BRASS™

Wyoming Department of Transportation

Analysis, Design and Rating

of

Reinforced Concrete Box Culverts

BRASS - CULVERT™

Version 2.7

Technical Manual

August 2015

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Acknowledgement

The Wyoming Department of Transportation has developed this program through the cooperative efforts of the Federal Highway Administration, the North Carolina Department of Transportation, the New York State Department of Transportation, and the University of Wyoming.

Disclaimer

AASHTO Specification

The BRASS-CULVERT™ program is current with the AASHTO Standard Specifications for Highway Bridges, 17th Edition, 2002, the AASHTO LRFD Bridge Design Specifications, Seventh Edition, 2014, with 2015 Interim Revisions, and the AASHTO Manual for Bridge Evaluation, 2nd Edition, 2010, with 2011, 2013, 2014, and 2015 Interim Revisions.

Additional Information and Technical Assistance

Additional information may be obtained from:

Wyoming Department of Transportation
Bridge Program
5300 Bishop Boulevard
Cheyenne, WY 82009-3340
Telephone: (307) 777-4427
Fax: (307) 777-4279
Web Page: http://www.dot.state.wy.us/wydot/engineering_technical_programs/bridge/brass
FTP Site: ftp://brass:password@wydot-ftp.dot.state.wy.us

Technical assistance may be obtained from:

Telephone: (307) 777-4489
E-mail: BRASSTechSupport@wyo.gov
Web: www.wydot-brass.com

Purchasing, billing and licensing assistance may be obtained from:

Telephone: (307) 777-4489
E-mail: BRASSBilling@wyo.gov

When requesting technical assistance, please visit the incident tracking system at www.wydot-brass.com. Users without an account on the incident tracking system can request an account by clicking on the "Open a Technical Support Account" link/button and e-mailing the address or calling the phone number listed. A username and password will be created and sent to the user. With this system, you may upload your data file and a description of the incident, any error messages, any bridge drawings, and any hand computations, which illustrate the concern. An Incident number will be assigned to track the progress of resolving the incident.

BRASS™ Suite of Programs

BRASS™ is a suite of programs that assist the engineer in many aspects of bridge design and rating. These programs are described below.

BRASS-GIRDER™	Performs a design review or rating of highway bridge girders using plane frame analysis and the AASHTO Standard or LRFD Specifications. Load and resistance factor and load factor computations are performed for steel and composite steel, reinforced concrete, and prestressed concrete girders. Load and resistance factor and allowable stress computations are performed for timber girders.
BRASS-GIRDER(STD)	Performs a design review or rating of highway bridges decks and girders using plane frame analysis and the AASHTO Standard Specifications. Load factor and working stress computations are performed. This program was fully sunset after the November 2014 release.
BRASS-GIRDER(LRFD)™	Performs a design review or rating of highway bridge girders using plane frame analysis and the AASHTO LRFD Specifications. Load and resistance factor computations are performed. This program was fully sunset after the November 2014 release.
BRASS-PIER™	Performs an analysis of a bridge transverse section at pier locations. The program provides a comprehensive analysis of bridge decks, piers, and selected foundation types. All AASHTO loads and group loads are considered. Live load is automatically positioned for maximum actions. Load factor and working stress computations are performed.
BRASS-PIER(LRFD)™	Performs an analysis of a bridge transverse section at pier locations. Provides a comprehensive analysis of bridge decks, piers, and selected foundation types. All AASHTO (LRFD) loads and group loads are considered. Live load is automatically positioned for maximum actions.
BRASS-CULVERT™	Performs analysis or design of one, two, three, or four barrel reinforced concrete rigid or flexible box culverts, with or without bottom slab. End skews can also be defined. Wall and slab thickness may be specified or the program will set the thickness. AASHTO guidelines are followed and Service Load Design, Load Factor Design, or Load and Resistance Factor Design may be specified. Member capacities are designed based on applied truck load, soil fill, self weight and water pressure. Standard AASHTO and user defined truck loadings can be specified. Output generated by the program includes: culvert geometry; moments, shears, and axial forces at tenth points; stresses; required area of reinforcement; steel design table; splice length; weights and volumes of steel and concrete; and influence ordinates. Critical design moments, shears, and axial forces for each member are summarized. Flexural rating computations may be optionally computed.

BRASS-SPLICE™	Performs the design of field splices for rolled beam or welded plate steel girders. Design criteria are in compliance with the AASHTO Standard Specifications and WYDOT design practice. Load factor and working stress computations are performed.
BRASS-PAD™	Performs analysis and design of steel or fabric reinforced elastomeric bearing pads according to the AASHTO Standard or LRFD Specifications.
BRASS-DIST™	Performs a finite-strip element analysis to determine the factor for wheel load distribution for any axle spacing or width and any tire configuration of a truck placed at any position on the bridge deck. Standard trucks may also be used. NOTE: AASHTO formulas are based on empirical data and are applicable to six-foot axle widths. Also provides results for a simple beam "deck-to-girder" analysis for dead loads.
BRASS-TRUSS™	Performs a comprehensive working stress analysis or rating of simple or continuous truss or girder floorbeam stringer type bridges.
BRASS-POLE™	Performs a working stress analysis of cantilever sign, luminaire and signal support structures. Round or polygonal steel poles may be analyzed according to the AASHTO Standard Specifications.

Introduction

BRASS-CULVERT™ designs, analyzes, and/or rates one-, two-, three-, or four-cell reinforced concrete box culverts with prismatic members (precast or cast-in-place) with or without a bottom slab. All cells are assumed the same size, and the clear opening dimensions remain constant during the design process. The wall and slab thicknesses may be specified and/or sized by the program. Analyses and designs may accommodate either detailing with continuous or simply-supported slab-wall details.

The program designs the box culvert by either Allowable Stress Design (ASD) or Load Factor Design (LFD) using the AASHTO Standard Specifications for Highway Bridges or by Load and Resistance Factor (LRFD) using the AASHTO LRFD Bridge Design Specifications. LRFR analyses are available using the AASHTO Manual For Bridge Evaluation. Alternatively, BRASS-CULVERT™ reviews a known design or existing system and performs specification and resistance checking. LRFR, LFD and ASD rating factors for flexure and shear are computed for both the design and review modes. All applicable specification checks are computed /reviewed. These computations and checks include:

1. Minimum wall/slab thicknesses
2. Live load distribution and dead load computations. Live loads are automatically positioned and dead and lateral earth loads are automatically computed. Worst-case combinations are considered for live, lateral earth pressure, interior water pressure, and dead load actions
3. Standard AASHTO and user-defined truck loadings may be specified
4. Other live loads can be defined by the user with the BRASS Library Utility
5. Service and factored load effects, including actions and stresses
6. Fatigue stress checks
7. Crack control stress checks
8. Allowable stresses and stress due to load for ASD and service limit states. The presence of axial force is considered in all computations
9. Ultimate strength resistances for shear, moment, and axial force-moment interaction.
10. Slenderness effects

Output consists of the following reports:

1. Reprint of input
2. Wall and slab thicknesses
3. Unfactored moments, shears, and axial forces due to each load case
4. Reinforcement serviceability check based on fatigue (LFD and LRFD only)
5. Required bar reinforcement
6. Output at critical sections
7. Weight of bars and volume of concrete
8. Reinforcing steel bar schedule
9. Splice-length chart
10. Factored moment, shear and axial forces at member tenth points
11. Optional influence line value output
12. Optional detailed computation file
13. Optional live load positioning file

Abbreviations

The following is a list of definitions for abbreviations commonly used throughout the manuals.

Abbreviation	Phase or Term
LRFD	Load and Resistance Factor Design
ASD	Allowable Stress Design
LFD	Load Factor Design
STD xx.yy	AASHTO Article reference for *Standard Specification for Highway Bridges*
LRFD xx.yy	AASHTO Article reference for *Load and Resistance Factor Design Specification for Highway Bridges*
RATING xx.yy	AASHTO Article reference for *Manual For Bridge Evaluation*
BRASS	Bridge Rating & Analysis of Structural Systems
BRASS-CULVERT™	Program for the Design and Rating of Reinforced Concrete Box Culverts
WYDOT	Wyoming Department of Transportation
NYDOT	New York Department of Transportation
AASHTO	American Association of State Highway and Transportation Officials
US	Customary United States measurement units
SI	International System of Units

Herein, "BRASS" refers to the BRASS-CULVERT™ program.

Files Required and Produced

The files required or produced are printed at the start of each *.xml file (ACSII output file). An example is illustrated below.

```
Input Filename                  : C:\BRASS\Culvert\Exe\jp1cellflex UStoSI.DAT
Output Filename                 : C:\BRASS\Culvert\Exe\jp1cellflex UStoSI.XML

The following filenames may be used in this run
Live Load Influence Ordinates    File name : C:\BRASS\Culvert\Exe\jp1cellflex UStoSI.ill
Live Load Actions (w/o DF or IM) File name : C:\BRASS\Culvert\Exe\jp1cellflex UStoSI.oll
Intermediate Computations        File name : C:\BRASS\Culvert\Exe\jp1cellflex UStoSI.ooo
Data Modelling                   File name : C:\BRASS\Culvert\Exe\jp1cellflex UStoSI.tmp
```

The files used or produced by BRASS-CULVERT™ are described below.

File Name	Purpose
InputFileName.CUS	IMPORTANT: This is the file used by BRASS-CULVERT™ to define a culvert. This binary file defines the culvert and the loads and is generated by the GUI. This file should be archived for the structure definition, i.e., it is your data file. If you require technical assistance, please submit this file.
BRASS-Vehicles.blv	This ASCII file is used to define the vehicle library for all BRASS applications. It may be maintained by the truck library utility application *BrassLibraryUtility-GUI.exe*. If you encounter problems with the vehicle library of the BRASS Library Utility, please report those problems under that program.
BRASS-BarSpacing-Std.blb BRASS-BarSpacing-User.blb BRASS-BarSpacing-WyDot.blb	These ASCII files are used to provide combinations of reinforcement bars and areas. The *Std* file is for default, *User* file is for a user-defined file, and *WyDOT* is specific to WYDOT practice. The file is self documenting.
InputFileName.ERR	This is an ASCII file that is internal and is used to pass messages from the computational processor to the GUI.
InputFileName.DAT	This file is an ASCII file that is used to transfer data from the UI to the analysis engine. The commands therein are not documented, and it is not intended that the user modify this file. IMPORTANT: The GUI does not read this file; hence modification made within this file will not appear in the GUI.
InputFileName.XML	This XML file is the output from the computational processor. It contains the most useful and often used results.
InputFileName.OLL	This ASCII file contains data on live load positioning. Typically used by developers only.
InputFileName.OOO	This ASCII file contains data illustrating how computations are performed. The output is for debugging but might be of benefit to users as well. The output format varies from something familiar to the programmer to some reports that are fairly well formatted. The readability (by a non developer) may be improved in future releases.
InputFileName.TMP	This ASCII file contains debugging information where the programmer can run many (hundreds) of culverts with various cell heights, spans, depth of fill, and number of cells. This file provides many important parametric inputs and outputs. This is extremely useful as a programming aid to view trends in data. It is primarily used for debugging but could be used for development of standard plans, etc. Contact WYDOT if you

File Name	Purpose
	wish to use this file.
InputFileName.ILL	This ASCII file contains influence line data and may be used for plotting. Typically used by developers only.

Units

The input and/or output data may be in either US or SI units. Input is read in the user-defined units system and then converted to US units (in-lb system) for computation. If the user requests SI output, then the output is converted to SI. All computations are performed with US units (in-lb system). Reinforcement bar sizes may be entered in US standard, SI, Canadian, or EU sizes. The various metric sizes are available if 'SI' is selected as the input method. The computations are performed on a unit-width basis, i.e., one-foot. The output from SI is reported for a one-meter section. Hence, the unit conversion factors should convert the results (typically action, e.g., moment) but also the unit-width basis. Intermediate <u>and</u> detailed output files are written in US units only.

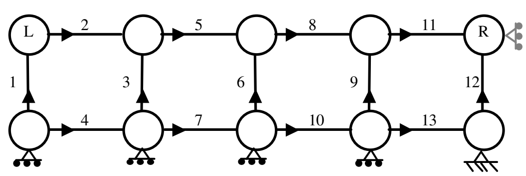
Method of Analysis

General

The method of analysis is the stiffness method. Plane frame elements are used.

Cell Layout

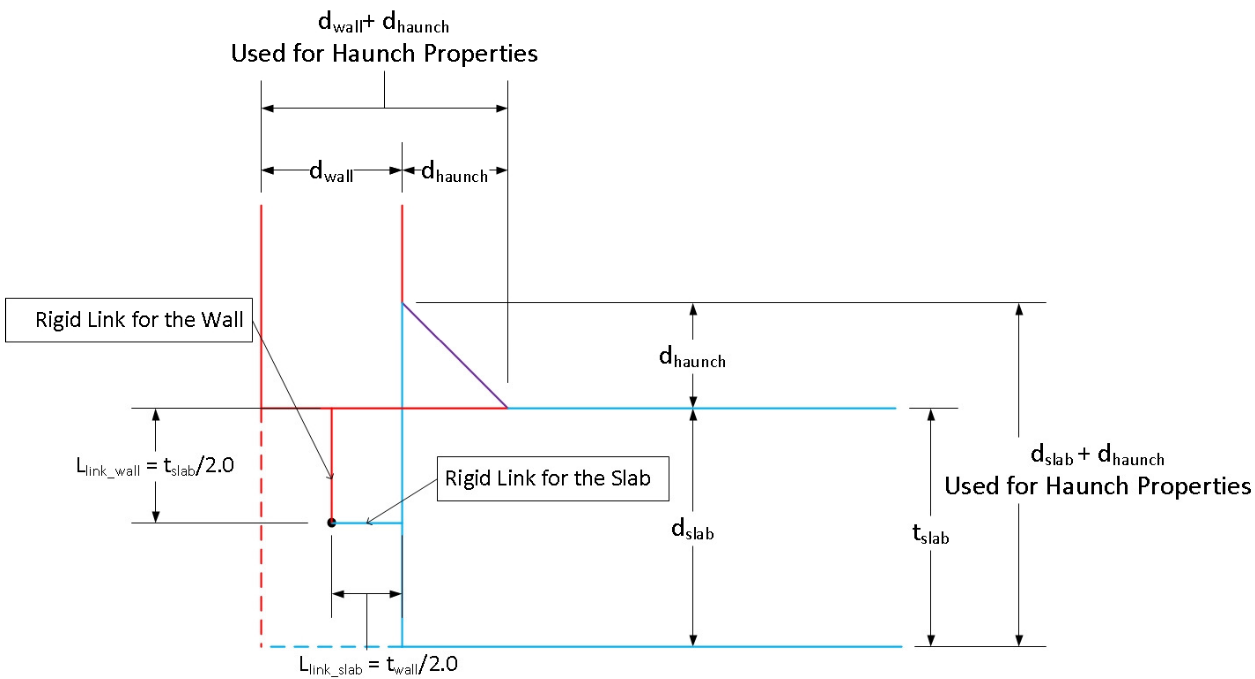
BRASS-CULVERT™ can model culverts with one to four cells. As illustrated below, physical joints are denoted by circles and members by numbers along the lines connecting the circles. If no haunches are used in the analysis, one plane frame element is used to model each member. The culvert structure is modeled using the walls and slabs of the cell layout. Left and right sides of the members are as denoted with L and R, respectively. The start and end of members are indicated by the direction of arrows (points toward the end). The sign convention for loads and actions are described later.



General Culvert Layout

The top and bottom spans of the culvert model are considered to be horizontal and the culvert walls are considered to be vertical. Sloped walls are not permitted.

If haunches are included in the structural analysis, it is assumed that each haunch is a single frame element with a depth equal to the full depth of the haunch plus the depth of the associated slab or wall. The length of the element is equal to the length/depth of the haunch itself. The portion of the culvert from the end of the haunch element to the center line of the adjoining slab/wall is modeled as a rigid link.



Boundary Conditions and Continuity

The nodes along the bottom slab are all restrained against vertical displacement. The right-most node is also restrained against horizontal displacement (pinned). The upper-right node is also restrained against horizontal displacement. See the figure above.

Span Length

The length of each member is based upon the adjoining member centerlines. The design span length is explained in the output. The user must define the span length for the reinforcement configuration. No correction is made for skew distribution factors.

Moments at the geometric centers, moments at faces of support, or moments within fillets (haunches) built monolithic with the member and support may be selected for member design. BRASS-CULVERT™ automatically computes the moments at these locations based on the user-defined preference. The shear is computed at a distance equal to the effective depth away from the support face.

Load Modeling

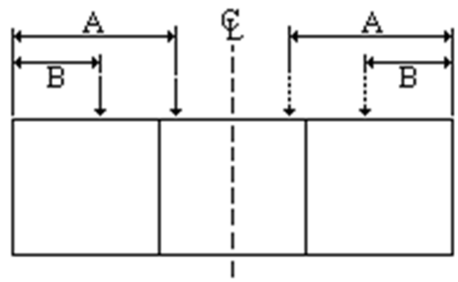
The loading applied to the top slab is uniformly distributed over the entire bottom slab. A more refined assumption appears impractical due to the lack of precise soil information for each site. This load distribution is used for all loadings, i.e., dead load and unit live loads used in the development of influence lines. Therefore, the influence lines for actions include both the load effects of the unit load applied to the top of the box and the unit load uniformly distributed on the bottom. The details about the influence lines are addressed later.

Self Weight

The culvert self-weight is automatically computed based on the wall thicknesses. The top-slab weight is applied to the top of the box. The wall weight and the top slab weight are applied to the bottom slab (upward). The bottom slab weight is not applied in the model because its load is directly resisted by the soil. The wall weight is not included in the fixed-end-action computations for axial forces. Hence, the wall axial force is the same at the top and bottom of the wall. The default concrete density is 150 pcf.

Concentrated Dead Loads

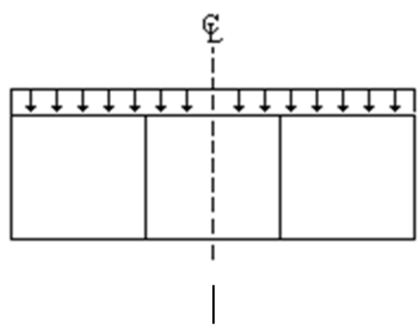
Concentrated loads may be applied downward (positive) or upward (negative) and always act in the vertical direction. However, the resulting load must be symmetrical about the centerline of the culvert structure in order to see proper results. An example is shown. BRASS-CULVERT™ analyzes the full structure but reports analysis and design results on the left half. Hence, the requirement for symmetrical loading exists. A non-symmetrical load may be entered, but the full non-symmetrical results will not be reported or analyzed.



Concentrated Dead Loads

Distributed Dead Loads

A uniform distributed load may be applied on the top slab. The distributed load always acts perpendicular to the span and may be applied downward (positive) or upward (negative) to act across the entire top slab.



Uniform Dead Load

Dead Loads

The dead load on the top slab consists of soil weight (100% for service load design and 100% for load factor design) plus the weight of slab at 150 pcf (concrete default). The weight of the wearing surface is also applied. The default soil weight is 120 pcf. LRFD soil unit weights are adjusted by the soil structure interaction factor.

Soil Loads

The equivalent fluid weight for lateral earth pressure on the walls is 60 pcf (default). BRASS-CULVERT™ also investigates the condition of submerged soil pressure acting on the walls. The submerged soil pressure is taken as one-half of the earth pressure acting on the outside walls. The user may override the maximum and minimum soil pressures. The maximum or minimum pressure is used to establish the most critical actions at every tenth point in the box, i.e., an envelope is used. (STD 3.20, LRFD 3.4.1)

For embankment installations, the modification of earth loads for soil structure interactions conform to Standard Specifications 16.6.4.2 and 16.7.4.2 and LRFD Specifications 12.11.2.2. These articles state that unfactored earth loads on the culvert may be multiplied by soil-structure interaction factors, F_e and F_t which account for the type and condition of installation.

The fill depth multiplier in LRFD Specifications 3.6.1.2.6 allows wheel loads to be distributed over a width of 1.15 times the depth of the fill for select granular backfill, or width equal to the depth of fill for other installations.

Water Pressure

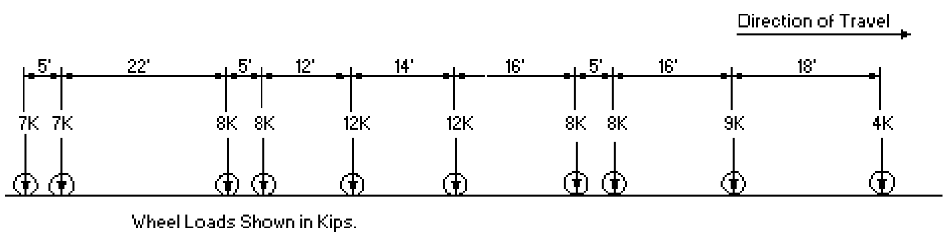
Water pressure inside culvert cells can reverse the wall moments and add to the slab positive moments and is checked when input by the user. BRASS-CULVERT™ uses water pressure due to a water surface at the top of the culvert and no water pressure as the two loading cases. The water pressure is illustrated in the output tables for actions and in the user interface for shear and moment plotting. The water imposes an outward force on the exterior walls. To check for water pressure actions, the unit weight of water must be entered. It is not considered by default.

Temperature Loads

Temperature load effects are neglected.

Truck Live Loads

The pre-defined truck live load configurations are stored in the truck library with a reference title. For each designation, the library stores axle weights and spacings; weights of lane loads are also specified. An example from the user-defined truck is illustrated. Standard vehicles are available in the library.



General Truck Configuration

Truck data then becomes a series of point loads at given spacings that represent an *axle* (lane). Such data may be used to define a specific truck or used to define a truck to the user-defined truck library. The BRASS Library Utility is used to edit/maintain the library.

Live Load Distribution Factors

For the Standard Specification, when the cover on the culvert is 2 feet or less, wheel loads are distributed as though they are applied directly to the top slab, as in ordinary slab bridges. BRASS-CULVERT™ distributes wheel loads over a slab width, E, equal to $4 + 0.06(S)$, where S is the perpendicular distance between wall centerlines.

For the LRFD Specification, see LRFD 4.6.2.10 for cases when the fill is less than 2 feet, otherwise, see LRFD 3.6.1.2.6 and 3.6.1.3.3.

For the Standard Specification, when the cover equals two feet but less than eight feet, wheel loads are distributed to the top slab over squares having sides equal to 1-3/4 times the depth of the fill. See STD 6.4. When these top slab loading "squares" overlap, the wheel loads are spread evenly over the gross loaded area. When the cover is between two and eight feet minimum, these loaded areas merge so that live load is uniform (in the direction of the truck). Distributed loads are then discretized into concentrated loads. (See section Longitudinal Live Load Distribution below.) These concentrated loads are then placed on BRASS-CULVERT™-generated influence lines (see section Moving Loads below) to generate the critical actions. These loads and spacing are printed in the output. Also see LRFD 3.6.1.2.6.

The wheel load is distributed to the bottom slab in accordance with STD 16.6.4.3 and 16.7.4.3. For LRFD, this reduction is not applied (see 12.11.2.3). The user can override these requirements for Standard Specification analyses.

Live loads can be ignored when the depth of the fill exceeds eight feet and exceeds the clear span of a single-cell box culvert, or exceeds the distance between faces of outer walls for a multiple-cell culvert (STD 6.4.2). If the culvert meets the above criteria, then BRASS-CULVERT™ neglects live load. However, the user can choose to override this and include the load.

The total distribution width shall not exceed the total width of the supporting slab. For precast elements, the distribution width can be limited to the width of the precast unit for a three-sided culvert (see STD 16.8.5.4). For all four-sided culverts, the load is distributed across the precast elements in the same manner at a cast-in-place box, i.e., the only limit is the total culvert length.

For ASD and LFD, the program considers two-, three-, and four-adjacent vehicle lanes and selects the critical case. Appropriate AASHTO lane reduction percentages are used for the three- and four-lane loading cases.

For LRFD distribution factors and fills less than 2 feet, only the one lane loaded condition is considered, along with the single lane multiple presence factor. For fills greater than or equal to 2 feet, the one and two lane loaded conditions with the appropriate multiple presence factors are considered. The controlling strip with is used. See articles 4.6.2.10, 3.6.1.3.3., and 12.11.2.

Patch Loading

A wheel load can either be considered as a concentrated point load or a load distributed over tire patch area. The patch load is not required in the STD and this option defaults to a concentrated load. In LRFD, the option defaults to a patch load. See LRFD 3.6.1.2.5.

Longitudinal Live Load Distribution

BRASS-CULVERT™ distributes vehicle loads through the soil to account for longitudinal live load distribution through the soil fill above a culvert. The method used is best described by using an example. The following example considers the Rocky Mount Double 7 Axle 105k Gvw (Us) Truck from the BRASS-Vehicles.BLV library file. The first three axles of the truck (12.0 kips, 15.5 kips, and 15.5 kips, respectively, spaced at 9 feet and 4 feet) are shown positioned above a culvert under 4 feet of fill in Figure 1. The next axle is spaced at 31 feet from the third axle, so it is not shown in Figure 1.

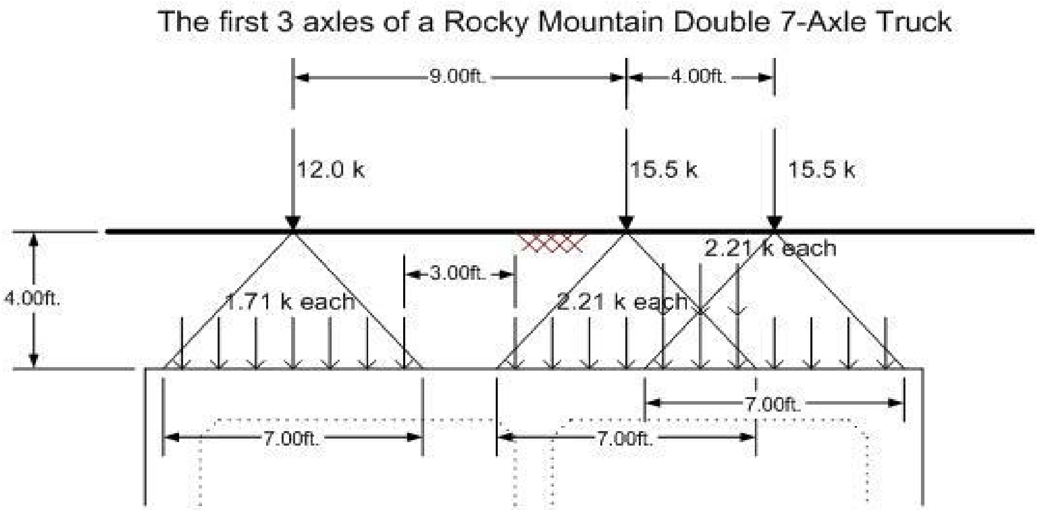


Figure 1 – Three Axles on a Culvert

For the AASHTO Standard Specifications, the load is assumed to be distributed through the soil at a slope of 1.75. Therefore, the load for any given axle is distributed over a length of the culvert as follows:

$$D_f := 4\,ft$$
$$Slope_{STD} := 1.75$$
$$Dist_{axle} := D_f \cdot Slope_{STD}$$
$$Dist_{axle} = 7\,ft$$

where: D_f = the depth of fill
$Slope_{STD}$ = the soil distribution slope (6.4.1)
$Dist_{axle}$ = the length of the culvert

Once it has been determined that each axle load will be distributed over a length of seven feet, seven point loads are created. The point loads are spaced at 1 foot, and have a value of:

12.0 kips/7.0 feet = 1.71 kips for the first axle, and
15.5 kips/7.0 feet = 2.21 kips for the second axle.

These loads are centered longitudinally under the axle. Since the first and second axles are spaced nine feet apart, there is a 3 foot gap between the distributed point loads. The second and third axles, however, are spaced only 4 feet apart, so there is an overlap of three feet. Where the distributions of the loads of different axles overlap, they are simply added. Therefore, the first three axles of the Rocky Mount Double 7 Axle 105k Gvw (Us) Truck results in 18 distributed point loads.

Table 1 illustrates how the load of each axle is distributed into point loads, and Table 2 demonstrates how the distributed point loads are combined.

	Axle Load	Distribution Length	Distributed Point Load	Number of Distributed Point
	(kips)	(feet)	(kips)	
Axle 1	12.00	7.00	1.714	7
Axle 2	15.50	7.00	2.214	7
Axle 3	15.50	7.00	2.214	7

Table 1 – Axle Load Distribution

	Sample BRASS Output		**Additional Information**			
	Truck facing backward		Total Distributed Point Load	Distributed Point Loads by Truck Axle		
Position	Axle wts.	Spacing		Axle 1	Axle 2	Axle 3
(feet)	(kips)	(ft)	(kips)	(kips)	(kips)	(kips)
0	1.71	0.00	1.71	1.71	0.00	0.00
1	1.71	1.00	1.71	1.71	0.00	0.00
2	1.71	1.00	1.71	1.71	0.00	0.00
3	1.71	1.00	1.71	1.71	0.00	0.00
4	1.71	1.00	1.71	1.71	0.00	0.00
5	1.71	1.00	1.71	1.71	0.00	0.00
6	1.71	1.00	1.71	1.71	0.00	0.00
7	2.21	3.00	2.21	0.00	2.21	0.00
8	2.21	1.00	2.21	0.00	2.21	0.00
9	2.21	1.00	2.21	0.00	2.21	0.00
10	2.21	1.00	2.21	0.00	2.21	0.00
11	4.43	1.00	4.43	0.00	2.21	2.21
12	4.43	1.00	4.43	0.00	2.21	2.21
13	4.43	1.00	4.43	0.00	2.21	2.21
14	2.21	1.00	2.21	0.00	0.00	2.21
15	2.21	1.00	2.21	0.00	0.00	2.21
16	2.21	1.00	2.21	0.00	0.00	2.21
17	2.21	1.00	2.21	0.00	0.00	2.21

Table 2 – Distributed Point Load Computation and Position

Once the number, position, and magnitude of the distributed point loads have been determined, they are applied directly to the culvert and moved across it in the same manner any truck is moved across a culvert with no fill. The critical position of the distributed point loads is then used to calculate the live load actions in the culvert. Note that this approach is slightly different than the AASHTO specification where the total load of 31 kips is uniformly applied over an 11 ft (3.5 + 4.0 + 3.5) length, or 2.82 kip/ft. The difference in load effect is relatively small.

BRASS-CULVERT™ distributes concentrated live loads longitudinally through fill by distributing the load uniformly over a length of the culvert as described in the *Longitudinal Live Load Distribution* section above. On first inspection, this method appears to vary from the method described in Articles 4.6.2.10.2 and 3.6.1.2.6 of the AASHTO LRFD Bridge Design Specifications. The difference is that a series of concentrated loads is used by BRASS-CULVERT™, and they are applied over a slightly shorter length than a true uniformly-distributed load.

The following formulation illustrates that the two methods, when applied to an influence surface, are effectively the same. First, consider the application of a series of concentrated loads to an influence surface, as shown in Figure 2.

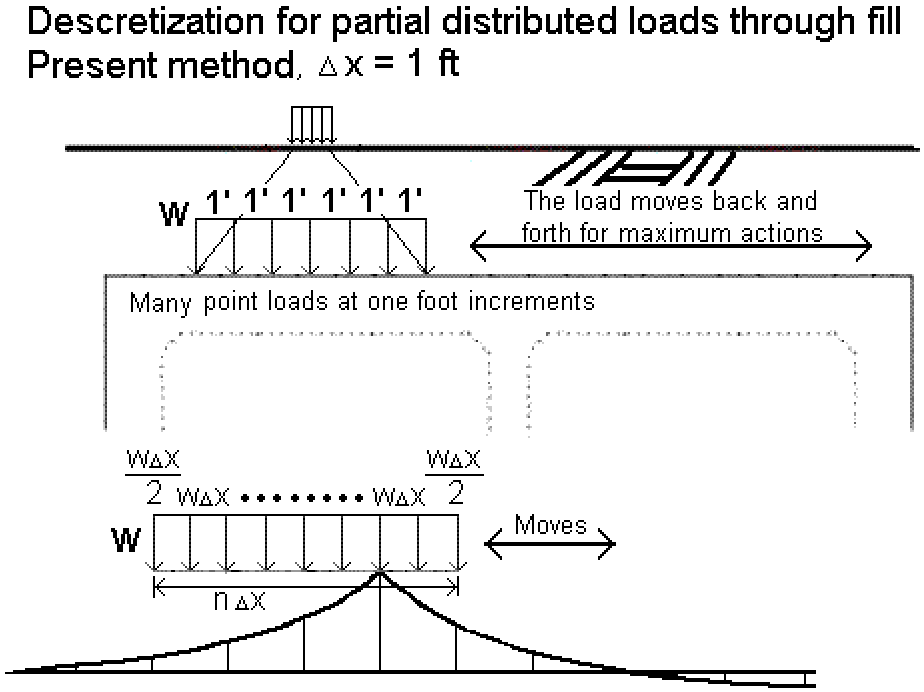


Figure 2 – Application of a Series of Concentrated Loads to an Influence Line

The load effect of a single concentrated load is determined as shown in Figure 3.

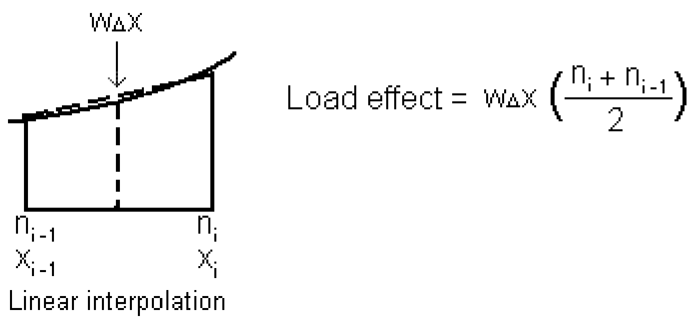
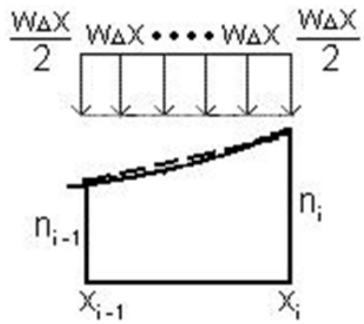


Figure 3 – Load Effect of a Single Concentrated Load

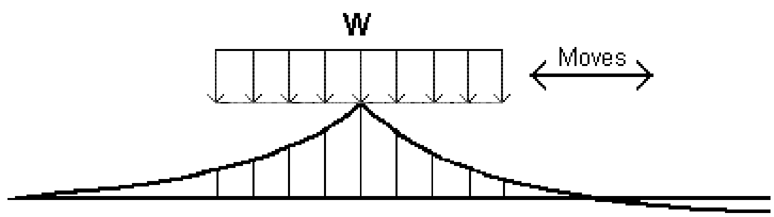
When a series of concentrated loads is considered, the total load effect is shown in Figure 4. Here, linear interpolation is used again which is the same as a resultant force.



$$\text{Load effect} = \sum_{j} \frac{w\Delta x}{2} n_{i-1} + w\Delta x\, n_j \cdots \frac{w\Delta x}{2} n_i$$

Figure 4 – Summation of a Series of Concentrated Loads

Next, consider the application of a true distributed load, w, to the same influence line. Figure 5 gives the total load effect for the distributed load as it is integrated over the influence line.



$$\text{Load effect} = \int_{x_s}^{x_e} wn(x)\,dx = w\int_{x_s}^{x_e} n(x)\,dx = w\,(\text{Area from } x_s \text{ to } x_e)$$

Figure 5 – Application of a Distributed Load to and Influence Line

The integrals can be expressed as shown below.

$$\text{Using trapezoidal rule, Area} = \sum \left(\frac{n_1}{2} + n_2 + n_3 \cdots n_{n-1} + \frac{n_n}{2} \right)$$

$$\text{Load effect} = w \sum \left(\frac{n_1}{2} + n_2 + n_3 \quad n_{n-1} + \frac{n_n}{2} \right) \Delta x$$

$$= \sum \left(\frac{w\, n_1}{2} \Delta x + w n_2 \Delta x + w n_3 \Delta x \cdots \frac{w\, n_n}{2} \Delta x \right)$$

Which is the same equation shown above in Figure 4.

$$\sum_{j} \frac{w\Delta x}{2} n_{i-1} + w\Delta x\, n_j \cdots \frac{w\Delta x}{2} n_i$$

Simplification of Uniform Load Effect

As can be seen from the derivations above, the methods produce the same final result.

Live Load Surcharge

By default, for ASD and LFD analyses, BRASS-CULVERT™ adds a two-foot live load surcharge on to the lateral load to simulate highway live loads when the cover is less than two feet. The user can override this behavior and enter an equivalent surcharge depth.

For an LRFD analysis, BRASS-CULVERT™ defaults to computing the surcharge height based on article 3.11.6.4. The user can choose to override this computation.

The user can input an equivalent fluid pressure for the live load surcharge. This is traditionally the same as the maximum at-rest fluid pressure.

Impact

Dynamic load allowance (impact) is applied per STD 3.8.2.3 and LRFD 3.6.2.2. Bottom slabs are not designed for impact.

Influence Lines (functions)

To generate influence lines, a concentrated load of one kip is moved across the culvert from left to right at a small increment. This increment is defaulted to 1/100th of the length of span. The one-kip load is evenly distributed as a uniform load along bottom of the culvert. For each position of the concentrated load, all actions at all ends of elements are calculated and stored. These stored actions become influence lines with ordinates at each increment of distance across each element of the culvert.

For the Standard Specification, the distribution areas for live loads are different for the top and bottom of the box, the uniform load on the bottom is multiplied by the ratio of the distribution factor to the bottom of the box divided into that used for the top. When the influence line is later used, the load applied includes the top distribution and this result in the appropriate load effect to the bottom. This ratio is reported near the influence line tables output in the .ILL file. See STD 17.6.4.3.

For the LRFD Specification, the live load distribution is assumed be the same for the top, side, and bottom slabs. Hence, this adjustment is not necessary. *Note that the distribution factor to the bottom slab, i.e., whether the same as the top or more distributed creates significantly different moments and associated reinforcement in the bottom slab.*

Moving Loads

The truck is moved incrementally across the top slab (influence line) in order to find the critical live load actions. The actions calculated for each increment of movement, are stored and compared to all actions resulting from previous truck positions. The truck is positioned moving both directions.

To obtain critical actions for all elements, BRASS-CULVERT™ moves the truck across an influence line in the same incremental steps as the concentrated load was moved across the culvert. At each position, the weight of each axle is multiplied times the influence line ordinate. Linear interpolation is used where axles fall between ordinates. The action is compared to the previously determined maximum action and, if greater, the current action becomes the stored maximum action. Similarly, the action is compared to the previously determined minimum action, and if less, the current action becomes the stored minimum action.

Load Sign Convention

The sign convention for the applied load and the internal actions is illustrated in the figure below. The positive sense is shown. The following loadings are applied:

The dead load is applied on top and automatically computed.

The self weight for the top slab is applied to top of the box.

The wall weight is applied to the bottom slab upward.

The bottom slab dead load is the top slab plus the wall weights.

The water load is applied outward.

No water load is applied vertically.

The equivalent hydrostatic soil pressure is applied inward on the exterior walls.

The soil pressure has upper and lower values.

The structure is analyzed for maximum and minimum soil pressures, and the most critical load effect is used.

The live load surcharge is a uniform lateral load.

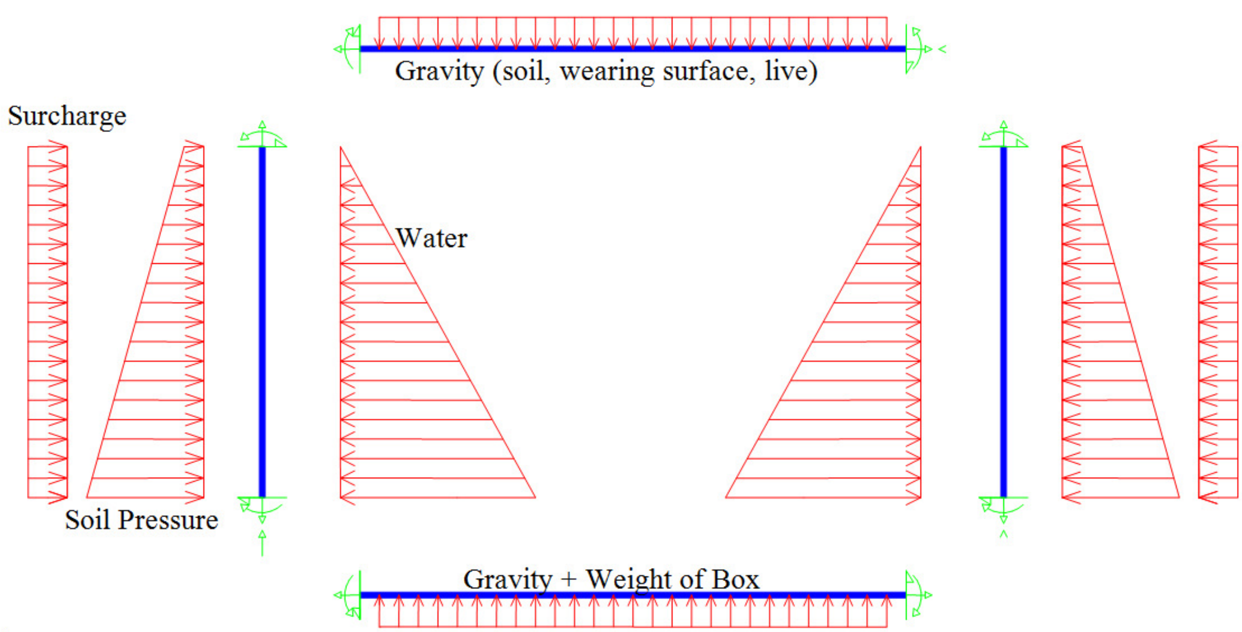
Applied uniform and concentrated dead loads are positive downward.

Live loads are applied downward and positioned for critical load effects.

The distributed live load is applied on the influence line.

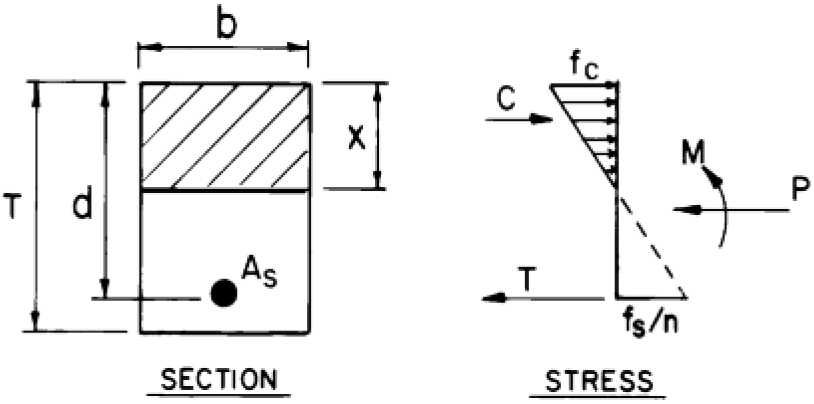
The positive senses of the internal actions are shown on the member.

The member references are reported in the output.



Service Load Design and Stress Computations for Service Limit States

The following procedure is used to compute the required area of steel at three critical sections of each member (left end, midpoint, right end). The steel stress is set to its allowable input value of f_s, and the height of the stress block is determined by an iterative process. No compression steel is considered and all tension steel assumed to be in one layer. This routine is used for service-level stress computations within the LFD process.



The AASHTO Subcommittee on Bridges and Structures recommended that the axial thrust be included when computing the tensile steel stress. See articles 16.6.4.7 in the Standard Specifications and C12.11.3 in the LRFD Specifications.

The axial load is considered as follows:

$$f_s = \frac{M_s + N_s\left(d - \frac{h}{2}\right)}{A_s ijd}$$

$$e = \frac{M_s}{N_s} + d - \frac{h}{2}$$

$$\frac{e}{d} \geq 1.15$$

$$i = \frac{1}{1 - \frac{jd}{e}}$$

$$j = 0.74 + 0.1\left(\frac{e}{d}\right) \leq 0.9$$

BRASS-CULVERT™ uses this process. Parametric studies by the development team have illustrated that this method is sufficiently close to the rigorous procedure based upon first principles to warrant inclusion and simplification. Note that the rigorous procedure was used in early version of the program but was difficult to validate for the user. The simplified method is readily verified by hand computations.

If no tension stresses exist (large P and small M), the concrete stress at the steel location, $f_{csteel} = Mc/I - P/A$, and the minimum amount of reinforcing steel is used.

The average shear stress (f_v) is computed as follows:

$f_v = V / b(d)$ where b = 12 inches

At the left end or right end of a member, where sections are located less than a distance d from the face of the support, the design is performed for the same shear is that computed at a distance d.

The default allowable concrete stress in compression is assumed to be $0.40f'_c$. (ASD only) The allowable concrete shear stress is computed as follows:

For fill height less than 2 feet:

$v_c = 0.95 \sqrt{f'_c}$ or

$v_c = 0.90 \sqrt{f'_c} + 1100(\rho)(V)(d) / M \le 1.6 \sqrt{f'_c}$

Whichever is greater.

ρ = reinforcement ratio = $A_s / b(d)$ *and* $V(d) / M \le 1.0$

For fill height greater than or equal to 2 feet:

$v_c = \sqrt{f'_c} + 2200(\rho)(V)(d) / M \le 1.8 \sqrt{f'_c}$

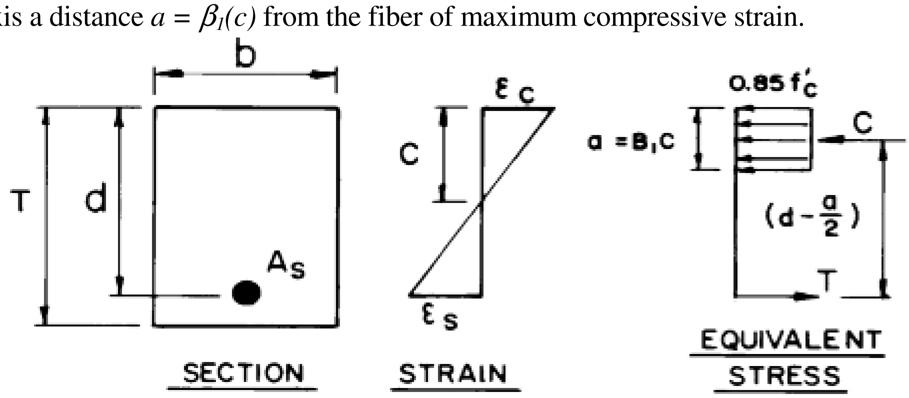
For single-cell box culverts only, $v_{cmin} = 1.4 \sqrt{f'_c}$.

ρ = reinforcement ratio = $A_s / b(d)$ and $V(d) / M \le 1.0$.

Strength Limit State Analysis For LFD and LRFD

The following procedure is used to compute the required area of steel at three critical sections of each member (left end, within the span (span), and right end).

1. Load Factors are outlined in STD 3.2.2 and in the LRFD in LRFD 3.4.1. DL includes concrete, soil and water dead loads. The effects of surcharge, live load, max/min pressure, and water are considered for critical load effects.
2. A concrete stress of $0.85(f'_c)$ is assumed uniformly distributed over an equivalent compression zone bounded by the edges of a cross section and a straight line located parallel to the neutral axis a distance $a = \beta_1(c)$ from the fiber of maximum compressive strain.



$\beta_1 = 0.85$ *or* $\beta_1 = 0.85 - 0.05(f'_c - 4000)/1000$ for f'_c greater than 4000 psi, but β_1 cannot be less than 0.65.

3. No compression steel is considered and all tension steel is assumed to be in one layer.
4. Compute A_s

   Set $R_u = \phi M_n / [\phi(b)(d^2)]$

   $\rho = 0.85(f'_c)[1 - \sqrt{1 - 2(R_u) / 0.85f'_c}] / f_y$ (required)

   $\rho_b = 0.85(\beta_1)(f'_c)(87000) / (87000 + f_y)$ (balanced condition)

   $\rho \leq 0.5\rho_b$ where $\rho \geq 0.002$

   $A_s = \rho bd$

5. Compute ϕM_n (Pure Flexure)

   $\phi M_n = \phi(A_s)(f_y)(d - a/2)$

   where $a = A_s(f_y) / 0.85(f'_c)(b)$
6. Compute P_o (Pure Compression)

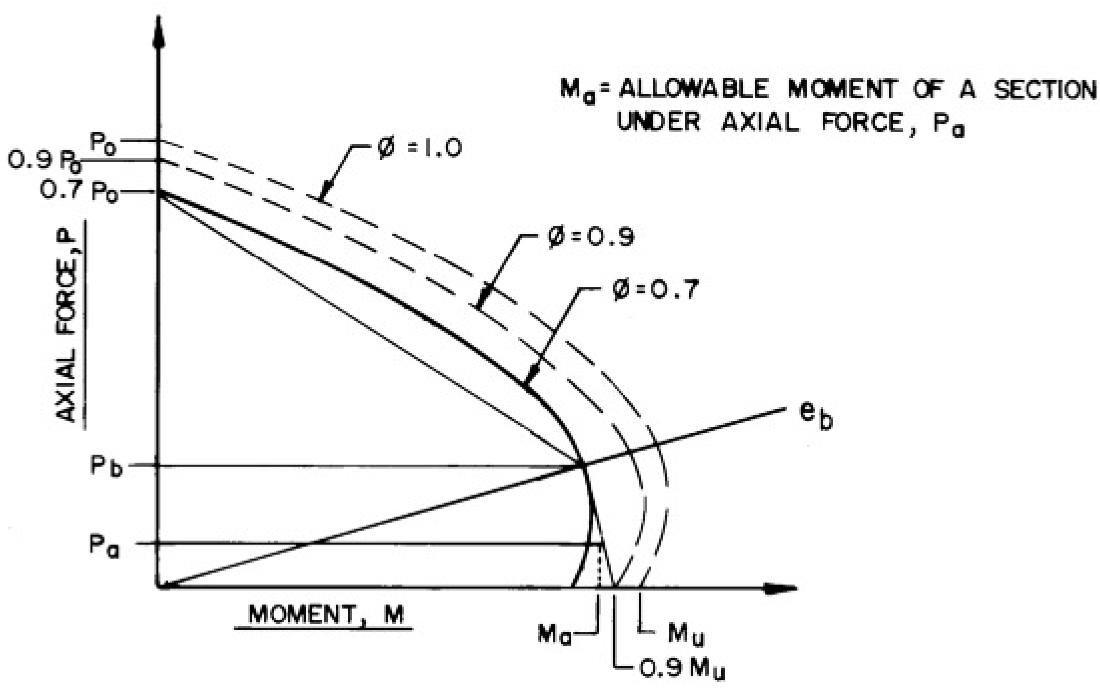
   $P_o = \phi[0.85(f'_c)(A_g - A_{st}) + A_{st}(f_y)]$

   $A_{st} = A_s + A_{s(min)}$
7. Compute P_b and M_b (Balanced Condition)

   $P_b = \phi[0.85(f'_c)(12)(a_b) - A_s(f_y)]$

   Where $a_b = 87000(\beta_1)(d) / (87000 + f_y)$

   $M_b = P_b(e_b) = \phi[0.85(f'_c)(12)(a_b)(T/2 - a_b / 2) + A_s(f_y)(d - T/2)]$
8. A straight-line interpolation between pure compression and balanced condition and balanced condition and pure flexure is used.



9. The shear stress (f_v) is computed as follows:

$f_v = \phi V_n / \phi(b)(d)$ where $b = 12$ inches

The allowable concrete shear stress is computed as follows:

For fill height less than 2 feet:

$\phi v_c = \phi 2 \sqrt{f'_c}$ or

$\phi v_c = \phi 1.9 \sqrt{f'_c} + \phi 2500(\rho)(V_u)(d) / M_u \leq 3.5\phi\sqrt{f'_c}$ whichever is greater.

$\rho = A_s / b(d)$ and $V_u(d) / M_u \leq 1.0$

For fill height greater than or equal to 2 feet:

$\phi v_c = 2.14\ \phi\sqrt{f'_c} + 4600\phi(\rho)(V_u)(d) / M_u \leq \phi 4 \sqrt{f'_c}$

For single-cell box culverts only, $\phi v_{cmin} = \phi 3 \sqrt{f'_c}$

ρ = reinforcement ratio = $A_s / b(d)$ and $V_u(d) / M_u \leq 1.0$

Resistance in terms of forces are obtained by multiplication by *bd*. Similar provision are found in LRFD 5.14.5. Note strengths are in ksi for LRFD and the coefficients are, therefore, different.

Fatigue Stress Limits

The fatigue stress limits on reinforcement due to the repeated application of live loads are evaluated. The range between a maximum and minimum stress in straight reinforcement caused by live load plus impact at service load shall not exceed:

$f_f = 24 - 0.33(f_{min}) + 2.4$ where f_f = stress range, ksi

f_{min} = algebraic minimum stress level, tension positive, compression negative, ksi

At a section where stress is not reversed:

$f_s = M / A_s(jd)$ where M = live load moment range

At a section where stress is reversed:

$f_s = (+M) / A_s(jd)$ (tensile part of stress range)

$f'_s = (-M)\{[k - (d'/d)] / (1 - k)\} / A_s(jd)$ (compressive part of stress range)

Total stress range = $f_s + f'_s$

A similar procedure is found in LRFD 5.5.3.2.

Crack Control

BRASS-CULVERT™ checks maximum service load stresses in the reinforcing steel for crack control per STD 17.6.4.7, 17.7.4.7 and LRFD 5.7.3.4. These articles often control the steel selection/area.

Optionally, a large *Z* may be used to avoid this article controlling. This is a check-box option in the UI. Axial force is considered in the computation of the service-level stresses.

Reinforcing Steel Design

During a reinforced concrete box culvert design, BRASS-CULVERT™ uses a Bar Library (BRASS-BarSpacing-Std.blb) to select the required area of steel, the bar spacing, and bar size. If the user wishes to modify or print the contents of the library, follow the directions in Chapter 3 of the Getting Started Manual. If you make changes to the library, be sure to save the library using the file name BRASS-BarSpacing-User.blb and specify "User" in the Bar Spacing File box on the Design Control Tab.

During a design, BRASS-CULVERT™ uses the first bar spacing/size combination from the Bar Library which has sufficient area of steel ($A_s > A_{req}$). It then checks to see if the spacing is between the maximum and minimum spacing specified on the Design Control tab in the GUI. If the spacing is between the spacings on the tab, it then checks the bar size to see if it is between the minimum and maximum size. If any of the three criteria are not met, the program looks at the next record in the Bar Library.

If the area of steel, the bar spacing, and bar size requirements are met, the program uses that combination to check crack control. If the bar size/spacing combination does not pass the checks for crack control, the program goes back to the next entry in the Bar Library and checks the next bar spacing/size entry until an appropriate combination is found. If no combination is found which meets the max/min entered in the GUI, the program exits with an error message stating that an acceptable combination could not be found.

The user has some control over this process. First, the contents of the Bar Library may be changed by the user to meet agency specifications. For example, if the user's agency prefers only certain bar size/spacing combinations, the user can move these combinations to the top of the list in the library and either delete combinations which the agency will not use or keep these combinations at the bottom of the list. The user can also add combinations to the library provided the bar size is constant (i.e. #5 at 6" and #6 at 6" is not yet permitted).

If the user wants to "fix" a particular bar spacing, simply enter the same value for the minimum spacing and maximum spacing. Similarly, if the user wants to "fix" a particular bar size, simply enter the same value for the minimum bar size and maximum bar size.

Minimum Reinforcement

Provision for Minimum Steel in Culverts

Standard Specifications

Type	Fill Depth	Article	Brief Description	BRASS
CIP	All depths	16.6.4.8	8.17.1 for all cross sections. Use temperature and shrinkage steel on inside faces per 8.20.	See below.
		8.17.1.1	A_{smin} greater or equal to amount required for 1.2 M_{cr}.	Uses lesser of this and 8.17.1.2.
		8.17.1.2	A_{smin} greater or equal to an amount 1/3 greater than that required from analysis.	Uses lesser of this and 8.17.1.1.
		8.20	At least 0.125 in2 per ft.	Uses A_s >0.002 A_g instead. This will only control is thickness is less than 5.2-in. Used 0.002 to be same for both CIP and P/C.
Precast – four sides	Less than 2-ft	16.7.4.8	0.002 A_g. 8.20 do not apply except for units with lengths over 16-ft. No guidance on fills greater than 2-ft[1].	As stated.
Precast – three sides	Less than 2-ft	16.8.5.8	0.002 A_g. 8.20 do not apply. No guidance on fills greater than 2-ft.	As stated.

[1] BRASS uses same minimum areas for fills greater than 2-ft, likely other criteria will control.

LRFD Specification

Type	Fill Depth	Article	Brief Description	BRASS
CIP	All depths	12.11.4.3.1	5.7.3.3.2 and 5.10.8.	As stated.
		5.7.3.3.2	A_{smin} greater or equal to amount required for 1.2 M_{cr}.	As stated.
		5.10.8	A_{smin} greater than 0.11 A_g/f_y. This is 0.0018 for grade 60 steel.	Conservatively uses greater of 5.7.3.3.2 and 0.0020 for all systems.
Precast – four sides	Less than 2-ft	12.11.4.3.2	0.002 A_g. 5.10.8 does not apply except for units with lengths over 16-ft. No guidance on fills greater than 2-ft.	Conservatively uses greater of 5.7.3.3.2 and 0.0020 for all systems.
Precast – three sides	Less than 2-ft	12.14.5.8	0.002 A_g , 5.10.8.2 does not apply. No guidance for fills greater than 2-ft[2].	Conservatively uses lesser of 5.7.3.3.2 and 0.0020 for all systems.
		5.10.8.2	A_{smin} greater than 0.11 A_g/f_y. This is 0.0018 for grade 60 steel.	Conservatively uses lesser of 5.7.3.3.2 and 0.0020 for all systems.

Minimum Eccentricity

Minimum eccentricity is checked for all members.

$$e = M / P$$

If e is less than 1", then e is set equal to 1"

If e is less than 0.1(T), then e is set equal to 0.1(T) where T = member thickness. This article will seldom, if ever, control for culverts.

Slenderness

Slenderness is checked per STD 8.16.5 and LRFD 5.7.4.3. Slenderness effects are often minimal and can typically be neglected but are included for completeness.

[2] Used same minimum areas for fills greater than 2-ft, likely other criteria will control.

Load Rating

Rating a Design

The program initially determines areas of steel required to satisfy moments, shears and axial forces from analysis. This area of steel is then checked for minimum area of steel requirements and fatigue stress limits and, if necessary, is increased. The program then selects a trial reinforcing bar size and spacing to satisfy this area of steel requirement and the reinforcement pattern selection is checked against the required limit states. The bar size and spacing are modified until all design limit states are satisfied.

The designed reinforcement pattern that appears in the Required Bar Reinforcement table in the output is used to obtain a moment inventory and operating load rating for each culvert member. For rating a design or an existing culvert, the allowable stress design portion of BRASS-CULVERT sets the allowable steel stress used for inventory rating at .6 * fy. The operating allowable stress varies based on the yield strength as follows per RATING 6.6.2.3:

fy >= 60 ksi - 0.6*fy

fy < 60 ksi and >= 50 ksi - 0.65*fy

fy < 50 ksi and >= 40 ksi - 0.7*fy

fy < 40 ksi - 0.7576*fy

The user cannot override these values. Note that axial load effects are used to rate the strength limit state only.

Rating an Existing Culvert

BRASS-CULVERT™ is used in review (analysis) mode. Here the reinforcement and wall thicknesses are known and defined. The program performs a design review, thereby checking all appropriate limit states. A rating is performed for flexural strength as part of this review. The rating resistance is based on the flexural allowable (capacity) given in the summary table and includes axial load effects. The soil pressure is assumed to be a maximum. Live load surcharge is considered a live load for rating. If there is no live load action at the point of interest, then no rating factor is produced. If a live load action exists at the point of interest, but the dead load action is greater than the capacity a zero rating factor will result.

LRFR Analysis

The Manual for Bridge Evaluation (*MBE*), *Second Edition/2011, 2014 Interims* by AASHTO outlines the method of analysis for load and resistance factor rating. The load rating section of the *MBE* is written primarily with bridge superstructures in mind, and gives no guidance on several issues that apply to culverts. This section outlines the approach taken to implement LRFR in BRASS-CULVERT™.

Limit State Applicability

The MBE clearly identifies the limit states to be applied for rating for various materials in Table 6A.4.2.2-1. This table also identifies the various load factors to be applied for different rating conditions (inventory, operating, legal, and permit). The table lacks specific load factors for several load cases applicable to culverts. These loadings include vertical and horizontal earth pressure, live load surcharge, and water pressure. Together with dead load component, dead load wearing surface, and live load, these loadings make up all the loadings considered by BRASS-CULVERT™. See Table 3 for the loadings considered for culverts. These loadings and associated factors are discussed in more detail in the following section.

For BRASS-CULVERT™, the only material option is reinforced concrete, as the program only considers precast and cast-in-place concrete box culverts. Therefore, only the reinforced concrete limit states are considered, i.e., Strength I, Strength II, and Service I.

Loading Applicability

Equation 6A4.2.1-1 in the MBE presents the basic load and resistance factor rating equation as:

$$RF = \frac{C - (\gamma_{DC})(DC) - (\gamma_{DW})(DW) \pm (\gamma_P)(P)}{(\gamma_{LL})(LL + IM)}$$

where:

$C = \varphi_c \varphi_s \varphi_n C_0$

C_0 = the computed nominal resistance of the section

φ_c = condition factor

φ_s = system factor

φ_n = LRFD resistance factor

γ_{DC} = LRFD load factor for structural components

γ_{DW} = LRFD load factor for wearing surfaces and utilities

γ_P = LRFD load factor for permanent loads other than dead loads

γ_{LL} = LRFD load factor for live loads

DC = Dead load effect due to structural components

DW = Dead load effect due to wearing surface and utilities

LL = Live load effect

IM = Dynamic Load Allowance

P = Load effect due to other permanent loads.

Culverts experience several loadings that are not applicable to most bridge superstructures, including water pressure and vertical and horizontal soil loads. In addition, the design specifications indicate that a live load surcharge should be applied as a lateral soil pressure. This loading accounts for a vehicle axle positioned just off the end of the culvert which creates additional soil pressure. See Figure 6 for a graphical illustration of typical culvert loads.

Horizontal earth pressures can create top slab moments with the opposite sense of vertical live loads. Horizontal earth pressures also result in axial forces in the top and bottom slabs of a culvert. Similarly, vertical loads on the top slab can counteract soil pressure on the exterior walls. All actions must, therefore, be considered as adding to, or subtracting from, the nominal resistance in the numerator of the rating factor equation. The appropriate maximum and minimum load factors should be considered for each loading.

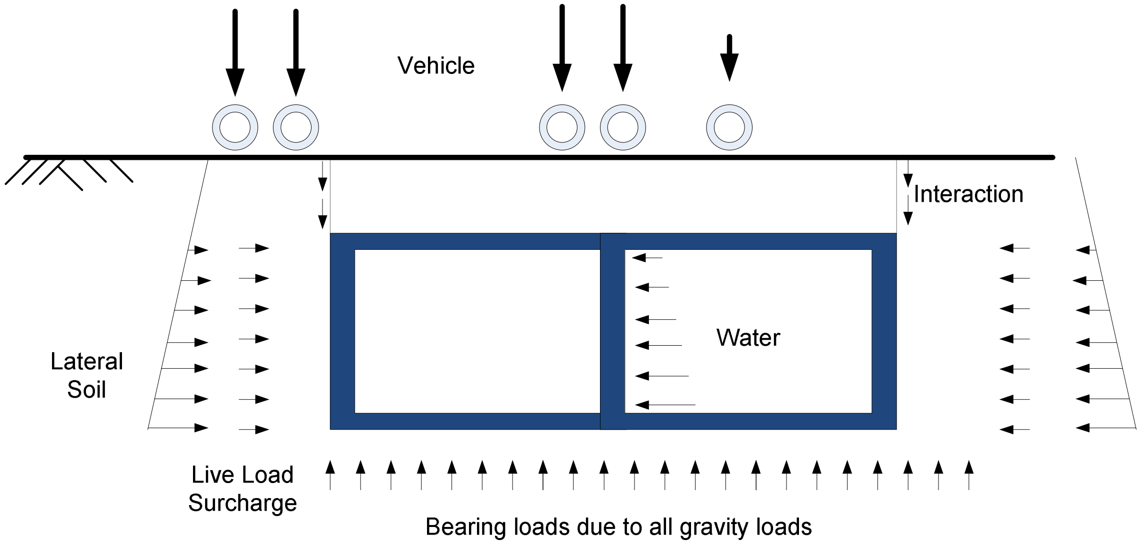


Figure 6. Culvert Loads (typical)

BRASS-CULVERT™ considers the live load surcharge actions as live loads; therefore they are placed with the other live loads in the denominator of the rating equation. Dynamic load allowance is not considered for live load surcharge, and live load distribution factors are not applied.

Based on these considerations, the load rating equation for culverts is considered as:

$$RF = \frac{C \pm (\gamma_{DC})(DC) \pm (\gamma_{DW})(DW) \pm (\gamma_{EH})(EH) \pm (\gamma_{EV})(EV) \pm (\gamma_{WA})(WA)}{(\gamma_{LL})(LL + IM) \pm (\gamma_{LL})(LS)}$$

where:

γ_{EH} = LRFD load factor for horizontal earth pressure

γ_{EV} = LRFD load factor for vertical earth pressure

γ_{WA} = LRFD load factor for vertical earth pressure

EH = Effects due to horizontal earth pressure

EV = Effects due to vertical earth pressure

WA = Effects due to water pressure

LS = Effects due to live load surcharge.

This equation is not available or prescribed in the MBE or elsewhere.

In the program analysis, a user has several options regarding the application of the live load surcharge in BRASS-CULVERT™. The maximum and minimum load factors can be modified in the same manner as the other loadings. Setting the maximum and minimum factors to zero results in a load effect being ignored. For example, water loads on an interior wall might be considered for design but not deemed important for evaluation.

The application of the live load surcharge may also be turned off in the live load combination input. A check box indicates whether or not the live load surcharge should be applied on a per-vehicle combination basis. This decision could be based upon consideration of vehicle length, axle configurations, etc.

Load and Resistance Factors

For the analysis of a culvert, application of a minimum load factor is required to compute the controlling actions in various members of the culvert. For example, a horizontal earth pressure on the exterior wall tends to produce a moment in the top slab that acts in the opposite sense of the live load moment generated by a vehicle loading on the top slab. For this reason, it was decided that load combinations should be computed with a maximum and minimum load factor for all loadings.

Table 3 shows the load factors specified in the MBE in Table 6A.4.2.2-1 and augmented with the additional factors required to perform a culvert rating. The values presented here are the defaults used by BRASS-CULVERT™, which users can change. As BRASS-CULVERT™ only considers mildly-reinforced concrete boxes, the other bridge types specified in the MBE are not considered.

The live load factors indicated as "Table Lookup" are based on the ADTT for Legal loads and the combination of ADTT, trip frequency, and vehicle weight for Permit loads. The program offers default values; however, users need to modify these values based on the specific vehicle and structure as required.

Table 3 - Load Factor Table for Culverts

Bridge Type	Limit State	DC		DW		Design		Legal	Permit	EH		EV		WA	
		max	min	max	min	Inventory	Operating			max	min	max	min	max	min
Reinforced Concrete	Strength I	1.25	0.9	1.5	0.65	1.75	1.35	1.4 (Table lookup)		1.35	0.9	1.3	0.9	1	1
	Strength II	1.25	0.9	1.5	0.65				1.3 (Table lookup)	1.35	0.9	1.3	0.9	1	1
	Service I	1	1	1	1				1	1	1	1	1	1	1

In order to force a case where a specific loading is ignored (e.g., no water load), the user can enter zero for the minimum load factor. The program will then analyze the case with the maximum load factor and the zero minimum load factors, which effectively ignores that loading. To completely skip a loading, both maximum and minimum factors can be set to zero.

The MBE specifies System Modification Factors for rating. These factors correspond to the Load Modifiers in the LRFD Specifications, except that they are applied to the resistance instead of the load. The MBE includes some vague language about the applicability of the System Modifiers as opposed to the Load Modifiers in article 6A4.2.4. Based on this, BRASS-CULVERT™ currently allows the user to enter values for both the System and Load Modifiers, all of which are defaulted to 1.0. It appears that the intent of the MBE is that the Load Modifiers be left at 1.0.

The various modifiers that apply to culverts are presented in Table 4. This is a summary of Tables 6A4.2.3-1 and 6A.4.2.4-1 from the MBE.

Condition Factors	
Structural Condition of Member	**φ_c**
Good or Satisfactory	1.00
Fair	0.95
Poor	0.85
System Factors	
Superstructure Type	**φ_s**
Slab Bridges	1.00

Table 4 - Condition and System Factors

Output File – A Brief Description

Reprint of Input

The file *.DAT is printed as part of the output. The input variables are also repeated in a different format with descriptive headings. This allows the engineer to check the input variables.

Unfactored Moments And Shears Due To Dead And Live Loads

This table provides a breakdown of moments, shears, and axial forces due to the dead and live loads acting on the culvert. It is output once for each live load when the program is in the review (analysis) mode, however, it may appear several times when in the design mode. This duplication appears because while in the design mode the program follows an iterative process to determine the required slab and wall thickness, and the table may be output for each trial until the final design is established. The user can control (omit) this repeated printing.

Computations and Results

The output is designed to be self-explanatory. Endnotes have been provided to illustrate/explain computations. Load computations are illustrated and distribution factors are computed. Note that the load combinations for factored loads are not usually obvious and the .ooo file (see below) might be reviewed for explanation.

Output Influence Line Tables

Influence line tables may be optionally printed. This can be a long printout for multiple-cell units. Influence line values are output for moment, shear, and axial force. This appears in the .ILL file.

Live Load Positioning

The .OLL file contains a detailed report on where the live loads are positioned for critical load effect. This file is typically not of interest to the user.

Detailed Computations

During development, extensive output was implemented in the program to monitor progress, assess the correctness, and aid debugging. This output was placed in a separate file with extension *ooo*. The formatting of the output varies, and will be improved with future releases. At present, many computations are illustrated with inputs, output, and intermediate computations for load factoring, rating factors, resistance, and specification checks.

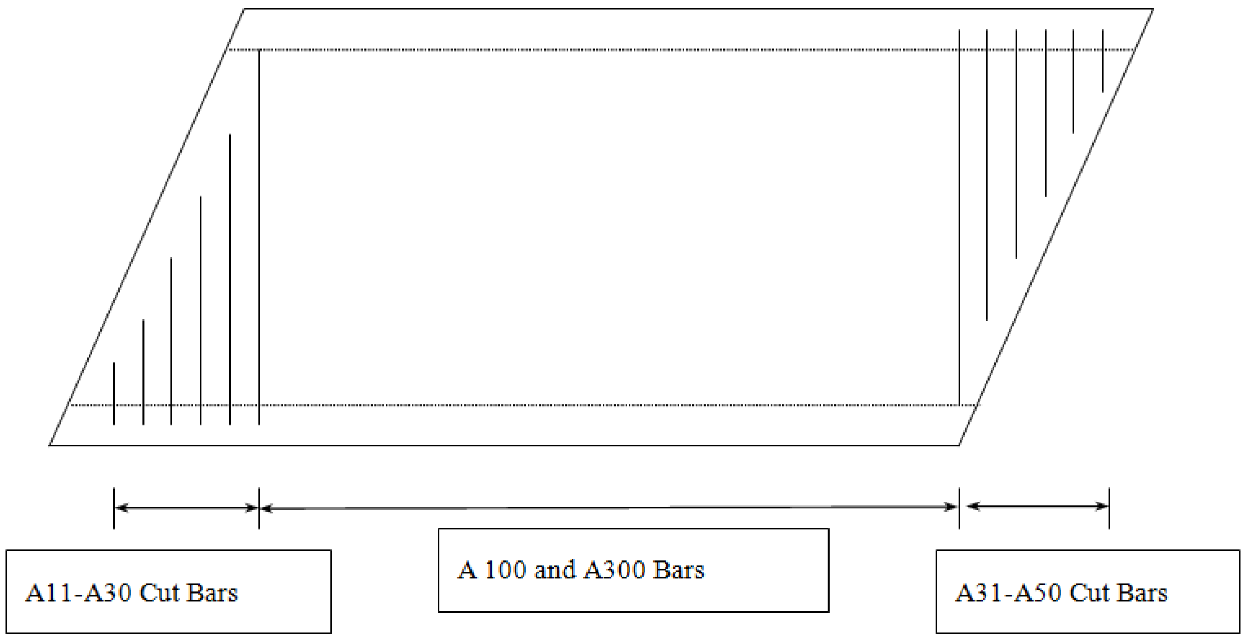
Bar Schedule

The following is a list of all the possible bar marks that may appear in the output. The bar marks in **bold** are the ones that are most common. "Cut bars" are the result of cast-in-place culverts having skewed ends. The cross section is shown below with the references.

Bar Designation	**Location/type**
A1	**Top corner bars (design steel).**
A2	**Bottom corner bars (design steel).**
A11 – A30	Top corner, left side cut bars.
A31 - A50	Top corner, right side cut bars.
A51 - A70	Bottom corner, left side cut bars.
A71 - A90	Bottom corner, right side cut bars.
A100	**Top slab, inside face transverse bars (design steel).**
A101 - A150	Top slab, inside face, left side cut bars.
A151 - A199	Top slab, inside face, right side cut bars.
A200	**Bottom slab, inside face transverse bars (design steel).**
A201 - A250	Bottom slab, inside face, left side cut bars.
A251 - A299	Bottom slab, inside face, right side cut bars.
A300	**Top slab, outside face transverse bars (design steel for multiple-cells).**
A301 - A350	Top slab, outside face, left side cut bars.
A351 - A399	Top slab, outside face, right side cut bars.
A401 - A450	Bottom slab, outside face, left side cut bars.
A451 - A499	Bottom slab, outside face, right side cut bars.
A400	**Bottom slab, outside face transverse bars (design steel for multiple-cells).**
B1	**Exterior wall, inside face vertical bars (design steel).**
B2	**Exterior wall, outside face vertical bars (design steel used in combination with A1 and A2 bar if a U-bar is not used).**
B3	**Interior wall, vertical bars (design steel both faces).**
C1	**Top slab, bottom slab, and wall longitudinal bars (temperature reinforcement).**
C100	**Top slab, inside face longitudinal bars (design distribution steel).**
C200	**Bottom slab, inside face longitudinal bars (design distribution steel).**
G1	Left side edge beam bars (see cast-in-place culverts with skewed ends).
G2	Right side edge beam bars (see cast-in-place culverts with skewed

Bar Designation	Location/type
S1	Left side edge beam bars (see cast-in-place culverts with skewed ends)

Reinforcement Layout



Typical Cut Set Bar Marks

Reinforcement Bar Types

Bar Type Abbreviation	Reference
STR	Straight bar
L-BAR	L-shaped bar
U-BAR	U-shaped bar

BRASS-CULVERT™ assumes that all reinforcing steel entered for a review or selected by the program for a design is fully developed. The Bar Schedule in the output does not include any lengths for embedment. It is left to the Engineer to determine this length.

Bar sizes range from #4 to #11. Bar spacings range from 3 to 12 inches. The user may control the ranges. The program assumes a 3/4-inch diameter reinforcing bar (#6) when locating design reinforcement. Therefore, when bar sizes #9, #10 or #11 are required by design, slab thicknesses are incremented by 1 inch to satisfy cover requirements.

When the clear height of the box is greater than 6 feet, then the bars **A1**, **A2**, and **B2** are arranged to have the same spacing so that Class C splices may be used.

When the clear height of the box is less than 6 feet, BRASS-CULVERT™ omits the **B2** bar and the vertical legs of the **A1** and **A2** are spaced together and overlap with a Class C splice. For multiple-cell culverts, the bars **A300** and **A400** match the above spacing. Note that some fabricators prefer to combine bars **A1**, **A2** and **B2** or **A1** and **A2** into one large U-shaped bar instead of separate bars.

When single-cell boxes have clear spans less than 5 feet, BRASS-CULVERT™ combines bars **A1** and **A300** into one U-shaped bar for the top mat of the top slab and bars **A2** and **A400** into one U-shaped bar for the bottom mat of the bottom slab. This U-shaped bar are given bar mark **A1** for the top slab and **A2** for the bottom slab and is displayed as a U-BAR in the bar schedule.

Epoxy-coated reinforcement should be considered when fill heights are less than 2 feet. This affects bars **A1**, **A300** and **C1**. When epoxy-coated bars are required, their bars are displayed as **AE1**, **AE300** and **CE1** in the bar schedule.

Splice Length Chart

BRASS-CULVERT™ computes and prints splice lengths for bars **B1**, **B3**, **C1**, **C100** and **C200** as per AASHTO Specifications. Bar splices for bars **A100**, **A200**, **A300** and **A400** are printed only if the required bar length exceeds 60 feet.