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PRECAST CONCRETE BOX SECTIONS

Cast-in-place reinforced concrete box culverts have been designed and used for many years because of special waterway requirements, unusual load conditions at certain locations, or 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. The American Concrete Pipe Association's precast concrete box section program was implemented to develop a product for these applications and to provide an opportunity for specifiers to utilize the inherent advantages of a precast product. For any project, the use of precast concrete pipe with its recognized superior hydraulic, structural and construction advantages should be thoroughly evaluated. This and the feasibility, availability and construction details of box sections should be discussed with local concrete pipe producers.

INTRODUCTION

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 and standard designs for precast reinforced concrete box sections that would be adaptable as a national specification under the auspices of American Association of State Highway and Transportation Officials or American Society for Testing and Materials. From the beginning, it was believed that the same production and construction methods used with precast concrete pipe could be successfully applied to precast concrete box sections; in other words, these could be considered as precast concrete pipe of rectangular cross section.

COMPUTERIZED DESIGN

A preliminary study using conventional box culvert design methods was made to determine the effect of parameter variation and to give some indication as to what sizes should be considered for standard designs. The infinite number of cross-sectional dimensions and possible designs was the principle 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 for sizes rarely used in his area.

The preliminary study also indicated existing computer design programs could not properly handle the high-strength welded-wire fabric considered for use in the manufacture of the box section were 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 did not include haunches in the design and analysis procedures. The firm of Simpson Gumpertz & Heger Inc., Cambridge, Massachusetts, was selected to develop a new program because of past experience in similar work with precast concrete pipe.

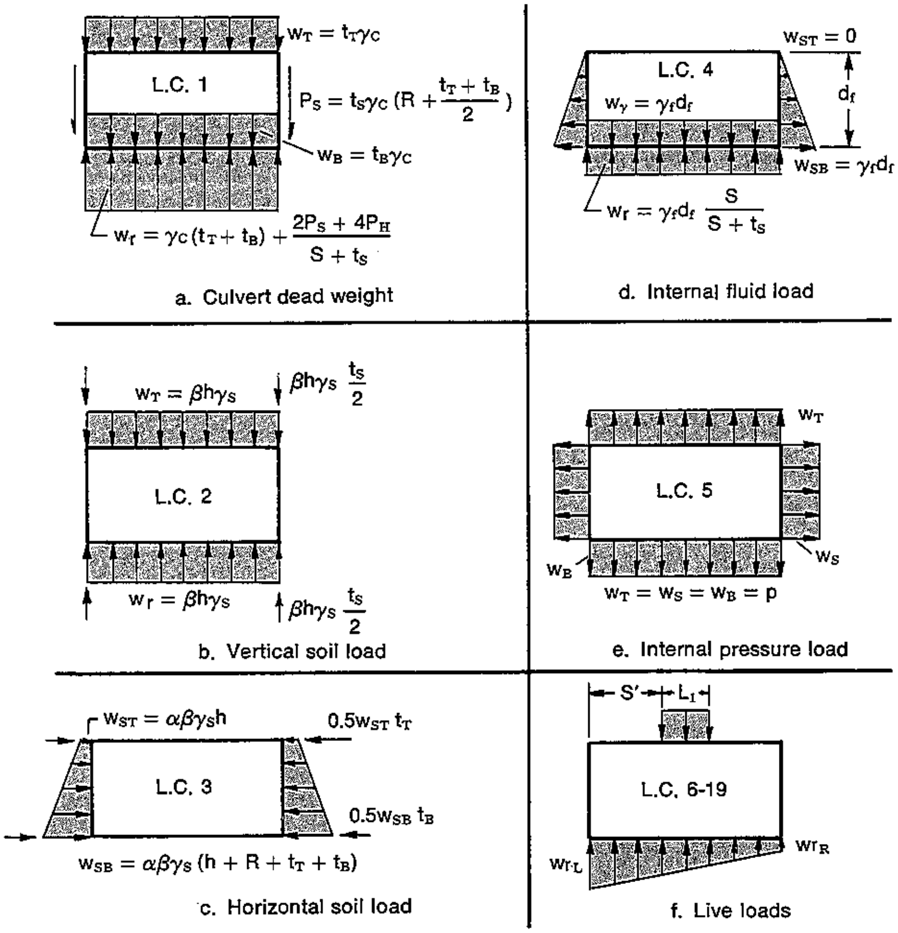
Computer Program

The development, criteria and applications of the program are reported in a publication of the Transportation Research Board(1). The program designs buried single-cell, precast reinforced concrete box sections in accordance with the loading requirements of

AASHTO(2) and ultimate strength design provisions of ACI(3). The designer describes geometry and loading conditions, 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 thicknesses are sufficient without shear reinforcement. A crack-control provision based on work by Gergely and Lutz(4) is included. The top and bottom slabs of the section may have different thicknesses, and the side walls of the section 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 loading cases analyzed are shown in Figure 1. 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.

Design forces are evaluated at the cross sections M & V indicated in Figure 2 and the steel areas designated AS1, AS2, AS3 and AS4 as well as the cutoff lengths L_T and L_B are selected and checked for crack control and shear stresses. The program does not design for shear reinforcement but prints a message when shear reinforcement is required.



a. Culvert dead weight

d. Internal fluid load

b. Vertical soil load

e. Internal pressure load

c. Horizontal soil load

f. Live loads

FIGURE 1. LOAD CASES.

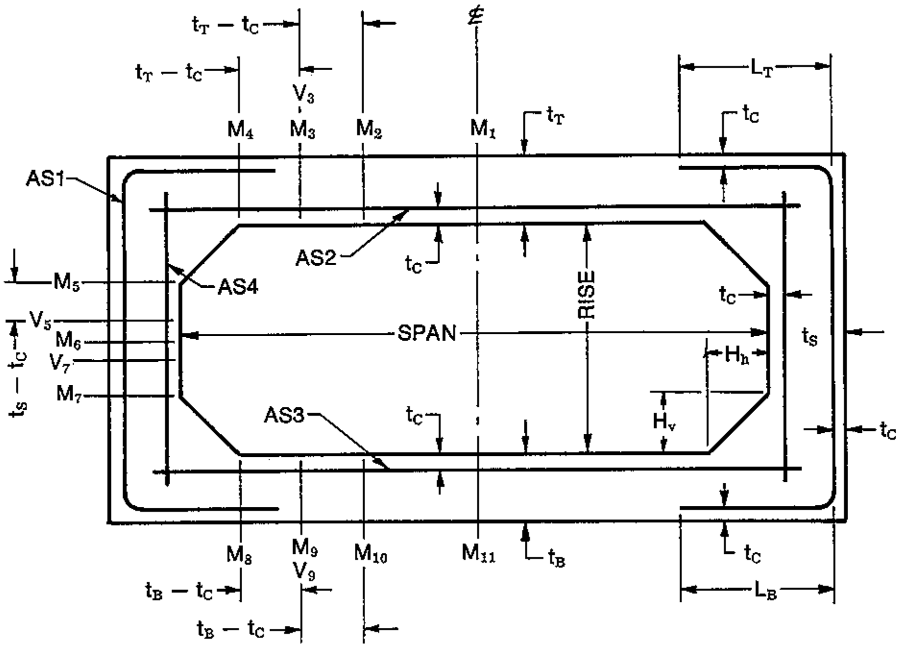


FIGURE 2. STRUCTURAL ARRANGEMENTS AND LOCATION OF DESIGN FORCES.

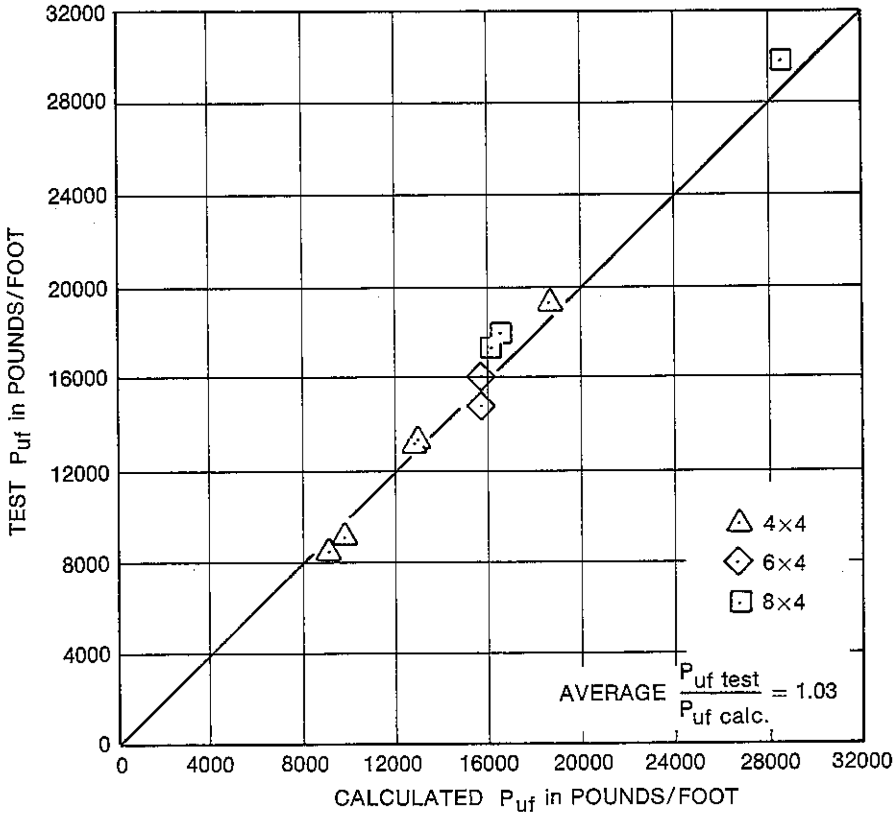


FIGURE 5. COMPARISON OF TEST AND CALCULATED ULTIMATE FLEXURAL STRENGTHS.

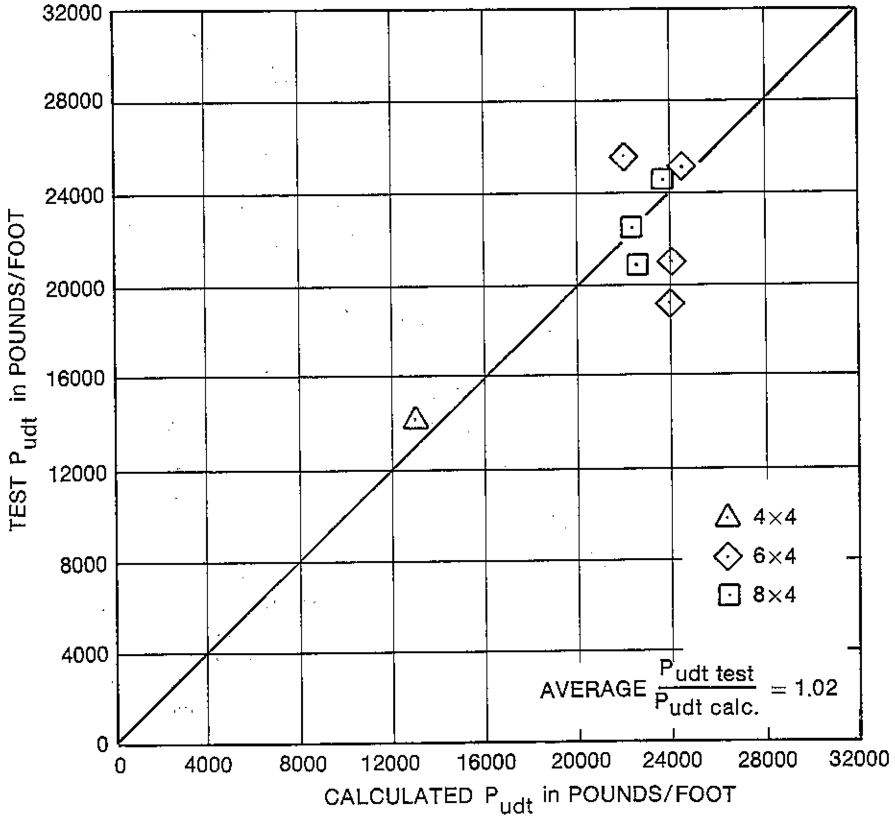


FIGURE 6. COMPARISON OF TEST AND CALCULATED ULTIMATE DIAGONAL TENSION STRENGTHS.

reached their ultimate load carrying capacity in diagonal tension, the average of the ratio of the ultimate diagonal tension test load to the ultimate diagonal tension calculated load was 1.02. The coefficient of variation of 12% shows excellent correlation between test and calculated strengths for ultimate diagonal tension.

Evaluation of Standard Box Culvert Designs—The test results were used for a direct evaluation of the standard designs by determining the test load which represents the "equivalent design earth load in the test arrangement" and the test load which represents the "required ultimate test load in the test arrangement." The "equivalent design earth load in the test arrangement" is the test load which produces the same mid-span bending moment in the test section as the design earth fill height (with a unit weight of earth of 120 lbs per cu ft) produces in a buried box section.

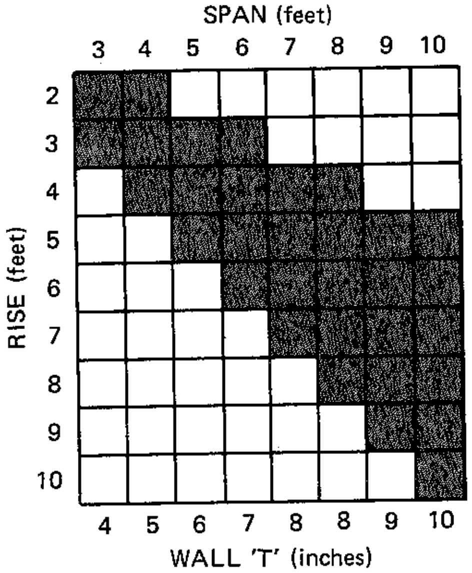
Design earth fill heights and "equivalent design loads in test arrangement," P_{design} are compared with the 0.01-inch crack test load, $P_{.01\ test}$, in Figure 7. All test sections exhibited a higher test 0.01-inch crack load than the test load which produces the same maximum slab bending moment as the design earth fill height, with the average

$$\frac{P_{.01\ test}}{P_{design}} = 1.41.$$

The required minimum ultimate load for the design earth fill height is the test load which equals 1.5 times the weight of a column of 120 lbs per cu ft earth extending between the critical shear sections on each side of the top slab. The critical shear section is at a distance "d" into the slab from the edge of the haunch on each side. The spacing of test loads was established to obtain the same ratio of mid-span posi-

TABLE 1. STANDARD SIZES.

SIZES AND WALL THICKNESS



RISE (feet)	SPAN (feet) 3	4	5	6	7	8	9	10
2	▨	▨						
3	▨	▨	▨	▨				
4		▨	▨	▨	▨	▨		
5			▨	▨	▨	▨	▨	▨
6				▨	▨	▨	▨	▨
7					▨	▨	▨	▨
8						▨	▨	▨
9							▨	▨
10								▨
WALL 'T' (inches)	4	5	6	7	8	8	9	10

Precast box structural designs other than standard are available through American Concrete Pipe Association Member Companies.

TABLE 2.
STANDARD DESIGN CRITERIA.

MATERIAL PROPERTIES	
Steel—Minimum Specified Yield Stress, PSI	65,000
Concrete—Specified Compressive Strength, PSI	5,000
SOIL DATA	
Unit Weight, PCF	120
Ratio of Lateral to Vertical Pressure	0.33
Effective Weight Coefficient	1.0
LOADING DATA	
Load Factor—Dead Load	1.5
Load Factor—Live Load	2.2
Uniform Internal Pressure, PSI	0.0
CONCRETE DATA	
Concrete Cover Over Steel, In.	1.0
Wire Diameter Used for Computing Depth of Steel, In.	0.6
REINFORCING STEEL DATA	
Minimum Wire Spacing, In.	2
Maximum Wire Spacing, In.	4

STANDARD DESIGNS

The program has been used to generate standard designs to be included in the manufacturing specification under the consideration and jurisdiction of ASTM Committee C-13 on Concrete Pipe.

Table 1 gives the sizes proposed and designed as standard. The sizes selected are a compromise reached by interested producers representing all parts of the United States and Canada. Figure 2 depicts the box shape and structural arrangement assumed for the standard designs. In Table 1, "span" and "rise" are as shown in Figure 2, and the column headed "thickness" applies to top slab, side walls, and bottom slab. Also, the proposed standard sizes have 45-degree 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 to 6 feet in 1-foot increments, and then increased in 2-foot increments until a depth was reached where shear reinforcing was required. Designs were made for box sections with no truck load, AASHTO HS20 truck load, and interstate alternate load. Table 2 lists the design criteria values assumed for the standard designs. About 1,200 designs have been generated and in every design the area of steel designated AS4 was not required.

TEST PROGRAM

A Transportation Research Board publication ⁽⁵⁾ describes the test program and results instituted to verify the computer design method and the proposed standard designs. To show that the test results verify the proposed design method, they were compared with test strengths calculated using the proposed design method. Furthermore, to show that the test results verify the proposed standard designs, they were also compared with the required equivalent design and ultimate loads for prototype box section designs.

Test Specimens—Three sizes were selected to represent small, intermediate, and large spans. Three designs for each size were selected to represent low, intermediate and high heights of cover. The highest height of cover is at, or just above, the design limit of diagonal tension strength for the standard wall thickness and concrete strength of the standard box section design. All test specimens were designed with the nominal spans, rises, wall thicknesses, haunch dimensions and arrangement of reinforcing as required for the standard designs.

Material Control Tests—Control tests were carried out to determine significant structural properties of steel and concrete materials in the test specimens. Reinforcing steel strengths obtained from samples taken from each style of the actual reinforcing used in the test specimens were well in excess of the 75,000 psi minimum ultimate strength requirement of ASTM A185.

Concrete compressive strengths in the actual test specimens were measured by tests on both standard cylinders and cores cut from the wall of the sections after test and were representative of average strengths expected for typical 5000 psi design mixes in commercial precasting plants.

Test Procedure—The arrangement of loads used for loading of test specimens is shown in Figure 3 and produces approximately the same ratio of positive moment at mid-span to shear at a distance "d" out from the end of the haunch in the top and bottom slabs for the test specimen as is produced by a uniformly distributed earth load on the top and bottom slabs of the buried box section. These two structural parameters are the most significant governing the field strength of box sections.

Evaluation of Design Method for Limiting Crack Width—The 0.01 inch crack strengths obtained in the tests are compared with the corresponding calculated strengths for the test load arrangement in Figure 4 which provides an evaluation and verification of the design method for limiting crack width. For the entire 18 test specimens in the test program, the average of the ratio of the 0.01-inch crack test load to the 0.01-inch calculated load was 1.29. The coefficient of variation is 34%. If the two specimens with the lowest steel areas for each size are excluded from the statistical analysis, for the 12 remaining specimens the average ratio of test to calculated load was 1.08 and the coefficient of variation is 14%. Excluding the lightly reinforced test specimens, the correlation between test 0.01-inch crack strength and calculated 0.01-inch crack strength is very good.

Evaluation of Design Methods for Ultimate Strength—The ultimate strengths obtained in the test sections are compared with the corresponding calculated strengths in both flexure and diagonal tension for the test load arrangement in Figure 5 and 6 which provide an evaluation and verification of the design methods.

For the 10 test specimens which reached their ultimate load carrying capacity in flexure, the average of the ratio of the ultimate flexure test load to the ultimate flexure calculated load was 1.03.

The coefficient of variation of 6% shows excellent correlation between test and calculated results.

For the 8 test specimens which

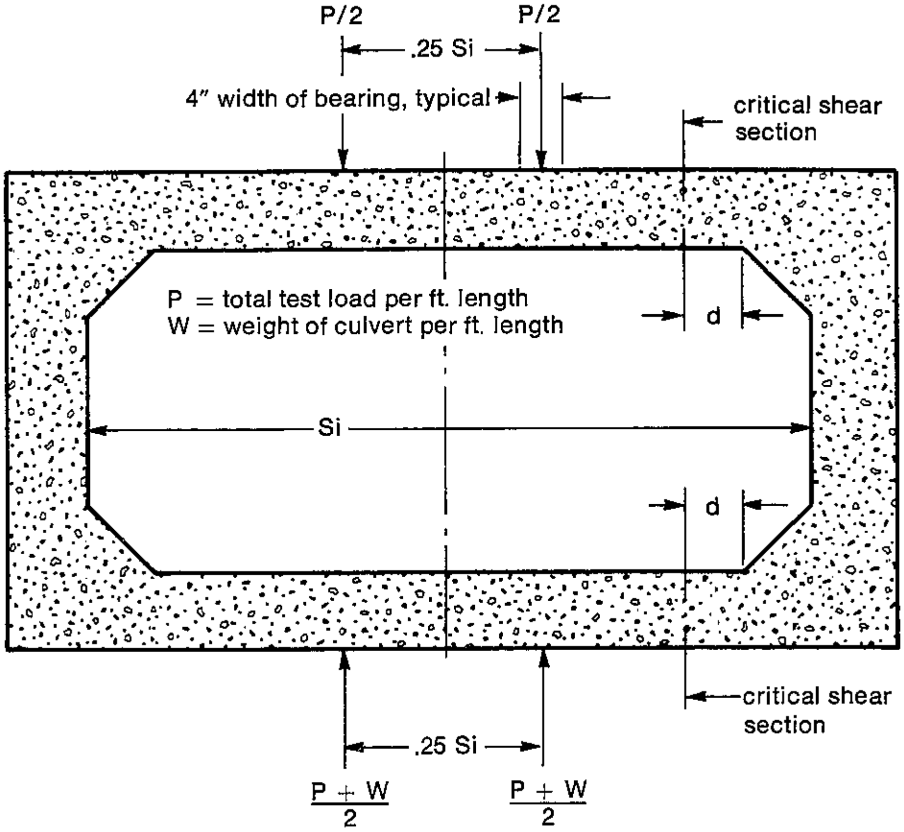


FIGURE 3. TEST LOADING ARRANGEMENT.

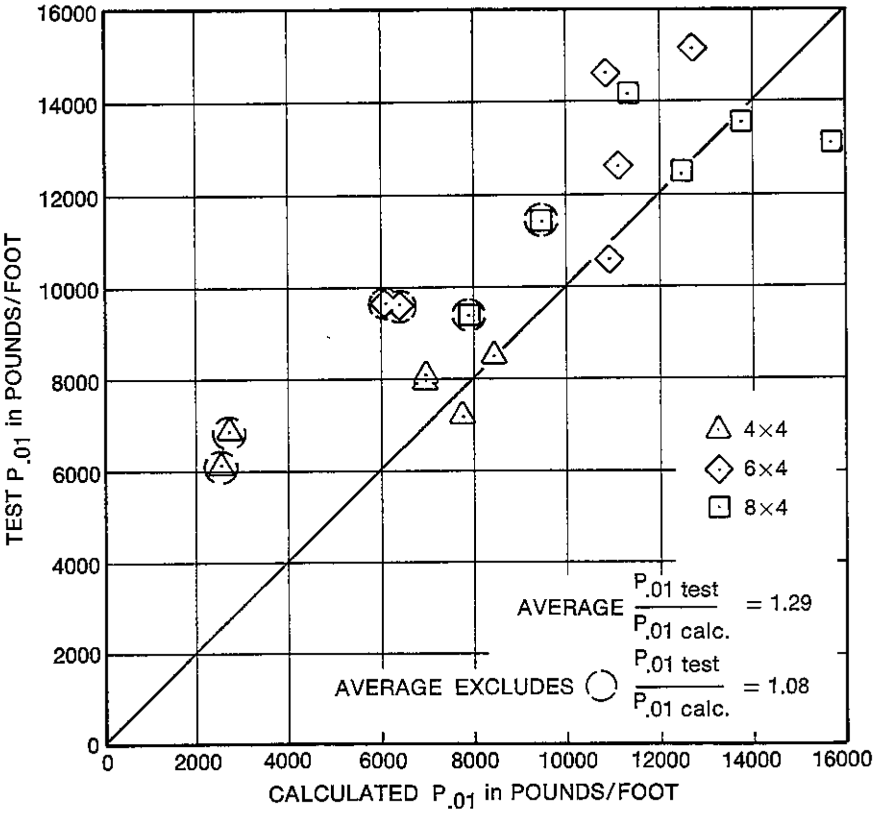


FIGURE 4. COMPARISON OF TEST AND CALCULATED .01-INCH CRACK STRENGTHS.

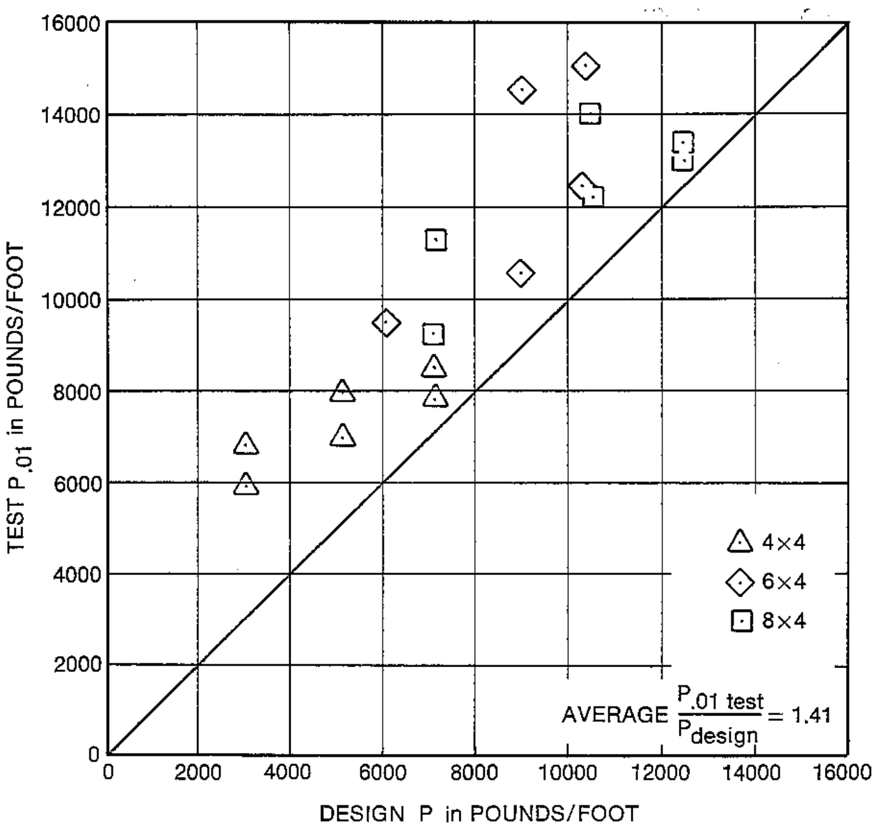


FIGURE 7. COMPARISON OF TEST LOADS AND DESIGN LOADS.

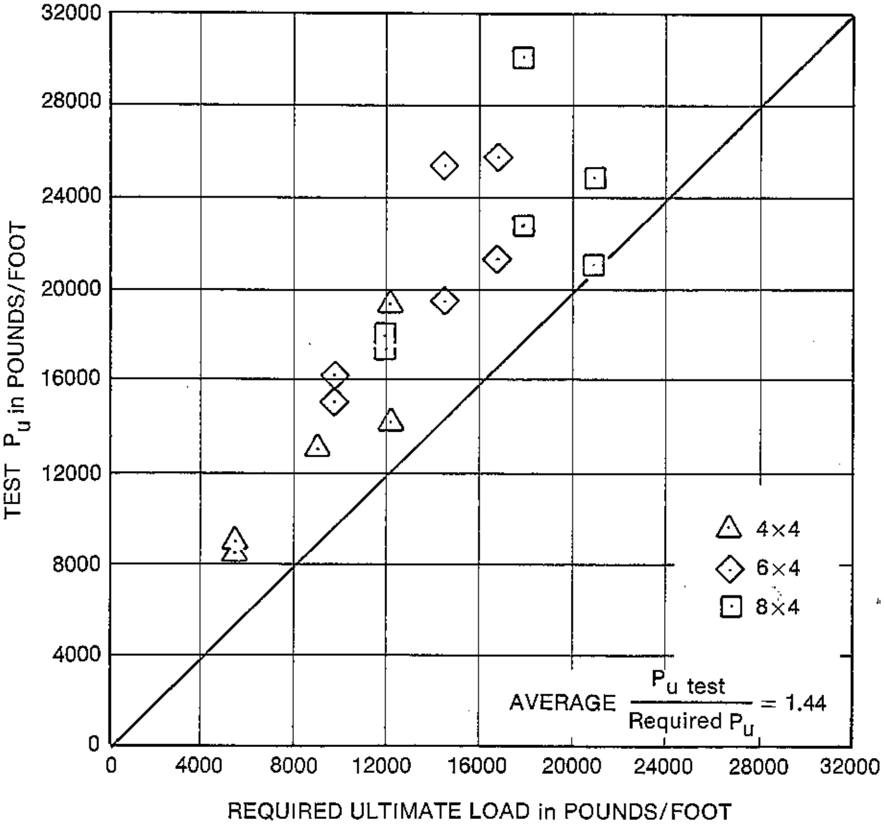


FIGURE 8. COMPARISON OF TEST LOADS AND REQUIRED ULTIMATE LOAD.

tive moment to shear at the above described critical section in the test specimen as occurs in a similar buried box section. Test loads equivalent to "required minimum load for design earth fill height", $P_{u\ design}$ are compared with the test ultimate loads, P_u test in Figure 8. All test sections had a higher test ultimate load than the required $P_{u\ design}$ with the average $\frac{P_{u\ test}}{P_{u\ design}} = 1.44$.

CONCLUSIONS

The results of the test program verify that the design method provides satisfactory designs for precast concrete box sections within the range of earth fill heights and dimensions used for the standard designs and also provides a direct verification of the adequacy of the standard designs which cover the range of strength and dimensions of the proposed standard designs.

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