USER'S MANUAL FOR

LFD BOX CULVERT DESIGN AND RATING
(BOX5)

pennsylvania
DEPARTMENT OF TRANSPORTATION

Version 5.9.0.1

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USER'S MANUAL FOR

COMPUTER PROGRAM BOX5

BOX CULVERT DESIGN AND RATING

VERSION 5.9.0.1

Prepared by:

Pennsylvania Department of Transportation
Bureau of Business Solutions and Services
Engineering Software Section

June 2017

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SUMMARY OF JANUARY 1982 REVISIONS

The program has been revised to conform to Article 1.5.29(b) of the AASHTO Interim Specifications Bridges 1982. The following revisions are made.

1. A new input item called M OR S has been added to the input form.

2. Formulas for computations of shear stress carried by concrete have been revised.

3. The Program Documentation has been revised to include the instructions for the new input item and the revised output for the example problems.

SUMMARY OF FEBRUARY 1984 REVISIONS

1. The program has been extensively revised to allow for Load Factor Design. The following changes are made: Either Load Factor Design or Service Load Design can be specified as a method of design.

2. The Input Form is rearranged allowing the user to enter the first three lines for problem identification. Some new input items have also been added.

3. Output from the program has been revised to accommodate Load Factor Design.

SUMMARY OF JUNE 1984 REVISIONS

The program has been revised to allow for precast culvert design. The following changes are made:

1. Either a precast or a cast-in-place culvert can be designed.

2. For precast culverts, either a welded wire fabric or rebars can be specified.

3. Three new input items have been added to the input form.

4. The documentation has been revised for bar covers, effective thicknesses and instructions for new input items.

5. Example Problem 1 has been revised to design a precast culvert.

6. The revised input form and the revised pages for Example Problem 1 have been provided.

SUMMARY OF AUGUST 1986 REVISIONS

The program has been revised to check serviceability criteria for crack control in accordance with AASHTO for load factor design.

SUMMARY OF JUNE 1988 REVISIONS - VERSION 4.9

The program has been revised to check for all three design loads (HS25, IML and P-82) in a single run. The output identifies the governing load at each section. The table for Minimum Design Thicknesses (Table 5.4.1 on page 5-15) has been revised. The program version, documentation date and last update date are printed as header information. The revised program is referred to as Version 4.9.

SUMMARY OF APRIL 1990 REVISIONS - VERSION 5.0

The program has been revised primarily for the computation of live load ratings and the consideration of monolithic haunches. Changes are as follows:

1. The input forms have been revised to include haunch dimensions and wall and slab reinforcement. The special live load input format has been changed to provide the capability for more axle loads.

2. For a design problem, the program computes bar spacings at critical sections based on the reinforcement required. An optimum bar size and spacing is selected at each critical section for the purpose of computing ratings.

3. The live load ratings of an existing box culvert can be obtained if the wall and slab reinforcement is known.

4. The culvert may have monolithic haunches at the junction of walls and slab, except in the bottom slab with a fish channel. Haunches are considered only for providing stiffness in the frame analysis. They are neglected for the calculation of flexural and shear reinforcement.

5. Default values of load factors have been revised per 1989 AASHTO specifications.

6. Output from the program was reformatted to fit on 8½ x 11 inch paper.

7. The revised program is referred to as version 5.0.

SUMMARY OF FEBRUARY 1992 REVISIONS - VERSION 5.2

The program has been revised as follows:

1. An input item has been added for Live Load Surcharge. Previously this was automatically set to 2.0' only when live load was applicable (# LANES > 0 and height of fill less than limitation). The user may now enter 2.0' or 3.0' or leave blank and the program will apply the effect accordingly.

2. Live Load Surcharge has been separated from the rest of the lateral earth pressure so that the Beta factor for live load can be applied to the surcharge. The previous version applied the Beta factor for earth pressure to both the lateral earth pressure and live load surcharge.

3. A new loading condition has been added which doubles the effect of lateral earth pressure in conjunction with vertical earth pressure, structure dead load, live load and live load surcharge. The program already had a provision for full and half lateral earth pressure.

4. A new construction loading condition has been added for design only. This consists of double lateral earth pressure, structure dead load and live load surcharge, but no vertical loads due to fill.

5. An error correction has been made to the shear capacity calculation. The program did not convert ALPHA to radians before taking the SINE when calculating the capacity for shear reinforcement.

6. An error correction has been made to the axle spacings for an ML-80 loading.

7. As a tie breaker when different bar size/spacings have the exact same area of steel per foot, the program will pick the smaller bar. This will give a little more capacity because the effective depth is based on cover plus half the bar diameter.

8. For a precast culvert with bars, the program will print spacings for different bar sizes. The program previously would only allow one diameter throughout a precast culvert, whether it was a bar or wire. The program will still only print one spacing for the given diameter when designing a precast culvert with welded wire fabric.

9. A modification has been added to use the section with the greatest moment when the program cannot compute a required area of steel to determine the critical section for flexural rating in a member.

10. When there is no live load, the program will now print the dead load effects, section capacities and stresses at critical sections.

11. The program will now consider axial force in both design and rating. An input item has been added to indicate whether or not the program should consider axial force.

12. Ratings for the Service Load Method are now based on stresses. A table of allowable stresses has been added for the Service Load Method.

13. Modifications have been made to increase program speed. Some examples now run up to three times faster.

14. An input item has been added for Overlay Thickness and the input item for Unit Weight of Earth has been redefined to also represent the Unit Weight of Overlay. For a culvert at grade (Height of Fill = 0), an Overlay Thickness may be entered and the design or rating will consider this additional dead load.

SUMMARY OF SEPTEMBER 1993 REVISIONS - VERSION 5.3

The program has been revised as follows:

1. For Load Factor Design, shear strength provided by concrete in slabs is now calculated based on AASHTO 8.16.6.2.1 Equation (8-48) or 8.16.6.7.1 Equation (8-59) instead of Equation (8-49).

2. For Load Factor Design, shear strength provided by concrete in walls is now calculated based on AASHTO 8.16.6.2.2 Equation (8-50) instead of Equation (8-51).

3. For Service Load Design, shear stress carried by concrete in slabs is now calculated based on AASHTO 8.15.5.2.1 Equation (8-4) or 8.15.5.7 Equation (8-14) instead of 0.95 $\sqrt{f_c'}$.

4. For Service Load Design, shear stress carried by concrete in walls is now calculated based on AASHTO 8.15.5.2.2 Equation (8-5) instead of 0.95 $\sqrt{f_c'}$.

5. An iteration process has been introduced to rate shear in slabs based on the above referenced equations.

6. An iteration process has been introduced when using Load Factor Design for rating moment in both walls and slabs.

7. The data item M OR S on the Specifications input has been reintroduced for use with the new shear equations referenced above.

8. The output for live load ratings and dead load effects vs. capacities has been updated to print the moment occurring simultaneously with the shear at sections where shear is critical.

9. The design output for each wall and slab section has been updated to include a code next to the THRUST value that indicates the controlling dead load earth pressure condition (Full, Half, Double or Construction).

10. An input item has been added for FILL HEIGHT ADJUSTMENT FACTOR on the Specifications Data. This corresponds with the γ in Design Manual Part 4 Article 6.2.2P.

11. An input item has been added for FILL + 100 on the Culvert Data. This allows the program to consider a fill height greater than 99.9 feet.

12. An error correction has been made to keep the program from abnormally terminating when calculating the required area of reinforcement for Load Factor Design.

13. An error correction has been made to neglect the effect of an axial load when computing the thickness required at a section for Service Load Design.

14. Several output lines have been reformatted to fit on 80 columns for the Service Load Design.

15. Minor error corrections have been made to fix problems which occurred using Service Load Design.

16. An error correction has been made to the calculation of lateral earth pressure for the construction loading condition when the culvert is under a sloping fill.

17. An error correction has been made where in some instances the program was not using the appropriate cover to calculate the eccentricity of the axial force or the gross area of the concrete section.

18. An error correction has been made to the calculation of foundation pressure. The pressure due to the live load was incorrect because the program was applying the live load distribution factor twice.

19. An error correction has been made to the calculation of cracking moment. The program was incorrectly using transformed section properties to calculate y_t and I_g. Reinforcement is now neglected as per AASHTO 8.13.3.

20. The revised program is referred to as version 5.3.

SUMMARY OF MARCH 1994 REVISIONS - VERSION 5.4

The program has been revised as follows:

1. An error correction has been made to the calculation of foundation pressure. The dead load plus live load combination is used to calculate the maximum foundation pressure. The impact effect is excluded from the foundation pressure calculation. The program output for foundation pressure has been enhanced.

2. An input item has been added for PRECAST SEGMENT LENGTH on the Culvert Data. This item is used to limit the value of the distribution width, E, when calculating the live load distribution factor for precast culverts. Refer to AASHTO 3.24.3.2 Case B.

3. The revised program is referred to as version 5.4.

SUMMARY OF MAY 1997 REVISIONS - VERSION 5.5

The program has been revised as follows:

1. Various minor corrections and revisions made during the verification of the LRFD Box Culvert Analysis and Design program and other corrections for program malfunctions reported by the users have been incorporated.

2. A tension in the soil reaction at the bottom slab is allowed when a unit load is placed on the top slab to generate the influence lines. Previously no tension in the soil reaction was allowed and the compression reaction loading on the bottom slab was adjusted such that the sum of the forces acting on the top slab and the bottom slab was zero.

3. When lateral earth pressures are unequal due to a sloping fill or the top slab with a grade, an additional passive pressure is added to the side with the lower earth pressure to make the culvert in equilibrium.

4. The top slab can be simply supported by walls or the culvert may not have a top slab.

5. For a cast-in-place culvert, the program now checks a loading condition where the weight of the top slab and walls is supported by the bottom slab. Previously, only the weight of walls was assumed to be supported by the bottom slab.

6. The program now applies appropriate dead load conditions for a precast culvert. Previously, the program did not differentiate between a cast-in-place and a precast culvert for the structure dead loads.

7. The strength of a section subjected to combined bending and axial force is now calculated by using the line joining the dead load and the dead load plus live load points. Previously, the moment strength was calculated by using the line joining the origin and the dead load plus live load point. This revision will affect the live load rating results.

8. The User's Manual has been revised. The entire manual has been reprinted.

9. The revised program is referred to as version 5.5.

SUMMARY OF AUGUST 1997 REVISIONS - VERSION 5.6

The program has been revised as follows:

1. Various error corrections and revisions have been made to avoid malfunctions reported in version 5.5.

2. The program now uses the same strength curve for both design and rating including the provisions of AASHTO Article 8.16.1.2.2. In version 5.5 the program did not use these provisions for design. This resulted in designs with ratings lower than the design load.

3. The User's Manual has been revised to reflect the above changes and other editorial revisions. The revised pages are marked as Revised 8/97.

4. The revised program is referred to as version 5.6.

SUMMARY OF MAY 1998 REVISIONS - VERSION 5.7

The program has been revised as follows:

1. Various error corrections and revisions have been made to avoid malfunctions reported in version 5.6, particularly for culverts with no top slab.

2. The program now incorporates the correct calculation of P_{bal} (tension) for heavily overreinforced sections. The program now issues a fatal error when heavily overreinforced sections are encountered for a design with known thickness. A warning is issued when rating heavily overreinforced sections.

3. The program has been enhanced to allow up to eight special live loads, and the input forms have been revised accordingly.

4. An error correction has been made for inclusion of pressure on the bottom slab due to the weight of overlay or future wearing surface.

5. An error correction has been made to reverse the sign of wall moments when there is no top slab.

6. Bar covers and thicknesses to be deducted to get effective thickness are not printed for slabs that do not exist when there is no top or bottom slab.

7. A live load rating summary table has been added to the program output. A new input item, OUTPUT, has been added to the Specifications data for allowing the options of printing the standard output, a rating summary table only or the rating summary with input echo.

8. The input item DESIGN has been changed to RUN TYPE, and a new "Z" option has been added. The new "Z" option is used to indicate a rating run for a cast-in-place culvert using a different method to model the self weight (DC1 and DC2) loading condition.

9. The User's Manual has been revised. The entire manual has been reprinted.

10. The revised program is referred to as version 5.7.

SUMMARY OF JULY 2002 REVISIONS - VERSION 5.8

The program has been revised as follows:

1. The program will automatically override and set the LIVE LOAD input value to “9” when the special live load input comes from a separate file.

2. A correction has been made to allow 24 axle special live loads.

3. The output of ratings given in tons has been standardized to print a maximum of 999.9 and a minimum of –99.9 (show single decimal place).

4. The printing of the summary rating operating factor has been limited to a maximum of 99.99.

5. A check has been added for a linearly varying load having a zero resultant to avoid a divide by zero error. Also, the program will not attempt to find the location of a zero resultant.

6. The size of various program arrays has been increased to permit some larger or more complex jobs to run.

7. A tolerance check has been added to fix a problem where some designs were erroneously giving a fatal error message about a severely over-reinforced section.

8. The new PA legal load configuration for the 5 to 7 axle dump truck (designated TK527) has been added to all live load groups which currently include the ML80 loading.

9. The axle weights for the ML-80 and TK527 loadings include the 3% scale tolerance allowed by the vehicle code. When computing the gross vehicle weight of these vehicles for determining the rating in tons, the 3% tolerance is removed. This also applies to special live loads when “Y” is entered for the 3% INCR parameter.

10. The revised program is referred to as version 5.8.

SUMMARY OF MAY 2015 REVISIONS - VERSION 5.9.0.0

Since the release of BOX5 Version 5.8, several error reports and user requested enhancements have been received. This release of BOX5 Version 5.9.0.0 contains the following revisions.

Input Revisions

1. Increased the number of axle loads of special live loads from 24 to 80. (Request 004)

2. Added cross edit check for “Bottom Slab” and “Fish Channel”. If “Bottom Slab” = N and “Fish Channel” is not blank, then change “Fish Channel” to blank to avoid a program crash. (Request 007)

3. If zero or blank is entered for f’c, a default value of 3000 psi for cast-in-place culverts or 4500psi for precast culverts is used. This will preclude an unexpected execution error. (Request 009)

Program Revisions

4. A tolerance check for comparison for very small numbers to avoid unexpected negative values. (Request 010)

5. Standardized code and conversion to a DLL (Dynamic Link Library) Program. (Request 002)

6. Broke all subroutines and functions into separate files from one big main file. Each subroutine or function will be saved as one file with a file extension FOR. (Request 003)

7. Increased the range of the valid license numbers and implemented the use of license keys. (Request 005)

8. Upgraded to Intel Visual Fortran Composer XE 2013 SP1 Update 3 and Microsoft Visual Studio .NET 2012. (Request 006)

9. The program has been enhanced to provide a PDF output file in addition to the text output file. The PDF file makes it easier to print and paginate the program output. (Request 008)

Input Processor

10. The Input Processor (BOX5IP) at the command prompt is no longer supported. It is replaced by the user-friendly Engineering Assistant v2.5.0.0 (EngAsst). Therefore, Chapter 4 of this user manual was completely replaced.

SUMMARY OF JUNE 2017 REVISIONS - VERSION 5.9.0.1

Since the release of BOX5 Version 5.9.0.0, several error reports and user requested enhancements have been received. This release of BOX5 Version 5.9.0.1 contains the following revisions.

Input Revisions

1. Added a new loading code, (LIVE LOAD = 2), to automatically evaluate the EV2, EV3, and SU6TV loadings per the FHWA load rating for FAST Act's emergency vehicles memo dated November 3, 2016 (Request 011).

   EV2: single rear axle emergency vehicle
   Two axles: 24k – 15' – 33.5k
   EV3: tandem rear axle emergency vehicle
   Three axles: 24k – 15' – 31k – 4' – 31k
   SU6TV: heavy-duty tow and recovery vehicle
   11 axles: 5.75k – 10' - 8k – 4' - 8k – 4' – 25.36k – 4' – 25.36k – 4' - 8k – 14' – 8k – 4' - 8k – 4' - 17k – 4' - 17k – 4' - 8k

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1 GENERAL DESCRIPTION

1.1 PROGRAM IDENTIFICATION

Program Title: LFD Box Culvert Design and Rating

Program Name: BOX5

Version: 5.9.0.1

Subsystem: Substructure

Authors: Hasmukh M. Lathia, P. E.
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ABSTRACT:

The Box Culvert Design and Rating program designs and/or rates a single-cell or a twin-cell reinforced concrete box culvert in accordance with the AASHTO Specifications using either the Load Factor Design or Service Load Design method. The top slab of the culvert may be at grade or under fill and the bottom slab may be of constant thickness or variable thickness (fish channel). The culvert can be a frame (no bottom slab). The culvert can have monolithic haunches. The program designs the culvert for the thicknesses and areas of reinforcement required for walls and slabs. The program will compute load ratings for an existing culvert with known reinforcement or for a new design with optimum reinforcement.

1.2 ABBREVIATIONS

This section provides definitions of abbreviations that are commonly used throughout this User's Manual.

AASHTO	-	American Association of State Highway and Transportation Officials.
AASHTO Specifications	-	AASHTO Standard Specifications for Highway Bridges, Fifteenth Edition, 1992. This publication can be ordered from: American Association of State Highway and Transportation Officials 444 North Capitol Street, N.W., Suite 249 Washington, D.C. 20001
AASHTO Manual	-	AASHTO Manual for Condition Evaluation of Bridges, Second Edition, 1994 as revised by the 1995, 1996, 1998 and 2000 Interim Revisions. This publication can be ordered from: American Association of State Highway and Transportation Officials 444 North Capitol Street, N.W., Suite 249 Washington, D.C. 20001
BD Standards	-	Standards for Bridge Design, Prestressed Concrete, Reinforced Concrete and Steel Structures, January 1989 Edition, Pennsylvania Department of Transportation.
DM-4	-	Pennsylvania Department of Transportation Design Manual Part 4, August 1993 Edition. This publication can be ordered from: Pennsylvania Department of Transportation Publication Sales P.O. Box 2028 Harrisburg, PA 17105
PennDOT	-	Pennsylvania Department of Transportation.
BOX5	-	Box Culvert Design and Rating Program

2 PROGRAM DESCRIPTION

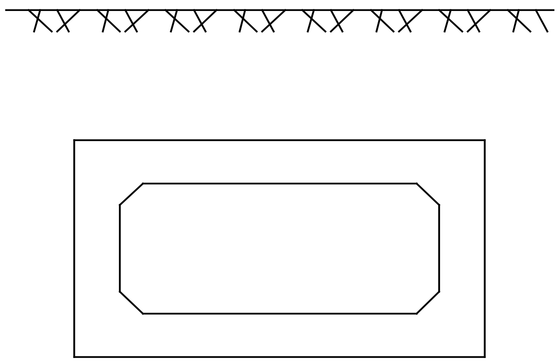
2.1 GENERAL

The Box Culvert Design and Rating program performs the structural analysis and designs and/or rates the members of a single-cell or a twin-cell reinforced concrete box culvert. The design and rating computations are performed in accordance with the AASHTO Specifications, AASHTO Manual, and Pennsylvania Department of Transportation Design Manual Part 4. Either Load Factor Design (LFD) or Service Load Design (SLD) can be specified.

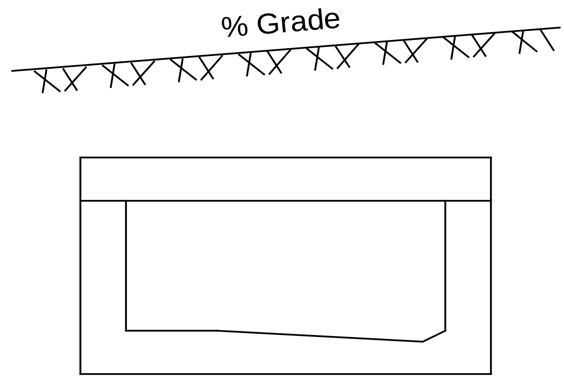
The top slab may be at grade with a constant or variable thickness or under fill. The top slab may be monolithic with walls or simply supported by walls or may not be there at all. The bottom slab may be of constant thickness or with a notch for a fish channel. The fish channel may be a standard one (See Figure 5.3.1 on page 5-8) or one that is described by the user (See Figure 2.1.1 on page 2-2). The inside corners of walls and slabs may have monolithic haunches.

The program computes moments, thrusts and shears at various sections in the slab and wall and then designs the sections for the thickness and areas of reinforcement required for moments and shears. It also calculates the flexural and shear ratings of critical sections. The effect of thrust at a section may be included or neglected.

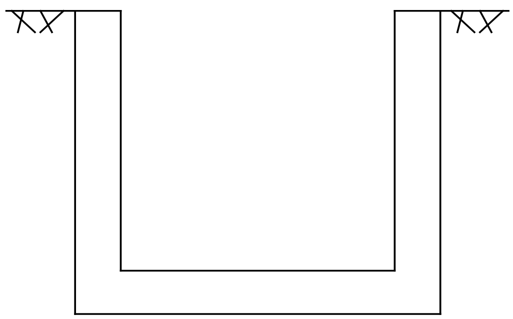
The computed values are printed out in a tabular form.



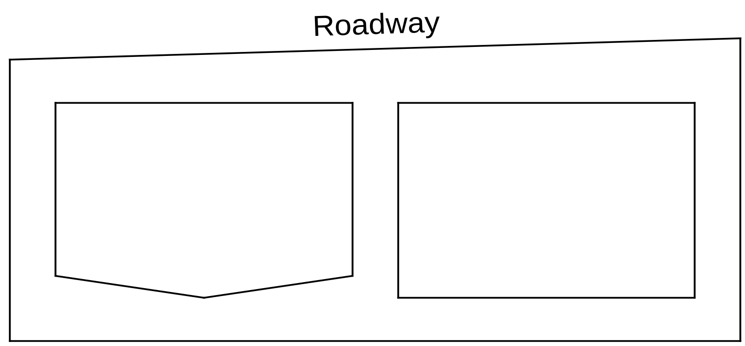
(a) Single Cell - Level Fill
No Fish Channel



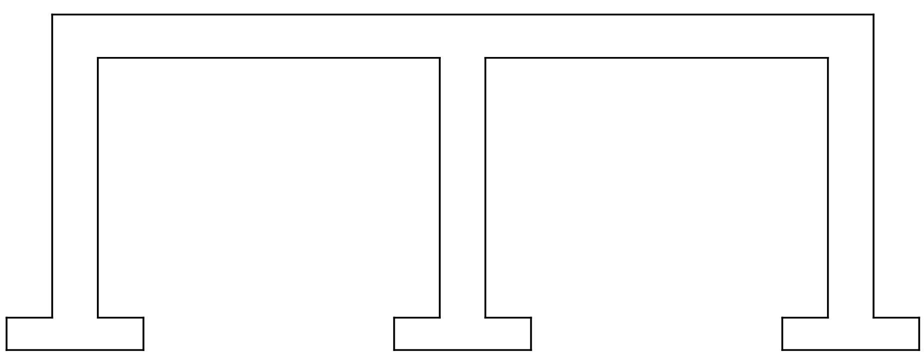
(b) Single Cell - Under Fill
Standard Fish Channel
Top Slab Simply Supported



(c) Single Cell
No Top Slab



(d) Twin Cell - Top Slab at Grade
Non-Standard Fish Channel



(e) Twin Cell - No Bottom Slab
Frame Culvert

Figure 2.1.1 Types of Culvert

2.2 LIVE LOADINGS

Thirteen standard live loadings are built into the program. These are designated as H20, HS20, HS25, AML (Alternate Military Load), IML (Increased Military Load), ML80, TK527, P-82 (204 Kips Permit Vehicle), EV2 (FAST Act Emergency Vehicle), EV3 (FAST Act Emergency vehicle), and SU6TV (FAST Act Heavy-Duty Tow and Recovery Vehicle). See Figure 2.2.1on page 2-4. The loadings H20 and HS20 are described in the AASHTO Specifications. An ML80 is the maximum legal load in Pennsylvania. The TK527 is a new posting vehicle effective January 1, 2002. EV2, EV3, and SU6TV are described in FAST Act effective December 4, 2015. For each loading, one unit of truck is considered in each lane that is loaded. The HS25 loading is a 25% higher loading than the HS20 loading, For loadings H20, HS20, and HS25, an equivalent lane loading (uniform load and one or two concentrated floating loads) is also considered and the governing effects are stored. Equivalent lane loadings for loadings H20 and HS20 are shown in the AASHTO Specifications. Like an HS25 truck, an HS25 lane loading is also 25% higher than the HS20 lane loading. The program provides options to analyze a bridge for different groups of these loadings. These options are explained in the Chapter 5 Input Data Requirements of this manual.

In place of standard loadings described above, the bridge can also be analyzed for a maximum of eight special loadings that can be described by entering various parameters of the loadings. This may be useful in analyzing a permit load or a set of loadings customized by the user when it may be necessary to consider more than one unit of standard loading in a lane. A special live load may have 2 to 80 axles for a truck loading and an associated lane loading.

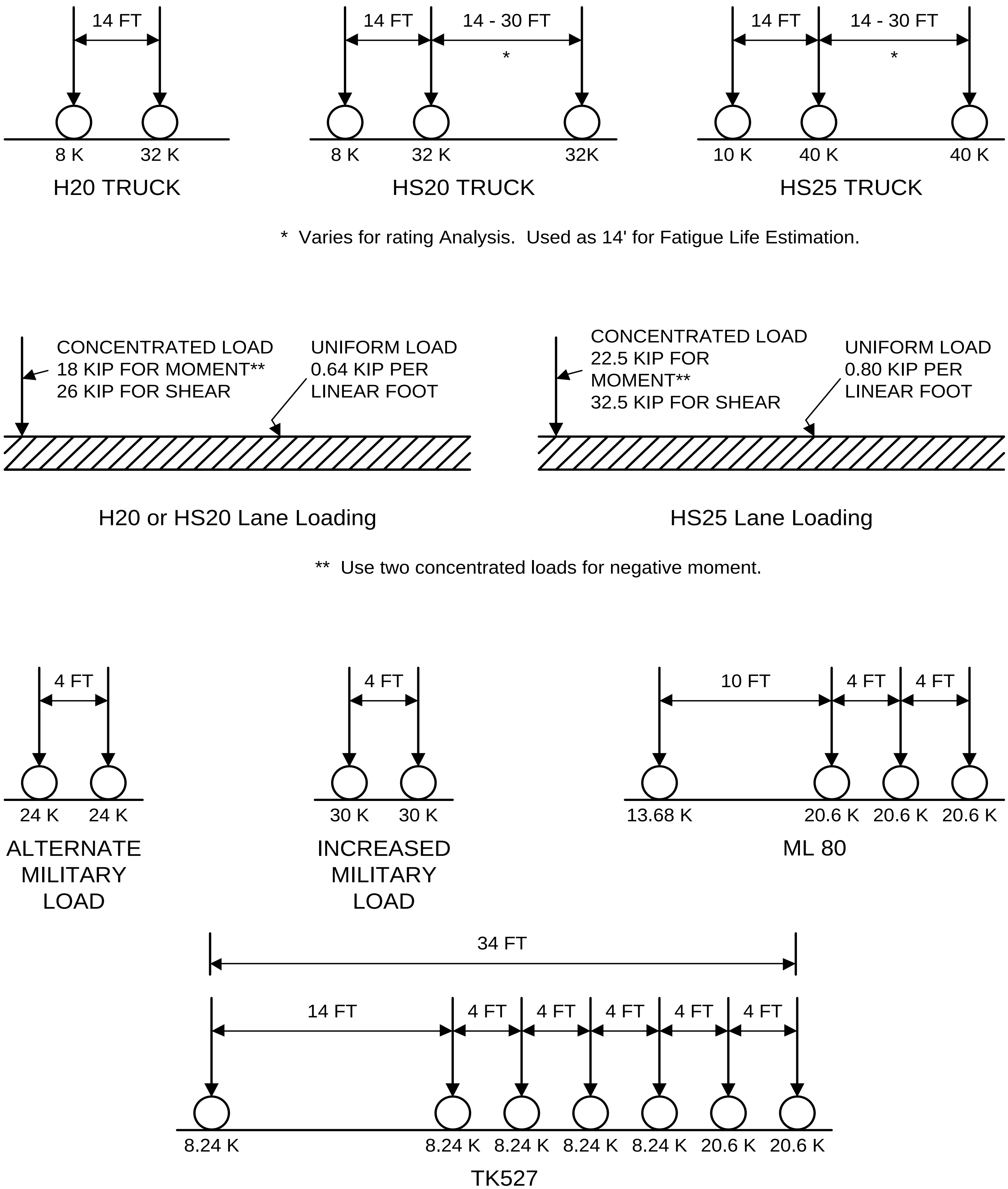
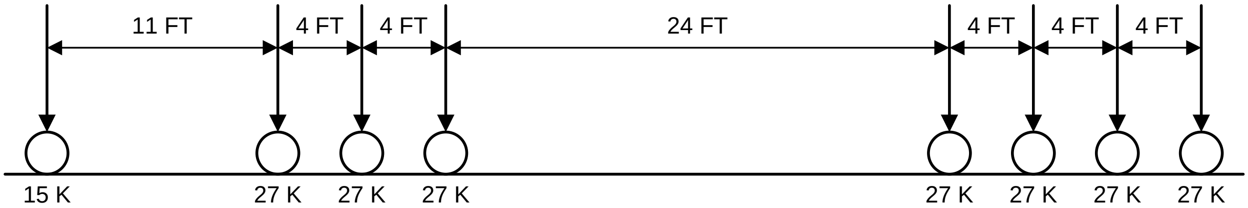
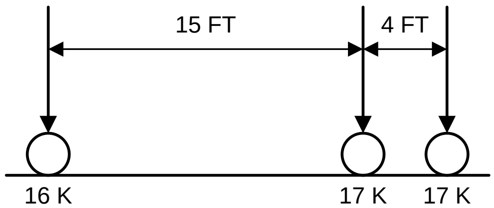


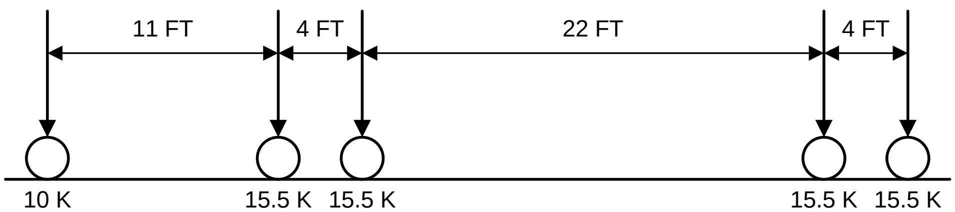
Figure 2.2.1 Standard Live Loadings



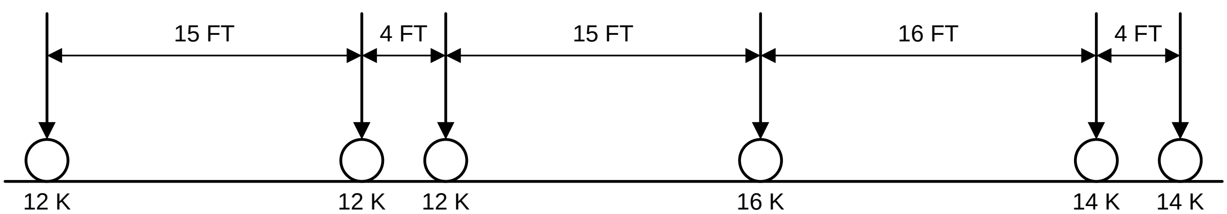
P-82
204 KIPS PERMIT VEHICLE



Type 3

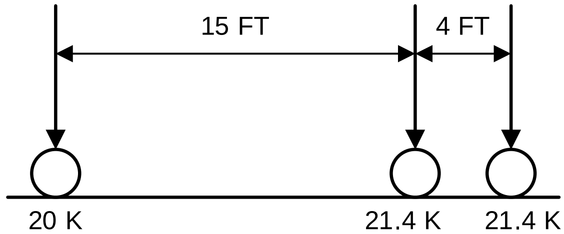


Type 3S2

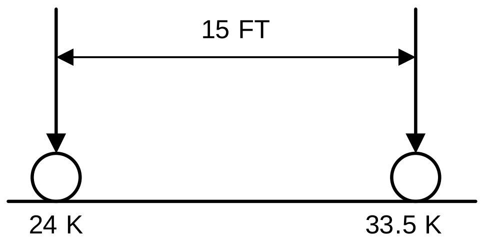


Type 3-3

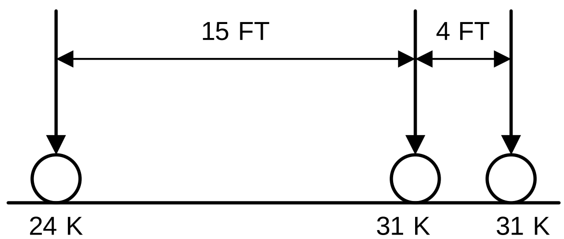
Figure 2.2.1 Standard Live Loadings (cont'd)



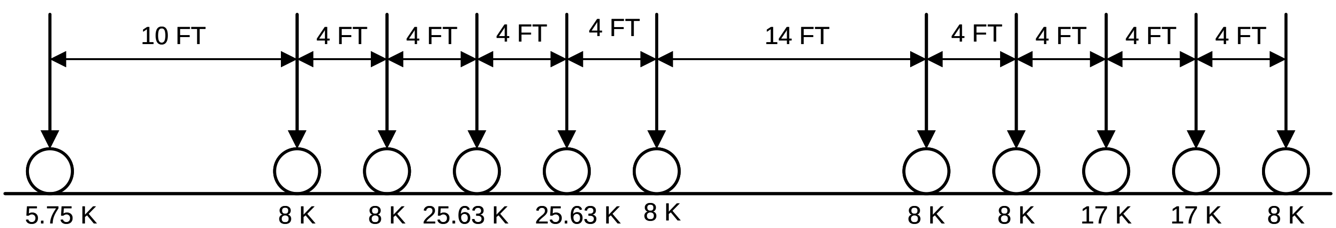
PA 58



EV2



EV3



SU6TV
Heavy-Duty Tow and Recovery Vehicle

Figure 2.2.1 Standard Live Loadings(cont'd)

3 METHOD OF SOLUTION

3.1 GENERAL

The program analyzes the culvert as a frame using the slope deflection equations and designs the reinforced concrete section either by Load Factor Design or Service Load Design depending upon the method chosen by the user. For the purpose of analysis, a one-foot wide strip of the culvert is assumed (See Figure 3.1.1 below). A rectangular frame (shown in heavy lines in Figure 3.1.1) is assumed joining the center lines of walls and slabs. The frame is analyzed and the reactions, shears and moments at each end of the member are computed. The moments, thrusts and shears at 10^{th} points along the clear span of the slab and the clear height of the wall are computed next. These sections are taken from left to right for a slab and from bottom to top for a wall. The clear height and clear span of the culvert opening are input by the user and they remain constant throughout the design process.

If the member thicknesses are known, the program analyzes the culvert with given thicknesses and computes the areas of reinforcement required at various sections. If the thicknesses are to be designed, then the program starts with the minimum thicknesses specified by the user.

The following sections explain the procedure used in the program.

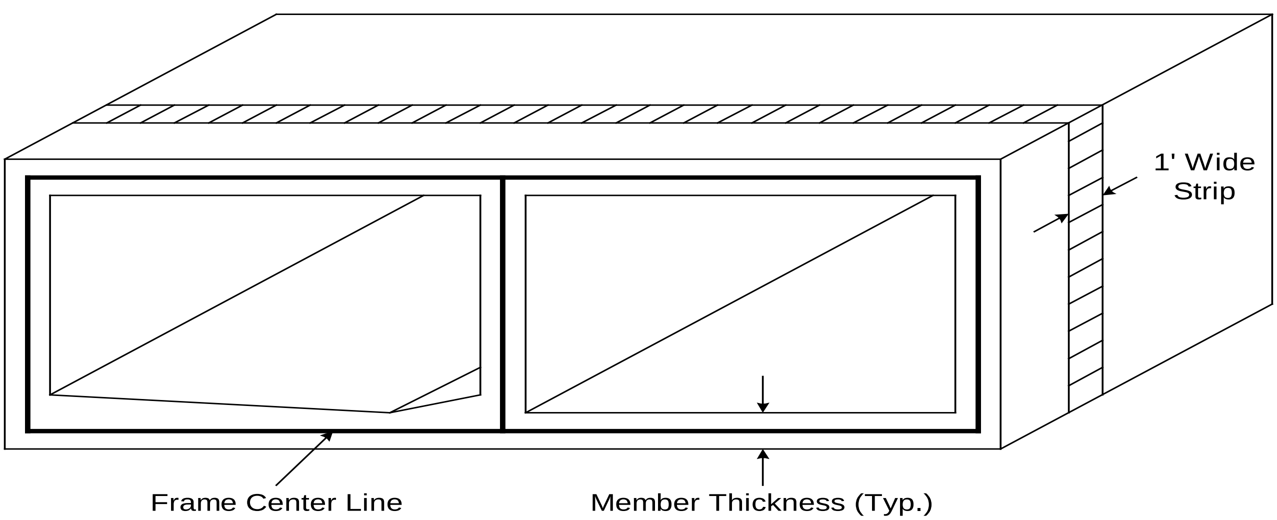


Figure 3.1.1 Culvert as a Frame

3.2 NOTATIONS

The notations used in the equations given here are as follows:

A_g = Gross area of section – in^2.

A_s = Area of flexural reinforcement – in^2.

A_v = Area of shear reinforcement – in^2.

b = Width of compression face of member - in.

c = Cover to the centroid of reinforcement - in.

d = Distance from extreme compression fiber to centroid of tension reinforcement - in.

d'' = Distance from centroid of gross section, neglecting the reinforcement, to centroid of tension reinforcement - in.

D = Dead load effect.

e = Eccentricity of unit live load measured from centroid of culvert - ft.

e_L = Eccentricity of load in the L direction measured from centroid of culvert - ft.

E = Earth pressure effect.

E = Distribution width for wheel loads - ft.

E_c = Modulus of elasticity of concrete - ksi.

E_s = Modulus of elasticity of reinforcement - ksi.

f_c = Actual extreme fiber stress in concrete - ksi.

f_c' = Specified compressive strength of concrete - psi.

f_{ca} = Allowable compressive stress in concrete - ksi.

f_{cir} = Extreme fiber compressive stress in concrete at inventory rating level - ksi.

f_{cor} = Extreme fiber compressive stress in concrete at operating rating level - ksi.

f_r = Modulus of rupture of concrete - ksi.

f_s = Actual extreme fiber stress in reinforcement - ksi.

f_{sa} = Allowable tensile stress in reinforcement - ksi.

f_{sir} = Tensile stress in reinforcement at inventory rating level - ksi.

f_{sor} = Tensile stress in reinforcement at operating rating level - ksi.

f_y = Specified yield strength of reinforcement - psi.

h_1 = Moment arm for force due to earth pressure on wall - ft.

h_2 = Moment arm for force due to earth pressure on wall - ft.

h_3 = Moment arm for force due to passive pressure on wall - ft.

I = Impact effect.

I_g = Moment of inertia of the gross concrete section about centroidal axis, neglecting reinforcement – in^4.

I_x = Moment of inertia of the section about the neutral axis – in^4.

j = Ratio of distance between resultants of compressive and tensile stresses to effective depth.

k = Ratio of distance between extreme fiber and neutral axis to effective depth.

L = Live load effect.

L = Total culvert foundation length - ft.

M = Service load moment - kip-ft.

M_{cr} = Cracking moment - kip-ft.

M_D = Unfactored dead load moment - kip-ft.

M_E = Unfactored earth pressure moment - kip-ft.

M_f = Factored moment acting at a section - kip-ft.

M_{LI} = Unfactored live load plus impact moment - kip-ft.

M_n = Nominal moment strength of a section - kip-ft.

M_u = Factored moment occurring simultaneously with V_u. at a section - kip-ft.

M_U = Moment capacity of a section - kip-ft.

n = Modular ratio of elasticity $\left[\frac{E_s}{E_c}\right]$.

N = Axial compression at a section - kips.

N_e = Equivalent service load moment at a section - kip-ft.

N_u = Factored axial compression occurring simultaneously with V_u. at a section - pounds.

N_v = Design axial compression occurring simultaneously with V at a section - pounds.

P = Weight of uncured top slab - kips.

P = Unit load for live load - kips.

P_1 = Force due to earth pressure on wall - kips.

P_2 = Force due to earth pressure on wall - kips.

P_3 = Force due to passive pressure on wall - kips.

q = Earth pressure due to live load surcharge at a given point - ksf.

q_a = Pressure at a given point due to unit live load - ksf.

q_b = Pressure at a given point - ksf.

q_b = Pressure at a given point due to unit live load - ksf.

q_{b1} = Earth pressure at the bottom of the wall - ksf.

q_{b2} = Earth pressure at the bottom of the wall - ksf.

q_{b3} = Passive pressure at the bottom of the wall - ksf.

q_c = Pressure at a given point due to unit live load - ksf.

q_e = Pressure at a given point - ksf.

q_{e1} = Earth pressure at the top of the wall - ksf.

q_{e2} = Earth pressure at the top of the wall - ksf.

q_{e3} = Passive pressure at the top of the wall - ksf.

q_1 = Pressure at a given point - ksf.

q_2 = Pressure at a given point - ksf.

q_{max} = Maximum foundation contact pressure - ksf.

Q = Total force on foundation - kips.

Q_1 = Load acting on the bottom slab due to weight of wall and top slab - kips.

Q_2 = Load acting on the bottom slab due to weight of wall and top slab - kips.

R = Reaction due to unit live load - kips.

R_a = Reaction at bottom of left wall due to unit live load - kips.

R_b = Reaction at bottom of center wall due to unit live load - kips.

R_c = Reaction at bottom of right wall due to unit live load - kips.

R_1 = Reaction at a point due to the weight of the top slab - kips.

R_2 = Reaction at a point due to the weight of the top slab - kips.

s = Center to center spacing of reinforcement - in.

S = Effective span length - ft.

t = Total depth of section - in.

v = Design shear stress at a section - ksi.

V = Design shear force at a section - kips.

v_c = Permissible shear stress that can be carried by concrete - ksi.

V_c = Nominal shear strength provided by concrete - kips.

V_D = Unfactored dead load shear - kips.

V_E = Unfactored earth pressure shear – kips.

V_f = Factored shear acting at a section - kips.

V_{L+I} = Unfactored live load plus impact shear - kips.

v_s = Shear stress to be carried by shear reinforcement - ksi.

V_s = Nominal shear strength provided by shear reinforcement - kips.

v_{smax} = Permissible shear stress carried by shear reinforcement - ksi.

V_{smax} = Maximum shear that can be carried by a group of bent up bars - kips.

V_u = Factored shear force at a section - kips.

V_U = Shear capacity of a section - kips.

W_1 = Weight of wall - kips.

W_2 = Weight of wall - kips.

x = Depth of neutral axis - in.

y_t = Distance from centroidal axis of gross concrete section, neglecting reinforcement, to extreme fiber in tension - in.

z = Quantity limiting distribution of flexural reinforcement.

z_c = Section moduli for extreme concrete fiber – in^3.

z_s = Section moduli for reinforcement – in^3.

γ = Load factor.

β_1 = Ratio of depth equivalent compression zone to depth from fiber of maximum compressive strain to the neutral axis.

β_D = Load combination coefficient for dead load.

β_E = Load combination coefficient for earth pressure.

β_L = Load combination coefficient for live load.

ϕ = Strength reduction factor.

ϕ_b = Strength reduction factor for flexure.

ϕ_c = Strength reduction factor for axial compression.

ρ = Tension reinforcement ratio.

α = Angle of bent up bars to be used as shear reinforcement - degrees.

Table 3.2.1 Allowable Steel Stresses

f_y	f_{sir}	f_{sor}
unknown	18 ksi	25 ksi
33	18 ksi	25 ksi
40	20 ksi	28 ksi
50	20 ksi	32.5 ksi
60	24 ksi	36 ksi
65	26 ksi	39 ksi

3.3 STRUCTURAL ANALYSIS

3.3.1 Structural Modeling

From the input values of culvert dimensions and thicknesses, the program builds a plane frame model by assuming a joint at the intersection of the culvert slab and wall centerlines. A member is assumed between these joints for each slab and each wall. Each member can be prismatic or non-prismatic depending on the grade of the top slab, presence or absence of haunches and fish channel. Each member is divided into a number of elements such that the analysis points can be obtained at the tenth points of the clear length of the slab or wall and other points such as transition of the haunches and the fish channel. Each element of the member is assumed to have a constant cross section, which is equal to the average of the actual cross sections at the ends of the element.

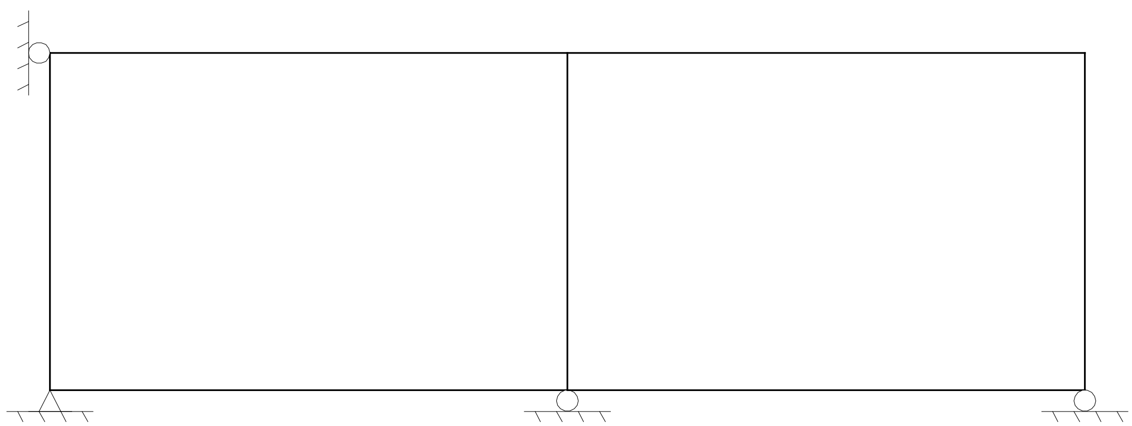
The program employs the slope deflection method of analysis assuming no side sway and no axial deformations. For slope deflection equations, it is assumed that the structure is in equilibrium under applied loadings so there is no need to apply boundary conditions. Comparable results can be obtained by using an accepted general purpose structural analysis program by assuming boundary conditions shown in Figure 3.3.1 on page 3-7 and forcing negligible axial deformations. Negligible axial deformations can be attained by entering a large value of cross sectional area of a member.

3.3.2 Slope Deflection Solution

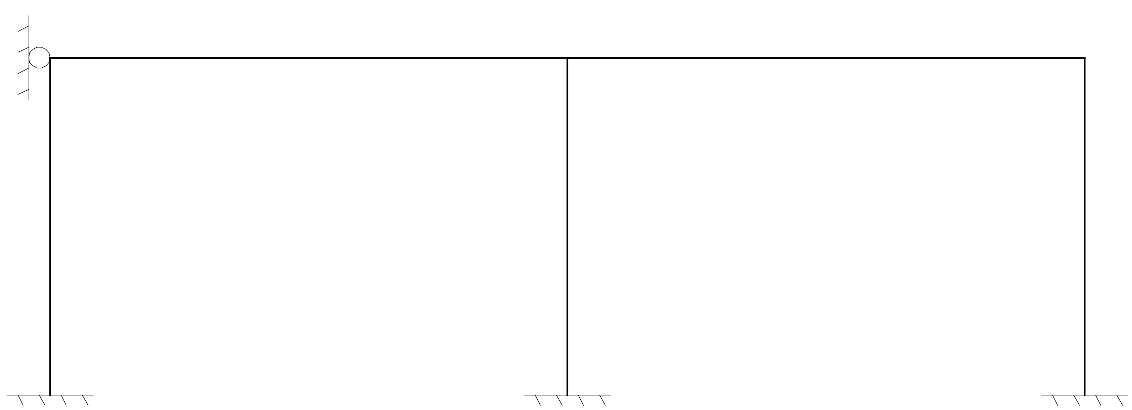
For each loading condition described in Section 3.3, the structural model described in Section 3.2.1 is analyzed as follows. For the slope deflection equations, the unknowns are assumed as the end moments (M_{ij}) in each of the slab and wall members and the rotations (θ_1) of the joints at the intersections of these members. The following slope deflection equations (shown here for the member between joints 1 and 2) are used for each member. Refer to Figure 3.3.2 on page 3-9 which shows joint numbers for a twin cell culvert and fixed end moments (FM_{ij}) for a typical loading condition.

Single Cell Box Culvert

Note: Structural models shown are with member centerlines



Twin Cell Box Culvert



Twin Cell Frame

Figure 3.3.1 Structural Model Boundary Conditions

$$M_{12} = FM_{12} - SF_{12}\theta_1 - SF_{21}CO_{21}\theta_2$$

$$M_{21} = FM_{21} - SF_{21}\theta_2 - SF_{12}CO_{12}\theta_1$$

where: A and B are the ends of a member

M_{12}	=	end moment at end 1 (unknown)
M_{21}	=	end moment at end 2 (unknown)
FM_{12}	=	fixed end moment at end 1 due to member loading
FM_{21}	=	fixed end moment at end 2 due to member loading
SF_{12}	=	stiffness factor at end 1
SF_{21}	=	stiffness factor at end 2
CO_{12}	=	carry-over factor from 1 to 2
CO_{21}	=	carry-over factor from 2 to 1
θ_1	=	rotation at joint 1 (unknown)
θ_2	=	rotation at joint 2 (unknown)

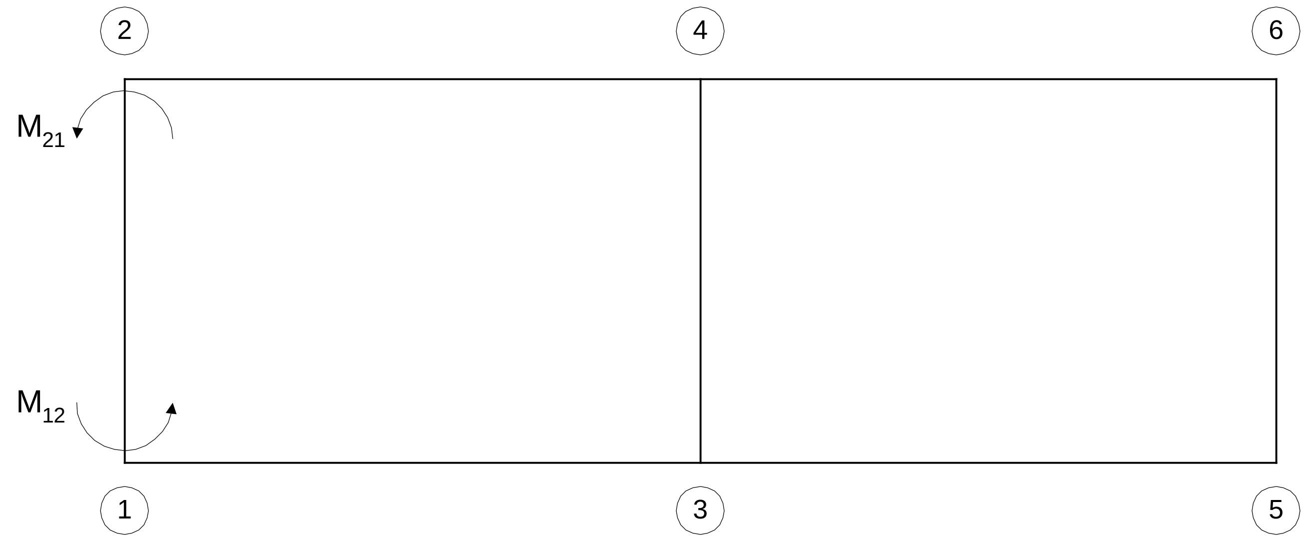
At each joint whose rotation is unknown, the following equation (shown for joint 1) is applied.

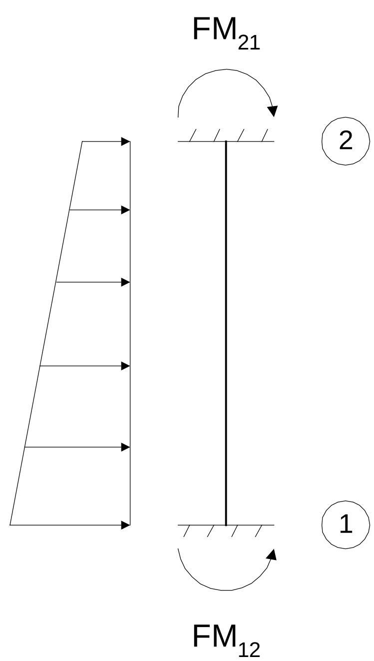
$$M_{12} + M_{13} = 0$$

where: $M_{12} = FM_{12} - SF_{12}\theta_{12}\theta_1 - SF_{21}CO_{21}\theta_2$

$M_{13} = FM_{13} - SF_{13}\theta_1 - SF_{31}CO_{31}\theta_3$

The above equations are applied to all members and joints and give as many simultaneous slope deflection equations as there are unknowns. The solution of these equations provides end moments in each member. These equations are solved by matrix algebra. For this method, refer to any standard text book on structural engineering. Once the end moments are known, end reactions are obtained by superposition of simple beam reaction due to member load and reactions to balance end moments. The moment, shear and thrust at the tenth point section in the member are computed by applying principles of statics.





Earth Pressure Loading

Figure 3.3.2 Slope Deflection Solution - Joint Numbers

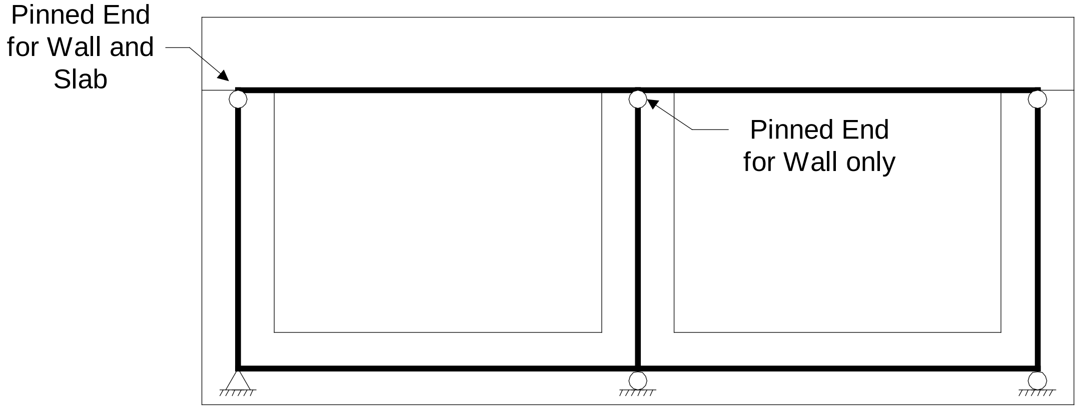


Figure 3.3.3 Structural Model for Simply Supported Top Slab

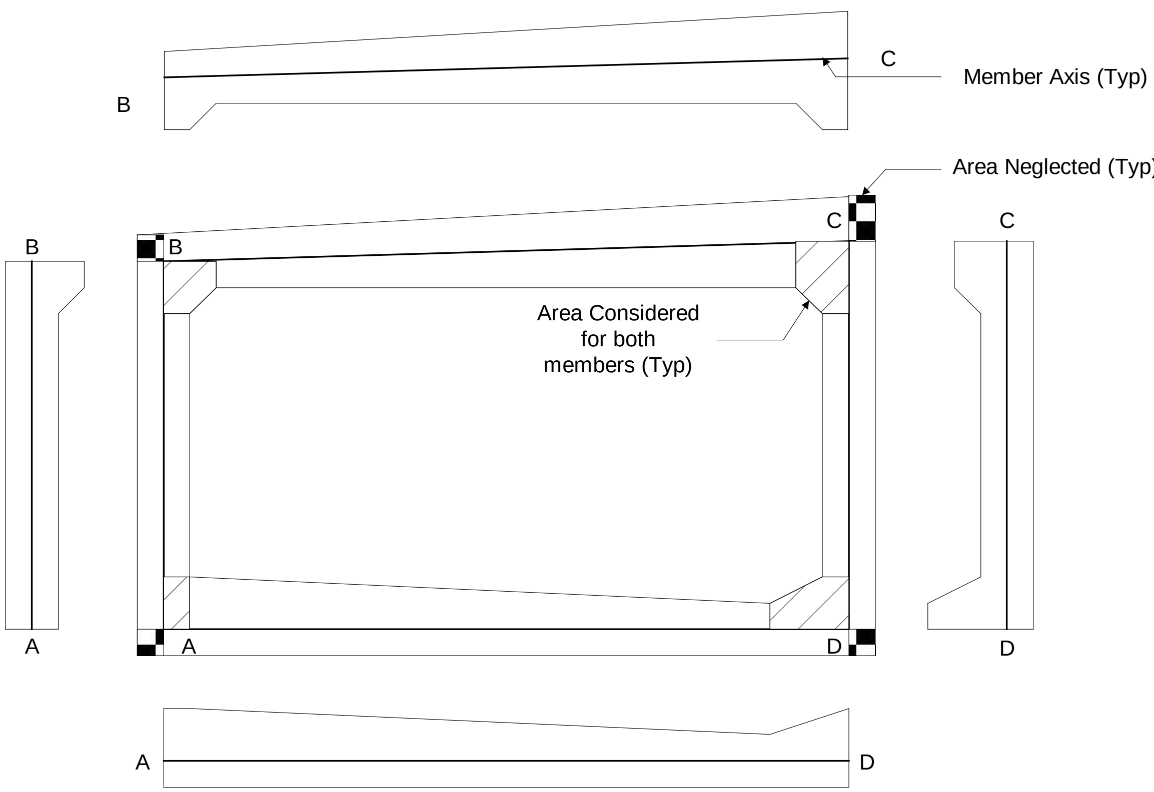


Figure 3.3.4 Section Properties for Stiffness

For a culvert having non-prismatic members (top slab at grade, bottom slab with fish channel or monolithic haunches), the fixed end moments, stiffness factors and carry-over factors used for solving the slope deflection equations are computed using the column analogy method. For a culvert with a simply supported top slab, the stiffness and carry-over factors and the fixed end moments at the top ends of walls and the left and right ends of the top slab are modified assuming a pinned condition (shear transfer, but no moment transfer) at the clear height of wall as shown in Figure 3.3.3 on page 3-10. The section properties used to calculate the stiffness factors and carry-over factors for a culvert with non-prismatic members are shown in Figure 3.3.4 on page 3-10.

3.4 LOADINGS

The culvert is designed for the dead load, live load, live load surcharge and lateral earth pressure in accordance with the AASHTO Specifications using appropriate load factors for the method of design specified by the user. The following loads and loading combinations are considered.

3.4.1 Weight of Structure

The loads due to the weight of structural components (walls and slabs) are applied to the culvert based on the type of construction. The methods used by the program to determine the effects of the loads due to the weight of the structure are described next. Refer to Figure 3.4.1 on page 3-12.

3.4.1.1 Method A for Cast-in-place Culvert

For this method, the bottom slab is poured and allowed to cure first. The walls and the top slab are poured next. When the walls and the top slab are poured, the bottom slab is assumed to act as an infinitely stiff beam resting on an unyielding foundation carrying the weight of uncured concrete in the walls and the top slab. The weight of uncured walls and the top slab acts as concentrated loads on the bottom slab at the centerlines of walls (DC1 loading). When the formwork supporting the top slab is removed, the frame action is realized. To simulate the effect of removing the forms (DC2 loading), the concentrated loads due to the weight of the top slab acting on the bottom slab considered in the DC1 loading are applied in the opposite direction to keep the system in equilibrium with the weight of the top slab applied as shown in Figure 3.4.1 on page 3-12. The effects of the DC1 and DC2 loadings are added together to get the DC effects. The bottom slab is designed and rated for both the DC1 and DC loadings. The design runs and the ratings only runs can be made using this method.

3.4.1.2 Method B for Cast-in-place Culvert

For this method, the bottom slab is poured and allowed to cure first. The walls are poured next. When the walls are poured, the bottom slab is assumed to act as an infinitely stiff beam resting on an unyielding foundation (DC1 loading). Next, the top slab is poured. When the top slab is poured, the walls are assumed to act integral with the bottom slab. The weight of the top slab is assumed to be carried by the frame action of all members (DC2 loading). The bottom slab is designed and rated for the combined effects of DC1 and DC2 loadings. The rating only runs can be made using this method. This method is not allowed for design runs.

3.4.1.3 Method C for Precast Culvert

A precast culvert is assumed to be placed as a unit and the dead load due to the weight of the culvert is assumed to be distributed by a frame action (designated as DC loading). Both design and rating runs are done using this method.

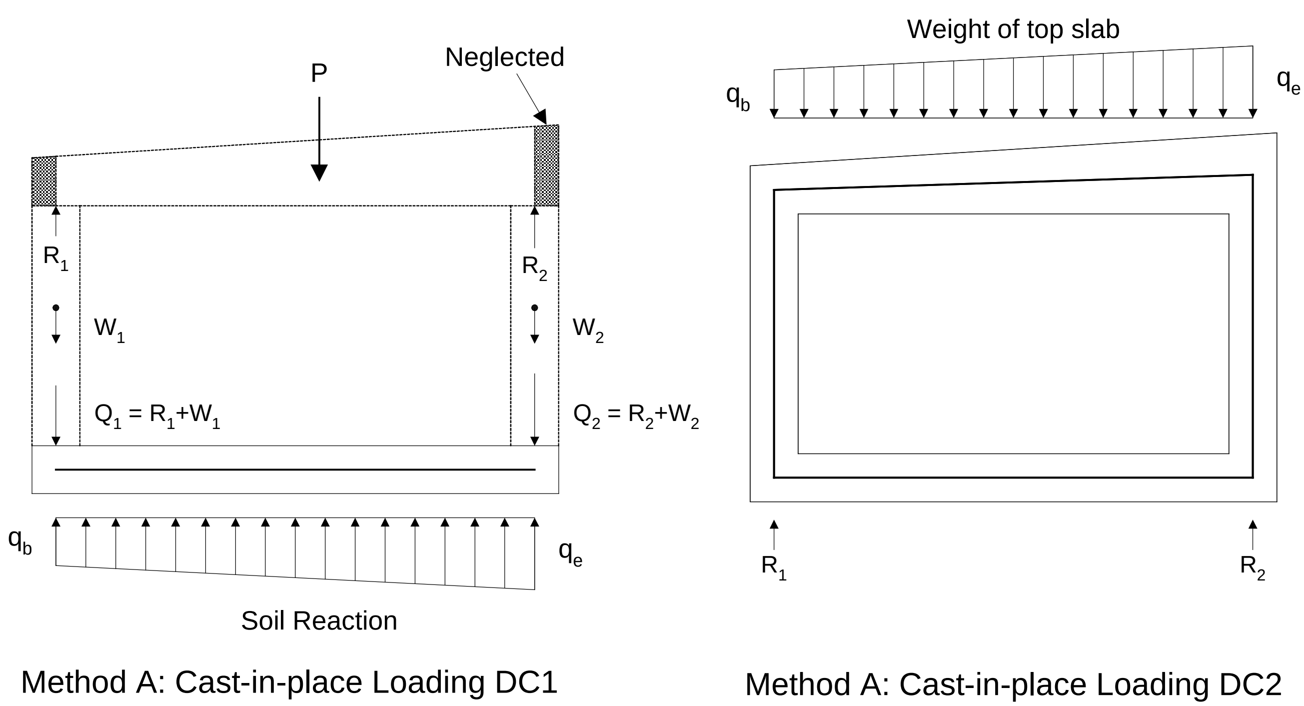
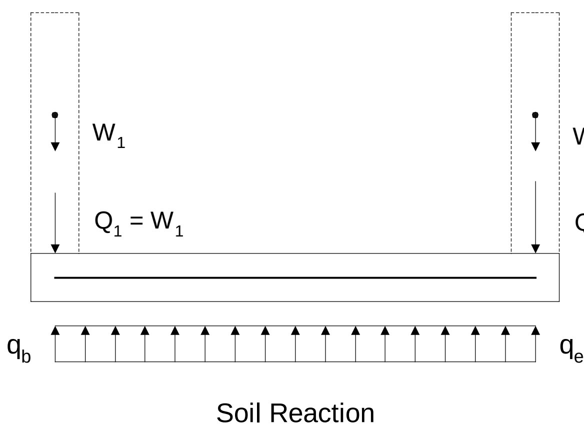
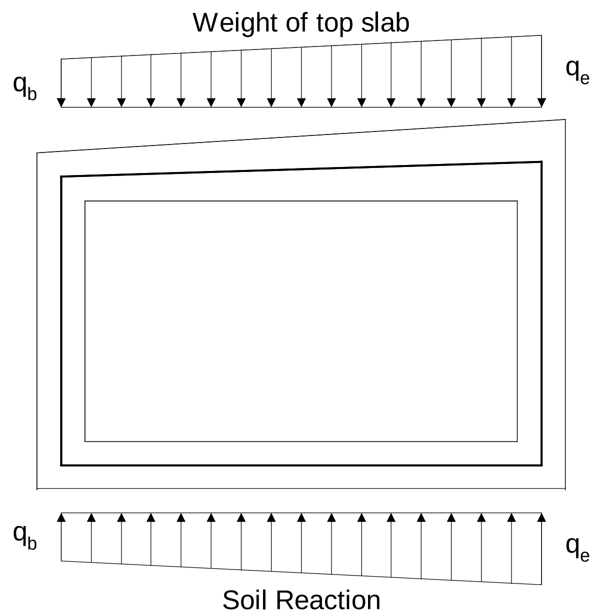


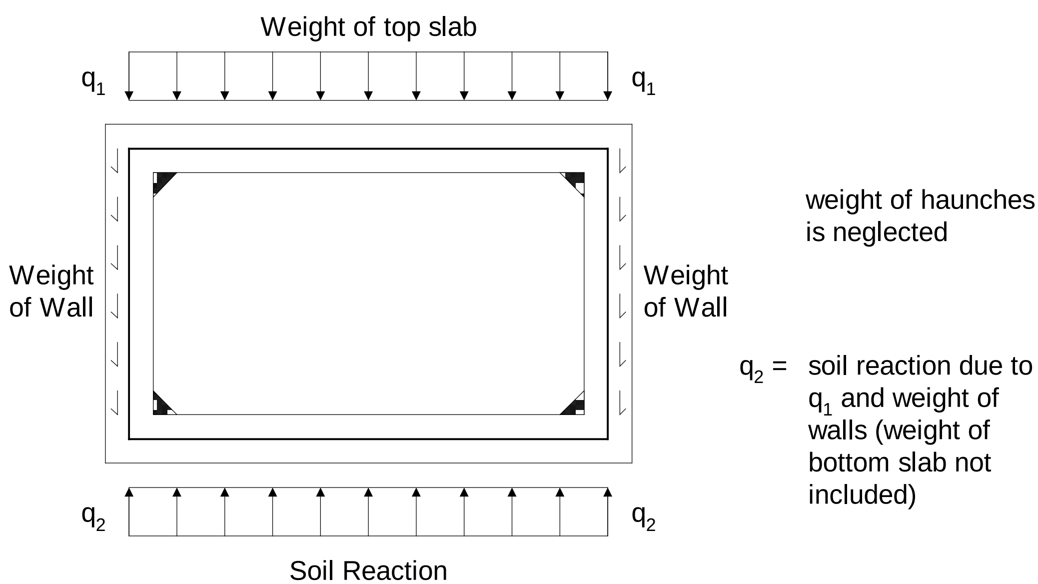
Figure 3.4.1 Loadings - Weight of Structure



Method B: Cast-in-place Loading DC1



Method B: Cast-in-place Loading DC2



Method C: Precast Culvert Loading DC

Figure 3.4.1 Loadings - Weight of Structure (cont)

3.4.2 Weight of Fill

If the culvert is under fill, the dead loads due to the weight of fill is applied as a trapezoidal load for a sloping fill or as a uniform load due to level fill. An equal and opposite force is applied to the bottom slab such that the culvert is in equilibrium. The weights of soil above the left half of the left wall thickness and above the right half of the right wall thickness are neglected. Figure 3.4.2 on page 3-15 shows a typical loading condition for a twin cell culvert under a sloping fill.

3.4.3 Earth Pressure

The culvert is analyzed for a lateral earth pressure in accordance with the Design Manual Part 4 and the AASHTO Specifications. The moments, shears and thrusts are computed for a full value of lateral earth pressure and these effects are then combined with the effects of other loads by applying appropriate load factors as explained under LOADING COMBINATIONS. The culvert under fill with a grade may be subject to unequal pressures on side walls. For this loading condition an additional passive pressure is added to the side with a lower pressure so that the forces due to lateral earth pressure are in equilibrium. Refer to Figure 3.4.3 on page 3-16.

3.4.4 Live Load Surcharge

The live load surcharge is expressed as an equivalent height of fill. This load is applied as a horizontal pressure equal to equivalent fluid pressure (input by the user) times the live load surcharge (also input by the user). This load is applied in combination with other loads as explained under Loading Combinations. Refer to Figure 3.4.3 on page 3-16.

3.4.5 Unit Load for Influence Line

The influence lines for moments, shears, and axial forces at all analysis points are generated by placing a unit load one at a time at each of the top slab analysis points. For a given unit load on the top slab, a reaction loading acting on the bottom slab is calculated. The loadings applied for a unit load condition and the formulae used to calculate the reaction loading acting on the bottom slab is shown in Figure 3.4.4 on page 3-17. The moments, shears and axial forces acting at various analysis points in the slabs and walls for the above loading condition are calculated using the slope deflection method explained earlier. When these effects are calculated for all unit load positions on the top slab, the influence lines are generated. These influence lines are then used to calculate the maximum positive and the maximum negative effect at a given analysis point due to a live load.

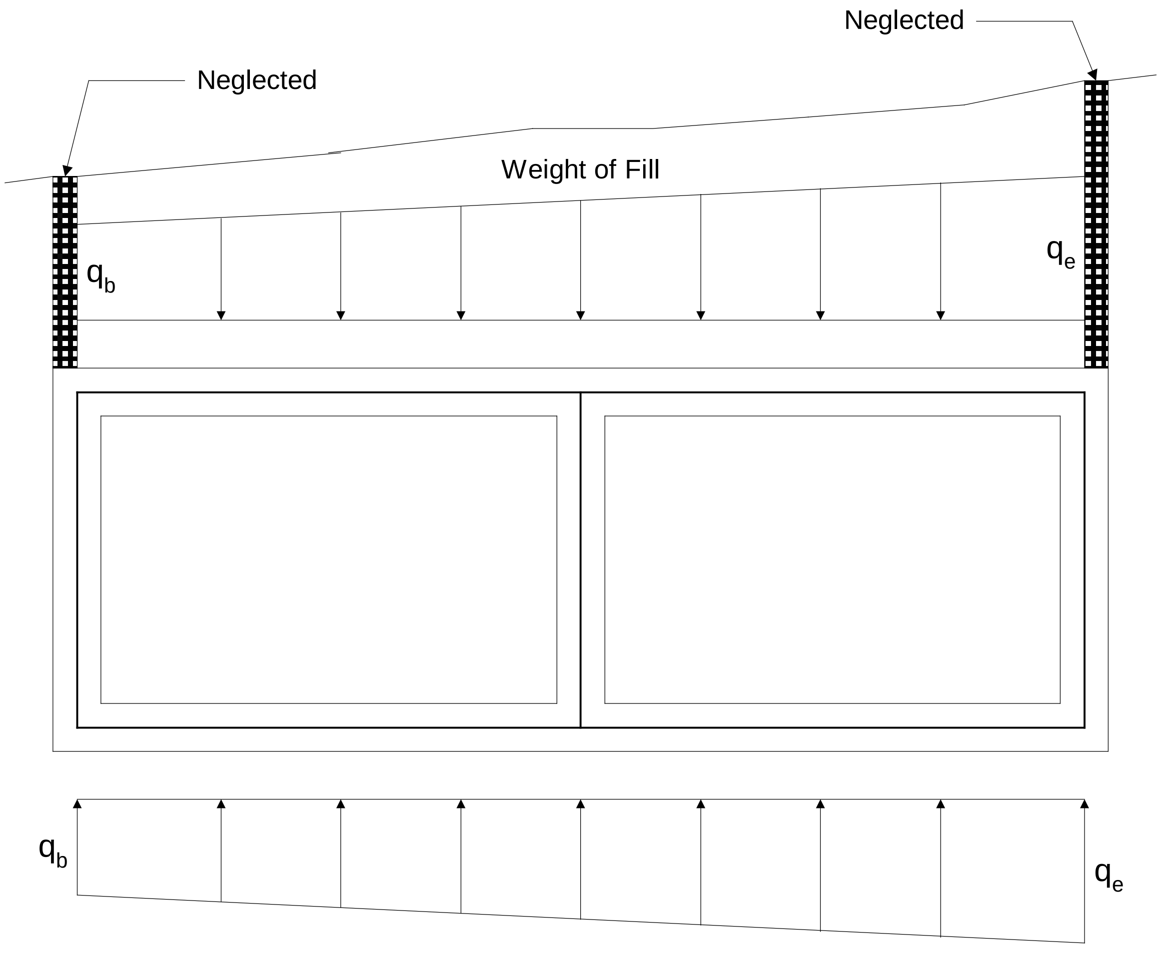
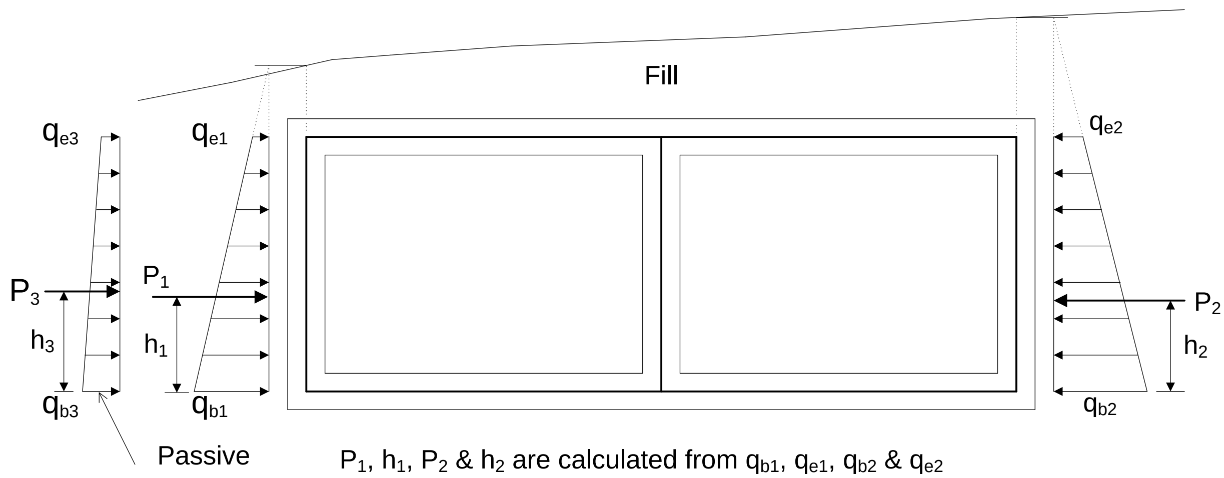


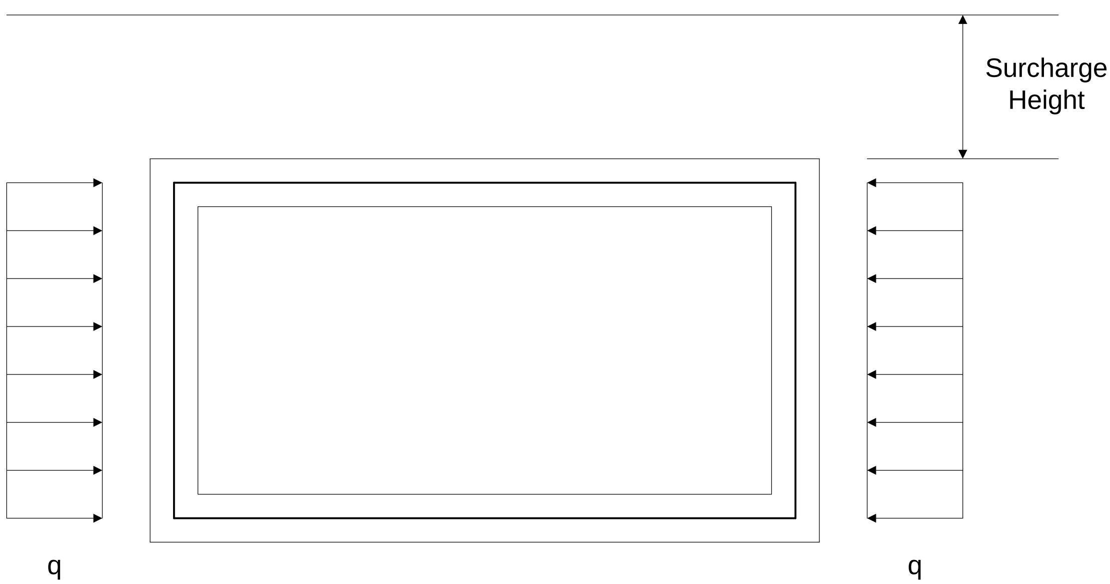
Figure 3.4.2 Loadings - Weight of Fill



P_1, h_1, P_2 & h_2 are calculated from q_{b1}, q_{e1}, q_{b2} & q_{e2}

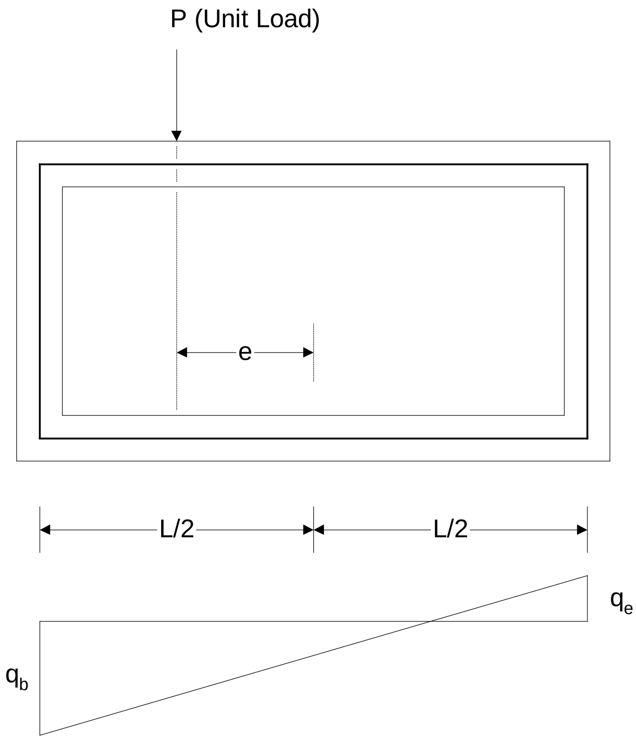
P_3 and h_3 are calculated using: $P_1h_1 - P_2h_2 + P_3h_3 = 0$

$P_1 - P_2 + P_3 = 0$



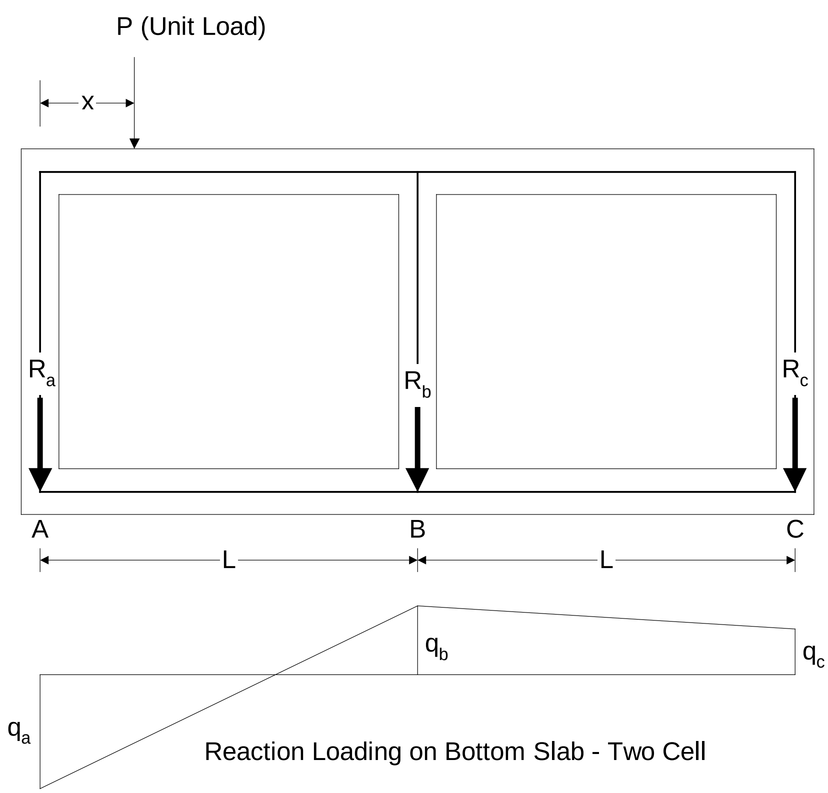
q = Surcharge Height x Equivalent Fluid Pressure

Figure 3.4.3 Loadings - Earth Pressure and Surcharge



$$q_e = \frac{P}{L}\left(1 - \frac{6e}{L}\right)$$

$$q_b = \frac{P}{L}\left(1 + \frac{6e}{L}\right)$$



Reaction Loading on Bottom Slab - Two Cell

$$R = \left|\frac{L - x}{L}\right|$$

$$R_a = \frac{2R + 3R^2 - R^3}{4}$$

$$R_c = \frac{-2R + 3R^2 - R^3}{4}$$

$$R_b = \frac{4 - 6R^2 + 2R^3}{4}$$

$$q_b = \frac{2R_b - R_a - R_c}{L}$$

$$q_c = \frac{R_c - q_b \frac{L}{6}}{\frac{L}{3}}$$

$$q_a = \frac{R_a - q_b \frac{L}{6}}{\frac{L}{3}}$$

Figure 3.4.4 Loadings - Unit Load for Influence Line

3.4.6 Live Loads

The live loads considered by the program are: HS25 Truck loading, Increased Military loading (IML), Maximum Legal load in Pennsylvania (ML-80), TK527 posting vehicle, 204-kip Permit Load (P-82), HS20 Truck loading, Alternate Military loading (AML), and a user-defined loading (SPEC). A set of live loads consisting of either the HS25, IML and P-82 loadings or the HS20 and AML loadings can be used as a design load. A user-defined loading can also be used in place of the standard design loads. A serviceability check for crack control (if required) is performed for all loads except for the ML-80, TK527, and P-82 loadings.

The live load moments, shears, and thrusts are computed using the influence line method. The influence line ordinates are generated by placing a unit load at each of the tenth points along the top slab. The influence line is then analyzed for the maximum effect of a live load. The maximum live load plus impact effect is computed by applying the impact factor and the lateral distribution factor.

3.4.7 Distribution of Live Loads

The live load, if applicable in accordance with AASHTO 6.4.2, is distributed to one-foot wide strip of culvert shown in Figure 3.1.1 on page 3-1. For the effects due to the wheel load directly on the top slab, the distribution width E is calculated per AASHTO Equation (3-18). For the effects due to the wheel load through the fill, the distribution width E is calculated in accordance with AASHTO 6.4.1. The program stores and works with the axles loads of a live load and thus uses the distribution factor of 1/2E in calculating the live load effect. The live load effect through the fill in the moving (parallel to traffic) direction is calculated in accordance with AASTHO 6.4.2. If the culvert is under 2 feet or less fill, the smaller of the wheel load effect directly on the top slab and the wheel load effect through the fill is used as a governing effect in accordance with AASTHO 6.4.2.

3.4.8 Loading Combinations

AASHTO Group loadings IB and X are used for combinations of the above-mentioned loads. In checking the effect of a P-82 loading, Group IB is used for a loading combination. For all other loads, Group X is used. The following equation is used for a loading combination.

$$\text{Group Load} = \gamma\,[\beta_D \cdot D + \beta_D \cdot (L + I) + \beta_D \cdot E\,]$$

The Gamma and Beta factors used in the above equation are either the input values defined by the user or the default values set by the program. The effects of the full lateral earth pressure, double lateral earth pressure, and one-half lateral earth pressure are considered in accordance with the Department's current specifications.

The following loading conditions are checked.

1. A combination of double lateral earth pressure, structure dead load, and lateral pressure due to live load surcharge with fill up to the top of the culvert (for design only).
2. A combination of double lateral earth pressure, structure dead load, full height of fill, live load, and lateral pressure due to live load surcharge (for design and rating).
3. A combination of full lateral earth pressure, structure dead load, full height of fill, live load, and lateral pressure due to live load surcharge (for design and rating).
4. A combination of one-half lateral earth pressure, structure dead load, full height of fill, live load, and lateral pressure due to live load surcharge (for design and rating).
5. For a "rating only" run of the standard live loadings (H20, HS20, ML-80, TK527 and P-82), the critical section in a member is determined by comparing factored loads for AAASHTO Group IB loading combination, i.e. by comparing the BL (1.67 or the input value) times the H20, HS20, ML-80 and TK527 effects verses one (1) time the P-82 effect and taking the largest factored effect. The rating factor is calculated for each live load using the appropriate load factors.

3.5 SECTION DESIGN

The design of section is based on either Load Factor Design or Service Load Design depending on the method specified by the user. The section is designed to resist bending moment. The following designs are given:

1. DESIGN WITH KNOWN THICKNESSES - when the thicknesses are known, the sections are designed for the areas of flexural and shear reinforcement required for the given thicknesses.
2. DESIGN FOR THICKNESS AND REINFORCEMENT - when the thicknesses are not known, the members are designed for the thickness required to resist bending moment and then the sections are designed for the areas of flexural and shear reinforcement.
3. DESIGN WITHOUT SHEAR REINFORCEMENT - when the thicknesses are not known, the members are also designed for the thickness required to resist the bending moment and shear without providing any shear reinforcement.

The general procedure used for design is as follows. If the thickness of the member is to be computed, the program starts with the minimum thickness specified by the user. The thickness required at a section to resist the bending moment is computed and compared with the thickness provided. The difference between the thickness required and the thickness provided is computed at each section of a member and the maximum difference is stored. If the maximum difference is less than half an inch, the thickness assumed for a member is considered sufficient. If the maximum difference is greater than or equal to half an inch then this difference is divided by two and is converted to the nearest whole inch. This value is then added to the current assumed thickness to find the new assumed thickness. This is done for each member. The culvert is analyzed with these new member thicknesses and again the required member thicknesses are computed. This process is repeated until the difference between the assumed thickness and the required thickness is less than half an inch for all members. The area of reinforcement required to resist bending moment and the area of shear reinforcement are then computed using the equations given in the AASHTO specifications or this documentation. If a design without shear reinforcement is required, the thicknesses are computed to resist the bending moment and shear.

The following two sections give equations or AASHTO Article references for each method of design.

3.5.1 Load Factor Design

If the load factor design is specified as a design method, the program designs the sections of the wall and slab in accordance with the applicable provisions of AASHTO 8.16 Strength Design Method (Load Factor Design).

3.5.1.1 Member Thickness for Flexure

The thickness required at a section is computed by the following equation, assuming the reinforcement ratio equal to 0.5 times the balanced reinforcement ratio. The program assumes that this is an economical reinforcement ratio. The effect of the axial force is neglected here.

$$d = \sqrt{\frac{M_f}{\Phi \rho b f_y \left(1\text{-}0.6\,\rho \frac{f_y}{f_c'}\right)}}$$

where: $\rho = 0.5\ \rho_b$

$$\rho_b = \frac{0.85\,\beta_1 f_c'}{f_y}\,\frac{87000}{87000 + f_y}$$

$\beta_1 = 0.85$ for $f_c' \le 4.0$

$\beta_1 = 0.85 - 0.05\left(f_c' - 4.0\right)$ for $f_c' > 4.0$

but not < 0.65

$\Phi = 0.9$ for cast-in-place culvert

$\Phi = 1.0$ for precast culvert

If the thickness (d_{req}) required computed by the above equation is less than the thickness (d_a) assumed (initial input or set in the previous cycle), a new thickness ($d_a = d_a + (d_{req} - d_a)/2 + 1''$ converted to the nearest inch) is assumed and the culvert is reanalyzed.

3.5.1.2 Flexural Reinforcement

If the assumed thickness and the thickness required are within one-half inch, the area of reinforcement, A_s, required at the section is computed by solving the following equation:

$$\Phi_b \frac{f_y^{\,2}}{1.7\, f_c'\, b} A_s^2 - \Phi_b\, f_y\, d\, A_s + M_f = 0$$

If the section is subject to combined axial force and bending moment, a strength curve (flexure-axial interaction diagram) for the section is constructed as shown in Figure 3.5.1 on page 3-23. The factored loads are then checked against corresponding strengths. The key points of the strength curve are computed in accordance with AASHTO Articles 8.16.1.2 and 8.16.4 using the following equations.

$$\rho = \frac{A_s}{b\, d}$$

$$\varepsilon_{cu} = 0.003 \qquad C_c = 0.85 f_c' \beta_1 x_b b$$

$$M_0 = \rho b d f_y \left[d - \frac{\rho}{2} \left(\frac{f_y}{0.85 f_c'} \right) d \right]$$

$$x_b = \frac{\varepsilon_{cu} d}{\frac{f_y}{E_s} + \varepsilon_{cu}} \qquad T = A_{st} f_y$$

$$P_b = C_c - T$$

$$P_{0,comp} = 0.85 f_c' \left(A_g - A_s \right) + f_y A_s$$

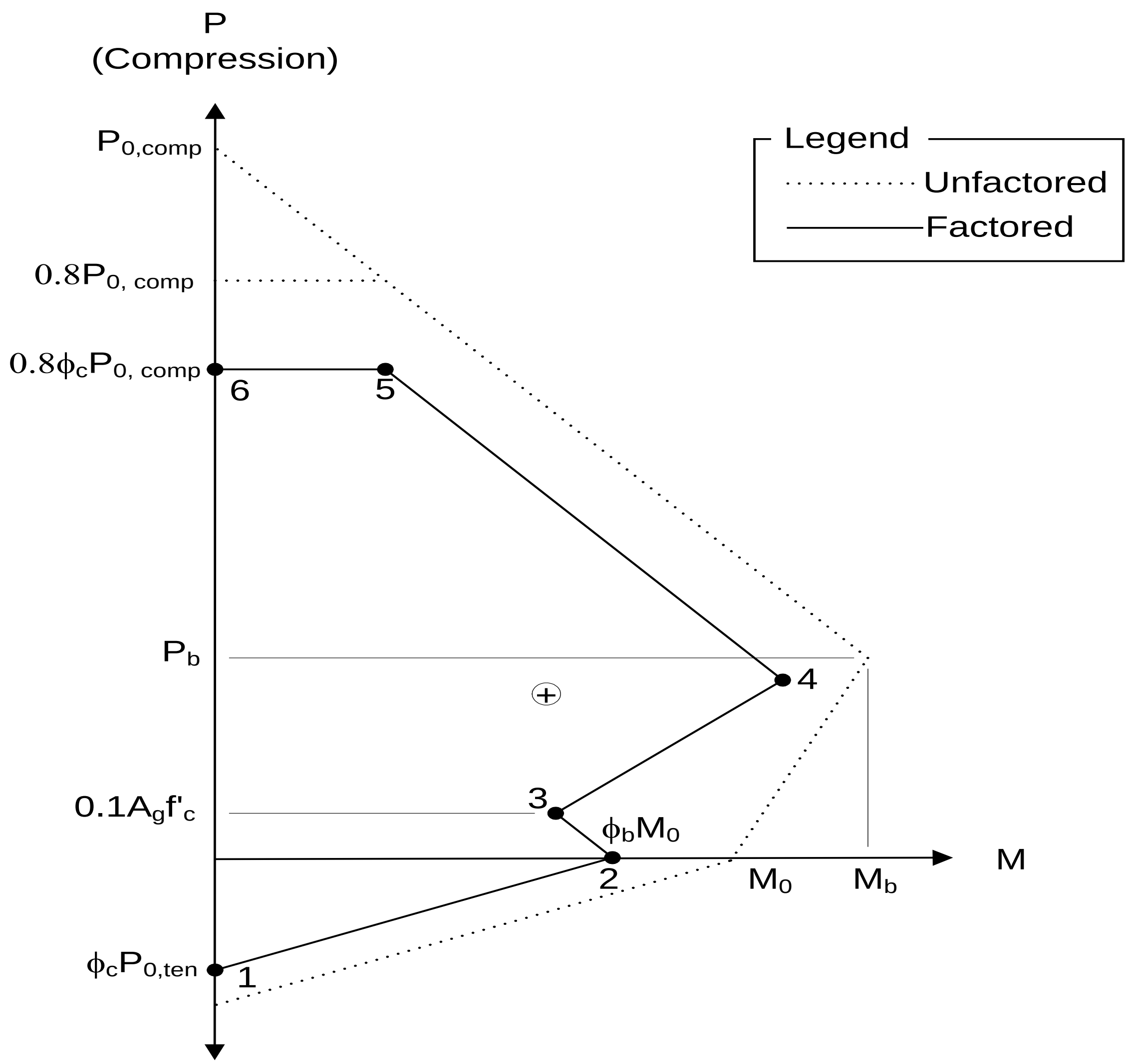
$$a_b = \beta_1 x_b$$

$$M_b = C_c \left(d - \frac{a_b}{2} - d'' \right) + T d''$$

$$P_{0,ten} = A_g f_y$$

If any of the factored loads falls outside the strength curve, then A_s is increased by 0.01 in^2 and another strength curve is constructed. Each load is checked against corresponding strength and the whole procedure is repeated until A_s provided is such that all load points fall within the strength curve.

If all factored loads are within the strength curve, then A_s is decreased by 0.01 in^2 and another strength curve is constructed. Each load is checked against corresponding strength and the whole procedure is repeated until A_s provided is such that at least one point falls on or very near the curve and all other load points are still within the strength curve.



1 - Pure Tension $[0,\ \phi_c P_{0,ten}]$

2 - Pure Flexure $[\phi_b M_0,\ 0]$

3 - Strength Reduction Factor Transition

$$\left[\phi_c\left(M_o\,\frac{0.1f'_c A_g\left(M_b - M_0\right)}{P_b}\right), 0.1f'_c A_g\right]$$

4 - Balanced Strain $[\phi_c M_b,\ \phi_c P_b]$

5 - Horizontal line thru 6

6 - $[0,\ 0.8\phi_c P_{0,comp}]$

⊕ - Factored Load

Figure 3.5.1 Strength Curve

Then it is checked if the moment strength, ϕM_n, provided by the area of reinforcement computed by the above equation is at least 1.2 times the cracking moment, M_{cr}, computed by the following equations:

$$\Phi M_n = \Phi\left[A_s f_y \left(d - \frac{a}{2}\right)\right] \quad \text{where,} \quad a = \frac{A_s f_y}{\beta_1 f_c' b} \quad \beta_1 = 0.85 \quad \text{for} \quad f_c' \le 4.0$$

$$\beta_1 = 0.85 - 0.05(f_c' - 4.0) \quad \text{for} \quad f_c' > 4.0$$

but not < 0.65

$$M_{cr} = \frac{f_r I_g}{y_t} \quad \text{where,} \quad f_r = 7.5\sqrt{f_c'}$$

The area of reinforcement is increased until the area of reinforcement is equal to 1.33 times the area of reinforcement required by design or the above criterion is met as per AASHTO 8.17.1, whichever occurs first.

The AASHTO requirements of maximum reinforcement are also checked in accordance with AASHTO Articles 8.16.3.1.1. If the area of reinforcement provided exceeds the maximum reinforcement, the member thickness is increased and the whole process is repeated.

3.5.1.3 Serviceability Check

When the load factor method is used for design of a section, and if a reinforcement with yield strength greater than 40 ksi is specified, the program performs some additional calculations to check serviceability requirements to control flexural cracking in accordance with AASTHO 8.16.8.4. The allowable stress in the reinforcement at service load, f_{sa}, is computed by:

$$f_{sa} = \frac{z}{(2c^2 s)^{1/3}}$$

where,

z = 98 per AASHTO 17.6.4.6

c = 2” + ½ (bar diameter) for cast-in-place culvert
= 1.5” + ½ (bar diameter) for precast culvert

s = bar spacing inches

For this, the program performs the following calculations at critical sections in each member. The critical sections are: two end sections for walls or the section with the maximum area of reinforcement required by load factor design in each positive and negative moment region for slabs. Sections within a monolithic haunch are not considered.

First, for each critical section, the service load moment is computed and the area of reinforcement that was required by load factor design is stored. Then, for a given bar size or wire gauge, the maximum allowable spacing nearest to the lowest half an inch is computed which would provide at least the area of reinforcement required by load factor design. Using this spacing and bar size, next the stress in reinforcement due to service load is computed. For this the program uses an iteration process. In this process, the depth of neutral axis is assumed in each iteration. The stresses in concrete and reinforcement and corresponding internal forces are computed using the elastic theory. The moment due to internal forces is compared with the service load moment. This process is repeated until the moment due to internal forces is within 1 percent of the service load moment.

The above procedure gives the stress in reinforcement due to service load, f_s. The program next checks this stress against allowable stress in reinforcement at service load, f_{sa}. If f_s is less than f_{sa}, the bar spacing is satisfactory, and the program checks the next bar size.

If f_s is greater than f_{sa}, the bar spacing is reduced by 0.5 inch and a new f_s is calculated. The spacing is reduced until the stress due to service load is within 1.5% of the allowable stress. The maximum allowable bar spacing is stored and printed out. The above procedure is repeated for each bar size and each section mentioned before.

For a culvert with bars, the maximum bar spacings for bar sizes 5 through 11, that are required to meet the serviceability criteria for crack control, are computed and printed out. For a precast culvert with welded wire fabric, the maximum bar spacing, that is required to meet the serviceability criteria, is computed for a given wire diameter (an input value).

3.5.1.4 Design for Shear

Once the section is designed for flexure, the program next checks for shear. For this, first the shear strength provided by concrete is computed by the following equations.

For slabs when fill height is less than 2 feet:

$$V_c = \left(1.9\sqrt{f_c'} + 2500\,\rho\frac{V_u d}{M_u}\right) b\,d \qquad \text{but not} > 3.5\sqrt{f_c'}\,b\,d$$

For slabs when fill height is 2 feet or more:

$$V_c = \left(2.14\sqrt{f_c'} + 4600\,\rho \frac{V_u d}{M_u} \right) b\,d \quad \text{but not} > 4\sqrt{f_c'}\,b\,d$$

The quantity $\frac{V_u d}{M_u}$ shall not be greater than 1.0.

For single cell culverts with slabs monolithic with walls,

minimum $V_c = 3\sqrt{f_c'}\,b\,d$.

For single cell culverts with slabs simply supported,

minimum $V_c = 2.5\sqrt{f_c'}\,b\,d$.

For walls:

$$V_c = 2\left(1 + \frac{N_u}{2000\,A_g} \right) \sqrt{f_c'}\,b\,d$$

V_c is compared with factored shear V_f. If V_f is less than 1.015 ϕ V_c (1.5% tolerance is allowed), the shear strength provided by concrete is adequate and thus the section is adequate to resist shear.

If V_f exceeds ϕ V_c beyond tolerance and a design without shear reinforcement is requested, the member thickness is increased and the culvert is reanalyzed. The procedure is repeated until the above criterion is met.

If V_f exceeds ϕ V_c beyond tolerance and a design with shear reinforcement can be provided, the program calculates the maximum shear that can be carried by a group of bent up bars by the following equations:

$$V_s = \frac{\left(V_f - \Phi V_c \right)}{\Phi}$$

where, ϕ = 0.85 for cast-in-place culvert

= 0.9 for precast culvert

$$V_{s\,max} = 3\sqrt{f_c'}\,b\,d$$

If V_s is greater than V_{smax}, the member thickness is increased and the culvert is reanalyzed. The procedure is repeated until the above criterion is met.

If V_s is less than or equal to V_{smax}, the area of shear reinforcement is computed using the following equation:

$$A_v = \frac{V_s}{f_y \sin\alpha}$$

3.5.2 Service Load Design

If the service load design is specified as a design method, the program designs the sections of the wall and slab in accordance with applicable provisions of AASHTO 8.15 Service Load Design Method (Allowable Stress Design).

3.5.2.1 Member Thickness for Flexure

The thickness required at a section is computed by the following equation neglecting the effect of an axial load (refer to Figure 3.5.2 below).

$$d = \sqrt{\frac{M}{0.5 f_{ca}\, b\, j\, k}}$$

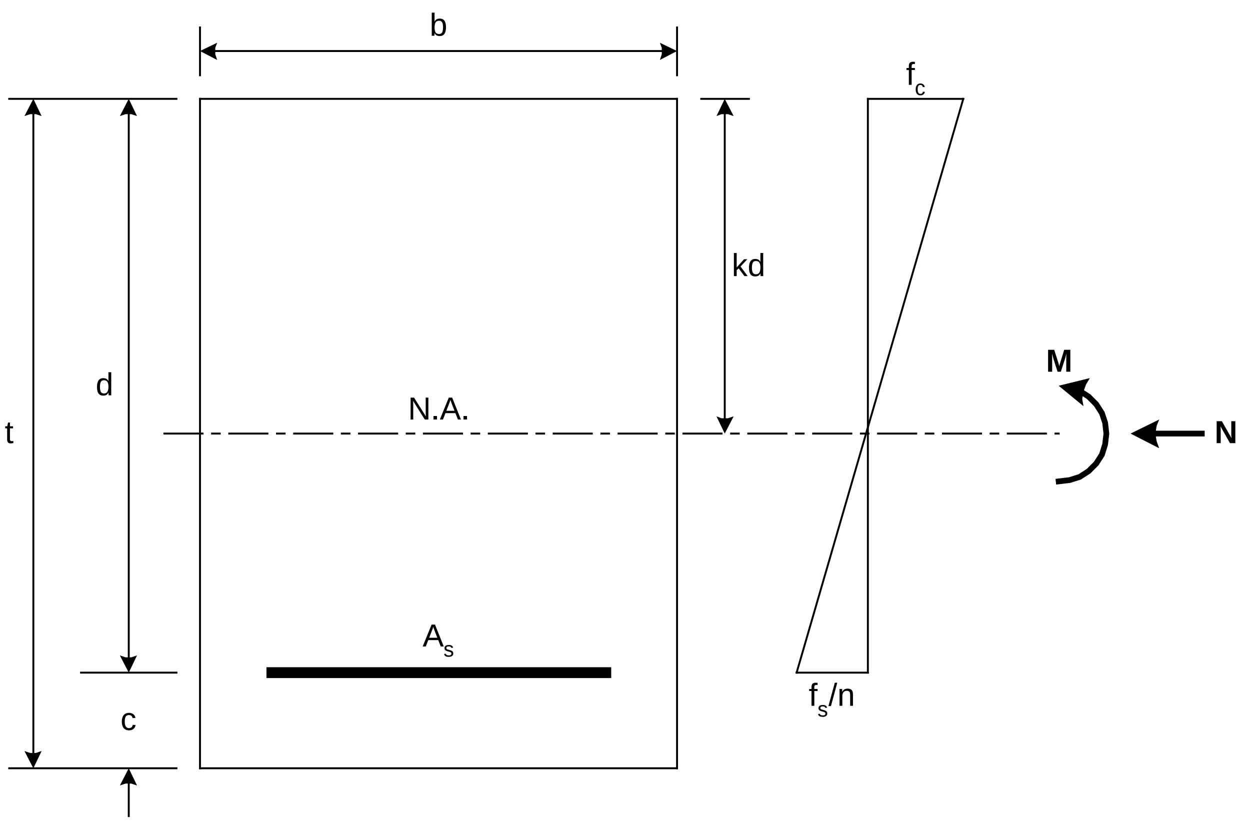


Figure 3.5.2 Section Design

3.5.2.2 Flexural Reinforcement

The area of reinforcement is first computed by solving the following equations.

The service loads M and N are converted to an equivalent moment N_e by:

$$N_e = M + N\left(\frac{t}{2} - c\right)$$

The balanced moment M_b is computed by:

$$M_b = \frac{1}{2} f_c\, b\, j\, k\, d^2 \qquad \text{where,} \quad k = \frac{1}{1 + f_s/(n f_c)}$$

$$\text{and,} \quad j = 1 - \frac{k}{3}$$

First it is determined whether the section under consideration is under-reinforced (N_e less than M_b) or over-reinforced (N_e greater than M_b).

The depth of neutral axis, x, for an under-reinforced section is computed by solving the following cubic equation.

$$\frac{f_{sa}\, b}{6n} x^3 - \frac{f_{sa}\, b\, d}{2n} x^2 - N_e\, x + N_e\, d = 0$$

The depth of neutral axis, x, for an over-reinforced section is computed by solving the following quadratic equation.

$$\frac{f_{ca}\, b}{6} x^2 - \frac{f_{ca}\, b\, d}{2} x + N_e = 0$$

The factor k is determined from:

$$k = \frac{x}{d}$$

The area of flexural reinforcement A_s is then determined from:

$$A_s = \frac{N_e}{f_s\, j\, d} - \frac{N}{f_s}$$ where, f_s = actual steel stress

= f_{sa} if the section is under-reinforced

= $f_{ca}\left(\frac{1-k}{k}\right)n$ if the section is over-reinforced

Then it is checked if the moment strength, ϕM_n, provided by the area of reinforcement computed by the above equation is at least 1.2 times the cracking moment, M_{cr}, computed by the following equations:

$$\Phi M_n = \Phi\left[A_s f_y \left(d - \frac{a}{2}\right)\right]$$ where, $a = \frac{A_s f_y}{\beta_1 f_c' b}$

$\beta_1 = 0.85$ for $f_c' \le 4.0$

$\beta_1 = 0.85 - 0.05(f_c' - 4.0)$ for $f_c' > 4.0$

but not < 0.65

$$M_{cr} = \frac{f_r I_g}{y_t}$$ where, $f_r = 7.5\sqrt{f_c'}$

The area of reinforcement is increased until the area of reinforcement is equal to 1.33 times the area of reinforcement required by design or the above criterion is met as per AASHTO 8.17.1, whichever occurs first.

3.5.2.3 Design for Shear

Once the section is designed for flexure, the program next checks for shear. For this, first the shear stress at a section is computed by:

$$v = \frac{V}{b\,d}$$

Next the allowable shear stress that can be carried by concrete is computed by the following equations.

For slabs when fill height is less than 2 feet:

$$v_c = 0.9\sqrt{f_c'} + 1100\ \rho \frac{V\,d}{M} \qquad \text{but not} > 1.6\sqrt{f_c'}$$

For slabs when fill height is 2 feet or more:

$$v_c = \sqrt{f_c'} + 2200\ \rho \frac{V\,d}{M} \qquad \text{but not} > 1.8\sqrt{f_c'}$$

The quantity $\frac{V\,d}{M}$ shall not be greater than 1.0.

For single cell culverts with slabs monolithic with walls,

$$\text{minimum } v_c = 1.4\sqrt{f_c'}$$

For single cell culverts with slabs simply supported,

$$\text{minimum } v_c = 1.2\sqrt{f_c'}$$

For walls:

$$v_c = 0.9\left(1 + 0.0006\frac{N_v}{2000\,A_g}\right)\sqrt{f_c'}$$

The value of v_c is compared with v. If v is less than 1.015 v_c (1.5% overstress is allowed), the shear stress in concrete is within allowable limits and thus the section is adequate to resist shear.

If v exceeds v_c beyond tolerance and a design without shear reinforcement is requested, the member thickness is increased and the culvert is reanalyzed. The procedure is repeated until the above criterion is met.

If v exceeds v_c beyond tolerance and a design with shear reinforcement can be provided, the program calculates the maximum shear stress that can be carried by a group of bent-up bars by the following equations:

$$v_s = v - v_c$$

$$v_{s\,max} = 1.5\sqrt{f_c'}$$

If v_s is greater than v_{smax}, the member thickness is increased and the culvert is reanalyzed. The procedure is repeated until the above criterion is met.

If v_s is less than or equal to v_{smax}, the area of shear reinforcement is computed using the following equation:

$$A_V = \frac{v_S\, b\ d}{f_S \sin \alpha}$$

3.6 LIVE LOAD RATINGS

When live load is applicable, the program calculates the flexural and shear ratings based on either the Load Factor Method or the Service Load Method. The ratings are computed for H20, HS20, ML-80, TK527, and P-82 loadings. If a special live load is entered, the ratings are given for that loading.

The program calculates the Inventory and Operating ratings based on flexure and shear using the equations given later in this section. The moments, shears and stresses due to the dead load, earth pressure and live load at different sections are calculated and stored as explained earlier. The Rating Factor is then computed by the following formula:

$$\text{Rating Factor} = \frac{\text{Section Capacity or Allowable Stress} - (D + E)}{(L + I)}$$

The ratings are computed at the following sections. The moment rating is computed at end sections of each wall, and at end sections and the point of maximum moment in each slab. The following sections explain the equations used in computing the moment and shear rating based on the Load Factor and Service Load Methods.

3.6.1 Service Load Ratings

1. The allowable stresses, f_{cir}, f_{sir}, f_{cor} and f_{sor}, for inventory and operating rating for concrete and steel respectively are set according to AASHTO Maintenance Manual.
2. Next, the dead load stresses, f_{cdl} and f_{sdl}, due to dead load plus earth pressure moment and axial force are calculated. The program uses an iterative process to determine the location of the neutral axis and then finds stresses using the straight line theory of stress-strain relation.
3. The program then calculates the live load stresses, f_{cll} and f_{sll}, due to live load moment and axial force using the same procedure used for calculating dead load stresses.

4. The ratings are calculated by the following equations:

$$IR_1 = \frac{f_{cir} - f_{cdl}}{f_{cll}} \qquad OR_1 = \frac{f_{cor} - f_{cdl}}{f_{cll}}$$

$$IR_2 = \frac{f_{sir} - f_{sdl}}{f_{sll}} \qquad OR_2 = \frac{f_{sor} - f_{sdl}}{f_{sll}}$$

$$IR = Smaller\ of\ IR_1\ and\ IR_2 \qquad OR = Smaller\ of\ OR_1\ and\ OR_2$$

5. The shear capacity of the section for Inventory Rating, V_{Cir}, is calculated using the following equation:

$V_{Cir} = v_{cir}\, bd + V_{sir}$ where,

$v_{cir} = v_c$	As defined on pages 3-28 and 3-29 for 1974 Interim and later specifications.
$v_{cir} = 0.03 f_c'$	for 1973 and earlier specifications, but not greater than 90 psi.
$V_{sir} = A_V \sin\alpha\, f_{sir}$	but not greater than $1.5\sqrt{f_c'}\,bd$

6. The Inventory Rating for shear is calculated by the following equation:

$$IR = \frac{V_{Cir} - V_D - V_E}{V_{L+I}}$$

7. The shear capacity of the section for Operating Rating, V_{Cor}, is computed by:

$V_{Cor} = v_{cor}\, bd + V_{sor}$ where,

$v_{cor} = 1.27\, v_{cir}$

$v_{sor} = f_{sor}$

$V_{sor} = A_V \sin\alpha\, v_{sor}$ but not greater than

$(1.27)(1.5)\sqrt{f_c'}\,bd$

* Note: To maintain the same factor of safety for service load and load factor methods, the Bureau of Design has decided to use this value.

8. The Operating Rating for shear is calculated by the following equation:

$$OR = \frac{V_{Cor} - V_D - V_E}{V_{L+I}}$$

3.6.2 Load Factor Ratings

1. For a given section, the member properties and the area of flexural reinforcement are known. The strength curve (flexure-axial interaction diagram) for the section is constructed as explained under Load Factor Design. The combined moment and axial force at a section due to dead loads and earth pressure are determined. This gives the (DL+E) load point (shown as 7 on Figure 3.6.1 on page 3-36). The combined moment and axial force at a section due to dead loads, earth pressure and live load are determined. This gives the (DL+E+LL) load point (shown as 8 on Figure 3.6.1). A straight line passing through the (DL+E) point and the (DL+E+LL) point is intersected with the strength curve (point 9 in Figure 3.6.1). The coordinate of this point along the moment axis of the strength curve is the moment capacity M_U of the section.

2. Inventory and Operating Rating factors for moment are computed by the following equations:

$$IR = \frac{M_u - \gamma\,\beta_D M_D - \gamma\,\beta_E M_E}{\gamma\,\beta_L M_{L+I}}$$

$$OR = \frac{M_u - \gamma\,\beta_D M_D - \gamma\,\beta_E M_E}{\gamma(1.0) M_{L+I}}$$

3. The shear capacity of the section is computed by:

$$V_U = \Phi\left[V_c + V_s\right]$$

where,

For slabs when fill height is less than 2 feet:

$$V_c = \left(1.9\sqrt{f_c'} + 2500\,\rho\frac{V_u d}{M_u}\right) b\,d$$

but not $> 3.5\sqrt{f_c'}\,b\,d$

For slabs when fill height is 2 feet or more:

$$V_c = \left(2.14\sqrt{f_c'} + 4600\,\rho\frac{V_u d}{M_u}\right) b\,d$$

but not $> 4\sqrt{f_c'}\,b\,d$

The quantity $\frac{V_u d}{M_u}$ shall not be greater than 1.0.

For single cell culverts with slabs monolithic with walls,

Minimum $V_c = 3\sqrt{f_c'}\,b\,d$.

For single cell culverts with slabs simply supported,

Minimum $V_c = 2.5\sqrt{f_c'}\,b\,d$.

For walls:

$$V_c = 2\left(1 + \frac{N_u}{2000\,A_g}\right)\sqrt{f_c'}\,b\,d$$

$V_s = A_v \sin\alpha\, f_y$ but not greater than $3\sqrt{f_c'}\,b\,d$

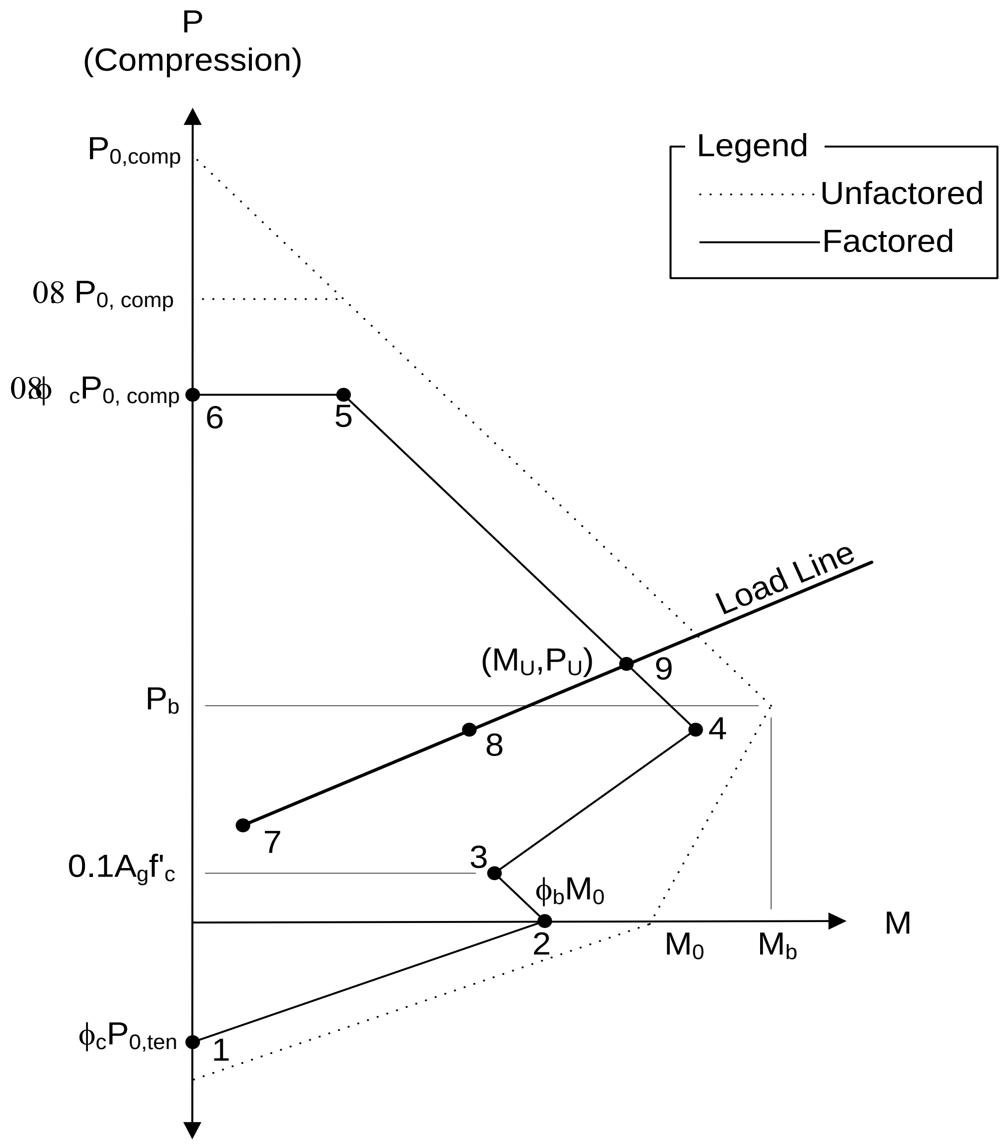
$\Phi = 0.85$ for cast-in-place culvert

$\Phi = 0.9$ for precast culvert

4. Inventory and Operating Rating factors for shear are computed by:

$$IR = \frac{V_u - \gamma\,\beta_D V_D - \gamma\,\beta_E V_E}{\gamma\,\beta_L V_{L+I}}$$

$$OR = \frac{V_u - \gamma\,\beta_D V_D - \gamma\,\beta_E V_E}{\gamma(1.0)V_{L+I}}$$



1 - Pure Tension $[0, \phi_c P_0]$

2 - Pure Flexure $[\phi_b M_0, 0]$

3 - Strength Reduction Factor Transition

$$\left[\phi_c\left(M_o \frac{0.1f_c' A_g\left(M_b - M_0\right)}{P_b}\right), 0.1f_c' A_g\right]$$

4 - Balanced Strain $[\phi_c M_b, \phi_c P_b]$

5 - Horizontal line thru 6

6 - $[0,\ 0.8\phi_c P_0]$

7 - (DL+E) Load Point

8 - (DL+E+LL) Load Point

9 - Strength Point

Figure 3.6.1 Moment Capacity of a Section

3.7 FOUNDATION PRESSURE

The maximum foundation pressure is calculated based on a combination of total dead load including water at full depth and the live load without impact.

When the height of fill is less than 2 feet, axle loads are distributed over a width of 2E, where E is (4 + 0.06S) but not greater than 7.0 feet. Also, E is limited to the minimum segment length for a precast culvert.

When the height of fill is 2 feet or more, concentrated loads are considered uniformly distributed over a square with sides equal to 1.75 times the height of fill.

The weight of water is acting on the clear span portions of the bottom slab.

An iteration process is used to find the live load position that causes the maximum foundation pressure at the left edge of the culvert. For each load position, the total dead load is placed as a uniform load over the entire span of the culvert and the eccentricity (e_L) in the L direction is calculated for that combination of dead load and live load. The actual maximum contact pressure for a one-foot segment of culvert is determined as follows:

For e_L < L/6

$$q_{max} = \frac{Q\left[1+\left(6e_L/L\right)\right]}{L}$$

For L/6 < e_L < L/2

$$q_{max} = \frac{2Q}{\left(3\left[(L/2)-e_L\right]\right)}$$

3.8 CONSTANTS, ASSUMPTIONS AND CRITERIA

Certain assumptions, constants and design criteria used in the program are listed here for reference. For details on specifications refer to the AASHTO Specifications and the Department Design Manual Part 4.

1. One-foot length of the structure is considered for design.
2. The weight of concrete is assumed to be equal to 150 lbs/ft^3.

3. The modulus of elasticity of concrete, E_c, is computed by the following formula:

   $E_c = (145)^{1.5}(33)\sqrt{f_c'}$ where E_c and f_c' are in psi.

4. The modulus of elasticity of steel, E_s, is assumed to be equal to 29,000,000 psi.
5. For the total thickness of the top slab at grade, one half (0.5) inch thickness for integral wearing surface is assumed. However, this is not considered in the design of the effective thickness of the slab.
6. For the total thickness of the bottom slab, one half (0.5) inch thickness for scouring effects at the top surface is assumed. However, this is not considered in the design of the effective thickness of the slab.
7. For a cast-in-place culvert, the total thickness of the bottom slab includes one (1.0) inch of thickness for foundation unevenness. However, in the design of the effective thickness of the bottom slab, the thickness for foundation unevenness is neglected. For a precast culvert, the thickness for foundation unevenness is assumed as zero.
8. The total thickness of a member is used in computing the dead load and the effective thickness is used in computing the member strength or stresses.
9. If bar covers are not specified, the program assumes bar covers as shown in Figure 3.8.1on page 3-40. All covers are clear and are measured from the outer face of the bar.
10. The effective thickness of a section is computed by deducting the bar cover plus half the bar diameter plus the wearing surface thickness plus the thickness for foundation unevenness from the total thickness (See Figure 3.8.1 on page 3-40).
11. The allowable compressive stress in concrete f_{ca} is assumed to be equal to 0.4 times f_c'.
12. The sign conventions used by the program are as follows:

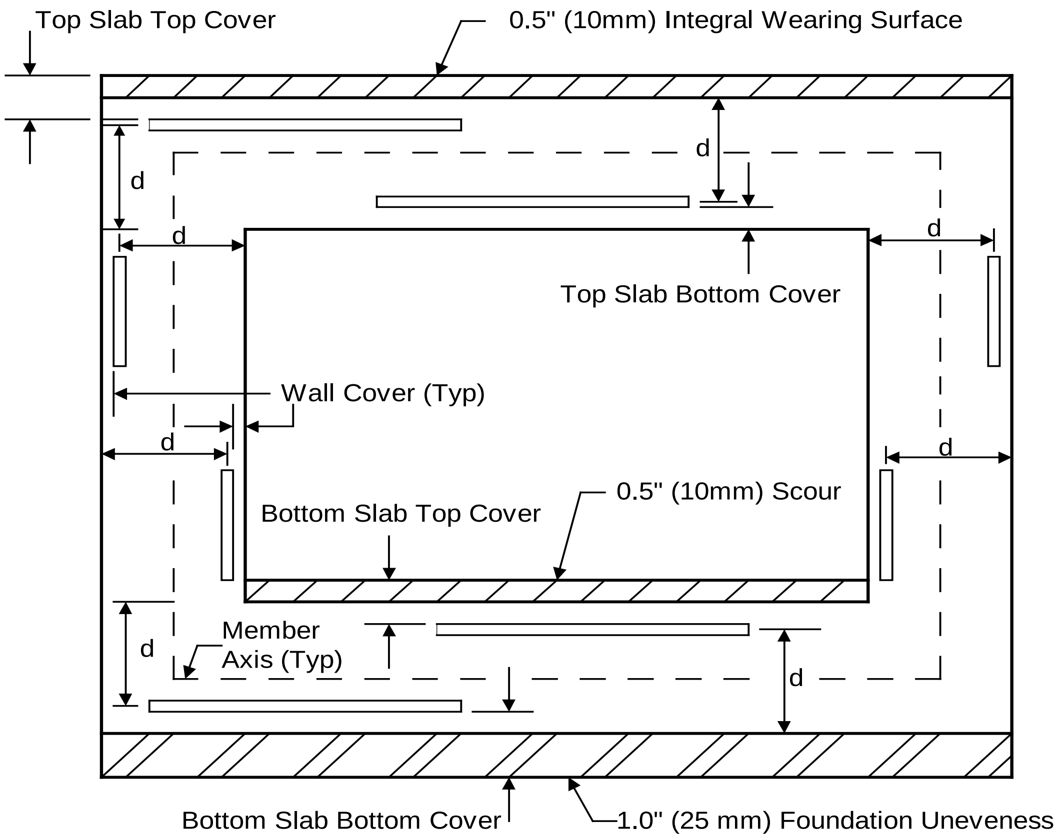
    LOADS: Positive when acting down (slab). Positive when acting from left to right (wall).

    MOMENT: Positive when it produces a tension in the bottom fiber of a slab or in the rightmost fiber of a wall.

    THRUST: Positive when it produces a compression in the section.

13. For a design problem, the minimum thickness for any member cannot be less than 4 inches. This restriction has been established arbitrarily to avoid the program to go into an endless loop.
14. For design only, if the top slab is at grade and no overlay thickness is entered, an additional dead load of 30 lbs/ft^2 due to the future wearing surface is applied on the top slab. This 30 lbs/ft^2 will not be considered when rating an existing culvert.
15. For a twin cell culvert with a fish channel, the thickness of the bottom slab at the lowest point in the fish channel and the thickness of the bottom slab in the right cell are assumed to be the same.
16. A surcharge equal to the input value of equivalent fill is considered when applicable.
17. Effects of the full value, half value, and double value of the horizontal earth pressure are considered in accordance with the provisions of AASHTO 3.20.2 and Department criteria.
18. The effect of an axial load is either neglected or considered in computing the area of flexural reinforcement and the rating as specified by user input (Refer to input data item AXIAL FORCE).

19. In checking the serviceability criteria for load factor design (AASHTO 8.16.8.4), the program uses a concrete cover of 2 inches for a cast-in-place culvert and a cover of 1.5 inches for a precast culvert. Any additional cover is considered sacrificial and is therefore not included in the cover thickness used for calculating the allowable stress for serviceability. A value of z = 98 is used for AASHTO equation (8-61) as per AASHTO 17.6.4.6.
20. Haunches are considered for stiffness only. They do not add to the effective thickness of the section for computing the flexural or shear reinforcement.
21. For a Service Load design or rating, the program assumes a default value of BETA E VERT equal to 1.0. This may result in a lower rating factor for culverts designed using the old standards which may have assumed a value of 0.7 for BETA E VERT.
22. The impact effect, if applicable, is considered for analysis, design, and ratings of all members.
23. The live load distribution per foot strip width of culvert is considered for analysis, design, and rating.



d = effective depth of the section measured to the center of reinforcement

Member axis assumed at one-half of total member thickness including sacrificial covers.

If bar covers are not specified, the minimum bar covers shown in Table 3.8.1 on page 3-41 are used.

Figure 3.8.1 Bar Covers

Table 3.8.1 Minimum Bar Covers

	Cast-in-place	Precast Welded Wire	Precast Rebars
Top Slab Under Fill, Top Bar	2.0”	A	2.0”
Top Slab At Grade, Top Bar	2.5”	2.5”	2.5”
Top Slab, Bottom Bar	2.0”	B	1.5”
Bottom Slab, Top Bar	2.5”	B+0.5”	2.0”
Bottom Slab, Bottom Bar	3.0”	B	1.5”
Wall, Both Sides	2.0”	B	1.5”

Where: A = 3d (but not less than 1” or greater than 2”) for fill ≥ 2’
2” for fill < 2’
B = 3d (but not less than 1” or greater than 1.5”)
d = wire diameter

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4

GETTING STARTED

4.1 INSTALLATION

This program is delivered via download from the Department's website. Once payment has been received by PennDOT, you will receive a confirmation e-mail with instructions on how to download the software. The download file is a self-extracting installation file for the licensed PennDOT engineering software. The engineering program runs as a 32-bit application and is supported on Windows Vista, Windows 7 (32 and 64 bit versions), and Windows 8 (32 and 64 bit versions), and Windows 10 operating systems.

Your license number, license key and registered company name, found in the e-mail received from the Department, are required to be entered when installing the program and must be entered exactly as shown in the e-mail. The license number, license key and registered company name will also be needed when requesting future versions of the program (i.e., enhancements, modifications, or error corrections), and requesting program support. A backup copy of the program download and e-mail instructions should be made and used for future installations. You may want to print the software license agreement, record the license number, license key and registered company name and keep it in a safe place.

To install the program, follow the installation instructions provided with the original e-mail from the Department.

The following files will be installed in the program destination folder, which defaults to “C:\Program Files\PennDOT\BXO5 v<version_number>\” or "C:\Program Files (x86)\PennDOT\BOX5 v<version number>\" for 64-bit operating systems:

BOX5.exe, BOX5_DLL.dll	–	Executable program and Dynamic Link Library.
BOX5 Users Manual.pdf	–	Program User’s Manual (PDF Format).
BOX5RevisionRequestForm.dotx	–	Revision Request form (MS WORD template).
GettingStarted.pdf	–	A document describing installation and running of the program.
LicenseAgreement.pdf	–	The program license agreement.
MSVCR71.dll	–	Runtime Dynamic Link Library.

The program example problem files (BOX5EX*.dat) will be installed in the program example folder, which defaults to "C:\PennDOT\BOX5 v<*version_number*> Examples\". Users must have write access to this folder in order to run the input files from this folder.

4.2 PREPARING INPUT

The program requires an ASCII input file. The input file consists of a series of data lines. Each data line consists of a number of fixed length data fields. Chapter 5 of the User's Manual includes descriptions of the input and input forms to facilitate data preparation. The input can be created using Engineering Assistant, described below, or any text editor (such as Notepad).

4.3 ENGINEERING ASSISTANT

Engineering Assistant (EngAsst) is a Windows application developed by the Pennsylvania Department of Transportation (PennDOT) to provide a graphical user interface (GUI) for PennDOT's engineering programs. The data for the input to the engineering program is presented in a user-friendly format, reflecting the implied structure of the data, showing each record type on a separate tab page in the display and showing each field on each record with a defining label.

With EngAsst the user can create a new input file, modify an existing input file, import input files, run the associated engineering program and view the output in a Windows environment. The help and documentation are provided, including text descriptions of each field, relevant images, and extended help text at both the record/tab level and the field level. Access to all parts of the Engineering Program User's Manual, where available, is also provided within EngAsst.

EngAsst is not included with this software. It requires a separate license that can be obtained through the Department's standard engineering software licensing procedures. Order forms can be obtained from program support website at http://penndot.engrprograms.com.

4.4 RUNNING THE PROGRAM WITHOUT ENGINEERING ASSISTANT

BOX5 is a FORTRAN console application program. It may be run from a command window, by double-clicking on the program icon from Windows Explorer, by selecting the shortcut from the Start menu under Program\PennDOT Programs, or by double-clicking the shortcut icon on the desktop. To run the program in a command window, the user must specify the directory in which the program has been installed or change to the directory.

The program will first prompt for an input file name, and the user should then enter the appropriate input file name. The input file must be created before running the program. Next, the program will then prompt for whether the output should be reviewed on the screen. The user should enter “Y” if the output is to be reviewed on the screen after execution or “N” if the output is not to be reviewed on the screen. The program will then prompt for the name of the output file in which the output is to be stored, and the user should then enter the desired output file name. If a file with the specified output file name already exists, the program gives the option of overwriting the existing file or entering a new output file output file name. If no output file name is entered, a default output file will be used. The program will then execute.

To cancel the program during execution, press <Ctrl C> or <Ctrl Break>.

When the program execution is completed, the output will be displayed on the screen if the user requested it. To cancel this review, enter “Q” to quit.

The user can view the output file from within EngAsst or using a text editor (such as Notepad).

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5 INPUT DATA REQUIREMENTS

5.1 INPUT FORMS

Input Forms (Figure 5.1.1, Figure 5.1.2 and Figure 5.1.3 on pages 5-2 through 5-4) have been prepared to facilitate data preparation for execution of this program. The following sections describe each data item and explain which data items must be entered for the solution of a problem.

PENNSYLVANIA DEPARTMENT OF TRANSPORTATION
BUREAU OF INFORMATION SYSTEMS

Form 1 of 3

BOX5
LFD BOX CULVERT DESIGN AND RATING

PROBLEM IDENTIFICATION

PROBLEM IDENTIFICATION
1
*
*
*

SPECIFICATIONS

METHOD	RUN TYPE	BOTTOM SLAB	HAUNCH	FISH CHANNEL	LIVE LOAD	NO. OF CELLS	TOP SLAB	NO. OF LANES	LOAD FACTORS					UNIT WT OF EARTH OR OVER-LAY	EQUIV FLUID PRESS	f 'c	f 'c (TOP SLAB AT GRADE)	REBAR GRADE	REBAR OR WIRE DIAMETER	P OR C	W OR B	SPECS	ALPHA	LIVE LOAD SURCH.	AXIAL FORCE	FILL HEIGHT ADJUST-MENT FACTOR	NO. SPEC. LL	OUTPUT
									GAMMA	BETA D	BETA L	BETA E VERT	BETA E HORZ															
1	3	4	5	6	7	8	9	10	11	14	17	20	23	26	29	32	36	40	42	46	47	48	49	51 54	55	56	61	62

CULVERT DATA

CLEAR SPAN	CLEAR HEIGHT	SLAB THICKNESS		WALL THICKNESS			HEIGHT OF FILL	% GRADE	BAR COVERS					OVERLAY THICKNESS	FILL + 100	PRECAST SEGMENT LENGTH
									TOP SLAB		BOTTOM SLAB		WALLS			
		TOP	BOTTOM	LEFT	INTERIOR	RIGHT			TOP BAR	BOT BAR	TOP BAR	BOT BAR				
1	5	9	13	17	21	25	29	32	37	41	45	49	53	57	61	62

Figure 5.1.1 Input Form 1 of 3

PENNSYLVANIA DEPARTMENT OF TRANSPORTATION
BUREAU OF INFORMATION SYSTEMS

Form 2 of 3

BOX5
LFD BOX CULVERT DESIGN AND RATING

HAUNCH DIMENSIONS

BOTTOM						TOP					
LEFT		INTERIOR		RIGHT		LEFT		INTERIOR		RIGHT	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
1	5	9	13	17	21	25	29	33	37	41	45
.	.	.	.	.	.	.	.	.	.	.	.

NON-STANDARD FISH CHANNEL

1		2		3		4	
X	Y	X	Y	X	Y	X	Y
1	5	9	13	17	21	25	29
.	.	.	.	.	.	.	.

SPECIAL LIVE LOAD

SP. LL NO.	NUMBER OF AXLES	3% INCR.	GAGE DISTANCE	PASSING DISTANCE
1	2	4	5	8
			.	.

AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST
1	5	8	12	15	19	22	26	29	33	36	40	43	47	50	54
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Figure 5.1.2 Input Form 2 of 3

PENNSYLVANIA DEPARTMENT OF TRANSPORTATION
BUREAU OF INFORMATION SYSTEMS

Form 3 of 3

BOX5
LFD BOX CULVERT DESIGN AND RATING

WALL REINFORCEMENT

WALL 1 (LEFT WALL)						WALL 2 (RIGHT WALL SINGLE CELL OR INTERIOR WALL TWIN CELL)						WALL 3 (RIGHT WALL TWIN CELL)					
BOTTOM			TOP			BOTTOM			TOP			BOTTOM			TOP		
As	SIZE	SPAC	As	SIZE	SPAC	As	SIZE	SPAC	As	SIZE	SPAC	As	SIZE	SPAC	As	SIZE	SPAC
1	5	7	10	14	16	19	23	25	28	32	34	37	41	43	46	50	52

SLAB REINFORCEMENT

SLAB NO	AT LEFT END OF SPAN						AT MID SPAN			AT RIGHT END OF SPAN					
	As	SIZE	SPAC	Av	SIZE	SPAC	As	SIZE	SPAC	As	SIZE	SPAC	Av	SIZE	SPAC
1	2	6	8	11	15	17	20	24	26	29	33	35	38	42	44

Figure 5.1.3 Input Form 3 of 3

5.2 PROBLEM IDENTIFICATION

Lines are provided to enter user comments for problem identification. The first column of each line must contain an asterisk (*) to indicate that this is a user comment. Any number of these lines of data may be supplied within the input data, but only the first three lines will be printed on the output.

5.3 SPECIFICATIONS

METHOD

Enter LF if Load Factor Design is requested.

Enter SL if Service Load Design is requested.

If a value is not entered here, the program will use the default value of LF.

RUN TYPE

The program can design and rate the culvert in several different ways. The following options are available:

Enter "A" if the member thicknesses are known and the DESIGN WITH KNOWN THICKNESSES and LIVE LOAD RATINGS are desired. If "A" is entered here, enter the actual slab and wall thicknesses in the CULVERT DATA line explained later in this section.

Enter "D" if both the member thicknesses and reinforcement are to be designed. If "D" is entered here, enter the minimum design thicknesses in the CULVERT DATA line explained later in this section. When "D" is entered here, the DESIGN FOR THICKNESS AND REINFORCEMENT, the DESIGN WITHOUT SHEAR REINFORCEMENT (if necessary) and LIVE LOAD RATINGS are given.

Enter "R" if the member thicknesses and the areas of reinforcement are known and the live load ratings are desired. If "R" is entered here, also enter the actual slab and wall thicknesses in the CULVERT DATA line and enter the WALL REINFORCEMENT and the SLAB REINFORCEMENT. Only the LIVE LOAD RATINGS are given for this option.

Enter "Z" if the member thicknesses and the areas of reinforcement are known for a cast-in place culvert and the ratings are to be calculated assuming that the culvert was designed to carry the weights of the walls and the top slab by Method B described in Section 3.3.1.2. This option is not available for a precast culvert. If "Z" is entered here, also enter the actual slab and wall thicknesses in the CULVERT DATA line and enter the WALL REINFORCEMENT and the SLAB REINFORCEMENT. Only the LIVE LOAD RATINGS are given for this option.

Leave this blank if only the DESIGN WITHOUT SHEAR REINFORCEMENT and LIVE LOAD RATINGS are desired. Enter the minimum design thicknesses in the CULVERT DATA line explained later in this section. The DESIGN FOR THICKNESS AND REINFORCEMENT and corresponding LIVE LOAD RATINGS will not be printed when this item is left blank.

When "Z" is not entered here, the weights of the walls and the top slab for a cast-in-place culvert are applied as per Method A described in Section 3.4.1.1.

BOTTOM SLAB

Enter "Y" if the bottom slab is present.
Enter "N" if the culvert does not have a bottom slab and the culvert is to be analyzed as a frame with walls fixed at the bottom (See Figure 2.1.1 on page 2-2).

HAUNCH

Enter "Y" if the culvert has monolithic haunches.
Enter "N" or leave blank if the culvert does not have monolithic haunches.
If “Y” is entered, also supply the HAUNCH DIMENSIONS data.

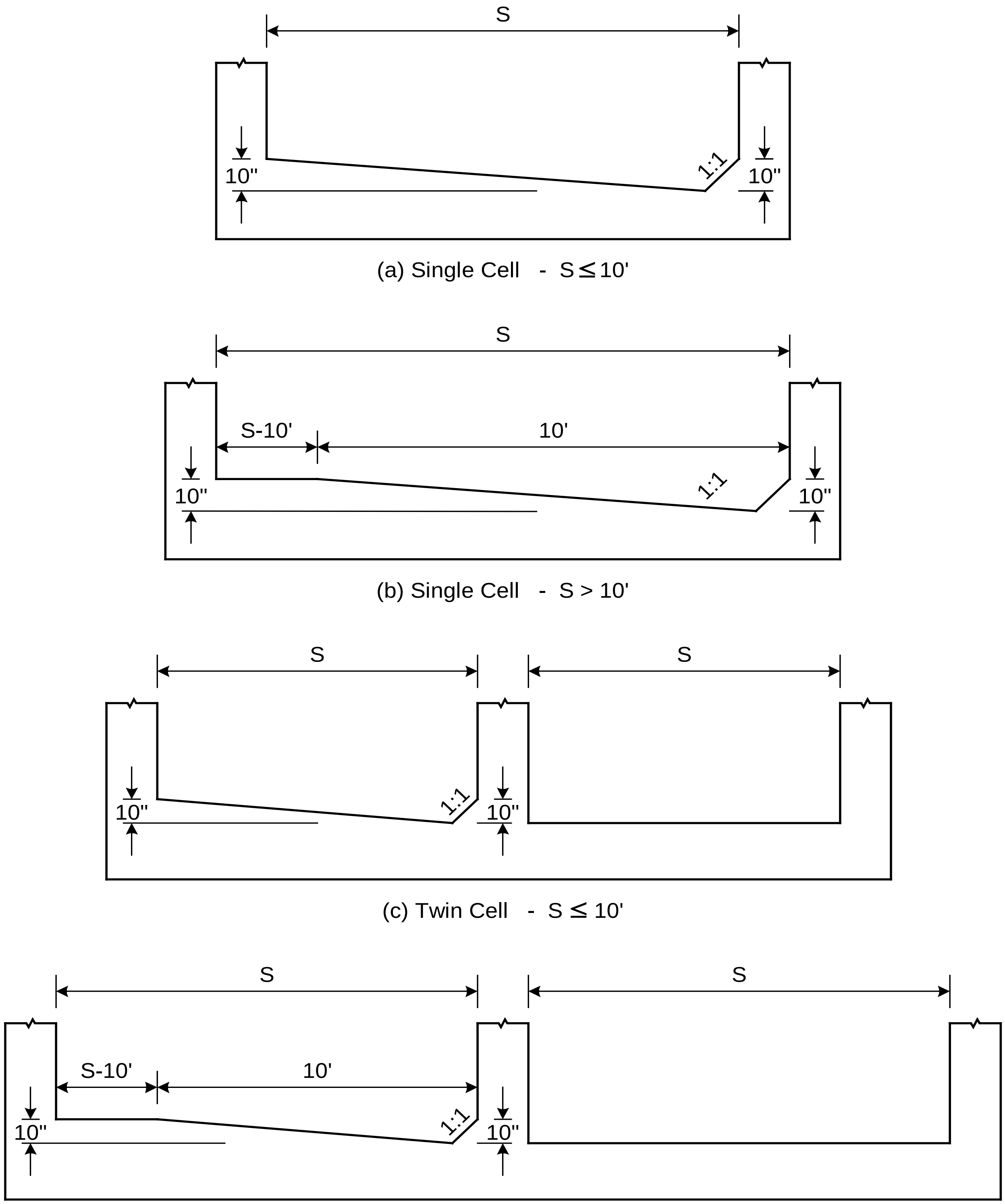
FISH CHANNEL

Leave blank if there is no fish channel or bottom slab. Check into the current Department criteria regarding the use of a fish channel for low flow treatment in a box culvert (See Circular Letter C-2928).

Enter "S" if a standard fish channel as shown in Figure 5.3.1 on page 5-8 is to be provided.

Enter "N" if the fish channel is not a standard one and provide the NON-STANDARD FISH CHANNEL data described later.

The program assumes that the fish channel is present in the left cell of a twin cell culvert. If the fish channel is present in the right cell, the user should view the cross section from the other end of the culvert and describe it as a standard or a non-standard fish channel as it may appear in the cross section (See Figure 5.3.1 on page 5-8).



(a) Single Cell - S ≤ 10'

(b) Single Cell - S > 10'

(c) Twin Cell - S ≤ 10'

(d) Twin Cell - S > 10'

Figure 5.3.1 Standard Fish Channel

LIVE LOAD

If “A”, “D” or blank is entered for RUN TYPE, enter one of the following codes based on the group of loads that are to be considered as design loads.

0 – HS25, IML and P-82 (for LFD only)

1 – HS20 and AML (for SLD only)

2 – EV2, EV3, and US6TV loadings

9 – SPEC (Special Live Load, for LFD or SLD)

If "A", "D" or blank is entered for RUN TYPE, the group of loads that are to be considered as rating loads are given as follows:

0 or 1 – H20, HS20, ML-80, TK527 and P-82 loadings

2 – EV2, EV3, and US6TV loadings

9 – SPEC (Special Live Load, for LFD or SLD)

If "R" or "Z" is entered for RUN TYPE, enter one of the following codes based on the group of loads that are to be considered as rating loads.

0 - H20, HS20, ML-80, TK527 and P-82 (for LFD or SLD)

2 – EV2, EV3, and US6TV loadings

9 - SPEC (Special Live Load, for LFD or SLD)

If 9 is entered, you shall also supply the SPECIAL LIVE LOAD data.

NO. OF CELLS

Enter 1 if it is a single cell culvert or 2 if it is a twin cell culvert.

TOP SLAB

Enter "M" if the top slab is acting as monolithic with the walls.

Enter "S" if the top slab is simply supported by the walls.

Enter "N" if there is no top slab. This option allows to analyze or design a culvert which is open at the top (sometimes used in the median crossing). This option is valid for single cell only.

The default is "M".

NO. OF LANES

The number of design traffic lanes carried by the roadway. This is used for the computation of lateral distribution of the wheel loads. A maximum of four (4) lanes are allowed.

Enter 0 if the effect of the live load is to be neglected.

LOAD FACTORS

Enter the following gamma and beta factors by which the loads must be multiplied in order to get factored or design loads acting on a section. If any of the factors is not specified, the program will assume a default value. Refer to AASHTO 3.22 and Table 3.22.1A.

GAMMA (γ)

Gamma factor. Default values are 1.0 for Service Load Design and 1.3 for Load Factor Design.

BETA D (β_D)

Beta factor for dead loads. Default value is 1.0 both for Service Load Design and Load Factor Design.

BETA L (β_L)

Beta factor for live load plus impact. Default values are 1.0 for Service Load Design and 1.67 for Load Factor Design.

BETA E VERT (β_E Vertical)

Beta factor for vertical earth pressure. Default values are 1.0 for both Service Load Design and Load Factor Design.

BETA E HORZ (β_E Horizontal)

Beta factor for horizontal earth pressure. For Service Load Design, the default value is 1.0 both for the box culvert and rigid frame (no bottom slab). For Load Factor Design, the default values are 1.0 for a box culvert and 1.3 for a rigid frame.

UNIT WEIGHT OF EARTH OR OVERLAY

The unit weight of earth or overlay material in lbs/ft^3. Normal values for this item are 120 lbs/ft^3 for earth fill or 150 lbs/ ft^3 for concrete overlay. This item correlates with either HEIGHT OF FILL or OVERLAY THICKNESS in the CULVERT DATA line.

EQUIV. FLUID PRESS

The lateral earth pressure in lbs/ ft^3. The program checks for full earth pressure, half earth pressure, and double earth pressure conditions and uses the critical condition for design. Normal value for this item is 35 lbs/ft^3.

f'c

The compressive strength of concrete in psi. This applies to the walls, bottom slab, and top slab under fill. Normal values for this item are 3,000 psi for a cast-in-place culvert and 5,000 psi for a precast culvert.

f'c (TOP SLAB AT GRADE)

The compressive strength of concrete for the top slab at grade in psi. Normal values for this item are 4,500 psi for a cast-in-place culvert and 5,000 psi for a precast culvert. Leave this blank if the top slab is under fill.

REBAR GRADE

Enter the grade of rebar or welded wire fabric as "33", "40", "50", "60", or "65".

For Load Factor Design, this value is used as the yield stress of reinforcement.

For Service Load Design, this value is used in computing the allowable stress in reinforcement. The program uses the allowable stress shown as f_{sir} in Table 3.2.1 on page 3-5.

REBAR OR WIRE DIAMETER

Enter the diameter of the largest size reinforcement bar or wire of the welded fabric that may be used as flexural reinforcement in design - inches. This value must be entered.

The program uses this value to calculate the effective depth of a member. It is also used to calculate the required cover for a precast culvert with welded wire fabric (See Figure 3.8.1 on page 3-40).

P OR C

Enter "P" if it is a precast culvert.

Enter "C" if it is a cast-in-place culvert.

If a value is not entered here, the program will use the default value of C.

W OR B

Leave this blank for a cast-in-place culvert.

For a precast culvert, enter "W" if welded wire fabric is used as reinforcement or enter "B" if bars are used as reinforcement.

SPECS

Enter 4 or leave blank if the program should use the 1974 Interim or later AASHTO Specifications for shear design and rating. For a new design this option should always be used.

Enter 3 if the program should use the 1973 or earlier AASHTO specifications for shear design and rating. This should only be used for rating analysis of an existing culvert that was designed using the 1973 or earlier AASHTO Specifications.

ALPHA (α)

Enter the angle of bent up bars to be used as shear reinforcement in degrees. The angle is measured from a horizontal line parallel to the slab. The default is 45º.

LIVE LOAD SURCHARGE

Enter the live load surcharge, expressed as a height of fill in feet. Normally, a live load surcharge of 2 or 3 feet is applied for highway bridges. Enter zero or leave blank if no live load surcharge is to be applied. The value entered here is multiplied by the value entered for EQUIV. FLUID PRESS and is applied as a horizontal load to the outside of walls.

AXIAL FORCE

Enter "Y" or leave blank if the effect of axial force is to be considered in the design and rating of a section.

Enter "N" if the effect of axial force is to be neglected in the design and rating of a section.

FILL HEIGHT ADJUSTMENT FACTOR

For a culvert untrenched on unyielding foundation, enter the Height of Cover Adjustment Factor, γ, as per Design Manual Part 4 Article 6.2.2P. The program will assume 1.0 if this item is left blank.

NO. SPEC. LL

When 9 is entered for LIVE LOAD, enter the number of special live loads. A maximum of eight special live loads are allowed. If this is not entered when 9 is entered for LIVE LOAD, the program will assume there is only one special live load and that the Special Live Load data is in the old format prior to Version 5.7.

OUTPUT

Enter 0 or leave blank for standard output.

Enter 1 for rating summary only.

Enter 2 for rating summary with input echo.

5.4 CULVERT DATA

Refer to Figure 5.4.1 on page 5-16 for input items described here.

CLEAR SPAN AND CLEAR HEIGHT

Enter these values in feet. The same values are used for both cells of a twin cell culvert. The clear height is measured from the lowest point in the fish channel. For a single cell culvert without a top slab, the clear height entered must be at the left wall. The height of the right wall is calculated by the program using the % GRADE entered later.

These two dimensions remain constant for all designs.

SLAB THICKNESS - TOP

Enter the thickness at the left end of the top slab in inches.

If the member thicknesses are known and if "A", "R" or "Z" was entered for RUN TYPE in the SPECIFICATIONS line, enter the actual top slab thickness.

If the member thicknesses are to be designed and if "D" or blank was entered for RUN TYPE in the SPECIFICATIONS line, enter the minimum design thickness for the top slab. For the minimum design thickness, refer to Table 5.4.1 on page 5-15.

Include the integral wearing thickness if the top slab is at grade, but do not include the bituminous future wearing surface.

The thicknesses of sections at other locations in the top slab at grade are computed by the program per the input item % GRADE.

SLAB THICKNESS - BOTTOM

The total thickness of the bottom slab including the thicknesses for scouring effects and foundation unevenness in inches.

If the member thicknesses are known and if "A", "R" or "Z" was entered for RUN TYPE in the SPECIFICATIONS line, enter the actual bottom slab thickness.

If the member thicknesses are to be designed and if "D" or blank was entered for RUN TYPE in the SPECIFICATIONS line, enter the minimum design thickness for the bottom slab. For the minimum design thickness, refer to Table 5.4.1 on page 5-15.

If this is a frame culvert and "N" was entered for BOTTOM SLAB in the SPECIFICATIONS line, enter the footing thickness if the point of fixity at the bottom of the wall is to be considered at the c.g. of the footing thickness. Otherwise, leave blank if the point of fixity at the bottom of the wall is to be considered at the top of the footing.

For a culvert with a fish channel, enter the thickness of the bottom slab at the lowest point in the fish channel, which must be equal to the thickness of the bottom slab in the second cell of a twin cell culvert.

WALL THICKNESS - LEFT, INTERIOR AND RIGHT

Enter the wall thickness in inches.

If the member thicknesses are known and if "A", "R" or "Z" was entered for RUN TYPE in the SPECIFICATIONS line, enter the actual wall thickness.

If the member thicknesses are to be designed and if "D" or blank was entered for RUN TYPE in the SPECIFICATIONS line, enter the minimum design thickness for the wall. For the minimum design thickness, refer to Table 5.4.1 on page 5-15.

Leave the INTERIOR thickness blank if it is a single cell culvert.

HEIGHT OF FILL

Enter the height of fill measured from the upper left corner of the culvert in feet.

This item must be left blank if the top slab is at grade.

If the top slab has an overlay, enter the thickness of overlay as OVERLAY THICKNESS and leave this item blank.

This item correlates with UNIT WEIGHT OF EARTH OR OVRLAY in the SPECIFICATIONS line.

Table 5.4.1 Minimum Design Thicknesses

Compute the minimum design thickness as specified in the following table.
For span lengths not specified herein, compute the thickness based on the nearest span length which gives a higher value. All thicknesses are inches.

Member	Cast-in-Place	Precast	
		Fill ≥ 2’	Fill < 2’
Top Slab	10” Under Fill 10.5” At Grade	12” for S ≥ 12’ s for 8’ ≤ S < 12’ s + 1” for S ≤ 7’	12” for S ≥ 12’ s for 8’ ≤ S < 12’ s + 1” for S = 7’ s + 2” for S = 6’ s + 3” for S = 5’ s + 3.5” for S = 4’ s + 4” for S = 3’ Add 0.5” if at grade
Bottom Slab	11.5”	12.5” for S > 12’ s + 0.5” for 8’ ≤ S ≤ 12’ s + 1.5” for S ≤ 7’	12.5” for S > 12’ s + 0.5” for 8’ ≤ S ≤ 12’ s + 1.5” for 5’ < S ≤ 7’ s + 2.5” for 3’ < S ≤ 5’ s + 3.5” for S = 3’
Wall	10” for H ≤ 5’ 12” for H > 5’	12” for S > 12’ s for 8’ ≤ S ≤ 12’ s + 1” for S ≤ 7’	12” for S > 12’ s for 8’ ≤ S ≤ 12’ s + 1” for S ≤ 7’

where: S = Span (feet), s = S/12 (inches) and H = Height (feet)

% GRADE

Enter the grade of the roadway in percent. A plus (+) grade is upward and a minus grade is downward, working from the left to the right of the cross section.

BAR COVERS

Enter the clear bar covers in inches, measured from the outer face of the bar, if they are different than that assumed by the program (see CONSTANTS, ASSUMPTIONS AND CRITERIA and Figure 3.8.1 on page 3-40).

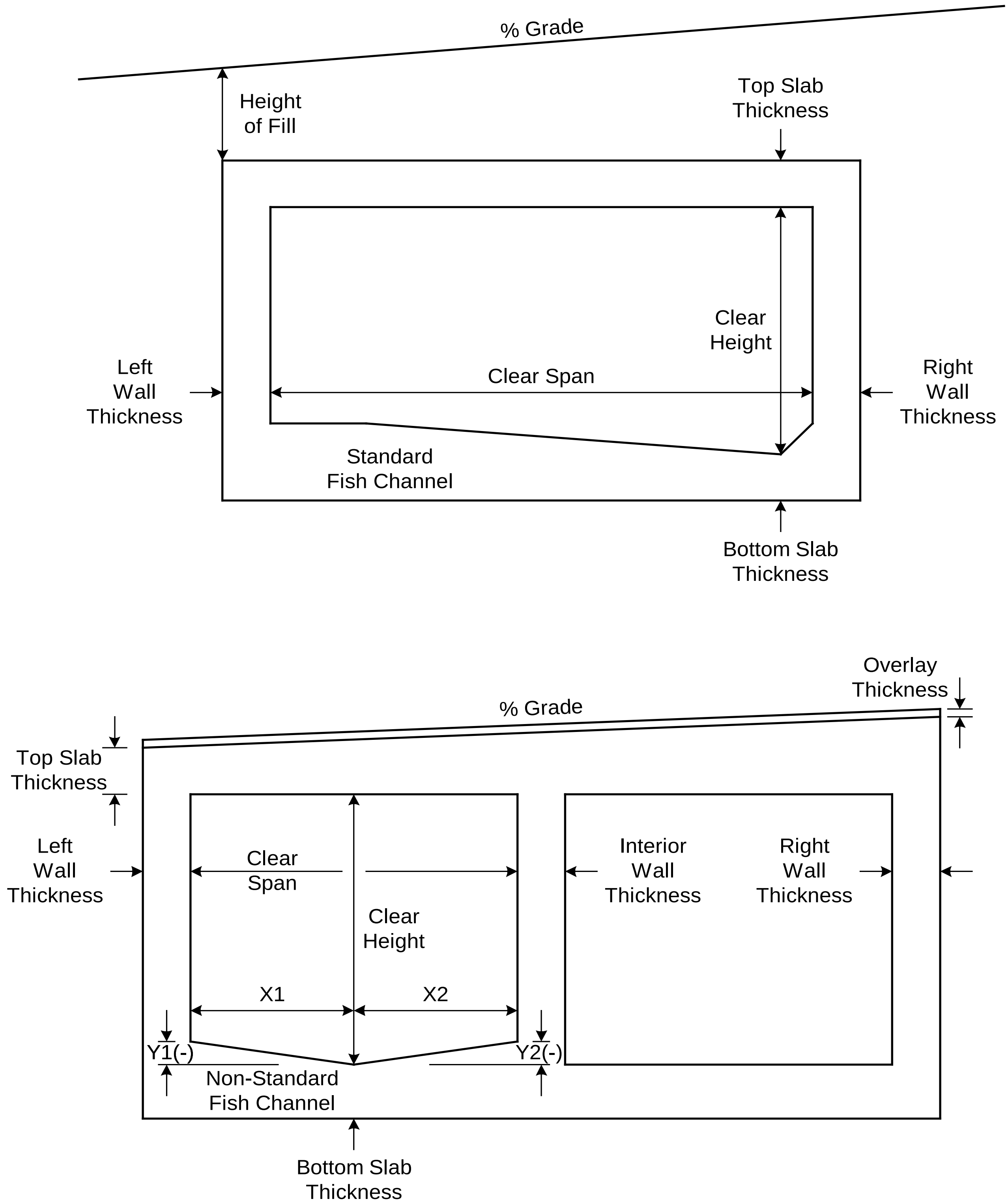


Figure 5.4.1 Culvert Data

OVERLAY THICKNESS

Enter the thickness of the overlay in inches.

This item must be left blank if the top slab is under fill.

This item correlates with UNIT WEIGHT OF EARTH OR OVRLAY in the SPECIFICATIONS line.

FILL + 100

Enter "Y" if the actual height of fill is greater than 99.9 feet. In this case, the program will add 100.0 feet to the amount entered in the HEIGHT OF FILL field. For example, if the actual height of fill is 113.7 feet, enter 13.7 in HEIGHT OF FILL and enter "Y" here.

This item should be left blank when the height of fill is less than 100.0 feet.

PRECAST SEGMENT LENGTH

Enter the minimum segment length for precast culverts, in feet. This item is used to limit the value of the distribution width, E, when calculating the live load distribution factor for precast culverts.

This item should be left blank for cast-in-place culverts or when live load is not applicable.

5.5 HAUNCH DIMENSIONS

If the culvert has monolithic haunches, i.e. if "Y" was entered for HAUNCH in the SPECIFICATIONS line, enter the horizontal ("X") and vertical ("Y") dimensions of each haunch, in inches. For a single cell culvert, provide haunch dimensions at each corner (BOTTOM LEFT, BOTTOM RIGHT, TOP LEFT, TOP RIGHT) and leave INTERIOR X and Y's blank. For a twin cell culvert, the haunch dimensions at the corners of the interior wall should also be entered (BOTTOM INTERIOR and TOP INTERIOR). The program assumes haunches to be symmetrical about the top and bottom of an interior wall. Refer to Figure 5.5.1 below.

Haunch dimensions should not be entered for the bottom of a culvert which contains a fish channel.

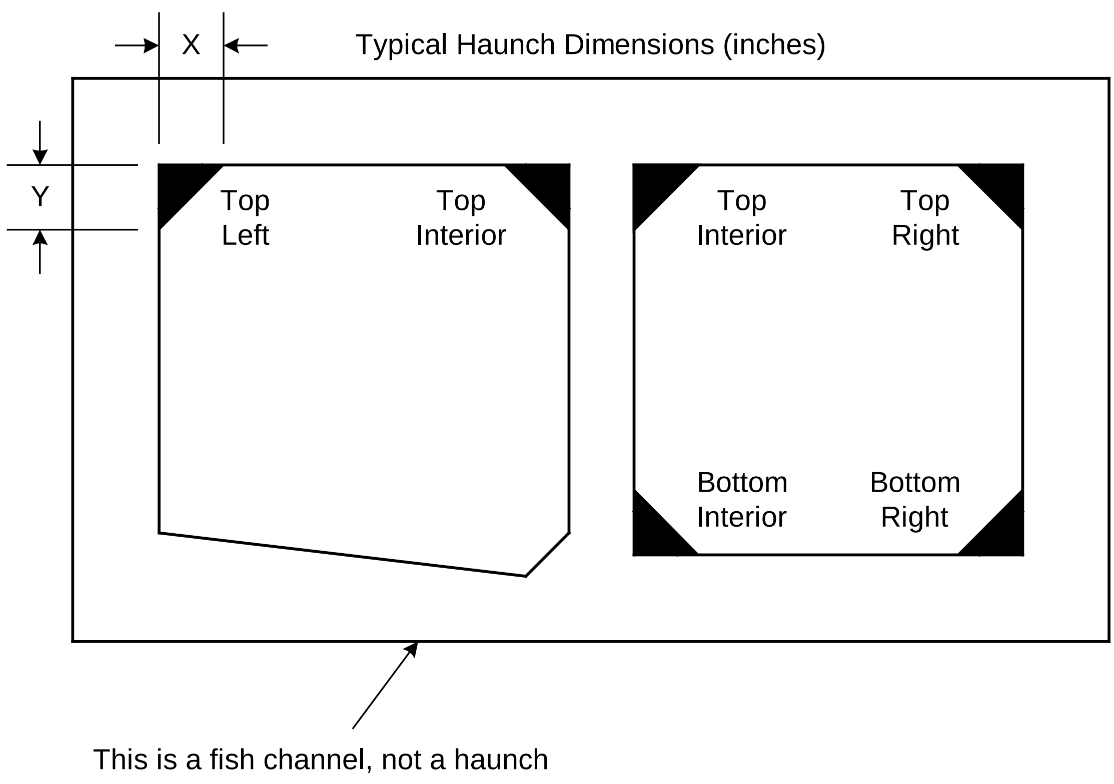


Figure 5.5.1 Haunch Dimensions

5.6 NON-STANDARD FISH CHANNEL

If the culvert has a non-standard fish channel, i.e. if "N" was entered for FISH CHANNEL in the SPECIFICATIONS line, enter the horizontal distance "X" and the rise or drop in elevation "Y" measured in feet from the previous point for all points on the top surface of the bottom slab with non-standard fish channel where there is a change in the distance or elevation or both. The first value of X is measured from the inside face of the left wall. Y is positive if it is a rise and it is negative if there is a drop-in elevation. A maximum of four (4) sets of X and Y values may be entered. The fish channel will be considered in the left cell of a twin cell culvert. Refer to Figure 5.4.1.

Do not enter this line if the culvert has a standard fish channel.

5.7 SPECIAL LIVE LOAD

If 9 was entered for the input item LIVE LOAD, enter the following values. A maximum of eighty (80) axles are allowed on a special live load. The program can analyze a maximum of eight special live loads in a given run.

SP. LL NO

The identification number of the special live loading, from 1 to 8.

NUMBER OF AXLES

The number of axles on the Truck Load of the special live load. There may be a maximum of 80 axles on a Truck Load.

3% INCR

Enter Y if all entered axle loads are to be increased by 3%. This option allows to check permit loads for a 3% over weight.

Enter N or leave blank if the entered axle loads are not to be increased.

GAGE DISTANCE

The lateral distance between the wheels on an axle in feet. This value is used in computing the lateral distribution of wheel loads. If a value is not entered here, the program will use the default value of 6 feet.

PASSING DISTANCE

The minimum lateral distance between adjacent wheels of passing vehicles in feet. If a value is not entered here, the program will use the default value of 4 feet.

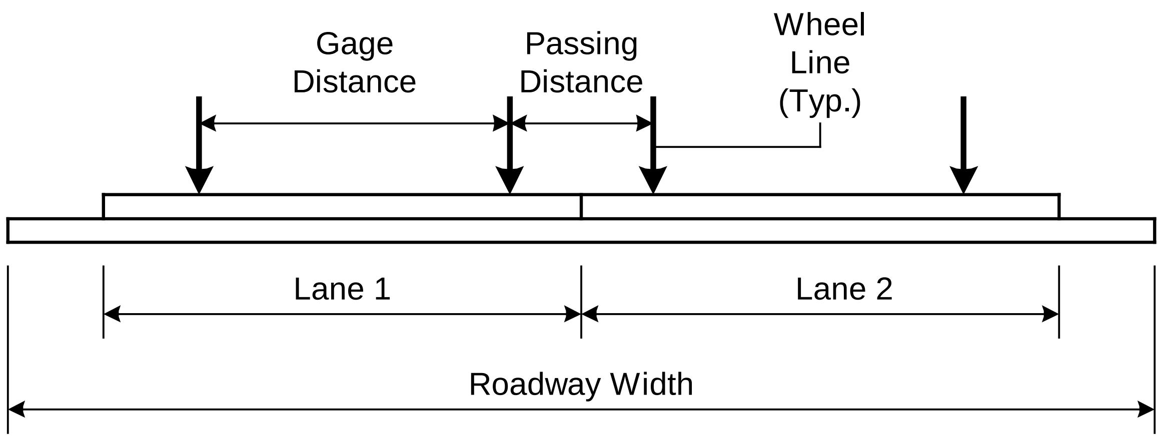
Only eight (8) axle loads can be entered on a line of AXLE LOAD and DIST data. For nine to sixteen axles, enter two lines. Enter three to ten lines when there are more than sixteen axles.

AXLE LOAD

The total load on each axle in kips. Describe the loads from left to right. The number of axle loads entered must correspond to NUMBER OF AXLES entered earlier.

DIST

The distance from the axle under consideration to the next axle in feet. For example, the fourth distance is the distance between axles 4 and 5. The total number of distances entered must be one less than the total number of axle loads.



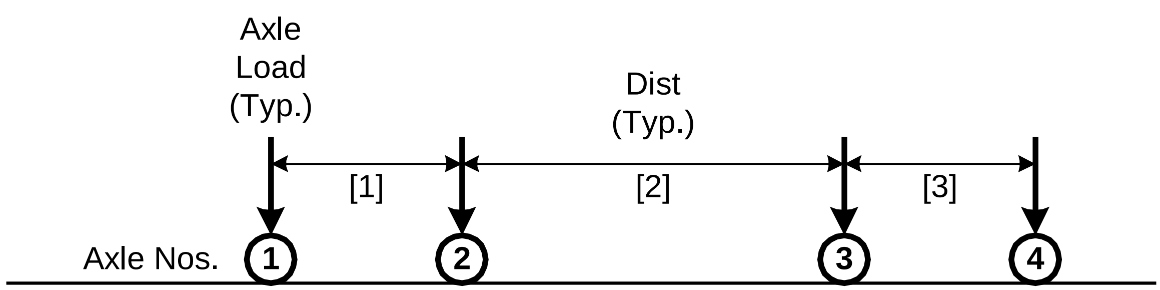


Figure 5.7.1 Special Live Load

5.8 WALL REINFORCEMENT

If "R" or "Z" is entered for the input item RUN TYPE in the SPECIFICATIONS line, enter the flexural reinforcement provided at the BOTTOM and TOP of each WALL. This reinforcement may be entered as either the area of steel (A_s) in in^2 or the standard bar size (SIZE) and spacing (SPAC) in inches. A_s is the total area of reinforcement per foot strip of the culvert. If A_s is entered, do not enter SIZE and SPAC.

Walls are numbered from left to right, and the data for WALL 2 (Interior Wall) is only entered for a twin cell culvert. Refer to Figure 5.8.1 on page 5-23.

Figure 5.8.1 on page 5-23 shows both A_s Top and A_s Bot on the outside face of the wall for a governing loading condition of negative moments occurring at both ends of the wall. If the plan shows the main reinforcement at the bottom of the wall on the inside face of the wall, as the case may be for a tall box or frame culvert, enter this reinforcement as BOTTOM A_s.

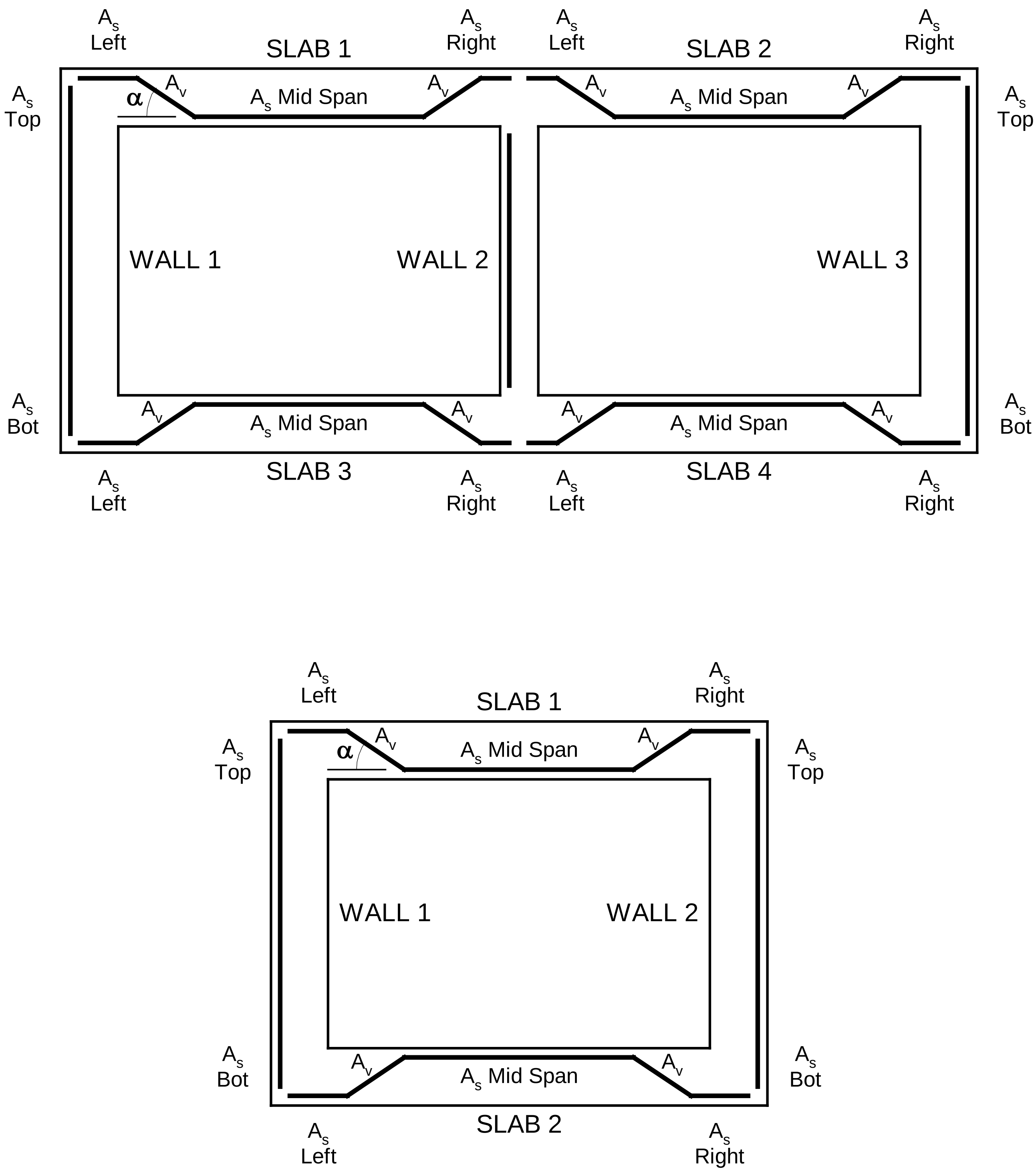


Figure 5.8.1 Wall and Slab Reinforcement

5.9 SLAB REINFORCEMENT

If "R" or "Z" is entered for the input item RUN TYPE in the SPECIFICATIONS line, enter the flexural reinforcement provided at the LEFT END, MID section and RIGHT END of span for each slab. The flexural reinforcement may be entered as either the area of steel (As) in in^2 or the standard bar size (SIZE) and spacing (SPAC) in inches. As is the total area of reinforcement per foot strip of the culvert. If As is entered, do not enter SIZE and SPAC.

Users also enter shear reinforcement at the LEFT END and RIGHT END of span for each slab when applicable. The shear reinforcement should be entered as an area of steel (Av) in in^2 or a standard bar size (SIZE) and the spacing (SPAC) of bent up bars, in inches. Enter the shear reinforcement which is at a critical section (usually at a distance "d" from the wall face) for each end of slab.

One line of data is needed for each slab, and the slabs must be entered in order. Slabs are numbered from left to right and top to bottom as shown in Figure 5.8.1 on page 5-23.

6 DESCRIPTION OF OUTPUT

The printed output consists of a repeat of all input values and the following computed values. For numbering of members and for the sign conventions used in the program, refer to the METHOD OF SOLUTION section. Also see on page 6-3.

6.1 DESIGN

The following three types of designs are given:

1. DESIGN WITH KNOWN THICKNESSES
2. DESIGN FOR THICKNESS AND REINFORCEMENT
3. DESIGN WITHOUT SHEAR REINFORCEMENT

If the member thicknesses are entered (RUN TYPE = "A"), the first design mentioned above is given. If the actual member thicknesses are not entered (RUN TYPE = "D"), the last two designs are given. For design (2), if the shear stresses were such that the shear reinforcement was not required, the third design is not given.

The following computed values are printed at the junction of haunch and uniform member, at every tenth point, at the low point in a fish channel and at a section at distance "d" equal to the effective depth from each end of a member.

DIST

The distance along the clear span of the slab or the clear height of the wall in feet. Sections in the slab are measured from left to right along the span. Sections in the wall are measured from bottom to top along the height. Refer to Figure 6.1.1 on page 6-3.

For a bottom slab with standard fish channel, the section at the notch of the fish channel (low point) is assumed critical for shear instead of at a distance "d" equal to effective depth. For a culvert with haunches, the section at the junction of haunch and uniform member thickness is considered as the critical section for shear if the distance "d" falls within the haunch.

THICK

The total thickness of the section in inches. For the design (1), these are input thicknesses, and for design (2) or (3), these are the thicknesses computed by the program.

SERVICE LOAD MOMENT OR FACTORED MOMENT

The design moment for Service Load Design or the factored moment for Load Factor Design - kip-ft.

SERVICE LOAD THRUST OR FACTORED THRUST

The thrust corresponding to the accompanying moment - kips.

The design thrust for Service Load Design or the factored thrust for Load Factor Design.

FLEX REINF

The area of reinforcement required to resist the bending moment – in^2. This reinforcement should be provided at the bottom of the slab (or the right face of the wall) if the moment printed is positive. It should be provided at the top of the slab (or the left face of the wall) if the moment printed is negative (Refer to Figure 6.1.1 on page 6-3). This is true regardless of the section distance or member. The program follows only one set of sign conventions for all members and sections (Refer to CONSTANTS, ASSUMPTIONS AND CRITERIA, Paragraph 12).

CONC STRESS

The extreme fiber compressive stress in concrete - ksi. This is printed for Service Load Design only.

STEEL STRESS

The tensile stress in reinforcement - ksi. This is printed for Service Load Design only.

NOTE:

When the FLEX REINF, CONC STRESS and STEEL STRESS are printed equal to zero, it indicates that the moment is very small compared to the axial load.

MAX SHEAR or FACTORED SHEAR

The design shear for Service Load Design or the factored shear for Load Factor Design - kips.

FACTORED THRUST

The factored axial compression (N_u) occurring simultaneously with the factored shear in a wall section - kips. This is printed for Load Factor Design only.

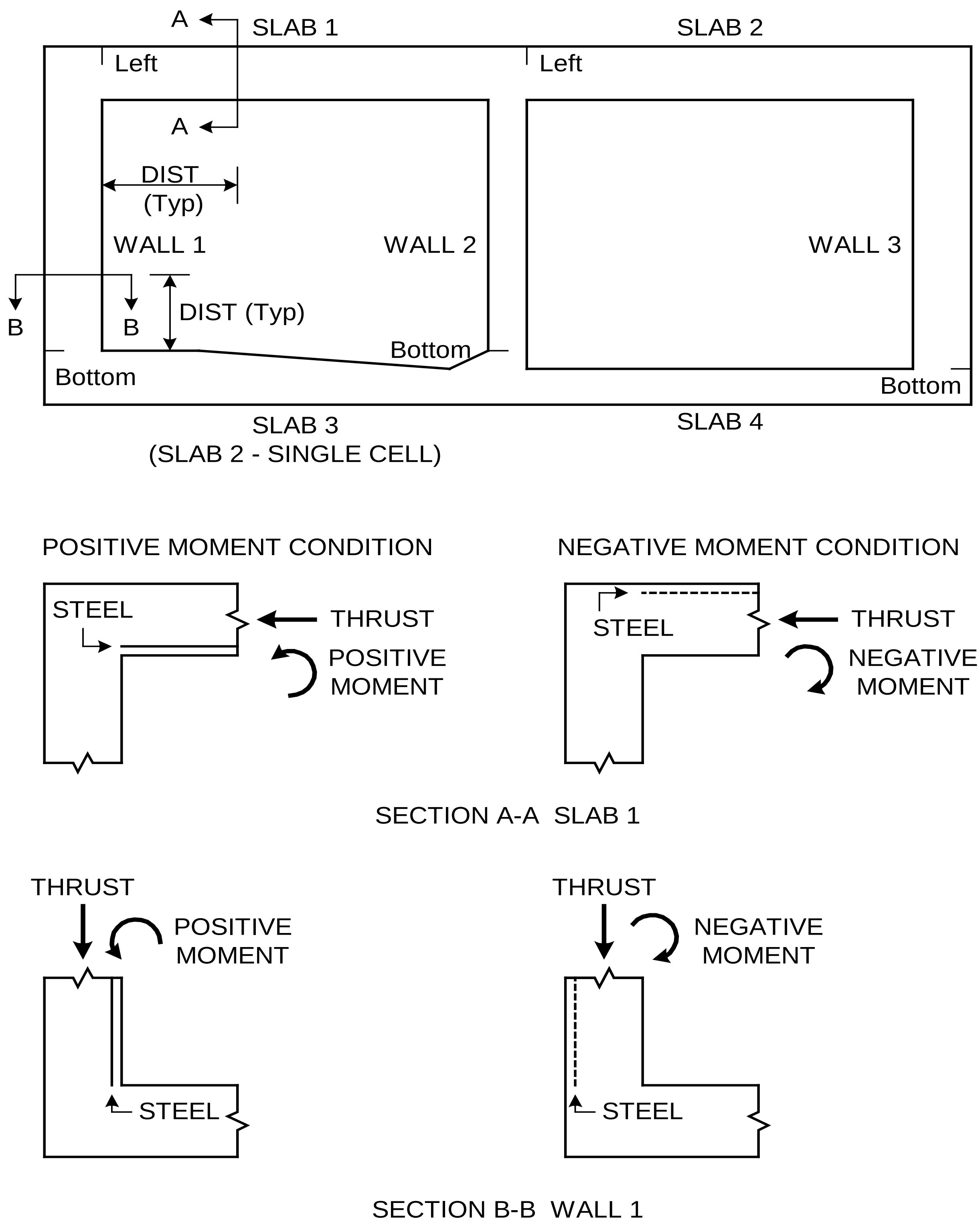


Figure 6.1.1 Members, Sections and Forces

SHEAR STRESS

The design shear stress - ksi. This is printed for Service Load Design only.

SHEAR CONC or SHEAR CAPACITY

The shear stress carried by concrete in ksi for Service Load Design or the shear strength of concrete section in kips for Load Factor Design.

SHEAR REINF

The required area of shear reinforcement – in^2.

If asterisks are printed for this item for design (1), it indicates that the shear carried by the bent up bars exceeds the maximum allowable.

BOX5 calculates the shear capacity of a slab based on the reinforcement ratio required for flexural strength. Thus, the shear reinforcement required or the thickness of slab required without shear reinforcement is based on the flexural reinforcement required for strength. If the bar size and spacing are used for which the serviceability criteria for crack control governs, the shear reinforcement or the thickness required without shear reinforcement given by the program may result in a conservative design.

6.2 REINFORCEMENT DESIGN

The following values are printed at critical sections for flexure. A section is assumed critical at the ends of each wall and at the points in the slab where the maximum reinforcement was needed in each positive and negative moment region. A serviceability check is performed only if the load factor method and reinforcement grade greater than 40 are specified.

DIST

The distance along the clear span of the slab or clear height of the wall in feet.

SERVICE LOAD MOMENT

The moment due to the service load - kip-ft.

SERVICE LOAD THRUST

The axial force due to the service load acting in combination with service load moment - kips.

FLEX REINF

The area of reinforcement required to resist bending moment at this section – in^2. This is the same value printed for FLEX REINF earlier under Section 6.1 DESIGN.

MAXIMUM BAR SPACING

The maximum bar spacing that can be used to provide the area of reinforcement required by design or to meet the serviceability criteria for crack control - inches. For a cast-in-place culvert or a precast culvert with bars, the printed values are for bar sizes 5 through 11. For a precast culvert with welded wire fabric, the value printed is for a given wire (input item REBAR OR WIRE DIA). If serviceability criteria govern and the area of reinforcement for the printed spacing exceeds the area of reinforcement required by load factor design (FLEX REINF), an "S" is printed next to the value of bar spacing.

Also printed are the following values for each design:

DEAD LOAD FOUNDATION PRESSURES

The soil pressure due to each component of dead load, i.e., fill, top slab, walls, bottom slab, water and future wearing surface - $kips/ft^2$.

MAXIMUM FOUNDATION PRESSURE

The maximum resulting soil pressure due to the total dead load, the flowing water at full depth, and the live load excluding impact - $kips/ft^2$.

When live load is applicable, the live load type, i.e., HS20, IML, -82, SPEC, etc., and position causing the maximum foundation pressure are printed.

Foundation pressures are not given for a frame culvert (no bottom slab).

VOLUME OF CONCRETE

The total volume of concrete per foot width, including haunches and excluding footings - cubic yards.

6.3 ALLOWABLE STRESSES

If "SL" is entered for METHOD, the program will print a table of allowable stresses that are used for inventory and operating ratings. The values printed are in ksi and are self-explanatory.

6.4 LIVE LOAD RATINGS

If the live load is applicable (i.e. NO. OF LANES greater than 0), HEIGHT OF FILL is less than total span, and HEIGHT OF FILL is less than eight feet for single cells, then the flexural and shear ratings are printed for critical sections.

The ratings are given for the H20, HS20, ML-80, TK527 and P-82 loadings if LIVE LOAD is entered as 0 or 1, and the ratings are given for the Special Live Load if LIVE LOAD is entered as 9.

If an "F" is printed next to the DIST, this section is critical in flexure and the rating values are for moments. A "V" designates a shear rating.

The critical sections which had the minimum inventory and operating ratings are summarized for each loading.

DIST

The distance along the clear span of the slab or clear height of the wall in feet.

DL+EP MOMENT THRUST SHEAR

For a section where the rating is governed by flexure ("F"), the moment and thrust due to dead load plus earth pressure in kip-ft and kips respectively.

For a section where the rating is governed by shear ("V"), the shear due to dead load plus earth pressure in kips and the moment occurring simultaneously in kip-ft.

The governing lateral earth pressure condition is indicated by DL+EPF for full earth pressure, DL+EPH for half earth pressure and DL+EPD for double earth pressure.

LL+I MOMENT THRUST SHEAR

For a section where the rating is governed by flexure ("F"), the moment and thrust due to live load plus impact in kip-ft and kips respectively.

For a section where the rating is governed by shear ("V"), the shear due to live load plus impact in kips and the moment occurring simultaneously in kip-ft.

ULT CAPAC (Load Factor Method)

For a section where the rating is governed by flexure ("F"), the ultimate moment capacity, M_U, of the section in kip-ft.

For a section where the rating is governed by shear ("V"), the ultimate shear capacity, V_U, of the section in kips.

FC OR VCIR (Service Load Method)

For a section where the rating is governed by flexure ("F"), the stress in extreme fiber of concrete, f_c, for dead load plus earth pressure and live load plus impact, in ksi.

For a section where the rating is governed by shear ("V"), the shear capacity of the section for Inventory Rating, V_{cir}, in kips.

FS OR VCOR (Service Load Method)

For a section where the rating is governed by flexure ("F"), the steel stress, f_s, for dead load plus earth pressure and live load plus impact, in ksi.

For a section where the rating is governed by shear ("V"), the shear capacity of the section for Operating Rating, V_{cor}, in kips.

RATING FACTOR IR OR

The rating factors for Inventory and Operating ratings respectively.

ACTUAL REINF

The area of flexural reinforcement that corresponds to the optimum area of reinforcement derived from the MAX BAR SPACING printed under REINFORCEMENT DESIGN. For a cast-in-place culvert or precast culvert with bars, the bar size and spacing are printed. For a precast culvert with welded wire fabric, the area of reinforcement is printed. This area of reinforcement may be more than the area of reinforcement printed as FLEX REINF under DESIGN FOR THICKNESS AND REINFORCEMENT or DESIGN WITHOUT SHEAR REINFORCEMENT because serviceability criteria for crack control might have governed for REINFORCEMENT DESIGN.

For RUN TYPE = "R" or "Z", this is the actual reinforcement from the SLAB REINFORCEMENT and WALL REINFORCEMENT input.

SHEAR REINF

The area of shear reinforcement at this section in in^2.

RATING TONS IR OR

The Inventory and Operating ratings in tons.

6.5 DEAD LOAD EFFECTS VS. CAPACITIES

If the live load is not applicable, i.e. NO OF LANES is entered as zero or the height of fill is such that the effects of a live load can be neglected, the program will print the dead load effects and capacities at critical sections whenever "LF" is entered for METHOD.

Since the live load is not applicable, theoretically the live load ratings are infinite. However, the values printed here will be helpful in determining whether the sections can sustain the dead load and earth pressure effects.

Refer to LIVE LOAD RATINGS for explanation of values printed here. Since the live load is not applicable, the LL+I effects are not printed.

6.6 DEAD LOAD EFFECTS AND STRESSES

If the live load is not applicable, i.e. NO OF LANES is entered as zero or the height of fill is such that the effects of a live load can be neglected, the program will print the dead load effects and stresses at critical sections whenever "SL" is entered for METHOD.

Since the live load is not applicable, theoretically the live load ratings are infinite. However, the values printed here will be helpful in determining whether the stresses produced by the dead load and earth pressure are more or less than the allowable stresses.

Refer to LIVE LOAD RATINGS for explanation of values printed here. Since the live load is not applicable, the LL+I effects are not printed.

7 FLOW CHART

7.1 GENERAL

Figure 7.1.1 on page 7-2 shows the general flow of the program.

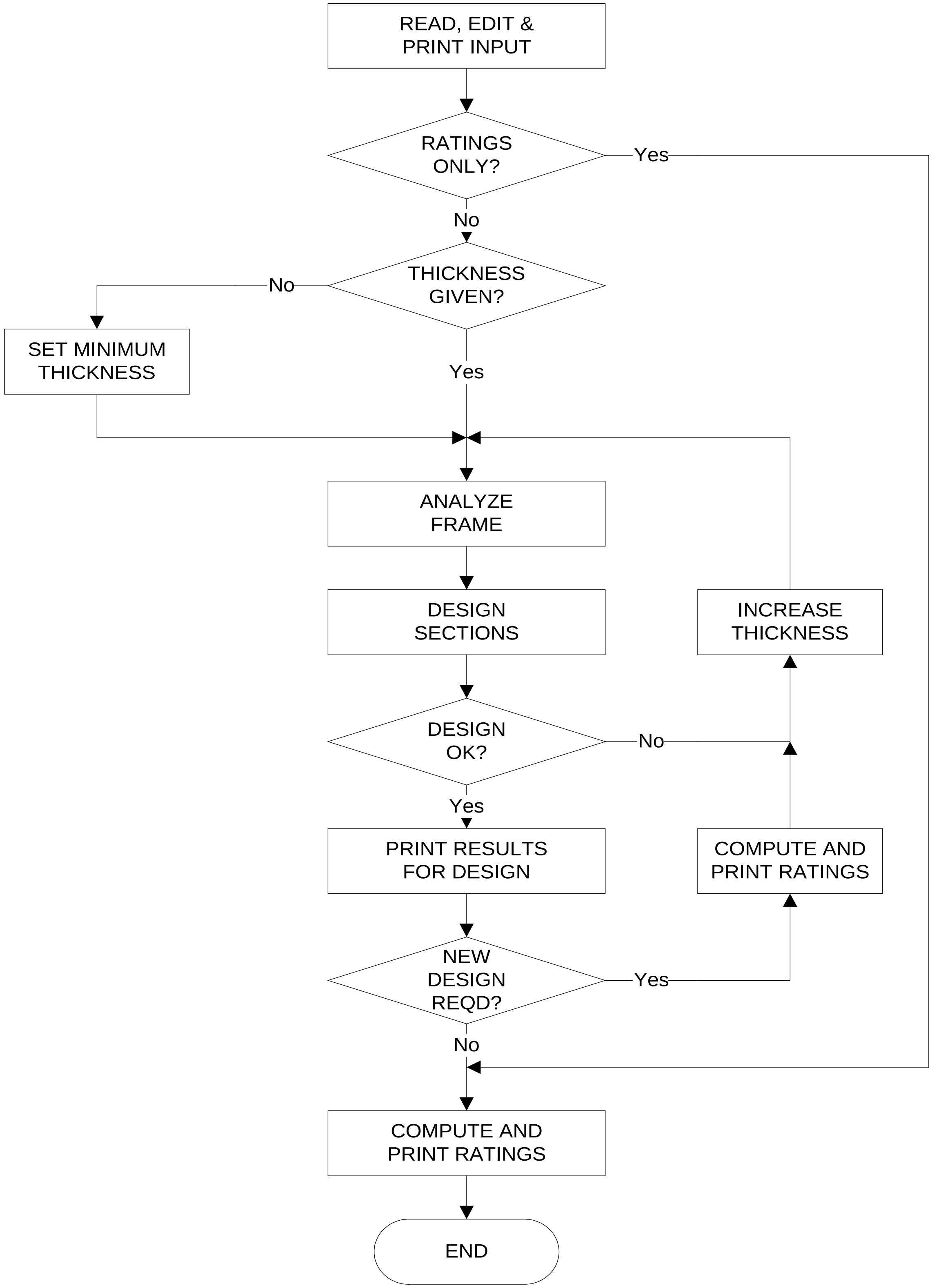


Figure 7.1.1 Program Flow Chart

8 EXAMPLE PROBLEMS

This chapter contains six (6) example problems to aid users in preparing data for their problems. A general description and a detailed description of the required input, along with completed input forms, are given for each example. Refer to Chapter 5 Input Descriptions when preparing data for your specific problem. The following six example problems are included in this chapter.

1. Example Problem 1 – Load Factor design of a precast single cell culvert that is under fill.

2. Example Problem 2 – Load Factor design with known thicknesses for a twin cell culvert with a standard fish channel that is under fill.

3. Example Problem 3 – Service Load design with known thicknesses and live load rating for a single cell culvert with a non-standard fish channel that is under fill on a negative grade.

4. Example Problem 4 – Load Factor design of a frame culvert (no bottom slab) with the top slab at grade (1%). The design is for a special live load.

5. Example Problem 5 – Load Factor rating of an existing twin cell culvert at grade (-2.91%) with a 3-inch concrete overlay.

6. Example Problem 6 – Load Factor design of a single cell culvert at grade (3.2%) with no top slab.

The actual input data files and resulting output for the example problems are not listed in this manual, but input files are included electronically with the executable program and can be run so that the output can be viewed.

8.1 EXAMPLE PROBLEM 1

8.1.1 Problem Description

This is an example of a precast single cell culvert under fill. Figure 8.1.1 on page 8-4 shows the cross section and dimensions of the culvert. The member thicknesses are to be designed. The bottom slab does not have a fish channel. Figure 8.1.2 on page 8-5 shows the completed input data sheets.

8.1.2 Input

The following input lines are entered. Refer to the completed input data sheets shown in Figure 8.1.2.

1. Problem Identification
   - Three lines are coded to enter comments to identify the problem.
   - Any number of lines may be coded, but only the first three lines will be printed on the output.

2. Specifications
   - METHOD is "LF" for Load Factor Design.
   - RUN TYPE is "D" for a design of both member thicknesses and reinforcement.
   - BOTTOM SLAB is "Y".
   - HAUNCH is "Y" to include monolithic haunches.
   - FISH CHANNEL is left blank because there is no fish channel.
   - LIVE LOAD is 0 so that the HS25, IML and P-82 loads are considered as design loads.
   - NO. OF CELLS is 1.
   - TOP SLAB is acting as monolithic with the walls. This is the default when left blank.
   - NO. OF LANES is 1.
   - LOAD FACTORS are all left blank so that the program will use all the defaults.
   - UNIT WEIGHT OF EARTH is 120 pounds per cubic foot.
   - EQUIV. FLUID PRESS. (lateral earth pressure) is 35.0 pounds per cubic foot.
   - The f 'c of the concrete is 5,000.0 psi.
   - REBAR GRADE is 65 ksi.
   - The diameter of the largest size wire reinforcement that may be used as flexural reinforcement in the design is 0.75 inches.
   - P OR C is coded as "P" for precast.
   - W OR B is coded as "W" for welded wire fabric.
   - The LIVE LOAD SURCH is equal to 3 feet of fill.

- AXIAL FORCE is coded as “Y” so that the effect of axial force is considered in the design and rating of a section.

3. Culvert Data
   - CLEAR SPAN, CLEAR HEIGHT, HEIGHT OF FILL, and % GRADE are taken from the sketch in Figure 8.1.1on page 8-4.
   - The minimum design SLAB THICKNESS for the TOP slab is 9 inches and the minimum design SLAB THICKNESS for the BOTTOM slab is 9.5 inches. Refer to Figure 8.1.1 on page 8-4.
   - The minimum design WALL THICKNESS for both the LEFT and RIGHT wall is 9.0 inches. Refer to Figure 8.1.1 Example Problem 1 – Details.
   - The minimum PRECAST SEGMENT LENGTH is 8 feet.

4. Haunch Dimensions
   - Symmetrical 6 inch monolithic haunches coded for all 4 corners as shown in Figure 8.1.1 on page 8-4.

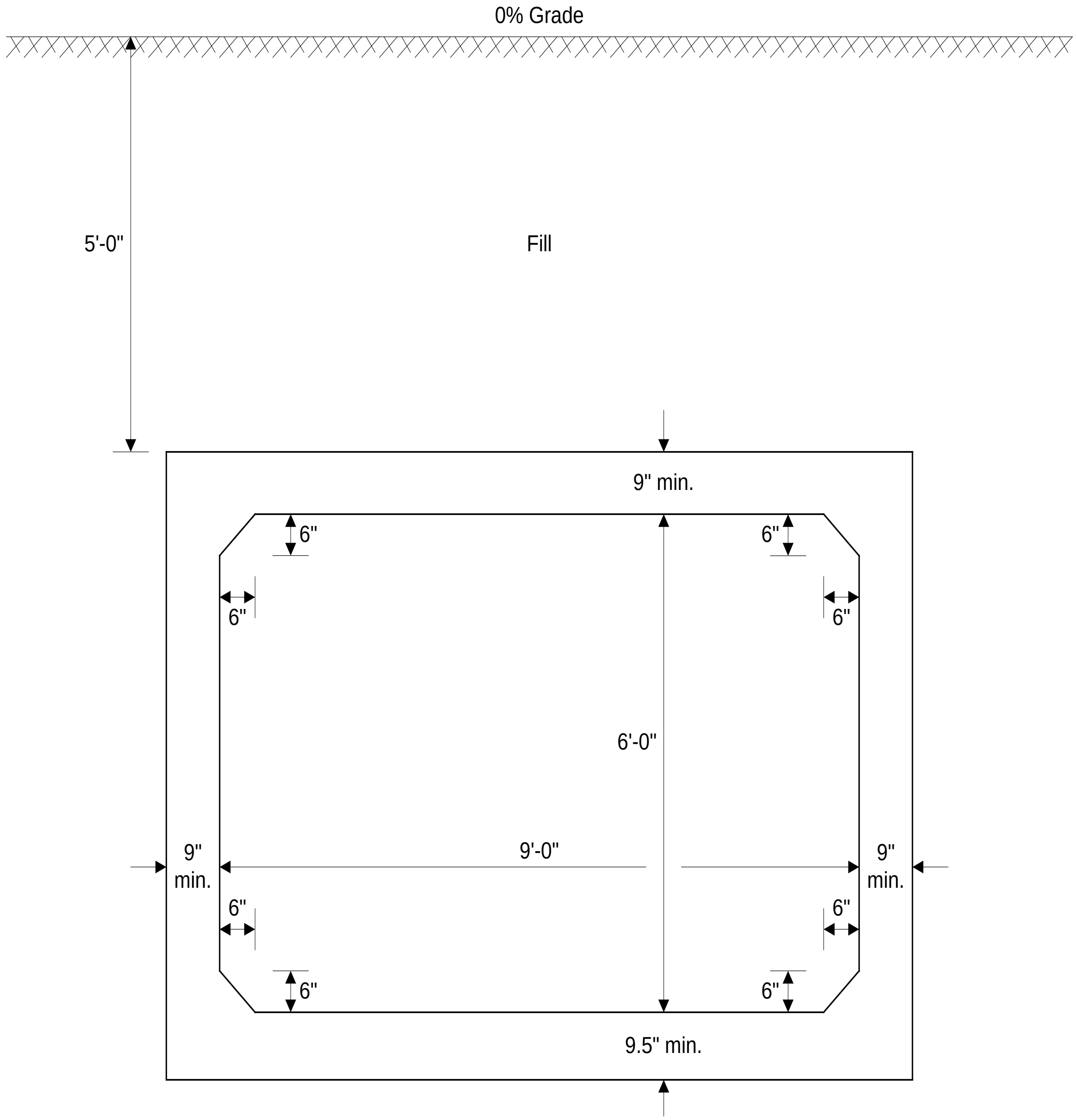


Figure 8.1.1 Example Problem 1 – Details

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Form 1 of 3

BOX5
LFD BOX CULVERT DESIGN AND RATING

PROBLEM IDENTIFICATION

1
*EXAMPLE PROBLEM 1 - LOAD FACTOR DESIGN
*PRECAST SINGLE CELL W/O FISH CHANNEL
*DESIGN THICKNESS

SPECIFICATIONS

METHOD	RUN TYPE	BOTTOM SLAB	HAUNCH	FISH CHANNEL	LIVE LOAD	NO. OF CELLS	TOP SLAB	NO. OF LANES	LOAD FACTORS: GAMMA	LOAD FACTORS: BETA D	LOAD FACTORS: BETA L	LOAD FACTORS: BETA E VERT	LOAD FACTORS: BETA E HORZ	UNIT WT OF EARTH OR OVER-LAY	EQUIV FLUID PRESS	f 'c	f 'c (TOP SLAB AT GRADE)	REBAR GRADE	REBAR OR WIRE DIAMETER	P OR C	W OR B	SPECS	ALPHA	LIVE LOAD SURCH.	AXIAL FORCE	FILL HEIGHT ADJUST-MENT FACTOR	NO. SPEC. LL	OUTPUT
1	3	4	5	6	7	8	9	10	11	14	17	20	23	26	29	32	36	40	42	46	47	48	49	51 54	55	56	61	62
LF	D	Y	Y		0	1		1	.	.	.	.	.	120	35.0	5000		65	0.750	P	W			3.00	Y	.		

CULVERT DATA

CLEAR SPAN	CLEAR HEIGHT	SLAB THICKNESS: TOP	SLAB THICKNESS: BOTTOM	WALL THICKNESS: LEFT	WALL THICKNESS: INTERIOR	WALL THICKNESS: RIGHT	HEIGHT OF FILL	% GRADE	BAR COVERS: TOP SLAB: TOP BAR	BAR COVERS: TOP SLAB: BOT BAR	BAR COVERS: BOTTOM SLAB: TOP BAR	BAR COVERS: BOTTOM SLAB: BOT BAR	BAR COVERS: WALLS	OVERLAY THICKNESS	FILL + 100	PRECAST SEGMENT LENGTH
1	5	9	13	17	21	25	29	32	37	41	45	49	53	57	61	62
9.00	6.00	9.00	9.50	9.00	.	9.00	5.0	0.00	.	.	.	.	.	.		8.00

Figure 8.1.2 Example Problem 1 – Input

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BOX5
LFD BOX CULVERT DESIGN AND RATING

Form 2 of 3

HAUNCH DIMENSIONS

BOTTOM						TOP					
LEFT		INTERIOR		RIGHT		LEFT		INTERIOR		RIGHT	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
1	5	9	13	17	21	25	29	33	37	41	45
6.00	6.00			6.00	6.00	6.00	6.00			6.00	6.00

NON-STANDARD FISH CHANNEL

1		2		3		4	
X	Y	X	Y	X	Y	X	Y
1	5	9	13	17	21	25	29

SPECIAL LIVE LOAD

SP. LL NO.	NUMBER OF AXLES	3% INCR.	GAGE DISTANCE	PASSING DISTANCE
1	2	4	5	8

AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST
1	5	8	12	15	19	22	26	29	33	36	40	43	47	50	54

Figure 8.1.2 Example Problem 1 – Input (cont)

8.2 EXAMPLE PROBLEM 2

8.2.1 Problem Description

This is an example of a twin cell culvert with a standard fish channel. Figure 8.2.1 on page 8-9 shows the cross section and dimensions of the culvert. Member thicknesses are known and have been entered. The live load effect has been neglected. Figure 8.2.2 on page 8-10 shows the completed input data sheet.

8.2.2 Input

The following input lines are entered. Refer to the completed input data sheets shown in Figure 8.2.2.

1. Problem Identification
   - Three lines are coded to enter comments to identify the problem.
   - Any number of lines may be coded, but only the first three lines will be printed on the output.

2. Specifications
   - METHOD is “LF” for Load Factor Design.
   - RUN TYPE is “A” since member thicknesses are known.
   - BOTTOM SLAB is “Y”.
   - HAUNCH is left blank because there are no monolithic haunches.
   - FISH CHANNEL is “S” because there is a standard fish channel.
   - LIVE LOAD is left blank because live loads are to be neglected.
   - NO. OF CELLS is 2.
   - TOP SLAB is acting as monolithic with the walls. This is the default when left blank.
   - NO. OF LANES is entered as 0 to indicate that the effect of live load is to be neglected.
   - LOAD FACTORS are all left blank so that the program will use all the defaults.
   - UNIT WEIGHT OF EARTH is 120 pounds per cubic foot.
   - EQUIV. FLUID PRESS. (lateral earth pressure) is 35.0 pounds per cubic foot.
   - The f ’c of the concrete is 3,000.0 psi.
   - REBAR GRADE is 60.
   - The diameter of the largest reinforcement bar that may be used as flexural reinforcement in the design is 1.410 inches (#11 bar).
   - P OR C is coded as “C” for cast-in-place.
   - W OR B is left blank for a cast-in-place culvert.
   - The LIVE LOAD SURCH. is equal to 3 feet of fill.

- AXIAL FORCE is coded as “Y” so that the effect of axial force is considered in the design and rating of a section.

3. Culvert Data
   - CLEAR SPAN, CLEAR HEIGHT and HEIGHT OF FILL are taken from the sketch in Figure 8.2.1.
   - The actual SLAB THICKNESS for the TOP slab is 21 inches and the actual SLAB THICKNESS for the BOTTOM slab is 24 inches. Refer to Figure 8.2.1.
   - The actual WALL THICKNESS for both the LEFT and RIGHT walls is 20.0 inches. The actual WALL THICKNESS for the INTERIOR wall is 16.0 inches. Refer to Figure 8.2.1.
   - BAR COVERS are all left blank so that the program will use all the defaults. See Figure 8.2.1.

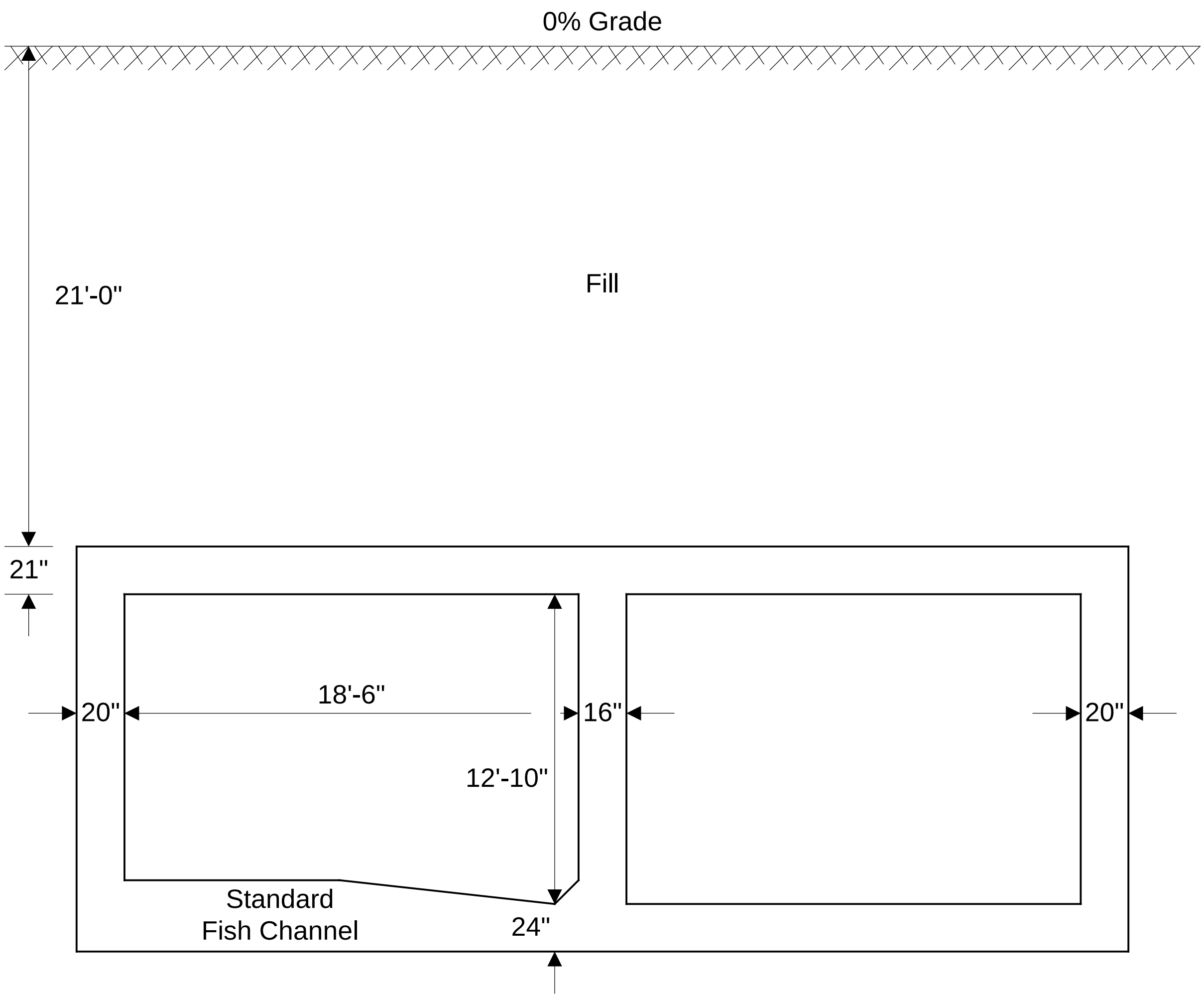

Figure 8.2.1 Example Problem 2 – Details

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BOX5
LFD BOX CULVERT DESIGN AND RATING

PROBLEM IDENTIFICATION

1
* EXAMPLE PROBLEM 2 - LOAD FACTOR DESIGN
* TWIN CELL WITH STANDARD FISH CHANNEL
* KNOWN THICKNESSES

SPECIFICATIONS

METHOD	RUN TYPE	BOTTOM SLAB	HAUNCH	FISH CHANNEL	LIVE LOAD	NO. OF CELLS	TOP SLAB	NO. OF LANES	LOAD FACTORS: GAMMA	LOAD FACTORS: BETA D	LOAD FACTORS: BETA L	LOAD FACTORS: BETA E VERT	LOAD FACTORS: BETA E HORZ	UNIT WT OF EARTH OR OVER-LAY	EQUIV FLUID PRESS	f 'c	f 'c (TOP SLAB AT GRADE)	REBAR GRADE	REBAR OR WIRE DIAMETER	P OR C	W OR B	SPECS	ALPHA	LIVE LOAD SURCH.	AXIAL FORCE	FILL HEIGHT ADJUST-MENT FACTOR	NO. SPEC. LL	OUTPUT
1	3	4	5	6	7	8	9	10	11	14	17	20	23	26	29	32	36	40	42	46	47	48	49	51 54	55	56	61	62
LF	A	Y		S		2		0	.	.	.	.	.	120	35.0	3000		60	1.410	C				3.00	Y	.		

CULVERT DATA

CLEAR SPAN	CLEAR HEIGHT	SLAB THICKNESS: TOP	SLAB THICKNESS: BOTTOM	WALL THICKNESS: LEFT	WALL THICKNESS: INTERIOR	WALL THICKNESS: RIGHT	HEIGHT OF FILL	% GRADE	BAR COVERS: TOP SLAB: TOP BAR	BAR COVERS: TOP SLAB: BOT BAR	BAR COVERS: BOTTOM SLAB: TOP BAR	BAR COVERS: BOTTOM SLAB: BOT BAR	BAR COVERS: WALLS	OVERLAY THICKNESS	FILL + 100	PRECAST SEGMENT LENGTH
1	5	9	13	17	21	25	29	32	37	41	45	49	53	57	61	62
18.50	12.83	21.00	24.00	20.00	16.00	20.00	21.0	0.00	.	.	.	.	.	.		.

Figure 8.2.2 Example Problem 2 – Input

8.3 EXAMPLE PROBLEM 3

8.3.1 Problem Description

This is an example of a single cell culvert with a non-standard fish channel. Figure 8.3.1 on page 8-13 shows the cross section and dimensions of the culvert. Member thicknesses are known and have been entered. The fill has a negative grade of 6.98%. Figure 8.3.2 on page 8-14 shows the completed input data sheets.

8.3.2 Input

The following input lines are entered. Refer to the completed input data sheets shown in Figure 8.3.2.

1. Problem Identification
   - Three lines are coded to enter comments to identify the problem.
   - Any number of lines may be coded, but only the first three lines will be printed on the output.

2. Specifications
   - METHOD is “SL” for Service Load Design.
   - RUN TYPE is “A” since member thicknesses are known.
   - BOTTOM SLAB is “Y”.
   - HAUNCH is left blank because there are no monolithic haunches.
   - FISH CHANNEL is “N” because there is a non-standard fish channel.
   - LIVE LOAD is 1 so that the HS20 and AML live loads will be considered for the design using SLD.
   - NO. OF CELLS is 1.
   - TOP SLAB is acting as monolithic with the walls. This is the default when left blank.
   - NO. OF LANES is entered as 2.
   - LOAD FACTORS are all left blank so that the program will use all the defaults.
   - UNIT WEIGHT OF EARTH is 120 pounds per cubic foot.
   - EQUIV. FLUID PRESS. (lateral earth pressure) is 35.0 pounds per cubic foot.
   - The f ’c of the concrete is 3,000.0 psi.
   - REBAR GRADE is 40.
   - The diameter of the largest reinforcement bar that may be used as flexural reinforcement in the design is 1.000 inches (#8 bar).
   - P OR C is coded as “C” for cast-in-place.
   - W OR B is left blank for a cast-in-place culvert.
   - The LIVE LOAD SURCH. is equal to 2 feet of fill.

- AXIAL FORCE is coded as “Y” so that the effect of axial force is considered in the design and rating of a section.

3. Culvert Data
   - CLEAR SPAN, CLEAR HEIGHT, HEIGHT OF FILL, and % GRADE are taken from the sketch in Figure 8.3.1.
   - The actual SLAB THICKNESS for the TOP and BOTTOM slab is 12 inches and the actual WALL THICKNESS for both the LEFT and RIGHT walls is 12.0 inches. Refer to Figure 8.3.1.
   - Actual BAR COVERS are entered as follows:

TOP SLAB – TOP BAR	2.25 inches
TOP SLAB – BOTTOM BAR	2.25 inches
BOTTOM SLAB – TOP BAR	2.50 inches
BOTTOM SLAB – BOTTOM BAR	3.25 inches
WALLS	2.25 inches

4. Non-Standard Fish Channel Data
   - The values for the horizontal distance X and the drop-in elevation Y are coded in feet as explained in Chapter 5. Refer to the sketch in Figure 8.3.1.

     X1 = 5', Y1 = -0.83' = 10”, X2 = 5', Y2 = 0.83' = 10 “

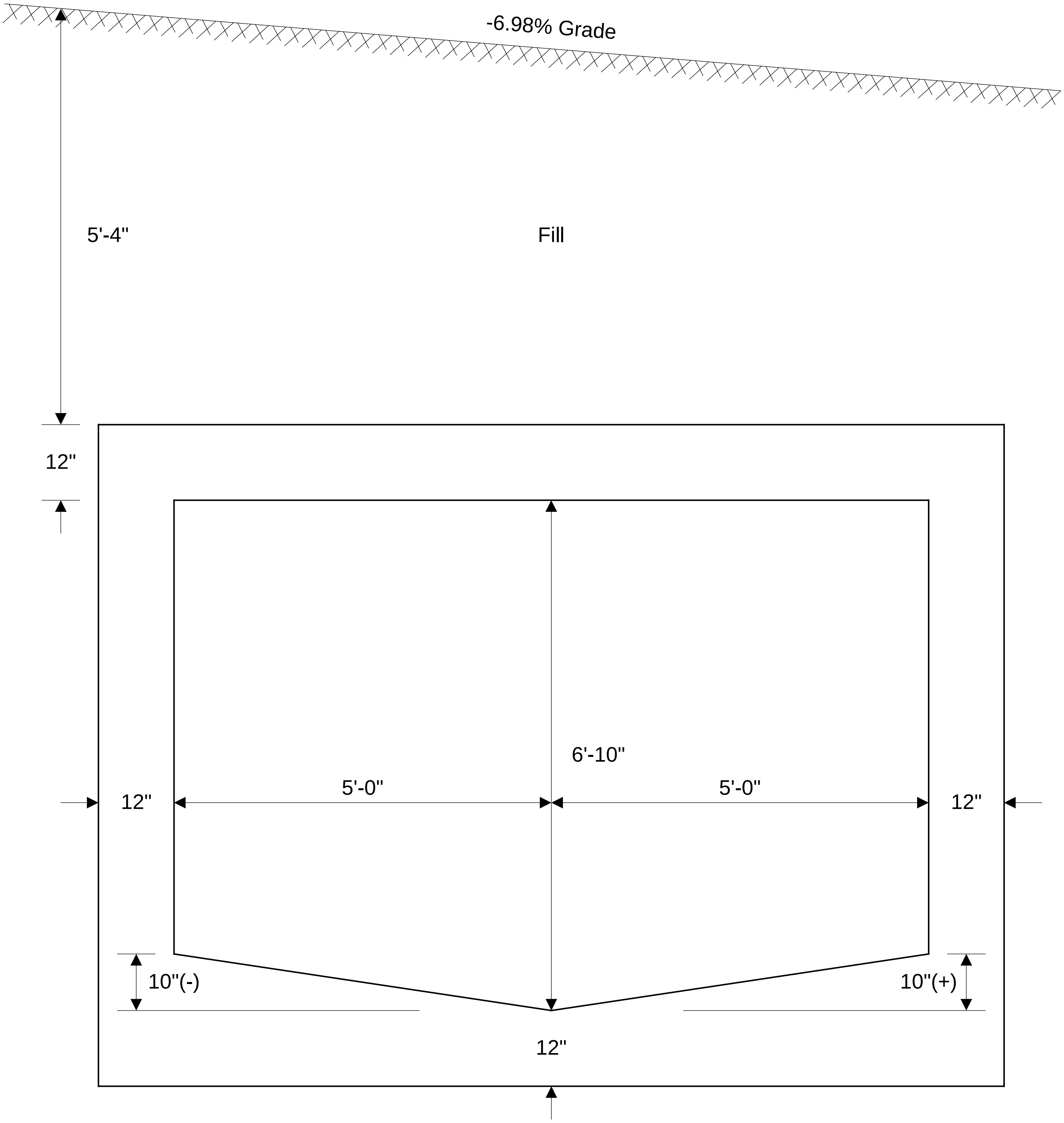

Figure 8.3.1 Example Problem 3 – Details

PENNSYLVANIA DEPARTMENT OF TRANSPORTATION
BUREAU OF INFORMATION SYSTEMS

BOX5
LFD BOX CULVERT DESIGN AND RATING

Form 1 of 3

PROBLEM IDENTIFICATION

1
*EXAMPLE PROBLEM 3 - SERVICE LOAD DESIGN
*SINGLE CELL NON-STANDARD FISH CHANNEL HS20 LOADING
*MEMBER THICKNESSES AND BAR COVERS ENTERED

SPECIFICATIONS

METHOD	RUN TYPE	BOTTOM SLAB	HAUNCH	FISH CHANNEL	LIVE LOAD	NO. OF CELLS	TOP SLAB	NO. OF LANES	LOAD FACTORS					UNIT WT OF EARTH OR OVER-LAY	EQUIV FLUID PRESS	f 'c	f 'c (TOP SLAB AT GRADE)	REBAR GRADE	REBAR OR WIRE DIAMETER	P OR C	W OR B	SPECS	ALPHA	LIVE LOAD SURCH.	AXIAL FORCE	FILL HEIGHT ADJUST-MENT FACTOR	NO. SPEC. LL	OUTPUT
									GAMMA	BETA D	BETA L	BETA E VERT	BETA E HORZ															
1	3	4	5	6	7	8	9	10	11	14	17	20	23	26	29	32	36	40	42	46	47	48	49	51 54	55	56	61	62
SL	A	Y		N	1	1		2	.	.	.	.	.	120	35.0	3000		40	1.000	C				2.00	Y	.		

CULVERT DATA

CLEAR SPAN	CLEAR HEIGHT	SLAB THICKNESS		WALL THICKNESS			HEIGHT OF FILL	% GRADE	BAR COVERS					OVERLAY THICKNESS	FILL + 100	PRECAST SEGMENT LENGTH
									TOP SLAB		BOTTOM SLAB		WALLS			
		TOP	BOTTOM	LEFT	INTERIOR	RIGHT			TOP BAR	BOT BAR	TOP BAR	BOT BAR				
1	5	9	13	17	21	25	29	32	37	41	45	49	53	57	61	62
10.00	6.83	12.00	12.00	12.00	.	12.00	5.3	-6.98	2.250	2.250	2.500	3.250	2.250	.		.

Figure 8.3.2 Example Problem 3 – Input

BOX5
LFD BOX CULVERT DESIGN AND RATING

HAUNCH DIMENSIONS

BOTTOM						TOP					
LEFT		INTERIOR		RIGHT		LEFT		INTERIOR		RIGHT	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
1	5	9	13	17	21	25	29	33	37	41	45

NON-STANDARD FISH CHANNEL

1		2		3		4	
X	Y	X	Y	X	Y	X	Y
1	5	9	13	17	21	25	29
5.00	-0.83	5.00	0.83				

SPECIAL LIVE LOAD

SP. LL NO.	NUMBER OF AXLES	3% INCR.	GAGE DISTANCE	PASSING DISTANCE
1	2	4	5	8

AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST
1	5	8	12	15	19	22	26	29	33	36	40	43	47	50	54

Figure 8.3.2 Example Problem 3 – Input (cont)

8.4 EXAMPLE PROBLEM 4

8.4.1 Problem Description

This is an example of a frame culvert (no bottom slab). Figure 8.4.1 on page 8-18 shows the cross section and dimensions of the culvert. The top slab is at grade (1%) and the culvert is designed for a special live load. Load Factors are entered for illustration only and they may not be conforming to any specifications. Figure 8.4.2 on page 8-19 shows the completed input data sheets.

8.4.2 Input

The following input lines are entered. Refer to the completed input data sheets shown in Figure 8.4.2.

1. Problem Identification
   - Three lines are coded to enter comments to identify the problem.
   - Any number of lines may be coded, but only the first three lines will be printed on the output.

2. Specifications
   - METHOD is "LF" for Load Factor Design.
   - RUN TYPE is "D" for a design of both member thicknesses and reinforcement.
   - BOTTOM SLAB is "N" because there is no bottom slab.
   - HAUNCH is left blank because there are no monolithic haunches.
   - FISH CHANNEL is left blank because there is no fish channel.
   - LIVE LOAD is 9 indicating that a special live load will be entered.
   - NO. OF CELLS is 1.
   - TOP SLAB is acting as monolithic with the walls. This is the default when left blank.
   - NO. OF LANES is entered as 2.
   - LOAD FACTORS are entered as follows:

GAMMA	1.2
BETA D	1.0
BETA L	1.5
BETA E VERT	1.1
BETA E HORZ	1.25

   - UNIT WEIGHT OF EARTH is 120 pounds per cubic foot.
   - EQUIV. FLUID PRESS. (lateral earth pressure) is 35.0 pounds per cubic foot.
   - The f 'c of the concrete in the walls is 3,000.0 psi.
   - The f 'c of the concrete in the top slab at grade is 4,500.0 psi.

- REBAR GRADE is 60.
- The diameter of the largest reinforcement bar that may be used as flexural reinforcement in the design is 1.128 inches (#9 bar).
- P OR C is coded as “C” for cast-in-place.
- W OR B is left blank for a cast-in-place culvert.
- The LIVE LOAD SURCH. is equal to 3 feet of fill.
- AXIAL FORCE is coded as “Y” so that the effect of axial force is considered in the design and rating of a section.
- The NO. SPEC. LL is 1.

3. Culvert Data
   - CLEAR SPAN, CLEAR HEIGHT, and % GRADE are taken from the sketch in Figure 8.4.1.
   - The actual SLAB THICKNESS for the TOP slab is 10 inches and the actual WALL THICKNESS for both the LEFT and RIGHT walls is 12.0 inches. Refer to Figure 8.4.1.
   - HEIGHT OF FILL is entered as 0.0 for a culvert at grade.

4. Special Live Load Data
   - SP. LL. NO. is 1.
   - NUMBER OF AXLES is 4.
   - 3% INCR. is left blank because the axle loads are not to be increased by the 3% scale tolerance.
   - The GAGE DISTANCE for this special vehicle is 6 feet.
   - The PASSING DISTANCE for this special vehicle is 4 feet.
   - The AXLE LOAD for each of the 4 axles and the DIST between the axles are taken from the sketch in Figure 8.4.1.

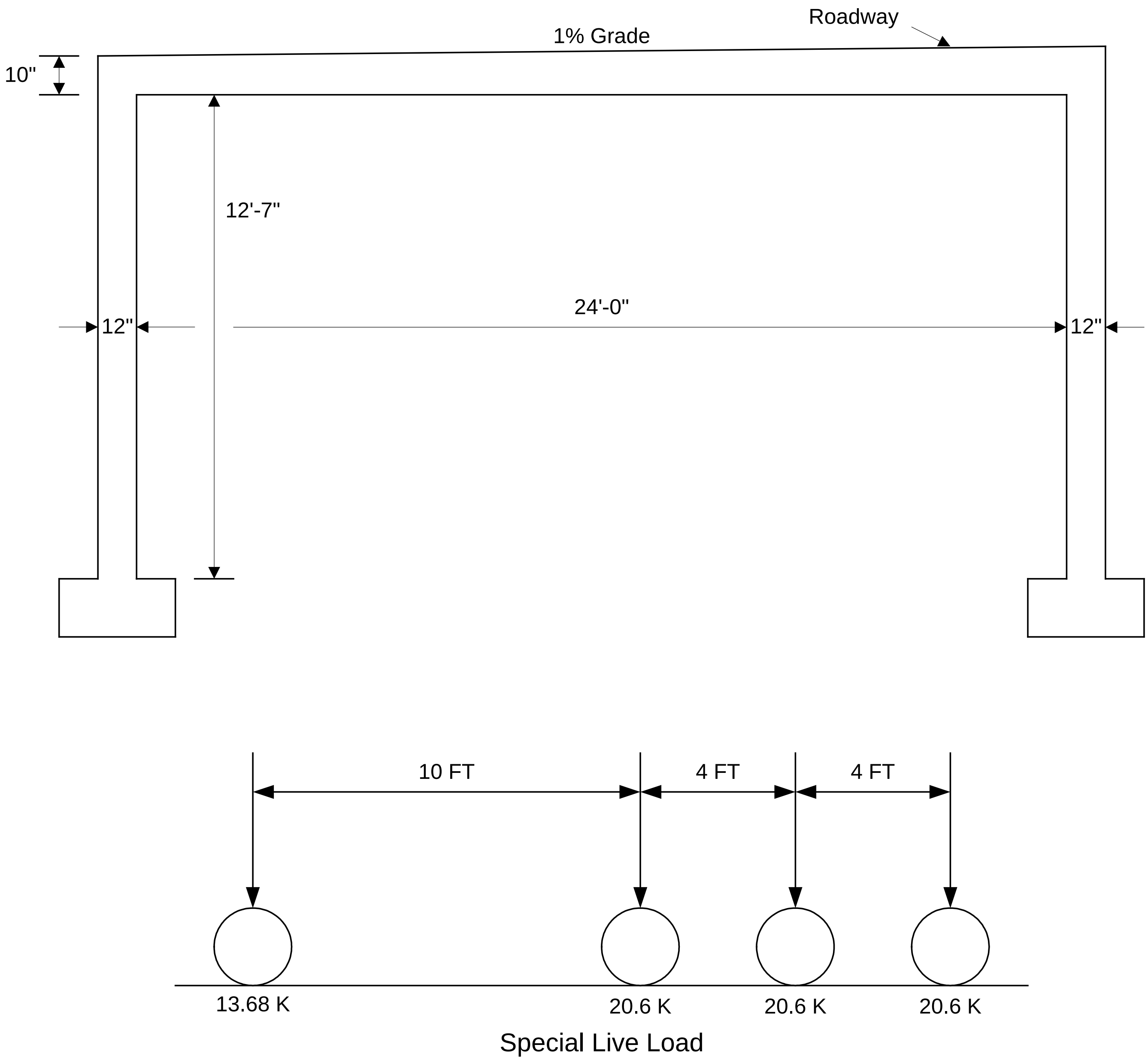

Figure 8.4.1 Example Problem 4 – Details

BOX5
LFD BOX CULVERT DESIGN AND RATING

PROBLEM IDENTIFICATION

1
* EXAMPLE PROBLEM 4 - FRAME CULVERT
* LOAD FACTOR DESIGN
* SPECIAL LIVE LOAD

SPECIFICATIONS

METHOD	RUN TYPE	BOTTOM SLAB	HAUNCH	FISH CHANNEL	LIVE LOAD	NO. OF CELLS	TOP SLAB	NO. OF LANES	LOAD FACTORS					UNIT WT OF EARTH OR OVER-LAY	EQUIV FLUID PRESS	f 'c	f 'c (TOP SLAB AT GRADE)	REBAR GRADE	REBAR OR WIRE DIAMETER	P OR C	W OR B	SPECS	ALPHA	LIVE LOAD SURCH.	AXIAL FORCE	FILL HEIGHT ADJUST-MENT FACTOR	NO. SPEC. LL	OUTPUT
									GAMMA	BETA D	BETA L	BETA E VERT	BETA E HORZ															
1	3	4	5	6	7	8	9	10	11	14	17	20	23	26	29	32	36	40	42	46	47	48	49	51 54	55	56	61	62
LF	D	N			9	1		2	1.20	1.00	1.50	1.10	1.25	120	35.0	3000	4500	60	1.128	C				3.00	Y	.	1	

CULVERT DATA

CLEAR SPAN	CLEAR HEIGHT	SLAB THICKNESS		WALL THICKNESS			HEIGHT OF FILL	% GRADE	BAR COVERS					OVERLAY THICKNESS	FILL + 100	PRECAST SEGMENT LENGTH
									TOP SLAB		BOTTOM SLAB		WALLS			
		TOP	BOTTOM	LEFT	INTERIOR	RIGHT			TOP BAR	BOT BAR	TOP BAR	BOT BAR				
1	5	9	13	17	21	25	29	32	37	41	45	49	53	57	61	62
24.00	12.60	10.00	.	12.00	.	12.00	0.0	1.00	.	.	.	.	.	.		.

Figure 8.4.2 Example Problem 4 – Input

BOX5
LFD BOX CULVERT DESIGN AND RATING

HAUNCH DIMENSIONS

BOTTOM						TOP					
LEFT		INTERIOR		RIGHT		LEFT		INTERIOR		RIGHT	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
1	5	9	13	17	21	25	29	33	37	41	45

NON-STANDARD FISH CHANNEL

1		2		3		4	
X	Y	X	Y	X	Y	X	Y
1	5	9	13	17	21	25	29

SPECIAL LIVE LOAD

SP. LL NO.	NUMBER OF AXLES	3% INCR.	GAGE DISTANCE	PASSING DISTANCE
1	2	4	5	8
1	4		6.00	4.00

AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST	AXLE LOAD	DIST
1	5	8	12	15	19	22	26	29	33	36	40	43	47	50	54
13.68	10.0	20.60	4.0	20.60	4.0	20.60									

Figure 8.4.2 Input for Example 4 (cont)

8.5 EXAMPLE PROBLEM 5

8.5.1 Problem Description

This is an example of a twin cell culvert at grade with a 3-inch concrete overlay. Figure 8.5.1 on page 8-24 shows the cross section and dimensions of the culvert. The top slab is at grade (-2.91%) and the culvert is rated for the standard LFD rating loads. Figure 8.5.2 on page 8-25 shows the completed input data sheets.

8.5.2 Input

The following input lines are entered. Refer to the completed input data sheets shown in Figure 8.5.2.

1. Problem Identification
   - Three lines are coded to enter comments to identify the problem.
   - Any number of lines may be coded, but only the first three lines will be printed on the output.

2. Specifications
   - METHOD is “LF” for Load Factor Design.
   - RUN TYPE is “R” for rating an existing culvert.
   - METHOD is “LF” for Load Factor Design.
   - RUN TYPE is “R” for rating an existing culvert.
   - BOTTOM SLAB is “Y” because there is a bottom slab.
   - HAUNCH is left blank because there are no monolithic haunches.
   - FISH CHANNEL is left blank because there is no fish channel.
   - LIVE LOAD is 0 indicating that the standard group of rating loads should be used.
   - NO. OF CELLS is 2.
   - TOP SLAB is “S” to indicate that the top slab is simply supported on the walls.
   - NO. OF LANES is entered as 2.
   - LOAD FACTORS are all left blank so that the program will use all the defaults.
   - UNIT WEIGHT OF OVERLAY is 150 pounds per cubic foot.
   - EQUIV. FLUID PRESS. (lateral earth pressure) is 35.0 pounds per cubic foot.
   - The f ’c of the concrete in the walls is 3,000.0 psi.
   - The f ’c of the concrete in the top slab at grade is 4,500.0 psi.
   - REBAR GRADE is 60.
   - The diameter of the largest reinforcement bar that may be used as flexural reinforcement in the design is 1.128 inches (#9 bar).
   - P OR C is coded as “C” for cast-in-place.

- W OR B is left blank for a cast-in-place culvert.
- The LIVE LOAD SURCH. is equal to 3 feet of fill.
- SPECS is entered as 3 to indicate that the program should use the 1973 or earlier AASHTO specifications for shear ratings because this existing culvert was designed using 1973 AASHTO specifications.
- ALPHA is entered as 45, indicating the angle in degrees measured from the horizontal of bent up bars used as shear reinforcement.
- The LIVE LOAD SURCH. is equal to 3 feet of fill.
- AXIAL FORCE is coded as "Y" so that the effect of axial force is considered in the rating of a section.

3. Culvert Data
   - CLEAR SPAN, CLEAR HEIGHT, and % GRADE are taken from the sketch in Figure 8.5.1.
   - The actual SLAB THICKNESS for the left end of the TOP slab is 25.7 inches and the actual SLAB THICKNESS for the BOTTOM slab is 15 inches. Refer to Figure 8.5.1.
   - The actual WALL THICKNESS for the LEFT, INTERIOR and RIGHT walls is 12.0 inches. Refer to Figure 8.5.1.
   - HEIGHT OF FILL is entered as 0.0 for a culvert at grade.

4. Wall Reinforcement
   - SIZE 7 bars spaced at 7.0 inches are in the BOTTOM of the LEFT WALL.
   - SIZE 5 bars spaced at 10.5 inches are in the TOP of the LEFT WALL.
   - SIZE 5 bars spaced at 9.5 inches are in the BOTTOM of the INTERIOR WALL.
   - SIZE 5 bars spaced at 11.5 inches are in the TOP of the INTERIOR WALL.
   - SIZE 6 bars spaced at 7.0 inches are in the BOTTOM of the RIGHT WALL.
   - SIZE 6 bars spaced at 7.0 inches are in the TOP of the RIGHT WALL.

5. Slab Reinforcement
   - SIZE 7 bars spaced at 6.5 inches are at the LEFT end of SLAB 1.
   - SIZE 7 bars spaced at 7.5 inches are at the MID SPAN of SLAB 1.
   - SIZE 7 bars spaced at 6.5 inches are at the RIGHT end of SLAB 1.
   - SIZE 7 bars spaced at 6.0 inches are at the LEFT end of SLAB 2.
   - SIZE 8 bars spaced at 7.0 inches are at the MID SPAN of SLAB 2.
   - SIZE 5 bars spaced at 5.5 inches are at the RIGHT end of SLAB 2 along with SIZE 3 bars spaced at 11.0 inches for shear.
   - SIZE 5 bars spaced at 5.5 inches are at the LEFT end of SLAB 3 along with SIZE 3 bars spaced at 11.0 inches for shear.

- SIZE 9 bars spaced at 6.0 inches are at the MID SPAN of SLAB 3.
- SIZE 6 bars spaced at 6.0 inches are at the RIGHT end of SLAB 3 along with SIZE 3 bars spaced at 18.0 inches for shear.
- SIZE 6 bars spaced at 6.5 inches are at the LEFT end of SLAB 4 along with SIZE 3 bars spaced at 19.5 inches for shear.
- SIZE 9 bars spaced at 6.5 inches are at the MID SPAN of SLAB 4.
- SIZE 5 bars spaced at 7.5 inches are at the RIGHT end of SLAB 4 along with SIZE 3 bars spaced at 15.0 inches for shear.

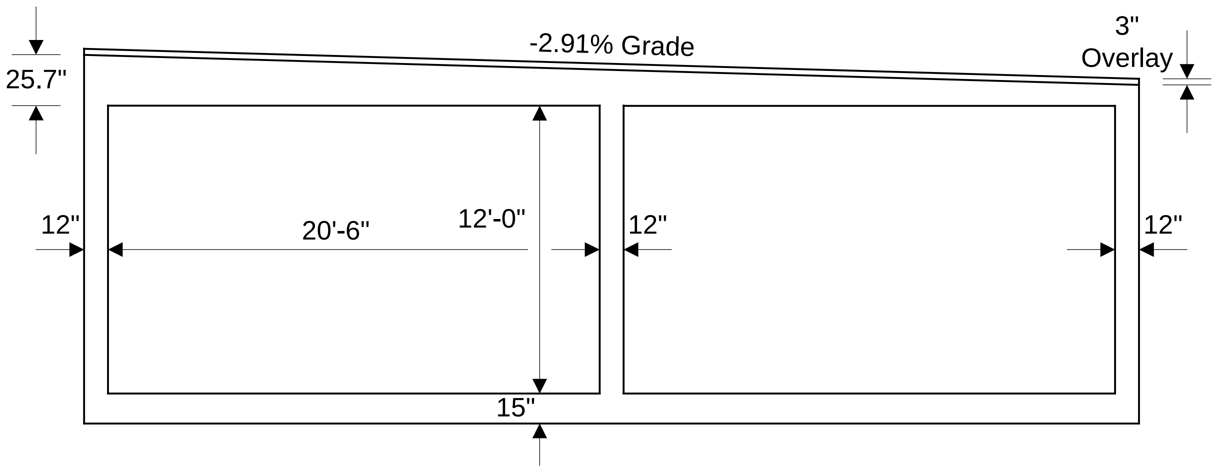

Figure 8.5.1 Example Problem 5 – Details

PENNSYLVANIA DEPARTMENT OF TRANSPORTATION
BUREAU OF INFORMATION SYSTEMS

BOX5
LFD BOX CULVERT DESIGN AND RATING

Form 1 of 3

PROBLEM IDENTIFICATION

1
* EXAMPLE PROBLEM 5 - LOAD FACTOR DESIGN
* TWIN CELL AT GRADE
* RATING

SPECIFICATIONS

METHOD	RUN TYPE	BOTTOM SLAB	HAUNCH	FISH CHANNEL	LIVE LOAD	NO. OF CELLS	TOP SLAB	NO. OF LANES	LOAD FACTORS: GAMMA	LOAD FACTORS: BETA D	LOAD FACTORS: BETA L	LOAD FACTORS: BETA E VERT	LOAD FACTORS: BETA E HORZ	UNIT WT OF EARTH OR OVER-LAY	EQUIV FLUID PRESS	f 'c	f 'c (TOP SLAB AT GRADE)	REBAR GRADE	REBAR OR WIRE DIAMETER	P OR C	W OR B	SPECS	ALPHA	LIVE LOAD SURCH.	AXIAL FORCE	FILL HEIGHT ADJUST-MENT FACTOR	NO. SPEC. LL	OUTPUT
1	3	4	5	6	7	8	9	10	11	14	17	20	23	26	29	32	36	40	42	46	47	48	49	51 54	55	56	61	62
LF	R	Y			0	2	S	2	.	.	.	.	.	150	35.0	3000	4500	60	1.128	C			45	3.00	Y	.		

CULVERT DATA

CLEAR SPAN	CLEAR HEIGHT	SLAB THICKNESS: TOP	SLAB THICKNESS: BOTTOM	WALL THICKNESS: LEFT	WALL THICKNESS: INTERIOR	WALL THICKNESS: RIGHT	HEIGHT OF FILL	% GRADE	BAR COVERS: TOP SLAB: TOP BAR	BAR COVERS: TOP SLAB: BOT BAR	BAR COVERS: BOTTOM SLAB: TOP BAR	BAR COVERS: BOTTOM SLAB: BOT BAR	BAR COVERS: WALLS	OVERLAY THICKNESS	FILL + 100	PRECAST SEGMENT LENGTH
1	5	9	13	17	21	25	29	32	37	41	45	49	53	57	61	62
20.50	12.00	25.70	15.00	12.00	12.00	12.00	0.0	-2.91	.	.	.	.	.	3.00		.

Figure 8.5.2 Example Problem 5 – Input

BOX5
LFD BOX CULVERT DESIGN AND RATING

WALL REINFORCEMENT

WALL 1 (LEFT WALL)						WALL 2 (RIGHT WALL SINGLE CELL OR INTERIOR WALL TWIN CELL)						WALL 3 (RIGHT WALL TWIN CELL)					
BOTTOM			TOP			BOTTOM			TOP			BOTTOM			TOP		
As	SIZE	SPAC	As	SIZE	SPAC	As	SIZE	SPAC	As	SIZE	SPAC	As	SIZE	SPAC	As	SIZE	SPAC
1	5	7	10	14	16	19	23	25	28	32	34	37	41	43	46	50	52
	7	7.0		5	10.5		5	9.5		5	11.5		6	7.0		6	7.0

SLAB REINFORCEMENT

SLAB NO	AT LEFT END OF SPAN						AT MID SPAN			AT RIGHT END OF SPAN					
	As	SIZE	SPAC	Av	SIZE	SPAC	As	SIZE	SPAC	As	SIZE	SPAC	Av	SIZE	SPAC
1	2	6	8	11	15	17	20	24	26	29	33	35	38	42	44
1		7	6.5					7	7.5		7	6.5			
2		7	6.0					8	7.0		5	5.5		3	11.0
3		5	5.5		3	11.0		9	6.0		6	6.0		3	18.0
4		6	6.5		3	19.5		9	6.5		5	7.5		3	15.0

Figure 8.5.2 Example Problem 5 – Input (cont)

8.6 EXAMPLE PROBLEM 6

8.6.1 Problem Description

This is an example of a single cell culvert with no top slab. Figure 8.6.1 on page 8-29 shows the cross section and dimensions of the culvert. The fill has a grade of 3.2%. Figure 8.6.2 on page 8-30 shows the completed input data sheets.

8.6.2 Input

The following input lines are entered. Refer to the completed input data sheets shown in Figure 8.6.2.

1. Problem Identification
   - Three lines are coded to enter comments to identify the problem.
   - Any number of lines may be coded, but only the first three lines will be printed on the output.

2. Specifications
   - METHOD is “LF” for Load Factor Design.
   - RUN TYPE is “D” for a design of both member thicknesses and reinforcement.
   - BOTTOM SLAB is “Y”.
   - HAUNCH is left blank because there are no monolithic haunches.
   - FISH CHANNEL is left blank because there is no fish channel.
   - LIVE LOAD is 0 so that the HS25, IML, and P-82 loads are considered as design loads.
   - NO. OF CELLS is 1.
   - TOP SLAB is “N” because there is no top slab.
   - NO. OF LANES is 0 because there is no live load.
   - LOAD FACTORS are all left blank so that the program will use all the defaults.
   - UNIT WEIGHT OF EARTH OR OVERLAY is left blank because there is no top slab.
   - EQUIV. FLUID PRESS. (lateral earth pressure) is 35.0 pounds per cubic foot.
   - The f ’c of the concrete is 3,000 psi.
   - REBAR GRADE is 40.
   - The diameter of the largest reinforcement bar that may be used as flexural reinforcement in the design is 1.128 inches (#9 bar).
   - P OR C is coded as “C” for cast-in-place.
   - W OR B is left blank for a cast-in-place culvert.
   - The LIVE LOAD SURCH. is equal to 3 feet of fill.

- AXIAL FORCE is coded as “Y” so that the effect of axial force is considered in the design and rating of a section.

3. Culvert Data
   - CLEAR SPAN, CLEAR HEIGHT and %GRADE are taken from the sketch in Figure 8.6.1. The clear height entered must be at the left wall. The height of the right wall is calculated by the program using the % GRADE entered here.
   - The minimum SLAB THICKNESS for the BOTTOM slab is 11.5 inches.
   - The minimum WALL THICKNESS for both the LEFT and RIGHT walls is 12.0 inches.
   - HEIGHT OF FILL is 0.0 because there is no top slab.
   - %GRADE is 3.20.
   - BAR COVERS are all left blank so that the program will use all the defaults. See Figure 8.6.1.
   - OVERLAY THICKNESS is left blank because there is no top slab.

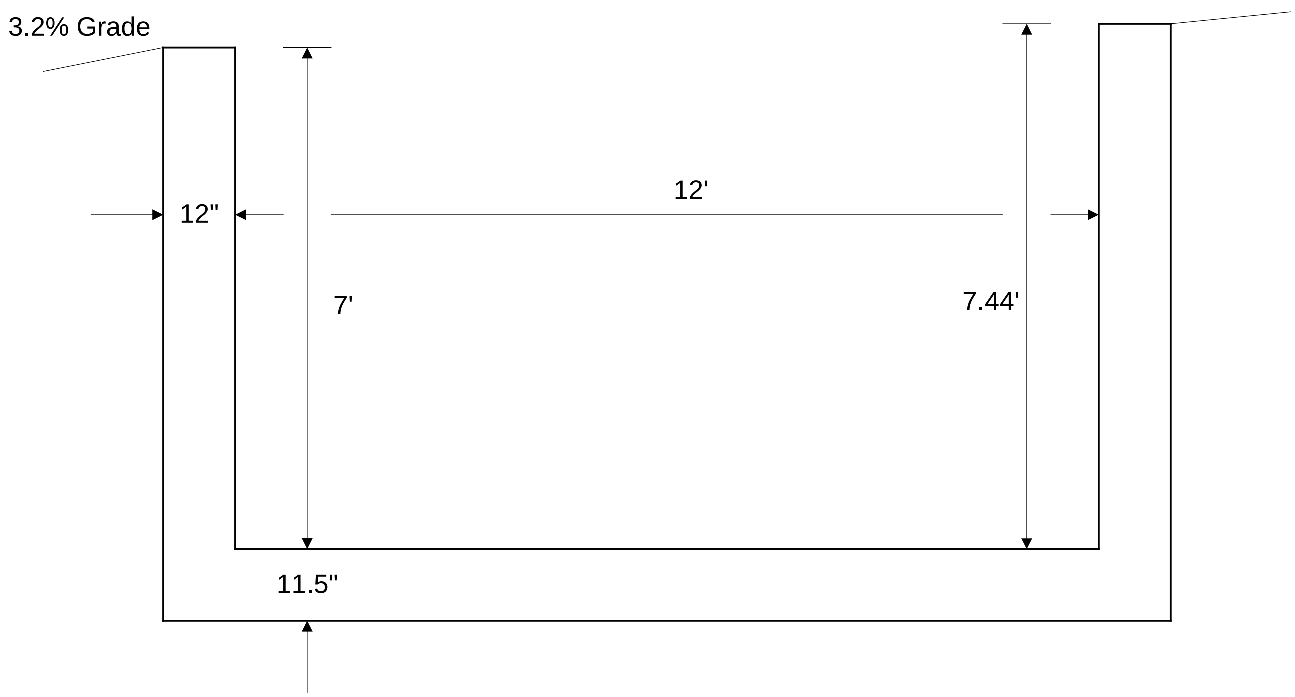

Figure 8.6.1 Example Problem 6 – Details

BOX5
LFD BOX CULVERT DESIGN AND RATING

PROBLEM IDENTIFICATION

1
*EXAMPLE PROBLEM 6 - LOAD FACTOR DESIGN
*SINGLE CELL WITH NO TOP SLAB
*DESIGN THICKNESS

SPECIFICATIONS

METHOD	RUN TYPE	BOTTOM SLAB	HAUNCH	FISH CHANNEL	LIVE LOAD	NO. OF CELLS	TOP SLAB	NO. OF LANES	LOAD FACTORS					UNIT WT OF EARTH OR OVER-LAY	EQUIV FLUID PRESS	f 'c	f 'c (TOP SLAB AT GRADE)	REBAR GRADE	REBAR OR WIRE DIAMETER	P OR C	W OR B	SPECS	ALPHA	LIVE LOAD SURCH.	AXIAL FORCE	FILL HEIGHT ADJUST-MENT FACTOR	NO. SPEC. LL	OUTPUT
									GAMMA	BETA D	BETA L	BETA E VERT	BETA E HORZ															
1	3	4	5	6	7	8	9	10	11	14	17	20	23	26	29	32	36	40	42	46	47	48	49	51 54	55	56	61	62
LF	D	Y			0	1	N	0							35.0	3000		40	1.128	C			45	3.00	Y			

CULVERT DATA

CLEAR SPAN	CLEAR HEIGHT	SLAB THICKNESS		WALL THICKNESS			HEIGHT OF FILL	% GRADE	BAR COVERS					OVERLAY THICKNESS	FILL + 100	PRECAST SEGMENT LENGTH
									TOP SLAB		BOTTOM SLAB		WALLS			
		TOP	BOTTOM	LEFT	INTERIOR	RIGHT			TOP BAR	BOT BAR	TOP BAR	BOT BAR				
1	5	9	13	17	21	25	29	32	37	41	45	49	53	57	61	62
12.00	7.00		11.50	12.00		12.00	0.0	3.20								

Figure 8.6.2 Example Problem 6 – Input

9 TECHNICAL QUESTIONS AND REVISION REQUESTS

This chapter contains reply forms to make it easier for users to convey their questions, problems or comments to the proper unit within the Department. General procedures for using these forms are given. Users should keep the forms in the manual as master copies which can be reproduced as needed. They are also included as a Word template on the disk that has been provided for the program.

9.1 TECHNICAL QUESTIONS

Technical questions related to the interpretations of the design specifications as implemented in this program, why certain assumptions are made, applicability and limitations of this program, and other questions not related to the operation of this program can be directed to the appropriate person in PennDOT using this form or the information provided on this form. Please review the information provided in this User's Manual and the references given in Chapter 1 before submitting this form for processing or calling for assistance. The completed form should be sent to the Bridge Quality Assurance Division (see form for complete address).

9.2 REVISION REQUESTS

This form is to be used to report suspected program malfunctions that may require revisions to the program. It can also be used to request revisions that may be required due to changes in specifications and for the enhancement of the program. Unexpected or incorrect output, rejection of input data, endless program cycling, and program abortion are examples of program malfunctions. Users are requested to review their input data and the program User's Manual before submitting this form for processing.

This form may also be used to submit suggestions for improving the User's Manual for this program. Suggestions might include typographical error correction, clarification of confusing sections, expansion of certain sections, changes in format, and the inclusion of additional information, diagrams, or examples.

The completed form should be sent to the Engineering Unit via mail, fax, or e-mail.

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BOX5
TECHNICAL QUESTIONS

This form is to be used to ask questions on technical issues related to this engineering program. Questions on the interpretations of the design specifications as implemented in this program, why certain assumptions are made by the program and other questions not related to the operation of this program may be submitted using this form or by calling the telephone number listed in this form. Users are requested to read the User's Manual, LRFD Specifications and DM-4 before submitting this form or calling to ask questions.

CONTACT PERSON: ____ DATE: _____________________
ORGANIZATION: _______________________________________ PHONE: _____________________
E-MAIL ADDRESS: _______________________________________ FAX: _____________________
PROGRAM VERSION: ________

Clearly state your question(s) and attach documentation you feel would be helpful in answering your question(s). If you require more space, use additional 8½ x 11 sheets of plain paper.

FORWARD COMPLETED FORM TO: Pennsylvania Dept. of Transportation
Bridge Design and Technology Division
Commonwealth Keystone Building, 7th Floor
400 North Street
Harrisburg, PA 17120-0094
PHONE: (717) 787-2881
FAX: (717) 787-2882

FOR DEPARTMENT USE ONLY
RECEIVED BY: ________________ ASSIGNED TO: ___________________ DATE: _____________

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BOX5
REVISION REQUEST

This form is to be used to report suspected program malfunctions, or to request revisions to the program or its documentation. Users are requested to review their input data and the program User's Manual before submitting this form.

CONTACT PERSON: ______________________________ DATE: ____________________
ORGANIZATION: ______________________________ PHONE: ____________________
E-MAIL ADDRESS: ______________________________ FAX: ____________________
PROGRAM VERSION: _________

Define your problem and attach samples and/or documentation you feel would be helpful in correcting the problem. If the input data is more than 4 or 5 lines, Licensees should provide the input data file on a diskette. If you require more space, use additional 8½ x 11 sheets of plain paper.

FORWARD COMPLETED FORM TO:

Pennsylvania Department of Transportation
Bureau of Business Solutions and Services
Engineering Software Section
Commonwealth Keystone Building, 5th Floor
400 North Street
Harrisburg, PA 17120-0041
PHONE: (717) 787-8407 / (717) 783-8822
FAX: (717) 705-5529
E-MAIL: penndotbisengineer@pa.gov

FOR DEPARTMENT USE ONLY

RECEIVED BY: ________________ ASSIGNED TO: ___________________ DATE: _____________

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