USER'S MANUAL FOR

LRFD BOX CULVERT DESIGN AND RATING (BXLRFD)

pennsylvania
DEPARTMENT OF TRANSPORTATION

Version 2.10.0.0

USER'S MANUAL FOR

COMPUTER PROGRAM BXLRFD

LRFD BOX CULVERT DESIGN AND RATING

VERSION 2.10.0.0

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LRFD BOX CULVERT DESIGN AND RATING

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SUMMARY OF JUNE 1999 REVISIONS - VERSION 1.1

Since the release of BXLRFD Version 1.0 some error reports and user requested enhancements have been received. This release of BXLRFD Version 1.1 contains the following error corrections and enhancements:

1. The strip footing bearing pressure calculation was corrected.

2. The OUI input command was fixed so Parameter 21 SP (Soil Pressure) will print soil pressure results in the intermediate data reports when it is entered by itself.

3. The Shear Reinforcement calculation for SI runs was corrected and now properly displays in the Shear Design output table. Also, the Concrete Shear Capacity calculation was corrected for both SI and US runs so it is no longer reduced by the Phi factor.

4. The Future Wearing Surface output field in the input summary table under the Load Control input card was increased to eliminate it occasionally appearing with asterisks for SI units.

5. The program was corrected to display a Foundation Pressure Report when there is no live load.

6. All dates were modified to display a 4 digit year in the output file.

7. The default value for reinforcement grade in SI units was changed to 420 MPa and the upper limit for reinforcement grade was changed to 450 MPa.

8. The program now uses soft metric reinforcement (the dimensions and data of US units bars converted to SI units) as per PennDOT standard drawing BC-736M-1-A. The true SI units reinforcement that was allowed in the previous version has been disabled.

9. The program was converted to the Digital Visual Fortran Version 6.0B compiler as a Win32 application. It will run on Windows 95, Windows 98 and Windows NT Version 4.0 operating systems. It will NOT run under the DOS 6.22 and below operating system.

LRFD BOX CULVERT DESIGN AND RATING

SUMMARY OF AUGUST 2000 REVISIONS - VERSION 1.2

Since the release of BXLRFD Version 1.1 several error reports and user requested enhancements have been received. This release of BXLRFD Version 1.2 contains these error corrections and user requested enhancements.

BXLRFD Version 1.2 contains the following revisions:

1. Fixed a problem that caused the program to crash when designing a frame culvert without shear reinforcement.

2. Fixed the program to prevent it from crashing while printing intermediate output files for a culvert with no live load.

3. Parameter file validation is now independent of daylight savings time change.

4. The program now produces a bearing pressure report for culverts that have strip footings and no live load.

5. Revised the Truck Axle distribution for Precast Culverts under 2 feet of fill so that results are more comparable to the Load Factor Method.

6. Revised the lower and upper limits for the input parameter Segment Length on the LDC command based on the Precast versus Cast-In-Place culverts.

7. Revised the program so that it can run under Windows 2000. It should also run under Windows 9x, and Windows NT.

8. Revised the calculations of shear depth d_v for Design and Analysis runs so that, when Design results are entered as an Analysis, the culvert will rate okay.

9. The input parameter f’c for Top Slab is now called f’c for Top Slab At Grade. Added a warning message to indicate when this input parameter is ignored. It is only used for Cast-In-Place culverts at grade.

10. Enhanced the program so input files do not have to reside in the same directory as the executable file.

11. Example problems have been revised to reflect above revisions.

12. User’s Manual pages have been revised to reflect above revisions. The revised pages are identified as "Revised 8/00".

SUMMARY OF MAY 2003 REVISIONS - VERSION 1.3

Since the release of BXLRFD Version 1.2 several revision requests and user requested enhancements have been received. This release of BXLRFD Version 1.3 corrects the following known problems and provides enhancements. There are still several outstanding enhancements and problems that will be addressed in the future releases of BXLRFD. What follows are two lists, one containing the revisions included in Version 1.3 and the other containing revisions that have yet to be included in the BXLRFD program.

BXLRFD Version 1.3 contains the following revisions:

1. The output routines have been revamped to decrease program size and to allow easier modification. A blank page that appears when no warnings are present at the end of the input echo has been removed. (Request 014)

2. Revised program to show HL-93 rating information during an Analysis run for Live Load Code “B”. (Request 020)

3. Revised how the program calculates bearing pressure to resolve a negative pressure (uplift) issue. Revised the foundation pressure output to show a corresponding pressure for each wall and the effective foundation bearing width. Created a new foundation pressure summary output table that shows the maximum foundation pressure under each wall for each limit state. (Request 021)

4. Added information to the User Manual stating which components in the culvert have impact applied. (Request 022)

5. The parameter definition file is now named BXLRFD.PD, previously it was using the .PDF file extension that would cause confusion with Adobe Acrobat Files. (Request 024)

6. Updated contact information in Chapter 9 of the User Manual. (Request 025)

7. Added Rating Tonnage to the output. (Request 026)

8. Added Live Load option “D” for design that is the same as “A” except the ML-80 vehicle is included. (Request 028)

9. Added a pause to the program that prevents automatic closing of the run-time window after the program has executed. (Request 030)

10. Provided the User Manual in an Adobe Acrobat PDF file. (Request 031)

11. Added the Total Weight of Culvert based on segment length to the Quantities Table in the output. (Request 032)

12. Revised the PHL-93 dual tandem axle weight to 110 kN (25 kips) to get maximum negative moment at the interior wall of a twin cell culvert. (Request 035)

13. Revised tire patch calculation as per DM-4 2000 Section 3.6.1.2.5. (Request 036)

14. Added c/de check for calculation of dv for compliance with DM-4 2000 Section 5.8.2.9P. (Request 039)

15. Revised the User Manual to describe how the program locates shear regions. Added new input check to make certain all haunches are 45 degrees, excluding fish channels. (Request 044)

16. Added new Serviceability Tables to the program that check maximum and minimum spacing, temperature and shrinkage, and crack control criteria for an Analysis run. (Request 047)

17. Revised the program to use the average height of fill to identify which shear equations to use and then use the average height of fill in the equations. (Request 048)

18. Revised how the program calculates section properties for the haunch when a shear region extends into it. (Request 049)

19. Revised the User Manual for the TVA and BVA commands so that the Shear steel information is consistent with the program. (Request 050)

20. Revised the Limit State Table (Table 3.4-2) in the User Manual to clarify which limit states the program uses. (Request 054)

21. Revised the program to allow negative rating values that indicate a failure. Also a footnote was added to describe the significance of the negative rating factor.(Request 055)

22. Revised Maximum Temperature and Spacing limits to meet DM-4 2000 Section 5.10.3 standards. (Request 056)

23. Added a new input parameter for the Maximum Impact Factor for the P-82 Truck Load. (Request 057)

24. Revised the User Manual for the minimum strip width used by the program for precast culverts under a fill of less than 2 feet. The minimum strip width for precast culverts under a fill of less than 2 feet is now taken as

either maximum of ELAT or two times the segment length. Also application of impact in bearing pressure calculations was removed. (Request 059)

25. Revised program to not require a maximum bar or wire size for an analysis run. (Request 60)

The following is a list of reported problems, user requests and clarifications that have not been addressed in Version 1.3

1. Add a U-channel design/Analysis capability to the program. (Request 027)

2. Add shear reinforcement design capabilities to the program with detailed design including bar sizes and spacing. (Request 037, 038)

3. Revise program to display Resistance Demand Ratios in the OUI file when they are displayed in the output. (Request 046)

4. Revise headings in the OUI file to be more meaningful. (Request 051)

5. Add shear region geometry checks and warnings to program for an analysis run when a single bar is entered. (Request 052)

6. Add TK527 Truck Load to the program and use when ML-80 is used. (Request 058)

7. Eta Factor values will set to 1.0 by default. (Request 062)

8. Locations where shear is evaluated will be revised. (Request 069)

SUMMARY OF MAY 2004 REVISIONS - VERSION 1.3.0.5

Since the release of BXLRFD Version 1.3 several revision requests and user requested enhancements have been received. This release of BXLRFD Version 1.3.0.5 corrects the following known problems and provides enhancements.

BXLRFD Version 1.3.0.5 contains the following revisions:

1. The following changes have been made to the serviceability tables in the program.
   a. The crack control stress and tensile reinforcement stress is now converted correctly for US Customary Units. (Request 080)
   b. The output shows the corresponding allowable crack control stress for the tensile side of a section. (Request 080)
   c. The program now always assumes that the concrete section is cracked. (Request 091, Request 082)

2. The user entered vehicle loads on the SAL Command have been revised to convert the US Customary Units loads into tons for correct rating tonnage output. (Request 084)

3. A Live Load Distribution and Dynamic Load Allowance Table has been added to the program output. (Request 090)

4. The User's Manual has been updated to inform the user that reinforcement commands should not be entered for design runs (Request 092)

5. The program does not report crack control stress values for the P-82 truck since Service-I limit state is not computed for the P-82 truck. (Request 093)

6. The array used to store the influence line points for truck load distribution has been increased to accommodate long vehicles on short span culverts. (Request 096)

7. The live load distribution calculations for case 2 (less than 2 ft [600mm] of fill and span greater than 15 ft [4600 mm]) have been modified to include the multiple lane case. (Request 095, Request 097)

8. The live load distribution width calculation for the Fatigue limit state is now calculated correctly without the multiple presence factor or the multiple presence reduction factor. (Request 099)

There are still several outstanding enhancements and problems that will be addressed in the future releases of BXLRFD. For a list of revisions that have yet to be included in the BXLRFD program refer to the summary of revisions for version 1.3.

SUMMARY OF OCTOBER 2006 REVISIONS - VERSION 1.4.0.0

Since the release of BXLRFD Version 1.3.0.5 several revision requests and user requested enhancements have been received. This release of BXLRFD Version 1.4.0.0 corrects the following known problems and provides enhancements.

General Revisions

1. The BXLRFD program has been enhanced to support long file names. (Request 086)

Input Revisions

2. The character limit for the SAL command has been increased 512 characters. (Request 108)

Output Revisions

3. The program has been revised to display a more meaningful warning message when the thickness of a strip footing is greater than the left or right projection. (Request 128)

Earth Load Revisions

4. The Vertical Earth Load during the construction limit state has been modified to apply force on strip footings. The Horizontal Earth Pressure during the Construction limit state has also been revised so the height of fill is limited to the top of the culvert. (Request 078)

5. A warning message when the vertical resultant eccentricity is outside the strip footing has been modified to provide the user with more detailed information. (Request 078b)

Live Load and Live Load Distribution Revisions

6. The TK-527 load has been added to the design and analysis load options. (Request 058,131)

7. The default values for the Eta factors in the program have been changed to 1.0 and the program has been revised to prevent a value other than 1.0 from being used. (Request 062)

8. The live load distribution factor equations for less than 2 ft (600 mm) of fill have been revised to conform to DM-4 Section 4.6.2.12.1P (Request 124)

9. The program has been revised so the user may override the live load application criteria for multi-cell culvert installations. (Request 125)

10. Lane load has been removed from the top slab of box culverts during design and analysis runs as per D3.6.1.3.3. Lane load is still applied to the other components of the culvert. (Request 134)

11. The gross vehicle weight of the ML-80 vehicle has been revised within the program to not include the 3% scale tolerance when calculating rating tonnage. The Special Live Load command gross vehicle weight no longer includes the user entered percent scale tolerance for rating tonnage calculations. (Request 137)

Shear Revisions

12. The shear reinforcement location warning messages have been revised to warn of a non-reinforced shear point of interest (POI) when shear reinforcement is specified. Also when checking if a warning message should be printed a tolerance has been added to the calculation of the first and last analyzed shear POI. (Request 110)

Crack Control and Temperature &Shrinkage Revisions

13. The Maximum Temperature and Shrinkage Spacing Values for the Right/Bottom side of walls has been modified to display the correct maximum spacing value. (Request 122)

14. The crack control equations have been revised in the program to conform to DM-4 Section 5.7.3.4. (Request 123)

User Manual Revisions

15. Miscellaneous typographical corrections have been made to the User's Manual. (Request 101,139)

16. The format of the example input file details in Chapter 8 have been changed to match the input summary table from the output. The example files have been modified so warning messages are no longer produced during processing. (Request 109)

17. The LRFD and ML-80 Live Loading figure in Chapter 2 has been modified to reflect the correct front axle load for the ML-80 vehicle. (Request 121)

Engineering Assistant Revisions

18. The Engineering Assistant figures have been modified to include descriptive captions (Request 105).

Programming Revisions

19. The program is now compatible with APRAS. (Request 034)

20. The program has been converted to a Windows DLL based application. (Request 094)

21. The Box Culvert program has been upgraded to the Intel Fortran compiler (v9.0.025) (Request 118)

There are still several outstanding enhancements and problems that will be addressed in the future releases of BXLRFD. For a list of revisions that have yet to be included in the BXLRFD program refer to the summary of revisions for version 1.3.

SUMMARY OF APRIL 2008 REVISIONS - VERSION 2.0.0.0

Since the release of BXLRFD Version 1.4.0.0 several revision requests and user requested enhancements have been received. This release of BXLRFD Version 2.0.0.0 corrects the following known problems and provides enhancements.

Input Revisions

1. The Fatigue Dynamic Live Load allowance Lower limit has been revised on the LDC command from 0.75 to 1.0 (Request 117).

2. The number of special live load axles allowed in the program has been increased to 80 axles with 79 spacings. (Request 120)

3. The program has been revised so the fill height of a culvert may be left blank. The fill height will be interpreted as zero if left blank. (Request 144)

Output Revisions

4. The description of the axle loads in the “Summary of Input File” report has been revised to no longer indicate a “1” or an “n” after the axle load. (Request 141)

5. The “Serviceability Spacing Summary” output table has been revised to prevent a failure indicator from appearing when no failure actually occurs. (Request 148)

6. The foundation pressure tables have been revised to show limit state information and foundation pressure for the case when live load was not present. Previously the program only displayed the Strength-I foundation pressure and the limit state was not identified. (Request 149)

7. A footnote indicating the design thickness of the slab has been added to the Gross Section Properties table. It will appear beneath the bottom slab output when a fish channel is present. (Request 153)

8. The Concrete Shear Capacity on the Shear Design output table is now displayed as the factored concrete shear capacity. Previously the program showed the gross concrete section shear capacity. (Request 154)

Calculation Revisions

9. A U-channel design and analysis capability has been added to the BXLRFD program. (Request 027)

10. The program has been revised to include fish channel concrete in the calculation of dead loads in the program. Previously the program would ignore the weight of the fish channel concrete. Also an issue has been fixed where the full wall weight was not being considered in the foundation pressure calculation when a fish channel is present. In addition the FSH command input checks have been revised so a user can leave the Segment Width and Height Dimensions blank for a Standard Fish Channel. Previously, the program would halt with an error if these parameters were left blank for a Standard Fish Channel. (Request 151)

User Manual Revisions

11. The Shear Design parameter name on the OUR command has been modified to be consistent in the User's Manual and the parameter definition file. (Request 116)

12. A service load stress calculation procedure has been added to the Users Manual to document how the program computes the tension stress in the reinforcement. (Request 146)

13. The crack width parameter assumption for the obsolete allowable crack control stress calculation has been removed from Chapter 2. (Request 147)

Engineering Assistant Revisions

14. The number of walls allowed on the WLR command in Engineering Assistant has been revised to three walls. Previously the WLR would incorrectly only allow data entry for two walls. (Request 160)

SUMMARY OF FEBRUARY 2009 REVISIONS - VERSION 2.1.0.0

Since the release of BXLRFD Version 2.0.0.0 several revision requests and user requested enhancements have been received. This release of BXLRFD Version 2.1.0.0 corrects the following known problems and provides enhancements.

Input Revisions

1. A new input load has been added to the LDC command to account for a concrete barrier placed atop the culvert. (Request 155)

2. The parameters on the SID command have been modified so State Route, Segment and Offset parameters can be entered as zeros. (Request 156)

Output Revisions

3. The OUI file headings for connection objects have been clarified to reflect that bearing pressure values are reported and the pressure corresponds to walls in the culvert. Previously the program would provide information with generic headers. Also the strip footing OUI information has been revised to provide more complete information regarding the calculation of bearing pressure at each POI. (Request 075)

4. The program has been revised so the correct corresponding response values for the construction limit site in the OUI file are now being correctly reported. Previously, the program was incorrectly calculating the corresponding response value for the EV load for the construction limit state by using the full height of fill instead of the construction height of fill. (Request 127)

5. The Serviceability Spacing Summary table has been modified to prevent a failure footnote from appearing when there are no failures in the Serviceability Spacing Check table. (Request 172)

Calculation Revisions

6. The program has been modified to re-analyze a culvert with strip footings during a design run when only one external wall requires an increase in thickness. Previously, the program would crash due to adjustments made in footing geometry which had not been re-analyzed. (Request 152)

User Manual Revisions

7. The equation for the strip footing force resultant N in User Manual Section 3.9.2 has been revised to fix a typographical error. The equation used in the program was correct. (Request 150)

8. The DIM command has been revised to indicate that the lower limit for section thicknesses can be equal to zero and minimum thickness checks are only enforced when the parameter is left blank. (Request 157)

9. The contact information in Chapter 9 has been updated to reflect the new organizational name changes at PennDOT. (Request 163)

10. A typographical error in the equations for Influence Line Loading in User Manual Section 3.3.7 has been corrected. (Request 167)

SUMMARY OF AUGUST 2009 REVISIONS - VERSION 2.1.0.1

Since the release of BXLRFD Version 2.1.0.0 several revision requests and user requested enhancements have been received. This release of BXLRFD Version 2.1.0.1 corrects the following known problems and provides enhancements.

Calculation Revisions

1. The program has been modified to correctly apply the Barrier Dead Load from the LDC command to Cast-In-Place culverts. Previously, the program would return incorrect live load results for Cast-In-Place culvert runs that included Barrier Dead Load input. This revision only affects Cast-In-Place culverts. (Request 152)

SUMMARY OF MAY 2010 REVISIONS - VERSION 2.2.0.0

Since the release of BXLRFD Version 2.1.0.1 several revision requests and user requested enhancements have been received. This release of BXLRFD Version 2.2.0.0 corrects the following known problems and provides enhancements.

Input Revisions

1. A new load has been added to the program to account for approach slabs supported by culverts. Dead load and Live load can be entered independently for each wall. (Request 179)

2. Minimum toe and heel projection checks have been added to the program for frame culverts. (Request 182)

Output Revisions

3. The output has been modified to now indicate the origins where the slab and wall distances are referenced from. (Request 175)

4. The Allowable Crack Control Spacing has been added to the Output of Intermediate Data file. Previously, the now obsolete Allowable Crack Control Stress was shown. (Request 169)

5. The program has been enhanced to generate a PDF file for each output file. When possible, the PDF file contains bookmarks for easier navigation of the output. The PDF file also makes it easier to print and paginate the program output. (Request 170)

6. The Bottom Slab Steel Area Range values on the Input Summary Table have been revised to show the correct values. Previously, the program would incorrectly show the range values for the Top Slab. (Request 180)

7. The Output of Results parameters shown in the Input Summary table have been corrected. Previously, the Rating Summary and Dead Load Effects and Capacities parameters were shown in the wrong order. (Request 189)

Reinforcement Revisions

8. The program has been revised to prevent the design of shear reinforcement within the walls of a culvert. The program will now increase the wall thickness if the shear capacity is not adequate for DR run types. Previously, the program could potentially design shear steel in the walls of a culvert during a design run, but for an analysis run there was no way to enter the shear steel for the wall. (Request 176)

9. The program has been enhanced to check the development length of wall bars which extend into a strip footing for the controlling face of the wall during design runs. (Request 177)

10. The allowable crack control spacing calculation has been revised to return a large reinforcement spacing when the tensile stress within the reinforcement is less than zero (i.e. bar is in compression). Previously, the program would calculate the allowable crack control spacing with the negative tensile reinforcement stress and incorrectly return a design controlling spacing of zero. (Request 195)

General Program Revisions

11. The BXLRFD program has been revised to no longer support SI unit input files. This is based on a decision by AASHTO Subcommittee on Bridges and Structures to no longer publish updates to the SI unit version 2007 AASHTO LRFD Bridge Design Specifications. (Request 188)

User Manual Revisions

12. The On-Deck Live Load Distribution equation reference in Chapter 3 has been updated to cite the 2007 AASHTO LRFD Bridge Design Specifications. Previously, the equation cited a section of DM-4 that does not exist. (Request 166)

LRFD BOX CULVERT DESIGN AND RATING

SUMMARY OF MARCH 2011 REVISIONS - VERSION 2.3.0.0

Since the release of BXLRFD Version 2.2.0.0 several revision requests and user requested enhancements have been received. This release of BXLRFD Version 2.3.0.0 corrects the following known problems and provides enhancements.

Input Revisions

1. The program has been enhanced to now design and analyze precast frame culverts which are placed on cast-in-place strip footings. Previously the program could only design and analyze cast-in-place frame culverts with strip footings. (Request 174)

Output Revisions

2. The headers for the Finite Element Model Output File (.FEM) have been revised to be more descriptive and provide units. (Request 197)

Strip Footing Revisions

3. The Strip Footing Shear Design table has been revised to include the TK527 live load code. Previously, if the TK527 load would control for the shear design in a strip footing, the program would stop with an error. (Request 198)

4. The Serviceability Spacing Check for Strip Footings has been revised to use the correct load cases when determining the tensile reinforcement stress in the footing under the right wall. Previously, the program was incorrectly accessing the positive load case instead of the negative load case. Also, the Serviceability Summary Table has been revised to prevent the program from erroneously indicating a fault with a component when no fault is present. (Revision 199)

5. The Development Length Table has been revised to correctly select the controlling face of the wall when the Required Area of Steel for each face at the bottom of the wall is equal. Previously, the program would only select the left face if the Area of Steel Required was equal for both faces. (Request 202)

Finite Element Revisions

6. The program was revised to provide better symmetry within the finite element model results and more closely matches the results from the BOX5 program. This was accomplished, as a temporary workaround, by increasing the axial areas within the finite element model to a large value so the axial deformations will be negligible. (Request 193)

General Program Revisions

7. An erroneous program crash has been resolved related to the lack of shear steel in external walls during a design run. Previously, for certain input files, during an iterative design run the program would halt with an error when attempting to clear out memory for shear reinforcement in the external and internal walls during an iterative design run. Due to a recent change, the program no longer designs shear reinforcement in the walls and therefore should not try to clear out memory for reinforcement in walls. (Request 200)

User Manual Revisions

8. The User Manual has been modified to describe efficient design of walls when the top slab thickness is incremented during a design run. (Request 171)

Engineering Assistant Revisions

9. The Fill Grade field on the DIM command in Engineering Assistant has been revised to allow negative numbers to be entered. Previously, only positive values could be entered using Engineering Assistant. (Revision 186)

SUMMARY OF SEPTEMBER 2012 REVISIONS - VERSION 2.4.0.0

Since the release of BXLRFD Version 2.3.0.0 several revision requests and user requested enhancements have been received. This release of BXLRFD Version 2.4.0.0 contains the following revisions and enhancements.

General

1. The BXLRFD program has been updated to the AASHTO LRFD Bridge Design Specifications Fifth Edition 2010 and the 2012 PennDOT Design Manual Part 4.

2. The program has been revised to no longer evaluate the Fatigue limit state based on the 2010 AASHTO LRFD Specification section 5.5.3.1. (Request 215)

Flexural Revisions

3. The Flexural Phi factor has been revised to comply with the 2010 AASHTO LRFD Specifications. The phi factor now varies linearly based on the strain in the section. Also, the moment axial interaction envelope has been revised to include the tension controlled strain point and the point based on $0.1A_{gross}f'_c$. has been removed.(Request 218)

4. The temperature and shrinkage reinforcement calculations for Serviceability have been revised to comply with new shrinkage and temperature reinforcement specifications In the 2012 DM-4 Article 5.10.8 and the 2010 AASHTO LRFD Specification. (Request 217)

Program Source Revisions

5. The BXLRFD program has been updated to the Intel Fortran Composer XE 2011 Compiler. (Request 207)

User Manual Revisions

6. The two right most axle loads in User Manual Figure 2.4-2 for the TK527 vehicle have been corrected. (Request 211)

LRFD BOX CULVERT DESIGN AND RATING

SUMMARY OF MAY 2013 REVISIONS - VERSION 2.5.0.0

Since the release of BXLRFD Version 2.4.0.0 several revision requests and user requested enhancements have been received. This release of BXLRFD Version 2.5.0.0 contains the following revisions and enhancements.

Input Revisions

1. The upper limit for f'c of All Members on the MAT command has been revised to provide input warnings based on whether the structure is Cast-In-Place or Precast. Previously, the program would only issue a warning if the entered f'c would exceed the upper value for Precast only. (Request 214)

2. The default value for "Live Load Code" for design runs of the program has been changed to "E" to ensure inventory rating factors for the ML-80 and TK527 vehicles > 1.0 as specified by DM-4 Sections 3.6.1.2.8P and 3.6.1.2.9P. Additionally, if the user specifies a live load code other than "E" for a design run, a warning message will appear in the program output The default live load code for analysis runs remains unchanged as code “A”. (Request 225)

Output Revisions

3. The program has been revised to generate Live Load Ratings for an analysis run with and without Future Wearing Surface in a single run. Previously, the user would have to generate two sets of rating values by running the program twice. (Request 206)

4. The program has been revised to generate a new output table, named Combined Load Ratings Summary, that shows in one table the controlling rating for each of the different live loads. The table also includes the component and location where the controlling rating occurs. Previously, the user had to review multiple tables to determine the controlling rating for each live load. (Request 210)

Reinforcement Revisions

5. The program has been revised to accommodate the use of high strength reinforcement. When the reinforcement grade exceeds 60 ksi, Chief Bridge Engineer approval is required and limitations are placed on fy for flexure, axial and shear based on the AASHTO LRFD Section C5.4.3.3. Previously, the user could enter values larger than 60 ksi for fy and the program would perform all calculations with the entered reinforcement grade. (Request 204)

Serviceability Revisions

6. The program has been revised to prevent an erroneous serviceability failure on the Serviceability Spacing Summary table which was occurring when the Serviceability Spacing Check table was turned off on the OUR command. (Request 213)

SUMMARY OF MAY 2014 REVISIONS - VERSION 2.6.0.0

Since the release of BXLRFD Version 2.5.0.0 several revision requests and user requested enhancements have been received. This release of BXLRFD Version 2.6.0.0 contains the following revisions and enhancements.

General Program Revisions

1. The method of calling the engineering program DLL from the Engineering Assistant has been changed for compatibility with EngAsst v2.5.0.0 which uses Microsoft's .NET Framework, version 4.5. Because of this, BXLRFD will no longer work with EngAsst v2.4.0.6 or v2.4.0.9 unless the EngAsst "Edit / Run EXE – Command Window" option is selected. BXLRFD will no longer work with EngAsst v2.4.0.0 and earlier. (Request 230)

2. The BXLRFD program has been updated to compile with Intel Fortran XE 2013 SP1 Update 1 using Visual Studio 2012 Update 4. (Request 226)

3. The BXLRFD program finite element model generation has been revised so the results more closely match those found in STAAD.Pro V8i. Previously, the results of the BXLRFD finite element models had been set up to replicate the force results for PennDOT's BOX5 culvert analysis program. (Request 201)

Input Revisions

4. The concrete density has been converted into a user specified input item. The user now has the ability to specify two concrete densities. One for calculating the Modulus of Elasticity and the other for calculating the concrete dead load. Previously the program always used a concrete density of 150 pcf for dead load and 145 pcf for Modulus of Elasticity. (Request 033)

5. The program has been revised to allow for the analysis of a single axle load input through the SLL command. Previously, the program would require a minimum of two axle loads. (Request 159)

6. A new input for Backfill Type has been added to the LDC command. The Backfill Type input is used by the program per A3.6.1.2.6 to determine the distribution of wheel loads through earth fills. For select granular backfill the wheel load is distributed by the tire contact area increased by 1.15 times the depth of fill. For other backfill materials the wheel load is distributed by the tire contact area increased by 1.0 times the depth of fill. Previously, the program never considered select granular backfill material when calculation the wheel distribution through earth fills. (Request 221)

Output Revisions

7. A new Geometry Output table has been added to the Additional Information section of the output. The new table displays a concise list of all final component thicknesses for both analysis and design runs. Previously, the user would have to search the Gross Section Properties table to assemble a list of the same information. (Request 194)

8. The Flexure Design Output Tables have been modified to now provide the Factored Resisting Thrust and Moment based on the Design Area of Steel. In addition, the table now provides the applicable bending Phi Factor controlling zone used to calculate the Resisting Moment. Previously, the program would only show the Applied Factored Forces and the Designed Area of Steel.(Request 220)

9. The Live Load Ratings and Dead Load Effects and Capacities Output tables for analysis runs have been revised to now check that the provided area of steel, for each POI, is not less than the minimum required area of steel. Previously, the program would only show the Provided Area of Steel in the output and would not perform any minimum area of steel check for analysis runs. (Request 223)

User Manual Revisions

10. The Height of Fill parameter description on the LDC command in Chapter 5 and the Overlay Weight/Density and Overlay Thickness input parameter descriptions on the LDC command in Chapter 6 have been updated to provide more information on the modeling of an Overlay slab in the BXLRFD program. Previously, the command descriptions did not address how to model an Overlay slab within BXLRFD.(Request 196)

SUMMARY OF JULY 2016 REVISIONS - VERSION 2.7.0.0

Since the release of BXLRFD Version 2.6.0.0 several revision requests and user requested enhancements have been received. This release of BXLRFD Version 2.7.0.0 contains the following revisions and enhancements.

Input Revisions

1. The Lower Limit for the LDC command “Minimum Equivalent Fluid Pressure” parameter has been changed from 0 to 1 to prevent a divide-by-zero error. The Lower Limit for the LDC command “Maximum Equivalent Fluid Pressure” parameter has also been changed from 0 to 1 for consistency. (Request 246)

Output Revisions

2. The format of the COMBINED RATING SUMMARY table has been revised to the program to report rating information similar to DM-4 Part A Table 1.8.3-1. (Request 228)

3. For certain input files using the minimum required reinforcement (#4 @ 12”), the LIVE LOAD RATING output table displays an incorrect warning indicating that the provided reinforcement is less than the required minimum when the values are actually equal. The program has been revised so the provided reinforcement can be equal to the minimum required reinforcement which prevents this erroneous warning from appearing. (Request 234)

4. The page layout of the output file has been enhanced to allow for more characters per page width and more lines per page in the PDF output file. The new layout has 102 characters per page width and 83 lines per page. (Request 240)

5. The column headings have been corrected for the three Load Modification Factor parameters which appear in the Input Summary output table for the LDC command. The headings are now correctly labelled in order of, Ductility Factor, Redundancy Factor and Importance Factor. (Request 248)

Specification Revisions

6. A fix has been made to the Crack Control Spacing value displayed in the SERVICEABILITY SPACING CHECK output table to prevent the Crack Control Spacing column from displaying “99.99” when the actual Crack Control Spacing is computed as a negative number. The program will now display the Crack Control Spacing as 0.00 when the calculated value is negative. (Request 233)

7. The program has been revised to allow the user to enter the number of precast segments that provide shear transfer as defined in DM-4 Section 4.6.2.10.4. The program uses this new input to compute the lateral distribution width. Previously, the program always assumed that 2 precast segments provided shear transfer. (Request 235B)

8. The program has been revised to follow the 2014 AASHTO Section 3.6.1.2.6 for the distribution of wheel loads through fill by always using a 2:1.15 slope (approximately 60 degree angle) regardless of the backfill type. See User Manual Section 3.3.17.2 for details. Previously, the program would use 2:1.15 slope for granular backfill and 2:1 slope for other backfill types. (Request 238)

9. The calculation of Cracking Moment has been revised to use a new equation from the 2015 DM-4 Section 5.7.3.3.2 which applies multiple factors. Previously, the program would calculate the Cracking Moment using a constant 1.2 factor. (Request 242)

10. The Crack Control spacing calculation has been revised to limit the calculated tensile stress in the reinforcement to be no greater than 0.6*fy based on the 2014 AASHTO LRFD A5.7.3.4. Previously, the program would use the computed tensile stress in the calculation of the Crack Control spacing without limitation. (Request 243)

General Program Revisions

11. The program is now compatible with APRAS NextGen. The CTL Type of Run “AP” has been removed from the program for consistency with the STLRFD and PSLRFD programs. (Request 164)

12. A problem has been fixed for certain input files, representing symmetrical two cell box culverts with no live load, which would stop with an error while writing the Interior Wall results for the SHEAR DESIGN output table. (Request 236)

13. The concrete quantity that appears in the output for the strip footing has been corrected to use the correct footing thickness. (Request 245)

14. The program has been revised to provide a new WVA input command to allow for the definition of shear reinforcement areas in the walls when performing an Analysis (Type AR) run. This new command enables the user to take the required wall shear reinforcement calculated from a Design run and enter it into an Analysis run input file for processing. (Request 237)

User Manual Revisions

15. The BXLRFD User Manual title page has been revised to use a new format and a new logo.(Request 235A)

LRFD BOX CULVERT DESIGN AND RATING

The following is a list of enhancements from the 2014 AASHTO LRFD Specifications that are not included in this version but will be implemented in a later version:

1. The 2014 AASHTO LRFD Specifications include the variation of the resistance factor, φ, for sections in the transition zone between tension-controlled and compression-controlled defined by the net tensile strain in the extreme tension steel and the compression-controlled and tension-controlled strain limits. Previously, the variation in the resistance factor was expressed in terms of the ratio dt/c. (Request 244)

LRFD BOX CULVERT DESIGN AND RATING

SUMMARY OF SEPTEMBER 2018 REVISIONS - VERSION 2.8.0.0

Since the release of BXLRFD Version 2.7.0.0 several revision requests and user requested enhancements have been received. This release of BXLRFD Version 2.7.1.0 contains the following revisions and enhancements.

Input Revisions

1. A problem was fixed with the WVA command where an error was returned when more than one shear reinforcement range was entered. (Request 258)

2. An inconsistency between the valid MAT Alpha parameter values and the BXLRFD User Manual documentation was corrected. The LOWER LIMIT for Alpha was changed from 0.0 to 1.0 degree. A default value of 90 degrees for Alpha was added. (Request 268)

Output Revisions

3. A new output table called MINIMUM REINFORCEMENT CHECK has been added to the program for both Analysis and Design runs to report the various reinforcement steel areas at each POI that are used to determine the minimum required reinforcement area. Reinforcement areas reported are: cracking moment, $\frac{4}{3}$*ultimate moment, ρ_{min} area, temperature and shrinkage area, and 0.002*gross concrete area (A12.11.4.3.2). (Request 065)

4. A problem which caused some incorrect phi-factor 'Zone' values to be displayed in the LIVE LOAD RATING output tables for certain Wall components has been fixed. (Request 282, also see Request 253 below)

Specification Revisions

5. The calculation of ϕ factor has been revised to use the new strain-based equation from AASHTO Section 5.5.4.2 for the situations where loading causes the strain in the section to be between the tension-controlled and compression-controlled regions. Also, calculations for computing and considering the moment resistance and axial resistance for the compression-controlled strain condition of the section have been added to BXLRFD moment axial interaction calculations. (Request 244)

6. The program no longer considers sections to be under-reinforced or over-reinforced. Previously, sections having a “c/de” ratio greater than 0.42 were considered to be over-reinforced as defined in AASHTO Article 5.7.3.3.1. AASHTO Article 5.7.3.3 notes that Article 5.7.3.3.1 was deleted in 2005. The ϕ factor value computed by the program to determine if the reinforcement is sufficient, has been added for each POI to the LIVE LOAD RATING and FLEXURAL REINFORCEMENT DESIGN output tables. The current column titled 'Phi Factor' has been renamed, more appropriately, to 'Zone'. (Request 253)

LRFD BOX CULVERT DESIGN AND RATING

7. The FAST Act live load vehicles EV2, EV3, and SU6TV have been added to the program for Analysis runs using Live Load code “G” on the LDC command. (Request 254)

8. The P2016-13 permit live load vehicle has been added to the program for Design runs using Live Load code “F” on the LDC command, and for Analysis runs using Live Load codes “H or I” on the LDC command. (Request 255)

9. The Strength IA Load Factors for the live load earth surcharge (LS), approach slab live load (AL), and live load vehicle with dynamic load allowance (LLIM) Load Types used in the BXLRFD program have been updated from 1.10 to 1.35 to reflect the 2012 DM-4 updated values. (Request 272)

10. A fix has been made to the Shear Rating Factor calculations for certain input conditions which would cause the program to stop responding. The program had been oscillation indefinitely between two rating factors. If oscillation is detected then a second iteration is performed starting from the lower shear rating factor, ending at the higher shear rating factor. (Request 289)

General Program Revisions

11. A "Division by zero" problem which only occurred in certain Analysis run input files with Live Load Code "D" has been fixed. (Request 271)

12. A problem has been fixed for certain Design runs with live load code "E". It was found that when two such runs were compared -- one with a 1.99' Fill and one with a 2.00' Fill -- the top slab bottom face and the bottom slab top face reinforcement areas varied by more than 65%. The ELAT value was found to be calculated incorrectly in the 2.00' case and was corrected. (Request 265)

13. A problem was fixed where the P-82 vehicle Maximum Dynamic Load Allowance (LDC Command Parameter 17) was not being applied correctly for Design run loading code “E”. For Design run loading code “E” the Dynamic Load Allowance for the P-82 vehicle was computed as 0.0, which would then zero out the P-82 live load results. (Request 275)

User Manual Revisions

14. BXLRFD User Manual Figure 7.4.3-1 has been revised to more accurately reflect the current output of the program. (Request 250)

15. The description of the folder structure on the Start Menu has been modified in the BXLRFD User Manual Section 4.4 to correctly reflect the program installation. (Request 252)

16. Sections 5.10.21 and 6.10.21 of the BXLRFD User Manual have been updated to clarify how the user may distribute the barrier dead load over the culvert design width. (Request 256)

17. Additional explanation has been added to BXLRFD User Manual Section 5.10.26, LDC command, Number of Precast Shear Transfer Segments providing direction on what value the user should enter. (Request 259)

18. A reference to the obsolete "Example Problem Manual" was removed from BXLRFD User Manual Section 8.1. (Request 260)

Programming Revisions

19. The BXLRFD program is now compiled with the Intel FORTRAN Parallel Studio XE 2017 Update 5 Composer Edition using Microsoft Visual Studio 2017. (Request 264)

SUMMARY OF JANUARY 2021 REVISIONS - VERSION 2.9.0.0

Since the release of BXLRFD Version 2.8.0.0 several revision requests and user requested enhancements have been received. This release of BXLRFD Version 2.9.0.0 contains the following revisions and enhancements.

Specification Related Revisions

1. AASHTO / DM-4 references in BXLRFD have been updated to the 8th Edition AASHTO LRFD Specifications / 2019 DM-4 (Request 315).

2. The concrete density modification factor (λ) has been added to shear resistance calculations, as specified in the 8th Edition LRFD Specifications or 2019 DM-4 revisions. (Request 316)

3. The methods for calculating the elastic modulus of concrete and the modular ratio between the concrete and reinforcement have been revised to match the LRFD Specifications, 8th Edition, and the tables of values in the 2019 DM-4 Sections 5.4.2.1 and 5.4.2.4. Along with these changes, the MAT command has been enhanced with additional input checks, and upper and lower limits changed for consistency with the LRFD Specifications and DM-4 (Request 317).

4. The calculation of development length for hooks in tension has been updated to match the notation and equation of the 8th Edition LRFD Specifications. The only numerical differences will be for culverts with lightweight concrete (Request 318).

5. The calculation for the modulus of rupture of concrete has been revised to include the concrete density modification factor, and to now use a single equation for both lightweight and normal weight concrete (Request 320).

6. A new factor, α_1, has been added to the program to replace the previous stress block factor of 0.85, as specified in LRFD Specifications Section 5.6.2.2. The new factor is only less than 0.85 for concrete strengths greater than 10 ksi, decreasing linearly to a minimum value of 0.75 at 15 ksi (Request 326).

7. The "Rho Min Area" check on the MINIMUM REINFORCEMENT CHECK output table is no longer calculated for precast culverts with less than 16 ft. segment lengths, matching the description of the checks in Section 3.5.1.2.1 of the User's Manual which follow the LRFD Specifications 12.11.5.3.2 (Request 328).

8. When calculating the required flexural resistance to find the minimum reinforcement, the coefficient of 4/3 times the factored moment has been updated to 1.33 times the factored moment, to match DM-4 Section 5.6.3.3 (Request 329).

9. The PA Traffic Factor has been removed from DM-4. As a result, the program has been changed so this input is no longer used by the program. Also, the EngAsst Field help for the Fatigue Dynamic Load Allowance and Load Factor Fatigue input parameters has been removed because these input values are not used by the program (Request 303).

Program Input Revisions

10. Up to eight special live load vehicles can now be analyzed and rated in a single run of the program. See the updated User's Manual pages for the new required input on the SLL and SAL commands (Request 257).

    NOTE: This change requires that any previously existing input files using special live loads be updated because of additional input now required.

11. An input check has been added to ensure that all reinforcement commands consistently enter either size and spacing of all reinforcement, or area for all reinforcement. The user cannot combine commands that specify the reinforcement by size and spacing, with commands that specify the reinforcement by area (Request 261).

12. A new input parameter, STRIP FOOTING PC OR CIP has been added to the CTL command to allow the user to specify the type of strip footing being used. This allows the program to choose the correct phi factors to use for the strip footing (Request 284).

    NOTE: This change will require that any previously existing input files for precast frame culverts be modified to enter this input value. Cast in place frame culverts will default to cast in place strip footings.

13. Input checks were added to TSA, TSR, BSA, BSR, WLA, WLR, FTA, and FTR commands to ensure that sufficient data has been entered to define the reinforcement at the top and bottom (or left and right) of each component. If consistent input is not provided, the program will now stop with an error (Request 300).

14. The EngAsst configuration files for the SID command were revised to allow for alphanumeric input for the Span ID parameter (Request 307).

15. The input parameter MULTIPLE PRESENCE REDUCTION on the load control (LDC) command has been revised to be consistent with other input parameters that are no longer used by the program. The parameter is not to be entered by the user because DM-4 does not allow for the reduction of the multiple presence factor based on low ADTT. If the parameter is entered, a warning will be generated and the input value will be ignored (Request 330).

Program Output Revisions

16. On the SERVICEABILITY SPACING CHECK output report, an asterisk indicating a CRACK CONTROL SPACING failure will now print immediately adjacent to the CRACK CONTROL SPACING column for clarity, rather than at the end of the line (Request 274).

LRFD BOX CULVERT DESIGN AND RATING

17. The size of the output field for HEIGHT OF FILL on the LOAD CONTROL output report has been increased to allow output of fill heights greater than 99.99 feet (Request 285).

18. A tolerance has been added to resistance/demand ratio check on the DEAD LOAD EFFECTS AND CAPACITIES output report. A resistance/demand ratio between 0.995 and 1.0 will no longer indicate a failure (Request 287).

19. Top slab output or warnings will no longer be displayed on the SERVICEABILITY SPACING SUMMARY output report for U-Channel structures (Request 294).

20. For precast culverts with a strip footing, the bottom slab top and bottom cover values have been changed to "N/A" (from 0.0), and the instructions for entering these values as zero has been removed from the program documentation (Request 310).

Program Documentation Revisions

21. The alpha value (angle of bent up bars for shear reinforcement) has been changed from 45 degrees to the more commonly used 90 degrees for all delivered example input files (Request 270).

22. The revision request forms provided with the program and in the User's Manual have been revised to remove the mailing address. The email address, phone number, and FAX number have been retained (Request 293).

23. A section number incorrectly specified as "19.10.6" has been changed to the correct value of "6.10.6" in the User's Manual (Request 297).

24. Chapter 9 of the User's Manual has been revised to remove references to providing a program input file on a diskette. Program input files should be provided in an e-mail or as an e-mail attachment (Request 299).

25. Chapters 3 of the User’s Manual was revised to update the structural model boundary conditions that BXLRFD uses as well as to document the EH1 and EH2 loads. Chapter 7 was revised and extended to define the positive sign conventions of the finite element model, as well as showing the direction of positive forces and moments that act on strip footings (Request 305).

26. The name of the new DM-4 permit vehicle has been changed from "PA2016-13" to "P2016-13" in the User's Manual, configuration files, and program output (Request 306).

27. Additional direction and description have been added to Chapters 5 and 6 of the User's Manual regarding the entry of the Height of Fill and Overlay Thickness parameters of the Load Control (LDC) command. The program also now computes a horizontal earth load EH2 due to the Overlay Thickness (see Section 3.3.5 of the User's Manual). Also, the User’s Manual now documents what the calculated EH1 and EH2 horizontal earth loads represent (Request 286, 313).

28. Section 3.5.3.1 of the User's Manual has been modified to document that DM-4 Sections 5.10.3.2 and 5.10.6.1P are the source for the program's maximum bar spacing limits.

Programming Revisions

29. A tolerance has been added to the maximum bar spacing checks on the SERVICEABILITY SPACING CHECK output report to avoid situations where the calculated maximum spacing and input spacing appear to be equal but show a specification failure. This situation will no longer result in a failure (Request 298).

30. BXLRFD has been revised to use Visual Studio 2019 and Intel Parallel Studio XE 2019 Fortran Update 5 for compilation and linking (Request 301).

31. Fatigue-related source code that is no longer used by the program has been removed from the project files and source code repository (Request 319).

32. The functions SIFSACC and SIZ were removed from the program as they were no longer needed by the program (Request 321).

APRAS Requests

33. For APRAS runs, the program will no longer produce any OUI, FEM, FER, MM, OR ANN files (Request 296).

34. The program source code now has the option to build a 64-bit executable (EXE) and dynamic link library (DLL). The program now also has the option to create a 32-bit executable and dynamic link library that uses the Compact Visual Fortran (CVF) calling convention. Both revisions have been provided to support APRAS (Request 302).

35. The parameter DLLERR text and appropriate return code (0 or 1) are now returned by the program to external calling programs (such as APRAS) (Request 308).

SUMMARY OF JULY 2022 REVISIONS - VERSION 2.10.0.0

Since the release of BXLRFD Version 2.9.0.0 several revision requests and user requested enhancements have been received. This release of BXLRFD Version 2.10.0.0 contains the following revisions and enhancements.

General Revisions

1. **Type of Run DA (Design with Shear Reinforcement; CTL command), now applies to all members of the culvert. Previously, Wall members would be designed without Shear Reinforcement for Type of Run DA. Also, Type of Run DR (Design with Known Thickness), will not increment the member thickness and will design shear reinforcement if necessary for all members of the culvert. Previously, wall member thicknesses would be incremented to allow design without shear reinforcement for Type of Run DR. (Request 341)**

Input Revisions

2. **The Special Live Load Command (SLL) now has a parameter for the Vehicle Type that allows identifying the special live load as either Design or Permit vehicle. Based on the Vehicle Type the dynamic load allowance (Impact) will be set for a Design Truck or for a Permit Truck. (Request 277)**

3. **Separate input items are now available for the fill material around the culvert up to the top of the culvert and for fill material above the top of the culvert on the Load Control (LDC) command. The input variable, "Backfill Unit Weight" is used for material around the culvert and "Fill Unit Weight" is used for material above the culvert. (Request 324)**

4. **Providing the Bottom Slab Shear Reinforcement Area command (BVA) or the Wall Slab Shear Reinforcement Area command (WVA) for U-Channel Structure Types now results in an error message because these commands cannot be used with U-Channel structures. Similarly, specifying a Run Type of DA or DR for U-Channel Structure Types now results in an error message. Both error messages are consistent with prior information in the User Manual. (Request 354)**

5. **Checks on user entered f'c values matching Bridge Standard Drawing BD-632M are now made after default values are applied to the input f'c values. (Request 365)**

Output Revisions

6. **The Dead Load Effects and Capacities output report now provides the correct Zone and Phi Factors for External Wall 2 of a Single Cell culvert. Previously, the Zone was reported as "xx" and the Phi Factor was reported as 0.00 for U-Channels and Single Cell Box Culverts. Also, for Two-Cell Box Culverts the Zone and Phi Factors for External Wall 2 were incorrectly reported the same as Internal Wall 1. This has also been corrected. (Request 312)**

7. **The Rating Summary output table and the Combined Rating Summary output table now report negative shear ratings when negative shear ratings are computed for the Live Load Rating. Previously, negative shear ratings were overlooked when the results were reported in the Rating Summary output table and the Combined Rating Summary output table. (Request 332)**

8. **The phi factors reported in the Flexural Reinforcement Design output table have been corrected. Previously, the phi factors did not always agree with the Zone reported in the output table. (Request 342)**

9. **An issue that could cause the reported Factored Resistances in the Flexural Reinforcement Design output table to incorrectly report the same resistances at multiple locations has been corrected. (Request 347)**

<u>Programming Revisions</u>

10. **Verified that input files containing the plus sign character are valid file names and do not cause any issues in the program. Previously, the program would stop with an error message if an input file contained a plus sign. (Request 247)**

11. **An input file is now processed by all input routines to allow more input warnings and errors to be reported to the user for a single run of the program. Previously, an error message could stop processing of the input by the remaining input routines. Sometimes new warnings and errors would be reported after correcting all previously reported errors and warnings. Also, input variables for a command now are set even when an error occurs processing that command. Previously, none of the input variables for that command would be set when a command had an error. This was causing warning and error messages that did not apply. (Request 249)**

12. **Responses from Live Load Surcharge and Approach Slab Live Load are now combined in the Live Load Response for each Limit State. Previously, Live Load Surcharge and Approach Slab Live Load were considered in the Dead Load Response for each Limit State. (Request 278)**

13. **The program is now able to provide output for design runs where the flexural reinforcement design failed due to the member thicknesses being too small for the applied loads. This could happen for the Reinforcement Design of a DR Type of Run specified on the CTL Command. Previously, this type of run would stop with a cryptic and unhelpful error message. (Request 309)**

<u>Reinforcement Revisions</u>

14. **The Flexural Reinforcement Design output report can now report U-channels with wire mesh reinforcement. Previously, a U-channel designed with wire mesh reinforcement would give a cryptic error message and exit after starting the Flexural Reinforcement Design output report. (Request 281)**

15. For components with large axial loads compared to the moments, the area of reinforcement in both faces is incremented or decremented together during the reinforcement design. This will apply to the internal wall of a symmetrical two cell box with symmetrical loadings. Previously, the area of reinforcement of only one face of an internal wall was incremented which could lead to one face of an internal wall with two to three times the reinforcement of the other face for a symmetrical culvert. (Request 345)

16. The Flexural Reinforcement Design output table now correctly computes the required area of flexural reinforcement for DR runs with undersized member thicknesses. (Request 348)

17. The Wall Shear Reinforcement Area command (WVA) now correctly processes input data for 2-cell culverts when reinforcement has not been specified for each wall. (Request 355)

Shear Requests

18. The shear region of each component is now determined using the effective shear depth, dv. Previously, the shear region was determined using the effective depth, de. (Request 311)

Specification Requests

19. Specifying a Reinforcement Grade greater than 60 ksi on the MAT command now results in a District Bridge Engineer approval required warning message. Previously, this resulted in a Chief Bridge Engineer message. (Request 304)

20. The compression-control strain limit used to determine the factored resistance of concrete components for reinforcement with yield strengths, fy, less than or equal to 60 ksi is now the minimum of 0.002 and fy/Es. Previously, the compression-control strain limit for yield strengths less than or equal to 60 ksi was 0.002. (Request 349)

Strip Footing Requests

21. The Flexural Reinforcement Design output table for Strip Footings is now calculated and reported in the output table. Previously, the Flexure Loading Code, Factored Moment/Thrust, Factored Resistance Moment/Thrust, Zone, and Phi Factor were always blank. (Request 279)

22. The Strip Footing Results table in the Intermediate Data Output (.OUI file) has been verified to be correct for design and analysis runs. (Request 280)

User Manual Requests

23. Guidance is now provided in the User Manual for the Clear Span to enter when the primary reinforcement is along the skew of the box culvert. (Request 263)

24. **The User Manual now defines the criteria used by the program to select the reinforcement (Top or Bottom) used when calculating de and dv for the shear resistance. (Request 314)**

25. **The Revision Request Forms (User Manual and Word Template) no longer refer to a PennDOT fax number. (Request 364)**

1 GENERAL DESCRIPTION

1.1 PROGRAM IDENTIFICATION

Program Title: LRFD Box Culvert Design and Rating

Program Name: BXLRFD

Version: 2.10.0.0

Subsystem: Substructure

Authors: Pennsylvania Department of Transportation,
Imbsen and Associates, Inc.,
Michael Baker International and
Modjeski and Masters, Inc.

ABSTRACT:

The LRFD Box Culvert Design and Rating program (BXLRFD) performs an analysis and specifications check in accordance with the AASHTO LRFD Bridge Design Specifications and the Pennsylvania Department of Transportation Design Manual Part 4, for cast-in-place and precast box culverts and U-channels. As result of a decision by the AASHTO Subcommittee on Bridges and Structures to longer publish System International (SI) unit specifications, the program only supports US customary (US) units.

The program can perform an analysis or design of a one or two cell, reinforced concrete precast or cast-in-place box culvert, with or without haunches, and a fish channel, and of a one or two cell reinforced concrete cast-in-place or precast rigid frame culvert. A variable top slab, sloped fill, and/or a variety of live loads, including a user specified special live load, can be specified and analyzed.

The program can perform an analysis or design of a one cell, reinforced concrete precast or cast-in-place U-channel, with or without haunches, and a fish channel.

The loads applied to the structure are based on the LRFD limit state combinations that have been adjusted to incorporate PennDOT policies. The limit state combinations include strength, service and construction limit states for final and temporary construction stages. The program uses a 2-dimensional finite - element frame model to analyze the culvert for all load effects.

The program can perform analysis (rating) or design. For analysis, the program performs specifications checking and rates the sections for moment and shear at 10th points, other critical sections, and user defined points. For

design, the program can size member thicknesses, compute the required flexural reinforcement, and compute the bar size and spacings for strength and crack control at 10th points, and other critical sections. Shear reinforcement can also be computed for design or specified for analyses in the top slab, bottom slab and walls **for box culverts and frame culverts**. **Shear reinforcement is not considered for U-Channel culverts.**

1.2 ABBREVIATIONS

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

AASHTO	- American Association of State Highway and Transportation Officials.
BXLRFD	- LRFD Box Culvert Design and Rating program.
DM-4	- Design Manual Part 4, December 2019 Edition, published by Pennsylvania Department of Transportation. This publication can be downloaded free of charge from PennDOT's website.
LRFD Specifications	- AASHTO LRFD Bridge Design Specifications, Eighth Edition, 2017, published by: American Association of State Highway and Transportation Officials 444 North Capitol Street, N.W., Suite 249 Washington, D.C. 20001
PennDOT	- Pennsylvania Department of Transportation.

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2 PROGRAM DESCRIPTION

2.1 GENERAL

The purpose of the LRFD Box Culvert Design and Rating program (BXLRFD) is to provide bridge engineers with a tool to design or analyze single or two cell reinforced concrete boxes, rigid frame culverts and U-channels in accordance with the AASHTO LRFD Bridge Design Specifications and the Pennsylvania Department of Transportation Design Manual Part 4.

The structural analysis is based on a 1 ft length of the culvert, and uses the direct stiffness method to compute all member forces produced by the dead, earth, and live loads. The live load can be an LRFD loading or a user - defined loading, including a combination of truck and lane loading.

After the structural analysis is performed and the limit state combinations computed, the program checks for compliance with the specifications for shear, moment and moment-axial interaction stresses. The live load ratings are also produced if applicable.

2.2 CULVERT TYPES

Single and two cell box and rigid frame culverts or single cell U-channels can be analyzed or designed by this program. Examples of these types are shown in Figure 1. Box culverts and U-channels may be either cast-in-place or precast. Rigid Frame culverts can either be cast-in-place or precast. The top slab of the culvert may be analyzed as monolithic or simply supported, and may be at grade or under fill. The culvert may be analyzed with or without monolithic haunches. Standard or nonstandard fish channels can be defined in the bottom slab of box culverts and U-channels. Fish channels in two cell box culverts are permitted to be in the left cell only.

2.3 PROGRAM FUNCTIONS

BXLRFD performs the following functions:

1. Input Processing - The program prompts the users for the name of input and output files and then processes the input. The program checks the user-entered input values and compares them with lower and upper limits stored in the program. If the user value is less than the lower limit, or greater than the upper limit, an error or warning is issued. If an error is detected, the program will stop processing; otherwise, the program will continue to the calculations concerning the geometry. The program inserts default values for items for which default values are available and for which no user values were entered.

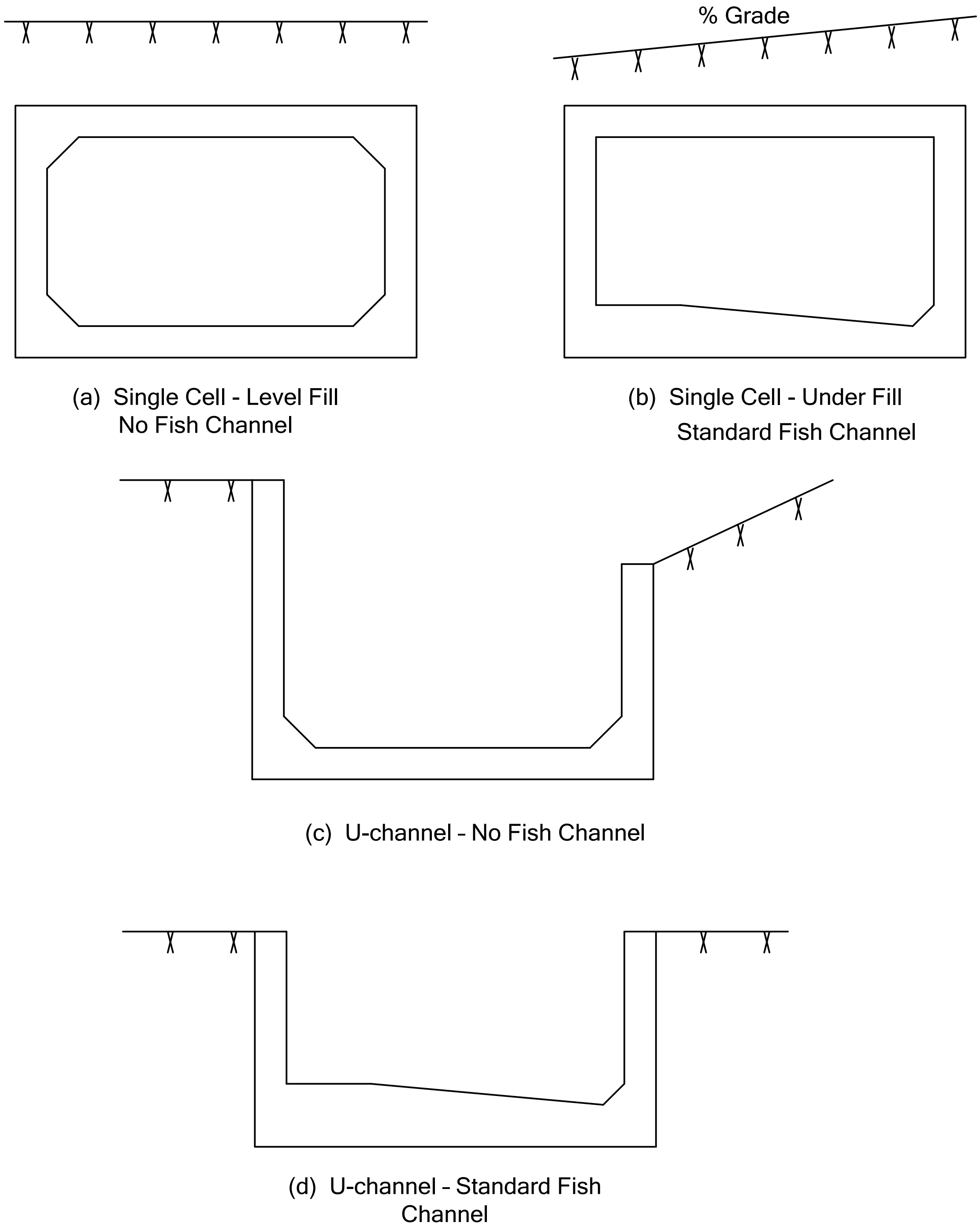
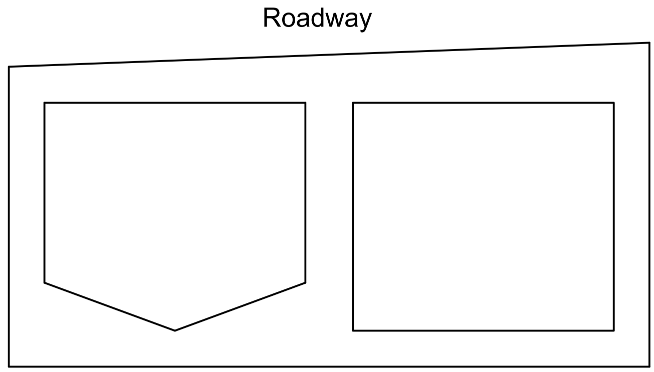
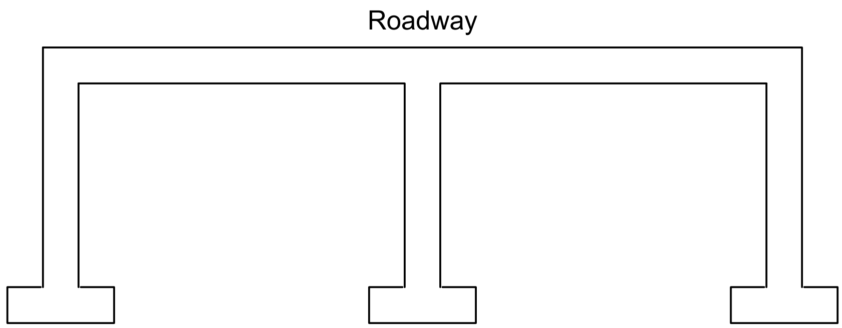


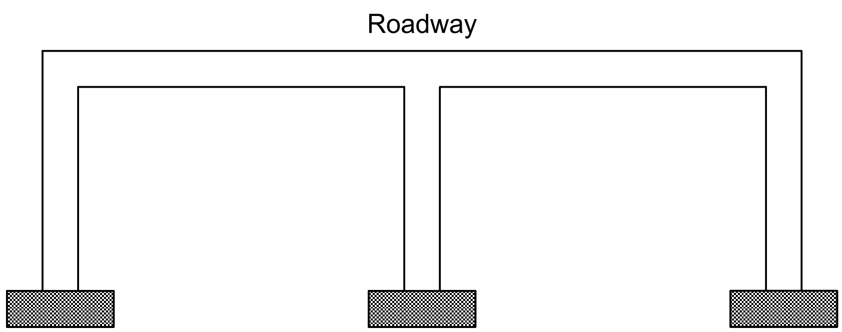
Figure 2.2-1 Types of Culverts



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



(f) Cast-in-place Twin Cell Rigid Frame - Top Slab at Grade
(No Bottom Slab)



(g) Precast Twin Cell Rigid Frame - Top Slab at Grade
(No Bottom Slab – User Designed Footings)

Figure 2.2-2 Types of Culverts (cont.)

2. Structural Modeling / Geometry - 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 center lines. Each culvert slab and wall is divided into a number of members 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. For box culverts, a pinned support is assumed at the left bottom corner of the model and roller supports are assumed at the left top corner and the right bottom corner of the model. For cast in place frame culverts, fixed connections are assumed at the bottom of each wall and a roller support is assumed at the top left corner. For precast frame culverts, pinned connections are assumed at the bottom of each wall and a roller

support is assumed at the top left corner. Each member of the model is assumed to have a constant cross section. The finite element model cross section is set to a large value to minimize the effects of axial deformation in the finite element model to more closely match the results of the Pennsylvania Department of Transportation's BOX5 program, which utilizes the slope deflection method and does not consider axial deformation. The joint coordinates, member connectivity, and member properties are used for the direct stiffness method of analysis for the model.

3. Structural Analysis - The plane frame model described above is analyzed for a variety of dead, earth and live loadings to get the effects (moments, shears and axial forces) at all analysis points. The loads applied are the self weight of components (DC), wearing surface (DW), overlay weight (OV), weight of fill (EV), earth pressure (EH), live load surcharge (LS), weight of water (WA), and live loading (LL). For live loading effects, influence lines for moments, shears and axial forces at analysis points are generated first and then these influence lines are processed to produce the positive and negative live load effects.

4. Load Combination - The culvert load effects from all applied loads are factored by maximum and minimum load factors and combined into the following limit states:
    - Strength I
    - Strength IA
    - Strength II
    - Construction
    - Service I

   The same load factor is applied to both the horizontal and vertical components of EH and/or LS since the resultants of those loads each represent inclined forces.

5. Analyze / Design Section - The program operates in two modes: Analysis (Rating) or Design. For Analysis, the member thicknesses and reinforcement are known and the program performs specifications checking, and then rates the sections for moment and shear. For Design, three options are available. In the first design option, the program designs the flexural reinforcement and shear reinforcement (if required) for known member thicknesses. In the second design option, the program designs both the member thicknesses for flexure and shear (without shear reinforcement) and the flexural reinforcement. In the third design option, the program designs the member thickness for flexure and both the flexural reinforcement and the shear reinforcement (if required). Ratings are not provided in design runs.

6. Culvert Reinforcement - The culvert reinforcement consists of flexural and shear reinforcement for each component, i.e., top slab, bottom slab, walls, and strip footings. For analysis, all strength and serviceability requirements for the reinforcement entered by the user are checked, including minimum steel area, and minimum and maximum spacing. However, the calculated rating factors are based on the strength requirements only. For design, the program calculates the required reinforcement. The reinforcement requirements are based on strength and serviceability for crack control for bars, and based only on strength for wires. Minimum and

maximum bar spacing, and minimum area of steel are checked for all components. The development length is not checked.

7. Footing Reinforcement - The strip footing of a rigid frame culvert is assumed to have flexural reinforcement only; i.e., no shear reinforcement is allowed. For analysis, all reinforcement must be entered by the user. For design, the program calculates the required flexural reinforcement in the user defined strip footings to satisfy all strength and serviceability requirements. The development length is not checked.

8. Bearing Pressure - The actual bearing pressure is calculated for the strip footings of rigid frame culverts and the bottom slab of box culverts. The maximum actual bearing pressure under each wall of a rigid frame culvert and under the bottom slab of a box culvert is reported. The program does not check the maximum actual bearing pressure against an allowable bearing pressure.

9. Quantity - The volume of concrete for each component is reported by the program.

2.4 LIVE LOADINGS

The user has several live load options for performing an analysis or design. The following live loadings may be considered:

HL-93	-	AASHTO LRFD live loading
PHL-93	-	PennDOT LRFD live loading
ML-80	-	PennDOT maximum legal live loading
P-82	-	PennDOT permit live loading
HS20	-	AASHTO HS20 live loading
H20	-	AASHTO H20 live loading
SLL	-	User-defined special live loading
TK527	-	PennDOT TK527 live loading
EV2	-	FAST Act EV2 live loading
EV3	-	FAST Act EV3 live loading
SU6TV	-	FAST Act SU6TV live loading
P2016-13	-	P2016-13 permit live loading

The HL-93 loading is the vehicular live load consisting of the design truck, design tandem, and design lane load as defined in the LRFD Specifications. The PHL-93 loading is the same as the HL-93 loading except that the axle loads on the design tandem for the PHL-93 loading are multiplied by a factor of 1.25.

The PennDOT maximum legal live loading (ML-80) is the maximum legal truck allowed in Pennsylvania. The PennDOT permit live loading (P-82) is a notional load used to check the Strength II limit state. The AASHTO HS20 live loading and AASHTO H20 live loading are in accordance with the AASHTO Standard Specifications for Highway Bridges. For special live loadings (SLL), the user can input the axle loads, the axle spacings, uniform lane loading, and the corresponding load factors for each limit state.

The axle loads and axle spacings for the HL-93 and PHL-93 design truck, HL-93 design tandem, PHL-93 design tandem, and ML-80 rating truck are presented in Figure 1. The P-82 permit truck, TK527 truck, HS20 truck and H20 truck loadings are presented in Figure 2. (Note: This program does not apply the HS20 or H20 lane loading to the culverts since it is assumed that these loadings will not control over the HS20 or H20 truck loadings for a culvert.) Figure 3 presents the FAST Act EV2, EV3, and SU6TV vehicle loadings. The FAST Act vehicles are not considered notional loads. The design lane load for both the HL-93 and PHL-93 loading is taken as 0.64 kips per linear foot. However, design lane loads will not be applied to the top slab(s) of culverts as required by D3.6.1.3.3.

The P2016-13 special design permit vehicle shown in Figure 4 is considered a notional load and the vehicle has two variable spaced axles. The first variable spaced axle is between axles 7 and 8 with a spacing that varies from a minimum of 30 feet to a maximum of 50 feet. The second variable axle between axles 10 and 11 varies from 5 feet to 14 feet. Vehicle definitions in BXLRFD are limited to vehicles with a single variable axle. Because of this limitation, the vehicular loading for the P2016-13 vehicle was modeled as a live load envelope in the program. The P2016-13 live load envelope consists of ten vehicles, each with a single variable axle spacing between axles 7 and 8. For each of the ten vehicles the other variable axle is held constant. The first vehicle consists of a 5 foot axle spacing between axles 10 and 11; the second vehicle consists of a 6 foot axle spacing between axles 10 and 11; and so on until the last vehicle which consists of a 14 foot axle spacing between axles 10 and 11.

In place of the above live loadings, the culvert can be analyzed for a special live loading (SLL) by specifying the axle loads, axle spacings, and/or the uniform lane load. The SLL command can be used to analyze a permit load, analyze more than one truck unit on the structure, or to check the combination of a truck load and a lane load. A special live load may have up to a maximum of 24 axles.

The live loads to be used for an analysis or design are designated by the user by entering a live load code. The live load designations used for each live load code and each load case are summarized in Tables 1 and 2.

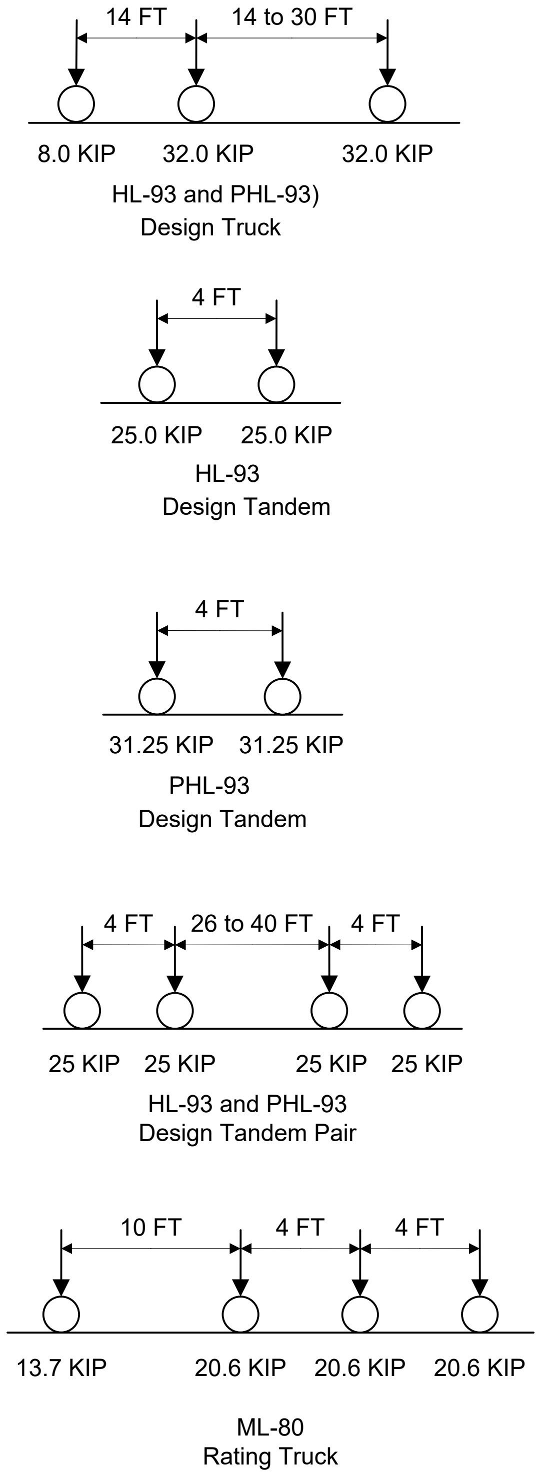


Figure 2.4-1 LRFD and ML-80 Live Loading

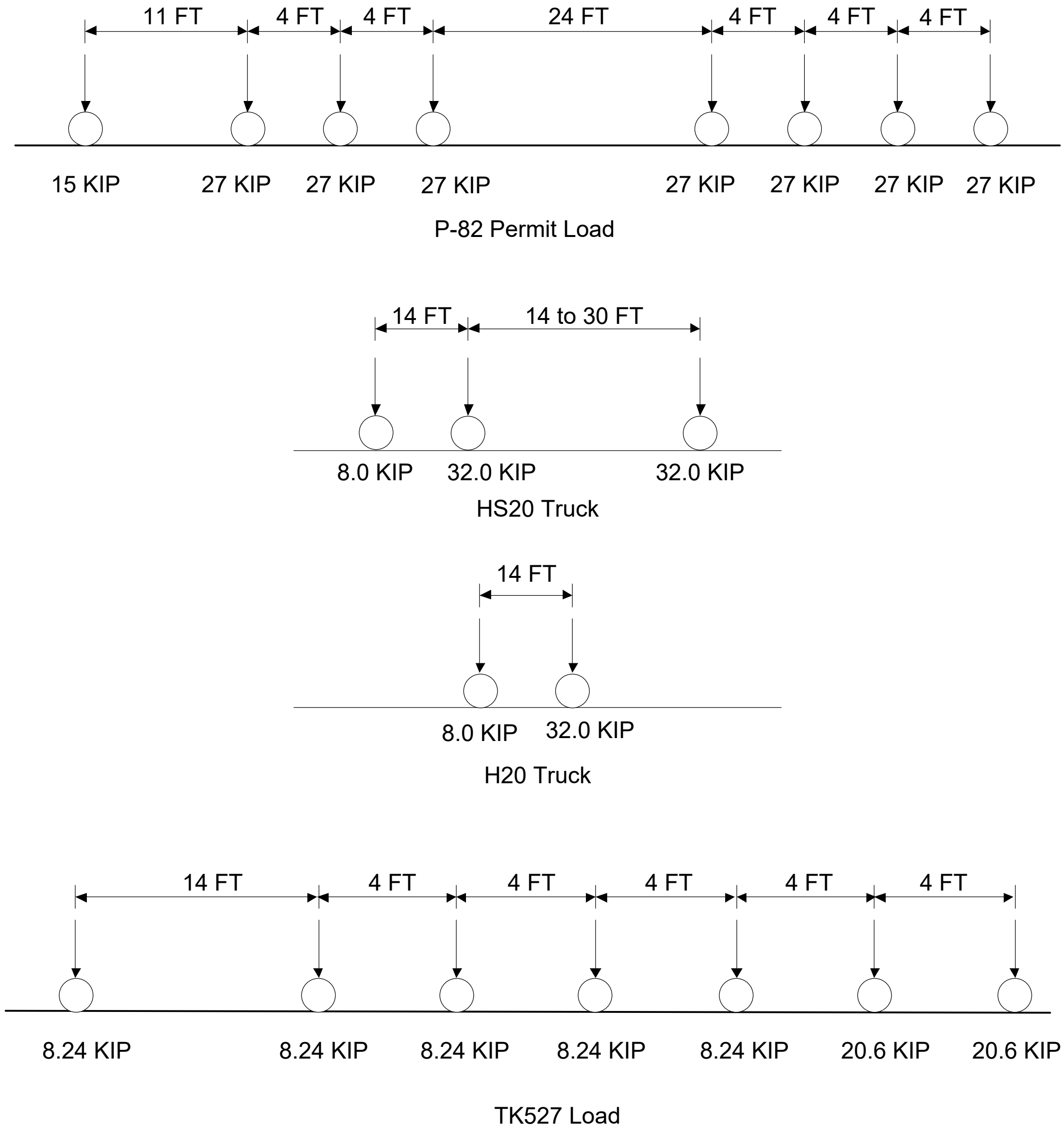


Figure 2.4-2 P-82, HS20, H20, and TK527 Live Loading

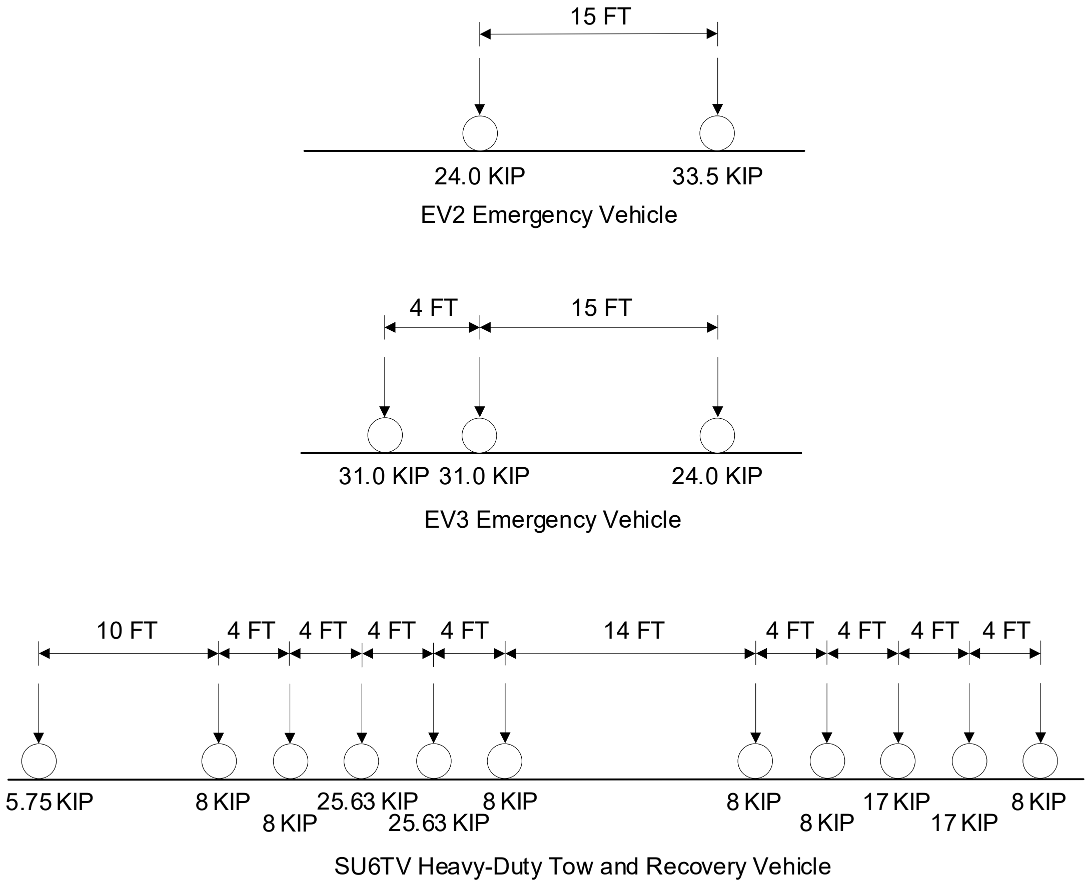


Figure 2.4-3 EV2, EV3, and SU6TV Live Loading

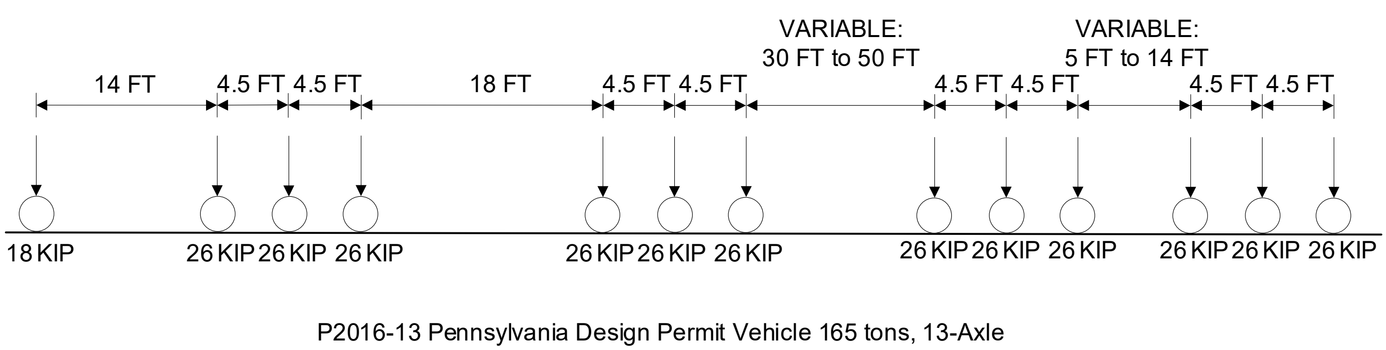


Figure 2.4-4 P2016-13 Live Loading

Table 2.4-1 Live Loadings for Design

Load Case	Live Load Code for Design					
	A	B	C	D	E	F
Strength I Limit State	PHL-93	HL-93	HL-93	PHL-93, ML-80	PHL-93, ML-80, TK527	PHL-93, ML-80, TK527
Strength II Limit State	P-82	P-82	none	P-82, ML-80	P-82, ML-80, TK527	P-82, ML-80, TK527, P2016-13
Service I Limit State	PHL-93	HL-93	HL-93	PHL-93, ML-80	PHL-93, ML-80, TK527	PHL-93, ML-80, TK527

Table 2.4-2 Live Loadings for Analysis/Rating

Load Case	Live Load Code for Analysis								
	A	B	C	D	E	F	G	H	I
Strength I Limit State	PHL-93 H20 HS20 ML-80 TK527	HL-93 H20 HS20	ML-80	none	SLL	TK527	none	none	PHL-93 H20 HS20 ML-80 TK527
Strength IA Limit State	PHL-93	HL-93	none	none	none	none	none	none	PHL-93
Strength II Limit State	P-82 H20 HS20 ML-80 TK527	H20 HS20	ML-80	P-82	SLL	TK527	EV2 EV3 SU6T V	P2016-13	P-82 H20 HS20 ML-80 TK527 P2016-13
Service I Limit State	PHL-93 H20 HS20 ML-80 TK527	HL-93 H20 HS20	ML-80	P-82	SLL	TK527	EV2 EV3 SU6T V	P2016-13	PHL-93 H20 HS20 ML-80 TK527

Notes:

1. "none" denotes that the specified live load designation does not apply for the live load code.

2.5 RATINGS DEFINITION

The program computes the live loading rating factors for flexure and shear for the Strength I, Strength IA, and Strength II limit states. The live load rating factor is the ratio of the live load reserve capacity divided by the factored live load effect. The program computes inventory and operating ratings for the appropriate live loadings and limit states as shown in Table 1. The inventory rating is the load that can be carried by the structure for an infinite period of time. The operating rating is the load that may produce the absolute maximum permissible stress, and it is the maximum load allowed on the structure. By specifying an input value, the program is able to generate ratings with and without Future Wearing Surface loading in a single run of the program.

When a live load is not applicable, the program computes the resistance to demand ratios in lieu of the live load rating factors. This provides a measure of performance of the culvert when only the dead loads and earth loads are present.

Table 2.5-1 Live Loading Ratings

	Limit States		
Live Loading	**Strength I**	**Strength IA**	**Strength II**
PHL-93/HL-93	I	O	--
P-82	--	--	O
ML-80	I	--	O
HS20	I	--	O
H20	I	--	O
Special Live Load	I	--	O
TK527	I	--	O
EV2, EV3, SU6TV	--	--	O
P2016-13	--	--	O

Notes: I=Inventory O=Operating

2.6 ASSUMPTIONS AND LIMITATIONS

The following assumptions are made by BXLRFD for the analysis or design of box culverts:

1. A one ft (one m) length of culvert is considered for analysis and design.

2. The modulus of elasticity of reinforcement, E_s, is assumed to be 29,000 ksi.

3. When the top slab is at grade, a 0.5 inch thickness for integral wearing surface is included in the total slab thickness. This integral wearing surface is considered in calculating the culvert self weight, but is ignored for calculating the strength of the slab. It is however considered in the determination of section stiffness properties. Applicable to box culverts only.

4. For all culverts and U-channels, the bottom slab total thickness includes a 0.5 in thickness for scouring effects. This thickness is considered in the culvert self weight, but is ignored for calculating the strength of the slab. The thickness is however considered in the determination of section stiffness properties.

5. For cast-in-place culverts and U-channels, the bottom slab total thickness includes a 1.0 in thickness for foundation unevenness. The thickness is considered in the culvert self weight, but is ignored for calculating the strength of the slab. It is, however, considered in the determination of section stiffness properties.

6. For design, member thicknesses are increased using 0.5 inch increments.

7. For design, reinforcement spacing is determined using 0.5 inch increments.

8. For two cell culverts with fish channels, the minimum thickness of the bottom slab with a fish channel is equal to the thickness of the bottom slab without a fish channel.

9. All bar covers are clear distances, measured from the outside concrete face (or assumed structural face) to the face of the bar.

10. When checking the crack control criteria (LRFD Specifications Section 5.6.7), the program limits the clear cover to 2 inches. The clear cover is the distance from the extreme tension face to the face of bar or wire. The scour, foundation unevenness and wearing surface thicknesses are considered sacrificial, and therefore, are ignored.

11. Haunch thickness is considered for calculation of section stiffness properties. Haunches are not considered for strength calculations and the haunch self weight is ignored in the dead load calculations.

12. Slab thickness variations in the top slab due to grade and in the bottom slab with a fish channel are considered for stiffness calculations and member flexure and shear design.

13. For variable thickness slabs, the reinforcement is considered to be at a constant distance from the face of the member.

14. The maximum size (diameter) of aggregate is 1 inch. This data item is used to calculate minimum rebar spacing per LRFD Specifications Section 5.10.3.1.1 (CIP) and LRFD Specifications Section 5.10.3.1.2 (PC).

15. If a future wearing surface is not specified, a default load of 30 lbs/ft^2 is placed on the culvert for design. This default wearing surface is not placed on the culvert for rating. If a future wearing surface is specified, it is used for both design and rating.

16. For the calculation of F_e, the structure type is CULVERT and the backfill condition is COMPACTED (LRFD Specifications Section 12.11.2.1). The structure type is CULVERT for ϕ in flexure and shear (LRFD Specifications Section 12.5.5), and is RC for ϕ in axial compression (LRFD Specifications Section 5.5.4.2).

17. The value of beta, the factor indicating the ability of diagonally cracked concrete to transmit tension (LRFD Specifications Section 5.7.3.4.1) is 2.0.

18. The value of theta, the angle of inclination of diagonally compressive stresses (LRFD Specifications Section 5.7.3.4.1), is 45 degrees.

19. Shear reinforcement is not considered for U-channels.

20. Approach slab loads are only applied at the top of the centerline of the exterior walls.

21. The live load vehicle effects are not calculated for approach slabs by the program. The user must calculate the live load from the approach slab to be applied to the culvert.

22. For Frame Culverts the minimum footing toe and heel projection is 1 foot.

23. The program does not consider Fatigue when designing or analyzing culverts or frames.

24. The BXLRFD program does not automatically design or analyze an edge beam, if one is required per DM-4 Section 12.11.2.1. See User Manual Section 3.11 and Elat, Section 7.6.6.

3 METHOD OF SOLUTION

The primary purpose of this program is to design or analyze and rate a single or two cell reinforced concrete box or frame culverts and U-channels following the LRFD specifications and DM-4. This chapter provides detailed information regarding the method of solution used in the program.

In the design and rating of reinforced concrete box culverts and U-channels, the following steps are generally required:

1. Generate structural model using geometry
2. Determine loads and calculate load effects
3. Determine combined load effects
4. Determine member thickness
5. Calculate section resistance
6. Calculate reinforcement
7. Check resistance against load effects
8. Adjust section for adequate shear resistance
9. Calculate ratings
10. Calculate foundation pressure

The program performs the above calculations using the direct stiffness method of structural analysis and following the specifications provided in the LRFD and DM-4. For this program, two types of runs can be made: Analysis (Rating) and Design. For Analysis, all member thicknesses and reinforcements are known and the program performs all calculations mentioned above except Steps 4, 6 and 8. For Design, the program performs all calculations mentioned above except Step 9.

The following sections describe the above calculations in detail. Refer to any standard textbook on structural analysis and the appropriate sections of this manual for calculations performed in Steps 1 and 2. Refer to the LRFD Specifications and DM-4 for calculations performed in Steps 3, 5, and 6. Refer to appropriate sections of this manual for calculations performed in Steps 4, 5, 6, 7, 8 and 9.

Chapter 3 Method of Solution

3.1 NOTATION

The following notations are used in this chapter:

A_b = area of individual bar

A_g = gross area of a cross section

A_s = flexure reinforcement per unit length of culvert for a face of a cross section

$A_{s,min2}$ = minimum allowed reinforcement for flexure

$A_{s,min1}$ = minimum allowed reinforcement for temperature and shrinkage

$A_{s,min}$ = minimum allowed reinforcement

A_v = required area of shear steel per unit length

A_t = area of concrete having the same centroid as the principle tensile reinforcement and bounded by the surfaces of the cross-section and a straight line parallel to the neutral axis, divided by the number of bars or wire.

b = unit width of culvert section resisting M, N, V, (1 ft)

B = width of the footing

B_c = contact width of the footing

bot_c = clear cover for bottom/right face reinforcement

b_v = effective web width for shear

c = distance from extreme compression fiber to the neutral axis

d_b = nominal diameter of reinforcement bar and wire

d_c = thickness of concrete cover measured from extreme tension fiber to center of bar or wire

DC = dead load of structural and non-structural components

DC0 = dead load of components for bottom slab only effects

DC1 = dead load of components for stage 1 of a cast-in-place culvert

DC2 = dead load of components for stage 2 of a cast-in-place culvert

d_e = effective depth from extreme compression fiber to the centroid of the tensile force in the tensile reinforcement

D_E = minimum depth of earth cover

d_{neg} = effective depth from extreme compression fiber to the centroid of the tensile force in the tensile reinforcement for negative moment

d_{pos} = effective depth from extreme compression fiber to the centroid of the tensile force in the tensile reinforcement for positive moment

d_v = effective shear depth

d_w = width of lane loading assumed to be equal to 10.0 feet

DW = dead load of wearing surface and utilities

e = eccentricity of the load resultant, N, relative to the centerline of the footing

E = earth loadings

E_c = modulus of elasticity of concrete

EH = horizontal earth pressure load

E_{lat} = equivalent strip width for lateral distribution, LRFD Specifications Sections 4.6.2.1.3 or 4.6.2.3

EV = vertical pressure from dead load of fill

f'_c = minimum specified compressive strength of concrete at 28 days

F_e = soil-structure interaction factor for embankment installation

f_r = modulus of rupture of concrete

f_s = service stress in the reinforcement

f_{ss} = tensile strength in rebar for crack control calculation

f_{sa} = allowable service stress in reinforcement

f_u = ultimate tensile strength of reinforcement bars

f_y = specified minimum yield strength of reinforcement bars

H_{end} = height of fill at the end of the culvert

H_{fill} = height of fill at left edge of the culvert

H_{EV} = height of fill for EV loading

H_{Ls} = height of live load surcharge

I = effect due to dynamic load allowance

IM = vehicle Dynamic Load Allowance

IR = inventory rating factor

$LLIM$ = live load + dynamic load allowance effect

L_1 = modified span length

LS = live load surcharge load

ℓ = length used in computing tire contact area

M_b = nominal flexure resistance in pure bending

M_{cr} = cracking moment

M_{DL} = dead load moment

M_{nb} = nominal flexure capacity at balanced strain condition

M_o = moment of all footing external loadings about point of interest

MPF = multiple presence factor

M_r = factored flexural resistance of a section in bending

M_{RF} = moment rating factor

M_T = total (dead + live) moment

M_u = factored moment at a section

N = footing vertical force resultant

OR = operating rating factor

OV = overlay loading

$P_{axle,max}$ = maximum axle load

P_b = nominal axial resistance at balanced strain condition

P_{DL} = dead load axial force

$P_{o,ten}$ = nominal axial resistance in pure tension

$P_{o,comp}$ = nominal axial resistance in pure compression

POI = points-of-interest or analysis point

P_r = factored axial resistance

P_{RF} = axial rating factor

P_u = factored axial force

q_b = footing settlement pressure

$Q_{i\ (Lane)}$ = the design lane load effect on the culvert, part of HL-93 and PHL-93

$Q_{i\ (Truck)}$ = truck effect on the culvert

q_L = soil pressure at left edge of footing

q_{max} = maximum footing pressure

q_R = soil pressure at right edge of footing

s = reinforcement bar spacing

s_v = shear reinforcement bar spacing

$s_{b,CC}$ = reinforcement bar spacing for crack control

$s_{b,STR}$ = reinforcement bar spacing for strength

s_{max} = maximum reinforcement bar spacing

s_{min} = minimum reinforcement bar spacing

t = section thickness

t_{FU} = thickness of foundation unevenness

top_c = clear cover for top/left face reinforcement

t_{scour} = thickness of scour on top surface of bottom slab

t_{ws} = thickness of wearing surface

V_c = nominal shear capacity of concrete

V_r = factored shear resistance

V_{RF} = shear rating factor

V_s = nominal shear resistance of shear reinforcement

V_{smax} = maximum shear that can be carried by shear reinforcement

V_{sreq} = required shear demand to be carried by the shear reinforcement

V_u = factored shear force

W_1 = modified width for spans > 30 ft

W_2 = modified width for spans > 60 ft

WA = load due to weight of water and stream pressure

W_{axle} = width of a truck axle

W_{culv} = total width of the culvert

W_{DC} = distributed loading due to DC

W_{EV} = distributed loading due to EV

W_{LS} = distributed loading due to LS

W_{seg} = width of a precast segment or distance between expansion joints

x_o = distance from left edge of footing to the resultant, N

α = angle of inclination of shear reinforcement

α_1 = ratio of the maximum equivalent concrete compressive stress block intensity to the design compressive strength of the concrete

β_s = crack width factor used in crack control calculations

β_1 = ratio of the depth of the equivalent uniformly stressed compression zone assumed in the strength limit state to the depth of the actual compression zone, i.e., Whitney stress block factor

γ_e = exposure factor used in crack control calculations

γ_{EH} = load factor for EH loading

γ_{eq} = equivalent fluid density

γ_{EV} = load factor for EV loading

γ_i = load factor as per DM-4

η = general load factor

θ = angle of inclination of diagonal compressive stresses

λ = concrete density modification factor

ρ_b = reinforcement ratio at balanced strain condition

ρ_c = density of concrete

ρ_{min} = minimum allowed reinforcement ratio

ρ_{soil} = density of soil

φ = resistance factor

φ_v = resistance factor for shear

3.2 GEOMETRY/STRUCTURAL MODEL

The type of structure, structure geometry and other dimensions are entered by the user. These input values are used to generate the structural model and the loads acting on a culvert or U-channel. The type of structure, precast, or cast-in-place, is used to determine the loading conditions for which the structure is to be analyzed. Structure geometry, clear span and clear height of the culvert, or height of walls for a U-channel, and member thicknesses are used to generate the geometric properties of the structural model. The presence or absence of haunches (fillets at the interior corners of the cell) or fish channel is used to calculate additional analysis points and the stiffness of slabs and walls. The presence or absence of the bottom slab is used to determine whether a culvert is a box culvert or a frame culvert (no bottom slab). The top slab support (monolithic or simply supported) is used to generate the correct type of structural model, i.e., whether there is a transfer of moment between the top of the wall and the top slab. The grade of the top slab is used to determine the stiffness of the non-prismatic top slab.

Based on the information provided by the user, the program generates a plane frame structural model. For this, the program finds the centerlines of each wall and the top and bottom slabs. These centerlines and their intersections form a plane frame structural model as shown in Figure 1. The bottom slab centerline is always taken as a horizontal line (even for a fish channel). The wall centerlines are always taken as a vertical line. Thus, the wall centerlines and the bottom slab centerline are always perpendicular to each other. The bottom slab centerline is assumed to pass through the centroid of the cross section at the lowest point of the fish channel, and is assumed to pass through the centroid of the bottom slab without a fish channel. The top slab centerline may be horizontal or sloping depending on whether the top surface of the top slab is level or has a grade. The plane frame is assumed to be supported as shown in Figure 1. A roller support is assumed at the bottom of the interior wall centerline and at the bottom of the right wall centerline. A pinned support is assumed at the bottom left corner of the frame. If the top slab is simply supported, a pinned end is also assumed at the top of each wall clear height as shown Figure 2. For a cast in place frame culvert (culvert without a bottom slab) a fixed support is assumed at the bottom of each wall and a roller support is assumed at the top left corner as shown in Figure 1. For a precast frame culvert (culvert without a bottom slab) a pinned support is assumed at the bottom of each wall and a roller support is assumed at the top left corner as shown in Figure1. For a U-channel a fixed support is located at the bottom of Wall 1 with a roller support located under Wall 2 as shown in Figure 1.

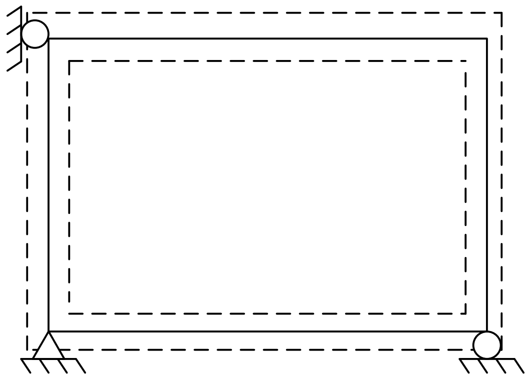
3.2.1 Analysis Points

Once the basic plane frame model as explained above is generated, the program establishes the analysis points or the points-of-interest (POI's). These POI's are located at the tenth points of clear span of each top slab and each bottom slab and the tenth points of the clear wall height. Also, a POI is defined at the beginning of each haunch, and at an abrupt change in the section in the bottom slab with a fish channel. Each POI is classified as a moment only (M) POI or a Shear and Moment (V/M) POI. The first POI which is to be classified as a shear and moment (V/M) POI depends on whether the member is prismatic or non-prismatic. If the member has haunches, the first moment POI is located at the end of the haunch. For a prismatic member, the first V/M POI does not start until the effective **shear** depth of the member. For a non-prismatic member, the first V/M POI does not start until the one-half the effective **shear** depth of the member. **Refer to Section 3.5.5 for equations to compute the effective shear depth for design and analysis.** Refer to Figures 1, 2, 3 and 4 for POI's and their classifications. For a precast frame culvert, the POIs at the bottom of each wall at the pinned connections are classified as V/M POI's.

The specification checks are performed at these POI's according to their classification, i.e., flexural checks are done at all M and V/M POI's, but shear checks are performed only at V/M POI's. The shear and moment check locations are in conformance with the provisions of LRFD Specifications Sections 5.12.8.6.1 and 12.11.5.2.

3.2.2 Cross Sections

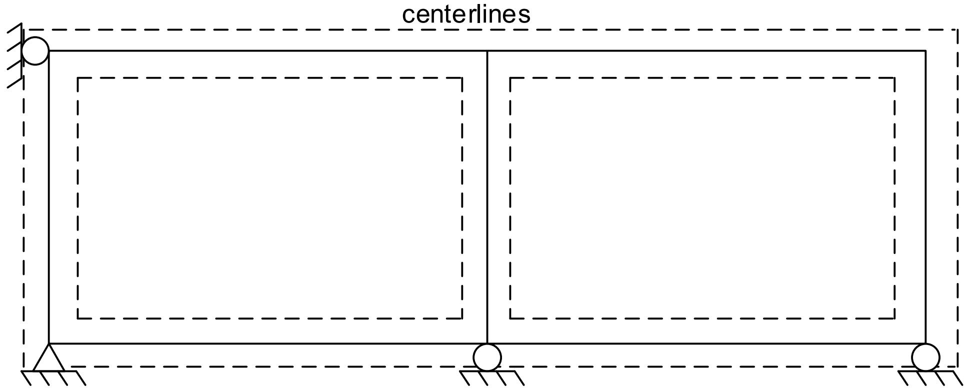
To perform a structural analysis, the program must determine the stiffness of members. A joint (node) is assumed at each POI and at the intersections of slab and wall centerlines. A member (element) is assumed between the two adjacent joints, and member properties (cross sectional area and moment of inertia) are calculated. For section design member property calculations, it is assumed that the member (element) has a constant cross section which is the average thickness of the two cross sections at the ends of each member. The plane frame model showing joints, average cross sections, and sections considered for special cases (fish channel and haunches) are shown in Figures 1 and 2.



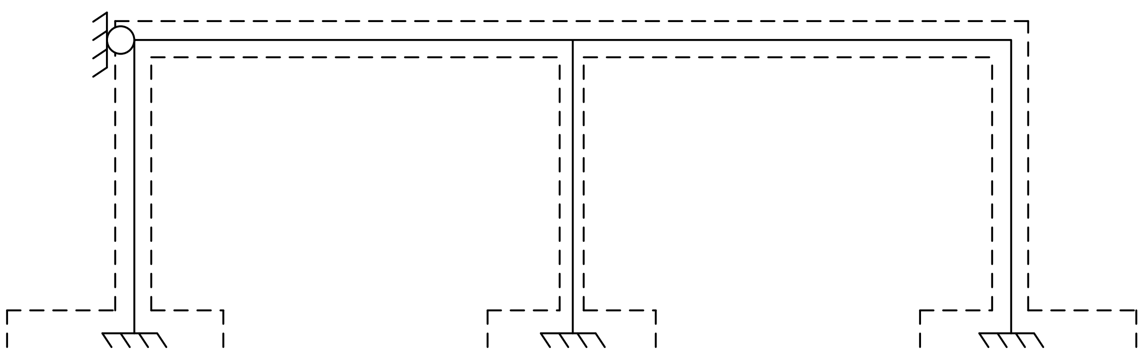
Single Cell Box Culvert

U-channel

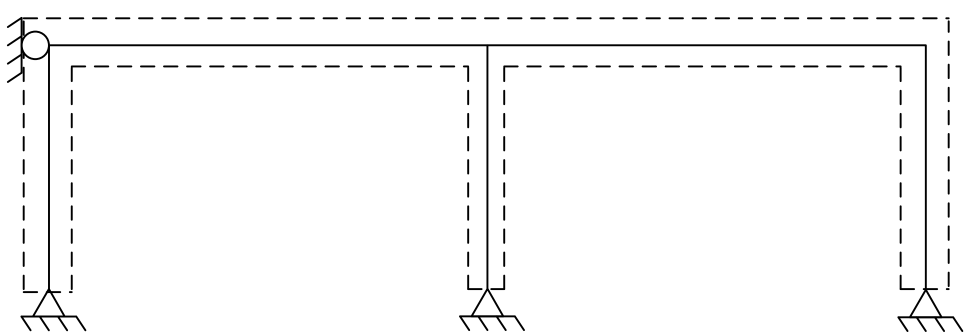
Note: Structural models shown are with member centerlines



Twin Cell Box Culvert



Twin Cell Cast-In-Place Frame



Twin Cell Precast Frame

Figure 3.2-1 Structural Model Boundary Conditions

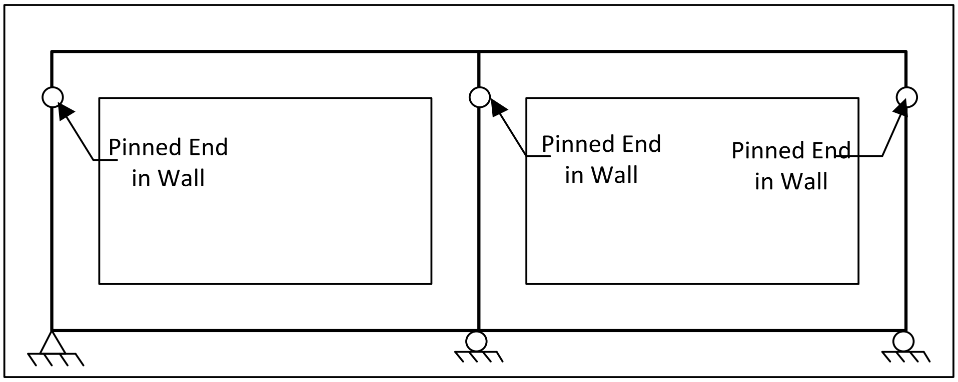
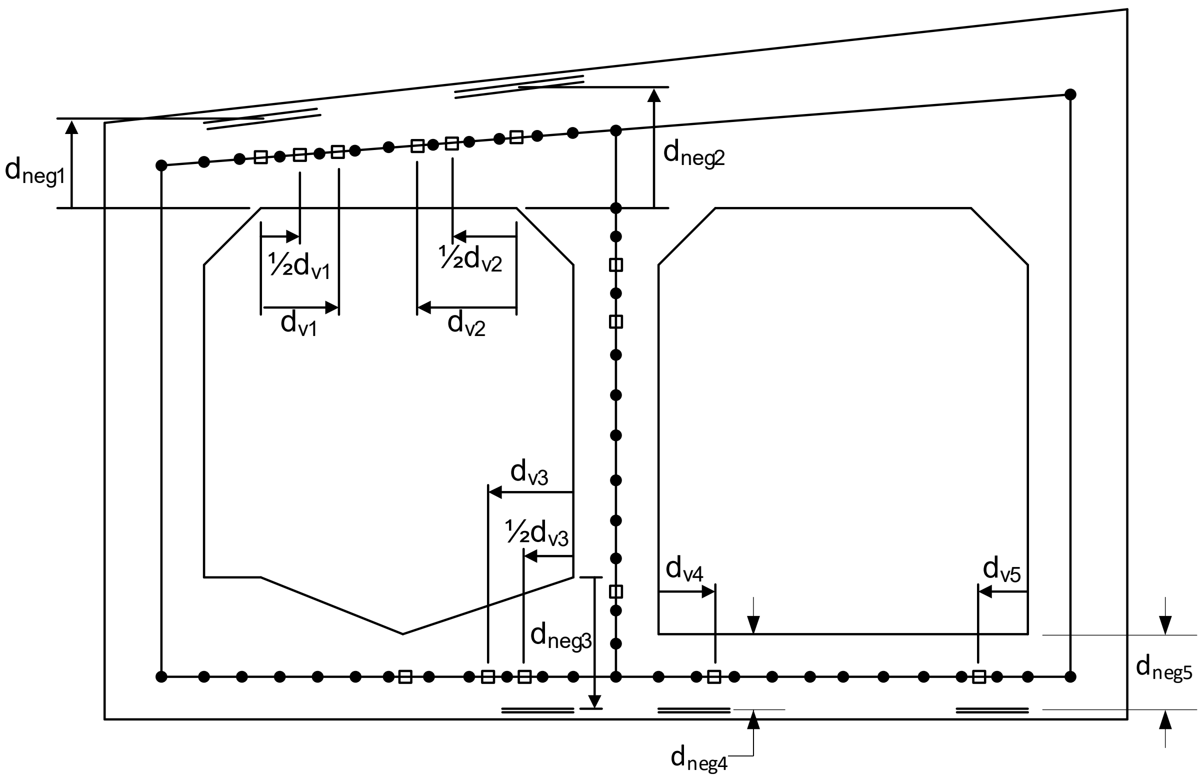


Figure 3.2-2 Structural Model for Simply Supported Top Slab



- End and 10 th point Nodes
- ▫ Special Points: at haunches, distance-dv and ½ distance-dv (non-prismatic members only), fish channel low point

Note: For a Design, distances d_{neg} are computed using the maximum bar size or diameter.

Figure 3.2.1-1 Typical Points-Of-Interest (POIs)

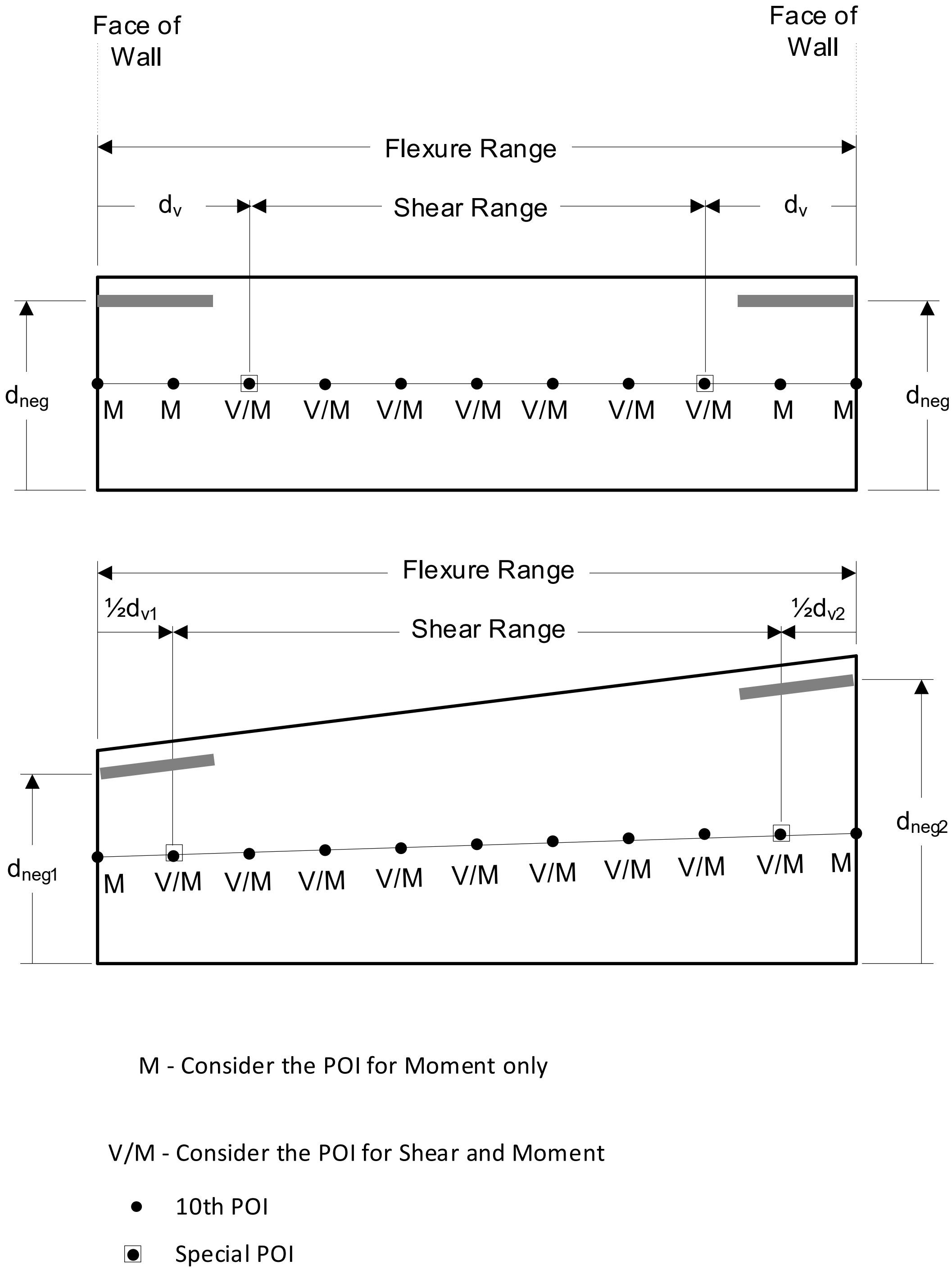


Figure 3.2.1-2 POI Classifications for Members Without Haunches

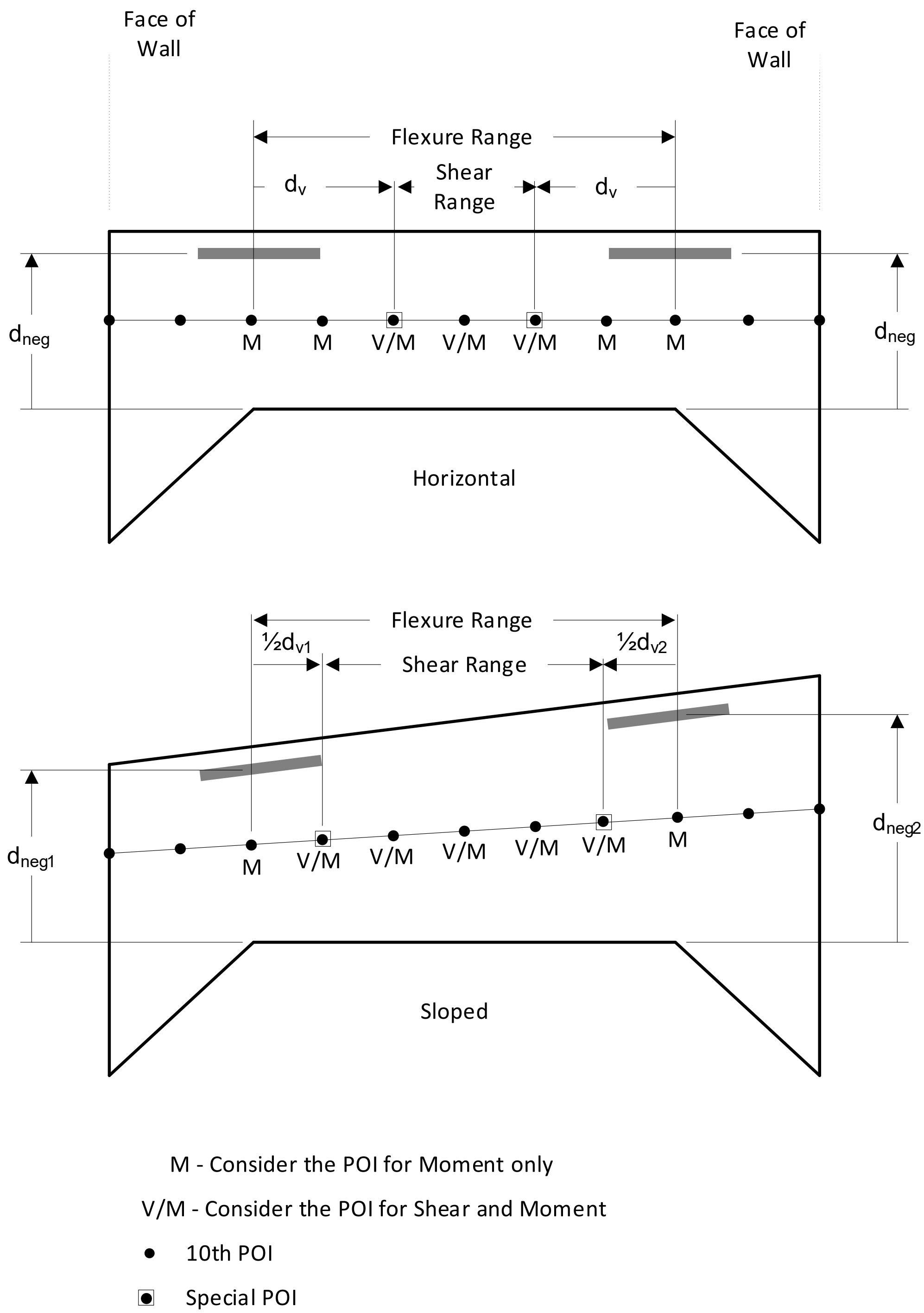


Figure 3.2.1-3 POI Classifications for Members With Haunches

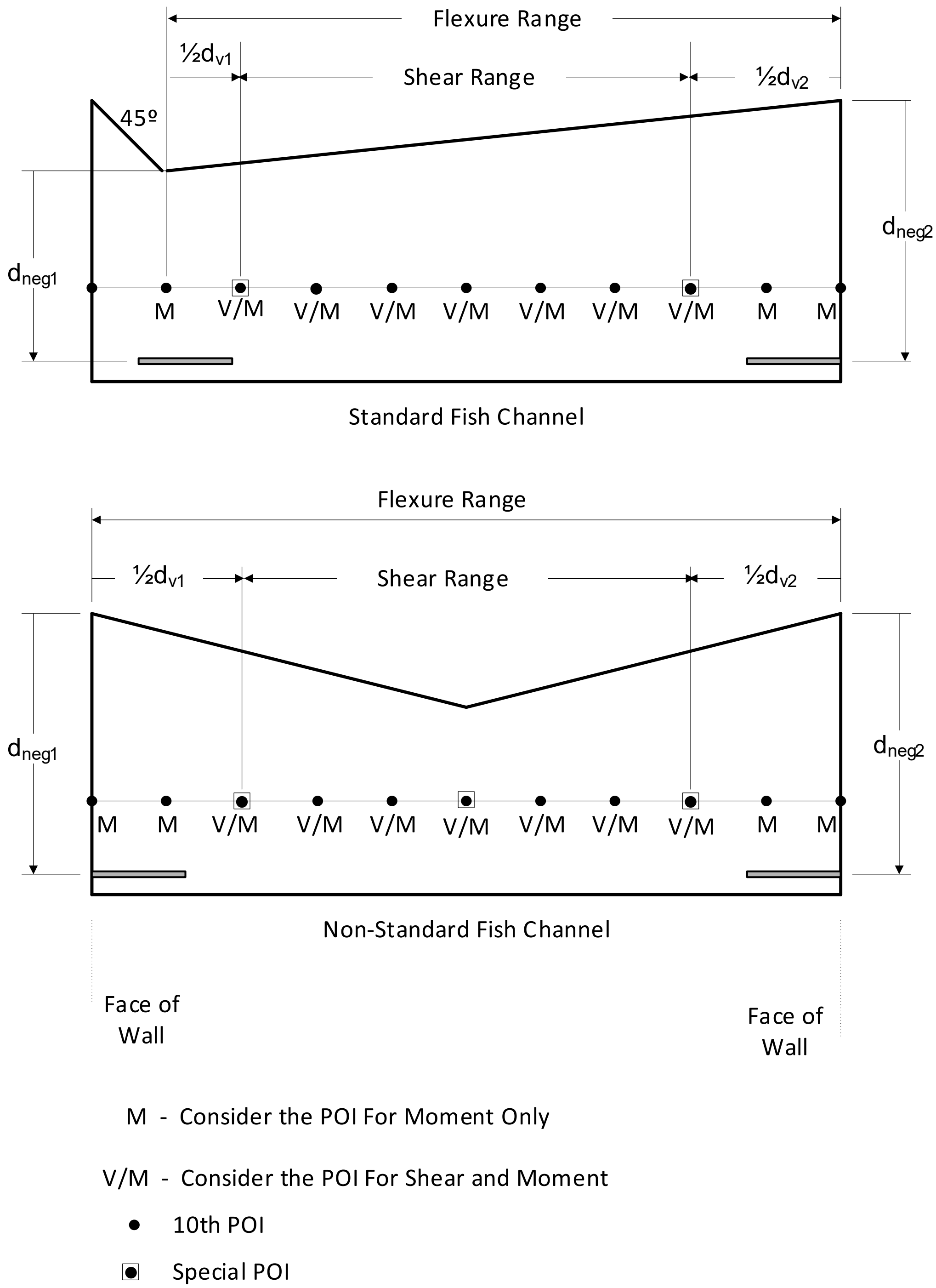


Figure 3.2.1-4 POI Classifications for Bottom Slab Members with a Fish Channel

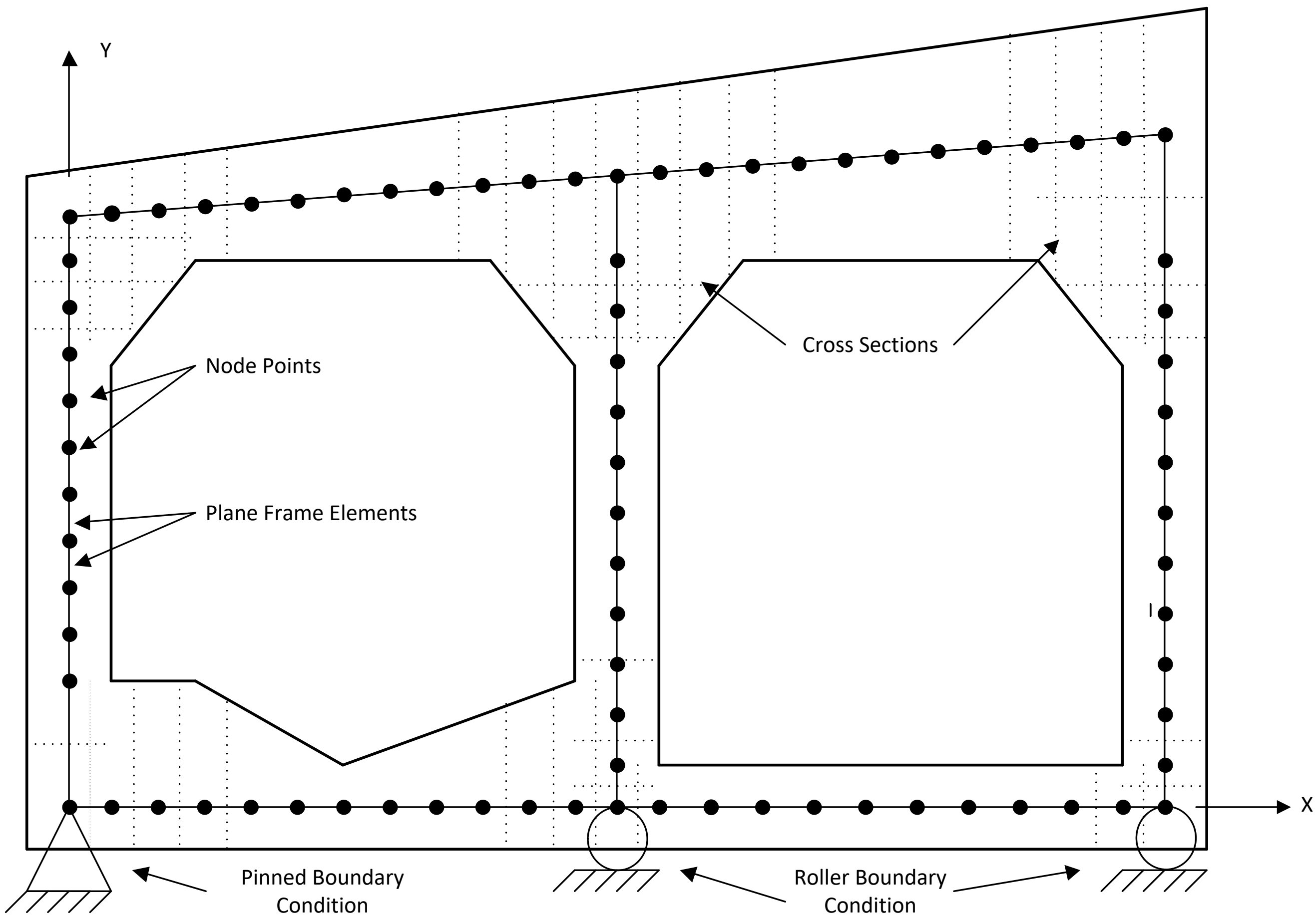


Figure 3.2.2-1 Basic Finite Element Model

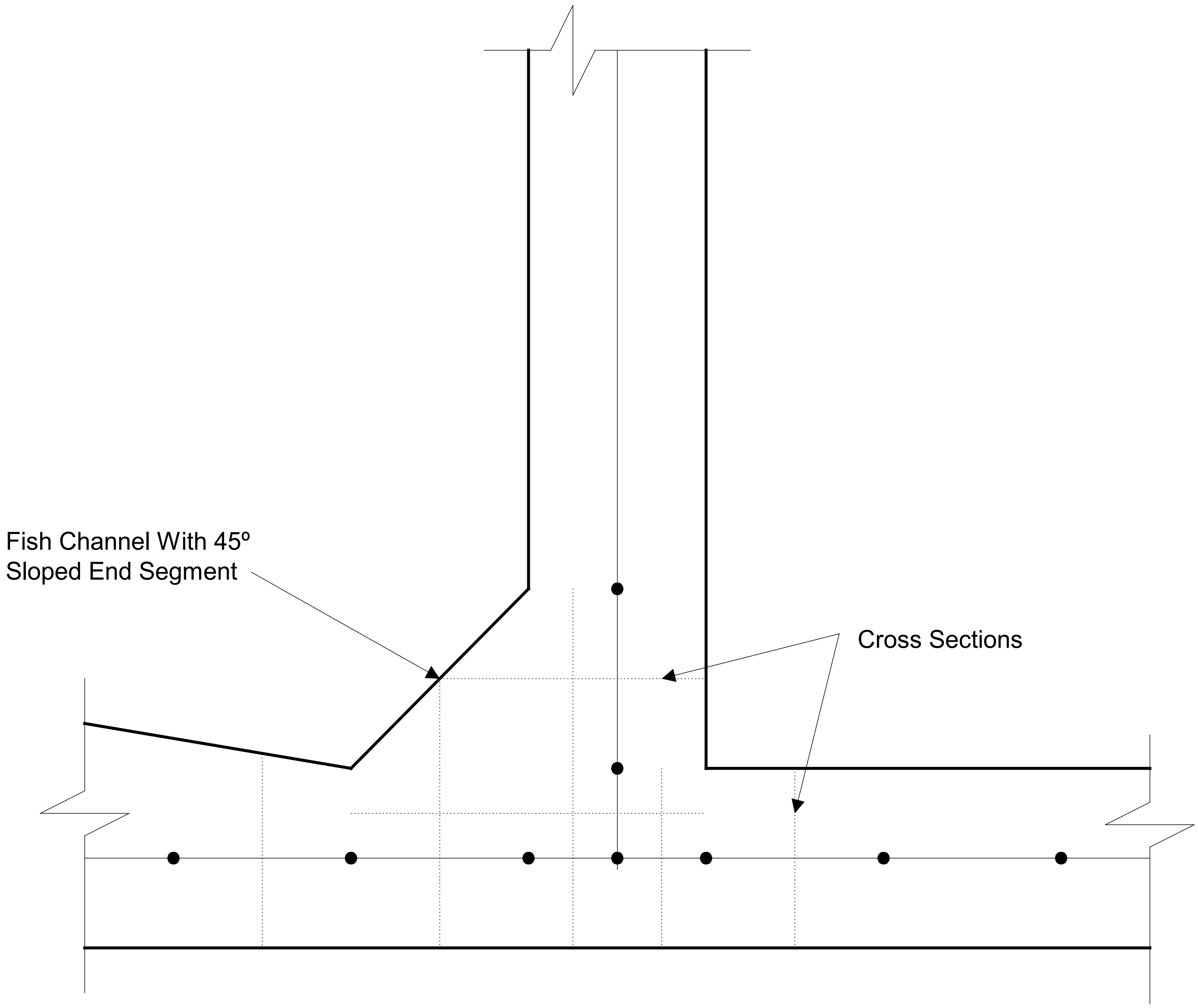


Figure 3.2.2-2 Cross Sections for A Fish Channel

3.3 LOADS AND STRUCTURAL ANALYSIS

Once the Plane Frame Model described in Section 3.2 is generated, the program considers different loading conditions and solves for moments, shears and axial forces at analysis points. The program uses the direct stiffness method to solve for load effects for each loading condition described below. For the direct stiffness method, refer to any standard text book on structural analysis. The program calculates moments, shears and axial forces at all analysis points for the following loading conditions. Tables 1 and 2 list the applicable loads for each structure type in the program.

Table 3.3-1 Box Culvert Applied Loads

Load	Description
DC	Loading due to self weight of structural components
DW	Loading due to wearing surface
EV	Loading due to vertically applied fill pressure
OV	Loading due to vertically applied overlay material
EH	Loading due to horizontally applied earth pressure
LS	Loading due to live load fill surcharge
LLIM	Loading due to Live Load with Dynamic Load Allowance
WA	Pressure due to water weight (Used for Foundation Pressure Only)
AD & AL	Loading due to Approach Slab (Dead and Live Load)

Table 3.3-2 U-channel Applied Loads

Load	Description
DC	Loading due to self weight of structural components
EH	Loading due to horizontally applied earth pressure
LS	Loading due to live load fill surcharge
WA	Pressure due to water weight (Used for Foundation Pressure Only)

3.3.1 Dead Load DC

DC is the self weight of structural components (walls and slabs). In Figures 1 and 2, R_1, R_2 and R_3 are reaction forces, W_1, W_2 and W_3 are the weights of the walls, and q_b and q_e are beginning and ending pressures. The weight of a fish channel is approximated as a uniform load and is only included in the dead load calculation of the foundation pressure applied to the bottom slab. The foundation pressure due to the fish channel for a twin cell culvert is distributed to all three walls using the pressure equations in section 3.10. For a one cell culvert or u-channel it is evenly distributed between the two walls.

3.3.1.1 Precast Culverts

DC loadings for a precast culvert are shown in the lower portions of Figures 1 and 2. A reaction loading acting on the bottom slab is calculated considering vertically distributed loads applied to the walls and the top slab as shown in Figures 1 and 2.

3.3.1.2 Cast In Place Culverts

The DC loading is separated into DC1 and DC2 loadings for cast-in-place culverts because a cast-in-place culvert is constructed in stages. The upper portions of Figures 1 and 2 show DC loadings for cast in place culverts. DC1 is the weight of uncured top slab and walls acting on the cured bottom slab which is assumed to act as an infinitely stiff beam resting on an unyielding foundation. The DC1 effects are stored for the bottom slab. The weight of the top slab acts on the plane frame when concrete in the top slab and walls has cured, and the forms are removed. To simulate the effect of removing the forms (DC2), the point loads acting on the bottom slab for 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 Figures 1 and 2. The effects of DC1 and DC2 are added to get the DC effects. The bottom slab for a cast-in-place culvert is checked for both the DC1 and DC loadings.

3.3.2 Dead Load DCB

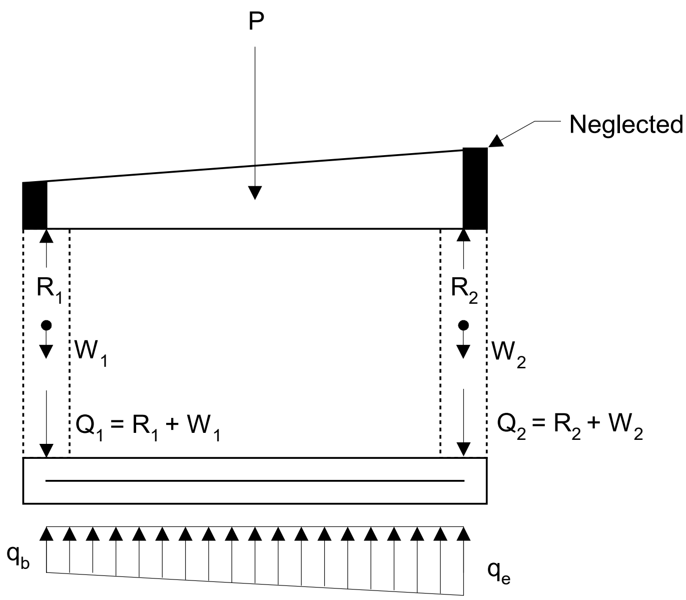
DCB is a uniform dead load due to a traffic barrier placed atop the culvert. Figure 1 shows the application of the DCB loading for cast-in-place and precast culverts. In this figure, w is the uniformly distributed barrier dead load applied to the top slab and it is assumed to produce a uniformly applied reaction loading on the bottom slab.

3.3.3 Dead Loads DW and OV

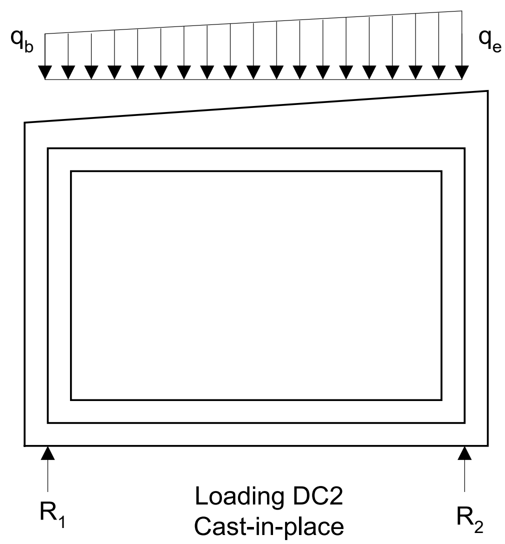
DW is the dead load due to future wearing surface, while OV is the dead load due to an overlay of uniform thickness. Figure 1 shows the DW and OV loading for both precast and cast-in-place culverts. In this figure, w is the uniformly distributed wearing surface or overlay loading. A uniformly distributed loading is applied to the top slab and it is assumed to produce a uniformly applied reaction loading on the bottom slab.

3.3.4 Dead Load EV

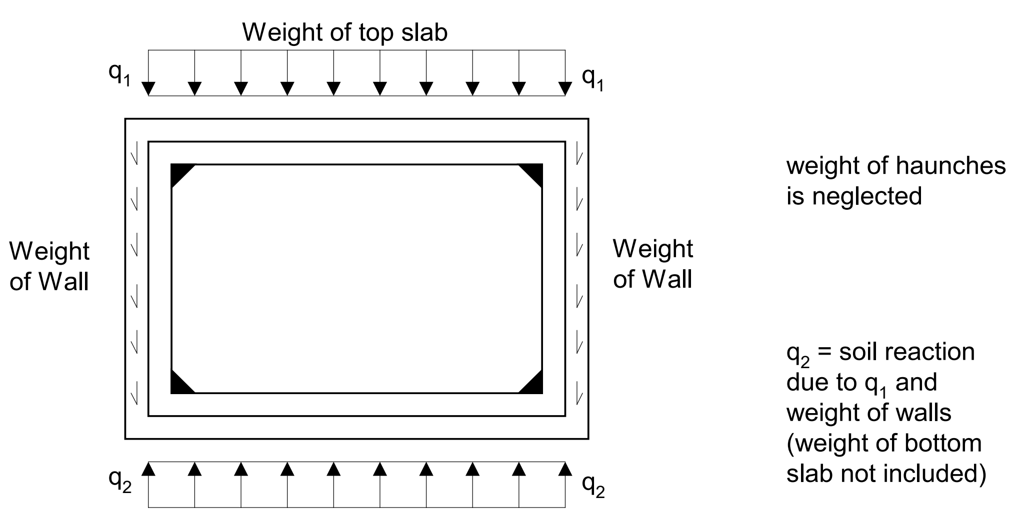
EV is the vertically applied weight of fill (soil and/or asphalt) acting on the culvert. Figure 1 shows the EV loading which is applied to both the cast-in-place and precast culverts. In this figure, H_B and H_E are the heights of fill at the beginning and end of the culvert, and w_B and w_E are the beginning and ending values of the trapezoidal loading due to H_B and H_E. A trapezoidal loading due to weight of fill is applied to the top slab and an equal and opposite reaction loading is applied to the bottom slab. The magnitude of intensity of trapezoidal loading is determined by calculating the height of fill above the centerline of the external walls. The weight of fill beyond the centerlines of exterior walls is neglected; however, this load is further adjusted by the soil-structure interaction coefficient, F_e, based on an assumed embankment construction. For culverts with strip footings during the Construction Limit State, the program applies an EV force by setting the fill height to zero for the Construction Limit State. This force is applied to the exterior projection of the strip footing.



Loading DC1
Cast-in-place

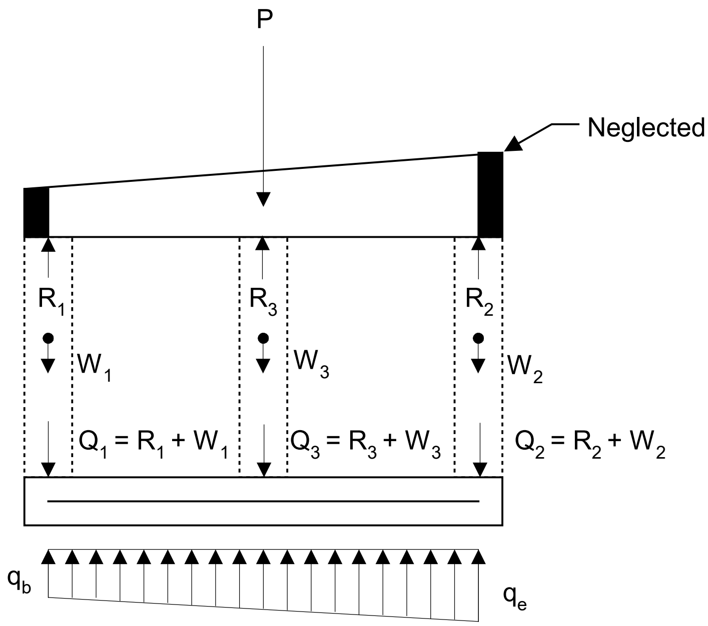


Loading DC2
Cast-in-place

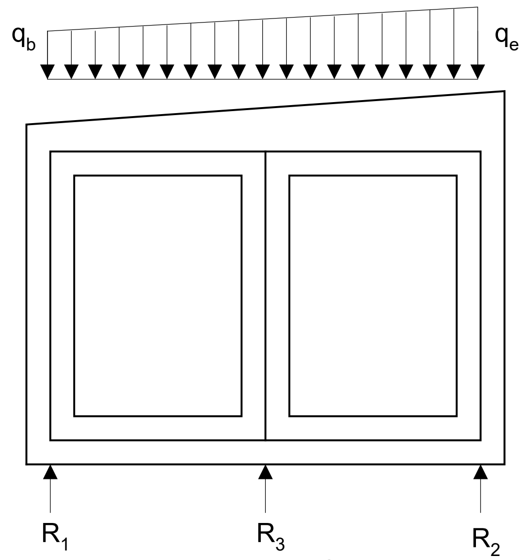


Loading DC
Precast Culvert

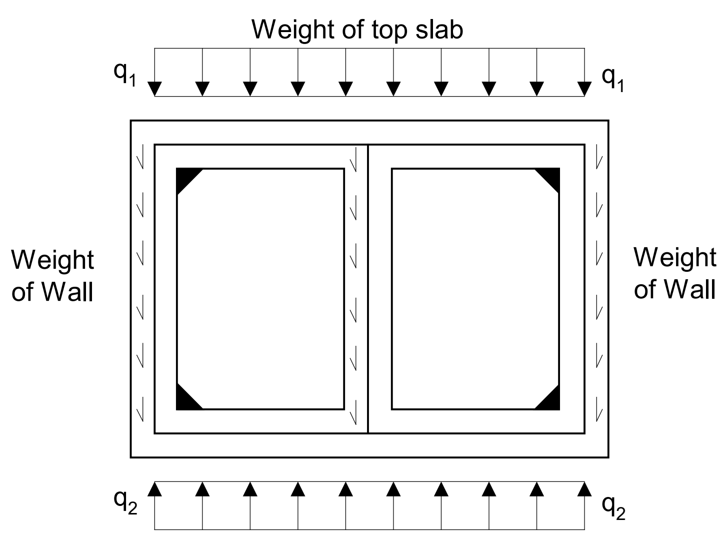
Figure 3.3.1-1 Loadings - Weight of Structure for One-Cell Culverts



Loading DC1
Cast-in-place



Loading DC2
Cast-in-place



Loading DC
Precast Culvert

weight of haunches is neglected

q_2 = soil reaction due to q_1 and weight of walls (weight of bottom slab not included)

Figure 3.3.1-2 DC Loadings - Weight for Two-Cell Culverts

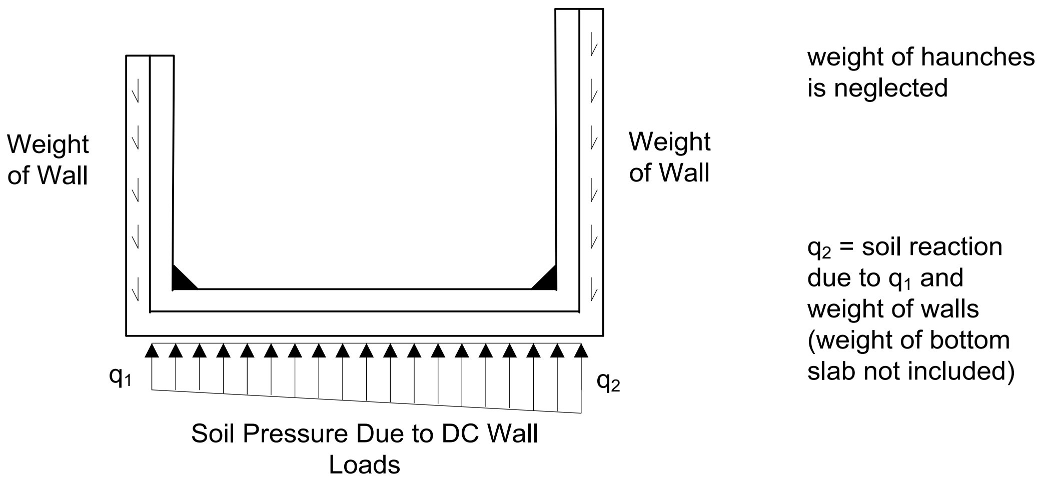


Figure 3.3.1-3 DC Loadings - Weight for U-channels

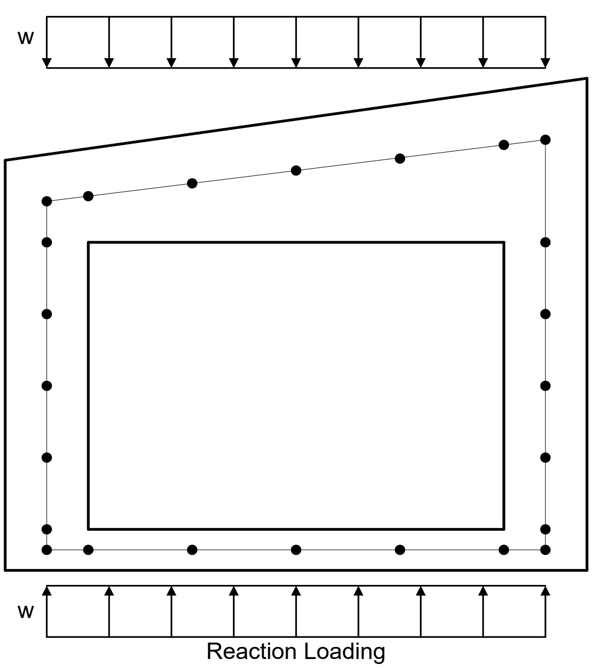


Figure 3.3.2-1 DCB Loading (Barrier Dead Load)

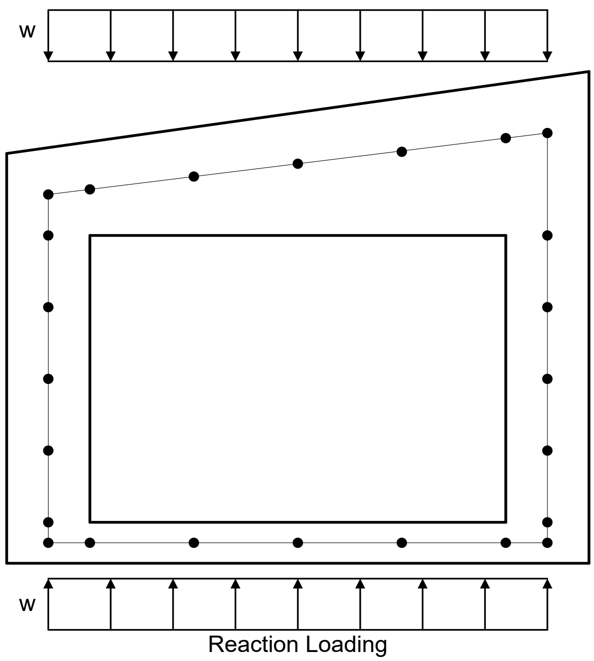


Figure 3.3.3-1 DW and OV Loading

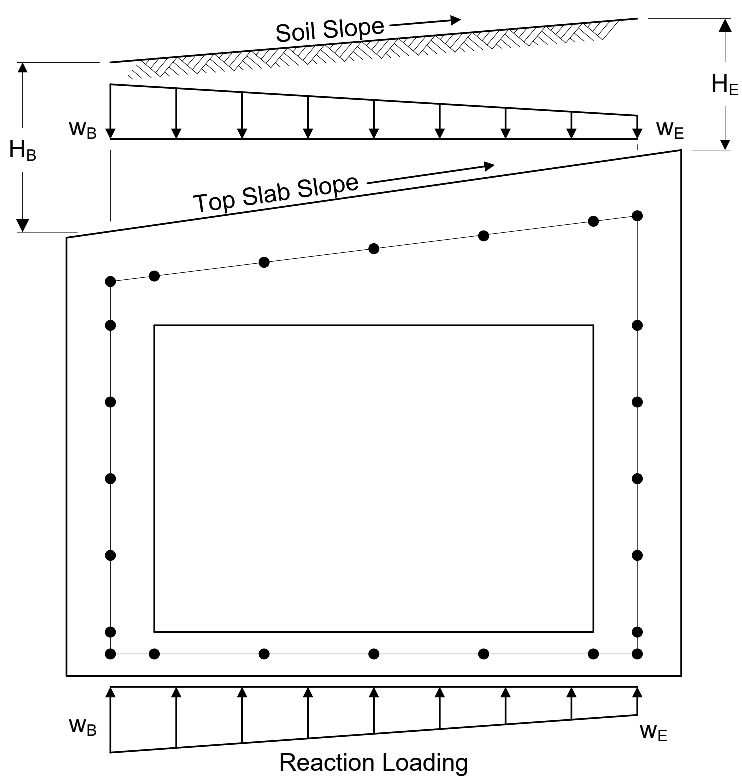


Figure 3.3.4-1 EV Loading (Fill Vertical)

3.3.5 Earth Horizontal EH

EH is the loading due to earth pressure acting on the exterior walls. Figure 1 shows the EH loading which is applied to both the cast-in-place and precast culverts and U-channels. The intensity of earth pressure is a function of the height of fill, overlay thickness, and equivalent fluid density, γ_{eq}. The program uses the minimum and maximum values of the equivalent fluid density, from user input entered on the LDC command, in combinations with the minimum and maximum load factors for EH (see Table 3.4-3) to produce the extreme force effects. For a culvert under sloping fill, a top slab at grade or a U-channel of unequal wall heights the exterior walls of culvert may be subjected to different horizontal earth pressures. For this case the pressure on the wall having the lower earth pressure is adjusted by applying an additional pressure to keep the culvert in equilibrium. The calculation of this pressure is shown in Figure 1. In this figure, q_{b1} and q_{e1} are the beginning and ending lateral pressures on the left side (with associated resultant, P_1, and eccentricity, h_1), q_{b2} and q_{e2} are the beginning and ending lateral pressures on the right side (with associated resultant, P2 and eccentricity, h_2), and q_{b3} and q_{e3} are computed lateral pressures to keep the structure in equilibrium. For the Construction Limit State the program temporarily sets the height of fill equal to zero.

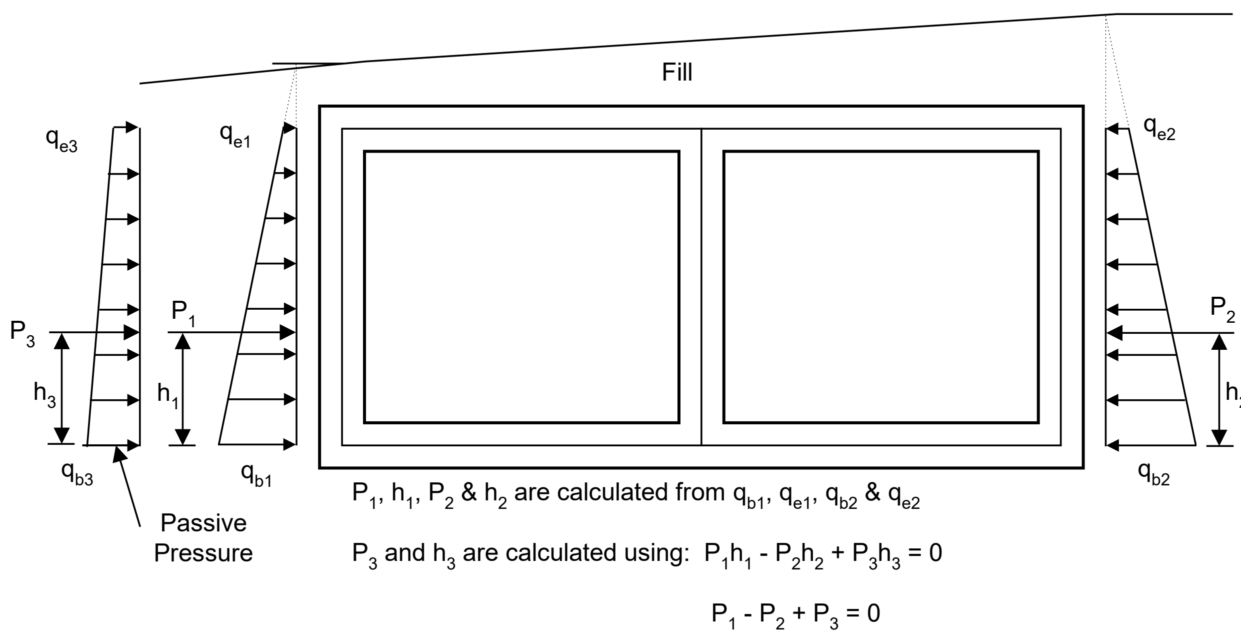
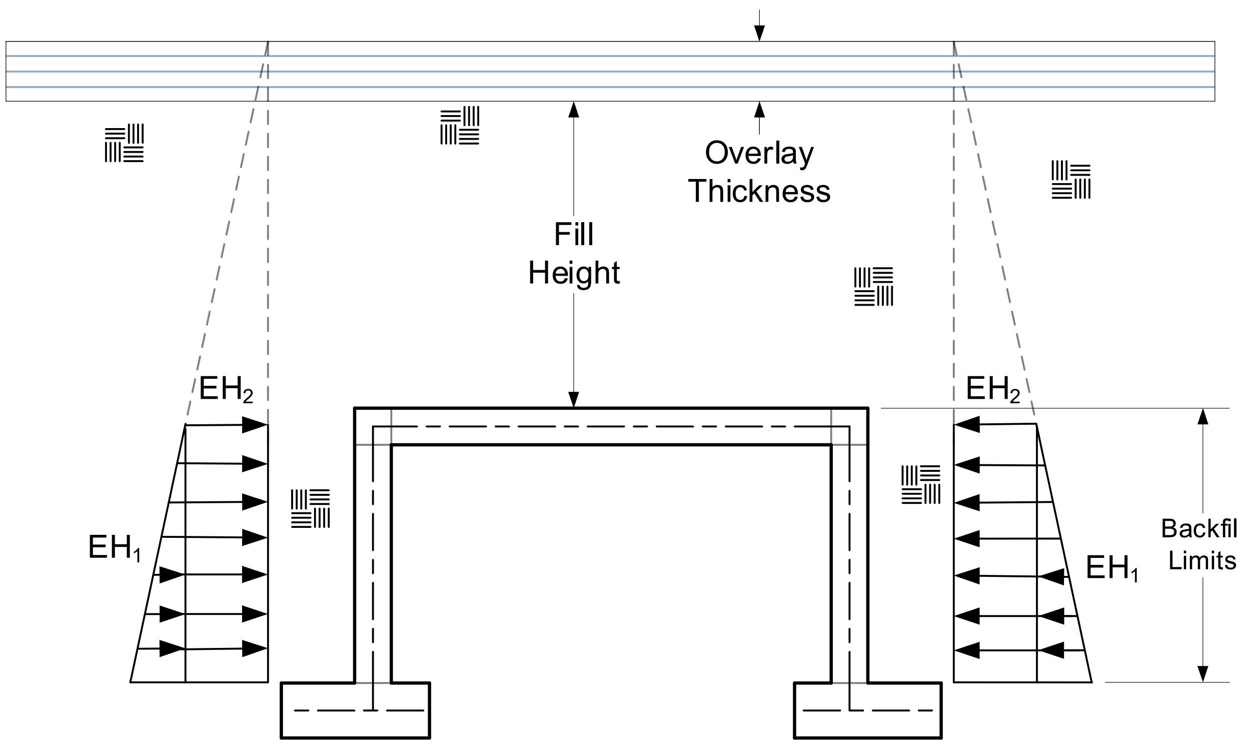


Figure 3.3.5-1 EH - Horizontal Earth Loading

The trapezoidal horizontal load on each exterior wall is divided into a rectangular load and a triangular load. The results of the triangular load are reported as EH1. The results of the rectangular load are reported as EH2. See Figure 3.3.5-2. The EH2 load is calculated by **adjusting** the Height of Fill and the Overlay Thickness (both entered on the LDC command) **to account for the differences between the fill unit**

weight, the overlay unit weight, and the backfill unit weight and then multiplying **the adjusted height and thickness** by the equivalent fluid density **as shown in the equation below**.

$$q_{EH2} = \left[Ht_{Fill} \times \frac{\gamma_{fill}}{\gamma_{backfill}} + Thick_{overlay} \times \frac{\gamma_{overlay}}{\gamma_{backfill}}\right] \times \gamma_{EQ}$$



- EH1 = Triangular Horizontal Earth Pressure
- EH2 = Rectangular Horizontal Earth Pressure

Figure 3.3.5-2 EH1 and EH2 Horizontal Earth Loads

3.3.6 Live Load Surcharge LS

LS is the loading due to live load surcharge. If the live load is applicable a horizontal pressure equal to an equivalent height of fill is applied to the exterior walls. The distributed load is uniform and its magnitude is a function of Live Load Surcharge Height specified in the input and the equivalent fluid density, γ_{eq}. Figure 1 shows the LS loading which is applied to both precast and cast-in-place culverts and U-channels. For a culvert under sloping fill, a top slab at grade or a U-channel with unequal wall heights the difference in horizontal pressure is adjusted in the same manner as explained under the EH loading.

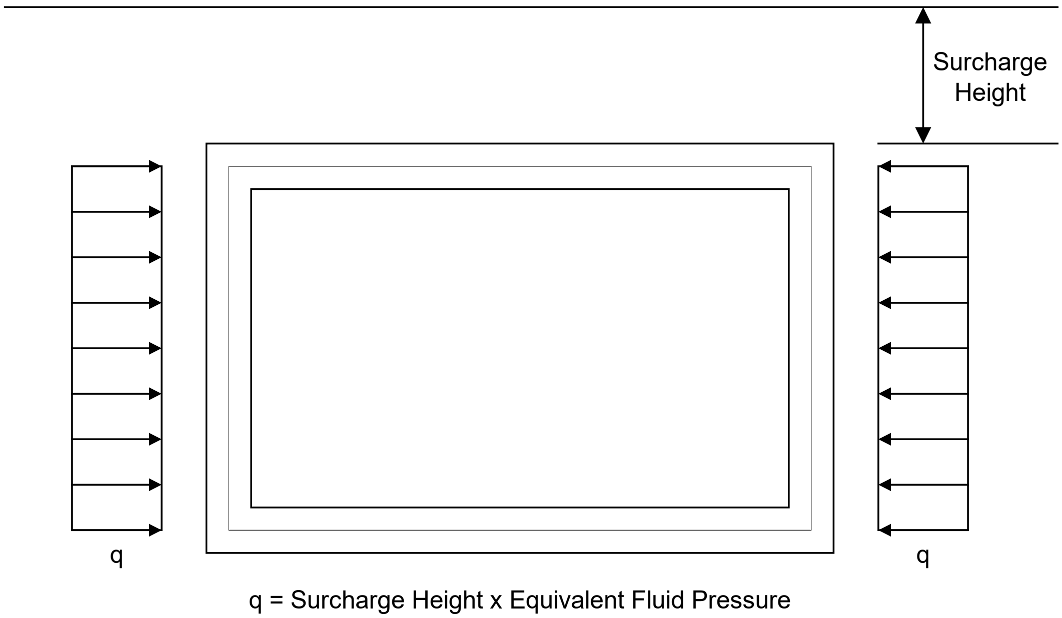


Figure 3.3.6-1 LS Loading (Live Load Surcharge)

3.3.7 Approach Slab Loads **AD and AL**

The approach slab load consists of a dead **(AD)** and live **(AL)** load component which both act on the exterior walls of a culvert. Figure 1 shows the application of approach slab loading for cast-in-place and precast culverts. In this figure AD_1 ,AL_1, AD_2 and AL_2 are concentrated loads that are applied at the top slab of the culvert at the centerline of each exterior wall and is assumed to produce a uniformly applied reaction loading on the bottom slab. All approach slab loads should be calculated based on the 1 foot design section width of the culvert. The approach slab loads are only applicable when the culvert is at grade. The program does not determine the live load vehicle position for the culvert with any consideration for the effects on approach slabs. The AL is a user determined live load reaction.

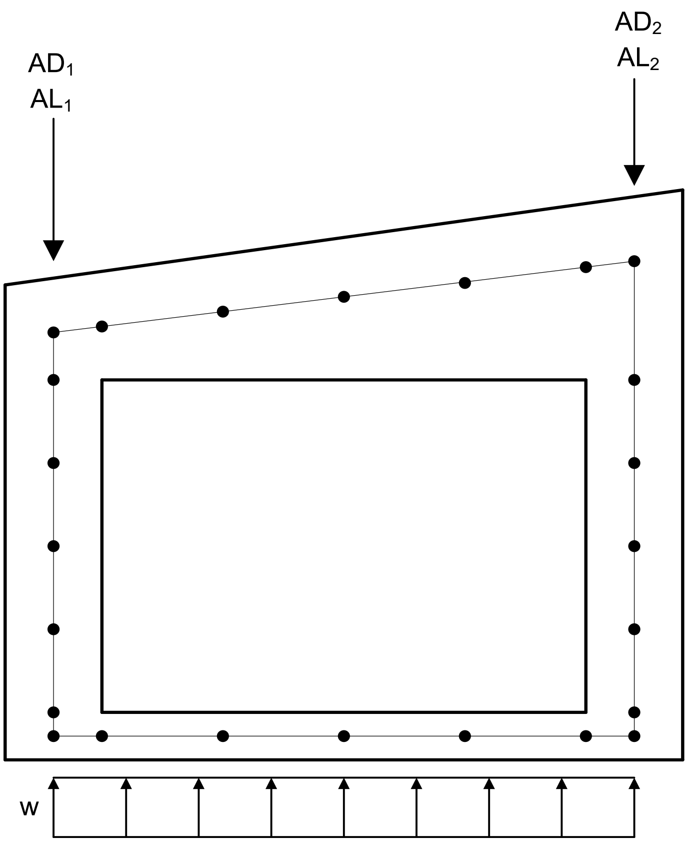
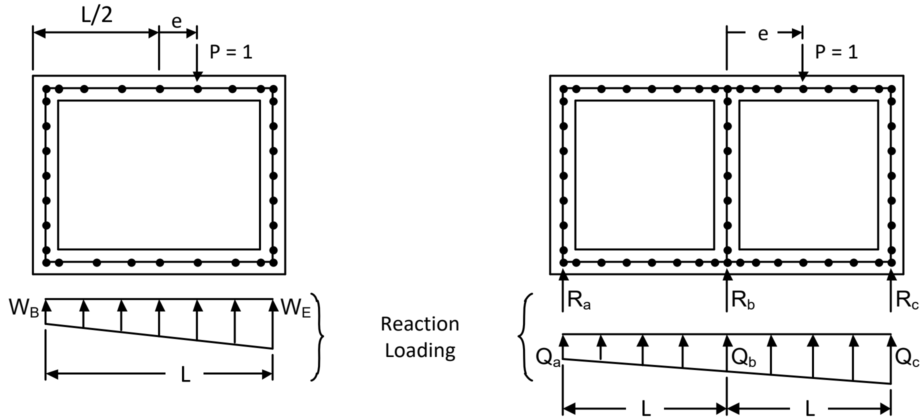


Figure 3.3.7-1 Approach Slab Loading

3.3.8 Loading for Influence Lines

To obtain the live load effects the program uses influence lines. These influence lines for various effects at analysis points are generated by placing a unit vertical load at each analysis point, one at a time and calculating its effects at other analysis points. For a typical loading a unit vertical load is applied at the analysis point on the top slab and a reaction loading on the bottom slab is calculated. The reaction loading is computed differently for a single cell culvert or U-channel versus a two cell culvert. The reaction for the single cell structure is based on the assumption that the structure is rigid. The reaction force intensities for the two cell culvert are based on load intensities that produce appropriate reactions at the centerlines of walls. The wall centerline reaction is a function of the location of the unit load on the top slab. The distributed load reactions are computed as follows:



$$W_B = \frac{P}{L} - \frac{Pe\frac{L}{2}}{\frac{L^3}{12}}$$

$$W_E = \frac{P}{L} + \frac{Pe\frac{L}{2}}{\frac{L^3}{12}}$$

$$R = (\frac{e}{L})$$

$$R = (2R + 3R^2 - R^3)\, P/4$$

$$R_b = (4 - 6R^2 + 2R^3)\, P/4$$

$$R_c = (-2R + 3R^2 - R^3)\, P/4$$

$$Q_b = (2R_b - R_a - R_c)/L$$

$$Q_a = (R_a - Q_b L/6)/(L/3)$$

$$Q_c = (R_c - Q_b L/6)/(L/3)$$

Figure 3.3.8-1 Loadings for Influence Lines

The equations for R_a, R_b and R_c are based on a derivation of the “Continuous Beam – Two Equal Spans Concentrated Load At Any Point” equations for reactions in the “Beam Diagrams and Formulas” Section of the AISC steel manual.

3.3.9 Live Loading

The effect of a live loading at a given POI is calculated by loading the influence line for that effect at a POI under consideration. The truck is marched over the influence line and the maximum load effect is obtained. This effect is referred to as "On Deck" effect. If the culvert is under fill the axle loads are replaced by patch loads and these patch loads are marched across the influence line to get the effect referred to as "Thru Fill" effect.

The program calculates the moments, shears and axial forces due to live loadings at appropriate POI's as defined earlier. The live loadings used for design are: PHL-93, HL-93, P-82, and P2016-13. The live loadings used for analysis (rating) are: PHL-93, HL-93, P-82, P2016-13, ML-80, TK527, EV2, EV3, SU6TV, HS20, H20, and SLL. Live loadings are shown in Figures 2.4-1, 2.4-2, 2.4-3, and 2.4-4.

BXLRFD first determines if the live load should be considered. It applies the provisions of LRFD Specifications Section 3.6.1.2.6 as follows. If the user has entered the number of design lanes equal to zero, the program does not calculate the live load effect. Otherwise, if the height of fill is greater than 8 feet and is greater than the center to center distance of the exterior walls, the program does not calculate the live load effects. Also, if the height of fill is greater than or equal to 2 feet and if the live load is applicable by the above definition, the program also considers the "Thru Fill" effect.

If the top slab is at grade or under less than 2.0 feet of fill, then the culvert is analyzed as if the Live Load applied directly on the deck. However, if the culvert is under 2.0 feet of fill or greater, and if the Live Load is applicable according to LRFD Specifications Section 3.6.1.2.6, the culvert is analyzed for both conditions as if the live load is applied directly on the deck, and the live load is applied through the fill. The lesser of the two effects is considered as per LRFD Specifications Section 3.6.1.2.6.

The program also has a Live Load Override feature which may be selected to design or analyze culvert with live load regardless of fill height. This feature allows for program compliance with DM-4 Section 12.11.5.9P. See User's Manual Section 6.10.18 for more information on this feature.

3.3.10 HL-93 Loading and PHL-93 Loading

For this program, the vehicular live loading consisting of the Design Truck, Design Tandem, and Design Lane Load, as defined in the LRFD Specifications, is referred to as the HL-93 loading. For the design of its structures, PennDOT has modified the HL-93 loading, and it is called the PHL-93 loading. Refer to Figures 2.4-1 and 2.4-2 for a summary of the live loads stored in the program. The PHL-93 loading is the same as the HL-93 loading except that the axle loads on the Design Tandem for the PHL-93 loading are multiplied by a factor of 1.25. In addition, for negative moment between points of dead load contraflexure and for axial force at the interior walls only, PHL-93 includes the effect of two design tandems separated by a variable spacing of 26.0 to 40.0 ft which is combined with the lane load at 100%. The 1.25 factor is not applied to the design tandem pair for the PHL-93 loading. H20 and HS20 loadings are as defined in the current AASHTO Standard Specifications for Highway Bridges.

3.3.11 Variable Axle Spacing of Design Truck

BXLRFD also loads influence lines with live load vehicles having a variable axle spacing. For example, the second and third axles of the HS-20 vehicle have a variable spacing from 14 to 30 feet.

3.3.12 Variable Spacing of Design Tandem Pair

In accordance with DM-4 Section 3.6.1.3.1, two Design Tandems are used to calculate the live load effects at POI's placed between the points of dead load contraflexure. The maximum effects are calculated for the top and bottom slabs and the interior wall. The optimum effect can be obtained by varying spacing between the design Tandems from 26.0 to 40.0 feet. Note that the pair of Design Trucks is not considered for culverts as the minimum distance between the two Design Trucks is to be kept at 50 feet which is on the upper limit of a total width for a twin cell culvert.

3.3.13 Truck Load Effect

For the On Deck loading, the effect is obtained by stepping point loads, representing the live load axles of a vehicle, over the axial, shear, and moment influence lines. For Thru Fill, the live load vehicle axle loads are distributed through the Fill, resulting in a series of patch loadings. The patch loadings are then stepped over the influence lines generating the vehicle live load effect.

The On Deck effect is calculated using the LRFD concept of notional loading. Notional loading stipulates that when an effect is being optimized (i.e., maximized or minimized), if a particular axle decreases the effect, then that axle should be ignored. In essence, different live load configurations from a single live load can be used to optimize different effects. All live load vehicles are considered notional vehicles. The special live loads, specified by using the SLL and SAL commands, may be either notional or non-notional. In calculating the concurrent action, the truck configuration used is the same as the one used to maximize the primary action.

The Thru Fill effect is non-notional: all axles are used to optimize each effect. The Thru Fill effect is obtained by distributing the vehicle axle loads through the fill, resulting in a series of patch loadings. These patch loadings are then stepped over the influence lines. Figure 5 illustrates the distribution of axle loads through a fill into two patch loads, which are then stepped over influence lines. The figure shows that a tire footprint and axle load are at the top of the fill, which get distributed through the fill to the top of the culvert as a patch load. It also shows that Axles 1 and 2 are close enough together for this fill height that they form a single patch.

The tire footprint, ℓ, is set for all design trucks, except for the user entered Special Live Load trucks, according to DM-4 Section 3.6.1.2.5. For the Special Live Load truck the values are calculated based on the max axle weight and dynamic load allowance using equations in DM-4 Section C3.6.1.2.5. The live load factor, γ, is set at a constant value for all limit states at 1.35 for this calculation.

Figure 1 illustrates notional loading. In this figure, a three-axle truck is used to load an influence line for a particular location. In the top part of the figure, just the front two axles are considered since the third axle is over a negative portion of the influence line and therefore would decrease the effect. Similarly, the truck is in a different location in the bottom part of the figure and only the third axle is considered since the first two axles are over a negative portion.

BXLRFD implements notional loading by separating influence lines into positive and negative portions, and loading them in a normal fashion. Figure 2 shows a shear influence line separated into just its positive components. Once this modified influence line has been generated from the original version and all negative effects have been eliminated, stepping a truck over it will result in only positive or zero contributions.

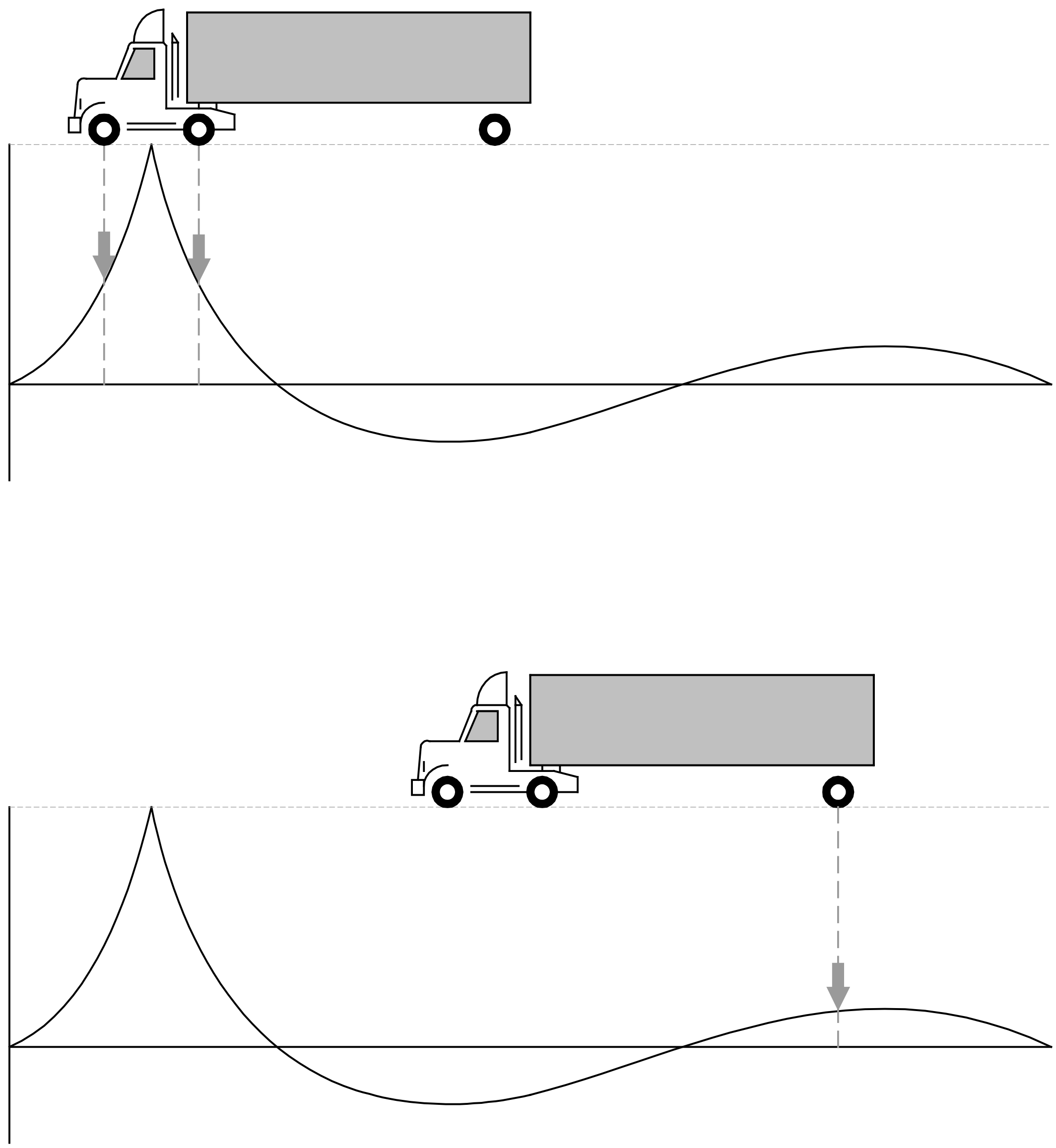


Figure 3.3.12-1 Notional Truck Concept Showing Axles That Do Not Contribute To The Effect

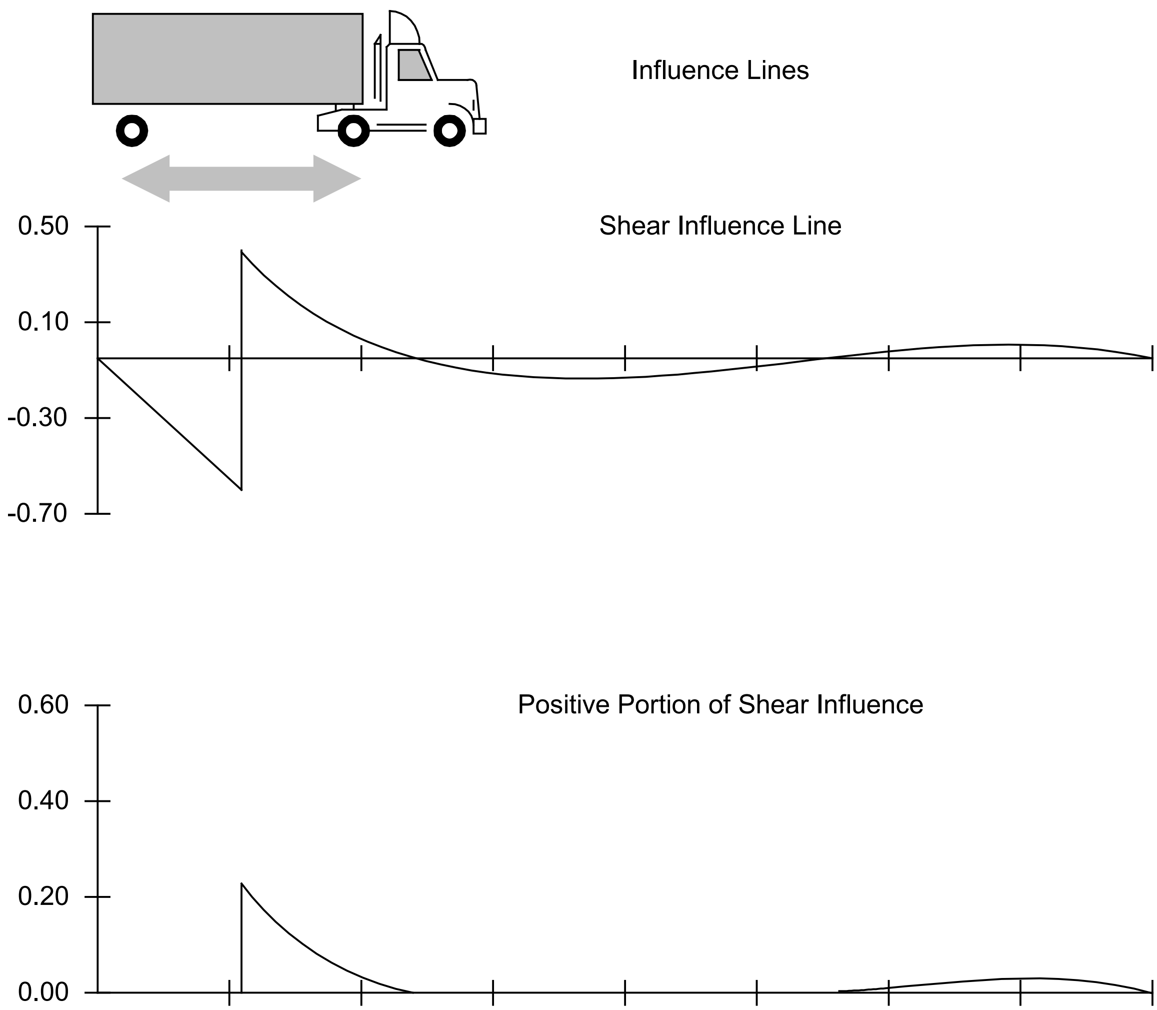


Figure 3.3.12-2 Separating Influence Lines Into Positive and Negative Parts

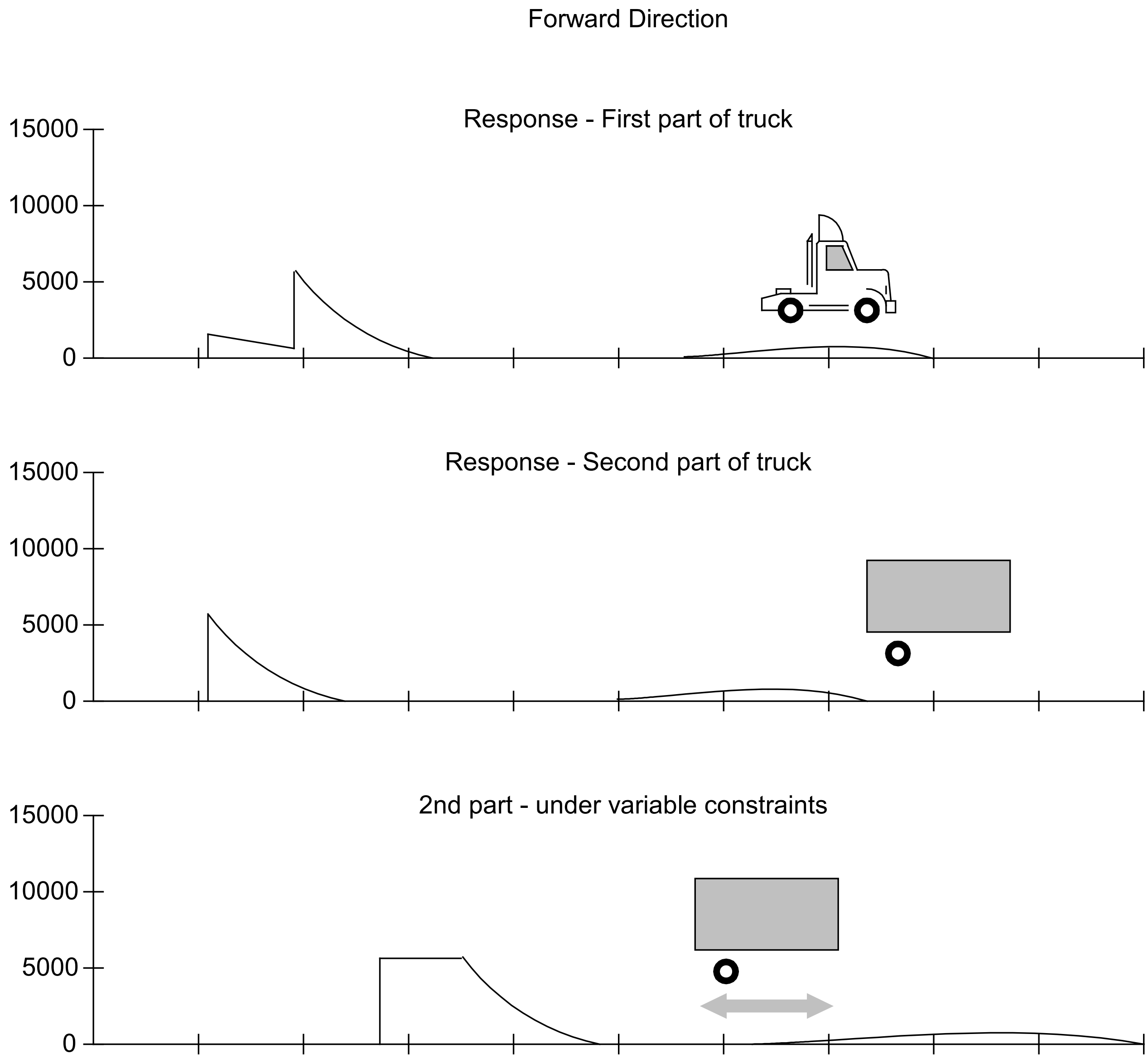


Figure 3.3.12-3 Combination of Effects For a Variable Axle Notional Truck

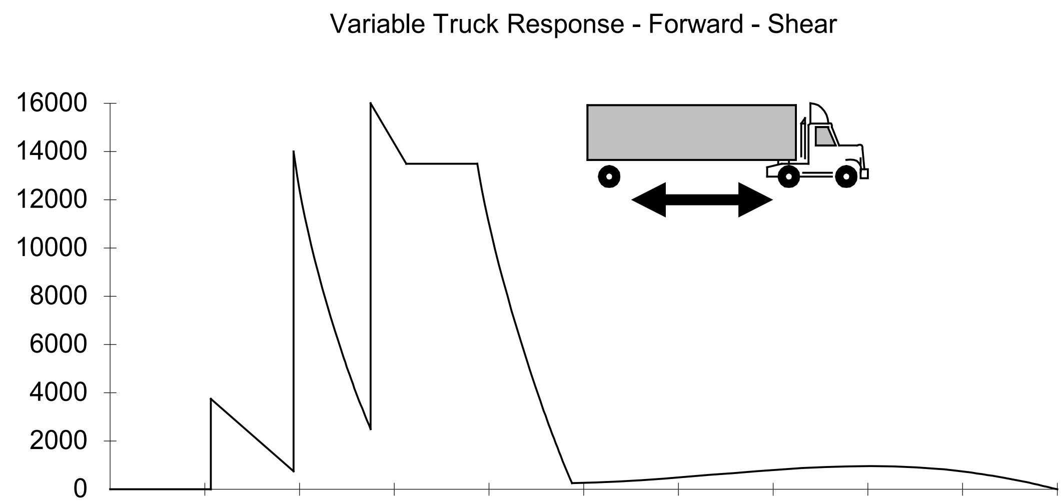


Figure 3.3.12-4 Total Effect For A Variable Axle Notional Truck

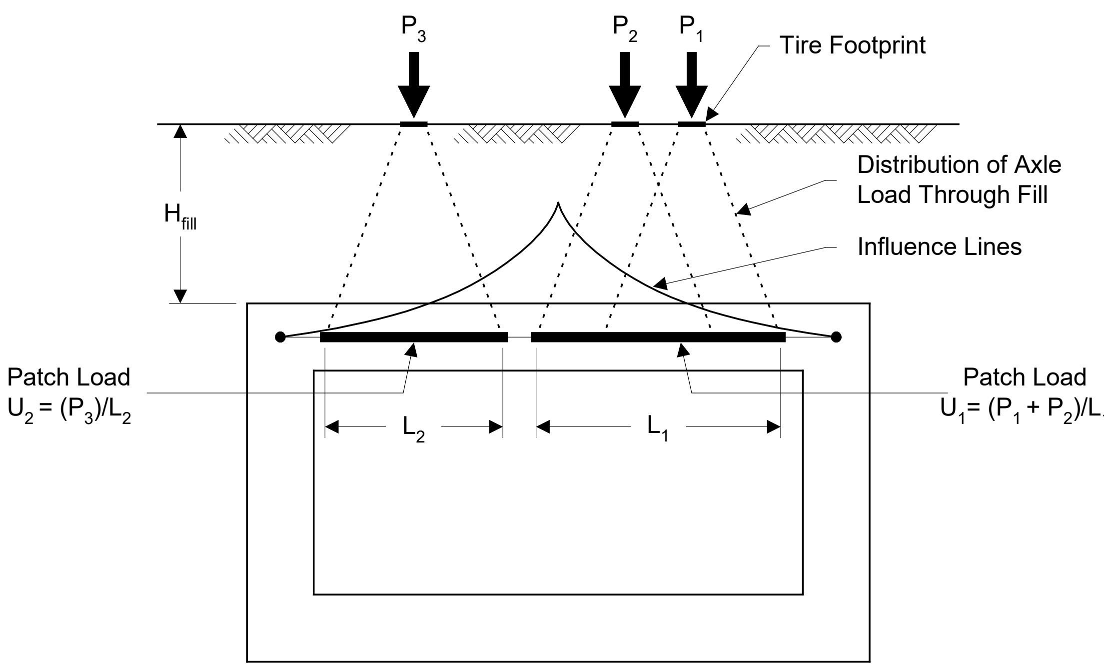


Figure 3.3.12-5 Loading Influence Lines for the Through Fill Effect

In addition to the notional loading of influence lines, BXLRFD also loads influence lines with live load vehicles having a variable axle spacing. For example, the second and third axles of the HS-20 vehicle have a variable spacing from 14 to 30 feet BXLRFD determines the response of a variable axle, notional truck by separating the influence line into positive and negative portions, and separating the vehicle into two fixed axle vehicles. The response of the second vehicle has constraints applied to it to account for the variable axle spacing. Figure 3 shows a truck with variable spacing between Axles 2 and 3 separated into two fixed axle trucks, with the effect of each fixed axle truck. The bottom of the figure shows the effect of the second fixed axle truck with the variable axle constraints applied to it. Figure 4 shows the total effect for the variable axle truck (notional), obtained by adding the effect of the first fixed axle truck to the effect of the constrained second fixed axle truck. BXLRFD determines the effect of a variable axle, notional truck by separating the influence line into positive and negative portions, and separating the vehicle into two fixed axle vehicles. The effect of the second vehicle has constraints applied to it to account for the variable axle spacing.

The Thru Fill effect for variably spaced axle vehicles are obtained by creating a series of fixed axle trucks with axle spacings increased by 1 foot Each of these fixed axle trucks have their axle loads distributed through the fill to obtain patch lengths and intensities, which are subsequently stepped over the influence lines. The maximum effect among all the generated fixed axle trucks is used for the final effect of the variable axle truck loading. Figure 5 shows how patch lengths (L_1 and L_2) and intensities are calculated. In this figure, P_1, P2 and P3 are the truck axle loads, and U_1 and U2 are the patch load intensities.

3.3.14 Lane Load Effect

In calculating the HL-93 or PHL-93 effect, the program also considers the effect of a Design Lane Load. This is a uniform lane load applied to the positive or negative regions of the influence line. The lane load can also be a part of the Special Live Load. If the positive lane load effect is being sought, the sum of the positive areas of the influence line is multiplied by the value of the uniform lane load, and the result is stored as the positive lane load effect. The negative lane load effect is calculated similarly using the negative areas of the influence line. The lane load effect is not considered when analyzing the top slab(s) of culverts in accordance with DM-4 Section 3.6.1.3.3. The lane load effect is still considered for all other components of the culvert.

A Lane Load is always applied directly to the culvert top slab for culverts at grade or under fill; it is not distributed through the fill. When the lane load is placed on fill above the culvert deck, there is no lateral distribution of load through the fill as there is with wheel loads; the lane load is assumed to act straight down through the fill and is uniformly distributed over a 10.0 foot lane width. The lane load effect is factored by the multiple presence factors for the Thru Fill case. If live load is not applied at all, i.e., the number of specified lanes is zero, then the program uses only dead load in forming the load effects.

3.3.15 Fatigue Load Effect

The effects of a Fatigue Load are not considered by this program in accordance with LRFD Specifications Section 5.5.3.1.

3.3.16 Special Live Load

The effects of a Special Live Load are calculated in the same manner as explained in Section 3.3.11. The effects of all axles are considered unless the user has specified to neglect the effects of those axles that do not produce the same effect as the effect being sought. Also, if the combined effect of a Special Lane Load and the Special Live Load is requested, the program computes these effects in a similar manner as the LRFD loading.

In calculating the effect of a Special Live Load, the effects of all axle loads are considered only if the user specifies to include the effects of all axles.

3.3.17 Live Load Envelopes

The program computes the live load effect considering dynamic load allowance, multiple presence factor, and the equivalent strip width for the On Deck, Thru Fill, or both conditions depending on the fill height. If Live Load is applied, Dynamic Load Allowance will be applied to all components of the culvert except for strip footings. IM is not used for calculation of foundation bearing pressures as per DM-4 Section 3.6.2.2. For the P-82 and P2016-13 loads, Dynamic Load Allowance is limited to the user-input value "Permit Truck Maximum Dynamic Load Allowance" on the LDC command (defaults to 20%).

3.3.17.1 On Deck Live Loads

The general equation used to determine live load effect, applied directly to the culvert deck, $(Q_i)_{deck}$, on a unit strip of culvert is:

$$(Q_i)_{(Deck)} = \gamma_i \{Q_{i\,(Lane)} + Q_{i\,(truck)}\,(1+IM)\} / E_{lat}$$

The above equation considers the multiple presence factor associated with the number of loaded lanes. The multiple presence factor is used only when the equivalent strip width is calculated as per LRFD Specifications Section 4.6.2.1.3. The lane effect is determined by loading only the portion of the influence line that contributes to the effect being sought. Truck axles that do not contribute to the extreme force effect under consideration (notional load concept) are ignored when loading the influence lines.

The live load distribution factor for the On Deck condition is calculated by one of the following methods.

Case 1 - Height of fill less than 2 ft

For this case the program uses the Equivalent Strip method from LRFD Specifications Section 4.6.2.10.

$$E_{lat} = \frac{96.0 + 1.44(Culvert\ Span)}{12} \text{ (Span in feet)}$$

E_{lat} = Minimum (E_{lat} M+, E_{lat} M-) / MPF

Where:

MPF is equal to (1.2*Multiple Presence Reduction Factor) for a single lane

Culvert Span = center-of-wall to center-of-wall culvert span of a single cell, in feet

For Cast-In-Place, the E_{lat} value must be less than or equal to the Culvert Segment Length. For precast, E_{lat} value must be less than or equal to the number of precast shear segments with shear transfer times the Culvert Segment Length.

The dynamic load allowance is then computed. Finally, the load effect is computed per unit length using the equivalent strip width, E_{lat}.

3.3.17.2 Thru Fill Live Loads

Here, the wheel loads are applied as a uniform load distributed over a rectangular area with sides equal to the tire contact area, as per LRFD Specifications Section 3.6.1.2.5. As stated in DM-4 Section C3.6.1.2.5, a load factor of 1.35 is used for the calculation of tire length for all live loads. The sides are increased by 1.15 times the fill depth in accordance with LRFD Specifications 3.6.1.2.6 and projected through the fill. Unlike the On Deck loading, the entire projected wheel area is placed on the culvert. Loading only the portion of the influence line that maximizes the desired effect is not considered.

The general equation used to determine total factored live load effect, distributed through the fill depth, $(Q_i)_{Thru\ Fill}$, on a unit strip of culvert is :

$$(Q_i)_{Thru\ Fill} = \gamma_i \{Q_{i\ (Lane)} \times MPF/d_w + Q_{i\ (Truck)}\ (1 + IM)/E_{lat}\}$$

Note that the above equation is different from the one for the On Deck envelope. The live load distribution for Thru Fill effects is determined as shown in Figure 1. This figure depicts what is considered Case 2 or the Thru Fill Case. First the lateral distribution distance, $E_{lat}(1)$, of the axle loads for one lane loaded is determined. This distance is a function of the wheel axle spacing and the height of fill. Then, if the number of design lanes is more than one, a second lane is loaded and $E_{lat}(2)$ is determined. This continues for as many design lanes as is specified in the input file.

Elat is computed using the following equations:

I = number of lanes

LANE(i) = The geometric distance shown in Figure 3.3.17.2-1

$$Elat(i) = \frac{LANE(i)}{i * MPF} \leq Live\ Load\ Distribution\ Length$$

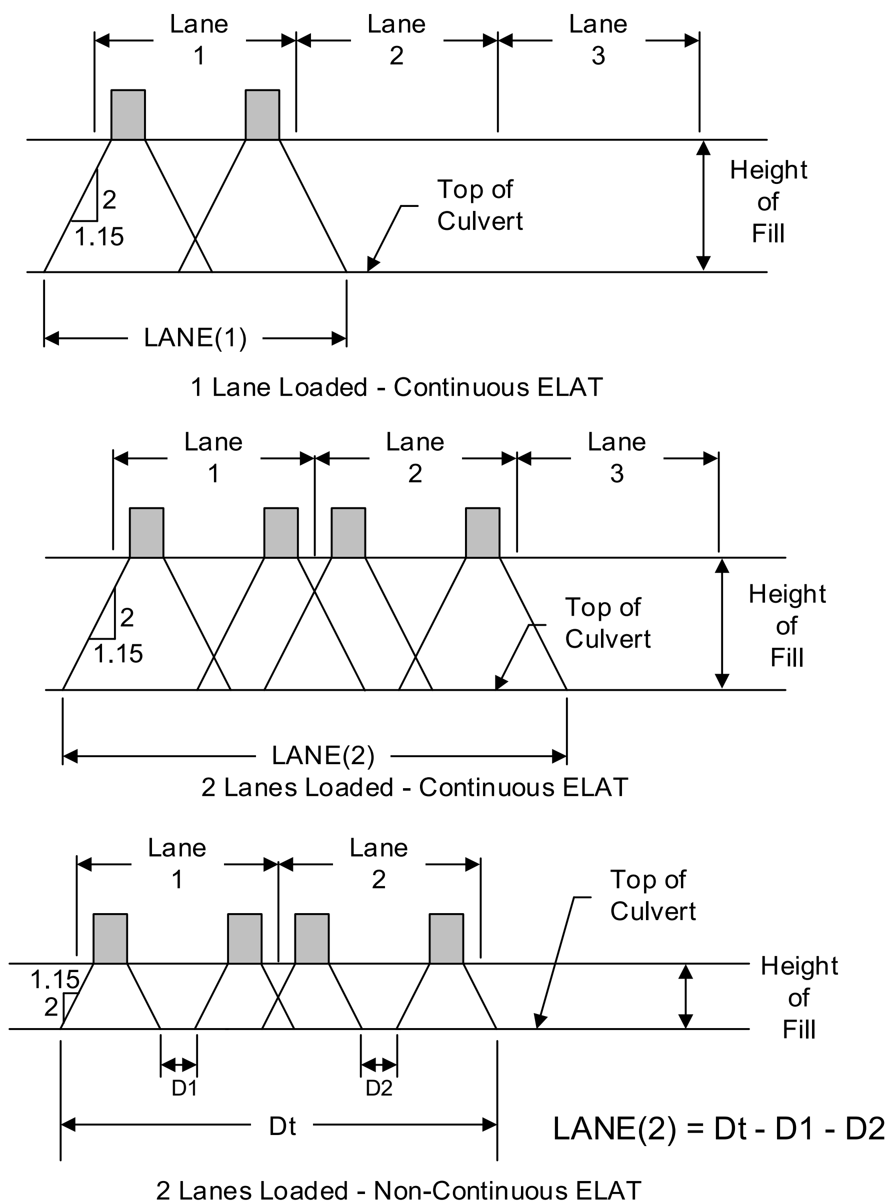


Figure 3.3.17.2-1 Case 2— Live Load Distribution Distances for Thru Fill Effect

3.4 LOAD COMBINATIONS AND STRESSES

After the effects of all loads are calculated, as described in Section 3.3, the program computes the factored moments, shears, deflections, reactions, and stresses as required by the LRFD Specifications and DM-4. In accordance with DM-4, the program computes the total factored loads using the following equation:

$$Q = \Sigma\left(\eta_i \gamma_i q_i \ or \ \frac{\gamma_i q_i}{\eta_i}\right)$$

where: Q = total factored load

η_i = load modifier (See Table 3.4-1)

γ_i = Load Factor (See Table 3.4-2)

q_i = Load (unfactored analysis results)

In the above equation, when the maximum load factor is used for a given load, then $\eta_i \gamma_i q_i$ is used. When the minimum load factor is used with a given load, then $\gamma_i q_i / \eta_i$ is used.

The program computes the load modifier in accordance with LRFD Specifications Section 1.3.2 and the corresponding section of DM-4. The load modifier used for each combination is summarized in Table 3.4-1.

The unfactored analysis results are multiplied by the appropriate load factor. The load factor depends on the load type and the limit state, as specified in the LRFD Specifications. The program considers LRFD Strength I,, Strength IA, Strength II, and Service I limit states. In addition, the program uses load factors for checking construction / uncured slab loads. The load factors used for each load type per limit state and construction / uncured slab loads, are shown in Table 3.4-2. When two load factors are presented, the first load factor is the maximum load factor and the second load factor in the minimum load factor.

Using the method described in section 3.3, the effects due to dead loads, earth loads and live loadings at all POI's are obtained and stored. These effects are then combined into the maximum effect cases for the purpose of design or rating sections at POI's. The load factors are shown in Table 3.4-2. These loads provide the Factored Load side of the LRFD equation for various Limit States and Load Cases. The following sections describe how these factored loads for applicable Limit States and Maximum Effect are obtained.

Table 3.4-1 Load Modifier

Load Combination	Load Modifier
All Strength Limit States	η = product of importance factor, ductility factor and redundancy factor (see LDC command) Minimum η = 1.0 Maximum η = 1.16 As per PennDOT DM-4 Section 1.3.2.1, Eta factors other than 1.0 are not permitted by PennDOT.
All Service Limit States	η = 1.0
Construction/Uncured Slab	η = product of entered importance factor, ductility factor, and redundancy factor (see LDC command) Minimum η = 1.0 Maximum η = 1.16 As per PennDOT DM-4 Section 1.3.2.1, Eta factors other than 1.0 are not permitted by PennDOT.

Table 3.4-2 Load Factors(γ_i), Live Loadings and Applicable Ratings

Load	Service I	Strength I	Strength IA	Strength II	Min. For Constr. Case (Strength)
DC	1.00	1.25,0.90	1.25,0.90	1.25,0.90	1.25,0.90
DCB	1.00	1.25,0.90	1.25,0.90	1.25,0.90	1.25,0.90
DW	1.00	1.50,0.65	1.50,0.65	1.50,0.65	N/A
AD	1.00	1.25,0.9	1.25,0.9	1.25,0.9	1.25,0.9
OV	1.00	1.50,0.65	1.50,0.65	1.50,0.65	N/A
EV	1.00	γ_{EV}	γ_{EV}	γ_{EV}	γ_{EV}
EH	1.00	γ_{EH}	γ_{EH}	γ_{EH}	1.35, 0.90[1]
LS	1.00, 0	1.75, 0	1.35, 0	1.35,0	1.50, 0
AL	1.00, 0	1.75, 0	1.35, 0	1.35, 0	1.50, 0
LLIM	1.00, 0	1.75, 0	1.35, 0	1.35,0	-
WA	1.00,0	1.00,0	N/A	1.00,0	N/A
Design Live Loading	PHL93	PHL93	PHL93	P82, P2016-13	-
Rating Live Loading	**Rating Applicability: I = Inventory, O = Operating**				
PHL93	-	I	O	-	-
HL-93	-	I	O	-	-
P82	-	-	-	O	-
ML80	-	I	-	O	-
TK527	-	I	-	O	-
EV2	-	-	-	O	-
EV3	-	-	-	O	-
SU6TV	-	-	-	O	-
P2016-13	-	-	-	O	-
HS20	-	I	-	O	-
H20	-	I	-	O	-
Special Vehicle.	-	I	-	O	-

Notes: [1] Minimum load factor (EH) of 0.50 applies for top slabs of box culverts

	Earth Load Factors	
	Max	**Min**
γ_{EV}	1.30	0.90
γ_{EH}	1.35	0.90*
*Use 0.50 minimum for culvert top slab		

3.4.1 Maximum Effect Cases

The following six (6) maximum effect cases are used for design and an analysis:

i. Positive moment with concurrent thrust and shear
ii. Negative moment with concurrent thrust and shear
iii. Tension thrust with concurrent moment and shear
iv. Compression thrust with concurrent moment and shear
v. Positive shear with concurrent moment and thrust
vi. Negative shear with concurrent moment and thrust

Cases 1, 2, 3 and 4 are used for flexure, and Cases 1, 2, 5 and 6 are used for shear. The controlling case for flexure and the controlling case for shear are printed out.

3.4.2 Limit States and Load Factors

The effects from all applied loads are factored by maximum and minimum load factors and combined into the following LRFD limit states:

- Strength I
- Strength IA
- Strength II
- Construction
- Service I

Typically, Strength I, Strength II and Construction limit states are used for Design (sizing member thicknesses and reinforcement); Strength I, Strength IA and Strength II are used for an Analysis (section capacities and rating factors).

The factoring and combining of effects into limit states follows the DM-4 Specifications. Table 3.4-2 lists the minimum and maximum load factors for the various loading types, e.g., DC, DW, etc., for each limit state, and also which live load and limit state is used to compute Inventory and Operating ratings. If only a single load factor is listed, then it applies to both minimum and maximum. The program maximizes each case in each Limit State by using the appropriate (maximum or minimum) Load Factor which will add to the effect being sought. Once factored appropriately, the effects are summed together to form the limit state combined loads. These limit state loads are used to compute section capacities, rating factors, design member thicknesses and reinforcement, etc.

3.5 FACTORED RESISTANCE

The factored resistance of a section is calculated by computing nominal section resistance and applying the strength reduction factor, φ. The factored resistance is used in Analysis to compute Rating Factors, and for determining required flexure and shear reinforcement in Design.

Figure 1 defines section dimensions that will be used throughout the remainder of this chapter. In computing the nominal resistance of a section, any sacrificial thicknesses of the section are ignored. Sacrificial thicknesses are: wearing surface on a top slab when the slab is on grade, bottom slab scour, and foundation unevenness for a CIP culvert. The section dimension, h, in the figure is the total thickness of the section as specified by the user or being considered by the program. It is used to calculate member self weight and compute member stiffness. Top and Bottom reinforcement covers have default values that are the minimum allowed by DM-4; the user may increase the bar covers but not reduce them. The top face (top A_s, top_c and d_{neg}) is physically the top of the top and bottom slabs, and the left side of the walls, while the bottom face (bottom A_s, bot_c and d_{pos}) is physically the bottom of the top and bottom slabs, and the right side of the walls. The distances, d_{neg} and d_{pos} are used in all strength calculations.

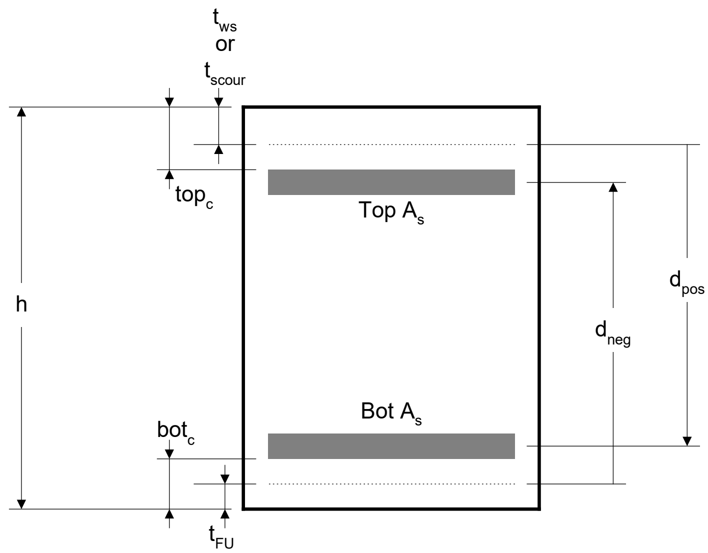
3.5.1 Section Design

BXLRFD has the capability to provide three types of design:

1. DESIGN WITH KNOWN THICKNESSES **(DR)** - when the thicknesses are known, the sections are designed for the areas of flexural and shear reinforcement required for the given thicknesses. Note that if the specified thickness is sufficient for shear, no shear reinforcement will be required.

2. DESIGN WITH SHEAR REINFORCEMENT **(DA)** - 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. **If the shear reinforcement required (with thickness based on bending moment) is greater than the maximum shear reinforcement permitted, then the thickness will be increased so the shear reinforcement does not exceed the maximum shear reinforcement permitted.**

3. DESIGN WITHOUT SHEAR REINFORCEMENT **(DC)** - 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.



h = Specified Section Thickness

t_{ws} = Top Slab Integral Wearing Surface Thickness (H_{fill} = 0.0) - 0.5 inch

t_{scour} = Bottom Scour Thickness - 0.5 inch

t_{FU} = Foundation Unevenness Thickness (CIP only) - 1.0 inch

top_c = Top Reinforcement Cover

bot_c = Bottom Reinforcement Cover

Note: h used for self weight and stiffness, d_{neg} and d_{pos} used for capacity

Figure 3.5-1 Cross Section Dimensions

All design strength limit states, all flexure maximum effect cases and all points-of-interest are considered. The general procedure used for design is as follows. If the thickness of the member is to be computed, the program starts with the greater of the thickness specified by the user or the minimum allowed thicknesses in Table 5.8-1. The thickness required at a section to resist the bending moment (without consideration of axial load) 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 0.5 inch, the thickness assumed for a member is considered sufficient. If the maximum difference is greater than or equal to 0.5 inch then this difference is rounded up to the next 0.5 inch thickness increment. This value is then added to the current assumed thickness to find the new assumed thickness. This is done for each member. The structure 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 0.5 inch for all members.

For design types DA and DC, the factored load effect for Strength I, Strength II and Construction limit state combinations are first generated, and then required member thickness, assuming a reinforcement ratio, ρ, equal to 0.5 of balanced reinforcement ratio, (ρ_b), at a given POI. The minimum flexure reinforcement is determined and the required amount of flexure reinforcement is computed using the minimum as a starting point. The Service I limit state combination is then generated, then bar spacings required for strength and crack control for eight bar sizes are computed. For a DC Design, member thicknesses are increased if necessary to resist the shear force, without considering shear reinforcement. For a DA Design, member thicknesses are increased to resist the shear force, with consideration of shear reinforcement.

For design type DR, Strength I, Strength II and Construction limit state combinations are generated, minimum flexure reinforcement is determined and the required amount of flexure reinforcement is computed. The Service I limit state combination is then generated, the bar spacings required for strength and crack control for eight bar sizes are computed. The shear reinforcement to resist the total factored shear force is computed, if required.

3.5.1.1 Member Thickness for Flexure

For design types DA and DC, the thicknesses of structure components other than strip footings are first determined either starting from the minimum allowed thicknesses (see Table 5.8-1) or those specified in the input file whichever is greater. The required thickness is equal to the required effective depth, d_{req}, plus the distance from the centroid of the bar to the face of the member. The required member thickness for strength is calculated by using the following formula, assuming a reinforcement ratio, ρ, equal to one-half of the balanced reinforcement ratio, ρ_b. The ϕ is calculated as described in Section 3.5.1.3.

$$d_{req} = \sqrt{\frac{\frac{|M_u|}{\phi_b}}{0.5\rho_b b f_y \left(1 - \frac{0.5\rho_b f_y}{2\alpha_1 f_c'}\right)}}$$

After the required thicknesses have been determined for all members, the overall structure geometry is updated if any change in thickness is more than 0.5 inch. Each member thickness can change independently of the other components except for top slabs: in a two cell culvert. The maximum thickness among the two slabs is determined. This is necessary to maintain a constant slope for the top slabs. The bottom slab thickness in a two cell culvert can be different due to a fish channel. However, the minimum thicknesses must be the same.

For design type DR, the thickness of culvert components is specified by the user.

3.5.1.2 Flexural Reinforcement

The flexural reinforcement is determined by iterative procedure considering the interaction of moments and axial forces. This procedure uses a very small amount of flexural reinforcement (0.001 A_{smin}) as a starting point to build the first moment-axial interaction curve as shown in Figure 1. The equations shown on the next several pages are used to build the interaction diagram. The f_y for flexural and axial reinforcement calculations is limited to 75 ksi as per LRFD Specifications Section 5.4.3.1.

The program iterates by varying the flexural reinforcement depending on where the total factored loads point (M_u, P_u) falls. If it falls outside the interaction curve, then the flexure reinforcement is increased until (M_u, P_u) falls within the curve. If the total factored load point (M_u, P_u) falls within the interaction curve, then flexure reinforcement is decreased until (M_u, P_u) point falls on or very near the curve. **The flexural reinforcement area is limited to 10% of the gross area of the cross section. If the area exceeds the limit the area is set to the limit and the factored resistances are reported that correspond to this limit. This allows normal output to be provided even though the design has failed.**

Separate flexure reinforcement areas are used for positive bending and for negative bending. These areas are incremented or decremented based on the sign of the applied moment except when the Load Line intersects the interaction curve between points 5 and 8 in Figure 1. When the Load Line intersects the interaction curve between point 5 and 8, the member is treated as a primary axial member and both the positive and the negative reinforcement area is incremented or decremented together. This is done to allow the reinforcement in components that have nearly zero moments to have symmetrical reinforcement.

Figure 1 presents the moment-axial interaction curve used by BXLRFD to calculate the factored moment resistance, M_r, and factored axial resistance, P_r. The interaction curve is defined by **12** discrete points, **six** for each face of the cross section. Face B of Figure 1 represents the interaction curve for positive bending and face A represents the interaction curve for negative bending. The area of steel on the compression face is ignored. Both curves have similar shapes but different magnitudes because the effective depths of a section vary for positive and negative bending **and the positive and negative reinforcement areas vary**. Points 1 and **12** are at ($0,\varphi P_{o,ten}$), Points 2 and **11** are at ($\varphi M_o,0$), Points 3 and **10** are at ($\varphi M_t,\varphi P_t$), Points 4 and **9** are at ($\varphi M_b,\varphi P_b$), Points **5** and **8** are found by computing the intersection of two lines. Points **6** and **7** are at ($0,0.8\,\varphi P_{o,comp}$).

The **colored** lines in Figure 1 define the factored resistance curve, whereas the dashed lines define the unfactored or nominal section resistance curve. The factored moment and axial resistance, M_r and P_r, are found by extending a load line from the (DL+E) load point to the (DL+E+LL) load point. The Load Line is a linear line extended from the (DL+E) load point to the (DL+E+LL) load point. If the (DL+E+LL) load point is inside the interaction curve, the load line is extended to find the intersection. If the (DL+E) load point is zero, then the Load Line goes from the origin to the (DL+E+LL) load point. If the (DL+E) load point is outside the interaction curve, the Load Line goes from the origin to the (DL+E) load point.

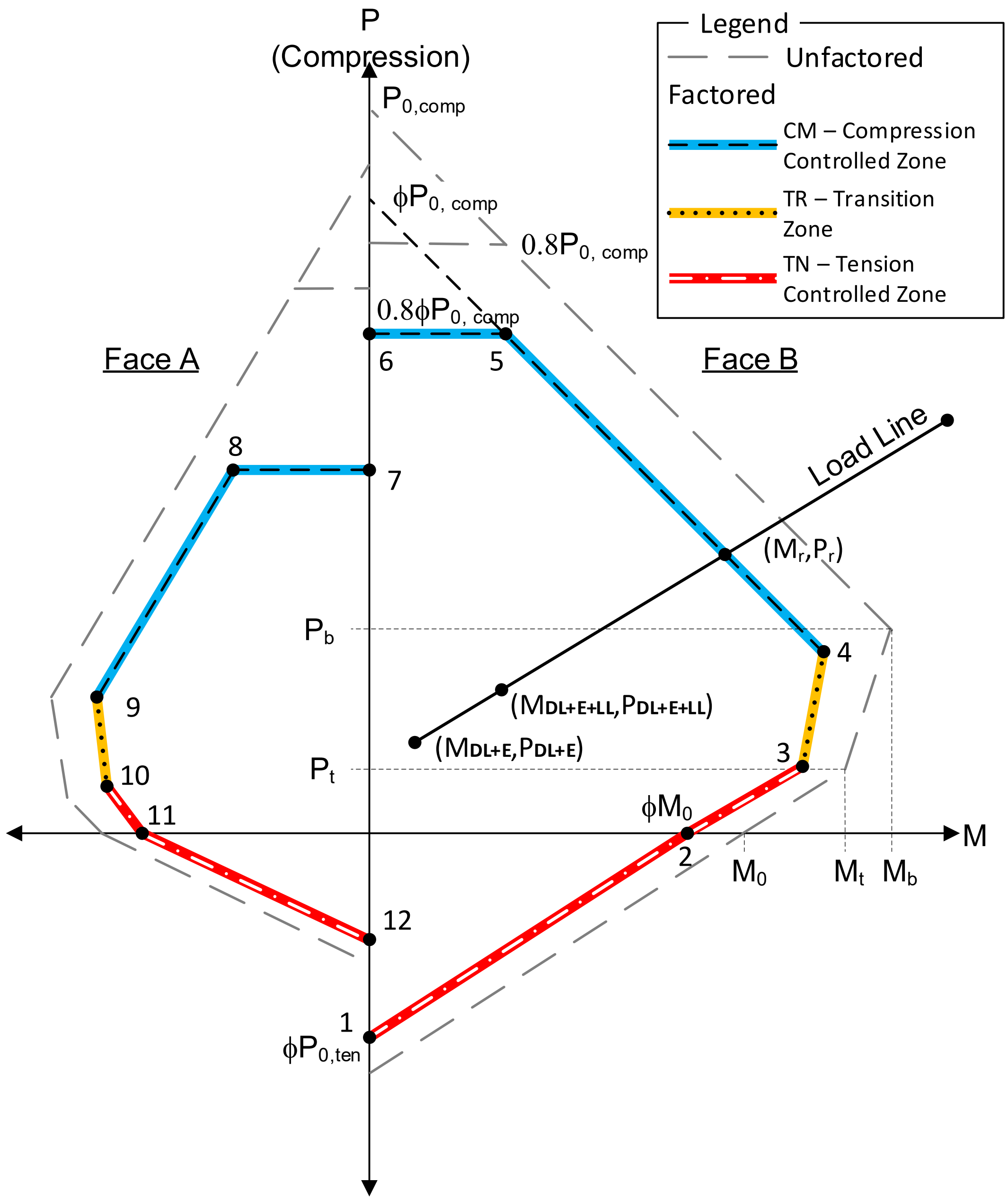


Figure 3.5.1.2-1 Two Face Moment-Axial Interaction Curve Showing Load Line

The **twelve** points, (1) to (**12**), correspond to the following factored conditions, as shown in Figure 1:

1 & **12**. Pure axial tensile strength (based on reinforcement only)

$\phi = 0.9$ (for CIP Box, CIP Frame, and CIP U-Channel)

$= 0.95$ (for Precast Frame and Precast U-Channel)

$= 1.0$ (for Precast Box)

Positive Flexure

$$P_{(1)} = \phi A_{stp} f_y$$

$$M_{(1)} = 0$$ (eccentricity of tensile force is ignored)

Negative Flexure

$$P_{(12)} = \phi A_{stn} f_y$$

$$M_{(12)} = 0$$ (eccentricity of tensile force is ignored)

2 & **11**. Pure flexural strength (axial capacity = 0.0)

The resistance factor, ϕ, is computed considering strain compatibility when appropriate, as shown below. The ϕ limit is 0.9 for cast-in-place boxes, cast-in-place frames, and cast-in-place U-channels, 0.95 for precast frames and precast U-channels, and 1.0 for precast box culverts.

Positive Flexure

$$P_{(2)} = 0$$

$$M_{(2)} = \phi \left\{ A_{stp} f_s \left[d_{pos} - \frac{A_{stp}\, f_s}{2\,(\alpha_1\, f_c'\, b)} \right] \right\}$$

Negative Flexure

$$P_{(11)} = 0$$

$$M_{(11)} = \phi \left\{ A_{stn} f_s \left[d_{neg} - \frac{A_{stn}\, f_s}{2\,(\alpha_1\, f_c'\, b)} \right] \right\}$$

With the known area of steel, the quadratic equation is solved for the moment resistance, $M_{(2)}$ and $M_{(11)}$, with ϕ equal to the ϕ limit and assuming the stress in the reinforcement steel, f_s, is equal to the specified minimum yield strength, f_y.

The net tensile strain and the stress in the reinforcement is computed from the following:

$$c = \frac{A_s\, f_s}{\alpha_1\, f_c'\, \beta_1\, b}$$

$$\varepsilon_t = 0.003 \left(\frac{d_s}{c} - 1 \right)$$

$$f_s = min(\varepsilon_t \cdot E_s,\, f_y)$$

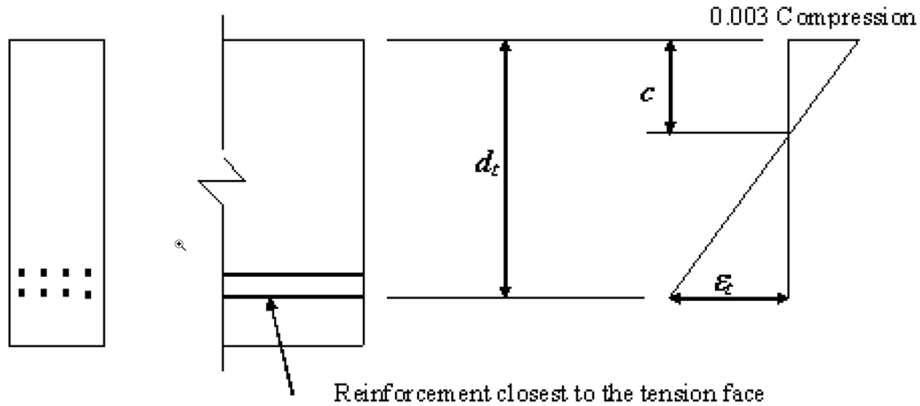


Figure 3.5.1.2-2 Strain Distribution and Net Tensile Strain (LRFD Specifications Figure C5.6.2.1-1)

If the mild steel stress, f_S, is less than the yield strength, f_y, then the initial assumption was incorrect, and the nominal flexural resistance is determined based on conditions of equilibrium and strain compatibility.

The resistance factor ϕ is computed with the net tensile strain using the equation:

$$0.75 \leq \phi = 0.75 + \frac{0.15(\varepsilon_t - \varepsilon_{cl})}{(\varepsilon_{tl} - \varepsilon_{cl})} \leq 0.9$$ (for CIP Box, CIP Frame, and CIP U-Channel)

$$0.75 \leq \phi = 0.75 + \frac{0.20(\varepsilon_t - \varepsilon_{cl})}{(\varepsilon_{tl} - \varepsilon_{cl})} \leq 0.95$$ (for Precast Frame and Precast U-Channel)

$$0.75 \leq \phi = 0.75 + \frac{0.25(\varepsilon_t - \varepsilon_{cl})}{(\varepsilon_{tl} - \varepsilon_{cl})} \leq 1.0$$ (for Precast Box)

where:

ε_{cl} = *compression-controlled strain limit*

$= min\left(\frac{f_y}{E_s}, 0.002\right)$ for $f_y \leq 60.0$ ksi

$= 0.002 + \frac{(f_y - 60.0)}{40.0}(0.002)$ for $60.0 \text{ ksi} < f_y \leq 75.0$ ksi

ε_{tl} = *tension-controlled strain limit,* 0.005

Finally, the factored flexural resistance is computed by multiplying the nominal flexural resistance by ϕ. If the computed ϕ factor is less than 0.90 (CIP Box, CIP Frame, and CIP U-Channel) or 0.95 (Precast Frame and Precast U-Channel) or 1.0 (Precast Box), then the process is repeated with ϕ assumed to be 0.75 and a second moment resistance is computed. Using the second moment resistance a new factored flexural resistance is computed. If the second moment resistance is less than the applied factored moment then the cross section is considered inadequate; otherwise, the phi factor is iterated until the assumed phi factor is equal to the computed phi factor. For analysis, the inadequate resistance is reported; for design, the culvert thickness or area of steel is incremented.

3 & **10**. Tension controlled strain condition

$\phi = 0.9$ (for CIP Box, CIP Frame, and CIP U-Channel)

$= 0.95$ (for Precast Frame and Precast U-Channel)

$= 1.0$ (for Precast Box)

Positive Flexure

$$\varepsilon_{cu} = 0.003$$

$$\varepsilon_t = \varepsilon_{tl} = 0.005$$ (program limited to $f_y \leq 75.0$ ksi)

$$d_{pos}'' = d_{pos} - \frac{h}{2}$$

$$c_{pos} = \frac{\varepsilon_{cu}\, d_{pos}}{\varepsilon_t + \varepsilon_{cu}}$$

$$a_{pos} = \beta_1 c_{pos}$$

$$C_c = \alpha_1 f'_c\, \beta_1 c_{pos} b$$

$$T = A_{stp} MIN(f_y, \varepsilon_t E_s)$$

$$P_{(3)} = \phi\, \{C_c - T\}$$

$$M_{(3)} = \phi\, \left\{C_c \left(d_{pos} - \frac{a_{pos}}{2} - d_{pos}''\right) + T d_{pos}''\right\}$$

Negative Flexure

$$\varepsilon_{cu} = 0.003$$

$$\varepsilon_t = \varepsilon_{tl} = 0.005$$ (program limited to $f_y \leq 75.0$ ksi)

$$d_{neg}'' = d_{neg} - \frac{h}{2}$$

$$c_{neg} = \frac{\varepsilon_{cu}\, d_{neg}}{\varepsilon_t + \varepsilon_{cu}}$$

$$a_{neg} = \beta_1 c_{neg}$$

$$C_c = \alpha_1 f'_c\, \beta_1 c_{neg} b$$

$$T = A_{stn} MIN(f_y, \varepsilon_t E_s)$$

$$P_{(12)} = \phi\, \{C_c - T\}$$

$$M_{(12)} = \phi\, \left\{C_c \left(d_{neg} - \frac{a_{neg}}{2} - d_{neg}''\right) + T d_{neg}''\right\}$$

4 & 9. Balanced condition

Positive Flexure

$$\varepsilon_{cu} = 0.003$$

$$\varepsilon_t = \varepsilon_{cl}$$

$$d_{pos}'' = d_{pos} - \frac{h}{2}$$

$$c_{pos} = \frac{\varepsilon_{cu}\, d_{pos}}{\varepsilon_t + \varepsilon_{cu}}$$

$$a_{pos} = \beta_1 c_{pos}$$

$$C_c = \alpha_1 f'_c\, \beta_1 c_{pos} b$$

$$T = A_{stp} MIN(f_y, \varepsilon_t E_s)$$

$$\phi = 0.75$$

$$P_{(4)} = \phi\,\{C_c - T\}$$

$$M_{(4)} = \phi\,\left\{C_c\left(d_{pos} - \frac{a_{pos}}{2} - d_{pos}''\right) + T d_{pos}''\right\}$$

Negative Flexure

$$\varepsilon_{cu} = 0.003$$

$$\varepsilon_t = \varepsilon_{cl}$$

$$d_{neg}'' = d_{neg} - \frac{h}{2}$$

$$c_{neg} = \frac{\varepsilon_{cu}\, d_{neg}}{\varepsilon_t + \varepsilon_{cu}}$$

$$a_{neg} = \beta_1 c_{neg}$$

$$C_c = \alpha_1 f'_c\, \beta_1 c_{neg} b$$

$$T = A_{stn} MIN(f_y, \varepsilon_t E_s)$$

$$\phi = 0.75$$

$$P_{(9)} = \phi\,\{C_c - T\}$$

$$M_{(9)} = \phi\,\left\{C_c\left(d_{neg} - \frac{a_{neg}}{2} - d_{neg}''\right) + T d_{neg}''\right\}$$

5 & 8. Interaction point when axial load = $0.8P_o$

$$\phi = 0.75$$

Positive Flexure

$$P_{(5)} = \phi\,\{0.8[\alpha_1\, f'_c\,(A_g - A_{stp}) + f_y\, A_{stp}]\}$$

$M_{(5)}$ = The intersection of the horizontal line from $P_{(6)}$ with the line between points 4 and $\phi(P_{o,comp})$

Negative Flexure

$$P_{(8)} = \phi\,\{0.8[\alpha_1\, f'_c\,(A_g - A_{stn}) + f_y\, A_{stn}]\}$$

$M_{(8)}$ = The intersection of the horizontal line from $P_{(7)}$ with the line between points **9** and $\phi(P_{o,comp})$

6 & **7**. P_o - Pure axial compressive strength, P_o (Flexural Strength = 0.0)

$$\phi = 0.75$$

Positive Flexure

$$P_{(6)} = P_{(5)}$$

$M_{(6)} = 0$ (eccentricity of compressive force is ignored)

Negative Flexure

$$P_{(7)} = P_{(8)}$$

$M_{(7)} = 0$ (eccentricity of compressive force is ignored)

The factored points 1 to **5** and **12** to **8** are then sorted by increasing axial value, P, and stored as points **13** to **17** and **24** to **20**, respectively shown in Figure 2. Then, the P value of point **18** is set equal to the P value of point **17** and the P value of point **19** is set equal to the P value of point **20**.

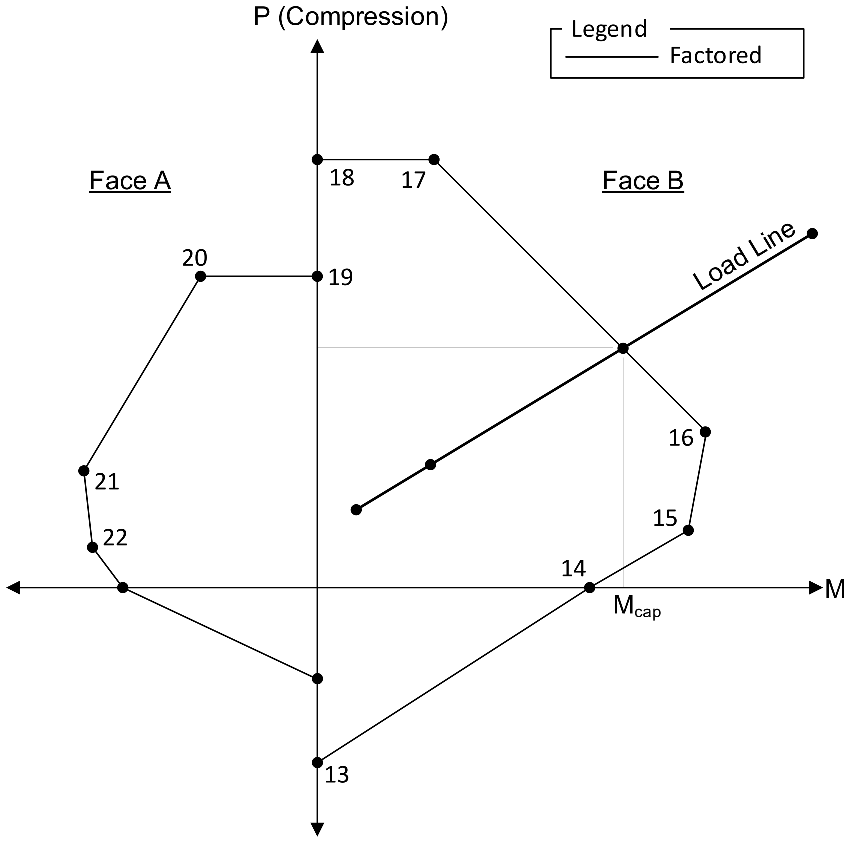


Figure 3.5.1.2-3 Sorted, Factored Two Face Moment-Axial Interaction Diagram

Where:

ϕ = Resistance factor

A_{stp} is the area of the positive reinforcement

A_{stn} is the area of the negative reinforcement

β_1= 0.85 for f'_c <= 4 ksi

β_1= $0.85 - 0.05 * (f'_c - 4.0)$ for f'_c > 4, but not less than 0.65

LRFD Specifications Section 5.7.2.2

d_{pos} is the positive flexure reinforcement effective depth

d_{neg} is the negative flexure reinforcement effective depth

h is the total structural depth

ε_{cu} is the crushing concrete strain (0.003)

ε_t is the net tensile strain at nominal resistance

ε_{cl} is the compression-controlled strain limit

ε_{tl} is the tension-controlled strain limit

a_{pos} is the depth rectangular stress distribution for positive flexure reinforcement

a_{neg} is the depth rectangular stress distribution for negative flexure reinforcement

b is the width of the section (12.0 inches)

c_{pos} is the distance from outer compressive fiber to neutral-axis for positive flexure reinforcement

c_{neg} is the distance from outer compressive fiber to neutral-axis for negative flexure reinforcement

C_c is the concrete compressive force

T is the steel tensile force

3.5.1.2.1 Minimum Transverse Reinforcement

Cast-In-Place Culverts

For cast-in-place culverts the minimum transverse flexure reinforcement is based on a required flexural resistance of the lesser of 1) the temperature and shrinkage reinforcement in each face of the section as calculated per DM-4 Section 5.10.6 and LRFD Specifications Section 12.11.5.3, and 2) 1.33 M_u or M_{cr} as per DM-4 Section 5.6.3.3.

A_{sTmin1}:

See Section 3.5.3.2 Temperature and Shrinkage Spacing Check.

A_{sTmin2}:

$A_{sTmin2} = \rho_{min}\, bd$

Where

$$\rho_{min} = \alpha_1 \left(\frac{f_c'}{f_y}\right) - \frac{\sqrt{-b(\alpha_1 f_c')\phi\left[2M_{r-req} - \phi b d^2(\alpha_1 f_c')\right]}}{\phi b d f_y}$$

Where

$$M_{r-req} = min\left(\mathbf{1.33}|M_u|, \gamma_3(\gamma_1 f_r S)\right)$$

Where

$S = b\,h^2 / 6$

$f_r = 0.24\boldsymbol{\lambda}\sqrt{f_c'}\ (ksi)$

γ_1 = 1.6 for non prestressed concrete (DM-4 Section 5.6.3.3)

$\gamma_3 = f_y / f_u$ (DM-4 Section 5.6.3.3)

M_u = Applied Moment

Minimum transverse steel reinforcement for cast-in-place culverts (A_{sTmin}) is the larger of A_{sTmin1} and A_{sTmin2}.

Precast Culverts

For precast culverts, the minimum transverse flexure reinforcement is based on the greater of 1) the temperature and shrinkage reinforcement in each face of the section as calculated per DM-4 Section 5.10.6 (for segment lengths greater than 16.0 feet) and 2) 0.002 times the gross concrete area as per LRFD Specifications Section 12.11.5.3. Therefore, the minimum steel (A_{sTmin}) is the larger of A_{sTmin1} and A_{sTmin2} which are calculated as follows:

A_{sTmin1}:

If the Segment Length ≤ 16.0 feet, A_{sTmin1} = 0.0 in^2 / ft

Otherwise, A_{sTmin1} is computed as documented in Section 3.5.3.2 Temperature and Shrinkage Spacing Check.

A_{sTmin2}:

$A_{sTmin2} = 0.002\ A_g$ (LRFD Specifications Section 12.11.5.3.2)

Where

A_g = gross area of a cross section

$A_{sTmin} = MAX(A_{sTmin1}, A_{sTmin2})$

3.5.1.2.2 Minimum Longitudinal Reinforcement

Cast-in-Place Culverts

For cast-in-place culverts the program does not design or detail the longitudinal reinforcement.

Precast Culverts

Location: Top Slab, Bottom Bars

For precast culverts with a fill height less than 2.0 feet, the bottom longitudinal reinforcement, AsLmin1, in the top slab is calculated as:

$Percent = \frac{100}{\sqrt{S}} \leq 50\%$ (LRFD Specifications Section 9.7.3.2)

$AsLmin1a = Percent \cdot AsTmin$

$AsLmin1b = 0.002\ Ag$ (LRFD Specifications Section 12.11.5.3.2)

$AsLmin1 = MAX(AsLmin1a, AsLmin1b)$ (bottom longitudinal reinforcement only)

Where

A_g = gross area of a cross section

S = Clear Span (in feet)

b = unit width of culvert section

d = thickness of culvert section

Location: All Other Longitudinal Bars

For all precast culverts, the minimum longitudinal reinforcement is always at least 0.03 in^2 / ft at each face.

A_{sLmin1} = 0.03 in^2 / ft

For precast culverts with a culvert segment length ≤ 16.0 feet, the minimum longitudinal reinforcement area is equal to AsLmin1:

$A_{sLmin} = A_{sLmin1}$

For precast culverts with a culvert segment length > 16.0 feet, the minimum longitudinal reinforcement area is at least as large as calculated in Section 3.5.3.2 Temperature and Shrinkage Spacing Check.

A_{sLmin} = MAX(value from Section 3.5.3.2, A_{sLmin1})

3.5.1.3 Resistance Phi Factor

The relationships that apply are based on the cross-section illustrated in Figure 3.5.1.3-1.

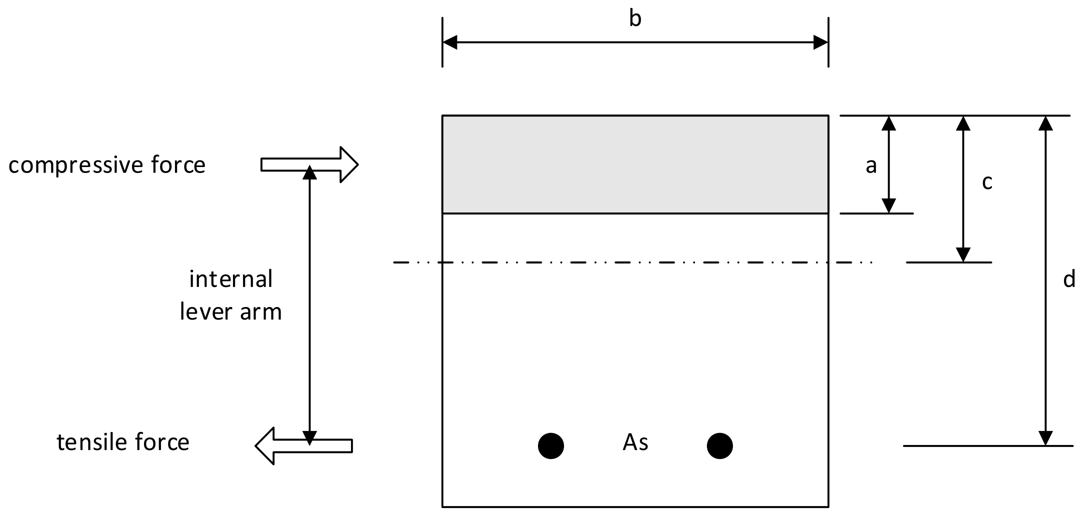


Figure 3.5.1.3-1 Singly Reinforced Section

The LRFD Specifications reduce the phi factor based on the strain condition at the cross-section. A reduction in the phi factor for compression-controlled sections is used to compensate for decreased ductility in comparison to tension-controlled sections. The variant resistance phi factor is computed by the following equation:

$$\varepsilon_t = \frac{0.003(d_t - c)}{c}$$ LRFD Specifications Figure C5.6.2.1-1

Cast-In-Place Box, Cast-In-Place Frame, and Cast-In-Place U-Channel

$$0.75 \leq \phi = 0.75 + \frac{0.15(\varepsilon_t - \varepsilon_{cl})}{(\varepsilon_{tl} - \varepsilon_{cl})} \leq 0.9$$ LRFD Specifications Equation 5.5.4.2-2

Precast Frame and Precast U-Channel

$$0.75 \leq \phi = 0.75 + \frac{0.20(\varepsilon_t - \varepsilon_{cl})}{(\varepsilon_{tl} - \varepsilon_{cl})} \leq 0.95$$

Precast Box

$$0.75 \leq \phi = 0.75 + \frac{0.25(\varepsilon_t - \varepsilon_{cl})}{(\varepsilon_{tl} - \varepsilon_{cl})} \leq 1.0$$ LRFD Specifications Equation 5.5.4.2-1

where:

ε_t = net tensile strain in the extreme tension steel at nominal resistance (in./in.)

ε_{cl} = compression-controlled strain limit in the extreme tension steel (in./in.)

ε_{tl} = tension-controlled strain limit in the extreme tension steel (in./in.)

c = distance from extreme compression fiber to neutral axis (in.)

d_t = distance from the extreme compression fiber to the centroid of the extreme tension steel (in.)

3.5.2 Service Load Stress

This section describes how the stress in the rebar is evaluated. This section can be applied to all double reinforced sections experiencing flexural and axial loads. The program always assumes the section has cracked and determines the tensile stress in the flexural reinforcement accordingly. The actual stress is based on the reinforced concrete section theory for a cracked section under service limit states. The program uses an iterative process to determine the tensile stress in the reinforcement as described in the following steps as described in the following steps.

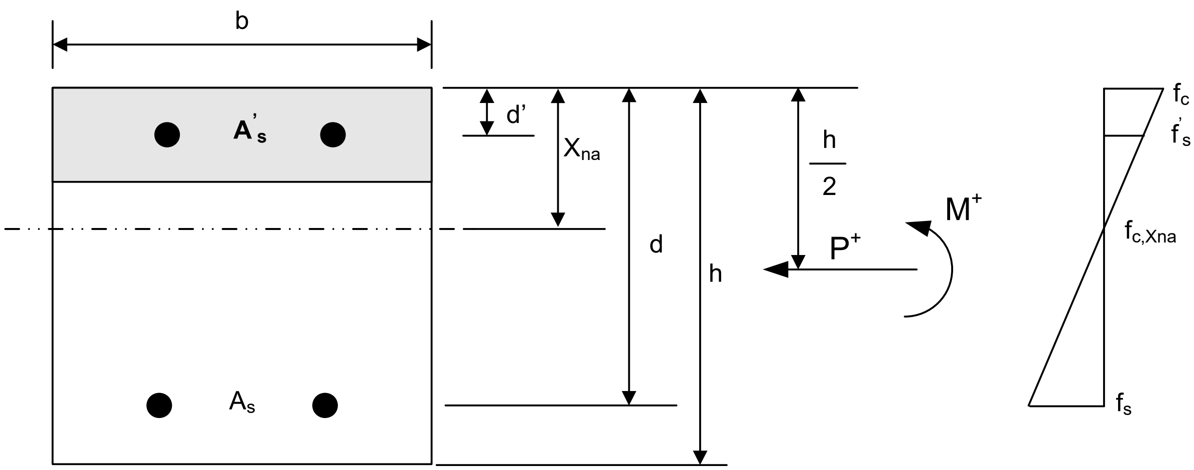


Figure 3.5.2-1 Double Reinforced Section and Stress Locations

1. The initial Neutral Axis is located at the center of the concrete section.

$$X_c = \frac{h}{2}$$

2. The modular ratio is calculated as described in Section 3.5.2.1.

3. The tensile and compressive areas of steel are then transformed

$$A_{tr} = n\left(A_s + A_s^{'}\right) + b * X_c$$

4. A new neutral axis is calculated based on the transformed areas

$$X_{na} = \frac{n\left(A_s * d + A_s^{'} * d^{'}\right) + \frac{b * X_c^{2}}{2}}{A_{tr}}$$

5. The moment due to eccentric loading is then calculated using the new neutral axis

$$M_{use} = \left|M\right| - P * \left(\frac{h}{2} - X_{na}\right)$$

6. The transformed moment of inertia is then calculated for the section

$$I_c = \frac{b * X_c^{\ 3}}{12} + b * X_c * \left(\frac{X_c}{2} - X_{na} \right)^2$$

$$I_s = n\left[A_s \left(d - X_{na}\right)^2 + A_s^{'} \left(d^{'} - X_{na}\right)^2\right]$$

$$I_{tr} = I_c + I_s$$

7. The tensile and compressive stresses are calculated based on the transformed section

Tensile Steel Stress

$$f_s = n\left[\frac{P}{A_{tr}} - \frac{M_{use}\left(d - X_{na}\right)}{I_{tr}}\right]$$

Compressive Steel Stress

$$f_s^{'} = n\left[\frac{P}{A_{tr}} - \frac{M_{use}\left(d^{'} - X_{na}\right)}{I_{tr}}\right]$$

Compressive Concrete Stress at the Current Neutral Axis

$$f_c = \frac{P}{A_{tr}} - \frac{M_{use}\left(0 - X_{na}\right)}{I_{tr}}$$

Compressive Concrete Stress at Assumed Neutral Axis

$$f_{c,X_c} = \frac{P}{A_{tr}} - \frac{M_{use}\left(X_c - X_{na}\right)}{I_{tr}}$$

The above calculations are iterated until $f_{c,xc}$ approaches zero. If $f_{c,xc}$ a is not equal to zero within a small tolerance a new X_c is calculated with the following equation and used starting at Step 3.

When $f_{c,xc}$ is less than zero

$$X_{c,new} = X_c - \frac{\left|X_c - X_{c,last}\right|}{2}$$

When $f_{c,xc}$ is greater than zero

$$X_{c,new} = X_c + \frac{\left|X_c - X_{c,last}\right|}{2}$$

Where:

$X_{c,last}$ = X_c from the previous iteration (For first iteration set to zero)

$X_{c,new}$ = X_c to be used in next iteration

M = Applied Moment from the Service Limit State

P = Applied Axial Load from the Service Limit State

M_{use} = Combined moment due to Applied Moment and Axial Forces

3.5.2.1 Modulus of Elasticity and Modular Ratio

The program computes the concrete elastic modulus, E_C, based on the Concrete Unit Weight for E (w_C; parameter 9 of the MAT command) and the concrete strength input by the user (f'_C; parameters 1 and 2 of the MAT command). The modular ratio, n, is then calculated as the ratio of the steel elastic modulus, E_S, to E_C.

The program assumes that concrete is normal weight when it has a w_C greater than or equal to 0.135 kcf. Lightweight concrete has a w_C less than 0.135 kcf.

Several steps are followed for the determination of the concrete elastic modulus (E_c) and the modular ratio (n) used by the program. In all of these steps, the steel elastic modulus (E_S) is assumed to be equal to 29,000 ksi.

1. DM-4 Sections 5.4.2.1 and 5.4.2.4 specify values for n and E_C based on specific f'_c and w_C values. The concrete densities are specified as either normal weight, with a density of 0.145 kcf, or lightweight, with a density of 0.110 kcf. If the user enters a w_C value of exactly 0.145 kcf or 0.110 kcf, along with an f'_C value of exactly 4.0, 3.5, 3.0, or 2.0 ksi, the E_C and n values will be set to the values shown in DM-4 Sections 5.4.2.1 and 5.4.2.4.

2. If the user enters a w_C value of exactly 0.145 kcf or 0.110 kcf, along with an f'_C value between 4.0 ksi and 2.0 ksi (and not 4.0, 3.5, 3.0, or 2.0 ksi), the E_C and n values will be interpolated between the values shown in DM-4 Sections 5.4.2.1 and 5.4.2.4. The E_C value will be rounded to the nearest 100 ksi, and n will be rounded to the nearest integer value.

3. If the user enters a w_C value of exactly 0.145 kcf, along with an f'_C value greater than 4.0 ksi and less than or equal to 10.0 ksi, the E_C value will be calculated with LRFD Specifications Equation C5.4.2.4-2:

$$E_c = 33{,}000 w_c^{1.5}\sqrt{f_c'}$$

where: E_C = Concrete elastic modulus

w_C = Concrete density for Ec

f'_C = Compressive strength of concrete

The E_C value will be rounded to the nearest 100 ksi. The rounded E_C value is then used to calculate n, which will be rounded to the nearest integer value.

4. If the user enters a w_C value of exactly 0.145 kcf, along with an f'_C value greater than 10.0 ksi, the E_C value will be calculated with LRFD Specifications Equation 5.4.2.4-1:

$$E_c = 120{,}000 K_1 w_c^{2.0} (f_c')^{0.33}$$

where: E_C = Concrete elastic modulus

K_1 = Correction factor for source of aggregate. BXLRFD uses a value of 1.0.

w_C = Concrete density for E_C

f'_C = Compressive strength of concrete

The E_C value will be rounded to the nearest 100 ksi. The rounded E_C value is then used to calculate n, which will be rounded to the nearest integer value.

5. If the user enters a w_C value of exactly 0.110 kcf, along with an f'_C value greater than 4.0 ksi, the E_C value will be calculated with LRFD Specifications Equation 5.4.2.4-1, shown in step 4.

6. If the user enters a w_C value other than 0.110 kcf or 0.145 kcf, along with any f'_C value, the E_C value will be calculated with LRFD Specifications Equation 5.4.2.4-1 shown in step 4.

3.5.3 Serviceability Check

Serviceability is always checked since the concrete section is always considered cracked. Once the required A_s has been determined, then reinforcement bar spacings are calculated for eight different bar sizes. The program begins by computing the spacing required just to satisfy strength requirements, rounding down to the nearest spacing increment, 0.5 inch. Then the crack control spacing for the reinforcement is computed. If the spacing exceeds the allowable spacing as per DM-4 Section 5.6.7, then the spacing is reduced by the spacing increment. This process continues until the spacing for the reinforcement is less than or equal to the allowable spacing. The minimum allowed bar spacing is computed and checked against the computed bar spacing. Next, the maximum allowed bar spacing is computed and checked against the computed bar spacing. If the computed bar spacing is larger than the maximum allowed, then the computed spacing is set equal to the maximum allowed.

3.5.3.1 Maximum and Minimum Allowable Spacing Check

The maximum spacing for a #4 bar is:

$$S_{MAX} = min(1.5t, 12\ in)$$ DM-4 Section 5.10.3.2 and DM-4 Section 5.10.6.1P

The maximum spacing for bar sizes #5 or larger is:

$$S_{MAX} = min(1.5t, 18\ in)$$ DM-4 Section 5.10.3.2 and DM-4 Section 5.10.6.1P

The minimum spacing is checked as per LRFD Specifications and DM-4 Section 5.10.3.1 which limits spacing with the following equations:

$$S_{MIN} = max(1.5 * Bar\ Diameter, 1.5 * Max\ Aggregate, 2.5\ in)$$ for Cast-In-Place

$$S_{MIN} = max(Bar\ Diameter, 1.33 * Max\ Aggregate, 1.5\ in)$$ for Precast

3.5.3.2 Temperature and Shrinkage Spacing Check

$$A_{s1} = \frac{1.3bh}{2(b+h)f_y}$$ (in²/ft) LRFD Specifications Equation 5.10.6-1

If A_{s1} < 0.11 Then

A_{s1} = 0.11 in²/ft

If A_{s1} > 0.6 Then

A_{s1} = 0.6 in²/ft

A_{s2} = #4's @ 12 in = 0.2 in²/ft DM-4 Section 5.10.6.1P

$A_{smin1} = MAX\ [A_{s1}, A_{s2}]$

Where:

h = least height of the component (in)

b = least width of the component (in)

BXLRFD sets the least width of the component equal to the full width of the culvert for slabs, the full height of the culvert for walls and the width of the footing for footings as illustrated in Figure 3.5.3.1-1.

The 0.12 in²/ft requirement from DM-4 Section 5.10.6 does not control over DM-4 Section 5.10.6.1P, so it is not considered by the BXLRFD program.

The maximum temperature and shrinkage spacing is:

- 12 in for a # 4 bar
- 18 in for a # 5 bar or greater

The spacing is specified as per DM-4 Section 5.10.6.1P.

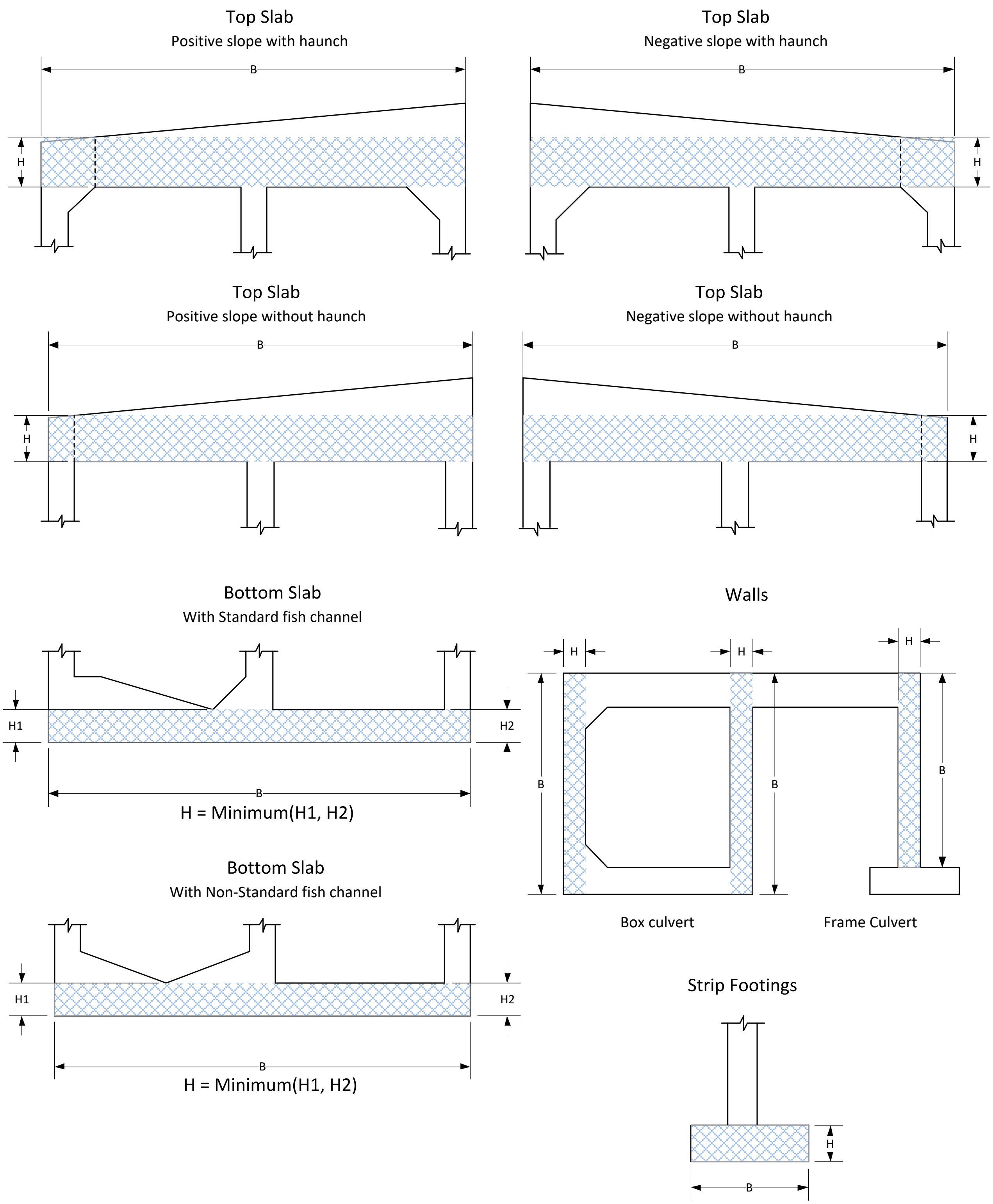


Figure 3.5.3.1-1 Temperature and Shrinkage Dimensions

3.5.3.3 Crack Control Check

The crack control is checked as per LRFD Specifications and DM-4 Section 5.6.7 where the spacing of the main tensile reinforcement is checked against the result of LRFD Specifications Equation 5.6.7-1

$$s \leq \frac{700\gamma_e}{\beta_s f_{ss}} - 2d_c$$

Where γ_e = 0.75 for a culvert (Class 2 Exposure as per DM-4 Section 5.6.7)

f_{ss} = MIN(f_s, 0.6*f_y)

$\beta_s = 1 + \frac{d_c}{0.7(h - d_c)}$

3.5.3.4 Development Length

The development length of a hooked reinforcing bar is calculated by the program during a rigid frame culvert design run for the wall reinforcement of the controlling face entering the strip footing.

The following equation is used to compute the required hooked development length (ℓ_{dh}) for given bar sizes. The basic development length is adjusted by the correction factors (λ_{rc}, λ_{cw}, λ_{er}, and λ), which are described further in the next sub-section. The basic development length considers the yield strength of the reinforcement and concrete, while the correction factors consider the confinement of the bar, epoxy coating on the bar, and the area of reinforcement.

$$\ell_{dh} = max\begin{pmatrix} 8.0 * d_b \\ 6.0" \\ \ell_{hb} * \left(\frac{\lambda_{rc}\lambda_{cw}\lambda_{er}}{\lambda}\right) \end{pmatrix}$$

where:

ℓ_{dh} = modified development length (in) (LRFD Specifications Equation 5.10.8.2.4a-1)

d_b = nominal diameter of reinforcing bar (in)

ℓ_{hb} = basic development length (in) (see next equation)

λ_{rc} = reinforcement confinement factor

λ_{cw} = coating factor

λ_{er} = excess reinforcement factor

λ = concrete density modification factor (LRFD Specifications Section 5.4.2.8)

$$\ell_{hb} = \frac{38.0 d_b}{60.0}\left(\frac{f_y}{\sqrt{f_c'}}\right)$$

where: ℓ_{hb} = basic development length (in) (LRFD Specifications Equation 5.10.8.2.4a-2)

d_b = nominal diameter of reinforcing bar (in)

fy = specified minimum yield strength of reinforcement (ksi)

f'c = compressive strength of concrete

3.5.3.5 Development Length Correction Factors

The basic development length for hooked bars is multiplied by the following factors (LRFD Specifications Section 5.10.8.2.4b):

- λ_{rc}, reinforcement confinement factor is conservatively assumed to always equal 1.0
- λ_{cw}, coating factor is 1.2 if epoxy coated and 1.0 for plain
- λ_{er}, excess reinforcement factor adjusts the length by the ratio:

$$\lambda_{er} = \frac{(A_s\ required)}{(A_x\ provided)}$$

3.5.4 Design For Fatigue

Fatigue checks are not performed by this program in accordance with LRFD Specifications Section 5.5.3.1.

3.5.5 Design For Shear

Once the section is designed for flexure, the program next designs the section for shear, satisfying the following equation:

$$\phi_v V_n \geq V_u$$

Where:

φ_v = 0.85 for cast-in-place culvert (DM-4 Table 12.5.5-1)

φ_v = 0.90 for precast culvert (DM-4 Table 12.5.5-1)

The nominal shear resistance, V_n, is determined as per LRFD Specifications Section 5.7.3.3 and the factored load, V_u, is determined for all strength limit state combinations as per Section 3.4 of this chapter. The ϕ_v is determined as per DM-4 Table 12.5.5-1. The f_y for shear reinforcement calculations is limited to 60 ksi.

The Corresponding Moment when the Maximum Shear occurs is used to determine which reinforcement (Top or Bottom) to use when calculating de and dv for the shear resistance. If the

Corresponding Moment is Positive, then the Bottom Reinforcement is used otherwise the Top Reinforcement is used.

The nominal shear resistance is determined as the lesser of:

$$V_n = V_c + V_s$$ LRFD Specifications Equation A5.7.3.3-1

$$V_n = 0.25 f_c' b_v d_v$$ LRFD Specifications Equation 5.7.3.3-2

Where V_c is the shear resistance provided by concrete and V_s is the shear resistance provided by shear reinforcement.

For box culvert analysis runs that do not define specific shear reinforcement (TVA, BVA, and WVA commands), and for all box culvert design runs, the value of V_s in the above equation is calculated as follows:

$$V_s = A_v f_y \sin\alpha \leq 0.095\lambda\sqrt{f_c'} b_v d_v$$ LRFD Specifications Equation 5.7.3.3-5

For box culvert analysis runs that do define shear reinforcement, the value of V_s is calculated as:

$$V_S = \frac{A_v f_y d_v (\cot\theta + \cot\alpha)\sin\alpha}{s}$$ LRFD Specifications Equation 5.7.3.3-4

where: θ = angle of inclination of diagonal compressive stresses (hard-coded to 45 degrees in BXLRFD as per LRFD Specifications Section 5.7.3.4.1)

α = angle of inclination of transverse reinforcement to longitudinal axis (user input on MAT command)

s = spacing of transverse reinforcement (user input on TVA, BVA, and WVA commands)

The value of d_v in the above equations is calculated as follows:

For Design:

$$d_v = max\ (0.9\ d_e, 0.72\ h)$$ LRFD Specifications Section 5.7.2.8

For Analysis:

$$d_v = max\left(d_e - \frac{f_y A_s}{2\alpha_1 f_c' \beta_1 b}, 0.9\ d_e, 0.72\ h\right)$$ LRFD Specifications Section C5.7.2.8

Where, h is the overall member depth and the effective member depth, d_e, is computed based on the section thickness minus the distance from the centroid of the tension flexure reinforcement bar to the face of the member. For design, the centroid location is based on the largest permissible reinforcement bar or wire size as indicated in the Material Command. For analysis, the centroid location is based on the largest reinforcement bar or wire size as specified along the entire length of the individual wall or slab.

The value of V_c in the above equation for V_n is calculated as follows:

For walls of culverts under any fill height and slabs of culverts under less than 2.0 feet of fill height or U-channels, the values of V_c and V_s are calculated assuming β = 2 in the following equations:

$$V_c = 0.0316\beta\lambda\sqrt{f_c'}\,b_v d_v$$ LRFD Specifications Equation A5.7.3.3-3

For both the top slab and the bottom slab of a culvert under a height of fill 2.0 feet or more, the value of V_c is computed as per LRFD Specifications Section 5.12.7.3 using the following equations and limits:

$$V_c = \left[0.0676\lambda\sqrt{f_c'} + 4.6\frac{A_s}{b_v d_e}\left|\frac{V_u d_e}{M_u}\right|\right] b_v d_e$$

Where: $\left|\frac{V_u d_e}{M_u}\right|$ cannot be greater than 1. V_c is calculated for all applicable limit state cases using corresponding values of V_u and M_u, and the maximum value of V_c is limited to:

$$0.126\lambda\sqrt{f_c'}\,b_v d_e$$ LRFD Specifications Equation 5.12.7.3-2

The minimum value of V_c for a Single Cell Culvert with slabs monolithic with walls is limited to:

$$0.0948\lambda\sqrt{f_c'}\,b_v d_e$$ LRFD Specifications Section 5.12.7.3

The minimum value of V_c for a Single Cell Culvert with a simply supported slab is limited to:

$$0.0791\lambda\sqrt{f_c'}\,b_v d_e$$ LRFD Specifications Section 5.12.7.3

The above minimum limits do not apply to multi-cell culverts.

Once V_c is calculated as explained above, the value of $\varphi_v V_c$ is compared with the ultimate factored shear, V_u. If V_u is less than $\varphi_v V_c$, the shear strength provided by concrete is adequate and thus the section is adequate to resist shear. Note that depending on the controlling equation for V_c, the value of M_u may or may not affect the concrete shear strength.

If V_u exceeds $\varphi_v V_c$ and a design without shear reinforcement is requested, the member thickness is increased and the structure is reanalyzed. The procedure is repeated until the shear resistance provided by concrete is adequate.

If V_u exceeds $\varphi_v V_c$ and a design with shear reinforcement is requested, the program calculates the maximum shear that can be resisted by shear reinforcement, V_{sreq}, as follows:

$$V_{sreq} = \frac{V_u}{\phi_v} - V_c$$

If V_{sreq} calculated above exceeds V_{smax} calculated as follows, V_{sreq} is set to V_{smax}.

$$V_s = 0.095\lambda\sqrt{f_c'}b_v d_v$$ LRFD Specifications Equation A5.7.3.3-5

$$V_{smax} = 0.025 f_c' b_v d_v - V_c$$ LRFD Specifications Equation A5.7.3.3-2 (rearranged)

If V_{sreq} is greater than V_{smax} , the member thickness is increased and the structure is analyzed. The procedure is repeated until the shear resistance is adequate.

If V_{sreq} is less than or equal to V_{smax}, the area of shear reinforcement, A_v, is computed assuming a single bar as follows:

$$A_v = \frac{V_{sreq}}{f_y \sin\alpha}$$

α = the angle between the shear reinforcement and the longitudinal tension reinforcement

3.6 LIVE LOAD RATINGS

When live load is applicable, the program calculates the flexure and shear ratings. If live load is not applicable, the program computes resistance/demand ratio (R/D). The ratings are computed for PHL-93, P-82, P2016-13, ML-80, TK527, EV2, EV3, SU6TV, HS20, and H20 Loadings. If a special live load is entered, the ratings are given for that loading.

Live Load Rating Factors and Resistance/Demand Ratios, if live load is not applicable, are the primary indicators of performance for the culvert. A ratio less than one indicates that the culvert is inadequate for a particular live load or just dead load if the R/D ratio is less than one. Rating factors are computed for all strength limit states, all live loads in the analysis and all maximum effect cases. They are computed by reverse implementation of the LRFD limit state combination. By specifying an input value, the program is able to generate ratings with and without Future Wearing Surface loading in a single run of the program.

3.6.1 Strength Limit State Ratings

For a given section, all strength limits state combinations are generated. The section properties and flexural and shear reinforcement areas are known. The ratings and resistance demand ratios are computed using the following general equations:

$$Rating\ Factor = \frac{Section\ Resistance - (DL + E)Effect}{(LL + I)Effect}$$

$$Resistance\ Demand\ Ratio = \frac{Section\ Resistance}{(DL + E)Effect}$$

The interaction curve for the section is constructed as explained under section 3.5.1.2. 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 Point (M_{DL+E}, P_{DL+E}) on Figure 3.5.1.2-1). 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 Point ($M_{DL+E+LL}$, $P_{DL+E+LL}$) on Figure 3.5.1.2-1). A straight line passing through the (DL+E) point and the (DL+E+LL) point is intersected with the interaction curve (point (M_r, P_r) in Figure 3.5.1.2-1). The coordinate of this point along the moment axis of the strength curve is the moment resistance M_r of the section.

All strength limit states ratings and resistance demand ratios are computed as follows:

1. Flexure Rating Factor:

$$RF_M = \frac{M_r - \gamma_{DL}M_{DL} - \gamma_{EV}M_{EV} - \gamma_{EH}M_{EH}}{\gamma_{LLIM}M_{LLIM} + \gamma_{LS}M_{LS} + \gamma_{AL}M_{AL}}$$

Resistance/Demand Ratio:

$$RDR_M = \frac{M_r}{\gamma_{DL}M_{DL} + \gamma_{EV}M_{EV} + \gamma_{EH}M_{EH}}$$

Where,

M_r	=	Factored flexural resistance
M_{DL}	=	Dead load moment
M_{EV}	=	Vertical earth moment
M_{EH}	=	Horizontal earth moment
M_{LS}	=	Live load surcharge moment
M_{LLIM}	=	Live load moment including dynamic allowance.
M_{AL}	**=**	**Approach slab live load moment**
γ_{DL}	=	Dead load factor
γ_{EV}	=	Vertical earth load factor
γ_{EH}	=	Horizontal earth load factor
γ_{LS}	=	Live Load surcharge load factor
γ_{AL}	**=**	**Approach slab live load factor**
γ_{LLIM}	=	Live load factor

2. Shear Rating Factor:

$$RF_V = \frac{V_r - \gamma_{DL}V_{DL} - \gamma_{EV}V_{EV} - \gamma_{EH}V_{EH}}{\gamma_{LLIM}V_{LLIM} + \gamma_{LS}V_{LS} + \gamma_{AL}V_{AL}}$$

Resistance/Demand Ratio:

$$RDR_V = \frac{V_r}{\gamma_{DL}V_{DL} + \gamma_{EV}V_{EV} + \gamma_{EH}V_{EH}}$$

Where,

V_r	=	Factored shear resistance
V_{DL}	=	Dead load shear
V_{EV}	=	Vertical earth shear
V_{EH}	=	Horizontal earth shear
V_{LS}	=	Live load surcharge shear
V_{LLIM}	=	Live load shear including dynamic allowance.
V_{AL}	**=**	**Approach slab live load shear**
γ_{DL}	=	Dead load factor

γ_{EV}	=	Vertical earth load factor
γ_{EH}	=	Horizontal earth load factor
γ_{LS}	=	Live Load surcharge load factor
γ_{AL}	=	**Approach slab live load factor**
γ_{LLIM}	=	Live load factor

The procedure to compute the rating factor for shear is iterative because V_c and consequently V_r ($V_r = \varphi_v V_n$, $V_n = V_c + V_s$, see Section 3.5.5), depends on the ratio of factored shear to factored moment, not just live load. However, if the spacing of shear reinforcement is known (i.e., entered), V_s is calculated assuming θ = 45° in the following equation:

$$V_s = \frac{A_v f_y d_v(\cot\theta + \cot\alpha)\sin\alpha}{s}$$ LRFD Specifications Equation 5.7.3.3-4

The iterative procedure assumes a starting Rating Factor of 1.0. The Factored shear and moment are then computed. Then a new Rating Factor is computed. If the Factor is not within 1%, the procedure recalculates a new set of factored shear and moment based on the computed Rating Factors. This procedure is repeated until the final Rating Factor is within 1% of the previous one. The procedure is limited to 100 iterations. If, after 100 iterations, the Rating Factors between calculations in two successive iterations are not with 1%, an error will result. Or, if after 100 iterations, an oscillation between two Rating Factors is detected, then the program will step from the lower Rating Factor to the higher Rating Factor, incrementing the assumed rating factor by 0.1 each time to determine the point at which the calculated and the assumed rating factors converge. The smaller of the assumed and calculated Rating Factors at the point of convergence is reported by the program. In addition to Live Load Ratings, the program performs the serviceability analysis as explained below.

The Rating Tonnage is calculated by taking the gross weight of the design vehicle and multiplying it by the live load rating factor. The axle loads for ML-80 and TK527 vehicles include a 3% scale tolerance. When computing the rating tonnages for ML-80 and TK527 vehicles, the program must remove the 3% scale tolerance. The program divides the total of all the axle loads by the 3% scale tolerance before multiplying by the rating factor to find the rating tonnage. For special live loads the axles should be entered without the scale tolerance and the scale tolerance should be entered separately by the user as a PERCENT INCREASE entered on the SLL command. The program then totals the special vehicle axle loads and multiplies it by the rating factor to find the rating tonnage.

3.7 SERVICEABILITY CHECK

Serviceability is always checked since the concrete section is assumed to always be cracked. The allowable crack control spacing for the reinforcement is computed as per LRFD Specifications and DM-4 Section 5.6.7.

The program next checks if the crack control bar spacing is greater than the flexural bar spacing. If the actual bar spacing is less than the allowable, the bar spacing is satisfactory, and the program checks the next bar size. Detailed description of checks is shown in Section 3.5.3.

3.8 FATIGUE ANALYSIS

The Fatigue Analysis is no longer performed in accordance with LRFD Specifications Section 5.5.3.1.

3.9 STRIP FOOTINGS

This section describes the procedures used for the analysis and design of a strip footing used at the bottom of external and internal walls when a bottom slab is not part of the culvert. See the discussion of the CTL command in Section 5.5 pertaining to the bottom slab. For an Analysis, Performance Ratios are calculated instead of rating factors. Performance ratios are resistances divided by demands, and are similar to rating factors. For a Design, flexure reinforcement is calculated assuming zero axial force, and bar spacings determined. No shear steel is considered for strip footings.

3.9.1 Loading

When a bottom slab is not present, the culvert is analyzed as an open, one or two bay frame with fixed boundary conditions at the bottom of the walls. The strip footing is not part of the structural analysis, rather, the factored effects at the bottom of the walls (total limit state axial, shear and moment), are used to obtain soil pressures acting on the bottom of the footings. The self weight of the footing and the weight of soil above the footing also contribute to the calculated soil pressure. The external loads acting on the footing are used to compute internal shears and moments (see Section 3.9.3) that are subsequently used in the calculation of the Performance Ratios (see Section 3.9.4) or to design the reinforcement (see Section 3.9.5).

Figure 1 provides definitions for a two cell culvert with strip footings. The vertical uniformly distributed loadings, W_{EV} and W_{LS} are factored loadings for Vertical Earth Pressure and Live Load Surcharge. The expressions used to calculate the loadings and those used to compute the self weight loading, W_{DC}, are as follows:

$$W_{EV} = \left[\rho_{soil} \times H_{EV}(Fill) + \rho_{backfill} \times H_{EV}(Backfill)\right] \times \gamma_{EV_{max}}$$

$$W_{LS} = \rho_{soil} \times H_{LS} \times \gamma_{LS}$$

$$W_{DC} = A_{ftg} \times \rho_c \times \gamma_{DC_{max}}$$

Maximum load factors are used to factor the loadings, and the load factors are multiplied by η. The height of fill above the center of the footing heel is used to compute W_{EV}.

3.9.2 Foundation Pressure and Eccentricity

Figure 1 shows the forces used for calculating footing force resultants, N and M_0, and the associated eccentricity (x_0 or e). N is obtained by summing the total limit state axial force in the wall (P_w), the soil loadings (W_{EV} and W_{LS}) and the footing self weight.

$$N = P_w + (W_{EV} + W_{LS})\,(L_{Heel}) + (W_{DC})$$

The moment of those forces (P_W, W_{EV}, W_{LS}, W_{DC}), and of the total limit state shear and moment at the bottom of the wall (V_W, M_W), is taken about Point "O" in the figure.

$$M_0 = P_w\,(B/2 - e_p) - M_w - V_w(t_f) + (W_{EV} + W_{LS})\,L_{Heel}\,(B - L_{Heel}/2) + W_{DC}(B/2)$$

Where:

e_p is the distance from the center of the footing to the center of the wall

t_f is the thickness of the footing

The distance from point "O" to the location of N, x_0, is obtained as shown below.

$$x_0 = M_0 / N$$

And finally, the eccentricity of N, from the center of the footing, e, is calculated:

$$e = B/2 - x_0$$

The force resultants, and the eccentricity, are calculated for all strength and service limit states, all live loadings in those limit states, and all six maximum effect cases.

Figure 2 shows the pressure distribution for calculating the left and right edge soil pressures, q_L and q_R, for the case when the resultant, N, is within the middle third of the footing (i.e., $|e| \le B / 6$).

Figure 3 shows the pressure distribution when the resultant is outside the middle third (i.e.,$|e| > B/6$). The left and right edge pressures for cases a and b as shown in figure are as follows:

$$q_R = \frac{N}{B} - \frac{Ne\frac{B}{2}}{\frac{B^3}{12}}$$

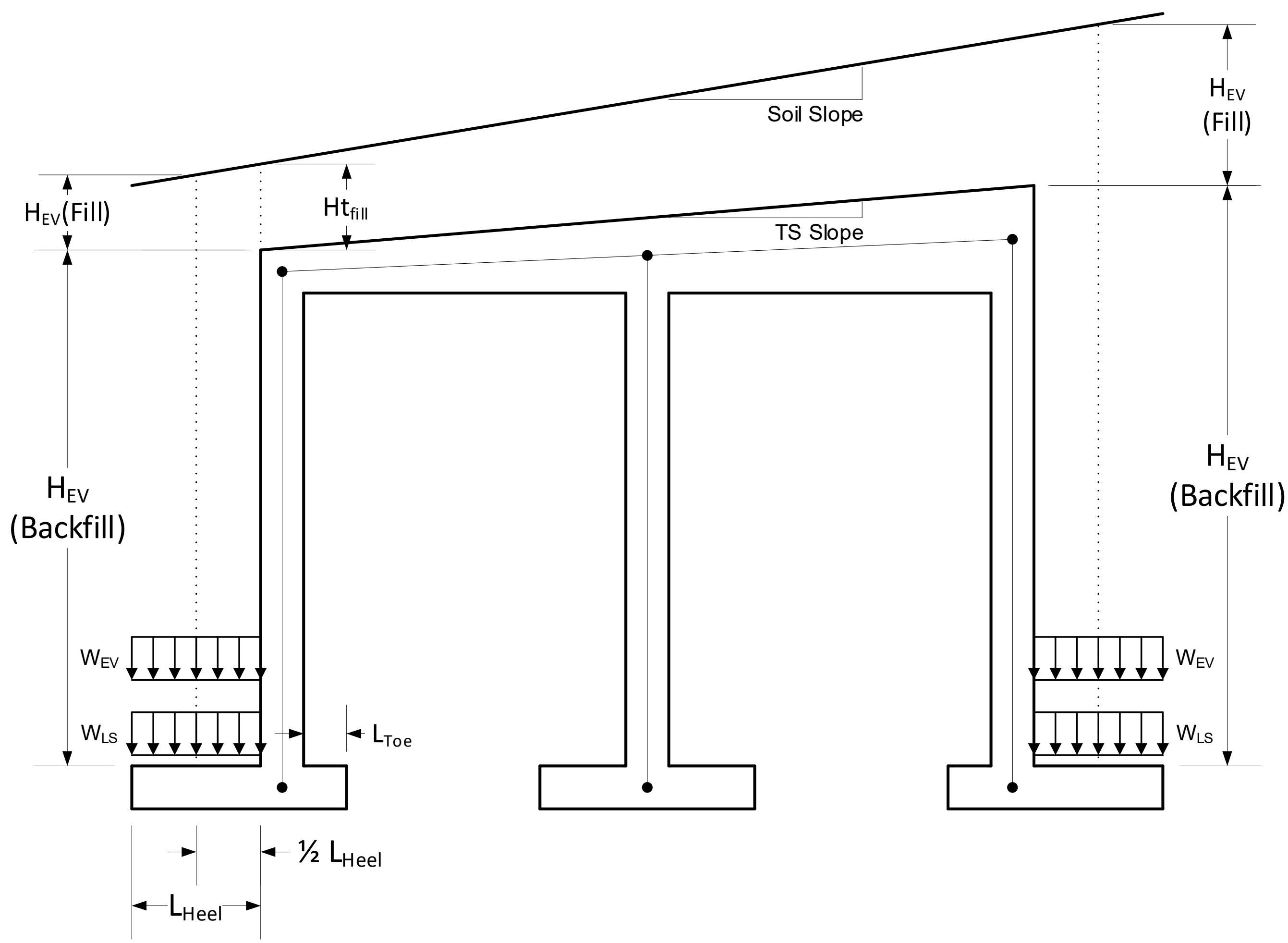


Figure 3.9.1-1 Strip Footing Definitions And Loads

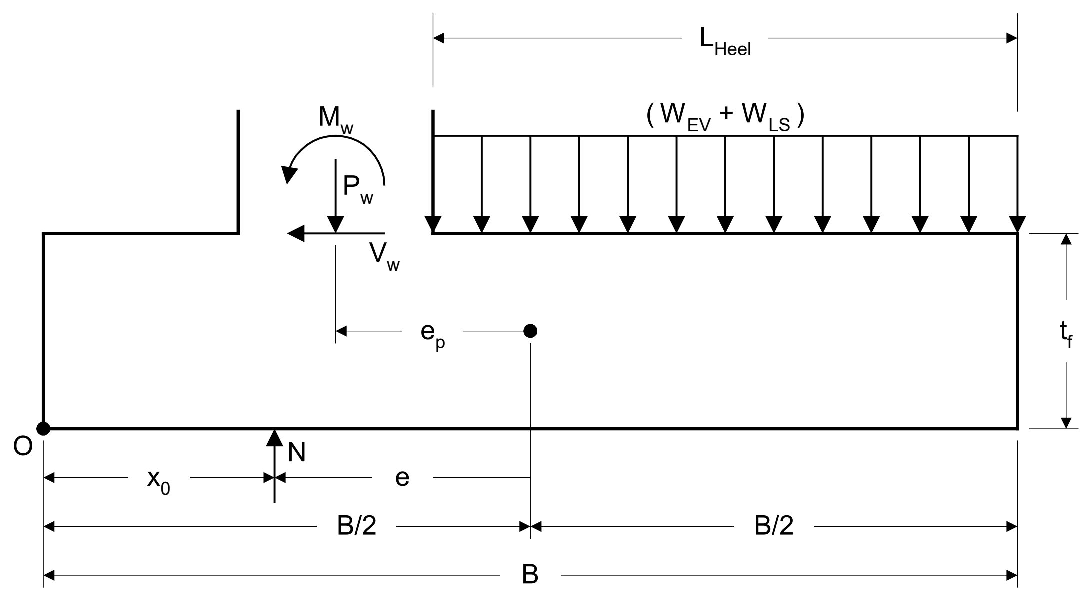


Figure 3.9.2-1 Strip Footing Force Resultants and Eccentricity

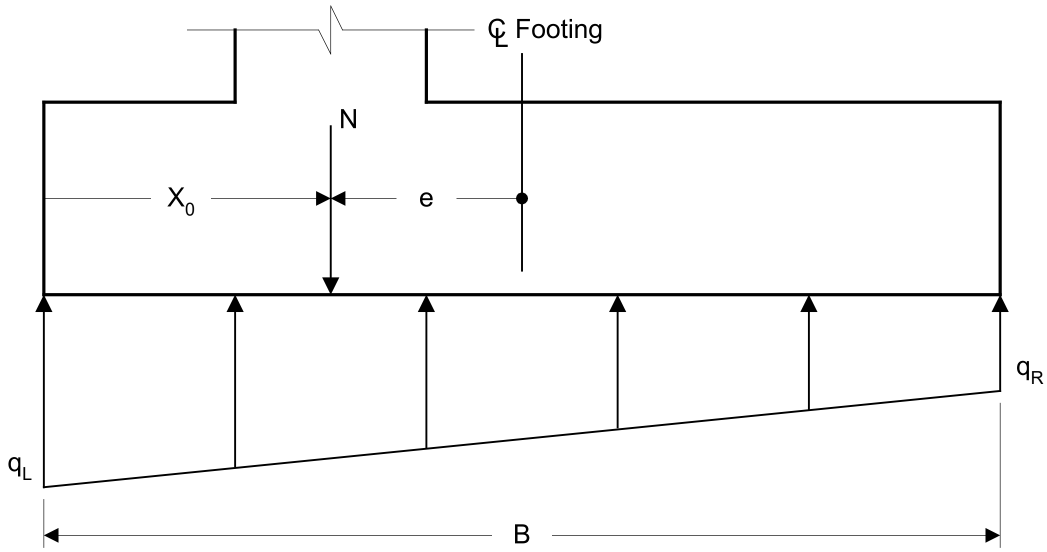


Figure 3.9.2-2 Strip Footing Soil Pressure Distribution When The Resultant Is In The Middle Third

$$q_L = \frac{N}{B} + \frac{Ne\frac{B}{2}}{\frac{B^3}{12}}$$

$B_c = B$

<u>Case a</u>: $e > B/6$

$$q_L = \frac{2N}{3\,x_0} \qquad q_R = 0$$

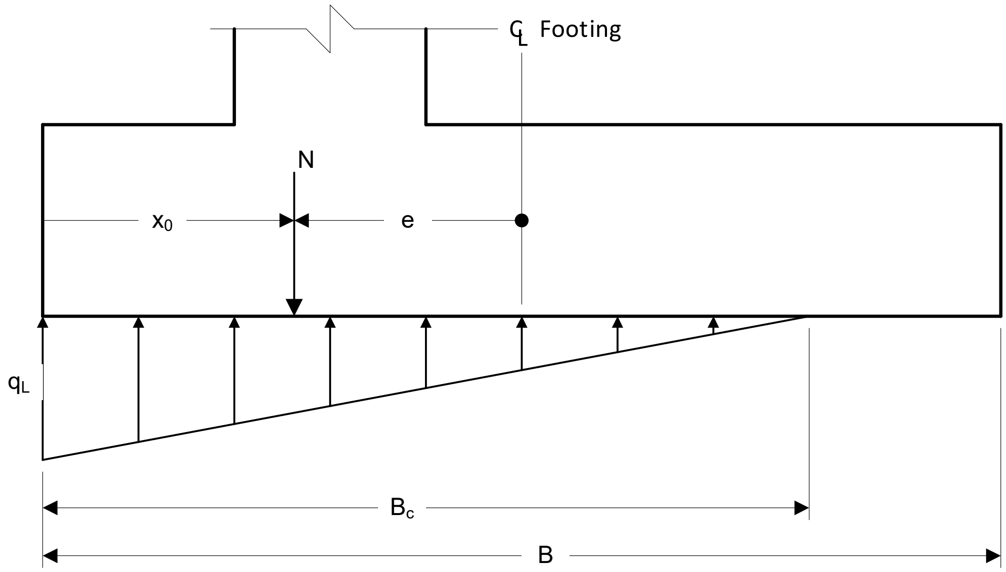
$B_c = 3x_0$

<u>Case b</u>: $e < -B/6$

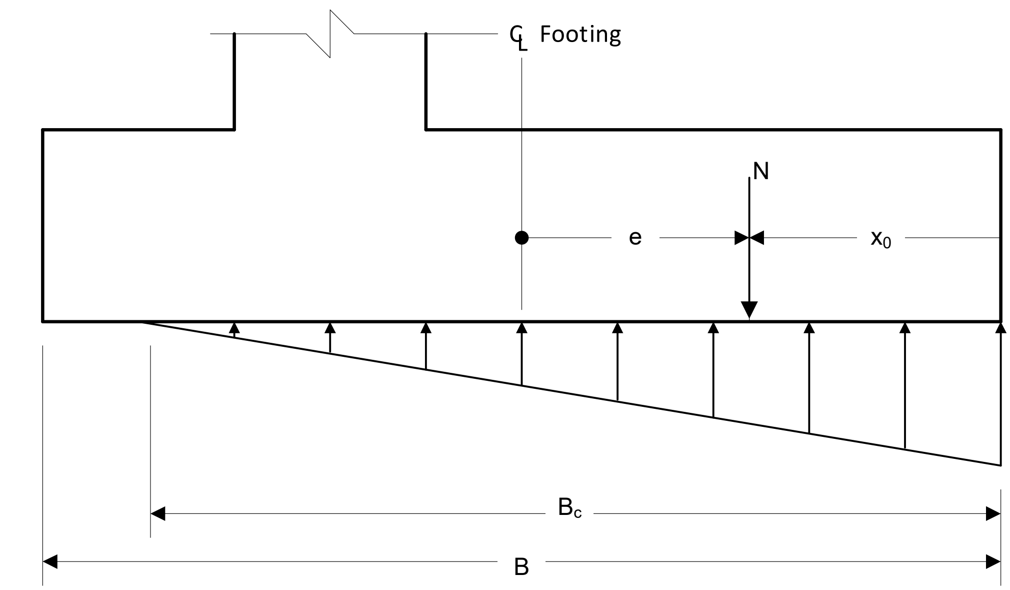
$q_L = 0$

$$q_R = \frac{2N}{3(B - x_0)}$$

$B_c = 3(B - x_0)$



Case a: e > B/6



Case b: e < -B/6

Figure 3.9.2-3 Strip Footing Soil Pressure Distribution When Resultant Not In Middle Third

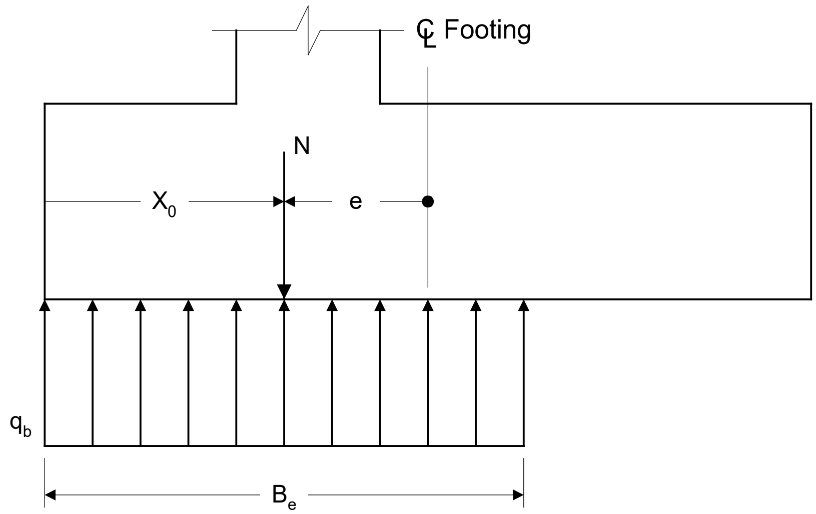


Figure 3.9.2-4 Strip Footing Settlement Pressure, q_b, for soil

Figure 4 shows the settlement pressure, q_b, which is used for reporting only. BXLRFD assumes the footing is always founded on Soil.

$$B_e = 2X_0$$

$$q_b = \frac{N}{B_e}$$

Where:

B_e is the distance over which q_b is applicable

3.9.3 Forces at Critical Sections

Once the soil pressure is known, the internal shears and moments can be obtained. They are computed using simple statics and for the POIs shown in Figure 1. The POIs shown in the figure are classified as indicated. Shear is checked at the face of the wall if there is tension in the top of the footing. Shear is checked at a distance d from the face of wall if the top of the footing is in compression.

Figure 2 shows the loads for computing the shears and moments. These include distributed loads, i.e., soil pressure, W_{EV}, WLS and W_{DC}, and concentrated loads for a given limit state from the bottom of the wall, i.e., P_w, V_w, and M_w. The following notation is used in the equations show in this section:

q_a is the starting value of a soil loading.

q_b is the ending value of a soil loading.

V_2 is the shear at a section within a loading.

V_3 is the shear at a section past a loading.

M_2 is the moment at a section within a loading.

M_3 is the moment at a section past a loading.

The equations are as follows:

Forces from distributed loads (soil pressure, EV, LS, DC)

<u>At Section 2</u> *($d_a > d_2 > d_b$)*

$$r = \frac{d_2 - d_a}{d_b - d_a}$$

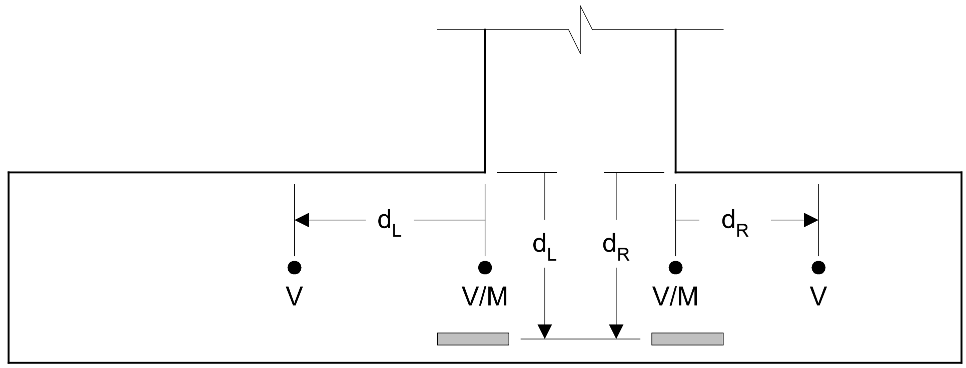
$$V_2 = -\left(\frac{q_a + (1-r)q_a + rq_b}{2}\right)(d_2 - d_a)$$

$$M_2 = \frac{q_a(d_2 - d_a)^2}{2} + \left[\frac{(1-r)q_a + rq_b - q_a}{2}\right]\frac{(d_2 - d_a)^2}{3}$$

<u>At Section 3</u> *($d_3 > d_b$)*

$$V_3 = -\left(\frac{q_a + q_b}{2}\right)(d_b - d_a)$$

$$M_3 = q_a(d_b - d_a)\left(d_3 - \frac{d_a + d_b}{2}\right) + \frac{(q_b - q_a)(d_b - d_a)}{2}\left(d_3 - \left(d_a + \frac{2}{3}(d_b - d_a)\right)\right)$$



- ● - Locations of POIs
- V - Consider POI For Shear Only
- M - Consider POI For Moment Only
- V/M - Consider POI For Shear And Moment

Note: POIs at faces are considered for shear only if the moment is negative (tension in top face).

Figure 3.9.3-1 POI Locations and Type Definitions for Strip Footings

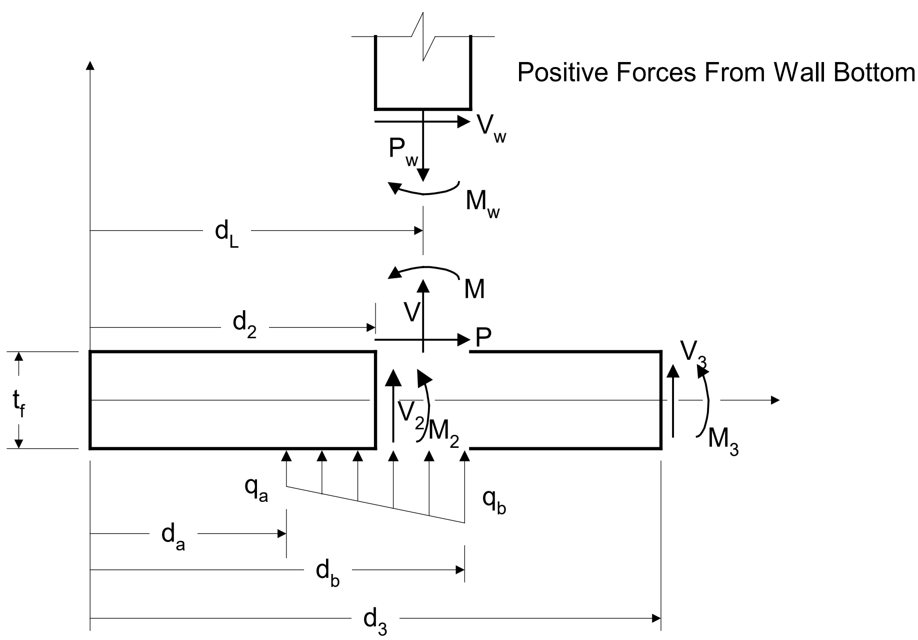


Figure 3.9.3-2 Strip Footing Shear And Moment

Actions from concentrated loads *(P_w, V_w, M_w)*:

At Section 2 *($d_2 \leq d_L$)*

$V_2 = 0$

$M_2 = 0$

At Section 3 *($d_3 > d_L$)*

$P = -V_w$

$V = P_w$

$M = M_w$

$V_3 = -V$

$M_3 = -(M - Pt_f) + V(d_3 - d_b)$

3.9.4 Section Resistance and Performance Ratios

For an Analysis run, Performance Ratios are calculated, instead of rating factors. Performance Ratio is the ratio of Section Resistance to Factored Forces acting at a section. The demands are the shears and moments calculated as discussed in Section 3.9.3, and the capacities (resistances) are calculated as follows (Minimum/Maximum rebar spacings are also calculated in an Analysis run.).

Moment Resistance *(M_r)*:

$$M_r = \phi M_O$$

$$M_0 = A_s f_s \left[d - \frac{A_s\, f_s}{2(\alpha_1\, f_c'\, b)} \right]$$

The resistance factor, ϕ, is computed considering strain compatibility when appropriate, as shown below. The ϕ limit is 0.9 for cast-in-place boxes, cast-in-place frames, and cast-in-place U-channels, 0.95 for precast frames and precast U-channels, and 1.0 for precast box culverts.

With the known area of steel the quadratic equation is solved for the moment resistance, M_0, with ϕ equal to the ϕ limit and assuming the stress in the reinforcement steel, fs, is equal to the specified minimum yield strength, fy.

The net tensile strain and the stress in the reinforcement is computed from the following:

$$c = \frac{A_s\, f_s}{\alpha_1\, f_c'\, \beta_1\, b}$$

$$\varepsilon_t = 0.003\left(\frac{d_s}{c} - 1\right)$$

$$f_s = min(\varepsilon_t \cdot E_s,\ f_y)$$

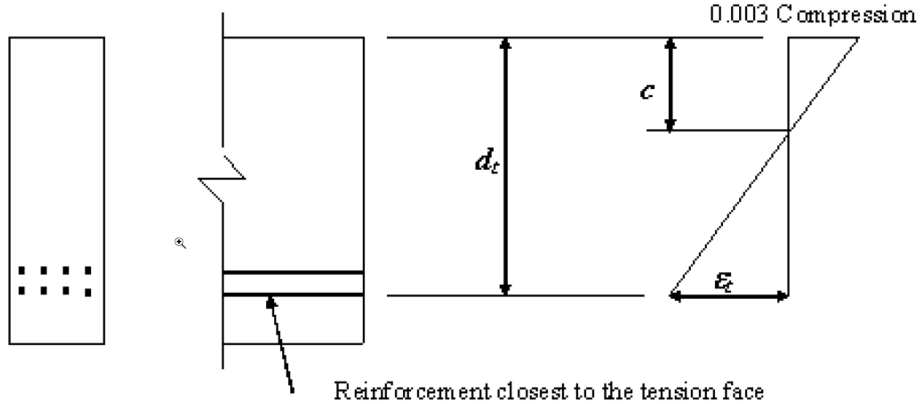


Figure 3.9.4-1 Strain Distribution and Net Tensile Strain (LRFD Specifications Figure C5.6.2.1-1)

If the mild steel stress, f_s, is less than the yield strength, f_y, then the initial assumption was incorrect and the nominal flexural resistance is determined based on conditions of equilibrium and strain compatibility.

The resistance factor ϕ is computed with the net tensile strain using the equation:

$$0.75 \le \phi = 0.75 + \frac{0.15(\varepsilon_t - \varepsilon_{cl})}{(\varepsilon_{tl} - \varepsilon_{cl})} \le 0.9$$ (for CIP Box, CIP Frame, and CIP U-Channel)

$$0.75 \le \phi = 0.75 + \frac{0.20(\varepsilon_t - \varepsilon_{cl})}{(\varepsilon_{tl} - \varepsilon_{cl})} \le 0.95$$ (for Precast Frame and Precast U-Channel)

$$0.75 \le \phi = 0.75 + \frac{0.25(\varepsilon_t - \varepsilon_{cl})}{(\varepsilon_{tl} - \varepsilon_{cl})} \le 1.0$$ (for Precast Box)

where:

$$\varepsilon_{cl} = compression\text{-}controlled\ strain\ limit$$

$$= min\left(\frac{f_y}{E_s}, 0.002\right) \text{ for } f_y \le 60.0 \text{ ksi}$$

$$= 0.002 + \frac{(f_y - 60.0)}{40.0}(0.002) \text{ for } 60.0 \text{ ksi} < f_y \le 75.0 \text{ ksi}$$

$$\varepsilon_{tl} = tension\text{-}controlled\ strain\ limit, 0.005$$

Finally, the factored flexural resistance is computed by multiplying the nominal flexural resistance by ϕ. If the computed ϕ factor is less than 0.90 (CIP Box, CIP Frame, and CIP U-Channel) or 0.95 (Precast Frame and Precast U-Channel) or 1.0 (Precast Box), then the process is repeated with ϕ assumed to be 0.75 and a second moment resistance is computed. Using the second moment resistance a new factored flexural resistance is computed. If the second moment resistance is less than the applied factored moment then the cross section is considered inadequate; otherwise, the phi factor is iterated until the assumed phi factor is equal to the computed phi factor. For analysis, the inadequate resistance is reported.

Shear Resistance *(V_r)*:

$$V_r = \phi_v V_C$$

$$V_C = 0.316\beta\sqrt{f_c'}b_v d_v$$

Where:

$\beta = 2$

d_v = *See Section 3.5.5 for calculation of d_v*

3.9.5 Reinforcement Design

For a Design run, flexure reinforcement and rebar spacings are calculated. Shear reinforcement is not considered, and the thickness of the footing is not changed. The design of the flexure reinforcement is accomplished by solving the following quadratic equation with phi, ϕ, assumed to be 0.90 (CIP Box, CIP Frame, and CIP U-Channel) or 0.95 (Precast Frame and Precast U-Channel) or 1.00 (Precast Box) for all limit states, all flexure maximum effect cases, and all points-of-interest. Note that in this case, A_s is based on moment only, not moment and axial effects.

$$\frac{f_y^2}{2\,\alpha_1 f_c'\,b}A_s^2 - f_y d_s A_s + \frac{|M_{UT}|}{\phi} = 0$$

where:

$$A_s = \frac{-b_{coef} \pm \sqrt{b_{coef}^2 - 4a_{coef}c_{coef}}}{2a_{coef}}$$

$$a_{coef} = \frac{f_y^2}{2\alpha_1 f_c' b}$$

$$b_{coef} = -f_y d_s$$

$$c_{coef} = ABS\left(\frac{M_{UT}}{\phi}\right)$$

M_{UT} = the total factored moment

Note: For very thin footing thicknesses with large factored moments, the quantity under the radical can become negative indicating no rational solution for the steel area. For these undersized footings the program will stop with an error noting that the quadratic equation could not be solved.

The nominal moment resistance is computed with the assumption that f_s is equal to f_y in the following equations:

$$c = \frac{A_s f_s}{\alpha_1 f_c' \beta_1 b}$$

$$a = \beta_1 c$$

$$M_n = A_s f_s \left(d - \frac{a}{2}\right)$$

where: c = distance from the extreme compression fiber to the neutral axis (in)

A_S = area of tension reinforcement (in^2)

f_S = stress in mild steel tension reinforcement at nominal flexural resistance (ksi)

α_1 = ratio of the maximum equivalent concrete compressive stress block intensity to the design compressive strength of the concrete

f_c' = Concrete design strength (ksi)

β_1 = ratio of the depth of the equivalent uniformly stressed compression zone to the depth of the actual compression zone

b = width of the compression face of the member (in)

a = depth of equivalent rectangular stress block (in)

M_n = nominal flexural resistance (in-kips)

d = distance from compression face to centroid of tension reinforcement (in)

The net tensile strain and the stress in the reinforcement is computed from the following:

$$\varepsilon_t = 0.003\left(\frac{d_s}{c} - 1\right)$$

$$f_s = min(\varepsilon_t \cdot E_s, f_y)$$

where: ε_t = net tensile strain in extreme tension steel at nominal resistance (in/in)

d_S = distance from extreme compression fiber to the centroid of the nonprestressed tensile reinforcement (in)

E_S = modulus of elasticity of reinforcing bars (ksi)

f_y = specified minimum yield strength of reinforcing bars (ksi)

If the mild steel stress, f_S, is less than the yield strength, f_y, than the initial assumption was incorrect and the nominal flexural resistance is determined based on conditions of equilibrium and strain compatibility.

The resistance factor phi is computed with the net tensile strain using the following equation:

$$0.75 \le \phi = 0.75 + \frac{0.15(\varepsilon_t - \varepsilon_{cl})}{(\varepsilon_{tl} - \varepsilon_{cl})} \le 0.9$$ (for CIP Box, CIP Frame, and CIP U-Channel)

$$0.75 \leq \phi = 0.75 + \frac{0.20(\varepsilon_t - \varepsilon_{cl})}{(\varepsilon_{tl} - \varepsilon_{cl})} \leq 0.95$$ (for Precast Frame and Precast U-Channel)

$$0.75 \leq \phi = 0.75 + \frac{0.25(\varepsilon_t - \varepsilon_{cl})}{(\varepsilon_{tl} - \varepsilon_{cl})} \leq 1.0$$ (for Precast Box)

where: ε_{cl} = compression-controlled strain limit

$= min\left(\frac{f_y}{E_s}, 0.002\right)$ for $f_y \leq 60.0$ ksi

$= 0.002 + \frac{(f_y - 60.0)}{40.0}(0.002)$ for 60.0 ksi $< f_y \leq 75.0$ ksi

ε_{tl} = tension-controlled strain limit, 0.005

Finally, the factored flexural resistance is computed by multiplying nominal flexural resistance by phi. If the computed phi factor is less than 0.90 (for CIP Box, CIP Frame, and CIP U-Channel) or 0.95 (for Precast Frame and Precast U-Channel) or 1.00 (for Precast Box), then the process is repeated with phi assumed to be 0.75 and a second steel area is computed from the quadratic equation. Using the second steel area a new factored flexural resistance is computed. If the new factored flexural resistance is less than the applied factored moment then the cross section is considered inadequate. Otherwise, an iterative procedure is used to find an area of steel that results in a factored flexural resistance that equals (within a tolerance) the applied factored moment.

If the resulting reinforcement is less than the minimum then the required A_s is set to the minimum steel. Refer to Section 3.5.1.2 for calculation of minimum steel.

3.10 FOUNDATION PRESSURE FOR BOX CULVERTS AND U-CHANNELS

This section discusses how the pressure in the soil under the centerline of external and internal walls of a box culvert and U-channel is calculated. Foundation pressure is computed for both an Analysis and a Design. Foundation pressure is calculated for Strength and Service limit states.

The procedure uses the distributed reaction loadings computed on the bottom slab for all LRFD vertical dead and earth loadings, i.e., DC, DW, OV, EV and WA as applicable for structure type. See Section 3.3 in this chapter for a discussion of how these loads are applied. The expressions used to compute WA and the DC of the bottom slab is presented in this section since they are not needed to analyze/design the structure components.

The program next generates vertical soil pressure influence lines for pressures under the centerlines of external and internal walls. It does this by making use of the distributed reaction loading associated with the point loads used to generated influence lines. See discussion of how influence lines are generated in this chapter. In calculating a vertical soil pressure influence line ordinate at a given location, e.g., the left external wall, the pressure under the interior wall (if present) and the right external wall are saved as associated values.

Pressures due to dead and earth loadings and vertical soil pressure influence lines are computed at the centerline of the two external walls, and the centerline of the internal wall for two-cell culverts. The influence lines are loaded identically to the axial, shear and moment influence lines generated for the other culvert components, e.g., top slab, to produce raw truck and thru fill live load responses, and also lane response. Next, live load envelopes are computed without dynamic load allowance as per DM-4 Section 3.6.2.2, and finally, limit state load effects as described in Section 3.4.

The vertical influence line pressures are computed for dead loads and live loads under the wall in question and the corresponding pressures are saved for the other walls. The dead load vertical influence line pressure is applied to a free body diagram of the bottom of footing and the moment and vertical force is computed. The same is done with the live load vertical influence line pressure to obtain the moment and vertical force for the live load vertical influence line pressures. Next, the DL and LL moments and vertical loads are totaled and an equivalent vertical load (P) and eccentricity (e) is computed.

The equivalent vertical load (P) and eccentricity (e) are then used in the following equations to obtain the maximum and minimum corresponding bearing pressures under the maximized current wall for each load and limit state.

For $e < \frac{L}{6}$ (Trapezoidal Pressure Distribution)

$$q_{max} = \frac{P}{L}\left[1 + \left(\frac{6e}{L}\right)\right]$$

$$q_{min} = \frac{P}{L}\left[1 - \left(\frac{6e}{L}\right)\right]$$

For $\frac{L}{6} \leq e < \frac{L}{2}$ (Triangular Pressure Distribution)

$$q_{max} = \frac{2P}{3\left(\frac{L}{2} - |e|\right)}$$

$$q_{min} = 0$$

Effective Foundation Length (Triangular Pressure Distribution)

$$L_{eff} = \frac{3L}{2} - 3|e|$$

3.10.1 Self Weight for Bottom Slab

This section discusses how BXLRFD computes the LRFD load response, DC, for the bottom slab. This loading is not needed to analyze/design the main culvert components, so it is only done in order to compute the soil foundation pressure. The bottom slab DC load response in the soil is calculated simply by multiplying the thickness of the bottom slab by the density of the reinforced concrete. If there is a fish channel, the thickness of the bottom slab at the low point is used.

3.10.2 Pressure Due to Water, WA

This loading is not needed to analyze/design the main structure components, so it is only done in order to compute the soil foundation pressure. When a fish channel is present the area of the fish channel is subtracted from the area of the cell when the water weight is calculated. A load factor of 1.0 is used for all limit states. The soil pressure, W, is calculated by the following expression:

$$W = \frac{\left(N_{cell}SH - A_{fc}\right)\gamma_w}{L}$$

Where:

N_{cell} = number of cells

S = clear span of culvert openings

H = clear height of culvert opening

A_{fc} = area of the fish channel

γ_W = density of water

L = distance between centerline of exterior walls

3.11 EDGE BEAM DESIGN

The BXLRFD program does not automatically design or analyze an edge beam, if one is required per DM-4 Section 12.11.2.1. The user is responsible for determining if an edge beam design is required and if so, the user must make a second (edge beam) run of the program using the length along the skewed side of the culvert as the span length. The top slab moments from the edge beam run (1' strip width) should then be multiplied by the "equivalent strip width" calculated by the program, ELAT, Section 7.6.6 and divided by the edge width (LRFD Specifications Section 4.6.2.1.4b) and the result should then be used to design the reinforcement for the edge beam shown in DM-4 Figure 12.6.2.2.5-1P.

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 8.1 and Windows 10 operating systems (32 and 64 bit versions) **and Windows 11**.

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\BXLRFD v<version number>\” or "C:\Program Files (x86)\PennDOT\BXLRFD v<version number>\" for 64-bit operating systems:

1. BXLRFD.exe, BXLRFD_DLL.dll - Executable program and Dynamic Link Library.
2. BXLRFD.pd - Parameter definition file.
3. BXLRFD Users Manual.pdf - Program User’s Manual (PDF Format).
4. BXLRFDRevReq.dot - Revision Request form (MS Word template).
5. GettingStarted.pdf - A document describing installation and running of the - program
6. LicenseAgreement.pdf - The program license agreement
7. MSVCR71.dll - Runtime Dynamic Link Libraries

The program example problem files (ex*.dat) will be installed in the program example folder, which defaults to “C:\PennDOT\ BXLRFD v<version number> Examples\”. Users must have write access 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 command lines. Each command line defines a set of input parameters that are associated with that command. A description of the input commands can be found in Chapter 5 of the User’s Manual. The input can be created using Engineering Assistant, described below or any text editor.

4.3 ENGINEERING ASSISTANT

The 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 ENGASST

BXLRFD 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 PennDOT BXLRFD vx.x.x.x subfolder, 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 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. 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 will ask the user whether to overwrite the existing file. The user should enter Y if the existing file is to be overwritten or N if the existing file is not to be overwritten. If the user enters N to specify that the existing file is not to be overwritten, the program will prompt the user for another output file name. The program will then execute.

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

When the program completes execution, the user is prompted to “Press <ENTER> to exit program.” This allows the user to view the last messages written to the screen when the program was started by double-clicking on the program icon from Windows Explorer.

The user can view the *.OUT output file with a text editor and the *.PDF output file with Adobe Acrobat.

5 INPUT DESCRIPTION

5.1 INPUT DATA REQUIREMENTS

Before running the Box Culvert Design and Rating program, the user must create an input file. The input file consists of a series of command lines. Each command line defines a set of input parameters that are associated with that command. The program interprets each command line and checks the input parameters to insure that the input data is of the correct type and within the allowable ranges set by the program.

The syntax of a command line is given as:

```
KWD    parm1,  parm2,  ,  ,  parm5,  ,
```

Where, KWD is a 3 character keyword representing a command and,
parm1, parm2... are the parameter values associated with KWD.

If a command line begins with an exclamation point (!), then it is treated as a comment line that is not used by the program. Comment lines can be inserted by the user to provide descriptions and clarifications. The following are two examples of a comment line:

```
! The Following Command is used to specify the top slab reinforcing.
! Top Slab Reinforcement Area is for #11 @ 24 inches
```

To temporarily make a command line void, the user can use an exclamation point (!) to transform the command line into a comment line. For an input line to be treated as a comment line, the exclamation point must be put in column one of the input line. For example, in the following case, the program will use the input data on the second line, but will not use the input data on the first line:

```
! MAT   3.5, 4.0, 40.0, B, 45.0, 11
 MAT    5.0, 4.0, 40.0, B, 45.0, 11
```

A command line must not exceed 256 characters in length. Command lines can be continued on any number of data lines in the input file by placing a hyphen (-) at the end of each data line to be continued, and by placing any remaining parameters on the following lines starting in column 4 of each continuation line. The limit of 256 characters includes all characters and parameters on all continuation lines of a given command line. Some commands are repeatable and some commands have parameters or groups of parameters that are repeatable. When parameters are repeatable, the user has the option of repeating the parameters in a single command or repeating the command. For example, the BSA (Bottom Slab Reinforcement Areas) command has Range Distance and Reinforced Area as repeatable parameters. The user could enter the Range Distance and Reinforced Area two times on one command and one time on another command, or one time on a single command.

```
BSA  1, T, 3.0, 0.25, 4.5, 0.33
BSA  1, T, 7.2, 0.11
```

or

```
BSA  1, T, 3.0, 0.25, 4.5, 0.33, 7.2, 0.11
```

Groups of repeatable parameters, such as Range Distance and Reinforced Area, must stay together in a command line unless a continuation character (-) is used. That is, a command cannot end with a Range Distance input and continue using another BSA command having the Reinforced Area input. When a continuation character is used, the repeatable data can be separated on two lines. The program reads all continuation lines as one command. For example,

Incorrect input:

```
BSA     1, T, 3.0, 0.25, 4.5, 0.33, 7.2
                              -0.11
```

Correct input:

```
BSA     1, T, 3.0, 0.25, 4.5, 0.33, -
             7.2, 0.11
```

The first three columns of each command line are reserved for keywords that define the command type. Columns 4 through 256 are to be used to input the parameters associated with a command. One or more spaces are recommended between the keyword and the input parameters to improve readability.

The parameters associated with each command must be entered in the order they appear in the command description tables. The user must place commas to separate the parameters on the command line. Blank spaces cannot be used to separate parameters. The parameter field width is not restricted; however, the total number of characters cannot exceed 256.

The default value for a parameter is assigned by the program by placing a comma without any value for the parameter. For example, in the command syntax example shown below, the default values will be assigned to parameters parm3 and parm4.

```
KWD parm1,   parm2,   ,   ,   parm5
```

If the user places a comma and there is no default value, the program will return an error status. If a comma is entered after the command keyword, the program will assign the default value to the first parameter. If the user does not enter all the parameters for a command, the program will assign default values for those parameters not entered. That is, the user is not required to place commas at the end of a command line. If the above example required 7 parameters, parm6 and parm7 would also be assigned default values by the program.

The default values are stored in a parameter file which can be changed by the Department's system manager. The parameter file stores the parameter description, type of data, units, upper limit, lower limit, error or warning status if the upper or lower limits are exceeded, and the default value for each parameter.

Any numerical value, within the upper and lower limits, can be entered for a parameter. The status codes, shown in parentheses below the lower and upper limits, indicate the status if an input item exceeds the lower or upper limits. The status code, (E), indicates an error. The status code, (W), indicates a warning.

In the following sections, all available commands and associated parameters are described with two tables for each command. The first table contains the keyword for a particular command along with a description of the command. The second table gives all the parameters associated with the given command, parameter description, units, limits and default values.

The program will process all input and will check for errors and warnings. If the number of errors exceed 25 during input processing, the program will terminate immediately. After all input is processed, the program checks if any errors were found. If an error was found, the program will terminate. If warnings are found, the program will continue to process. If the number of warnings exceed 200 during input processing for a single run, the program will terminate immediately. The user should review all warnings in the output file to insure that the input data is correct. Warnings are an indication that the input value has exceeded normally acceptable limits for that parameter.

For parameters which are defined in ranges (such as top slab reinforcement, bottom slab reinforcement, wall reinforcement) the ranges cannot overlap.

5.2 ORDER OF COMMANDS

If the user wants to control the number of lines printed on a page or the number of lines to be left blank at the top of each page, the CFG (configure) command should be the first command. The CFG command is optional and the program will use default values if the CFG command is not entered. The first required command is the TTL (title) command which is printed in the header at the top of each output page. A maximum of ten TTL commands are printed on the first page of the output. The second required command after the title commands is the CTL (control) command. The CTL command includes major control parameters, such as number of cells, type of run, precast of cast-in-place, bottom slab, and top slab support.

The remaining commands can be entered in any order, provided certain parameters for a given command have been entered previously. For example, the reinforcement type is defined by specifying the reinforcement type parameter in the MAT (material) command. Since the reinforcement type is required to be defined in order to select the appropriate reinforcement size or wire diameter on the TSR (Top Slab Reinforcement) command, the MAT command must precede the TSR command. The program will return an error status if a command required data that has not been previously entered.

The recommended order of commands is shown in Table 1. The commands are shown in alphabetical order in Table 2. The section headings in these tables refer to the section number of this chapter where these commands are described. Figure 1 shows the overall view of the typical input file with these commands.

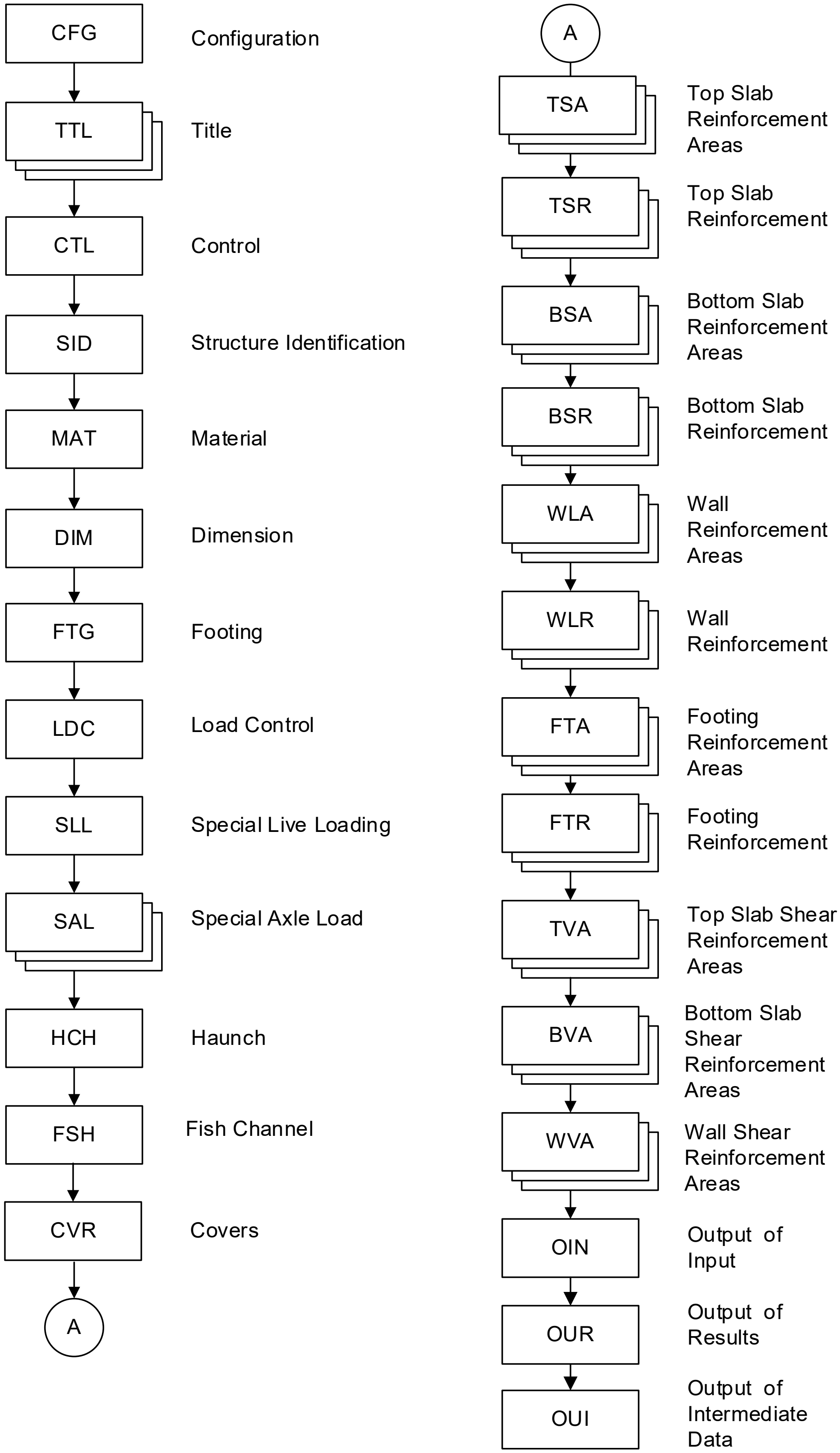


Figure 5.2-1 Overall View of Input File

Table 5.2-1 Recommended Order of Commands

Command	Command Description	Comments/Requirements	Section No.
CFG	Configuration	Optional for both design and analysis	5.3
TTL	Title	At least one TTL command required for both design and analysis	5.4
CTL	Control	Required before other structure commands for both design and analysis	5.5
SID	Structure Identification	Required only for APRAS runs	5.6
MAT	Material	Required for both design and analysis	5.7
DIM	Dimensions	Required for both design and analysis	5.8
FTG	Footing	Required for both design and analysis only if CTL parameter specifies bottom slab is not present	5.9
LDC	Load Control	Required for both design and analysis	5.10
SLL	Special Live Loading	Required only for analysis with special live loading; not used for design	5.11
SAL	Special Axle Load	Required with SLL command only for analysis with special live loading; not used for design	5.12
HCH	Haunch	Optional for both design and analysis	5.13
FSH	Fish Channel	Optional for both design and analysis	5.14
CVR	Covers	Required for both design and analysis	5.15
TSA	Top Slab Reinforcement Areas	Optional only for analysis; not used for design; either TSA or TSR can be used, not both	5.16
TSR	Top Slab Reinforcement	Optional only for analysis; not used for design; either TSA or TSR can be used, not both	5.17
BSA	Bottom Slab Reinforcement Areas	Optional only for analysis; not used for design; either BSA or BSR can be used, not both	5.18
BSR	Bottom Slab Reinforcement	Optional only for analysis; not used for design; either BSR or BSA can be used, not both	5.19
WLA	Wall Reinforcement Areas	Optional only for analysis; not used for design; either WLA or WLR can be used, not both	5.20
WLR	Wall Reinforcement	Optional only for analysis; not used for design; either WLR or WLA can be used, not both	5.21
FTA	Footing Reinforcement Areas	Optional for both design and analysis with FTG command; either FTA or FTR can be used, not both	5.22
FTR	Footing Reinforcement	Optional for both design and analysis with FTG command; either FTR or FTA can be used, not both	5.23

Table 5.2-1 Recommended Order of Commands (Cont.)

Command	Command Description	Comments/Requirements	Section No.
TVA	Top Slab Shear Reinforcement Areas	Optional only for analysis; not used for design	5.24
BVA	Bottom Slab Shear Reinforcement Areas	Optional only for analysis; not used for design	5.25
WVA	Wall Shear Reinforcement Areas	Optional only for analysis; not used for design	5.26
OIN	Output of Input	Optional for both design and analysis	5.27
OUR	Output of Results	Optional for both design and analysis	5.28
OUI	Output of Intermediate Data	Optional for both design and analysis	5.29

Note: Design means DR, DA, or DC runs. Analysis means AR runs. See CTL command, Parameter 3.

Table 5.2-2 Commands in Alphabetical Order

Command	Command Description	Comments/Requirements	Section No.
BSA	Bottom Slab Reinforcement Areas	Optional only for analysis; not used for design; either BSA or BSR can be used, not both	5.18
BSR	Bottom Slab Reinforcement	Optional only for analysis; not used for design; either BSR or BSA can be used, not both	5.19
BVA	Bottom Slab Shear Reinforcement Areas	Optional only for analysis; not used for design	5.25
CFG	Configuration	Optional for both design and analysis	5.3
CTL	Control	Required before other structure commands for both design and analysis	5.5
CVR	Covers	Required for both design and analysis	5.15
DIM	Dimensions	Required for both design and analysis	5.8
FSH	Fish Channel	Optional for both design and analysis	5.14
FTA	Footing Reinforcement Areas	Optional for both design and analysis with FTG command; either FTA or FTR can be used, not both	5.22
FTG	Footing	Required for both design and analysis only if CTL parameter specifies bottom slab is not present	5.9
FTR	Footing Reinforcement	Optional for both design and analysis with FTG command; either FTR or FTA can be used, not both	5.23
HCH	Haunch	Optional for both design and analysis	5.13
LDC	Load Control	Required for both design and analysis	5.10
MAT	Material	Required for both design and analysis	5.7
OIN	Output of Input	Optional for both design and analysis	5.27
OUI	Output of Intermediate Data	Optional for both design and analysis	5.29
OUR	Output of Results	Optional for both design and analysis	5.28
SAL	Special Axle Load	Required with SLL command only for analysis with special live loading; not used for design	5.12
SID	Structure Identification	Required only for APRAS runs	5.6
SLL	Special Live Loading	Required only for analysis with special live loading; not used for design	5.11
TSA	Top Slab Reinforcement Areas	Optional only for analysis; not used for design; either TSA or TSR can be used, not both	5.16
TSR	Top Slab Reinforcement	Optional only for analysis; not used for design; either TSA or TSR can be used, not both	5.17
TTL	Title	At least one TTL command required for both design and analysis	5.4

Table 5.2-2 Commands in Alphabetical Order (Cont.)

Command	Command Description	Comments/Requirements	Section No.
TVA	Top Slab Shear Reinforcement Areas	Optional only for analysis; not used for design	5.24
WLA	Wall Reinforcement Areas	Optional only for analysis; not used for design; either WLA or WLR can be used, not both	5.20
WLR	Wall Reinforcement	Optional only for analysis; not used for design; either WLR or WLA can be used, not both	5.21
WVA	Wall Shear Reinforcement Areas	Optional only for analysis; not used for design	5.26

Note: Design means DR, DA, or DC runs. Analysis means AR runs. See CTL command, Parameter 3.

5.3 CFG - CONFIGURATION COMMAND

KEYWORD	COMMAND DESCRIPTION
CFG	CONFIGURATION - This command is used to set the control parameters for the characteristics of the printed output. An input file can have only one configuration command.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Lines per Page	Enter the maximum number of lines that will be allowed to be printed on each page of output.	--	50 (E)	83 (E)	83
2. Top Blank Lines per Page	Enter the number of blank lines that the program should leave at the top of each page of output to create a top of margin.	--	0 (E)	10 (E)	0

5.4 TTL - TITLE COMMAND

KEYWORD	COMMAND DESCRIPTION
TTL	TITLE - As many as ten TTL commands may be entered by the user. The first TTL command is printed in the header at the top of each output page. A maximum of ten TTL commands are printed on the first page of the output. If more than ten TTL commands are entered, the program will not use the TTL commands following the first ten TTL commands and a warning will be printed. The input file must have at least one TTL command.

PARAMETER	DESCRIPTION
1. Title	Enter any descriptive information about the project or structure. Title information can be entered anywhere between column 4 and column 79.

5.5 CTL - CONTROL COMMAND

KEYWORD	COMMAND DESCRIPTION
CTL	CONTROL - This command is used to set up the control parameters for the input. The control command is required input, and can only be entered once. Only the CFG command and the TTL command can precede the control command.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. System of Units	Units to be used in the input computations and output reports: US - US Customary Units	--	US (E)	--	US
2. Structure Type	Select the structure type: 1 – Single Cell Culvert 2 – Twin Cell Culvert U – U-Channel	--	1,2,U (E)	-- (E)	--
3. Type of Run	Indicate type of run: DR - **DESIGN WITH KNOWN THICKNESS: Design reinforcement area for bending moment and shear for the specified thickness. If the specified thickness is sufficient for shear, no shear reinforcement will be designed.** (Not applicable for U-channels) DA - **DESIGN WITH SHEAR REINFORCEMENT: Design member thickness required to resist bending moment and design the sections for flexural reinforcement and when necessary, shear reinforcement. If the bending thickness is sufficient for shear, no shear reinforcement will be designed. NOTE: The thickness will be increased, if the shear reinforcement required for the thickness based on bending moment is greater than the maximum shear reinforcement permitted.** (Not applicable for U-channels) DC - **DESIGN WITHOUT SHEAR REINFORCEMENT:** Design **members thicknesses for both bending moment and shear** without **providing any** shear reinforcement. AR - **ANALYZE & RATE:** Analyze, do specifications checking, and then rate members. Member thickness and reinforcement are known.	--	DR DA DC AR (E)	--	--

5.5 CTL – CONTROL COMMAND (Cont.)

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
4. Culvert PC or CIP	Indicate if the structure is precast or cast-in-place: P - Precast Box, U-Channel, or Rigid Frame Culvert C - Cast-in-Place Box, U-Channel, or Rigid Frame Culvert See Parameter 8 for similar input for the strip footing.	--	P, C (E)	--	--
5. Bottom Slab	Specify whether the culvert has a bottom slab or no bottom slab: Y - If the bottom slab is present. N - If the bottom slab is not present. If the bottom slab is not present, the culvert will be analyzed as a rigid frame with walls, footings, and a top slab. Leave blank for U-channels.	--	Y, N (E)	--	--
6. Top Slab Support	For a cast-in-place culvert, indicate if the top slab is constructed monolithic with walls or it is simply supported on walls. Leave blank for precast culverts and U-channels. M - Top slab is monolithic with walls. S - Top slab is simply supported on walls.	--	M, S (E)	--	M
7. Frame Support	Frame support condition parameter. P - Pinned Support Precast Rigid Frame Culvert. F - Fixed Support Cast-in-place Rigid Frame Culvert Leave blank for U-channels and culverts with bottom slabs.	--	P,F (E)	--	--
8. Strip Footing PC or CIP	Indicate if the strip footing is precast or cast-in-place: P - Precast Strip Footing C - Cast-in-Place Strip Footing This input should only be entered for box culverts with no bottom slab. See Parameter 4 for similar input for the culvert.	--	P, C (E)	--	*

* For cast-in-place rigid frame culverts (no bottom slab), this value will default to "C". For precast rigid frame culverts, there is no default, and the user must enter a value.

5.6 SID - STRUCTURE IDENTIFICATION COMMAND

KEYWORD	COMMAND DESCRIPTION
SID	STRUCTURE IDENTIFICATION - This command is used to pass parameters to APRAS (Automated Permit Routing Analysis System) for processing a permit load. The input file must have this command if this data file is to be processed by APRAS. This command is optional for other data files. Only one SID command can be used. Refer to PennDOT's Bridge Management System (BMS2) Coding Manual, Publication 100A for instructions on how to enter this data.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Program Identification	Enter =BXLRFD to identify that the data file is for the LRFD Box Culvert Design and Rating program.	--	=BXLRFD (E)	--	=BXLRFD
2. County	Enter the county number as per PennDOT's Bridge Management System (BMS2) (the 2 digit subfield of item number 5A01).	--	1 (E)	99 (E)	--
3. State Route	Enter the state route number as per PennDOT's Bridge Management System (BMS2) (the 4 digit numeric subfield of item number 5A01).	--	0 (E)	9999 (E)	--
4. Segment	Enter the segment number as per PennDOT's Bridge Management System (BMS2) (the 4 digit subfield of item number 5A01).	--	0 (E)	9999 (E)	--
5. Offset	Enter the offset distance as per PennDOT's Bridge Management System (BMS2) (the 4 digit subfield of item number 5A01).	--	0 (E)	9999 (E)	--
6. Span Identification	Enter the four character alphanumeric Span Identification number as per PennDOT's Bridge Management System (BMS2) (item number SS01). Note: For APRAS data files, the third character must be "F" to identify BXLRFD is used to analyze the span.	--	--	--	--

5.7 MAT - MATERIAL COMMAND

KEYWORD	COMMAND DESCRIPTION
MAT	MATERIAL - This command is used to specify concrete and steel material properties. This command may only be specified once.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. f'_c for All Members	For cast-in-place structures, enter the f'_c for the walls and bottom slab or strip footings. For precast structures, enter the f'_c for the entire structure. For cast-in-place culverts, this value should be entered as 3.0 ksi, corresponding to Class A concrete (BD-632M, Sheet 1). For precast culverts, this value should be entered as 5.0 ksi (BD-632M, Sheet 4).	ksi	*	*	*
2. f'_c for Top Slab	f'_c for the top slab of cast-in-place culverts at grade. This parameter defaults to f'_c described above if left blank. Leave blank for precast culverts and cast-in-place culverts under fill and U-channels. This value should be entered as 4.0 ksi, corresponding to Class AAAP concrete (BD-632, Sheet 1).	ksi	*	*	*
3. Reinforcement Grade	The culvert reinforcement grade. When f_y is greater than 60, refer to Section 6.7.3 for information on how f_y is utilized by the program.	ksi	33.0 (W)	65.0 (W)	60.0
4. Reinforcement Type	For a precast structure, enter: W - if reinforcement is a wire mesh B - if reinforcement is a bar Leave blank for a cast-in-place structure.	--	B, W (E)	--	B
5. Alpha	Angle of bent-up bars for shear reinforcement. The angle is measured from a horizontal line parallel to the bottom face of the slab. See Figure 5.24-1. Leave blank for U-channels or if no shear reinforcement is analyzed or designed.	degree	1.0 (E)	90.0 (E)	90
6. Rebar Size or Wire Diameter	For design of cast-in-place structures, largest reinforcement bar that may be used. For design of precast structures, largest reinforcement bar or wire diameter that may be used. Leave blank for analysis runs.	--	**	**	--

* See Table 5.7-1
** See Tables 5.7-2 and 5.7-3

5.7 MAT - MATERIAL COMMAND (Cont.)

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
7. Epoxy Coated Reinforcement	Enter: Y – Reinforcement is epoxy coated N – Reinforcement is not epoxy coated Used only for design of cast in place rigid frame culverts where wall reinforcement extends into the strip footings. Leave blank for all other types of culverts including precast rigid frame culverts.	--	Y,N (E)	--	Y
8. Concrete Unit Weight for DL	Enter the concrete unit weight/density for computing the dead load of the culvert. This value should be entered as 150 lb/ft^3 for normal weight concrete or as 115 lb/ft^3 for lightweight concrete. This value must be greater than or equal to the "Concrete Unit Weight for E" (parameter 9)	lb/ft^3	95. (E)	160. (E)	150.
9. Concrete Unit Weight for E	Enter the unit weight/density for computing the concrete modulus of elasticity. This value should be entered as 145 lb/ft^3 for normal weight concrete or as 110 lb/ft^3 for lightweight concrete. If the value entered is less than 135 lb/ft^3, the concrete is considered to be lightweight.	lb/ft^3	90. (E)	155. (E)	145.
10. Reinforcement Ultimate Strength (f_u)	The ultimate strength of reinforcing steel in the culvert.	ksi	50.0 (W)	100.0 (W)	--[1]

[1] Defaults to 90 ksi when f_y is 60 ksi; otherwise no default value.

Table 5.7-1 Limits and Defaults for f'_c for All Members and f'_c for Top Slab

PARAMETER	UNITS	LOWER LIMIT	UPPER LIMIT	Default
f'_c for All Members Cast-in-Place	ksi	2.5 (E)	10. (lightweight) 15. (normal weight) (E)	3.0
f'_c for All Members Precast	ksi	3.0 (E)	10. (lightweight) 15. (normal weight) (E)	5.0
f'_c for Top Slab Cast-in-Place	ksi	2.5 (E)	10. (lightweight) 15. (normal weight) (E)	f'_c for All Members

Table 5.7-2 Rebar Size or Wire Diameter Units, Limits and Defaults

PARAMETER	UNITS	LOWER LIMIT	UPPER LIMIT	Default
Rebar Size	US	4 (E)	11 (W)	--
Wire Diameter	in	0.1 (E)	0.6 (W)	--

Table 5.7-3 Valid Rebar Sizes

UNITS	SIZES							
US	4	5	6	7	8	9	10	11

5.8 DIM - DIMENSIONS COMMAND

KEYWORD	COMMAND DESCRIPTION
DIM	DIMENSIONS - This command describes the physical dimensions of a box culvert or U-channel. This command may only be specified once.

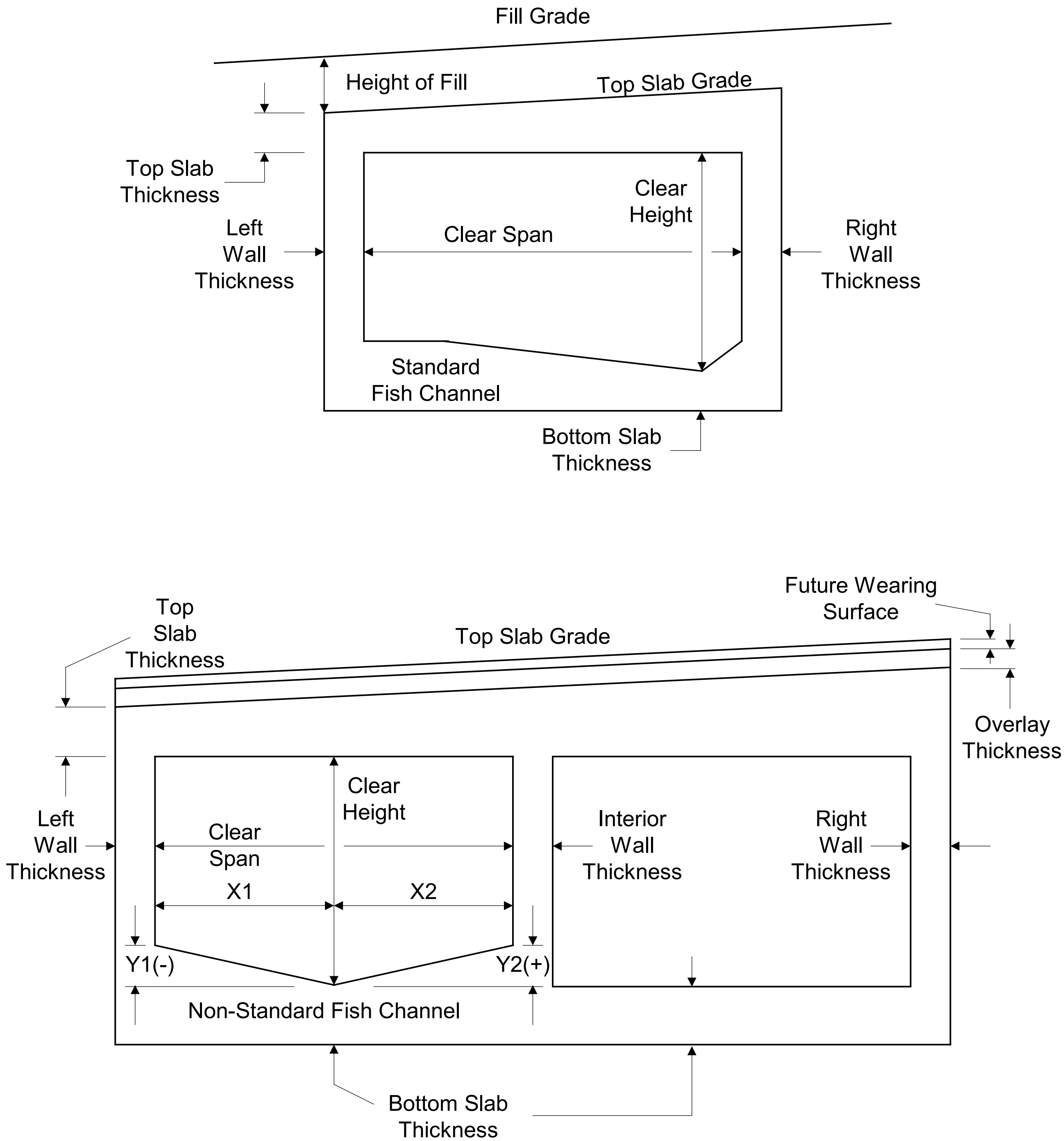
PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Clear Span	The clear span of the culvert **in the direction of the primary reinforcement**. **If the primary reinforcement is along the skew, enter the span length along the skew rather than the span perpendicular to the box wall.** The same value is used for both spans in a two cell culvert. See Figure 1.	ft	0.0 (E)	40.0 (W)	--
2. Clear Height	The clear height of the culvert. If a fish channel is present, the height is measured from the low point of the fish channel. The same value is used for both spans in a two cell culvert. See Figure 1. Leave blank for a U-channel	ft	0.0 (E)	20.0 (W)	--
3. Top Slab Thickness	The actual thickness of the top slab for Type of Run DR or AR. The minimum thickness of the top slab for Type of Run DA or DC. The slab thickness is entered for the outside left wall face. See Figure 1. Leave blank for a U-channel	in	0.0 (E)	48.0 (W)	*
4. Bottom Slab Thickness	Bottom slab thickness. The actual thickness of the bottom slab for Type of Run DR or AR. The minimum thickness of the bottom slab for Type of Run DA or DC. If a fish channel is present, this is the thickness at the lowest point in the fish channel. In a two cell culvert, the slab thickness in the cell without the fish channel is also set to this thickness. See Figure 1. Leave blank for frame culvert.	in	0.0 (E)	48.0 (W)	*
5. Left Wall Thickness	Thickness of the left wall. The actual thickness of the left wall for Type of Run DR or AR. The minimum thickness of the left wall for Type of Run DA or DC. See Figure 1.	in	0.0 (E)	36.0 (W)	*
6. Right Wall Thickness	Thickness of the right wall. The actual thickness of the right wall for Type of Run DR or AR. The minimum thickness of the right wall for Type of Run DA or DC. See Figure 1.	in	0.0 (E)	36.0 (W)	*
7. Interior Wall Thickness	Thickness of the interior wall of a two cell culvert. The actual thickness of the interior wall for Type of Run DR or AR. The minimum thickness of the interior wall for Type of Run DA or DC. See Figure 1. Leave blank for a one cell culvert or a U-channel.	in	0.0 (E)	36.0 (W)	*

*If the program is to design the member thicknesses **(Type of Run DA or DC)**, defaults are the minimum allowable member thickness as per DM-4 and are only enforced when the thickness parameter is left blank. See Tables 1 and 2. **No default for Type of Run DR or AR.**

5.8 DIM - DIMENSIONS COMMAND (Cont.)

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
8. Fill Grade	For culvert under fill, the slope of ground line expressed as a percent grade. The grade may be positive or negative. A positive grade is a ground line going up from left to right. See Figure 1. Leave blank for a culvert at grade or a U-channel.	%	-50.0 (W)	50.0 (W)	0.0
9. Top Slab Grade	If the top surface of the top slab is sloping, regardless if the culvert is under fill or at grade, enter the slope of the top face of slab expressed as a percent grade. The grade may be positive or negative. A positive grade is the surface of top slab going up from left to right. See Figure 1. Leave blank for a U-channel	%	-10.0 (W)	10.0 (W)	0.0
10. U-Channel Left Wall Height	The clear height of the left U-channel wall. If a fish channel is present, the height is measured from the low point of the fish channel. See Figure 2. Leave blank for a box culvert.	ft	0.0 (E)	20.0 (W)	--
11. U-Channel Right Wall Height	The clear height of the right U-channel wall. If a fish channel is present, the height is measured from the low point of the fish channel. See Figure 2. Leave blank for a box culvert.	ft	0.0 (E)	20.0 (W)	--

5.8 DIM - DIMENSIONS COMMAND (Cont.)



Note: positive grades are shown.

Figure 5.8-1 Culvert Dimensions

5.8 DIM - DIMENSIONS COMMAND (Cont.)

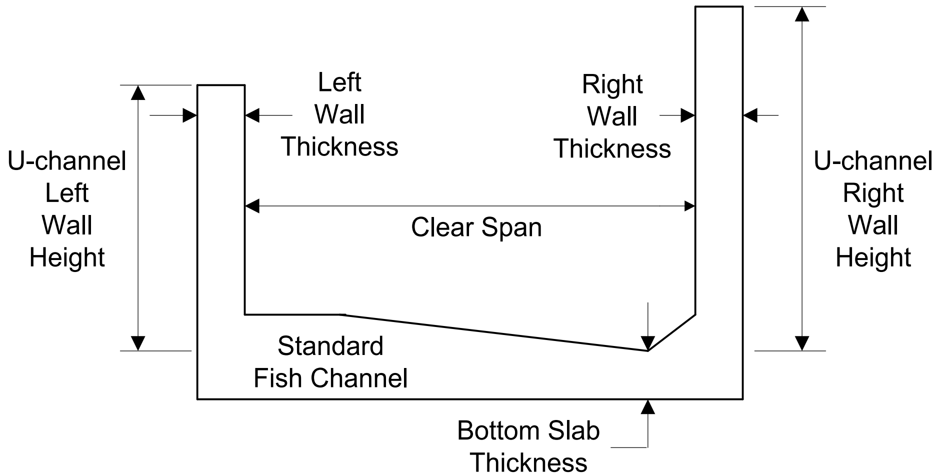


Figure 5.8-2 U-channel Dimensions

Table 5.8-1 Minimum Design Thicknesses

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 = Span (inches)/12 and H = Wall Height (feet)			

Note: The scour, foundation, unevenness, and integral wearing thicknesses, if applicable, are included in the required design thickness specified.

5.9 FTG - FOOTING COMMAND

KEYWORD	COMMAND DESCRIPTION
FTG	FOOTING - This command specifies geometric data describing the footing of a frame culvert. The dimensions entered in this command do not change for either an analysis or a design run. This command is used in culverts which do not have a bottom slab. This command may only be specified once. This command is not applicable for U-channels. See Figure 1.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Left Footing Width	Footing width at the bottom of the left wall.	in	0.0 (E)	108.0 (W)	--
2. Left Footing Thickness	Footing thickness at the bottom of the left wall.	in	0.0 (E)	36.0 (W)	--
3. Left Toe Projection	Left footing toe projection.	in	12.0 (E)	36.0 (W)	--
4. Right Footing Width	Footing width at the bottom of the right wall.	in	0.0 (E)	108.0 (W)	--
5. Right Footing Thickness	Footing thickness at the bottom of the right wall	in	0.0 (E)	36.0 (W)	--
6. Right Toe Projection	Right footing toe projection.	in	12.0 (E)	36.0 (W)	--
7. Interior Footing Width	Footing width at the bottom of the interior wall for a two-cell culvert. The footing will be centered on the interior wall. Leave blank for a single cell culvert.	in	0.0 (E)	108.0 (W)	--
8. Interior Footing Thickness	Footing thickness at the bottom of the interior wall for a two-cell culvert. Leave blank for a single cell culvert.	in	0.0 (E)	36.0 (W)	--

5.9 FTG - FOOTING COMMAND (Cont.)

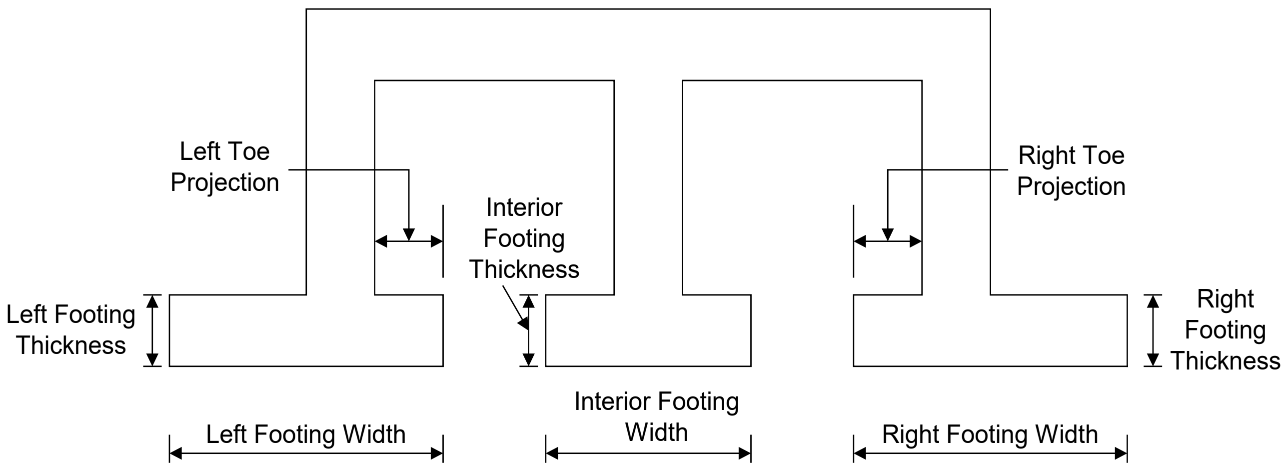


Figure 5.9-1 Footing Dimensions

5.10 LDC - LOAD CONTROL COMMAND

KEYWORD	COMMAND DESCRIPTION
LDC	LOAD CONTROL - This command describes the data needed to load the structure. This command may only be specified once.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Fill **Unit** Weight	**Enter the Fill Unit Weight as the weighted average of the fill materials above the box culvert. See Section 6.10.2 for how to calculate the weighted average for various conditions.**	lb/ft^3	0.0 (E)	150.0 (W)	140.0
2. Height of Fill	The height of fill measured from the upper left corner of the culvert. Leave blank if the top slab is at roadway grade. See Figures 5.10-2 and 5.10-4. For a U-Channel, leave blank. If Approach Slabs will be entered, leave blank. Overlay Thickness and Overlay **Unit** Weight may also be entered. See Sections 6.10.2 and 6.10.7 for how to define Height of Fill and Overlay Thickness.	ft	0.0 (E)	100.0 (W)	--
3. Number of Lanes	The number of design traffic lanes to be used for lateral distribution of wheel loads. Enter zero if the effect of the live load is to be neglected. Even if a number is entered here, the program will determine the applicability of a live load based on the height of fill and span length. Leave blank for a U-channel.	--	0 (E)	8 (W)	2
4. Live Load Surcharge	Live load surcharge expressed as a height of fill. Enter zero if no live load surcharge is to be applied.	ft	0.0 (E)	5.0 (W)	3.0

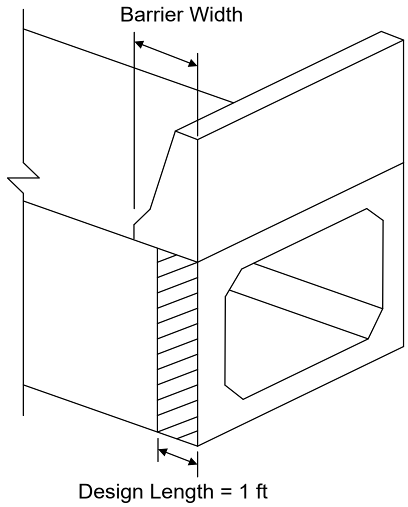
5.10 LDC - LOAD CONTROL COMMAND (Cont.)

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
5. Live Load	Standard live loading or user defined special live loading. Live load options for design are: A - PHL-93 and P-82 B - HL-93 and P-82 C - HL-93 only D - PHL-93, ML-80, and P-82 E - PHL-93, ML-80, TK527 and P-82 F - PHL-93,ML-80,TK527, P-82, and P2016-13 For design runs, choose option E to ensure that the ML-80 and TK527 inventory ratings are greater than 1.0 as per D3.6.1.2.8P and 3.6.12.9P. To also ensure the P2016-13 Permit Vehicle operating ratings are greater than 1.0, choose option F. Live load options for analysis, specification checking and rating are: A - PHL-93,P-82, ML-80, TK527, HS20 and H20 B - HL-93, HS20 and H20 C - ML-80 only D - P-82 only E - Special Live Loading F - TK527 only G - EV2, EV3, and SU6TV H - P2016-13 only I - PHL-93, P-82, P2016-13, ML-80, TK527, HS20,and H20 Leave blank for a U-channel or an APRAS run.	--	A, B, C, D, E, F (E) A, B, C, D, E, F, G, H, I (E)	--	E A
6. Overlay Unit Weight	Unit weight of the top slab overlay. Leave blank for a U-channel.	lb/ft^3	0.0 (E)	160.0 (W)	150.0
7. Overlay Thickness	The top slab overlay thickness. It can be applied to culverts at or below grade. See Figures 5.10-3 and 5.10-4. Leave blank for a U-channel. See Sections 6.10.2 and 6.10.7 for how to define Height of Fill and Overlay Thickness.	in	0.0 (E)	12.0 (W)	--
8. Future Wearing Surface	Uniform load of future wearing surface. Can be applied to culverts at or below grade. Leave blank for a U-channel.	lb/ft^2	0.0 (E)	30.0 (W)	*[1]
9. Maximum Live Load Distribution Length	The maximum length of culvert over which the live load may be distributed in the culvert longitudinal direction. The program calculates the actual distribution length to be used, which is limited to the value entered for this parameter. See Figure 1. Leave blank for a U-channel.	ft	0.0 (E)	400.0 (W)	--

5.10 LDC - LOAD CONTROL COMMAND (Cont.)

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
10. Segment Length	The length of a single precast (PC) culvert segment or distance between expansion joints in cast-in-place (CIP) culverts. This length is used to determine axle load distribution factors for live loads applied directly on the culvert top slab.	ft	0.0(PC) 20.0(CIP) (E)	12.0(PC) 90.0(CIP) (W)	--(PC) 90.0(CIP)
11. Multiple Presence Reduction	NOTE: This parameter is no longer used and should be left blank.	--	--	--	--
12. PA Traffic Factor	NOTE: This parameter is no longer used and should be left blank.	--	--	--	--
13. Fatigue Dynamic Load Allowance	NOTE: This parameter is no longer used and should be left blank.	--	--	--	--
14. Ductility Factor	Factor applied to the force effects relating to ductility. As per DM-4 Section 1.3.4, a factor other than 1.0 is not permitted by PennDOT	--	0.95 (E)	1.05 (E)	1.0
15. Redundancy Factor	Factor applied to the force effects relating to redundancy. As per DM-4 Section 1.3.5, a factor other than 1.0 is not permitted by PennDOT	--	0.95 (E)	1.05 (E)	1.0
16. Importance Factor	Factor applied to the force effects relating to operational importance. As per DM-4 Section 1.3.3, a factor other than 1.0 is not permitted by PennDOT	--	1.0 (E)	1.28 (E)	1.0
17. Permit Truck Maximum Dynamic Load Allowance	The Dynamic Load Allowance limit to be used for P-82 and P2016-13 truck loads.	--	1.00 (E)	2.0 (E)	1.20
18. Live Load Override	Live Load Override allows for the application of live load regardless of the fill height. 0 – The program determines when live load is applicable. 1 – The program will apply live load. See Section 6.10.18 for more information.	--	0 (E)	1 (E)	0
19. Minimum Equivalent Fluid Pressure	Minimum equivalent fluid pressure used to determine horizontal earth pressure for the minimum load case.	lb/ft^3	1.0 (E)	80.0 (W)	45.0

5.10 LDC - LOAD CONTROL COMMAND (Cont.)

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
20. Maximum Equivalent Fluid Pressure	Maximum equivalent fluid pressure used to determine horizontal earth pressure for the maximum load case.	lb/ft³	1.0 (E)	80.0 (W)	70.0
21. Barrier Dead Load	Proportion of Barrier dead load applied to the culvert design length as a uniform load along the top slab of the culvert. 	kips/ft	0.0 (E)	1.0 (W)	--
22. Approach Slab Dead Load - Left External Wall	Approach Slab dead load **(AD)** on the left exterior wall of the culvert applied at the centerline of the wall over the 1 foot design width of the culvert. The application of this load is based on BD-632. This load should be left blank when culvert is not at grade.	kips	0.0 (E)	3.0 (W)	
23. Approach Slab Live Load – Left External Wall	Approach Slab live load **(AL)** on the left exterior wall of the culvert applied at the centerline of the wall over the 1 foot design width of the culvert. The application of this load is based on BD-632. This load should be left blank when culvert is not at grade or if live load is not applied to the culvert. For program runs with multiple live loads, enter the maximum approach slab live load. The approach slab live load will be factored with the standard live load factors, not any modified load factors entered via the SLL command.	kips	0.0 (E)	5.0 (W)	
24. Approach Slab Dead Load – Right External Wall	Approach Slab dead load **(AD)** on the right exterior wall of the culvert applied at the centerline of the wall over the 1 foot design width of the culvert. The application of this load is based on BD-632. This load should be left blank when culvert is not at grade.	kips	0.0 (E)	3.0 (W)	

5.10 LDC - LOAD CONTROL COMMAND (Cont.)

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
25. Approach Slab Live Load - Right External Wall	Approach Slab live load **(AL)** on the right exterior wall of the culvert applied at the centerline of the wall over the 1 foot design width of the culvert. The application of this load is based on BD-632. This load should be left blank when culvert is not at grade or if live load is not applied to the culvert. For program runs with multiple live loads, enter the maximum approach slab live load. The approach slab live load will be factored with the standard live load factors, not any modified load factors entered via the SLL command.	kips	0.0 (E)	5.0 (W)	
26. Ratings Without Future Wearing Surface	For analysis runs when Future Wearing Surface is specified. The program will calculate and output ratings with and without Future Wearing surface. Not applicable for Design runs or U-channels.	--	Y, N (E)	--	N
27. Backfill Type	NOTE: This parameter is no longer used and should be left blank.	--	--	--	--
28. Number of Precast Shear Transfer Segments	Number of precast segments with shear transfer as defined in DM-4 Section 4.6.2.10.4. Leave blank for Cast In Place culverts. Only set to 1 when there are no other means of shear transfer. All PennDOT projects follow BC-798M which provides shear transfer, therefore a value of at least 2 should be used for this parameter.	--	1 (E)	20 (W)	2
29. Backfill Unit Weight	**Unit weight of backfill around the culvert.**	**lb/ft^3**	**0.0 (E)**	**150.0 (W)**	***2**

[1] For design runs, 30.0 lbs/ft^2.
For analysis runs, 0.0 lbs/ft^2.

[2] Defaults to Fill Unit Weight.

5.10 LDC - LOAD CONTROL COMMAND (Cont.)

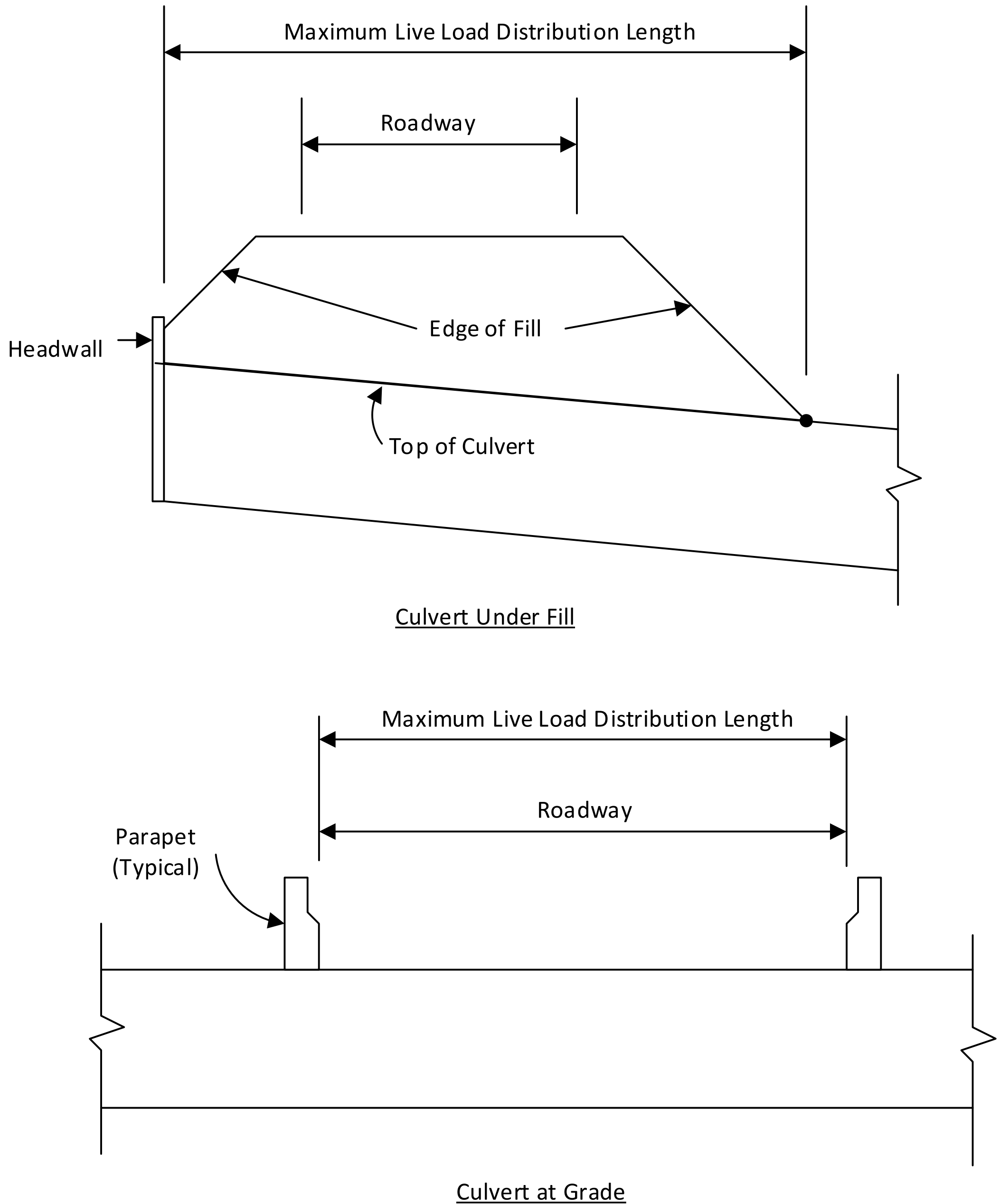


Figure 5.10-1 Maximum Live Load Distribution Length

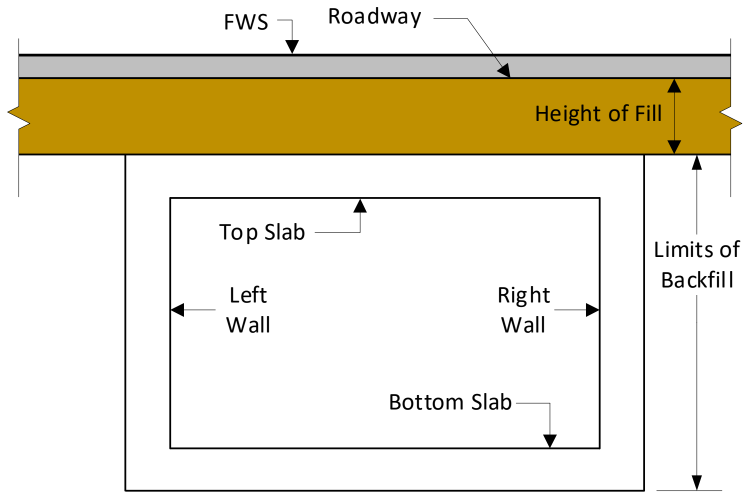


Figure 5.10-2 Height of Fill Example

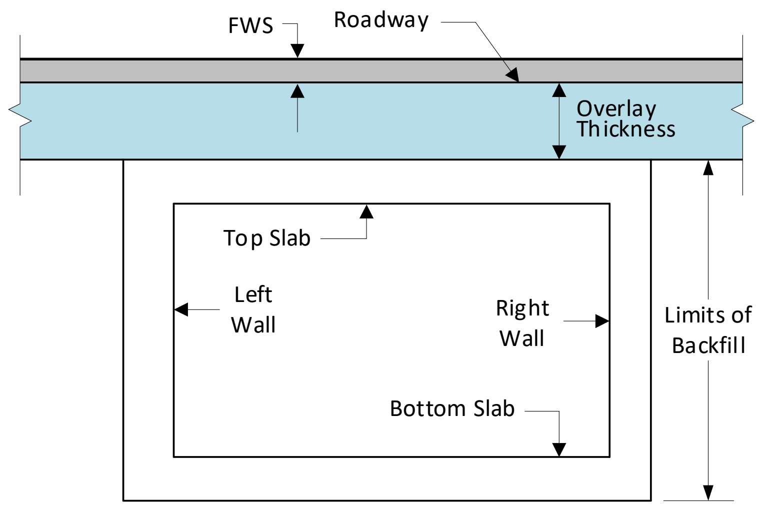


Figure 5.10-3 Overlay Thickness Example

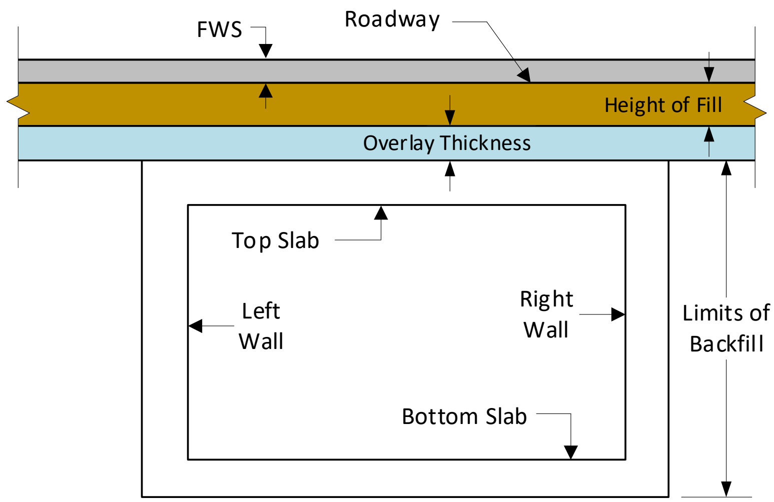


Figure 5.10-4 Combined Height of Fill / Overlay Thickness Example

5.11 SLL - SPECIAL LIVE LOADING COMMAND

KEYWORD	COMMAND DESCRIPTION
SLL	SPECIAL LIVE LOADING - This command is required when a special live loading is requested as the live load option in the LDC command. This command is not applicable for U-channels. Up to eight SLL commands can be used (Eight SpecLL record sets with one SLL command in each record set).

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Special LL Number	Enter the number of the special live load being defined. Up to eight special live loads can be defined. These live loads must have continuous numbering; that is, if special live loads 1 and 3 are defined, then special live load 2 must also be defined. These live loads must be entered in order.	--	1 (E)	8 (E)	--
2. Gage Distance	The distance between the truck wheel lines.	ft	0.0 (E)	10.0 (W)	6.0
3. Passing Distance	If more than one vehicle is assumed to be loaded on the culvert at a time, specify the minimum lateral distance between the adjacent wheels of passing vehicles.	ft	0.0 (E)	10.0 (W)	4.0
4. Axle Effect	Enter "Y" if the effects of all axle loads are to be included in calculating a given load effect. Enter "N" if the axle loads that do not contribute to the effect are to be neglected.	--	Y, N (E)	--	N
5. Lane Load	Enter a uniform lane load to be applied in combination with the SAL command.	kip/ft	0.0 (E)	1.5 (W)	0.0
6. Percent Increase	Enter the percentage to increase the live load for checking permit loads for over-weight.	--	0.0 (E)	10.0 (W)	3.0
7. Load Factor Strength I	The load factor to be applied to the Strength I Limit State.	--	0.0 (E)	2.0 (W)	--
8. Load Factor Strength II	The load factor to be applied to the Special Live Load in the Strength II Limit State.	--	0.0 (E)	2.0 (W)	--
9. Load Factor Service I	The load factor to be applied to the Special Live Load in the Service I Limit State.	--	0.0 (E)	2.0 (W)	--
10. Load Factor Fatigue	NOTE: This parameter is no longer used and should be left blank.	--	--	--	--

5.11 SLL – SPECIAL LIVE LOADING COMMAND (Cont.)

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
11.Vehicle Type	Enter: D - If the Dynamic Load Allowance (Impact) is for Design vehicles. P - If the Dynamic Load Allowance (Impact) is for Permit vehicles. The Dynamic Load Allowance for Design vehicles is automatically computed by the program using DM-4 equation 3.6.2.2-1. The Dynamic Load Allowance for Permit vehicles is specified on the LDC command as parameter "Permit Truck Maximum Dynamic Load Allowance".	--	D, P (E)	--	D

5.12 SAL - SPECIAL AXLE LOADS COMMAND

KEYWORD	COMMAND DESCRIPTION
SAL	SPECIAL AXLE LOADS - This command is required when a special live loading is requested as the live load option in the LDC command. Up to eight different live loads can be defined. This command and the parameters of this command may be repeated starting with parameter 2. For the last vehicle axle, the axle spacing can be left blank. This command is repeatable but the total number of axles from each SAL card must not exceed a maximum of 80 axle loads, 79 spacings. This command is not applicable for U-channels.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Special LL Number	Enter the number of the special live load being defined. Up to eight special live loads can be defined. These live loads must have continuous numbering; that is, if special live loads 1 and 3 are defined, then special live load 2 must also be defined. These live loads must be entered in order.	--	1 (E)	8 (E)	--
2. Axle Load	Enter the magnitude of the axle load corresponding to the previously specified axle spacing.	kips	0.0 (E)	150.0 (W)	--
3. Axle Spacing	Enter the spacing from the axle under consideration to the next axle. For example, the fourth spacing is the distance between axle 4 and axle 5. Leave blank for last axle.	ft	0.0 (E)	50.0 (W)	--

5.13 HCH - HAUNCH COMMAND

KEYWORD	COMMAND DESCRIPTION
HCH	HAUNCH - This command is used to describe the presence and dimensions of haunches in the corners of box culverts and U-channels. If only the top left haunch is described for box culverts, all remaining haunches will default to those dimensions when haunches are applicable. The bottom haunches must be individually specified for U-channels. Haunches may not be placed at bottom slabs with fish channels, or at the bottom of culverts without a bottom slab. Haunch x and y dimensions must be equal or the program will stop. This command may only be specified once. See Figure 1.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Top Left x	Haunch horizontal dimension at culvert top left corner. Leave blank for U-channels.	in	0.0 (E)	30.0 (W)	--
2. Top Left y	Haunch vertical dimension at culvert top left corner. Leave blank for U-channels.	in	0.0 (E)	30.0 (W)	--
3. Top Right x	Haunch horizontal dimension at culvert top right corner. Leave blank for U-channels.	in	0.0 (E)	30.0 (W)	*
4. Top Right y	Haunch vertical dimension at culvert top right corner. Leave blank for U-channels.	in	0.0 (E)	30.0 (W)	*
5. Bottom Left x	Haunch horizontal dimension at culvert bottom left corner.	in	0.0 (E)	30.0 (W)	*
6. Bottom Left y	Haunch vertical dimension at culvert bottom left corner.	in	0.0 (E)	30.0 (W)	*
7. Bottom Right x	Haunch horizontal dimension at culvert bottom right corner.	in	0.0 (E)	30.0 (W)	*
8. Bottom Right y	Haunch vertical dimension at culvert bottom right corner.	in	0.0 (E)	30.0 (W)	*
9. Top Interior x	Haunch horizontal dimension at interior wall top of two cell culverts. Leave blank for U-channels.	in	0.0 (E)	30.0 (W)	*
10. Top Interior y	Haunch vertical dimension at interior wall top of two cell culverts. Leave blank for U-channels.	in	0.0 (E)	30.0 750.0 (W)	*
11. Bottom Interior x	Haunch horizontal dimension at interior wall bottom of two cell culverts. Leave blank for U-channels.	in	0.0 (E)	30.0 (W)	*
12. Bottom Interior y	Haunch vertical dimension at interior wall bottom of two cell culverts. Leave blank for U-channels.	in	0.0 (E)	30.0 (W)	*

*Horizontal dimensions will default to the “top left x” dimension, and vertical dimensions will default to the “top left y” dimension for box culverts only.

5.13 HCH - HAUNCH COMMAND (Cont.)

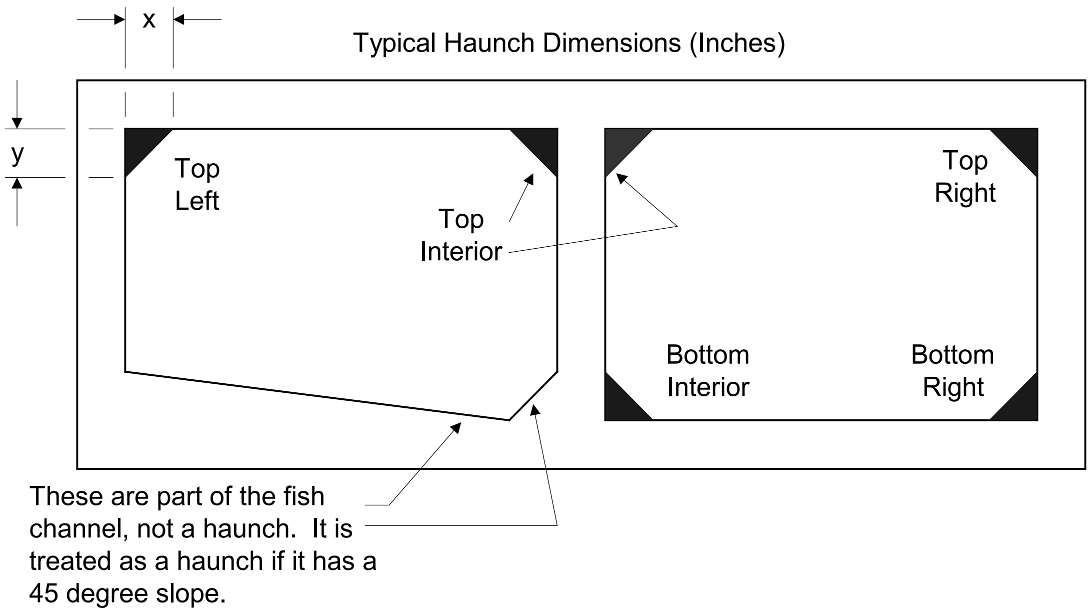


Figure 5.13-1 Haunch Dimensions

5.14 FSH - FISH CHANNEL COMMAND

KEYWORD	COMMAND DESCRIPTION
FSH	FISH CHANNEL - This command is used to describe the type and dimensions of a fish channel. A standard or a non-standard may be specified. When a standard fish channel is specified, the program will use the fish channel dimensions shown in Figure 1. For a two cell culvert, the fish channel is assumed in the left cell bottom slab. When a standard fish channel is specified, parameters 2 and 3 are ignored. A non-standard fish channel can be described by entering the fish channel dimensions (segment length and change in slab thickness). A maximum of 4 segments can be entered. The fish channel command may only be specified once. Parameters 2 and 3 are repeatable a maximum of 4 times. See Figures 1 and 2.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Type	Type of fish channel. See Figures 1 and 2. S - Standard Fish Channel N - Non-Standard Fish Channel	--	S, N (E)	--	--
2. Segment Length	Horizontal distance of segment measured from previous segment. See Figure 2. Leave blank for a Standard Fish Channel.	in	0.0 (E)	240.0 (W)	--
3. Thickness Change	Change in bottom slab thickness in segment 1. Positive if thickness increases in segment, negative if drop in thickness. See Figure 2. Leave blank for a Standard Fish Channel.	in	-24.0 (E)	24.0 (W)	--

5.14 FSH - FISH CHANNEL COMMAND (Cont.)

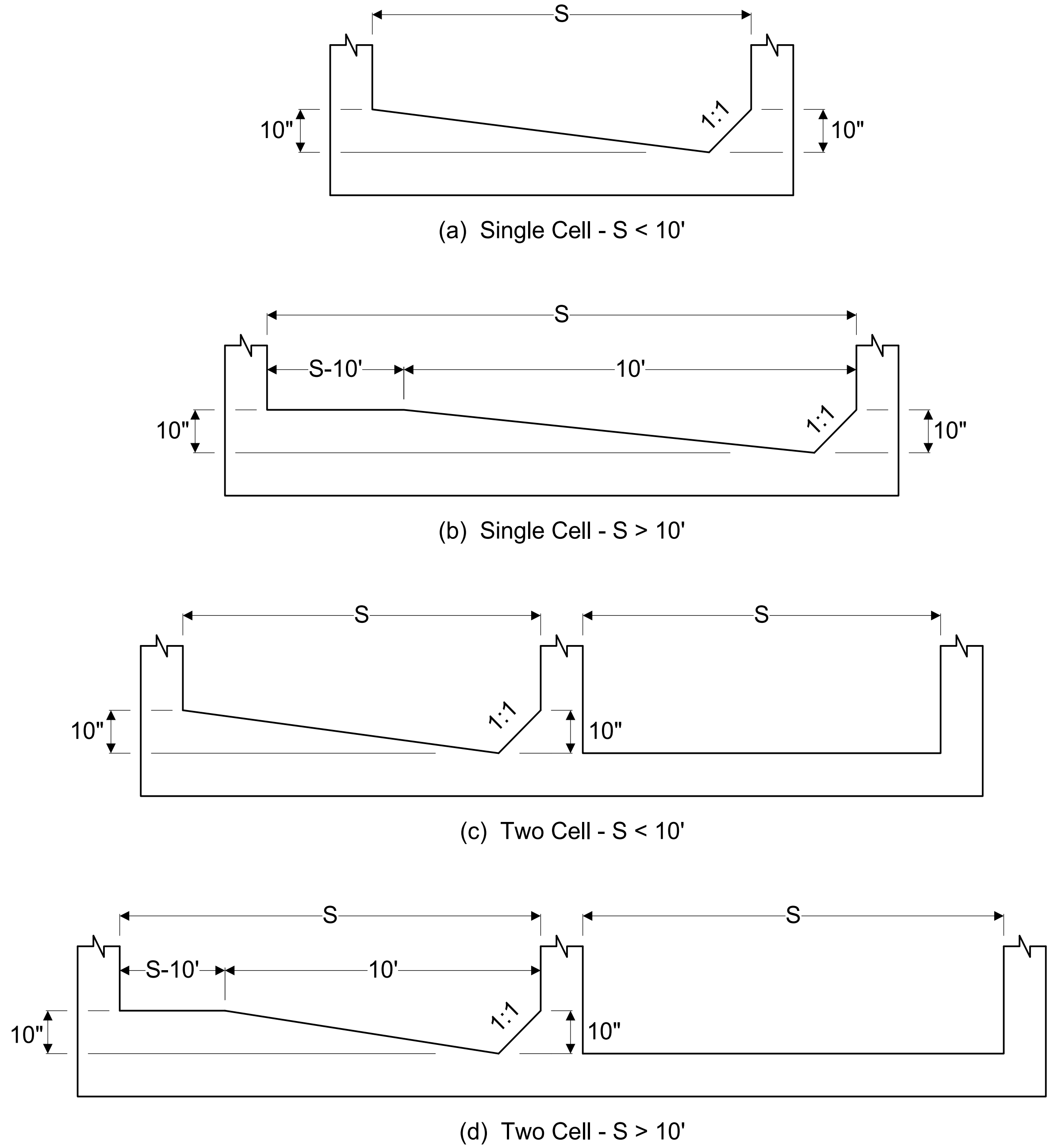


Figure 5.14-1   Standard Fish Channel

5.14 FSH - FISH CHANNEL COMMAND (Cont.)

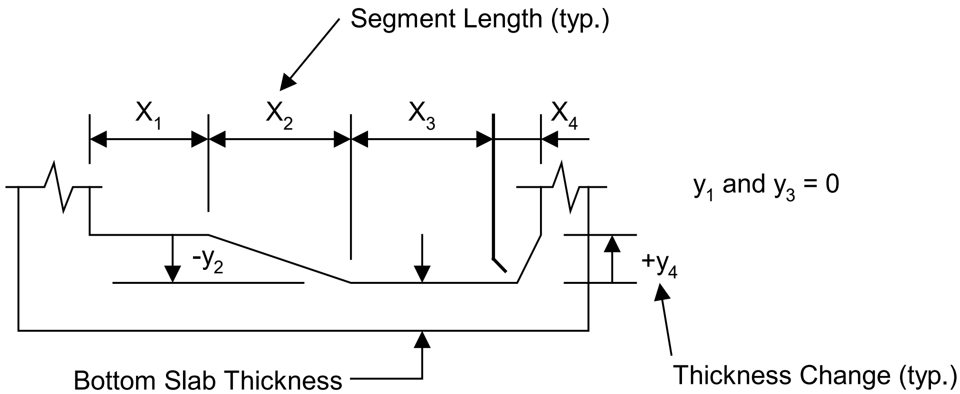


Figure 5.14-2 Non-Standard Fish Channel

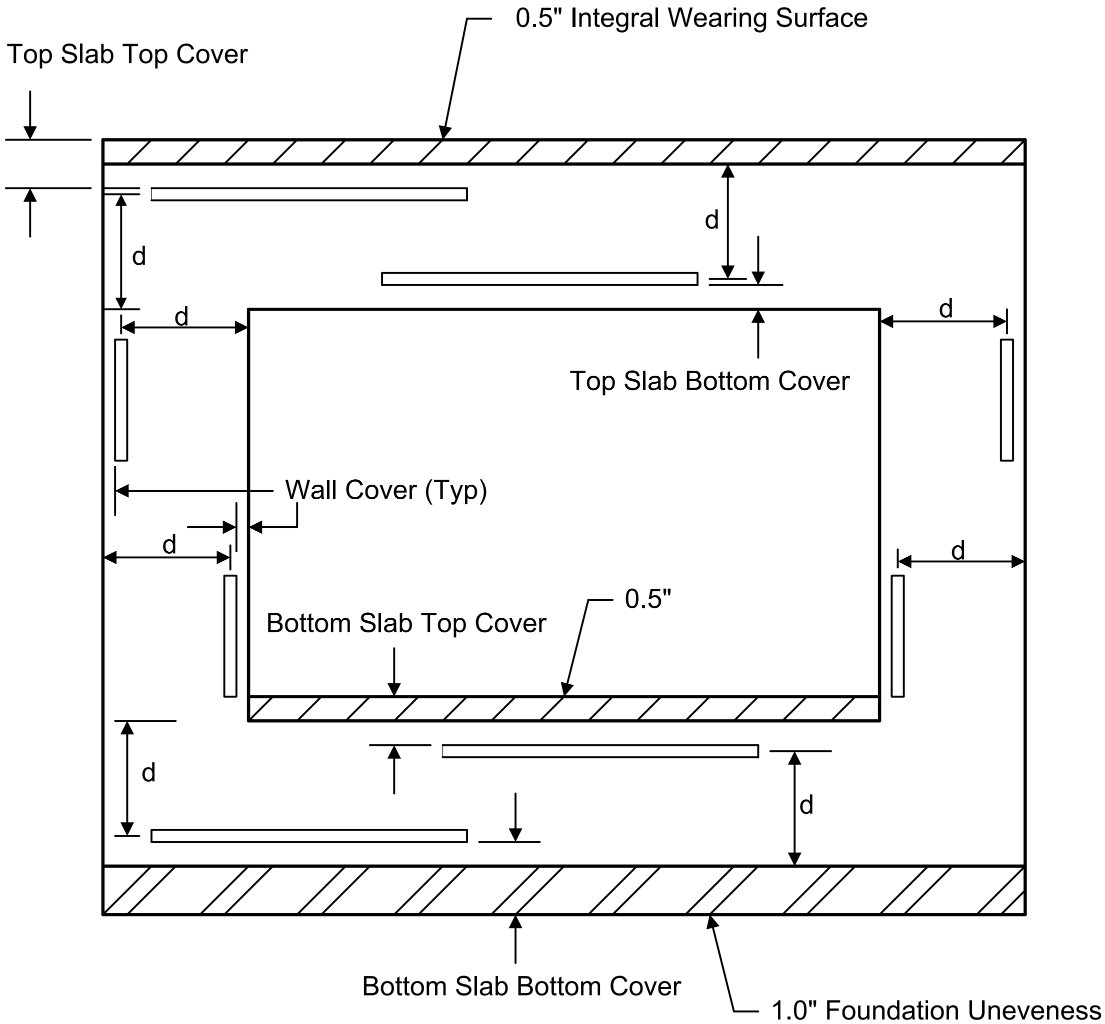
5.15 CVR - COVER COMMAND

KEYWORD	COMMAND DESCRIPTION
CVR	COVERS - This command is used to specify the clear concrete covers over reinforcement. The cover is measured from the concrete face to the nearest face of the reinforcement. (See Figure 1.) The default values of covers are dependent on the structure type, either precast or cast-in-place and are shown in Table 1. The cover command may only be specified once.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Top Slab - Top Cover	Clear concrete cover for top reinforcement in top slab, including applicable integral wearing surface. Leave blank for a U-channel.	in	**	10.0 (W)	*
2. Top Slab - Bottom Cover	Clear concrete cover for bottom reinforcement in top slab. Leave blank for a U-channel.	in	**	10.0 (W)	*
3. Bottom Slab - Top Cover	Clear concrete cover for top reinforcement in bottom slab, including applicable scour thickness. Leave blank for a culvert with footings.	in	**	10.0 (W)	*
4. Bottom Slab - Bottom Cover	Clear concrete cover for bottom reinforcement in bottom slab, including foundation unevenness. Leave blank for a culvert with footings.	in	**	10.0 (W)	*
5. All Wall Covers	Clear concrete cover for all reinforcement in the walls.	in	**	10.0 (W)	*
6. Footing - Top Cover	Clear concrete cover for top reinforcement in footing. Leave blank for a U-channel and a culvert without footings.	in	**	10.0 (W)	*
7. Footing - Bottom Cover	Clear concrete cover for bottom reinforcement in footing. Leave blank for a U-channel and a culvert without footings.	in	**	10.0 (W)	*

* See Table 1.
**For Analysis Runs, AR, the lower limit is equal to the minimum allowable as per DM-4 and is processed as a warning. For Design Runs, DR, DA or DC, the lower limit is equal to the minimum allowable as per DM-4 and is processed as an error check. See Table 1.

5.15 CVR - COVER COMMAND (Cont.)



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

Figure 5.15-1 Reinforcement Covers

5.15 CVR - COVER COMMAND (Cont.)

Table 5.15-1 DM-4 Minimum Values of Reinforcement Covers

PARAMETER	UNITS	CAST-IN-PLACE	PRECAST WELDED WIRE	PRECAST REBAR
Top Slab Under Fill -Top Cover	in	2.0	A	2.0
Top Slab at Grade - Top Cover	in	2.5	2.5	2.5
Top Slab - Bottom Cover	in	2.0	1.5	1.5
Bottom Slab - Top Cover	in	2.5	2.0	2.0
Bottom Slab - Bottom Cover	in	3.0	1.5	1.5
All Wall Covers	in	2.0	1.5	1.5
Footing - Top Cover	in	2.0	2.0	2.0
Footing - Bottom Cover	in	3.0	1.5	1.5

Where: A = 1.5" for fill ≥ 2'
= 2" for fill < 2'

NOTE: See DM-4 Table 5.10.1-1 and BD-632M, Sheet 4.

5.16 TSA - TOP SLAB REINFORCEMENT AREAS COMMAND

KEYWORD	COMMAND DESCRIPTION
TSA	TOP SLAB REINFORCEMENT AREAS - This command is used to specify the top slab reinforcement when the areas of reinforcement per unit length of culvert are known for an existing culvert. This command is required when AR is entered as the type of run in the CTL command, and should not be entered for all other types. Either the TSA or the TSR command can be used to describe the reinforcement, but not both. The reinforcement for all components must be specified using a similar set of commands -- either by size and spacing commands or by area commands. The reinforcement areas are described by ranges within a given slab. The program assumes that the beginning of each range is the end of the previous range. The first range is assumed to begin at the left end of the slab. The last range distance must be equal to the clear span. This command can be repeated to specify the reinforcement areas for each face of each top slab. Up to 3 reinforcement ranges may be specified for each top slab, thus parameters 3 and 4 are repeatable. See Figures 1 and 2. This command is not applicable for U-channels.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Slab Number	The number of the top slab for which the reinforcement is being described. Enter 1 if it is a single cell culvert or the left-most slab of a two cell culvert. Enter 2 if it is the right-most slab of a two cell culvert.	--	1 (E)	NCEL[1] (E)	--
2. Face	Indicate at which face the reinforcement is located. T - Reinforcement is at top face B - Reinforcement is at bottom face	--	T, B (E)	--	--
3. Range Distance	Distance along the top slab from the left wall face for a single cell culvert or from the interior wall face for slab 2 of a two cell culvert to the location where the specified Range ends.	ft	0.0 (E)	* (E)	--
4. Area	The area of reinforcement per unit length of culvert for this Range.	in^2	0.0 (E)	6.25 (W)	--

[1]NCEL is equal to the number of cells entered on the CTL command.
*Dependent on the Clear Span: the last Range Distance for each top slab must be equal to the Clear Span of the given top slab.

5.16 TSA - TOP SLAB REINFORCEMENT AREAS COMMAND (Cont.)

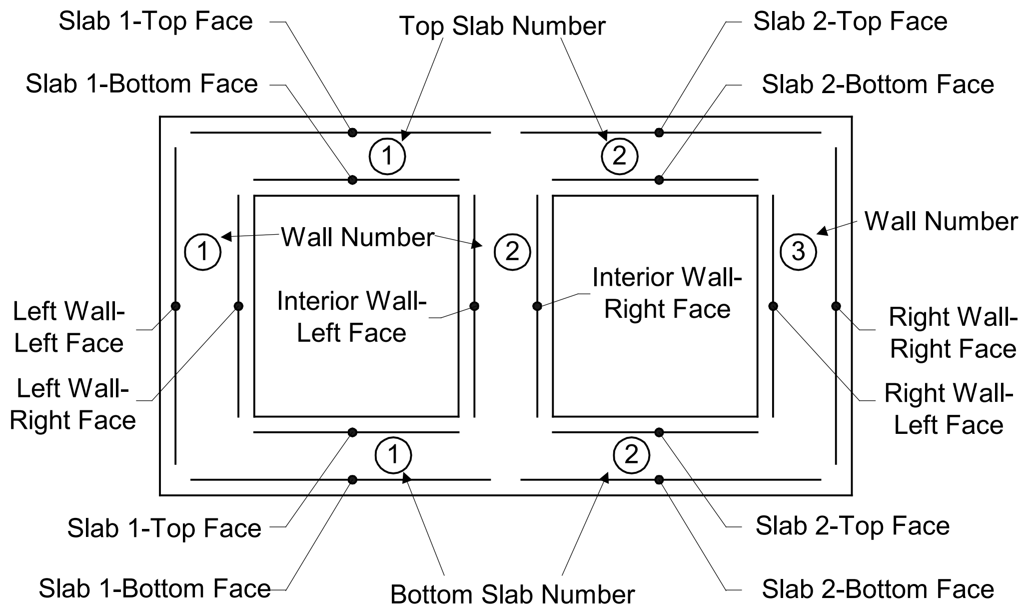
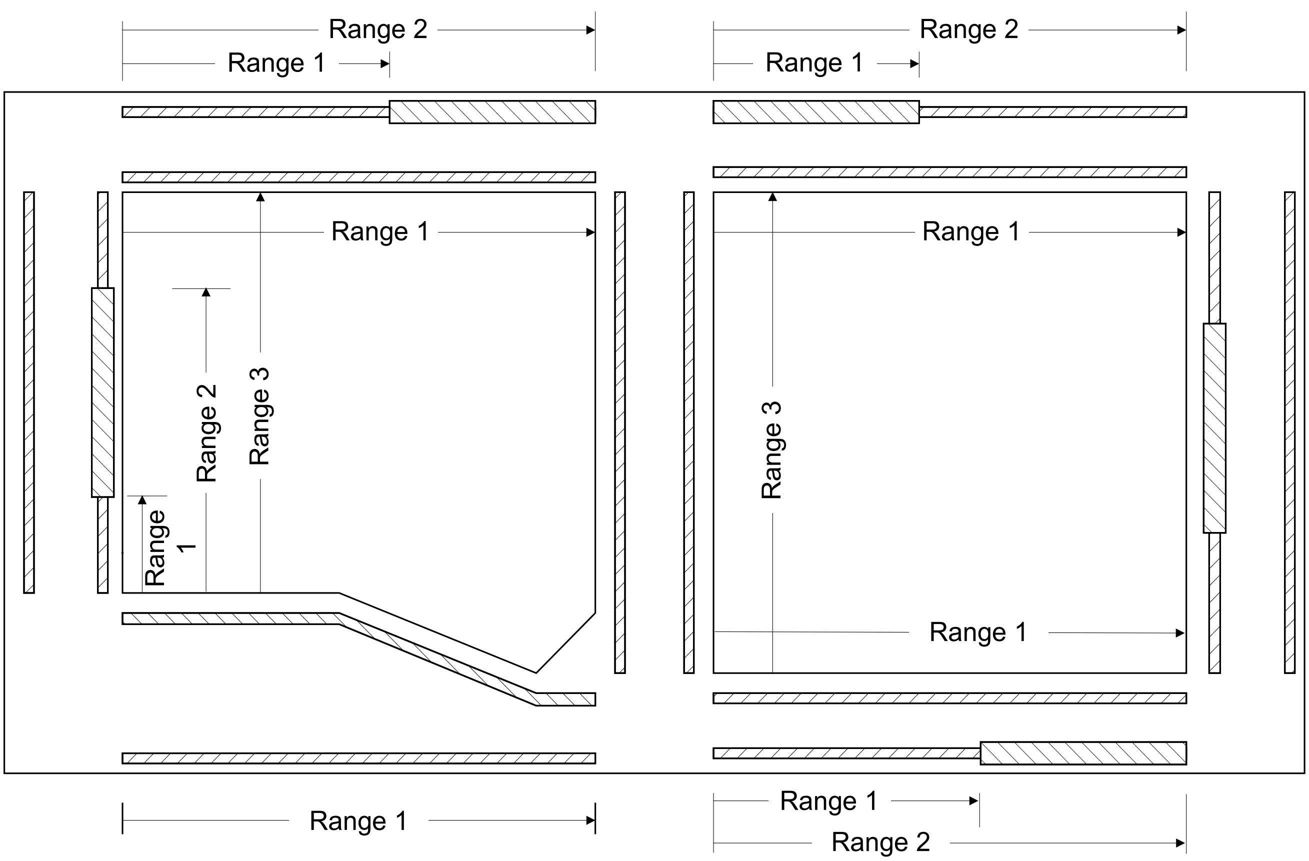


Figure 5.16-1 Reinforcement Locations



Note: Reinforcement in each slab or wall may be specified by a maximum of three ranges.

Figure 5.16-2 Reinforcement Range Distances

5.17 TSR - TOP SLAB REINFORCEMENT COMMAND

KEYWORD	COMMAND DESCRIPTION
TSR	TOP SLAB REINFORCEMENT - This command is used to specify the top slab reinforcement when the reinforcement size and spacing are known in existing culverts. This command is required when AR is entered as the type of run in the CTL command, and should not be entered for all other types. Either the TSR or the TSA command can be used to describe the reinforcement, but not both. The reinforcement for all components must be specified using a similar set of commands -- either by size and spacing commands or by area commands. The reinforcement areas are described by ranges within a given slab. The program assumes that the beginning of each region is the end of the previous range. The first range is assumed to begin at the left end of the slab. The last range distance must be equal to the clear span. This command can be repeated to specify the reinforcement for each face of each top slab. Up to 3 reinforcement ranges may be specified for each top slab, thus parameters 3, 4, and 5 are repeatable. See Figures 5.16-1 and 5.16-2. This command is not applicable for U-channels.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Slab Number	Number of the top slab for which the reinforcement is being described. Enter 1 if it is a single cell culvert or the left-most slab of a two cell culvert. Enter 2 if it is the right-most slab of a two cell culvert.	--	1 (E)	NCEL[1] (E)	--
2. Face	Indicate at which face the reinforcement is located. T - Reinforcement is at top face B - Reinforcement is at bottom face	--	T, B (E)	--	--
3. Range Distance	Distance along the top slab from the left wall face for a single cell culvert or from the interior wall face for slab 2 of a two cell culvert to the location where the specified Range ends.	ft	0.0 (E)	** (E)	--
4. Reinf. Size or Wire Diameter	Reinforcement size in the specified Range.	--	*	*	--
5. Spacing	Reinforcement spacing in the specified Range.	in	0.0 (E)	24.0 (W)	--

[1] NCEL is equal to the number of cells entered on the CTL command.
**Dependent on the Clear Span: the last Range Distance for each top slab must be equal to the Clear Span of the given top slab.
*See Table 5.7-2.

5.18 BSA - BOTTOM SLAB REINFORCEMENT AREAS COMMAND

KEYWORD	COMMAND DESCRIPTION
BSA	BOTTOM SLAB REINFORCEMENT AREAS - This command is used to specify the bottom slab reinforcement when the areas of reinforcement per unit length of culvert are known for an existing culvert. This command is required when AR is entered as the type of run in the CTL command, and should not be entered for all other types. Either the BSA or the BSR command can be used to describe the reinforcement, but not both. The reinforcement for all components must be specified using a similar set of commands -- either by size and spacing commands or by area commands. The reinforcement areas are described by ranges within a given slab. The program assumes that the beginning of each range is the end of the previous range. The first range is assumed to begin at the left end of the slab. The last range distance must be equal to the clear span. This command can be repeated to specify the reinforcement areas of each face of each bottom slab. Up to 3 reinforcement ranges may be specified for each bottom slab, thus parameters 3 and 4 are repeatable. See Figures 5.16-1 and 5.16-2.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Slab Number	The number of the bottom slab for which the reinforcement is being described. Enter 1 if it is a single cell culvert or the left-most slab of a two cell culvert. Enter 2 if it is the right-most slab of a two cell culvert.	--	1 (E)	NCEL[1] (E)	--
2. Face	Indicate at which face the reinforcement is located. T - Reinforcement is at top face B - Reinforcement is at bottom face	--	T, B (E)	--	--
3. Range Distance	Distance along the bottom slab face from the left wall face for a single cell culvert or from the interior wall face for slab 2 of a two cell culvert to the location where the specified Range ends.	ft	0.0 (E)	* (E)	--
4. Area	The area of reinforcement per unit length of culvert for this Range.	in^2	0.0 (E)	6.25 (W)	--

[1]NCEL is equal to the number of cells entered on the CTL command.
*Dependent on the Clear Span: the last Range Distance for each bottom slab must be equal to the Clear Span of the given bottom slab.

5.19 BSR - BOTTOM SLAB REINFORCEMENT COMMAND

KEYWORD	COMMAND DESCRIPTION
BSR	BOTTOM SLAB REINFORCEMENT - This command is used to specify the bottom slab reinforcement when the reinforcement size and spacing are known in existing culverts. This command is required when AR is entered as the type of run in the CTL command, and should not be entered for all other types. Either the BSR command or the BSA command can be used to describe the reinforcement, but not both. The reinforcement for all components must be specified using a similar set of commands -- either by size and spacing commands or by area commands. The reinforcement areas are described by ranges within a given slab. The program assumes that the beginning of each range is the end of the previous range. The first range is assumed to begin at the left end of the slab. The last range distance must be equal to the clear span. This command can be repeated to specify the reinforcement for each face of each bottom slab. Up to 3 reinforcement ranges may be specified for each bottom slab, thus parameters 3, 4, and 5 are repeatable. See Figures 5.16-1 and 5.16-2.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Slab Number	Number of the bottom slab for which the reinforcement is being described. Enter 1 if it is a single cell culvert or the left-most slab of a two cell culvert. Enter 2 if it is the right-most slab of a two cell culvert.	--	1 (E)	NCEL[1] (E)	--
2. Face	Indicate at which face the reinforcement is located. T - Reinforcement is at top face B - Reinforcement is at bottom face	--	T, B (E)	--	--
3. Range Distance	Distance along the bottom slab from the left wall face for a single cell culvert or from the interior wall face for slab 2 of a two cell culvert to the location where the specified Range ends.	ft	0.0 (E)	** (E)	--
4. Reinf. Size or Wire Diameter	Reinforcement size in the specified Range.	--	*	*	--
5. Spacing	Reinforcement spacing in the specified Range.	in	0.0 (E)	24.0 (W)	--

[1]NCEL is equal to the number of cells entered on the CTL command.
**Dependent on the Clear Span: the last Range Distance for each bottom slab must be equal to the Clear Span for the given bottom slab.
*See Table 5.7-2.

5.20 WLA - WALL REINFORCEMENT AREAS COMMAND

KEYWORD	COMMAND DESCRIPTION
WLA	WALL REINFORCEMENT AREAS - This command is used to specify the wall reinforcement when the areas of reinforcement per unit length of culvert are known for an existing culvert. This command is required when AR is entered as the type of run in the CTL command, and should not be entered for all other types. Either the WLA command or the WLR command can be used to describe the reinforcement, but not both. The reinforcement for all components must be specified using a similar set of commands -- either by size and spacing commands or by area commands. The reinforcement areas are described by ranges within a given wall. The program assumes that the beginning of each range is the end of the previous range. The first range is assumed to begin at the bottom of the wall or bottom slab face. The last range for each wall must be equal to the clear height for the given wall. This command can be repeated to specify reinforcement areas for each face of each external and the internal walls. Up to 3 reinforcement ranges may be specified for each wall, thus parameters 3 and 4 are repeatable. See Figures 5.16-1 and 5.16-2.

PARAMETER	DESCRIPTION	UNITS	LOWE R LIMIT	UPPER LIMIT	Default
1. Wall Number	Number of the wall for which the reinforcement is being described. Walls are numbered from left to right.	--	1 (E)	NCEL[1]+1 (E)	--
2. Face	Indicate at which face the reinforcement is located. L - Reinforcement is at left face R - Reinforcement is at right face	--	L, R (E)	--	--
3. Range Distance	Distance along the wall from the bottom slab face to the location where the specified Range ends.	ft	0.0 (E)	* (E)	--
4. Area	The area of reinforcement per unit length of culvert for this Range.	in^2	0.0 (E)	6.25 (W)	--

[1]NCEL is equal to the number of cells entered on the CTL command.
*Dependent on the Clear Height: the last Range Distance for each wall must be equal to the Clear Height for the given wall.

5.21 WLR - WALL REINFORCEMENT COMMAND

KEYWORD	COMMAND DESCRIPTION
WLR	WALL REINFORCEMENT - This command is used to specify the wall reinforcement when the reinforcement size and spacing are known in existing culverts. This command is required when AR is entered as the type of run in the CTL command, and should not be entered for all other types. Either the WLR command or the WLA command can be used to describe the reinforcement, but not both. The reinforcement for all components must be specified using a similar set of commands -- either by size and spacing commands or by area commands. The reinforcement areas are described by ranges within a given wall. The program assumes that the beginning of each range is the end of the previous range. The first range is assumed to begin at the left bottom of the wall or bottom slab face. The last range distance for each wall must be equal to the clear height for the given wall. This command can be repeated to specify reinforcement areas for each face of each external and the internal walls. Up to 3 reinforcement ranges may be specified for each wall, thus parameters 3, 4 and 5 are repeatable. See Figures 5.16-1 and 5.16-2.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Wall Number	Number of the wall for which the reinforcement is being described. Walls are numbered from left to right.	--	1 (E)	NCEL[1]+1 (E)	--
2. Face	Indicate at which face the reinforcement is located. L - Reinforcement is at the left face R - Reinforcement is at the right face	--	L,R (E)	--	--
3. Range Distance	Distance along the wall from the bottom slab face to the location where the specified Range ends.	ft	0.0 (E)	** (E)	--
4. Reinf. Size or Wire Diameter	Reinforcement size in the specified Range.	--	*	*	--
5. Spacing	Reinforcement spacing in the specified Range.	in	0.0 (E)	24.0 (W)	--

[1]NCEL is equal to the number of cells entered on the CTL command.
**Dependent on the Clear Height: the last Range Distance for each wall must be equal to the Clear Height for the given wall.
*See Table 5.7-2.

5.22 FTA - FOOTING REINFORCEMENT AREAS COMMAND

KEYWORD	COMMAND DESCRIPTION
FTA	FOOTING REINFORCEMENT AREAS - This command is used to specify the footing reinforcement when the areas of reinforcement per unit length of strip footing are known for an existing culvert. This command is required when AR is entered as the type of run in the CTL command, and should not be entered for all other types. Either the FTA or the FTR command can be used to describe the reinforcement, but not both. The reinforcement for all components must be specified using a similar set of commands -- either by size and spacing commands or by area commands. This command can be repeated to specify the reinforcement areas for each face of each strip footing. See Figure 1. This command is not applicable for U-channels.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Footing Number	The number of the footing for which the reinforcement is being described.	--	1 (E)	NCEL[1]+1 (E)	--
2. Face	Indicate at which face the reinforcement is located. T - Reinforcement is at top face B - Reinforcement is at bottom face	--	T, B (E)	--	--
3. Area	The area of reinforcement per unit length of culvert for the specified face.	in^2	0.0 (E)	6.25 (W)	--

[1]NCEL is equal to the number of cells entered on the CTL command.

5.22 FTA - FOOTING REINFORCEMENT AREAS COMMAND (Cont.)

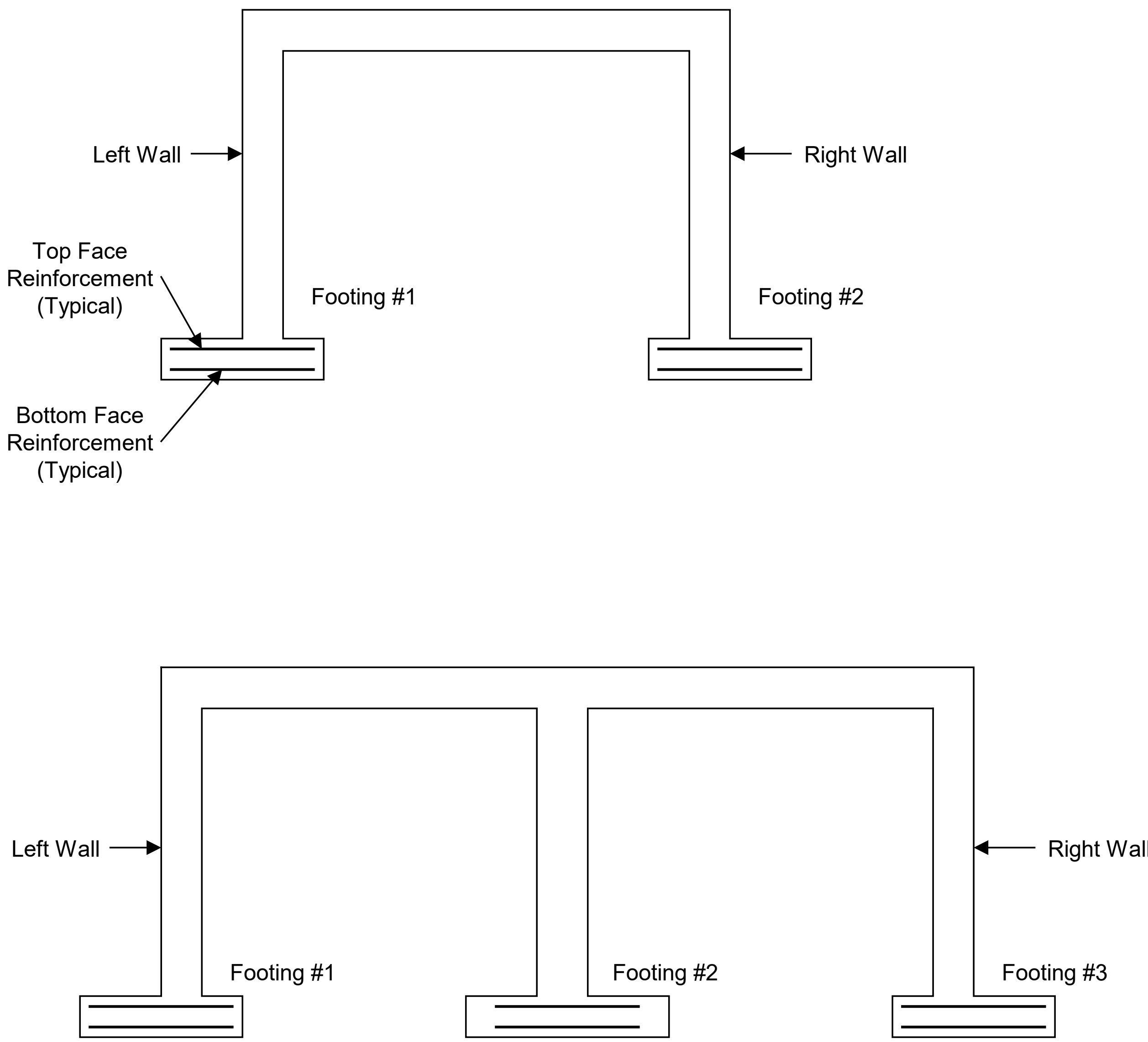


Figure 5.22-1 Footing Reinforcement Locations

5.23 FTR - FOOTING REINFORCEMENT COMMAND

KEYWORD	COMMAND DESCRIPTION
FTR	FOOTING REINFORCEMENT - This command is used to specify the strip footing reinforcement when the reinforcement size and spacing are known in existing culverts. This command is required when AR is entered as the type of run in the CTL command, and should not be entered for all other types. Either the FTR command or the FTA command can be used to describe the reinforcement, but not both. The reinforcement for all components must be specified using a similar set of commands -- either by size and spacing commands or by area commands. This command can be repeated to specify the reinforcement for each face of each strip footing. See Figure 5.22-1. This command is not applicable for U-channels.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Footing Number	Number of the footing for which the reinforcement is being described.	--	1 (E)	NCEL[1]+1 (E)	--
2. Face	Indicate at which face the reinforcement is located. T - Reinforcement is at top face B - Reinforcement is at bottom face	--	T, B (E)	--	--
3. Reinforcement Size or Wire Diameter	Reinforcement bar size at the specified face.	--	*	*	--
4. Spacing	Reinforcement spacing at the specified face.	in	0.0 (E)	24.0 (W)	--

[1]NCEL is equal to the number of cells entered on the CTL command.
*See Table 5.7-2.

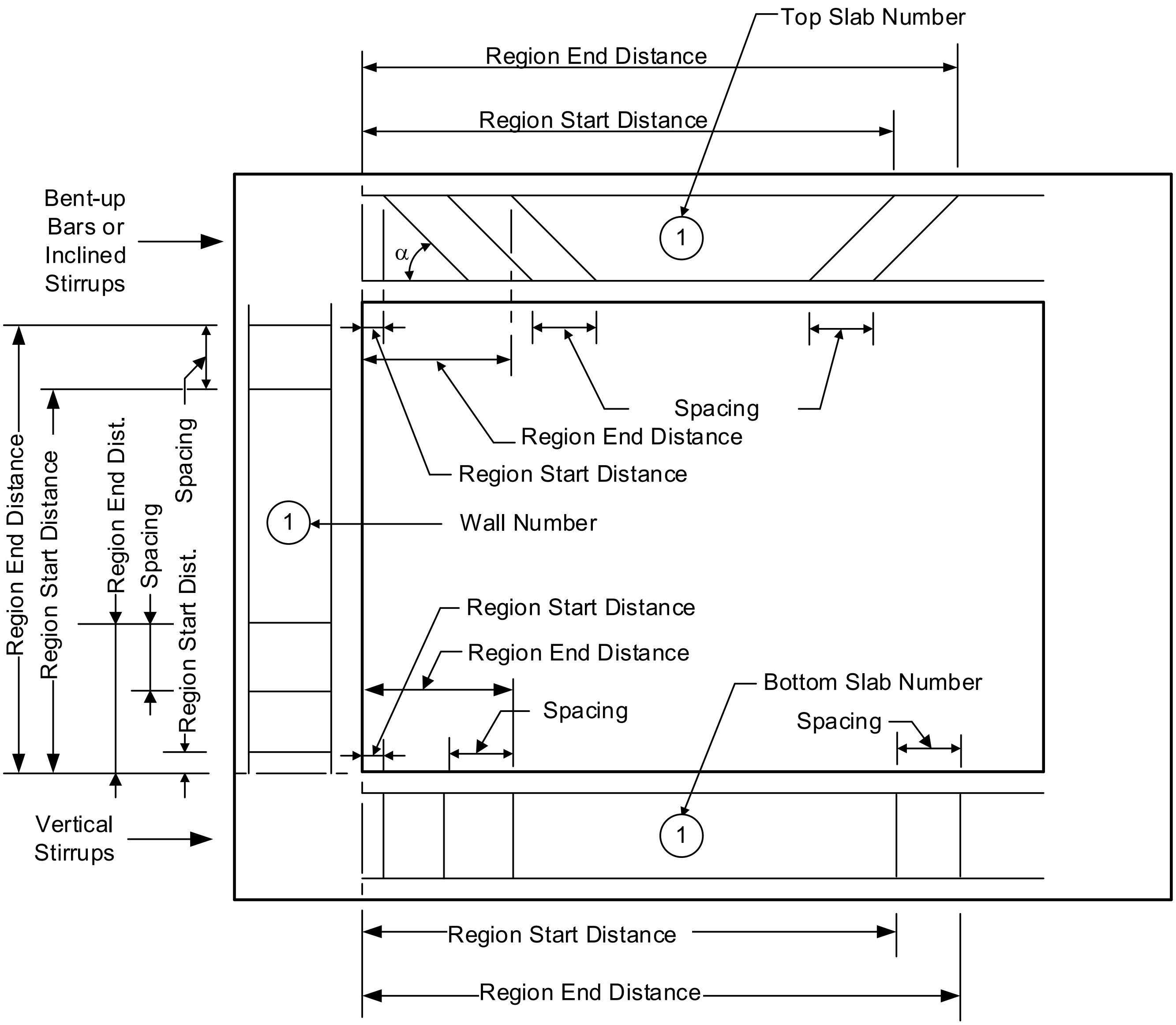
5.24 TVA - TOP SLAB SHEAR REINFORCEMENT AREAS COMMAND

KEYWORD	COMMAND DESCRIPTION
TVA	TOP SLAB SHEAR REINFORCEMENT AREAS - This command is used to specify the top slab shear reinforcement areas, Av, in existing culverts. This command can be repeated to specify the shear reinforcement areas for each top slab. Up to 2 shear reinforcement regions may be specified per slab, thus parameters 2 through 5 are repeatable. The regions need not be continuous, but they cannot overlap. See Figure 1. This command is not applicable for U-channels.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Slab Number	Number of the top slab for which the reinforcement is being described. Enter 1 if it is a single cell culvert or the left-most slab of a two cell culvert. Enter 2 if it is the right-most slab of a two cell culvert.	--	1 (E)	NCEL[1] (E)	--
2. Region Start Distance	Distance along the top slab from the left wall face for a single cell culvert or from the interior wall for slab 2 of a two cell culvert to the location where the specified Region starts.	ft	0.0 (E)	* (E)	--
3. Region End Distance	Distance along the top slab from the left wall face for a single cell culvert or from the interior wall for slab 2 or a two cell culvert to the location where the specified Region ends.	ft	0.0 (E)	* (E)	--
4. Shear Reinf. Area	Shear reinforcement area per unit culvert length in the Region.	in^2	0.0 (E)	1.80 (W)	--
5. Spacing	Shear reinforcement spacing within the Region.	in	0.0 (E)	24.0 (W)	--

[1]NCEL is equal to the number of cells entered on the CTL command.
*Dependent on the Clear Span: the Region End Distance for each top slab must be $\leq$ to the Clear Span of the given top slab.

5.24 TVA - TOP SLAB SHEAR REINFORCEMENT AREAS COMMAND (Cont.)



α = angle of inclination of bent-up bars (Alpha) as specified on the MAT command.

Figure 5.24-1 Shear Reinforcement

5.25 BVA - BOTTOM SLAB SHEAR REINFORCEMENT AREAS

KEYWORD	COMMAND DESCRIPTION
BVA	BOTTOM SLAB SHEAR REINFORCEMENT AREAS - This command is used to specify the bottom slab shear reinforcement areas, Av, in existing culverts. This command can be repeated to specify the shear reinforcement area for each bottom slab. Up to 2 shear reinforcement regions may be specified per slab, thus parameters 2 through 5 are repeatable. The regions need not be continuous, but they cannot overlap. See Figure 5.24-1. This command is not applicable for U-channels.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Slab Number	Number of the bottom slab for which the reinforcement is being described. Enter 1 if it is a single cell culvert or the left-most slab of a two cell culvert. Enter 2 if it is the right-most slab of a two cell culvert.	--	1 (E)	NCEL[1] (E)	--
2. Region Start Distance	Distance along the bottom slab from the left wall face for a single cell culvert or from the interior wall for slab 2 of a two cell culvert to the location where the specified Region starts.	ft	0.0 (E)	* (E)	--
3. Region End Distance	Distance along the bottom slab from the left wall face for a single cell culvert or from the interior wall for slab 2 of a two cell culvert to the location where the specified Region ends.	ft	0.0 (E)	* (E)	--
4. Shear Reinf. Area	Shear reinforcement area per unit culvert length in the Region.	in^2	0.0 (E)	1.80 (W)	--
5. Spacing	Shear reinforcement spacing within the Region.	in	0.0 (E)	24.0 (W)	--

[1]NCEL is equal to the number of cells entered on the CTL command.
*Dependent on the Clear Span: the Region End Distance for each bottom slab must be $\leq$ to the Clear Span of the given bottom slab.

5.26 WVA - WALL SHEAR REINFORCEMENT AREAS

KEYWORD	COMMAND DESCRIPTION
WVA	WALL SHEAR REINFORCEMENT AREAS - This command is used to specify the wall shear reinforcement areas, Av, in existing culverts. This command can be repeated to specify the shear reinforcement area for each wall. Up to 2 shear reinforcement regions may be specified per wall, thus parameters 2 through 5 are repeatable. The regions need not be continuous, but they cannot overlap. See Figure 5.24-1. This command is not applicable for U-channels.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Wall Number	Number of the wall for which the reinforcement is being described. Walls are numbered from left to right.	--	1 (E)	NCEL+1[1] (E)	--
2. Region Start Distance	Distance along the wall from the bottom slab face to the location where the specified Region starts.	ft	0.0 (E)	* (E)	--
3. Region End Distance	Distance along the wall from bottom slab face to the location where the specified Region ends.	ft	0.0 (E)	* (E)	--
4. Shear Reinf. Area	Shear reinforcement area per unit culvert length in the Region.	in^2	0.0 (E)	1.80 (W)	--
5. Spacing	Shear reinforcement spacing within the Region.	in	0.0 (E)	24.0 (W)	--

[1]NCEL is equal to the number of cells entered on the CTL command.
*Dependent on the Clear Height: the Region End Distance for each wall must be $\leq$ to the Clear Height.

5.27 OIN - OUTPUT OF INPUT COMMAND

KEYWORD	COMMAND DESCRIPTION
OIN	OUTPUT OF INPUT - This command is used to control the type of input data reports which can be requested by the user. This command may only be specified once.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Input File Echo	An input file echo may be generated in the output. 0 - Do not print input file echo. 1 - Print echo of input file.	--	0 (E)	1 (E)	0
2. Input Commands	The input data may be organized according to command, with a short description for each data item. 0 - Do not print input commands. 1 - Print input commands.	--	0 (E)	1 (E)	0
3. Input Summary	A summary of the input data may be printed. 0 - Do not print input summary. 1 - Print input summary.	--	0 (E)	1 (E)	1

5.28 OUR - OUTPUT OF RESULTS

KEYWORD	COMMAND DESCRIPTION
OUR	OUTPUT OF RESULTS - This command is used to control the type of result reports which can be requested by the user. This command is only entered if the user wants to select output other than the standard output produced by the program. Standard output tables printed are those indicated by the default values as shown for each parameter in this command.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. Section Properties	0 - Do not print Section Properties 1 - Print Section Properties	--	0 (E)	1 (E)	*
2. Live Load Rating	0 - Do not print Live Load Rating 1 - Print Live Load Rating	--	0 (E)	1 (E)	*
3. Rating Summary	0 - Do not print Rating Summary 1 - Print Rating Summary	--	0 (E)	1 (E)	*
4. DL Effects and Capacities	0 - Do not print DL Effects and Capacities 1 - Print DL Effects and Capacities	--	0 (E)	1 (E)	*
5. Flexural Reinforcement	0 - Do not print flexural Reinforcement Design 1 - Print flexural Reinforcement Design	--	0 (E)	1 (E)	*
6. Shear Design	0 - Do not print Shear Design 1 - Print Bar Shear Design	--	0 (E)	1 (E)	*
7. Foundation Pressure	0 - Do not print Foundation Pressure 1 - Print Foundation Pressures	--	0 (E)	1 (E)	*
8. Quantities	0 - Do not print Quantities 1 - Print Quantities	--	0 (E)	1 (E)	*
9. Serviceability Table	0 - Do not print Serviceability Table 1 - Print Serviceability Table	--	0 (E)	1 (E)	*
10. Serviceability Summary	0 - Do not print Serviceability Summary Table 1 - Print Serviceability Summary Table	--	0 (E)	1 (E)	*
11. Foundation Pressure Summary	0 - Do not print Foundation Pressure Summary Table 1 - Print Foundation Press Summary Table	--	0 (E)	1 (E)	*
12. Minimum Reinforcement Check	0 - Do not print Minimum Reinforcement Check 1 - Print Minimum Reinforcement Check	--	0 (E)	1 (E)	*

*The default values for every parameter on this command are determined based on the type of run (analysis or design). The defaults are detailed in Chapter 6.

5.29 OUI - OUTPUT OF INTERMEDIATE DATA COMMAND

KEYWORD	COMMAND DESCRIPTION
OUI	OUTPUT OF INTERMEDIATE DATA - This command is used to control the type of intermediate data reports which can be requested by the user. These reports are applicable for both design and analysis. This command may only be specified once.

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
1. General POI Data	General POI data 0 - Do not print General POI data 1 - Print General POI data	--	0 (E)	1 (E)	0
2. Non-Live Load Results	Non-live load results 0 - Do not print Non-Live Load Results 1 - Print Non-Live Load Results	--	0 (E)	1 (E)	0
3. Influence Lines	Influence Lines 0 - Do not print Influence Lines 1 - Print Influence Lines	--	0 (E)	1 (E)	0
4. Truck Responses	Truck Responses 0 - Do not print Truck Responses 1 - Print Truck Responses	--	0 (E)	1 (E)	0
5. Truck Thru Fill Response	Truck Thru Fill Response 0 - Do not print Truck Thru Fill Response 1 - Print Truck Thru Fill Response	--	0 (E)	1 (E)	0
6. Lane Response	Lane Response 0 - Do not print Lane Response 1 - Print Lane Response	--	0 (E)	1 (E)	0
7. Envelope Responses	Envelope Responses 0 - Do not print Envelope Responses 1 - Print Envelope Responses	--	0 (E)	1 (E)	0
8. Limit State Dead Load Results	Limit State Dead Load Results 0 - Do not print Limit State Dead Load Results 1 - Print Limit State Dead Load Results	--	0 (E)	1 (E)	0
9. Limit State Live Load Results	Limit State Live Load Results 0 - Do not print Limit State Live Load Results 1 - Print Limit State Live Load Results	--	0 (E)	1 (E)	0
10. Bar Table Results	Bar Table Results 0 - Do not print Bar Table Results 1 - Print Bar Table Results	--	0 (E)	1 (E)	0
11. Limit State Section Capacities	Limit State Section Capacities 0 - Do not print Limit State Section Capacities 1 - Print Limit State Section Capacities	--	0 (E)	1 (E)	0

5.29 OUI - OUTPUT OF INTERMEDIATE DATA COMMAND (Cont.)

PARAMETER	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT	Default
12. Limit State Rating Factors	Limit State Rating Factors 0 - Do not print Limit State Rating Factors 1 - Print Limit State Rating Factors	--	0 (E)	1 (E)	0
13. Limit State Resist/ Demand Ratios	Limit State Resistance/Demand Ratios 0 - Do not print Limit State Resistance/ Demand Ratios 1 - Print Limit State Resistance/Demand Ratios	--	0 (E)	1 (E)	0
14. Limit State Allowable Spacing	Limit State Allowable Spacing 0 - Do not print Limit State Allowable Spacings 1 - Print Limit State Allowable Spacings	--	0 (E)	1 (E)	0
15. Limit State Service Stresses	Limit State Service Stresses 0 - Do not print Limit State Service Stresses 1 - Print Limit State Service Stresses	--	0 (E)	1 (E)	0
16. Stiffness Analysis Model Report	Stiffness Analysis Model Report 0 - Do not print Finite Element Model Report 1 - Print Finite Element Model Report	--	0 (E)	1 (E)	0
17. Stiffness Analysis Result Report	Stiffness Analysis Result Report 0 - Do not print Finite Element Result Report 1 - Print Finite Element Result Report	--	0 (E)	1 (E)	0
18. CMO1 (Nonlive Load)	CMO1 (Nonlive Load). Same results as those produced with Parameter 2, but formatted for easy import into a spread sheet. 0 - Do not print CMO1 (Nonlive Load) 1 - Print CMO1 (Nonlive Load)	--	0 (E)	1 (E)	0
19. CMO2 (Envelopes)	CMO2 (Envelopes). Same results as those produced with Parameter 7, but formatted for easy import into a spread sheet. 0 - Do not print CMO2 (Envelopes) 1 - Print CMO2 (Envelopes)	--	0 (E)	1 (E)	0
20. ACS1 (Influence Lines)	ACS1 (Influence Lines). Same results as those produced with Parameter 3, but formatted for easy import into a spread sheet. 0 - Do not print ACS1 (Influence Lines) 1 - Print ACS1 (Influence Lines)	--	0 (E)	1 (E)	0
21. SP (Soil Pressure)	SP (Soil Pressure) 0 - Do not print SP (Soil Pressure) 1 - Print SP (Soil Pressure)	--	0 (E)	1 (E)	0

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6 DETAILED INPUT DESCRIPTION

This chapter provides a detailed description of some of the input parameters which were described in Chapter 5, but may need further explanation or commentary. The numbering scheme used in this chapter is as follows. The section number for a command corresponds to the same section number in Chapter 5. The parameter being described is preceded by a section number, whose last extension number refers to the parameter number in the corresponding command in Chapter 5. For example, 6.10.9 Live Load Distribution Length corresponds to Section 5.10 LDC - Load Control Command, Parameter 9. Only the commands and parameters for which detailed description is given are included in this chapter.

6.5 CTL - CONTROL COMMAND

6.5.3 Type of Run

This parameter is used to specify whether the user wants to have BXLRFD perform an Analysis (rating) or one of three different types of design.

DR **– DESIGN WITH KNOWN THICKNESS:** all **member** thicknesses must be specified and flexure reinforcement is designed for strength. Bar spacings are computed for strength and crack control. Shear reinforcement is computed if required for capacity.

DA **– DESIGN WITH SHEAR REINFORCEMENT:** all member thicknesses are designed **for bending moment and the required shear resistance provided by the concrete. The** flexure reinforcement **area** is designed for strength. Bar spacings are computed for strength and crack control. Shear reinforcement is designed **to provide the shear resistance not provided by the concrete**. **NOTE: The thickness will be increased, if the shear reinforcement required (with thickness based on bending moment) is greater than the maximum shear reinforcement permitted.**

DC – DESIGN WITHOUT SHEAR REINFORCEMENT: all member thicknesses are designed and flexure reinforcement is designed for strength. Bar spacings are computed for strength and crack control. Member thicknesses are designed to have the concrete provide all required shear resistance.

AR – ANALYZE & RATE: all member thicknesses and reinforcement must be specified and the program performs a structural analysis, does specification checking, and then rates the members for shear and moment.

6.5.7 Frame Support

This parameter is used to specify whether the user wants to have BXLRFD perform an Analysis (rating) or Design of a rigid frame culvert with either fixed supports at the bottom of the wall or pinned supports. The pinned support option has been added to allow for analysis and design of precast frame culverts which are placed upon cast-in-place footings. When the pinned precast frame culvert is selected, the precast or cast-in-place parameter on the CTL command must be set to precast.

The pinned option is exclusive to precast frame culverts while fixed supports are exclusive to cast-in-place frame culverts.

6.7 MAT – MATERIAL COMMAND

6.7.2 f'_c for Top Slab

This parameter is used to specify f'_c for just the top slab of cast-in-place constructed culverts. Its value defaults to the value of f'_c for all members (Parameter 1 on this command) if left blank. This parameter is not applicable to precast culverts or U-channels and therefore it should be left blank.

6.7.3 Reinforcement Grade

This parameter is used to specify the f_y grade for the reinforcement. While this value is typically 60 ksi, values up to 100 ksi are also allowed with certain limitations. If an f_y larger than 60 ksi is specified, **District** Bridge Engineer approval is required. Also, limitations are placed on the f_y value used for flexure, axial, and shear capacities.

f_y for flexure/axial is the lesser of input f_y or 75 ksi.
f_y for shear is the lesser of input f_y or 60 ksi.
f_y for development length is the input f_y.

The f_y for shear is limited to 60 ksi due to application recommendations for high strength reinforcement outlined in 2010 LRFD Specifications Section C5.4.3.3.

6.7.4 Reinforcement Type

This parameter is used to specify whether reinforcing bars or wire mesh is to be used in a precast structure. Structures that are cast-in-place always use reinforcing bars and therefore this parameter should be left blank.

When the Type of Run is AR (an analysis/rating), reinforcement commands (TSA or TSR, WLA or WLR, BSA or BSR, FTA or FTR) must also be given and the value of this parameter dictates how those commands treat the “Reinf. Size or Wire Diameter” parameter on those commands. Specifying “B” for this parameter will cause the reinforcement commands to interpret the “Reinf. Size or Wire Diameter” parameter to be a bar size; if “W” is specified, then it will be interpreted to be a wire diameter. Similarly, Parameter 6 of the MAT command, “Rebar Size or Wire Diameter”, depends on the value of this parameter.

When the Type of Run is DR, DC or DA (a design), reinforcement commands cannot be specified and this parameter is used to tell BXLRFD if it should use the maximum bar size or the maximum bar diameter when it needs to compute the distance between the c.g. of reinforcement and the extreme compression fiber. This is needed during the design of reinforcement area to determine the minimum concrete clear covers.

In addition, the calculation of shear capacity, V_c (LRFD Specifications Equation 5.12.7.3-1) depends on the amount of the flexure reinforcement, A_s, and the distance between the c.g. of reinforcement and the extreme compression fiber.

6.7.5 Alpha

This parameter is the angle of inclination of shear reinforcement to the longitudinal reinforcement used to compute the shear capacity of shear reinforcing steel, V_s.

6.7.6 Rebar Size or Wire Diameter

Section 6.7.4 above explains the relationship between Reinforcement Type and this parameter. For instance, if the Reinforcing Type is “B” for a design, then BXLRFD uses the maximum Rebar Size (this parameter) to compute the distance between the c.g. of reinforcement and the extreme compression fiber when it designs the flexure reinforcement. If the Reinforcement Type is “W”, then is uses the maximum Wire Diameter.

6.8 DIM – DIMENSION COMMAND

In order to design the most efficient culvert geometry two design runs should be made. The first design run should begin with small initial wall and slab thicknesses, which the program will increment if necessary. The second design run should begin with initial slab thicknesses set equal to the final slab thicknesses from the first design run, and setting the initial wall thicknesses to values that are smaller than those computed by the first design run.

6.8.3 Top Slab Thickness

This parameter is used to specify the thickness of the top slab measured from the outside face of the left external wall, from the top of the wall (end of the clear height) to the top of the top slab. The measurement includes the thickness of the assumed waste material for an integral wearing surface, i.e., 0.5 inches when there is zero fill height. When Type of Run is AR **or DR**, this parameter (and the other member thicknesses) represents the actual thickness of the top slab. When Type of Run is DC **or** DA, this parameter (and the other member thicknesses) represents the starting design thickness and is subsequently increased if necessary for strength (flexure and shear) considerations.

6.10 LDC – LOAD CONTROL COMMAND

6.10.2 Height of Fill

This parameter is used to specify the height of fill above the culvert. Fill height is used in determining the culvert vertical and horizontal earth pressure responses to the fill above the culvert. If specified, the program also uses the fill height to determine whether to consider the "Thru Fill" effect of any live loadings (see Section 3.3.9). In the following two examples a schematic is shown representing the dimensions of construction items contributing to culvert loading from above the culvert. If the height of fill above the culvert is composed of more than one material, then the relative sizes/properties of each fill component should be considered, using the combined thickness and a single, average fill **unit weight** as program input. On the left side the construction items and their physical dimensions are shown. The right side of the schematic shows the program input and the load factor applied to **each** item for these examples.

Example 1: Asphalt Pavement Over Earth Fill, with Fill Height ≥ 24"

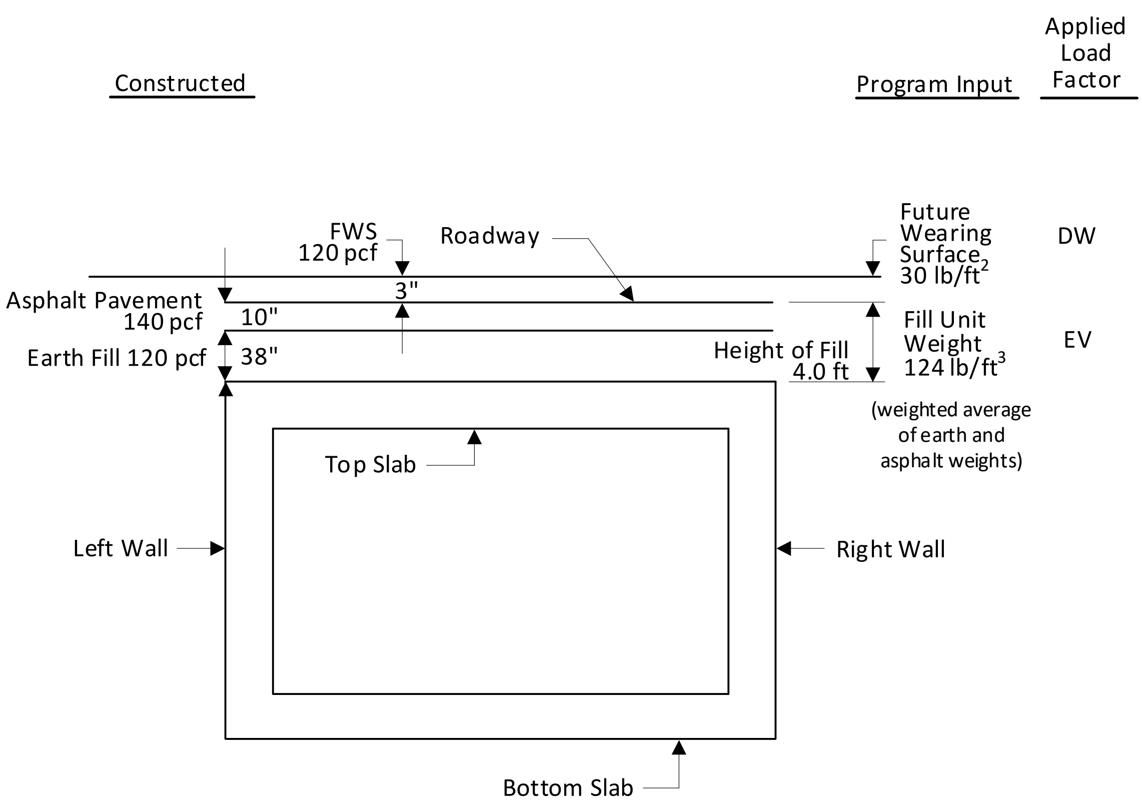


Figure 6.10-1 Fill Input Example - Fill Height ≥ 24"

In this example, the "Thru Fill" effect applies for distributing the live load because the fill height is greater than or equal to 2 feet. The program applies the DW load factor to the Future Wearing Surface load and the EV load factor to the Fill vertical loading. See Section 6.10.8 for more information on Future Wearing Surface loading. Fill **unit** weight is equal to ((140 pcf * 10 in) + (120 pcf * 38 in)) / 48 in = 124 pcf.

Example 2: Asphalt Pavement Over Earth Fill, with Fill Height < 24"

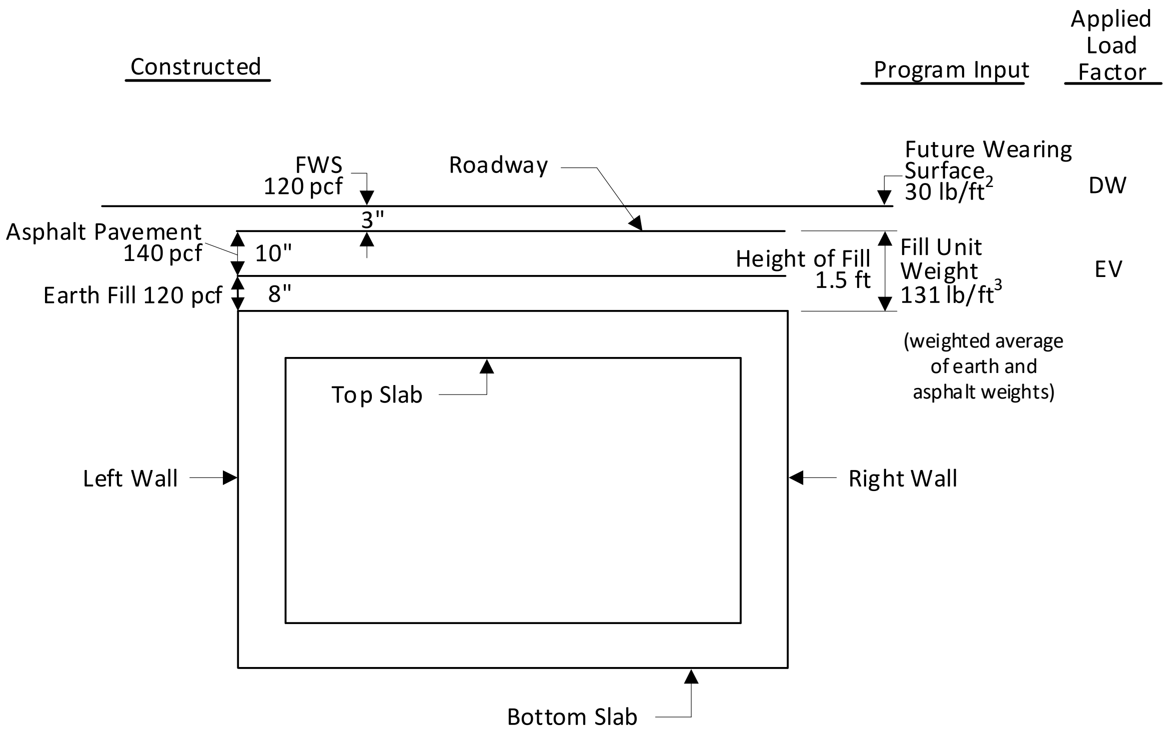


Figure 6.10-2 Fill Input Example - Fill Height < 24"

In this example, the "Thru Fill" effect will not be applied for distributing the live load because the fill height is less than 2 feet. The program applies the DW load factor to the Future Wearing Surface load and the EV load factor to the Fill vertical loading. See Section 6.10.8 for more information on Future Wearing Surface loading.

If a concrete slab is present above the culvert, it should be entered using the Overlay Thickness parameter of this command so that the proper load factors are applied. See Section 6.10.7 for a discussion of the combination of Height of Fill and Overlay Thickness when a concrete slab is present.

6.10.3 Number of Lanes

This parameter is utilized to specify the number of design traffic lanes to be used in determining the response of the culvert for multiple loaded lanes. This is accomplished by using lateral distribution factors. BXLRFD will determine if live load is applicable regardless of what is specified for this parameter.

6.10.6 Overlay **Unit** Weight

This parameter is used to specify **unit weight** of the overlay material. The value is multiplied by the Overlay Thickness to determine the uniformly distributed loading to apply to the top slab. If the thickness is zero, then there is no response for an overlay. If the thickness is greater than zero, then this loading gets applied for either an Analysis or a Design.

If a culvert is set below road grade, but not enough to place fill, an overlay slab may be added by using the Overlay Thickness parameter to specify the thickness of the overlay slab. If an overlay slab is to be placed on the culvert, the Overlay **Unit Weight** should be set equal to the **unit weight** of the overlay slab material. If an overlay slab is specified, and no other fill is present, the Height of Fill parameter on the LDC command should be left blank.

6.10.7 Overlay Thickness

This parameter is used to specify thickness of the overlay material, if any. Overlay thickness is used in determining the culvert vertical load and horizontal earth pressure responses. If the thickness is zero, then there is no response for an overlay. If the thickness is greater than zero, then this loading gets applied for either an Analysis or a Design.

Example 1: Overlay Slab ≤ 12" Thick and No Fill

For the case where the culvert is below grade, but not enough to require fill, there is only a concrete slab, so the Height of Fill should be entered as zero, and the thickness of the concrete slab entered on the Overlay Thickness parameter, as shown in Figure 6.10-3.

In this example, the "Thru Fill" effect will not be applied for distributing the live load because there is no fill. The program applies the DW load factor to the Future Wearing Surface load and the OV load factor to the Overlay vertical loading.

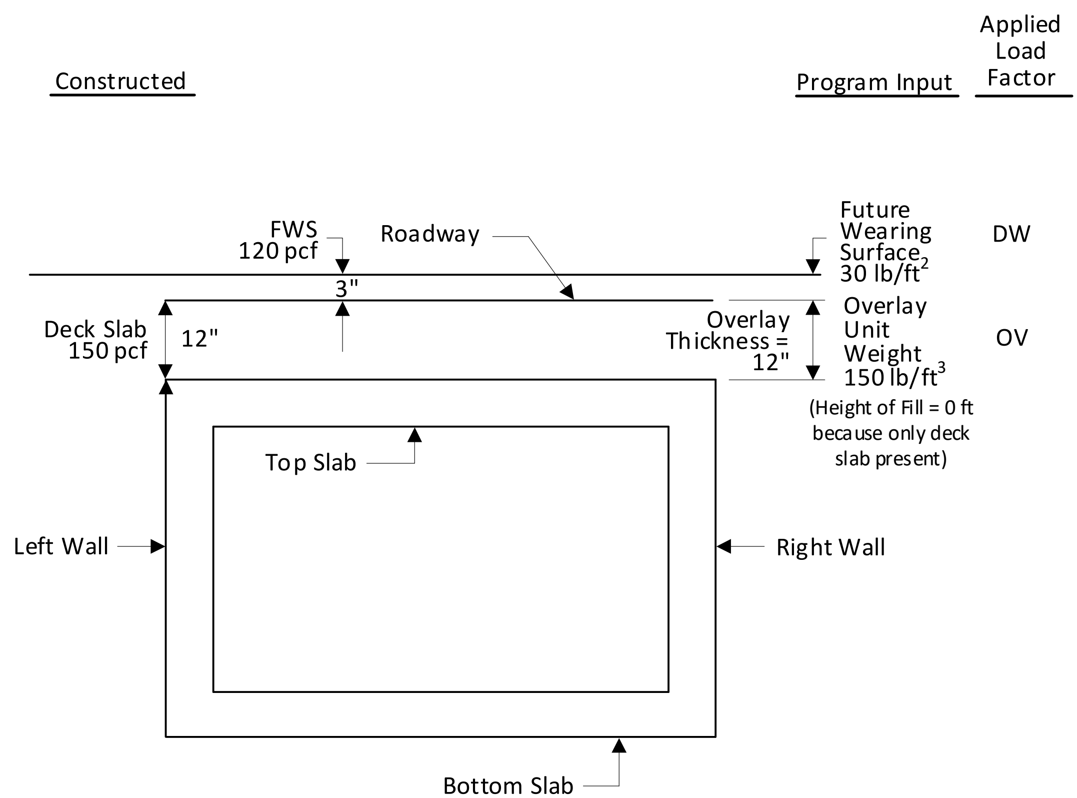


Figure 6.10-3 Overlay Input Example - Roadway to Top Slab ≤ 12"

Example 2: Overlay Slab and Fill, with Fill < 24"

Another case where a concrete slab is present is when there is asphalt pavement over a concrete distribution slab. In this case, the thickness of the asphalt pavement should be entered as the Height of Fill, and the thickness of the distribution slab entered as the Overlay Thickness, as shown in Figure 6.10-4.

In this example, the "Thru Fill" effect will not be applied for distributing the live load because the fill height is less than 2 feet. The program applies the DW load factor to the Future Wearing Surface load, the EV load factor to the Fill vertical loading, and the OV load factor to the Overlay vertical loading.

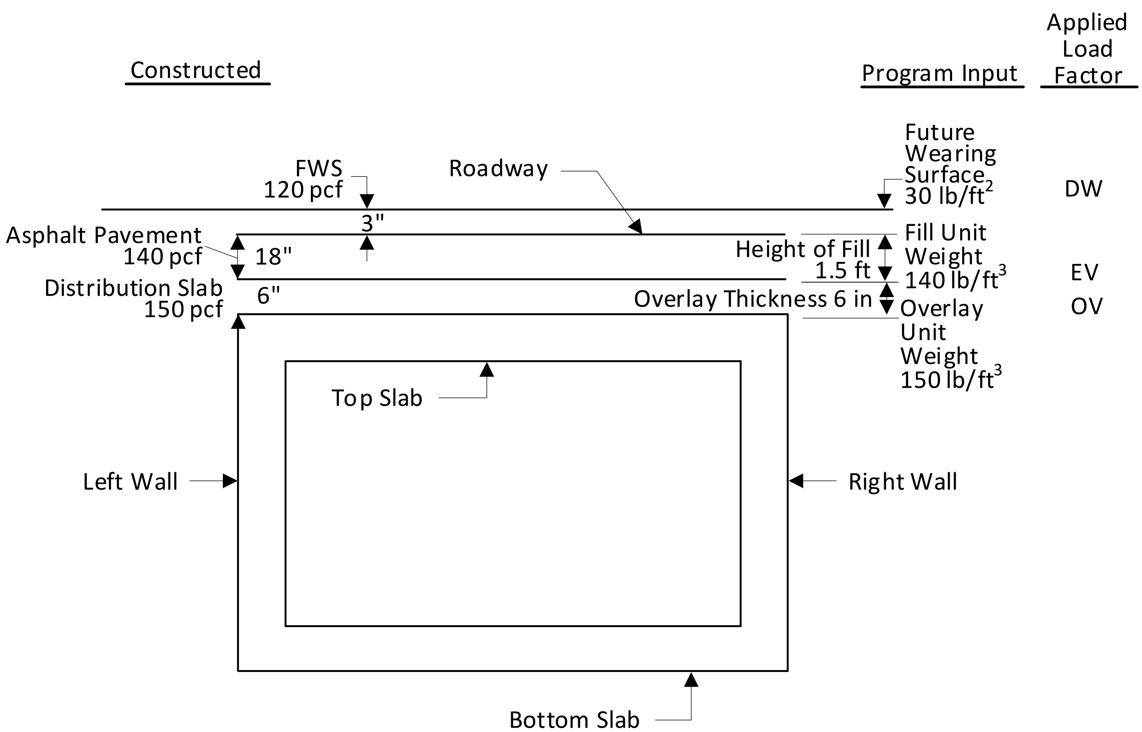


Figure 6.10-4 Overlay Slab and Fill Input Example - Fill Height < 24"

Example 3: Overlay Slab and Fill, with Fill ≥ 24"

A third case where a concrete slab is present is when there is a concrete pavement slab on top of fill. In this case, the thickness of the concrete pavement slab should be entered as the Overlay Thickness, and the thickness of the fill entered as the Height of Fill, as shown in Figure 6.10-5.

In this example, the "Thru Fill" effect will be applied for distributing the live load because the fill height is greater than or equal to 2 feet. The program applies the DW load factor to the Future Wearing Surface load, the EV load factor to the Fill vertical loading, and the OV load factor to the Overlay vertical loading.

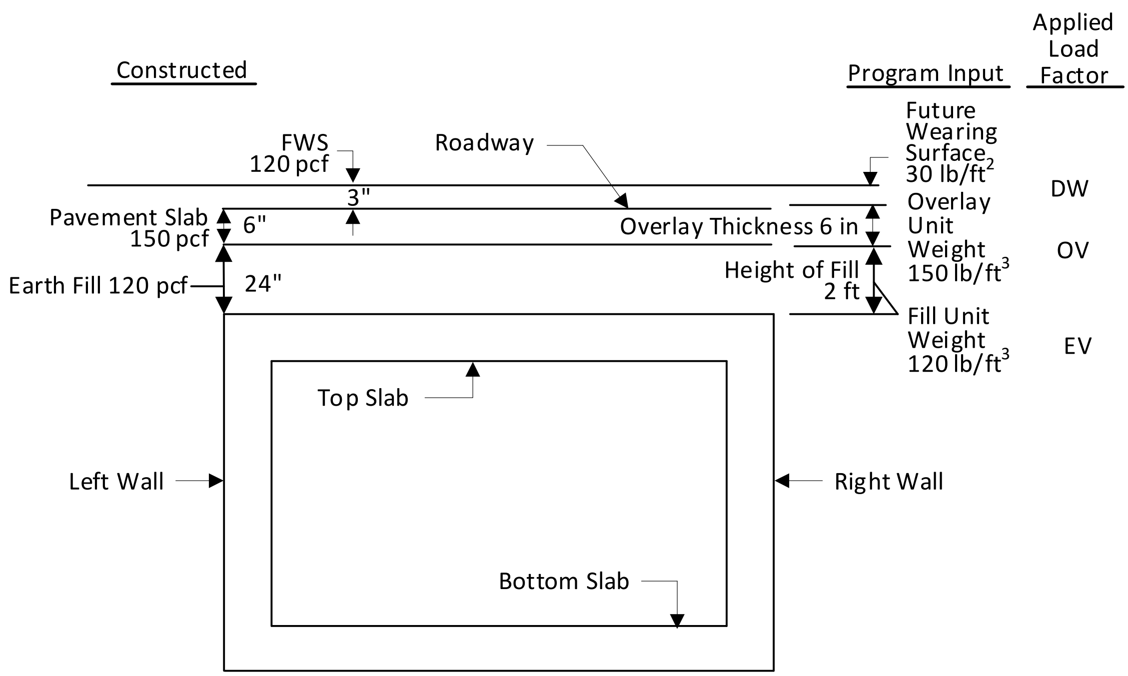


Figure 6.10-5 Overlay Slab and Fill Input Example - Fill Height ≥ 24"

6.10.8 Future Wearing Surface

This parameter is used to specify that a uniformly distributed loading applied to the top slab representing a future wearing surface. If specified, it gets applied to culverts at or below grade. The program assumes a value of zero for this parameter for an Analysis, and a value of 30 lbs/ft^2 for a Design, if it is left blank. A value of zero must be specified for a Design if the response of the culvert to a future wearing surface is to be ignored.

6.10.9 Maximum Live Load Distribution Length

This parameter is used to limit the distribution of live load to the portion of the culvert where it physically can be applied. For on-deck loading, it is the distance between the curbs. For the Thru Fill loading, it is the limits of maximum fill width on the culvert. For the on-deck case, and for cell lengths less than 15 feet, this parameter does not affect the solution. For cell lengths greater than 15 feet, the lateral distribution factor for the greater than one lane case is limited to this parameter divided by the number of design lanes. For the Thru-Fill case, the distribution factor for any number of lanes specified in parameter 5.10.3 is limited to this parameter.

6.10.10 Segment Length

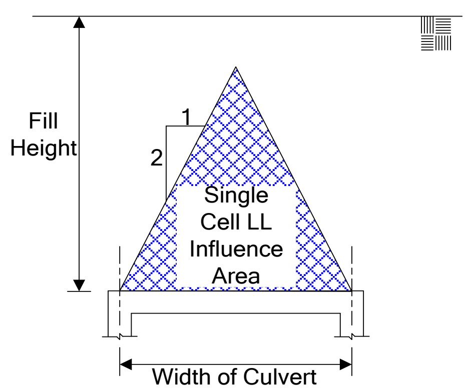
This parameter is used to limit the lateral distribution factors associated with the on-deck loading. This parameter does not affect the Thru-Fill loading. Value is also used to compute volume and weight in the quantities section of the output.

6.10.18 Live Load Override

To demonstrate the appropriate use of the live load override parameter, a description of the live load applicability is illustrated with the following conditions.

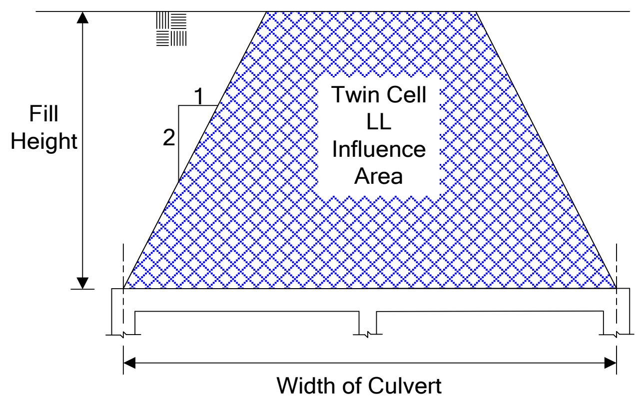
<u>Condition 1 – Single Cell Culvert – Fill Height > 8 feet & Culvert Width < Fill Height</u>

For this condition the Influence Area where live load would be applied to the culvert does not intersect with the ground line. In this case the program will not apply live load as the fill height is greater than the 8 feet and greater than the center to center width of the exterior walls. The live load override is not required for a single cell culvert that will be placed independently in the field (meaning it will not be adjacent to another culvert).



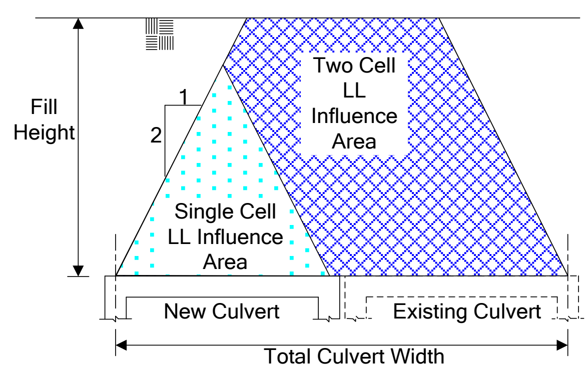
Condition 2 – Twin Cell Culvert – Fill Height > 8 ft & Culvert Width > Fill Height

For this condition the twin cell culvert Influence Area intersects the ground level because the height of fill is less than the width of the culvert between the center of the external walls. The program will automatically apply live load and the live load override is not required.



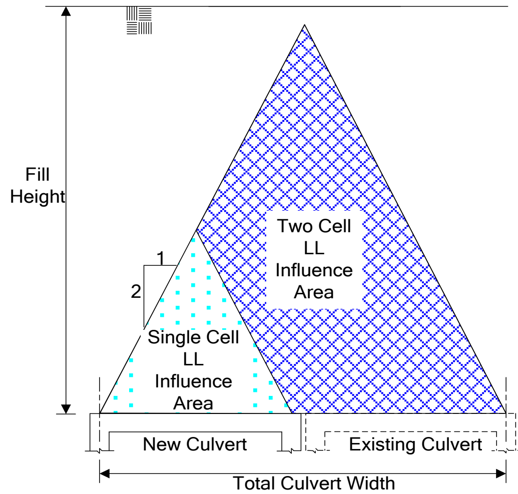
Condition 3 – Two Single Cell Culverts – Fill Height > 8 feet & Total Culvert Width > Fill Height

For this condition a single cell culvert is placed next to an existing single cell culvert. When considering for DM-4 Section 12.11.5.9P, the two single cell culverts will act as a single culvert as shown in the following diagram. The design width of culvert, which is used to determine application of live load, should be the total width of both culverts. In this diagram it can be seen that as a single cell culvert, the live load Influence Area does not intersect with ground level so Live Load would not be applied by the program, however, as a two cell culvert, the Influence Area intersects with the ground level indicating that live load should be considered during design and or analysis. For this condition the live load override must be used to force the program to consider live load for the single cell culvert.



Condition 4 – Two Single Cell Culverts – Fill Height > 8 feet & Culvert Width < Fill Height

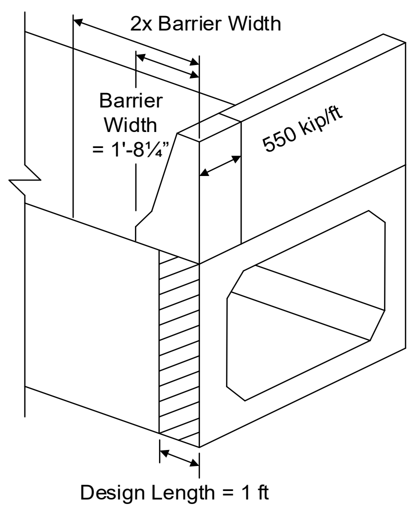
There are some cases where the live load override should not be used as even with the larger live load Influence Area, the culvert will not have any live load applied. The following figure shows a case were the live load override should not be applied because the height of fill exceeds the total culvert width.



The previous described conditions provide general guidelines of when the live load override factor should be used.

6.10.21 Barrier Dead Load

The barrier dead load may be assumed to be distributed over twice the width of the barrier.



Following this assumption, the Barrier Dead Load input for a Typical HT barrier (550 lb/ft) would be:

$$Barrier\ Dead\ Load = 0.550\frac{kips}{ft}PA\ HT\ Barrier\ Dead\ Load * \frac{1'\ Design\ Length}{2 * \left(1' - 8\frac{1}{4}"\ Barrier\ Width\right)}$$

$$Barrier\ Dead\ Load = 0.163\frac{kip}{ft}$$

6.23 FTR – FOOTING REINFORCEMENT COMMAND

Reinforcement Size or Wire Diameter

This parameter is used to specify a reinforcement bar size (if Reinforcement Type is "B") or wire diameter (if Reinforcement Type is "W"). Reinforcement must be specified for a Type of Run of AR, using either this command or the FTA command.

If the Reinforcing Type is "W", then BXLRFD interprets this parameter as a wire diameter and uses it as necessary, no conversion or translation is done.

6.24 TVA – TOP SLAB SHEAR REINFORCEMENT COMMAND

Command Variable Information
Shear Reinf. Area

This parameter is used to specify the shear reinforcement per unit length of culvert for the top slab. This parameter, along with the Spacing parameter, is used to compute the shear capacity of the shear reinforcement, V_s, during an Analysis (AR for Type of Run).

Spacing

This parameter is used to specify the spacing of the shear reinforcement along the top slab. This parameter, along with the Shear Reinf. Area parameter, is used to compute the shear capacity of the shear reinforcement, V_s, during an Analysis (AR for Type of Run). Section 3.6 and specifically LRFD Specifications Section 5.7.3.3 shows how V_s is computed for a single shear reinforcing bar (spacing = 0) and for multiple shear rebars (spacing > 0).

Additional Procedural Information

This section is provided to help explain how the BXLRFD program displays shear reinforcement design and how to enter that information in an analysis problem. Information will be provided on where the program checks shear based on culvert type, and how to determine if a failed Live Load Rating is due to incorrectly set shear reinforcement regions.

Determining the Shear Region

Prismatic Culvert with and without haunches

For a prismatic culvert, the BXLRFD program determines the shear regions based on the calculation of d_v, **the effective shear depth,** and whether the culvert has haunches. For a culvert with haunches the start of the shear region is the distance d_v from the end of the haunch (see Figure 1). When there is not a haunch present, the shear region starts at distance d_v from the face of the wall (see Figure 1).

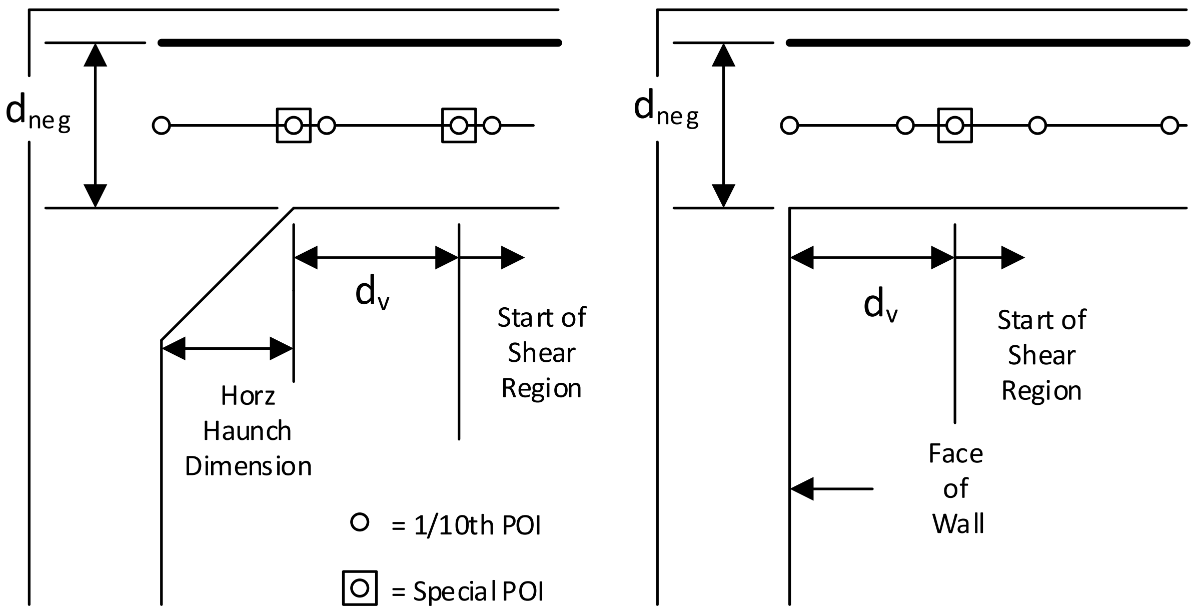


Figure 6.24-1 Shear Region Location on a Prismatic Culvert With and Without Haunch

Note: **The effective shear depth, d_v, is a function of the effective depth, d_e. Refer to User Manual section 3.5.5 for calculation of d_v. The effective depth is computed for both the positive reinforcement, d_{pos}, and the negative reinforcement, d_{neg}. For this example, the corresponding moment with the maximum shear is assumed to be negative (the typical condition) and calculations use d_{neg}.**

For Design d_{neg} is calculated using the maximum bar size.

For Analysis d_{neg} is calculated using the entered flexural bar size.

Non-Prismatic Culvert with and without haunches

The calculation of the shear regions for the non-prismatic culvert is like the prismatic except the change in slab grade provides two different d_{neg} values. The d_v for both ends of the slab must be calculated and then 1/2 d_v is used to locate the beginning of the shear region on each end of the slab respectively (see Figure 2).

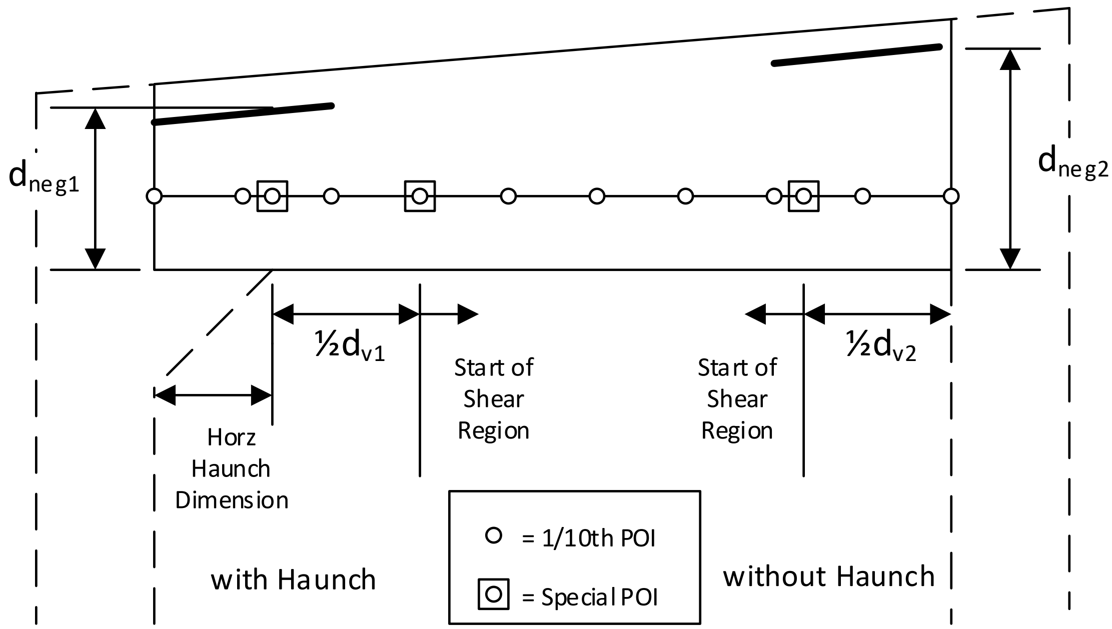


Figure 6.24-2 Shear Region Location and d_{neg} on a Non-Prismatic Culvert With and Without Haunch

Culvert with a Standard Fish Channel

When a standard fish channel is present in the bottom slab of a culvert, the location of the shear region is determined by treating the short 45^{o} side as a haunch. By calculating d_{neg} for the haunch end and using 1/2 d_v from the end of the haunch, the start of the first shear region is set. The slab end opposite of the haunch is treated as a slab with grade taking **one-**half d_v from the face of the wall to set the shear area (see Figure 3).

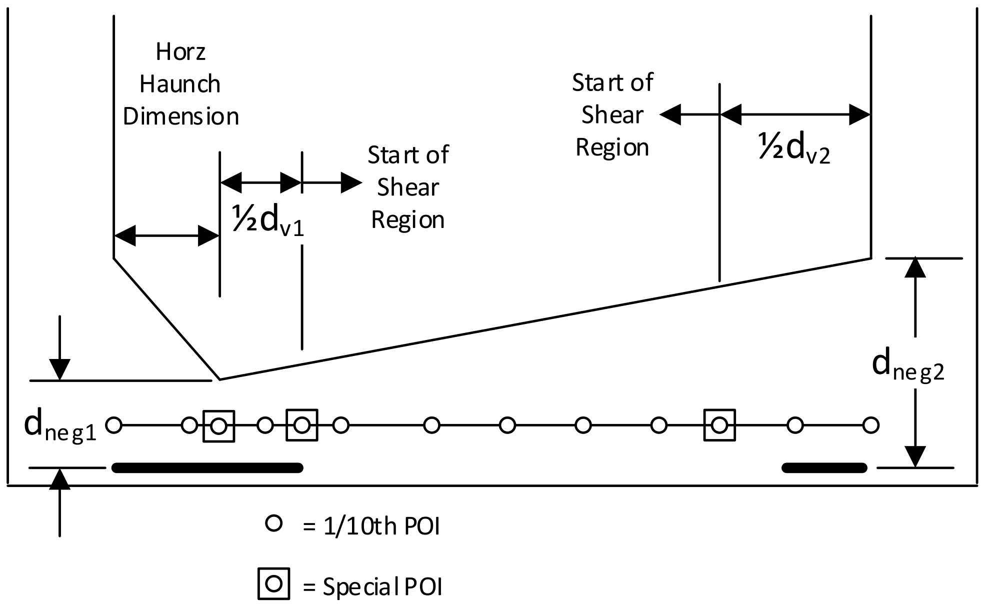


Figure 6.24-3 Shear Region Location on a Culvert With a Standard Fish Channel

Culvert with a Non-Standard Fish Channel

A culvert with a non-standard fish channel is treated as a slab with a grade. Both d_{neg}'s are calculated independently and 1/2 d_v is used from the face of the wall to set the shear region on both sides.

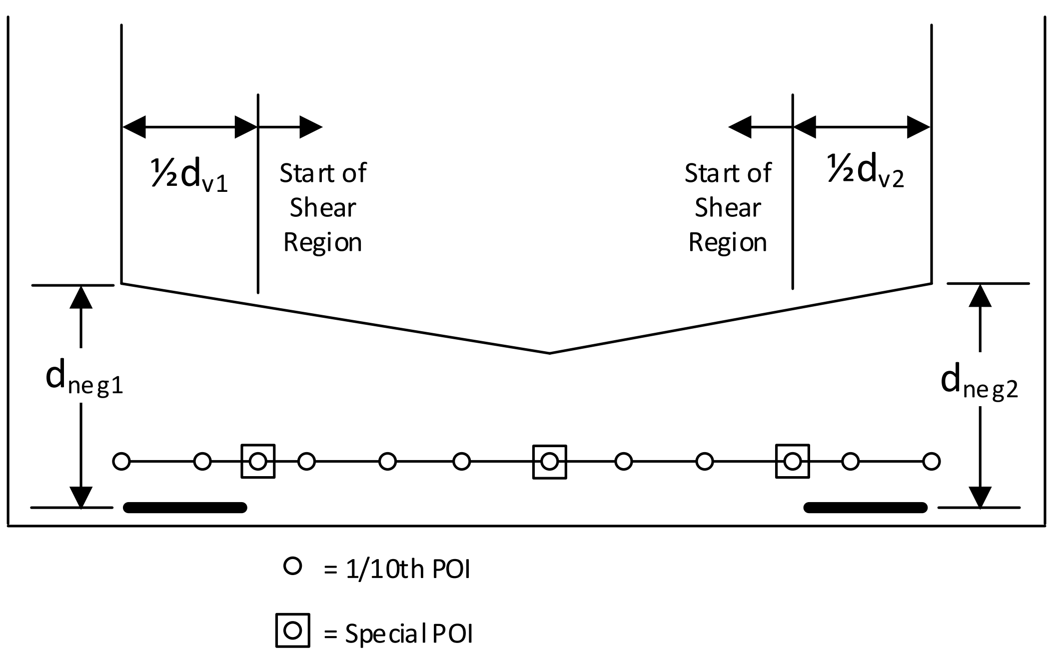


Figure 6.24-4 Shear Region Location on a Culvert With a Non-Standard Fish Channel

<u>Checking if the Shear Region was set incorrectly and caused a Rating Failure</u>

When a design is produced in the BXLRFD program and is run as an analysis problem it is important to make sure that the shear regions are being defined correctly. This text will provide guidelines to enter the shear region from a design output, and how to check the shear regions in an analysis output file.

Below is the typical output from a design run that has been set to design the shear reinforcement. The distances marked 1 and 4 represent the beginning of the first region and the end of the second region as design in the program. The locations marked in rectangles show the locations where shear reinforcement becomes unnecessary in the slab. By following the lines to the distance column marked 2 and 3, these values represent the end of the first region and the start of the second.

```
     LRFD Box Culvert Design and Rating, Version 2.2.0.0                PAGE  23
     Input File: aaaaa.DAT                                       xx/xx/xx  xx:xx:xx
     ---------------------------------------------------------------------------

                                    SHEAR DESIGN
     ---------------------------------------------------------------------------

                                   Top Slab No. 1

              Shear                                                Conc+
             Loading        Factored          Flex      Shear      Shear      Shear
      Dist     Code       Shear     Moment    Reinf     Depth      Capac      Reinf
      (ft)   A B C D     (kips)   (kips-ft)   (in^2)    (in)      (kips)     (in^2)
1     1.22   1 6 1 1    -16.29     -12.16      1.17      8.23      10.80      0.192
      2.00   1 6 1 1    -15.46      -4.52      1.17      8.23      10.80      0.170
      4.00   1 6 1 1    -13.08      14.01      1.17      8.23      10.80      0.104
2     6.00   1 6 1 1    -10.49      28.27      1.17      8.23      10.80      0.034
      8.00   1 6 1 1     -7.80      36.74      1.17      8.23      10.80      0.000
     10.00   1 6 1 1     -5.14      38.83      1.17      8.23      10.80      0.000
3    12.00   1 5 1 1      7.77      36.43      1.17      8.23      10.80      0.000
     14.00   1 5 1 1     10.46      28.03      1.17      8.23      10.80      0.033
     16.00   1 5 1 1     13.06      13.81      1.17      8.23      10.80      0.104
4    18.00   1 5 1 1     15.45      -4.76      1.17      8.23      10.80      0.169
     18.78   1 5 1 1     16.29     -12.44      1.17      8.23      10.80      0.192
```

It is important to note that when the program produces a design run, it will calculate the d_v based on the maximum bar size entered on the MAT card. When the design is entered into an analysis run, the program will use the actual bar size entered for the flexural reinforcement to calculate d_v. This will produce variations between design and analysis and is the most probable cause of shear reinforcement issues.

The shear information provided from the design output can now be entered into the analysis input card TVA or BVA. To accurately set the shear regions it will most likely require two analysis runs. The first run will help to locate the analysis shear regions and redefine them for the next analysis run. For this example we will enter the design shear regions as shown, but shorten the end of the first region one POI distance so the rating fails.

Moved end region one POI back to provide a failed rating.

```
         1ST      1ST     AREA             2ND     2ND      AREA
 Slab   REGION   REGION    OF             REGION  REGION     OF
  No    START     END     STEEL  SPACING   START   END      STEEL   SPACING

TVA 1,    1.22,    6.00    0.20,   8.0,    12.00, 18.78,   0.20,     8.0
```

1 3 4

To view the location of the shear region the Live Load Rating Option must be set to 1 on the OUR card. This will display the rating for all POI's in the problem. We can see below that for our example the rating for shear at 6.00 feet has failed. It should be noted that looking over at the Reinforcement Column that no shear steel is present. This means that the shear region must be extended to the next POI, in this case we should set the end of the region to 8.00 feet It can be seen for the start of the region that the POI distance is 12.36 feet which is within the entered shear region.

```
LRFD Box Culvert Design and Rating, Version 2.2.0.0              PAGE  23
Input File: aaaaa.DAT                                    xx/xx/xx  xx:xx:xx
---------------------------------------------------------------------------

                              LIVE LOAD RATING
---------------------------------------------------------------------------

              PHL-93 Loading:    Top Slab No. 1

                                             Fact       Rating Factor
                   Fact     Fact     Fact    Resist       IR      OR
                  Moment   Thrust   Shear   (kips-ft)   STR-I   STR-IA    Reinf
 (ft)           (kips-ft)  (kips)   (kips)   (kips)                       (in^2)
  0.50 DL+E      -11.17     4.12            -53.32 F2   1.61              1.60 T
       LL+I      -26.16     1.14
       DL+E      -11.01     3.52            -53.39 F2           2.58      1.60 T
       LL+I      -16.44     0.72
  1.25 DL+E       -8.07     4.12    -3.99   -53.19 F2   2.32              1.60 T
       LL+I      -19.46     1.18   -12.29   -64.32 V6   1.27              0.20
       DL+E       -7.91     3.52    -3.99   -53.27 F2           3.71      1.60 T
       LL+I      -12.23     0.74    -7.72   -53.08 V6           2.02      0.20
  2.00 DL+E       -5.16     4.12    -3.64   -52.72 F2   3.46              1.60 T
       LL+I      -13.76     1.83   -11.82   -64.32 V6   1.35              0.20
       DL+E       -5.00     3.52    -3.64   -52.79 F2           5.52      1.60 T
       LL+I       -8.65     1.15    -7.43   -64.32 V6           2.15      0.20
  4.00 DL+E        2.02     1.39    -2.73    53.60 F1   3.88              1.60 B
       LL+I       13.03    -0.99   -10.34   -64.32 V6   1.63              0.20
       DL+E        2.02     1.39    -2.73    52.60 F1           6.17      1.60 B
       LL+I        8.19    -0.62    -6.50   -64.32 V6           2.59      0.20
  5.25 DL+E        6.58     1.39    -1.82    53.62 F1   2.07              1.60 B
       LL+I       22.76     1.12    -8.66   -30.35 V6   0.86              0.00
       DL+E        6.58     1.39    -1.82    53.62 F1           3.29      1.60 B
       LL+I       14.30     0.71    -5.44   -30.35 V6           1.36      0.00
  8.00 DL+E        9.33     1.39    -0.92    53.56 F1   1.54              1.60 B
       LL+I       28.80     1.78    -6.89   -30.35 V6   1.                0.00
       DL+E        9.33     1.39    -0.92    53.56 F1           2.44      1.60 B
       LL+I       18.10     1.12    -4.33   -30.35 V6           1.93      0.00
```

This POI is the shear region start location. It is within the region entered for the analysis run.

Location where the rating fails

When producing an analysis run with an existing culvert that contains shear reinforcement it is recommended to check the Live Load Rating report to make certain that the shear regions are correct. By utilizing the checking method described, the chances of having a culvert not rate due to shear regions is greatly reduced.

6.25 BVA – BOTTOM SLAB SHEAR REINFORCEMENT COMMAND

The BVA command is similar to the TVA command. See Section 6.24 – TVA – Top Shear Reinforcement Command

6.26 WVA – BOTTOM SLAB SHEAR REINFORCEMENT COMMAND

The BVA command is similar to the TVA command. See Section 6.24 – TVA – Top Shear Reinforcement Command

6.27 OIN - OUTPUT OF INPUT COMMAND

The defaults for this command are dependent on whether an analysis or design run is being generated. A summary of the defaults is presented in Table 1. Also presented in Table 1 is a list of the output tables printed with each parameter.

Table 6.27-1 Summary of Defaults for OIN Command

PARAMETER	OUTPUT TABLES INCLUDED	DEFAULTS	
		ANALYSIS RUN	DESIGN RUN
1. Input File Echo	INPUT DATA FILE ECHO	0	0
2. Input Commands	COMMAND LINE INPUT	0	0
3. Input Summary	Summary of All Input Commands	1	1

6.28 OUR - OUTPUT OF RESULTS COMMAND

The defaults for this command are dependent on whether an analysis or design run is being generated. A summary of the defaults is presented in Table 1. Also presented in Table 1 is a list of the output tables printed with each parameter.

Table 6.28-1 Summary of Defaults for OUR Command

PARAMETER	OUTPUT TABLES INCLUDED	DEFAULTS	
		ANALYSIS RUN	DESIGN RUN
1. Section Properties	GROSS SECTION PROPERTIES	0	0
2. Live Load Rating	LIVE LOAD RATING	0	N/A
3. Rating Summary	RATING SUMMARY	1	N/A
4. DL Effects and Capacities	DEAD LOAD EFFECTS AND CAPACITIES	1	N/A
5. Flexural Reinforcement	DESIGN OF REINFORCEMENT	N/A	1
6. Shear Design	SHEAR REINFORCEMENT	N/A	1
7. Foundation Pressure	FOUNDATION PRESSURE	0	0
8. Quantities	QUANTITIES	1	1
9. Serviceability Table	SERVICABILITY TABLE	0	N/A
10. Serviceability Summary	SERVICEABILITY SUMMARY	1	N/A
11. Foundation Pressure Summary	FOUNDATION PRESSURE SUMMARY	1	1
12. Minimum Reinforcement Check	MINIMUM REINFORCEMENT CHECK	1	1

Note: N/A means option is not available.

6.29 OUI - OUTPUT OF INTERMEDIATE DATA COMMAND

The defaults for this command are dependent on whether an analysis or design run is being generated. A summary of the defaults is presented in Table 1. Also presented in Table 1 is a list of the output tables printed with each parameter. Parameters 18 (CMO1) and 19 (CMO2) give the same information as Parameters 2 and 7, respectively, except the information is formatted for easy import into spread sheets. Parameter 20 (ASC1) gives the same information as Parameter 3, except the information is formatted for easy import into spread sheets.

Table 6.29-1 Summary of Defaults for OUI Command

PARAMETER	OUTPUT TABLES INCLUDED	DEFAULTS	
		ANALYSIS RUN	DESIGN RUN
1. General POI Data	GROSS SECTION PROPERTIES	0	0
2. Non-Live Load Results	NONLIVE LOAD RESPONSE	0	0
3. Influence Lines	INFLUENCE LINES	0	0
4. Truck Responses	TRUCK RESPONSES	0	0
5. Truck Through Fill Responses	TRUCK THROUGH FILL RESPONSES	0	0
6. Lane Responses	LANE RESPONSES	0	0
7. Envelope Responses	ENVELOPE RESPONSES	0	0
8. Limit State Dead Load Results	LIMIT STATE DEAD LOAD RESPONSES	0	0
9. Limit State Live Load Results	LIMIT STATE LL AND LL+DL RESPONSES	0	0
10. Bar Table Results	REINFORCEMENT DESIGN	0	0
11. Limit State Section Capacities	LIMIT STATE SECTION CAPACITY RESULTS	0	0
12. Limit State Rating Factors	LIMIT STATE RATING FACTOR RESULTS	0	0

Table 6.29-1 Summary of Defaults for OUI Command (Cont.)

PARAMETER	OUTPUT TABLES INCLUDED	DEFAULTS	
		ANALYSIS RUN	DESIGN RUN
13. Limit State Resistance/ Demand Ratios	LIMIT STATE RESISTANCE/DEMAND RATIOS	0	0
14. Limit State Allowable Spacing	LIMIT STATE ALLOWABLE SPACING RESULTS	0	0
15. Limit State Service Stresses	LIMIT STATE SERVICE STRESS RESULTS	0	0
16. Stiffness Analysis Model	NODE POINT COORDINATES BOUNDARY CONDITION INFORMATION EQUATION/NODE NUMBER MAPPING ELEMENT CONNECTIVITY ELEMENT SECTION PROPERTIES	0	0
17. Stiffness Analysis Results	STATIC_DISP STATIC_FORCES	0	0
18. CMO1 (Non-live Load)	NON-LIVE LOAD RESPONSES	0	0
20. ACS1 (Influence Lines)	INFLUENCE LINES	0	0
21. Soil Pressure	STRIP FOOTING RESULTS	0	0

7 OUTPUT DESCRIPTION

This chapter describes the various reports that are generated by BXLRFD. Individual reports are included in the output file by requesting them using the OIN and OUR commands discussed in Sections 5.27 and 5.28, respectively. If the OIN and OUR commands are not specified, a standard set of reports is produced. It consists of:

Input Summary
Rating Summary
Dead Load Effects and Capacities (for when live load is not applicable)
Design of Reinforcement
Shear Design
Foundation Pressure
Quantities

Some of the above listed reports are applicable to an ANALYSIS and some to a DESIGN, and some to both.

7.1 GENERAL OUTPUT INFORMATION

Information is provided for describing output table controls, page format, page numbering, and page header. In general, the page format is built into the program and cannot be changed by the user for either the .OUT output file or the .PDF output file. The one exception is that the user can specify the number of blank lines to be printed at the top of each page before the page header is printed. This formatting change will be reflected in both the .OUT and .PDF output files accordingly.

7.1.1 Output Table Controls

The output table controls are specified using several input commands and parameters to control which output reports will be printed. These controls are specified using three different input commands, according to which kind of output they represent. These three kinds of output are: input data, analysis and design results, and intermediate results. The commands and their defaults are discussed in Sections 6.27 through 6.29.

7.1.2 Page Format

There is a maximum of 99 columns in the output file. Column 1 has been left blank because it is reserved for print characters. The output is therefore limited to 98 characters: column 2 to column 99. The user can specify the number of lines to be left blank at the top of the page with the CFG command.

7.1.3 Page Numbering

The program assigns page numbers and determines when a new page should begin. There are certain rules built into the program to determine when a new page should begin. The program will attempt to fit up to the number of lines specified on the CFG command on each page. Internally, the program keeps track of how many lines are left on the page and adjusts according to the number of lines in the heading of the output table and a minimum number of data lines required after the heading.

7.1.4 Page Header

After the cover page, header information is printed at the top of each page. A sample header is shown in Figure 1.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                        PAGE x
Input File: xxx.DAT                                                          xx/xx/xxxx  xx:xx:xx
-------------------------------------------------------------------------------------------------
                                   BXLRFD EXAMPLE PROBLEM #x
                                       ECHO OF INPUT FILE
-------------------------------------------------------------------------------------------------
```

Figure 7.1.4-1 Page Header

Information printed in the header includes:

1. Program Title, Version Number - the program name and version number is located at the top left corner of the header.
2. Page Number - the page number appears at the top right corner of the header.
3. Input File - the name of the input data file used to create this output is shown at the beginning of the second line.
4. Date and Time - the data and time of the program execution for this problem is printed at the right side of the second line.
5. A separator line is printed between program specific header information and user specified header information.
6. The next header line contains the first title line input by the user via the TTL command. This should be a general descriptive line used to describe the problem to be run.

7. The next header line contains the type of output specified by the user.
8. The final header line is another separator line.

7.1.5 Units

For each value presented in the output, the corresponding units are provided. The units are presented in the column headings directly below the column description. Presented in Table 1 is a summary of the basic units of measure used by this program.

Table 7.1.5-1 Units

Variable	Unit of Measure
AREA	in^2
AXLE LOAD	kips
AXLE SPACING	ft
CLEAR SPAN	ft
CLEAR HEIGHT	ft
CONCRETE CLEAR COVERS	in
CONCRETE DENSITY or UNIT WEIGHT	lbf/ft^3
DIAMETER	in
DISTANCE ALONG SLAB OR WALL	ft
DISTRIBUTED LOAD	kip/ft
FILL **UNIT** WEIGHT	lbf/ft^3
FISH CHANNEL DIMENSIONS	in
FORCE	kips
FUTURE WEARING SURFACE	lbf/ft^2
f 'c	ksi
GAGE DISTANCE	ft
HAUNCH DIMENSIONS	in
LANE LOAD	kip/ft
LANE WIDTH	ft
LIVE LOAD SURCHARGE	ft
MASS	N/A
MODULUS OF ELASTICITY	ksi
MOMENT	kip-ft
MOMENT OF INERTIA	in^4
OVERLAY **UNIT** WEIGHT	lbf/ft^3
PASSING DISTANCE	ft

Variable	Unit of Measure
REINFORCEMENT AREA	in^2/ft
REINFORCEMENT SPACING	in
ROTATION	radians
SHEAR	kips
STRESS	ksi
THICKNESS	in
WEIGHT	lbf
WIDTH	in

7.1.6 Sign Conventions

The sign convention used for forces and moments associated with each culvert component is shown in Figures 1, 2 and 3. This convention is as follows:

Moment: Positive when it produces tension in the bottom fiber of a slab or in a right most fiber of a wall.

Shear: Positive when it decreases the moment going from left to right on slabs, or bottom to top on walls.

Load: Positive where it acts towards the culvert.

Axial Force: Positive when it produces compression in the section.

Stress: Positive when it is tensile.

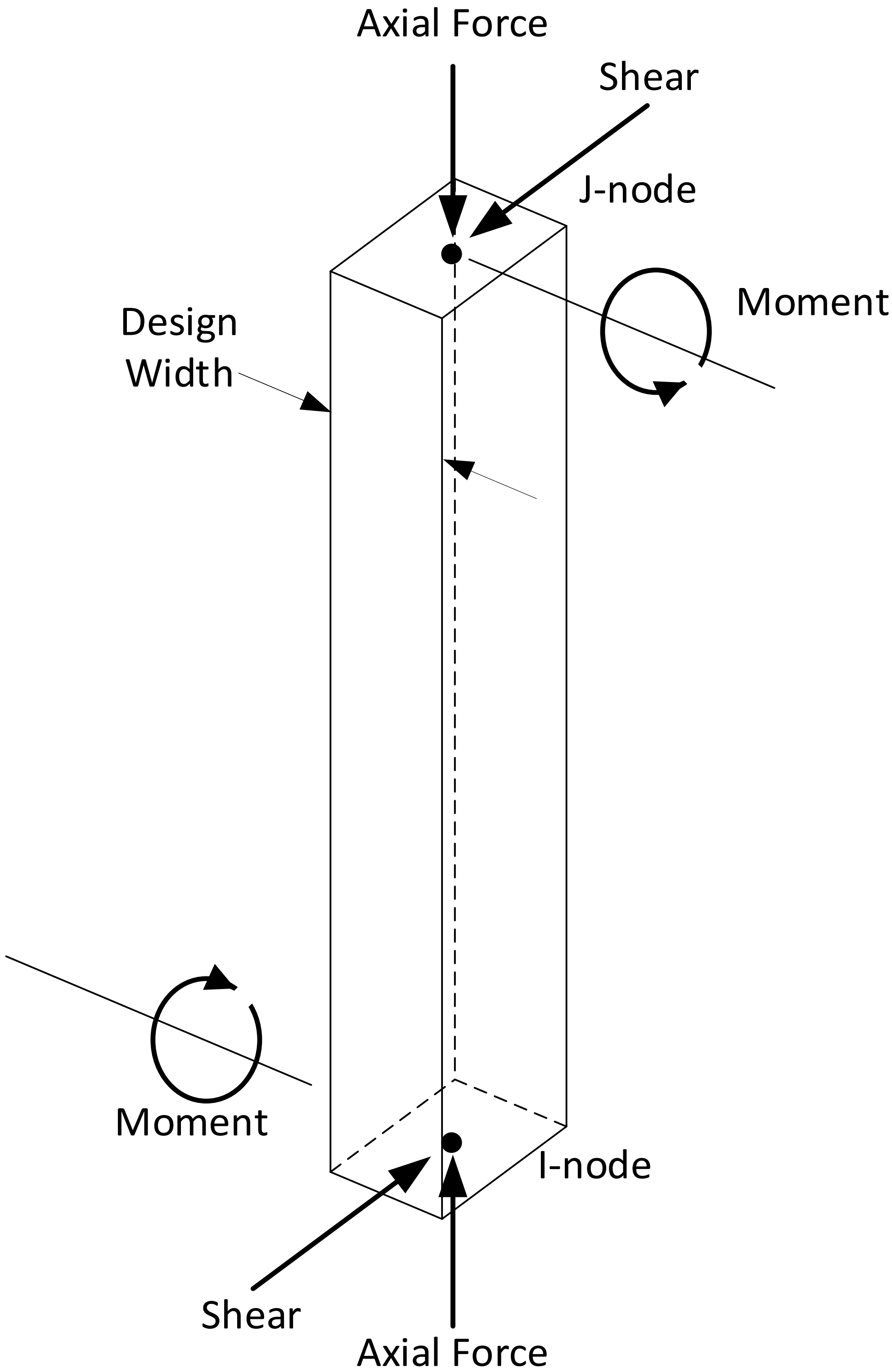


Figure 7.1.6-1 Positive Sign Convention for Axial/Shear/Moment in Walls

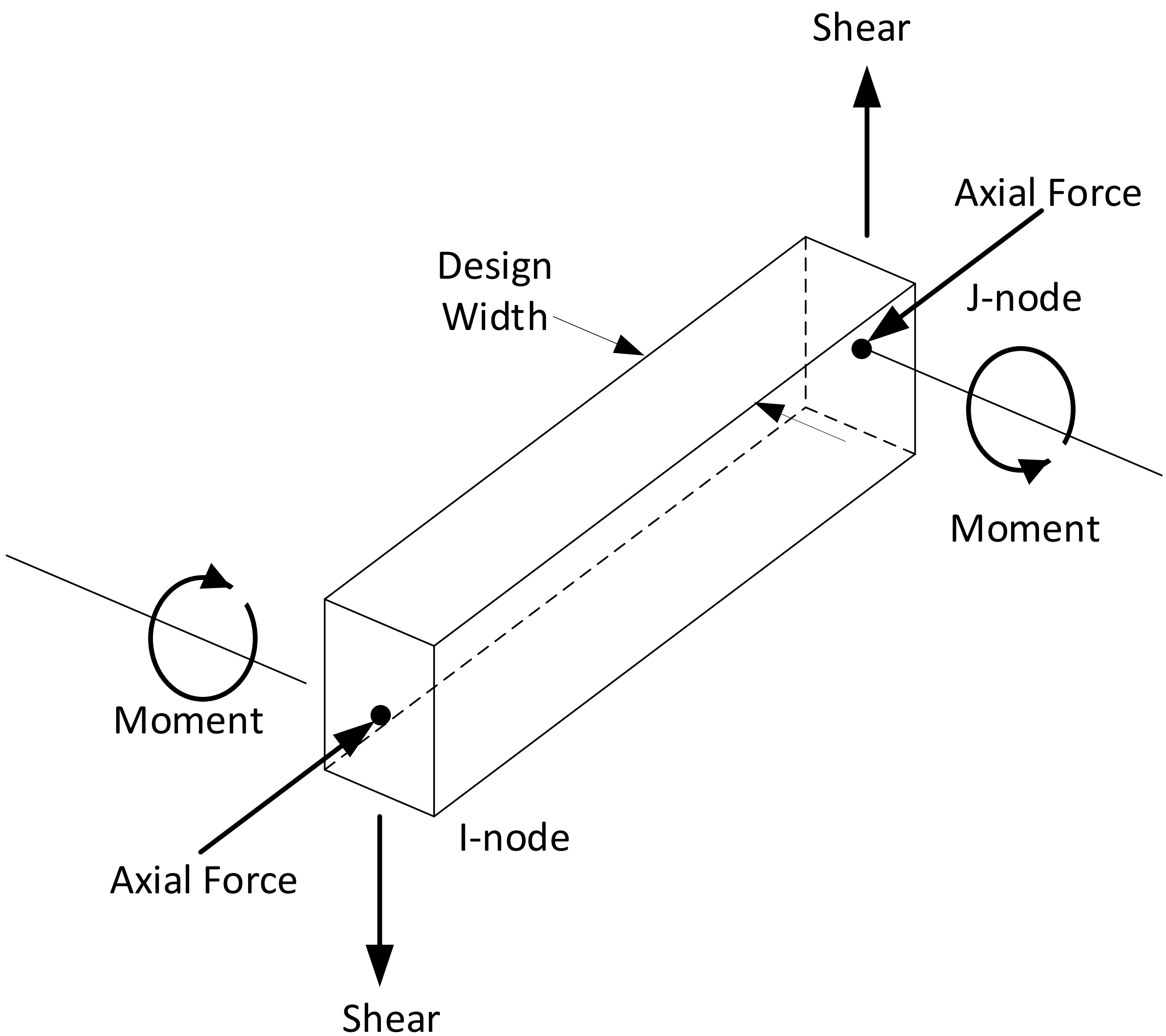


Figure 7.1.6-2 Positive Sign Convention for Axial/Shear/Moment in Slabs

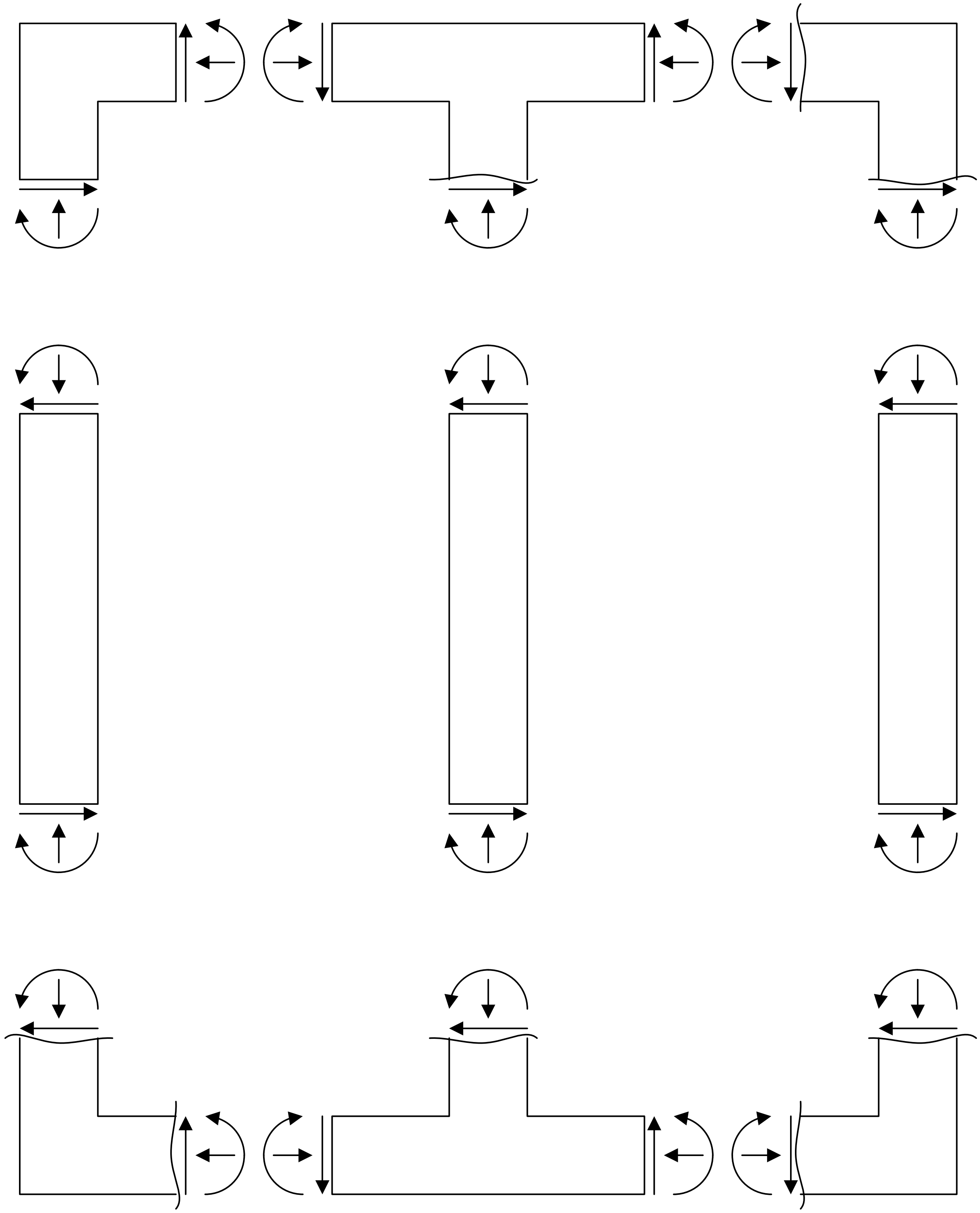


Figure 7.1.6-3 Positive Sign Convention for Axial/Shear/Moments

7.2 COVER PAGE

The first page of the output is the cover page. The following information is shown at the top of the cover page:

1. Program Title - LRFD Box Culvert Design and Rating
2. Program Name - BXLRFD
3. Version ii.nn - where ii represents the numeric designation for major revisions and enhancements to the program and nn represents the numeric designation for minor revisions.
4. Last Updated - this is the date the program was last revised.
5. Documentation - this is the date the User’s Manual was last revised.
6. License Number - this is a unique number assigned to all licensees per the License Agreement.

The middle section of the cover page is reserved for the first 10 TTL commands input by the user. This information typically should describe the bridge, location, stationing, span length, type of structure, and any other information the user would need to identify the output.

The copyright notice is placed at the bottom of the cover page. This is the standard copyright notice and warranty disclaimer which is printed by all PennDOT programs. Per the license agreement, any duplications, alterations, or unauthorized use of these materials is strictly prohibited. A sample Cover Page is shown in Figure 1.

```
*********************************************************************************************************
*                                                                                                       *
*  Program Title         LRFD Box Culvert Design and Rating                                             *
*  Program Name          BXLRFD                                                                         *
*  Version               x.x.x.x                                                                        *
*  Last Updated          xx/xx/xxxx                                                                     *
*  Documentation         xx/xxxx                                                                        *
*  License No.           xxxxxx                                                                         *
*                                                                                                       *
*********************************************************************************************************
*                                                                                                       *
*   Line  1 - This is the first   TTL line of the ten allowed                                           *
*   Line  2 - This is the second  TTL line of the ten allowed                                           *
*   Line  3 - This is the third   TTL line of the ten allowed                                           *
*   Line  4 - This is the fourth  TTL line of the ten allowed                                           *
*   Line  5 - This is the fifth   TTL line of the ten allowed                                           *
*   Line  6 - This is the sixth   TTL line of the ten allowed                                           *
*   Line  7 - This is the seventh TTL line of the ten allowed                                           *
*   Line  8 - This is the eighth  TTL line of the ten allowed                                           *
*   Line  9 - This is the ninth   TTL line of the ten allowed                                           *
*   Line 10 - This is the tenth   TTL line of the ten allowed                                           *
*                                                                                                       *
*********************************************************************************************************
*                                                                                                       *
*                                    COPYRIGHT (C) 1997-20xx                                            *
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*      ACCOMPANYING DOCUMENTATION.                                                                      *
*                                                                                                       *
*********************************************************************************************************
```

Figure 7.2-1 Cover Page

7.3 INPUT DATA

The input data consists of an echo of the input file, summary of input commands, and input summary tables. Each of these can individually be turned on or off. A summary of the output tables included is given in Section 6.26.

7.3.1 Input File Echo

The input file echo is a listing of the input commands and comments as entered by the user. The user can refer to this section to trace input errors and warnings by comparing the input data to the input descriptions provided in Chapter 5. The input file can contain 256 characters in a single line, but the output is limited to 75 characters on a single line. If the input line contains more than 75 characters, the input file echo will be wrapped to the next row. Other than this limitation, the echo of the input file should appear the same as the input data file. A sample Input Echo Report is shown in Figure 1.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                        PAGE x
Input File: xxx.DAT                                                          xx/xx/xxxx  xx:xx:xx
-------------------------------------------------------------------------------------------------
                    Line  1 - This is the first   TTL line of the ten allowed
                                        ECHO OF INPUT FILE
-------------------------------------------------------------------------------------------------

                                             EX1A.DAT
                                             --------
!
! ** Created by EngAsst **
! EngAsst Information: [Program=BXLRFD] [Version=x.x.x.x]
! ** Data Records Start Here **
TTL Line  1 - This is the first   TTL line of the ten allowed
TTL Line  2 - This is the second  TTL line of the ten allowed
TTL Line  3 - This is the third   TTL line of the ten allowed
TTL Line  4 - This is the fourth  TTL line of the ten allowed
TTL Line  5 - This is the fifth   TTL line of the ten allowed
TTL Line  6 - This is the sixth   TTL line of the ten allowed
TTL Line  7 - This is the seventh TTL line of the ten allowed
TTL Line  8 - This is the eighth  TTL line of the ten allowed
TTL Line  9 - This is the ninth   TTL line of the ten allowed
TTL Line 10 - This is the tenth   TTL line of the ten allowed
CTL US,1,AR,P,Y,M
SID =BXLRFD,50,666,555,9996,654
MAT 5.0,,60.0,W,90.0,0.6
DIM 9.0,6.0,9.0,9.5,9.0,9.0,0.0,0.0,0.0
LDC 120.0,5.0,1,3.0,A,0.0,0.0,0.0,25.,12.,,,,1.0,1.0,1.0,,,,,,,,,,,,2
HCH 6.0,6.0,6.0,6.0,6.0,6.0,6.0,6.0,0.,0.,0.,0.
CVR 2.0,1.5,2.0,1.5,1.5,0.0,0.0
TSR 1,T,9.0,0.75,20.5
TSR 1,B,9.0,0.75,9.5
BSR 1,T,9.0,0.75,8.5
BSR 1,B,9.0,0.75,44.0
WLR 1,L,3.0,0.75,18.0,6.0,0.75,14.0
WLR 1,R,6.0,0.75,14.0
```

Figure 7.3.1-1 Input Echo

7.3.2 Input Commands

This section is a summary that includes a detailed description of each input parameter for all input commands entered by the user. The summary of input commands is in a vertical format. A sample Input Commands Report is shown in Figure 1.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                    PAGE x
Input File: xxx.DAT                                                       xx/xx/xxxx  xx:xx:xx
-------------------------------------------------------------------------------------------------
                    Line  1 - This is the first   TTL line of the ten allowed
                                      SUMMARY OF INPUT FILE
-------------------------------------------------------------------------------------------------

    COMMAND:  CTL
      SYSTEM OF UNITS                     US
      STRUCTURE TYPE                       1
      TYPE OF RUN                         AR
      BOX CULVERT PC OR CIP                P
      BOTTOM SLAB                          Y
      TOP SLAB SUPPORT                     M
      FRAME SUPPORT                        *        (computed, if necessary)
      STRIP FOOTING PC OR CIP              *        (computed, if necessary)

    COMMAND:  SID
      PROGRAM IDENTIFICATION         =BXLRFD
      COUNTY                              50
      STATE ROUTE                        666
      SEGMENT                            555
      OFFSET                            9996
      SPAN IDENTIFICATION                654

    COMMAND:  MAT
      f'c FOR ALL MEMBERS                5.0 ksi
      f'c FOR TOP SLAB AT GRADE            * ksi    (computed, if necessary)
      REINFORCEMENT GRADE               60.0 ksi
      REINFORCEMENT TYPE                   W
      ALPHA                             90.0 degrees
      REBAR SIZE OR WIRE DIAM            0.6 *
      EPOXY COATED                         Y            (default)
      DENSITY OF CONC. FOR DL          150.0 lb/ft^3    (default)
      DENSITY OF CONC. FOR E           145.0 lb/ft^3    (default)
      REINF ULT TENS STRENGTH              * ksi    (computed, if necessary)
```

Figure 7.3.2-1 Sample Input Command Report

The summary of input commands includes the following information:

1. Command keyword.
2. Input parameter description.
3. Value of the input parameter as entered or the default value as stored in the program. The value is displayed to the same number of significant figures as entered by the user or as stored in the input parameter file. The word (default) is placed to the right of the units when default values are used. An asterisk (*) indicates the input value is optional and was not entered.
4. Units if applicable.
5. Any warnings or errors encountered with respect to the input data.

Input values may be optional or required. Required input is input that is entered by the user or set to the default value stored in the program. Default values are indicated with the text (default) placed to the right of the units. If there is no default value stored in the program and the user does not enter a value, an error message is displayed.

Optional input does not need to be entered by the user. An asterisk (*) is printed for the value indicating the input value is optional. In some cases when input is not entered, the program sets the value. An example of an optional input parameter set by the program is the reinforcement cover. Some input is optional because it is not required for the particular problem being run. For example, the footing dimension is not required for a closed box analysis. For more information regarding specific input requirements, refer to Chapter 5.

Any warnings or errors encountered while processing the input data will be reflected with the appropriate input command under the summary of input commands. If this level of input data output is turned off, the warnings will still appear, though without the added benefit of the warnings and errors being grouped with the corresponding input command. After encountering warnings or errors, the program also prints a message to the screen advising the user to review the output file for explanations of the warnings and errors.

7.3.3 Input Summary

The input summary consists of tables that include summaries of all input parameters in horizontal tabular format. The input summary tables also include any processed input. Processed input is input that gets computed by the program based on other input items, including program set optional input values. A more complete description of all input items can be found in Chapters 5 and 6. A sample Summary of Input File Report is shown in Figure 1.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                           PAGE x
Input File: xxx.DAT                                                                 xx/xx/xxxx  xx:xx:xx
----------------------------------------------------------------------------------------------------
                    Line  1 - This is the first   TTL line of the ten allowed
                                          INPUT SUMMARY
----------------------------------------------------------------------------------------------------


                                                CONTROL
   Sys of    Structure    Type     Culvert   Bottom     Top Slab     Frame    Footing
    Units       Type     of Run    P or C     Slab       Support    Support   P or C
     US     1-CELL BOX     AR         P         Y           M         N/A       N/A


                                        STRUCTURE IDENTIFICATION
   Program               State                           Span
      ID      County    Route      Segment    Offset    ID
   =BXLRFD      50        666        555       9996     654


                                                MATERIAL
   f'c All       f'c       Reinf     Reinf              Wire     Epoxy
   Members    Top Slab    Grade      Type     Alpha     Diam     Coated
    (ksi)      (ksi)      (ksi)               (deg)     (in)
     5.00       5.00       60.0        W       90.0     0.60      N/A


   Concrete Density
    For DL   For Ec        fu
  (lb/ft^3) (lb/ft^3)     (ksi)
    150.0     145.0       90.00

                                               DIMENSIONS
   Clear     Clear    Slab Thickness     Wall Thickness       Fill    Top Slab
    Span    Height      Top   Bottom    Left  Right  Int     Grade      Grade
    (ft)      (ft)     (in)    (in)     (in)   (in)  (in)     (%)        (%)
    9.00      6.00      9.0     9.5      9.0    9.0   0.0     0.00       0.00

   Left U-channel    Right U-channel
    Wall Height        Wall Height
       (ft)               (ft)
       0.00               0.00

                                              LOAD CONTROL
             Height                                                     Future
     Fill      of    No of   Live Load   Live   Overlay  Overlay   Wearing
    Wt/Den    Fill   Lanes   Surcharge   Load    Wt/Den   Thick    Surface
    (pcf)     (ft)              (ft)              (pcf)    (in)     (psf)
     120.0    5.00     1        3.00       A        0.0     0.0       0.0

   Live Load            Multiple     PA       Fatigue
    Distrib   Segment   Presence  Traffic  Dynamic Load    Duct   Redund
     Length    Length   Reduction  Factor    Allowance    Factor  Factor
      (ft)      (ft)
     25.00     12.00      N/A       N/A        N/A        1.00    1.00

            Permit Max       Live     Min Equiv  Max Equiv    Barrier
   Import  Dynamic Load      Load       Fluid      Fluid        Dead
   Factor    Allowance     Override   Pressure   Pressure       Load
                                        (pcf)      (pcf)     (kips/ft)
    1.00       1.20            0       45.00      70.00        0.00
```

Figure 7.3.3-1 Sample Summary of Input Commands Report

The input summary tables contain the following information:

1. A description of the input data.
2. Input parameter header containing an abbreviated parameter description and units.
3. Input parameter values. The input values are shown to a fixed number of decimal places because of the tabular format. The actual input value may be rounded to fit the output format. Refer to the summary of input commands for the actual value input by the user.

7.4 RESULTS

This section describes in detail the Analysis, Design and general reports that can be generated by BXLRFD. Each subsection discusses a single report. The report is described in general terms, then each column of data is identified, and then a sample report is presented and discussed in detail. Some of the reports are quite involved and actual numbers are used to help clarify what the numbers mean and where they come from.

7.4.1 Additional Information

The additional information report provides information relevant to the run such as computed values and additional geometric information.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                             PAGE x
Input File: xxx.DAT                                                                xx/xx/xxxx  xx:xx:xx
-------------------------------------------------------------------------------------------------------
                    Line  1 - This is the first   TTL line of the ten allowed
                                      ADDITIONAL INFORMATION
-------------------------------------------------------------------------------------------------------

                                          COMPUTED VALUES

             Computed  Computed  Computed   Computed
     Input   Flexure    Axial     Shear    Development
     Reinf    Reinf     Reinf     Reinf       Reinf
     Grade    Grade     Grade     Grade       Grade
     (ksi)    (ksi)     (ksi)     (ksi)       (ksi)
     60.000   60.000    60.000   60.000       60.000
```

Figure 7.4.1-1 Sample Additional Information Report

The following information is reported for all structure types:

1. Input Reinforcement Grade – user entered reinforcement grade from the MAT command
2. Computed Flexure Reinforcement Grade – reinforcement grade used for all flexural capacity calculations
3. Computed Axial Reinforcement Grade – reinforcement grade used for all axial capacity calculations
4. Computed Shear Reinforcement Grade – reinforcement grade used for all shear capacity calculations
5. Computed Development Reinforcement Grade – reinforcement grade used for all development length calculations

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                         PAGE x
Input File: xxx.DAT                                                                xx/xx/xxxx  xx:xx:xx
----------------------------------------------------------------------------------------------------
                                    BXLRFD EXAMPLE PROBLEM #x
                                     ADDITIONAL INFORMATION
----------------------------------------------------------------------------------------------------

                                      ADDITIONAL GEOMETRY

        Final Component Thickness

   Top Slab #1 Lft:   25.35 in
   Top Slab #1 Rgt:   18.19 in
   Top Slab #2 Lft:   17.84 in
   Top Slab #2 Rgt:   10.68 in

   Note: For sloped Top Slabs, the thickness is measured at the
         face of the walls or the end of haunches if present.

       Wall #1    :   12.00 in
       Wall #2    :   12.00 in
       Wall #3    :   12.00 in
   Bot Slab #1    :   15.00 in
   Bot Slab #2    :   15.00 in
```

Figure 7.4.1-2 Sample Additional Geometry Report

The following information is reported for top slabs of box culverts

No Slope

1. Top Slab #1 – thickness of the Top Slab for the first cell
2. Top Slab #2 - thickness of the Top Slab for the second cell

With Slope

1. Top Slab#1 Lft: - thickness of the top slab at the face (or end of haunch if present) of wall 1
2. Top Slab#1 Rgt: - thickness of the top slab at the face (or end of haunch if present) of wall 2
3. Top Slab#2 Lft: - thickness of the top slab at the face (or end of haunch if present) of wall 2
4. Top Slab#2 Rgt: - thickness of the top slab at the face (or end of haunch if present) of wall 3

The following information is reported for walls of box culverts

1. Wall #1 – thickness of the wall 1
2. Wall #2 – thickness of the wall 2
3. Wall #3 – thickness of the wall 3

The following information is reported for bottom slabs of box culverts. For bottom slabs with fish channels, the program will report the thickness at the bottom of the fish channel.

1. Bot Slab #1 – thickness of the bottom slab 1
2. Bot Slab #2 – thickness of the bottom slab 2

The following information is reported for strip footings of frame culverts

1. Left Wall Toe Projection – toe projection of the footing under the left wall
2. Left Wall Heel Projection – heel projection of the footing under the left wall
3. Center Wall Projection – projection for the footing on either side of the center wall

4. Right Wall Toe Projection – toe projection of the footing under the right wall
5. Right Wall Heel Projection – heel projection of the footing under the right wall

7.4.2 Gross Section Properties

This table is applicable for any “Type of Run”, and includes all culvert components, e.g., top slab, external wall, etc., and strip footings. This table provides component lengths and gross section properties: member thickness, moment of inertia and cross sectional area. The properties are associated with the unreduced section, e.g., before section reductions are made for scour, foundation unevenness, integral wearing surface, and are reported at all points-of-interest, POI’s.

The following information is reported in the GROSS SECTION PROPERTIES output tables:

1. Clear Span - clear span of a culvert cell
2. Dist - distance from the beginning of the culvert component (i.e., the face of wall or slab) to the point-of-interest, POI
3. Dist/Span Ratio - distance to span ratio of the POI
4. Member Thickness - total thickness of the member at the POI (includes any sacrificial covers)
5. M of Inertia - moment of inertia about the centroid of the section
6. Area - cross sectional area

A sample Gross Section Report is shown in Figure 1.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                          PAGE x
Input File: xxx.DAT                                                              xx/xx/xxxx  xx:xx:xx
---------------------------------------------------------------------------------------------------
                                    BXLRFD EXAMPLE PROBLEM #x
                                     GROSS SECTION PROPERTIES
---------------------------------------------------------------------------------------------------

                                          Top Slab No. 1
                              Clear  Span:   20.50 (ft)

              Dist/Span      Member          M of
    Dist        Ratio       Thickness       Inertia        Area
    (ft)                      (in)          (in^4)        (in^2)
     0.00       0.00          25.35        16292.02       304.21
     0.93       0.05          25.02        15671.33       300.30
     1.87       0.09          24.70        15066.61       296.38
     2.05       0.10          24.63        14950.46       295.62
     4.10       0.20          23.92        13684.64       287.03
     6.15       0.30          23.20        12492.37       278.44
     8.20       0.40          22.49        11371.44       269.85
    10.25       0.50          21.77        10319.65       261.26
    12.30       0.60          21.06         9334.81       252.67
    14.35       0.70          20.34         8414.70       244.08
    16.40       0.80          19.62         7557.14       235.49
    18.45       0.90          18.91         6759.91       226.90
    19.23       0.94          18.64         6472.41       223.63
    19.86       0.97          18.41         6243.89       220.97
    20.50       1.00          18.19         6020.82       218.31
```

Figure 7.4.2-1 Sample Gross Section Properties Report

7.4.3 Live Load ELAT and IM Table

This table is applicable for design and analysis runs only when live loading is applied to the culvert. The table reports the Dynamic Load Allowance and Live Load Distribution values used by the program, along with intermediate information where applicable.

The following information is reported in the LIVE LOAD ELAT & IM output table:
Dynamic Load Allowance

1. Fill Height - average height of fill above the culvert.
2. IM - the calculated Dynamic Load Allowance factor.
3. Permit Truck IM - the calculated Dynamic Load Allowance factor for the P-82 and P2016-13 truck load.

Case 1 - On Deck Loading

1. No. of Lanes Loaded - number of loaded lanes ELAT is calculated for.
2. c-c Culvert Span - distance between the centerlines of the walls for a single span.
3. MPF - Multiple Presence factor including multiple presence reduction factor.
4. Calc Elat - calculated ELAT value based on LRFD Specifications Equation 4.6.2.10.2-1.
5. Calc Elat/MPF - Calculated Elat divided by MPF.
6. Seg Length – For cast-in-place culverts, this is the culvert segment length.
   For precast culverts, this is the culvert segment length times the number of precast

shear transfer segments

7. Elat Used - final ELAT used by the program.

Case 2 - Thru Fill Loading

1. No. of Lanes Loaded - number of loaded lanes ELAT is calculated for.
2. Fill Height - average height of fill above culvert.
3. Live Load Distribution Length - user entered distribution length.
4. MPF - Multiple Presence factor including multiple presence reduction factor.
5. Total Width (LANE(i)) - Geometric lane width less thru-fill gaps (Section 3.3.17.2).
6. Elat Used - final ELAT used by program for the number of lanes.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                         PAGE x
Input File: xxx.DAT                                                          xx/xx/xxxx  xx:xx:xx
---------------------------------------------------------------------------------------------------
                                    BXLRFD EXAMPLE PROBLEM #x
                                    LIVE LOAD ELAT & IM TABLE
---------------------------------------------------------------------------------------------------

                                      Dynamic Load Allowance

       Fill              Permit
      Height        IM      IM
       (ft)
       4.91        1.15    1.15

                                     Case 1 - On Deck Loading

   No. of      c-c                 Calc Elat
    Lanes    Culvert          Calc    ---------                 Elat
   Loaded      Span   MPF *   Elat       MPF      Seg Length    Used
               (ft)           (ft)      (ft)          (ft)      (ft)
      1       11.00   1.20    9.32      7.77          90.0      7.77

                                    Case 2 - Thru Fill Loading

   No. of              LL                   Total
    Lanes     Fill   Distribution           Width      Elat
   Loaded    Height     Length      MPF *   (LANE(i))  Used
              (ft)      (ft)                  (ft)      (ft)
      1       4.91      38.0       1.20      13.31     11.10
      2       4.91      38.0       1.00      23.31     11.66

   *  Includes Multiple Presence Reduction Factor
```

Figure 7.4.3-1 Sample Live Load ELAT & IM Table

7.4.4 Serviceability Check Table

This table is applicable for an analysis run and gives detailed information for all POI's of all culvert components e.g. slabs, walls, strip footings. The table reports whether a POI has failed for any of the serviceability checks listed below by placing an asterisk next to the allowable spacing or controlling stress value.

The following information is reported in the SERVICEABILITY CHECK output table for slabs and walls:

1. Dist – distance from the beginning of the culvert component to the POI.
2. Location – Whether the location at the POI is on the Top/Bottom Or Left/Right.
3. Bar Size - User entered bar size for the POI location.
4. Input Spacing - User entered bar spacing for the POI location.
5. Minimum Primary Spacing - Calculated allowable minimum spacing for the primary steel.
6. Maximum Primary spacing - Calculated allowable maximum spacing for the primary steel.
7. Temp/Shrink Spacing - Calculated allowable temperature and shrinkage spacing for the primary steel.
8. Crack Control Spacing – Calculated allowable crack control spacing.
9. Tens Reinf Stress – actual stress of the primary reinforcement that is in tension.
10. Codes - A - used to indicate live loading.

Due to the lengthiness of the information in this table a secondary table provides some of the information in the Serviceability Summary Table described in Section 7.4.5. The program will only display the Serviceability Check and Summary (Section 7.4.4) tables when a user entered bar size and spacing is detected.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                           PAGE xx
Input File: xxx.dat                                                                xx/xx/xxxx  xx:xx:xx
-------------------------------------------------------------------------------------------------
                                    BXLRFD EXAMPLE PROBLEM #x
                                   SERVICEABILITY SPACING CHECK
-------------------------------------------------------------------------------------------------

                                          Top Slab No. 1

                          Minimum  Maximum   Temp/    Crack      Tens
              Bar  Input  Primary  Primary  Shrink    Control    Reinf  Codes
    Dist  Loc Size Spacing Spacing  Spacing  Spacing   Spacing    Stress A
    (ft)            (in)     (in)     (in)    (in)      (in)      (ksi)
   0.00    T   6    18.00     2.50   18.00   18.00
           B   7     7.50     2.50   18.00   18.00      50.70      8.13  7.8
   1.76    T   6    18.00     2.50   18.00   18.00
           B   7     7.50     2.50   18.00   18.00       7.68     37.46  7.8
   4.00    T   6    18.00     2.50   18.00   18.00
           B   7     7.50     2.50   18.00   18.00       7.68     69.58  7.8

   ERROR!:    User entered bar size and spacing has failed to meet
              serviceability criteria. An asterisk (*) indicates which
              criteria failed. Check the bar size and spacing against
              the allowable serviceability criteria. Refer to DM-4 Section 5.6.7.

   Temp/Shrinkage Codes:        Code A: Loading
    A   - Steel Area is less     1  PHL-93
          than allowable         2  HL-93
    B   - Steel Spacing is       3  P-82
          greater than           4  ML-80
          allowable              5  HS-20
    N/A - Section thickness is   6  H-20
          greater than 18 in     7  SLL (number after decimal denotes governing SLL vehicle)
                                 8  TK527
                                 9  EV2
                                 Z  EV3
                                 Y  SU6TV
                                 X  P2016-13
          Note: Wall distances begin at the bottom of the wall and slab distances
                begin at the left side of the slab.
```

Figure 7.4.4-1 Sample Serviceability Check Report for slabs and walls

The following information is reported in the SERVICEABILITY CHECK output table for strip footings:

1. Dist - distance from the face of the wall, left or right, to the POI.
2. Direction - Either L or R indicating which direction the POI is from the face of the wall
3. Face Location - either T or B indicating whether the crack control spacing is for the top face or the bottom face.
4. Bar Size - User entered bar size for the POI location.
5. Input Spacing - User entered bar spacing for the POI location.
6. Minimum Primary Spacing - Calculated allowable minimum spacing for the primary steel.
7. Maximum Primary spacing - Calculated allowable maximum spacing for the primary steel.

8. Temp/Shrink Spacing - Calculated allowable temperature and shrinkage spacing for the primary steel.
9. Crack Control Spacing – Calculated allowable crack control spacing.
10. Tens Reinf Stress – actual stress of the primary reinforcement that is in tension.
11. Codes - A - used to indicate live loading.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                     PAGE xx
Input File: xxx.dat                                                           xx/xx/xxxx  xx:xx:xx
-------------------------------------------------------------------------------------------------
                                   BXLRFD EXAMPLE PROBLEM #x
                              SERVICEABILITY SPACING CHECK (cont.)
-------------------------------------------------------------------------------------------------

                               STRIP FOOTING: Wall No. 1

                              Minimum  Maximum   Temp/    Crack     Tens
               Bar  Input   Primary  Primary  Shrink    Control   Reinf  Codes
    Dist   Loc Size Spacing Spacing  Spacing  Spacing   Spacing   Stress A
    (ft)             (in)     (in)     (in)    (in)      (in)     (ksi)
   2.16L    T   9     5.00     2.50   18.00   18.00
            B   9     5.00     2.50   18.00   18.00      99.99     1.16  4
   0.00L    T   9     5.00     2.50   18.00   18.00
            B   9     5.00     2.50   18.00   18.00      62.93     6.76  4
   0.00R    T   9     5.00     2.50   18.00   18.00
            B   9     5.00     2.50   18.00   18.00      99.99     2.14  4
   2.16R    T   9     5.00     2.50   18.00   18.00
            B   9     5.00     2.50   18.00   18.00      99.99     0.13  4

   ERROR!:    User entered bar size and spacing has failed to meet
              serviceability criteria. An asterisk (*) indicates which
              criteria failed. Check the bar size and spacing against
              the allowable serviceability criteria. Refer to DM-4 Section 5.6.7.

   Temp/Shrinkage Codes:        Code A: Loading
    A   - Steel Area is less     1  PHL-93
          than allowable         2  HL-93
    B   - Steel Spacing is       3  P-82
          greater than           4  ML-80
          allowable              5  HS-20
    N/A - Section thickness is   6  H-20
          greater than 18 in     7  SLL (number after decimal denotes governing SLL vehicle)
                                 8  TK527
                                 9  EV2
                                 Z  EV3
                                 Y  SU6TV
                                 X  P2016-13
          Note: Wall distances begin at the bottom of the wall and slab distances
                begin at the left side of the slab.
```

Figure 7.4.4-2 Sample Serviceability Check Report for strip footings

7.4.5 Serviceability Summary Table

This table is applicable for an Analysis run and displays a summary of whether any serviceability conditions have failed for all components.

The following information is reported in the SERVICEABILITY SUMMARY output table:

1. Minimum Primary Spacing – Indicates whether allowable minimum spacing for the primary steel has passed.
2. Maximum Primary spacing – Indicates whether allowable maximum spacing for the primary steel has

passed.

3. Temp/Shrink Spacing – Indicates whether allowable temperature and shrinkage spacing for the primary steel has passed.
4. Crack Control Spacing – Indicates whether allowable crack control spacing has passed.

This table is switched on by default. If both the Serviceability Check Table (Section 7.4.3) and the Serviceability summary Table are switched off and a component fails to meet serviceability criteria, an error message will be displayed in the output under the Serviceability Summary heading.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                  PAGE xx
Input File: xxx.dat                                                        xx/xx/xxxx  xx:xx:xx
-------------------------------------------------------------------------------------------------
                                    BXLRFD EXAMPLE PROBLEM #x
                                  SERVICEABILITY SPACING SUMMARY
-------------------------------------------------------------------------------------------------

                            Minimum  Maximum   Temp/    Crack
                            Primary  Primary  Shrink   Control
   Location                 Spacing  Spacing  Spacing  Spacing

  Top Slab No. 1               OK       OK       OK       OK
  Top Slab No. 2               OK       OK       OK       OK
  Bottom Slab No. 1            OK       OK       OK       OK
  Bottom Slab No. 2            OK       OK       OK       OK
  Wall No. 1                   OK       OK       OK       NG
  Wall No. 2                   OK       OK       OK       OK
  Wall No. 3                   OK       OK       OK       OK

   ERROR!:    Serviceability criteria has not been met. For further details
              activate the Serviceability Check Table in the OUR command.
              Then verify entered bar size and spacing values.
```

Figure 7.4.5-1 Sample Serviceability Summary Report

7.4.6 Live Load Rating

This table is applicable for an Analysis with live load (see Section 3.3.9 for a discussion when live load is applicable), and includes all culvert components, e.g., top slab, external wall, etc., other than strip footings. (The Strip Footing Rating Report is described in Section 7.4.7.) This table gives very detailed information (and can be quite voluminous) on the demands and capacities (flexure and shear) of all analysis points, referred to as Points-Of-Interest, POIs. A smaller version of this table, containing a summary of just some of the information in this table, is the Rating Summary Report described in Section 7.4.8. The table indicates in the heading whether Future Wearing Surface load is included in the ratings.

The following information is reported in the LIVE LOAD RATING output tables:

1. Name of Live Load - the name of the live load appears in the table heading, along with the name and number of the component, e.g., Top Slab No. 1.
2. Dist - distance from the beginning of the culvert component to the POI.
3. Loading category - either “DL+E” for dead load results or “LL+I” for live load results.

4. Fact Moment - factored moment, either dead or live load, associated with the smallest flexure rating factor.
5. Fact Thrust -factored axial force, either dead or live load, associated with the smallest flexure rating factor.
6. Fact Shear -factored shear, either dead or live load, associated with the smallest shear rating factor.
7. Fact Resist - factored moment or shear resistance.
8. Zone – the controlling zone, either tension, compression, or transition.
9. Rating Factors - Inventory, IR, and Operating, OR, rating factors.
10. Prov Reinf – provided flexure reinforcement.
11. Face Location - either T or B indicating whether the smallest rating factor is for the top face of the bottom face.
12. Min Reinf – Minimum required reinforcement.
13. Phi Factor – the flexural resistance factor.

A sample Live Load Rating table is shown in Figure 1. Blank lines have been added for clarity around the POI at a distance of 0.77 feet. Note that the information for each POI includes 4 lines. The first two are the inventory rating, and the last two are the operating rating information. All demands and capacities are associated with the Maximum Effect Case with the smallest rating factor. Cases 1, 2, 3 and 4 are considered for flexure, and Cases 1, 2, 5 and 6 are considered for shear. See Section 3.4 for a description of the six Maximum Effect Cases.

The number of live loads reported in this table depends on the Live Load selected on the LDC Command: A, B, C, D, E, F, G, H, or I. Each live load uses a particular limit state to compute its Inventory and Operating rating. For example, the PHL-93 live load uses Strength I for Inventory and Strength IA for Operating, while the ML-80 and TK527 live loads use Strength I for Inventory and Strength II for Operating. In addition, the P-82 and P2016-13 live load and FAST ACT live loads EV2, EV3, SU6TV are considered just at the Operating level, using Strength II for its rating, and consequently has two fewer lines of information for each POI. See Table 2.5-1 for complete information on which limit states are used to compute the IR and OR for each possible live load.

The amount of flexural reinforcement for the appropriate face (top/bottom, or left/right) as well as the minimum amount of required flexural reinforcement is also reported for each POI, as is any shear reinforcement. Any blank entries in the table (usually associated with shear information) are due to the fact the some POIs are used to check just moment, not moment and shear, and therefore shear results are not applicable. Usually the POI closest to the ends of the components is just a moment POI and will not contain any shear results. More POIs will be moment only if haunches are present since only moment is considered within the haunch.

The smallest flexure and shear Inventory and Operating Rating factors are reported for each POI, along with the associated factored dead and live loads. Dead load + earth are labeled "DL+E", and live load + dynamic load allowance are labeled "LL+I." The factored flexure resistance is the M_r value shown in Section 3.5.1.2. The factored shear resistance is the V_r value shown in Section 3.5.

In Figure 1, at a distance of 0.77 feet, the smallest flexure IR, among all Maximum Effect Cases, is 35.94. The "F" just to the left of the 35.94 indicates that this is a flexure rating; the number "1" to the right of the "F" indicates that Maximum Effect Case 1 (Maximum Positive Moment and Concurrent Thrust) had the smallest flexure rating. The factored dead load moment and concurrent thrust associated with Maximum Effect Case 1 for Strength I for the PHL-93 live loading are 0.25 kip-ft and -0.79 kips, respectively. The factored live load moment and concurrent thrust are on the line below, and are 1.70 kip-ft and 0.09 kips, respectively; the factored moment resistance is 61.50 kip-ft (on the line with the rating factor). Thus all the information is present to compute the flexure rating factor, i.e., RF = $(M_r-M_{udl})/M_{ull}$, or (61.50-0.25)/1.70 = 35.97, close to the reported value of 35.94. Note that M_{udl} and M_{ull} are the factored dead and live load moments. Finally, the amount of flexural reinforcement at this POI location is 1.56 in^2 and the letter "B" next to it indicates that the controlling face is the bottom (the positive sign of M_r reflects this also).

The smallest shear IR, among all Maximum Effect Cases, is 3.12. The "V" just to the left indicates that this is a shear rating; the number 6 to the right of the "V" indicates that Maximum Effect Case 6 (Maximum Negative Shear and Concurrent Moment) had the smallest shear rating. The factored dead load shear associated with Maximum Effect Case 6 for Strength I for the PHL-93 live loading is -4.40 kips. The associated factored live load shear is on the line below, and is -5.14 kips; the factored shear resistance, φ_v (V_c+V_s), is -20.43 kips (on the line with the rating factor). Thus all the information is present to compute the shear rating factor, i.e., RF = $(V_r-V_{udl})/V_{ull}$, or (-20.43-(-4.40))/(-5.14) = 3.11, close to the reported value of 3.12. Note that V_{udl} and V_{ull} are the factored dead and live load shears. Finally, the amount of shear reinforcement at this POI location is 0.00 in^2 indicating that no shear steel exists at this location.

Similar information to that just discussed is reported on the next two lines and is associated with the Operating level rating factors and Strength IA for this live load.

Lastly, the POI at location 0.00 feet and at 9.00 feet are moment only POIs due to the fact that only flexure results are reported.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                   PAGE xx
Input File: xxx.DAT                                                        xx/xx/xxxx  xx:xx:xx
-----------------------------------------------------------------------------------------------
                                    BXLRFD EXAMPLE PROBLEM #x
                                     LIVE LOAD RATING W/O FWS
-----------------------------------------------------------------------------------------------

                                 HL-93 Loading:    Top Slab No. 1

                                                    Fact            Rating Factor
                 Fact    Fact    Fact     Resist             IR      OR      Prov  Min      Phi
   Dist          Moment  Thrust  Shear   (kips-ft)   Zone  STR-I   STR-IA   Reinf  Reinf   Factor
   (ft)         (kips-ft) (kips) (kips)    (kips)                           (in^2) (in^2)
     0.00 DL+E       0.99    0.68            71.77 F1   TN    9.80           0.96 B  0.20    0.90
          LL+I       7.22   -1.31
          DL+E       0.99    0.68            71.77 F1   TN           12.70   0.96 B  0.20    0.90
          LL+I       5.57   -1.01
     0.93 DL+E       3.94    0.69   -3.21    83.52 F1   TN    4.57           0.96 B  0.29    0.90
          LL+I      17.43   -1.24  -11.36   -27.57 V6         2.14           0.00
          DL+E       3.94    0.69   -3.19    83.52 F1   TN            5.92   0.96 B  0.29    0.90
          LL+I      13.44   -0.95   -8.76   -27.57 V6                 2.78   0.00
     1.87 DL+E       6.51    0.69   -2.79    86.02 F1   TN    3.01           0.96 B  0.45    0.90
          LL+I      26.38   -1.16  -10.68   -27.15 V6         2.28           0.00
          DL+E       6.51    0.69   -2.77    86.02 F1   TN            3.91   0.96 B  0.45    0.90
          LL+I      20.35   -0.90   -8.24   -27.15 V6                 2.96   0.00
     2.05 DL+E       6.96    0.70   -2.71    86.20 F1   TN    2.83           0.96 B  0.48    0.90
          LL+I      27.97   -1.15  -10.55   -27.06 V6         2.31           0.00
          DL+E       6.96    0.70   -2.69    86.20 F1   TN            3.67   0.96 B  0.48    0.90
          LL+I      21.58   -0.89   -8.14   -27.06 V6                 2.99   0.00

    *  Negative Rating due to deadload effects being greater than capacity

   F or V reported after the Fact Resist indicates whether the Rating is for
   Flexure (F) or Shear (V).  The numerical code reported after F or V
   corresponds to the governing Maximum Effect Case for the Rating Factor.

   Maximum Effect Cases:
    1  Maximum Positive    Moment and Concurrent Thrust
    2  Maximum Negative    Moment and Concurrent Thrust
    3  Maximum Tension     Thrust and Concurrent Moment
    4  Maximum Compression Thrust and Concurrent Moment
    5  Maximum Positive    Shear  and Concurrent Moment
    6  Maximum negative    Shear  and Concurrent Moment

   T, B, L, or R reported after the Reinforcement (Reinf) indicates the
   location of the flexural reinforcement reported:
    T  Top    steel in a slab
    B  Bottom steel in a slab
    L  Left   steel in a wall
    R  Right  steel in a wall

   Zone Code Descriptions
         TN - Tension controlled section
         TR - Transition section
         CM - Compression controlled section

   Phi Factor Epsilon (cl) =  0.00200
   Phi Factor Epsilon (tl) =  0.00500

   Note: Wall distances begin at the bottom of the wall and slab distances
         begin at the left side of the slab.
```

Figure 7.4.6-1 Sample Live Load Rating Report

7.4.7 Strip Footing Performance Ratios

This table is applicable for an Analysis and includes only strip footings. (The Live Load Rating Report is described in Section 7.4.6.) It gives Shear and Moment Performance Ratios, which are the factored resistance divided by the factored force. The table indicates in the heading whether Future Wearing Surface load is included in the ratings.

The following information is reported in the STRIP FOOTING PERFORMANCE RATIOS output tables:

1. Dist - distance from the face of the wall, left or right, to the POI.
2. Direction - Either L or R indicating which direction the POI is from the face of the wall
3. Face Location - either T or B indicating whether the smallest rating factor is for the top face of the bottom face.
4. Flexure Load Code - limit state (A), maximum effect case (B), live load (C), live load type (D) associated with the smallest flexure performance ratio.
5. Factored Moment - factored moment associated with the smallest flexure performance ratio.
6. Moment Resistance - factored moment resistance associated with the smallest performance ratio.
7. Moment Performance Ratio - smallest flexure performance ratio.
8. Phi Factor – the flexural resistance factor.
9. Shear Loading Code - limit state (A), maximum effect case (B), live load (C), live load type (D) associated with the smallest shear performance ratio.
10. Factored Shear - factored shear associated with the smallest flexure performance ratio.
11. Shear Resistance - factored shear resistance associated with the smallest performance ratio.
12. Shear Performance Ratio - smallest shear performance ratio.

A sample Strip Footing Rating Report is shown in Figure 1. All demands and capacities are associated with the Limit State, Maximum Effect Case, Live Load and Live Load Type (On Deck or Through Fill) that minimizes the performance ratio.

Limit States Strength I, Strength II and Strength IA, and all Maximum Effect Cases are considered for both flexure and shear. (Recall that the moment in the footing is calculated from the total limit state response at the bottom of the wall, so all six Maximum Effect Cases must be investigated.) Different live loads are used for each limit state and the number and type of live loads used for the analysis depend on the selected live load type on the LDC command. See Section 5.10 for a description of the LDC command. See Section 3.4 for a description of the six Maximum Effect Cases.

Two lines of information are used for each flexure POI: one for the top face, and one for the bottom face. Only one line is used for each shear POI.

Four columns are associated with the flexure information and four columns for the shear information. The Flexure and Shear Loading Code part of each line of information indicates the controlling Limit State, Maximum Effect Case, Live Load and Live Load Type: Code A is the Limit State, Code B is the Maximum

Effect Case, Code C is the Live Load and Code D is the Live Load Type. The Legend at the end of the table describes the values of the four Loading Codes.

The four columns of flexure information are reported first. The Flexure Loading Code is the condition that causes the least performance ratio.

The four columns of shear information are reported after the flexure information. The Shear Loading Code is the condition that causes least performance ratio.

In Figure 1, at a location of 0.00 feet from right face of Wall No. 1. The Moment Performance Ratio is 14.60 for the top face and bottom face. The Flexure Loading Codes indicate that Limit State Strength I, Maximum Effect Case 4 (Maximum Compression Thrust with concurrent moment and shear in the wall), Special Live Load #2 and Thru Fill, cause this smallest ratio to occur. The total factored moment and factored resistance associated with Strength I, Maximum Effect Case 4, Special Live Load #2, and Thru Fill are 17.81 k-ft and 260.10 k-ft, respectively.

In Figure 1, at a location of 2.16 ft from left face of Wall No. 1, the Shear Performance Ratio is 2.15. The Shear Loading Codes indicate that Limit State Strength II and Maximum Effect Case 1 (Maximum Positive Moment and Concurrent Thrust in the wall), Special Live Load #8 and On Deck, cause this smallest ratio to occur. The total factored shear and factored resistance associated with Strength II and Maximum Effect Case 1, Special Live Load #8 and On Deck are -12.26 k and -26.33 k, respectively.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                        PAGE xx
Input File: xxx.dat                                                            xx/xx/xxxx  xx:xx:xx
---------------------------------------------------------------------------------------------------
                                    BXLRFD EXAMPLE PROBLEM #x
                             STRIP FOOTING PERFORMANCE RATIOS W/O FWS
---------------------------------------------------------------------------------------------------


                                          Wall No. 1

            Flexure                                    Moment    Shear                   Shear
            Loading     Fact      Moment   Phi   Perf    Loading   Fact    Shear   Perf
    Dist     Code      Moment     Resist  Factor Ratio     Code     Shear  Resist  Ratio
    (ft)    A B  C  D (kips-ft) (kips-ft)               A B  C  D  (kips)  (kips)
     2.16L                                              2 1 7.8 1  -12.26  -26.33   2.15
     0.00LT 2 1 7.8 1     50.22   260.10   0.90   5.18
         LB 2 1 7.8 1     50.22   260.10   0.90   5.18
     0.00RT 1 4 7.2 2     17.81   260.10   0.90  14.60
         RB 1 4 7.2 2     17.81   260.10   0.90  14.60
     2.16R                                              1 2 7.7 2    2.86   26.33   9.21

                                          Wall No. 2

            Flexure                                    Moment    Shear                   Shear
            Loading     Fact      Moment   Phi   Perf    Loading   Fact    Shear   Perf
    Dist     Code      Moment     Resist  Factor Ratio     Code     Shear  Resist  Ratio
    (ft)    A B  C  D (kips-ft) (kips-ft)               A B  C  D  (kips)  (kips)
     2.16L                                              1 5 7.7 2   -2.95  -26.33   8.91
     0.00LT 1 4 7.2 2     18.78   260.10   0.90  13.85
         LB 1 4 7.2 2     18.78   260.10   0.90  13.85
     0.00RT 2 2 7.8 2     50.09   260.10   0.90   5.19
         RB 2 2 7.8 2     50.09   260.10   0.90   5.19
     2.16R                                              2 2 7.8 2   12.22   26.33   2.15

   L or R after the distance indicates the Left or Right side
   of the strip footing.

   T or B after the distance indicates the location of the
   flexural reinforcement reported:
    T  Top    steel in footing
    B  Bottom steel in footing

   Flexure/Shear Loading Codes:
    Code A           Code B                         Code C      Code D
     1  Strength-I    1  Maximum Positive    Moment  1  PHL-93   1  On Deck
     2  Strength-II   2  Maximum Negative    Moment  2  HL-93    2  Thru Fill
     3  Strength-IA   3  Maximum Tension     Thrust  3  P-82
                      4  Maximum Compression Thrust  4  ML-80
                      5  Maximum Positive    Shear   5  HS-20
                      6  Maximum Negative    Shear   6  H-20
                                                     7  SLL (number after decimal denotes
                                                              governing SLL vehicle)
                                                     8  TK527
                                                     9  EV2
                                                     Z  EV3
                                                     Y  SU6TV
                                                     X  P2016-13
```

Figure 7.4.7-1 Sample Strip Footing Performance Ratios Report

7.4.8 Rating Summary

This table is applicable for an Analysis with live load, and includes all culvert components, e.g., top slab, external wall, etc., other than strip footings. This table gives just a summary of controlling rating factors at the Inventory and Operating levels, and indicates whether they are shear or moment, and where they occur within each component. Minimum Inventory and Operating rating factors for the entire culvert are identified by type and location within the component in which they occur. The table indicates in the heading whether Future Wearing Surface load is included in the ratings. Finally, a table is located at the end of the Rating Summary that provides the single controlling rating and tonnage for each load as well as the controlling component and location.

The following information is reported in the RATING SUMMARY output tables:

1. Live Loading - the name of the live load is shown in the table header.
2. Member No. - Culvert member and number.
3. Dist - distance from the beginning of the culvert component to the controlling IR POI.
4. Dist/Span Ratio - distance ratio of the controlling IR POI.
5. IR Rating Factor - name of the live load associated with the Inventory Rating, IR, and the rating factor.
6. IR Rating Tonnage - rating value displayed in tons.
7. Dist - distance from the beginning of the culvert component to the controlling OR POI.
8. Dist/Span Ratio - distance ratio of the controlling OR POI.
9. OR Rating Factor - name of the live load associated with the Operating Rating, OR, and the rating factor.
10. OR Rating Tonnage - rating value displayed in tons.

A sample Rating Summary Report is shown in Figure 1. There is a table for each live load in the analysis. The number of live loads reported in this table depends on the Live Load selected on the LDC Command: A, B, C, D, E or F, G, H or I. Each live load uses a particular limit state to compute its Inventory and Operating rating. For example, the PHL-93 live load uses Strength I for Inventory, and Strength IA for Operating, while the ML-80 and TK527 live loads use Strength I for Inventory, and Strength II for Operating. In addition, the P-82 and P2016-13 live load and FAST Act live loads EV2, EV3, SU6TV are considered just at the Operating level, using Strength II for its rating, and consequently has three fewer columns of information.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                        PAGE xx
Input File: xxx.DAT                                                                  xx/xx/xxxx  xx:xx:xx
---------------------------------------------------------------------------------------------------
                                    BXLRFD EXAMPLE PROBLEM #x
                                      RATING SUMMARY W/O FWS
---------------------------------------------------------------------------------------------------

                                        Loading:    PHL-93

                            Dist/    IR       IR          Dist/    OR       OR
                            Span   Rating   Rating        Span   Rating   Rating
        Member  No.  Dist   Ratio  Factor   Tonnage  Dist  Ratio  Factor   Tonnage
                     (ft)          STR-I     (ton)   (ft)         STR-II    (ton)
        Top Slab  1   4.50  0.50    2.49 F   89.67   4.50  0.50    3.23 F  116.24
        Bot Slab  1   0.50  0.06    1.61 F   57.79   0.50  0.06    2.17 F   78.15
            Wall  1   0.50  0.08    2.15 F   77.35   0.50  0.08    2.79 F  100.27
            Wall  2   0.50  0.08    2.14 F   77.09   0.50  0.08    2.78 F   99.93

        *   Negative Rating due to deadload effects being greater than capacity

        The Minimum Inventory Rating is governed by SHEAR.
        The Minimum Inventory Rating Factor is   3.56 at Distance   0.82 (ft)
        in TOP SLAB 1.

        The Minimum Operating Rating is governed by SHEAR.
        The Minimum Operating Rating Factor is   5.67 at Distance   0.82 (ft)
        in TOP SLAB 1.

   F or V reported after the Rating Factor indicates whether the Rating
   is for Flexure (F) or Shear (V).

   Note: Wall distances begin at the bottom of the wall and slab distances
         begin at the left side of the slab.
```

Figure 7.4.8-1 Sample Rating Summary Report

The following information is reported in the COMBINED RATING SUMMARY output tables:

1. Member – Location of controlling inventory rating for the Live Load Vehicle
2. Distance – Distance to controlling inventory rating along member for the Live Load Vehicle
3. Limit State – Limit State which generated the controlling inventory rating for the Live Load Vehicle
4. Rating – Controlling inventory rating for the Live Load Vehicle
5. Rating Tons – Controlling inventory tonnage for the Live Load Vehicle
6. Member – Location of controlling operating rating for the Live Load Vehicle
7. Distance – Distance to controlling operating rating along member for the Live Load Vehicle
8. Limit State – Limit State which generated the controlling operating rating for the Live Load Vehicle
9. Rating – Controlling operating rating for the Live Load Vehicle
10. Rating Tons – Controlling operating tonnage for the Live Load Vehicle

A sample Combined Rating Summary Report is shown in Figure 2. There is a column for each live load in the analysis. The number of live loads reported in this table depends on the Live Load selected on the LDC Command: A, B, C, D, E or F.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                      PAGE xx
Input File: xxx.DAT                                                           xx/xx/xxxx  xx:xx:xx
-----------------------------------------------------------------------------------------------------
                                BXLRFD EXAMPLE PROBLEM #x
                              RATING SUMMARY W/O FWS (cont.)
-----------------------------------------------------------------------------------------------------
                  +++++++++++++++++++++++++++++++++++++++++++++
                  +                                           +
                  +             C O M B I N E D               +
                  +        R A T I N G   S U M M A R Y        +
                  +                                           +
                  +++++++++++++++++++++++++++++++++++++++++++++

                                H20         HS20        HL-93
   INVENTORY    Member       Top Slab 2  Top Slab 2  Top Slab 2
   RATING       Dist.  (ft)     20.17       20.17       20.17
   (IR)         Limit State    STR-I       STR-I       STR-I
                Rating         0.95 V      0.84 V      0.74
V
                Rating Tons     18.95       30.10        --

                                H20         HS20        HL-93
   OPERATING    Member       Top Slab 2  Top Slab 2  Top Slab 2
   RATING       Dist.  (ft)     20.17       20.17       20.17
   (OR)         Limit State    STR-II      STR-II      STR-IA
                Rating         1.23 V      1.09 V      1.18 V
                Rating Tons     24.60       39.08        --

   All ratings are based on the exclusion of the design future wearing surface.

   F or V reported after the Rating Factor indicates whether the Rating
   is for Flexure (F) or Shear (V).
```

Figure 7.4.8-2 Sample Combined Rating Summary

7.4.9 Dead Load Effects and Capacities

This table is applicable for an Analysis without live load, and includes all culvert components, e.g., top slab, external wall, etc., other than strip footings.

The following information is reported in the DEAD LOAD EFFECTS AND CAPACITIES output tables:

1. Dist - distance from the beginning of the culvert component to the controlling IR POI.
2. Dist/Span Ratio - distance ratio of the controlling IR POI.
3. Loading Code - limit state (A) and maximum effect case (B) associated with the smallest resistance/demand ratio.
4. Moment - factored moment associated with the smallest flexure resistance/demand ratio.
5. Thrust - factored axial force associated with the smallest flexure resistance/demand ratio.
6. Shear - factored shear force associated with the smallest shear resistance/demand ratio.
7. Factored Resist - factored resistance, moment or shear, associated with the smallest resistance/demand ratio.
8. Zone – the controlling zone, either tension, compression, or transition.
9. Resist/Demand Ratio - the smallest flexure or shear resistance/demand ratios.

10. Prov Reinf – Provided flexure or shear reinforcement.
11. Min Reinf – Minimum required reinforcement.
12. Phi Factor – the flexural resistance factor.

A sample Dead Load Effects And Capacities Report is shown in Figure 1. Blank lines have been added for clarity around the POI at a distance of 0.77 feet. (The string 999.99 is printed if the smallest resistance/demand ratio is larger than 999.99.) An “F” is printed next to the factored resistance to indicate moment information, and a “V” indicates shear information. All demands and capacities are associated with the Limit State and Maximum Effect Case with the smallest resistance/demand ratio. Cases 1, 2, 3 and 4 are considered for flexure, and Cases 1, 2, 5 and 6 are considered for shear. See Section 3.4 for a description of the six Maximum Effect Cases.

Two lines of information are given for each POI: one for moment and one for shear. The Loading Code part of each line of information indicates the controlling Limit State and Maximum Effect Case: Code A is the Limit State and Code B is the Maximum Effect Case. The Legend at the end of the table describes the values of the two Loading Codes.

The amount of flexural reinforcement for the appropriate face (top/bottom, or left/right) as well as the minimum amount of required flexural reinforcement is also reported for each POI, as is any shear reinforcement. Any POI that has just a single line of information is due to the fact the some POIs are used to check just moment, not moment and shear, and therefore shear results are not applicable. Usually the POI closest to the ends of the components is just a moment POI and will not contain any shear results. More POIs will be moment only if haunches are present since only moment is considered within the haunch.

In Figure 1, at a distance of 0.77 feet, the smallest flexure resistance/demand ratio, among all Maximum Effect Cases, is 7.69. The “F” just to the left of the 7.69 indicates that this is a flexure resistance/demand ratio; the number “1” for Loading Code A and the number “1” for Load Code B indicates that Limit State Strength I and Maximum Effect Case 1 (Maximum Positive Moment and Concurrent Thrust) had the smallest flexure resistance/demand ratio. The associated factored dead load moment and thrust associated with Strength I and Maximum Effect Case 1 are 8.50 kip-ft and -8.77 kips, respectively, and the factored moment resistance is 65.40 kip-ft. Thus all the information is present to compute the flexure resistance/demand ratio, i.e., $r/d = M_r / M_{udl}$, or 65.40/8.50 = 7.69. Finally, the amount of flexural reinforcement at this POI location is 1.56 in^2 and the letter “B” next to it indicates that the controlling face is the bottom (the positive sign of M reflects this also).

The smallest shear resistance/demand ratio, among all Maximum Effect Cases, is 0.27. The “V” just to the left of the 0.27 indicates that this is a shear resistance/demand ratio; the number “1” for Loading Code A and the number “6” for Load Code B indicates that Limit State Strength I and Maximum Effect Case 6 (Maximum Negative Shear and Concurrent Moment) had the smallest shear resistance/demand ratio. The associated factored dead load shear associated with Strength I and Maximum Effect Case 6 is -74.78 kips, and the factored shear resistance, $\varphi_v (V_c+V_s)$, is -20.43 kips. Thus all the information is present to compute the shear resistance/demand ratio, i.e., r/d = V_r / V_{udl}, or -20.43)/-74.78 = 0.27. Finally, the amount of shear reinforcement at this POI location is 0.00 in^2 indicating that no shear steel exists at this location.

Lastly, the POI at location 0.00 feet and at 9.00 feet are moment only POIs due to the fact that only flexure results are reported.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                     PAGE x
Input File: xxx.dat                                                          xx/xx/xxxx  xx:xx:xx
---------------------------------------------------------------------------------------------------
                                  DESIGN D - 3 X 4, F'C = 6 KSI
                                 DEAD LOAD EFFECTS AND CAPACITIES
---------------------------------------------------------------------------------------------------

                                         Top Slab No. 1

       Dist/                                       Factored        Resist/
       Span  Loading                                Resist         Demand   Prov   Min       Phi
Dist   Ratio   Code    Moment  Thrust   Shear  (kips-ft)  Zone    Ratio    Reinf  Reinf     Factor
(ft)           A  B (kips-ft)  (kips)  (kips)    (kips)                    (in^2) (in^2)
 0.00   0.00   1  2     -7.15    4.04              -2.60 F  TN     0.36 *  0.07 T  0.22 ** 1.00

 0.48   0.06   1  2     -2.91    4.08              -3.48 F  TN     1.19    0.07 T  0.20 ** 1.00
               1  6                      -8.31    -13.16 V         1.58    0.00

 0.80   0.10   1  1      1.26    0.92              15.13 F  TN    12.05    0.38 B  0.20    1.00
               1  6                      -7.56    -13.16 V         1.74    0.00


        Loading Codes:
          Code A             Code B
          1  Strength-I      1  Maximum Positive Moment
          2  Strength-II        and Concurrent Thrust
          3  Strength-IA     2  Maximum Negative Moment
                                and Concurrent Thrust
                             3  Maximum Tension Thrust
                                and Concurrent Moment
                             4  Maximum Compression Thrust
                                and Concurrent Moment
                             5  Maximum Positive Shear
                                and Concurrent Moment
                             6  Maximum Negative Shear
                                and Concurrent Moment

         F or V reported after the Factored Resistance indicates whether the
         Resistance, Ratio, and Reinforcement reported are for Flexure (F)
         or Shear (V).

         Zone Code Descriptions
                TN - Tension controlled section
                TR - Transition section
                CM - Compression controlled section

     Phi Factor Epsilon (cl) =  0.00200
     Phi Factor Epsilon (tl) =  0.00500

     Note: Wall distances begin at the bottom of the wall and slab distances
           begin at the left side of the slab.
```

Figure 7.4.9-1 Sample Dead Load and Capacities Report

7.4.10 Flexural Reinforcement Design - Reinforcement Bar

This table is applicable for a Design and includes all culvert components, e.g., top slab, external wall, strip footings, etc. This table provides the primary result for a design: the amount of top and bottom flexure reinforcement at each POI required to resist the applied factored forces and moments, and the permitted reinforcement bar spacings. The spacings are given for eight rebar sizes, and are the smaller of that required to satisfy strength, i.e., to provide the required As per unit length, and that to satisfy crack control requirements. See Section 3.5.2 for a discussion of how the crack control spacings are calculated. Spacings are rounded down to the nearest 0.5 in.

The following information is reported in the FLEXURAL REINFORCEMENT DESIGN output tables:

1. Member Name - the culvert member, e.g., Top Slab, appears in the table heading.
2. Face Location - the flexure reinforcement location, either Top or Bottom Face appears in the heading.
3. Dist - distance from the beginning of the culvert component to the POI.
4. Flexure Load Code - limit state (A), maximum effect case (B), live load (C), live load type (D) associated with the largest amount of flexure reinforcement.
5. Factored Moment - factored moment associated with the required flexure reinforcement.
6. Factored Thrust - factored axial force associated with the largest amount of flexure reinforcement.
7. Factored Resisting Moment – factored resisting moment based on the required area of steel.
8. Factored Resisting Thrust – factored resisting thrust based on the required area of steel.
9. Zone – the controlling zone, either tension, compression, or transition. **See Figure 3.5.1.2-1 for CM, TN, and TR locations.**
10. Flex Reinf - required flexure reinforcement **calculated per Section 3.5.1.2 for a singly reinforced section**.
11. Phi Factor – the flexural resistance factor **calculated per Section 3.5.1.3**.
12. Bar Spacing - bar spacings for eight (8) bar sizes, with any associated codes.

A sample Flexural Reinforcement Design Report is shown in Figure 1. There is a table for the top or left face, and the bottom or right face for each culvert component. There are always two lines of information printed for each POI: one for the first four bar sizes, and one for the second four. The first line also contains the required area of flexure reinforcement for strength and the set of Strength Loading Codes associated with the required area. The controlling total limit state moment is also printed on the first line. The thrust is printed on the second line. If reinforcement is not required, then the Loading Codes and demands are not applicable and they are left blank.

The Flexure Loading Code part of the first line of information indicates the controlling Limit State, Maximum Effect Case, Live Load and Live Load Type: Code A is the Limit State, Code B is the Maximum Effect Case, Code C is the Live Load, and Code D is the Live Load Type. The Legend at the end of the table describes the values of the four Strength Loading Codes. Limit States Strength I, Strength II and Construction, and Maximum Effect Cases 1, 2, 3 and 4 are considered for flexure design. Different live loads are used for each limit state and the number and type of live loads used for the design depend on the selected live load type on the LDC command. See Section 5.10 for a description of the LDC command. See Section 3.4 for a description of the six Maximum Effect Cases.

The total factored moment and thrust used to design the flexure reinforcement are given after the Flexure Loading Code. The required flexure reinforcement is reported after the factored moment and thrust. This amount of reinforcement is required in the indicated face for strength considerations to resist all factored loads. If an "M" is printed next to the flexure reinforcement, then the minimum reinforcement controls the design at the POI location. **If an "%" is printed next to the Flexural Reinforcement, the area is the maximum reinforcement considered. If an "*" is printed next to the Factored Resistances, they are less than the Factored Loads.**

For each point of interest, the applicable condition for that section is reported in the Zone column - TN for tension-controlled, CM for compression-controlled, and TR for **transition between compression-controlled and tension-controlled** condition (see Section 3.5.1.2).

The phi resistance factor used in determining the **factored** flexural resistance of the section for analysis runs is shown in the Phi Factor column. For design runs, the phi resistance factor shown in the Phi Factor column is used to compute the required area of reinforcement.

Bar spacings that are controlled by crack control requirements are indicated by an integer Crack Control Code (1 through 8, see the Legend at the end of the table) and any spacing that exceeds the minimum or maximum allowed is indicated by a letter code (V or W, again, see the table Legend). Bar spacings with an integer Crack Control Code have a spacing less than that required to provide the design As, and therefore will provide more As than that required for strength.

The Crack Control Codes contain only the Maximum Effect Cases and On Deck or Through Fill because there is only one Limit State (Service I) and only one Live Load (PHL 93) used in crack control calculations.

In Figure 1, for the bottom face of the top slab, at a location of 5.55 feet, the amount of flexure reinforcement is 0.52 in^2. The Strength Loading Codes indicate that Strength I, Maximum Effect Case 1 (Maximum Positive Moment and Concurrent Thrust), PHL-93 and On Deck loading caused the 41.8 kip-ft moment and 2.14 kip thrust which requires 0.52 in^2 flexure reinforcement which is the largest among all Limit States and Maximum Effect Cases. If Flexure Loading Codes C and D are blank, then live load would not have been applicable.

The bar spacings for all bar sizes are controlled by strength requirements, due to the fact that no integer codes appear after the spacings. The bar spacings for bar sizes #10 and #11 are controlled by maximum spacing requirements because of Code W after the spacings.

For Strip Footings, if the eccentricity is off the footing a warning message is displayed with a table that includes the eccentricity and the edge of footing to centerline width for each limit state.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                         PAGE xx
Input File: xxx.DAT                                                              xx/xx/xxxx  xx:xx:xx
---------------------------------------------------------------------------------------------------
                                    BXLRFD EXAMPLE PROBLEM #xx
                                  FLEXURAL REINFORCEMENT DESIGN
---------------------------------------------------------------------------------------------------

                                   Top Slab No. 1 - Bottom Face

      Flexure    Factored   Fact Resist
Dist  Loading Moment/Thrust Mom/Thrust       Flex    Phi                 Bar Spacing
        Code     (kips-ft)    (kips-ft)  Zone Reinf  Factor  # 4/# 8   # 5/# 9   # 6/#10   # 7/#11
(ft)   A B C D     (kips)      (kips)          (in^2)           (in)      (in)      (in)      (in)
 5.55  1 1 1 1      41.80      41.81       TN   0.52   0.90      4.5       7.0      10.0      13.5
                     2.14       2.15                   0.90     18.0      23.0      24.0  W   24.0  W

   Flexure Loading Codes:
    Code A            Code B                        Code C     Code D
     1  Strength-I     1  Maximum Positive Moment    1  PHL-93  1  On Deck
     2  Strength-II       and Concurrent Thrust      2  HL-93   2  Thru Fill
     3  Construction   2  Maximum Negative Moment    3  P-82
     4  Bot Slab Only     and Concurrent Thrust      4  ML-80
                       3  Maximum Tension Thrust     8  TK527
                          and Concurrent Moment      X  P2016-13
                       4  Maximum Compression Thrust
                          and Concurrent Moment
                       5  Maximum Positive Shear
                          and Concurrent Moment
                       6  Maximum Negative Shear
                          and Concurrent Moment

   If the Flexure Loading Code is blank, no reinforcement is required for
   strength.

   If an M is printed next to the Flexural Reinforcement, the design is
   governed by minimum reinforcement.

   If an % is printed next to the Flexural Reinforcement, the area is the
   maximum reinforcement considered.

   If an * is printed next to the Factored Resistances, they are less than
   the Factored Loads.

   Zone Code Descriptions
         TN - Tension controlled section
         TR - Transition section
         CM - Compression controlled section
```

```
Phi Factor Epsilon (cl) =  0.00200
Phi Factor Epsilon (tl) =  0.00500

If a number appears after the spacing, it has been calculated using
crack control requirements.  That number corresponds to the Crack Control
Codes listed below.  If a number does not appear after the spacing, it has
been calculated using the reported flexural reinforcement.  The flexural
reinforcement is based on the reported Flexure Loading Code.

Crack Control Codes:
   1  On Deck      - Maximum Positive    Moment and Concurrent Thrust
   2  On Deck      - Maximum Negative    Moment and Concurrent Thrust
   3  On Deck      - Maximum Tension     Thrust and Concurrent Moment
   4  On Deck      - Maximum Compression Thrust and Concurrent Moment
   5  On Deck      - Maximum Positive    Shear  and Concurrent Effects
   6  On Deck      - Maximum Negative    Shear  and Concurrent Effects
   7  Through Fill - Maximum Positive    Moment and Concurrent Thrust
   8  Through Fill - Maximum Negative    Moment and Concurrent Thrust
   9  Through Fill - Maximum Tension     Thrust and Concurrent Moment
   A  Through Fill - Maximum Compression Thrust and Concurrent Moment
   B  Through Fill - Maximum Positive    Shear  and Concurrent Effects
   C  Through Fill - Maximum Negative    Shear  and Concurrent Effects

When Live Load is not applicable, i.e., when Flexure Loading Codes
C and D are blank, Crack Control Codes 1-4 will be used to indicate
the Dead Load Maximum Effect Case.  Ignore the 'On Deck' part of the
code message.
If a letter appears after the spacing, the letter corresponds to one of
the following errors or messages:
   V  Spacing < minimum (LRFD Specifications and DM-4 5.10.3.1)
   W  Actual bar spacing was governed by DM-4 maximum spacing requirements
      (LRFD Specifications and DM-4 5.10.3.2 and 5.10.6, DM-4 5.10.6.1P)

Note: Wall distances begin at the bottom of the wall and slab distances
      begin at the left side of the slab.
```

Figure 7.4.10-1 Sample Design of Flexural Reinforcement Report – Reinforcement Bar

7.4.11 Flexural Reinforcement Design - Wire Mesh

This table is applicable for a Design and includes all culvert components, e.g., top slab, external wall, strip footings, etc. This table provides the primary result for a design: the amount of top and bottom flexure reinforcement at each POI required to resist the applied factored forces and moments.

The following information is reported in the FLEXURAL REINFORCEMENT DESIGN output tables:

1. Member Name - the culvert member, e.g., Top Slab, appears in the table heading.
2. Face Location - the flexure reinforcement location, either Top Face or Bottom Face appears in the table heading.
3. Dist - distance from the beginning of the culvert component to the POI.
4. Flexure Load Code - limit state (A), maximum effect case (B), live load (C), live load type (D) associated with the largest amount of flexure reinforcement.
5. Factored Moment - factored moment associated with the required flexure reinforcement.
6. Factored Thrust - factored axial force associated with the largest amount of flexure reinforcement.
7. Factored Resisting Moment – factored resisting moment based on required area of steel.
8. Factored resisting Thrust – factored axial resistance based on required area of steel.
9. Zone – the controlling zone, either tension, compression, or transition.
10. Flex Reinf - required flexure reinforcement.
11. Phi Factor - the flexural resistance factor.

A sample Flexural Reinforcement Design Report is shown in Figure 1. There is a table for the top or left face, and the bottom or right face for each culvert component. The first line contains the required area of flexure reinforcement for strength and the set of Strength Loading Codes associated with the required area. The controlling total limit state moment is also printed on the first line. The thrust is printed on the second line. If reinforcement is not required, then the Loading Codes and demands are not applicable and they are left blank.

The Flexure Loading Code part of the first line of information indicates the controlling Limit State, Maximum Effect Case, Live Load and Live Load Type: Code A is the Limit State, Code B is the Maximum Effect Case, Code C is the Live Load, and Code D is the Live Load Type. The Legend at the end of the table describes the values of the four Strength Loading Codes. Limit States Strength I, Strength II and Construction, and Maximum Effect Cases 1, 2, 3 and 4 are considered for flexure design. Different live loads are used for each limit state and the number and type of live loads used for the design depend on the selected live load type on the LDC command. See Section 5.10 for a description of the LDC command. See Section 3.4 for a description of the six Maximum Effect Cases.

The total factored moment and thrust used to design the flexure reinforcement are given after the Flexure Loading Code. The required flexure reinforcement is reported after the factored moment and thrust. This amount of reinforcement is required in the indicated face for strength considerations to resist all factored loads. If an “M” is printed next to the flexure reinforcement, then the minimum reinforcement controls the design at the particular POI location.

In Figure 1, for the bottom face of the top slab, at a location of 1.80 feet, the amount of flexure reinforcement is 0.21 in^2. The Strength Loading Codes indicate that Strength I, Maximum Effect Case 1 (Maximum Positive Moment and Concurrent Thrust caused the 6.52 kip-ft moment and 10.77 kip thrust which requires 0.21 in^2 flexure reinforcement which is the minimum required amount. If Flexure Loading Codes C and D are blank, then live load would not have been applicable.

For Strip Footings, if the eccentricity is off the footing a warning message is displayed with a table that includes the eccentricity and the edge of footing to centerline width for each limit state.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                         PAGE x
Input File: xxx.dat                                                              xx/xx/xxxx  xx:xx:xx
----------------------------------------------------------------------------------------------------
                                    BXLRFD EXAMPLE PROBLEM #x
                                  FLEXURAL REINFORCEMENT DESIGN
----------------------------------------------------------------------------------------------------

                                    Top Slab No. 1 - Top Face

           Flexure    Factored   Fact Resist
      Dist  Loading Moment/Thrust Mom/Thrust          Flex      Phi
             Code    (kips-ft)    (kips-ft)    Zone    Reinf     Factor
     (ft)    A B C D   (kips)        (kips)            (in^2)
      0.00  1 2 1 2    -9.98         -9.98      TN      0.29M     1.00
                        4.00          4.01

         Flexure Loading Codes:
          Code A            Code B                        Code C     Code D
           1  Strength-I      1  Maximum Positive Moment    1  PHL-93   1  On Deck
           2  Strength-II        and Concurrent Thrust      2  HL-93    2  Thru Fill
           3  Construction    2  Maximum Negative Moment    3  P-82
           4  Bot Slab Only      and Concurrent Thrust      4  ML-80
                              3  Maximum Tension Thrust     8  TK527
                                 and Concurrent Moment      X  P2016-13
                              4  Maximum Compression Thrust
                                 and Concurrent Moment
                              5  Maximum Positive Shear
                                 and Concurrent Moment
                              6  Maximum Negative Shear
                                 and Concurrent Moment

         If the Flexure Loading Code is blank, no reinforcement is required for
         strength.

         If an M is printed next to the Flexural Reinforcement, the design is
         governed by minimum reinforcement.

         Zone Code Descriptions
               TN - Tension controlled section
               TR - Transition section
               CM - Compression controlled section

         Phi Factor Epsilon (cl) =  0.00200
         Phi Factor Epsilon (tl) =  0.00500

         Note: Wall distances begin at the bottom of the wall and slab distances
          begin at the left side of the slab.
```

Figure 7.4.11-1 Sample Design of Flexural Reinforcement Report – Wire Mesh

7.4.12 Development Length Check Table

This table is only displayed for the design of cast in place rigid frame fixed support culverts. This table shows the hook development length of reinforcement bars (for the controlling face of the wall) that enter the strip footings. This table is not applicable for precast rigid frame pinned support culverts.

This table is based on the results of the Design of Flexural Reinforcement and only shows development for the bars that have been designed for flexure with unique spacing from each face of the wall. The data is sorted based on smallest to largest bar size and shows the development length along with an indicator if the bar cannot develop into the footing.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                        PAGE xx
Input File: xxx.dat                                                            xx/xx/xxxx  xx:xx:xx
---------------------------------------------------------------------------------------------------
                               LANCASTER COUNTY SR 0030 SECTION 11
                                     DEVELOPMENT LENGTH CHECK
---------------------------------------------------------------------------------------------------

                                WALL BAR DEVELOPMENT INTO FOOTING

                                           Wall No. 1
                                    Right Face is controlling
                                (Area Steel Required = 0.262 in^2)

         Bar                              Hooked Bar Development Length
       Spacing    # 4      # 5      # 6      # 7      # 8      # 9      #10      #11
        (in)      (in)     (in)     (in)     (in)     (in)     (in)     (in)     (in)
         9.0     12.92      --       --       --       --       --       --       --
        14.0       --     16.20      --       --       --       --       --       --
        18.0       --       --     17.61*   15.07    13.08    11.65    10.33    11.28

          * - indicates the bar cannot develop into the footing
```

Figure 7.4.12-1 Sample Design of Development Length Check Report

The following information is reported in the DEVELOPMENT LENGTH CHECK output tables:

1. Wall Number - the culvert wall number appears in the table heading
2. Area Steel Required – the area of steel required at the bottom of the wall, appears in the table heading
3. Bar Spacing – All applicable flexural design spacings for a wall are shown.
4. Hooked Bar Development Length – The development length for relevant bars are shown.

7.4.13 Shear Design

This table is applicable for a Design and includes all culvert components, e.g., top slab, external wall, etc., other than strip footings. (The Strip Footing Shear Design Report described in Section 7.4.9.) This table provides shear information for a design: the amount of shear reinforcement required to resist the applied factored shear force above the concrete shear capacity if shear steel has been asked for in the design. Requesting that shear steel be included in the design is done with the CTL command which is discussed in Section 5.5.

The following information is reported in the SHEAR DESIGN output tables:

1. Dist - distance from the beginning of the culvert component to the POI.
2. Shear Loading Code - limit state (A), maximum effect case (B), live load (C), live load type (D) associated with the largest amount of shear reinforcement or smallest V_c.
3. Fact Shear - factored shear associated with the largest amount of shear reinforcement.
4. Factored Moment - factored moment associated with the largest amount of flexure reinforcement. Note that this value may or may not affect the shear capacity, as shown in Section 3.5.4. Therefore, it is possible to see unsymmetrical moment values in a symmetrical culvert structure.

5. Flex Reinf - amount of flexure reinforcement used for shear design.
6. Shear Depth - the shear depth.
7. Concrete Shear Capac - smallest concrete shear capacity.
8. Shear Reinf - largest amount of shear reinforcement.

A sample Shear Design Report is shown in Figure 1. The largest amount of shear reinforcement needed controls the shear loading code, if shear steel has been included in the design. Otherwise, the smallest shear capacity of concrete, V_c. The shear loading codes are associated with the Limit State, Maximum Effect Case, live load and live loading type (On Deck or Through Fill) that either maximize or minimize these conditions.

Limit States Strength I, Strength II and Construction, and Cases 1, 2, 5 and 6 are considered for shear. Different live loads are used for each limit state and the number and type of live loads used for the design depend on the selected live load type on the LDC command. See Section 5.10 for a description of the LDC command. See Section 3.4 for a description of the six Maximum Effect Cases.

The Shear Loading Code indicates the controlling Limit State, Maximum Effect Case, Live Load and Live Load Type: Code A is the Limit State, Code B is the Maximum Effect Case, Code C is the Live Load and Code D is the Live Load Type. The Legend at the end of the table describes the values of the four Loading Codes.

If the required shear area is zero at a POI, then the smallest concrete shear capacity will control Shear Loading Codes. The Shear Capacity is the capacity of the concrete alone, V_c. When shear steel has been requested in the design and the factored shear loading is greater **than** the capacity of the concrete, then the required shear reinforcement will be computed.

In Figure 1, at a location of 5.55 feet, the amount of shear reinforcement required at this POI location is 0.00 in^2. Since there is no required shear steel, then the reported Shear Capacity is the smallest among all Limit States, Maximum Effect Cases, Live Loadings and Live Loading Types. If there would have been shear steel required, then the reported value for Av would have been the largest among those conditions, and the Shear Capacity would be that associated with the set of Loading Codes.

The Shear Loading Codes indicate that Limit State Strength-I and Maximum Effect Case 6 (Maximum Negative Shear and Concurrent Moment) causes the Shear Capacity of 19.76 kips to occur and it is the smallest among all Limit States and Maximum Effect Cases. Loading Codes C and D would be blank if a construction limit state controlled. The total factored shear associated with Strength-I and Maximum Effect Case 6 is -10.95 kips. The total factored moment is 36.84 kip-ft.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                     PAGE xx
Input File: xxx.dat                                                          xx/xx/xxxx  xx:xx:xx
---------------------------------------------------------------------------------------------------
                                    BXLRFD EXAMPLE PROBLEM #x
                                           SHEAR DESIGN
---------------------------------------------------------------------------------------------------

                                         Top Slab No. 1

            Shear                                               Conc+
           Loading      Factored        Flex     Shear    Shear     Shear
    Dist    Code     Shear    Moment     Reinf    Depth    Capac     Reinf
    (ft)   A B C D   (kips)  (kips-ft)   (in^2)    (in)    (kips)    (in^2)
    0.79   1 6 1 2    -9.55     -2.05     0.29     8.64    21.63     0.000
    1.00   1 6 1 2    -9.09     -0.33     0.29     8.64    21.63     0.000
    2.00   1 6 1 1    -7.01      6.47     0.30     8.64    21.63     0.000
    3.00   1 6 1 1    -5.03     10.57     0.48     8.64    21.63     0.000
    4.00   1 6 1 1    -3.23     12.68     0.59     8.64    21.63     0.000
    5.00   1 5 1 2     1.65     12.82     0.63     8.64    21.63     0.000
    6.00   1 5 1 2     3.31     12.52     0.59     8.64    21.63     0.000
    7.00   1 5 1 2     5.08     10.58     0.48     8.64    21.63     0.000
    8.00   1 5 1 2     7.01      6.21     0.29     8.64    21.63     0.000
    9.00   1 5 1 2     9.01     -0.53     0.29     8.64    21.63     0.000
    9.21   1 5 1 2     9.45     -2.23     0.29     8.64    21.63     0.000

  * After the Shear Reinforcement Area indicates Vs required > Vs max

  Shear Loading Codes:
   Code A             Code B                         Code C     Code D
    1  Strength-I      1  Maximum Positive Moment     1  PHL-93  1  On Deck
    2  Strength-II        and Concurrent Thrust       2  HL-93   2  Thru Fill
    3  Construction    2  Maximum Negative Moment     3  P-82
    4  Bot Slab Only      and Concurrent Thrust       4  ML-80
                       3  Maximum Tension Thrust      8  TK527
                          and Concurrent Moment       X  P2016-13
                       4  Maximum Compression Thrust
                          and Concurrent Moment
                       5  Maximum Positive Shear
                          and Concurrent Moment
                       6  Maximum Negative Shear
                          and Concurrent Moment

  + The Concrete Shear Capacity shown is the factored shear capacity (phiv*Vc)

  The Factored Moments shown are the moments associated with the reported
  Shear Loading Code (i.e., limit state, max effect case, live load,
  on deck/thru fill).

  Areas of flexural reinforcement printed here are used in shear
  calculations are optimized values that satisfy strength and
  serviceability requirements for member flexural regions.
  See section 3.5 in user's manual for further information.

  A "t" or "%" after the Flexural Reinforcement Area indicates a valid
  bar size and bar spacing combination was not found.
    "t" the area is the theoretical area required to satisfy strength requirements.
    "%" the area is the maximum reinforcement considered.
  Consider increasing member thickness and/or concrete strength.

  Note: Wall distances begin at the bottom of the wall and slab distances
        begin at the left side of the slab.
```

Figure 7.4.13-1 Sample Design of Shear Reinforcement Report

7.4.14 Strip Footing Shear Design

This table is applicable for a Design and includes only strip footings. (The Shear Design Report described in Section 7.4.11.) This table provides strip footing shear information for a design: the Shear Performance Ratio, which is the Factored Shear Resistance divided by the Factored Shear. If the eccentricity is off the footing a warning message is displayed with a table that includes the eccentricity and the edge of footing to centerline width for each limit state.

The following information is reported in the STRIP FOOTING SHEAR DESIGN output tables:

1. Dist - distance from the beginning of the culvert component to the POI.
2. Side of Wall - either Left or Right indicating from which side of the wall the POI is measured.
3. Shear Loading Code - limit state (A), maximum effect case (B), live load (C), live load type (D) associated with the smallest shear performance ratio.
4. Fact Shear - factored shear associated with the smallest shear performance ratio.
5. Shear Depth - the shear depth.
6. Concrete Shear Resist - factored shear resistance associated with the smallest shear performance ratio.
7. Shear Perform - smallest shear performance ratio.

A sample Strip Footing Shear Design table is shown in Figure 1. The shear loading code is controlled by the smallest Shear Performance Ratio. All demands and resistances are associated with the Limit State, Maximum Effect Case, Live Load and Live Loading Type (On Deck or Through Fill) that maximizes the shear performance ratio.

Limit States Strength I, Strength II and Construction, and all Maximum Effect Cases are considered for shear. (Recall that the moment in the footing is calculated from the total limit state response at the bottom of the wall, so all six Maximum Effect Cases must be investigated.) Different live loads are used for each limit state and the number and type of live loads used for the design depend on the selected live load type on the LDC command. See Section 5.10 for a description of the LDC command. See Section 3.4 for a description of the six Maximum Effect Cases.

The Shear Loading Code indicates the controlling Limit State, Maximum Effect Case, Live Load and Live Load Type: Code A is the Limit State, Code B is the Maximum Effect Case, Code C is the Live Load and Code D is the Live Load Type. The Legend at the end of the table describes the values of the four Loading Codes.

The Shear Loading Code is the condition that causes the smallest performance ratio. The Shear Resistance is the capacity of the concrete alone,,V_c.

In Figure 1, at a location of 1.58 ft for Wall No. 2, which is a distance-d from the right face, the Shear Performance Ratio is 4.52. The Shear Loading Codes indicate that Limit State Strength I and Maximum Effect Case 2 (Maximum Negative Moment and Concurrent Thrust in the wall) cause this smallest ratio to occur. Loading Codes C and D are left blank when live load is not applicable or a construction limit state controls. The total factored shear and factored resistance associated with Strength I and Maximum Effect Case 2 are 4.69 kips and 21.21 kips, respectively.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                        PAGE xx
Input File: xxx.dat                                                             xx/xx/xxxx  xx:xx:xx
---------------------------------------------------------------------------------------------------
                                    BXLRFD EXAMPLE PROBLEM #x
                                    STRIP FOOTING SHEAR DESIGN
---------------------------------------------------------------------------------------------------

                                         Under Wall No. 1

    Dist    Side    Shear
    from     of    Loading    Fact     Shear     Shear   Performance
    Face    Wall     Code     Shear    Depth     Resist     Ratio
    (ft)           A B C D   (kips)    (in)      (kips)
     2.67   Left   1 2         4.43    28.80     32.16       7.26
     0.00   Left   1 2         7.74    28.80     32.16       4.15
     0.00  Right
     2.67  Right   1 2         1.41    28.80     32.16      22.73

   Shear Loading Codes:
    Code A           Code B                        Code C     Code D
     1  Strength-I    1  Maximum Positive Moment    1  PHL-93  1  On Deck
     2  Strength-II      and Concurrent Thrust      2  HL-93   2  Thru Fill
     3  Construction  2  Maximum Negative Moment    3  P-82
                         and Concurrent Thrust      4  ML-80
                      3  Maximum Tension Thrust     8  TK527
                         and Concurrent Moment      X  P2016-13
                      4  Maximum Compression Thrust
                         and Concurrent Moment
                      5  Maximum Positive Shear
                         and Concurrent Moment
                      6  Maximum Negative Shear
                         and Concurrent Moment

   Note: Wall distances begin at the bottom of the wall and slab distances
         begin at the left side of the slab.
```

Figure 7.4.14-1 Sample Strip Footing Design Report

7.4.15 Minimum Reinforcement Check

This table reports calculated minimum reinforcement for relevant POI's for the various conditions. This table is applicable for both an Analysis and Design.

The following information is reported in the MINIMUM REINFORCEMENT CHECK output tables:

1. Dist - distance from the beginning of the culvert component to the POI.
2. Cracking Moment - cracking moment for the section.
3. 1.33*M(u) - 1.33 * maximum applied moment.

4. Rho Min Area - minimum required reinforcement area for flexure.
5. Temp Shrink Area - minimum required reinforcement area for temperature and shrinkage.
6. 0.002Ag - 0.002 * gross section area.
7. Phi Factor – resistance factor in pure bending.

8. Area Prov/Width - reinforcement area specified (for analysis)/required (for design) for a unit width.
9. Status Code – used to indicate if the reinforcement area provided is less than required.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                         PAGE xx
Input File: xxx.dat                                                              xx/xx/xxxx  xx:xx:xx
---------------------------------------------------------------------------------------------------
                                    BXLRFD EXAMPLE PROBLEM #x
                                   MINIMUM REINFORCEMENT CHECK
---------------------------------------------------------------------------------------------------

                                    Top Slab No. 1 -  Top Face

          Cracking                             Temp                          Area
           Moment                   Rho Min   Shrink    0.002      Phi      Reqd/    Status
  Dist     M(cr)     1.33*M(u)      Area      Area       Ag       Factor    Width     Code
  (ft)    (kip-ft)   (kip-ft)      (in^2)    (in^2)    (in^2)              (in^2)
  0.00       7.57      -16.93+      0.24*     0.20       N/A     0.900     0.332
  0.30       7.62      -14.20+      0.24*     0.20       N/A     0.900     0.259
  0.59       7.68      -11.68+      0.25*     0.20       N/A     0.900     0.245
  0.80       7.71      -10.55+      0.25*     0.20       N/A     0.900     0.246
  1.60       7.86+      -6.90       0.22*     0.20       N/A     0.900     0.216
  2.40       8.01+      -4.30       0.13      0.20*      N/A     0.900     0.200
  3.20       8.15                             0.20*      N/A               0.200
  4.00       8.30                             0.20*      N/A               0.200
  4.80       8.45                             0.20*      N/A               0.200
  5.60       8.61+      -4.59       0.13      0.20*      N/A     0.900     0.200
  6.40       8.76+      -7.32       0.21*     0.20       N/A     0.900     0.212
  7.20       8.92      -11.12+      0.26*     0.20       N/A     0.900     0.256
  7.33       8.94      -11.82+      0.26*     0.20       N/A     0.900     0.256
  7.66       9.01      -14.51+      0.26*     0.20       N/A     0.900     0.257
  8.00       9.07      -17.66+      0.26*     0.20       N/A     0.900     0.298

   Status Code Descriptions
       + - Controlling moment for Rho Min Area calculation
       * - Controlling minimum area of steel
       A - Area provided smaller than required minimum area of steel
```

Figure 7.4.15-1 Sample Reinforcement Check Report

7.4.16 Foundation Pressure

This table is applicable for both an Analysis and Design, and when a bottom slab is present. (The Strip Footing Bearing Pressure Report is described in Section 7.4.14.) The foundation pressure is reported at the centerline of each wall for all live loads and for the limit states: Strength I, Strength II and Service I. The number of live loads reported in this table depends on the Live Load selected on the LDC Command: A, B, C, D, or E for a Design, and A, B, C, D, E or F for an Analysis. The maximum pressure in each limit state, among all the walls, is indicated with an asterisk, "*".

The following information is reported in the FOUNDATION PRSSURE output tables:

1. Lim St – Indicates which limit state results are being reported for.
2. Load - a live loading, e.g., PHL-93.
3. Wall Pressure – Indicates what the foundation pressure is under the indicated wall for the current maximized wall location.

4. Effective Foundation Bearing Width – Shows the width of the culvert foundation that is exerting force on the soil. For Trapezoidal distribution this is always the distance between the centerline of the exterior walls. For Triangular distribution it is the distance from the center of the exterior wall that has foundation pressure to the location where pressure goes to zero.

A sample Foundation Pressure Report is shown in Figure 1.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                       PAGE xx
Input File: xxx.dat                                                             xx/xx/xxxx  xx:xx:xx
--------------------------------------------------------------------------------------------------
                                    BXLRFD Example Problem #x
                                       FOUNDATION PRESSURE
--------------------------------------------------------------------------------------------------

                          Maximum Influence Line  Pressure at Wall No. 1

                       Wall 1      Wall 2     Eff Foundation
   Lim St   Load       Press       Press      Bearing Width
                       (ksf)       (ksf)           (ft)
   STR-I    PHL-93      3.08        1.67           9.75
            ML-80       2.55        1.67           9.75
            HS20        2.68        1.67           9.75
            H20         2.68        1.67           9.75
            TK527       2.25        1.67           9.75
   STR-II   P-82        2.60        1.65           9.75
            ML-80       2.35        1.67           9.75
            HS20        2.45        1.67           9.75
            H20         2.45        1.67           9.75
            TK527       2.11        1.66           9.75
   SER-I    PHL-93      2.18        1.38           9.75
            ML-80       1.88        1.38           9.75
            HS20        1.95        1.38           9.75
            H20         1.95        1.38           9.75
            TK527       1.71        1.37           9.75

                          Maximum Influence Line  Pressure at Wall No. 2

                       Wall 1      Wall 2     Eff Foundation
   Lim St   Load       Press       Press      Bearing Width
                       (ksf)       (ksf)           (ft)
   STR-I    PHL-93      1.65        3.08 *         9.75
            ML-80       1.65        2.55           9.75
            HS20        1.65        2.68           9.75
            H20         1.65        2.68           9.75
            TK527       1.66        2.25           9.75
   STR-II   P-82        1.66        2.60 *         9.75
            ML-80       1.66        2.35           9.75
            HS20        1.66        2.45           9.75
            H20         1.66        2.45           9.75
            TK527       1.66        2.11           9.75
   SER-I    PHL-93      1.37        2.18 *         9.75
            ML-80       1.37        1.88           9.75
            HS20        1.37        1.95           9.75
            H20         1.37        1.95           9.75
            TK527       1.37        1.71           9.75

   * Indicates the maximum Foundation Pressure for each limit state.
```

Figure 7.4.16-1 Sample Foundation Pressure Report

7.4.17 Foundation Pressure Summary Table

This table is applicable for both Analysis and Design and displays a summary of maximum foundation pressure under each wall for each limit state.

The following information is reported in the FOUNDATION PRESSURE SUMMARY output table:

1. Lim St – Indicates which limit state results are being reported for.
2. Load - a live loading, e.g., PHL-93.
3. Wall Pressure – Indicates what the maximum foundation pressure is under the indicated wall for the indicated limit state.

This table is switched on by default.

A sample Foundation Pressure Summary Report is shown in Figure 1.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                           PAGE xx
Input File: xxx.dat                                                                 xx/xx/xxxx  xx:xx:xx
-------------------------------------------------------------------------------------------------------
                                    BXLRFD Example Problem #xx
                                   FOUNDATION PRESSURE SUMMARY
-------------------------------------------------------------------------------------------------------

                                   Maximum Foundation Pressure

                       Wall 1      Wall 2      Wall 3
   Lim St   Load       Press       Press       Press
                       (ksf)       (ksf)       (ksf)
   STR-I    ML-80       3.16 *      2.14        3.16
   STR-II   ML-80       2.74 *      1.95        2.74
   SER-I    ML-80       2.09 *      1.54        2.09

   * Indicates the maximum Foundation Pressure for each limit state.
```

Figure 7.4.17-1 Sample Foundation Pressure Summary Report

7.4.18 Strip Footing Bearing Pressure

This table is applicable for both an Analysis and Design, and when a bottom slab is not present. (The Foundation Pressure Report described in Section 7.4.13.) The Strip Footing Bearing Pressure is reported at the left and right edges of each footing for all live loads and for the limit states: Strength I, Strength II and Service I. The number of live loads reported in this table depends on the Live Load selected on the LDC Command: A, B, C, D or E for a Design, and A, B, C, D, E or F for an Analysis.

The following information is reported in the STRIP FOOTING BEARING PRSSURE output tables:

1. Wall Location - the wall number for which the pressures are reported appears in the table heading
2. Live Load - a live loading, e.g., PHL-93.
3. Location - either “L” or “R” indicating which edge of the footing the pressures are being reported.
4. e/B - resultant eccentricity / footing width ratio.

5. Bearing Pressure - soil bearing pressure.

The ratio of the eccentricity of the resultant of all external vertical loads: total factored axial force in the wall; factored live load surcharge (LS) and factored weight of the column of soil above the midpoint of the heel (EV); and the factored weight of the footing (DC), to the width of the footing, is reported as e/B. See Section 3.7 for details on how the eccentricity and the pressure in the soil are calculated. The maximum e/B ratio and pressure in each limit state and considering all six Maximum Effect Cases, among all the footings, are indicated with an asterisk, "*". The reported e/B ratios and soil pressures are independent from each other, i.e., they are not associated quantities.

A sample Strip Footing Bearing Pressure Report is shown in Figure 1.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                         PAGE xx
Input File: xxx.dat                                                              xx/xx/xxxx  xx:xx:xx
----------------------------------------------------------------------------------------------------
                                  SR2011 CULVERT DESIGN
                              STRIP FOOTING BEARING PRESSURE
----------------------------------------------------------------------------------------------------

                                        Wall No. 1

                   STR-I    STR-I      STR-II   STR-II       SER-I    SER-I
    Live            e/B    Bearing      e/B    Bearing       e/B    Bearing
    Load    Locn   Ratio  Pressure     Ratio  Pressure      Ratio  Pressure
                            (ksf)               (ksf)                (ksf)
    PHL-93    L    -0.35     10.69                          -0.25      5.72
              R              11.35                                     7.17 *
    P-82      L                        -0.34      9.52
              R                                  10.32

   L  Left  edge of the footing
   R  Right edge of the footing

   A maximum value for qb of    8.51 (ksf)   (qb = N/Be) occurs for the
   STR-I  limit state,  PHL-93   live load, maximum effect case 1.
   For this reported condition, Be is   1.31 (ft).  This average
   pressure is used in the calculation of settlement for soils.

   * Indicates the maximum e/B Ratio and Footing Pressure, among all
     maximum effect cases, for each limit state.
```

Figure 7.4.18-1 Sample Strip Footing Bearing Pressure Report

7.4.19 Quantities

This table is applicable for both an Analysis and Design. It always contains the same seven line items, some of which may have zero volume values if the particular item is not present in the culvert.

The following information is reported in the QUANTITIES output tables:

1. Segment Length - Distance the quantities are based on.
2. Top Slab - volume of concrete for all top slabs.
3. Bottom Slab -volume of concrete for all bottom slabs.
4. Left Wall - volume of concrete for the left external wall.
5. Interior Wall - volume of concrete for the interior wall for two cell culverts.
6. Right Wall - volume of concrete for the right external wall.
7. Haunches - volume of concrete for all haunches if present.
8. Strip Footing - volume of concrete for all strip footings, if present.
9. Total - total volume of concrete.
10. Segment Weight - Weight of a precast culvert segment.

A sample Quantities Report is shown in Figure 1.

```
LRFD Box Culvert Design and Rating, Version x.x.x.x                                   PAGE xx
Input File: xxx.dat                                                       xx/xx/xxxx  xx:xx:xx
-----------------------------------------------------------------------------------------------
                                   BXLRFD Example Problem #xx
                                           QUANTITIES
-----------------------------------------------------------------------------------------------

                                       Volume of Concrete

                            Based on a segment length of:  90.00 ft.

                           Top Slab:   106.77  (yd^3)
                        Bottom Slab:    78.12  (yd^3)
                          Left Wall:    24.44  (yd^3)
                      Interior Wall:    24.44  (yd^3)
                         Right Wall:    24.44  (yd^3)
                           Haunches:     7.50* (yd^3)

                              TOTAL:   265.73  (yd^3)


   * All haunches are included only in this total
```

Figure 7.4.19-1 Sample Quantities Report

7.5 INTERMEDIATE DATA

This section describes the various tables of data that constitute the intermediate report which is obtained by using the OUI command.

7.5.1 General POI Data Table

This table presents general POI information. It is the first table printed (if requested) for each POI. A sample table is shown in Figure 7.5.1-1.

The following information is reported in the General POI Table:

1. POI - the POI number
2. LOCN - distance location of the POI along the member (ft)
3. %SPAN - percent distance location of the POI along the member
4. Type - POI type classification: 1=axial; 2=shear; 3=moment; 4=shear and moment
5. Thick - structural thickness, i.e., nominal - waste material (inches)
6. Width - width of the unit strip of culvert (inches)
7. Top Cvr - top or left face rebar cover less waste material/sacrificial cover (inches)
8. Bot Cvr - bottom or right face rebar cover less waste material/sacrificial cover (inches)
9. Top As -specified top or left face flexural steel area (inches^2)
10. Bot As - specified bottom or right face flexural steel area (inches^2)
11. Shr Spc - specified spacing of shear steel along the member (inches)
12. Av - specified shear steel area (inches^2)
13. Top d - distance-d from bottom or right face to top flexural steel centroid (inches)
14. Bot d - distance-d from top or left face to bottom flexural steel centroid (inches)
15. STR ANG - shear rebar angle (degrees)
16. FILL HT - fill height (ft)
17. PHI SHR - resistance factor for shear
18. BETA1 - beta-1
19. ALPHA1 - stress block factor, LRFD Specifications Section 5.6.2.2
20. E STEEL - modulus of elasticity for rebar (kip/ft^2)
21. (ksi) - modulus of elasticity for rebar (kip/in^2)
22. E CONCR - modulus of elasticity for concrete (kip/ft^2)
23. (ksi) - modulus of elasticity for concrete (kip/in^2)
24. FPC - f’c of concrete (kip/ft^2)
25. FY - fy of rebar (kip/ft^2)
26. ASMN1T - As1-minimum for top or left face (inches^2)
27. ASMN1B - As1-minimum for bottom or right face (inches^2)
28. ASMN2T - As2-minimum for top or left face (inches^2)

29. ASMN2B - As2-minimum for bottom or right face (inches^2)
30. ASMINN - As minimum for negative (top or left) face (inches^2)
31. ASMINP - As-minimum for positive (bottom or right) face (inches^2)
32. SPMIN - minimum spacing for primary reinforcement (inches)
33. SPPMXT - maximum spacing for primary top or left reinforcement (inches)
34. SPPMXB - maximum spacing for primary bottom or right reinforcement (inches)
35. SPTXMX - maximum spacing for temperature / shrinkage concerns (inches)
36. SPDMAX - maximum spacing for distribution concerns (inches)
37. SPMAXT - final maximum spacing for top or left rebars (inches)
38. SPMAXB - final maximum spacing for bottom or right rebars (inches)
39. POSRCH - positive region change flag
40. NEGRCH - negative region change flag
41. ASPLS - As positive controlling limit state
42. ASPLL - As positive controlling live load
43. ASPCS - As positive controlling maximum effect case
44. ASPPUT - As positive controlling axial force (kips)
45. ASPMUT - As positive controlling moment (kip-ft)
46. ASPOS - As positive (inches^2)
47. ASNLS - As negative controlling limit state
48. ASNLL - As negative controlling live load
49. ASNCS - As negative controlling maximum effect case
50. ASNPUT - As negative controlling axial force (kips)
51. ASNMUT - As negative controlling moment (kip-ft)
52. ASNEG - As negative (inches^2)
53. VLS - shear controlling limit state
54. VLL - shear controlling live load
55. VCS - shear controlling maximum effect case
56. VVUT - shear controlling shear force (kips)
57. VMUT - shear controlling moment (kip-ft)
58. VC - concrete shear capacity (kip/ft^2)
59. VSREQ - Vs-required (kips)
60. VSMAX - Vs-maximum (kips)
61. VAREQ - Va-required (inches^2)

7.5.2 Non-Live Results

The non-live load table presents unfactored axial (kips), shear (kips) and moment (kip-ft) responses due to applied non-live loads. A sample table is shown in Figure 7.5.2-1. For connection objects the non-live load table presents unfactored bearing pressure response values due to applied non-live loads for each wall. A sample table is shown in Figure 7.5.2-2.

7.5.3 Influence Lines

The influence line table presents influence line x-ordinate (ft) and y-ordinate (axial, shear and moment) values. The x-ordinate values are above the dashed lines and are measured from the center of the left wall. These influence lines are generated by placing point loads at every node point on the top slabs (including walls), along with a reaction load on the bottom slab. A sample table is shown in Figure 7.5.3-1. For connection objects the y-ordinate denotes bearing pressure values under each wall. A sample table is shown in Figure 7.5.3-2.

7.5.4 Truck Response

The truck response table presents raw live load results for every live load in the analysis. For each live load, a 6x6 matrix is given. The first three columns are the results when optimizing positive responses, and the second three columns are the results when optimizing negative responses. The diagonals are therefore the primary optimized responses and the off-diagonals are the associated responses. Axial and shear forces are in units of kips, and moments are in units of kip-ft Column 3 is Maximum Case 1, column 6 is Case 2, column 1 is Case 3, column 4 is Case 4, column 2 is Case 5, and column 5 is Case 6.

The second three rows present information on the location of the live load when a response was optimized. The TRKDIR row is a two-digit code: if the first digit is a 2, then the truck is a variable axial truck, if the first digit is a 1, then it is a fixed axial truck. If the second digit is a 1, then the truck was moving left-to-right when the response was optimized, if the second digit is a 2, then the truck was moving right-to-left. The first TRKPOS row gives information on where the first truck axle was when the response was optimized, relative to the center of the left wall. The second TRKPOS gives the spacing between the variable axles, if applicable. A sample table is shown in Figure 7.5.4-1.

For connection objects the truck response table presents raw live load bearing pressure results for every live load in the analysis. For each live load, a 6x6 or 4x4 matrix is given depending on the number of walls in the culvert. For a twin cell culvert, the first three columns are the results when optimizing positive responses, and the second three columns are the results when optimizing negative responses. For a single cell culvert, the first two columns are the results when optimizing positive responses, and the second two columns are the results when optimizing negative responses.

The diagonals are therefore the primary optimized responses and the off-diagonals are the associated responses. All bearing pressures are in units of kips/ft^2. A sample table is shown in Figure 7.5.4-2.

7.5.5 Truck Thru Fill Response

The Truck Thru Fill table presents similar information to the Truck Response table, but for responses due to moving patch loads over the influence lines. The patches represent truck tire footprints distributed through the fill onto the top of the culvert. A sample table is shown in Figure 7.5.5-1. A sample table for connection objects is shown in Figure 7.5.5-2.

7.5.6 Lane Response

The Lane Response table gives axial, shear and moment responses due to loading the influence lines with a uniformly distributed lane load. The first three columns are for optimized positive responses, and the second three columns for optimized negative responses. The off-diagonal values are the associated responses. A sample table is shown in Figure 7.5.6-1.

For connection objects, the Lane Response table gives bearing pressure responses under each wall due to loading the influence lines with a uniformly distributed lane load. For a twin cell culvert, the first three columns are for optimized positive responses, and the second three columns for optimized negative responses. For a single cell culvert, the first two columns are for optimized positive responses, and the second two columns for optimized negative responses. The off-diagonal values are the associated responses. A sample table is shown in Figure 7.5.6-2.

7.5.7 Envelope Response

The Envelope Response table presents results when the raw Truck, Truck Thru Fill and Lane responses are enveloped to form the final live load responses before load factors are applied to build the limit states for design or specification checking. Lateral distribution factors, the dynamic load allowance factor, multiple presence factors and the maximum number of design lanes are considered in the formation of the envelopes. The first three columns are for optimized positive responses, and the second three columns for optimized negative responses. The off-diagonal values are the associated responses. The row labeled, TRUCK, indicates which truck controlled the optimized response. The row labeled, Trk/TF, indicates if the Truck Response or the Truck Thru Fill Response controlled. A sample table is shown in Figure 7.5.7-1.
For connection objects of a twin cell culvert, the first three columns are for optimized positive responses, and the second three columns for optimized negative responses. For connection objects of a single cell culvert, the first two columns are for optimized positive responses, and the second two columns for optimized negative responses. The off-diagonal values are the associated responses. The row labeled, TRUCK, indicates which truck controlled the optimized response. The row labeled, Trk/TF, indicates if the Truck Response or the Truck Thru Fill Response controlled. A sample table is shown in Figure 7.5.7-2.

7.5.8 Limit State Dead Load Response

The Limit State Dead Load table presents information on the factored non-live responses. A sample table is shown in Figure 7.5.8-1. For connection objects the sample table is shown in Figure 7.5.8-2.

7.5.9 Limit State Live Load and Total Responses

The Limit State Live Load and Total Response table presents factored live load envelope responses and then the sum of the Limit State Dead Load and Limit State Live Load responses, i.e., Total Limit State Responses. The Total Limit State Responses are those used for design or specification checks. A sample table is shown in Figure 7.5.9-1. For connection objects the sample table is shown in Figure 7.5.9-2.

7.5.10 Bar Table Results

The Bar table presents reinforcement bar information for the eight different bar sizes used in design. A sample table is shown in Figure 7.5.10-1.

The following information is reported for each bar size in the Bar table:

1. S POS STR - positive (bottom or right) face bar spacing for strength (inches).
2. S NEG STR - negative (top or left) face bar spacing for strength (inches).
3. S POS CC - positive (bottom or right) face bar spacing for crack control (inches).
4. S NEG CC - negative (top or left) face bar spacing for crack control (inches).
5. S POS<MIN - True/False flag indicating if positive spacing is less than the minimum.
6. S NEG<MIN - True/False flag indicating if negative spacing is less than the minimum.
7. S POS>MAX -True/False flag indicating if positive spacing is greater than the maximum.
8. S NEG>MAX -True/False flag indicating if negative spacing is greater than the maximum.
9. POS CC LS - controlling limit state for positive face crack control spacing.
10. POS CC LL - controlling live load for the positive face crack control spacing.
11. POS CC CS - controlling maximum effect case for positive face crack control spacing.
12. POS CC PU - controlling axial force for positive face crack control spacing (kips).
13. POS CC MU - controlling moment for positive face crack control spacing (kip-ft).
14. NEG CC LS -controlling limit state for negative face crack control spacing.
15. NEG CC LL -controlling live load for the negative face crack control spacing.
16. NEG CC CS -controlling maximum effect case for negative face crack control spacing.
17. NEG CC PU -controlling axial force for negative face crack control spacing (kips).
18. NEG CC MU - controlling moment for negative face crack control spacing (kip-ft).

7.5.11 Limit State Section Capacities

The Limit State Section Capacities table presents information for axial (Pr), shear (Vr) and moment (Mr) factored resistances. Column 3 is Maximum Effect Case 1, column 6 is Case 2, column 1 is Case 3 and column 4 is Case 4. These are the four flexure cases and have axial and moment resistances. Column 2 is Case 5 and column 5 is Case 6. These two cases, along with Cases 1 and 2, are the four shear cases and have only shear resistances. A sample table is shown in Figure 7.5.11-1.

7.5.12 Limit State Rating Factors

The Limit State Rating Factors table presents axial, shear and moment rating factors. There is a table for each live load envelope in the analysis. Axial and moment rating factors within a column should be identical. A sample table is shown in Figure 7.5.12-1.

7.5.13 Limit State Resistance/Demand Ratios

The Limit State Resistance/Demand Ratios table presents similar information to the Rating Factors in cases when there is no live load. A sample table is shown in Figure 7.5.13-1.

7.5.14 Limit State Allowable Spacings

The Limit State Allowable Spacings table presents allowable reinforcement spacings for all live load envelopes and for all service limit states in the analysis. A sample table is shown in Figure 7.5.14-1.

7.5.15 Limit State Service Stresses

The Limit State Service Stresses table presents actual concrete and reinforcement stresses. Both tension and compression stresses are presented, for all live load envelopes and for all service limit states in the analysis. Also presented is the modular ratio used to compute the stresses. A sample table is shown in Figure 7.5.15-1.

7.5.16 Stiffness Analysis Model Report (.FEM Output File)

This section presents finite element model information for the generated plane frame model. The model is generated based on the information in the input file and internal assumptions. The first table details the generated node points and their X-Y-Z coordinates. The model is generated in the X-Y plane, so the Z-coordinate will always be zero. The second table gives boundary condition codes for all nodes acting as boundary nodes. The integer boundary condition code is a packed integer representing the six possible degrees-of-freedom, DOF, at each node. A zero represents a free DOF, and a 1 represents a fixed DOF. The right-most digit represents the x-displacement, the next digit to the left is the y-displacement, the next digit to the left is the z-displacement, the next digit to the left is the rotation about the x-axis (always fixed), the next digit to the left is the rotation about the y-axis (always fixed) and the last digit is the rotation about the z-axis (always zero or blank). The third table is presents information on the mappings between node number and equation numbers for the six DOFs at each node point. The fourth table in this section is the element connectivity table which gives information on the type, description, number and end node points for all plane frame elements in the generated model. The last table is the element section properties table which provides cross-sectional area, moments of inertia, modulus of elasticity, shear area, and shear modulus for each member. Sample tables are shown in Figure 7.5.16-1.

7.5.17 Stiffness Analysis Results Report (.FER Output File)

This section presents finite element response information. The first table presents nodal displacements for all nodes and for all load cases. Global X, Y, and Z translational displacements, and global X, Y and Z rotations are presented. The column labeled, “M#”, represents the base finite element load cases applied to the system, e.g., non-live loads and point loads for influence lines. The second table presents element forces for all elements and all load cases. Initial and terminal end, axial, shear and moment responses are presented. The responses in the column labeled, “3-Shear”, is the shear in the Z-direction and will always be zero. In addition, the responses in the columns labeled, “Torsion” and “2-Moment”, will also always be zero. Sample tables are shown in Figure 7.5.17-1.

7.5.18 CMO1 (Non-Live Load) (.MM Output File)

The information in this table is identical to that in Section 7.5.2 but it is presented in a format suitable for easy transfer into a spread sheet.

7.5.19 CMO2 (Envelopes) (.MM Output File)

The information in this table is identical to that in Section 7.5.7 but it is presented in a format suitable for easy transfer into a spread sheet.

7.5.20 ASC1 (Influence Lines) (.ANN Output File)

The information in this table is identical to that in Section 7.5.3 but it is presented in a format suitable for easy transfer into a spread sheet.

7.5.21 Soil Pressures

The Soil Pressure table presents a variety of information for strip footings. The response in strip footings is obtained by using the Total Limit State Responses at the bottom of the wall, so all six Maximum Effect Cases need to be investigated for the footing. A sample table is shown in Figure 7.5.21-1.

The following information is reported:

1. P – Axial load force from the wall.
2. M – Moment force at bottom of wall.
3. V – Shear force at bottom of wall.
4. B_c – Effective footing width.
5. ecc – Eccentricity of wall loads.
6. N – Normalized axial load entering the footing for current POI.
7. M_o – Normalized moment load entering the footing for current POI.
8. Xo – Eccentricity of walls referenced to left edge of footing.
9. PRESS – Bearing pressure at current POI.
10. SHEAR – Shear force within footing.
11. MOMENT – Moment force within footing.
12. V_r – Shear resistance.
13. M_r – Moment resistance.

7.5.22 Strip Footing Results

The Strip Footing Results table presents a variety of information for strip footings. The loads on strip footing from the wall are obtained by using the the first three rows of the table which corresponds to the Total Limit State Responses at the bottom of the wall, so all six Maximum Effect Cases need to be investigated for the footing. The Strip Footing Results table is presented twice, once for the Strength Limit State and once for the Service Limit State. The tables are presented for each of the POI's for the strip footing. The loads from the wall are the same at each POI, so any of the POI's can be used to get the loads on the footing from the wall. Sample tables are shown in Figure 7.5.22-1 for Strength and Service limit states.

Strip Footing Results
Envelope: HL93

	.........Positive.........			.........Negative.........		
	Max Ax	Max Shr	Max Mmt	Max Ax	Max Shr	Max Mmt
P *	13.19	27.66	18.91	31.39	13.19	18.91
V *	-0.77	10.23	1.49	5.74	-0.77	1.49
M *	0.00	-0.00	-0.00	-0.00	0.00	-0.00
Bc	6.00	6.00	6.00	6.00	6.00	6.00
ecc	-0.43	0.13	-0.36	-0.32	-0.43	-0.36
N	23.50	37.98	29.22	41.70	23.50	29.22
Mo	80.64	109.13	98.17	138.43	80.64	98.17
Xo	3.43	2.87	3.36	3.32	3.43	3.36
PRESS+	2.23	7.13	3.12	4.73	2.23	3.12
SHEAR	0.00	0.00	0.00	0.00	0.00	0.00
MOMENT	0.00	0.00	0.00	0.00	0.00	0.00
Vr	0.00	48.25	48.25	0.00	48.25	48.25
Mr	0.00	0.00	0.00	0.00	0.00	0.00

Strength Limit State

* NOTE: P,V and M are from POI 1 in External Wall 1
\+ NOTE: PRESS is the bearing pressure at the POI of the footing for the indicated load case

Strip Footing Results
Envelope: HL93
.........Positive......... ....Negative.........

	Max Ax	Max Shr	Max Mmt	Max Ax	Max Shr	Max Mmt
P *	14.78	19.78	14.78	21.91	14.78	14.78
V *	1.49	6.43	1.49	3.92	1.49	1.49
M *	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00
Bc	6.00	6.00	6.00	6.00	6.00	6.00
ecc	-0.34	0.03	-0.34	-0.31	-0.34	-0.34
N	22.59	27.60	22.59	29.72	22.59	22.59
Mo	75.40	81.83	75.40	98.40	75.40	75.40
Xo	3.34	2.97	3.34	3.31	3.34	3.34
PRESS+	2.50	4.76	2.50	3.42	2.50	2.50
SHEAR	0.00	0.00	0.00	0.00	0.00	0.00
MOMENT	0.00	0.00	0.00	0.00	0.00	0.00
Vr	0.00	48.25	48.25	0.00	48.25	48.25
Mr	0.00	0.00	0.00	0.00	0.00	0.00

Service Limit State

* NOTE: P,V and M are from POI 1 in External Wall 1
+ NOTE: PRESS is the bearing pressure at the POI of the footing for the indicated load case

Figure 7.5.22-1 Strip Footing Results

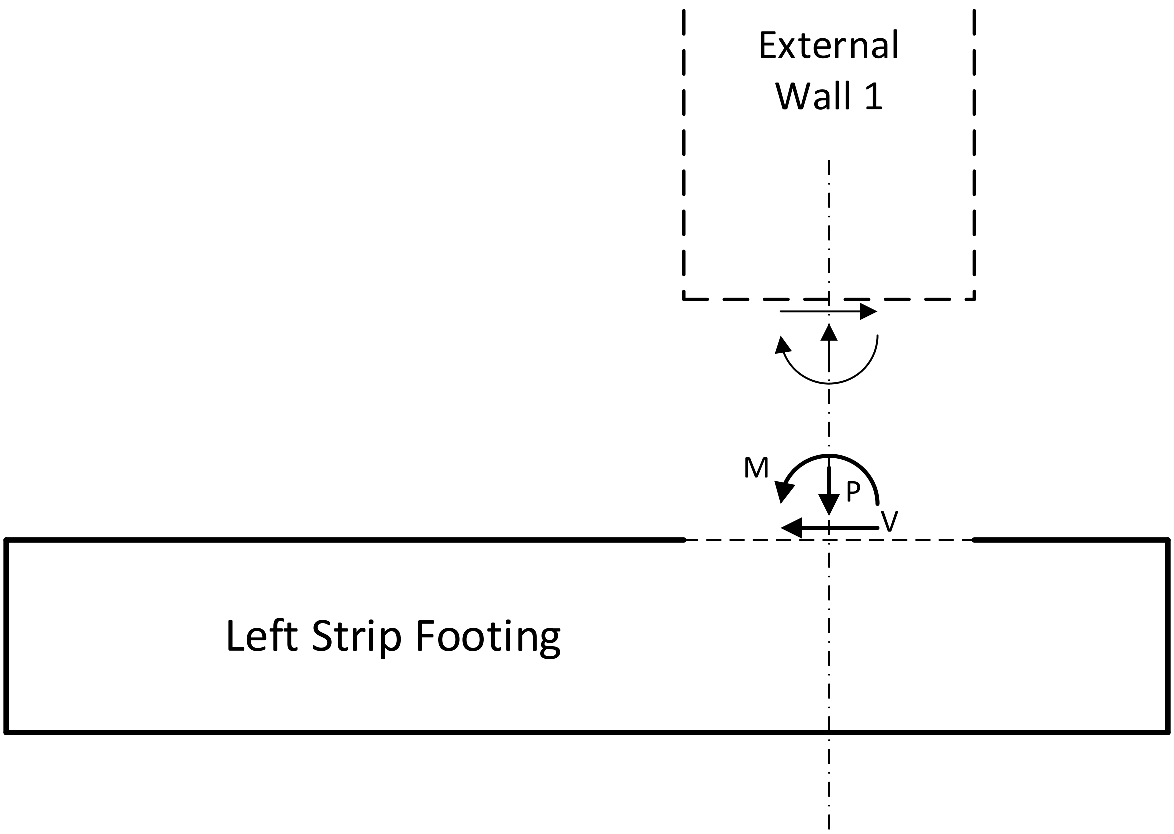

Figure 7.5.22-2 Positive Forces on Strip Footing

Figure 7.5.1-1 POI Information

POI information for Top Span: 1

POI	LOCN	% SPAN	Type	Thick	Width	Top Cvr	Bot Cvr	Top As	Bot As	Shr Spc	Av	Top d	Bot d
6	3.20	0.40	Shr/Mmt	8.00	12.00	2.00	1.50	0.00	0.00	0.00	0.0	5.75	6.25

STR ANG	FILL HT	PHI SHR	BETA1	ALPHA1	E STEEL	(ksi)	E CONCR	(ksi)	FPC	FY
90.00	0.00	0.85	0.65	0.75	4176000.	29000.	892800.	6200.	2160.00	8640.00

ASMN1T	ASMN1B	ASMN2T	ASMN2B	ASMINN	ASMINP	SPMIN	SPPMXT	SPPMXB	SPTSMX	SPDMAX	SPMAXT	SPMAXB
0.072	0.072	0.065	0.207	0.072	0.207	0.00	0.00	0.00	0.00	0.00	0.00	0.00

OVRREN	OVRREP	POSRCH	NEGRCH
No	No	No	No

ASPLS	ASPLL	ASPCS	ASPPUT	ASPMUT	ASPOS	ASNLS	ASNLL	ASNCS	ASNPUT	ASNMUT	ASNEG
STR-I		pos mom	0.92	12.59	0.385				0.00	0.00	0.072

VLS	VLL	VCS	VVUT	VMUT	VC	VSREQ	VSMAX	VAREQ
STR-I		pos mom	-1.89	13.	15.90	0.00	15.31	0.000

Figure 7.5.2-1 Non-Live Load Results

NonLive Load Response

	WA	DC	DW	OV	EV	EH1	EH2	DCB
AXIAL	0.000	-0.090	0.000	0.000	0.101	0.374	1.488	0.036
SHEAR	0.000	-0.080	0.000	0.000	-1.334	0.001	- small	-2.000
MOMENT	0.000	0.641	0.000	0.000	9.133	-0.240	-0.714	-0.742

Figure 7.5.2-2 Non-Live Load Results – Connection Object

NonLive Load Response

BRG PRS	DC	DCB	DW	OV	EV	WA
WALL1	0.892	0.000	0.000	0.000	0.121	0.697
WALL2	0.829	0.000	0.000	0.000	0.121	0.723
WALL3	0.766	0.000	0.000	0.000	0.121	0.749

Figure 7.5.3-1 Influence Lines

Influence Lines

	0.000	0.500	0.500	1.000	2.045	2.233	3.591	5.136	6.681	8.227
AXIAL	0.003146	0.014347	0.014347	0.025916	0.051556	0.056327	0.091409	0.130006	0.163330	0.187364
SHEAR	0.002393	0.025027	-0.974973	-0.951500	-0.898294	-0.888124	-0.809635	-0.711766	-0.607743	-0.500620
MOMENT	0.018543	0.309715	0.309715	0.111984	-0.244551	-0.299686	-0.624197	-0.849079	-0.942870	-0.929244

	9.772	11.317	12.862	14.220	14.408	15.453	15.953	16.453
AXIAL	0.198093	0.191500	0.163570	0.118240	0.110285	0.057834	0.028261	-0.003146
SHEAR	-0.393454	-0.289298	-0.191209	-0.112454	-0.102241	-0.048777	-0.025168	-0.002393
MOMENT	-0.831876	-0.674439	-0.480607	-0.299017	-0.274053	-0.139094	-0.077879	-0.018543

Figure 7.5.3-2 Influence Lines - Connection Object

Influence Lines

BRG PRS	0.000	0.833	2.358	2.683	4.533	6.383	8.233	10.083	11.933	13.783
WALL1	-0.050000	-0.040630	-0.023596	-0.019994	0.000127	0.019374	0.037393	0.053826	0.068319	0.080513
WALL2	0.175000	0.162505	0.139754	0.134931	0.107873	0.081688	0.056732	0.033361	0.011931	-0.007201
WALL3	0.025000	0.018755	0.007439	0.005056	-0.008127	-0.020437	-0.031518	-0.041014	-0.048569	-0.053826

BRG PRS	15.633	17.483	17.809	19.333	20.000	20.667	22.191	22.517	24.367	26.217
WALL1	0.090055	0.096587	0.097398	0.099753	0.100000	0.099753	0.097398	0.096587	0.090055	0.080513
WALL2	-0.023680	-0.037149	-0.039181	-0.047253	-0.050000	-0.052253	-0.055615	-0.056024	-0.056430	-0.053826
WALL3	-0.056430	-0.056024	-0.055615	-0.052253	-0.050000	-0.047253	-0.039181	-0.037149	-0.023680	-0.007201

Figure 7.5.4-1 Truck Responses

Truck Responses

HS20

	..Tens..	....Positive.....		..Compr.	....Negative.....	
	Max Ax	Max Shr	Max Mmt	Max Ax	Max Shr	Max Mmt
AXIAL	-0.10	0.10	0.46	6.34	3.84	5.23
SHEAR	-0.08	0.08	-31.20	-12.59	-34.33	-19.45
MOMENT	-0.59	0.59	9.91	-26.62	1.52	-30.17
TRKDIR	21	21	21	21	21	21
TRKPOS	16.45	0.00	0.50	9.77	14.50	6.68
TRKPOS	14.00	14.00	14.00	14.00	14.00	14.00

DESTNDB

	..Tens..	....Positive.....		..Compr.	....Negative.....	
	Max Ax	Max Shr	Max Mmt	Max Ax	Max Shr	Max Mmt
AXIAL	-0.10	0.10	0.45	11.40	4.01	10.12
SHEAR	-0.07	0.07	-30.47	-26.65	-53.97	-35.92
MOMENT	-0.58	0.58	9.68	-50.36	-13.97	-53.78
TRKDIR	11	11	11	11	11	11
TRKPOS	20.45	0.00	0.50	11.32	4.50	9.14
TRKPOS	0.00	0.00	0.00	0.00	0.00	0.00

Figure 7.5.4-2 Truck Responses – Connection Object

Truck Responses

HS20

BRG PRS	Positive Response WALL 1	Positive Response WALL 2	Positive Response WALL 3	Negative Response WALL 1	Negative Response WALL 2	Negative Response WALL 3
WALL1	4.82	-2.00	-2.00	-2.00	4.26	4.32
WALL2	-1.67	5.80	2.20	2.20	-2.25	0.01
WALL3	-1.58	2.20	5.80	5.80	0.14	-2.25
TRKDIR	21	21	22	22	22	22
TRKPOS	41.19	40.00	0.00	0.00	3.98	-5.72
TRKPOS	14.00	26.00	26.00	26.00	14.00	14.00

DESTNDB

BRG PRS	Positive Response WALL 1	Positive Response WALL 2	Positive Response WALL 3	Negative Response WALL 1	Negative Response WALL 2	Negative Response WALL 3
WALL1	6.11	-1.74	-1.74	-1.74	5.56	5.56
WALL2	-2.94	9.08	0.65	9.08	-3.42	-1.46
WALL3	-3.02	0.65	9.08	0.65	-1.46	-3.42
TRKDIR	11	11	11	11	11	11
TRKPOS	21.81	4.00	40.00	4.00	26.19	17.81
TRKPOS	0.00	0.00	0.00	0.00	0.00	0.00

Figure 7.5.5-1 Truck Thru Fill Responses

Truck Through Fill Responses

HS20

	..Tens.. Max Ax	....Positive..... Max Shr	....Positive..... Max Mmt	..Compr. Max Ax	....Negative..... Max Shr	....Negative..... Max Mmt
AXIAL	-0.63	-0.10	-0.26	1.43	0.64	1.29
SHEAR	-0.56	0.06	-2.97	-14.31	-21.46	-17.14
MOMENT	-0.64	0.50	1.13	-17.54	-15.75	-18.31
TRKDIR	1	1	1	1	1	1
TRKPOS	14.19	0.32	0.98	8.34	6.39	7.58
TRKPOS	0.00	0.00	0.00	0.00	0.00	0.00

DESTNDB

	..Tens.. Max Ax	....Positive..... Max Shr	....Positive..... Max Mmt	..Compr. Max Ax	....Negative..... Max Shr	....Negative..... Max Mmt
AXIAL	-0.76	-0.12	-0.31	1.16	0.50	0.70
SHEAR	-0.66	0.07	-3.56	-28.00	-28.77	-25.41
MOMENT	-0.74	0.60	1.36	-21.97	-23.30	-24.14
TRKDIR	1	1	1	1	1	1
TRKPOS	17.98	0.32	0.98	8.12	10.07	10.73
TRKPOS	0.00	0.00	0.00	0.00	0.00	0.00

Figure 7.5.5-2 Truck Thru Fill Responses – Connection Object

Truck Through Fill Responses

HS20

	Positive Response			Negative Response		
BRG PRS	WALL 1	WALL 2	WALL 3	WALL 1	WALL 2	WALL 3
WALL1	4.78	-1.85	0.35	-2.25	4.78	0.29
WALL2	-0.93	4.85	-0.93	4.24	-0.93	4.23
WALL3	0.35	-1.35	4.78	0.27	0.35	-2.25
TRKDIR	2	1	1	1	2	2
TRKPOS	-28.97	43.86	68.97	48.00	-28.97	-8.06
TRKPOS	15.00	14.00	15.00	14.00	15.00	14.00

DESTNDB

	Positive Response			Negative Response		
BRG PRS	WALL 1	WALL 2	WALL 3	WALL 1	WALL 2	WALL 3
WALL1	7.39	-2.99	-0.19	-3.40	0.35	-1.63
WALL2	-0.48	6.11	-0.47	5.68	-0.89	5.67
WALL3	-0.18	-2.93	7.42	-1.66	4.45	-3.40
TRKDIR	1	1	1	1	1	1
TRKPOS	7.72	24.00	40.00	27.59	44.14	20.14
TRKPOS	0.00	0.00	0.00	0.00	0.00	0.00

Figure 7.5.6-1 Lane Responses

Lane Responses

	..Tens..	....Positive.....		..Compr.	....Negative.....	
	Max Ax	Max Shr	Max Mmt	Max Ax	Max Shr	Max Mmt
AXIAL	-0.13	-0.01	-0.04	0.17	0.05	0.09
SHEAR	-1.34	0.01	-0.36	-1.54	-2.89	-2.52
MOMENT	-0.31	0.07	0.14	-1.97	-2.35	-2.42

Figure 7.5.6-2 Lane Responses – Connection Object

Lane Responses

	Positive Response			Negative Response		
BRG PRS	WALL 1	WALL 2	WALL 3	WALL 1	WALL 2	WALL 3
WALL1	0.72	-0.27	0.17	-0.55	0.43	0.00
WALL2	0.09	1.26	0.09	1.03	-0.14	1.03
WALL3	0.17	-0.27	0.72	0.00	0.43	-0.55

Figure 7.5.7-1 Envelope Responses

Envelope Responses

PHL93

	..Tens..	....Positive.....		..Compr.	....Negative.....	
	Max Ax	Max Shr	Max Mmt	Max Ax	Max Shr	Max Mmt
AXIAL	-0.10	-0.01	-0.04	0.18	0.06	0.09
SHEAR	-0.23	0.01	-0.43	-1.74	-3.48	-3.07
MOMENT	-0.12	0.07	0.16	-2.15	-2.82	-2.92
TRUCK	DESTNDB	DESTNDB	DESTNDB	HS20	DESTNDB	DESTNDB
Trk/TF	TTF	TTF	TTF	TTF	TTF	TTF

ML80E

	..Tens..	....Positive.....		..Compr.	....Negative.....	
	Max Ax	Max Shr	Max Mmt	Max Ax	Max Shr	Max Mmt
AXIAL	-0.07	-0.01	-0.02	0.09	0.04	0.05
SHEAR	-0.78	0.01	-0.27	-2.11	-2.17	-1.88
MOMENT	-0.39	0.05	0.10	-1.66	-1.77	-1.82
TRUCK	ML80	ML80	ML80	ML80	ML80	ML80
Trk/TF	TTF	TTF	TTF	TTF	TTF	TTF

Figure 7.5.7-2 Envelope Responses – Connection Object

Envelope Responses

PHL93

	Positive Response			Negative Response		
BRG PRS	WALL 1	WALL 2	WALL 3	WALL 1	WALL 2	WALL 3
WALL1	1.04	-0.37	0.00	-0.46	0.61	-0.17
WALL2	-0.05	0.85	-0.05	0.76	-0.20	0.76
WALL3	0.00	-0.38	1.04	-0.17	0.55	-0.46
TRUCK	DESTNDB	DESTNDB	DESTNDB	DESTNDB	DESTND2	DESTNDB
Trk/TF	TTF	Truck	TTF	Truck	TTF	Truck

P82E

	Positive Response			Negative Response		
BRG PRS	WALL 1	WALL 2	WALL 3	WALL 1	WALL 2	WALL 3
WALL1	0.97	-0.49	0.33	-0.59	0.52	-0.20
WALL2	0.23	1.12	0.23	1.02	-0.10	1.02
WALL3	0.33	-0.50	0.97	-0.20	0.04	-0.59
TRUCK	P82	P82	P82	P82	P82	P82
Trk/TF	TTF	Truck	TTF	Truck	TTF	Truck

Figure 7.5.8-1 Limit State Dead Load Responses

Limit State Dead Load Response

	..Tens..	....Positive.....		..Compr.	....Negative.....	
	Max Ax	Max Shr	Max Mmt	Max Ax	Max Shr	Max Mmt
AXIAL	0.44	3.11	0.49	3.13	3.08	3.08
SHEAR	-3.29	-3.11	-3.12	-4.30	-4.47	-4.47
MOMENT	-2.77	-4.10	-2.68	-5.05	-5.14	-5.14

Figure 7.5.8-2 Limit State Dead Load Responses – Connection Object

Limit State Dead Load Response

BRG PRS	Positive Response WALL 1	WALL 2	WALL 3	Negative Response WALL 1	WALL 2	WALL 3
WALL1	2.29	2.29	2.29	1.13	1.13	1.13
WALL2	2.23	2.23	2.23	1.07	1.07	1.07
WALL3	2.18	2.18	2.18	1.02	1.02	1.02

Figure 7.5.9-1 Limit State Live Load and Total Responses

Limit State LL and LL+DL Responses
Envelope: PHL93

	..Tens.. Max Ax	....Positive..... Max Shr	Max Mmt	..Compr. Max Ax	....Negative..... Max Shr	Max Mmt
AXIAL	-0.17	-0.02	-0.07	0.31	0.11	0.15
SHEAR	-0.41	0.01	-0.75	-3.05	-6.09	-5.37
MOMENT	-0.21	0.13	0.29	-3.76	-4.94	-5.11

Dead Load + PHL93 Response

	..Tens.. Max Ax	....Positive..... Max Shr	Max Mmt	..Compr. Max Ax	....Negative..... Max Shr	Max Mmt
AXIAL	0.27	3.09	0.42	3.44	3.19	3.24
SHEAR	-3.70	-3.10	-3.87	-7.35	-10.57	-9.85
MOMENT	-2.98	-3.97	-2.40	-8.81	-10.08	-10.25

Figure 7.5.9-2 Limit State Live Load and Total Responses – Connection Object

Limit State LL and LL+DL Responses
Envelope: PHL93

BRG PRS	Positive Response WALL 1	WALL 2	WALL 3	Negative Response WALL 1	WALL 2	WALL 3
WALL1	1.81	-0.65	-0.01	-0.80	1.07	-0.29
WALL2	-0.09	1.49	-0.09	1.33	-0.35	1.33
WALL3	0.00	-0.67	1.82	-0.29	0.96	-0.80

Dead Load + PHL93 Response

BRG PRS	Positive Response WALL 1	WALL 2	WALL 3	Negative Response WALL 1	WALL 2	WALL 3
WALL1	4.10	1.64	2.28	0.33	2.20	0.84
WALL2	2.14	3.72	2.15	2.41	0.72	2.41
WALL3	2.18	1.52	4.00	0.72	1.97	0.22

Figure 7.5.10-1 Reinforcement Design

REINFORCEMENT DESIGN

Bar Size	4	5	6	7	8	9	10	11
S POS STR	14.50	22.50	32.50	44.00	58.50	74.00	94.00	115.50
S NEG STR	6.50	10.00	14.00	19.50	25.50	32.50	41.00	50.50
S POS CC	12.00	18.00	24.00	24.00	24.00	24.00	24.00	24.00
S NEG CC	6.50	10.00	14.00	19.50	24.00	24.00	24.00	24.00
S POS<MIN	F	F	F	F	F	F	F	F
S NEG<MIN	F	F	F	F	F	F	F	F
S POS>MAX	T	T	T	T	T	T	T	T
S NEG>MAX	F	F	F	F	T	T	T	T
POS CC LS								
POS CC LL								
POS CC CS								
POS CC PU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
POS CC MU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NEG CC LS								
NEG CC LL								
NEG CC CS								
NEG CC PU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NEG CC MU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 7.5.11-1 Limit State Section Capacities

```
Limit State Section Capacity Results
Envelope: PHL93
        ..Tens.. ....Positive.....  ..Compr. ....Negative.....
          Max Ax  Max Shr  Max Mmt    Max Ax  Max Shr  Max Mmt
        -------- -------- --------  -------- -------- --------
 AXIAL      -6.3      0.0     -7.5       4.2      0.0      3.5
 SHEAR       0.0     28.9     28.9       0.0     28.9     28.9
MOMENT     -10.9      0.0     30.6     -18.4      0.0    -18.3
```

```
Envelope: ML80E
        ..Tens.. ....Positive.....  ..Compr. ....Negative.....
          Max Ax  Max Shr  Max Mmt    Max Ax  Max Shr  Max Mmt
        -------- -------- --------  -------- -------- --------
 AXIAL      -1.9      0.0     -7.3       3.8      0.0      3.5
 SHEAR       0.0     28.9     28.9       0.0     28.9     28.9
MOMENT     -15.5      0.0     30.9     -18.3      0.0    -18.3
```

Figure 7.5-12-1 Limit State Rating Factors

```
Limit State Rating Factor Results
Envelope: PHL93
        .........Positive.........  .........Negative.........
          Max Ax  Max Shr  Max Mmt    Max Ax  Max Shr  Max Mmt
        -------- -------- --------  -------- -------- --------
 AXIAL     39.26     0.00   115.99      3.56     0.00     2.57
 SHEAR      0.00  2168.29    34.19      0.00     4.01     4.55
MOMENT     39.26     0.00   115.99      3.56     0.00     2.57
```

```
Envelope: ML80E
        .........Positive.........  .........Negative.........
          Max Ax  Max Shr  Max Mmt    Max Ax  Max Shr  Max Mmt
        -------- -------- --------  -------- -------- --------
 AXIAL     18.63     0.00   187.85      4.57     0.00     4.12
 SHEAR      0.00  3529.00    54.98      0.00     6.44     7.41
MOMENT     18.63     0.00   187.85      4.57     0.00     4.12
```

Figure 7.5.13-1 Limit State Resistance/Demand Ratios

```
Limit State Resistance/Demand Ratios

        .........Positive.........  .........Negative.........
          Max Ax  Max Shr  Max Mmt    Max Ax  Max Shr  Max Mmt
        -------- -------- --------  -------- -------- --------
 AXIAL      1.51     0.00     1.00      1.20     0.00     2.047-61
 SHEAR      0.00    11.59     7.57      0.00     7.58    11.59
MOMENT      1.51     0.00     1.00      1.20     0.00     2.04
```

Figure 7.5.14-1 Limit State Allowable Spacings

```
Limit State Allowable Spacing Results
Envelope: PHL93
             .........Positive.........  .........Negative.........
               Max Ax  Max Shr  Max Mmt    Max Ax  Max Shr  Max Mmt
             -------- -------- --------  -------- -------- --------
Spacing (in)    72.23     0.00     0.00     19.07     0.00    17.41
Location      Top/Lft      --       --    Top/Lft      --   Top/Lft
```

Figure 7.5.15-1 Limit State Service Stresses

```
Limit State Service Stress Results
Envelope: HL93                                                              Envelope: HS20E
        .........Positive.........  .........Negative.........                      .........Positive.........  .........Negative.........
          Max Ax  Max Shr  Max Mmt    Max Ax  Max Shr  Max Mmt                        Max Ax  Max Shr  Max Mmt    Max Ax  Max Shr  Max Mmt
        -------- -------- --------  -------- -------- --------                     -------- -------- --------  -------- -------- --------
CONC C    -0.04     0.00    -0.08     -0.03     0.00    -0.04      CONC C    -0.02     0.00    -0.07     -0.03     0.00    -0.03
CONC T     0.00     0.00     0.00      0.00     0.00     0.00      CONC T     0.00     0.00     0.00      0.00     0.00     0.00
REIN T     0.81     0.00     1.88      0.08     0.00     0.13      REIN T     0.26     0.00     1.66      0.07     0.00     0.11
REIN C    -0.33     0.00    -0.63     -0.26     0.00    -0.29      REIN C    -0.17     0.00    -0.57     -0.25     0.00    -0.28
CRACKD     1.00     0.00     1.00      1.00     0.00     1.00      CRACKD     1.00     0.00     1.00      1.00     0.00     1.00
COMPSI     2.00     0.00     2.00      1.00     0.00     1.00      COMPSI     2.00     0.00     2.00      1.00     0.00     1.00
MODRAT     8.00     0.00     8.00      8.00     0.00     8.00      MODRAT     8.00     0.00     8.00      8.00     0.00     8.00

    CRACKD - Cracked Section: 1 = Section has cracked, 0 = Not Cracked
    COMPSI - Compression Side: 1 = Top/Left , 2 = Bottom/Right
    MODRAT - Modular ratio = steel elastic modulus / concrete elastic modulus
```

Figure 7.5.16-1 Stiffness Analysis Model Report (.FEM Output File)

Node Point Coordinates

NODE	X (ft)	Y (ft)	Z (ft)
1	0.83333	14.70500	0.00000
2	2.35792	14.70500	0.00000
3	2.68333	14.70500	0.00000
4	4.53333	14.70500	0.00000
5	6.38333	14.70500	0.00000

Boundary Condition Information

NODE	CODE
95	011101
96	011111
98	011110
100	011110

Equation Numbering NEQ= 295 Bandwidth= 12

NODE NUMBER	UNKNOWN NUMBER FX	FY	FZ	THETA-X	THETA-Y	THETA-Z
1	189	190	0	0	0	191
2	180	181	0	0	0	182
3	171	172	0	0	0	173
4	162	163	0	0	0	164
5	153	154	0	0	0	155

Element Connectivity

	Type	Description	Element Number	Nodes NI	NJ			
2	PFRAME	TopSlab	1	1	2	0	0	0
3	PFRAME	TopSlab	2	2	3	0	0	0
4	PFRAME	TopSlab	3	3	4	0	0	0
5	PFRAME	TopSlab	4	4	5	0	0	0
6	PFRAME	TopSlab	5	5	6	0	0	0

Element Section Properties

Element ID	Seg Length (ft)	Cross Section Area (ft^2)	Moments of Inertia I11 (ft^4)	I22 (ft^4)	I33 (ft^4)	E (ksf)	Shear Areas AV2 (ft^2)	Shear Areas AV3 (ft^2)	Shear Modulus G (ksf)
2	1.89	10000.00	0.00	0.00	0.82	454453.09	0.00	0.00	189355.46
3	0.11	10000.00	0.00	0.00	0.82	454453.09	0.00	0.00	189355.46
	0.05	10000.00	0.00	0.00	0.82	454453.09	0.00	0.00	189355.46
4	2.05	10000.00	0.00	0.00	0.82	454453.09	0.00	0.00	189355.46
5	2.05	10000.00	0.00	0.00	0.82	454453.09	0.00	0.00	189355.46

Figure 7.5.17-1 Stiffness Analysis Results Report (.FER Output File)

STATIC_DISP for SuperElement CULVERT 1

Node	X (Node Coordinates)	Y	Z	M#	X-Tran	Y-Tran	Z-Tran	X-Rot	Y-Rot	Z-Rot
1	0.38	6.77	0.00	(1)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
				(2)	7.03383E-08	-5.41165E-05	0.00000E+00	0.00000E+00	0.00000E+00	-1.11591E-04
				(3)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
				(4)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
				(5)	-2.42374E-08	-2.20826E-04	0.00000E+00	0.00000E+00	0.00000E+00	-4.73644E-04
				(6)	-1.99741E-07	2.04068E-05	0.00000E+00	0.00000E+00	0.00000E+00	5.38628E-05
				(7)	-3.85262E-07	2.92678E-05	0.00000E+00	0.00000E+00	0.00000E+00	7.73066E-05

STATIC_FORCES for SuperElement CULVERT 1

Description	#	LC		Axial	2-Shear	3-Shear	Torsion	2-Moment	3-Moment
TopSlab	1	(1)	I	0.00	0.00	0.00	0.00	0.00	0.00
			J	0.00	0.00	0.00	0.00	0.00	0.00
		(2)	I	-0.14	0.51	0.00	0.00	0.00	0.25
			J	0.14	-0.45	0.00	0.00	0.00	-0.01
		(3)	I	0.00	0.00	0.00	0.00	0.00	0.00
			J	0.00	0.00	0.00	0.00	0.00	0.00
		(4)	I	0.00	0.00	0.00	0.00	0.00	0.00
			J	0.00	0.00	0.00	0.00	0.00	0.00
		(5)	I	0.05	2.96	0.00	0.00	0.00	2.37
			J	-0.05	-2.63	0.00	0.00	0.00	-0.98

Figure 7.5.21-1 Soil Pressures

Strip Footing Results

Envelope: PHL93

	Positive			Negative		
	Max Ax	Max Shr	Max Mmt	Max Ax	Max Shr	Max Mmt
P *	3.90	13.07	13.07	22.55	18.40	18.40
V *	6.76	6.78	6.78	4.85	-1.38	-1.38
M *	9.39	9.45	9.45	3.28	-8.71	-8.71
Bc	1.94	3.76	3.76	4.25	4.25	4.25
ecc	1.48	0.87	0.87	0.30	-0.63	-0.63
N	11.09	20.26	20.26	29.74	25.59	25.59
Mo	7.17	25.41	25.41	54.40	70.55	70.55
Xo	0.65	1.25	1.25	1.83	2.76	2.76
PRESS+	7.02	8.62	8.62	8.89	2.55	2.55
SHEAR	-6.64	-6.99	-6.99	-6.77	-0.92	-0.92
MOMENT	2.70	2.72	2.72	2.59	0.26	0.26
Vr	0.00	22.32	22.32	0.00	22.32	22.32
Mr	19.05	0.00	19.05	19.05	0.00	19.05

Envelope: ML80E

	Positive			Negative		
	Max Ax	Max Shr	Max Mmt	Max Ax	Max Shr	Max Mmt
P *	3.90	9.80	9.80	18.82	16.03	16.03
V *	6.76	6.77	6.77	4.64	-0.67	-0.67
M *	9.39	9.43	9.43	2.61	-6.44	-6.44
Bc	1.94	3.34	3.34	4.25	4.25	4.25
ecc	1.48	1.01	1.01	0.28	-0.55	-0.55
N	11.09	16.99	16.99	26.01	23.22	23.22
Mo	7.17	18.91	18.91	48.02	62.12	62.12
Xo	0.65	1.11	1.11	1.85	2.67	2.67
PRESS+	7.02	7.89	7.89	7.68	2.72	2.72
SHEAR	-6.64	-6.50	-6.50	-5.80	-1.20	-1.20
MOMENT	2.70	2.54	2.54	2.21	0.38	0.38
Vr	0.00	22.32	22.32	0.00	22.32	22.32
Mr	19.05	0.00	19.05	19.05	0.00	19.05

* NOTE: P,V and M are from POI 1 in External Wall 1

+ NOTE: PRESS is the bearing pressure at the POI of the footing for the indicated load case

7.6 FORMATTED OUTPUT TABLES

The following pages contain the format (i.e. the title, output parameters, units, field width and decimal locations, and legends) for each output table described in this chapter, in the order listed in this chapter. On each table, the character "a" represents a character value for that column, and the number of "a" characters shows the number of characters possible there. The character "I" represents an integer value for that column, and the character "x" represents a real value for that column, with the decimal location indicated. The output available for every run of the program may not include all of the output tables shown. Depending on such items as the live loadings, type of run, specifications checked, and output commands and parameters chosen; the program will print different combinations of these output reports.

7.6.1 INPUT FILE ECHO Report Format

```
                                                  xxx.DAT
                                                  -------
 !
 ! ** Created by EngAsst **
 ! EngAsst Information: [Program=BXLRFD] [Version=x.x.x.x]
 ! ** Data Records Start Here **
TTL BXLRFD EXAMPLE PROBLEM #x
TTL SINGLE CELL, HAUNCHES, NO FISH CHANNEL, LEVEL FILL AND LEVEL TOP SLAB
CTL US,1,AR,P,Y,M
SID =BXLRFD,50,666,555,9996,654
MAT 5.0,,60.0,W,90.0,0.6
DIM 9.0,6.0,9.0,9.5,9.0,9.0,0.0,0.0,0.0
LDC 120.0,5.0,1,3.0,A,0.0,0.0,0.0,25.,12.,,,,1.0,1.0,1.0,,,,,,,,,,,2
HCH 6.0,6.0,6.0,6.0,6.0,6.0,6.0,6.0,0.,0.,0.,0.
CVR 2.0,1.5,2.0,1.5,1.5,0.0,0.0
TSR 1,T,9.0,0.75,20.5
TSR 1,B,9.0,0.75,9.5
BSR 1,T,9.0,0.75,8.5
BSR 1,B,9.0,0.75,44.0
WLR 1,L,3.0,0.75,18.0,6.0,0.75,14.0
WLR 1,R,6.0,0.75,14.0
WLR 2,L,6.0,0.75,14.0
WLR 2,R,3.0,0.75,18.0,6.0,0.75,14.0
OIN 1,,1
OUR 1,1,1,1,,,0,1,0,0,1
```

7.6.2 INPUT COMMANDS Report Format

```
COMMAND:  CTL
  SYSTEM OF UNITS                       US
  STRUCTURE TYPE                         1
  TYPE OF RUN                           AR
  BOX CULVERT PC OR CIP                  P
  BOTTOM SLAB                            Y
  TOP SLAB SUPPORT                       M
  FRAME SUPPORT                          *         (computed, if necessary)
  STRIP FOOTING PC OR CIP                *         (computed, if necessary)

COMMAND:  SID
  PROGRAM IDENTIFICATION           =BXLRFD
  COUNTY                                50
  STATE ROUTE                          666
  SEGMENT                              555
  OFFSET                              9996
  SPAN IDENTIFICATION                  654

COMMAND:  MAT
  f'c FOR ALL MEMBERS                  5.0 ksi
  f'c FOR TOP SLAB AT GRADE              * ksi     (computed, if necessary)
  REINFORCEMENT GRADE                 60.0 ksi
  REINFORCEMENT TYPE                     W
  ALPHA                               90.0 degrees
  REBAR SIZE OR WIRE DIAM              0.6 *
  EPOXY COATED                           Y             (default)
  DENSITY OF CONC. FOR DL            150.0 lb/ft^3     (default)
  DENSITY OF CONC. FOR E             145.0 lb/ft^3     (default)
  REINF ULT TENS STRENGTH                * ksi     (computed, if necessary)

COMMAND:  DIM
  CLEAR SPAN                           9.0 ft
  CLEAR HEIGHT                         6.0 ft
  TOP SLAB THICKNESS                   9.0 in
  BOTTOM SLAB THICKNESS                9.5 in
  LEFT WALL THICKNESS                  9.0 in
  RIGHT WALL THICKNESS                 9.0 in
  INTERIOR WALL THICKNESS              0.0 in
  FILL GRADE                           0.0
  TOP SLAB GRADE                       0.0
  UCHNL LEFT WALL HEIGHT                 * ft      (computed, if necessary)
  UCHNL RIGHT WALL HEIGHT                * ft      (computed, if necessary)

COMMAND:  LDC
  FILL UNIT WEIGHT                   120.0 lbf/ft^3
  HEIGHT OF FILL                       5.0 ft
  NUMBER OF LANES                        1
  LIVE LOAD SURCHARGE                  3.0 ft
  LIVE LOAD                              A
  OVERLAY UNIT WEIGHT                  0.0 lbf/ft^3
  OVERLAY THICKNESS                    0.0 in
  FUTURE WEARING SURFACE               0.0 lbf/ft^2
  LL DISTRIBUTION LENGTH               25. ft
  SEGMENT LENGTH                       12. ft
  MULTIPLE PRESENCE REDUCT               *         (computed, if necessary)
  PA TRAFFIC FACTOR                      *         (computed, if necessary)
  FATIGUE DYN. LOAD ALLOW.               *         (computed, if necessary)
```

```
  DUCTILITY FACTOR                  1.0
  REDUNDANCY FACTOR                 1.0
  IMPORTANCE FACTOR                 1.0
  PERMIT DYN. LOAD ALLOW.          1.20              (default)
  LIVE LOAD OVERRIDE                  0              (default)
  MIN EQUIV FLUID PRESS            45.0 lbf/ft^3     (default)
  MAX EQUIV FLUID PRESS            70.0 lbf/ft^3     (default)
  BARRIER DEAD LOAD                   0 kip/ft       (default)
  APPROACH SLAB DL-LEFT               0 kip          (default)
  APPROACH SLAB LL-LEFT               0 kip          (default)
  APPROACH SLAB DL-RIGHT              0 kip          (default)
  APPROACH SLAB LL-RIGHT              0 kip          (default)
  RATINGS W/O FWS                     N              (default)
  BACKFILL TYPE                       *         (computed, if necessary)
  NO. PC SHEAR TRNS SEG               2

COMMAND:  HCH
  TOP LEFT X                        6.0 in
  TOP LEFT Y                        6.0 in
  TOP RIGHT X                       6.0 in
  TOP RIGHT Y                       6.0 in
  BOTTOM LEFT X                     6.0 in
  BOTTOM LEFT Y                     6.0 in
  BOTTOM RIGHT X                    6.0 in
  BOTTOM RIGHT Y                    6.0 in
  TOP INTERIOR X                     0. in
  TOP INTERIOR Y                     0. in
  BOTTOM INTERIOR X                  0. in
  BOTTOM INTERIOR X                  0. in
```

7.6.3 INPUT SUMMARY Report Format

```
                                   CONFIGURATION
     Lines      Blank
      per       Lines
      Page     on Top
       ii         ii

                                       TITLE
     aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa
     aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa
     aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa
     aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa

                                      CONTROL
     Sys of    No of     Type              Bottom     Top Slab    Frame
      Units    Cells    of Run    P or C     Slab       Support   Support
       aa        i        aa        a         a           a         aaa

                              STRUCTURE IDENTIFICATION
     Program              State                            Span
        ID      County    Route     Segment     Offset    ID
     =aaaaaa      ii       iiii       iiii       iiii    iiii

                                     MATERIAL
     f'c All       f'c        Reinf     Reinf               Rebar   Epoxy
     Members     Top Slab     Grade       Type    Alpha       Size   Coated
      (ksi)       (ksi)      (ksi)                (deg)
       x.xx        x.xx       xx.x         a      xx.x       ii       a

 When using bars (instead of wires)

                                     MATERIAL
     f'c All       f'c        Reinf     Reinf              Wire     Epoxy
     Members     Top Slab     Grade       Type    Alpha    Diam     Coated
      (ksi)       (ksi)      (ksi)                (deg)    (in)
       x.xx        x.xx      xxx.x         a      xx.x    x.xx       a

 When using wires (instead of bars)

    Concrete Density
     For DL   For Ec
   (lb/ft^3) (lb/ft^3)
    xxxx.x    xxxx.x

                                    DIMENSIONS
     Clear     Clear    Slab Thickness     Wall Thickness       Fill     Top Slab
      Span     Height     Top   Bottom    Left  Right  Int      Grade      Grade
      (ft)      (ft)     (in)    (in)     (in)   (in)  (in)       (%)        (%)
     xx.xx     xx.xx     xx.x    xx.x     xx.x   xx.x  xx.x     xx.xx      xx.xx

    Left U-channel    Right U-channel
     Wall Height       Wall Height
        (ft)              (ft)
       xx.xx             xx.xx
```

FOOTING

Left Footing Width (in)	Left Footing Thick (in)	Left Footing Proj (in)	Right Footing Width (in)	Right Footing Thick (in)	Right Footing Proj (in)	Inter Footing Width (in)	Inter Footing Thick (in)
xxx.x	xxx.x	xxx.x	xxx.x	xxx.x	xxx.x	xxx.x	xxx.x

LOAD CONTROL

Fill Unit Weight (pcf)	Height of Fill (ft)	No of Lanes	Live Load Surcharge (ft)	Live Load	**Overlay Unit Weight** (pcf)	Overlay Thick (in)	Future Wearing Surface (psf)
xxx.x	xxx.xx	i	xx.xx	a	xxx.x	xxxx.x	xx.x

Live Load Distrib Length (ft)	Segment Length (ft)	Multiple Presence Reduction	PA Traffic Factor	Fatigue Dynamic Load Allowance	Duct Factor	Redund Factor
xxx.xx	xxx.xx	N/A	N/A	N/A	x.xx	x.xx

Import Factor	Permit Max Dynamic Load Allowance	Live Load Override	Min Equiv Fluid Pressure (pcf)	Max Equiv Fluid Pressure (pcf)	Barrier Dead Load (kips/ft)
x.xx	x.xx	i	xxx.xx	xxx.xx	xx.xx

Left Approach Slab Dead Load (kips)	Left Approach Slab Live Load (kips)	Right Approach Slab Dead Load (kips)	Right Approach Slab Live Load (kips)	Ratings w/o Future Wearing Surface	Backfill Type	No. of Precast Shr Trns Segments	**Backfill Unit Weight (pcf)**
xx.xx	xx.xx a	xx.xx	xx.xx a	a	N/A	aaa	**xxx.0**

* Note: Live Load set to 0.00 because Number of Lanes is zero

SPECIAL LIVE LOAD

LL No.	Gage Dist (ft)	Pass Dist (ft)	Axle Effect	Lane Load (klf)	Load Percent Increase	Load Factor STR-I	Load Factor STR-II	Load Factor SER-I	Factor Fatigue	**Vehicle Type**
x	xx.xx	xx.xx	a	x.xx	xx.xx	x.xx	x.xx	x.xx	N/A	**a**

SPECIAL AXLE LOADS

LL No.	Axle Load (kips)	Axle Spac (ft)	Axle Load (kips)	Axle Spac (ft)	Axle Load (kips)	Axle Spac (ft)	Axle Load (kips)	Axle Spac (ft)
x	xxx.xx	xx.xx	xxx.xx	xx.xx	xxx.xx	xx.xx	xxx.xx	xx.xx

HAUNCH

Top Left X (in)	Top Left Y (in)	Top Right X (in)	Top Right Y (in)	Bot Left X (in)	Bot Left Y (in)	Bot Right X (in)	Bot Right Y (in)	Top Int X (in)	Top Int Y (in)	Bot Int X (in)	Bot Int Y (in)
xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x

```
                                   FISH CHANNEL
          Segment   Thick    Segment   Thick    Segment   Thick
     Type  Length  Change     Length  Change     Length  Change
             (in)    (in)       (in)    (in)       (in)    (in)
      a     xx.xx    x.xx      xx.xx    x.xx      xx.xx    x.xx
            x.xxx   x.xxx      x.xxx   x.xxx      x.xxx   x.xxx

                                      COVERS
      Top Slab     Bottom Slab                Footing
      Top   Bot      Top   Bot     Walls      Top   Bot
     (in)  (in)     (in)  (in)      (in)     (in)  (in)
     xx.x  xx.x     xx.x  xx.x      xx.x     xx.x  xx.x

                                 TOP SLAB AREAS
                              BOTTOM SLAB AREAS
                                      WALL AREAS
     Slab            Range  1         Range  2         Range  3
      No    Face    Dist   Area      Dist   Area      Dist   Area
                    (ft)  (in^2)     (ft)  (in^2)     (ft)  (in^2)
      i      a     xx.xx  xx.xxx    xx.xx  xx.xxx    xx.xx  xx.xxx
      i      a     xx.xx  xx.xxx    xx.xx  xx.xxx    xx.xx  xx.xxx

                             TOP SLAB REINFORCEMENT
                          BOTTOM SLAB REINFORCEMENT
                                 WALL REINFORCEMENT
     Slab       Range   Bar  Reinf   Range   Bar  Reinf   Range   Bar  Reinf
      No   Face  No 1  Size   Spac    No 2  Size   Spac    No 3  Size   Spac
                 (ft)         (in)    (ft)         (in)    (ft)         (in)
      i     a   xx.xx   ii    xx.x   xx.xx   ii    xx.x   xx.xx   ii    xx.x
      i     a   xx.xx   ii    xx.x   xx.xx   ii    xx.x   xx.xx   ii    xx.x

This table is used if BARS are specified (instead of wires)
                             TOP SLAB REINFORCEMENT
     Slab       Range  Wire  Reinf    Range  Wire  Reinf    Range  Wire  Reinf
      No    Face  1    Diam   Spac      2    Diam   Spac      3    Diam   Spac
                 (ft)  (in)   (in)    (ft)  (in)   (in)    (ft)  (in)   (in)
      i      a  xx.xx xx.xx   xx.x    xx.xx xx.xx   xx.x    xx.xx xx.xx   xx.x
      i      a  xx.xx xx.xx   xx.x    xx.xx xx.xx   xx.x    xx.xx xx.xx   xx.x

 This table is used if WIRES are specified (instead of bars)


                          TOP SLAB SHEAR REINFORCEMENT AREAS
                       BOTTOM SLAB SHEAR REINFORCEMENT AREAS
     Slab
      No   Region   Start    End      Av     Spac
                     (ft)    (ft)   (in^2)   (in)
      i      i      xx.xx   xx.xx   xx.xxx   xx.x
             i      xx.xx   xx.xx   xx.xxx   xx.x

                       WALL SHEAR REINFORCEMENT AREAS
     Wall
      No   Region   Start    End      Av     Spac
                     (ft)    (ft)   (in^2)   (in)
      i      i      xx.xx   xx.xx   xx.xxx   xx.x
             i      xx.xx   xx.xx   xx.xxx   xx.x
```

```
                                FOOTING AREAS
Footing
 Number   Face      Area
                   (in^2)
   i        a      xx.xxx
   i        a      xx.xxx

                            FOOTING REINFORCEMENT
Footing             Bar   Reinf
 Number   Face     Size    Spac
                           (in)
   i        a       ii     xx.x
   i        a       ii     xx.x
```

This table is used if BARS are specified (instead of wires)

```
                            FOOTING REINFORCEMENT
Footing            Wire   Reinf
 Number   Face     Diam    Spac
                   (in)    (in)
   i        a      x.xx    xx.x
   i        a      x.xx    xx.x
```

This table is used if WIRES are specified (instead of bars)

```
                              OUTPUT OF INPUT
Input     Input     Input
 Echo   Commands   Summary
  i        i          I

                             OUTPUT OF RESULTS
Section   LL   Rating  DL Eff   Design  Shear  Found         Serv   Serv
 Props  Rating  Sum    & Capac  Reinf  Design  Press  Quant  Table  Sum
   i       i     i       i        i       i      i      i      i      i

Found Press
  Summary
     i

                         OUTPUT INTERMEDIATE RESULTS
Genl  Non-Live                      Truck                          Limit St
 POI    Load     Infl    Truck    Thru Fill    Lane    Envelope  Dead Load
Data   Results  Lines  Response   Response  Response  Response    Results
  i       i       i        i          i         i         i          i

 Limit St        Limit St  Limit St  Limit St  Limit St
Live Load   Bar   Section   Rating    Allow    Service    FE      FE
 Results   Table   Capac   Factors  Spacings   Stresses  Model  Results
    i        i       i        i         i          i       i       i

                  Soil
CMO1  CMO2  ACS1  Pressure
  i     i     i      i
```

7.6.4 ADDITIONAL INFORMATION Report Format

```
                                COMPUTED VALUES

          Computed  Computed  Computed   Computed
  Input   Flexure    Axial     Shear    Development
  Reinf    Reinf     Reinf     Reinf       Reinf
  Grade    Grade     Grade     Grade       Grade
  (ksi)    (ksi)     (ksi)     (ksi)       (ksi)
 xxx.xxx  xxx.xxx   xxx.xxx  xxx.xxx      xxx.xxx

                              ADDITIONAL GEOMETRY

     Final Component Thickness

Top Slab #1    :  xxx.xx in
Top Slab #1    :  xxx.xx in
Top Slab #1 Lft:  xxx.xx in
Top Slab #1 Rgt:  xxx.xx in

Note: For sloped Top Slabs, the thickness is measured at the
      face of the walls or the end of haunches if present.

    Wall #1    :  xxx.xx in
    Wall #2    :  xxx.xx in
    Wall #3    :  xxx.xx in
Bot Slab #1    :  xxx.xx in
Bot Slab #2    :  xxx.xx in


     Final Strip Footing Projections

 Left Wall Toe  Projection   :  xxx.xx in
 Left Wall Heel Projection   :  xxx.xx in
    Center Wall Projection   :  xxx.xx in
Right Wall Toe  Projection   :  xxx.xx in
Right Wall Heel Projection   :  xxx.xx in
```

7.6.5 GROSS SECTION PROPERTIES Report Format

```
                          Bottom Slab No.  i
                             Top Slab No.  i
                                 Wall No.  i
                         Clear Span:  xx.xxx (ft)
                       Clear Height:  xxx.xx (ft)

          Dist/Span      Member
         Dist/Height     Member         M of
  Dist      Ratio       Thickness      Inertia        Area
  (ft)                    (in)         (in^4)        (in^2)
 xx.xxx     x.xx         xxxx.         xxx.xxx        xx.xx
 xx.xxx     x.xx         xxxx.         xxx.xxx        xx.xx
 xx.xxx     x.xx         xxxx.         xxx.xxx        xx.xx

 The minimum slab thickness for Bottom Slab No. 1 is xxx.xx (in)

 Note: Wall distances begin at the bottom of the wall and slab distances
       begin at the left side of the slab.
```

7.6.6 LIVE LOAD ELAT & IM Report Format

```
                              Dynamic Load Allowance

        Fill                   Permit
       Height         IM        IM
        (ft)
       xx.xx        xx.xx    xx.xx

                             Case 1 - On Deck Loading

    No. of      c-c                     Calc Elat
     Lanes    Culvert          Calc    ---------                Elat
    Loaded      Span   MPF *   Elat       MPF       Seg Length   Used   (Cast In Place)
    Loaded      Span   MPF *   Elat       MPF    aa(Seg Length)  Used   (Precast)
                (ft)           (ft)      (ft)          (ft)      (ft)
       x       xx.xx  x.xxx   xx.xx      xx.xx         xx.xx    xx.xx


                            Case 2 - Thru Fill Loading

    No. of                 LL                     Total
     Lanes      Fill    Distribution              Width      Elat
    Loaded     Height      Length      MPF *    (LANE(i))    Used
                (ft)        (ft)                  (ft)       (ft)
       x       x.xx        xx.x      x.xxx       xx.xx      xx.xx

    *  Includes Multiple Presence Reduction Factor
    +  Indicates controlling Elat for On/Deck
    ** Indicates: Min Elat = Min(Elat M+, Elat M-)
```

7.6.7 SERVICEABILITY CHECK Report Format

```
                               Top Slab No. 1
                            Bottom Slab No. 1
                                   Wall No. 1
                    STRIP FOOTING: Wall No. 1

                         Minimum  Maximum   Temp/    Crack     Tens
             Bar  Input  Primary  Primary  Shrink    Control   Reinf  Codes
   Dist   Loc Size Spacing Spacing  Spacing  Spacing   Spacing   Stress A
   (ft)            (in)     (in)     (in)      (in)     (in)    (ksi)
 xxx.xx   T   ii  xx.xx    xx.xxa   xx.xxa    xx.xxaa xxxx.xx xxxx.xx  a  a

  ERROR!:    User entered bar size and spacing has failed to meet
             serviceability criteria. An asterisk (*) indicates which
             criteria failed. Check the bar size and spacing against
             the allowable serviceability criteria. Refer to DM-4 Section 5.6.7.
   NOTE: The Crack Control Stress criteria does not apply to
         the P-82 and P2016-13 Permit Load Vehicle.

         Temp/Shrinkage Codes:        Code A: Loading
          A   - Steel Area is less     1  PHL-93
                than allowable         2  HL-93
          B   - Steel Spacing is       3  P-82
                greater than           4  ML-80
                allowable              5  HS-20
          N/A - Section thickness is   6  H-20
                greater than 18 in     7  SLL (number after decimal denotes governing SLL vehicle)
                                       8  TK527
                                       9  EV2
                                       Z  EV3
                                       Y  SU6TV
                                       X  P2016-13

   Note: Wall distances begin at the bottom of the wall and slab distances
         begin at the left side of the slab.
```

7.6.8 SERVICEABILITY SUMMARY Report Format

```
                           Minimum  Maximum   Temp/    Crack
                           Primary  Primary  Shrink   Control
 Location                  Spacing  Spacing  Spacing  Spacing

Top Slab No. 1                aa       aa       aa       aa
Wall No. 1                    aa       aa       aa       aa
STRIP FOOTING: Wall No. 1     aa       aa       aa       aa

 ERROR!:    Serviceability criteria has not been met. For further details
            activate the Serviceability Check Table in the OUR command.
            Then verify entered bar size and spacing values.
```

7.6.9 LIVE LOAD RATING Report Format

```
                          LIVE LOAD RATING W/  FWS
                          LIVE LOAD RATING W/O FWS

                     PHL-93 Loading:    Top Slab No. 1
                       P-82 Loading: Bottom Slab No. 1
                       P-82 Loading:        Wall No. 1

                                             Fact          Rating Factor
              Fact    Fact    Fact      Resist             IR      OR      Prov      Min       Phi
 Dist        Moment  Thrust   Shear   (kips-ft)   Zone   STR-I  STR-IA    Reinf     Reinf    Factor
 (ft)      (kips-ft)  (kip)   (kip)     (kip)                             (in^2)    (in^2)
xx.xx  DL+E  xxxx.xx  xxx.xx  xxx.xx   xxxx.xx F1  aa    xx.xx            xxx.xx T  xxx.xx aa x.xx
       LL+I  xxxx.xx  xxx.xx  xxx.xx   xxxx.xx V2        xx.xx            xxx.xx
       DL+E  xxxx.xx  xxx.xx  xxx.xx   xxxx.xx F1  aa            xx.xx    xxx.xx T  xxx.xx aa x.xx
       LL+I  xxxx.xx  xxx.xx  xxx.xx   xxxx.xx V1                xx.xx
xx.xx  DL+E  xxxx.xx  xxx.xx  xxx.xx   xxxx.xx F2  aa    xx.xx            xxx.xx T  xxx.xx aa x.xx
       LL+I  xxxx.xx  xxx.xx  xxx.xx   xxxx.xx V5        xx.xx            xxx.xx
       DL+E  xxxx.xx  xxx.xx  xxx.xx   xxxx.xx F3  aa            xx.xx    xxx.xx B  xxx.xx aa x.xx
       LL+I  xxxx.xx  xxx.xx  xxx.xx   xxxx.xx V6                xx.xx

     *   Negative Rating due to deadload effects being greater than capacity

     ** Warning: The provided area of steel is less than
                 the required minimum area of steel.

     F or V reported after the Fact Resist indicates whether the Rating is for
     Flexure (F) or Shear (V).  The numerical code reported after F or V
     corresponds to the governing Maximum Effect Case for the Rating Factor.

     Maximum Effect Cases:
      1  Maximum Positive    Moment and Concurrent Thrust
      2  Maximum Negative    Moment and Concurrent Thrust
      3  Maximum Tension     Thrust and Concurrent Moment
      4  Maximum Compression Thrust and Concurrent Moment
      5  Maximum Positive    Shear  and Concurrent Moment
      6  Maximum negative    Shear  and Concurrent Moment

     T, B, L, or R reported after the Reinforcement (Reinf) indicates the
     location of the flexural reinforcement reported:
      T  Top    steel in a slab
      B  Bottom steel in a slab
      L  Left   steel in a wall
      R  Right  steel in a wall

       Zone Code Descriptions
            TN - Tension controlled section
            TR - Transition section
```

```
          CM - Compression controlled section

     Phi Factor Epsilon (cl) =  x.xxxxx
     Phi Factor Epsilon (tl) =  x.xxxxx

           Note: Wall distances begin at the bottom of the wall and slab distances
          begin at the left side of the slab.

               +++++++++++++++++++++++++++++++++++++++++++++
               +                                           +
               +              C O M B I N E D              +
               +         R A T I N G   S U M M A R Y       +
               +                                           +
               +++++++++++++++++++++++++++++++++++++++++++++

                              H20         HS20        ML-80     TK527       PHL-93
    INVENTORY    Member       aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa
    RATING       Dist. (ft)   aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa
    (IR)         Limit State  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa
                 Rating       aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa
                 Rating Tons  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa

                              H20         HS20        ML-80     TK527       PHL-93      P-82
    OPERATING    Member       aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa aaaaaaaaaa
    RATING       Dist. (ft)   aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa aaaaaaaaaa
    (OR)         Limit State  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa aaaaaaaaaa
                 Rating       aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa aaaaaaaaaa
                 Rating Tons  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa aaaaaaaaaa

                              EV2          EV3        SU6TV     P2016-13
    OPERATING    Member       aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa
    RATING       Dist.  (ft)  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa
    (OR)         Limit State  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa
                 Rating       aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa
                 Rating Tons  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa  aaaaaaaaaa

All ratings are based on the inclusion of the design future wearing surface.
All ratings are based on the exclusion of the design future wearing surface.

F or V reported after the Rating Factor indicates whether the Rating
is for Flexure (F) or Shear (V).
```

7.6.10 STRIP FOOTING PERFORMANCE RATIOS Report Format

```
                  STRIP FOOTING PERFORMANCE RATIOS W/  FWS
                  STRIP FOOTING PERFORMANCE RATIOS W/O FWS

                                         Wall No. 1

          Flexure                            Moment    Shear                   Shear
          Loading     Fact      Moment   Phi   Perf    Loading   Fact    Shear   Perf
 Dist      Code      Moment    Resist  Factor Ratio     Code    Shear  Resist  Ratio
 (ft)    A B  C  D (kips-ft) (kips-ft)               A B  C  D  (kips)  (kips)
xxx.xxL                                              i i aaa i xxxx.xx xxxx.xx xxx.xx
xxx.xxLT i i aaa i xxxxxx.xx xxxxx.xx   x.xx xxx.xx
      LB i i aaa i xxxxxx.xx xxxxx.xx   x.xx xxx.xx
xxx.xxRT i i aaa i xxxxxx.xx xxxxx.xx   x.xx xxx.xx
      RB i i aaa i xxxxxx.xx xxxxx.xx   x.xx xxx.xx
xxx.xxR                                              i i aaa i xxxx.xx xxxx.xx xxx.xx

L or R after the distance indicates the Left or Right side
of the strip footing.

T or B after the distance indicates the location of the
flexural reinforcement reported:
 T  Top    steel in footing
 B  Bottom steel in footing

Flexure/Shear Loading Codes:
 Code A           Code B                         Code C      Code D
  1  Strength-I    1  Maximum Positive    Moment  1  PHL-93   1  On Deck
  2  Strength-II   2  Maximum Negative    Moment  2  HL-93    2  Thru Fill
  3  Strength-IA   3  Maximum Tension     Thrust  3  P-82
                   4  Maximum Compression Thrust  4  ML-80
                   5  Maximum Positive    Shear   5  HS-20
                   6  Maximum Negative    Shear   6  H-20
                                                  7  SLL (number after decimal denotes
                                                          governing SLL vehicle)
                                                  8  TK527
                                                  9  EV2
                                                  Z  EV3
                                                  Y  SU6TV
                                                  X  P2016-13
```

7.6.11 RATING SUMMARY Report Format

```
                        RATING SUMMARY W/ FWS
                        RATING SUMMARY W/O FWS

                                 Loading:  PHL-93
                                 Loading:  P-82
                                 Loading:  ML-80
                                 Loading:  SPECIAL
                                 Loading:  TK527

                       Dist/    IR       IR          Dist/    OR       OR
                       Span   Rating   Rating        Span   Rating   Rating
    Member   No. Dist  Ratio  Factor   Tonnage  Dist  Ratio  Factor   Tonnage
                 (ft)          STR-I    (ton)   (ft)         STR-II    (ton)
  Top Slab  1  xx.xx xx.xx   xx.xx F  xxx.xx   xx.xx xx.xx   xx.xx F  xxx.xx
  Top Slab  2  xx.xx xx.xx   xx.xx F  xxx.xx   xx.xx xx.xx   xx.xx V  xxx.xx
  Bot Slab  1  xx.xx xx.xx   xx.xx F  xxx.xx   xx.xx xx.xx   xx.xx F  xxx.xx
  Bot Slab  2  xx.xx xx.xx   xx.xx V  xxx.xx   xx.xx xx.xx   xx.xx V  xxx.xx
      Wall  1  xx.xx xx.xx   xx.xx F  xxx.xx   xx.xx xx.xx   xx.xx V  xxx.xx
      Wall  2  xx.xx xx.xx   xx.xx F  xxx.xx   xx.xx xx.xx   xx.xx F  xxx.xx
      Wall  3  xx.xx xx.xx   xx.xx F  xxx.xx   xx.xx xx.xx   xx.xx F  xxx.xx

   *   Negative Rating due to deadload effects being greater than capacity

   The Minimum Inventory Rating is governed by FLEXURE.
   The Minimum Inventory Rating is governed by   SHEAR.
   The Minimum Inventory Rating Factor is xxx.xx at Distance xx.xxx (ft)
   in TOP SLAB 1.
   in BOTTOM SLAB 1.
   in WALL 1.

    The Minimum Operating Rating is governed by FLEXURE.
    The Minimum Operating Rating is governed by   SHEAR.
    The Minimum Operating Rating Factor is xxx.xx at Distance xx.xxx (ft)
    in TOP SLAB 1.
    in BOTTOM SLAB 1.
    in WALL 1.

    F or V reported after the Rating Factor indicates whether the Rating
    is for Flexure (F) or Shear (V).

    Note: Wall distances begin at the bottom of the wall and slab distances
          begin at the left side of the slab.
```

7.6.12 DEAD LOAD EFFECTS AND CAPACITIES Report Format

```
                                  Top Slab No. 1
                               Bottom Slab No. 1
                                      Wall No. 1

        Dist/                                         Factored          Resist/
       Height Loading                                  Resist           Demand   Prov    Min      Phi
  Dist  Ratio   Code    Moment  Thrust   Shear (kips-ft)    Zone   Ratio    Reinf   Reinf    Factor
  (ft)          A  B (kips-ft)  (kips)  (kips)    (kips)                     (in^2)  (in^2)
 xx.xx   x.xx   i  i   xxxx.xx  xxx.xx            xxxx.xx F  aa      x.xx    xx.xx T xxx.xx aa x.xx
                i  i                    xxx.xx   xxxx.xx V          x.xx*   xx.xx
xx.xxx   x.xx   i  i   xxxx.xx  xxx.xx            xxxx.xx F  aa      x.xx    xx.xx T xxx.xx aa x.xx
                i  i                    xxx.xx   xxxx.xx V          x.xx    xx.xx

     ** Warning: The provided area of steel is less than
                 The required minimum area of steel.

    Loading Codes:
     Code A            Code B
      1  Strength-I     1  Maximum Positive Moment
      2  Strength-II       and Concurrent Thrust
      3  Strength-IA    2  Maximum Negative Moment
                           and Concurrent Thrust
                        3  Maximum Tension Thrust
                           and Concurrent Moment
                        4  Maximum Compression Thrust
                           and Concurrent Moment
                        5  Maximum Positive Shear
                           and Concurrent Moment
                        6  Maximum Negative Shear
                           and Concurrent Moment

     F or V reported after the Factored Resistance indicates whether the
     Resistance, Ratio, and Reinforcement reported are for Flexure (F)
     or Shear (V).

     * Indicates a performance ratio of less than 1.0

     Zone Code Descriptions
           TN - Tension controlled section
           TR - Transition section
           CM - Compression controlled section

      Phi Factor Epsilon (cl) =  x.xxxxx
      Phi Factor Epsilon (tl) =  x.xxxxx

            Note: Wall distances begin at the bottom of the wall and slab distances
           begin at the left side of the slab.
```

7.6.13 FLEXURAL REINFORCEMENT DESIGN Report Format

```
                              Top Slab No. 1 - Top Face
                              Top Slab No. 1 - Bottom Face
                              Top Slab No. 2 - Top Face
                              Top Slab No. 2 - Bottom Face
                           Bottom Slab No. 1 - Top Face
                           Bottom Slab No. 1 - Bottom Face
                           Bottom Slab No. 2 - Top Face
                           Bottom Slab No. 2 - Bottom Face
                                  Wall No. 1 - Left Face
                                  Wall No. 1 - Right Face
                                  Wall No. 2 - Left Face
                                  Wall No. 2 - Right Face
                                  Wall No. 3 - Left Face
                                  Wall No. 3 - Right Face
                 STRIP FOOTING:   Wall No. 1 - Top Face

           Flexure  Factored   Fact Resist
     Dist  Loading Mom/Thrust  Mom/Thrust         Flex    Phi              Bar Spacing
             Code   (kips-ft)  (kips-ft)   Zone   Reinf  Factor # 4/# 8   # 5/# 9   # 6/#10   # 7/#11
     (ft)  A B C D    (kips)    (kips)            (in^2)           (in)      (in)      (in)      (in)
   XXX.XXL i i i i   XXXX.XX   XXXX.XXa    aa     XX.XXa  x.xxx XXX.X ia  XXX.X ia  XXX.X ia  XXX.X ia
                      XXX.XX    XXX.XXa                         XXX.X ia  XXX.X ia  XXX.X ia  XXX.X ia
   XXX.XXR i i i i   XXXX.XX   XXXX.XXa    aa     XX.XXa        XXX.X ia  XXX.X ia  XXX.X ia  XXX.X ia
                      XXX.XX    XXX.XXa                         XXX.X ia  XXX.X ia  XXX.X ia  XXX.X ia

                                      Wall No. 1
                                      Wall No. 2
                                      Wall No. 3
        The footing has a vertical force resultant outside the footing
        therefore, a design cannot be obtained. The controlling
        limit state(s) and corresponding eccentricity is shown below.

                                         Footing CL to
          Limit State   Eccentricity    Edge Distance
                            (ft)            (ft)
            aaaaaa        xxx.xxa          xxx.xx

        * Indicates the vertical force resultant is outside the footing.
```

```
Flexure Loading Codes:
 Code A            Code B                         Code C     Code D
  1  Strength-I     1  Maximum Positive Moment    1  PHL-93  1  On Deck
  2  Strength-II       and Concurrent Thrust      2  HL-93   2  Thru Fill
  3  Construction   2  Maximum Negative Moment    3  P-82
  4  Bot Slab Only     and Concurrent Thrust      4  ML-80
                    3  Maximum Tension Thrust     8  TK527
                       and Concurrent Moment      X  P2016-13
                    4  Maximum Compression Thrust
                       and Concurrent Moment
```

If the Flexure Loading Code is blank, no reinforcement is required for strength.

If an M is printed next to the Flexural Reinforcement, the design is governed by minimum reinforcement.

If an % is printed next to the Flexural Reinforcement, the area is the maximum reinforcement considered.

If an * is printed next to the Factored Resistances, they are less than the Factored Loads.

```
Zone Code Descriptions
      TN – Tension controlled section
      TR – Transition section
      CM – Compression controlled section
```

```
Phi Factor Epsilon (cl) =  x.xxxxx
Phi Factor Epsilon (tl) =  x.xxxxx
```

If a number appears after the spacing, it has been calculated using crack control requirements. That number corresponds to the Crack Control Codes listed below. If a number does not appear after the spacing, it has been calculated using the reported flexural reinforcement. The flexural reinforcement is based on the reported Flexure Loading Code.

```
Crack Control Codes:
   1  On Deck      - Maximum Positive    Moment and Concurrent Thrust
   2  On Deck      - Maximum Negative    Moment and Concurrent Thrust
   3  On Deck      - Maximum Tension     Thrust and Concurrent Moment
   4  On Deck      - Maximum Compression Thrust and Concurrent Moment
   5  Through Fill - Maximum Positive    Moment and Concurrent Thrust
   6  Through Fill - Maximum Negative    Moment and Concurrent Thrust
   7  Through Fill - Maximum Tension     Thrust and Concurrent Moment
   8  Through Fill - Maximum Compression Thrust and Concurrent Moment

When Live Load is not applicable, i.e., when Flexure Loading Codes
C and D are blank, Crack Control Codes 1-4 will be used to indicate
the Dead Load Maximum Effect Case.  Ignore the 'On Deck' part of the
code message.

If a letter appears after the spacing, the letter corresponds to one of
the following errors or messages:
   V  Spacing < minimum (LRFD Specifications and DM-4 5.10.3.1)
   W  Actual bar spacing was governed by DM-4 maximum spacing requirements
      (LRFD Specifications and DM-4 5.10.3.2 and 5.10.6, DM-4 5.10.6.1P)

Note: Wall distances begin at the bottom of the wall and slab distances
      begin at the left side of the slab.
```

7.6.14 DEVELOPMENT LENGTH CHECK Report Format

```
                              WALL BAR DEVELOPMENT INTO FOOTING

                                         Wall No. i
                           aaaaaaaaaaaa Face is controlling
                              (Area Steel Required = x.xxx in^2)

       Bar                                 Hooked Bar Development Length
     Spacing     # 4       # 5       # 6       # 7       # 8       # 9       #10       #11
      (in)       (in)      (in)      (in)      (in)      (in)      (in)      (in)      (in)
      xx.xx      xx.xx     xx.xx     xx.xx     xx.xx     xx.xx     xx.xx     xx.xx     xx.xx

      * - indicates the bar cannot develop into the footing
```

7.6.15 SHEAR DESIGN Report Format

```
                          Bottom Slab No. i
                             Top Slab No. i
                                 Wall No. i

           Shear                                                 Conc+
          Loading         Factored          Flex      Shear      Shear      Shear
   Dist     Code       Shear     Moment     Reinf     Depth      Capac      Reinf
   (ft)   A  B  C  D  (kips)   (kips-ft)   (in^2)     (in)      (kips)     (in^2)
  xx.xx   i  i  i  i  xxx.xx    xxxx.xx    xx.xxa     xx.xx     xxx.xx     xx.xx*
  xx.xx   i  i  i  i  xxx.xx    xxxx.xx    xx.xxa     xx.xx     xxx.xx     xx.xx

  * After the Shear Reinforcement Area indicates Vs required > Vs max

  Shear Loading Codes:
   Code A              Code B                         Code C      Code D
    1  Strength-I       1  Maximum Positive Moment     1  PHL-93   1  On Deck
    2  Strength-II         and Concurrent Thrust       2  HL-93    2  Thru Fill
    3  Construction     2  Maximum Negative Moment     3  P-82
    4  Bot Slab Only       and Concurrent Thrust       4  ML-80
                        3  Maximum Tension Thrust      5  HS-20
                           and Concurrent Moment       8  TK527
                        4  Maximum Compression Thrust  X  P2016-13
                           and Concurrent Moment
                        5  Maximum Positive Shear
                           and Concurrent Moment
                        6  Maximum Negative Shear
                           and Concurrent Moment

  + The Concrete Shear Capacity shown is the factored shear capacity (phiv*Vc)

  The Factored Moments shown are the moments associated with the reported
  Shear Loading Code (i.e., limit state, max effect case, live load,
  on deck/thru fill).

  Areas of flexural reinforcement printed here are used in shear
  calculations are optimized values that satisfy strength and
  serviceability requirements for member flexural regions.
  See section 3.5 in user's manual for further information.
```

```
A "t" or "%" after the Flexural Reinforcement Area indicates a valid
bar size and bar spacing combination was not found.
  "t" the area is the theoretical area required to satisfy strength requirements.
  "%" the area is the maximum reinforcement considered.
Considered increasing member thickness and/or concrete strength.

Note: Wall distances begin at the bottom of the wall and slab distances
      begin at the left side of the slab.
```

7.6.16 STRIP FOOTING SHEAR DESIGN Report Format

```
                             Under Wall No. i

  Dist     Side     Shear
  from      of     Loading     Fact      Shear      Shear    Performance
  Face     Wall      Code      Shear     Depth      Resist      Ratio
  (ft)             A B C D    (kips)     (in)      (kips)
 XXX.XX    Left    i i i i   XXXX.XX    XX.XX    XXXX.XX     XXX.XX
 XXX.XX   Right    i i i i   XXXX.XX    XX.XX    XXXX.XX     XXX.XX

    The footing has a vertical force resultant outside the footing
    therefore, a design cannot be obtained. The controlling
    limit state(s) and corresponding eccentricity is shown below.

                                       Footing CL to
       Limit State    Eccentricity     Edge Distance
                          (ft)             (ft)
         aaaaaa        xxx.xxa           xxx.xx

    * Indicates the vertical force resultant is outside the footing.

 Shear Loading Codes:
  Code A           Code B                        Code C     Code D
   1  Strength-I     1  Maximum Positive Moment    1  PHL-93  1  On Deck
   2  Strength-II       and Concurrent Thrust      2  HL-93   2  Thru Fill
   3  Construction   2  Maximum Negative Moment    3  P-82
                        and Concurrent Thrust      4  ML-80
                     3  Maximum Tension Thrust     8  TK527
                        and Concurrent Moment      X  P2016-13
                     4  Maximum Compression Thrust
                        and Concurrent Moment
                     5  Maximum Positive Shear
                        and Concurrent Moment
                     6  Maximum Negative Shear
                        and Concurrent Moment

 Shear POI check at distance d not being done/reported on left side
 because distance d is outside the footing.

 * Indicates a performance ratio of less than 1.0

     The footing under this wall has a vertical force resultant outside the
     footing, therefore, a design cannot be obtained. See the STRIP FOOTING
     BEARING PRESSURE Report for more information on which Limit State
     caused this condition.

 Shear POI check at  left face of wall not done/reported because
 there is no negative moment at this location.
```

7.6.17 MINIMUM REINFORCEMENT CHECK Report Format

```
       Cracking                             Temp                          Area
        Moment               Rho Min       Shrink     0.002     Phi       Prov/  Status
  Dist   M(cr)  1.33*M(u)     Area          Area        Ag     Factor     Width   Code
  (ft)  (kip-ft)  (kip-ft)    (in^2)        (in^2)     (in^2)             (in^2)
 xx.xx     xx.xx     xx.xx+     x.xx*       x.xx      xx.xx    x.xxx     x.xxx
 xx.xx     xx.xx+    xx.xx      x.xx*       x.xx      xx.xx    x.xxx     x.xxx      A
 xx.xx     xx.xx+    xx.xx      x.xx        x.xx*     xx.xx    x.xxx     x.xxx
 xx.xx     xx.xx     xx.xx+     x.xx        x.xx*     xx.xx    x.xxx     x.xxx

    Status Code Descriptions
        + - Controlling moment for Rho Min Area calculation
        * - Controlling minimum area of steel
        A - Area provided smaller than required minimum area of steel
```

7.6.18 FOUNDATION PRESSURE Report Format

```
                    Maximum Influence Line Pressure at Wall No. 1
                    Maximum Influence Line Pressure at Wall No. 2
                    Maximum Influence Line Pressure at Wall No. 3


                        Wall 1      Wall 2      Wall 3    Eff Foundation
    Lim St   Load       Press       Press       Press     Bearing Width
                        (ksf)       (ksf)       (ksf)         (ft)
    STR-I   PHL-93    xxxx.xx *   xxxx.xx     xxxx.xx       xxxx.xx
              P-82    xxxx.xx     xxxx.xx     xxxx.xx       xxxx.xx
             HL-93    xxxx.xx     xxxx.xx     xxxx.xx       xxxx.xx
             ML-80    xxxx.xx     xxxx.xx     xxxx.xx       xxxx.xx
             HS-20    xxxx.xx     xxxx.xx     xxxx.xx       xxxx.xx
              H-20    xxxx.xx     xxxx.xx     xxxx.xx       xxxx.xx
               SLL    xxxx.xx     xxxx.xx     xxxx.xx       xxxx.xx
             TK527    xxxx.xx     xxxx.xx     xxxx.xx       xxxx.xx
               EV2    xxxx.xx     xxxx.xx     xxxx.xx       xxxx.xx
               EV3    xxxx.xx     xxxx.xx     xxxx.xx       xxxx.xx
             SU6TV    xxxx.xx     xxxx.xx     xxxx.xx       xxxx.xx
          P2016-13    xxxx.xx     xxxx.xx     xxxx.xx       xxxx.xx

    * Indicates the maximum Foundation Pressure for each limit state.
```

7.6.19 FOUNDATION PRESSURE SUMMARY Report Format

```
                           Maximum Foundation Pressure

                       Wall 1      Wall 2      Wall 3
   Lim St   Load        Press       Press       Press
                        (ksf)       (ksf)       (ksf)
   STR-I   PHL-93     xxxx.xx *   xxxx.xx     xxxx.xx
             P-82     xxxx.xx     xxxx.xx     xxxx.xx
            HL-93     xxxx.xx     xxxx.xx     xxxx.xx
            ML-80     xxxx.xx     xxxx.xx     xxxx.xx
            TK527     xxxx.xx     xxxx.xx     xxxx.xx
              EV2     xxxx.xx     xxxx.xx     xxxx.xx
              EV3     xxxx.xx     xxxx.xx     xxxx.xx
            SU6TV     xxxx.xx     xxxx.xx     xxxx.xx
          P2016-13    xxxx.xx     xxxx.xx     xxxx.xx
           aaaaaa     xxxx.xx     xxxx.xx     xxxx.xx

   * Indicates the maximum Foundation Pressure for each limit state.
```

7.6.20 STRIP FOOTING BEARING PRESSURE Report Format

```
                                   Wall No. 1

                  STR-I    STR-I        STR-II   STR-II        SER-I    SER-I
     Live          e/B    Bearing        e/B    Bearing         e/B    Bearing
     Load   Locn  Ratio  Pressure       Ratio  Pressure        Ratio  Pressure
                            (ksf)                 (ksf)                  (ksf)
   PHL-93    L    xx.xx    xxx.xx       xx.xx *  xxx.xx        xx.xx    xxx.xx
             R             xxx.xx                xxx.xx                 xxx.xx
     P-82    L    xx.xx    xxx.xx       xx.xx    xxx.xx        xx.xx    xxx.xx
             R             xxx.xx                xxx.xx                 xxx.xx
    HL-93    L    xx.xx *  xxx.xx       xx.xx    xxx.xx        xx.xx    xxx.xx
             R             xxx.xx                xxx.xx                 xxx.xx
      SLL    L    xx.xx    xxx.xx       xx.xx    xxx.xx        xx.xx    xxx.xx
             R             xxx.xx                xxx.xx                 xxx.xx
    ML-80    L    xx.xx    xxx.xx       xx.xx    xxx.xx        xx.xx    xxx.xx
             R             xxx.xx *              xxx.xx                 xxx.xx *
    HS-20    L    xx.xx    xxx.xx       xx.xx    xxx.xx        xx.xx    xxx.xx
             R             xxx.xx                xxx.xx                 xxx.xx
     H-20    L    xx.xx    xxx.xx       xx.xx    xxx.xx        xx.xx    xxx.xx
             R             xxx.xx                xxx.xx                 xxx.xx
    TK527    L    xx.xx    xxx.xx       xx.xx    xxx.xx        xx.xx    xxx.xx
             R             xxx.xx                xxx.xx                 xxx.xx
      EV2    L    xx.xx    xxx.xx       xx.xx    xxx.xx        xx.xx    xxx.xx
             R             xxx.xx                xxx.xx                 xxx.xx
      EV3    L    xx.xx    xxx.xx       xx.xx    xxx.xx        xx.xx    xxx.xx
             R             xxx.xx                xxx.xx                 xxx.xx
    SU6TV    L    xx.xx    xxx.xx       xx.xx    xxx.xx        xx.xx    xxx.xx
             R             xxx.xx                xxx.xx                 xxx.xx
    P2016-13 L    xx.xx    xxx.xx       xx.xx    xxx.xx        xx.xx    xxx.xx
             R             xxx.xx                xxx.xx                 xxx.xx

   * Indicates the maximum e/B Ratio and Footing Pressure, among all
     maximum effect cases, for each limit state.

    L  Left  edge of the footing
    R  Right edge of the footing
```

```
A maximum value for qb of  xxx.xx (ksf)   (qb = N/Be) occurs for the
STR-II limit state,  PHL-93 live load, maximum effect case 3.
For this reported condition, Be is  xxx.xx (ft).  This average
pressure is used in the calculation of settlement for soils.
```

7.6.21 QUANTITIES Report Format

```
                           Volume of Concrete

                Based on a segment length of: xxx.xx ft.

                      Top Slab:  xxx.xx  (yd^3)
                   Bottom Slab:  xxx.xx  (yd^3)
                     Left Wall:  xxx.xx  (yd^3)
                    Right Wall:  xxx.xx  (yd^3)
                      Haunches:  xxx.xx* (yd^3)

                         TOTAL:  xxx.xx  (yd^3)

                            Weight of Segment

                Segment Weight:  xxx.xx  Kips


* All haunches are included only in this total
```

7.7 SPECIFICATION CHECK FAILURES

BXLRFD does not have an output table that gives a summary of output tables containing specification check failures. Codes are printed next to data items in individual report tables, and footnotes are printed after tables, to indicate specification check failures.

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8 EXAMPLE PROBLEMS

8.1 EXAMPLE PROBLEMS

This chapter contains the example problems used to test and verify this program. Table 1 shows the example problem matrix, which lists each example problem and the key input items used to differentiate the problems. For each example problem, the following information is given: a brief narrative description of the problem; the input items from the example problem matrix; additional assumptions and input items required to create the input data file; and a sketch which shows the culvert geometry. The actual input data file for each example problem is listed in this manual, and is included electronically along with the executable program.

Table 8.1-1 Example Problem Matrix

	Example Problem				
Input Item	**1***	**2***	**3***	**4***	**5**
# cells	1	2	1	1	2
Design Type (1)	AR	DR	DR	DA	AR
PC or CIP	PC	CIP	CIP	CIP	CIP
Units	US	US	US	US	US
Fill Ht or @grade	5.0'	1.0'	5.33'	@grade	@grade
Live Loading Type(2)	A	E	E	E	B
No. of LL Lanes	1	1	2	2	2
Clear Span Length	9.0'	18.5'	10.0'	24.0'	20.5'
Clear Height	6.0'	12.83'	6.83'	12.583'	12.0'
Top Slab Thickness	9.0"	21.0"	12.0"	10.0"	25.7"
Bottom Slab Thickness	9.5"	24.0"	12.0"	None	15.0"
Exterior Wall Thickness	9.0"	20.0"	12.0"	12.0"	12.0"
Interior Wall Thickness	---	16.0"	---	---	12.0"
Steel Grade (f_y)	60 ksi	60 ksi	40 ksi	60 ksi	60 ksi
Concrete F'c	5.0 ksi	3.0 ksi	3.0 ksi	3.0 ksi	3.0 ksi
% Soil Grade	0.0	0.0	-6.98	0.0	0.0
% Deck Grade	0.0	0.0	0.0	1.0	-2.91
Live Load Surcharge	3.0'	3.0'	2.0'	3.0'	3.0'
Fish Channel (Std or Non-Std)	None	Std	Non-Std	---	None
Haunch	Yes	No	No	No	No
Simply Supported Top Slab	No	No	No	No	Yes
Shear α	90°	90°	90°	90°	90°
Max L.L Dist. Length	25'	48'	38'	76'	50'
Culvert Segment L	12'	90'	90'	20'	90'
Fill **Unit Weight**	120lb/ft^3	120lb/ft^3	120lb/ft^3	120lb/ft^3	120lb/ft^3
Overlay **Unit Weight**	N.A.	N.A.	N.A.	N.A.	150lb/ft^3

Table 8.1-1 Example Problem Matrix (cont.)

	Example Problem				
Input Item	**1***	**2***	**3***	**4***	**5***
Overlay Thickness	0.0	0.0	0.0	0.0	3.0"
Top Slab f'c	N.A.	Default	Default	4.0ksi	4.0ksi
User Specified FWS	none	none	none	none	none
MPRF	N.A.	N.A.	N.A.	N.A.	N.A.
PA Traffic Factor	N.A.	N.A.	N.A.	N.A.	N.A.
PA Fatigue Factor	N.A.	N.A.	N.A.	N.A.	N.A.
Eta - D	1.0	1.0	1.0	1.0	1.0
Eta - R	1.0	1.0	1.0	1.0	1.0
Eta - I	1.0	1.0	1.0	1.0	1.0
Haunch Size	6.0"	N.A.	N.A.	N.A.	N.A.
Strip Footing Width	N.A.	N.A.	N.A.	84.0"	N.A.
Strip Footing Depth	N.A.	N.A.	N.A.	24.0"	N.A.
Max Bar or Wire Dia.	Wire-.60"	#11	#11	#8	#9
U-channel Left Wall Height	N.A.	N.A.	N.A.	N.A.	N.A.
U-channel Right Wall Height	N.A.	N.A.	N.A.	N.A.	N.A.
Min Equivalent Fluid Pressure	45lb/ft^3	45lb/ft^3	45lb/ft^3	45lb/ft^3	45lb/ft^3
Max Equivalent Fluid Pressure	70lb/ft^3	70lb/ft^3	70lb/ft^3	70lb/ft^3	70lb/ft^3

(1) DR = Design reinforcement with known slab t; DA = Design flexure reinforcement, shear reinforcement. and slab thickness;
DC = design flexure reinforcement and slab thickness without shear reinforcement; AR = known reinforcement and slab thickness, perform rating.

(2) Design Options Are: A = PHL93, P82 and ML80; B = HL93 and P82; C = HL93; D = PHL-93, ML-80 and P-82; E = PHL93, ML80, TK527, and P82; F = PHL93, ML80, TK527, P2016-13, and P82
Rating Options Are: A = PHL93, P82 and ML80; B = HL93; C = ML80; D = P82; E = Special (user defined); F = TK527; G = EV2, EV3, SU6TV; H = P2016-13; I = PHL93, P82, ML80, TK527, P2016-13, HS20, H20

* Example problem taken from existing culvert program manual (BOX5).

Table 8.1-1 Example Problem Matrix (cont.)

	Example Problem			
Input Item	**7**	**8**	**9**	**10**
# cells	1	1	2	2
Design Type (1)	DC	AR	AR	AR
PC or CIP	CIP	CIP	CIP	CIP
Units	US	US	US	US
Fill Ht or @grade	4.25 ft	7.25 ft	@grade	2.0 ft
Live Loading Type(2)	E	C	C	E
No. of LL Lanes	3	2	2	1
Clear Span Length	13.0 ft	29.5 ft	15.0 ft	12.0 ft
Clear Height	6.5 ft	13 ft	10.0 ft	7.0 ft
Top Slab Thickness	10 in	22.5 in	22 in	10 in
Bottom Slab Thickness	10 in	None	12 in	12 in
Exterior Wall Thickness	12 in	22 in	12 in	12 in
Interior Wall Thickness	N.A.	N.A.	12 in	10 in
Steel Grade (f_y)	60 ksi	60 ksi	40 ksi	60 ksi
Concrete f'_c	3.0 ksi	3.0 ksi	3.0 ksi	3.0 ksi
% Soil Grade	0.0	2.2	0.0	0.0
% Deck Grade	0.0	1.0	-2.0	0.0
Live Load Surcharge	2.0 ft	1.33 ft	2.0 ft	3.0 ft
Fish Channel (Std or Non-Std)	Non-Std	N.A.	Non-Std	None
Haunch	No	No	Yes	No
Simply Supported Top Slab	Yes	No	No	No
Shear α	90^o	90^o	90^o	90^o
Max L.L. Dist. Length	54 ft	66 ft	56 ft	59 ft
Culvert Segment L	90 ft	90 ft	90 ft	90 ft
Fill **Unit Weight**	140 lb/ft^3	140 lb/ft^3	140 lb/ft^3	default
Overlay **Unit Weight**	N.A.	N.A.	N.A.	140 lb/ft^3

Table 8.1-1 Example Problem Matrix (cont.)

	Example Problem			
Input Item	**7**	**8**	**9**	**10**
Overlay Thickness	0.0	0.0	0.0	4 in
Top Slab f'_c	N.A.	N.A.	4.0 ksi	N.A.
User Specified FWS	none	none	30.7 lb/ft^2	none
MPRF	N.A.	N.A.	N.A.	N.A.
PA Traffic Factor	N.A.	N.A.	N.A.	N.A.
PA Fatigue Factor	N.A.	N.A.	N.A.	N.A.
Eta - D	0.95	1.0	1.0	1.0
Eta - R	1.0	0.98	1.0	1.0
Eta - I	1.0	1.05	1.0	1.0
Haunch Size	N.A.	N.A.	6 in	N.A.
Strip Footing Width	N.A.	100 in	N.A.	N.A.
Strip Footing Depth	N.A.	30 in	N.A.	N.A.
Max Bar or Wire Dia.	#9	#11	#9	#9
U-channel Left Wall Height	N.A.	N.A.	N.A.	N.A.
U-channel Right Wall Height	N.A.	N.A.	N.A.	N.A.
Min Equivalent Fluid Pressure	45 lb/ft^3	45 lb/ft^3	45 lb/ft^3	45 lb/ft^3
Max Equivalent Fluid Pressure	70 lb/ft^3	70 lb/ft^3	70 lb/ft^3	70 lb/ft^3

Table 8.1-1 Example Problem Matrix (cont.)

	Example Problem		
Input Item	**11**	**12**	**13**
# cells	1	2	U
Design Type (1)	DA	DA	DC
PC or CIP	PC	CIP	CIP
Units	US	US	US
Fill Ht or @grade	10.0'	4.5'	N.A.
Live Loading Type(2)	N.A.	E	N.A.
No. of LL Lanes	N.A.	2	N.A
Clear Span Length	8.0'	12.0'	8.0’
Clear Height	6.0'	8.0'	N.A.
Top Slab Thickness	default	10.5'	N.A.
Bottom Slab Thickness	default	11.5'	11.5 in
Exterior Wall Thickness	default	12.0"	12.0”
Interior Wall Thickness	N.A.	12.0"	12.0”
Steel Grade (f_y)	60 ksi	60 ksi	60 ksi
Concrete f'_c	5.0 ksi	3.0 ksi	3.0 ksi
% Soil Grade	0.0	0.0	N.A.
% Deck Grade	0.0	0.0	N.A.
Live Load Surcharge	N.A.	3.0	3.0’
Fish Channel (Std or Non-Std)	None	Std	None
Haunch	No	Yes	No
Simply Supported Top Slab	No	No	N.A.
Shear α	90^o	90^o	90^o
Max L.L. Dist. Length	80'	60'	N.A
Culvert Segment L	12'	90'	90‘
Fill **Unit Weight**	145lb/ft^3	140lb/ft^3	120lb/ft^3
Overlay Unit Weight	**N.A.**	**N.A.**	**N.A.**

Table 8.1-1 Example Problem Matrix (cont.)

	Example Problem		
Input Item	**11**	**12**	**13**
Overlay Thickness	0.0	0.0	N.A.
Top Slab f'_c	N.A.	N.A.	N.A.
User Specified FWS	none	none	N.A.
MPRF	N.A.	N.A.	N.A.
PA Traffic Factor	N.A.	N.A.	N.A.
PA Fatigue Factor	N.A.	N.A.	N.A.
Eta - D	1.0	1.05	1.0
Eta - R	1.03	1.0	1.0
Eta - I	1.0	1.0	1.0
Haunch Size	N.A.	9.0"	N.A.
Strip Footing Width	N.A.	N.A.	N.A.
Strip Footing Depth	N.A.	N.A.	N.A.
Max Bar or Wire Dia.	Wire - 0.5"	#8	#8
U-channel Left Wall Height	N.A.	N.A.	10’
U-channel Right Wall Height	N.A.	N.A.	15’
Min Equivalent Fluid Pressure	45lb/ft^3	45lb/ft^3	45lb/ft^3
Max Equivalent Fluid Pressure	70lb/ft^3	70lb/ft^3	70lb/ft^3

8.2 EXAMPLE 1

Example 1 is a precast single cell culvert under 5.0 feet of fill. The structure geometry is shown in Figure 8.2-1. The culvert is to be rated. Haunches are present. The culvert reinforcement is wire.

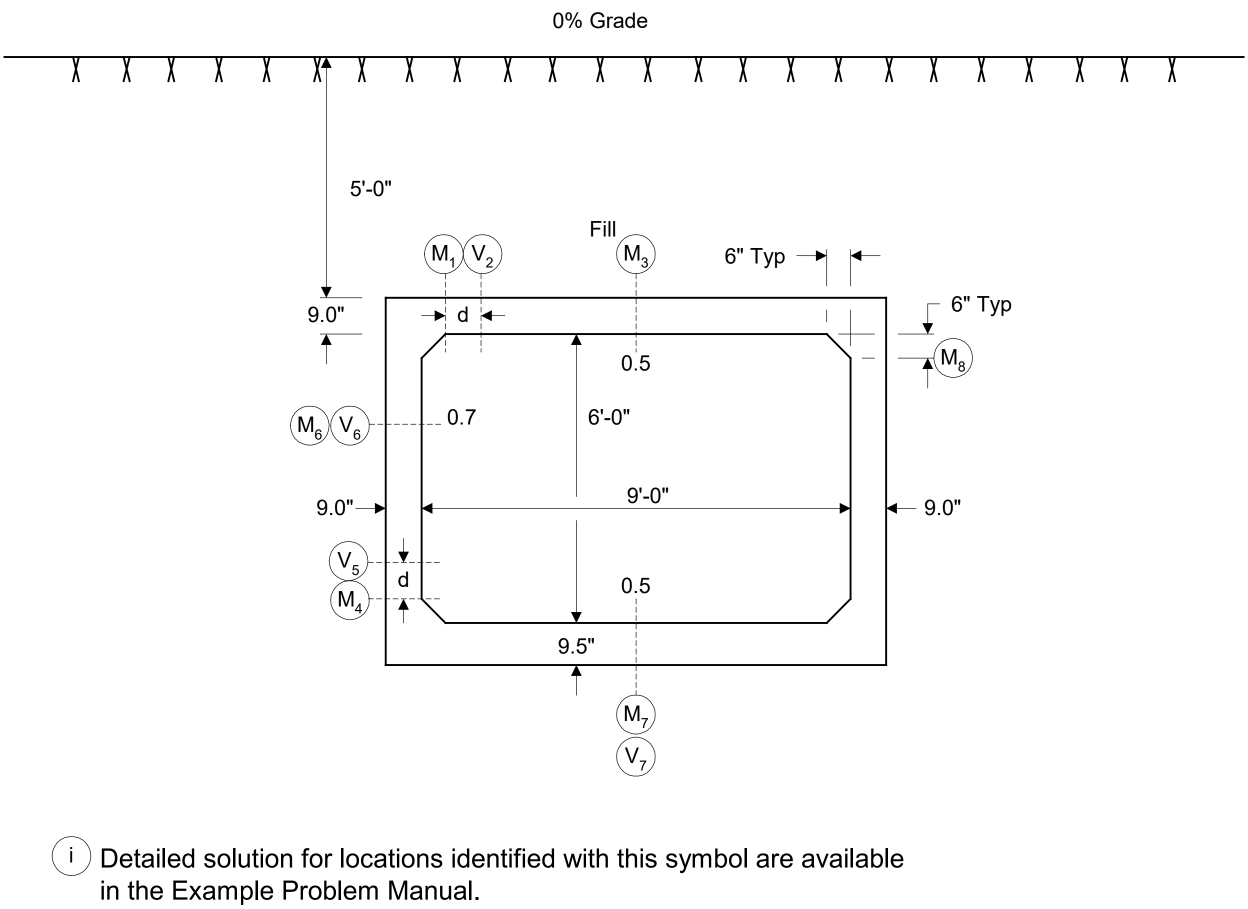


Figure 8.2-1 Example 1 Culvert Geometry

CONTROL

Sys of Units	Structure Type	Type of Run	**Culvert P or C**	Bottom Slab	Top Slab Support	Frame Support	**Footing P or C**
US	1-CELL BOX	AR	P	Y	M	N/A	**N/A**

STRUCTURE IDENTIFICATION

Program ID	County	State Route	Segment	Offset	Span ID
=BXLRFD	50	666	555	9996	654

MATERIAL

f'c All Members (ksi)	f'c Top Slab (ksi)	Reinf Grade (ksi)	Reinf Type	Alpha (deg)	Wire Diam (in)	Epoxy Coated
5.00	5.00	60.0	W	90.0	0.60	N/A

Concrete Density For DL (lb/ft^3)	Concrete Density For Ec (lb/ft^3)	fu (ksi)
150.0	145.0	90.00

DIMENSIONS

Clear Span (ft)	Clear Height (ft)	Slab Thickness Top (in)	Slab Thickness Bottom (in)	Wall Thickness Left (in)	Wall Thickness Right (in)	Wall Thickness Int (in)	Fill Grade (%)	Top Slab Grade (%)
9.00	6.00	9.0	9.5	9.0	9.0	0.0	0.00	0.00

Left U-channel Wall Height (ft)	Right U-channel Wall Height (ft)
0.00	0.00

LOAD CONTROL

Fill Unit Weight (pcf)	Height of Fill (ft)	No of Lanes	Live Load Surcharge (ft)	Live Load	**Overlay Unit Weight** (pcf)	Overlay Thick (in)	Future Wearing Surface (psf)
120.0	5.00	1	3.00	A	0.0	0.0	0.0

Live Load Distrib Length (ft)	Segment Length (ft)	Multiple Presence Reduction	PA Traffic Factor	Fatigue Dynamic Load Allowance	Duct Factor	Redund Factor
25.00	12.00	N/A	N/A	N/A	1.00	1.00

Import Factor	Permit Max Dynamic Load Allowance	Live Load Override	Min Equiv Fluid Pressure (pcf)	Max Equiv Fluid Pressure (pcf)	Barrier Dead Load (kips/ft)
1.00	1.20	0	45.00	70.00	0.00

Left Approach Slab Dead Load (kips)	Left Approach Slab Live Load (kips)	Right Approach Slab Dead Load (kips)	Right Approach Slab Live Load (kips)	Ratings w/o Future Wearing Surface	Backfill Type	No. of Precast Shr Trns Segments	**Backfill Unit Weight (pcf)**
0.00	0.00	0.00	0.00	N	N/A	2	**120.0**

HAUNCH

Top Left X (in)	Top Left Y (in)	Top Right X (in)	Top Right Y (in)	Bot Left X (in)	Bot Left Y (in)	Bot Right X (in)	Bot Right Y (in)	Top Int X (in)	Top Int Y (in)	Bot Int X (in)	Bot Int Y (in)
6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	0.0	0.0	0.0	0.0

COVERS

Top Slab Top (in)	Top Slab Bot (in)	Bottom Slab Top (in)	Bottom Slab Bot (in)	Walls (in)	Footing Top (in)	Footing Bot (in)
2.0	1.5	2.0	1.5	1.5	**N/A**	**N/A**

TOP SLAB REINFORCEMENT

Slab No	Face	Range 1 (ft)	Wire Diam (in)	Reinf Spac (in)	Range 2 (ft)	Wire Diam (in)	Reinf Spac (in)	Range 3 (ft)	Wire Diam (in)	Reinf Spac (in)
1	T	9.00	0.75	20.5						
1	B	9.00	0.75	9.5						

BOTTOM SLAB REINFORCEMENT

Slab No	Face	Range 1 (ft)	Wire Diam (in)	Reinf Spac (in)	Range 2 (ft)	Wire Diam (in)	Reinf Spac (in)	Range 3 (ft)	Wire Diam (in)	Reinf Spac (in)
1	T	9.00	0.75	8.5						
1	B	9.00	0.75	44.0						

WALL REINFORCEMENT

Wall No	Face	Range 1 (ft)	Wire Diam (in)	Reinf Spac (in)	Range 2 (ft)	Wire Diam (in)	Reinf Spac (in)	Range 3 (ft)	Wire Diam (in)	Reinf Spac (in)
1	L	3.00	0.75	18.0	6.00	0.75	14.0			
1	R	6.00	0.75	14.0						
2	L	6.00	0.75	14.0						
2	R	3.00	0.75	18.0	6.00	0.75	14.0			

OUTPUT OF INPUT

Input Echo	Input Commands	Input Summary
1	0	1

OUTPUT OF RESULTS

Section Props	LL Rating	Rating Sum	DL Eff & Capac	Design Reinf	Shear Design	Found Press	Quant	Serv Table	Serv Sum
1	1	1	1	0	0	0	1	0	0

Found Press Summary	**Min Rein**
1	**1**

8.3 EXAMPLE 2

Example 2 is a cast-in-place two cell culvert under a 1.0 foot fill height. The structure geometry is shown in Figure 8.3-1. The culvert bar reinforcement is to be designed with known member thickness. The culvert has a standard fish channel.

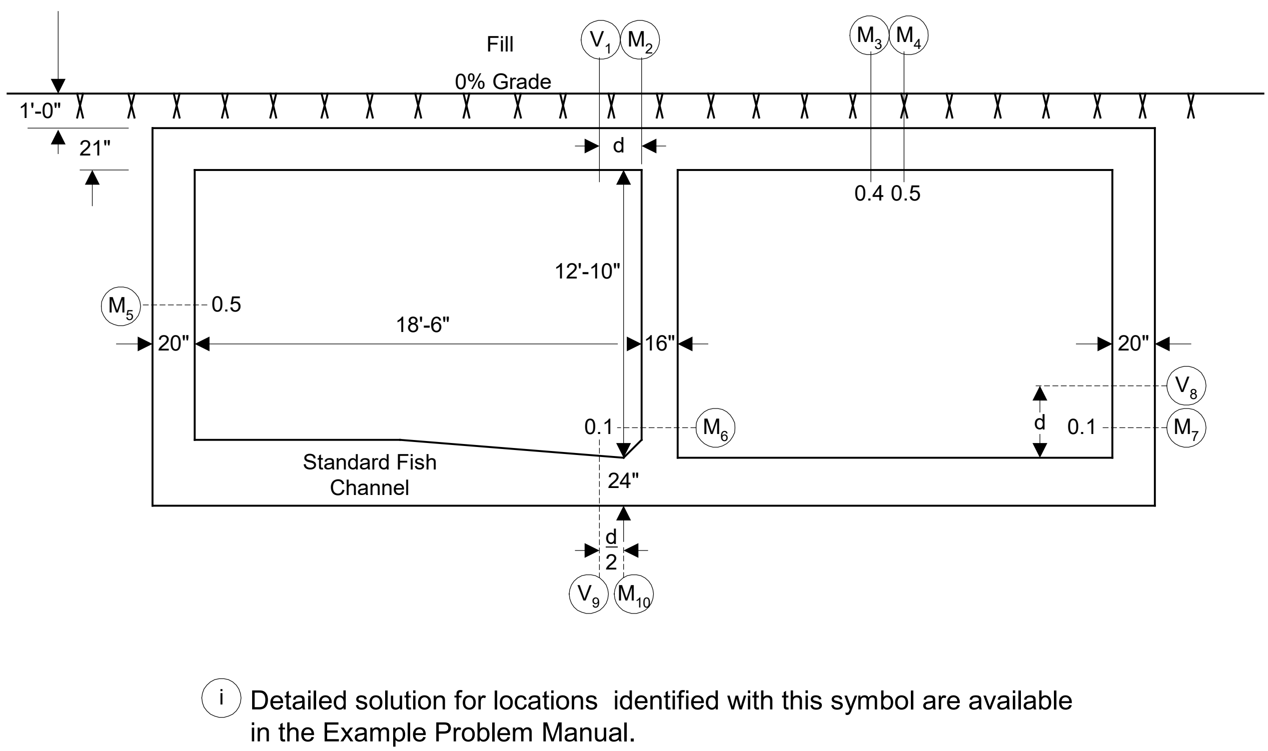


Figure 8.3-1 Example 2 Culvert Geometry

CONTROL

Sys of Units	Structure Type	Type of Run	**Culvert P or C**	Bottom Slab	Top Slab Support	Frame Support	**Footing P or C**
US	2-CELL BOX	DR	C	Y	M	N/A	**N/A**

STRUCTURE IDENTIFICATION

Program ID	County	State Route	Segment	Offset	Span ID
=BXLRFD	50	666	555	9996	654

MATERIAL

f'c All Members (ksi)	f'c Top Slab (ksi)	Reinf Grade (ksi)	Reinf Type	Alpha (deg)	Rebar Size	Epoxy Coated
3.00	3.00	60.0	B	90.0	11	Y

Concrete Density For DL (lb/ft^3)	Concrete Density For Ec (lb/ft^3)	fu (ksi)
150.0	145.0	90.00

DIMENSIONS

Clear Span (ft)	Clear Height (ft)	Slab Thickness Top (in)	Slab Thickness Bottom (in)	Wall Thickness Left (in)	Wall Thickness Right (in)	Wall Thickness Int (in)	Fill Grade (%)	Top Slab Grade (%)
18.50	12.83	21.0	24.0	20.0	20.0	16.0	0.00	0.00

Left U-channel Wall Height (ft)	Right U-channel Wall Height (ft)
0.00	0.00

LOAD CONTROL

Fill Unit Weight (pcf)	Height of Fill (ft)	No of Lanes	Live Load Surcharge (ft)	Live Load	**Overlay Unit Weight** (pcf)	Overlay Thick (in)	Future Wearing Surface (psf)
120.0	1.00	1	3.00	E	0.0	0.0	0.0

Live Load Distrib Length (ft)	Segment Length (ft)	Multiple Presence Reduction	PA Traffic Factor	Fatigue Dynamic Load Allowance	Duct Factor	Redund Factor
48.00	90.00	N/A	N/A	N/A	1.00	1.00

Import Factor	Permit Max Dynamic Load Allowance	Live Load Override	Min Equiv Fluid Pressure (pcf)	Max Equiv Fluid Pressure (pcf)	Barrier Dead Load (kips/ft)
1.00	1.20	0	45.00	70.00	0.00

Left Approach Slab Dead Load (kips)	Left Approach Slab Live Load (kips)	Right Approach Slab Dead Load (kips)	Right Approach Slab Live Load (kips)	Ratings w/o Future Wearing Surface	Backfill Type	No. of Precast Shr Trns Segments	**Backfill Unit Weight (pcf)**
0.00	0.00	0.00	0.00	N/A	N/A	N/A	**120.0**

FISH CHANNEL

Type	Segment Length (in)	Thick Change (in)	Segment Length (in)	Thick Change (in)	Segment Length (in)	Thick Change (in)
S	102.00	0.00	110.00	-10.00	10.00	10.00

COVERS

Top Slab		Bottom Slab		Walls	Footing	
Top (in)	Bot (in)	Top (in)	Bot (in)	(in)	Top (in)	Bot (in)
2.0	2.0	2.5	3.0	2.0	**N/A**	**N/A**

OUTPUT OF INPUT

Input Echo	Input Commands	Input Summary
1	0	1

OUTPUT OF RESULTS

Section Props	LL Rating	Rating Sum	DL Eff & Capac	Design Reinf	Shear Design	Found Press	Quant	Serv Table	Serv Sum
1	0	0	0	1	1	0	1	0	1

Found Press Summary	**Min Rein**
1	**1**

8.4 EXAMPLE 3

Example 3 is a cast-in-place single cell culvert under 5.33 feet of fill. The structure geometry is shown in Figure 8.4-1. The culvert bar reinforcement is to be designed with known member thickness. The culvert has a non-standard fish channel.

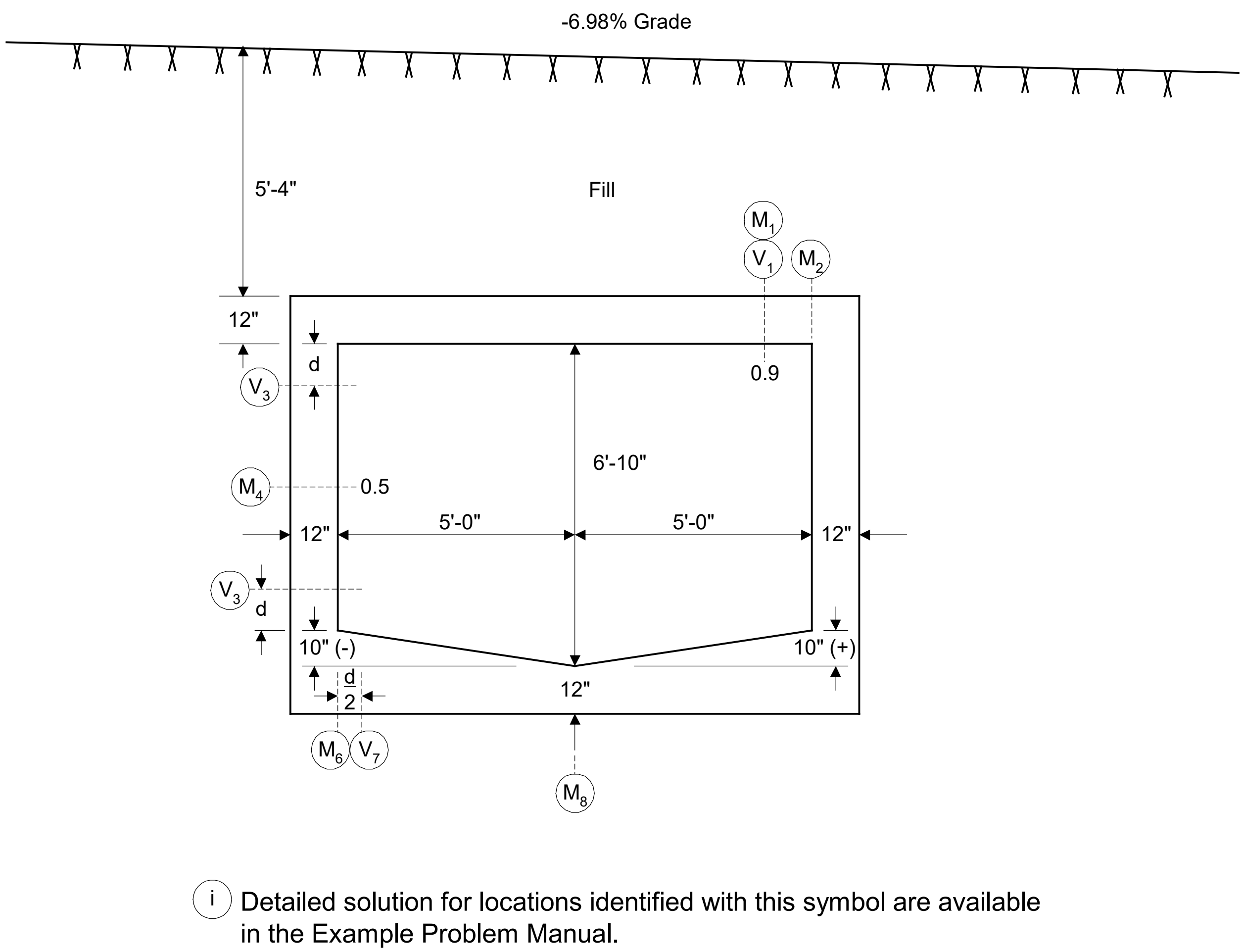


Figure 8.4-1 Example 3 Culvert Geometry

CONTROL

Sys of Units	Structure Type	Type of Run	**Culvert P or C**	Bottom Slab	Top Slab Support	Frame Support	**Footing P or C**
US	1-CELL BOX	DR	C	Y	M	N/A	**N/A**

STRUCTURE IDENTIFICATION

Program ID	County	State Route	Segment	Offset	Span ID
=BXLRFD	50	666	555	9996	654

MATERIAL

f'c All Members (ksi)	f'c Top Slab (ksi)	Reinf Grade (ksi)	Reinf Type	Alpha (deg)	Rebar Size	Epoxy Coated
3.00	3.00	40.0	B	90.0	11	Y

Concrete Density For DL (lb/ft^3)	Concrete Density For Ec (lb/ft^3)	fu (ksi)
150.0	145.0	55.00

DIMENSIONS

Clear Span (ft)	Clear Height (ft)	Slab Thickness Top (in)	Slab Thickness Bottom (in)	Wall Thickness Left (in)	Wall Thickness Right (in)	Wall Thickness Int (in)	Fill Grade (%)	Top Slab Grade (%)
10.00	6.83	12.0	12.0	12.0	12.0	0.0	-6.98	0.00

Left U-channel Wall Height (ft)	Right U-channel Wall Height (ft)
0.00	0.00

LOAD CONTROL

Fill Unit Weight (pcf)	Height of Fill (ft)	No of Lanes	Live Load Surcharge (ft)	Live Load	**Overlay Unit Weight** (pcf)	Overlay Thick (in)	Future Wearing Surface (psf)
120.0	5.33	2	2.00	E	150.0	0.0	0.0

Live Load Distrib Length (ft)	Segment Length (ft)	Multiple Presence Reduction	PA Traffic Factor	Fatigue Dynamic Load Allowance	Duct Factor	Redund Factor
38.00	90.00	N/A	N/A	N/A	1.00	1.00

Import Factor	Permit Max Dynamic Load Allowance	Live Load Override	Min Equiv Fluid Pressure (pcf)	Max Equiv Fluid Pressure (pcf)	Barrier Dead Load (kips/ft)
1.00	1.20	0	45.00	70.00	0.00

Left Approach Slab Dead Load (kips)	Left Approach Slab Live Load (kips)	Right Approach Slab Dead Load (kips)	Right Approach Slab Live Load (kips)	Ratings w/o Future Wearing Surface	Backfill Type	No. of Precast Shr Trns Segments	**Backfill Unit Weight (pcf)**
0.00	0.00	0.00	0.00	N/A	N/A	N/A	**120.0**

FISH CHANNEL

Type	Segment Length (in)	Thick Change (in)	Segment Length (in)	Thick Change (in)	Segment Length (in)	Thick Change (in)
N	60.00	-10.00	60.00	10.00		

COVERS

Top Slab Top (in)	Top Slab Bot (in)	Bottom Slab Top (in)	Bottom Slab Bot (in)	Walls (in)	Footing Top (in)	Footing Bot (in)
2.2	2.2	2.5	3.2	2.2	**N/A**	**N/A**

OUTPUT OF INPUT

Input Echo	Input Commands	Input Summary
1	0	1

OUTPUT OF RESULTS

Section Props	LL Rating	Rating Sum	DL Eff & Capac	Design Reinf	Shear Design	Found Press	Quant	Serv Table	Serv Sum
1	0	0	0	1	1	0	1	0	1

Found Press Summary	**Min Rein**
1	**1**

8.5 EXAMPLE 4

Example 4 is a cast-in-place single cell rigid frame culvert located at grade. The structure geometry is shown in Figure 8.5-1. The culvert bar reinforcement and member thicknesses, with shear reinforcement, are to be designed. The culvert does not have a bottom slab.

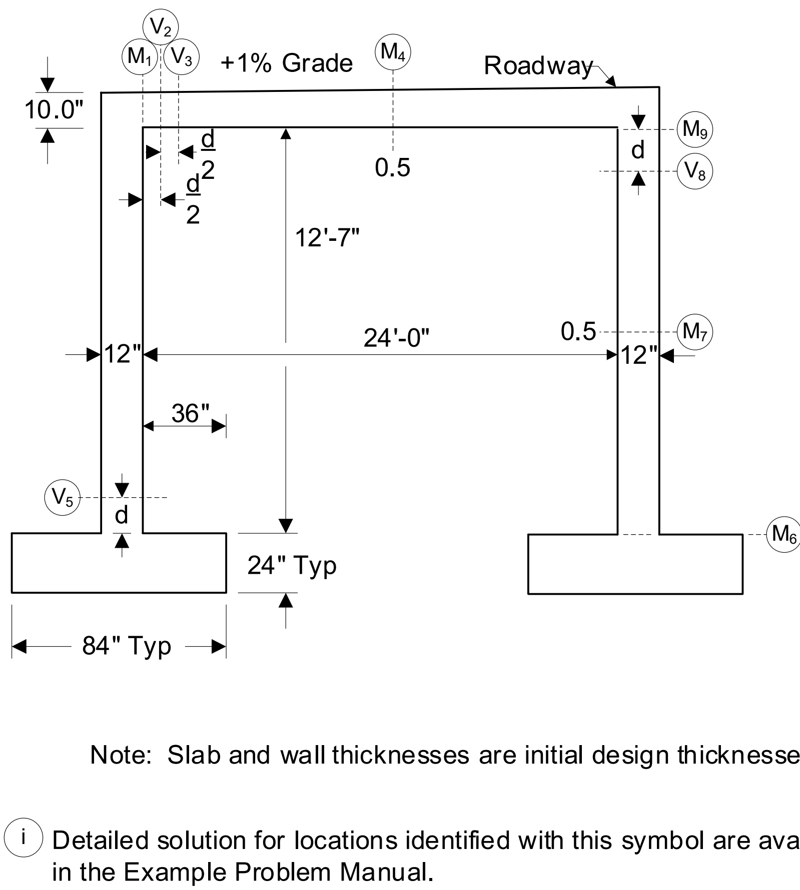


Figure 8.5-1 Example 4 Culvert Geometry

CONTROL

Sys of Units	Structure Type	Type of Run	Culvert P or C	Bottom Slab	Top Slab Support	Frame Support	Footing P or C
US	1-CELL BOX	DA	C	N	M	F	C

STRUCTURE IDENTIFICATION

Program ID	County	State Route	Segment	Offset	Span ID
=BXLRFD	50	6666	5555	9996	65F

MATERIAL

f'c All Members (ksi)	f'c Top Slab (ksi)	Reinf Grade (ksi)	Reinf Type	Alpha (deg)	Rebar Size	Epoxy Coated
3.00	4.00	60.0	B	90.0	8	Y

Concrete Density For DL (lb/ft^3)	Concrete Density For Ec (lb/ft^3)	fu (ksi)
150.0	145.0	90.00

DIMENSIONS

Clear Span (ft)	Clear Height (ft)	Slab Thickness Top (in)	Slab Thickness Bottom (in)	Wall Thickness Left (in)	Wall Thickness Right (in)	Wall Thickness Int (in)	Fill Grade (%)	Top Slab Grade (%)
24.00	12.58	10.0	0.0	12.0	12.0	0.0	0.00	1.00

Left U-channel Wall Height (ft)	Right U-channel Wall Height (ft)
0.00	0.00

FOOTING

Left Footing Width (in)	Left Footing Thick (in)	Left Footing Proj (in)	Right Footing Width (in)	Right Footing Thick (in)	Right Footing Proj (in)	Inter Footing Width (in)	Inter Footing Thick (in)
84.0	24.0	36.0	84.0	24.0	36.0	0.0	0.0

LOAD CONTROL

Fill Unit Weight (pcf)	Height of Fill (ft)	No of Lanes	Live Load Surcharge (ft)	Live Load	**Overlay Unit Weight** (pcf)	Overlay Thick (in)	Future Wearing Surface (psf)
120.0	0.00	2	3.00	E	150.0	0.0	30.0

Live Load Distrib Length (ft)	Segment Length (ft)	Multiple Presence Reduction	PA Traffic Factor	Fatigue Dynamic Load Allowance	Duct Factor	Redund Factor
76.00	20.00	N/A	N/A	N/A	1.00	1.00

Import Factor	Permit Max Dynamic Load Allowance	Live Load Override	Min Equiv Fluid Pressure (pcf)	Max Equiv Fluid Pressure (pcf)	Barrier Dead Load (kips/ft)
1.00	1.20	0	45.00	70.00	0.00

Left Approach Slab Dead Load (kips)	Left Approach Slab Live Load (kips)	Right Approach Slab Dead Load (kips)	Right Approach Slab Live Load (kips)	Ratings w/o Future Wearing Surface	Backfill Type	No. of Precast Shr Trns Segments	**Backfill Unit Weight (pcf)**
0.00	0.00	0.00	0.00	N/A	N/A	N/A	**120.0**

COVERS						
Top Slab		Bottom Slab			Footing	
Top (in)	Bot (in)	Top (in)	Bot (in)	Walls (in)	Top (in)	Bot (in)
2.5	2.0	N/A	N/A	2.0	2.5	3.0

OUTPUT OF INPUT

Input Echo	Input Commands	Input Summary
1	0	1

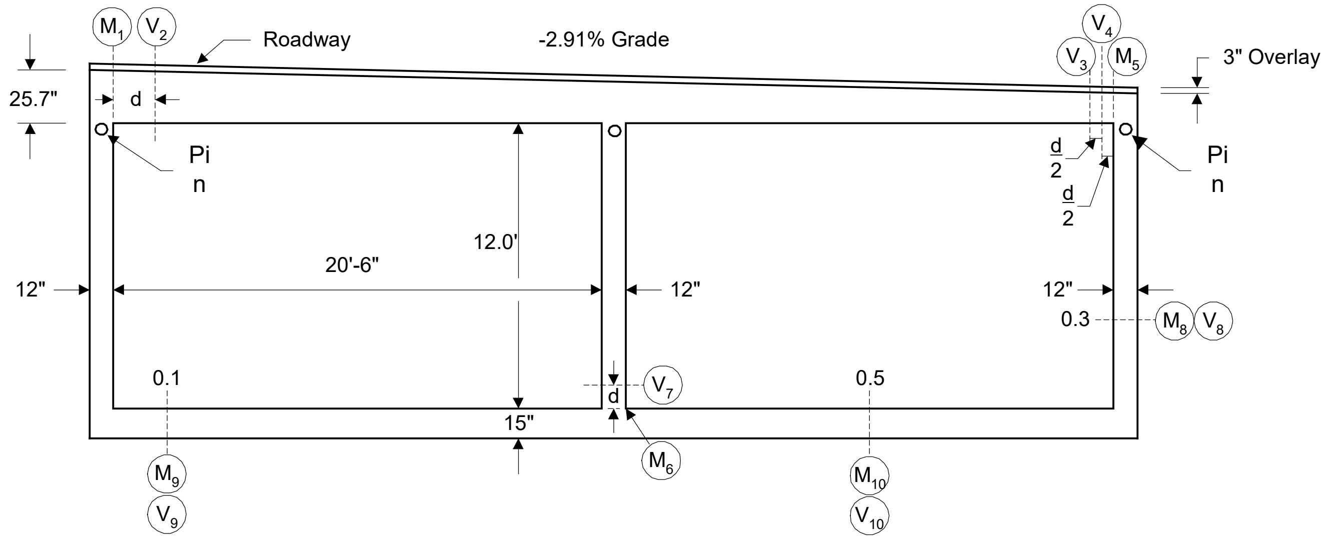
OUTPUT OF RESULTS

Section Props	LL Rating	Rating Sum	DL Eff & Capac	Design Reinf	Shear Design	Found Press	Quant	Serv Table	Serv Sum
1	0	0	0	1	1	1	1	1	1

Found Press Summary	Min Rein
1	1

8.6 EXAMPLE 5

Example 5 is a cast-in-place two cell culvert located at grade. The structure geometry is shown in Figure 8.6-1. The culvert is to be rated. Haunches are not present, and the top slab thickness varies and is pinned to the top of the walls.



i Detailed solution for locations identified with this symbol are available in the Example Problem Manual.

Figure 8.6-1 Example 5 Culvert Geometry

CONTROL

Sys of Units	Structure Type	Type of Run	Culvert P or C	Bottom Slab	Top Slab Support	Frame Support	Footing P or C
US	2-CELL BOX	AR	C	Y	S	N/A	N/A

STRUCTURE IDENTIFICATION

Program ID	County	State Route	Segment	Offset	Span ID
=BXLRFD	50	6666	5555	9996	65F

MATERIAL

f'c All Members (ksi)	f'c Top Slab (ksi)	Reinf Grade (ksi)	Reinf Type	Alpha (deg)	Rebar Size	Epoxy Coated
3.00	4.00	60.0	B	90.0	9	Y

Concrete Density For DL (lb/ft^3)	Concrete Density For Ec (lb/ft^3)	fu (ksi)
150.0	145.0	90.00

DIMENSIONS

Clear Span (ft)	Clear Height (ft)	Slab Thickness Top (in)	Slab Thickness Bottom (in)	Wall Thickness Left (in)	Wall Thickness Right (in)	Wall Thickness Int (in)	Fill Grade (%)	Top Slab Grade (%)
20.50	12.00	25.7	15.0	12.0	12.0	12.0	0.00	-2.91

Left U-channel Wall Height (ft)	Right U-channel Wall Height (ft)
0.00	0.00

LOAD CONTROL

Fill Unit Weight (pcf)	Height of Fill (ft)	No of Lanes	Live Load Surcharge (ft)	Live Load	**Overlay Unit Weight** (pcf)	Overlay Thick (in)	Future Wearing Surface (psf)
120.0	0.00	2	3.00	B	150.0	3.0	0.0

Live Load Distrib Length (ft)	Segment Length (ft)	Multiple Presence Reduction	PA Traffic Factor	Fatigue Dynamic Load Allowance	Duct Factor	Redund Factor
50.00	90.00	N/A	N/A	N/A	1.00	1.00

Import Factor	Permit Max Dynamic Load Allowance	Live Load Override	Min Equiv Fluid Pressure (pcf)	Max Equiv Fluid Pressure (pcf)	Barrier Dead Load (kips/ft)
1.00	1.20	0	45.00	70.00	0.00

Left Approach Slab Dead Load (kips)	Left Approach Slab Live Load (kips)	Right Approach Slab Dead Load (kips)	Right Approach Slab Live Load (kips)	Ratings w/o Future Wearing Surface	Backfill Type	No. of Precast Shr Trns Segments	**Backfill Unit Weight (pcf)**
0.00	0.00	0.00	0.00	N	N/A	N/A	**120.0**

COVERS

Top Slab Top (in)	Top Slab Bot (in)	Bottom Slab Top (in)	Bottom Slab Bot (in)	Walls (in)	Footing Top (in)	Footing Bot (in)
2.5	2.0	2.5	3.0	2.0	N/A	N/A

TOP SLAB REINFORCEMENT

Slab No	Face	Range No 1 (ft)	Bar Size	Reinf Spac (in)	Range No 2 (ft)	Bar Size	Reinf Spac (in)	Range No 3 (ft)	Bar Size	Reinf Spac (in)
1	T	20.50	7	6.5						
1	B	20.50	7	7.5						
2	T	10.25	7	6.0	20.50	5	5.5			
2	B	20.50	8	7.0						

BOTTOM SLAB REINFORCEMENT

Slab No	Face	Range No 1 (ft)	Bar Size	Reinf Spac (in)	Range No 2 (ft)	Bar Size	Reinf Spac (in)	Range No 3 (ft)	Bar Size	Reinf Spac (in)
1	T	20.50	9	6.0						
1	B	10.25	5	5.5	20.50	6	6.0			
2	T	20.50	9	6.5						
2	B	10.25	6	6.5	20.50	5	7.5			

WALL REINFORCEMENT

Wall No	Face	Range No 1 (ft)	Bar Size	Reinf Spac (in)	Range No 2 (ft)	Bar Size	Reinf Spac (in)	Range No 3 (ft)	Bar Size	Reinf Spac (in)
1	L	9.00	7	7.0	12.00	5	10.5			
1	R	9.00	7	7.0	12.00	5	10.5			
2	L	6.00	5	9.5	12.00	5	11.5			
2	R	6.00	5	9.5	12.00	5	11.5			
3	L	12.00	6	7.0						
3	R	12.00	6	7.0						

TOP SLAB SHEAR REINFORCEMENT AREAS

Slab No	Region	Start (ft)	End (ft)	Av (in^2)	Spac (in)
2	1	14.50	20.00	0.110	11.0

BOTTOM SLAB SHEAR REINFORCEMENT AREAS

Slab No	Region	Start (ft)	End (ft)	Av (in^2)	Spac (in)
1	1	0.00	6.00	0.110	11.0
	2	14.50	20.00	0.110	18.0
2	1	0.00	6.00	0.110	19.5
	2	14.50	20.00	0.110	15.0

OUTPUT OF INPUT

Input Echo	Input Commands	Input Summary
1	0	1

OUTPUT OF RESULTS

Section Props	LL Rating	Rating Sum	DL Eff & Capac	Design Reinf	Shear Design	Found Press	Quant	Serv Table	Serv Sum
1	1	1	1	0	0	0	1	1	1

Found Press Summary	Min Rein
1	1

8.7 EXAMPLE 6

In previous versions of BXLRFD, Example 6 was the metric version of Example 1. Since SI units are no longer available, Example 6 was eliminated.

8.8 EXAMPLE 7

Example 7 is a cast-in-place single cell culvert under 4.25 ft of fill. The structure geometry is shown in Figure 8.8-1. The culvert bar reinforcement and member thicknesses, without shear reinforcement, are to be designed. The culvert has a non-standard fish channel and the top slab is pinned to the top of the walls.

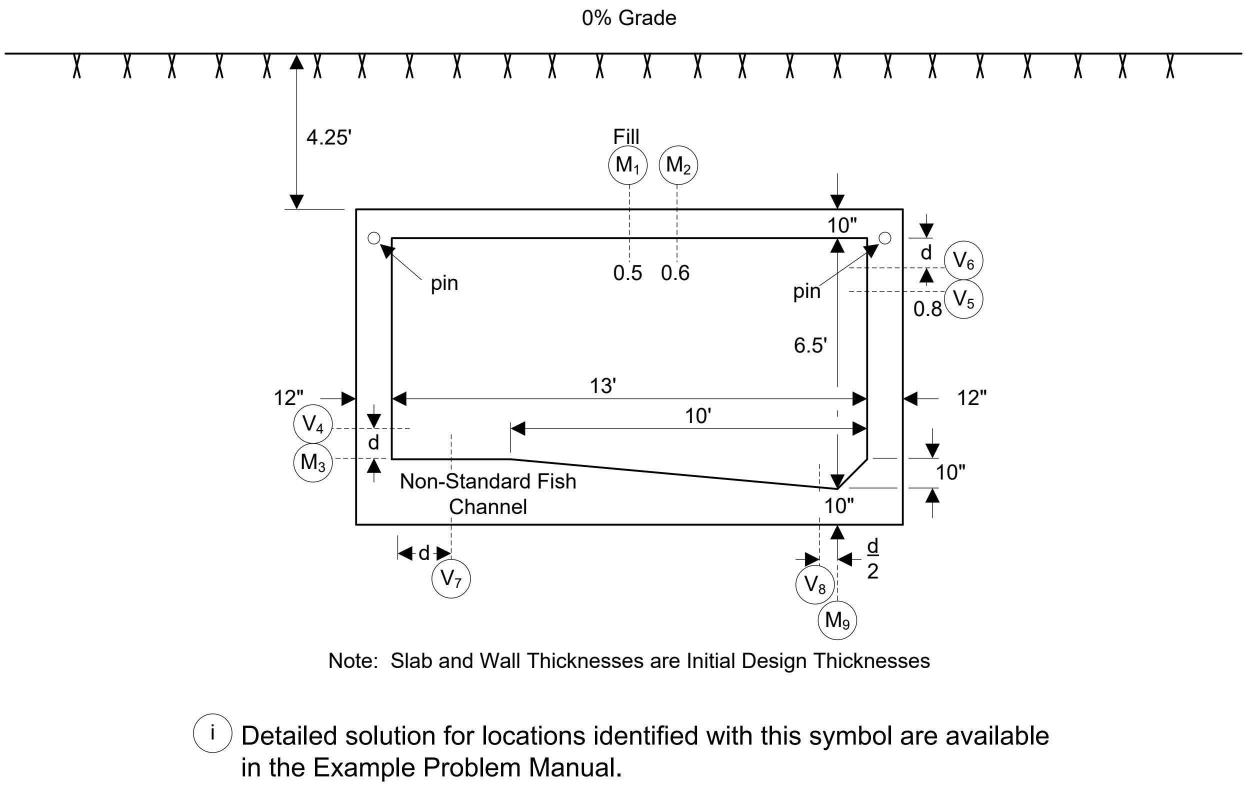


Figure 8.8-1 Example 7 Culvert Geometry

CONTROL

Sys of Units	Structure Type	Type of Run	**Culvert P or C**	Bottom Slab	Top Slab Support	Frame Support	**Footing P or C**
US	1-CELL BOX	DC	C	Y	S	N/A	**N/A**

STRUCTURE IDENTIFICATION

Program ID	County	State Route	Segment	Offset	Span ID
=BXLRFD	50	666	555	9996	654

MATERIAL

f'c All Members (ksi)	f'c Top Slab (ksi)	Reinf Grade (ksi)	Reinf Type	Alpha (deg)	Rebar Size	Epoxy Coated
3.00	3.00	60.0	B	90.0	9	Y

Concrete Density For DL (lb/ft^3)	Concrete Density For Ec (lb/ft^3)	fu (ksi)
150.0	145.0	90.00

DIMENSIONS

Clear Span (ft)	Clear Height (ft)	Slab Thickness Top (in)	Slab Thickness Bottom (in)	Wall Thickness Left (in)	Wall Thickness Right (in)	Wall Thickness Int (in)	Fill Grade (%)	Top Slab Grade (%)
13.00	6.50	10.0	10.0	12.0	12.0	0.0	0.00	0.00

Left U-channel Wall Height (ft)	Right U-channel Wall Height (ft)
0.00	0.00

LOAD CONTROL

Fill Unit Weight (pcf)	Height of Fill (ft)	No of Lanes	Live Load Surcharge (ft)	Live Load	**Overlay Unit Weight** (pcf)	Overlay Thick (in)	Future Wearing Surface (psf)
140.0	4.25	3	2.00	E	150.0	0.0	0.0

Live Load Distrib Length (ft)	Segment Length (ft)	Multiple Presence Reduction	PA Traffic Factor	Fatigue Dynamic Load Allowance	Duct Factor	Redund Factor
54.00	90.00	N/A	N/A	N/A	0.95	1.00

Import Factor	Permit Max Dynamic Load Allowance	Live Load Override	Min Equiv Fluid Pressure (pcf)	Max Equiv Fluid Pressure (pcf)	Barrier Dead Load (kips/ft)
1.00	1.20	0	45.00	70.00	0.00

Left Approach Slab Dead Load (kips)	Left Approach Slab Live Load (kips)	Right Approach Slab Dead Load (kips)	Right Approach Slab Live Load (kips)	Ratings w/o Future Wearing Surface	Backfill Type	No. of Precast Shr Trns Segments	**Backfill Unit Weight (pcf)**
0.00	0.00	0.00	0.00	N/A	N/A	N/A	**140.0**

FISH CHANNEL

Type	Segment Length (in)	Thick Change (in)	Segment Length (in)	Thick Change (in)	Segment Length (in)	Thick Change (in)
N	39.00	0.00	108.00	-10.00	9.00	10.00

COVERS							
Top Slab		Bottom Slab			Footing	
Top (in)	Bot (in)	Top (in)	Bot (in)	Walls (in)	Top (in)	Bot (in)
2.0	2.0	2.5	3.0	2.0	**N/A**	**N/A**

OUTPUT OF INPUT

Input Echo	Input Commands	Input Summary
1	0	1

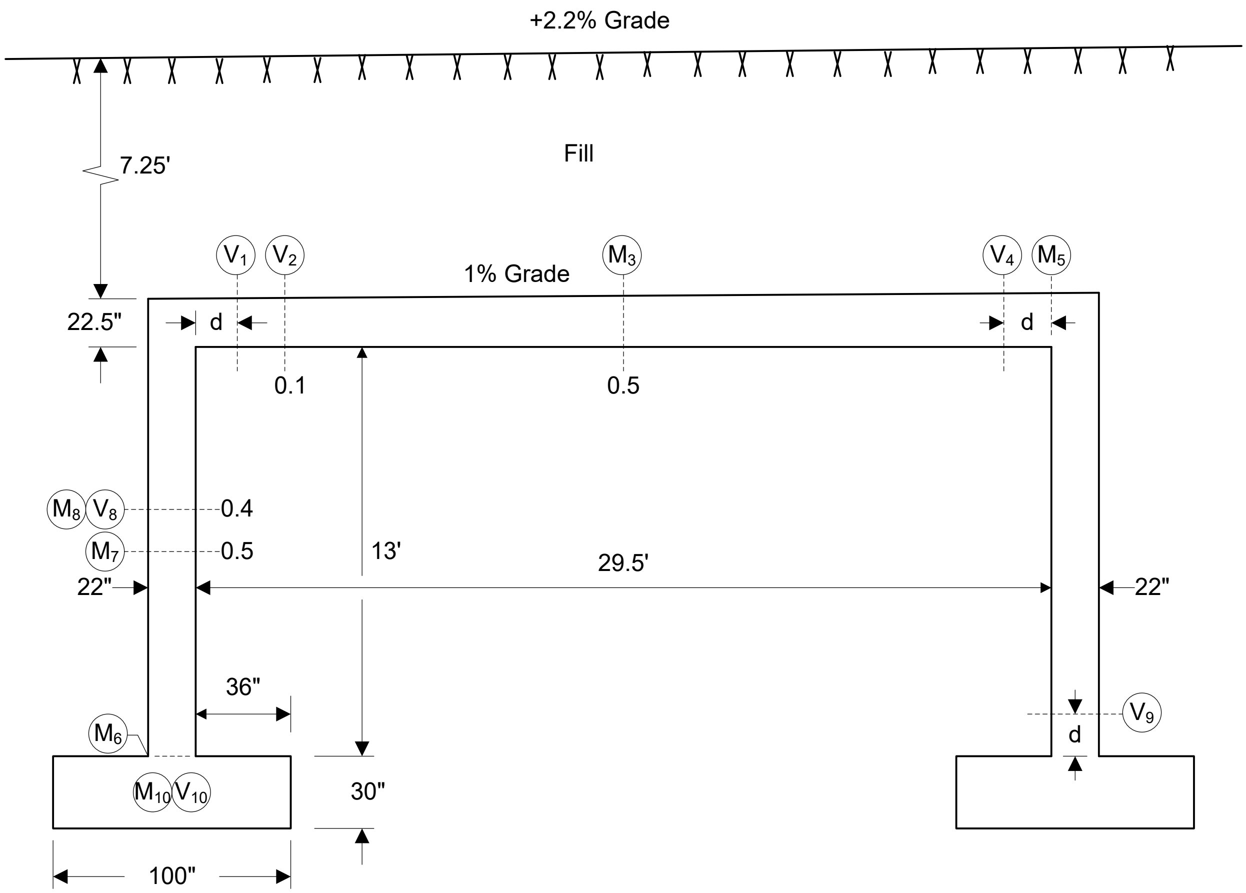
OUTPUT OF RESULTS

Section Props	LL Rating	Rating Sum	DL Eff & Capac	Design Reinf	Shear Design	Found Press	Quant	Serv Table	Serv Sum
1	0	0	0	1	1	0	1	0	1

Found Press Summary	**Min Rein**
1	**1**

8.9 EXAMPLE 8

Example 8 is a cast-in-place single cell rigid frame culvert under 7.25 ft of fill. The structure geometry is shown in Figure 8.9-1. The culvert is to be rated. The culvert does not have a bottom slab.



ⓘ Detailed solution for locations identified with this symbol are available in the Example Problem Manual.

Figure 8.9-1 Example 8 Culvert Geometry

CONTROL

Sys of Units	Structure Type	Type of Run	**Culvert P or C**	Bottom Slab	Top Slab Support	Frame Support	**Footing P or C**
US	1-CELL BOX	AR	C	N	M	F	**C**

STRUCTURE IDENTIFICATION

Program ID	County	State Route	Segment	Offset	Span ID
=BXLRFD	50	666	555	9996	654

MATERIAL

f'c All Members (ksi)	f'c Top Slab (ksi)	Reinf Grade (ksi)	Reinf Type	Alpha (deg)	Rebar Size	Epoxy Coated
3.00	3.00	60.0	B	90.0	11	Y

Concrete Density For DL (lb/ft^3)	Concrete Density For Ec (lb/ft^3)	fu (ksi)
150.0	145.0	90.00

DIMENSIONS

Clear Span (ft)	Clear Height (ft)	Slab Thickness Top (in)	Slab Thickness Bottom (in)	Wall Thickness Left (in)	Wall Thickness Right (in)	Wall Thickness Int (in)	Fill Grade (%)	Top Slab Grade (%)
29.50	13.00	22.5	0.0	22.0	22.0	0.0	2.20	1.00

Left U-channel Wall Height (ft)	Right U-channel Wall Height (ft)
0.00	0.00

FOOTING

Left Footing Width (in)	Left Footing Thick (in)	Left Footing Proj (in)	Right Footing Width (in)	Right Footing Thick (in)	Right Footing Proj (in)	Inter Footing Width (in)	Inter Footing Thick (in)
100.0	30.0	36.0	100.0	30.0	36.0	0.0	0.0

LOAD CONTROL

Fill Unit Weight (pcf)	Height of Fill (ft)	No of Lanes	Live Load Surcharge (ft)	Live Load	**Overlay Unit Weight** (pcf)	Overlay Thick (in)	Future Wearing Surface (psf)
140.0	7.25	2	1.33	C	150.0	0.0	0.0

Live Load Distrib Length (ft)	Segment Length (ft)	Multiple Presence Reduction	PA Traffic Factor	Fatigue Dynamic Load Allowance	Duct Factor	Redund Factor
66.00	90.00	N/A	N/A	N/A	1.00	0.98

Import Factor	Permit Max Dynamic Load Allowance	Live Load Override	Min Equiv Fluid Pressure (pcf)	Max Equiv Fluid Pressure (pcf)	Barrier Dead Load (kips/ft)
1.05	1.20	0	45.00	70.00	0.00

Left Approach Slab Dead Load (kips)	Left Approach Slab Live Load (kips)	Right Approach Slab Dead Load (kips)	Right Approach Slab Live Load (kips)	Ratings w/o Future Wearing Surface	Backfill Type	No. of Precast Shr Trns Segments	**Backfill Unit Weight (pcf)**
0.00	0.00	0.00	0.00	N	N/A	N/A	**140.0**

COVERS

Top Slab Top (in)	Top Slab Bot (in)	Bottom Slab Top (in)	Bottom Slab Bot (in)	Walls (in)	Footing Top (in)	Footing Bot (in)
2.5	2.0	2.5	3.0	2.0	2.0	3.0

TOP SLAB REINFORCEMENT

Slab No	Face	Range No 1 (ft)	Bar Size	Reinf Spac (in)	Range No 2 (ft)	Bar Size	Reinf Spac (in)	Range No 3 (ft)	Bar Size	Reinf Spac (in)
1	T	6.00	9	6.0	20.50	6	9.0	29.50	8	8.0
1	B	29.50	11	6.0						

WALL REINFORCEMENT

Wall No	Face	Range No 1 (ft)	Bar Size	Reinf Spac (in)	Range No 2 (ft)	Bar Size	Reinf Spac (in)	Range No 3 (ft)	Bar Size	Reinf Spac (in)
1	L	13.00	8	6.0						
1	R	13.00	6	8.0						
2	L	13.00	8	9.0						
2	R	8.00	6	8.0	13.00	8	5.0			

FOOTING REINFORCEMENT

Footing Number	Face	Bar Size	Reinf Spac (in)
1	T	9	5.0
	B	9	5.0
2	T	9	5.0
	B	9	5.0

OUTPUT OF INPUT

Input Echo	Input Commands	Input Summary
1	0	1

OUTPUT OF RESULTS

Section Props	LL Rating	Rating Sum	DL Eff & Capac	Design Reinf	Shear Design	Found Press	Quant	Serv Table	Serv Sum
1	1	1	1	0	0	0	1	0	1

Found Press Summary	**Min Rein**
1	**1**

8.10 EXAMPLE 9

Example 9 is a cast-in-place two cell culvert at grade. The structure geometry is shown in Figure 8.10-1. The culvert is to be rated. Haunches are present, and the culvert has a non-standard fish channel.

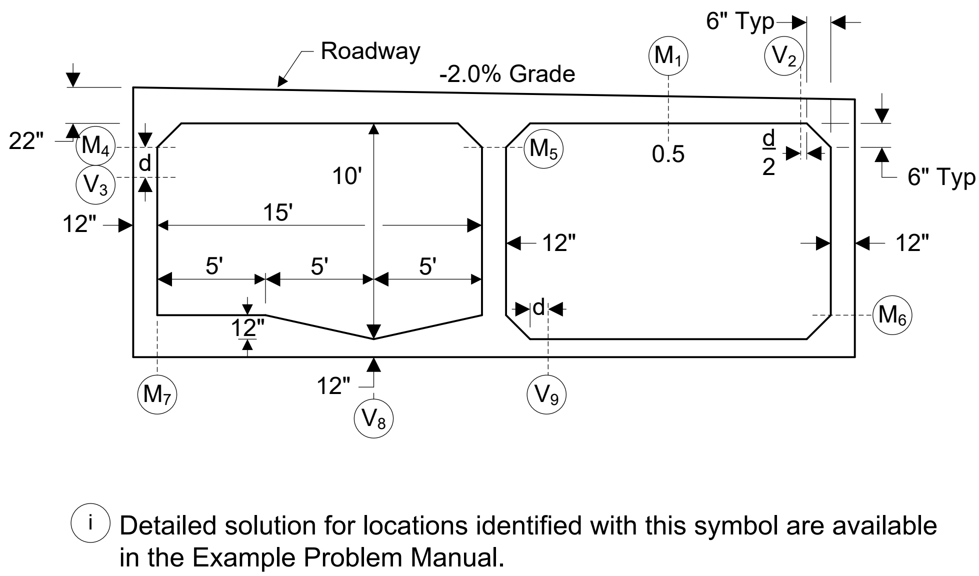


Figure 8.10-1 Example 9 Culvert Geometry

CONTROL

Sys of Units	Structure Type	Type of Run	**Culvert P or C**	Bottom Slab	Top Slab Support	Frame Support	**Footing P or C**
US	2-CELL BOX	AR	C	Y	M	N/A	**N/A**

STRUCTURE IDENTIFICATION

Program ID	County	State Route	Segment	Offset	Span ID
=BXLRFD	50	666	555	9996	654

MATERIAL

f'c All Members (ksi)	f'c Top Slab (ksi)	Reinf Grade (ksi)	Reinf Type	Alpha (deg)	Rebar Size	Epoxy Coated
3.00	4.00	40.0	B	90.0	9	Y

Concrete Density For DL (lb/ft^3)	Concrete Density For Ec (lb/ft^3)	fu (ksi)
150.0	145.0	55.00

DIMENSIONS

Clear Span (ft)	Clear Height (ft)	Slab Thickness Top (in)	Slab Thickness Bottom (in)	Wall Thickness Left (in)	Wall Thickness Right (in)	Wall Thickness Int (in)	Fill Grade (%)	Top Slab Grade (%)
15.00	10.00	22.0	12.0	12.0	12.0	12.0	0.00	-2.00

Left U-channel Wall Height (ft)	Right U-channel Wall Height (ft)
0.00	0.00

LOAD CONTROL

Fill Unit Weight (pcf)	Height of Fill (ft)	No of Lanes	Live Load Surcharge (ft)	Live Load	**Overlay Unit Weight** (pcf)	Overlay Thick (in)	Future Wearing Surface (psf)
140.0	0.00	2	2.00	C	150.0	0.0	30.0

Live Load Distrib Length (ft)	Segment Length (ft)	Multiple Presence Reduction	PA Traffic Factor	Fatigue Dynamic Load Allowance	Duct Factor	Redund Factor
56.00	90.00	N/A	N/A	N/A	1.00	1.00

Import Factor	Permit Max Dynamic Load Allowance	Live Load Override	Min Equiv Fluid Pressure (pcf)	Max Equiv Fluid Pressure (pcf)	Barrier Dead Load (kips/ft)
1.00	1.20	0	45.00	70.00	0.00

Left Approach Slab Dead Load (kips)	Left Approach Slab Live Load (kips)	Right Approach Slab Dead Load (kips)	Right Approach Slab Live Load (kips)	Ratings w/o Future Wearing Surface	Backfill Type	No. of Precast Shr Trns Segments	**Backfill Unit Weight (pcf)**
0.00	0.00	0.00	0.00	N	N/A	N/A	**140.0**

HAUNCH

Top Left X (in)	Top Left Y (in)	Top Right X (in)	Top Right Y (in)	Bot Left X (in)	Bot Left Y (in)	Bot Right X (in)	Bot Right Y (in)	Top Int X (in)	Top Int Y (in)	Bot Int X (in)	Bot Int Y (in)
6.0	6.0	6.0	6.0	0.0	0.0	6.0	6.0	6.0	6.0	6.0	6.0

FISH CHANNEL

Type	Segment Length (in)	Thick Change (in)	Segment Length (in)	Thick Change (in)	Segment Length (in)	Thick Change (in)
N	60.00	0.00	60.00	-12.00	60.00	12.00

COVERS

Top Slab Top (in)	Top Slab Bot (in)	Bottom Slab Top (in)	Bottom Slab Bot (in)	Walls (in)	Footing Top (in)	Footing Bot (in)
2.5	2.0	2.5	3.0	2.0	2.0	3.0

TOP SLAB REINFORCEMENT

Slab No	Face	Range No 1 (ft)	Bar Size	Reinf Spac (in)	Range No 2 (ft)	Bar Size	Reinf Spac (in)	Range No 3 (ft)	Bar Size	Reinf Spac (in)
1	T	15.00	8	6.0						
1	B	15.00	6	6.0						
2	T	15.00	8	6.0						
2	B	15.00	7	6.0						

BOTTOM SLAB REINFORCEMENT

Slab No	Face	Range No 1 (ft)	Bar Size	Reinf Spac (in)	Range No 2 (ft)	Bar Size	Reinf Spac (in)	Range No 3 (ft)	Bar Size	Reinf Spac (in)
1	T	5.00	6	6.0	11.50	9	6.0	15.00	6	6.0
1	B	15.00	8	12.0						
2	T	4.00	8	6.0	15.00	9	6.0			
2	B	2.50	8	8.0	13.00	4	5.0	15.00	5	5.0

WALL REINFORCEMENT

Wall No	Face	Range No 1 (ft)	Bar Size	Reinf Spac (in)	Range No 2 (ft)	Bar Size	Reinf Spac (in)	Range No 3 (ft)	Bar Size	Reinf Spac (in)
1	L	10.00	5	6.0						
1	R	10.00	5	12.0						
2	L	10.00	5	6.0						
2	R	10.00	5	6.0						
3	L	10.00	5	12.0						
3	R	10.00	5	6.0						

BOTTOM SLAB SHEAR REINFORCEMENT AREAS

Slab No	Region	Start (ft)	End (ft)	Av (in^2)	Spac (in)
2	1	0.00	15.00	1.550	9.0

OUTPUT OF INPUT

Input Echo	Input Commands	Input Summary
1	0	1

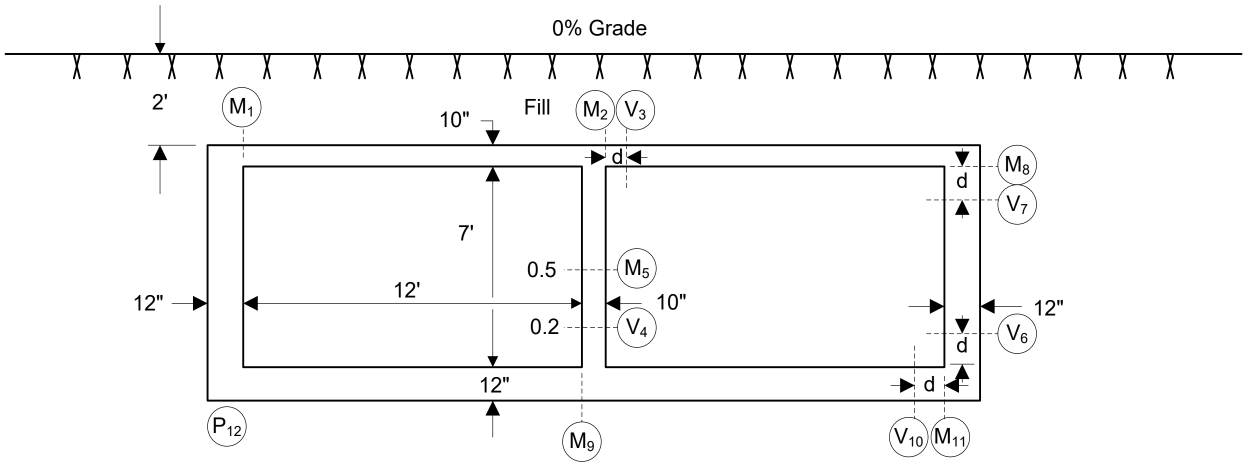
OUTPUT OF RESULTS

Section Props	LL Rating	Rating Sum	DL Eff & Capac	Design Reinf	Shear Design	Found Press	Quant	Serv Table	Serv Sum
1	1	1	1	0	0	1	1	1	1

Found Press Summary	**Min Rein**
1	**1**

8.11 EXAMPLE 10

Example 10 is a cast-in-place two cell culvert under 2 feet of fill. The structure geometry is shown in Figure 8.11-1. The culvert is rated for the special live load specified in the following BXLRFD input.



ⓘ Detailed solution for locations identified with this symbol are available in the Example Problem Manual.

Figure 8.11-1 Example 10 Culvert Geometry

CONTROL

Sys of Units	Structure Type	Type of Run	**Culvert P or C**	Bottom Slab	Top Slab Support	Frame Support	**Footing P or C**
US	2-CELL BOX	AR	C	Y	M	N/A	**N/A**

STRUCTURE IDENTIFICATION

Program ID	County	State Route	Segment	Offset	Span ID
=BXLRFD	50	666	555	9996	654

MATERIAL

f'c All Members (ksi)	f'c Top Slab (ksi)	Reinf Grade (ksi)	Reinf Type	Alpha (deg)	Rebar Size	Epoxy Coated
3.00	3.00	60.0	B	90.0	9	Y

Concrete Density For DL (lb/ft^3)	Concrete Density For Ec (lb/ft^3)	fu (ksi)
150.0	145.0	90.00

DIMENSIONS

Clear Span (ft)	Clear Height (ft)	Slab Thickness Top (in)	Slab Thickness Bottom (in)	Wall Thickness Left (in)	Wall Thickness Right (in)	Wall Thickness Int (in)	Fill Grade (%)	Top Slab Grade (%)
12.00	7.00	10.0	12.0	12.0	12.0	10.0	0.00	0.00

Left U-channel Wall Height (ft)	Right U-channel Wall Height (ft)
0.00	0.00

LOAD CONTROL

Fill Unit Weight (pcf)	Height of Fill (ft)	No of Lanes	Live Load Surcharge (ft)	Live Load	**Overlay Unit Weight** (pcf)	Overlay Thick (in)	Future Wearing Surface (psf)
140.0	2.00	1	3.00	E	140.0	4.0	0.0

Live Load Distrib Length (ft)	Segment Length (ft)	Multiple Presence Reduction	PA Traffic Factor	Fatigue Dynamic Load Allowance	Duct Factor	Redund Factor
59.00	90.00	N/A	N/A	N/A	1.00	1.00

Import Factor	Permit Max Dynamic Load Allowance	Live Load Override	Min Equiv Fluid Pressure (pcf)	Max Equiv Fluid Pressure (pcf)	Barrier Dead Load (kips/ft)
1.00	1.20	0	45.00	70.00	0.00

Left Approach Slab Dead Load (kips)	Left Approach Slab Live Load (kips)	Right Approach Slab Dead Load (kips)	Right Approach Slab Live Load (kips)	Ratings w/o Future Wearing Surface	Backfill Type	No. of Precast Shr Trns Segments	**Backfill Unit Weight (pcf)**
0.00	0.00	0.00	0.00	N	N/A	N/A	**140.0**

SPECIAL LIVE LOAD

LL No.	Gage Dist (ft)	Pass Dist (ft)	Axle Effect	Lane Load (klf)	Load Percent Increase	Load Factor STR-I	Load Factor STR-II	Load Factor SER-I	Factor Fatigue	**Vehicle Type**
1	6.00	4.00	Y	0.00	0.00	1.70	1.35	1.00	N/A	**D**

SPECIAL AXLE LOADS

LL No.	Axle Load (kips)	Axle Spac (ft)	Axle Load (kips)	Axle Spac (ft)	Axle Load (kips)	Axle Spac (ft)	Axle Load (kips)	Axle Spac (ft)
1	15.70	11.00	27.00	4.00	27.00	4.00	27.00	24.00
1	27.00	4.00	27.00	4.00	27.00	4.00	27.00	

COVERS

Top Slab Top (in)	Top Slab Bot (in)	Bottom Slab Top (in)	Bottom Slab Bot (in)	Walls (in)	Footing Top (in)	Footing Bot (in)
2.0	2.0	2.5	3.0	2.0	2.0	3.0

TOP SLAB REINFORCEMENT

Slab No	Face	Range No 1 (ft)	Bar Size	Reinf Spac (in)	Range No 2 (ft)	Bar Size	Reinf Spac (in)	Range No 3 (ft)	Bar Size	Reinf Spac (in)
1	T	12.00	8	6.0						
1	B	12.00	8	6.0						
2	T	12.00	8	6.0						
2	B	12.00	8	6.0						

BOTTOM SLAB REINFORCEMENT

Slab No	Face	Range No 1 (ft)	Bar Size	Reinf Spac (in)	Range No 2 (ft)	Bar Size	Reinf Spac (in)	Range No 3 (ft)	Bar Size	Reinf Spac (in)
1	T	12.00	9	6.0						
1	B	12.00	9	6.0						
2	T	12.00	9	6.0						
2	B	12.00	9	6.0						

WALL REINFORCEMENT

Wall No	Face	Range No 1 (ft)	Bar Size	Reinf Spac (in)	Range No 2 (ft)	Bar Size	Reinf Spac (in)	Range No 3 (ft)	Bar Size	Reinf Spac (in)
1	L	7.00	6	9.0						
1	R	7.00	6	9.0						
2	L	7.00	5	10.0						
2	R	7.00	5	10.0						
3	L	7.00	6	9.0						
3	R	7.00	6	9.0						

TOP SLAB SHEAR REINFORCEMENT AREAS

Slab No	Region	Start (ft)	End (ft)	Av (in^2)	Spac (in)
1	1	0.00	12.00	0.200	18.0
2	1	0.00	12.00	0.200	18.0

OUTPUT OF INPUT

Input Echo	Input Commands	Input Summary
1	0	1

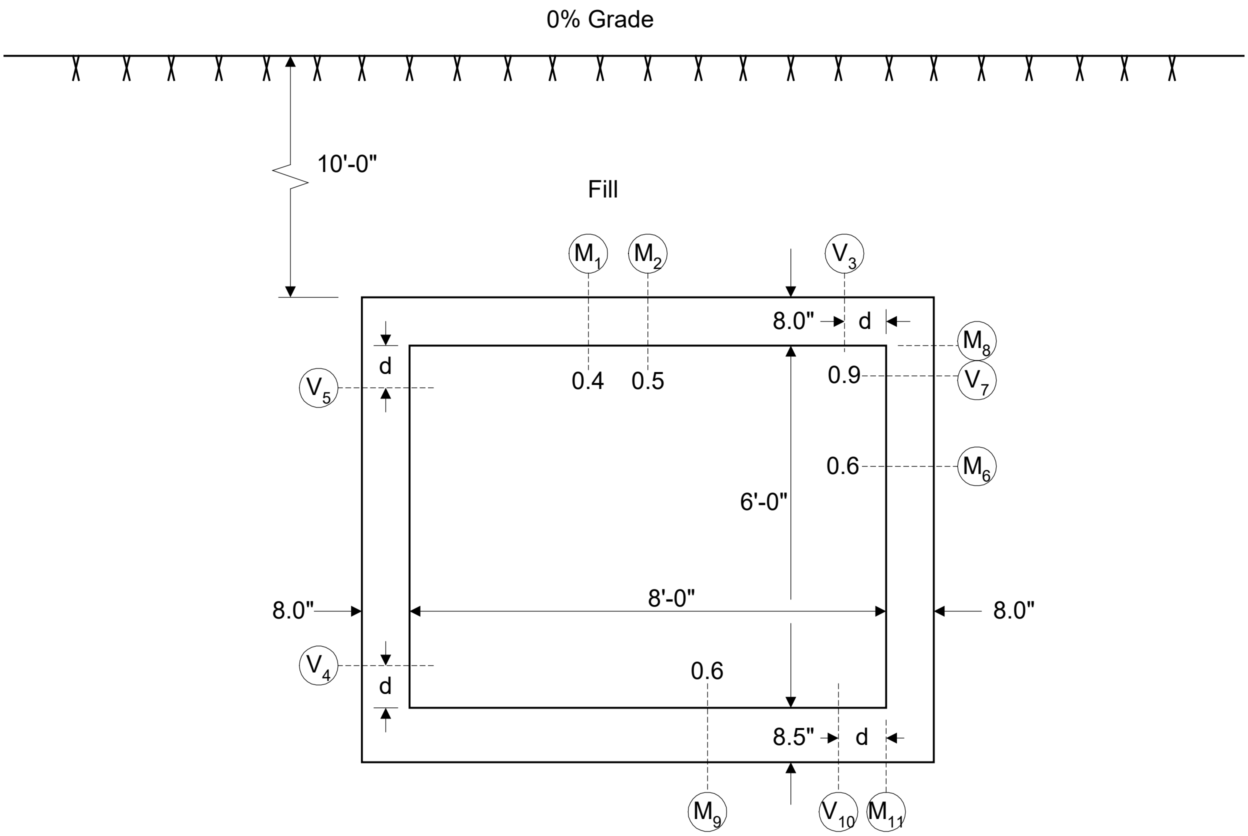
OUTPUT OF RESULTS

Section Props	LL Rating	Rating Sum	DL Eff & Capac	Design Reinf	Shear Design	Found Press	Quant	Serv Table	Serv Sum
1	1	1	1	0	0	0	1	0	1

Found Press Summary	**Min Rein**
1	**1**

8.12 EXAMPLE 11

Example 11 is a precast single cell culvert under a fill height of 10.0 feet. The structure geometry is shown in Figure 8.12-1. The culvert wire reinforcement and member thicknesses, with shear reinforcement, are to be designed.



(i) Detailed solution for locations identified with this symbol are available in the Example Problem Manual.

Note: Slab and wall thicknesses are initial design thicknesses.

Figure 8.12-1 Example 11 Culvert Geometry

CONTROL

Sys of Units	Structure Type	Type of Run	**Culvert P or C**	Bottom Slab	Top Slab Support	Frame Support	**Footing P or C**
US	1-CELL BOX	DA	P	Y	M	N/A	**N/A**

STRUCTURE IDENTIFICATION

Program ID	County	State Route	Segment	Offset	Span ID
=BXLRFD	50	666	555	9996	654

MATERIAL

f'c All Members (ksi)	f'c Top Slab (ksi)	Reinf Grade (ksi)	Reinf Type	Alpha (deg)	Wire Diam (in)	Epoxy Coated
5.00	5.00	60.0	W	90.0	0.50	N/A

Concrete Density For DL (lb/ft^3)	Concrete Density For Ec (lb/ft^3)	fu (ksi)
150.0	145.0	90.00

DIMENSIONS

Clear Span (ft)	Clear Height (ft)	Slab Thickness Top (in)	Slab Thickness Bottom (in)	Wall Thickness Left (in)	Wall Thickness Right (in)	Wall Thickness Int (in)	Fill Grade (%)	Top Slab Grade (%)
8.00	6.00	0.0	0.0	0.0	0.0	0.0	0.00	0.00

Left U-channel Wall Height (ft)	Right U-channel Wall Height (ft)
0.00	0.00

LOAD CONTROL

Fill Unit Weight (pcf)	Height of Fill (ft)	No of Lanes	Live Load Surcharge (ft)	Live Load	**Overlay Unit Weight** (pcf)	Overlay Thick (in)	Future Wearing Surface (psf)
145.0	10.00	2	3.00	E	0.0	0.0	0.0

Live Load Distrib Length (ft)	Segment Length (ft)	Multiple Presence Reduction	PA Traffic Factor	Fatigue Dynamic Load Allowance	Duct Factor	Redund Factor
80.00	12.00	N/A	N/A	N/A	1.00	1.03

Import Factor	Permit Max Dynamic Load Allowance	Live Load Override	Min Equiv Fluid Pressure (pcf)	Max Equiv Fluid Pressure (pcf)	Barrier Dead Load (kips/ft)
1.00	1.20	0	45.00	70.00	0.00

Left Approach Slab Dead Load (kips)	Left Approach Slab Live Load (kips)	Right Approach Slab Dead Load (kips)	Right Approach Slab Live Load (kips)	Ratings w/o Future Wearing Surface	Backfill Type	No. of Precast Shr Trns Segments	**Backfill Unit Weight (pcf)**
0.00	0.00	0.00	0.00	N/A	N/A	2	**145.0**

COVERS

Top Slab Top (in)	Top Slab Bot (in)	Bottom Slab Top (in)	Bottom Slab Bot (in)	Walls (in)	Footing Top (in)	Footing Bot (in)
2.0	1.5	2.0	1.5	1.5	**N/A**	**N/A**

OUTPUT OF INPUT

Input Echo	Input Commands	Input Summary
1	0	1

OUTPUT OF RESULTS

Section Props	LL Rating	Rating Sum	DL Eff & Capac	Design Reinf	Shear Design	Found Press	Quant	Serv Table	Serv Sum
1	0	0	0	1	1	0	1	0	1

Found Press Summary	**Min Rein**
1	**1**

8.13 EXAMPLE 12

Example 12 is a cast-in-place two cell culvert under 4.5 feet of fill. The structure geometry is shown in Figure 8.13-1. The culvert bar reinforcement and member thicknesses, both with and without shear reinforcement, are to be designed. Haunches are present, and the culvert has a standard fish channel.

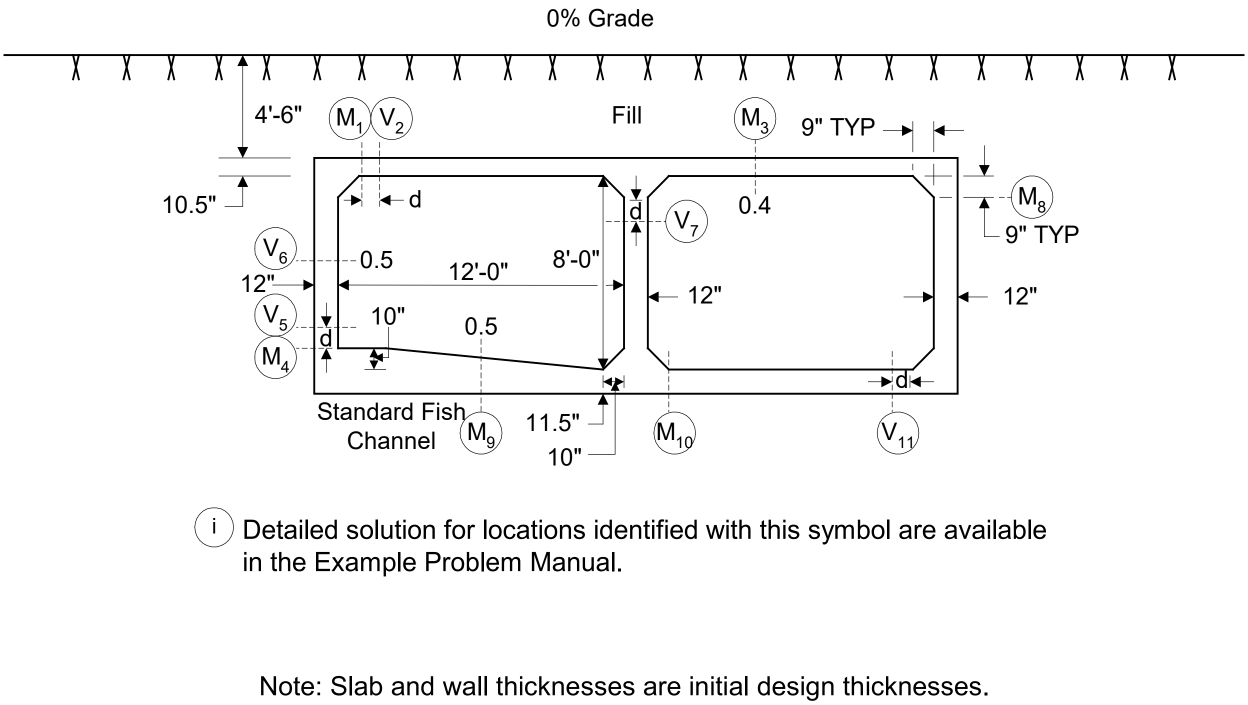


Figure 8.13-1 Example 12 Culvert Geometry

CONTROL

Sys of Units	Structure Type	Type of Run	**Culvert P or C**	Bottom Slab	Top Slab Support	Frame Support	**Footing P or C**
US	2-CELL BOX	DA	C	Y	M	N/A	**N/A**

STRUCTURE IDENTIFICATION

Program ID	County	State Route	Segment	Offset	Span ID
=BXLRFD	50	666	555	9996	654

MATERIAL

f'c All Members (ksi)	f'c Top Slab (ksi)	Reinf Grade (ksi)	Reinf Type	Alpha (deg)	Rebar Size	Epoxy Coated
3.00	3.00	60.0	B	90.0	8	Y

Concrete Density For DL (lb/ft^3)	Concrete Density For Ec (lb/ft^3)	fu (ksi)
150.0	145.0	90.00

DIMENSIONS

Clear Span (ft)	Clear Height (ft)	Slab Thickness Top (in)	Slab Thickness Bottom (in)	Wall Thickness Left (in)	Wall Thickness Right (in)	Wall Thickness Int (in)	Fill Grade (%)	Top Slab Grade (%)
12.00	8.00	10.5	11.5	12.0	12.0	12.0	0.00	0.00

Left U-channel Wall Height (ft)	Right U-channel Wall Height (ft)
0.00	0.00

LOAD CONTROL

Fill Unit Weight (pcf)	Height of Fill (ft)	No of Lanes	Live Load Surcharge (ft)	Live Load	**Overlay Unit Weight** (pcf)	Overlay Thick (in)	Future Wearing Surface (psf)
140.0	4.50	2	3.00	E	150.0	0.0	0.0

Live Load Distrib Length (ft)	Segment Length (ft)	Multiple Presence Reduction	PA Traffic Factor	Fatigue Dynamic Load Allowance	Duct Factor	Redund Factor
60.00	90.00	N/A	N/A	N/A	1.05	1.00

Import Factor	Permit Max Dynamic Load Allowance	Live Load Override	Min Equiv Fluid Pressure (pcf)	Max Equiv Fluid Pressure (pcf)	Barrier Dead Load (kips/ft)
1.00	1.20	0	45.00	70.00	0.00

Left Approach Slab Dead Load (kips)	Left Approach Slab Live Load (kips)	Right Approach Slab Dead Load (kips)	Right Approach Slab Live Load (kips)	Ratings w/o Future Wearing Surface	Backfill Type	No. of Precast Shr Trns Segments	**Backfill Unit Weight (pcf)**
0.00	0.00	0.00	0.00	N/A	N/A	N/A	**140.0**

HAUNCH

Top Left X (in)	Top Left Y (in)	Top Right X (in)	Top Right Y (in)	Bot Left X (in)	Bot Left Y (in)	Bot Right X (in)	Bot Right Y (in)	Top Int X (in)	Top Int Y (in)	Bot Int X (in)	Bot Int Y (in)
9.0	9.0	9.0	9.0	0.0	0.0	9.0	9.0	9.0	9.0	9.0	9.0

FISH CHANNEL

Type	Segment Length (in)	Thick Change (in)	Segment Length (in)	Thick Change (in)	Segment Length (in)	Thick Change (in)
S	24.00	0.00	110.00	-10.00	10.00	10.00

COVERS

Top Slab Top (in)	Top Slab Bot (in)	Bottom Slab Top (in)	Bottom Slab Bot (in)	Walls (in)	Footing Top (in)	Footing Bot (in)
2.0	2.0	2.5	3.0	2.0	**N/A**	**N/A**

OUTPUT OF INPUT

Input Echo	Input Commands	Input Summary
1	0	1

OUTPUT OF RESULTS

Section Props	LL Rating	Rating Sum	DL Eff & Capac	Design Reinf	Shear Design	Found Press	Quant	Serv Table	Serv Sum
1	0	0	0	1	1	0	1	0	1

Found Press Summary	**Min Rein**
1	**1**

8.14 EXAMPLE 13

Example 13 is a cast-in-place U-channel. The structure geometry is shown in Figure 8.14-1. The U-channel reinforcement and member thicknesses are to be designed.

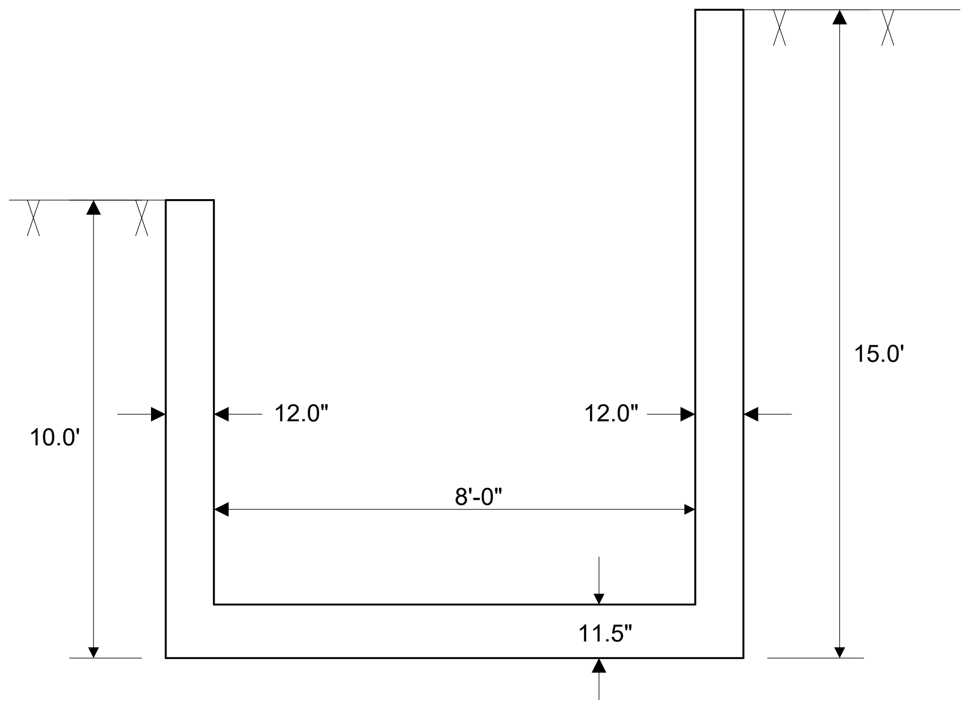


Figure 8.14-1 Example 13 U-channel Geometry

CONTROL

Sys of Units	Structure Type	Type of Run	**Culvert P or C**	Bottom Slab	Top Slab Support	Frame Support	**Footing P or C**
US	U-CHANNEL	DC	C	Y	M	N/A	**N/A**

STRUCTURE IDENTIFICATION

Program ID	County	State Route	Segment	Offset	Span ID
=BXLRFD	50	666	555	9996	654

MATERIAL

f'c All Members (ksi)	f'c Top Slab (ksi)	Reinf Grade (ksi)	Reinf Type	Alpha (deg)	Rebar Size	Epoxy Coated
3.00	3.00	60.0	B	90.0	8	Y

Concrete Density For DL (lb/ft^3)	Concrete Density For Ec (lb/ft^3)	fu (ksi)
150.0	145.0	90.00

DIMENSIONS

Clear Span (ft)	Clear Height (ft)	Slab Thickness Top (in)	Slab Thickness Bottom (in)	Wall Thickness Left (in)	Wall Thickness Right (in)	Wall Thickness Int (in)	Fill Grade (%)	Top Slab Grade (%)
8.00	0.00	0.0	11.5	12.0	12.0	0.0	0.00	0.00

Left U-channel Wall Height (ft)	Right U-channel Wall Height (ft)
10.00	15.00

LOAD CONTROL

Fill Unit Weight (pcf)	Height of Fill (ft)	No of Lanes	Live Load Surcharge (ft)	Live Load	**Overlay Unit Weight** (pcf)	Overlay Thick (in)	Future Wearing Surface (psf)
120.0	0.00	2	3.00	E	150.0	0.0	30.0

Live Load Distrib Length (ft)	Segment Length (ft)	Multiple Presence Reduction	PA Traffic Factor	Fatigue Dynamic Load Allowance	Duct Factor	Redund Factor
0.00	90.00	N/A	N/A	N/A	1.00	1.00

Import Factor	Permit Max Dynamic Load Allowance	Live Load Override	Min Equiv Fluid Pressure (pcf)	Max Equiv Fluid Pressure (pcf)	Barrier Dead Load (kips/ft)
1.00	1.20	0	45.00	70.00	0.00

Left Approach Slab Dead Load (kips)	Left Approach Slab Live Load (kips)	Right Approach Slab Dead Load (kips)	Right Approach Slab Live Load (kips)	Ratings w/o Future Wearing Surface	Backfill Type	No. of Precast Shr Trns Segments	**Backfill Unit Weight (pcf)**
0.00	0.00	0.00	0.00	N/A	N/A	N/A	**120.0**

COVERS

Top Slab Top (in)	Top Slab Bot (in)	Bottom Slab Top (in)	Bottom Slab Bot (in)	Walls (in)	Footing Top (in)	Footing Bot (in)
2.0	2.0	2.5	3.0	2.0	**N/A**	**N/A**

```
                                          OUTPUT OF INPUT
    Input     Input     Input
     Echo   Commands   Summary
      1         0         1


                                         OUTPUT OF RESULTS
    Section    LL   Rating   DL Eff  Design  Shear  Found         Serv   Serv
     Props   Rating   Sum   & Capac  Reinf  Design  Press  Quant  Table  Sum
       1       0       0       0       1       1       0      1      0     1

    Found Press   Min
      Summary    Rein
        1          1
```

9 TECHNICAL QUESTIONS AND REVISION REQUESTS

This chapter contains a reply form to make it easier for users to convey their questions, problems or comments to the proper unit within the Department. General procedures for using this form are given. Users should keep the form in the manual as a master copy which can be reproduced as needed. It is also included as a Word template as part of the program installation.

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 the form or the information provided on the 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 form can also be used to report suspected program malfunctions that may require revisions to the program or 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 the form for processing.

The 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 **Highway Applications Division** via e-mail.

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BXLRFD
TECHNICAL QUESTION / 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, please provide the input data file as an e-mail attachment. If you require more space, use additional 8½ x 11 sheets of plain paper.

FORWARD COMPLETED FORM TO: Pennsylvania Office of Administration
Infrastructure and Economic Development
Bureau of Solutions Management
Highway Applications Division
EMAIL: penndotbisengineer@pa.gov
PHONE: (717) 783-8822

FOR DEPARTMENT USE ONLY

RECEIVED BY: ________________ ASSIGNED TO: ___________________ DATE: _____________

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