
 2003 FORMAT(6X,8H ELEMENT,8X,2H37,/,2X,'X',3X,3(E12.5,2X),/,
     12X,'Y',3X,3(E12.5,2X),/,1X,'ROT',2X,3(E12.5,2X))
 2000 FORMAT(//,51X,22HDISPLACEMENTS, INCHES    ,/)
 2001 FORMAT(23X,7HLOADING,32X,7HLOADING,31X,7HLOADING)
 2002 FORMAT(14X,'1',11X,'2',11X,'3',14X,'1',11X,'2',5X,'3',
     114X,'1',11X,'2',11X,'3',/)
 2100 FORMAT(6X,8H ELEMENT,8X,I2,38X,I2,38X,I2)
 1    FORMAT(2X,'X',5X,3E12.5,2X,3E12.5,2X,3E12.5)
 2    FORMAT(2X,'Y',5X,3E12.5,2X,3E12.5,2X,3E12.5)
 3    FORMAT(1X,'ROT',4X,3E12.5,2X,3E12.5,2X,3E12.5)
 2500 CONTINUE
      RETURN
      END
```



```
      SUBROUTINE REACT
C
C   CALCULATES THE MOMENTS, THRUSTS AND SHEARS AT JOINT 1(INVERT) AND
C   JOINT 37(CROWN)
C
C
      COMMON/REACTI/R(3,3,2)
      COMMON/DESIGN/DM(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/IDBUG,IPATH
      DOUBLE PRECISION  K1, K2, K12, F1, F2, UN
      DOUBLE PRECISION R,T(3,3),B(3,3),C(3,3)
C
      CALL MATMPY(K12(1,1,1),UN(1,1,2),B)
      DO 100 I=1,3
      DO 100 J=1,3
      R(I,J,1)=B(I,J)-F1(I,J,1)
100   CONTINUE
      DO 200 I=1,3,2
      T(1,1)=K12(1,I,36)
      T(1,2)=K12(2,I,36)
      T(1,3)=K12(3,I,36)
      T(2,1)=0.0D0
      T(2,2)=0.0D0
      T(2,3)=0.0D0
      T(3,1)=0.0D0
      T(3,2)=0.0D0
      T(3,3)=0.0D0
      CALL MATMPY(T,UN(1,1,36),C)
      DO 300 J=1,3
      R(I,J,2) = C(1,J) - F2(I,J,36) + K2(I,2,36)*UN(2,J,37)
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 (DABS(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   DM(5)=-R(3,1,2)-R(3,2,2)
```

```
      DM(5)=-R(3,1,2)-R(3,2,2)
      DP(5)=R(1,1,2)+R(1,2,2)
      IF (DABS(DM(5)-R(3,3,2)) .LT. ABS(DM(5))) GO TO 800
      DM(5)=DM(5)-R(3,3,2)
      DP(5)=DP(5)+R(1,3,2)
  800 CONTINUE
      DO 801 J=1,3
      R(3,J,2) = -R(3,J,2)
```



```
  801 CONTINUE
      RETURN
      END
```



```
      SUBROUTINE THSHMO
C
C   CALCULATES THE INTERNAL THRUSTS, SHEARS AND MOMENTS AT EACH END OF
C   EACH MEMBER
C       PVM1 REPRESENTS THE FORCES AT THE LEFT END OF A MEMBER
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 LOADING CONDITION
C                    Z REFERS TO THE ELEMENT
C   A PRINTOUT OF THE SERVICE LOAD FORCES IS AVAILABLE WITH AN IDBUG
C   VALUE GREATER THAN 1
C
C
      COMMON/PROP/SI(37),CO(37),ALEN(37)
      COMMON/LOAD/F1(3,3,36),F2(3,3,36)
      COMMON/ISCALE/IDBUG,IPATH
      COMMON/CONST/K1(3,3,36),K2(3,3,36),K12(3,3,36)
      COMMON/DISP/UN(3,3,37)
      COMMON/PVM/PVM1(3,3,36),PVM2(3,3,36)
      DOUBLE PRECISION K1, K2, K12, K12T(3,3), PVM1, PVM2, UN,F1,F2
      DOUBLE PRECISION T(3,3),D(3,3),R(3,3),F(3,3),G(3,3),S(3,3),W(3,3)
      COMMON/REACTI/REAC(3,3,2)
      DOUBLE PRECISION A(9),REAC
C
      IF (IDBUG .LT. 2)   GO TO 2
      WRITE(6,99)
   99 FORMAT(1H1)
      WRITE(6,600)
2     CONTINUE
      DEG = 0.0
      DO 290 I=1,36
      T(1,1)=CO(I)
      T(1,2)=SI(I)
      T(1,3)=0.0D0
      T(2,1) = -SI(I)
      T(2,2)=CO(I)
      T(2,3)=0.0D0
      T(3,1)=0.0D0
      T(3,2)=0.0D0
      T(3,3)=1.0D0
      DO 300 L=1,3
      DO 300 M=1,3
      K12T(M,L) = K12(L,M,I)
  300 CONTINUE
      CALL MATMPY(K1(1,1,I),UN(1,1,I),D)
      CALL MATMPY(K12(1,1,I),UN(1,1,I+1),E)
```

```
      CALL MATMPY(K12T(1,1),UN(1,1,I),R)
      CALL MATMPY(K2(1,1,I),UN(1,1,I+1),S)
```



```
      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,I))
      CALL MATMPY(T,W,PVM2(1,1,I))
      IF (IDBUG .LT.2) GO TO 200
C
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,I)-PVM2(J2,J1,I-1))/2.0000000
  203     CONTINUE
      DEG=(I-1)*5.00000
      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),
     1        (REAC(J6,3,1),J6=1,3)
  200 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),
     1     (REAC(J6,3,2),J6=1,3)
  600 FORMAT(//T36,'SERVICE LOAD THRUST(KIPS/FT), SHEAR(KIPS/FT), ',
     1'MOMENT(IN.KIPS/FT)'//,T36,'DEAD LOAD',T71,'SOIL LOAD',T105,
     2  'FLUID LOAD'/,T12,'DEG. FROM',5X,30(1H-),5X,30(1H-),5X,30(1H-),
     3 /,' JOINT',T12,'VERTICAL',T30,2('N',9X,'V',9X,'M',14X),'N',9X,
     4 'V',9X,'M'      )
  204 FORMAT(2X,I2,T12,F4.0,T24,2(3F10.4,5X),3F10.4   )
 1200 CONTINUE
      RETURN
      END
```

IV G LEVEL 21 MATINV DATE = 82252 12/34/24

```
      SUBROUTINE MATINV(A,B)
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)*
     1A(3,2)-A(3,1)*A(2,2)*A(1,3)-A(3,2)*A(2,3)*A(1,1)-A(3,3)*A(2,1)*
     1A(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(3,2)*A(1,3))/DELTA
      B(1,3)=(A(1,2)*A(2,3)-A(2,2)*A(1,3))/DELTA
      B(2,1)=-(A(2,1)*A(3,3)-A(3,1)*A(2,3))/DELTA
      B(2,2)=(A(1,1)*A(3,3)-A(1,3)*A(3,1))/DELTA
      B(2,3)=-(A(1,1)*A(2,3)-A(2,1)*A(1,3))/DELTA
      B(3,1)=(A(2,1)*A(3,2)-A(3,1)*A(2,2))/DELTA
      B(3,2)=-(A(1,1)*A(3,2)-A(3,1)*A(1,2))/DELTA
      B(3,3)=(A(1,1)*A(2,2)-A(2,1)*A(1,2))/DELTA
      RETURN
      END
```

IV G LEVEL 21 MATMPY DATE = 82252 12/34/24

```
      SUBROUTINE MATMPY(A,B,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(I,J)=0.0D0
      DO 10 K=1,3
      C(I,J)=C(I,J)+A(I,K)*B(K,J)
   10 CONTINUE
      RETURN
      END
```

IV G LEVEL 21 MATXCO DATE = 82252 12/34/24

```
      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) = 0.0D0
      DO 10 K=1,3
      Y(I)=Y(I)+A(I,K)*X(K)
10    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PVMMAX
C
C   LOCATES AND CALCULATES THE THRUSTS, SHEARS AND MOMENTS AT THE 5
C   CRITICAL DESIGN SECTIONS. THE PROCEDURE FOR FINDING THE EXACT
C   LOCATION OF M/PHIVD=3.0 ASSUMES LINEAR SHEAR AND QUADRATIC
C   MOMENT DISTRIBUTION ON A MEMBER.
C   LOAD FACTORS ARE THEN USED TO CONVERT DESIGN FORCES TO ULTIMATE
C   FORCES.
C
      COMMON/PVM/PVM1(3,3,36),PVM2(3,3,36)
      COMMON/RSCALE/RADI1,RADI2,H,U,V,TH,BETA,HH,GAMAS,GAMAC,GAMAF,DF,
     1FY,FCP,COUT,CIN,FLMV,FLN,DIN,DOUT,RTYPE,NLAY,SPIN,SPOUT,PO,FCR,
     1EST,ECON,RADM1,RADM2,EQUID,BETAS,POD
      COMMON/PROP/SI(37),CO(37),ALEN(37)
      COMMON/COORD/X(37),Y(37),A(37),R,BS
      COMMON/DESIGN/DM(5),DP(5),DV(5),VLOC(5)
      COMMON/ISCALE/IDBUG,IPATH
      DOUBLE PRECISION PVM1, PVM2
      REAL MMAX
C
C   L IS INDEX FOR LOCATIONS AT WHICH DESIGN WILL BE CHECKED
C
      L=2
C
C   SEARCH FOR MEMBER NEAR INVERT WHERE M/VD=3
C
      N=0
      DO 300 I=2, 36
      G=PVM1(3,1,I)+PVM1(3,2,I)
      C=(PVM1(2,1,I)+PVM1(2,2,I)-PVM2(2,1,I-1)-PVM2(2,2,I-1))/2.
      F=0.5*(PVM1(1,1,I)+PVM1(1,2,I)-PVM2(1,1,I-1)-PVM2(1,2,I-1))
      IF(DABS(C+(PVM1(2,3,I)-PVM2(2,3,I-1))/2.) .LT. ABS(C)) GO TO 400
      C=C+(PVM1(2,3,I)-PVM2(2,3,I-1))/2.
      G=G+PVM1(3,3,I)
      F=F+0.5*(PVM1(1,3,I)-PVM1(1,3,I-1))
400   CONTINUE
      D=POD*(TH-CIN-DIN/2.)
      IF (DIN .EQ.0.0) D=D-POD*0.04*TH
      IF (G .GT. 0.0) GO TO 350
      D=POD*(TH-COUT-DOUT/2.)
      IF (DOUT .EQ. 0.0) D=D-POD*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=I-1
```

```
      J1=1
      J2=J
 2000 CONTINUE
      VUNIT=(C-C1)/ALEN(J)
      BQ=3.0*D*VUNIT+C1
      XL=(-BQ+SQRT(BQ*BQ-2.*VUNIT*(3.0*D*C1-G1)))/VUNIT
      DM(L)=G1-C1*XL-0.5*VUNIT*XL*XL
      DP(L)=F1+(F-F1)*XL/ALEN(J)
      DV(L)=C1+VUNIT*XL
      VLOC(L)=A(J2)+0.087266*XL/ALEN(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=PVM1(3,1,I)+PVM1(3,2,I)
      IF(DABS(S+PVM1(3,3,I)) .GT. ABS(S)) GO TO 1100
      IF (ABS(S) .LT. ABS(MMAX)) GO TO 1000
      MMAX=S
      GO TO 1300
 1100 CONTINUE
      IF(DABS(S+PVM1(3,3,I)) .LT. ABS(MMAX)) GO TO 1000
      MMAX=S+PVM1(3,3,I)
 1300 CONTINUE
      DM(3)=S
      DV(3)=(PVM1(2,1,I)+PVM1(2,2,I)-PVM2(2,1,I-1)-PVM2(2,2,I-1))/2.
      DP(3)=(PVM1(1,1,I)+PVM1(1,2,I)-PVM2(1,1,I-1)-PVM2(1,2,I-1))/2.
      VLOC(3)=A(I)
      IF(DABS(DM(3)+PVM1(3,3,I)) .LT. ABS(DM(3))) GO TO 1000
      DM(3)=PVM1(3,3,I)+DM(3)
      DP(3)=(PVM1(1,3,I)-PVM2(1,3,I-1))/2.+DP(3)
      DV(3)=(PVM1(2,3,I)-PVM2(2,3,I-1))/2.+DV(3)
 1000 CONTINUE
C
C   SEARCH FOR MEMBER NEAR CROWN WHERE M/VD=3
C
      I=36
 1400 CONTINUE
      G=PVM1(3,1,I)+PVM1(3,2,I)
      C=(PVM1(2,1,I)+PVM1(2,2,I)-PVM2(2,1,I-1)-PVM2(2,2,I-1))/2.
      F=0.5*(PVM1(1,1,I)+PVM1(1,2,I)-PVM2(1,1,I-1)-PVM2(1,2,I-1))
      IF(DABS(C+(PVM1(2,3,I)-PVM2(2,3,I-1))/2.) .LT. ABS(C)) GO TO 1500
      C=C+(PVM1(2,3,I)-PVM2(2,3,I-1))/2.
      G=G+PVM1(3,3,I)
      F=F+0.5*(PVM1(1,3,I)-PVM2(1,3,I-1))
 1500 CONTINUE
      D=POD*(TH-CIN-DIN/2.)
```

```
      IF (DIN .EQ. 0.0) D=D-POD*(0.04*TH)
      IF (G .GT.0.0) GO TO 1450
      D=POD*(TH-DOUT-DOUT/2.)
      IF (DOUT .EQ. 0.0) D=D-POD*0.04*TH
 1450 CONTINUE
      C=ABS(C)
      IF(ABS(G/C/D) .LE. 3.0) GO TO 1600
      G1=G
      C1=C
      F1=F
      I=I-1
      GO TO 1400
 1600 CONTINUE
      L=4
      J=I
      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)*FLM
 2400 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DESGN
C
C   CALCULATES THE REQUIRED STEEL AREAS AT DESIGN LOCATIONS 1, 3 AND 5
C   BASED ON THE FOLLOWING: FLEXURE
C                           MINIMUM STEEL FOR FLEXURE
C                           LIMITING CONCRETE COMPRESSION
C                           0.01** CRACK AT SERVICE LOADS
C   IT CHECKS FOR RADIAL TENSION AT DESIGN LOCATIONS 1 AND 5 AND
C   IF REQUIRED CALCULATES THE CIRCUMFERENTIAL EXTENT AND MAXIMUM
C   SPACING OF STIRRUPS.
C   IT ALSO CHECKS THE DIAGONAL TENSION SHEAR AT DESIGN LOCATIONS 2
C   AND 4 AND IF REQUIRED, CALCULATES THE CIRCUMFERENTIAL EXTENT AND
C   MAXIMUM SPACING OF STIRRUPS.
C   ALL THE CALCULATED STEEL AREAS ARE PASSED TO THE PRINT SUBROUTINE
C   THROUGH THE COMMOM BLOCK STLAR
C   A PRINTOUT OF THE ULTIMATE FORCES AT EACH DESIGN SECTION, ALONG
C   WITH FLEXURE AND SHEAR DESIGN TABLES ARE AVAILABLE WITH AN IDBUG
C   VALUE GREATER THAN 0.
C
      COMMON/RSCALE/RADI1,RADI2,H,U,V,TH,BETA,HH,GAMAS,GAMAC,GAMAF,DF,   10060
     1FY,FCP,COUT,CIN,FLMV,FLN,DIN,DOUT,RTYPE,NLAY,SPIN,SPOUT,PO,FCR,EST   10070
     1,ECON,RADM1,RADM2,EQUID,BETAS,POD,FPP,FVP
      COMMON/ISCALE/IDBUG,IPATH                                         10040
      COMMON/PVM/PVM1(3,3,36),PVM2(3,3,36)                              10050
      COMMON/DESIGN/DM(5),DP(5),DV(5),VLOC(5)
      COMMON/STLAR/AREA1(5),SRATIO(5),SGOV(5),AREADT(5),STEXT(5),       10100
     1STSPA(5)                                                          10110
      DOUBLE PRECISION PVM1, PVM2
C
C   AREA1(1) = INSIDE STEEL AT INVERT                                   10130
C   AREA1(2) = M/VD=3 NEAR INVERT                                       10140
C      TAKE MAX OF (1) AND (2) FOR INSIDE STEEL AT INVERT.              10150
C   AREA1(3) = OUTSIDE STEEL                                            10160
C   AREA1(4) = M/VD=3 NEAR CROWN                                        10170
C   AREA1(5) = INSIDE STEEL AT CROWN                                    10180
C      TAKE MAX OF (4) AND (5) FOR INSIDE STEEL AT CROWN                10181
C
      COMMON/COORD/X(37),Y(37),A(37),R                                  10200
      REAL J,M0,N0,M1,N1,M1PSI,N1PSI,NLAY,MRAD,NRAD                     10210
      DIMENSION AREAF(5),AREAC(5),RDT(5),CRIND(5)
      DIMENSION RLOC(9),GOVERN(27),RAD(2),DAG(2)                        10220
C
      DATA RAD/4HRADI,4HAL  /,DAG/4HDIAG,4HONAL/,RLOC/4HINVE,4HRT  ,    10230
     12H  ,4HSPRI,4HNGLI,2HNE,4HCROW,4HN   ,2H  /                       10240
      DATA GOVERN/4HDOES,4HNOTG,4HOVRN,4HFLEX,4HURE ,4H    ,4HMIN ,     10250
     14HSTEE,4HL   ,4H0.01,4H CRA,4HCK  ,4HRADT,4HEN+F,4HLEX ,4HRADT,   10260
     14HEN+C,4HR   ,4HDT N,4HOSTI,4HRUPS,4HDT+S,4HTIRR,4HUPS ,4HMAXC,   10270
     14HONCC,4HOMPR/                                                    10271
```

```
C
      DO 901 I=1,5
      AREA1(I)=0.0
      AREAF(I)=0.0
      AREAC(I)=0.0
      RDT(I)=0.0
      SRATIO(I)=0.0
      AREADT(I)=0.0
      STEXT(I)=0.0
      SGOV(I)=0.0
901   CONTINUE
      W = ATAN(U/V)
      B1=0.85-0.05*(FCP-4.)
      IF (B1 .GT. 0.85) B1=0.85
      IF( B1 .LT. 0.65) B1=0.65
      FCPPSI=FCP*1000.
      FYPSI=FY*1000.
      PI=3.1415926535897
      SPMN=(RADM1+U)*2.
C
C    DESIGN STEEL AT THREE MOMENT SECTIONS
C
      DO 1 L=1,5,2
      CASMN=1.0
      C01=0.
      FLAY=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.)  DH=DIAM/2.
      CIM=CIN
      IF(L .EQ. 3)  CIM=COUT
      D=PO*(TH-CIM-DH)
      Q=10.2*FCPPSI
C
C    REQUIRED STEEL FOR FLEXURE
C
      IF(Q*(Q*D*D-N1PSI*(2.*D-TH)-2.*M1PSI) .LT. 0.) GO TO 1111
      AREA1(L)=(Q*D-N1PSI-SQRT(Q*(Q*D*D-N1PSI*(2.*D-TH)-2.*M1PSI))
     1)/FYPSI
      AREAF(L)=AREA1(L)
      SRATIO(L)=AREA1(L)/(12.*D)
      SGOV(L)=1.
C
```

```
      C                             MINIMUM STEEL AREA FOR FLEXURE                  10630
      C
            IF (L .EQ. 3) CASMN=0.75                                                10650
            IF(AREA1(L) .GT. CASMN*SPMN**2./65000.)  GO TO 2
            AREA1(L)=CASMN*SPMN**2./65000.
            AREAF(L)=AREA1(L)
            SRATIO(L) = AREA1(L)/(12.*D)                                            10671
            SGOV(L)=2.                                                              10680
      C
      C   CHECK CONCRETE COMPRESSION                                                10700
      C
      2     AREAMF=5.5E4*12.*B1*FCPPSI*D/                                           10720
           1(FYPSI*(87000.+FYPSI))-0.75*N1PSI/FYPSI                                 10730
            IF(AREA1(L) .LT. AREAMF)  GO TO 3                                       10740
      1111  WRITE(6,10)L,DM(L),DP(L),AREA1(L),AREAMF                                10750
      10    FORMAT(//,1H0,95(1H*),/    ,5X,29HDESIGN NOT POSSIBLE AT POINT ,I1,
           17H DUE TO,/,5X,34HEXCESSIVE CONCRETE COMPRESSION M1=,F7.2,              10770
           112H IN.KIPS/FT.,5X,3HN1=,F7.2,9H KIPS/FT. ,///,5X,20HREQUIRED STEE      10780
           1L AREA=,                                                                10780
           1F6.3,11H SQ.IN./FT.,15X,19HMAXIMUM STEEL AREA=,F6.3,11H SQ.IN./FT.      10790
           1,/,                                                                     10790
           195(1H*))                                                                10791
            AREA1(L)=1.0E26
            AREAF(L)=AREA1(L)
            RDT(L)=1.0E26
            SRATIO(L)=1.0E26
            SGOV(L) =8.0                                                            10801
            GO TO 1                                                                 10810
      C
      C   CHECK RADIAL TENSION AT CROWN AND INVERT                                  10830
      C   DESIGN RADIAL TENSION STIRRUPS IF REQUIRED                                10840
      C
      3     IF(L .EQ. 3)  GO TO 990                                                 10860
            RADTEN=(M1PSI-0.45*N1PSI*D)/12./D/(RADI2+CIM)/1.2/SQRT(FCPPSI)*FRP
            RDT(L)=RADTEN
            IF(RADTEN .LE. 1.)  GO TO 990                                           10880
            SGOV(L)=4.                                                              10890
            K=L/2.+0.75                                                             10900
            WRITE(6,859) RLOC(3*K-2),RLOC(3*K-1),RLOC(3*K),RAD(1),RAD(2)            10910
      C
      C  SIZE RADIAL TENSION STIRRUPS
      C
            AREADT(L)= 1.1*(M1PSI-0.45*N1PSI*D)/(D*(RADI2+CIM))                     10920
      C
      C  EXTENT OF RADIAL TENSION STIRRUPS
      C
            K=2                                                                     10930
            IF(L .EQ. 5)K=36                                                        10931
```

```
 872   CONTINUE
       MRAD=(PVM1(3,1,K)+PVM1(3,2,K))*FLMV*1000.
       NRAD = 0.5*(PVM1(1,1,K)+PVM1(1,2,K)-PVM2(1,1,K-1)-PVM2(1,2,K-1))*
      1FLN*1000.
       IF(PVM1(3,3,K) .LT. 0.0) GO TO 871
       MRAD=(MRAD+PVM1(3,3,K)*FLMV*1000.)
       NRAD=NRAD+(0.5*(PVM1(1,3,K)-PVM2(1,3,K-1)))*FLN*1000.
 871   CONTINUE
       RADST= RADI2+CIN
       IF(A(K) .GT. W)RADST=RADI1+CIN
       RADTEN=(MRAD-0.45*NRAD*D)/(12.*D*(RADST)*1.2*SQRT(FCPPSI))
       IF(RADTEN .LT. 1) GO TO 873
       K=K+1
       IF(L .EQ. 5)K=K-2
       GO TO 872
 873   CONTINUE
       IF(L .EQ. 5) K=38-K
       STSPA(L) = 0.7*D
       IF(A(K) .LT. W) GO TO 874
       STEXT(L) =(RADM2*W+RADM1*(A(K)-W))*2.
       GO TO 990
 874   CONTINUE
       STEXT(L)=2.*RADM2*A(K)
C
C                           STEEL AREA BASED ON 0.01 INCH CRACK
C
 990   CONTINUE
       SIM=SPIN
       IF(L .EQ. 3)  SIM=SPOUT
       ITMP = IFIX(RTYPE)
       GO TO (1000,2000,3000),ITMP
 1000  C0=1.0
       B2=(0.5*CIM**2*SIM/NLAY)**(1./3.)
       GO TO 140
 2000  C0=1.5
       B2=1.0
       FLAY=CIM**2.*SIM/NLAY
       GO TO 140
 3000  C0=1.9
       B2=(0.5*CIM**2*SIM/NLAY)**(1./3.)
 140   M0=M1PSI/FLMV
       N0=N1PSI/FLN
       D=D/PD
       E=M0/N0+D-TH/2.
       IF((E/D) .LT. 1.15)  GO TO 1
 619   J=0.74+0.1*E/D
       IF(J .GT. 0.90)  J=0.90
       P=1./(1.-J*D/E)
```

```
 620   CONTINUE
       Q1=(M0+N0*(D-TH/2.))*B2/(30000.*J*F*P0*D*FCR)
       R1=CC*B2*12.*TH**2.*SQRT(FCPPSI)/(30000.*FCR*D*P0)
       AREA01=Q1-R1
       IF(CC1 .EQ. 1.)  GO TO 625
       IF(FLAY .LT. 3.) GO TO 650
       CC1=1.
       CC=1.9
       B2=(7.5*FLAY)**(1./3.)
       AREC12=AREA01
       GO TO 620
 625   IF(AREC12 .GT. AREA01)  AREA01=AREC12
 650   CONTINUE
       CRACK=AREA01/AREA1(L)
       CRIND(L)=CRACK
       AREAC(L)=AREA01
C
C                            SERVICE LOAD CRACK CONTROL INDEX LIMIT
C
       IF(CRACK .LE.1.)  GO TO 1
       IF(SGOV(L) .EQ. 4.)  GO TO 666
       SGOV(L)=3.
       GO TO 667
 666   CONTINUE
       SGOV(L)=5.
 667   CONTINUE
C
C   STEEL AREA IS DETERMINED BY CRACK CONTROL
C
       AREA1(L)=AREA01
       SRATIO(L)=AREA1(L)/(12.*D*P0)
 1     CONTINUE
C
C                            EVALUATE DIAGONAL TENSION SHEAR
C
       DO 810 K=2,4,2
       STIND=0.0
       AREVRT=0.0
       AREVDT=0.0
       M1=ABS(DM(K))
       N1=DP(K)
       VU=ABS(DV(K))
       IF(K .EQ. 4) GO TO 1051
       SRAT=SRATIO(1)*P0/P00
       IF(SGOV(1) .LT. 8.) GO TO 1052
       SGOV(K) = 8.0
       AREA1(K)=1.0E26
       SRATIO(K)=1.0E26
```

```
      GO TO 810                                                         11796
 1051 SRAT=SRATIO(5)*PD/POD
      IF(SGOV(5) .LT. 8.0)GO TO 1052                                    11798
      SGOV(K) = 8.0                                                     11799
      AREA1(K)=1.0E26
      SRATIO(K)=1.0E26
1052  CONTINUE                                                          11801
      IF (SRAT .GT. 0.02) SRAT=0.02                                     11820
      M1PSI=M1*1000.                                                    11830
      N1PSI=N1*1000.                                                    11840
      VUPSI=VU*1000.                                                    11850
      DH=0.04*TH                                                        11860
      IF (DIN .GT. 0.0) DH=DIN/2.                                       11870
      D=TH-CIN-DH
      FD=0.8+1.6/D                                                      11890
      IF(FD .GT. 1.25)  FD=1.25                                         11900
      FN=0.5-(N1/6./VU)+SQRT(0.25+(N1/6./VU)**2.)                       11910
      IF(FN .LT. 0.75) FN=0.75                                          11911
      R=RADM1                                                           11920
      IF(VLOC(K) .LT. W)  R=RADM2                                       11930
      IF(VLOC(K) .GT. PI-W) R=RADM2                                     11940
      RADST=R+CIN+TH/2.                                                 11950
      IF ( FCPPSI .GT. 7000. ) FCPPSI=7000.                             11960
      FC=1.0+D/2./R                                                     11970
      VC=(1.1+63.0*SRAT)*SQRT(FCPPSI)*POD*12.0*D*FD*FVP/(FC*FN)
      RDTIN=VUPSI/VC
      IF( RDTIN .LE. 1.) GO TO 8
      AREA1(K)=0.1587*FC*FN*VUPSI/(FD*FVP*SQRT(FCPPSI))-0.20952*POD*D
      SGOV(K)=6.                                                        12040
      SRATIO(K)=AREA1(K)/(12.*D*POD)
      IF(SRATIO(K) .LT. 0.02)  GO TO 9050                               12060
      SGOV(K)=7.0                                                       12061
      AREA1(K)=1.0E26
      SRATIO(K)=1.0E26
9050  CONTINUE                                                          12063
      IF(K .EQ. 4)GO TO 9                                               12070
      WRITE(6,850)RLOC(1),RLOC(2),RLOC(3),DAG(1),DAG(2)                 12071
      GO TO 6                                                           12072
9     WRITE(6,850)RLOC(7),RLOC(8),RLOC(9),DAG(1),DAG(2)                 12073
6     STIND=2.                                                          12080
8     CONTINUE                                                          12120
C
C                       STIRRUP DESIGN                                  12140
C
      IF(STIND .EQ. 0.0)  GO TO 830                                     12160
C
CSTIRRUP DESIGN FOR RADIAL TENSION                                      12180
C
```

```
      AREVRT=1.1*(M1PSI-0.45*N1PSI*D*POD)/(POD*D*RADST)
C
CSTIRRUP DESIGN FOR DIAGONAL TENSION
C
      IF ( VC .GT. 2*SQRT(FCPPSI)*12.*POD*D) VC=2.*SQRT(FCPPSI)
     1*12.*POD*D
      AREVDT=1.1/(POD*D)*(VUPSI*FC-POD*VC)+AREVRT
880   CONTINUE
      AREAUT(K)=AREVDT
      N=VLOC(K)/0.087266+0.5
5000  CONTINUE
      V1=0.5*(PVM1(2,1,N)+PVM1(2,2,N)-PVM2(2,1,N-1)-PVM2(2,2,N-1))*FLMV
      M1=(PVM1(3,1,N)+PVM1(3,2,N))*FLMV
      N1=0.5*(PVM1(1,1,N)+PVM1(1,2,N)-PVM2(1,1,N-1)-PVM2(1,2,N-1))*FLN
      IF(DABS(V1+(0.5*(PVM1(2,3,N)-PVM2(2,3,N-1)))*FLMV) .LT. ABS(V1))
     1 GO TO 4000
      V1=V1+0.5*(PVM1(2,3,N)-PVM2(2,3,N-1))*FLMV
      M1=M1+PVM1(3,3,N)*FLMV
      N1=N1+0.5*(PVM1(1,3,N)-PVM2(1,3,N-1))*FLM
4000  CONTINUE
      DH=DOUT
      CIM=COUT
      IF (M1 .LT. 0.0) GO TO 6600
      CIM=CIN
      DH=DIN
6600  CONTINUE
      V1=ABS(V1)
      M1PSI=ABS(M1*1000.)
      N1PSI=N1*1000.
      V1PSI=V1*1000.
      IF(DH .EQ. 0.0)DH=0.08*TH
      D=TH-CIM-DH/2.
      FD=0.80+1.6/D
      IF (FD .GT. 1.25 ) FD=1.25
      FN=0.5-(N1/V1/6.)+SQRT(0.25+(N1/V1/6.)**2)
      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)*PD/POD
      IF(L .EQ. 4)SRAT=SRATIO(5)*PD/POD
      IF(M1 .GT. 0.0) GO TO 6601
      FC=1.0-D/(2.*R)
      SRAT=SRATIO(3)*PD/POD
6601  CONTINUE
      VC=(1.1+63.0*SRAT)*SQRT(FCPPSI)*POD*D*12.*FD*FVP/(FC*FN)
     1*4./(M1PSI/(V1PSI*POD*D)+1)
```

```
      IF ( VC .GT. 4.5*SQRT(FCPPSI)*POD*D*12./FN) VC=4.5*SQRT(FCPPSI)
     1*POD*D*12./FN
      IF (VC .GE. VIPSI) GO TO 6000
      N=N+1
      IF(K .EQ.4)  N=N-2.
      GO TO 5000
 6000 CONTINUE
      IF(K .EQ. 4)  GO TO 7000
      STEXT(K)=RADM2*A(N)*2.0
      IF(A(N) .GT. W)  STEXT(K)=(RADM2*W+(A(N)-W)*RADM1)*2.
      STSPA(K)=0.75*POD*D
      GO TO 810
 7000 CONTINUE
      STEXT(K)=(PI-A(N))*RADM2*2.
      IF(A(N) .LT. (PI-W))  STEXT(K)=(W*RADM2+(PI-A(N)-W)*RADM1)*2.
      STSPA(K)=0.75*POD*D
      GO TO 810
 830  AREADT(K)=0.0
 810  CONTINUE
      IF(IDBUG .LT. 1)  GO TO 950
      WRITE(6,849)
      WRITE(6,851)
      DO 848 L=1,5
      KF = (SGOV(L)+1.) * 3.
      JF = KF - 2
      VLCTM = VLOC(L)*180./PI
      WRITE(6,852)VLCTM,DM(L),DP(L),DV(L)
 848  CONTINUE
  849 FORMAT(1H1,/////,16X,24HTABLE OF ULTIMATE FORCES,/,1X,57(1H-))
 850  FORMAT(//,T30,50(1H*),/,T30,1H*,48X,1H*,/,T30,1H*,18X,
     17HWARNING,23X,1H*,/,T30,1H*,9X,21HSTIRRUPS REQUIRED AT ,2A4,A2,8X,
     11H*,
     1/,T30,1H*,9X,10HTO RESIST ,2A4,8H TENSION,13X,1H*,/,T30,50(1H*))
  851 FORMAT(//,1X,7H DESIGN,/,1X,8HLOCATION,10X,6HMOMENT,9X,6HTHRUST,
     19X,5HSHEAR,/,1X,57(1H-),/,1X,8HDEG FROM,7X,12HIN.KIPS/FOOT,5X,
     29HKIPS/FOOT,5X,9HKIPS/FOOT,/,2X,6HINVERT)
  852 FORMAT(/,2X,F6.2,6X,F12.3,4X,F10.3,4X,F10.3)
      WRITE(6,710)
 710  FORMAT(1H1,/////,49X,'FLEXURE DESIGN TABLE',/,1X,117(1H-),//,
     15X,'DESIGN',/,4X,'LOCATION',21X,'DESIGN VALUES',36X,'GOVERNING DES
     2IGN',/,4X,8(1H-),3X,45(1H-),4X,50(1H-),//,4X,'DEG FROM',10X,'REINF
     3ORCING',9X,'CRACK',3X,'RADIAL TENSION',15X,'STEEL',3X,'STIRRUP',
     43X,'STIRRUP',5X,'GOVERNING',/,5X,'INVERT',5X,'FLEXURE',3X,'CRACK C
     5ONTROL',3X,'INDEX',7X,'INDEX',11X,'AREA',5X,'RATIO',3X,'FACTOR',
     64X,'EXTENT',7X,'MODE',/,15X,'SQ.IN./FT',4X,'SQ.IN./FT',31X,'SQ.IN.
     7/FT',22X,'IN.')
      DO 701 L=1,5,2
      KF=(SGOV(L)+1.)*3.
```

```
      JF=KF-2
      VLCTM=VLOC(L)*180./PI
      IF(AREAC(L) .GE. 0) GO TO 719
      AREAC(L)=0
      CRIMD(L)=0.0
 718  CONTINUE
 719  WRITE(6,720) VLCTM,AREAF(L),AREAC(L),CRIND(L),RDT(L),AREA1(L),
     1SRATIO(L),AREADT(L),STEXT(L),(GOVERN(LF),LF=JF,KF)
  720 FORMAT(/,5X,F6.2,5X,F7.3,6X,F7.3,5X,F5.3,9X,F6.3,10X,F7.3,2X,F6.4,
     11X,F8.1,2X,F8.1,3X,3A4)
  701 CONTINUE
      WRITE(6,711)
  711 FORMAT(/////////,29X,'SHEAR DESIGN TABLE',/,1X,76(1H-),/,
     15X,'DESIGN',7X,'REQUIRED',7X,'STEEL',5X,'STIRRUP',5X,'STIRRUP',
     25X,'GOVERNING',/,4X,'LOCATION',5X,'REINFORCING',5X,'RATIO',6X,
     3'FACTOR',6X,'EXTENT',7X,'MODE',/,4X,'DEG FROM',6X,'SQ.IN./FT',30X,
     4'IN.',/,5X,'INVERT')
      DO 702 L=2,4,2
      KF=(SGOV(L)+1.)*3.
      JF=KF-2
      VLCTM=VLOC(L)*180./PI
      WRITE(6,721)VLCTM,AREA1(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,F8.1,4X,3A4)
  702 CONTINUE
 950  CONTINUE                                                         13020
      END                                                              13030
```

```
      SUBROUTINE PRINT                                                  13070
C
C   ORGANIZES AND PRINTS OUT A PIPE DESIGN SUMMARY SHEET FROM DATA
C   ACCUMULATED IN THE COMMON BLOCKS STLAR(CALCULATED STEEL AREAS FROM
C   SUBROUTINE DESIGN) AND RSCALE(RDATA ARRAY GENERATED IN SUBROUTINES
C   READ AND INIT)
C   THE PRINTOUT INCLUDES THE FOLLOWING:
C     INSTALLATION DATA
C     MATERIAL PROPERTIES
C     LOADING DATA
C     PIPE DATA
C     FLUID DATA
C     REINFORCING DATA
C   THE OUTPUT IS AVAILABLE WITH ALL IDBUG VALUES.
C
      COMMON/RSCALE/RADI1,RADI2,H,U,V,TH,BETA,HH,GAMAS,GAMAC,GAMAF,DF,  13080
     1FY,FCP,COUT,CIN,FLMV,FLN,DIN,DOUT,RTYPE,NLAY,SPIN,SPOUT,PS,FCR    13090
     1,EST,ECON,RADM1,RADM2,EQUID,BETAS,POD
      COMMON/STLAR/AREA1(5),SRATIO(5),SGOV(5),AREADT(5),STEXT(5)        13110
     1,STSPA(5)                                                         13120
      INTEGER RTYPE,P                                                   13130
C
C   SET UP DESIGN TABLES
C
      WRITE(6,99)                                                       13140
 99   FORMAT(1H1)
      IF (RADI1 .EQ. RADI2) GO TO 10                                    13160
      SPAN=2.0*(U+RADI1)
      RISE=2.0*(RADI2-V)
      WRITE(6,1000)SPAN,RISE
 1000 FORMAT(1H0,F5.1,12HINCH SPAN X ,F5.1,45HINCH RISE REINFORCED ELLIP
     1TICAL CONCRETE PIPE,/,71(1H*))
      GO TO 20                                                          13210
10    R1TMP = RADI1*2.
      WRITE(6,2000)R1TMP
 2000 FORMAT(1H0,F5.1,47HINCH DIAMETER REINFORCED CONCRETE CIRCULAR PIPE
     1,/,71(1H*))
20    CONTINUE                                                          13260
      WRITE(6,6000)                                                     13380
 6000 FORMAT(1H0,/,34H I N S T A L L A T I O N  D A T A ,/,1X,71(1H-))
      BTMP = BETA*180./3.1415926536
      BTMPS= BETAS*180.0/3.1415926536
      WRITE(6,7000)H,GAMAS,HH,BTMP,BTMPS
 7000 FORMAT(5X,31HHEIGHT OF FILL ABOVE CROWN, FT,29X,F6.2,/,5X,16HUNIT
     1WEIGHT, PCF,44X,F6.2,/,5X,
     138HSOIL-STRUCTURE INTERACTION COEFFICIENT ,22X,F6.2 ,
     1/,5X,22HBEDDING ANGLE, DEGREES ,38X,F6.2 ,
     2/,5X,20HLOAD ANGLE, DEGREES ,40X,F6.2)
```

```
      WRITE(6,3000)
 3000 FORMAT(1H0,/,38H M A T E R I A L   P R O P E R T I E S ,/,1X
     1,71(1H-))
      FYTMP = FY*1000.
      FCPTM = FCP*1000.
      WRITE(6,4000)FYTMP,RTYPE,NLAY,FCPTM
 4000  FORMAT(5X,43HSTEEL - MINIMUM SPECIFIED YIELD STRESS, PSI ,
     117X,F6.0,/,13X,16HREINFORCING TYPE ,36X,F6.0,
     1/,13X,28HNO. OF LAYERS OF REINFORCING ,24X,F6.0,
     1/,5X,45HCONCRETE - SPECIFIED COMPRESSIVE STRESS, PSI  ,
     115X,F6.0)
      WRITE(6,9000)
 9000 FORMAT(1H0,/,24H L O A D I N G   D A T A ,/,1X,71(1H-))
      WRITE(6,1001) FLMV,FLN,PC,PCD,FCR
 1001  FORMAT(5X,30HLOAD FACTOR - MOMENT AND SHEAR,30X,F6.2,/
     1,5X,20HLOAD FACTOR - THRUST ,40X,F6.2,/,5X,
     133HSTRENGTH REDUCTION FACTOR-FLEXURE,27X,F6.2,/,
     15X,42HSTRENGTH REDUCTION FACTOR-DIAGONAL TENSION,18X,F6.2,/,5X,
     128HLIMITING CRACK WIDTH FACTOR ,32X,F6.2)
      WRITE(6,2001)
 2001 FORMAT(1H0,/,18H P I P E   D A T A ,/,1X,71(1H-))
      IF (RADI1 .NE. RADI2)  WRITE(6,3002) RADI1,RADI2
      WRITE(6,3001) TH,CIN,COUT
 3002  FORMAT(5X,13HRADIUS 1, IN.,47X,F6.2,/,5X,13HRADIUS 2, IN.,
     147X,F6.2)
 3001  FORMAT(5X,19HWALL THICKNESS, IN. ,41X,F6.2,/,
     15X,38HINSIDE CONCRETE COVER OVER STEEL, IN. ,22X,F6.2,
     1/,5X,38HOUTSIDE CONCRETE COVER OVER STEEL, IN. ,22X,F6.2)
      WRITE(6,4001) GAMAF,DF
 4001 FORMAT(1H0,/,20H F L U I D   D A T A ,/,1X,71(1H-),/,
     15X,19HFLUID DENSITY, PCF. ,41X,F6.2,/,5X,
     134HDEPTH OF FLUID,INCHES ABOVE INVERT ,26X,F6.2)
      WRITE(6,5001)
 5001 FORMAT(1H0,/,44H R E I N F O R C I N G   S T E E L   D A T A
     1/,1X,71(1H-))
      ASINV=AREA1(1)
      ASSPR=AREA1(3)
      ASCRN=AREA1(5)
      STEXTM = AMAX1(STEXT(1)+0.5,STEXT(2)+0.5 )
      AREDTX = AMAX1(AREADT(1),AREADT(2))
      STSPAM = STSPA(2)
      IF (STSPA(1) .NE. 0.)STSPAM=AMIN1(STSPA(1),STSPA(2))
      IF (SGOV(1) .LT. 4. )GO TO 101
      WRITE(6,6001) ASINV,ASSPR,ASCRN
 6001  FORMAT(5X,38HINVERT- INSIDE REINFORCING, SQ.IN./FT. ,22X,
     1F6.3,/,5X,43HSPRINGLINE- OUTSIDE REINFORCING, SQ.IN./FT.,17X,
     1F6.3,/,5X,37HCROWN- INSIDE REINFORCING, SQ.IN./FT.,23X,F6.3)
      IF ( SGOV(1) .EQ. 8.) GO TO 103
```

```
      WRITE(6,7001) STEXTM,AREDTX,STSPAM
 7001 FORMAT(/,5X,22HSTIRRUPS REQUIRED OVER ,F6.0,2X,                   13830
     116HINCHES AT INVERT, /,5X,21HSTIRRUP DESIGN FACTOR
     132H; AV=SDF*SPACING/(STIRRUP YIELD)  ,8X,F6.1,/,
     15X,31HMAXIMUM STIRRUP SPACING, INCHES,29X,F6.1)                   13850
      GO TO 103                                                         13860
  101 IF (SGOV(2) .LT. 7. ) GO TO 102                                   13870
      WRITE(6,6001) ASINV,ASSPR,ASCRN                                   13880
      WRITE(6,7001) STEXTM,AREDTX,STSPAM
      GO TO 103                                                         13900
  102 IF (SGOV(2) .NE. 6.) GO TO 108                                    13920
      WRITE(6,6001)ASINV,ASSPR,ASCRN                                    13930
      WRITE(6,7001) STEXTM,AREDTX,STSPAM
      ASINV=AREA1(2)                                                    13950
  103 CREXTM = AMAX1(STEXT(4)+0.5,STEXT(5)+0.5  )
      CRASTM = AMAX1(AREADT(4),AREADT(5))
      CRSTSP = STSPA(4)
      IF (STSPA(5) .NE. 0.)CRSTSP=AMIN1(STSPA(4),STSPA(5))
      IF (SGOV(5) .LT. 4.) GO TO 104                                    14010
      IF ( SGOV(5) .EQ. 8.) GO TO 110
      WRITE(6,8001) CREXTM,CRASTM,CRSTSP
 8001 FORMAT(/,5X,22HSTIRRUPS REQUIRED OVER ,F6.0,2X,                   14030
     115HINCHES AT CROWN ,/,5X,21HSTIRRUP DESIGN FACTOR
     132H; AV=SDF*SPACING/(STIRRUP YIELD)  ,8X,F6.1,/,
     15X,31HMAXIMUM STIRRUP SPACING, INCHES,29X,F6.1)                   14050
      GO TO 110                                                         14060
  104 IF (SGOV(4) .LT. 7.) GO TO 105                                    14080
      WRITE(6,8001) CREXTM,CRASTM,CRSTSP
      GO TO 110                                                         14100
  105 IF (SGOV(4) .NE. 6. ) GO TO 106                                   14120
      WRITE(6,8001) CREXTM,CRASTM,CRSTSP
      ASCRN=AREA1(4)                                                    14140
      IF(SGOV(1) .GE. 4.0)GO TO 109                                     14141
      IF(SGOV(2) .NE. 6.0)GO TO 109                                     14142
      WRITE(6,9001)                                                     14143
      WRITE(6,6001) ASINV,ASSPR,ASCRN                                   14144
      GO TO 110                                                         14145
  109 WRITE(6,9002)                                                     14146
 9002 FORMAT(/,45H0ALTERNATE REINFORCING WITHOUT CROWN STIRRUPS,/)
      WRITE(6,6001)ASINV,ASSPR,ASCRN                                    14148
      IF(SGOV(2) .EQ. 8.0 ) GO TO 110
      WRITE(6,7001) STEXTM,AREDTX,STSPAM
      GO TO 110                                                         14150
  106 IF (SGOV(1) .GE. 4.) GO TO 110                                    14170
      IF (SGOV(2) .NE. 6.) GO TO 110                                    14180
  107 WRITE(6,9001)                                                     14190
 9001 FORMAT(/,39H0ALTERNATE REINFORCING WITHOUT STIRRUPS ,/)
      WRITE(6,6001) ASINV,ASSPR,ASCRN                                   14210
```



```
      GO TO 110                                                         14220
  108 CONTINUE                                                          14240
      WRITE(6,6001) ASINV,ASSPR,ASCRN                                   14250
  110 CONTINUE                                                          14270
      RETURN                                                            14280
      END                                                               14290
```

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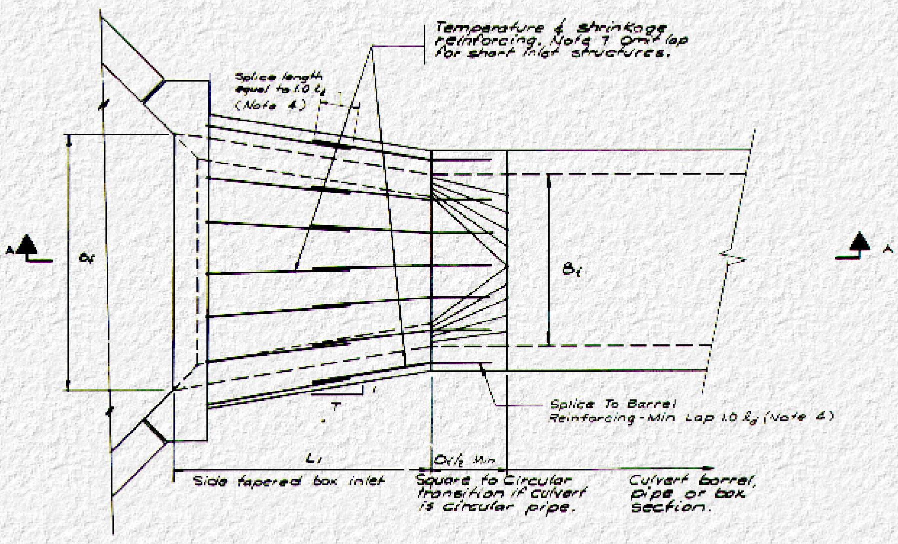
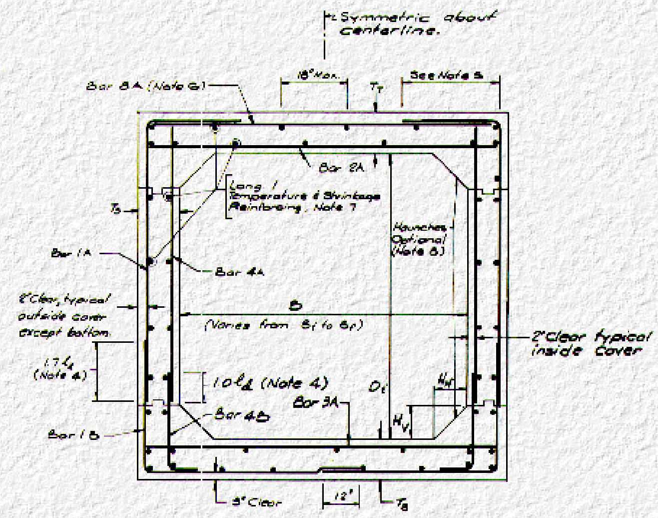
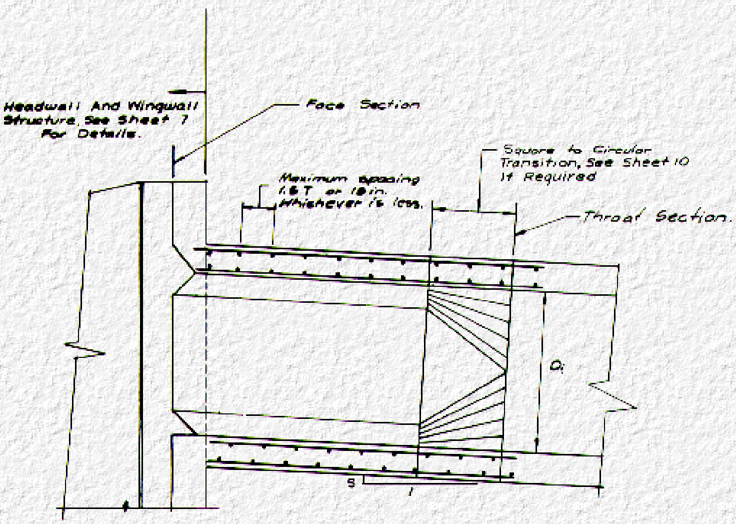
Sheet #1: Typical Reinforcing Layout - Side Tapered Single Cell Box Inlets



TYPICAL PLAN



TYPICAL SECTION - SINGLE CELL BOX INLETS



SECTION A-A

NOTES:

1. Design Specifications: AASHTO Standard Specifications for Highway Bridges, 1977 and 1978, 1979, 1980 and 1981 Interim Specifications.

2. For reinforcing schedule for specific inlet sizes see Appendix E.

3. For reinforcing and cover requirements for precast concrete box sections see ASTM Standard Specification C789 (AASHTO M259).

4. For deformed bar reinforcing, the basic development length (ℓ_d) is determined according to AASHTO Section 1.5.14 for #11 or smaller bars as:

$$\ell_d = \frac{0.04\, A_b\, f_y}{\sqrt{f'_c}} \geq 0.0004\, d_b f_y \geq 12 \text{ in.}$$

   See Section 1.5.14 for required development lengths of other types of reinforcing.

5. If (H_H + T_S - 2 in.) < ℓ_d for bar 8A then bar 1A must be extended beyond the tip of the haunch by:

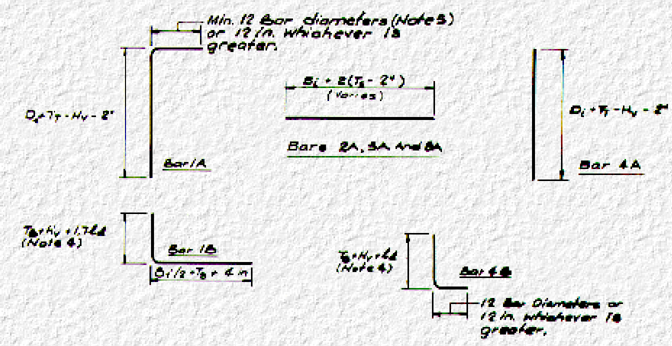
$$\frac{(\ell_d \text{ bar 8A}) - (H_H + T_S - 2 \text{ in.})\ (\text{Area of bar 8A})}{(\ell_d \text{ bar 8A})\ (\text{Area bar 1A})}\ (\ell_d \text{ bar 1A}) \geq 12"$$

6. Alternate reinforcing scheme is to omit bar 8A, make bar 1A the size of 1A or 8A whichever is larger, and extend it across the top of slab, lapping it 12 in.

7. Temperature and shrinkage reinforcing must meet the requirements of the AASHTO Bridge Specification Section 1.5.12. The total reinforcing provided shall be at least 1/8 sq in./ft and be spaced not more than 3 times the wall or slab thickness nor 18 in.

8. If haunches are not used, or if reinforcing sizes larger than #8 are used for bars 1A or 1B, additional reinforcing area, above that needed to meet flexural requirements, may be necessary to meet the development length requirements of the AASHTO Bridge Specification Section 1.5.13.

9. See notes on Sheet 9 for reinforcing and concrete requirements.



CIRCUMFERENTIAL REINFORCING DIMENSIONS

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
WASHINGTON, D.C.

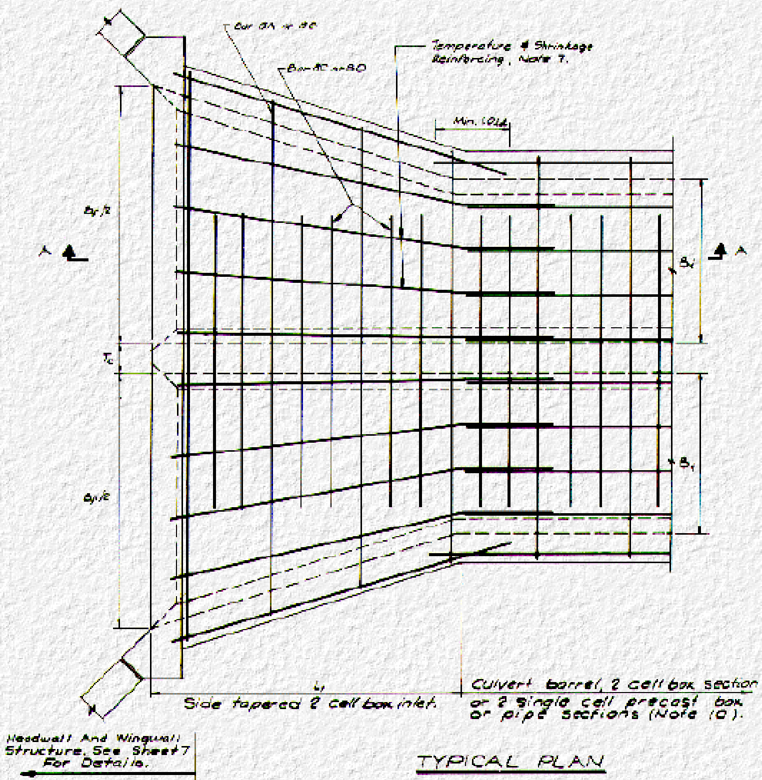
Example Standard Plans For Improved Inlets

TYPICAL REINFORCING LAYOUT
SIDE TAPERED SINGLE CELL BOX INLETS
Do Not Scale

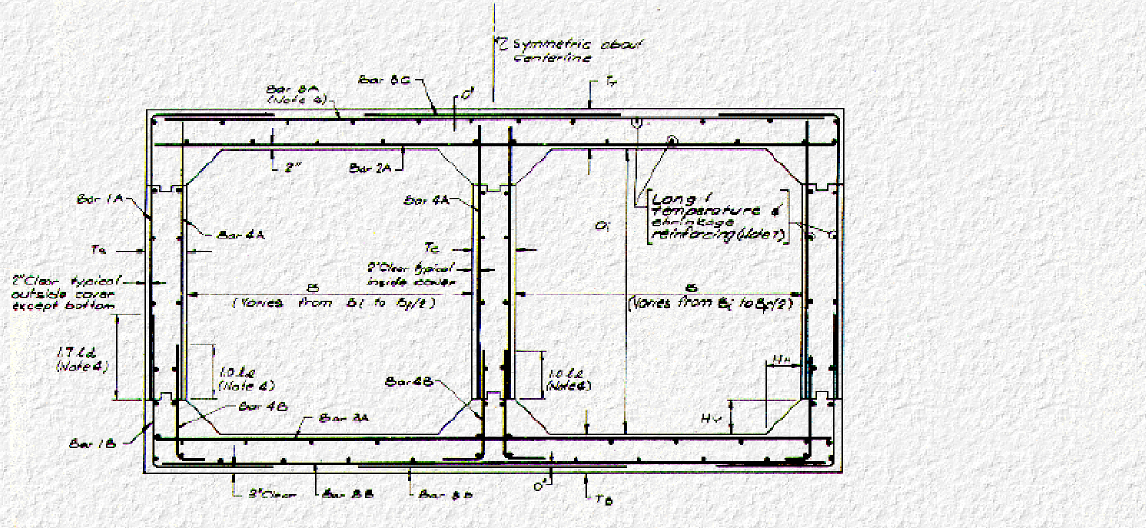
RECOMMENDED — Chief, Design and Inspection Branch
RECOMMENDED — Chief, Bridge Division
RECOMMENDED — Chief, Hydraulics Branch
APPROVED — Director, Office of Engineering
SHEET NO. 1

Go to Appendix G Go to Sheet #2

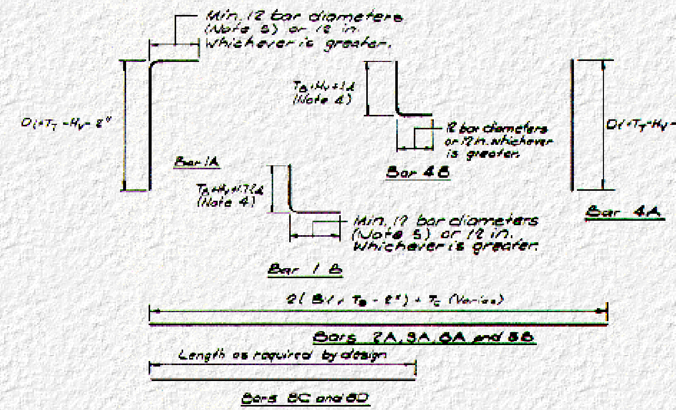
Sheet #2: Typical Reinforcing Layout - Side Tapered Two Cell Box Inlets



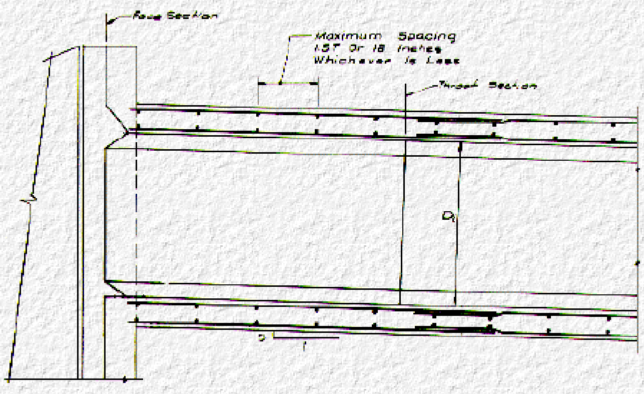
TYPICAL PLAN



TYPICAL SECTION - TWO CELL BOX INLET



CIRCUMFERENTIAL REINFORCING DIMENSIONS



SECTION A-A

NOTES:

1. Design Specifications: AASHTO Standard Specifications for Highway Bridges, 1977 and 1978, 1979, 1980 and 1981 Interim Specifications.

2. For reinforcing schedule for specific inlet sizes see Appendix E.

3. For reinforcing requirements for precast concrete box sections see ASTM Standard Specification C789 (AASHTO M259).

4. For deformed bar reinforcing, basic development length (ℓ_d) is determined according to the AASHTO Bridge Specification Section 1.5.14 for #11 or smaller bars as:

$$\ell_d = \frac{0.04 A_b f_y}{\sqrt{f'_c}} \geq 0.0004 d_b f_y \geq 12 \text{ in.}$$

See Section 1.5.14 for required development lengths of other types of reinforcing.

5. If $(H_H + T_S - 2 \text{ in.}) < \ell_d$ for bar 8A then bar 1A must be extended beyond the tip of the haunch by:

$$\frac{(\ell_d \text{ bar 8A}) - (H_H + T_s - 2 \text{ in.}) \text{ (Area of bar 8A)}}{(\ell_d \text{ bar 8A}) \text{ (Area bar 1A)}} (\ell_d \text{ bar 1A}) \geq 12"$$

6. Alternate reinforcing scheme is to omit bar 8A, make bar 1A the size of 1A or 8A whichever is larger, and extend it across the top of slab, lapping it 12 in. with bar 8C.

7. Temperature and shrinkage reinforcing must meet the requirements of the AASHTO Bridge Specification Section 1.5.12. The total reinforcing provided shall be at least 1/8 sq in./ft and be spaced not more than 3 times the wall or slab thickness nor 18 in.

8. If haunches are not used, or if reinforcing sizes larger than #8 are used for bars 1A or 1B, additional reinforcing area, above that needed to meet flexural requirements, may be necessary to meet the development length requirements of the AASHTO Bridge Specification Section 1.5.13.

9. See notes on Sheet 9 for reinforcing and concrete requirements.

10. If precast box or pipe sections are used to form the two cell culvert, the two cell inlet may still be used as shown provided the engineer modifies the center wall geometry for a box section barrel, or designs a two cell square to circular transition section similar to that shown for one cell transitions in Sheet 10.

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

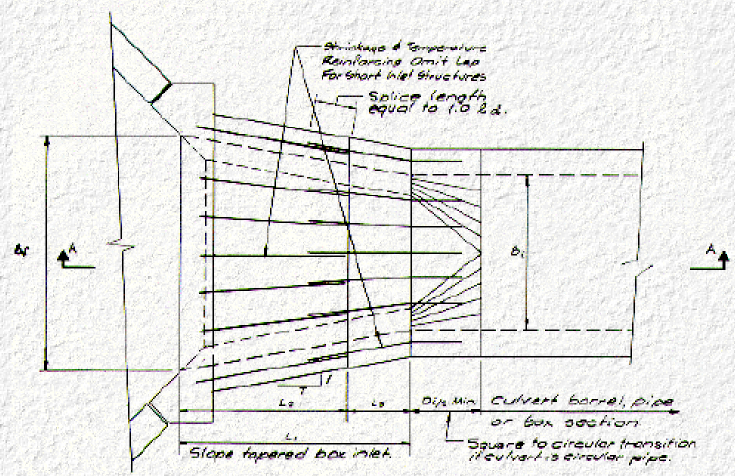
WASHINGTON, D.C.

Example Standard Plans For Improved Inlets

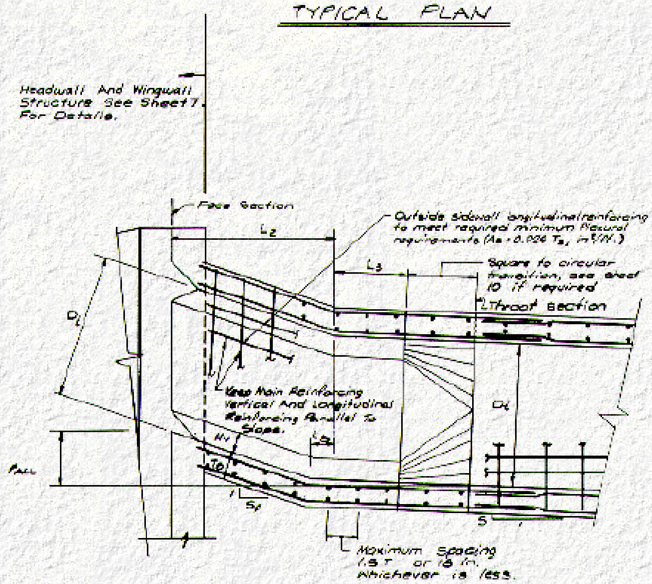
TYPICAL REINFORCING LAYOUT
SIDE TAPERED TWO CELL BOX INLETS
Do Not Scale

RECOMMENDED — Chief Design and Inspection Branch
RECOMMENDED — Chief, Bridge Division
RECOMMENDED — Chief Hydraulics Branch
APPROVED — Director, Office of Engineering
SHEET NO. 2

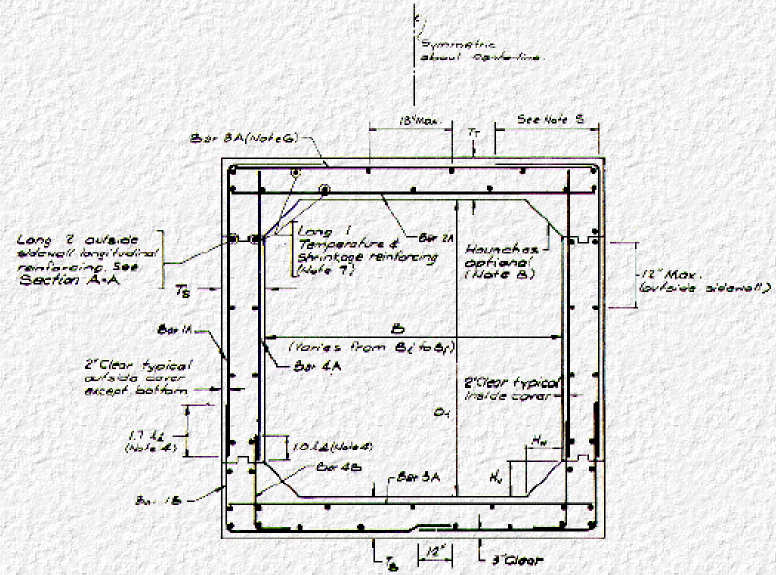
Go to Appendix G Go to Sheet #3



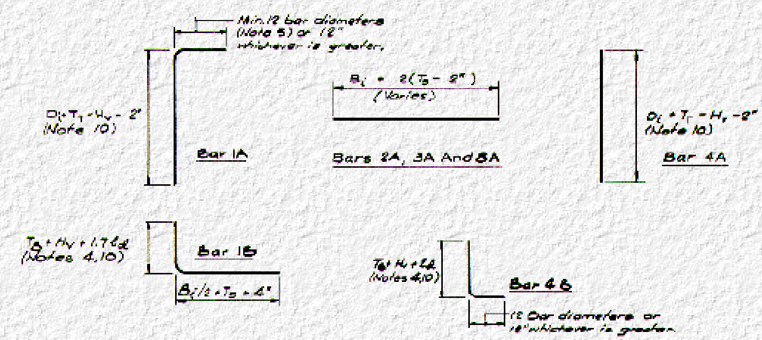
TYPICAL PLAN



SECTION A-A



TYPICAL SECTION - SINGLE CELL BOX INLETS



CIRCUMFERENTIAL REINFORCING DIMENSIONS

NOTES:

1. Design Specifications: AASHTO Standard Specifications for Highway Bridges, 1977 and 1978, 1979, 1980 and 1981 Interim Specifications.

2. For reinforcing schedule for specific inlet sizes see Appendix E.

3. For reinforcing and cover requirements for precast concrete box sections see ASTM Standard Specification C789 (AASHTO M259).

4. For deformed bar reinforcing basic development length (ℓ_d) is determined according to the AASHTO Bridge Specification Section 1.5.14 for #11 or smaller bars as:

$$\ell_d = \frac{0.04\, A_b\, f_y}{\sqrt{f'_c}} \geq 0.0004\, d_b f_y \geq 12 \text{ in.}$$

See Section 1.5.14 for required development lengths of other types of reinforcing.

5. If $(H_H + T_B - 2 \text{ in.}) < \ell_d$ for bar 8A then bar 1A must be extended beyond the tip of the haunch by:

$$\frac{(\ell_d \text{ bar 8A}) - (H_H + T_s - 2 \text{ in.})\ (\text{Area of bar 8A})}{(\ell_d \text{ bar 8A})\ (\text{Area bar 1A})}\ (\ell_d \text{ bar 1A}) \geq 12"$$

6. Alternate reinforcing scheme is to omit bar 8A, make bar 1A the size of 1A or 8A whichever is larger, and extend it across the top of slab, lapping it for 12 in.

7. Temperature and shrinkage reinforcing must meet the requirements of the AASHTO Bridge Specification Section 1.5.12. The total reinforcing provided shall be at least 1/8 sq in./ft and be spaced not more than 3 times the wall or slab thickness nor 18 in.

8. If haunches are not used, or if reinforcing sizes larger than #8 are used for bars 1A or 1B, then additional reinforcing area, above that needed to meet flexural requirements may be necessary to meet the development length requirements of the AASHTO Bridge Specification Section 1.5.13.

9. See notes on Sheet 9 for reinforcing and concrete requirements.

10. The lengths of bars 1A, 1B, 4A, and 4B are for the L_3 segment. These lengths must be multiplied by $\sqrt{1 + (1/S_s)^2}$ for all of the L_2 segment, except the segment L_B where transition lengths occur.

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
WASHINGTON, D.C.

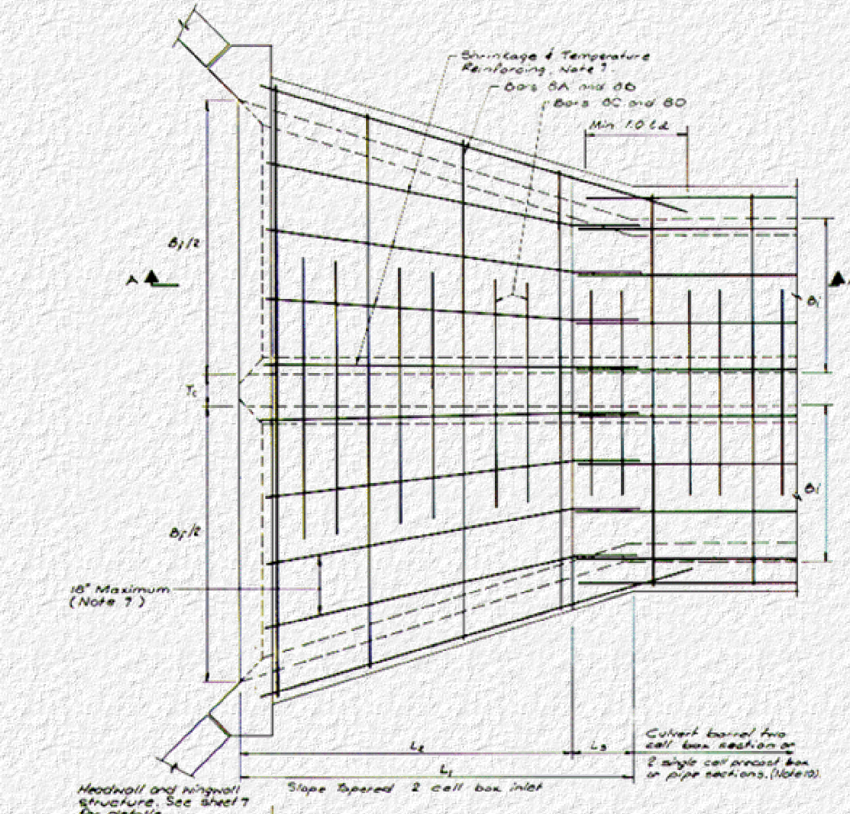
Example Standard Plans For Improved Inlets

TYPICAL REINFORCING LAYOUT
SLOPE TAPERED SINGLE CELL BOX INLETS
Do Not Scale

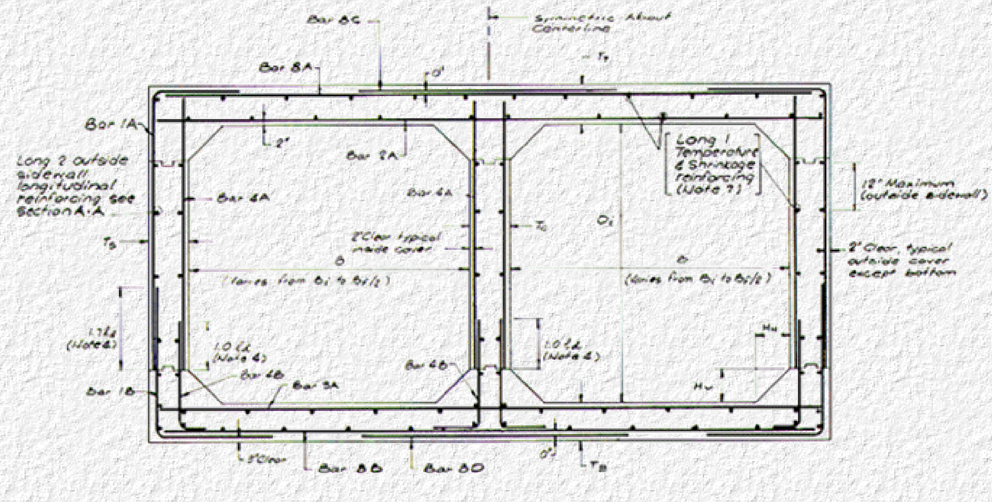
RECOMMENDED John J. Ahlskog, Chief, Design and Inspection Branch	RECOMMENDED [signature], Chief, Bridge Division	SHEET NO. 3
RECOMMENDED [signature] R. Davis, Chief, Hydraulics Branch	APPROVED [signature], Director, Office of Engineering	

Go to [Appendix G](#)   Go to [Sheet #4](#)

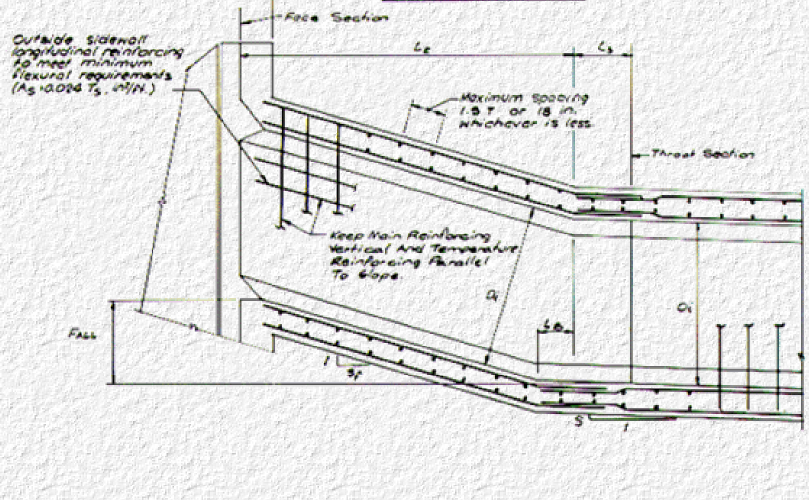
Sheet #4 : Typical Reinforcing Layout - Slope tapered Two Cell Box Inlets



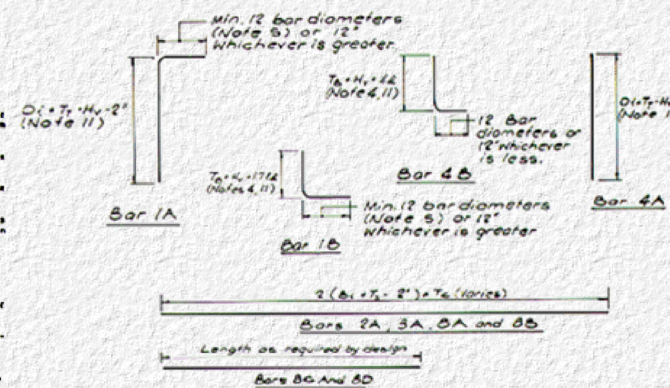
TYPICAL PLAN



TYPICAL SECTION - TWO CELL BOX INLET



SECTION A-A



CIRCUMFERENTIAL REINFORCING DIMENSIONS

NOTES:

1. Design Specifications: AASHTO Standard Specifications for Highway Bridges, 1977 and 1978, 1979, 1980 and 1981 Interim Specifications.
2. For reinforcing schedule for specific inlet sizes see Appendix F.
3. For reinforcing and cover requirements for precast concrete box sections see ASTM Standard Specification C789 (AASHTO M259).
4. For deformed bar reinforcing, basic development length (ℓ_d) is determined according to the AASHTO Bridge Specification Section 1.5.14 for #11 or smaller bars as:

$$\ell_d = \frac{0.04 A_b f_y}{\sqrt{f'_c}} \geq 0.0004 d_b f_y \geq 12 \text{ in.}$$

See Section 1.5.14 for required development lengths of other types of reinforcing.

5. If $(H_H + T_S - 2 \text{ in.}) < \ell_d$ for bar 8A then bar 1A must be extended beyond the tip of the haunch by:

$$\frac{(\ell_d \text{ bar 8A}) - (H_H + T_S - 2 \text{ in.})\text{ (Area of bar 8A)}}{(\ell_d \text{ bar 8A})\text{ (Area bar 1A)}} (\ell_d \text{ bar 1A}) \geq 12"$$

6. Alternate reinforcing scheme is to omit bar 8A, make bar 1A the size of 1A or 8A whichever is larger, and extend it across the top of slab, lapping it for 12 in. with bar 8C.
7. Temperature and shrinkage reinforcing must meet the requirements of the AASHTO Bridge Specification Section 1.5.12. The total reinforcing provided shall be at least 1/8 sq in./ft and be spaced not more than 3 times the wall or slab thickness nor 18 in.
8. If haunches are not used, or if reinforcing sizes larger than #8 are used for bars 1A or 1B, additional reinforcing area, above that needed to meet flexural requirements, may be necessary to meet the development length requirements of the AASHTO Bridge Specification Section 1.5.13.
9. See notes on Sheet 9 for reinforcing and concrete requirements.
10. If precast box or pipe sections are used to form the two cell culvert, the two cell inlet may still be used as shown provided the engineer modifies the center wall geometry for a box section barrel, or designs a two cell square to circular transition section similar to that shown for one cell transitions in Sheet 10.
11. The lengths of bars 1A, 1B, 4A, and 4B are for the L_3 segment. These lengths must be multiplied by $\sqrt{1 + (1/S_f)^2}$ for all of the L_2 segment, except the segment L_B where transition lengths occur.

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FEDERAL HIGHWAY ADMINISTRATION

WASHINGTON, D.C.

Example Standard Plans For Improved Inlets

TYPICAL REINFORCING LAYOUT

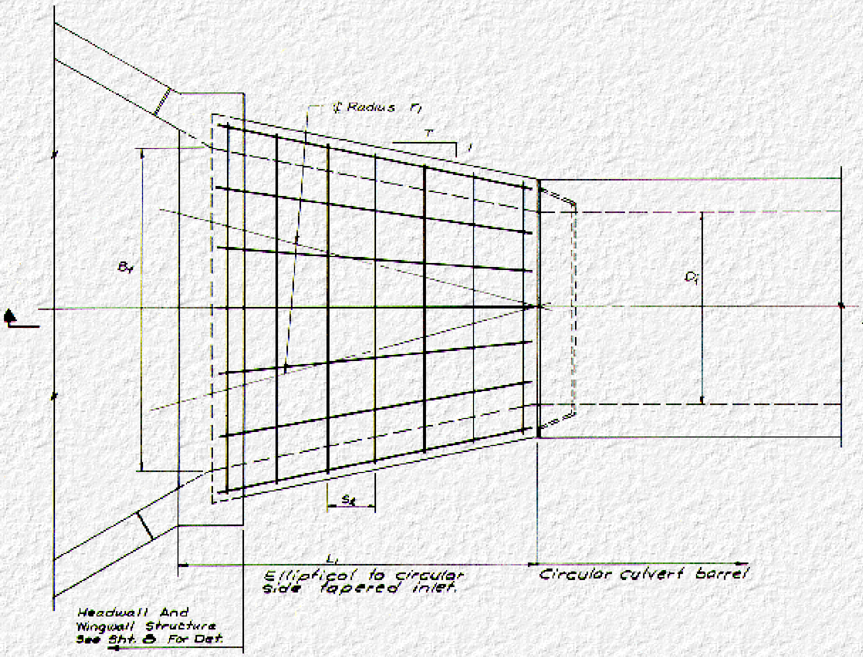
SLOPE TAPERED TWO CELL BOX INLETS

Do Not Scale

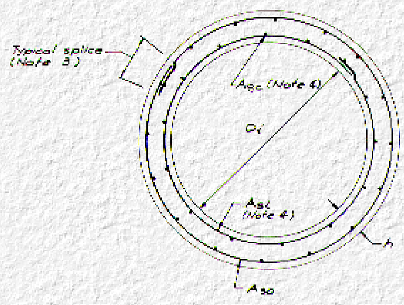
RECOMMENDED [signature] Chief, Design and Inspection Branch	RECOMMENDED [signature] Chief, Bridge Division	SHEET NO. 4
RECOMMENDED [signature] Chief, Hydraulics Branch	APPROVED [signature] Director, Office of Engineering	

Go to Appendix G   Go to Sheet #5

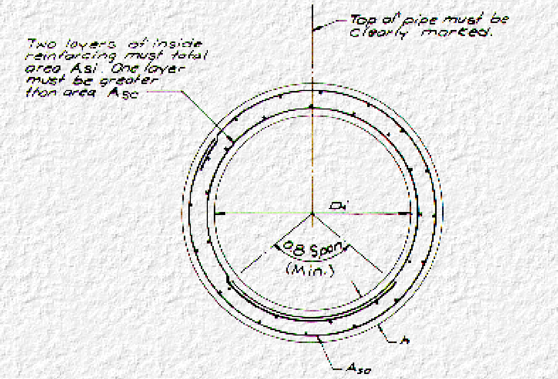
Sheet #5: Typical Reinforcing Layout - Side Tapered Reinforced Concrete Pipe Inlets



TYPICAL PLAN

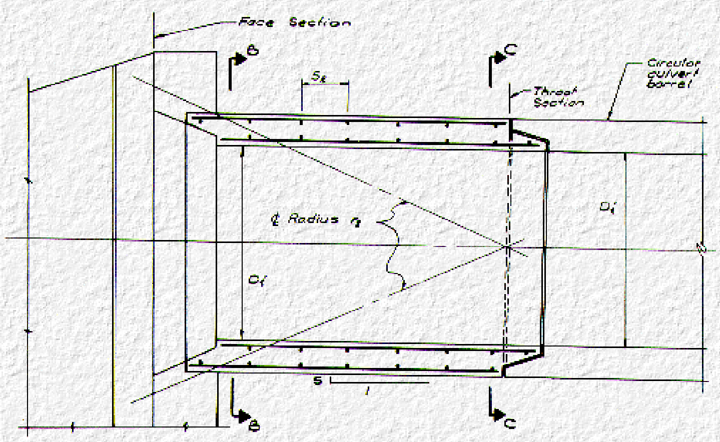


TYPICAL SECTION C-C

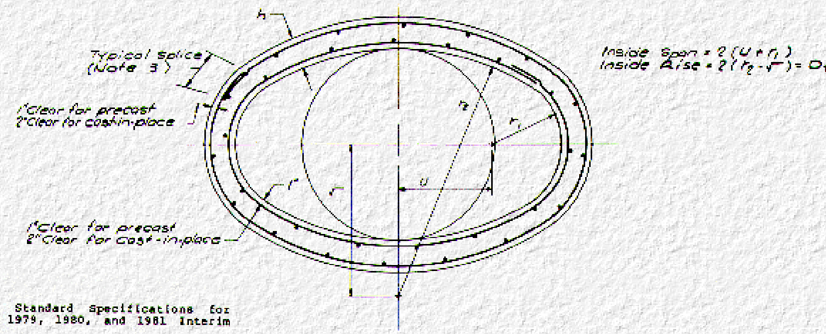


ALTERNATE REINFORCING LAYOUT (NOTE 5)

Applies to both circular and elliptical sections.



SECTION A-A



FACE SECTION B-B

NOTES:

1. Design Specifications: AASHTO Standard Specifications for Highway Bridges, 1977 and 1978, 1979, 1980, and 1981 Interim Specifications.

2. Material properties, dimensional tolerances and longitudinal reinforcing to conform to the requirements of ASTM C76 (AASHTO M170).

3. For splices in welded smooth wire fabric, the length of overlap, measured from the outermost cross wires of each fabric sheet shall not be less than one spacing of cross wire plus 2 in., nor less than $1.5\ell_d$ nor 6 in. ℓ_d is determined according to AASHTO Section 1.5.20B as:

$$\ell_d = \frac{0.27\,A_w}{S_w}\;\frac{f_y}{\sqrt{f'_c}}$$

   See the AASHTO Bridge Specifications for splice requirements of other types of reinforcing.

4. Inside crown reinforcing area A_{sc} will be equal to inside invert reinforcing area A_{si} unless an alternate reinforcing scheme is used.

5. Alternate reinforcing scheme consists of overlapping the inside cage at the invert in order to provide the extra reinforcing normally required at that location. Other alternate reinforcing schemes may be used provided they meet the requirements of the AASHTO Bridge Specifications. Any pipe in which an alternate reinforcing scheme is used must have the top clearly marked to assure proper installation.

U.S. DEPARTMENT OF TRANSPORTATION
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WASHINGTON, D.C.

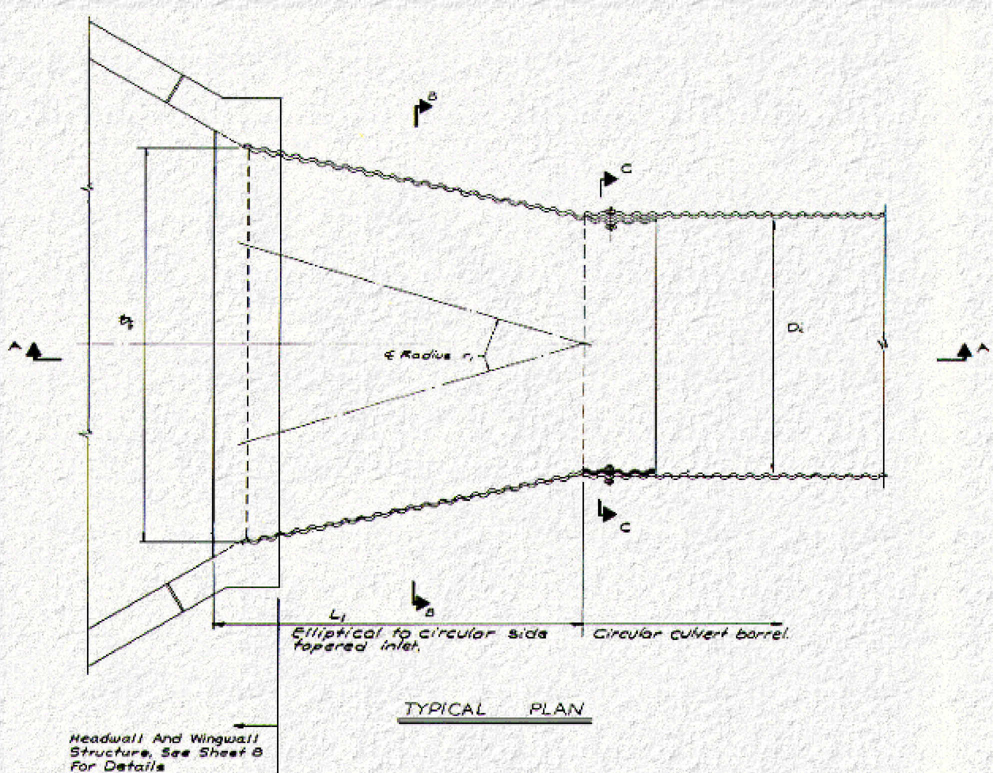
Example Standard Plans For Improved Inlets

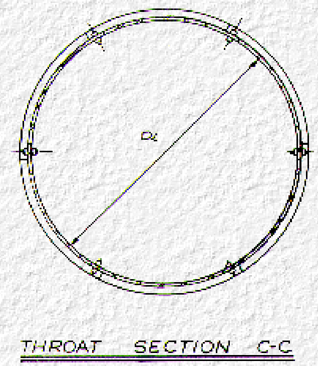
TYPICAL REINFORCING LAYOUT
SIDE TAPERED PIPE INLET
Do Not Scale

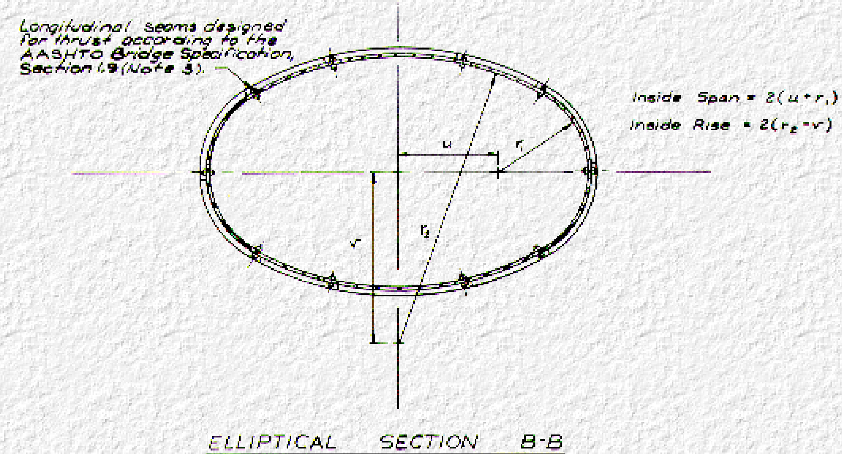
RECOMMENDED ____ Chief Design and Inspection Branch	RECOMMENDED ____ Chief Bridge Division	SHEET NO. 5
RECOMMENDED ____ Chief Hydraulics Branch	APPROVED ____ Director, Office of Engineering	

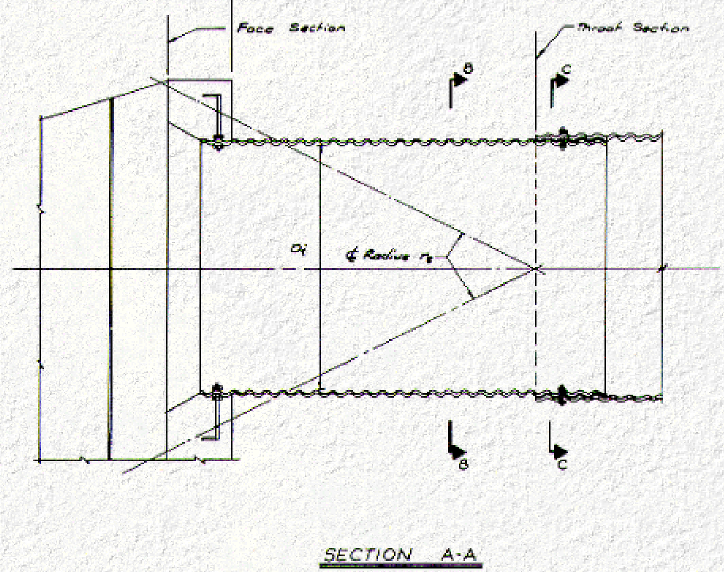
Go to Appendix G   Go to Sheet #6

Sheet #6: Side tapered Corrugated Metal Inlet









NOTES:

1. Design Specifications: AASHTO Standard Specifications for Highway Bridges 1977, and 1978, 1979, 1980, and 1981 Interim Specifications.

2. Corrugated metal inlets are flexible culverts, and their performance is dependent on soil-structure interaction and soil stiffness. See AASHTO 1.9.1(G).

3. Seams may be bolted, as shown, riveted or spot welded provided they meet the strength requirements of the AASHTO Bridge Specification.

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Example Standard Plans For Improved Inlets

SIDE TAPERED CORRUGATED METAL INLET

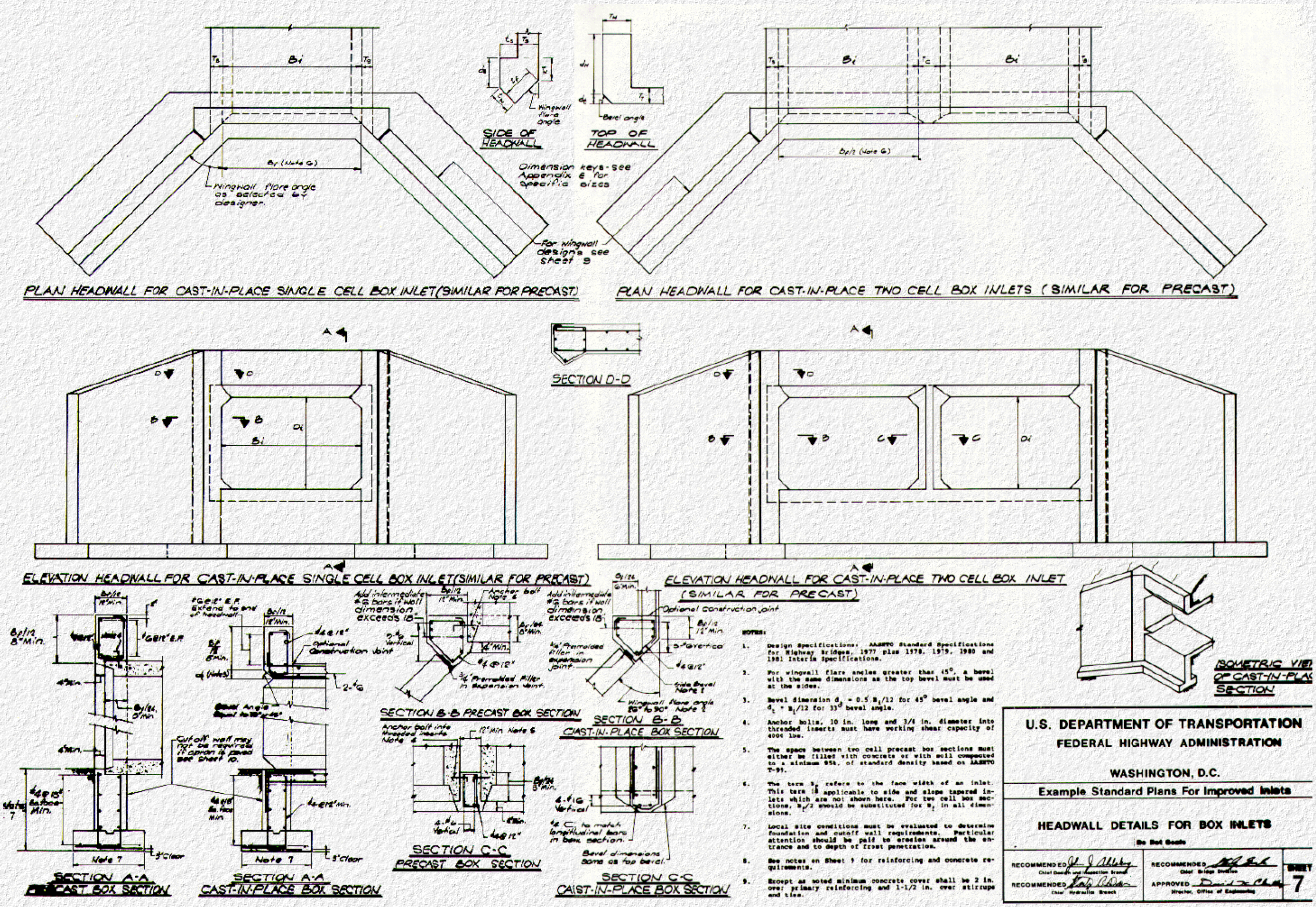
Do Not Scale

RECOMMENDED — Chief Design and Implementation Division
RECOMMENDED — Chief Hydraulics Branch
RECOMMENDED — Chief Bridge Division
APPROVED — Director, Office of Engineering

SHEET NO. 6

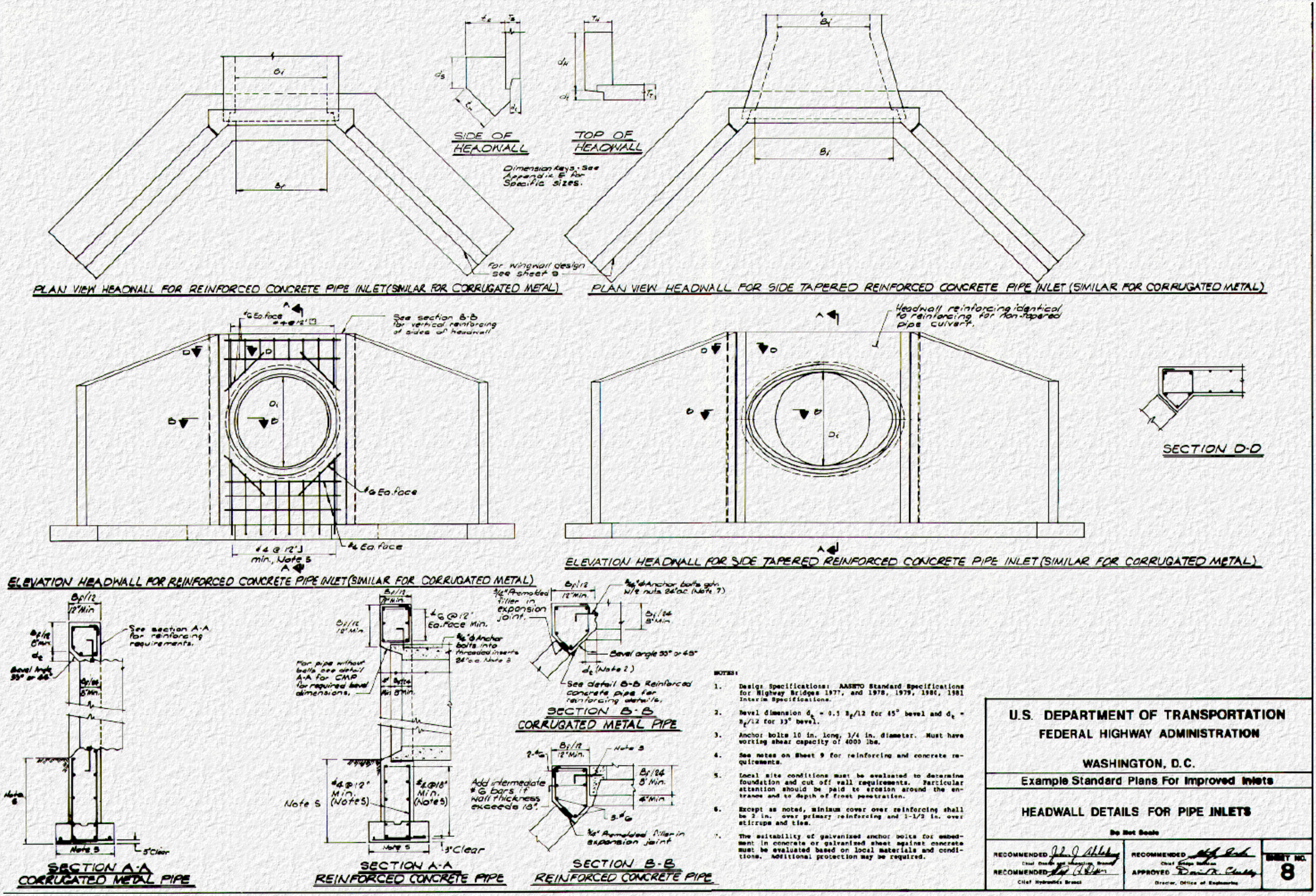
Go to Appendix G Go to Sheet #7

Sheet #7: Headwall Details for Box Inlets



Go to Appendix G   Go to Sheet #8

Sheet #8: Headwall Details for Pipe Inlets

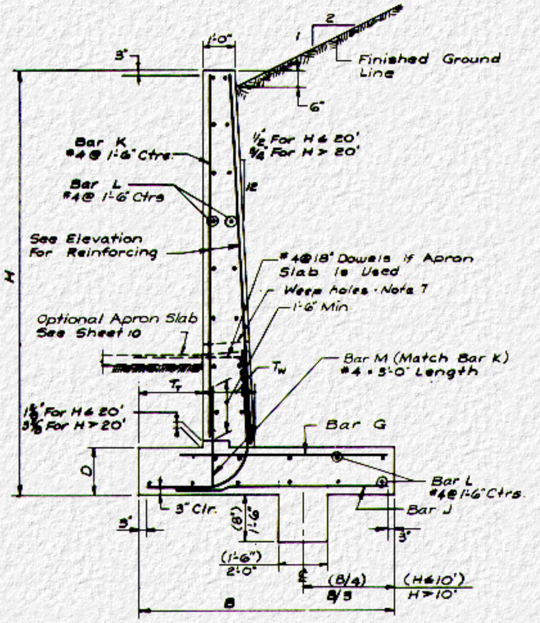


Go to Appendix G Go to Sheet #9

Sheet #9: Cantilever Wingwall Designs

WALL DIMENSIONS					REINFORCING STEEL SCHEDULE																									QUANTITIES Per Lin. Ft. of Wall		MAXIMUM BEARING PRESSURE	H
					Bar A					Bar C					Bar E					Bar F			Bar G			Bar J			Bar K	Concrete	Reinf. Steel		
H Ft	B	T_T	T_W	D	Size	Spacing	a	b	Length	Size	Spacing	a	b	Length	Size	Spacing	a	b	Length	Size	Spacing	Length	Size	Spacing	Length	Size	Spacing	Length	Length	Cu. Yds	** Lbs	Kips/Sq Ft.	
6	4'-0"	0'-9"	1'-2½"	1'-3"	4	1'-6"	5'-7"	1'-7"	6'-10"														4	1'-6"	3'-7"	4	1'-6"	3'-7"	4'-5"	0.416	20.2	1.01	6
7	4-8	0-10	1-3	1-3	4	1-6	6-7	1-9	8-0														4	1-6	4-1	4	1-6	4-1	5-5	0.492	23.0	1.22	7
8	5-4	1-0	1-3½	1-3	4	1-6	7-7	1-11	9-2														4	1-6	4-7	4	1-6	4-7	6-5	0.569	26.4	1.39	8
9	6-0	1-1	1-4	1-3	4	1-6	8-7	2-1	10-4														4	1-6	5-1	4	1-6	5-1	7-5	0.648	29.2	1.60	9
10	6-7	1-3	1-4½	1-3	4	1-1½	9-7	2-3	11-6														4	1-1½	5-6	4	1-1½	5-6	8-5	0.725	33.9	1.76	10
11	7-4	1-5	1-4¾	1-6	4	1-8½	10-7	2-6	12-9	4	1'-8½"	5'-0"	2'-6"	7'-2"									4	0-10¼	6-1	4	1-8½	6-1	9-2	0.905	37.0	1.95	11
12	8-0	1-6	1-5¼	1-6	4	1-3½	11-7	2-7	13-8	5	1-3½	5-6	2-7	7-9									4	0-7¾	6-11	4	1-3½	6-7	10-2	0.993	47.7	2.16	12
13	8-8	1-8	1-5¾	1-6	5	1-6	12-7	2-10	15-1	5	1-6	5-7	2-10	8-1									5	0-9	7-4	4	1-6	7-1	11-2	1.084	55.2	2.52	13
14	9-2	1-9	1-6¼	1-6	6	1-8½	13-7	2-11	16-2	6	1-8½	6-4	2-11	8-11									5	0-10¼	7-9	4	1-8½	7-5	12-2	1.167	61.7	2.58	14
15	9-11	1-11	1-6¾	1-6	6	1-5	14-7	3-2	17-5	6	1-5	6-7	3-2	9-5									6	0-8½	8-7	4	1-5	8-0	13-2	1.266	79.9	2.72	15
16	10-7	2-1	1-7¼	1-6	6	1-9	8-4	3-4	11-4	6	1-9	5-6	3-4	8-6	6	1'-9"	3'-6"	3'-4"	5'-11"	6	1'-9"	14'-4"	6	0-7	9-1	4	1-9	8-9	14-2	1.361	92.0	2.89	16
17	11-3	2-3	1-7¾	1-6	7	1-11¼	9-0	3-7	12-3	7	1-11¼	5-11	3-7	9-2	7	1-11¼	3-10	3-7	6-9	7	1-11¼	15-4	6	0-7¾	9-6	4	1-11¼	9-3	15-2	1.459	104.4	3.04	17
18	11-10	2-4	1-8¼	1-6	7	1-9	9-6	3-8	12-10	7	1-9	6-4	3-8	9-8	7	1-9	3-10	3-8	6-10	7	1-9	16-4	7	0-7	10-5	4	1-9	9-7	16-2	1.555	127.9	3.28	18
19	12-7	2-6	1-8¾	1-9	7	1-6	10-0	3-11	13-7	7	1-6	6-9	3-11	10-4	7	1-6	4-1	3-11	7-4	7	1-6	17-1	7	0-6	10-11	4	1-6	10-2	16-11	1.758	151.7	3.45	19
20	13-3	2-8	1-9¼	1-9	8	1-9	10-8	4-2	14-6	8	1-9	6-11	4-2	10-9	8	1-9	4-6	4-2	8-4	8	1-9	18-1	7	0-7	11-4	4	1-9	10-6	17-11	1.866	160.3	3.58	20
21	13-11	2-10	2-2¼	2-0	8	1-9¾	11-2	4-9	15-7	8	1-9¾	7-3	4-9	11-8	8	1-9¾	4-9	4-9	9-2	8	1-9¾	18-10	7	0-7¼	11-6	4	1-9¾	10-8	18-6	2.227	162.4	3.82	21
22	14-6	3-0	2-3	2-0	8	1-7½	11-10	4-11	16-5	8	1-7½	7-8	4-11	12-3	8	1-7½	4-9	4-11	9-4	8	1-7½	19-10	7	0-6½	11-10	4	1-7½	11-0	19-6	2.352	186.5	4.00	22
23	15-3	3-0	2-3¾	2-0	9	1-9¾	12-5	5-0	17-1	9	1-9¾	8-1	5-0	12-9	9	1-9¾	5-7	5-0	10-3	9	1-9¾	20-10	8	0-7¼	12-10	4	1-9¾	11-9	20-6	2.492	217.0	4.25	23
24	15-11	3-3	2-4¼	2-3	9	1-9	13-3	5-4	18-3	9	1-9	8-8	5-4	13-8	9	1-9	5-10	5-4	10-10	9	1-9	21-7	8	0-7	13-3	4	1-9	12-1	21-3	2.754	233.4	4.40	24
25	16-7	3-3	2-5	2-3	10	1-11¼	14-0	5-5	19-1	10	1-11¼	9-3	5-5	14-4	10	1-11¼	6-10	5-5	11-11	10	1-11¼	22-7	9	0-7¾	14-3	4	1-11¼	12-8	22-3	2.898	278.2	4.67	25
26	17-2	3-6	2-5¾	2-6	10	1-9¾	14-7	5-8	19-11	10	1-9¾	9-8	5-8	15-0	10	1-9¾	7-1	5-8	12-5	10	1-9¾	23-4	9	0-7¼	14-6	4	1-9¾	13-0	23-0	3.175	300.8	4.82	26
27	17-11	3-6	2-6½	2-6	10	1-7½	15-0	5-9	20-5	10	1-7½	9-11	5-9	15-4	10	1-7½	7-1	5-9	12-6	10	1-7½	24-4	9	0-6½	15-3	4	1-7½	13-8	24-0	3.335	344.0	5.08	27
28	18-7	3-9	2-7	2-9	10	1-6	15-6	6-1	21-2	10	1-6	10-2	6-1	15-11	10	1-6	7-4	6-1	13-1	10	1-6	25-1	9	0-6	15-7	4	1-6	14-0	24-9	3.640	379.6	5.21	28
29	19-3	3-9	2-7¾	2-9	11	1-9	16-5	6-2	22-3	11	1-9	11-0	6-2	16-10	11	1-9	8-5	6-2	14-3	11	1-9	26-1	10	0-7	16-8	4	1-9	14-8	25-9	3.805	421.0	5.49	29
30	19-10	4-0	2-8¼	3-0	11	1-6¾	16-11	6-5	23-0	11	1-6¾	11-2	6-5	17-3	11	1-6¾	8-8	6-5	14-9	11	1-6¾	26-10	10	0-6¼	16-11	4	1-6¾	14-11	26-6	4.122	477.0	5.68	30

**



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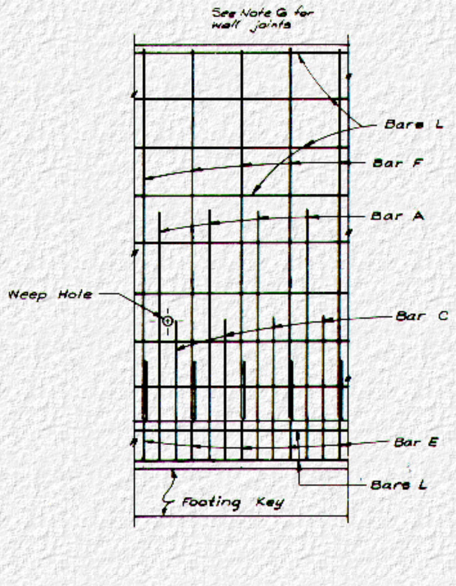


ELEVATION

(Back Face)

NOTES

1. The designs presented here are based on the Federal Highway Administration Publication "Reinforced Concrete Retaining Walls," September 1967. Wing walls may be designed as retaining walls according to current AASHTO working stress or ultimate strength procedures.

2. **DESIGN DATA:** n = 10, f_c = 1200 psi; f_s = 24000 psi; Weight of soil = 120 pcf; Weight of concrete = 150 pcf; Angle of Internal Friction = 33°41'; Earth pressures determined from Rankine's formula.
   For Sliding: The coefficient of friction between masonry and soil is taken as 0.45. A safety factor of 1.5 is provided against sliding.

   For Overturning: A minimum safety factor of 2 is provided against overturning. Resultant of the loads is at or within the middle third of the footing.

3. **CONCRETE:** All concrete shall be Class A(AE) with a minimum 28 day compressive strength f'_c = 3,000 psi. The air entraining agent shall meet with the approval of the engineer. All exposed edges of walls shall be chamfered 3/4 in. except as noted.

4. **REINFORCING STEEL:** Reinforcing steel shall be deformed bars conforming to ASTM A615. Dimensions relating to spacing of reinforcing steel are from center to center of bars. Bending dimensions are from out to out of the bars. Minimum cover for reinforcing bars shall be 2 in. clear unless shown otherwise. Bars A and C are extended 35 bar diameters beyond point of theoretical cut-off.

5. **FOUNDATION PRESSURE:** When the maximum bearing pressures shown in the tables exceed the allowable bearing pressure of the soil at the site, a pile footing may be used, or the width of footing may be modified to reduce the maximum bearing pressures.

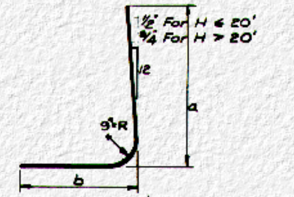
6. **WALL JOINTS:** Expansion joints at a maximum spacing of 90 ft. and contraction joints at a maximum spacing of 30 ft. shall be provided in the walls. If rustication grooves are used, the joints shall be spaced to correspond with rustications.

7. **WEEP HOLES:** Weep holes shall be provided at a spacing not to exceed 15 ft. Suitable underdrains located at the back of the stem and connected to an outlet pipe may be used in lieu of weep holes.

8. **BACKFILL:** The wall shall be backfilled with a well graded, free draining material.

9. **FOUNDATIONS ON ROCK:** Footings placed on non-yielding material may be permitted to have the resultant of the loads fall within the middle half. The designs of these footings are beyond the scope of this project.

10. **ALTERNATE DESIGN:** The apron slab may be cast integrally with the retaining wall and the foundation omitted. This combination of wing walls and apron slab requires a separate analysis and reinforcing layout and is beyond the scope of this project.



BARS A, C & E

Note: The reinforcing schedules shown are only for the corresponding wall dimensions listed. If footing dimensions are varied to obtain a more desirable soil pressure, a corresponding change must be made in the footing design to adjust reinforcing.

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

WASHINGTON, D.C.

Example Standard Plans For Improved Inlets

CANTILEVER WINGWALL DESIGNS

Do Not Scale

RECOMMENDED John J. Ahlskog
Chief Design and Inspection Branch

RECOMMENDED [signature]
Chief Hydraulics Branch

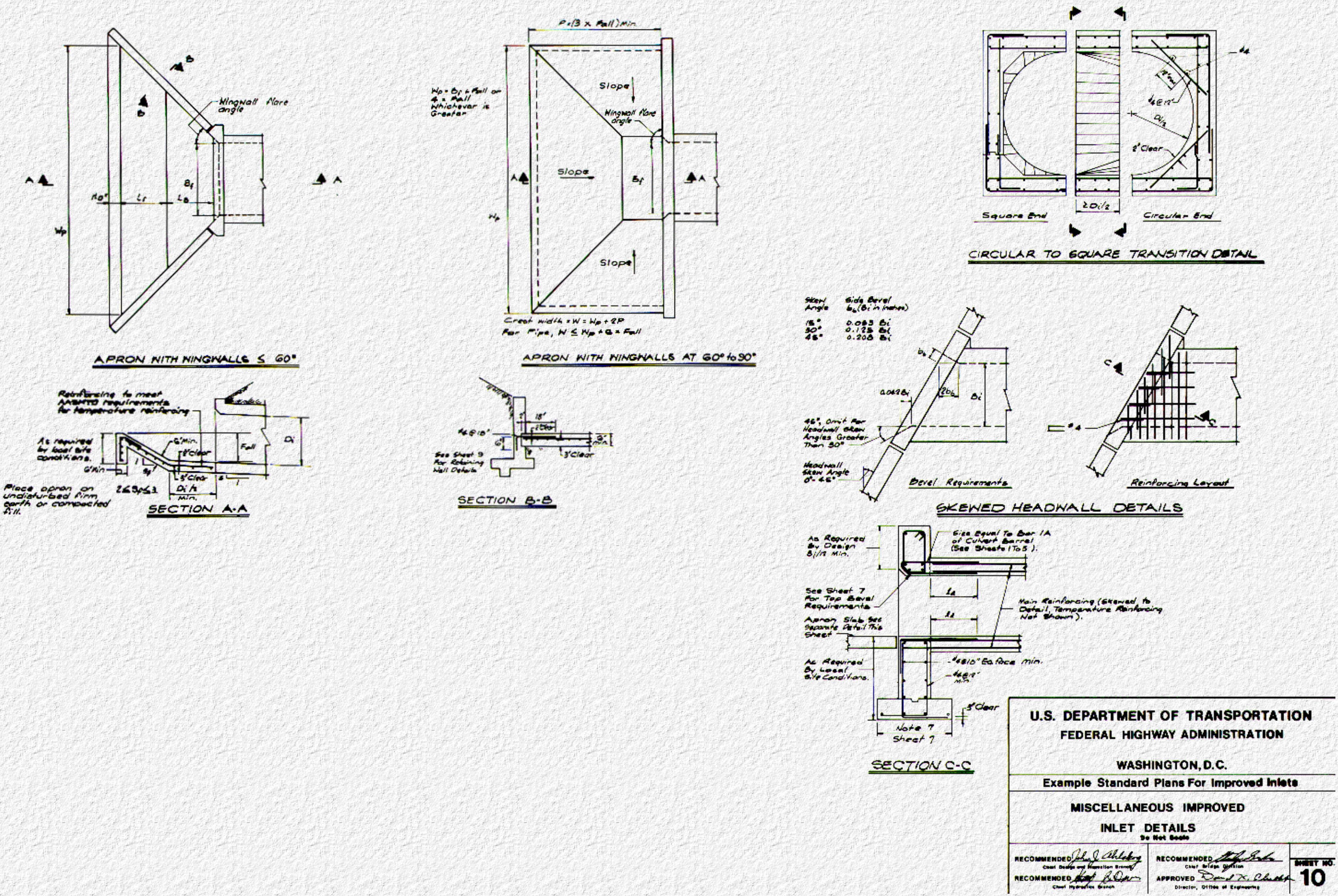
RECOMMENDED [signature]
Chief Bridge Division

APPROVED David K. Chatley
Director, Office of Engineering

SHEET NO. 9

Go to Appendix G Go to Sheet #10

Sheet #10: Miscellaneous Improved Inlet Details



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Go to [Appendix H]

List of Tables for FHWA-IP-83-6-Structural Design Manual for Improved Inlets and Culverts

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List of Equations for FHWA-IP-83-6-Structural Design Manual for Improved Inlets and Culverts

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Structural Design Manual for Improved Inlets and Culverts		June 1983
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7. Author(s)		**8. Performing Organization Report No.**
Timothy J. McGrath and Frank J. Heger		
9. Performing Organization Name and Address		**10. Work Unit No. (TRAIS)**
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		11. Contract or Grant No.
		DOT-FH-11-9692
12. Sponsoring Agency Name and Address		**13. Type of Report and Period Covered**
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		14. Sponsoring Agency Code
15. Supplementary Notes		
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.

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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
$F_1, F_2 \ldots$	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}
$G_1, G_2 \ldots$	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_b moment in bottom slab of box section acting on section of width b, service load conditions, in.-lbs

M_c maximum midspan moment acting on cross section of width b, in.-lbs

M_o moment at corner of box section acting on section of width b, service load conditions, in.-lbs

M_s moment in side wall of box section acting on section of width b, service load conditions, in.-lbs

M_u ultimate moment acting on cross section of width b, in.-lbs

N axial thrust acting on cross section of width b, service load condition (+ when compressive, - when tensile), lbs

N_t, N_s, N_b axial thrust acting on cross section of width b, of top, side or bottom slab, respectively, service load condition (+ when compressive, - when tensile), lbs

N_u ultimate axial thrust acting on cross section of width b, lbs

n number of layers of reinforcement in a cage (1 or 2)

p ratio of area of tension reinforcement to area of concrete section, Eq. 4.25

p_b soil pressure at bottom of pipe or box section that reacts soil, fluid, and dead load, lbs/in./section width b

p_f fluid pressure acting on inside of pipe, lb/in./section width b

p_l soil pressure at invert of pipe section, lb/in./section width b

p_o soil pressure at crown of pipe section, lb/in./section width b

p_s lateral soil pressure on box section, lbs/in./section width b

p_t 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

r_m radius to centerline of pipe wall, in.

r_s radius to inside reinforcement, in.

r_1 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_o slope of natural channel, ft/ft

s circumferential spacing of shear or radial tension stirrup reinforcement, in.

s_ℓ 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_1, 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 $M/V\phi_v d < 3.0$, lbs

V_c general shear strength of cross-section of width b, where $M/V\phi_v d < 3.0$, lbs

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 $M/V\phi_v d = 3.0$, 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.

$\alpha_{max}, \alpha_{min}$ ratio of lateral to vertical soil pressure on box culvert

β AASHTO coefficient used to compute design loads

β_1 angle over which earth load is applied to buried pipe, degrees

β_2 bedding angle over which soil support is provided to pipe to resist applied loads, degrees

γ_c unit weight of concrete, lb/ft^3

γ_f unit weight of internal fluid, lbs/ft^3

γ_s unit weight of soil, lbs/ft^3

θ 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

ϕ_f flexure strength reduction factor for variability in material strengths or manufacturing tolerances

ϕ_v shear strength reduction factor for variability in material strengths or manufacturing tolerances

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