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Fourteen laboratory quasi-ring compression tests were performed on short lengths of slotted drain to determine the relative strengths of various designs. Five 16-foot-long sections of drains having two different grate designs and various grate-to-pipe weld patterns, were installed using various backfill materials in a simulated roadbed section. While the vertical deflections were monitored, each drain was statically loaded to at least 30 kips over an area of 100 square inches. One drain was instrumented with 25 rosette strain gages in order to determine the magnitude and distribution of stresses in the loaded pipe. Pipe stresses were found to be substantially lower with soil cement as opposed to soil backfill used for bedding.

Recommendations are made to permit a greater variety of aggregate gradings, meeting other current Caltrans specifications, to be used in the soil cement bedding mix. No change in the present slotted drain design is suggested. A method of strengthening the grate of older existing slotted drains having single cross bar spacers is outlined. Cyclic loading of different slotted drains is suggested for future research to determine service life.

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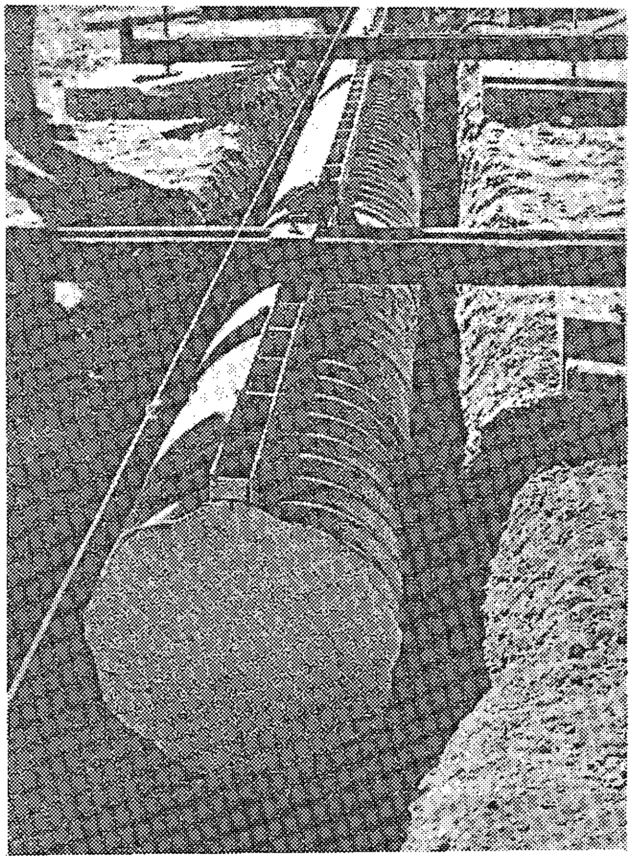

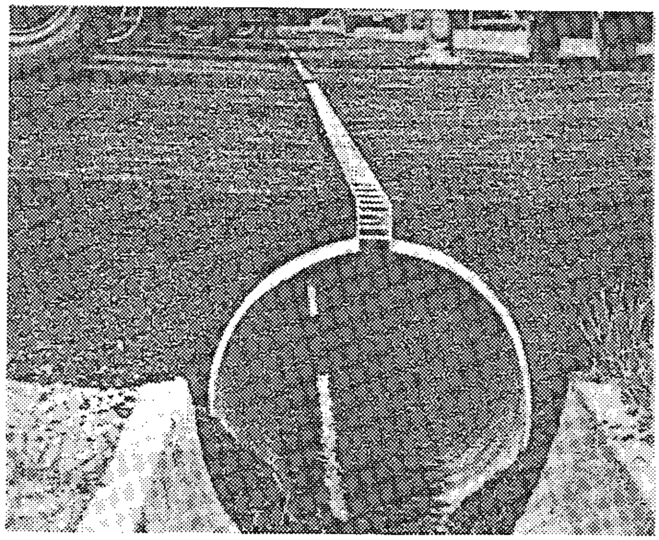

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LOAD-CARRYING CAPABILITIES OF 18-INCH DIAMETER SLOTTED CORRUGATED STEEL PIPE DRAINS

Study Made by .... Structural Materials Branch

Under the Supervision of .... E. F. Nordlin, P.E.

Principal Investigator .... J. R. Stoker, P.E.

Co-Investigator .... J. P. Dusel, Jr., P.E.

Report Prepared by .... J. P. Dusel, Jr., P.E. and
D. H. Andersen, P.E.

APPROVED BY

NEAL ANDERSEN
Chief, Office of Transportation Laboratory

CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mmm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2) acres	.09290 .4047	square metres (m^2) hectares (ha)
Volume	gallons (gal)	3.785	litres (l)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph) feet per second (fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s^2)
Weight Density	pounds per cubic (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs) kips (1000 lbs)	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (ft-lbs) foot-pounds (ft-lbs)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch ($ksi \sqrt{in}$)	1.0988	mega pascals $\sqrt{metre}$ ($MPa \sqrt{m}$)
	pounds per square inch square root inch ($psi \sqrt{in}$)	1.0988	kilo pascals $\sqrt{metre}$ ($KPa \sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{tF - 32}{1.8} = tC$	degrees celsius (°C)

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1. INTRODUCTION

An important element of the drainage system incorporated in California's highways today is a hydraulic structure called the Slotted Corrugated Steel Pipe (CSP) Drain. A slotted CSP drain is comprised of corrugated steel pipe with a steel grate structure fastened in a two-inch-wide slot cut from the top of the entire length of the pipe. Slotted drains are usually installed along the edge of and parallel to the roadway with the top of the grate structure at the same elevation as the surface of the pavement (see Figure 1).

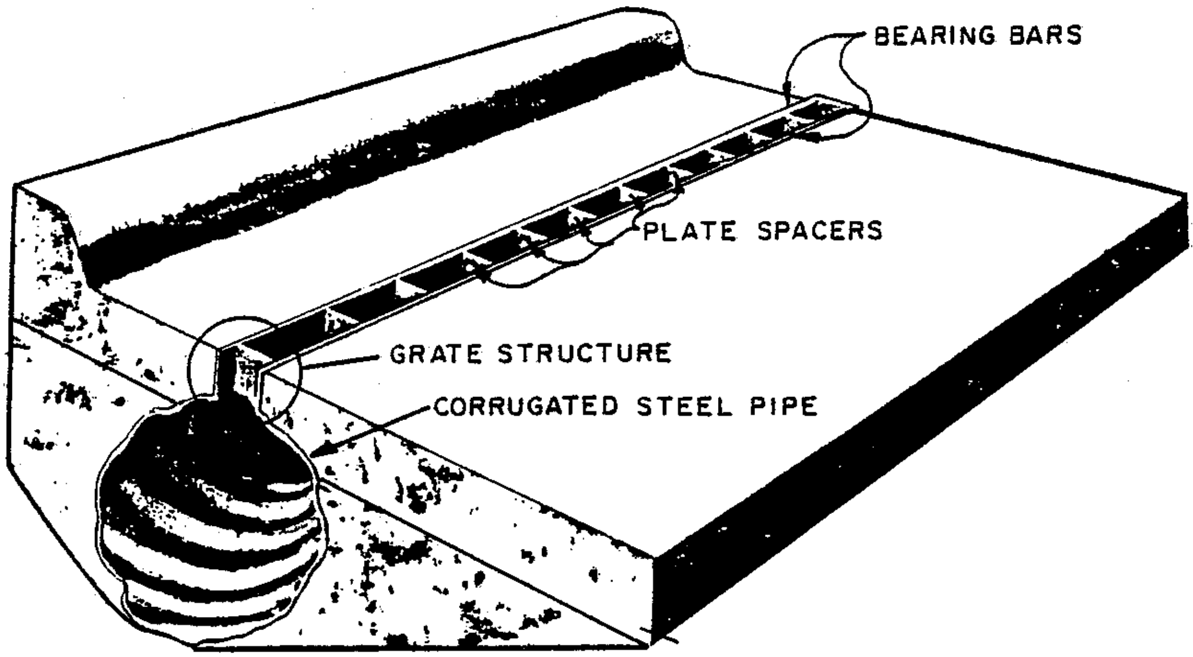


FIGURE 1 A SLOTTED CORRUGATED STEEL PIPE DRAIN

The prime purpose of the slotted drain is to intercept sheet flows of water before they cross the road surface and to quickly drain large volumes of water which might otherwise pond on the road surface during periods of heavy rainfall. Rapid removal of water from the road surface is imperative to prevent accidents caused by vehicles hydroplaning or being slowed down suddenly when encountering ponded water.

Since the conception of the original slotted CSP drain (see Appendix 7.1.1, page 98) in the 1960s in California, there have been continual improvements and changes made. The original design was not welded, but three welded grate design modifications evolved over the subsequent years with each an improvement over and superseding its predecessor. These designs in order of their development are:

(1) a grate consisting of a single row of hexagonal cross bar spacers (see Standard Plan D98-6, Appendix 7.1.2, page 99),

(2) a grate consisting of a double row of hexagonal cross bar spacers (see Standard Plan D98-9, Appendix 7.1.3, page 100), and

(3) a grate consisting of solid plate spacers (see Standard Plan D98-B.1, Appendix 7.1.4, page 101).

In addition to these major design changes in the grate structure, other improvements and changes have been made. Most of these changes have been made for three main reasons:

(1) to improve the hydraulic flow properties of the drain,

(2) to reduce manufacturing costs, and

(3) to strengthen the grate and drain structure.

Modifications made to the original design in order to improve hydraulics of the drain system include:

- Elimination of pipe or structural tubing spacers to increase the water flow through the grate.

- Increasing the slot width of the grate from 1-5/8 inches to 1-3/4 inches.

Changes made in the manufacturing process to reduce fabrication costs include:

- Eliminating bolts used in the grate structure and for attaching the grate structure to the pipe.

- Discontinuing the use of riveted, annularly corrugated CSP and employing either continuously welded or lock-seam-joined helically corrugated CSP.

- Removal of the requirement for hot-dip galvanizing the grate structure.

In order to perform the primary function of providing rapid surface water drainage from the traveled way, the slotted CSP drain must be strong enough to carry repetitive wheel loadings from heavy vehicles. Thus, many changes have been made to strengthen the grate and drain structure as follows:

- The pipe and tubing cross spacers, and single and double hexagonal crossbar spacers have been replaced by solid 3/16-in. by 1-3/4-in. by 2-5/16-in. plate spacers to make the grate structure more rigid.

- Intermittent fillet welds connecting the grate structure to the corrugated pipe have been lengthened from a minimum of 1 inch to 1-1/2 inches and their spacing reduced from about 7-1/2 inches to 6 inches.

- These grate-to-pipe welds have also been positioned at each plate spacer to provide a more direct load transfer from the grate structure to the corrugated pipe.

- A soil cement backfill is now required for bedding slotted drains (Sections 66-3.09 and 19-3.025C of the Caltrans 1978 Standard Specifications). This soil cement backfill has replaced a previously specified soil backfill, for which a wider trench was required to insure adequate compaction, and whose compressive strength was considerably less than that of the soil cement backfill.

These structural changes have strengthened the slotted CSP drain considerably, and have enabled the drain to be used in locations along highways where increased traffic volume and larger wheel loads from heavy vehicles have occurred. The development and use of flotation tires, which have enabled heavy trucks and maintenance vehicles to carry single wheel loads of as much as 11,000 pounds, have caused wheel loads applied to the slotted CSP drains to be much higher and more concentrated.

The effects of all these changes on the load carrying capacity of the 18-inch-diameter slotted pipe drain were unknown, and the ability of the different drain designs to withstand heavy loads was uncertain.

The purpose of this study was to evaluate the static load carrying capacity of the two most recent CSP drain designs having grates with double bars and plate spacers, and to determine if the current grate structure with plate spacers is strong enough to withstand occasional heavy vehicle traffic and large loads imposed by flotation tires. Variables considered important in this research project were the type of backfill, the length and location of the welds attaching the grate bearing bars to the corrugated steel pipe, the position and magnitude of the applied wheel load, and the type of spacers connecting the bearing bars of the grate.

In carrying out the research, independent grate sections were first tested to determine the actual tensile and shear strengths of welds attaching the bearing bars and crossbar spacers. Next, fourteen 4-foot-long sections of slotted CSP drains having various grate designs and grate-to-pipe weld patterns were tested in quasi-ring compression in a large universal testing machine to determine the relative strengths, vertical deflections, and grate angle deformations. The results of these preliminary tests are briefly summarized in Section 5.1, pages 62 to 65, of this report.

An asphalt-paved road having a structural section approximating that of a typical highway was then constructed, and five 16-foot-long, 18-inch-diameter slotted CSP drains were installed. The following parameters were varied for the five slotted drains tested: grate design; bar/plate spacing; grate-to-pipe weld length, location, and spacing; and backfill type.

Each slotted pipe drain was loaded at the third points using an 8-inch by 12-1/2-inch steel plate with a bearing area of 100 square inches. This is the bearing area of an 8-inch-wide flotation tire. The side of the plate having the longer dimension was positioned parallel with the grate bearing bars. Both a centered and an eccentric offset loading position were used to load the drains. One of the slotted pipe drains was also instrumented with 25 rosette strain gages to determine the stress distribution in the walls of the corrugated pipe, due to the applied simulated wheel load of a typical flotation tire.

In each test, the external load was increased while the vertical deflections inside the pipe were monitored and recorded. The effects of backfill type, grate type and weld pattern, and position of the load on the load carrying capability of each slotted drain are discussed in the following report.

2. CONCLUSIONS

2.1 Conclusions from Laboratory Tests Performed on 4-foot-long Sections of Slotted Pipe Drain

2.1.1 Slotted Pipe Drain Deflections

For the slotted pipe drain designs tested, the type of cross spacer in the grate made no clear difference in the deflections measured inside the pipe.

For the slotted pipe drain designs tested, the location of the grate-to-pipe welds with respect to the cross spacers or bearing bars did not noticeably influence the deflections measured inside the pipe.

A decrease in the spacing of grate-to-pipe welds from 3 to 2 corrugations per weld did not significantly decrease vertical pipe deflections as measured in laboratory testing.

2.1.2 Grate Rotation

When the pipe was loaded eccentrically in the laboratory tests, the grates rotated about the grate-to-pipe welds. These welds offered little resistance to bending and appear to be the weakest part of the slotted drain.

The use of plate spacers instead of bar spacers did not seem to reduce the downward vertical deflection of the grate under center loading, however, under eccentric loading, average angular rotation of the grate structure having plate spacers was reduced slightly because of its increased torsional stiffness.

2.1.3 Factors Affecting Maximum Load Capacity

Because of the limited number of drain specimens tested in the laboratory and the apparent inconsistency in the data obtained, no definite conclusions may be made with regard to the effect which many of the parameters have on the load capacity of the various slotted drains. Often the data appears to be conflicting, and against one's engineering judgment. This was partially due to the fact that slotted drains in the laboratory tests were only supported up to the spring line of the pipe, i.e., the sides of the grate and the upper half of the pipe had no external support.

- It is evident, however, that the slotted drain with a grate fabricated with single hex bar cross spacers was one of the designs least able to support higher vertical loads (the maximum load for Specimen No. 10, Table 7, page 63 was only 7,550 lbs).

- The effect of either (1) the spacing of the grate-to-pipe welds, or (2) their location with respect to the cross spacers on the ability of the short drain sections to withstand vertical compressive loads is not clear from the data obtained, nor is the effect of the location of these grate-to-pipe welds with respect to the crests and valleys of the corrugated pipe.

- Slotted drain designs had the least maximum load supporting capability when the load in the laboratory tests was applied eccentrically to the edge of the grate (Loading Method (3), Eccentric-Bearing on One Side of Grate).

- The two control sections of plain corrugated steel pipe withstood the highest average maximum applied loads of any specimens tested in the laboratory.

2.2 Conclusions from In-Situ Tests on 16-foot-long Drain Sections

It has been determined from the in-situ tests conducted, that the 18-inch-diameter slotted CSP drain with the current grate structure with plate spacers is strong enough to withstand occasional heavy vehicle traffic, provided that a soil cement bedding is used. The following are important findings which were determined from the test data in this research project.

2.2.1 Factors Affecting Maximum Load Capacity

- There was no apparent difference in the static strength of slotted pipe drains fabricated with grate designs employing either the double hexagonal cross bar spacers or the solid cross plate spacers.

- There were no apparent differences in the static strength of slotted drains attributable to the changes in the grate-to-pipe weld designs that were considered. Nonetheless, it is felt that the grate-to-pipe welds should be placed at the cross spacers to promote direct load transfer from the grate into the pipe walls and minimize grate distortion.

- The type of backfill had a dramatic effect on the vertical deflections and stress distribution in the pipe walls of the slotted pipe drain systems tested. The soil cement backfills carried a large portion of the applied load and decreased the vertical deflections and bending stresses in the slotted pipe drain. The ready-mixed lean concrete of the same cement factor proved to be considerably stronger than the site-mixed soil cement required by current specifications.

- In most cases, the deflection of the asphalt concrete pavement adjacent to the grate, rather than the acutal deflections of the slotted drain pipe grate, will probably limit the loading which the slotted drain installation can withstand. With an asphalt concrete thickness of approximately 2 inches next to the grate bearing bars, tolerable asphalt concrete deflections will vary between 0.040 inch (Traffic Index=6) and 0.017 inch (Traffic Index=11) depending on the expected traffic volume and the type and compaction of base material(16). Similar deflections of the slotted drain grate were obtained in Test 3B with single flotation tire static wheel loadings of 14 kips (0.040 inch) and 8 kips (0.017 inch) - see Figure 35, page 73.

2.2.2 Effect of Load Positions on Slotted Drain Deflections

Of the various load positions, the centerline parallel position of the loading plate caused the greatest vertical deflections with both bearing bars (grate side plates) deflecting the same amount. The eccentric parallel position of the loading plate caused the greatest grate rotation.

2.2.3 Effect of Different Types of Backfill on Stress Distributions and Vertical Deflections of the Slotted Drain

Slotted drains tested had greater deflections in soil backfill than in the soil cement backfill. Also, the soil backfill allowed the pipe to distort more under load, and transferred more load to the slotted drain than did the soil cement backfill. The magnitudes of bending stresses were greater in the slotted pipe drains which were backfilled with soil material than slotted drain with soil cement backfill. There seemed to be little difference in the strength of slotted drains backfilled with site-mixed soil cement and ready-mixed lean concrete of the same cement factor according to the vertical deflection data. However, the ready-mixed lean concrete had significantly higher 28-day compressive strength (1800 pounds per square inch) than did the site-mixed soil cement (720 pounds per square inch).

2.2.4 Effect of Various Load Positions on Stress Distribution in the Corrugated Steel Pipe of the Slotted Drain

The position of external wheel load which produces both the highest stresses and vertical deflections in the drain pipe is the centerline parallel loading for both soil and soil cement backfills. The highest bending stresses in the pipe wall occurred 45 degrees from the center of the grate with the corrugation crests in tension and the corrugation valleys in compression. For almost all load positions, stresses measured at the spring line in the pipe walls of slotted drain backfilled with soil cement were predominantly compressive.

3. RECOMMENDATIONS AND IMPLEMENTATION

3.1 Recommended Changes to Standard Specifications and Plans

Based on the observations and conclusions from the laboratory and in-situ testing of the 18-inch-diameter slotted drain, the following recommendations are made:

- Modify the Caltrans 1978 Standard Specifications(12), Section 19-3.025C to allow other gradings of aggregates to be used in soil cement bedding. The same minimum cement factor, 282 pounds of Type II Modified portland cement per cubic yard of soil cement backfill would be used for any of these aggregate blends. These other acceptable blends of aggregates and the respective sections of the current Caltrans Standard Specifications under which their requirements are explained are as follows:

  (1) 1-inch maximum combined aggregate gradings shown for portland cement concrete, Section 90-3.04

  (2) Class 2 AB, having a maximum coarse aggregate size of 3/4 inch, Section 26-1.02B

  (3) Class A CTB, Section 27-1.02

- Continue to manufacture slotted CSP drains in accordance with current Caltrans Standard Plan D98-B.1 (Appendix 7.1.4, page 101). Allow the use of this

18-inch-diameter slotted drain where occasional heavy vehicle traffic (maximum single flotation tire load of 11,000 lbs) will occur, provided that a soil cement bedding is required.

- Leave older style slotted pipe drains which have been installed in the past in service, provided that the slotted drains are not damaged and will not be subjected to heavy vehicle traffic or any bicycle traffic.

- Repair these older style bar spacer grates only when they show signs of fatigue or weld failure or when they will be subjected to heavy vehicle or bicycle traffic. When grate repairs are necessary, new solid plate spacers may be welded into the grate at 6-inch spacings while the drain is still installed in the ground in lieu of removing the old style drain and replacing with new. With the grate spacer plates at 6 inches on centers, bicycle wheel entrapment will not occur.

- Based on the stresses obtained in the pipe wall of the 18-inch-diameter drain tested in this project, the use of slotted pipe drains larger than 18 inches should be restricted to light traffic bearing areas only.

3.2 Future Research

In order to determine actual service life under moderate truck loading, it is recommended that any future testing include cyclic loading of slotted drains. It is suspected that many of the older style slotted drains having either single or double rows of plug welded hexagonal cross bar spacers may perform satisfactorily under static loading as performed in this research study. However, when subjected to repeated dynamic loading, either the plug welds attaching the hexagonal cross bar spacers to the bearing bars or the grate-to-pipe welds may fail. It is recommended that in future research, fatigue tests be conducted on slotted drains having grates manufactured with double hexagonal cross bars in addition to those with solid plate spacers to determine durability of welds under fatigue loading.

3.3 Implementation

The major finding of this research study has already been implemented. The improved grate structure in which solid steel spacer plates at 6-inch centers are used instead of hexagonal bars has been adopted as the standard design (see Appendix 7.1.4, page 101). It is expected that the recommendation to allow a broader variety of backfill material will soon be incorporated into the Standard Specifications(12).

4. DESCRIPTION OF EXPERIMENTAL PROGRAM

4.1 Testing Program - General Discussion

The objectives of this research program were to obtain a relative strength comparison between the various types or designs of slotted pipe drains tested, and to determine by static load tests if any of the types of slotted pipe drains would be suitable for use in areas where a moderate amount of heavy truck traffic is expected. To accomplish these objectives, the following parameters were considered important:

- Strength of the grate-to-pipe welds to resist tension, shear, and torsion.

- Strength of the grate structure to resist shear and to be able to carry ring compression.

- The type of loading which would induce the highest stresses in the slotted pipe drain.

- Type of backfill material so as to minimize stresses in the slotted pipe drain structure.

The physical characteristics of the slotted pipe drains tested along with certain geometric variables which were thought to influence the slotted drain's load carrying capacity are listed as follows:

•General description of slotted pipe drains:

Nominal pipe diameter: 18 inches
Lengths: (1) Laboratory tests: 4 feet
(2) In-situ tests: 16 feet
Pipe thickness: 0.064 inch (16 gauge)

•Pipe geometry:

Helix: 23.9°
Corrugation depth: 0.45 to 0.50 inch
Corrugation distance crest to crest: 2.65 inches normal to corrugation centerlines

•Pipe manufacturing process: Continuous helical welded seam

•Grate geometry:

Bearing bar dimensions: 2-1/2 inches high, 3/16 inch thick

Types of cross spacers tested:

(1) Single 5/16-inch-diameter hexagonal bars
(2) Double 5/16-inch-diameter hexagonal bars
(3) 3/16-in. by 1-3/4-in. by 2-5/16-in. solid plate

Spacing intervals of cross spacers:

(1) 4 inches
(2) 6 inches

Spacings of grate-to-pipe welds used:

(1) 6 inches
(2) 2 corrugations per weld
(3) 2-1/2 corrugations per weld
(4) 3 corrugations per weld

Lengths of grate-to-pipe welds tested:

(1) 1-1/2 inches
(2) 1-3/4 inches
(3) 2 inches

Positions of grate-to-pipe welds with respect to the cross spacers tested:

(1) at spacer
(2) at 1/4 points between spacers
(3) centered between spacers
(4) random - no relation to spacer position

Fourteen 18-inch-diameter, 4-foot-long slotted pipe drain sections were tested in quasi-ring compression in the laboratory to see how they would perform under both centered and eccentric loading and to verify the need for more extensive testing. The results from the laboratory testing were of some benefit in determining relative strength comparisons and were used mainly for information to aid in planning in-situ tests.

The in-situ testing was accomplished by applying a vertical load in different positions to five 18-inch-diameter, 16-foot-long slotted pipe drains installed in a simulated roadbed test section. Two different grate designs, one with double cross bar spacers and the other having solid plate spacers, were used in these five drains.

One of the five slotted drains having a grate with solid plate spacers was instrumented with 25 strain gages in order to gain knowledge about the distribution and magnitude of pipe stresses in a loaded slotted drain. This pipe was tested using both soil and soil cement backfill and applying loads in various positions.

4.2 Detailed Description of Test Phases

4.2.1 Laboratory Testing

In an attempt to determine the structural effects that different methods of loading and different grate designs would have on the relative abilities of the slotted pipe drains to resist vertical compression loading, fourteen 4-foot sections of 18-inch-diameter slotted drains were tested in the laboratory. A wooden cradle was constructed and used in all tests to give lateral support to the bottom half of the corrugated steel pipe as would a backfill material. In addition, two sections of plain corrugated steel pipe were tested so that the compressive loads attained could be compared with those from the various sections of slotted pipe drain.

The various parameters considered important in this series of laboratory tests included: (1) the method of applying the external load; (2) the type and spacing of the cross spacers; and (3) the spacing, length, and location of the grate-to-pipe fillet welds. These are outlined in Table 1.

TABLE 1 DESCRIPTION OF SHORT SECTIONS OF SLOTTED CSP DRAIN TESTED IN THE LABORATORY

Specimen Nos.	Methods of Loading (See Figure 11) Pg. 40	Type of Cross Spacer (Spacing, inches)	No. Corr. per Weld (Weld Spacing inches)	Length of grate-to-pipe Welds (in.)	Position of grate-to-pipe Side Welds With Respect to: Corrugations*	Position of grate-to-pipe Side Welds With Respect to: Spacers**
1	Eccentric Rod	Double Hexagonal Bar (6")	3 (9")	1-1/2	NCR	Between Spacers
7	Eccentric Block			1-3/4	C-V	Near Spacers
3	Eccentric Bearing on grate				C-V	Every Other Weld @ Spacer
11	Center on Plate					
15	Eccentric Block				C-V	Near Spacers
4	Eccentric Bearing on grate		2 5-3/4"		C-V	Near Spacers
5	Eccentric Block				Crest	At Spacer
12	Center on Plate				C-V	Near Spacers
16	Eccentric Block				C-V	At Spacer
10		Single (4") Hex. Bar	2-1/2 7-3/4"	1-1/2	NCR	Near Spacers
2	Eccentric Rod	3/16 Inch Plate (6")	2 5-3/4"	1-3/4	Crest	At Spacer
8	Eccentric Block				Crest	Near Spacers
9					Crest	Between Spacers
13	Center on Plate				Crest	Near Spacers
6	Eccentric Block	Unslotted Pipe	0	—	—	—
14	Center Block					

Note: * NCR : No Consistent Relationship
C-V : Crest to Valley

** Description of position of grate-to-pipe welds with respect to spacers is approximate.

Four different methods of applying incremental vertical loads to the sections of slotted pipe drain were used in the laboratory testing and are outlined as follows: (a) an eccentric load applied to a 16-inch-long rod, tack welded to the pipe wall 3.4 inches from the center of the grate; (b) an eccentric load applied to a 4-inch by 16-inch-long wooden block with a molded bottom to fit the pipe corrugations; (c) an eccentric line load applied to the top of one bearing bar only; and (d) a line load applied to a 2-1/2-inch by 16-inch-long steel plate resting on both bearing bars. Wooden blocks with molded bottoms were also used to apply the test loads to two sections of plain corrugated steel pipe. All of these loading methods are further described in Sections 4.4.1.1 and 4.4.1.2 and are shown in Figures 11 through 14 (pages 40-42) of this report.

4.2.2 In-Situ Testing

Five sections of slotted drains, each 16 feet long were installed in a simulated roadbed section and loaded to failure. These were tested in order to learn what magnitude of wheel loads slotted drains having grates with (a) double cross bar spacers and (b) solid plate spacers can withstand without deflecting significantly. The 130-foot-long, 10-foot-wide simulated roadbed was built on the grounds of the Transportation Laboratory. The roadbed cross section of 0.60-foot-thick asphalt concrete pavement placed on top of 2.4 feet of aggregate base and native clay basement soil with an R-value of 15 is depicted in Figure 2. It was designed according to Section 7-600 of the Highway Design Manual(14) assuming a Traffic Index of 12.0. After the roadbed was built, a 21-inch-wide x 21-inch-deep trench was dug the entire length and down its

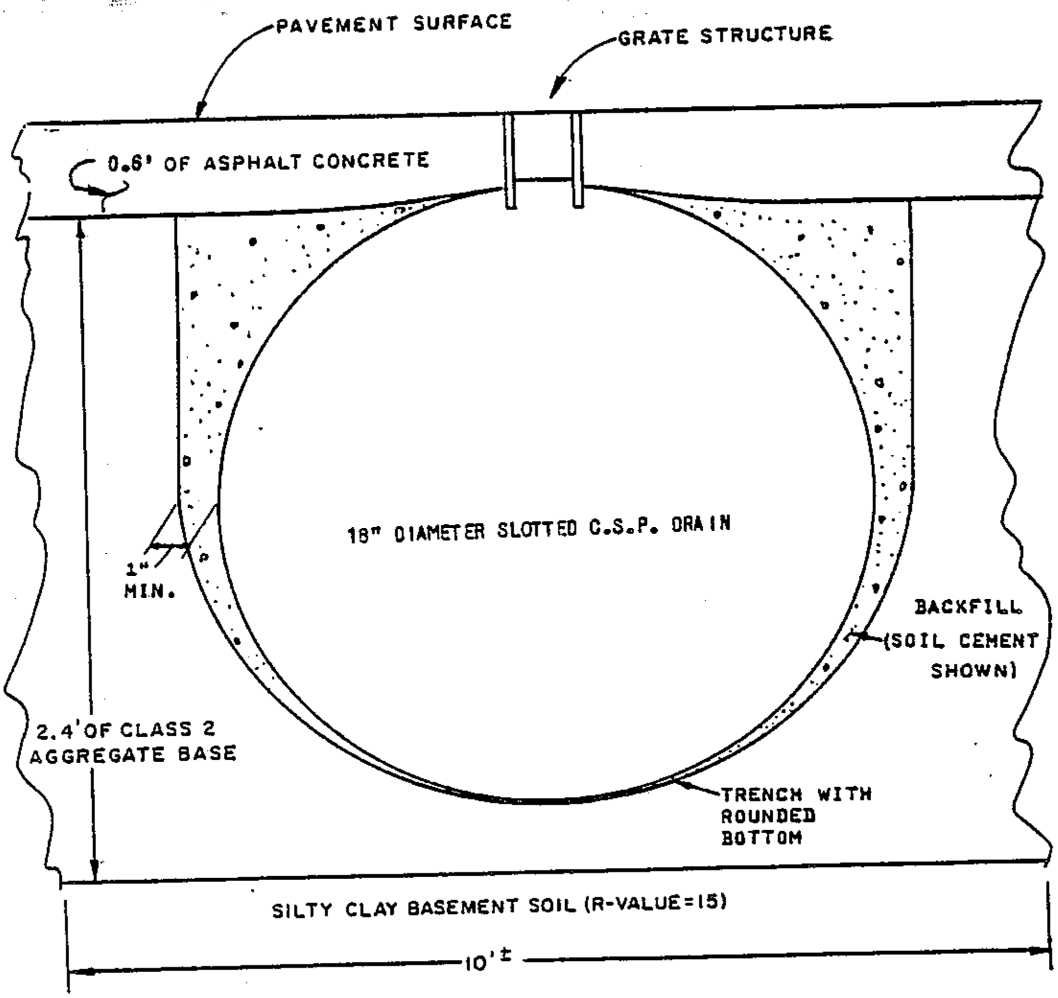


FIGURE 2. A CROSS SECTION OF THE SIMULATED ROADBED WITH A SLOTTED DRAIN INSTALLED.

center. The trench bottom was shaped to conform to the arc of the drain pipe. The five slotted pipe drains, manufactured according to the standard plans and specifications shown in Table 2, were installed in the trench and were assigned identification numbers 1 through 5. The slotted drains were placed six feet apart in the trench. Slotted Drain No. 1 was placed at the westernmost end with the other slotted drains placed numerically in order toward the eastern end of the trench. General procedures used to install and backfill the slotted pipe drains are given in Appendices 7.2.1 and 7.2.2 (pages 102-105). The trench was widened to 44 inches for Slotted Drains, Nos. 1, 2, and 3, where an untreated soil backfill was used, so that the backfill material could be compacted.

A description of the grate structure in each of the five slotted drains tested in situ, in addition to a description of the length and location of the intermittent grate-to-pipe fillet welds with respect to the corrugation crests and the cross spacers, is given in Table 2. The description of each standard plan used to manufacture the respective slotted drains, and the type of backfill used for each of the six test series, including Test Series 3A and 3B, is also listed.

4.2.2.1 Explanation of Test Series 1, 2, 4, and 5

The methods of conducting these four test series were identical. Two loading positions, numbers ① and ② as shown in Figure 3, were used in each of these four test series. In both loading positions, the 8-inch by 12 1/2-inch steel plate was always centered longitudinally on

TABLE 2. DESCRIPTION OF SLOTTED DRAINS TESTED IN SITU.

Slotted Drain No. and Location	1	2	3 *	4	5
Test Series Designation	1	2	3A(soil) 3B(soil cement)	4	5
Grate Spacer Type	3/16" PLATE	Double Hexognal Bar	3/16" PLATE	Double Hexognal Bar	Double Hexognal Bar
Distance Between Spacers	6"	6"	6"	6"	6"
Distance Between Welds Grate-To-Pipe	6"	One Every 3 Corrugations	6"	One Every 3 Corrugations	6"
Actual Intermittent Grate-To-Pipe Weld Lengths	1-3/4"	1-3/4"	2"	1-3/4"	1-3/4"
Grate-To-Pipe Weld Position	Corrugation Valley at Spacer	Crest to Valley	Crest to Valley at Spacer	Crest to Valley	Crest to Valley at Spacer
Cross Spacer Weld Type	3/16" x 1-3/4" Fillet Weld	Plug Weld	3/16" x 1-3/4" Fillet Weld	Plug Weld	Plug Weld
Standard** Plan No.	D98-B.1	D98-9	D98-B.1	D98-9	D98-9 (Modified)***
Type of Backfill/ Trench Width	SOIL/44"	SOIL/44"	Soil(Test 3A)/44" Site Mixed Soil Cement (Test 3B)/44"	Ready Mixed Lean Concrete/ 21"	Site Mixed Soil Cement/ 21"

* Strain gage instrumented slotted drain

** See Appendices 7.1.3 and 7.1.4, pages 100 and 101

*** A grate-to-pipe intermittent fillet weld spacing of 6 inches was used.

the closest grate spacer. The method of loading and the various positions are discussed in greater detail in Section 4.4.2.1, In-Situ Testing, General Equipment and Test Set-Up, pages 45 through 49 of this report.

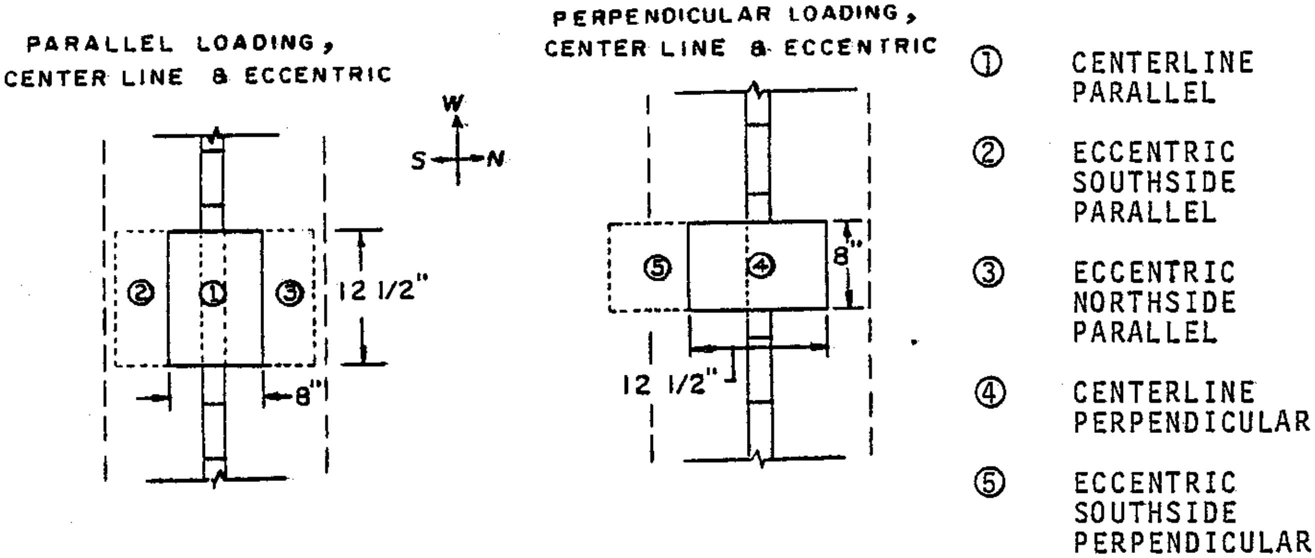


FIGURE 3. VARIOUS POSITIONS OF LOADING PLATE USED FOR IN-SITU TESTING.

In these four test series, two different load tests were run on each of the four slotted drains, one test 5 feet from the end of each drain at about the third point, using a different loading position in each case. These loading positions were called "Centerline Parallel" and "Eccentric Southside Parallel". The term "Centerline Parallel" loading means that the slotted drain was loaded with the long direction of the loading plate parallel with the grate bearing bars and with the middle of the loading plate positioned at the middle of a cross spacer. The term "Eccentric Southside Parallel" loading is similar except the steel plate is offset 4-3/4 inches to the "south" with one edge overhanging a grate bearing bar 1/4 inch.

In both load tests on each of the four slotted drains, the load was incrementally increased, and after each increase dropped to zero. This procedure was continued until noticeable permanent deformation or vertical deflection of the grate structure occurred. Vertical deflections at the base of both grate bearing bars and 2-1/2 inches to each side of the pipe invert were measured at each incremental loading step increase and again each time the load was reduced to zero. The same instrumentation was used to measure these vertical deflections in all load tests in Test Series 1, 2, 4, and 5, and is further described in Section 4.4.2, <u>In-Situ Testing</u> (page 45). The difference between each of these four test series are further explained in Table 2.

4.2.2.2 Explanation of Test Series 3A

In Test Series 3A, Slotted Drain No. 3 had a grate structure with solid cross plate spacers and was instrumented with 25 rosette strain gages. These gages were attached to the outside walls of the corrugated steel pipe near the longitudinal center of the 16-foot-long section of slotted drain. In this initial Test Series 3A, the slotted drain was bedded with untreated soil backfill, and was loaded incrementally to 15 kips at the longitudinal center of the pipe over the strain gages using both the "Centerline Parallel" and "Eccentric Southside Parallel" loading positions. Because this strain-gaged slotted drain would be loaded again in a future Test Series 3B, the maximum external loads applied in Test Series 3A were limited to 15 kips; hence, yielding of the steel in the pipe walls would be prevented and no damage would occur to the costly strain gages. The exact loading procedure is further discussed in Section 4.4.2, <u>In-Situ Testing</u> (page 45). A different instrumentation system was used for this test series than was used in Series 1, 2, 4, or 5. The instrumentation system for Test Series 3A was comprised of an electromechanical data acquisition system, which measured and recorded strains (differences in voltage potential) in three directions in each of the 25 rectangular rosette strain gage elements. The system also measured the corresponding incremental loads and the vertical deflections of the slotted drain as was done in Test Series 1, 2, 4, and 5. Also in this Test Series 3A, the deflected shapes of the upper half of the slotted drain were recorded at each incremental load level and at corresponding zero loads. This was done by photographing the positions of small black magnetic pins which were placed in front of a fine grid background positioned inside the pipe on a plane perpendicular to the axis of the pipe directly under the center of the loading plate. From this photographic data, shapes of deflected slotted drains were determined and drawn.

A computer program was written to calculate stresses from the strain gage data compiled for each loading case run in Test Series 3A and 3B. A copy of the computer program and a sample data printout are shown in Appendices 7.3.2 and 7.3.3 (pages 110-114).

4.2.2.3 Explanation of Test Series 3B

After the conclusion of Test Series 3A performed on the strain gaged Slotted Drain No. 3, the asphalt concrete paving around the grate structure and the untreated soil backfill surrounding the drain pipe were carefully removed. The same length of instrumented slotted pipe drain was then replaced in the trench and backfilled with soil cement bedding. In Test Series 3B, the slotted drain with strain gages was again loaded at its longitudinal center incrementally up to 15 kips in each of the five load positions previously shown in Figure 3, page 24.

The "perpendicular" loading case was so named because the longest side of the loading plate was perpendicular to the slotted drain grate bearing bars. The instrumentation for Series 3B tests was the same as that used on Test Series 3A. In the last test conducted in Test Series 3B, the slotted drain was loaded in the centerline parallel position to 32 kips. Further loading was discontinued at this point as this load level approached the dead weight of the concrete and steel ballasts set on the testing apparatus.

4.3 Materials

4.3.1 Slotted Drains

In the following section, materials used in the fabrication of slotted pipe drains tested in the laboratory and in the simulated roadbed test section are discussed. The slotted drains and their components were inspected at the vendor's yard and then tested in the laboratory for compliance to the Caltrans Standard Plans and the Standard Specifications before they were used for this research.

4.3.1.1 Material Properties

Required and measured properties of the various materials which were used in manufacturing the slotted pipe drain include:

Steel strength:

- Corrugated steel pipe met specifications in ANSI/ASTM A444 for copper steel. Also met material requirements in AASHTO M218.

- Minimum required strengths of flat galvanized culvert sheets:

$$\text{Yield Strength} = \sigma_y = 33{,}000 \text{ psi}$$
$$\text{Ultimate Tensile Strength} = \sigma ult = 45{,}000 \text{ psi}$$

- Actual average strengths as determined from steel specimens cut from the tangent sections of the corrugated steel pipe:

$$\text{Yield Strength} = \sigma_y = 54{,}150 \text{ psi}$$
$$\text{Ultimate Tensile Strength} = \sigma ult = 61{,}900 \text{ psi}$$

Cross plate spacer weld strength:

- Minimum required tensile force = 12,000 pounds normal to the longitudinal axis of the bearing bars.

- Actual tensile force measured exceeded 17,500 pounds, which is the capacity of the test fixture.

Corrosion protection of the corrugated steel pipe:

- The pipe section met the requirement for the average thickness of the hot-dip galvanized zinc coating of 2 ounces per square foot (total on both sides of sheet metal) required for the corrugated steel pipe. (AASHTO Designation: M218)

4.3.2 Backfill Materials

The five slotted drains installed in the 130-foot-long trench were backfilled with three types of materials: (1) a soil backfill (sand), (2) a site-mixed soil cement, and (3) a ready-mixed lean concrete. A sand was used for the soil backfill because its grading met that of the earlier specifications for soil backfill and it was readily available. This sand took more time to place than either the soil cement or lean concrete backfill. This was because the sandy backfill (see Figure 4) was difficult to compact and there was a much greater volume of material to compact since the trench had to be widened to 44 inches. The trench widening was necessary in order to provide enough room to operate foot compactors and nuclear instruments to measure relative compaction of the backfill material (see Figures 5 and 6). In comparison, two slotted drains, Nos. 4 and 5, with the lean concrete and soil cement respectively, required only a 21-inch wide trench as shown in Figure 7. The relative compactions of the compacted untreated soil backfill around two slotted drains Nos. 2 and 3 were determined using a nuclear gage according to procedures outlined in California Test 231(13) and averaged 96% and 97% respectively. Figure 8a gives the grading analysis for the sand used as untreated soil backfill.

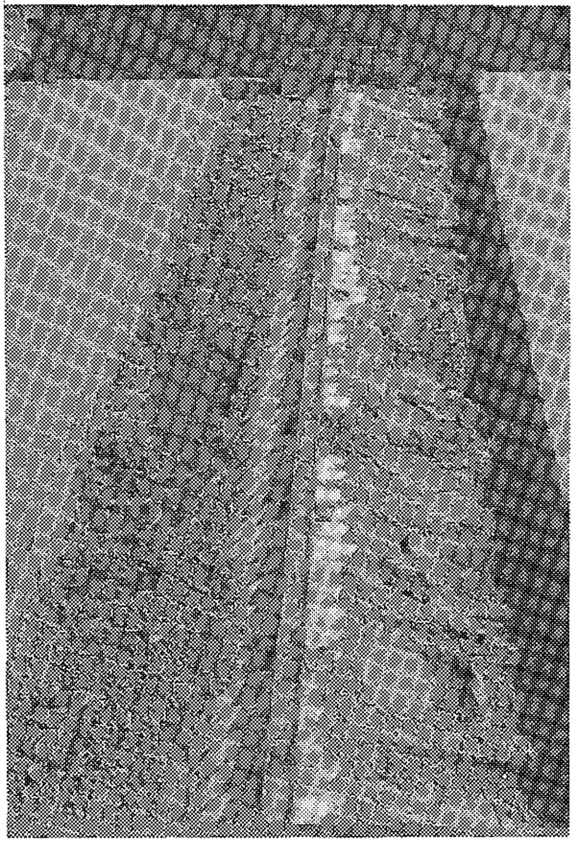


FIGURE 4. TYPICAL TRENCH FOR SLOTTED DRAIN BACKFILLED WITH SOIL.

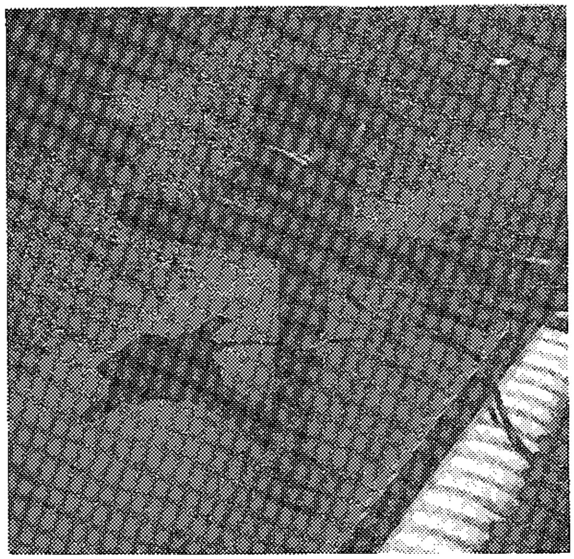


FIGURE 5. COMPACTION OF THE SOIL BACKFILL.

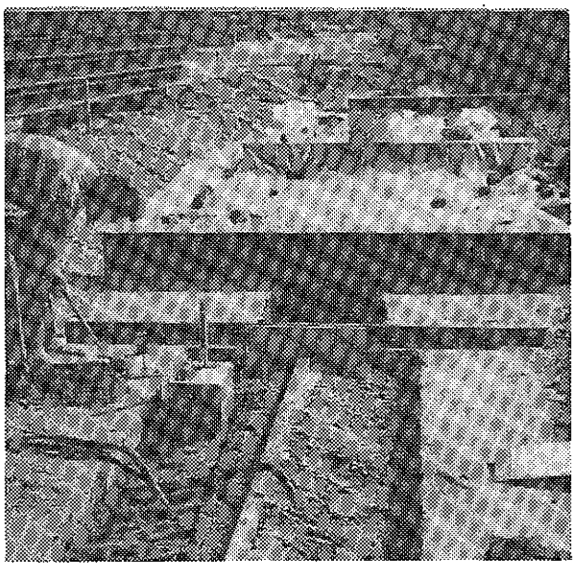


FIGURE 6. MEASURING THE RELATIVE COMPACTION OF THE SOIL BACKFILL WITH A NUCLEAR DENSITY-MOISTURE GAGE.

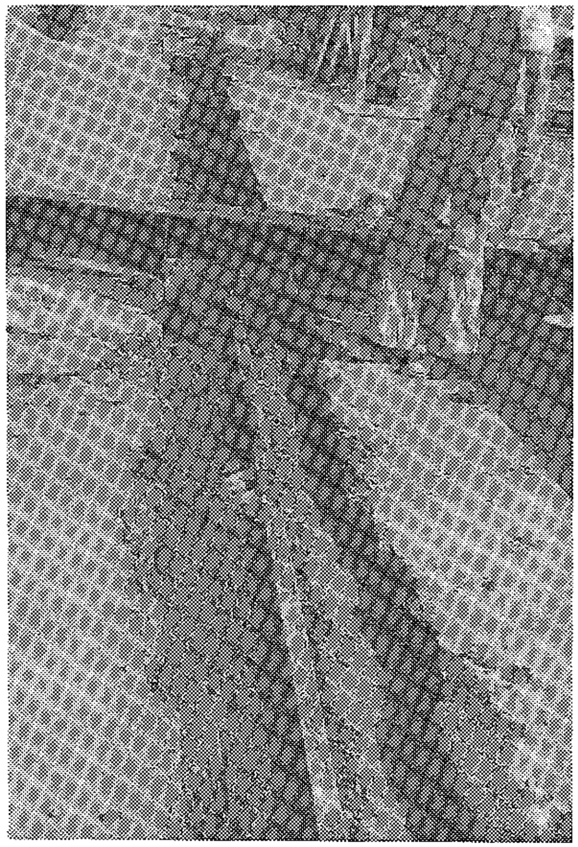


FIGURE 7. TYPICAL TRENCH FOR SLOTTED DRAIN BACKFILLED WITH SOIL CEMENT.

FIGURE 8a

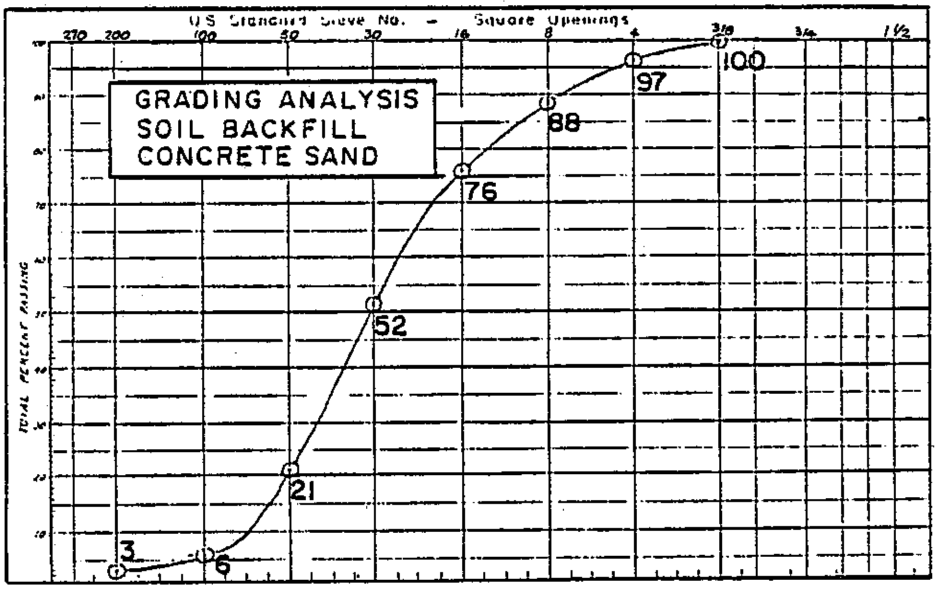


FIGURE 8b

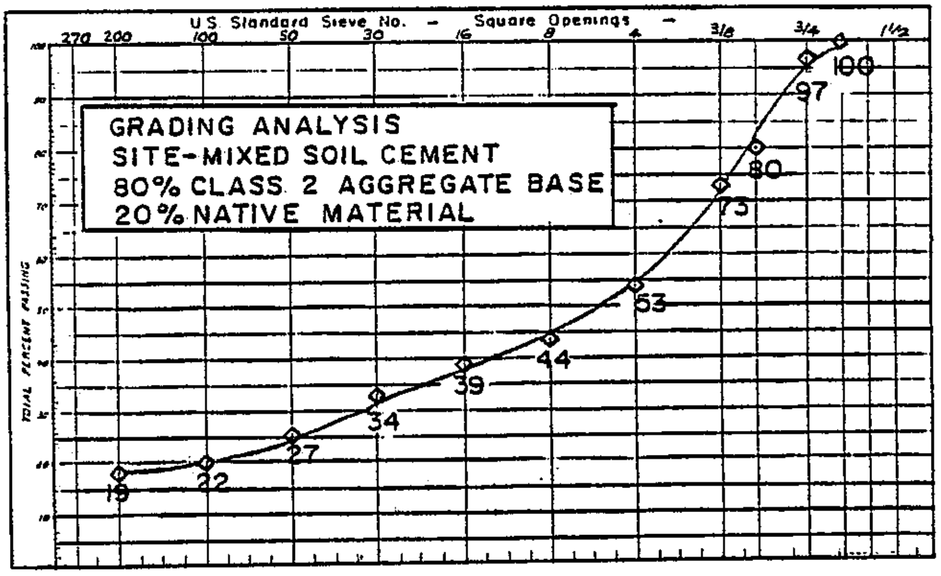


FIGURE 8c

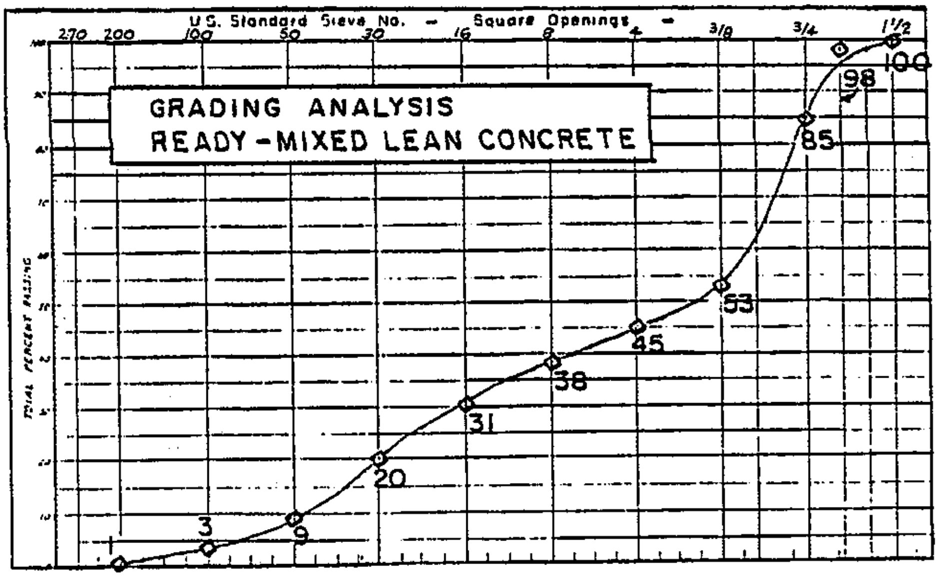


FIGURE 8. GRADING ANALYSES OF BACKFILL MATERIALS.

The first series of load tests (Test Series 3A) were performed on Slotted Drain No. 3, backfilled with a untreated soil (sand) material. This drain, instrumented with 25 rosette strain gages, was carefully removed after conducting load tests in Series 3A, and reinstalled in the same trench and backfilled carefully with site-mixed soil cement. This was done in order to determine the effect of a strong backfill on the stress distribution in the slotted drain.

The soil cement backfill, a blend of native silty clay soil, Class 2 aggregate base, and portland cement, was mixed in a 3-cubic-foot concrete mixer and then placed along the sides of the slotted drain and vibrated thoroughly. Each slotted pipe drain was adequately braced so it would not float out of place. The grading for the site-mixed soil is shown in Figure 8b, page 31 and Table 3. The mix design used for the soil cement backfill is shown in Table 5. This same soil cement design was used for the backfill material around Slotted Drain No. 5. The compressive strength of the site-mixed soil cement mix is displayed in Figure 9, page 36.

A lean concrete backfill (282 pounds of portland cement per cubic yard) was used for Slotted Pipe Drain No. 4. It was comprised of a readily available, well graded sand and coarse aggregate, and Type II Modified portland cement (see Tables 4 and 5). The lean concrete mix was brought to the site in a ready-mix truck, placed around the slotted drain, and then thoroughly vibrated. The purpose of the use of the lean concrete was to save time and labor in batching and mixing. Time and labor were indeed saved and also the lean concrete had a much higher

TABLE 3. AGGREGATE BLEND FOR SITE-MIXED SOIL CEMENT.

Sieve Size	Cl. 2 AB	Soil	Combined Grading	Limits
1 1/2"	-	-	-	
1"	100	-	-	100
3/4"	97	100	97	80-100
1/2"	81	99	80	60-100
3/8"	71	99	73	-
#4	51	98	54	50-100
#8	38	97	44	40-80
#16	30	96	39	
#30	23	95	34	
#50	15	91	27	
#100	10	83	22	10-40
#200	8	73	19	
Specific Gravity (S.S.D.)	2.70	2.65		
Blend:	80%	20%		

TABLE 4. AGGREGATE BLEND FOR READY-MIXED LEAN CONCRETE.

Sieve Size	1" x #4	Concrete Sand	Combined Grading	Limits
1 1/2"	100		100	100
1"	97		98	80-100
3/4"	72		85	60-100
1/2"	-		-	-
3/8"	14	100	53	50-100
#4	2	98	45	40-80
#8		85	38	
#16		69	31	
#30		45	20	
#50		20	9	
#100		6	3	
#200		3	1	
Specific Gravity (S.S.D.)	2.76	2.65		

TABLE 5. MIX DESIGNS FOR (A) THE SOIL CEMENT AND (B) LEAN CONCRETE BACKFILLS.

	(A) Ready-Mixed Lean Concrete	(B) Site-Mixed Soil Cement
• Volume of each batch	1 yd^3	3 ft^3
• Maximum size aggregates, inches	1	3/4
• Slump, inches	4-5	4-5
• Water-cement ratio - by weight	1.04	1.20
• Water-cement ratio - gallons/sack	11.67	12.90
• Water - pounds	292	36
• Water - gallons	35.0	4.3
• Cement - pounds	282	31
• Cement - sacks	3.0	1/3
• Fine aggregate - pounds	1524 (sand)	76 (silty clay)
• Coarse aggregate - pounds	1924 (gravel)	300 (Class 2 AB)
• Cement factor - sacks/$yard^3$	3.0	3.0
• Cement factor - pounds/$yard^3$	282	282

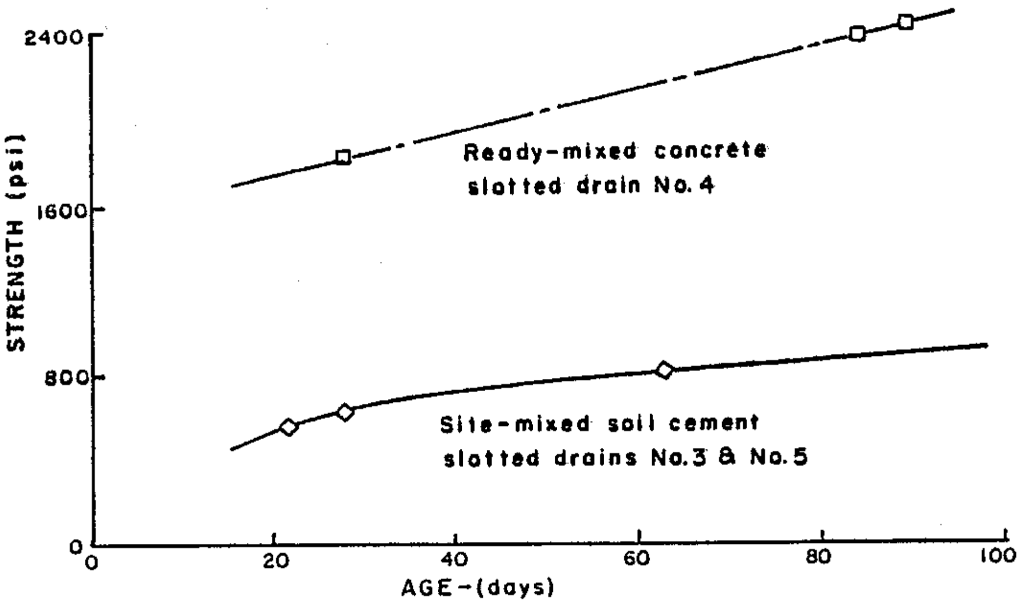


FIGURE 9. AGE VERSUS COMPRESSIVE STRENGTH FOR SOIL CEMENT AND LEAN CONCRETE USED AS BACKFILLS.

compressive strength than the soil cement backfill used. The 28-day compressive strength of the lean concrete as seen in Figure 9 was about 1800 pounds per square inch as compared to the 28-day compressive strength of the soil cement of 720 pounds per square inch. However, the readily available aggregate used to make the lean concrete, commonly used to make portland cement concrete, did not meet the gradation requirement for aggregate to be used for soil cement bedding as specified in Section 19-3.025C of the 1978 Standard Specifications(12). In order to meet current gradation requirements for soil cement backfill, a considerable amount of fine aggregate passing the No. 100 sieve would have to be added. This special blending would require considerable time, labor and expense.

4.4 Testing and Procedures

4.4.1 Laboratory Testing

4.4.1.1 Testing Equipment

Each of the 4-foot-long slotted drain specimens was tested in quasi-ring compression using a M.T.S. universal testing machine with a 1000 kip capacity. All specimens were loaded at a constant rate of 0.5 inch per minute. Before testing, a 500-pound preload was placed on each pipe to remove any initial movement prior to zeroing deflection instruments. All specimens were supported in a wooden cradle 20 inches high and 48 inches long, shown in Figure 10. The cradle was positioned on the lower platen of the testing machine.

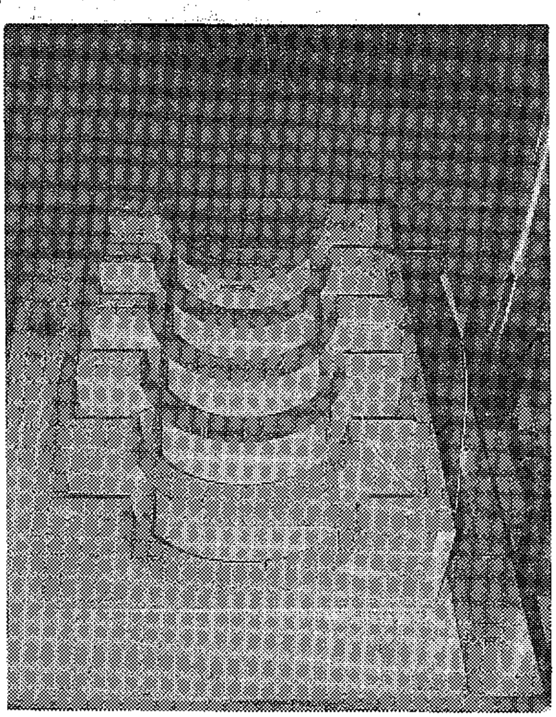


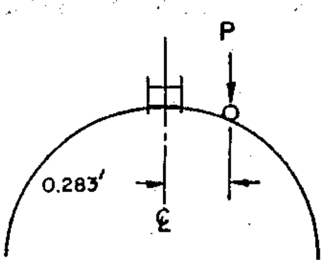
FIGURE 10. WOODEN CRADLE USED TO SUPPORT SHORT SLOTTED DRAIN TEST SPECIMENS.

4.4.1.2 Loading Methods Used in Laboratory Testing

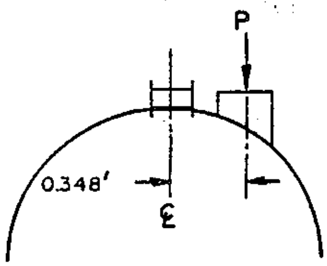
It was necessary to develop appropriate test equipment and load application methods for testing the short sections of slotted pipe drain in the laboratory using test procedures which would be relatively simple and easy to duplicate. These procedures were to approximate the same effects which a distributed wheel load of a heavy truck would impose on the slotted drain.

In the first stages of laboratory testing, a suitable method of applying an eccentric load to the slotted drains was sought. Initially, an eccentric load was applied through a 3/4-inch-diameter rod as shown in Loading Method (1), Figure 11a. This procedure was found to be unsuccessful, as the load was not distributed well and the resulting line load tended to cause buckling in the pipe wall directly under the loading bar. A side view of this unsuccessful Loading Method (1) is shown in Figure 12. Loading Method (2) also shown in Figure 11a, was found to work much better. By using a 4-inch-wide by 16-inch-long wooden block contoured to fit the corrugations of the slotted drain and cushioned over this contacting region with a thick sheet of neoprene rubber, the vertical load was applied evenly over a broader area. A photograph of this successful Loading Method (2) is shown in Figure 13. This method was used in the remaining tests to apply eccentric loads over the pipe corrugations adjacent to the grate structure of the slotted pipe drain, and also to apply loads to the lengths of the plain corrugated steel pipes (see similar Loading Methods (5) and (6) in Figure 11b).

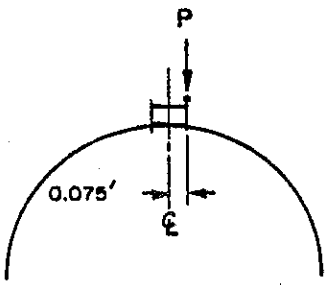
Two additional Loading Methods, (3) and (4), shown in Figure 11a, were simple to use. These were intended to represent a wheel load applied on top of and parallel to the grate section. Loading Method (4) approximated a wheel load centered over the grate bearing bars, and Loading Method (3), a slightly eccentric wheel load over one bearing bar only. A photograph of an end view of a slotted drain being tested using Loading Method (3) is shown in Figure 14.



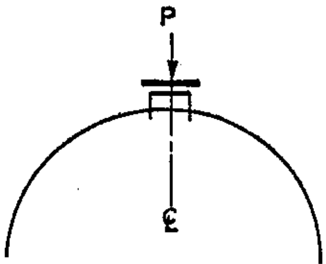
Loading Method (1)
Eccentric - Bearing on
a 3/4" Ø x 16" Rod Tack
Welded on the Pipe



Loading Method (2)
Eccentric - Bearing on
a 4" x 16" Block with
Bearing Area Fitting
the Pipe Corrugations

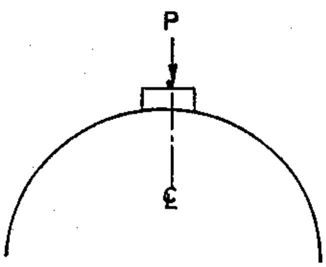


Loading Method (3)
Eccentric - Bearing on
One Side of Grate

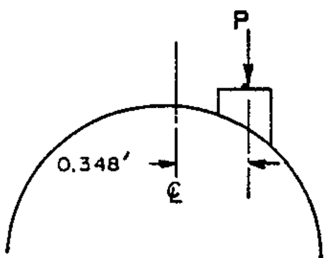


Loading Method (4)
Center - Bearing on a
Plate Set on the Grate

FIGURE 11a. LOADING METHODS USED IN THE LABORATORY ON SLOTTED DRAINS.



Loading Method (5)
Center - Bearing on a
4" x 16" Block with
Bearing Area Fitting
the Pipe Corrugations



Loading Method (6)
Eccentric - Bearing on
a 4" x 16" Block with
Bearing Area Fitting
the Pipe Corrugations

FIGURE 11b. LOADING METHODS USED IN THE LABORATORY ON PLAIN CORRUGATED STEEL PIPE.

FIGURE 11. LOADING METHODS USED IN LABORATORY TESTING.

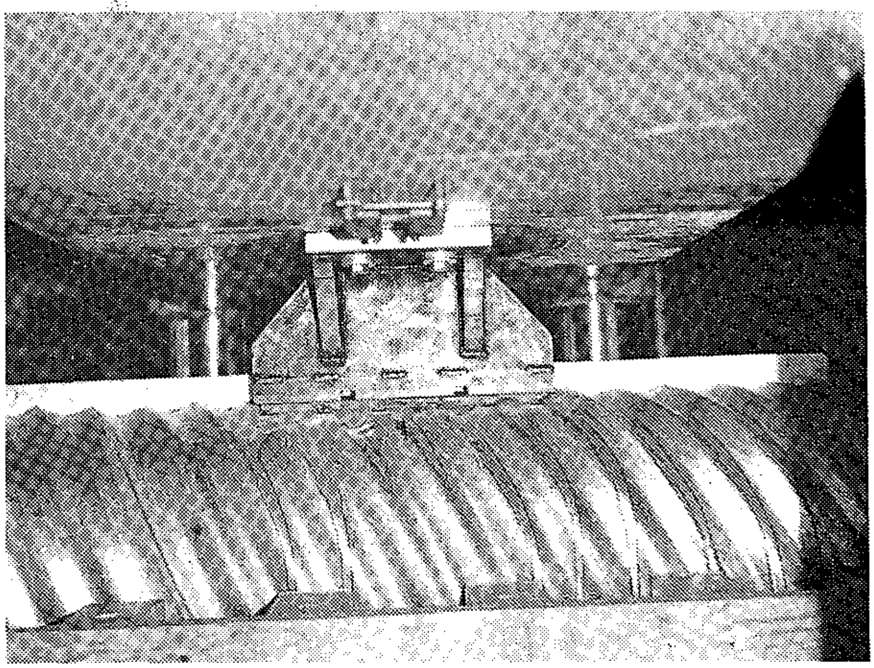


FIGURE 12. LOADING METHOD (1): ECCENTRIC LOADING APPLIED TO A ROD, TACK-WELDED TO CORRUGATED PIPE OF SLOTTED DRAIN.

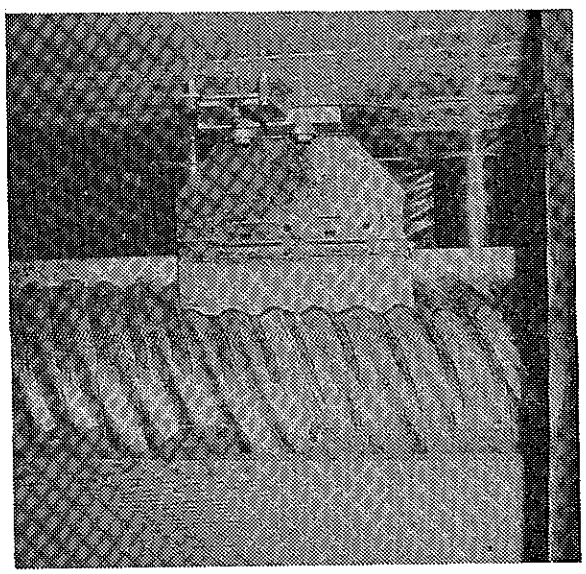


FIGURE 13. LOADING METHOD (2): ECCENTRIC LOADING APPLIED TO CORRUGATIONS OF SLOTTED DRAIN USING A CONTOURED BLOCK.

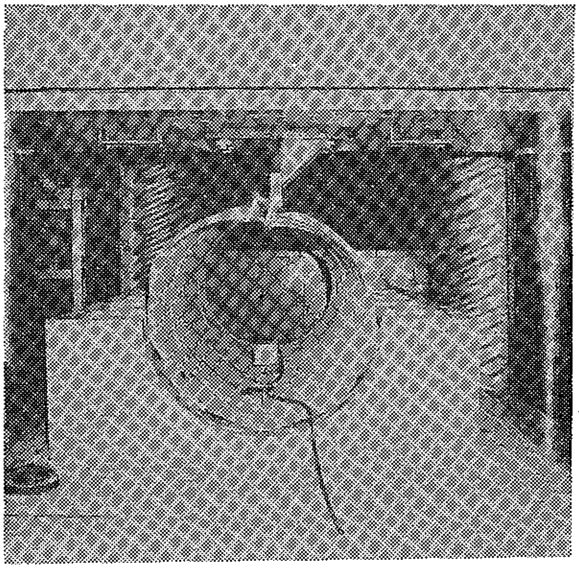


FIGURE 14. LOADING METHOD (3): ECCENTRIC LOADING APPLIED TO ONE BEARING BAR OF THE GRATE OF A SLOTTED DRAIN.

4.4.1.3 Measurements Made During Laboratory Testing

The measurements read and recorded were: maximum grate deflections, the testing machine platen deflection, applied loads, and grate angle changes.

The maximum grate deflection at the center of the bearing bar closest to the applied load was measured using a Houston Scientific Position Transducer shown in Figure 15. This instrument was a multi-turn rotary potentiometer, capable of measuring up to 13 inches of deflection with an accuracy of ±0.01 inch.

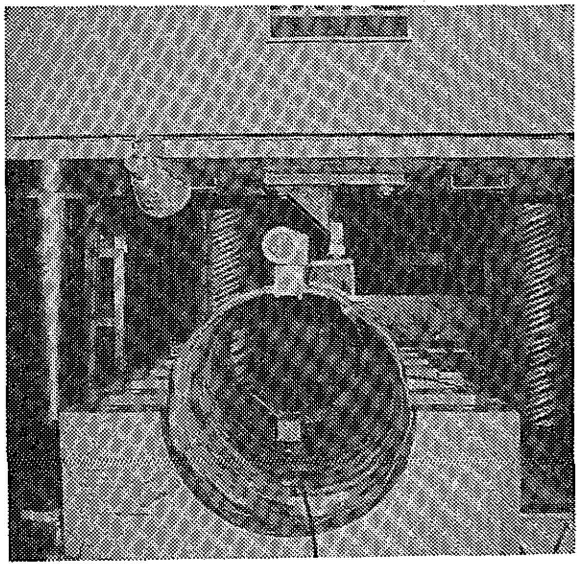


FIGURE 15. MEASUREMENT OF GRATE ANGLE CHANGE AND GRATE DEFLECTION.

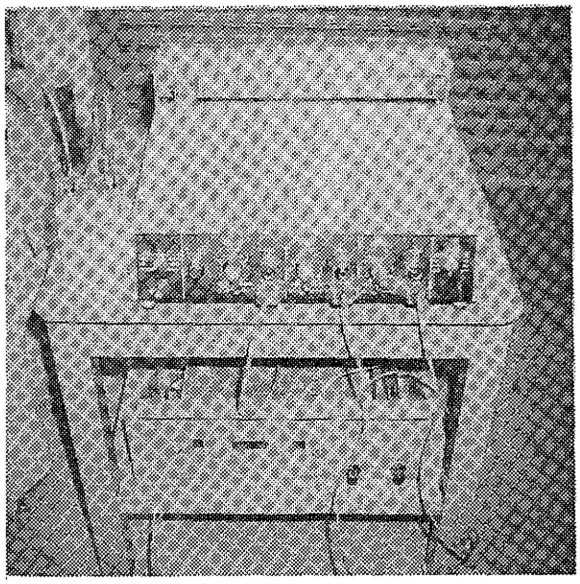


FIGURE 16. THE $X-Y_1-Y_2$ PLOTTER USED TO RECORD LOAD (P) VERSUS DEFLECTION (Δ), SHOWN WITH SUPPORTING ELECTRONIC EQUIPMENT.

The grate deflection (Y_1 axis) was recorded versus load (X axis) on a 10-inch x 15-inch chart. The testing machine platen deflection (Y_2 axis) was similarly recorded versus load (X axis) concurrently on the same chart. The recording instrument was a Hewlett-Packard dual stylus $X-Y_1-Y_2$ plotter shown in Figure 16. The grate angle change was read and recorded manually by observing a universal protractor plumb and level mounted on the grate, shown in Figure 15. These readings were recorded at the preload of 500 lbs and every 2000 lbs afterwards. The readings taken at or near 6000 lbs are tabulated in the data summary presented in Table 7, page 63, Section 5.1 of this report. The observations consisted of two angles, so noted in Figure 17.

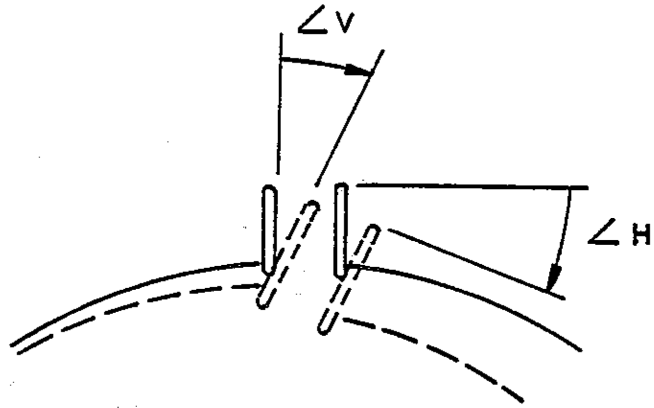


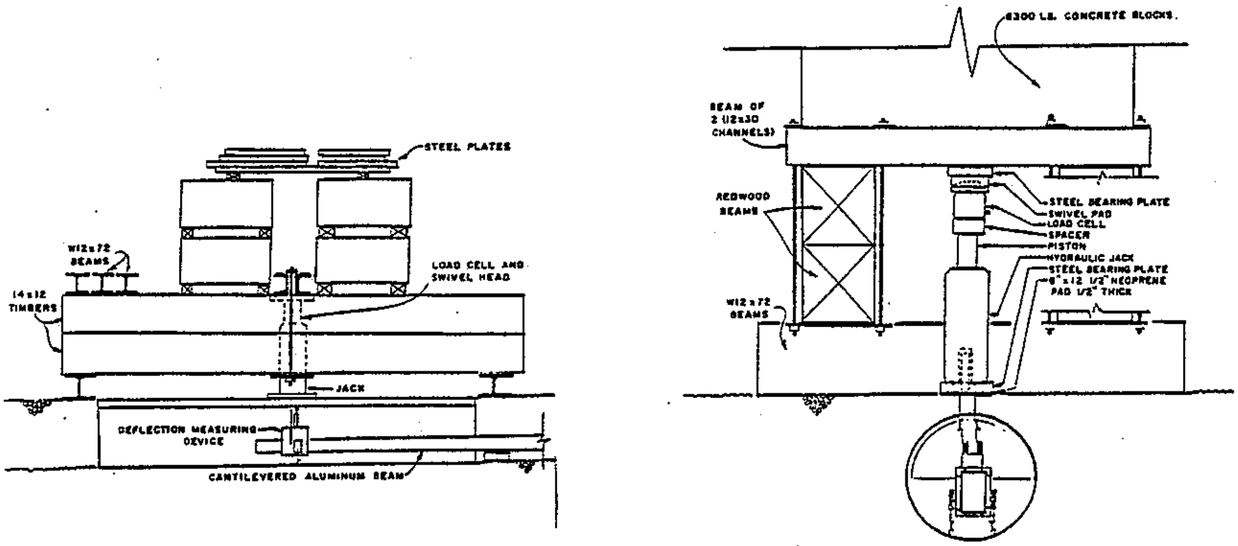
FIGURE 17. GRATE ANGLE CHANGES OBSERVED DURING THE LABORATORY TESTING OF SLOTTED DRAIN.

Other data recorded during laboratory testing included maximum load (P_{max}), grate descriptions, weld lengths, failure modes, and time and date of test. Photographs were taken of test fixtures, instruments, test specimens, and the loading methods used.

4.4.2 In-Situ Testing

4.4.2.1 General Equipment and Test Set-Up

Each of the field tests was conducted using the same general procedure and loading equipment with minor variations in the monitoring and recording instruments. The dead load testing frame which was used for all tests is shown in Figure 18. Four wooden timbers, 12 inches wide by 14 inches deep by 19 feet long, and having a total weight of 2300 pounds, were used to support dead load weights consisting of concrete blocks, steel "I" beams and steel plates. These timbers were stacked in pairs and were simply supported by two 10-foot-long W12x72 steel beams, one under each end of the two pairs of stacked timbers. The long wooden beams were used as a bridge so that the forces transmitted to the ground at their supported ends would not affect the stresses or deflections of the loaded slotted drain.



(a) SIDE VIEW

(b) END VIEW

FIGURE 18. POSITION OF TEST EQUIPMENT.

Four 6300-pound concrete blocks were placed on the wooden beams and were centered about the section of the slotted drain to be loaded. Steel plates having a total weight of 11,400 pounds were placed on top of the concrete block to provide additional dead load. Three 10-foot-long

W12x72 steel beams, all weighing approximately 2300 pounds, were placed on one end of the wooden beams to provide additional dead load and to stabilize the system. The total available dead load including the weights of the three steel beams, four wooden beams, four concrete blocks, and steel plates was 41,100 pounds, against which a jacking force could be applied. The wooden beams were bolted together using a steel beam made up of two C12x30 channel sections, four long steel rods, and two steel end plates (see Figure 18b). A 120-kip capacity hydraulic jack, placed under the center of the composite steel channel beam, was used to apply the static load to the slotted drain. This system provided a means by which a controlled incremental load could be applied to the various slotted drains.

For applying the load to the slotted drains in situ, an 8-inch-wide by 12 1/2-inch-long neoprene pad 1/2-inch thick was placed directly on top of the asphalt surface and over the grate of the slotted drain in the various positions shown in Figure 19.

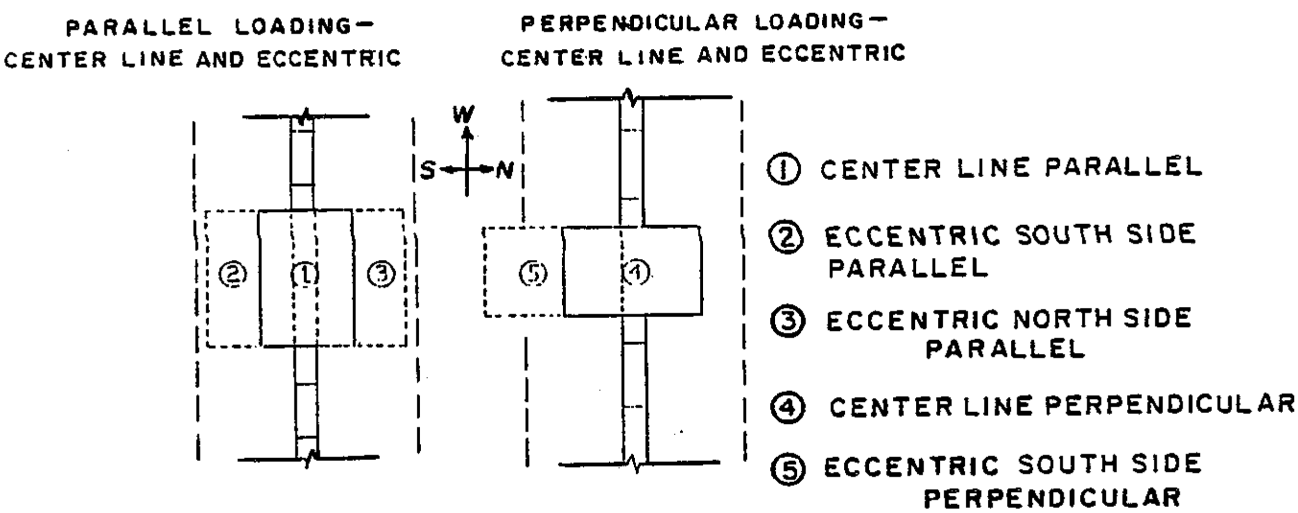


FIGURE 19. LOADING POSITIONS USED FOR IN-SITU TESTING.

A 1 1/2-inch-thick steel plate, having the same rectangular dimensions as the pad, was placed directly on top of the pad and distributed the applied jack load evenly over the surface of the neoprene. The 100-square-inch surface area of the pad represents the same approximate contact surface area as a commonly used pneumatic "flotation" truck tire. Loading positions ① and ② were used in Test Series 3A. In Test Series 3B, each of the five loading positions was employed. Only loading positions ① and ② however, were used in the load tests performed on the other four slotted drains.

In both the loading positions ① and ④, designated respectively as "centerline parallel" and "centerline perpendicular", the pad was simply centered on the grate either parallel or perpendicular to the grate bearing bars. For the other various loading positions designated either as "eccentric parallel", ② or ③, or "eccentric perpendicular", ⑤, the pad was placed with one of its edges overhanging a bearing bar of the grate by 1/4 inch, as shown in Figure 19.

The bottom of the hollow hydraulic jack was positioned over a solid steel pin which protruded up from the center of the steel bearing plate. A number of items were positioned on top of the jack ram. These included a hollow spacer cylinder, a load cell having a 200-kip capacity, a swivel seat, and a 2-inch-thick steel plate which bore against the channel beams when the jack was extended.

The load cell was calibrated for a range of 0 to 50 kips in a 60-kip-capacity universal testing machine. Calibration was verified just before each test with a resistance shunt calibration box.

The hydraulic system used to move the jack ram is shown in Figures 20, 21, and 22.

Both the fluid flow and pressure to the jack were controlled by a variable transformer which regulated the speed of the hydraulic pump. With this system, any magnitude of load could be applied to the slotted drain and held constant, while deflections and strain measurements were recorded.

4.4.2.2 Instrumentation-Deflections

A device was built to measure vertical deflections using linear displacement transducers (LDT's). LDT's are devices in which strain gages mounted on a coiled spring are used to determine the linear displacement of a small diameter steel shaft by changes in resistance. The deflection-measuring device, shown in Figure 23 was cantilevered on a 2-inch-wide by 5-inch-deep hollow rectangular aluminum beam. Vertical deflections, two at the grate bearing bars and two near the invert of the drain, were measured to the nearest ±0.001 inch.

Note: Digital load indicator was used to monitor load in testing of strain gage-instrumented drain.

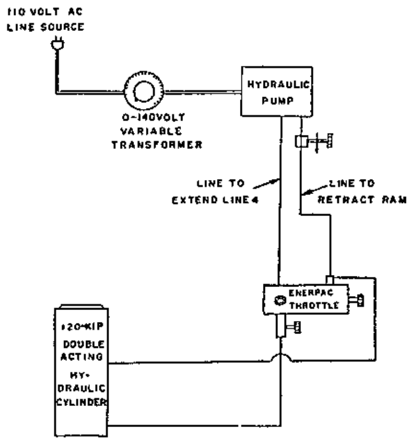


FIGURE 20. SCHEMATIC DIAGRAM OF HYDRAULIC SYSTEM.

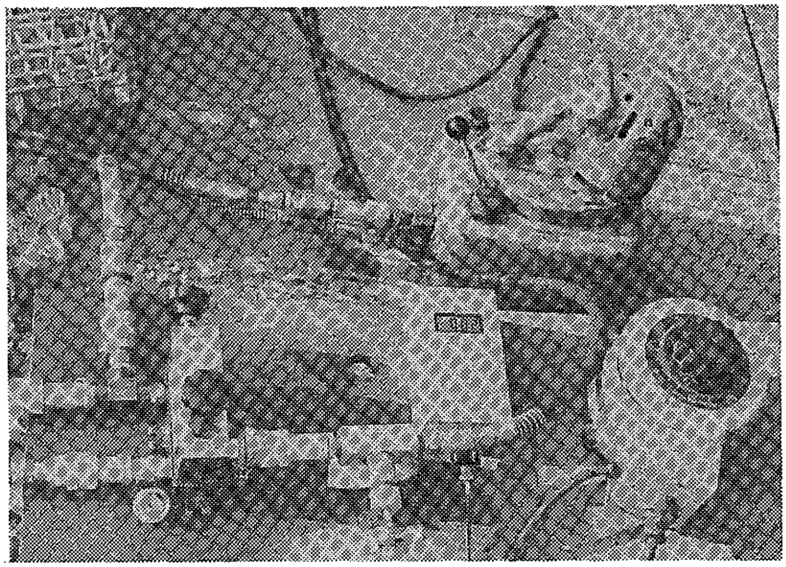
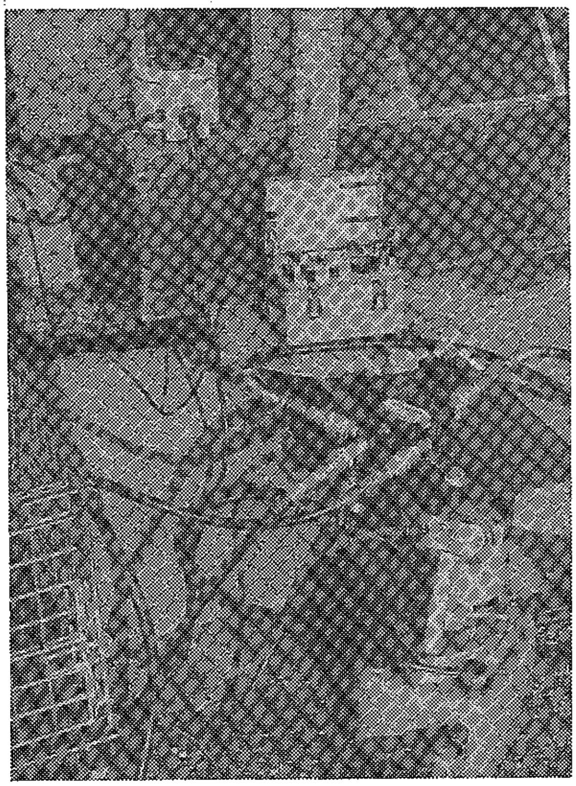


FIGURE 21. HYDRAULIC SYSTEM USED TO LOAD THE STRAIN GAGE-INSTRUMENTED SLOTTED DRAIN.



Note: Strainsert box used to monitor load in remaining tests.

FIGURE 22. HYDRAULIC SYSTEM USED TO LOAD SLOTTED DRAINS 1, 2, 4 AND 5, IN WHICH ONLY VERTICAL DEFLECTIONS AND LOADS WERE MEASURED.

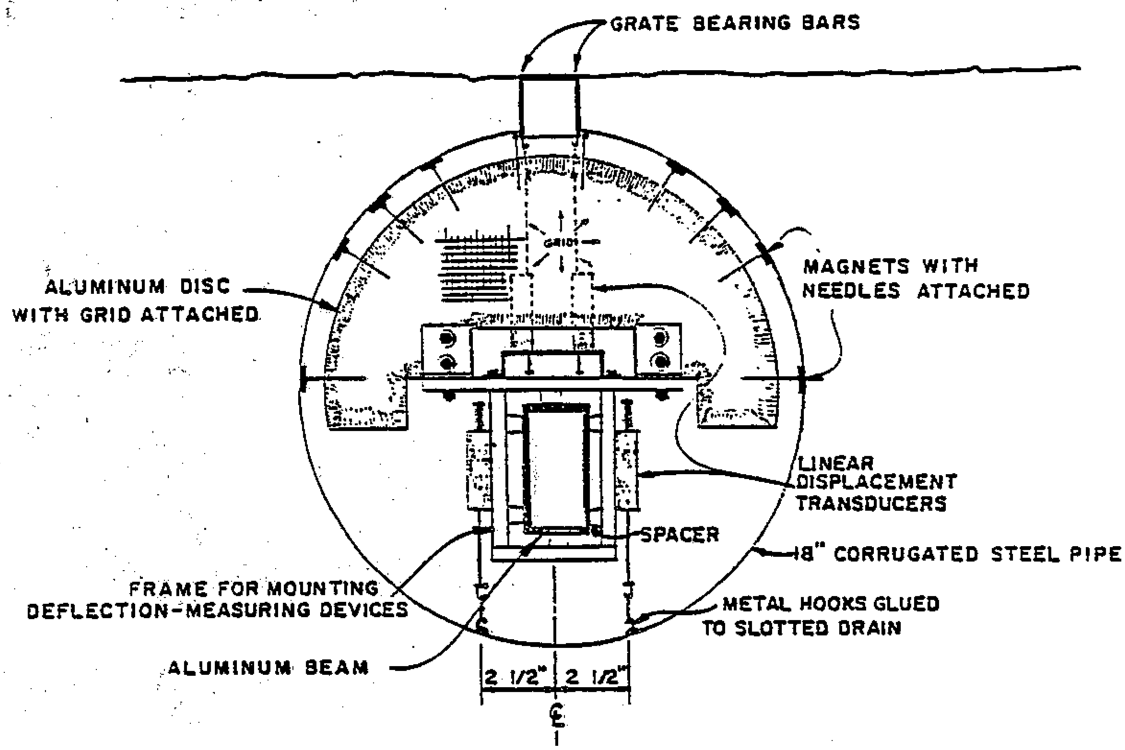


FIGURE 23. DEVICES FOR MONITORING DEFLECTIONS OF SLOTTED DRAINS, MOUNTED INSIDE OF DRAIN PIPE.

The deflection device shown in Figure 23 and used in all in-situ tests was mounted on the end of a 5-inch-deep, 2-inch-wide aluminum box beam which was cantilevered approximately five feet into the slotted drain pipe and supported just outside the slotted drain. When the device was in place, four small metal hooks were glued with epoxy, one each onto the bottom of both grate bearing bars and one onto each side of the drain invert where deflections were measured. Small diameter cables were then installed between each hook and its respective LDT. Care was taken that each of the four LDT's had sufficient travel in both directions to measure the expected vertical deflections. The locations of the points on the interior of the pipe at which the deflections were measured were the same for all tests.

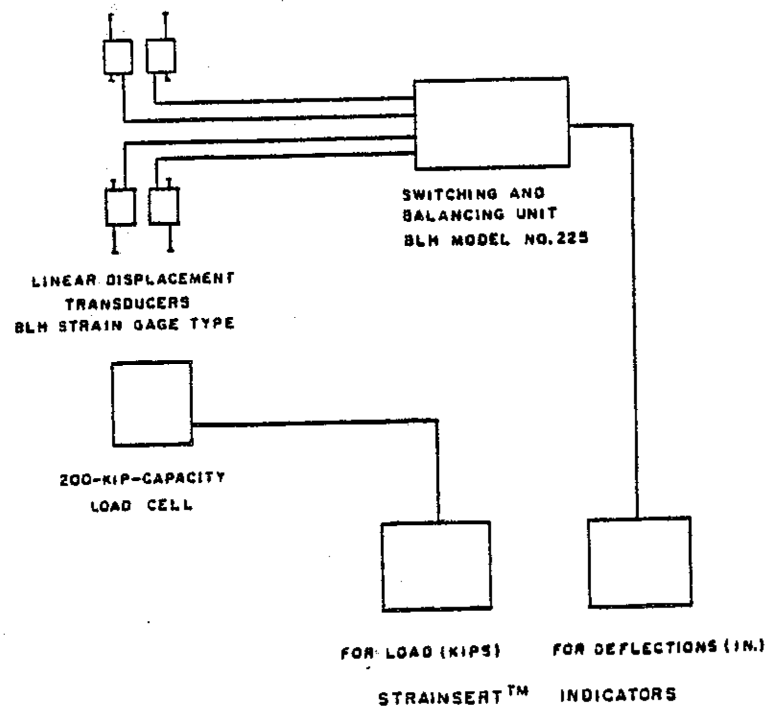


FIGURE 24. SCHEMATIC DIAGRAM FOR INSTRUMENTATION DEVICES USED FOR MONITORING VERTICAL DEFLECTIONS IN TESTS CONDUCTED ON SLOTTED DRAINS 1, 2, 4 AND 5.

The deflections at the grate and invert of the strain-gage-instrumented pipe and the pipe strains were recorded on punched tape using a binary number system, and also were printed on an additional tape (see schematic in Figure 24). The printed tape was used to quickly monitor the data during tests. A less sophisticated system using two Strainsert™ indicators and a resistance shunt calibration box was used to determine vertical deflections at the same locations in the remaining four slotted drains (see Figures 25 and 26, page 53). The LDT's were initially calibrated within a 0.2-inch range by using micrometer calibration board, and their accuracy was also quickly verified just before each test.

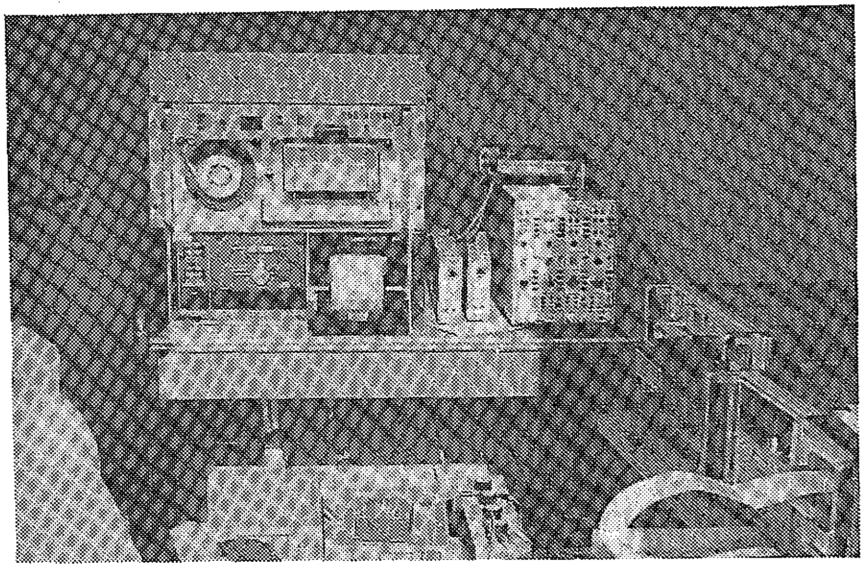
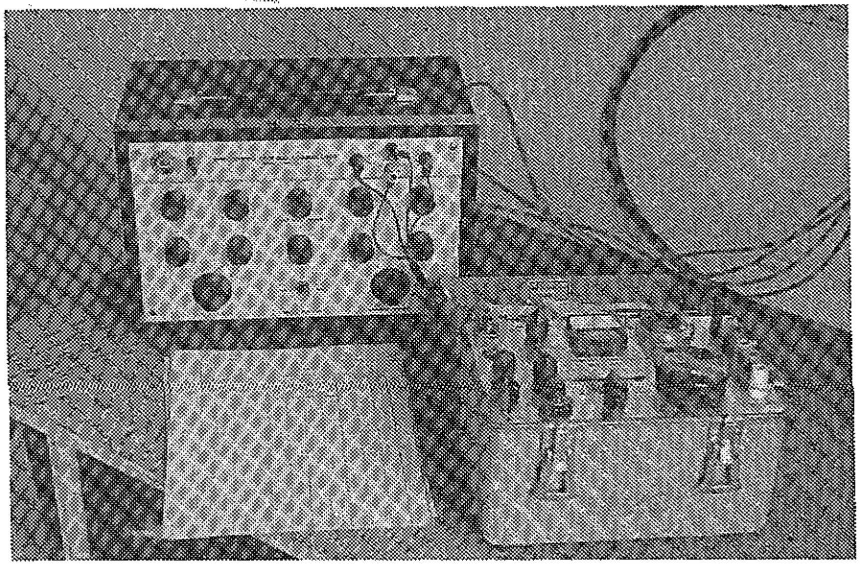


FIGURE 25. DATA ACQUISITION EQUIPMENT USED FOR MEASURING AND RECORDING STRAINS, DEFLECTIONS, AND LOADS ON THE STRAIN GAGE-INSTRUMENTED SLOTTED DRAIN.

Switching and balancing unit



Strainsert Indicator

FIGURE 26. ELECTRONIC EQUIPMENT USED FOR MEASURING DEFLECTIONS OF SLOTTED DRAINS 1, 2, 4 AND 5.

Inside of the strain gage-instrumented pipe, deflections of other various points on the interior pipe wall, in addition to those mechanically measured at the grate and invert, were determined photographically for five of the load tests performed on the strain gage-instrumented drain. This was accomplished by mounting a sheet of graph paper having a grid with 20x20 lines per inch on a semicircular shaped piece of sheet metal which was bolted on the top of the deflection device's aluminum frame. The grid-covered sheet metal was positioned so that its face was in the plane normal to the axis of the drain pipe and through the center of the loading plate, as shown in Figure 27. Magnetic pins mounted on small bar magnets were placed on the pipe wall and also on each bearing bar. The ends of these pins acted as indicators for determining movement of points on the inside pipe wall along the half circle defining the upper portion of the drain pipe. The interior of the drain pipe showing the pins projecting in front of the grid was photographed while the drain was loaded at each load increment and also at zero loads. The deflections at each point were determined with an accuracy of approximately ±0.01 inch by measuring changes of the pin positions shown on enlarged photographs.

4.4.2.3 Instrumentation-Rectangular Rosette Strain Gages

In the strain gage-instrumented drain the rosette gages were placed as shown in Figure 28. Information about the gages is included in the following list:

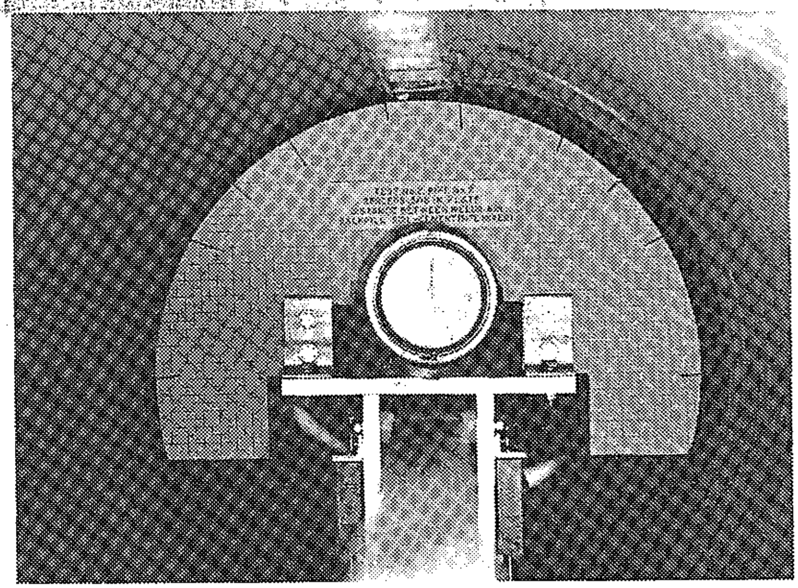


FIGURE 27. GRID SYSTEM AND MAGNETIC PINS INSIDE SLOTTED DRAIN NUMBER 3 USED TO DETERMINE DEFLECTED SHAPE OF THE DRAIN PIPE IN TEST SERIES 3A AND 3B

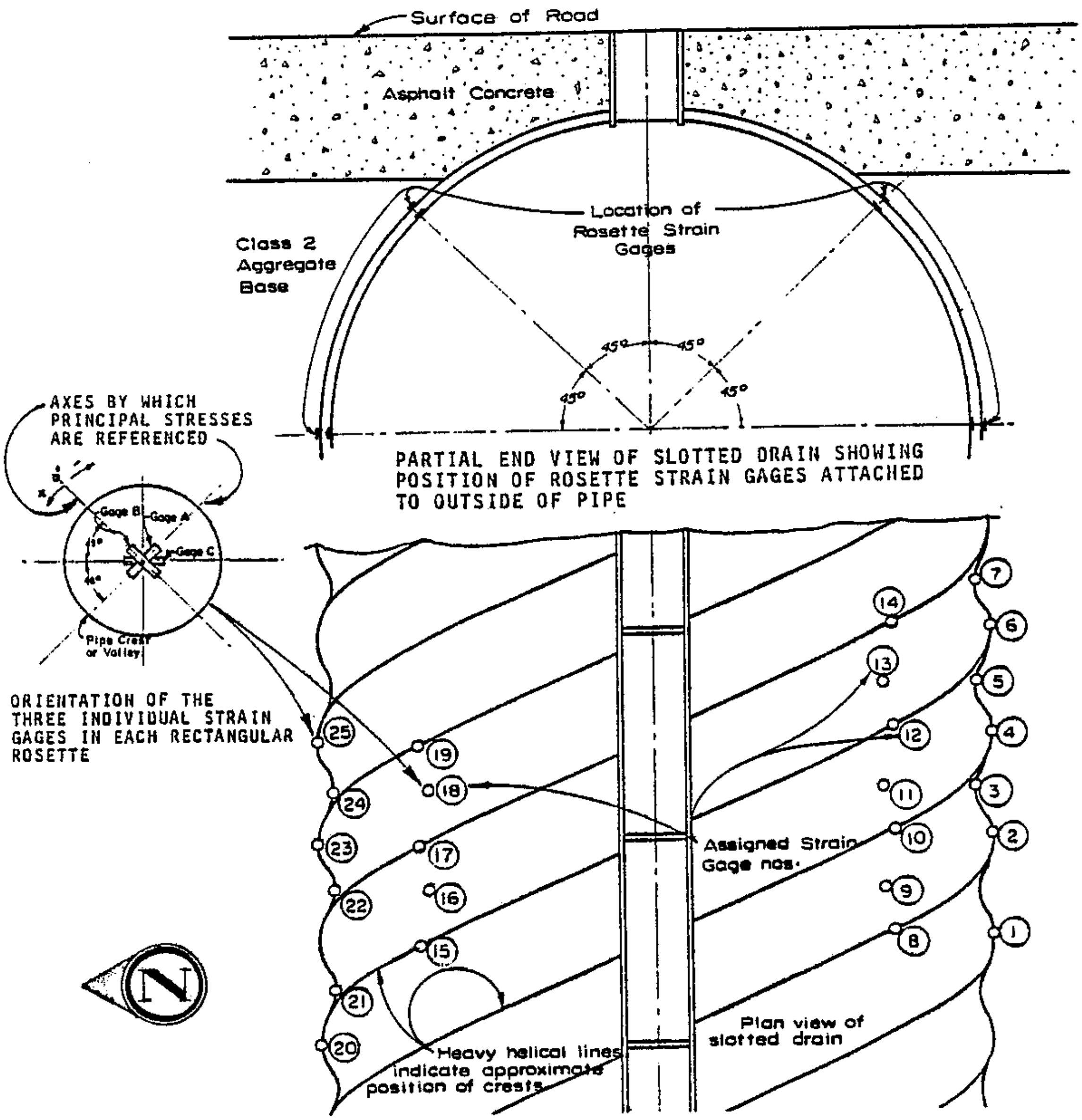


FIGURE 28. POSITIONS OF ROSETTE STRAIN GAGES ON SLOTTED DRAIN NUMBER 3.

Strain Gage Type: 3 gage stacked 45° rectangular rosettes
Manufacturer: Micro-Measurements, Inc., Romulus, Michigan
Manufacturer's No.: SA-06-120WR-126
Gage Length: 1/8 inch
Gage Factor @75°F: 2.07 nominal
Strain Limits: ±1.5% at room temperature
Resistance: 120 Ohms ±0.3%

The gages were placed at their numbered positions on the outside of the pipe only, either at the top of the corrugation crest or in the center corrugation valley. The strain gages were installed according to strain gage installation procedures, which are outlined in Chapter 3 of The Strain Gage Primer(15). A schematic diagram of equipment for measuring and recording strain at each gage is shown in Figure 29.

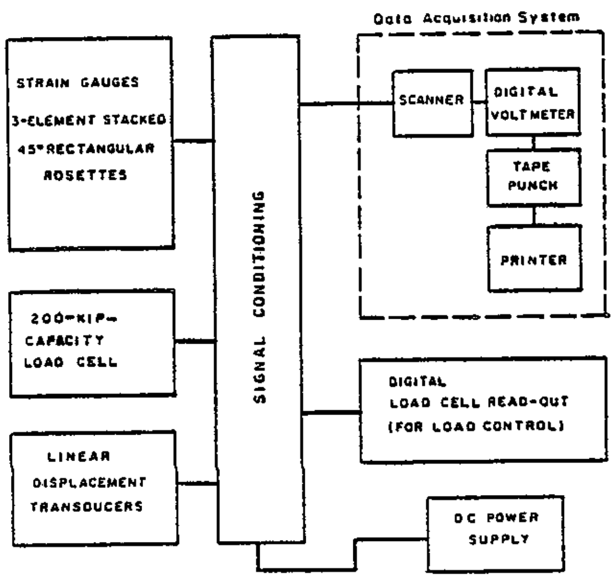


FIGURE 29. SCHEMATIC DIAGRAM FOR ELECTRONIC EQUIPMENT USED TO MONITOR LOADS AND DISPLACEMENTS FROM SLOTTED DRAIN NUMBER 3.

4.4.2.4 Description of Test Series and Loading Procedures used for Slotted Drain Load Tests Conducted in-Situ

Five different 16-foot-long slotted drains, numbered 1 through 5, were installed and tested in-situ in this phase of the research project. A total of six test series with code numbers 1, 2, 3A, 3B, 4, and 5 were performed; the integers in these code numbers were assigned so as to correspond to the pipe number on which a particular test series was performed.

In each of the Test Series 1, 2, 4, and 5 conducted on Slotted Drains Numbers 1, 2, 4, and 5 respectively, two loading tests were conducted. Each of these four slotted drains was loaded concentrically using a "centerline parallel" position centered five feet from one end, and then eccentrically five feet from the other end with an "eccentric southside parallel" position. These approximate third point positions were far enough apart from one another and away from the ends of each drain to prevent any influence from discontinuities at the ends of the drains or from adjacent loads. Loads were applied in each instance by jacking hydraulically on an 8-inch by 12 1/2-inch loading pad and against a dead load system supported by wooden beams, as previously described in Section 4.4.2.1 of this report. In each of these four test series, deflections of four different points inside the drain pipe, one at the bottom of each grate bearing bar and one on each side of the pipe invert, were monitored in conjunction with the hydraulically applied load as explained in Section 4.4.2.2 of this report.

In each of these test series, with the exception of Series 4, loads were increased in 2-kip increments from zero to 30 kips, and in 1-kip increments from 30 kips to the maximum applied load which varied slightly (see Table 6). For the eccentrically applied load in Test Series 4, loads were increased in 3-kip increments to 24 kips, and from 24 to 36 kips were raised in 1-kip increments. In all cases, initial "zero readings" of the four transducers were made at the beginning of each test with no external load applied to the drain. The external load was then raised to 2 kips, and deflections of the four transducers were recorded. The load was then reduced to zero and the four deflections were again recorded at zero load. This procedure of raising the applied load, reading deflections, dropping the load again, and reading "zero load" deflections was continued, each time increasing the applied load value incrementally, until a substantial grate deflection was noticed or until the magnitude of the applied load approached the total dead weight which was available to react against. Residual deflections, measured each time the incrementally increased load was reduced to zero, were plotted and are shown in Figures 31 through 34 (pages 68 through 71). These residual deflections, however, did not remain steady each time after the external loads were reduced to zero; thus they were recorded after the same time interval, approximately 30 seconds, had elapsed from the point in time when the external load actually reached zero.

The remaining two Test Series 3A and 3B were both conducted on the same section of strain gage-instrumented drain, Slotted Drain Number 3, which was especially instrumented with 25 rosette strain gages. The main

TABLE 6. LOADING POSITIONS AND PROCEDURES USED FOR EACH TEST SERIES.

Test Series Number	Loading Position (see page 47)	Loading Increments Used For Given Range of Load Values (kips)	Maximum Load Applied
1	Centerline Parallel	2 kips from 0 to 30 kips then 1 kip from 30 to 36 kips	36 kips
	Eccentric Southside Parallel	2 kips from 0 to 32 kips	32 kips
2	Centerline Parallel	2 kips from 0 to 30 kips then 1 kip from 30 to 38 kips	38 kips
	Eccentric Southside Parallel	2 kips from 0 to 30 kips then 1 kip from 30 to 33 kips	33 kips
3A	Centerline Parallel Eccentric Southside Parallel	2 kips from 0 to 10 kips then 1 kip from 10 to 15 kips	15 kips
3B	Centerline Parallel Centerline Perpendicular Eccentric Southside Parallel Eccentric Northside Parallel Eccentric Southside Perpendicular Centerline Parallel	1 kip from 15 to 20 kips then 2 kips from 20 to 32 kips	32 kips
4	Centerline Parallel	2 kips from 0 to 30 kips then 1 kip from 30 to 38 kips	38 kips
	Eccentric Southside Parallel	2 kips from 0 to 24 kips then 1 kip from 24 to 36 kips	36 kips
5	Centerline Parallel	2 kips from 0 to 30 kips then 1 kip from 30 to 39 kips	39 kips
	Eccentric Southside Parallel	2 kips from 0 to 30 kips then 1 kip from 30 to 36 kips	36 kips

difference between these two test series was the type of backfill used: in Test Series 3A, a soil backfill was used, whereas in Series 3B the same drain was reinstalled using soil cement bedding as a backfill. Although the maximum applied load levels as shown in Table 6 are lower for these two Test Series, 3A and 3B, the general testing procedures are the same as those employed for the four previously discussed test series. Slotted Drain Number 3 was loaded at its longitudinal center for all loading positions used in both Test Series 3A and 3B. Only loading positions 1 and 2 (see Figure 19, page 47) were used in Test Series 1, 2, 4, 5, and 3A. In Test Series 3B, these two positions, as well as three additional load positions, also shown in Figure 19, were employed. The load range of 0 to 15 kips, used for Test Series 3A and all but one loading position in Test Series 3B, was intended to keep the pipe wall stresses below the yield point so that the slotted drain could be retested by applying the external load in the same general area and results for each test would then hopefully be valid. The Slotted Drain Number 3 was finally loaded to failure at 32 kips during the last loading test in Test Series 3B using a centerline parallel loading position. This loading position was used to finally fail the instrumented drain as it produced the highest stresses and greatest deflections of any of the loading positions employed in the entire in-situ testing program.

5. DATA AND DATA ANALYSIS

5.1 Data Analysis and Conclusions from the Laboratory Tests

The data obtained from initial laboratory testing of the 4-foot sections of slotted drain is summarized in the following Table 7. Important variables considered in the initial quasi-ring compression laboratory testing include: (1) the method of applying a vertical load to the slotted drains, (2) the types of grate cross spacers and (3) the location of grate-to-pipe welds.

Parameters measured which gave an indication of the effects of these variables on the relative ability of the various types of slotted drains tested to withstand compressive loads include:

(1) the maximum load attained,

(2) the maximum deflection under the grate bearing bars,

(3) the maximum deflection at the center of the load, and

(4) the maximum angle change of the grate structure measured at a compressive load of 6000 pounds.

As a very limited number of tests were conducted for each loading condition, the following comments made and conclusions drawn from the data taken are very general:

TABLE 7. SUMMARY OF DATA FROM LABORATORY TESTING OF 18-INCH-DIAMETER BY 4-FOOT-LONG SLOTTED DRAINS.

VARIABLES						Specimen No.	DATA OBTAINED					
Type of Loading (See Figure 11, page 40)	Type of Cross Spacer and (Spacing Distance, inches)	No. Corrugations Per Weld	Length of Grate-to-Pipe Welds, (inches)	Position of Welds With Respect to: Corrugations	Position of Welds With Respect to: Spacers		Maximum Load(P) Pounds	Maximum Deflection Measured Under Grate Bearing Bar (inches)	Maximum Deflection at Center of Load (inches)	Grate Angle Changes at P=6000 lb. (degrees) ∠ V*	Grate Angle Changes at P=6000 lb. (degrees) ∠ H*	Distance Between Centerline of Slotted Drain and Load (feet)
Eccentric Rod	Double Hexagonal Bar (6)	3	1 1/2	No Consistent Relationship	Between Spacers	1	8,265	0.30	0.65	6°	5°	0.283
Eccentric Block			1 3/4	Crest-to-Valley	At 1/4 Points	7	9,200	0.15	1.10	6.5°	4.5°	0.348
Eccentric Bearing on Grate					At Spacer Every Other Weld	3	7,218	0.65	0.95	8°	7°	0.075
Center on Plate						11	9,518	1.15	1.05	-	-	0
Eccentric Block					Near Spacers	15	10,501	0.15	1.10	6°	4°	0.348
Eccentric Bearing on Grate		2			Near Spacers	4	7,321	0.65	0.90	7.5°	5°	0.075
Eccentric Block				Crest	At Spacer	5	9,771	0.20	0.85	7.5°	5.5°	0.312
Center on Plate				Crest-to-Valley	Near Spacers	12	9,827	0.90	0.85	-	-	0
Eccentric Block	(4) ↓				At Spacer	16	9,823	0.20	1.60	3°	3°	0.362
	Single Hex. Bar	2 1/2	1 1/2	No Consistent Relationship	At 1/4 Points	10	7,550	0.15	1.20	5°	6.5°	0.348
Eccentric Rod	3/16 Inch Plate (6)	2	1 3/4	Crest	At Spacer	2	8,276	0.30	0.65	4°	5°	0.283
Eccentric Block					Near Spacer	8	8,817	0.15	1.00	4°	3°	0.348
					Between Spacers	9	9,835	0.25	1.00	2°	2.5°	0.348
Center on Plate					At 1/4 Points	13	10,040	1.00	0.95	-	-	0
Eccentric Block	Unslotted Pipe (0)	0	-	-	-	6	10,390	0.40	1.20	-	-	0.353
Center Block						14	10,090	0.70	0.95	-	-	0

*See Figure 17, page 45

Ring Compression Strength. With regard to ring compression strengths of the various slotted drains tested, one of the lowest compressive load values, 7550 pounds, was obtained from the only piece of slotted drain which had a single bar grate. The two plain sections of corrugated steel pipe tested produced the highest average value of compressive strength measured, 10,340 pounds. The compressive load values for the various sections of slotted drains tested whose grates had either double hexagonal cross bar spacers or solid plate spacers were comparable to each other and were spread over a fairly wide range. These were between 7218 and 10,501 pounds for the nine sections of drain tested with grate having double hexagonal bar spacers, and between 8276 and 10,040 pounds for the four sections of drain having grate with solid plate spacers. Although the use of plate spacers instead of double bar spacers does not seem to significantly increase the load carrying capacity of the slotted drains in these laboratory tests, the plates tend to stiffen the grate section and somewhat reduce grate angle changes under heavy loading.

Grate and Pipe Deflections. For all initial tests conducted, deflection measurements made either under the grate bearing bars or at the center of the externally applied load were the highest when the external load was centered on the grate bearing bars.

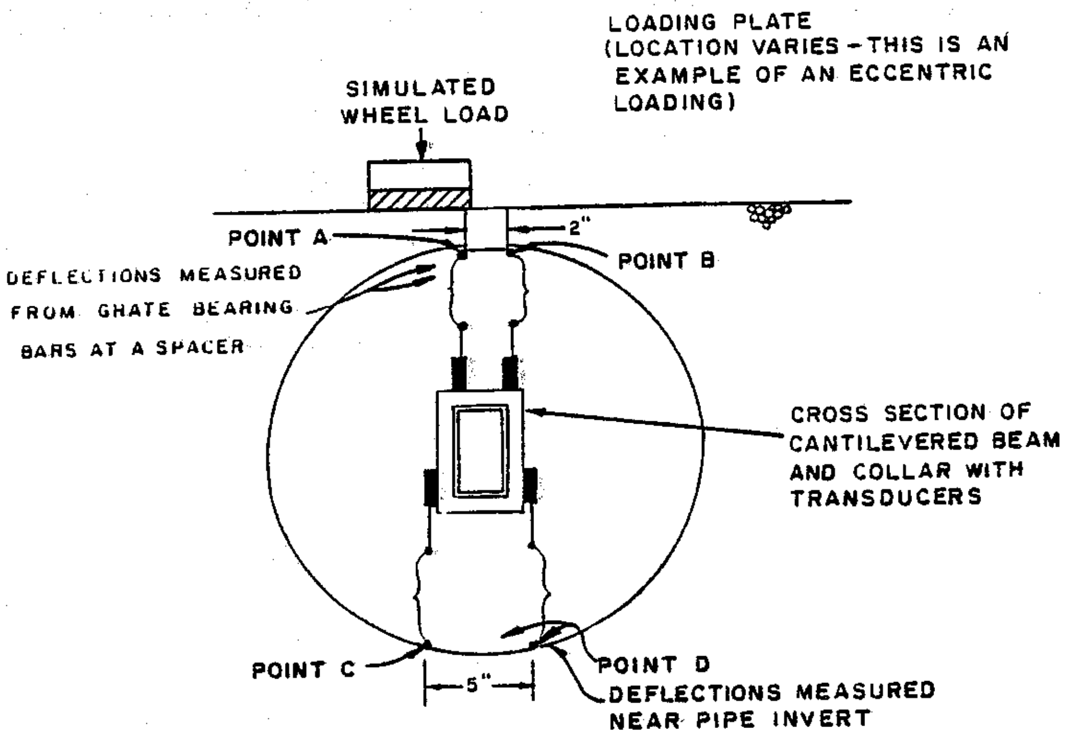
Grate Angle Changes. The lowest grate angle changes were recorded for the slotted drain having a grate design with solid cross plate spacers.

Spacing of Intermittent Welds Attaching the Grate to the Pipe. An increase in the number of intermittent grate-to-pipe welds, accomplished by decreasing the fillet weld spacing from 3 corrugations between welds to 2 corrugations between welds, did not appear to significantly increase maximum attainable loads or decrease pipe deflections.

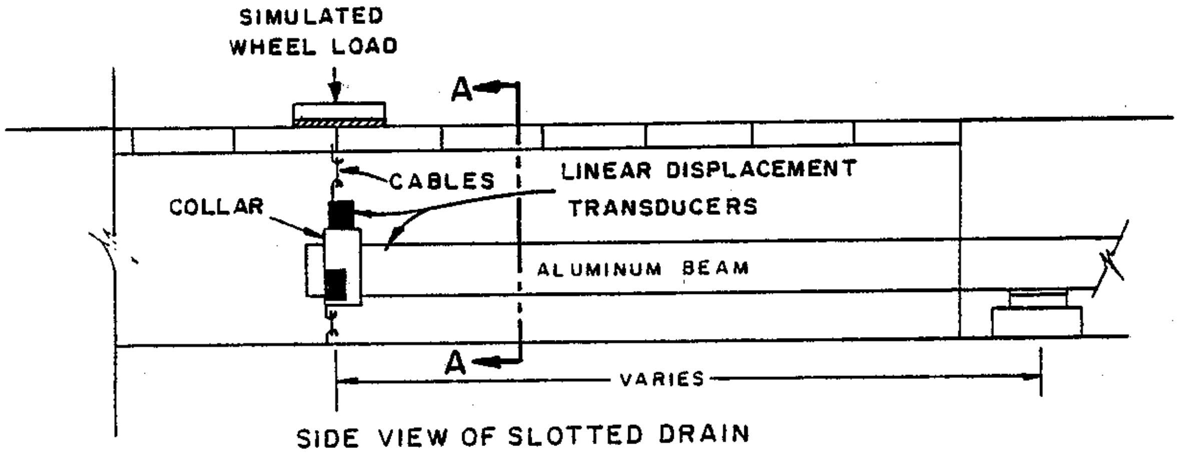
Strength of Grate-to-Pipe Fillet Welds. The weak point in the slotted drain structural system seems to be the intermittent fillet welds which attach the grate bearing bars to the pipe. The apparent effect which the location of these welds, relative to the position of the cross spacers, has on the load-carrying capacity of the drains is inconsistent. However, by one's engineering judgment and intuition, it would appear that if the positions of the intermittent welds were centered at each cross spacer, the load transfer from the grate structure to the pipe would be more direct and the distortion of the grate structure would be reduced considerably. Also locating these intermittent fillet welds so that they would run from the corrugation crest to the neighboring valley would tend to stiffen the welded junctions between the pipe and grate bearing bars. This welding pattern would reduce grate rotation under heavy wheel loads, and improve the durability of the slotted drain structure.

5.2 Analysis of Data from In-Situ Tests

Vertical movements at the bottom of the bearing bars of the grate and at the bottom of the pipe near the invert were measured for each of the five slotted drains tested (see Section AA, Figure 30, for the locations in the slotted drain). Movement at these positions was determined at each incremental load level placed on the slotted drain, and



SECTION AA ENLARGED END VIEW OF SLOTTED PIPE DRAIN SHOWING POINTS FROM WHICH VERTICAL DEFLECTIONS WERE MEASURED



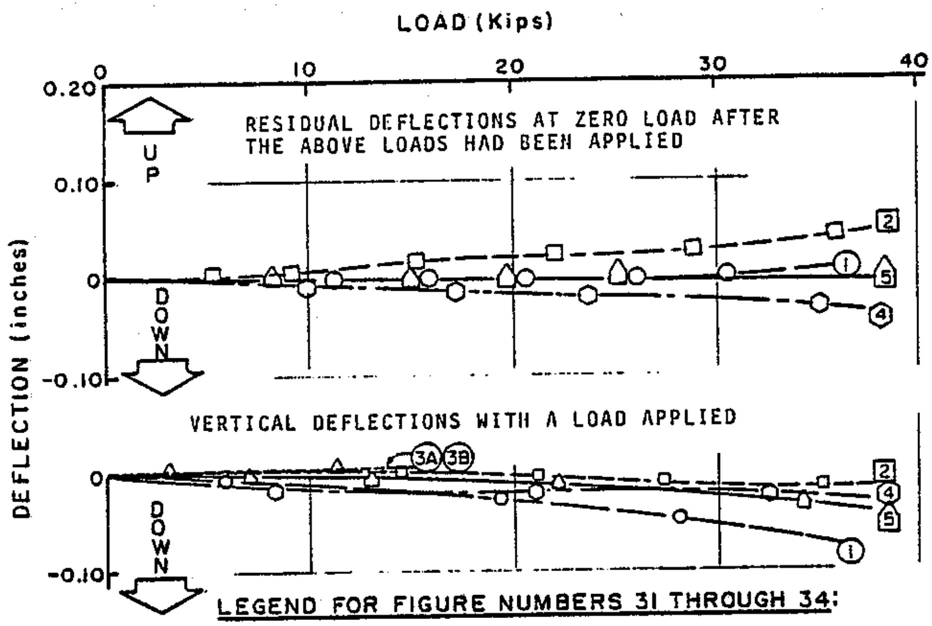
SIDE VIEW OF SLOTTED DRAIN AND CANTILEVERED ALUMINUM BEAM

FIGURE 30. POSITION OF CANTILEVERED ALUMINUM BEAM AND DEVICE FROM WHICH VERTICAL DEFLECTIONS WERE MEASURED.

also each time the load was removed after each incremental increase. These deflections were referenced from the original unloaded shape of the drain pipe and were measured with four transducers attached to the end of a cantilevered aluminum beam (see Figure 30). All deflections were measured inside of the slotted drain from points A, B, C, and D, shown in Figure 30. The locations along the slotted drain at which the loads were applied and the vertical deflections were measured were at the longitudinal midpoint of the drain section for in-situ Test Series 3A and 3B (see Figure 31 for legend), and at the 1/3 points for the remaining Test Series 1, 2, 4, and 5.

Loading positions have been previously explained in Section 4.4.2.4 of this report and the test series in which they were employed are shown in Table 6. Pipe deflections measured using a Strainsert indicator were adjusted using a calibration factor. In addition to this adjustment, all the interior pipe deflections measured from the end of the cantilevered aluminum beam were corrected for the small changes in deflections of the beam end. These changes in deflection at the end of the beam were caused by the slight variations in spring tensions of the LDT's as the slotted drain deflected.

The vertical deflections of the grate bearing bars and pipe invert are plotted in Figures 31, 32, 33, and 34, with vertical deflections in the direction of the vertical axis and externally applied load shown on the horizontal axis.



LEGEND FOR FIGURE NUMBERS 31 THROUGH 34:

(1) —○— —○—	Test Series 1, Slotted Drain 1	Plate spacers, soil backfill
(2) —□— —□—	Test Series 2, Slotted Drain 2	Double hex spacers, soil backfill
(3A) -◇- - - -◇- - -	Test Series 3A, Slotted Drain 3	Plate spacers, soil backfill, slotted drain instrumented with strain gages
(3B) —△— —△—	Test Series 3B, Slotted Drain 3	Plate spacers, soil cement backfill, slotted drain instrumented with strain gages
(4) —○— - —○—	Test Series 4, Slotted Drain 4	Double hex bar spacers, lean concrete backfill
(5) —△——△—	Test Series 5, Slotted Drain 5	Double hex bar spacers, soil cement backfill

Notes: .See TABLE 2 for further details about slotted drains.
.Symbols do not represent data points

FIGURE 31. AVERAGE VERTICAL DEFLECTIONS OF INVERT RESULTING FROM CENTERLINE PARALLEL LOADING.

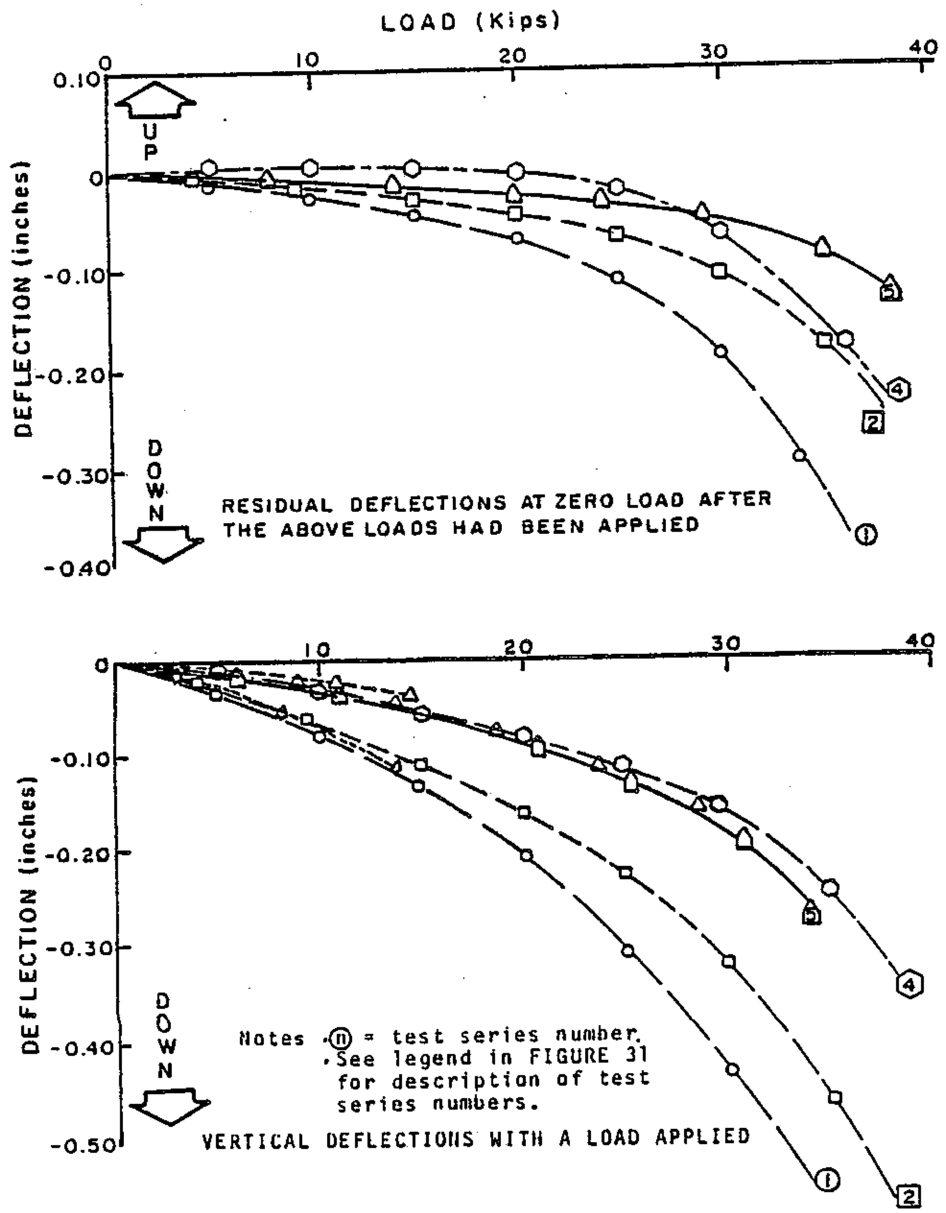


FIGURE 32. AVERAGE VERTICAL DEFLECTIONS OF GRATE BEARING BARS RESULTING FROM CENTERLINE PARALLEL LOADING.

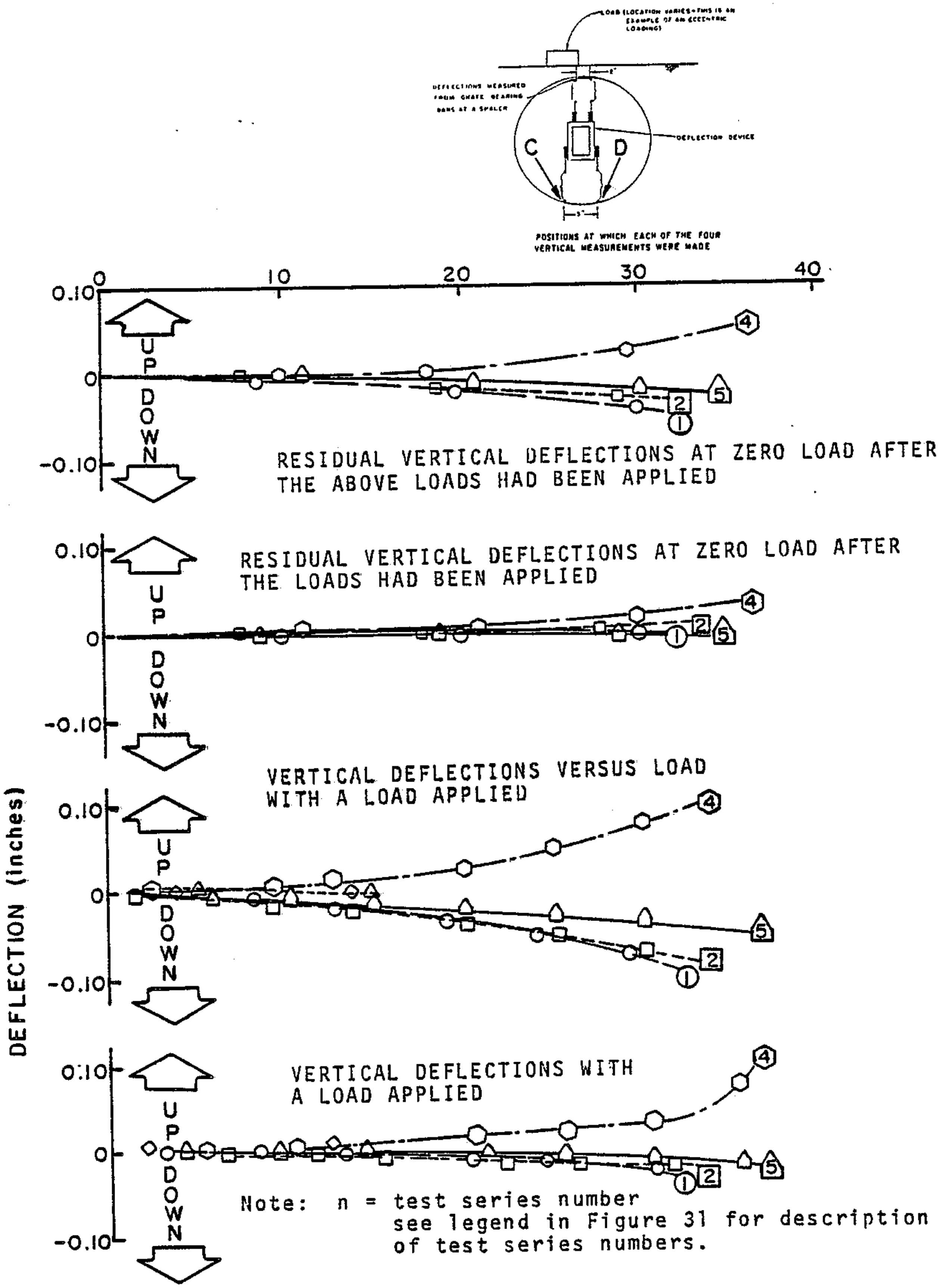


FIGURE 33. VERTICAL DEFLECTIONS MEASURED NEAR DRAIN INVERT WITH ECCENTRIC PARALLEL LOADING.

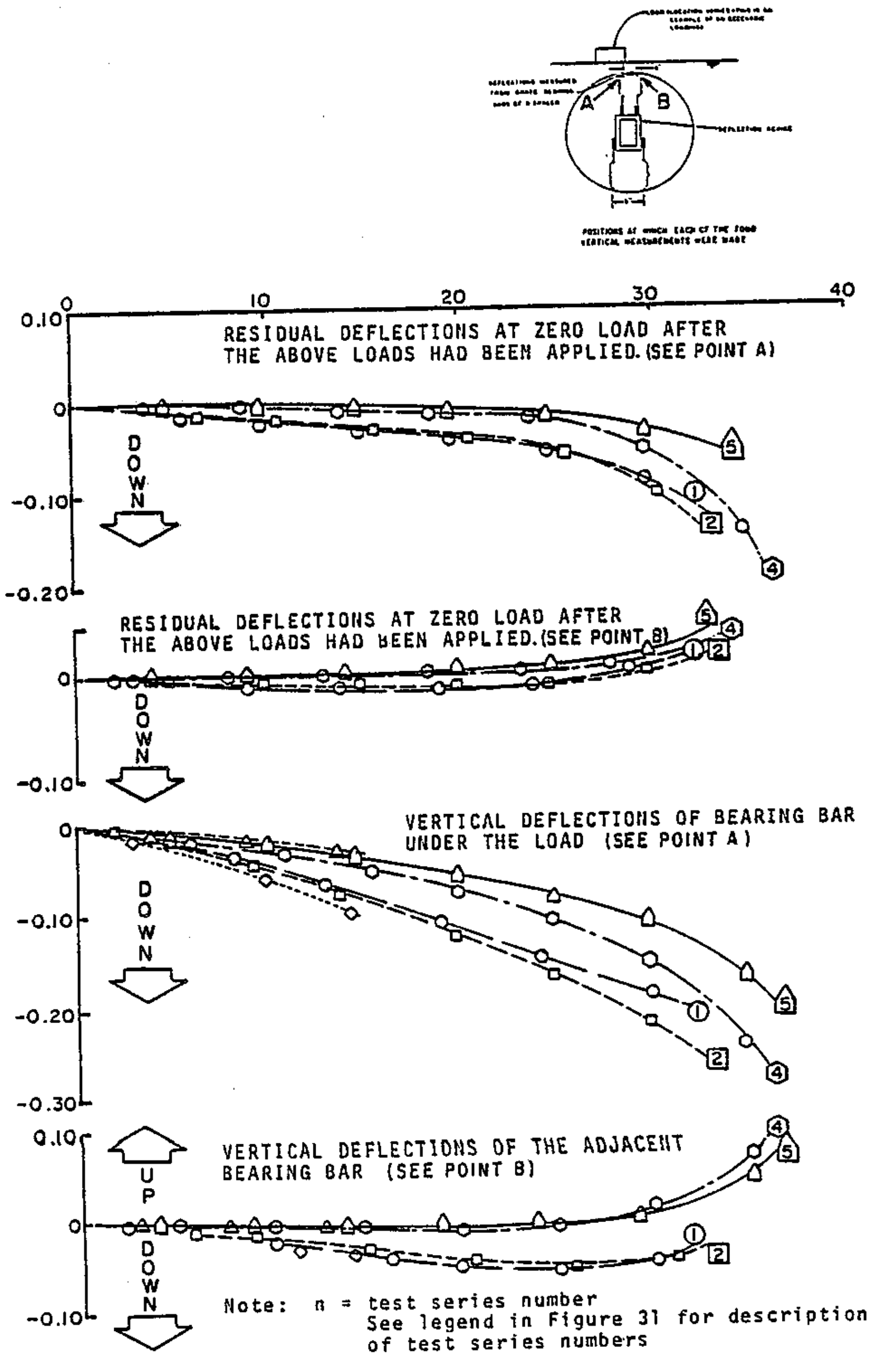
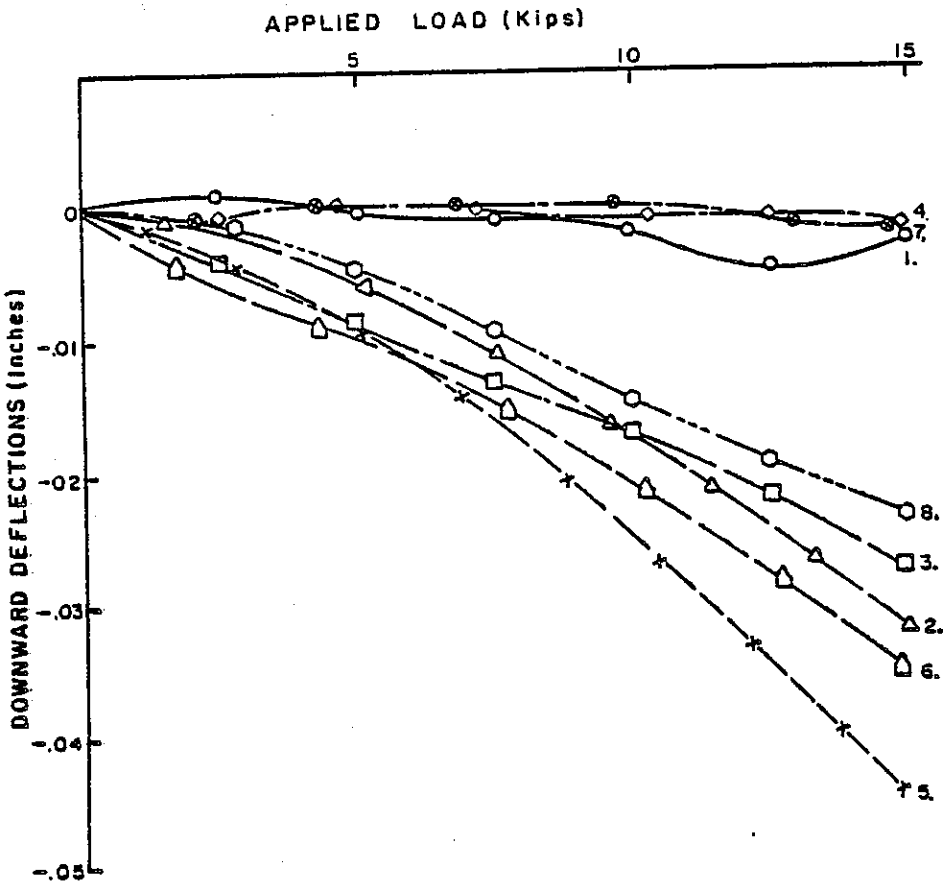


FIGURE 34. VERTICAL DEFLECTIONS OF GRATE BEARING BARS RESULTING FROM ECCENTRIC PARALLEL LOADING.

All deflections under centerline loading are the average of the two top or bottom deflections recorded. For eccentric loading, each individual deflection measurement is plotted with deflections under the load designated as Points A and C, and deflections opposite the load designated as Points B and D, Figure 30, page 66.

Four figures, Numbers 31, 32, 33, and 34 showing grate and invert deflections are presented on pages 68 through 71. Grate deflections are shown in Figures 32 and 34 with a load applied. The residual grate deflections at zero load, measured just after the incremental loads had been removed, are also shown at the top of the figures. These residual deflections shown at zero load are not permanent deflections or "set" that would remain in the slotted drain. It was observed that during testing, these deflections recorded at the zero loads, decreased with time. So that all of the deflection data could be compared, it was necessary to take each of the deflection readings at the same point in time after the external loads had been reduced to zero. Thus, all deflection readings taken at zero load were recorded approximately 30 seconds after the load was removed.

To determine which loading position produced the greatest deflections, five different loading positions were monitored during Test Series 3B. In Figure 35 the greatest deflection of the grate bearing bars is shown to occur during centerline loading by applying the load with the pad parallel to the slotted drain grate. Slotted drain invert deflections were not significantly influenced by the loading position as all five positions produced deflections less than ± 0.005".



1. ○ Parallel loading - eccentric southside - deflections at B (adjacent bearing bar)
2. △ Parallel loading - eccentric southside - deflections at A (loaded bearing bar)
3. □ Parallel loading - eccentric northside - deflections at B (adjacent bearing bar)
4. ◇ Parallel loading - eccentric northside - deflections at A (loaded bearing bar)
5. X Parallel loading - centerline - average of deflections at A and B.
6. △ Perpendicular loading - centerline - average of deflections at A and B.
7. ⊗ Perpendicular - eccentric southside - deflections at B (adjacent bearing bar)
8. ○ Perpendicular - eccentric southside - deflections at A (loaded bearing bar)

Notes: •Points A and B are shown in FIGURE 30.
•Symbols do not represent data points.

FIGURE 35. VERTICAL DEFLECTIONS OF GRATE BEARING BARS VERSUS APPLIED LOAD, TEST SERIES NO. 3B.

5.2.1 Soil Backfill Versus Soil Cement Backfill

Generally, the deflections measured with the soil backfill were much greater than those found with soil cement backfills in both centerline and eccentric loading positions. In addition to plotting the vertical deflection of the grate and invert versus load, the shapes of the deflected slotted drains obtained photographically in Test Series 3A and 3B were plotted and are shown in Figures 36, 37, 38, 39, and 40. The soil cement backfill restrained the pipes from deflecting laterally at the springline better than soil backfill and also resulted in vertical deflections at the drain grate being much smaller than those measured with the soil backfill. The slotted drain grate installed with soil backfill deflected approximately four times more under centerline loading and approximately three times more under eccentric loading. The invert deflections in both backfills were less than ±0.006" and were considered negligible.

5.2.2 Influence of Position of Grate-to-Pipe Welds

In the static load tests conducted in this in-situ research program, the three variables associated with grate-to-pipe welds in the slotted drain sections tested did not significantly influence their load-carrying ability. The three variables are: (1) center-to-center distances between the intermittent fillet welds, 6 inches versus 9 inches; (2) weld length, 1-3/4 inches versus 2 inches; and (3) weld locations: (a) with respect to locations of crests and valleys of the pipe corrugations and (b) with respect to the locations of the cross spacers in the grate structure.

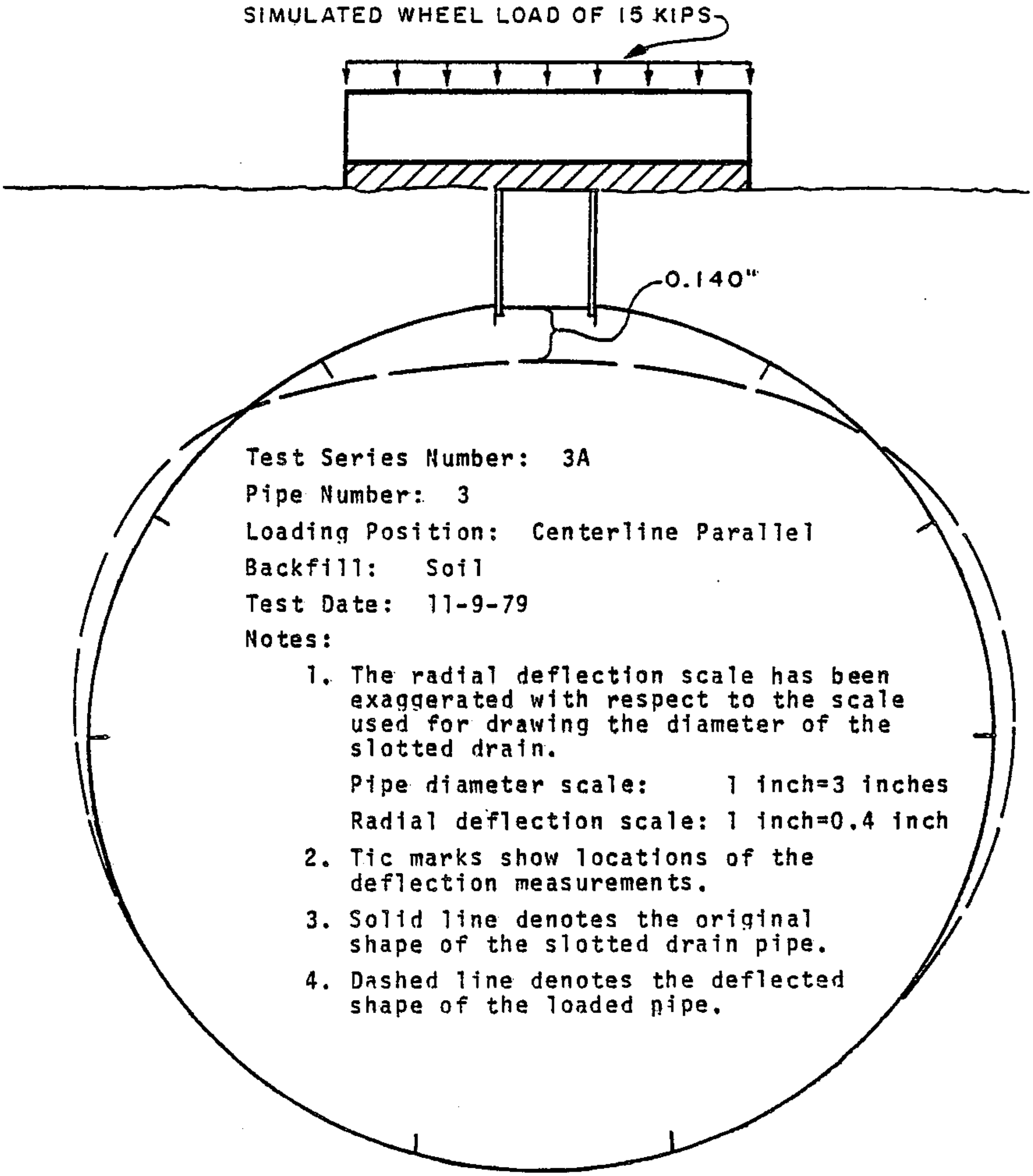


FIGURE 36. DEFLECTED SHAPE OF SLOTTED DRAIN NUMBER 3 BEDDED WITH SOIL BACKFILL AND LOADED IN A CENTERLINE PARALLEL POSITION WITH 15 KIPS.

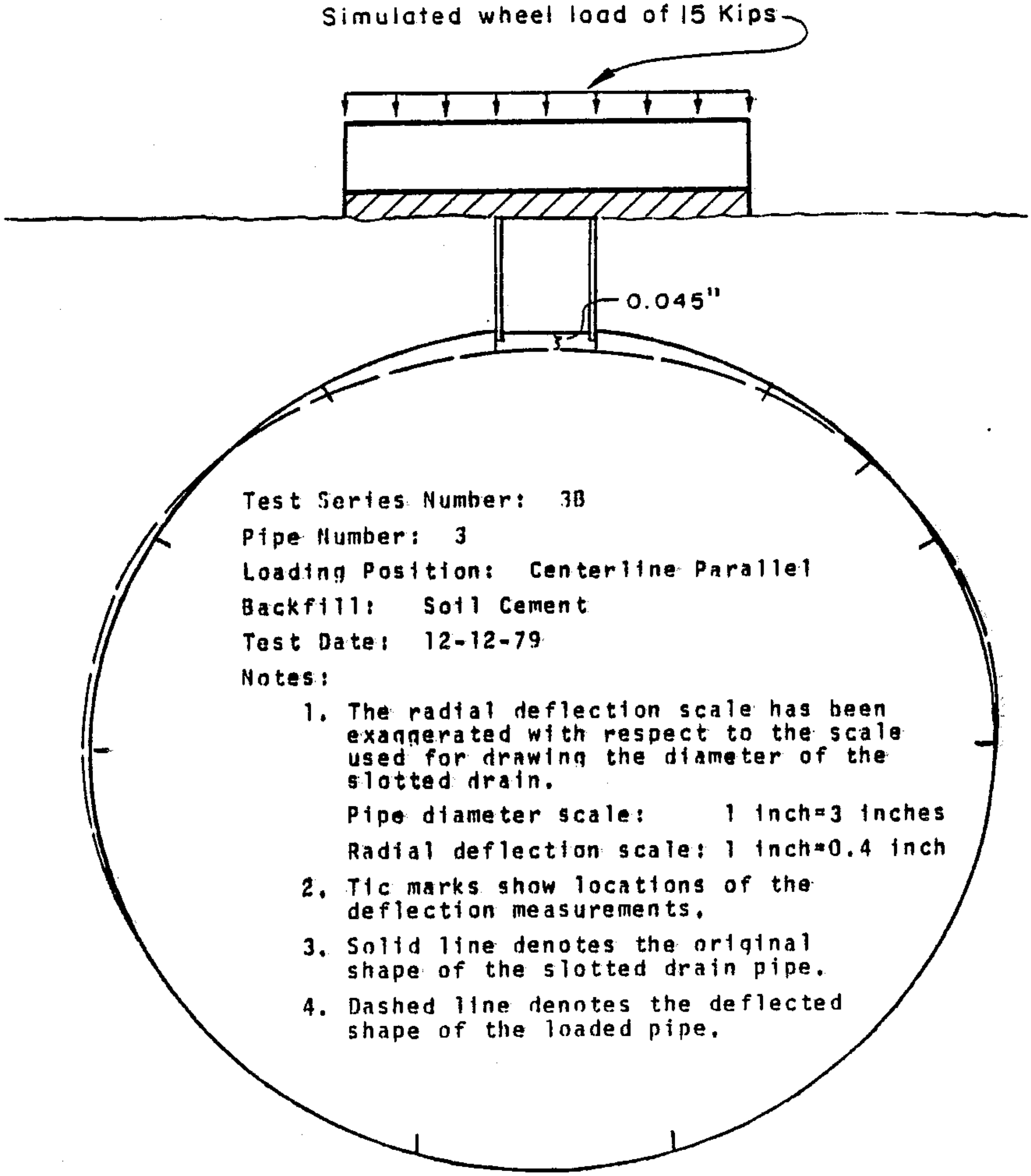


FIGURE 37. DEFLECTED SHAPE OF SLOTTED DRAIN NUMBER 3 BEDDED WITH SOIL CEMENT BACKFILL AND LOADED IN A CENTERLINE PARALLEL POSITION WITH 15 KIPS.

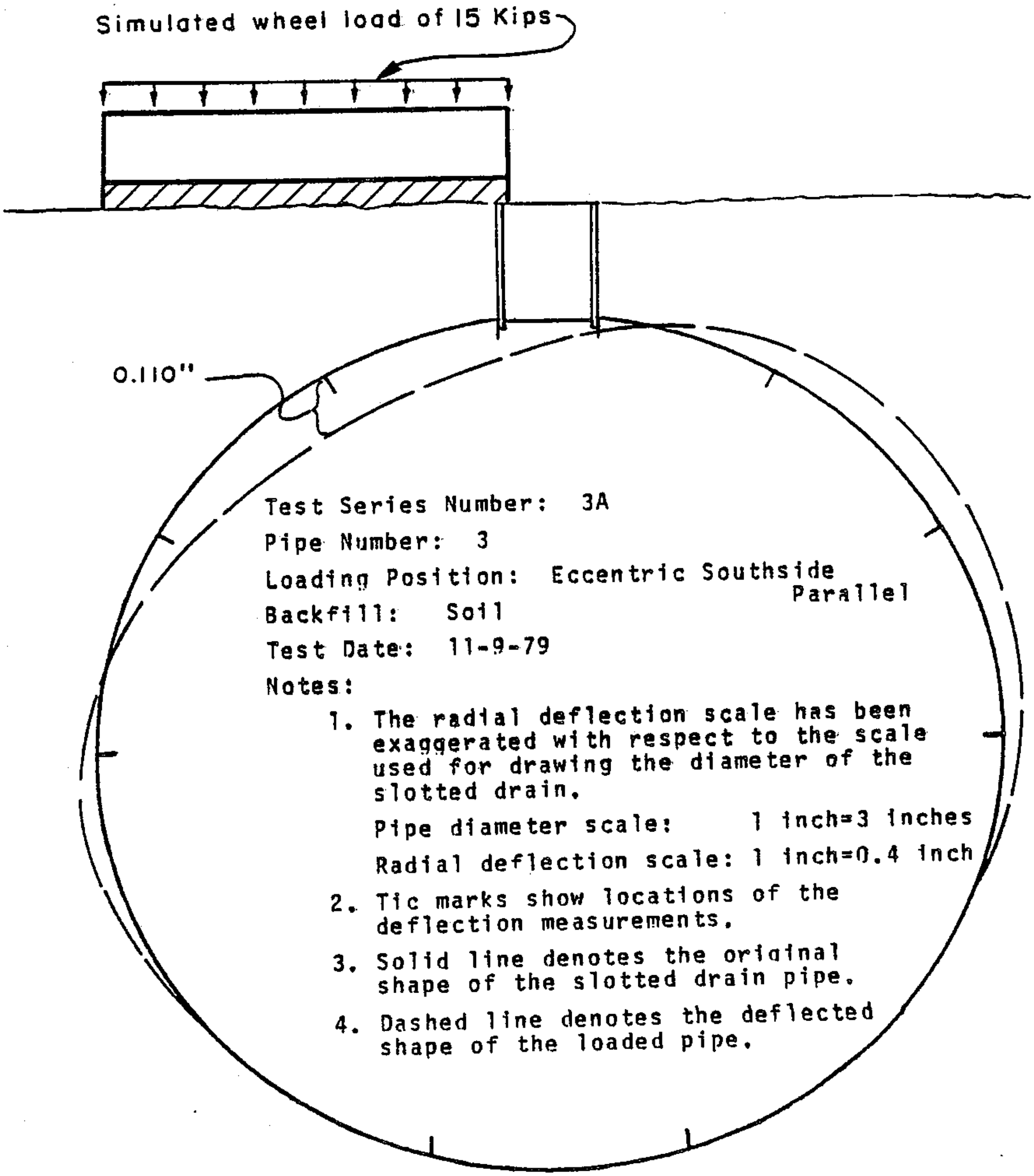


FIGURE 38. DEFLECTED SHAPE OF SLOTTED DRAIN NUMBER 3 BEDDED WITH SOIL BACKFILL AND LOADED IN AN ECCENTRIC SOUTHSIDE PARALLEL POSITION WITH 15 KIPS.

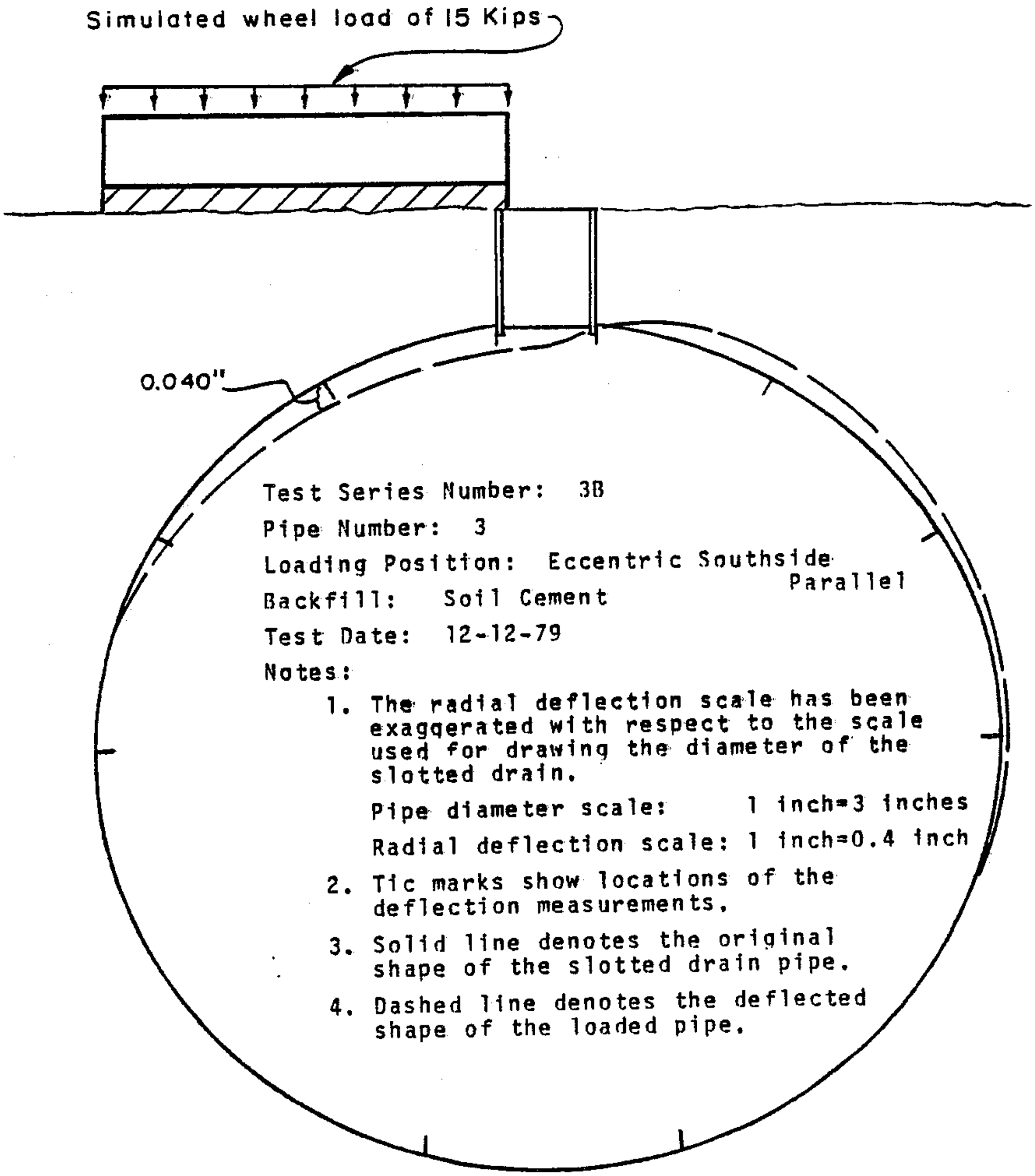


FIGURE 39. DEFLECTED SHAPE OF SLOTTED DRAIN NUMBER 3 BEDDED WITH SOIL CEMENT BACKFILL AND LOADED IN AN ECCENTRIC SOUTHSIDE PARALLEL POSITION WITH 15 KIPS.

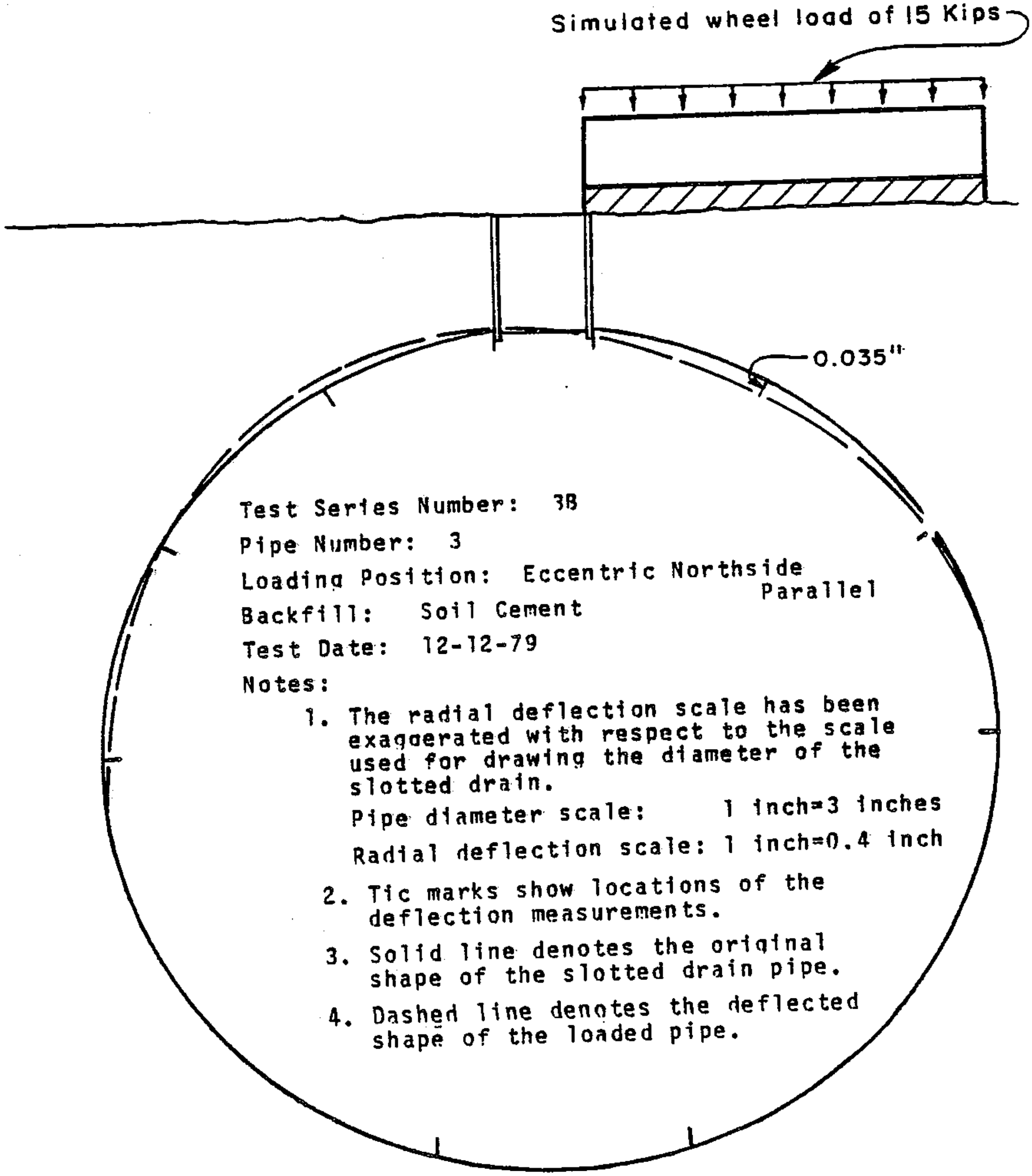


FIGURE 40. DEFLECTED SHAPE OF SLOTTED DRAIN NUMBER 3 BEDDED WITH SOIL CEMENT BACKFILL AND LOADED IN AN ECCENTRIC NORTHSIDE PARALLEL POSITION WITH 15 KIPS.

5.2.3 Effect of Loading Positions on Drain Deflection

The deflection-load charts (Figures 31 through 35, pages 68-73) show that both types of centerline loading, parallel and perpendicular, produce greater vertical downward deflections than the two types of eccentric loading. In Figure 34, a slight upward or + deflection is shown for the grate bar opposite the load application for eccentric parallel loading. This is due to lateral support of the backfill allowing only a slight downward vertical translation of the grate structure. The grate structure is still forced to rotate approximately about its center of mass with the moment producing force applied on the grate bar by the edge of the neoprene loading pad. Thus, with a large rotation and only a small translation downward, the bottom edge of the bearing bar opposite of the load moves slightly upward.

This type of grate rotation was different from that observed in the grate structures of the slotted drain sections which were eccentrically loaded in the laboratory. These were permitted to translate downward a substantial amount because of the lack of any lateral support to the upper half of the pipe structure, as well as rotate. As expected, deflections near all pipe inverts were small.

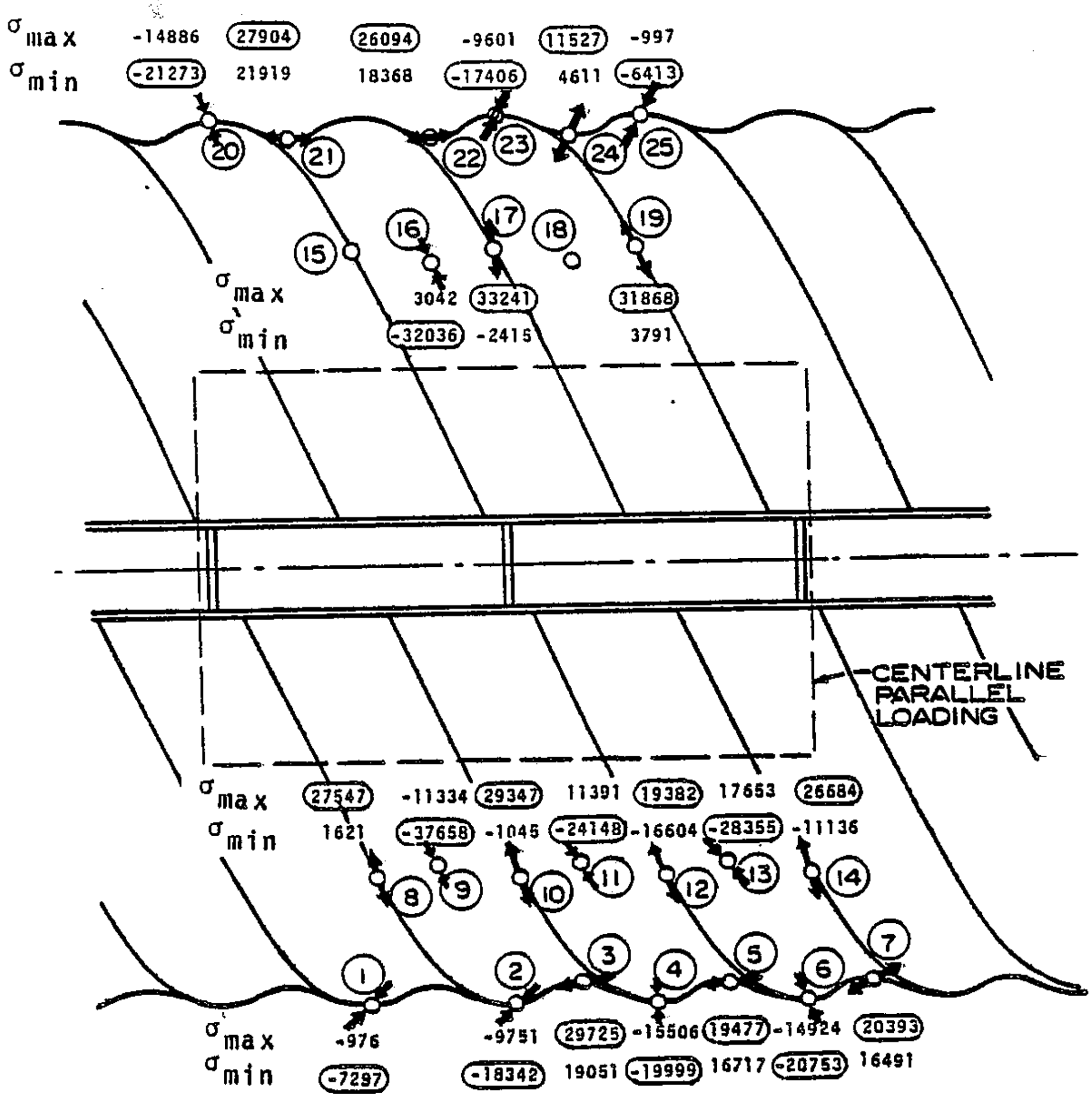
The effect which the orientation of the applied wheel load had on the maximum vertical pipe deflections measured at the 15-kip load level in either Test Series 3A or 3B was slight (see Figures 36 through 40, pages 75-79). In Test Series 3A (strain-gaged drain bedded with soil backfill) the greatest drain deflection for the centerline parallel loading position (0.14 inch) was only 27 percent larger than the one measured in eccentric loading position (0.11 inch). When bedded with a soil cement backfill in Test Series 3B, the same drain yielded a deflection of 0.045 inch when loaded with 15 kips in the centerline parallel position, only 20 percent greater than the average of two largest deflections, 0.038 inch, measured for north and southside eccentric parallel loading positions. As previously mentioned, the backfill type, not the loading orientation, appears to have the greater influence on the magnitude of vertical drain deflections.

5.2.4 Discussion of Test Results Obtained from the Strain Gage-Instrumented Slotted Drain, Test Series 3A and 3B

Because of the complex geometry of the helical corrugated slotted drain, the strains measured and the stresses calculated are highly localized and true only at exact gage locations. In order to determine the magnitude and distribution of stresses in the pipe walls of a slotted drain, twenty-five stacked rectangular rosette strain gages each having a 1/8-inch gage length were attached on the outside of Slotted Drain Number 3 and used to measure strains in Test Series 3A and 3B. The strains measured in the three strain gage elements of each rosette gage were used to calculate a maximum principal stress, σ_{max}, a minimum principal stress, σ_{min}, a maximum shear stress, γ_{max}, and the angle, ϕ_p, between the axis of strain gage element B (see Figure 28, page 56) and the maximum principal stress at each numbered gage site. The equations used for calculating these values from the measured strains are shown in Appendix 7.3.1 (pages 106-109). These transformation equations for strain and stress were derived for an element in the state of plane stress and strain.

According to the sign convention used in this report, the maximum principal stress, σ_{max}, is always algebraically greater than the minimum principal stress, but when comparing the absolute value of both stresses, the maximum principal stress will not always be greater. To use an example, if +1 ksi represents the value of a maximum principal stress, and -10 ksi, the value of a minimum principal stress, +1 is greater than -10, algebraically, but the absolute value of -10 is obviously greater than +1. Also in the sign convention used in this report, a positive signed stress value is a tension stress whereas a negative signed stress value is a compressive stress.

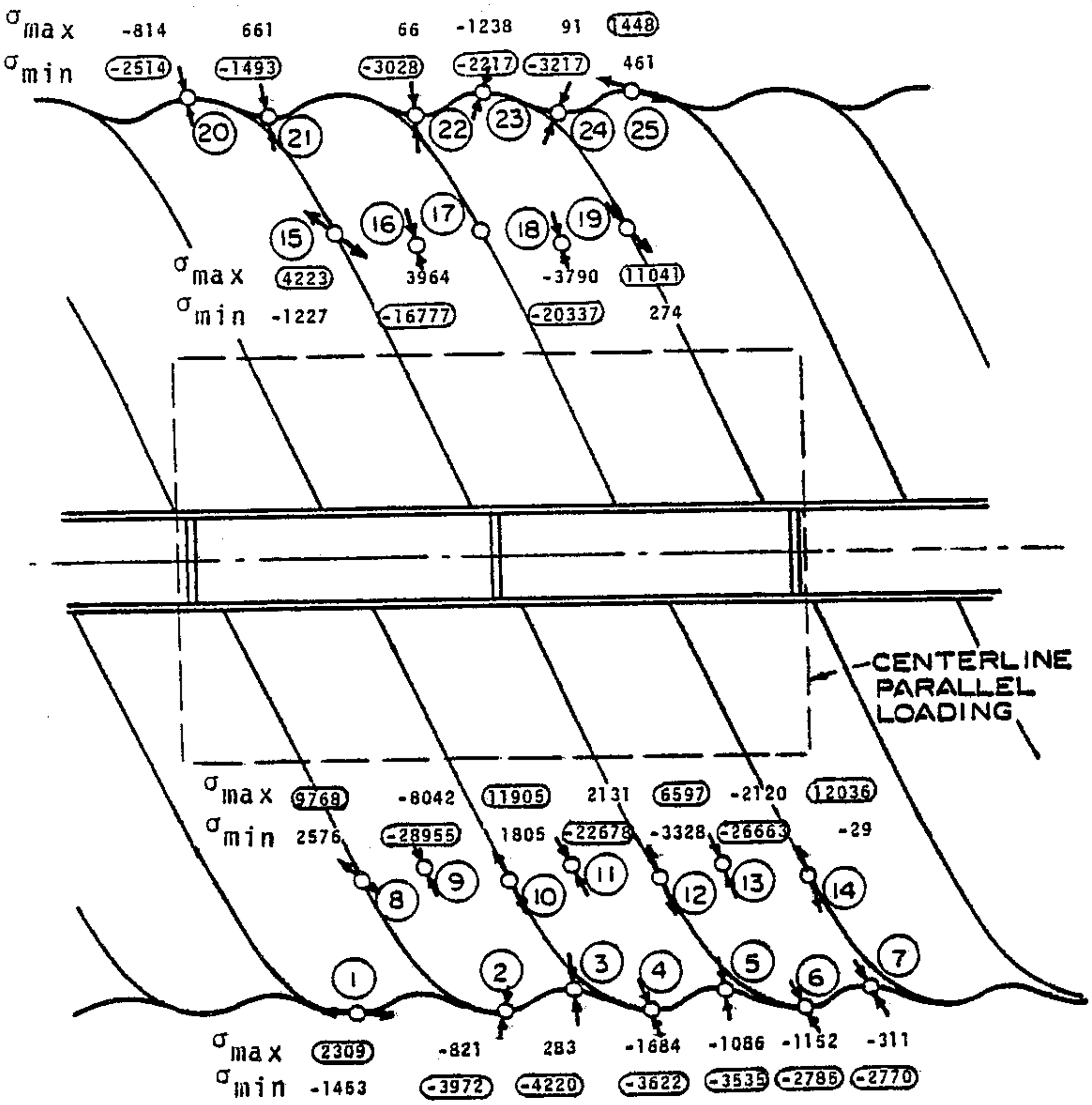
In the following seven figures, which include Figures 41 through 47, maximum and minimum principal stresses are shown for certain loading cases performed in Test Series 3A and 3B on Slotted Drain Number 3. These principal stresses at each gage location are for a 15-kip load and for each type of backfill and each loading position used. The figures are laid out similar to Figure 28, page 56, which shows the assigned code of each rosette strain gage, denoted by a number within a large circle, and its location, denoted by a dot within a small circle. On each figure is a rectangular shape denoted by a dashed line which illustrates the location of the loading pad for that particular test. Values for both the maximum and minimum principal stresses at each gage location are shown with the principal stress having the largest absolute value circled. Arrows at the gage locations show the direction in which the principal stress having the largest absolute value acts, and indicate whether this stress is in tension (← ⊙ →) or compression (→ ⊙ ←).



NOTE: • σ_{max} = MAXIMUM PRINCIPAL STRESS
• σ_{min} = MINIMUM PRINCIPAL STRESS
• ARROWS DENOTE DIRECTION IN WHICH LARGEST ABSOLUTE PRINCIPAL STRESSES (CIRCLED) ACT.

FIGURE 41. STRESS DISTRIBUTION IN SLOTTED DRAIN NUMBER 3 AT A 15-KIP LOAD.

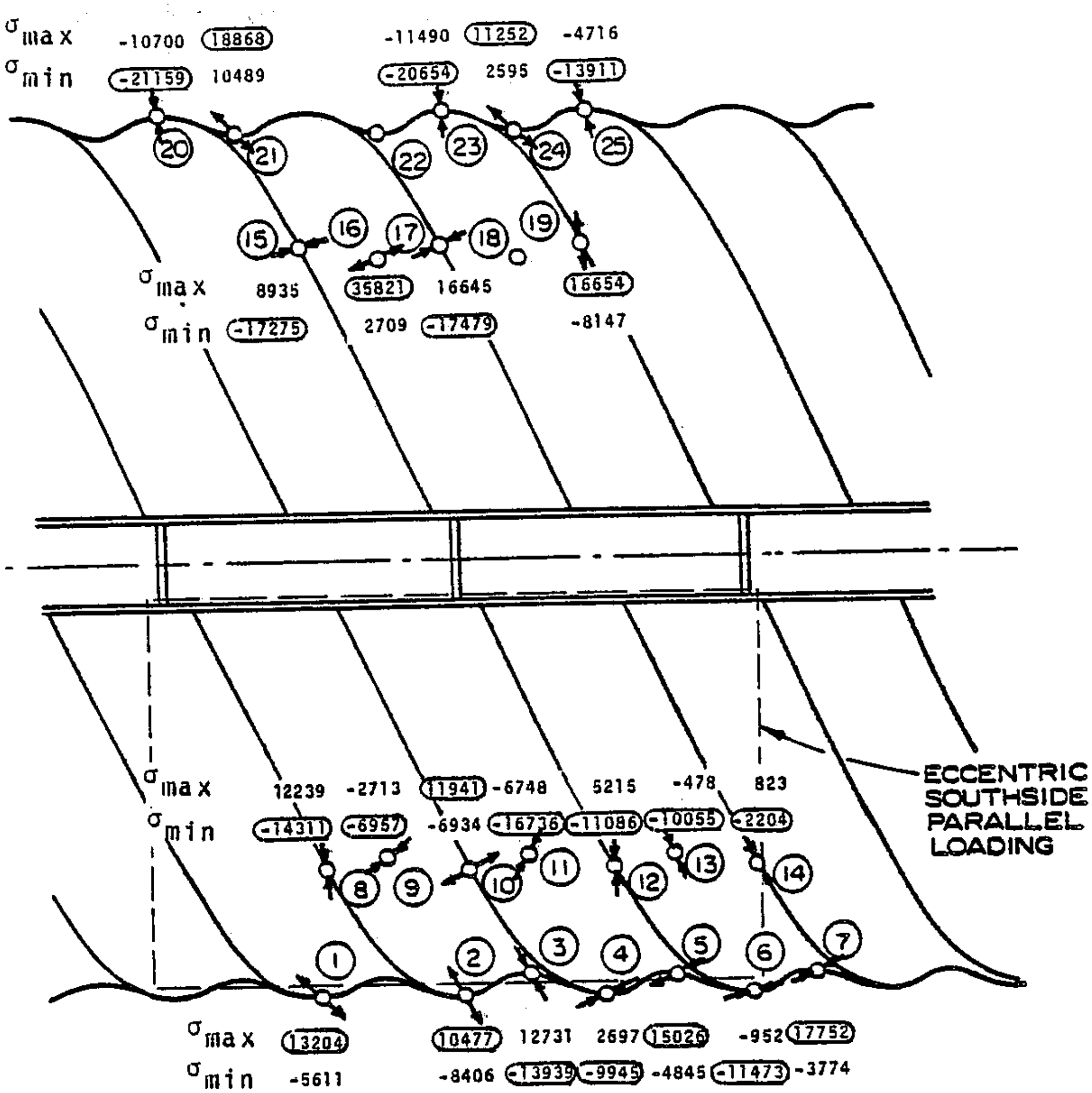
BACKFILL: SOIL
LOADING POSITION: CENTERLINE PARALLEL
TEST DATE: 11-9-79 TEST SERIES: 3A



NOTE: • σ_{max} = MAXIMUM PRINCIPAL STRESS
• σ_{min} = MINIMUM PRINCIPAL STRESS
• ARROWS DENOTE DIRECTION IN WHICH LARGEST ABSOLUTE PRINCIPAL STRESSES (CIRCLED) ACT.

FIGURE 42. STRESS DISTRIBUTION IN SLOTTED DRAIN NUMBER 3 AT A 15-KIP LOAD.

BACKFILL: SITE-MIXED SOIL CEMENT
LOADING POSITION: CENTERLINE PARALLEL
TEST DATE: 12-12-79 TEST SERIES: 3B



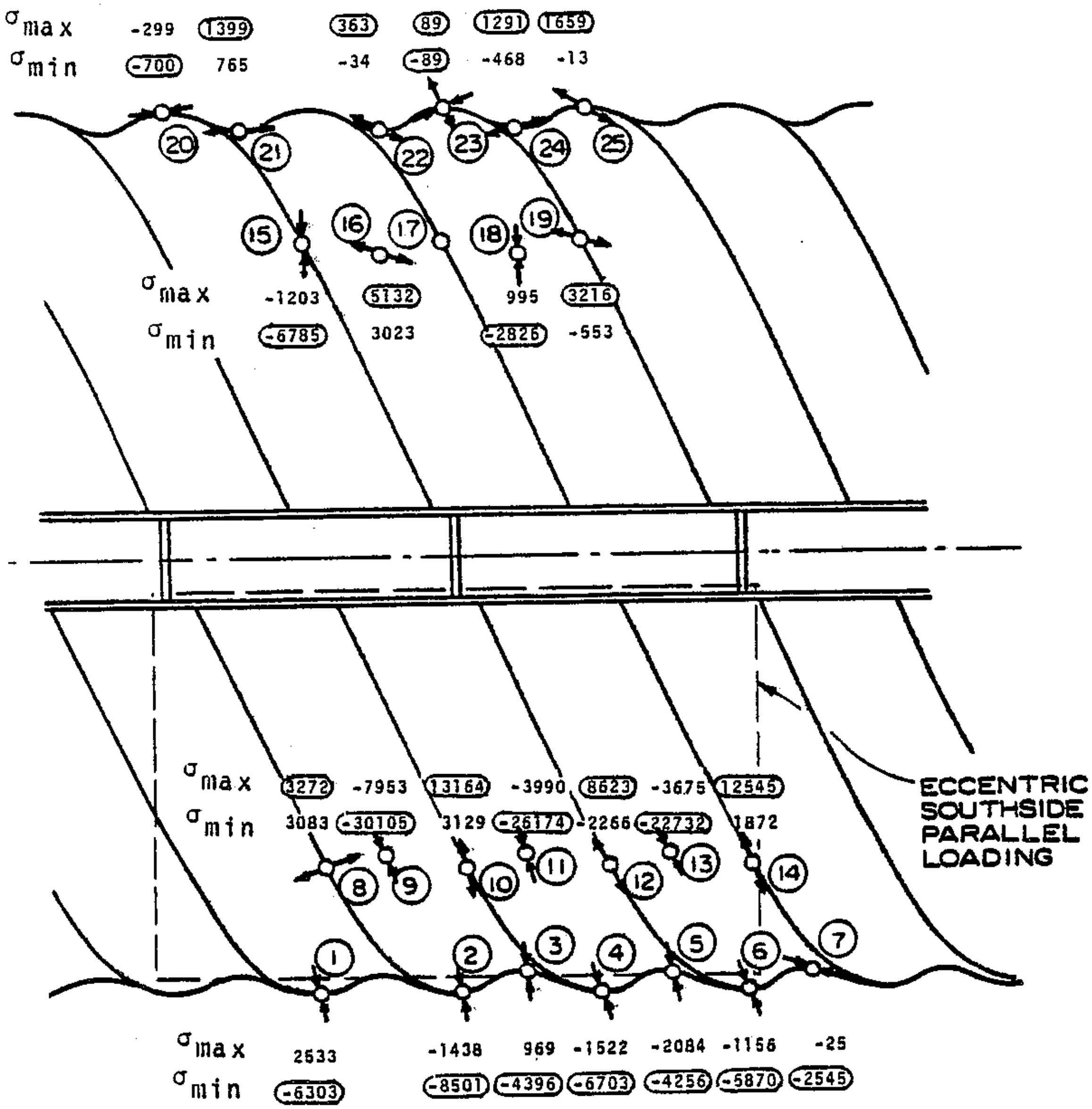
NOTE: • σ_{max} = MAXIMUM PRINCIPAL STRESS

• σ_{min} = MINIMUM PRINCIPAL STRESS

• ARROWS DENOTE DIRECTION IN WHICH LARGEST ABSOLUTE PRINCIPAL STRESSES (CIRCLED) ACT.

FIGURE 43. STRESS DISTRIBUTION IN SLOTTED DRAIN NUMBER 3 AT A 15-KIP LOAD.

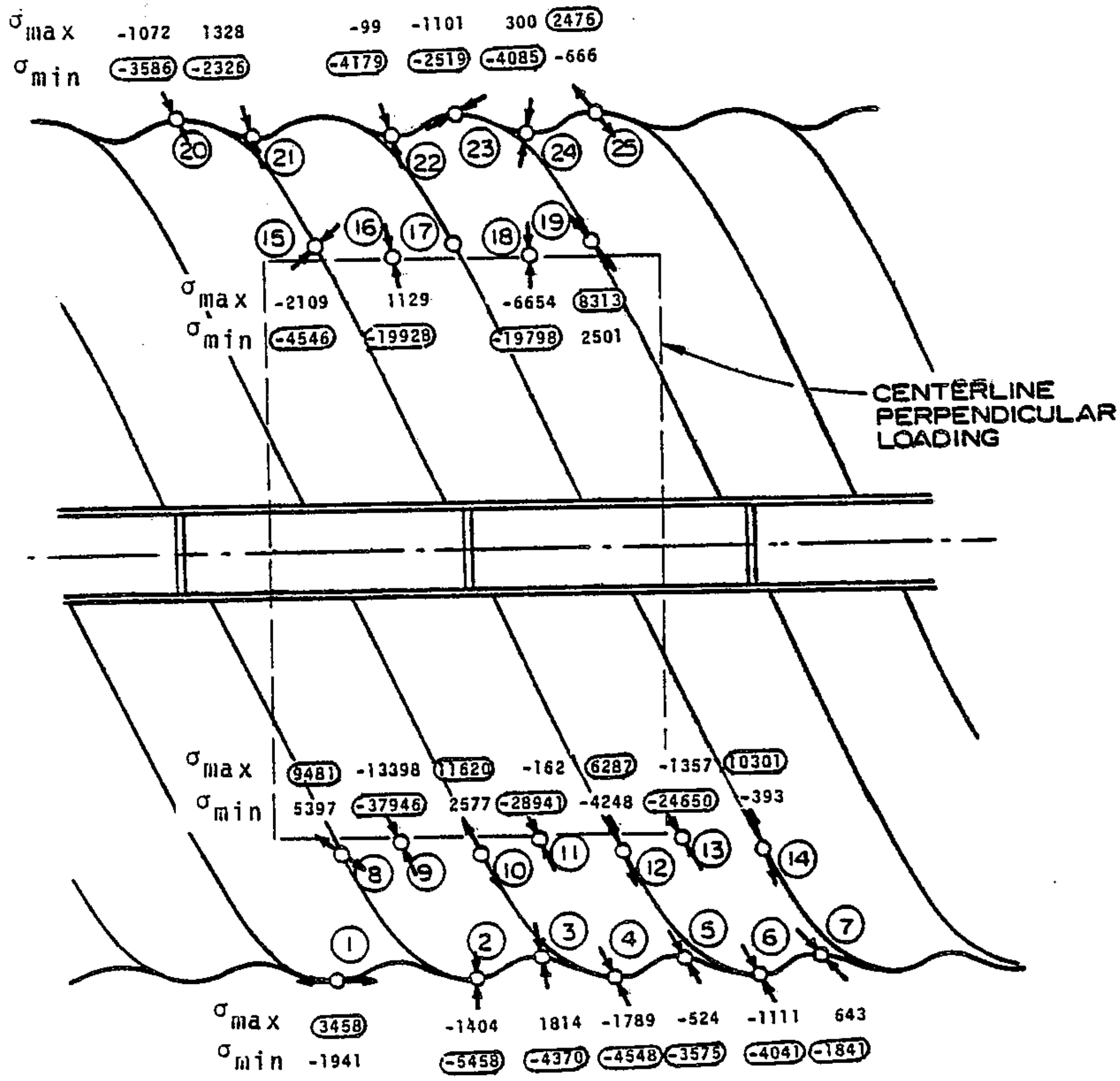
BACKFILL: SOIL
LOADING POSITION: ECCENTRIC SOUTHSIDE PARALLEL
TEST DATE: 11-9-79 TEST SERIES: 3A



NOTE: • σ_{max} = MAXIMUM PRINCIPAL STRESS
• σ_{min} = MINIMUM PRINCIPAL STRESS
• ARROWS DENOTE DIRECTION IN WHICH LARGEST ABSOLUTE PRINCIPAL STRESSES (CIRCLED) ACT.

FIGURE 44. STRESS DISTRIBUTION IN SLOTTED DRAIN NUMBER 3 AT A 15-KIP LOAD.

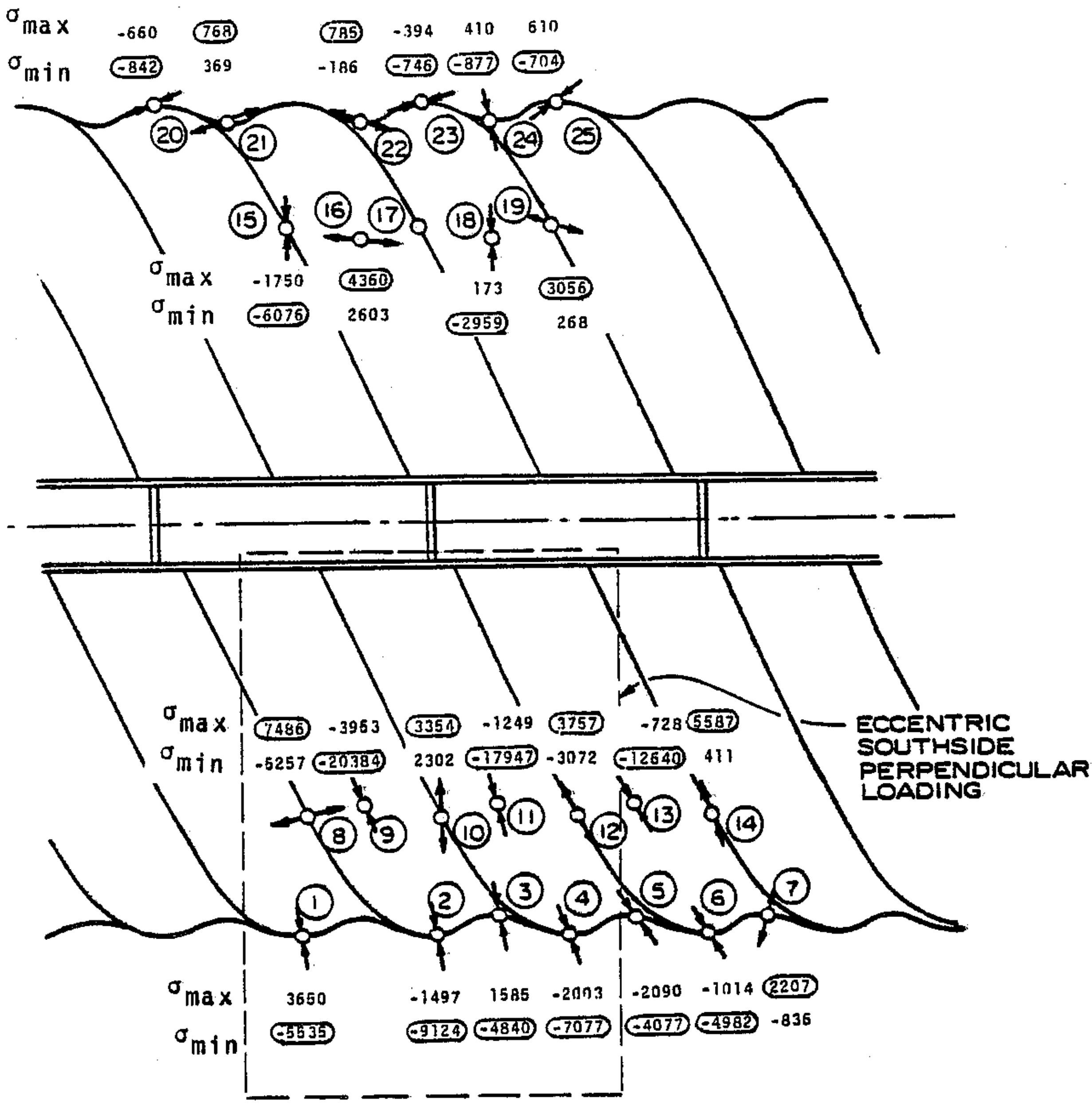
BACKFILL: SITE-MIXED SOIL CEMENT
LOADING POSITION: ECCENTRIC SOUTHSIDE PARALLEL
TEST DATE: 12-12-79 TEST SERIES: 3B



NOTE:
- σ_{max} = MAXIMUM PRINCIPAL STRESS
- σ_{min} = MINIMUM PRINCIPAL STRESS
- ARROWS DENOTE DIRECTION IN WHICH LARGEST ABSOLUTE PRINCIPAL STRESSES (CIRCLED) ACT.

FIGURE 45. STRESS DISTRIBUTION IN SLOTTED DRAIN NUMBER 3 AT A 15-KIP LOAD.

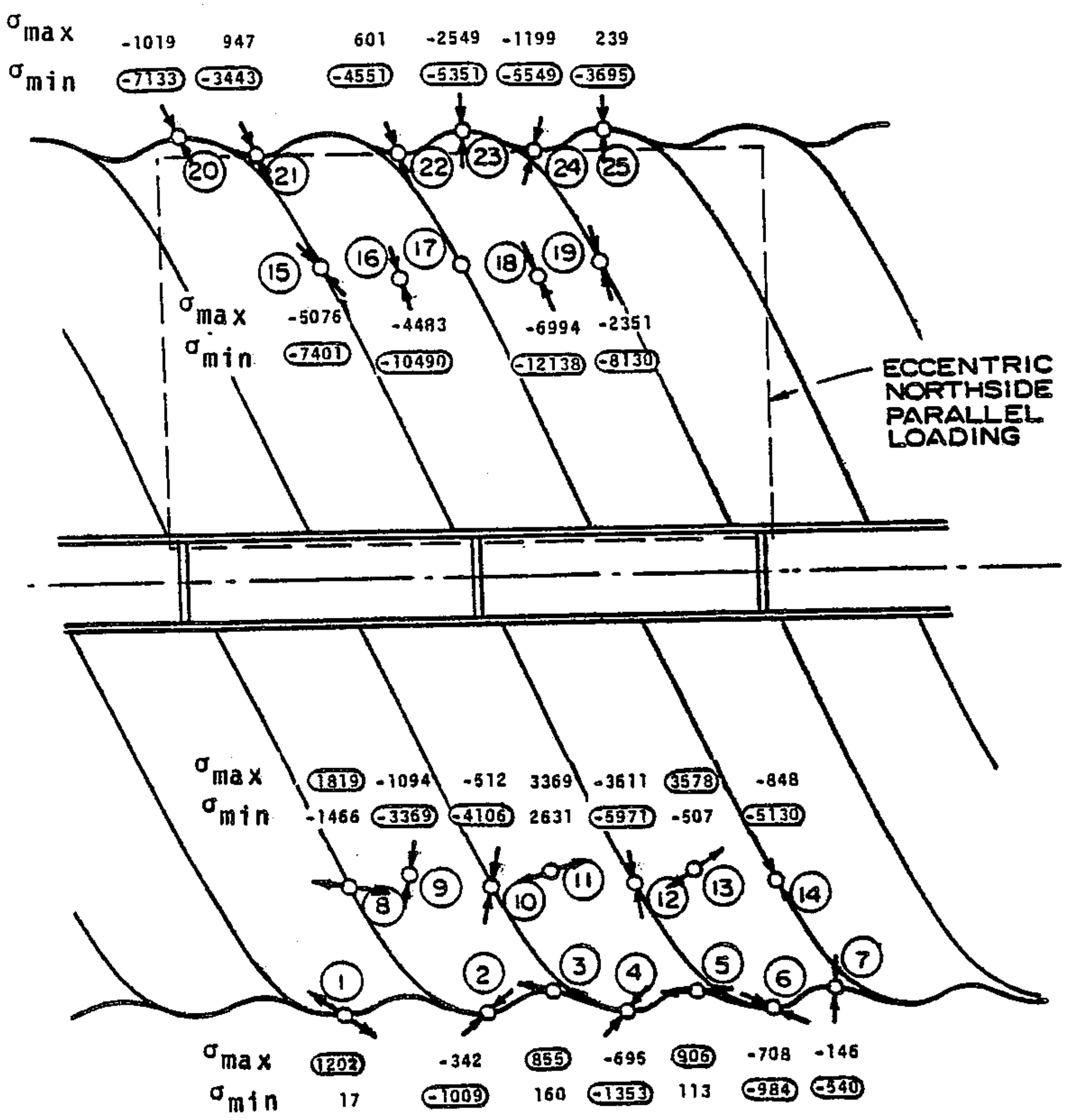
BACKFILL: SITE-MIXED SOIL CEMENT
LOADING POSITION: CENTERLINE PERPENDICULAR
TEST DATE: 12-12-79 TEST SERIES: 38



NOTE: • σ_{max} = MAXIMUM PRINCIPAL STRESS
• σ_{min} = MINIMUM PRINCIPAL STRESS
• ARROWS DENOTE DIRECTION IN WHICH LARGEST ABSOLUTE PRINCIPAL STRESSES (CIRCLED) ACT.

FIGURE 46. STRESS DISTRIBUTION IN SLOTTED DRAIN NUMBER 3 AT A 15-KIP LOAD.

BACKFILL: SITE-MIXED SOIL CEMENT
LOADING POSITION: ECCENTRIC SOUTHSIDE PERPENDICULAR
TEST DATE: 12-12-79 TEST SERIES: 3B



NOTE: • σ_{max} = MAXIMUM PRINCIPAL STRESS
• σ_{min} = MINIMUM PRINCIPAL STRESS
• ARROWS DENOTE DIRECTION IN WHICH LARGEST ABSOLUTE PRINCIPAL STRESSES (CIRCLED) ACT.

FIGURE 47. STRESS DISTRIBUTION IN SLOTTED DRAIN NUMBER 3 AT A 15-KIP LOAD.

BACKFILL: SITE-MIXED SOIL CEMENT
LOADING POSITION: ECCENTRIC NORTHSIDE PARALLEL
TEST DATE: 12-12-79 TEST SERIES: 3B

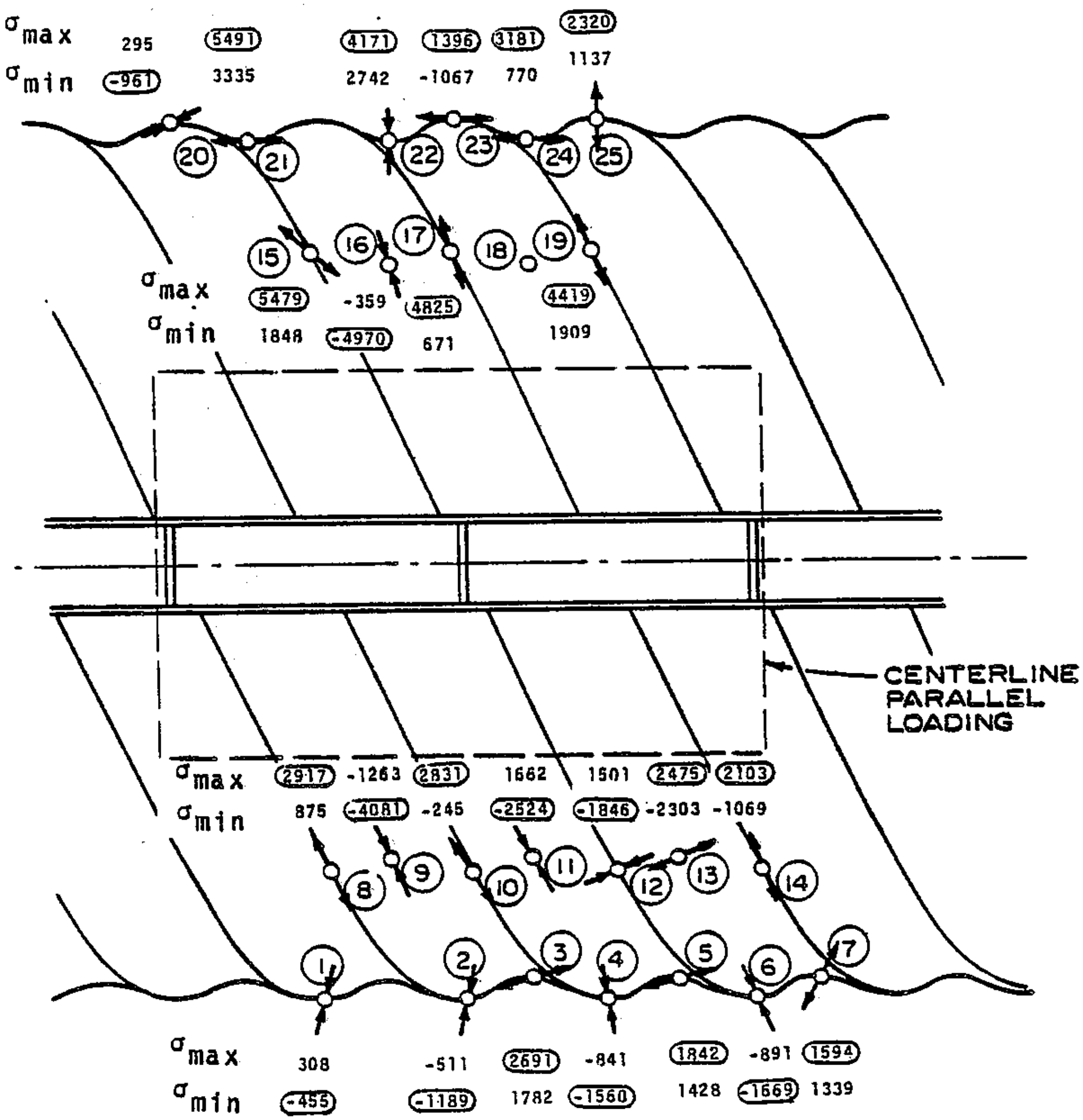
At some gage locations denoted on the figures, no stress values are given. This was due to either a malfunction of the strain gages or an electrical problem in the data acquisition equipment.

Figures 48 and 49 which follow are of the same layout as the previously mentioned seven figures; however, they show stress distribution at a 2-kip load using a centerline parallel loading position. These two figures were used to compare differences in pipe stresses at a low load level due to the two different backfills. This comparison would be representative of normal automobile and small truck traffic. A further discussion of the comparison of these stresses is presented in Section 5.3.1 of this report.

Additional tabulations of the maximum principal stress and minimum principal stress for both backfill types and all five load positions are given in Appendices 7.4, pages 116-122, and 7.5, pages 123-129, for the 2, 6, 10, 13, and 15-kip load level. Higher loads of up to 32 kips were applied but because stress levels in pipe walls at many of the gage locations were above the yield point of steel at this high load level, these stress values are invalid and are not shown.

5.2.4.1 The Effect of Different Backfills on Stresses in the Strain Gage-Instrumented Slotted Drain

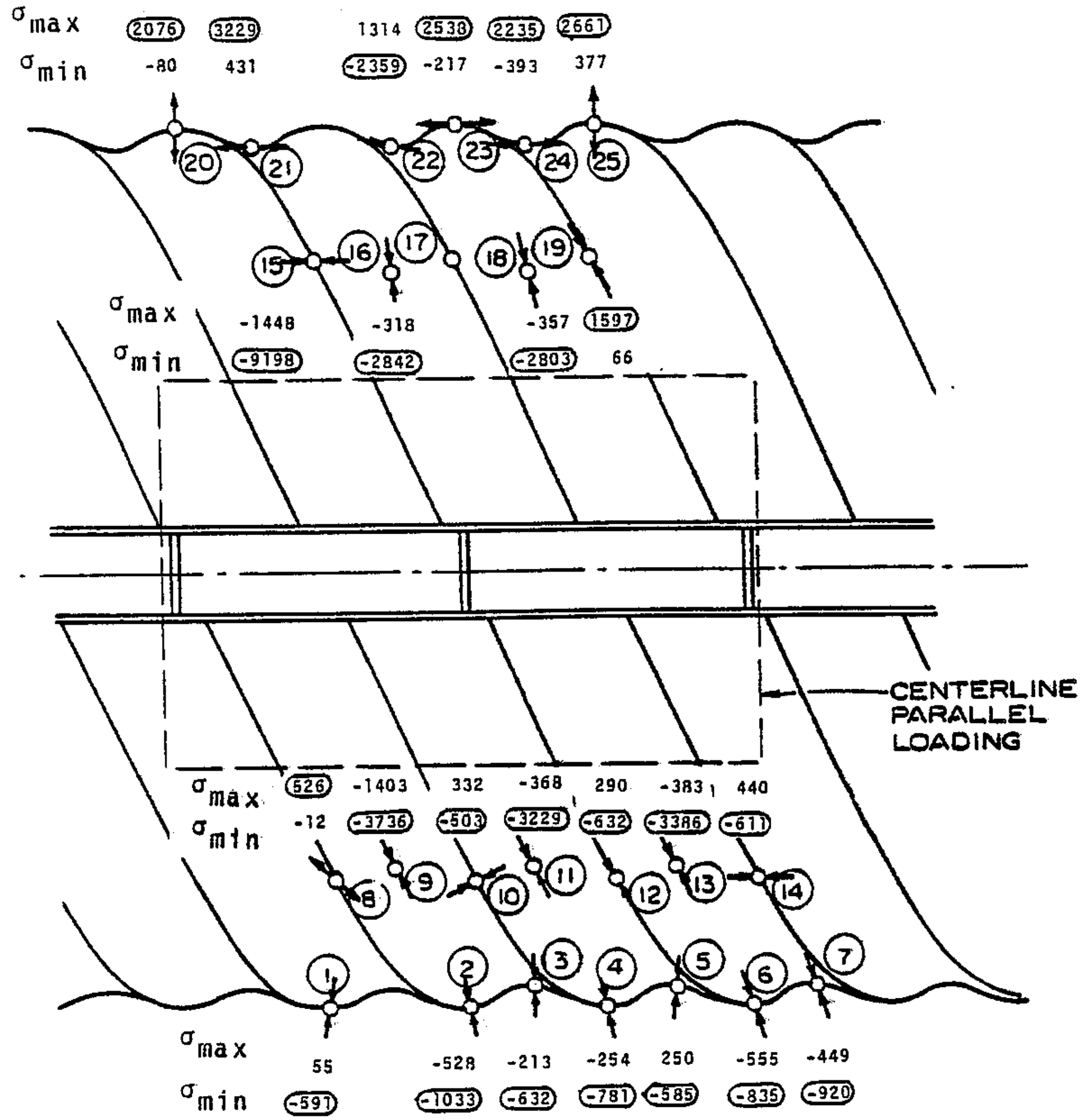
After making a comparison between results shown in Figures 41 and 42, it is noted that the magnitude of the stresses are greater for the soil-backfilled slotted drain than for the soil cement-backfilled slotted drain. This difference



NOTE: • σ_{max} = MAXIMUM PRINCIPAL STRESS
• σ_{min} = MINIMUM PRINCIPAL STRESS
• ARROWS DENOTE DIRECTION IN WHICH LARGEST ABSOLUTE PRINCIPAL STRESSES (CIRCLED) ACT.

FIGURE 48. STRESS DISTRIBUTION IN SLOTTED DRAIN NUMBER 3 AT A 2-KIP LOAD.

BACKFILL: SOIL
LOADING POSITION: CENTERLINE PARALLEL
TEST DATE: 11-9-79 TEST SERIES: 3A



NOTE: • σ_{max} = MAXIMUM PRINCIPAL STRESS
• σ_{min} = MINIMUM PRINCIPAL STRESS
• ARROWS DENOTE DIRECTION IN WHICH LARGEST ABSOLUTE PRINCIPAL STRESSES (CIRCLED) ACT.

FIGURE 49. STRESS DISTRIBUTION IN SLOTTED DRAIN NUMBER 3 AT A 2-KIP LOAD.

BACKFILL: SITE-MIXED SOIL-CEMENT
LOADING POSITION: CENTERLINE PARALLEL
TEST DATE: 12-12-79 TEST SERIES: 3B

is especially noticeable at the 45-degree line of gages on both sides of the centerline parallel-loaded slotted drain. The soil-backfilled slotted drain exhibited greater stress levels along all four rows of gages than did the soil cement-backfilled slotted drains. Stresses at the springline were markedly greater for the soil-backfilled slotted drain. This is due to the soil-backfilled slotted drain flexing horizontally outward. This action is confirmed after noting the horizontal deflections in the slotted drain wall shown in the corrugation valleys at the pipe springline.

The above described differences between pipe stresses for soil and soil cement-backfilled slotted drain for the eccentric southside loading are generally the same with one exception. The stresses exhibited by strain gages at the 45-degree line beneath the loading plate are higher for the soil cement-backfilled slotted drain than for the comparable soil-backfilled slotted drain (see Figures 43 and 44, pages 85 and 86). It is speculated that this apparent inconsistency was caused by either (1) natural differences in density of the asphalt concrete paving and backfill material surrounding the pipe because of the inherent heterogeneity of these materials, or by (2) the backfill material above the strain gages at the 45-degree line being previously compacted in an earlier load test of the drain in an overlapping centerline position and hence offered less support when subsequently loaded. Either of these reasons may have caused the loading plate in contact with the near grate bearing bar to transfer more load to the slotted drain wall in the case of the soil cement-backfilled drain than occurred for the soil-backfilled drain.

It is interesting to note that the stresses obtained from gages at the 45-degree line along the southside of the pipe are very similar for the soil cement-backfilled drain for either centerline parallel loading or eccentric southside loading.

The ability of the soil cement backfill to carry some of the external load and reduce the magnitude of stresses in the pipe wall is more dramatically shown at the 2-kip load level as seen in Figures 48 and 49 (pages 91 and 92). The flexural stresses in the wall of the soil cement-backfilled pipe are significantly less than for the soil-backfilled pipe and generally are of a magnitude that they are exceeded by ring compression stresses. Thus the wall of this pipe is subjected to compressive stresses only.

5.2.4.2 The Effect of Different Loading Positions on the Strain Gage-Instrumented Slotted Drain

After an inspection of results shown in Figures 41 through 47 (pages 83-89), it is apparent that loading at the centerline parallel position generally caused the highest stresses at all gage locations in the slotted drain for both the soil and soil cement backfill (see Figures 41 and 42 on pages 83 and 84). The slotted drain was stressed more with the soil backfill than with the soil cement backfill as discussed in the previous section.

Comparing results shown in Figure 42 (page 84), the stresses in the pipe walls of the soil cement-backfilled slotted drain loaded in the centerline parallel position, with results in Figure 45 (page 87), the stresses in the pipe walls of the soil cement-backfilled slotted drain loaded in the centerline perpendicular position, it is found that all corresponding stress values are practically the same. The stresses at the 45-degree lines for both parallel and perpendicular loading positions alternated from tension at the corrugation crests to compression in the corrugation valleys. This indicates that there was significant bending at the 45-degree lines. At the 90-degree lines, also called the springlines, the high number of negative stresses indicates that there was mostly ring compression in this region.

The next highest stress level observed in the slotted drain loadings resulted from the eccentric southside parallel loading. This is true for both soil and soil cement backfills. Since the loading plate bore down on the near longitudinal bearing bar of the grate, this would account for the high stresses which resulted from this loading position.

In contrast to the stresses shown in the aforegoing figures, the soil cement-backfilled slotted drain loaded in the eccentric southside perpendicular position (see Figure 46, page 88) had the next-to-lowest pipe stresses and the soil cement-backfilled slotted drain loaded in the eccentric northside parallel position (see Figure 47, page 89) showed the lowest of all stress levels.

6. REFERENCES

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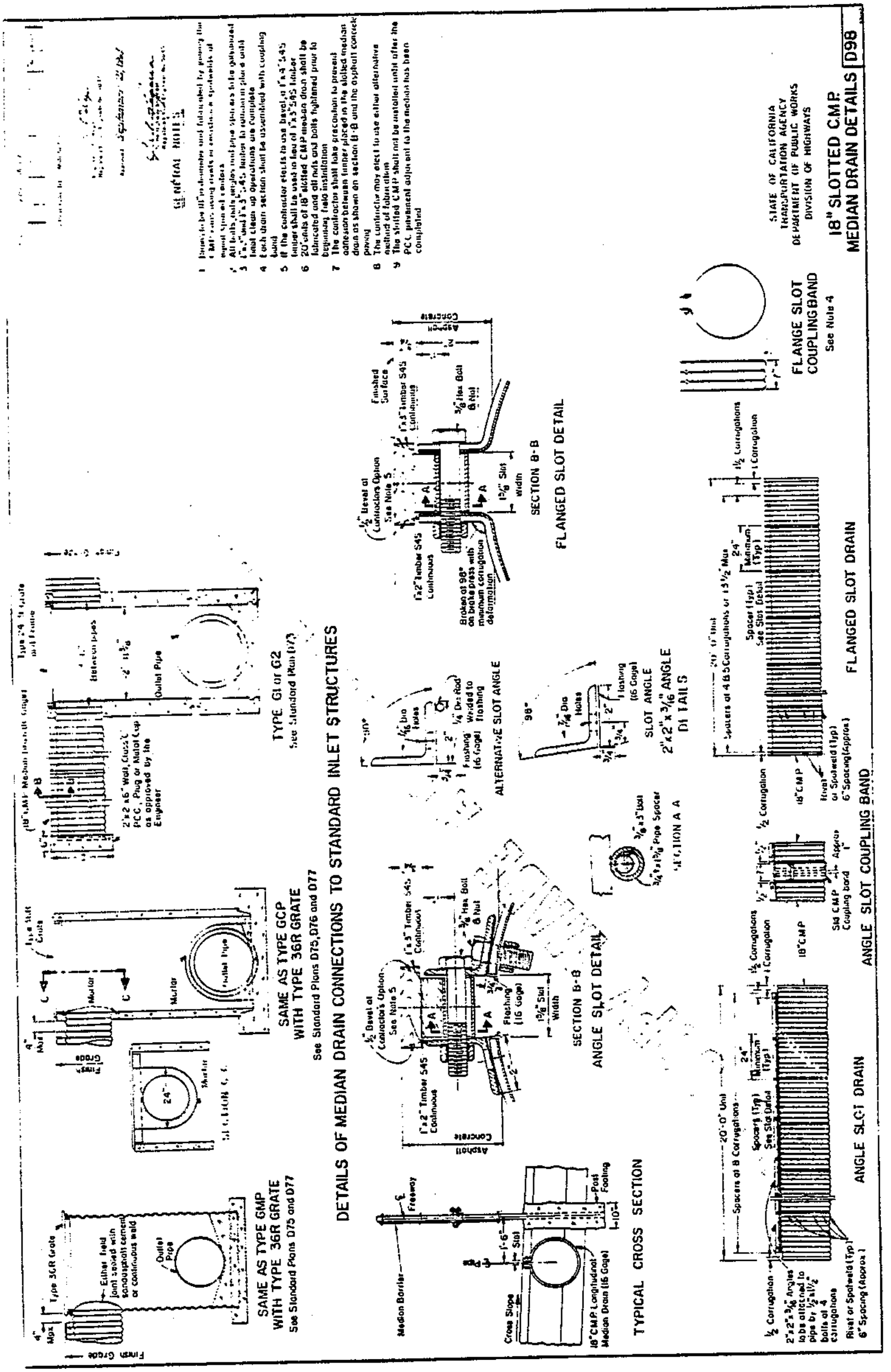
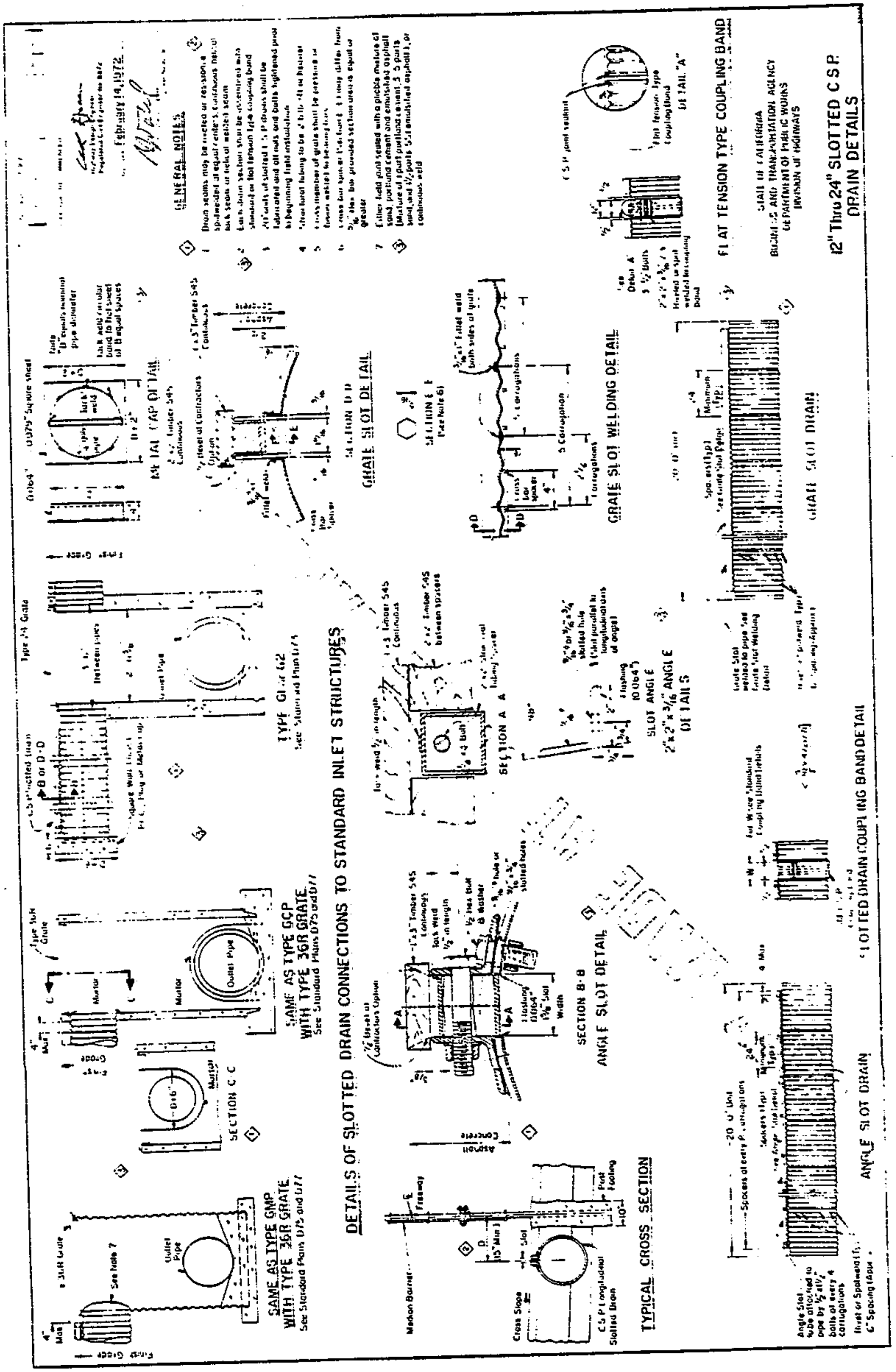
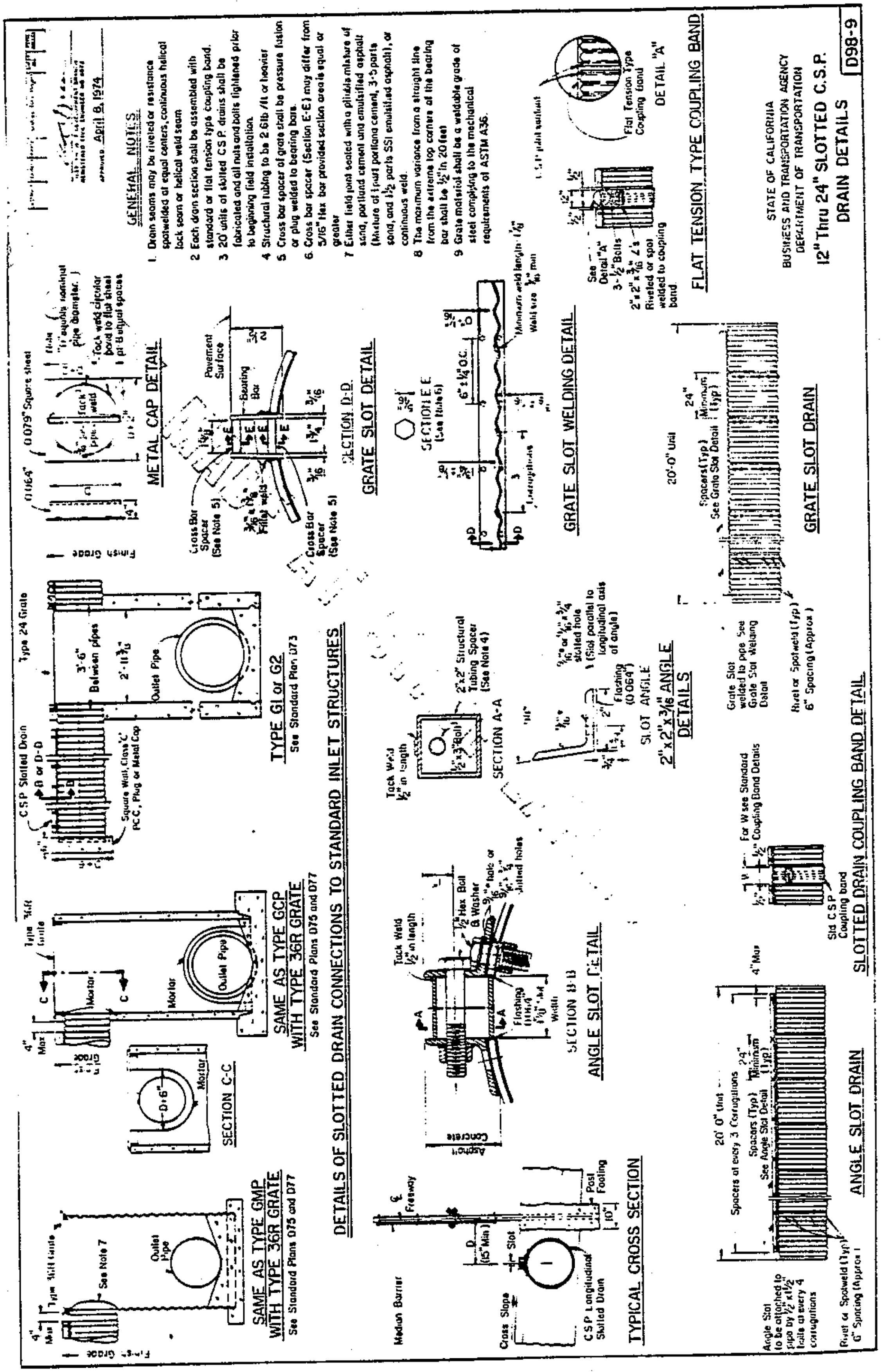


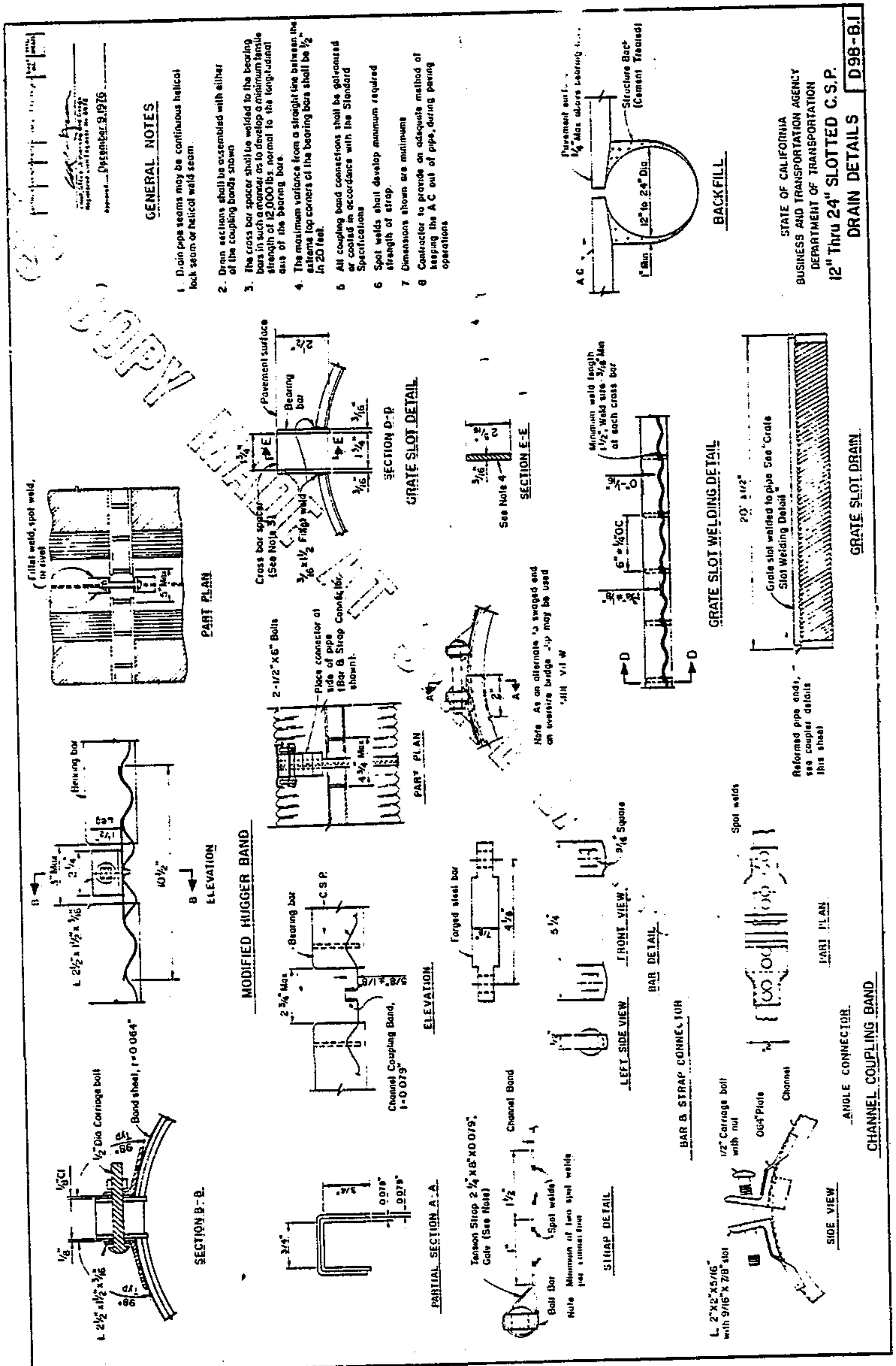
APPENDIX 7.1.1 STANDARD PLAN D98.



APPENDIX 7.1.2   STANDARD PLAN D98-6.



APPENDIX 7.1.3 STANDARD PLAN D98-9.



APPENDIX 7.1.4 STANDARD PLAN D98-B.1.

APPENDIX 7.2.1

PROCEDURE FOR INSTALLING AND PLACING SOIL CEMENT BACKFILL AROUND SLOTTED PIPE DRAINS

The installation of the 18-inch-diameter slotted drain for this research project was performed according to the requirements and specifications listed in the current Standard Plans (March 1977) and the Standard Specifications (January 1978) of the California Department of Transportation (Caltrans).

The slotted drain trench was excavated in the center of a simulated roadbed section, built as shown in Figure A below. The excavation conformed to Section 19-3 of the Caltrans Standard Specifications and Plan D98-B.1 of the Caltrans Standard Plans.

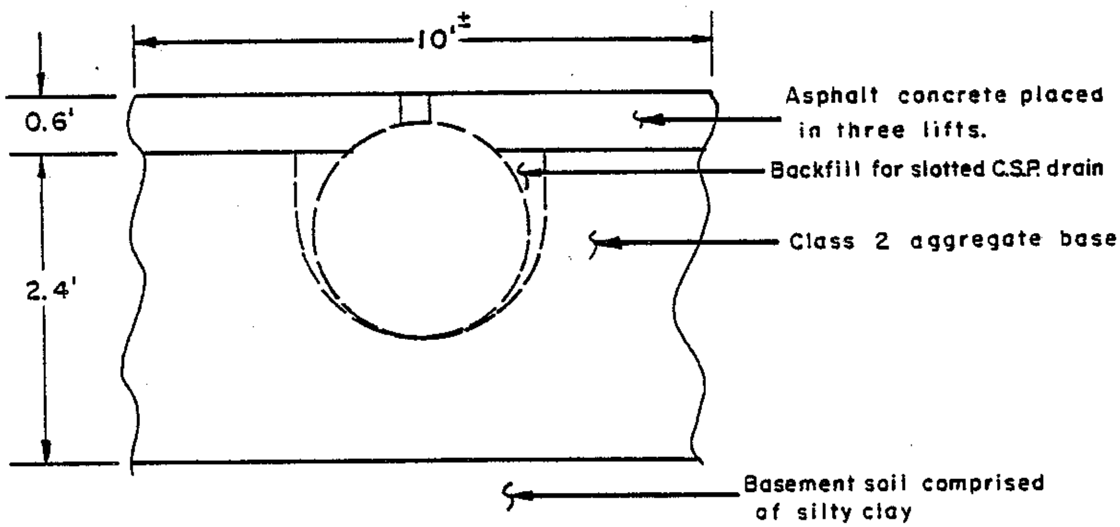


FIGURE A. CROSS SECTION OF THE SIMULATED ROADBED USED FOR THE PLACEMENT OF THE SLOTTED DRAINS.

Before installation, the slotted drain was inspected for conformance to the specifications with regard to materials and construction. The pipe bedding, installation method, and soil cement backfill material all conformed to Sections 19-3.025C, 66-3.09 and 75 of the Caltrans Standard Specifications.

After the backfill was in place, a liquid asphalt curing seal (MC-250) conforming to the provisions of Section 93 of the Caltrans Standard Specifications was applied. Asphalt concrete meeting the requirements in Section 39 of the Standard Specifications was placed and compacted around and up to the top of the slotted drain grate, completing the installation procedure.

APPENDIX 7.2.2

PROCEDURE FOR INSTALLING AND PLACING
SOIL BACKFILL AROUND SLOTTED PIPE DRAINS

All procedures, requirements and specifications followed for installing slotted drain with a soil backfill were the same as were used in backfilling the drain with a soil cement bedding except for the trench width, and type and method of placement of the backfill material.

The trench width was increased from 21 to 44 inches in order to make room to operate compaction equipment on both sides of the slotted drain.

The backfill material, placement and compaction conformed to Section 19-3.06 of the Standard Specifications.

APPENDIX 7.3

DESCRIPTION OF COMPUTER PROGRAMS USED FOR PROCESSING STRAIN GAGE DATA

7.3.1 Brief Summary of Computer Programs and Data Output Used in this Research Study

A program titled "Strain Analysis - Slotted CSP Drains" was written in the TENET BASIC computer language to compute and tabulate the stresses in the slotted drain from strain values measured under load. The coded program for processing the strain data is given in Appendix 7.3.2. A sample of the data printout from this strain analysis program is shown in Appendix 7.3.3. Another program in BASIC language called "MERGE DATA" was written to combine all data and punch it onto one tape before using it in the strain analysis program previously shown. This "MERGE DATA" program is listed in Appendix 7.3.4.

The following is an explanation of symbols and a listing of equations used in the "strain analysis" program, and also a list of equipment and references used in the course of performing the computer work:

<u>INPUT</u>:

E = Modulus of Elasticity for Steel 30×10^6 psi

μ = Poisson's Ratio   0.3

ε_1 = Strain Measured in Gage Element B $(\frac{in.}{in.})$

ε_2 = Strain Measured in Gage Element C $(\frac{in.}{in.})$

ε_3 = Strain Measured in Gage Element A $(\frac{in.}{in.})$

ε_n = Strain Measured in Gage Element n

G.F. = Gage Factor = 2.07 at 75°F

E_x = Excitation Voltage of Sockets (10^{-5} volts) when load is applied

E_o = Recorded Potential of each Gage Element when load is applied (10^{-3} volts)

E_{xo} = Excitation Voltage at zero load prior to each loading (10^{-5} volts)

E_{oo} = Recorded Potential of each Gage Element at zero load prior to each loading (10^{-3} volts)

<u>OUTPUT</u>:

σ_{max} = Maximum Principal Stress

σ_{min} = Minimum Principal Stress

τ_{max} = Maximum Shear Stress

ϕ_p = Angle Between Axis of Gage B and Maximum Principal Stress

EQUATIONS:

$$\varepsilon_n = \frac{4 \times 10^4}{G.F.} \left[\frac{E_o}{E_x} - \frac{E_{oo}}{E_{xo}}\right] \quad \text{(microinches/inch)} \qquad (1)$$

$$\sigma_{max} = \frac{E}{2}\left[\frac{\varepsilon_1+\varepsilon_3}{1-\mu} + \frac{[(\varepsilon_1-\varepsilon_3)^2 + (2\varepsilon_2-\varepsilon_1-\varepsilon_3)^2]^{\frac{1}{2}}}{1+\mu}\right] \quad \text{(psi)} \qquad (2)$$

$$\sigma_{min} = \frac{E}{2}\left[\frac{\varepsilon_1+\varepsilon_3}{1-\mu} - \frac{[(\varepsilon_1-\varepsilon_3)^2 + (2\varepsilon_2-\varepsilon_1-\varepsilon_3)^2]^{\frac{1}{2}}}{1+\mu}\right] \quad \text{(psi)} \qquad (3)$$

$$\tau_{max} = \frac{E}{2(1+\mu)} \; [(\varepsilon_1-\varepsilon_3)^2 + (2\varepsilon_2-\varepsilon_1-\varepsilon_3)^2]^{\frac{1}{2}} \quad \text{(psi)} \qquad (4)$$

$$\phi_p = \frac{1}{2}\tan^{-1}\left[\frac{2\varepsilon_2-(\varepsilon_1+\varepsilon_3)}{\varepsilon_1-\varepsilon_3}\right] \quad \text{(degrees)} \qquad (5)$$

EQUIPMENT:

Tenet, Inc., 210 Time Sharing System
TrendWriter Terminal
DSI Tape Reader

REFERENCES

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5. TENET USER'S MANUAL - EXECUTIVE

```
LIST
100 REM     AUTHOR : LAI A.H.     WRITTEN : 11-20-79
110 REM -----------------------------------------------------
120 REM           STRAIN ANALYSIS - SLOTTED CSP DRAINS
130 REM -----------------------------------------------------
140 REM DETERMINATION OF LOAD CARRYING CAPABILITY OF 18 IN. OR 24 IN.
150 REM DIAMETER SLOTTED DRAIN PIPES CONFORM TO STD. PLAN 098-9
160 REM WITH DOUBLE BAR GRATE AND IMPROVED SECTION WITH GRATE PLATE
170 REM SPACERS (SD 98-8 11-18-75),USING VARIOUS TYPES OF BACKFILL.
180 REM RECTANGULAR ROSETTE STRAIN GAGES ARE USED TO DETERMINE MAX
190 REM AND MIN VALUES OF STRESSES,MAX SHEARING STRESS AND THE ANGLE
200 REM OF THE DIRECTION OF THE MAX PRINCIPAL STRAIN WITH THE AXIS
210 REM OF GAGE 1.
220 REM  VARIABLES :
230 REM         A$ = HEADING STRING FROM DATAFILE
240 REM         C$ = CHANNEL NO.,ALSO TRAILER STRING IF 'T' IS FIRST
250 REM              LETTER (EOF)
260 REM         F$ = FLAG
270 REM         R$ = READINGS
280 REM  NOTE : 3 SETS OF C$,F$,R$ ARE READ IN AT THE BEGINNING OF EACH
290 REM          GROUP OF 25 CHANNELS.SUBSTRINGS OF THE FIRST 2 R$'S
300 REM          COMPOSE THE SOCKET NUMBER.THE 3RD R$ IS VOLTAGE READING
.
310 INTEGER SOCO(4),SOCX(4),CHOO(4,25),CHOX(4,25),FX(4,25)
320 DOUBLE EXO(25),EX(25),STO(4,25),STX(4,25),EXI(25),STI(4,25),ES1(4,2
5),ES2(4,25),
ES3(4,25),ES1I(4,7),ES2I(4,7),ES3I(4,7),SMAX(4,25),SMIN(4,25),TMAX(4,25
),PHIP(4,25),
A(4,25),B(4,25),C(4,25)
322 REAL VARO(4,5),VARX(4,5),NG,SG,NI,SI,LOD
330 REM            *** GAGE FACTOR ***
331 D$='%50(C127)'
340 PRINT 'SET TOP OF FORM & AUTO SKIP'
350 PAUSE
360 FACT=4E+4/2.07
370 EL=30E+6
380 MU=0.3
390 PRINT 'ENTER RECORDFILE NAME':
400 INPUT F1$
410 OPEN F1$,1,INPUT,OLD
420 PRINT 'ENTER END TIME OF TEST:HOUR,MIN':
430 INPUT TIM3,TIM4
440 REM       *** READ IN HEADER STRING ***
450 INPUT FROM 1:A$
460 CK$=SUBSTR(A$,1,1)
470 IF CK$ #'H' THEN GOTO 2210
480 TEST=VAL(SUBSTR(A$,2,3)),TEMP=VAL(SUBSTR(A$,7,2)),MON=VAL(SUBSTR(A$
,9,2))
490 DAY=VAL(SUBSTR(A$,11,2)),YEAR=VAL(SUBSTR(A$,13,2))
500 TIM1=VAL(SUBSTR(A$,15,2)),TIM2=VAL(SUBSTR(A$,17,2))
510 PAGE=1
520 SW=1
620 REM     *** READ IN VALUES FROM DATAFILE ***
630 HO=1
640 FOR I1=1 TO 3
650 INPUT FROM 1:C$,F$,R$
660 IF SUBSTR(C$,1,1)='T' THEN GOTO 2210
670 IF I1=1 THEN S1$=SUBSTR(R$,2,2)
680 IF I1=2 THEN S2$=SUBSTR(R$,3,1),SOCO(HO)=VAL(S1$+S2$)
690 IF I1=3 THEN EXO(HO)=VAL(SUBSTR(R$,1,6))
700 NEXT I1
710 J=1
720 INPUT FROM 1:C$,F$,R$
730 CHOO(HO,J)=VAL(SUBSTR(C$,1,2)),STO(HO,J)=VAL(SUBSTR(R$,1,6))
740 J=J+1
750 INPUT FROM 1:C$,F$,R$
760 CHOO(HO,J)=VAL(SUBSTR(C$,1,2)),STO(HO,J)=VAL(SUBSTR(R$,1,6))
770 J=J+1
780 INPUT FROM 1:C$,F$,R$
790 CHOO(HO,J)=VAL(SUBSTR(C$,1,2)),STO(HO,J)=VAL(SUBSTR(R$,1,6))
800 J=J+1
810 IF J<22 THEN GOTO 720
820 IF J=22 THEN INPUT FROM 1:C$,F$,R$
```

APPENDIX 7.3.2 PROGRAM FOR PROCESSING STRAIN DATA FOR THE SLOTTED DRAIN PROJECT.

```
830 HO=HO+1
840 IF HO=4 THEN GOTO 860
850 IF HO<4 THEN GOTO 640
851 IF HO>4 THEN GOTO 1055
860 FOR I2=1 TO 3
870 INPUT FROM 1:C$,F$,R$
880 IF I2=1 THEN S1$=SUBSTR(R$,2,2)
890 IF I2=2 THEN S2$=SUBSTR(R$,3,1),SOCO(HO)=VAL(S1$+S2$)
900 IF I2=3 THEN EXO(HO)=VAL(SUBSTR(R$,1,6))
910 NEXT I2
920 J=1
930 INPUT FROM 1:C$,F$,R$
940 CHOO(HO,J)=VAL(SUBSTR(C$,1,2)),STO(HO,J)=VAL(SUBSTR(R$,1,6))
950 J=J+1
960 INPUT FROM 1:C$,F$,R$
970 CHOO(HO,J)=VAL(SUBSTR(C$,1,2)),STO(HO,J)=VAL(SUBSTR(R$,1,6))
980 J=J+1
990 INPUT FROM 1:C$,F$,R$
1000 CHOO(HO,J)=VAL(SUBSTR(C$,1,2)),STO(HO,J)=VAL(SUBSTR(R$,1,6))
1010 J=J+1
1020 IF J<13 THEN GOTO 930
1030 FOR J=1 TO 5
1040 INPUT FROM 1:C$,F$,R$
1041 IF J=1 THEN VARO(HO,1)=VAL(SUBSTR(R$,1,6))
1042 IF J=2 THEN VARO(HO,2)=VAL(SUBSTR(R$,1,6))
1043 IF J=3 THEN VARO(HO,3)=VAL(SUBSTR(R$,1,6))
1044 IF J=4 THEN VARO(HO,4)=VAL(SUBSTR(R$,1,6))
1045 IF J=5 THEN VARO(HO,5)=VAL(SUBSTR(R$,1,6))
1050 NEXT J
1051 FOR J=1 TO 5
1052 INPUT FROM 1:C$,F$,R$
1053 NEXT J
1054 GOTO 830
1055 IF SW=1 THEN GOTO 1056 ELSE GOTO 1067
1056 IF HO#4 THEN GOTO 1057 ELSE GOTO 1062
1057 FOR HO=1 TO 3
1058 EXI(HO)=EXO(HO)
1059 FOR J=1 TO 21
1060 STI(HO,J)=STO(HO,J)
1061 NEXT J,HO
1062 HO=4
1063 EXI(HO)=EXO(HO)
1064 FOR J=1 TO 12
1065 STI(HO,J)=STO(HO,J)
1066 NEXT J
1067 HX=1!
1070 FOR I3=1 TO 3
1080 INPUT FROM 1:C$,F$,R$
1100 IF I3=1 THEN S1$=SUBSTR(R$,2,2)
1110 IF I3=2 THEN S2$=SUBSTR(R$,3,1),SOCX(HX)=VAL(S1$+S2$)
1120 IF I3=3 THEN EX(HX)=VAL(SUBSTR(R$,1,6))
1130 NEXT I3
1140 J=1
1150 INPUT FROM 1:C$,F$,R$
1160 CHOX(HX,J)=VAL(SUBSTR(C$,1,2)),FX(HX,J)=VAL(SUBSTR(F$,1,1)),STX(HX
,J)=VAL
(SUBSTR(R$,1,6))
1170 J=J+1
1180 INPUT FROM 1:C$,F$,R$
1190 CHOX(HX,J)=VAL(SUBSTR(C$,1,2)),FX(HX,J)=VAL(SUBSTR(F$,1,1)),STX(HX
,J)=VAL
(SUBSTR(R$,1,6))
1200 J=J+1
1210 INPUT FROM 1:C$,F$,R$
1220 CHOX(HX,J)=VAL(SUBSTR(C$,1,2)),FX(HX,J)=VAL(SUBSTR(F$,1,1)),STX(HX
,J)=VAL
(SUBSTR(R$,1,6))
1240 J=J+1
1250 IF J<22 THEN GOTO 1150
1260 IF J=22 THEN INPUT FROM 1:C$,F$,R$
1270 GOTO 1530
1280 HX=HX+1
1290 IF HX=4 THEN GOTO 1310
1300 IF HX<4 THEN GOTO 1070
1310 FOR I4=1 TO 3
1320 INPUT FROM 1:C$,F$,R$
```

APPENDIX 7.3.2 CONTINUED

```
1330 IF I4=1 THEN S1$=SUBSTR(R$,2,2)
1340 IF I4=2 THEN S2$=SUBSTR(R$,3,1),SOCX(4)=VAL(S1$+S2$)
1350 IF I4=3 THEN EX(4)=VAL(SUBSTR(R$,1,6))
1360 NEXT I4
1370 J=1
1380 INPUT FROM 1:C$,F$,R$
1390 CHOX(4,J)=VAL(SUBSTR(C$,1,2)),FX(4,J)=VAL(SUBSTR(F$,1,1)),STX(4,J)
=VAL
(SUBSTR(R$,1,6))
1400 J=J+1
1410 INPUT FROM 1:C$,F$,R$
1420 CHOX(4,J)=VAL(SUBSTR(C$,1,2)),FX(4,J)=VAL(SUBSTR(F$,1,1)),STX(4,J)
=VAL
(SUBSTR(R$,1,6))
1430 J=J+1
1440 INPUT FROM 1:C$,F$,R$
1450 CHOX(4,J)=VAL(SUBSTR(C$,1,2)),FX(4,J)=VAL(SUBSTR(F$,1,1)),STX(4,J)
=VAL
(SUBSTR(R$,1,6))  -
1460 J=J+1
1470 IF J<13 THEN GOTO 1380
1480 FOR J=1 TO 5
1490 INPUT FROM 1:C$,F$,R$
1491 IF J=1 THEN VARX(HX,1)=VAL(SUBSTR(R$,1,6))
1492 IF J=2 THEN VARX(HX,2)=VAL(SUBSTR(R$,1,6))
1493 IF J=3 THEN VARX(HX,3)=VAL(SUBSTR(R$,1,6))
1494 IF J=4 THEN VARX(HX,4)=VAL(SUBSTR(R$,1,6))
1495 IF J=5 THEN VARX(HX,5)=VAL(SUBSTR(R$,1,6))
1500 NEXT J
1501 FOR J=1 TO 5
1502 INPUT FROM 1:C$,F$,R$
1510 NEXT J
1520 REM   *** CALCULATE STRAINS,STRESSES AND ASSIGN CIRCUIT NOS.
TO SOCKET NOS. ***
1530 FOR HO=1 TO 4
1540 IF SOCO(HO)=SOCX(HX) THEN GOTO 1560
1550 NEXT HO
1560 N=HO
1570 J=1
1580 K=1
1590 ES3(HX,K)=FACT*((STX(HX,J)/EX(HX)) - (STO(N,J)/EXO(N)))
1600 ES3I(HX,K)=FACT*((STI(N,J)/EXI(N)) - (STO(N,J)/EXO(N)))
1610 J=J+1
1620 ES1(HX,K)=FACT*((STX(HX,J)/EX(HX)) - (STO(N,J)/EXO(N)))
1630 ES1I(HX,K)=FACT*((STI(N,J)/EXI(N)) - (STO(N,J)/EXO(N)))
1640 J=J+1
1650 ES2(HX,K)=FACT*((STX(HX,J)/EX(HX)) - (STO(N,J)/EXO(N)))
1660 ES2I(HX,K)=FACT*((STI(N,J)/EXI(N)) - (STO(N,J)/EXO(N)))
1690 A(HX,K)=((ES1(HX,K)+ES3(HX,K))/(1-MU))
1700 B(HX,K)=(SQRT((ES1(HX,K)-ES3(HX,K))^2+(2*ES2(HX,K)-ES1(HX,K)-ES3(H
X,K))^2))
1710 SMAX(HX,K)=((A(HX,K)+B(HX,K)/(1+MU))*0.5*EL*1E-6)
1720 SMIN(HX,K)=((A(HX,K)-B(HX,K)/(1+MU))*0.5*EL*1E-6)
1730 TMAX(HX,K)=((B(HX,K)*0.5*EL/(1+MU))*1E-6)
1731 DENO = ES1(HX,K) - ES3(HX,K)
1732 NUM=2*ES2(HX,K)-(ES1(HX,K)+ES3(HX,K))
1733 IF DENO = 0 THEN GOTO 1740
1734 IF NUM=0 THEN GOTO 1742
1735 PHIP(HX,K) = (DEG(ATAN(NUM/DENO)))/2
1736 IF PHIP(HX,K)>0 AND DENO>0 THEN GOTO 1770
1737 IF PHIP(HX,K)>0 AND DENO<0 THEN GOTO 1744
1738 IF PHIP(HX,K)<0 AND DENO>0 THEN GOTO 1770
1739 IF PHIP(HX,K)<0 AND DENO<0 THEN GOTO 1746
1740 PHIP(HX,K)=90.0000
1741 GOTO 1770
1742 PHIP(HX,K)=0.0000
1743 GOTO 1770
1744 PHIP(HX,K)=PHIP(HX,K)+90.0000
1745 GOTO 1770
1746 PHIP(HX,K)=PHIP(HX,K)-90.0000
1770 J=J+1
1780 K=K+1
1782 IF SOCO(N)=4 THEN GOTO 1783 ELSE GOTO 1790
1783 IF K<=4 THEN GOTO 1590 ELSE GOTO 1810
1790 IF SOCO(N)#4 AND K<=7 THEN GOTO 1590
1800 GOTO 1280
1810 REM      *** PRINT ROUTINE ***
1812 SG=(VARX(4,1)-VARO(4,1))*1E-4
1814 NG=(VARX(4,2)-VARO(4,2))*1E-4
```

APPENDIX 7.3.2 CONTINUED

```
1816 SI=-((VARX(4,3)-VARO(4,3))*1E-4)
1818 NI=-((VARX(4,4)-VARO(4,4))*1E-4)
1820 LOD=(VARX(4,5)-VARO(4,5))*1E-3
1821 PRINT IN FORM D$:CHAR(12)
1822 PRINT IN FORM '//12B"CALIFORNIA DEPARTMENT OF TRANSPORTATION"
5B"PAGE"
2B2%':PAGE
1823 PRINT IN FORM '/19B"TRANSPORTATION LABORATORY"//':
1824 PRINT IN FORM '10B"LOAD CARRYING CAPABILITY OF SLOTTED DRAINS
"/':
1825 PRINT IN FORM '23B"PROJECT NO. 636853"//':
1826 PRINT IN FORM '/5B"TYPE OF PIPE : SLOTTED CSP DRAIN,18 IN. DIAMETER"/':
1827 PRINT IN FORM '20B"8 IN.X12.50 IN. LOADING PLATE"':
1828 PRINT IN FORM '/B"TEST NUMBER:"4%4B"TEMPERATURE:"B3%B"DEGREES
 F."
2B"DATE"B2%"-"2%"-19"2%':TEST,TEMP,MON,DAY,YEAR
1830 PRINT IN FORM '/B"START TIME"B2%":"2%24B"END TIME"B2%":"2%':T
IM1,TIM2,
TIM3,TIM4
1840 PRINT IN FORM '/23B"MAGNITUDE OF LOAD:"4%.2%B"KIPS"':LOD
1850 PRINT IN FORM '/23B"POSITION OF LOAD:"/23B"GRATE TYPE : "/
23B"GRATE TO PIPE WELDS : "/31B"LOCATION     :"/31B"SPACING     :"/
31B"LENGTH      :"/23B"TYPE OF BACKFILL:"':
1860 PRINT IN FORM '/5B"VERTICAL DEFLECTIONS (INCHES) AT LOAD :"/':
:
1870 PRINT IN FORM '22B"NORTH SIDE OF GRATE  :"B4%.3%':NG
1880 PRINT IN FORM '/22B"SOUTH SIDE OF GRATE  :"B4%.3%':SG
1890 PRINT IN FORM '/22B"NORTH SIDE OF INVERT :"B4%.3%':NI
1900 PRINT IN FORM '/22B"SOUTH SIDE OF INVERT :"B4%.3%':SI
1910 PRINT IN FORM '/3B"NOTES:"/9B"1-VALUES OF STRAINS SHOWN BELOW IN
 PARENTHESES ARE DIFFERENCES"/5B"BETWEEN INITIAL 0 READINGS OF STRAIN G
AGES AND
0 READINGS PRIOR TO"/5B"THIS LOADING."/':
1920 PRINT IN FORM '9B"2-SIGN CONVENTION OF VERTICAL DEFLECTIONS:"/27B
"+ = UPWARD DEFLECTION"/27B"- = DOWNWARD DEFLECTION"':
1930 HX=1
1940 J=1
1950 K=1
1960 PRINT IN FORM '//6B"SOCKET NO.:"2B2%':SOCX(HX)
1970 PRINT IN FORM '/"CHANNEL"B"GAGE"4B"STRAIN"5B"MAX STRESS"
B"MIN STRESS"B"MAX SHEAR"B"ANGLE OF MAX"':
1980 PRINT IN FORM '/2B"NO."3B"NO."2B"(MICRO-IN/IN)"3B"(PSI)"7B"(PSI)"4B
"STRESS"3B"PRINC.STRAIN"':
1990 PRINT IN FORM '/51B"(PSI)"5B"(DEGREES)"':
2000 IF HX=1 THEN L=1
2010 IF HX=2 THEN L=8
2020 IF HX=3 THEN L=15
2030 IF HX=4 THEN L=22
2040 M=L
2042 IF FX(HX,J)=1 THEN GOTO 2044 ELSE GOTO 2050
2044 PRINT IN FORM '//2B2%4B2%"A"2B"("6B") OVERLOAD"':CHOX(HX,J),M
2046 GOTO 2060
2050 PRINT IN FORM '//2B2%4B2%"A"2B"("6%")"6%':CHOX(HX,J),M,ES3I(HX,K),
ES3(HX,K)
2060 J=J+1
2062 IF FX(HX,J)=1 THEN GOTO 2064 ELSE GOTO 2070
2064 PRINT IN FORM '/2B2%4B2%"B"2B"("6B") OVERLOAD"':CHOX(HX,J),M
2066 GOTO 2080
2070 PRINT IN FORM '/2B2%4B2%"B"2B"("6%")"6%':CHOX(HX,J),M,ES1I(HX,K),
ES1(HX,K)
2080 J=J+1
2082 IF FX(HX,J)=1 THEN GOTO 2084 ELSE GOTO 2090
2084 PRINT IN FORM '/2B2%4B2%"C"2B"("6B") OVERLOAD"':CHOX(HX,J),M
2086 GOTO 2100
2090 PRINT IN FORM '/2B2%4B2%"C"2B"("6%")"6%B8%2B8%2B8%5B4%.4%':CHOX(HX
,J),M,
ES2I(HX,K),ES2(HX,K),SMAX(HX,K),SMIN(HX,K),TMAX(HX,K),PHIP(HX,K)
2100 J=J+1
2110 K=K+1
2120 M=M+1
2130 IF SOCX(HX)=4 THEN GOTO 2140 ELSE GOTO 2150
2140 IF K<=4 THEN GOTO 2042 ELSE GOTO 2180
2150 IF SOCX(HX)#4 AND K<=7 THEN GOTO 2042
2160 HX=HX+1
2170 GOTO 1940
2180 PAGE=PAGE+1
2190 SW=SW+1
2200 GOTO 630
2210 CLOSE 1,2
2220 END
```

APPENDIX 7.3.2 CONTINUED

CALIFORNIA DEPARTMENT OF TRANSPORTATION
TRANSPORTATION LABORATORY
LOAD CARRYING CAPABILITY OF SLOTTED DRAINS
PROJECT NO. 636853

TYPE OF PIPE : SLOTTED CSP DRAIN,18 IN. DIAMETER
8 IN.X12.50 IN. LOADING PLATE

TEST NUMBER: 6 TEMPERATURE: 55 DEGREES F. DATE 12-13-1979
START TIME 10:30 END TIME 12: 0

MAGNITUDE OF LOAD: 15.02 KIPS
POSITION OF LOAD: CENTERLINE PERPENDICULAR
GRATE TYPE : 3/16-INCH-THICK SOLID PLATE SPACER
GRATE TO PIPE WELDS :
LOCATION :AT SPACER/ CREST-TO-VALLEY
SPACING : 6 INCHES
LENGTH : 2 INCHES
TYPE OF BACKFILL: SOIL CEMENT

VERTICAL DEFLECTIONS (INCHES) AT LOAD :
NORTH SIDE OF GRATE : -.035
SOUTH SIDE OF GRATE : -.029
NORTH SIDE OF INVERT : .002
SOUTH SIDE OF INVERT : .001

NOTES:
1-VALUES OF STRAINS SHOWN BELOW IN PARENTHESES ARE DIFFERENCES BETWEEN INITIAL 0 READINGS OF STRAIN GAGES AND 0 READINGS PRIOR TO THIS LOADING.
2-SIGN CONVENTION OF VERTICAL DEFLECTIONS:
+ = UPWARD DEFLECTION
- = DOWNWARD DEFLECTION

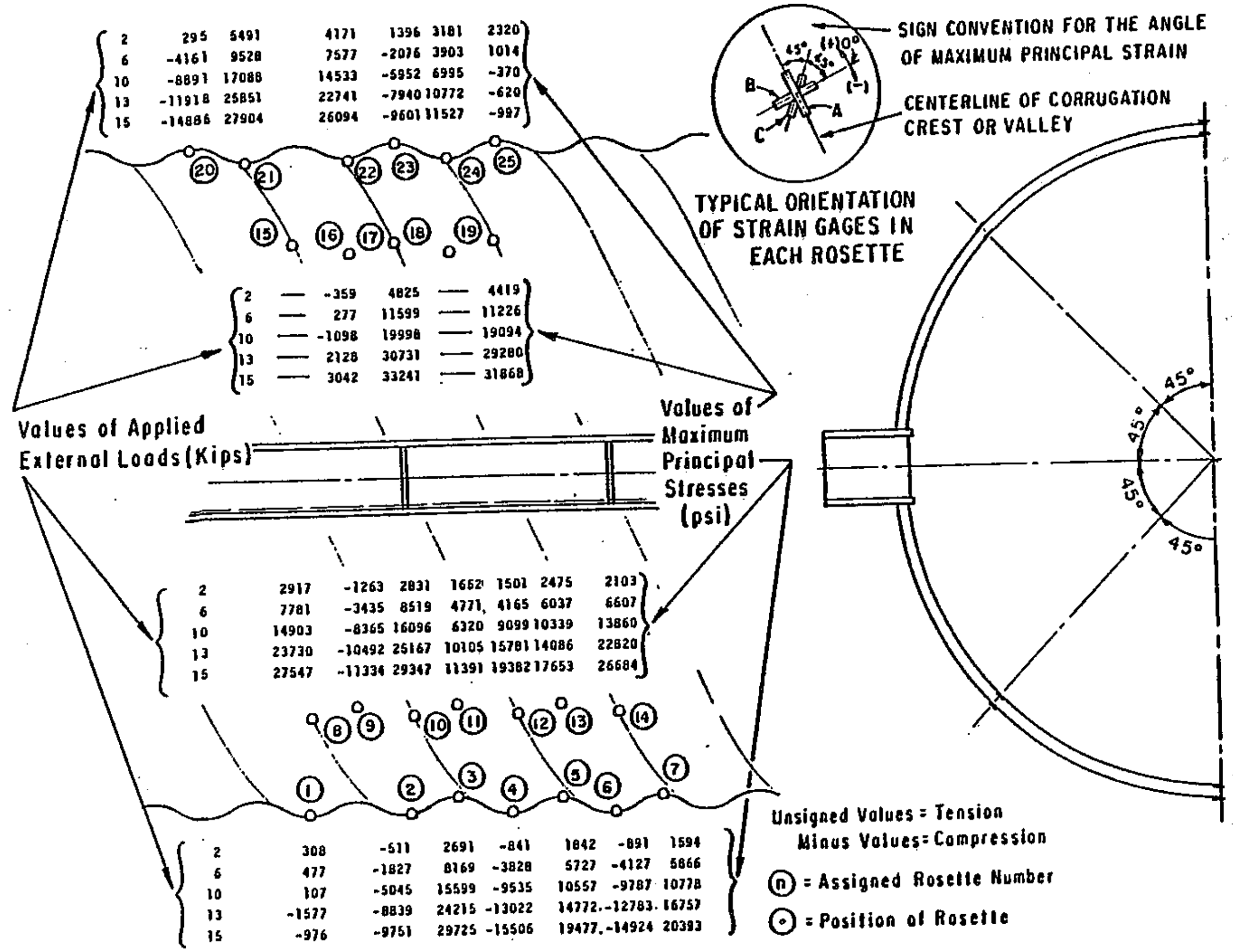
SOCKET NO.: 1

CHANNEL NO.	GAGE NO.	STRAIN (MICRO-IN/IN)		MAX STRESS (PSI)	MIN STRESS (PSI)	MAX SHEAR STRESS (PSI)	ANGLE OF MAX PRINC.STRAIN (DEGREES)
4	1A	(-38)	-50				
5	1B	(30)	85				
6	1C	(6)	-78	3458	-1941	2700	-27.2928
7	2A	(18)	-134				
8	2B	(46)	-26				
9	2C	(34)	-149	-1404	-5458	2027	-26.0862
10	3A	(-30)	-158				
11	3B	(-18)	98				
12	3C	(-6)	-70	1814	-4370	3092	-8.6892
13	4A	(38)	-134				
14	4B	(38)	-14				
15	4C	(50)	-74	-1789	-4548	1379	.1488
16	5A	(22)	-114				
17	5B	(-30)	18				
18	5C	(-14)	-54	-524	-3575	1526	-2.6063
19	6A	(18)	-118				
20	6B	(34)	-2				
21	6C	(18)	-34	-1111	-4041	1465	12.2624

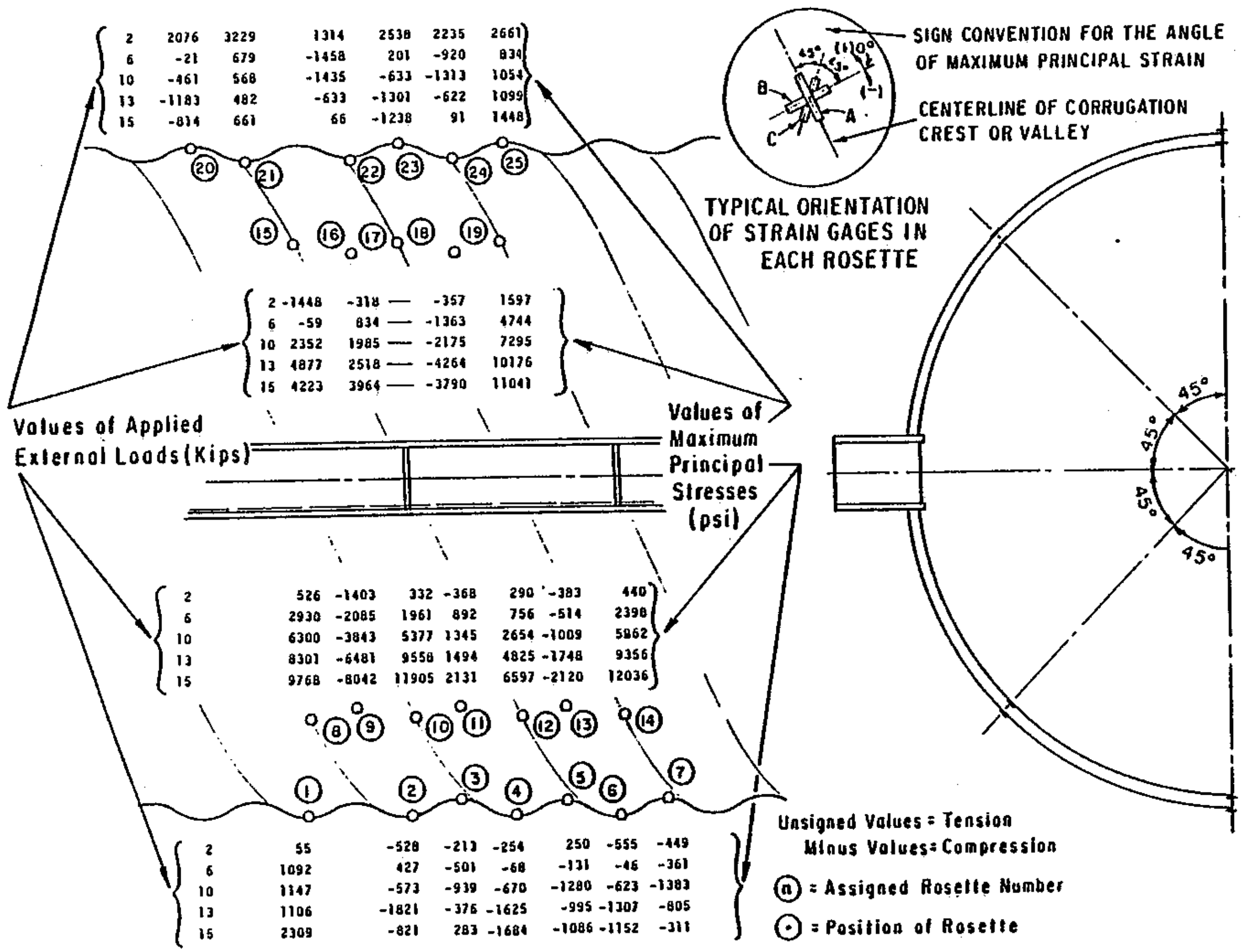
APPENDIX 7.3.3 SAMPLE COMPUTER DATA PRINTOUT FROM THE PROGRAM "STRAIN ANALYSIS - SLOTTED CSP DRAIN".

```
100 REM       AUTHOR : LAI A.T.    WRITTEN : 12-20-79
110 REM      THIS PROGRAM MERGES DATA FROM TWO FILES HEREBY CALLED FILE 1 AND
120 REM FILE 2. FILE 1 CONTAINS RECORDS OF SOCKETS 1&2. EACH SOCKET NUMBER
130 REM REPRESENTS 25 CHANNELS. FILE 2 CONTAINS RECORDS OF SOCKETS 3&4. FOR EAC
140 REM MAGNITUDE OF THE LOAD READINDS OF THE 4 SOCKETS ARE MERGED SEQUENTIALLY
145 REM IN THAT ORDER 1,2,3,4.
150 INTEGER SOC1(4),SOC2(4)
160 DIM CHN(4,25),FLG(4,25),RDG(4,25)
170 PRINT 'ENTER FILE 1':
180 INPUT F1$
190 OPEN F1$,1,INPUT,OLD
200 PRINT 'ENTER FILE 2':
210 INPUT F2$
220 OPEN F2$,2,INPUT,OLD
230 PRINT 'ENTER NAME OF OUTPUT FILE':
240 INPUT F3$
250 OPEN F3$,3,OUTPUT
260 INPUT FROM 1:A1$
270 CK1$=SUBSTR(A1$,1,1)
280 IF CK1$#'H' THEN GOTO 750
290 PRINT ON 3 IN FORM '18%",'':A1$
300 INPUT FROM 2:A2$
310 CK2$=SUBSTR(A2$,1,1)
320 IF CK2$#'H' THEN GOTO 760
330 FOR H=1 TO 2
340 FOR J=1 TO 25
350 INPUT FROM 1:C$,F$,R$
360 CHN(H,J)=VAL(SUBSTR(C$,1,2)),FLG(H,J)=VAL(SUBSTR(F$,1,1)),RDG(H,J)=VAL
(SUBSTR(R$,1,6))
370 IF J=1 THEN S11$=SUBSTR(R$,2,2)
380 IF J=2 THEN S12$=SUBSTR(R$,2,2),SOC1(H)=VAL(S11$+S12$)
390 NEXT J,H
400 FOR H=3 TO 4
410 FOR J=1 TO 25
420 INPUT FROM 2:C$,F$,R$
430 CHN(H,J)=VAL(SUBSTR(C$,1,2)),FLG(H,J)=VAL(SUBSTR(F$,1,2)),RDG(H,J)=VAL
(SUBSTR(R$,1,6))
440 IF J=1 THEN S21$=SUBSTR(R$,2,2)
450 IF J=2 THEN S22$=SUBSTR(R$,2,2),SOC2(H)=VAL(S21$+S22$)
460 NEXT J,H
470 N=1
480 H=1
490 IF SOC1(H)=N THEN GOTO 500 ELSE GOTO 560
500 J=1
510 PRINT ON 3 IN FORM'2%",'#','6D'E-5,'2%','#','6D'E-5,'2%','#','6D'E-5,'2%','
','6D'E-5,'':CHN(H,J),FLG(H,J),RDG(H,J),CHN(H,J+1),FLG(H,J+1),RDG(H,J+1),
CHN(H,J+2),FLG(H,J+2),RDG(H,J+2),CHN(H,J+3),FLG(H,J+3),RDG(H,J+3)
520 J=J+4
530 IF J<25 THEN GOTO 510 ELSE GOTO 540
540 IF J=25 THEN GOTO 550 ELSE GOTO 560
550 PRINT ON 3 IN FORM'2%','#','6D'E-5,'':CHN(H,J),FLG(H,J),RDG(H,J)
560 N=N+1
570 H=H+1
580 IF SOC1(H)=N THEN GOTO 590 ELSE GOTO 610
590 J=1
600 GOTO 510
610 IF SOC2(H)=N THEN GOTO 620 ELSE GOTO 680
620 J=1
630 PRINT ON 3 IN FORM'2%','#','6D'E-5,'2%','#','6D'E-5,'2%','#','6D'E-5,'2%','
','6D'E-5,'':CHN(H,J),FLG(H,J),RDG(H,J),CHN(H,J+1),FLG(H,J+1),RDG(H,J+1),
CHN(H,J+2),FLG(H,J+2),RDG(H,J+2),CHN(H,J+3),FLG(H,J+3),RDG(H,J+3)
640 J=J+4
650 IF J<25 THEN GOTO 630 ELSE GOTO 660
660 IF J=25 THEN GOTO 670 ELSE GOTO 680
670 PRINT ON 3 IN FORM'2%','#','6D'E-5,'':CHN(H,J),FLG(H,J),RDG(H,J)
680 N=N+1
690 H=H+1
700 IF H>4 THEN GOTO 710 ELSE GOTO 740
710 H=1
720 N=1
730 GOTO 330
740 IF SOC2(H)=N THEN GOTO 620 ELSE GOTO 330
750 CLOSE 1
760 CLOSE 2,3
770 END
```

APPENDIX 7.3.4 PROGRAM CALLED "MERGEDATA" FOR COMBINING ALL DATA ONTO A SINGLE TAPE BEFORE PROCESSING.



APPENDIX 7.4.1 TABULATION OF MAXIMUM PRINCIPAL STRESSES (PSI) FOR STRAIN GAGE INSTRUMENTED SLOTTED DRAIN. CENTERLINE PARALLEL LOADING, SOIL BACKFILL, TEST DATE: 11-9-79.



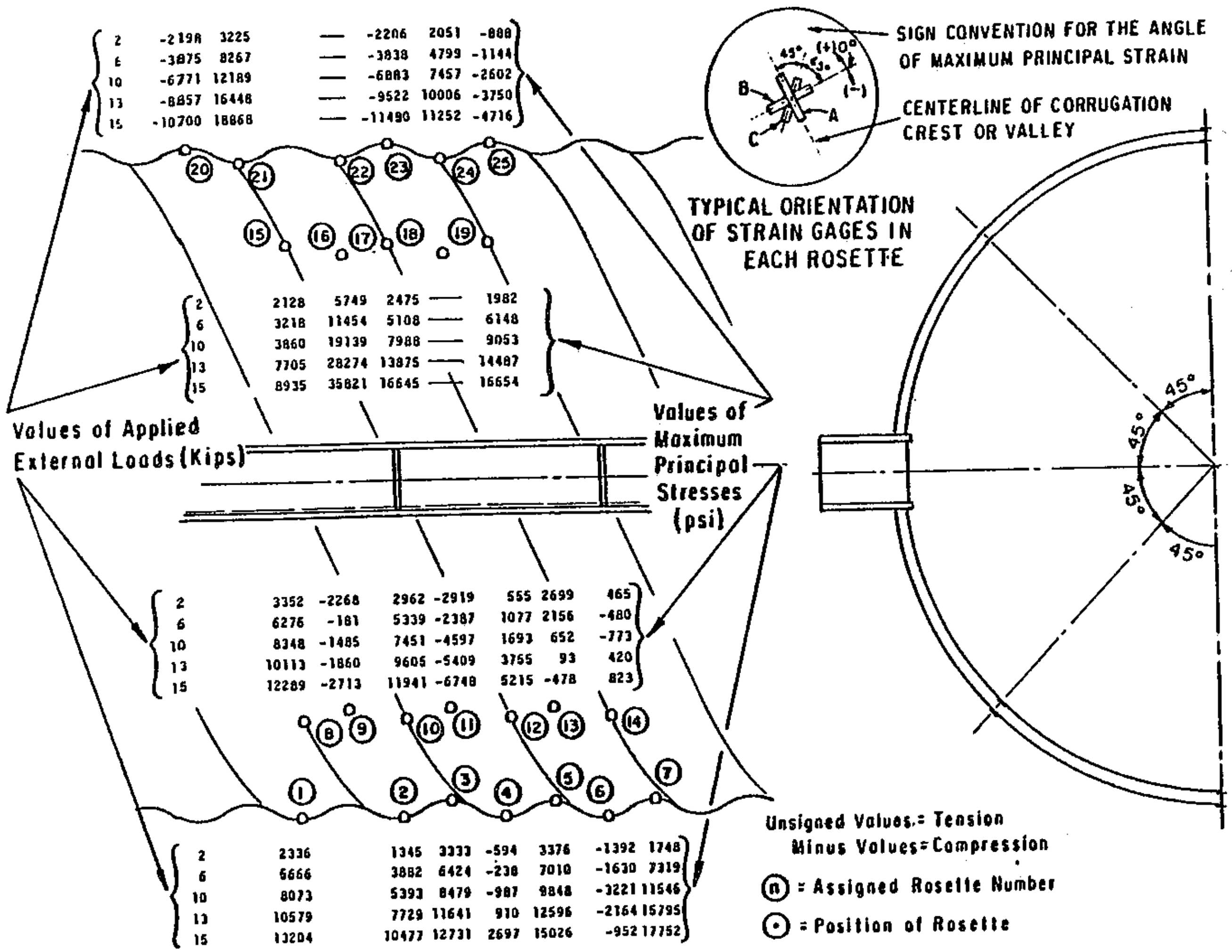
2	2076	3229	1314	2538	2235	2661
6	-21	679	-1458	201	-920	834
10	-461	568	-1435	-633	-1313	1054
13	-1183	482	-633	-1301	-622	1099
15	-814	661	66	-1238	91	1448

2	-1448	-318	—	-357	1597
6	-59	834	—	-1363	4744
10	2352	1985	—	-2175	7295
13	4877	2518	—	-4264	10176
15	4223	3964	—	-3790	11041

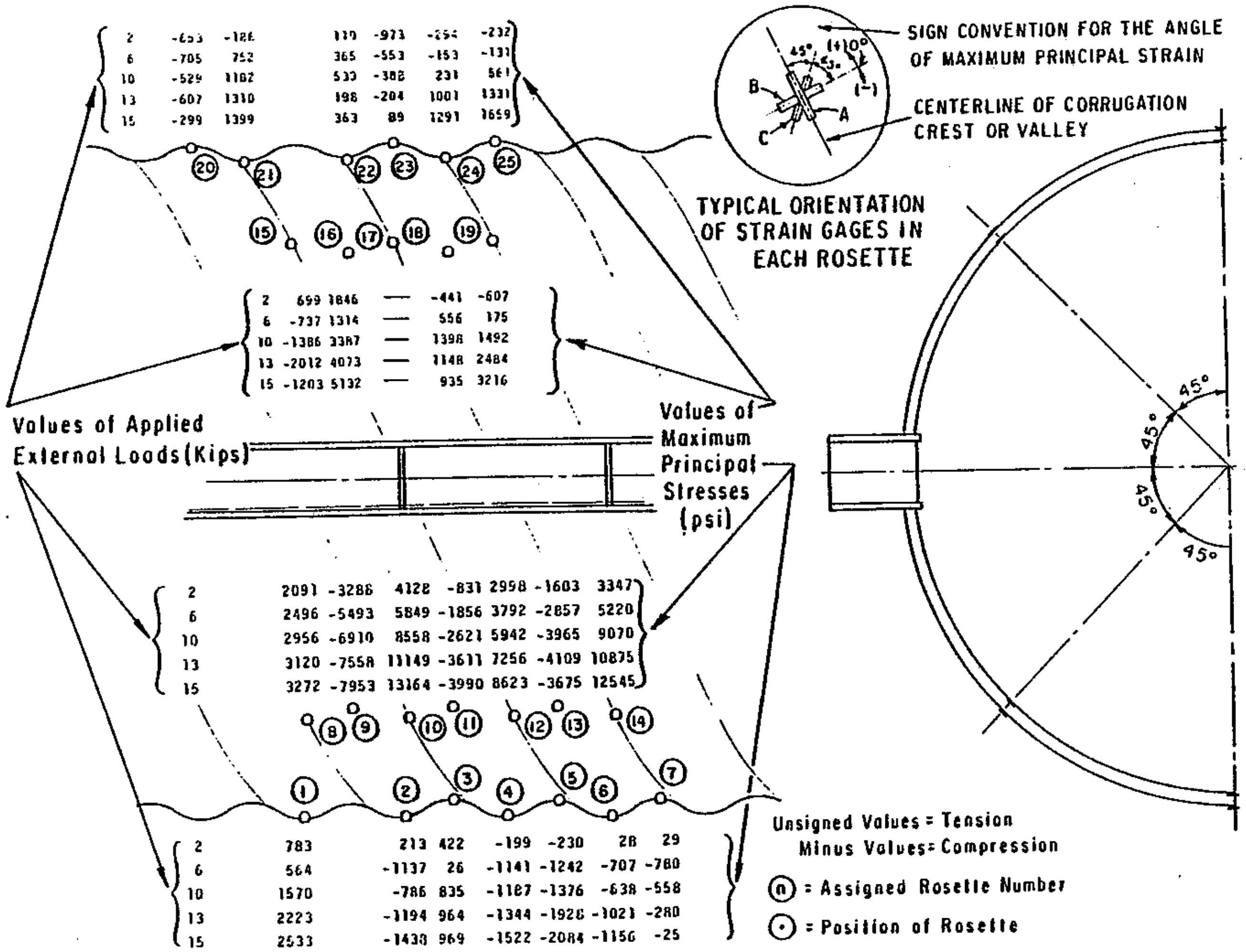
2	526	-1403	332	-368	290	-383	440
6	2930	-2085	1961	892	756	-514	2398
10	6300	-3843	5377	1345	2654	-1009	5862
13	8301	-6481	9558	1494	4825	-1748	9356
15	9768	-8042	11905	2131	6597	-2120	12036

2	55	-528	-213	-254	250	-555	-449
6	1092	427	-501	-68	-131	-46	-361
10	1147	-573	-939	-670	-1280	-623	-1383
13	1106	-1821	-376	-1625	-995	-1307	-805
15	2309	-821	283	-1684	-1086	-1152	-311

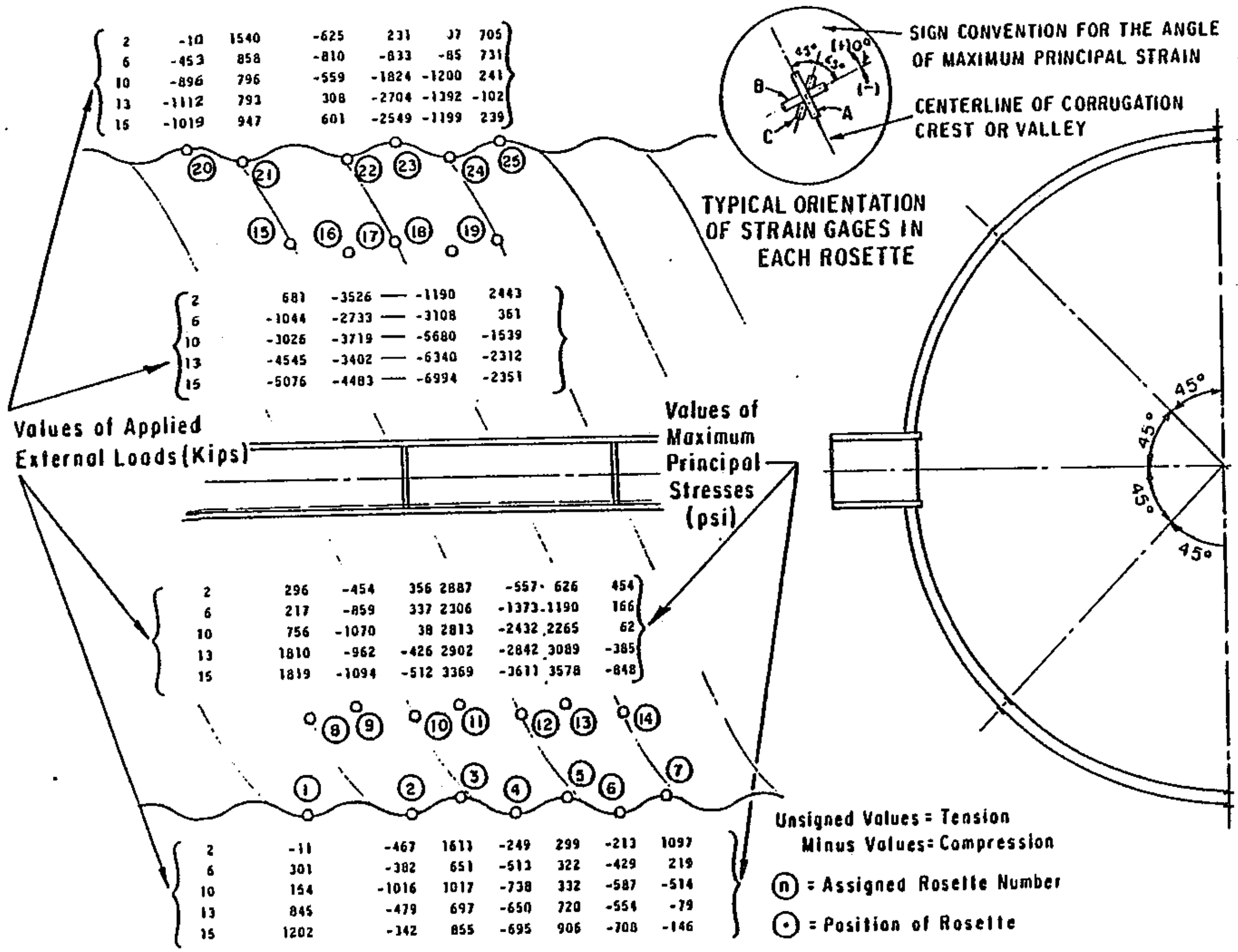
APPENDIX 7.4.2 TABULATION OF MAXIMUM PRINCIPAL STRESSES (PSI) FOR STRAIN GAGE INSTRUMENTED SLOTTED DRAIN. CENTERLINE PARALLEL LOADING, SITE-MIXED SOIL CEMENT BACKFILL, TEST DATE: 12-12-79.



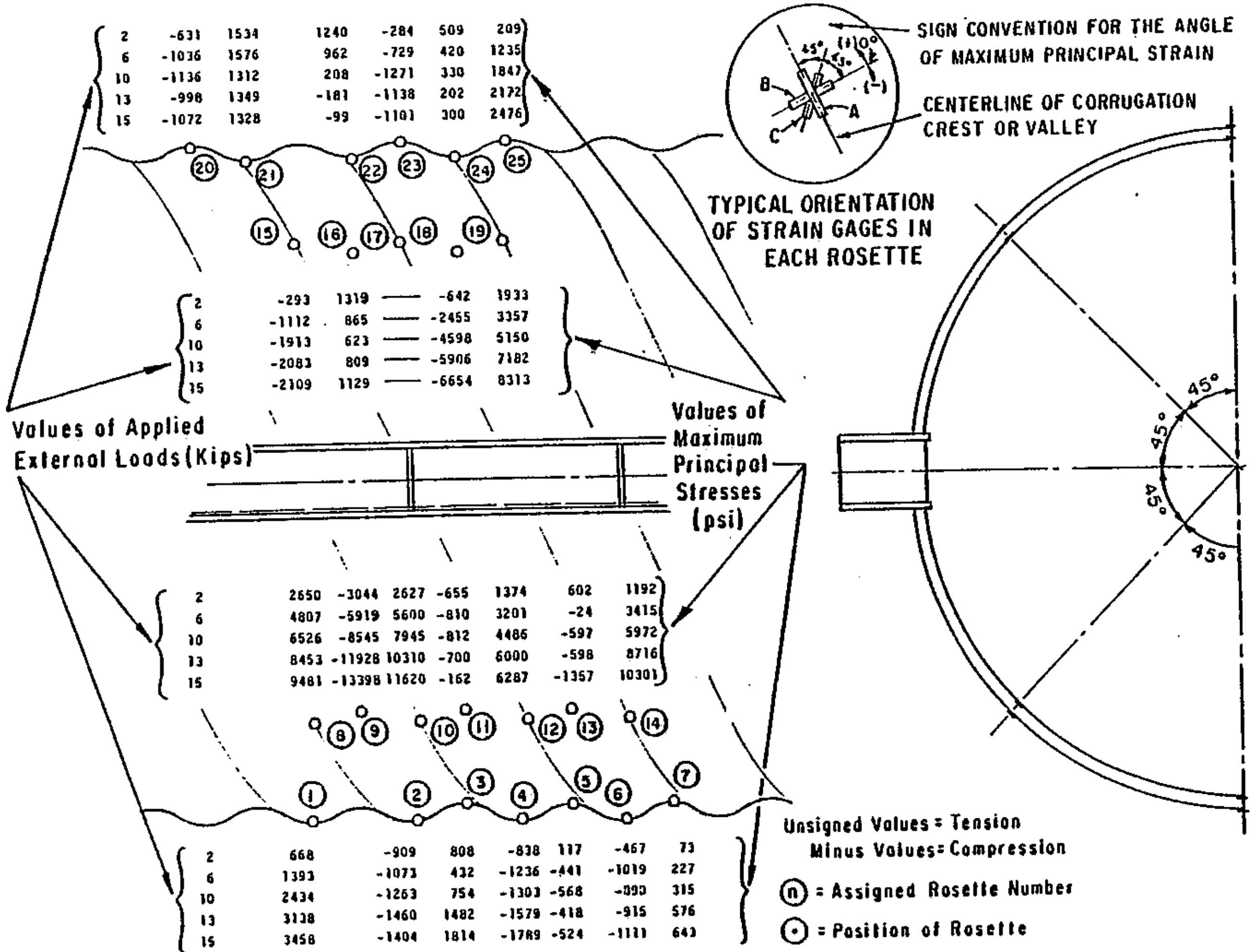
APPENDIX 7.4.3 TABULATION OF THE MAXIMUM PRINCIPAL STRESSES (PSI) FOR STRAIN GAGE INSTRUMENTED SLOTTED DRAIN. ECCENTRIC SOUTHSIDE PARALLEL LOADING, SOIL BACKFILL, TEST DATE: 11-9-79.



APPENDIX 7.4.4 TABULATION OF MAXIMUM PRINCIPAL STRESSES (PSI) FOR STRAIN GAGE INSTRUMENTED SLOTTED DRAIN. ECCENTRIC SOUTHSIDE PARALLEL LOADING, SITE-MIXED CEMENT BACKFILL, TEST DATE: 12-12-79.



APPENDIX 7.4.5 TABULATION OF MAXIMUM PRINCIPAL STRESSES (PSI) FOR STRAIN GAGE INSTRUMENTED SLOTTED DRAIN. ECCENTRIC NORTHSIDE PARALLEL LOADING, SITE-MIXED SOIL CEMENT BACKFILL, TEST DATE: 12-12-79.



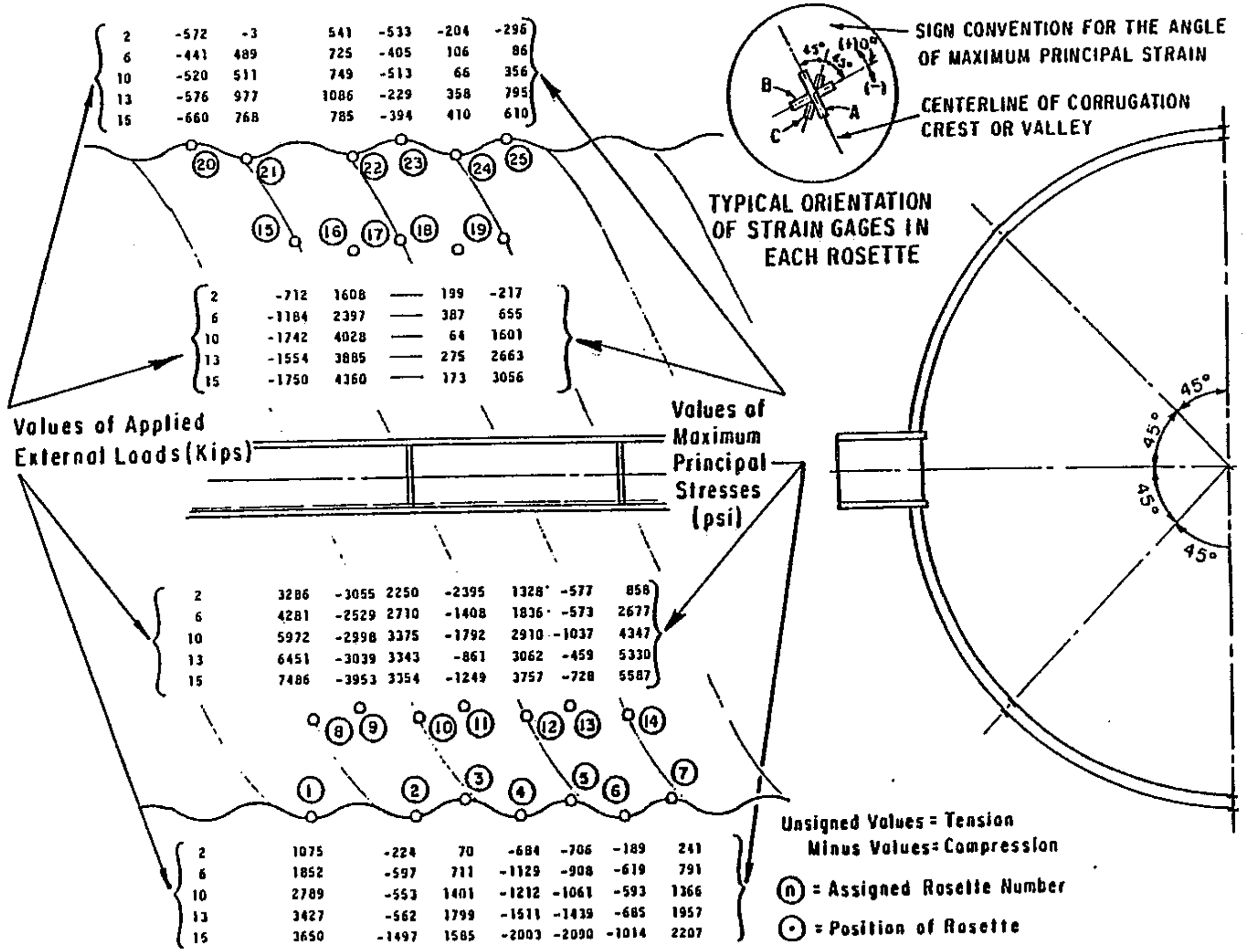
2	-631	1534	1240	-284	509	209
6	-1036	1576	962	-729	420	1235
10	-1136	1312	208	-1271	330	1847
13	-998	1349	-181	-1138	202	2172
15	-1072	1328	-99	-1101	300	2476

2	-293	1319	——	-642	1933
6	-1112	865	——	-2455	3357
10	-1913	623	——	-4598	5150
13	-2083	809	——	-5906	7182
15	-2109	1129	——	-6654	8313

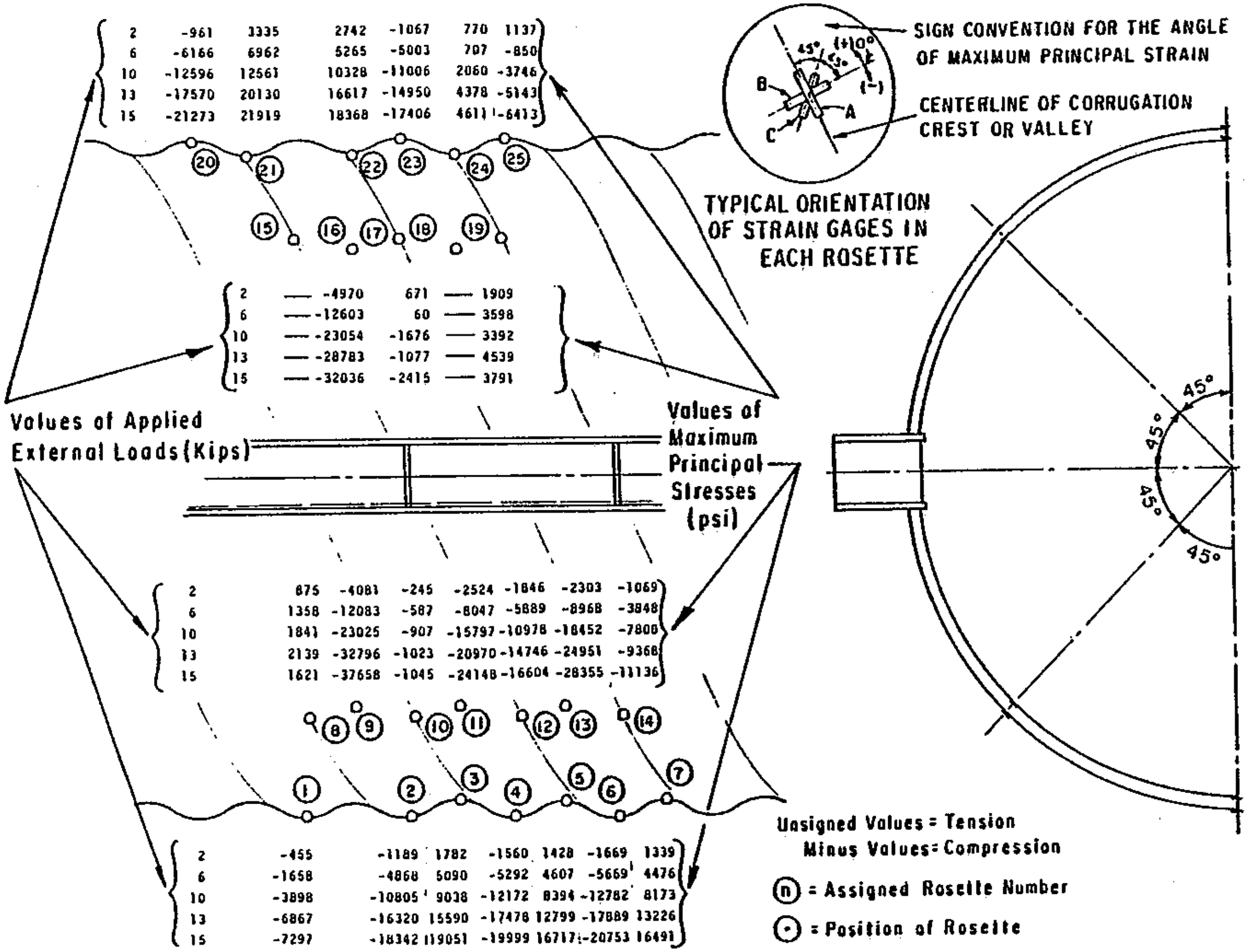
2	2650	-3044	2627	-655	1374	602	1192
6	4807	-5919	5600	-810	3201	-24	3415
10	6526	-8545	7945	-812	4486	-597	5972
13	8453	-11928	10310	-700	6000	-598	8716
15	9481	-13398	11620	-162	6287	-1357	10301

2	668	-909	808	-838	117	-467	73
6	1393	-1073	432	-1236	-441	-1019	227
10	2434	-1263	754	-1303	-568	-893	315
13	3138	-1460	1482	-1579	-418	-915	576
15	3458	-1404	1814	-1789	-524	-1111	643

APPENDIX 7.4.6 TABULATION OF MAXIMUM PRINCIPAL STRESSES (PSI) FOR STRAIN GAGE INSTRUMENTED SLOTTED DRAIN. CENTERLINE PERPENDICULAR LOADING, SITE-MIXED SOIL CEMENT BACKFILL, TEST DATE: 12-12-79.



APPENDIX 7.4.7 TABULATION OF MAXIMUM PRINCIPAL STRESSES (PSI) FOR STRAIN GAGE INSTRUMENTED SLOTTED DRAIN. ECCENTRIC SOUTHSIDE PERPENDICULAR LOADING, SITE-MIXED SOIL CEMENT BACKFILL, TEST DATE: 12-12-79.



Rosettes 20–25:

Load (Kips)	20	21	22	23	24	25
2	-961	3335	2742	-1067	770	1137
6	-6166	6962	5265	-5003	707	-850
10	-12596	12561	10328	-11006	2060	-3746
13	-17570	20130	16617	-14950	4378	-5143
15	-21273	21919	18368	-17406	4611	-6413

Rosettes 15–19:

Load (Kips)	15	16	17	18	19
2	—	-4970	671	—	1909
6	—	-12603	60	—	3598
10	—	-23054	-1676	—	3392
13	—	-28783	-1077	—	4539
15	—	-32036	-2415	—	3791

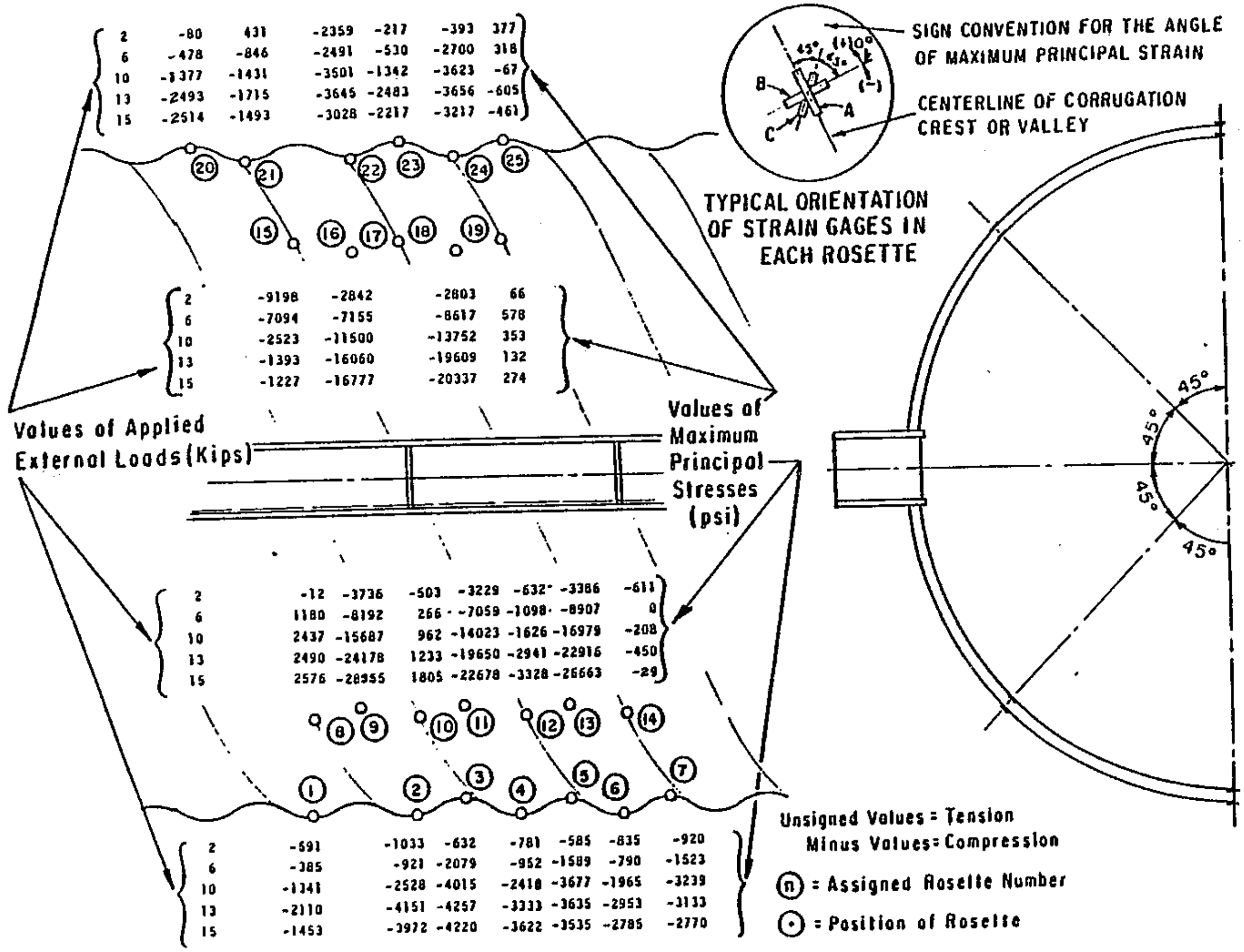
Rosettes 8–14:

Load (Kips)	8	9	10	11	12	13	14
2	875	-4081	-245	-2524	-1846	-2303	-1069
6	1358	-12083	-587	-8047	-5889	-8968	-3848
10	1841	-23025	-907	-15797	-10978	-18452	-7800
13	2139	-32796	-1023	-20970	-14746	-24951	-9368
15	1621	-37658	-1045	-24148	-16604	-28355	-11136

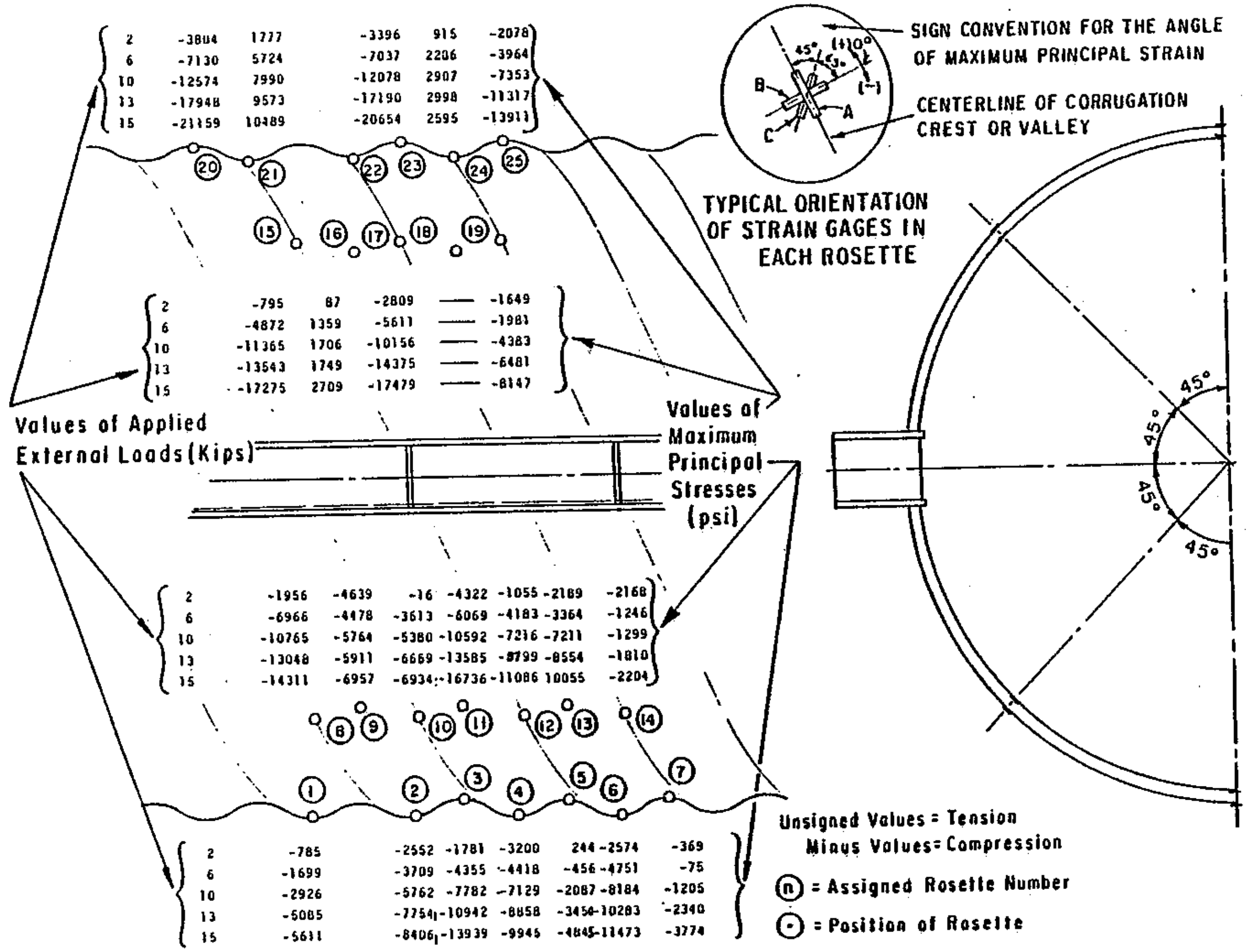
Rosettes 1–7:

Load (Kips)	1	2	3	4	5	6	7
2	-455	-1189	1782	-1560	1428	-1669	1339
6	-1658	-4868	5090	-5292	4607	-5669	4476
10	-3898	-10805	9038	-12172	8394	-12782	8173
13	-6867	-16320	15590	-17478	12799	-17889	13226
15	-7297	-18342	19051	-19999	16717	-20753	16491

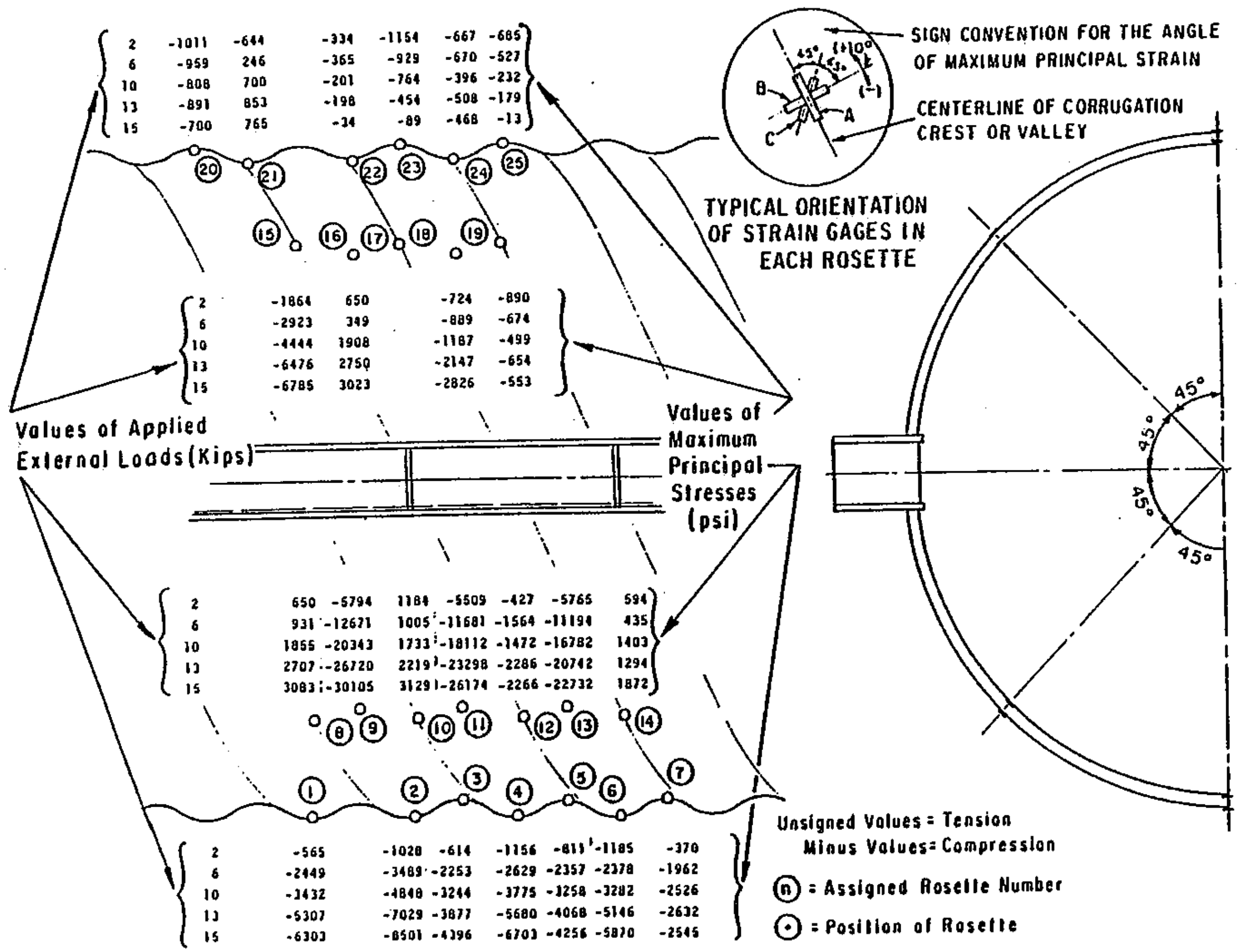
APPENDIX 7.5.1 TABULATION OF MINIMUM PRINCIPAL STRESSES (PSI) FOR STRAIN GAGE INSTRUMENTED SLOTTED DRAIN. CENTERLINE PARALLEL LOADING, SOIL BACKFILL, TEST DATE: 11-9-79.



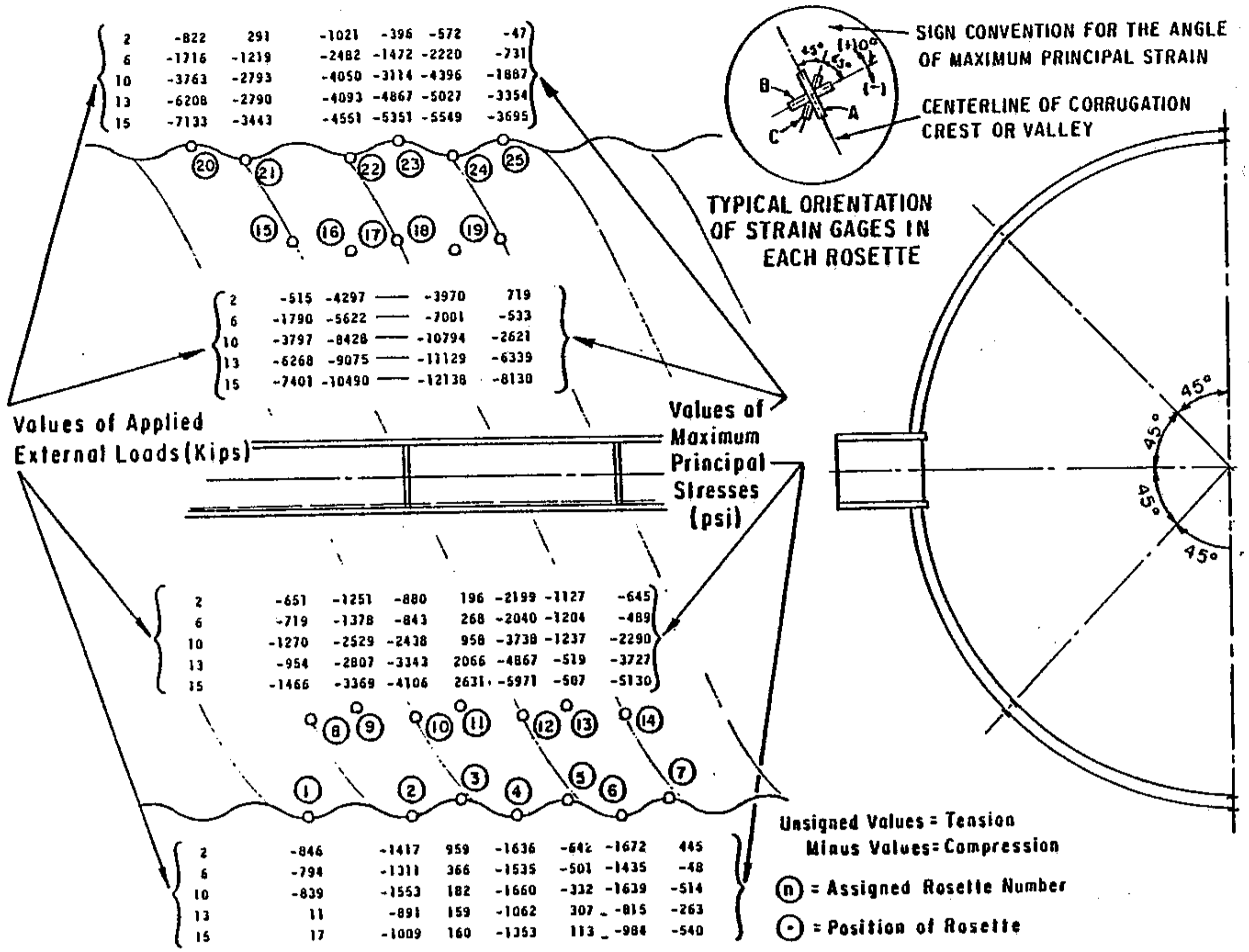
APPENDIX 7.5.2 TABULATION OF MINIMUM PRINCIPAL STRESSES (PSI) FOR STRAIN GAGE INSTRUMENTED SLOTTED DRAIN. CENTERLINE PARALLEL LOADING, SITE-MIXED SOIL CEMENT BACKFILL, TEST DATE: 12-12-79.



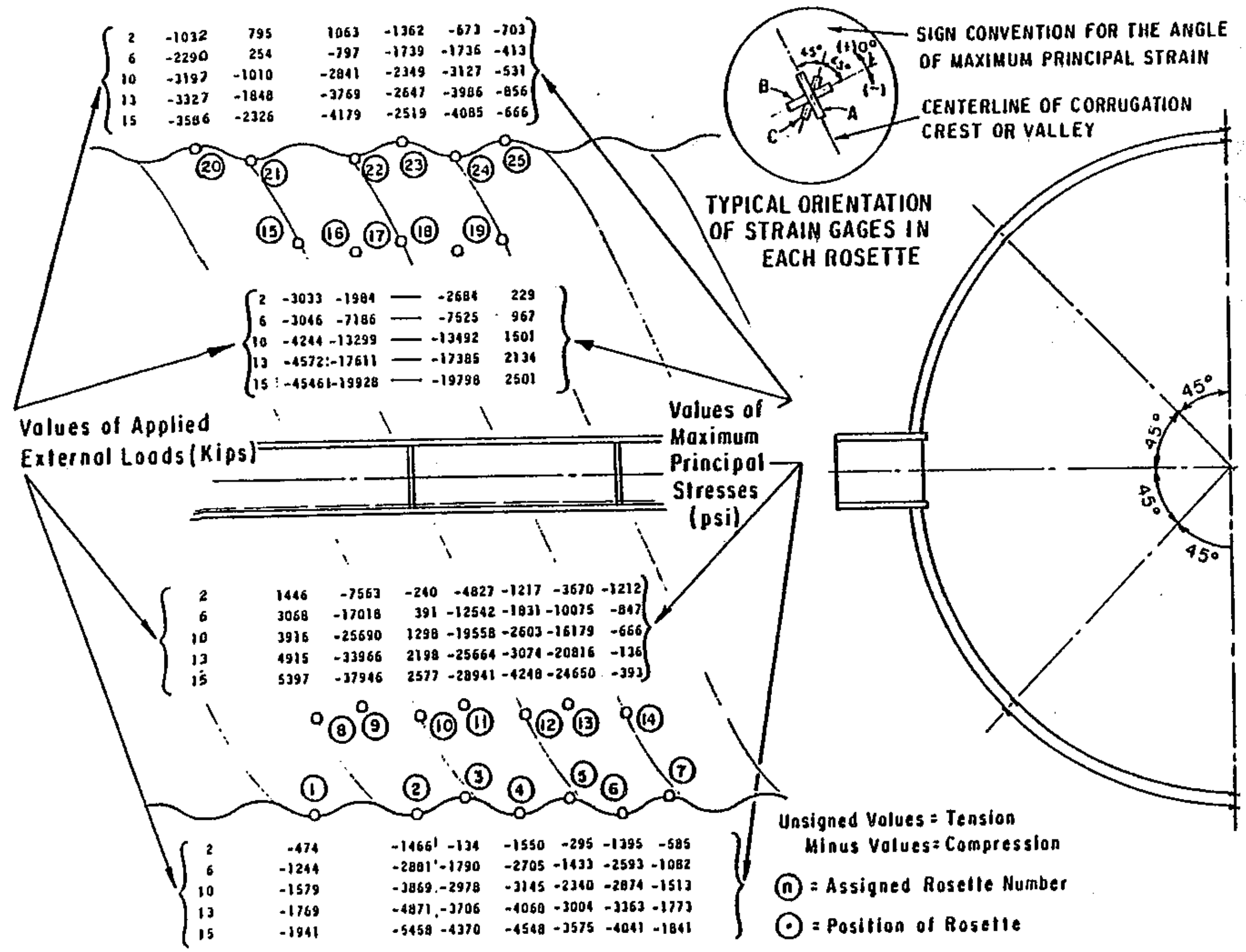
APPENDIX 7.5.3 TABULATION OF MINIMUM PRINCIPAL STRESSES (PSI) FOR STRAIN GAGE INSTRUMENTED SLOTTED DRAIN. ECCENTRIC SOUTHSIDE PARALLEL LOADING, SOIL BACKFILL, TEST DATE: 11-9-79



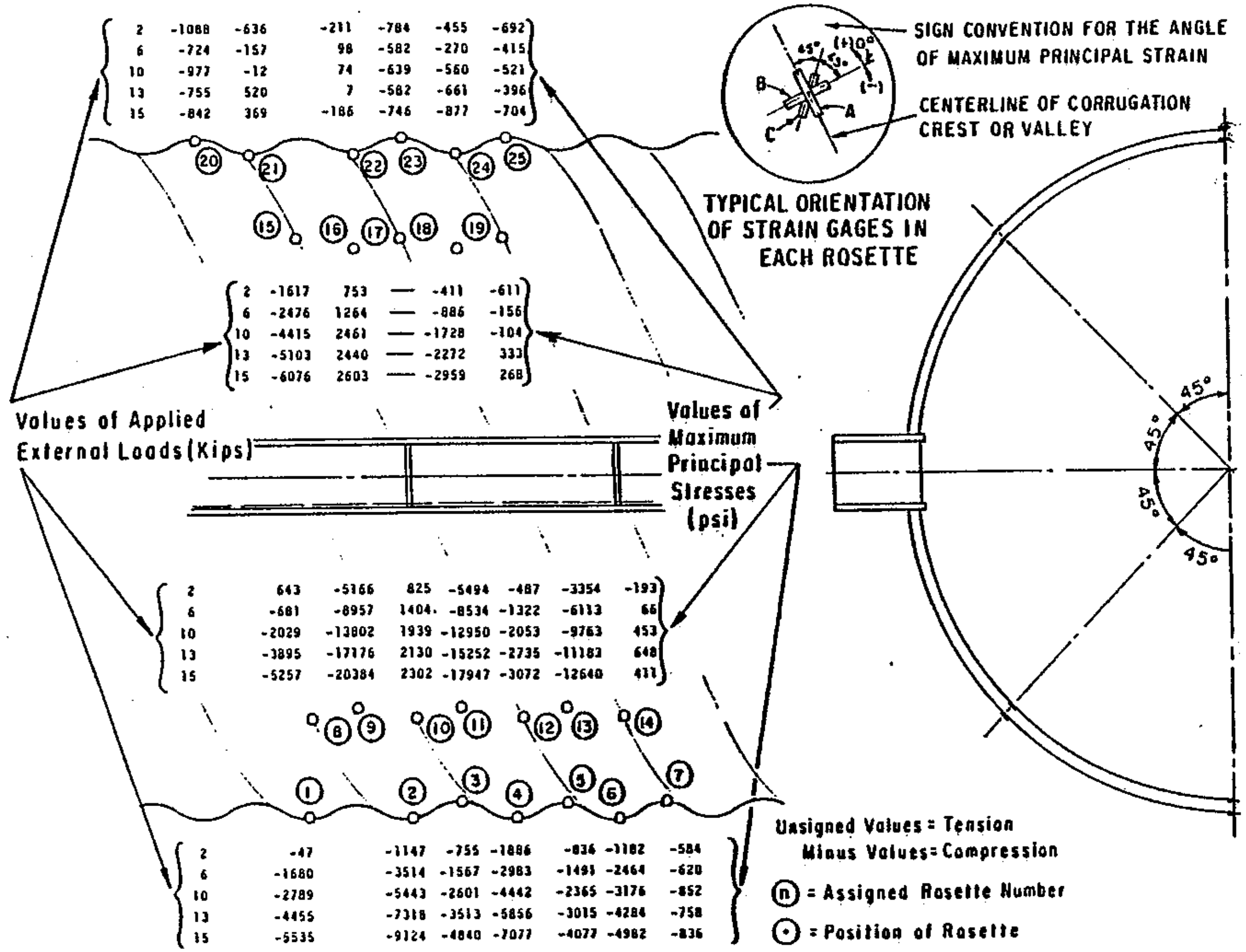
APPENDIX 7.5.4 TABULATION OF MINIMUM PRINCIPAL STRESSES (PSI) FOR STRAIN GAGE INSTRUMENTED SLOTTED DRAIN. ECCENTRIC SOUTHSIDE PARALLEL LOADING, SITE-MIXED SOIL CEMENT BACKFILL, TEST DATE: 12-12-79.



APPENDIX 7.5.5 TABULATION OF MINIMUM PRINCIPAL STRESSES (PSI) FOR STRAIN GAGE INSTRUMENTED SLOTTED DRAIN. ECCENTRIC NORTHSIDE PARALLEL LOADING, SITE-MIXED SOIL CEMENT BACKFILL, TEST DATE: 12-12-79.



APPENDIX 7.5.6 TABULATION OF MINIMUM PRINCIPAL STRESSES (PSI) FOR STRAIN GAGE INSTRUMENTED SLOTTED DRAIN. CENTERLINE PERPENDICULAR LOADING, SITE-MIXED SOIL CEMENT, TEST DATE: 12-12-79.



APPENDIX 7.5.7 TABULATION OF MINIMUM PRINCIPAL STRESSES (PSI) FOR STRAIN GAGE INSTRUMENTED SLOTTED DRAIN. ECCENTRIC SOUTHSIDE PERPENDICULAR LOADING, SITE-MIXED SOIL-CEMENT BACKFILL, TEST DATE: 12-12-79.