COMPUTERIZED DESIGN OF
PRECAST REINFORCED CONCRETE BOX CULVERTS

Raymond W. LaTona and Frank J. Heger, Simpson, Gumpertz and Heger, Inc.; and
Mike Bealey, American Concrete Pipe Association

This paper describes the development of a general computer method for
design of single-cell, precast reinforced concrete box culverts. The
method uses the loading requirements of the American Association of State
Highway Officials and the ultimate strength design approach of the Ameri-
can Concrete Institute. The user describes geometry and loading condi-
tions, and the program analyzes many loading cases by the stiffness matrix
method and determines the design forces by appropriate combinations of
the results of those analyses. Based on the design forces, reinforcing steel
is selected to provide adequate strength to resist the bending moments and
axial forces. Shear stresses are checked to determine whether slab thick-
nesses are sufficient without shear reinforcement; no shear reinforcement
is included in the design. A crack-control provision based on work by
Gergely and Lutz is included. Culvert spans of 3 to 12 ft, rises of 2 to 12
ft, and burial depths of 2 to 100 ft are permitted. The top and bottom slabs
of the culvert may have different thicknesses, and the side walls of the
culvert may be a third as thick. Linear haunches may be specified and are
taken into account in both the analysis and the design procedures. The
computer program and its applications are discussed, and 2 sample prob-
lems are included.

•CAST-IN-PLACE, reinforced concrete box culverts have been designed and used for
many years because of special waterway requirements or unusual load conditions at
certain locations or because of designer preference. As labor costs continue to rise,
so do the costs associated with cast-in-place reinforced concrete. As the volume of
highway traffic increases, so does the cost of inconvenience and delay associated with
cast-in-place construction methods. Therefore, attempts have been made to develop
and specify precast concrete box sections, but they have been unsuccessful because the
approach was local in nature or confined to one project.

In early 1971, the Virginia Department of Highways and the American Concrete Pipe
Association (ACPA), with financial support of the Wire Reinforcement Institute (WRI),
began a cooperative venture to develop a manufacturing specification including standard
designs for precast reinforced concrete box sections that would be used primarily by
the Virginia highway department but could be adaptable as a national specification under
the auspices of AASHO or ASTM. From the beginning, both groups believed that the
same production and construction methods used with precast concrete pipe could be suc-
cessfully applied to precast concrete box sections; in other words, these could be con-
sidered as precast concrete pipe of rectangular cross section. The proposal was that
standard box culverts be plant-produced, be manufactured under strict quality control
procedures and subject to inspection, and be installed by rapid cut-and-fill procedures.
The venture quickly evolved into 2 efforts—the manufacturing specification and the
standard designs—although certain parameters were important and common to both.

PRELIMINARY STUDY

The objectives of the preliminary study were to determine the effect of parameter variation and to give some indication as to what sizes should be selected for publication as standard designs. The infinite number of cross-sectional dimensions and of designs possible with box sections was the main problem. In plant production, the capital cost and inventory of forms are critical items in determining product costs. Obviously a producer cannot be expected to maintain infinite numbers of forms and sizes or forms for sizes rarely used in his area.

The initial sizes selected for study were a compromise reached by interested producers representing all parts of the United States and Canada. The slab and wall thicknesses and the steel design stress were varied to produce 384 designs that were analyzed by the ACPA Technical Committee.

After the analysis was reviewed, it was evident that, although final design parameters could be selected, the existing computer design program was inadequate for designing precast reinforced concrete box sections for several reasons. The existing program could not properly handle the high-strength, welded-wire fabric considered for use in the manufacture of the box section; the program was set up for covers over the steel as normally used in cast-in-place design and not the lesser covers that could be maintained through plant production as evidenced by those used in precast concrete pipe; and the existing program did not include haunches in the design and analysis procedures.

It was necessary, therefore, to develop a new program. It was proposed that a general computer method be developed for the design of single-cell, precast reinforced concrete box sections. The method would take into account the close tolerances, the quality and high concrete strength capabilities of plant production, and the characteristics of high-strength, welded-wire fabric and would include haunches in the design and analysis procedures. The remainder of this paper describes the development, criteria, and applications of the computer program.

GENERAL CAPABILITIES AND LIMITATIONS OF THE PROGRAM

Application

The program designs buried precast reinforced concrete box culverts in accordance with the loading requirements of AASHO (1) and ultimate strength design provisions of ACI (2). The program is general, can be used to design any rectangular culvert with or without haunches, and gives the designer the capability of specifying the following information:

1. Culvert geometry—span, rise, wall thicknesses, and haunch dimensions;
2. Loading data—depth of fill, density of fill, lateral pressure and effective height coefficients for soil, truck loading, and internal pressure loading;
3. Material properties—steel strength, concrete strength, and concrete density; and
4. Design data—concrete cover over reinforcement, diameter of reinforcement, and minimum spacing of reinforcement.

Only the span, rise, and depth of fill have to be given as input data. Specification of additional input data is optional with the user. Standard values are used when specific input data are omitted.

The program has the following limitations:

1. Only single-cell culverts can be considered;
2. The range of burial depth permitted is 2.0 to 100.0 ft;
3. The range of spans permitted is 3.0 to 12.0 ft;
4. The range of rises permitted is 2.0 to 12.0 ft; and
5. Only those loading cases that are discussed below can be considered.

The limitations on the range of culvert sizes and maximum burial depth are arbitrary and easily modified, but modification of the other limitations listed above would require major programming changes.

Design

The design capabilities of the program are based on the ACI ultimate strength design method. The area of required tension steel is selected by taking bending moment, axial forces, and cracking control into account, and the shearing stresses are checked. Welded-wire fabric will be used in the standard designs; therefore, in addition to the area of steel that is required, the maximum wire spacing that is consistent with controlled cracking is computed. However, the design produced by the program is also valid for culverts reinforced with bar reinforcing, provided the correct yield strength is input.

The following limitations apply to the design in the program:

    1. Only transverse reinforcing is selected;

    2. Anchorage lengths are not computed;

    3. The program does not design wall thicknesses;

    4. The present version of the program does not design shear reinforcement, but it does print a message when shear reinforcement is required; and

    5. Maximum wire spacing is determined based on the assumption that a single layer of reinforcing is to be used for each of the reinforcing locations.

Cost

When the design of a culvert is complete, the volume of concrete and steel used in the design is computed. The cost per unit length of culvert is determined based on input unit costs for materials. Only material costs are considered; consequently, other costs such as transportation and installation must be added to determine the cost in place.

STRUCTURAL CRITERIA FOR ANALYSIS AND DESIGN

Notation

The notation used in this section is defined below.

A_s = area of steel;

 b = width of unit strip (12 in.);

 d = depth from extreme compression fiber to centroid of tension reinforcement;

 d_f = depth of fluid in culvert;

 f_c' = compressive strength of concrete;

f_{DL} = load factor for dead load;

f_{LL} = load factor for live load;

 f_s = stress in reinforcement at service loads;

 f_y = yield stress of reinforcing steel;

 h = height of fill;

H_h = horizontal length of haunch;

H_v = vertical length of haunch;

L_l = length of distributed wheel load along span;

 m = $f_y/0.85\ f_c'$;

M_u = ultimate design moment;

P_H = $0.5\ H_v\ H_h\ \gamma_c$;

P_u = ultimate design axial force (positive for compression);

 R = rise;

 s_ℓ = spacing of longitudinal wires;

 S = span;

 S' = $S + t_s$;

 t_b = distance from centroid of tension steel to outermost concrete tension fiber;

 t_B = thickness of bottom slab;

 t_c = thickness of concrete cover over reinforcing steel;

 t_s = thickness of side wall;

 t_T = thickness of top slab;

V_u = ultimate design shear;

w_T = load intensity on top slab;

w_S = load intensity on side wall;

w_B = load intensity on bottom slab;

w_{ST} = load intensity on side wall at top;

w_{SB} = load intensity on side wall at bottom;

w_{rL} = reaction intensity at left;

w_{rR} = reaction intensity at right;

α = coefficient for lateral soil pressure;

β = effective height coefficient;

γ_c = density of concrete;

γ_f = density of fluid (water);

γ_s = density of soil;

ρ = pressure head;

ξ = nondimensional fraction of S'; and

φ = capacity reduction factor.

Structural Arrangement

Figure 1 shows the structural arrangement. The top and bottom slabs may be different thicknesses, and the side walls may be a third as thick. At the user's option, linear haunches of arbitrary dimensions may be specified. The steel arrangement is shown, and the steel areas designated AS1, AS2, AS3, and AS4 are to be designed as well as the cutoff lengths L_T and L_B. Design forces are evaluated at the cross sections indicated; the design based on those forces is discussed in another section of this report.

Loadings

The loading cases that are analyzed are shown in Figure 2. The loadings are separated into 3 groups: permanent dead loads, additional dead loads, and live loads. Load cases 1, 2, and 3 are the permanent dead loads; load cases 4 and 5 are the additional dead loads; and load cases 6 through 19 are live loads. The distinction between permanent and additional dead loads is made so that maximum force effects may be evaluated. Additional dead loads are considered to be acting only when they tend to increase the particular design force under consideration.

In load cases 1, 2, and 4, the soil reaction is assumed to be uniformly distributed across the width of the culvert. Load cases 3 and 5 have no soil reaction on the bottom slab. In load cases 6 through 19, the soil reaction on the bottom slab is assumed to vary linearly across the width of the culvert. It is assumed that no soil reactions are imposed on the sides of the culvert.

Load cases 6 through 19 are truck loadings. Load cases 6 through 12 are for an AASHO truck, and load cases 13 through 19 are for the truck loading required on Interstate Highways. Depending on the culvert span and depth of burial, as many as 7 load cases are used to simulate different positions of a wheel load as a truck traverses the culvert. The 7 cases are obtained by selecting different values of the parameter ξ in Figure 2f. The truck load design force that is selected at each section is the maximum force that occurs at that section under any of the truck loadings.

The length of the distribution of the wheel load in the direction of the span (length L_l in Fig. 2f) is determined in accordance with the AASHO standards (1); however, a modification of the width of the AASHO distribution is used in the direction of the axis of the culvert. The maximum width over which the load from a truck is distributed is the width of 1 lane, i.e., 10 ft. This modification is made because distribution of loads along the length of the culvert will be discontinuous at the joints between culvert segments, and, with multiple traffic lanes over more than 1 culvert segment, the modified load intensity represents a maximum design condition. Thus, the length of the culvert does not affect the design requirements.

The AASHO standards (1) allow the use of 70 percent of the soil weight in culvert design and allow the designer to neglect truck loads when the depth of overburden exceeds 8.0 ft. However, they allow this reduction in load on the presumption that the concrete

design will be in accordance with the AASHO working stress design approach, which leads to conservative steel stresses. In the method described here, the ACI ultimate strength design approach is used rather than the AASHO working stress design approach; consequently, 100 percent of the weight of the soil is used, and truck loads are considered for all overburden depths.

Method of Analysis

Structural analysis is performed by using the stiffness matrix method. A 1-ft slice of the culvert is analyzed as a 4-member frame (Fig. 1). For each member of the frame, the flexibility matrix is determined and inverted to obtain the member stiffness matrix. The member stiffness matrices are then assembled into a structure joint stiffness matrix, a joint load matrix is assembled, and conventional methods of matrix analysis are employed.

For simplicity, the fixed-end force terms and flexibility coefficients for a member with linearly varying haunches are determined by numerical integrations. Analytic integration is possible, but the algebraic expressions that result are cumbersome. The trapezoidal rule with 50 integration points per member is used, and a sufficiently high degree of accuracy is obtained.

Method of Design

The design procedure consists of selecting the steel that is required to resist the design bending moment and axial force, checking for crack control, and checking shear stresses. The wall thicknesses and haunch geometry are input parameters that are selected by the designer. The equation that is used for steel selection is based on the ACI ultimate strength design approach for combined bending and axial compression where the cross section is proportioned so that its ultimate strength is governed by the tension steel. Three-quarters of the steel corresponding to balanced conditions for bending alone is the maximum percentage of steel that is permitted.

Design forces resulting from the design loads multiplied by load factors are evaluated at the cross sections shown in Figure 1. The load factors are input parameters that may be specified by the designer; if they are not specified, load factors of 1.5 and 2.2 are used for dead loads and live loads respectively. The maximum design forces are obtained by summing the permanent dead load forces, the additional dead load forces when they tend to increase the design force, and the maximum force resulting from the live load cases.

The four steel areas designated AS1, AS2, AS3, and AS4 in Figure 1 are designed. The area AS1 is the maximum of the steel areas required to resist M_4 (i. e., the moment at the cross section labeled M_4, Fig. 1), M_5, M_7, or M_8. AS2 is designed to resist M_1, AS3 is designed to resist M_{11}, and AS4 is designed to resist M_6. V_3 (i. e., the shear at the cross section labeled V_3, Fig. 1) is used to check the shear stress in the top slab, the maximum of V_5 and V_7 is used to check the shear stress in the side wall, and V_9 is used to check the shear stress in the bottom slab. Moments M_2, M_3, and M_4 are used to determine the theoretical cutoff length L_T for AS1 in the top slab; and moments M_8, M_9, and M_{10} are used to determine the theoretical cutoff length L_B for AS1 in the bottom slab. Linear interpolation or extrapolation is used to determine the point at which the negative moment envelope is zero.

The following ultimate strength design formula is used to select the bending reinforcement:

$$A_s = \frac{bd}{m} - \sqrt{\left(\frac{bd}{m}\right)^2 - \left[\frac{2b\,M_u}{\varphi\,f_y\,m} - \frac{P_u\,bd}{\varphi\,f_y\,m} + \left(\frac{P_u}{\varphi\,f_y}\right)^2\right]} \tag{1}$$

The derivation of Eq. 1 is given below:

1. Figure 3 shows the forces acting on the cross section of a reinforced concrete flexural member at ultimate strength conditions when subjected to flexure plus axial compression.

2. Writing equilibrium of the forces in the vertical direction and imposing a capacity reduction factor leads to

$$P_u = \varphi(0.85\, f'_c\, ba - A_s f_y) \tag{2}$$

3. Writing moment equilibrium about the point $x = a/2$ leads to

$$M_u - P_u \left(\frac{d-a}{2}\right) = \varphi A_s f_y \left(d - \frac{a}{2}\right) \tag{3}$$

4. Solving Eq. 2 for a, substituting the result into Eq. 3, and rearranging terms give

$$A_s^2 - \frac{2bd}{m} A_s + \left[\frac{2b\, M_u}{\varphi f_y\, m} - \frac{P_u\, bd}{\varphi f_y\, m} + \left(\frac{P_u}{\varphi f_y}\right)^2\right] = 0 \tag{4}$$

5. Solving Eq. 4 for A_s gives Eq. 1.

The crack-control criterion that is used is somewhat more conservative than the crack-control provision given in the ACI code. It is based on tests by Lloyd, Rejali, and Kesler (3) of slabs reinforced with welded-wire fabric. Essentially, the research determined that the semi-empirical equation presented by Gergely and Lutz (4) may be used for slabs reinforced with smooth and deformed welded-wire fabric.

Using the Gergely and Lutz equation leads to the following requirement for the stress in the reinforcement when a single layer of reinforcement is used and the maximum permissible crack width at service load levels is 0.01 in.:

$$f_s \le \frac{65}{\sqrt[3]{t_b^2 s_\ell}} + 5 \tag{5}$$

The derivation of Eq. 5 is given below:

1. The semi-empirical equation proposed by Gergely and Lutz (3) for relating maximum crack width to other design parameters is

$$w_b = 0.091 \times 10^{-3} \sqrt[3]{t_b\, A}\, (f_s - 5)\, R \tag{6}$$

where $R = (h - kd)/[(1 - k)d]$; f_s = reinforcing steel stress, in ksi; t = thickness of slab; t_b = distance from bottom of slab to centroid of tension reinforcing; and A = area of concrete surrounding one bar or wire. For slabs with a single layer of reinforcing, $A = 2t_b s_\ell$.

2. Maximum crack width is limited to 0.01 in. at working stress; thus, $w_b = 0.01$ in. when $f_s = f_y \varphi / \text{avg load factor}$.

3. $R_{max} = 1.34$ is used for typical culvert slabs.

4. Then,

$$0.01 = 0.091 \times 10^{-3} \sqrt[3]{t_b\, 2t_b\, s_\ell}\, (f_s - 5)\, (1.34) \tag{7}$$

$$f_s - 5 = \frac{65}{\sqrt[3]{t_b^2 s_\ell}}$$

which is the same as Eq. 5.

5. Equation 5 is compared to ACI crack-control criteria for ordinary exterior exposure ($w_b = 0.012$).

$$\max f_s = \frac{145}{\sqrt[3]{d_c \, A}}$$

$$\max f_s = \frac{145}{\sqrt[3]{2 t_b^2 \, s_\ell}} \tag{8}$$

$$\max f_s = \frac{115}{\sqrt[3]{t_b^2 \, s_\ell}}$$

Correction is made for reduction of maximum crack width from 0.012 to 0.01 in.

$$\max f_s = \frac{96}{\sqrt[3]{t_b^2 \, s_\ell}} \tag{9}$$

The conclusion is that max f_s obtained by ACI criteria is significantly higher than max f_s obtained from the Gergely and Lutz equations for use with typical slabs.

Shear reinforcing is not required if

$$\frac{V_u}{\varphi b d} \le 2\sqrt{f_c'} \tag{10}$$

where $\varphi = 0.85$ and b and d are as given above. Equation 10 is obtained from the requirements of ACI 318-71 (2, paragraphs 11.2.1 and 11.4.1).

Assumptions and Limitations

Although the design and analysis procedures that were developed in this work are intended to be as general as possible, there are inherent limitations to the applicability of the design program due to the assumptions that were made in developing the design procedure. The major design assumptions are given below:

1. The moments M_1 and M_{11} (Fig. 1) always cause tension on the inside face of the culvert wall, and the moments M_4, M_5, M_7, and M_8 always cause tension on the outside face of the culvert wall.
2. Critical sections for shear and moment do not occur within the haunch.
3. Based on the notation in Figure 1, SPAN $\ge 4(t_B - t_c) + 2H_h$, SPAN $\ge 4(t_r - t_c) + 2H_h$, and RISE $\ge 2(t_s - t_c) + 2H_v$.
4. A single layer of reinforcement is used.
5. For welded-wire fabric made of smooth wire, the maximum cross-wire spacing is 6 in. For welded-wire fabric made of deformed wire, there is no cross-wire spacing limitation.

Assumptions 1, 2, and 3 are valid for culverts with "normal" proportions; however, for unusual conditions where some of the assumptions are violated, application of the design procedure may give erroneous results. For example, if very flat haunches are used, the critical section for shear or moment or both may lie within the haunch, and unconservative results would be obtained. The designer-user should be aware of those assumptions so that the design program is not used for cases where the assumptions are violated.

Assumptions 4 and 5 affect the crack-control criterion. If more than one layer of reinforcing is used, the wire spacing computed by the program is overly conservative. If smooth welded-wire fabric is used with cross-wire spacing greater than 6 in., the longitudinal wire spacing that is computed may be unconservative.

The conclusions of Lloyd, Rejali, and Kesler (3) state that welded smooth-wire fabric and welded deformed-wire fabric are equally effective for crack control in slabs. However, it is well established that cross-wire spacing influences the effectiveness of welded smooth-wire fabric for crack control. Because no limits for cross-wire spacing

are given by Lloyd, Rejali, and Kesler, the above limitation restricting the maximum cross-wire spacing to 6 in. requires further confirmation.

COMPUTER PROGRAM

General Description

The program using the design method presented in this report was written in FOR-TRAN IV and implemented on an IBM 360 model 65 computer. The input data requirements for the program are flexible because many data are optional. The amount of input data for the design of a particular culvert ranges from a minimum of 3 cards to a maximum of 15 cards; standard values for optional input data are assumed if specific data are not input by the user.

The output data consist of an echo print of the input data and a 1-page summary of the design. (Figs. 5 and 7 show typical designs obtained from the program.) The first line of output identifies the culvert size and the depth of overburden. These are required data items and must be supplied to the program by the user. The material properties, soil data, loading data, and concrete data are optional data items; when they are not supplied by the user, values are assigned by the program. The reinforcing steel data and the weight and cost data are generated by the program.

Standard Designs

The program has been used to generate data for culverts that will be proposed for standards and incorporated in a specification by the ACPA Technical Committee. Table 1 gives the standard sizes that have been designed.

In Table 1, "span" and "rise" are as shown in Figure 1, and the column headed "thickness" applies to top slab, side walls, and bottom slab. Also, the proposed standard sizes have 45-deg haunches with a leg dimension equal to the wall thickness. Designs were made for each standard size at many burial depths; the depth of overburden was increased from 2.0 to 6.0 ft in 1.0-ft increments, and then increased in 2.0-ft increments until a depth was reached where shear reinforcing was required. Designs were made for culverts with no truck load, AASHO HS20 truck load, and Interstate loading. About 1,200 designs have been generated for the ACPA Technical Committee, and in every design the area of steel designated AS4 in Figure 1 was not required; therefore, the standard culverts that are included in the specification may not have AS4.

Special Designs and Parameter Studies

The program can be used for designing or evaluating special nonstandard culverts. Many geometric quantities may be varied including the span; rise; depth of overburden; thickness of the top, bottom, and side walls; horizontal and vertical haunch dimensions; and thickness of concrete cover over the reinforcement. Also, steel and concrete strengths can be changed and soil parameters can be varied. These freedoms in describing a problem allow the user to design a nonstandard culvert for a special condition or to evaluate the adequacy of a proposed design. Further, by making several runs, the program can be used to evaluate the maximum or minimum burial depths or both that a given culvert design can sustain.

Another application of the program is its use in performing parameter studies. Often, a designer would like to determine how changing one or more parameters affects the final design, particularly the cost of the design. Making several runs and varying a particular parameter allow the impact of that parameter on the design to be evaluated. For example, the program could be used to study how cost is affected by wall thickness, and the designer could readily establish the wall thickness that optimizes the culvert cost.

Sample Problem 1

Sample problem 1 demonstrates the use of the program for the design of a culvert when all input data are specified. Figure 4a shows the culvert geometry, and Figure 4b

Figure 1. Structural arrangement and location of design forces.

Figure 2. Load cases.

(a) Culvert dead weight

(b) Vertical soil load

(c) Horizontal soil load

(d) Internal fluid load

(e) Internal pressure load
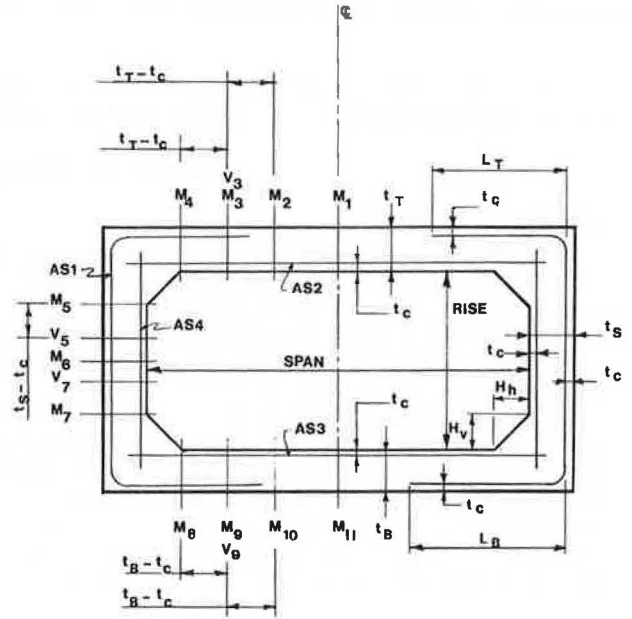
(f) Live loads
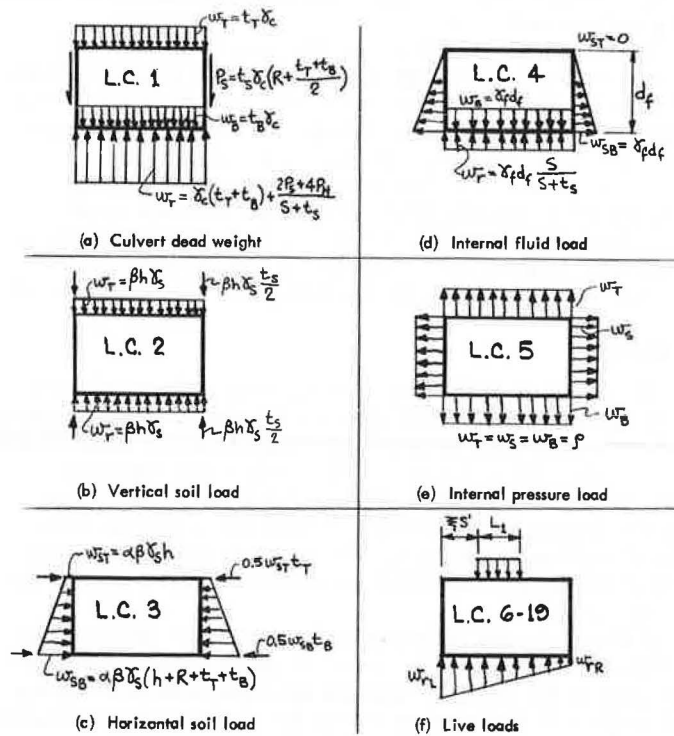
Figure 3. Forces on cross section.
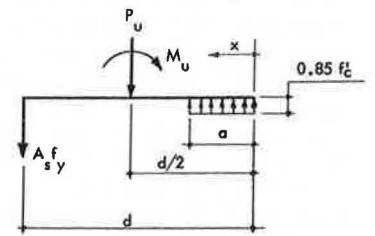
Table 1. Standard sizes.

Span (ft)	Thickness (in.)	Rise (ft)								
		2	3	4	5	6	7	8	9	10
3	4	X	X							
4	5	X	X	X						
5	6		X	X	X					
6	7		X	X	X	X				
7	8			X	X	X	X			
8	8			X	X	X	X	X		
9	9				X	X	X	X	X	
10	10				X	X	X	X	X	X

Figure 4. Geometry and input data for sample problem 1.

(a) Culvert Geometry

```
SAMPLE PROBLEM 1 - COMPLETE INPUT DATA
 1 SPAN.RISE.DEPTH        6.500     4.500    10.750
 2 T-TOP.T-BOT.T-S        7.000     7.500     6.000
 3 HAUNCH-HH.HV           8.000     6.000
 4 SOIL.CONC.WATER      110.000   145.000    62.400
 5 SOIL PARM              0.400     1.100     0.0
 6 TRUCK-INTERSTATE       4.000
 7 WATER DEPTH.PRESS      4.000     0.0
 8 FY. F'C               60.000     4.500
 9 CONCRETE COVER         1.250
10 LOAD FACTORS           1.400     1.700
11 CUST-STEEL.CONC        0.135     6.250
12 DIAMETERS              0.250     0.375     0.375     0.250
13 WIRE SPACING           3.000     3.000     0.0       0.0
14 END
```

(b) Echo Print of Input Data

Figure 5. Output for sample problem 1.

```
6.5 FT. X  4.5 FT. PRECAST CONCRETE CULVERT WITH 10.750 FT. OF OVERBURDEN
**********************************************************************************

M A T E R I A L    P R O P E R T I E S
-----------------------------------------------------------------------
  STEEL - MINIMUM SPECIFIED YIELD STRESS, KSI               60.000
  CONCRETE - SPECIFIED COMPRESSIVE STRENGTH, KSI             4.500

S O I L    D A T A
-----------------------------------------------------------------------
  UNIT WEIGHT, PCF                                          110.000
  RATIO OF LATERAL TO VERTICAL PRESSURE                      0.400
  EFFECTIVE HEIGHT COEFFICIENT                               1.100

L O A D I N G    D A T A
-----------------------------------------------------------------------
  LOAD FACTOR - DEAD LOAD                                    1.400
  LOAD FACTOR - LIVE LOAD                                    1.700
  TRUCK LOAD.                       INTERSTATE OR AASHO HS-20
  UNIFORM INTERNAL PRESSURE, PSI                             0.0

C O N C R E T E    D A T A
-----------------------------------------------------------------------
  TOP SLAB THICKNESS, IN.                                    7.000
  BOTTOM SLAB THICKNESS, IN.                                 7.500
  SIDE WALL THICKNESS, IN.                                   6.000
  HORIZONTAL HAUNCH DIMENSION, IN.                           8.000
  VERTICAL HAUNCH DIMENSION, IN.                             6.000
  CONCRETE COVER OVER STEEL, IN.                             1.250

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

| LOCATION	AREA SQ. IN. PER FT.	MIN. WIRE SPAC'G IN.	MAX. WIRE SPAC'G IN.
TOP SLAB - INSIDE FACE	0.303	3.0	3.6
BOTTOM SLAB - INSIDE FACE	0.315	2.0*	3.6
SIDE WALL - OUTSIDE FACE	0.185	3.0	5.5
SIDE WALL - INSIDE FACE	0.0	2.0*	0.0

```
  *PROGRAM ASSIGNED VALUE

  THE SIDE WALL OUTSIDE FACE STEEL IS BENT AT THE CULVERT CORNERS AND
  EXTENDED INTO THE OUTSIDE FACE OF THE TOP AND BOTTOM SLABS.  THE
  THEORETICAL CUT-OFF LENGTHS MEASURED FROM THE BEND POINT
  ARE 13.2 AND 10.6 IN. AT THE TOP AND BOTTOM RESPECTIVELY.
  ANCHORAGE LENGTHS MUST BE ADDED.

W E I G H T    A N D    C O S T    D A T A
-----------------------------------------------------------------------
  WEIGHT OF CULVERT, KIPS/FT.                                2.090
  WEIGHT OF STEEL, LB./FT. OF CULVERT LENGTH                38.154
  UNIT COST OF CONCRETE, $/TON                               6.250
  UNIT COST OF STEEL, $/LB.                                  0.135
  COST OF STEEL, $/FT. OF CULVERT LENGTH                     5.151
  COST OF CONCRETE, $/FT. OF CULVERT LENGTH                  6.412
  TOTAL COST, $/FT. OF CULVERT LENGTH                       11.563
```

Figure 6. Geometry and input data for sample problem 2.
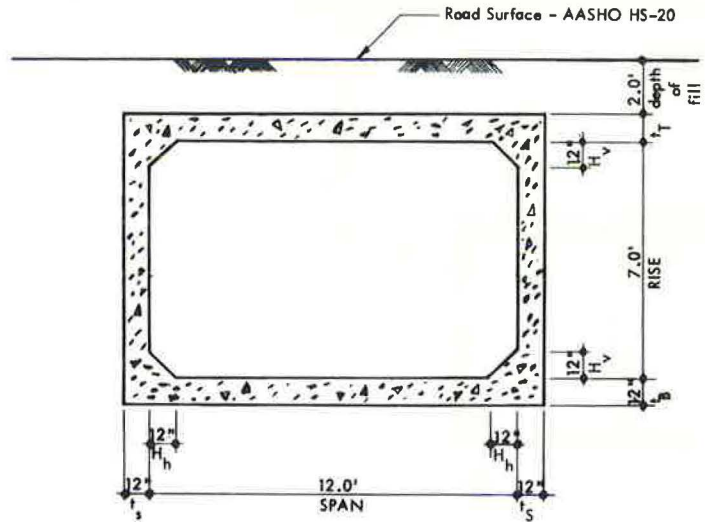
(a) Culvert Geometry

```
SAMPLE PROBLEM 2 - MINIMUM DATA
1 SPAN.RISE.DEPTH      12.000      7.000      2.000
99 END OF DATA
```

(b) Echo Print of Input

Figure 7. Output for sample problem 2.

```
12.0 FT. X  7.0 FT. PRECAST CONCRETE CULVERT WITH  2.000 FT. OF OVERBURDEN
**********************************************************************************
```

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

STEEL - MINIMUM SPECIFIED YIELD STRESS, KSI	65.000
CONCRETE - SPECIFIED COMPRESSIVE STRENGTH, KSI	5.000

S O I L   D A T A

UNIT WEIGHT, PCF	120.000
RATIO OF LATERAL TO VERTICAL PRESSURE	0.330
EFFECTIVE HEIGHT COEFFICIENT	1.000

L O A D I N G   D A T A

LOAD FACTOR - DEAD LOAD	1.500
LOAD FACTOR - LIVE LOAD	2.200
TRUCK LOAD.	AASHO HS-20
UNIFORM INTERNAL PRESSURE, PSI	0.0

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

TOP SLAB THICKNESS, IN.	12.000
BOTTOM SLAB THICKNESS, IN.	12.000
SIDE WALL THICKNESS, IN.	12.000
HORIZONTAL HAUNCH DIMENSION, IN.	12.000
VERTICAL HAUNCH DIMENSION, IN.	12.000
CONCRETE COVER OVER STEEL, IN.	1.000
WIRE DIAMETER USED FOR COMPUTING DEPTH OF STEEL, IN.	0.600

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

LOCATION	AREA SQ. IN. PER FT.	MIN. WIRE SPAC'G IN.	MAX. WIRE SPAC'G IN.
TOP SLAB - INSIDE FACE	0.494	2.0*	9.3
BOTTOM SLAB - INSIDE FACE	0.354	2.0*	7.7
SIDE WALL - OUTSIDE FACE	0.362	2.0*	8.3
SIDE WALL - INSIDE FACE	0.0	2.0*	0.0

*PROGRAM ASSIGNED VALUE

THE SIDE WALL OUTSIDE FACE STEEL IS BENT AT THE CULVERT CORNERS AND
EXTENDED INTO THE OUTSIDE FACE OF THE TOP AND BOTTOM SLABS. THE
THEORETICAL CUT-OFF LENGTHS MEASURED FROM THE BEND POINT
ARE 36.9 AND 37.7 IN. AT THE TOP AND BOTTOM RESPECTIVELY.
ANCHORAGE LENGTHS MUST BE ADDED.

W E I G H T   A N D   C O S T   D A T A

WEIGHT OF CULVERT, KIPS/FT.	6.447
WEIGHT OF STEEL, LB./FT. OF CULVERT LENGTH	94.776

shows the echo print of the input data for the problem. Each line in this echo print gives the information that was input on a data card. The first card is a title card for the problem, and the remainder of the cards are data cards that contain a comment field that is convenient to use to identify the data items on the card. Data cards 1, 2, and 3 define the culvert geometry; the comment field on each card identifies the data items. Data card 4 gives the densities of the soil, concrete, and water. Data card 5 gives the soil parameters to be used for the analysis: 0.400 is the coefficient for lateral soil pressure, 1.100 is the effective height coefficient, and 0.0 is a code that indicates that the lateral earth pressure will be considered as a permanent dead load. Data card 6 gives the code that indicates that the Interstate truck loading is to be considered. Data card 7 gives the depth of water, 4.00 ft, and the internal pressure, 0.0 psi. Data card 8 gives the yield strength of the reinforcing steel and the ultimate strength of the concrete. Data card 9 gives the concrete cover over the reinforcement, and data card 10 gives the load factors for dead load and live load respectively. Data card 11 gives the unit prices for steel and concrete in dollars per pound and in dollars per ton respectively. Data card 12 gives the reinforcement diameters that are to be considered for the design of the steel areas AS1, AS2, AS3, and AS4 in that order. Data card 13 gives the minimum wire spacing that will be allowed for the 4 steel areas; the spacings that are printed as 0.0 indicate that the minimum wire spacing was not specified for those steel areas. Data card 14 indicates that the end of the input stream has been reached.

Figure 5 shows the summary of the design that was obtained for sample problem 1.

Sample Problem 2

Sample problem 2 demonstrates the use of the program with minimum input data. Figure 6a shows the culvert geometry for this design, and Figure 6b shows the echo print of the input data. Only the problem title card and 2 data cards are necessary; the first data card gives the span, rise, and depth of fill, and the second one indicates the end of the input stream. Figure 7 shows the design that was obtained for sample problem 2 and the standard values that are assumed for materials properties, soil data, loading data, and concrete data when those data are not input. All of the concrete data with the exception of the concrete cover over steel are determined as a function of the culvert span. The weight and cost data show only the weight of culvert and the weight of steel; because no unit costs were input, no culvert costs are determined.

REFERENCES

1. Standard Specifications for Highway Bridges, 10th Ed. AASHO, Washington, D.C., 1969.
2. Building Code Requirements for Reinforced Concrete (ACI 381-71). ACI, Detroit, 1971.
3. Lloyd, J. P., Rejali, H. M., and Kesler, C. E. Crack Control in One-Way Slabs Reinforced With Deformed Welded Wire Fabric. ACI Jour., Proc., Vol. 66, No. 5, May 1969.
4. Gergely, P., and Lutz, L. A. Maximum Crack Width in Reinforced Concrete Flexural Members. Symp. Cracking of Concrete, ACI, March 1966.