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August 13, 1975

MEMO TO: J. R. Harbison
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Chairman, Research Committee

SUBJECT: Research Report No. 431; "Loads on Box Culverts under High Embankments: Positive Projection, without Imperfect Trench;" KYHPR-72-68; HPR-PL-1(11); Part II.

Report 386, April 1974, gave short-term measurements of pressures, settlements, and strains in reinforcing steel obtained from three, instrumented box culverts designed by the imperfect trench method and constructed in 1971 [U.S. 27, McCreary County; F-170(17), SP 74-593-6]. Bearing pressures at two of the three sites remain significantly less than the dead weight of earth (Wh) over the culvert. The higher pressures recorded at the third site were accompanied by greater compression of the cushion material in the imperfect trench over the culvert. It seems likely that bedrock dipped below culvert grade through a portion of the foundation line. Measurements will be made at these sites until long-term, load histories have been established.

In order to obtain comparisons between culverts having the imperfect trench feature and otherwise normal and untrenched situations, two culverts on KY 627 [Clark County; RF-167(12), SP 25-82] constructed during 1974-1975 were instrumented. Measurements there have shown some roof and bottom loads significantly greater than Wh; sidewall pressures are also sometimes greater than expected. Report No. 431 relates those significant findings.

There seems to be some possibility for failure at either or both of the Clark County sites due to the high bearing pressures. The culverts will be observed regularly, and gages will be read periodically.

At least one additional culvert involving the imperfect trench and a rather deep, yielding foundation will be instrumented in the near future in order to complete the study and to include all types of designs.

Respectfully submitted,

Jas. H. Havens
Director of Research

JHH:gd
Attachment
cc's: Research Committee

TECHNICAL REPORT STANDARD TITLE PAGE

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16. Abstract

This report describes the instrumentation and measurements of settlements and pressures on two box culverts in Clark County, Kentucky, designed without the imperfect trench -- one for yielding and one for unyielding foundation conditions. The structures were primarily instrumented for comparison with three structures previously constructed in McCreary County, which were designed using the imperfect trench method. Pressures on the two structures in Clark County generally exceed the product of the unit weight of the overlying material and its height. The pressures on the culverts in McCreary County appear to be lower than expected -- indicating that the imperfect trench is generally effective in reducing loads.

17. Key Words	18. Distribution Statement
Culverts, high embankments, untrenched, settlement, earth pressures, positive projecting	

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Research Report
431

LOADS ON BOX CULVERTS UNDER HIGH EMBANKMENTS: POSITIVE PROJECTION, WITHOUT IMPERFECT TRENCH

INTERIM REPORT
KYHPR-72-68; HPR-PL-1(11), Part II

by

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in cooperation with
Federal Highway Administration
U. S. DEPARTMENT OF TRANSPORTATION

August 1975

INTRODUCTION

The purpose of this study is to ascertain the effectiveness, reliability, and persistence of the imperfect trench design (Figure 1) in reducing loads on box culverts under high fills. More specifically, the objectives are:

1. to evaluate factors affecting load configurations under high fills and devise methods of predicting loads more accurately;
2. to compare calculated values of loads to measured loads using Marston's *(1)*, Spangler's *(2, 3)*, and Costes' *(4)* theories; and
3. to examine the adequacy of the design of the culverts under study and make recommendations for future designs.

Three culverts with the imperfect trench design in McCreary County, Kentucky [US 27, F-170(17), SP 74-593-6] (see Figure 2), were instrumented with settlement gages, pressure cells, and piezometers *(5)*. Two control structures on the relocation of KY 627 in Clark County, near Boonesboro, were also instrumented with settlement gages, pressure cells, and piezometers. This report describes the construction, instrumentation, and results obtained there.

PROJECT DESCRIPTION

Location and Design

The two structures are on relocated KY 627 between Winchester and the Kentucky River [RF-167(12), SP 25-82] (see Figure 3). The sites were chosen because they were designed to be untrenched and positive projecting and did not have the imperfect trench feature. At Station 123 + 95, a 4-ft x 4-ft (1.22-m x 1.22-m) reinforced concrete box culvert was designed for yielding foundation conditions under 77 feet (23.5 m) of fill. The second structure, at Station 268 + 30, a 4-ft x 5-ft (1.22-m x 1.52-m) reinforced concrete box culvert, was designed for unyielding foundation conditions under 37.5 feet (11.4 m) of fill. The structures at Stations 123 + 95 and 268 + 30 project 1 foot (0.31 m) and 3.5 feet (1.06 m), respectively, above the natural ground nearby (Figure 4).

The culvert at Station 123 + 95 was designed using a rigid frame analysis. Thus, the structure was assumed to have moment-resisting joints which would not allow any joint translation. The culvert has two different designs due to the various depths of overburden. One design pertained to the two 70-foot (21.3-m) sections at each end of the structure (Figure 5). The remaining 260 feet (79 m) of the culvert was designed as shown in Figure 6.

The culvert located at Station 268 + 30 was designed as a continuous beam structure without moment constraints. Again, there were two different designs due to different depths of overburden. Two 30-foot (9.1-m) sections, at each end of the culvert, were designed as shown in Figure 7. The remaining portion of the structure, approximately 130 feet (39.5 m), was designed as shown in Figure 8.

One important difference in the two designs is that the structure at Station 123 + 95 had diagonal reinforcement in both the top and bottom slabs in the center portion to resist shear. The culvert at Station 268 + 30 had no diagonal reinforcement.

Method of Construction

The original soil at both sites was excavated approximately 15 feet (4.6 m) wide and 4 feet (1.2 m) deep. Bedrock encountered at Station 123 + 95 was excavated to 1 foot below foundation level and backfilled with 1 foot of DGA; soil encountered was also undercut; and the site was releveled to the foundation line with DGA. The structure was then constructed on the layer of DGA, and the trenches on each side of the culvert were backfilled with the original excavated material. A layer of the original soil approximately 3 feet (0.9 m) deep was then deposited above the top slab. The remainder of the fill was constructed in alternating layers of shot limestone rock and soil (Figure 4).

At Station 268 + 30, bedrock encountered was excavated to slightly below foundation level; soil encountered was removed to bedrock and refilled with crushed rock; the site was smoothed with the crushed rock. The embankment was constructed in two distinct layers. The lower layer consisted of the original soil and extended from the top of the culvert to approximately one half the fill height. The top layer was shot limestone rock and extended from 15 feet (4.6 m) above the top slab to the top of embankment.

Soil Classification

Soils used in the embankments at Stations 123 + 95 and 268 + 30 were classified as MH and ML-CL, respectively. Soils at both locations contained a large percentage of clayey and silty material. The soil at Station 123 + 95 was composed of 43 percent clay and 40 percent silty material; at Station 268 + 30, the soil was composed of 31 percent clay and 31 percent silt. Other pertinent soil characteristics are listed in Table 1.

INSTRUMENTATION

Pressure Cells

Ten Carlson earth pressure cells *(6)* were installed at each culvert location. Two were placed in each of the sidewalls, in the top slab, in the bottom slab, and in the foundation. Figures 9 and 10 show the positions of the pressure cells in the box culverts located at Stations 123 + 95 and 268 + 30, respectively.

Installation consisted of either casting the cells in place or placing them in the slab after the concrete had cured. Cells in the sidewalls and bottom slab were cast in place. Installation of the two cells in the sidewalls consisted of bolting them to the outside form before concreting (Figure 11). Electrical cables were inserted through the inside wall form and tied to steel reinforcing bars for support. The cells in the footer were also cast in place. However, rather than bolting the pressure cells in place, they were seated against the foundation material with a thin layer of sand as a cushion. The cables were tied to reinforcing bars for support during concreting. Cells in the top slab were installed after the concrete had cured. This method was used to insure that no air voids would occur under the pressure cells. Square ports with an electrical conduit extending through the slab were cast at planned locations when placing the concrete (Figure 12). After the concrete had cured, the cells were installed using a 3M underground insulating resin to secure the cells firmly in place. Cables were inserted through the electrical conduits to the inside of the culvert and extended to external terminals (Figure 13).

Similarly, two cells, one on each side of the culvert, were placed in the bedrock approximately 3 feet (0.91 m) removed from the edge of the bottom slab by excavating a hole and embedding the cells in a layer of insulating resin. The cells were placed face down with the cables running through ports in the sidewall to the remote terminals.

Mercury Settlement Gages

Settlement gages were installed at the time of construction. Five gages were installed at Station 123 + 95. One gage (No. 1) was placed in the lower section of the footer at the time the concrete was placed. Prior to placing the concrete, the gage was tied to the reinforcing steel for support and was positioned approximately 1 foot (0.31 m) from the south sidewall and extending 200 feet (61 m) from the culvert inlet. The remaining four gages were installed in the fill material above the culvert (Figure 14). They were placed as nearly over the center of the culvert barrel as possible and extend from the centerline of the roadway to the culvert inlet. Gages No. 1, 2, 3, and 4 had five settlement points each, equally spaced along the settlement gage. The top settlement gage in the fill (No. 5) had only two settlement points because of its short length.

Gages No. 2, 3, 4, and 5 were all installed in the following manner: When the embankment was constructed to a predetermined height, a ditch was cut directly over and parallel to the culvert barrel with the blade of a road grader (Figure 15). The settlement gages were subsequently placed in the ditches and covered.

Gages No. 1 and 3 are inoperative; both were damaged during construction. Settlement Gage No. 1, located in the footer, was crimped, probably during placement of the concrete. Gage No. 3 was damaged during construction of the rock fill. Gages No. 2, 4, and 5 were, subsequently, installed in 2-inch (5.1-cm) PVC pipe for protection.

Four settlement gages were installed at the culvert at Station 268 + 30. Installation procedures were the same as those used at Station 123 + 95. Gage No. 1 was located in the footer approximately 1 foot (0.31 m) from the south sidewall and extends 106 feet (32.3 m) from the culvert inlet. Gages No. 2, 3, and 4 were placed over the center of the culvert barrel at respective distances of 1.5 feet (0.46 m), 11.5 feet (3.4 m), and 26.5 feet (8.1 m) above the top slab (Figure 16). All gages, excluding Gage No. 4, had five settlement points positioned equidistant along the gage. Gage No. 4 only had three settlement points because of its short length.

Piezometers

Two piezometers (SINCO) were placed at both culvert locations to ascertain the magnitude of pore pressures in the embankments. The piezometers are very sensitive, having the capability of measuring changes in pore pressure of less than 0.5 inch (1.27 cm) of water, and give reliable results over long periods of time.

The piezometers were read by measuring the air pressure required to close a hydraulic balance system *(7)*. Pore-water pressure in the soil induces a small movement of a diaphragm, causing a ball valve to open. Air pressure was introduced into the input tube causing air to flow through the hydraulic balance system and into the output tube (Figure 17). When the pressures in the two tubes become equal, the hydraulic valve closes. At this point, the pressure in the output tube, equivalent to the pore-water pressure, was read on a panel-mounted indicator.

The piezometers were installed during construction of the embankments. Two holes were drilled at Station 123 + 95, one on each side of the culvert (Figure 18). Subsequently, a thin layer of sand was deposited in the bottom of the boreholes, the pore-pressure transducers were lowered into the holes, and sand deposited around them. Two layers of bentonite, separated by sand, were used to seal the transducer from water draining down from above.

Installation at Station 268 + 30 consisted of manually drilling two holes approximately 4.5 feet (1.4 m) below the top of the culvert (Figure 18). The holes were made when the fill height was slightly above the culvert. A hole was located on each side of the culvert about 1 foot (0.31 m) from the sidewall and approximately 15 feet (4.6 m) west of the roadway centerline. The piezometers were then installed in the same manner as those at Station 123 + 95.

DATA PRESENTATION

The settlement gages, pressure cells, and piezometers are currently being read periodically. At this time, there are long time intervals between readings because both embankments are in the secondary stage of consolidation.

Pressure Cells

The pressures obtained from the Carlson cells have been plotted against time as shown in Figures 19-28. Curves representing the expected pressure versus time were plotted for comparison purposes. Pressures expected to occur at the top slab were calculated for untrenched culverts using design formulas outlined in Section 1.2.2 of the current AASHTO **Standard Specifications for Highway Bridges.** Pressures expected in the sidewalls were calculated by multiplying the vertical pressures at the respective cells by Rankine's coefficient for lateral pressure. Calculated pressures in the footers were obtained by summing the weight of the soil and the weight of the structure. Pressure expected on the bedrock beside the culverts were calcuated using P = Wh, where W is the unit weight of the soil and h is the height of the soil above the point of interest.

The pressure-time plots show that greater than expected pressures are occurring in the top slab and footer at both culvert locations. At Station 268 + 30, the pressure at Cell PE-55 in the top slab exceeded the expected value by 20 psi (2.9 kPa) (46 percent). At Cells PE-43 and PE-44, located in the footer, the pressures were 20 psi (2.9 kPa) (44 percent) and 41 psi (6.0 kPa) (91 percent) greater, respectively. Also, Cells 50 and 51, located in the right sidewall, indicated excess pressures of 12 psi (1.7 kPa) (83 percent) and 6 psi (0.9 kPa) (41 percent), respectively. Cells PE-52 and PE-58 indicated excessive pressures at the soil-bedrock interface. Cell PE-52 recorded 16 psi (2.3 kPa) (40 percent) higher than the expected pressure whereas Cell PE-58 recorded a pressure 66 psi (9.6 kPa) (165 percent) greater than the expected value.

Actual pressures exceeded Wh at Station 123 + 95 (the top slab and the footer). The measured pressure on the top slab was 38 psi (5.5 kPa) (53 percent) greater than that anticipated. The measured pressure on the cells in the footer (PE-54 and PE-47) was 75 psi (10.9 kPa) (100 percent) and 35 psi (5.1 kPa) (47 percent) greater than expected, respectively.

Piezometers

Piezometers were installed at both culvert locations to ascertain the effect which pore-water pressures have on the total pressure bearing on the structure. Two piezometers at Station 268 + 30 indicated that 123 days after installation there was zero pore pressure in the embankment. Similarly, piezometers located at Station 123 + 95 showed that zero pore pressure existed in the embankment 96 days after installation. The piezometers were read periodically; and after 217 and 325 days, no pore-water pressure was recorded at Station 123 + 95 or Station 268 + 30.

Settlement

Settlement data, obtained from settlement gages, were plotted versus time for both culvert locations. The plots are shown in Figures 29-31 and 32-35 for the culverts at Stations 123 + 95 and 268 + 30, respectively.

Settlement-time plots for Station 123 + 95 indicate that the largest portion of the settlement occurred within a few days after completion of the fill. The plots show realistic values of settlement of approximately 4 inches (10.2 cm) at Gage No. 2, 6 inches (15.2 cm) at Gage No. 4, and 3 inches (7.6 cm) at Gage No. 5. In addition, Figures 36-38 show that the settlement increases with increasing distance from the culvert inlet and approaches a maximum toward the center of the embankment.

Settlement occurred in the embankment at Station 268 + 30, according to the settlement-time plots as shown in Figures 32-35. The maximum settlement was 0.35 inches (0.89 cm) at Gage No. 1 and 0.6 inches (2.1 cm), 1.4 inches (3.6 cm), and 0.2 inches (0.51 cm) at Gages No. 2, 3, and 4, respectively. There was no trend of increasing settlement with increasing distance from the culvert inlet.

DISCUSSION

The excessively high pressures which occurred in the top slab and footer at both culvert locations might have resulted simply from the fact that both of the culverts were positive projecting structures constructed on a varying foundation. High pressures would develop because the backfill material alongside the box can consolidate whereas the box cannot. Any local subsidence of the foundation transfers load to nearby, less-yielding points in the foundation. Contraflexure may occur beyond *(8)*.

From a review of design criteria *(9)*, it appears that the options allowed for varying foundation conditions along the length of a culvert can lead to very high pressure rises at points where bedrock rises or dips away. Where the foundation changes from bedrock to soil or where rock rises to or above the foundation line, it appears that one option allows the rock to be undercut at least 1 foot and backfilled with select (earth) material to prequalify the design situation to meet yielding-type foundation conditions throughout. The other most comparable option allows soil between bedrock and the foundation line to be excavated and a backfill of select material (presumably crushed rock) to be placed to the foundation line to prequalify the design situation to meet unyielding foundation conditions throughout. Comparative cost estimates determine which of these designs is specified on plans. Two factors appear to make these options structurally incomparable and unequal: (1) when the bedrock is undercut only 1 foot, a very soft, plastic, or compressible cushion material would be needed for backfill - the depth of undercutting and the type of backfill should be sufficient to balance the settlement and bearing in the soil portion of the foundation; and (2) crushed rock (such as DGA) seems inappropriate for cushion material.

At the one imperfect trench site on US 27 where the roof pressure exceeded Wh, the earth pressure alongside the box was less than Wh (but seems to be increasing with time); in the opposite direction from the centerline, the roof pressure was very low. There were no pressure-measuring devices underneath the boxes there; some were installed on KY 627. There, the bearing pressures underneath (footer) exceeded the pressures on the roof slab. These observations are believed to be indications of box-beam action along the line of the culvert and of differential settlement.

The high bearing pressures on the bedrock at Station 268 + 30 (Pressure Cells PE 52 and 58) remain unexplained. They seem to accompany high pressures on the right sidewall, roof slab, and footer. The low settlement readings at Station 268 + 30 can be attributed to firmness of the foundation at that site.

Also of importance are the zero pore-pressure readings obtained at both Stations 123 + 30 and 268 + 30. These readings were considered to be realistic values because the embankment is composed of shot limestone rock, which would be conducive to good drainage.

RECOMMENDATIONS

It is recommended that the design procedure and options allowed for varying foundations be reviewed from the standpoint of the depth of undercutting rock and cushion material provided when the foundation condition is treated as a yielding situation.

The significance of and relationships involving some variables of box culvert design still remain indefinite. Thus, additional research of the following factors is recommended:

a. It is recommended that additional box culverts involving the imperfect trench design be instrumented to include settlement gages outside the interior soil prism to provide the capability of determining the height of the equal settlement plane.

b. The embankments of any additional culvert sites should be composed of soil rather than shot rock so that parameters of the fill material could be more readily defined.

c. An attempt should be made to choose culvert sites where construction would be fairly rapid to insure that the primary stage of the consolidation process could be observed.

d. Another site should be chosen where the culvert would be constructed on a rather deep yielding foundation without the imperfect trench, with soil fill material. This would typify many culverts built in the state.

TABLE 1. SUMMARY OF SOIL TEST DATA FOR FOUNDATION MATERIAL

	STATION 123+95	STATION 268+30
Classification		
AASHO	A-7-5	A-7-6
Unified	MH	ML-CL
Particle-Size Distribution		
% Sand (4.7 mm - 74 μ)	11.0	6.7
% Silt (74μ - 5μ)	39.5	31.2
% Clay (< 5μ)	43.0	31.0
Liquid Limit (%)	52.0	47.2
Plasticity Index (%)	18.0	18.6
Triaxial Tests		
ϕ' (degrees)	33.0	26.7
C' (psi)	1.5	2.2
(kPa)	10.3	15.2
Specific Gravity	2.57	2.63

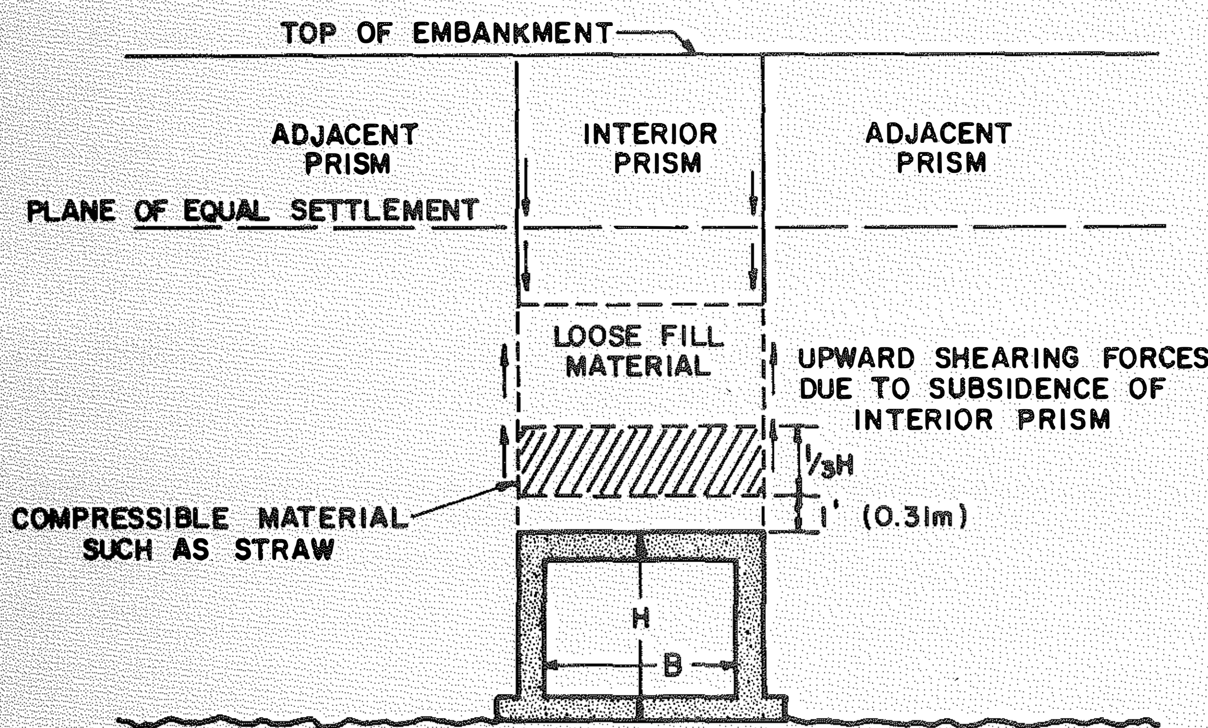


Figure 1. Imperfect Trench Design.

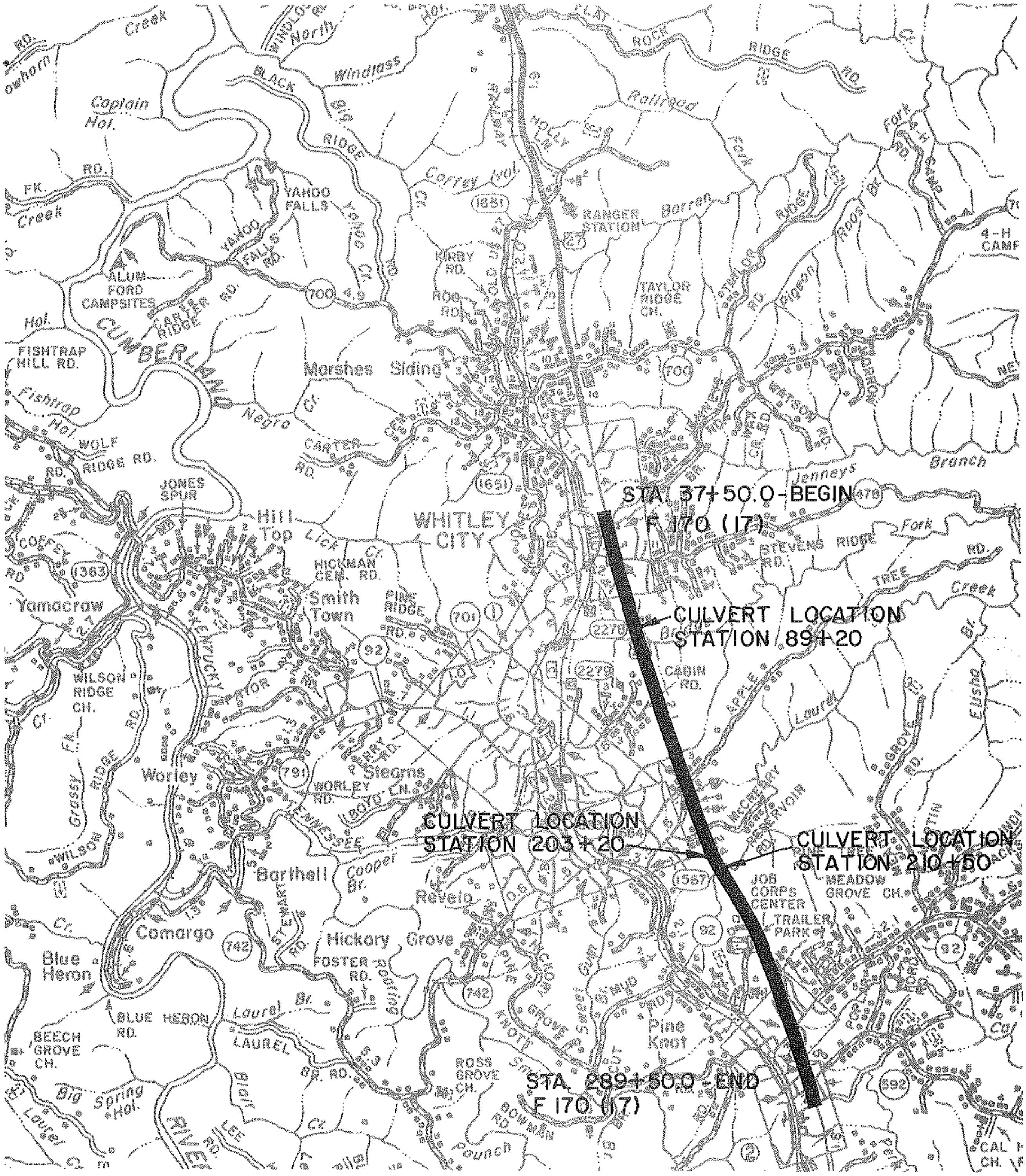


Figure 2. Plan View of the Project Location in McCreary County.

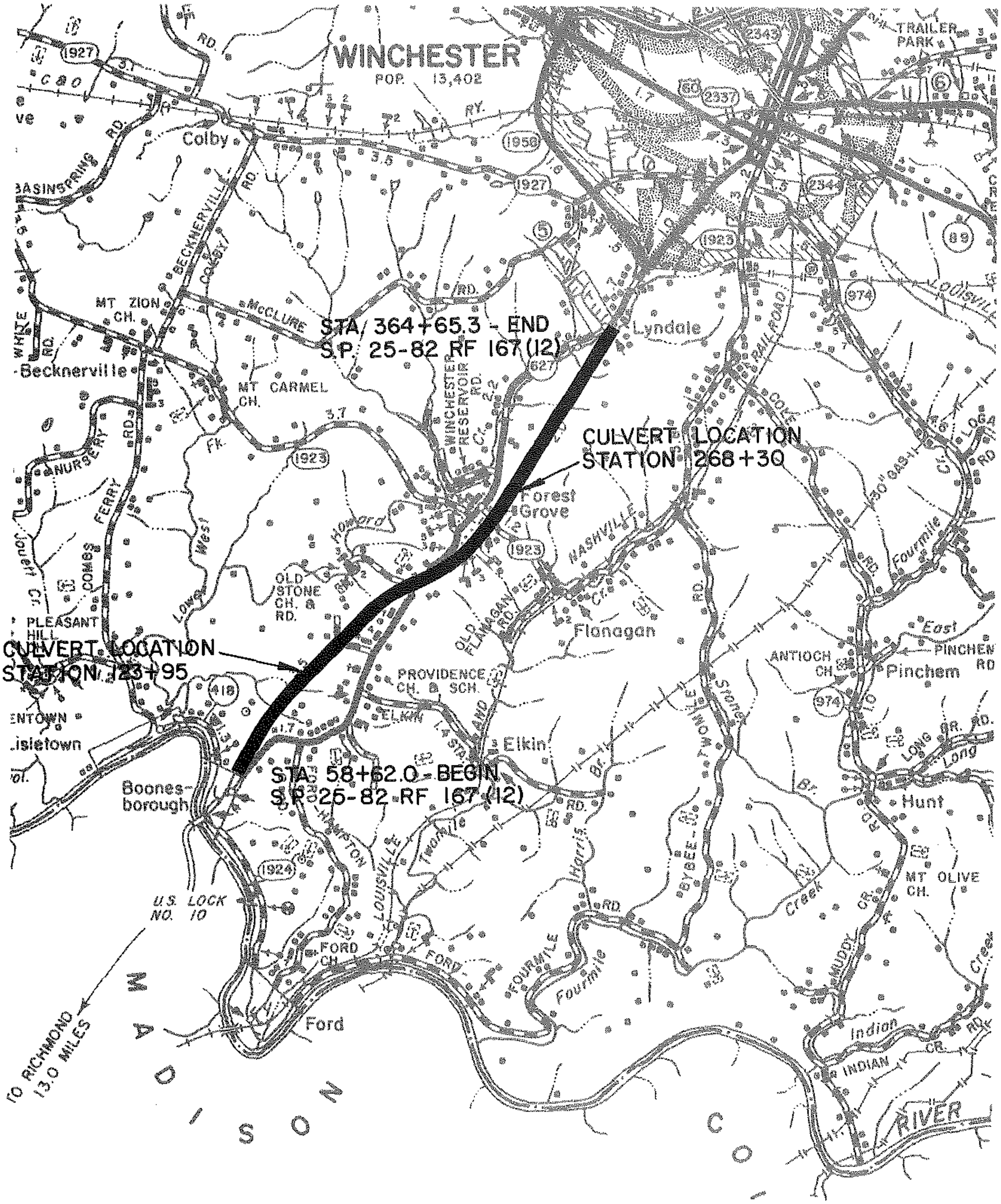


Figure 3. Plan View of the Project Location in Clark County.

Figure 4. Backfilling and Construction of Embankments at Stations 123 + 95 and 268 + 30.

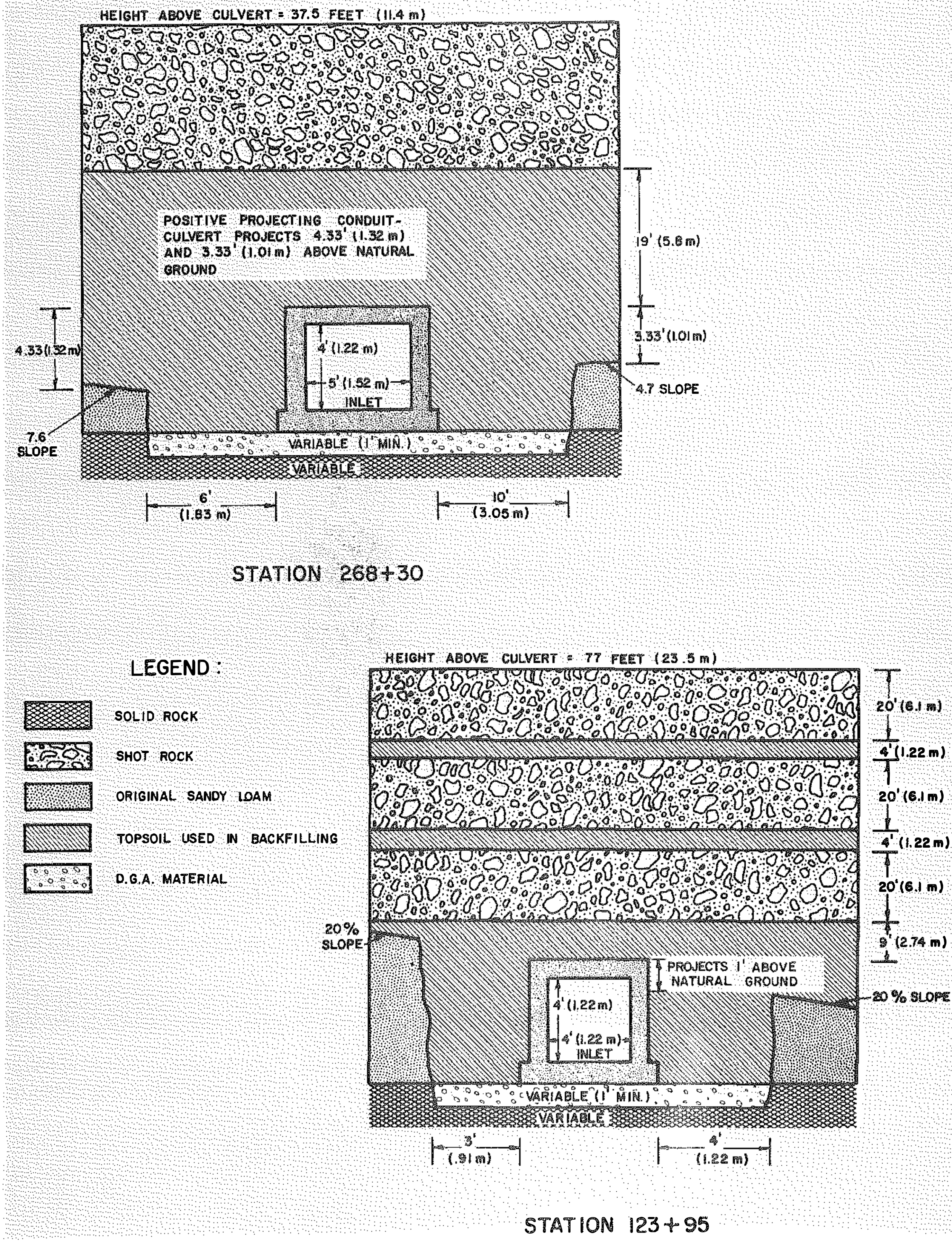
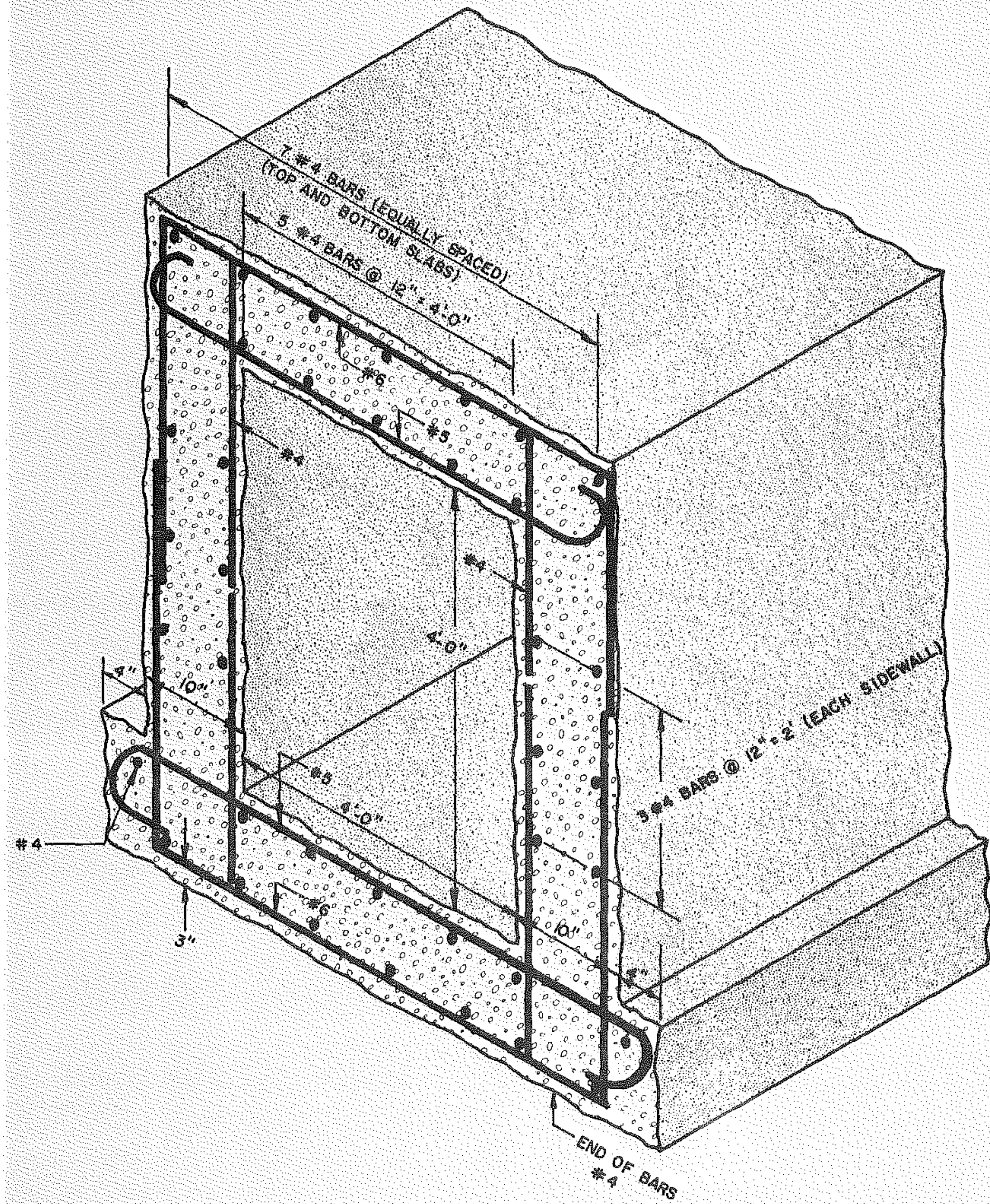


Figure 5. Design of the End Portions of the Culvert at Station 123 + 95.



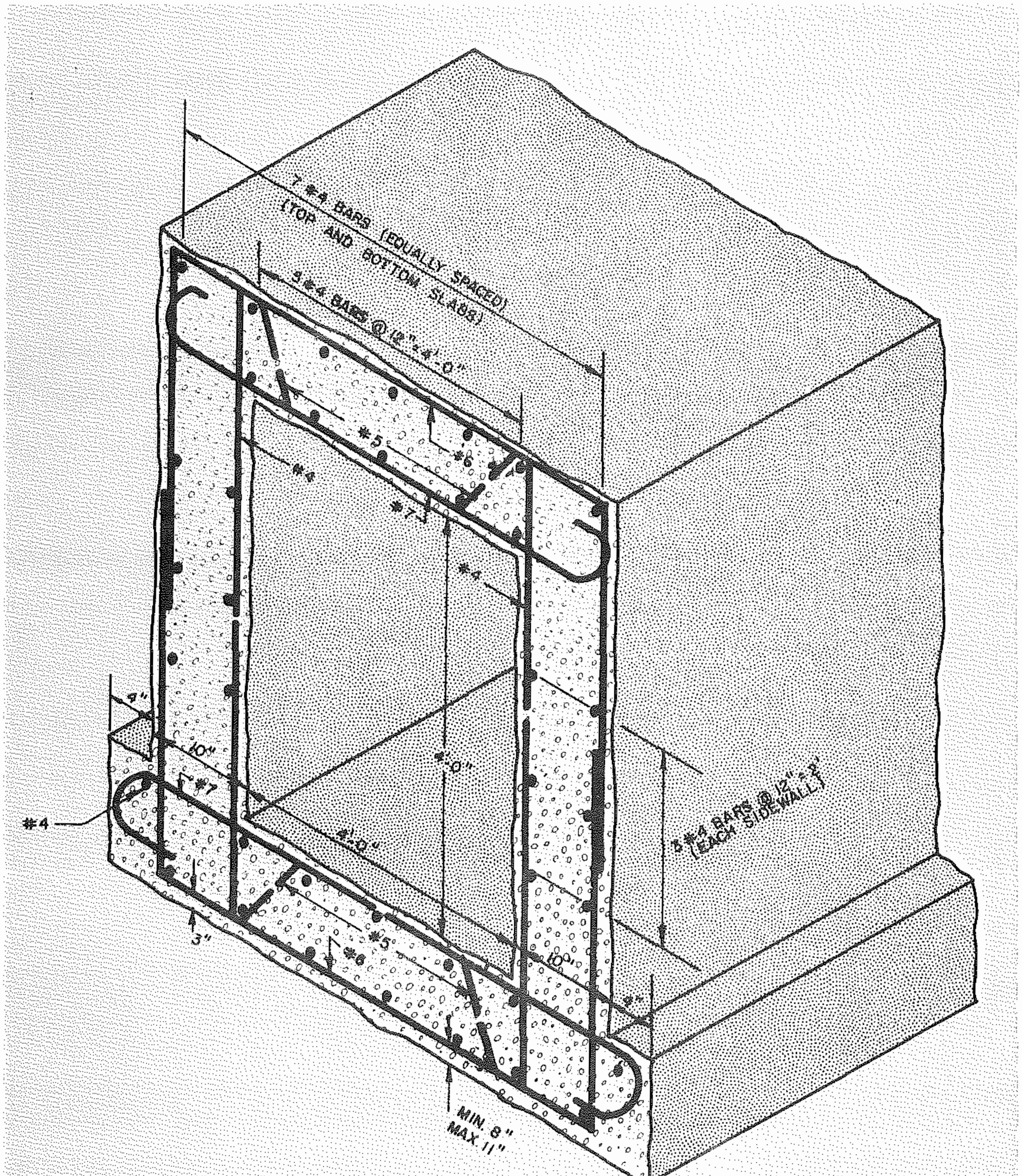


Figure 6. Design of the Central Portion of the Culvert at Station 123 + 95.

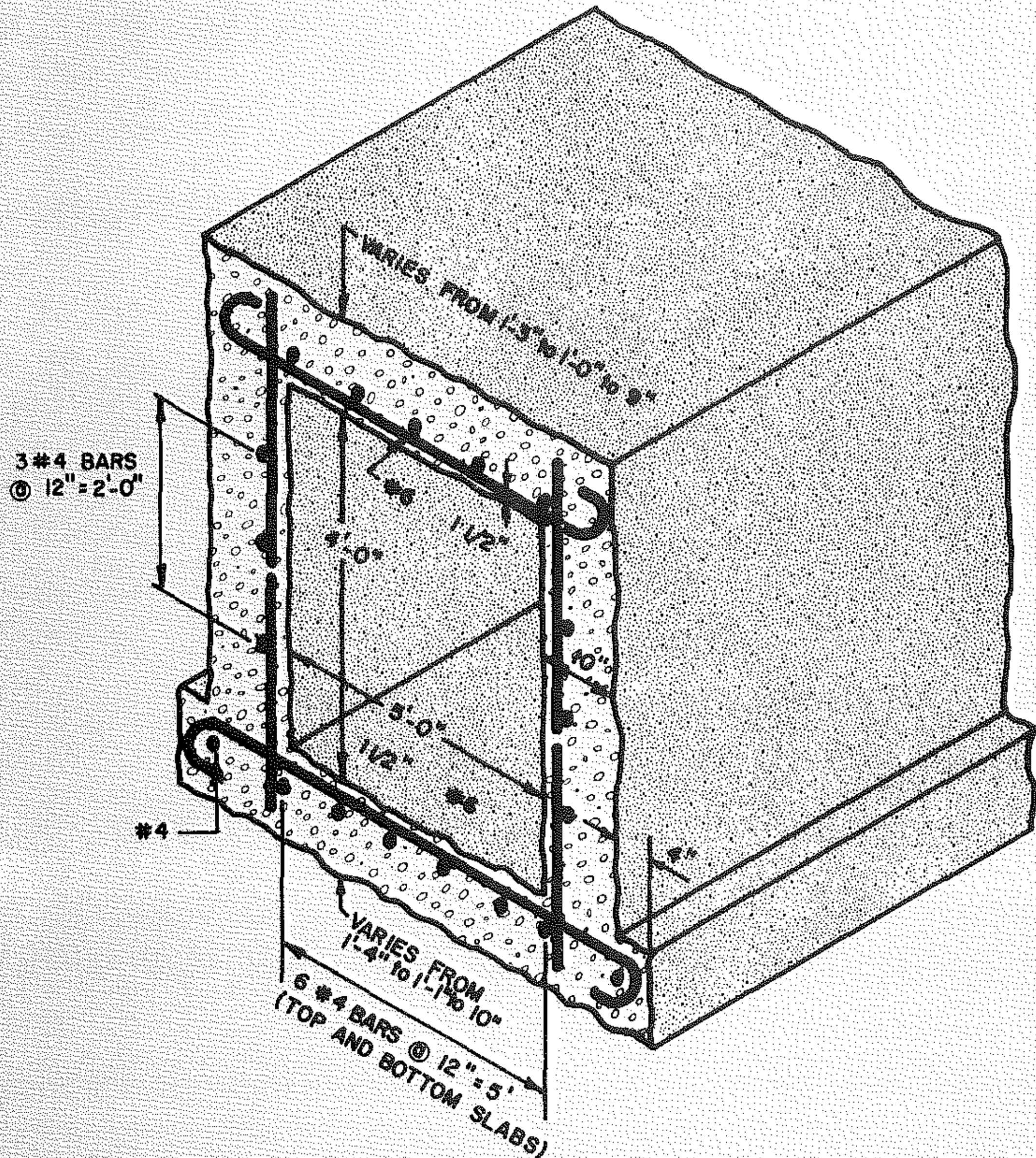


Figure 7. Design of the End Portions of the Culvert at Station 268 + 30.

Figure 8. Design of the Central Portion of the Culvert at Station 268 + 30.

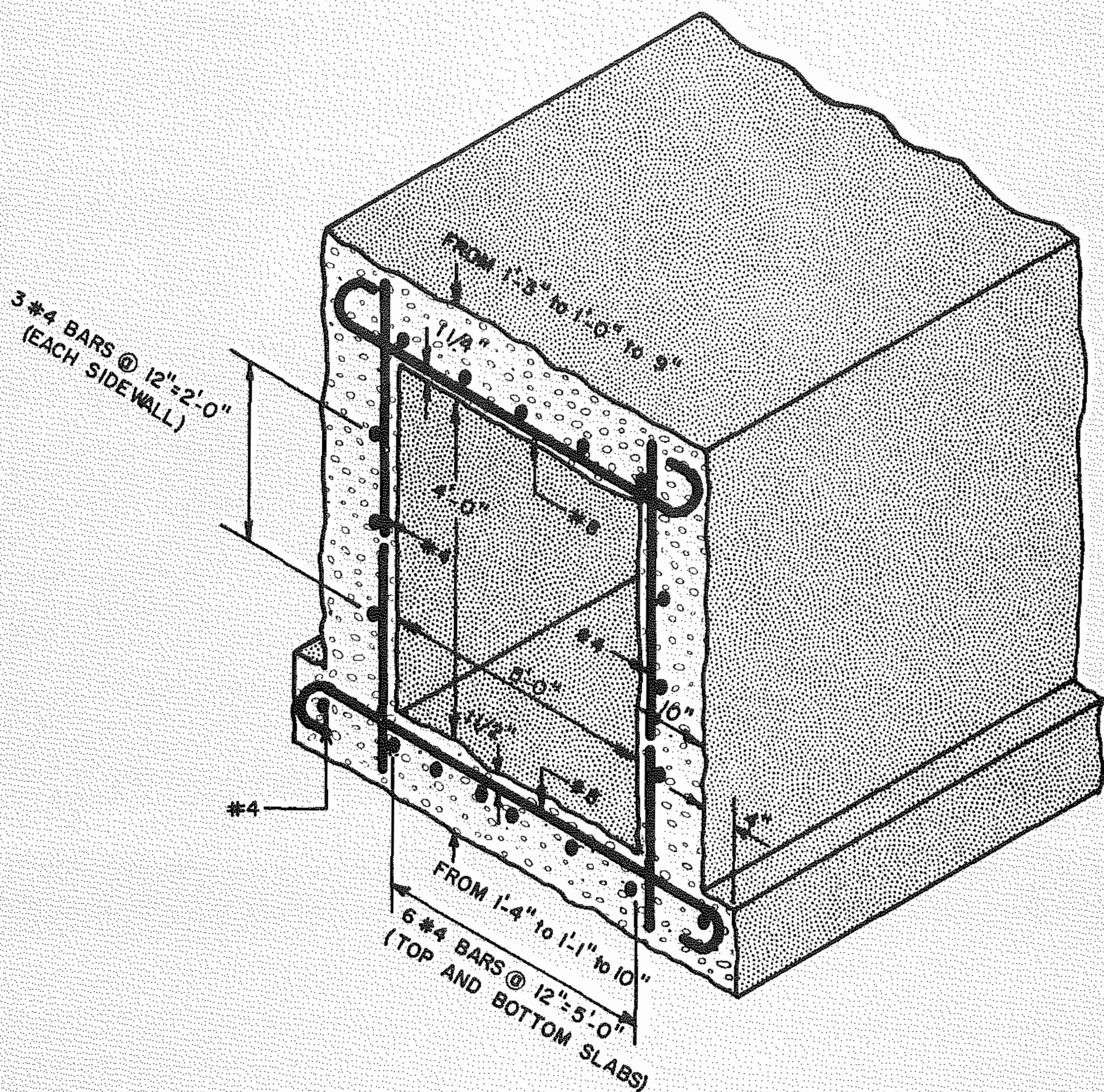
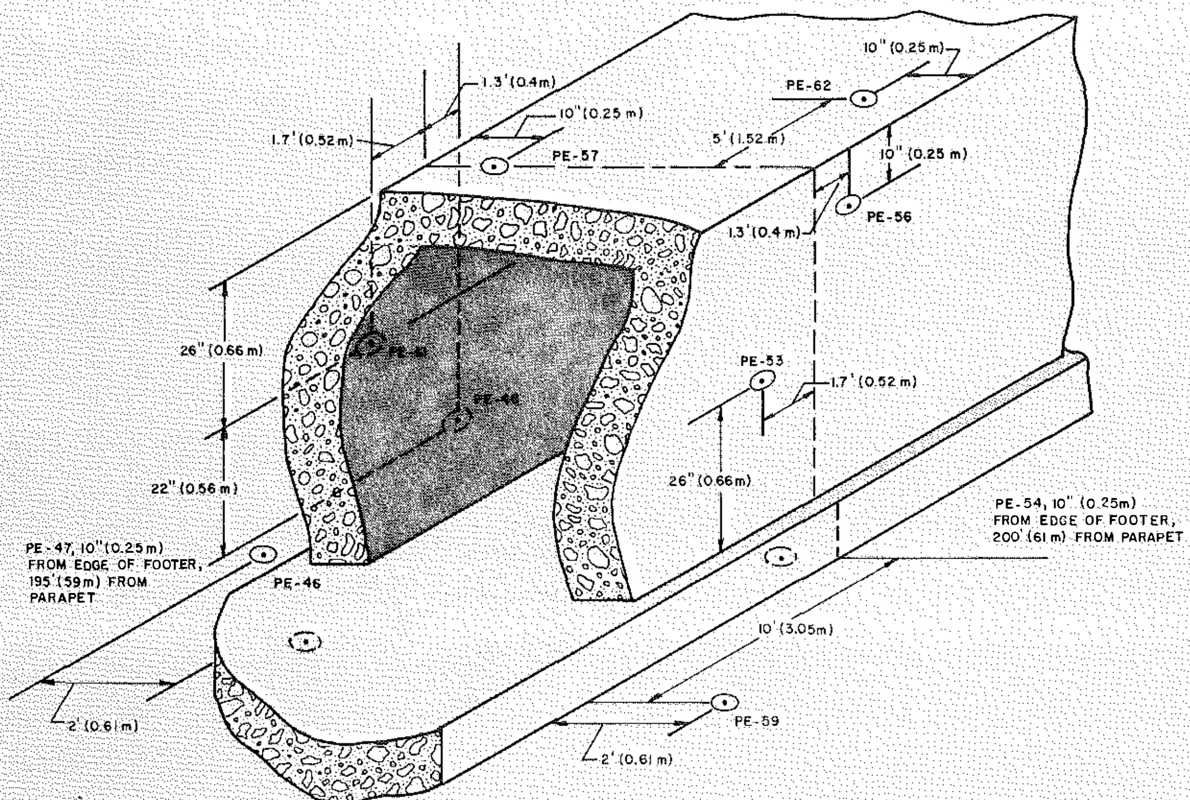


Figure 9. Isommetric Representation of Carlson Pressure. Cell Locations in The Box Culvert Located at Station 123 + 95.



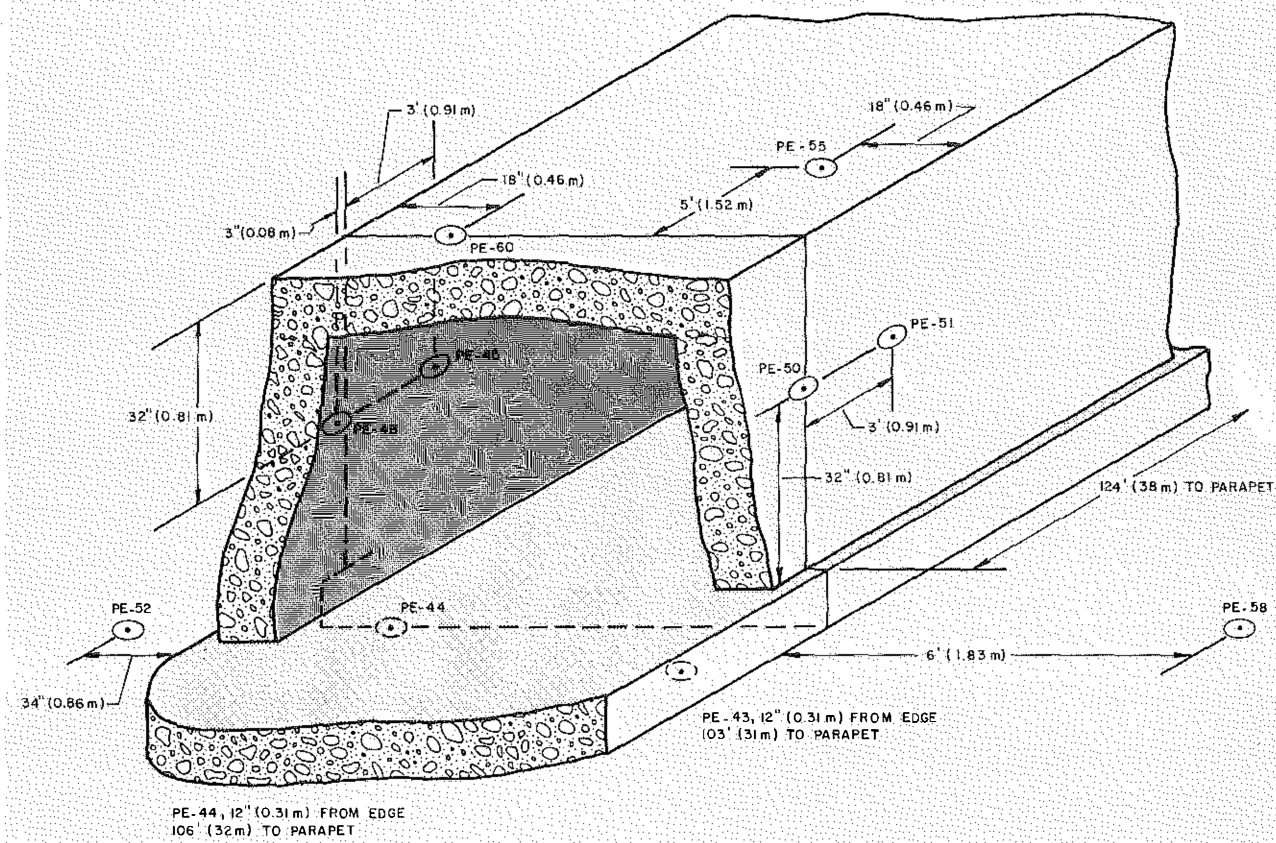
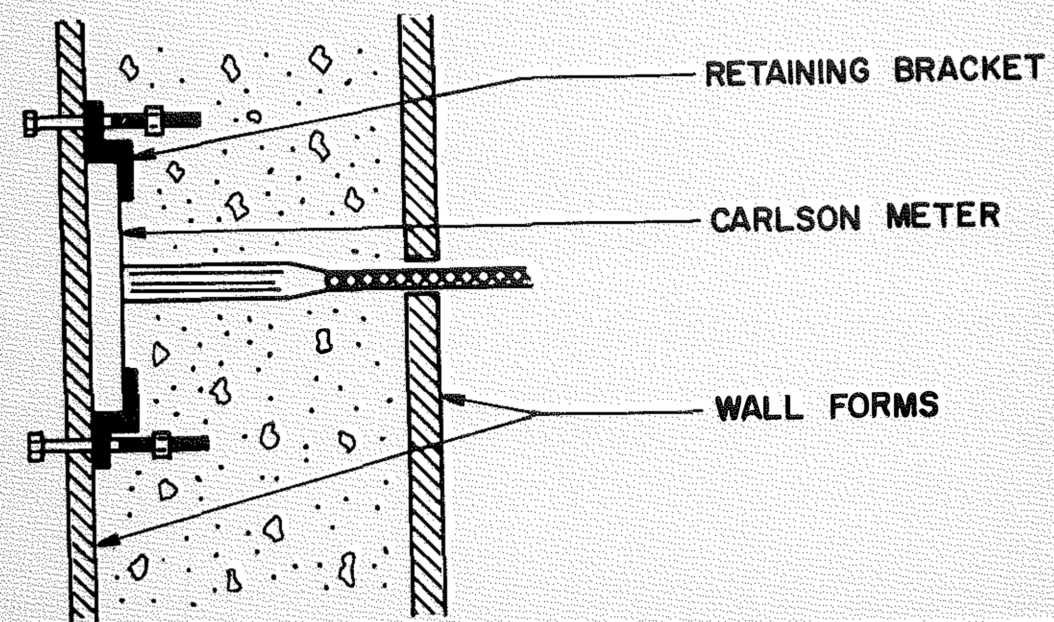


Figure 10. **Isommetric Representation of Carlson Pressure Cell Locations at Station 268 + 30.**

Figure 11. Carlson Meter Attached to Sidewall Form.



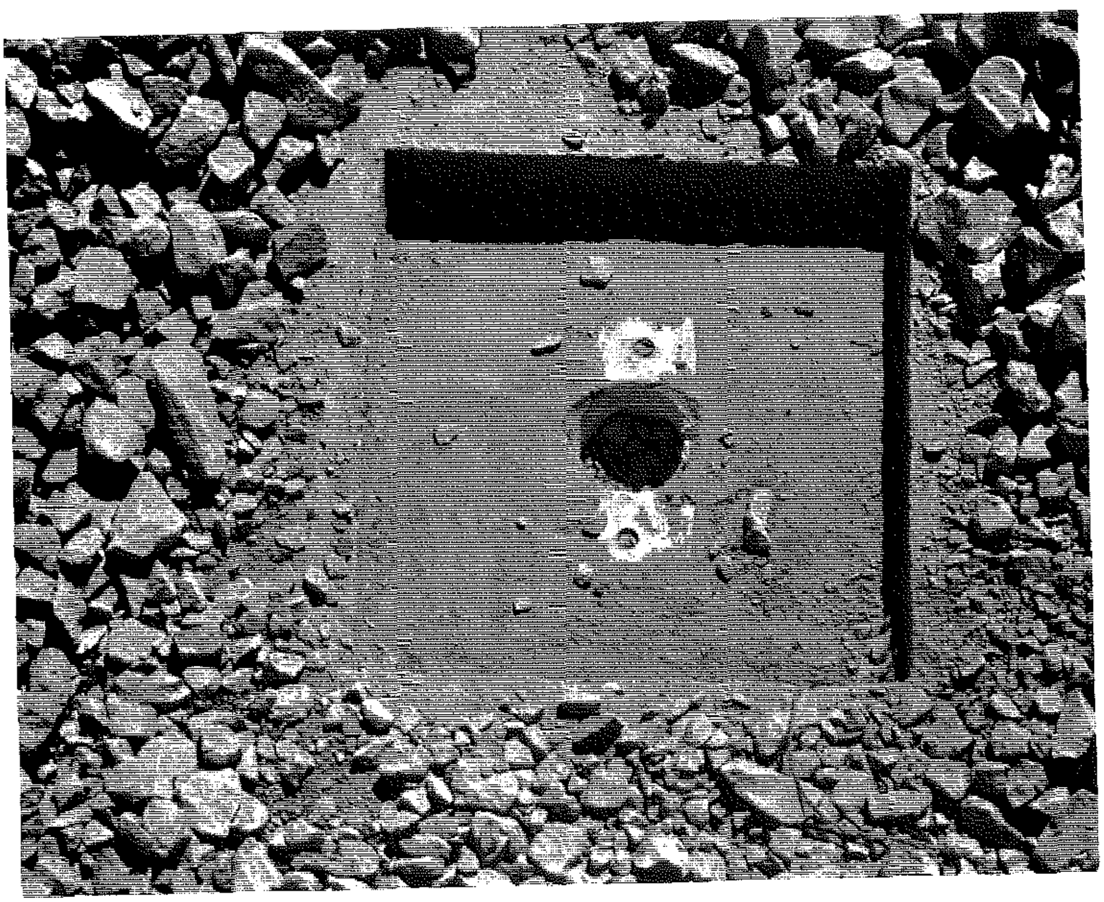


Figure 12. Square Ports Used to Install the Pressure Cells.

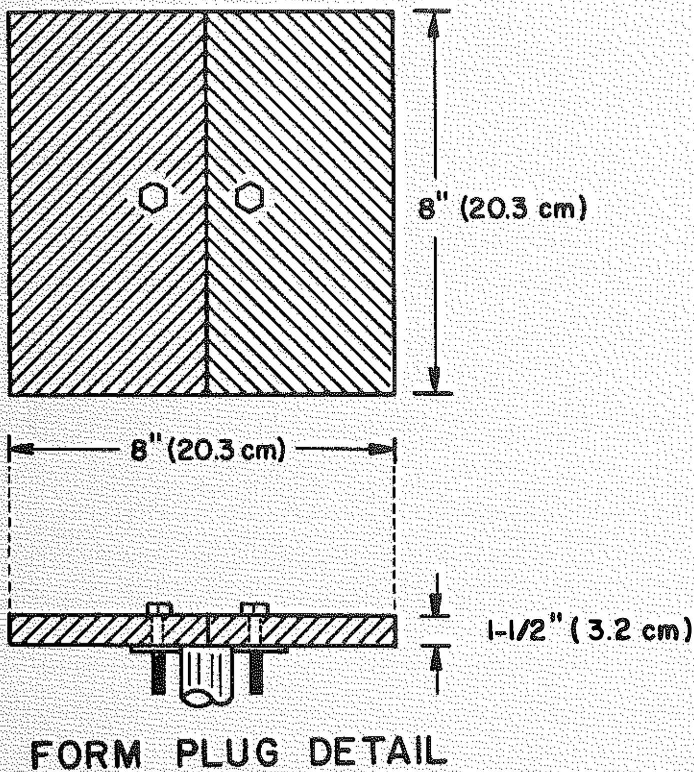


Figure 13. Top Slab Ports.

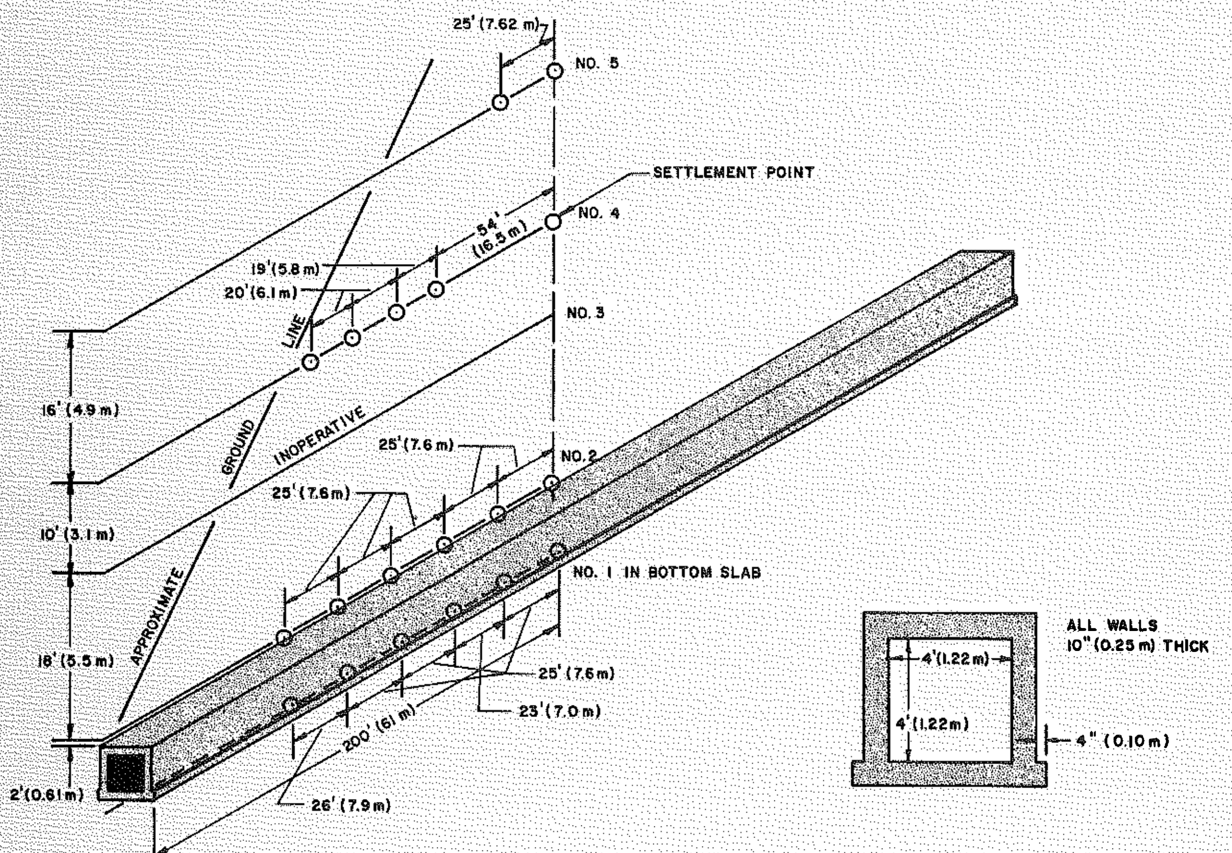


Figure 14. Locations of the Settlement Gages in the Embankment at Station 123 + 95.

Figure 15. Formation of a Ditch Used in Installing a Settlement Gage.

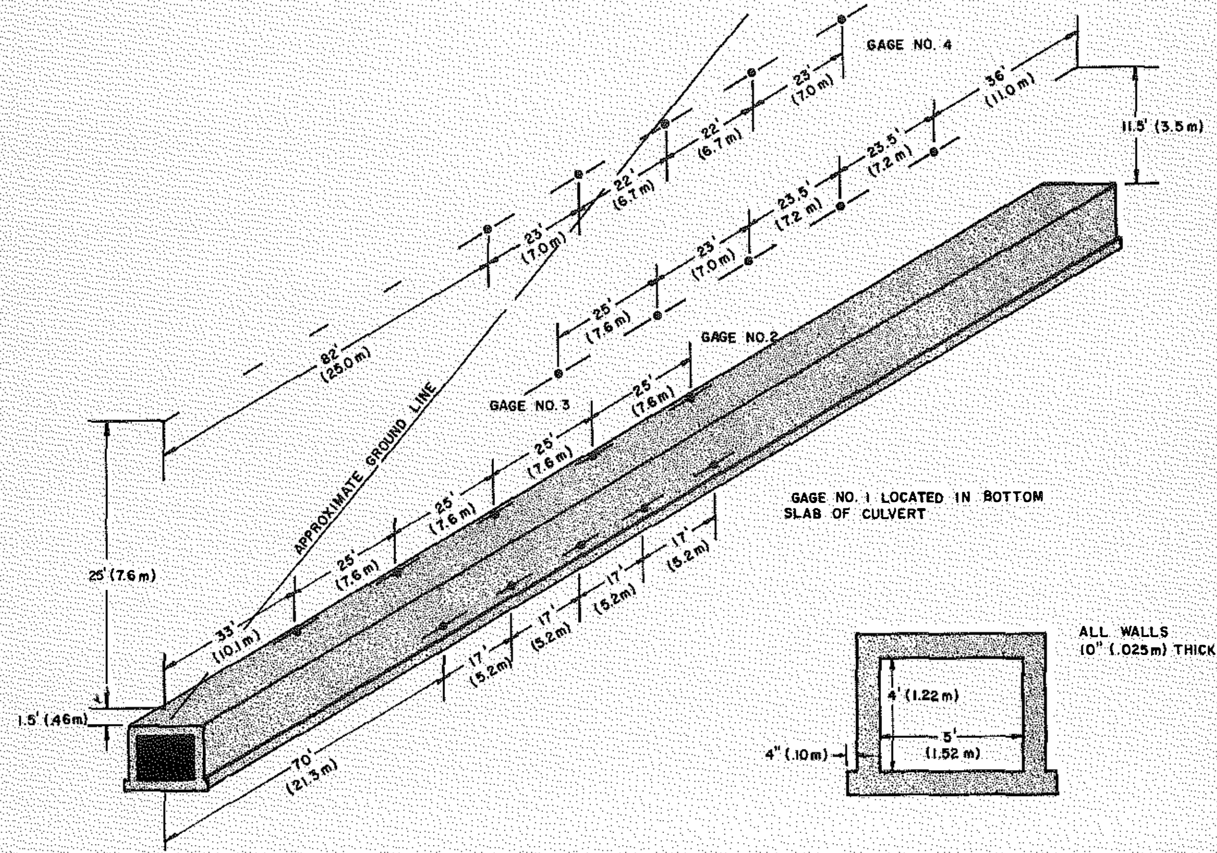


Figure 16. Locations of Settlement Gages in the Embankment at Station 268 + 30.

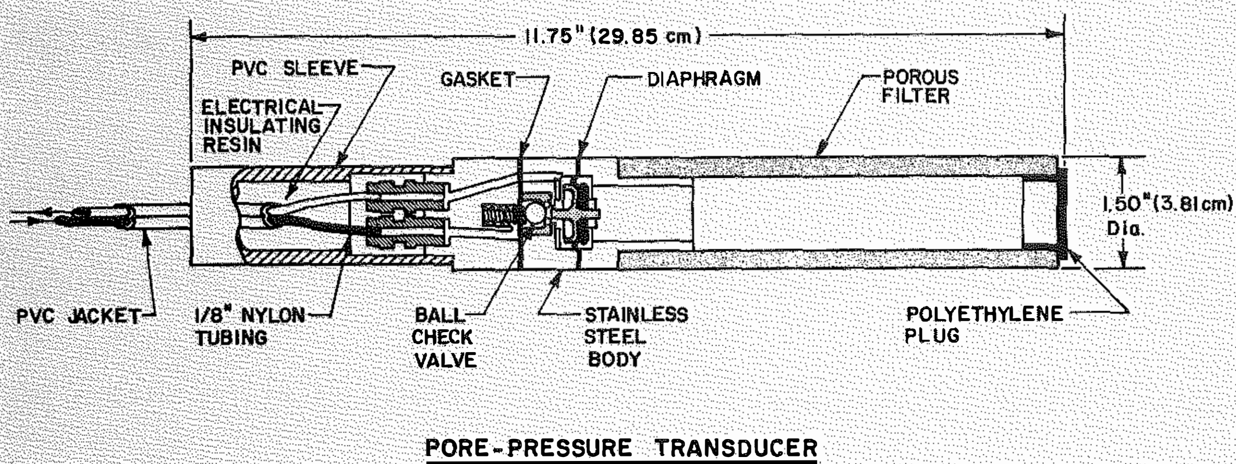


Figure 17. Schematic of Sinco Pore-Pressure Transducer.

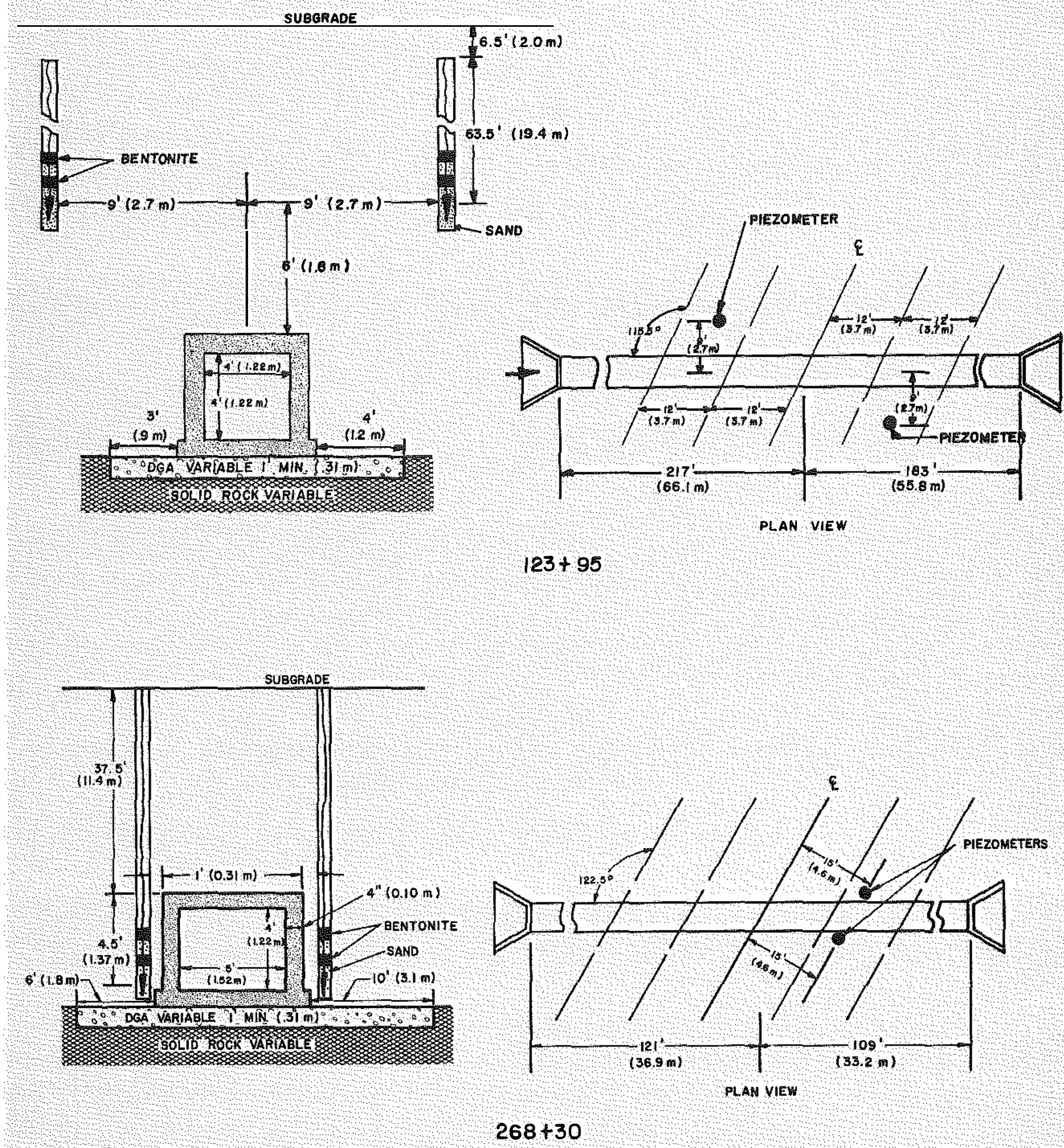
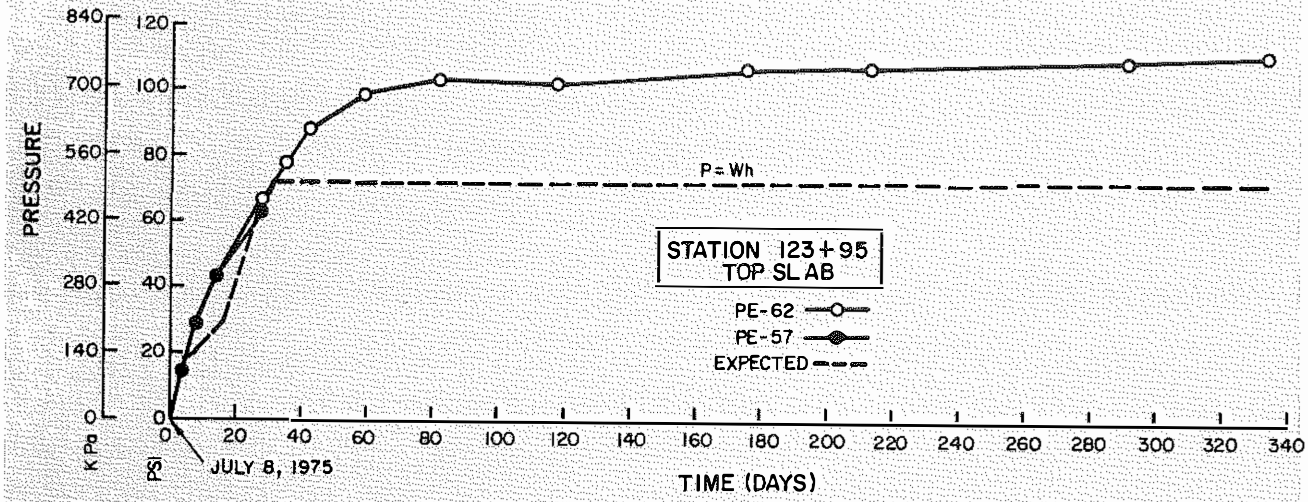


Figure 18. **Piezometer Installations at Stations 123 + 95 and 268 + 30.**

Figure 19. Pressure-Time Curves for Carlson Cells 57 and 62 Located in the Top Slab at Station 123 + 95.



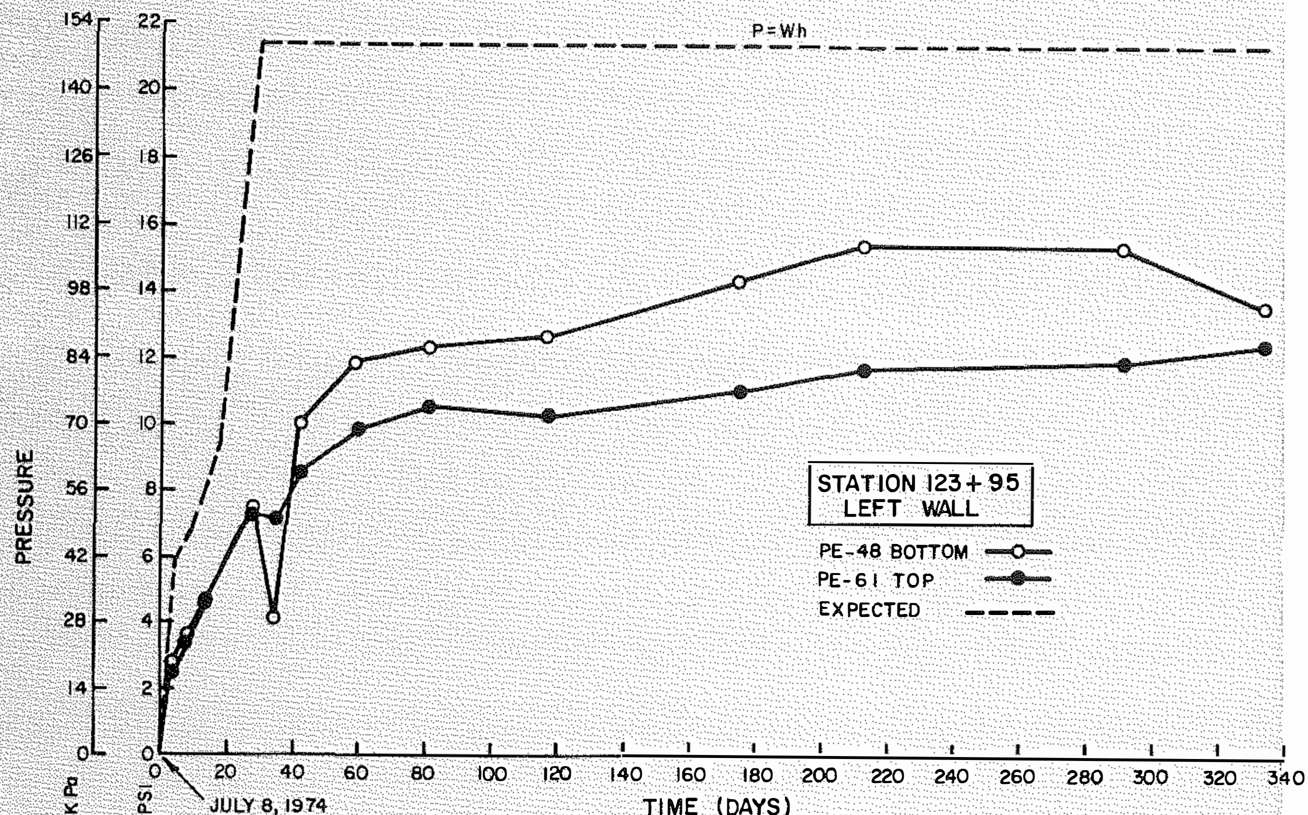
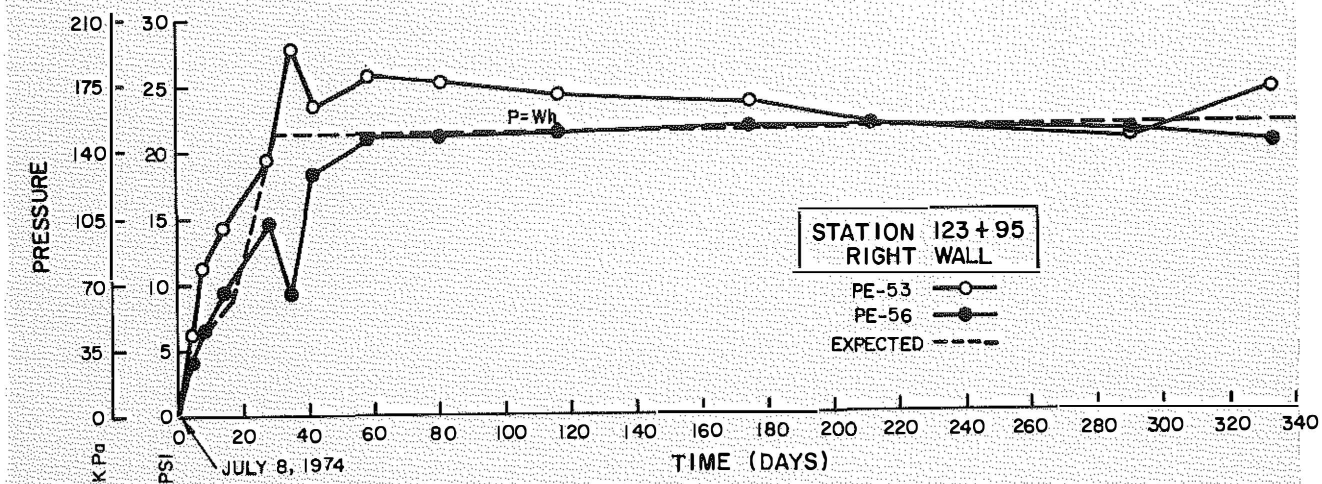


Figure 20. Pressure-Time Curves for Carlson Cells 48 and 61 Located in the Left Side Wall at Station 123 + 95.

Figure 21. Pressure-Time Curves for Carlson Cells 53 and 56 Located in the Right Side Wall at Station 123 + 95.



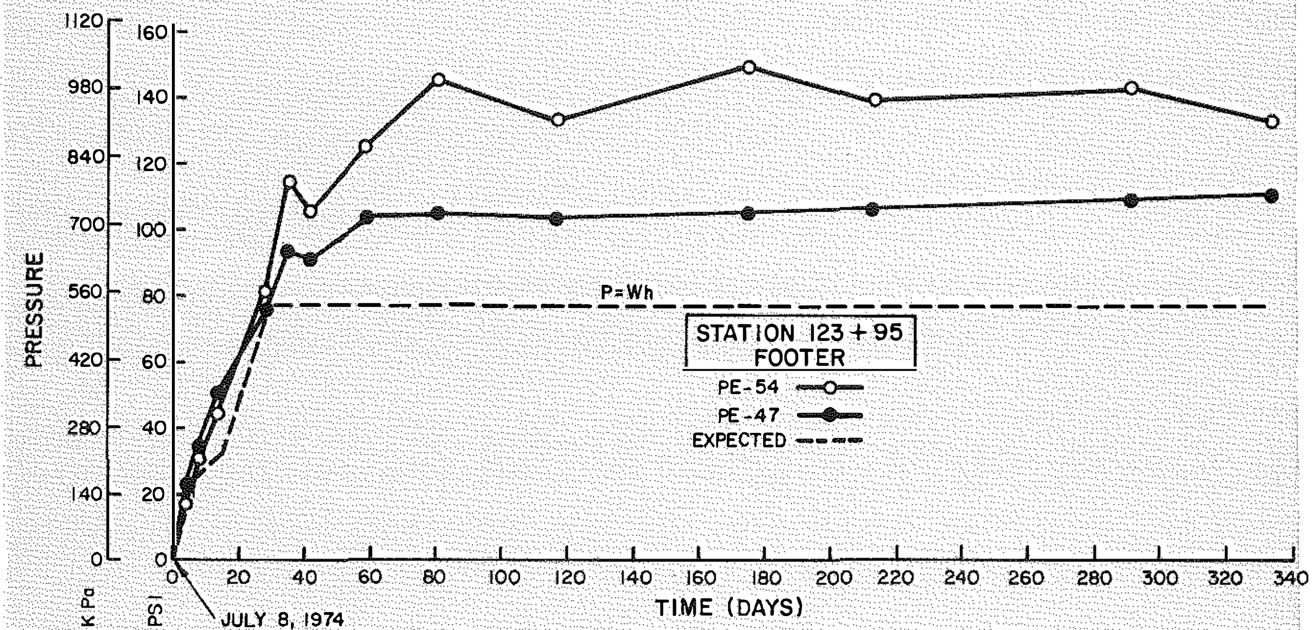
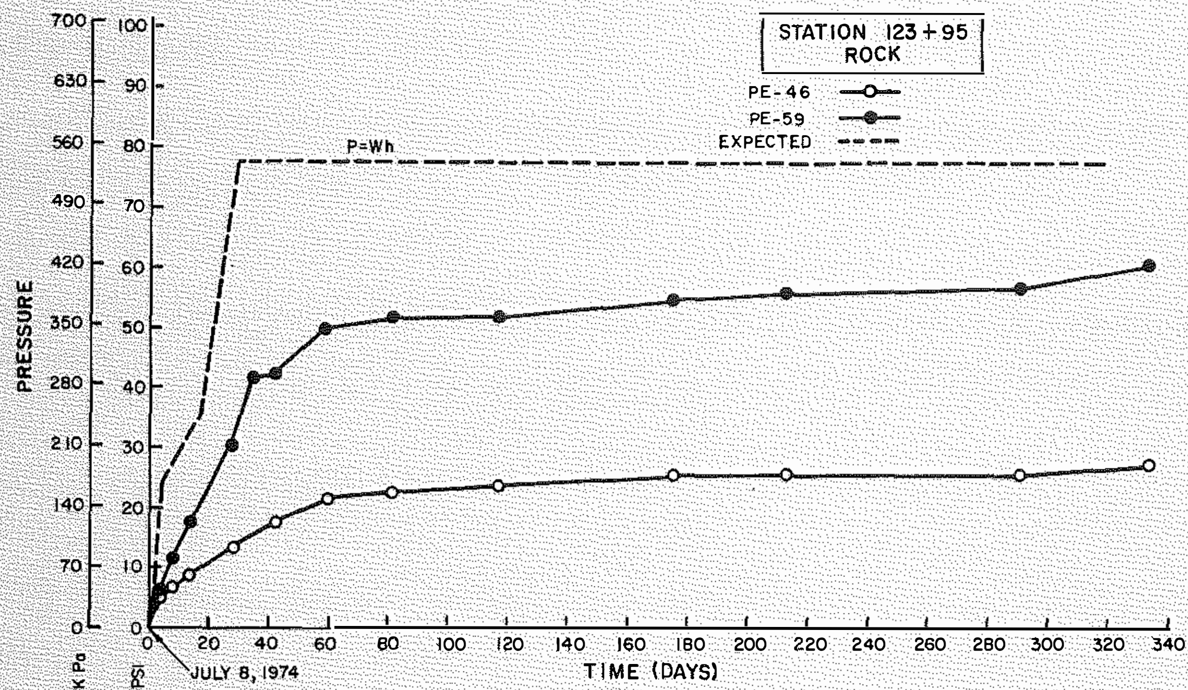


Figure 22. Pressure-Time Curves for Carlson Cells 47 and 54 Located in the Footer at Station 123 + 95.

Figure 23. Pressure-Time Curves for Carlson Cells 46 and 59 Located in Rock at Station 123 + 95.



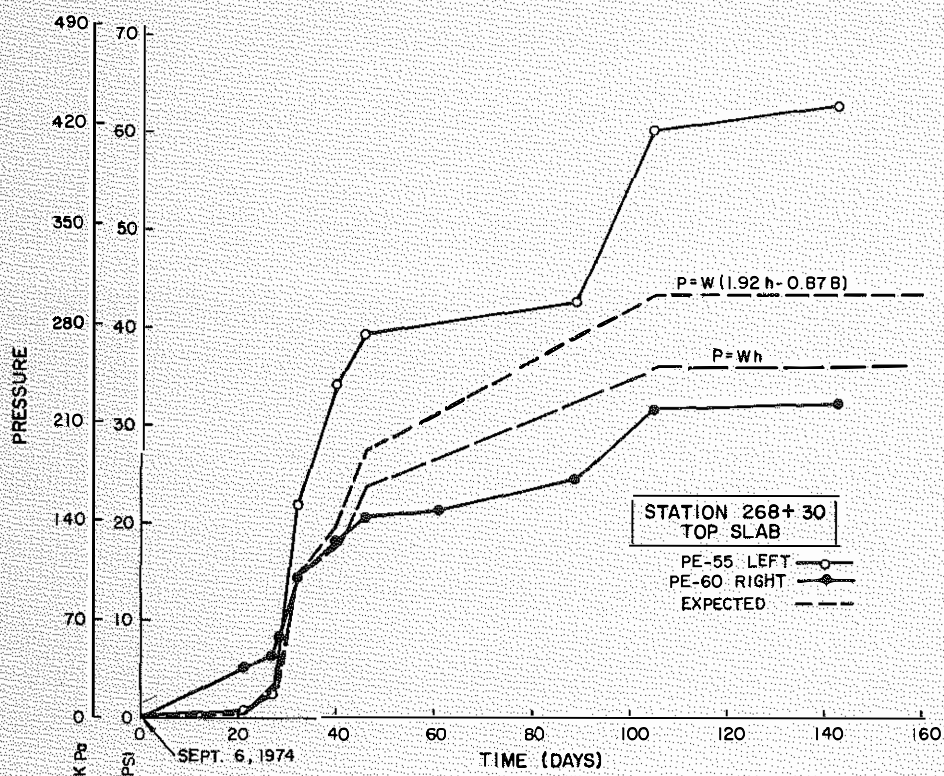
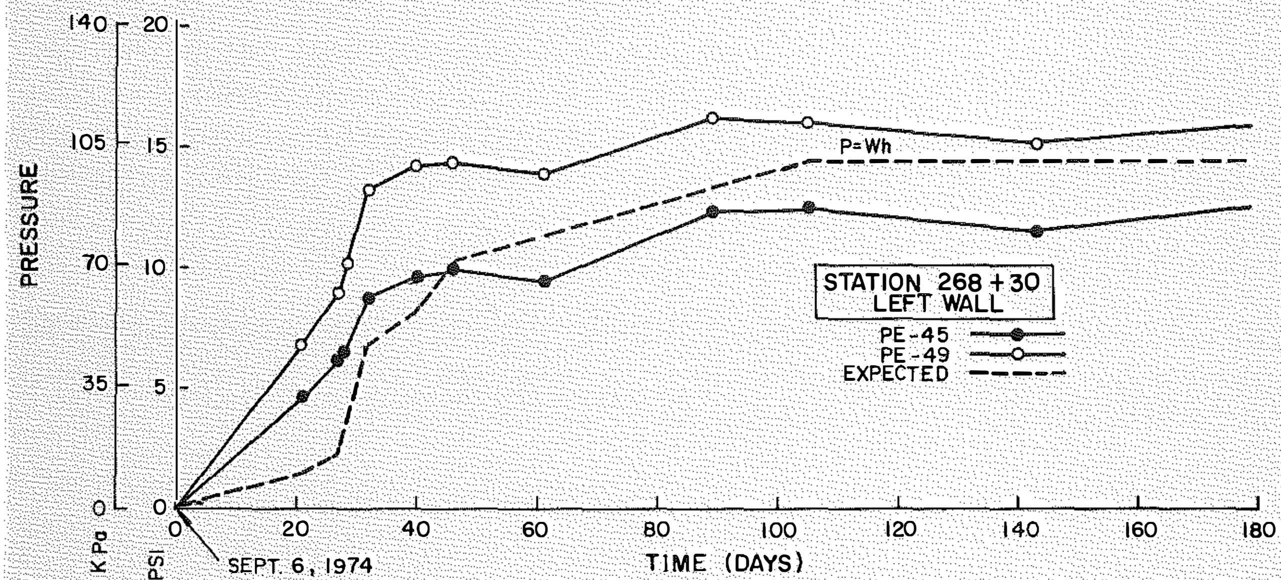


Figure 24. Pressure-Time Curves for Carlson Cells 55 and 60 Located in the Top Slab at Station 268 + 30.

Figure 25. Pressure-Time Curves for Carlson Cells 45 and 49 Located in the Left Sidewall at Station 268 + 30.



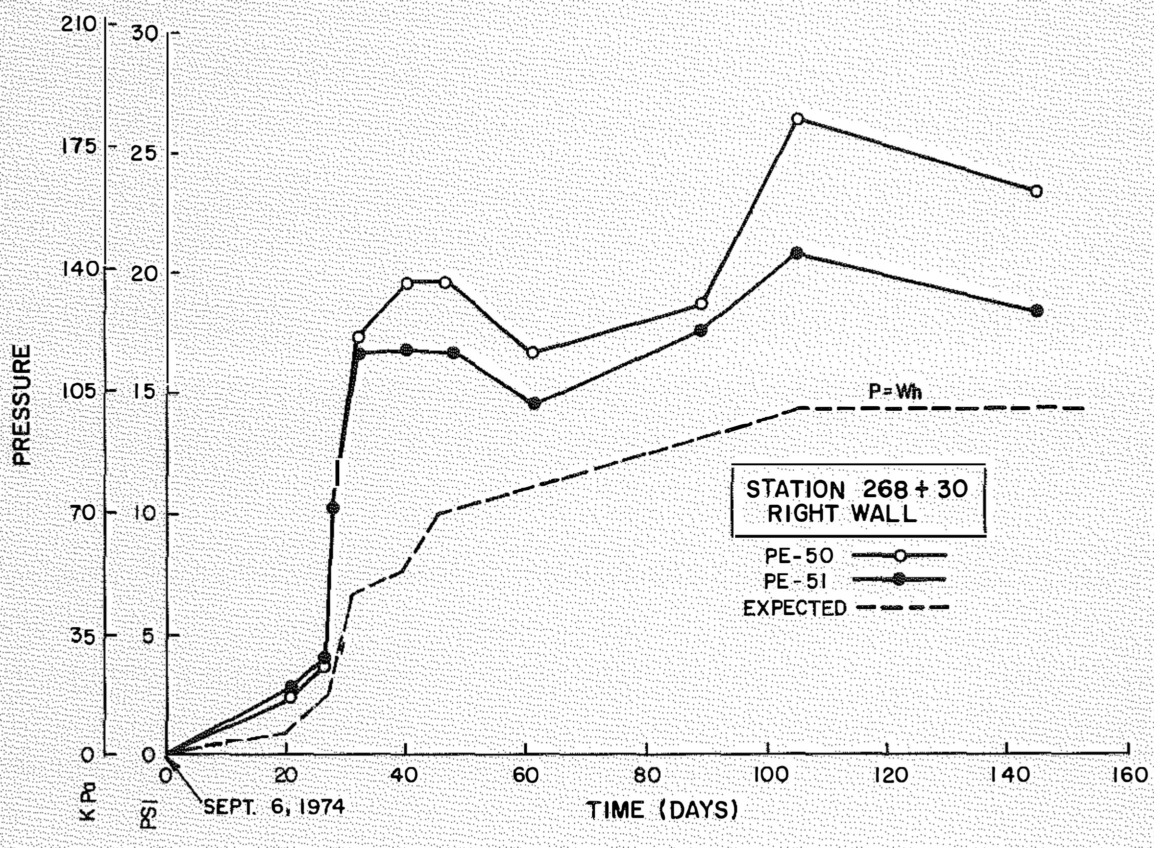
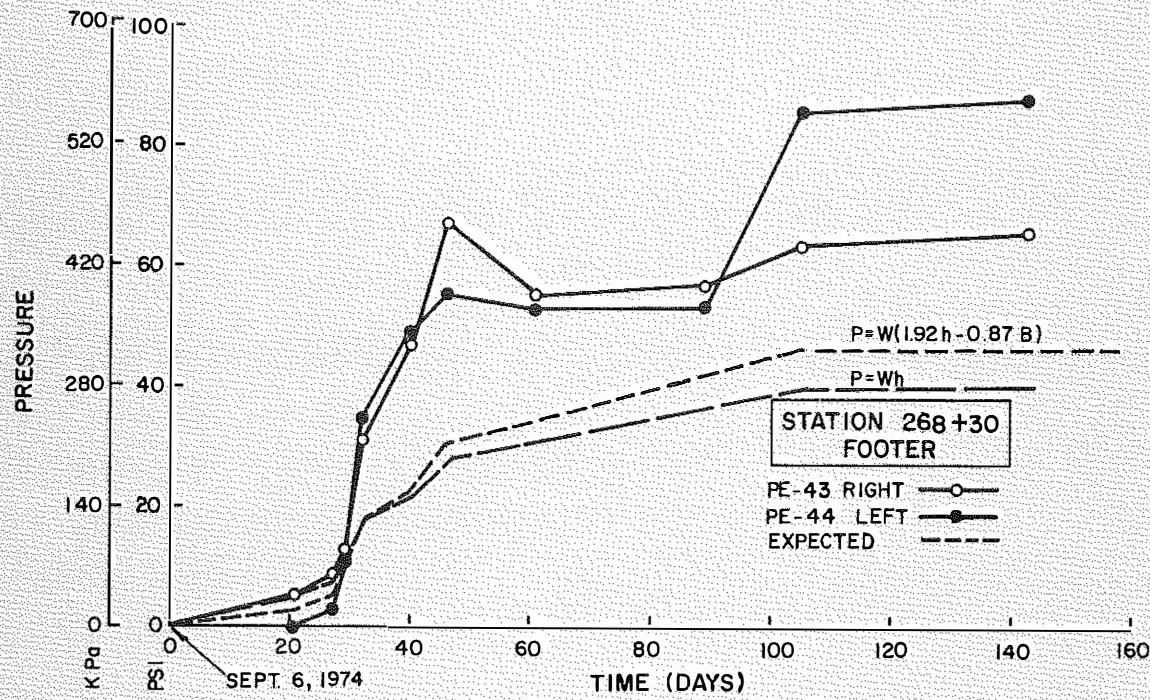


Figure 26. Pressure-Time Curves for Carlson Cells 50 and 51 Located in the Right Side Wall at Station 268 + 30.

Figure 27. Pressure-Time Curves for Carlson Cells 43 and 44 Location in the Footer at Station 268 + 30.



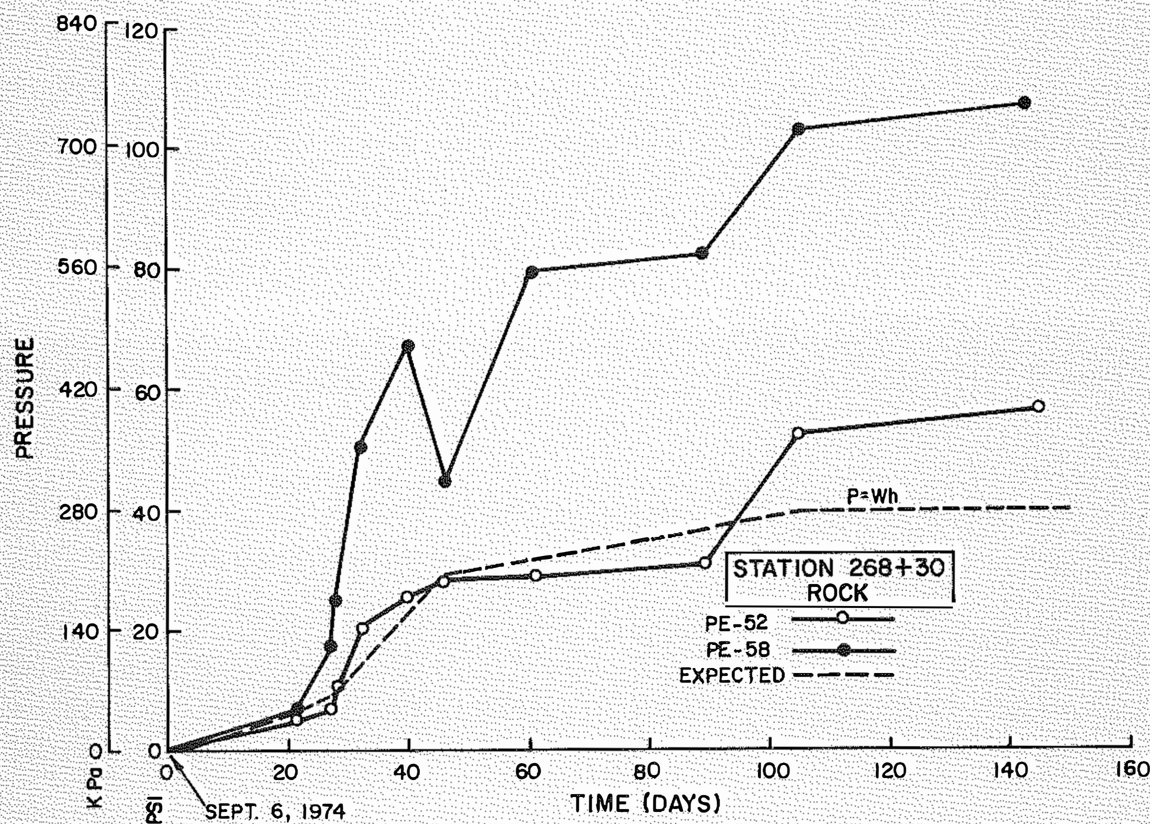


Figure 28. Pressure-Time Curves for Carlson Cells 52 and 58 Located in Rock at Station 268 + 30.

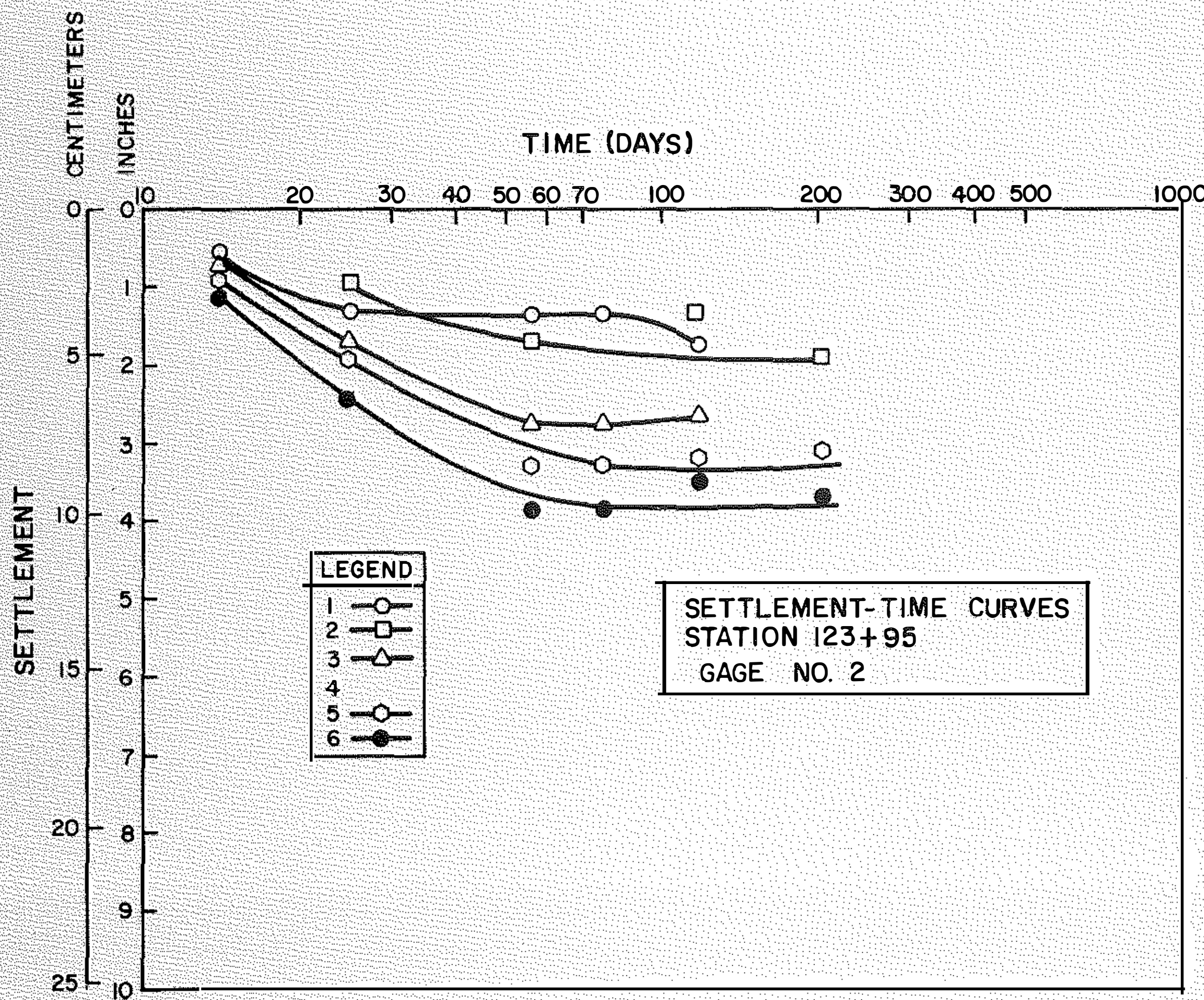


Figure 29. Settlement Versus Time for Settlement Gage 2 Located at Station 123 + 95.

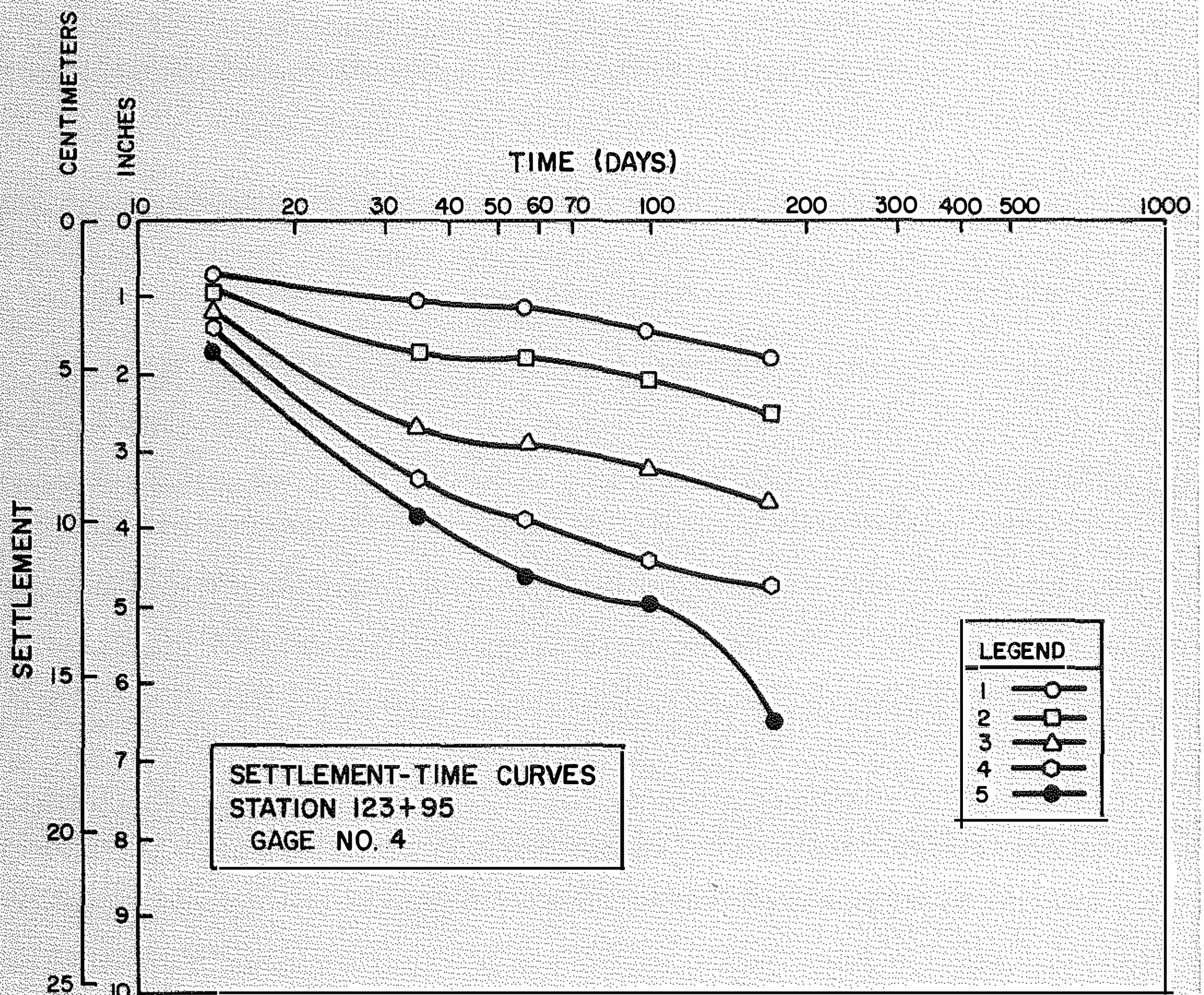
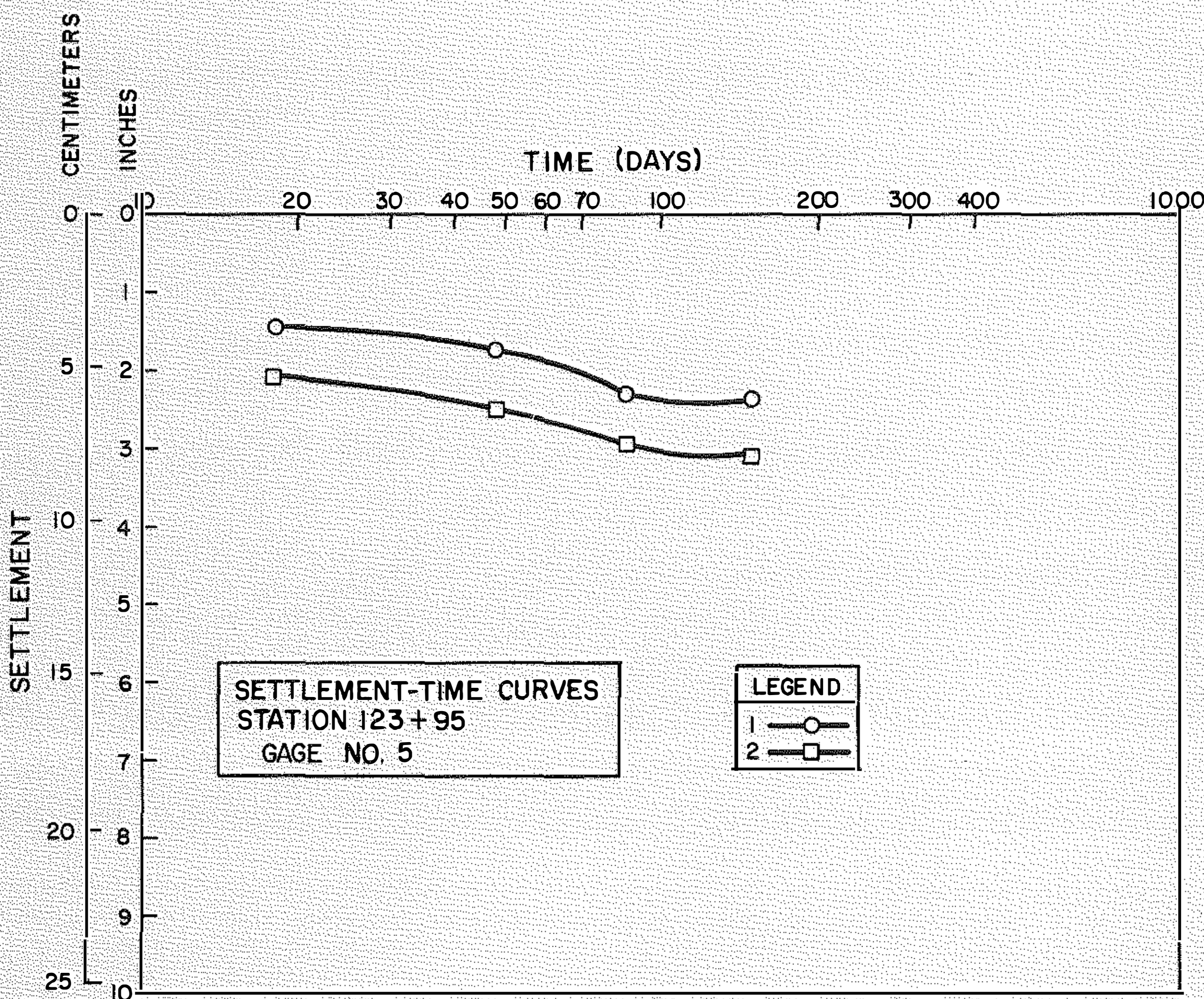


Figure 30. **Settlement Versus Time for Settlement Gage 4 Located at Station 123 + 95.**

Figure 31. Settlement Versus Time for Settlement Gage 5 Located at Station 123 + 95.



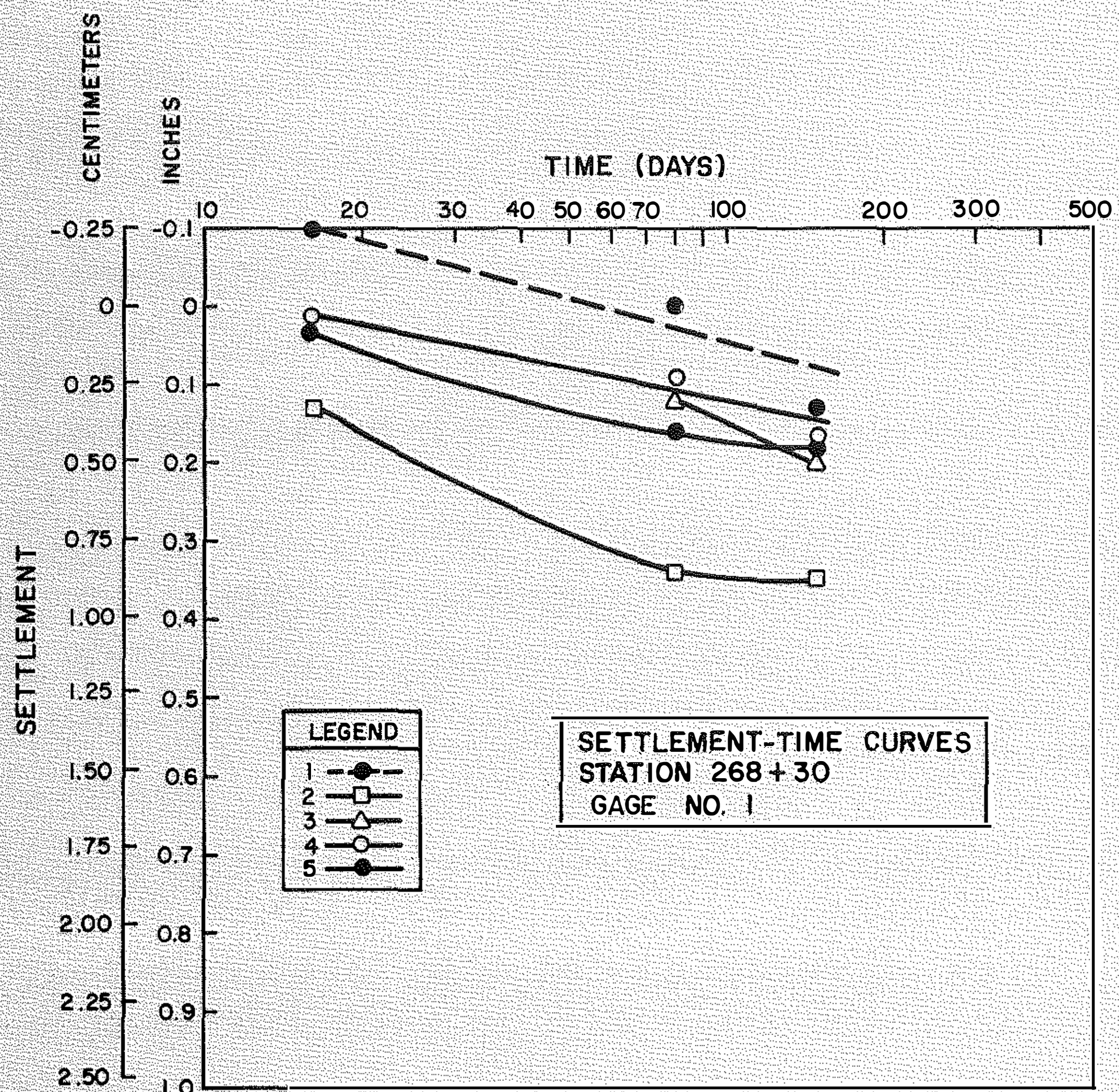
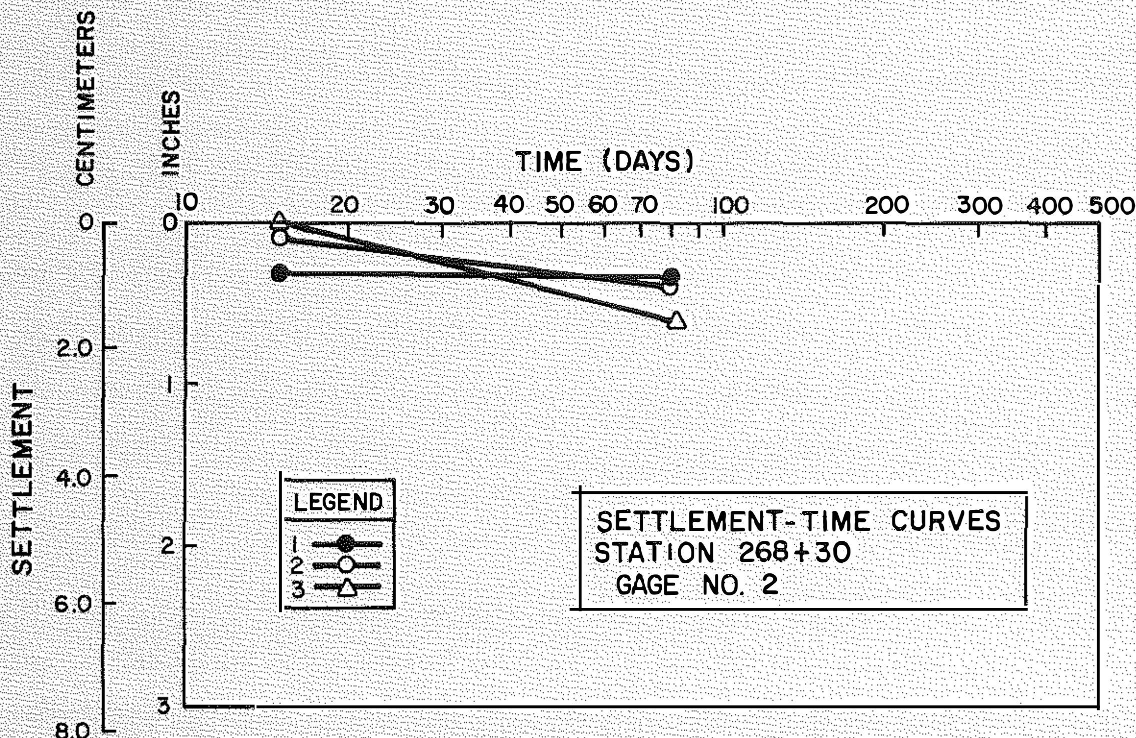


Figure 32. Settlement Versus Time for Settlement Gage 1 Located at Station 268 + 30.

Figure 33. Settlement Verus Time for Settlement Gage 3 Located at Station 268 + 30.



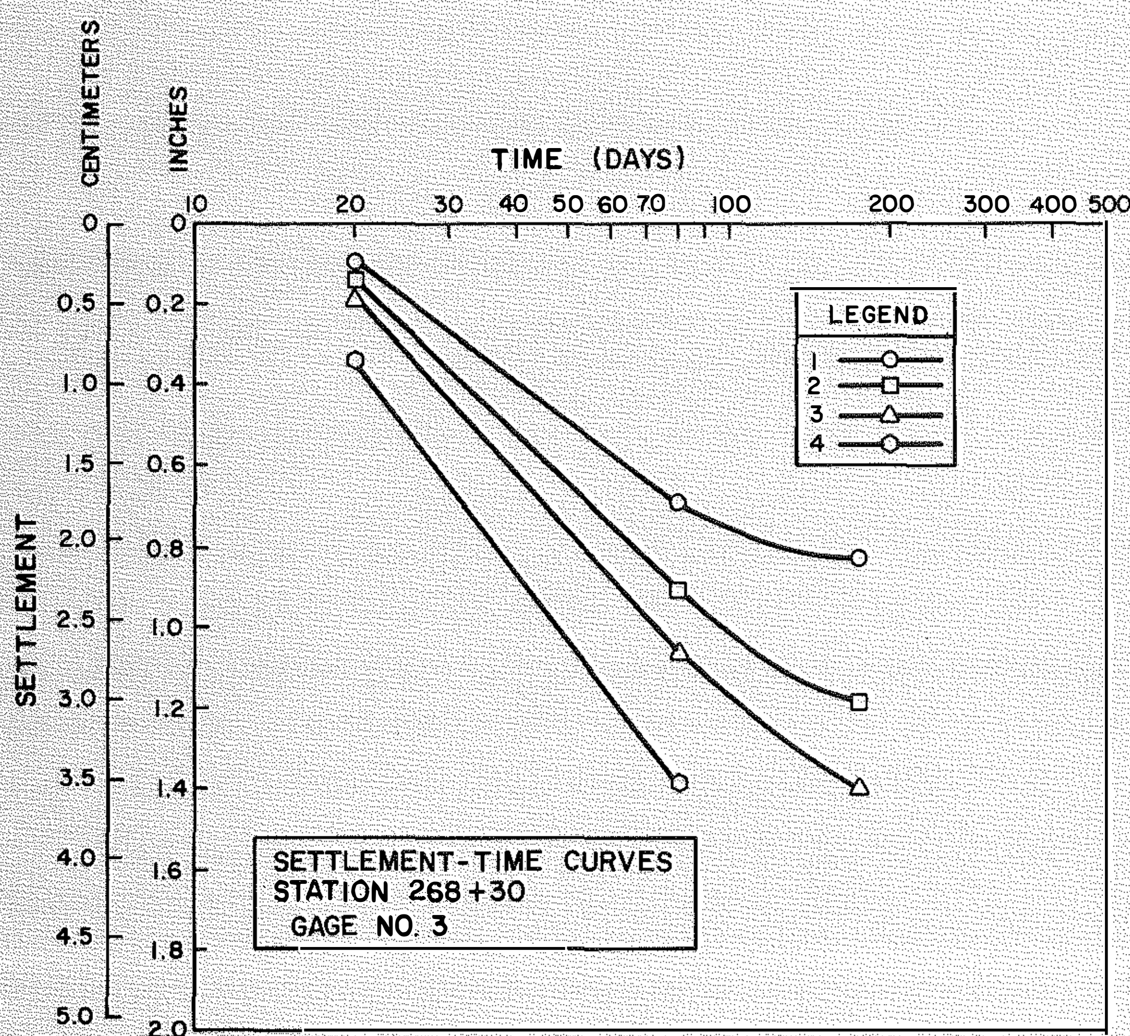
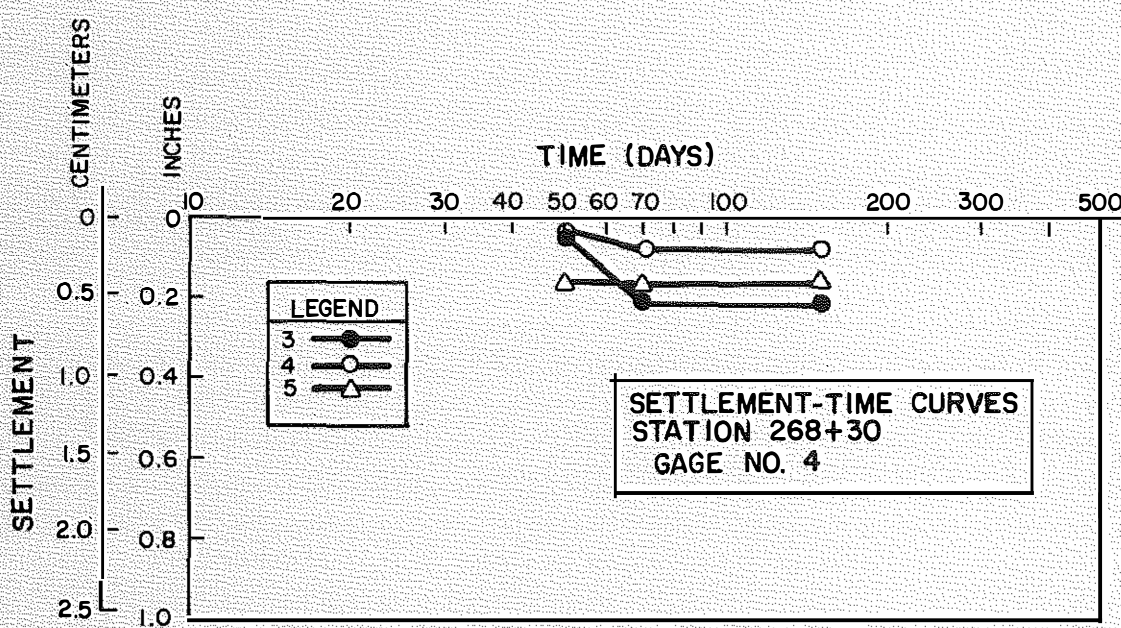


Figure 34. Settlement Versus Time for Settlement Gage 3 Located at Station 268 + 30.

Figure 35. Settlement Versus Time for Settlement Gage 4 Located at Station 268 + 30.



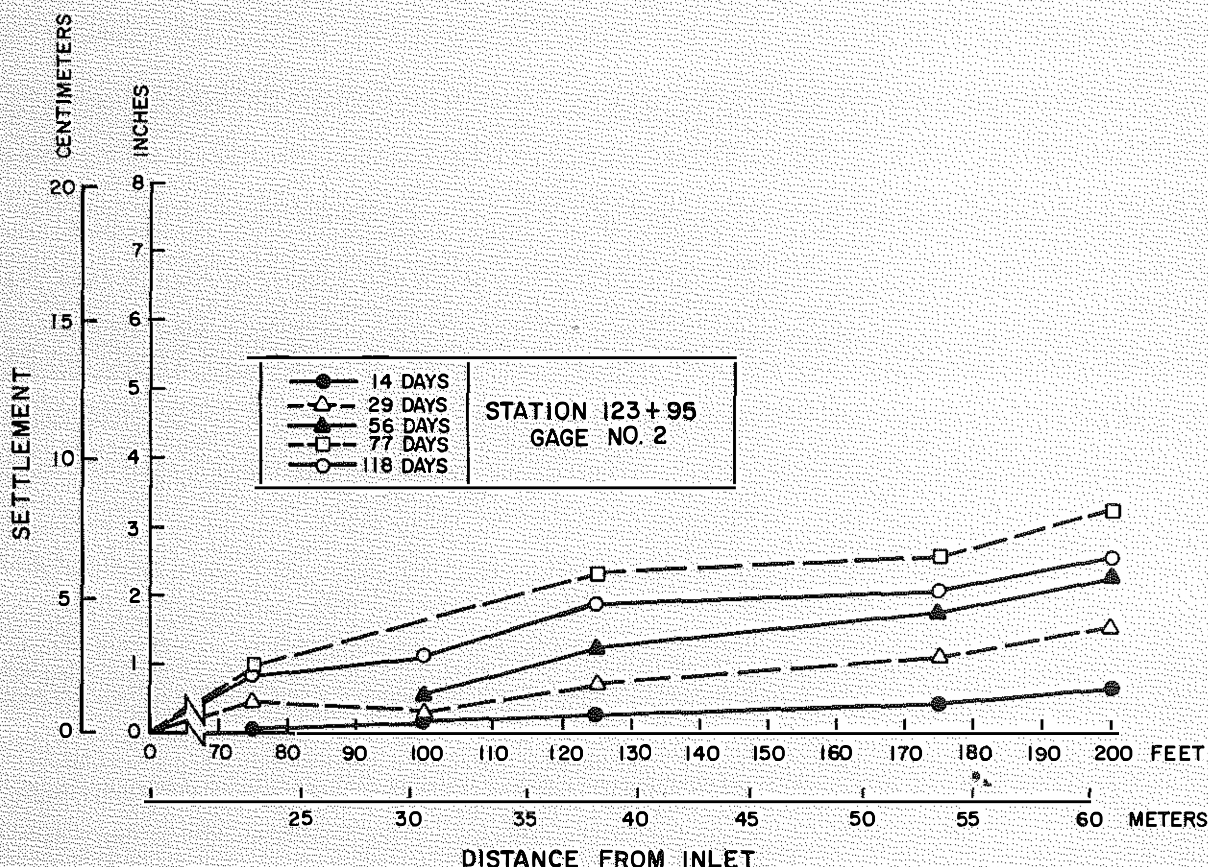
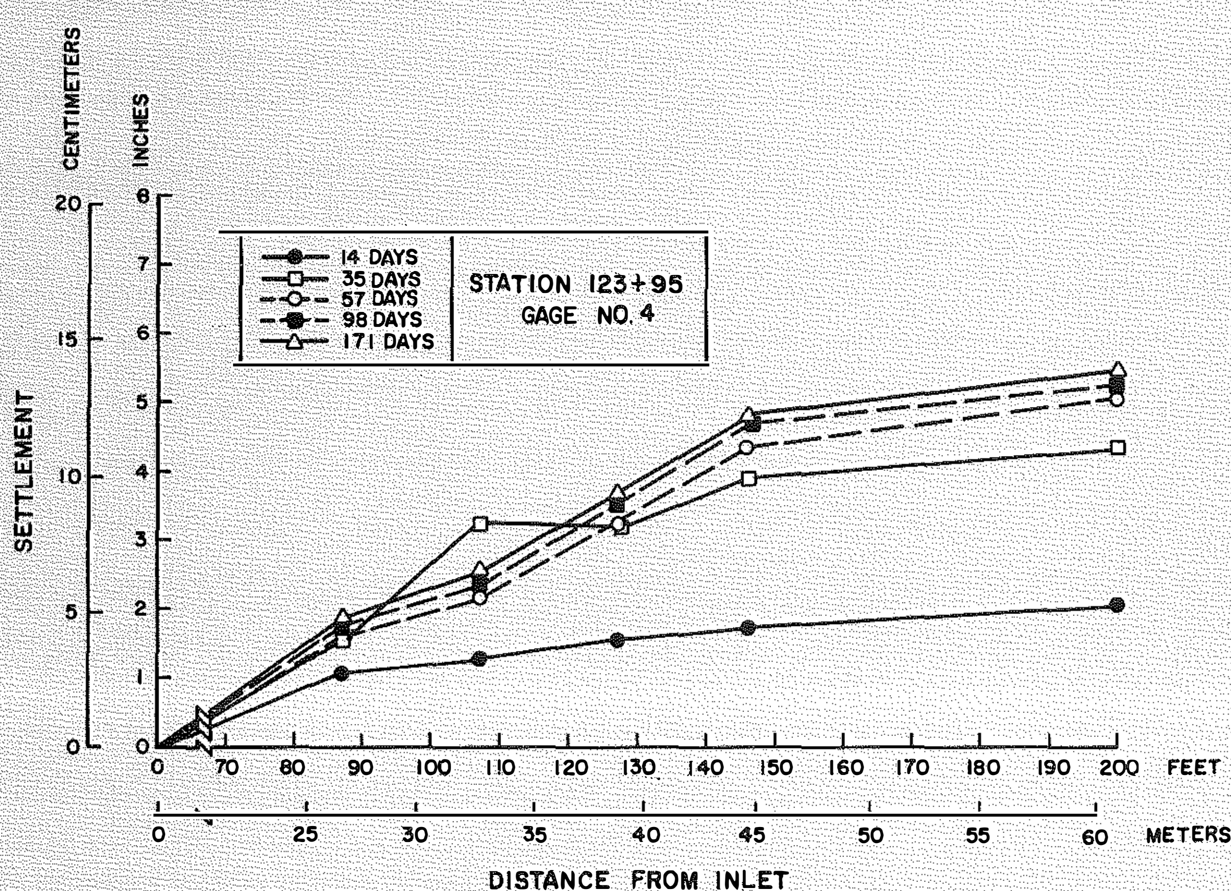


Figure 36. Settlement Versus Distance from the Culvert Inlet for Settlement Gage 2 at Station 123 + 95.

Figure 37. Settlement Versus Distance from the Culvert Inlet for Settlement Gage 4 at Station 123 + 95.



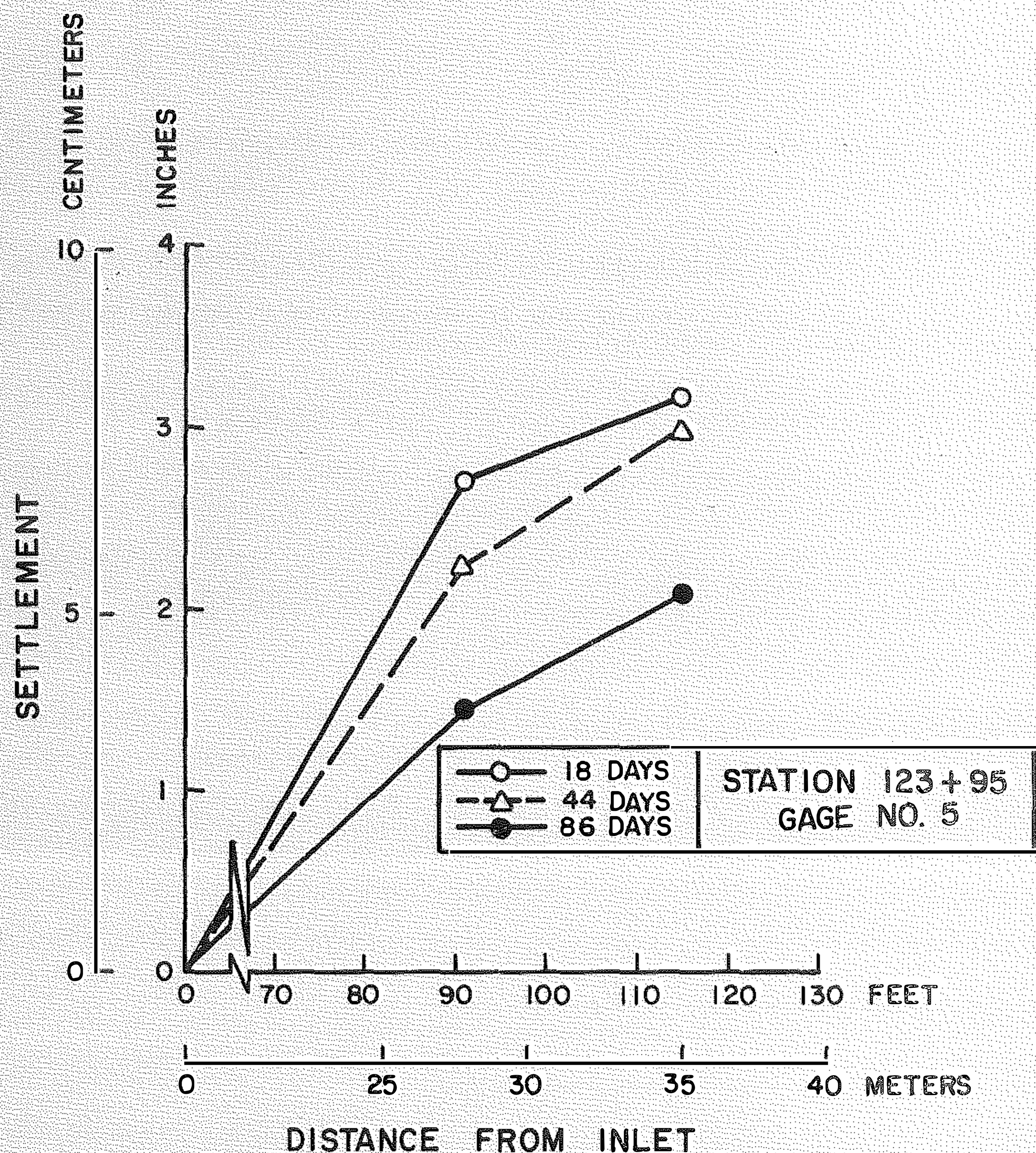


Figure 38. Settlement Versus Distance from the Culvert Inlet for Settlement Gage 5 at Station 123 + 95.

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