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COMPARISON OF MEASURED PILE CAPACITY TO PILE CAPACITY PREDICTIONS MADE USING ELECTRONIC CONE PENETRATION DATA

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English Unit	Multiply By	To Get Metric Equivalent
Length	inches (in) or (")	25.40	millimetres (mm)
		.02540	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)	.09290	square metres (m^2)
	acres	.4047	hectares (ha)
Volume	gallons (gal)	3.785	litre (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)	.4470	metres per second (m/s)
	feet per second (fps)	.3048	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)
Density	(lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lb)	4.448	newtons (N)
	kips (1000 lb)	4448	newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb)	1.356	joules (J)
	foot-kips (ft-k)	1356	joules (J)
Bending Moment or Torque	inch-pounds (in-lb)	.1130	newton-metres (Nm)
	foot-pounds (ft-lb)	1.356	newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (°F)	$\frac{°F - 32}{1.8} = °C$	degrees celsius (°C)
Concentration	parts per million (ppm)	1	milligrams per kilogram (mg/kg)

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INTRODUCTION

This report compares the results of static pile load tests with pile capacity predictions obtained using cone penetration test data. Cone penetration test (CPT) data were collected at 27 sites where Caltrans had conducted 32 static pile load tests for highway construction. These penetration test data were used to predict pile capacity through application of six previously published CPT-based analytical procedures. Even though some of the procedures were developed for a limited range of soil conditions, all six were applied to the penetration data set to evaluate applicability for a variety of soil conditions. The predicted pile capacities were then compared to those determined by static load tests to determine which method performed best.

After a brief description of the cone penetration test, the body of the report presents a description of the criteria used to select the 32 pile load tests. This is followed by an overview of the methods used for analyzing the CPT data, a comparison between predicted and actual capacities, and recommendations for departmental implementation.

Background

In 1980, Caltrans evaluated a penetrometer conceptually similar to the CPT called the Dutch Cone Penetrometer (John, 1980). The Dutch Cone (Figures 1 and 2) transmits resisting forces at the tip and along the sides of the probe through a set of coaxial push rods to the ground surface where the forces are read from pressure gauges. It is advanced by alternately pushing the tip and friction jacket while taking manual readings of soil resistance, a process which is discontinuous and involves many operator manipulations. For the three sites investigated in the 1980 study, the Dutch Cone was found to provide an accurate measurement of in situ soil conditions. The equipment used to push the

Dutch Cone, however, limited the reaction weight which could be generated and, thereby, the depth of penetration.

Advancements in electronics have allowed the Dutch Cone concept to develop into a device which eliminates many previously undesirable aspects. This modern cone penetrometer, the electronic cone penetrometer, first developed by Fugro in 1965 (Broms and Flodin, 1988), is fully described by the ISSMFE Technical Committee on Penetration Testing (DeBeer et al, 1988). The CPT consists of a stress-sensitive probe that is hydraulically pushed into the ground (Figure 3). While pushing at a constant rate, soil resistance at the tip and along the side of the probe is measured by strain gages and relayed to the surface. A computer at the surface displays and records the data. Unlike the Dutch Cone, the electronic cone penetrometer provides a nearly continuous record of subsurface soil information with readings every 5 centimeters. Also, it advances at a rate of 2 cm/sec and only stops at one-meter intervals to add additional push rod. Therefore a sounding can be made in a relatively short period of time.

Both the electronic cone penetrometer and Dutch Cone have been part of routine geotechnical investigations in Europe since about 1930, but until recently, have received only limited acceptance in the U.S. Consequently, the majority of foundation design procedures for CPT data have originated in Europe or have been developed on the basis of European experience. These design procedures are generally empirical and do not necessarily apply to soil conditions encountered elsewhere.

In excess of 20 procedures (Gwizdala, 1984) have been developed for predicting the static capacity of piles using data from a cone penetration test. Work by Briaud and Tucker (1988) and Robertson et al (1988), has shown a few design procedures to be more promising than others.

This research was undertaken to determine whether six of the more prevalent CPT pile capacity analysis methods can be successfully applied to

a wide variety of soil types. The soils of the 27 sites in the data base of this report vary from predominately granular alluvial fan and basin deposits to moderately sensitive cohesive soils from marine tidal environments. This variety of soil types represents a significant portion of the wide spectrum of conditions routinely encountered during soil investigations throughout California.

Equipment

The cone penetrometers used for this research were 35.7 mm diameter electric and electronic cones (Figures 4 and 5). All cones and testing procedures met the guidelines set forth in ASTM Designation D3441-79. Both 10and 20-ton penetrometer rigs were used (Figure 6). These heavy vehicles enabled a penetration depth far in excess of that which could be achieved by the equipment used to push the Dutch Cone in the 1980 study and provided greater stability when dense granular and hard cohesive soils were being penetrated.

ESTABLISHING A DATA BASE

Initial Site Selection

To test the six CPT pile capacity analysis methods, CPT data were collected at locations where Caltrans had load tested piles for highway construction projects. An effort was made to select a representative sample of the pile and soil types encountered throughout California. Pile load test records and boring logs were screened to locate sites where there was a reasonable expectation of pushing the cone penetrometer deeper than the pile tip and where failure of the load test pile was indicated. The locations were then field reviewed to determine

accessibility for the CPT equipment and the presence of conflicts which would hamper data collection. Also, sites were reviewed to determine if previous construction would influence the CPT data.

Static Pile Load Tests

Davisson's failure criterion (Vanikar, 1985) was used to evaluate 350 pile load tests from Caltrans bridge construction projects. The Davisson criterion was chosen because it is easily defined, repeatable, and considers the material properties of the pile. Also, it is comparable to the failure criteria used by Caltrans (California Foundation Manual, 1984).

Using the Davisson criterion, 47 of the 350 pile load tests reached failure, or were so close to failure that a confident extrapolation could be made. This group of load tests represents data from 40 sites and consists of driven precast concrete piles, driven closed-end steel pipe piles, steel H-piles, 16-inch diameter bored piles, one 36-inch diameter drilled shaft, and one 48-inch diameter drilled shaft.

The load test method used by Caltrans is most similar to the cyclic loading procedure referenced in ASTM-D1143. Piles were typically loaded in 20-ton increments with each load being held until the pile head deflection rate was less than 0.01 inch per hour. At double design load, the load was maintained for 60 hours. Pile load tests were terminated prior to application of double design load for 60 hours if the pile plunged. This procedure is essentially a construction proof-test with the addition of a 60-hour load period which is an attempt to allow for time-dependent mechanisms such as creep. For purposes of this investigation, settlement resulting from sustaining a load for more than one hour was accounted for by subtracting this pile head movement from the load test record prior to applying the Davisson failure criterion.

Soil Conditions

Soil conditions at the 40 selected sites were evaluated by reviewing boring logs of the original design investigation. In some cases, the piles passed through dense granular or cemented soils of sufficient thickness to prevent penetration by the cone penetrometer. Thus, 10 pile load tests at nine sites were eliminated due to soil conditions inappropriate for use of the CPT equipment.

Site Access

A significant number of the remaining sites are located in what has become congested urban areas. These locations were field inspected to determine accessibility for the CPT equipment. Two sites of one pile load test each were dropped from this study due to traffic and utility conflicts.

At the completion of the site selection process, 35 pile load tests at 29 sites were candidates for field testing.

Field Testing

The aim of the field program was to use the CPT equipment to gather the type and quantity of data required for all six design procedures. The primary criterion was that the cone penetrometer sounding be advanced a minimum of four pile diameters below the pile tip, typically four feet. Also, in order to evaluate the variability of the soils, an effort was made to conduct two or three cone penetration tests at each pile site.

The soil conditions at two sites proved to be inappropriate for cone penetration testing due to a 10-foot, or thicker, layer of very weak

soils underlain by very hard or very dense soils. When the penetrometer probe reached the more resistant lower soils, the sounding rods developed excessive bowing because the weak upper soils did not provide sufficient lateral support. Penetration testing was consequently abandoned for the three pile load tests at these two sites. Thus, the data base was reduced to 32 pile load tests at 27 sites.

The CPT and pile load test data, which together make up the data base, are presented in the Appendix. A summary of the data is shown in Table 1.

PILE CAPACITY PREDICTION METHODS

Many analytical procedures for predicting pile capacity using CPT data exist. However, the scope of this study was purposely limited to six procedures. In general, an effort was made to select analytical procedures which had fundamentally different approaches. Analytical procedures which appeared frequently in the geotechnical engineering literature were included. Also, recommendations of the Federal Highway Administration (FHWA) and the availability of complete references influenced the selection.

A brief summary of the six design procedures follows.

Cone-M Method

Tumay and Fakhroo (1981) used 37 test piles from 10 sites to develop the Cone-M procedure. All test piles were driven piles and the sites were widely scattered throughout Louisiana in order to test a variety of representative soils. It is important to note that most of the test

sites are underlain by very soft to stiff cohesive soils. This method does not take soil, pile type, or installation method into consideration.

The end bearing component of pile capacity is calculated using a weighted average of cone tip pressure readings for a distance of four pile diameters below, and eight pile diameters above, the specified pile tip.

Pile skin friction is developed using the product of cone sleeve friction data and a hyperbolic adherence coefficient. The adherence coefficient, denoted as "m", is a function of the observed cone sleeve friction ratio.

A FORTRAN program entitled PILECAP was obtained from the Louisiana Department of Transportation and Development and used to analyze the data. The PILECAP program requires only cone penetrometer tip and sleeve data and pile geometry.

Schmertmann's Method

The procedure presented by Schmertmann (1978), and Nottingham and Schmertmann (1975), is a refinement of work first reported by Nottingham in his Ph.D. dissertation (1975). Both the original procedure and its modification were based on load tests conducted with model piles and full-scale displacement piles in the states of Georgia and Florida. The procedure recommended by Schmertmann (1978) considers soil and pile type for skin friction capacities but not for pile end bearing.

Pile end bearing is calculated by means of a weighted average of cone penetrometer tip readings between 0.7 and four diameters below, and eight diameters above, the specified pile tip elevation. Limiting values are recommended for the raw cone penetrometer values and the computed pile end bearing stress.

Skin friction capacity calculations differ for cohesive and granular soils but both categories of soil use friction sleeve data. A series of formulae is presented with which the unit skin resistance is calculated for each soil layer.

Schmertmann's recommendations were incorporated into a spreadsheet program and require input of pile geometry, soil stratigraphy, and cone penetrometer tip and sleeve data.

Bustamante's Method

Bustamante's method refers to the static pile capacity calculation procedure by Bustamante and Gianeselli (1982) of the Laboratoire Central des Ponts et Chaussees. This method is based on load tests to failure of 96 piles at 48 sites in France. Of these tests, 55 were for bored piles, 31 for driven piles, 8 for grouted piles, one for a pier, and one for a burrette. Soils at the sites are described as consisting of "...clay, silt, sand, gravel or even weathered rock, but also mud, peat, more or less weathered chalk, and marl." The Bustamante method considers both pile and soil type for pile end bearing and skin friction capacities.

Pile end bearing is calculated by multiplying a "bearing capacity factor" by the "equivalent cone resistance". Equivalent cone resistance is determined by means of an averaging procedure applied to cone penetrometer tip readings 1.5 pile diameters above and below the specified pile tip elevation. The bearing capacity factor is a function of pile and soil type, method of pile installation, and cone penetrometer tip reading.

Pile skin friction capacity is the product of cone penetrometer tip reading and a reduction factor. A limiting value is applied to the calculated pile skin friction. Both the reduction factor and limiting

values are functions of pile and soil type, method of installation and cone penetrometer tip reading.

Bustamante's recommendations were incorporated into a spreadsheet program and require input of pile geometry, soil stratigraphy, and cone penetrometer tip data.

LPC Cone Method

The LPC Cone method refers to a set of rules proposed by the Laboratoire Central des Ponts et Chaussees in France and subsequently modified as described by Briaud et al (1985). This method is based upon the Bustamante method, but provides substantially more detail with regard to installation method, pile type, and soil type.

Pile end bearing capacity is calculated by multiplying the average cone penetrometer tip resistance between four pile diameters above and below specified tip by a "point bearing factor". The "point bearing factor" is a function of pile and soil type.

Pile skin friction is determined from an extensive family of curves which relate pile skin friction to cone penetrometer tip resistance, soil type, installation method, and pile type.

A BASIC program which utilizes the LPC Cone method (Tucker and Briaud, 1986) was obtained and used to analyze the data. Input parameters for the program include pile type, installation method, pile geometry, soil type and layer thickness, and cone penetrometer tip resistance data.

Direct CPT Method

The procedure referred to as Direct CPT (Briaud et al, 1985) is the simplest application of cone penetrometer data for pile capacity

determination. It was developed by the Dutch (Sanglerat, 1972) as one of the original applications for the cone penetrometer. The method does not consider soil type, pile type, or pile installation method. The primary concept of this method is the same as that behind the development of the CPT, the penetrometer probe is considered to be a model pile penetrating soil. The early Dutch work was primarily for sandy soils, hence this method is generally assumed to give better results in sands.

The end bearing stress of a pile is taken as the tip pressure of the cone penetrometer at the specified pile tip elevation.

Pile skin friction stresses are equivalent to friction sleeve values.

The Direct CPT procedure was incorporated into a BASIC program. Input consists of pile geometry and cone penetrometer tip and friction sleeve data.

European Method

The European method refers to the method described by de Ruiter and Beringen (1979). This method is based on correlations to pile load tests and considers two soil types, sand and clay. There is no consideration of pile type or installation method but the target application of offshore structures suggests that it is intended for driven pipe piles.

Pile end bearing for cohesive soils is determined using the correlation between undrained shear strength and cone penetrometer tip resistance (Lunne et al, 1976 and Kjekstad et al, 1979). Pile end bearing in cohesionless soil is determined by means of a weighted average of cone penetrometer tip readings in a zone between 0.7 to four pile diameters below, and eight pile diameters above, specified pile tip. The weighted average is further reduced using functions which consider the overconsolidation ratio.

Pile skin friction in cohesive soils is calculated by multiplying the undrained shear strength, as determined from cone penetrometer tip resistance, by an adhesion factor. The adhesion factor is a function of the overconsolidation ratio. Skin friction in cohesionless soil is the minimum of three values: the cone penetrometer sleeve friction readings, the cone tip resistance divided by 300, or 1.25 TSF.

Calculations of ultimate pile resistance using the European method were done, in part, by using a BASIC program. The remainder of the calculations were performed by hand. Input parameters consist of pile geometry, soil type and layer thickness, and cone penetrometer tip and friction sleeve data.

COMPARISON OF MEASURED AND PREDICTED CAPACITIES

Measured pile capacity for each pile load test and predicted pile capacities for each CPT sounding using the six methods are presented in Table 1. Each pile load test was assigned one predicted value for each method by averaging the results obtained by the soundings at that location. In this way, each pile load test was represented by a single value in subsequent statistical evaluations.

For each method, the predicted versus measured pile capacities are plotted in Figures 7 through 12. Values which fall below the "predicted equals measured" line are conservative.

When considering all pile types and installation methods, the LPC Cone method performed significantly better than any of the other methods. For driven piles, all methods, except the Direct CPT method, yield good to very good accuracy. However, the Bustamante method for driven piles consistently tends to yield conservative predictions.

In order to statistically evaluate the six prediction methods, the ratio of predicted to measured capacity was calculated for each method for the 32 pile load tests. The mean (μ), standard deviation (s), and coefficient of variation (COV) of these ratios were determined and are shown in Table 2.

These parameters support the assertion that, overall, the LPC Cone method is the most accurate (mean of 1.09) and most precise (COV of 0.39). The statistical parameters support different conclusions when driven and bored piles are considered separately.

When only driven piles are considered, the Schmertmann procedure clearly performed best; having both very good accuracy (mean of 0.96) and precision (COV of 0.36). The LPC Cone method also exhibits very good accuracy (mean of 1.01) but only fair precision (COV of 0.45). With a COV of 0.35, the Bustamante procedure exhibited a precision practically identical to the Schmertmann method, but lacks accuracy, having a mean of only 0.79.

For bored piles, the statistical parameters indicate that the LPC Cone method performs best; having a mean of 1.15 and COV of 0.37. All other methods were considerably less accurate or precise when applied to bored piles.

DISCUSSION

The Schmertmann method performed best for driven piles. The LPC Cone method performed best for bored piles and when all piles are considered together. The LPC Cone method performed reasonably well for driven piles.

One difference between these methods is that the LPC Cone method employs lower end bearing pressures for bored piles than for driven piles. The Schmertmann method does not differentiate end bearing pressure for construction methods. Ultimate tip pressure cutoff values recommended by Schmertmann are 160 TSF in silty sand and 150 TSF in sand, values that are appropriate for driven piles in dense to very dense sands.

A means of evaluating the accuracy with which a method will predict the end bearing capacity of a pile is to compare the predicted skin friction capacity to the measured total pile capacity. Therefore, for bored piles, the skin resistance component of the predicted capacity was plotted against the measured total capacity and statistical parameters were calculated. As expected, Figures 13 through 18 and Table 2 show that the skin friction component of the predicted capacities are, with the exception of the Direct CPT method, mostly less than the measured total capacities. For this comparison, the precision of Schmertmann's method is superior to the other methods. The LPC Cone and Cone-M methods provide slightly less precise results.

The precision exhibited by the Schmertmann method when comparing predicted skin friction to total measured capacity of bored piles, together with the poor performance it displayed when considering total capacity of bored piles and the good performance for driven piles, indicate that the results from applying the Schmertmann method to all piles are poor because of inaccuracies in calculating the end bearing component for bored piles. The data collected for this work suggest that a 20 TSF cut-off pressure is realistic for the tested 16-inch diameter bored piles. It is suggested that 20 TSF is an appropriate end bearing pressure for piles tipped in loose to slightly compact granular soils. If the bored piles were overdrilled or soil caved from the side of the boreholes, the state of material accumulated in the bottom of a bored pile prior to concrete placement could likely be loose to moderately dense. Although the load test records are free of any references to overdrilling or loose soil on the bottom of bored piles,

such a condition would be difficult to detect given that Caltrans does not routinely clean out the bottom of small diameter bored piles and visual inspection is difficult. Other in-house studies also support a 20 TSF limit for end bearing of bored piles.

When the 20 TSF ultimate tip bearing pressure is applied to bored piles using the Schmertmann method, the statistical parameters for bored piles improve from a mean of 1.68 and a COV of 0.58 to a mean of 1.00 and a COV of 0.26. These results are the best of the six methods for bored piles. Combining these modified Schmertmann results with those obtained with driven piles gives an overall mean of 0.98 and COV of 0.31. Predicted versus measured pile capacity using this modification to the Schmertmann method is shown in Figure 19.

The findings presented here are comparable to those reported in two recent similar studies. Briaud and Tucker (1988) had a data base of 98 pile load tests. They evaluated 13 analytical procedures, of which, 6 used cone penetrometer data. Of these procedures, the LPC Cone method was found to perform best. Briaud and Tucker observed that all 13 design procedures tended to overpredict static pile capacity and that the better design procedures yielded COV values of about 0.40. This compares well with the results of this study; Schmertmann's modified procedure had a COV of 0.31 and the LPC Cone method had a COV of 0.39. A similar study by Robertson et al (1988) was limited to eight pipe piles of various lengths at one site. Thirteen design procedures using cone penetrometer data were evaluated. The three methods which performed best were the LPC Cone method, Schmertmann's method, and the European method.

LIMITATIONS

The data used in this study may be influenced by the manner in which the load tests were conducted, the soil conditions at the various sites,

and the time span between the load testing and cone penetrometer work. These limitations were recognized at the beginning of this study and minimized as best as possible.

Pile groups used for load testing consisted of three colinear piles. Center to center spacing between these piles was typically three to five feet. This distance is close enough to allow for the overlapping of pressure bulbs when the test is performed, thereby lowering measured pile capacities.

Applied test loads were measured by a pressure gauge in the hydraulic line to the jack. This procedure is not as accurate as could result with a load cell at the point of load application. Fellenius (1980) reports that this technique of load measurement may give an error of 15 to 20 percent.

Maintenance records from several of the sites underlain by soft cohesive and loose cohesionless soils indicate that settlement, in response to fill placement, has taken place since test pile installation. At these locations, the effects of soil changes on the capacity comparisons have been minimized by performing CPTs at locations outside their zone of influence.

At sites where settlement was not noted, cone penetration tests were performed as close to the test pile as possible, often within the influence zone of embankment vertical stress.

The static load tests for the 13 driven piles were performed one to seven days after the piles were driven. These piles have cohesive soils along all, or part, of their length. Soil setup, the time-dependent increase in soil/pile adhesion which occurs after pile driving in cohesive soils, was not evaluated with the pile load testing program. Therefore the potential increase was not accounted for in the comparison of measured and predicted ultimate pile capacities.

CONCLUSIONS AND RECOMMENDATIONS

For 32 piles, the results of pile load tests were compared to the pile capacities predicted using CPT data and six analytical procedures. Of the 32 piles evaluated, 19 were bored piles and 13 were driven piles.

Both the LPC Cone method and a modification of the Schmertmann method performed satisfactorily with this data set. Based on the data presented in this report, static pile capacity predictions made using the LPC Cone procedure will be within 30 percent of the true ultimate capacity 57 percent of the time. The Schmertmann procedure with a 20 TSF tip stress limitation for bored piles would predict capacities within these limits 70 percent of the time. These results are considered acceptable for predicting pile capacities.

It is recommended that both of these procedures be implemented for the determination of pile tip elevations for vertical compressive load. To achieve this, Schmertmann's method should be developed into a computer program which incorporates the 20 TSF limitation for bored pile end bearing. The spreadsheet program used in this research for the Schmertmann method may provide a good starting point. The LPC Cone procedure is currently available as a computer program.

Future work is needed to fully develop the application of cone penetration testing to pile design. Data are needed specifically for piles with tips in cohesionless soils so that the recommended ultimate tip bearing calculation procedures and cut-off values can be analyzed. Also, more test data are needed for bored piles with diameters other than 16 inches.

With regard to the pile load test, it is suggested that all test piles be constructed with at least a telltale device at the pile tip. This would be a simple and inexpensive means of gathering quantitative information on load transfer at the pile tip and provide a rational means of separating pile tip and skin resistances.

The set of pile load tests used for this evaluation should be used to evaluate the pile load capacity prediction procedures presently used by the Engineering Geology Branch. This evaluation should include the procedures of Meyerhof (1976), Nordlund (1963), O'Neill and Rèese (1978), Tomlinson (1980), and the Department of the Navy (1982).

IMPLEMENTATION

Copies of this final report will be distributed to appropriate personnel within Caltrans, and to the Federal Highway Administration for distribution within their organization.

In-house training on the application of the CPT for geotechnical investigations will be provided to appropriate personnel within Caltrans.

Standard Plans for load test piles will be changed to incorporate a telltale at the tip of all test piles.

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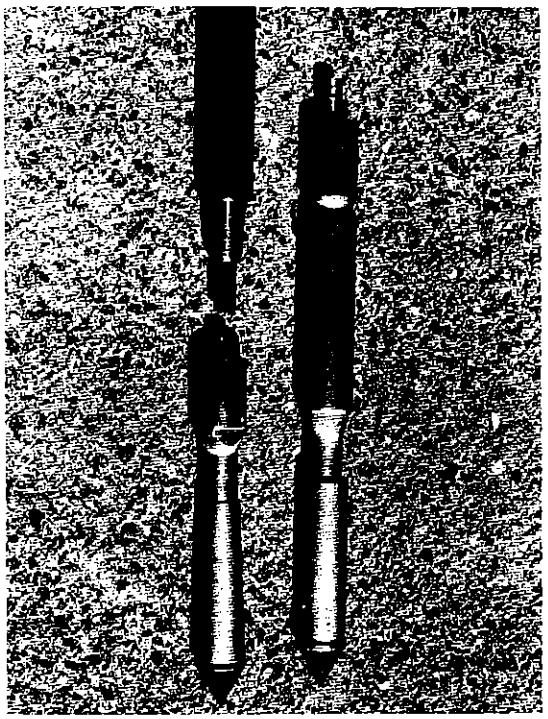


Fig. 1. Dutch Cone Penetrometers (John, 1980)

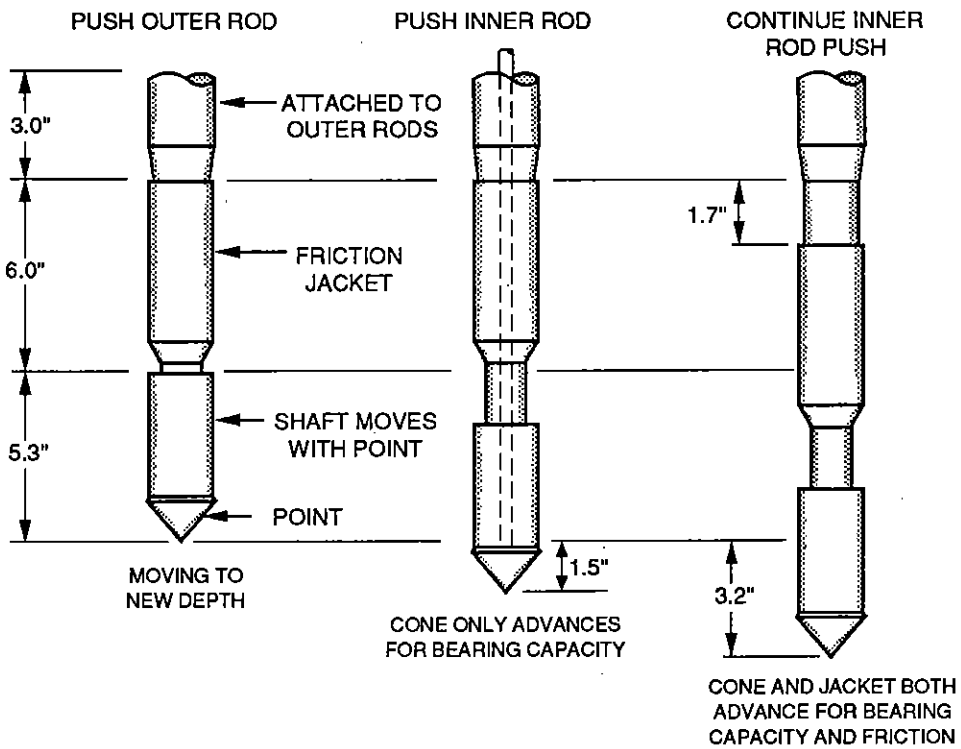


Fig. 2. Schematic Drawing of Dutch Cone During Test (John, 1980)

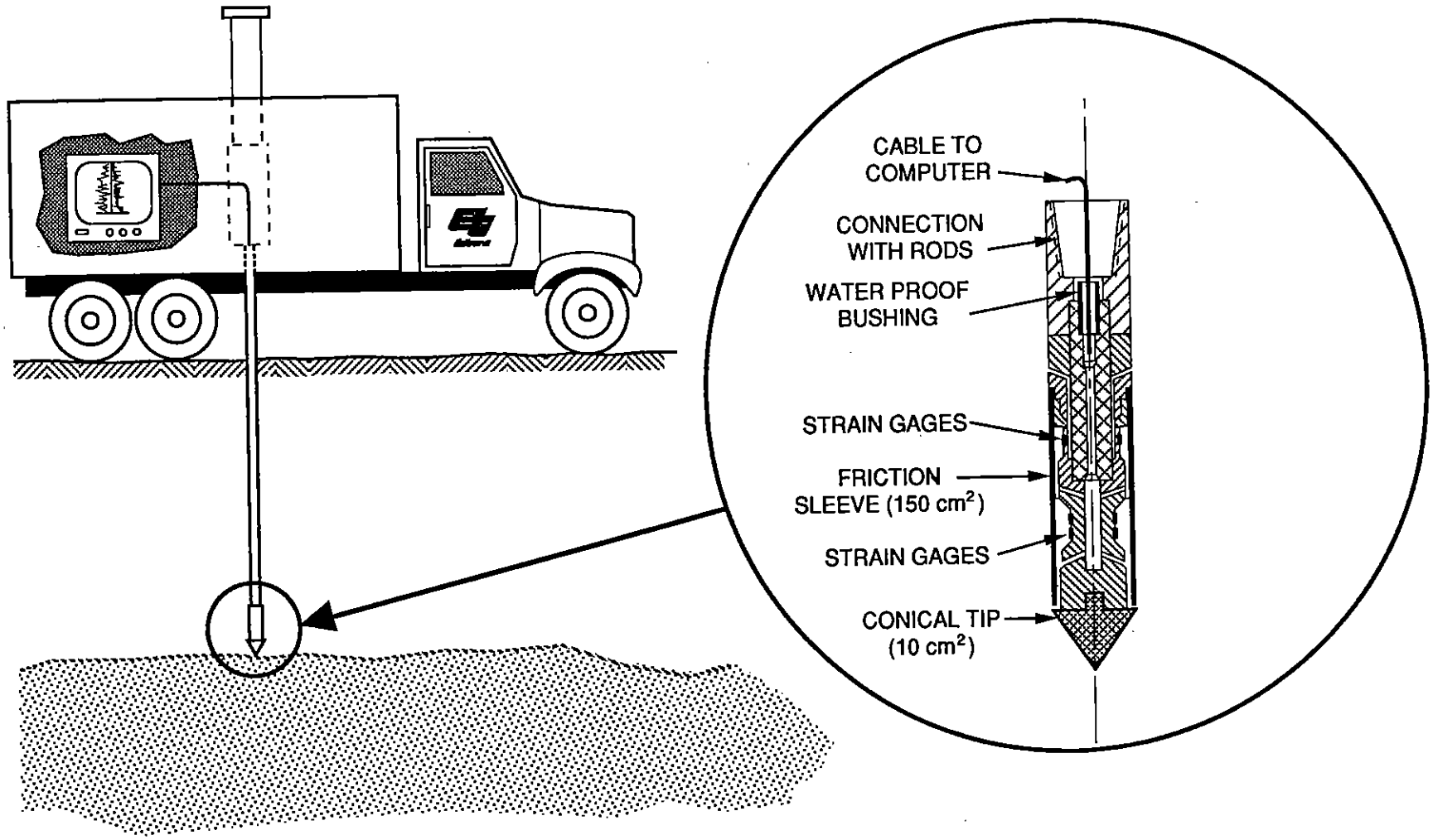


Fig. 3. Cone Penetration Test Equipment

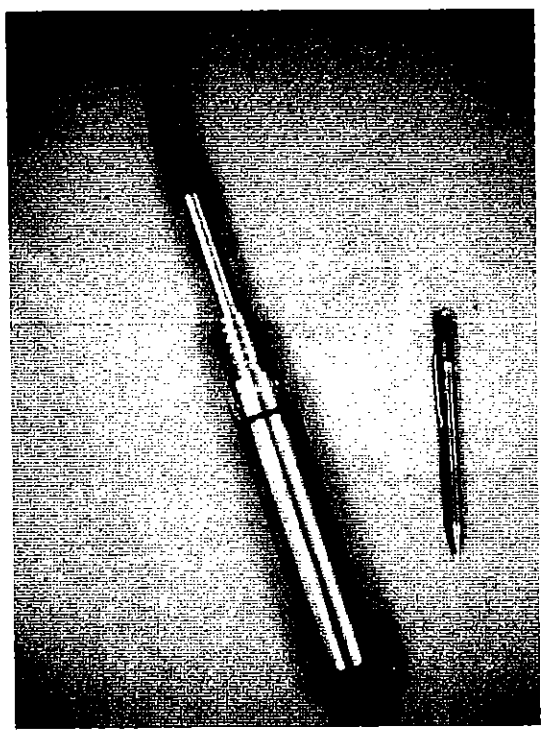


Fig. 4.
Electric Cone Penetrometer

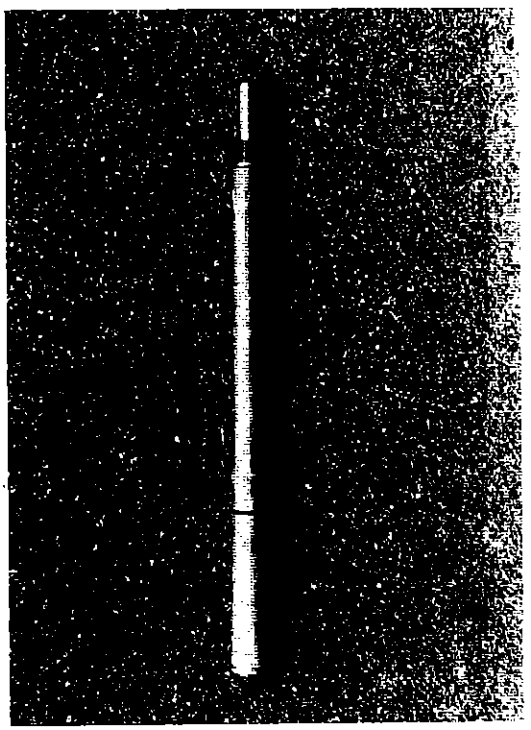


Fig. 5.
Electronic Cone Penetrometer

Fig. 6. 20-Ton Penetrometer Rig

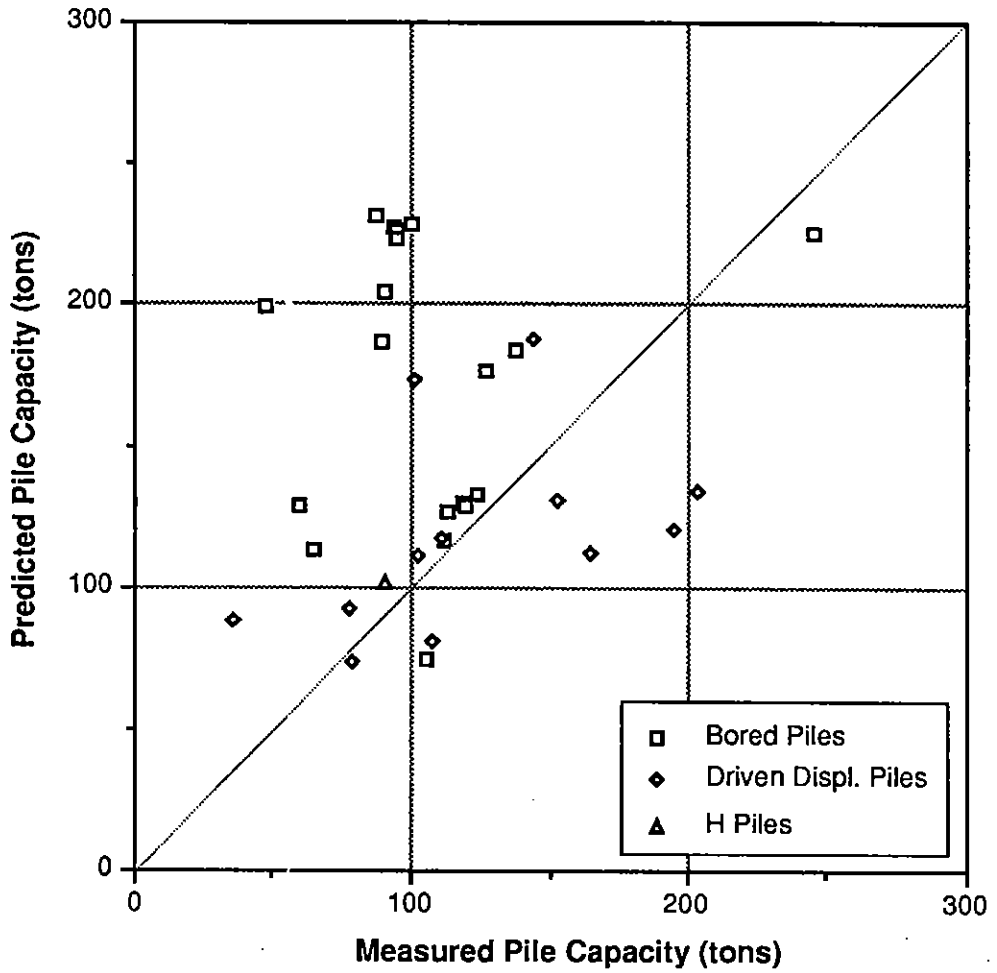


Fig. 7. Cone M: Predicted vs. Measured Pile Capacity

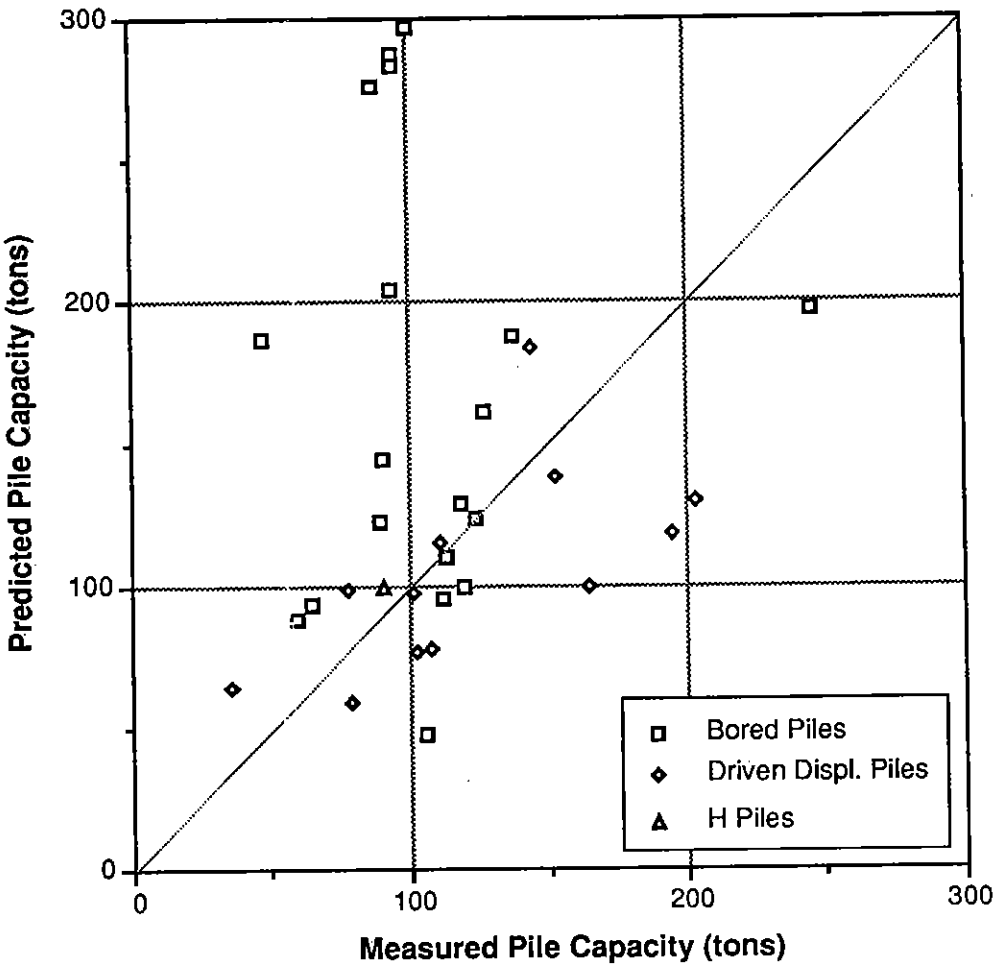


Fig. 8. Schmertmann: Predicted vs. Measured Pile Capacity

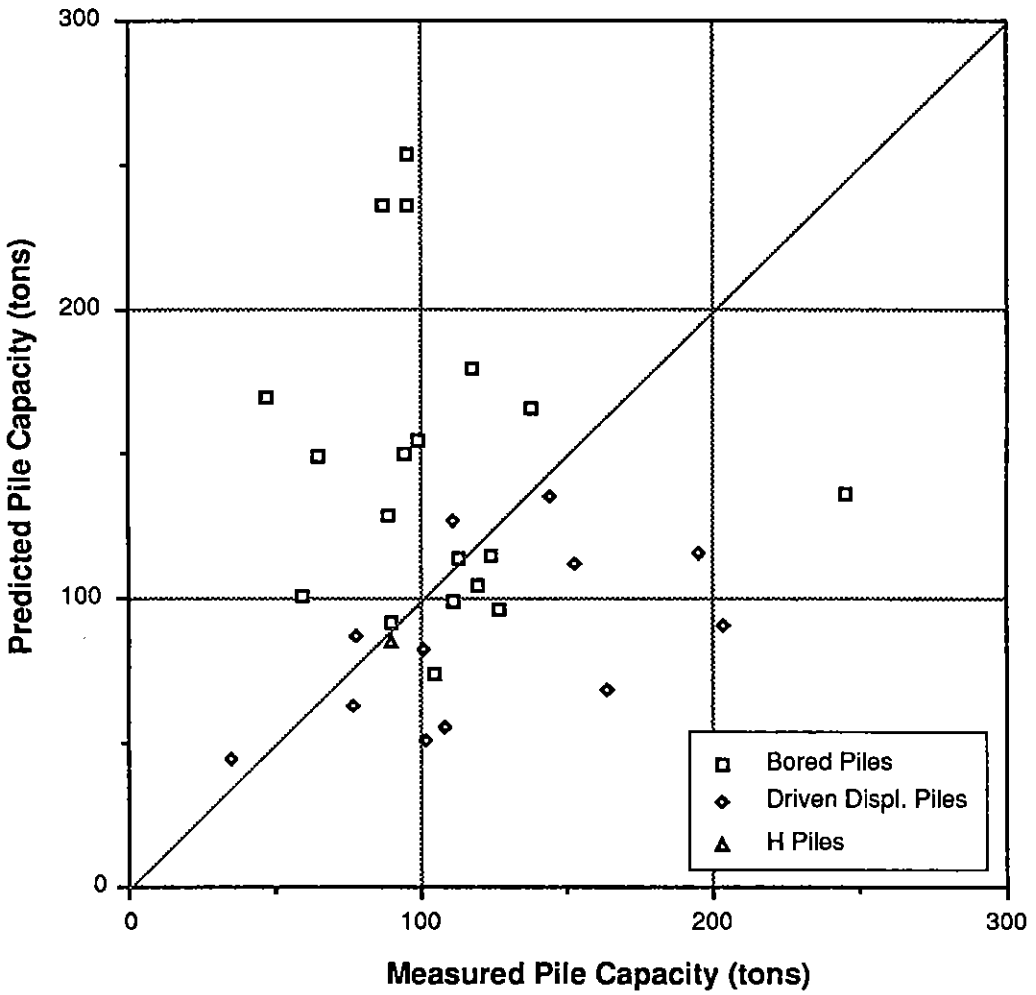


Fig. 9. Bustamante: Predicted vs. Measured Pile Capacity

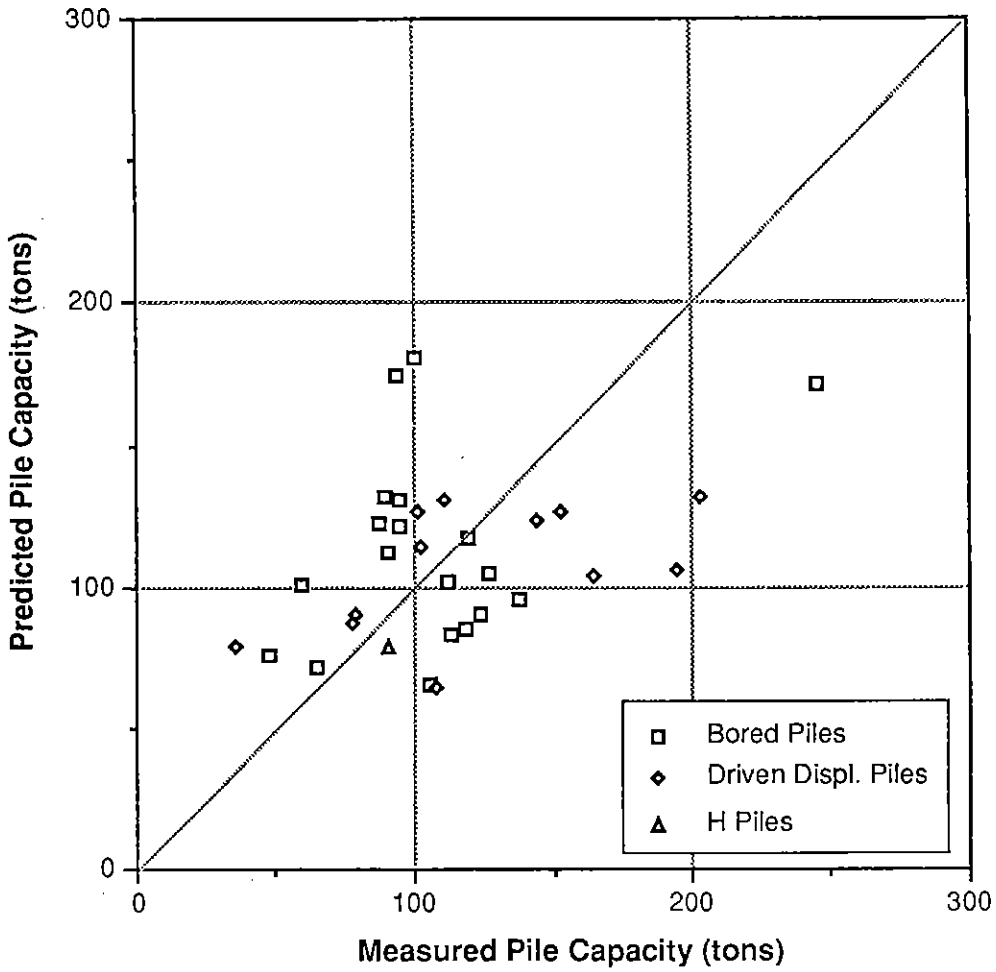


Fig. 10. LPC Cone: Predicted vs. Measured Pile Capacity

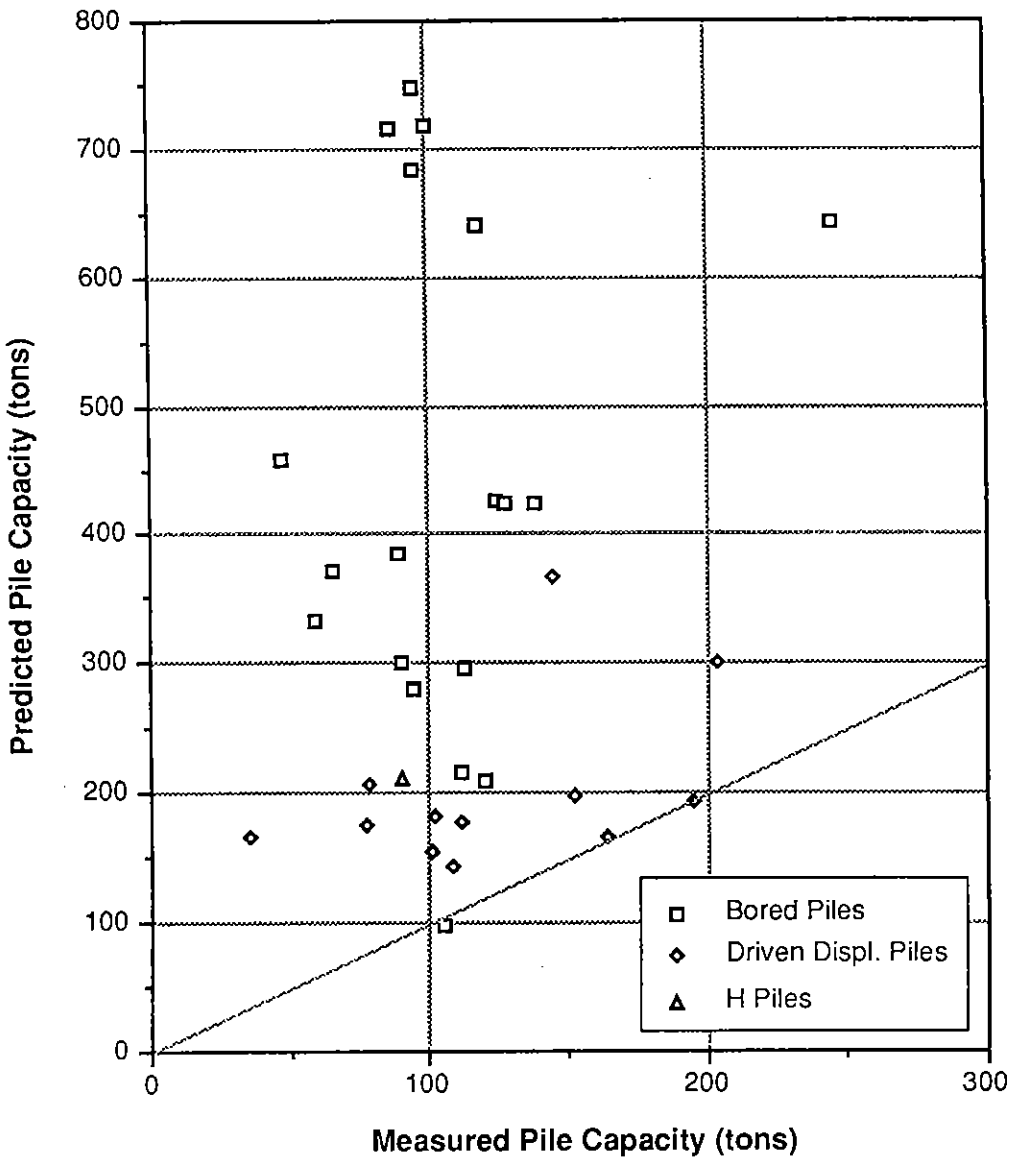


Fig. 11. Direct CPT: Predicted vs. Measured Pile Capacity

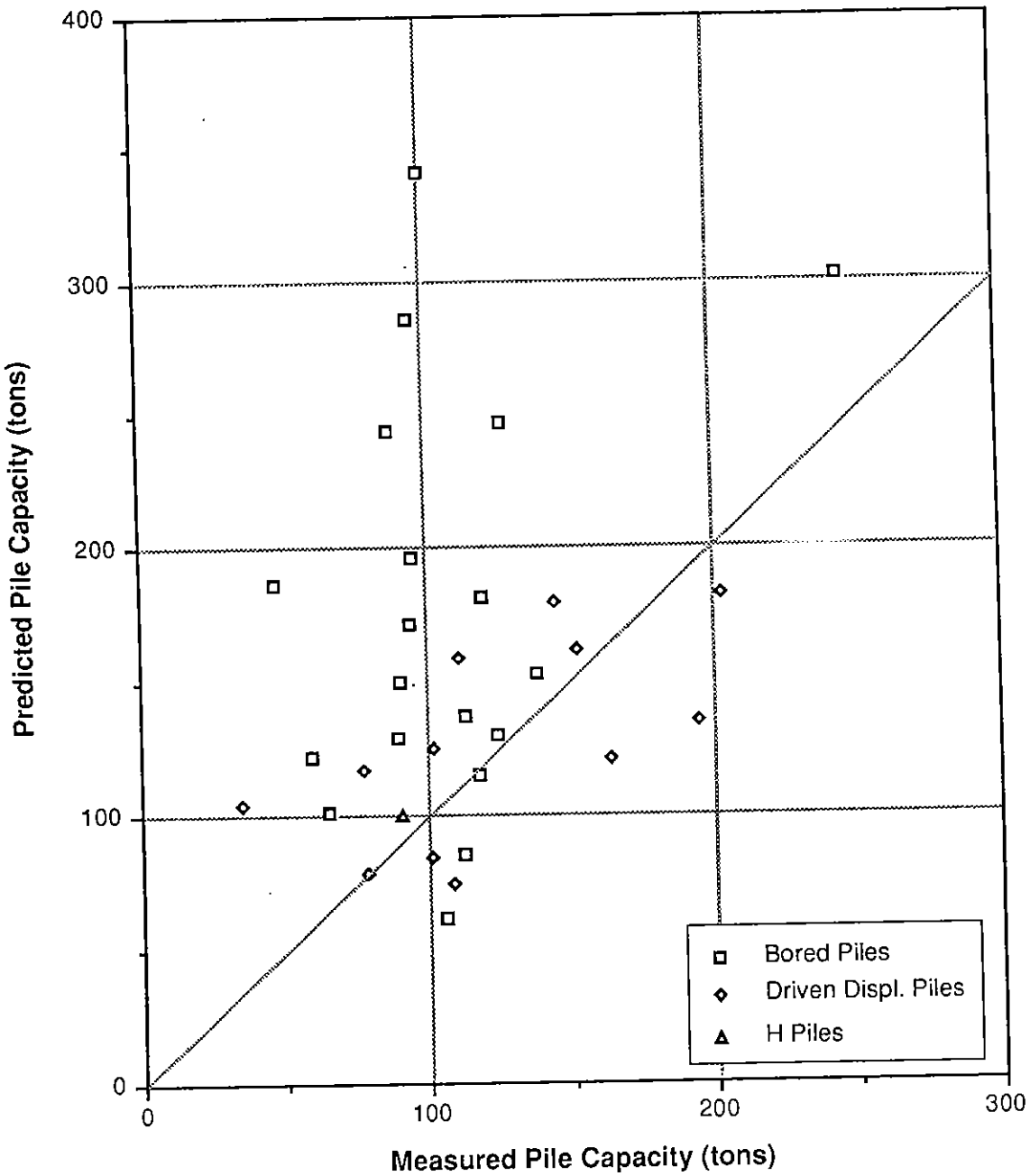


Fig. 12. European: Predicted vs. Measured Pile Capacity

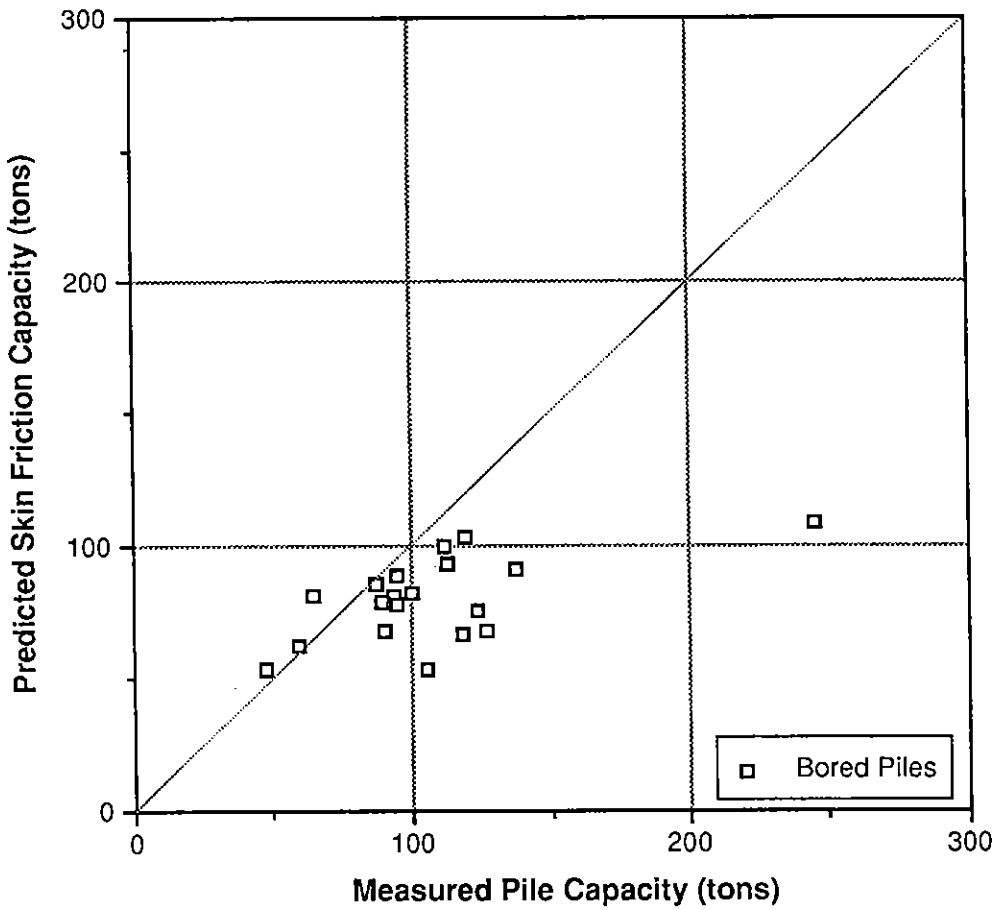


Fig. 13. Cone-M: Predicted Skin Resistance vs. Measured Capacity

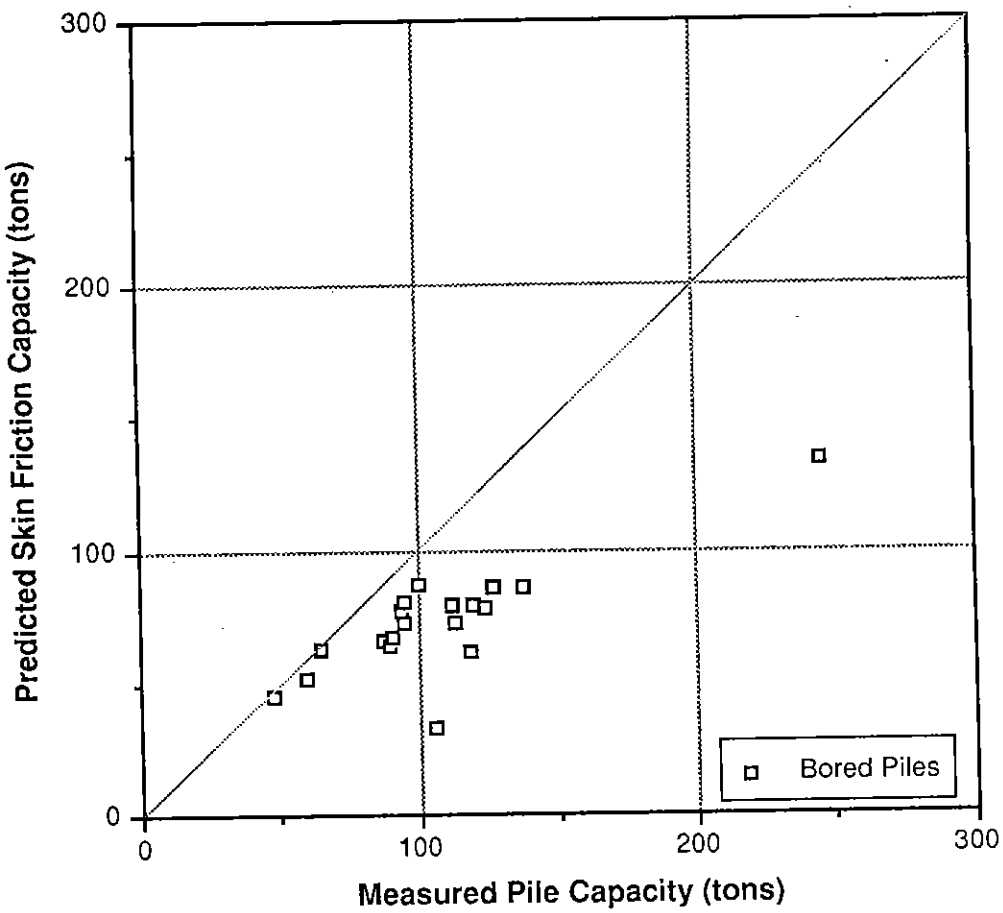


Fig. 14. Schmertmann: Predicted Skin Resistance vs. Measured Capacity

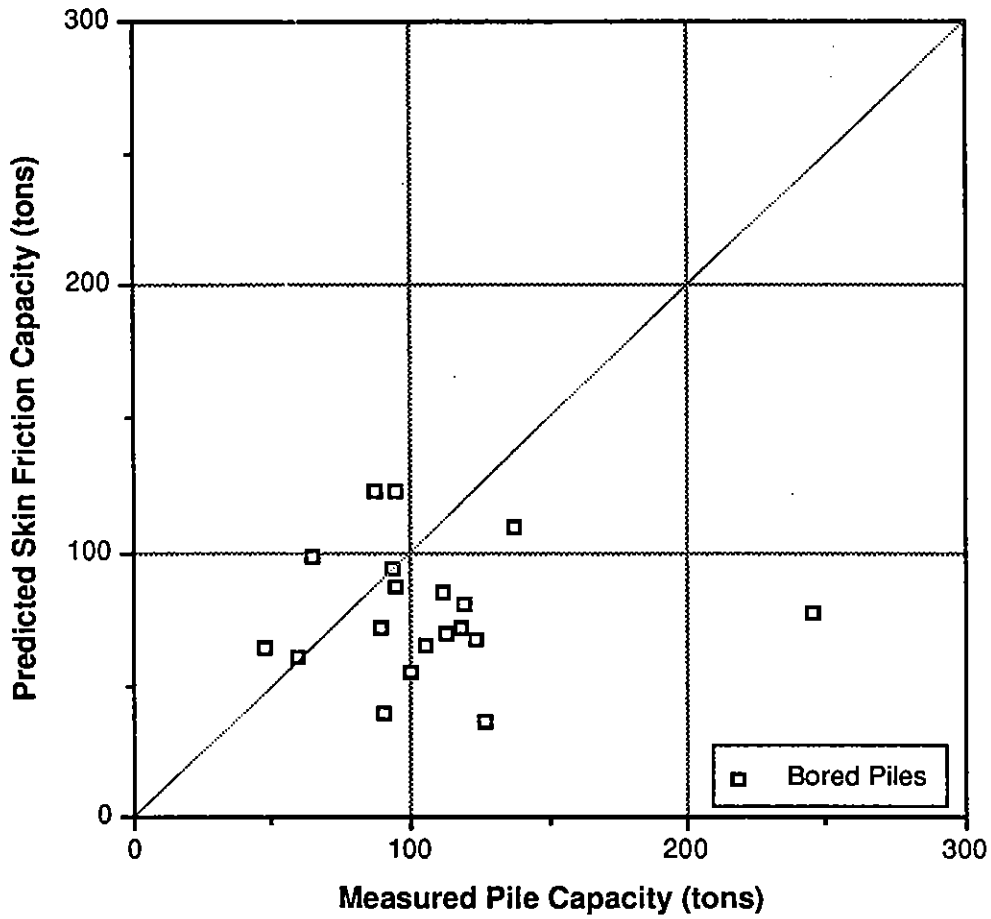


Fig. 15. Bustamante: Predicted Skin Resistance vs. Measured Capacity

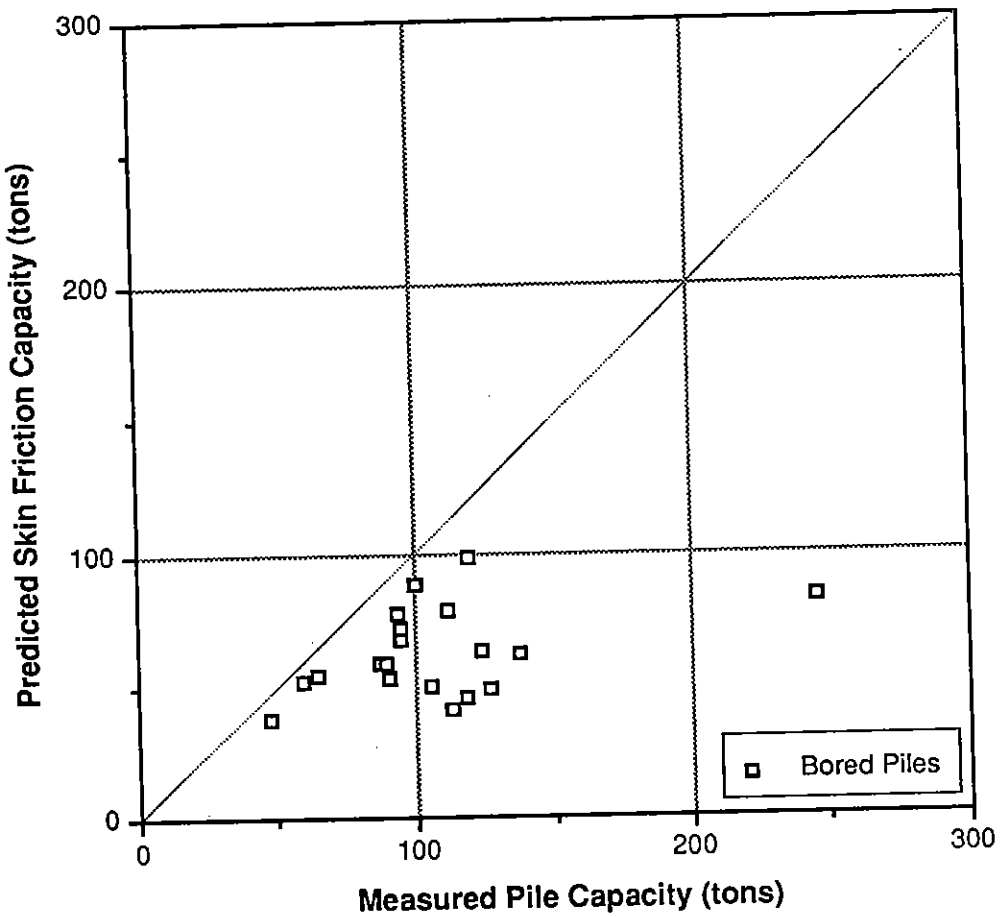


Fig. 16. LPC Cone: Predicted Skin Resistance vs. Measured Capacity

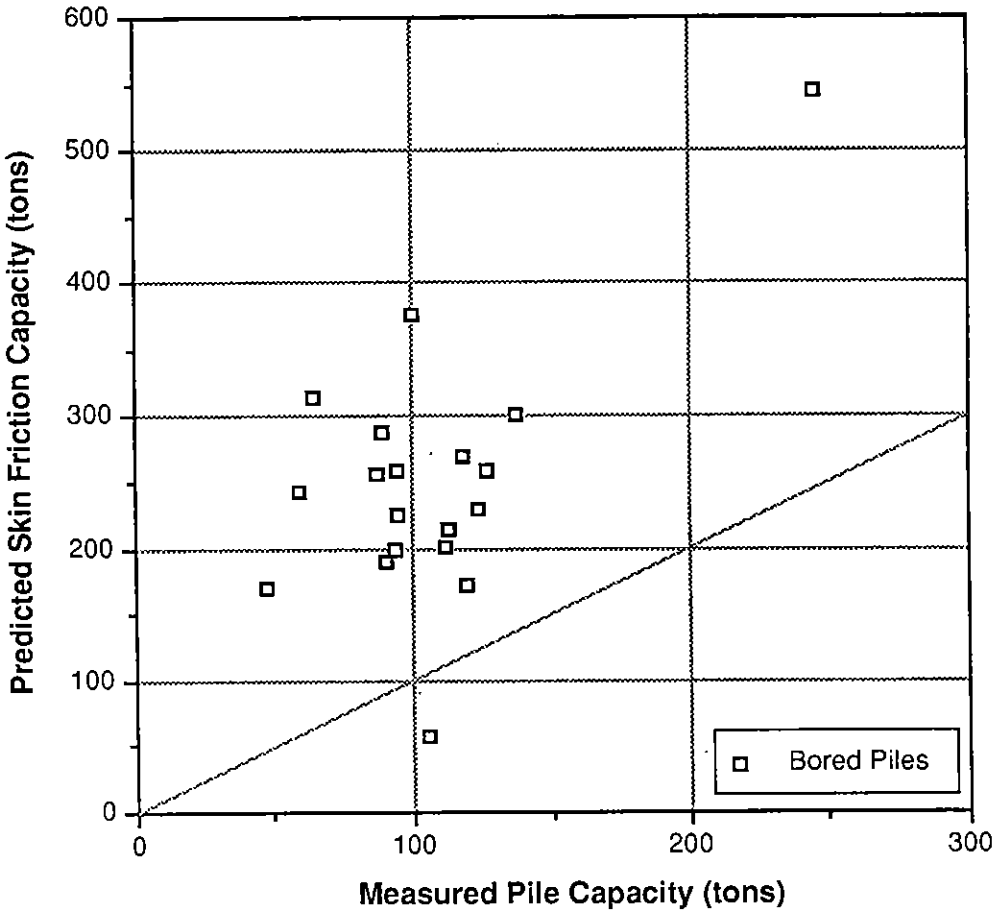


Fig. 17. Direct CPT: Predicted Skin Resistance vs Measured Capacity

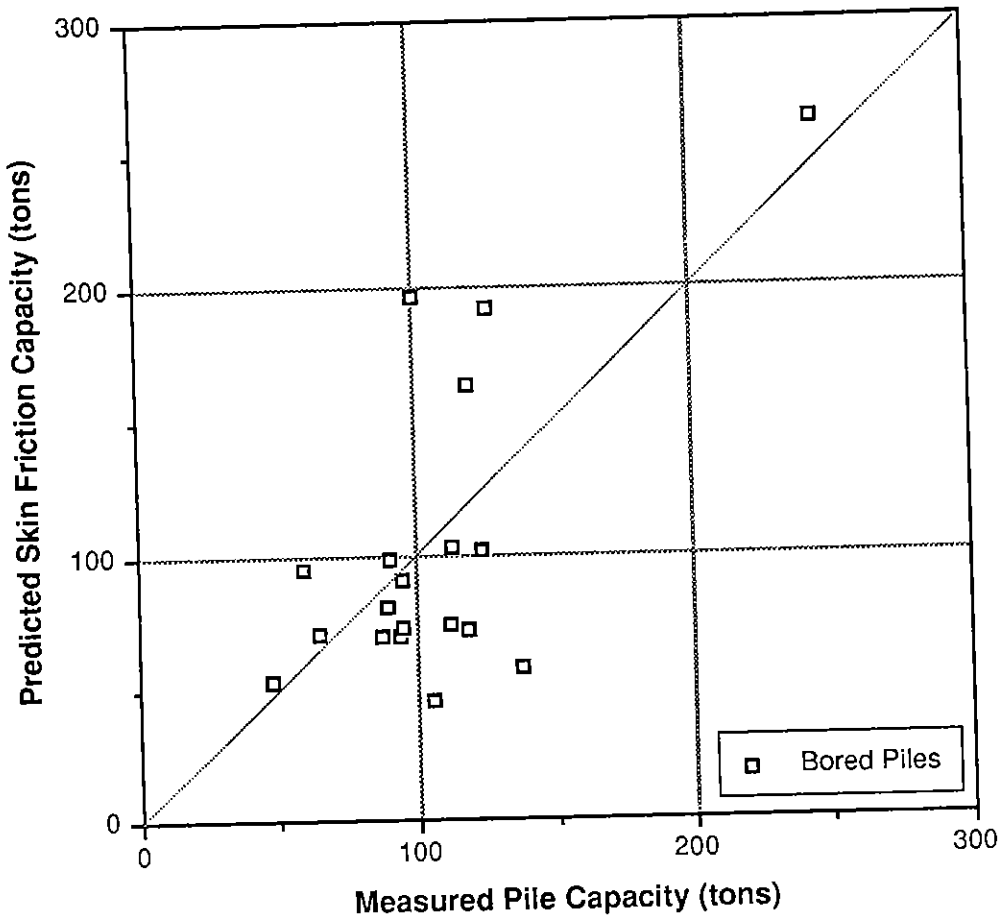


Fig. 18. European: Predicted Skin Resistance vs. Measured Capacity

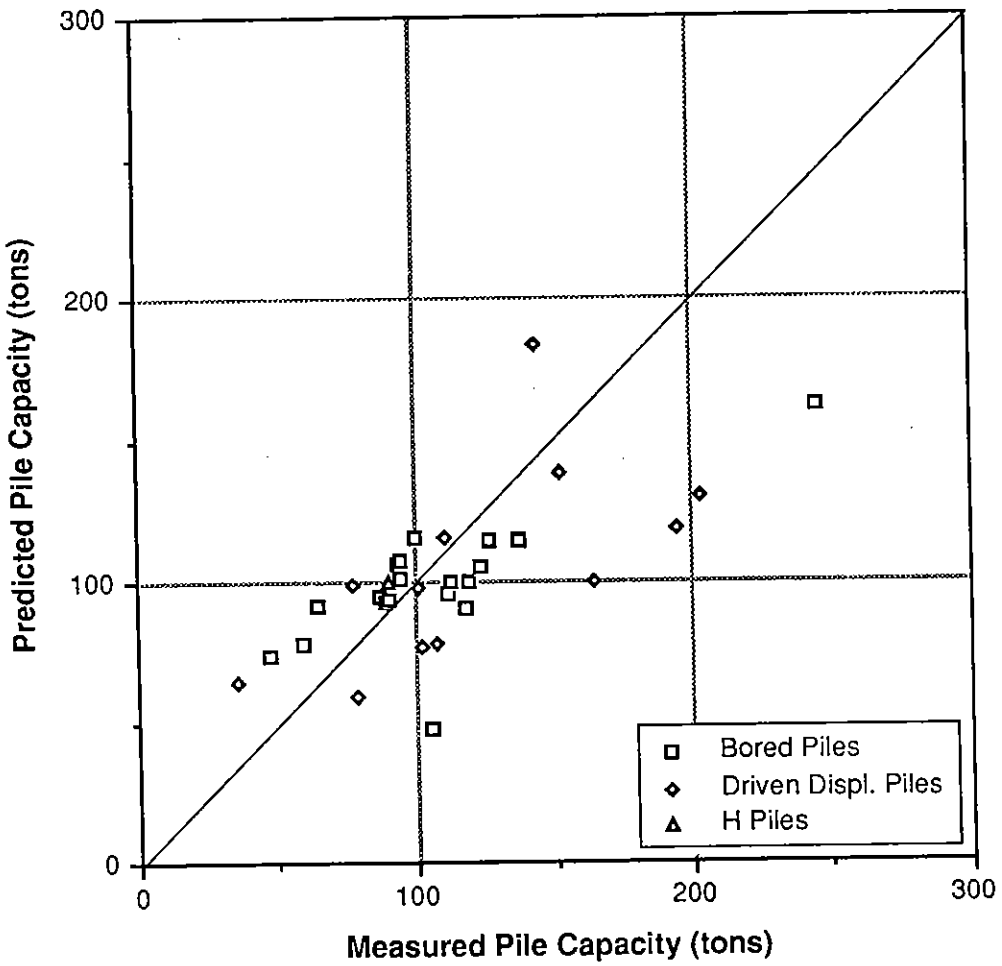


Fig. 19. Schmertman - with 20 tsf Tip Bearing Pressure Limit Applied to Bored Piles: Predicted vs Measured Pile Capacity

Pile Load Test	Location	Pile Type	X-Section	Pile Capacity min/max (tons)	Pile Capacity average (tons)	Cone - M tip (tons)	Cone - M skin (tons)	Cone - M total (tons)	Schmertmann tip (tons)	Schmertmann skin (tons)	Schmertmann total (tons)	Bustamante tip (tons)	Bustamante skin (tons)	Bustamante total (tons)	LPC Cone tip (tons)	LPC Cone skin (tons)	LPC Cone total (tons)	CPT Direct tip (tons)	CPT Direct skin (tons)	CPT Direct total (tons)	European tip (tons)	European skin (tons)	European total (tons)
1	East End Ave. U.C.	Bored	16" diam	105 / 118	111.5	17.0	99.5	116.5	16.0	79.5	95.5	14.0	85.0	99.0	23.0	78.5	101.5	17.0	200.5	217.5	11.0	74.5	85.5
	- sounding 1					16.0	89.0	105.0	15.0	79.0	94.0	14.0	83.0	97.0	24.0	76.0	100.0	18.0	191.0	209.0	10.0	67.0	77.0
	- sounding 2					18.0	110.0	128.0	17.0	80.0	97.0	14.0	87.0	101.0	22.0	81.0	103.0	16.0	210.0	226.0	12.0	82.0	94.0
2	San Timoteo Creek	Bored	15.5" diam	105 / 105	105	21.0	53.5	74.5	14.5	33.5	48.0	9.0	65.0	74.0	16.0	49.5	65.5	40.0	57.0	97.0	17.0	45.0	62.0
	- sounding 1					10.0	54.0	64.0	9.0	32.0	41.0	4.0	63.0	67.0	5.0	44.0	49.0	12.0	52.0	64.0	9.0	38.0	47.0
	- sounding 2					32.0	53.0	85.0	20.0	35.0	55.0	14.0	67.0	81.0	27.0	55.0	82.0	68.0	62.0	130.0	25.0	52.0	77.0
3	Tippecanoe Ave. U.C.	Bored	16" diam	89 / 89	89	107.5	79.0	186.5	58.0	64.0	122.0	57.0	71.5	128.5	72.5	59.0	131.5	97.5	288.5	386.0	48.5	80.5	129.0
	- sounding 1					132.0	76.0	208.0	76.0	65.0	141.0	54.0	68.0	122.0	83.0	54.0	137.0	63.0	228.0	291.0	71.0	94.0	165.0
	- sounding 2					83.0	82.0	165.0	40.0	63.0	103.0	60.0	75.0	135.0	62.0	64.0	126.0	132.0	349.0	481.0	26.0	67.0	93.0
4	Baseline St OC, Tip=1095	Bored	16" diam	47 / 47	47	146.0	53.5	199.5	141.5	45.5	187.0	105.5	64.0	169.5	38.0	38.0	76.0	286.0	171.5	457.5	133.5	53.0	186.5
	- sounding 2					146.0	58.0	204.0	150.0	45.0	195.0	78.0	82.0	160.0	38.0	40.0	78.0	289.0	188.0	477.0	134.0	46.0	180.0
	- sounding 3					146.0	49.0	195.0	133.0	46.0	179.0	133.0	46.0	179.0	38.0	36.0	74.0	283.0	155.0	438.0	133.0	60.0	193.0
5	Baseline St OC, Tip=1086	Bored	16" diam	87 / 87	87	146.0	85.0	231.0	210.0	66.0	276.0	113.0	123.0	236.0	64.0	59.0	123.0	458.0	257.0	715.0	174.0	70.0	244.0
6	Sixteenth St. O.C.	Bored	16" diam	65 / 65	65	32.0	81.0	113.0	30.0	63.0	93.0	51.0	98.0	149.0	18.0	54.0	72.0	57.0	315.0	372.0	30.0	71.0	101.0
7	Jefferson St. U.C.	Bored	15.5" diam	120 / 128	124	57.0	75.5	132.5	45.0	79.0	124.0	47.0	68.0	115.0	26.5	63.5	90.0	196.5	230.5	427.0	29.0	101.5	130.5
	- sounding 2					56.0	72.0	128.0	40.0	78.0	118.0	32.0	67.0	99.0	34.0	59.0	93.0	48.0	219.0	267.0	24.0	110.0	134.0
	- sounding 3					58.0	79.0	137.0	50.0	80.0	130.0	62.0	69.0	131.0	19.0	68.0	87.0	345.0	242.0	587.0	34.0	93.0	127.0
8	Monroe St. U.C.	Bored	15.5" diam	90 / 90	90	137.0	67.0	204.0	77.0	67.0	144.0	52.0	40.0	92.0	59.0	53.0	112.0	109.0	191.0	300.0	51.0	99.0	150.0
9	Gibert St. U.C.	Bored	15.5" diam	59 / 59	59	67.0	61.5	128.5	36.5	51.5	88.0	40.0	61.0	101.0	48.5	52.5	101.0	89.5	243.5	333.0	26.5	95.5	122.0
	- sounding 1					59.0	61.0	120.0	42.0	57.0	99.0	36.0	61.0	97.0	38.0	47.0	85.0	81.0	243.0	324.0	23.0	103.0	126.0
	- sounding 2					75.0	62.0	137.0	31.0	46.0	77.0	44.0	61.0	105.0	59.0	58.0	117.0	98.0	244.0	342.0	30.0	88.0	118.0
10	Newport Ave. U.C.	Bored	15.5" diam	105 / 120	112.5	34.5	92.5	127.0	37.0	73.5	110.5	44.0	69.5	113.5	42.5	40.5	83.0	82.5	214.0	296.5	34.0	102.5	136.5
	- sounding 1					36.0	89.0	125.0	40.0	71.0	111.0	45.0	68.0	113.0	15.0	63.0	78.0	122.0	202.0	324.0	35.0	96.0	131.0
	- sounding 2					33.0	96.0	129.0	34.0	76.0	110.0	43.0	71.0	114.0	70.0	18.0	88.0	43.0	226.0	269.0	33.0	109.0	142.0
11	105/110 - NW Conn, Tip=106	Bored	16" diam	127 / 127	127	109.7	67.0	176.7	74.0	86.7	160.7	60.0	36.7	96.7	56.7	48.3	105.0	166.0	258.3	424.3	55.0	192.3	247.3
	- sounding 1					146.0	67.0	213.0	81.0	84.0	165.0	66.0	41.0	107.0	80.0	47.0	127.0	118.0	316.0	434.0	59.0	175.0	234.0
	- sounding 2					98.0	67.0	165.0	73.0	89.0	162.0	65.0	33.0	98.0	42.0	48.0	90.0	296.0	149.0	445.0	61.0	207.0	268.0
	- sounding 3					85.0	67.0	152.0	68.0	87.0	155.0	49.0	36.0	85.0	48.0	50.0	98.0	84.0	310.0	394.0	45.0	195.0	240.0
12	105/110 - NW Conn, Tip=92.5	Bored	16" diam	240 / 250	245	117.0	108.5	225.5	63.5	133.5	197.0	58.5	78.0	136.5	88.5	82.5	171.0	97.5	544.5	642.0	39.5	262.5	302.0
	- sounding 2					108.0	109.0	217.0	65.0	135.0	200.0	60.0	76.0	136.0	87.0	83.0	170.0	128.0	544.0	672.0	38.0	278.0	316.0
	- sounding 3					126.0	108.0	234.0	62.0	132.0	194.0	57.0	80.0	137.0	90.0	82.0	172.0	67.0	545.0	612.0	41.0	247.0	288.0
13	Victoria Ave.	Bored	16" diam	115 / 124	119.5	25.5	103.0	128.5	20.5	79.5	100.0	23.5	81.0	104.5	18.5	99.0	117.5	37.5	172.5	210.0	18.5	163.5	182.0
	- sounding 1					28.0	103.0	131.0	21.0	77.0	98.0	20.0	77.0	97.0	27.0	95.0	122.0	22.0	174.0	196.0	14.0	176.0	190.0
	- sounding 2					23.0	103.0	126.0	20.0	82.0	102.0	27.0	85.0	112.0	10.0	103.0	113.0	53.0	171.0	224.0	23.0	151.0	174.0
14	Saticoy Avenue O.C.	Bored	16" diam	90 / 109	99.5	146.0	82.0	228.0	210.0	87.0	297.0	100.0	55.0	155.0	92.0	89.0	181.0	342.0	375.5	717.5	144.0	197.5	341.5
	- sounding 1					146.0	82.0	228.0	210.0	90.0	300.0	97.0	53.0	150.0	132.0	68.0	200.0	404.0	355.0	759.0	154.0	202.0	356.0
	- sounding 2					146.0	82.0	228.0	210.0	84.0	294.0	103.0	57.0	160.0	52.0	110.0	162.0	280.0	396.0	676.0	134.0	193.0	327.0
15	Jeffery Road O.C.	Bored	15.5" diam	90 / 100	95	137.0	89.0	226.0	207.0	81.0	288.0	131.0	123.0	254.0	59.0	72.0	131.0	425.0	258.0	683.0	106.0	91.0	197.0
16	105/605 - SW Conn, Bent 3	Bored	16" diam	118 / 118	118	64.0	66.0	130.0	67.0	62.0	129.0	108.0	72.0	180.0	40.0	45.0	85.0	370.0	271.0	641.0	43.0	72.0	115.0
17	105/605 - SW Conn, Bent 9	Bored	16" diam	94 / 94	94	146.0	81.0	227.0	127.0	78.0	205.0	56.0	94.0	150.0	96.0	78.0	174.0	80.0	200.0	280.0	102.0	70.0	172.0
18	105/605 - NW Conn, Bent 5	Bored	16" diam	95 / 95	95	146.0	77.0	223.0	210.0	73.0	283.0	149.0	87.0	236.0	54.0	67.0	121.0	521.0	226.0	747.0	213.0	73.0	286.0
19	105/605 - NW Conn, Bent 10	Bored	16" diam	138 / 138	138	93.0	91.0	184.0	102.0	86.0	188.0	56.0	110.0	166.0	34.0	62.0	96.0	124.0	301.0	425.0	95.0	58.0	153.0

Key:

	tip (tons)	skin (tons)	total (tons)
average prediction for all soundings	17.5	83.0	100.5
prediction for sounding 1	19.0	82.0	101.0
prediction for sounding 2	16.0	84.0	100.0

Table 1. Summary of Measured and Predicted Pile Capacities

Pile Load Test	Location	Pile Type	X-Section	Pile Capacity min/max (tons)	Pile Capacity average (tons)	Cone - M tip (tons)	Cone - M skin (tons)	Cone - M total (tons)	Schmertmann tip (tons)	Schmertmann skin (tons)	Schmertmann total (tons)	Bustamante tip (tons)	Bustamante skin (tons)	Bustamante total (tons)	LPC Cone tip (tons)	LPC Cone skin (tons)	LPC Cone total (tons)	CPT Direct tip (tons)	CPT Direct skin (tons)	CPT Direct total (tons)	European tip (tons)	European skin (tons)	European total (tons)
20	Mullen Overhead	P/S Conc	12" square	200 / 207	203.5	29.5	104.5	134.0	26.0	103.5	129.5	19.0	71.5	90.5	25.5	106.0	131.5	76.0	224.5	300.5	23.0	159.5	182.5
	- sounding 1					30.0	111.0	141.0	28.0	105.0	133.0	21.0	71.0	92.0	28.0	105.0	133.0	89.0	240.0	329.0	24.0	144.0	168.0
	- sounding 2					29.0	98.0	127.0	24.0	102.0	126.0	17.0	72.0	89.0	23.0	107.0	130.0	63.0	209.0	272.0	22.0	175.0	197.0
21	Guadalupe Connector Viaduct	P/S Conc	12" square	101 / 101	101	105.0	68.5	173.5	24.5	73.5	98.0	14.5	68.0	82.5	58.0	68.5	126.5	26.0	129.5	155.5	23.5	61.0	84.5
	- sounding 1					105.0	66.0	171.0	28.0	75.0	103.0	17.0	65.0	82.0	47.0	67.0	114.0	27.0	128.0	155.0	29.0	54.0	83.0
	- sounding 2					105.0	71.0	176.0	21.0	72.0	93.0	12.0	71.0	83.0	69.0	70.0	139.0	25.0	131.0	156.0	18.0	68.0	86.0
22	Garden Street UC	P/S Conc	12" square	108 / 108	108	35.0	46.0	81.0	24.0	53.5	77.5	19.5	36.0	55.5	32.5	32.0	64.5	39.0	103.5	142.5	24.5	49.5	74.0
	- sounding 1					43.0	44.0	87.0	27.0	50.0	77.0	17.0	37.0	54.0	37.0	29.0	66.0	55.0	81.0	136.0	28.0	28.0	56.0
	- sounding 2					27.0	48.0	75.0	21.0	57.0	78.0	22.0	35.0	57.0	28.0	35.0	63.0	23.0	126.0	149.0	21.0	71.0	92.0
23	Park Avenue UC	P/S Conc	12" square	140 / 149	144.5	105.0	83.0	188.0	95.0	89.0	184.0	65.0	70.0	135.0	46.0	78.0	124.0	203.0	163.0	366.0	83.0	97.0	180.0
24	Bay View O.C.	P/S Conc	15" Oct	164 / 164	164	33.0	79.0	112.0	31.0	69.0	100.0	15.0	53.5	68.5	27.5	76.0	103.5	31.0	136.0	167.0	15.0	106.5	121.5
	- sounding 1					33.0	75.0	108.0	31.0	63.0	94.0	15.0	52.0	67.0	29.0	73.0	102.0	31.0	119.0	150.0	18.0	107.0	125.0
	- sounding 2					33.0	83.0	116.0	31.0	75.0	106.0	15.0	55.0	70.0	26.0	79.0	105.0	31.0	153.0	184.0	12.0	106.0	118.0
25	East Gum Ave	P/S Conc	12" square	111 / 111	111	17.0	100.7	117.7	15.3	99.7	115.0	9.0	117.7	126.7	15.7	115.7	131.3	17.0	161.3	178.3	10.7	148.7	159.3
	- sounding 1					15.0	104.0	119.0	13.0	110.0	123.0	8.0	117.0	125.0	14.0	120.0	134.0	15.0	179.0	194.0	10.0	140.0	150.0
	- sounding 2					19.0	95.0	114.0	17.0	95.0	112.0	10.0	117.0	127.0	18.0	112.0	130.0	19.0	147.0	166.0	11.0	148.0	159.0
	- sounding 3					17.0	103.0	120.0	16.0	94.0	110.0	9.0	119.0	128.0	15.0	115.0	130.0	17.0	158.0	175.0	11.0	158.0	169.0
26	101/280/680 - SW Conn	P/S Conc	12" square	140 / 165	152.5	26.7	104.7	131.3	25.3	113.0	138.3	14.7	97.3	112.0	12.7	113.7	126.3	28.0	171.3	199.3	25.3	136.0	161.3
	- sounding 1					24.0	101.0	125.0	23.0	108.0	131.0	13.0	99.0	112.0	15.0	116.0	131.0	24.0	157.0	181.0	23.0	118.0	141.0
	- sounding 2					27.0	108.0	135.0	26.0	116.0	142.0	16.0	101.0	117.0	11.0	114.0	125.0	28.0	182.0	210.0	26.0	153.0	179.0
	- sounding 3					29.0	105.0	134.0	27.0	115.0	142.0	15.0	92.0	107.0	12.0	111.0	123.0	32.0	175.0	207.0	27.0	137.0	164.0
27	Basset Street OH	P/S Conc	12" square	195 / 195	195	18.0	102.0	120.0	18.0	100.0	118.0	9.5	106.5	116.0	11.0	94.5	105.5	20.0	174.0	194.0	14.5	120.0	134.5
	- sounding 3					17.0	106.0	123.0	17.0	113.0	130.0	9.0	113.0	122.0	14.0	110.0	124.0	19.0	208.0	227.0	10.0	153.0	163.0
	- sounding 4					19.0	98.0	117.0	19.0	87.0	106.0	10.0	100.0	110.0	8.0	79.0	87.0	21.0	140.0	161.0	19.0	87.0	106.0
28	South Tustin O.H.	P/S Conc	10.75" diam	77 / 77	77	14.0	78.0	92.0	14.5	84.0	98.5	9.0	54.0	63.0	12.5	74.5	87.0	15.5	159.5	175.0	12.5	105.0	117.5
	- sounding 1					16.0	79.0	95.0	16.0	86.0	102.0	10.0	55.0	65.0	14.0	77.0	91.0	18.0	166.0	184.0	15.0	105.0	120.0
	- sounding 4					12.0	77.0	89.0	13.0	82.0	95.0	8.0	53.0	61.0	11.0	72.0	83.0	13.0	153.0	166.0	10.0	105.0	115.0
29	Chestnut Street O.H.	CFSS*	12" diam	102 / 102	102	32.5	79.0	111.5	12.0	65.0	77.0	6.0	44.5	50.5	46.5	67.5	114.0	13.5	168.5	182.0	6.5	119.0	125.5
	- sounding 1					51.0	80.0	131.0	12.0	65.0	77.0	6.0	44.0	50.0	67.0	66.0	133.0	12.0	171.0	183.0	6.0	120.0	126.0
	- sounding 2					14.0	78.0	92.0	12.0	65.0	77.0	6.0	45.0	51.0	26.0	69.0	95.0	15.0	166.0	181.0	7.0	118.0	125.0
30	Ventura Underpass	CFSS*	12" diam	35 / 35	35	23.5	65.0	88.5	13.0	51.5	64.5	8.0	36.5	44.5	24.5	54.5	79.0	15.5	151.5	167.0	8.0	96.0	104.0
	- sounding 1					13.0	64.0	77.0	12.0	51.0	63.0	8.0	35.0	43.0	18.0	55.0	73.0	16.0	146.0	162.0	7.0	94.0	101.0
	- sounding 2					34.0	66.0	100.0	14.0	52.0	66.0	8.0	38.0	46.0	31.0	54.0	85.0	15.0	157.0	172.0	9.0	98.0	107.0
31	Almond Drive O.C.	CFSS*	12" diam	78 / 78	78	23.5	50.0	73.5	16.0	43.5	59.5	44.5	42.5	87.0	46.0	44.0	90.0	111.5	96.0	207.5	14.0	64.0	78.0
	- sounding 1					23.0	49.0	72.0	14.0	43.0	57.0	45.0	41.0	86.0	46.0	43.0	89.0	108.0	92.0	200.0	11.0	53.0	64.0
	- sounding 2					24.0	51.0	75.0	18.0	44.0	62.0	44.0	44.0	88.0	46.0	45.0	91.0	115.0	100.0	215.0	17.0	75.0	92.0
32	Cuyama River Bridge	H Pile	HP 10x57	90 / 90	90	21.0	81.0	102.0	18.0	81.5	99.5	34.0	51.5	85.5	20.5	58.0	78.5	28.5	184.0	212.5	17.5	83.0	100.5
	- sounding 1					21.0	79.0	100.0	20.0	81.0	101.0	31.0	46.0	77.0	24.0	63.0	87.0	25.0	175.0	200.0	19.0	82.0	101.0
	- sounding 2					21.0	83.0	104.0	16.0	82.0	98.0	37.0	57.0	94.0	17.0	53.0	70.0	32.0	193.0	225.0	16.0	84.0	100.0

* CFSS = Concrete Filled Steel Shell

Key:

	tip (tons)	skin (tons)	total (tons)
average prediction for all soundings	17.5	83.0	100.5
prediction for sounding 1	19.0	82.0	101.0
prediction for sounding 2	16.0	84.0	100.0

Table 1. (continued) Summary of Measured and Predicted Pile Capacities

All Piles (N=32)

	Cone - M	Schmertmann	Bustamante	LPC Cone	Direct CPT	European
Mean	1.53	1.39	1.24	1.09	3.53	1.55
Std. Dev.	0.81	0.85	0.76	0.43	2.40	0.85
COV*	0.53	0.61	0.61	0.39	0.68	0.55

Driven Piles (N=13)

	Cone - M	Schmertmann	Bustamante	LPC Cone	Direct CPT	European
Mean	1.12	0.96	0.79	1.01	1.97	1.19
Std. Dev.	0.52	0.35	0.28	0.45	1.01	0.60
COV*	0.46	0.36	0.35	0.45	0.51	0.50

Bored Piles - Total Resistance (N=19)

	Cone - M	Schmertmann	Bustamante	LPC Cone	Direct CPT	European
Mean	1.81	1.68	1.55	1.15	4.60	1.80
Std. Dev.	0.86	0.97	0.84	0.42	2.50	0.92
COV*	0.48	0.58	0.54	0.37	0.54	0.51

Bored Piles - Skin Resistance (N=19)

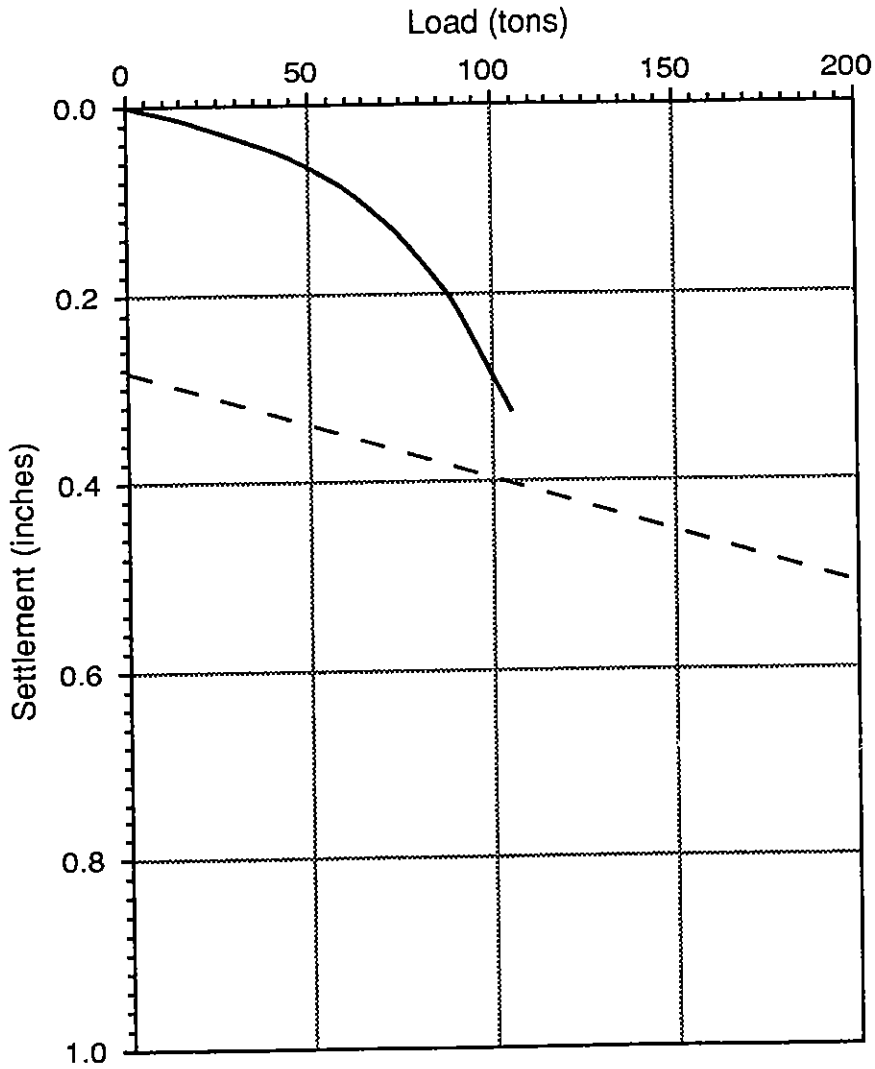
	Cone - M	Schmertmann	Bustamante	LPC Cone	Direct CPT	European
Mean	0.81	0.72	0.82	0.64	2.54	0.99
Std. Dev.	0.22	0.16	0.36	0.19	1.02	0.40
COV*	0.27	0.22	0.44	0.30	0.40	0.40

*COV = Coefficient of Variation

Table 2. Summary of Statistical Parameters
Based on Ratios of Predicted to Measured Pile Capacity

APPENDIX

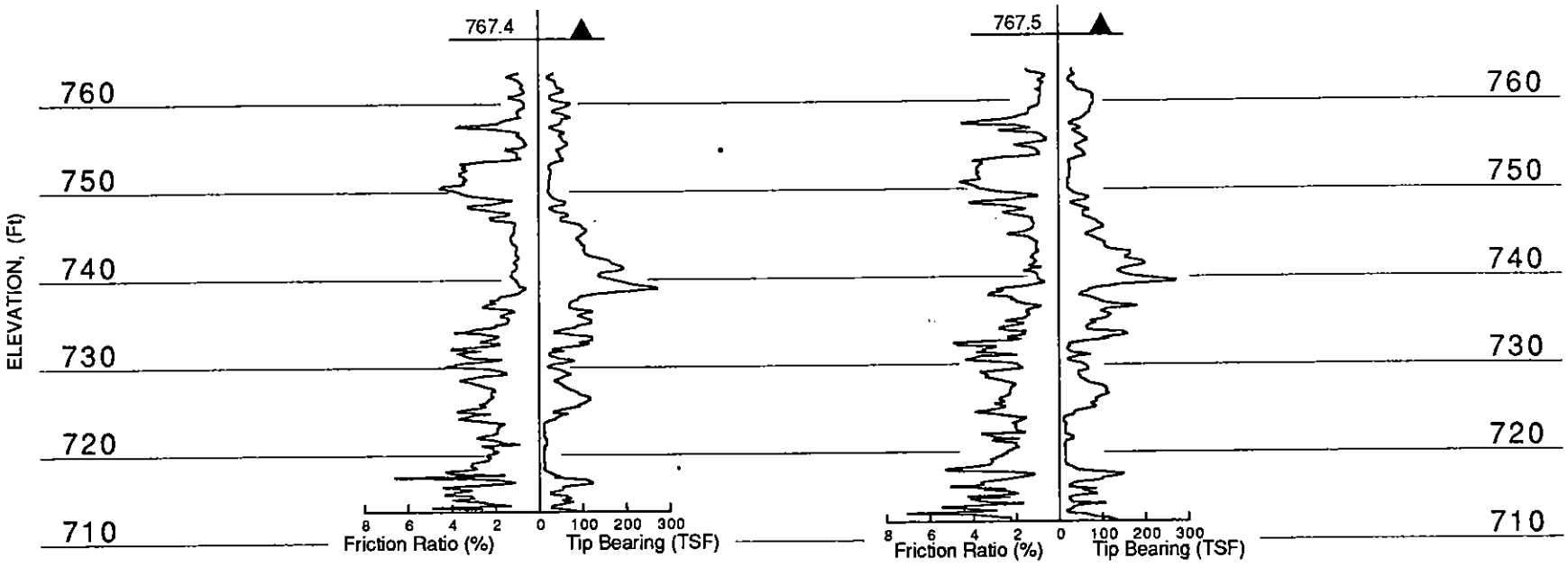
CPT AND PILE LOAD TEST DATA



Pile Load Test # 1

Project	:	East End Avenue UC
Location	:	37 Ft Lt. 16+02 C/L Rte. 60
Brdg No	:	54-742 R/L
Date	:	9/16/89
Pile Type	:	Bored
X Section	:	16 inch diameter
Ftg Elev	:	762.0 feet
Tip Elev	:	723.8 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -

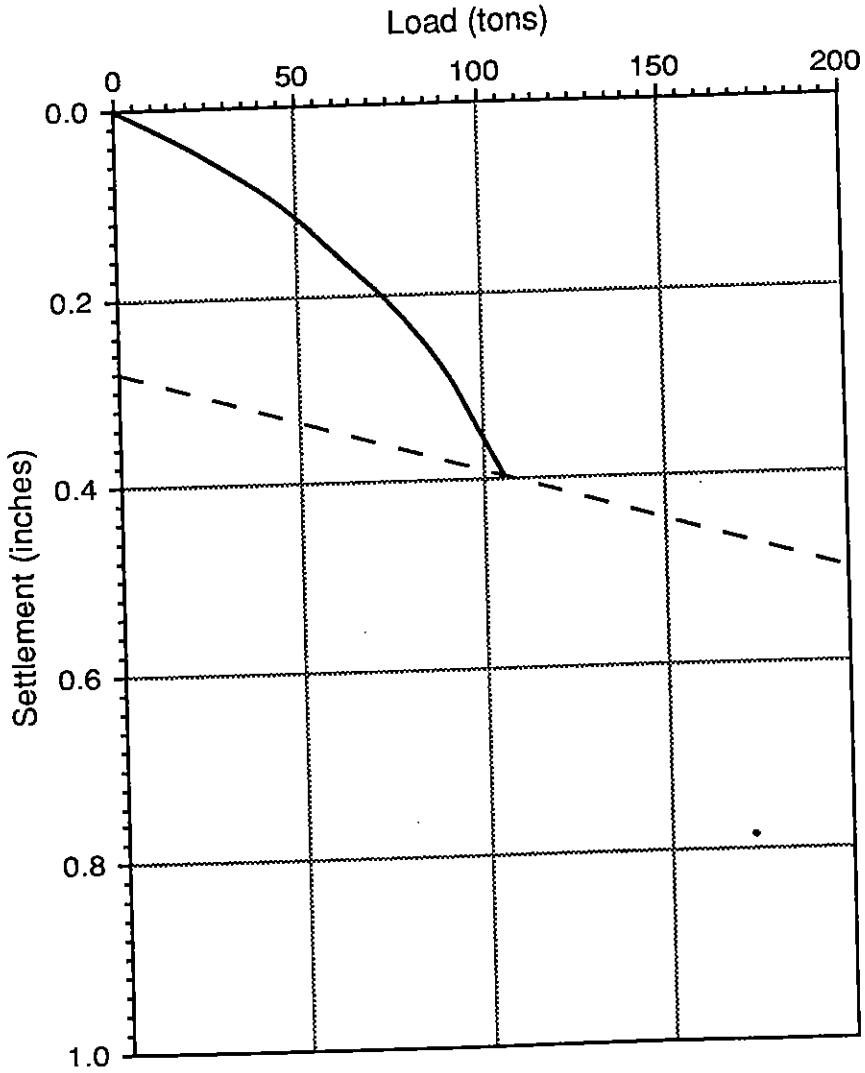


SOUNDING 1
(30 Ft Lt 16+15 C/L Rte 60)

SOUNDING 2
(38 Ft Lt 16+19 C/L Rte 60)

Cone Penetrometer Test Data

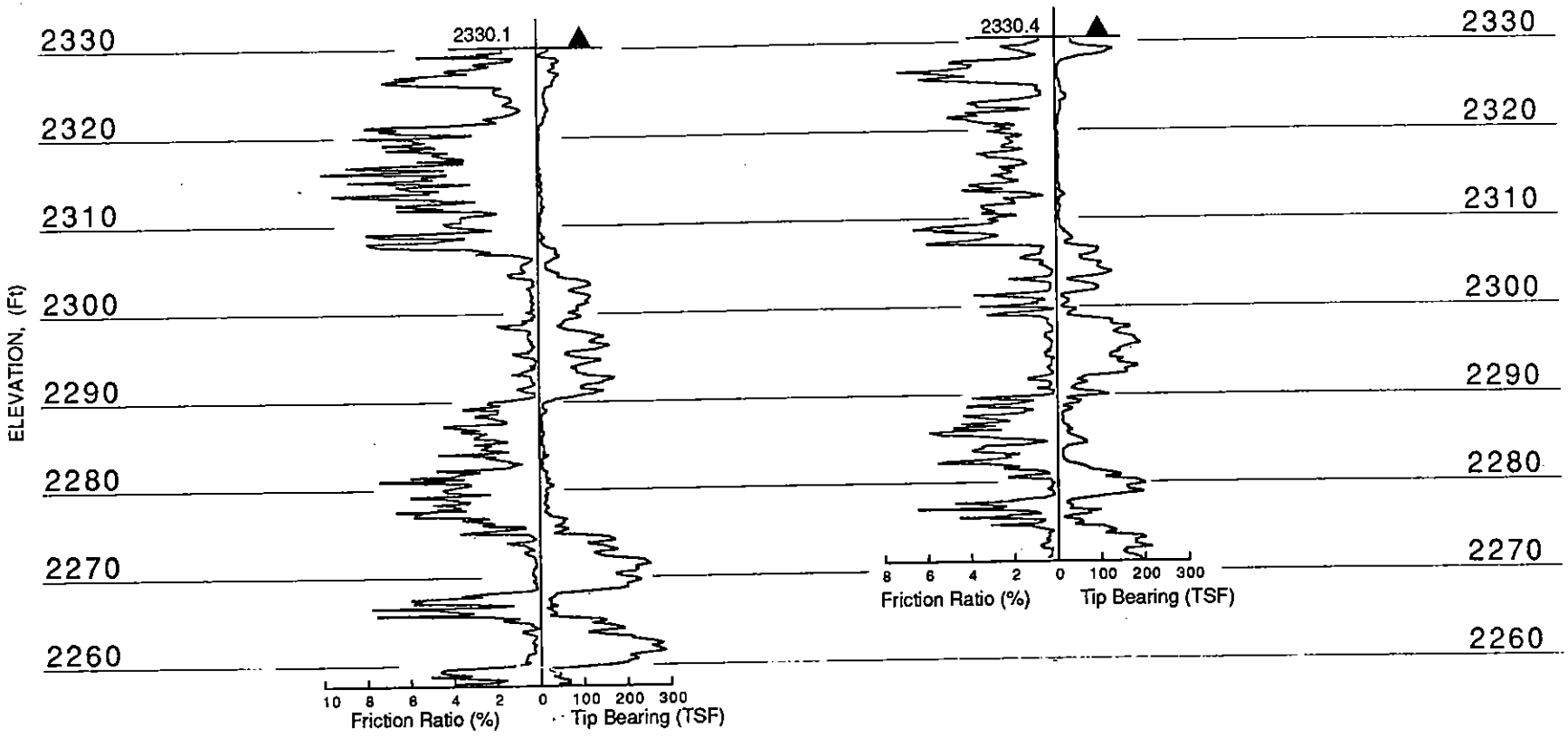
East End Avenue UC



Pile Load Test # 2

Project : San Timoteo Creek Bridge
Location : 39 Ft Rt 363+66 C/L Improvement
Brdg No : 56-65
Date : 11/10/58
Pile Type : Bored
X Section : 15.5 inch diameter
Ftg Elev : 2320.0 feet
Tip Elev : 2285.0 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -



SOUNDING 1

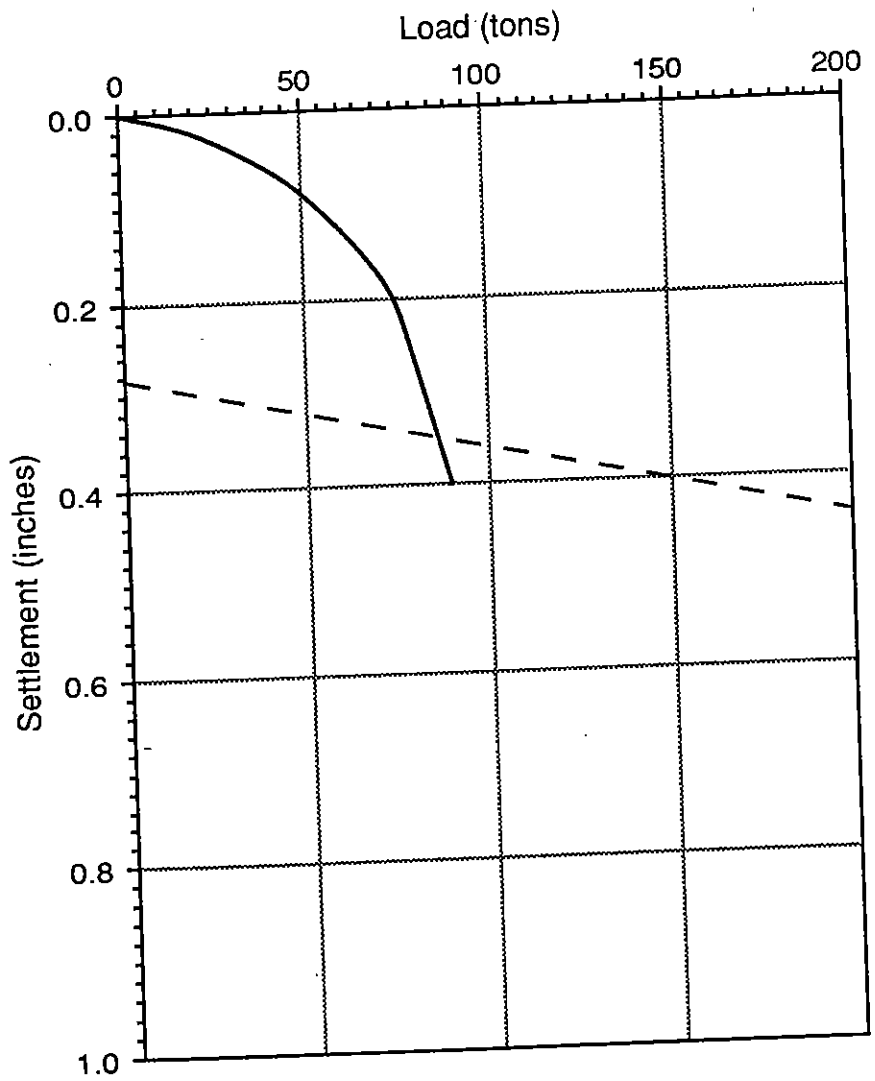
(73 Ft Rt 363+44 C/L Improvement)

SOUNDING 2

(69 Ft Rt 363+22 C/L Improvement)

Cone Penetrometer Test Data

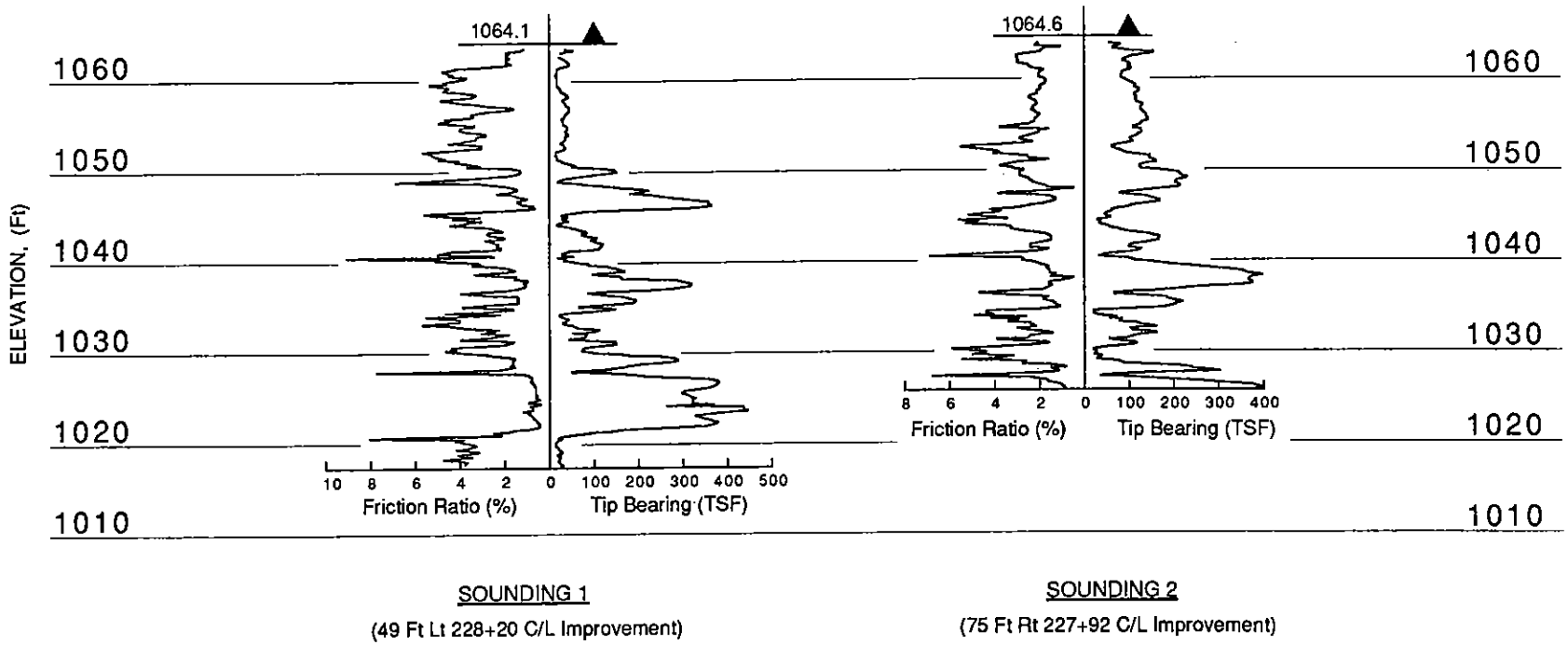
San Timoteo Creek



Pile Load Test # 3

Project	:	Tippecanoe Avenue UC
Location	:	228+01 C/L Improvement
Brdg No	:	54-598 R/L
Date	:	5/12/61
Pile Type	:	Bored
X Section	:	16 inch diameter
Ftg Elev	:	1058.0 feet
Tip Elev	:	1031.5 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -

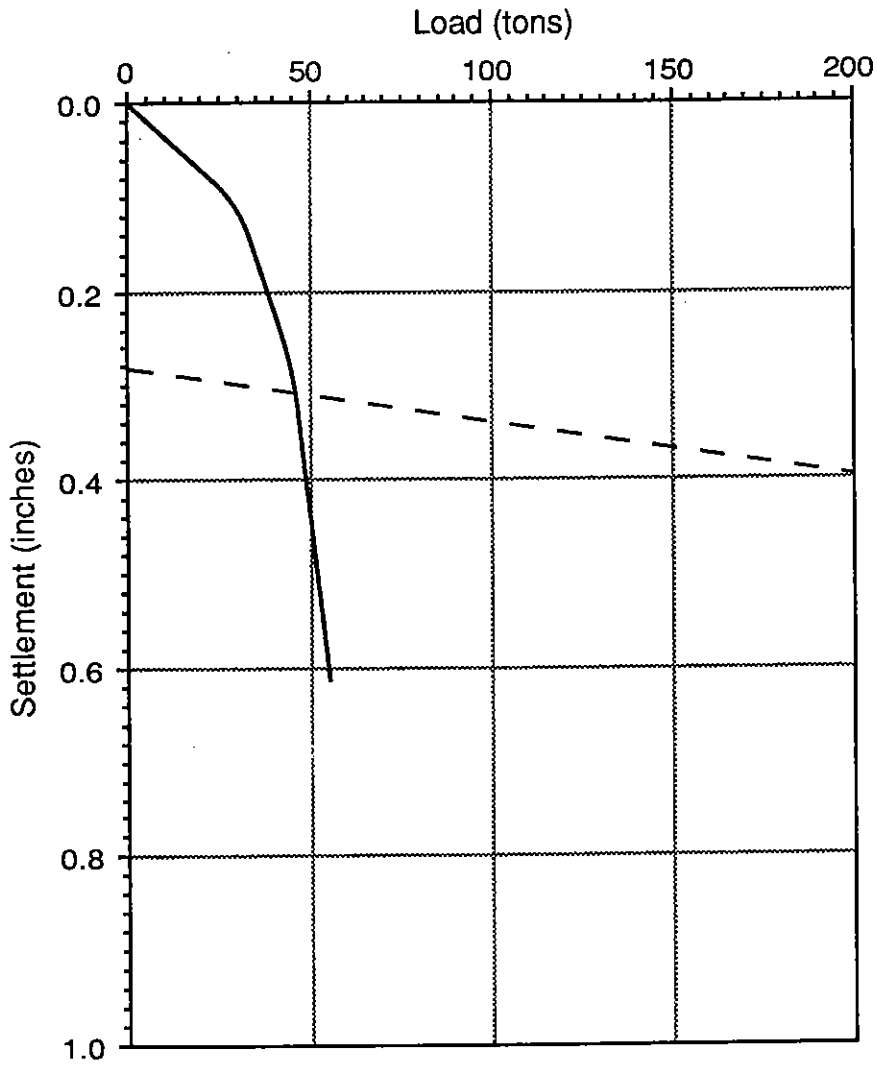


SOUNDING 1
(49 Ft Lt 228+20 C/L Improvement)

SOUNDING 2
(75 Ft Rt 227+92 C/L Improvement)

Cone Penetrometer Test Data

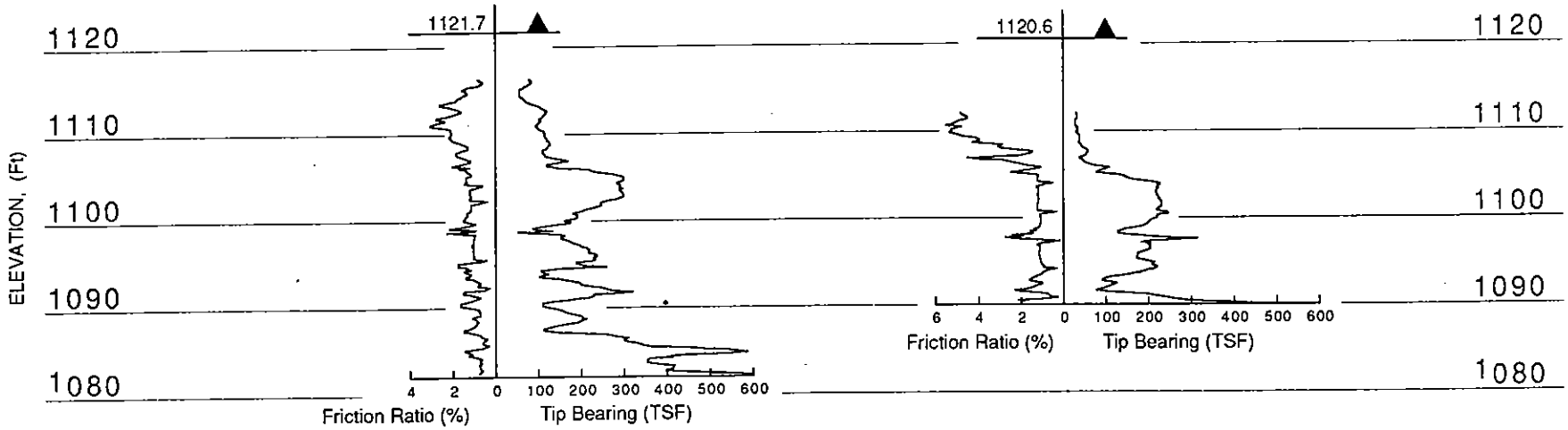
Tippecanoe Avenue UC



Pile Load Test # 4

Project : Baseline Street OC
Location : 24 Ft Lt 10+11 C/L Baseline St
Brdg No : 54-498
Date : 10/6/58
Pile Type : Bored
X Section : 16 inch diameter
Ftg Elev : 1113.5 feet
Tip Elev : 1095.0 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -



SOUNDING 1

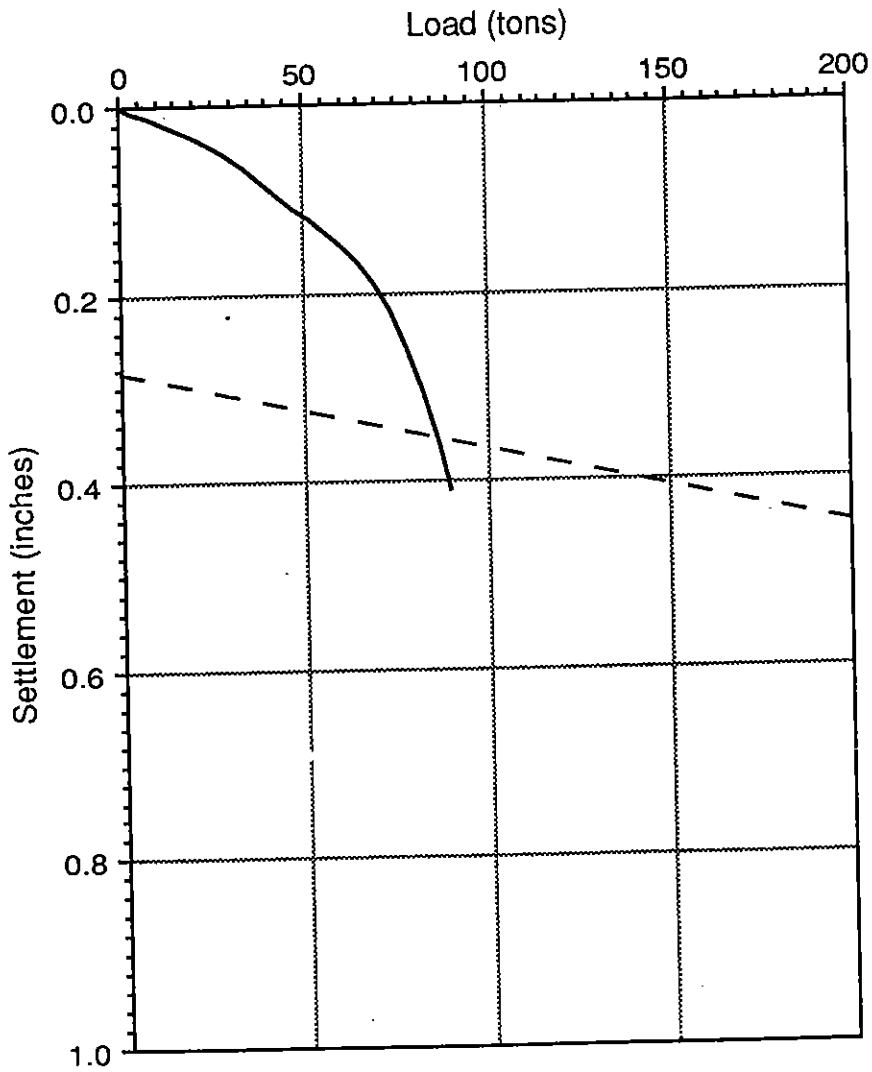
(70 Ft Lt 10+20 C/L Baseline St)

SOUNDING 2

(44 Ft Rt 10+19 C/L Baseline St)

Cone Penetrometer Test Data

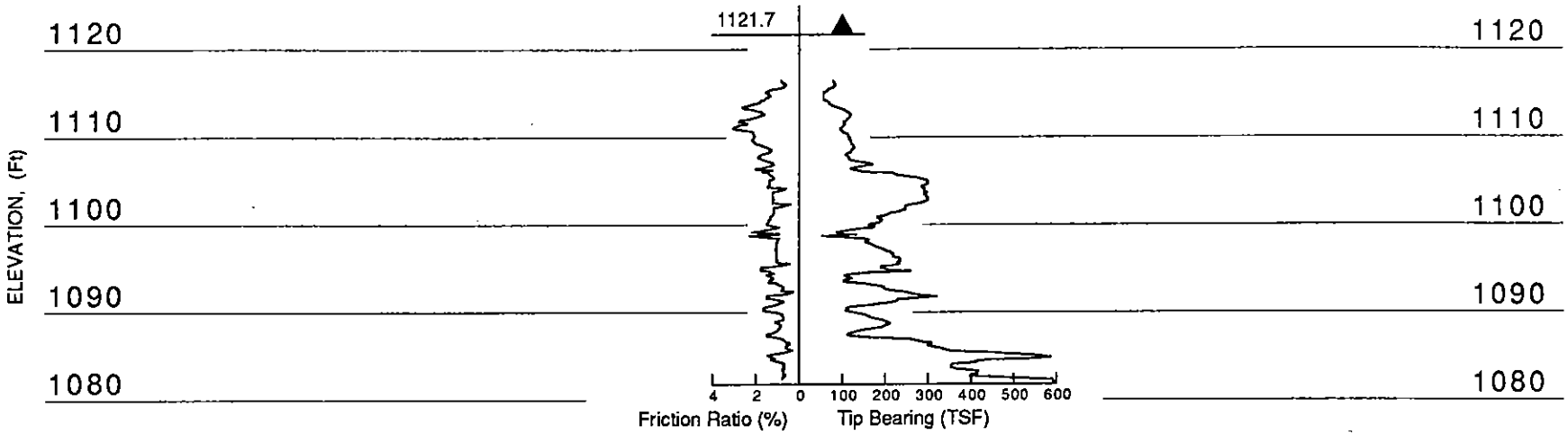
Baseline Street OC, Tip = 1095



Pile Load Test # 5

Project : Baseline Street OC
Location : 24 Ft Lt 10+13 C/L Baseline St
Brdg No : 54-498
Date : 10/20/58
Pile Type : Bored
X Section : 16 inch diameter
Ftg Elev : 1113.5 feet
Tip Elev : 1086.0 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -

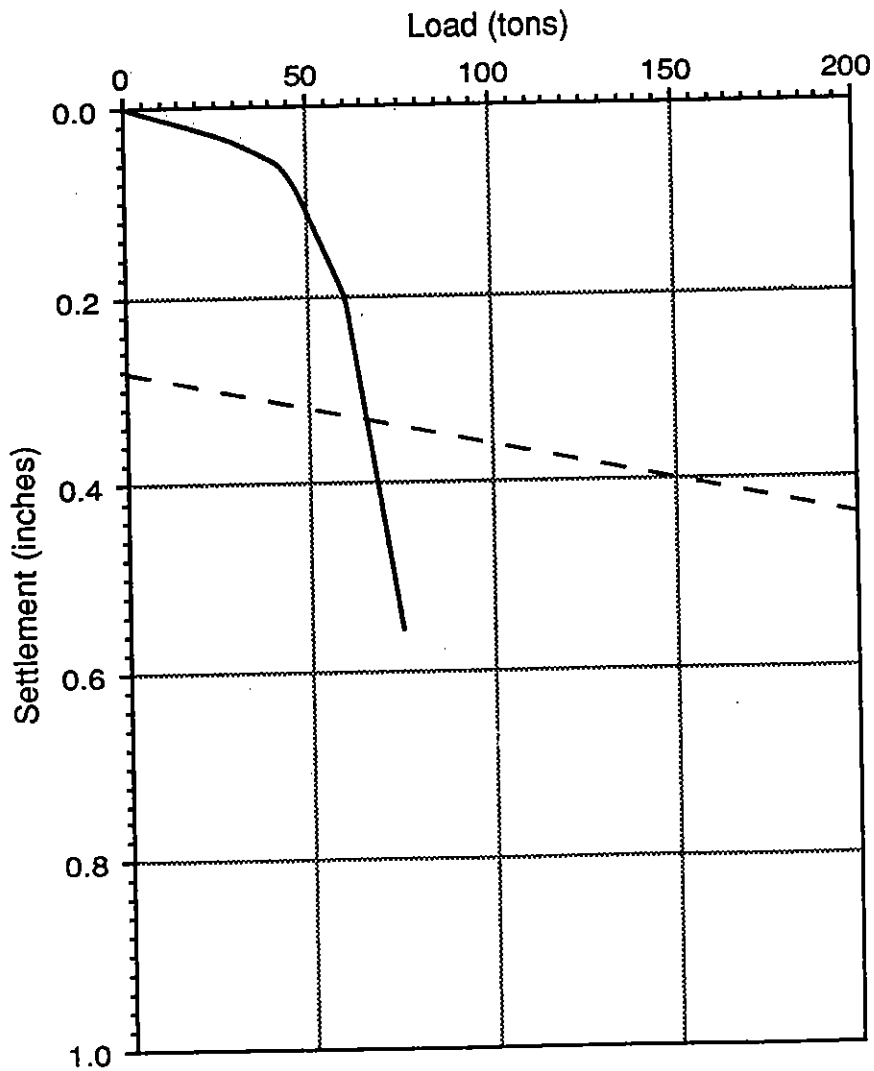


SOUNDING 1

(70 Ft Lt 10+20 C/L Baseline St)

Cone Penetrometer Test Data

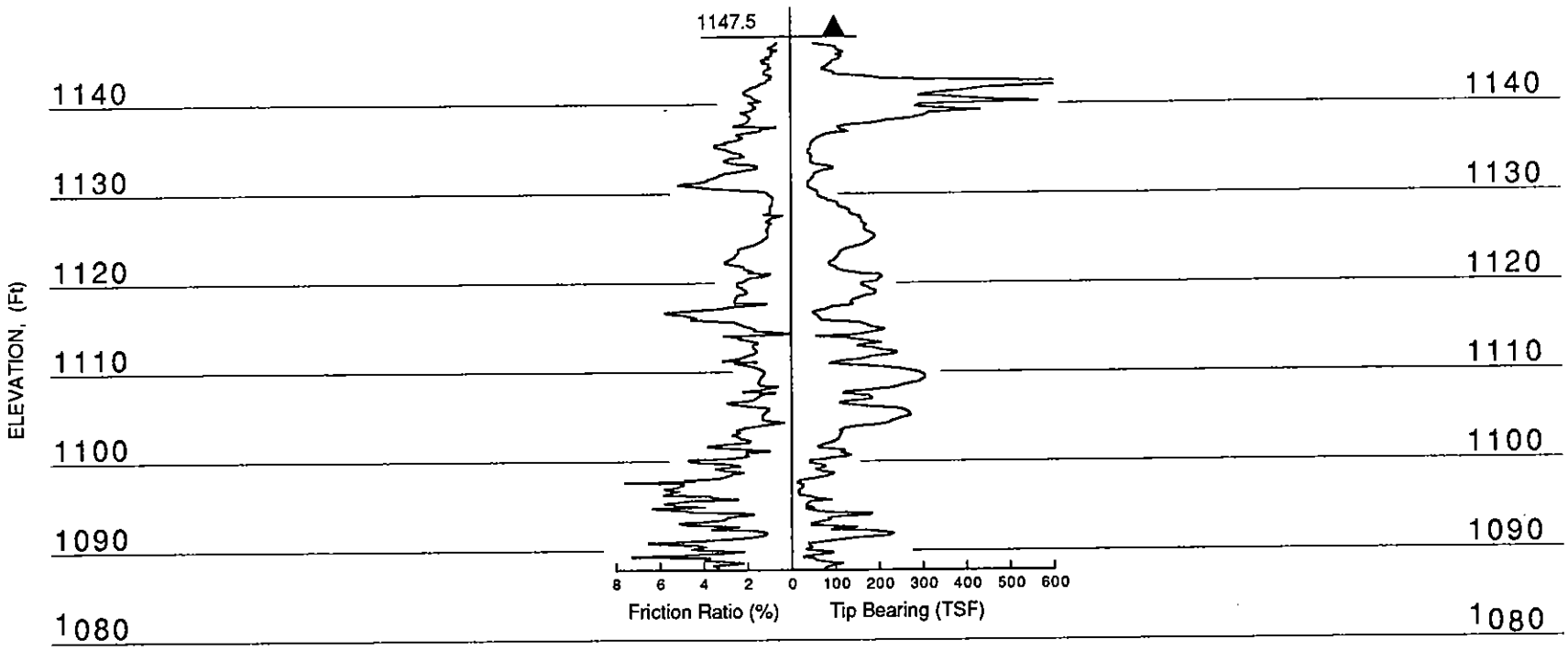
Baseline Street OC, Tip = 1086



Pile Load Test # 6

Project : Sixteenth Street OC
Location : 15 Ft Lt 10+00 C/L 16th St
Brdg No : 54-522
Date : 8/11/58
Pile Type : Bored
X Section : 16 inch diameter
Ftg Elev : 1126.0 feet
Tip Elev : 1100.0 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -

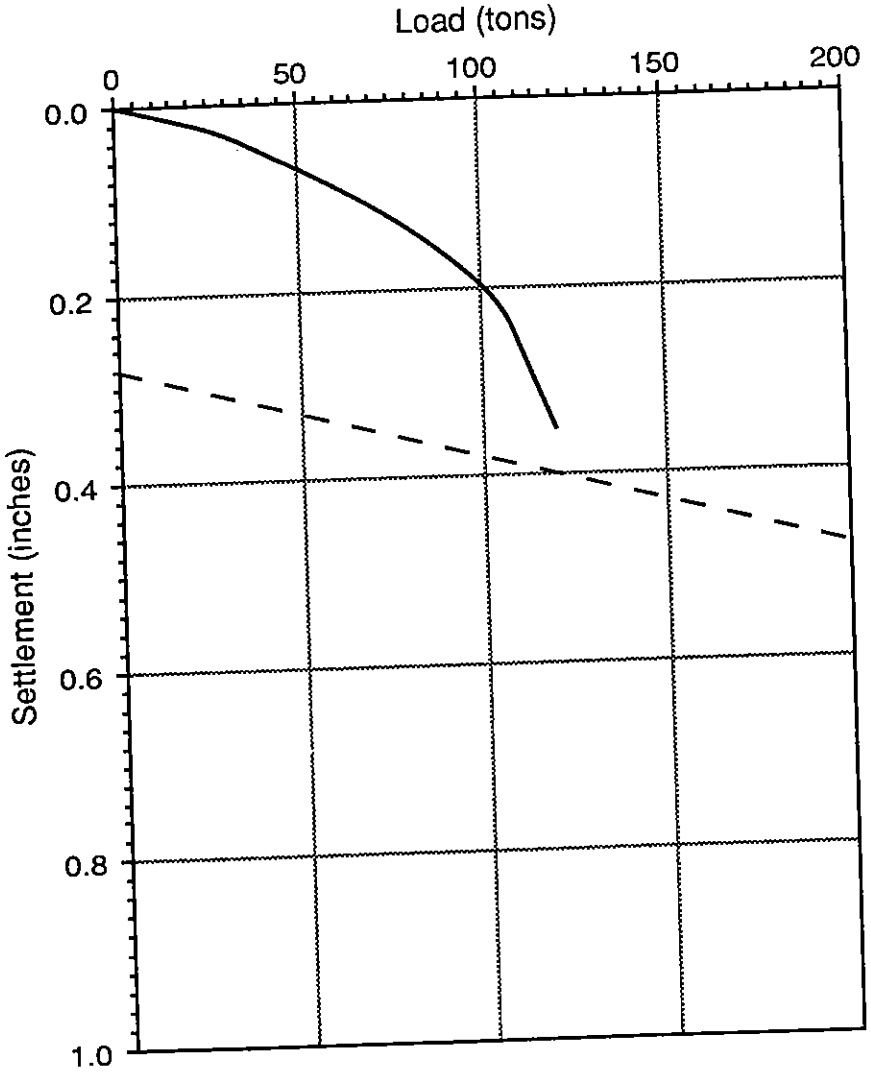


SOUNDING 1

(65 Ft Rt 9+96 C/L 16th St)

Cone Penetrometer Test Data

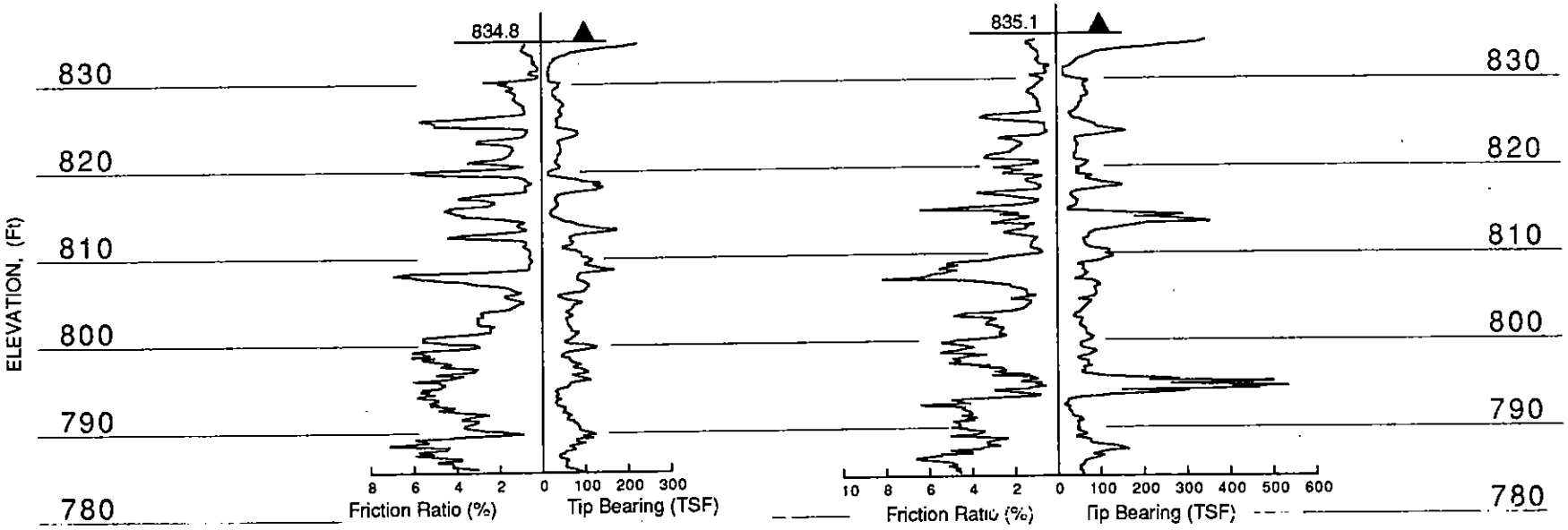
Sixteenth Street OC



Pile Load Test # 7

Project : Jefferson Street UC
Location : 6 Ft Lt 171+31 C/L Improvement
Brdg No : 56-387
Date : 8/5/58
Pile Type : Bored
X Section : 15.5 inch diameter
Ftg Elev : 828.0 feet
Tip Elev : 795.0 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -

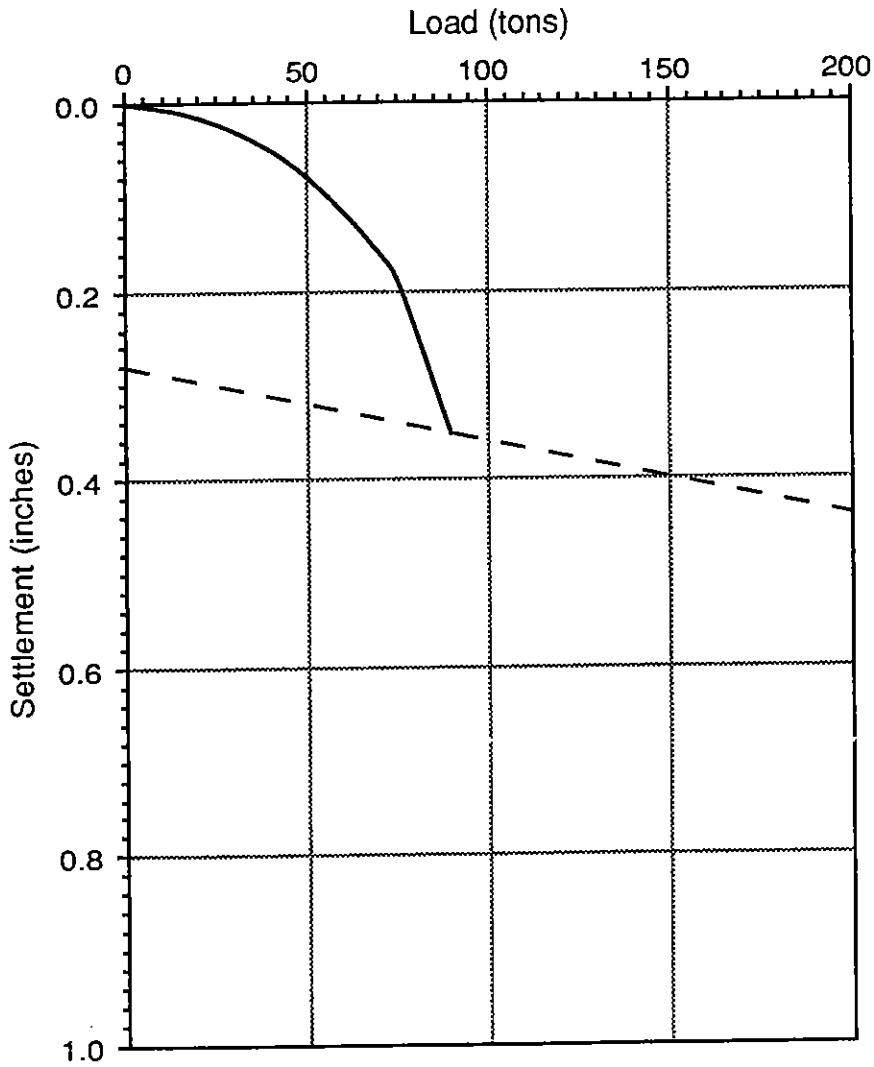


SOUNDING 1
(4 Ft Lt 171+25 C/L Improvement)

SOUNDING 2
(8 Ft Rt 171+25 C/L Improvement)

Cone Penetrometer Test Data

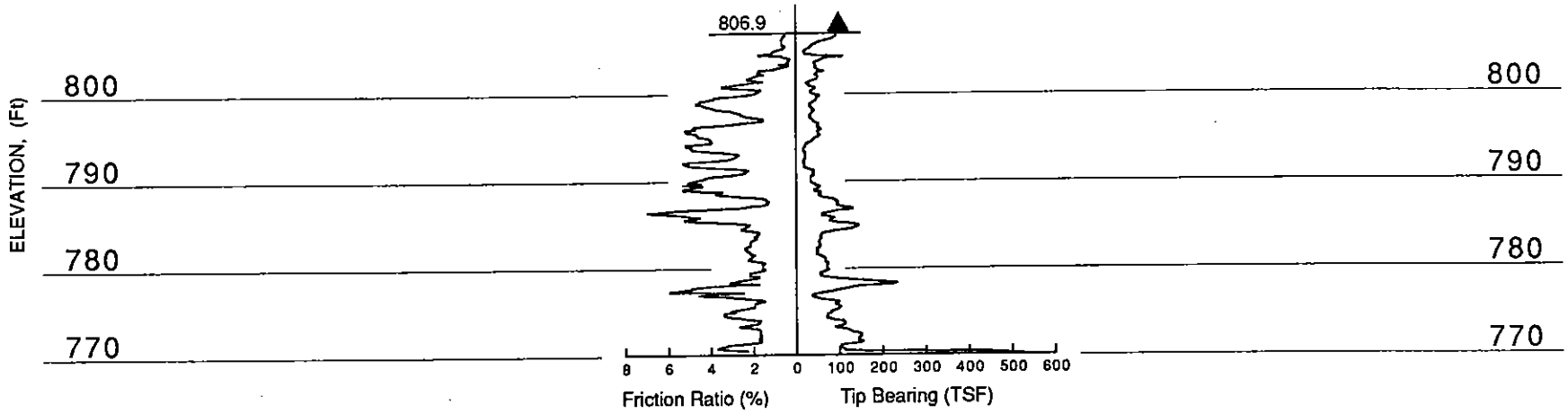
Jefferson Street UC



Pile Load Test # 8

Project : Monroe Street UC
Location : 12 Ft Lt 116+02 C/L Improvement
Brdg No : 56-391
Date : 8/26/58
Pile Type : Bored
X Section : 15.5 inch diameter
Ftg Elev : 800.0 feet
Tip Elev : 775.0 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -

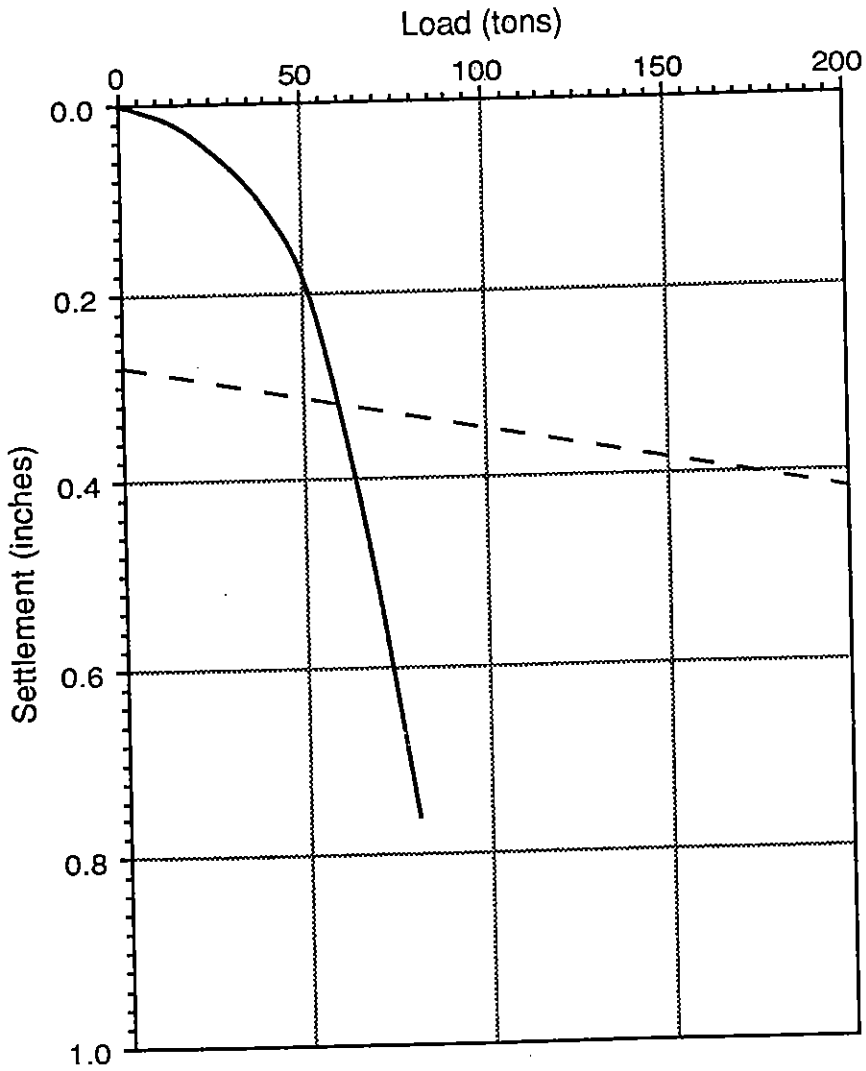


SOUNDING 1

(25 Ft Lt 116+13 C/L Improvement)

Cone Penetrometer Test Data

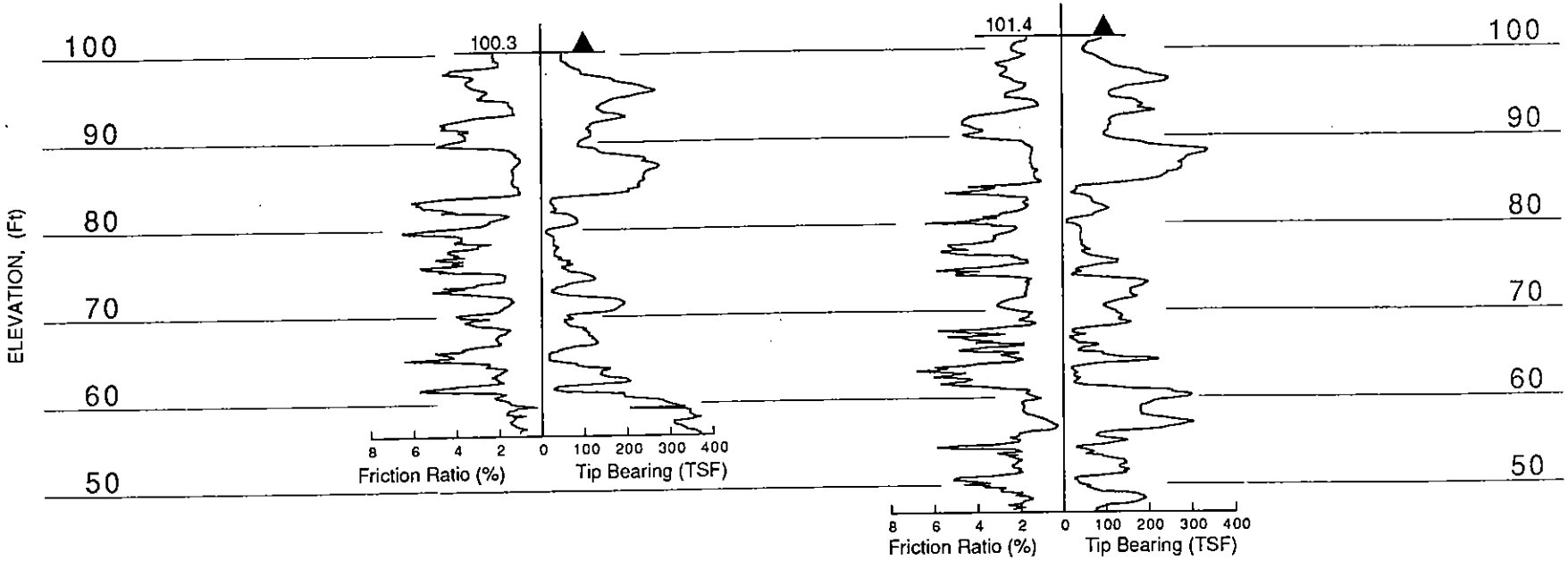
Monroe Street UC



Pile Load Test # 9

Project : Gilbert Street UC
Location : 26 Ft Lt 92+87 A1 Line
Brdg No : 55-287
Date : 9/9/87
Pile Type : Bored
X Section : 15.5 inch diameter
Ftg Elev : 96.5 feet
Tip Elev : 75.2 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -

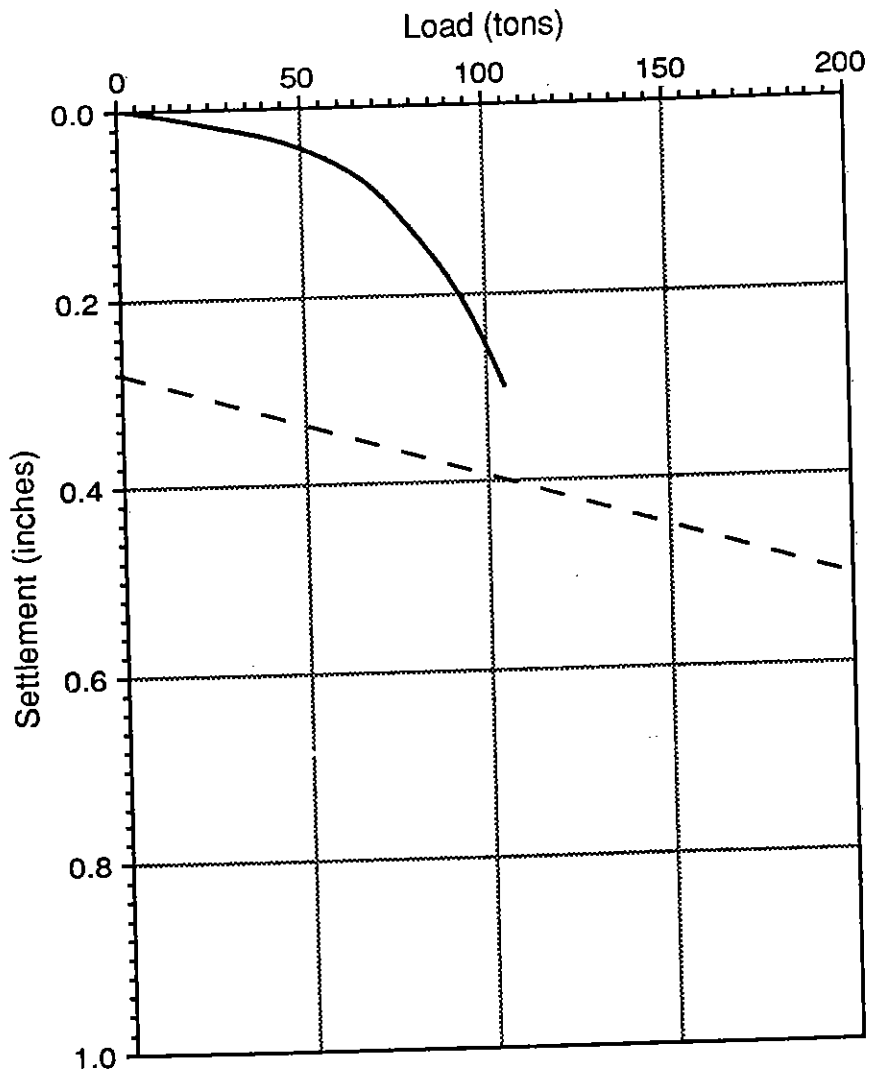


SOUNDING 1
(147 Ft Rt 93+72 A1 Line)

SOUNDING 2
(122 Ft Rt 93+38 A1 Line)

Cone Penetrometer Test Data

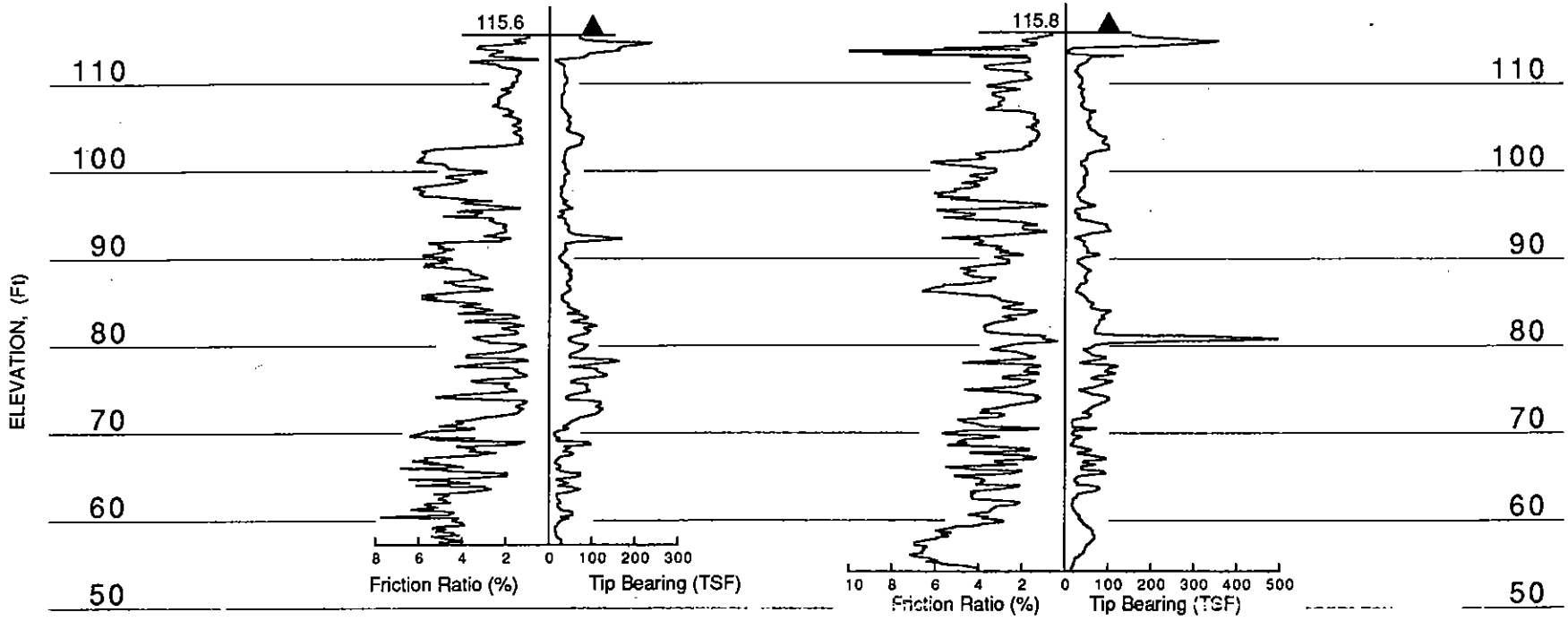
Gilbert Street UC



Pile Load Test # 10

Project : Newport Avenue UC
Location : 34 Ft Rt 302+93 C/L Const.
Brdg No : 55-192
Date : 8/20/54
Pile Type : Bored
X Section : 15.5 inch diameter
Ftg Elev : 110.0 feet
Tip Elev : 75.0 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -

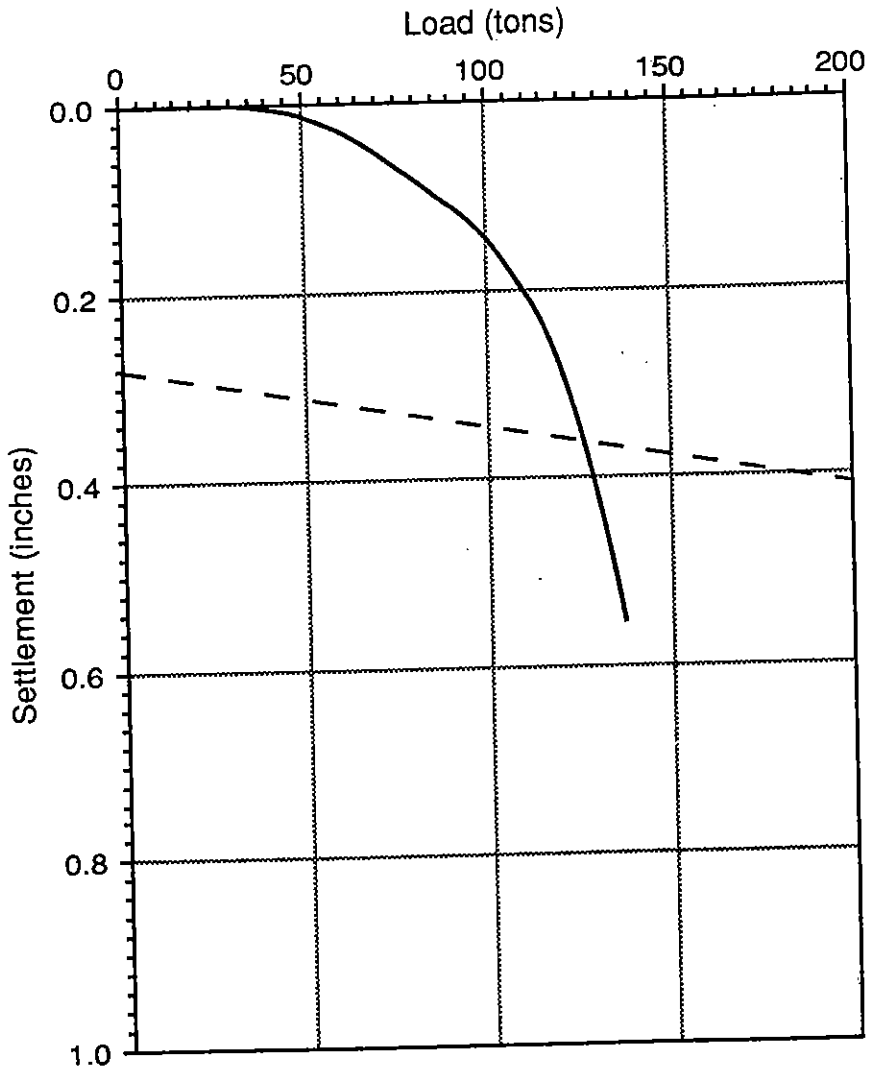


SOUNDING 1
(23 Ft Rt 303+05 C/L Const)

SOUNDING 2
(33 Ft Rt 302+92 C/L Const)

Cone Penetrometer Test Data

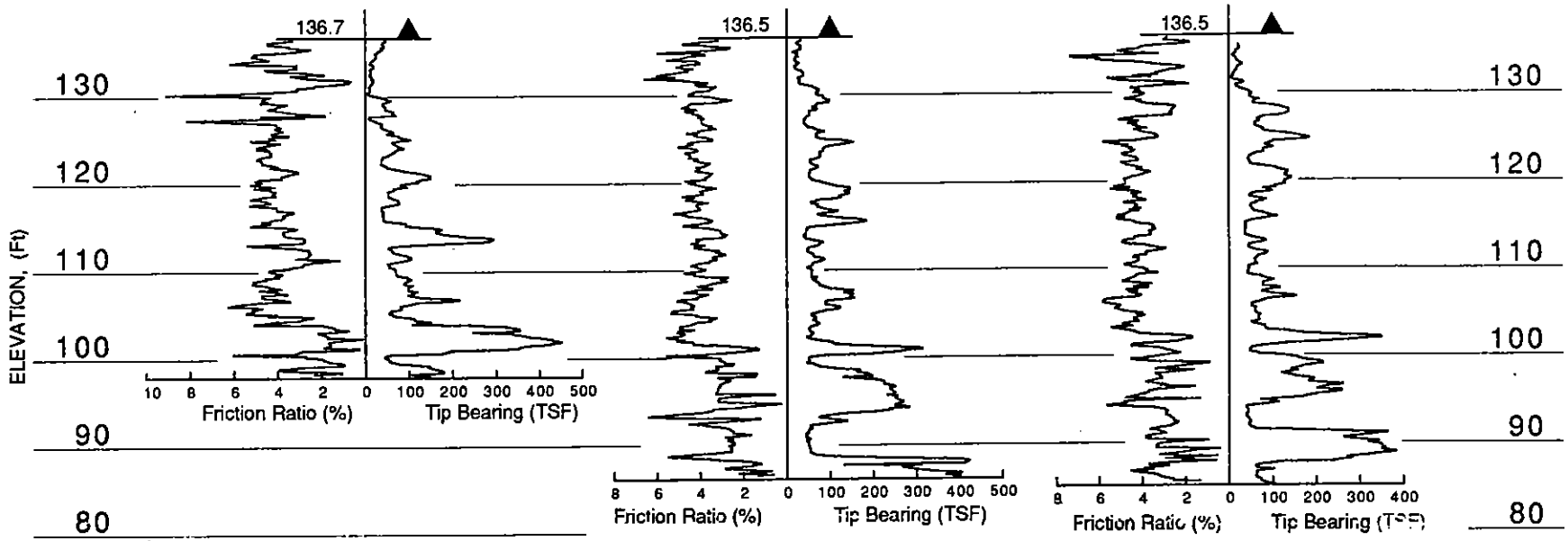
Newport Avenue UC



Pile Load Test # 11

Project : 105/110 Northwest Connector OC
Location : 31 Ft Rt 59+99 C7 Line
Brdg No : 53-2404G
Date : 10/13/86
Pile Type : Bored
X Section : 16 inch diameter
Ftg Elev : 127.5 feet
Tip Elev : 106.0 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -



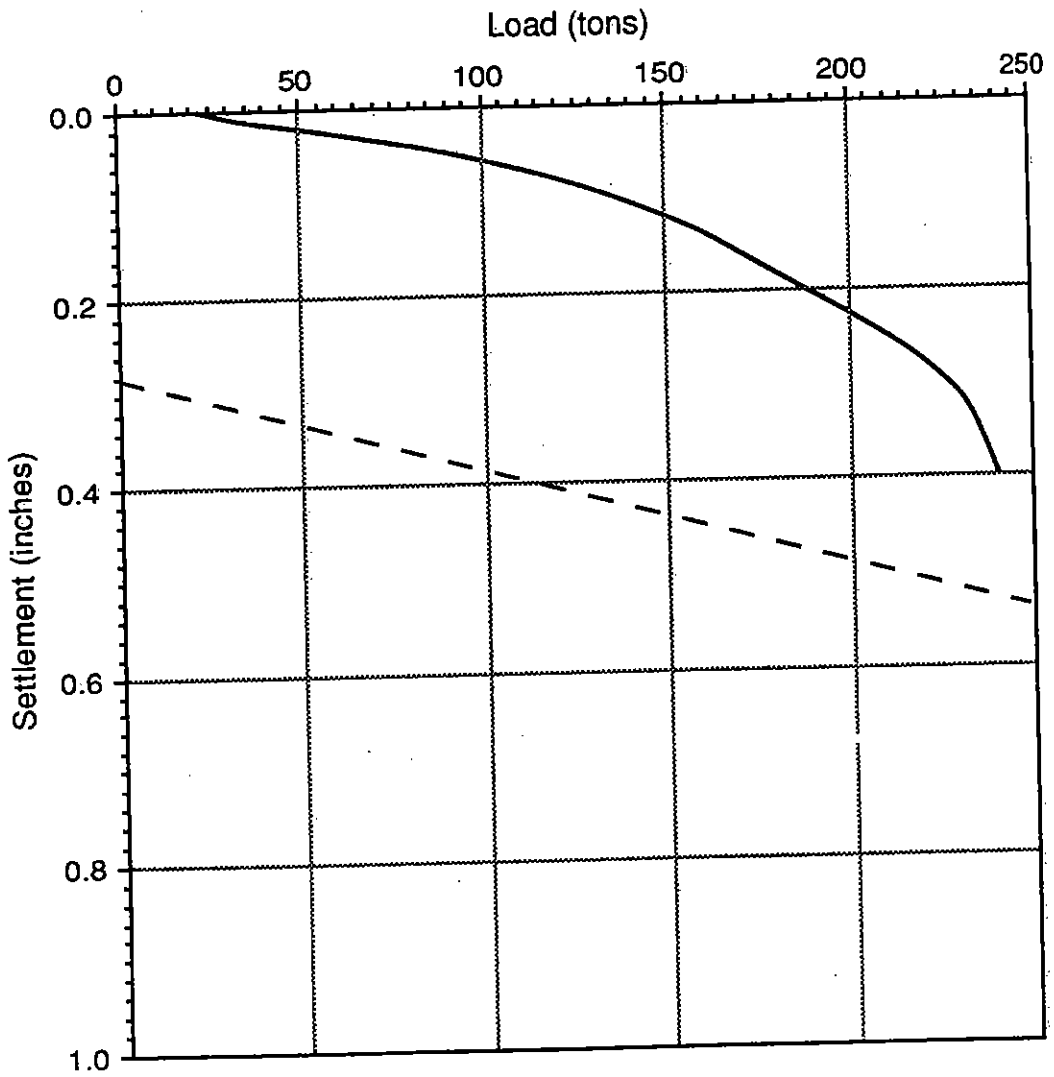
SOUNDING 1
(16 Ft Rt 59+99 C7 Line)

SOUNDING 2
(43 Ft Rt 59+98 C7 Line)

SOUNDING 3
(32 Ft Rt 59+92 C7 Line)

Cone Penetrometer Test Data

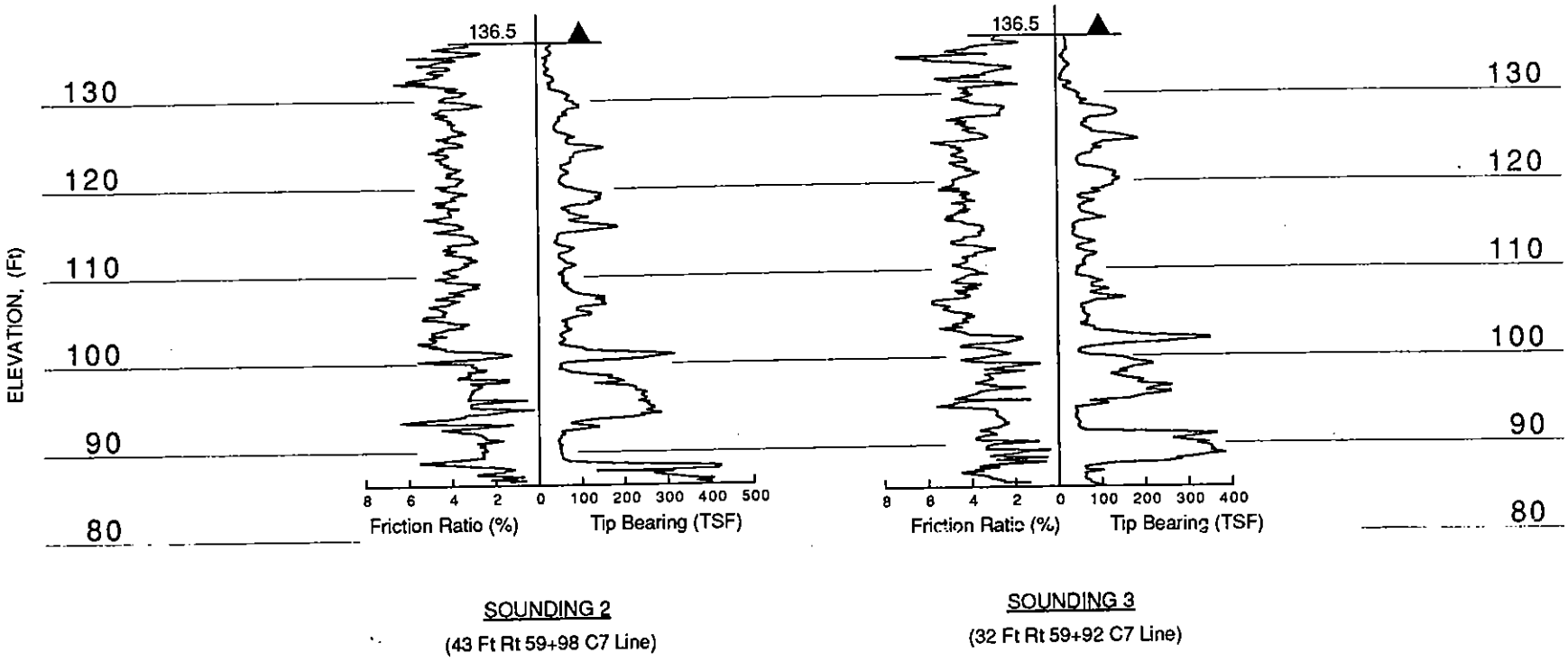
105/110 Northwest Connector OC, Tip = 106



Pile Load Test # 12

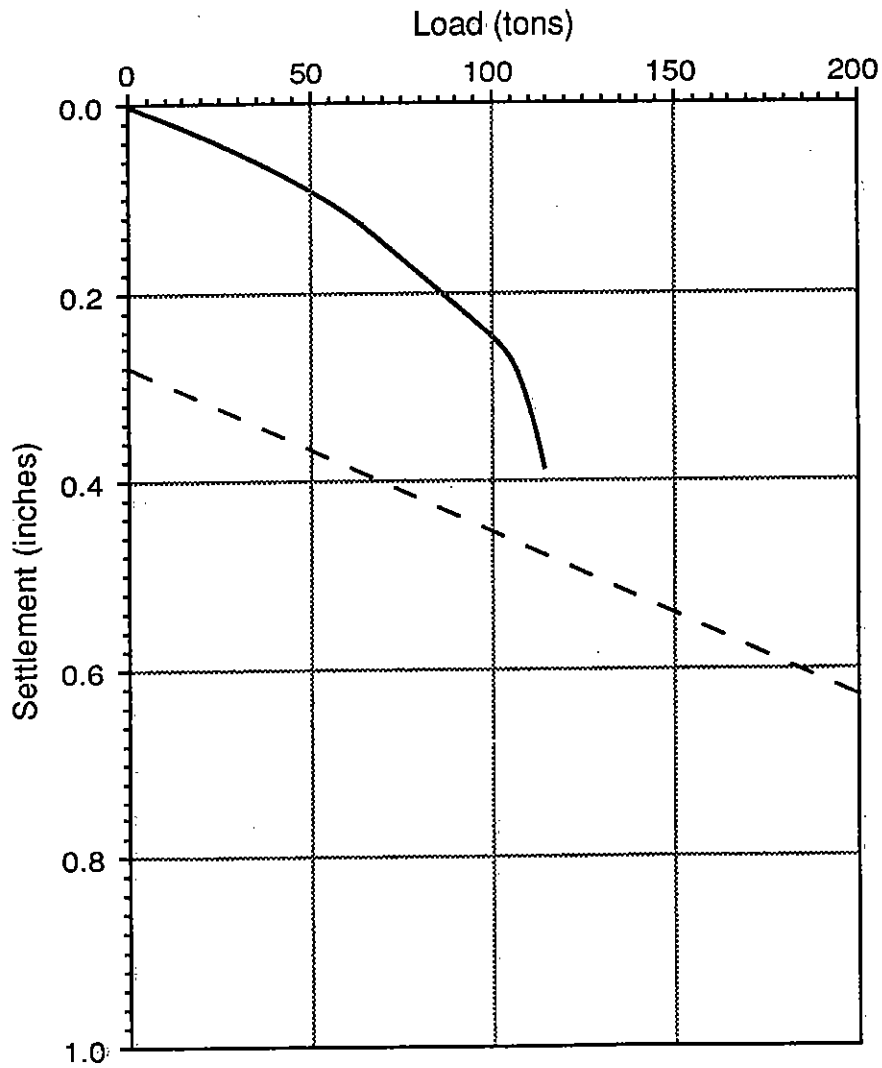
Project : 105/110 Northwest Connector OC
Location : 31 Ft Rt 59+99 C7 Line
Brdg No : 53-2404G
Date : 11/8/86
Pile Type : Bored
X Section : 16 inch diameter
Ftg Elev : 127.5 feet
Tip Elev : 92.5 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - -



Cone Penetrometer Test Data

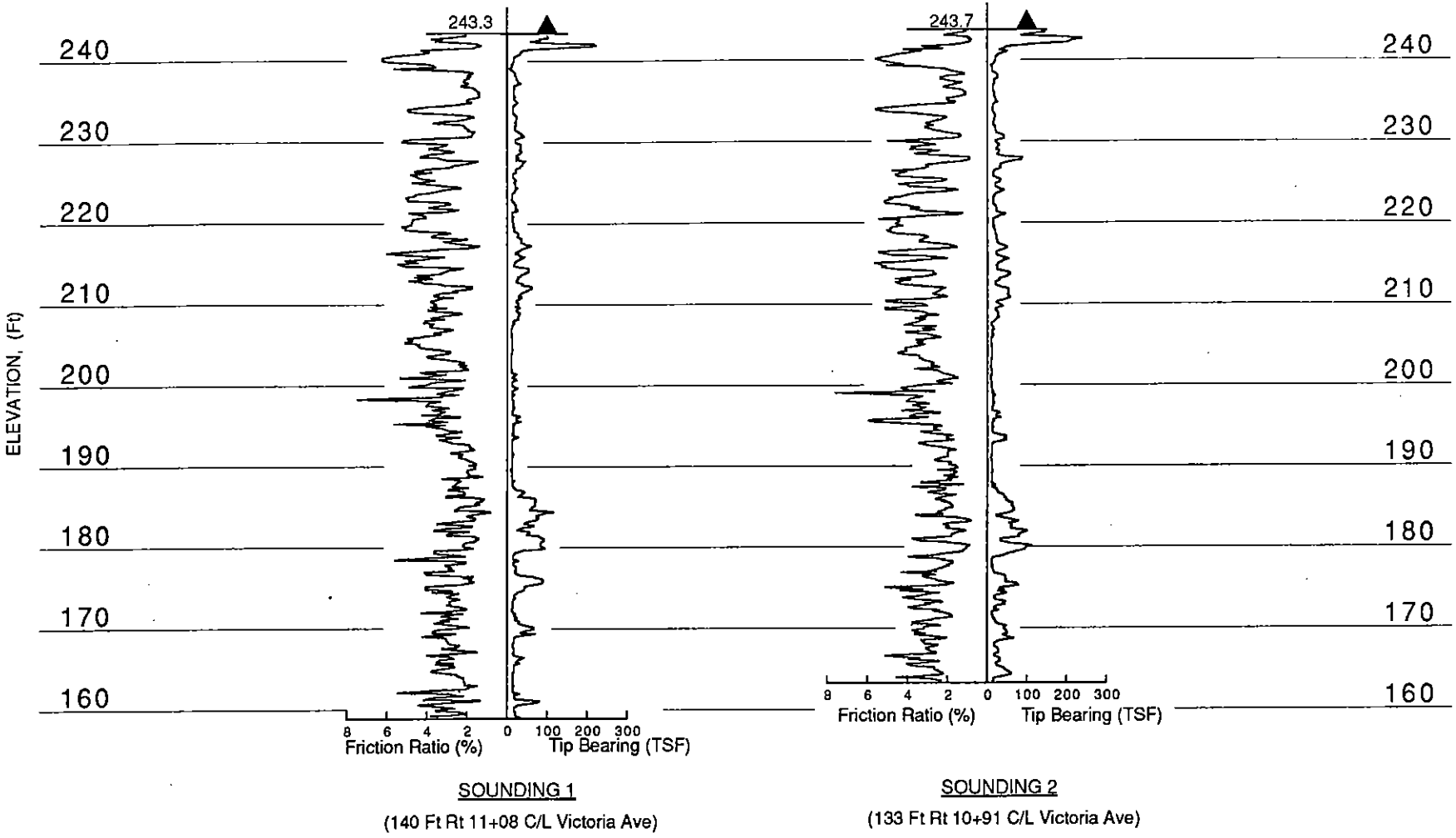
105/110 Northwest Connector OC, Tip = 92.5



Pile Load Test # 13

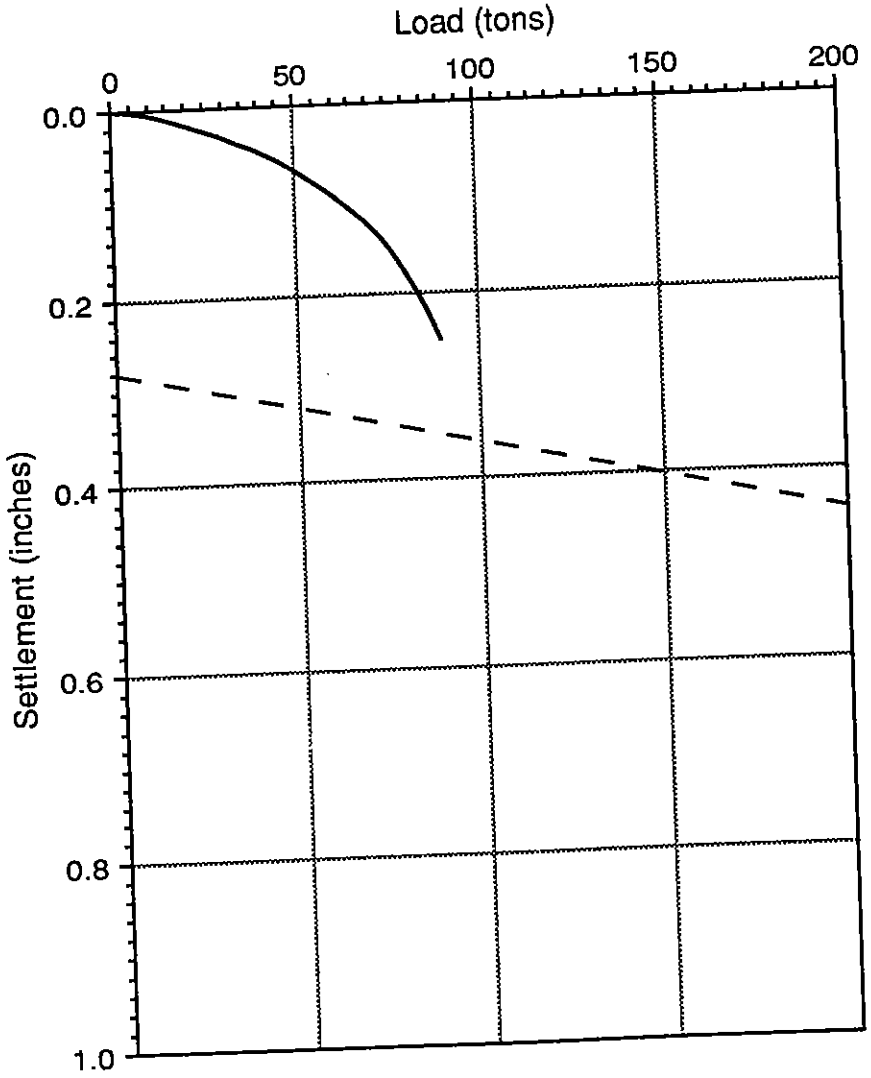
Project : Victoria Avenue OC
Location : 18 Ft Rt 11+07 C/L Victoria Ave
Brdg No : 52-226
Date : 10/26/61
Pile Type : Bored
X Section : 16 inch diameter
Ftg Elev : 237.0 feet
Tip Elev : 179.0 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -



Cone Penetrometer Test Data

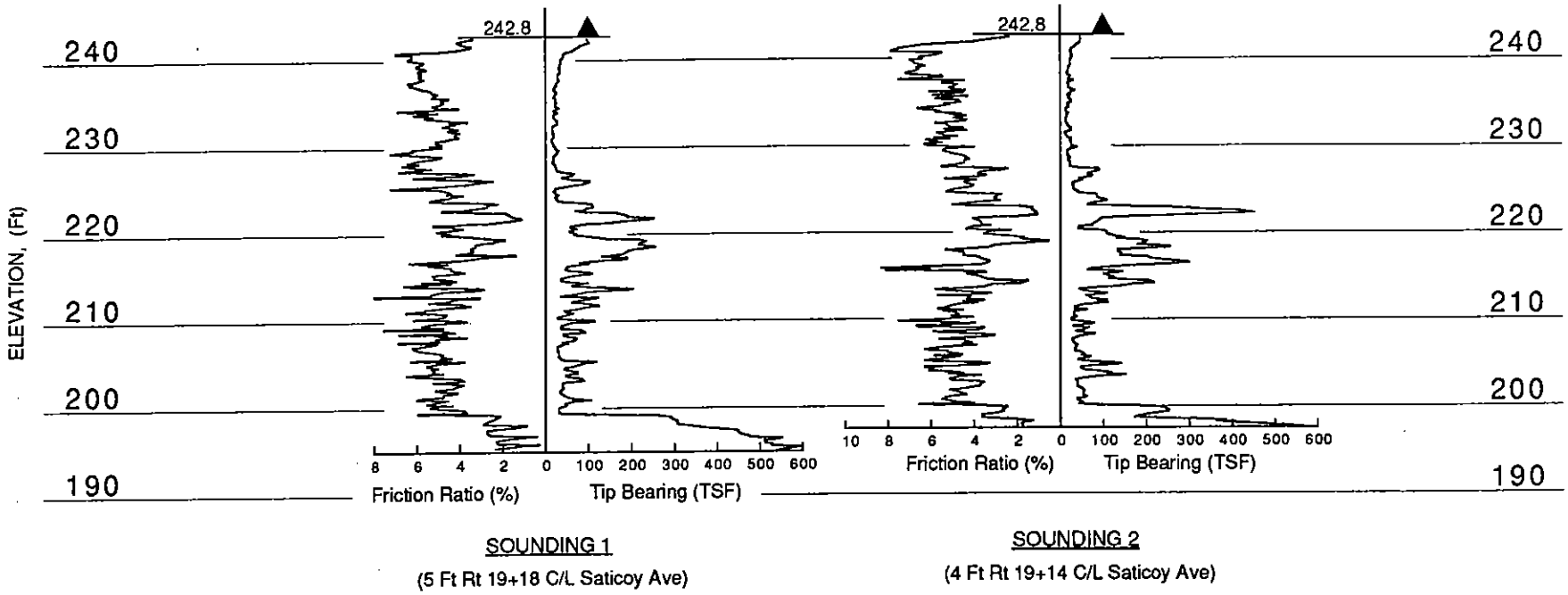
Victoria Avenue OC



Pile Load Test # 14

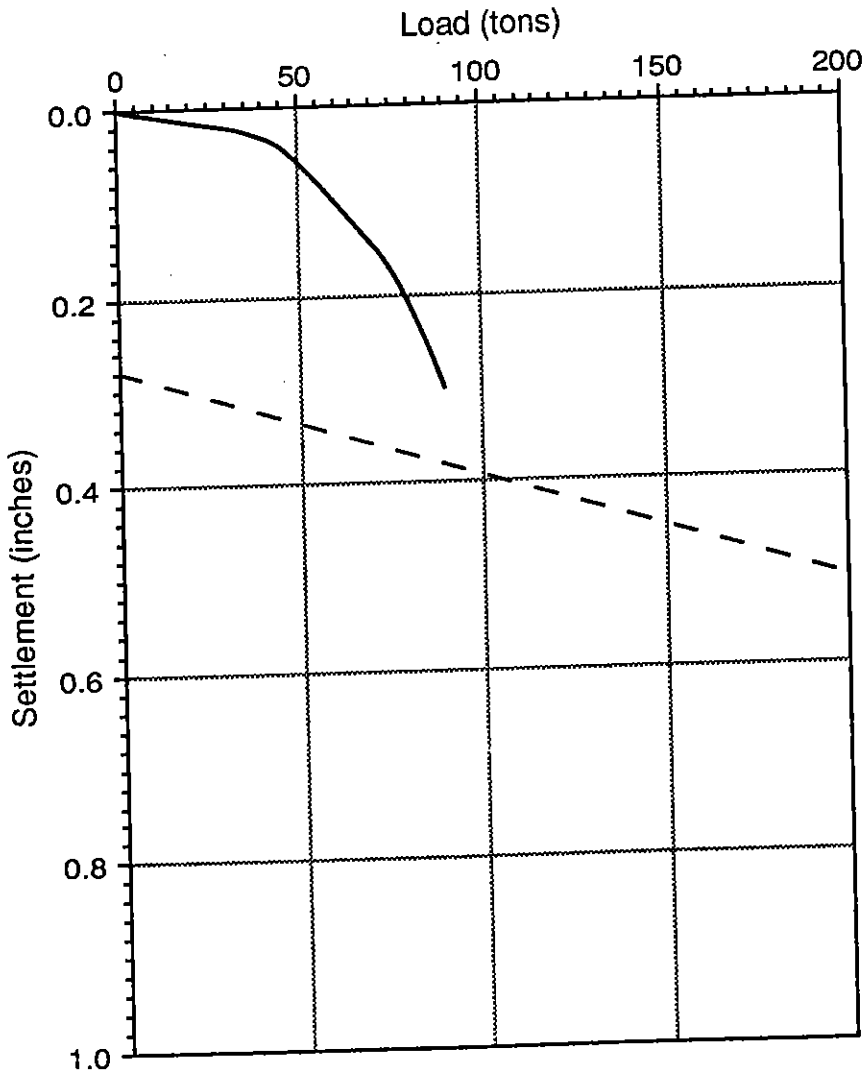
Project	:	Saticoy Avenue OC
Location	:	15 Ft Rt 19+18 C/L Saticoy Ave
Brdg No	:	52-229
Date	:	10/31/61
Pile Type	:	Bored
X Section	:	16 inch diameter
Ftg Elev	:	225.5 feet
Tip Elev	:	199.0 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -



Cone Penetrometer Test Data

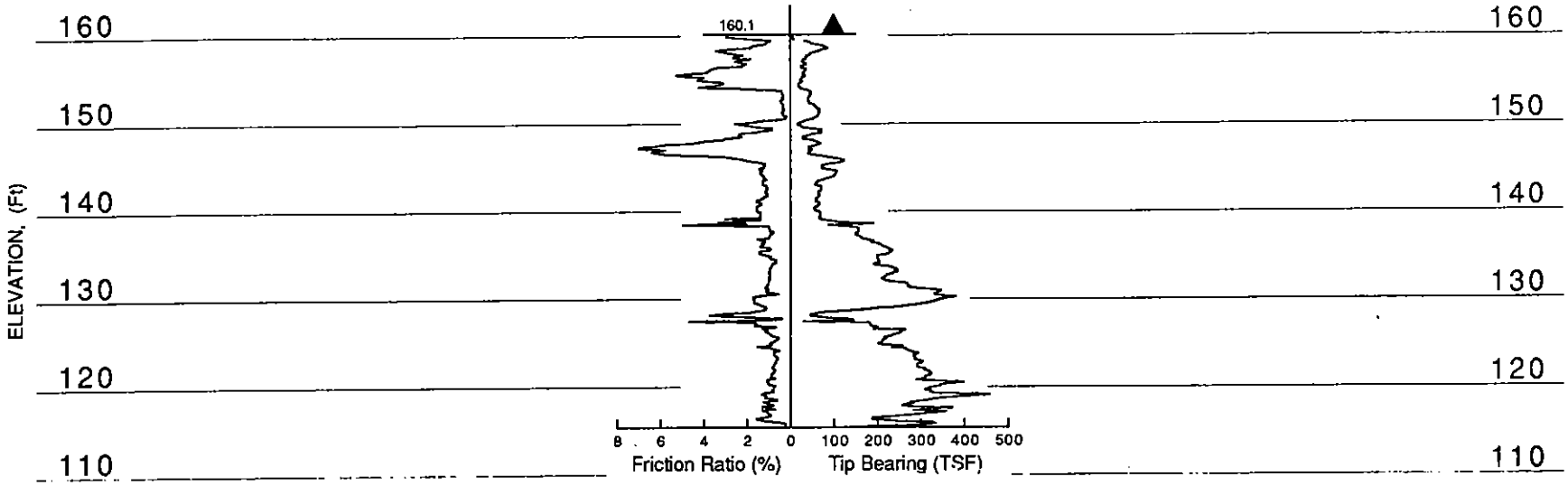
Saticoy Avenue OC



Pile Load Test # 15

Project	:	Jeffrey Road OC
Location	:	11 Ft Lt 10+90 C/L Jeffrey Rd
Brdg No	:	55-215
Date	:	4/16/57
Pile Type	:	Bored
X Section	:	15.5 inch diameter
Ftg Elev	:	155.0 feet
Tip Elev	:	119.9 feet

Displacement Under Load ——
Davisson Failure Criterion - - - - - -

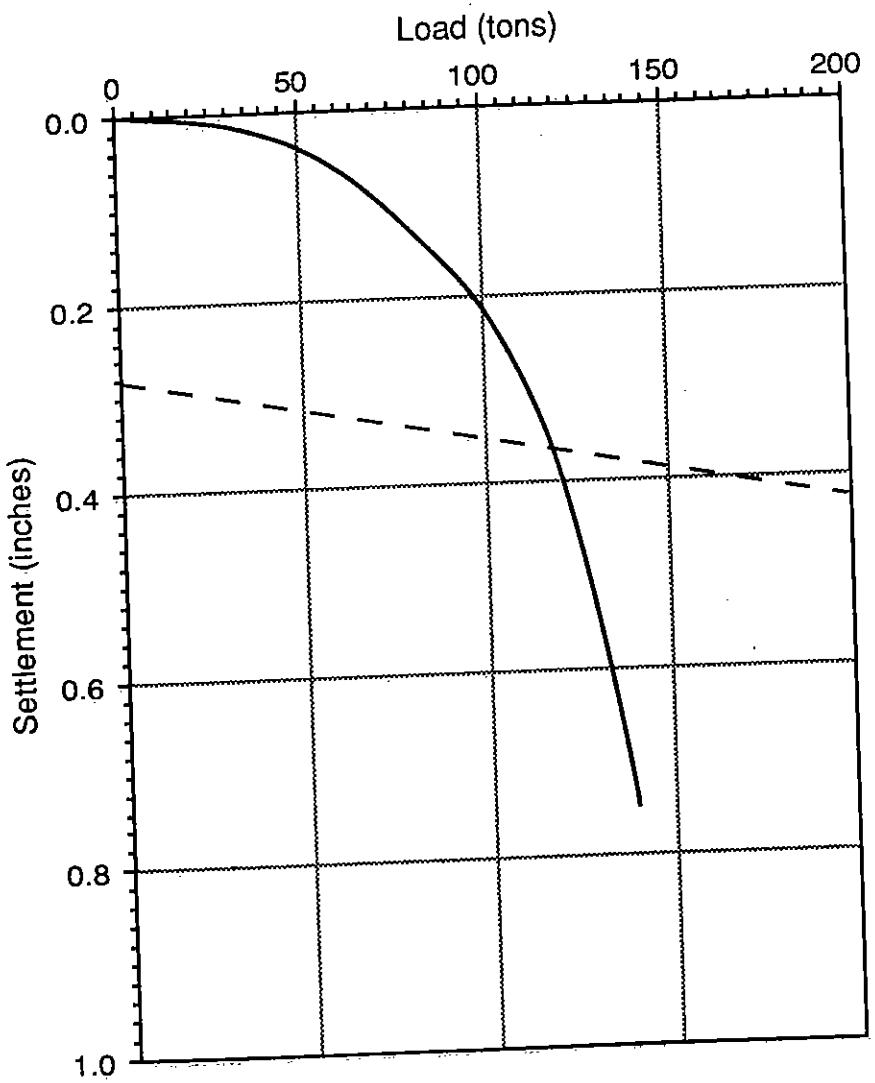


SOUNDING 1

(67 Ft Rt 10+90 C/L Jeffrey Rd)

Cone Penetrometer Test Data

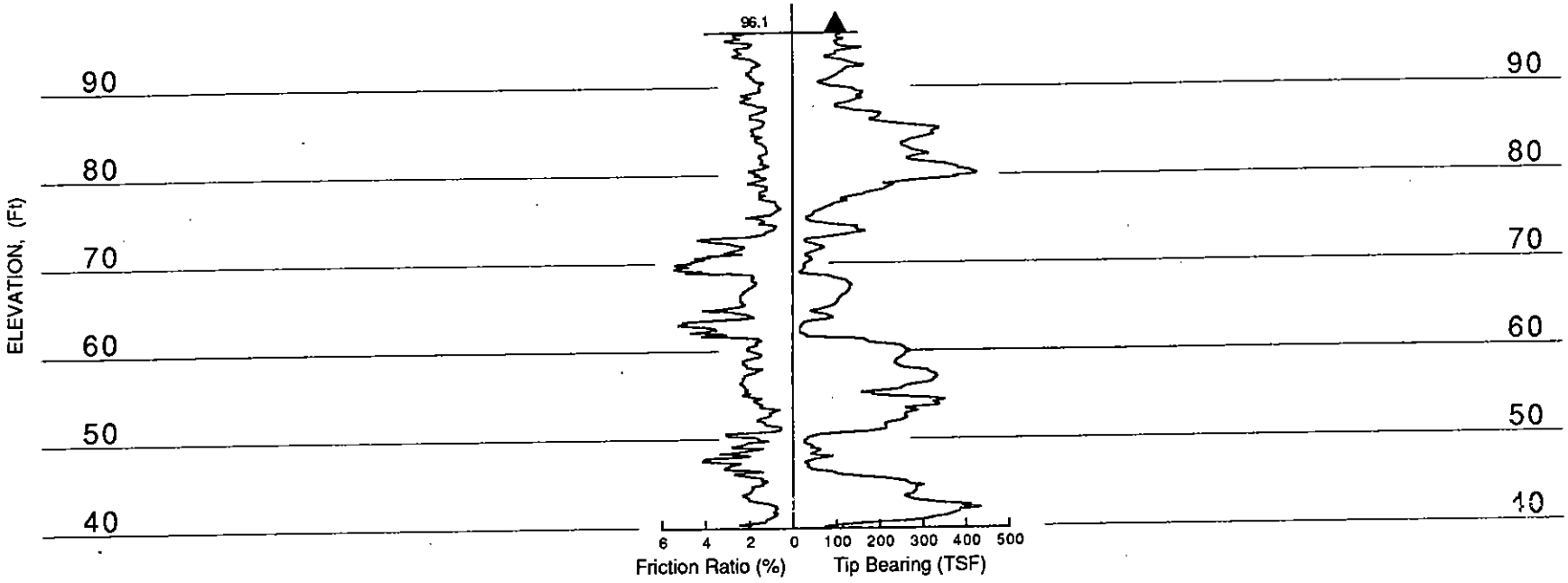
Jeffrey Road OC



Pile Load Test # 16

Project : 105/605 SW Connector OC, Bent 3
Location : 14 Ft Lt 279+13 S/L Conn 2
Brdg No : 53-2700G
Date : 11/8/88
Pile Type : Bored
X Section : 16 inch diameter
Ftg Elev : 75.5 feet
Tip Elev : 52.5 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -

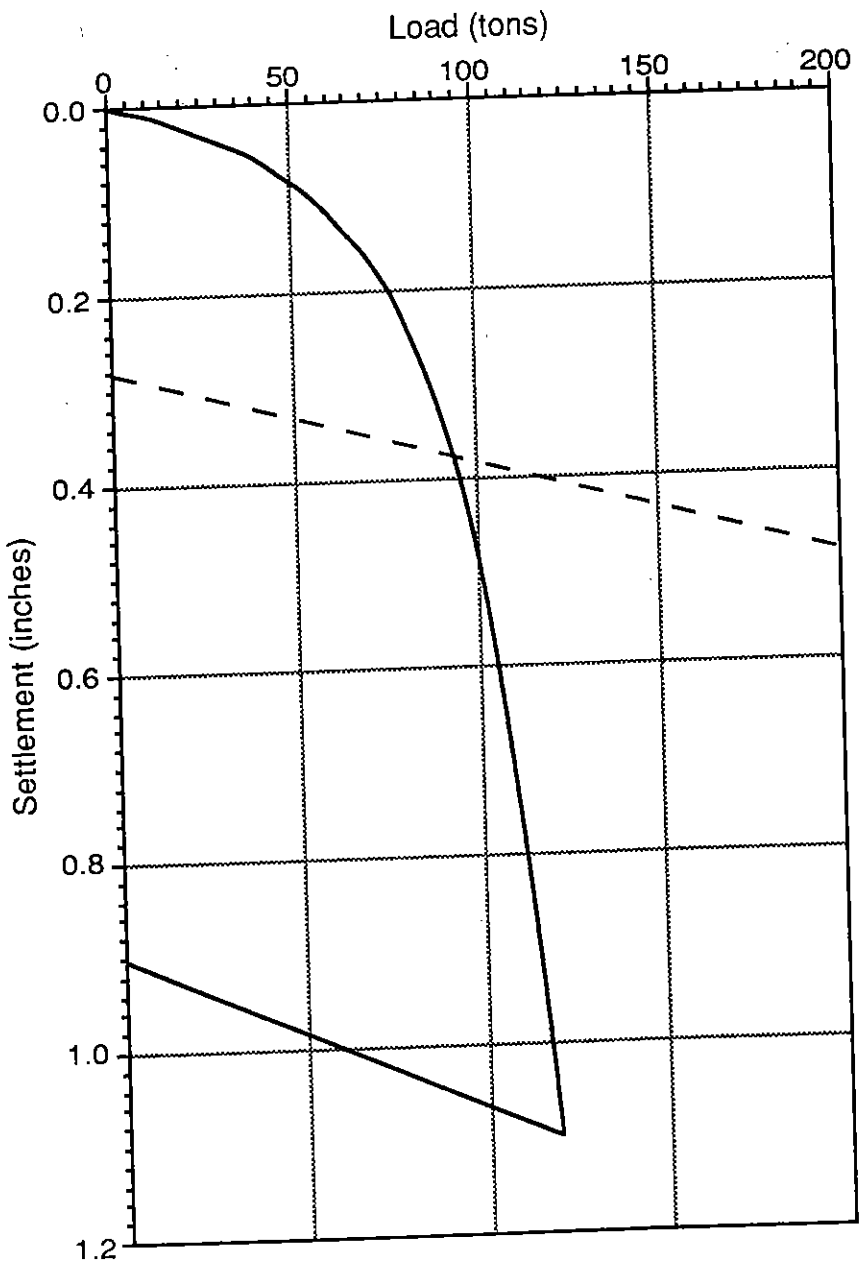


SOUNDING 1

(3 Ft Lt 279+29 S/L Conn 2)

Cone Penetrometer Test Data

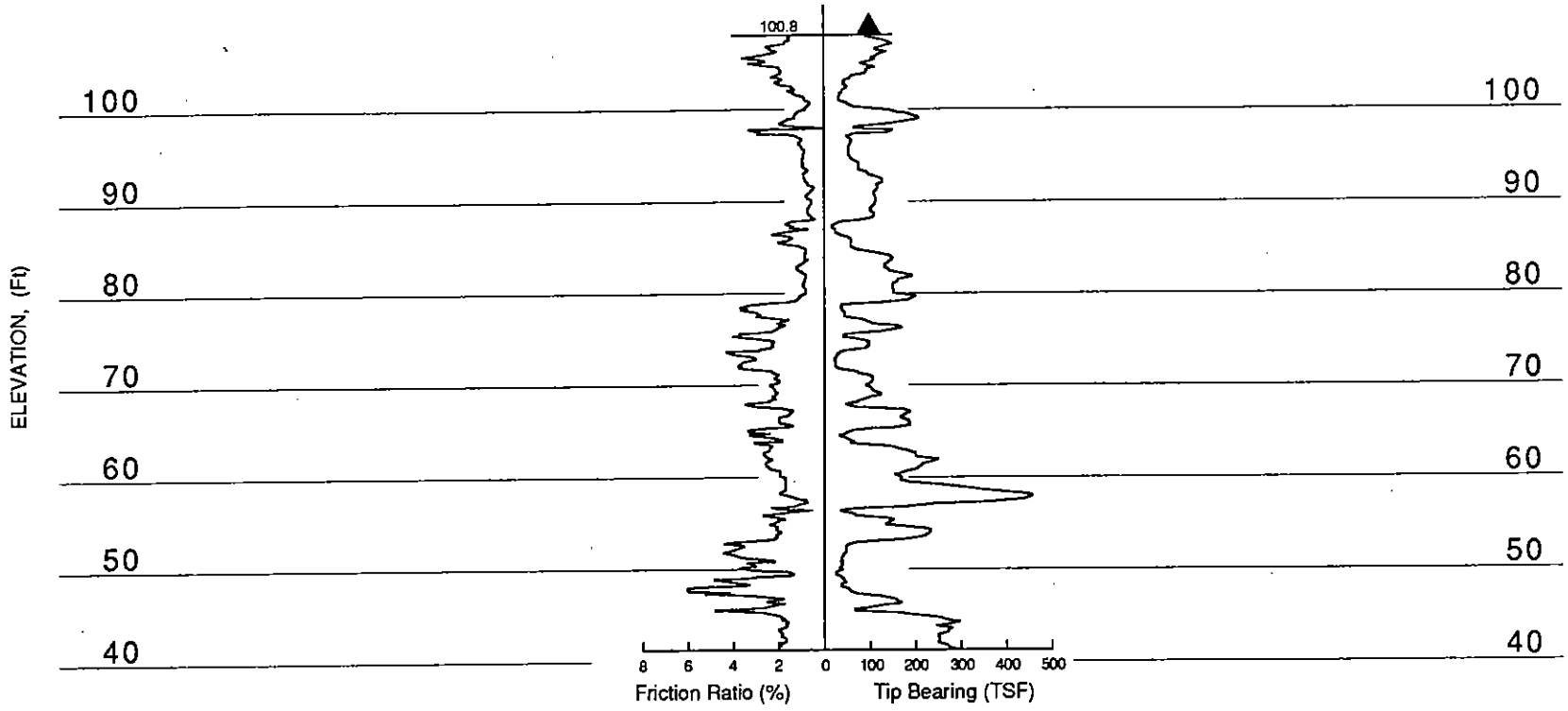
105/605 SW Connector OC, Bent 3



Pile Load Test # 17

Project : 105/605 SW Connector OC, Bent 9
Location : 14 Ft Lt 289+96 S/L Conn 2
Brdg No : 53-2700G
Date : 10/11/88
Pile Type : Bored
X Section : 16 inch diameter
Ftg Elev : 90.5 feet
Tip Elev : 56.5 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -

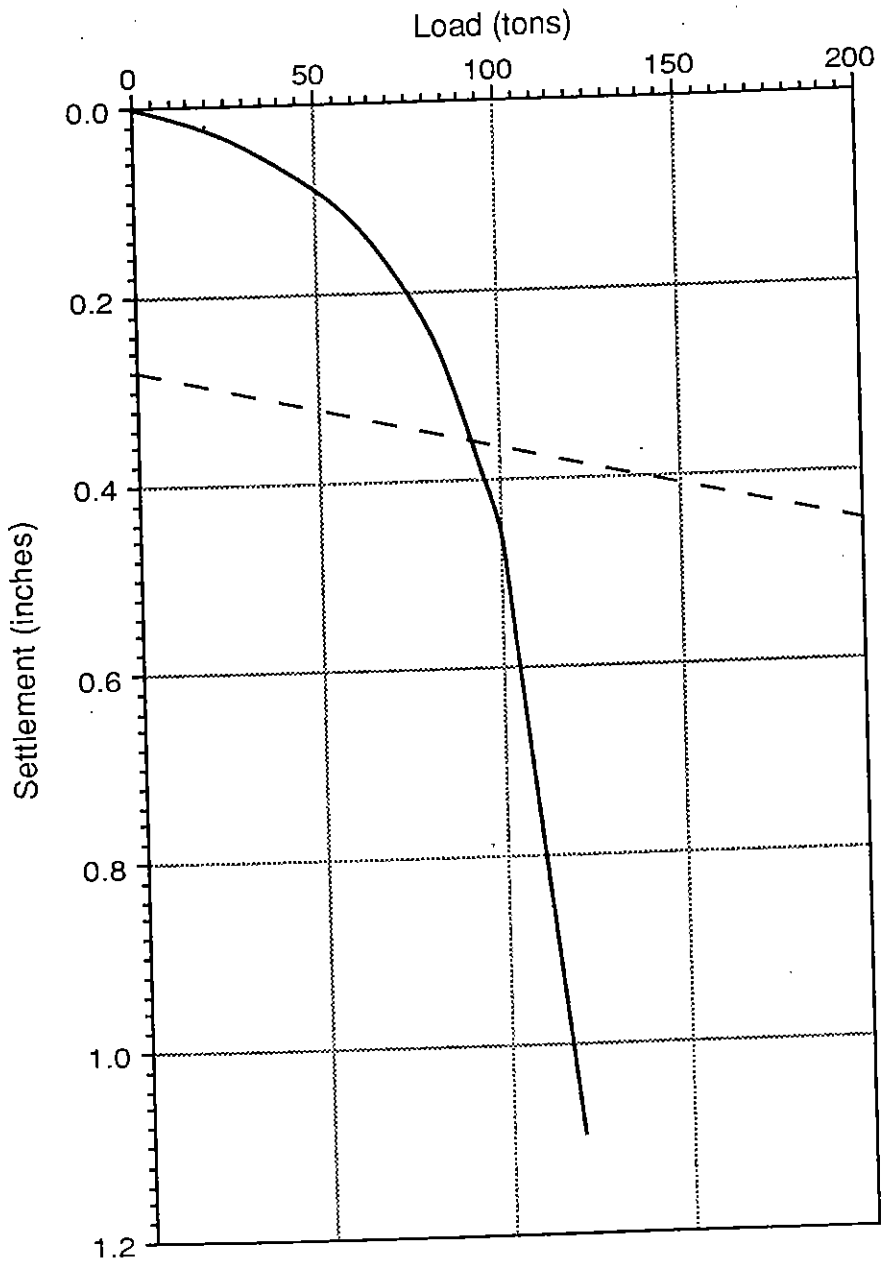


SOUNDING 2

(32 Ft Lt 290+00 S/L Conn 2)

Cone Penetrometer Test Data

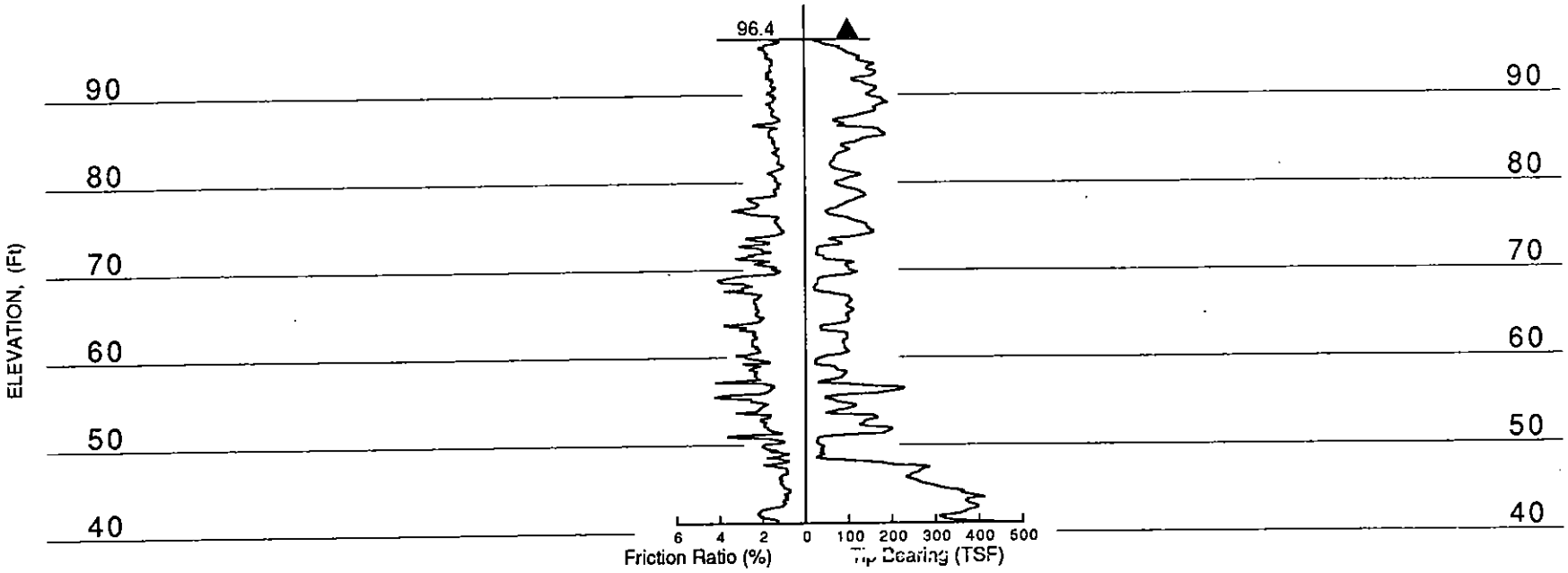
105/605 SW Connector OC, Bent 9



Pile Load Test # 18

Project : 105/605 NW Connector OC, Bent 5
Location : 14 Ft Rt 182+33 S/L Conn 1
Brdg No : 53-2702G
Date : 10/88
Pile Type : Bored
X Section : 16 inch diameter
Ftg Elev : 71.5 feet
Tip Elev : 43.8 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -

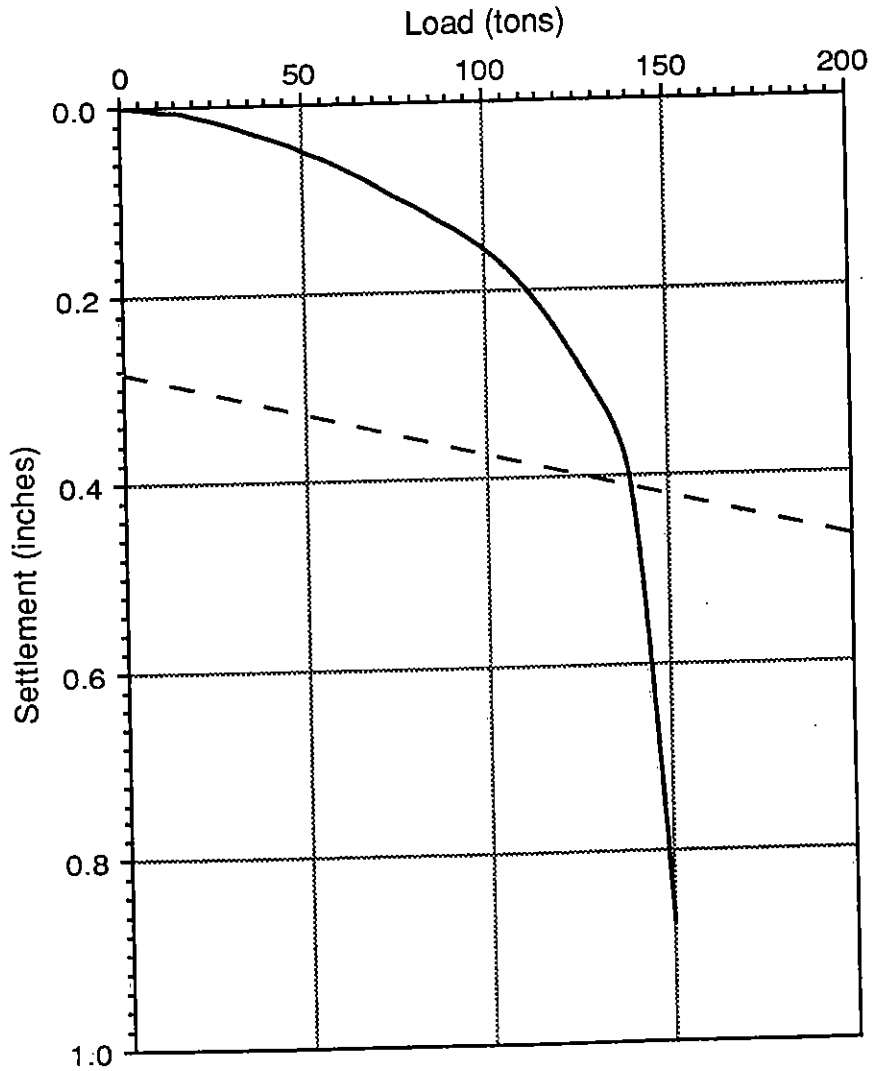


SOUNDING 1

(17 Ft Rt 182+14 S/L Conn 1)

Cone Penetrometer Test Data

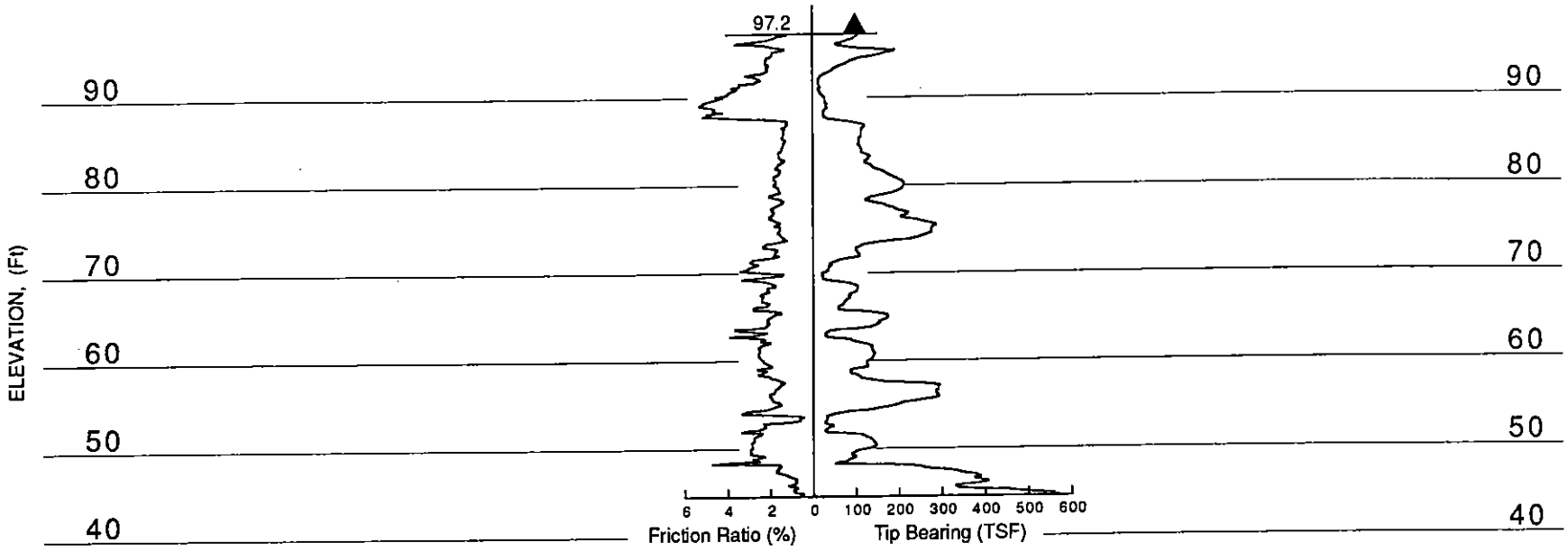
105/605 NW Connector OC, Bent 5



Pile Load Test # 19

Project : 105/605 NW Connector OC, Bent 10
Location : 14 Ft Rt 190+87 S/L Conn. 1
Brdg No : 53-2702G
Date : 10/88
Pile Type : Bored
X Section : 16 inch diameter
Ftg Elev : 89.5 feet
Tip Elev : 59.0 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -

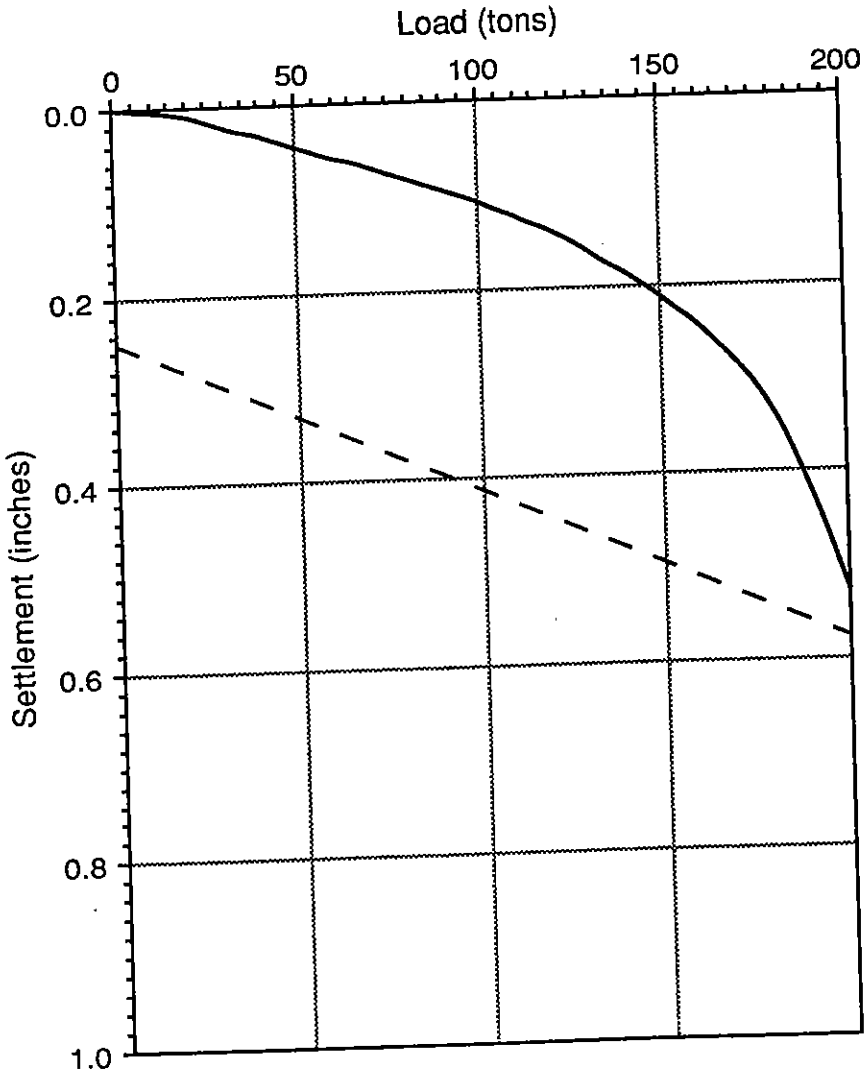


SOUNDING 2

(45 Ft Rt 190+95 S/L Conn 1)

Cone Penetrometer Test Data

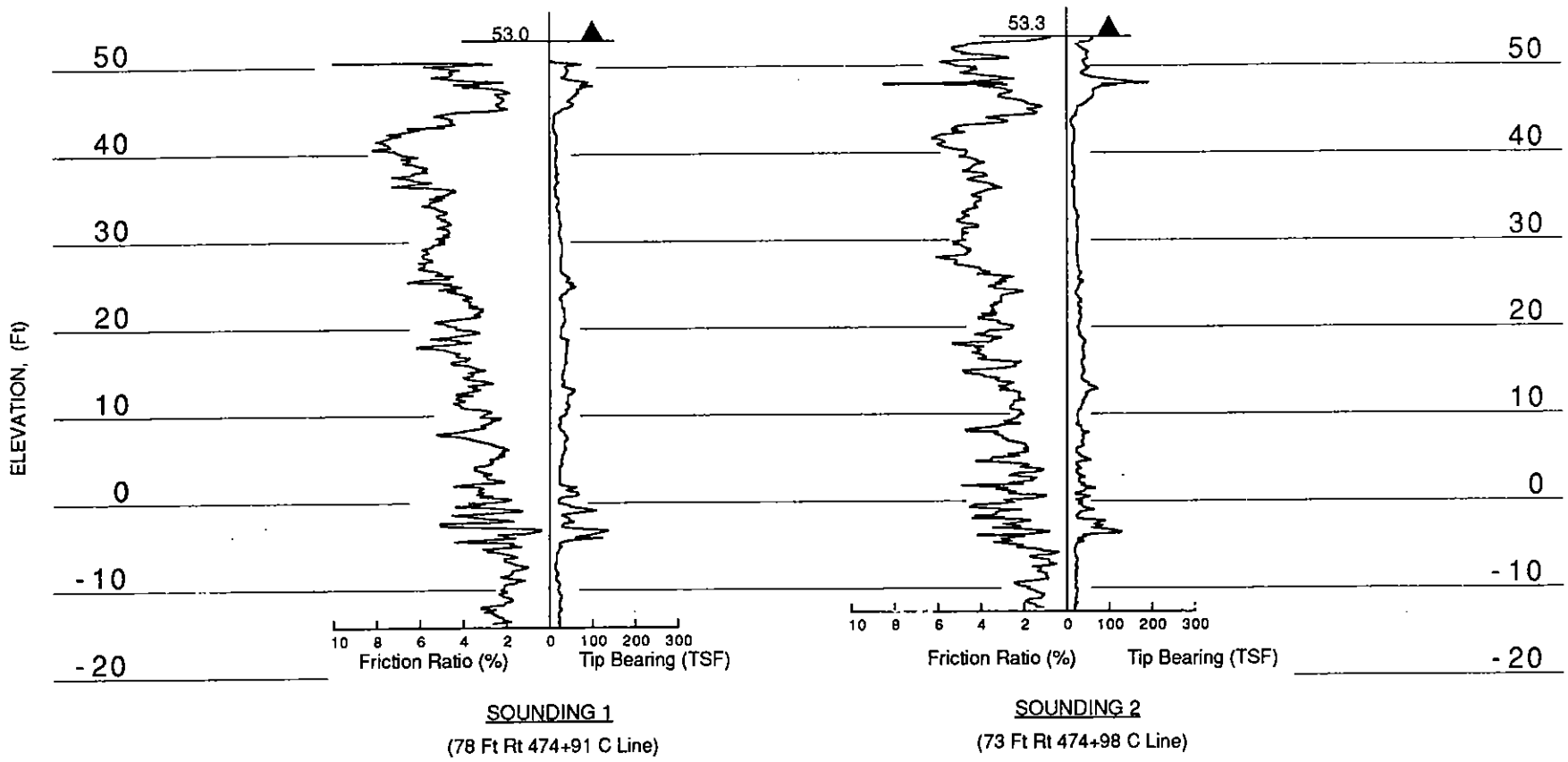
105/605 NW Connector OC, Bent 10



Pile Load Test # 20

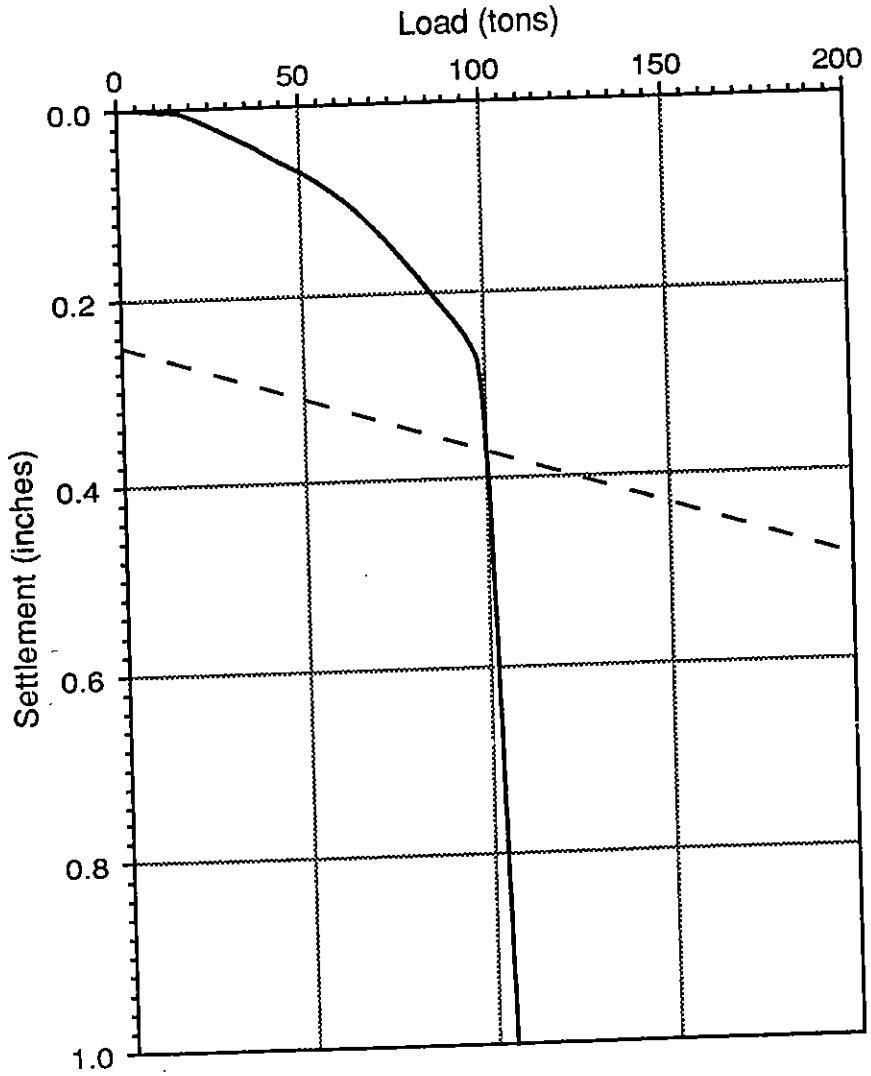
Project : Mullen Overhead
Location : 62 Ft Rt 474+86 C Line
Brdg No : 22-62R
Date : 12/6/88
Pile Type : Driven P/S concrete
X Section : 12 inch square
Ftg Elev : 48.3 feet
Tip Elev : -1.0 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -



Cone Penetrometer Test Data

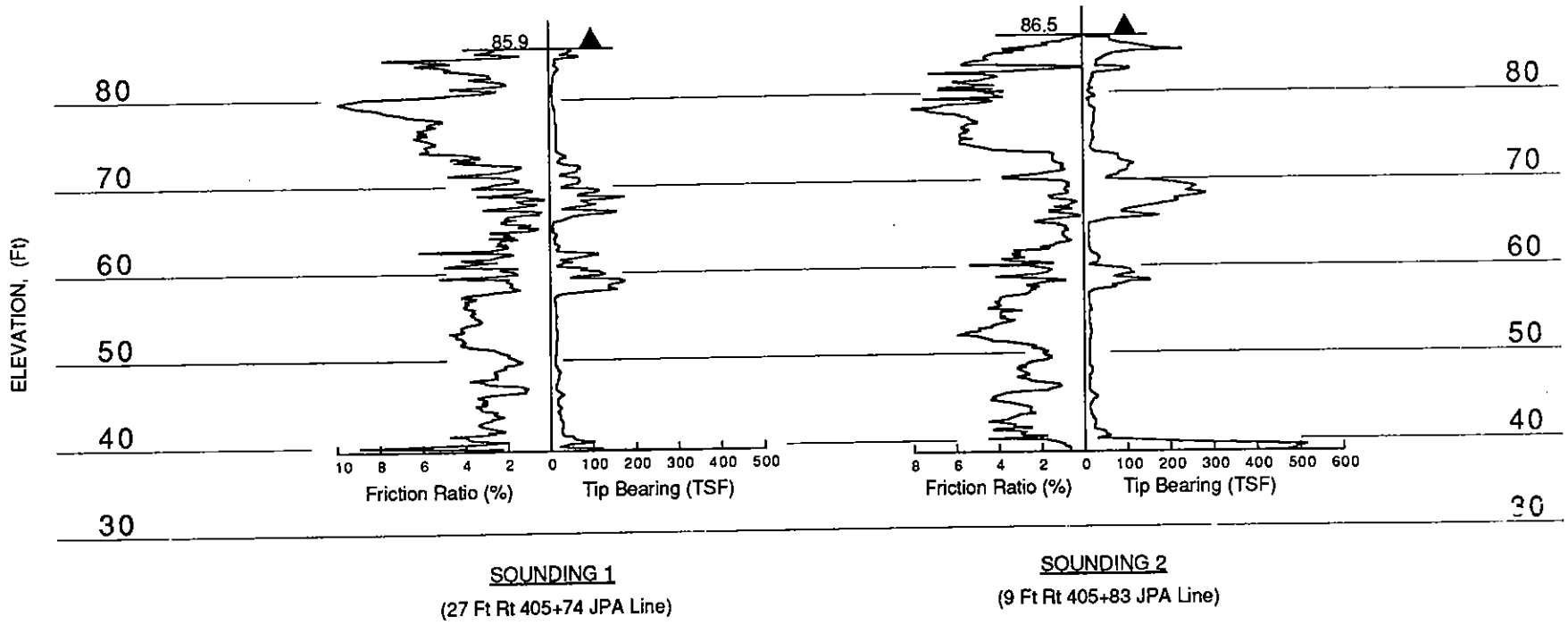
Mullen Overhead



Pile Load Test # 21

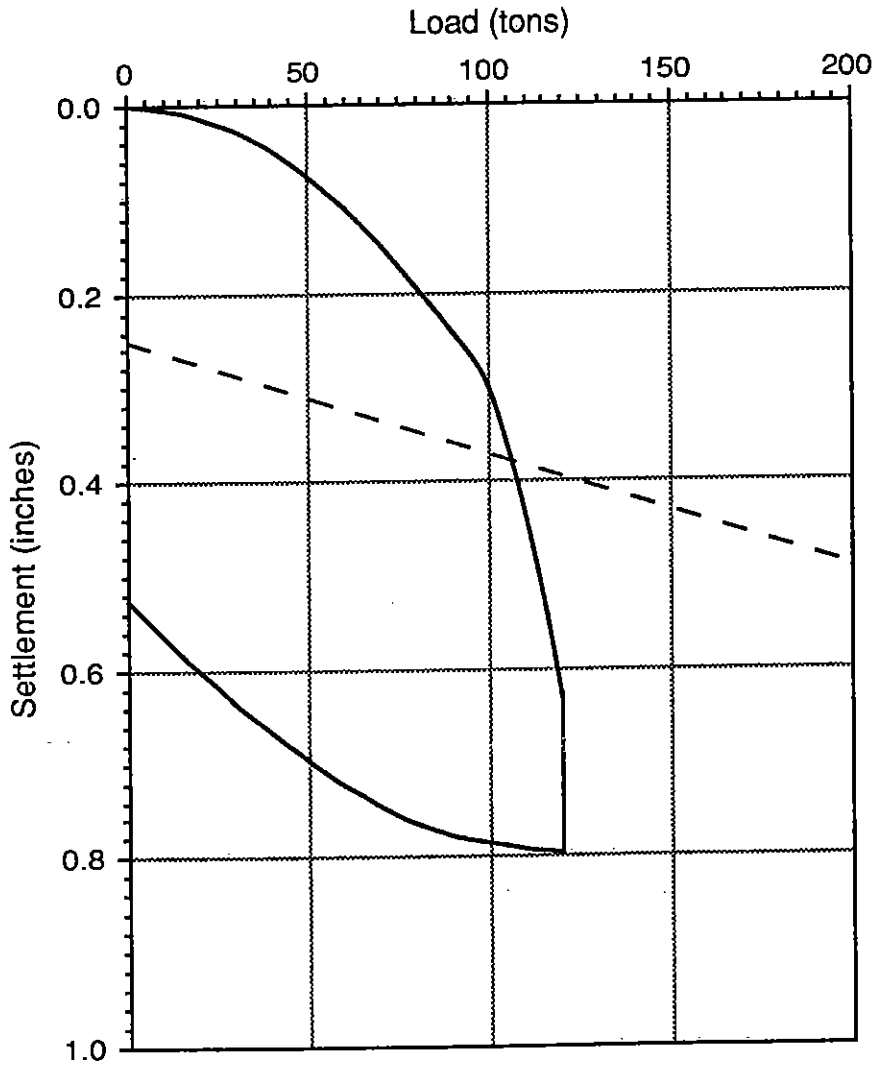
Project	:	Guadalupe Connector Viaduct
Location	:	33.5 Ft Rt 405+58 JPA Line
Brdg No	:	37-410H
Date	:	12/9/85
Pile Type	:	Driven P/S Concrete
X Section	:	12 inch square
Ftg Elev	:	78.2 feet
Tip Elev	:	41.7 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -



Cone Penetrometer Test Data

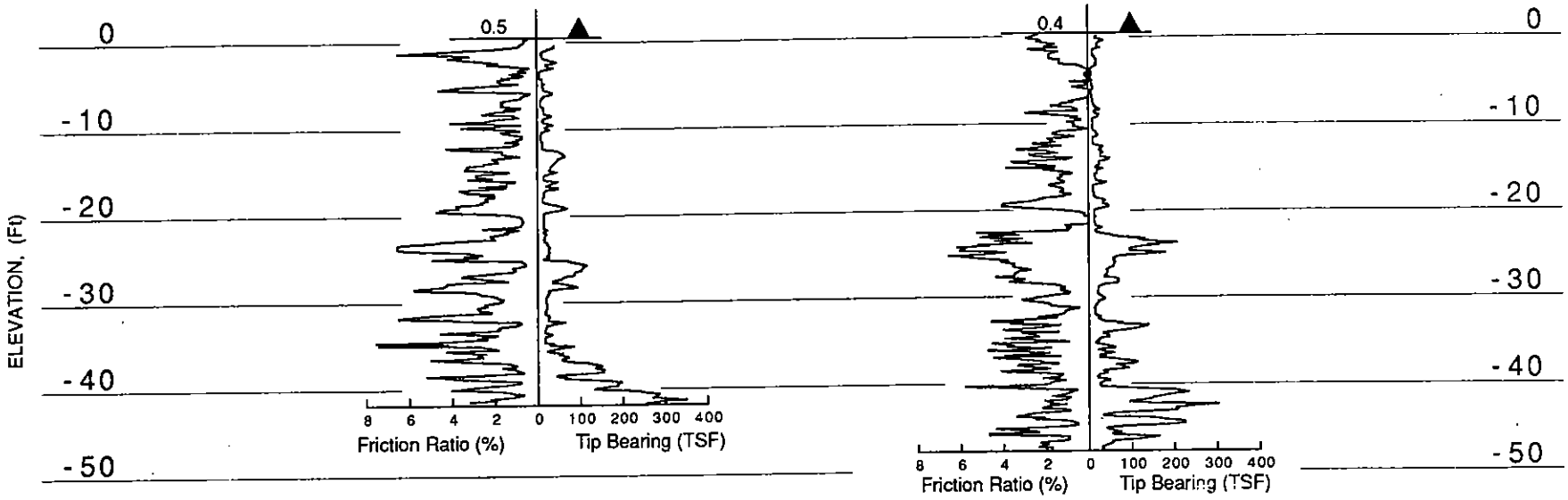
Guadalupe Connector Viaduct



Pile Load Test # 22

Project	:	Garden Street UC
Location	:	4 Ft Lt 20+04 C/L Garden St
Brdg No	:	51-273 R/L
Date	:	1/10/89
Pile Type	:	Driven P/S Concrete
X Section	:	12 inch square
Casing Elev	:	-10.0 feet
Tip Elev	:	-35.0 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -

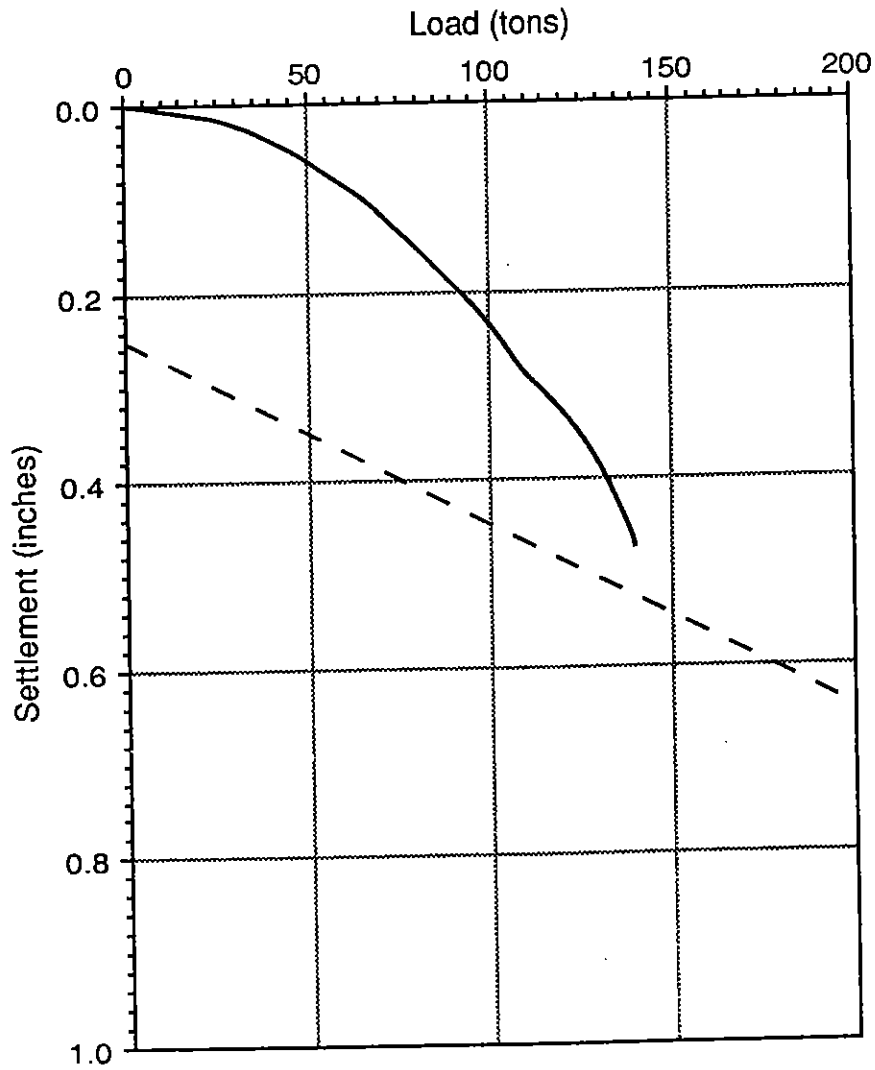


SOUNDING 1
(12 Ft Lt 19+96 C/L Garden St)

SOUNDING 2
(5 Ft Rt 19+96 C/L Garden St)

Cone Penetrometer Test Data

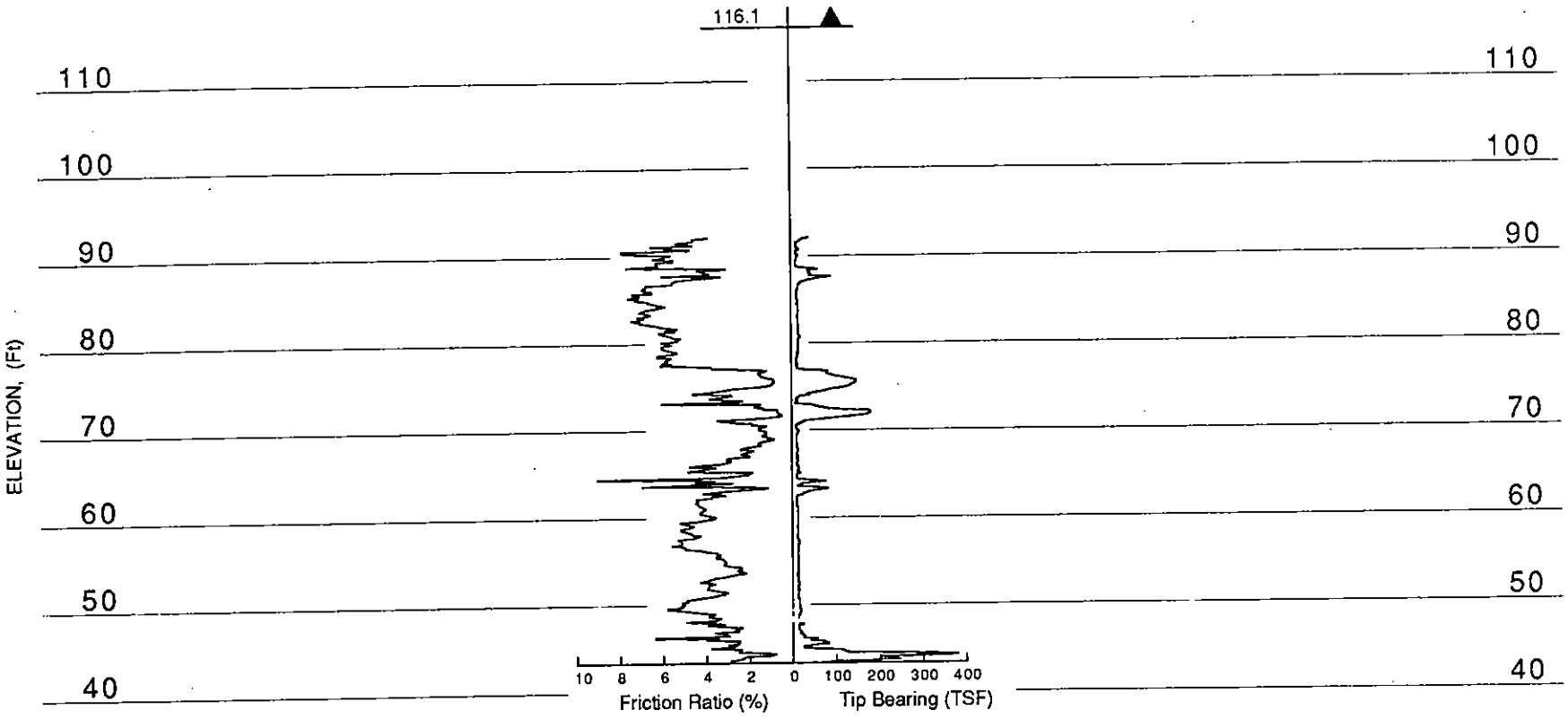
Garden Street UC



Pile Load Test # 23

Project	:	Park Avenue UC
Location	:	9 Ft Rt 405+58 G3 Line
Brdg No	:	37-310
Date	:	3/7/77
Pile Type	:	Driven P/S Concrete
X Section	:	12 inch square
Ftg Elev	:	104.0 feet
Predrill Elev	:	90.0 feet
Tip Elev	:	44.0 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -

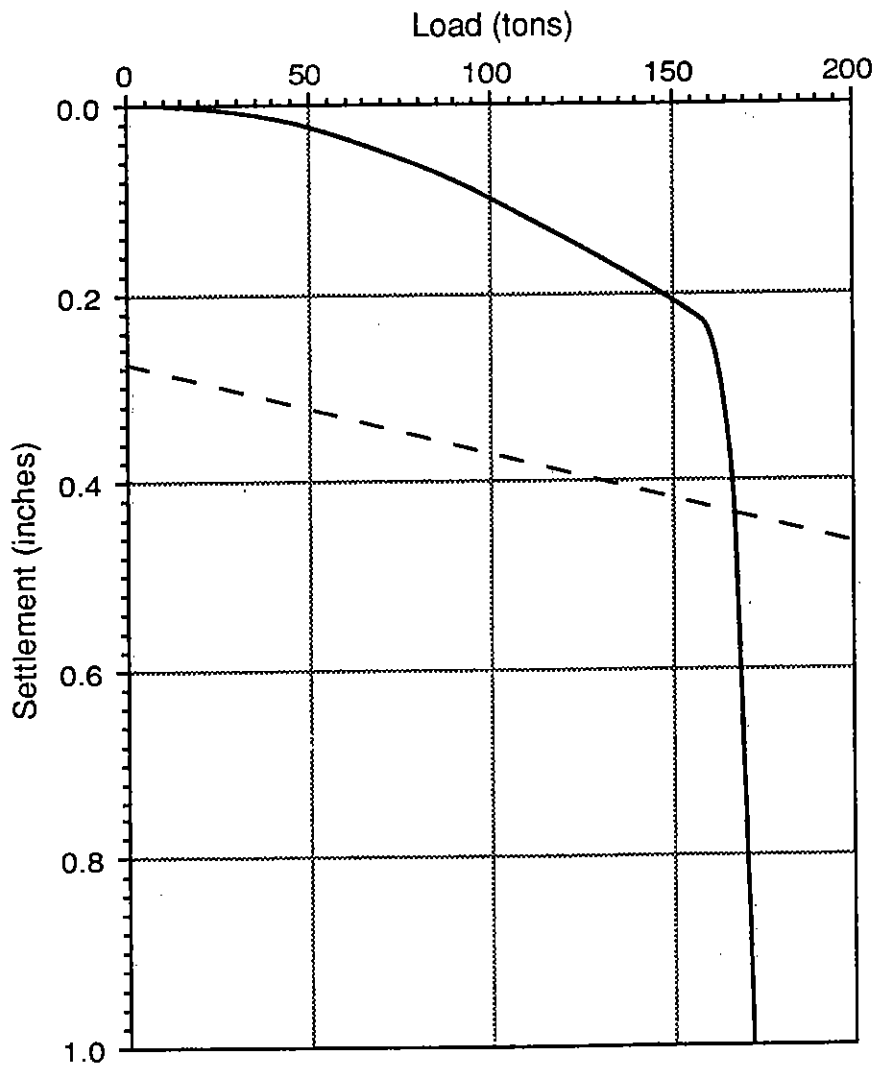


SOUNDING 1

(C/L 405+89 G3 Line)

Cone Penetrometer Test Data

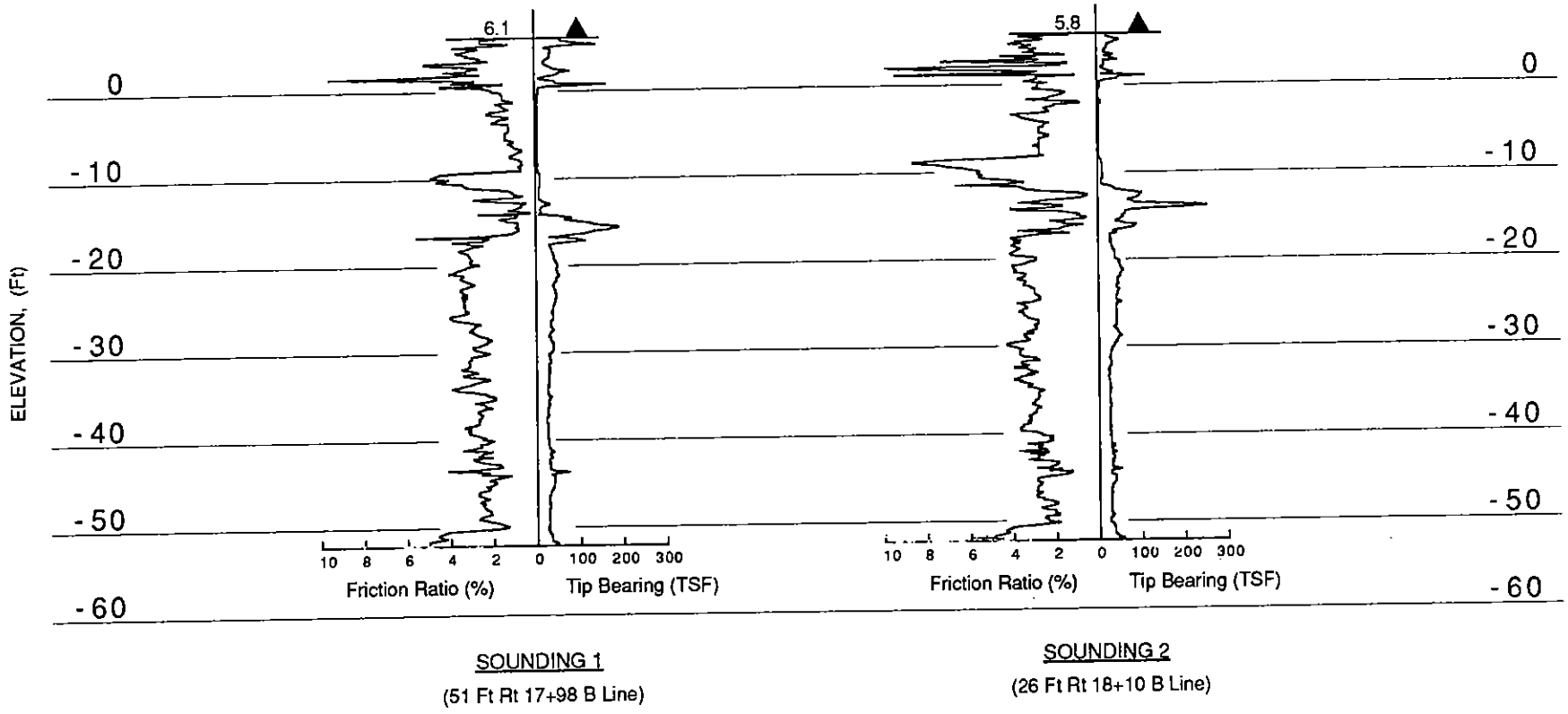
Park Avenue UC



Pile Load Test # 24

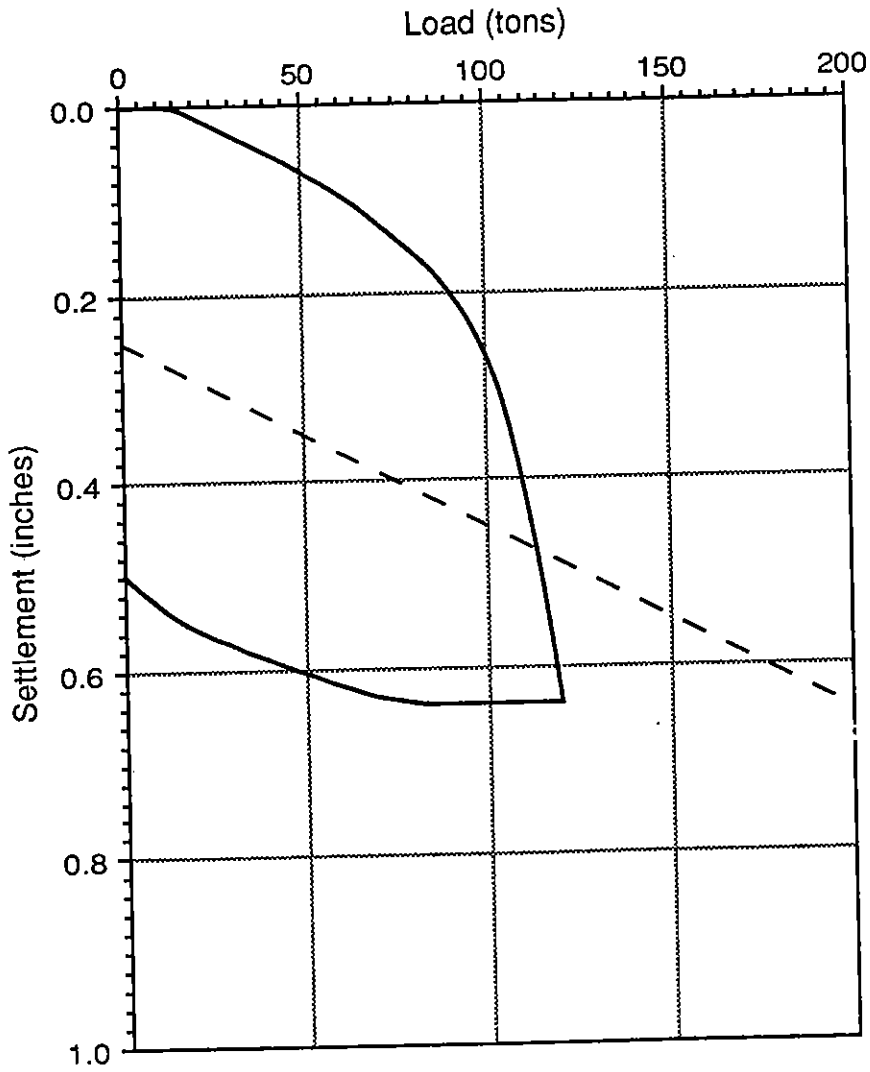
Project	:	Bayview Avenue OC
Location	:	33 Ft Rt 17+98 B Line
Brdg No	:	28-271
Date	:	2/27/85
Pile Type	:	Driven P/S Concrete
X Section	:	15 inch octagonal
Ftg Elev	:	0.0 feet
Tip Elev	:	-38.0 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -



Cone Penetrometer Test Data

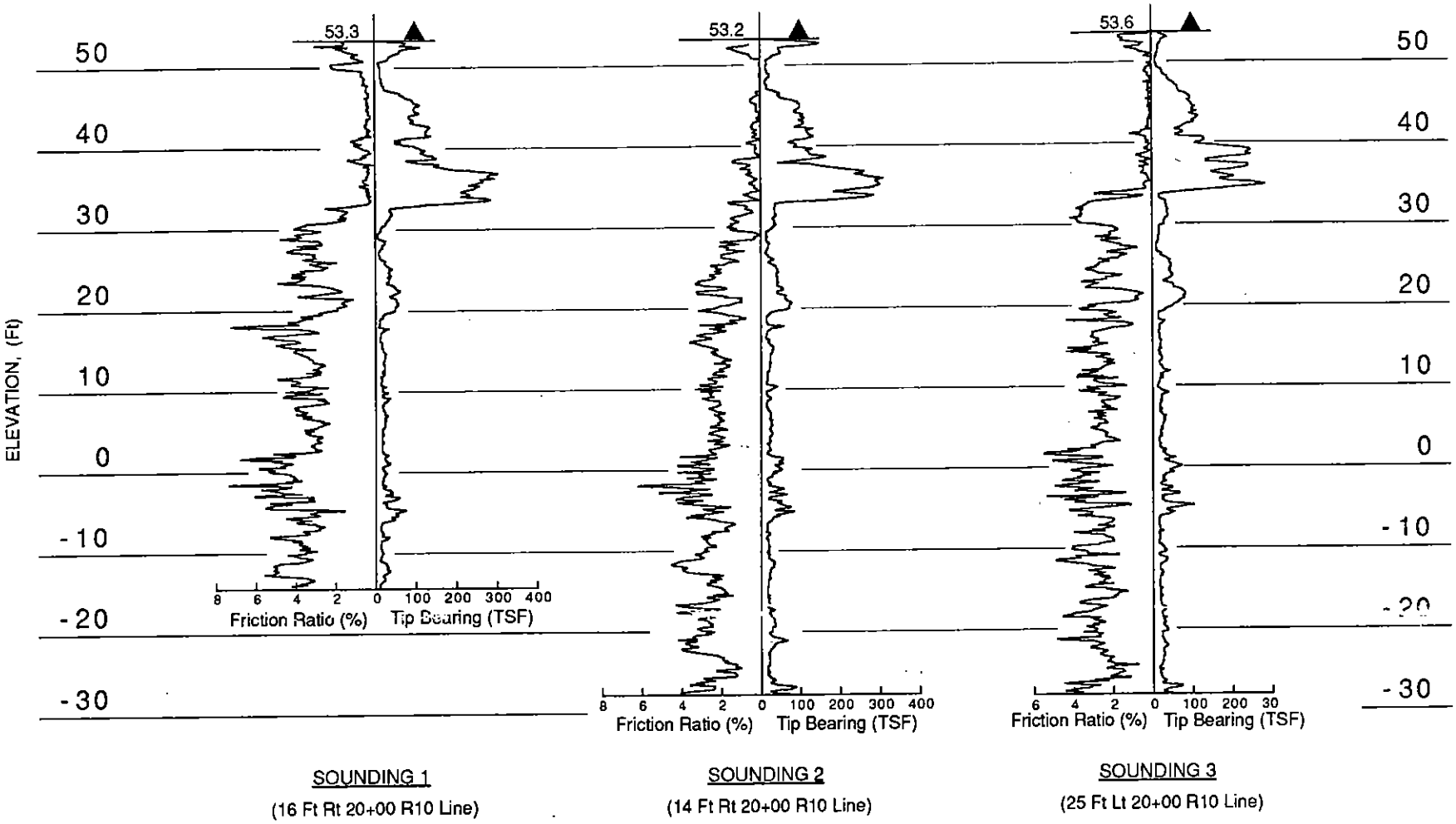
Bay View Avenue OC



Pile Load Test # 25

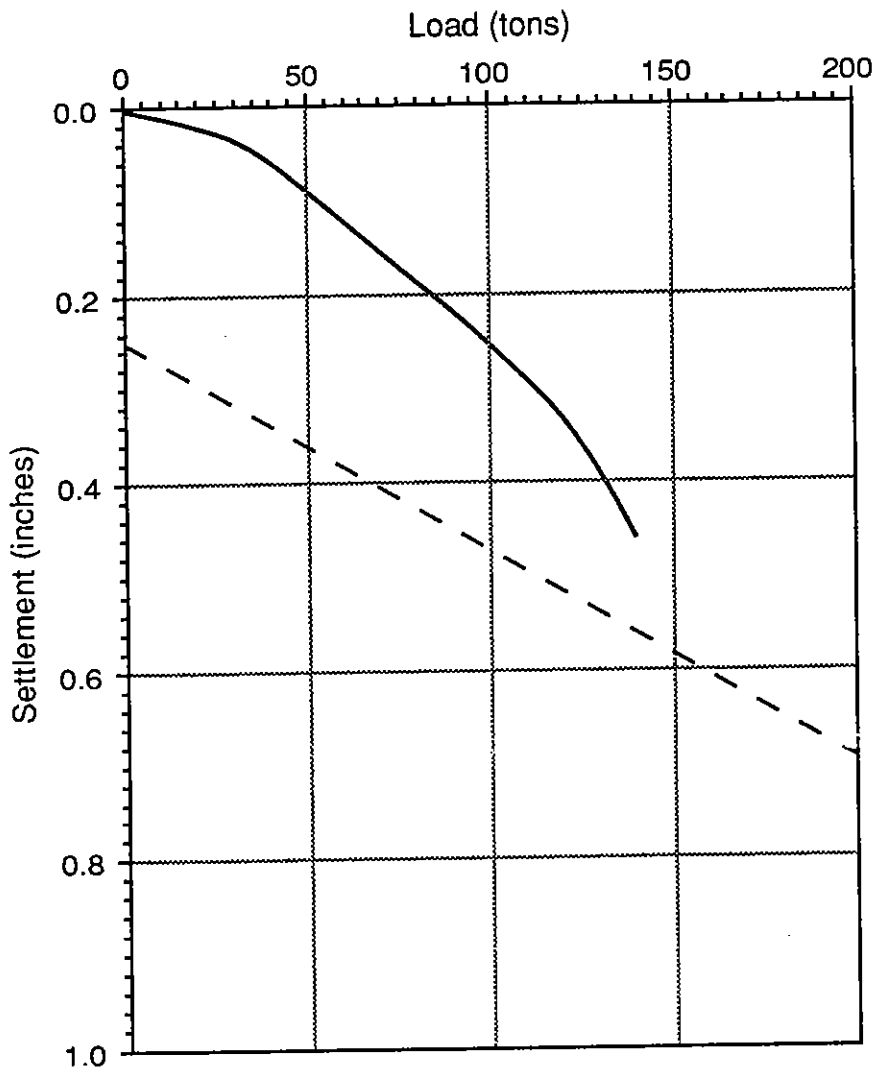
Project : East Gum Avenue
Location : 16 Ft Rt 20+00 R10 Line
Brdg No : 22-192
Date : 8/9/89
Pile Type : Driven P/S Concrete
X Section : 12 inch square
Ftg Elev : 52.0 feet
Tip Elev : -9.0 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -



Cone Penetrometer Test Data

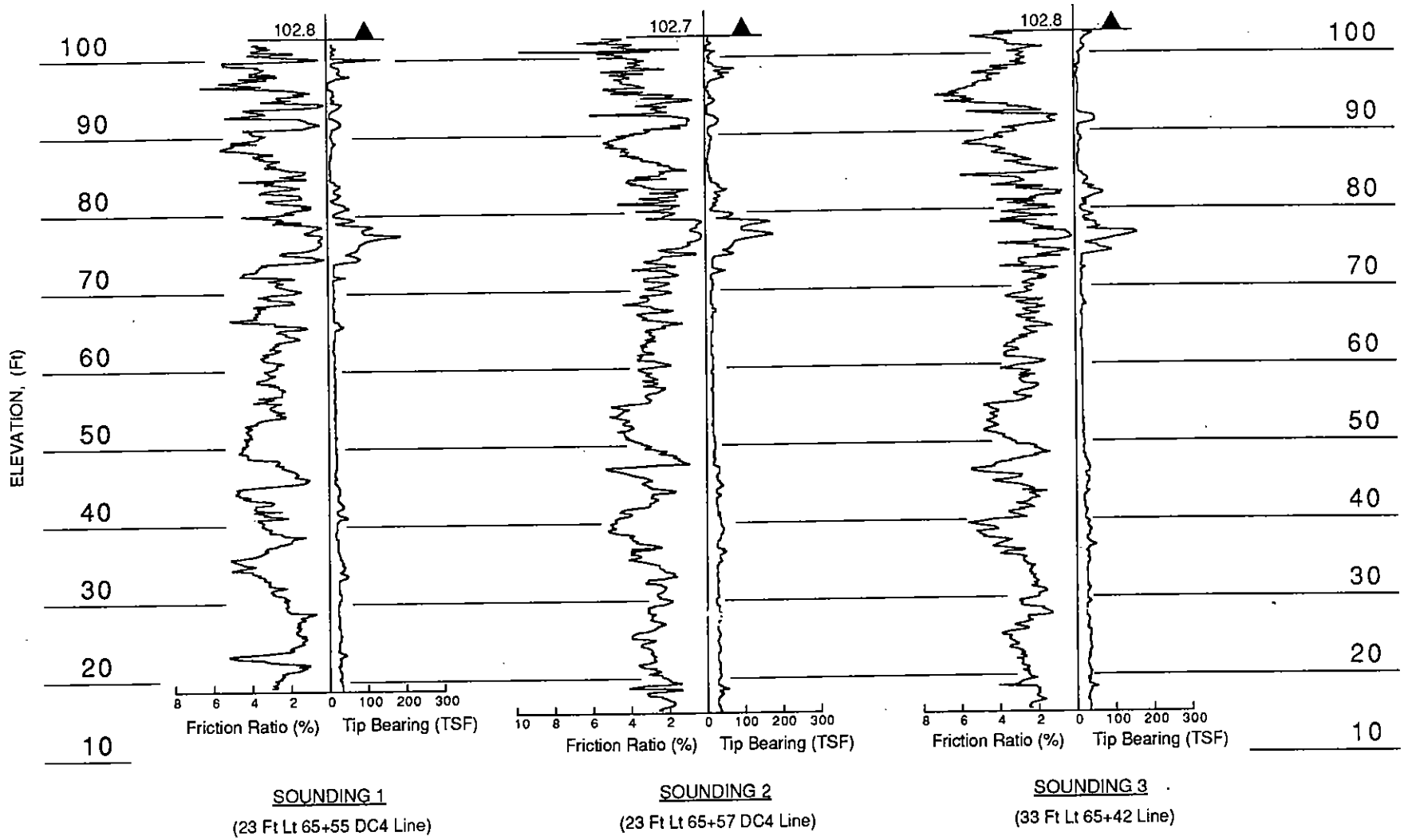
East Gum Avenue



Pile Load Test # 26

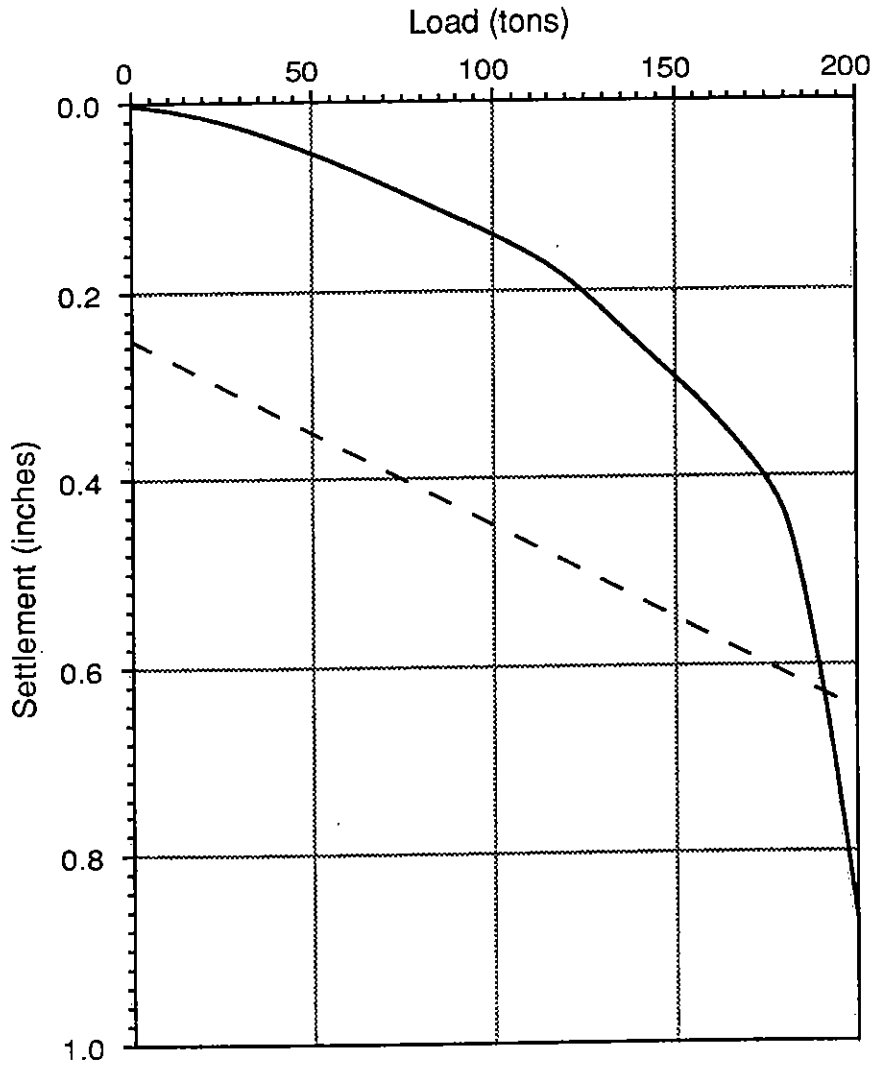
Project	:	101/280/680 SW Connector OC
Location	:	32 Ft Lt 65+62 DC4 Line
Brdg No	:	37-353
Date	:	7/9/80
Pile Type	:	Driven P/S Concrete
X Section	:	12 inch square
Ftg Elev	:	94.5 feet
Tip Elev	:	27.0 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -



Cone Penetrometer Test Data

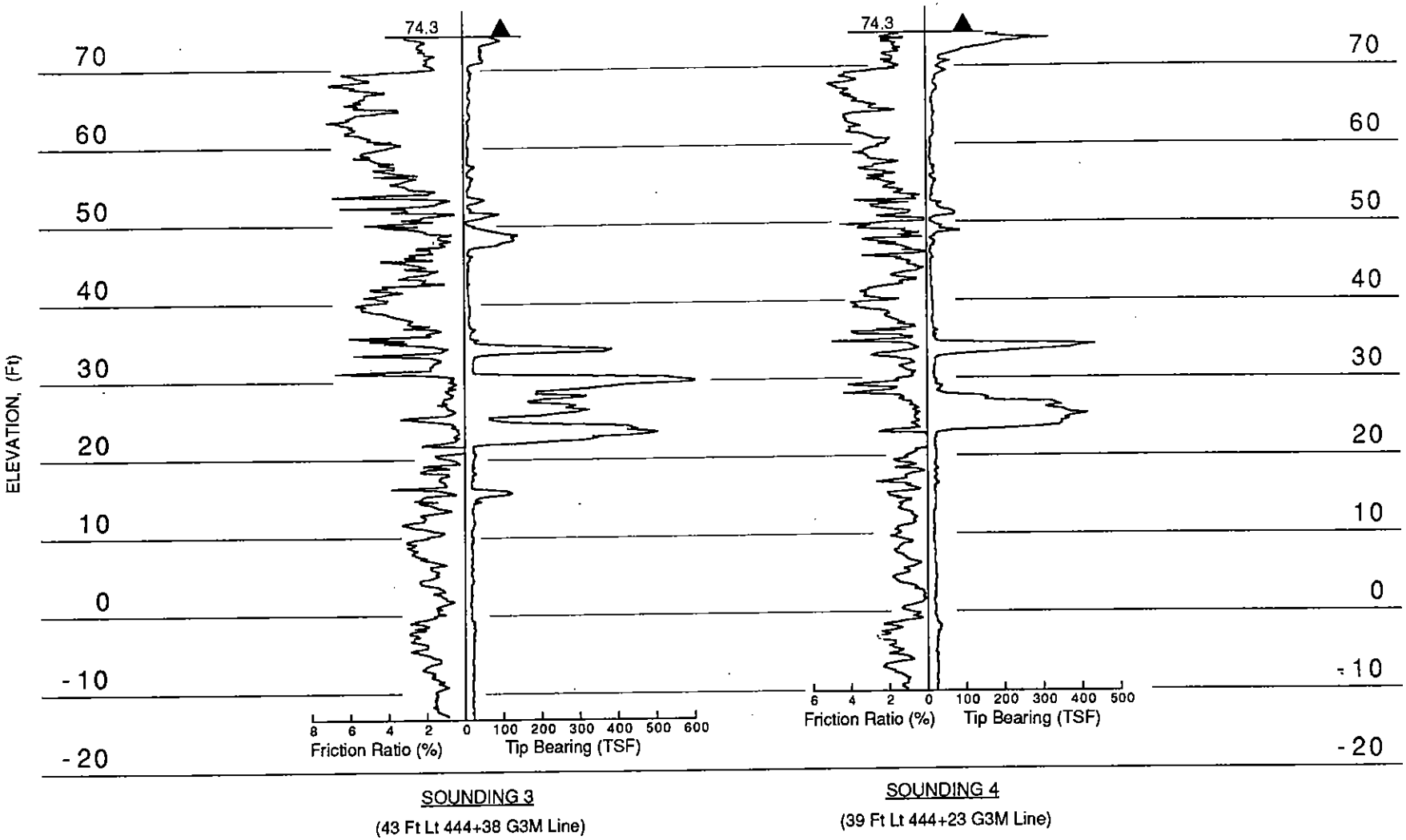
101/280/680 SW Connector OC



Pile Load Test # 27

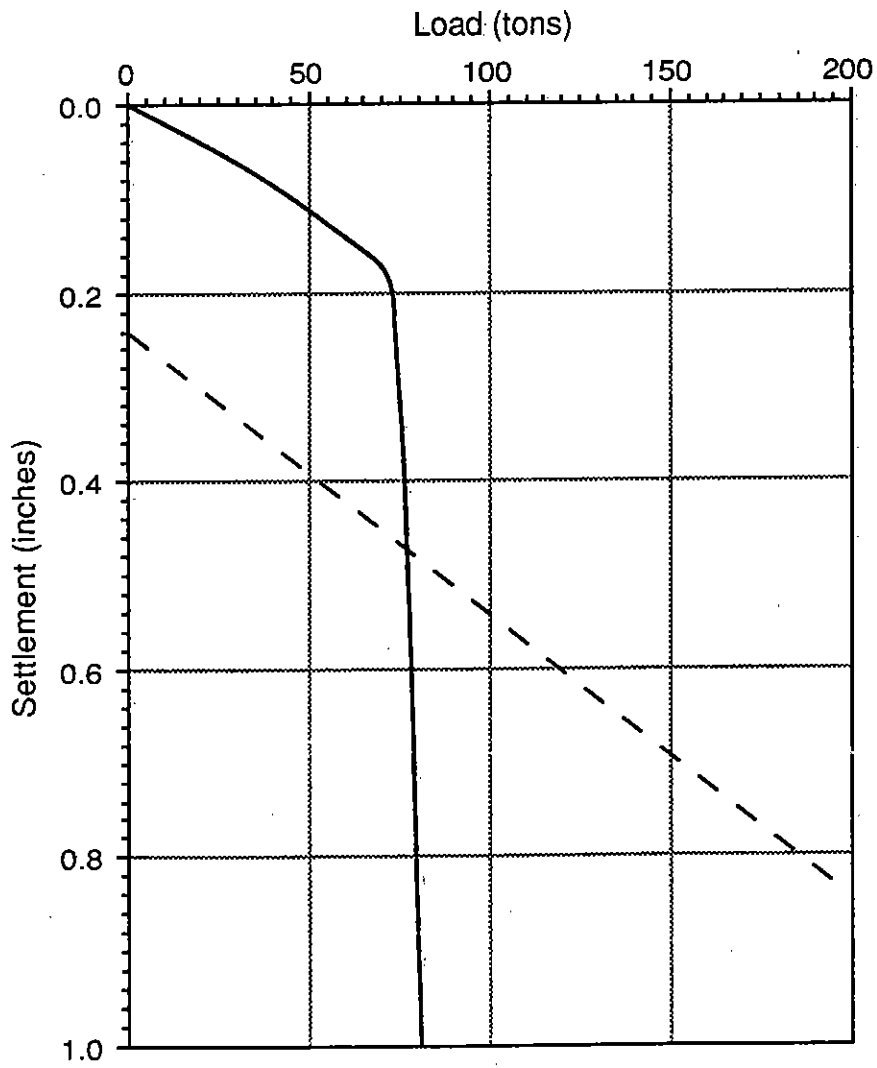
Project	:	Basset Street OH
Location	:	47 Ft Lt 444+23 G3M Line
Brdg No	:	37-11
Date	:	11/4/85
Pile Type	:	Driven P/S Concrete
X Section	:	12 inch square
Ftg Elev	:	68.0 feet
Tip Elev	:	7.6 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -



Cone Penetrometer Test Data

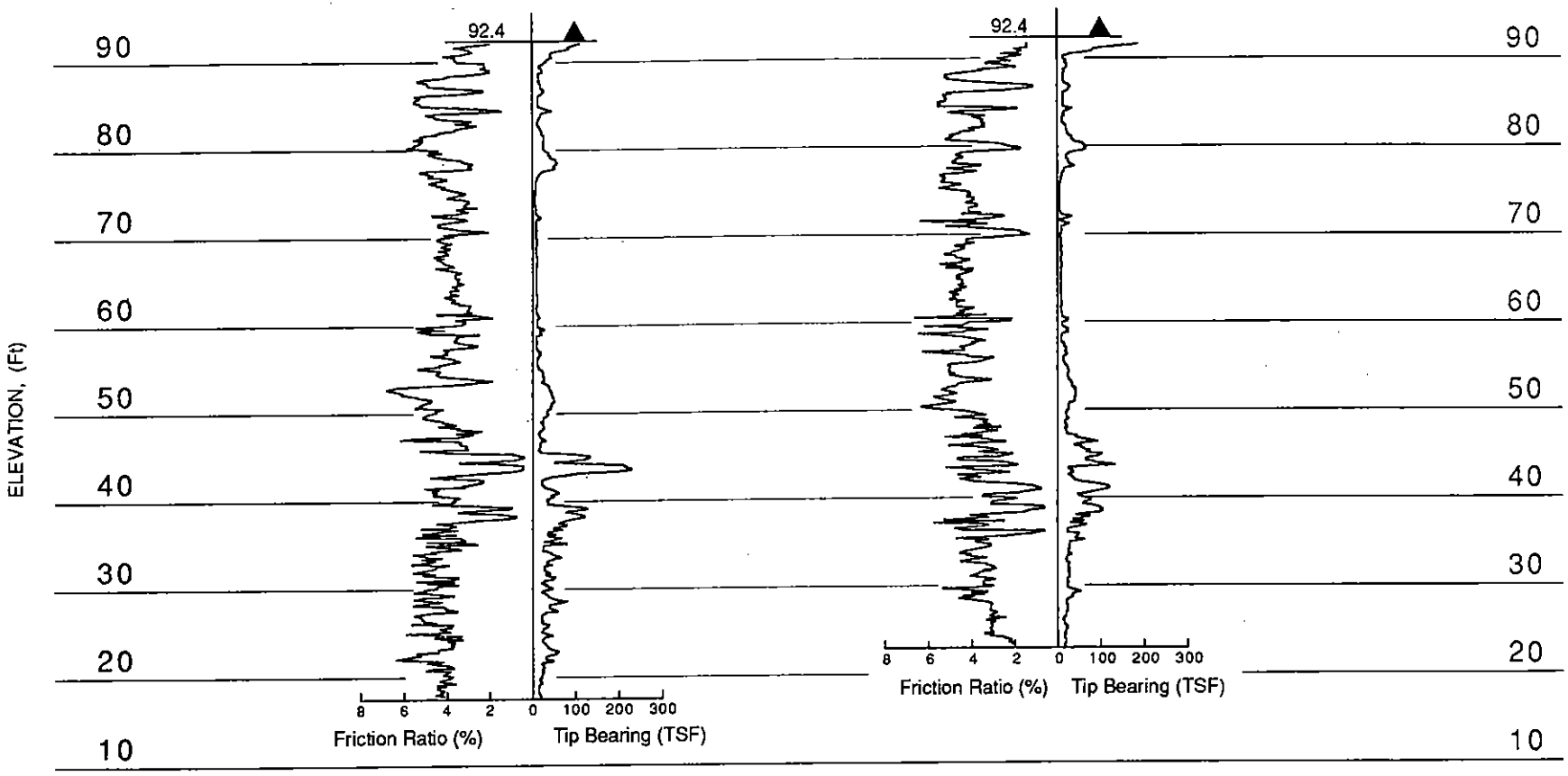
Basset Street OH



Pile Load Test # 28

Project : South Tustin OH
Location : 53 Ft Rt 502+43 C/L Const.
Brdg No : 52-26R
Date : 10/17/63
Pile Type : Driven P/S Concrete
X Section : 10.75 inch diameter
Ftg Elev : 87.0 feet
Tip Elev : 30.0 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -

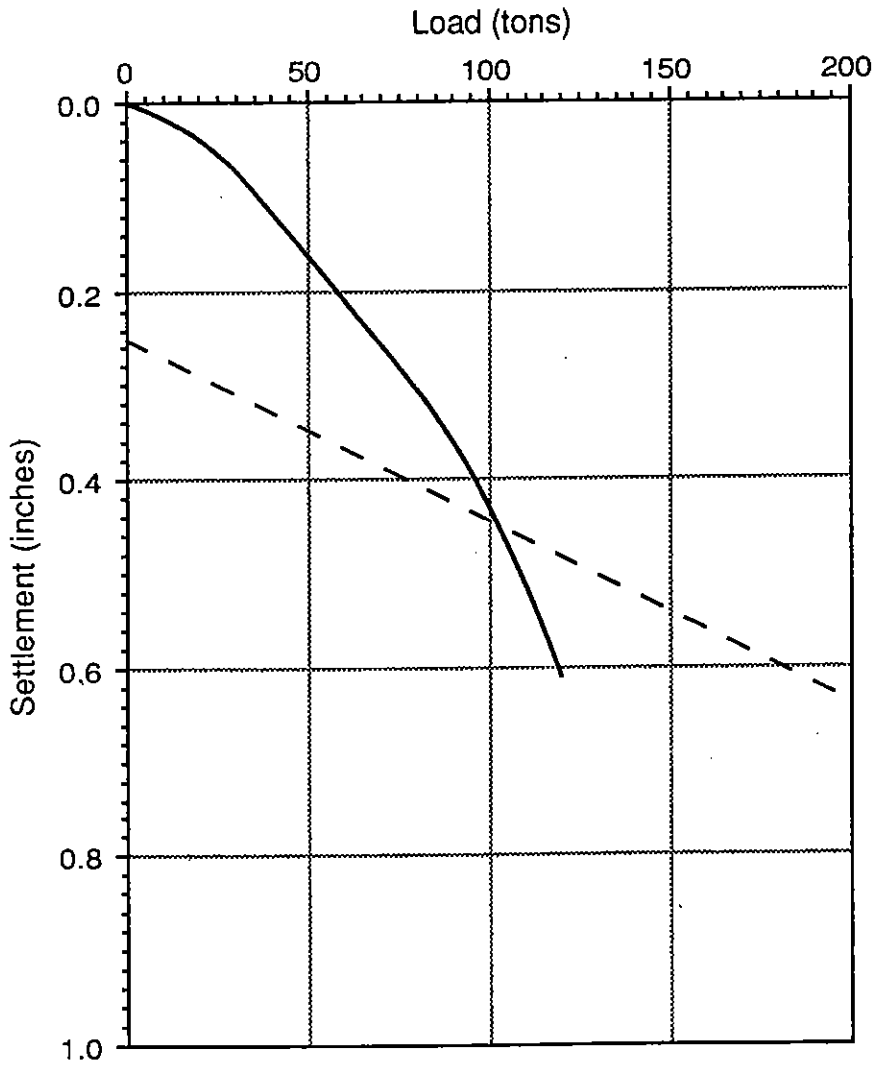


SOUNDING 1
(23 Ft Rt 502+52 C/L Const)

SOUNDING 4
(54 Ft Rt 502+52 C/L Const)

Cone Penetrometer Test Data

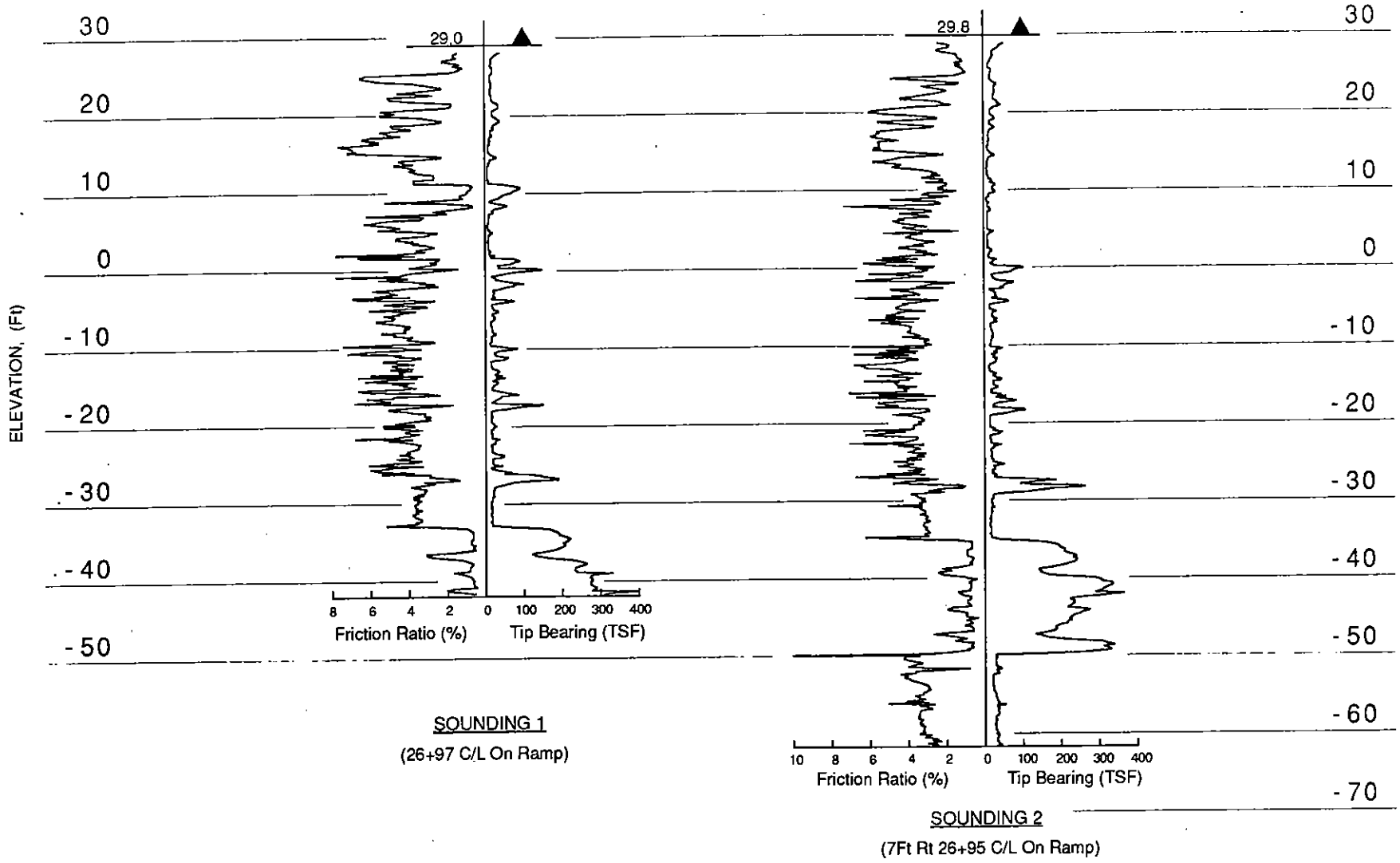
South Tustin OH



Pile Load Test # 29

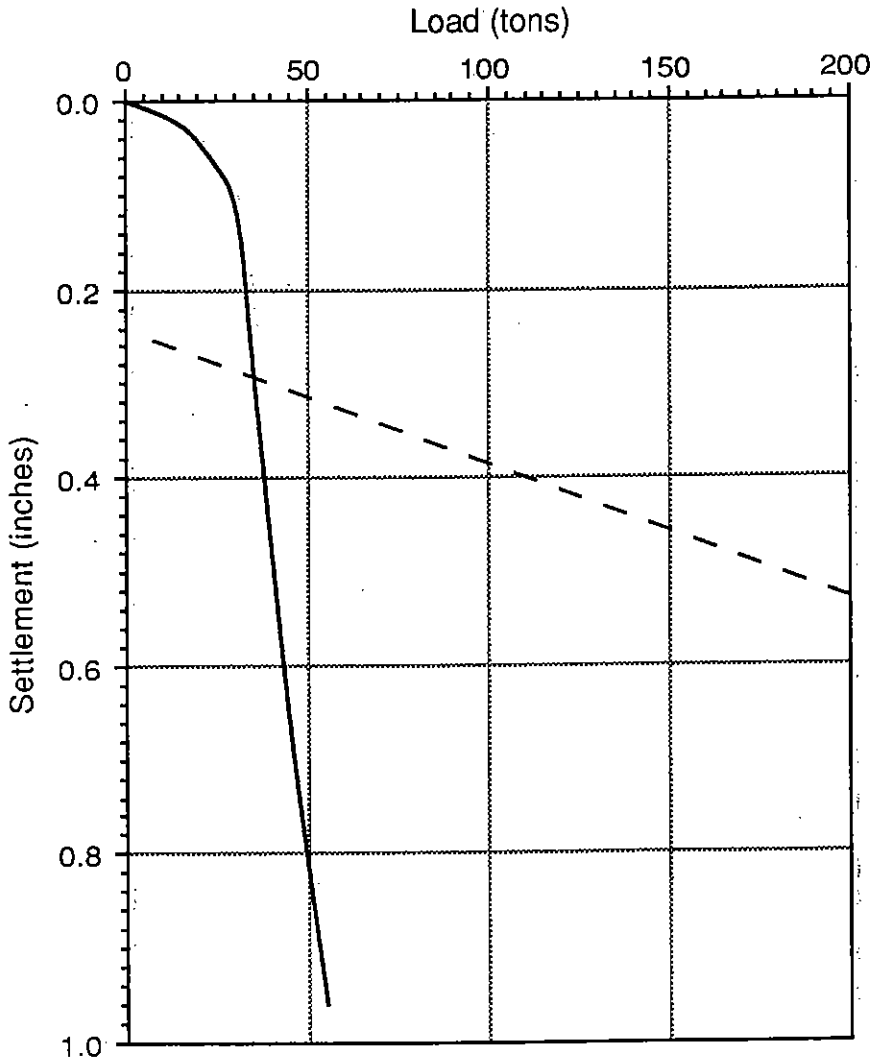
Project : Chestnut Street OH (On Ramp)
Location : 3 Ft Lt 26+95 C/L On Ramp
Brdg No : 52-217
Date : 4/11/60
Pile Type : Concrete Filled Steel Shell
X Section : 12 inch diam, wall 0.18 inch thick
Ftg Elev : 22.0 feet
Tip Elev : -31.3 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -



Cone Penetrometer Test Data

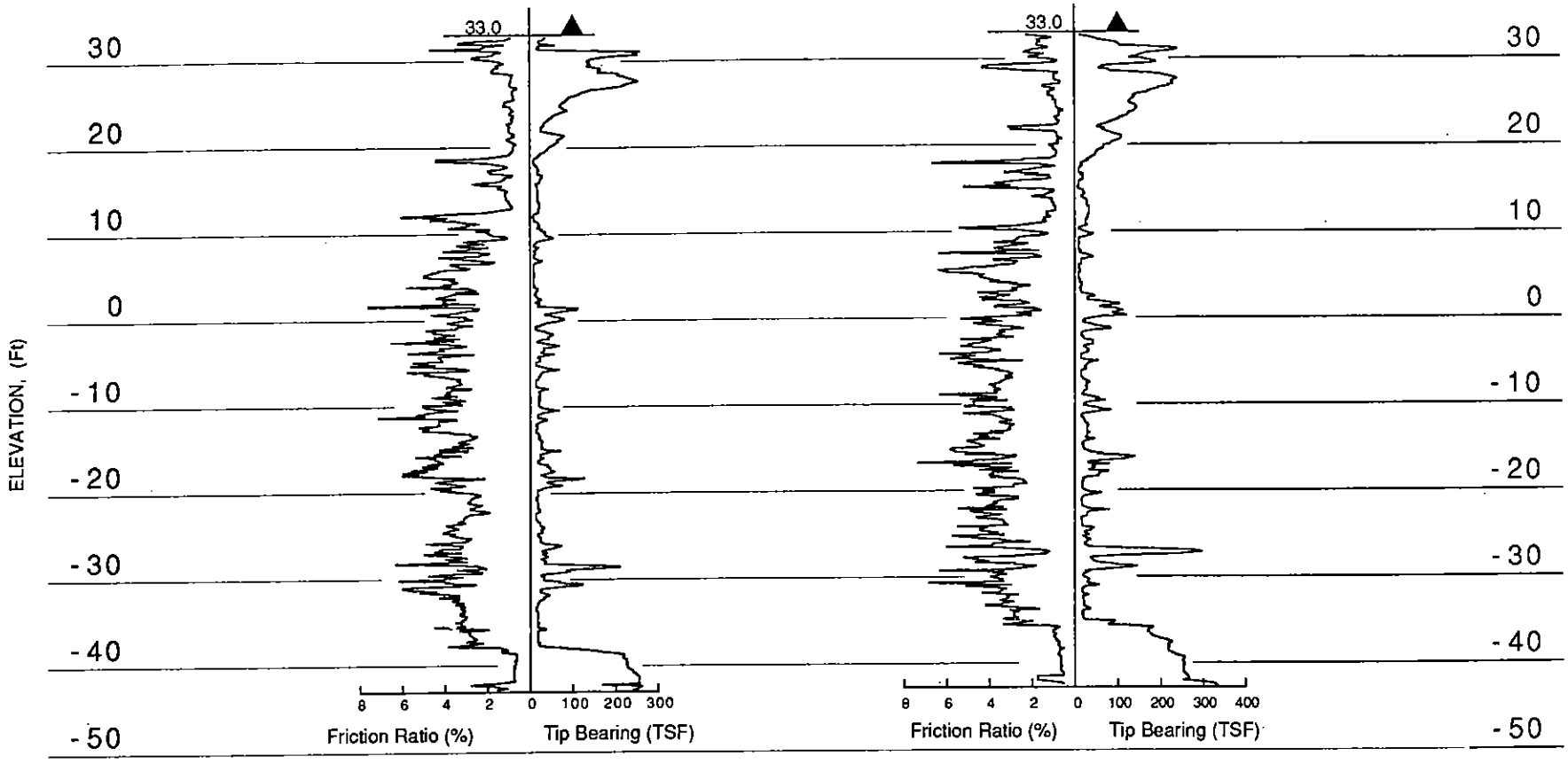
Chestnut Street OH (On Ramp)



Pile Load Test # 30

Project : Ventura Underpass
Location : 10 Ft Rt 159+68 C/L RR
Brdg No : 52-178
Date : 5/1/61
Pile Type : Concrete Filled Steel Shell
X Section : 12 inch diam, wall 0.18 inch thick
Ftg Elev : 6.0 feet
Tip Elev : -32.8 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -

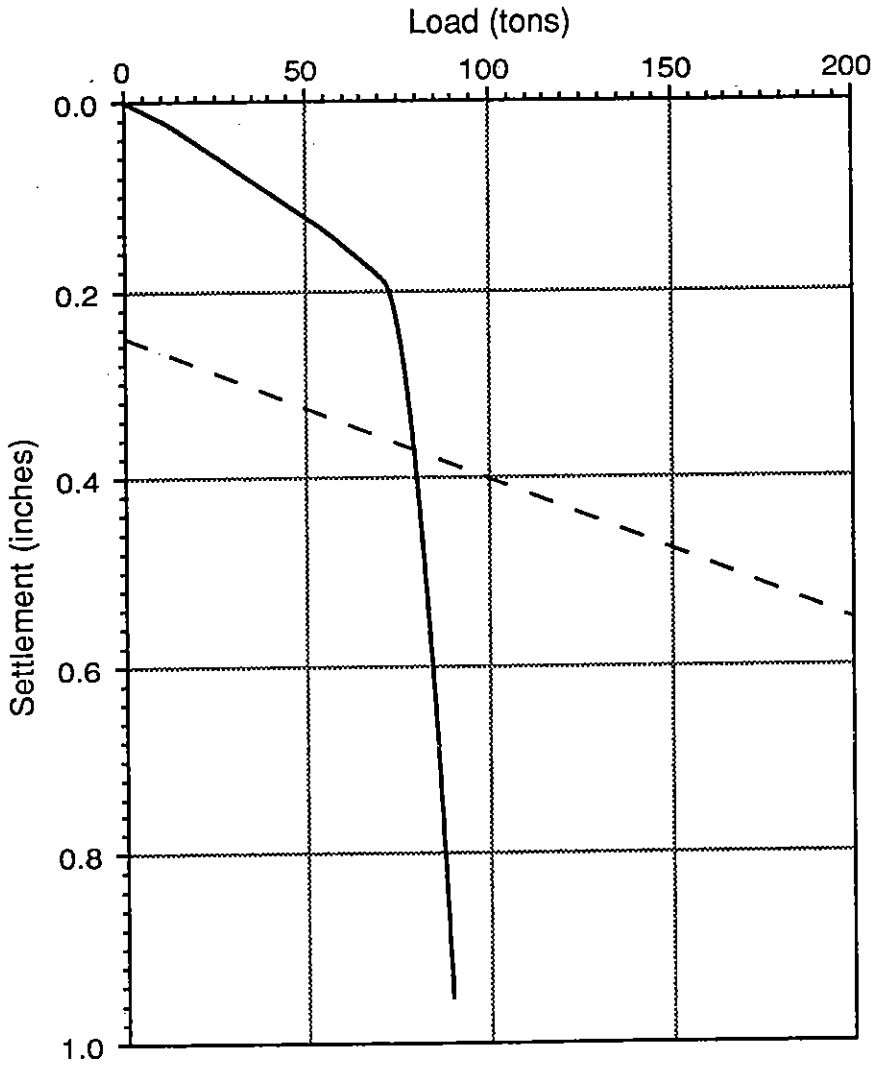


SOUNDING 1
(35 Ft Rt 158+95 C/L RR)

SOUNDING 2
(833 Ft Rt 159+03 C/L RR)

Cone Penetrometer Test Data

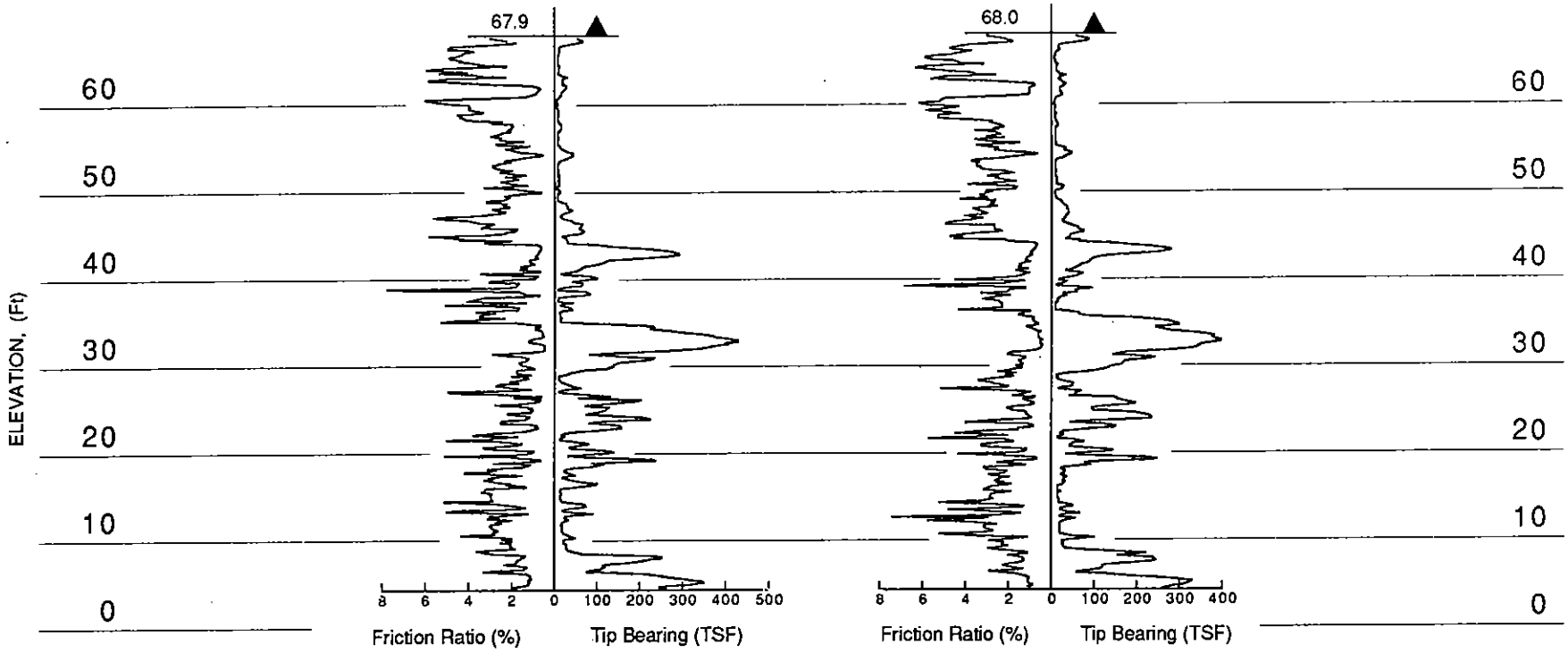
Ventura Underpass



Pile Load Test # 31

Project : Almond Drive OC
Location : 4 Ft Lt 20+00 C/L Almond Dr
Brdg No : 52-271
Date : 5/11/64
Pile Type : Concrete Filled Steel Shell
X Section : 12 inch diam, wall 0.18 inch thick
Ftg Elev : 62.5 feet
Tip Elev : 30.0 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -

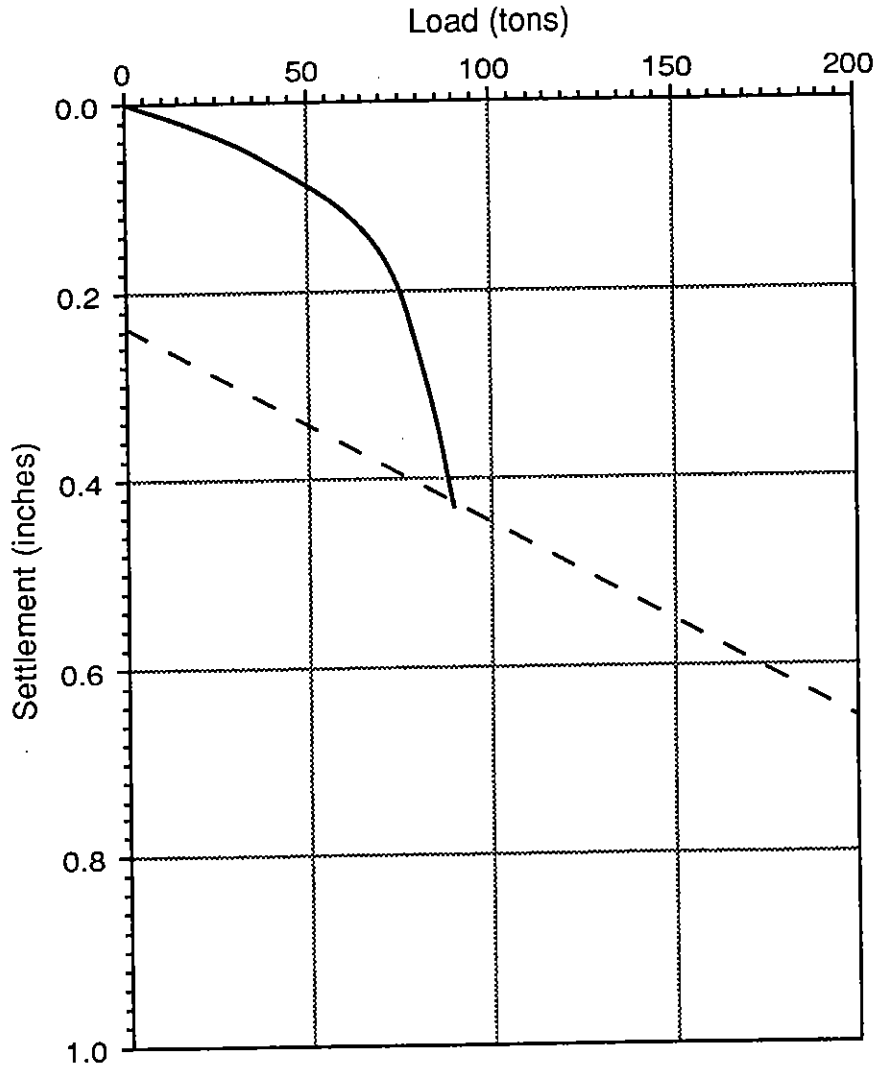


SOUNDING 1
(87 Ft Rt 20+67 C/L Almond Dr)

SOUNDING 2
(82 Ft Rt 20+67 C/L Almond Dr)

Cone Penetrometer Test Data

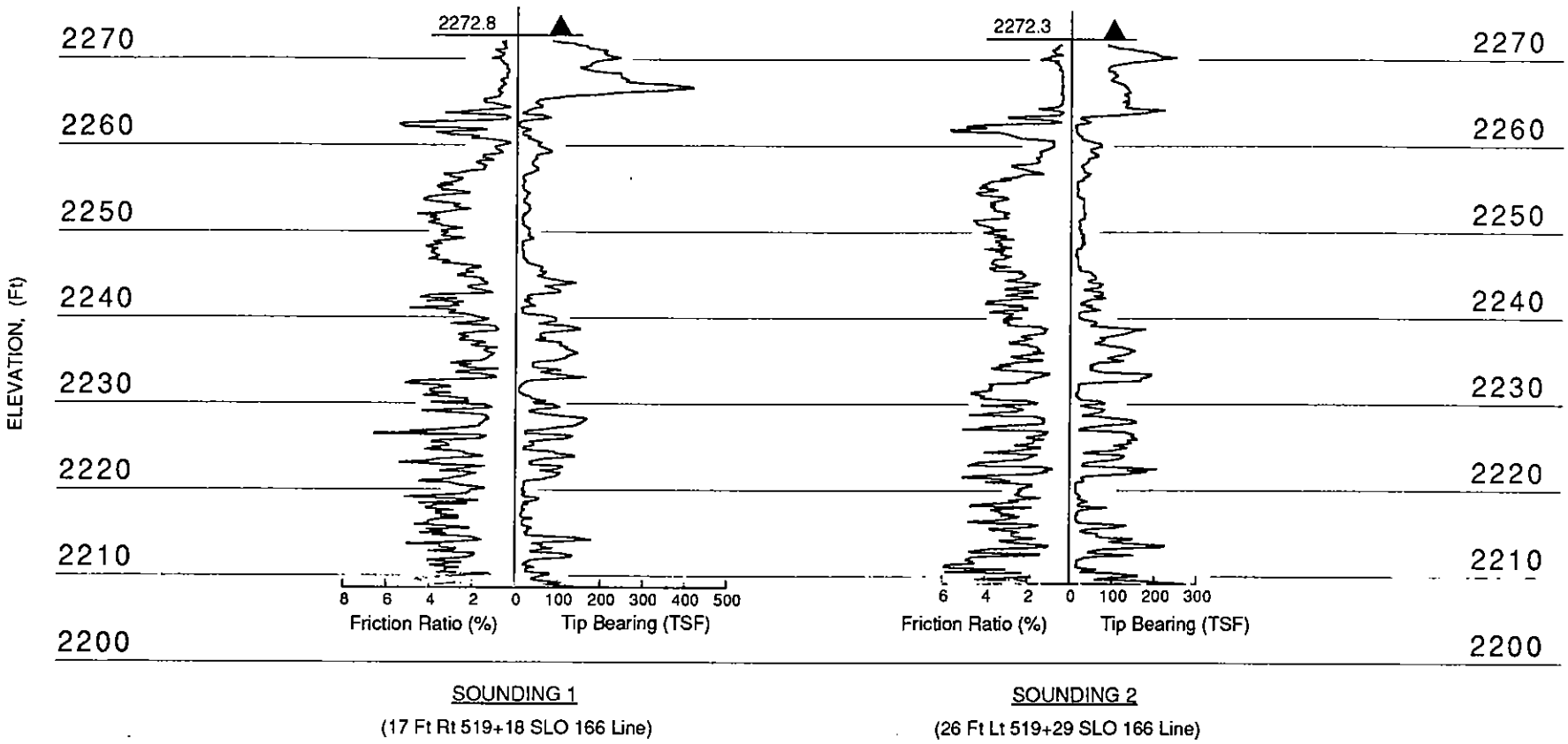
Almond Drive OC



Pile Load Test # 32

Project : Cuyama River Bridge
Location : 12 Ft Rt 518+65 SLO 166 Line
Brdg No : 51-66
Date : 6/29/79
Pile Type : Driven Steel Pile
X Section : HP 10x57
Ftg Elev : 2256.0 feet
Tip Elev : 2213.0 feet

Displacement Under Load ———
Davisson Failure Criterion - - - - - -



SOUNDING 1
(17 Ft Rt 519+18 SLO 166 Line)

SOUNDING 2
(26 Ft Lt 519+29 SLO 166 Line)

Cone Penetrometer Test Data

Cuyama River Bridge