EARTH PRESSURES ON REINFORCED CONCRETE BOX CULVERTS

by

Ray W. James
Dale E. Brown
Richard E. Bartoskewitz
Harry M. Coyle

Research Report Number 294-2F
Research Project 2-5-81-294

Conducted for
The Texas State Department Of Highways
and Public Transportation

In Cooperation With the
U. S. Department of Transportation
Federal Highway Administration

by the
TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas

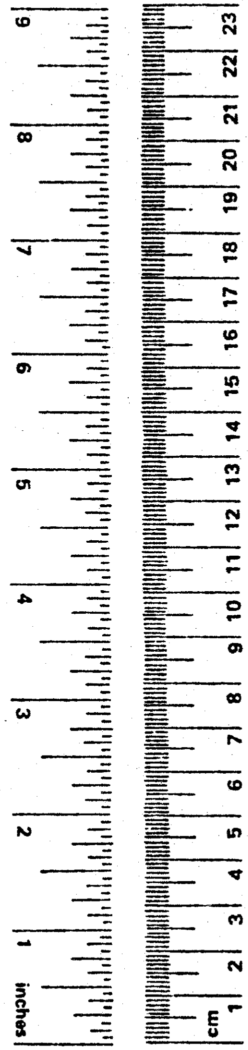
January 1986

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

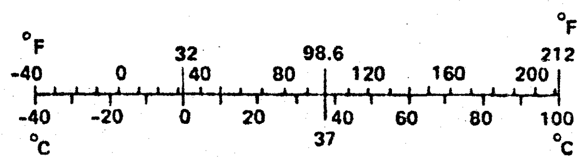
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FHWA/TX-86/ 27+294-2F	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Earth Pressures on Reinforced Concrete Box Culverts		5. Report Date January 1986
		6. Performing Organization Code
7. Author(s) Ray W. James, Dale E. Brown, Richard E. Bartoskewitz and Harry M. Coyle		8. Performing Organization Report No. Research Report 294-2F
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77840		10. Work Unit No.
		11. Contract or Grant No. Study No. 2-5-81-294
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation; Transportation Planning Division; P. O. Box 5051 Austin, Texas 78763		13. Type of Report and Period Covered Final - September 1980 January 1986
		14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with DOT, FHWA.
Research Study Title: Determination of Earth Pressures on Reinforced Concrete Box Culverts

16. Abstract

An 8 ft. by 44 ft. reinforced concrete box culvert was constructed and instrumented with twenty pressure cells on the top and side slabs, and with six resistance strain gauges on the tension reinforcing steel in the top slab. Earth pressures, reinforcing steel strains and top slab deflections were measured for various combinations of dead load and live load. Dead loads were due to backfill and earth covers up to 8 ft over the top slab. Live loads were applied by parking a test vehicle having a 48 kip (214 kN) tandem rear axle at various distances from the centerline of the culvert along a perpendicular roadway constructed on the embankment above the culvert.

A set of emperical equations was developed to fit the measured earth pressures. These equations account for the effect of individual wheel leads applied at any point on the horizontal roadway above the culvert. Reinforcing steel stresses, calculated from the measured strains are also presented. A comparison of the measured pressures with the AASHTO design pressures is also presented, and a proposed design procedure is developed and presented.

17. Key Words Box Culverts, Culverts, Earth Pressures.	18. Distribution Statement No restrictions. This document is available to the public through the National Information Technical Service, 5285 Port Royal Road, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	268	

Form DOT F 1700.7 (8-69)

SUMMARY

An 8 ft by 8 ft by 44 ft reinforced concrete box culvert was constructed and instrumented with twenty pressure cells on the top and side slabs, and with six resistance strain gages on the tension reinforcing steel in the top slab. Earth pressures, reinforcing steel strains and top slab deflections were measured for various combinations of dead load and live load. Dead loads were due to backfill and earth covers up to 8 ft over the top slab. Live loads were applied by parking a test vehicle having a 48 kip (214 kN) tandem rear axle at various distances from the centerline of the culvert along a perpendicular roadway constructed on the embankment above the culvert.

A set of emperical equations was developed to fit the measured earth pressures. These equations account for the effect of individual wheel loads applied at any point on the horizontal roadway above the culvert. Reinforcing steel stresses, calculated from the measured strains are also presented. A comparison of the measured pressures with the AASHTO design pressures is also presented, and a proposed design procedure is developed and presented.

SUMMARY STATEMENT ON RESEARCH IMPLEMENTATION

The findings indicate that the AASHTO design pressures are not completely in agreement with the measured pressures on the culvert studied. In particular the measured pressures on the top slab are generally higher than the design pressures. On the side walls the measured pressures are in some cases higher, and in some cases lower than the design pressures. The emperical equations can be used in place of the AASHTO design pressure specifications, and it is recommended that these equations be evaluated by the designers in parallel with current design procedures. Further research and/or experience with the proposed equations is recommended before incorporation into AASHTO specifications. Accordingly, it is recommended that a few culverts designed according to the proposed procedure be constructed and observed in a field study before formal adoption of the proposed procedure.

ACKNOWLEDGEMENTS

This study was conducted in cooperation with the Department of Transportation, Federal Highway Administration, whose support is gratefully acknowledged.

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the State Department of Highways and Public Transportation. This report does not constitute a standard, specification or regulation.

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

Table of Contents

LIST OF FIGURES

List of Tables

Chapter 1

INTRODUCTION

1.1 Background Information

Thousands of reinforced concrete box (RCB) culverts have been constructed throughout the United States. Most of the culverts are structurally safe and are performing satisfactorily, even though actual wheel loads have increased significantly over the years. This indicates that the culverts may be frequently over-designed. The primary design procedure used by most state highway agencies is that recommended by the American Association of State Highway and Transportation Officials (AASHTO) (1).

Much field testing of circular culverts under deep and shallow fills has been accomplished (3,4,8,13). The results of the circular culvert experiments are not applicable to box culverts, since the soil-structure interaction is different for box culverts. Circular culverts experience a more significant soil arching effect, and the soil pressure on the sides tends to support them. In addition, steel and even concrete circular culverts are normally more flexible than RCB culverts. The greater flexibility of circular culverts increases the effects of any soil-structure interaction. In addition, all circular culverts derive part of their strength from interacting with the soil, while RCB culverts derive less of their strength from the adjacent soil. Thus, the results of the circular culvert research are of limited value for study of reinforced concrete box culverts.

Most previous field testing on RCB culverts has been under deep fills. The information gained from deep-fill culverts is only partially useful. A large portion of the deep-fill research has centered around imperfect trenching techniques and effects. An imperfect trench is constructed by placing an extremely compressible material above the culvert. This directs the vertical soil load away from the culvert and onto the surrounding soil, creating an arching action. The portion of the deep-fill culvert research that deals with normally compacted fills gives some information concerning vertical and lateral soil loads (8). The primary problem involved in comparing the deep-fill circular and RCB culverts is the soil arching effect. Soil loads on deep-fill culverts are almost exclusively controlled by settlements of the soil next to, above and below the culvert. Differential settlements cause considerable arching to develop, and soil loads are redirected and redistributed. Soil loads on shallow circular and RCB culverts are also affected by arching, but not to the extent of deep-fill culverts.

Katona (11) has performed many computer simulations of RCB culverts. Also, data from field tests on braced excavations (6,10,15,16,20,22) and retaining walls (7,23) may provide information concerning lateral earth pressures on the sides of RCB culverts. A braced excavation is in some respects similar to a RCB culvert, although the soil adjacent to a braced excavation has not been compacted. Pressure distributions on retaining walls are dependent upon compaction of the backfill soil and differential movement between the structure and soil. Thus, this information is primarily useful in determining if compaction of the backfill soil or differential movement between the culvert and backfill soil has affected the pressure distribution on the sides of the culvert.

Theoretically, the simplest design procedure would include Rankine's theory (17) to determine dead load earth pressures and Boussinesq's elastic solution (5) to determine live load pressures. The current AASHTO design procedure for predicting dead load earth pressures is similar to the Rankine theory. However, the current AASHTO design procedure includes a greatly simplified method for calculating live load earth pressures.

1.2 Objective

The objective of this study was to verify or modify the current AASHTO design procedure for RCB culverts by developing an improved method for predicting earth pressures on RCB culverts. The procedure used to develop the new earth pressure prediction method was as follows:

1. A literature review was accomplished in order to identify any previous research directly related to this study.

2. An instrumented RCB culvert was constructed. The instrumentation consisted of commercial soil pressure gages and resistance strain gages mounted on the top slab reinforcing steel.

3. A tractor-trailer test vehicle was loaded to apply a live load equivalent to the interstate design loading, ie., two 24 k (107 kN) axles in a 4 ft (1.22 m) tandem.

4. Dead load and live load earth pressures, reinforcing steel strains and top slab deflections were measured at levels of backfill equal to 8 in. (0.20 m), 2 ft (0.61 m), 4 ft (1.22 m), 6 ft (1.83 m), and 8 ft (2.44 m).

5. Soil tests were performed on the backfill material to determine in-situ soil densities, grain size distribution, Atterberg limits, and effective stress shear strength parameters.

6. A new procedure for predicting earth pressures due to live and dead loads on RCB culverts was developed from the results of the load test data.

7. A simplified design method for predicting earth pressures on RCB culverts was developed.

Chapter 2

DESCRIPTION OF TEST FACILITY

2.1 Test Site Selection and Description

The original research plan was to conduct tests on a highway culvert under construction. There were several problem areas in this plan such as:

1. The testing might interfere with construction schedules.

2. The maximum fill height above the top of the culvert would be controlled by the highway design.

At a meeting of Texas State Department of Highways and Public Transportation (SDHPT) and Texas Transportation Institute (TTI) engineers in November 1980, it was determined that:

1. No suitable highway culverts were under construction in the Bryan-College Station area.

2. Construction of a test culvert at the Texas A&M University (TAMU) Research and Extension Center offered the following significant advantages:

    1. Conflicting construction schedule needs of contractors and researchers could be avoided.

    2. The option of altering the final cover depth, or excavating the culvert, could be reserved.

3. Better quality control of all testing operations could be obtained.

4. Technical and earth-moving services would be readily available from the Engineering and Construction Section of the TTI Proving Grounds Research Program and the Construction Equipment Training Division (CETD), Texas Engineering Extension Service (TEES), which is located on the grounds of the TAMU Research and Extension Center.

A search for a suitable site on the TAMU Research and Extension Center was begun. It was decided to construct the culvert below the existing ground surface for the following reasons:

1. Construction of the culvert below the existing ground surface would reduce the amount of required embankment material considerably.

2. The time required to place and compact the embankment material would be greatly reduced.

3. A smaller land area would be required for the site location.

One disadvantage of construction of the culvert below existing groung elevation was the necessity of providing storm water drainage from the site. Several test sites were considered and eliminated because of drainage problems, lack of suitable nearby embankment material nearby, or disturbance of ongoing TAMU College of Veterinary Medicine operations. The test site finally selected met the requirements of drainage, sufficient embankment material, and an adequate land area.

The test site is located in an open pasture near the eastern boundary of the TAMU Research and Extension Center. The site is approximately one mile (1.6 km) from the Center's main entrance as shown in Fig. 1. The general topography of the area includes level or gently sloping terrain, with approximately 10 ft (3 m) of relief in the surrounding 2.5 acres (1.0 ha). Many small storm runoff channels empty into a small pond northeast of the site. Since the embankment would block the channels, the channels were redirected to carry the runoff around the test site.

2.2 Soil Conditions

The soils in the test site area are sedimentary deposits from an ancient course of the Brazos River, consisting of thin layers of pea gravel, sugar sands, and silts interlain with thicker layers of a fine, red, clayey sand and a fine, light tan sand. The geotechnical tests used to document the soil properties included sieve analyses, Atterberg limits, standard Proctor compaction, in-situ unit weight, moisture content determinations, direct shear, and consolidation tests. A summary of the test results is given in Tables 1 through 4.

TABLE 1 - Soil Classification and Atterberg Limits

Soil Description	Classification: Unified	Classification: AASHTO	Atterberg Limits in %: Liquid Limit	Atterberg Limits in %: Plasticity Index
Fine, Red, Clayey Sand	SC-SP	A-2-6(0)	37.5	21.3
Fine, Light Tan Sand	SP	A-3(0)	N/A	Non-Plastic

Note: ASTM spec. D4318-83

TABLE 2 - Standard Proctor Compaction Results

Soil Description	Maximum Dry Unit Weight in pcf	Optimum Moisture Content in %
Fine, Red, Clayey Sand	116	8.4

Note: 1 pcf = 0.157 kN/m^3, ASTM spec. D698-78

TABLE 3 - In-Situ Dry Unit Weights and Moisture Contents of the Fine, Red, Clayey Sand at the Test Site

Location	Test Method	Dry Unit Weight in pcf		Moisture Content in %	
		Range	Average	Range	Average
Natural Ground	Balloon Volumeter	87-103	95	14.2-20.0	17.5
	Nuclear Density Meter	96-101	98	18.6-25.1	22.0
Backfill	Balloon Volumeter	-----	88 (*)	-------	5.8 (*)
	Nuclear Density Meter	86-98	94	20.8-23.1	21.9
	SDHPT Harris Cup	107-114	109	12.7-18.3	15.7
Compacted Roadway	Nuclear Probe	103-112	108	4.5-16.5	7.7

Note: (*) only one test of this type performed,

1 pcf = 0.157 kN/m^3, ASTM specs. D2167-66, D2922-71, D3017-72

TABLE 4 - Direct Shear and Consolidation Test Results

Soil Description	Effective Stress Parameters		Range of Moisture Contents in %	Range of Coefficient of Consolidation in cm^2/sec
	' in Degrees	C' in psf		
Fine, Red, Clayey Sand	31.8	zero	22.6-23.4	2×10^{-4}-3×10^{-4}

Note: 1 psf = 47.9 Pa, ASTM spec. D3080-72

A grain size distribution for the red, clayey sand is given in Fig. 2. Dry unit weight values are tabulated because they are not affected by changes in moisture content. If moist unit weights are needed, the values can be computed by the following relationship:

$$\gamma_{wet} = \gamma_{dry}(1 + w/100) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where w = moisture content expressed as a percentage of the dry weight of the soil, and

γ = unit weight of soil.

The culvert was constructed directly on a layer of the naturally occurring, free-draining, fine, light tan sand. A 4 in. (10 cm) blanket of the light tan sand was placed around and on top of the culvert to promote drainage. The sand blanket allows any excess pore water to drain away. This blanket hopefully prevented the pressure cells from measuring pore-water pressure along with earth pressure. The backfill, embankment and roadway were constructed of the fine, red, clayey sand, since this material was readily available. This material also provides an adequately strong and stable roadway. A Shelby tube sample of the compacted roadway soil at 2 ft (0.6 m) of fill was taken to provide a visual examination of the compacted soil. The compacted soil consisted of 1-2 in.-diameter (2-5 cm) clayey sand lumps surrounded by thin layers of sand. This type of compacted material is considered to be representative of field construction, since a uniform material is difficult to achieve in practice.

2.3 Test Culvert Description

The test culvert was constructed in February 1982 by a general contractor with offices in Bryan, Texas. The culvert is an 8 x 8 x 44 ft (2.4 x 2.4 x 13.4 m) single box, having 7 in.-thick (18 cm) slabs, 8 in.-thick (20 cm) walls, and flared wings. The culvert was constructed according to current SDHPT standard specifications for SC-NB type 3 single culverts-normal. The 44 ft (13.4 m) barrel length was selected to allow for 2:1 side slopes, maximum cover of 8 ft (2.4 m), and a roadway width of 12 ft (3.7 m) across the culvert.

2.4 Test Culvert Construction

After test site selection, the location and orientation of the culvert on the test site had to be determined. A topographic survey was made on February 19, 1981. It was determined that a maximum elevation variation of 13.6 ft (4.1 m) existed at the test site. The test site consisted of two approximately level areas at different elevations, separated by a steep slope. The culvert was located below the ground surface of the higher area by digging a trench from the face of the slope back toward the higher ground. This excavation was completed during the last week of August, 1981. The excavated soil was used as backfill and embankment material. Construction of the culvert was accomplished during the period February 4-23, 1982. SDHPT specifications require class A concrete. The specifications and batch testing results are given in Table 5. Measured concrete compressive strength results are plotted as a function of time in Fig. 3.

TABLE 5 - SDHPT Class A Concrete Specifications and Batch Concrete Testing Results

Parameter	SDHPT Specifications	Batch Concrete
Sacks of Cement/yd^3	5.0	5.0
Min. 28 day Compressive Strength in psi	3000	4150
Max. Water/Cement Ratio in gallons/sack	7.0	5.4 - 5.7
Slump Range in inches	3 - 4	3.5 - 5.5

Note: 1 yd^3 = 0.765 m^3, 1 psi = 6.89 kPa, 1 in. = 2.54 cm., 1 sack of cement = 94 lb, 1 lb = 0.454 kg, 1 gal = 3.79 L, ASTM specs. C39-83, C143-78

2.5 Instrumentation

Twenty earth pressure cells were installed on the culvert; four on each side and twelve on top, as shown in Fig. 4. Six resistance strain gages were attached to the tensile reinforcing steel in the top slab of the culvert as shown in Fig. 5. A deflection dial gage with a resolution of 0.0001 in. (0.0025 mm) was attached to a steel post at the geometric centerline of the culvert, as shown in Fig. 6.

The pressure cells record total earth pressures on the culvert caused by the combined effects of live and dead loads. The side pressure cells were securely attached to the formwork prior to placement of the concrete. This installation procedure resulted in the active face of the cell being flush with the exterior wall of the culvert. This condition permits the greatest accuracy in "cell registration," i.e., cell reading of pressure at the soil-structure interface. It also provides the highest degree of confidence that full contact between pressure cell and concrete is obtained. A feasible way of attaching the top pressure cells to the roof slab could not be devised. Consequently, the top pressure cells were installed immediately after placement of the concrete, while it was still plastic. Large coarse aggregate in the concrete hindered exact positioning of the pressure cells. The top pressure cell leads could not be fully embedded in the concrete, and therefore were left exposed on the top of the culvert. A chisel was used to remove concrete from the exposed surface of the pressure cells after the concrete had hardened. Pressure cells No. 1-4 and No. 20 were manufactured by Slope Indicator Company (Model No. 51482). Pressure cells No. 5-19 were manufactured by Terra Tec (Model No.

T9010).

The strain gages were attached to the reinforcing steel under laboratory conditions prior to the bars being tied in place on the culvert. The gages chosen were Micro-Measurements CEA-06-W250A-120 weldable gages. The gages were attached by spotwelding in the laboratory, and all wiring and waterproofing was done in the laboratory. Apparently either strain gage No. 5 or the lead wires from the strain gage were damaged during placement of the concrete, since gage No. 5 could be balanced properly before placement of the concrete, but was inoperative after concrete placement.

All lead wires from the top pressure cells and strain gages were routed through a section of 2 in. (50 cm) PVC pipe extending through the top slab. The side pressure cell leads were also routed through a section of 2 in. (50 cm) PVC pipe on their respective sides. This allowed the lead wires to be routed to a terminal box inside the culvert.

2.6 Backfill and Roadbed Construction

Backfilling of the culvert sides began in January 1983 and was completed in April 1983. Roadbed construction began in April 1983 and was completed in August 1984. SDHPT construction specifications (21) require that the soil should be placed in layers less than 6 in. (15 cm) in depth (loose measurement) and that compaction equipment be of the rolling or tamping type. The soil was placed in layers approximately 4 in. (10 cm) thick and a crawler tractor was used for compaction.

Crawler tractors are adequate compaction devices for coarse-grained soils (9). The treads provide a kneading motion similiar to that of a roller, while the equipment's vibration is similiar to that of a vibratory compactor.

Chapter 3

EXPERIMENT DESIGN

3.1 Fill Height Selection

Initial plans were to conduct one series of tests with no fill on the culvert. Since the pressure cell leads could not be completely embedded in the top of the culvert, it was thought that direct traffic on top of the culvert would damage the leads, and the first series of tests was performed at 8 in. (0.2 m) of fill.

Subsequent tests were planned at fill depths of 2 ft (0.61 m), 4 ft (1.22 m), 6 ft (1.83 m), and 8 ft (2.44 m). The 8 ft (2.44 m) limit was determined from the AASHTO design procedure (1). This project was concerned with the design of culverts with shallow fills, which are defined by AASHTO to be fills less than 8 ft (2.44 m).

3.2 Live Load Selection

Original plans were to use a test vehicle simulating an AASHTO HS20-44 design vehicle. Because a test vehicle capable of supporting 32 kips (142kN) on a single axle could not be located, the alternate interstate or military axle configuration (1) was used. The alternate interstate loading is a tandem axle bogey with a combined load of 48 kips (214 kN) or 24 kips/axle (107 kN/axle). These axle loads were obtained by placing two 5 x 7 x 7.5 ft (1.5 x 2.1 x 2.3 m) precast concrete box culverts, tested in an earlier phase of this project and weighing approximately 22 kips (98 kN) each, on the rear of the trailer over the tandem axles, resulting in the test vehicle configuration shown in Fig. 7.

3.2.1 Load Location Notation

To define the location and heading of the live load for record purposes, a simple notation system was developed. To define left and right directions, consider an observer standing on the longitudinal centerline of the culvert looking downstream (northeast). Right is then to the observer's right, and left is toward his left. To define the position of the load, the imaginary point "P_L" which is on the longitudinal centerline of the semi-trailer midway between the rear axles is used in association with the point "O" which is located at the geometric center of the culvert, as shown in Fig. 8. Point "O" is on the longitudinal centerline of the culvert and exactly halfway between the headwalls. All tests were conducted with the tractor and semi-trailer aligned with the roadway centerline, which is transverse to the longitudinal centerline of the culvert. By these definitions then, a load position designated as 4.7LR is interpreted as follows: "Point P_L is located 4.7 ft (1.43 m) left of point O, with the test vehicle heading right." This is represented schematically in Fig. 8.

3.2.2 Live Load Location

The pressure cells can only record a static pressure. Thus, the test vehicle was parked during testing. To simulate a moving load the tests were repeated at one or two foot intervals at locations from 14.7 ft (4.5 m) left of centerline to 14.7 ft (4.5 m) right of centerline. This procedure caused some errors in measured strains and deflections, as is discussed later. The live load positions for each level of fill are shown in Table 6.

Load locations between 0 and 6.7 ft (0 to 2.04 m) apply one or more wheel loads directly above the top slab of the culvert. At 6.7 ft (2.04 m) one axle is still directly above the side wall of the culvert. The tests performed at 3.0 to 14.7 ft (0.91 to 4.48 m) aid in determining the magnitude and extent of lateral loads on the sides of the culvert, since one or both axles are off the culvert.

The reasons for duplicating many of the tests with the truck pointed both right and left were to insure repeatability and to negate any unknown effects introduced by the truck being headed in one direction only. In other words, the effect of the location of the tractor axles was unknown at the time of field testing.

TABLE 6 - Live Load Positions for Tests

Position of Truck with respect to Centerline of Culvert in feet	Level of Fill		
	8 in.	2 ft	4 ft
	Direction of Truck Heading		
14.7 Left	Right	No Test	No Test
12.7 Left	Right and Left	Right	Right
10.7 Left	Right	No Test	No Test
8.7 Left	Right and Left	Right and Left	Right
6.7 Left	Right	Right	Right
4.7 Left	Right and Left	Right and Left	Right
4.3 Left	Right and Left	No Test	No Test
4.0 Left	Right	No Test	No Test
3.0 Left	Right	Right	Right
2.0 Left	Right and Left	Right and Left	Right and Left
1.0 Left	Right	Right	Right
On Centerline	Right and Left	Right and Left	Right
1.0 Right	Right	Right	Right
2.0 Right	Right and Left	Right and Left	Right and Left
3.0 Right	Right	Right	Right
4.0 Right	Right	No Test	No Test
4.3 Right	Right and Left	No Test	No Test
4.7 Right	Right and Left	Right and Left	Right
6.7 Right	Right	Right	Right
8.7 Right	Right and Left	Right and Left	Right
10.7 Right	Right	No Test	No Test
12.7 Right	Right and Left	Right	Right
14.7 Right	Right	No Test	No Test

Note: 1 in. = 2.54 cm, and 1 ft = 0.305 m.

3.3 Instrument Location

Pressure cell locations were determined by assuming an AASHTO HS20-44 loading condition on the culvert at different levels of fill and determining locations that outline the AASHTO design pyramid. The AASHTO design pyramid is explained in the section entitled "Earth Pressure Prediction Methods." Pressure cells No. 11-16 define the AASHTO pyramid outer limits of a HS20-44 wheel load at 2 ft (0.6 m) of fill as shown in Fig. 9. Pressure cells No. 5-10 define one half of the AASHTO pyramid at 6 ft (1.8 m) of fill as shown in Fig. 10. The 37 in. (94 cm) offset from the longitudinal centerline for pressure cells No. 5, 7, 8, and 10 is equal to 1/3 of the culvert's width, see Fig. 4. The 37 in. (94 cm) offset was chosen to space the instruments evenly in one direction. Pressure cells No. 9 and 12 are positioned to be directly under AASHTO HS20-44 wheel loads.

The strain gage positions were determined by treating the top slab as a fixed-end beam under two different loading conditions. The beam diagrams for the loading conditions are shown in Figs. 11 and 12. From these beam diagrams it is apparent that the maximum moments occur at the midspan and ends. Strain gages No. 5 and 6 are located at the midspan under the AASHTO HS20-44 wheel loads, see Fig. 5. Strain gages No. 1 through 4 are located at the ends and were spaced out on one side to determine how the moments were transferred into the adjoining wall, if possible.

The dial gage location was chosen to be at the geometric center of the culvert, where the maximum deflections were expected.

Chapter 4

PRESSURE CELL DATA ANALYSIS

4.1 Calibration

Instrument calibration began in September 1982 and was completed in December 1982. Pressure cell calibration consisted of a calibration for preload temperature effects and a calibration for nitrogen flow rate.

Each pressure cell has a factory built-in preload pressure. However, the manufacturers recommend that a preload calibration be performed on the pressure cells after they have been installed in the field. The field preload value is normally slightly different from the factory setting. Bruner (7) reported that the preload value is actually temperature dependent. The factory preload value does not take into account the thermal expansion and contraction of the structure. Since the pressure cells are partially embedded in the structure, the thermal effects must be accounted for. The pressure cells were temperature calibrated over a range of 48°F to 87°F (9°C to 31°C). This range was believed to cover all possible operating temperatures. A linear least squares regression was then performed on the calibration data for each pressure cell. The resulting equations were then used to determine the temperature corrections for all of the field tests. The corrected pressure equation is:

Corrected pressure = measured pressure -

temperature correction .... (2)

where,

temperature correction = C1 + C2 * T .... (3)

The parameters C1 and C2 are regression coefficients, and T is the measured cell temperature (^{o}F).

The calibration data are given in Appendix C, and the regression coefficients are given in Table 7. A typical temperature calibration curve is shown in Fig. 13.

TABLE 7 - Pressure Cell Calibration Coefficients

Pressure Cell #	C1 (Intercept) in psi	C2 (Slope) in psi/^{o}F
1	- 1.1732	0.0375
2	0.0067	0.1920
3	- 0.0619	0.0280
4	- 0.1556	0.0281
5	0.8826	0.0906
6	- 1.8277	0.1192
7	0.1524	0.0874
8	- 1.1366	0.1160
9	1.8906	0.0923
10	4.2928	0.1110
11	- 0.9175	0.1424
12	- 0.5259	0.1349
13	0.1076	0.1190
14	- 1.1933	0.1084
15	- 3.0561	0.1342
16	0.1427	0.1218
17	- 1.2612	0.1318
18	- 2.4161	0.1149
19	- 0.0112	0.1127
20	0.1832	0.0156

Note: 1 psi = 6.89 kPa, 1 psi/^{o}F = 12.4 kPa/^{o}C

The need for a nitrogen flow-rate calibration arose from the different flow rates required by the Slope Indicator and Terra Tec pressure cells. The Slope Indicator cells require 0.2 standard cubic feet per hour (scfh) (0.0057 m^3/hr). The Terra Tec cells require 1.0 scfh (0.028 m^3/hr). Field measurements could be made more rapidly and simply if both instrument types could be operated at the higher flow rate. Therefore, a spare Slope Indicator pressure cell was flow-rate calibrated at a constant temperature with varying pressures in a laboratory pressure chamber capable of applying 40 psi (280 kPa). These calibration data are shown graphically in Figs. 14-16 and are also presented in Appendix C. From these graphs it is apparent that the preload pressure is dependent on flow rate and that the manufacturer's specified preload value is only valid at the specified flow rate. It is also apparent that the instruments do not respond until the applied pressure exceeds the preload value. The minimum preload value is desired in order to achieve best accuracy at low earth pressures in the field. The smallest preload value for both Slope Indicator and Terra Tec pressure cells was assumed to occur at the factory specified flow rate. Accordingly all pressure cells were operated at the manufacturers' specified flow rates.

4.2 Data Collection

Data acquisition with 8 in. (20 cm) of fill began on April 14 and was completed on July 8, 1983. Data acquisition with 2 ft (0.6 m) of fill was accomplished during the period July 22-29, 1983. With 4 ft (1.2 m) of fill, data acquisition occured during the period August 10-24, 1983. Data acquisition with 6 ft (1.83 m) of fill was accomplished on July 13, 1984. Data acquisition with 8 ft (2.44 m) of fill began on September 12, 1984 and was completed on January 9, 1985. Fill placement took approximately 2 weeks for each lift due to scheduling difficulties encountered by the contractor, the Construction Equipment Training Division, TAMU. Each set of instrument readings, including truck positioning, took approximately one hour to complete. The practical limit on the number of testing that could be performed in one day was found to be five tests.

Two procedures were used to obtain the data. The first procedure was used for fill heights up to 6 ft (1.83 m), and the second procedure was adopted for the 8 ft (2.44 m) data. The reasons for the test procedure change are discussed in the section entitled "Analysis of Strain Gage Data--Live Loads". The first procedure required parking the test vehicle on the roadway at the desired location. All instruments were read and the values recorded. Periodically the instruments were read and the values recorded with the truck parked a large distance away from the culvert, to record dead load data. The second procedure, used only for the live load strain gage data at 8 ft (2.44 m) cover, involved driving the test vehicle slowly across the culvert. Live load soil pressures at 8 ft (2.44 m) were not obtained in these tests, but were obtained using the first procedure.

4.3 Preliminary Data Analysis

4.3.1 Graphical Analysis

Preliminary plots of temperature-corrected measured earth pressures versus load location were prepared. The graphs revealed that approximately 10% of the data points were apparently in error. Most of the errors were not very severe and could be minimized by simply averaging several data points to achieve a reasonable pressure reading, as shown by the example in Fig. 17. The few data points that were most obviously incorrect were replaced by data points from other tests where the wheel loads were a similar distance from the pressure cell. The original data, temperature corrections, and corrected pressures are given in Appendix B.

4.3.2 Determination of Dead Load Pressures

The dead load effects were initially determined from the set of data where only dead loads were applied. The results of this analysis were inconsistent for reasons that were not explained until later in the study. The live load data include the effect of the dead load, therefore, it was decided to use the live load data to determine the dead load pressures on the culvert. Three methods to determine the dead load were evaluated; all are based on plots of corrected pressure versus load location. These plots indicated that a constant offset pressure occurs in the pressure readings for each pressure cell for each level of fill, as shown in Figs. 18-23. The constant offset pressure appears to consist of two parts. The first part is caused by the dead weight of the soil. The second part is a variable offset that is thought to be caused by the action of placing and compacting the fill material around and above the culvert. In addition, the total offset pressure changes in an inconsistent manner for each pressure cell at each level of fill. The three methods evaluated to determine the total offset pressures are explained in the following paragraphs:

At this point it should be noted that the temperature corrected pressures were converted to pounds per square foot (psf) from pounds per square inch (psi). This was done because the design equations were being developed, and results presented in psf are commonly used by geotechnical engineers.

The first method consisted of using the lowest corrected pressure for each instrument from the plots of corrected pressure versus load location. These minimums occurred when the truck was parked a large distance away from the culvert. These values provide a lower bound of the total offset pressures. The difficulty with this method is caused by the specified pressure cell accuracy of 0.25 psi (1.72 kPa). Since this method allows the total offset pressure to be underestimated by as much as 0.25 psi (1.72 kPa), it may overestimate the live load pressures by the same amount.

The second method of determining the total offset pressure consisted of averaging several data points from the plots of the corrected pressure versus load location for each pressure cell where the wheel loads had no noticeable effect. This method, assuming random errors, yields values that are not dependent on pressure cell accuracy, since several data points were averaged. The major problem with this method is that it was not repeatable, but rather is dependent on which data are selected for averaging.

The third method for determining the total offset pressure consisted of fitting the analytical expression for the live load pressure, plus a constant, to the data for pressure versus load location for each pressure cell, at each level of fill, individually. In other words, the data consist of live load plus dead load pressures. The live load pressures are a function of load location, and the dead load pressure is a constant. Therefore, the constant determined from the regression will be the total offset or dead load pressure for that particular instrument. The data from each instrument at each level of fill were analyzed separately. An iterative linear least squares regression was used with the equation:

$$P_{ni} = P_{oi} + B \exp(-k_v R_j^2) \quad \text{.................................} \quad (4)$$

where P_{ni} is the corrected pressure (psf) for test n and pressure cell i, P_{oi} is the total offset pressure (psf) from regression for pressure cell i, B and K_v are regression coefficients that describe the influence of wheel loads, depth of fill and soil properties, and R_j is the horizontal distance from wheel load j to pressure cell i (ft).

This equation is illustrated in Fig. 24. The total offset pressures for each pressure cell, for each level of fill, are shown in Figs. 25-28. No figure is shown for 8 ft (2.44 m) of fill since the results of the regression analysis at that level of fill were inconclusive. This third method is considered to be superior to the others in that it incorporates an influence from the individual wheel loads and because it is repeatable. The wheel load influence is assumed to be of the form:

$$\sigma_{vl} = B \exp(-k_v R_j^2) \quad \text{.......................................} \quad (5)$$

where σ_{vl} is the vertical live load pressure (psf). This equation was chosen for the following reasons:

1. The general appearance of the plots of corrected pressure versus load location suggests this type of equation.

2. The graph of the equation has roughly the same bell shape as the graph of Boussinesq's equation for vertical stress due to a point load on the surface of an elastic half-space (5).

3. The equation fits the pressure gradient boundary conditions at distances of zero and infinity.

It should be noted that the overall effect caused by the live load has not been determined. However, the total offset pressure for each pressure cell at each level of fill has been determined. The offset pressures will be used to determine the dead load pressures on the culvert.

Results from the second and third methods of analysis for determining the total offset pressures are in good agreement. This agreement was expected since the second method was essentially a curve fitting performed by eye. The results from the third analysis were used for all subsequent calculations, since they are numerically repeatable.

4.4 Development of Vertical Live Load Pressure Equations

4.4.1 Analysis of Vertical Live Load Pressures

The total offset pressures for each pressure cell at each level of fill were subtracted from the live load data. The remaining pressures were assumed to be due only to the wheel loads. An iterative linear least squares regression was then performed on the resulting wheel load pressures for the top pressure cells using Eq. 5 to determine the value of the regression coefficient k_v at each level of fill. The predicted pressure distribution, Eq. 5, was integrated at each level of fill with the corresponding value of k_v. The value of B at each level of fill was determined by equating the integrated pressure distributions to the average actual wheel load of 12,160 lbf (54.1 kN).

An iterative linear least squares regression was performed on the values of k_v and on the values of B to provide a check. The equations used were of the form:

$k_v = k_{vo} \exp(-cz)$ .... (6)

$B = (P\, k_{vo}/\pi) \exp(-cz)$ .... (7)

where k_{vo} and c are regression coefficients that describe the influence of wheel loads for the soil used,

π = the irrational number 3.14159...,

z = the depth below ground surface (ft), and

P = the wheel load (lbf), taken to be 12,160 lbf in this analysis.

These equation forms were chosen for the following reasons:

1. The values of B and k_v suggest these types of curves, as seen in Figs. 29 and 30.

2. The equations fit the following boundary conditions:

   1. k_v approaches zero at infinite depths, ie., the pressure distribution is uniform at infinite depths.

   2. B approaches zero at infinite depths, ie., the pressure approaches zero at infinite depths.

3. The equations are continuous and differentiable.

4. If k_v is assumed to be of the form given in Eq. 6, then B can be shown to be of the form of Eq. 7 by the following derivation:

Equilibrium leads to the following equation:

$$\int \sigma_{vl}\, R\, dR\, d\theta = P \qquad (8)$$

where σ_{vl} = vertical live load pressure (psf),

R = radial cylindrical coordinate (ft),

θ = angular cylindrical coordinate (rad), and

P = wheel load (lbf).

Therefore;

$$2\pi \int \sigma_{v1} \, R \, dR = P \qquad (9)$$

Combining Eq. 5 with Eq. 9 yields;

$$2\pi B \int \exp(-k_v R^2) \, R \, dR = P \qquad (10)$$

To solve Eq. 10 the following substitution is performed:

$$x = R\sqrt{k_v} \qquad (11)$$

or,

$$R = x/\sqrt{k_v} \qquad (12)$$

Then,

$$\frac{dR}{dx} = \sqrt{\frac{1}{k_v}} \qquad (13)$$

or,

$$dR = dx/\sqrt{k_v} \qquad (14)$$

Substituting Eqs. 12 and 14 into Eq. 10 yields:

$$\frac{2\pi B}{k_v} \int x \exp(-x^2) \, dx = P \qquad (15)$$

Therefore, the solution is:

$$P = \pi B/k_v \qquad (16)$$

or,

$$B/k_v = P/\pi = \text{a constant with units of force} \qquad (17)$$

Therefore the form of the equation for B must be the same as that assumed for k_v in Eq. 6.

4.4.2 Results of Vertical Live Load Analysis

The iterative linear regression results of the vertical live load equations, Eqs. 5, 6 and 7, are:

$$k_{vo} = 4.545\ ft^{-2}\ (49.02\ m^{-2}) \quad \ldots \quad (18)$$

$$c = 1.170\ ft^{-1}\ (3.846\ m^{-1}) \quad \ldots \quad (19)$$

The constants for the live load equation, Eqs. 5, 6, and 7 were determined empirically by regression analysis. Consequently, there is no analytical method for determining the constants for other soil types. The constants are believed to be related to soil properties.

The vertical live load pressure prediction equations determined in this study are summarized below:

$$\sigma_{vl} = B_j \sum \exp(-k_v\ R_j^2) \quad \ldots \quad (20)$$

$$B_j = P_j\ k_v\ /\pi \quad \ldots \quad (21)$$

$$k_v = (4.545\ ft^{-2})\ \exp(-1.170\ ft^{-1}\ z) \quad \ldots \quad (22)$$

where σ_{vl} = vertical live load pressure at point of interest (psf),

R_j = horizontal distance from wheel load j to point of interest (ft),

P_j = weight of wheel load j (lbf),

z = depth from ground surface (ft),

π = the irrational number 3.14159..., and j = wheel load identification number.

4.4.3 Simplification of Vertical Live Load Pressure Equations

The reason for simplifying the vertical live load pressure equations, Eqs. 20 through 22, is to create a more practical method of calculating live load pressure distributions. The practical use of the live load equations is cumbersome, unless done on a computer. The simplification was accomplished by transforming the bell-shaped curve shown in Fig. 24 into an approximately equivalent uniform distribution as shown in Fig. 31. The transformation is shown graphically in Fig. 32 and is based the following derivation:

The vertical live load pressure distribution for a single wheel load is given by the equation:

$$\sigma_{vl} = B \exp(-k_v R^2) \quad \ldots \quad (23)$$

The first and second derivatives of Eq. 23 with respect to R are:

$$d\sigma_{vl}/dR = -2 k_v R B \exp(-k_v R^2) \quad \ldots \quad (24)$$

$$d^2\sigma_{vl}/dR^2 = 2 k_v B \exp(-k_v R^2) (2 k_v R^2 - 1) \quad \ldots \quad (25)$$

Setting Eq. 25 equal to zero and solving for R yields R_I, the radial coordinate of the inflection point as shown in Fig. 32. This yields the following result:

$$R_I = \sqrt{0.5/k_v} \quad \ldots \quad (26)$$

When Eq. 26 is combined with Eq. 23 the vertical live load pressure at the inflection point is found to be:

$$\sigma_I = B \exp(-0.5) \quad \ldots \quad (27)$$

When Eq. 26 is combined with Eq. 24 the slope of the vertical live load pressure distribution at the inflection point is found to be:

$$m = -\sqrt{2\ k_v}\ B\ \exp(-0.5) \qquad (28)$$

The slope of the tangent line on Fig. 32 is given by Eq. 28 and can be written as:

$$m = (0 - \sigma_I)/(R_e - R_I) \qquad (29)$$

where R_e = effective horizontal distance at which the vertical live load pressure can be neglected.

Combining Eqs. 26, 27, 28 and 29 yields:

$$\frac{-B\ \exp(-0.5)}{(R_e - R_I)} = -\sqrt{2\ k_v}\ B\ \exp(-0.5) \qquad (30)$$

When Eq. 30 is solved for R_e the result is:

$$R_e = \sqrt{2\ /\ k_v} \qquad (31)$$

Eq. 31 defines the radius of a circular area over which the vertical live load can be assumed to be uniformly distributed, which results in the distribution shown in Fig. 31. The area of the circular area is then:

$$A = \pi R_e^2 = 2\pi/k_v \qquad (32)$$

Transforming the circular area of Eq. 32 to that of a square of side W having the same area results in:

$$A = 2\pi/k_v = W^2 \qquad (33)$$

or,

$$W = \sqrt{2\pi/k_v} \qquad (34)$$

Combining Eq. 22 with Eqs. 33 and 34 and simplifying results in:

$$A = 1.38\ ft^2\ \exp(1.17\ ft^{-1}\ z) \qquad (35)$$

and,

$$W = 1.38\ ft^2 \exp(1.17\ ft^{-1}\ z) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (36)$$

The uniform vertical live load distribution intensity is then given by:

$$\sigma_{vl} = P/A = P/W^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (37)$$

where P is the wheel load (lbf).

Equations 35 through 37 are the simplified vertical live load pressure prediction equations determined in this study, and are shown graphically in Fig. 33.

4.5 Development of Horizontal Live Load Pressure Equations

4.5.1 Analysis of Horizontal Live Load Data

Live load pressures were determined as in the vertical live load section. Pressure cells 4 and 17 were the only ones to exhibit any live load influence. They exhibited a live load influence only when the wheel loads were on their respective side of the culvert. At fill heights greater than 4 ft (1.2 m) no live load influence was observed in any pressure cell output. Consequently, only the data from pressure cells 4 and 17 were used to develop the horizontal live load pressure prediction equations.

The vertical live loads cause the horizontal live load pressures. Therefore, the horizontal live load pressure prediction is based on the vertical live load pressures. Terzaghi's horizontal earth pressure equation (19) is:

$$\sigma_h = k\sigma_v \quad (38)$$

where σ_h = horizontal pressure,

σ_v = vertical pressure, and

k = lateral earth pressure coefficient.

This equation did not model the observed horizontal pressure distribution accurately. Consequently, the vertical live load equation, Eq. 5, was modified to more closely approximate the measured pressures. The form of equation chosen is:

$$\sigma_{hl} = B \sum [\exp(-k_v R_1^2) - \exp(-k_h R_1^2)] \quad (39)$$

where σ_{hl} is the horizontal live load pressure (psf), k_h is a regression coefficient that describes how vertical pressures are transformed into horizontal pressures, and B and k_v are of the same form as in Eqs. 6 and 7.

This equation was chosen for the following reasons:

1. The general appearance of the data suggested this type of equation, as seen in Fig. 34.

2. The graph of the equation has roughly the same shape as the graph of Eq. 5, Boussinesq's equation for the horizontal stress due to a point load on the surface of an elastic half-space, as shown in Fig 35.

3. The equation fits the boundary conditions of vanishing pressure and pressure gradient at an infinite horizontal distance.

4. The equation fits the boundary conditions of vanishing pressure and pressure gradient at an infinite fill height.

5. The equation relates the horizontal pressure to the

vertical pressure.

It should be noted that Eq. 39 is in cylindrical coordinates while the culvert geometry is naturally Cartesian. The simplifying assumption that the earth pressure distribution along the face of the culvert tangent to the surface R=constant equals the predicted radial normal stress at R=constant is conservative An iterative linear least squares regression was performed on the data from pressure cells 4 and 17 with Eq. 39.

4.5.2 Results of Horizontal Live Load Data Analysis

The result of the iterative linear regression of the horizontal live load equation, Eq. 39, is:

$$k_h = 1.74\ k_v \qquad (40)$$

As stated earlier, no horizontal live load pressures were noted when the wheel loads were directly above the top of the culvert or adjacent to the opposite side of the culvert. Horizontal live load pressures were only observed on the side adjacent to the wheel loads.

From this research, the following horizontal live load pressure prediction equation was developed:

$$\sigma_{hl} = \sum B_1\ [\exp(-k_v\ R_1^2) - \exp(-1.74\ k_v\ R_1^2)] \qquad (41)$$

Substituting Eq. 20 into Eq. 41 yields:

$$\sigma_{hl} = \sum [\sigma_{vl}\ (1 - \exp(-0.74\ k_v\ R_1^2))] \qquad (42)$$

where the definition of variables is the same as in Eqs. 20 and 39. An example of these results is shown in Fig. 36.

4.5.3 Simplification of Horizontal Live Load Pressure Equations

The reason for simplifying the horizontal live load equations, Eqs. 20, 39, 41, and 42, is identical to that given for the vertical live load equations, Eqs. 20 through 22. The simplification was accomplished by integrating the live load pressure distribution for a unit slice of culvert and determining the wheel load location for which the integrated pressure distribution is a maximum. This was done for several culvert geometries under several depths of cover. The simplification of the horizontal live load equations is given by the following derivation:

The horizontal live load pressure distribution for a single wheel load is given by the following equation:

$$\sigma_{hl} = \frac{P\ k_{vo}}{\pi} \exp(-c\ z)\ \exp[-k_{vo} \exp(-c\ z\ R^2)] - \frac{P\ k_{vo}}{\pi} \exp(-c\ z)\ \exp[-1.74\ k_{vo} \exp(-c\ z\ R^2)] \quad \ldots\ldots (43)$$

The integrated distribution for a unit slice of the culvert with respect to depth is:

$$\int_{z_1}^{z_2} \sigma_{h1} dz = \frac{P}{\pi c R^2} \exp[-k_{vo} \exp(-c z_2 R^2)] - \frac{P}{\pi c R^2} \exp[-k_{vo} \exp(-c z_1 R^2)] - \frac{P}{1.74 \pi c R^2} \exp[-1.74 k_{vo} \exp(-c z_2 R^2)] + \frac{P}{1.74 \pi c R^2} \exp[-1.74 k_{vo} \exp(-c z_1 R^2)] \quad \ldots\ldots\ldots (44)$$

where z_1 = depth to top of culvert measured from ground surface, and

z_2 = depth to bottom of culvert measured from ground surface.

Eq. 44 is a maximum, or minimum, with respect to wheel load location when its derivative with respect to R equals zero. The derivative with respect to wheel load location of Eq. 44 is:

$$\frac{d}{dR} \int \sigma_{h1} dz =$$

$$\frac{2P}{\pi c R^3} [-k_{vo} \exp(-c z_2) R^2 - 1] \exp[-k_{vo} \exp(-c z_2 R^2)] - \frac{2P}{\pi c R^3} [-k_{vo} \exp(-c z_1) R^2 - 1] \exp[-k_{vo} \exp(-c z_1 R^2)] - \frac{2P}{1.74 \pi c R^3} [-1.74 k_{vo} \exp(-c z_2 R^2) - 1] \exp[-1.74 k_{vo} \exp(-c z_2 R^2)] + \frac{2P}{1.74 \pi c R^3} [-1.74 k_{vo} \exp(-c z_1 R^2) - 1] \exp[-1.74 k_{vo} \exp(-c z_1 R^2)] \quad \ldots\ldots (45)$$

Sample solutions for the maximum value of the integrated pressure distribution, Eq. 44, obtained by setting Eq. 45 equal to zero are given in Table 8.

TABLE 8 - Sample Solutions for Simplification of Horizontal Live Load Pressure Prediction Equations

Depth to Top of Culvert (z_1) in feet	External Height of Culvert ($z_2 - z_1$) in feet	Horizontal Distance (R) in feet	Integrated Distribution ($_{hl}$) in lbf/ft
0	2	0.54	2410
0	4	0.54	2470
0	6	0.55	2480
0	12	0.55	2480
2	2	1.73	232
2	4	1.76	238
2	6	1.75	238
2	12	1.76	238
5	2	10.0	7.0
5	4	10.2	7.1
5	6	10.2	7.1
5	12	10.2	7.1
8	2	58	0.2
8	4	59	0.2
8	6	59	0.2
8	12	59	0.2

Note: 1 ft = 0.305 m, and 1 lbf = 4.45 N.

From Table 8 it is easily seen that the height of the culvert is relatively unimportant and that the results for any culvert with a height greater than 4 ft are similar. Therefore, the culvert height can be ignored, and if the results for the 12 ft-tall culvert are applied to all culvert sizes, the method will be slightly conservative.

An example maximum pressure distribution is shown in Fig.

37. This figure is characteristic of all the maximum pressure distributions. From Fig. 37 it is apparent that the maximum pressure distribution can be closely approximated by a triangle with an area equal to the resultant of the maximum pressure distribution. The vertical length of the triangular area, denoted by l in Fig. 37, was found to be approximately 1.7 ft regardless of culvert size or depth of cover. Therefore, it is recommended that the simplified pressure distribution should consist of a triangular distribution 1.7 ft long with a height equal to the pressure at the top of the culvert, P_{max} from the maximum pressure distributions. Values of P_{max} vs. height of cover are given in Fig. 38. This figure is the simplified horizontal live load pressure prediction design chart.

4.6 Development of Vertical Dead Load Pressure Equations

4.6.1 Analysis of Vertical Dead Load Data

The inconsistencies noted in the dead load pressures were found to be due to thermal effects. These thermally induced pressures are believed to be real pressures caused by expansion and contraction of the culvert, causing the culvert to push into or pull away from the fill material. The thermally induced soil pressures differ from the temperature calibration pressures, since the temperature calibration pressures are erroneous indicated pressures. The thermally induced calibration pressures are a property of both the instrument and the culvert. A combination of internal instrument errors and instrument deformations caused by distortion of the surrounding concrete, in absence of soil, causes these pressure errors, which are subtracted from the signal. The thermally induced soil pressures on the other hand, are due to the culvert and embedded instrument being forced against the earth by thermal expansion of the culvert and the soil. An example of the average vertical dead load pressures for the top pressure cells vs. temperature is shown in Fig. 39.

The slope of the line on Fig. 39 is the thermally caused pressure at 8 ft of cover for a unit temperature change. Since the lifts of fill were placed at different temperatures, the vertical dead load pressures were incrementally corrected for the thermally caused pressure changes between each lift. The thermally caused pressure changes for each lift were determined by using the slope of the pressure vs. temperature graphs at 8 in. and 8 ft of cover and linearly interpolating the slopes for the intermediate cover heights. Data for the determination of the pressure vs. temperature relationships for the other cover heights were either insufficient or non-existent. This temperature correction process results in vertical dead load pressures with all temperature caused pressures removed. In other words, the results of the temperature correction process are the vertical dead load pressures which would have been observed had the fill material been placed at constant temperature, and if the instrument errors were non-existent. The temperature correction process is shown schematically in Fig. 40.

4.6.2 Results of Vertical Dead Load Data Analysis

Before the results are presented, it is important to note that regression analyses were performed twice, using cover height as the independent variable in the first analysis and calculated overburden pressure as the independent variable in the second analysis. Better results were achieved when calculated overburden pressure was used as the independent variable. The calculated overburden pressure is simply the cover height corrected for changes in density between lifts.

Fig. 41 shows the slope of the pressure vs. temperature curves used in the temperature correction. Theoretically, the line drawn on Fig. 41 should pass through the origin. The deviation is probably due to flexure of the top slab and embedded instruments caused by soil loads on the side walls, and the deviation is not considered significant. Vertical dead load pressures corrected for temperature changes between lifts are shown in Fig. 42. This figure shows that if the fill material is all placed at the same temperature the vertical dead load on the culvert at the time of construction will be approximately equal to the overburden pressure.

From this research the following vertical dead load pressure prediction equations were developed:

$$\sigma_{vd} = P_{vd} + P_{vt} \quad \text{......} \quad (46)$$

where σ_{vd} = total vertical dead load pressure (psf),

P_{vd} = vertical dead load pressure due to dead weight of overburden soil (psf), and

P_{vt} = vertical dead load pressure due to temperature caused pressures (psf).

From Fig. 42, the value of P_{vd} can be taken as:

$$P_{vd} = \gamma H \quad \text{......} \quad (47)$$

where γ is the total unit weight of soil (pcf), and

H is the height of cover (ft).

From Fig. 41, the value of P_{vt} can be taken as:

$$P_{vt} = (0.0272 / {}^{o}F)\,(T_t - T_c)\,(\gamma H) \quad \text{......} \quad (48)$$

where T_t = temperature of culvert at time the pressure is being predicted (^oF), and

T_c = temperature of culvert and soil at time the fill was constructed (^oF).

Eqs. 46 through 48 are the proposed design equations and require no further simplification. However, a few comments concerning the use of Eq. 48 are warranted.

1. The value of T_c is a constant for any culvert after the fill material has been placed, assuming there are no long delays in the placement of the fill material.

2. Since most construction occurs during the warmer part of the year, the design engineer usually can conservatively ignore earth pressure variations caused by thermal effects.

3. If the fill material is placed during cold weather, the vertical dead load pressures may increase considerably during warm weather. Conversely, if the fill material is placed during warm weather, the vertical dead load pressures may decrease considerably during cold weather. Therefore, overloads might be permitted on culverts during such warmer periods.

4. The values of T_t and T_c may be approximated by using the ambient air temperature.

4.7 Development of Horizontal Dead Load Pressure Equations

4.7.1 Analysis of Horizontal Dead Load Pressures

The horizontal dead load pressures were observed to be temperature dependent, as were the vertical dead load pressures. An example of the temperature dependent earth pressures is shown in Fig. 43. The analysis of the horizontal dead load pressures was essentially the same as the vertical dead load pressure analysis, except that the data were not averaged, and the final interpretation of the data is somewhat different. Averages were not taken since there is only one pressure cell at each level on each side, as shown in Fig. 4.

An example of the corrected earth pressure is shown in Fig. 44. This figure was developed in the same manner as was Fig. 42 in the vertical dead load pressure analysis section. Theoretically, the line drawn on Fig. 44 should intersect zero pressure at the overburden pressure corresponding to the location of the instrument. This error is probably due to preloading or deformation of the instrument when the compaction equipment was operating adjacent to the instrument. The slope of the line drawn on Fig. 44 is a measure of the lateral earth pressure coefficient at the instrument location. The difference between the horizontal pressure at the pressure cell location and the horizontal pressure at the top of the culvert on Fig. 44 is the horizontal pressure for that instrument when no cover was above the culvert. The zero cover horizontal dead load pressures determined from the analysis of Fig. 44 are shown in Fig. 45.

The upper 4 data points on Fig. 45 show very little scatter, while the lower 4 data points indicate more scatter. The data from pressure cell no. 19 are apparently in error, while the data from pressure cells no. 1 and 20 are thought to be correct. Therefore, the data point from pressure cell no. 19 was omitted from the analysis, and the other data points were averaged to create one set of data for analysis as shown in Fig. 46.

The upper 2 data points on Fig. 46 are thought to be in a linearly increasing, or hydrostatic, pressure distribution. The lower 2 data points on Fig. 46 are thought to be in a soil arching zone because they represent lower values of pressure than do the upper 2 data points. Fig. 47 shows that relatively soft soil is overlain by relatively stiff soil. This corresponds to one of the necessary configurations for soil arching to develop. Based on the data shown in Fig. 46 it is considered likely that significant soil arching is developing at 4 to 5 feet (1.2 to 1.5 m) below the top of the culvert. The literature review revealed only two existing soil arching theories, Marston's (13) and Terzaghi's (19). Marston's theory is widely used (1,2,4,14), and Terzaghi's theory is an extension of Marston's theory. Both theories are based upon a sliding block of soil, the geometry of which is shown in Fig. 48. From this figure it is apparent that the sliding block involves two fixed boundaries. However, there is only one fixed boundary for the soil adjacent to the culvert, and it is the culvert wall itself. Therefore, a soil arching theory is proposed that satisfies the single fixed boundary geometry for the soil adjacent to the culvert. The proposed theory is based on a sliding wedge of soil, the geometry of which is shown in Fig. 49. The shear plane orientation and existence of a sliding wedge in the soil adjacent to the culvert is discussed next.

Rankine's (17) shear plane pattern for the passive case of a retaining wall is shown in Fig. 50. When this shear plane pattern is applied to the compaction of soil the resulting shear plane pattern shown in Fig. 51 is developed. The theoretical shear plane pattern for a foundation failure (19) is shown in Fig. 52. Bowles (6) indicates that the angle the shear plane makes with the vertical has been found to be approximately $(45-\phi/2)$ for real foundations and soils. Therefore, when the information from Figs. 49 through 52 is applied to the compaction of soil adjacent to a culvert, Fig. 53 is developed. This figure shows that the shear planes do exist and that the sliding wedge shown in Fig. 49 is an accurate representation of a soil arching zone.

Solution of equations governing arching theories ordinarily requires knowledge of which shear planes define the boundaries of the arching zone. The arching zone is the wedge shown in Fig. 49, and the plane bounding the zone is a shear plane such as plane a-b in Fig. 53 for example. However, for this research the shear plane location was back-calculated by fitting the equation of the proposed arching theory to the data.

The proposed arching theory can be expressed by the following equation:

$$\sigma_v = \frac{z\gamma}{(c-1)}[1 - (z/z_t)^{(c-1)}] + q_v\ (z/z_t)^c \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (49)$$

where σ_v = vertical pressure,

k = lateral earth pressure coefficient,

B = half-width of sliding prism,

γ = unit weight of soil,

ϕ = effective stress angle of internal friction of soil,

q_v = vertical surcharge pressure, and

z = height above reference plane,

z_t = depth of reference plane below top of active shearing stress zone, and

$$c = \frac{2\ k\ \tan\phi}{\tan(45 - \phi/2)}$$

The horizontal stress for the proposed equation, Eq. 49, is found by using Eq. 38. The coefficient c in Eq. 49 can be considered a description of the strength and load transmission characteristics of the soil.

A two-dimensional Newton-Raphson root-finding scheme was used to fit the proposed equation to the data. Derivations of Marston's, Terzaghi's, and the proposed theory of arching, along with the details of the Newton-Raphson root-finding scheme are given in Appendix VI.

4.7.2 Results of Horizontal Dead Load Data Analysis

The average slope of the corrected earth pressure vs. overburden curves, such as shown in Fig. 44, was found to be 0.422. This translates into:

$$\sigma_{hs} = k \gamma H \qquad (50)$$

where σ_{hs} = horizontal surcharge pressure on side of culvert due to fill material above culvert (psf),

k = lateral earth pressure coefficient,

γ = unit weight of soil above culvert (pcf), and

H = height of fill above top of culvert (ft).

The lateral earth pressure coefficient k may be taken to be the average slope value of 0.422. From Lambe and Whitman (12), the at-rest lateral earth pressure coefficient for a sand is given by:

$$k_o = 1 - \sin \phi \qquad (51)$$

where k_o = at-rest lateral earth pressure coefficient, and

ϕ = effective stress angle of internal friction of soil.

Using ϕ = 31.8 degrees, Eq. 51 yields an at-rest lateral earth pressure coefficient equal to 0.473. The results of the zero cover analysis, see Fig. 46, are presented next.

A linear least squares regression was performed on the upper two data points from Fig. 46 with the equation:

$$\sigma_{hh} = k \gamma H \quad \text{.......................................} \quad (52)$$

where σ_{hh} = horizontal pressure in hydrostatic zone (psf),

k = lateral earth pressure coefficient,

γ = total unit weight of soil in hydrostatic zone, taken to be 125.2 pcf in this study, and

H = depth of zero shearing stress plane below top of culvert (ft).

The resulting value for k is 0.623. This is a reasonable value for compacted earth. This value of the lateral earth pressure coefficient is greater than the theoretical value of 0.473 from Eq. 51, which is expected since residual lateral earth stresses caused by the compaction of the soil adjacent to the culvert are expected to influence the horizontal pressures on the side of the culvert caused by the soil adjacent to the culvert. These residual stresses are not expected to influence the horizontal pressures on the side of the culvert caused by the soil above the culvert.

In order to analyze the soil arching zone, the top of the active shearing zone in the proposed theory must be located. From Figs. 46 and 47 the zone is estimated to be 4 to 5 feet (1.2

to 1.5 m) below the top of the culvert. The proposed equations, Eqs. 38 and 49, were solved by assuming the top of the shearing zone location to be 4.5 ft (1.37 m) below the top of the culvert. The results of the Newton-Raphson solution are:

$k = 0.434$ .... (53)

$z_t = 7.06$ ft (2.15 m) .... (54)

This value for k is between the two previous values of 0.422 from the surcharge portion and 0.623 from the hydrostatic portion of the horizontal dead load pressure analysis. This value of the lateral earth pressure coefficient, Eq. 53, compares very well with the two previous values considering the residual lateral earth stresses due to compaction and the moisture contents shown in Fig. 47. The value for z_t cannot be determined analytically. Fig. 54 shows the shear plane and shearing zone geometry given by this solution. From Fig. 54 two observations can be made. First, the reference plane is located below the culvert. Second, the width of the shear zone at the bottom of the culvert is approximately the same as the crawler tractor track width of 14 in. (0.356 m).

The width of the shear plane at the bottom of the culvert and the crawler tractor track width may be related. The lowest level at which the soil was compacted was adjacent to the bottom of the culvert. Since the crawler tractor was used to compact the soil, the first or most important shear plane may be located approximately one track width away from the culvert. In other words, the first or most important shear plane may have been locked into the soil by the compaction equipment and was able to propagate itself vertically upward due to the compaction and high moisture contents of the lower portion of the backfill, as seen in Fig. 47.

The reference plane is expected to be located below the culvert since the compaction equipment probably created shear planes in the soil when it was operating directly adjacent to the bottom of the culvert. However, the reference plane location was not expected to be more than one or two feet below the culvert since compaction and shear plane creation at that depth is very difficult to achieve with relatively light compaction equipment. Therefore, it appears that the value of z_t determined from the numerical solution is such that it sets the width of the shear zone to be approximately equal to one track width.

All zero cover horizontal dead load equations and data are shown in Fig. 55. The dashed line extensions of the arching and non-arching cases on Fig. 55 are the predicted horizontal dead load pressures for the case when the backfill material is placed at a uniform moisture content. In other words, if the backfill material had all been placed at a high moisture content, it is believed that the arching case would apply along the entire depth of the culvert. If the backfill had all been placed at a low moisture content, it is believed that the non-arching case would apply along the entire depth of the culvert.

Based on this theory the following equations can be developed:

$$\sigma_{hd} = P_{h0} + P_{hs} + P_{ht} \quad (55)$$

where σ_{hd} = total horizontal dead load pressure at point of interest (psf),

P_{h0} = horizontal dead load pressure caused by backfill soil adjacent to the culvert with zero cover. This pressure is determined from the arching or non-arching cases, whichever applies (psf),

P_{hs} = horizontal dead load pressure caused by weight of fill material above the culvert. This pressure is determined through at-rest soil mechanics (psf), and

P_{ht} = horizontal dead load pressures caused by temperature effects (psf).

For the soil arching case, P_{h0} is calculated by:

$$P_{h0} = k\,\sigma_v \qquad (56)$$

and,

$$\sigma_v = \frac{\gamma z}{(c-1)}[1 - (z/z_t)^{(c-1)}] + q_v\,(z/z_t)^c \qquad (49)$$

where σ_v = vertical pressure,

k = lateral earth pressure coefficient,

B = half-width of sliding prism,

γ = total unit weight of soil,

ϕ = effective stress angle of internal friction of soil,

q_v = vertical surcharge pressure, and

z = height above reference plane,

z_t = depth of reference plane below top of active shearing stress zone, and

$$c = \frac{2\,k\,\tan\phi}{\tan(45 - \phi/2)}$$

For the non-soil arching case, P_{h0} is calculated by:

$$P_{h0} = k\,\gamma\,H \qquad (57)$$

where k = lateral earth pressure coefficient,

γ = unit weight of soil (pcf), and

H = depth below top of culvert (ft).

The value of P_{hs} is calculated by the equation:

$$P_{h0} = k \gamma H \quad \text{.......} \quad (58)$$

where k = lateral earth pressure coefficient,

γ = unit weight of soil (pcf), and

H = height of cover above culvert (ft).

The value of P_{ht} is calculated by the equation:

$$P_{ht} = (0.0115 / {}^{o}F)\ (T_t - T_c)\ (\gamma z) \quad \text{.......} \quad (59)$$

where T_t = temperature of culvert at the time the pressure is being predicted (^{o}F),

T_c = temperature of culvert and soil at the time the backfill was constructed,

γ = total unit weight of soil (pcf), and

z = depth from ground surface to point of interest (ft).

Eq's. 49 and 55 through 59 are the final design equations determined from this research and require no further simplification. However, the comments concerning the use of Eq. 48 at the end of the preceding section also apply to Eq. 59.

4.8 Summary of Proposed Pressure Prediction Equations

4.8.1 Vertical Live Load Pressure Equations

It is recommended that vertical live load pressures be predicted with the following equations:

$$\sigma_{vl} = \sum B_j \exp(-k_v R_j^2) \qquad (20)$$

$$B_j = P_j k_v / \pi \qquad (21)$$

$$k_v = (4.545 \text{ ft}^{-2}) \exp[-(1.170 \text{ ft}^{-1} z)] \qquad (22)$$

where σ_{vl} = vertical live load pressure at point of interest (psf),

R_j = horizontal distance from wheel load j to point of interest (ft),

P_j = weight of wheel load j (lbf),

z = depth from ground surface (ft),

π = the irrational number 3.14159..., and

j = wheel load identification number.

The simplified procedure for obtaining vertical live load pressures is:

$$\sigma_{vl} = P/A \qquad (37)$$

and,

$$A = 1.38 \text{ ft}^2 \exp(1.170 \text{ ft}^{-1} z) \qquad (38)$$

where σ_{vl} = intensity of uniform pressure over the area A given by Eq. 38 (psf),

P = weight of wheel load (lbf),

A = area of square over which the wheel load P is uniformly distributed (ft^2), and

z = depth from ground surface (ft).

4.8.2 Horizontal Live Load Pressure Equations

It is recommended that horizontal live load pressures be predicted with the following equations:

$$\sigma_{hl} = \sum B_j \, [\exp(-k_v \, R_j^{\,2}) - \exp(-1.74 \, k_v \, R_j^{\,2})] \quad \ldots\ldots\ldots\ldots\ldots \quad (41)$$

where $_{hl}$ = horizontal live load pressure, and the variables B_j, k_v, and R_j are the same as in Eqs. 20 through 22.

An alternate form Eq. 41 is:

$$\sigma_{hl} = \sum [\sigma_{vl} \; (1 - \exp(-0.74 \, k_v \, R_j^{\,2}))] \quad \ldots\ldots\ldots\ldots\ldots \quad (42)$$

The simplified procedure for obtaining horizontal live load pressures is illustrated in Fig. 38.

4.8.3 Vertical Dead Load Pressure Equations

It is recommended that vertical dead load pressures be predicted with the following equations:

$$\sigma_{vd} = P_{vd} + P_{vt} \quad \ldots\ldots\ldots\ldots\ldots \quad (46)$$

where σ_{vd} = total vertical dead load pressure (psf),

P_{vd} = vertical dead load pressure due to dead weight of overburden soil (psf), and

P_{vt} = vertical dead load pressure due to temperature caused pressures (psf).

The value of P_{vd} is given by:

$$P_{vd} = \gamma H \quad \ldots\ldots\ldots\ldots\ldots \quad (47)$$

where γ = total unit weight of soil (pcf), and

H = height of cover (ft).

The value of P_{vt} is given by:

$$P_{vt} = (0.0272 / {}^{o}F)\ (T_t - T_c)\ (\gamma H) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (48)$$

where T_t = temperature of culvert at time the pressure is being predicted (^{o}F), and

T_c = temperature of culvert and soil at time the fill was constructed (^{o}F).

4.8.4 Horizontal Dead Load Pressure Prediction Equations

It is recommended that horizontal dead load pressures for soil adjacent to the culvert be predicted with the following equations:

$$\sigma_{hd} = P_{h0} + P_{hs} + P_{ht} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (55)$$

where σ_{hd} = total horizontal dead load pressure at point of interest (psf),

P_{h0} = horizontal dead load pressure caused by backfill soil adjacent to the culvert with zero cover. This pressure is determined from the arching or non-arching cases, whichever applies (psf),

P_{hs} = horizontal dead load pressure caused by weight of fill material above the culvert. This pressure is determined through at-rest soil mechanics (psf), and

P_{ht} = horizontal dead load pressures caused by temperature effects (psf).

For the soil arching case, P_{h0} is calculated by:

$$P_{h0} = k\sigma_v \qquad (56)$$

and,

$$\sigma_v = \frac{\gamma z}{(c-1)}[1 - (z/z_t)^{(c-1)}] + q_v\,(z/z_t)^c \qquad (49)$$

where σ_v = vertical pressure,

k = lateral earth pressure coefficient,

B = half-width of sliding prism,

γ = total unit weight of soil,

ϕ = effective stress angle of internal friction of soil,

q_v = vertical surcharge pressure, and

z = height above reference plane,

z_t = depth of reference plane below top of active shearing stress zone, and

$$c = \frac{2\,k\,\tan\phi}{\tan(45 - \phi/2)}$$

For the non-soil arching case, P_{h0} is calculated by:

$$P_{h0} = k\gamma H \qquad (57)$$

where k = lateral earth pressure coefficient,

γ = unit weight of soil (pcf), and

H = depth down from top of culvert (ft).

The value of P_{hs} is calculated by the equation:

$$P_{hs} = k\gamma H \qquad (58)$$

where k = lateral earth pressure coefficient,

γ = unit weight of soil (pcf), and

H = height of cover above culvert (ft).

The value of P_{ht} is calculated by the equation:

$$P_{ht} = (0.0115 / {}^{o}F)\ (T_t - T_c)\ (\gamma z) \qquad (59)$$

where T_t = temperature of culvert at the time the pressure is being predicted (^{o}F),

T_c = temperature of culvert and soil at the time the backfill was constructed,

γ = total unit weight of soil (pcf), and

z = depth from ground surface to point of interest (ft).

Chapter 5

EARTH PRESSURE PREDICTION METHODS

5.1 AASHTO Method

The AASHTO pressure prediction method (1) consists of three parts. Part 1 is determination of live load pressures. There are three separate types of vertical live load conditions, and two horizontal live load conditions, based on fill height. Part 2 is the determination of externally caused dead load pressures. These pressures are caused by the soil around and above the culvert. There are three separate types of externally caused vertical dead loads based on bedding conditions and fill heights. There is only one type of externally caused horizontal dead load. Part 3 is the determination of internally caused dead load pressures. These pressures are caused by the weight of the culvert and are all vertical.

The live loads cause design vertical pressures defined as follows:

For less than 2 feet of fill, the wheel loads are placed directly on the top slab in a line load. The length of line load, for each wheel load, is computed from the following formula:

$$E = 4 \text{ ft} + 0.6\ S \qquad (60)$$

where E = length of line load (ft), and

S = span width of culvert (ft).

The line load intensity is determined by dividing the wheel load by the length of line load.

For cover depths between 2 ft and either 8 ft or 1 span width, whichever is greater, the wheel load is assumed to be uniformly distributed over a rectangular area defined by the AASHTO pyramid. The rectangular area for each wheel load is equal to the base of a 4-sided pyramid (AASHTO pyramid) with side slopes of 0.875 to 1 and height equal to the depth of fill material above the culvert. If influence areas overlap, the total influence area is defined by the outer limits of the combined areas, and the total load is distributed over that area. However, the width of an influence area cannot exceed the width of the culvert. The AASHTO pyramid is shown in Fig. 56. For fill heights greater than 8 ft or the total culvert width, whichever is greater, the live load is ignored.

Design horizontal earth pressures are calculated from the live loads as follows:

For fill heights less than 8 ft or 1 span width, whichever is greater, the horizontal live load is equal to 60 psf and is uniformly distributed over the entire side of the culvert. For levels of fill greater than 8 ft or 1 span width, whichever is greater, the live load is ignored.

Design vertical earth pressures are calculated from the dead loads as follows:

Under normal bedding conditions the externally caused vertical dead load on the top and bottom of the culvert is computed by:

$$P = 0.7 \gamma H \quad (61)$$

where P = externally caused vertical dead load pressure on top and bottom of the culvert,

γ = total unit weight of soil, and

H = height of fill above surface in question.

Under normal bedding conditions, no relative movement between the culvert and soil is expected.

For conditions where the soil adjacent to the culvert is expected to compress, and the height of fill is less than 1.7 times the culvert width, the externally caused vertical dead load on the top and bottom of the culvert is computed by:

$$P = 1.81 B \; [\exp(k) - 1] \quad (62)$$

$$k = 0.358 H/B \quad (63)$$

where B is the width of culvert.

For conditions where the soil adjacent to the culvert will compress, and the height of fill is greater than 1.7 times the culvert width, the externally caused vertical dead load on the top and bottom of the culvert is computed by:

$$P = 0.7(1.92H - 0.87B) \quad (64)$$

The horizontal earth pressure on the sides of the culvert due to the dead load of the soil is always hydrostatic and computed from:

$$P = WH \qquad (65)$$

where W = 30 pcf equivalent fluid weight density, and

H = height of fill (ft).

The vertical dead loads due to the weight of the culvert are equal to the weight of the culvert multiplied by a factor of 0.70. Use of the current AASHTO method is illustrated by the following numerical example:

5.2 Example Illustrating AASHTO Method

The geometry for this example is shown in Fig. 57. The following values are assumed:

Impact factor = 1.2,

Total unit weight of soil = 120 pcf,

Unit weight of concrete = 150 pcf, and

Normal bedding conditions.

From Fig. 56, the wheel load influence area is calculated to be:

$$(1.75 \times 2 \text{ ft})^2 = (3.5 \text{ ft})^2 = 12.25 \text{ ft}^2$$

The resulting vertical live load pressure is then:

$$(32{,}000 \text{ lbf})(1.2)/(12.25 \text{ ft}^2) = 3130 \text{ psf}$$

The horizontal live load surcharge pressure (AASHTO 3.20.3) is taken to be 60 psf along the entire side of the culvert. The factored vertical earth pressures on the top and bottom of the culvert due to the dead load of the overburden are:

$$(0.7)(120 \text{ pcf})(2 \text{ ft}) = 168 \text{ psf}$$

The externally caused horizontal dead load at the top of the side of the culvert is:

$$(30 \text{ pcf})(2 \text{ ft}) = 60 \text{ psf}$$

The externally caused horizontal dead load at the bottom of the side of the culvert is:

$$(30 \text{ pcf})(2 \text{ ft} + 9.5 \text{ ft}) = 345 \text{ psf}$$

The horizontal earth pressures due to dead load of soil are linearly distributed along the side, having an intensity of 60 psf at the top and an intensity of 345 psf at the bottom. The culvert is to be analysed by the unit strip method, so the resultant vertical live load per foot of culvert, calculated to be

$$(3130 \text{ psf})(3.5 \text{ ft}^2) = 11{,}000 \text{ lbf}$$

is equilibrated by a uniformly distributed upward earth pressure on the bottom slab equal to

$$11{,}000 \text{ lbf}/(9.5 \text{ ft}^2) = 1160 \text{ psf}$$

The results of the live loads and externally caused dead loads are shown in Fig. 58. The internally caused dead loads will be computed next.

The weight of the top slab is:

$$(9/12)\text{ft}(9.5\text{ ft})(1\text{ ft})(150\text{ pcf}) = 1070\text{ lbf}$$

The corresponding uniformly distributed load on the top slab is

$$1070\text{ lbf}/(9.5\text{ ft}^2) = 113\text{ psf}$$

This dead load is sometimes multiplied by the same 0.70 load factor used for dead load vertical earth pressures, based on the same philosophy as that leading to the use of the 0.70 factor for dead load vertical earth pressures. The factored uniformly distributed vertical earth pressure acting upward on the bottom slab equilibrating the weight of the top slab is

$$0.7\ (1070\text{ lbf})/(9.5\text{ ft}^2) = 79\text{ psf}$$

The total weight of the two walls, per foot of culvert length, is:

$$2(9/12\text{ ft})(8\text{ ft})(1\text{ ft})(150\text{ pcf}) = 1800\text{ lbf}$$

The factored upward earth pressure reaction distributed uniformly over the bottom slab equilibrating the weight of the two walls is

$$0.7\ (1800\text{ lbf})/(9.5\text{ ft}^2) = 133\text{ psf}$$

The design pressures calculated here are based on the interpretation of the AASHTO design specification by the Texas SDHPT. Some aspects of this procedure, such as the reduction of the self-weight dead load of the top slab by the 0.70 load factor, are not directly addressed by the AASHTO specification. The resulting design pressures, including both the externally and internally caused earth pressures, are shown in Fig. 59.

5.3 Proposed Method

The proposed pressure prediction method consists of four parts. Part 1 is the determination of vertical live load pressures. Part 2 is the determination of horizontal live load pressures. Part 3 is the determination of vertical dead load pressures. Part 4 is the determination of horizontal dead load pressures. There are two horizontal dead load pressure prediction methods. The first method does not consider soil arching, while the second method includes the effects of soil arching. A summary of the recommended equations used to predict both live and dead load pressures is given in Chapter IV, section 4.8. The procedure for using these equations is shown in the following numerical examples.

5.4 Examples Illustrating Proposed Method Examples

5.4.1 Vertical Live Load Pressure Example

The geometry for this example is shown in Fig. 60, and is the same as the AASHTO example. For purposes of this example, it is assumed that the five points labelled A through E on Fig. 60 will be adequate to define the pressure distribution on the top slab. It is also assumed that the impact factor is 1.20.

The value of k_v, calculated using Eq. 22, is:

$$k_v = 4.545 \text{ ft}^{-2} \exp[-(1.170 \text{ ft}^{-1})(2 \text{ ft})] = 0.438 \text{ ft}^{-2}$$

The value of B, Eq. 21, is:

$$B = (32{,}000\ \text{lbf})(0.438\ \text{ft}^2)/3.14 = 4460\ \text{psf}$$

From Eq. 20, the pressure at point C with the impact factor is:

$$\sigma_{vl} = 1.2\ (4460\ \text{psf})\ \exp[0] = 5350\ \text{psf}$$

Similarly, the pressure at point B with the impact factor is:

$$\sigma_{vl} = 1.2\ (4460\ \text{psf})\ \exp[-1.752] = 928\ \text{psf}$$

The vertical live load pressures at points A-E, including the effect of impact, are as follows:

Point	R, ft	Vertical Live Load Pressure, psf
A	4.75	0
B	2.00	928
C	0.00	5350
D	2.00	928
E	4.75	0

To determine the vertical live load pressures on the bottom slab the pressure distribution is integrated, and the resultant force is distributed uniformly over the bottom slab. The resultant of the integrated distribution is then:

$$2[(928\ \text{psf})(2.75\ \text{ft})/2 + (928\ \text{psf} + 5350\ \text{psf})(2\ \text{ft})/2] = 15{,}100\ \text{lbf/ft}$$

The uniform pressure on the bottom slab is:

$$(15{,}100\ \text{lbf/ft})/(9.5\ \text{ft}) = 1590\ \text{psf}$$

The resulting pressure distributions are shown in Fig. 61. For hand calculations a 1-ft long strip of culvert is analyzed, neglecting the loading variations along the length of the culvert.

In this example five points were used to model the pressure distribution due to a single wheel load. If more points are used a more accurate pressure distribution can be predicted. One method of comparing the proposed method with the AASHTO method is to integrate the two pressure distributions over a 1 ft slice of the culvert. From Fig. 58, the total AASHTO vertical live load on the slice is:

$$(3130\ \text{psf})(3.5\ \text{ft})(1\ \text{ft}) = 11{,}000\ \text{lbf}$$

The ratio of the resultants predicted by the two methods is then:

$$\frac{\text{Proposed}}{\text{AASHTO}} = \frac{(15{,}100\ \text{lbf/ft})(1\ \text{ft})}{11{,}000\ \text{lbf}} = 1.37$$

Therefore, for this comparison the proposed method is predicting a total vertical live load on the culvert of 37% more than does the AASHTO method. An alternate comparison of the two methods is by integration of the two distributions over the region covered by the AASHTO pressure distribution.

The proposed method's vertical live load pressure on the culvert at a horizontal distance of 1.75 ft with the impact factor is:

$$1.2\ (4460\ \text{psf})\ \exp[(-0.438\ \text{ft}^{-2})\ (1.75\ \text{ft})^2] = 1400\ \text{psf}$$

The total load over the area covered by the AASHTO pyramid is then:

$$2[(1400 \text{ psf} + 5350 \text{ psf})(1.75 \text{ ft})(1 \text{ ft})/2] = 11{,}800 \text{ lbf}$$

This comparison yields a ratio of:

$$\frac{\text{Proposed}}{\text{AASHTO}} = \frac{11{,}800 \text{ lbf}}{11{,}000 \text{ lbf}} = 1.07$$

Therefore, this comparison also shows the proposed method to result in higher design pressures than the AASHTO procedure. The proposed method is conservative in the same sense that the AASHTO procedure is, in that it neglects the pressure variation in the longitudinal direction. Also, the use of only 5 points in the proposed procedure results in increasing the resultant design vertical live loads. For final design calculations, including the pressure variation in the longitudinal direction and using more than 5 points to define the pressure distribution will reduce this margin of safety.

If the vertical live load pressure distribution specified by Eq. 20 is integrated, using the parameters of this example problem, the resultant vertical earth pressure load on the top slab can be calculated to be 9150 lbf per foot of culvert. The 11,000 lbf resultant of the AASHTO design pressure distribution is more than 20% greater than this value. The following example of the simplified proposed method yields a vertical earth pressure resultant more nearly in agreement with this lower value.

5.4.2 Simplified Vertical Live Load Pressure Example

The geometry for this example is the same as in the preceding example. Assume an impact factor of 1.20. The area of the square over which the load is uniformly distributed, calculated using Eq. 35, is:

$$A = 1.38\ ft^{2} \exp(2\ ft / 0.855\ ft) = 14.3\ ft^{2}$$

The length of a side of the square is therefore:

$$W = 14.3\ ft^{\ 2} = 3.78\ ft$$

The intensity of the vertical live load distribution, using Eq. 37, is:

$$\sigma_{vl} = 1.2\ (32{,}000\ lbf / 14.3\ ft^{2}) = 2690\ psf$$

The integrated pressure distribution for a unit width of culvert is:

$$(1\ ft)\ (3.78\ ft)\ (2690\ psf) = 10{,}200\ lbf$$

The integrated vertical live load pressure distribution is spread uniformly over the bottom slab to predict vertical live load pressures for that slab. The intensity of the uniform vertical live load pressure on the bottom slab is:

$$(10{,}200\ lbf)/[(1\ ft)\ (9.5\ ft)] = 1{,}070\ psf$$

The resulting pressure distributions are shown in Fig. 62. Comparing these results with the AASHTO method yields:

$$\frac{\text{Proposed}}{\text{AASHTO}} = \frac{10{,}200\ lbf}{11{,}000\ lbf} = 0.93$$

This comparison shows the simplified proposed method to be less conservative than the AASHTO method. While both procedures are made conservative by the use of the unit strip method of analysis, in this example the proposed method distributes the live load pressures over a greater length of culvert than the AASHTO pyramid, and therefore results in lower design live load pressures on the unit strip analyzed. This comparison is shown in Fig. 63.

5.4.3 Horizontal Live Load Pressure Example

The geometry for this example is shown in Fig. 64. As discussed in the analysis section, each wheel load affects only the nearer wall of the culvert. Therefore, due to symmetry, only one set of calculations need be performed. Calculations of vertical live load pressures on the top and bottom slabs are omitted for brevity.

Assume the following:

Impact factor = 1.2

For hand calculations the five points (E-I) on Fig. 64 are adequate to define the pressure distribution.

From Eq's 21 and 22, the values of k_v and B at point E are:

$$k_v = 4.545 \text{ ft}^{-2} \exp[-(1.170 \text{ ft}^{-1})(2 \text{ ft})] = 0.438 \text{ ft}^{-2}$$
$$B = (32{,}000 \text{ lbf})\ (0.438 \text{ ft}^{-2})/\pi = 4460 \text{ psf}$$

The values of k_v and B at each of the points are:

Point	Fill, ft	k_v, ft^{-2}	B, psf
E	2.00	0.438	4460
F	4.00	0.042	428
G	6.00	0.004	41
H	8.75	0.000	0
I	11.50	0.000	0

From Eq. 41, with a horizontal distance of 2 ft the resulting pressure at point E with the impact factor is:

$$\sigma_{hl} = 1.2\ (4460\ \text{psf})\ \{\exp[(-0.438\ \text{ft}^{-2})\ (2\ \text{ft})^2] - \exp[-1.74\ (0.438\ \text{ft}^{-2})\ (2\ \text{ft})^2]\} = 674\ \text{psf}.$$

The horizontal live load pressures at all the points are:

Point	Horizontal Live Load Pressure, psf
E	674
F	51
G	1
H	0
I	0

The resulting pressure distributions are shown in Fig. 65. Assuming a unit thickness, and neglecting the pressure decay in the longitudinal direction, the resultant of the distribution on one side is:

$$1 \text{ ft}[(674 \text{ psf} + 51 \text{ psf})(2 \text{ ft})/2 + (51 \text{ psf} + 1 \text{ psf})(2 \text{ ft})/2 + (1 \text{ psf} + 0)(2.75 \text{ ft})/2] = 778 \text{ lbf}.$$

The resultant of the AASHTO distribution, from Fig. 58, is:

$$(9.5 \text{ ft})(1 \text{ ft})(60 \text{ psf}) = 570 \text{ lbf}.$$

The ratio is then:

$$\frac{\text{Proposed}}{\text{AASHTO}} = \frac{778 \text{ lbf}}{570 \text{ lbf}} = 1.36$$

However, the moments in the side walls due to this distribution will be considerably less than those due to the AASHTO distribution. The resultant of the proposed design pressure distribution is also dependent upon wheel location. For design purposes, it is necessary to calculate several horizontal live load pressure distributions in order to determine the critical wheel position. Alternatively the proposed simplified method may be used, since it includes an evaluation of the critical wheel position. In addition, for final design calculations, it is advisable to include the pressure decay in the longitudinal direction, and to use more than 5 points to define the pressure distribution.

5.4.4 Simplified Horizontal Live Load Pressure Example

The geometry for this example is the same as in the preceding example. Assume an impact factor of 1.2. From Fig. 38 with a height of cover equal to 2 ft and a wheel load weight of 32,000 lbf, the value of P_{max} is found to be:

$$(32{,}000 \text{ lbf}/16{,}000 \text{ lbf})(1.2)(370 \text{ psf}) = 888 \text{ psf}$$

The design pressure distribution is shown in Fig. 66. The resultant of this distribution for a unit width is then:

$$(0.5)\ (1.7\ \text{ft})\ (1\ \text{ft})\ (888\ \text{psf}) = 755\ \text{lbf}$$

Comparing these results to the AASHTO method is difficult since the resultant of the proposed distribution is highly dependent on depth of cover, as seen in Fig. 38.

5.4.5 Vertical Dead Load Pressure Example

The geometry for this example is the same as in the preceding examples. Assume a total unit weight of 120 pcf. From Eq's. 46 through 48, at the time of construction, the vertical dead load pressure is:

$$\sigma_{vd} = (120\ \text{pcf})\ (2\ \text{ft}) + 0 = 240\ \text{psf}$$

Variations in temperature will result in variations of the earth pressures from this value. For a 30^{o}F temperature drop, the vertical dead load pressure will be:

$$\sigma_{vd} = (120\ \text{pcf})\ (2\ \text{ft}) + (0.0272/^{o}\text{F})\ (-30^{o}\text{F})\ (120\ \text{pcf})\ (2\ \text{ft}) = 44\ \text{psf}$$

Similarly, for a 30^{o}F temperature increase, the vertical dead load pressure will be:

$$\sigma_{vd} = (120\ \text{pcf})\ (2\ \text{ft}) + (0.0272/^{o}\text{F})\ (30^{o}\text{F})\ (120\ \text{pcf})\ (2\ \text{ft}) = 436\ \text{psf}$$

The vertical dead load pressures at the time of construction are shown in Fig. 67. The preceding calculations indicate that temperature induced pressures can be significant.

5.4.6 Horizontal Dead Load Pressure Example--Neglecting Arching

The geometry for this example is the same as in the preceding examples. Assume the following:

Total unit weight of soil = 120 pcf

Lateral earth pressure coefficient next to culvert = 0.6

Effective stress angle of internal friction of soil = 32°

As mentioned in the analysis section, the soil above the culvert acts on the sides of the culvert as a surcharge. The at-rest lateral earth pressure coefficient, from Eq. 51, is:

$$1 - \sin(32^{\circ}) = 0.47$$

The horizontal surcharge pressure acting on the entire side of the culvert is given by Eq. 58:

$$(0.47)(120 \text{ pcf})(2 \text{ ft}) = 113 \text{ psf}$$

As mentioned in the analysis section, the soil adjacent to the culvert acts on the side of the culvert as a well compacted soil, and the pressure increases linearly with depth. The horizontal pressure at the top of the culvert due to the soil adjacent to the culvert, from Eq. 57, is:

$$(0.6)(120 \text{ pcf})(0 \text{ ft}) = 0 \text{ psf}$$

The horizontal pressure at the bottom of the culvert due to the soil adjacent to the culvert is:

$$(0.6)(120 \text{ pcf})(9.5 \text{ ft}) = 684 \text{ psf}$$

The resulting horizontal pressure at the top of the culvert is then:

$$113 \text{ psf} + 0 \text{ psf} = 113 \text{ psf}$$

The resulting horizontal pressure at the bottom of the culvert is then:

$$113 \text{ psf} + 684 \text{ psf} = 797 \text{ psf}$$

The resulting horizontal pressure distribution is shown in Fig. 68. Comparison of Fig. 68 with the AASHTO method in Fig. 58 shows that the AASHTO method under-estimates horizontal dead load pressures. The practical significance of this is twofold:

1. The side walls may experience significantly more dead load moment than that corresponding to the pressure distribution prescribed by the AASHTO method. This effect may be partially or completely offset by the live load pressures on the walls prescribed by the AASHTO method, which are generally higher than observed in this study.

2. The top and bottom slabs of an RCB culvert may have a different thrust than results from the AASHTO dead load horizontal pressure distribution, and are therefore capable of carrying different live load moments.

5.4.7 Horizontal Dead Load Pressure Example--With Arching but No Cover

The geometry for this example is shown in Fig. 69. It should be noted that the arching zone begins at the ground surface and that no surcharge is being applied. This is a simplifying assumption in this example to illustrate the nature of the lateral earth pressure distribution in the proposed theory of arching. Similar pressure distributions, approximately parabolic in shape, have been measured on the sides of braced excavations (20).

Assume the following:

Total unit weight of soil = 120 pcf

Lateral earth pressure coefficient next to culvert = 0.4

Effective stress angle of internal friction of soil = 32°

The reference plane for proposed theory is located at the bottom of the culvert.

For hand calculations the five points (J-N) on Fig. 69 adequately define the pressure distribution.

The value of c in Eq. 49 is:

$$c = (2)(0.4)(\tan 32^{\circ})/\tan(45^{\circ}-16^{\circ}) = 0.902$$

From Eq. 49 with z = 7.25 ft, and with $q_v = 0$, the vertical dead load pressure at point K is:

$$\sigma_v = \frac{(120 \text{ pcf})(7.25 \text{ ft})}{(0.902 - 1)} [1 - (7.25 \text{ ft}/9.50 \text{ ft})^{(0.902 - 1)}]$$

$$= 238 \text{ psf.}$$

From Eq. 38, the horizontal dead load pressure at point K is:

$$\sigma_h = 0.4(238 \text{ psf}) = 95 \text{ psf.}$$

The vertical and horizontal dead load pressures at points J-N are:

Point	z, ft	Vertical Dead Load Pressure, psf	Horizontal Dead Load Pressure, psf
J	9.50	0	0
K	7.25	238	95
L	4.75	409	164
M	2.25	418	167
N	0.00	0	0

The results of this analysis are shown in Fig. 70, with a smooth curve drawn through the points. The vertical surcharge pressure is equal to the weight of soil adjacent to the culvert above the arching zone. Any soil above the culvert acts in an at-rest fashion and is added to soil pressures within the arching zone as in the next example.

5.4.8 Horizontal Dead Load Pressure Example--With Arching and a Surcharge

The geometry for this example is shown in Fig. 71. This geometry is identical to that in the previous example except for the presence of fill material above the culvert.

Assume the following:

Total unit weight of soil = 120 pcf

Lateral earth pressure coefficient next to culvert = 0.4

Effective stress angle of internal friction of soil = 32°

The reference plane for proposed theory is located at the bottom of the culvert.

For hand calculations the five points O-S on Fig. 71. adequately define the pressure distribution.

As mentioned in the analysis section, the soil above the culvert acts as a surcharge according to at-rest soil mechanics, and simply adds to the pressures calculated in the arching zone. The surcharge term in Eq. 49 applies only to surcharges that are in contact with the culvert wall. In other words, the term only applies to zones of soil that share a common fixed boundary with the arching zone.

The at-rest lateral earth pressure coefficient, from Eq. 51, is:

$$1 - \sin(32^{o}) = 0.47$$

The horizontal surcharge pressure on the entire side of the culvert due to the fill material above the culvert, from Eq. 58, is:

$$(0.47)(120 \text{ pcf})(2 \text{ ft}) = 113 \text{ psf}$$

From the previous example problem, the horizontal pressures without the surcharge at points O-S are:

Point	Horizontal Pressure without Surcharge, psf
O	0
P	95
Q	164
R	167
S	0

Therefore, the total horizontal dead load pressure at point P is:

$$113 \text{ psf} + 95 \text{ psf} = 208 \text{ psf}$$

The total horizontal dead load pressures for all of the points are summarized below and are shown in Fig. 72.

Point	Horizontal Dead Load Pressure, psf
O	113
P	208
Q	277
R	280
S	113

5.5 Summary of Examples

From the preceding example problems, several summary diagrams can be developed.

1. The result of combining the vertical and horizontal live load pressures shown in Figs. 62 and 66 is shown in Fig. 73.

2. The result of combining the vertical and horizontal dead load pressures shown in Figs. 67 and 68 is shown in Fig. 74.

3. The result of combining the vertical and horizontal dead load pressures shown in Figs. 67 and 72 is shown in Fig.

75.

4. The result of combining the live and dead load pressures shown in Figs. 73 and 74 is shown in Fig. 76, which can be directly compared to the corresponding pressure distributions of the AASHTO method presented in Fig. 58.

5. The result of combining the live and dead load pressures shown in Figs. 73 and 75 is shown in Fig. 77, which can also be compared to the corresponding pressure distributions of the AASHTO method presented in Fig. 58.

Chapter 6

STRAIN GAGE DATA REDUCTION AND ANALYSIS

The resistance strain gages mounted on the reinforcing steel were secondary instrumentation. The measured earth pressures were of primary interest. Strain gages were included because of the possibility that the strain gage data might provide some qualitative confirmation of the measured pressures, and because the cost of the additional instrumentation was low.

6.1 Analysis of Strain Gage Data--Dead Loads

The data obtained at constant fill height were tested to determine whether thermal effects were significant. The raw and reduced data used in this analysis are summarized in Table 9. For the eight data points taken at 8 in. cover during the period April 1983 through June 1983, a best straight line fit to temperature was determined, and correlation coefficients were calculated for each strain gage. Figs. 79 through 83 show this data set plotted versus temperature. Gages 1 and 6 exhibit a temperature-dependent output, but there was no significant correlation of output at constant cover to temperature for gages 2 through 4. Gage 2, however, did exhibit a significant time-dependent output, indicating that there were probably some instrumentation problems with gage 2. A possible explanation of this thermal sensitivity is damaged or inadequate moisture protection of the gage or leadwires, which resulted in a zero offset caused by corrosion-induced resistance changes. Figs. 84 through 88 show the corrected strains plotted versus time, from which the increasing offset of gage 2 is apparent. The linear correction shown in Fig. 85 was applied to all data from gage 2. Between August 1983 and June 1984, gage 2 experienced a large zero shift, during which time the cover was being increased. The change in the zero was considerably larger than any change experienced by gages 1, 3 and 4, which should have responded identically. This change in the zero offset of gage 2 is thought to result from a significant attack by corrosion. Data from gage 2 are not credible after August 1983, and data from this gage before this time are perhaps less credible than that from the other gages.

The observed zero shift with time of gage 2 is indicative of instrumentation problems. Since there are three other gages sensing steel strains in the tension steel at the end of the top slab, the data from gage 2 are not critical, and could be ignored. It is worthwhile to note that the gage 2 strains, corrected for the observed drift at 8 in. cover, agree relatively well with the strains from gages 1, 3 and 4 prior to the relatively sudden and large shift in zero of gage 2 after August 1983. It is thought that the corrected gage 2 data taken prior to August 1983 are accurate. The temperature induced offset observed in gage 6 and the less significant temperature induced offset observed in gage 1 may or may not be indicative of instrumentation problems with these two gages. Since gage 1 is in good agreement with gages 2, 3 and 4 after correction for the observed temperature-induced zero offset, the thermal sensitivity of gage 1 is thought to result from temperature-dependent lead wire resistances not fully compensated by the three lead wire arrangement, which ordinarily serves to compensate for such

TABLE 9. Dead Load Strain Gage Data

DATE	TIME	TEMP		FILL	GAGE 1				GAGE 2				GAGE 3				GAGE 4				GAGE 6			
	MO.	(12)			RAW	RED.	FIT	CORR.	RAW	RED.	FIT	CORR.	RAW	RED.	FIT	CORR.	RAW	RED.	FIT	CORR.	RAW	RED.	FIT	COR.
25-Aug-82	0.0 *	80	80	-9	-976	0	54	-58	-449	0	71	-81	-715	0		-81	-2260	0		-89	-2224	0	-17	23
21-Sep-82	0.9	80	75	-9	-960	16	54	-42	-423	26	83	-66	-708	7		-74	-2230	30		-59	-2201	23	-17	46
14-Jan-83	4.7 *	51	51	-5	-929	47	121	-78	-349	100	133	-43	-694	21		-60	-2175	85		-4	-2165	59	131	-66
27-Jan-83	5.1	50	51	-5	-900	76	124	-51	-304	145	139	-4	-664	51		-30	-2141	119		30	-2131	93	137	-37
14-Apr-83	7.6	61	63	0.7	-874	102	98	0	-266	183	173	0	-634	81		0	-2171	89		0	-2150	74	80	0
19-Apr-83	7.8	63	65	0.7	-884	92	93	-5	-270	179	175	-6	-640	75		-6	-2126	134		45	-2155	69	70	5
03-May-83	8.3	69	69	0.7	-894	82	80	-2	-282	167	182	-24	-652	63		-18	-2136	124		35	-2184	40	39	7
05-May-83	8.3	68	69	0.7	-892	84	82	-2	-282	167	182	-25	-654	61		-20	-2142	118		29	-2182	42	44	4
17-May-83	8.7	68	72	0.7	-890	86	82	0	-246	203	188	5	-634	81		0	-2120	140		51	-2172	52	44	14
02-Jun-83	9.2	70	76	0.7	-910	66	77	-15	-250	199	195	-6	-690	25		-56	-2142	118		29	-2187	37	34	9
22-Jun-83	9.9	80	79	0.7	-928	48	54	-10	-262	187	204	-26	-688	27		-54	-2162	98		9	-2246	-22	-17	1
30-Jun-83	10.2	83	81	0.7	-921	55	47	4	-228	221	207	4	-684	31		-50	-2151	109		20	-2385	-161	-33	-122
28-Jul-83	11.1	83	82	2	-1044	-68	47	-119	-212	237	219	8	-700	15		-66	-2170	90		1	-2209	15	-33	54
10-Aug-83	11.5	79	81	4	-917	59	57	-1	-174	275	225	40	-687	28		-53	-2140	120		31	-2148	76	-12	94
14-Jun-84	21.7	74	78	4	-910	66	68	-6	-1488	-1039	362	-1411	-674	41		-40	-2103	157		68	-2090	134	13	127
13-Jul-84	22.6	82	82	6	-896	80	50	27	-1490	-1041	374	-1425	-651	64		-17	-2083	177		88	-2085	139	-28	173
12-Sep-84	24.6	81	77	8	-902	74	52	18	-1345	-896	401	-1307	-661	54		-27	-2004	256		167	-2033	191	-23	220
14-Sep-84	24.7	81	76	8	-900	76	52	20	-1356	-907	402	-1319	-663	52		-29	-2005	255		166	-2015	209	-23	238
14-Sep-84	24.7	81	76	8	-889	87	52	31	-1346	-897	402	-1309	-647	68		-13	-2085	175		86	-2010	214	-23	243
18-Sep-84	24.8	77	75	8	-852	124	61	59	-1191	-742	404	-1156	-611	104		23	-2054	206		117	-1970	254	-2	262
03-Dec-84	27.3	55	57	8					-962	-513	438	-960	-604	111		30	-2048	212		123	-1945	279	111	174

* = TEMP NOT AVAIL.

errors. Unfortunately, since gage 5 was irreparably damaged during the concrete placement operation at the time of construction, there is no back-up data to allow a corresponding verification of gage 6. While the cause of the temperature induced offset of gage 6 cannot therefore be positively attributed to either instrumentation errors, thermally induced stresses in the culvert or some combination of both factors, the following observations are offered:

1. The direction of the indicated strain change with temperature for both gages 2 and 6 is consistent with the expected stresses resulting from thermal expansion and contraction of the culvert against an earth reaction.

2. The magnitude of the indicated strain change with temperature for gage 6 is roughly equal to that strain corresponding to the stresses resulting from thermal expansion of the culvert against an earth reaction. Assuming a coefficient of linear expansion of 10 micro in./in. per degree Fahrenheit and a rigid earth reaction, a 20 degree temperature increase would result in an indicated compressive strain of approximately 200 micro in./in. Any flexibility in the earth reaction will result in a smaller indicated compressive strain. The indicated strain change corresponding to a 20 degree temperature increase as shown in the correction curve in Fig. 83 is approximately 125 micro in./in., compression, which is not inconsistent with expected earth reaction stiffness.

The reinforcing steel stresses, corrected for any observed temperature-induced offset and any observed time-dependent drift, are plotted versus cover depth in Figs. 89 through 93. From these figures, the following observations are made:

1. The stresses at each of the gages tend to remain constant, or vary only slightly as the fill is increased, until the fill reaches the top slab (0 ft on Figs. 89 through 93). This is consistent with the expected top slab thrust and moment, which are expected to be small during backfilling operations.

2. The stresses at each of the gages tend to increase approximately proportionally to cover over the top slab, after the fill reaches the top slab. This is interpreted as the total flexure stress less thrust stress caused by the cover.

3. The maximum stresses in the tension steel at gage locations 1 through 4, ie. in the top steel layer at the ends of the top slab, are significantly less than the maximum stress at gage 6, ie. in the bottom steel layer at midspan of the top slab. For a fixed-end beam carrying a uniformly distributed load, the end moments are twice the midspan moments, except for any superimposed thrust which reduces the steel stress equally at each gage. The gross section modulus of the top steel at gage stations 1 through 4 is approximately 15% larger than the gross section modulus of the bottom steel at gage station 6, however.

4. The rate at which the stress at gage 6 increases with cover is approximately 900 psi per foot of cover, corresponding to a strain increase of approximately 30 micro in./in. per foot of cover.

5. The rate at which the stresses at gage stations 1 through 4 increase with cover is smaller and more difficult to estimate. An average value of 250 psi per foot of cover is suggested, corresponding to a strain increase of aapproximately 9 micro in./in. per foot of cover.

6.2 Analysis of Strain Gage Data--Live Loads

The difficulties of obtaining and analyzing live load strain gage data are different from those difficulties encountered during the dead load strain data aquisition and analysis. Thermally induced zero offsets, drift (or increasing zero offset with time), and other similar factors causing long term problems are generally not troublesome, since the live load readings are made by zeroing the instrument before application of a live load and recording the incremental strain caused by the live load application. However, other difficulties were encountered.

Two methods were used to acquire the live load strain gage data. The first method employed a null indicating strain gage indicator, which was used to record the zero offset of each of the five gages while the test vehicle used to apply the live load was distant from the culvert. Then for various live load locations, the incremental indicated strain was recorded for each strain gage in turn. Unfortunately this method apparently introduced measurement errors which are thought to be related to the following factors:

1. The necessity to disconnect and reconnect the leads to each strain gage during the process of measuring at various live load locations probably caused a random error in the indicated strains because of variations in leadwire and connection resistances.
2. The time required to take the measurements probably

resulted in a significant viscoelastic soil response, which could cause significant systematic errors. That is, the longer the vehicle rests above the culvert, the greater the indicated strain, because of the time-dependent, inelastic soil behavior. Therefore, readings which were taken in more rapid sequence may differ from readings which were taken in slower sequence. This viscoelastic, or time-dependent soil response could clearly be seen in the strain readings. The indicated strains generally varied, usually increasing with time, while the live load was maintained. This time-dependent effect was also evident in the culvert top slab displacement which tended to increase similarly, and which was not immediately recovered, but required hours to return to zero after long periods of live load application.

These difficulties resulted in random and systematic errors in the reported data of Figs. 94 through 97, which show measured live load reinforcing steel stresses for a 48 kip tandem centered on the culvert. Because the measured strains become increasingly smaller with increasing earth cover, these errors become more significant as cover increases. Neglecting for a moment these errors, the following general observations are offered:

1. Maximum indicated strains occur when the 48 kip tandem was centered over the culvert centerline.

2. Stresses calculated from the measured strains are small, usually less than 2000 psi, and when the cover is 4 ft or more, usually less than 500 psi.

3. The signal-to-noise ratio decreases as the cover depth increases.

The live load data obtained at 8 ft cover were recorded with a second technique and apparatus, which largely eliminated the error sources discussed above. The strain gage lead wires were connected through a ten channel switch and balance unit to the null balancing strain indicator, which eliminated the necessity to disconnect and reconnect the leads between measurements. Furthermore, the test vehicle was driven across the culvert, along the roadway centerline, at a nearly constant velocity, estimated to be 1 to 4 miles per hour. This loading procedure largely eliminated the observed inelastic effects described above. No attempt was made to determine the effect of vehicle speed on the observed strains, or to duplicate typical vehicular traffic speeds. The test was repeated several times, recording the data from each channel in sequence in a continuous analog fashion using a calibrated strip chart recorder. The strain gage signal conditioning therefore consisted of the bridge completion resistors and balancing potentiometers in the switch and balance unit and in the strain indicator, the amplifier and power supply in the strain indicator, and the amplifier in the strip chart recorder. The combined gain of the system was calibrated using a shunt calibration resistor, which, when shunted across one leg of the bridge, gives a bridge output which can be compared to a calculated bridge output. The gain of the strip chart recorder was adjusted so that the observed shunt calibration output equalled the calculated output. This process calibrates the power supply and all amplifiers in the signal conditioning system described. Fig. 98 shows the resulting data, reduced by reading the maximum indicated strain from the analog recording, calculating the steel stress by multiplying by the modulus of elasticity for the reinforcing steel bar, and plotting this stress as a function of the known axle or tandem weight causing the stress. From Fig. 98 it can be seen that as before, gage 6 is the most highly stressed, indicating a reinforcing steel stress of approximately 5.9 psi per 1000 lb of tandem axle load.

Gages 1 through 4 indicate smaller stresses, averaging approximately 2.6 psi per 1000 lb of tandem axle load.

6.3 Summary of Measured Dead Load and Live Load Stresses

The observed steel stresses caused by the dead and live loads are summarized in the following table:

TABLE 10. Summary of Measured Re-Bar Tensile Stresses

	DL Stress (psi/ft cover)	Thermal Stress (psi/degree F)	LL Stress (psi/1000 lb)
Gages 1-4 (averaged)	250	neg.	2.6
Gage 6	900	-180	5.9

6.4 Comparison of Predicted and Measured Reinforcing Steel Stresses

The predicted reinforcing steel stresses are presented in TTI report 326-2F. These predictions are based on simulations of a two-dimensional model of culvert and soil using the so-called unit strip method of loading simulation. For purposes of comparison to measurements made in this study, the 326-2F predictions are processed as follows: The predicted moments reported in 326-2F Fig. 4-18, are the predicted internal moments for both the soil load only and the soil load in combination with two live loads. These moments are divided by the transformed area section modulus at the tension steel and multiplied by the modular ratio to calculate reinforcing steel stresses. The modular ratio used is 8.05, and the section moduli are calculated from the moments of inertia and distance to the tension steel tabulated in 326-2F Table 3.2 for material types 1 (gage 6 location) and 4 (gages 1-4 locations). The units of the resulting section moduli are converted to $in.^3/in.$, and values used are reported in Table 11.

TABLE 11. Structural Properties Used in SSTIPN Post Processing

	Gross Section	Cracked Section
Strain Gage Stations 1-4 (2.0 in. cover)		
Moment of Inertia ($in.^4/in.$)	30.2	4.56
c_{steel} (in.)	1.31	3.23
S_{steel} ($in.^3/in.$)	23.0	1.41
Strain Gage Station 6 (1.5 in. cover)		
Moment of Inertia ($in.^4/in.$)	29.7	6.30
c_{steel} (in.)	1.51	3.54
S_{steel} ($in.^3/in.$)	19.7	1.78

Notes: Linear strain distribution assumed.
Modular ratio n = 8.05 assumed.

Table 12 shows the steel stresses calculated from the SSTIPN predicted moments, compared with the measured steel stresses.

TABLE 12. Predicted Stresses Compared to Measured Stresses

	Reinforcing Bar Stress (ksi)		
	DL (8 ft cover)	LL (48 k tandem)	TL
Gages 1-4 (average)			
SSTIPN (gross section)	2.0	0.5	2.5
SSTIPN (cracked section)	32.	8.6	40.
Measured	2.0	0.1	2.1
Gage 6			
SSTIPN (gross section)	2.1	1.0	3.1
SSTIPN (cracked section)	20.	9.5	29.
Measured	6.7	0.3	7.3

A study of Table 12 leads to the following observations:

1. In general the predicted stresses using the gross section properties agree more closely with the stresses calculated from the measured reinforcing steel strains.

2. Predicted SSTIPN live load stresses are too high. This is consistent with the observed differences in the distribution of vertical live load soil pressures. SSTIPN uses a strip loading over a user-defined culvert length. If this length is defined on the basis of current AASHTO design procedures, the resulting live load soil pressures on the top slab of the culvert will be conservative, and

higher predicted stresses will result.

3. Predicted SSTIPN dead load stresses are in somewhat better agreement with measured dead load stresses. The predicted top slab mid-span stresses are unconservative. If the joints between top and side slabs were not rigid as is modelled by SSTIPN, the predicted end-span stresses would be reduced, while the predicted low top slab mid-span stresses would be increased. The joints in question include construction joints, which reduce to some unknown extent the rigidity of the joint. Even so, because the reinforced concrete joint is not subject to excessive moments (judged by the low reinforcing steel stresses), this explanation is not thought to be fully responsible for the differences in predicted stresses.

Chapter 7

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

An 8 x 8 x 44 ft reinforced concrete box culvert was built to standard SDHPT specifications. The slab was constructed on a natural deposit of sand; the backfill and embankment soil was a poorly graded clayey sand. Pressure cells were installed on the sides and top of the culvert to measure dead-load earth pressures due to the surrounding soil and live-load earth pressures caused by a 48 kip tandem, the alternate interstate design loading. Electrical resistance strain gages were installed in the roof slab to measure the strains induced at selected points by the various loads.

Tests were conducted at fill depths of 8 in. and 2, 4, 6, and 8 ft above the top of the culvert. At each fill depth a series of measurements was made with the live load placed at various distances left and right of the transverse centerline of the culvert. The individual pressure cell temperatures were recorded each time the cells were read for the purpose of correcting the data for temperature-induced errors. Deflection of the culvert at the center of the roof slab was measured periodically during every test.

The pressure cell data was used to develop a set of empirical equations for determining various pressures which affect performance of the culvert, and which are needed to properly design the structure. The independent variables in the equations are the depth of fill, wheel load (force units), and distance from the wheel to the point at which the pressure is desired. The empirical equations for vertical pressure were used to develop a simplified design procedure which involves the determination of an "equivalent pressure distribution" and the corresponding area over which the equivalent pressure is applied, such that the simplified procedure yields similar results as would be obtained by the more rigorous empirical equations.

A design example is given wherein first the current AASHTO method for determination of the earth pressures acting on a culvert is presented, followed by an explanation of the new, proposed design procedure based on the empirical equations as well as the simplified methodology. Finally, a comparison of the AASHTO with the proposed method is made.

7.2 Conclusions

Based on the analysis of the data obtained during this study, the following conclusions are drawn:

1. The pressures that were obtained from the field measurements, after corrections for inaccuracies associated with temperature variations and irregularities in soil compaction, are for the most part representative of the true pressures on the structure. Several of the questionable data points were rectified by an averaging

technique or by replacement with data from geometrically equivalent tests.

2. Generally speaking, the proposed method yields pressures and resultants due to the soil dead loads that are comparable to those predicted by the AASHTO method, while the proposed method yields pressure distributions due to wheel loads which will probably result in lower slab and wall moments than those of the AASHTO method. In particular the AASHTO method prescribes a uniform pressure distribution over the side walls which is much more severe than the measured pressures, as reflected by the proposed method.

3. The reinforcing steel strains observed in the test culvert are in qualitative agreement with the measured earth pressures. The reinforcing steel strains are generally low, although the measured dead load strains in the top slab indicate that the AASHTO design dead load pressures may not be conservative.

4. Analysis of the test data resulted in the determination that the soil in the lower portion of the backfill was compacted to a lesser extent than the soil in the upper zone. This led to the development of a soil arching theory to explain the measured horizontal pressure profiles, which in turn led to the development of two design procedures, one for soil with arching, the other for soil without arching. This was a necessary consequence of the data obtained. However, in consideration of the practical implications of the design process, it was concluded that the soil with arching procedure be disregarded for design. In order for the soil without arching theory to be applicable, the necessity for complete and strict adherence to generally accepted soil compaction techniques cannot be

overemphasized. It is important that a uniform, well-compacted backfill and cover be achieved.

7.3 Recommendations

The empirical design equations that were developed for the proposed procedure are general equations, presumably not constrained by culvert dimensions or soil type. The possibility for extension of the equations to conditions different from those encountered in this study is immediately recognized. However, it is recommended that, before any such extension is initiated, the validity of the equations be verified or at least tested by performing additional full-scale tests. The parameters to be investigated should include, but not necessarily be limited to, variations of soil type, culvert geometry (with particular emphasis on the effect of aspect ratio, i.e., the ratio of culvert width to culvert height), and compaction techniques.

Recommendations

The following recommendations for future research are offered:

1. Additional field studies should be performed with culverts identical to the one used in this study with different soil types.
2. A series of tests should be performed with the express purpose of investigating soil arching.

3. The effect of neglecting longitudinal decay of pressure should be investigated.

With respect to implementing results of this research, specific recommendations are as follows:

1. The range of culvert dimensions for which the results are applicable should be studied.

2. The permissible soil types for which the results can be implemented should be studied.

Appendix A

FIGURES

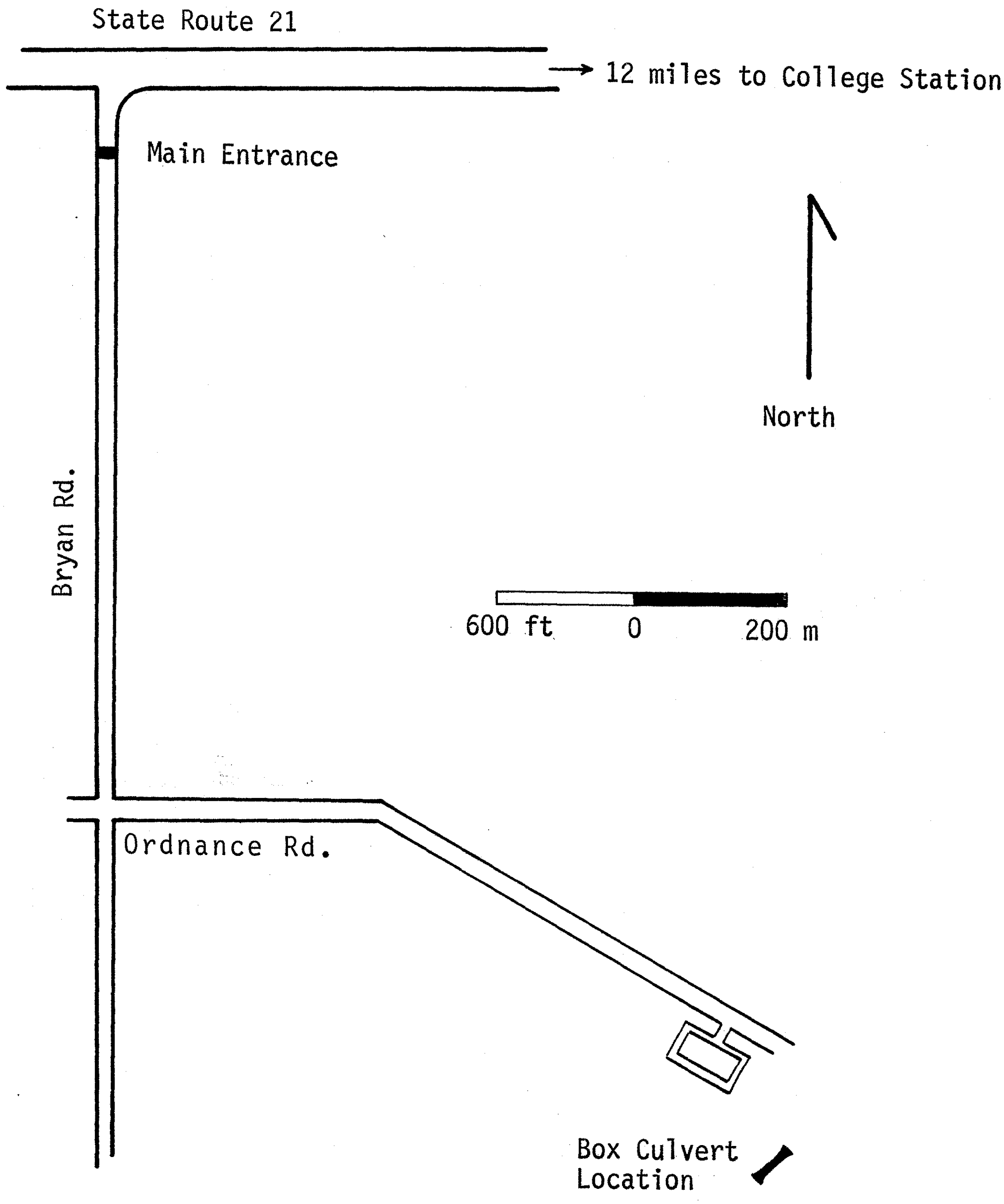


FIG. 1 - Location of the Reinforced Concrete Box Culvert Test Site on the TAMU Research and Extension Center

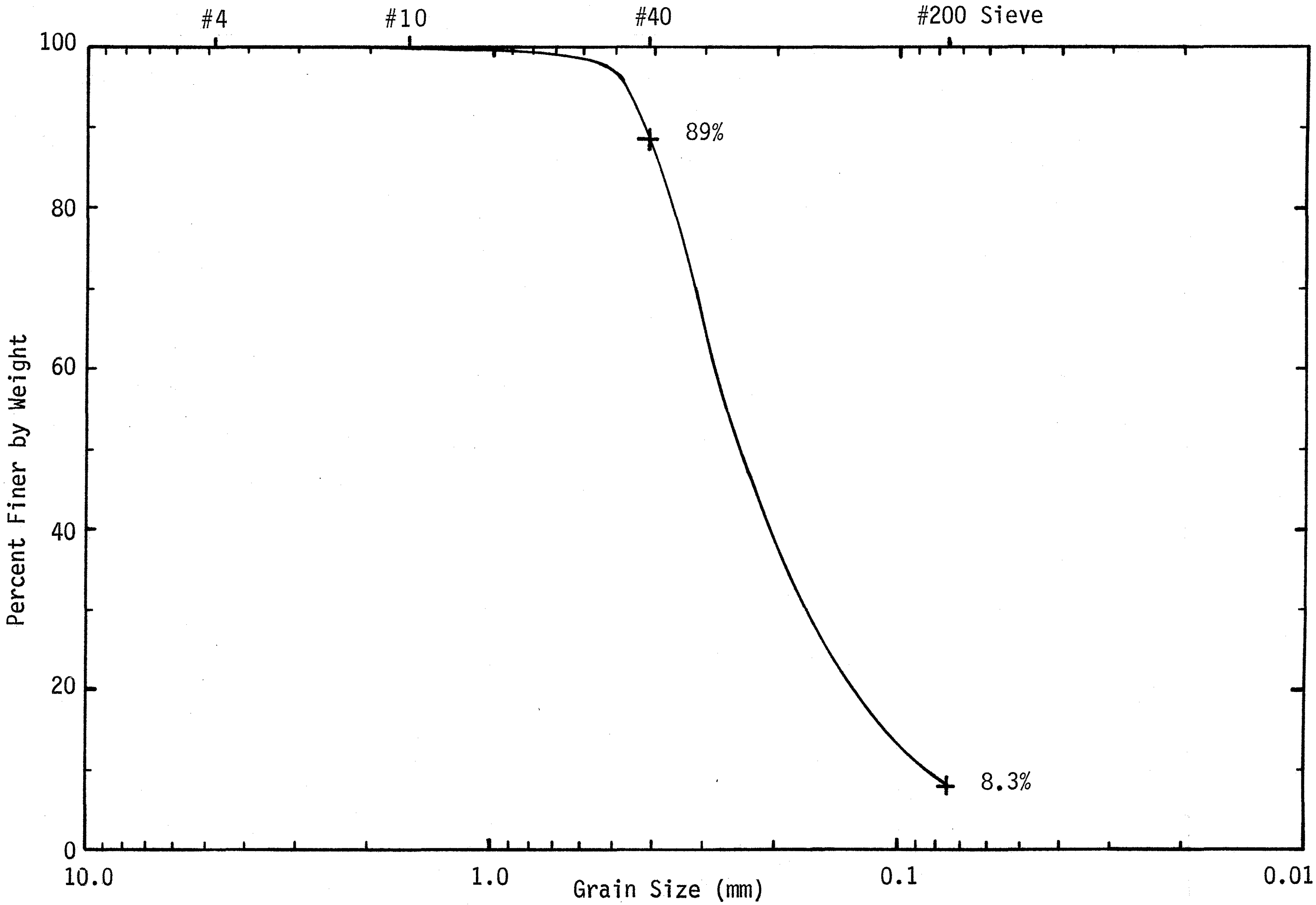


FIG. 2 - Grain Size Curve for Fine, Red, Clayey Sand

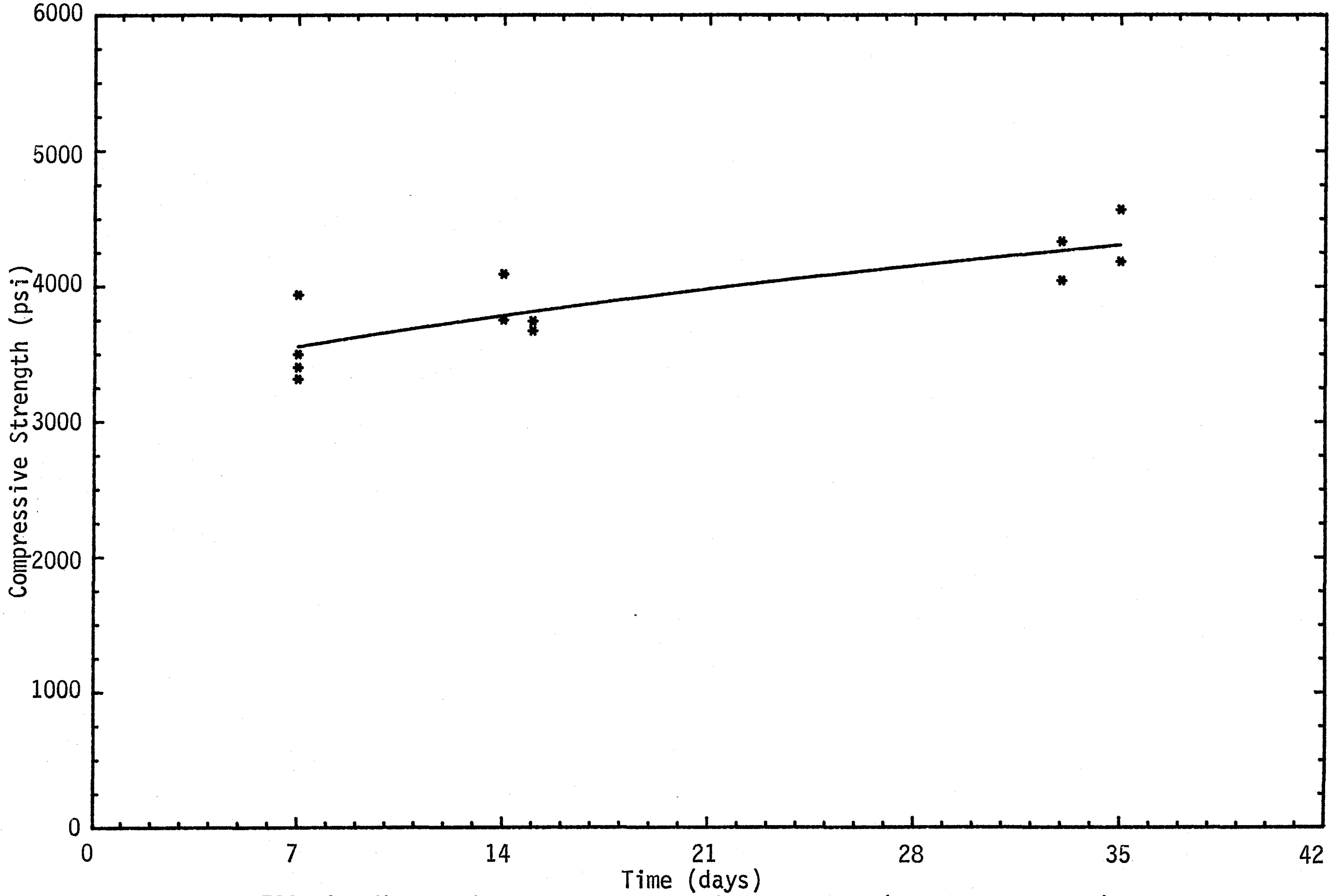


FIG. 3 - Measured Concrete Compressive Strength (1 psi = 6.89 kPa)

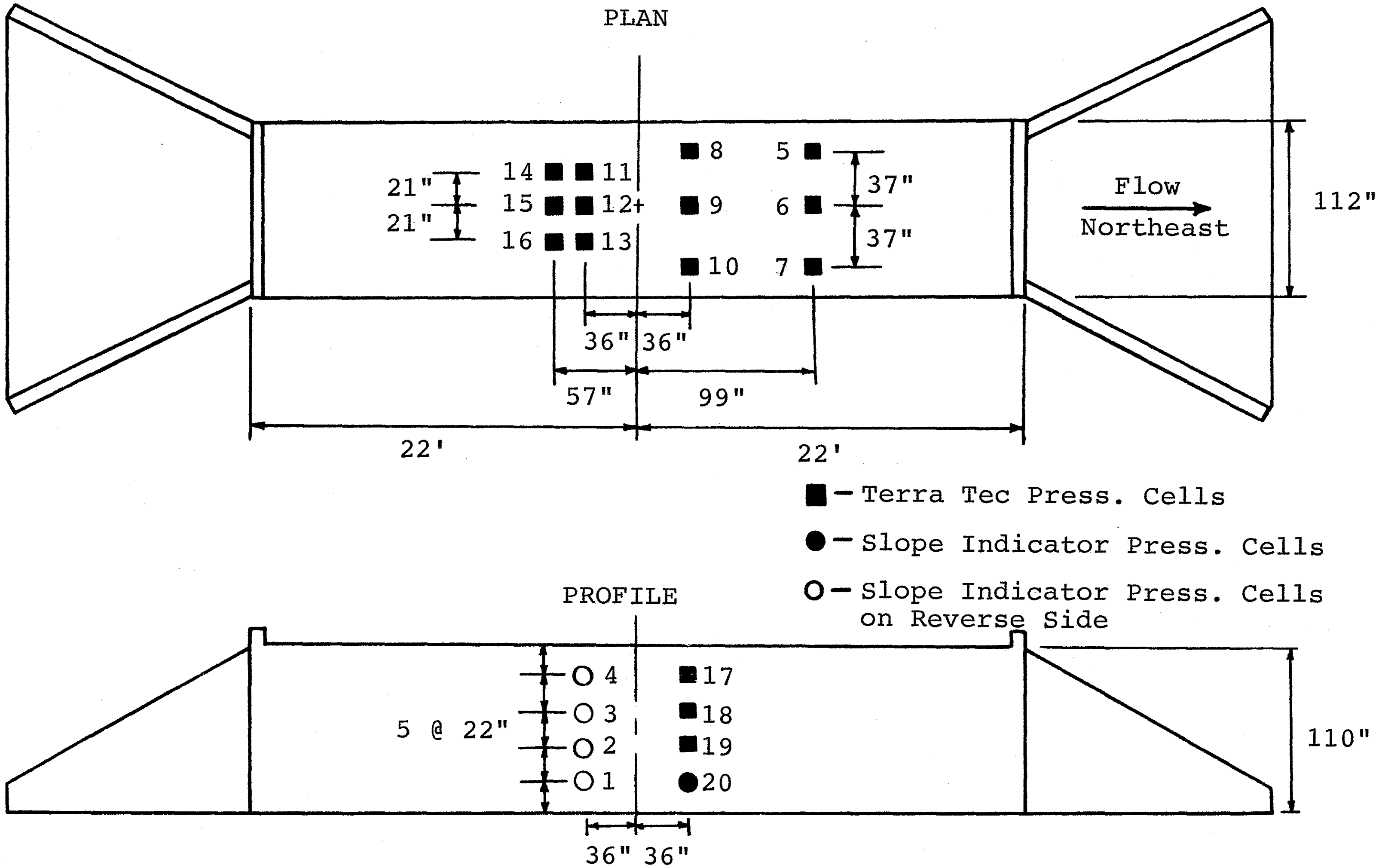


FIG. 4 - Location and Identification of Pressure Cells (1 in. = 2.54 cm, 1 ft = 0.305 m)

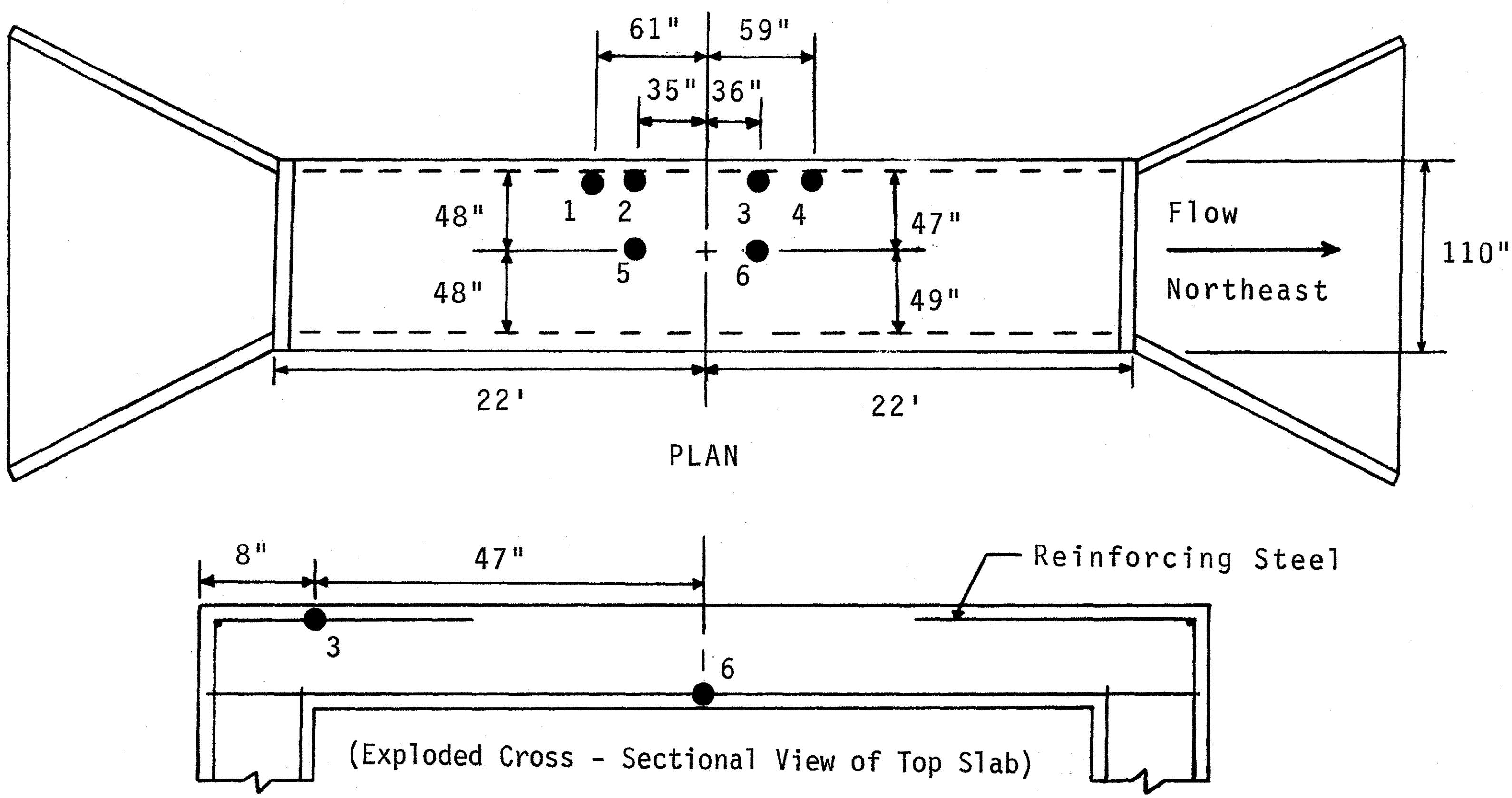


FIG. 5 - Location and Identification of Strain Gages
(1 in. = 2.54 cm, 1 ft = 0.305 m)

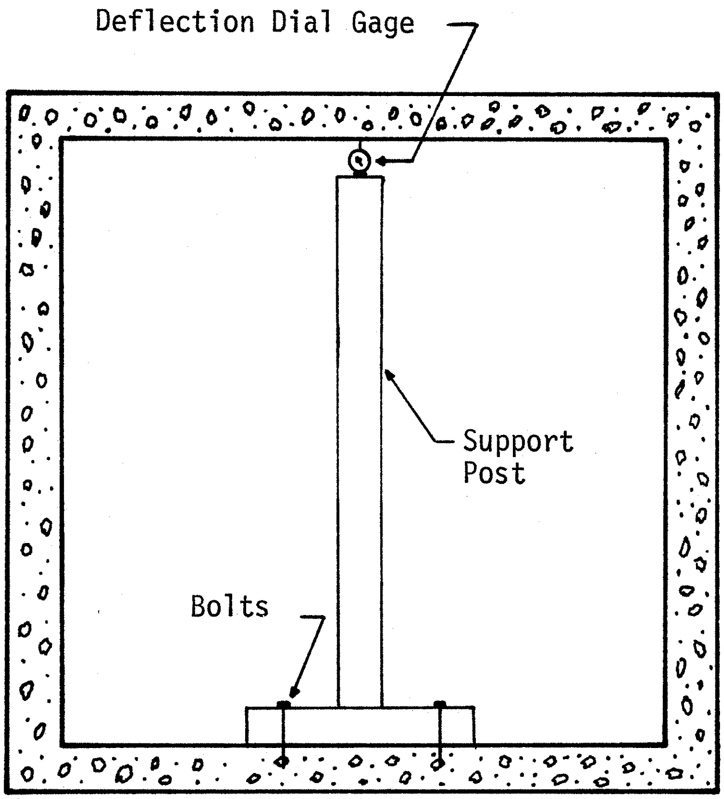
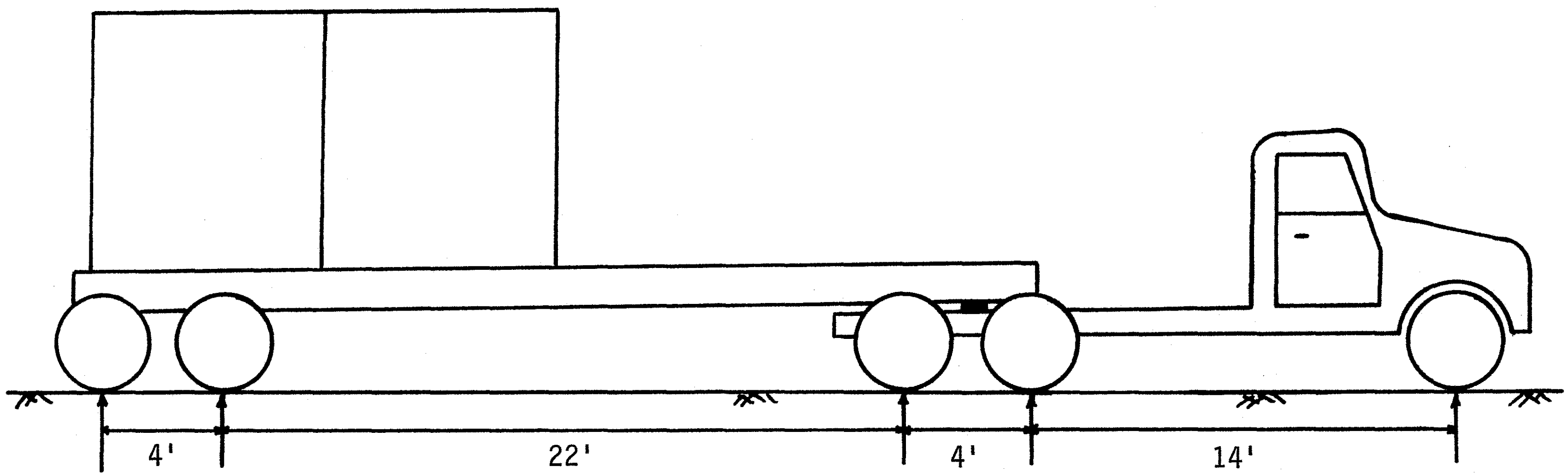


FIG. 6 - Dial Gage Mounting



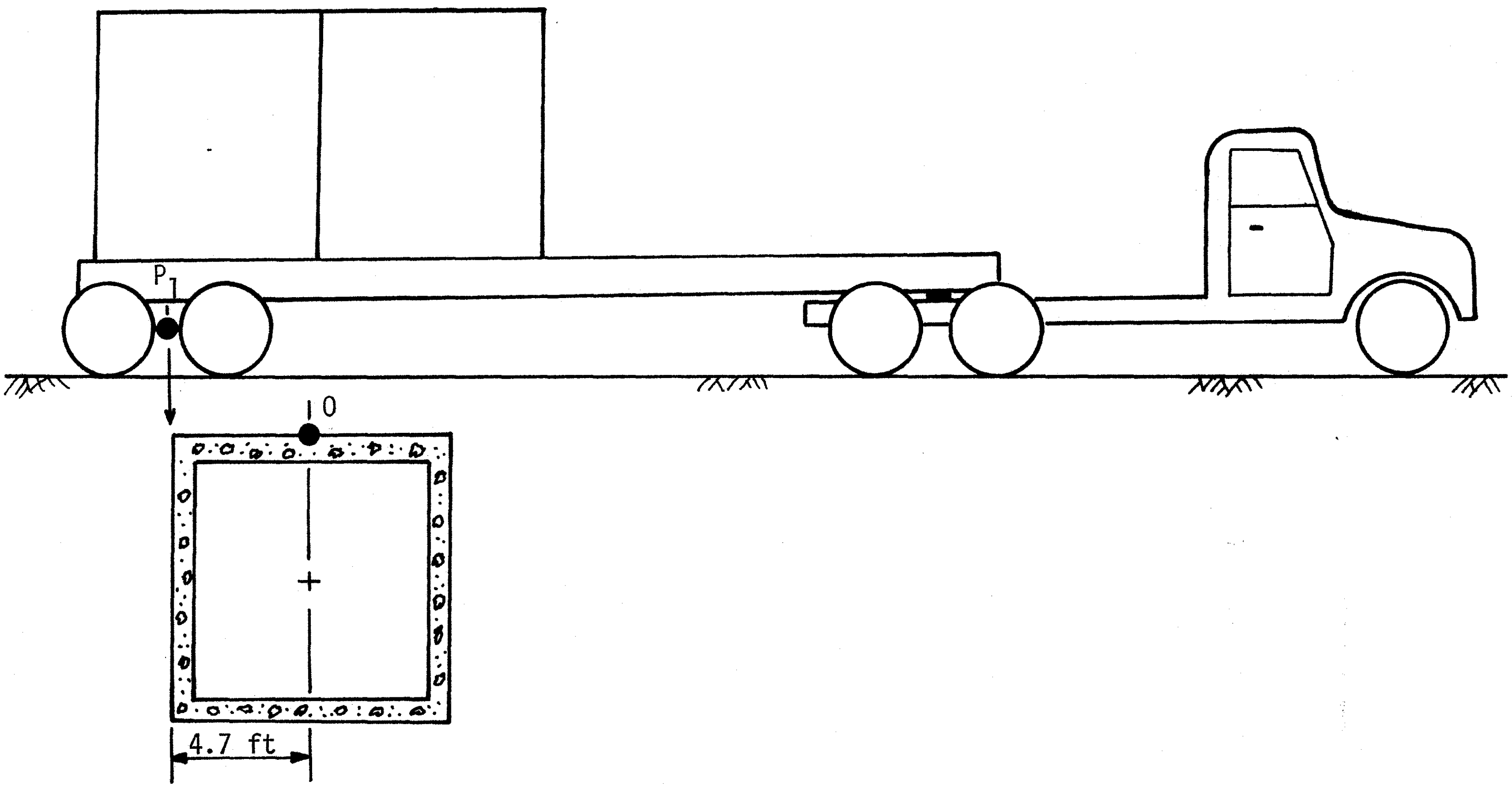
April 1983

Left Side	11,800	11,720	3,810	4,100	4,500
Right Side	12,340	12,770	3,930	4,170	4,500
Total	24,140	24,490	7,740	8,270	9,000

June 1984

Left Side	11,450	11,390	No Data Taken	No Data Taken
Right Side	12,980	12,870		
Total	24,430	24,260		

FIG. 7 - Weight Distribution on Truck (All Weights are in Pounds)
(1 lbf = 4.45 N)



Section Through Culvert Looking Downstream (Northeast)

FIG. 8 - Diagram Illustrating Load Position Notation 4.7 LR (1 ft= 0.305 m)

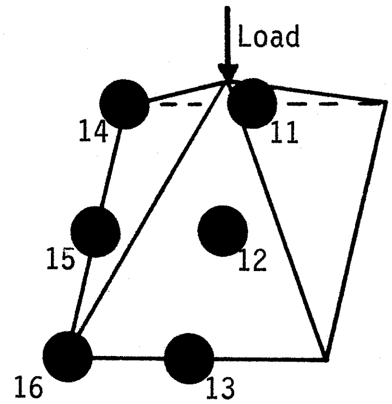


FIG. 9 - Pressure Cells 11-16 Under AASHTO Pyramid

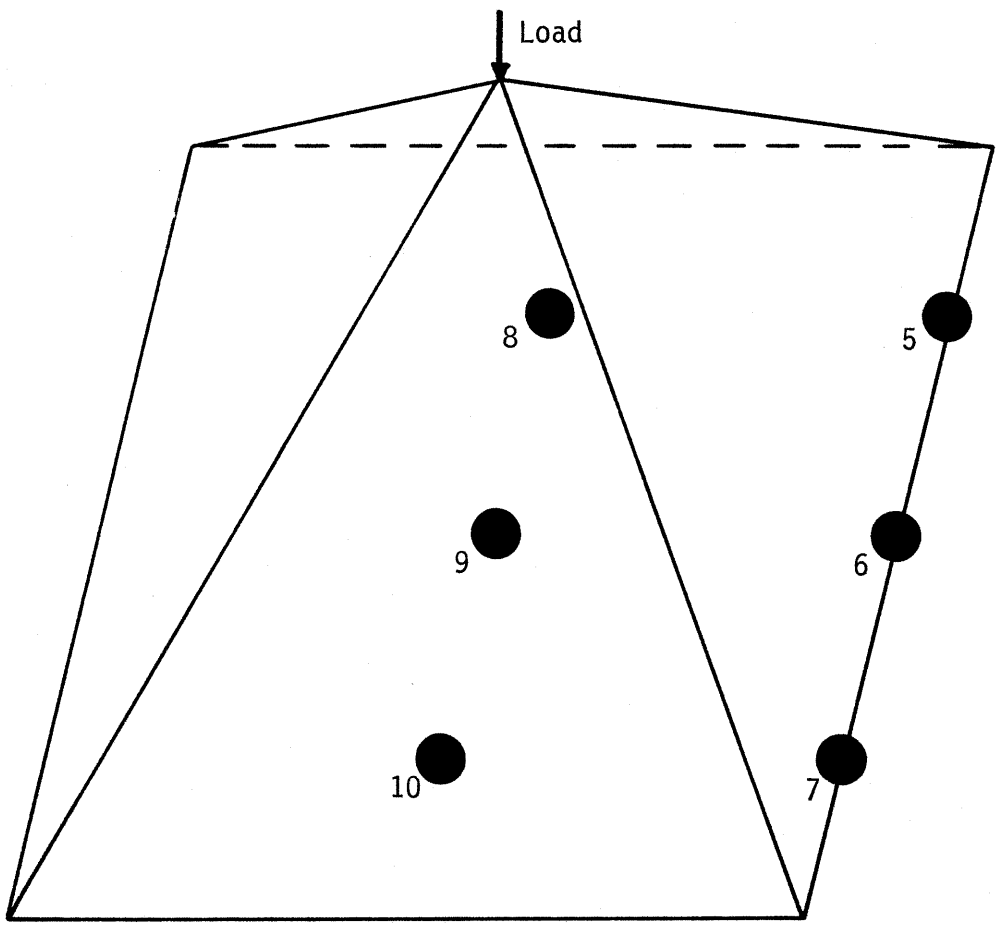


FIG. 10 - Pressure Cells 5-10 Under AASHTO Pyramid

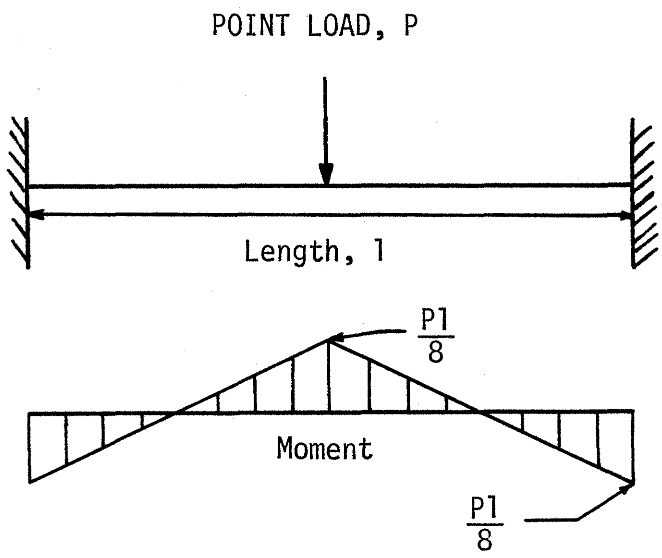


FIG. 11 - Beam Diagrams for Fixed Ended Beam with Point Load

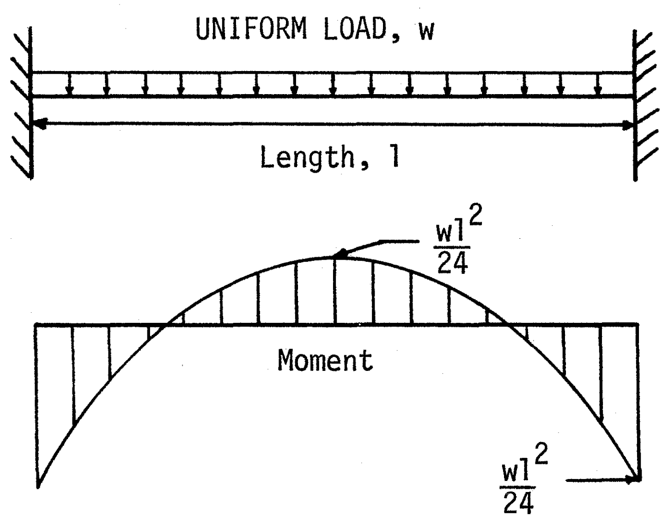


FIG. 12 - Beam Diagrams for Fixed Ended Beam with Uniform Load

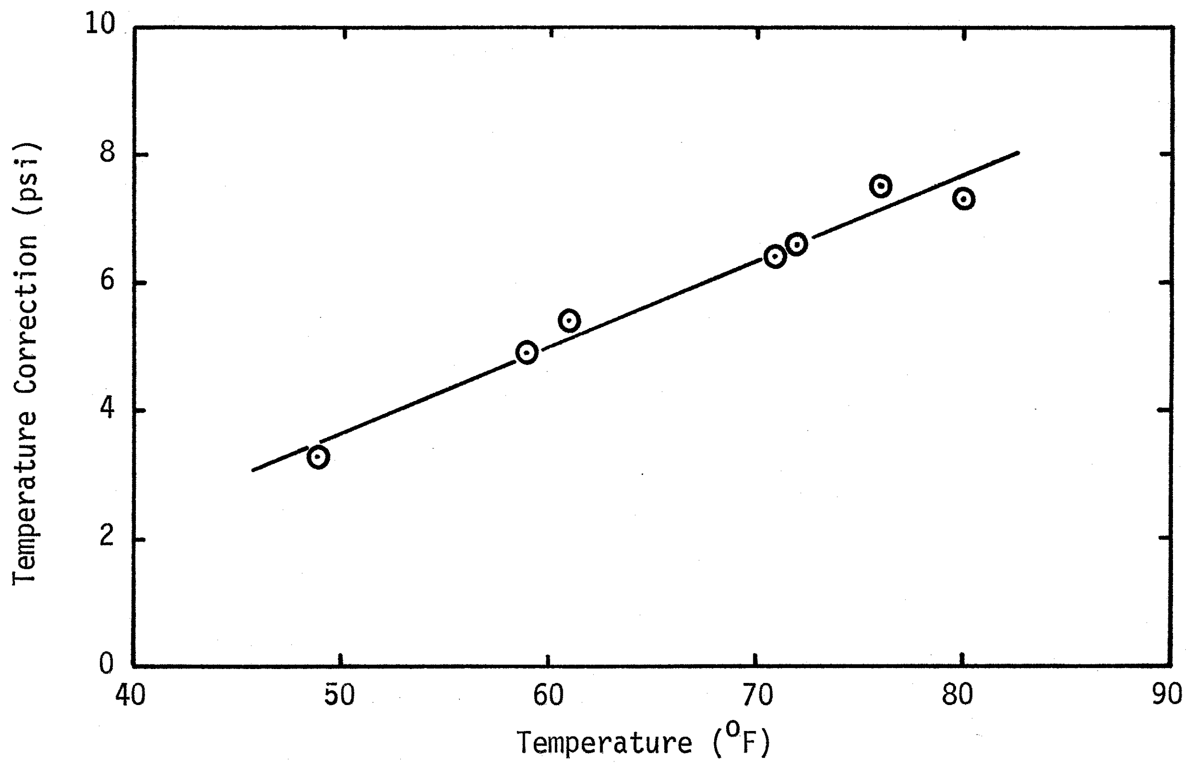


FIG. 13 - Calibration Data and Curve for Pressure Cell 15

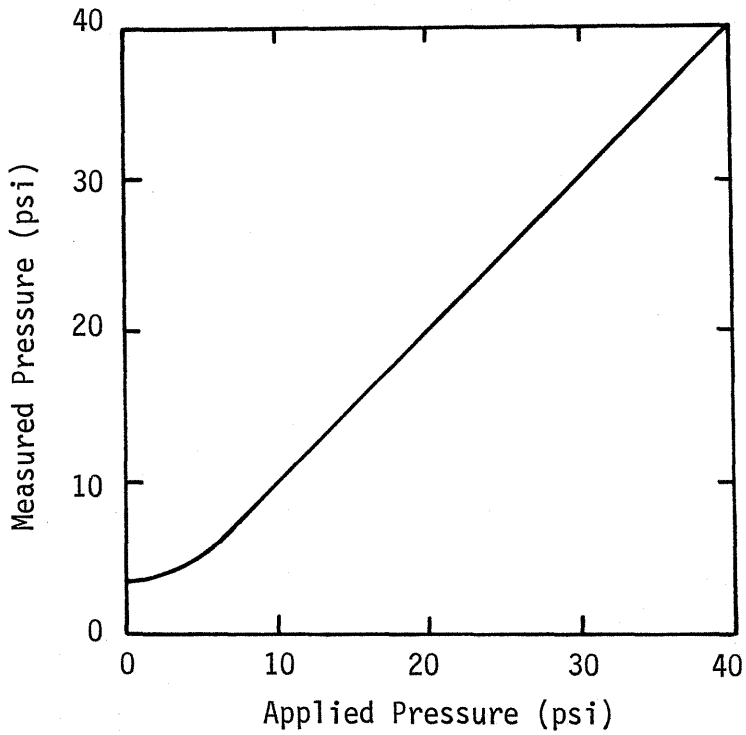


FIG. 14 - Flow Rate Calibration, Flow Rate = 1.0 scfh
(1 scfh = 0.028 m^3/hr, 1 psi = 6.89 kPa)

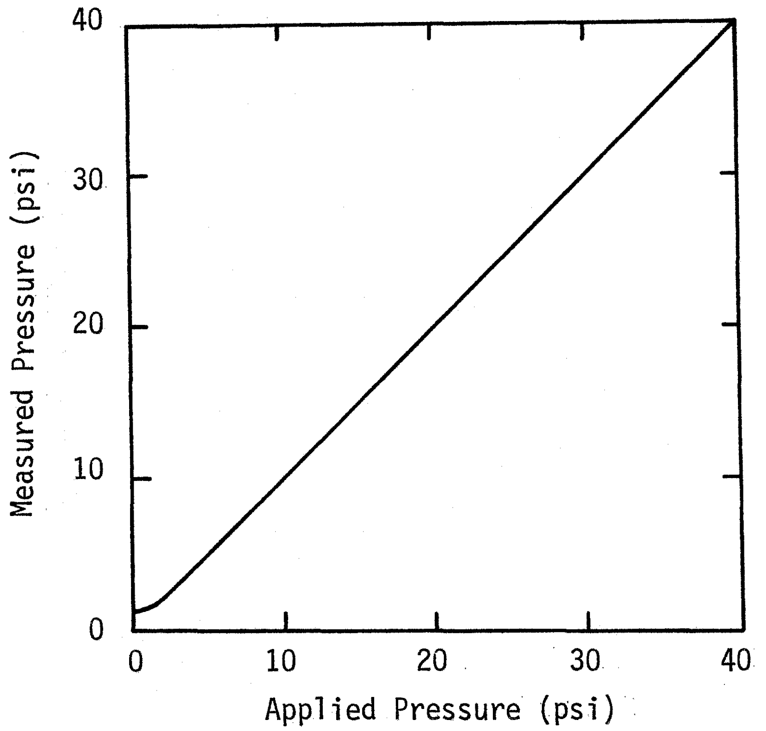


FIG. 15 - Flow Rate Calibration, Flow Rate = 0.6 scfh
(1 scfh = 0.028 m^3/hr, 1 psi = 6.89kPa)

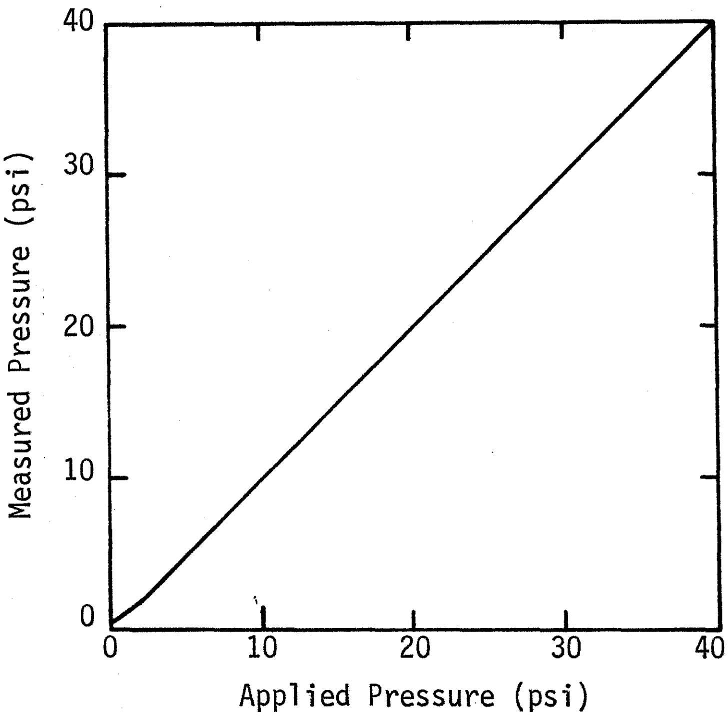


FIG. 16 - Flow Rate Calibration, Flow Rate = 0.2 scfh
(1 scfh = 0.028 m^3/hr, 1 psi = 6.89 kPa)

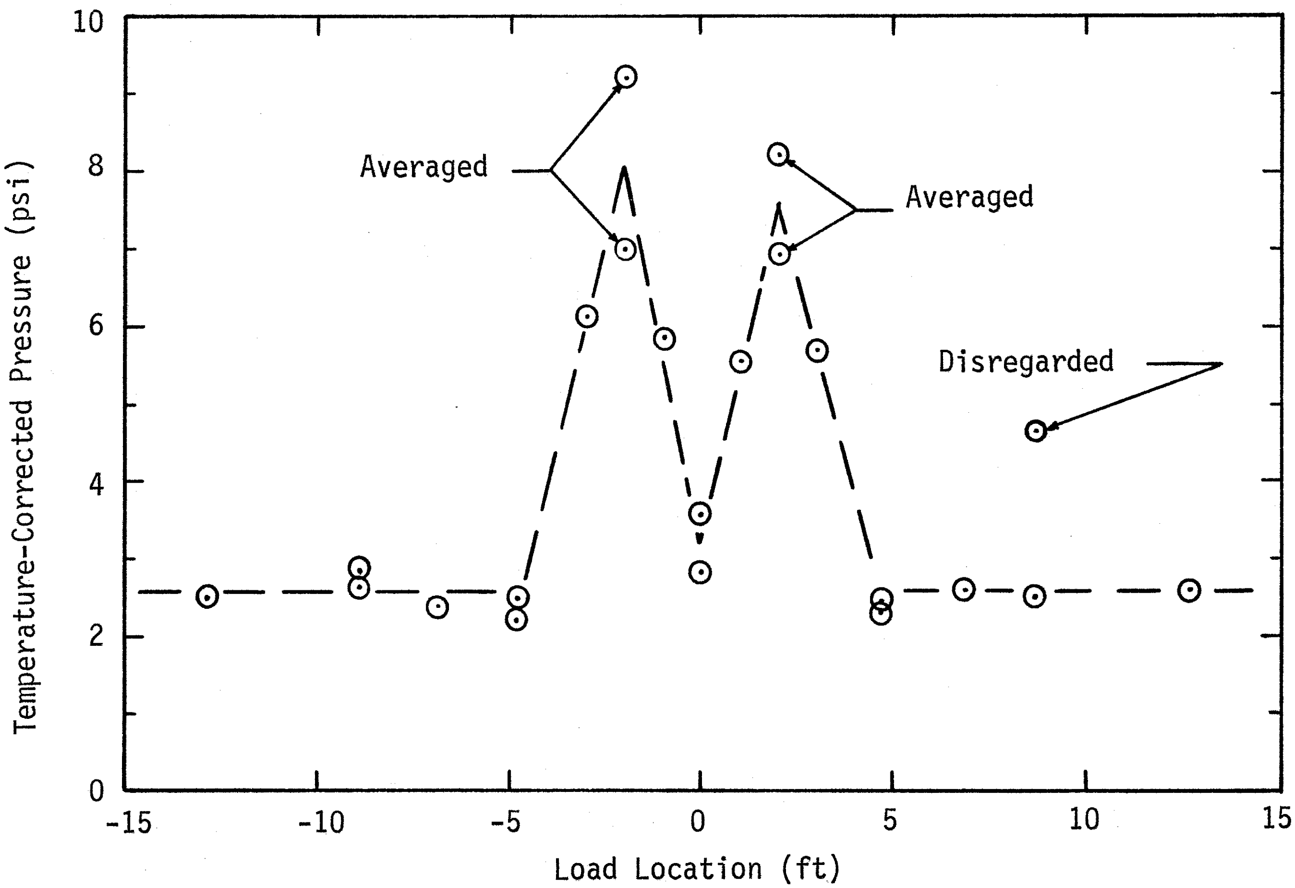


FIG. 17 - Illustrations of Errors in Data, PC 15 at 2 ft of Fill
(1 ft = 0.305 m, 1 psi = 6.89 kPa)

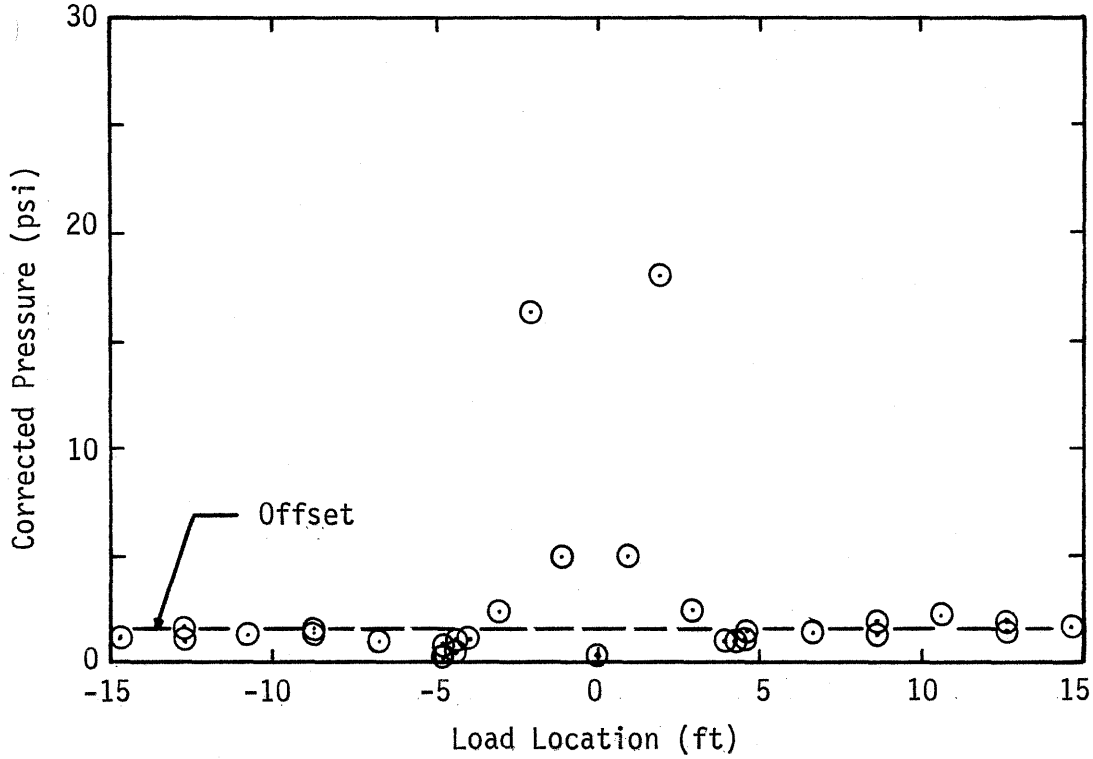


FIG. 18 - Corrected Pressure vs. Load Location for PC 9 at 8 in. of Fill (1 in. = 2.54 cm, 1 ft = 0.305 m, 1 psi = 6.89 kPa)

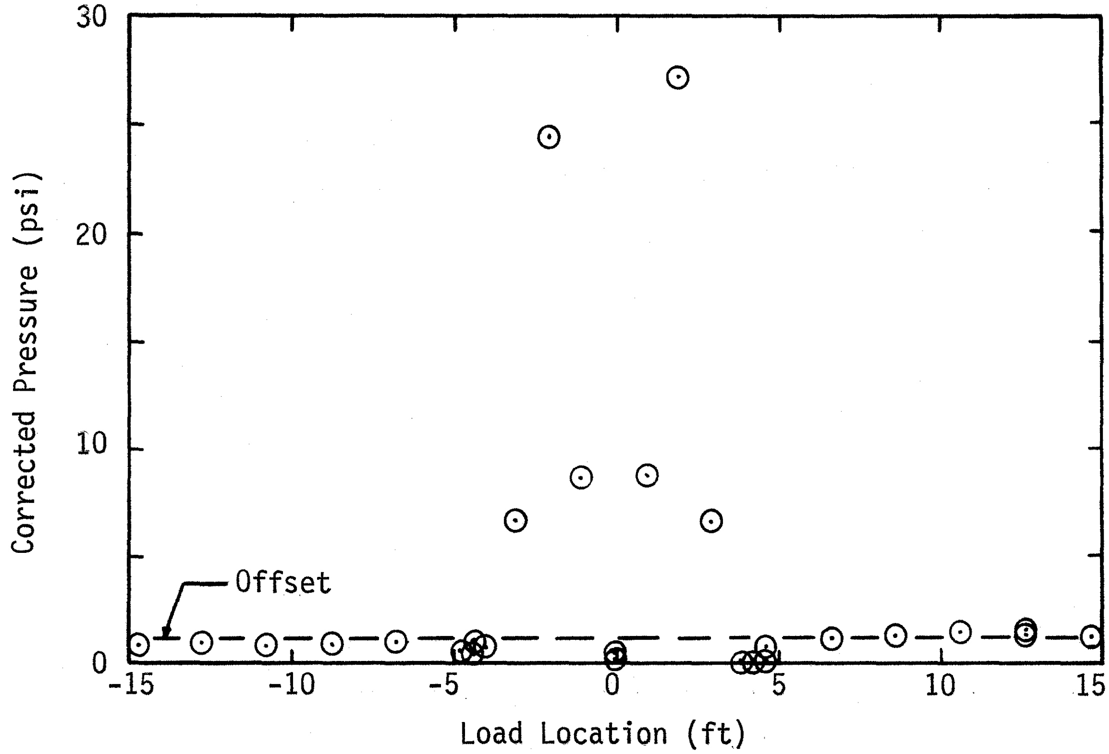


FIG. 19 - Corrected Pressure vs. Load Location for PC 12 at 8 in. of Fill (1 in. = 2.54 cm, 1 ft = 0.305 m, 1 psi = 6.89 kPa)

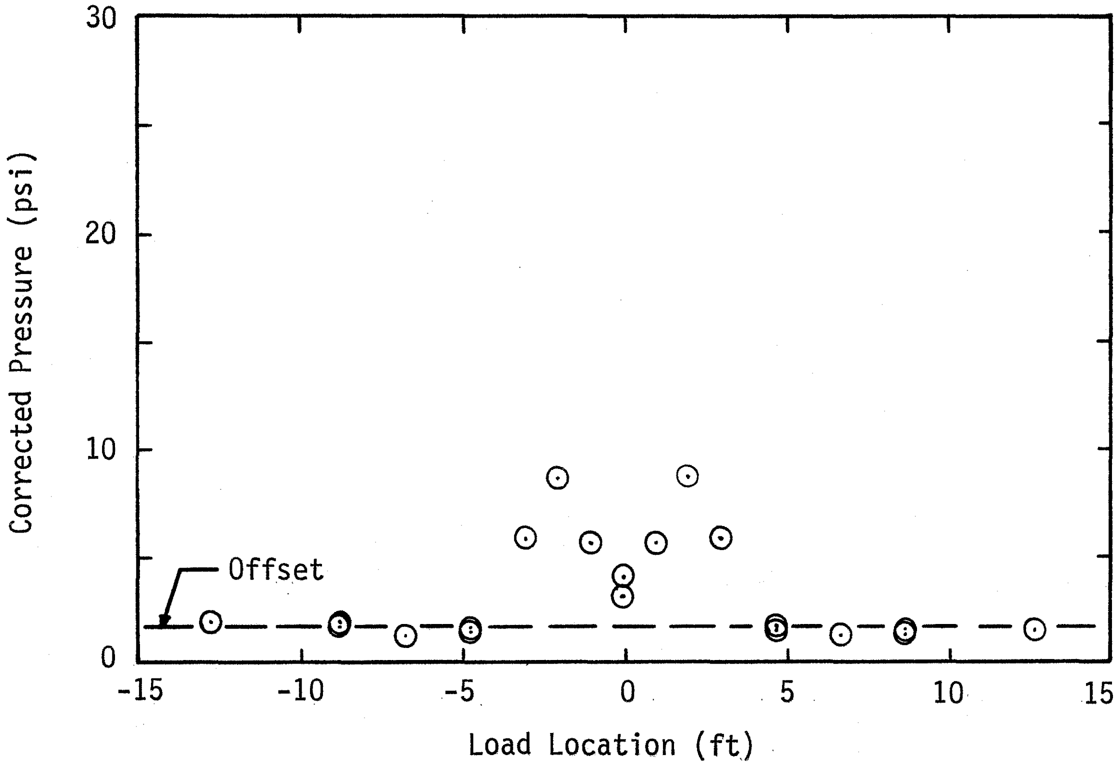


FIG. 20 - Corrected Pressure vs. Load Location for PC 9 at 2 ft of Fill (1 ft = 0.305 m, 1 psi = 6.89 kPa)

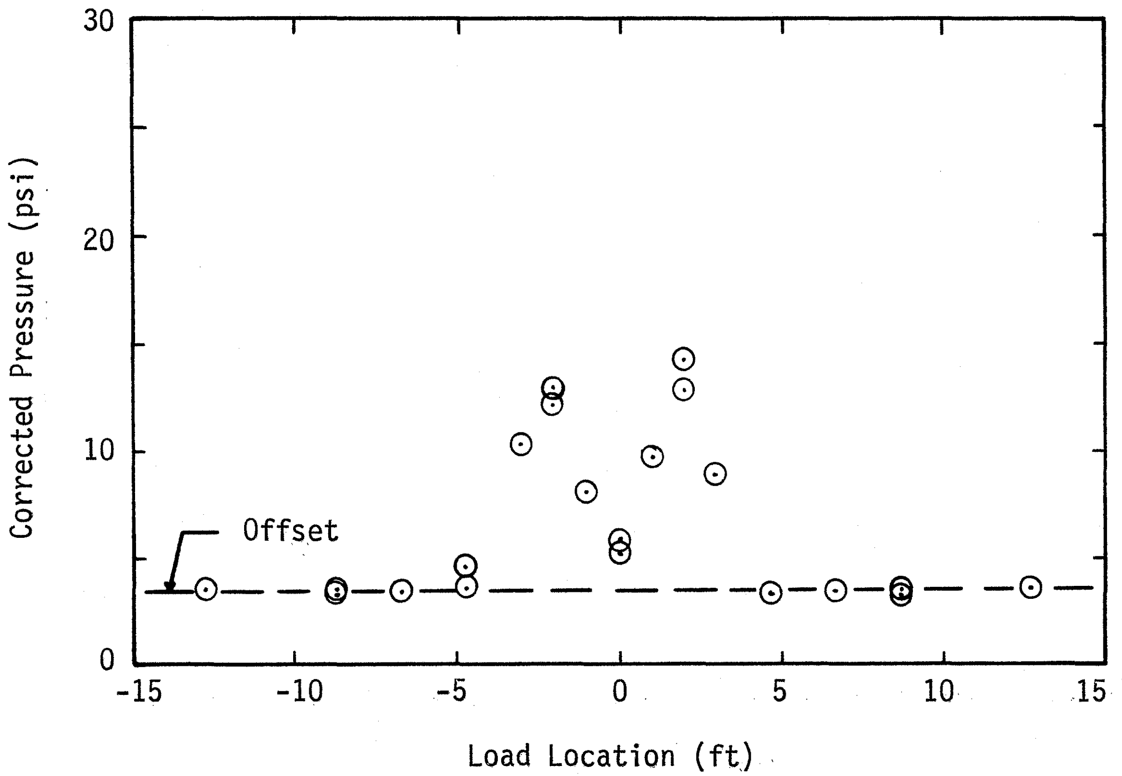


FIG. 21 - Corrected Pressure vs. Load Location for PC 12 at 2 ft of Fill (1 ft = 0.305 m, 1 psi = 6.89 kPa)

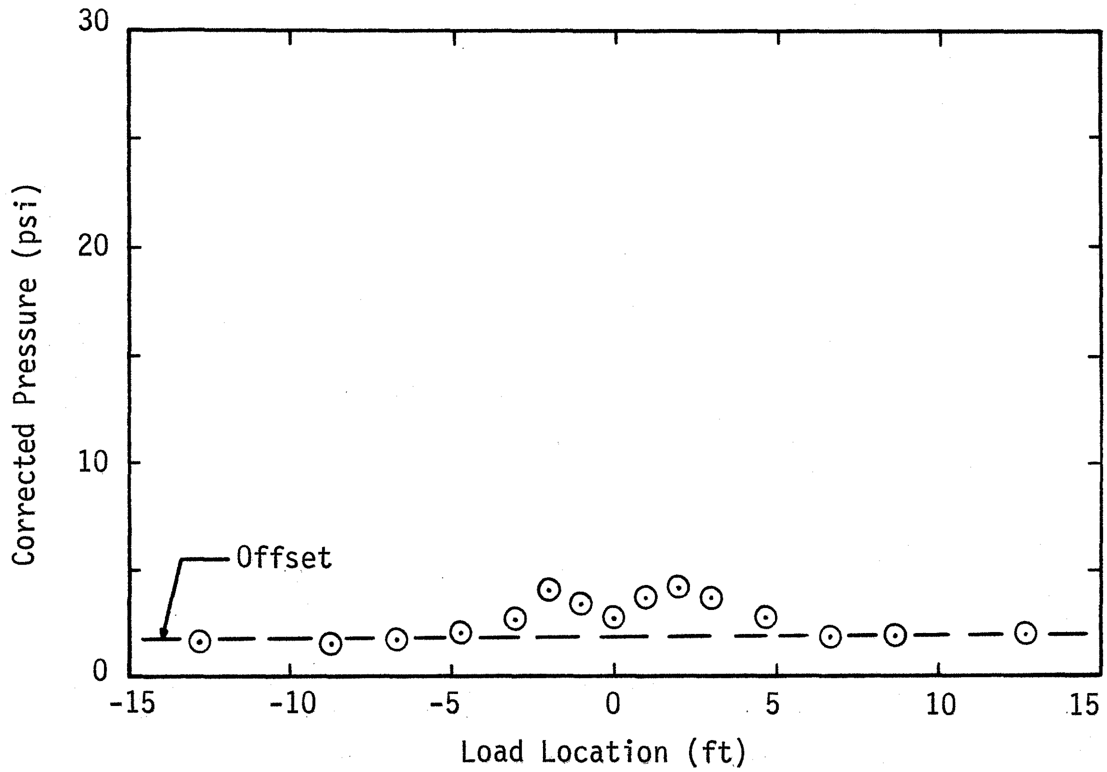


FIG. 22 - Corrected Pressure vs. Load Location for PC 9 at 4 ft of Fill (1 ft = 0.305 m, 1 psi = 6.89 kPa)

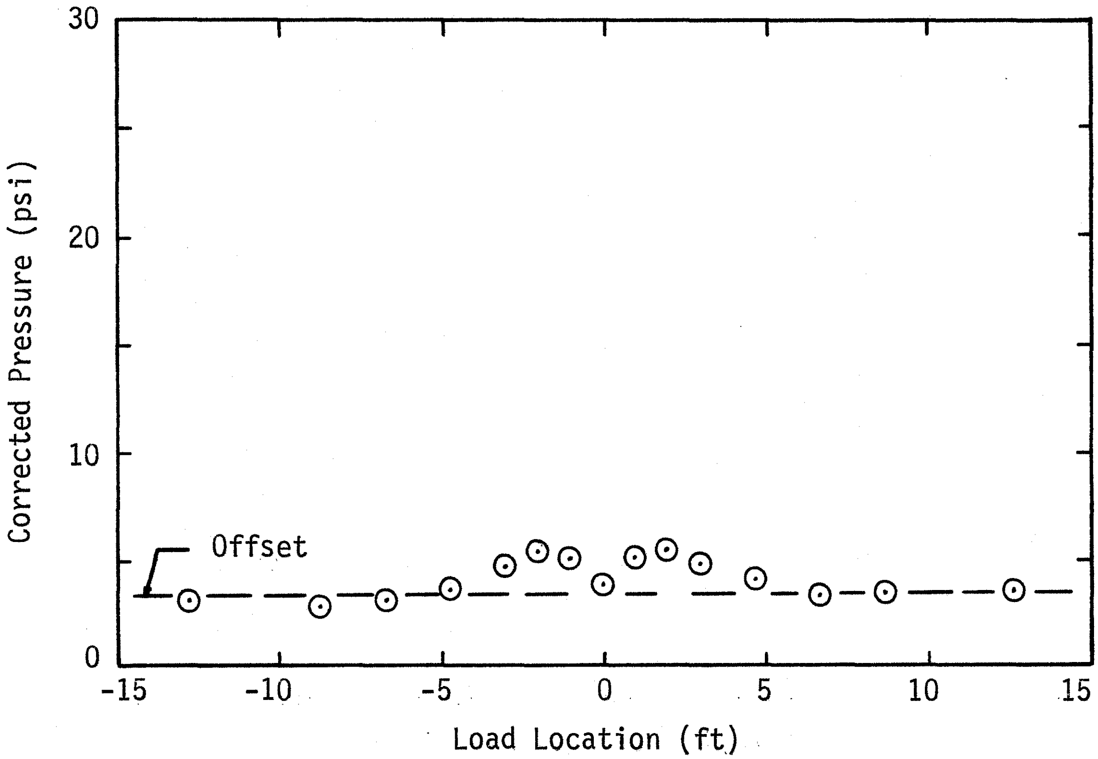


FIG. 23 - Corrected Pressure vs. Load Location for PC 12 at 4 ft of Fill (1 ft = 0.305 m, 1 psi = 6.89 kPa)

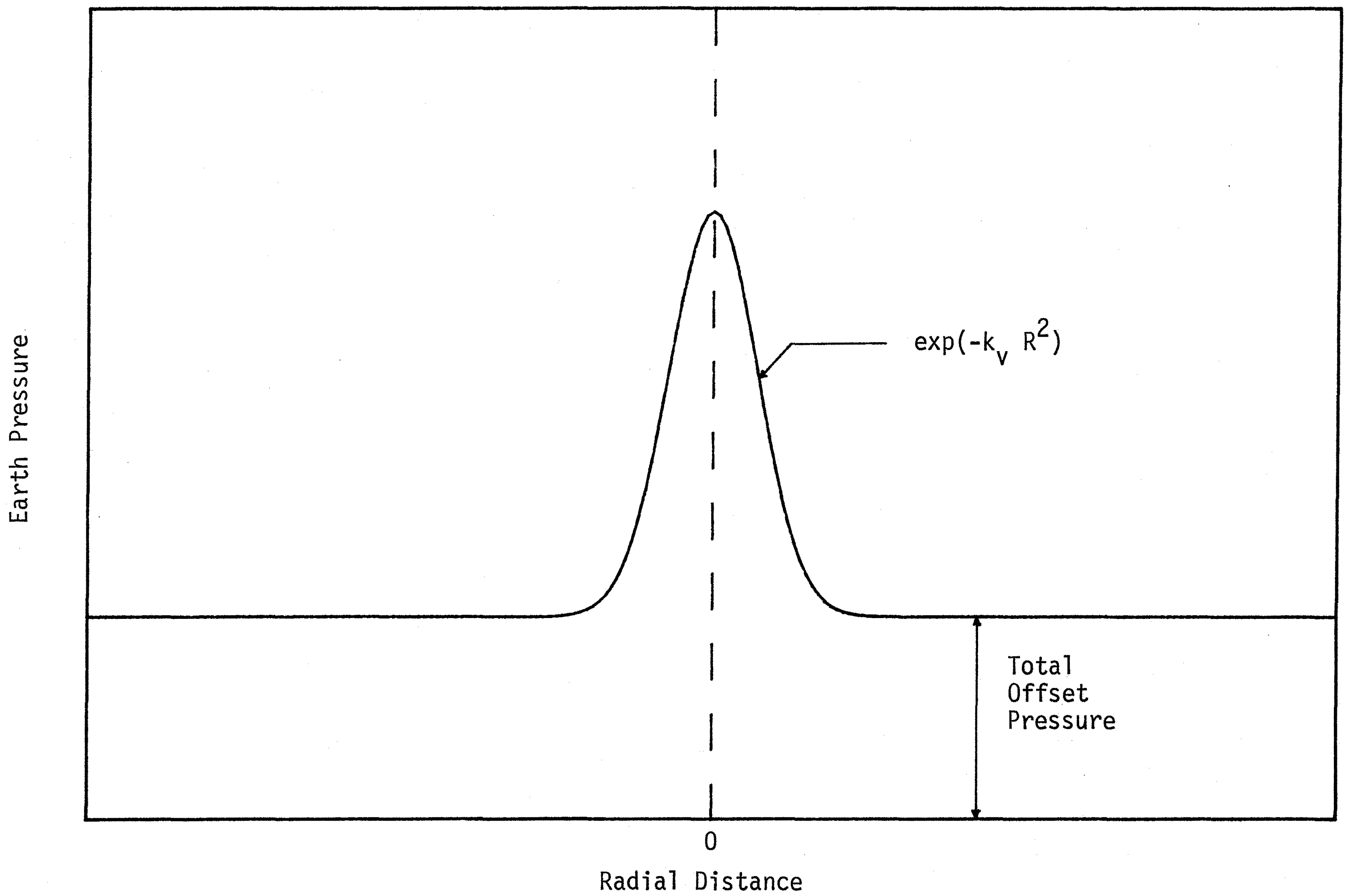


FIG. 24 - Qualitative Example of Vertical Live Load Equation

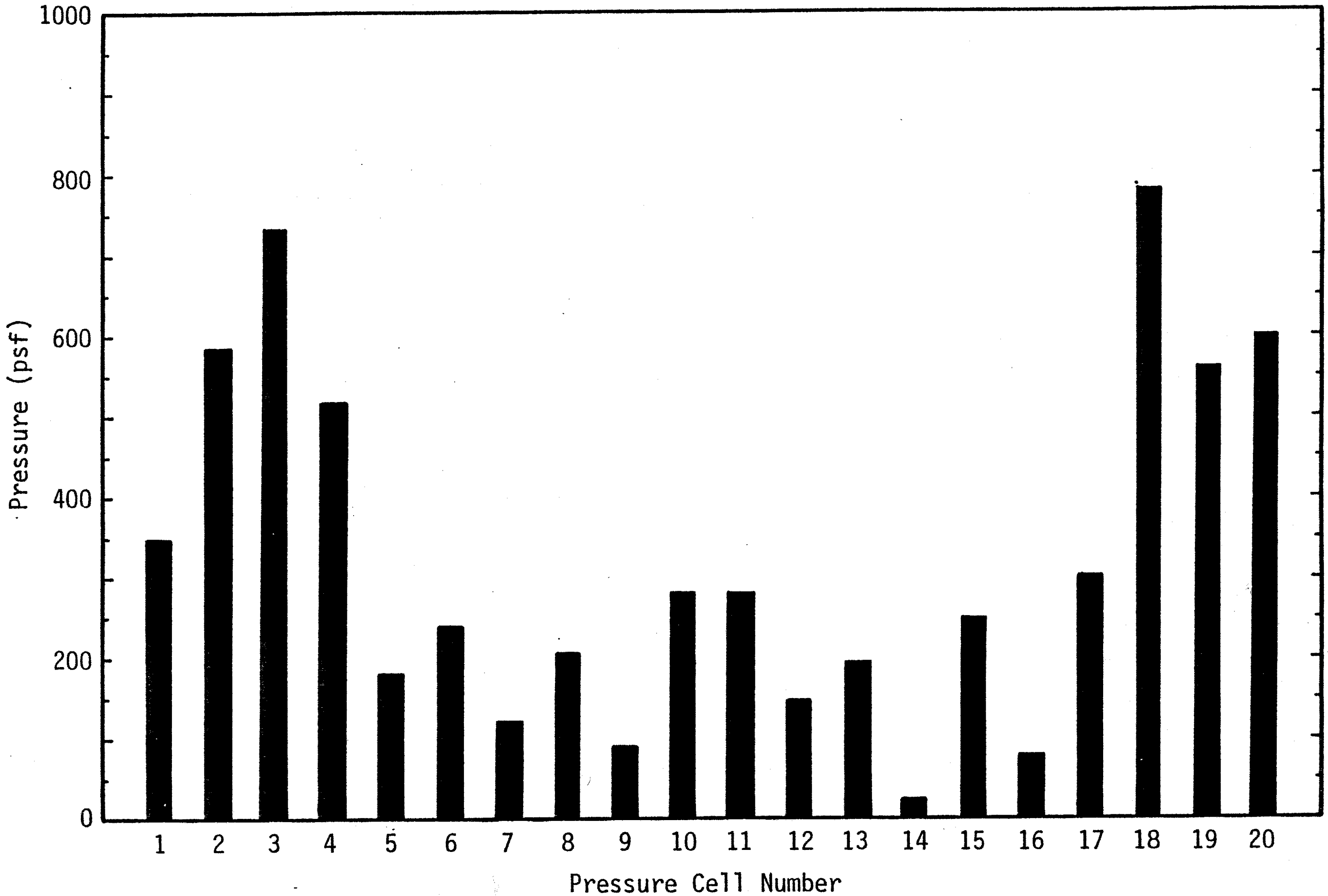


FIG. 25 - Total Offset Pressures at 8 in. of Fill
(1 in. = 2.54 cm, 1 psf = 47.9 Pa)

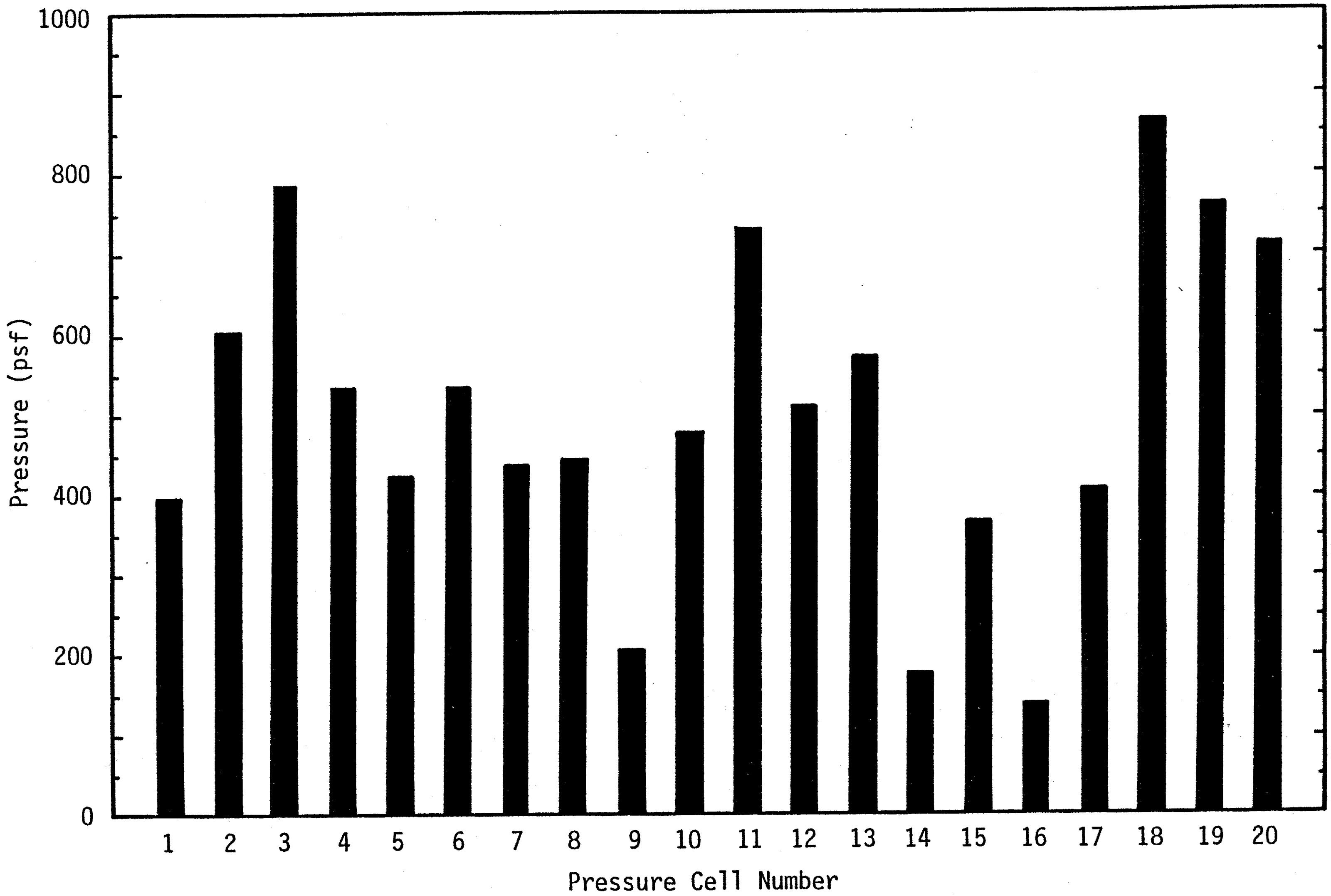


FIG. 26 - Total Offset Pressures at 2 ft of Fill
(1 ft = 0.305 m, 1 psf = 47.9 Pa)

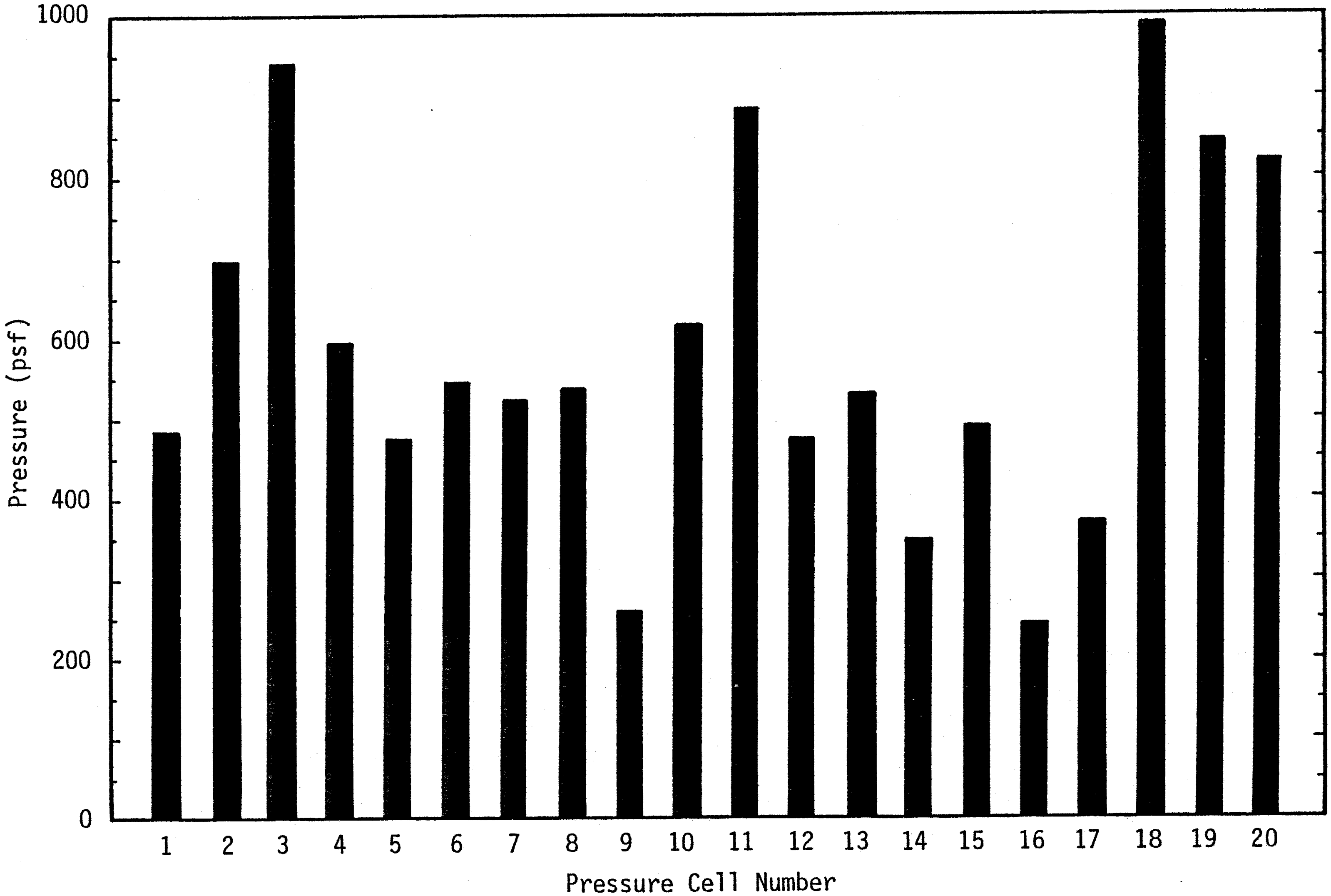


FIG. 27 - Total Offset Pressures at 4 ft of Fill
(1 ft = 0.305 m, 1 psf = 47.9 Pa)

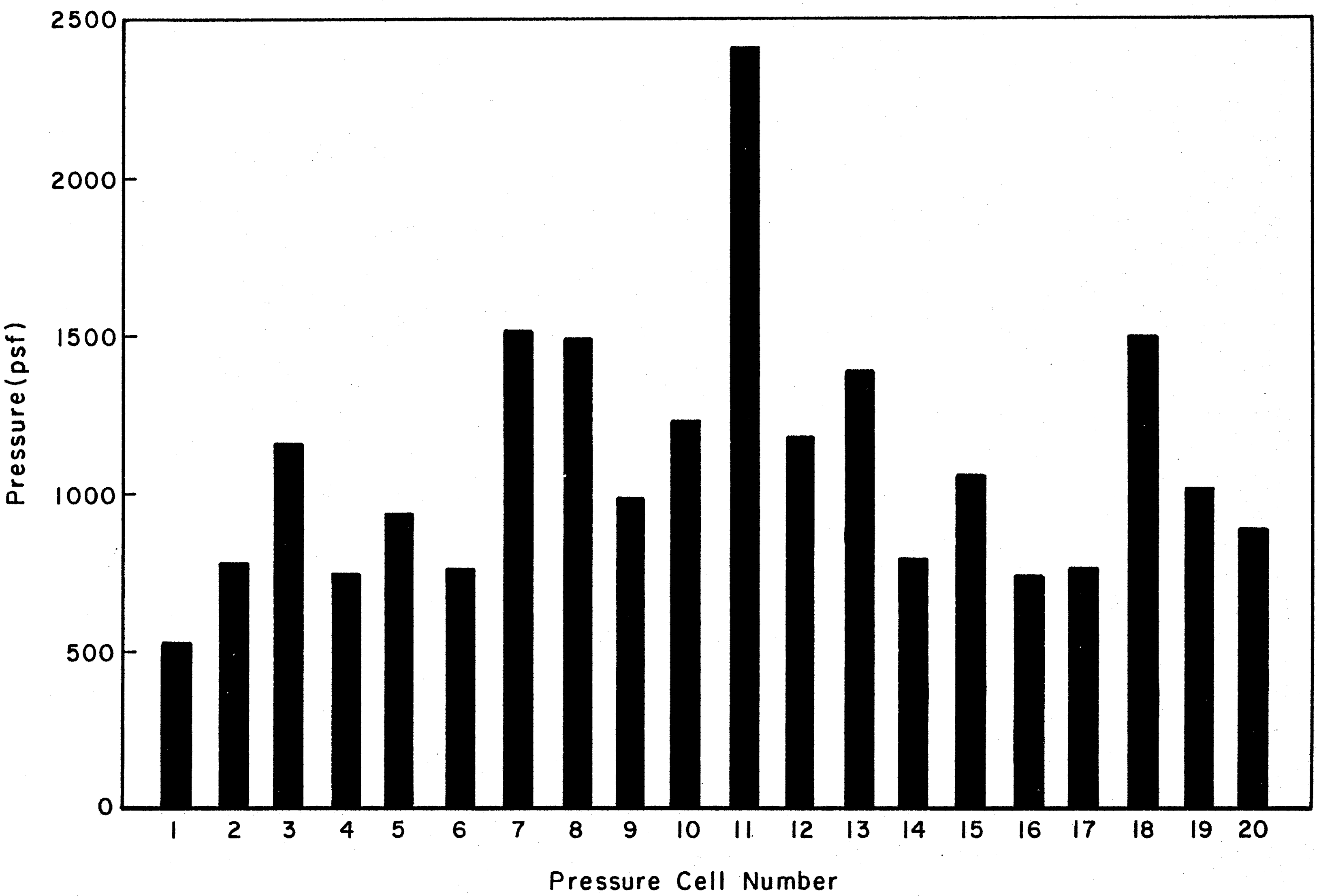


FIG. 28 - Total Offset Pressures at 6 ft of Fill
(1 ft = 0.305 m, 1 psf = 47.9 Pa)

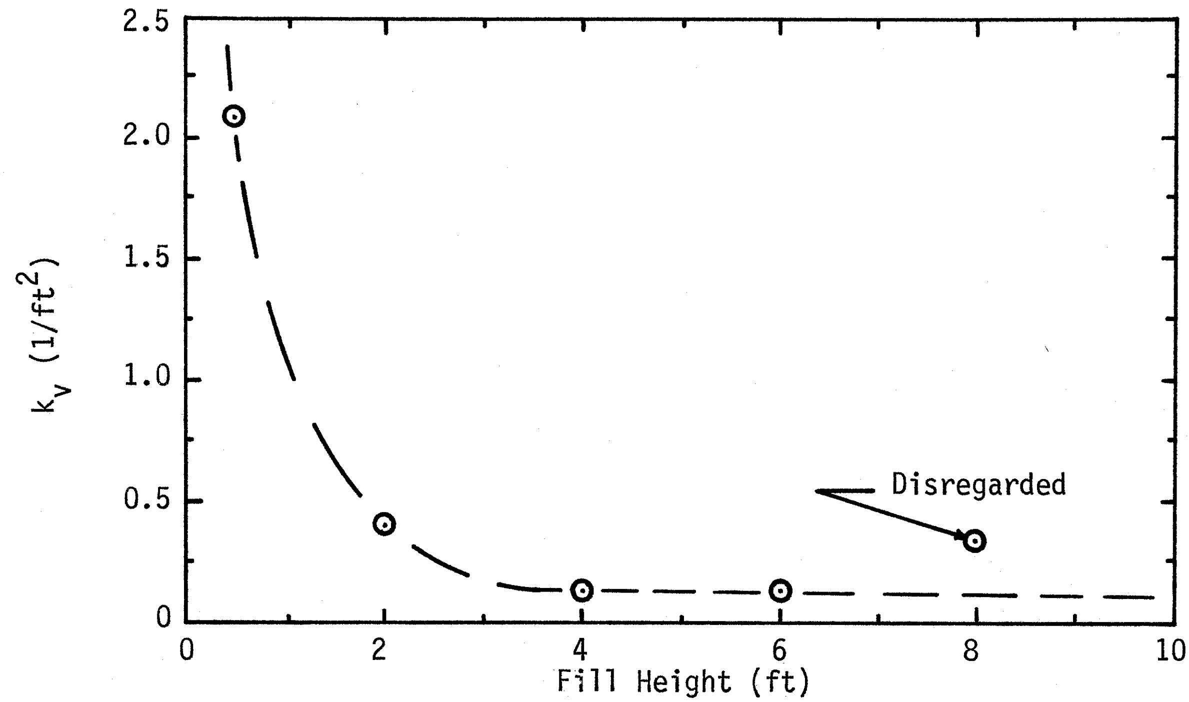


FIG. 29 - Values of k_v from Regression Analysis (1 ft = o.305 m)

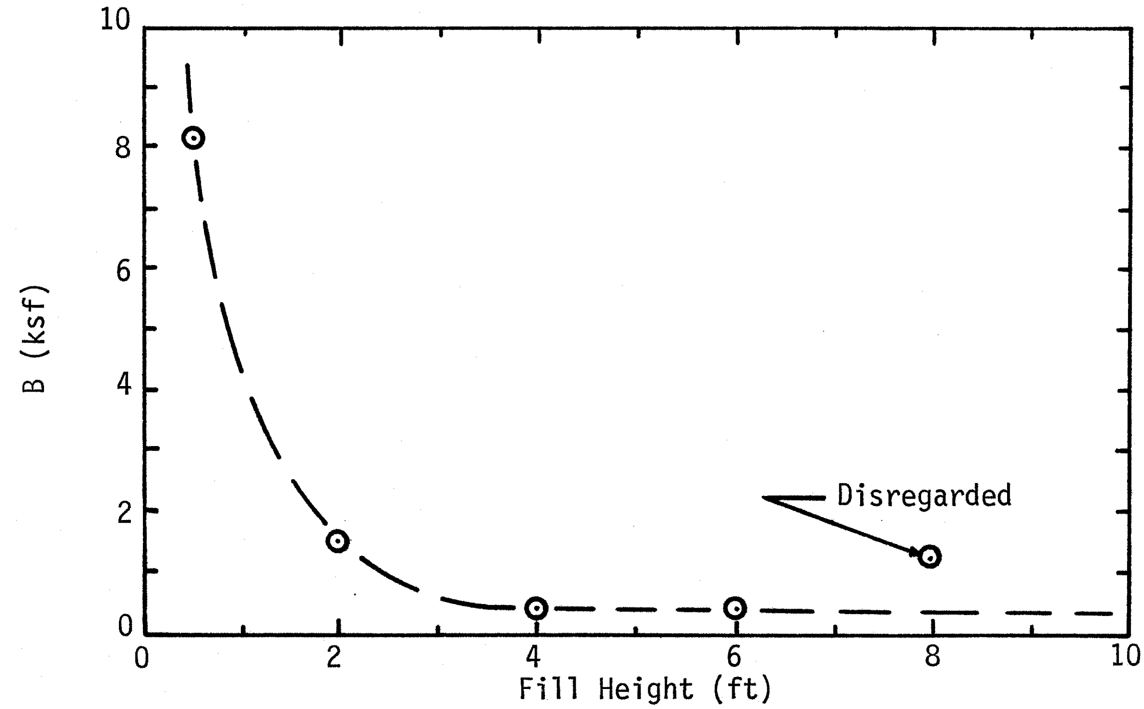


FIG. 30 - Values of B from Integration Analysis (1 ft = 0.305 m, 1 ksf = 47.9 kPa)

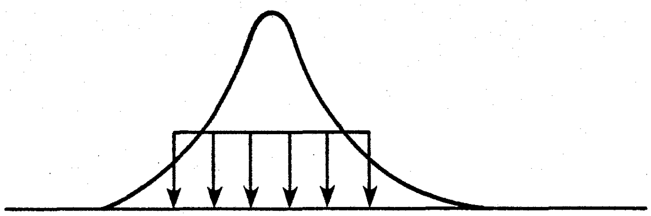


FIG. 31 - Wheel Load Pressure
Distribution and Equivalent
Uniform Distribution

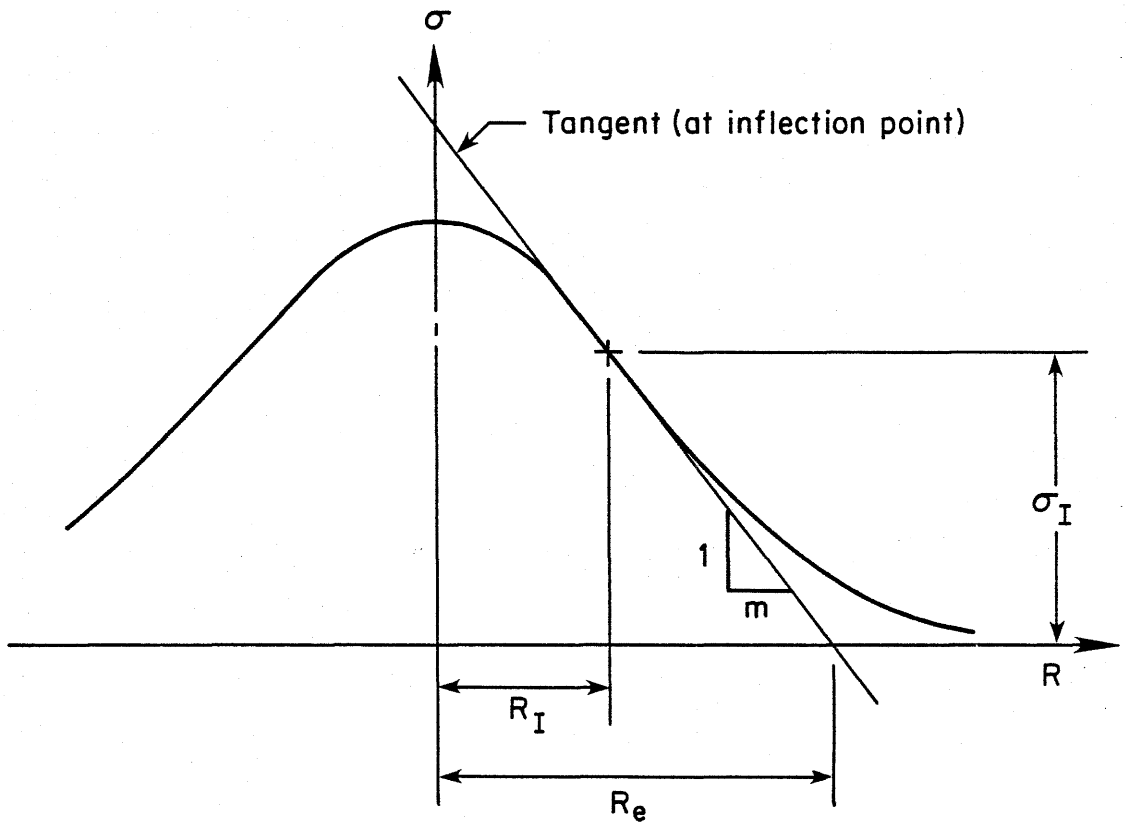


FIG. 32 - Geometry of Wheel Load
Pressure Distribution

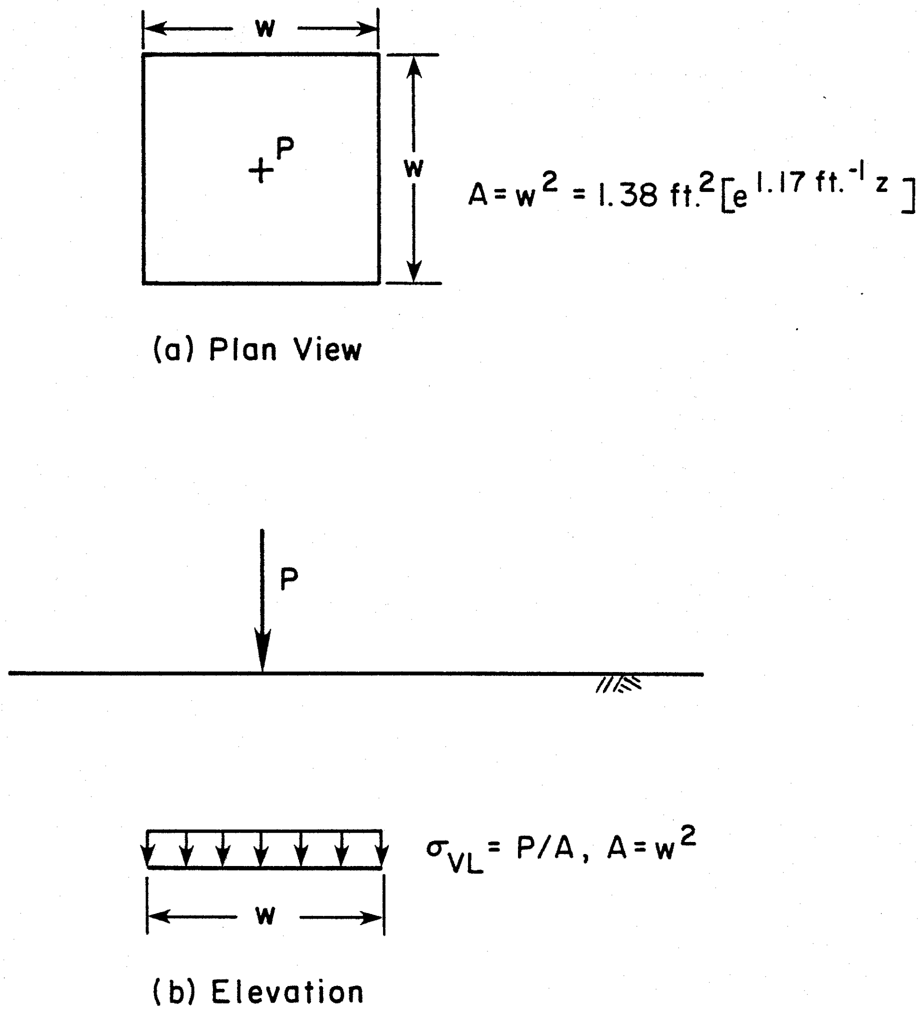
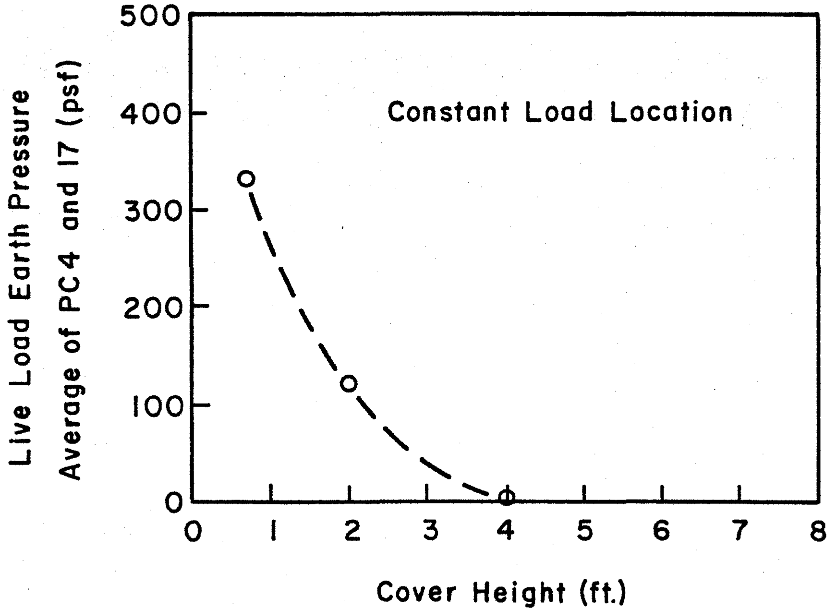
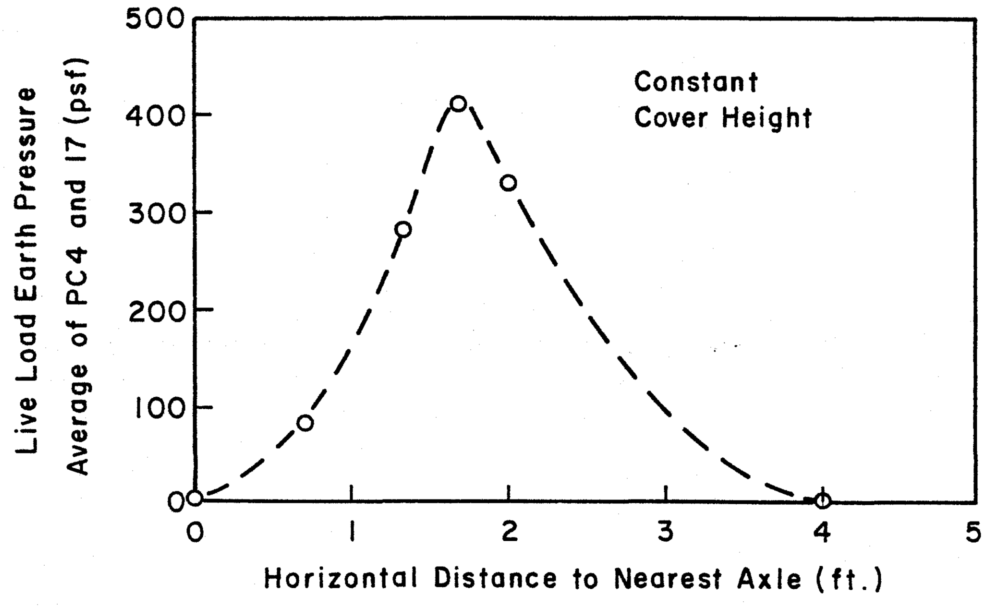


FIG. 33 - Live Load Vertical
Earth Pressure Distribution-
Simplified Method



(a) Horizontal Earth Pressure vs. Cover Height



(b) Horizontal Earth Pressure vs. Load Location

FIG. 34 - Horizontal Live Load Pressures
(1 ft = 0.305 m, 1 psf = 47.9 Pa)

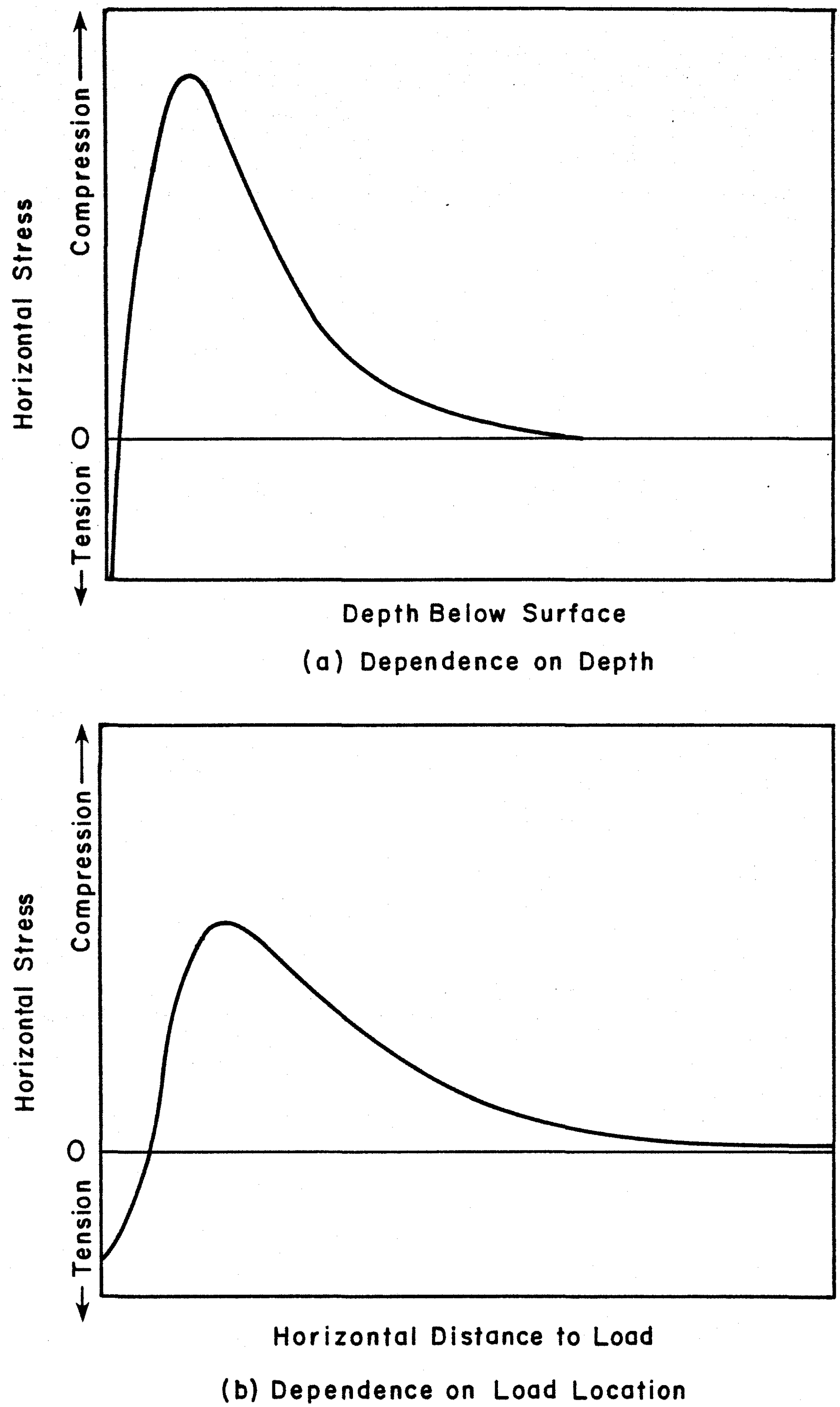


FIG. 35 - Boussinesq's Equation for Horizontal Earth Pressures

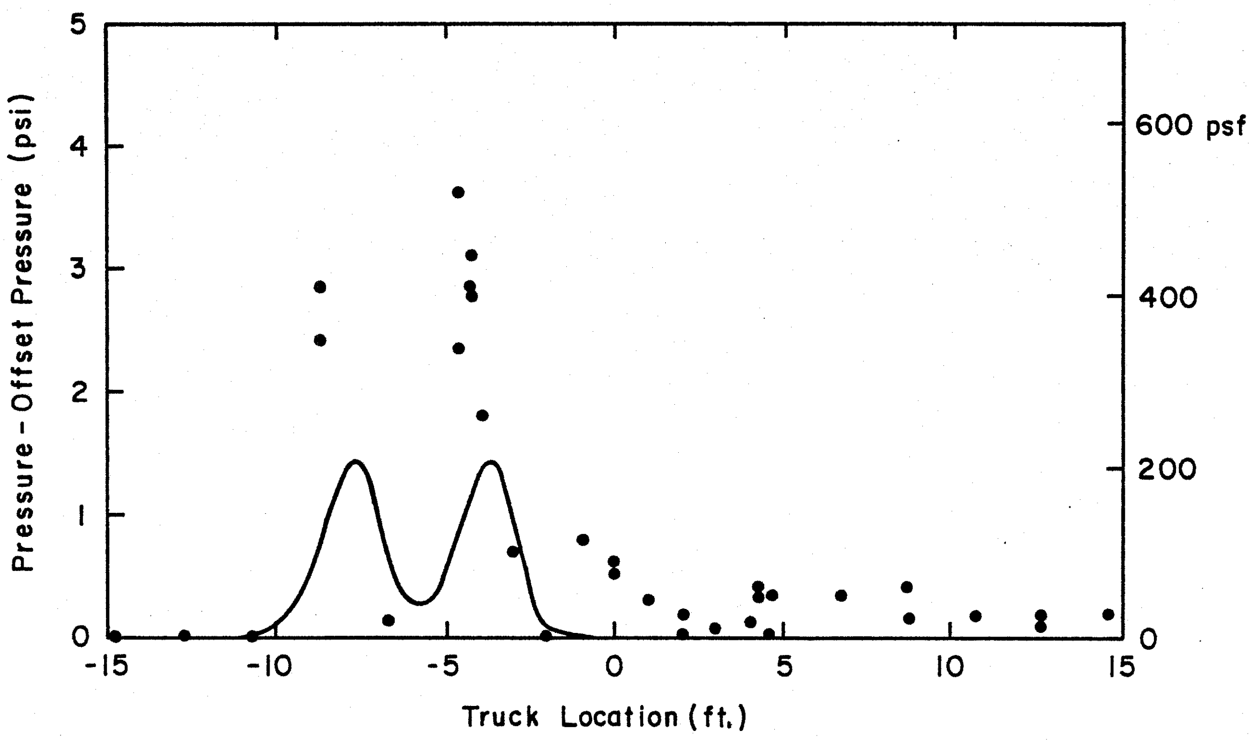


FIG. 36 - Influence Diagram for PC 4 at 8 in. of Fill

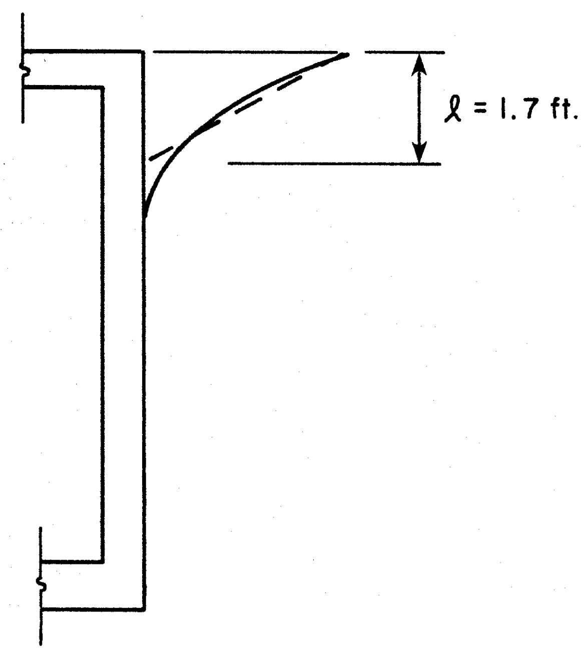


FIG. 37 - Example Maximum Pressure Distribution for
a 12-ft Tall Culvert Under 2-ft Cover

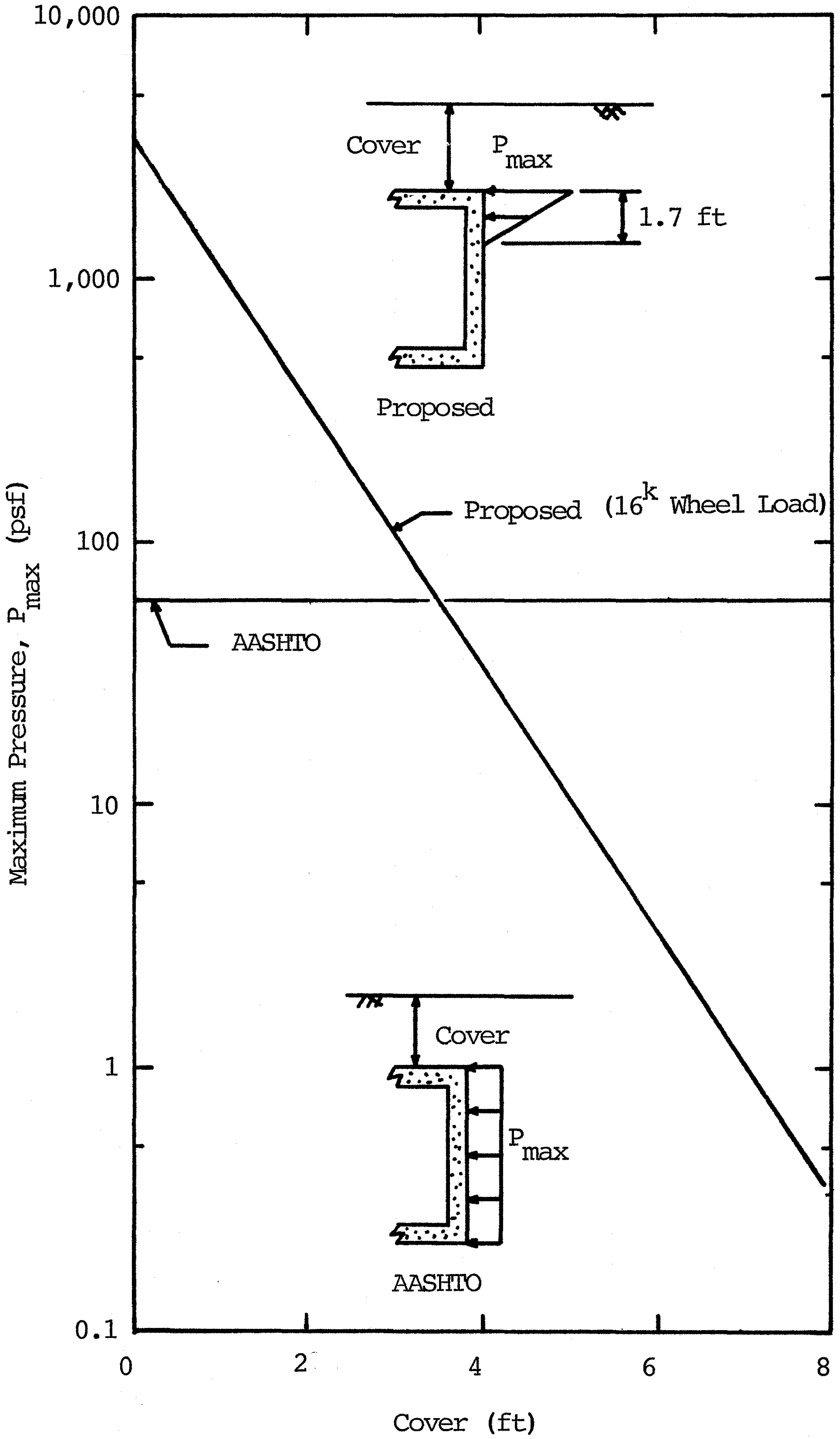


FIG. 38 - Horizontal Live Load Design Pressures for AASHTO and Proposed Methods (1 psf = 47.9 Pa, 1 ft = 0.305 m)

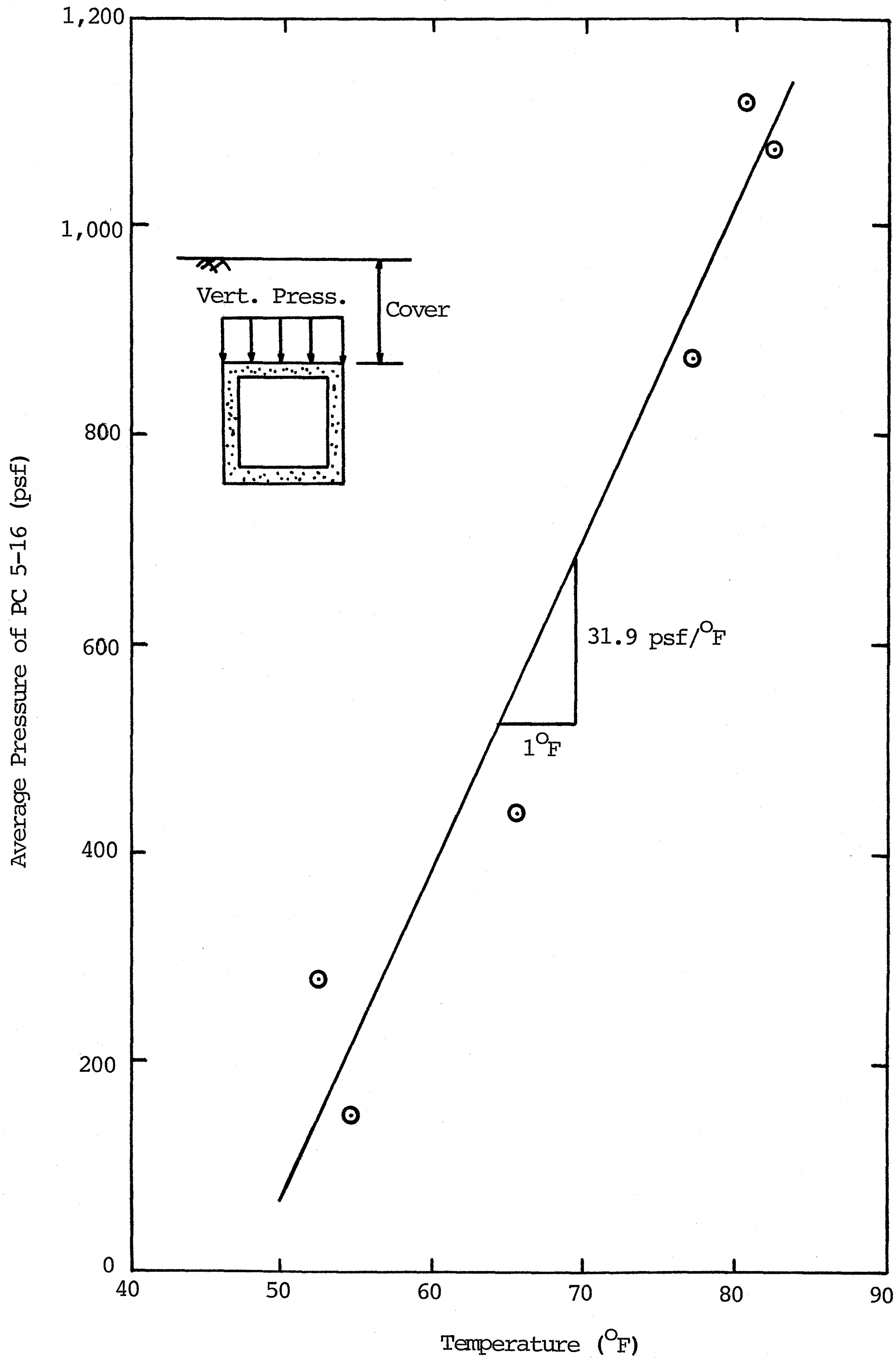


FIG. 39 - Vertical Dead Load Pressures vs. Temperature at 8 ft of Cover (1 psf = 47.9 Pa, 1 °F = 0.56 °C, 1 ft = 0.305 m)

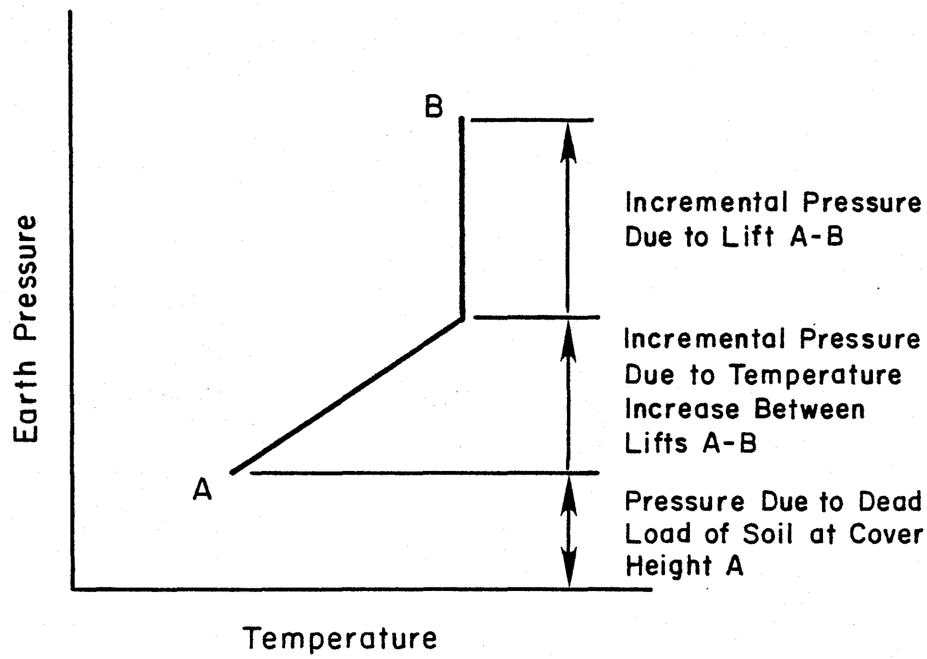


FIG. 40 - Illustrating Incremental Pressure
Changes During Construction

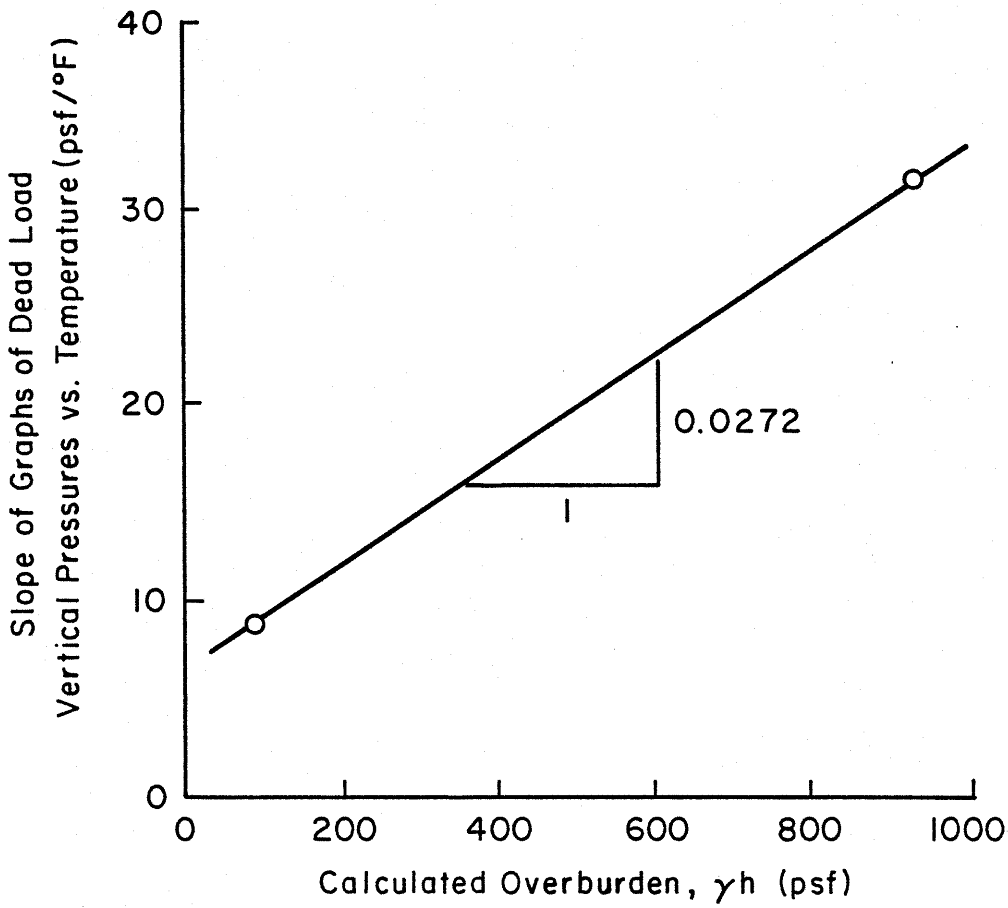


FIG. 41 - Dead Load Vertical Earth Pressure
Dependence on Temperature

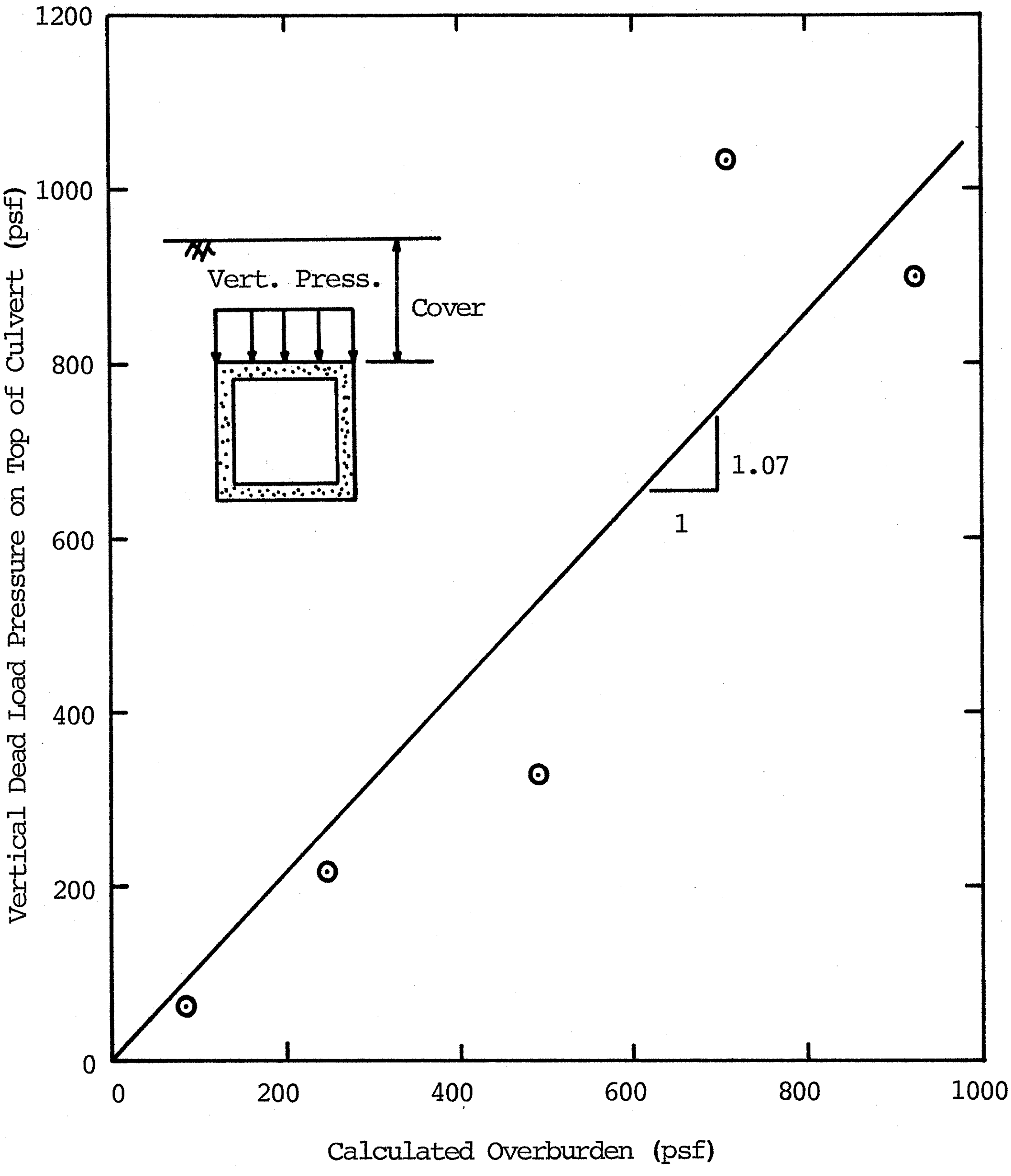


FIG. 42 - Vertical Dead Load Pressures Corrected for Temperature Changes Since Construction (1 psf = 47.9 Pa)

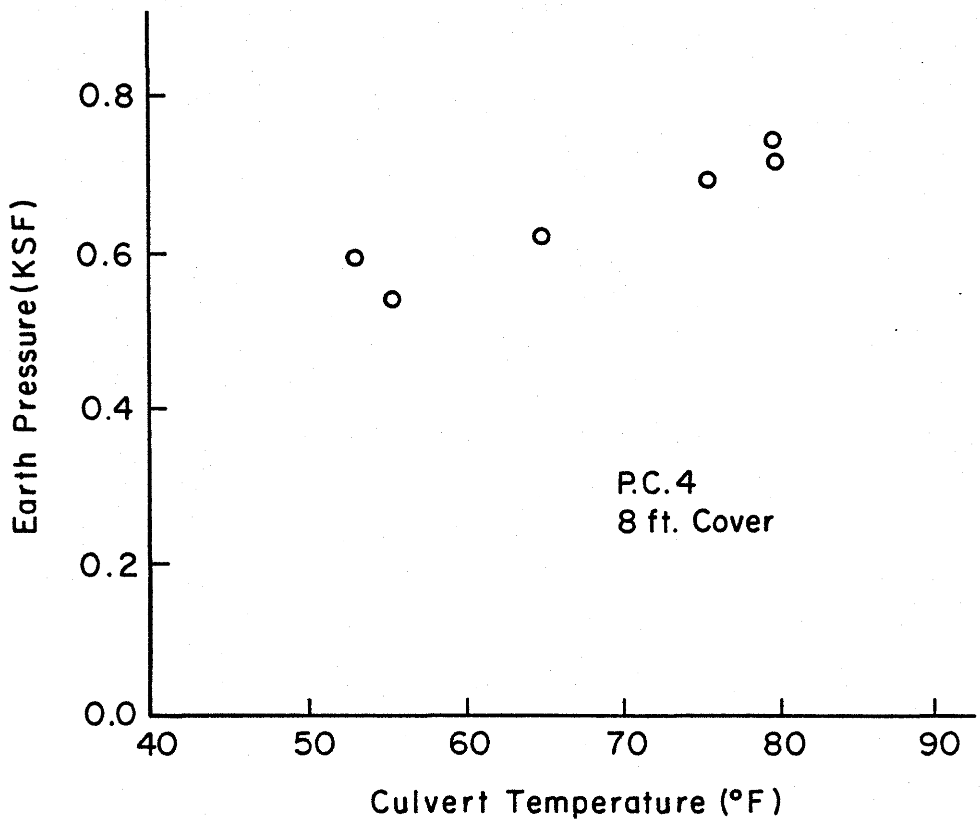


FIG. 43 - Dead Load Horizontal Pressure
vs. Temperature

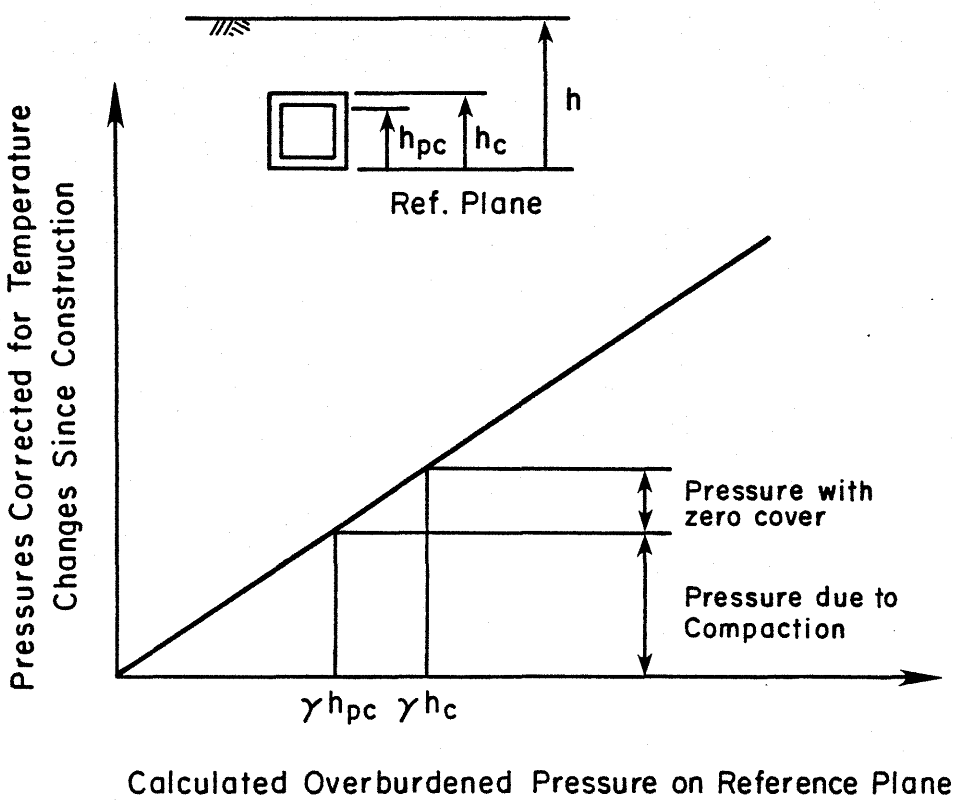


FIG. 44 - Interpretation of Dead Load Horizontal Pressures

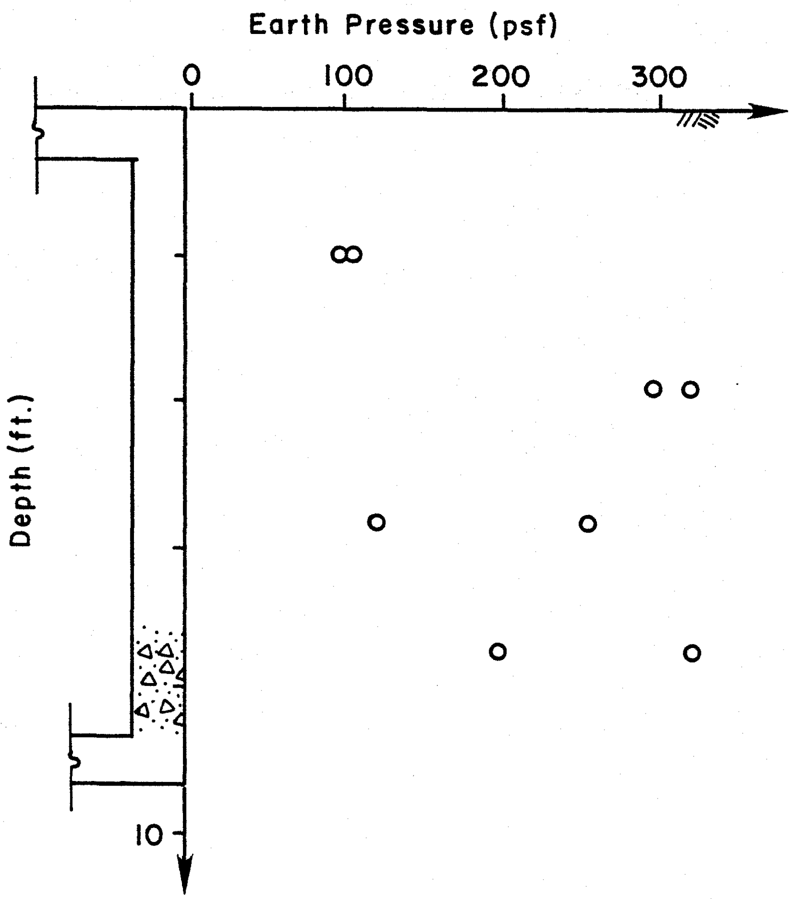


FIG. 45 - Dead Load Horizontal Earth Pressures at Zero Cover

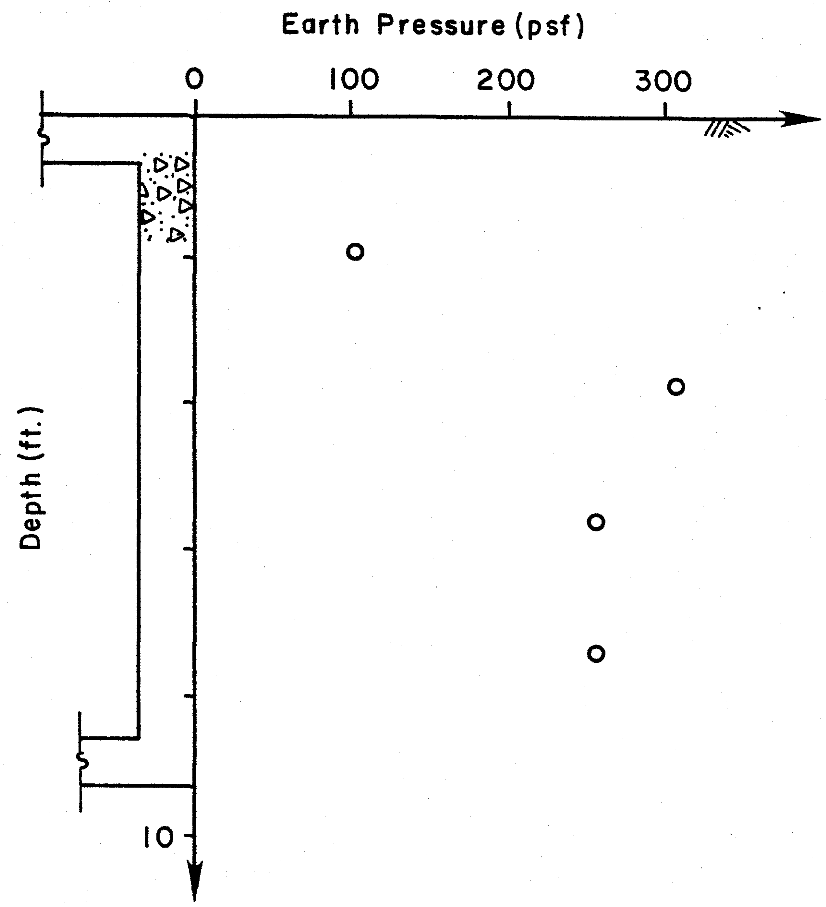


FIG. 46 - Averaged Dead Load
Horizontal Earth Pressures
at Zero Cover

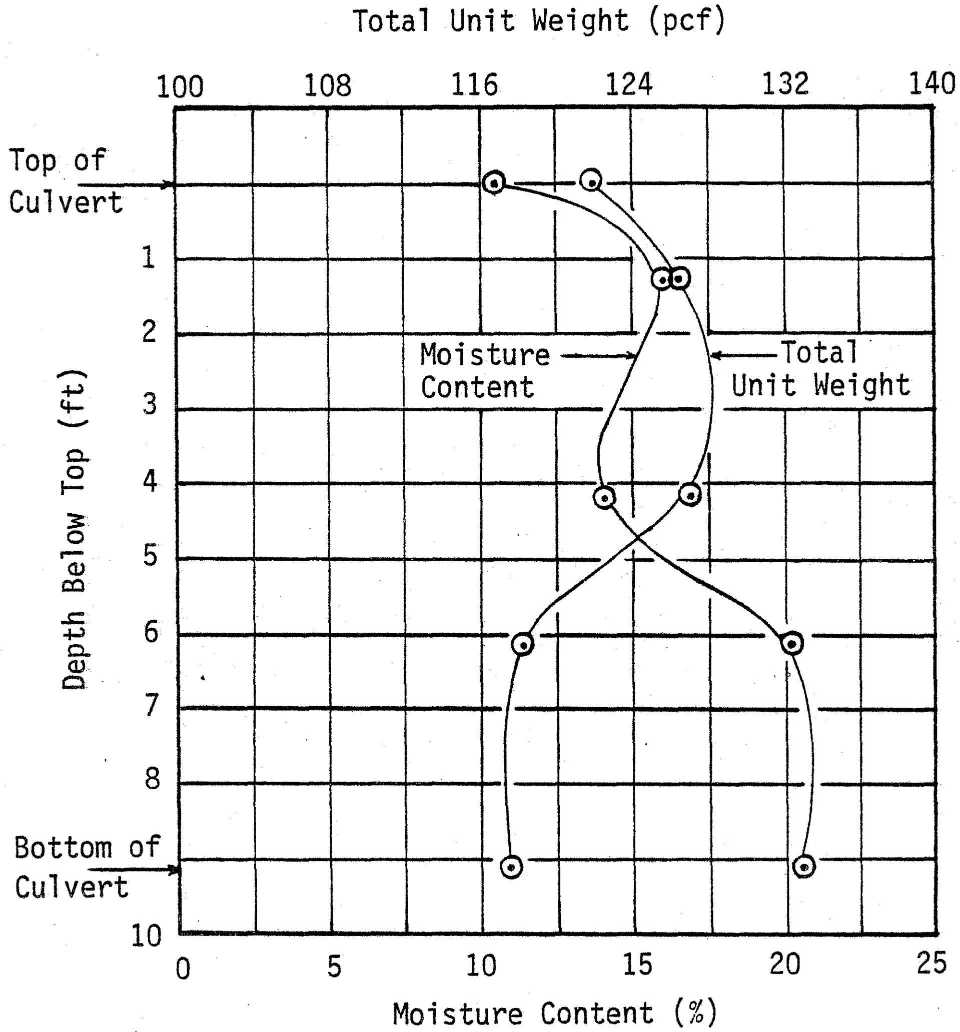


FIG. 47 - Total Unit Weights and Moisture Contents of Soil Adjacent to Culvert (1 ft = 0.305 m, 1 pcf = 0.157 kN/m^3)

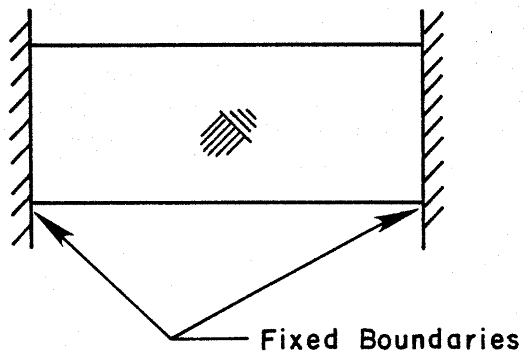


FIG. 48 - Sliding Block of Soil
Between Rigid Boundaries

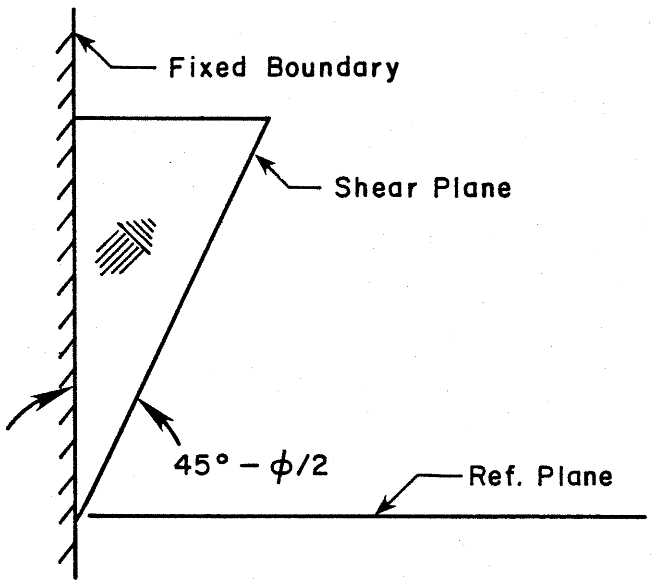


FIG. 49. - Sliding Wedge of Soil
Adjacent to Rigid Boundary

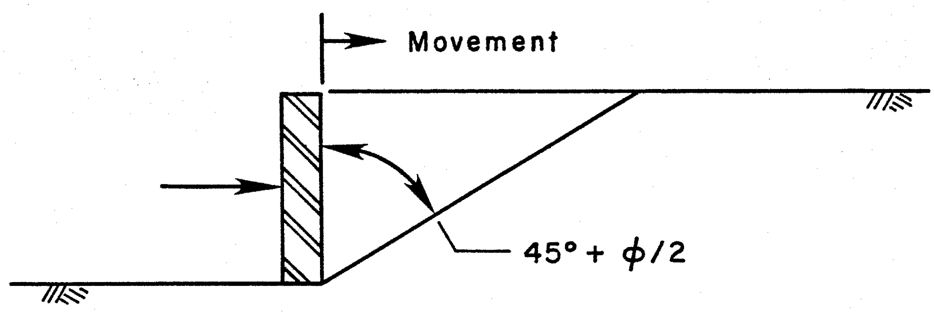


FIG. 50 - Shear Plane for Passive Failure of Soil Behind Retaining Wall

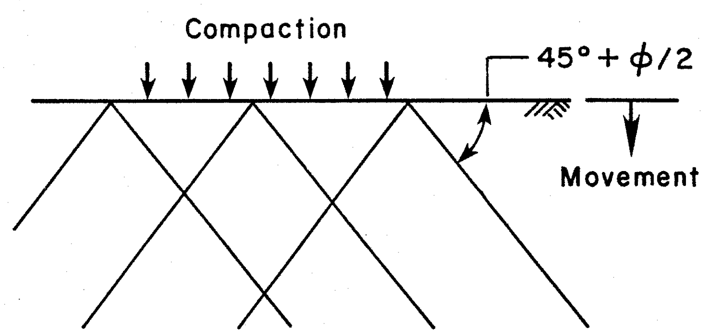


FIG. 51 - Shear Plane Pattern for Compaction of Soil

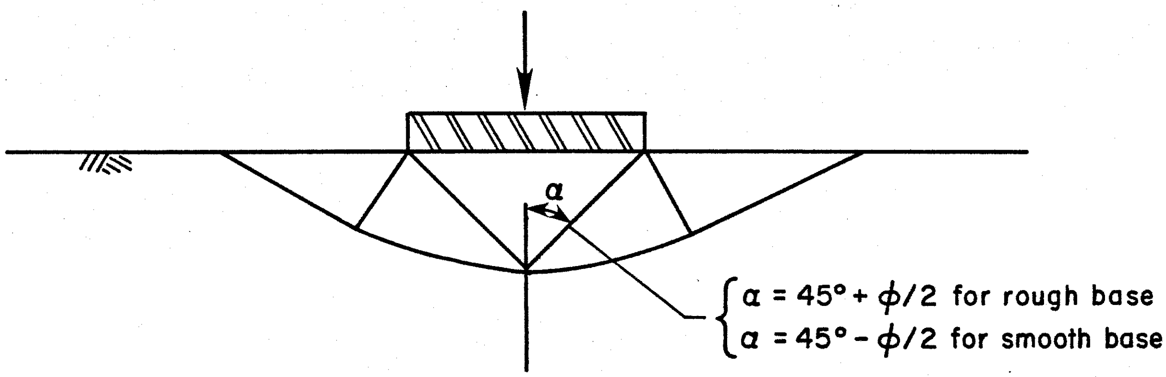


FIG. 52 - Shear Planes for Rigid Punch on Ideal Soil

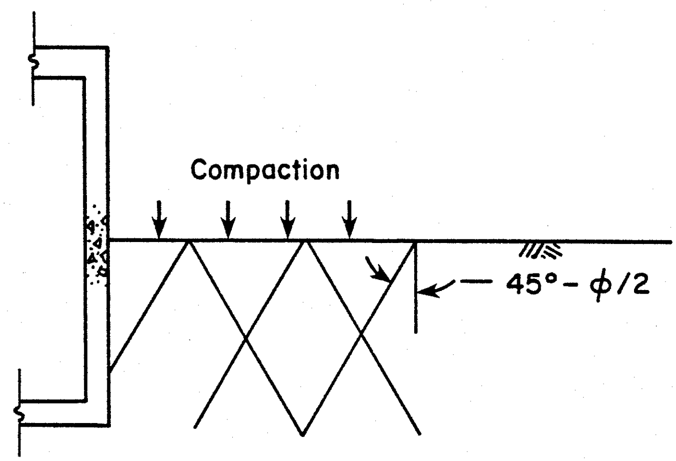


FIG. 53 - Shear Planes in Soil Adjacent to Culvert Subject to Compaction

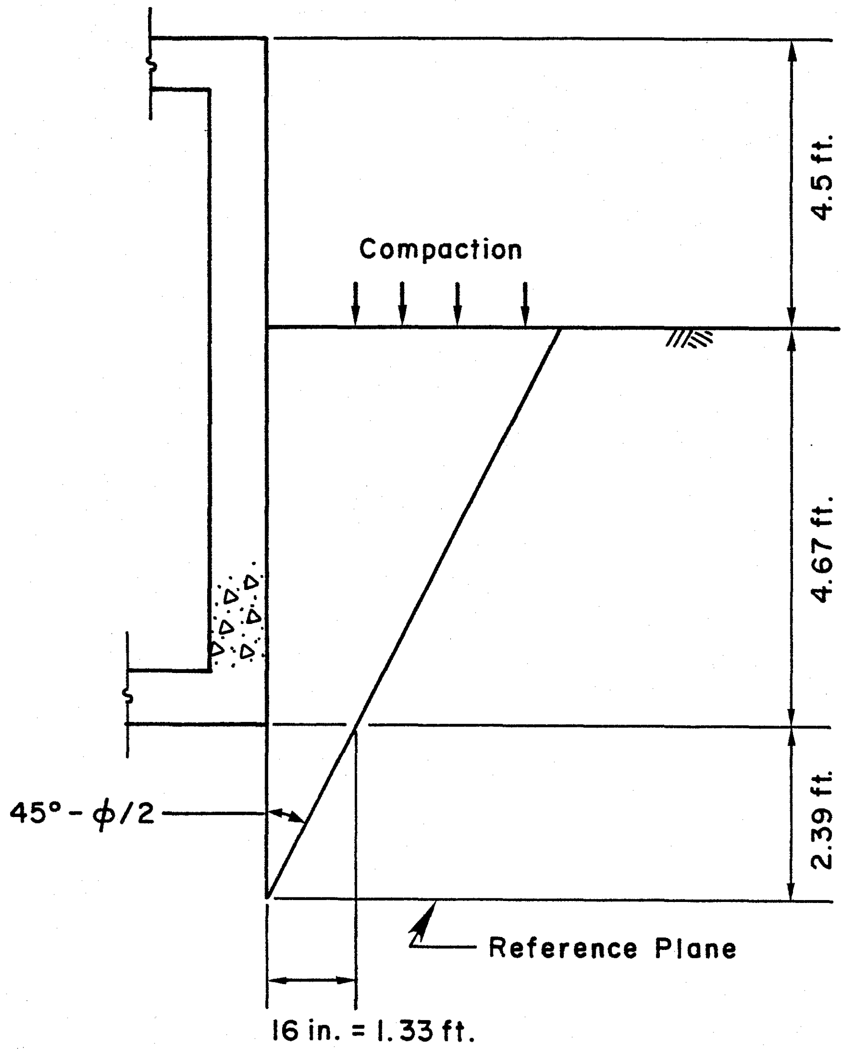


FIG. 54 - Deduced Shearing Plane Geometry

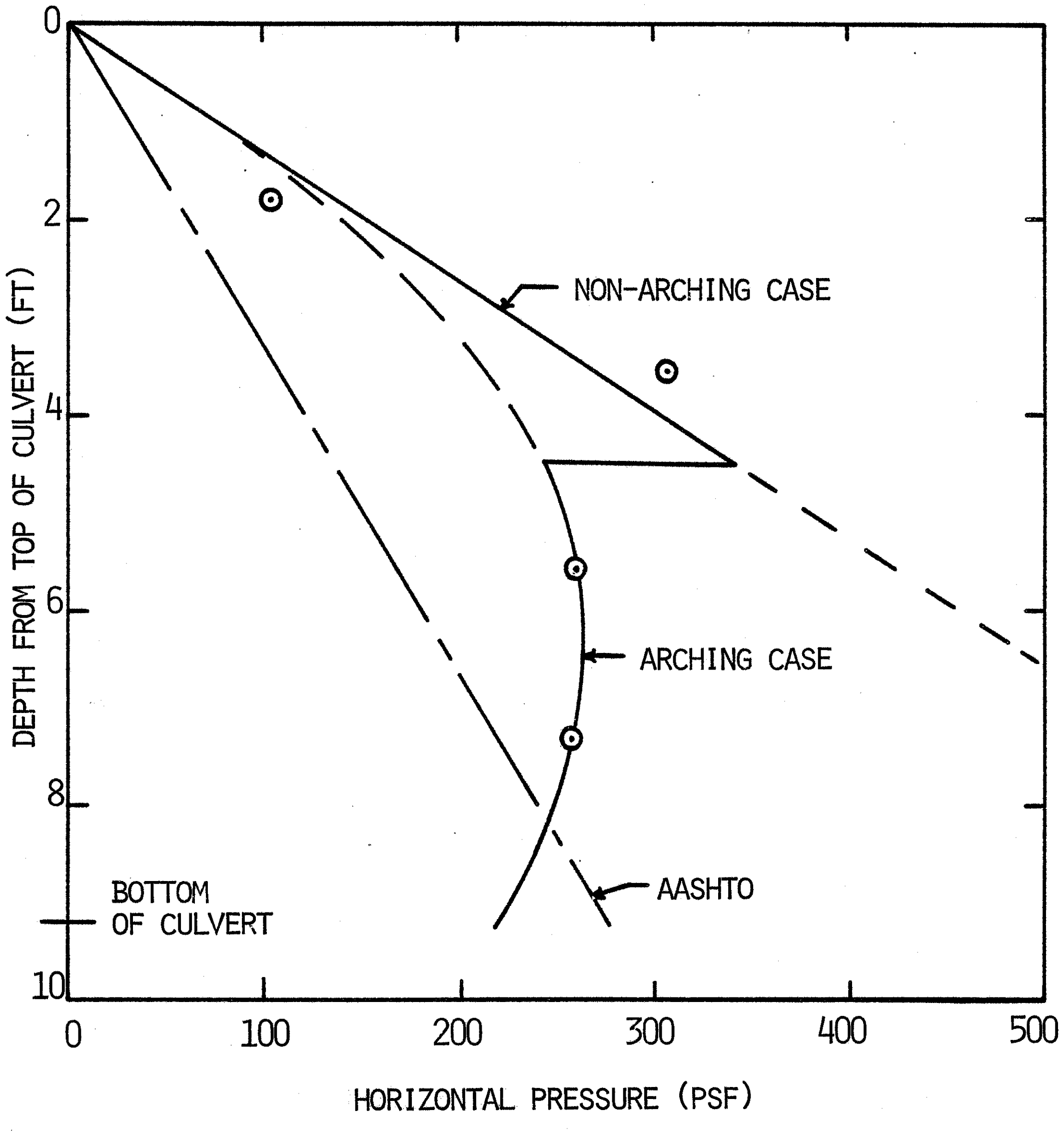


FIG. 55- INTERPRETATION OF MEASURED DATA
WITH NO COVER

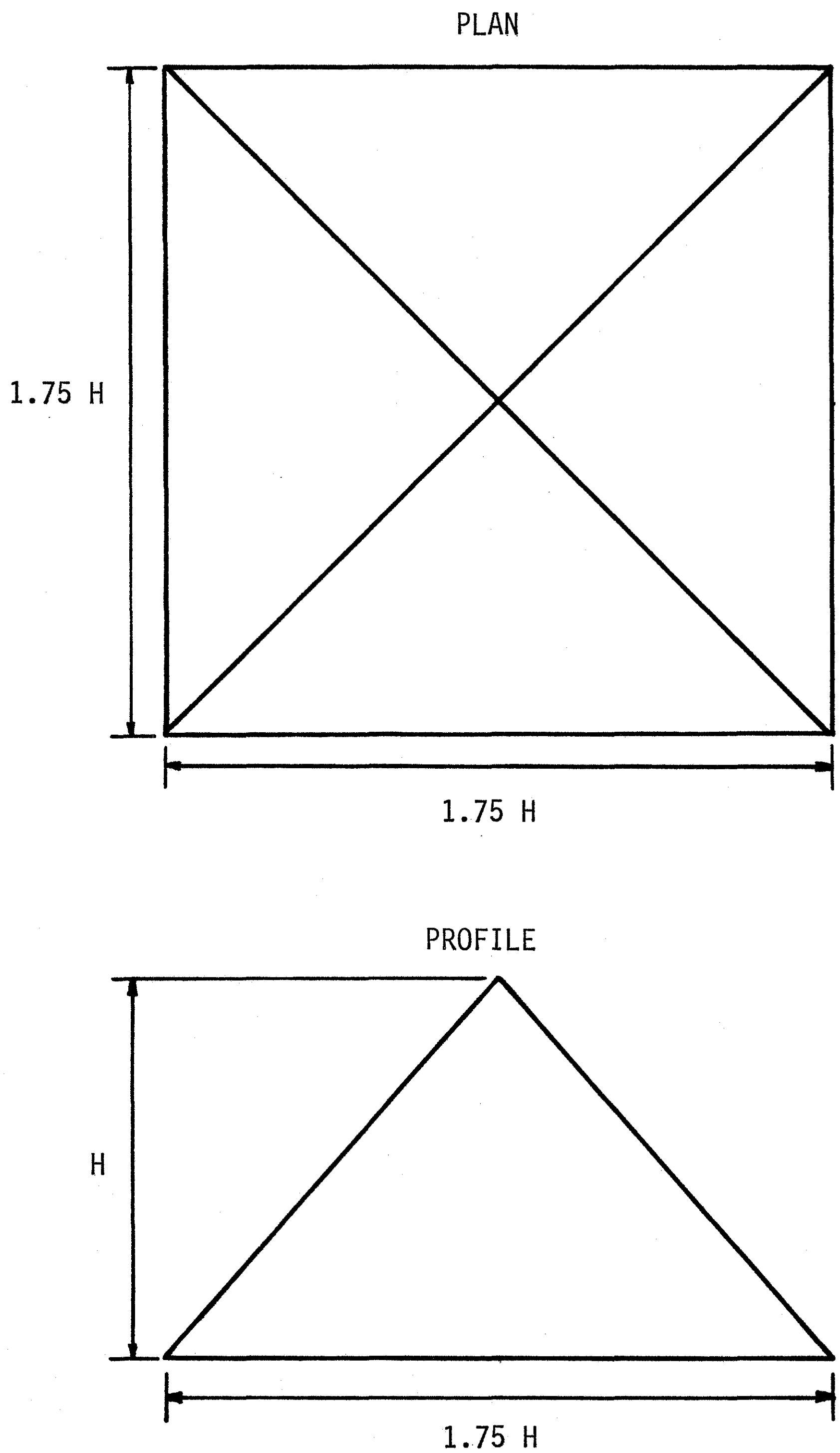


FIG. 56 - AASHTO Pyramid

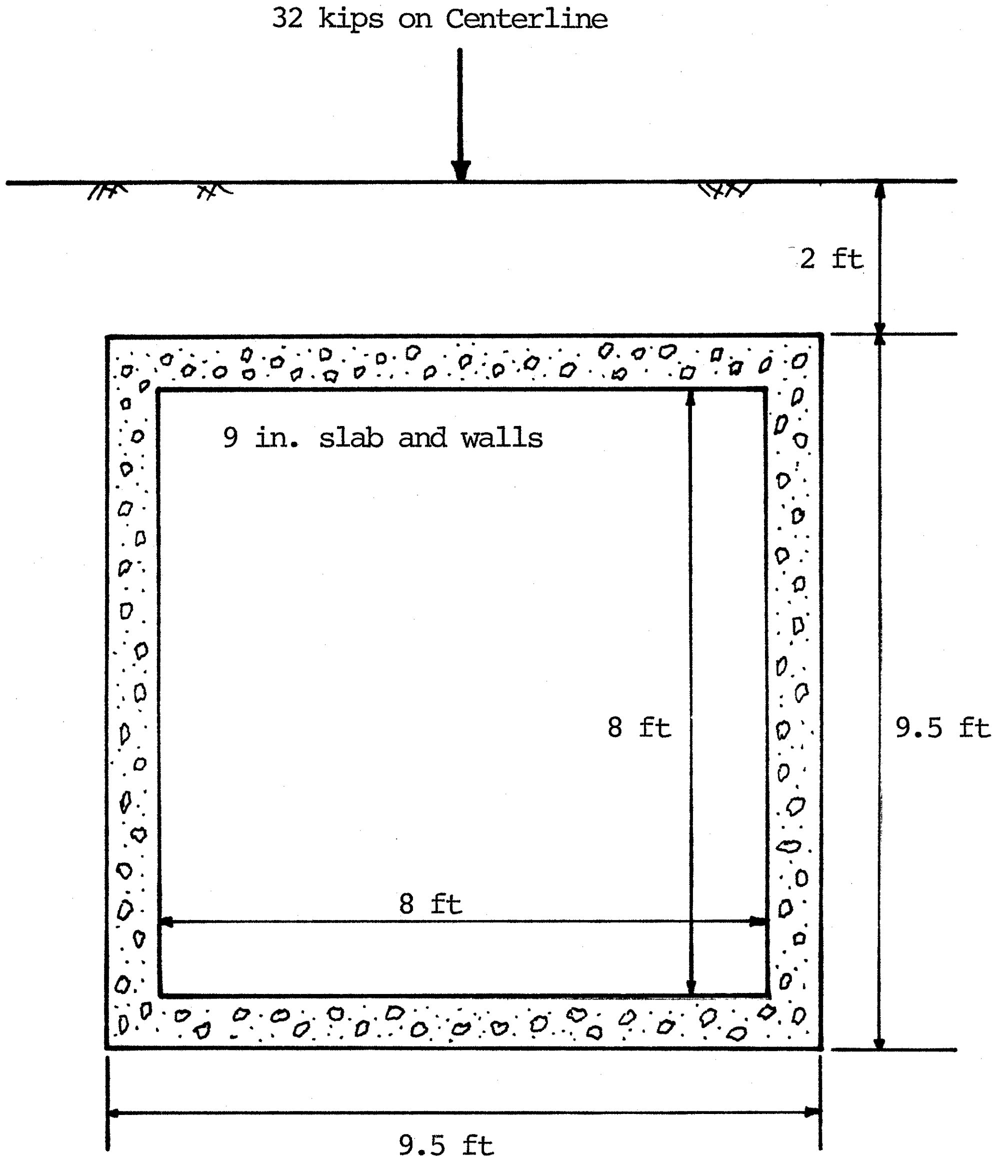


FIG. 57 - Geometry for AASHTO Example
(1 in. = 2.54 cm, 1 ft = 0.305 m,
1 lbf = 4.45 N)

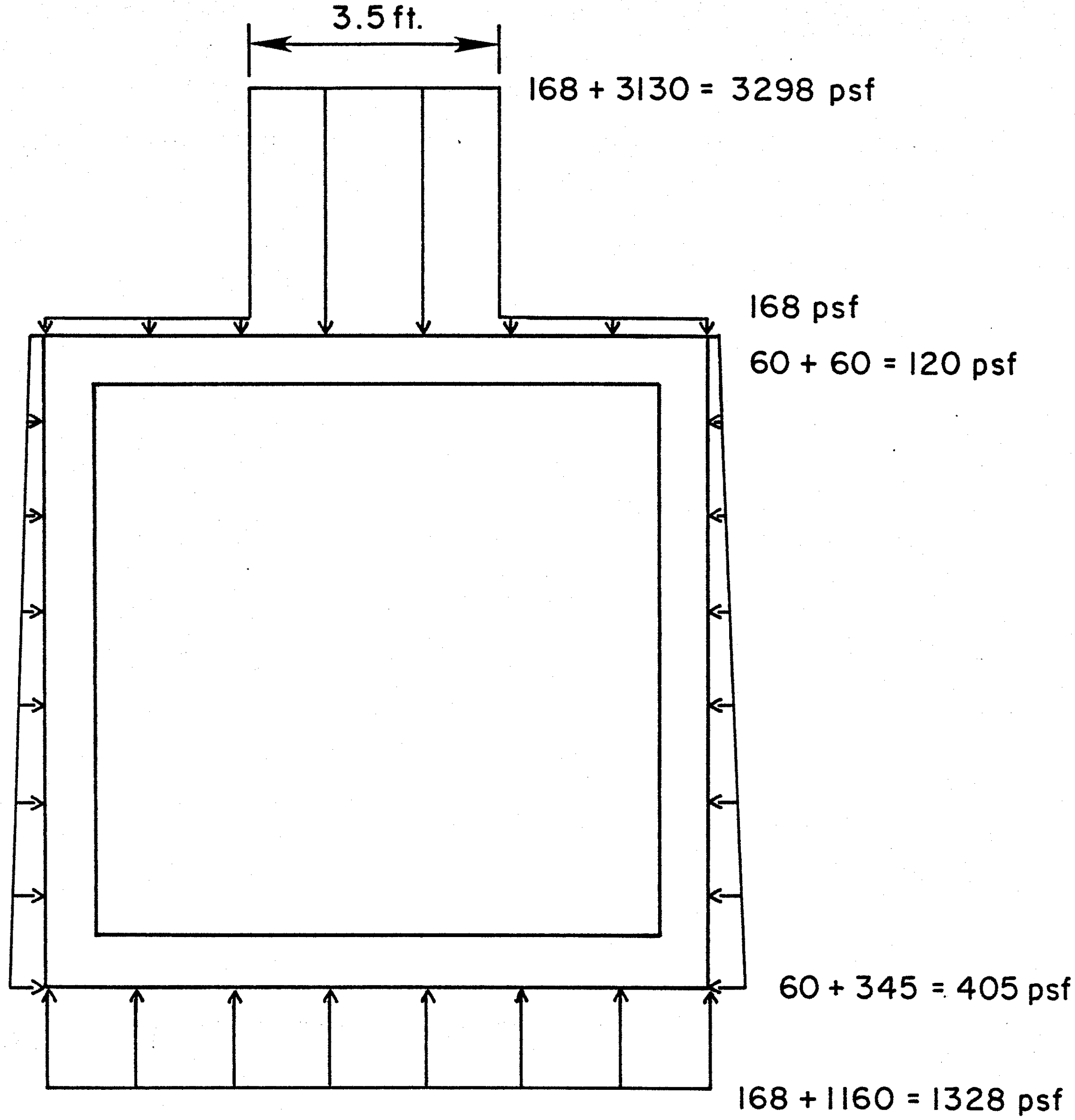


FIG. 58 - External Loads for Example Illustrating AASHTO Method (1 ft = 0.305 m, 1 psf = 47.9 Pa)

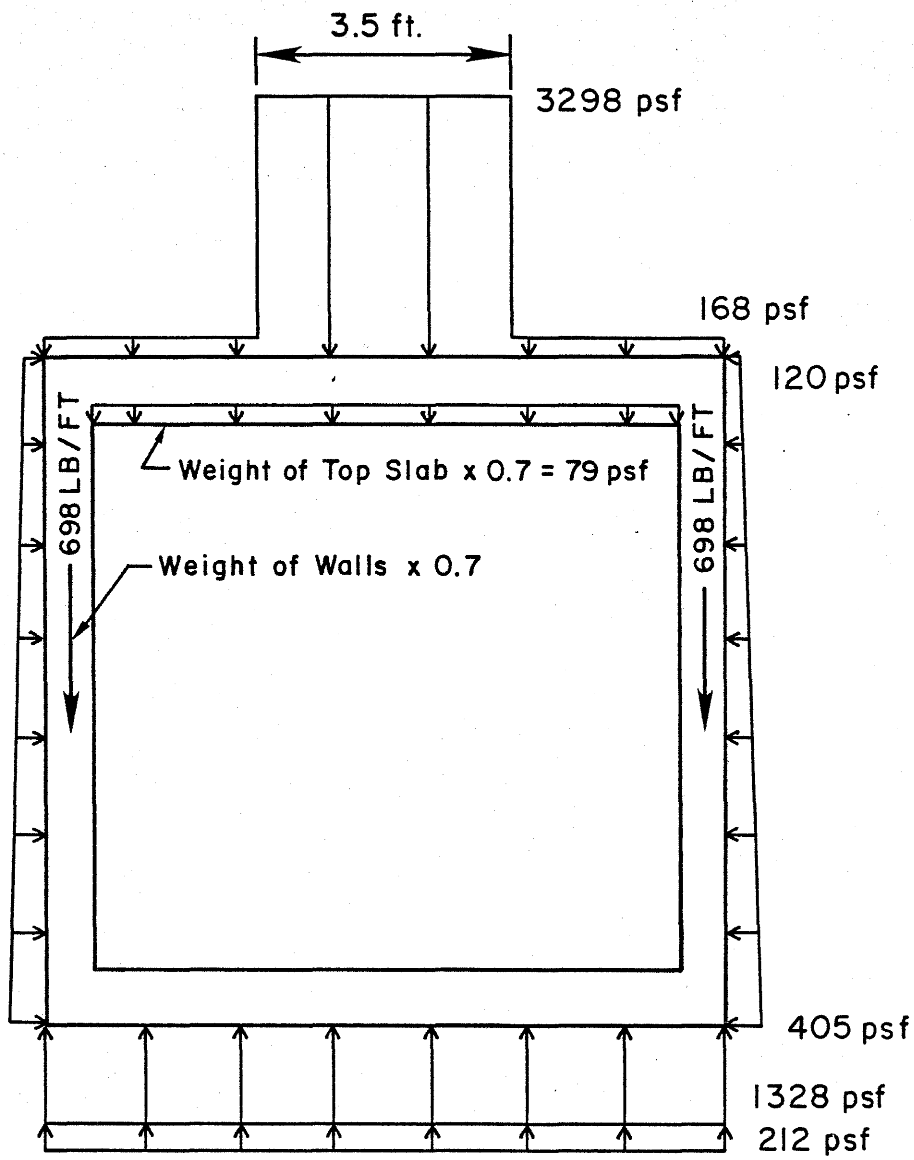


FIG. 59 - Total Loads for Example Illustrating AASHTO Method (1 ft = 0.305 m, 1 lb = 4.45N, 1 psf = 47.9 Pa)

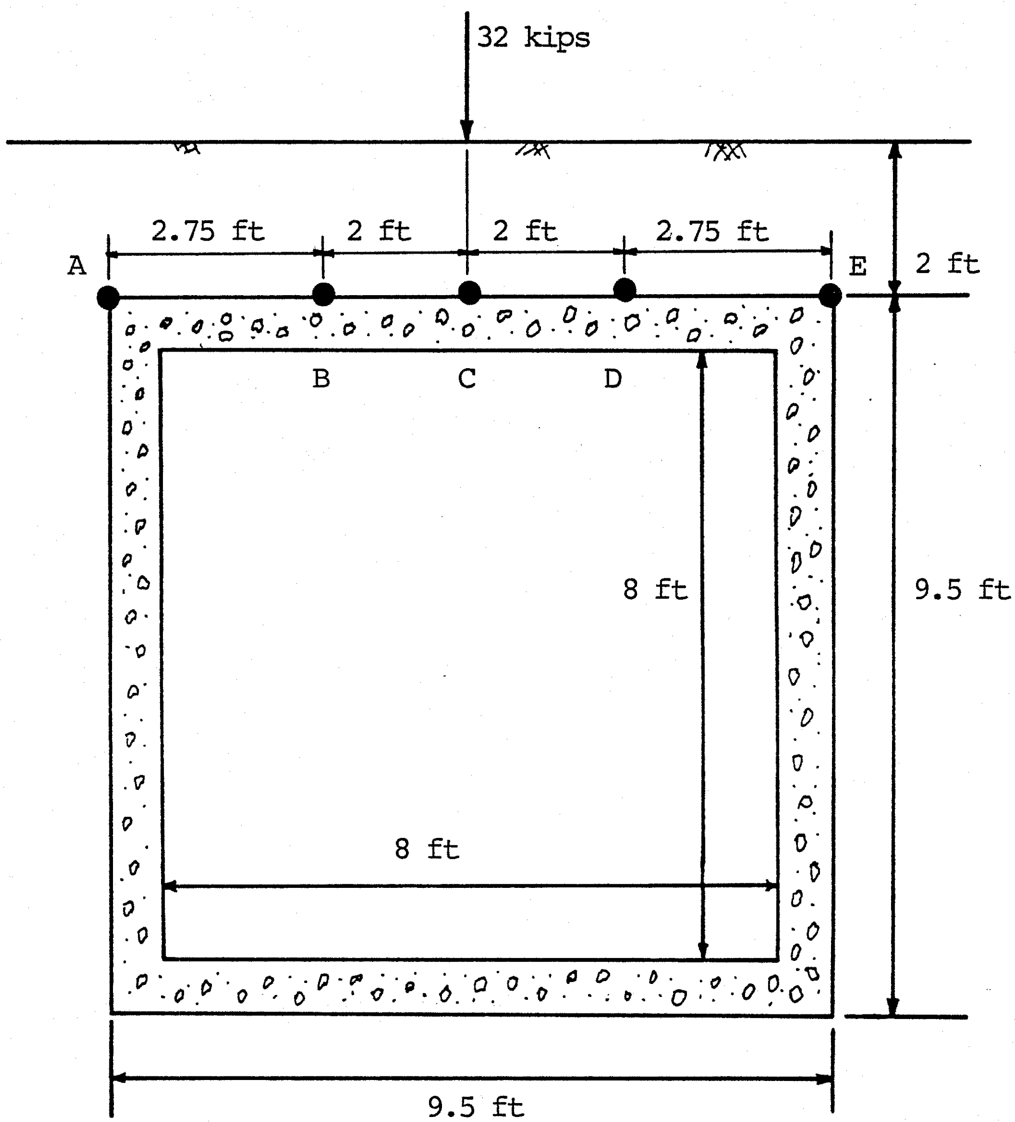


FIG. 60 - Geometry for Proposed Method's Vertical Live Load Example (1 ft = 0.305 m, 1 lbf = 4.45 N)

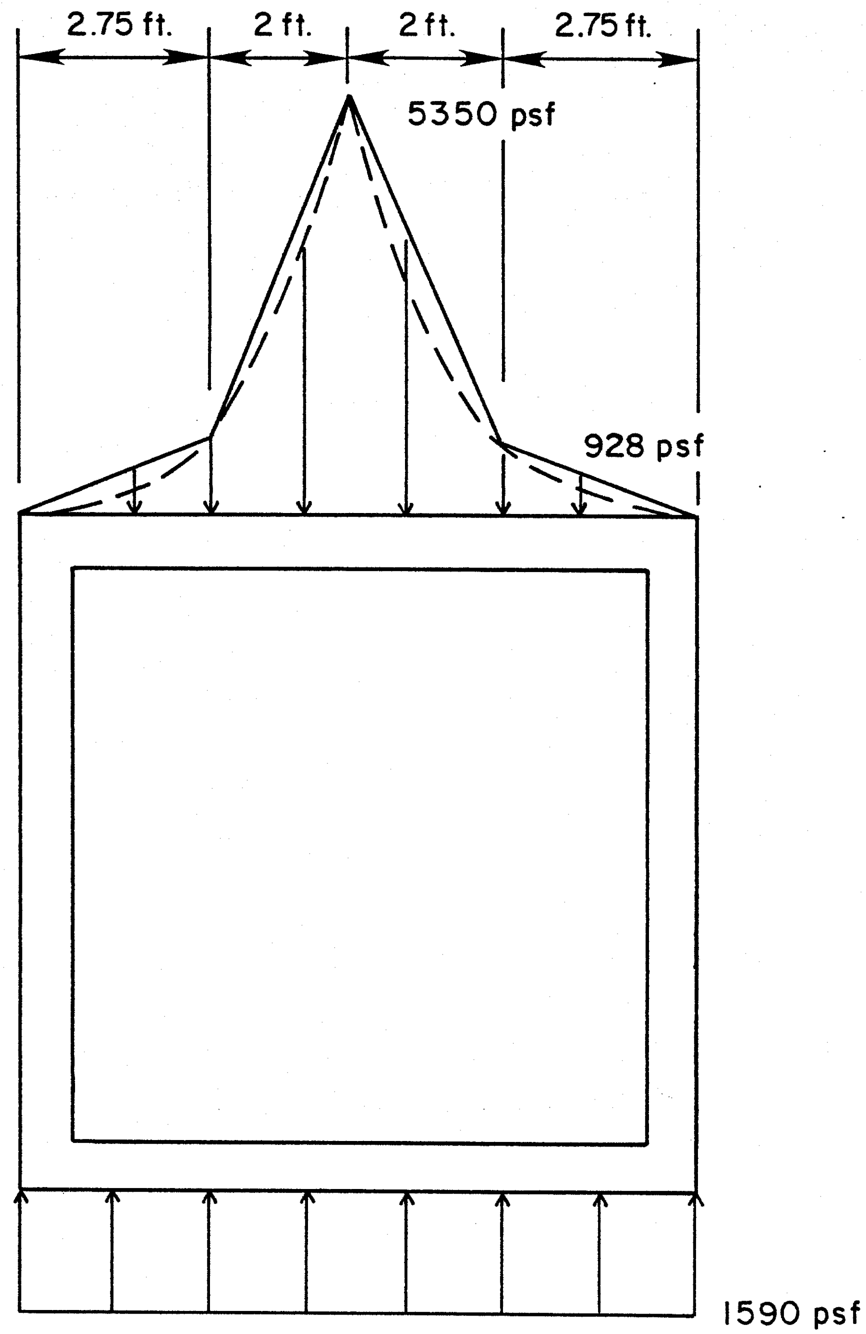


FIG. 61 - Vertical Live Load Pressures for Example Illustrating, Proposed Method (1 ft = 0.305 m, 1 psf = 47.9 Pa)

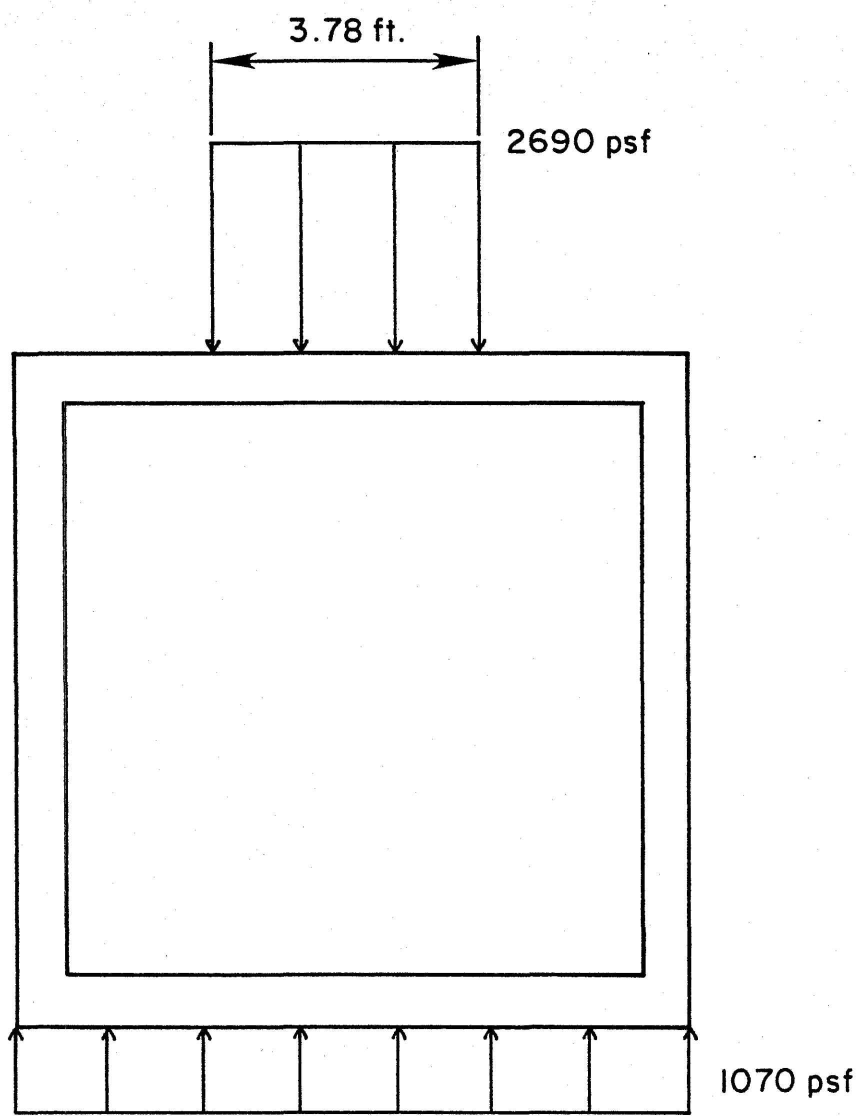


FIG. 62 - Vertical Live Load Pressures for Example Illustrating Simplified Procedure (1 ft = 0.305 m, 1 psf = 47.9 Pa)

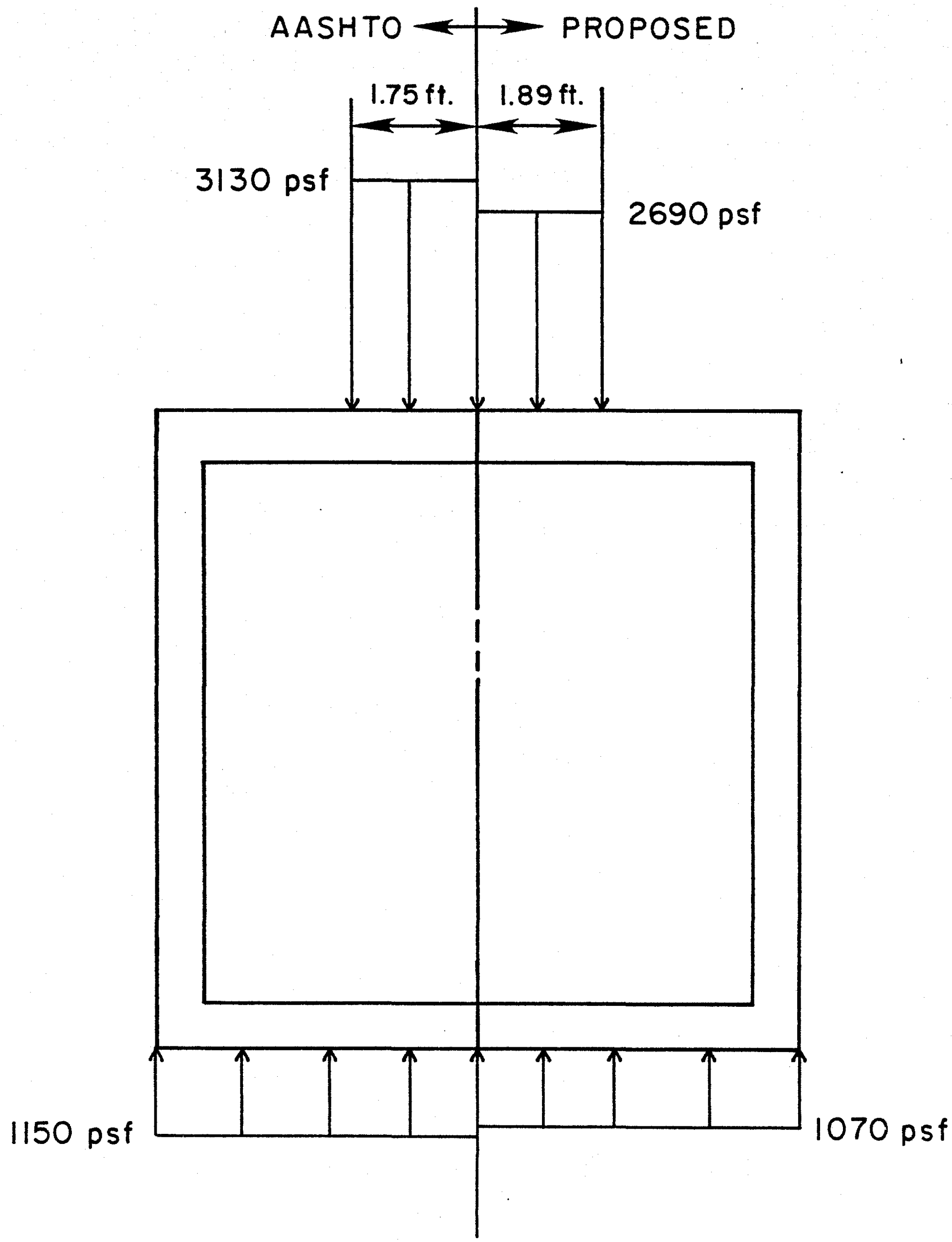


FIG. 63 - Comparison of Vertical Live Load Design Pressures for Examples Illustrating AASHTO Method and Proposed Method (1 ft = 0.305 m, 1 psf = 47.9 Pa)

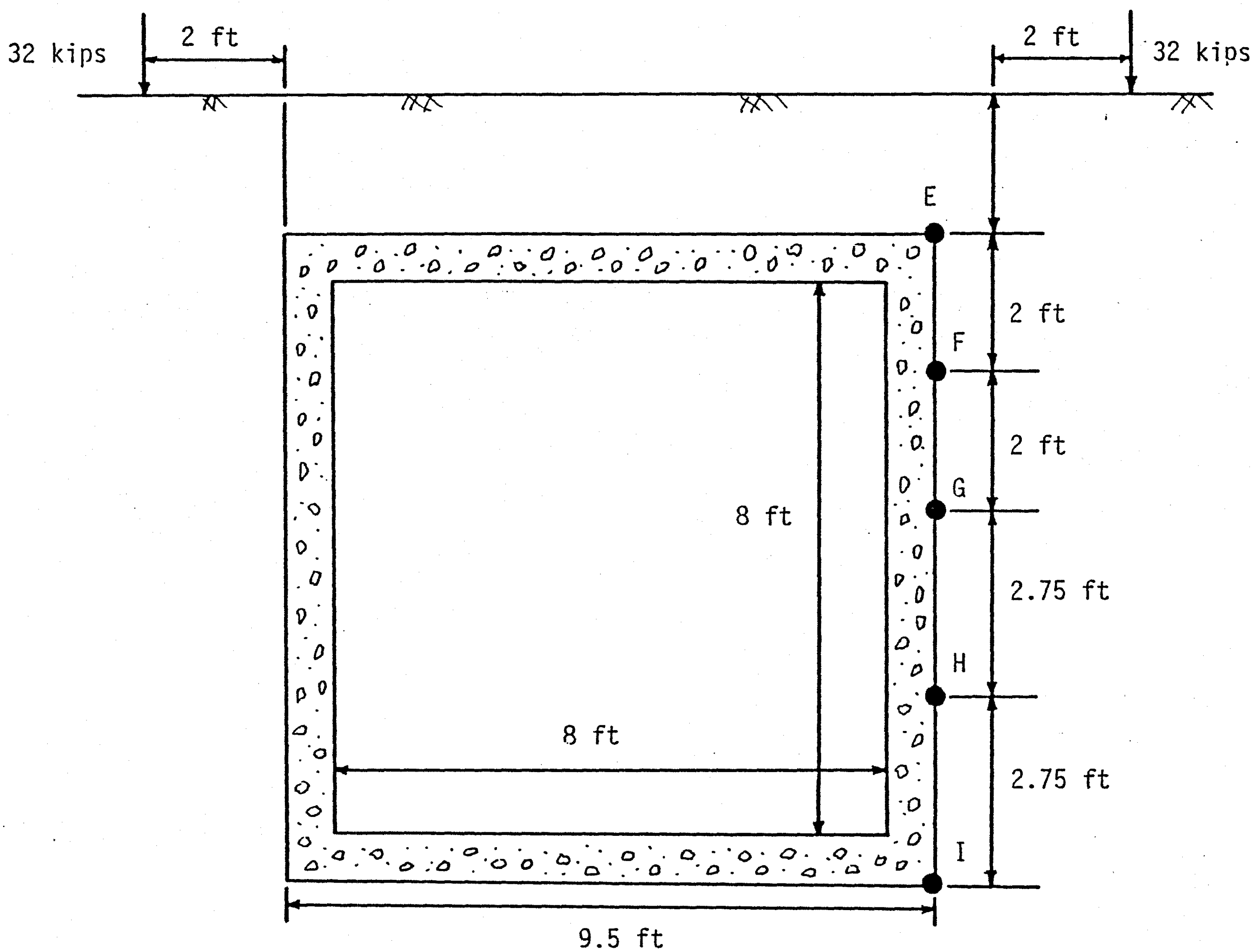


FIG. 64 - Geometry for Proposed Method's Horizontal Live Load Example (1 ft = 0.305 m, 1 lb = 4.45 N)

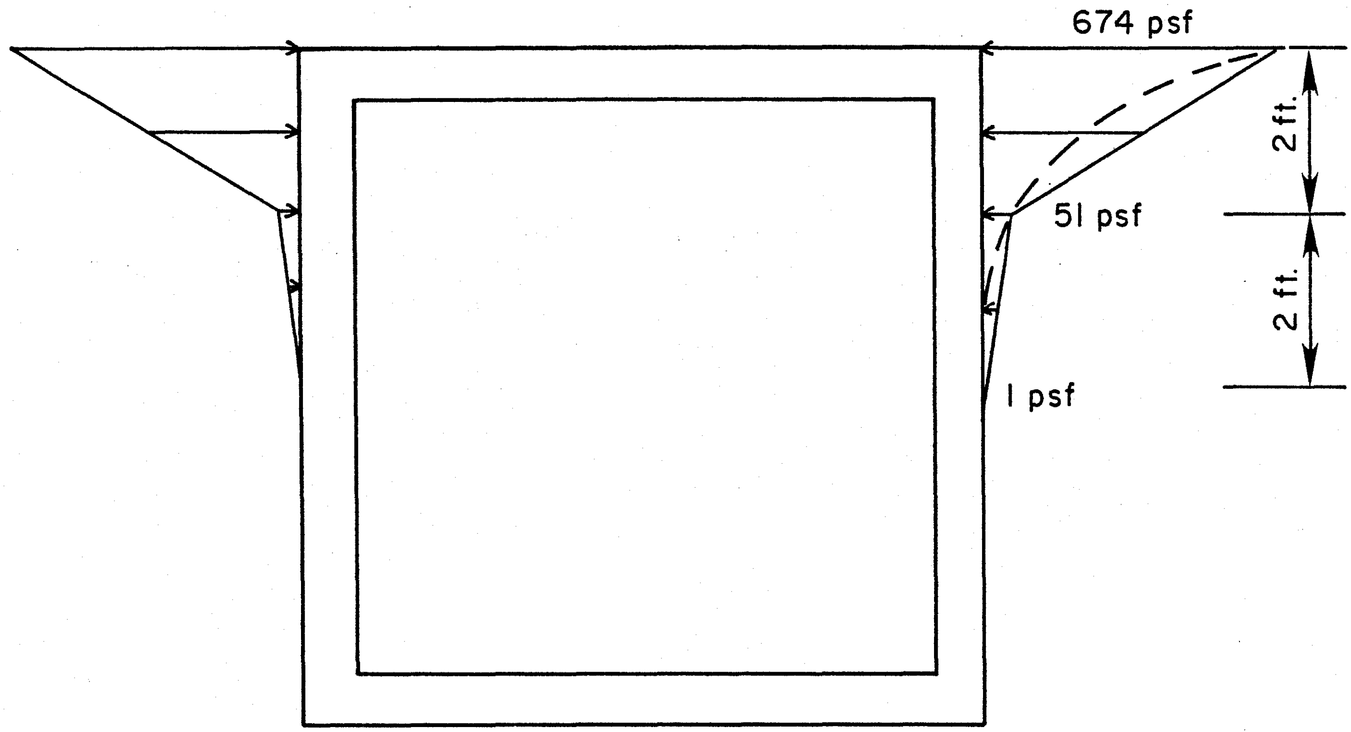


FIG. 65 - Horizontal Live Load Pressures
for Example Illustrating Proposed
Method (1 ft = 0.305 m, 1 psf = 47.9 Pa)

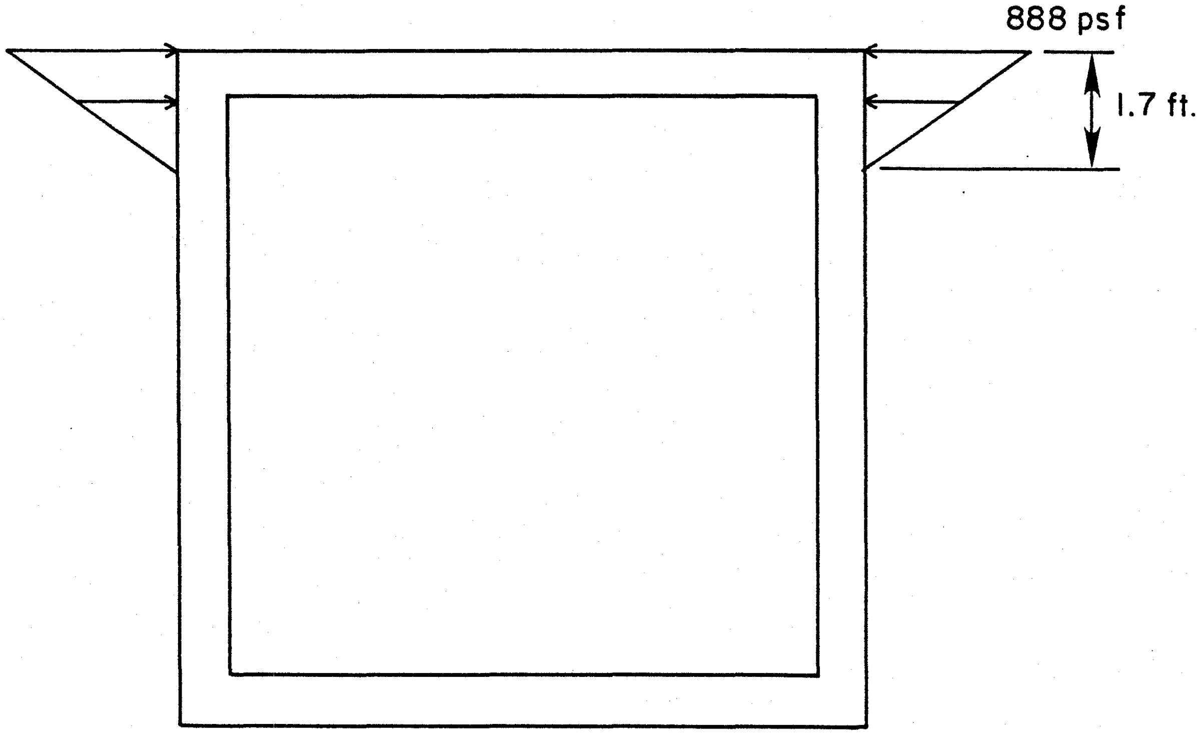


FIG. 66 - Horizontal Live Load Pressure for Example Illustrating Simplified Method (1 ft = 0.305 m, 1 psf = 47.9 Pa)

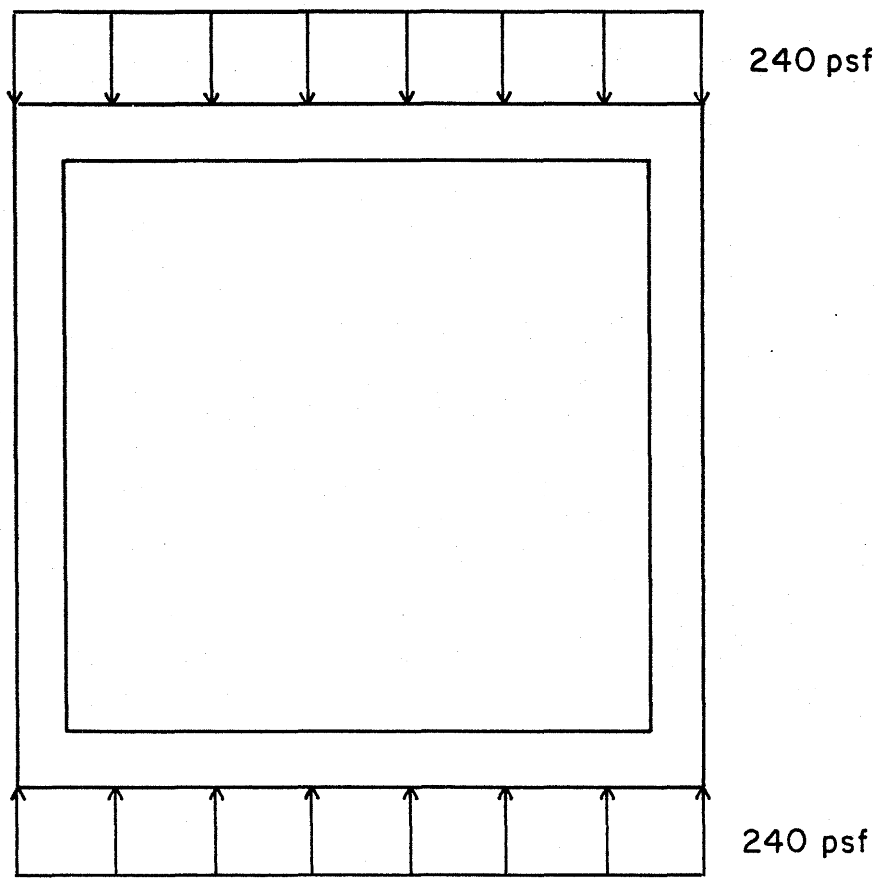


FIG. 67 - Vertical Dead Load Pressures for Example Illustrating Proposed Method (1 psf _ 47.9 Pa)

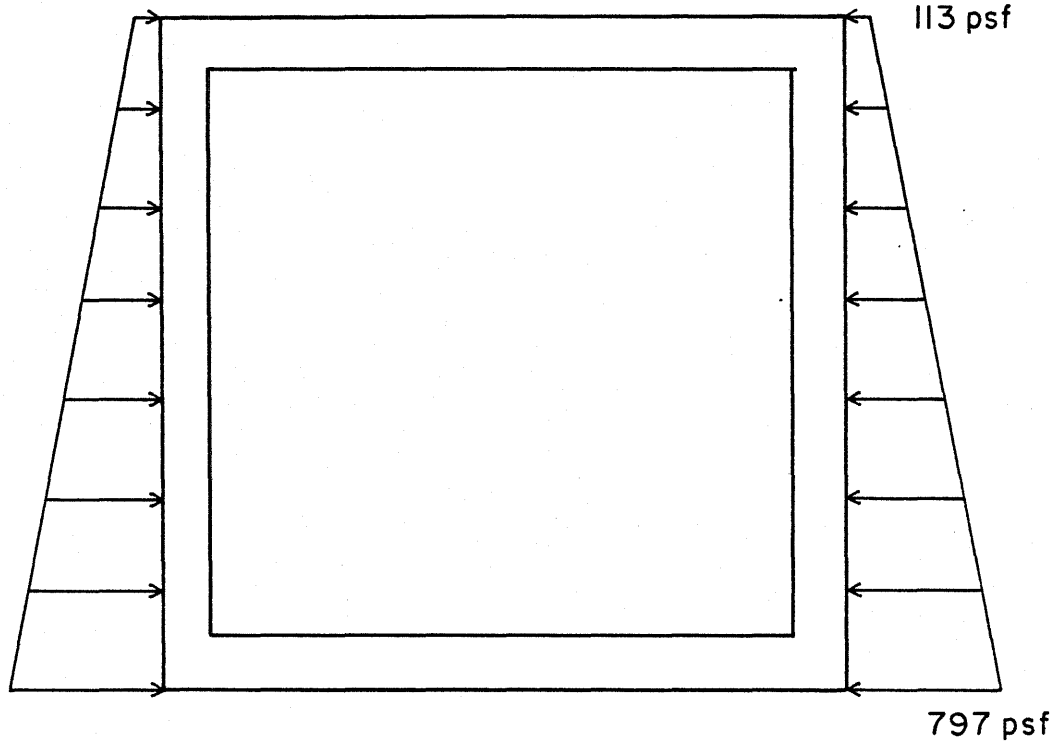


FIG. 68 - Horizontal Dead Load Pressures
for Example Illustrating Propsoed
Method with No Arching
(1 psf = 47.9 Pa)

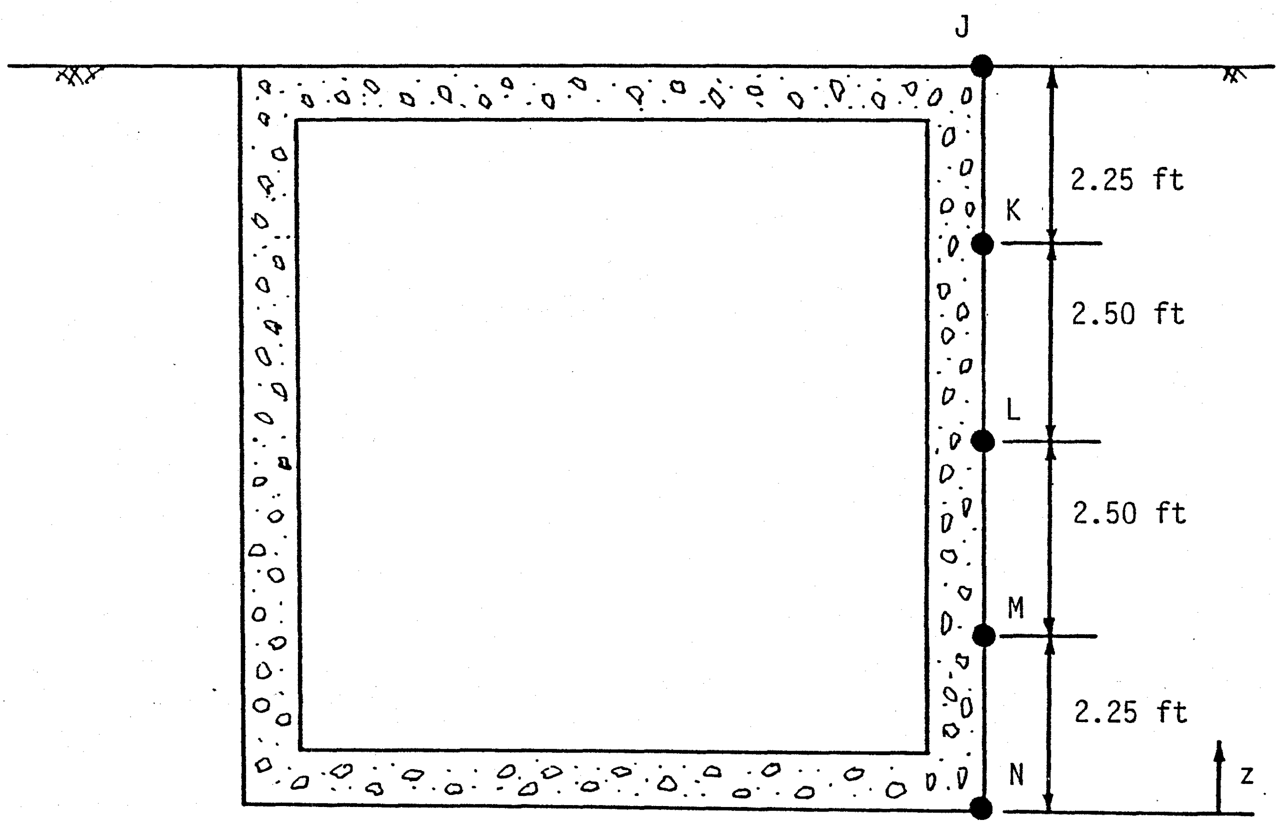


FIG. 69- Geometry for Example Illustrating Horizontal Dead Load Pressures by Proposed Method with Arching (1 ft = 0.305 m)

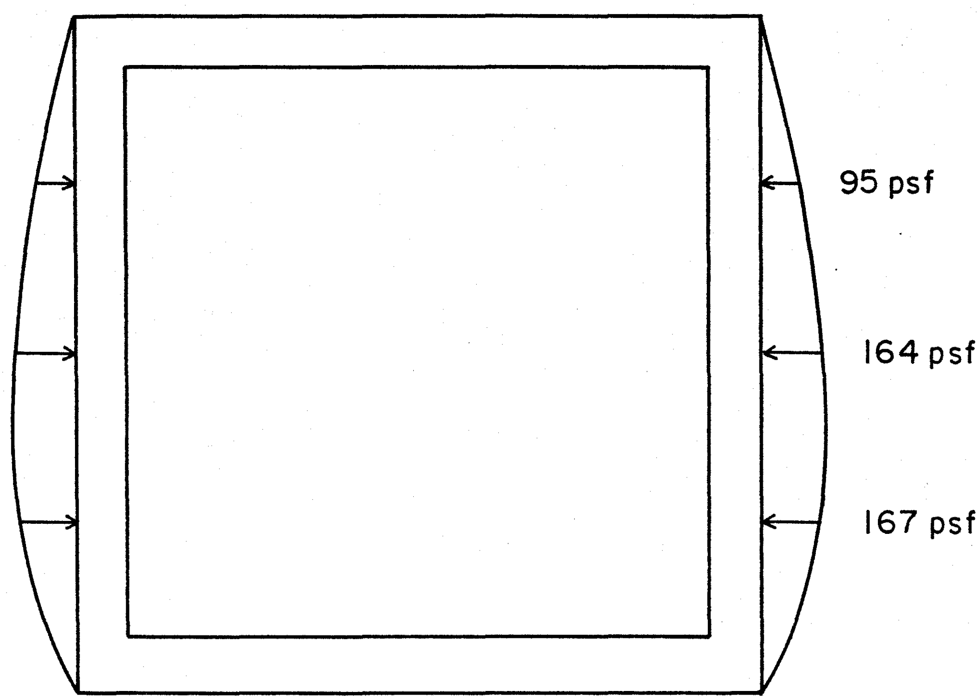


FIG. 70 - Horizon Dead Load Pressures for Example Illustrating Proposed Method with Arching (1 psf = 47.9 Pa)

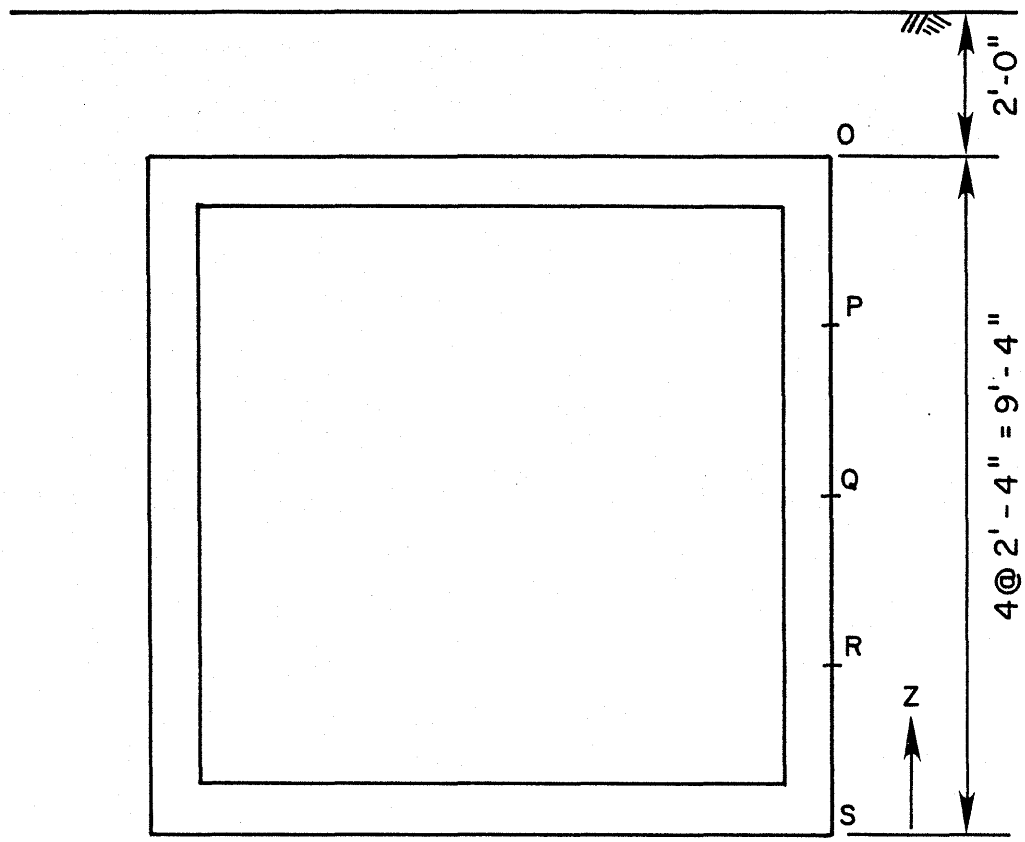


FIG. 71 - Geometry for Example Illustrating Proposed Method's Horizontal Dead Load With Arching and Cover (1 ft = 0.305 m)

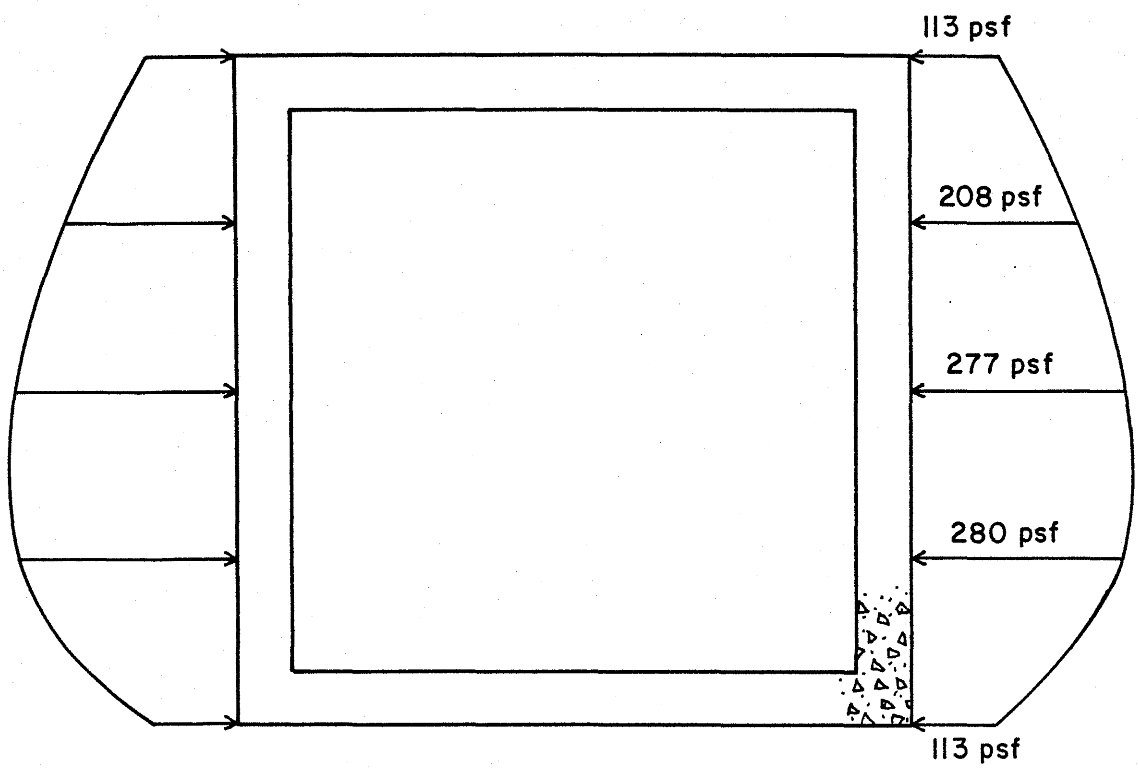


FIG. 72 - Horizontal Dead Load Pressures with Arching and Surchage for Proposed Method (psf = 47.9 Pa)

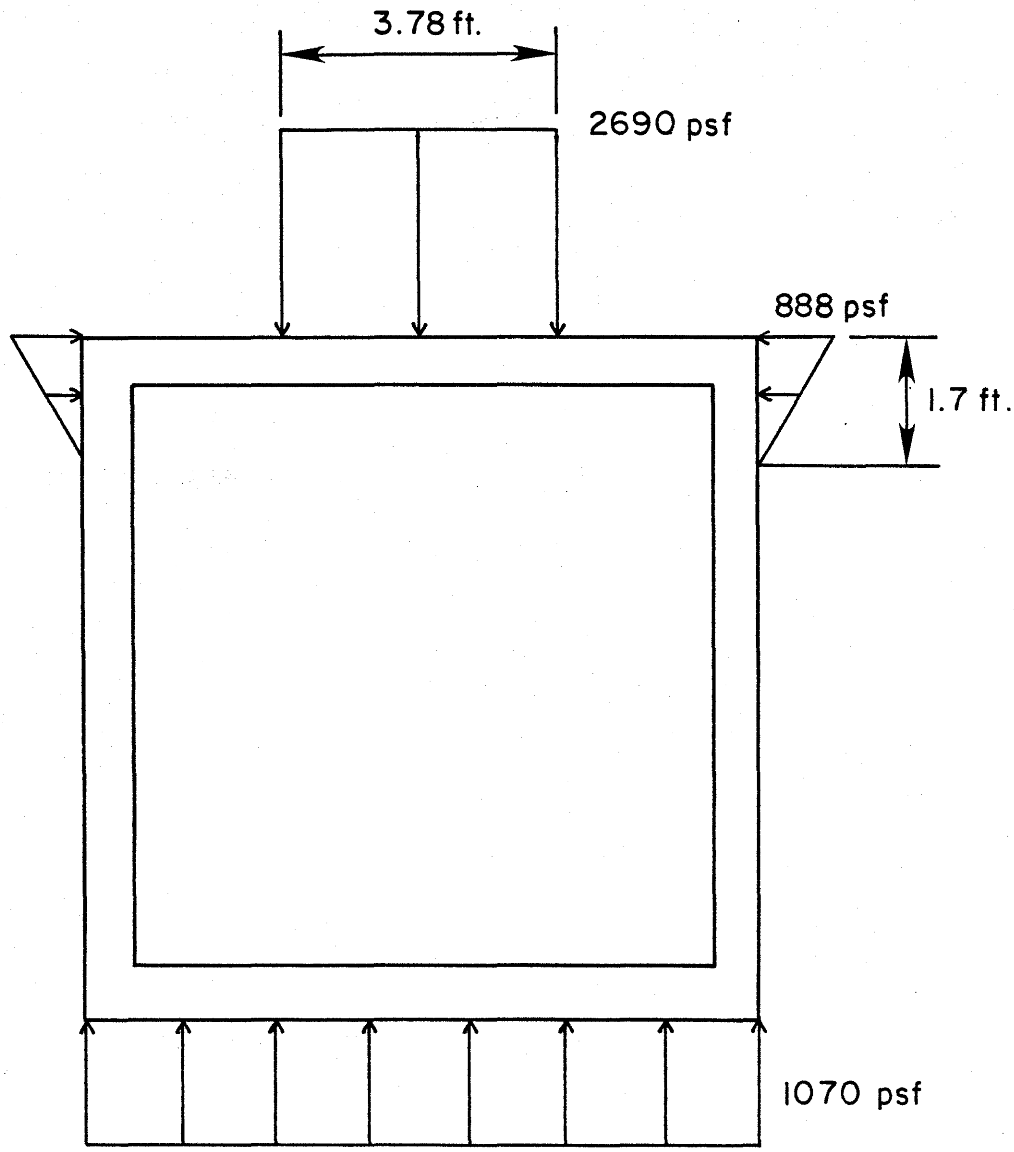


FIG. 73 - Vertical and Horizontal Live Load Pressures for Simplified Procedure Example (1 psf = 47.9 Pa, 1 ft = 0.305 m)

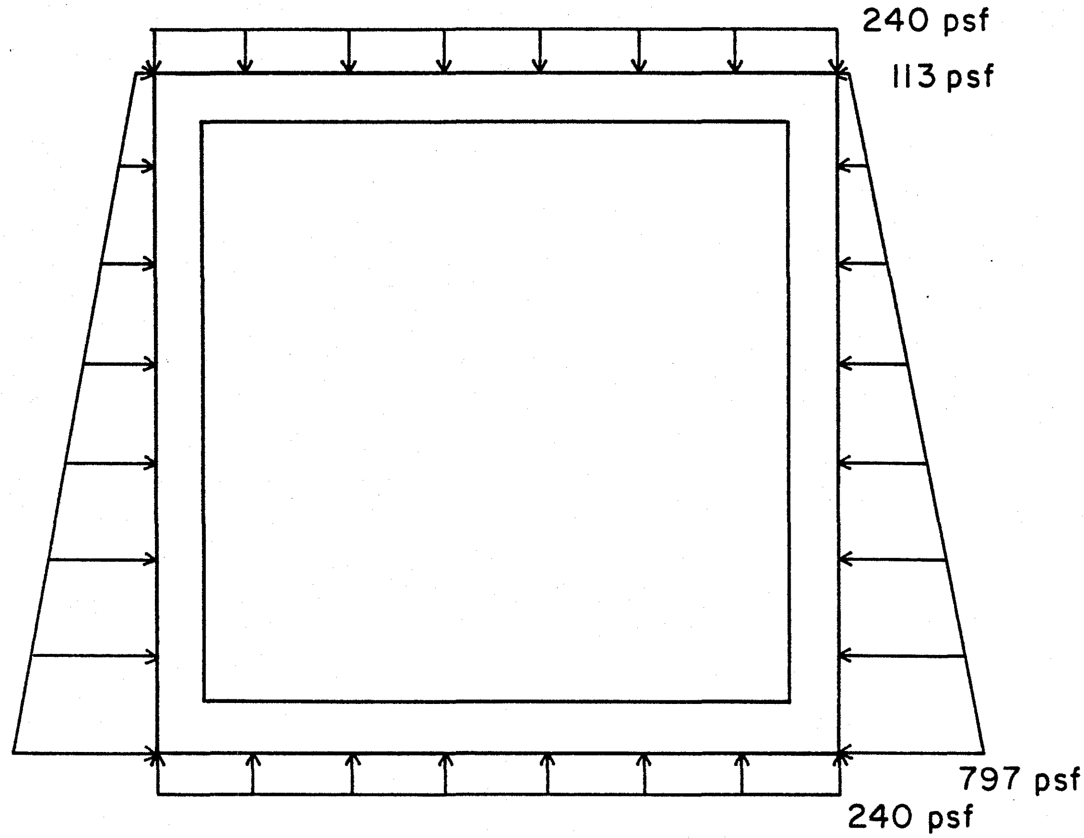


FIG. 74 - Vertical and Horizontal Dead Load Pressures for Example Illustrating Proposed Method with No Arching (1 psf = 47.9 psf)

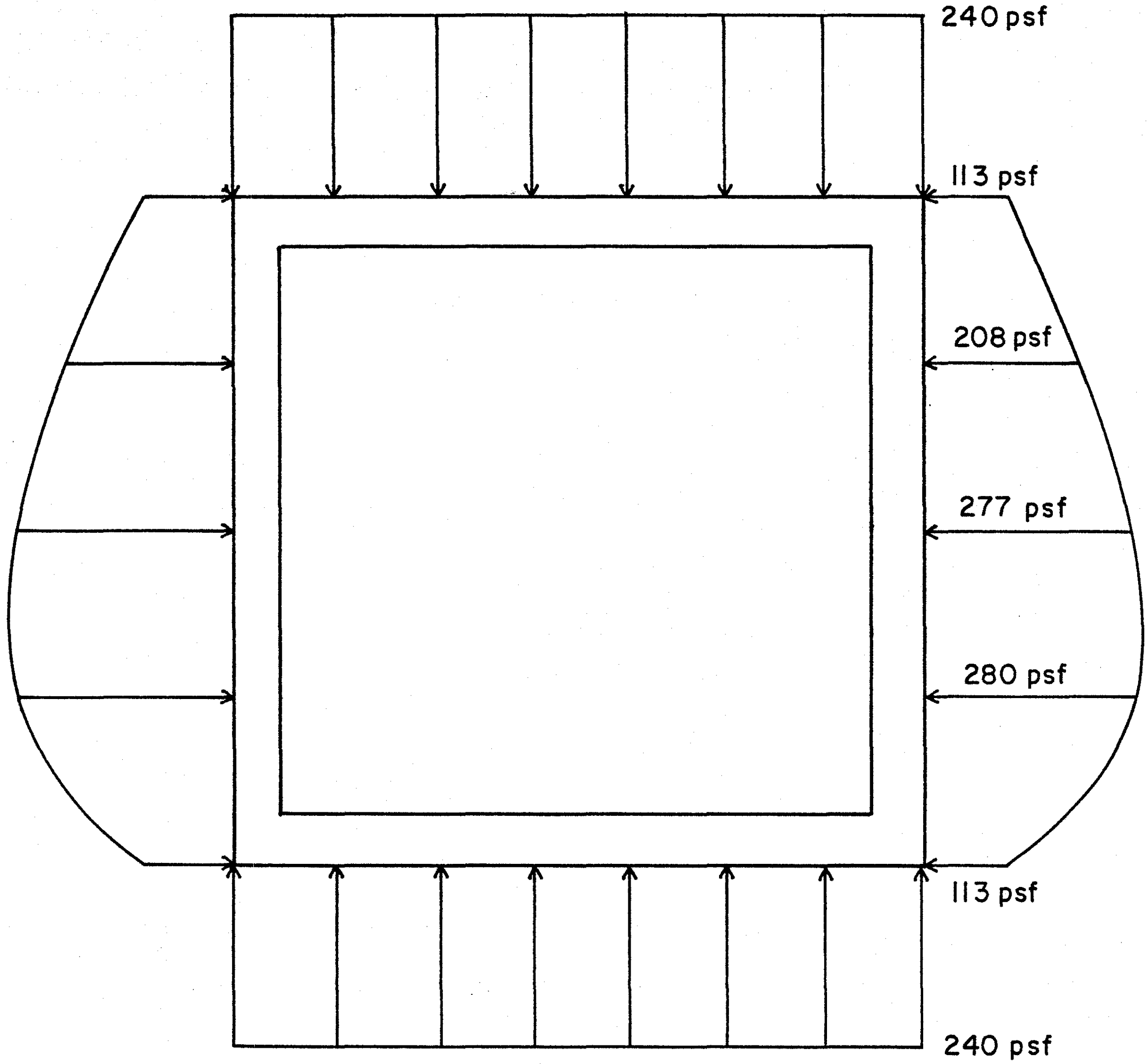


FIG. 75 - Vertical and Horizontal Dead Load Pressures for Example Illustrating Proposed Method with Arching
(1 psf = 47.9 Pa)

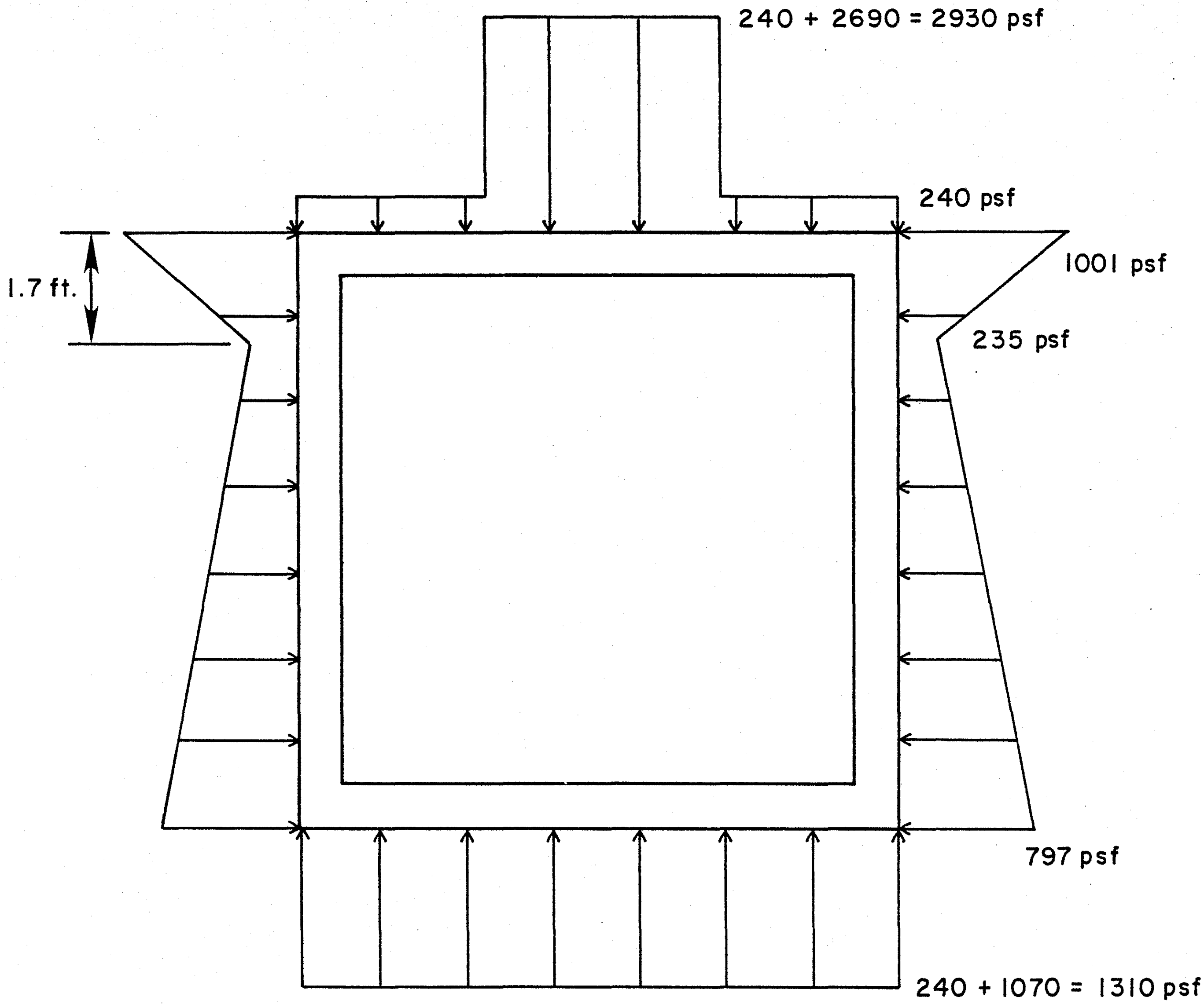


FIG. 76 - Live and Dead Load Pressures for Example Illustrating Proposed Method with No Arching (1 ft = 0.305 m, 1 psf = 47.9 Pa)

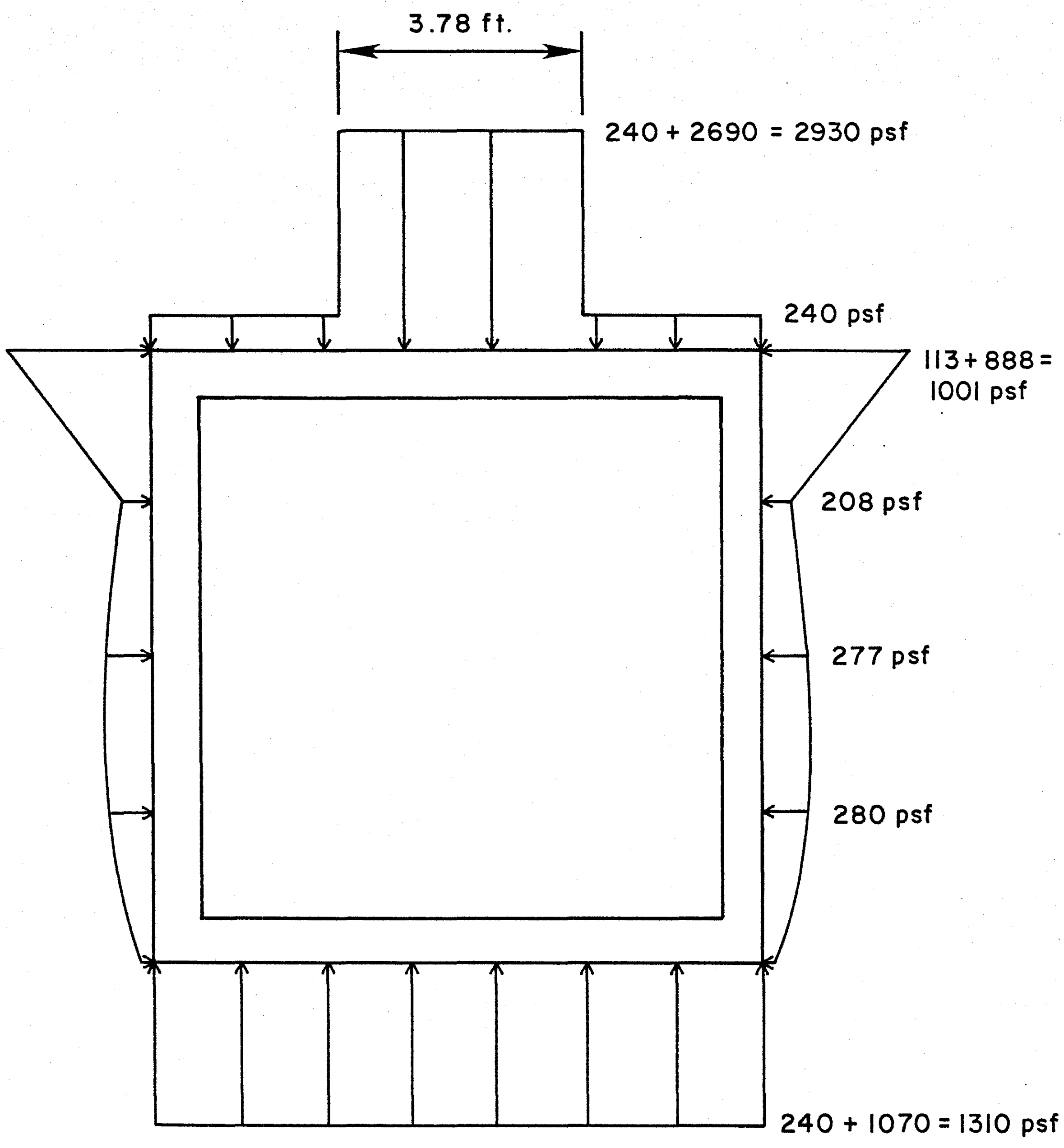


FIG. 77 - Live and Dead Load Pressures for Example Illustrating Proposed Method with Arching (1 ft = 0.305 m, 1 psf = 47.9 Pa)

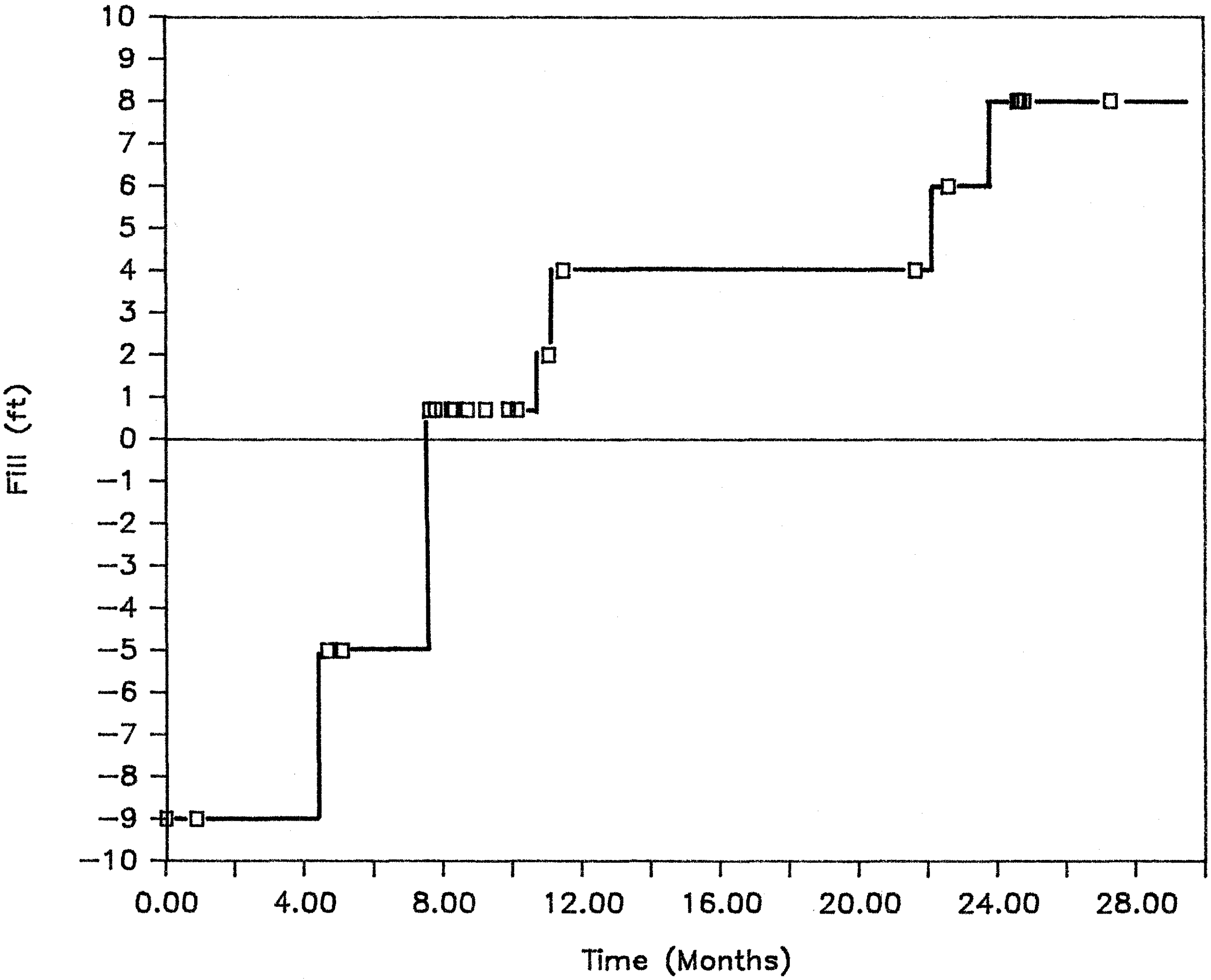


FIG. 78 - Construction Schedule: Depth of Cover Over Top Slab

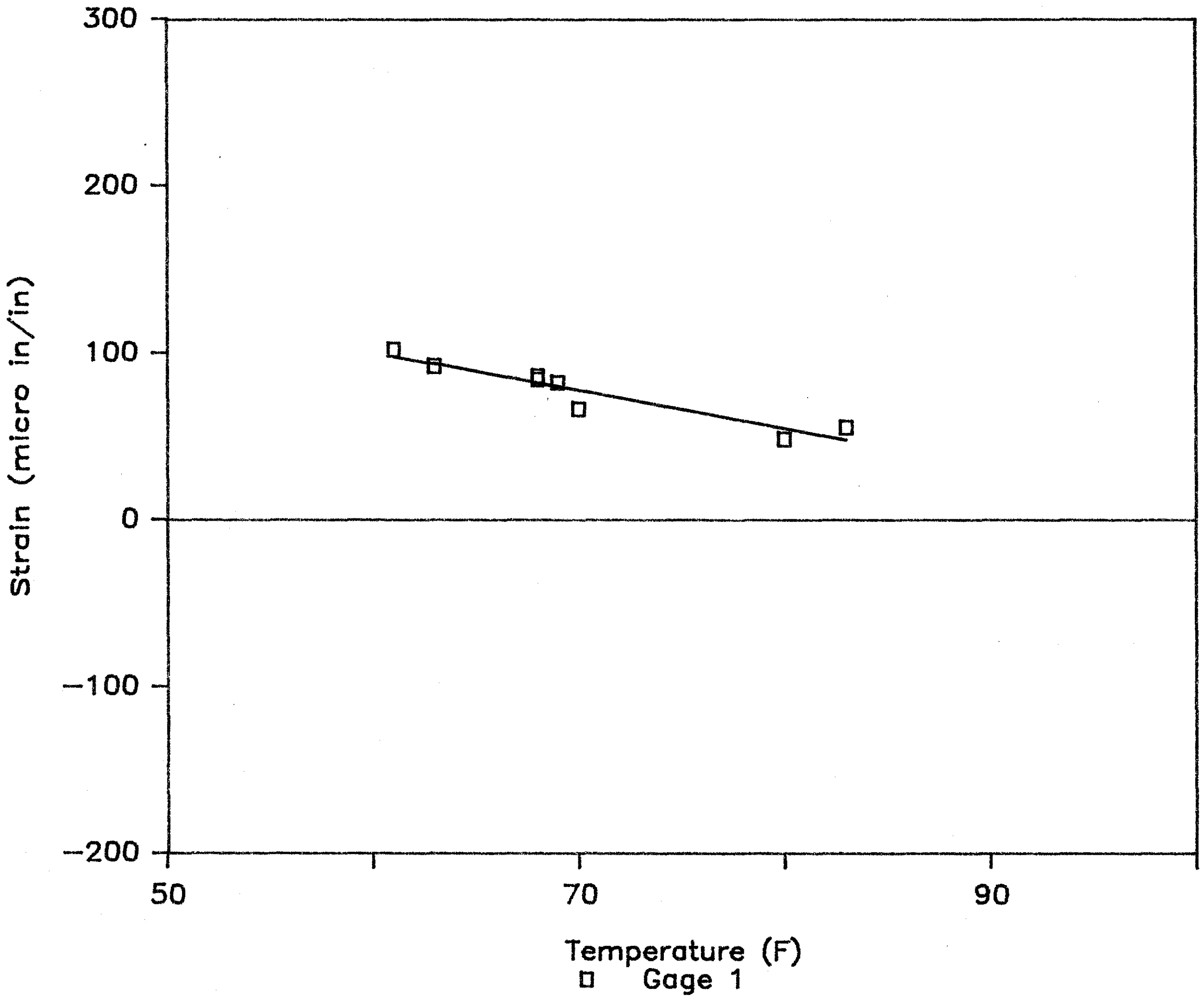


FIG. 79 - Effect of Culvert Temperature on Indicated Strain, Strain Gage 1

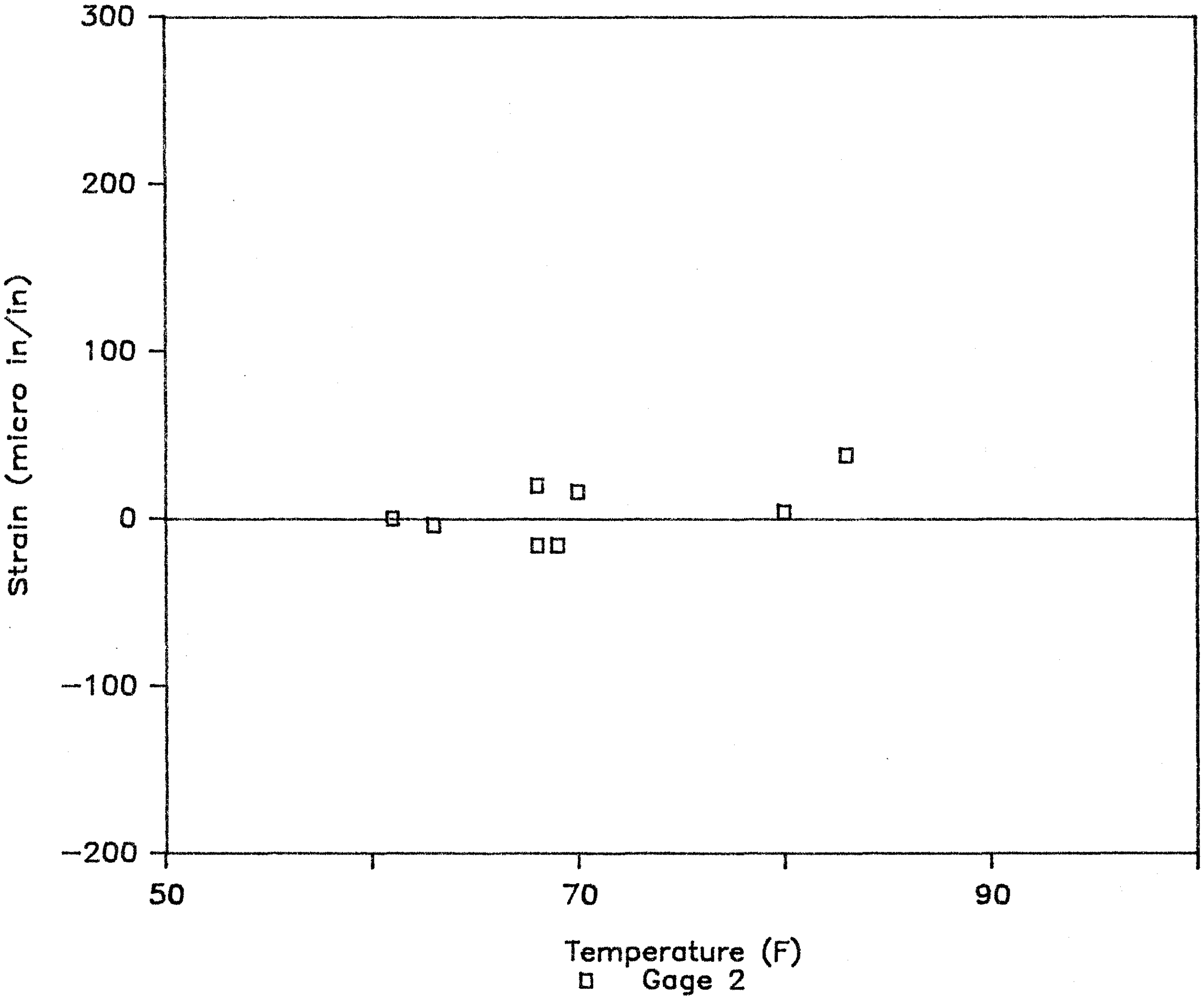


FIG. 80 - Effect of Culvert Temperature on Indicated Strain, Strain Gage 2

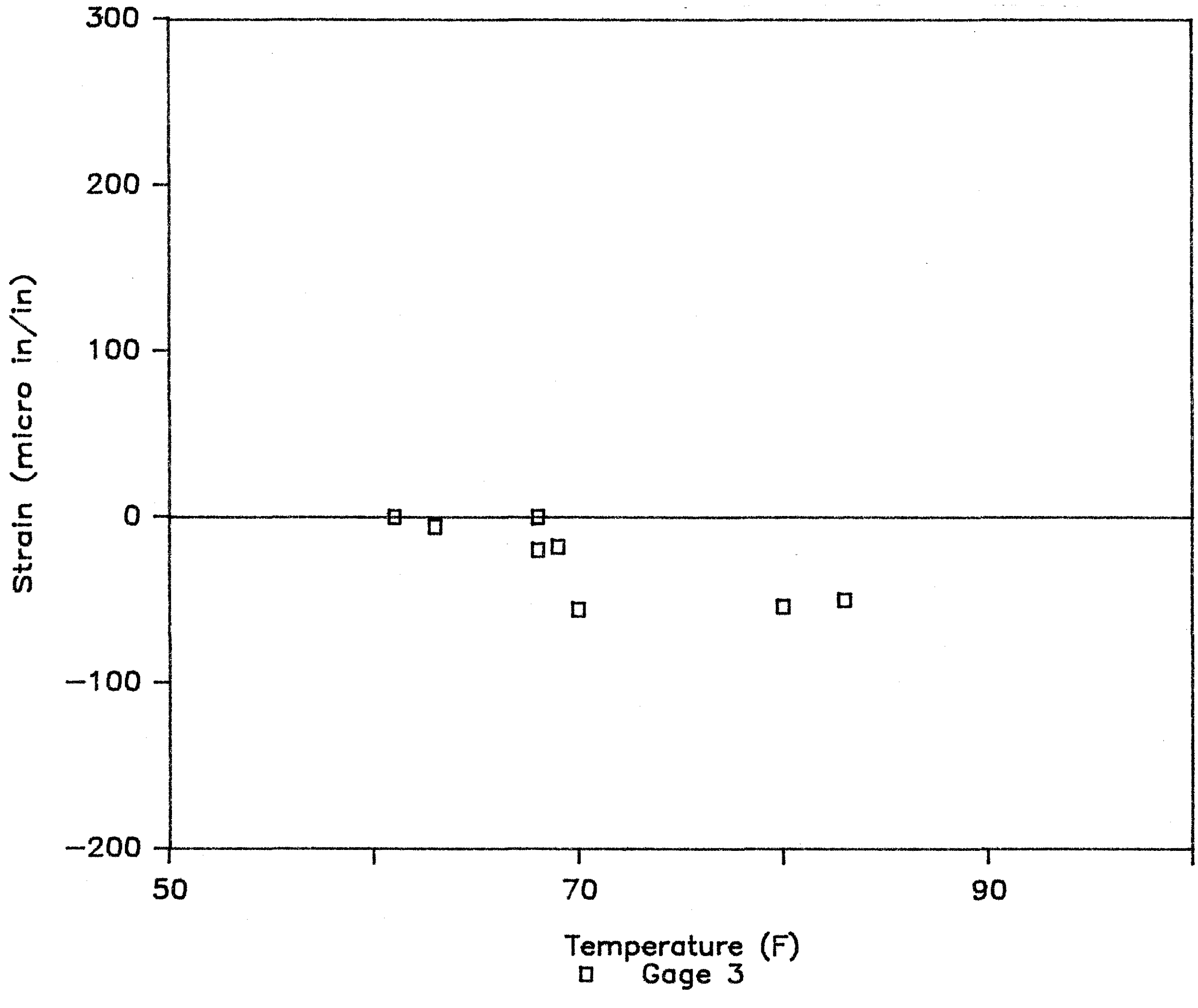


FIG. 81 - Effect of Culvert Temperature on Indicated Strain, Strain Gage 3

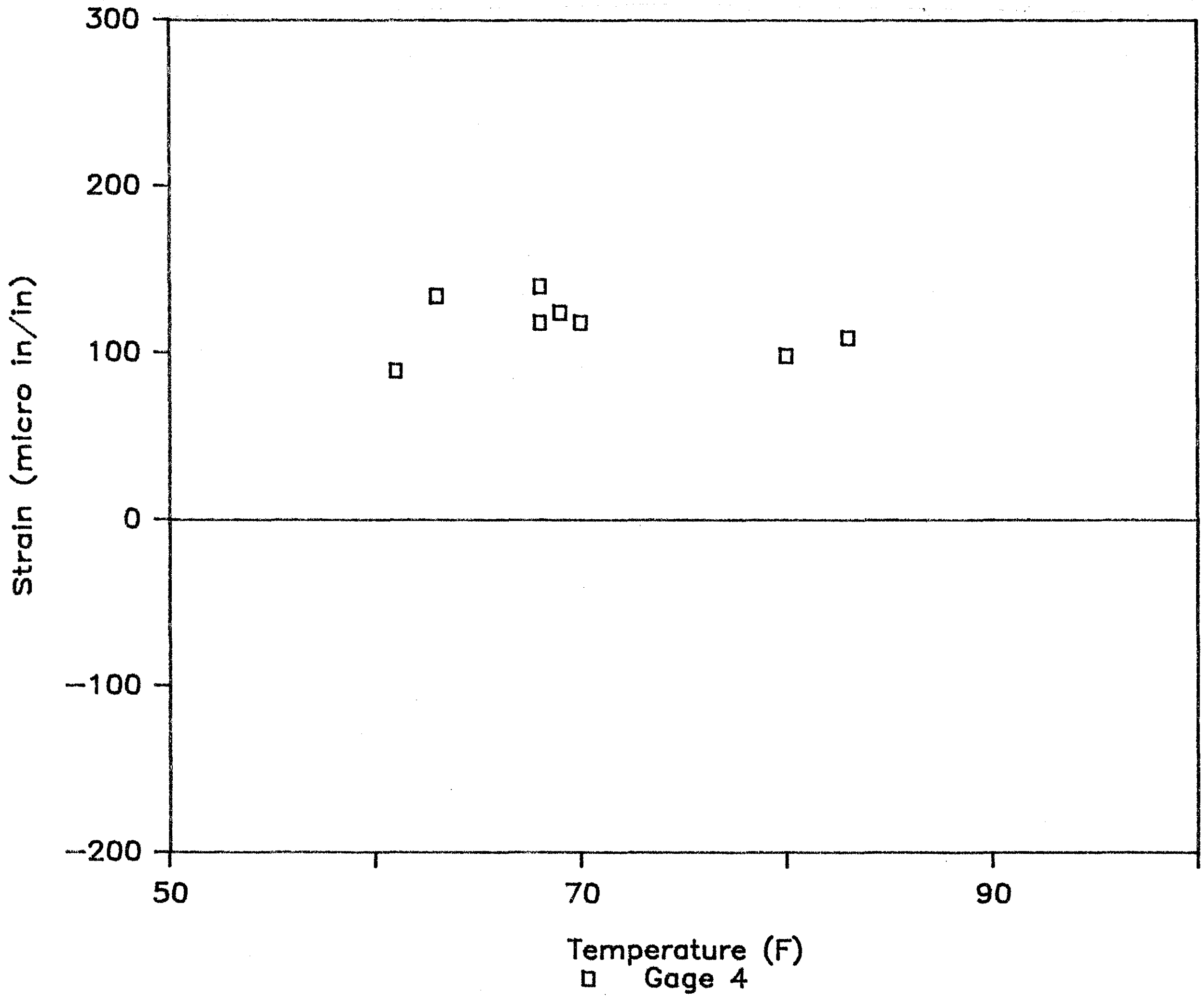


FIG. 82 - Effect of Culvert Temperature on Indicated Strain, Strain Gage 4

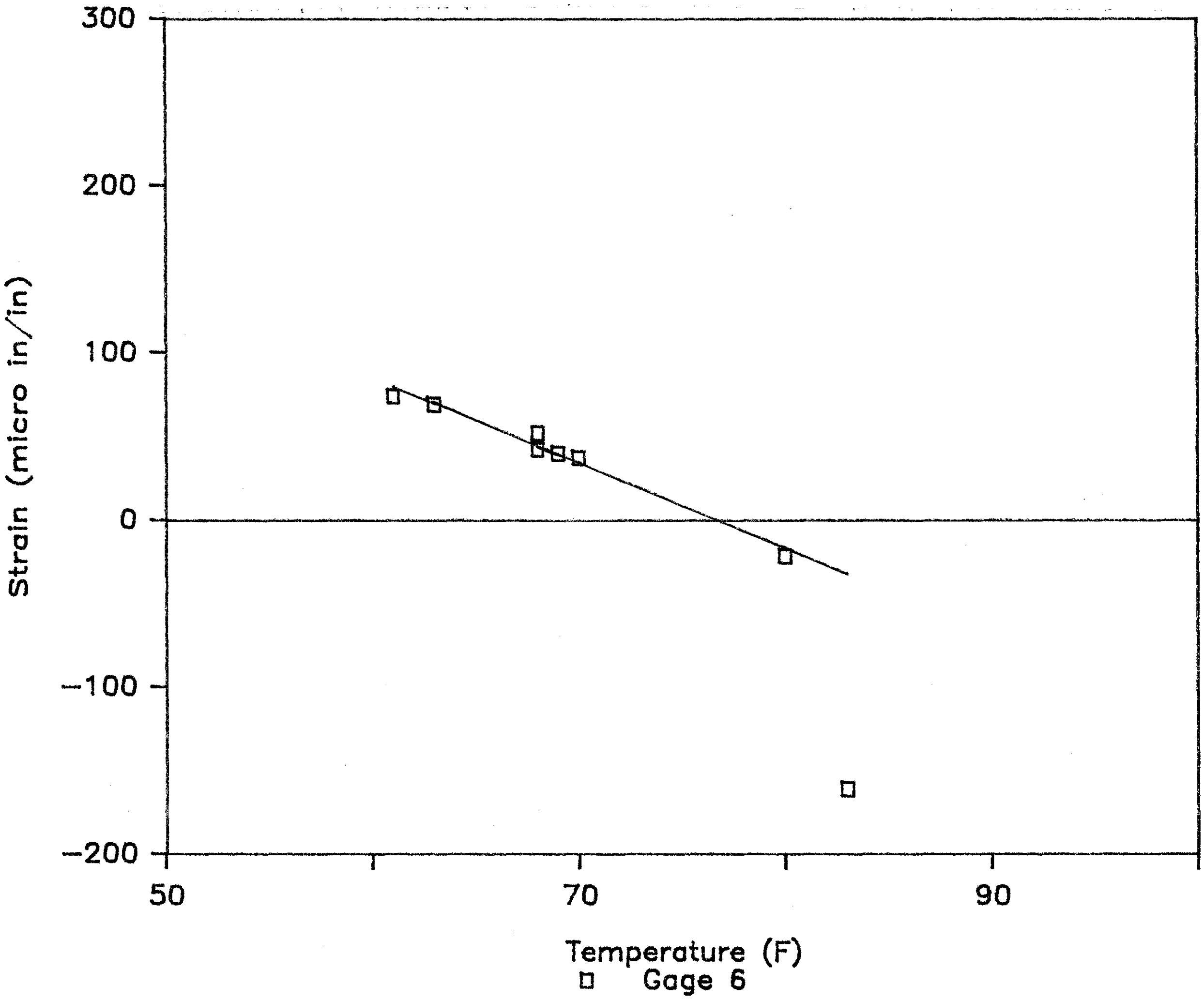


FIG. 83 - Effect of Culvert Temperature on Indicated Strain, Strain Gage 6

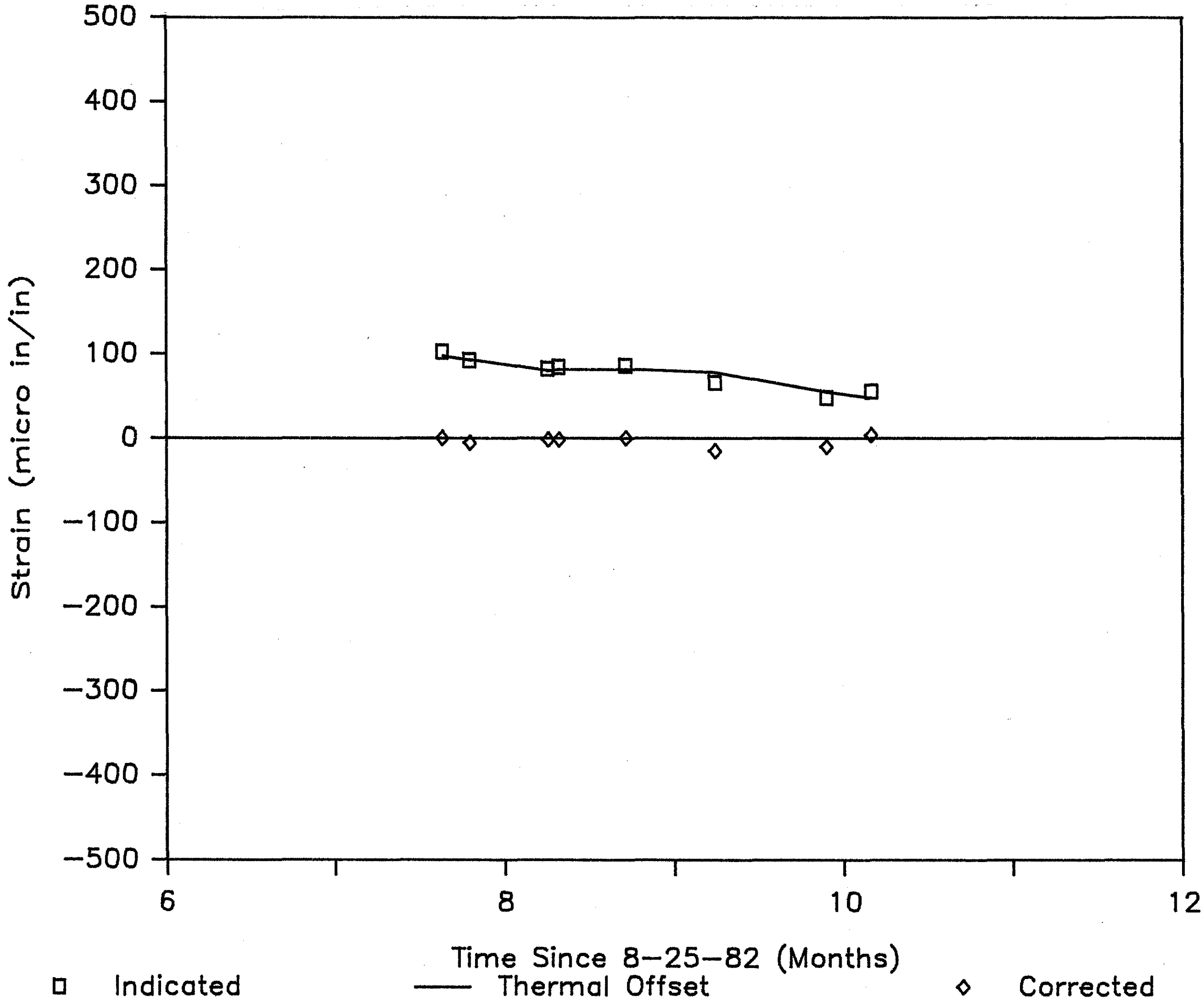


FIG. 84 - Constant Soil Cover Time History of Indicated Strain, Strain Gage 1

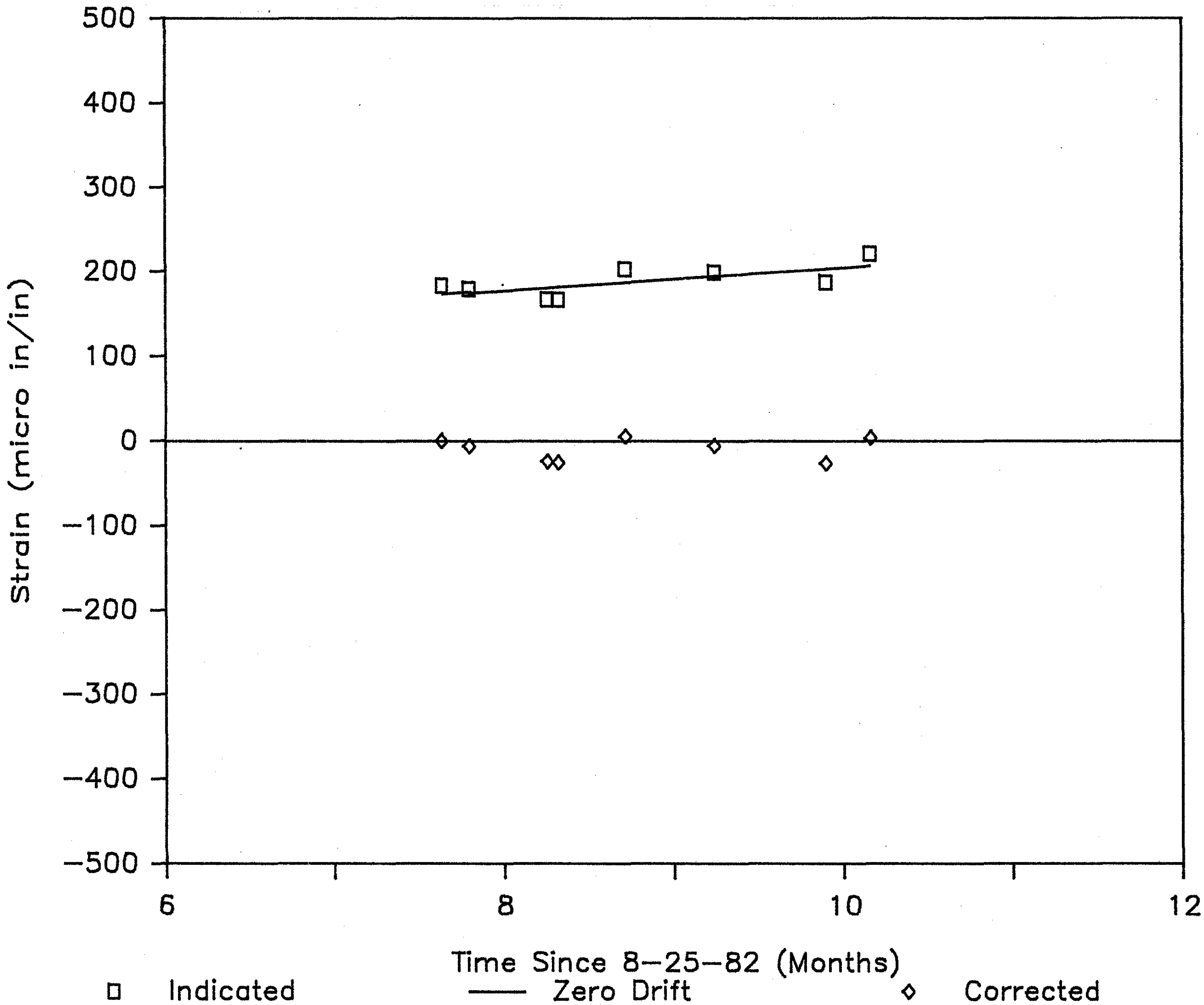


FIG. 85 - Constant Soil Cover Time History of Indicated Strain, Strain Gage 2

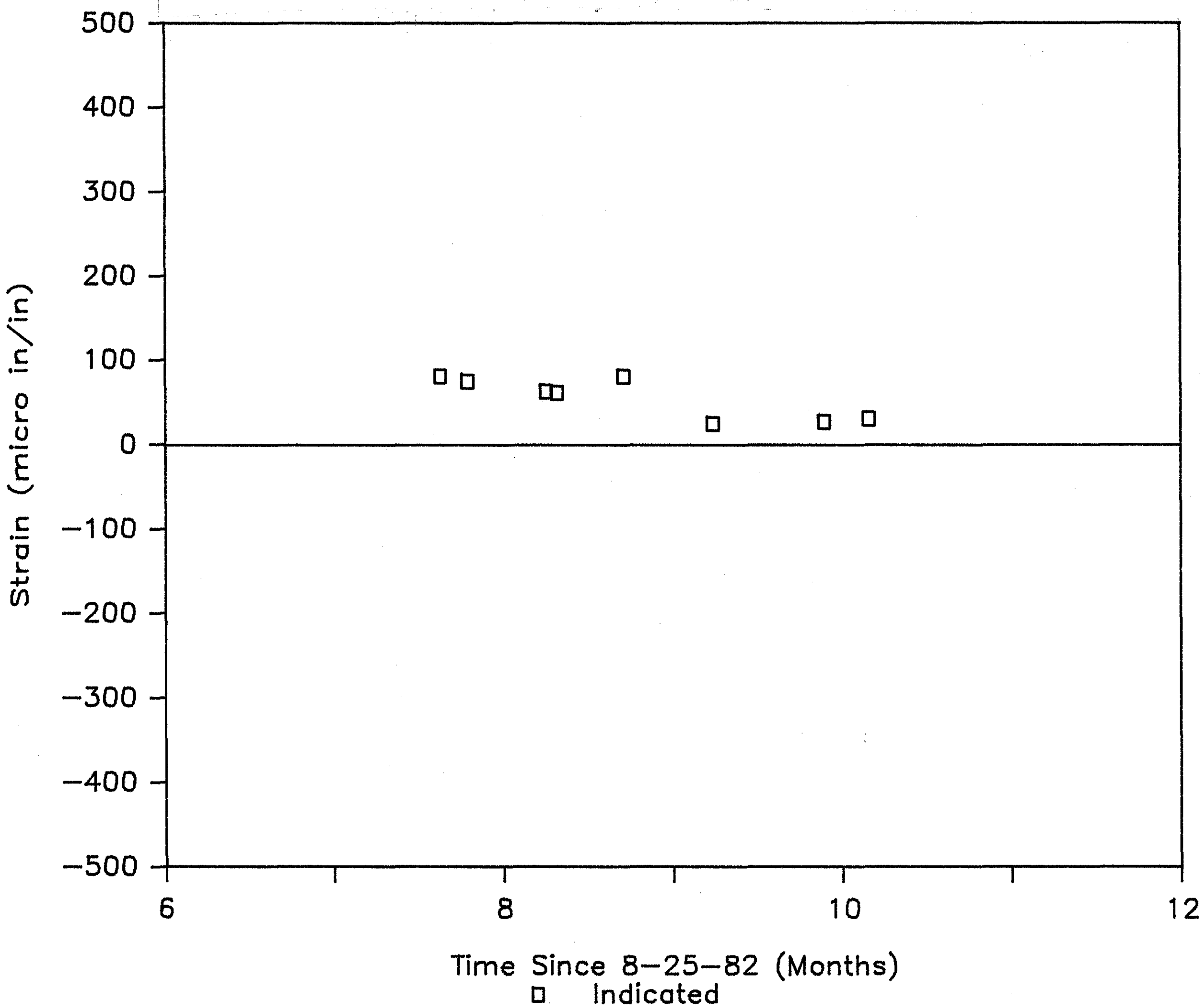


FIG. 86 - Constant Soil Cover Time History of Indicated Strain, Strain Gage 3

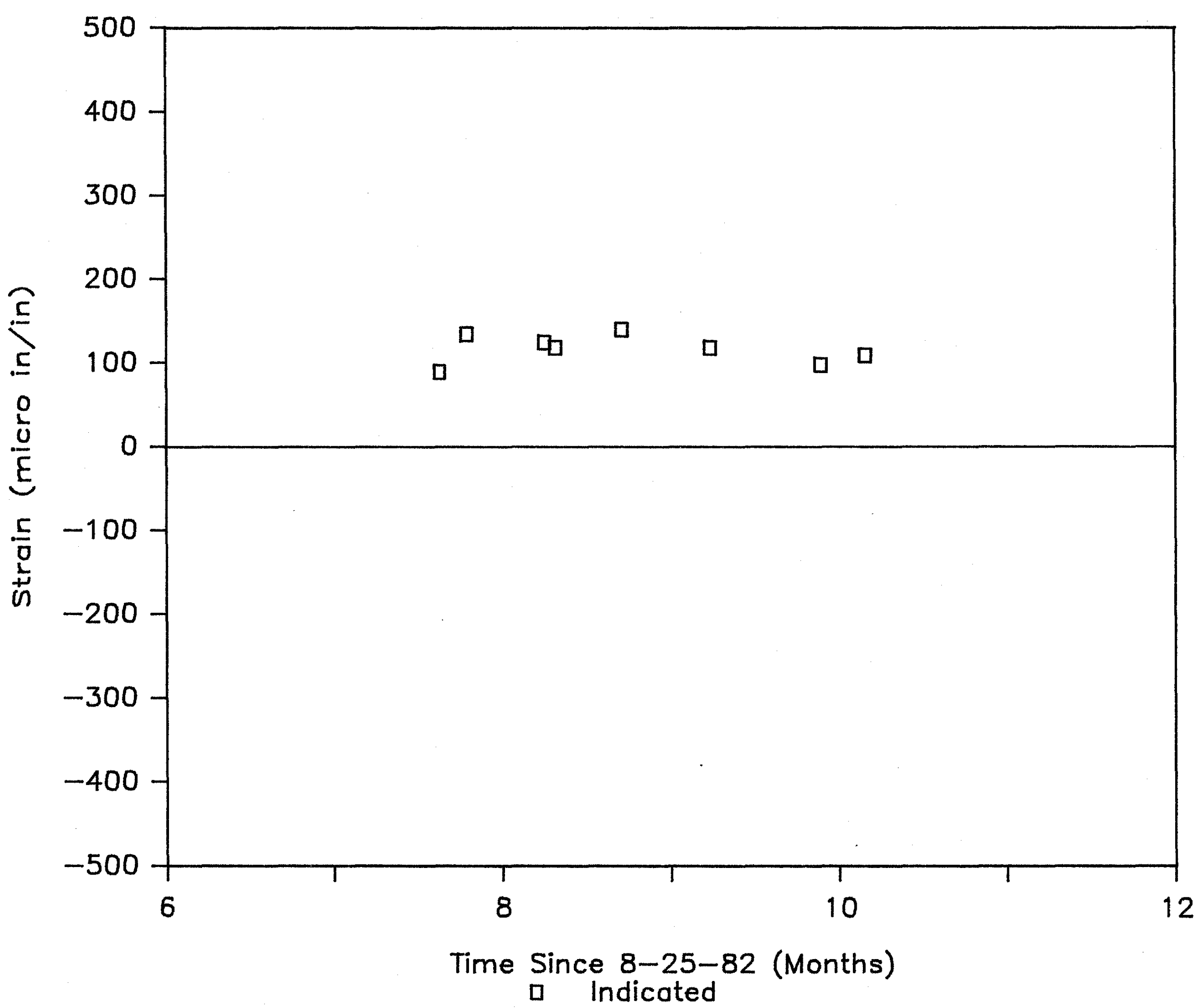


FIG. 87 - Constant Soil Cover Time History of Indicated Strain, Strain Gage 4

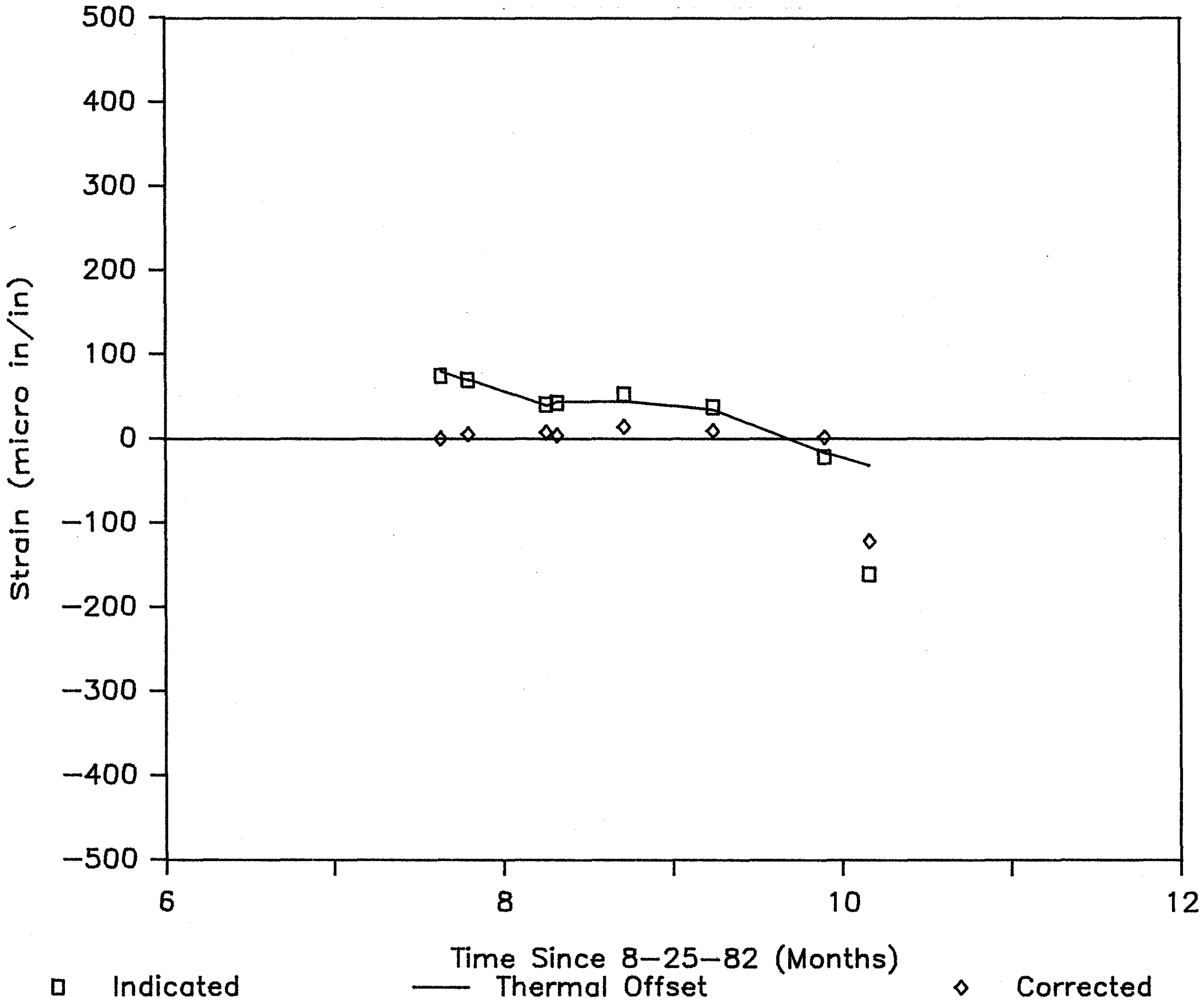


FIG. 88 - Constant Soil Cover Time History of Indicated Strain,
Strain Gage 6

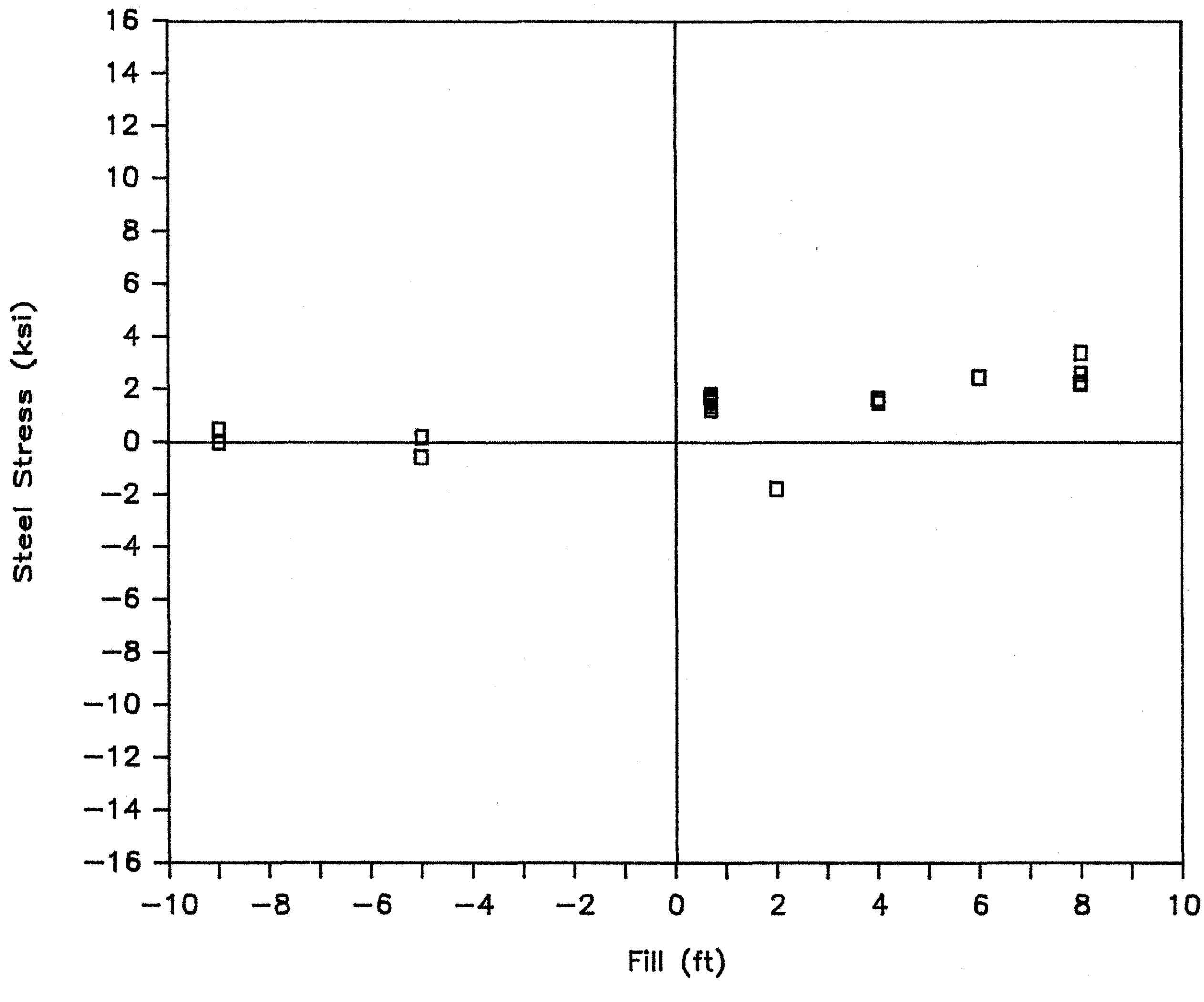


FIG. 89 - Effect of Soil Cover on Measured Steel Stress, Strain Gage 1

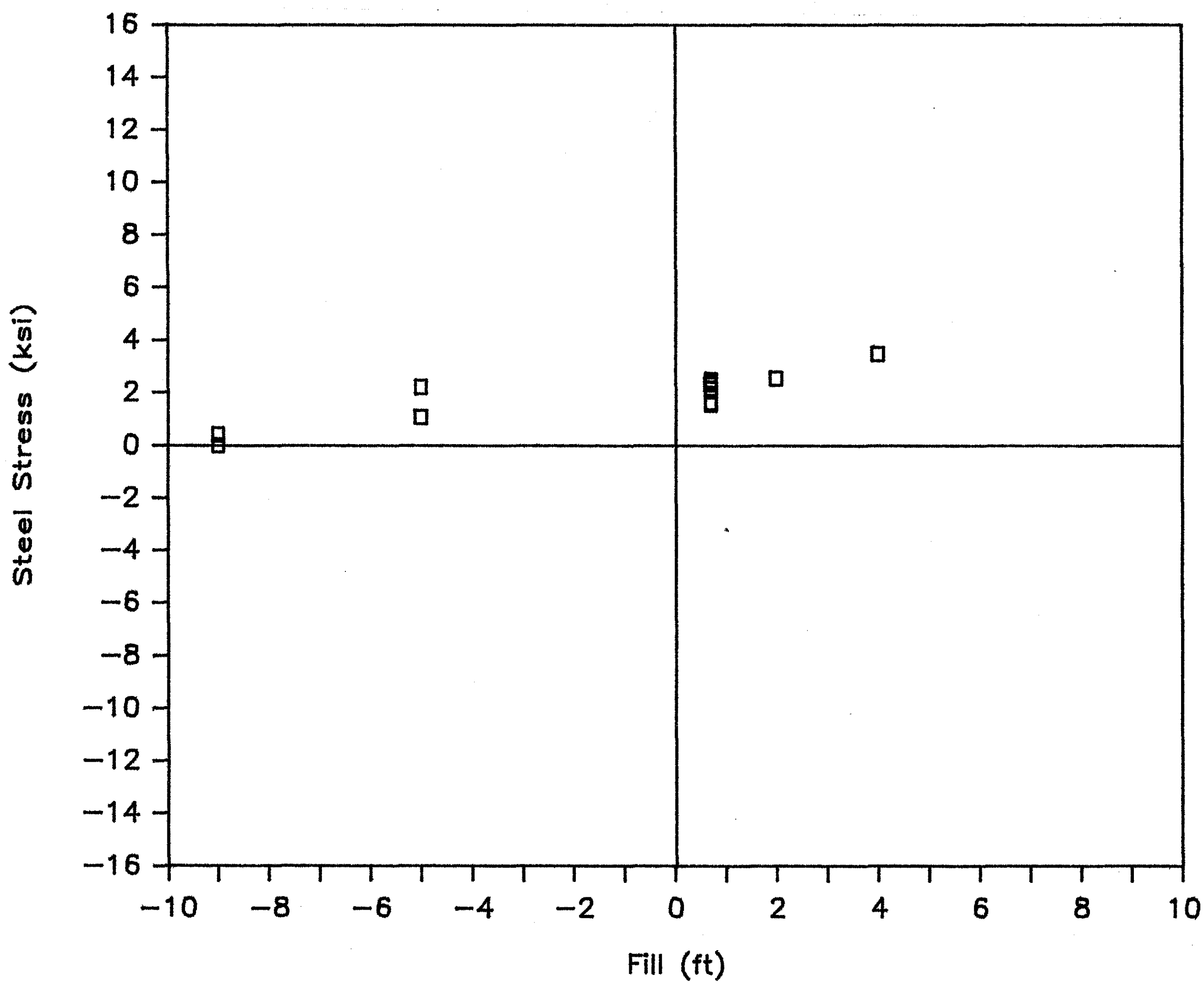


FIG. 90 - Effect of Soil Cover on Measured Steel Stress,
Strain Gage 2

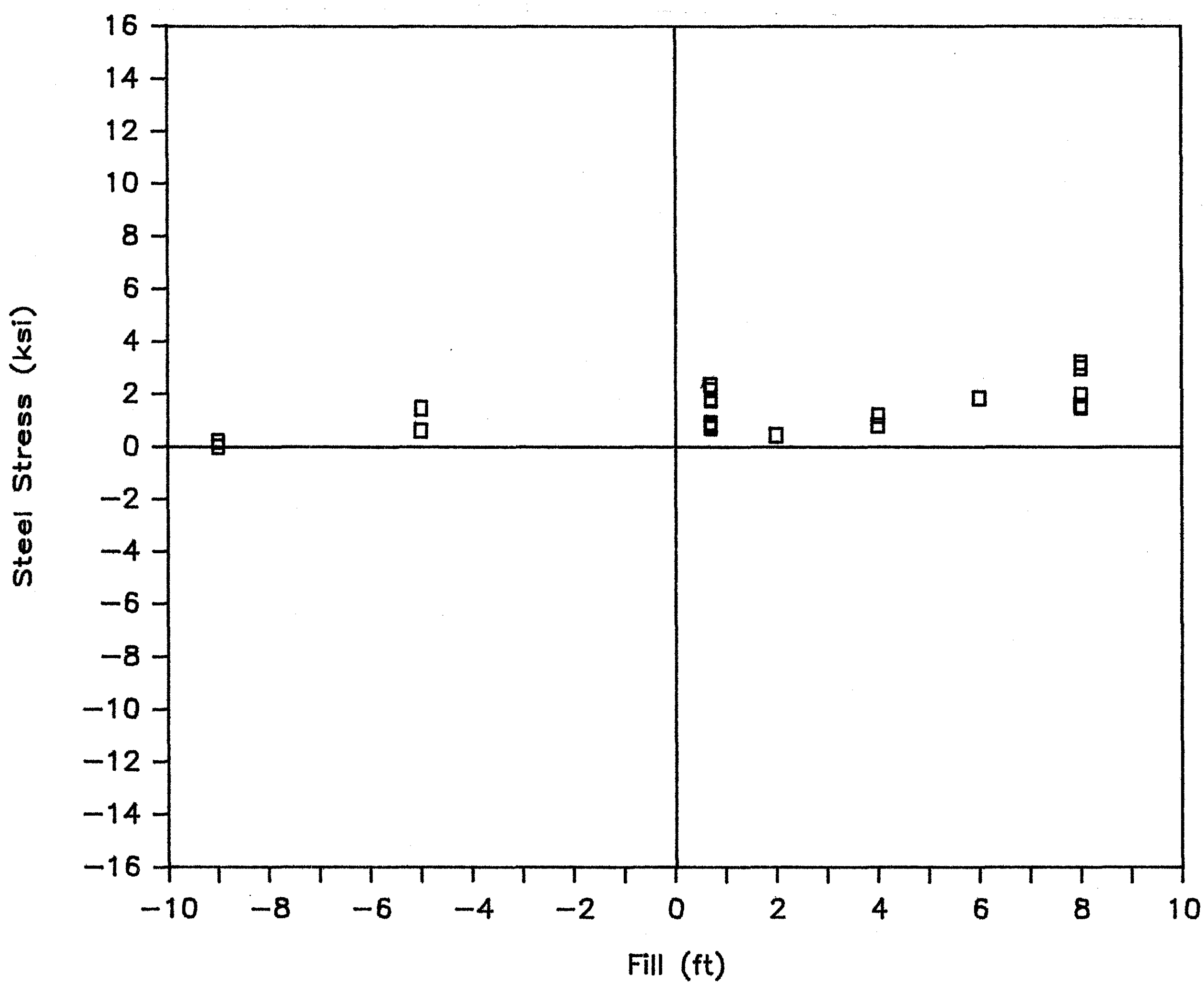


FIG. 91 - Effect of Soil Cover on Measured Steel Stress, Strain Gage 3

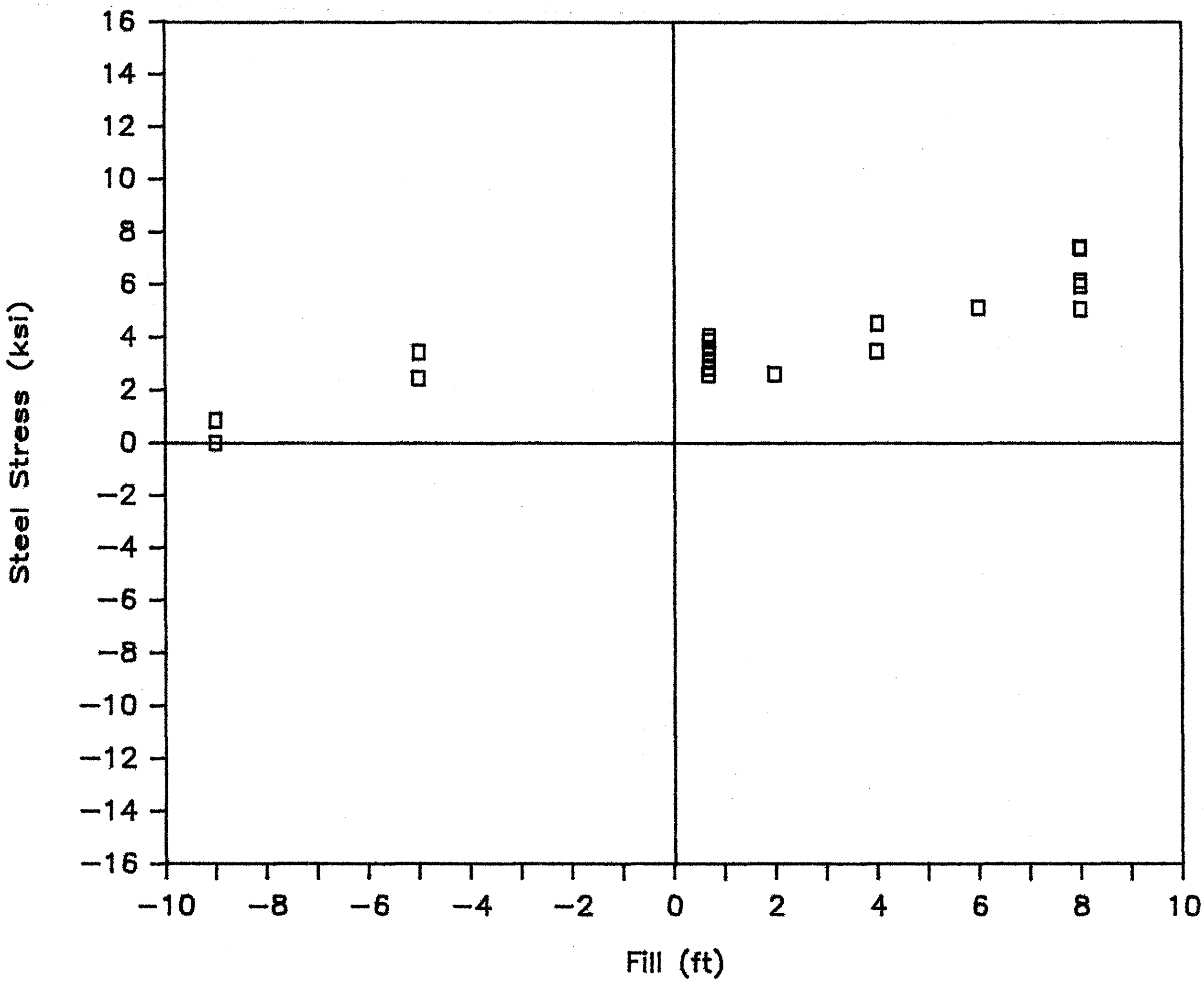


FIG. 92 - Effect of Soil Cover on Measured Steel Stress,
Strain Gage 4

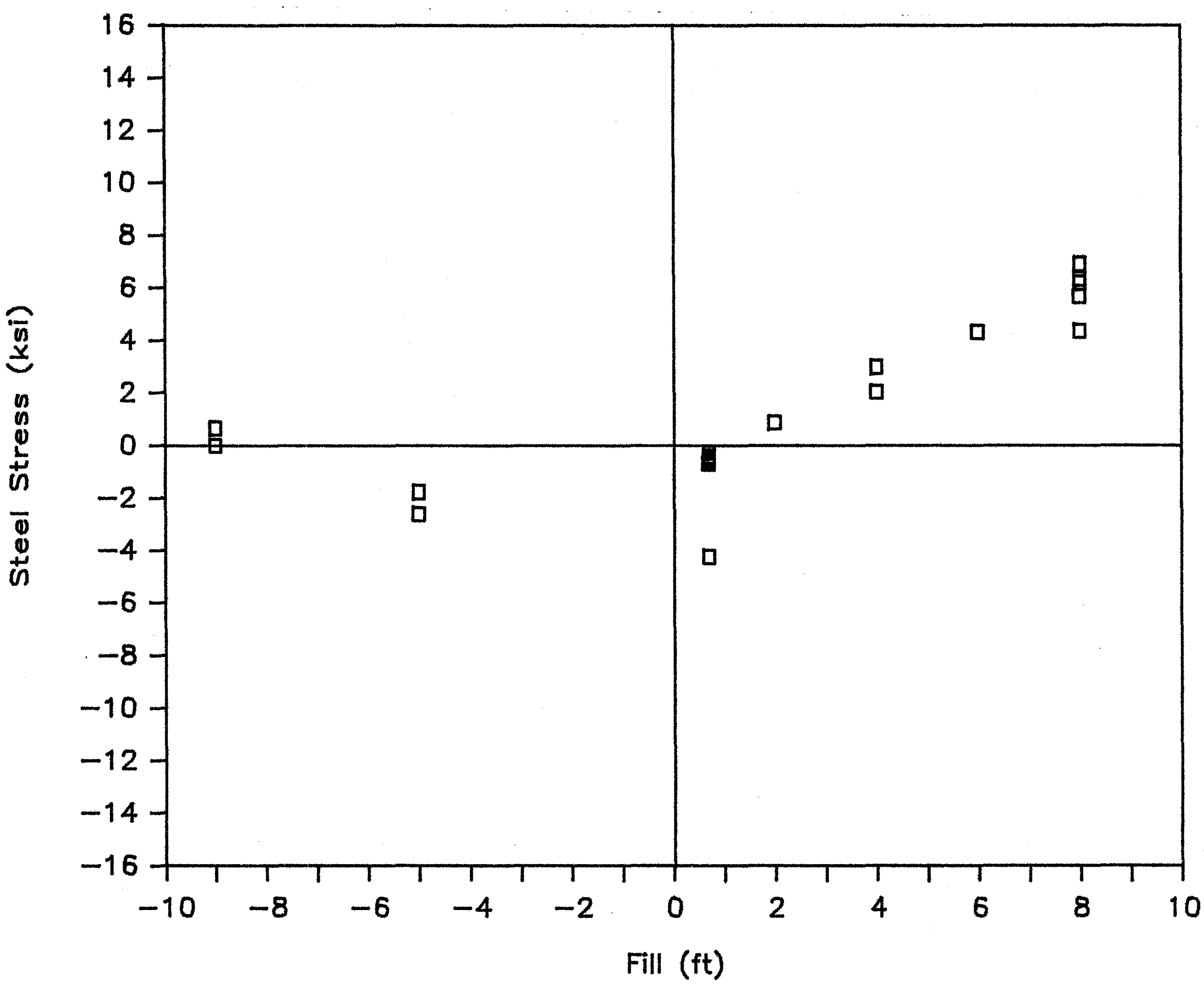


FIG. 93 - Effect of Soil Cover on Measured Steel Stress,
Strain Gage 6

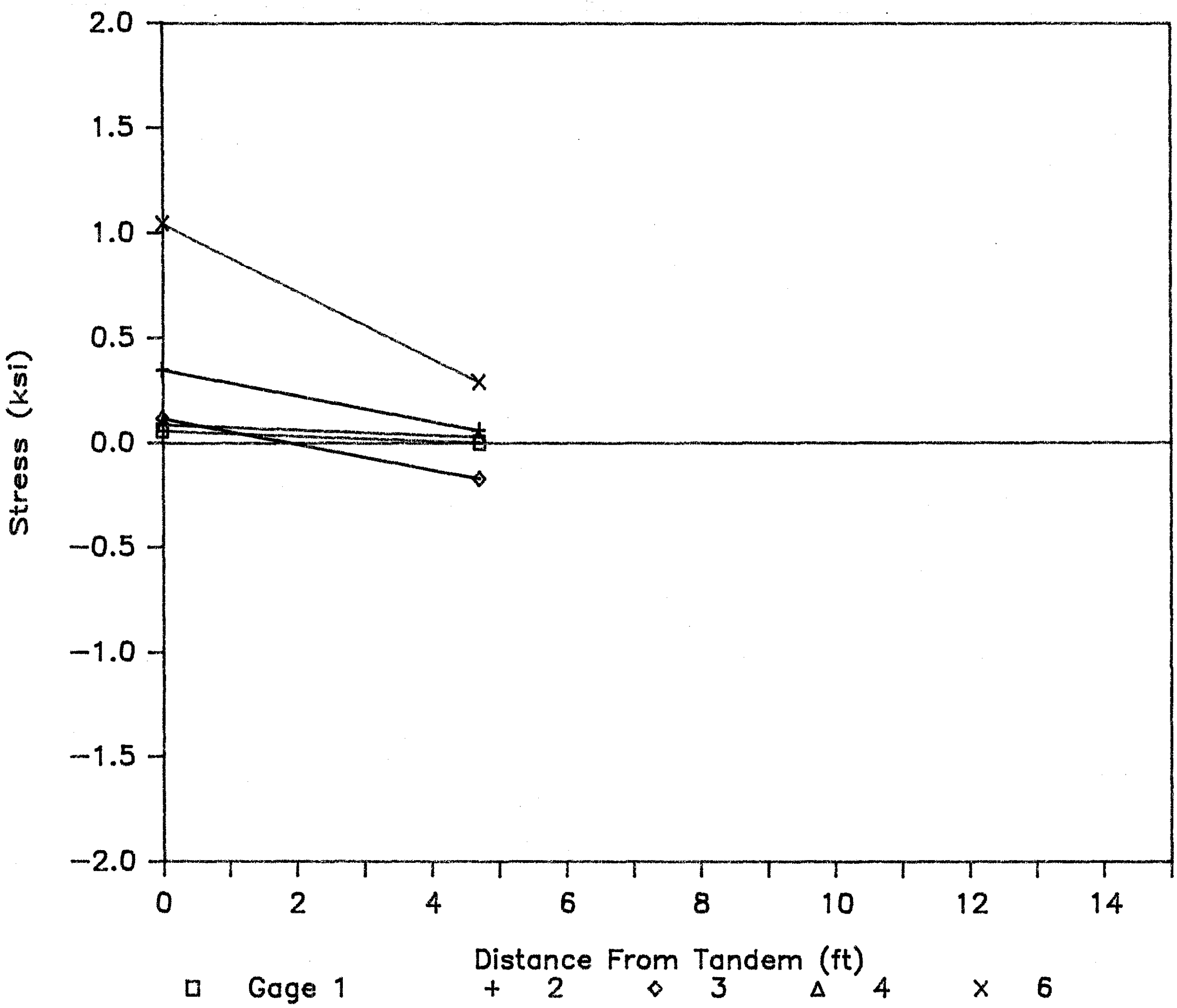


FIG. 94 - Measured Reinforcing Steel Stresses--Interstate Loading at Midspan, 8 in. Earth Cover

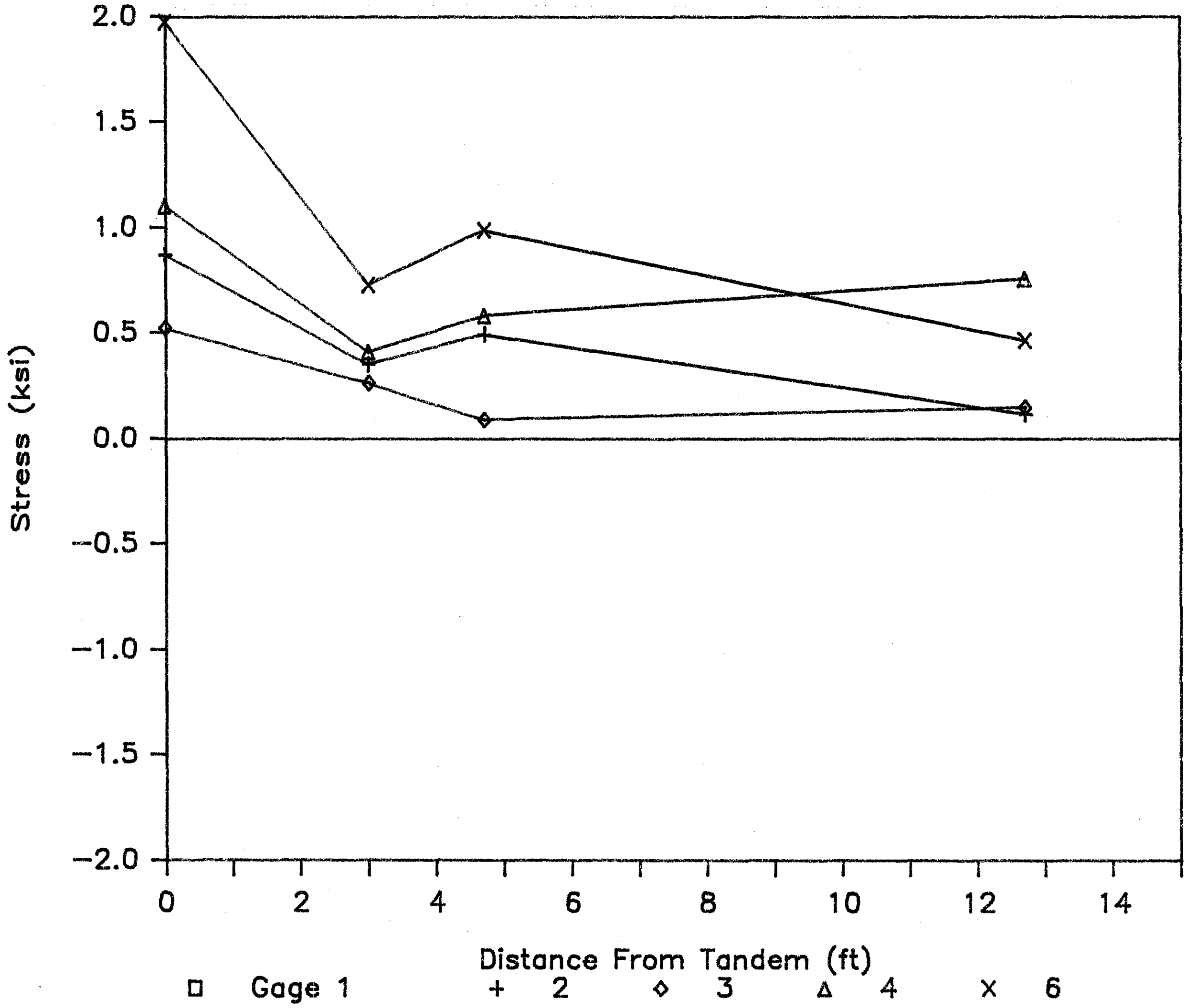


FIG. 95 - Measured Reinforcing Steel Stresses--Interstate Loading at Midspan, 2 ft Earth Cover

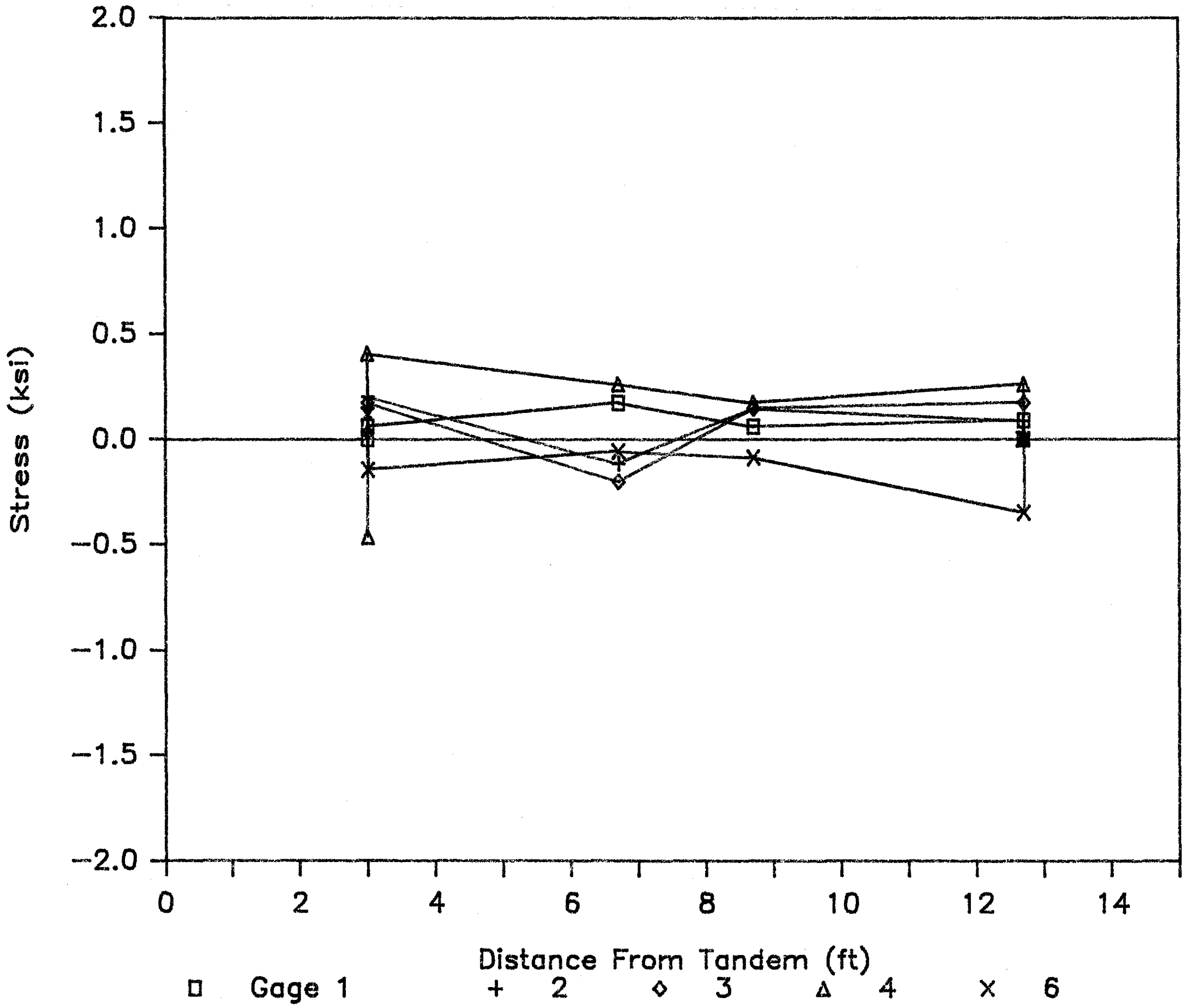


FIG. 96 - Measured Reinforcing Steel Stresses--Interstate Loading at Midspan, 4 ft Earth Cover

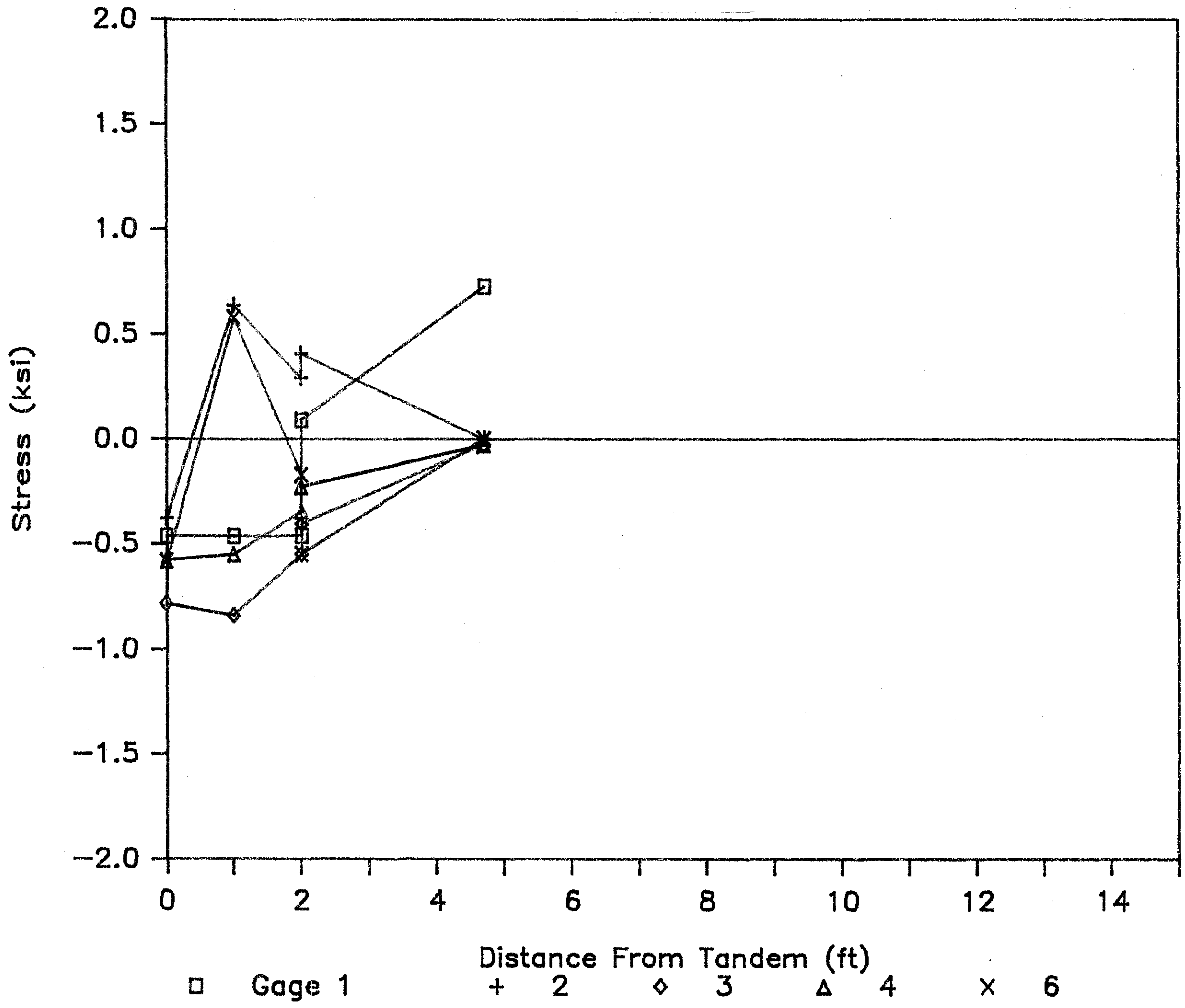


FIG. 97 - Measured Reinforcing Steel Stresses--Interstate Loading at Midspan, 6 ft Earth Cover

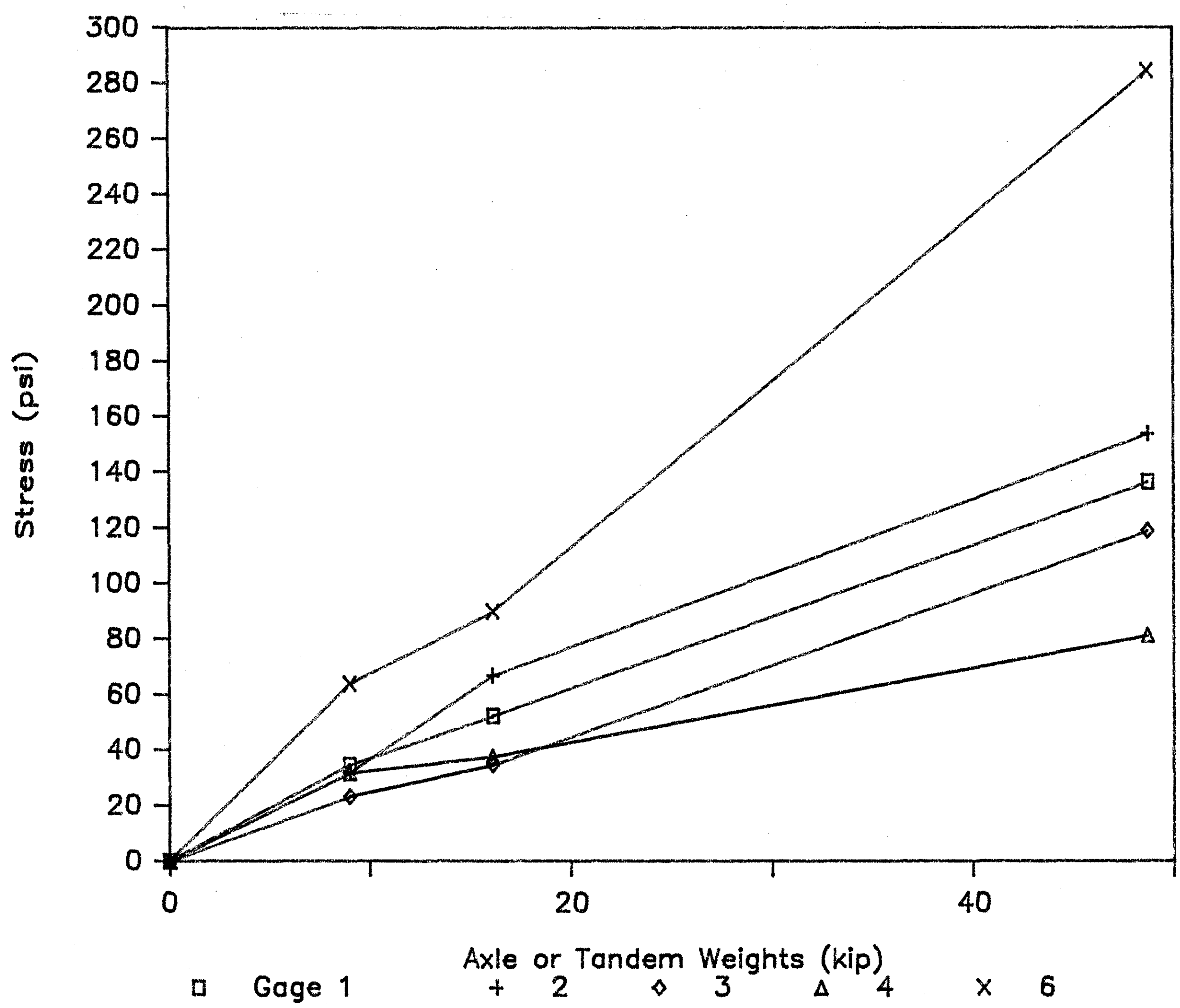


FIG. 98 - Measured Reinforcing Steel Stresses for Various Test Vehicle Locations, 8 ft Earth Cover

Appendix B

RAW AND CORRECTED DATA

TABLE III.1 - Field Test Data - 4/14/83 2/3

Fill Height = 8 in. Load Location = 4.7LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.5	58	1.00	2.50
2	4.7	59	----	3.97
3	7.0	60	1.62	5.38
4	7.5	61	1.56	5.94
5	6.5	60	6.32	0.18
6	5.7	60	5.33	0.37
7	5.6	61	5.48	0.12
8	22.1	61	5.94	16.16
9	8.1	61	7.52	0.58
10	11.9	61	11.06	0.84
11	9.6	60	7.63	1.97
12	8.0	61	7.70	0.30
13	8.0	60	7.25	0.75
14	5.6	60	5.31	0.29
15	6.5	60	4.99	1.51
16	8.1	60	7.45	0.65
17	8.1	61	6.78	1.32
18	9.0	60	4.48	4.52
19	9.1	59	6.64	2.46
20	4.5	57	1.07	3.43

1°F = 0.56°C

Note: 1 psi = 6.89 kPa

1 in. = 2.54 cm

TABLE III.2 - Field Test Data - 4/14/83 3/3

Fill Height = 8 in. Load Location = 0.0RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.4	58	1.00	2.40
2	5.0	59	----	4.12
3	7.0	60	1.62	5.38
4	4.6	61	1.56	3.04
5	6.7	62	----	1.36
6	6.0	62	5.56	0.44
7	5.8	62	5.57	0.23
8	6.1	61	5.94	0.16
9	8.0	60	7.43	0.57
10	15.4	61	11.06	4.34
11	42.1	60	7.63	34.47
12	8.0	60	7.57	0.43
13	25.1	60	----	30.93
14	5.7	61	5.42	0.28
15	6.4	61	----	2.66
16	8.0	61	7.57	0.43
17	8.0	61	6.78	1.22
18	9.3	60	4.48	4.82
19	9.4	59	6.64	2.76
20	4.7	57	1.07	3.63

1°F = 0.56°C

Note: 1 psi = 6.89 kPa

1 in. = 2.54 cm

TABLE III.3 - Field Test Data - 4/18/83 1/3

Fill Height = 8 in. Load Location = 4.7RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.1	57	0.96	2.14
2	4.6	59	----	4.08
3	6.6	60	1.62	4.98
4	4.6	61	1.56	3.04
5	7.0	63	----	1.42
6	6.2	63	5.68	0.52
7	5.9	62	5.57	0.33
8	6.6	62	6.06	0.54
9	8.2	62	7.61	0.59
10	39.0	62	11.17	27.83
11	8.5	63	8.05	0.45
12	8.8	63	7.97	0.83
13	8.9	62	----	3.90
14	5.8	62	5.53	0.27
15	7.0	63	5.40	1.60
16	7.7	62	7.69	0.01
17	9.6	61	6.78	2.82
18	7.7	60	4.48	3.22
19	9.4	59	6.64	2.76
20	4.8	57	1.07	3.73

Note: 1 psi = 6.89 kPa; 1°F = 0.56°C; 1 in. = 2.54 cm

TABLE III.4 - Field Test Data - 4/18/83 2/3

Fill Height = 8 in. Load Location = 4.7RL

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.1	57	0.96	2.14
2	4.5	59	----	4.08
3	6.5	60	1.62	4.88
4	4.5	62	1.59	2.91
5	7.7	67	----	1.42
6	7.3	67	6.16	1.14
7	6.5	66	5.92	0.58
8	7.0	66	6.52	0.48
9	8.6	64	7.80	0.80
10	44.4	64	11.40	33.00
11	8.9	64	8.20	0.70
12	9.2	64	8.11	1.09
13	8.4	64	----	3.90
14	6.1	64	5.75	0.35
15	7.5	64	5.53	1.97
16	8.6	63	7.81	0.79
17	10.1	61	6.78	3.32
18	8.7	60	4.48	4.22
19	9.4	59	6.64	2.76
20	4.8	57	1.07	3.73

Note: 1 psi = 6.89 kPa; 1°F = 0.56°C; 1 in. = 2.54 cm

TABLE III.5 - Field Test Data - 4/18/83 3/3

Fill Height = 8 in. Load Location = 0.0LL

Cell No.	Measured Pressure (psi)	Temp (^{o}F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.2	57	0.96	2.24
2	4.9	60	----	4.12
3	7.0	61	1.65	5.35
4	4.7	62	1.59	3.11
5	8.0	71	----	1.36
6	7.6	71	6.64	0.96
7	6.5	70	6.27	0.23
8	7.0	76	6.64	0.36
9	8.5	66	7.98	0.52
10	12.3	65	11.51	0.79
11	48.1	65	----	40.51
12	8.6	65	8.24	0.36
13	37.6	65	----	30.93
14	6.1	65	5.85	0.25
15	7.5	66	----	2.66
16	8.6	66	8.18	0.42
17	8.6	62	6.91	1.69
18	9.4	61	4.60	4.80
19	9.5	60	6.75	2.75
20	4.5	57	1.07	3.43

Note: 1 psi = 6.89 kPa
1°F = 0.56°C
1 in. = 2.54 cm

TABLE III.6 - Field Test Data - 4/19/83 1/2

Fill Height = 8 in. Load Location = 4.3LL

Cell No.	Measured Pressure (psi)	Temp (^{o}F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.2	58	1.00	3.20
2	5.1	60	----	3.85
3	7.2	61	1.65	5.55
4	8.0	62	1.59	6.41
5	7.0	63	6.59	0.41
6	6.1	63	5.68	0.42
7	5.7	63	5.66	0.04
8	6.8	62	6.06	0.74
9	8.2	62	7.61	0.59
10	11.7	62	11.17	0.53
11	17.7	62	7.91	9.79
12	8.6	63	7.97	0.63
13	8.2	62	7.49	0.71
14	5.9	63	5.64	0.26
15	6.9	63	5.40	1.50
16	8.4	63	7.81	0.59
17	8.5	62	6.91	1.59
18	9.0	61	4.60	4.40
19	9.5	60	6.75	2.75
20	4.8	58	1.09	3.71

Note: 1 psi = 6.89 kPa
1°F = 0.56°C
1 in. = 2.54 cm

TABLE III.7 - Field Test Data - 5/03/83 2/4

Fill Height = 8 in. Load Location = 14.7LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.5	65	1.26	3.24
2	5.5	66	1.27	4.23
3	7.3	68	1.84	5.46
4	4.5	70	1.81	2.69
5	7.5	69	7.13	0.37
6	6.7	69	6.40	0.30
7	6.2	69	6.18	0.02
8	7.5	69	6.87	0.63
9	9.0	68	8.17	0.83
10	12.8	69	11.95	0.85
11	9.5	68	8.77	0.73
12	9.9	69	8.78	1.12
13	9.3	69	8.32	0.98
14	6.4	68	6.18	0.22
15	7.6	68	6.07	1.53
16	8.9	69	8.54	0.36
17	9.5	70	7.96	1.54
18	11.5	68	5.40	6.10
19	10.6	67	7.54	3.06
20	5.5	65	1.20	4.30

Note: 1 psi = 6.89 kPa; 1°F = 0.56°C; 1 in. = 2.54 cm

TABLE III.8 - Field Test Data - 5/03/83 3/4

Fill Height = 8 in. Load Location = 10.7LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.4	65	1.26	3.14
2	5.4	67	1.29	4.11
3	7.5	68	1.84	5.66
4	4.9	70	1.81	3.09
5	8.0	72	7.41	0.59
6	7.8	72	6.76	1.04
7	6.9	71	6.35	0.55
8	7.6	69	6.87	0.73
9	9.1	69	8.26	0.84
10	13.0	69	11.95	1.05
11	9.7	69	8.91	0.79
12	10.0	69	8.78	1.22
13	9.5	69	8.32	1.18
14	6.7	69	6.29	0.41
15	7.9	69	6.20	1.70
16	9.0	70	8.67	0.33
17	9.4	70	7.96	1.44
18	11.5	68	5.40	6.10
19	10.6	67	7.54	3.06
20	5.4	65	1.20	4.20

Note: 1 psi = 6.89 kPa; 1°F = 0.56°C; 1 in. = 2.54 cm

TABLE III.9 - Field Test Data - 5/03/83 4/4

Fill Height = 8 in. Load Location = 8.7LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.5	65	1.26	3.24
2	5.2	67	1.29	3.91
3	7.3	68	1.84	5.46
4	7.8	70	1.81	5.99
5	8.3	73	7.50	0.80
6	8.2	73	6.88	1.32
7	7.2	73	6.53	0.67
8	7.5	69	6.87	0.63
9	9.2	69	8.26	0.94
10	13.1	70	12.06	1.04
11	9.9	69	8.91	0.99
12	10.1	70	8.91	1.19
13	9.6	70	8.44	1.16
14	6.9	70	6.40	0.50
15	8.0	70	6.34	1.66
16	9.2	70	8.67	0.53
17	9.5	70	7.96	1.54
18	11.8	69	5.51	6.29
19	10.7	67	7.54	3.16
20	5.3	65	1.20	4.10

1°F = 0.56°C

Note: 1 psi = 6.89 kPa

1 in. = 2.54 cm

TABLE III.10 - Field Test Data - 5/05/83 1/2

Fill Height = 8 in. Load Location = 12.7LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.5	64	1.23	2.27
2	5.1	65	1.25	3.85
3	6.9	67	1.81	5.09
4	4.5	69	1.78	2.72
5	7.5	68	7.04	0.46
6	7.0	68	6.28	0.72
7	6.1	68	6.09	0.01
8	7.1	67	6.64	0.46
9	9.0	68	8.17	0.83
10	12.5	68	11.84	0.66
11	9.6	68	8.77	0.83
12	9.6	68	8.65	0.95
13	9.0	68	8.20	0.80
14	6.6	69	6.29	0.31
15	7.6	69	6.20	1.40
16	9.0	69	8.54	0.46
17	9.5	69	7.83	1.67
18	10.4	67	5.28	5.12
19	10.5	66	7.43	3.07
20	5.0	64	1.18	3.82

1°F = 0.56°C

Note: 1 psi = 6.89 kPa

1 in. = 2.54 cm

TABLE III.11 - Field Test Data - 5/05/83 2/2

Fill Height = 8 in. Load Location = 6.7LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.6	64	1.23	2.37
2	5.2	66	1.27	3.93
3	6.9	67	1.81	5.09
4	5.5	69	1.78	3.72
5	7.8	70	7.22	0.58
6	7.5	70	6.52	0.98
7	6.5	70	6.27	0.23
8	7.0	69	6.87	0.13
9	9.2	69	8.26	0.94
10	12.8	69	11.95	0.85
11	9.8	69	8.91	0.89
12	9.7	69	8.78	0.92
13	9.2	68	8.20	1.00
14	6.5	69	6.29	0.21
15	7.7	69	6.20	1.50
16	9.0	69	8.54	0.46
17	9.4	69	7.83	1.57
18	10.5	67	5.28	5.22
19	10.4	66	7.43	2.97
20	4.7	64	1.18	3.52

Note: 1 psi = 6.89 kPa
1°F = 0.56°C
1 in. = 2.54 cm

TABLE III.12 - Field Test Data - 5/17/83 1/2

Fill Height = 8 in. Load Location = 4.3LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.6	64	1.23	2.37
2	5.0	66	----	3.85
3	7.2	66	1.79	5.41
4	8.1	67	1.73	6.37
5	7.5	68	7.04	0.46
6	7.4	67	6.16	1.24
7	6.3	68	6.09	0.21
8	8.6	68	6.75	1.85
9	8.5	67	8.07	0.43
10	12.5	67	11.73	0.77
11	21.5	67	8.62	12.88
12	9.0	68	8.65	0.35
13	8.7	67	8.08	0.62
14	6.5	67	6.07	0.43
15	7.5	67	5.93	1.57
16	8.9	67	8.30	0.60
17	9.0	66	7.44	1.56
18	10.1	66	5.17	4.93
19	10.3	66	7.43	2.87
20	4.8	64	1.18	3.62

Note: 1 psi = 6.89 kPa
1°F = 0.56°C
1 in. = 2.54 cm

TABLE III.13 - Field Test Data - 6/02/83 1/1

Fill Height = 8 in. Load Location = 4.3LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.8	66	1.30	2.50
2	5.2	68	----	3.85
3	7.4	69	1.87	5.53
4	8.5	70	1.81	6.69
5	8.7	69	7.13	1.57
6	8.5	70	6.52	1.98
7	7.0	70	6.27	0.73
8	11.7	69	6.87	4.83
9	9.3	69	8.26	1.04
10	14.0	70	12.06	1.94
11	32.7	70	9.05	23.65
12	9.9	70	8.91	0.99
13	10.5	70	8.44	2.06
14	7.3	70	6.40	0.90
15	8.2	70	6.34	1.86
16	9.3	70	8.67	0.63
17	10.0	70	7.96	2.04
18	12.5	69	5.51	6.99
19	11.6	68	7.65	3.95
20	5.1	66	1.21	3.89

Note: 1 psi = 6.89 kPa; 1°F = 0.56°C; 1 in. = 2.54 cm

TABLE III.14 - Field Test Data - 6/10/83 1/4

Fill Height = 8 in. Load Location = 14.7RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.7	69	1.41	2.29
2	5.4	71	1.37	4.03
3	6.7	72	1.95	4.75
4	5.7	75	1.95	3.75
5	8.8	75	7.68	1.12
6	9.1	76	7.23	1.87
7	7.5	75	6.70	0.80
8	9.5	75	7.57	1.93
9	10.0	75	8.81	1.19
10	14.8	75	12.62	2.18
11	11.3	75	9.76	1.54
12	11.1	74	9.45	1.65
13	10.4	75	9.03	1.37
14	7.3	75	6.94	0.36
15	8.8	75	7.01	1.79
16	9.7	75	9.27	0.43
17	10.4	74	8.49	1.91
18	11.6	72	5.86	5.74
19	11.9	71	7.99	3.91
20	5.5	69	1.26	4.24

Note: 1 psi = 6.89 kPa; 1°F = 0.56°C; 1 in. = 2.54 cm

TABLE III.15 - Field Test Data - 6/10/83 2/4

Fill Height = 8 in. Load Location = 12.7RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.8	69	1.41	2.39
2	5.4	71	1.37	4.03
3	6.6	72	1.95	4.65
4	5.6	74	1.92	3.68
5	9.0	75	7.68	1.32
6	9.4	76	7.23	2.17
7	7.8	75	6.70	1.10
8	9.8	75	7.57	2.23
9	10.3	75	8.81	1.49
10	15.0	75	12.62	2.38
11	11.8	75	9.76	2.04
12	11.4	75	9.59	1.81
13	10.9	75	9.03	1.87
14	7.3	75	6.94	0.36
15	9.0	75	7.01	1.99
16	9.8	75	9.27	0.53
17	10.6	74	8.49	2.11
18	11.9	72	5.86	6.04
19	12.0	71	7.99	4.01
20	5.7	69	1.26	4.44

1°F = 0.56°C

Note: 1 psi = 6.89 kPa

1 in. = 2.54 cm

TABLE III.16 - Field Test Data - 6/10/83 3/4

Fill Height = 8 in. Load Location = 10.7RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.8	69	1.41	2.39
2	5.4	71	1.37	4.03
3	6.7	72	1.95	4.75
4	5.7	75	1.95	3.75
5	9.1	75	7.68	1.42
6	9.5	76	7.23	2.27
7	7.9	75	6.70	1.20
8	10.0	75	7.57	2.43
9	10.1	75	8.81	1.29
10	15.2	75	12.62	2.58
11	12.1	75	9.76	2.34
12	11.6	74	9.45	2.15
13	11.1	75	9.03	2.07
14	7.5	75	6.94	0.56
15	9.2	75	7.01	2.19
16	10.0	75	9.27	0.73
17	10.8	74	8.49	2.31
18	9.9	72	5.86	4.04
19	12.1	71	7.99	4.11
20	5.6	69	1.26	4.34

1°F = 0.56°C

Note: 1 psi = 6.89 kPa

1 in. = 2.54 cm

TABLE III.17 - Field Test Data - 6/10/83 4/4

Fill Height = 8 in.   Load Location = 8.7RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.8	69	1.41	2.39
2	5.4	72	1.39	4.01
3	6.8	72	1.95	4.85
4	5.9	74	1.92	3.98
5	9.2	77	7.86	1.34
6	9.6	77	7.35	2.25
7	8.0	77	6.88	1.12
8	10.2	77	7.80	2.40
9	10.1	77	9.00	1.10
10	15.2	76	12.73	2.47
11	12.4	77	10.05	2.35
12	11.8	78	9.99	1.81
13	11.3	78	9.39	1.91
14	7.5	76	7.05	0.45
15	9.4	77	7.27	2.13
16	10.0	76	9.40	0.60
17	12.4	74	8.49	3.91
18	9.6	72	5.86	3.74
19	12.0	71	7.99	4.01
20	5.7	69	1.26	4.44

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 in. = 2.54 cm

TABLE III.18 - Field Test Data - 6/13/83 1/4

Fill Height = 8 in.   Load Location = 6.7RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.9	72	1.53	2.37
2	5.5	73	1.41	4.09
3	7.0	74	2.01	4.99
4	5.9	76	1.98	3.92
5	9.5	77	7.86	1.64
6	9.2	78	7.47	1.73
7	7.8	77	6.88	0.92
8	9.6	77	7.80	1.80
9	10.1	77	9.00	1.10
10	14.9	77	12.84	2.06
11	12.1	77	10.05	2.05
12	11.2	77	9.86	1.34
13	11.0	77	9.27	1.73
14	7.6	77	7.16	0.44
15	9.3	77	7.27	2.03
16	9.8	77	9.52	0.28
17	11.0	76	8.75	2.25
18	10.8	74	6.09	4.71
19	12.9	73	8.22	4.68
20	6.0	72	1.31	4.69

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 in. = 2.54 cm

TABLE III.19 - Field Test Data - 6/13/83 2/4

Fill Height = 8 in. Load Location = 0.0RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.1	72	1.53	2.57
2	5.9	73	----	4.12
3	7.6	74	2.01	5.59
4	6.1	76	1.98	4.12
5	9.3	78	7.95	1.35
6	9.0	78	7.47	1.53
7	7.9	78	6.97	0.93
8	12.4	77	7.80	4.60
9	8.9	77	9.00	- 0.10
10	14.8	77	12.84	1.96
11	57.5	78	----	40.51
12	10.3	78	9.99	0.31
13	46.0	78	----	30.93
14	7.5	77	7.16	0.34
15	13.8	78	----	2.66
16	9.6	77	9.52	0.08
17	11.3	76	8.75	2.55
18	12.0	74	6.09	5.91
19	13.0	73	8.22	4.78
20	5.9	72	1.31	4.59

1°F = 0.56°C

Note: 1 psi = 6.89 kPa

1 in. = 2.54 cm

TABLE III.20 - Field Test Data - 6/13/83 3/4

Fill Height = 8 in. Load Location = 4.3RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.8	72	1.53	2.27
2	5.5	73	1.41	4.09
3	7.2	74	2.01	5.19
4	5.9	76	1.98	3.92
5	9.5	78	7.95	1.55
6	9.1	78	7.47	1.63
7	7.9	78	6.97	0.93
8	9.7	77	7.80	1.90
9	9.0	77	9.00	0.00
10	15.6	77	12.84	2.76
11	12.5	78	10.19	2.31
12	11.0	78	9.99	1.01
13	37.3	78	----	26.15
14	7.5	77	7.16	0.34
15	9.1	78	7.41	1.69
16	9.5	77	----	1.36
17	13.3	76	8.75	4.55
18	11.0	74	6.09	4.91
19	12.9	73	8.22	4.68
20	6.0	72	1.31	4.69

1°F = 0.56°C

Note: 1 psi = 6.89 kPa

1 in. = 2.54 cm

TABLE III.21 - Field Test Data - 6/13/83 4/4

Fill Height = 8 in.   Load Location = 4.7RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.9	72	1.53	2.37
2	5.5	73	1.41	4.09
3	7.2	74	2.01	5.19
4	5.9	76	1.98	3.92
5	9.6	79	8.04	1.56
6	9.2	79	7.59	1.61
7	7.9	78	6.97	0.93
8	9.8	79	8.03	1.77
9	9.1	78	9.09	0.01
10	25.7	78	----	29.42
11	12.6	78	10.19	2.41
12	11.3	78	9.99	1.31
13	17.2	78	----	3.90
14	7.7	78	7.26	0.44
15	9.3	78	7.41	1.89
16	9.6	78	9.64	-0.04
17	13.3	76	8.75	4.55
18	11.1	74	6.09	5.01
19	12.8	73	8.22	4.48
20	6.0	72	1.31	4.69

1°F = 0.56°C

Note: 1 psi = 6.89 kPa

1 in. = 2.54 cm

TABLE III.22 - Field Test Data - 6/20/83 1/5

Fill Height = 8 in.   Load Location = 4.7RL

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.9	73	1.56	2.34
2	5.5	74	1.43	4.07
3	7.2	75	2.04	5.16
4	5.9	77	2.01	3.89
5	9.4	80	8.13	1.27
6	10.2	80	7.71	2.49
7	8.6	80	7.14	1.46
8	10.2	80	8.15	2.05
9	9.2	80	9.27	-0.07
10	40.5	79	13.06	27.44
11	12.5	79	10.33	2.17
12	11.0	78	9.99	1.01
13	15.1	78	----	3.90
14	7.6	79	7.37	0.23
15	9.2	80	7.68	1.52
16	9.8	79	9.76	0.04
17	13.5	78	9.02	4.48
18	11.2	75	6.20	5.00
19	12.8	74	8.33	4.47
20	6.0	72	1.31	4.69

1°F = 0.56°C

Note: 1 psi = 6.89 kPa

1 in. = 2.54 cm

TABLE III.23 - Field Test Data 6 20 /83 2/5

Fill Height = 8 in. Load Location = 4.7LL

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.2	72	1.53	2.67
2	5.4	74	1.43	3.97
3	7.2	75	2.04	5.16
4	9.2	77	2.01	7.19
5	9.5	80	8.13	1.37
6	10.3	80	7.71	2.59
7	8.7	79	7.05	1.65
8	21.9	80	8.15	13.75
9	9.8	80	9.27	0.53
10	16.0	80	13.17	2.83
11	15.8	79	10.33	5.47
12	10.9	79	10.13	0.77
13	11.3	79	9.51	1.79
14	7.9	79	7.37	0.53
15	9.1	79	7.54	1.56
16	10.1	79	9.76	0.34
17	11.5	78	9.02	2.48
18	11.5	75	6.20	5.30
19	12.8	75	8.44	4.36
20	5.5	73	1.32	4.18

Note: 1 psi = 6.89 kPa 1°F = 0.56°C 1 in. = 2.54 cm

TABLE III.24 - Field Test Data - 6/20/83 3/5

Fill Height = 8 in. Load Location = 0.0LL

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.1	72	1.53	2.57
2	5.8	74	----	4.12
3	7.5	75	2.04	5.46
4	6.2	77	2.01	4.19
5	9.5	80	8.13	1.37
6	10.4	80	7.71	2.69
7	8.7	79	7.05	1.65
8	10.6	80	8.15	2.45
9	8.8	80	9.27	-0.47
10	16.1	80	13.17	2.93
11	44.8	79	----	40.51
12	10.3	79	10.13	0.17
13	49.0	79	----	30.93
14	10.1	79	----	0.29
15	8.8	79	----	2.66
16	15.6	79	----	0.31
17	11.8	78	9.02	2.78
18	11.6	75	6.20	5.40
19	13.1	75	8.44	4.66
20	5.8	73	1.32	4.48

Note: 1 psi = 6.89 kPa 1°F = 0.56°C 1 in. = 2.54 cm

TABLE III.25 - Field Test Data - 6/20/83 4/5

Fill Height = 8 in. Load Location = 4.3RL

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.0	72	1.53	2.47
2	5.5	74	1.43	4.07
3	7.1	75	2.04	5.06
4	6.0	77	2.01	3.99
5	9.6	80	8.13	1.47
6	10.4	80	7.71	2.69
7	8.7	80	7.14	1.56
8	10.4	80	8.15	2.25
9	9.2	80	9.27	-0.07
10	21.7	79	13.06	8.64
11	13.1	79	10.33	2.77
12	11.0	79	10.13	0.87
13	33.9	79	----	26.15
14	8.0	78	7.26	0.74
15	9.5	79	7.54	1.96
16	12.5	79	----	1.36
17	14.0	78	9.02	4.98
18	11.4	75	6.20	5.20
19	12.9	74	8.33	4.57
20	6.0	73	1.32	4.68

Note: 1 psi = 6.89 kPa 1°F = 0.56°C 1 in. = 2.54 cm

TABLE III.26 - Field Test Data - 6/20/83 5/5

Fill Height = 8 in. Load Location = 4.7LL

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.3	72	1.53	2.77
2	5.4	74	1.43	3.97
3	7.3	75	2.04	5.26
4	9.2	77	2.01	7.19
5	9.6	80	8.13	1.47
6	10.5	80	7.71	2.79
7	8.9	80	7.14	1.76
8	25.9	80	8.15	17.75
9	9.8	80	9.27	0.53
10	15.8	79	13.06	2.74
11	14.0	79	10.33	3.67
12	10.9	79	10.13	0.77
13	11.7	79	9.51	2.19
14	7.7	78	7.26	0.44
15	9.4	79	7.54	1.86
16	10.3	79	9.76	0.54
17	11.7	78	9.02	2.68
18	11.5	75	6.20	5.30
19	12.7	74	8.33	4.37
20	5.6	73	1.32	4.28

Note: 1 psi = 6.89 kPa 1°F = 0.56°C 1 in. = 2.54 cm

TABLE III.27 - Field Test Data - 6/22/83 2/3

Fill Height = 8 in. Load Location = 8.7RL

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.9	74	1.60	2.30
2	5.6	76	1.47	4.13
3	7.0	77	2.09	4.91
4	5.8	79	2.06	3.74
5	9.9	82	8.31	1.59
6	10.3	82	7.95	2.35
7	8.4	82	7.32	1.08
8	10.5	82	8.38	2.12
9	10.6	81	9.37	1.23
10	15.5	82	13.39	2.11
11	12.7	80	10.48	2.22
12	11.4	80	10.26	1.14
13	11.5	80	9.63	1.87
14	7.9	81	7.59	0.31
15	9.6	80	7.68	1.92
16	10.3	81	10.00	0.30
17	13.5	79	9.15	4.35
18	10.7	77	6.43	4.27
19	13.1	76	8.55	4.55
20	5.9	74	1.34	4.56

Note: 1 psi = 6.89 kPa; 1°F = 0.56°C; 1 in. = 2.54 cm

TABLE III.28 - Field Test Data - 6/22/83 3/3

Fill Height = 8 in. Load Location = 12.7RL

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.1	74	1.60	2.50
2	5.6	75	1.45	4.15
3	7.1	76	2.07	5.03
4	5.8	79	2.06	3.74
5	9.9	81	8.22	1.68
6	10.2	81	7.83	2.37
7	8.3	81	7.23	1.07
8	10.4	80	8.15	2.25
9	10.5	80	9.27	1.23
10	15.7	81	13.28	2.42
11	12.8	79	10.33	2.47
12	11.5	80	10.26	1.24
13	11.6	79	9.51	2.09
14	7.9	80	7.48	0.42
15	9.6	79	7.54	2.06
16	10.3	80	9.88	0.42
17	11.4	79	9.15	2.25
18	11.4	77	6.43	4.97
19	13.1	75	8.44	4.66
20	5.9	74	1.34	4.56

Note: 1 psi = 6.89 kPa; 1°F = 0.56°C; 1 in. = 2.54°C

TABLE III.29 - Field Test Data - 6/30/83 2/3

Fill Height = 8 in. Load Location = 2.0LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.4	76	1.68	2.72
2	5.8	78	1.50	4.30
3	7.4	79	2.15	5.25
4	5.7	81	2.12	3.58
5	10.0	84	8.49	1.51
6	11.1	84	8.19	2.91
7	9.0	84	7.49	1.51
8	13.0	83	----	18.43
9	21.5	83	----	24.29
10	15.7	83	13.51	2.19
11	13.8	83	10.90	2.90
12	38.0	83	----	16.25
13	11.7	83	9.99	1.71
14	8.3	83	7.81	0.49
15	11.0	83	----	2.04
16	10.4	83	10.25	0.15
17	12.3	82	9.54	2.76
18	13.0	78	6.55	6.45
19	14.0	77	8.67	5.33
20	6.0	76	1.37	4.63

Note: 1 psi = 6.89 kPa; 1°F = 0.56°C; 1 in. = 2.54 cm

TABLE III.30 - Field Test Data - 6/30/83 3/3

Fill Height = 8 in. Load Location = 1.0LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.3	76	1.68	2.62
2	5.9	78	1.50	4.40
3	7.6	79	2.15	5.45
4	6.5	81	2.12	4.38
5	10.3	84	8.49	1.81
6	11.1	84	8.19	2.91
7	9.0	84	7.49	1.51
8	47.2	83	8.49	38.71
9	27.2	83	----	8.59
10	15.4	83	13.51	1.89
11	13.9	83	10.90	3.00
12	11.4	83	----	4.87
13	13.8	83	9.99	3.81
14	8.0	83	7.81	0.19
15	9.5	83	----	2.16
16	10.4	83	10.25	0.15
17	12.2	82	9.54	2.66
18	13.5	78	6.55	6.95
19	14.0	77	8.67	5.33
20	6.0	76	1.37	4.63

Note: 1 psi = 6.89 kPa; 1°F = 0.56°C; 1 in. = 2.54 cm

TABLE III.31 - Field Test Data - 7/01/83 1/2

Fill Height = 8 in. Load Location = 3.0LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.4	76	1.68	2.72
2	5.7	78	1.50	4.20
3	6.9	79	2.15	4.75
4	6.4	81	2.12	4.28
5	10.6	84	8.49	2.11
6	10.7	83	8.07	2.63
7	8.5	84	7.49	1.01
8	9.6	82	8.38	1.22
9	9.6	82	----	6.49
10	15.6	83	13.51	2.09
11	28.6	81	10.62	17.98
12	14.4	81	----	2.30
13	11.7	81	9.75	1.95
14	15.7	82	----	0.19
15	10.7	81	----	2.16
16	10.2	82	10.13	0.07
17	12.0	82	9.54	2.46
18	11.4	79	6.66	4.74
19	13.8	78	8.78	5.02
20	5.9	76	1.37	4.53

1°F = 0.56°C
Note: 1 psi = 6.89 kPa
1 in. = 2.54 cm

TABLE III.32 - Field Test Data - 7/1 /83 2/2

Fill Height = 8 in. Load Location = 4.0LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.4	76	1.68	2.72
2	5.5	78	1.50	4.00
3	6.7	79	2.15	4.55
4	7.5	81	2.12	5.38
5	10.7	84	8.49	2.21
6	10.9	84	8.19	2.71
7	8.5	84	7.49	1.01
8	9.8	82	8.38	1.42
9	10.3	83	9.55	0.75
10	16.7	83	13.51	3.19
11	34.6	82	10.76	23.84
12	11.5	81	10.40	1.10
13	12.3	81	9.75	2.55
14	32.7	81	----	0.48
15	9.4	81	7.81	1.59
16	10.9	82	10.13	0.77
17	12.2	81	9.41	2.79
18	13.1	79	6.66	6.44
19	14.0	78	8.78	5.22
20	5.9	76	1.37	4.53

1°F = 0.56°C
Note: 1 psi = 6.89 kPa
1 in. = 2.54 cm

TABLE III.33 - Field Test Data - 7/6 /83 1/3

Fill Height = 8 in. Load Location = 2.0RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.0	77	1.71	2.29
2	5.7	79	1.52	4.18
3	7.6	80	2.18	5.42
4	5.9	82	2.15	3.75
5	9.8	81	8.22	1.58
6	9.6	81	7.83	1.77
7	7.8	82	7.32	0.48
8	10.8	81	8.26	2.54
9	34.9	81	----	27.03
10	17.9	81	13.28	4.62
11	12.9	81	10.62	2.28
12	30.9	81	----	17.91
13	10.8	81	9.75	1.05
14	8.0	81	7.59	0.41
15	10.4	81	----	1.89
16	10.2	81	10.00	0.20
17	11.4	82	9.54	1.86
18	12.9	80	6.78	6.12
19	13.8	79	8.89	4.91
20	6.1	76	1.37	4.73

Note: 1 psi = 6.89 kPa; 1°F = 0.56°C; 1 in. = 2.54 cm

TABLE III.34 - Field Test Data - 7/6 /83 2/3

Fill Height = 8 in. Load Location = 1.0RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.0	76	1.68	2.32
2	5.7	78	1.50	4.20
3	7.6	80	2.18	5.42
4	6.0	81	2.12	3.88
5	9.6	81	8.22	1.38
6	9.7	81	7.83	1.87
7	7.9	81	7.23	0.67
8	10.2	81	8.26	1.94
9	8.9	81	----	8.59
10	45.2	81	13.28	31.92
11	18.7	81	10.62	8.08
12	19.4	81	----	4.87
13	11.2	81	9.75	1.45
14	7.7	81	7.59	0.11
15	8.9	81	7.81	1.09
16	10.1	81	10.00	0.10
17	11.7	82	9.54	2.16
18	13.2	80	6.78	6.42
19	13.7	78	8.78	4.92
20	5.9	76	1.37	4.53

Note: 1 psi = 6.89 kPa; 1°F = 0.56°C; 1 in. = 2.54 cm

TABLE III.35 - Field Test Data - 7/6 /83 3/3

Fill Height = 8 in. Load Location = 3.0RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.9	77	1.71	2.19
2	5.5	79	1.52	3.98
3	7.4	80	2.18	5.22
4	5.8	82	2.15	3.65
5	9.9	83	8.40	1.50
6	10.0	82	7.95	2.05
7	8.3	83	7.40	0.90
8	11.5	82	8.38	3.12
9	22.3	82	----	6.49
10	14.9	81	13.28	1.62
11	13.4	81	10.62	2.78
12	11.0	81	----	2.30
13	18.5	81	9.75	8.75
14	8.1	81	7.59	0.51
15	9.0	81	7.81	1.19
16	10.2	81	10.00	0.20
17	12.2	82	9.54	2.66
18	12.5	80	6.78	5.72
19	13.8	78	8.78	5.02
20	6.1	77	1.39	4.71

Note: 1 psi = 6.89 kPa, 1°F = 0.56°C, 1 in. = 2.54 cm

TABLE III.36 - Field Test Data - 7/8 /83 1/5

Fill Height = 8 in. Load Location = 4.0RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.7	75	1.64	2.06
2	5.4	77	1.48	3.92
3	7.3	79	2.15	5.15
4	5.8	80	2.09	3.71
5	9.5	79	8.04	1.46
6	9.2	79	7.59	1.61
7	7.6	80	7.14	0.46
8	10.2	80	8.15	2.05
9	8.8	79	9.18	-0.38
10	15.5	79	13.06	2.44
11	13.0	79	10.33	2.67
12	11.0	78	9.99	1.01
13	45.9	79	9.51	36.39
14	8.0	78	7.26	0.74
15	8.8	78	7.41	1.39
16	10.9	78	9.64	1.26
17	13.5	80	9.28	4.22
18	11.6	78	6.55	5.05
19	13.1	77	8.67	4.43
20	5.7	75	1.35	4.35

Note: 1 psi = 6.89 kPa, 1°F = 0.56°C, 1 in. = 2.54 cm

TABLE III.37 - Field Test Data - 7/8 /83 2/5

Fill Height = 8 in. Load Location = 2.0RL

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.8	75	1.64	2.16
2	5.5	77	1.48	4.02
3	7.4	79	2.15	5.25
4	5.7	80	2.09	3.61
5	9.3	79	8.04	1.26
6	9.2	79	7.59	1.61
7	7.6	80	7.14	0.46
8	9.9	80	8.15	1.75
9	37.7	79	----	27.03
10	15.8	79	13.06	2.74
11	12.4	79	10.33	2.07
12	25.3	78	----	17.91
13	10.4	79	9.51	0.89
14	7.9	78	7.26	0.64
15	8.6	78	----	1.89
16	10.5	78	9.64	0.86
17	11.4	80	9.28	2.12
18	12.0	78	6.55	5.45
19	13.2	77	8.67	4.53
20	5.7	75	1.35	4.35

Note: 1 psi = 6.89 kPa 1°F = 0.56°C
1 in. = 2.54 cm

TABLE III.38 - Field Test Data - 7/8 /83 3/5

Fill Height = 8 in. Load Location = 2.0LL

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.0	74	1.60	2.40
2	5.7	76	1.47	4.23
3	7.4	78	2.12	5.28
4	5.6	79	2.06	3.54
5	9.4	80	8.13	1.27
6	9.4	79	7.59	1.81
7	8.0	80	7.14	0.86
8	40.5	80	----	18.43
9	45.8	79	----	24.29
10	15.4	79	13.06	2.34
11	13.0	79	10.33	2.67
12	15.3	79	----	16.25
13	10.8	79	9.51	1.29
14	7.9	79	7.37	0.53
15	8.7	79	----	2.04
16	10.4	79	9.76	0.64
17	11.9	80	9.28	2.62
18	12.2	78	6.55	5.65
19	13.2	77	8.67	4.53
20	5.5	74	1.34	4.16

Note: 1 psi = 6.89 kPa 1°F = 0.56°C
1 in. = 0.54 cm

TABLE III.39 - Field Test Data - 7/08/83 4/5

Fill Height = 8 in. Load Location = 8.7LL

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.1	74	1.60	2.50
2	5.3	76	1.47	3.83
3	7.1	78	2.12	4.98
4	8.5	79	2.06	6.44
5	9.2	80	8.13	1.07
6	9.6	79	7.59	2.01
7	8.0	80	7.14	0.86
8	10.1	80	8.15	1.95
9	10.0	79	9.18	0.82
10	15.6	79	13.06	2.54
11	12.9	79	10.33	2.57
12	11.6	79	10.13	1.47
13	11.1	79	9.51	1.59
14	8.1	79	7.37	0.73
15	9.1	79	7.54	1.56
16	10.9	79	9.76	1.14
17	11.6	80	9.28	2.32
18	11.5	78	6.55	4.95
19	13.0	77	8.67	4.33
20	5.5	74	1.34	4.16

Note: 1 psi = 6.89 kPa; 1°F = 0.56°C; 1 in. = 2.54 cm

TABLE III.40 - Field Test Data - 7/08/83 5/5

Fill Height = 8 in. Load Location = 12.7LL

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.1	75	1.64	2.46
2	5.4	77	1.48	3.92
3	6.9	78	2.12	4.78
4	5.4	80	2.09	3.31
5	9.4	80	8.13	1.27
6	9.8	80	7.71	2.09
7	8.1	81	7.23	0.87
8	10.6	80	8.15	2.45
9	10.2	79	9.18	1.02
10	15.5	80	13.17	2.33
11	13.0	79	10.33	2.67
12	11.7	79	10.13	1.57
13	11.2	80	9.63	1.57
14	8.3	79	7.37	0.93
15	9.2	79	7.54	1.66
16	10.9	79	9.76	1.14
17	11.5	80	9.28	2.22
18	11.8	78	6.55	5.25
19	13.1	77	8.67	4.43
20	5.5	74	1.34	4.16

Note: 1 psi = 6.89 kPa; 1°F = 0.56°C; 1 in. = 2.54 cm

TABLE III.41 - Field Test Data - 7/22/83 2/3

Fill Height = 2 ft   Load Location = 0.0RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.7	75	1.64	3.06
2	6.1	76	1.47	4.63
3	7.9	77	2.09	5.81
4	6.2	78	2.04	4.16
5	10.3	80	----	3.02
6	10.5	80	----	3.59
7	9.4	80	----	2.84
8	15.5	80	----	8.77
9	12.4	80	9.27	3.13
10	21.0	80	----	8.66
11	27.5	80	10.48	17.02
12	16.1	80	10.26	5.84
13	22.5	80	----	14.24
14	13.9	80	----	4.96
15	11.2	80	7.68	3.52
16	16.2	80	----	5.48
17	11.5	78	----	2.84
18	11.0	77	----	5.90
19	13.5	76	----	5.28
20	6.4	74	1.34	5.06

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.42 - Field Test Data - 7/22/83 2/3

Fill Height = 2 ft   Load Location = 2.0LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.8	75	1.64	3.16
2	6.0	76	1.47	4.53
3	7.5	77	2.09	5.41
4	5.7	78	2.04	3.66
5	10.2	80	----	3.02
6	10.5	80	----	3.59
7	9.5	80	----	2.89
8	16.1	80	----	9.77
9	16.1	80	----	8.50
10	16.5	80	13.17	3.33
11	18.1	80	10.48	7.62
12	22.4	80	10.26	12.14
13	14.9	80	9.63	5.27
14	9.4	80	7.48	1.92
15	16.9	80	----	8.11
16	11.5	80	9.88	1.62
17	11.5	78	----	2.74
18	11.8	77	----	6.20
19	13.4	76	----	5.23
20	6.2	74	1.34	4.86

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.43 - Field Test Data - 7/22/83 3/3

Fill Height = 2 ft   Load Location = 4.7LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.8	75	1.64	3.16
2	5.7	77	1.48	4.22
3	7.3	77	2.09	5.21
4	7.0	78	2.04	4.96
5	10.2	81	----	3.02
6	10.8	80	----	3.61
7	9.5	8;	----	2.90
8	18.5	80	----	11.97
9	10.8	80	9.27	1.53
10	16.4	80	13.17	3.23
11	23.5	80	10.48	13.02
12	14.8	80	10.26	4.54
13	13.5	80	9.63	3.87
14	12.1	80	----	3.86
15	10.4	80	7.68	2.72
16	10.4	80	9.88	0.52
17	11.4	78	----	2.64
18	11.5	77	----	5.90
19	13.4	76	----	5.18
20	6.1	75	1.35	4.75

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.44 - Field Test Data - 7/25/83 1/4

Fill Height = 2 ft   Load Location = 12.7LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.7	76	1.68	3.02
2	5.8	78	1.50	4.30
3	7.4	79	2.15	5.25
4	5.5	80	2.09	3.41
5	11.0	83	840	2.60
6	11.8	83	8.07	3.73
7	10.4	83	7.40	3.00
8	11.7	83	8.49	3.21
9	11.4	83	9.55	1.85
10	17.0	83	13.51	3.49
11	15.9	83	10.90	5.00
12	14.1	82	10.53	3.57
13	14.0	82	9.87	4.13
14	9.1	82	7.70	1.40
15	10.6	83	8.08	2.52
16	11.3	83	10.25	1.05
17	12.2	89	9.28	2.92
18	12.5	79	6.66	5.84
19	14.0	76	8.78	5.22
20	6.5	76	1.37	5.13

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.45 - Field Test Data - 7/25/83 2/4

Fill Height = 2 ft Load Location = 8.7LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.7	76	1.68	3.02
2	5.7	78	1.50	4.20
3	7.3	79	2.15	5.15
4	7.0	80	2.09	4.91
5	11.1	83	8.40	2.70
6	11.8	83	8.07	3.73
7	10.5	83	7.40	3.10
8	12.0	83	8.49	3.51
9	11.4	83	9.55	1.85
10	17.4	83	13.51	3.89
11	15.8	83	10.90	4.90
12	14.1	82	10.53	3.57
13	14.0	82	9.87	4.13
14	9.1	82	7.70	1.40
15	10.7	83	8.08	2.62
16	11.4	83	10.25	1.15
17	12.1	80	9.28	2.82
18	12.6	79	6.66	5.94
19	14.0	78	8.78	5.22
20	6.4	76	1.37	5.03

Note: 1 psi = 6.89 kPa 1°F = 0.56°C 1 ft = 0.305 m

TABLE III.46 - Field Test Data - 7/25/83 3/4

Fill Height = 2 ft Load Location = 1.0LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	5.1	77	1.71	3.39
2	6.4	78	1.50	4.90
3	8.1	79	2.15	5.95
4	6.1	81	2.12	3.98
5	11.3	84	8.49	2.81
6	11.6	84	8.19	3.41
7	10.6	84	7.49	3.11
8	21.7	83	8.49	13.21
9	17.9	83	----	5.50
10	18.1	83	13.51	4.59
11	21.1	83	----	13.02
12	18.7	83	10.67	8.03
13	19.9	83	9.99	9.91
14	10.5	83	----	4.19
15	13.9	83	8.08	5.82
16	14.6	83	10.25	4.35
17	12.5	81	9.41	3.09
18	13.5	79	6.66	6.84
19	14.3	78	8.78	5.52
20	6.6	77	1.39	5.21

Note: 1 psi = 6.89 kPa 1°F = 0.56°C 1 ft = 0.305 m

TABLE III.47 - Field Test Data - 7/25/83 4/4

Fill Height = 2 ft   Load Location = 2.0RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.5	77	1.71	2.79
2	5.9	78	1.50	4.40
3	8.0	79	2.15	5.85
4	6.2	81	2.12	4.08
5	11.4	84	8.49	2.91
6	11.6	84	8.19	3.41
7	10.5	84	7.49	3.01
8	12.5	83	8.49	4.01
9	17.3	83	----	8.56
10	24.2	83	13.51	10.69
11	20.2	83	10.90	9.30
12	24.8	83	10.67	14.13
13	16.9	83	9.99	6.91
14	10.0	83	7.81	2.19
15	16.3	83	----	7.56
16	12.2	83	10.25	1.95
17	12.2	81	9.41	2.79
18	13.4	79	6.66	6.74
19	14.5	78	8.78	5.72
20	6.6	77	1.39	5.21

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.48 - Field Test Data - 7/26/83 1/4

Fill Height = 2 ft   Load Location = 3.0LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.8	76	1.68	3.12
2	6.1	78	1.50	4.60
3	7.6	79	2.15	5.45
4	6.0	80	2.09	3.91
5	11.2	83	8.40	2.80
6	11.5	83	8.07	3.43
7	10.4	83	7.40	3.00
8	14.0	83	8.49	5.51
9	12.1	82	----	5.70
10	17.0	83	13.51	3.49
11	26.6	82	----	13.02
12	20.9	83	10.67	10.23
13	13.7	82	9.87	3.83
14	12.7	83	7.81	4.89
15	14.2	83	8.08	6.12
16	11.0	83	10.25	0.75
17	12.3	80	9.28	3.02
18	13.1	79	6.66	6.44
19	14.1	78	8.78	5.32
20	6.3	76	1.37	4.93

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.49 - Field Test Data - 7/26/83 2/4

Fill Height = 2 ft   Load Location = 6.7LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.8	76	1.68	3.12
2	5.8	78	1.50	4.30
3	7.5	79	2.15	5.35
4	6.0	80	2.09	3.91
5	11.1	83	8.40	2.70
6	11.6	83	8.07	3.53
7	10.4	83	7.40	3.00
8	13.9	83	8.49	5.41
9	10.7	82	9.46	1.24
10	16.8	83	13.51	3.29
11	15.7	82	10.76	4.94
12	14.1	83	10.67	3.43
13	13.9	82	9.87	4.03
14	8.8	83	7.81	0.99
15	10.5	83	8.08	2.42
16	11.2	83	10.25	0.95
17	12.0	80	9.28	2.72
18	12.7	79	6.66	6.04
19	13.9	78	8.78	5.12
20	6.3	76	1.37	4.93

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.50 - Field Test Data - 7/26/83 3/4

Fill Height = 2 ft   Load Location = 1.0RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.5	77	1.71	2.79
2	6.0	78	1.50	4.50
3	8.0	79	2.15	5.85
4	6.1	81	2.12	3.98
5	11.4	84	8.49	2.91
6	11.6	84	8.19	3.41
7	10.4	84	7.49	2.91
8	12.7	83	8.49	4.21
9	12.2	83	----	5.50
10	25.0	83	13.51	11.49
11	27.4	83	10.90	16.50
12	20.3	83	10.67	9.63
13	19.8	83	9.99	9.81
14	13.5	83	----	4.19
15	14.1	83	8.08	6.02
16	14.1	83	10.25	3.85
17	12.4	81	9.41	2.99
18	13.5	79	6.66	6.84
19	14.4	78	8.78	5.62
20	6.5	76	1.37	5.13

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.51 - Field Test Data - 7/26/83 4/4

Fill Height = 2 ft   Load Location = 4.7RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.4	77	1.71	2.69
2	5.7	78	1.50	4.20
3	7.6	79	2.15	5.45
4	5.9	81	2.12	3.78
5	11.4	84	8.49	2.91
6	11.7	84	8.19	3.51
7	10.3	84	7.49	2.81
8	11.5	83	8.49	3.01
9	11.2	83	9.55	1.65
10	24.0	83	----	12.54
11	15.9	83	10.90	5.00
12	14.0	83	10.67	3.33
13	22.0	83	9.99	12.01
14	8.9	83	7.81	1.09
15	10.5	83	8.08	2.42
16	16.0	83	----	4.59
17	12.6	81	9.41	3.19
18	12.7	79	6.66	6.04
19	14.1	78	8.78	5.32
20	6.6	76	1.37	5.23

1°F = 0.56°C

Note: 1 psi = 6.89 kPa

1 ft = 0.305 m

TABLE III.52 - Field Test Data - 7/27/83 1/2

Fill Height = 2 ft   Load Location = 6.7RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.3	76	1.68	2.62
2	5.5	78	1.50	4.00
3	7.4	79	2.15	5.25
4	5.6	81	2.12	3.48
5	11.5	84	8.49	3.01
6	11.9	84	8.19	3.71
7	10.5	84	7.49	3.01
8	11.5	83	8.49	3.01
9	10.7	82	9.46	1.24
10	19.5	83	13.51	5.99
11	15.6	82	10.76	4.84
12	13.9	82	10.53	3.37
13	14.3	82	9.87	4.43
14	9.1	83	7.81	1.29
15	10.5	82	7.95	2.55
16	11.3	83	10.25	1.05
17	12.2	81	9.41	2.79
18	12.5	79	6.66	5.84
19	14.3	78	8.78	5.52
20	6.6	77	1.39	5.21

1°F = 0.56°C

Note: 1 psi = 6.89 kPa

1 ft = 0.305 m

TABLE III.53 - Field Test Data - 7/27/83 2/2

Fill Height = 2 ft   Load Location = 8.7RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.4	76	1.68	2.72
2	5.6	78	1.50	4.10
3	7.4	79	2.15	5.25
4	5.6	81	2.12	3.48
5	11.5	84	8.49	3.01
6	11.9	84	8.19	3.71
7	10.6	84	7.49	3.11
8	11.5	83	8.49	3.01
9	10.9	82	9.46	1.44
10	16.7	83	13.51	3.19
11	15.7	82	10.76	4.94
12	13.9	82	10.53	3.37
13	14.1	82	9.87	4.23
14	9.1	83	7.81	1.29
15	10.7	82	7.95	2.75
16	11.2	83	10.25	0.95
17	12.5	81	9.41	3.09
18	12.4	79	6.66	5.74
19	14.2	78	8.78	5.42
20	6.6	77	1.39	5.21

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.54 - Field Test Data - 7/28/83 2/5

Fill Height = 2 ft   Load Location = 3.0RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.4	77	1.71	2.69
2	5.9	79	1.52	4.38
3	7.9	80	2.18	5.72
4	6.0	82	2.15	3.85
5	11.6	85	8.58	3.02
6	11.8	85	8.31	3.49
7	10.6	85	7.58	3.02
8	11.7	84	8.61	3.09
9	18.4	84	----	5.70
10	20.1	83	13.51	6.59
11	16.1	83	10.90	5.20
12	19.5	83	10.67	8.83
13	20.2	83	9.99	10.21
14	9.0	84	7.91	1.09
15	14.4	84	8.21	6.19
16	14.5	84	10.37	4.13
17	11.9	81	9.41	2.49
18	13.1	80	6.78	6.32
19	14.1	79	8.89	5.21
20	6.5	77	1.39	5.11

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.55 - Field Test Data - 7/28/83 3/5

Fill Height = 2 ft   Load Location = 12.7RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.5	77	1.71	2.79
2	5.6	79	1.52	4.08
3	7.4	80	2.18	5.22
4	5.5	82	2.15	3.35
5	11.5	85	8.58	2.92
6	12.0	85	8.31	3.69
7	10.6	85	7.58	3.02
8	11.6	84	8.61	2.99
9	11.1	84	9.64	1.46
10	16.9	83	13.51	3.39
11	16.0	83	10.90	5.10
12	14.2	83	10.67	3.53
13	14.1	83	9.99	4.11
14	9.1	84	7.91	1.19
15	10.8	84	8.21	2.59
16	11.3	84	10.37	0.93
17	12.1	81	9.41	2.69
18	12.6	80	6.78	5.82
19	14.2	79	8.89	5.31
20	6.5	77	1.39	5.11

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.56 - Field Test Data - 7/28/83 4/5

Fill Height = 2 ft   Load Location = 4.7RL

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.4	77	1.71	2.69
2	5.7	79	1.52	4.18
3	7.6	80	2.18	5.42
4	5.8	82	2.15	3.65
5	11.6	85	8.58	3.02
6	12.0	85	8.31	3.69
7	10.6	85	7.58	3.02
8	11.8	84	8.61	3.19
9	11.0	84	9.64	1.36
10	28.1	83	----	12.54
11	16.1	83	10.90	5.20
12	13.9	83	10.67	3.23
13	21.5	83	9.99	11.51
14	9.2	84	7.91	1.29
15	10.5	84	8.21	2.29
16	13.8	84	----	4.59
17	12.8	81	9.41	3.39
18	13.0	80	6.78	6.22
19	14.4	79	8.89	5.51
20	6.6	77	1.39	5.21

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.57 - Field Test Data - 7/28/83 5/5

Fill Height = 2 ft   Load Location = 0.0LL

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.6	71	1.49	3.11
2	6.0	79	1.52	4.48
3	7.6	80	2.18	5.42
4	6.1	82	2.15	3.95
5	11.6	85	8.58	3.02
6	11.9	85	8.31	3.59
7	11.0	85	----	2.84
8	18.8	84	----	10.19
9	13.5	83	9.55	3.95
10	23.0	83	----	8.66
11	29.0	83	10.90	18.10
12	15.9	83	10.67	5.23
13	25.6	83	----	14.24
14	11.4	84	----	4.96
15	11.0	84	8.21	2.79
16	15.0	84	----	5.48
17	12.6	81	----	2.84
18	14.0	80	----	5.90
19	14.5	79	----	5.28
20	6.5	77	1.39	5.11

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.58 - Field Test Data - 7/29/83 1/5

Fill Height = 2 ft   Load Location = 8.7RL

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.4	77	1.71	2.69
2	5.7	79	1.52	4.18
3	7.5	80	2.18	5.32
4	5.5	82	2.15	3.35
5	11.6	85	8.58	3.02
6	12.0	85	8.31	3.69
7	10.7	85	7.58	3.12
8	11.5	84	8.61	2.89
9	10.8	84	9.64	1.16
10	16.8	84	13.62	3.18
11	16.2	84	11.04	5.16
12	13.8	84	10.80	3.00
13	13.9	84	10.11	3.79
14	9.3	84	7.91	1.39
15	12.9	84	----	2.75
16	11.4	84	10.37	1.03
17	12.7	81	9.41	3.29
18	12.5	80	6.78	5.72
19	14.2	79	8.89	5.31
20	6.5	77	1.39	5.11

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.59 - Field Test Data - 7/29/83 2/5

Fill Height = 2 ft   Load Location = 2.0RL

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.5	77	1.71	2.79
2	5.9	79	1.52	4.38
3	8.0	80	2.18	5.82
4	6.0	82	2.15	3.85
5	11.7	85	8.58	3.12
6	11.9	85	8.31	3.59
7	10.9	85	7.58	3.32
8	11.5	84	8.61	2.89
9	19.0	84	----	8.56
10	24.2	84	13.62	10.58
11	19.0	84	11.04	7.86
12	23.5	84	10.80	12.70
13	16.4	83	9.99	6.41
14	9.6	84	7.91	1.69
15	15.1	84	----	7.56
16	11.9	84	10.37	1.53
17	12.0	81	9.41	2.59
18	13.5	80	6.78	6.72
19	14.5	79	8.89	5.61
20	6.5	77	1.39	5.11

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.60 - Field Test Data - 7/29/83 3/5

Fill Height = 2 ft   Load Location = 2.0LL

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.7	77	1.71	2.99
2	6.1	79	1.52	4.58
3	7.9	80	2.18	5.72
4	5.6	82	2.15	3.45
5	11.6	85	8.58	3.02
6	11.9	85	8.31	3.59
7	11.0	85	----	2.89
8	20.2	84	8.61	11.59
9	19.8	84	----	8.50
10	17.3	84	13.62	3.68
11	19.0	84	11.04	7.96
12	23.7	84	10.80	12.90
13	16.0	83	9.99	6.01
14	9.5	84	7.91	1.59
15	15.2	84	----	8.11
16	12.0	84	10.37	1.63
17	12.4	81	----	2.74
18	13.8	80	----	6.20
19	14.5	79	----	5.23
20	6.3	77	1.39	4.91

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.61 - Field Test Data - 7/29/83 4/5

Fill Height = 2 ft Load Location = 4.7LL

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.8	77	1.71	3.09
2	5.9	79	1.52	4.38
3	7.7	80	2.18	5.52
4	6.9	82	2.15	4.75
5	11.6	85	8.58	3.02
6	12.0	85	8.31	3.69
7	11.1	85	----	2.90
8	22.2	84	----	13.59
9	11.0	84	9.64	1.36
10	17.0	84	13.62	3.38
11	24.3	84	11.04	13.26
12	14.4	84	10.80	3.60
13	14.2	83	9.99	4.21
14	11.0	84	----	3.86
15	10.6	84	8.21	2.39
16	11.3	84	10.37	0.93
17	12.3	81	----	2.64
18	13.5	80	----	5.90
19	14.4	79	----	5.18
20	6.2	77	1.39	4.81

Note: 1 psi = 6.89 kPa 1°F = 0.56°C 1 ft = 0.305 m

TABLE III.62 - Field Test Data - 7/29/83 5/5

Fill Height = 2 ft Load Location = 8.7LL

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.7	77	1.71	2.99
2	5.6	79	1.52	4.08
3	7.5	80	2.18	5.32
4	6.8	82	2.15	4.65
5	11.6	85	8.58	3.02
6	12.1	85	8.31	3.79
7	10.9	85	7.58	3.32
8	11.8	85	8.73	3.07
9	11.2	84	9.64	1.56
10	17.0	84	13.62	3.38
11	15.9	84	11.04	4.86
12	14.2	84	10.80	3.40
13	14.4	84	10.11	4.29
14	9.1	85	8.02	1.08
15	11.0	84	8.21	2.79
16	11.4	85	10.49	0.91
17	12.1	81	9.41	2.69
18	13.1	81	6.89	6.21
19	14.4	79	8.89	5.51
20	6.2	77	1.39	4.81

Note: 1 psi = 6.89 kPa 1°F = 0.56°C 1 ft = 0.305 m

TABLE III.63 - Field Test Data - 8/10/83 2/2

Fill Height = 4 ft   Load Location = 0.0RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	5.2	76	1.68	3.52
2	6.4	77	1.48	4.92
3	8.6	78	2.12	6.48
4	6.3	79	2.06	4.24
5	11.1	81	----	3.31
6	10.8	80	----	3.39
7	10.1	80	----	3.70
8	14.0	80	8.15	5.85
9	12.0	80	9.27	2.73
10	19.6	80	13.17	6.43
11	19.2	80	10.48	8.72
12	14.0	79	10.13	3.87
13	14.8	79	----	5.91
14	11.2	79	7.37	3.83
15	12.0	79	7.54	4.46
16	13.2	79	9.76	3.44
17	11.6	79	9.15	2.45
18	13.1	78	6.55	6.55
19	14.0	77	8.67	5.33
20	7.4	76	1.37	6.03

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.64 - Field Test Data - 8/15/83 1/4

Fill Height = 4 ft   Load Location = 8.7LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	5.4	78	1.75	3.65
2	6.2	79	1.52	4.68
3	8.4	80	2.18	6.22
4	6.4	81	2.12	4.28
5	11.3	81	8.22	3.08
6	11.4	81	7.83	3.57
7	10.6	81	7.23	3.37
8	12.4	81	8.26	4.14
9	10.9	81	9.37	1.53
10	17.4	81	13.28	4.12
11	16.4	81	10.62	5.78
12	13.2	81	10.40	2.80
13	13.4	81	9.75	3.65
14	9.7	81	7.59	2.11
15	10.9	81	7.81	3.09
16	11.6	81	10.00	1.60
17	11.7	80	9.28	2.42
18	14.8	80	6.78	8.02
19	14.8	79	8.89	5.91
20	7.0	78	1.40	5.60

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.65 - Field Test Data - 8/15/83 2/4

Fill Height = 4 ft   Load Location = 6.7LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	5.4	78	1.75	3.65
2	6.4	79	1.52	4.88
3	8.4	80	2.18	6.22
4	6.3	81	2.12	4.18
5	11.6	81	8.22	3.38
6	11.6	81	7.83	3.77
7	10.9	81	7.23	3.67
8	14.5	81	8.26	6.24
9	11.1	81	9.37	1.73
10	17.6	81	13.28	4.32
11	17.4	81	10.62	6.78
12	13.5	81	10.40	3.10
13	13.6	81	9.75	3.85
14	10.3	81	7.59	2.71
15	11.2	81	7.81	3.39
16	11.8	81	10.00	1.80
17	12.0	80	9.28	2.72
18	14.0	80	6.78	7.22
19	15.0	79	8.89	6.11
20	7.0	78	1.40	5.60

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.66 - Field Test Data - 8/15/83 3/4

Fill Height = 4 ft   Load Location = 4.7LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	5.5	78	1.75	3.75
2	6.4	79	1.52	4.88
3	8.5	80	2.18	6.32
4	6.4	81	2.12	4.28
5	11.7	81	8.22	3.48
6	11.8	81	7.83	3.97
7	11.1	81	7.23	3.87
8	16.0	81	8.26	7.74
9	11.4	81	9.37	2.03
10	18.0	81	13.28	4.72
11	19.7	81	10.62	9.08
12	14.0	81	10.40	3.60
13	13.8	81	9.75	4.05
14	11.5	81	7.59	3.91
15	11.6	81	7.81	3.79
16	12.0	81	10.00	2.00
17	12.1	80	9.28	2.82
18	14.2	80	6.78	7.42
19	15.1	79	8.89	6.21
20	7.1	78	1.40	5.70

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.67 - Field Test Data - 8/15/83 4/4

Fill Height = 4 ft Load Location = 2.0LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	5.4	78	1.75	3.65
2	6.6	79	1.52	5.08
3	8.9	80	2.18	6.72
4	6.2	81	2.12	4.08
5	11.8	81	----	3.33
6	11.7	81	----	3.63
7	11.1	81	7.23	3.87
8	16.3	81	8.26	8.04
9	13.0	81	----	3.98
10	18.7	81	13.28	5.42
11	20.4	81	----	9.45
12	15.4	81	----	5.37
13	14.8	81	9.75	5.05
14	11.7	81	----	3.37
15	13.1	81	----	5.52
16	13.0	81	----	2.56
17	12.2	80	----	2.62
18	13.5	80	6.78	6.72
19	15.2	79	----	5.96
20	7.1	78	1.40	5.70

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.68 - Field Test Data - 8/16/83 1/4

Fill Height = 4 ft Load Location = 1.0LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	5.3	79	1.79	3.51
2	6.6	80	1.54	5.06
3	8.9	81	2.21	6.69
4	6.1	81	2.12	3.98
5	11.6	82	8.31	3.29
6	11.5	82	7.95	3.55
7	11.0	82	7.32	3.68
8	14.9	82	8.38	6.52
9	12.8	82	9.46	3.34
10	19.4	82	13.39	6.01
11	20.5	82	10.76	9.74
12	15.2	82	----	5.02
13	15.4	82	9.87	5.53
14	11.6	82	7.70	3.90
15	12.8	82	----	5.15
16	13.5	82	----	3.65
17	11.9	82	9.54	2.36
18	14.2	80	6.78	7.42
19	14.9	80	9.00	5.90
20	7.1	79	1.42	5.68

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.69 - Field Test Data - 8/16/83 2/4

Fill Height = 4 ft   Load Location = 1.0RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	5.2	79	1.79	3.41
2	6.6	80	1.54	5.06
3	9.0	81	2.21	6.79
4	6.4	82	2.15	4.25
5	12.0	83	8.40	3.60
6	11.9	83	8.07	3.83
7	11.2	82	7.32	3.88
8	14.4	82	8.38	6.02
9	13.1	82	9.46	3.64
10	21.4	82	13.39	8.01
11	21.2	81	10.62	10.58
12	15.9	82	----	5.02
13	16.2	82	9.87	6.33
14	12.0	82	7.70	4.30
15	13.4	82	----	5.15
16	14.2	82	----	3.65
17	12.1	81	9.41	2.69
18	14.6	81	6.89	7.71
19	15.4	80	9.00	6.40
20	7.2	79	1.42	5.78

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.70 - Field Test Data - 8/16/83 3/4

Fill Height = 4 ft   Load Location = 2.0RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	5.2	79	1.79	3.41
2	6.5	80	1.54	4.96
3	9.0	81	2.21	6.79
4	6.5	82	2.15	4.35
5	12.1	83	----	3.39
6	11.8	83	----	3.56
7	11.2	82	7.32	3.88
8	13.5	82	8.38	5.12
9	13.5	82	----	4.14
10	21.4	82	----	8.52
11	19.8	81	----	8.45
12	16.1	82	----	5.46
13	16.3	82	----	6.15
14	11.3	82	----	2.96
15	13.7	82	----	5.52
16	14.3	82	----	3.72
17	12.0	81	----	2.41
18	14.5	81	----	7.07
19	15.2	80	----	5.91
20	7.3	79	1.42	5.88

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.71 - Field Test Data - 8/16/83 4/4

Fill Height = 4 ft   Load Location = 4.7RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	5.1	79	1.79	3.31
2	6.4	80	1.54	4.86
3	8.8	81	2.21	6.59
4	6.4	82	2.15	4.25
5	12.1	83	8.40	3.70
6	11.9	83	8.07	3.83
7	11.2	82	7.32	3.88
8	12.7	82	8.38	4.32
9	12.2	82	9.46	2.74
10	21.6	82	13.39	8.21
11	17.9	81	10.62	7.28
12	14.6	82	10.53	4.07
13	16.4	82	----	5.91
14	10.5	82	7.70	2.80
15	12.2	82	7.95	4.25
16	14.2	82	----	3.72
17	12.0	81	9.41	2.59
18	14.1	81	6.89	7.21
19	15.2	80	9.00	6.20
20	7.4	79	1.42	5.98

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.72 - Field Test Data - 8/17/83 1/6

Fill Height = 4 ft   Load Location = 12.7LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	5.4	79	1.79	3.61
2	6.4	80	1.54	4.86
3	8.7	80	2.18	6.52
4	6.2	81	2.12	4.08
5	11.5	82	8.31	3.19
6	11.6	82	7.95	3.65
7	10.8	82	7.32	3.48
8	11.8	82	8.38	3.42
9	11.1	82	9.46	1.64
10	17.5	82	13.39	4.11
11	16.5	82	10.76	5.74
12	13.6	82	10.53	3.07
13	13.3	82	9.87	3.43
14	9.9	82	7.70	2.20
15	11.0	82	7.95	3.05
16	11.7	82	10.13	1.57
17	11.7	81	9.41	2.29
18	13.4	80	6.78	6.62
19	14.7	80	9.00	5.70
20	7.1	78	1.40	5.70

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.73 - Field Test Data - 8/17/83 2/6

Fill Height = 4 ft   Load Location = 3.0LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	5.4	79	1.79	3.61
2	6.6	80	1.54	5.06
3	8.9	80	2.18	6.72
4	6.1	81	2.12	3.98
5	11.5	82	8.31	3.19
6	11.5	82	7.95	3.55
7	11.0	82	7.32	3.68
8	15.6	82	8.38	7.22
9	12.1	82	9.46	2.64
10	18.2	82	13.39	4.81
11	20.5	82	10.76	9.74
12	15.2	82	10.53	4.67
13	13.8	82	----	4.28
14	11.5	82	7.70	3.80
15	12.2	82	7.95	4.25
16	12.0	82	10.13	1.87
17	11.9	81	9.41	2.49
18	14.0	80	6.78	7.22
19	14.9	80	9.00	5.90
20	7.0	78	1.40	5.60

1°F = 0.56°C

Note: 1 psi = 6.89 kPa

1 ft = 0.305 m

TABLE III.74 - Field Test Data - 8/17/83 3/6

Fill Height = 4 ft   Load Location = 3.0RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	5.1	79	1.79	3.31
2	6.5	80	1.54	4.96
3	3.0	80	----	6.72
4	6.4	81	2.12	4.28
5	11.7	82	8.31	3.39
6	11.6	82	7.95	3.65
7	11.0	82	7.32	3.68
8	12.8	82	8.38	4.42
9	13.1	82	9.46	3.64
10	21.3	82	13.39	7.91
11	18.2	82	10.76	7.44
12	15.3	82	10.53	4.77
13	16.1	82	9.87	6.23
14	10.5	82	7.70	2.80
15	12.7	82	7.95	4.75
16	13.9	82	10.13	3.77
17	11.6	81	9.41	2.19
18	13.9	80	6.78	7.12
19	15.0	80	9.00	6.00
20	7.3	78	1.40	5.90

1°F = 0.56°C

Note: 1 psi = 6.89 kPa

1 ft = 0.305 m

TABLE III.75 - Field Test Data - 8/17/83 4/6

Fill Height = 4 ft   Load Location = 6.7RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	5.0	78	1.75	3.25
2	6.4	80	1.54	4.86
3	8.7	80	2.18	6.52
4	6.1	81	2.12	3.98
5	11.6	83	8.40	3.20
6	11.7	82	7.95	3.75
7	10.9	82	7.32	3.58
8	12.3	83	8.49	3.81
9	11.3	82	9.46	1.84
10	20.4	82	13.39	7.01
11	17.2	83	10.90	6.30
12	13.9	82	10.53	3.37
13	14.5	82	----	4.28
14	10.0	82	7.70	2.30
15	11.4	82	7.95	3.45
16	12.2	82	10.13	2.07
17	11.9	81	9.41	2.49
18	13.5	80	6.78	6.72
19	14.9	80	9.00	5.90
20	7.4	78	1.40	6.00

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.76 - Field Test Data - 8/17/83 5/6

Fill Height = 4 ft   Load Location = 8.7RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	5.0	78	1.75	3.25
2	6.4	80	1.54	4.86
3	8.7	80	2.18	6.52
4	6.0	81	2.12	3.88
5	11.6	83	8.40	3.20
6	11.7	82	7.95	3.75
7	10.9	82	7.32	3.58
8	12.2	83	8.49	3.71
9	11.4	82	9.46	1.94
10	18.5	82	13.39	5.11
11	17.2	83	10.90	6.30
12	14.0	82	10.53	3.47
13	13.9	82	9.87	4.03
14	10.1	82	7.70	2.40
15	11.5	82	7.95	3.55
16	11.9	82	10.13	1.77
17	12.0	81	9.41	2.59
18	13.4	80	6.78	6.62
19	14.9	80	9.00	5.90
20	7.4	78	1.40	6.00

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.30 5m

TABLE III.77 - Field Test Data - 8/17/83 6/6

Fill Height = 4 ft   Load Location = 12.7RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	5.2	78	1.75	3.45
2	6.4	80	1.54	4.86
3	8.6	80	2.18	6.42
4	6.0	81	2.12	3.88
5	11.7	83	8.40	3.30
6	11.9	82	7.95	3.95
7	11.0	82	7.32	3.68
8	12.1	83	8.49	3.61
9	11.5	82	9.46	2.04
10	17.9	82	13.39	4.51
11	17.2	83	10.90	6.30
12	14.1	82	10.53	3.57
13	13.9	82	9.87	4.03
14	10.1	82	7.70	2.40
15	11.5	82	7.95	3.55
16	11.9	82	10.13	1.77
17	12.1	81	9.41	2.69
18	13.5	80	6.78	6.72
19	14.9	80	9.00	5.90
20	7.4	78	1.40	6.00

1°F = 0.56°C

Note: 1 psi = 6.89 kPa

1 ft = 0.305 m

TABLE III.78 - Field Test Data - 8/24/83 1.2

Fill Height = 4 ft   Load Location = 2.0RL

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	5.1	77	1.71	3.39
2	6.4	79	1.52	4.88
3	8.9	79	2.15	6.75
4	6.3	80	2.09	4.21
5	11.3	81	----	3.39
6	11.1	80	----	3.56
7	11.2	80	7.14	4.06
8	12.0	80	----	5.12
9	13.5	80	----	4.14
10	22.2	80	----	8.52
11	18.2	80	----	8.45
12	15.6	80	----	5.46
13	15.5	80	----	6.15
14	9.8	80	----	3.37
15	11.5	80	----	5.52
16	12.6	80	----	3.65
17	11.5	80	----	2.41
18	13.3	80	----	7.07
19	14.5	79	----	5.91
20	7.0	77	1.39	5.61

1°F = 0.56°C

Note: 1 psi = 6.89 kPa

1 ft = 0.305 m

TABLE III.79 - Field Test Data - 8/14/83 2/2

Fill Height = 4 ft   Load Location = 2.0LL

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	5.4	77	1.71	3.69
2	6.5	79	1.52	4.98
3	8.8	79	2.15	6.65
4	5.9	80	2.09	3.81
5	11.3	81	----	3.33
6	11.1	80	----	3.63
7	11.2	80	7.14	4.06
8	16.3	80	8.15	8.15
9	13.6	80	----	3.98
10	18.8	80	13.17	5.63
11	19.6	80	----	9.45
12	16.0	80	----	5.37
13	14.6	80	9.63	4.97
14	10.1	80	----	2.96
15	11.6	80	----	5.52
16	12.0	80	----	2.56
17	11.6	80	----	2.62
18	13.5	80	6.78	6.72
19	14.5	79	----	5.96
20	6.9	77	1.39	5.51

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.80 - Field Test Data - 7/13/84 1/6

Fill Height = 6 ft Load Location = 1.0LR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.9	75	1.64	3.26
2	6.6	78	1.50	5.10
3	10.1	79	2.15	7.95
4	7.0	80	2.09	4.91
5	14.7	82	8.31	6.39
6	13.0	82	7.95	5.05
7	18.0	81	7.32	10.68
8	19.9	81	8.26	11.64
9	16.5	82	9.46	7.04
10	22.4	81	13.28	9.12
11	29.0	81	10.62	18.38
12	18.0	81	10.40	7.60
13	19.7	81	9.75	9.95
14	13.7	82	7.70	6.00
15	15.4	82	7.95	7.45
16	15.4	81	10.00	5.48
17	14.8	80	9.28	5.52
18	17.2	79	6.66	10.54
19	15.8	78	8.78	7.02
20	7.2	75	1.35	5.85

Note: 1 psi = 6.89 kPa; 1°F = 0.56°C; 1 ft = 0.305 m

TABLE III.81 - Field Test Data - 7/13/84 2/6

Fill Height = 6 ft Load Location = 0.0RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.9	75	1.64	3.26
2	6.6	78	1.50	5.10
3	10.0	79	2.15	7.85
4	7.1	80	2.09	5.01
5	14.6	82	8.31	6.29
6	13.0	82	7.95	5.05
7	17.9	82	7.32	10.58
8	19.6	81	8.26	11.34
9	16.5	82	9.46	7.04
10	22.6	81	13.28	9.32
11	29.0	81	10.62	18.38
12	18.1	81	10.40	7.70
13	19.9	81	9.75	10.15
14	13.8	82	7.70	6.10
15	15.6	82	7.95	7.65
16	14.7	81	10.00	5.60
17	14.7	80	9.28	5.42
18	17.1	79	6.66	10.44
19	15.8	78	8.78	7.02
20	7.3	75	1.35	5.95

Note: 1 psi = 6.89 kPa; 1°F = 0.56°C; 1 ft = 0.305 m

TABLE III.82 - Field Test Data - 7/13/84 3/6

Fill Height = 6 ft Load Location = 2.0LR

Cell No.	Measured Pressure (psi)	Temp (^{o}F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.9	75	1.64	3.26
2	6.7	78	1.50	5.20
3	10.1	80	2.18	7.82
4	7.0	80	2.09	4.91
5	14.9	82	8.31	6.59
6	13.1	82	7.95	5.15
7	18.0	82	7.32	10.68
8	20.3	82	8.38	11.92
9	16.6	82	9.46	7.14
10	22.4	82	13.39	9.01
11	29.4	82	10.76	18.64
12	17.9	81	10.40	7.50
13	19.8	82	9.87	9.93
14	13.9	81	7.59	6.31
15	15.6	82	7.95	7.65
16	15.5	82	10.13	5.37
17	14.9	81	9.41	5.49
18	17.3	80	6.78	10.52
19	15.9	78	8.78	7.12
20	7.2	75	1.35	5.85

Note: 1 psi = 6.89 kPa 1°F = 0.56°C 1 ft = 0.305 m

TABLE III.83 - Field Test Data - 7/13/84 4/6

Fill Height = 6 ft Load Location = 2.0RR

Cell No.	Measured Pressure (psi)	Temp (^{o}F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.9	75	1.64	3.26
2	6.6	78	1.50	5.10
3	10.0	80	2.18	7.82
4	7.3	80	2.09	5.21
5	14.8	82	8.31	6.49
6	13.1	82	7.95	5.15
7	18.0	82	7.32	10.68
8	19.2	82	8.38	10.82
9	16.7	82	9.46	7.24
10	23.2	82	13.39	9.81
11	28.5	82	10.76	17.74
12	17.8	81	10.40	7.40
13	20.8	82	9.87	10.93
14	13.5	81	7.59	5.91
15	15.9	82	7.95	7.95
16	16.0	82	10.13	5.87
17	14.7	81	9.41	5.29
18	17.2	80	6.78	10.42
19	15.9	78	8.78	7.12
20	7.4	75	1.35	6.05

Note: 1 psi = 6.89 kPa 1°F = 0.56°C 1 ft = 0.305 m

TABLE III.84 - Field Test Data - 7/13/84 5/6

Fill Height = 6 ft   Load Location = 4.7RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.8	75	1.64	3.16
2	6.5	79	1.52	4.98
3	10.0	80	2.18	7.82
4	7.3	81	2.12	5.18
5	14.9	82	8.31	6.59
6	13.4	82	7.95	5.45
7	18.0	82	7.32	10.68
8	18.9	81	8.36	10.64
9	16.5	82	9.46	7.04
10	23.2	82	13.39	9.81
11	27.8	82	10.76	17.04
12	17.9	82	10.53	7.37
13	20.8	82	9.87	10.93
14	13.4	82	7.70	5.70
15	15.7	82	7.95	7.75
16	16.0	82	10.13	5.87
17	14.7	81	9.41	5.29
18	17.1	79	6.66	10.44
19	15.9	78	8.78	7.12
20	7.4	75	1.35	6.05

Note: 1 psi = 6.89 kPa; 1°F = 0.56°C; 1 ft = 0.305 m

TABLE III.85 - Field Test Data - 7/14/84 2/3

Fill Height = 8 ft   Load Location = 0.0RR

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	5.5	77	1.71	3.79
2	7.2	78	1.50	5.70
3	10.8	79	2.15	8.65
4	7.4	80	2.09	5.31
5	14.9	80	8.13	6.77
6	12.0	80	7.71	4.29
7	19.0	80	7.14	11.86
8	20.4	80	8.15	12.25
9	15.4	80	9.27	6.13
10	23.2	80	13.17	10.03
11	29.4	80	10.48	18.92
12	16.0	81	10.40	5.60
13	18.8	80	9.63	9.17
14	13.5	80	7.48	6.02
15	13.0	81	7.81	5.19
16	14.5	81	10.00	4.50
17	14.4	80	9.28	5.12
18	17.0	80	6.78	10.22
19	16.0	78	8.78	7.22
20	8.0	77	1.39	6.61

Note: 1 psi = 6.89 kPa; 1°F = 0.56°C; 1 ft = 0.305 m

TABLE III.86 - Field Test Data - 1/18/83

Fill Height =-6.0 ft   Load Location = NONE

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.3	49	0.66	2.64
2	2.6	49	0.95	1.65
3	1.5	50	1.34	0.16
4	1.5	50	1.25	0.25
5	5.0	49	5.32	-0.32
6	3.9	49	4.01	-0.11
7	4.3	49	4.43	-0.13
8	4.5	49	4.55	-0.05
9	6.3	49	6.41	-0.11
10	9.7	49	9.73	-0.03
11	6.2	49	6.06	0.14
12	6.5	47	5.81	0.69
13	5.9	48	5.82	0.08
14	4.1	49	4.12	-0.02
15	4.2	49	3.52	0.68
16	6.1	49	6.11	-0.01
17	5.5	49	5.20	0.30
18	3.5	50	3.33	0.17
19	6.8	50	5.62	1.18
20	3.5	50	0.96	2.54

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.87 - Field Test Data - 1/27/83 1/1

Fill Height = -4.0 ft   Load Location = NONE

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	1.8	43	0.44	1.36
2	3.3	42	0.81	2.49
3	1.4	43	1.14	0.26
4	1.1	46	1.14	-0.04
5	5.1	49	5.32	-0.22
6	4.0	50	4.3	-0.13
7	4.5	49	4.43	0.07
8	4.7	49	4.55	0.15
9	6.4	48	6.32	0.08
10	9.8	49	9.73	0.07
11	6.1	48	5.92	0.18
12	6.5	50	6.22	0.28
13	5.9	49	5.94	-0.04
14	4.2	48	4.01	0.19
15	4.2	47	3.25	0.95
16	6.1	48	5.99	0.11
17	5.2	46	4.80	0.40
18	3.1	46	2.87	0.23
19	6.2	42	4.72	1.48
20	2.4	44	0.87	1.53

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.88 - Field Test Data - 1/28/83 1/1

Fill Height = -2.0 ft. Load Location = NONE

Cell No.	Measured Pressure (psi)	Temp (^oF)	Temp Corr. (psi)	Corrected Pressure (psi)
1	1.9	45	0.51	1.39
2	3.6	43	0.83	2.77
3	4.4	45	1.20	3.20
4	1.3	53	1.33	-0.03
5	6.1	59	6.23	-0.13
6	5.5	59	5.21	0.29
7	5.5	59	5.31	0.19
8	5.8	59	5.71	0.09
9	7.5	59	7.34	0.16
10	10.9	59	10.84	0.06
11	7.3	59	7.48	-0.18
12	7.8	60	7.57	0.23
13	7.4	60	7.25	0.15
14	5.3	59	5.20	0.10
15	5.9	59	4.86	1.04
16	7.4	59	7.33	0.07
17	6.4	58	6.38	0.02
18	5.4	47	2.99	2.41
19	6.5	45	5.06	1.44
20	2.4	45	0.89	1.51

Note: 1 psi = 6.89 kPa; 1°F = 0.56°C; 1 ft = 0.305 m

TABLE III.89 - Field Test Data - 4/14/84 1/3

Fill Height = 8 in. Load Location = NONE

Cell No.	Measured Pressure (psi)	Temp (^oF)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.2	58	1.00	2.20
2	4.9	60	1.16	3.74
3	6.5	60	1.62	4.88
4	3.5	62	1.59	1.91
5	6.5	61	6.41	0.09
6	5.7	61	5.45	0.25
7	5.9	61	5.48	0.42
8	6.4	62	6.06	0.34
9	8.1	62	7.61	0.49
10	11.5	62	11.17	0.33
11	8.0	61	7.77	0.23
12	8.1	61	7.70	0.40
13	7.7	61	7.37	0.33
14	5.6	61	5.42	0.18
15	7.0	61	5.13	1.87
16	8.3	61	7.69	0.61
17	7.8	62	6.91	0.89
18	8.3	60	4.48	3.82
19	9.2	60	6.75	2.45
20	4.7	62	1.15	3.55

Note: 1 psi = 6.89 kPa; 1°F = 0.56°C; 1 ft = 0.305 m

TABLE III.90 - Field Test Data - 4/19/83 2/2

Fill Height = 8 in. Load Location = NONE

Cell No.	Measured Pressure (psi)	Temp (^oF)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.7	58	1.00	2.70
2	4.9	60	1.16	3.74
3	6.5	61	1.65	4.85
4	4.5	63	1.61	2.89
5	7.4	65	6.77	0.63
6	6.7	66	6.04	0.66
7	6.2	66	5.92	0.28
8	6.5	63	6.17	0.33
9	8.5	65	7.89	0.61
10	12.5	66	11.62	0.88
11	8.7	64	7.20	0.50
12	9.2	65	8.24	0.96
13	8.7	66	7.96	0.74
14	6.0	65	5.85	0.15
15	7.3	65	5.66	1.64
16	8.7	65	8.06	0.64
17	8.4	63	6.91	1.49
18	8.5	61	4.60	3.90
19	9.5	61	6.86	2.64
20	4.8	58	1.09	3.71

Note: 1 psi = 6.89 kPa 1°F = 0.56°C 1 ft = 0.305 m

TABLE III.91 - Field Test Data - 6/22/83 1/3

Fill Height = 8 in. Load Location = NONE

Cell No.	Measured Pressure (psi)	Temp (^oF)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.0	74	1.60	2.48
2	5.6	76	1.47	4.13
3	6.9	77	2.09	4.81
4	5.5	79	2.06	3.44
5	10.0	82	8.31	1.69
6	10.3	82	7.95	2.35
7	8.4	82	7.32	1.08
8	10.0	82	8.38	1.92
9	10.2	81	9.37	0.83
10	16.6	82	13.39	3.21
11	12.4	80	1.48	1.92
12	12.0	80	10.26	1.74
13	11.6	80	9.63	1.97
14	8.0	81	7.59	0.41
15	9.7	80	7.68	2.02
16	11.0	81	10.00	1.00
17	11.5	79	9.15	2.35
18	11.4	77	6.43	4.97
19	13.0	76	8.55	4.45
20	5.7	74	1.34	4.36

Note: 1 psi = 6.89 kPa 1°F = 0.56°C 1 ft = 0.305 m

TABLE III.92 - Field Test Data - 6/30/83 1/3

Fill Height = 8 in.   Load Location = NONE

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.2	76	1.68	2.52
2	5.6	78	1.50	4.10
3	7.0	79	2.15	4.85
4	5.7	81	2.12	3.58
5	10.5	84	8.49	2.01
6	11.2	84	8.19	3.01
7	9.1	84	7.49	1.61
8	10.1	83	8.49	1.61
9	10.7	83	9.55	1.15
10	16.0	83	13.51	2.49
11	13.6	83	10.90	2.70
12	12.1	83	10.67	1.43
13	12.1	83	9.99	2.11
14	8.7	83	7.81	0.89
15	10.2	83	8.08	2.12
16	10.8	83	10.25	0.55
17	12.2	81	9.41	2.79
18	12.8	79	6.66	6.14
19	13.8	78	8.78	5.02
20	6.0	76	1.37	4.63

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.93 - Field Test Data - 7/28/83 1/5

Fill Height = 2 ft   Load Location = NONE

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.4	77	1.71	2.69
2	5.6	79	1.52	4.08
3	7.3	80	2.18	5.12
4	5.4	82	2.15	3.25
5	11.5	85	8.58	2.92
6	12.0	85	8.31	3.69
7	10.6	85	7.58	3.02
8	11.7	84	8.61	3.09
9	11.0	84	9.64	1.36
10	17.0	83	13.51	3.49
11	15.8	83	10.90	4.90
12	13.8	83	10.67	3.13
13	14.0	83	9.99	4.01
14	9.2	84	7.91	1.29
15	11.0	84	8.21	2.79
16	11.5	84	10.37	1.13
17	11.9	81	9.41	2.49
18	12.5	80	6.78	5.72
19	14.0	79	8.89	5.11
20	6.3	77	1.39	4.91

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.94 - Field Test Data - 8/10/83 1/2

Fill Height = 4 ft   Load Location = NONE

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	5.0	76	1.68	3.32
2	6.0	77	1.48	4.52
3	8.0	78	2.12	5.88
4	5.8	79	2.06	3.74
5	10.9	81	8.22	2.68
6	11.0	80	7.71	3.29
7	10.0	80	7.14	2.86
8	10.7	80	8.15	2.55
9	10.5	80	9.27	1.23
10	16.7	80	13.17	3.53
11	15.1	80	10.48	4.62
12	12.5	79	10.13	2.37
13	12.6	79	9.51	3.09
14	9.4	79	7.37	2.03
15	10.4	79	7.54	2.86
16	11.1	79	9,76	1.34
17	11.1	79	9.15	1.95
18	11.8	78	6.55	5.25
19	13.8	77	8.67	5.13
20	6.9	76	1.37	5.53

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.95 - Field Test Data - 3/27/84 1/1

Fill Height = 4 ft   Load Location = NONE

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	3.4	60	1.08	2.32
2	4.5	62	1.20	3.30
3	6.5	62	1.67	4.83
4	5.1	62	1.59	3.51
5	10.1	63	6.59	3.51
6	9.6	63	5.68	3.92
7	12.5	63	5.66	6.84
8	12.1	63	6.17	5.93
9	11.8	63	7.70	4.18
10	16.8	63	11.29	5.51
11	17.5	63	8.05	9.45
12	13.5	63	7.97	5.53
13	14.1	63	7.61	6.49
14	9.9	64	5.75	4.15
15	11.4	64	5.53	5.87
16	11.5	64	7.93	3.57
17	9.9	62	6.91	2.99
18	9.0	62	4.71	4.29
19	11.0	62	6.98	4.02
20	5.0	60	1.12	3.88

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.96 - Field Test Data - 6/14/84 1/1

Fill Height = 4 ft   Load Location = NONE

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	4.2	70	1.45	2.75
2	5.6	72	1.39	4.21
3	8.4	73	1.98	6.42
4	6.0	74	1.92	4.08
5	12.6	75	7.68	4.92
6	12.0	76	7.23	4.77
7	15.9	75	6.70	9.20
8	16.0	75	7.57	8.43
9	14.1	75	8.81	5.29
10	19.8	75	12.62	7.18
11	23.2	75	9.76	13.44
12	15.9	74	9.45	6.45
13	17.0	75	9.03	7.97
14	11.9	75	6.94	4.96
15	13.5	75	7.01	6.49
16	14.0	75	9.27	4.73
17	12.8	74	8.49	4.31
18	13.9	73	5.97	7.98
19	13.9	72	8.10	5.80
20	6.4	70	1.28	5.12

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.97 - Field Test Data - 7/10/84 1/1

Fill Height = 4 ft   Load Location = NONE

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
	4.4	74	1.60	2.80
	6.0	77	1.48	4.52
	9.1	78	2.12	6.98
	6.4	79	2.06	4.34
	13.4	81	8.22	5.18
	12.5	81	7.83	4.67
	17.0	81	7.23	9.77
	17.5	81	8.26	9.24
	14.0	81	9.37	4.63
	20.6	81	13.28	7.32
	25.1	81	10.62	14.48
	16.5	81	10.40	6.10
	17.7	81	9.75	7.95
	12.6	81	7.59	5.01
	14.1	81	7.81	6.29
	14.2	80	9.88	4.32
	14.0	79	9.15	4.85
	15.7	78	6.55	9.15
	15.1	77	8.67	6.43
	6.7	75	1.35	5.35

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE III.98 - Field Test Data - 7/13/84 6/6

Fill Height = 6 ft Load Location = NONE

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr.	Corrected Pressure (psi)
1	4.9	75	1.64	3.26
2	6.5	79	1.52	4.98
3	9.7	80	2.18	7.52
4	6.9	81	2.12	4.78
5	14.8	82	8.31	6.49
6	13.4	82	7.95	5.45
7	17.7	82	7.32	10.38
8	18.4	81	8.26	10.14
9	16.0	82	9.46	6.54
10	21.4	82	13.39	8.01
11	27.1	82	10.76	16.34
12	17.6	82	10.53	7.07
13	19.2	82	9.87	9.33
14	13.0	82	7.70	5.30
15	15.1	82	7.95	7.15
16	14.9	82	10.13	4.77
17	14.9	81	9.41	5.19
18	17.0	79	6.66	10.34
19	15.9	78	8.78	7.12
20	7.2	75	1.35	5.85

Note: 1 psi = 6.89 kPa 1°F = 0.56°C 1 ft = 0.305 m

TABLE III.99 - Field Test Data - 9/12/84 1/1

Fill Height = 8 ft Load Location = NONE

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
	5.5	77	1.71	3.79
	7.0	78	1.50	5.50
	10.4	79	2.15	8.25
	7.2	80	2.09	5.11
	14.5	80	8.13	6.37
	12.1	80	7.71	4.39
	18.7	80	7.14	11.56
	18.9	80	8.14	10.76
	14.8	80	9.27	5.53
	21.9	80	13.17	8.73
	28.0	80	10.47	17.53
	15.6	81	10.40	5.20
	17.9	80	9.63	8.27
	12.9	80	7.48	5.42
	12.5	80	7.68	4.82
	14.1	80	9.89	4.21
	14.4	80	9.28	5.12
	16.7	79	6.66	10.04
	16.0	78	8.78	7.22
	7.9	77	1.38	6.52

Note: 1 psi = 6.89 kPa 1°F = 0.56°C 1 ft = 0.305 m

TABLE III.100 - Field Test Data - 9/14/84 1/3

Fill Height = 8 ft Load Location = NONE

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
1	5.5	77	1.71	3.79
2	7.0	78	1.50	5.50
3	10.5	79	2.15	8.35
4	7.1	80	2.09	5.01
5	14.2	80	8.13	6.07
6	12.0	80	7.71	4.29
7	18.4	80	7.14	11.26
8	18.5	80	8.14	10.36
9	14.5	80	9.27	5.23
10	21.6	80	13.17	8.43
11	27.7	80	10.47	17.23
12	15.4	81	10.40	5.00
13	17.5	80	9.63	7.87
14	12.8	80	7.48	5.32
15	12.2	81	7.81	4.39
16	13.6	81	10.01	3.57
17	14.2	80	9.28	4.02
18	16.5	80	6.78	9.72
19	15.8	78	8.78	7.02
20	7.8	77	1.38	6.42

1°F = 0.56°C

Note: 1 psi = 6.8 kPa

1 ft = 0.305 m

TABLE III.101 - Field Test Data - 9/18/84 1/1

Fill Height = 8 ft Load Location = NONE

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
	5.3	74	1.60	3.70
	6.6	75	1.45	5.15
	9.9	76	2.07	7.83
	6.8	76	1.98	4.82
	13.1	77	7.86	5.24
	10.5	77	7.35	3.15
	16.9	77	6.88	10.02
	16.9	77	7.80	9.10
	12.5	77	9.00	3.50
	20.3	77	12.84	7.46
	24.7	77	10.05	14.65
	13.8	77	9.86	3.94
	15.4	77	9.27	6.13
	11.5	77	7.15	4.35
	10.2	77	7.28	2.92
	12.0	77	9.52	2.48
	12.7	77	8.89	3.81
	13.6	76	6.32	7.28
	14.0	75	8.44	5.56
	7.5	74	1.34	6.16

1°F = 0.56°C

Note: 1 psi = 6.89 kPa

1 ft = 0.305 m

TABLE III.102 - Field Test Data - 11/5/84 1/1

Fill Height = 8 ft Load Location = NONE

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr.	Corrected Pressure (psi)
1	4.2	65	1.26	2.94
2	5.9	65	1.25	4.65
3	8.6	65	1.76	6.84
4	6.0	65	1.67	4.33
5	8.9	66	6.86	2.04
6	7.6	65	5.92	1.58
7	11.5	66	5.92	5.58
8	10.8	66	6.52	4.28
9	9.0	65	7.89	1.11
10	16.2	66	11.62	4.58
11	17.9	65	8.34	9.56
12	9.8	65	8.24	1.56
13	10.0	65	7.84	2.16
14	8.0	65	5.85	2.15
15	6.5	65	5.67	0.83
16	8.9	65	8.06	0.84
17	9.5	66	7.44	2.06
18	7.9	66	5.17	2.73
19	10.6	65	7.31	3.29
20	6.0	65	1.20	4.80

Note: 1 psi = 6.89 kPa 1°F = 0.56°C 1 ft = 0.305 m

TABLE III.103 - Field Test Data - 12/3/84 1/1

Fill Height = 8 ft Load Location = NONE

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr. (psi)	Corrected Pressure (psi)
	3.7	58	1.00	2.70
	3.8	56	1.08	2.72
	7.7	56	1.51	6.19
	5.1	56	1.42	3.68
	6.7	55	5.87	0.83
	5.6	54	4.61	0.99
	7.4	55	4.96	2.44
	6.5	55	4.24	1.26
	6.8	54	6.87	-0.07
	12.8	56	10.51	2.29
	11.8	54	6.77	5.03
	6.8	55	6.89	-0.09
	6.1	55	6.65	-0.55
	5.7	55	4.77	0.93
	3.6	55	4.32	-0.72
	6.9	55	6.84	0.06
	7.2	57	6.25	0.95
	3.6	56	4.02	-0.42
	8.2	57	6.41	1.79
	5.1	58	1.09	4.01

Note: 1 psi = 6.89 kPa 1°F = 0.56°C 1 ft = 0.305 m

TABLE III.104 - Field Test Data - 1/9/85 1/1

Fill Height = 8 ft   Load Location = NONE

Cell No.	Measured Pressure (psi)	Temp (°F)	Temp Corr.	Corrected Pressure (psi)
1	3.4	53	0.81	2.59
2	2.6	53	1.02	1.58
3	7.2	53	1.42	5.78
4	5.4	53	1.33	4.07
5	6.9	52	5.59	1.31
6	5.7	51	4.25	1.45
7	7.7	52	4.70	3.00
8	7.0	53	5.01	1.99
9	7.4	52	6.69	0.71
10	13.3	53	10.18	3.12
11	13.2	53	6.63	6.57
12	7.8	52	6.49	1.31
13	7.4	52	6.30	1.10
14	6.2	53	4.55	1.65
15	4.3	51	3.79	0.51
16	7.0	52	6.48	0.52
17	7.2	53	5.72	1.48
18	3.7	52	3.56	0.14
19	8.0	53	5.96	2.04
20	4.5	54	1.03	3.47

Note: 1 psi = 6.89 kPa   1°F = 0.56°C   1 ft = 0.305 m

TABLE VII - Strain Gage Data

Date	Depth Of Cover (ft)	Load Location	Strain Reading (10 in./in.)				
			Gage No.				
			1	2	3	4	6
8/25/82	- 9.2	N	976	449	715	2260	2224
9/21/82	- 9.2	N	960	423	708	2230	2201
1/14/83	- 9.2	N	929	349	694	2175	2165
1/27/83	- 5.2	N	900	304	664	2141	2131
4/14/83	0.7	N	874	266	634	2117	2150
		4.7LR	874	264	640	2116	2140
		0.0R	872	254	630	2114	2114
4/18/83	0.7	4.7RR	898	278	650	2134	2162
		4.7RL	867	266	634	2116	2153
		0.0L	860	246	616	2104	2115
4/19/83	0.7	4.3LL	886	266	640	2124	2142
		N	884	270	640	2126	2155
5/03/83	0.7	N	894	282	652	2136	2184
		14.7LR	901	294	666	2146	2191
		10.7LR	884	272	642	2124	2168
		8.7LR	874	262	628	2117	2160
5/05/83	0.7	N	892	282	654	2142	2182
		12.7LR	908	290	665	2152	2187
		6.7LR	892	286	660	2138	2176
		N	892	281	652	2134	2172
5/17/83	0.7	N	890	246	634	2120	2172
		4.3LR	890	248	633	2118	2158
		4.3RR	896	256	640	2123	2178
		N	906	257	640	2127	2182
6/02/83	0.7	4.3LR	910	250	690	2142	2187
6/10/83	0.7	14.7RR	916	254	698	2146	2198
		10.7RR	905	254	693	2145	2197
		8.7RR	900	263	688	2155	2226
6/13/83	0.7	6.7RR	924	259	700	2156	2225
		0.0R	920	242	694	2156	2180
		4.3RR	918	252	694	2151	2206
		4.7RR	912	248	691	2143	2210
		N	907	250	692	2140	2204
6/20/83		4.7RL	920	256	694	2167	2224
		4.7LL	924	250	693	2176	2314
		0.0LL	920	225	693	2160	2173
		4.3RL	920	234	706	2162	2220
		4.7	925	239	697	2162	2227
6/22/83	0.7	N	928	262	688	2162	2246
		8.7RL	917	220	685	2158	2226
		12.7RL	918	235	684	2173	2344
6/30/83	0.7	N	921	228	684	2151	2385
		2.0LR	923	225	684	2162	2187
		1.0LR	935	264	665	2160	2615

TABLE VII - (Continued)

Date	Depth Of Cover (ft)	Load Location	Strain Reading (10 in./in.)				
			Gage No.				
			1	2	3	4	6
7/06/83	0.7	2.0RR	915	236	680	2152	2162
		1.0RR	924	228	690	2148	2398
		3.0RR	915	208	685	2141	2162
7/08/83	0.7	4.0RR	913	207	683	2138	2241
		2.0RL	910	212	674	2141	2206
		2.0LL	910	198	673	2129	2130
		8.7LL	905	200	674	2129	2180
		12.7LL	912	201	677	2140	2180
7/22/83	2.0	0.0RR	901	179	669	2126	2222
		2.0LR	910	182	678	2134	2142
		4.7LR	921	190	688	2150	2221
7/25/83	2.0	12.7LR	928	215	701	2161	2231
		8.7LR	928	210	700	2154	2206
		1.0LR	925	200	693	2146	2183
		2.0RR	921	199	744	2135	2183
7/26/83	2.0	3.0LR	920	190	686	2141	2150
		6.7LR	929	204	695	2150	2177
		1.0RR	927	196	694	2147	2157
		4.7RR	926	201	694	2151	2201
7/27/83	2.0	6.7RR	925	201	694	2156	2186
		8.7RR	920	196	685	2137	2174
7/28/83	2.0	3.0RR	930	200	691	2156	2184
		12.7RR	927	208	695	2144	2193
		4.7RL	920	195	697	2150	2175
		0.0L	916	182	682	2132	2141
7/29/83	2.0	N	922	204	690	2151	2183
		8.7RL	927	206	694	2143	2184
		2.0RL	922	196	688	2142	2148
		2.0LL	926	196	690	2141	2148
		4.7LL	926	202	693	2140	2168
		8.7LL	927	206	693	2143	2179
8/10/83	4.0	N	917	174	687	2140	2148
		0.0R	902	152	670	2132	2122
8/15/83	4.0	N	918	180	687	2136	2134
		8.7LR	919	182	686	2143	2139
		6.7LR	912	174	683	2130	2136
		4.7LR	908	168	677	2127	2130
		2.0LR	907	165	677	2131	2123
8/16/83	4.0	N	901	168	670	2126	2118
		1.0LR	906	164	672	2130	2113
		1.0RR	912	172	688	2134	2120
		2.0RR	908	164	675	2128	2116
		4.7RR	910	168	658	2120	2124

TABLE VII. - (Continued)

Date	Depth Of Cover (ft)	Load Location	Strain Reading (10 in./in.)				
			Gage No.				
			1	2	3	4	6
8/17/83	4.0	12.7LR	916	177	688	2140	2132
		3.0LR	916	172	687	2156	2138
		3.0RR	914	170	682	2126	2137
		6.7RR	910	181	695	2131	2134
		8.7RR	914	172	683	2134	2135
		12.7RR	913	174	682	2131	2144
8/24/83	4.0	2.0RL	950	038	720	2088	2174
		2.0LL	903	162	670	2124	2128
6/14/84	4.0	N	910	1488	674	2103	2090
7/10/84	4.0	N	(+88)	(-463)	(+320)	(-1105)	(-1258)
7/13/84	6.0	1.0LR	912	1468	680	2102	2065
		0.0RR	912	1503	678	2103	2105
		2.0LR	912	1480	670	2095	2091
		2.0RR	893	1476	665	2091	2104
		4.7RR	871	1490	652	2084	2085
		N	896	1490	651	2083	2085
7/25/84	8.0	N	(+104)	(-177)	(+373)	(-1106)	(-970)
9/12/84	8.0	N	902	1345	661	2004	2033
		N	(+114)	(-264)	(+355	(-1086)	(-1015)
9/14/84	8.0	N	900	1356	663	2005	2015
		0.0RR	892	1346	652	2089	2003
		N	889	1346	647	2085	2010
9/18/84	8.0	N	852	1191	611	2054	1970
12/3/84	8.0	N	N/A	962	604	2048	1945

N denotes no live load

Data in paranthesis was recorded by strain gage indicator with Serial No. 033324.

Other data was recorded by strain gage indicator with Serial No. 1016.

TABLE VIII - Deflection Data

Date No.	Cover Depth (ft)	Load Position	Dial Reading (10^{-4} in.)	Temp (°F)
4/14/83	0.67	N	530	55
		4.7LR	615	
		N	520	
		0.0R	723	
		N	525	
4/18/83	0.67	N	528	74
		4.7RR	632	
		4.7RL	654	77
		0.0L	826	77
		N	620	
4/19/83	0.67	4.3LL	613	61
		4.3LL	634	
		4.3LL	665	67
		N	561	70
		N	540	
5/03/83	0.67	N	628	
		N	654	
		14.7LR	663	
		14.7LR	679	
		10.7LR	694	73
		19.7LR	700	
		8.7LR	700	75
		8.7LR	705	

TABLE VIII - (Continued)

Date	Cover Depth (ft)	Load Position	Dial Reading (10^{-4} in.)	Temp (°F)
5/03/83	0.67	8.7LR	696	
		2.0RR	773	
		N	702	
5/05/83	0.67	N	505	
		12.7LR	550	73
		12.7LR	572	
		6.7LR	588	
		6.7LR	600	
		N	600	
5/17/83	0.67	N	532	
		4.3LR	624	73
		4.3RR	624	71
		N	511	
6/02/83	0.67	4.3LR	624	84
		N	537	
6/10/83	0.67	14.7RR	918	74
		12.7RR	935	81
		10.7RR	940	82
		8.7RR	944	82
		N	944	
6/13/83	0.67	6.7RR	625	82

TABLE VIII - Deflection Data

Date No.	Cover Depth (ft)	Load Position	Dial Reading (10^{-4} in.)	Temp (^oF)
6/13/83	0.67	0.0R	815	
		0.0R	829	
		4.3RR	732	
		4.7RR	715	85
		4.7RR	723	
		N	640	
6/20/83	0.67	N	861	
		4.7RL	947	78
		4.7LL	972	
		0.0LL	1091	81
		4.3RL	1002	
		4.7LL	992	85
6/22/83	0.67	N	837	
		8.7RL	890	
		12.7RL	857	77
6/30/83	0,2.0LR, 1.0LR	No dial gage data		
7/01/83	0.67	4.0LR	1145	90
		4.0LR	1150	
7/06/83	0.67	N	1018	

TABLE VIII - (Continued)

Date	Cover Depth (ft)	Load Position	Dial Reading (10^{-4} in.)	Temp (^oF)
7/06/83	0.67	2.0RR	1047	
		1.0RR	1076	88
		3.0RR	1050	
7/08/83	0.67	4.0RR	980	81
		2 RL	1052	
		2 LL	1100	
		8.7LL	1015	
		12.7LL	913	88
		N	913	
7/22/83	2:0	N	985	79
		0.0RR	1145	
		2.0LR	1138	
		4.7LR	1092	85
7/25/83	2:0	12.7LR	979	90
		8.7LR	972	
		1 LR	1165	92
		2.0RR	1171	
		N	948	
7/26/83	2:0	N	976	80
		3 LR	1090	
		6.7LR	1014	
		6.7LR	1019	

TABLE VIII - Deflection Data

Date No.	Cover Depth (ft)	Load Position	Dial Reading (10^{-4} in.)	Temp ($^{\circ}F$)
7/26/83	2:0	1.0RR	1153	
		1.0RR	1182	88
		4.7RR	1111	
		4.7RR	1110	
7/27/83	2:0	6.7RR	1052	92
		8.7RR	1045	94
7/28/83	2:0	N	1019	88
		3 RR	1140	
		12.7RR	1043	91
		N	1050	
		0 L	1193	
		N	1055	
7/29/83	2:0	N	1021	88
		8.7RL	1021	
		2.0RL	1149	90
		2.0LL	1159	89
		4.7LL	1098	
		8.7LL	1046	89
8/10/83	4:0	N	1163	89
		0 RR	1269	
		N	1175	

TABLE VIII - (Continued)

Date	Cover Depth (ft)	Load Position	Dial Reading (10^{-4} in.)	Temp ($^{\circ}F$)
8/15/83	4:0	N	1160	85
		8.7LR	1168	
		6.7LR	1214	
		4.7LR	1234	92
		2.0LR	1270	90
8/16/83	4:0	N	1169	87
		1.0LR	1260	
		1.0RR	1284	91
		2.0RR	1293	
		4.7RR	1261	93
		N	1222	
8/17/83	4:0	N	1162	82
		12.7LR	1162	
		3.0LR	1238	
		3.0RR	1270	
		6.7RR	1220	88
		8.7RR	1210	
		12.7RR	1200	
8/24/83	4:0	N	1169	86
		2.0RL	1255	
		2.0LL	1278	

TABLE VIII - Deflection Data - Continued

Date No.	Cover Depth (ft)	Load Position	Dial Reading (10 in.)	Temp (°F)
7/13/84	6.0	N	1387	84
		1.0LR	1454	
		0.0RR	1476	87
		2.0LR	1488	89
		2.0RR	1486	89
		4.7RR	1484	91
		N	1445	92
9/12/84	8.0	N	1555	84
		N	23	80
9/14/84	8.0	0.0RR	74	

N denotes no live load.

Appendix C

PRESSURE CELL CALIBRATION DATA

TABLE V.1 - Flow Rate Calibration Data

Date	9/22/82	9/25/82	9/22/82
Flow Rate (scfh)	0.2	0.6	1.0
Temperature (°F)	68	68	68
Chamber Pressure (psi)	Measured Pressure (psi)		
0.0	0.5	1.1	4.0
2.0	2.0	2.5	4.0
4.0	4.0	4.1	4.1
6.0	6.0	6.0	6.0
8.0	7.8	8.1	8.0
10.0	9.8	10.1	9.9
12.0	12.0	12.0	11.9
14.0	13.9	14.1	13.9
20.0	19.9	20.2	20.1
30.0	30.0	30.1	29.9
40.0	39.8	40.1	39.9
30.0	29.9	30.4	29.8
20.0	20.1	20.4	20.4
10.0	10.0	10.3	10.3
0.0	0.5	2.1	4.0

Note: 1 psi = 6.89 kPa, 1°F = 0.56 °C,
1 scfh = 0.03 m^3/hr.

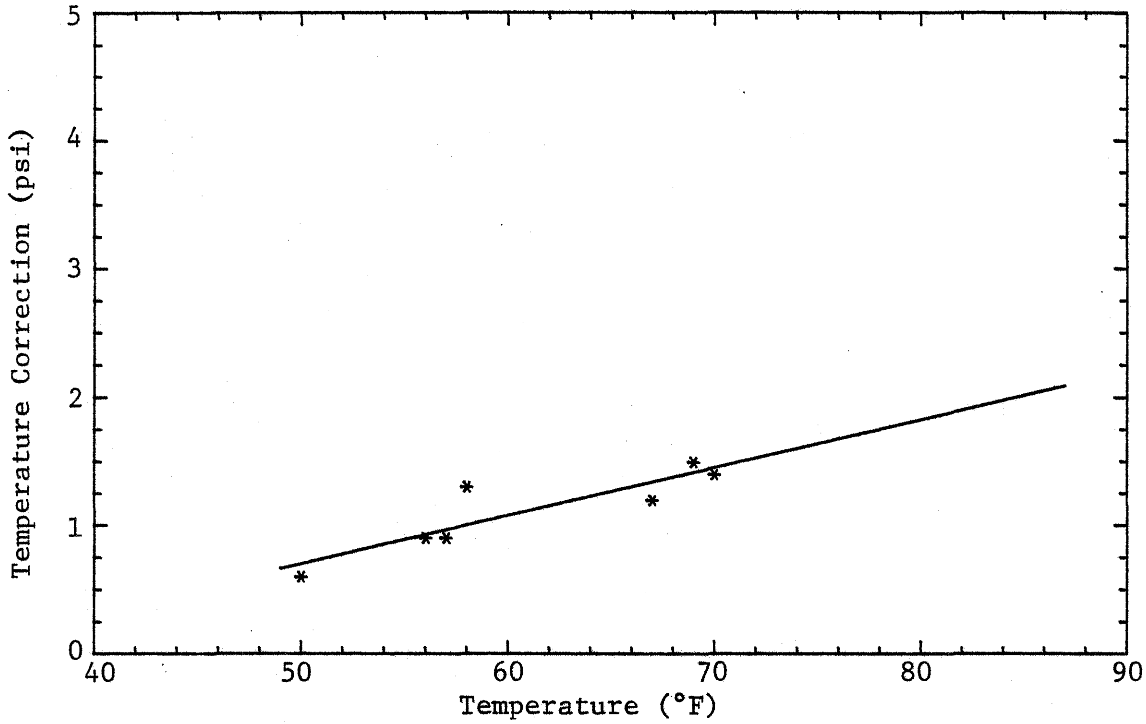


FIG. V.1. - Calibration Curve for Pressure Cell 1

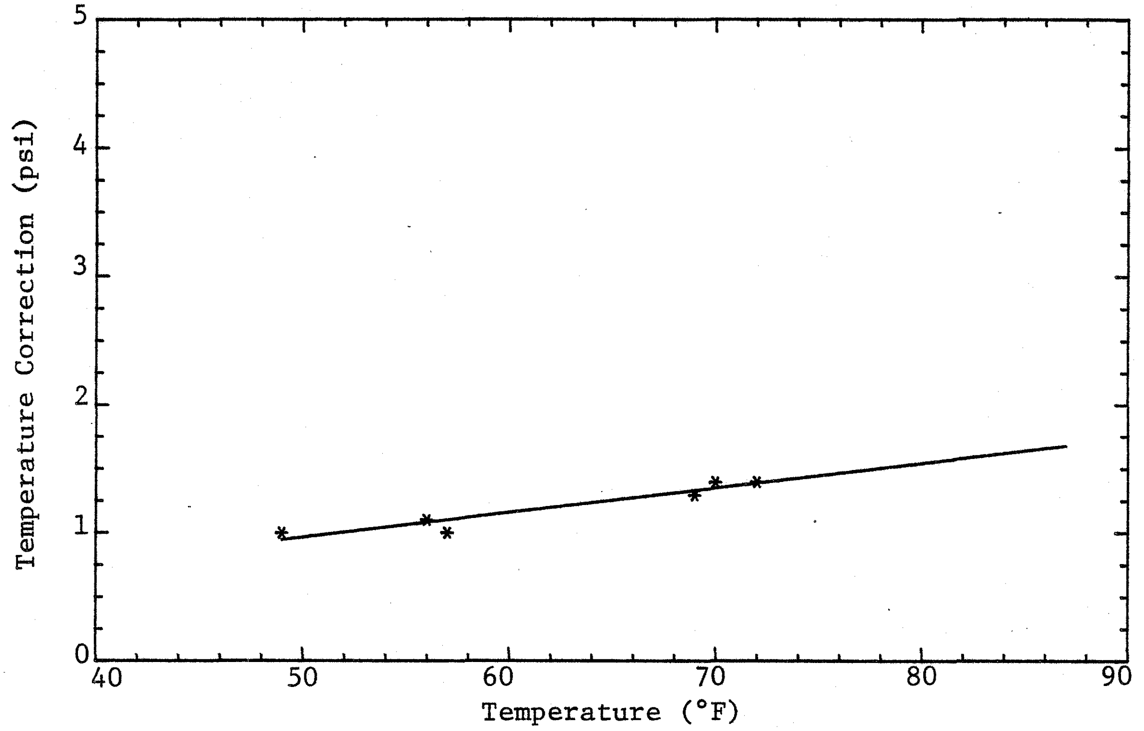


FIG. V.2. - Calibration Curve for Pressure Cell 2

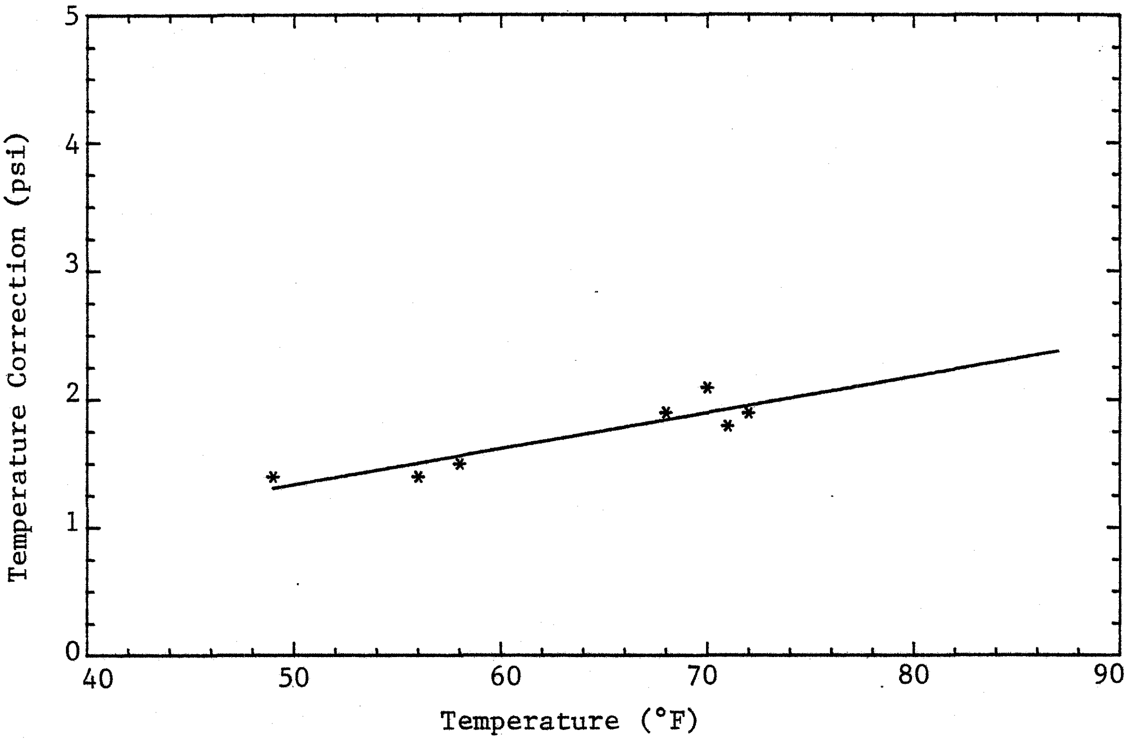


FIG. V.3. - Calibration Curve for Pressure Cell 3

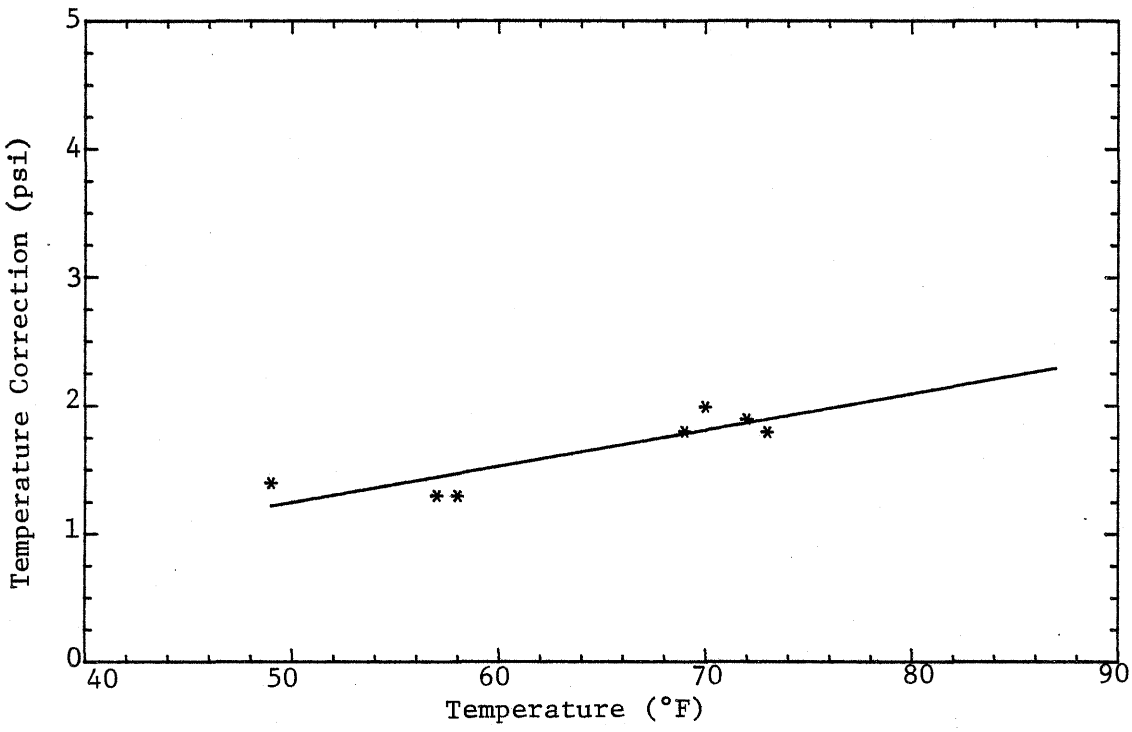


FIG. V.4. - Calibration Curve for Pressure Cell 4

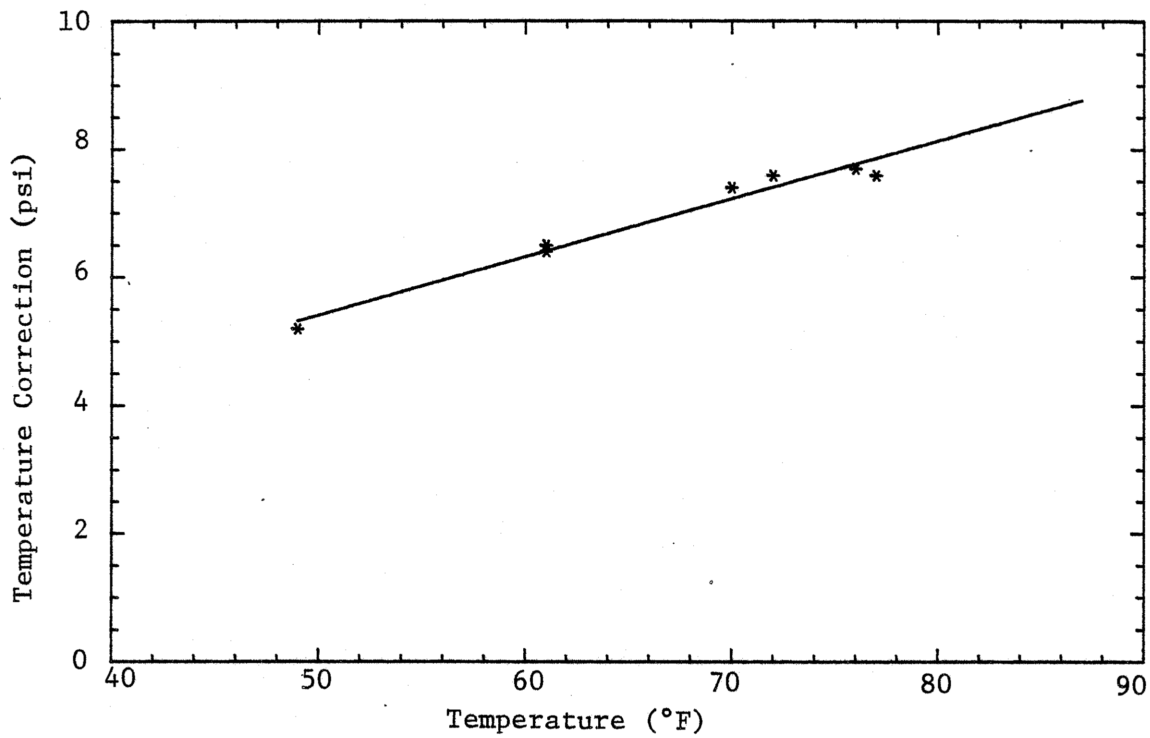


FIG. V.5. - Calibration Curve for Pressure Cell 5

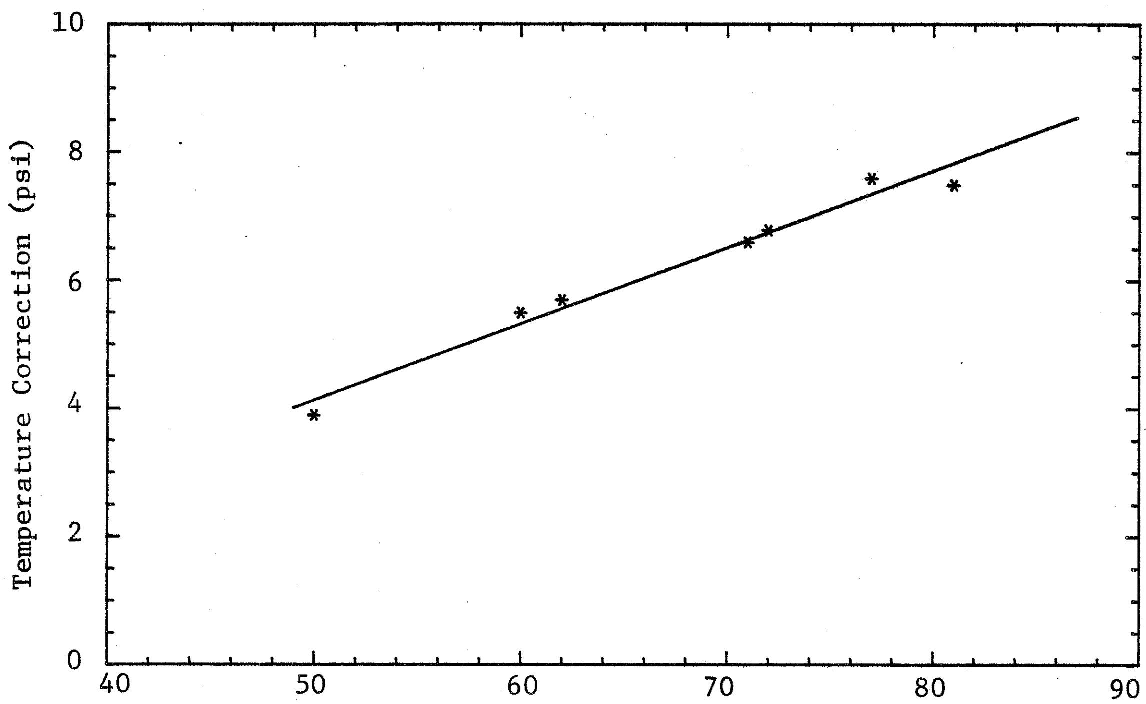


FIG. V.6. - Calibration Curve for Pressure Cell 6

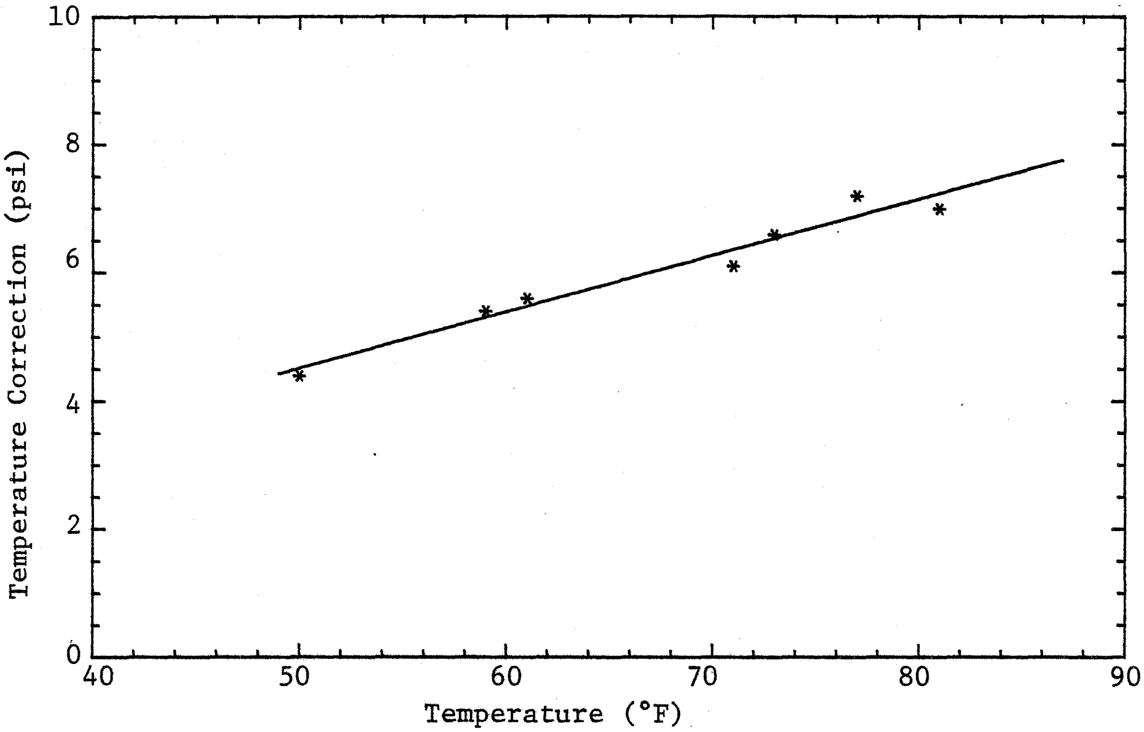


FIG. V.7. - Calibration Curve for Pressure Cell 7

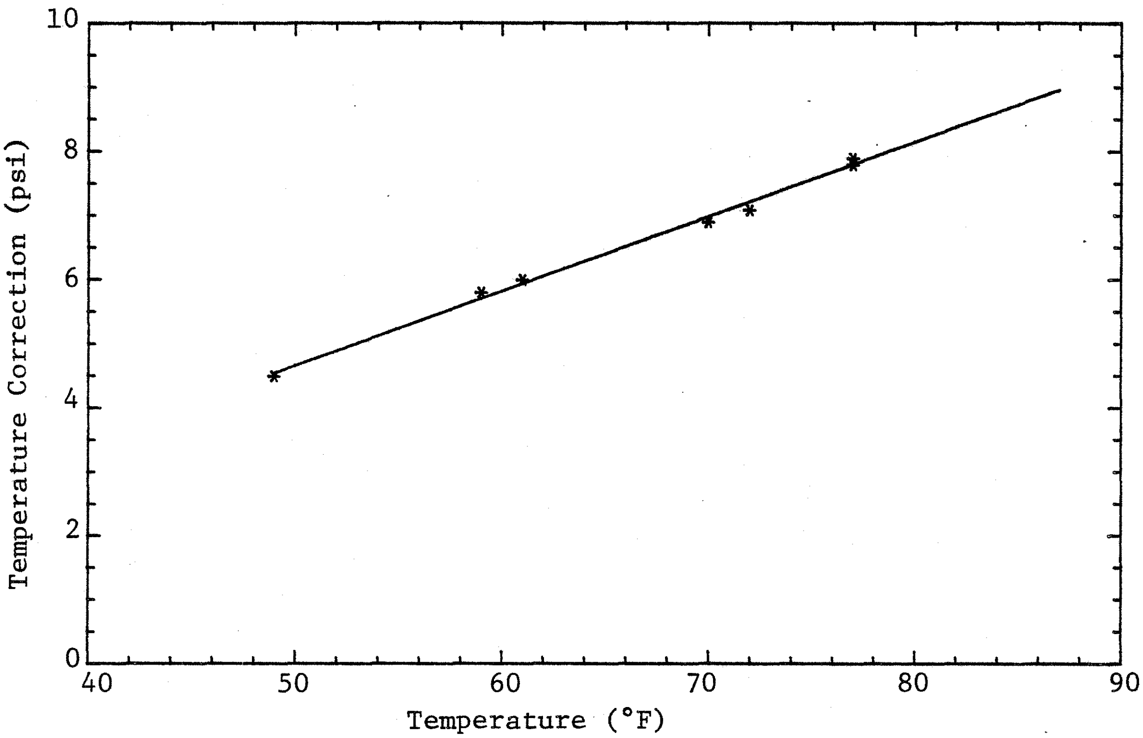


FIG. V.8. - Calibration Curve for Pressure Cell 8

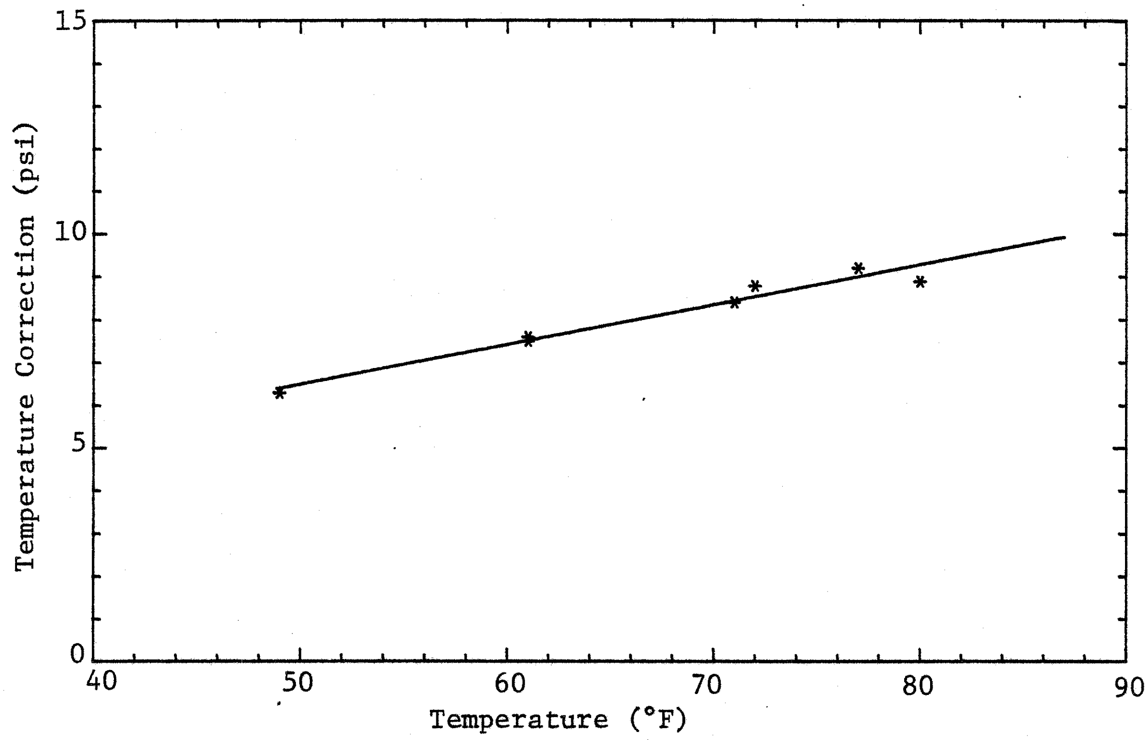


FIG. V.9. - Calibration Curve for Pressure Cell 9

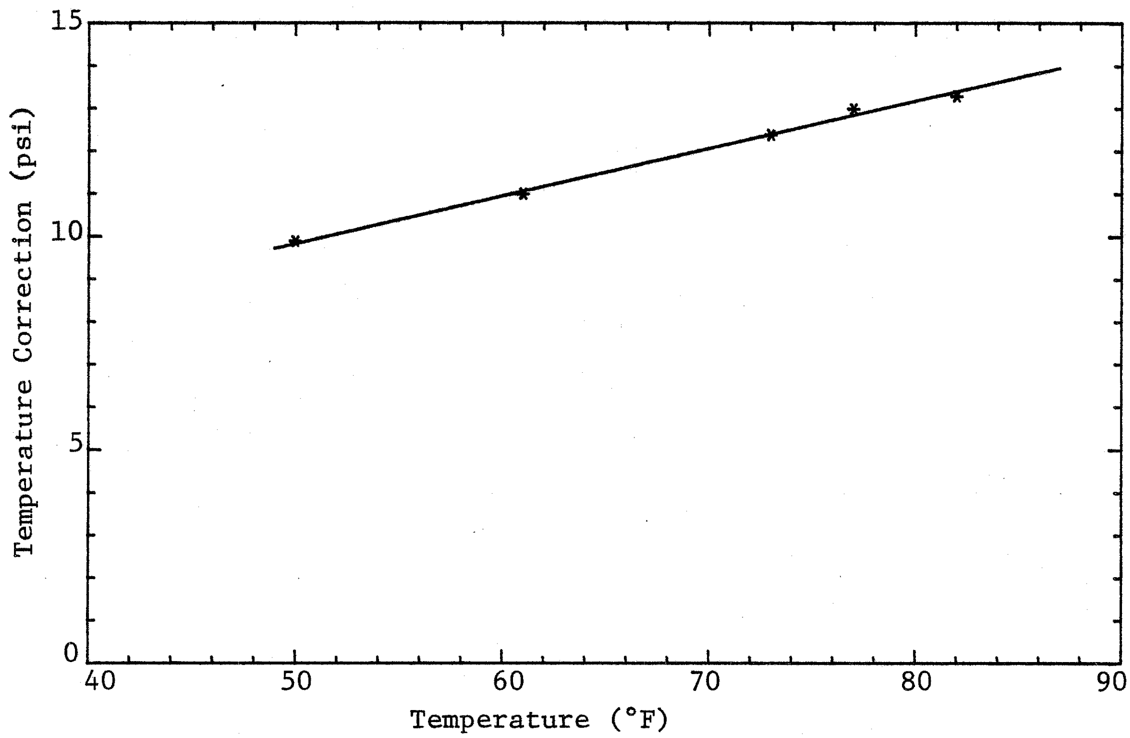


FIG. V.10. - Calibration Curve for Pressure Cell 10

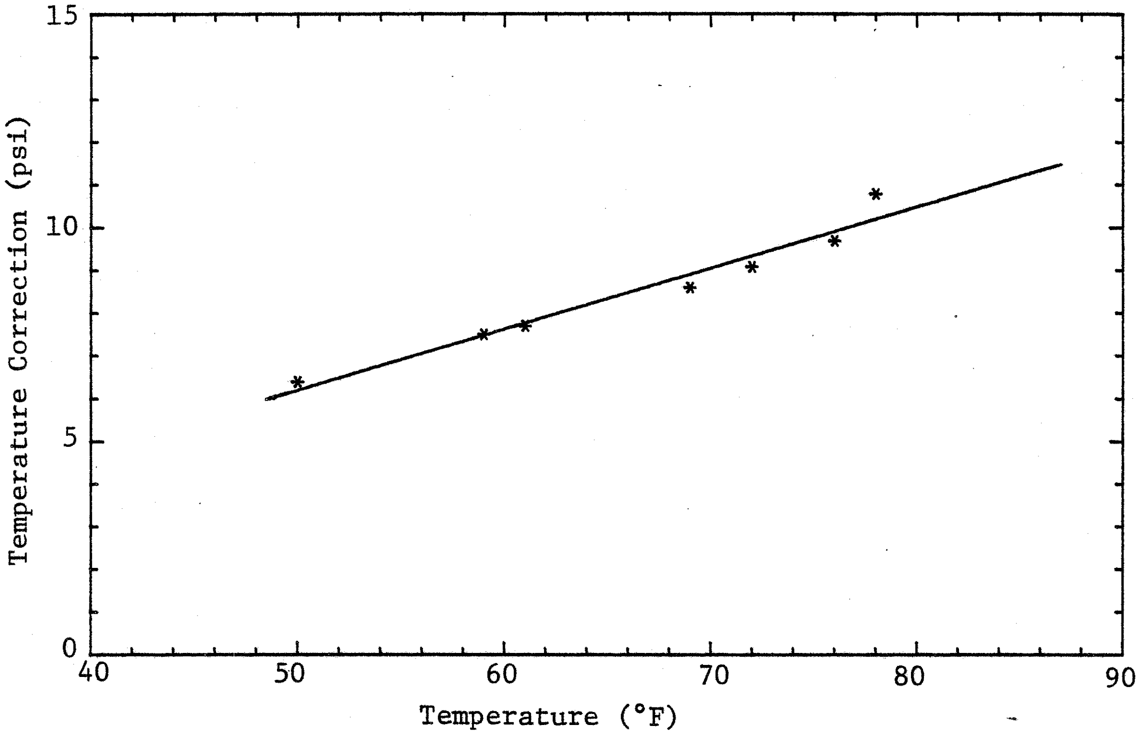


FIG. V.11. - Calibration Curve for Pressure Cell 11

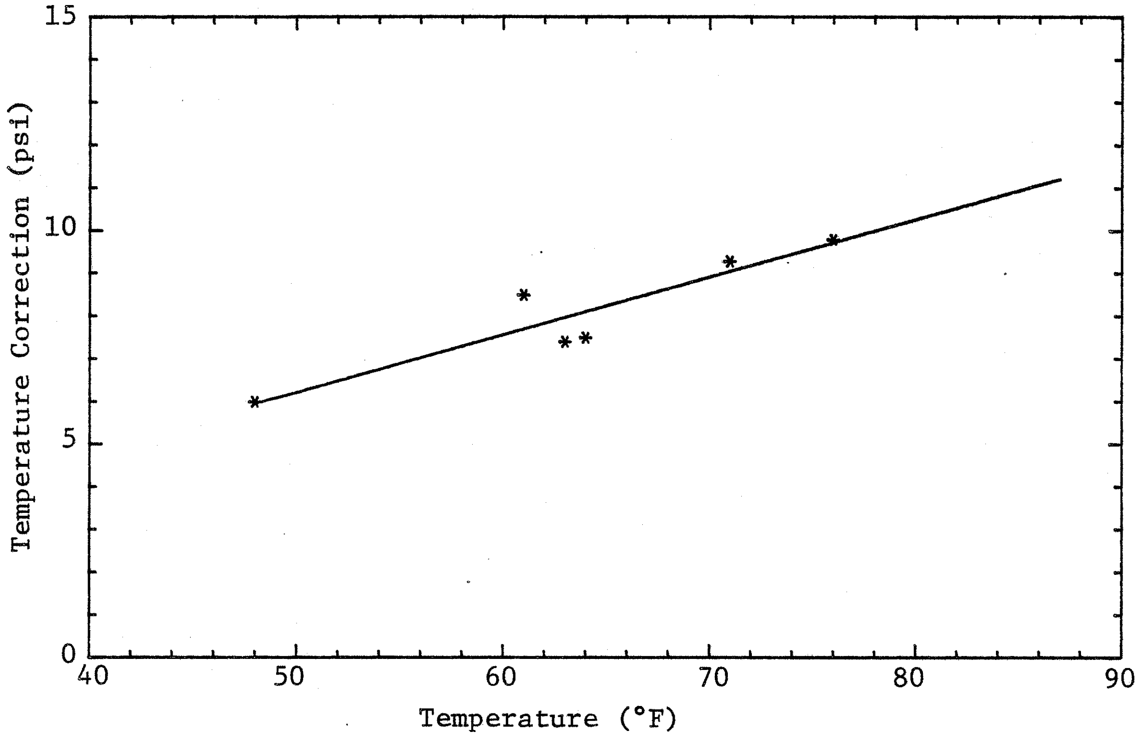


FIG. V.12. - Calibration Curve for Pressure Cell 12

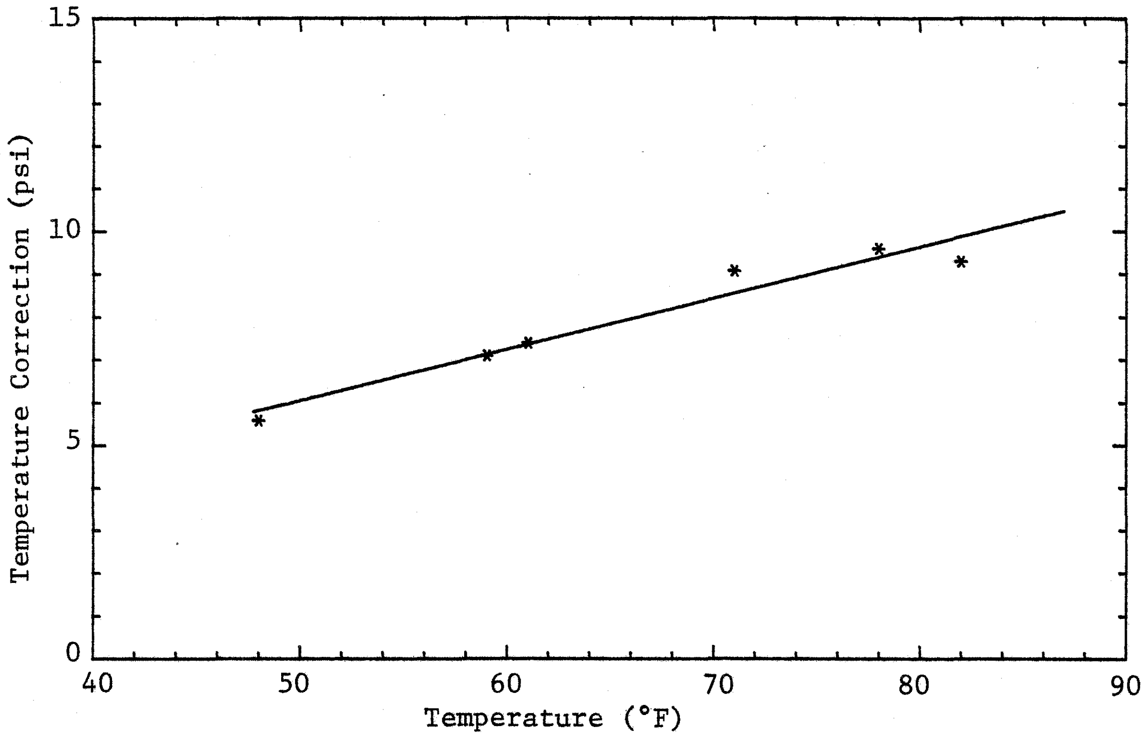


FIG. V.13. - Calibration Curve for Pressure Cell 13

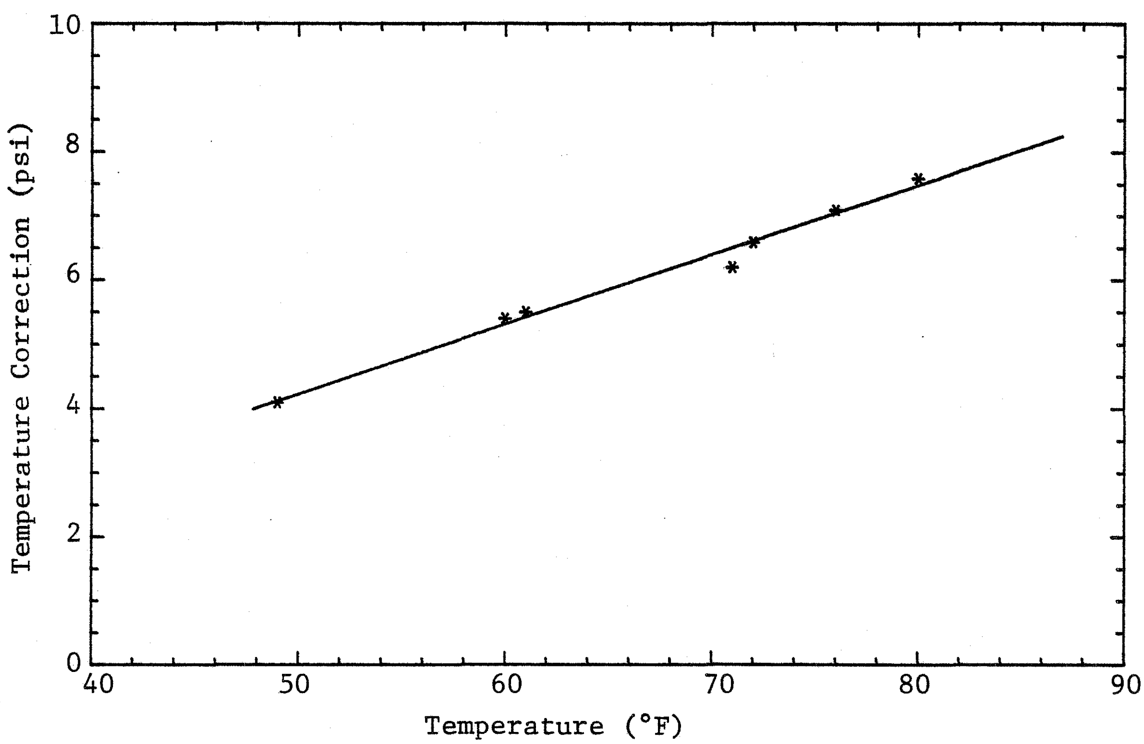


FIG. V.14. - Calibration Curve for Pressure Cell 14

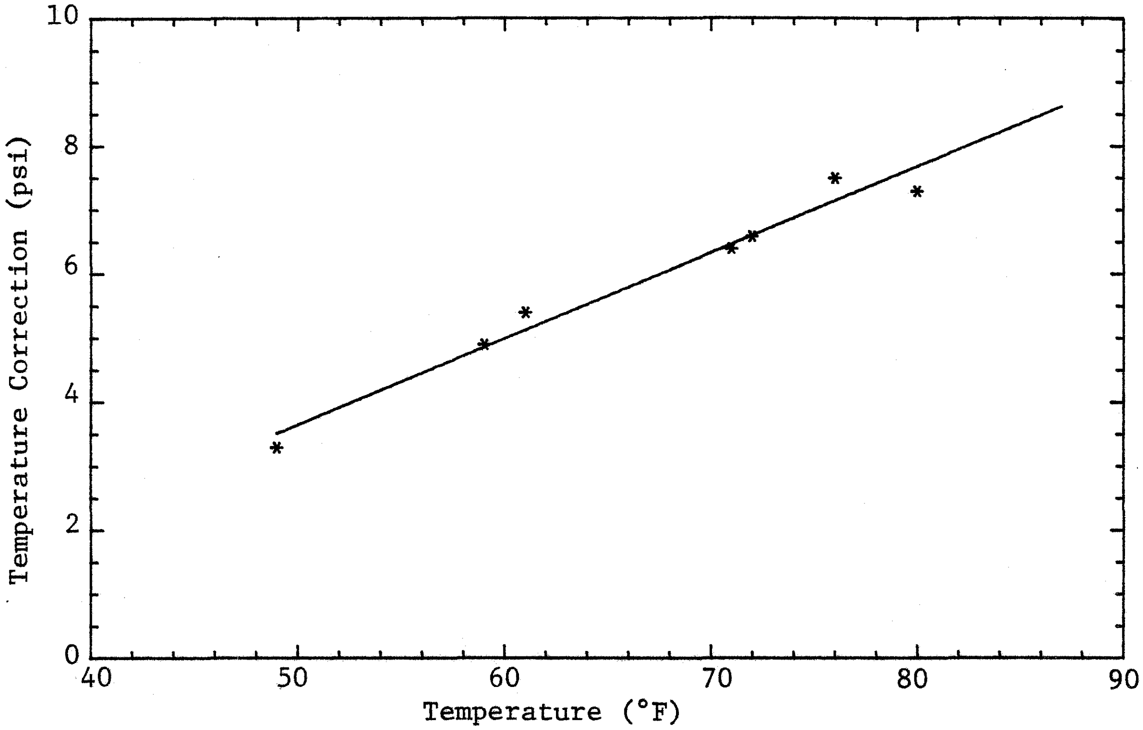


FIG. V.15. - Calibration Curve for Pressure Cell 15

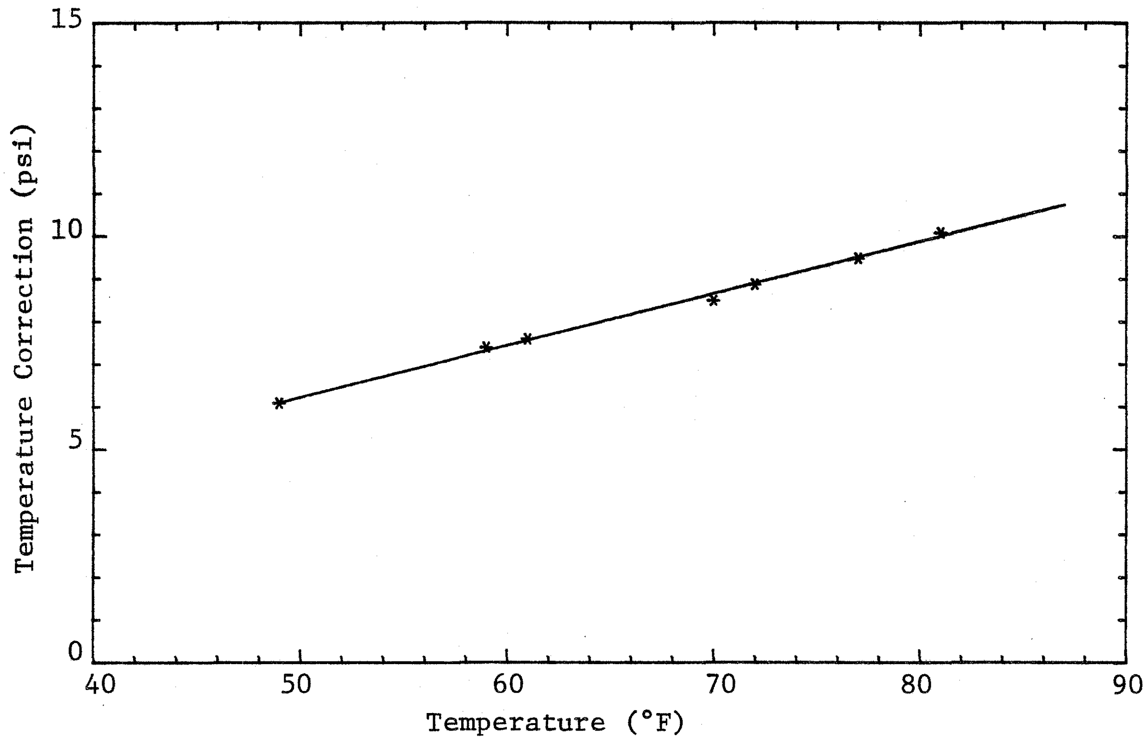


FIG. V.16. - Calibration Curve for Pressure Cell 16

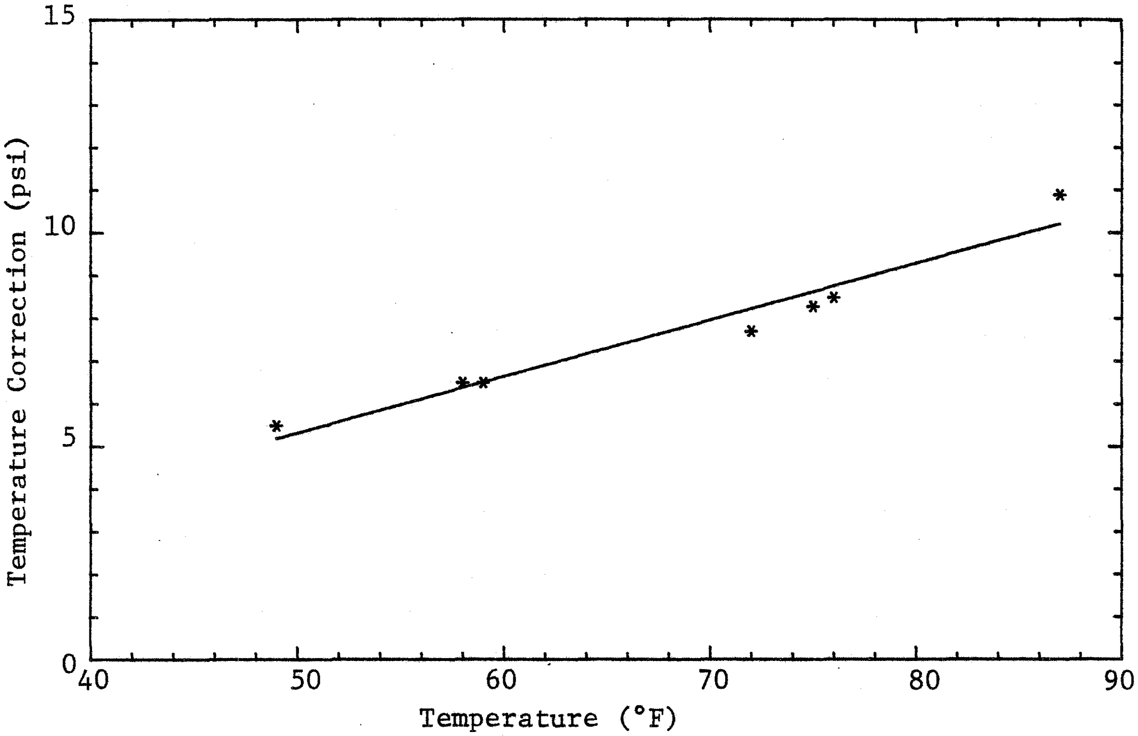


FIG. V.17. - Calibration Curve for Pressure Cell 17

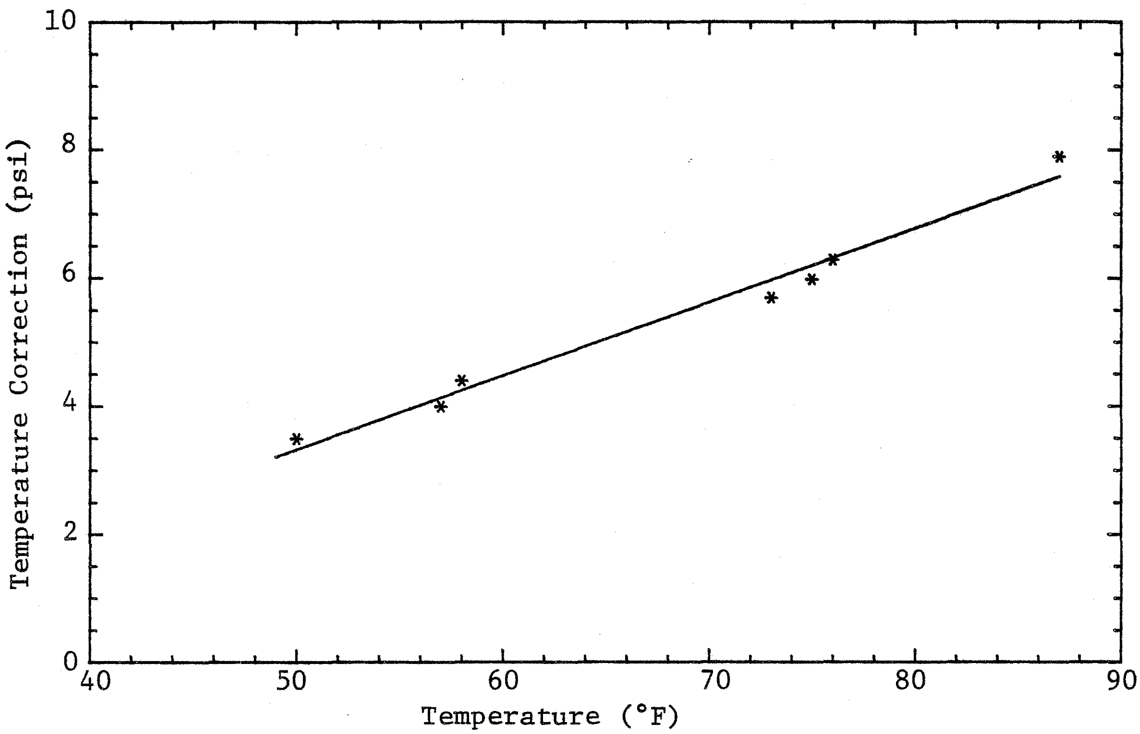


FIG. V.18. - Calibration Curve for Pressure Cell 18

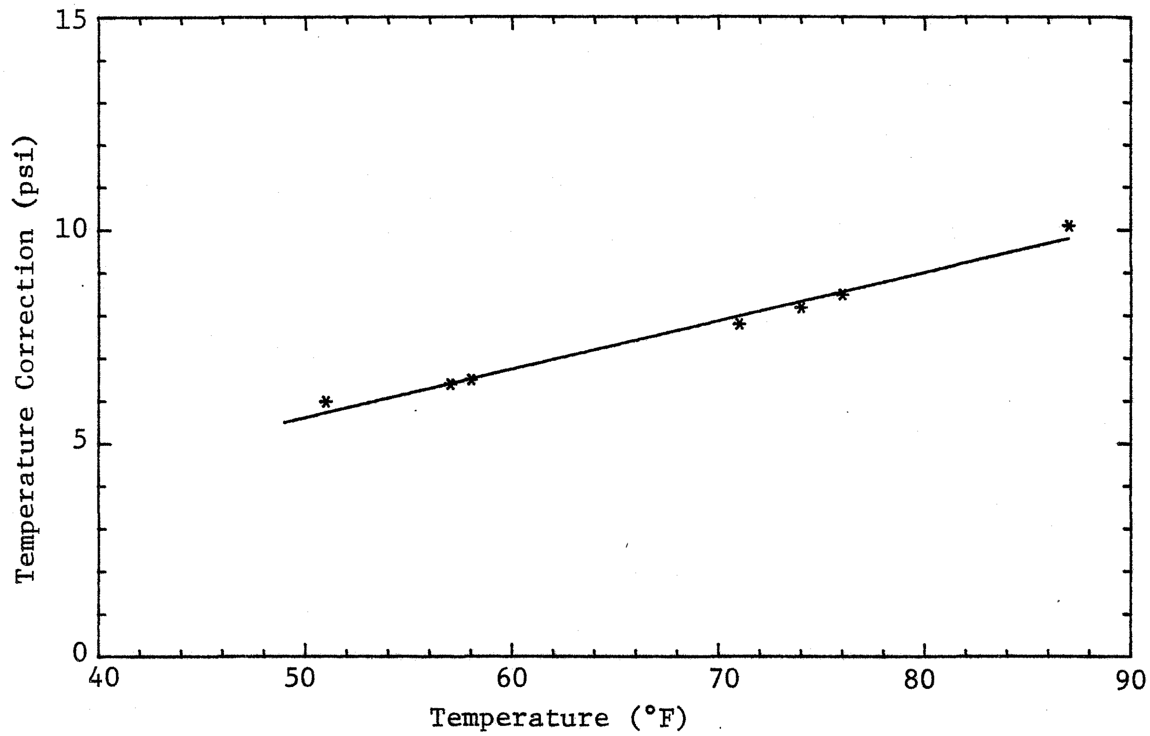


FIG. V.19. - Calibration Curve for Pressure Cell 19

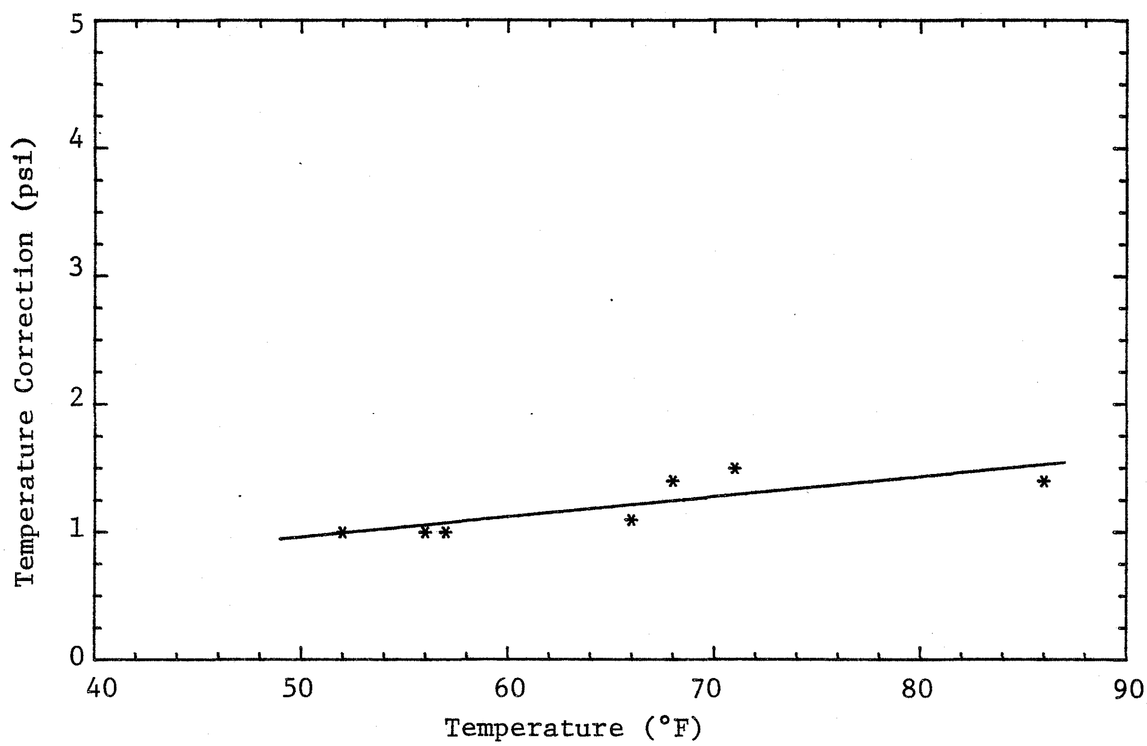


FIG. V.20. - Calibration Curve for Pressure Cell 20