

Research Report
KTC-89-49

Study Of Loads On Four Box Culverts
On The Alexandria - Ashland Highway

by

Bobby W. Meade
Research Investigator

and

David L. Allen
Chief Research Engineer

Kentucky Transportation Center
College of Engineering
University of Kentucky
Lexington, Kentucky

in cooperation with
Transportation Cabinet
Commonwealth of Kentucky

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October 1989

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EXECUTIVE SUMMARY

Study Of Loads On Four Box Culverts On The Alexandria - Ashland Highway.

Kentucky Highway Investigative Task Number 2

Culverts on the Alexandria - Ashland Highway (AA Highway) were designed with modifications recommended in a 1984 report titled "Analysis of Loads and Settlements For Reinforced Concrete Culverts". In 1986, the Kentucky Department of Highways requested the Kentucky Transportation Center monitor selected culverts on the AA Highway. The objectives of this study were to compare predicted loads on the culverts to measured loads and to monitor differential settlement of the embankment near the culvert.

Four culverts with varied box dimensions and embankment heights were selected. Each of the four culverts was instrumented with earth pressure meters on the sidewalls and top slab. Settlement monitoring instruments were placed in the embankment at each culvert.

Design loads for each culvert sidewall and top slab were calculated. Design loads and dead loads due to the weight of the embankment were compared to the measured loads. The new design method used by the Department of Highways was found to be very accurate for predicting top slab loads on positive projecting culverts on unyielding foundations. The Department of Highways method significantly underpredicted the top slab load for a culvert on a yielding foundation.

The Department of Highways does not include charts from the 1984 report for predicting sidewall loads. Charts from the 1984 report appear to be reasonably accurate, especially as sidewall loads increase.

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Introduction

In August 1984, a report titled "Analysis of Loads and Settlements For Reinforced Concrete Culverts" was published by the University of Kentucky (1). That report included charts and formulae which were used, with modifications, in designing box culverts for the Ashland - Alexandria Highway. The location of the AA Highway is shown in Figure 1.

A decision was made to study culverts having varied fill heights and dimensions. The objectives of the study were to determine actual pressures on the culverts and to evaluate the methods used for design. Four culverts were chosen for study with two being under high fills and two being under low fills. For each fill height, one culvert was of relatively small dimensions and one was of large box dimensions. The culverts were generally designed as positive projecting on unyielding foundations. All culverts are cast-in-place reinforced concrete box culverts.

Site Descriptions

The four culverts chosen for study will be referred to as :

- Culvert 1. - Station 1056+84 - Section 7,
- Culvert 2. - Station 1303+40 - Section 9,
- Culvert 3. - Station 49+03 on Ky 57 - Section 19, and
- Culvert 4. - Station 1667+72 - Section 19

Culvert 1 is located at Stepstone Creek in Pendleton County, Figure 2. Ky 154 runs along Stepstone Creek and intersects the AA Highway near the culvert. The culvert is on a 19 degree skew and is 561 feet long and is under 78 feet of fill (Figure 3). The culvert has twin barrels with each barrel being 10 feet high and 8 feet wide (Figure 4).

This culvert was designed as positive projecting on an unyielding foundation, but was actually constructed as zero

projecting on the south side. The foundation at this site was a fairly competent limestone and shale. Foundation bedrock is the Point Pleasant Formation of the Ordovician Period (2). It is comprised of approximately 30 percent shale and 70 percent limestone.

The embankment was constructed of locally excavated material primarily of the Kope Formation. This formation consists of approximately 80 percent shale and 20 percent limestone. Rock quality of this formation is described as moderately poor with an average S.D.I. (Slake Durability Index) of 46. This embankment was placed in accordance with provisions of the Kentucky Department of Highways Special Note for Construction of Shale Embankments (March 1985).

Culvert 2 is located at Lick Run in northeast Bracken County (Figure 5). Culvert 2 is on a 30 degree skew where the centerline of the highway and culvert intersect. The culvert length is 1,155 feet with a fill height of 99 feet (Figure 6). This is a single barrel culvert having 6-foot by 6-foot box dimensions (Figure 7).

Bedrock at this site is the Point Pleasant Formation of the Ordovician Period (3), but the culvert lies in an area where there are several feet (up to 15 feet) of alluvium over the bedrock. The foundation was excavated up to 5 feet below the bottom of the footer and replaced with stone. In many areas, no competent rock was located. The first 500 feet from the inlet were excavated and backfilled with No. 610 gradation stone. Toward the outlet end, less material was excavated and the stone backfill was No. 57 gradation. After the stone backfill was in place, a 2-inch concrete mud seal was placed, upon which the footer was constructed.

Embankment material at this site was primarily excavated rock of the Kope Formation. The Special Note for Construction of Shale Embankments was specified above elevation 540 feet for settlement control.

Culvert 3 is located at Ky 57 south of Tollsboro in western

Lewis County (Figure 8). The culvert is under relocated Ky 57 (Station 46+03 of Ky 57) approximately 100 feet north of the centerline of the AA Highway. The culvert is on a 20 degree skew to the centerline of Ky 57 and is roughly parallel to the AA Highway. The culvert length is 125 feet and is under 14 feet of fill (Figure 9). The culvert is a single barrel structure having a width of 6 feet and a height of 4 feet (Figure 10).

Bedrock at this site is the lower part of the Crab Orchard Formation and the Brassfield Formation of the Silurian Period (4). These formations consist of interbedded clay shale and dolomite. The shale is a relatively poor foundation material but the interbedded dolomite improves the material to a fair-to-good foundation material. The foundation was excavated and backfilled with approximately 1 foot of No. 57 gradation stone.

Culvert 4 is located at Bethel Creek in western Lewis County (Figure 8). This culvert is on a 22 degree skew having a total length of 148 feet and is under 17 feet of fill (Figure 11). The culvert has twin barrels each having a height of 10 feet and a width of 15 feet (Figure 12).

Bedrock at this site is the top of the Bull Fork Formation of the Ordovician Period (4). This formation is comprised of shale and interbedded limestone, with shale comprising 80 percent at this elevation. The foundation was under cut approximately 2 feet and backfilled with Number 57 gradation stone. Bedrock weathered rapidly when exposed to water.

Design

The culverts generally were designed as positive projecting on unyielding foundations. However, there were two exceptions. At Culvert 1, some portions of the culvert were zero projecting on the south side of the trench. At Culvert 2, the foundation was yielding, (5.5 inches settlement) as will be shown by field data.

A previous report (1) suggested that the pressure distribution

on the top slab of box culverts would be parabolic with lower pressures being in the center of the culvert. Design procedures adopted by the Kentucky Department of Highways (hereafter referred to as the DOH method) addressed this distribution by applying a uniform pressure (P1) over the span (L1) from center of sidewall to center of sidewall. (see Figure 13). The pressure was equal to 84 pounds per cubic foot x H, where H is the height of fill over the culvert. This pressure (P1) is supplemented by one additional uniform pressure (P2). P2 is equal to [(120 lb./ft³ x K1 x K2 x K3) - 84 lb./ft³] x H. K1, K2, and K3 are factors relating to fill height, box width, and box height and were reported in Reference 1. The load (P2) is located at the end quarter segments of span L1. These design parameters are shown in Figure 14 which is included in the Kentucky Department of Highways Bridge Design Manual.

The DOH method for calculating top slab pressure at zero projection, unyielding foundation conditions is similar to calculating positive projecting except that P(2) is multiplied by 0.75. (Definitions of projection are included in Figure 15.)

The DOH formula for calculating the pressure (P) on the top slab of culverts on yielding foundations is equal to WH where:

W = 120 pounds per cubic foot, and

H = height of fill, in feet, over the culvert.

The DOH method for calculating lateral pressure on culvert sidewalls is the method shown in NAVFAC DM - 7.2, May 1982, chapter 3. This method results in a constant sidewall pressure, regardless of fill height, box dimension, foundation condition, or trench condition, of 45 pounds per square foot. Alternate methods for calculating sidewall pressures are included in Reference 1.

Instrumentation

Instrumentation included earth pressure meters, multipoint settlement gages and settlement platforms. Earth pressure meters

were installed on the top slab and sidewalls of each culvert to monitor soil pressures exerted on the culvert. Settlement gages and platforms were installed to detect differential settlement between the soil beside the culverts and the soil above the culverts. Settlement gages were also placed higher in the embankments to confirm the plane of equal settlement or absence of differential settlement (1). Settlement platforms were only installed on the long culverts (Culverts 1 and 2) where the lengths of settlement gages placed near the top of the culverts were such that problems with the gages were anticipated.

Earth pressure meters were placed at the required locations prior to placing concrete. The monitoring leads were placed on the reinforcing steel, tied to the steel, and extended to an external monitoring point at one end of each culvert. The meters and leads were then cast within the concrete. When all concrete was in place, the leads were placed in a metal box bolted to the culvert. Initial data were collected before any backfill was placed.

One settlement gage was installed when the fill was 2 to 4 feet above each culvert, and one at a point higher in each fill. The higher gage within each fill was placed at an elevation slightly higher than the anticipated plane of equal settlement. Where possible, some points of gages were placed directly above each culvert, and other points were placed 5 or more feet laterally from the culvert sides.

Settlement platforms were installed when the fill was approximately 2 feet above the culvert. The platforms were inverted with the pipe extending through a hole cast in the top slab of the culvert. The platforms were monitored by measuring the pipe length extending into the culvert.

Nine earth pressure meters were installed on Culvert 1. Two meters were placed in each sidewall (one near the top and one near the bottom) and 5 meters were placed diagonally across the top slab. Both settlement gages and the settlement platforms were

installed at this site. The lower gage (Gage 1) was damaged during construction but and was repaired with only minor reduction in monitoring capability. ~~Earth pressure meters and the settlement platform~~ functioned properly. Settlement Gage 2 for this site was installed approximately 30 feet higher within the fill. Instrumentation locations are shown in Figures 16 and 17.

Culvert 2 was of much smaller dimensions than Culvert 1 and 7 earth pressure meters were installed. Two meters were placed on each sidewall wall, and 3 meters were installed diagonally across the top slab. A settlement platform was installed at this culvert and the lower settlement gage was installed. The settlement gage which should have been placed higher in the fill was not installed due to communication and scheduling difficulties.

The settlement platform at this site was vandalized some 5 months after installation. One earth pressure meter in the top slab was destroyed during construction. Instrumentation locations for Culvert 2 are shown in Figures 18 and 19.

Culvert 3, also of relatively small dimensions, had 7 earth pressure meters installed, with two being placed on each sidewall and 3 placed diagonally across the top slab. This culvert is relatively short, therefore no settlement platform was installed. Two settlement gages were installed with the second gage being approximately 8 feet higher in the fill. Instrumentation locations for Culvert 3 are shown in Figures 20 and 21.

Culvert 4, has a large cross section and a relatively short length and was instrumented with 9 earth pressure meters. Two meters were placed on each sidewall and 5 meters were placed diagonally across the top slab. This culvert did not require a settlement platform but was instrumented with two settlement gages with the second gage being approximately 7 feet higher in the fill. The earth pressure meters on the north sidewall were destroyed during construction. instrumentation locations for Culvert 4 are shown in Figures 22 and 23.

Instrumentation was placed as near as possible to the

intersection of the centerlines of each culvert and the roadway. This insures monitoring of the culvert under the highest part of the fill. Pressures exerted on the culverts were of primary interest in this study. Pressure on a culvert is influenced to some degree by differential settlement of the soil about the culvert, thus the inclusion of settlement instrumentation.

In addition to the instrumentation, culvert profiles were monitored by surveying. Culverts 1, 2, and 4 were surveyed prior to culvert loadings and after the fills were completed. Culvert 3 was not surveyed.

Construction

Contracts for construction of the three AA Highway Sections involving the study culverts were awarded in mid 1986. Clearing and foundation excavation began in late 1986, but no culvert construction began until January 1987. All culverts were completed and their respective fills were essentially to grade elevation by December of 1987.

Earth pressure meters were installed by the construction crews with assistance of University personnel. The meters were fixed to the forms for the sidewall installation (Figure 24) and were tied to beams set at design elevation of the top slab for top slab installation Figure 25. This introduced a problem in some instances in that the depth of concrete for the top slab was not precisely controlled. When the concrete rose above the face of the meter it was spread outward in a bowl shape. No data are available regarding the influence of this shape on the pressure distribution on the culvert surface. Three meters were inexplicably damaged during culvert construction. Figure 26 shows sidewall meters after the forms were removed.

Settlement gages and platforms were installed by University personnel. At the beginning of construction, inspection and

construction personnel were informed regarding the desired fill elevation for installation. In general, those personnel were cooperative and all settlement instrumentation except one gage was installed successfully.

Field Data

Earth Pressure

Pressures on the top slab of Culvert 1, as indicated by earth pressure meter data, ranged from 132 to 68.5 psi. The higher pressure occurred on the north side of the culvert top where the trench excavation produced a positive projecting condition. South side excavation was in rock, primarily limestone, and the trench configuration was such that a zero projection condition existed, Figure 27. Top slab meter data are shown in Figure 28.

Further reflections of the trenching conditions are evidenced by the sidewall pressure. The south sidewall maximum pressure was 7.2 psi while the north sidewall pressure reached 30 psi. Sidewall meter data are shown in Figure 29. A cross section of Culvert 1 with peak pressure distribution is shown in Figure 30.

At Culvert 2, one of the top slab meters was nonfunctional after construction, but the two remaining meters indicated pressures of 128 and 90 psi. The higher pressure occurred near the side of the culvert. Top slab meter data are shown in Figure 31.

Sidewall pressure was 39 and 23 psi on the south wall and 27 and 21 psi on the north wall. Sidewall meter data are shown in Figure 32. A cross section of Culvert 2 with peak pressure distribution is shown in Figure 33.

Top slab pressure on Culvert 3 ranged from 16.1 to 18.9 psi. Top slab meter data are shown in Figure 34.

Sidewall pressure was 12.2 and 17.5 psi on the south sidewall and 23.6 psi on the north sidewall. Sidewall meter data are shown in Figure 35. A cross section of Culvert 3 with peak pressure

distribution is shown in Figure 36.

Top slab pressure on Culvert 4 ranged from 23.4 psi near the north side to 7.0 psi nearer the center. The two highest top slab pressures were near the sides. Top slab meter data are shown in Figure 37.

Both meters on the north sidewall were nonfunctional after construction. South sidewall pressure was 4.5 and 1.3 psi. Sidewall meter data are shown in Figure 38. A cross section of Culvert 4 with peak pressure distribution is shown in Figure 39.

Settlement

Fill settlement around Culvert 1 was approximately 1.2 feet at point 3 and 0.60 foot at point 2. Both points were placed approximately 5 feet from the edge of the culvert. Settlement directly above the culvert, as reflected by settlement platform data, was 0.18 foot. Settlement data (Gage 1) are plotted versus time in Figure 40. Field data which are plotted versus time have the date of the first data obtained at each site as time zero. Therefore, each sites time scale will be unique to that site.

Gage 2, approximately 30 feet higher than Gage 1, indicated settlement of 0.29 foot at point 2 and 0.39 foot at point 4. Point 4 was placed directly over the culvert and point 2 is roughly 40 feet from the side of the culvert. Point 2 is not under the crest of the fill, thus settlement is less. Settlement data from Gage 2 are plotted versus time in Figure 41.

Fill settlement at Gage 1 of Culvert 2 is 0.9 foot, 1.5 feet, and 1.8 feet at points 2, 3, and 4 respectively. Gage 1 is approximately 2 feet above the top of the culvert and none of the points are located directly above the culvert. Points 3 and 4 are near the centerline of the road and are located 3 feet from each side of the culvert. Point 2 is approximately 5 feet from the side of the culvert. Settlement platform data indicated settlement of 0.2 foot directly over the culvert. Settlement data from Gage 1 are

shown in Figure 42.

Little settlement occurred at Culvert 3 which has a fill height of 14 feet. Settlement at Gage 1 was insignificant with final settlement in the range of 0.01 foot. Gage 2, approximately 10 feet above the culvert, indicated settlement of 0.03 foot, 0.15 foot, and 0.06 foot at points 2, 3, and 4, respectively. Point 4 is located directly over the culvert and points 2 and 3 are approximately 4 feet from the side of the culvert. Data from Gage 2 are shown in Figure 43.

Settlement at Culvert 4, Gage 1, was 0.15 foot, 0.10 foot, 0.08 foot and 0.08 foot at points 1 through 4, respectively. Gage 1 is 5 feet above the culvert with points 2 and 3 located directly above the culvert and points 1 and 4 located 5 and 15 feet from the culvert, respectively. Settlement at Gage 2 was 0.09 foot, 0.16 foot, and 0.32 foot at points 2, 3, and 4, respectively. Gage 2 is located 12 feet above the culvert with points 2 and 4 located 12 and 5 feet, respectively, from the culvert and point 3 located directly above the culvert. Settlement data from Gage 1 and Gage 2 are plotted versus time in Figures 44 and 45.

Before fill was placed on the culverts, elevations of the culvert barrels were established. This was accomplished by locating points on the ceiling of the barrels and surveying those points. After the fill was completed, the points were surveyed again. Both barrels of twin barreled culverts (Culverts 1 and 4) were monitored. Culvert 2 was monitored from the outlet to a point 416 feet into the culvert, or approximately 36 feet beyond the centerline of the highway. Culvert 3 was not monitored due to its small dimensions and the fact that one half of the culvert was completed several months before the other half. Culverts 1 and 4 settled less than 0.1 foot with the maximum settlement occurring near the center of the culvert. Culvert 2 settled approximately 0.45 foot. Culvert settlements are shown in Figures 46, 47, and 48.

Several cracks circumscribing the barrel were observed in Culvert 2. The cracks were concentrated in that part of the

culvert which was under the highest fill and which settled the most. Some cracks were approximately 0.25 inch wide.

Analysis

Measured culvert pressures are compared with calculated pressures. Pressure is calculated using the DOH method, Research Report UKTRP-84-22 method (FE method), and the older methods of $P = WH$ for top slabs and $P = (WH)/4$ for the side walls.

The Finite Element method (FE method) was developed in a previous study (1). An extensive finite element analysis of theoretical culvert conditions (including box dimensions, fill height, trench, projection, foundation and imperfect trench) was conducted with the results compared to known conditions at seven study sites. Charts and formulae developed from this analysis permit accurate prediction of loads on box culverts.

The WH method predicts the dead load due to the weight of the fill material. The dynamics of the fill-foundation-culvert interaction is not considered.

In cases where the assumed positive projection on unyielding foundation did not exist, pressures were calculated using the existing and assumed conditions.

Top Slab

The FE and DOH methods are equal in positive projecting unyielding foundation conditions until the culvert width exceeds 20 feet. The charts used for the DOH method are derived from the FE method but are extended beyond the 20-foot width dimension.

Culvert 1 is one of the sites where other than assumed, positive projection-unyielding foundation conditions exists. One side of the culvert was constructed under zero projection conditions. Measured pressure on the top slab was 132 psi on the positive projecting side and 99.5 psi. on the zero projecting side.

The DOH method predicts 126.4 psi, the FE method predicts 126.4 psi and the WH method predicts 64.3 psi for the positive projecting side. The zero projecting side predictions are 102 for DOH, 117 for FE, and 64.3 for WH.

Measured pressure on the top slab of Culvert 2 was 128 psi. Predicted pressure on Culvert 2 was 189 psi. for the DOH method and the FE method under assumed conditions. Under assumed conditions, the WH method predicted 82.5 psi. Settlement data indicate that the foundation is yielding; therefore, calculations were made for that condition. The DOH method predicts 82.5 psi and the FE method predicts 147.5 psi for Culvert 2 for a yielding foundation.

Measured top slab pressure on Culvert 3 was 18.9 psi. The various methods predicted pressures of 26.1 psi for the DOH and FE methods and 11.6 for the WH method.

Culvert 4 is another case where pressures predicted by the DOH and FE methods vary. The culvert width and height exceed the limits of the charts for the FE method. Measured pressure was 23.4 psi. Predicted pressures were 24.4 for DOH, 25.4 for FE, and 14.1 for WH.

The FE method consistently overpredicts top slab pressures. The FE method overpredicted by as much as 19.5 psi and underpredicted by as much as 10 psi with an average error of 11 psi. The DOH method over predicted by as much 7.2 psi and underpredicted by as much as 45.5 psi with an average error of 13 psi. The WH method underpredicts in all cases. This method underpredicted by as much as 68 psi with an average error of 32.2 psi. Measured pressures versus calculated pressures for the top slab are shown in Figure 49.

Sidewall

The DOH method for calculating sidewall pressure yields a constant 45 psi for all culverts. For Culvert 1, the FE method predicts 22.0 psi for positive projection and 14.0 psi. for zero

projection. The WH/4 method predicts 16.1 psi for both conditions at Culvert 1. Measured pressures at Culvert 1 were 30 psi for positive projection and 7.2 for zero projection.

The FE method predicts 37 psi for Culvert 2 and WH/4 predicts 21.0 psi. The measured pressure was 39 psi.

The predicted pressure for Culvert 3 was 5.6 psi by the FE method and 2.8 psi by the WH/4 method. The measured pressure was 13.6 psi.

The FE method predicts 5.4 psi for Culvert 4 and the WH/4 method predicts 3.5 psi. Measured pressure was 4.5 psi.

Computed sidewall pressures are somewhat more scattered than computed top slab pressures. In every case the FE method predicted closer to measured pressures than the WH/4 method. The FE method underpredicted by as much as 8 psi and overpredicted by as much as 6.8 psi. Average error for the FE method was 5.1 psi.

The WH/4 method underpredicted by as much as 18 psi and overpredicted by as much as 9.8 psi. Average error for this method was 11.0 psi. Measured versus calculated sidewall pressures are shown in Figure 50.

Settlement

Fill settlements were monitored to determine the differential settlement of soil prisms and the plane of equal settlement (assuming significant differential settlement existed). Settlement data at Culverts 1 and 2 indicated differential settlement of approximately 1 foot. This takes into account the 0.45-foot settlement of Culvert 2. Settlement data for Culverts 3 and 4 indicated no significant differential settlement.

Culvert 1 was the only culvert where significant differential settlement existed and the instrumentation was in place to locate the plane of equal settlement. Charts included in a previous report (1), page 142, indicate that the plane of equal settlement would be from 45 to 60 feet, depending on projection conditions above

the culvert. Settlement Gage 2 at Culvert 1 was installed 30 feet above the culvert. Data from this gage indicated that the plane of equal settlement was between the culvert and settlement gage. The indication that the plane of equal settlement was lower than anticipated is probably due to the special compaction that this fill received.

Conclusions

The DOH method accurately predicts pressure on the top slab of culverts installed at positive or zero projection on unyielding foundations. Under those conditions, the DOH and FE methods are virtually equal.

The DOH method does not accurately predict top slab pressure on culverts constructed on yielding foundations. The FE method is superior in cases involving yielding foundations.

The FE method provides a reasonable prediction of sidewall pressure, especially in cases where higher pressure occurs. The DOH method result of 45 psi is sufficient for the four culverts involved in this study, however sidewall pressure in excess of 45 psi. has been observed at other sites.

Foundation conditions varied considerably at the study sites. In one case, Culvert 2, the foundation permitted significant differential settlement of the culvert.

Data from this study tend to confirm that pressure is greater toward the edges of the top slab and lesser toward the center of the culvert.

RECOMMENDATIONS

Charts and formulae from the FE method should be incorporated in the DOH method for calculating sidewall pressure.

Additional study should be conducted on culverts on yielding foundations. Until other information is available, the FE method should be used to calculate top slab pressure on culverts constructed on yielding foundations.

Foundations should be uniform, either yielding or unyielding, throughout the length of the culvert.

Due to eccentric loading resulting from differing projection conditions, projection should be uniform throughout the length and on both sides of culverts.

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2. Luft, S.J.; Geologic Map of the Butler Quadrangle, Department of the Interior, United States Geological Survey, 1972.
3. Luft, S.J., Osborne, R.H., and Weiss, M.P.; Geologic Map of the Moscow Quadrangle, Department of the Interior, United States Geological Survey, 1973.
4. Peck, J.H., Geologic Map of the Tollesboro Quadrangle, Department of the Interior, United States Geologic Survey, 1967.

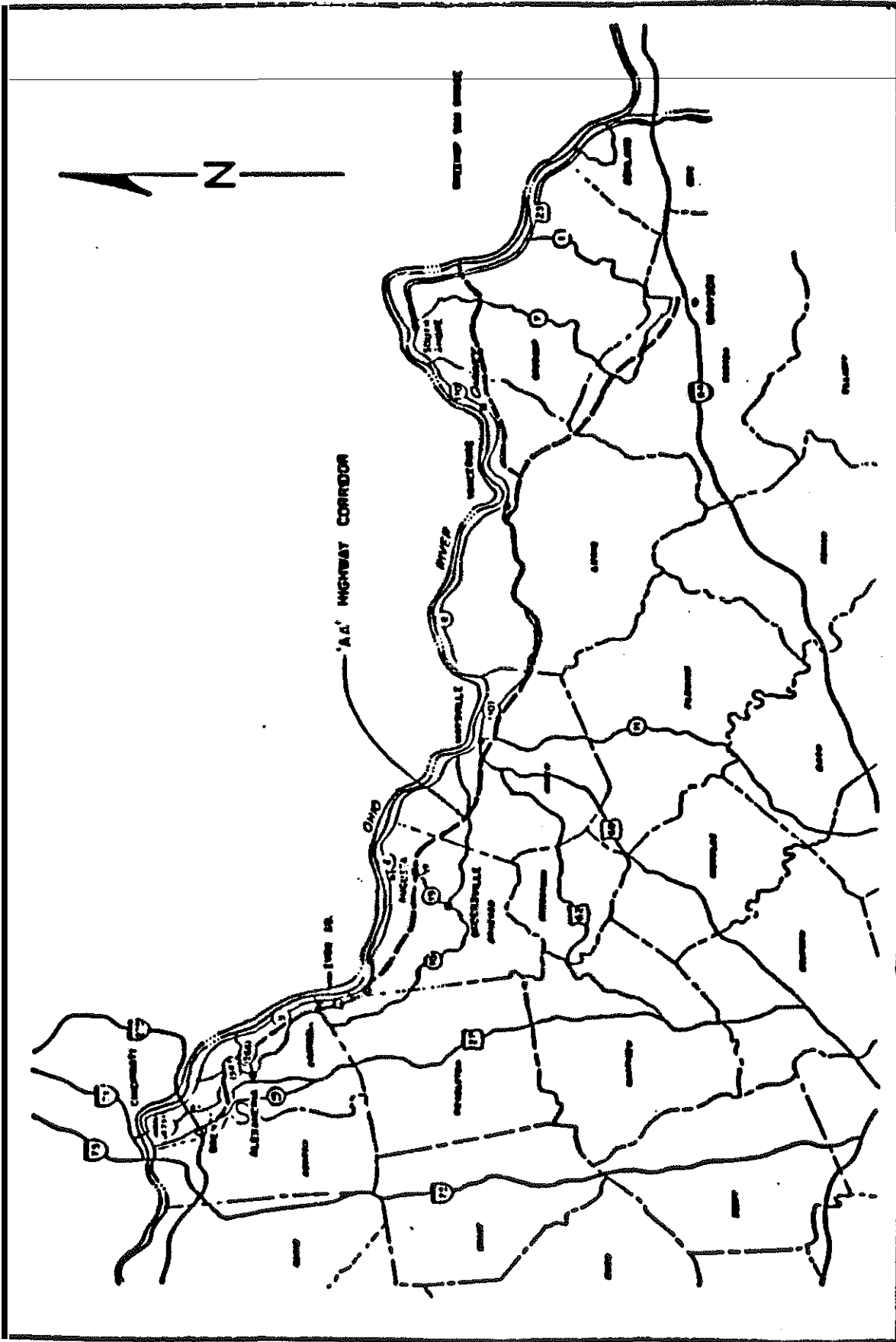


Figure 1. The AA Highway, Northern Kentucky.

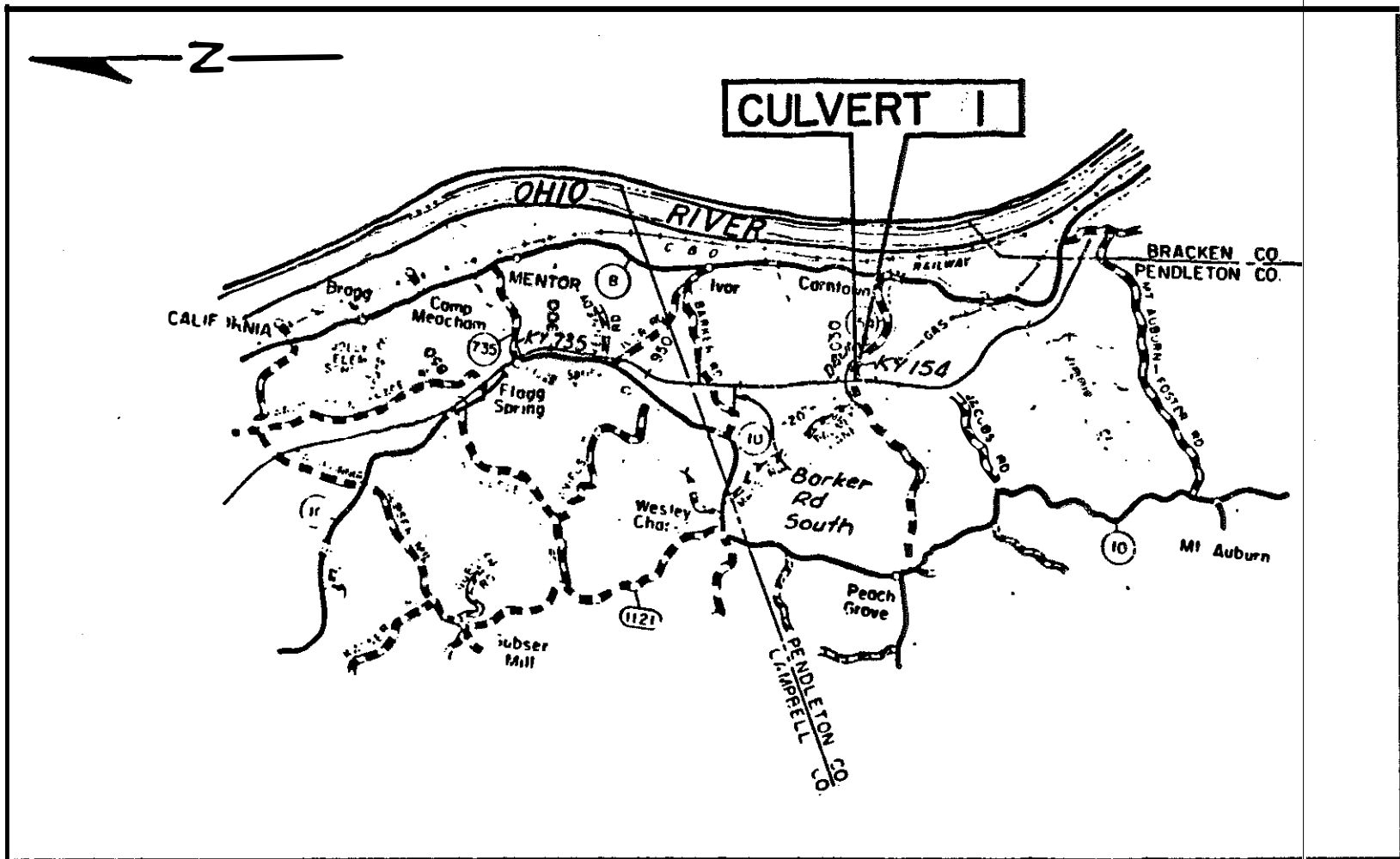


Figure 2. Location of Culvert 1 (Station 1056+84), Pendleton Co.

CULVERT 1
STA. 1056+84

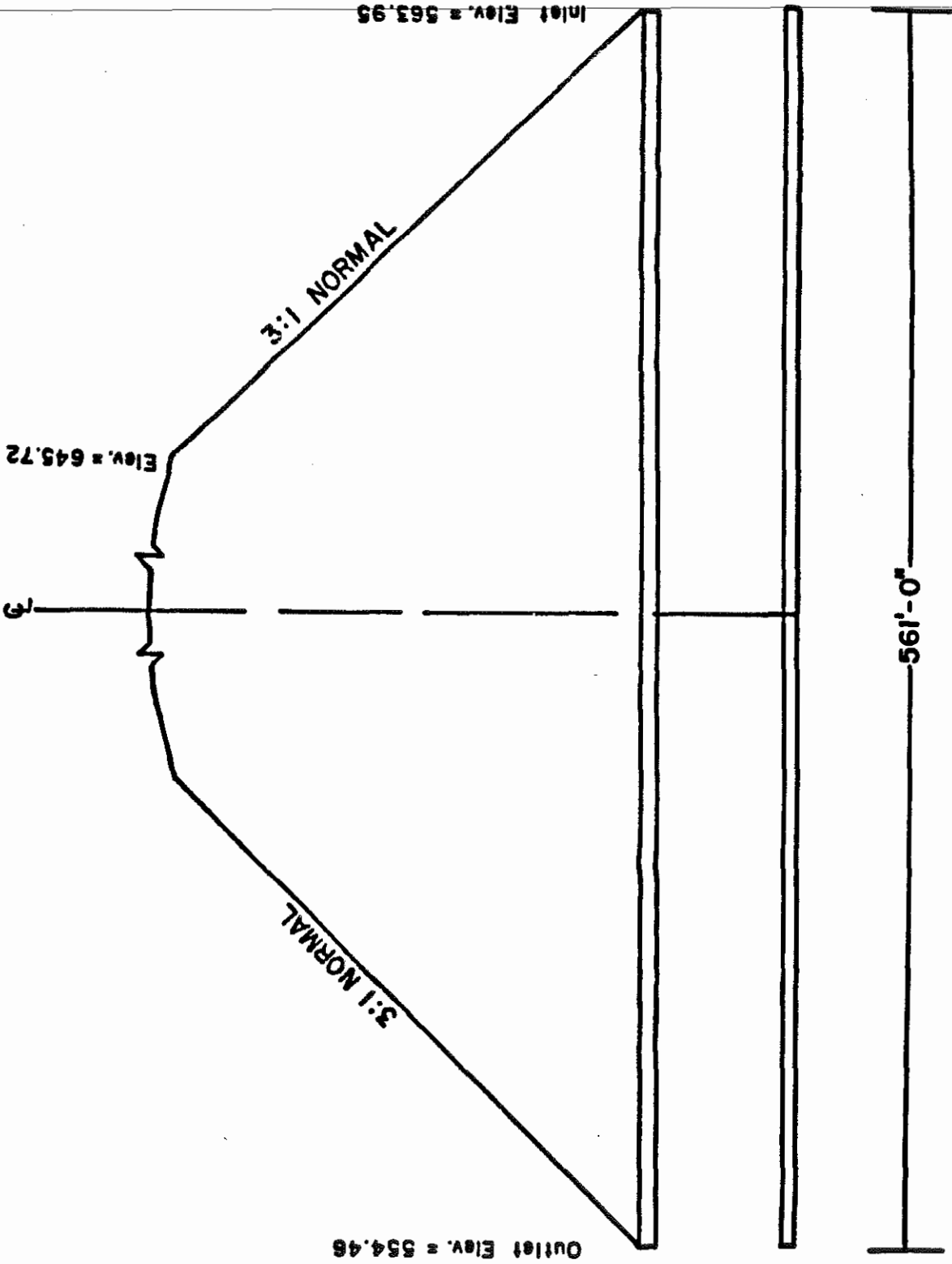


Figure 3. Section Along Centerline of Culvert 1.

CULVERT 2

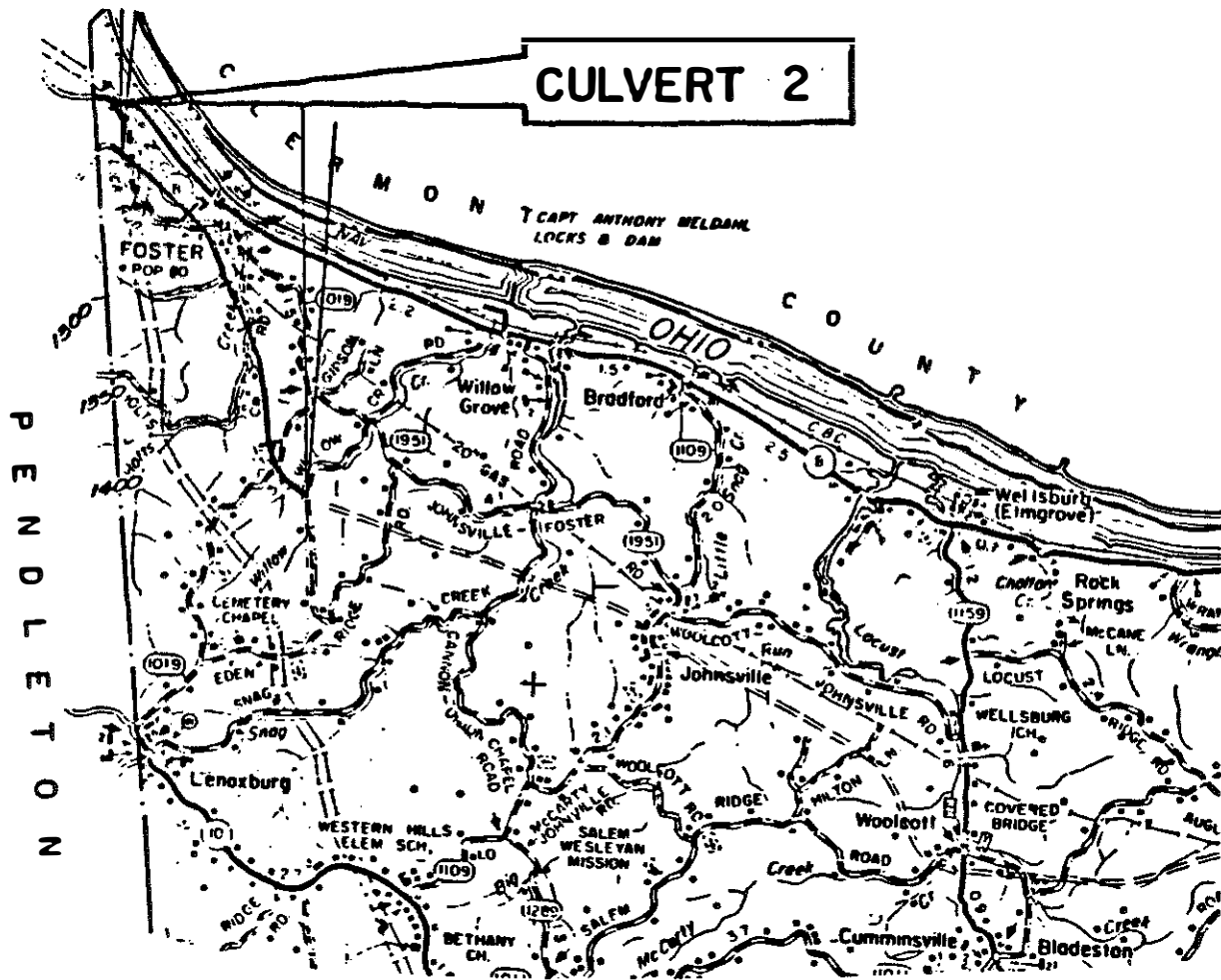


Figure 5. Location of Culvert 2 (Station 1303+40), Bracken Co.

**CULVERT 2
STA. 1303+40**

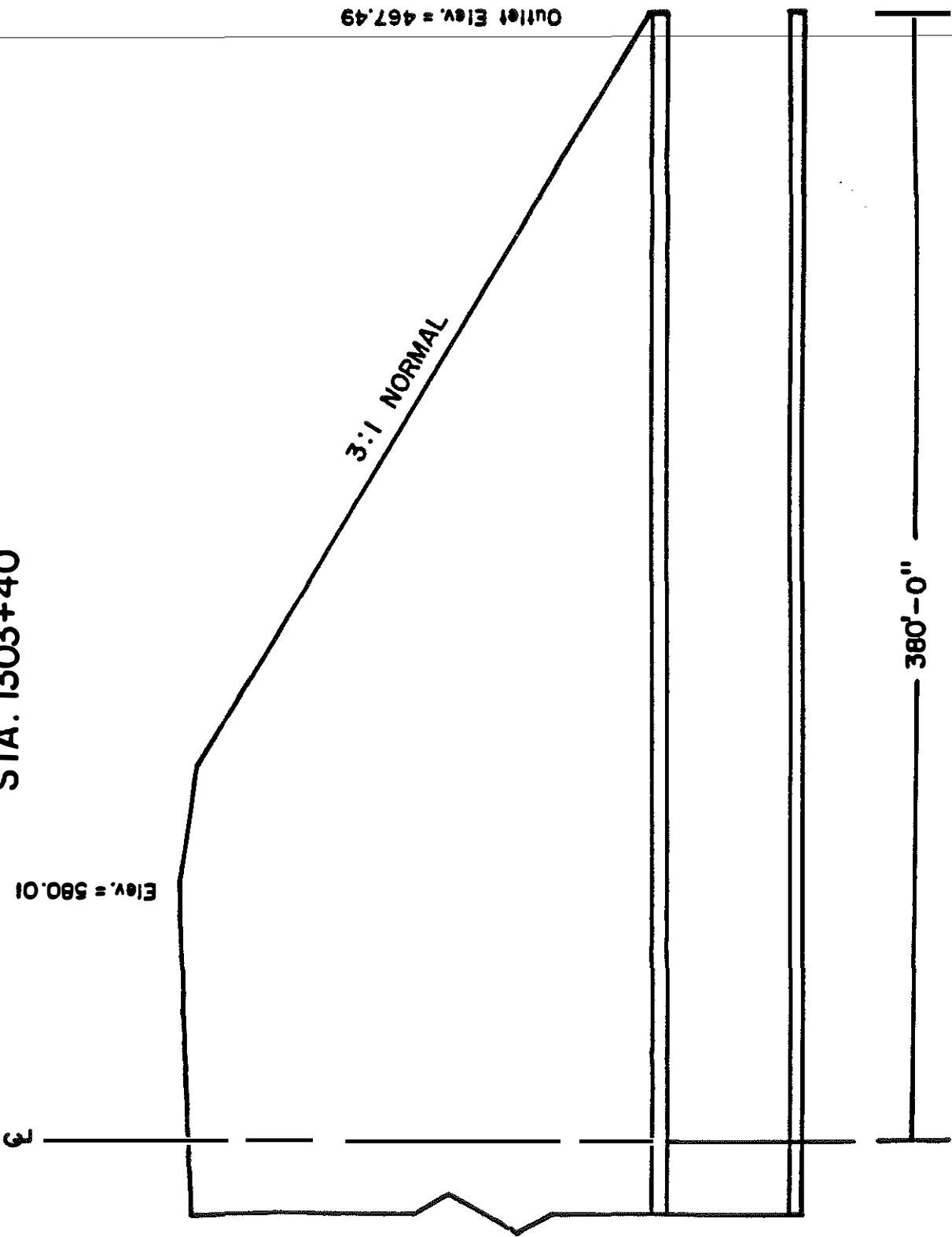
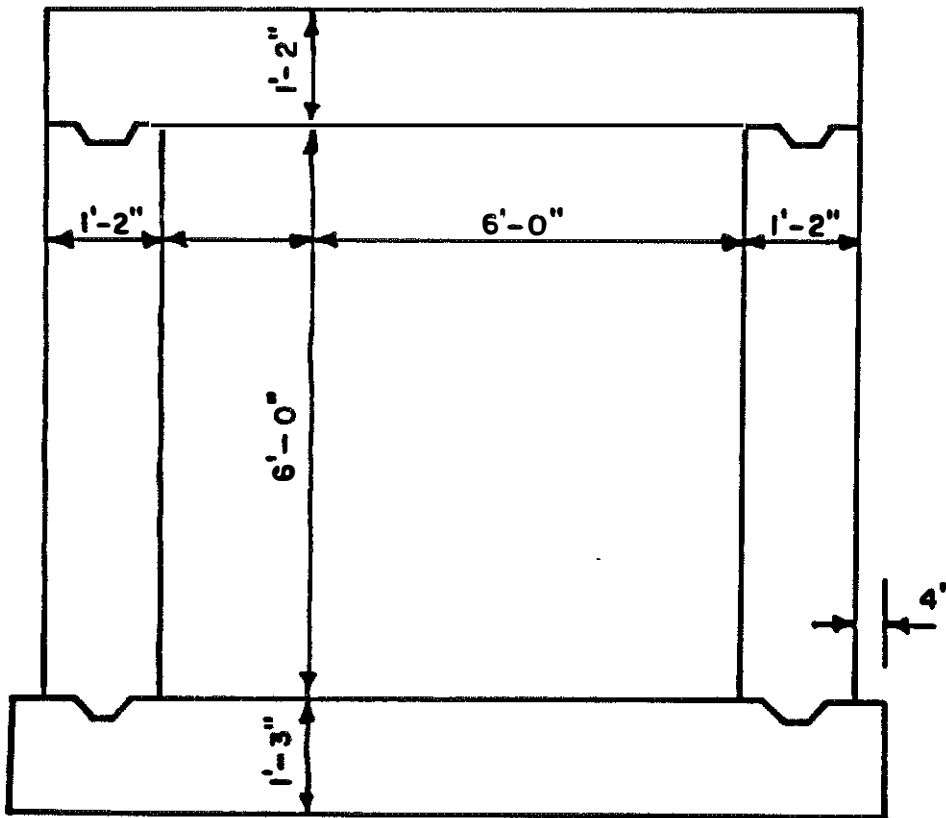


Figure 6. Section Along Centerline of Culvert 2.

CULVERT 2
STA. 1303+40



2' = 1"

Figure 7. Cross Section of Culvert 2.

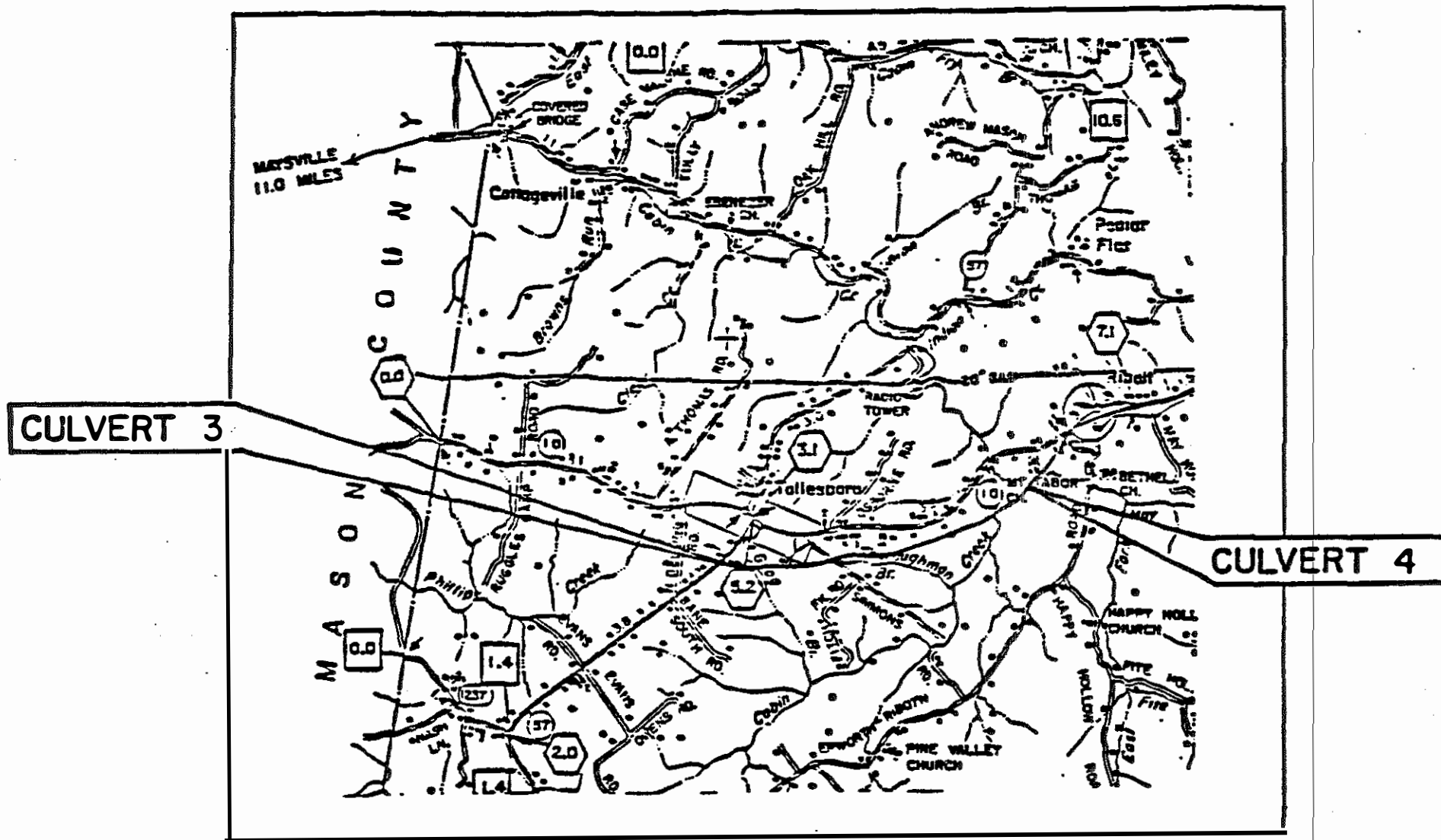


Figure 8. Location of Culvert 3 (Station 49+03) and Culvert 4 (Station 1667+72), Lewis Co.

CULVERT 3
STA. 49+03

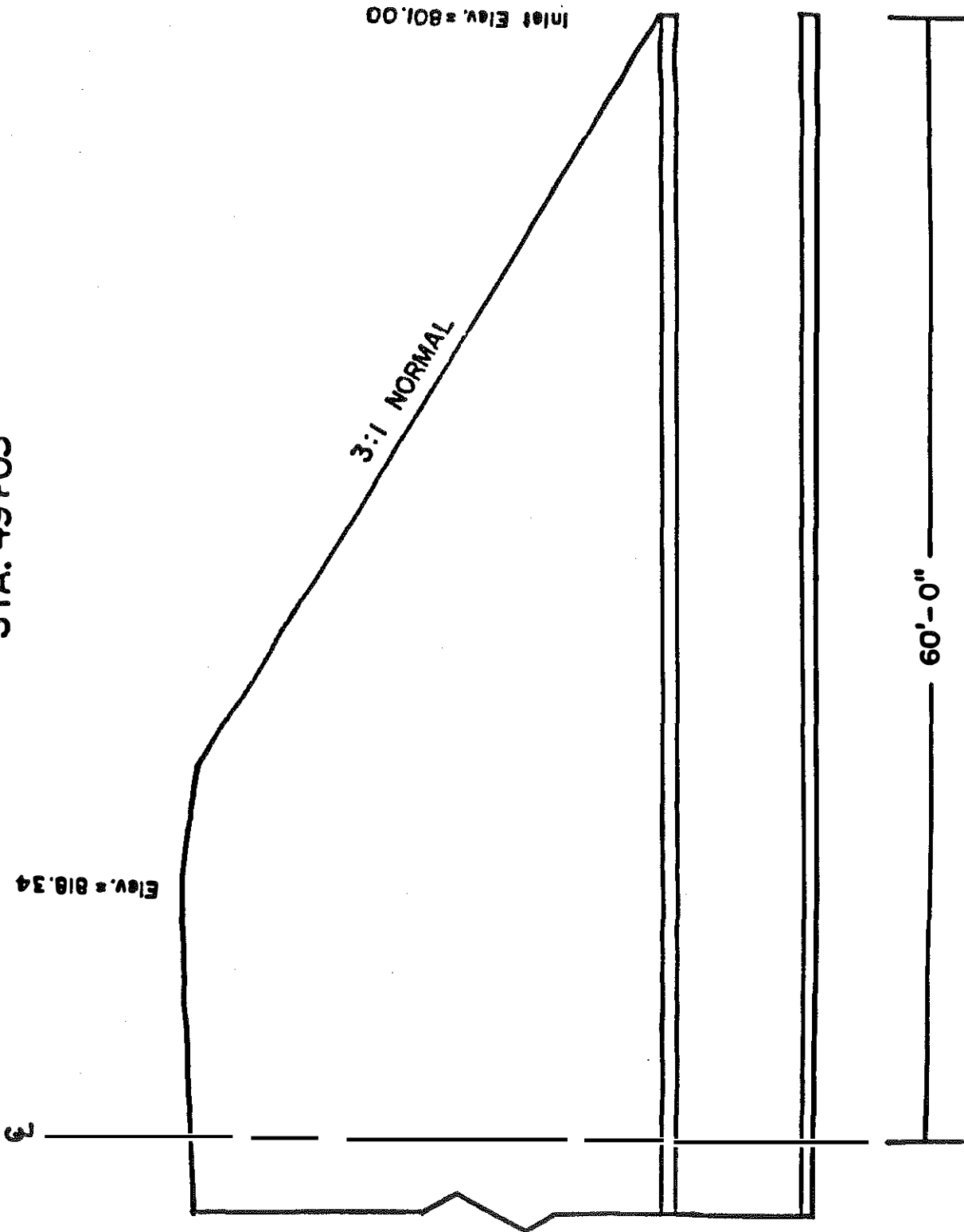
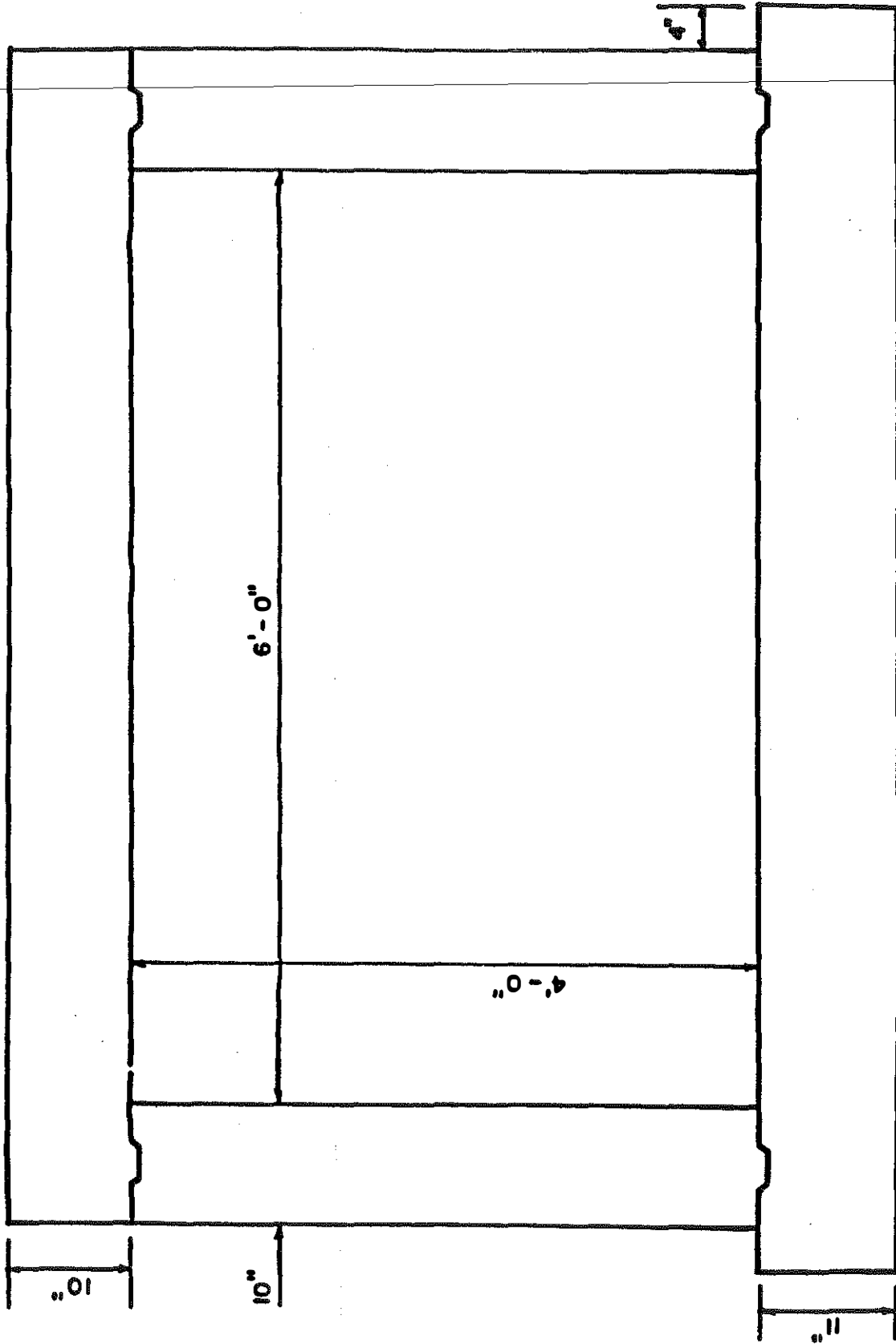


Figure 9. Section Along Centerline of Culvert 3.

CULVERT 3
STA. 49+03



1' = 11"

Figure 10. Cross Section of Culvert 3.

CULVERT 4
STA. 1667+72

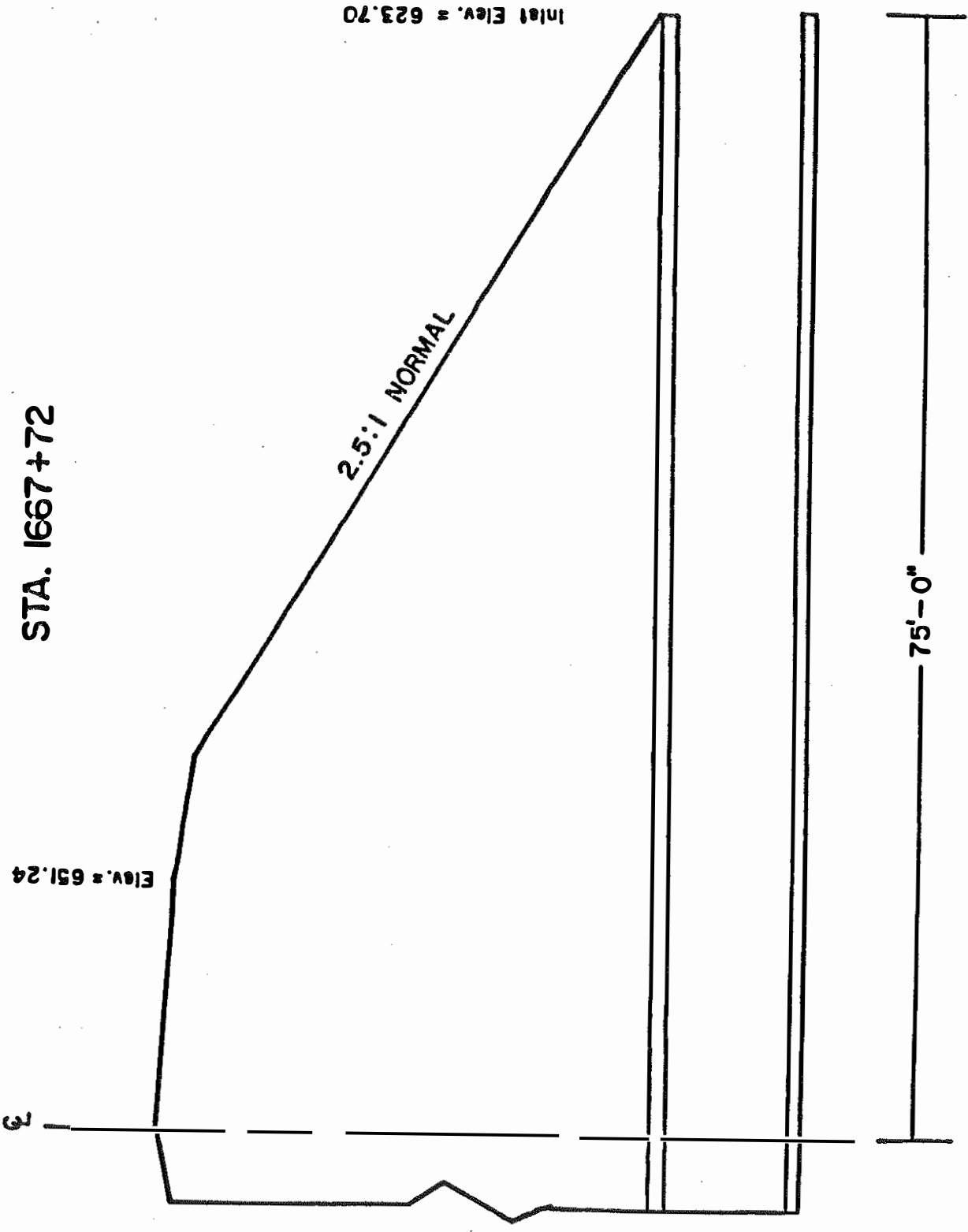


Figure 11. Section Along Centerline of Culvert 4.

CULVERT 4

STA. 1667+72

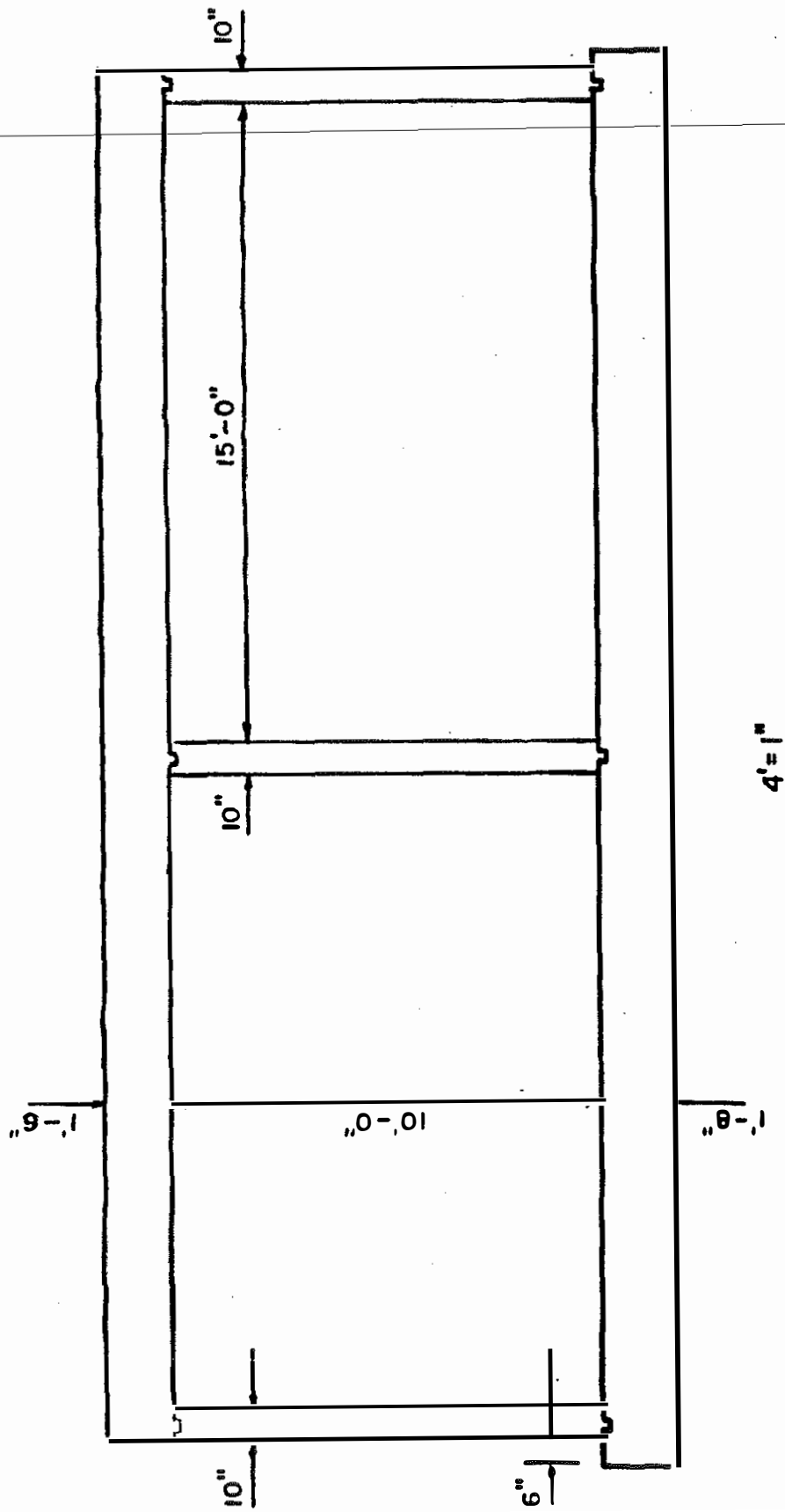
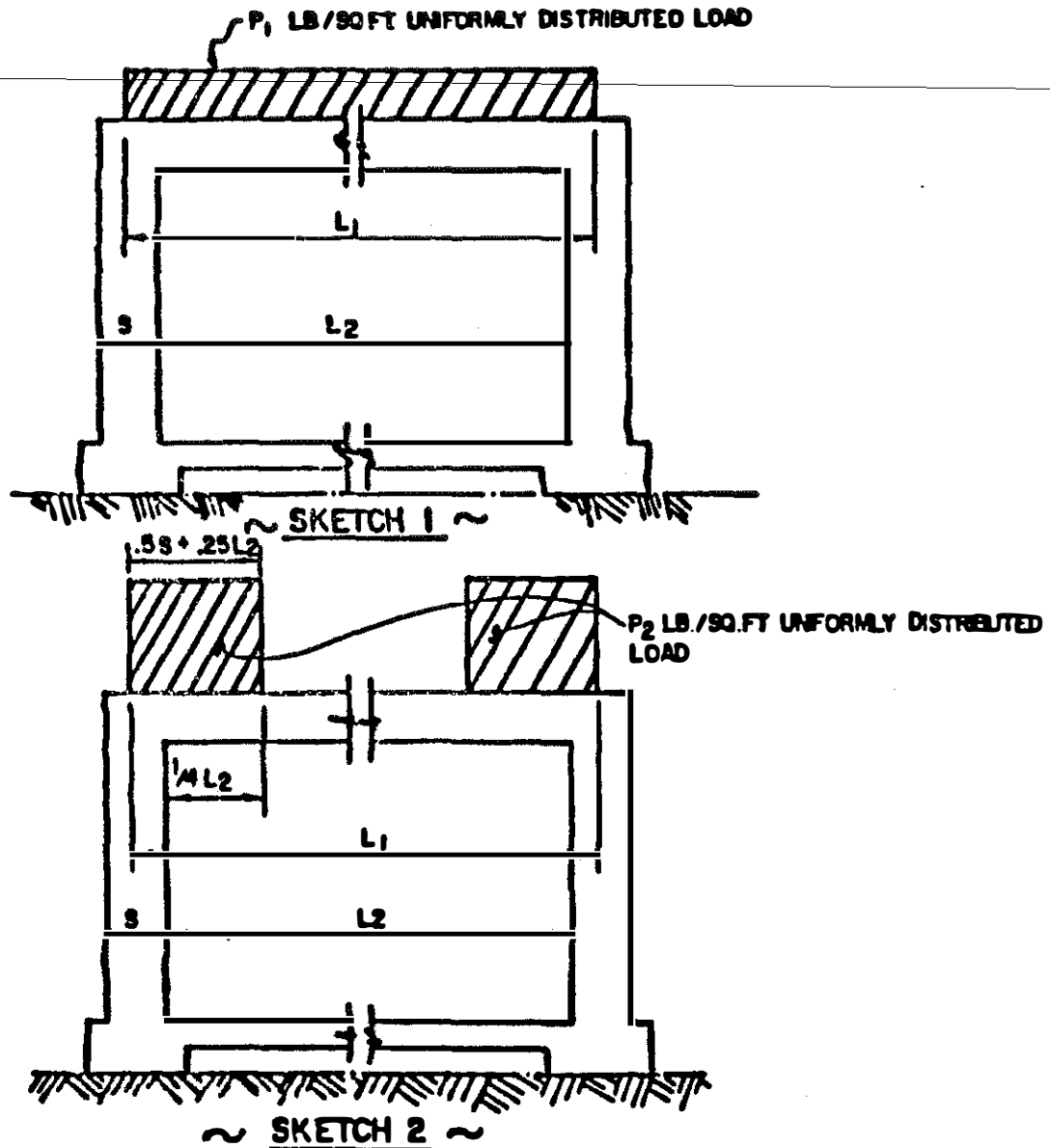


Figure 12. Cross Section of Culvert 4.



ON MULTIPLE BARREL CULVERTS: L_1 = DISTANCE CENTER TO CENTER OF EXTERIOR WALLS.
 L_2 = DISTANCE FROM INSIDE OF EXTERIOR WALL TO INSIDE OF EXTERIOR WALL.

Figure 13. Load Distribution Used By KDOH for Design of Culvert Top Slabs.

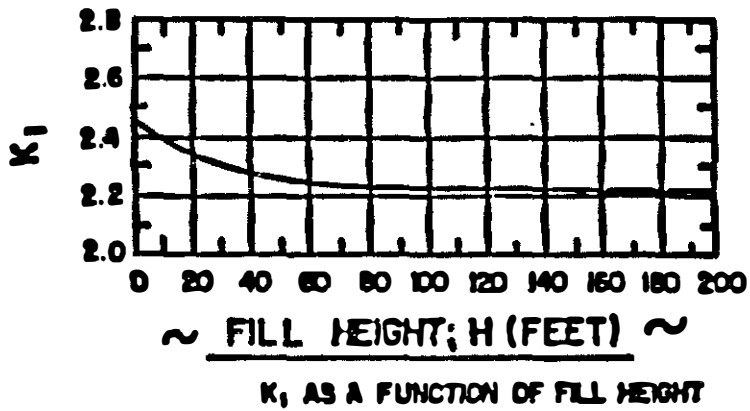
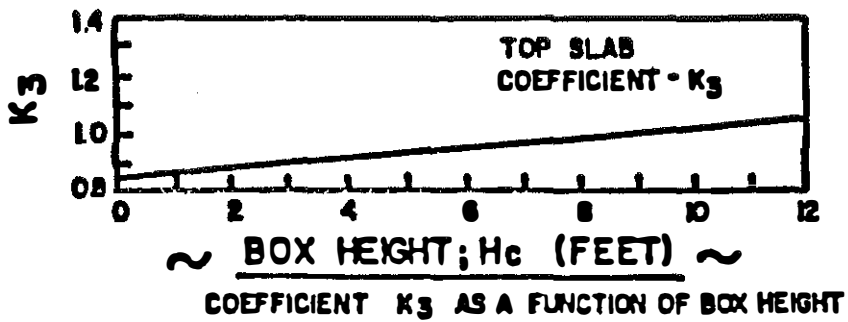
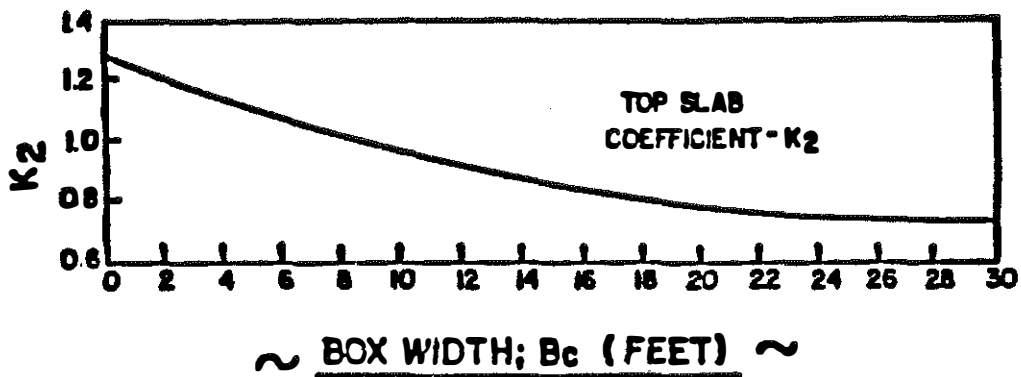
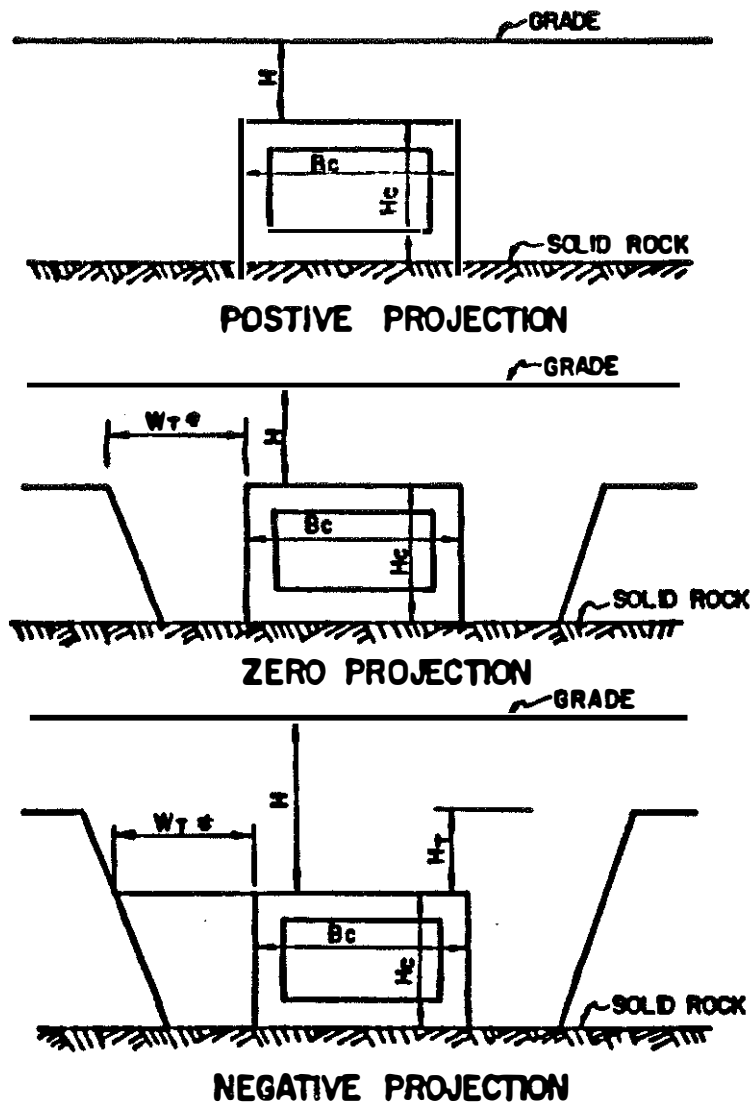


Figure 14. Load Coefficient Graphs Used By KDOH for Design of Culvert Top Slabs.



4 IF W_t EXCEEDS 6' THE CULVERT SHALL BE CONSIDERED TO BE IN A POSITIVE PROJECTION

Figure 15. Culvert Projection Conditions as Designated By KDOH.

CULVERT 1
STATION 1056 + 84

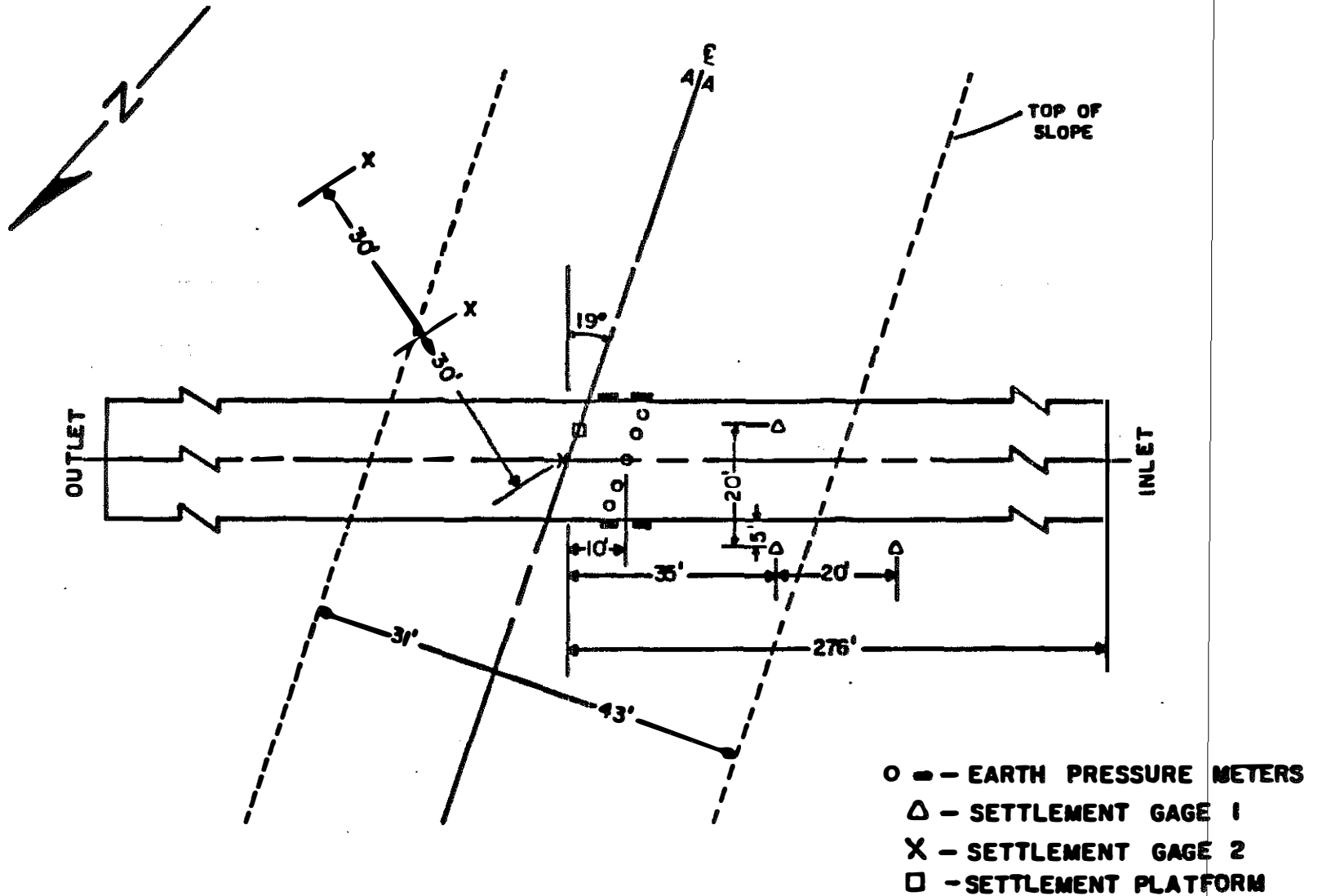


Figure 16. Plan View of Culvert 1 with Instrumentation Locations.

CULVERT 1

STA. 1056+84

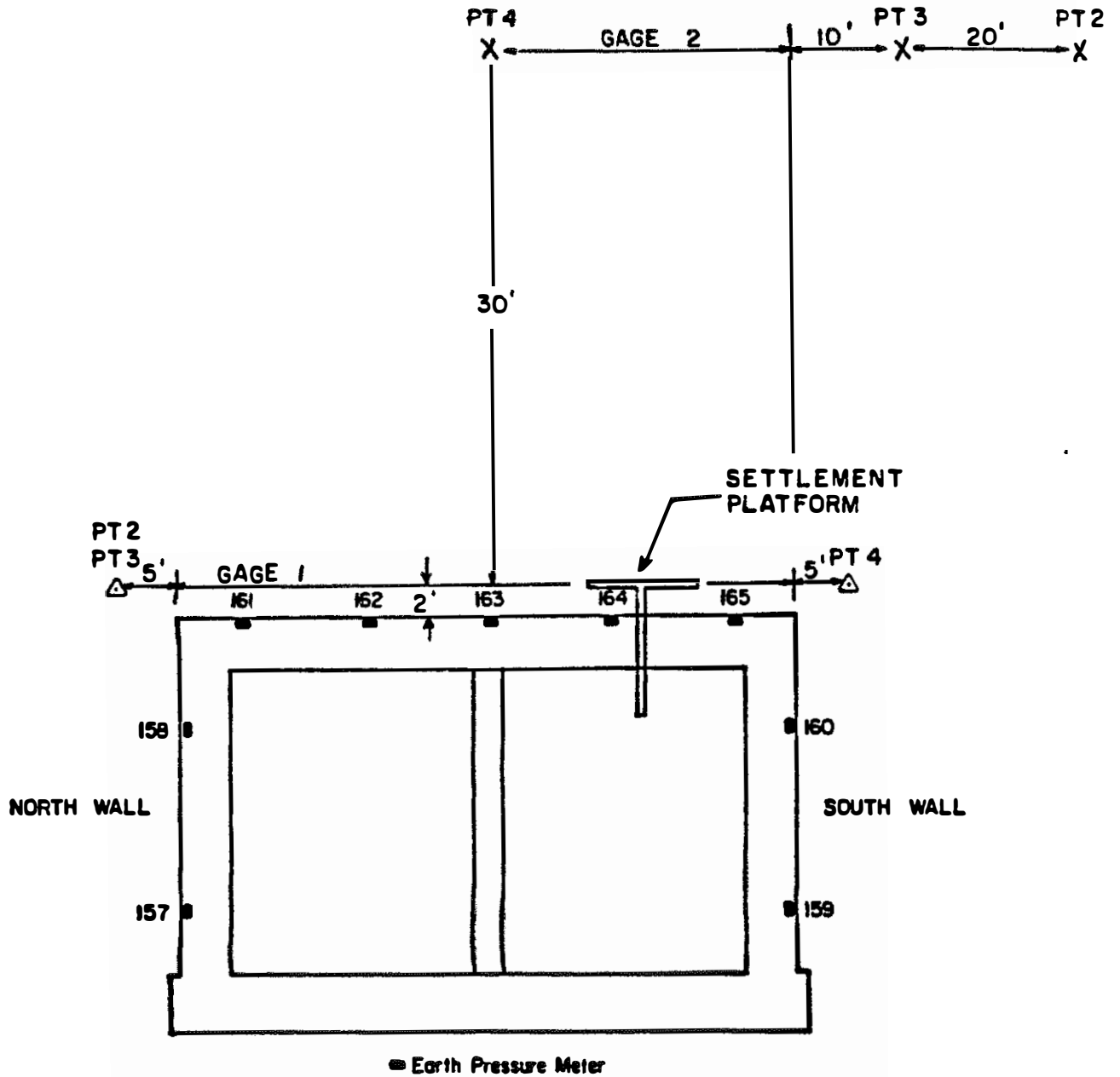


Figure 17. Cross Section of Culvert 1 with Instrumentation Locations.

CULVERT 2 STA. 1303+40

- - EARTH PRESSURE METERS
- △ - SETTLEMENT GAGE I
- - SETTLEMENT PLATFORM

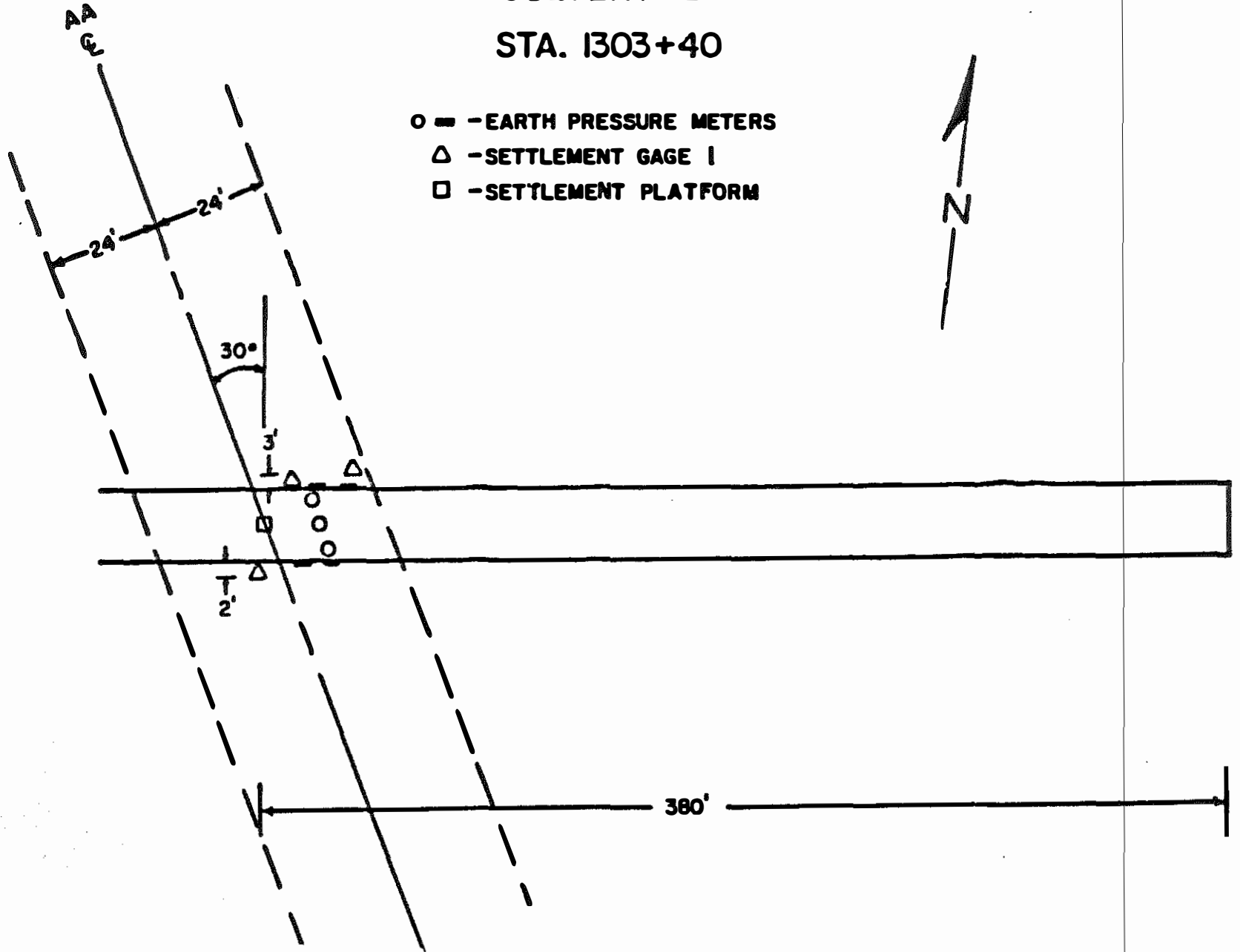


Figure 18. Plan View of Culvert 2 with Instrumentation Locations.

CULVERT 2
STA. 1303+40

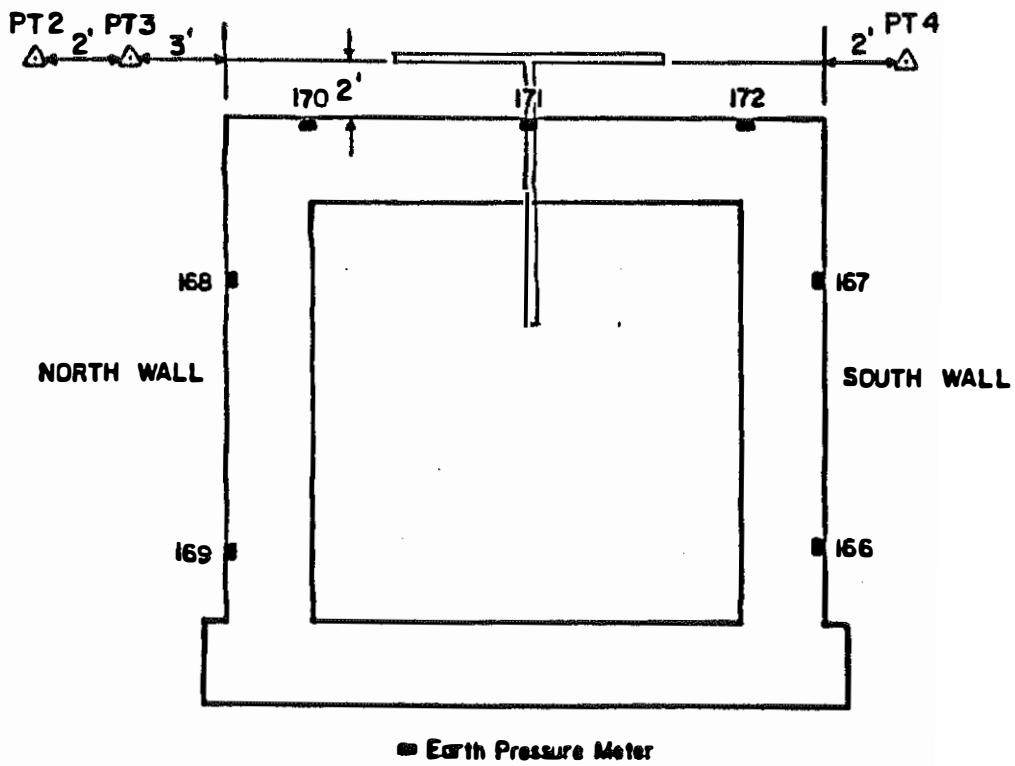
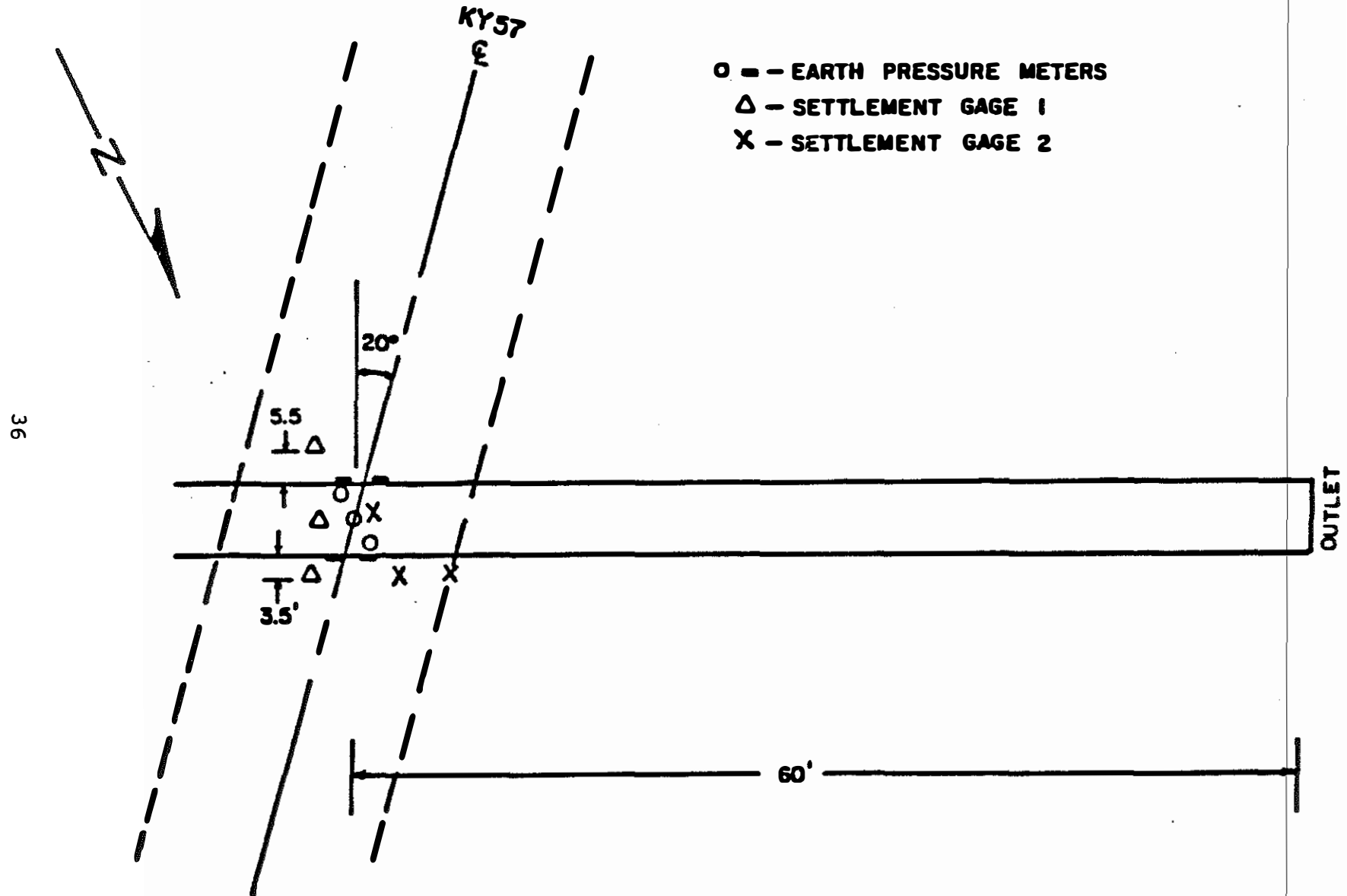


Figure 19. Cross Section of Culvert 2 with Instrumentation Locations.

CULVERT 3

STA. 49+03



36

Figure 20. Plan View of Culvert 3 with Instrumentation Locations.

CULVERT .3
STA. 49+03

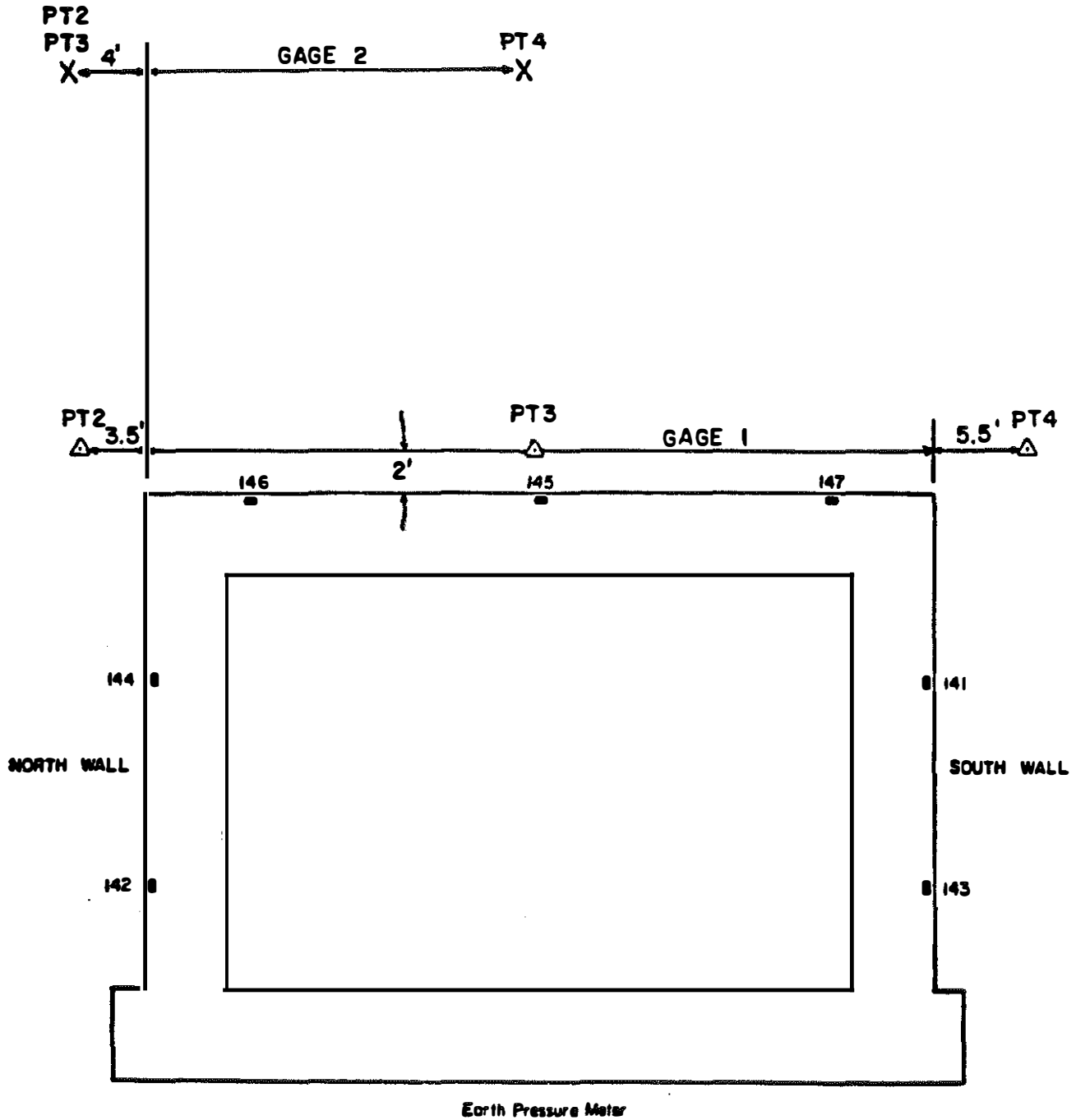


Figure 21. Cross Section of Culvert 3 with Instrumentation Locations.

CULVERT 4
STA. 1667+72

O - EARTH PRESSURE METERS
Δ - SETTLEMENT GAGE 1
X - SETTLEMENT GAGE 2

38

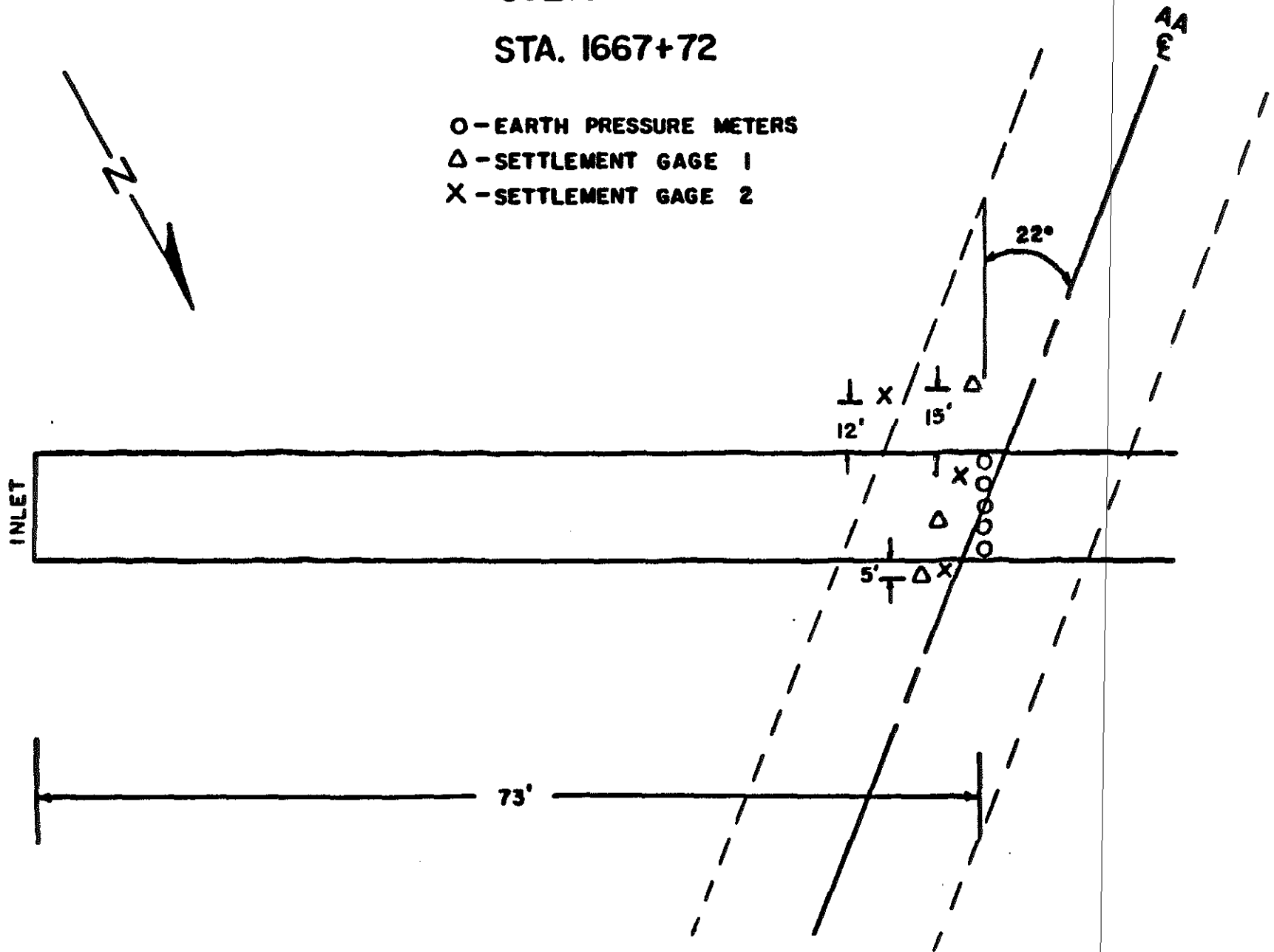


Figure 22. Plan View of Culvert 4 with Instrumentation Locations.

CULVERT 4
STA. 1667+72

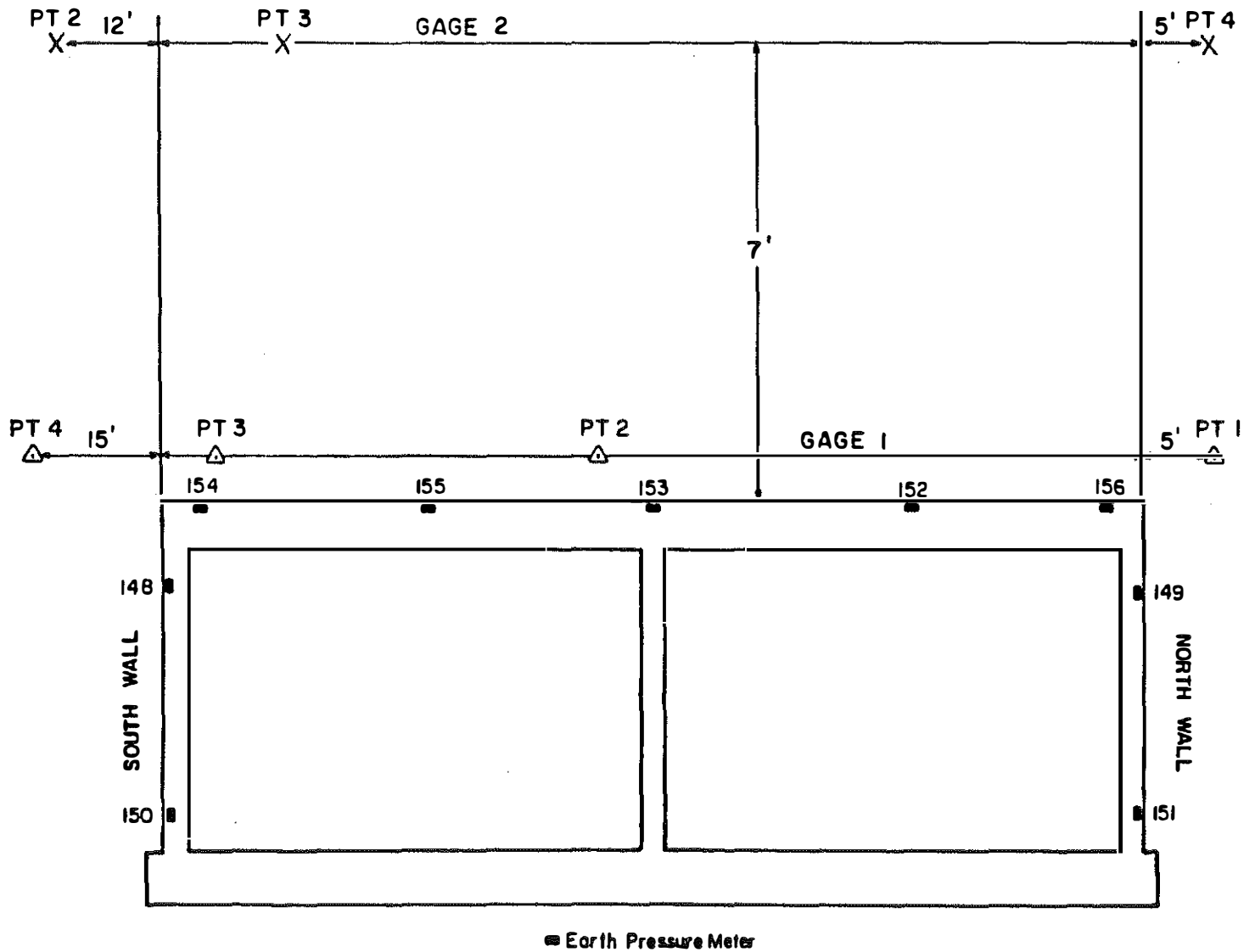


Figure 23. Cross Section of Culvert 4 with Instrumentation Locations.

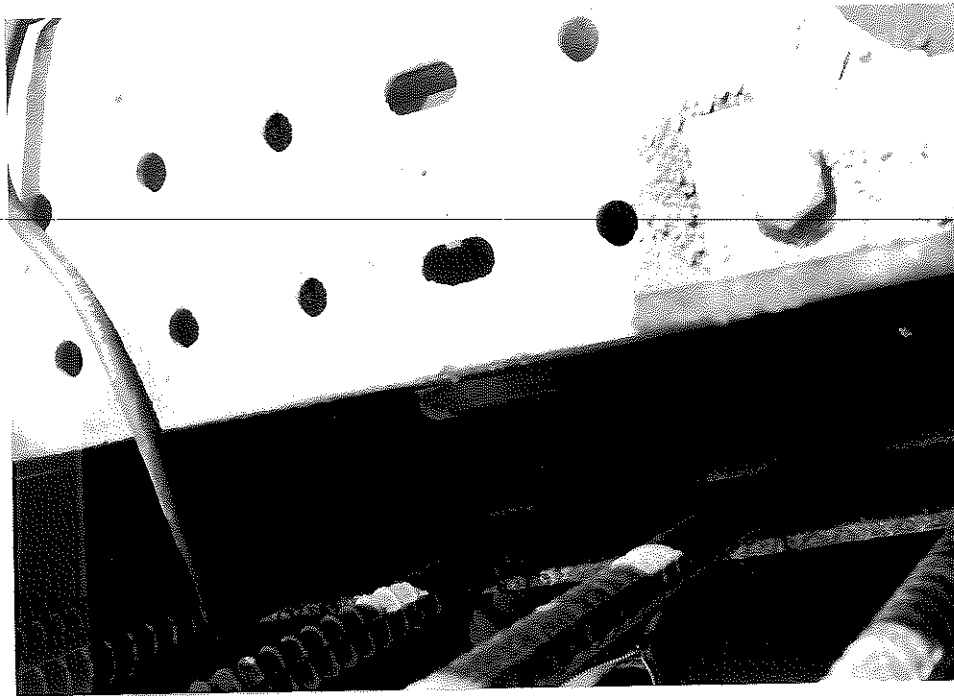


Figure 24. Photo of Earth Pressure Meter Attached to Sidewall Form Prior to Placement of Concrete.



Figure 25. Photo of Earth Pressure Meters Prior to Placement of Top Slab Concrete.



Figure 26. Photo of Sidewall Meters after Forms Have Been Removed.



Figure 27. Photo of Culvert 1 (Station 1056+84) Showing Positive Projection, Right Side, and Zero Projection, Left Side.

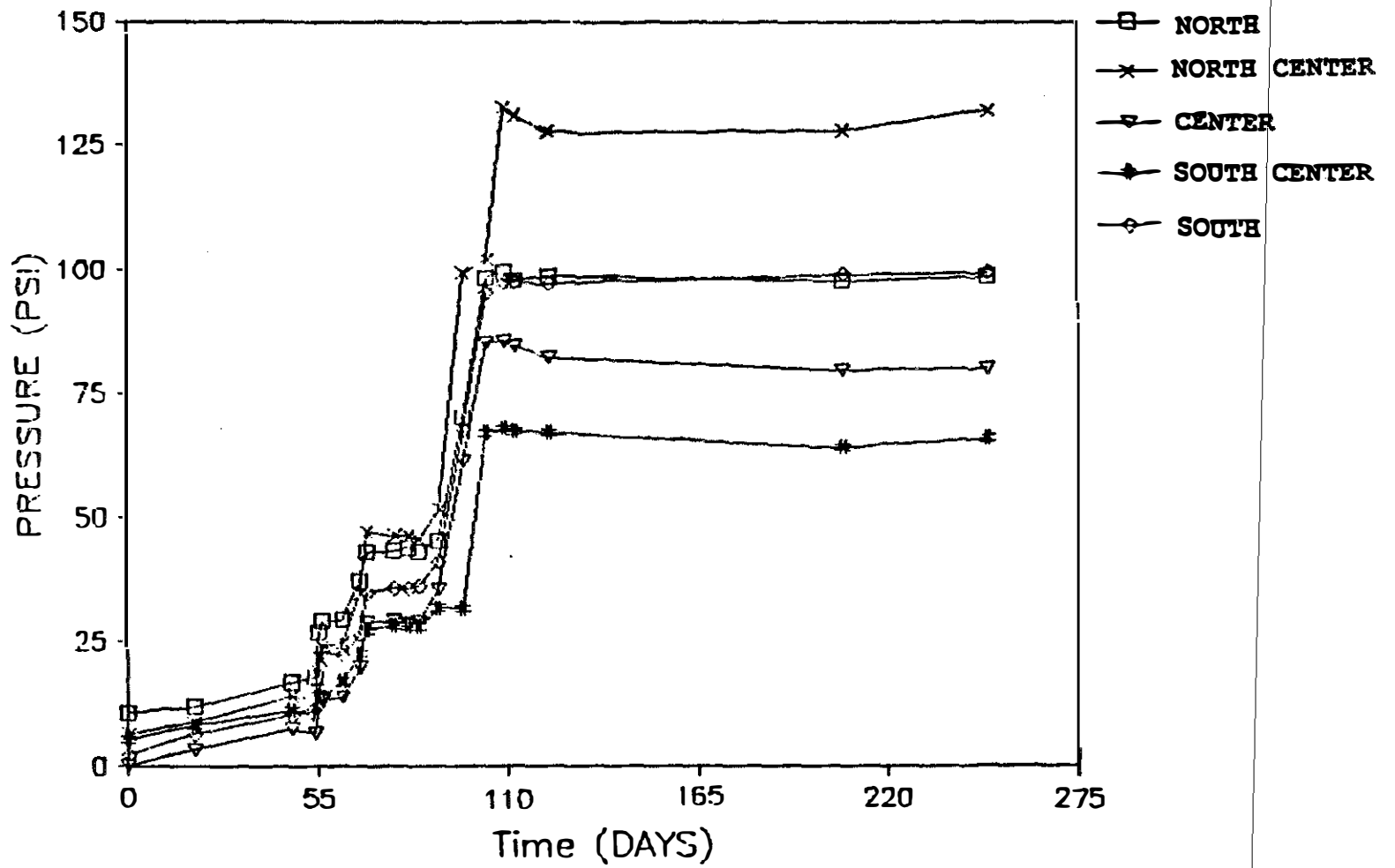


Figure 28. Measured Pressure on Top Slab of Culvert 1.

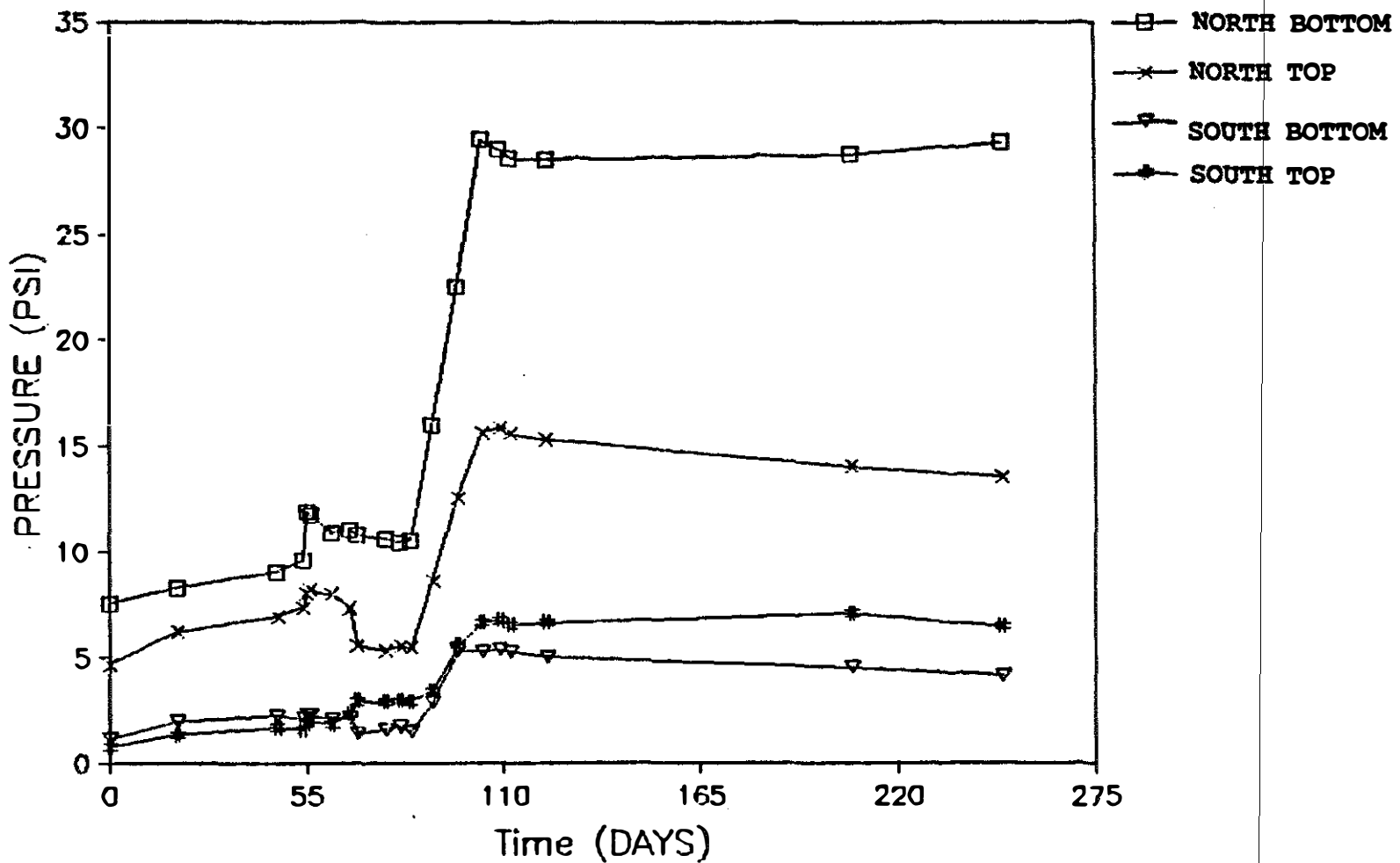
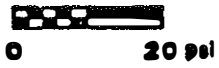


Figure 29. Measured Pressure on Sidewalls of Culvert 1.

STA. 1056+84

CULVERT 1



- ⊙ MEASURED
- △ (yh)
- FE method

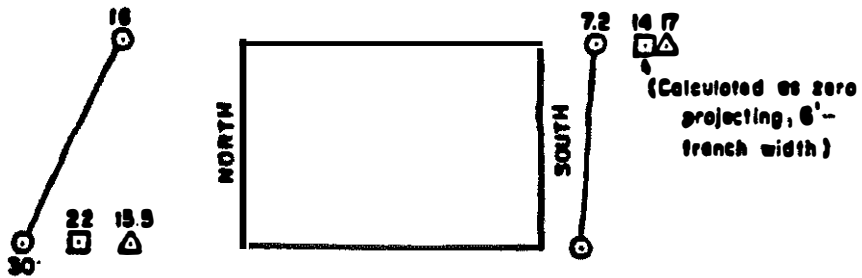
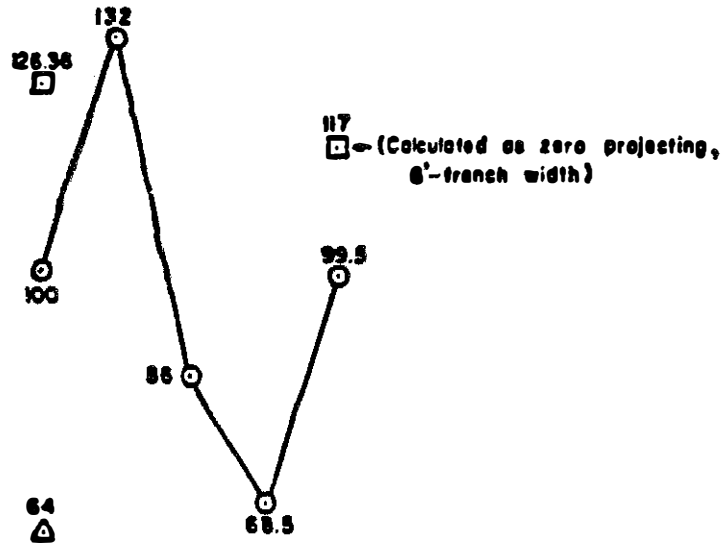


Figure 30. Peak Pressure Distribution on Culvert 1.

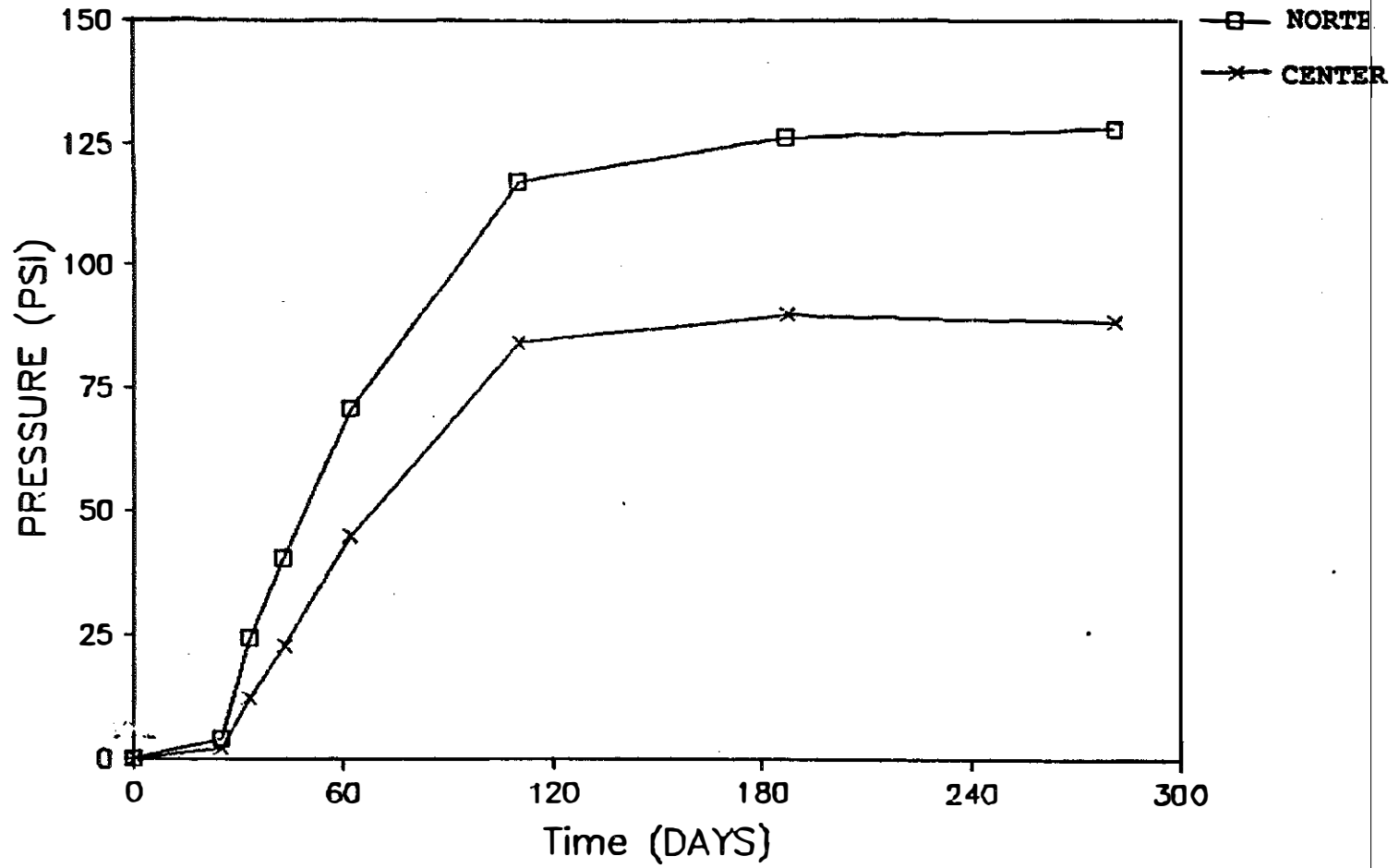


Figure 31. Measured Pressure on Top Slab of Culvert 2.

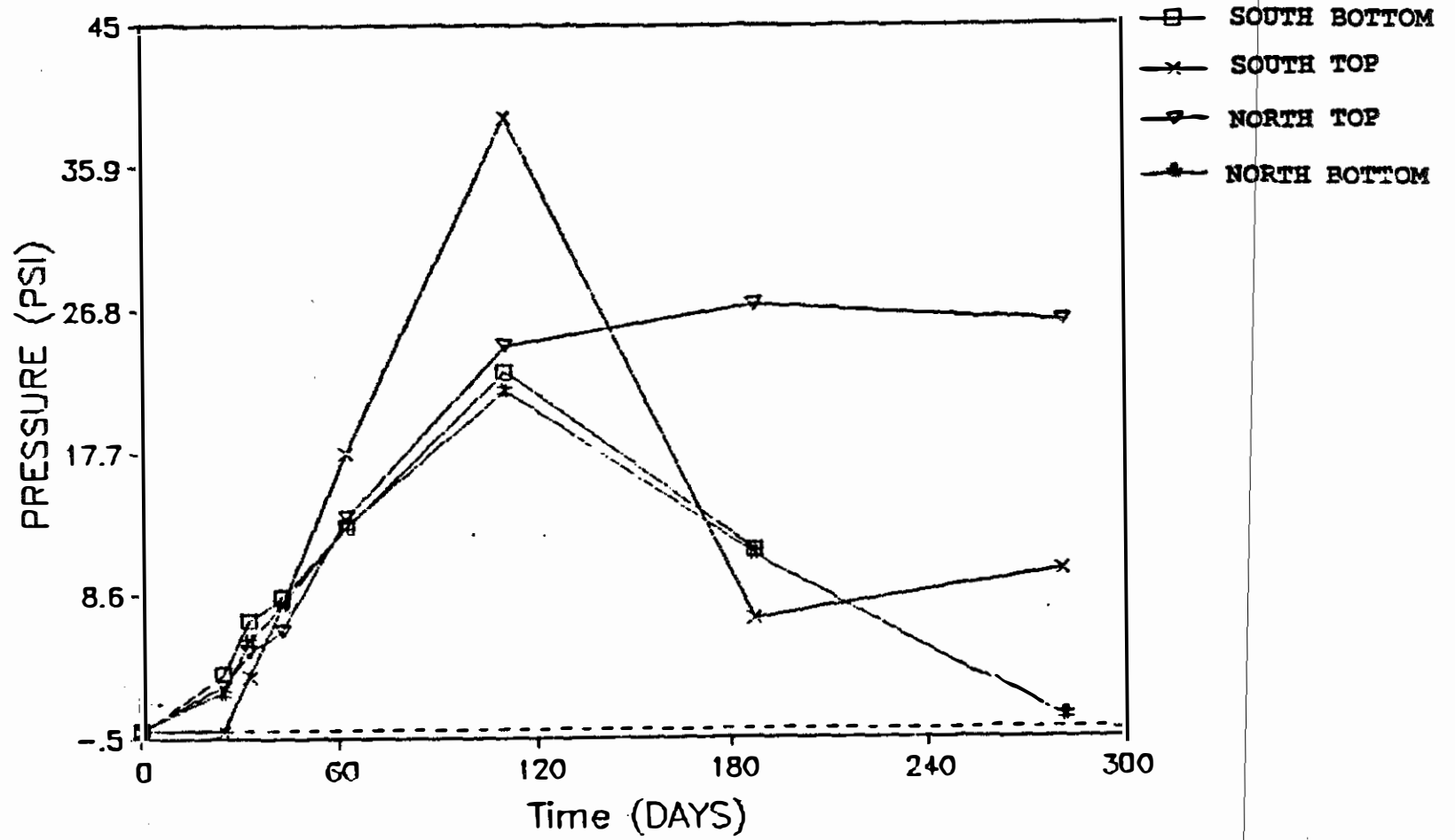
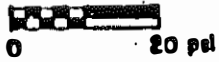


Figure 32. Measured Pressure on Sidewalls of Culvert 2.

STA. 1303+40



147.5
□

CULVERT (2)

- MEASURED
- △ (yh)
- FE method

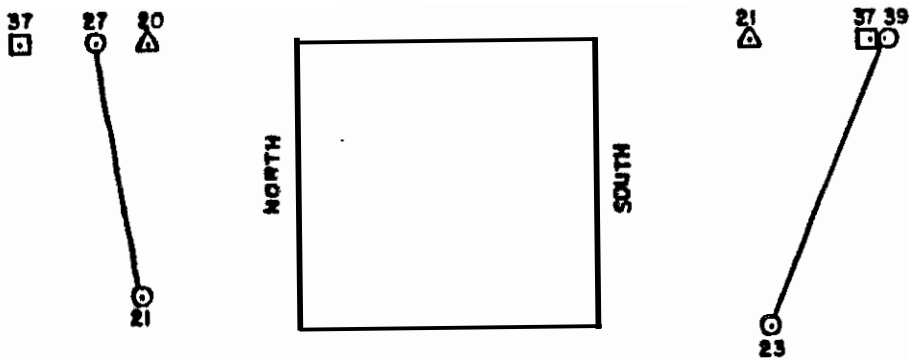
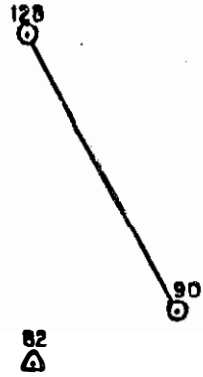


Figure 33. Peak Pressure Distribution on Culvert 2.

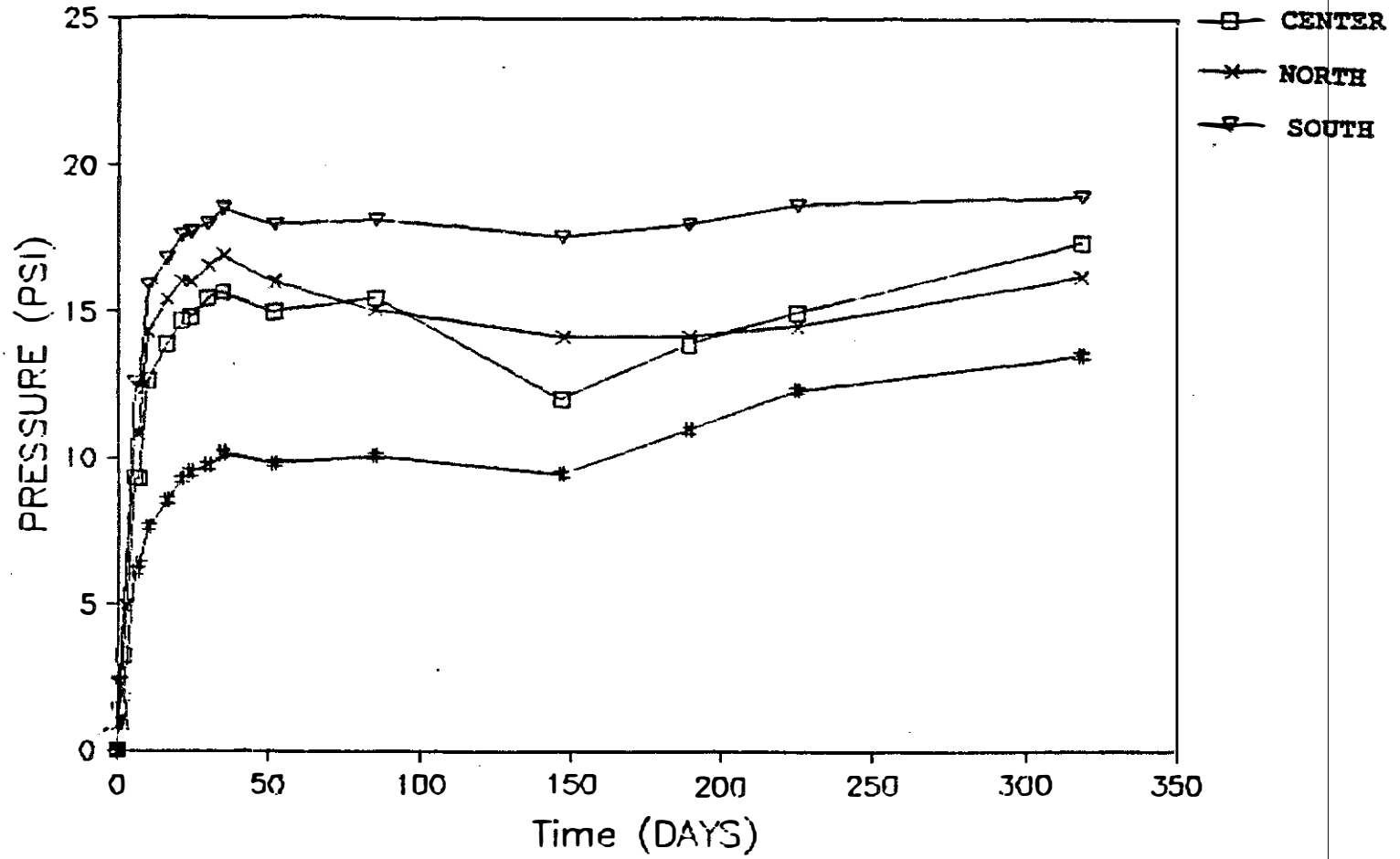


Figure 34. Measured Pressure on Top Slab of Culvert 3.

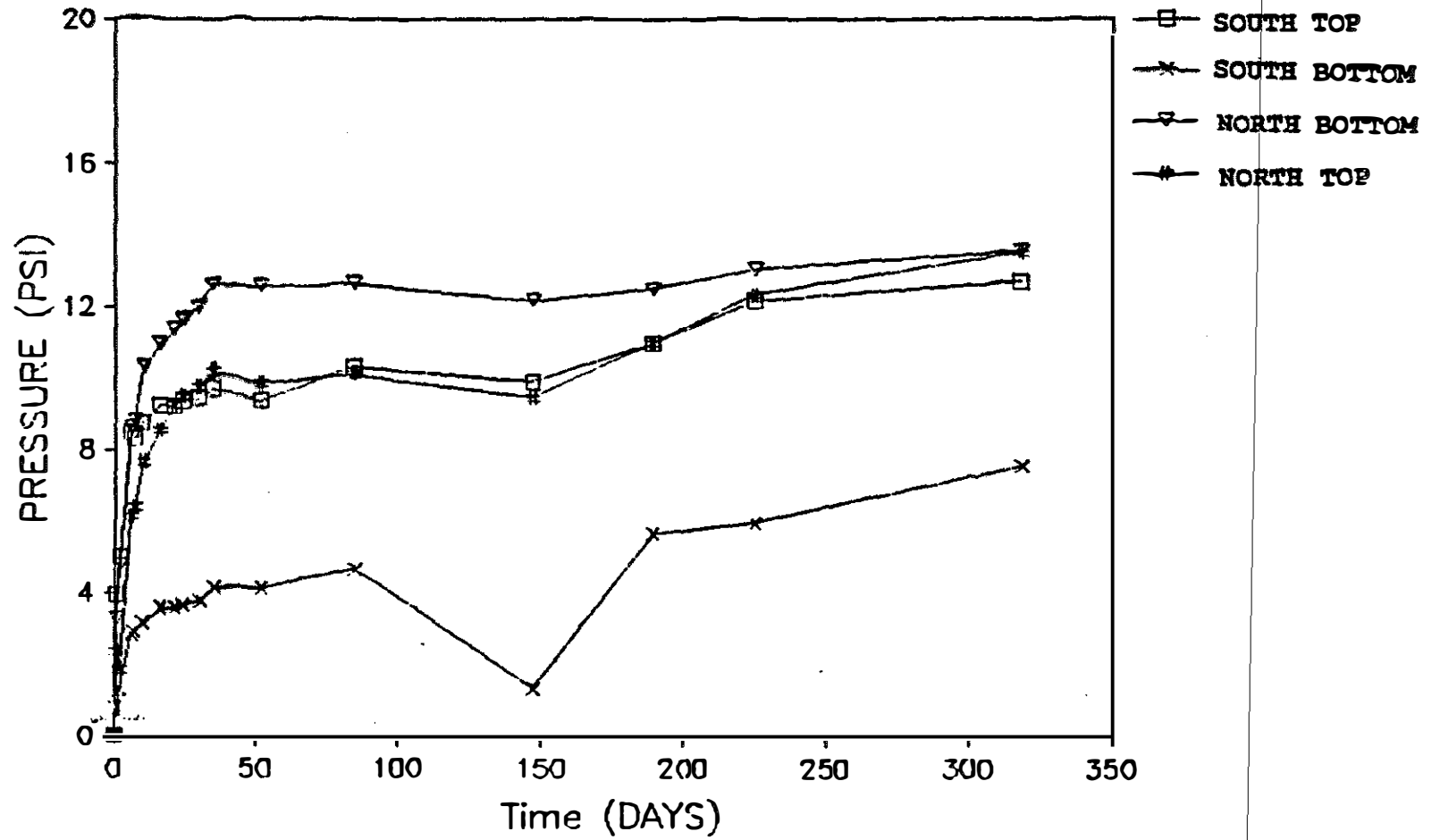
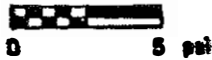


Figure 35. Measured Pressure on Sidewalls of Culvert 3.

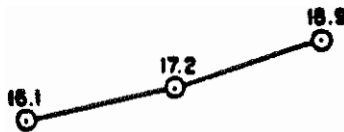
CULVERT (3)

STA. 49+03



- MEASURED
- △ (yh)
- FE method

28.12
□



III
△



5.3 □ 2.8 △

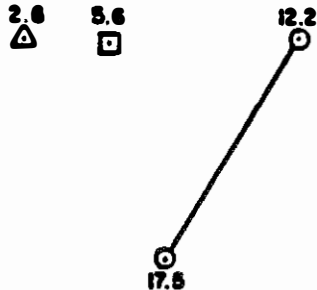
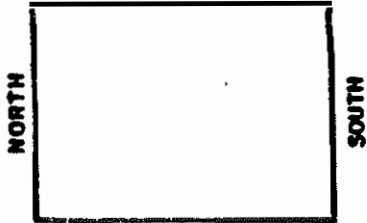


Figure 36. Peak Pressure Distribution on Culvert 3.

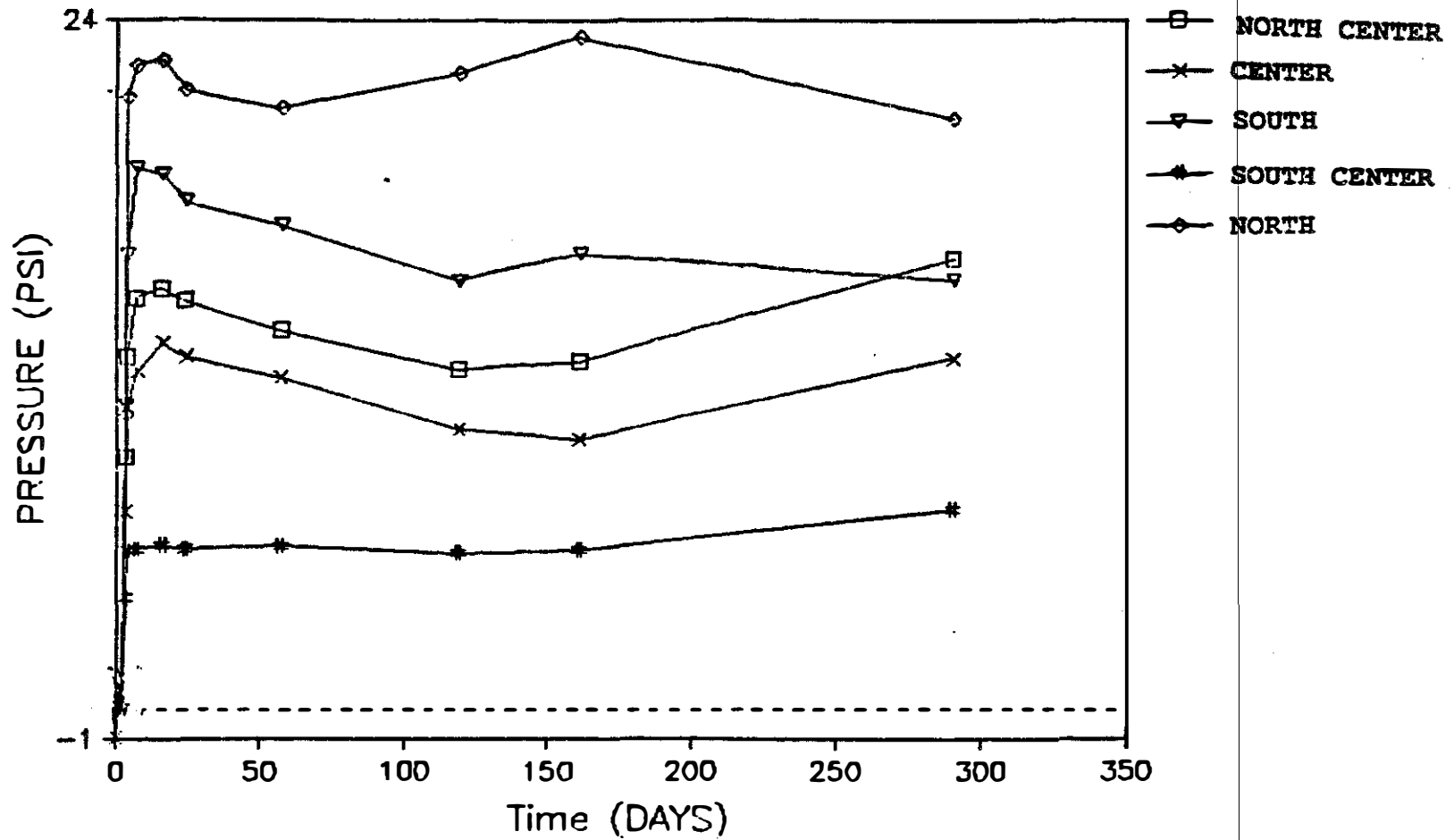


Figure 37. Measured Pressure on Top Slab of Culvert 4.

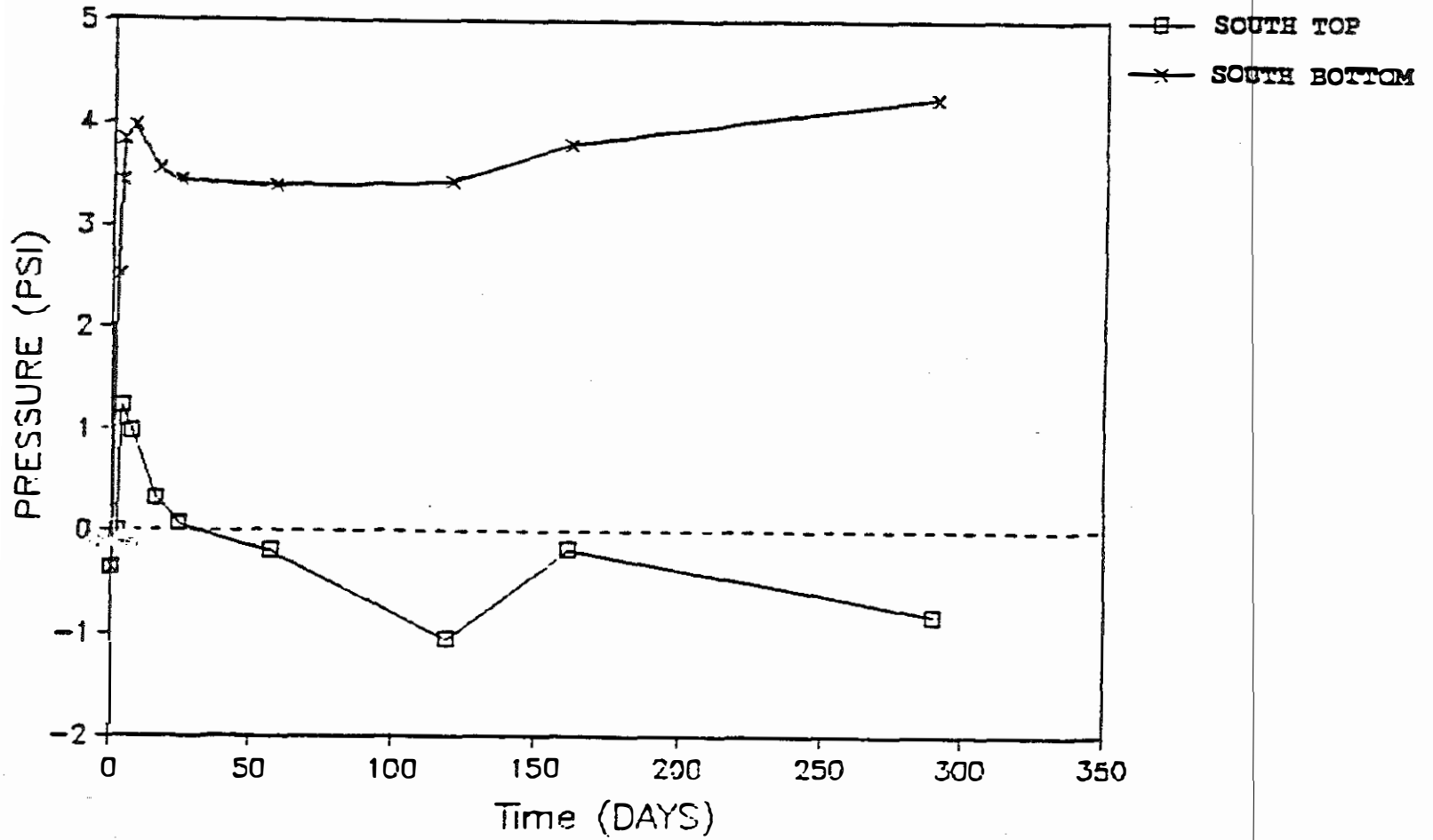


Figure 38. Measured Pressure on Sidewalls of Culvert 4.

STA. 1667+72

CULVERT (4)



- MEASURED
- △ (yh)
- FE method

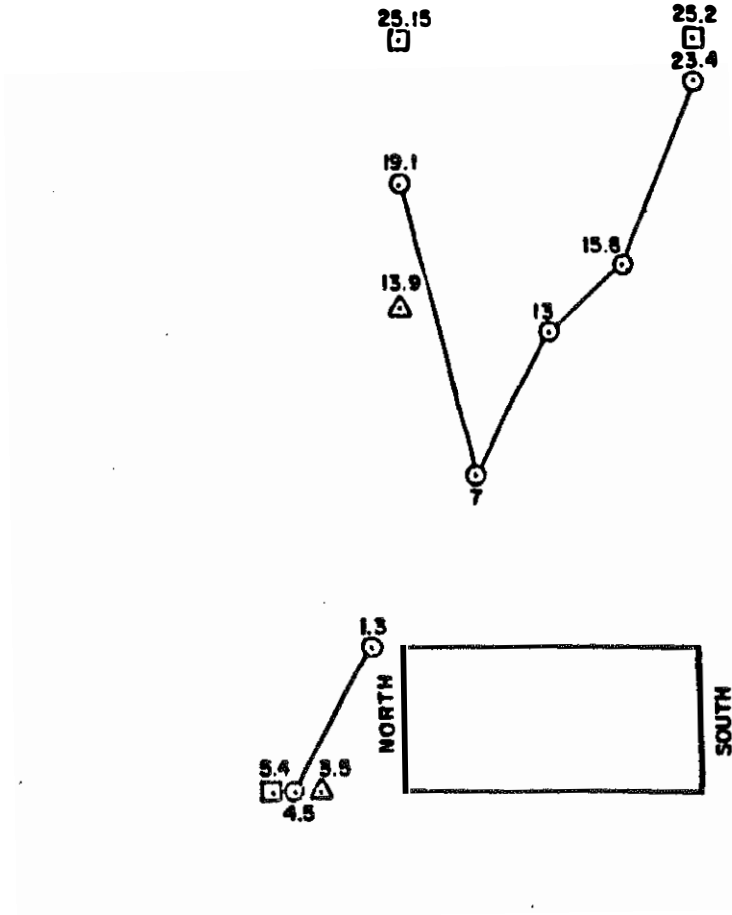


Figure 39. Peak Pressure Distribution on Culvert 4.

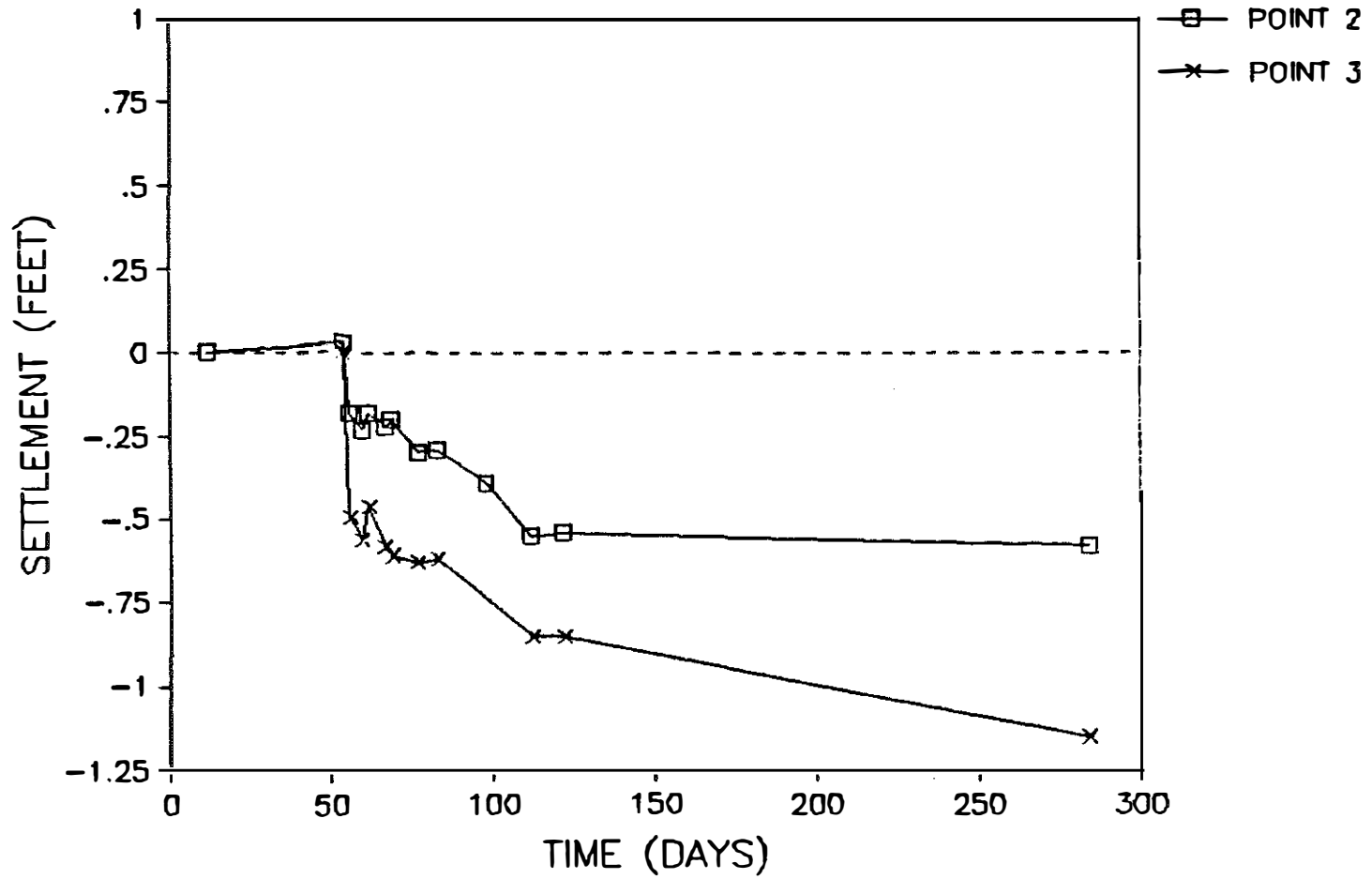


Figure 40. Fill Settlement of Gage 1 - Culvert 1.

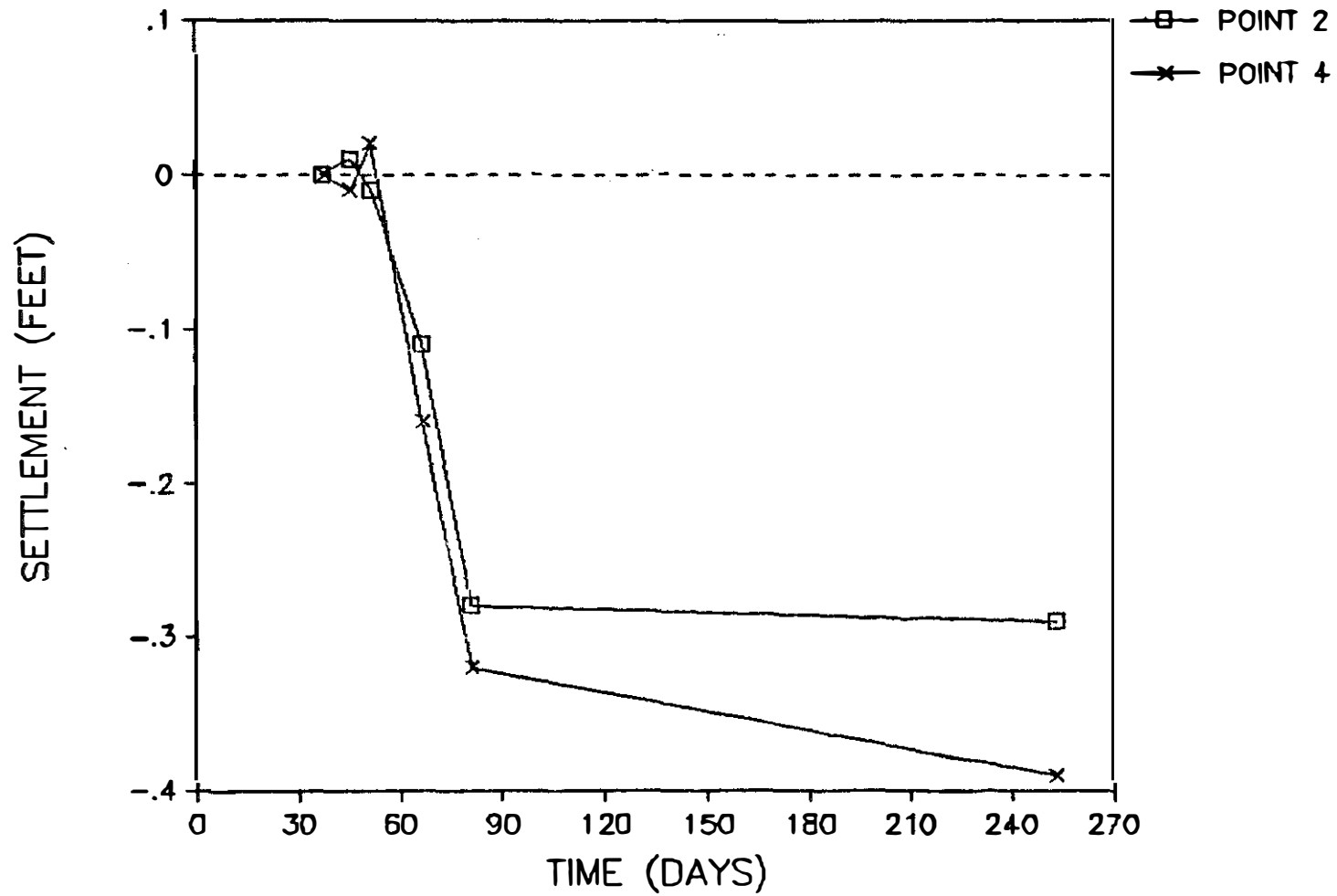


Figure 41. Fill Settlement of Gage 2 - Culvert 1.

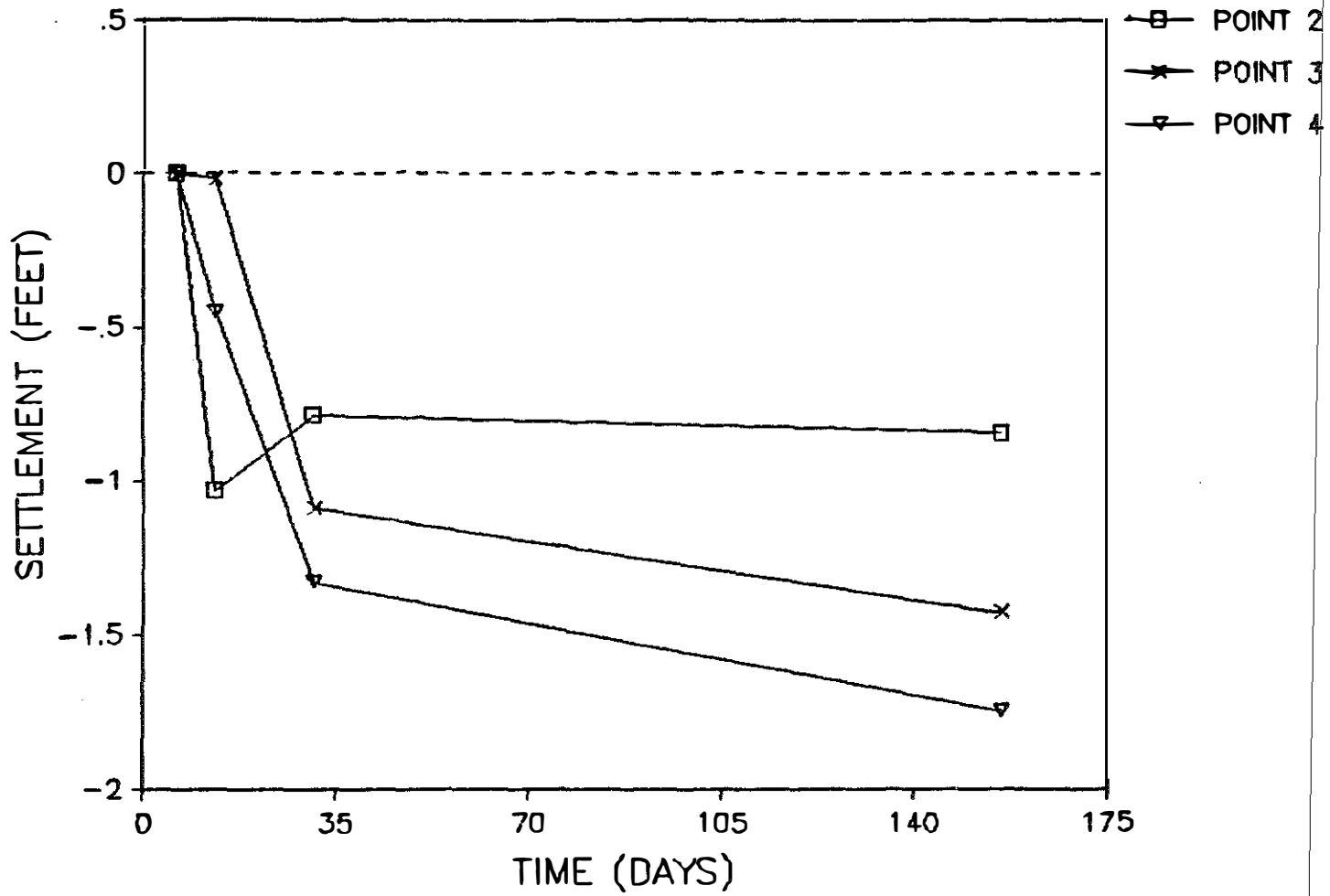


Figure 42. Fill Settlement of Gage 1 - Culvert 2.

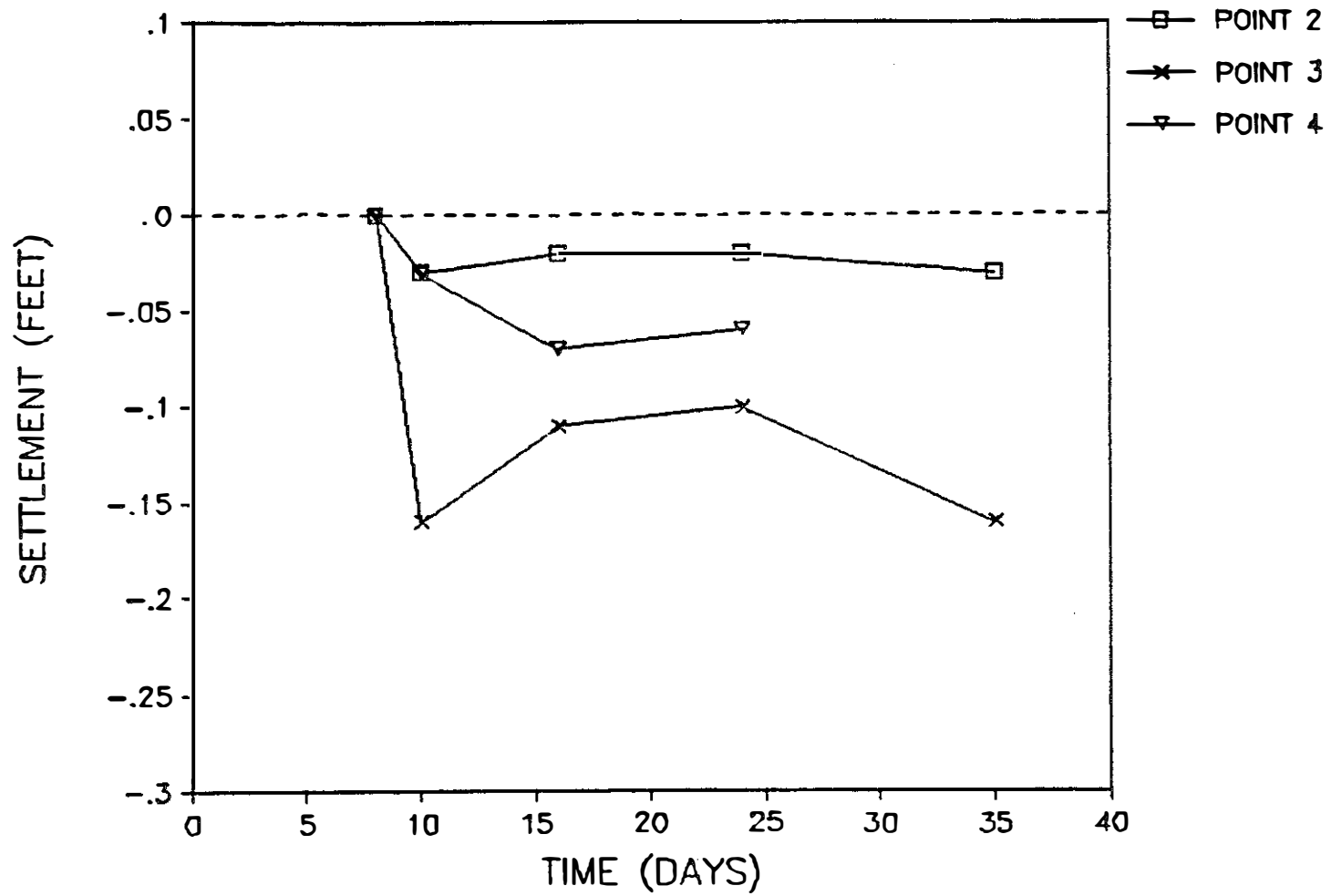


Figure 43. Fill Settlement of Gage 2 - Culvert 3.

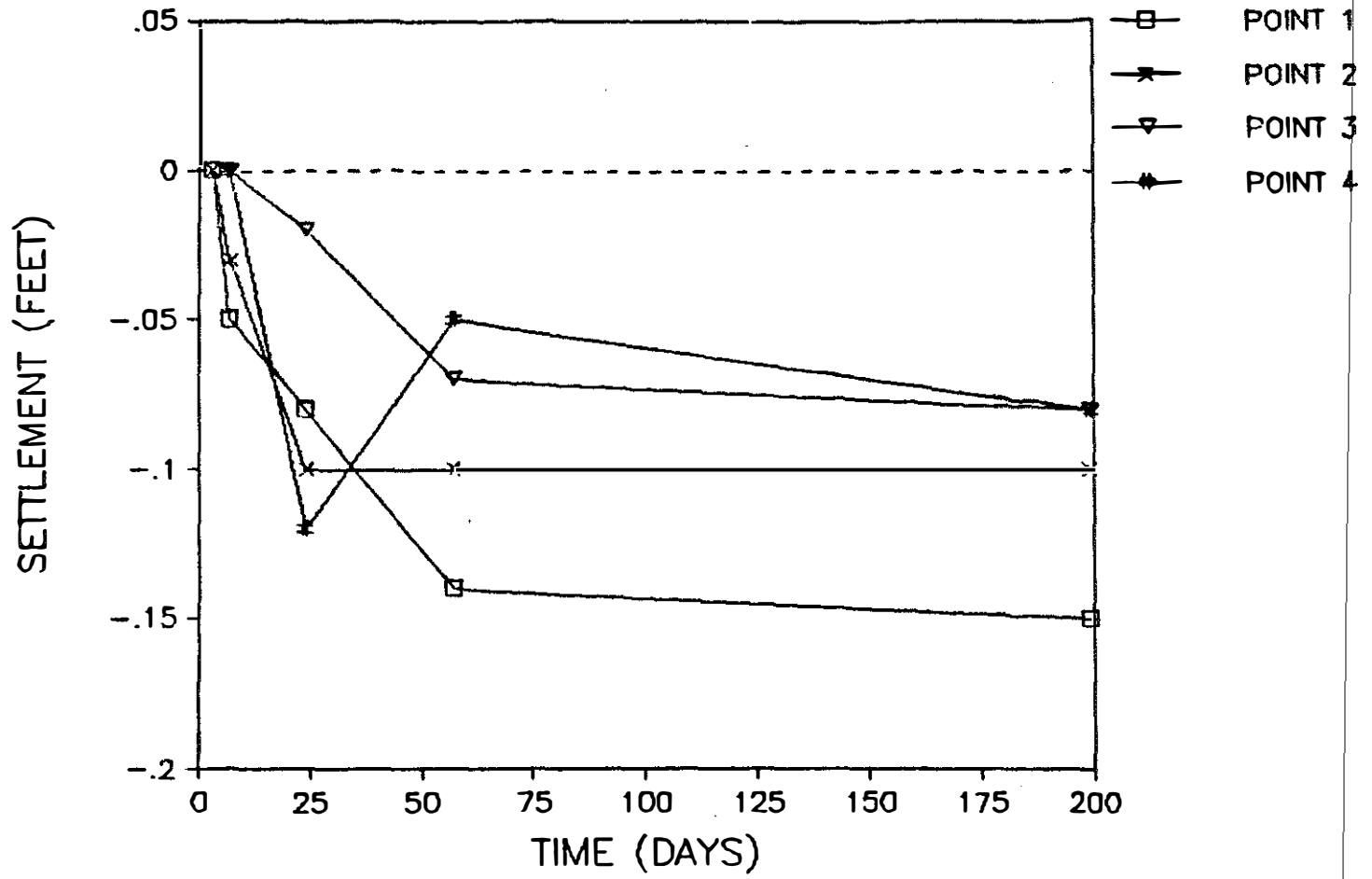


Figure 44. Fill Settlement of Gage 1 - Culvert 4.

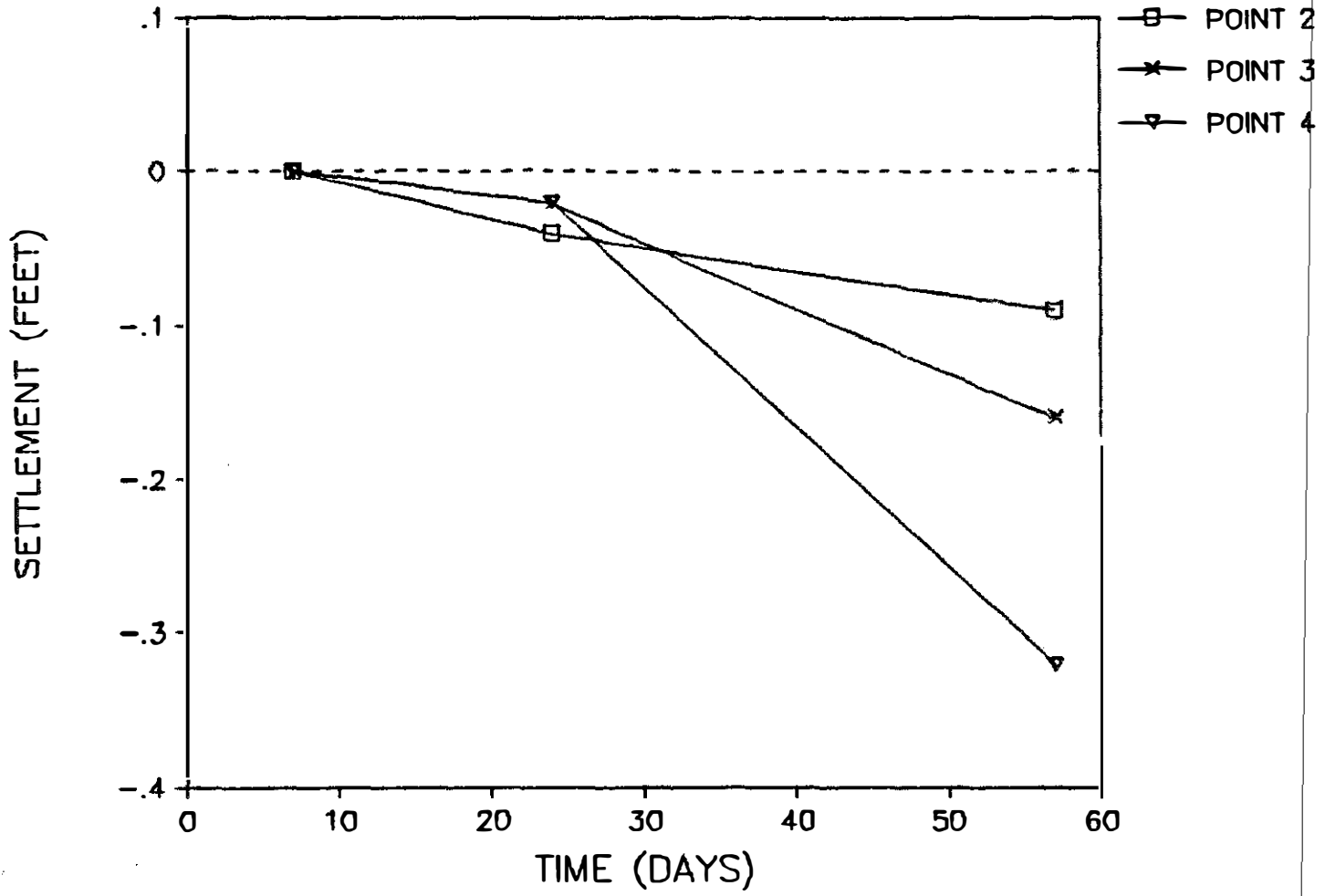


Figure 45. Fill Settlement of Gage 2 - Culvert 4.

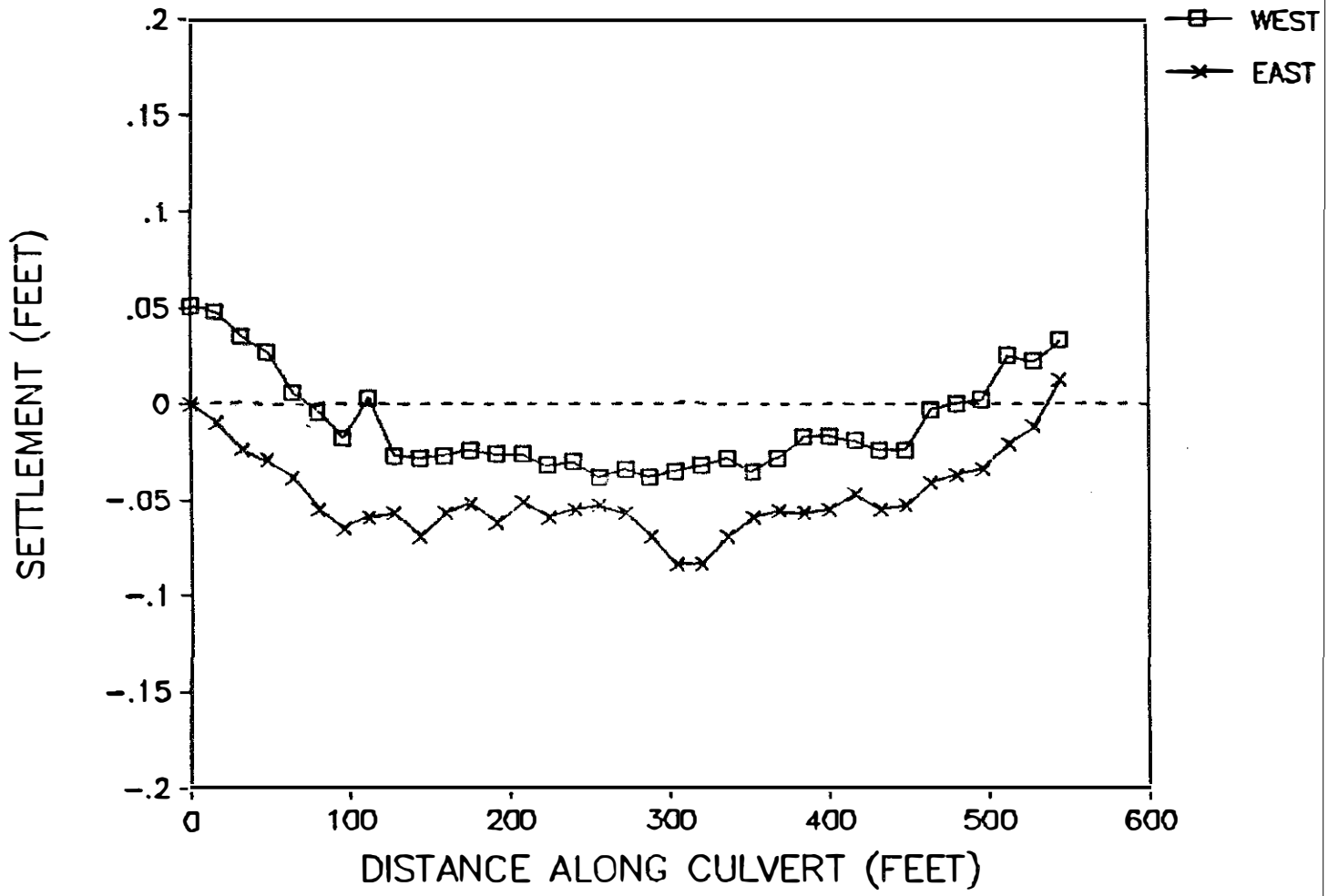


Figure 46. Culvert Settlement - Culvert 1.

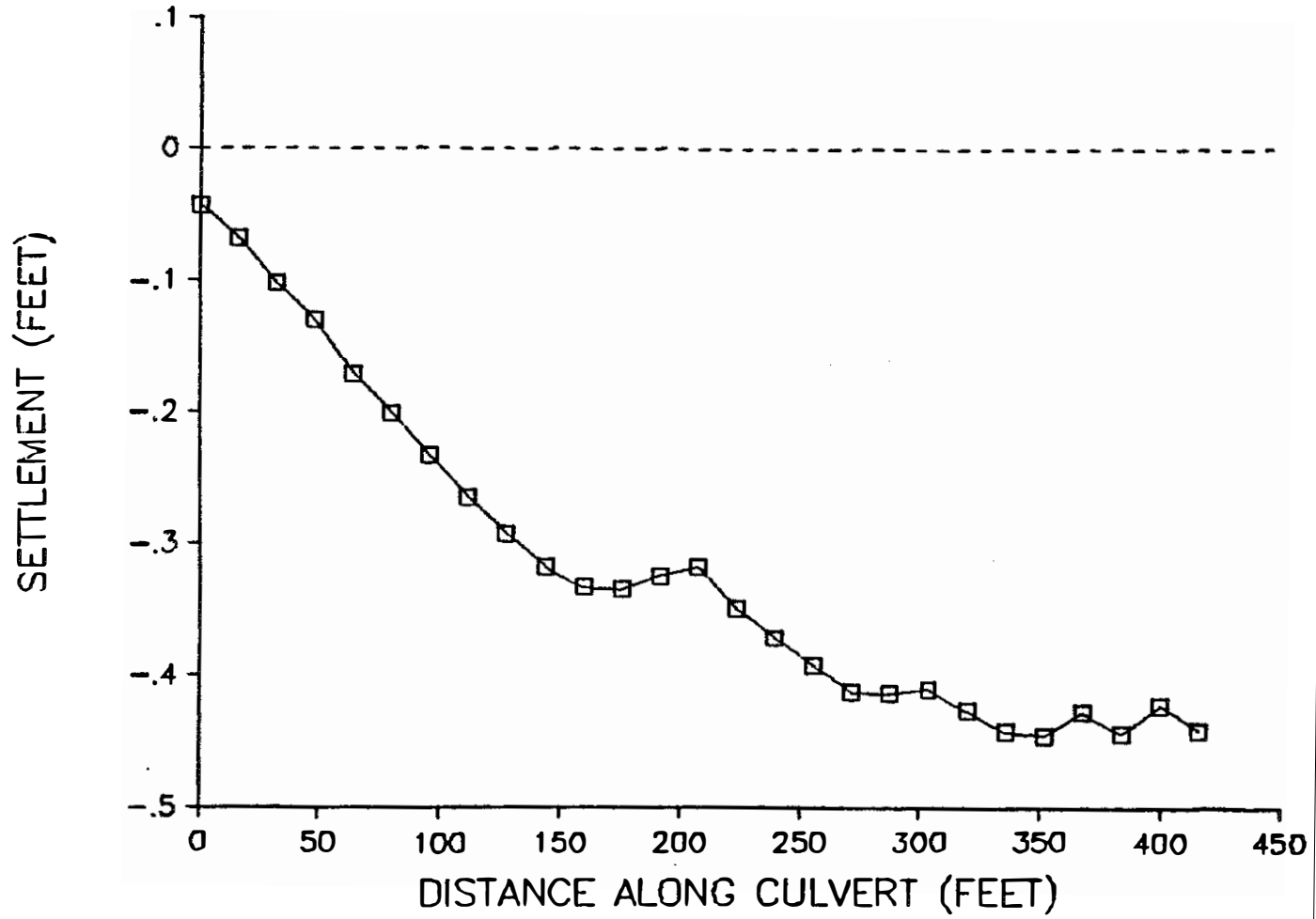


Figure 47. Culvert Settlement - Culvert 2.

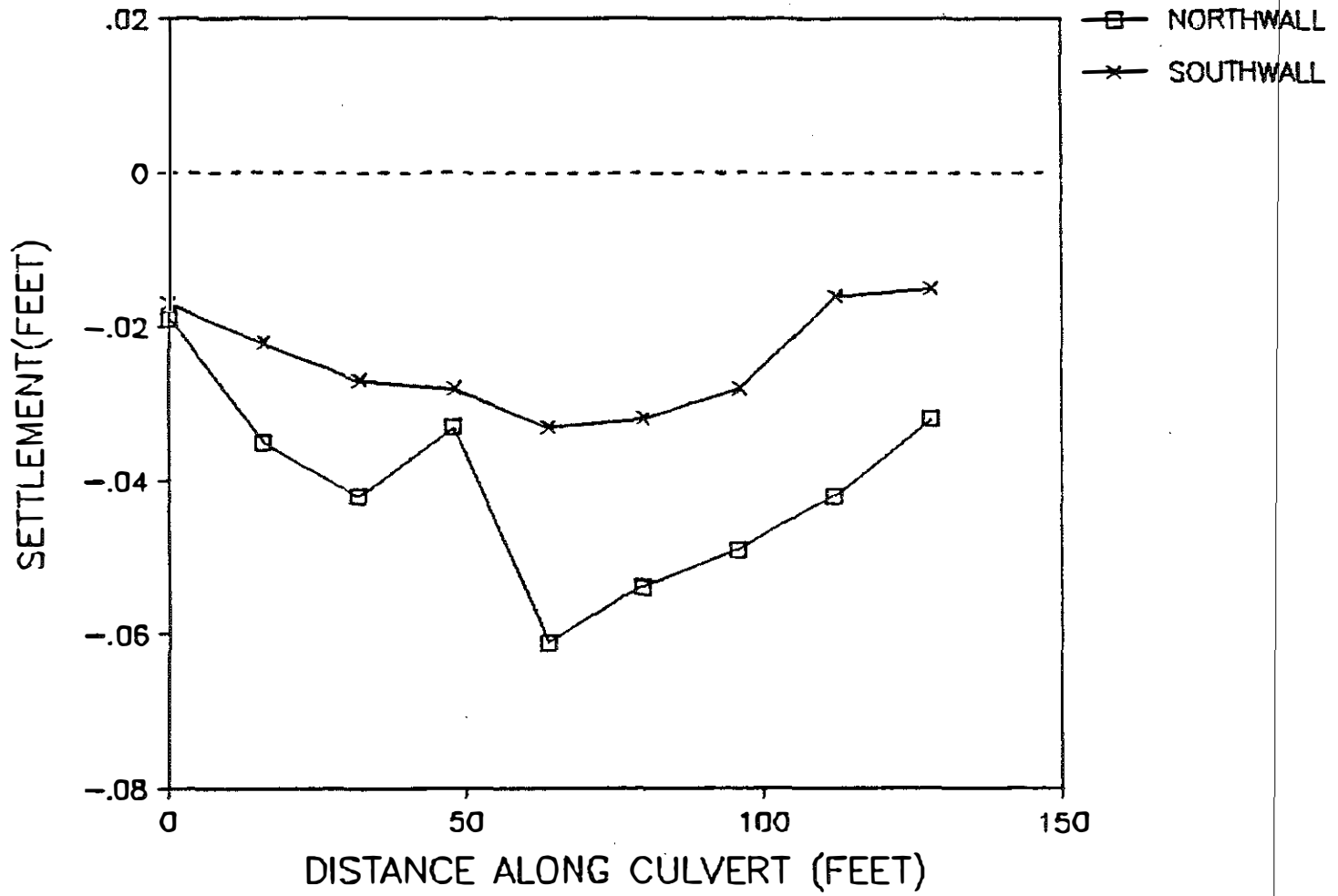


Figure 48. Culvert Settlement - Culvert 4.

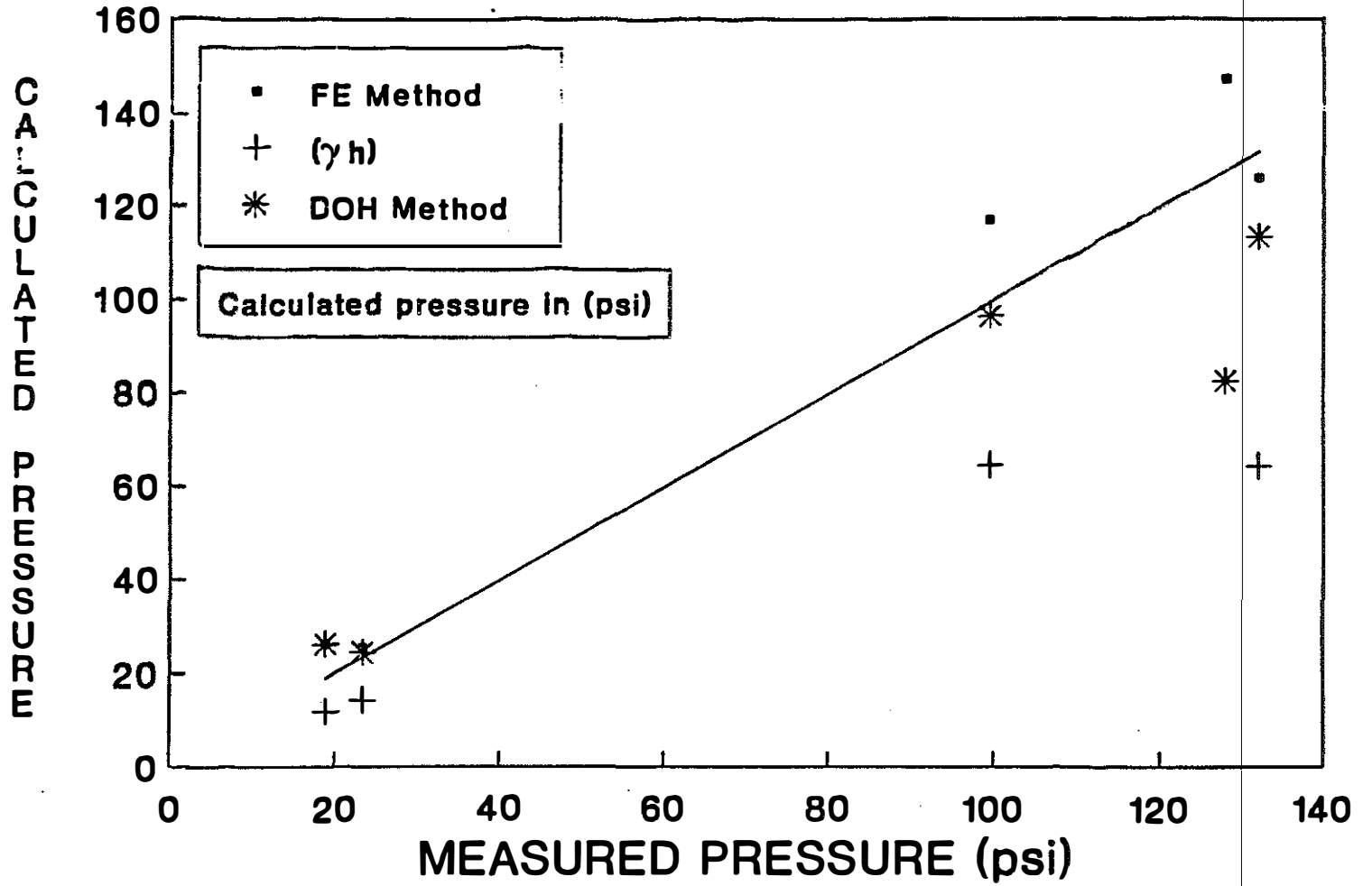


Figure 49. Measured Versus Calculated Pressures For Culvert Top Slabs.

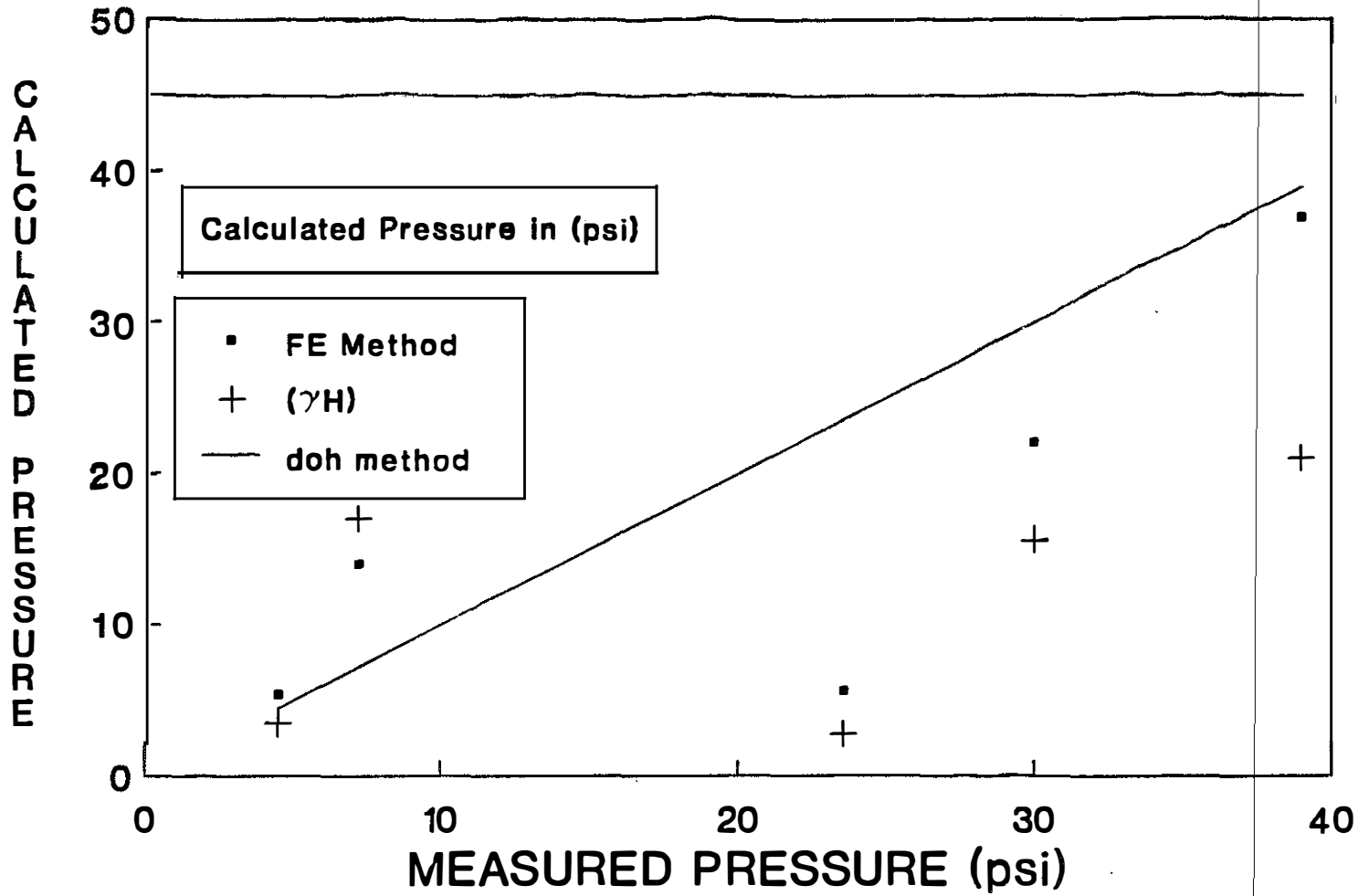


Figure 50. Measured Versus Calculated Pressures For Culvert Sidewalls.