THE ANALYSIS AND DESIGN OF MULTIPLE-CELL BOX CULVERTS

A

Fortran IV-F

Computer Program

A USER'S MANUAL

Bridge Division

THE ANALYSIS AND DESIGN OF MULTIPLE-CELL BOX CULVERTS

COMPUTER PROGRAM

FORTRAN IV-F

BY

GLENN H. SIKES
HIGHWAY BRIDGE ENGINEER

A USER'S MANUAL

PRESENTED BY THE
State Highway Department of Georgia
BRIDGE DIVISION

R. L. CHAPMAN, JR.
STATE HIGHWAY BRIDGE ENGINEER

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FOREWORD

This program represents our first effort in the application of data processing to the analysis and design of multiple-cell box culverts. Actually this is the second version of the program. The first program was written in SPS II for use on an IBM 1620 computer. Later, when the IBM 360 computer was installed, the program was rewritten in Fortran IV. However, no changes in the program were made. So, essentially it is the same program.

The program is limited to the structural analysis and design of box culverts. That is, hydraulic designs are not considered, nor other types of culverts, i.e., pipes, arches, etc. There is no provision for live loads, although an additional fill height may be used in lieu of a uniform live load. The program is written in Fortran IV F-level programming language. Processing time requirements are insignificant on a third-generation computer. Core storage requirements are approximately 38^k, and the only I/O devices required are a card reader and printer.

Glenn H. Sikes
September, 1971
Atlanta, Georgia

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I. DESCRIPTION OF PROGRAM

This program will analyze and design a one, two, three or four cell reinforced concrete box culvert. All cells are assumed to be the same size for any one culvert and the clear opening dimensions remain constant during the design process. At the present time the program designs using only dead loads and lateral side pressures. However, an equivalent additional weight of fill may be used in the place of a uniform live load. No concentrated loads are permitted. No fillets are considered by the program in the analysis and design process. The omission of any small fillets that exist has an insignificant effect in the design process.

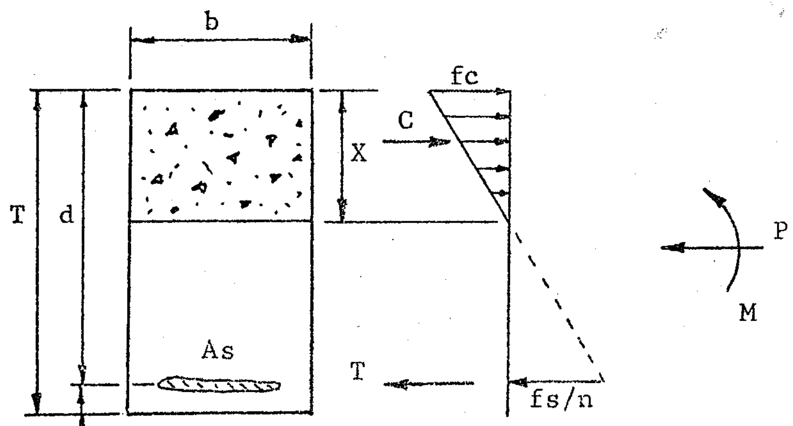
The program has provision for the designer to enter "design points". These "design points" are the positions in each member where the member is designed by using the moment, shear and thrust at these points. The "design points" may be the ends of the member (center line of supporting member), the quarter point of the supporting member, the edge of the supporting member or some point in the clear span. The point of maximum positive moment near the center of the span will automatically be considered a "design point".

The loads considered by the program are the weight of the fill, the side pressure of the fill and the dead load of the culvert. The load applied to the top slab is the sum of the weight of the fill and the weight of the top slab. The load applied to the bottom slab is the weight of the fill plus the weight of the top slab plus the weight of the walls spread uniformly over the total width of the culvert. Two loads are applied to the two exterior walls of the culvert: full side pressure and one-half the full side pressure.* No loads are applied to the interior walls. The combination of the two loads on the sides of the culvert with the vertical loads on the culvert gives a moment, shear and thrust envelope on each member for design purposes. The loads on the sides of the culvert are assumed to vary with the height of the culvert and will be trapezoidal in shape. The length of each member for analysis purposes will be from center line to center line of the supporting members.

Fixed-end moments are computed at the end of each member and then distributed by moment distribution. After each moment distribution the moments, shears and thrusts are computed at the "design points". The required thickness of each member is then computed and if any member thickness is increased the whole process of computing loads, moment distribution, etc., is repeated. This design process is repeated until each member thickness is adequate. When computing the required thickness of each member, the thickness is increased in increments of 1/4 inch until the actual stresses are equal to or less than the allowable stresses. The program will not decrease the thickness of a member from that entered in the input form. Therefore, it is important to enter member thicknesses that are less than or equal to the final required thicknesses. For example, the minimum size thicknesses required by construction would be ideal assumptions when designing for low-height fills.

*See Art. 1.2.19.paragraph 2 AASHO Specifications.

The following procedure (based on working stress design) is used to compute the required area of steel. The steel stress is set at 20,000 psi and the stress block found by an iteration process. No compression steel is considered and all tension steel is assumed to be in one layer.



2.44" = 2" clearance plus 1/2 (#7 bar diameter)

b = 12", d = T - 2.44", fs = 20,000 psi
n = 10

1. Mi = Me (Internal moment equals external moment)

$\sum M_{As} = 0$

$$fc(b)(\tfrac{1}{2})(d-\tfrac{X}{3}) = M + P(d-\tfrac{T}{2})$$

2. Linear Stress Distribution:

$$\frac{fc}{X} = \frac{fs/n}{d-X}$$

Equate 1 and 2 by eliminating fc.

$$\frac{X(fs)}{(d-X)n}\left(\frac{X}{2}\right)(b)\left(d-\frac{X}{3}\right) = M + P\left(d-\frac{T}{2}\right)$$

$$\left[\frac{fs(b)}{6(n)}\right]X^3 - \left[\frac{fs(b)d}{2(n)}\right]X^2 - \left[M + P(d-\tfrac{T}{2})\right]X + d\left[M + P(d-\tfrac{T}{2})\right] = 0$$

$$f(x) = C_1X^3 + C_2X^2 + C_3X + C_4$$

$$f'(x) = D_1X^2 + D_2X + D_3$$

Where: $C_1 = \frac{fs(b)}{6(n)} = 4.0$ $\quad D_1 = 3(C_1) = 12.0$

$C_2 = \frac{fs(b)(d)}{n(2)} = -12(d)$ $\quad D_2 = 2(C_2) = -24(d)$

$C_3 = M + P(d - \frac{T}{2})$ $\qquad D_3 = C_3$

$C_4 = C_3(d)$

The equation f(x) is solved by an iteration process using Newton's method for solving polynomial equations.

$$X_{n+1} = X_n - \frac{f(x)}{f'(x)}$$

The first value of X is found by assuming no reinforcing steel and an uncracked section (actual condition with large P and small M), i.e., tension resisted by concrete. If there are tension stresses the first value of X is the distance to the neutral axis from this analysis. If no tension stresses exist, the process is complete with no reinforcing steel. It can be shown that this iteration will always lead to the correct value of X, i.e., the desired root of the equation f(x).

The value of X is computed approximately to an accuracy of .01 inch. After computing the final value for X, the concrete stress fc is computed using equation 2 and the area of reinforcing steel is computed as follows:

$$^{*}As = \frac{T}{fs} = \frac{C-P}{fs} = \frac{\frac{1}{2}(fc)(X)(12) - P}{fs}$$

Then: $kd = X$ and $jd = d - \frac{kd}{3}$

NOTE: This design procedure is for minimum area of reinforcing steel. It is possible to use larger areas of steel at lower stress and decrease the member thickness required. However, the minimum area of steel design procedure will usually (not always) result in a cheaper structure.

The shear stress (fv) is computed as follows:

$$fv = \frac{V}{b(jd)}$$ where V equals the shear at the section.

The allowable concrete stress in compression is assumed to be 1200 psi. The allowable concrete shear stress in the walls of the culvert is assumed to be 90 psi and the allowable shear stress in the top and bottom slab may be 90 or 225 psi depending on an input code. The allowable bond stress is $4.8\,(f'c)^{\frac{1}{2}}/D$ for bottom bars (500 psi maximum), and $3.4\,(f'c)^{\frac{1}{2}}/D$ for top bars (350 psi maximum). f'c equals 3,000 psi and D equals the bar diameter.

*If As turns out to be negative, As is set equal to zero and the concrete stress found by direct solution of a cracked solution, i.e., no reinforcing steel required. However, in this case some minimum amount of reinforcing steel would be recommended.

In the design process the thickness of the members is increased if one of the following conditions exists:

1. fc is greater than 1,200 psi.
2. fv is greater than the allowable shear stress.
3. As is greater than 4.99 square inches; this being the maximum amount of reinforcing steel that can be placed in one layer in a 12 inch wide section.

The program computes the maximum bar size. This bar is the maximum bar size that can be used without exceeding the allowable bond stress. Bars in the bottom slab and bottom of walls are considered bottom bars. Bars in the top of the walls are bottom bars. The bars in the top slab may or may not be top bars. If the top slab is greater than 14.75 inches the bars are considered top bars. Otherwise, the bars in the top slab are bottom bars. Note that bond calculations are unnecessary at the maximum positive moment sections.

$\sum^{r} o = \frac{V}{fb(jd)}$ = required perimeter so that the allowable bond stress(fb) is not exceeded.

$\sum^{f} o = \frac{As(Pb)}{Asb}$ = furnished perimeter; where Pb and Asb are the perimeter and area of the maximum bar size.

$\sum^{f} o \geq \sum^{r} o$ for the maximum bar size.

If a bar size is used that is greater than the maximum bar size, anchorage bond must be considered for bar development. If a bar is used that is less than or equal to the maximum bar size, the allowable bond stress is not exceeded. The program only considers bar sizes 2 thru 11.

In some designs, especially with high fills, it becomes economical to use stirrups in the top and bottom slab to reinforce for shear rather than increasing the thickness of the top and bottom slab. In this case an allowable shear stress of 225 psi [.075 (f'c), f'c= 3000 psi] may be used in lieu of the 90 psi allowable for no web reinforcement. The program will then compute the stirrup spacings assuming one number 4 bar (vertical).

$$S = \frac{Av(f'v)jd}{(V-Vc)} = \frac{4000(jd)}{(jd)(b)(fv-fva)} = \frac{333.333}{(fv-90)}$$

Vc = .09(b)(jd) Av = 0.20 sq. in. fva = allowable shear stress.

f'v = 20,000 psi V = fv(b)(jd)

Maximum S is assumed to be the member thickness T.

This program has provision for analyzing (reviewing) an existing culvert. In this case the input is coded for "constant thickness" and the output of moments, stresses, etc., are computed using the input member thicknesses.

The dead load weight of the culvert (concrete) is assumed to be 150 lbs. per cubic foot.

This program also has provision for designing several different fill heights for the same size culvert (opening). In order to design a culvert for 10 ft. to 80 ft. fill heights in increments of 10 ft., the initial fill height (10 ft.), increment of fill height (10 ft.) and final fill height (80 ft.) must be given in the input form. In this way several design problems may be run with a minimum of input (two cards). In this process the final thicknesses of members in the preceding design are used as minimum thicknesses in the next height of fill design. Therefore, the initial height of fill must be the minimum height of fill. Note that the allowable shear stress in the top and bottom slab is constant for all fill height designs.

II. INPUT DATA REQUIREMENTS

IDENTIFICATION

The Identification card (* in c.c. 1) is used to enter the problem number (c.c. 5-8), the fill height or initial fill height (c.c. 9-11) and any remarks that are desired to head the output listing. Only one Identification card can be used. Always enter the project number, county, your name and date.

CULVERT DATA (1 in c.c. 1)

1. Number of Cells (c.c. 2) Form: x

   Enter the number of cells (1,2,3,4) in card column (c.c.) 2.

2. Code for Constant Thickness (c.c.3) Form: 1 or blank

   If the thicknesses of the members are to remain constant (review), enter the digit one (1) in c.c. 3, otherwise leave c.c. 3 blank or enter a zero (0) to denote a design problem.

3. Code for Allowable Shear Stress (c.c.4) Form: 1, 0 or blank

   Enter the digit one (1) in c.c.4 if the allowable shear stress is 90 psi in the top and bottom slab. If the allowable shear stress in the top and bottom slab is 225 psi, leave c.c.4 blank or enter a zero (0).

4. L_C (c.c. 5-9) Form: xxx.xx inches.

   The clear span length (opening) of the cells in inches is entered in this data field.

5. H_C (c.c. 10-14) Form: xxx.xx inches

   The clear span height (opening) of the cells in inches is given as H_C.

6. T_E (c.c. 15-18) Form: xx.xx inches

   The minimum thickness of the exterior walls in inches should be entered in this data field.

7. T_T (c.c. 19-22) Form: xx.xx inches

   The minimum thickness of the top slab in inches is entered as T_T.

8. T_B (c.c. 23-26) Form xx.xx inches

   The minimum thickness of the bottom slab in inches is given as T_B.

NOTE: In a review (analysis) problem the wall and slab thicknesses are actual or existing thicknesses.

9. T_I (c.c. 27-30) Form: xx.xx inches

The minimum thickness of the interior walls in inches is given here. When the culvert has only one cell this dimension must be entered and be equal to the T_E dimension.

The L_C, H_C, T_E, T_T, T_B, and T_I dimensions cannot be equal to zero (0) and must never be left blank.

10. D_H (c.c. 31,32) Form: xx feet

Enter the increment of fill height in this data field.

11. FFH (c.c.33-35) Form: xxx feet

This data field is for entering the final fill height.

If the culvert is to be designed for only one fill height, the final fill height must be equal to the beginning fill height.

12. W_S (c.c. 36-38) Form xxx $lbs./ft.^3$

Enter the weight of the fill soil in this input data field. Any reduction of the soil weight according to Article 1.2.2(A) of the AASHO Specifications must be made before the weight is entered., i.e., the program does not reduce the value.

13. W_{SP} (c.c. 39-41) Form xxx $lbs./ft.^2/ft.$

Enter the full lateral side pressure intensity in pounds per square foot per foot of fill height in this input data field.

14. K_{TL} (c.c. 42-45) Form x.xxx ratio

K_{TL} is the ratio of the distance to the left design point of the top slab from the left end, to the exterior wall thickness. A value of one-half (0.50) places the design point at the edge of the wall regardless of the thickness of the wall.

15. K_{TR} (c.c. 46-49) Form x.xxx ratio

Enter in this data field the ratio of the distance to the right design point of the top slab from the right end, to the interior wall thickness.

16. K_{SL} (c.c. 50-53) Form x.xxx ratio

The ratio of the distance to the left design point of the exterior (or interior) wall from the left end, to the bottom slab thickness, should be entered in this data field.

17. K_{SR} (c.c. 54-57) Form: x.xxx ratio

Enter the ratio of the distance to the right design point of the exterior (or interior) wall from the right end, to the top slab thickness in this data field.

18. K_{BL} (c.c. 58-61) Form: x.xxx ratio

Enter in this data field the ratio of the distance to the left design point of the bottom slab from the left end, to the interior wall thickness.

19. K_{BR} (c.c. 62-65) Form: x.xxx ratio

Enter in this data field the ratio of the distance to the right design point of the bottom slab from the right end, to the exterior wall thickness.

NOTE: By using ratios of supporting member thicknesses to express the distance to the design points, the design points can be specified at quarter-points and edges of supporting members even though the supporting member thicknesses may vary, i.e., the ratios remain constant. When the supporting member thickness increases, the distance to the design point is recomputed by multiplying the ratio times the new thickness.

GA. DEPT. OF TRANSPORTATION
BRIDGE DESIGN OFFICE

MULTIPLE-CELL BOX CULVERT
ANALYSIS AND DESIGN

IDENTIFICATION

BEG. FILL HT.

1	PROG	PROB. NO.	↓	PROJECT NUMBER, COUNTY, NAME, DATE, REMARKS 51 61 65
*	B07			

66 — 80

NUMBER OF CELLS.

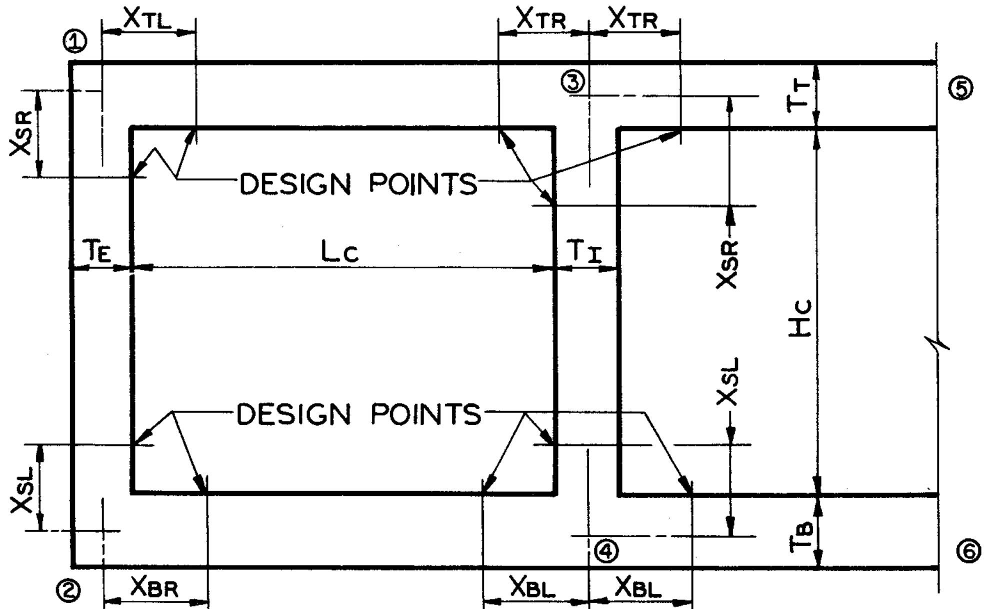
"1" THICKNESS OF MEMBERS REMAIN CONSTANT (REVIEW).
"0" THICKNESS OF MEMBERS DETERMINED BY ALLOWABLE STRESSES (DESIGN).

"1" ALLOWABLE SHEAR STRESS = 90 P.S.I.
"0" ALLOWABLE SHEAR STRESS = 225 P.S.I.

CULVERT DATA

1	↓	↓	↓	5 L_C 9	H_C 14	T_E 18	T_T 22	T_B 26	T_I 30	D_H	FFH	W_S	41 W_{SP}	K_{TL}	51 K_{TR}	K_{SL}	K_{SR}	61 K_{BL}	65 K_{BR}
1				.	.	.	.	.	.					.	.	.	.	.	.

FILL HT'S. ARE GIVEN IN FEET.
CULVERT DIMENSIONS ARE GIVEN IN INCHES.
$n = E_S/E_C = 10$



D_H - INCREMENT OF FILL HT.
FFH - FINAL FILL HT.
W_S - WT. OF SOIL, LBS/FT.^{3}
W_{SP} - SIDE PRESSURE PER FOOT OF FILL HT., LBS/FT.^{2}/FT.
K_{XX} - INPUT DATA ARE RATIOS OF DISTANCES TO DESIGN POINTS AND MEMBER THICKNESS.

$K_{TL} = X_{TL}/T_E$
$K_{TR} = X_{TR}/T_I$
$K_{SL} = X_{SL}/T_B$
$K_{SR} = X_{SR}/T_T$
$K_{BL} = X_{BL}/T_I$
$K_{BR} = X_{BR}/T_E$

NUMBER OF CELLS CANNOT EXCEED FOUR (4).
ALLOWABLE STRESSES:

f_C = 1,200 P.S.I.
f_S = 20,000 P.S.I.
f_V = 90 P.S.I. IN WALLS, 90 OR 225 P.S.I. IN TOP AND BOTTOM SLAB.
f_B = 180 P.S.I. TOP BAR
300 P.S.I. BOTTOM BAR

III. OUTPUT DATA

IDENTIFICATION

The information entered in the Identification card of the input form will head the output listing. The fill height for each design of fill height will also be given with the identification. One page of Output Data is given for each height of fill.

ANALYSIS OF CULVERT LOADS DATA

Thrust (Axial Force), Shear, Moments and Distances

The moments, shears, thrusts and distances are given at the following locations in each member for the two loading conditions: full side pressure plus vertical loads and one-half side pressure plus vertical loads.

A. THRUST (LBS.)

1. Left end of member (LT.END).
2. Right end of member (RT.END).

B. SHEAR (LBS.)

1. Left end of member (LT.END).
2. Left design point (LT.X).
3. Right design point (RT.X).
4. Right end of member (RT.END).

C. MOMENTS (FT.-LBS.)

1. Left end of member (LT.END).
2. Left design point (LT. X).
3. Left quarter point (1/4 L).
4. Maximum positive moment (MAX (+)).
5. Right quarter point (3/4 L).
6. Right design point (RT.X).
7. Right end of member (RT.END).

D. DISTANCES (IN.) TO

1. From left end to left contraflecture point (LT.CNF).
2. From left end to point of maximum positive moment (MAX.+MT).
3. From right end to right contraflecture point (RT.CFX).

The information in parentheses appears as headings in the output listing.

NOTE: Distances to contraflecture points can be used to assist in bar cut-offs and used as points for bending bars from one face to the other.

Two lines of data are given for each member; one-half side pressure data is given first, denoted by the letter "H" after the member number, and full side pressure data is given second denoted by the letter "F" after the member number. The member numbers are as follows (See sketch on input form):

2-1 H - Left exterior wall.
One-half side pressure data.

1-3 F - Top slab leftmost cell.
Full side pressure data.

4-2 - Bottom slab leftmost cell.

3-4 - First (leftmost) interior wall.

3-5 - Top slab second cell from left.

6-4 - Bottom slab second cell from left.

5-6 - Second (center) interior wall.

No data is given for members that would be a repeat of the data for a member already given. The first digit in the member number denotes the left end of the member and the second digit denotes the right end of the member.

For sign conventions consider yourself looking at each member from inside the leftmost cell. Then a negative moment will cause tension on the outside of the members and a positive moment causes tension on the inside of the members. A positive shear acts outward on the left of the member and inward on the right of the member. A negative shear acts inward on the left of the member and outward on the right end of the member. A positive thrust denotes compression and a negative thrust causes tension.

Note that the data for the bottom slab will be reversed since these members are looked at from above which causes the normal left end to become the right end.

CULVERT DESIGN DATA

The following data will be given at the three design points in each member for the two loading conditions: One-half side pressure plus vertical loads and full side pressure plus vertical loads.

A. LEFT DESIGN POINT (X)

1. Concrete shear stress (FV).
2. Steel stress (FS).
3. Concrete compression stress (FC).
4. Area of steel (AS).
5. Stirrup spacing (SS).
6. Maximum bar size (MBS).

B. Maximum Positive Moment Point (MAX. POS. MT. POINT)

1. Steel stress (FS).
2. Concrete compression stress (FC).
3. Area of steel (AS).

C. RIGHT DESIGN POINT (X).

1. Concrete shear stress (FV).
2. Steel stress (FS).
3. Concrete compression stress (FC).
4. Area of steel (AS).
5. Stirrup spacing (SS).
6. Maximum bar size (MBS).

D. Distances to Fv = 90 psi (X TO FV = 90).

1. Distance from left end of member to point where the shear stress is equal to 90 psi (LT).

2. Distance from right end of member to point where the shear stress is equal to 90 psi (RT).

The information in parentheses appears as headings in the output listing. The required thickness of each member is given on the left of the output sheet immediately after the member number (X-X). The member number notation is the same as previously defined.

Two lines of data are given for each member: one-half side pressure data is given first, denoted by the letter "H" after the member number, and full side pressure data is given second denoted by the letter "F" after the member number. No data is given for members that would be a repeat of the data for a member already given. The first digit of the member number denotes the left end of the member and the second digit denotes the right end of the member. Note that the data for the bottom slab will be reversed since these members are looked at from above which causes the normal left end to become the right end.

A negative steel stress indicates tension in the steel. All stresses are given in pounds per square inch. Thicknesses, stirrup spacings and distances to Fv = 90 psi are given in inches. Areas of steel are given in square inches. The bar size No. is the standard bar size notation. The maximum bar size is the largest bar size that satisfies the following equation:

$$\sum o = \frac{(As)(Psmb)}{Asmb}$$

Where: $\sum o$ = Required perimeter of steel based on allowable bond stress.

As = Area of steel.

Psmb = Perimeter of one bar of reinforcing steel.

Asmb = Area of one bar of reinforcing steel.

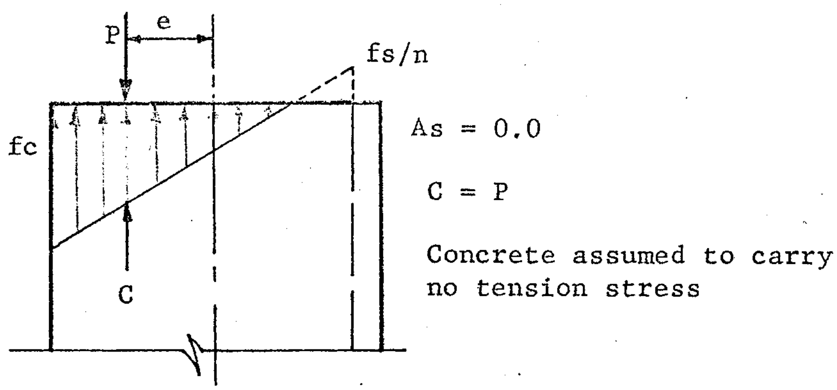
A letter code (T or B) immediately follows the maximum bar size. The letter T indicates the steel area is treated as a top bar and the letter B denotes a bottom bar.

The stirrup spacing is based on one number four (4) bar per 12 inch wide section (longitudinal) and is measured transversely.

The last line of the output data will contain a partial list of the input data. In addition the X_{TL}, X_{TR}, X_{SL}, X_{SR}, X_{BL}, X_{BR} dimensions (See sketch on input form) are given from the end of the members to the "design points".

NOTE: The "Distance to Fv = 90" indicates the distance the stirrups must be extended, i.e., no stirrups required past this distance.

If the area of steel is given as zero, it indicates that reinforcing steel is not really essential to carry the loads (M and P), i.e., use minimum required by appropriate specifications. The following stress diagram results:



VI. EXAMPLE PROBLEM

This example problem is for a two-cell box culvert with eight feet by eight feet clear openings. The culvert is to be designed for a ten foot and twenty foot fill height. Unit weight of the fill material is 120 pounds per cubic foot; but, since this value can be reduced 30%, the input value will be 84 pcf, i.e., 0.70 (120) = 84.0. The allowable shear stress is 90 psi so that no stirrups will be required. Design points near the ends of the members (walls and slabs) are assumed to be at the edge of the supporting members. This gives ratios (K_{XX}) equal to one-half. The side pressure is assumed to be 40 pounds per square foot per foot of fill height.

The input data is shown on the following page, and the output data for the two fill height designs are shown on pages 14,15. Page 16 contains a cross section of the 20 foot fill height design as determined by the program.

GA. DEPT. OF TRANSPORTATION
BRIDGE DESIGN OFFICE

MULTIPLE-CELL BOX CULVERT
ANALYSIS AND DESIGN

IDENTIFICATION

BEG. FILL HT.

1	PROG	PROB. NO	BEG. FILL HT.	PROJECT NUMBER, COUNTY, NAME, DATE, REMARKS (51, 61, 65; 66–80)
*	B07	EX. 1	10	EXAMPLE OF TWO CELL BOX CULVERT 8-0 X 8-0

NUMBER OF CELLS.

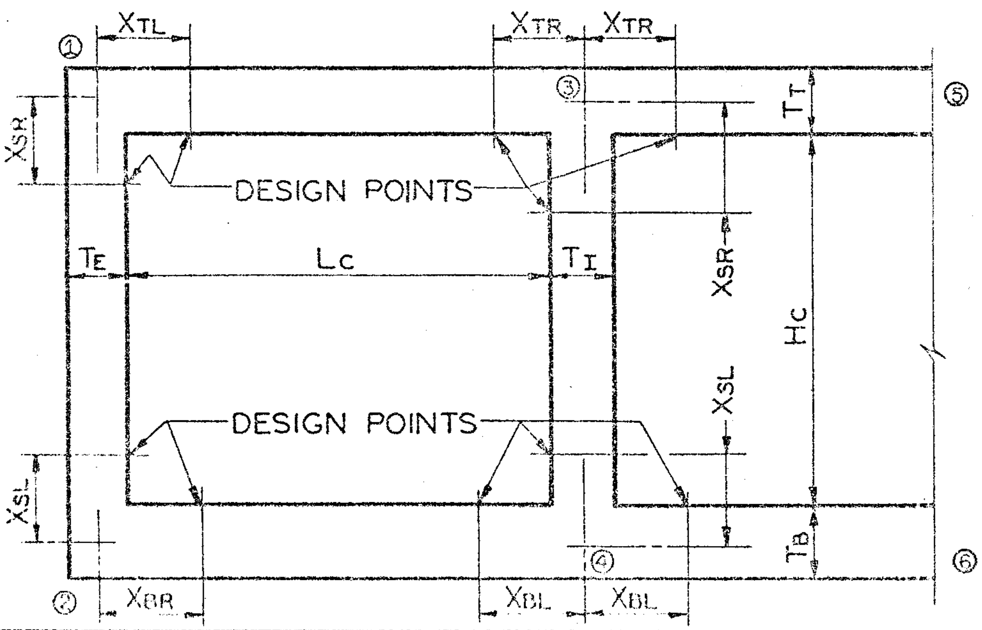
"1" THICKNESS OF MEMBERS REMAIN CONSTANT (REVIEW).
"0" THICKNESS OF MEMBERS DETERMINED BY ALLOWABLE STRESSES (DESIGN).

"1" ALLOWABLE SHEAR STRESS = 90 P.S.I.
"0" ALLOWABLE SHEAR STRESS = 225 P.S.I.

CULVERT DATA

1	No. of cells	Review/Design	Shear	5 L_C 9	H_C 14	T_E 18	T_T 22	T_B 28	T_I 30	D_H	FFH	W_S	W_{SP} 41	K_{TL}	K_{TR}	K_{SL} 51	K_{SR}	K_{BL} 61	K_{BR} 65
1	2	0	1	96.00	96.00	6.00	6.00	6.00	6.00	10	20	84	40	0.500	0.500	0.500	0.500	0.500	0.500

FILL HT'S. ARE GIVEN IN FEET.
CULVERT DIMENSIONS ARE GIVEN IN INCHES.
$n = E_S/E_C = 10$



D_H - INCREMENT OF FILL HT.
FFH - FINAL FILL HT.
W_S - WT. OF SOIL, LBS/FT^3
W_{SP} - SIDE PRESSURE PER FOOT OF FILL HT., $LBS/FT^2/FT$.
K_{XX} - INPUT DATA ARE RATIOS OF DISTANCES TO DESIGN POINTS AND MEMBER THICKNESS.

$K_{TL} = X_{TL}/T_E$
$K_{TR} = X_{TR}/T_I$
$K_{SL} = X_{SL}/T_B$
$K_{SR} = X_{SR}/T_T$
$K_{BL} = X_{BL}/T_I$
$K_{BR} = X_{BR}/T_E$

NUMBER OF CELLS CANNOT EXCEED FOUR (4).
ALLOWABLE STRESSES:

f_C = 1,200 P.S.I.
f_S = 20,000 P.S.I.
f_V = 90 P.S.I. IN WALLS, 90 OR 225 P.S.I. IN TOP AND BOTTOM SLAB.
f_B = 180 P.S.I. TOP BAR
300 P.S.I. BOTTOM BAR

GA. DEPT. OF TRANSPORTATION
BRIDGE DESIGN OFFICE

MULTIPLE-CELL BOX CULVERT
ANALYSIS AND DESIGN

IDENTIFICATION

BEG. FILL HT.

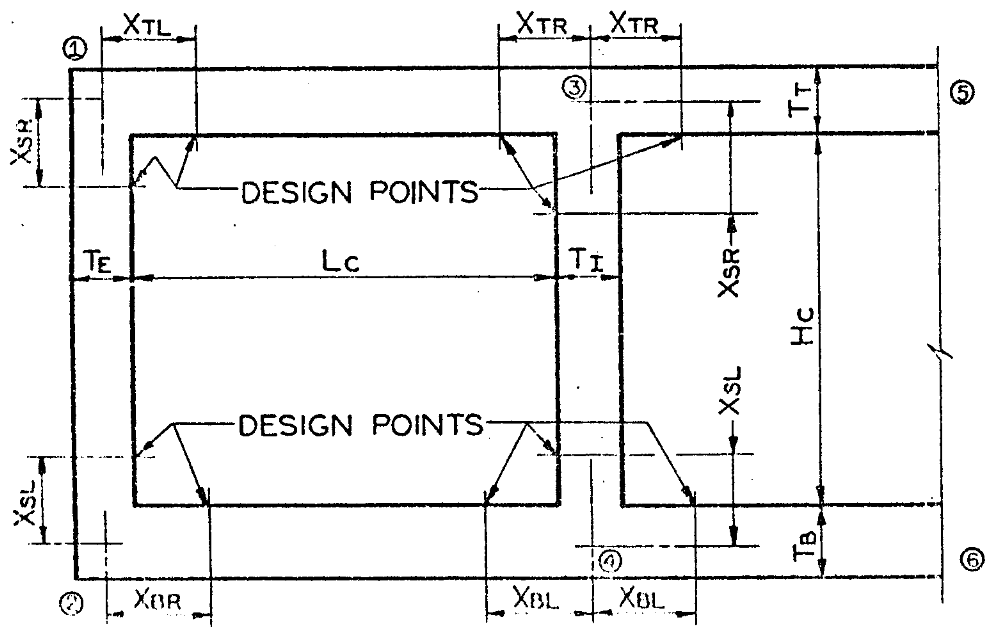
1 PROG	PROB. NO.		PROJECT NUMBER, COUNTY, NAME, DATE, REMARKS (51, 61, 65; 66–80)
* B07	EX. 1	10	EXAMPLE OF TWO CELL BOX CULVERT 8-0 X 8-0

- NUMBER OF CELLS.
- "1" THICKNESS OF MEMBERS REMAIN CONSTANT (REVIEW).
  "0" THICKNESS OF MEMBERS DETERMINED BY ALLOWABLE STRESSES (DESIGN).
- "1" ALLOWABLE SHEAR STRESS = 90 P.S.I.
  "0" ALLOWABLE SHEAR STRESS = 225 P.S.I.

CULVERT DATA

1				5 L_C 9	H_C 14	T_E 18	T_T 22	T_B 28	T_I 30	D_H	FFH	W_S	W_{SP} 41	K_{TL}	K_{TR}	K_{SL} 51	K_{SR}	K_{BL} 61	K_{BR} 65
1	2	0	1	96.00	96.00	6.00	6.00	6.00	6.00	10	120	84	40	0.500	0.500	0.500	0.500	0.500	0.500

FILL HT'S. ARE GIVEN IN FEET.
CULVERT DIMENSIONS ARE GIVEN IN INCHES.
$n = E_S/E_C = 10$



D_H - INCREMENT OF FILL HT.
FFH - FINAL FILL HT.
W_S - WT. OF SOIL, LBS/FT.³
W_{SP} - SIDE PRESSURE PER FOOT OF FILL HT., LBS/FT.²/FT.
K_{XX} - INPUT DATA ARE RATIOS OF DISTANCES TO DESIGN POINTS AND MEMBER THICKNESS.

$K_{TL} = X_{TL}/T_E$
$K_{TR} = X_{TR}/T_I$
$K_{SL} = X_{SL}/T_B$
$K_{SR} = X_{SR}/T_T$
$K_{BL} = X_{BL}/T_I$
$K_{BR} = X_{BR}/T_E$

NUMBER OF CELLS CANNOT EXCEED FOUR (4).
ALLOWABLE STRESSES:

f_C = 1,200 P.S.I.
f_S = 20,000 P.S.I.
f_V = 90 P.S.I. IN WALLS, 90 OR 225 P.S.I. IN TOP AND BOTTOM SLAB.
f_B = 180 P.S.I. TOP BAR
300 P.S.I. BOTTOM BAR

GEORGIA DEPARTMENT OF TRANSPORTATION

HIGHWAY DIVISION - BRIDGE DESIGN OFFICE

08/22/72 THE ANALYSIS OR DESIGN OF MULTIPLE-CELL BOX CULVERTS PROB. NO. EX.1

EXAMPLE OF TWO CELL BOX CULVERT 8-0 X 8-0

- 10 FEET FILL -

ANALYSIS OF CULVERT LOADS DATA

	THRUST(LBS.)		*	SHEAR (LBS.)				*	MOMENTS (FT.-LBS.)							*	DISTANCES(IN.) TO		
MEM.	LT.END	RT.END	*	LT.END	LT.X	RT.X	RT.END	*	LT.END	LT.X	1/4 L	MAX +	3/4 L	RT.X	RT.END	*	LT.CNF	MAX+MT	RT.CNF
2-1 H	4512	3787	*	1440	1307	-1043	-1116	*	-3037	-2550	-771	-98	-818	-2349	-2721	*	0.0	51.10	0.0
2-1 F	4743	4018	*	2864	2597	-2103	-2247	*	-4529	-3562	-32	1277	-199	-3291	-4040	*	26.37	50.77	-23.06
1-3 H	1185	1185	*	3502	3217	-4328	-4564	*	-2721	-1706	2610	3780	340	-6150	-7262	*	10.58	44.56	-24.09
1-3 F	2387	2387	*	3733	3448	-4097	-4333	*	-4040	-2954	1786	3348	504	-5548	-6603	*	15.52	47.50	-23.14
4-2 H	1577	1577	*	5127	4862	-3609	-3929	*	-8162	-6913	379	4250	2942	-1898	-3037	*	24.10	58.10	-10.52
4-2 F	3137	3137	*	4865	4601	-3870	-4190	*	-7416	-6232	566	3761	2009	-3311	-4529	*	23.15	55.14	-15.50
3-4 H	9128	9728	*	0	0	0	0	*	0	0	0	0	0	0	0	*	0.0	0.0	0.0
3-4 F	8665	9265	*	0	0	0	0	*	0	0	0	0	0	0	0	*	0.0	0.0	0.0

CULVERT DESIGN DATA

	REQD.	*	LEFT DESIGN POINT(X)						*	MAX. POS. MT. POINT			*	RIGHT DESIGN POINT(X)						*	X TO FV = 90	
MEM.	THICK.	*	FV	FS	FC	AS	SS	MBS	*	FS	FC	AS	*	FV	FS	FC	AS	SS	MBS	*	LT.	RT.
2-1 H	7.25	*	25	-20000	919	0.19	0.0	6B	*	523	57	0.0	*	20	-20000	866	0.19	0.0	7B	*	0.0	0.0
2-1 F	7.25	*	51	-20000	1109	0.33	0.0	6B	*	109	204	0.0	*	41	-20000	1047	0.32	0.0	6B	*	0.0	0.0
1-3 H	8.25	*	50	-20000	552	0.15	0.0	3B	*	-20000	863	0.39	*	71	-20000	1161	0.68	0.0	7B	*	0.0	0.0
1-3 F	8.25	*	55	-20000	772	0.26	0.0	5B	*	-20000	827	0.30	*	67	-20000	1109	0.57	0.0	6B	*	0.0	0.0
4-2 H	8.50	*	76	-20000	1191	0.73	0.0	7B	*	-20000	837	0.42	*	54	-20000	568	0.15	0.0	3B	*	0.0	0.0
4-2 F	8.50	*	72	-20000	1143	0.60	0.0	6B	*	-20000	855	0.31	*	59	-20000	798	0.26	0.0	4B	*	0.0	0.0
3-4 H	6.00	*	0	1268	127	0.0	0.0	11B	*	1268	127	0.0	*	0	1351	135	0.0	0.0	11B	*	0.0	0.0
3-4 F	6.00	*	0	1203	120	0.0	0.0	11B	*	1203	120	0.0	*	0	1287	129	0.0	0.0	11B	*	0.0	0.0

CL.S.= 96.00, CL.HT.= 96.00, WS= 84.0, WSP= 40.0, XTL= 3.625, XTR= 3.000, XSL= 4.250, XSR= 4.125, XBL= 3.000, XBR= 3.625

GEORGIA DEPARTMENT OF TRANSPORTATION

HIGHWAY DIVISION - BRIDGE DESIGN OFFICE

08/22/72 THE ANALYSIS OR DESIGN OF MULTIPLE-CELL BOX CULVERTS PROB. NO. EX.1

EXAMPLE OF: TWO CELL BOX CULVERT 8-0 X 8-0

- 20 FEET FILL -

ANALYSIS OF CULVERT LOADS DATA

	THRUST(LBS.)		*	SHEAR (LBS.)				*	MOMENTS (FT.-LBS.)							*	DISTANCES(IN.) TO		
MEM.	LT.END	RT.END	*	LT.END	LT.X	RT.X	RT.END	*	LT.END	LT.X	1/4 L	MAX +	3/4 L	RT.X	RT.END	*	LT.CNF	MAX+MT	RT.CNF
2-1 H	8253	7378	*	2376	2078	-1916	-2114	*	-4686	-3549	-796	348	-1040	-3753	-4719	*	38.20	52.24	-41.39
2-1 F	8714	7839	*	4795	4198	-3789	-4186	*	-7683	-5388	191	2571	-104	-5456	-7367	*	25.95	52.74	-27.53
1-3 H	2308	2308	*	6713	6048	-8542	-8998	*	-4719	-2392	5509	7636	589	-12365	-14558	*	9.43	44.17	-24.47
1-3 F	4574	4574	*	7174	6509	-8081	-8536	*	-7367	-4872	3854	6744	920	-11157	-13234	*	14.57	47.21	-23.53
4-2 H	2679	2679	*	9708	9219	-6418	-7130	*	-15789	-13422	585	8319	6137	-2216	-4686	*	24.59	59.60	-8.75
4-2 F	5401	5401	*	9186	8697	-6939	-7652	*	-14290	-12054	960	7295	4264	-5022	-7683	*	23.61	56.40	-14.19
3-4 H	17995	18595	*	0	0	0	0	*	0	0	0	0	0	0	0	*	0.0	0.0	0.0
3-4 F	17073	17673	*	0	0	0	0	*	0	0	0	0	0	0	0	*	0.0	0.0	0.0

CULVERT DESIGN DATA

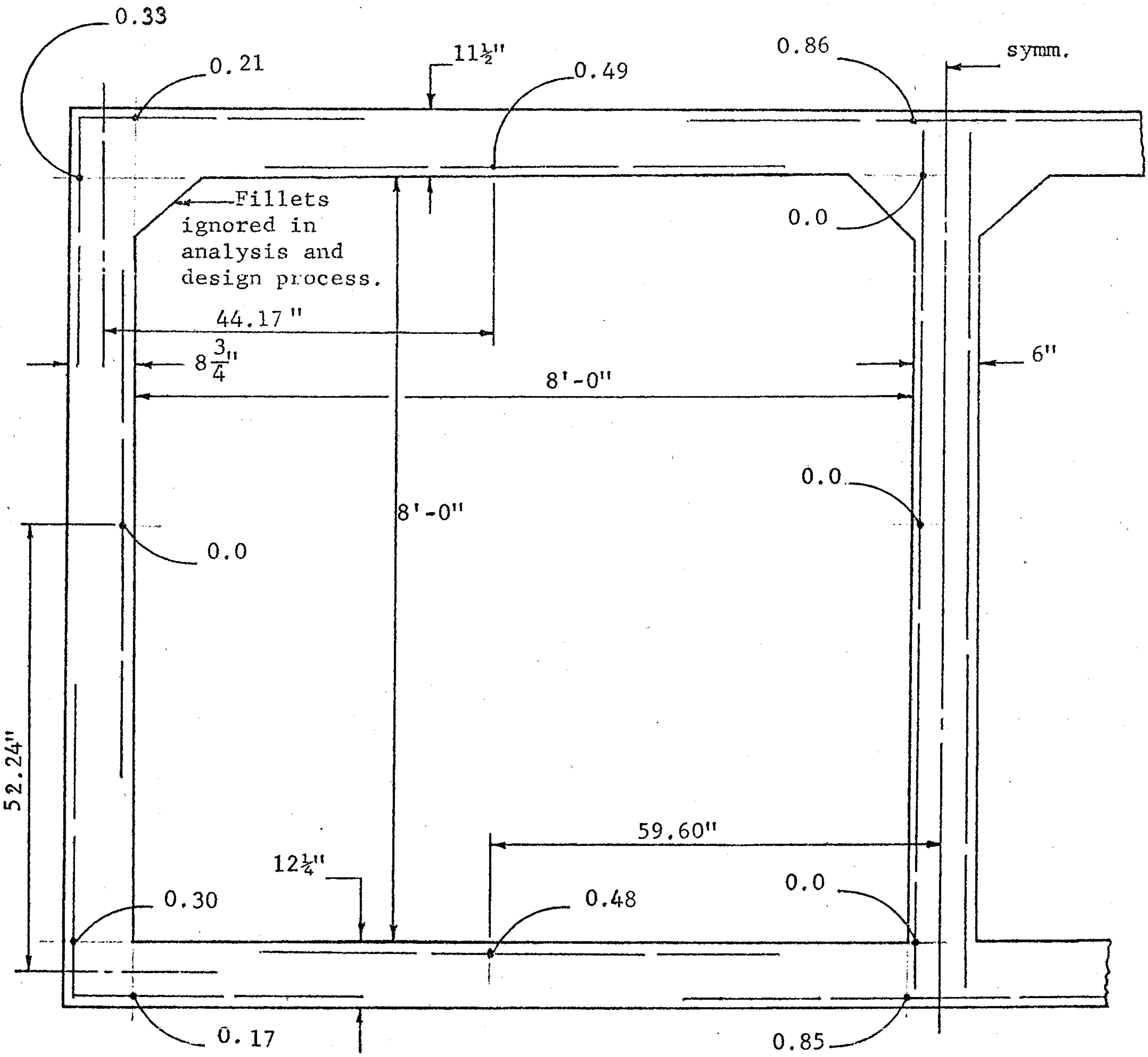
	REQD.	*	LEFT DESIGN POINT(X)					*	MAX. POS. MT. POINT			*	RIGHT DESIGN POINT(X)						*	X TO FV = 90	
MEM.	THICK.	*	FV	FS	FC	AS	SS	MBS	*	FS	FC	AS	*	FV	FS	FC	AS	SS	MBS	*	LT.	RT.
2-1 H	8.75	*	31	-20000	888	0.10	0.0	4B	*	706	110	0.0	*	28	-20000	895	0.16	0.0	5B	*	0.0	0.0
2-1 F	8.75	*	63	-20000	1094	0.30	0.0	5B	*	-5599	508	0.0	*	57	-20000	1086	0.33	0.0	5B	*	0.0	0.0
1-3 H	11.50	*	59	-20000	437	0.10	0.0	2B	*	-20000	788	0.49	*	89	-20000	1043	0.86	0.0	7B	*	0.0	0.0
1-3 F	11.50	*	65	-20000	658	0.21	0.0	4B	*	-20000	772	0.36	*	84	-20000	1013	0.70	0.0	6B	*	0.0	0.0
4-2 H	12.25	*	88	-20000	999	0.85	0.0	7B	*	-20000	760	0.48	*	58	-20000	401	0.06	0.0	0B	*	0.0	0.0
4-2 F	12.25	*	83	-20000	976	0.67	0.0	6B	*	-20000	750	0.33	*	64	-20000	630	0.17	0.0	3B	*	0.0	0.0
3-4 H	6.00	*	0	2499	250	0.0	0.0	11B	*	2499	250	0.0	*	0	2583	258	0.0	0.0	11B	*	0.0	0.0
3-4 F	6.00	*	0	2371	237	0.0	0.0	11B	*	2371	237	0.0	*	0	2455	245	0.0	0.0	11B	*	0.0	0.0

CL.S.= 96.00, CL.HT.= 96.00, WS= 84.0, WSP= 40.0, XTL= 4.375, XTR= 3.000, XSL= 6.125, XSR= 5.750, XBL= 3.000, XBR= 4.375

Following is a sketch showing the reinforcing steel requirements per foot of culvert length, and wall and slab thicknesses, as determined by the program. Steel areas, thicknesses, and dimensions to positive steel area locations are from the output data of the example problem for the 20 foot fill height design. The design data for the 10 foot fill height is not shown in cross section.

CULVERT CROSS SECTION

20 FOOT FILL DESIGN



V. ERROR MESSAGE

The Multiple-Cell Box Culvert Design/Analysis computer program checks the validity of the input data as it is processed with regard to procedure and omission of data. Of course the actual data could not be checked. If an error is detected by the program, processing of the program is terminated and, after an "Error Message" is printed, proceeds to the the next problem. The "Error Message" is in the following form:

ERROR - PROBLEM NUMBER xxxx

Where xxxx is the problem number that was given in the Identification data.

Possible causes of the error are as follows:

1. First card of problem does not contain an asterisk in card column one.

2. Second card of problem does not contain the digit one in card column one.

3. One or more of the following dimensions is zero or left blank: Lc, Hc, Te, Tt, Tb, Ti.

4. Number of cells is invalid, i.e., not equal to 1, 2, 3 or 4.