BEHAVIOR OF ASTM C 850 CONCRETE BOX CULVERTS WITHOUT SHEAR CONNECTORS

by

Ray W. James

Research Report 294-1

Determination of Earth Pressures on
Reinforced Concrete Box Culverts
Research Study No. 2-5-81-294

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KEY WORDS

Culverts, Concrete Box, Shear Connectors, Load Tests, Reinforcing Steel Stresses

ACKNOWLEDGMENTS

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The two box culverts were fabricated by Gifford-Hill & Co., Pipe Division, Ft. Worth, Texas. Materials and support were provided by Gifford-Hill & Co. and Ivy Steel and Wire Co. of Houston.

Numerical predictions of culvert response were provided by Mr. Charles Terry of the TSDHPT. His assistance is gratefully acknowledged. The testing was conducted at the Texas A&M University Research Annex. The author appreciates the assistance of the staff of the Research Annex and the Texas

Transportation Institute, particularly Mr. Richard E. Bartoskewitz, who assisted with the instrumentation and directed the testing.

IMPLEMENTATION STATEMENT

The results of this study suggest that shear connectors are not required in 7 x 5 ASTM C 850 culverts. Included are recommendations to perform field tests and further study to determine whether revisions to all C 850 standard designs may be recommended.

SUMMARY

A series of static loads simulating factored HS20-44 wheel loads was applied to the 7 ft and 5 ft spans of two experimental box culvert sections. The culverts were designed in accordance with ASTM C 850 except that the steel areas in the 5 ft slabs were sized according to the C 850 requirements for 5 x 5 boxes, and the steel areas in the 7 ft slabs were sized according to the C 850 requirements for 7 x 5 boxes, so that testing of 5 ft as well as 7 ft spans could be conducted.

The major objective of the study was to determine whether shear connectors required by ASTM C 850 and AASHTO might be safely omitted. To accomplish this objective, stresses in reinforcing steel were measured while simulated critical wheel loads were applied.

The following conclusions are apparent:

(1) Maximum measured steel stresses are well below design steel stresses for design service wheel loads and for factored ultimate design wheel loads.

(2) Cracking caused by the design ultimate wheel load is relatively insignificant with respect to cracking assumed in a "cracked section" design philosophy.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Background

Precast box culverts have been extensively used to economically span smaller drainage channels. Presently, design standards exist for two categories of box culverts: ASTM C 850 establishes standard designs for boxes with less than 2 ft of cover subject to highway loadings, while ASTM C 789 establishes standard designs for other precast box sections. The C 850 standard requires shear connectors between top slabs of adjacent box sections, a requirement that is also adopted by AASHTO.

Proposed structural criteria changes to ASTM C 850 or C 789 are first presented to the AASHTO Rigid Culvert Liaison Committee to the AASHTO Bridge Committee. The question of the necessity of shear connectors is being studied by this committee, and this project was initiated to determine the structural integrity of C 850 culverts without shear connectors subject to concentrated wheel loads. A similar research project has also been initiated in Ohio under the direction of Ohio Department of Transportation engineer John D. Herl. Preliminary reports of both these projects were presented to Transportation Research Board Committee A2C06 on January 17, 1983.

1.2 Present Design Standards

1.2.1 ASTM C 850 - The ASTM Standard C 850 [1]* establishes design standards for precast concrete box culverts to be used with less than 2 ft of cover. The standard specifies minimum steel and concrete strengths, areas, and geometries for 42 standard culvert sizes subject to two loadings. The design criteria, computer programs, and standard designs are based on studies and tests sponsored by the American Concrete Pipe Association, the Virginia Department of Highways, and the Wire Reinforcement Institute [2,3]. The required transverse steel areas are based on computer solutions using several simplifying assumptions, including the following assumptions regarding wheel load distribution:

(1) Wheel loads are distributed parallel to span over a length equal to (8 in. + 1.75 H), where H = height of soil cover, in.

(2) The effective width of top slab resisting wheel load is taken to be (48 in. + 0.06 (SPAN-HAUNCH)).

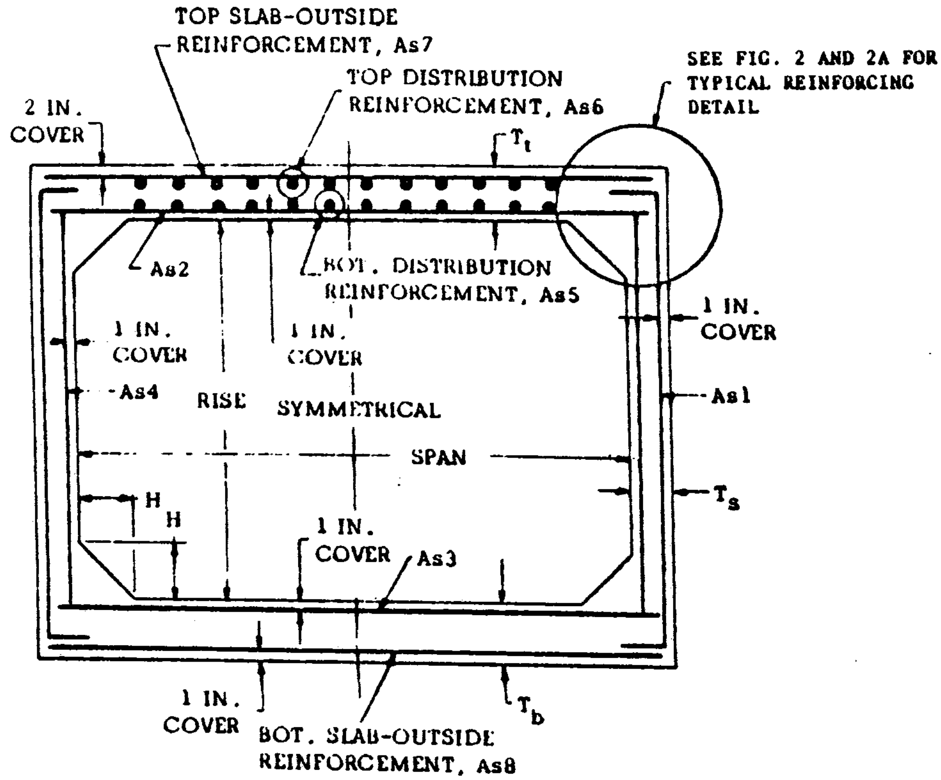
Figure 1 shows the reinforcement detail and cross section geometry for a C 850 box section. Figure 2 shows the assumed simplified wheel loading specified for the so-called "strip" design method.

The design procedure used to develop the standard box sections [2] limits the crack widths at service load to 0.010 in. by limiting the design service steel stress to a value given by

$$f_s = \frac{65}{\sqrt[3]{t_b^2\, s_\ell}} + 5(\text{ksi}), \tag{1}$$

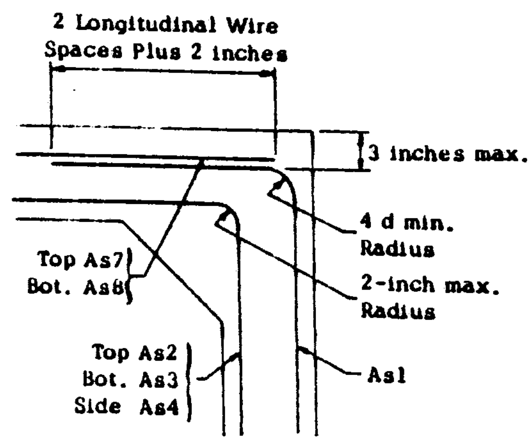
where t_b is the distance from the centroid of the tension steel to the outermost concrete tension fiber (in.), and s_ℓ is the spacing of the

*Numbers in brackets refer to numbered references.



NOTE 1 - The haunch dimension H, is equal to the thickness T.

Typical Box Section



Detail Option

FIGURE 1. ASTM C850 CONCRETE BOX SECTION REINFORCING STEEL (1)

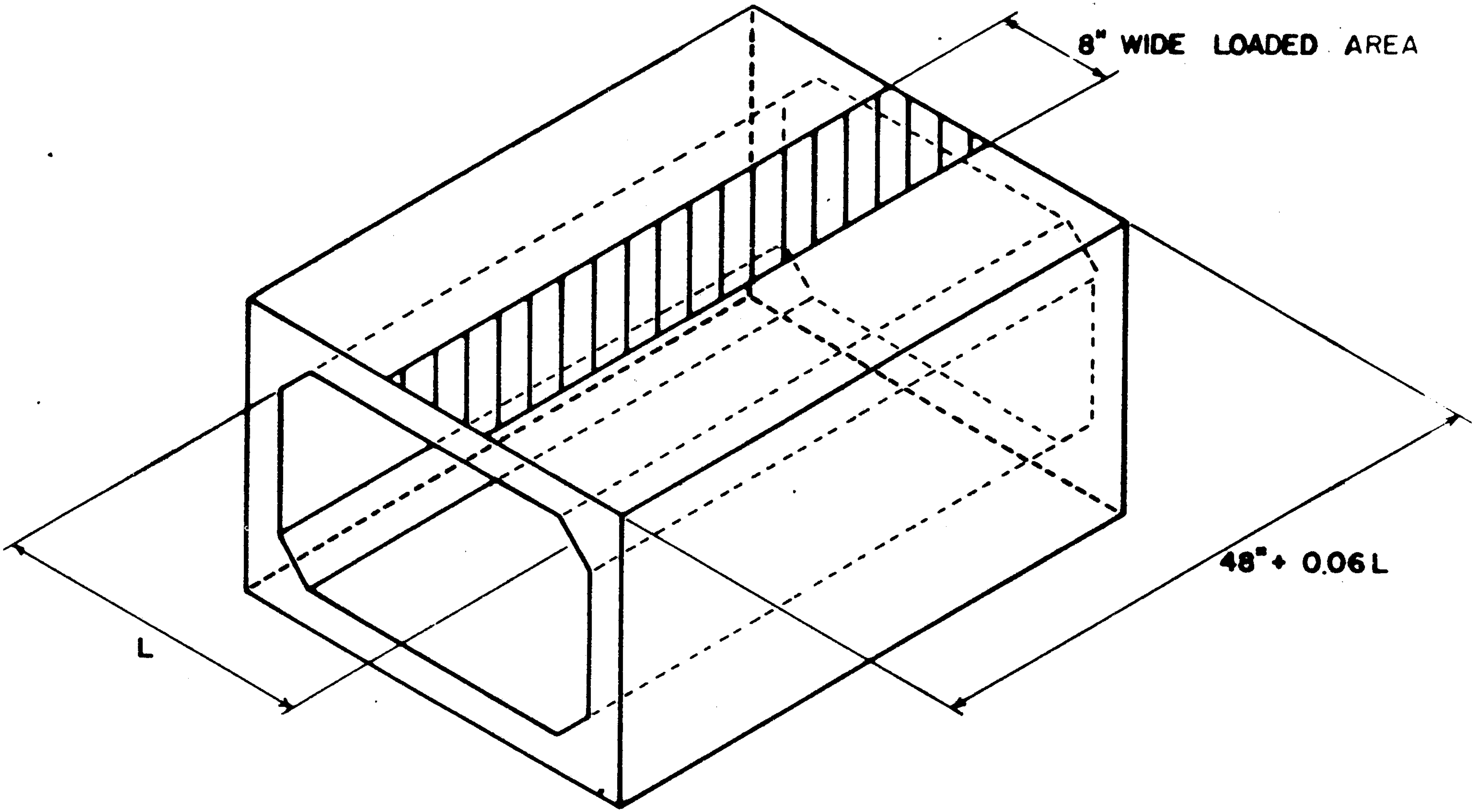


FIGURE 2. ASTM C850 DESIGN WHEEL LOAD
DISTRIBUTION - NO COVER

longitudinal reinforcing steel wires (in.). This equation is based on studies by Lloyd, Rejali and Kessler [4] and subsequent criteria developed by Gergely and Lutz [5], and is a more conservative limitation than the ACI crack control criteria [6] and the AASHTO crack control criteria [7]; but the stress allowed by this limitation may be greater than the AASHTO fatigue stress limitation of 21 ksi [8] or the ACI allowable service load stress of 36 ksi [7]. For example, the two 7 x 5 boxes tested here have t_b = 1.0 in. and s_ℓ = 3.0 in., so the maximum steel stress to limit cracking is approximately f_s = 50.1 ksi.

Additionally, ASTM C 850 specifies that the joint provide a smooth interior free of appreciable irregularities, and that the joint be designed or modified to transmit a minimum of 3000 lb of vertical shear force per foot of top slab joint. Shear connectors used to satisfy this requirement must be spaced no more than 30 in. on center and with a minimum of two connectors per joint. These requirements are intended to provide continuity of shears and deflections across joints to reduce culvert stresses when loaded near a joint and minimize relative displacements of culvert and cover.

1.2.2 AASHTO Standard Specification for Highway Bridges [7,8] - The AASHTO specifications include minimum requirements for design and methods of analysis for highway bridge structures, including culverts. These requirements are essentially satisfied by the ASTM C 850 standard. At longitudinal edges of reinforced concrete slabs, AASHTO 1.3.2(D) [8] requires an edge beam additional reinforcement in the slab, or an integral reinforced section of slab and curb. Since edge beams and curbs are not acceptable, and to provide continuity of deflections as well as shears, ASTM C 850 8.2 specifies that shear connectors be used to transmit the calculated shear across joints between culvert segments. This requirement is also adopted by AASHTO 1.15.7(D)(4) [7].

2. THEORETICAL ANALYSIS

2.1 Predicted Internal Moments

The FORTRAN code SLAB 49 [9] was used to predict the internal moments in the top slab of the model shown in Figure 3. For simplicity, the slab is assumed to be isotropic, neglecting the difference in distribution and flexural steel areas. SLAB 49 uses discrete elements which simulate linear, small deformation plate behavior. A 2.0 in. x 2.0 in. mesh size was used. The symmetric boundary conditions along the centerline were approximated with zero vertical restraint and essentially infinite rotational restraint along the centerline. Edge support at the side wall was approximated by a simple support and an elastic rotational restraint simulating the rotational stiffness of the side wall. Membrane reactions and forces were neglected, consistent with linear plate theory simplifications.

The predicted internal moments are shown in Figure 4 for two basic plate stiffnesses. The result labeled "uncracked" is the predicted moment distribution assuming the stiffness is equal to that of an uncracked 8 in. thick concrete plate, neglecting the reinforcing steel which would change the stiffness by only 6% approximately. The result labeled "cracked" is the predicted moment distribution neglecting the contribution of concrete in the tensile region. It is noteworthy that while the cracked stiffness is only 23% of the uncracked stiffness, the predicted maximum flexural moments are not significantly different. In addition to predicted moments, vertical deflections are also predicted, and Figure 5 presents the predicted top slab vertical deflection along the culvert centerline.

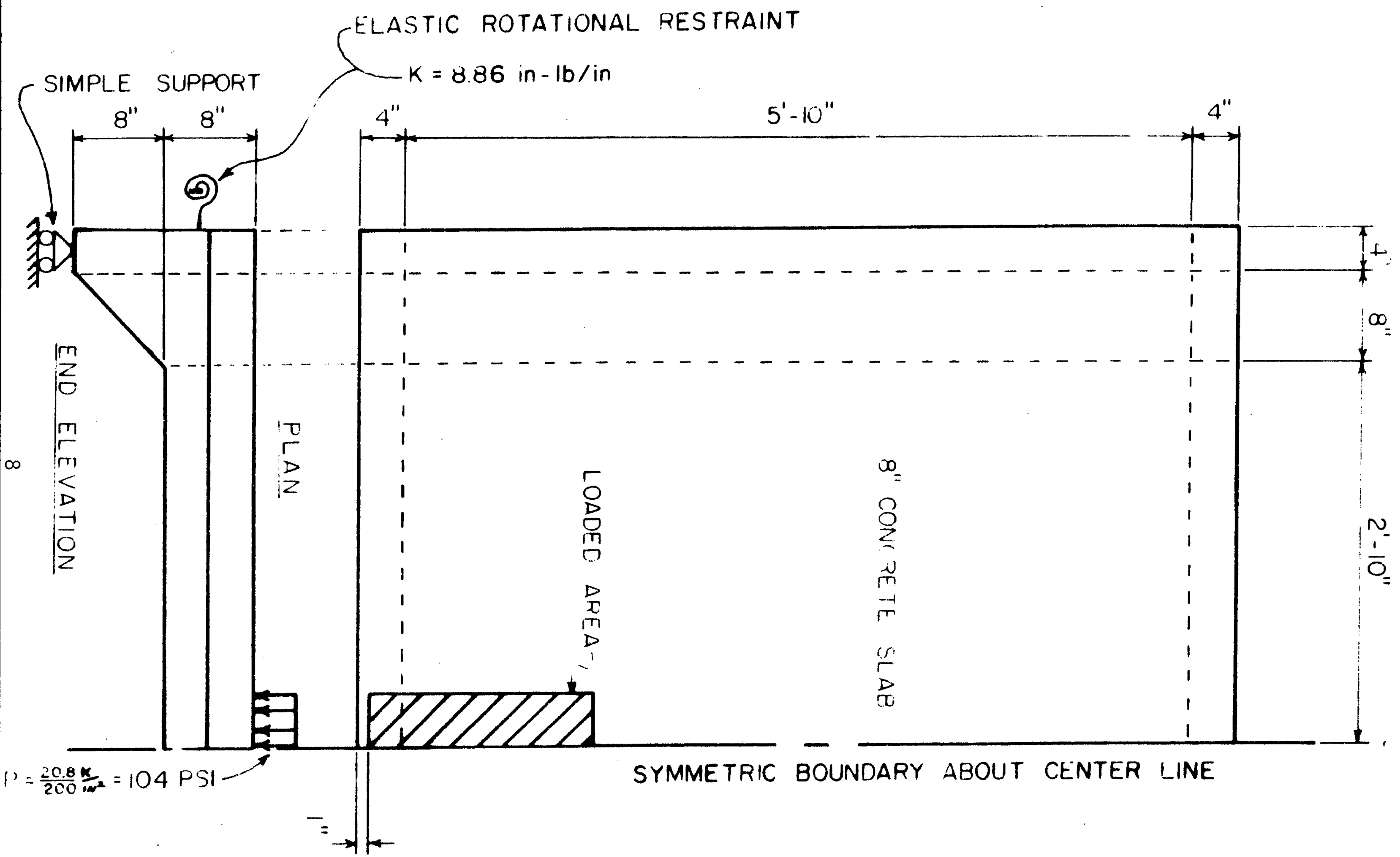
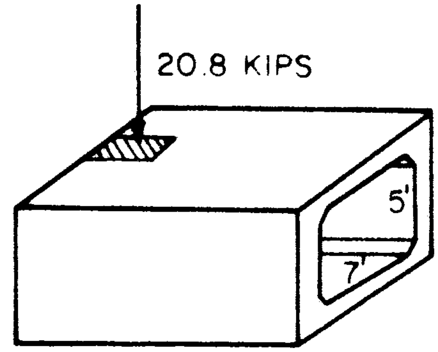


FIGURE 3. SLAB 49 MODEL OF 7ft TOP SLAB



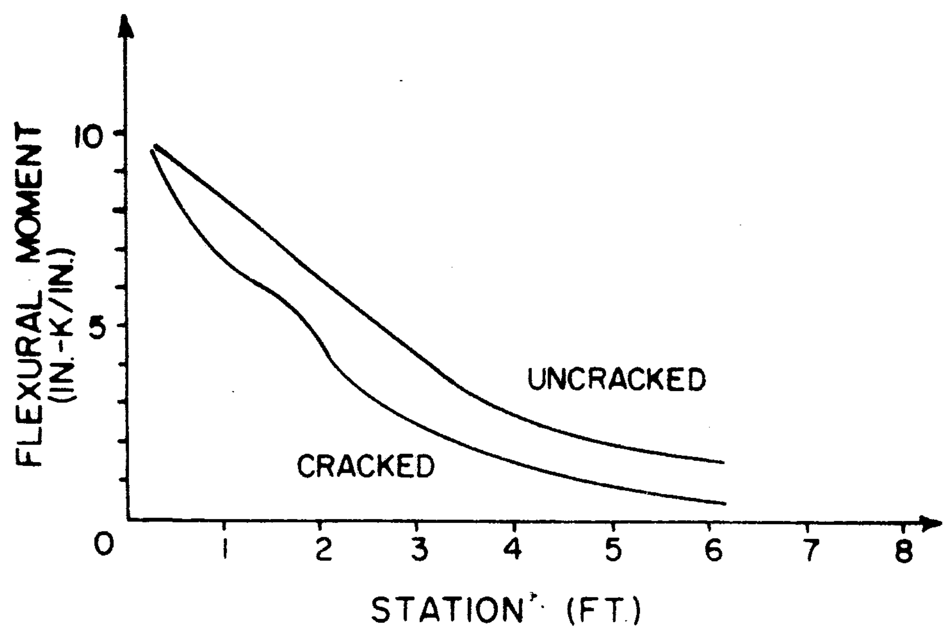
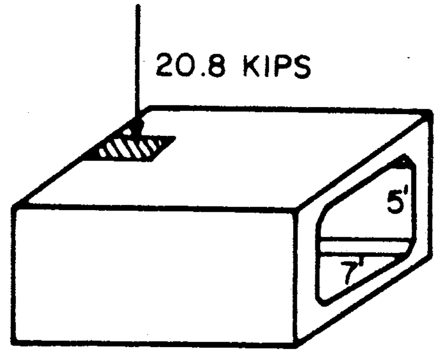


FIGURE 4. PREDICTED TOP SLAB FLEXURAL MOMENTS CENTERLINE OF 7FT SLAB



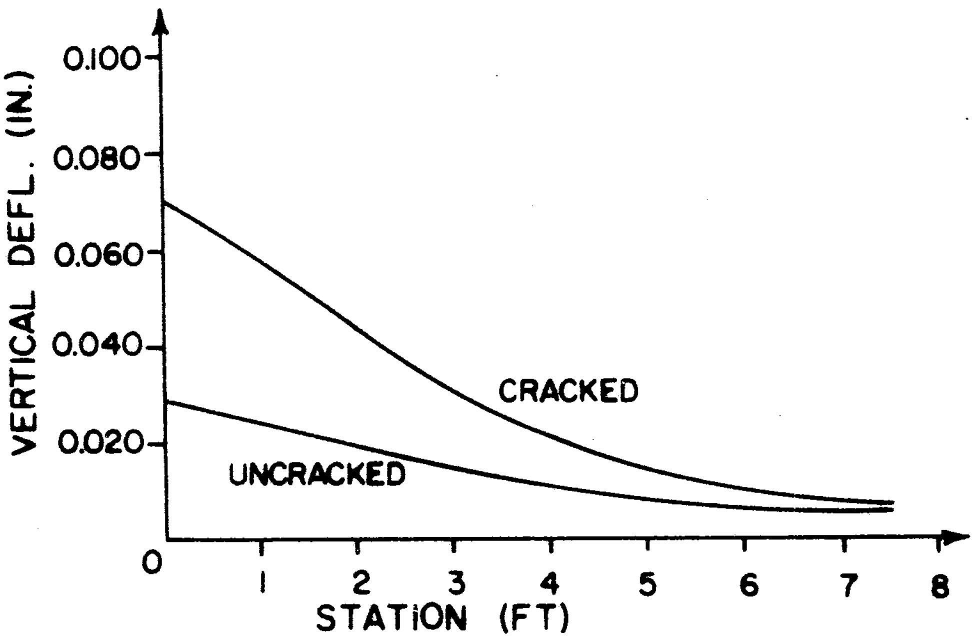


FIGURE 5. PREDICTED VERTICAL DEFLECTIONS CENTERLINE OF 7FT SLAB

2.2 Predicted Steel Stresses

Steel stresses are calculated from predicted slab flexural moments as follows: Assuming isotropic elastic plate behavior, the flexural stress in the reinforcing steel is

$$f_s = \frac{nM_1 y}{I_1} , \tag{2}$$

where $n = E_s/E_c$ is the modular ratio,

M_1 is the flexural moment per unit length,

y is the distance of the tension steel from the neutral surface,

and $I_1 = \frac{bh^3}{12(1 - \nu^2)}$ is the moment of inertia per unit width b for a slab of thickness h and Poisson's ratio ν.

Using $n = 7.44$,

$h = 8.0$ in.,

$\nu = 0.15$,

and $y = 3.0$ in.,

the moment of inertia becomes

$I_1 = 43.6\ \text{in.}^4/\text{in.}$,

and the steel stress is given by

$$f_s = M_1/1.96\ \text{in.}^3/\text{in.} \tag{3}$$

This calculation is based on the assumptions that the stresses are linearly distributed, and that the reinforcing steel areas may be neglected in computation of neutral surface location and moment of inertia.

If cracking occurs, the concrete stresses can be assumed to be nonzero in the compression region only, with the tensile force resultant provided entirely by the tension steel. Using this assumption, the calculated equivalent concrete section has a depth

$$c = 1.765 \text{ in.},$$

and the equivalent concrete section moment of inertia is approximately

$$I_1 = 10.22 \text{ in.}^4/\text{in.}$$

The distance from the neutral surface to the tension steel is approximately

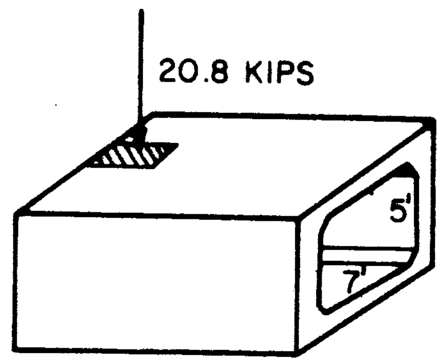
$$y = 5.235 \text{ in.},$$

and the resulting relation between flexural stress and moment becomes

$$f_s = M_1/0.262 \text{ in.}^3/\text{in.} \qquad (4)$$

Steel stresses calculated from predicted top slab moments are shown in Figure 6. While the predicted maximum moments in the uncracked and cracked section models differ by only approximately 2%, the predicted maximum steel stress in the cracked section is approximately 7.5 times the predicted steel stress in the uncracked section.

The maximum predicted steel stress of 37 ksi in the cracked section exceeds the 21 ksi AASHTO fatigue limit stress and the 36 ksi service load limit stress of ACI, but is less than the crack control limit stress for this geometry used in the ASTM C 850 design procedure.



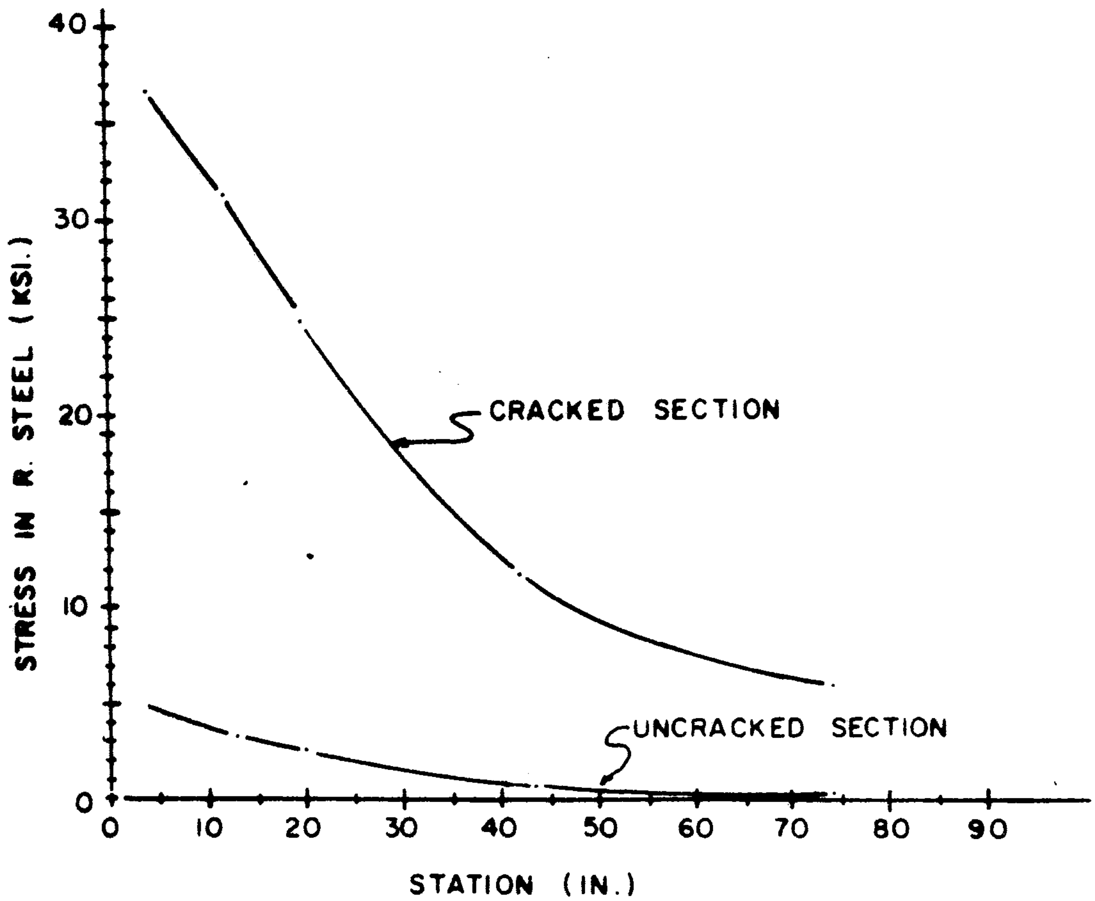


FIGURE 6. PREDICTED REINFORCING STEEL STRESSES - CENTERLINE OF 7FT. SLAB

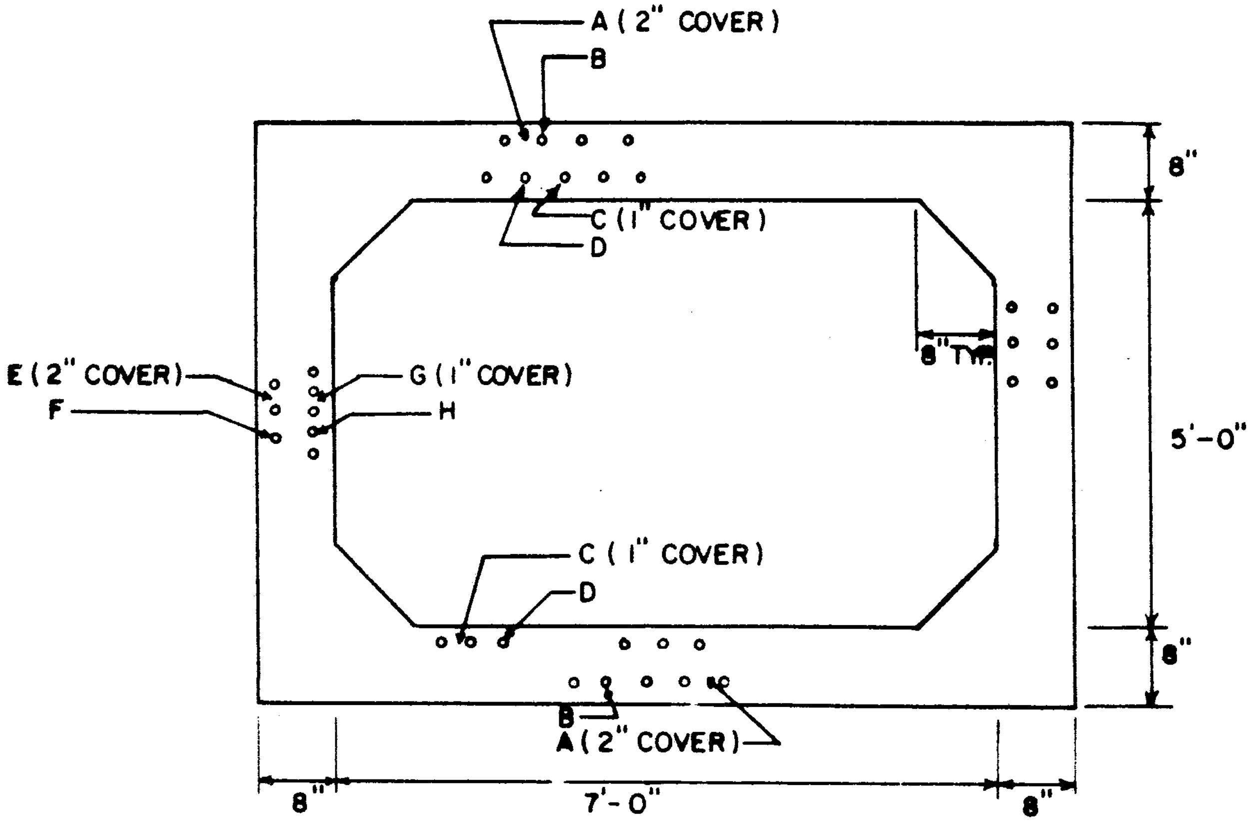
3. EXPERIMENTAL PROCEDURE

3.1 Test Sections

Two 7 x 5 precast concrete box culverts were fabricated at the Gifford-Hill & Co. plant in Ft. Worth, Texas. The geometry is described in Figure 7. The design and materials met ASTM C 850 minimum requirements with the exception of reinforcement area A_{s1}. Standard 5 x 5 box requirements for A_{s7} were given precedence over 7 x 5 requirements for A_{s1}. The steel areas were in accordance with C 850 except for the 5 ft slabs which were more heavily reinforced in order to approximately simulate behavior of standard 5 x 5 box culverts using the same 7 x 5 specimens rolled 90^{o}. The measured concrete compressive strength was 5725 psi, which exceeds the design compressive strength of 5000 psi. The reinforcing mesh is grade 65 (65 ksi yield strength). According to ASTM C 850, the yield strength is taken to be 60 ksi for purposes of analysis.

3.2 Instrumentation

The culverts were instrumented with strain gages bonded to the 8 gage main transverse reinforcing steel wires in theoretical maximum tensile stress regions. Strain gage locations are described in Figure 8. Six gages were installed in each culvert, however two gages were damaged during placement of concrete, leaving ten serviceable strain gages. The gages chosen were Tokyo Sokki Kenkyujo Type FLA-6-11. The gages were bonded with Micro-Measurements M-bond 200 adhesive, waterproofed with Micro-Measurements M-Coat A polyurethane and Dow Corning 3145 RTV. Additional mechanical protection was provided by wrapping each installation with several layers of aluminum foil tape. Lead wires were routed downward along longitudinal



WIRE	SIZE	AREA (in²/ft.)
A	W5.0x3	0.20
B	W4.8x3	0.19
C*	W8.0x2	0.48
D	W4.8x3	0.19
E	W4.8x3	0.19
F	W4.8x3	0.19
G*	W8.0x2	0.48
H	W5.5x3	0.22

*INSTRUMENTED WIRES.

FIGURE 7. GEOMETRY AND REINFORCEMENT SCHEDULE FOR TEST SPECIMENS.

Table 1. Comparison of Test Specimen Reinforcing Steel Schedule with ASTM C 850 Specification

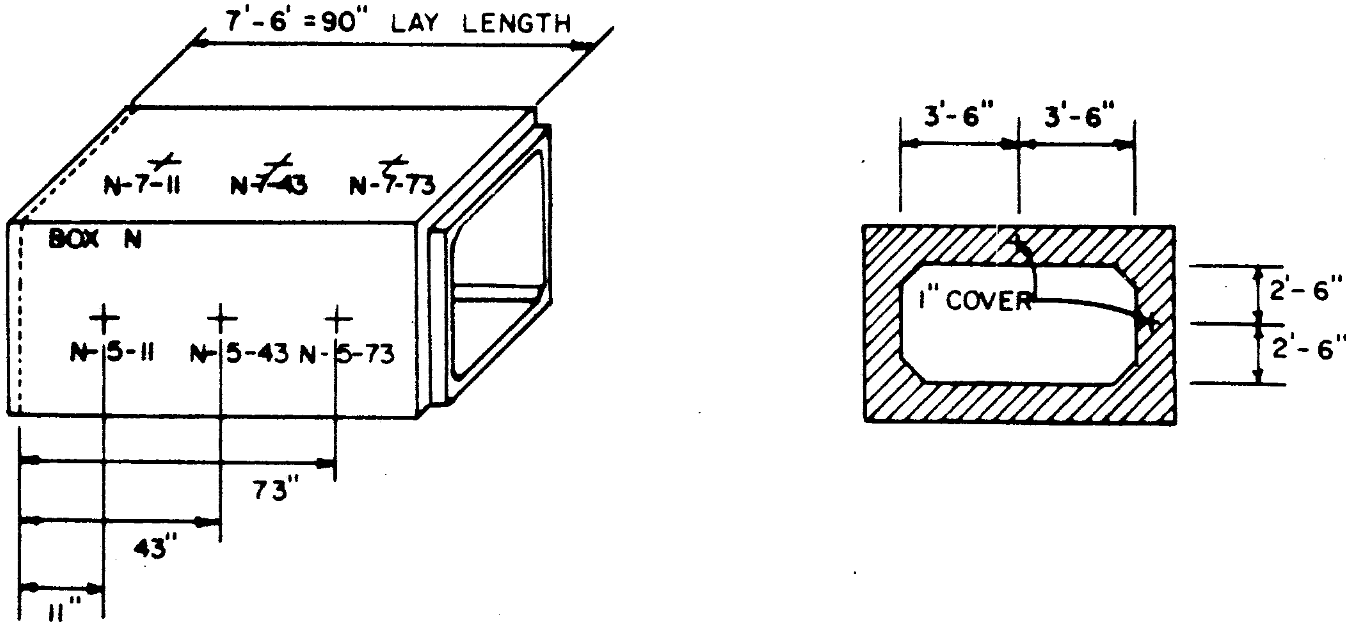
(a) 7 x 5 Test Configuration (7 ft Span)

Reinforcement	C 850 7 x 5 Required Area HS 20 (in.^{2}/ft)	C 850 7 x 5 Required Area Interstate (in.^{2}/ft)	As Built Area (in.^{2}/ft)
A_{s1}(E)	0.29	0.30	0.19
A_{s2}(C)	0.48	0.48	0.48
A_{s3}(C)	0.27	0.34	0.48
A_{s4}(G)	0.19[a]	0.19[a]	0.48
A_{s7}(A)	0.20	0.20	0.20
A_{s8}(a)	0.19[a]	0.19[a]	0.20
A_{s5}(D)	0.19[a]	0.19[a]	0.19
A_{s6}(B)	0.19[a]	0.19[a]	0.19

(b) 5 x 7 Test Configuration (5 ft Span)

Reinforcement	C 850 5 x 7 Required Area HS 20 (in.^{2}/ft)	C 850 5 x 7 Required Area Interstate (in.^{2}/ft)	As Built Area (in.^{2}/ft)
A_{s1}(A)	0.16	0.21	0.20
A_{s2}(G)	0.46	0.46	0.48
A_{s3}(G)	0.26	0.34	0.48
A_{s4}(C)	0.14[a]	0.14[a]	0.48
A_{s7}(E)	0.19[a]	0.19[a]	0.19
A_{s8}(E)	0.17[a]	0.17[a]	0.19
A_{s5}(H)	0.22	0.22	0.22
A_{s6}(F)	0.19[a]	0.19[a]	0.19

[a]Minimum reinforcement area is specified.



NOTES: "N" DENOTES BOX NUMBER 1 OR 2.
GAGES 1-5-11 AND 1-7-11 WERE DAMAGED DURING CONCRETE PLACEMENT.

FIGURE 8. STRAIN GAGE LOCATION & NOMENCLATURE

steel (perpendicular to traffic), exiting the reinforcing cage and form at the female connection end. The gages were wired into ten single active arm bridges using three wire hookups to eliminate signals due to thermally induced lead wire resistance changes.

Installed gage resistance was checked at the time of installation, but gage isolation resistance was not measured because of tight fabrication schedules. Gage isolation resistance was measured after testing had been completed, and after semi-destructive measurements of concrete cover had been made. Measured gage isolation resistances were approximately 150 MΩ or greater, which indicates acceptable isolation [10,11] at all but three gages as shown in Appendix A. Gages at stations 1-7-42, 2-7-11, and 2-7-43 all indicated unacceptably low gage isolation resistances. Strain gages at critical stations 1-5-73, 1-7-73, 2-5-73, and 2-7-73 all indicated open circuit gage isolation resistance with the analog ohmmeter used, which can detect resistances below 150 MΩ. The strain gage at station 1-5-42 had a marginal isolation resistance.

In addition to the resistance strain gages installed on the reinforcing steel, the culverts were instrumented with deflection dial indicators to measure vertical deflection at three of the top surface strain gage locations. The dial indicators were supported in fixtures mounted to the bottom slab inside surface. Deflections were monitored at the point of load application and at the two adjacent strain gage stations in order to monitor relative deflection across the joint.

3.3 Test Procedure

After curing, the culverts were transported to the test site and assembled in the fixture as shown schematically in Figure 9. Concentrated loads were applied to the top surface of the culvert through a 1 in. x 10 in. x 20 in. steel bearing plate and 1/2 in. neoprene pad located as shown in Figure 9. A hydraulic ram and electric motor driven hydraulic pump were used to apply the loads. A 100,000 lb compression load cell was used to measure the applied load. The lower surfaces of the culverts rested on 1/2 in. plywood sheets over doubled 3/4 in. rigid foam thermal insulating panels which rested on the steel reaction frame bed.

The culvert sections were aligned and fitted together snugly without grout, joint filler material, or shear transfer connectors. The fit of the joint was qualitatively evaluated by inserting a sheet of paper through the joint. The paper could be slipped through the joint at several places, but interference between the two faces prevented drawing the paper along the length of the joint. The visible joint was generally of uniform width, with no significant variations.

The reported test loads represent HS20-44 16 kip wheel loads multiplied by a 1.3 impact factor specified by AASHTO for a design service load of 20.8 kip and a 16 kip wheel multiplied by factors (1.3)(1.67)(1.3) = 2.82 for a design ultimate factored load of 45.2 kip. The 78.0 kip load reached in test No. 9 represents the limiting load on the test fixture compression members, which indicated impending lateral instability.

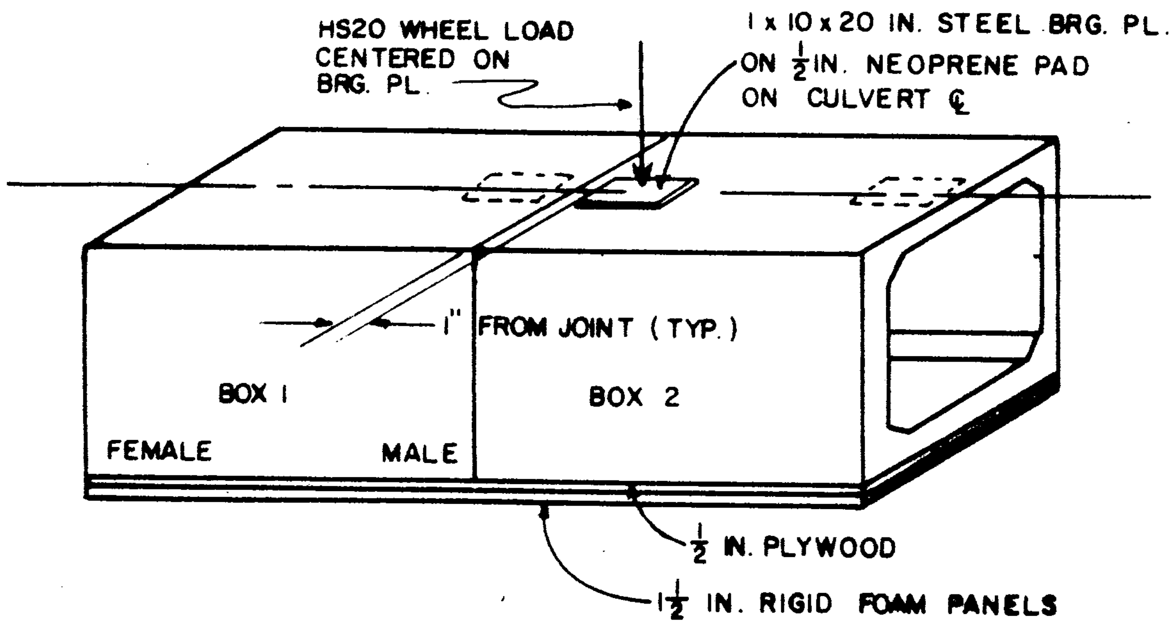


FIGURE 9. TEST CONFIGURATION SCHEMATIC

The testing schedule is summarized in the following table:

Table 2. Actual Test Schedule

Date	Test No.	Test Configuration Code[1]	Max. Test Load	Repetitions	Comments
7-29-82	1	7F2	20.8 k	2	
7-29-82	2	7M1	20.8 k	2	
8-17-82	3	5F2	20.8 k	3	
8-17-82	4	5M1	20.8 k	3	
8-17-82	5	5M1	45.2 k	2	Replaced 1/2" Brg. PL with 1" PL
8-18-82	5A	5M1	45.1 k	3	
8-18-82	6	5F2	45.2 k	3	
8-19-82	7	7F2	45.7 k	3	
8-19-82	8	7M1	45.5 k	3	
8-19-82	9	7M1	78.0 k	1	
8-20-82	10	7M2	45.5 k	3	

[1]The first digit in the test configuration code denotes the span in feet, the letter M or F refers to the male or female end, and the second digit refers to box No. 1 or 2.

4. TEST RESULTS

4.1 Measured Stresses

Calibration of the strain gages was accomplished by performing uniaxial tension tests on an instrumented steel wire. Measured tangent moduli were 31.1 x 10^3 ksi and 29.7 x 10^3 ksi in two tests, so measured strains were converted to steel stresses using an elastic modulus of 30 x 10^3 ksi. Measured ultimate tensile strength was 74.2 ksi.

Figure 10 presents measured steel stresses for test configurations 7M1, 7F2, and 7M2 for test loads of 20.8 kip and 45.2 kip. Critical loading occurs in test 7M1, and maximum steel stress for the design service loading of 20.8 kip is 6.4 ksi in the top slab steel at gage location 1-7-73. For the design ultimate load of 45.2 kip, the maximum steel stress is 17.2 ksi.

Figure 11 presents measured steel stresses for test configurations 5M1 and 5F2 and for test loads of 20.8 kip and 45.2 kip. Critical steel stresses occur in test configuration 5M1, however stresses are lower than measured stresses in tests of the 7 ft span.

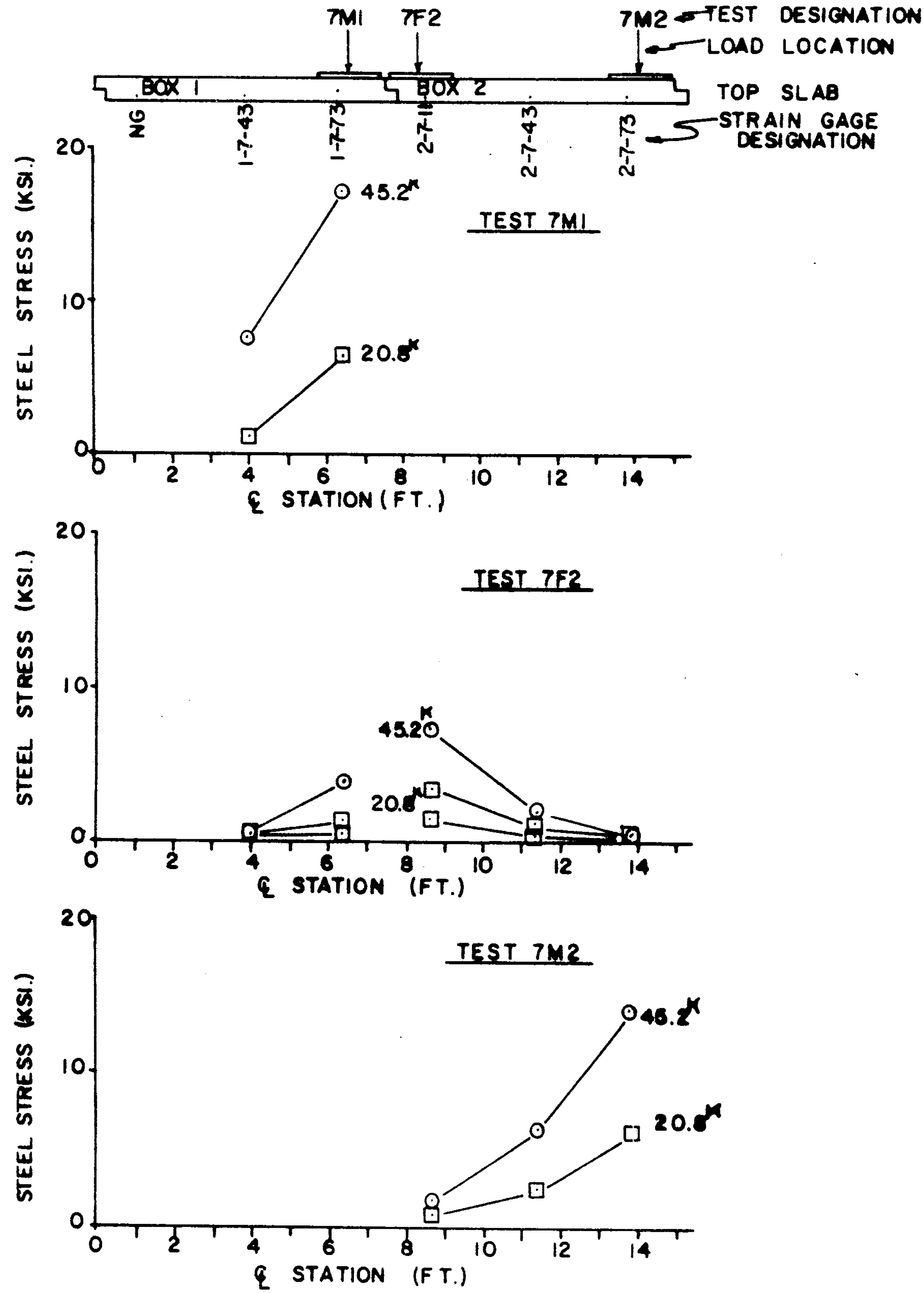


FIGURE 10. MEASURED REINFORCING STEEL STRESSES
— CENTERLINE OF 7FT. SLAB

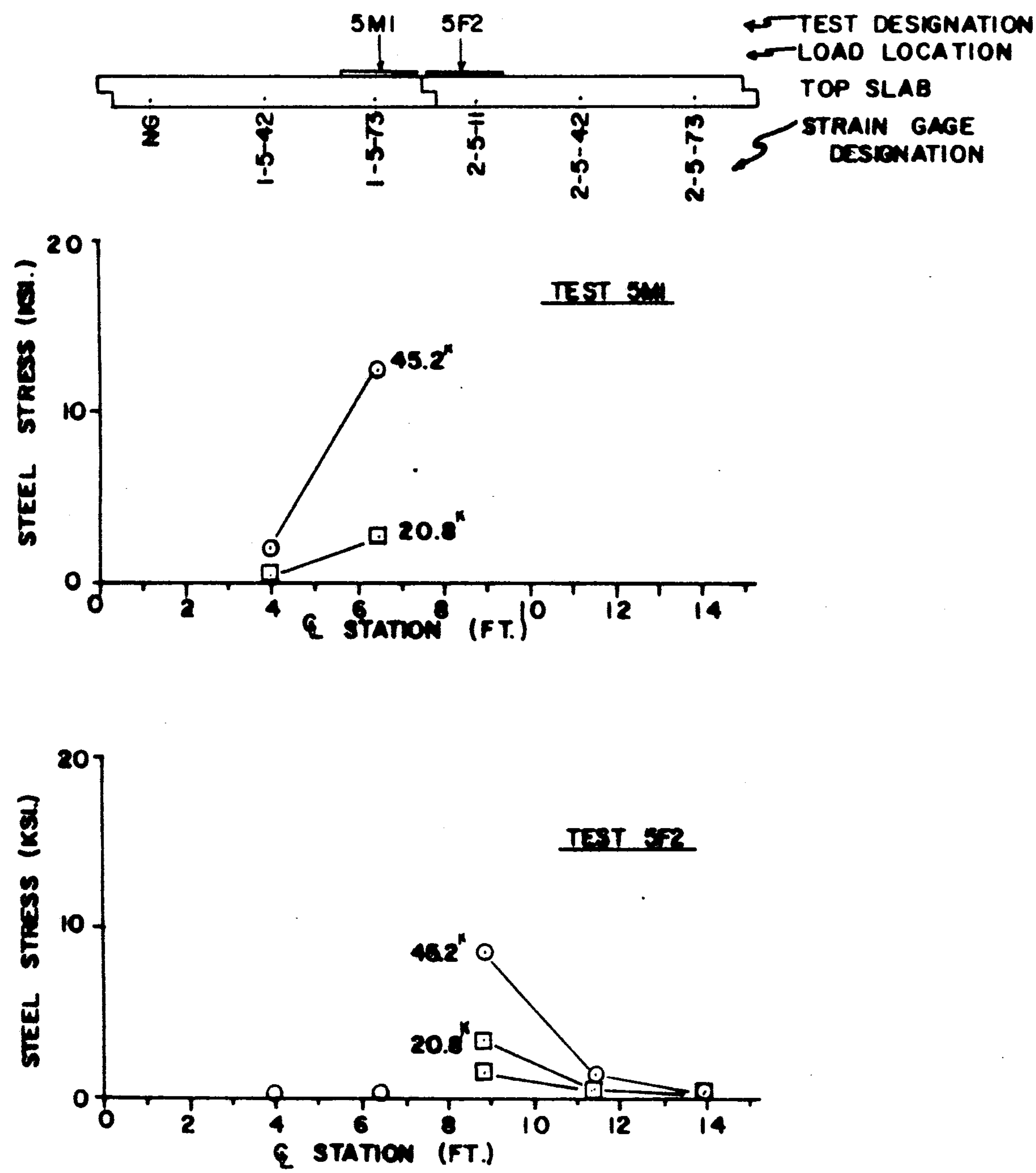


FIGURE 11. MEASURED REINFORCING STEEL STRESSES CENTERLINE OF 5FT. SLAB

4.2 Measured Deflections

Measured top slab deflections are presented in Figure 12 for test configurations 7M1, 7F2, and 7M2 and for test loads of 20.8 kip and 45.2 kip. Test configuration 7M1 is critical with respect to maximum absolute deflection and relative deflection across the joint.

Measured top slab deflections are presented in Figure 13 for tests 5M1 and 5F2 for test loads of 20.8 kip and 45.2 kip. Maximum absolute and relative deflections occur in configuration 5F2.

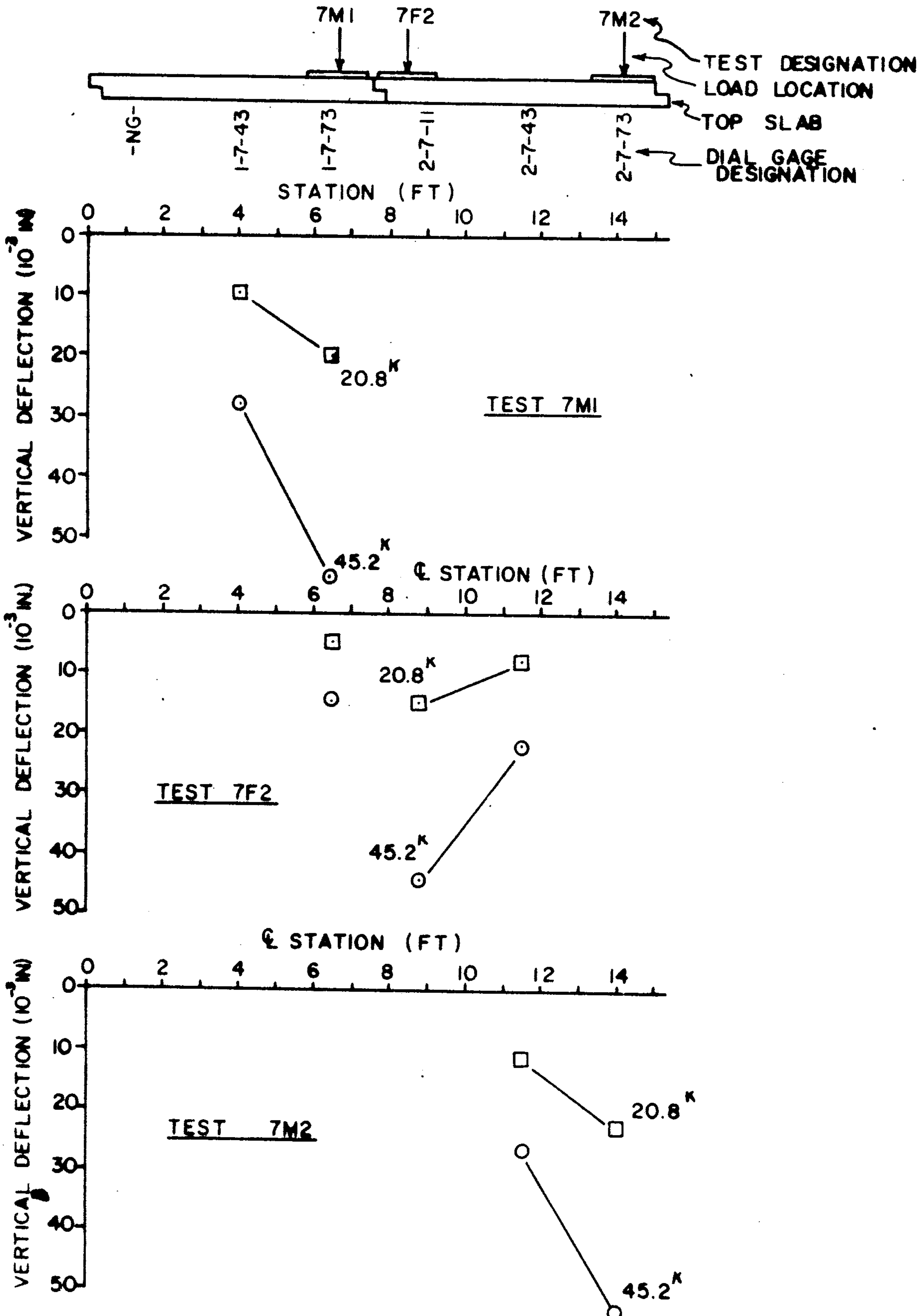


FIGURE 12. MEASURED VERTICAL DEFLECTIONS CENTERLINE OF 7FT SLAB

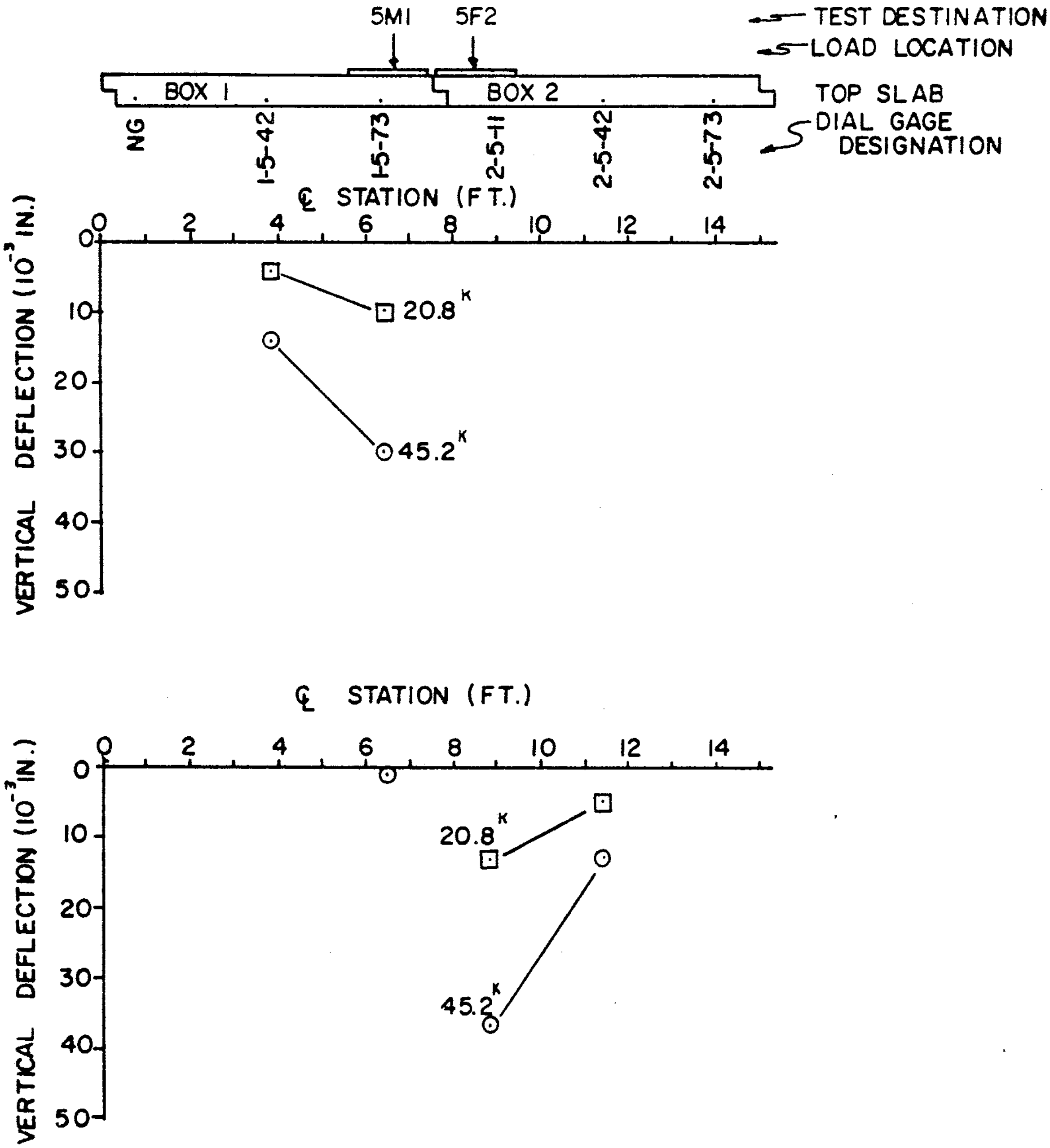


FIGURE 13. MEASURED VERTICAL DEFLECTIONS-CENTERLINE OF 5FT. SLAB

4.3 Discussion of Results

For test loads of 20.8 kip, representing the design service wheel load, all measured steel stresses are well below the C 850 live load fatigue limit stress of 21.0 ksi. The maximum measured stress is 6.4 ksi in configuration 7M1.

For test loads of 45.2 kip, representing the design ultimate wheel load, all measured steel stresses are well below the C 850 ultimate total load yield stress limitation of 60 ksi. The maximum measured steel stress is 17.2 ksi in configuration 7M1. Dead load stresses have not been calculated here.

Significant load transfer across the joint is obvious in the data from test configuration 7F2 only. Stress data for test configuration 5F2, in which load transfer is also possible, does not indicate any significant load transfer although deflection data does indicate some minor load transfer is occurring. As is expected, no load transfer across the joint is observed in test configurations 7M1 or 5M1. While maximum measured stresses occurred at gage locations 1-7-73 and 1-5-73, maximum deflections occurred at stations 1-7-73 and 2-5-11. The stiffness at stations 2-7-11 and 2-5-11 is expected to be less, neglecting shear interaction across the joint, than the stiffness at stations 1-7-73 and 1-5-73, respectively, because of the joint geometry. Both stations are located 11 in. from the joint line, but the male connection of stations 1-5-73 and 1-7-73 has more concrete outboard of the point of load application than does the female connection at stations 1-5-11 and 1-7-11. The vertical deflection in configuration 7F2 is less than the deflection in configuration 7M1 because of the significant shear transfer that occurs in configuration 7F2. Without significant shear transfer in configuration 5F2, the deflection is slightly greater than that of configuration 5M1.

A comparison of the measured stresses presented in Figure 10 and the predicted stresses in Figure 6 suggests that the top slab is behaving essentially as an uncracked section. Measured maximum service load steel stresses are approximately 6.1 to 6.4 ksi, approximately 75% greater than the predicted steel stress of 3.6 ksi assuming the section is uncracked, and well below the approximately 32 ksi predicted steel stress in the cracked section. Measured vertical deflections presented in Figure 12 more closely agree with predicted uncracked section deflections than predicted cracked section deflections presented in Figure 5.

Cracking was not observed in the top slab at service load. The first observed crack in the 7 ft slab appeared at a test load of 27 kip. Two other flexural cracks opened at test loads of 50 kip and 55 kip, respectively. These three cracks were the only observed cracks having planes which might intersect the instrumented tension steel. The width of the central crack was measured with a graduated reticle at various loads. The observed crack widths were 0.010 in. at 50 kip and 0.013 in. at 60 kip. The field sketch of observed cracks is included in Appendix E.

The effects of the progressive cracking are apparent in Figure 14 which presents steel stresses and vertical deflection histories at gage station 1-7-73 during repeated tests in configuration 7M1. The steel stress per unit load increases with repeated testing, apparently because crack development causes a change in the neutral surface location and a reduction in the effective moment of inertia. The stiffness of the top slab is also reduced for the same reason. The observed effects of the cracking are still significantly less than would be expected if the section is assumed to be fully cracked, according to the design philosophy of the ACI Building Code Requirements for Reinforced Concrete. This is interpreted as an indication that the observed cracking at the strain gage section is not fully developed in spite of the large overload applied, and that the fully cracked section design philosophically is overly conservative when applied to the reinforced slab with the concentrated load considered here.

The limiting crack width of 0.10 in. was observed at a test load of 50 kip. The measured steel stress at that load was approximately 21.7 ksi, considerably less than the 50.1 ksi limiting stress given by equation (1). The strain gage station is very close to the observed crack plane shown in Appendix E.

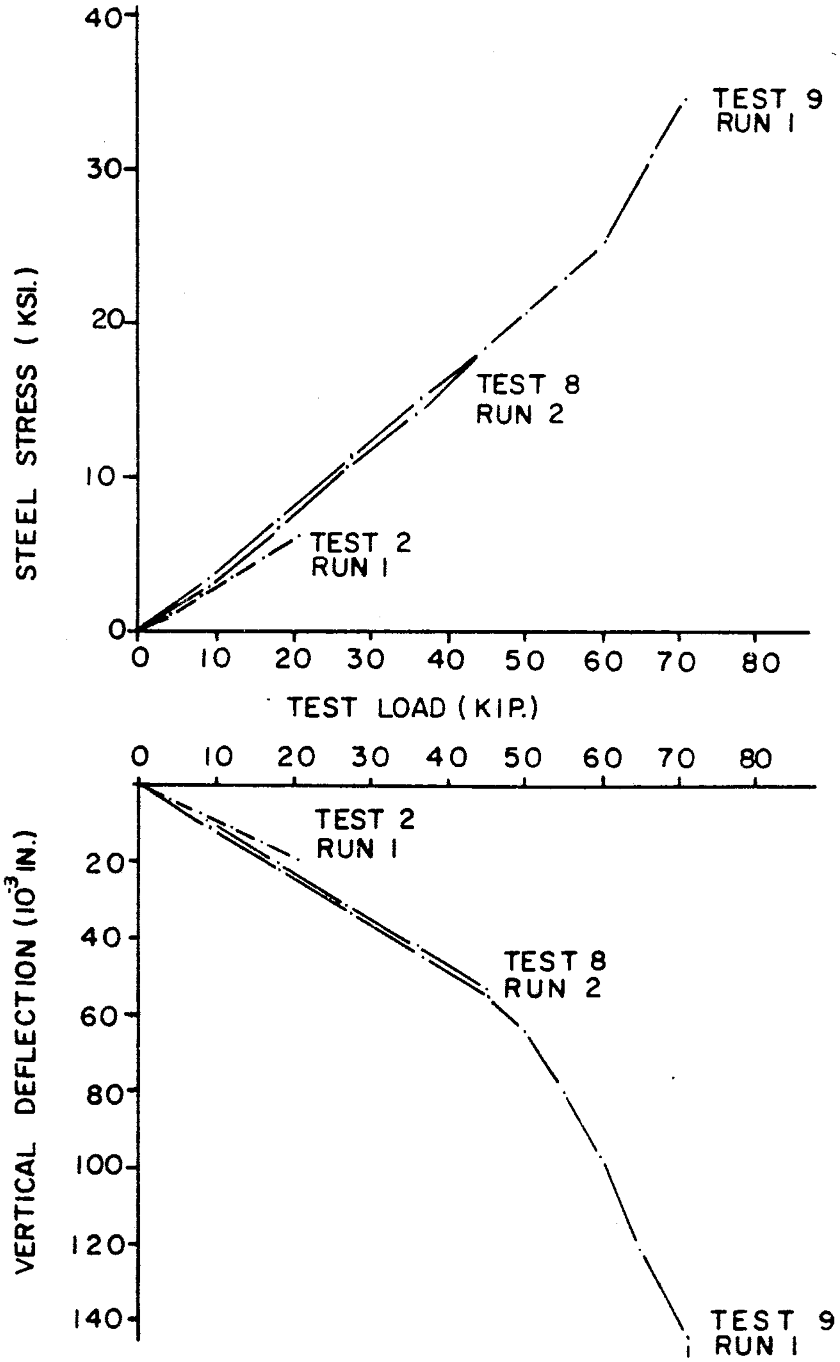


FIGURE 14. REPEATED LOAD-DEFLECTION DATA-STATION 1-7-73 TEST CONFIGURATION 7M1

5. HS 20 AXLE LOAD STRESSES

The live load stresses due to two wheels of an HS 20 axle can be approximated by superposition of measured wheel load stresses. Since the load locations of tests 7F2 and 7M2 are approximately 5'-8" apart, superposition of measured steel stresses in these two tests will allow a conservative approximation of steel stresses caused by two HS 20 wheels spaced 6'-0". By such superposition, the maximum steel stress expected under a design 32.0 kip axle with a 1.3 impact factor is approximately

$$6.1 \text{ ksi} + 0.3 \text{ ksi} = 6.4 \text{ ksi.}$$

This maximum stress occurs at gage station 2-7-73, the male joint end of the culvert.

The maximum steel stress due to a design ultimate axle load of 90.4 kip is

$$14.0 \text{ ksi} + 0.4 \text{ ksi} = 14.4 \text{ ksi.}$$

6. CONCLUSIONS

The following conclusions are drawn from the results:

1. Maximum reinforcing steel stresses in ASTM C 850 7 x 5 box culverts subjected to a design wheel load of 20.8 kip are significantly less than the AASHTO 1.5.26(B) design allowable service steel stress of 24 ksi. The maximum steel stress measured was approximately 6.4 ksi.
2. Maximum reinforcing steel stresses in ASTM C 850 7 x 5 box culverts subjected to a design ultimate wheel load of 45.2 kip are significantly less than the design yield strength of 60 ksi. The maximum measured steel stress was approximately 17.2 ksi.
3. Cracking caused by application of the design ultimate wheel load is relatively insignificant with respect to cracking in a fully cracked section condition specified by the ACI design criteria.

Live load stresses due to other forces and dead load stresses have not been investigated.

7. RECOMMENDATIONS

The following recommendations are offered:

1. ASTM C 850 size 7 x 5 reinforced concrete box sections appear to be conservatively designed due in part to design assumptions and simplifications regarding load distribution. A three-dimensional analysis and experimentally measured stresses support the use of these boxes without shear connectors.
2. A field trial of a C 850 box culvert installed without shear connectors is recommended. Sufficient instrumentation should be installed to verify the presented test results for 7 x 5 boxes, or in the case of boxes of other sizes, to extend the test results. Particular attention should be given to absolute and relative deflection measurements and long-term crack pattern observations.
3. The results of the present study, and future test results, should be presented for consideration to the AASHTO Rigid Culvert Liaison Committee to the AASHTO Bridge Committee, and to ASTM Committee C-13.

REFERENCES

[1] "Standard Specification for Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers with Less than 2 ft of Cover Subjected to Highway Loadings," (ASTM C 850-82), American Society for Testing and Materials, Philadelphia, April 1982, 12 pp.

[2] Latona, Raymond W., Heger, Frank J., and Bealy, Mike, "Computerized Design of Precast Reinforced Concrete Box Culverts," Transportation Research Record No. 443, Transportation Research Board, 1973, pp. 40-51.

[3] Boring, Marvin R., Heger, Frank J., and Bealy, "Test Program for Evaluating Design Method and Standard Designs for Precast Concrete Box Culverts with Wire Fabric Reinforcing," Transportation Research Record No. 518, Transportation Research Board, 1974, pp. 49-63.

[4] Lloyd, J. P., Rejali, H. M., and Kesler, C. E., "Crack Control in One-Way Slabs Reinforced with Deformed Welded Wire Fabric," ACI Journal, Oct. 1963.

[5] Gergely, P., and Lutz, L. A., "Maximum Crack Width in Reinforced Concrete," Symposium on Cracking of Concrete, American Concrete Institute, March 1966.

[6] ACI Committee 318, "Building Code Requirements for Reinforced Concrete (ACI 318-77)," 6th ed., American Concrete Institute, Detroit, March 1981, 103 pp.

[7] <u>Interim Specifications - Bridge 1981, American Association of State Highway and Transportation Officials,</u> Washington, D.C., 1981.

[8] <u>Standard Specifications for Highway Bridges, 12th ed., American Association of State Highway and Transportation</u> Officials, Washington, D.C., 1977, 496 pp.

[9] Panak, John J. and Matlock, Hudson, "A Discrete-Element Method of Analysis for Orthogonal Slab and Grid Bridge Floor Systems," Research Report 56-25, Project 3-5-63-56. Center for Highway Research, The University of Texas at Austin, May 1972, 155 pp.

[10] <u>Practical Strain Gage Measurements, Application Note 290-1, Hewlett Packard, September 1981, 29 pp.</u>

[11] Perry, C. C. and Lissner, H. R., <u>The Strain Gage Primer</u>, McGraw-Hill, Inc., New York, 1962.

APPENDIX A

MEASURED STRAIN GAGE ISOLATION RESISTANCE TO REINFORCING STEEL

MEASURED STRAIN GAGE ISOLATION RESISTANCE TO REINFORCING STEEL[1]

Gage Designation	Gage Isolation Resistance[2]
1-5-11	N-A
1-5-42	>100M Ω
1-5-73	∞
1-7-11	N-A
1-7-42	20M Ω
1-7-73	∞
2-5-11	∞
2-5-43	∞
2-5-73	∞
2-7-11	50M Ω
2-7-43	11M Ω
2-7-73	∞

Notes:

[1]Measured 3/83, six months after testing.

[2]Using analog ohmmeter, resolution 100 M Ω.

[3]"∞" reported resistance can be interpreted as "greater than approximately 500 M Ω".

APPENDIX B

STRAIN GAGE DATA

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 7-29-82 TIME: START 1025 FINISH 1109 TEST No. 1

LOAD APPLIED ON 7 -ft SIDE OF FEMALE END OF BOX No. 2

STRAIN INDICATOR GAGE FACTOR SETTING 2.00

LOAD CELL READING lb	STRAIN GAGE READING, in./in. X 10^6									
	1542	1573	2511	2542	2573	1743	1773	2711	2743	2773
	1	2	3	4	5	6	7	8	9	10
Run #1										
Zero	—	—	—	—	—	0	0	0	0	0
4,000	—	—	—	—	—	0	0	+10	0	0
8,000	—	—	—	—	—	0	+ 2	+20	+ 7	+ 2
12,000	—	—	—	—	—	0	+ 4	+28	+10	+ 4
16,000	—	—	—	—	—	0	+ 9	+35	+11	+ 6
20,840	—	—	—	—	—	+3	+14	+52	+16	+10
16,720	—	—	—	—	—	+2	+12	+52	+13	+ 8
10,640	—	—	—	—	—	0	+ 8	+42	+ 8	+ 8
8,120	—	—	—	—	—	0	+ 5	+37	+ 7	+ 7
4,100	—	—	—	—	—	0	0	+27	+ 5	+ 7
Zero	—	—	—	—	—	0	0	+15	0	+ 5
Run #2										
Zero						0	0	0	0	0
4,100	—	—	—	—	—	0	0	+13	+ 4	0
8,000	—	—	—	—	—	0	0	+20	+ 5	+ 4
12,000	—	—	—	—	—	0	+ 7	+30	+10	+ 8 ?
17,000	—	—	—	—	—	+1	+12	+42	+12	+ 4 ?
20,800	—	—	—	—	—	+5	+12	+50	+13	+ 8
16,100	—	—	—	—	—	+2	+10	+45	+12	+ 7
12,000	—	—	—	—	—	0	+ 8	+37	+10	+ 6
8,100	—	—	—	—	—	0	+4	+28	+ 8	+ 8
4,000	—	—	—	—	—	0	+2	+20	+ 6	+ 6
Zero	—	—	—	—	—	0	0	+ 6	+ 0	+ 8

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 7-29-82 TIME: START 1416 FINISH 1499 TEST No. 2

LOAD APPLIED ON 7 -ft SIDE OF MALE END OF BOX No. 1

STRAIN INDICATOR GAGE FACTOR SETTING 2.00

LOAD CELL READING lb	STRAIN GAGE READING, in./in. X 10^6									
	1542 1	1573 2	2511 3	2542 4	2573 5	1743 6	1773 7	2711 8	2743 9	2773 10
Run #1										
Zero	---	---	---	---	---	0	0	0	0	0
4,200	---	---	---	---	---	+ 5	+ 36	0	0	0
8,000	---	---	---	---	---	+12	+ 78	0	0	0
12,000	---	---	---	---	---	+18	+122	0	0	0
16,000	---	---	---	---	---	+25	+168	0	0	0
20,800	---	---	---	---	---	+37	+222	0	0	0
16,000	---	---	---	---	---	+32	+182	0	0	0
12,000	---	---	---	---	---	+25	+138	0	0	0
8,000	---	---	---	---	---	+16	+ 91	0	0	+ 3
4,000	---	---	---	---	---	+10	+ 45	0	0	0
Zero	---	---	---	---	---	0	0	0	0	0
Run #2										
Zero	---	---	---	---	---	0	0	0	0	0
4,100	---	---	---	---	---	+ 6	+ 37	+2	0	0
8,000	---	---	---	---	---	+14	+ 82	0	0	+ 3
12,000	---	---	---	---	---	+20	+137	0	0	+ 3
16,300	---	---	---	---	---	+28	+174	0	0	0
20,800	---	---	---	---	---	+39	+231	0	0	0
15,400	---	---	---	---	---	+32	+177	0	0	0
12,000	---	---	---	---	---	+25	+139	0	0	0
8,000	---	---	---	---	---	+16	+ 91	0	0	0
4,000	---	---	---	---	---	+ 8	+ 43	0	0	0
Zero	---	---	---	---	---	0	0	0	0	0

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 8-17-82 TIME: START - FINISH - TEST No. 3

LOAD APPLIED ON 5 -ft SIDE OF Female END OF BOX No. 2

STRAIN INDICATOR GAGE FACTOR SETTING 2.00

LOAD CELL READING lb	STRAIN GAGE READING, in./in. X 10^6									
	1542 1	1573 2	2511 3	2542 4	2573 5	1743 6	1773 7	2711 8	2743 9	2773 10
Run #1										
Zero	0	0	0	0	0	0	0	0	0	0
4000	+ 2	+ 1	+ 10	+ 6	+ 3	+ 1	0	0	0	+ 3
8000	+ 2	+ 2	+ 18	+ 8	+ 6	+ 3	0	0	0	0
12000	+ 2	+ 2	+ 28	+ 11	+ 6	+ 2	+ 2	0	0	0
16000	+ 4	+ 4	+ 37	+ 14	+ 8	+ 2	+ 2	- 3	0	0
21800	+ 4	+ 4	+ 57	+ 19	+ 10	+ 2	+ 2	- 6	- 2	0
16020	+ 4	+ 4	+ 50	+ 18	+ 8	+ 4	+ 2	- 2	0	+ 2
10480	+ 4	+ 4	+ 38	+ 16	+ 7	+ 4	+ 4	0	0	0
8300	+ 4	+ 4	+ 34	+ 15	+ 8	+ 4	+ 3	0	0	0
4660	+ 4	+ 4	+ 26	+ 12	+ 7	+ 4	+ 2	0	0	0
Zero	+ 4	+ 4	+ 8	+ 10	+ 6	+ 3	+ 3	+ 3	+ 3	+ 3
Run #2										
Zero	0	0	0	0	0	0	0	0	0	0
4000	0	0	+ 9	+ 4	+ 1	0	0	- 2	- 2	0
8000	+ 2	0	+ 17	+ 6	+ 2	0	0	- 2	0	0
12000	+ 2	0	+ 26	+ 8	+ 2	0	0	- 4	- 2	0
16000	+ 1	0	+ 35	+ 10	+ 4	0	0	- 4	- 4	0
20800	+ 2	+ 1	+ 47	+ 13	+ 4	0	0	- 8	- 5	- 2
16400	0	0	+ 40	+ 10	+ 4	0	0	- 6	- 4	0
10140	0	0	+ 26	+ 7	+ 2	0	- 2	- 4	- 2	0
6380	0	0	+ 18	+ 5	+ 1	0	0	- 2	- 2	0
3740	0	0	+ 12	+ 2	0	0	0	0	0	0
Zero	0	0	+ 4	+ 2	0	0	0	0	0	0

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 8-17-82 TIME: START - FINISH - TEST No. 3

LOAD APPLIED ON 5 -ft SIDE OF Female END OF BOX No. 2

STRAIN INDICATOR GAGE FACTOR SETTING 2.00

LOAD CELL READING lb	STRAIN GAGE READING, in./in. X 10^6									
	1542	1573	2511	2542	2573	1743	1773	2711	2743	2773
	1	2	3	4	5	6	7	8	9	10
Run #3										
Zero	0	0	0	0	0	0	0	0	0	0
4480	0	0	+ 8	+ 2	+ 1	0	0	0	0	0
8000	0	0	+ 15	+ 4	+ 2	0	0	÷ 2	- 2	0
12000	0	0	+ 25	+ 6	+ 2	0	- 2	0	- 4	- 4
16000	0	0	+ 35	+ 9	+ 4	0	- 2	- 6	- 4	- 2
20800	0	0	+ 49	+ 12	+ 6	0	- 1	- 9	- 6	- 2
15980	0	0	+ 40	+ 9	+ 4	0	- 1	- 7	- 4	0
12240	0	0	+ 31	+ 6	+ 4	0	0	- 5	- 3	0
8540	0	0	+ 23	+ 6	+ 3	0	0	- 3	- 2	0
4300	0	0	+ 13	+ 2	+ 2	0	0	- 2	- 2	0
Zero	0	0	+ 3	0	0	0	0	0	0	0

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 8-17-82 TIME: START - FINISH - TEST No. 4

LOAD APPLIED ON 5 -ft SIDE OF Male END OF BOX No. 1

STRAIN INDICATOR GAGE FACTOR SETTING 2.00

LOAD CELL READING lb	STRAIN GAGE READING, in./in. X 10^6									
	1542 1	1573 2	2511 3	2542 4	2573 5	1743 6	1773 7	2711 8	2743 9	2773 10
Run #1										
Zero	0	0	0	0	0	0	0	0	0	0
4300	+ 4	+ 12	0	0	0	0	- 3	0	0	0
8000	+ 6	+ 24	0	0	0	- 2	- 8	0	0	0
12950	+ 10	+ 37	+ 1	0	0	- 4	- 11	0	0	0
16000	+ 14	+ 54	+ 1	0	0	- 6	- 15	0	0	0
20800	+ 22	+ 99	0	0	0	- 8	- 18	0	0	0
15800	+ 15	+ 92	+ 2	0	0	- 5	- 15	0	0	0
11700	+ 12	+ 77	+ 2	0	0	- 4	- 12	0	0	0
8100	+ 9	+ 62	0	0	0	0	- 8	0	0	0
3800	+ 5	+ 43	0	0	0	0	- 3	0	0	0
Zero	0	+ 28	0	0	0	0	0	0	0	0
Run #2										
Zero	0	0	0	0	0	0	0	0	0	0
4100	+ 4	+ 14	0	0	0	0	- 3	0	0	0
8000	+ 6	+ 29	+ 2	0	0	0	- 6	0	0	+ 1
11900	+ 10	+ 47	+ 2	0	0	0	- 10	0	0	+ 3
16000	+ 15	+ 66	+ 3	0	0	- 4	- 6	0	0	+ 3
20800	+ 18	+ 90	+ 2	0	0	- 6	- 18	0	0	+ 2
15600	+ 14	+ 76	0	0	0	- 4	- 15	0	0	+ 3
6800	+ 6	+ 39	0	0	0	0	- 6	0	0	+ 3
3900	+ 4	+ 26	0	0	0	0	- 4	0	0	+ 3
Zero	0	+ 10	0	0	0	0	0	0	0	+ 3

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 8-17-82 TIME: START - FINISH - TEST No. 4

LOAD APPLIED ON ____-ft SIDE OF Male END OF BOX No. 1

STRAIN INDICATOR GAGE FACTOR SETTING 2.00

LOAD CELL READING lb	STRAIN GAGE READING, in./in. X 10^6									
	1542	1573	2511	2542	2573	1743	1773	2711	2743	2773
	1	2	3	4	5	6	7	8	9	10
Run #3										
Zero	0	0	0	0	0	0	0	0	0	0
4500	+ 4	+ 18	0	0	0	0	0	0	0	0
8100	+ 7	+ 32	0	0	0	0	- 6	0	0	0
12000	+ 10	+ 51	0	0	0	- 2	- 10	0	0	0
16000	+ 14	+ 69	+ 2	0	0	- 2	- 13	0	0	0
20800	+ 17	+ 92	0	0	0	- 5	- 17	0	0	0
15280	+ 14	+ 78	0	0	0	- 2	- 14	0	0	0
12200	+ 10	+ 62	0	0	0	0	- 11	0	0	0
8300	+ 8	+ 45	0	0	0	0	- 8	0	0	0
3700	+ 4	+ 23	0	0	0	0	0	0	0	0
Zero	0	+ 7	0	0	0	0	0	0	0	0

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 8-17-82 TIME: START ---- FINISH ----- TEST No. 5

LOAD APPLIED ON 5 -ft SIDE OF MALE END OF BOX No. 1

STRAIN INDICATOR GAGE FACTOR SETTING 2.00

LOAD CELL READING lb	STRAIN GAGE READING, in./in. X 10^6									
	1542	1573	2511	2542	2573	1743	1773	2711	2743	2773
	1	2	3	4	5	6	7	8	9	10
Run #1										
Zero	0	0	0	0	0	0	0	0	0	0
9,000	+ 4	+ 37	0	0	0	0	- 10	0	0	0
18,100	+ 15	+ 83	-2	0	0	-10	- 21	0	+2	0
27,000	+ 45	+312	-2	0	0	-15	- 30	0	+2	0
37,000	+ 66	+495	-3	-2	0	-25	- 44	-1	+2	0
45,150	+105	+591	-3	-2	0	-30	- 53	-1	+2	0
34,600	+ 98	+500	+2	0	+ 3	-23	- 49	+1	0	+4
27,780	+ 89	+427	0	0	+ 3	-18	- 43	0	0	0
17,900	+ 73	+321	0	0	+ 2	-13	- 34	0	0	0
9,500	+ 60	+232	0	0	0	- 7	- 22	0	0	+6
Zero	+ 44	+143	0	0	0	0	- 4	0	0	+6
Run #2										
Zero	0	0	0	0	0	0	0	0	0	0
9,200	+ 11	+ 71	0	0	0	- 2	- 12	0	0	0
18,000	+ 26	+166	0	0	0	-10	- 25	0	0	0
27,200	+ 40	+266	0	0	0	-15	- 35	0	0	0
36,200	+54	+358	0	0	0	-22	- 43	0	0	0
45,200	+70	+449	0	0	0	-25	- 51	0	0	0
36,400	+58	+365	0	0	0	-23	- 46	0	0	0
27,500	+45	+268	0	0	0	-17	- 40	0	0	0
15,700	+25	+131	0	0	0	-10	- 25	0	0	0
9,200	+14	+ 74	0	0	0	- 5	- 18	0	0	0
Zero	0	- 10	0	0	0	0	0	0	0	0

Test 5 terminated due to warped 1/2" thick steel bearing plate beneath load cell.

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 8-18-82 TIME: START - FINISH - TEST No. 5A

LOAD APPLIED ON 5 -ft SIDE OF Male END OF BOX No. 1

STRAIN INDICATOR GAGE FACTOR SETTING 2.00

LOAD CELL READING lb	STRAIN GAGE READING, in./in. X 10^6									
	1542 1	1573 2	2511 3	2542 4	2573 5	1743 6	1773 7	2711 8	2743 9	2773 10
Run #1										
Zero	0	0	0	0	0	0	0	0	0	0
9000	+ 11	+ 56	0	0	0	- 4	- 9	0	0	0
18000	+ 25	+145	0	0	0	- 10	- 18	0	0	0
29000	+ 40	+242	0	0	0	- 15	- 25	0	0	0
36000	+ 55	+334	0	0	0	- 20	- 34	0	0	0
45200	+ 70	+429	+ 2	0	0	- 25	- 42	0	0	0
36000	+ 61	+344	+ 4	+ 2	0	- 20	- 46	0	0	0
27600	+ 48	+256	+ 4	0	0	- 16	- 31	0	0	0
19900	+ 34	+160	+ 4	0	0	- 11	- 22	0	0	0
9600	+ 18	+ 75	+ 4	0	0	- 6	- 14	0	0	0
Zero	+ 4	+ 7	+ 4	0	0	0	0	0	0	0
Run #2										
Zero	0	0	0	0	0	0	0	0	0	0
9000	+ 10	+ 61	0	0	0	- 4	- 10	0	0	0
18000	+ 24	+154	0	0	0	- 10	- 20	0	0	0
27200	+ 40	+250	0	0	0	- 15	- 27	0	0	0
36000	+ 54	+338	0	0	0	- 20	- 35	0	0	0
34100	+ 70	+430	0	0	0	- 24	- 41	0	0	0
35900	+ 57	+343	0	0	0	- 19	- 36	0	0	0
13800	+ 22	+108	0	0	0	- 8	- 18	0	0	0
9500	+ 15	+ 74	0	0	0	- 5	- 14	0	0	0
Zero	0	0	0	0	0	0	0	0	0	0

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 8-18-82 TIME: START - FINISH - TEST No. 5A

LOAD APPLIED ON 5 -ft SIDE OF Male END OF BOX No. 1

STRAIN INDICATOR GAGE FACTOR SETTING 2.00

LOAD CELL READING lb	STRAIN GAGE READING, in./in. X 10^6									
	1542 1	1573 2	2511 3	2542 4	2573 5	1743 6	1773 7	2711 8	2743 9	2773 10
Run #3										
Zero	0	0	0	0	0	0	0	0	0	0
9200	+ 12	+ 69	0	0	0	- 3	- 10	0	0	0
18100	+ 28	+162	0	0	0	- 9	- 19	0	0	0
27100	+ 43	+256	0	0	0	- 14	- 25	0	0	0
36100	+ 55	+346	0	0	0	- 19	- 34	0	0	0
45100	+ 71	+436	0	0	0	- 23	- 40	0	0	0
36000	+ 60	+350	0	0	0	- 19	- 35	0	0	0
26800	+ 44	+252	0	0	0	- 15	- 30	0	0	0
18500	+ 34	+164	0	0	0	- 10	- 23	0	0	0
9600	+ 17	+ 17	0	0	0	- 4	- 6	0	0	0
Zero	0	+ 5	0	0	0	0	0	0	0	0

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 8-18-82 TIME: START - FINISH - TEST No. 6

LOAD APPLIED ON 5 -ft SIDE OF Female END OF BOX No. 2

STRAIN INDICATOR GAGE FACTOR SETTING 2.00

LOAD CELL READING lb	STRAIN GAGE READING, in./in. X 10^6									
	1542 1	1573 2	2511 3	2542 4	2573 5	1743 6	1773 7	2711 8	2743 9	2773 10
Run #1										
Zero	0	0	0	0	0	0	0	0	0	0
9300	0	0	+ 20	+ 5	0	0	0	0	0	0
18200	0	0	+ 41	+ 10	0	0	0	- 9	- 5	0
27200	0	0	+ 70	+ 17	+ 4	0	0	- 15	- 9	0
36200	0	0	+160	+ 24	+ 6	0	0	- 21	- 13	- 4
40300	0	0	+284	+ 28	+ 5	0	0	- 24	- 16	- 7
45100	0	0	+371	+ 29	+ 6	0	0	- 27	- 19	- 7
36300	0	0	+353	+ 23	+ 5	0	0	- 24	- 15	- 6
25700	0	0	+293	+ 16	+ 3	0	0	- 15	- 11	- 4
16900	0	0	+233	+ 9	0	0	0	- 12	- 8	- 3
9700	0	0	+184	+ 4	0	0	0	- 8	- 4	0
Zero	0	0	+120	0	0	0	0	0	0	0
Run #2										
Zero	0	0	0	0	0	0	0	0	0	0
9200	0	0	+ 31	+ 4	0	0	0	- 5	0	0
18200	0	0	+ 92	+ 16	0	0	0	- 10	- 8	- 4
27200	0	0	+154	+ 16	+ 4	0	0	- 15	- 11	- 5
36100	0	0	+215	+ 23	+ 6	0	0	- 20	- 15	- 7
45100	0	0	+283	+ 30	+ 8	0	0	- 25	- 20	- 8
39800	0	0	+238	+ 24	+ 6	0	0	- 19	- 15	- 6
27000	0	0	+188	+ 17	+ 4	0	0	- 14	- 12	- 4
18600	0	0	+126	+ 13	+ 3	0	0	- 10	- 6	- 2
8800	0	0	+ 56	+ 5	0	0	0	- 5	- 3	0
Zero	0	0	+ 5	0	0	0	0	0	0	0

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 8-18-82 TIME: START - FINISH - TEST No. 6

LOAD APPLIED ON 5 -ft SIDE OF Female END OF BOX No. 2

STRAIN INDICATOR GAGE FACTOR SETTING 2.00

LOAD CELL READING lb	STRAIN GAGE READING, in./in. X 10^6									
	1542 1	1573 2	2511 3	2542 4	2573 5	1743 6	1773 7	2711 8	2743 9	2773 10
Run #3										
Zero	0	0	0	0	0	0	0	0	0	0
9200	0	0	+ 37	+ 6	+ 3	0	0	- 5	- 4	0
18100	0	0	+102	+ 12	+ 6	0	0	- 10	- 8	- 2
27100	0	0	+170	+ 18	+ 8	0	0	- 16	- 12	- 5
36400	0	0	+233	+ 27	+ 10	0	0	- 20	- 15	- 6
45200	0	0	+294	+ 32	+ 11	0	0	- 25	- 20	- 9
37000	0	0	+260	+ 27	+ 9	0	0	- 21	- 15	- 6
45000	0	0	+300	+ 31	+ 11	0	0	- 26	- 20	- 8
35400	0	0	+259	+ 26	+ 10	0	0	- 20	- 16	- 6
27300	0	0	+198	+ 20	+ 8	0	0	- 17	- 13	- 4
18300	0	0	+128	+ 14	+ 6	0	0	- 10	- 9	- 4
9300	0	0	+ 64	+ 7	+ 5	0	0	- 4	- 4	0
Zero	0	0	+ 6	0	0	0	0	0	0	0

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 8-18-82 TIME: START - FINISH - TEST No. 7

LOAD APPLIED ON 7 -ft SIDE OF Female END OF BOX No. 2

STRAIN INDICATOR GAGE FACTOR SETTING 2.00

LOAD CELL READING lb	STRAIN GAGE READING, in./in. X 10^6									
	1542	1573	2511	2542	2573	1743	1773	2711	2743	2773
	1	2	3	4	5	6	7	8	9	10
Run #1										
Zero	0	0	0	0	0	0	0	0	0	0
9100	0	0	- 4	0	0	0	+ 3	+ 30	+ 9	+ 3
18000	0	0	- 13	- 4	0	+ 6	+ 26	+ 52	+ 17	+ 7
27100	0	0	- 22	- 8	0	+ 12	+ 55	+ 8	+ 26	+ 13
36100	0	- 8	- 30	- 10	0	+ 19	+ 90	+190	+ 42	+ 17
45300	- 8	- 14	- 44	- 16	- 6	+ 25	+125	+ 326	+104	+ 22
35600	- 4	- 9	- 36	- 12	- 4	+ 25	+111	+304	+105	+ 23
27200	0	- 5	- 30	- 9	- 4	+ 21	+ 83	+266	+ 98	+ 20
18100	0	0	- 22	- 5	0	+ 17	+ 53	+219	+ 86	+ 18
7900	0	0	- 10	0	0	+ 12	+ 24	+158	+ 72	+ 16
Zero	0	+ 12	0	0	0	+ 13	+ 20	+102	+ 57	+ 10
Run #2										
Zero	0	0	0	0	0	0	0	0	0	0
9000	0	0	- 7	0	0	0	+ 10	+ 50	+ 14	+ 5
18100	- 3	- 6	- 18	- 6	- 2	+ 7	+ 40	+101	+ 28	+ 8
27200	- 6	- 13	- 30	- 10	- 4	+ 12	+ 74	+152	+ 41	+ 12
36600	- 9	- 20	- 41	- 13	- 4	+ 18	+107	+204	+ 55	+ 15
45400	- 12	- 25	- 50	- 15	- 7	+ 25	+143	+264	+ 78	+ 20
36800	- 11	- 22	- 44	- 14	- 5	+ 22	+124	+232	+ 70	+ 19
27200	- 7	- 14	- 37	- 14	- 4	+ 18	+ 90	+186	+ 58	+ 17
18300	- 4	- 7	- 28	- 10	- 2	+ 13	+ 58	+135	+ 45	+ 14
7500	0	0	- 14	- 4	0	+ 8	+ 25	+ 68	+ 27	+ 10
Zero	0	+ 7	+ 5	0	0	+ 6	+ 20	+ 15	+ 10	+ 8

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 8-18-82 TIME: START - FINISH - TEST No. 7

LOAD APPLIED ON 7-ft SIDE OF Female END OF BOX No. 2

STRAIN INDICATOR GAGE FACTOR SETTING 2.00

LOAD CELL READING lb	STRAIN GAGE READING, in./in. X 10^6									
	1542	1573	2511	2542	2573	1743	1773	2711	2743	2773
	1	2	3	4	5	6	7	8	9	10
Run #3										
Zero	0	0	0	0	0	0	0	0	0	0
9100	0	- 3	- 10	- 6	0	+ 3	+ 8	+ 53	+ 14	+ 3
18200	0	- 10	- 26	- 9	0	+ 6	+ 40	+105	+ 29	+ 4
27300	- 4	- 17	- 35	- 10	0	+ 12	+ 73	+156	+ 44	+ 10
36100	- 6	- 22	- 42	- 13	- 4	+ 17	+105	+204	+ 57	+ 12
45600	- 10	- 30	- 54	- 20	- 7	+ 22	+140	+255	+ 71	+ 15
36100	- 10	- 27	- 48	- 17	- 6	+ 20	+114	+217	+ 65	+ 14
27000	- 7	- 20	- 40	- 12	- 4	+ 15	+ 82	+171	+ 51	+ 12
18400	- 4	- 13	- 33	- 11	- 4	+ 10	+ 50	+123	+ 40	+ 10
8600	0	- 3	- 20	- 7	0	+ 4	+ 18	+ 67	+ 21	+ 4
Zero	0	0	0	0	0	0	+ 11	0	0	0

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 8-18-82 TIME: START - FINISH - TEST No. 8

LOAD APPLIED ON 7 -ft SIDE OF Male END OF BOX No. 1

STRAIN INDICATOR GAGE FACTOR SETTING 2.00

LOAD CELL READING lb	STRAIN GAGE READING, in./in. X 10^6									
	1542	1573	2511	2542	2573	1743	1773	2711	2743	2773
	1	2	3	4	5	6	7	8	9	10
Run #1										
Zero	0	0	0	0	0	0	0	0	0	0
9000	- 5	- 15	0	+ 5	+ 9	+ 22	+ 7	+ 6	+ 6	+ 6
18000	- 17	- 32	- 2	0	0	+ 40	+213	0	0	0
27400	- 24	- 47	- 5	0	0	+116	+368	0	0	0
35300	- 36	- 65	0	0	0	+356	+533	+ 7	+ 3	+ 10
45500	- 52	- 94	0	0	0	+440	+731	+ 5	0	+ 5
35400	- 50	- 89	0	0	0	+409	+592	+ 4	0	+ 7
27900	- 42	- 82	0	0	0	+372	+483	+ 2	- 5	0
17700	- 39	- 70	0	0	0	+312	+338	+ 5	- 4	+ 9
8800	- 26	- 54	0	0	0	+256	+220	0	- 4	+ 9
Zero	- 13	- 30	- 5	0	0	+194	+103	+ 2	- 9	+ 6
Run #2										
Zero	0	0	0	0	0	0	0	0	0	0
9000	- 5	- 15	0	0	0	+ 34	+104	0	0	0
18100	- 15	- 30	0	0	0	+ 92	+235	0	0	0
27000	- 25	- 44	- 2	0	0	+146	+364	0	0	0
36200	- 34	- 58	- 2	0	0	+203	+495	0	0	0
45000	- 42	- 68	0	0	0	+264	+655	0	0	0
34100	- 35	- 61	0	0	0	+220	+484	0	0	0
27600	- 33	- 55	0	0	0	+187	+388	0	0	0
17500	- 21	- 42	0	0	0	+120	+242	0	0	0
8200	- 12	- 26	0	0	0	+ 53	+107	0	0	0
Zero	0	0	0	0	0	0	+ 10	0	0	0

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 8-18-82 TIME: START - FINISH - TEST No. 8

LOAD APPLIED ON 7 -ft SIDE OF Male END OF BOX No. 1

STRAIN INDICATOR GAGE FACTOR SETTING 2.00

LOAD CELL READING lb	STRAIN GAGE READING, in./in. X 10^6									
	1542 1	1573 2	2511 3	2542 4	2573 5	1743 6	1773 7	2711 8	2743 9	2773 10
Run #3										
Zero	0	0	0	0	0	0	0	0	0	0
9000	- 8	- 21	- 6	0	- 6	+ 30	+100	0	0	0
18300	- 20	- 38	- 7	0	- 7	+ 99	+240	0	0	0
27700	- 29	- 49	- 6	0	- 6	+160	+378	0	0	0
36300	- 40	- 61	- 7	0	- 8	+215	+499	0	0	0
45300	- 48	- 71	- 8	0	- 8	+271	+630	0	0	0
35000	- 40	- 65	- 7	0	- 8	+227	+495	0	0	0
26200	- 31	- 56	- 5	0	- 8	+178	+362	0	0	0
19000	- 26	- 48	- 2	0	- 6	+126	+259	0	0	0
8800	- 16	- 30	- 4	0	- 4	+ 50	+107	0	0	0
Zero	- 6	- 8	- 7	0	- 7	- 5	0	0	0	0

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 8-18-82 TIME: START - FINISH - TEST No. 9

LOAD APPLIED ON 7 -ft SIDE OF Male END OF BOX No. 1

STRAIN INDICATOR GAGE FACTOR SETTING 2.00

LOAD CELL READING lb	STRAIN GAGE READING, in./in. X 10^6									
	1542	1573	2511	2542	2573	1743	1773	2711	2743	2773
	1	2	3	4	5	6	7	8	9	10
Run #1										
Zero	0	0	–	–	–	0	0	–	–	–
9300	– 6	– 16	–	–	–	+ 47	+119	–	–	–
18100	– 12	– 30	–	–	–	+111	+252	–	–	–
27500	– 21	– 38	–	–	–	+183	+397	–	–	–
36800	– 28	– 47	–	–	–	+238	+531	–	–	–
45100	– 36	– 58	–	–	–	+286	+646	–	–	–
50200	– 42	– 65	–	–	–	+324	+727	–	–	–
55600	– 52	– 68	–	–	–	+376	+805	–	–	–
60600	– 60	– 72	–	–	–	+429	+892	–	–	–
66700	– 68	– 76	–	–	–	+494	+1060	–	–	–
71200	– 70	– 80	–	–	–	+523	+1220	–	–	–
78000	– 78	– 80	–	–	–	+564	+1635	–	–	–

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 8-20-82 TIME: START - FINISH - TEST No. 10

LOAD APPLIED ON 7 -ft SIDE OF Male END OF BOX No. 2

STRAIN INDICATOR GAGE FACTOR SETTING 2.00

LOAD CELL READING lb	STRAIN GAGE READING, in./in. X 10^6									
	1542 1	1573 2	2511 3	2542 4	2573 5	1743 6	1773 7	2711 8	2743 9	2773 10
Run #1										
Zero	-	-	0	0	0	-	-	0	0	0
9000	-	-	- 5	- 24	- 33	-	-	0	+ 2	+ 16
18200	-	-	- 10	- 12	- 20	-	-	+ 4	+ 16	+ 83
27300	-	-	- 19	- 23	- 33	-	-	+ 21	+ 50	+266
36100	-	-	- 20	- 26	- 38	-	-	+ 35	+121	+470
45500	-	-	-100	-109	-121	-	-	+ 12	+234	+528
35200	-	-	- 78	- 83	- 92	-	-	+ 5	+238	+450
26000	-	-	- 80	- 81	- 88	-	-	0	+206	+347
18600	-	-	- 76	- 76	- 81	-	-	0	+180	+270
9700	-	-	- 65	- 62	- 66	-	-	- 10	+135	+163
Zero	-	-	- 60	- 54	- 56	-	-	- 19	+ 81	+ 55
Run #2										
Zero	-	-	0	0	0	-	-	0	0	0
9400	-	-	0	0	- 14	-	-	+ 14	+ 27	+ 70
18500	-	-	0	- 5	- 11	-	-	+ 26	+ 28	+178
26900	-	-	- 3	- 10	- 17	-	-	+ 39	+112	+281
36100	-	-	- 8	- 17	- 26	-	-	+ 50	+154	+387
45400	-	-	- 12	- 23	- 36	-	-	+ 62	+216	+495
35800	-	-	- 10	- 19	- 25	-	-	+ 55	+191	+407
25600	-	-	- 6	- 14	- 17	-	-	+ 45	+149	+289
18300	-	-	- 4	- 7	- 11	-	-	+ 35	+116	+204
9100	-	-	0	- 3	- 2	-	-	+ 23	+ 66	+ 92
Zero	-	-	0	0	0	-	-	+ 8	+ 17	+ 4

Loose wire on strain gage readout at end of first load cycle (Run #1).

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 8-20-82 TIME: START - FINISH - TEST No. 10

LOAD APPLIED ON 7-ft SIDE OF Male END OF BOX No. 2

STRAIN INDICATOR GAGE FACTOR SETTING 2.00

LOAD CELL READING lb	STRAIN GAGE READING, in./in. X 10^6									
	1542 1	1573 2	2511 3	2542 4	2573 5	1743 6	1773 7	2711 8	2743 9	2773 10
Run #3										
Zero	–	–	0	0	0	–	–	0	0	0
8700	–	–	0	0	– 5	–	–	+ 10	+ 27	+ 66
18100	–	–	0	– 6	– 13	–	–	+ 20	+ 74	+178
27600	–	–	– 6	– 11	– 22	–	–	+ 33	+123	+292
35800	–	–	– 10	– 17	– 30	–	–	+ 44	+165	+388
44600	–	–	– 12	– 23	– 39	–	–	+ 56	+215	+485
36000	–	–	– 15	– 20	– 33	–	–	+ 49	+192	+405
27200	–	–	– 7	– 15	– 24	–	–	+ 43	+160	+309
17000	–	–	– 5	– 6	– 13	–	–	+ 27	+104	+183
8800	–	–	– 2	– 2	– 5	–	–	+ 14	+ 55	+ 84
Zero	–	–	0	0	0	–	–	0	+ 6	0
Run #4										
Zero	–	–	0	0	0	–	–	0	0	0
9000	–	–	– 2	– 2	– 3	–	–	+ 10	+ 30	+ 73
18100	–	–	– 2	– 6	– 12	–	–	+ 24	+ 80	+182
27000	–	–	– 6	– 12	– 19	–	–	+ 39	+129	+290
36600	–	–	– 9	– 17	– 30	–	–	+ 52	+182	+401
45200	–	–	– 11	– 24	– 38	–	–	+ 63	+230	+497
36200	–	–	– 7	– 17	– 28	–	–	+ 60	+207	+416
27100	–	–	– 6	– 12	– 19	–	–	+ 48	+165	+309
17700	–	–	0	– 4	– 10	–	–	+ 36	+112	+195
9300	–	–	0	– 2	– 4	–	–	+ 24	+ 61	+ 93
Zero	–	–	+ 2	0	0	–	–	+ 10	+ 5	+ 4

APPENDIX C

VERTICAL DEFLECTION DATA

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 29 July 82 TEST NO. 1

LOAD LOCATION 7F2

TIME	LOAD kips	DEFLECTION, in. x 10^4		
		2-7-11	2-7-43	1-7-73
0930	0	- 4	1	- 6
1025	0	0	0	0
	4.0	37	17	0
	8.0	65	32	8
	12.0	91	46	20
1035	16.0	115	60	33
	20.8	148	78	48
	16.7	127	65	37
	10.6	92	45	19
	8.1	77	37	12
	4.1	49	22	3
1048	0	9	3	2
	4.0	46	19	2
1055	8.0	73	33	11
	12.0	98	47	23
	17.2	128	53	38
	20.8	154	77	48
	16.1	126	62	35
1104	12.0	102	49	24
	8.1	79	36	13
	4.0	51	20	2
1109	0	11	2	1

DATE 29 July 82 TEST NO. 2

LOAD LOCATION 7M1

TIME	LOAD kips	DEFLECTION, in. x 10^4		
		1-7-73	1-7-43	2-7-11
1400	0	- 45	- 21	- 2
	20.0	175	88	1
	20.0	193	95	0
1416	0	0	0	0
	4.2	35	18	0
	8.0	70	34	- 1
	12.0	109	44	- 1
	16.0	150	73	- 1
1424	20.8	198	97	- 1
	16.0	159	78	- 3
	12.0	121	60	- 4
	8.0	81	41	- 5
	4.0	41	21	- 5
1430	0	- 1	- 3	- 3
1435	0	- 2	- 2	- 4
	4.1	38	21	- 1
	8.0	77	41	0
	12.0	116	59	0
	16.3	158	79	0
1443	20.8	205	101	0
	15.4	158	80	- 3
	12.0	125	65	- 3
	8.0	86	45	- 4
	4.0	45	25	- 4
1449	0	3	2	- 1

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 17 August 82 TEST NO. 3

LOAD LOCATION 5F2

TIME	LOAD kips	DEFLECTION, in. x 10^4 2-5-11	2-5-42	1-5-73
0900	0	-14	-7	-8
	0	-1	-2	-3
0935	0	0	0	0
	4.0	20	9	1
	8.0	40	17	2
	12.0	61	26	5
0942	16.0	84	35	6
	20.8	127	51	8
	16.0	97	40	7
	10.5	68	28	7
	8.3	56	24	6
	4.7	38	16	6
0951	0	13	6	5
	4.0	34	15	7
	8.0	54	23	8
	12.0	75	31	9
	16.0	97	41	10
	20.8	125	53	12
1005	16.4	105	43	11
	10.1	69	29	9
	6.4	51	22	9
	3.7	38	16	9
1012	0	17	8	8
	4.5	42	18	11
1018	8.0	60	25	12
	12.0	82	35	13
	16.0	105	44	14
	20.8	134	56	16
	16.0	112	46	16
1026	12.2	90	38	15
	8.5	71	29	14
	4.3	47	19	12
1030	0	23	9	11

DATE 17 August 82 TEST NO. 4

LOAD LOCATION 5M1

TIME	LOAD kips	DEFLECTION, in. x 10^4 1-5-73	1-5-42	2-5-11
	0	0	0	0
1110	4.3	16	5	0
	8.0	35	14	-1
	12.0	54	23	-1
	16.0	74	32	-2
1115	20.8	101	45	-2
	15.8	79	33	-4
	11.7	61	24	-3
	8.1	44	15	-2
	3.8	22	5	0
1122	0	2	-5	-1
	4.2	20	2	-2
	8.1	39	10	-2
	11.9	59	19	-4
1134	16.0	77	28	-4
	20.8	100	40	-5
	15.6	80	30	-6
	6.7	36	8	-4
	3.9	21	1	-4
1141	0	1	-9	-4
	4.5	23	2	-4
	8.1	39	6	-5
	12.0	59	14	-5
	16.0	77	23	-6
1148	20.8	99	33	-7
	15.7	77	21	-8
	12.2	61	14	-8
	8.4	42	5	-6
	3.7	18	-6	-5
1154	0	-1	-14	-5

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 17 August 82 TEST NO. 5

LOAD LOCATION 5M1

TIME	LOAD kips	DEFLECTION, in. x 10^4 1-5-73	1-5-42	2-5-11
1357	0	0	0	0
	9.1	45	21	1
	18.1	91	44	0
	27.1	170	75	- 1
	37.0	257	112	- 3
1405	45.1	337	147	- 4
	8.0	Jack Operator Accidentally Decreased Load to 8K		
	45.0	352	155	- 2
	34.6	297	130	- 6
	27.8	258	113	- 7
	17.9	195	85	- 4
1415	9.7	136	57	1
	0	71	25	2
1423	0	62	18	- 2
1427	9.0±	Test Aborted - Cloud caused Too Much Drift in Strain Data		
1428	0	62	18	- 4
	9.2	114	43	- 5
	18.1	173	70	- 7
	27.2	235	97	- 7
	36.2	291	122	- 8
1434	45.2	351	149	- 8
	36.4	305	129	- 11
	27.5	252	105	- 14
	15.7	169	68	- 11
	9.2	124	48	- 8
1441	0	62	20	- 6
	Test Stopped Because 1/2" Steel Bearing Plate Warped			

DATE 18 August 82 TEST NO. 5A

LOAD LOCATION 5M1

TIME	LOAD kips	DEFLECTION, in. x 10^4 1-5-73	1-5-42	2-5-11
0835	0	0	0	0
	9.0	54	27	2
	18.0	112	54	0
	27.0	170	80	0
0841	36.1	230	107	0
	45.1	290	138	- 1
0853	36.0	246	115	- 2
	27.6	195	92	- 4
	18.2	136	65	- 4
	9.6	76	38	1
0858	0	15	8	3
0905	0	11	8	5
	9.0	65	34	4
	18.0	125	61	4
	27.2	184	88	3
	36.0	241	115	4
0911	45.1	297	140	5
	35.9	250	118	1
	13.8	106	53	2
	9.5	80	41	5
0916	0	18	12	8
	9.2	71	37	7
	18.1	131	64	6
	27.1	188	91	6
	36.2	246	117	6
0922	45.1	302	142	7
	36.0	255	121	4
	26.8	200	96	4
	18.5	146	72	2
0927	9.6	85	46	8
	0	23	15	11

REB/26 Aug 82

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 18 August 82 TEST NO. 6

LOAD LOCATION 5F2

TIME	LOAD kips	DEFLECTION, in. x 10^4 2-5-11	2-5-42	1-5-73
1028	0	0	0	0
	9.3	57	22	- 1
	18.2	109	43	0
	27.2	164	64	3
	36.2	245	95	7
	40.3	307	112	9
1041	45.1	364	130	10
	36.3	311	111	7
	25.7	238	84	3
1051	16.9	174	60	1
	9.7	120	40	- 2
	0	49	11	- 5
1101	9.2	98	32	- 4
	18.2	164	56	- 1
1103	27.2	230	81	1
	36.1	296	106	4
	45.1	365	133	6
	34.9	307	109	6
1110	27.1	252	89	2
	18.7	188	66	0
	8.8	114	39	- 4
1115	0	50	12	- 8
	9.2	105	34	- 9
	18.0	170	59	- 6
	27.1	238	84	- 3
	36.4	309	110	0
1121	45.2	373	134	3
	37.0	325	119	1
1126	45.1	377	135	2
	35.4	317	112	1
	27.4	259	91	- 1
	18.3	190	65	- 4
	9.3	122	40	- 7
1132	0	53	13	- 10

DATE 19 August 82 TEST NO. 7

LOAD LOCATION 7F2

TIME	LOAD kips	DEFLECTION, in. x 10^4 2-7-11	2-7-43	1-7-73
0925	0	0	0	0
	9.1	84	39	2
	18.0	145	72	29
	27.1	208	106	58
	36.1	292	150	91
0935	45.0	390	208	128
0942	45.4	409	217	137
	35.6	353	184	107
	27.2	298	152	79
	18.1	231	118	49
	7.9	148	73	19
0952	0	66	30	11
1020	0	72	30	14
	9.0	158	71	24
	18.1	230	109	52
	27.2	299	146	84
	36.5	371	185	119
1032	45.4	451	227	148
1040	45.2	465	229	153
	36.8	413	201	127
	27.3	349	167	93
	18.5	284	132	63
	7.5	186	81	31
1048	0	106	40	20
	9.1	193	81	29
	18.3	265	119	56
	27.2	337	157	90
	36.0	402	191	122
1058	45.6	476	230	157
1102	45.7	482	232	156
	36.2	423	201	125
	27.0	359	167	94
	18.4	295	131	62
	8.6	214	87	29
1108	0	115	37	18

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 19 August 82 TEST NO. 8

LOAD LOCATION 7M1

TIME	LOAD kips	DEFLECTION, in. x 10^4		
		1-7-73	1-7-43	2-7-11
1313	0	0	0	0
	9.0	88	44	2
	18.0	177	88	1
1317	27.4	283	142	1
1325	27.4	291	152	- 1
	35.3	417	229	- 6
1337	35.3	429	235	- 8
	45.5	617	317	-12
1349	45.5	628	324	-15
	35.4	532	278	-19
	27.9	449	240	-19
	17.7	328	181	-18
	8.8	219	127	-16
1356	0	101	65	- 9
	9.0	192	109	- 9
	18.1	301	163	-10
	27.0	408	218	-10
1402	36.2	519	269	-11
	45.0	632	321	-13
1410	45.0	644	329	-14
	34.1	535	278	-17
	27.6	462	244	-18
	17.5	340	184	-18
	8.2	216	123	-14
1416	0	110	69	- 9
1430	0	99	62	-10
	9.0	195	110	-12
	18.3	311	167	-12
	27.7	429	225	-13
	36.3	535	275	-14
1439	45.3	645	324	-15
	35.0	551	281	-19
	26.2	449	234	-20
	19.0	362	192	-19
	8.8	226	125	-16
1443	0	110	68	- 9

DATE 19 August 82 TEST NO. 9

LOAD LOCATION 7M1

TIME	LOAD kips	DEFLECTION, in. x 10^4	
		1-7-73	1-7-43
1452	0	0	0
1453	9.3	106	53
	18.1	218	108
	27.5	337	166
	36.8	451	218
	45.1	550	226
1459	50.0	641	298
	55.0	792	350
	60.0	967	401
1508	65.0	1212	491
	71.0	1442	546
1510	71.0	1510	583

Test No. 9 stopped at 78 kips due to excessive deviation of jack from vertical.

TTI PROJECT 2294

PRECAST BOX CULVERT TEST DATA

DATE 20 August '82 TEST NO. 10

LOAD LOCATION 7M2

TIME	LOAD kips	DEFLECTION, in. x 10^4 2-7-73	2-7-43	
1007	0	0	0	
	9.0	78	41	
	18.2	158	84	
	27.3	265	137	
	36.1	397	207	
1020	45.5	573	303	
	35.2	481	258	
	26.0	383	210	
	18.7	300	168	
	9.9	193	115	
1026	0	83	55	
1030	0	78	51	
	9.1	164	96	
Loose connection noticed on strain in indicator.				
1033	0	82	54	
1038	0	82	54	
	9.4	172	98	
	18.5	274	149	
1041	26.9	371	199	
	36.1	480	254	
	45.5	585	307	
1043	35.8	506	269	
	25.6	393	212	
	18.3	309	169	
	9.1	194	111	
1048	0	87	55	
1051	0	89	56	
	8.7	172	98	
	18.1	280	152	
	27.5	392	210	
1055	35.8	485	257	
	44.6	586	308	
1058	44.6	596	312	
	36.0	518	273	

DATE 20 August '82 TEST NO. 10

LOAD LOCATION 7M2

TIME	LOAD kips	DEFLECTION, in. x 10^4 2-7-73	2-7-43	
	27.2	423	227	
	17.1	301	166	
	9.0	199	115	
1103	0	97	60	
	9.0	188	105	
	18.1	297	159	
	27.0	404	215	
	36.6	517	271	
1110	45.2	614	320	
	36.2	536	282	
	27.2	435	233	
	17.7	322	176	
	9.4	215	122	
1116	0	108	65	

APPENDIX D

MEASURED CONCRETE COVER

AT STRAIN GAGES

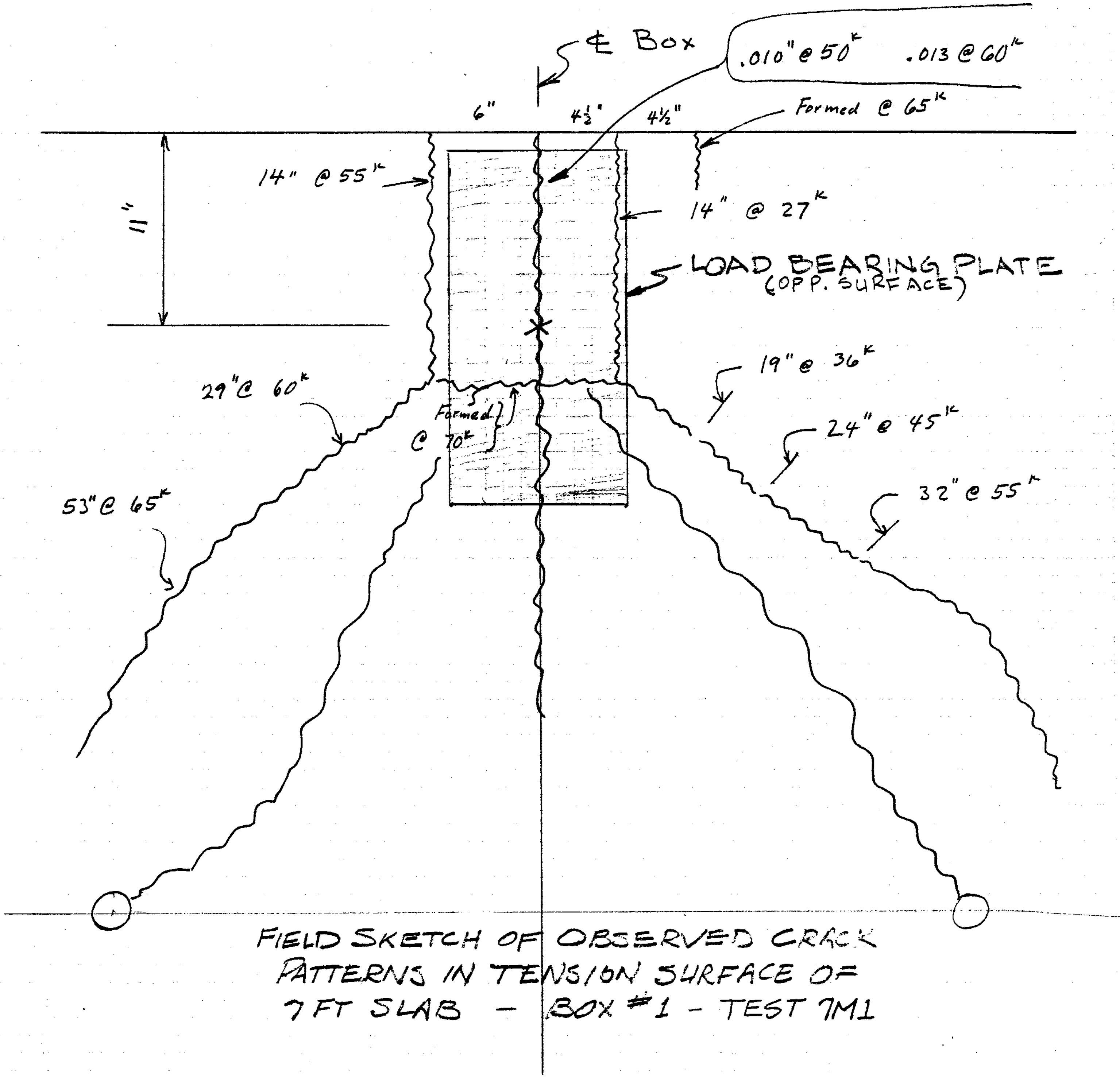
DATA

MEASURED CONCRETE COVER

Strain Gage Designation	Measured Cover	Design Cover
1-5-73	1.387 in.	1.00 in.
1-7-73	0.950 in.	1.00 in.
------	------	------
2-5-11	2.240 in.	1.00 in.
2-7-11	1.375 in.	1.00 in.
2-7-73	1.600 in.	1.00 in.

APPENDIX E

FIELD SKETCH OF OBSERVED CRACK PATTERNS



FIELD SKETCH OF OBSERVED CRACK PATTERNS IN TENSION SURFACE OF 7 FT SLAB - BOX #1 - TEST 7M1

CT 8-19-82