Extrapolation of Pile Capacity From Non-Failed Load Tests

PUBLICATION NO. FHWA-RD-99-170

DECEMBER 1999

PB2000-102368

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
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FOREWORD

A pile load test is often substituted for a proof test in which a load is applied to a certain factor (most often two) times the contemplated design load. This practice requires the ability to reliably estimate the ultimate bearing pile capacity. A practical analytical method is proposed, capable of extrapolating the measured load-settlement relations beyond the maximum tested load. The proposed procedure, along with two other possible methods, is evaluated.

The results obtained for 63 database cases suggest that even when the predicted ultimate capacity is four times the maximum actual tested load, the associated risk is zero for exceeding the design load, when using the extrapolated value with a factor of safety of 2.0.

Case history analysis of six load-tested driven piles at two sites are presented. The cases analyzed indicate possible substantial savings when the ultimate capacity well exceeds the maximum applied load. Moreover, the method already demonstrates its enormous importance from aspects of engineering and economics.

This report will be of interest to geotechnical researchers and practitioners, especially individuals dealing with structures involving driven piles.

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Research and Development

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-RD-99-170		

4. Title and Subtitle	5. Report Date
Extrapolation of Pile Capacity From Non-Failed Load Tests	December 1999
	6. Performing Organization Code
7. Author(s) Samuel G. Paikowsky and Terry A. Tolosko	8. Performing Organization Report No.
9. Performing Organization Name and Address Pruitt Energy Sources, Inc. 4307 Jefferson St., Suite 101 Hyattsville, MD 20781	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFH61-95-Z-00081
12. Sponsoring Agency Name and Address Office of Infrastructure Research and Development 6300 Georgetown Pike McLean, VA 22101-2296	13. Type of Report and Period Covered Final Report May 1995 – March 1998 14. Sponsoring Agency Code

15. Supplementary Notes

Contracting Officer's Technical Representative (COTR): Carl Ealy, HRD1
Technical Consultant: Jerry DiMaggio, HIBT-20

16. Abstract

Static pile load test to failure is the ultimate procedure available to examine the capacity and integrity of deep foundations. Being expensive and time-consuming, the procedure is often substituted for the application of a load to a certain factor (most often two) times the contemplated design load. In fact, only a proof test is carried out while the ultimate capacity and actual factor of safety remains unknown. This procedure results in an uneconomic foundation solution, unknown capacity when modifications are required, and the inability of the engineer to gain insight into the controlling mechanism for improved design.

The described state of the practice calls for the ability to reliably estimate the ultimate bearing pile capacity for non-failed load tests. A practical analytical method is proposed, capable of extrapolating the measured load-settlement relations beyond the maximum tested load. The proposed procedure, along with two other possible methods, is evaluated. The procedures are examined through a database of 63 driven piles load-tested to failure. Loading is assumed to be known for only 25%, 33%, 50%, 75%, and 100% of the actual bearing capacity (typically lower than the maximum applied load), and separately for 25%, 33%, 50%, 75%, and 100% of the entire load-settlement data points. The limited "known" data is then extrapolated using the different methods and the obtained bearing capacity is compared to the actual measurements. For consistency, only one failure criterion (Davisson) is applied. The obtained results are analyzed statistically to evaluate the accuracy and reliability of the three methods.

It is shown that the accuracy of the proposed method is 0.99 ± 0.21 (1S.D.), 0.96 ± 0.27, 0.87 ± 0.30, and 0.78 ± 0.33 when assuming 75%, 50%, 33%, and 25% of the data points to be known and 0.99 ± 0.26 (1S.D.), 0.89 ± 0.41, 0.74 ± 0.46, and 0.64 ± 0.44 when assuming 75%, 50%, 33%, and 25% of the bearing capacity to be known, respectively. The obtained results for the 63 database cases suggest that even when the predicted ultimate capacity is four times the maximum actual tested load, the associated risk is zero for exceeding the design load, when using the extrapolated value with a factor of safety of 2.0. All the case histories used in this research relate to driven piles. Even though it is expected to be valid, a detailed examination of the method is required before its safe application to cast-in-place piles.

Case history analyses of six load-tested driven piles at two sites are presented. The analyzed cases indicate possible substantial savings when the ultimate capacity well exceeds the maximum applied load. Moreover, the method already demonstrates its enormous importance from aspects of engineering and economics.

17. Key Words	18. Distribution Statement
Pile Load Test, Pile Capacity, Failure Criterion, Extrapolation Analysis, Reliability, Non-Failed Load Tests.	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	169	

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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CHAPTER 1: INTRODUCTION

1.1 OVERVIEW

The study of driven-pile foundations and their behavior under static loads dates back to the late 19th century. Until that time, the design of driven piles was mainly based on experience. Static load tests were the first attempt at verifying the design and determining the ultimate capacity of a driven pile. The load test involves physically loading the pile at specific time intervals and monitoring the settlement of the pile top until failure. These tests are expensive and time-consuming, and as a result, are not commonly performed.

A proof test, a limited form of the static load test, is used to determine the pile's performance in supporting a service load and is usually carried out to twice the design load. The proof test does not proceed to failure and as a result, is less expensive and is more frequently performed. The proof test does not commonly provide the ultimate pile capacity and as such, does not contribute to improved knowledge of pile analysis, increasing accuracy of design, or reduction in foundation costs.

Different methods exist for the interpretation of the ultimate pile capacity based on a pile load test to failure. These methods relate to different principles, such as limiting maximum settlement and ratio of settlement to load. Among these methods, two relate to the shape of the load-settlement curve and hence can be conceptually used for determining the ultimate capacity of piles from proof test information. Using these methods, the ultimate capacity could be based on the limited load-settlement information provided by the proof test. These methods include Chin's method (Chin, 1971a, 1971b and Chin and Vail, 1973) and the Brinch-Hansen method (Brinch-Hansen, 1963).

1.2 STATEMENT OF PROBLEM

Finding the ultimate pile capacity based on a proof test data is important as it allows us to answer the following questions: (1) What is the actual pile capacity and the resulting factor of safety? and (2) When change in design takes place, either during construction or for existing structures, can the piles support higher loads safely? In order to answer these questions (knowing the present state of proof testing), it is required: (1) to determine the reliability of the aforementioned methods (Chin and Brinch-Hansen) and (2) to develop an accurate method for determining the ultimate capacity of a pile based on a proof test data. Both needs are addressed by the present research.

1.3 SCOPE

This report presents the procedures, anticipated accuracy, and a recommended method of analysis allowing the prediction of the ultimate bearing capacity of a driven pile from proof tests. The present research study is based on the above outlined needs and consists of four major parts.

The first part (Chapter 3) describes the present research method of approach. The principle of evaluating extrapolation methods utilizing data from piles load-tested to failure is introduced. Two existing methods and the proposed method are presented next. The proposed method combines the manipulation of load-settlement data with general linear algebra. The method was first introduced by Paikowsky (1982) for one case history. It is examined and verified for a large data base in the present study.

The second part (Chapter 4) describes the buildup of the data set used in the analysis. The data set contains 63 driven-pile load-settlement measurements collected during static load tests to failure. The current methods of load-test interpretation and analysis are discussed and implemented.

The third part (Chapters 5 and 6) presents the analysis and interpretation of both the proposed and existing methods.

The fourth part (Chapters 7, 8, and 9) examines the performance of the proposed method using recent case histories. Recommendations for the use and the application of an adequate factor of safety are provided.

1.4 LIMITATIONS

All the case histories used in the present research are for driven piles only. Although the application of the method for cast-in-place piles is expected to be valid, its examination and verification for these cases are required in order to guarantee a safe application.

1.5 METHOD OF APPROACH

The steps outlining the method of approach used in this research are:

(1) Compile existing load-to-failure static load test records (data set PD/LT);
(2) Determine the representative ultimate capacity (static load) of the pile from several commonly used methods;
(3) Model the relationship between load and settlement using regression analysis;
(4) Develop an analytical method (as opposed to graphical) for load-settlement extrapolation and determining the ultimate capacity of the pile based on Davisson's Criterion;
(5) Using this analytical method, extrapolate the ultimate capacity of the pile using: (a) 25%, 33%, 50%, 75%, and 100% of the previously determined static load and (b) the same percentile of the complete load-settlement relations data points;
(6) Compare the results to the actual load settlement behavior;
(7) Assess the performance of the method;
(8) Determine an appropriate Factor of Safety for the proposed method and the associated risk;

(9) Examine the proposed method for recent case histories of piles driven for the construction of a highway bridge; and
(10) Provide conclusions and recommendations for using the proposed method.

1.6 MANUSCRIPT LAYOUT

The following are short descriptions of each of the chapters contained in this research report:

Chapter 2	Provides a brief background of static load test interpretation methods and reviews the load test specification of different highway departments across the United States.
Chapter 3	Details the various methods currently available for determining the pile capacity from non-failed load tests and presents the proposed method.
Chapter 4	Outlines the information related to data set PD/LT.
Chapter 5	Evaluates the performance of the existing methods.
Chapter 6	Provides an assessment of the proposed method and examines several controlling factors.
Chapter 7	Details the implementation of the proposed method utilizing recent case histories not included in the data base.
Chapter 8	Describes the engineering significance of the method.
Chapter 9	Provides a summary, conclusions, and recommendations.

1.7 CONTRIBUTIONS

The database used in this study was compiled by Paikowsky et al. (1994) and Paikowsky and LaBelle (1994). Both sources refer to and acknowledge the contributors of the original information.

Mary Canniff has greatly contributed to the performance of the analyses, the graphical representation of the results, and the manuscript preparation. Her assistance and dedication are greatly appreciated.

Geosciences Testing and Research, Inc. (GTR) of North Chelmsford, Massachusetts and the Massachusetts Highway Department had helped in obtaining and analyzing the case history data presented in Chapter 7. The assistance of Les Chernauskas of GTR and Vallerie McGrath (LaBelle) and Nabil Hourani of the Massachusetts Highway Department is acknowledged.

The assistance of the students in the Geotechnical Research Laboratory at the University of Massachusetts-Lowell is appreciated, in particular that of Michael Buchand and Edward Hajduk.

CHAPTER 2: BACKGROUND

2.1 DEEP FOUNDATIONS

2.1.1. Definition and Use

A deep foundation or a pile is a structural element used to transfer loads into soft soil or through weak soil and water to underlying competent layers of soil or rock.

The use of driven piles for foundation support is a practice that dates back to prehistoric times. The Neolithic inhabitants of Switzerland supported their homes 12,000 years ago on wooden poles driven into shallow lakes. The ancient Egyptians depicted manpowered pile driving operations and failures. During the Roman era, many of the bridges spanning the Rhine River were supported with driven timber piles.

Deep foundations are used for supporting a variety of structures, including bridges, high-rise buildings, towers, dams, and off-shore oil platforms. Deep foundations are also used for other load-carrying purposes such as slope stabilization, resisting uplift forces, and more.

According to their load transfer mechanism, piles can be categorized into two groups: friction piles and end-bearing piles. Friction piles develop their resistance through the friction that exists between the pile's shaft and the adjacent soil. End-bearing piles provide resistance from the pile point, which rests on firm soil or rock. Most piles operate as a combination of the two.

2.1.2 Quality Control

The ability to predict the capacity and inspect the integrity of deep foundations (once they are installed beneath the ground surface) is limited. Static pile design is based on theories and assumptions related to the soil and pile material properties. The theories used are generally ideal in nature, and back analysis and judgment are used to determine to what degree of accuracy the idealized theories agree with the real situation. As a result of these uncertainties and the inability to predict pile-soil interactions, high factors of safety are used when designing deep foundations. A direct relationship exists between the factor of safety used and the associated foundation cost.

Pile capacity may be estimated using static or dynamic analyses and may be confirmed by static load tests. Static load tests and their analyses are described below. Dynamic analyses predict pile capacity based on the monitored pile behavior during driving or the simulated hammer-pile-soil system. Dynamic analyses of piles during driving are beyond the scope of this research and do not relate to the conditions by which static load-settlement extrapolation is possible.

2.2 STATIC LOAD TESTS

Static load testing is currently the only reliable method available to determine the actual ultimate capacity of piles. This method involves physically loading the pile at specific time intervals and monitoring the settlement of the pile top until failure. The results of these tests are plotted as load versus settlement and the failure load is determined based on several interpretation techniques. Due to the expense and time-consuming nature of static load tests, the tests are conducted rather infrequently.

Pile load tests can be placed into two broad categories. Failure load tests are load tests that proceed until the pile plunges, when it experiences excessive displacements under small or no load increase. Load tests to failure are necessary to determine the pile's ultimate capacity. A "proof test" is used to determine the pile's ability to support a service load, usually taken as twice the design load. It is important to note that the proof test does not provide the ultimate pile capacity and, therefore, does not contribute to the effort of increasing accuracy and reducing foundation costs. Although the test is typically carried out to twice the design load, the actual employed factor of safety may be much higher since the ultimate capacity remains unknown. Proof testing is less expensive than loading a pile to failure and is, therefore, frequently performed. Section 2.5 summarizes the pile load test requirements in different state highway foundation specifications. The frequency of required proof tests, and other load tests indicated in the table, should be noted.

The American Society for Testing and Materials (ASTM) provides guidelines for conducting static load tests (ASTM D1143). State building codes throughout the United States have adopted or modified these guidelines for conducting proof testing, while few require load testing a pile to failure.

Data set PD/LT, which is presented in Chapter 4, contains cases of 63 piles load-tested to failure. The interpretation of the test results was carried out using a variety of methods as outlined in Section 2.3.

2.3 STATIC LOAD TEST INTERPRETATION

2.3.1 Overview

Various methods are currently available for interpreting static load test results in order to determine the pile's bearing capacity. The methods are based on different principles related to a limiting settlement, maximum load, ratio of load to settlement, shape of curve, and so on. As a result, no single unique value exists when determining the pile's bearing capacity based on a load test to failure. The present research study utilizes a data set named PD/LT, comprised of 63 case histories of piles load-tested to failure. Each of the cases was analyzed using five different interpretation methods to produce a representative static (average) resistance for each pile. A detailed description of the procedure and the analyses are presented by Paikowsky et al. (1994).

2.3.2 Data Manipulation and Presentation

For consistent interpretation of a load test load-settlement curve, a common scale was implemented. The scale was based on the elastic deformation of the pile as proposed by Vesic (1977). When plotting the load-settlement curve, the elastic deformation of a fixed-end, free-standing, frictionless pile is expressed as:

$$\delta = PL/EA \qquad (2.1)$$

where:

- δ = calculated elastic deformation of the pile
- P = applied load
- L = pile length
- E = elastic modulus of the pile's material
- A = cross-sectional area of the pile

The elastic compression obtained by Equation 2.1 is based on the assumption that the entire load applied to the pile top is transferred to the pile tip. To implement a scale proportional to all settlement curves, the elastic compression line was kept inclined at an angle of approximately 20 degrees to the load axis.

In order to facilitate this scale, all of the compiled load test data was digitized using the program DIGITIZE, developed at the University of Massachusetts at Lowell by Chernauskas and Paikowsky. The curves were then re-plotted using the graphics software GRAPHER to produce curves that were scaled to the elastic compression of the individual pile. Figure 1 shows an example of a scaled load-settlement curve using the above criterion.

After re-plotting, each curve was analyzed using five common failure load interpretation procedures outlined below: Davisson's Criterion, the Shape of the Curve, Limited Total Settlement Methods (Δ=1 inch and Δ=0.1B, where B = pile diameter), and DeBeer's method.

2.3.3 Davisson's Criterion

Davisson's Criterion (Davisson, 1972), or the offset limits, defines the failure load of a pile as the load corresponding to the settlement that exceeds the elastic compression of the pile (d) by an offset (X) equal to 0.15 inches (3.8 mm) plus the pile diameter (in inches) divided by 120:

$$X = 0.15 + B/120 \qquad (2.2)$$

where:

- X = offset displacement of the elastic compression line
- B = diameter of the pile in inches

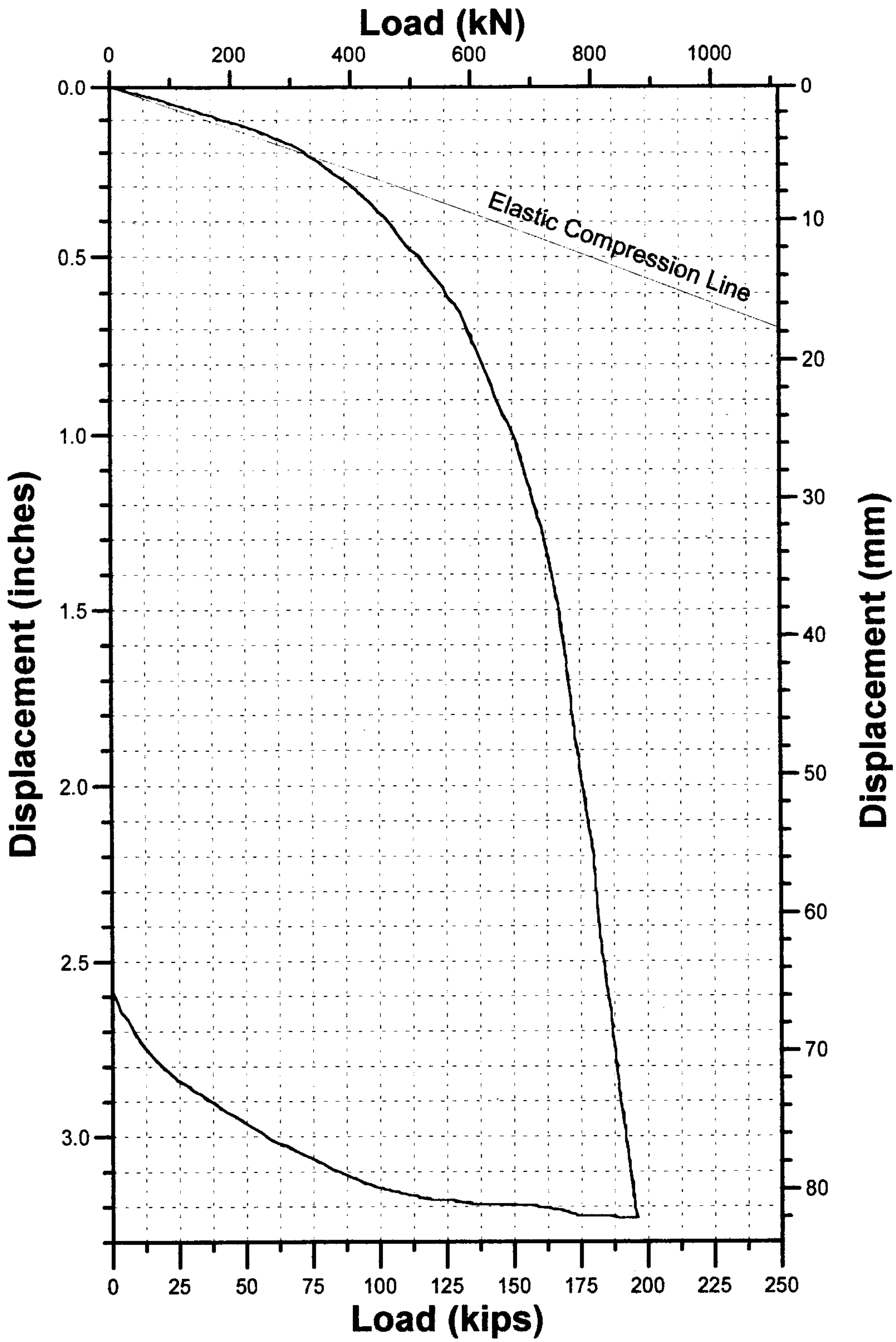

Figure 1. Load-Settlement Curve of Pile Case No. 5 With the Elastic Compression Line Inclined at 20 Degrees. (Paikowsky et al., 1994)

The Davisson's criterion line is parallel to the elastic compression line. The intersection of Davisson's line with the load-settlement curve provides the ultimate capacity of the pile. Figure 2 illustrates the use of Davisson's failure criterion for load-settlement relations of pile case no. 5 in the present database (equivalent to case 47 by Paikowsky et al., 1994). Davisson's criterion yields a capacity of 625 kips (2780 kN). Davisson's criterion has the advantage of being deterministic (and hence objective), while being able to consider the pile geometry and properties.

2.3.4 Shape of the Curve

The Shape of the Curve Method is a failure load approximation that usually yields a range of values over which the pile is considered at or near failure. The boundaries of this range can be determined by examining the minimum curvature in the load-settlement curve through lines drawn tangent to the load-settlement curve (similar to the method proposed by Butler and Hoy, 1977). The failure range is relatively easy to define for load-settlement curves that exhibit general failure or plunging failure (rapid settlement with slightly increased loads) (see Figure 2 for example). Piles that experience local failure, or non-plunging failure, are difficult to analyze using the shape-of-the-curve method because of the uniform changes in the slope of the lines drawn tangent to the curve. Figure 2 illustrates the use of the shape-of-the-curve procedure, yielding an estimated capacity range between 500 kips and 640 kips (2224 kN and 2847 kN) with a representative average of 570 kips (2535 kN) for pile case no. 5.

2.3.5 Limited Total Settlement Methods

The limited total settlement methods define the failure load as the load corresponding to the settlements of 1 inch (Δ=1 inch) and 0.1 times the pile diameter (Δ=0.1B) (Terzaghi, 1942). These methods are not applicable in many cases. For example, the elastic compression for a very long steel pile often exceeds 1 inch (25.4 mm) and/or 0.1B without inducing any plastic deformation in the soil. Figure 2 presents the load-settlement curve for pile case no. 5, a square concrete pile that experiences a plunging failure well before a displacement of 1 inch (25.4 mm) is achieved. Also, it is obvious in this case that a settlement of 0.1B, or 2.4 inches (61 mm), does not represent the failure load of this pile, and, therefore, is not applicable.

2.3.6 DeBeer's Log-Log Method

DeBeer defines the failure load as the load corresponding to the intersection of two distinct slopes created by the load-settlement data plotted using logarithmic scales (DeBeer, 1970). Figure 3 illustrates the use of DeBeer's criterion for the same load-settlement curve (pile case no. 5) presented in Figure 2, resulting in an estimated capacity of 648 kips (2882 kN). The two slopes are especially visible for piles that experience plunging failures, yet when using DeBeer's method on piles that undergo local failures, the result may be a range of values. As mentioned earlier, each load-settlement curve was digitized from the standard linear plots that they were presented

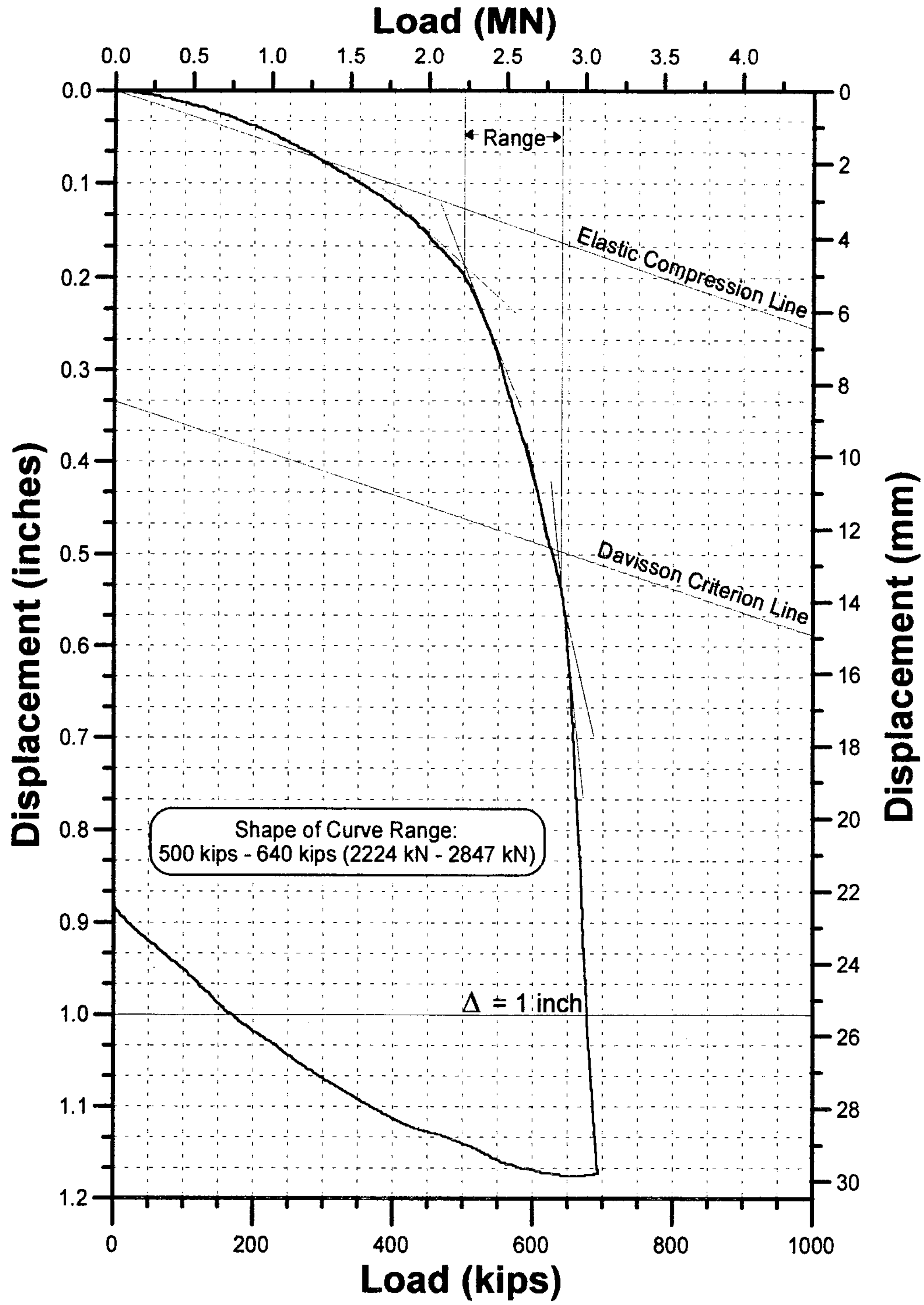

Figure 2. Load-Settlement Curve for Pile Case No. 5 of the PD/LT Data Set With the Elastic Compression Line Inclined at 20 Degrees and Different Ultimate Capacity Interpretation Methods. (Paikowsky et al., 1994)

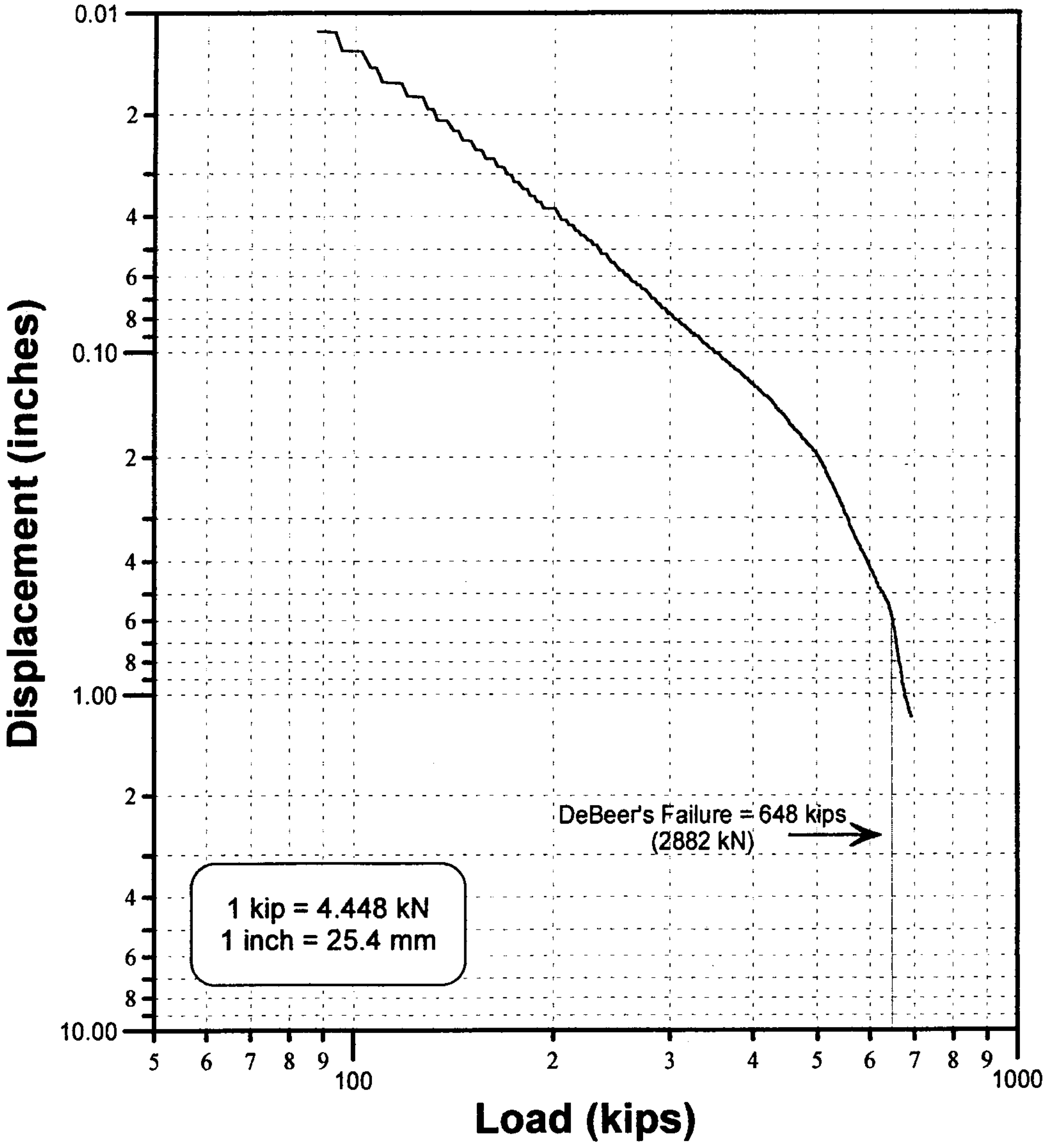

Figure 3. Load-Settlement Data Plotted on a Logarithmic Scale for Pile Case No. 5
to Determine the Failure Load According to DeBeer's Method.
(Paikowsky et al., 1994)

on and the data was stored. This data was later plotted using logarithmic scales to utilize DeBeer's method.

2.3.7 Brinch-Hansen's Method

Brinch-Hansen (1963) developed a method in which the failure is obtained based on the assumption that hyperbolic relationships exist between the load and the displacement. Two methods (90% and 80% criteria) were suggested. The first defines failure as the load that is associated with twice the movement of the pile head as obtained for 90% of the load. The 80% criterion defines the failure load as the load that is associated with four times the movement of the pile head as obtained for 80% of the load (Fellenius, 1989). The criterion provides the following simple relationship when used for calculating the pile capacity:

$$Q_u = \frac{1}{2\sqrt{(C_1 + C_2)}} \tag{2.3}$$

$$\delta_u = \frac{C_2}{C_1} \tag{2.4}$$

where: Q_u = pile load capacity (failure)
δ_u = movement at failure

C_1 and C_2 are the slope and y-intercept, respectively, of the straight line obtained by plotting the load-settlement relations using a vertical (y) axis of $\sqrt{\delta}/Q$ and a horizontal axis of Δ, in which Δ is the displacement and Q is the corresponding load. Figure 4 presents these relationships for pile case no. 5. Using the approximately linear segment ($\Delta > 0.2$ inches), the corresponding failure load is 603 kips (2682 kN).

As Brinch-Hansen's failure criterion is based on an assumed stress-strain relationship for the soil (represented by the load-displacement of the pile), it is reasonable to reduce the pile top displacement by the elastic shortening of the pile segment above the ground. In most cases, this length is very small compared to the penetration depth and hence can be neglected.

By using assumed load-displacement relationships, the obtained mathematical formulation can be used to extrapolate the load-displacement relations beyond the point of maximum load. This fact was already noted by Brinch-Hansen (1963).

2.3.8 Chin's Method

In Chin's method (Chin, 1971a, 1971b; Chin and Vail, 1973) it is assumed that the load-settlement (Q vs. Δ) relationship is hyperbolic and hence the inverse slope of a plot of Δ/P (vertical axis) vs. P results in the failure value.

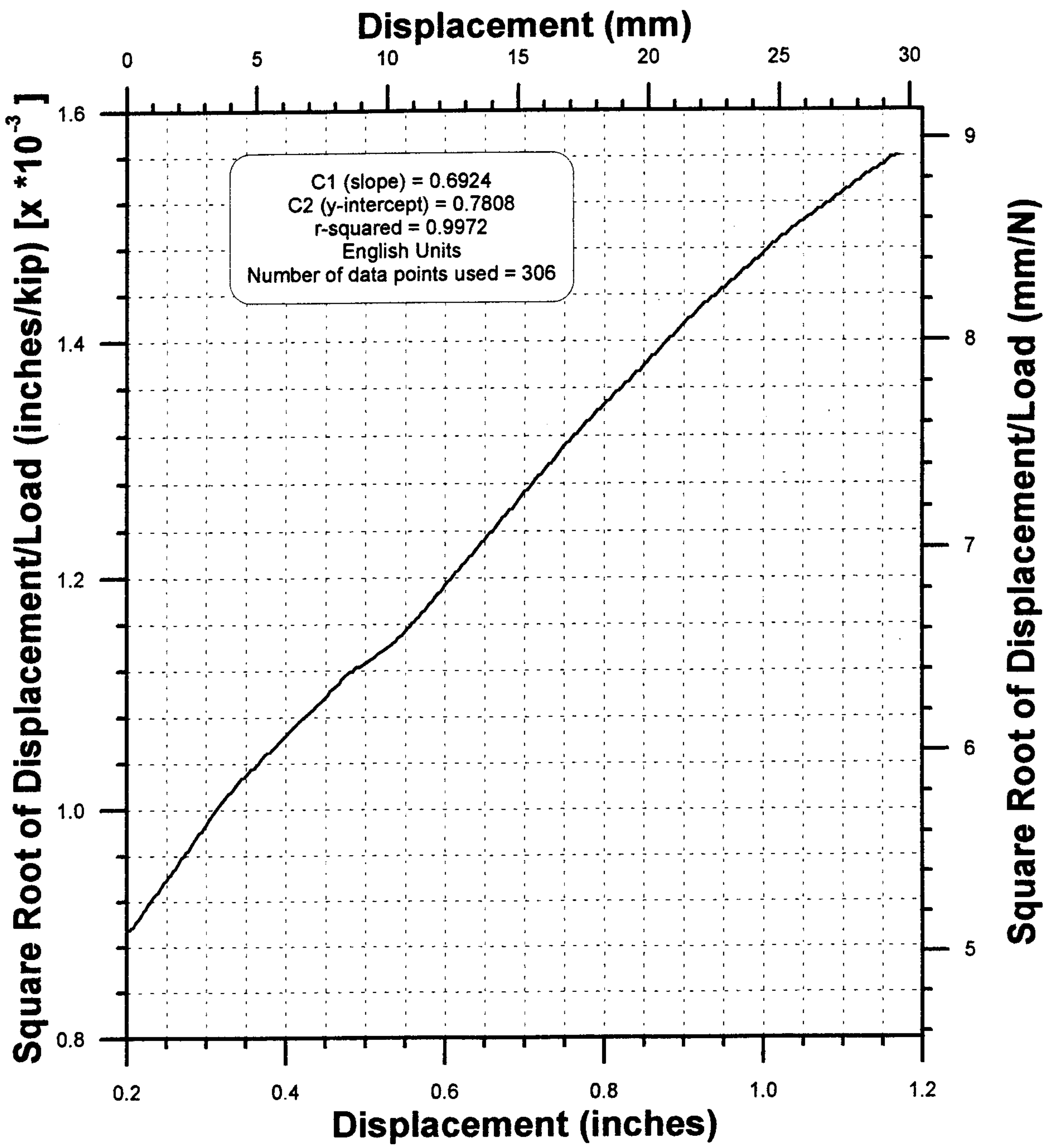

Figure 4. The Relationship of the Square Root of the Displacement Over Load Versus Displacement for Pile Case No. 5 According to Brinch-Hansen's Failure Determination Method.

$$\frac{\Delta}{Q} = C_1\Delta + C_2 \qquad (2.5)$$

$$Q_u = \frac{1}{C_1} \qquad (2.6)$$

Similarly to Brinch-Hansen's method, Chin's method can be used, through mathematical relationships, to extrapolate the load-settlement values beyond the maximum applied load.

Figure 5 describes the above relationship for pile case no. 5 of data set PD/LT. Using linear regression over the approximate linear portion of the curve (displacement greater than 0.5 mm), the corresponding Chin's method capacity is 748 kips (3327 kN). As with Brinch-Hansen's method, the proper use of Chin's method calls for the deduction of the elastic deformation in the pile segment above the ground surface.

2.3.9 Representative Static Capacity

The capacity results from Davisson's criterion, the Shape of the Curve, Limited Total Settlement methods, and DeBeer's method were independently evaluated for each pile based on the load-settlement curves. After considering the pile type, size, and the load test procedure, unrealistic results were eliminated and the acceptable values were averaged, yielding a final (representative) static pile capacity. For example, for pile case no. 5, presented in figures 2.2 and 2.3, the considered criteria were:

- Davisson's = 625 kips (2780 kN)
- Shape of Curve = 500 - 640 kips (2224 - 2847 kN)
- Δ = 1 inch = 679 kips (3020 kN)
- Δ = 0.1B = not applicable
- DeBeer's = 648 kips (2882 kN)

Excluding the Δ = 1 inch settlement method, which is clearly beyond failure and the Δ = 0.1B method, which does not apply, the average of all acceptable criteria led to a final static capacity of 614 kips (2731 kN).

The Chin and Brinch-Hansen methods were not considered as part of the static capacity determination as these methods are not widely used in practice. Their capacities for case no. 5 were 748 kips (3327 kN) and 603 kips (2677 kN), respectively.

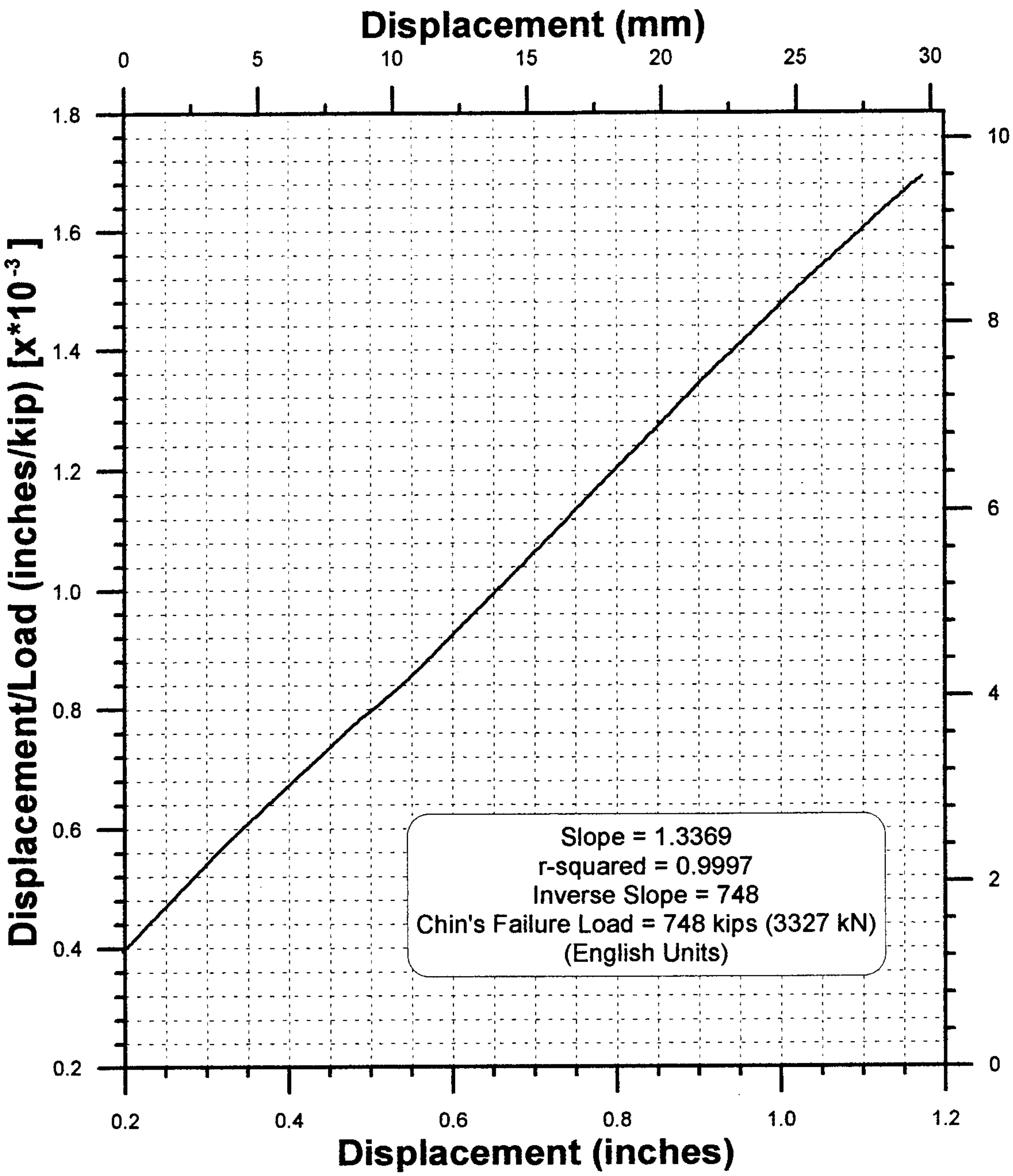

Figure 5. Displacement Over Load Versus Displacement for Pile Case No. 5 According to Chin's Failure Determination Method.

2.4 CURRENT PILE LOAD TEST REQUIREMENTS IN THE UNITED STATES

Pile load tests are most often being conducted in order to satisfy building codes. Typically, two types of requirements are used in each state; one is a building code specified by the state's legislator, and the other are the specifications outlined by the state highway departments. The current Massachusetts state building code (Section 1214.4) and the Massachusetts Highway Standard Specifications for Highways and Bridges (Section 940.62) require the application of a load test that is twice the contemplated design load. This type of load is referred to as a "proof test."

Table 1 summarizes the pile load test requirements as provided by the state highway foundation specifications across the United States. The information in Table 1 is based on a compilation of specifications prepared by the Deep Foundations Institute in two volumes related to the western and eastern parts of the country.

Table 1
Pile Load Test Requirements Based on State Highway Foundation Specifications

STATE	HIGHWAY FOUND. SPECS.	LOAD TEST REQUIREMENT
1. Alabama	505.03(b)3	Load to twice the design load, maintain for 48 hours, unload.
2. Alaska	505-3.01	Test piles driven to refusal...or to a bearing value as specified or directed.
3. Arizona	603-1	...pile load tests shall be performed in accordance with...the special provisions...
4. Arkansas	805.06(b)	The test pile shall be loaded to twice the minimum bearing value...
5. California	49-1.10	Continuous loading until plunging failure...
6. Colorado	None	None
7. Connecticut	616.16	Continuous loading until plunging failure...
8. Delaware	618.16	Continuous loading until plunging failure...
9. Florida	455-7.5.2	Tests shall be generally twice the design load...
10. Georgia	520.03.D.2	Loading per ASTM D1143...or 400% of the design load or 500 tons, whichever is the lesser.
11. Hawaii	None	None
12. Idaho	T-107	Loading until 2.5 times the design load.
13. Illinois	513.14(a)	50% of the load that produces a settlement of 1/4 inch after 48 hours.
14. Indiana	701.03(d)2	50% of the load that produces a settlement of 1/4 inch after 48 hours.

Table 1
Pile Load Test Requirements Based on State Highway Foundation Specifications (continued)

STATE	HIGHWAY FOUND. SPECS.	LOAD TEST REQUIREMENT
15. Iowa	2501.14	Loading until free movement indicates failure.
16. Kansas	Special Provisions	As indicated in the special provisions.
17. Kentucky	604.07(c)	Loading until a settlement of 1/4" is reached after continuous application of specified static load.
18. Louisiana	804.10(a)	Loading until 2 times the design load is reached, unloaded, and then reloaded to 2.5 times the design load.
19. Maine	501.04	Piles shall be tested to 3 times the design load.
20. Maryland	605.03.07	50% of the load that produces a settlement of 1/4 inch after 48 hours.
21. Massachu-setts	940.65b.1	Load tests equal to 2 times the design load.
22. Michigan	5.02.05	Piles shall be tested to 3 times the design load.
23. Minnesota	2452.3(D3b&c)	Type I - Loaded to 2 times the design load. Type II - Loaded to 4 times the design load.
24. Mississippi	803.06.4.2	Load shall be applied until 2.5 times the design load is reached.
25. Missouri	702.4.9	50% of the load that produces a settlement of 1/4 inch after 48 hours.
26. Montana	None	None
27. Nebraska	703.11	Load tests shall be in accordance with ASTM D1143.
28. Nevada	508.03.07	Special Provisions
29. New Hampshire	3.7.1.1.2	A test load equal to 200% of the design load shall be applied.
30. New Jersey	505.07(b)	Load pile as directed in the Supplemental Specifications.
31. New Mexico	505.036(8)	Load pile until the yield point is reached.
32. New York	551.3.01EA11	As specified by Deputy Chief Engineer for Structures (D.C.E.S.)
33. North Carolina	450-9	Load to not less than the design load.
34. North Dakota	None	None

Table 1
Pile Load Test Requirements Based on State Highway Foundation Specifications (continued)

STATE	HIGHWAY FOUND. SPECS.	LOAD TEST REQUIREMENT
35. Ohio	506.03	Load shall be applied until the yield point is reached.
36. Oklahoma	None	None
37. Oregon	None	None
38. Pennsylvania	1005.3(f)	As specified in the load test proposal.
39. Rhode Island	804.03.3	Load to 200% of the design load.
40. South Carolina	711.08	Load test piles as directed in the Special Provisions.
41. South Dakota	None	None
42. Tennessee	606.08	Load to 150% of the bearing values shown on the contract drawings.
43. Texas	405.4	Tests loads shall be carried to failure.
44. Utah	502.04	Tests loads shall be carried to failure.
45. Vermont	505.04(b)1	Test loads shall be twice the design load.
46. Virginia	403.10	Load to 200% of the design load.
47. Washington	None	None
48. West Virginia	616.8.1	50% of the load that produces a settlement of 1/4 inch.
49. Wisconsin	None	None
50. Wyoming	Unknown	Unknown

Reference: Deep Foundations Institute, 1988a, b

The survey of Table 1 indicates that only 8 states require pile load testing to failure or "yield," 10 states require load testing the pile to twice the design load, and 9 states require load testing the pile to other factors ranging from one to four times the design load. Numerous states, while not requiring load testing to failure, have other provisions for conducting load tests.

2.5 THE NEED FOR PILE BEARING CAPACITY EVALUATION BASED ON NON-FAILED LOAD TESTS

Following the execution of "proof tests," the actual pile capacity, in most cases, remains unknown. The actual factor of safety, therefore, also remains unknown, resulting in:

- Overdesign and hence unnecessary expenses;
- An unknown factor of safety when modifications or changes in the design take place; and

- The inability of design engineers to gain experience with pile behavior since very little knowledge is acquired if a pile is not tested to failure.

The necessary solution to this problem would be the modification of the building codes to mandate load testing to failure. Being unlikely, an analysis is proposed in the form of an analytical method capable of extrapolating the measured load-settlement relations beyond the maximum tested load.

CHAPTER 3: METHOD OF APPROACH

3.1 OVERVIEW

Three different methods to extrapolate the failure load from non-failed load tests were investigated. The methods were:

- Brinch-Hansen's Method.
- Chin's Method.
- The Proposed Method.

Paikowsky et al. (1994) has presented an extensive database, including cases of driven piles load-tested to failure. Sixty-three of the failure load tests compiled in data set PD/LT were examined using the above three methods. The three methods and their rationales are described in this chapter. The examination of the methods was conducted based on the principles described in the following section.

3.2 PRINCIPLE OF EVALUATION

In order to evaluate the extrapolated failure load using the above three methods, the actual load test was analyzed as if it was carried out only to a certain point of the existing load-displacement curve. These points were determined in two ways:

(1) By eliminating portions of the load test data. During the analysis, 25%, 33%, 50%, 75%, and 100% of the load test data was analyzed using Chin's, Brinch-Hansen's, and the Proposed Methods. The analysis began with 100% of the load test data and was subsequently decreased to 25% of the data. For each portion of the data analyzed, the failure loads generated by Chin's, Brinch-Hansen's, and the Proposed Methods were compared with the actual (real) load settlement behavior.
(2) By eliminating portions of the load test data related to 25%, 33%, 50%, 75%, and 100% of the representative pile's static bearing capacity as discussed in Section 2.3.9.

The results of both approaches were divided by the final ultimate capacity of the pile as determined from the actual load test using the representative capacity (see section 2.3.9), and separately, using Davisson's criterion. The ultimate bearing capacity taken as the representative capacity was determined by averaging the capacity loads generated by Davisson's criterion, the Shape of Curve Method, the Limited Total Settlement Methods, and DeBeer's Log-Log Method. Since Davisson's criterion is commonly applied and is an objective reproducible procedure, this criterion was applied to the extrapolated load-settlement relationship. The ratio between the extrapolated capacity and the actual one was used as an indicative measure of accuracy. A number equal to 1 indicates perfect agreement (prediction) between the extrapolated value and the actual load test derived capacity. A number greater than 1 indicates an overprediction of the extrapolated value, while a number less than 1 indicates an underprediction. Underpredicted extrapolated values are conservative and, therefore, more desirable than overpredicted values.

3.3 CHIN'S METHOD

The inverse slope of the plot of displacement divided by load versus displacement is the Chin failure load. The method was previously discussed in Section 2.3.7, and is illustrated in Figure 5.

3.4 BRINCH-HANSEN'S METHOD

The Brinch-Hansen Method, as described in Section 2.3.6, was used to analyze the compiled to-failure pile load tests. The method was previously illustrated in Figure 4 and its ability to extrapolate pile capacity is based on the aforementioned reasons.

3.5 THE PROPOSED METHOD

The Proposed Method's initial steps are similar to Chin's Method. Given the load versus settlement results from the load test to failure, each displacement value is divided by its corresponding load. Values of displacement divided by load are plotted versus displacement (Δ/P vs. Δ). After some initial scatter, the values eventually form a straight line. A sample plot is shown in Figure 5.

The data is then subjected to a linear regression analysis to determine the best-fit line ratio and the coefficient of regression. The value of displacement divided by the load (x) is considered the controlled variable, while the displacement (y) is considered to be the dependent variable. The coefficient of regression (r^2) is a measure of the dependence of y on x. The best-fit line was developed by Gauss and the line is fitted through the given points such that the sum of the squares of the distances to those points from the straight line is minimal (Grossman, 1984). The distance from the point to the line is measured in the vertical direction.

The coefficient of regression varies between zero and 1, with zero indicating that no line is obtainable, and 1 being a perfect best-fit line. Data points at the beginning of the plotted line (from the plot of displacement divided by load versus displacement) are eliminated until a regression coefficient of 0.8 or greater is produced.

With a coefficient of regression of 0.8 or greater, the general obtained equation of the line is:

$$y = ax + b \tag{3.1}$$

and

$$y = \frac{\Delta}{P} \tag{3.2}$$

$$x = \Delta \tag{3.3}$$

where:

	y	=	displacement divided by load
	a	=	slope of the line

x , Δ	=	displacement of pile top
b	=	intercept of the best-fit line through the y-axis
P	=	load corresponding to the displacement

Substituting gives:

$$\frac{\Delta}{P} = a\Delta + b \qquad (3.4)$$

Δ, yields:

$$\Delta = \frac{b}{\left(\frac{1}{P} - a\right)} \qquad (3.5)$$

The slope (m) and intercept (c) values are obtained from the linear best-fit analysis. Using Equation 3.5, load values (from the original load test) were used and the equation was solved for the displacement of the pile (Δ) for the 100%, 75%, 50%, 33%, and 25% cases for both the percent of data and percent static load case.

Since Davisson's criterion is often used and its rationale allows for pile geometry considerations, Equation 3.4 was used in conjunction with Davisson's criterion to mathematically determine the pile's ultimate capacity based on the constructed load-settlement relations and Davisson's criterion. From Davisson's analysis, the equation of Davisson's line is known to be:

$$\Delta = X + SP_{METH} \qquad (3.6)$$

where:

Δ	=	displacement of pile top at the capacity associated with Davisson's criterion
X	=	0.15 + B/120 (offset)
S	=	L/EA.
P_{METH}	=	extrapolated pile's ultimate capacity load based on Davisson's criterion.
B	=	pile diameter (inches)
L	=	pile length
E	=	elastic compression of the pile material
A	=	cross-sectional area of the pile

Substituting Equation 3.6 into Equation 3.5, and solving for P_{METH} (Davisson's ultimate capacity), yields:

$$P_{METH} = \frac{-B \pm \sqrt{B^2 + 4AX}}{2A} \qquad (3.7)$$

where:

P_{METH}	=	Davisson's ultimate capacity
B	=	aX + b - S
A	=	aS

The resultant P_{METH} was compared to the static load as actually measured in the original load test. The accuracy of the method P_{METH} is discussed in Chapter 6: Analysis of the Proposed Method.

CHAPTER 4: DATABASE

4.1 DATABASE PD/LT

The pile cases analyzed here have been gathered at the University of Massachusetts at Lowell. The database PD/LT contains information on 120 piles monitored during driving, followed by a static load test to failure. The data was obtained from various sources and reflected variable combinations of soil pile driving systems.

In order to facilitate the analysis of the pile data, all of the load-displacement relations were digitized using the program DIGITIZE, developed at the University of Massachusetts at Lowell by Chernauskas and Paikowsky. The curves were then re-plotted using the graphics software GRAPHER and were then analyzed.

4.2 CURRENT DATABASE

The current database includes 63 piles obtained from the PD/LT database. Thirty-six cases were obtained from the original PD/LT database presented by Paikowsky et al. (1994). Twenty-seven cases were obtained from the expanded database presented by Paikowsky and LaBelle (1994). The current database includes different pile types (open-end piles, pre-stressed concrete piles, and steel H-piles among others). Table 2 provides basic information for each analyzed pile, including pile geometry, the pile type, the cross-sectional dimensions, and the penetration depth at the time of the analysis. The case number is the pile number in the original data set PD/LT.

Table 2
Database Pile Information

Pile Number[1]	Case No.[2]	FHWA No.[3]	Pile Type[4]	Pile Area[5] (sq. in)	Length[6] (ft)	Penetration Depth[7] (ft)	Load Test Type[8]	Pile Capacity (kip)					
								Davisson	Shape of Curve	Δ=1"	Δ=0.1B	DeBeer	Static
1	fwa (t-1)	37	CEP 48"	111.3	152	24.8	SM	1300	1300	1300	NA	1150	1300
2	fwb (t-2)	39	CEP 48"	111.3	140	109	SM	1000	1200	1000	NA	1497	1225
3	ct1	41	PSC 18"sq	324	63	64	S	370	325-350	419	NA	334	345
4	ct2	44	PSC 18"sq	324	73	75	S	550	480-550	588	NA	541	535
5	ct3	47	PSC 24"sq	489	63	64	S	625	500-640	679	NA	648	614
6	fv15	55	HP14X73	21.4	92	75	Q	315	300-350	372	440	246	315
7	fv10	57	HP14X74	22.4	92	90	Q	345	230-300	400	484	240	313
8	fmn2	59	HP14X75	23.4	97	96	Q	765	720-740	722	752	724	740
9	fp5	61	Monotube	7	34.5	23.6	Q	243	220-235	NA	NA	211	227
10	fkg	63	PSC 14"sq	196	72	34.7	Q	366	480-520	530	NA	475	465
11	ca3/8	73	CEP10.24 "	8.74	73.8	64.4	Q	189	200-230	271	271	227	230
12	wc3	79	PSC 24"sq	576	48.4	27.5	FQ	610	550-650	NA	NA	620	610
13	wb9	84	PSC 30"sq	645.5	130	128.5	FQ	900	830-880	925	NA	855	884
14	wb15	85	PSC 30"sq	645.5	105	103.6	FQ	820	740-790	833	NA	767	766
15	35-1	91	HP12x74	21.8	60.1	48.5	S	322	320-350	354	366	318	325
16	35-4	92	CEP12.75 "	9.8	52.2	48.2	S	330	300-330	334	342	314	320
17	35-5	93	HP12x74	21.8	100.2	90.5	S	612	580-620	600	608	600	600
18	35-6	94	CEP12.75 "	9.8	105.4	90	S	600	500-550	530	548	526	530
19	35-7	95	T.Timber	157	44.4	41.6	S	122	120-170	152	146	144	142

Table 2
Database Pile Information (continued)

Pile Number[1]	Case No.[2]	FHWA No.[3]	Pile Type[4]	Pile Area[5] (sq. in)	Length[6] (ft)	Penetration Depth[7] (ft)	Load Test Type[8]	Pile Capacity (kip)					
								Davisson	Shape of Curve	Δ=1"	Δ=0.1B	DeBeer	Static
20	35-10	96	PSC 12"sq	144	50	48	S	402	370-420	432	444	376	400
21	a54	124	RC10.8" sq	147.2	67.9	67.6	CRP	652	630-652	618	638	639	638
22	a147	126	RC10.8" sq	117.22	67.9	67.6	CRP	558	547	555	560	540	552
23	a3	140	VC 24"sq	462.9	94	63.4	FQ	958	850-940	960	NA	958	939
24	a25	149	VC 24"sq	463.9	106	55.1	FQ	715	750-840	840	NA	845	800
25	fsb16	153	PSC 18"sq	324	65	60.6	FQ	315	275-315	350	NA	272	308
26	a41	156	VC 24"sq	462.9	91	52	FQ	524	500-525	540	NA	536	530
27	a101	159	VC 24"sq	462.9	88	61.8	FQ	812	800-840	NA	NA	800	810
28	a133	162	VC 24"sq	462.9	130	103.9	FQ	808	780-860	810	NA	866	826
29	a145	164	VC 24"sq	462.9	132	102.9	FQ	976	860-950	975	NA	913	940
30	cb3	167	PSC 24"sq	576	77.9	77	FQ	500	488-500	470	NA	472	484
31	cb11	171	VC 30"sq	645.53	97.6	85.7	FQ	1435	1370	1430	NA	1364	1400
32	cb17	173	VC 30"sq	646.53	97	77.7	FQ	1515	1400	1500	NA	1400	1453
33	cb23	177	VC 30"sq	647.53	96	80.3	FQ	643	640-810	732	NA	758	702
34	cb29	179	VC 30"sq	648.53	95.1	84.5	FQ	917	870-960	960	NA	910	926
35	cb35	181	VC 30"sq	649.53	97.1	78.5	FQ	1463	1400	1490	NA	1400	1437
36	cb41	184	VC 30"sq	650.53	102.3	64.7	FQ	1410	1380	1435	NA	1357	1396
37	cha1	1	CEP12.75"	14.6	137.8	123	Q	654	626-682	626	656	600-682	647
38	cha4	4	CEP12.75"	14.6	123.5	117	Q	506	488-506	506	504	506	504
39	chb2	5	HP12X73	18.4	157.3	155.3	Q	302	280-440	280	300	264-400	315
40	chb3	11	HP12X63	18.4	144.7	142.1	Q	200	176-246	212	224	186	214

Table 2
Database Pile Information (continued)

Pile Number[1]	Case No.[2]	FHWA No.[3]	Pile Type[4]	Pile Area[5] (sq. in)	Length[6] (ft)	Penetration Depth[7] (ft)	Load Test Type[8]	Pile Capacity (kip)					
								Davisson	Shape of Curve	Δ=1"	Δ=0.1B	DeBeer	Static
41	chc3	15	CEP 14"	67.5	156.5	155.2	Q	188	200-305	236	278	200-260	237
42	ch4	18	CEP 9.63"	15.6	162.9	142.5	Q	360	358-375	360	360	375	364
43	ch39	20	CEP 9.63"	16.4	147	142	Q	660	636-660	556	522	660	656
44	ch6-5b	23	CEP 9.63"	15.6	151.7	144	Q	376	338-376	376	376	376	372
45	ch95b	25	CEP 9.63"	15.6	163	139	Q	556	554	554	554	548	554
46	ch256	27	CEP 9.63"	15.6	145	140	Q	596	536-596	510	494	592	552
47	ch351	28	CEP 9.63"	15.6	158	156	Q	600	544-598	538	526	600	568
48	po2	29	PSC 18"sq	324	87	18.8	Q	274	276-334	324	362	272	284
49	er5	35	PSC 24"sq	576	104	85.2	Q	855	702-835	895	NA	800	830
50	bb13	40	VC 30"sq	746	143.9	92.8	Q	1006	900-1054	1044	NA	924	988
51	bb19	46	VC 30"sq	746	151.9	89	Q	1162	1000-1236	1218	NA	974-1200	1146
52	bb24	49	VC 30"sq	746	143.9	80.2	Q	1114	1000-1100	1124	NA	1084	1094
53	bb29	55	VC 30"sq	746	143.9		Q	1136	1138	1200	NA	1070	1134
54	abf6	57	PSC 24"sq	576	71	57.54	Q	752	620-744	872	912	858	816
55	abg13	59	PSC 24"sq	576	58		Q	1066	870-1044	1250	NA	818-1046	1052
56	abh2	60	PSC 24"sq	576	40.9	35.77	Q	566	486-600	670	NA	492-628	584
57	d1	66	PSC 9.7"sq	94.4	35.8	35.8	S	68	67	71	71	64	67
58	d2	67	PSC 9.7"sq	94.4	46.9	46.9	S	125	123	146	146	124	124
59	d3	68	PSC 9.7"sq	94.4	60	60	S	226	220	244	241	219	223

Table 2
Database Pile Information (continued)

Pile Number[1]	Case No.[2]	FHWA No.[3]	Pile Type[4]	Pile Area[5] (sq. in)	Length[6] (ft)	Penetration Depth[7] (ft)	Load Test Type[8]	Pile Capacity (kip)					
								Davisson	Shape of Curve	Δ=1"	Δ=0.1B	DeBeer	Static
60	d5	70	PSC 9.7" sq	94.4	62	62	S	236	220	265	263	223	228
61	mb1	72	PSC 16" sq	256	62	62	Q	807	771-938	916	NA	700	819
62	mb2	74	HP14x89	26.1	77	66	Q	897	867	785	959	870	872
63	mb3	75	OEP 16"	24.35	77	66	Q	932	937	831	985	956	928

1 - Pile number in the present research study.
Cases 1 through 36 obtained from Paikowsky et al., 1994.
Cases 37 through 63 obtained from Paikowsky and LaBelle, 1994.
2 - Case number used in the original references and database gathered at the University of Massachusetts - Lowell.
3 - Case number as used by Paikowsky et al., 1994.
4 - CEP or CP = closed-end pipe pile; HP = H-pile; OEP = opened-end pile; PSC = pre-stressed concrete pile; VC = voided concrete pile; RC = simple reinforced concrete pile.
5 - Cross-sectional area of pile at pile top.
6 - Length of pile below gauges during dynamic measurements.
7 - Length of pile penetration beneath the ground surface.
8 - Load test type: Q = quick test; SM = slow maintained; FQ = Florida modified quick; CRP = constant rate of penetration.

CHAPTER 5: THE PERFORMANCE OF THE EXISTING METHODS

5.1 OVERVIEW

Chapter 3.0 presented the concept concerning the extrapolation of the load-settlement data and the methods for its evaluation. Two of the methods available for determining the ultimate capacity (described in Chapter 2) can also be used for the projection of the load-settlement relations and hence the ultimate load. These methods include Chin's Method (presented in Section 2.3.8) and Brinch-Hansen's Method (presented in Section 2.3.7). The present chapter evaluates the ability of these two methods to serve as extrapolating methods under the proposed concept.

5.2 CHIN'S METHOD

Section 3.3 outlined the use of Chin's method in predicting the ultimate capacity of the pile. Using Chin's method, each of the 63 pile load test cases in data set PD/LT was analyzed individually in two ways: (1) using 25%, 33%, 50%, 75%, and 100% of the load-settlement curve's data points and (2) using the same ratios of the designated ultimate capacity.

Table 3 provides the results obtained from applying Chin's analysis to the entire set of load-displacement data points for the 63 pile cases analyzed. The first column lists the pile number in the current research study. The second column lists the case number as referenced in the complete data set PD/LT provided in the Federal Highway Administration Report by Paikowsky et al. (1994) (see Section 4.1 Data Base PD/LT). The third column lists the percentage of data points analyzed (25%, 33%, 50%, 75%, and 100%). The fourth column lists the slope of the best-fit line from the plot of displacement divided by load versus displacement. The slope of the line was obtained using all the load-displacement data points. The fifth column lists the designated static capacity of the pile determined from the five methods described in Section 2.3. The sixth column lists the inverse of the slope (fourth column), which is the ultimate capacity of the pile according to Chin's method. The seventh column lists the ratio between the ultimate capacity determined by Chin's method and the designated static bearing capacity. A number equal to 1 indicates perfect agreement between the designated static capacity and the Chin capacity. A number greater than 1 indicates a capacity by Chin's method greater than the designated static capacity.

Table 3
Analysis of Chin's Method Performance Using Ratios of Available Load-Test Data

Pile No.	Case No.	Data Analyzed (%)	Slope (in/kip/in) x10^3	Static Capacity of Pile (kip)	Chin's Ultimate Pile Capacity (kip)	Ratio of Chin's to Static Capacity
1	fwa(t-1)	100	0.28	1300	3571	2.75
		75	0.26		3846	2.96
		50	0.26		3846	2.96
		33	0.26		3846	2.96
		25	0.22		4545	3.50
2	fwb(t-2)	100	0.19	1225	5263	4.30
		75	0.18		5556	4.54
		50	0.23		4348	3.55
		33	0.33		3003	2.45
		25	0.58		1727	1.41
3	ct1	100	2.01	345	498	1.44
		75	1.87		535	1.55
		50	0.95		1057	3.06
		33	-2.15		--	--
		25	-0.48		--	--
4	ct2	100	1.44	535	693	1.29
		75	1.38		724	1.35
		50	1.65		606	1.13
		33	2.05		487	0.91
		25	2.05		488	0.91
5	ct3	100	1.35	614	743	1.21
		75	1.35		741	1.21
		50	1.47		681	1.11
		33	2.05		487	0.79
		25	2.74		365	0.59
6	fv15	100	1.56	315	641	2.04
		75	1.70		588	1.87
		50	2.13		470	1.49
		33	3.27		306	0.97
		25	4.39		228	0.72
7	fv10	100	0.97	313	1033	3.30
		75	1.10		908	2.90
		50	1.14		874	2.79
		33	1.50		666	2.13
		25	2.17		461	1.47
8	fmn2	100	0.86	740	1159	1.57
		75	0.64		1563	2.11
		50	0.71		1406	1.90
		33	0.78		1287	1.74
		25	0.77		1307	1.77

Table 3
Analysis of Chin's Method Performance Using Ratios of Available Load-Test Data (continued)

Pile No.	Case No.	Data Analyzed (%)	Slope (in/kip/in) x10^3	Static Capacity of Pile (kip)	Chin's Ultimate Pile Capacity (kip)	Ratio of Chin's to Static Capacity
9	fp5	100	2.68	227	373	1.64
		75	2.24		447	1.97
		50	2.27		440	1.94
		33	3.68		272	1.20
		25	5.59		179	0.79
10	fkg	100	1.18	465	845	1.82
		75	1.05		949	2.04
		50	1.54		648	1.39
		33	2.56		390	0.84
		25	3.56		281	0.60
11	ca3/8	100	2.40	230	416	1.81
		75	2.35		425	1.85
		50	2.90		345	1.50
		33	3.97		252	1.10
		25	4.08		245	1.07
12	wc3	100	1.02	610	981	1.61
		75	1.02		984	1.61
		50	1.27		790	1.29
		33	1.62		617	1.01
		25	1.89		530	0.87
13	wb9	100	0.95	884	1056	1.20
		75	0.92		1092	1.23
		50	0.93		1079	1.22
		33	1.08		925	1.05
		25	1.27		787	0.89
14	wb15	100	1.08	766	922	1.20
		75	1.02		984	1.29
		50	0.76		1310	1.71
		33	0.14		7146	9.33
		25	0.40		2492	3.25
15	35-1	100	2.26	325	443	1.36
		75	2.17		460	1.42
		50	1.63		612	1.88
		33	1.03		972	2.99
		25	-0.11		--	--
16	35-4	100	2.59	320	386	1.21
		75	2.59		387	1.21
		50	2.68		373	1.17
		33	3.61		277	0.87
		25	4.78		209	0.65

Table 3
Analysis of Chin's Method Performance Using Ratios of Available Load-Test Data (continued)

Pile No.	Case No.	Data Analyzed (%)	Slope (in/kip/in) x10^3	Static Capacity of Pile (kip)	Chin's Ultimate Pile Capacity (kip)	Ratio of Chin's to Static Capacity
17	35-5	100	1.30	600	770	1.28
		75	0.98		1026	1.71
		50	0.49		2033	3.39
		33	0.67		1486	2.48
		25	0.45		2222	3.70
18	35-6	100	1.52	530	659	1.24
		75	1.46		685	1.29
		50	1.58		631	1.19
		33	1.94		514	0.97
		25	2.54		394	0.74
19	35-7	100	4.63	142	216	1.52
		75	4.74		211	1.49
		50	4.80		208	1.47
		33	4.94		202	1.43
		25	4.94		203	1.43
20	35-10	100	1.88	400	531	1.33
		75	1.97		508	1.27
		50	1.87		535	1.34
		33	2.00		501	1.25
		25	2.08		480	1.20
21	a54	100	0.79	638	1263	1.98
		75	0.75		1326	2.08
		50	0.86		1167	1.83
		33	0.96		1047	1.64
		25	0.79		1271	1.99
22	a147	100	1.28	552	784	1.42
		75	0.72		1385	2.51
		50	0.72		1397	2.53
		33	0.79		1259	2.28
		25	1.20		833	1.51
23	a3	100	0.83	939	1203	1.28
		75	0.82		1224	1.30
		50	0.90		1116	1.19
		33	0.86		1159	1.23
		25	0.79		1263	1.35
24	a25	100	0.80	800	1244	1.55
		75	0.81		1241	1.55
		50	0.88		1131	1.41
		33	0.86		1168	1.46
		25	0.70		1425	1.78

Table 3
Analysis of Chin's Method Performance Using Ratios of Available Load-Test Data (continued)

Pile No.	Case No.	Data Analyzed (%)	Slope (in/kip/in) x10^3	Static Capacity of Pile (kip)	Chin's Ultimate Pile Capacity (kip)	Ratio of Chin's to Static Capacity
25	fsb16	100	4.99	308	200	0.65
		75	4.82		207	0.67
		50	3.85		260	0.84
		33	2.36		423	1.37
		25	3.57		280	0.91
26	a41	100	1.59	530	627	1.18
		75	1.50		665	1.26
		50	1.24		807	1.52
		33	0.80		1247	2.35
		25	1.47		682	1.29
27	a101	100	0.66	810	1522	1.88
		75	0.78		1280	1.58
		50	1.14		880	1.09
		33	1.53		652	0.81
		25	1.92		522	0.64
28	a133	100	0.81	826	1238	1.50
		75	0.91		1102	1.55
		50	1.32		760	1.07
		33	1.88		532	0.79
		25	2.01		498	0.63
29	a145	100	0.62	940	1623	1.73
		75	0.74		1344	1.43
		50	1.11		898	0.96
		33	1.44		695	0.74
		25	1.76		568	0.60
30	cb3	100	1.65	484	607	1.25
		75	1.59		628	1.30
		50	1.57		638	1.32
		33	1.54		650	1.34
		25	1.28		783	1.62
31	cb11	100	0.54	1400	1841	1.31
		75	0.37		2713	1.94
		50	0.43		2305	1.65
		33	0.49		2021	1.44
		25	0.63		1575	1.13
32	cb17	100	0.46	1453	2158	1.49
		75	0.37		2732	1.88
		50	0.42		2400	1.65
		33	0.53		1893	1.30
		25	0.66		1520	1.05

Table 3
Analysis of Chin's Method Performance Using Ratios of Available Load-Test Data (continued)

Pile No.	Case No.	Data Analyzed (%)	Slope (in/kip/in) x10^3	Static Capacity of Pile (kip)	Chin's Ultimate Pile Capacity (kip)	Ratio of Chin's to Static Capacity
33	cb23	100	1.08	702	926	1.32
		75	1.21		826	1.18
		50	1.53		652	0.93
		33	1.98		504	0.72
		25	2.19		457	0.65
34	cb29	100	1.78	926	563	0.61
		75	1.73		579	0.63
		50	1.90		527	0.57
		33	2.15		466	0.50
		25	3.49		286	0.31
35	cb35	100	0.96	1437	1041	0.72
		75	0.91		1101	0.77
		50	1.11		899	0.63
		33	1.28		780	0.54
		25	1.43		698	0.49
36	cb41	100	0.93	1396	1070	0.77
		75	0.97		1031	0.74
		50	1.40		714	0.51
		33	1.85		540	0.39
		25	2.09		478	0.34
37	cha1	100	1.04	647	957	1.48
		75	1.14		874	1.35
		50	1.58		632	0.98
		33	2.42		413	0.64
		25	3.19		314	0.48
38	cha4	100	2.23	504	448	0.89
		75	2.04		490	0.97
		50	1.85		541	1.07
		33	2.75		363	0.72
		25	3.63		275	0.55
39	chb2	100	1.37	315	731	2.32
		75	1.55		647	2.05
		50	1.87		535	1.70
		33	1.84		544	1.73
		25	2.02		496	1.57
40	chb3	100	2.68	214	374	1.75
		75	2.88		348	1.62
		50	3.02		332	1.55
		33	2.78		359	1.68
		25	1.89		529	2.47

Table 3
Analysis of Chin's Method Performance Using Ratios of Available Load-Test Data (continued)

Pile No.	Case No.	Data Analyzed (%)	Slope (in/kip/in) x10^3	Static Capacity of Pile (kip)	Chin's Ultimate Pile Capacity (kip)	Ratio of Chin's to Static Capacity
41	chc3	100	1.84	237	542	2.29
		75	1.89		528	2.23
		50	1.82		550	2.32
		33	1.42		705	2.98
		25	1.42		707	2.98
42	ch4	100	2.23	364	448	1.23
		75	2.04		490	1.35
		50	1.85		541	1.49
		33	2.75		363	1.00
		25	3.63		275	0.76
43	ch39	100	0.97	656	1035	1.58
		75	1.29		777	1.18
		50	2.01		498	0.76
		33	3.02		331	0.51
		25	3.90		257	0.39
44	ch6-5b	100	1.89	372	529	1.42
		75	2.30		435	1.17
		50	2.97		337	0.91
		33	3.52		284	0.76
		25	3.77		265	0.71
45	ch95b	100	1.23	554	812	1.46
		75	1.22		817	1.48
		50	1.72		583	1.05
		33	2.48		404	0.73
		25	3.14		318	0.57
46	ch256	100	1.20	552	836	1.51
		75	1.15		867	1.57
		50	1.72		581	1.05
		33	2.70		370	0.67
		25	3.53		283	0.51
47	ch351	100	1.13	568	887	1.56
		75	1.47		679	1.20
		50	2.17		461	0.81
		33	3.23		309	0.54
		25	4.48		223	0.39
48	po2	100	2.59	284	387	1.36
		75	2.77		361	1.27
		50	2.75		363	1.28
		33	2.64		379	1.33
		25	3.39		295	1.04

Table 3
Analysis of Chin's Method Performance Using Ratios of Available Load-Test Data (continued)

Pile No.	Case No.	Data Analyzed (%)	Slope (in/kip/in) x10^3	Static Capacity of Pile (kip)	Chin's Ultimate Pile Capacity (kip)	Ratio of Chin's to Static Capacity
49	er5	100	0.94	830	1065	1.28
		75	0.77		1300	1.57
		50	0.55		1827	2.20
		33	0.51		1967	2.37
		25	0.71		1402	1.69
50	bb13	100	0.68	988	1468	1.49
		75	0.64		1554	1.57
		50	0.70		1438	1.46
		33	1.09		918	0.93
		25	1.38		726	0.73
51	bb19	100	0.52	1146	1918	1.67
		75	0.54		1866	1.63
		50	0.59		1699	1.48
		33	0.58		1715	1.50
		25	0.51		1952	1.70
52	bb24	100	0.72	1094	1393	1.27
		75	0.39		2596	2.37
		50	0.29		3466	3.17
		33	0.34		2940	2.69
		25	0.28		3546	3.24
53	bb29	100	0.53	1134	1898	1.67
		75	0.43		2326	2.05
		50	0.24		4214	3.72
		33	0.06		17648	15.56
		25	-1.18		--	--
54	abf6	100	1.01	816	995	1.22
		75	1.01		987	1.21
		50	0.93		1076	1.32
		33	0.92		1093	1.34
		25	0.97		1029	1.26
55	abg13	100	0.62	1052	1601	1.52
		75	0.66		1511	1.44
		50	0.75		1326	1.26
		33	0.76		1310	1.25
		25	0.79		1266	1.20
56	abh2	100	1.24	584	809	1.38
		75	1.18		851	1.46
		50	1.07		936	1.60
		33	0.35		2892	4.95
		25	-2.22		--	--

Table 3
Analysis of Chin's Method Performance Using Ratios of Available Load-Test Data (continued)

Pile No.	Case No.	Data Analyzed (%)	Slope (in/kip/in) x10^3	Static Capacity of Pile (kip)	Chin's Ultimate Pile Capacity (kip)	Ratio of Chin's to Static Capacity
57	d1	100	13.09	67	76	1.14
		75	13.40		75	1.11
		50	12.66		79	1.18
		33	8.50		118	1.76
		25	8.34		120	1.79
58	d2	100	6.88	124	145	1.17
		75	6.69		149	1.21
		50	5.44		184	1.48
		33	4.72		212	1.71
		25	4.71		212	1.71
59	d3	100	3.43	223	291	1.31
		75	3.42		293	1.31
		50	3.07		326	1.46
		33	2.47		406	1.82
		25	2.38		420	1.88
60	d5	100	3.23	228	310	1.36
		75	3.17		316	1.38
		50	2.95		339	1.49
		33	3.07		326	1.43
		25	3.81		263	1.15
61	mb1	100	0.60	819	1678	2.05
		75	0.62		1622	1.98
		50	0.78		1278	1.56
		33	0.84		1194	1.46
		25	0.89		1119	1.37
62	mb2	100	0.31	872	3192	3.66
		75	0.21		4713	5.40
		50	0.20		5061	5.80
		33	0.30		3373	3.87
		25	0.34		2938	3.37
63	mb3	100	0.83	928	1211	1.30
		75	1.00		999	1.08
		50	1.27		788	0.85
		33	1.53		652	0.70
		25	1.82		550	0.59

Table 4 is similar in its structure to Table 3. The data in Table 4 that was used to determine the slope relates to the load-settlement data corresponding to the 25%, 33%, 50%, 75%, and 100% of the designated ultimate static capacity (while relating to percentile data in Table 3). As in Table 3, the predicted ultimate loads based on Chin's method are compared to the designated static load, presenting the ratio of the two.

Table 4
Analysis of Chin's Method Performance Using Ratios of the Designated Ultimate Capacity

Pile No.	Case No.	% of Designated Capacity	Slope (in/kip/in) x10^3	Static Capacity of Pile (kip)	Chin's Ultimate Pile Capacity (kip)	Ratio of Chin's to Static Capacity
1	fwa (t-1)	100	0.26	1300	3832	2.95
		75	0.20		4927	3.79
		50	0.05		20356	15.66
		33	--		--	--
		25	--		--	--
2	fwb (t-2)	100	0.19	1225	5181	4.23
		75	0.18		5464	4.46
		50	0.23		4348	3.55
		33	0.33		3003	2.45
		25	0.58		1727	1.41
3	ct1	100	1.53	345	655	1.90
		75	1.39		719	2.08
		50	0.39		2586	7.50
		33	--		--	--
		25	3.99		250	0.73
4	ct2	100	1.39	535	718	1.34
		75	1.70		589	1.10
		50	2.07		482	0.90
		33	1.80		554	1.04
		25	1.36		733	1.37
5	ct3	100	1.41	614	708	1.15
		75	1.81		552	0.90
		50	2.72		368	0.60
		33	4.26		234	0.38
		25	5.81		172	0.28
6	fv15	100	1.81	315	554	1.76
		75	2.29		437	1.39
		50	3.48		287	0.91
		33	5.47		183	0.58
		25	7.30		137	0.43
7	fv10	100	0.89	313	1124	3.59
		75	0.63		1594	5.09
		50	0.55		1830	5.85
		33	1.80		556	1.78
		25	3.01		333	1.06
8	fmn2	100	0.64	740	1560	2.11
		75	0.68		1464	1.98
		50	0.78		1289	1.74
		33	0.77		1301	1.76
		25	0.28		3537	4.78

Table 4
Analysis of Chin's Method Performance Using Ratios of the Designated Ultimate Capacity (continued)

Pile No.	Case No.	% of Designated Capacity	Slope (in/kip/in) x10^3	Static Capacity of Pile (kip)	Chin's Ultimate Pile Capacity (kip)	Ratio of Chin's to Static Capacity
9	fp5	100	1.60	227	626	2.76
		75	1.29		776	3.42
		50	1.30		767	3.38
		33	2.92		343	1.51
		25	3.50		286	1.26
10	fkg	100	0.76	465	1316	2.83
		75	0.85		1178	2.53
		50	1.34		744	1.60
		33	1.52		657	1.41
		25	1.59		629	1.35
11	ca3/8	100	2.37	230	422	1.84
		75	2.74		366	1.59
		50	3.78		264	1.15
		33	4.11		243	1.06
		25	4.38		228	0.99
12	wc3	100	1.33	610	750	1.23
		75	1.75		573	0.94
		50	2.43		411	0.67
		33	3.32		302	0.49
		25	4.08		245	0.40
13	wb9	100	0.91	884	1100	1.24
		75	0.97		1026	1.16
		50	1.20		835	0.94
		33	1.53		653	0.74
		25	1.49		669	0.76
14	wb15	100	0.79	766	1262	1.65
		75	0.71		1406	1.84
		50	0.53		1890	2.47
		33	--		--	--
		25	--		--	--
15	35-1	100	1.88	325	532	1.64
		75	1.88		533	1.64
		50	1.87		534	1.64
		33	0.11		8873	27.30
		25	--		--	--
16	35-4	100	2.68	320	373	1.16
		75	3.38		296	0.92
		50	5.17		193	0.60
		33	8.29		121	0.38
		25	11.21		89	0.28

Table 4
Analysis of Chin's Method Performance Using Ratios of the Designated Ultimate Capacity (continued)

Pile No.	Case No.	% of Designated Capacity	Slope (in/kip/in) x10^3	Static Capacity of Pile (kip)	Chin's Ultimate Pile Capacity (kip)	Ratio of Chin's to Static Capacity
17	35-5	100	0.80	600	1257	2.09
		75	0.71		1405	2.34
		50	0.61		1653	2.75
		33	0.71		1401	2.33
		25	0.56		1777	2.96
18	35-6	100	1.44	530	695	1.31
		75	1.61		620	1.17
		50	2.06		486	0.92
		33	3.28		305	0.58
		25	4.47		224	0.42
19	35-7	100	4.91	142	204	1.43
		75	4.94		203	1.43
		50	4.33		231	1.63
		33	6.21		161	1.13
		25	8.16		123	0.86
20	35-10	100	1.83	400	546	1.37
		75	1.97		507	1.27
		50	2.27		441	1.10
		33	3.23		310	0.77
		25	4.16		240	0.60
21	a54	100	0.75	638	1327	2.08
		75	0.82		1225	1.92
		50	0.92		1083	1.70
		33	0.79		1271	1.99
		25	0.64		1567	2.46
22	a147	100	0.79	552	1261	2.29
		75	0.73		1375	2.49
		50	1.01		989	1.79
		33	1.40		715	1.30
		25	--		--	--
23	a3	100	1.04	939	964	1.03
		75	1.33		750	0.80
		50	2.01		499	0.53
		33	2.89		346	0.37
		25	--		--	--
24	a25	100	1.16	800	861	1.08
		75	1.55		647	0.81
		50	2.39		419	0.52
		33	3.37		297	0.37
		25	4.15		241	0.30

Table 4
Analysis of Chin's Method Performance Using Ratios of the Designated Ultimate Capacity (continued)

Pile No.	Case No.	% of Designated Capacity	Slope (in/kip/in) x10^3	Static Capacity of Pile (kip)	Chin's Ultimate Pile Capacity (kip)	Ratio of Chin's to Static Capacity
25	fsb16	100	4.99	308	200	0.65
		75	4.99		200	0.65
		50	4.92		203	0.66
		33	4.35		230	0.75
		25	3.85		260	0.84
26	a41	100	1.09	530	922	1.74
		75	--		--	--
		50	--		--	--
		33	--		--	--
		25	--		--	--
27	a101	100	0.86	810	1161	1.43
		75	1.10		912	1.13
		50	1.67		600	0.74
		33	2.44		410	0.51
		25	3.26		307	0.38
28	a133	100	0.81	826	1227	1.49
		75	1.00		1002	1.10
		50	1.37		729	0.73
		33	1.72		581	0.50
		25	2.01		498	0.37
29	a145	100	0.82	940	1224	1.30
		75	1.08		929	0.99
		50	1.70		587	0.62
		33	2.50		400	0.43
		25	3.29		304	0.32
30	cb3	100	1.65	484	607	1.25
		75	1.59		628	1.30
		50	1.58		633	1.31
		33	1.54		650	1.34
		25	1.54		650	1.34
31	cb11	100	0.46	1400	2188	1.56
		75	0.37		2681	1.91
		50	0.43		2304	1.65
		33	0.54		1859	1.33
		25	0.64		1575	1.12
32	cb17	100	0.39	1453	2591	1.78
		75	0.40		2513	1.73
		50	0.49		2024	1.39
		33	0.66		1520	1.05
		25	0.78		1289	0.89

Table 4
Analysis of Chin's Method Performance Using Ratios of the Designated Ultimate Capacity (continued)

Pile No.	Case No.	% of Designated Capacity	Slope (in/kip/in) x10^3	Static Capacity of Pile (kip)	Chin's Ultimate Pile Capacity (kip)	Ratio of Chin's to Static Capacity
33	cb23	100	1.24	702	806	1.15
		75	1.53		652	0.93
		50	1.99		504	0.72
		33	2.19		457	0.65
		25	2.56		391	0.56
34	cb29	100	0.85	926	1175	1.27
		75	0.91		1094	1.18
		50	1.07		932	1.01
		33	1.30		767	0.83
		25	1.75		572	0.62
35	cb35	100	0.43	1437	2326	1.62
		75	0.49		2028	1.41
		50	0.56		1799	1.25
		33	0.60		1658	1.15
		25	0.72		1397	0.97
36	cb41	100	0.62	1396	1610	1.15
		75	0.85		1179	0.84
		50	1.26		792	0.57
		33	1.97		509	0.36
		25	2.42		413	0.30
37	cha1	100	1.04	647	965	1.49
		75	1.29		774	1.20
		50	1.91		524	0.81
		33	2.91		344	0.53
		25	3.84		261	0.40
38	cha4	100	1.27	504	785	1.56
		75	1.37		730	1.45
		50	1.27		789	1.57
		33	0.45		2232	4.43
		25	--		--	--
39	chb2	100	1.92	315	520	1.65
		75	1.92		520	1.65
		50	2.40		417	1.32
		33	2.88		347	1.10
		25	1.42		704	2.24
40	chb3	100	2.84	214	352	1.65
		75	1.49		673	3.15
		50	--		--	--
		33	--		--	--
		25	--		--	--

Table 4
Analysis of Chin's Method Performance Using Ratios of the Designated Ultimate Capacity (continued)

Pile No.	Case No.	% of Designated Capacity	Slope (in/kip/in) x10^3	Static Capacity of Pile (kip)	Chin's Ultimate Pile Capacity (kip)	Ratio of Chin's to Static Capacity
41	chc3	100	1.49	237	671	2.83
		75	1.39		719	3.04
		50	2.07		484	2.04
		33	4.10		244	1.03
		25	6.67		150	0.63
42	ch4	100	1.79	364	558	1.53
		75	2.36		423	1.16
		50	3.69		271	0.74
		33	6.27		159	0.44
		25	9.56		105	0.29
43	ch39	100	0.96	656	1047	1.60
		75	1.32		757	1.15
		50	2.13		470	0.72
		33	3.26		306	0.47
		25	4.33		231	0.35
44	ch6-5b	100	1.91	372	525	1.41
		75	2.49		402	1.08
		50	3.22		311	0.84
		33	3.68		272	0.73
		25	3.73		268	0.72
45	ch95b	100	1.13	554	883	1.59
		75	1.46		684	1.23
		50	2.09		479	0.86
		33	2.97		336	0.61
		25	3.70		271	0.49
46	ch256	100	1.24	552	807	1.46
		75	1.76		569	1.03
		50	2.63		381	0.69
		33	3.72		269	0.49
		25	4.95		202	0.37
47	ch351	100	1.19	568	838	1.47
		75	1.65		605	1.07
		50	2.43		412	0.72
		33	3.76		266	0.47
		25	5.26		190	0.33
48	po2	100	2.79	284	359	1.26
		75	2.64		379	1.33
		50	3.85		260	0.91
		33	--		--	--
		25	--		--	--

Table 4
Analysis of Chin's Method Performance Using Ratios of the Designated Ultimate Capacity (continued)

Pile No.	Case No.	% of Designated Capacity	Slope (in/kip/in) x10^3	Static Capacity of Pile (kip)	Chin's Ultimate Pile Capacity (kip)	Ratio of Chin's to Static Capacity
49	er5	100	0.93	830	1080	1.30
		75	0.81		1229	1.48
		50	0.71		1406	1.69
		33	1.03		968	1.17
		25	2.58		388	0.47
50	bb13	100	0.90	988	1115	1.13
		75	1.10		912	0.92
		50	1.93		519	0.53
		33	2.78		360	0.36
		25	4.19		239	0.24
51	bb19	100	0.78	1146	1279	1.12
		75	1.04		961	0.84
		50	1.58		631	0.55
		33	--		--	--
		25	--		--	--
52	bb24	100	0.84	1094	1198	1.09
		75	1.02		978	0.89
		50	1.24		809	0.74
		33	0.83		1211	1.11
		25	--		--	--
53	bb29	100	0.48	1134	2088	1.84
		75	0.48		2083	1.84
		50	0.55		1821	1.61
		33	0.66		1517	1.34
		25	0.73		1374	1.21
54	abf6	100	1.08	816	926	1.13
		75	1.24		810	0.99
		50	1.28		784	0.96
		33	1.56		641	0.79
		25	1.75		572	0.70
55	abg13	100	0.65	1052	1536	1.46
		75	0.72		1383	1.31
		50	0.77		1299	1.23
		33	0.78		1280	1.22
		25	0.84		1190	1.13
56	abh2	100	1.33	584	754	1.29
		75	1.73		578	0.99
		50	2.06		486	0.83
		33	2.01		498	0.85
		25	2.13		469	0.80

Table 4
Analysis of Chin's Method Performance Using Ratios of the Designated Ultimate Capacity (continued)

Pile No.	Case No.	% of Designated Capacity	Slope (in/kip/in) x10^3	Static Capacity of Pile (kip)	Chin's Ultimate Pile Capacity (kip)	Ratio of Chin's to Static Capacity
57	d1	100	10.86	67	92	1.37
		75	8.45		118	1.77
		50	7.57		132	1.97
		33	--		--	--
		25	--		--	--
58	d2	100	5.34	124	187	1.51
		75	4.72		212	1.71
		50	4.14		242	1.95
		33	--		--	--
		25	--		--	--
59	d3	100	2.66	223	376	1.68
		75	2.41		415	1.86
		50	2.43		412	1.85
		33	0.98		1016	4.56
		25	--		--	--
60	d5	100	2.84	228	352	1.55
		75	3.51		285	1.25
		50	4.68		214	0.94
		33	6.08		165	0.72
		25	7.00		143	0.63
61	mb1	100	0.66	819	1508	1.84
		75	0.79		1269	1.55
		50	0.84		1196	1.46
		33	1.00		998	1.22
		25	1.28		779	0.95
62	mb2	100	0.24	872	4202	4.82
		75	0.19		5348	6.13
		50	0.33		3012	3.45
		33	0.53		1880	2.16
		25	0.52		1942	2.23
63	mb3	100	0.77	928	1299	1.40
		75	0.93		1074	1.16
		50	1.20		833	0.90
		33	1.42		706	0.76
		25	1.67		600	0.65

Tables 5 and 6 provide a statistical analysis of Chin's prediction method based on the results presented in Tables 3 and 4, respectively. The tables list the average value and standard deviation for each data or load percentage analyzed. The number of cases is not identical for all load or data ratios as some rendered the method invalid.

Table 5
Average and Standard Deviation of the Ratio Between Chin's Method Capacity Prediction and the Designated Static Capacity Using Percentages of the Load-Settlement Data

Percentage of Data	100%	75%	50%	33%	25%
Number of Cases	63	63	63	62	59
Average	1.56	1.64	1.62	1.81	1.29
Standard Deviation	0.62	0.77	0.90	2.21	0.85

Table 6
Average and Standard Deviation of the Ratio Between Chin's Method Capacity Prediction and the Designated Static Capacity Using Percentages of the Static Capacity

Percentage of Data	100%	75%	50%	33%	25%
Number of Cases	63	62	61	56	49
Average	1.69	1.67	1.68	1.58	0.92
Standard Deviation	0.73	1.05	2.18	3.67	0.82

The information presented in Table 5, for the analysis using percentile of the load-settlement data, suggests that the average value for each category is greater than 1, with the greatest occurring at 33% of the data (1.81) and the least occurring at 25% of the data (1.29). The standard deviation is high for all cases, with the greatest occurring at 33% of the data and the least occurring at 100% of the data.

Examining Table 6 when using percentile of the designated static capacity, the results of Chin's method did not show better performance. The average for each percentage of the designated capacity is greater than 1, with an exception at 25% of the designated static capacity. At 25% of the designated static capacity, the average value is 0.92. The standard deviation is high for all cases and is the greatest at 33% and the lowest at 100%.

The data in Tables 5 and 6 indicates that Chin's method, on average, significantly overpredicts the designated static capacity of the pile. While more erratic values of the average and standard deviation may be expected as the percentage of data decreases, generally a reasonable correlation could be expected in the 100% case. As seen in

Tables 5 and 6, for the 100% case, the average ratio between Chin's method and the designated static capacity was 1.56 and 1.69, respectively. Chin's method overestimated the static capacity of the pile by more than 50%. The ratio increases as the percentage of data decreases (with the exception of 25% of the data), resulting in a greater overprediction. Additionally, in each table, in the 100% case, the standard deviations were 0.62 and 0.73, indicating large variations of the method performance for the analyzed piles. The obtained results suggest, therefore, that interpretation of pile capacity based on Chin's method either for a full load-displacement curve (pile loaded to failure) or for extrapolation purposes is inaccurate and unreliable.

5.3 BRINCH-HANSEN'S METHOD

Sections 2.3.7 and 3.4 outlined the use of the Brinch-Hansen method in interpreting and predicting the ultimate capacity of a pile. Using the Brinch-Hansen method, each of the 63 pile load test cases in data set PD/LT was analyzed individually using 25%, 33%, 50%, 75%, and 100% of the load-displacement test data. The data from the initial load test was plotted as the square root of displacement divided by load versus displacement. To remain consistent with Chin's method and the method proposed in this research, data were eliminated until a coefficient of regression of 0.8 or greater was obtained for the plotted relationship. The inverse slope of the remaining data points (when plotted as the square root of displacement divided by load versus displacement) was used to determine the Brinch-Hansen failure load. The process was completed analytically by solving the general equation of the line (Equation 3.1, Section 3.5), substituted into Equation 3.7 and using the program MathCad to solve it.

As described in Chapter 2, the Brinch-Hansen method was not analyzed using percentages of the designated static load, but the percentage of the data only.

Table 7 provides the results obtained from applying the Brinch-Hansen analysis to the 63 pile cases analyzed. The first column lists the pile number in the current research study. The second column lists the case number as referenced in the complete data set PD/LT provided in the Federal Highway Administration report by Paikowsky et al. (1994) (see Section 4.1, Data Base PD/LT). The third column lists the percentage of data analyzed. The fourth column lists the slope of the best-fit line of the plot of displacement divided by load versus displacement, squared. The fifth column lists the designated static capacity of the pile determined from the five methods described in Section 2.3. The sixth column lists the capacity of the pile as determined by the Brinch-Hansen method. The seventh and last column lists the ratio of the ultimate capacity determined by Brinch-Hansen's method and the designated static bearing capacity. A number equal to 1 indicates perfect agreement between the designated static capacity and the capacity determined by the Brinch-Hansen method. A number greater than 1 indicates a capacity by the Brinch-Hansen method of greater than the designated static capacity.

Table 7
Analysis of Brinch-Hansen's Method Performance Using Ratios of Available Load-Test Data

Pile No.	Case No.	Data Analyzed (%)	Static Capacity of Pile (kip)	Brinch Ultimate Pile Capacity (kip)	Ratio of Brinch to Static Capacity
1	fwa (t-1)	100	1300	1522	1.17
		75		1504	1.16
		50		1544	1.19
		33		1529	1.18
		25		1426	1.10
2	fwb (t-2)	100	1225	1794	1.46
		75		1727	1.41
		50		1532	1.25
		33		1210	0.99
		25		928	0.76
3	ct1	100	345	358	1.04
		75		366	1.06
		50		486	1.41
		33		1349	3.91
		25		875	2.54
4	ct2	100	535	522	0.98
		75		554	1.04
		50		802	1.50
		33		3554	6.64
		25		3784	7.07
5	ct3	100	614	603	0.98
		75		628	1.02
		50		859	1.40
		33		1672	2.72
		25		1021	1.66
6	fv15	100	315	330	1.05
		75		331	1.05
		50		330	1.05
		33		334	1.06
		25		333	1.06
7	fv10	100	313	323	1.03
		75		335	1.07
		50		1763	5.63
		33		1100	3.51
		25		858	2.74
8	fmn2	100	740	767	1.04
		75		789	1.07
		50		1094	1.48
		33		3177	4.29
		25		2785	3.76

Table 7
Analysis of Brinch-Hansen's Method Performance Using Ratios of Available Load-Test Data (continued)

Pile No.	Case No.	Data Analyzed (%)	Static Capacity of Pile (kip)	Brinch Ultimate Pile Capacity (kip)	Ratio of Brinch to Static Capacity
9	fp5	100	227	270	1.19
		75		293	1.29
		50		439	1.93
		33		1023	4.51
		25		790	3.48
10	fkg	100	465	448	0.96
		75		258	0.55
		50		301	0.65
		33		1832	3.94
		25		1373	2.95
11	ca3/8	100	230	289	1.26
		75		303	1.32
		50		384	1.67
		33		2121	9.22
		25		2022	8.79
12	wc3	100	610	614	1.01
		75		617	1.01
		50		624	1.02
		33		88	0.14
		25		636	1.04
13	wb9	100	884	904	1.02
		75		914	1.03
		50		978	1.11
		33		1198	1.36
		25		1587	1.80
14	wb15	100	766	827	1.08
		75		892	1.16
		50		2744	3.58
		33		842	1.10
		25		516	0.67
15	35-1	100	325	278	0.86
		75		280	0.86
		50		334	1.03
		33		1044	3.21
		25		775	2.38
16	35-4	100	320	321	1.00
		75		322	1.01
		50		340	1.06
		33		470	1.47
		25		2499	7.81

Table 7
Analysis of Brinch-Hansen's Method Performance Using Ratios of Available Load-Test Data (continued)

Pile No.	Case No.	Data Analyzed (%)	Static Capacity of Pile (kip)	Brinch Ultimate Pile Capacity (kip)	Ratio of Brinch to Static Capacity
17	35-5	100	600	584	0.97
		75		609	1.02
		50		4478	7.46
		33		1715	2.86
		25		1479	2.47
18	35-6	100	530	605	1.14
		75		4478	8.45
		50		3016	5.69
		33		1062	2.00
		25		649	1.22
19	35-7	100	142	110	0.77
		75		109	0.77
		50		109	0.77
		33		114	0.80
		25		128	0.90
20	35-10	100	400	337	0.84
		75		339	0.85
		50		424	1.06
		33		826	2.07
		25		429	1.07
21	a54	100	638	646	1.01
		75		659	1.03
		50		690	1.08
		33		700	1.10
		25		700	1.10
22	a147	100	552	531	0.96
		75		589	1.07
		50		3195	5.79
		33		2739	4.96
		25		2239	4.06
23	a3	100	939	886	0.94
		75		923	0.98
		50		994	1.06
		33		1155	1.23
		25		1239	1.32
24	a25	100	800	730	0.91
		75		725	0.91
		50		728	0.91
		33		731	0.91
		25		731	0.91

Table 7
Analysis of Brinch-Hansen's Method Performance Using Ratios of Available Load-Test Data (continued)

Pile No.	Case No.	Data Analyzed (%)	Static Capacity of Pile (kip)	Brinch Ultimate Pile Capacity (kip)	Ratio of Brinch to Static Capacity
25	fsb16	100	308	144	0.47
		75		153	0.50
		50		253	0.82
		33		1123	3.65
		25		895	2.91
26	a41	100	530	499	0.94
		75		494	0.93
		50		496	0.94
		33		517	0.98
		25		518	0.98
27	a101	100	810	679	0.84
		75		778	0.96
		50		3624	4.47
		33		3234	3.99
		25		2913	3.60
28	a133	100	826	705	0.85
		75		702	0.94
		50		692	4.39
		33		699	3.92
		25		703	3.53
29	a145	100	940	914	0.97
		75		935	0.99
		50		942	1.00
		33		954	1.01
		25		962	1.02
30	cb3	100	484	521	1.08
		75		637	1.32
		50		795	1.64
		33		716	1.48
		25		2323	4.80
31	cb11	100	1400	1244	0.89
		75		1315	0.94
		50		9064	6.47
		33		6360	4.54
		25		5760	4.11
32	cb17	100	1453	1332	0.92
		75		1326	0.91
		50		1532	1.05
		33		1795	1.24
		25		2156	1.48

Table 7
Analysis of Brinch-Hansen's Method Performance Using Ratios of Available Load-Test Data (continued)

Pile No.	Case No.	Data Analyzed (%)	Static Capacity of Pile (kip)	Brinch Ultimate Pile Capacity (kip)	Ratio of Brinch to Static Capacity
33	cb23	100	702	586	0.83
		75		593	0.84
		50		594	0.85
		33		600	0.85
		25		587	0.84
34	cb29	100	926	381	0.41
		75		387	0.42
		50		411	0.44
		33		477	0.52
		25		607	0.66
35	cb35	100	1437	592	0.41
		75		594	0.41
		50		617	0.43
		33		624	0.43
		25		633	0.44
36	cb41	100	1396	582	0.42
		75		572	0.41
		50		566	0.41
		33		566	0.41
		25		562	0.40
37	cha1	100	647	797	1.23
		75		1006	1.55
		50		6264	9.68
		33		3276	5.06
		25		6286	9.72
38	cha4	100	504	582	1.15
		75		736	1.46
		50		810	1.61
		33		1245	2.47
		25		751	1.49
39	chb2	100	315	330	1.05
		75		324	1.03
		50		319	1.01
		33		313	0.99
		25		314	1.00
40	chb3	100	214	190	0.89
		75		357	1.67
		50		127	0.59
		33		129	0.60
		25		129	0.60

Table 7
Analysis of Brinch-Hansen's Method Performance Using Ratios of Available Load-Test Data (continued)

Pile No.	Case No.	Data Analyzed (%)	Static Capacity of Pile (kip)	Brinch Ultimate Pile Capacity (kip)	Ratio of Brinch to Static Capacity
41	chc3	100	237	158	0.67
		75		157	0.66
		50		156	0.66
		33		155	0.65
		25		154	0.65
42	ch4	100	364	383	1.05
		75		388	1.07
		50		435	1.20
		33		1990	5.47
		25		1122	3.08
43	ch39	100	656	707	1.08
		75		1020	1.55
		50		4609	7.03
		33		4048	6.17
		25		4845	7.39
44	ch6-5b	100	372	--	NA
		75		--	NA
		50		--	NA
		33		--	NA
		25		--	NA
45	ch95b	100	554	--	NA
		75		--	NA
		50		--	NA
		33		--	NA
		25		--	NA
46	ch256	100	552	663	1.20
		75		769	1.39
		50		2783	5.04
		33		1321	2.39
		25		1115	2.02
47	ch351	100	568	1586	2.79
		75		1190	2.10
		50		1190	2.10
		33		1268	2.23
		25		1247	2.20
48	po2	100	284	292	1.03
		75		287	1.01
		50		347	1.22
		33		2446	8.61
		25		1292	4.55

Table 7
Analysis of Brinch-Hansen's Method Performance Using Ratios of Available Load-Test Data (continued)

Pile No.	Case No.	Data Analyzed (%)	Static Capacity of Pile (kip)	Brinch Ultimate Pile Capacity (kip)	Ratio of Brinch to Static Capacity
49	er5	100	830	810	0.98
		75		892	1.07
		50		2660	3.20
		33		1592	1.92
		25		1573	1.90
50	bb13	100	988	951	0.96
		75		961	0.97
		50		974	0.99
		33		1127	1.14
		25		1704	1.72
51	bb19	100	1146	1140	0.99
		75		1138	1.17
		50		1167	0.98
		33		1242	0.98
		25		1343	1.02
52	bb24	100	1094	1120	1.02
		75		1118	1.02
		50		1171	1.07
		33		1517	1.39
		25		1804	1.65
53	bb29	100	1134	729	0.64
		75		767	0.68
		50		949	0.84
		33		2031	1.79
		25		1255	1.11
54	abf6	100	816	1029	1.26
		75		1048	1.28
		50		1168	1.43
		33		1362	1.67
		25		1455	1.78
55	abg13	100	1052	1029	0.98
		75		1048	1.00
		50		1168	1.11
		33		1362	1.29
		25		1455	1.38
56	abh2	100	584	523	0.90
		75		522	0.89
		50		539	0.92
		33		650	1.11
		25		705	1.21

Table 7
Analysis of Brinch-Hansen's Method Performance Using Ratios of Available Load-Test Data (continued)

Pile No.	Case No.	Data Analyzed (%)	Static Capacity of Pile (kip)	Brinch Ultimate Pile Capacity (kip)	Ratio of Brinch to Static Capacity
57	d1	100	67	66	0.99
		75		67	1.00
		50		67	1.00
		33		67	1.00
		25		73	1.09
58	d2	100	124	123	0.99
		75		123	0.99
		50		126	1.02
		33		157	1.27
		25		235	1.90
59	d3	100	223	226	1.01
		75		225	1.01
		50		226	1.01
		33		240	1.08
		25		274	1.23
60	d5	100	228	234	1.03
		75		234	1.03
		50		239	1.05
		33		273	1.20
		25		416	1.82
61	mb1	100	819	808	0.99
		75		814	0.99
		50		823	1.00
		33		836	1.02
		25		837	1.02
62	mb2	100	872	963	1.10
		75		1055	1.21
		50		4603	5.28
		33		3703	4.25
		25		3174	3.64
63	mb3	100	928	798	0.86
		75		787	0.85
		50		792	0.85
		33		796	0.86
		25		813	0.88

Table 8 presents statistical analyses based on the information presented in Table 7 and lists the mean and standard deviation of the ratio between the capacity determined by Brinch-Hansen's method to the designated static capacity, for the 63 cases analyzed. As can be seen from the data presented in Table 7, the average for each percentage of data analyzed exceeds 1, except for the 100% case, where the average was 0.99. The method presents a good agreement with the designated capacity when applied to the analysis of load tests to failure. A large overprediction and/or unacceptable scatter was obtained, however, for incomplete data when used for extrapolation purposes. The standard deviation for each percentage of data varies widely, with the lowest standard deviation occurring in the 100% of the data case (0.31) and the greatest deviation occurring in the 25% of the data case (2.08).

Based on the above, it can be concluded that the Brinch-Hansen method, while reliable as a capacity interpretation method, cannot serve as a method for extrapolating non-failed load tests.

Table 8
Average and Standard Deviation of the Ratio Between Brinch-Hansen's Method, Capacity Prediction, and Designated Static Capacity Using Percentage of Load-Settlement Data.

Percentage of Data	100%	75%	50%	33%	25%
Number of Cases	61	61	61	61	61
Average	0.99	1.15	2.06	2.37	2.35
Standard Deviation	0.31	0.99	2.07	2.00	2.08

CHAPTER 6: ANALYSIS OF THE PROPOSED METHOD

6.1 OVERVIEW

This chapter presents the analyses of the proposed pile load-test extrapolation method, utilizing the pile cases in data set PD/LT. The analyses are carried out in the following stages:

(1) Determination of the ultimate capacity based on the ratios of available load-test data and ratios of the designated known ultimate capacity.
(2) Examination of the correlation between the prediction ratio of the results from the proposed method and the designated pile capacity and varying factors such as pile stiffness and pile slenderness.
(3) Statistical analyses of the obtained results, evaluating the performance of the proposed method and the associated risk of application, allowing the establishment of conclusions and recommendations.

6.2 PILE CAPACITY EVALUATION

6.2.1 The Analyzed Ranges

During a typical proof test, the actual capacity of the pile remains unknown. Therefore, the amount of load-displacement data necessary to complete the load test and the load test graph (the plot of load versus displacement) remains unknown as well. To account for this unknown, data was decreased from the original data (the 100% case) to ranges of the load and displacement data. The proposed method was repeated for each subsequent decrease in the range of data or load. The calculated capacity extrapolated for each range was then compared to the designated static capacity.

The performance evaluation of the proposed method was carried out in five ranges related to: (1) available data points for the entire load-settlement relations and (2) the designated ultimate capacity. The ranges include 25%, 33%, 50%, 75%, and 100% of either all the load-test data or the data related to the designated load. For the data-related cases, the 100% analysis means that the entire load-displacement relations were used. The 75% case under this category means that 75% of the available data points were used arbitrarily, regardless of its meaning in relation to the load-displacement relations. The other ranges of 50%, 33%, and 25% follow the same logic.

For the capacity-related cases, the 100% analysis means that the load-displacement data up to the designated static capacity was used. The 75% case under this category means that the data related to the load-settlement relationship from the start of the loading to the value of 75% of the designated pile capacity was used for the analysis. The other ranges of 50%, 33%, and 25% follow the same logic regardless of the actual number of data points associated with the analyzed loading level.

6.2.2 Detailed Procedures and Calculations

The results of the proposed method using ranges of the load-settlement data are presented in Table 9. See Section 3.5 for details of the equations used in the calculations. The first column provides the pile number. The second column lists the range of data used in the analysis. The third column lists the pile's stiffness, EA/L (elastic modulus of pile material multiplied by the cross-sectional area, all divided by pile length) of the pile. The fourth and fifth columns list the slope (a) and y-intercept (b) of the best-fit line from the plot of displacement divided by load versus displacement. The sixth column lists Davisson's offset line (X), which is equal to the pile diameter divided by 120, added to 0.15 inches (3.81 mm). The seventh column lists (S), which is the inverse of EA/L. The eighth column provides the values of coefficient A used in the analysis. Coefficient A is defined as the slope of the best-fit line (a) multiplied by the inverse of EA/L (S). The ninth column lists the values of coefficient B. Coefficient B is defined as the slope of the best-fit line (a) multiplied by Davisson's offset line (X) plus the y-intercept (b) minus S. Using the above variables, the calculated ultimate capacity of the proposed method is listed in the tenth column. The designated static capacity of the pile, calculated from the five methods listed in Section 2.3, is presented in the eleventh column. Davisson's ultimate pile capacity is listed in the twelfth column. The last column presents the ratio of the pile's capacity based on the proposed method to Davisson's pile capacity.

The results of the analysis using ranges of the static capacity are presented in Table 10. The table format is identical to that of Table 9. The results of Table 10, as described later in this chapter, have been adjusted considering such factors as pile stiffness and the length of the pile above the ground. The values presented in Table 9 have not been adjusted.

6.2.3 Elastic Modulus and Free-Length Adjustments

(a) Elastic Modulus Adjustments

The data for several of the concrete-filled steel piles listed in Table 10 had been adjusted to account for the combined elastic modulus. A combined modulus of elasticity was computed as a combination of a modulus of elasticity of 3000 pounds per square inch (psi) (20.67 MPa) for concrete and 30,000 psi (206.7 MPa) for steel. The following procedures were carried out:

(1) Determine the thickness of the steel pipe, based on the known cross-sectional area and outside diameter.

Table 9
Analysis of the Proposed Method Performance Using Percentages of Load-Test Data

Pile No.	Percent of Data	EA/L (lbs/sq.in)	a (x 1000)	b (x 1000)	X	S (x 1000)	A (x10-6)	B (x 10-5)	Method P	Static P	Davisson's P	Meth. P/Dav. P
1	100	1831	0.28	0.59	0.55	0.55	0.02	2.01	1347	1300	1300	1.04
	75		0.26	0.61	0.55	0.55	0.01	2.10	1357			1.04
	50		0.26	0.62	0.55	0.55	0.01	2.13	1364			1.05
	33		0.26	0.62	0.55	0.55	0.01	2.12	1367			1.05
	25		0.22	0.64	0.55	0.55	0.01	2.12	1432			1.10
2	100	1987	0.19	0.76	0.55	0.50	0.01	3.58	1167	1225	1000	1.17
	75		0.18	0.76	0.55	0.50	0.01	3.60	1174			1.17
	50		0.23	0.73	0.55	0.50	0.01	3.52	1137			1.14
	33		0.33	0.67	0.55	0.50	0.02	3.51	1045			1.05
	25		0.58	0.53	0.55	0.50	0.03	3.41	908			0.91
3	100	2584	2.01	0.34	0.30	0.39	0.08	5.55	360	345	370	0.97
	75		1.87	0.36	0.30	0.39	0.07	5.37	372			1.01
	50		0.95	0.45	0.30	0.39	0.04	3.49	546			1.48
	33		-2.15	0.59	0.30	0.39	-0.08	-4.45	--			--
	25		-0.48	0.53	0.30	0.39	-0.02	-0.04	--			--
4	100	2311	1.44	0.23	0.30	0.43	0.06	2.32	532	535	550	0.97
	75		1.38	0.24	0.30	0.43	0.06	2.24	546			0.99
	50		1.65	0.22	0.30	0.43	0.07	2.84	479			0.87
	33		2.05	0.20	0.30	0.43	0.09	3.88	402			0.73
	25		2.05	0.20	0.30	0.43	0.09	3.85	404			0.73
5	100	4031	1.35	0.13	0.35	0.25	0.03	3.50	626	614	625	1.00
	75		1.35	0.13	0.35	0.25	0.03	3.50	625			1.00
	50		1.47	0.12	0.35	0.25	0.04	3.81	588			0.94
	33		2.05	0.09	0.35	0.25	0.05	5.61	444			0.71
	25		2.74	0.07	0.35	0.25	0.07	7.84	344			0.55
6	100	581	1.56	1.12	0.27	1.72	0.27	-1.89	352	315	315	1.12
	75		1.70	1.07	0.27	1.72	0.29	-1.93	337			1.07
	50		2.13	1.00	0.27	1.72	0.37	-1.52	292			0.93
	33		3.27	0.89	0.27	1.72	0.56	0.38	214			0.68
	25		4.39	0.82	0.27	1.72	0.75	2.65	171			0.54

Table 9
Analysis of the Proposed Method Performance Using Percentages of Load-Test Data (continued)

Pile No.	Percent of Data	EA/L (lbs/sq.in)	a (x 1000)	b (x 1000)	X	S (x 1000)	A (x10-6)	B (x 10-5)	Method P	Static P	Davisson's P	Meth. P/Dav. P
7	100	581	0.97	1.54	0.27	1.72	0.17	0.81	377	313	345	1.09
	75		1.10	1.49	0.27	1.72	0.19	0.62	359			1.04
	50		1.14	1.48	0.27	1.72	0.20	0.61	353			1.02
	33		1.50	1.43	0.27	1.72	0.26	1.06	302			0.87
	25		2.17	1.36	0.27	1.72	0.37	2.18	240			0.69
8	100	569	0.86	0.68	0.27	1.76	0.15	-8.47	783	740	765	1.02
	75		0.64	0.77	0.27	1.76	0.11	-8.21	973			1.27
	50		0.71	0.75	0.27	1.76	0.12	-8.15	892			1.17
	33		0.78	0.75	0.27	1.76	0.14	-8.06	826			1.08
	25		0.77	0.75	0.27	1.76	0.13	-8.09	838			1.10
9	100	508	2.68	0.63	0.18	1.97	0.53	-8.72	282	227	243	1.16
	75		2.24	0.69	0.18	1.97	0.44	-8.92	325			1.34
	50		2.27	0.69	0.18	1.97	0.45	-8.82	319			1.31
	33		3.68	0.62	0.18	1.97	0.73	-7.02	211			0.87
	25		5.59	0.56	0.18	1.97	1.10	-4.27	147			0.60
10	100	1174	1.18	0.75	0.27	0.85	0.10	2.14	419	465	366	1.14
	75		1.05	0.79	0.27	0.85	0.09	2.17	438			1.20
	50		1.54	0.72	0.27	0.85	0.13	2.77	357			0.98
	33		2.56	0.62	0.27	0.85	0.22	4.56	260			0.71
	25		3.56	0.56	0.27	0.85	0.30	6.61	207			0.57
11	100	296	2.40	1.30	0.24	3.38	0.81	-15.09	287	230	189	1.52
	75		2.35	1.31	0.24	3.38	0.79	-15.09	291			1.54
	50		2.90	1.25	0.24	3.38	0.98	-14.49	246			1.30
	33		3.97	1.17	0.24	3.38	1.34	-12.75	188			1.00
	25		4.08	1.16	0.24	3.38	1.38	-12.56	184			0.97
12	100	6587	1.02	0.28	0.35	0.15	0.02	4.81	609	610	610	1.00
	75		1.02	0.28	0.35	0.15	0.02	4.81	609			1.00
	50		1.27	0.25	0.35	0.15	0.02	5.45	539			0.88
	33		1.62	0.24	0.35	0.15	0.02	6.50	459			0.75
	25		1.89	0.23	0.35	0.15	0.03	7.36	410			0.67

Table 9
Analysis of the Proposed Method Performance Using Percentages of Load-Test Data (continued)

Pile No.	Percent of Data	EA/L (lbs/sq.in)	a (x 1000)	b (x 1000)	X	S (x 1000)	A (x10-6)	B (x 10-5)	Method P	Static P	Davisson's P	Meth. P/Dav. P
13	100	2263	0.95	0.14	0.40	0.44	0.04	0.72	895	884	900	0.99
	75		0.92	0.14	0.40	0.44	0.04	0.66	915			1.02
	50		0.93	0.14	0.40	0.44	0.04	0.70	906			1.01
	33		1.08	0.13	0.40	0.44	0.05	1.25	793			0.88
	25		1.27	0.13	0.40	0.44	0.06	1.95	688			0.76
14	100	2759	1.15	0.05	0.40	0.36	0.04	1.42	824	766	820	1.01
	75		1.15	0.05	0.40	0.36	0.04	1.42	825			1.01
	50		1.16	0.04	0.40	0.36	0.04	1.41	821			1.00
	33		1.18	0.03	0.40	0.36	0.04	1.41	816			0.99
	25		1.19	0.03	0.40	0.36	0.04	1.41	813			0.99
15	100	907	2.26	0.65	0.25	1.10	0.25	1.09	296	325	322	0.92
	75		2.17	0.68	0.25	1.10	0.24	1.19	299			0.93
	50		1.63	0.79	0.25	1.10	0.18	0.97	347			1.08
	33		1.03	0.86	0.25	1.10	0.11	0.10	465			1.44
	25		-0.11	0.93	0.25	1.10	-0.01	-2.02	--			--
16	100	470	2.59	0.45	0.26	2.13	0.55	-10.13	326	320	330	0.99
	75		2.59	0.45	0.26	2.13	0.55	-10.13	327			0.99
	50		2.68	0.44	0.26	2.13	0.57	-10.05	318			0.96
	33		3.61	0.35	0.26	2.13	0.77	-8.55	247			0.75
	25		4.78	0.29	0.26	2.13	1.02	-6.14	192			0.58
17	100	544	1.30	0.61	0.25	1.84	0.24	-9.09	566	600	612	0.92
	75		0.98	0.74	0.25	1.84	0.18	-8.58	683			1.12
	50		0.49	0.86	0.25	1.84	0.09	-8.53	1177			1.92
	33		0.67	0.91	0.25	1.84	0.12	-7.56	849			1.39
	25		0.45	0.95	0.25	1.84	0.08	-7.73	1189			1.94
18	100	232	1.52	0.44	0.26	4.30	0.65	-34.77	598	530	600	1.00
	75		1.46	0.46	0.26	4.30	0.63	-34.72	619			1.03
	50		1.58	0.44	0.26	4.30	0.68	-34.58	573			0.95
	33		1.94	0.41	0.26	4.30	0.84	-33.97	471			0.79
	25		2.54	0.38	0.26	4.30	1.09	-32.77	364			0.61

Table 9
Analysis of the Proposed Method Performance Using Percentages of Load-Test Data (continued)

Pile No.	Percent of Data	EA/L (lbs/sq.in)	a (x 1000)	b (x 1000)	X	S (x 1000)	A (x10-6)	B (x 10-5)	Method P	Static P	Davisson's P	Meth. P/Dav. P
19	100	356	4.63	1.97	0.20	2.81	1.30	0.89	121	142	122	0.99
	75		4.74	1.89	0.20	2.81	1.33	0.28	122			1.00
	50		4.80	1.86	0.20	2.81	1.35	0.15	121			0.99
	33		4.94	1.83	0.20	2.81	1.39	0.09	120			0.98
	25		4.94	1.83	0.20	2.81	1.39	0.07	120			0.98
20	100	1313	1.88	0.40	0.25	0.76	0.14	1.09	381	400	402	0.95
	75		1.97	0.36	0.25	0.76	0.15	0.89	380			0.94
	50		1.87	0.38	0.25	0.76	0.14	0.83	391			0.97
	33		2.00	0.37	0.25	0.76	0.15	1.06	372			0.93
	25		2.08	0.36	0.25	0.76	0.16	1.23	360			0.90
21	100	702	0.79	0.85	0.24	1.43	0.11	-3.81	660	638	652	1.01
	75		0.75	0.87	0.24	1.43	0.11	-3.75	678			1.04
	50		0.86	0.85	0.24	1.43	0.12	-3.71	621			0.95
	33		0.96	0.84	0.24	1.43	0.14	-3.61	573			0.88
	25		0.79	0.85	0.24	1.43	0.11	-3.87	666			1.02
22	100	722	1.28	0.65	0.24	1.38	0.18	-4.26	508	552	558	0.91
	75		0.72	0.87	0.24	1.38	0.10	-3.40	688			1.23
	50		0.72	0.88	0.24	1.38	0.10	-3.38	691			1.24
	33		0.79	0.86	0.24	1.38	0.11	-3.35	644			1.15
	25		1.20	0.79	0.24	1.38	0.17	-3.04	482			0.86
23	100	2602	0.83	0.22	0.35	0.38	0.03	1.28	866	939	958	0.90
	75		0.82	0.23	0.35	0.38	0.03	1.27	872			0.91
	50		0.90	0.22	0.35	0.38	0.03	1.47	817			0.85
	33		0.86	0.22	0.35	0.38	0.03	1.37	842			0.88
	25		0.79	0.22	0.35	0.38	0.03	1.14	901			0.94
24	100	2258	0.80	0.40	0.35	0.44	0.04	2.38	712	800	715	1.00
	75		0.81	0.40	0.35	0.44	0.04	2.40	709			0.99
	50		0.88	0.39	0.35	0.44	0.04	2.56	673			0.94
	33		0.86	0.39	0.35	0.44	0.04	2.49	687			0.96
	25		0.70	0.40	0.35	0.44	0.03	2.04	783			1.09

Table 9
Analysis of the Proposed Method Performance Using Percentages of Load-Test Data (continued)

Pile No.	Percent of Data	EA/L (lbs/sq.in)	a (x 1000)	b (x 1000)	X	S (x 1000)	A (x10-6)	B (x 10-5)	Method P	Static P	Davisson's P	Meth. P/Dav. P
25	100	2773	4.99	6.30	0.30	0.36	0.18	74.34	40	308	315	0.13
	75		4.82	0.64	0.30	0.36	0.17	17.29	151			0.48
	50		3.85	0.68	0.30	0.36	0.14	14.72	175			0.56
	33		2.36	0.70	0.30	0.36	0.09	10.53	239			0.76
	25		3.57	0.72	0.30	0.36	0.13	14.24	181			0.57
26	100	2593	1.59	0.23	0.35	0.39	0.06	3.98	497	530	524	0.95
	75		1.50	0.28	0.35	0.39	0.06	4.17	496			0.95
	50		1.24	0.41	0.35	0.39	0.05	4.61	500			0.95
	33		0.80	0.62	0.35	0.39	0.03	5.18	516			0.99
	25		1.47	0.32	0.35	0.39	0.06	4.45	486			0.93
27	100	2745	0.66	0.47	0.35	0.36	0.02	3.35	698	810	812	0.86
	75		0.78	0.45	0.35	0.36	0.03	3.54	650			0.80
	50		1.14	0.40	0.35	0.36	0.04	4.31	536			0.66
	33		1.53	0.37	0.35	0.36	0.06	5.37	445			0.55
	25		1.92	0.34	0.35	0.36	0.07	6.49	382			0.47
28	100	1935	0.81	0.46	0.35	0.52	0.04	2.26	684	826	808	0.85
	75		0.91	0.44	0.35	0.52	0.05	2.39	646			0.80
	50		1.32	0.38	0.35	0.52	0.07	3.28	516			0.64
	33		1.88	0.35	0.35	0.52	0.10	4.87	400			0.49
	25		2.01	0.34	0.35	0.52	0.10	5.26	380			0.47
29	100	1907	0.62	0.42	0.35	0.52	0.03	1.06	889	940	976	0.91
	75		0.74	0.39	0.35	0.52	0.04	1.27	798			0.82
	50		1.11	0.35	0.35	0.52	0.06	2.10	615			0.63
	33		1.44	0.32	0.35	0.52	0.08	2.96	512			0.53
	25		1.76	0.30	0.35	0.52	0.09	3.89	440			0.45
30	100	3736	1.65	0.16	0.35	0.27	0.04	4.72	504	484	500	1.01
	75		1.59	0.17	0.35	0.27	0.04	4.57	517			1.03
	50		1.57	0.17	0.35	0.27	0.04	4.48	524			1.05
	33		1.54	0.17	0.35	0.27	0.04	4.39	532			1.06
	25		1.28	1.70	0.35	0.27	0.03	18.79	180			0.36

Table 9
Analysis of the Proposed Method Performance Using Percentages of Load-Test Data (continued)

Pile No.	Percent of Data	EA/L (lbs/sq.in)	a (x 1000)	b (x 1000)	X	S (x 1000)	A (x10-6)	B (x 10-5)	Method P	Static P	Davisson's P	Meth. P/Dav. P
31	100	4139	0.54	0.19	0.40	0.24	0.01	1.65	1228	1400	1435	0.86
	75		0.37	0.23	0.40	0.24	0.01	1.33	1501			1.05
	50		0.43	0.22	0.40	0.24	0.01	1.53	1355			0.94
	33		0.49	0.22	0.40	0.24	0.01	1.74	1241			0.86
	25		0.63	0.21	0.40	0.24	0.02	2.25	1041			0.73
32	100	3634	0.46	0.23	0.40	0.28	0.01	1.42	1301	1453	1515	0.86
	75		0.37	0.26	0.40	0.28	0.01	1.32	1443			0.95
	50		0.42	0.25	0.40	0.28	0.01	1.45	1339			0.88
	33		0.53	0.24	0.40	0.28	0.01	1.80	1151			0.76
	25		0.66	0.24	0.40	0.28	0.02	2.25	990			0.65
33	100	3986	1.08	0.26	0.40	0.25	0.03	4.45	645	702	643	1.00
	75		1.21	0.23	0.40	0.25	0.03	4.61	617			0.96
	50		1.53	0.18	0.40	0.25	0.04	5.47	532			0.83
	33		1.98	0.16	0.40	0.25	0.05	6.99	437			0.68
	25		2.19	0.15	0.40	0.25	0.05	7.73	402			0.63
34	100	3487	1.78	0.39	0.40	0.29	0.05	8.19	393	926	917	0.43
	75		1.73	0.41	0.40	0.29	0.05	8.14	396			0.43
	50		1.90	0.39	0.40	0.29	0.05	8.65	374			0.41
	33		2.15	0.38	0.40	0.29	0.06	9.51	344			0.38
	25		3.49	0.34	0.40	0.29	0.10	14.48	237			0.26
35	100	3553	0.96	0.44	0.40	0.28	0.03	5.42	574	1437	1463	0.39
	75		0.91	0.46	0.40	0.28	0.03	5.38	582			0.40
	50		1.11	0.44	0.40	0.28	0.03	6.00	524			0.36
	33		1.28	0.43	0.40	0.28	0.04	6.59	481			0.33
	25		1.43	0.42	0.40	0.28	0.04	7.14	447			0.31
36	100	3562	0.93	0.50	0.40	0.28	0.03	5.94	543	1396	1410	0.39
	75		0.97	0.50	0.40	0.28	0.03	6.07	532			0.38
	50		1.40	0.45	0.40	0.28	0.04	7.29	443			0.31
	33		1.85	0.42	0.40	0.28	0.05	8.81	372			0.26
	25		2.09	0.41	0.40	0.28	0.06	9.66	343			0.24

Table 9
Analysis of the Proposed Method Performance Using Percentages of Load-Test Data (continued)

Pile No.	Percent of Data	EA/L (lbs/sq.in)	a (x 1000)	b (x 1000)	X	S (x 1000)	A (x10-6)	B (x 10-5)	Method P	Static P	Davisson's P	Meth. P/Dav. P
37	100	256	1.04	0.62	0.26	3.91	0.41	-30.17	815	647	654	1.25
	75		1.14	0.60	0.26	3.91	0.45	-30.14	750			1.15
	50		1.58	0.53	0.26	3.91	0.62	-29.70	555			0.85
	33		2.42	0.46	0.26	3.91	0.95	-28.27	372			0.57
	25		3.19	0.42	0.26	3.91	1.25	-26.73	286			0.44
38	100	285	2.23	0.75	0.26	3.50	0.78	-21.78	368	504	506	0.73
	75		2.04	0.85	0.26	3.50	0.71	-21.28	390			0.77
	50		1.85	0.93	0.26	3.50	0.65	-21.02	419			0.83
	33		2.75	0.79	0.26	3.50	0.97	-20.04	297			0.59
	25		3.63	0.71	0.26	3.50	1.27	-18.65	233			0.46
39	100	299	1.37	2.04	0.25	3.35	0.46	-9.63	361	315	302	1.20
	75		1.55	1.86	0.25	3.35	0.52	-11.01	351			1.16
	50		1.87	1.66	0.25	3.35	0.63	-12.23	320			1.06
	33		1.84	1.66	0.25	3.35	0.62	-12.29	325			1.08
	25		2.02	1.62	0.25	3.35	0.68	-12.20	303			1.00
40	100	324	2.68	1.94	0.25	3.08	0.82	-4.76	205	214	200	1.03
	75		2.88	1.71	0.25	3.08	0.89	-6.57	209			1.04
	50		3.02	1.61	0.25	3.08	0.93	-7.17	207			1.04
	33		2.78	1.67	0.25	3.08	0.86	-7.15	217			1.09
	25		1.89	1.83	0.25	3.08	0.58	-7.77	284			1.42
41	100	970	1.84	2.60	0.27	1.03	0.19	20.56	117	237	188	0.62
	75		1.89	2.54	0.27	1.03	0.20	20.13	119			0.63
	50		1.82	2.58	0.27	1.03	0.19	20.34	118			0.63
	33		1.42	2.73	0.27	1.03	0.15	20.73	119			0.63
	25		1.42	2.73	0.27	1.03	0.15	20.76	119			0.63
42	100	239	2.23	0.75	0.23	4.19	0.94	-29.23	378	364	360	1.05
	75		2.04	0.85	0.23	4.19	0.85	-28.68	402			1.12
	50		1.85	0.93	0.23	4.19	0.77	-28.37	435			1.21
	33		2.75	0.79	0.23	4.19	1.15	-27.62	305			0.85
	25		3.63	0.71	0.23	4.19	1.52	-26.46	238			0.66

Table 9
Analysis of the Proposed Method Performance Using Percentages of Load-Test Data (continued)

Pile No.	Percent of Data	EA/L (lbs/sq.in)	a (x 1000)	b (x 1000)	X	S (x 1000)	A (x10-6)	B (x 10-5)	Method P	Static P	Davisson's P	Meth. P/Dav. P
43	100	279	0.97	0.89	0.23	3.58	0.35	-24.68	796	656	660	1.21
	75		1.29	0.79	0.23	3.58	0.46	-24.94	621			0.94
	50		2.01	0.65	0.23	3.58	0.72	-24.72	420			0.64
	33		3.02	0.53	0.23	3.58	1.08	-23.61	291			0.44
	25		3.90	0.46	0.23	3.58	1.40	-22.28	231			0.35
44	100	257	1.89	0.73	0.23	3.90	0.74	-27.27	441	372	376	1.17
	75		2.30	0.66	0.23	3.90	0.90	-27.01	371			0.99
	50		2.97	0.59	0.23	3.90	1.16	-26.19	294			0.78
	33		3.52	0.56	0.23	3.90	1.37	-25.27	251			0.67
	25		3.77	0.55	0.23	3.90	1.47	-24.78	235			0.63
45	100	239	1.23	0.72	0.23	4.19	0.52	-31.84	682	554	556	1.23
	75		1.22	0.73	0.23	4.19	0.51	-31.74	685			1.23
	50		1.72	0.65	0.23	4.19	0.72	-31.42	501			0.90
	33		2.48	0.58	0.23	4.19	1.04	-30.36	355			0.64
	25		3.14	0.54	0.23	4.19	1.32	-29.22	284			0.51
46	100	267	1.20	0.85	0.23	3.74	0.45	-26.12	661	552	596	1.11
	75		1.15	0.88	0.23	3.74	0.43	-25.95	680			1.14
	50		1.72	0.71	0.23	3.74	0.64	-26.33	483			0.81
	33		2.70	0.55	0.23	3.74	1.01	-25.72	325			0.54
	25		3.53	0.46	0.23	3.74	1.32	-24.68	255			0.43
47	100	245	1.13	0.84	0.23	4.08	0.46	-29.77	717	568	600	1.20
	75		1.47	0.75	0.23	4.08	0.60	-29.90	566			0.94
	50		2.17	0.63	0.23	4.08	0.88	-29.48	399			0.66
	33		3.23	0.53	0.23	4.08	1.32	-28.05	276			0.46
	25		4.48	0.46	0.23	4.08	1.83	-25.90	204			0.34
48	100	1730	2.59	0.36	0.30	0.58	0.15	5.62	298	284	274	1.09
	75		2.77	0.31	0.30	0.58	0.16	5.62	291			1.06
	50		2.75	0.31	0.30	0.58	0.16	5.58	293			1.07
	33		2.64	0.32	0.30	0.58	0.15	5.33	302			1.10
	25		3.39	0.28	0.30	0.58	0.20	7.16	249			0.91

Table 9
Analysis of the Proposed Method Performance Using Percentages of Load-Test Data (continued)

Pile No.	Percent of Data	EA/L (lbs/sq.in)	a (x 1000)	b (x 1000)	X	S (x 1000)	A (x10-6)	B (x 10-5)	Method P	Static P	Davisson's P	Meth. P/Dav. P
49	100	3148	0.94	0.18	0.35	0.32	0.03	1.88	813	830	855	0.95
	75		0.77	0.20	0.35	0.32	0.02	1.55	921			1.08
	50		0.55	0.22	0.35	0.32	0.02	0.99	1163			1.36
	33		0.51	0.23	0.35	0.32	0.02	0.86	1229			1.44
	25		0.71	0.22	0.35	0.32	0.02	1.52	952			1.11
50	100	2330	0.68	0.30	0.40	0.43	0.03	1.40	955	988	1006	0.95
	75		0.64	0.31	0.40	0.43	0.03	1.36	982			0.98
	50		0.70	0.30	0.40	0.43	0.03	1.53	930			0.92
	33		1.09	0.28	0.40	0.43	0.05	2.82	671			0.67
	25		1.38	0.26	0.40	0.43	0.06	3.84	559			0.56
51	100	2273	0.52	0.29	0.40	0.44	0.02	0.63	1190	1146	1162	1.02
	75		0.54	0.29	0.40	0.44	0.02	0.64	1173			1.01
	50		0.59	0.28	0.40	0.44	0.03	0.76	1106			0.95
	33		0.58	0.28	0.40	0.44	0.03	0.72	1116			0.96
	25		0.51	0.28	0.40	0.44	0.02	0.47	1231			1.06
52	100	2350	0.72	0.24	0.40	0.43	0.03	1.00	993	1094	1114	0.89
	75		0.39	0.32	0.40	0.43	0.02	0.49	1421			1.28
	50		0.29	0.34	0.40	0.43	0.01	0.25	1706			1.53
	33		0.34	0.33	0.40	0.43	0.01	0.42	1523			1.37
	25		0.28	0.33	0.40	0.43	0.01	0.22	1737			1.56
53	100	2376	0.55	0.30	0.40	0.42	0.02	0.96	1120	1134	1136	0.99
	75		0.52	0.31	0.40	0.42	0.02	0.93	1153			1.01
	50		0.48	0.32	0.40	0.42	0.02	0.87	1208			1.06
	33		0.55	0.31	0.40	0.42	0.02	1.07	1105			0.97
	25		0.59	0.31	0.40	0.42	0.02	1.18	1057			0.93
54	100	3530	1.01	0.18	0.35	0.28	0.03	2.44	760	816	752	1.01
	75		1.01	0.18	0.35	0.28	0.03	2.50	751			1.00
	50		0.93	0.18	0.35	0.28	0.03	2.26	801			1.07
	33		0.92	0.18	0.35	0.28	0.03	2.22	810			1.08
	25		0.97	0.18	0.35	0.28	0.03	2.40	773			1.03

Table 9
Analysis of the Proposed Method Performance Using Percentages of Load-Test Data (continued)

Pile No.	Percent of Data	EA/L (lbs/sq.in)	a (x 1000)	b (x 1000)	X	S (x 1000)	A (x10-6)	B (x 10-5)	Method P	Static P	Davisson's P	Meth. P/Dav. P
55	100	4433	0.62	0.18	0.35	0.23	0.01	1.74	1074	1052	1066	1.01
	75		0.66	0.18	0.35	0.23	0.01	1.82	1039			0.97
	50		0.75	0.17	0.35	0.23	0.02	2.06	951			0.89
	33		0.76	0.17	0.35	0.23	0.02	2.09	943			0.88
	25		0.79	0.17	0.35	0.23	0.02	2.18	918			0.86
56	100	6719	1.24	0.26	0.35	0.15	0.02	5.41	546	584	566	0.96
	75		1.18	0.27	0.35	0.15	0.02	5.34	555			0.98
	50		1.07	0.28	0.35	0.15	0.02	5.10	581			1.03
	33		0.35	0.32	0.35	0.15	0.01	2.88	1028			1.82
	25		-2.22	0.37	0.35	0.15	-0.03	-5.51	--			--
57	100	1126	13.09	0.76	0.23	0.89	1.16	28.97	63	67	68	0.93
	75		13.40	0.68	0.23	0.89	1.19	28.82	63			0.93
	50		12.66	0.77	0.23	0.89	1.12	28.02	65			0.96
	33		8.50	1.02	0.23	0.89	0.75	20.94	85			1.24
	25		8.34	1.03	0.23	0.89	0.74	20.68	85			1.26
58	100	859	6.88	0.56	0.23	1.16	0.80	9.86	119	124	125	0.95
	75		6.69	0.60	0.23	1.16	0.78	9.75	121			0.96
	50		5.44	0.72	0.23	1.16	0.63	8.10	137			1.10
	33		4.72	0.76	0.23	1.16	0.55	6.86	152			1.21
	25		4.71	0.76	0.23	1.16	0.55	6.84	152			1.22
59	100	671	3.43	0.62	0.23	1.49	0.51	-0.76	220	223	226	0.97
	75		3.42	0.63	0.23	1.49	0.51	-0.76	220			0.98
	50		3.07	0.70	0.23	1.49	0.46	-0.83	234			1.03
	33		2.47	0.78	0.23	1.49	0.37	-1.41	271			1.20
	25		2.38	0.79	0.23	1.49	0.36	-1.54	278			1.23
60	100	671	3.23	0.62	0.23	1.49	0.48	-1.31	233	228	236	0.99
	75		3.17	0.64	0.23	1.49	0.47	-1.24	235			0.99
	50		2.95	0.68	0.23	1.49	0.44	-1.35	245			1.04
	33		3.07	0.67	0.23	1.49	0.46	-1.13	237			1.01
	25		3.81	0.62	0.23	1.49	0.57	0.10	201			0.85

Table 9
Analysis of the Proposed Method Performance Using Percentages of Load-Test Data (continued)

Pile No.	Percent of Data	EA/L (lbs/sq.in)	a (x 1000)	b (x 1000)	X	S (x 1000)	A (x10-6)	B (x 10-5)	Method P	Static P	Davisson's P	Meth. P/Dav. P
61	100	1836	0.60	0.50	0.28	0.54	0.03	1.21	766	819	807	0.95
	75		0.62	0.49	0.28	0.54	0.03	1.21	756			0.94
	50		0.78	0.46	0.28	0.54	0.04	1.37	670			0.83
	33		0.84	0.45	0.28	0.54	0.05	1.46	644			0.80
	25		0.89	0.45	0.28	0.54	0.05	1.59	617			0.76
62	100	846	0.31	1.00	0.27	1.18	0.04	-1.03	999	872	897	1.11
	75		0.21	1.04	0.27	1.18	0.03	-0.87	1219			1.36
	50		0.20	1.05	0.27	1.18	0.02	-0.84	1264			1.41
	33		0.30	1.03	0.27	1.18	0.04	-0.77	988			1.10
	25		0.34	1.02	0.27	1.18	0.04	-0.71	907			1.01
63	100	1234	0.83	0.44	0.28	0.81	0.07	-1.35	759	928	932	0.81
	75		1.00	0.41	0.28	0.81	0.08	-1.18	668			0.72
	50		1.27	0.38	0.28	0.81	0.10	-0.71	561			0.60
	33		1.53	0.36	0.28	0.81	0.12	-0.12	482			0.52
	25		1.82	0.35	0.28	0.81	0.15	0.58	419			0.45

EA/L - Pile elastic modulus x area/pile length.
a - Slope of the best-fit line (see Section 3.5).
b - y-intercept of the best-fit line (see Section 3.5).
S - Pile length/(Pile Elastic Modulus x Pile Area).
A - Coefficient defined in Equation 3.7.
B - Coefficient defined in Equation 3.7.
Method P - Ultimate pile capacity as determined by the present method.
Static P - Ultimate pile capacity as determined in Section 2.3.9.
Davisson's P - Ultimate pile capacity as determined by Davisson's criterion.
Meth. P/Dav. P - Method P result divided by Davisson's ultimate pile capacity (Davisson's P).
-- No value obtained.

Table 10
Analysis of the Proposed Method Performance Using Ratios of the Designated Ultimate Capacity

Pile No.	Percent of Load	EA/L (lbs/sq.in)	a (x1000)	b (x1000)	X	S (x1000)	A (x10-6)	B (x10-4)	Method P	Static P	Davisson's P	Meth. P/Dav. P
1*	100	2435	0.26	0.61	0.55	0.41	0.01	3.47	1165	1300	1300	0.90
	75	2435	0.20	0.65	0.55	0.41	0.01	3.47	1225			0.94
	50	2435	0.05	0.71	0.55	0.41	0.00	3.29	1527			1.17
	33	2435	--	--	0.55	0.41	0.00	-4.11	--			--
	25	2435	--	--	0.55	0.41	0.00	-4.11	--			--
2*	100	2435	0.19	0.76	0.55	0.41	0.01	4.50	1033	1225	1000	1.03
	75	2435	0.18	0.76	0.55	0.41	0.01	4.53	1036			1.04
	50	2435	0.23	0.73	0.55	0.41	0.01	4.45	1017			1.02
	33	2435	0.33	0.67	0.55	0.41	0.01	4.43	958			0.96
	25	2435	0.58	0.53	0.55	0.41	0.02	4.34	861			0.86
3	100	2584	1.53	0.35	0.30	0.39	0.06	4.22	440	345	370	1.19
	75	2584	1.39	0.36	0.30	0.39	0.05	3.92	466			1.26
	50	2584	0.39	0.41	0.30	0.39	0.01	1.44	1015			2.74
	33	2584	-5.44	0.67	0.30	0.39	-0.21	-13.45	--			--
	25	2584	3.99	0.31	0.30	0.39	0.15	11.24	208			0.56
4	100	2311	1.39	0.24	0.30	0.43	0.06	2.26	542	535	550	0.99
	75	2311	1.70	0.22	0.30	0.43	0.07	2.96	469			0.85
	50	2311	2.07	0.20	0.30	0.43	0.09	3.92	399			0.73
	33	2311	1.80	0.21	0.30	0.43	0.08	3.17	449			0.82
	25	2311	1.36	0.22	0.30	0.43	0.06	1.92	569			1.03
5	100	4031	1.41	0.12	0.35	0.25	0.04	3.65	606	614	625	0.97
	75	4031	1.81	0.10	0.35	0.25	0.04	4.84	495			0.79
	50	4031	2.72	0.07	0.35	0.25	0.07	7.77	346			0.55
	33	4031	4.26	0.05	0.35	0.25	0.11	12.99	227			0.36
	25	4031	5.81	0.04	0.35	0.25	0.14	18.29	169			0.27

Table 10
Analysis of the Proposed Method Performance Using Ratios of the Designated Ultimate Capacity (continued)

Pile No.	Percent of Load	EA/L (lbs/sq.in)	a (x1000)	b (x1000)	X	S (x1000)	A (x10-6)	B (x10-4)	Method P	Static P	Davisson's P	Meth. P/Dav. P
6	100	581	1.81	1.05	0.27	1.72	0.31	-1.88	325	315	315	1.03
	75	581	2.29	0.98	0.27	1.72	0.39	-1.30	277			0.88
	50	581	3.48	0.87	0.27	1.72	0.60	0.80	204			0.65
	33	581	5.47	0.76	0.27	1.72	0.94	5.04	144			0.46
	25	581	7.30	0.70	0.27	1.72	1.26	9.28	113			0.36
7	100	581	0.89	1.59	0.27	1.72	0.15	1.07	384	313	345	1.11
	75	581	0.63	1.66	0.27	1.72	0.11	1.02	452			1.31
	50	581	0.55	1.67	0.27	1.72	0.09	0.98	483			1.40
	33	581	1.80	1.50	0.27	1.72	0.31	2.55	255			0.74
	25	581	3.01	1.35	0.27	1.72	0.52	4.33	189			0.55
8	100	569	0.64	0.77	0.27	1.76	0.11	-8.20	971	740	765	1.27
	75	569	0.68	0.76	0.27	1.76	0.12	-8.18	922			1.21
	50	569	0.78	0.74	0.27	1.76	0.14	-8.06	828			1.08
	33	569	0.77	0.75	0.27	1.76	0.14	-8.08	835			1.09
	25	569	0.28	0.77	0.27	1.76	0.05	-9.11	2090			2.73
9	100	508	1.60	0.79	0.18	1.97	0.31	-8.98	419	227	243	1.72
	75	508	1.29	0.82	0.18	1.97	0.25	-9.22	501			2.06
	50	508	1.30	0.82	0.18	1.97	0.26	-9.21	496			2.04
	33	508	2.92	0.75	0.18	1.97	0.57	-7.10	247			1.02
	25	508	3.50	0.73	0.18	1.97	0.69	-6.30	212			0.87
10	100	1174	0.76	0.91	0.27	0.85	0.06	2.63	470	465	366	1.28
	75	1174	0.85	0.90	0.27	0.85	0.07	2.72	447			1.22
	50	1174	1.34	0.83	0.27	0.85	0.11	3.35	358			0.98
	33	1174	1.52	0.81	0.27	0.85	0.13	3.63	335			0.91
	25	1174	1.59	0.80	0.27	0.85	0.14	3.76	326			0.89

Table 10
Analysis of the Proposed Method Performance Using Ratios of the Designated Ultimate Capacity (continued)

Pile No.	Percent of Load	EA/L (lbs/sq.in)	a (x1000)	b (x1000)	X	S (x1000)	A (x10-6)	B (x10-4)	Method P	Static P	Davisson's P	Meth. P/Dav. P
11*	100	545	2.37	1.31	0.24	1.83	0.43	0.34	229	230	189	1.21
	75	545	2.74	1.26	0.24	1.83	0.50	0.72	209			1.11
	50	545	3.78	1.18	0.24	1.83	0.69	2.35	168			0.89
	33	545	4.11	1.16	0.24	1.83	0.75	2.93	158			0.84
	25	545	4.38	1.15	0.24	1.83	0.80	3.48	151			0.80
12**	100	6587	1.33	0.14	0.35	0.15	0.02	4.58	603	610	610	0.99
	75	6587	1.75	0.12	0.35	0.15	0.03	5.79	493			0.81
	50	6587	2.43	0.10	0.35	0.15	0.04	7.99	373			0.61
	33	6587	3.32	0.09	0.35	0.15	0.05	10.95	283			0.46
	25	6587	4.08	0.08	0.35	0.15	0.06	13.55	233			0.38
13	100	2263	0.91	0.14	0.40	0.44	0.04	0.63	922	884	900	1.02
	75	2263	0.97	0.14	0.40	0.44	0.04	0.85	870			0.97
	50	2263	1.20	0.13	0.40	0.44	0.05	1.65	727			0.81
	33	2263	1.53	0.12	0.40	0.44	0.07	2.92	583			0.65
	25	2263	1.49	0.12	0.40	0.44	0.07	2.77	597			0.66
14	100	2759	0.79	0.13	0.40	0.36	0.03	0.85	1042	766	820	1.27
	75	2759	0.71	0.13	0.40	0.36	0.03	0.56	1142			1.39
	50	2759	0.53	0.14	0.40	0.36	0.02	-0.12	1476			1.80
	33	2759	-0.23	0.15	0.40	0.36	-0.01	-3.03	--			--
	25	2759	-1.38	0.16	0.40	0.36	-0.05	-7.53	--			--
15	100	907	1.88	0.70	0.25	1.10	0.21	0.67	331	325	322	1.03
	75	907	1.88	0.70	0.25	1.10	0.21	0.69	331			1.03
	50	907	1.87	0.70	0.25	1.10	0.21	0.67	332			1.03
	33	907	0.11	0.82	0.25	1.10	0.01	-2.56	--			--
	25	907	-5.70	1.16	0.25	1.10	-0.63	-13.69	--			--

Table 10
Analysis of the Proposed Method Performance Using Ratios of the Designated Ultimate Capacity (continued)

Pile No.	Percent of Load	EA/L (lbs/sq.in)	a (x1000)	b (x1000)	X	S (x1000)	A (x10-6)	B (x10-4)	Method P	Static P	Davisson's P	Meth. P/Dav. P
16*	100	1033	2.68	0.44	0.26	0.97	0.26	1.57	285	320	330	0.86
	75	1033	3.38	0.37	0.26	0.97	0.33	2.64	242			0.73
	50	1033	5.17	0.28	0.26	0.97	0.50	6.35	172			0.52
	33	1033	8.29	0.20	0.26	0.97	0.80	13.53	113			0.34
	25	1033	11.21	0.16	0.26	0.97	1.09	20.62	86			0.26
17	100	544	0.80	0.76	0.25	1.84	0.15	-8.77	810	600	612	1.32
	75	544	0.71	0.79	0.25	1.84	0.13	-8.75	885			1.45
	50	544	0.61	0.80	0.25	1.84	0.11	-8.87	1018			1.66
	33	544	0.71	0.79	0.25	1.84	0.13	-8.70	879			1.44
	25	544	0.56	0.80	0.25	1.84	0.10	-8.96	1088			1.78
18*	100	511	1.44	0.46	0.26	1.96	0.28	-11.26	562	530	600	0.94
	75	511	1.61	0.44	0.26	1.96	0.32	-11.08	510			0.85
	50	511	2.06	0.40	0.26	1.96	0.40	-10.30	411			0.69
	33	511	3.28	0.35	0.26	1.96	0.64	-7.72	269			0.45
	25	511	4.47	0.31	0.26	1.96	0.87	-5.03	202			0.34
19	100	356	4.91	1.83	0.20	2.81	1.38	0.09	120	142	122	0.98
	75	356	4.94	1.83	0.20	2.81	1.39	0.06	120			0.98
	50	356	4.33	1.88	0.20	2.81	1.22	-0.63	131			1.07
	33	356	6.21	1.79	0.20	2.81	1.74	2.25	101			0.83
	25	356	8.16	1.73	0.20	2.81	2.29	5.50	82			0.67
20	100	1313	1.83	0.38	0.25	0.76	0.14	0.78	396	400	402	0.99
	75	1313	1.97	0.37	0.25	0.76	0.15	1.02	375			0.93
	50	1313	2.27	0.36	0.25	0.76	0.17	1.61	336			0.84
	33	1313	3.23	0.32	0.25	0.76	0.25	3.70	252			0.63
	25	1313	4.16	0.30	0.25	0.76	0.32	5.83	204			0.51

Table 10
Analysis of the Proposed Method Performance Using Ratios of the Designated Ultimate Capacity (continued)

Pile No.	Percent of Load	EA/L (lbs/sq.in)	a (x1000)	b (x1000)	X	S (x1000)	A (x10-6)	B (x10-4)	Method P	Static P	Davisson's P	Meth. P/Dav. P
21	100	702	0.75	0.87	0.24	1.43	0.11	-3.76	679	638	652	1.04
	75	702	0.82	0.86	0.24	1.43	0.12	-3.74	642			0.99
	50	702	0.92	0.85	0.24	1.43	0.13	-3.55	583			0.89
	33	702	0.79	0.85	0.24	1.43	0.11	-3.87	667			1.02
	25	702	0.64	0.86	0.24	1.43	0.09	-4.12	788			1.21
22	100	722	0.79	0.85	0.24	1.38	0.11	-3.44	650	552	558	1.16
	75	722	0.73	0.87	0.24	1.38	0.10	-3.40	685			1.23
	50	722	1.01	0.83	0.24	1.38	0.14	-3.17	542			0.97
	33	722	1.40	0.77	0.24	1.38	0.19	-2.75	430			0.77
	25	722	-0.39	0.95	0.24	1.38	-0.05	-5.26	--			--
23**	100	2602	1.04	0.05	0.35	0.38	0.04	0.29	902	939	958	0.94
	75	2602	1.33	0.03	0.35	0.38	0.05	1.11	725			0.76
	50	2602	2.01	0.01	0.35	0.38	0.08	3.28	494			0.52
	33	2602	2.89	0.00	0.35	0.38	0.11	6.29	346			0.36
	25	2602	--	--	0.35	0.38	--	--	--			--
24**	100	2258	1.16	0.08	0.35	0.44	0.05	0.39	788	800	715	1.10
	75	2258	1.55	0.05	0.35	0.44	0.07	1.44	618			0.86
	50	2258	2.39	0.02	0.35	0.44	0.11	4.11	413			0.58
	33	2258	3.37	0.01	0.35	0.44	0.15	7.43	296			0.41
	25	2258	4.15	0.00	0.35	0.44	0.18	10.13	240			0.34
25	100	2773	4.99	0.63	0.30	0.36	0.18	17.67	148	308	315	0.47
	75	2773	4.99	0.63	0.30	0.36	0.18	17.67	148			0.47
	50	2773	4.92	0.64	0.30	0.36	0.18	17.51	149			0.47
	33	2773	4.35	0.66	0.30	0.36	0.16	16.09	161			0.51
	25	2773	3.85	0.68	0.30	0.36	0.14	14.72	175			0.56

Table 10
Analysis of the Proposed Method Performance Using Ratios of the Designated Ultimate Capacity (continued)

Pile No.	Percent of Load	EA/L (lbs/sq.in)	a (x1000)	b (x1000)	X	S (x1000)	A (x10-6)	B (x10-4)	Method P	Static P	Davisson's P	Meth. P/Dav. P
26**	100	2593	1.09	0.35	0.35	0.39	0.04	3.46	590	530	524	1.13
	75	2593	--	--	0.35	0.39	--	--	--			--
	50	2593	--	--	0.35	0.39	--	--	--			--
	33	2593	--	--	0.35	0.39	--	--	--			--
	25	2593	--	--	0.35	0.39	--	--	--			--
27**	100	2745	0.86	0.26	0.35	0.36	0.03	1.97	788	810	812	0.97
	75	2745	1.10	0.23	0.35	0.36	0.04	2.50	674			0.83
	50	2745	1.67	0.19	0.35	0.36	0.06	4.05	496			0.61
	33	2745	2.44	0.15	0.35	0.36	0.09	6.40	364			0.45
	25	2745	3.26	0.13	0.35	0.36	0.12	9.05	282			0.35
28	100	1935	0.81	0.46	0.35	0.52	0.04	2.27	682	826	808	0.84
	75	1935	1.00	0.42	0.35	0.52	0.05	2.56	612			0.76
	50	1935	1.37	0.38	0.35	0.52	0.07	3.43	501			0.62
	33	1935	1.72	0.35	0.35	0.52	0.09	4.40	427			0.53
	25	1935	2.01	0.34	0.35	0.52	0.10	5.26	380			0.47
29**	100	1907	0.82	0.91	0.35	0.52	0.04	6.75	411	940	976	0.42
	75	1907	1.08	0.16	0.35	0.52	0.06	0.15	774			0.79
	50	1907	1.70	0.12	0.35	0.52	0.09	1.92	528			0.54
	33	1907	2.50	0.09	0.35	0.52	0.13	4.40	375			0.38
	25	1907	3.29	0.07	0.35	0.52	0.17	6.99	291			0.30
30	100	3736	1.65	0.16	0.35	0.27	0.04	4.72	504	484	500	1.01
	75	3736	1.59	0.17	0.35	0.27	0.04	4.57	517			1.03
	50	3736	1.58	0.17	0.35	0.27	0.04	4.52	521			1.04
	33	3736	1.54	0.17	0.35	0.27	0.04	4.39	532			1.06
	25	3736	1.54	0.17	0.35	0.27	0.04	4.39	532			1.06

Table 10
Analysis of the Proposed Method Performance Using Ratios of the Designated Ultimate Capacity (continued)

Pile No.	Percent of Load	EA/L (lbs/sq.in)	a (x1000)	b (x1000)	X	S (x1000)	A (x10-6)	B (x10-4)	Method P	Static P	Davisson's P	Meth. P/Dav. P
31	100	4139	0.46	0.21	0.40	0.24	0.01	1.51	1338	1400	1435	0.93
	75	4139	0.37	0.23	0.40	0.24	0.01	1.34	1492			1.04
	50	4139	0.43	0.22	0.40	0.24	0.01	1.53	1355			0.94
	33	4139	0.54	0.22	0.40	0.24	0.01	1.90	1170			0.82
	25	4139	0.64	0.21	0.40	0.24	0.02	2.24	1041			0.73
32	100	3634	0.39	0.26	0.40	0.28	0.01	1.35	1406	1453	1515	0.93
	75	3634	0.40	0.26	0.40	0.28	0.01	1.40	1376			0.91
	50	3634	0.49	0.25	0.40	0.28	0.01	1.69	1202			0.79
	33	3634	0.66	0.24	0.40	0.28	0.02	2.25	990			0.65
	25	3634	0.78	0.23	0.40	0.28	0.02	2.68	878			0.58
33	100	3986	1.24	0.23	0.40	0.25	0.03	4.73	605	702	643	0.94
	75	3986	1.53	0.18	0.40	0.25	0.04	5.47	532			0.83
	50	3986	1.99	0.16	0.40	0.25	0.05	6.99	436			0.68
	33	3986	2.19	0.15	0.40	0.25	0.05	7.74	402			0.63
	25	3986	2.56	0.14	0.40	0.25	0.06	9.12	352			0.55
34	100	3487	0.85	0.21	0.40	0.29	0.02	2.61	853	926	917	0.93
	75	3487	0.91	0.20	0.40	0.29	0.03	2.78	814			0.89
	50	3487	1.07	0.19	0.40	0.29	0.03	3.32	721			0.79
	33	3487	1.30	0.18	0.40	0.29	0.04	4.16	618			0.67
	25	3487	1.75	0.17	0.40	0.29	0.05	5.81	485			0.53
35	100	3553	0.43	0.23	0.40	0.28	0.01	1.23	1381	1437	1463	0.94
	75	3553	0.49	0.22	0.40	0.28	0.01	1.40	1267			0.87
	50	3553	0.56	0.22	0.40	0.28	0.02	1.59	1170			0.80
	33	3553	0.60	0.22	0.40	0.28	0.02	1.75	1104			0.75
	25	3553	0.72	0.21	0.40	0.28	0.02	2.16	972			0.66

Table 10
Analysis of the Proposed Method Performance Using Ratios of the Designated Ultimate Capacity (continued)

Pile No.	Percent of Load	EA/L (lbs/sq.in)	a (x1000)	b (x1000)	X	S (x1000)	A (x10-6)	B (x10-4)	Method P	Static P	Davisson's P	Meth. P/Dav. P
36**	100	3562	0.62	0.07	0.40	0.28	0.02	0.40	1405	1396	1410	1.00
	75	3562	0.85	0.05	0.40	0.28	0.02	1.11	1084			0.77
	50	3562	1.26	0.03	0.40	0.28	0.04	2.57	760			0.54
	33	3562	1.97	0.02	0.40	0.28	0.06	5.25	500			0.35
	25	3562	2.42	0.01	0.40	0.28	0.07	7.03	408			0.29
37*	100	469	1.04	0.63	0.26	2.13	0.22	-12.39	722	647	654	1.10
	75	469	1.29	0.58	0.26	2.13	0.28	-12.26	600			0.92
	50	469	1.91	0.50	0.26	2.13	0.41	-11.42	428			0.65
	33	469	2.91	0.43	0.26	2.13	0.62	-9.55	294			0.45
	25	469	3.84	0.39	0.26	2.13	0.82	-7.55	229			0.35
38*	100	524	1.27	0.69	0.26	1.91	0.24	-8.92	556	504	506	1.10
	75	524	1.37	0.67	0.26	1.91	0.26	-8.87	526			1.04
	50	524	1.27	0.68	0.26	1.91	0.24	-9.03	562			1.11
	33	524	0.45	0.73	0.26	1.91	0.09	-10.65	1452			2.87
	25	524	-0.90	0.79	0.26	1.91	-0.17	-13.45	--			--
39	100	299	1.92	1.64	0.25	3.35	0.64	-12.32	315	315	302	1.04
	75	299	1.92	1.64	0.25	3.35	0.64	-12.26	314			1.04
	50	299	2.40	1.57	0.25	3.35	0.80	-11.78	265			0.88
	33	299	2.88	1.55	0.25	3.35	0.96	-10.76	226			0.75
	25	299	1.42	1.62	0.25	3.35	0.48	-13.73	415			1.38
40	100	324	2.84	1.66	0.25	3.08	0.87	-7.13	215	214	200	1.07
	75	324	1.49	1.89	0.25	3.08	0.46	-8.21	340			1.70
	50	324	-0.28	2.06	0.25	3.08	-0.09	-10.90	--			--
	33	324	-1.81	2.16	0.25	3.08	-0.56	-13.72	--			--
	25	324	-2.54	2.19	0.25	3.08	-0.78	-15.24	--			--

Table 10
Analysis of the Proposed Method Performance Using Ratios of the Designated Ultimate Capacity (continued)

Pile No.	Percent of Load	EA/L (lbs/sq.in)	a (x1000)	b (x1000)	X	S (x1000)	A (x10-6)	B (x10-4)	Method P	Static P	Davisson's P	Meth. P/Dav. P
41*	100	1218	1.49	2.70	0.27	0.82	0.12	22.81	110	237	188	0.59
	75	1218	1.39	2.73	0.27	0.82	0.11	22.84	111			0.59
	50	1218	2.07	2.63	0.27	0.82	0.17	23.60	105			0.56
	33	1218	4.10	2.43	0.27	0.82	0.34	27.00	89			0.47
	25	1218	6.67	2.26	0.27	0.82	0.55	32.16	74			0.39
42*	100	327	1.79	0.94	0.23	3.06	0.55	-17.05	413	364	360	1.15
	75	327	2.36	0.84	0.23	3.06	0.72	-16.71	328			0.91
	50	327	3.69	0.70	0.23	3.06	1.13	-15.04	224			0.62
	33	327	6.27	0.55	0.23	3.06	1.92	-10.62	141			0.39
	25	327	9.56	0.43	0.23	3.06	2.92	-4.27	96			0.27
43*	100	374	0.96	0.91	0.23	2.67	0.26	-15.46	729	656	660	1.10
	75	374	1.32	0.80	0.23	2.67	0.35	-15.74	562			0.85
	50	374	2.13	0.65	0.23	2.67	0.57	-15.39	377			0.57
	33	374	3.26	0.52	0.23	2.67	0.87	-14.02	262			0.40
	25	374	4.33	0.45	0.23	2.67	1.16	-12.31	204			0.31
44*	100	351	1.91	0.73	0.23	2.85	0.54	-16.80	412	372	376	1.10
	75	351	2.49	0.61	0.23	2.85	0.71	-16.63	333			0.88
	50	351	3.22	0.58	0.23	2.85	0.92	-15.33	263			0.70
	33	351	3.68	0.55	0.23	2.85	1.05	-14.50	233			0.62
	25	351	3.73	0.55	0.23	2.85	1.06	-14.41	230			0.61
45*	100	326	1.13	0.76	0.23	3.07	0.35	-20.52	687	554	556	1.24
	75	326	1.46	0.69	0.23	3.07	0.45	-20.43	549			0.99
	50	326	2.09	0.61	0.23	3.07	0.64	-19.74	399			0.72
	33	326	2.97	0.55	0.23	3.07	0.91	-18.31	288			0.52
	25	326	3.70	0.52	0.23	3.07	1.13	-16.95	236			0.42

Table 10
Analysis of the Proposed Method Performance Using Ratios of the Designated Ultimate Capacity (continued)

Pile No.	Percent of Load	EA/L (lbs/sq.in)	a (x1000)	b (x1000)	X	S (x1000)	A (x10-6)	B (x10-4)	Method P	Static P	Davisson's P	Meth. P/Dav. P
46*	100	367	1.24	0.89	0.23	2.72	0.34	-15.50	577	552	596	0.97
	75	367	1.76	0.75	0.23	2.72	0.48	-15.66	437			0.73
	50	367	2.63	0.61	0.23	2.72	0.72	-15.08	313			0.53
	33	367	3.72	0.51	0.23	2.72	1.01	-13.57	232			0.39
	25	367	4.95	0.44	0.23	2.72	1.35	-11.43	180			0.30
47*	100	337	1.19	0.82	0.23	2.97	0.35	-18.73	632	568	600	1.05
	75	337	1.65	0.71	0.23	2.97	0.49	-18.76	480			0.80
	50	337	2.43	0.60	0.23	2.97	0.72	-18.09	344			0.57
	33	337	3.76	0.49	0.23	2.97	1.11	-16.09	233			0.39
	25	337	5.26	0.42	0.23	2.97	1.56	-13.35	171			0.29
48	100	1730	2.79	0.31	0.30	0.58	0.16	5.65	290	284	274	1.06
	75	1730	2.64	0.32	0.30	0.58	0.15	5.20	305			1.11
	50	1730	3.85	0.25	0.30	0.58	0.22	8.97	217			0.79
	33	1730	--	--	0.30	0.58	--	--	--			--
	25	1730	--	--	0.30	0.58	--	--	--			--
49**	100	3148	0.93	0.10	0.35	0.32	0.03	1.05	926	830	855	1.08
	75	3148	0.81	0.11	0.35	0.32	0.03	0.72	1032			1.21
	50	3148	0.71	0.11	0.35	0.32	0.02	0.38	1163			1.36
	33	3148	1.03	0.10	0.35	0.32	0.03	1.47	833			0.97
	25	3148	2.58	0.09	0.35	0.32	0.08	6.73	361			0.42
50**	100	2330	0.90	0.09	0.40	0.43	0.04	0.24	989	988	1006	0.98
	75	2330	1.10	0.08	0.40	0.43	0.05	0.91	831			0.83
	50	2330	1.93	0.05	0.40	0.43	0.08	3.94	497			0.49
	33	2330	2.78	0.04	0.40	0.43	0.12	7.21	351			0.35
	25	2330	4.19	0.02	0.40	0.43	0.18	12.70	236			0.23

Table 10
Analysis of the Proposed Method Performance Using Ratios of the Designated Ultimate Capacity (continued)

Pile No.	Percent of Load	EA/L (lbs/sq.in)	a (x1000)	b (x1000)	X	S (x1000)	A (x10-6)	B (x10-4)	Method P	Static P	Davisson's P	Meth. P/Dav. P
51**	100	2273	0.78	0.05	0.40	0.44	0.03	-0.76	1194	1146	1162	1.03
	75	2273	1.04	0.03	0.40	0.44	0.05	0.05	929			0.80
	50	2273	1.58	0.08	0.40	0.44	0.07	2.76	585			0.50
	33	2273	--	--	0.40	0.44	--	--	--			--
	25	2273	--	--	0.40	0.44	--	--	--			--
52**	100	2350	0.84	0.03	0.40	0.43	0.04	-0.65	1156	1094	1114	1.04
	75	2350	1.02	0.02	0.40	0.43	0.04	0.05	953			0.86
	50	2350	1.24	0.02	0.40	0.43	0.05	0.88	793			0.71
	33	2350	0.83	0.02	0.40	0.43	0.04	-0.75	1179			1.06
	25	2350	--	--	0.40	0.43	--	--	--			--
53	100	2376	0.48	0.32	0.40	0.42	0.02	0.87	1210	1134	1136	1.06
	75	2376	0.48	0.32	0.40	0.42	0.02	0.87	1208			1.06
	50	2376	0.55	0.31	0.40	0.42	0.02	1.07	1105			0.97
	33	2376	0.66	0.30	0.40	0.42	0.03	1.42	972			0.86
	25	2376	0.73	0.30	0.40	0.42	0.03	1.65	904			0.80
54**	100	3530	1.08	0.11	0.35	0.28	0.03	2.05	786	816	752	1.05
	75	3530	1.24	0.10	0.35	0.28	0.03	2.47	708			0.94
	50	3530	1.28	0.10	0.35	0.28	0.04	2.59	689			0.92
	33	3530	1.56	0.09	0.35	0.28	0.04	3.54	575			0.76
	25	3530	1.75	0.09	0.35	0.28	0.05	4.18	518			0.69
55	100	4433	0.65	0.18	0.35	0.23	0.01	1.79	1050	1052	1066	0.98
	75	4433	0.72	0.17	0.35	0.23	0.02	1.97	980			0.92
	50	4433	0.77	0.17	0.35	0.23	0.02	2.11	937			0.88
	33	4433	0.78	0.17	0.35	0.23	0.02	2.15	926			0.87
	25	4433	0.84	0.17	0.35	0.23	0.02	2.34	875			0.82

Table 10
Analysis of the Proposed Method Performance Using Ratios of the Designated Ultimate Capacity (continued)

Pile No.	Percent of Load	EA/L (lbs/sq.in)	a (x1000)	b (x1000)	X	S (x1000)	A (x10-6)	B (x10-4)	Method P	Static P	Davisson's P	Meth. P/Dav. P
56	100	6719	1.33	1.99	0.35	0.15	0.02	23.06	150	584	566	0.26
	75	6719	1.73	0.17	0.35	0.15	0.03	6.27	468			0.83
	50	6719	2.06	0.16	0.35	0.15	0.03	7.27	411			0.73
	33	6719	2.01	0.16	0.35	0.15	0.03	7.11	419			0.74
	25	6719	2.13	0.16	0.35	0.15	0.03	7.52	399			0.70
57	100	1126	10.86	0.90	0.23	0.89	0.96	25.18	72	67	68	1.06
	75	1126	8.45	1.03	0.23	0.89	0.75	20.90	85			1.25
	50	1126	7.57	1.04	0.23	0.89	0.67	19.00	92			1.35
	33	1126	-9.40	1.23	0.23	0.89	-0.83	-18.31	--			--
	25	1126	-26.81	1.35	0.23	0.89	-2.38	-57.23	--			--
58	100	859	5.34	0.73	0.23	1.16	0.62	7.94	139	124	125	1.11
	75	859	4.72	0.76	0.23	1.16	0.55	6.87	152			1.21
	50	859	4.14	0.78	0.23	1.16	0.48	5.66	168			1.34
	33	859	-2.11	0.88	0.23	1.16	-0.25	-7.75	--			--
	25	859	-2.19	0.88	0.23	1.16	-0.26	-7.88	--			--
59	100	671	2.66	0.76	0.23	1.49	0.40	-1.18	256	223	226	1.13
	75	671	2.41	0.79	0.23	1.49	0.36	-1.49	275			1.22
	50	671	2.43	0.78	0.23	1.49	0.36	-1.48	274			1.21
	33	671	0.98	0.82	0.23	1.49	0.15	-4.43	575			2.55
	25	671	-1.55	0.87	0.23	1.49	-0.23	-9.81	--			--
60	100	671	2.84	0.69	0.23	1.49	0.42	-1.46	251	228	236	1.07
	75	671	3.51	0.64	0.23	1.49	0.52	-0.42	214			0.91
	50	671	4.68	0.58	0.23	1.49	0.70	1.71	170			0.72
	33	671	6.08	0.55	0.23	1.49	0.91	4.58	136			0.58
	25	671	7.00	0.53	0.23	1.49	1.04	6.54	121			0.51

Table 10
Analysis of the Proposed Method Performance Using Ratios of the Designated Ultimate Capacity (continued)

Pile No.	Percent of Load	EA/L (lbs/sq.in)	a (x1000)	b (x1000)	X	S (x1000)	A (x10-6)	B (x10-4)	Method P	Static P	Davisson's P	Meth. P/Dav. P
61	100	1836	0.66	0.48	0.28	0.54	0.04	1.23	732	819	807	0.91
	75	1836	0.79	0.46	0.28	0.54	0.04	1.37	668			0.83
	50	1836	0.84	0.45	0.28	0.54	0.05	1.46	645			0.80
	33	1836	1.00	0.45	0.28	0.54	0.05	1.84	571			0.71
	25	1836	1.28	0.43	0.28	0.54	0.07	2.52	481			0.60
62	100	846	0.24	1.03	0.27	1.18	0.03	-0.94	1155	872	897	1.29
	75	846	0.19	1.04	0.27	1.18	0.02	-0.90	1319			1.47
	50	846	0.33	1.01	0.27	1.18	0.04	-0.85	939			1.05
	33	846	0.53	0.98	0.27	1.18	0.06	-0.64	704			0.78
	25	846	0.52	0.98	0.27	1.18	0.06	-0.67	719			0.80
63*	100	1363	0.77	0.46	0.28	0.73	0.06	-0.60	763	928	932	0.82
	75	1363	0.93	0.42	0.28	0.73	0.07	-0.50	682			0.73
	50	1363	1.20	0.39	0.28	0.73	0.09	-0.08	572			0.61
	33	1363	1.42	0.37	0.28	0.73	0.10	0.38	504			0.54
	25	1363	1.67	0.36	0.28	0.73	0.12	0.97	443			0.48

* - Corrected for EA/L.
** - Corrected for Free Length.
EA/L - Pile elastic modulus x area/pile length.
a - Slope of the best-fit line (see Section 3.5).
b - y-intercept of the best-fit line (see Section 3.5).
S - Pile length/(Pile Elastic Modulus x Pile Area).
A - Coefficient defined in Equation 3.7.
B - Coefficient defined in Equation 3.7.

-- No value obtained.
Static P - Ultimate pile capacity as determined in Section 2.3.9.
Davisson's P - Ultimate pile capacity as determined by Davisson's criterion.
Meth. P/Dav. P - Method P result divided by Davisson's ultimate pile capacity.
Method P - Ultimate pile capacity as determined by the present method.

(2) Determine the combined modulus of elasticity:

$$E_{combined} = \frac{(A_{steel})(E_{steel}) + (A_{concrete})(E_{concrete})}{A_{steel} + A_{concrete}} \tag{6.1}$$

where:

$E_{combined}$ = combined modulus of elasticity (kips per square inch)
A_{steel} = area of steel pipe pile (square inch)
$A_{concrete}$ = area of concrete (square inch)
E_{steel} = steel modulus of elasticity (kips per square inch)
$E_{concrete}$ = concrete modulus of elasticity (kips per square inch)

The combined modulus of elasticity is used to compute EA/L. Piles with an adjusted EA/L have been marked in Table 10 with a single asterisk.

(b) Free-Length Adjustments

Data for piles in Table 10 have also been adjusted for the pile length above the ground surface, known as "free length". The proposed curve-fitting method is based on hyperbolic load-deformation relations. Pile sections outside of the soil will experience linear elastic deformation, which should reasonably be subtracted prior to curve fitting. The influence of this adjustment depends on the free length relative to the pile's penetration. For typical piles, this adjustment is not required; however, in the case of long, free, unsupported lengths (e.g., offshore piles), this adjustment may be of significant importance.

The displacement in the load test is adjusted using the equation:

$$\Delta_{new} = \Delta_{load-test} - \frac{(P)(L_{free})}{EA} \tag{6.2}$$

where:

Δ_{new} = adjusted displacement value (inch)
$\Delta_{load\ test}$ = unadjusted load-test displacement (inch)
P = load corresponding to unadjusted displacement (kip)
L_{free} = length of pile above ground surface (inch)
E = modulus of elasticity (kips per inch)
A = cross-sectional area of pile (square inch)

The plot of Δ_{new} versus Δ/P is plotted using the new displacement values, and the coefficient of determination of the best-fit line is obtained. Piles for which the free length above the mud-line was greater or equal to 20% of the total length were examined and reevaluated using the above procedure. The piles adjusted for free length are indicated in Table 10 with a double asterisk.

The above adjustment was applied to 12 relevant cases and the results are shown in Table 11. The first column lists the pile number in the present research, the second column lists the range of the static capacity that was analyzed, the third column provides the length of the pile, the fourth column lists the free length of the pile (above ground surface), the fifth column lists the unadjusted method predicted capacity, the sixth column lists the adjusted method predicted capacity, the seventh column lists Davisson's capacity, the eighth column lists the ratio of the unadjusted method capacity to Davisson's capacity, and the final column provides the adjusted method capacity to Davisson's capacity.

By inspection, the results were not greatly affected due to the adjustment. In two cases (pile nos. 23 and 26), the questionable performance is the result of a 0.5 inch (12.7 mm) subtraction of initial deformation as specified by the geotechnical report. In some other cases, a less desirable performance is indicated for the lower load ratios, while in some cases, better performance was certainly achieved. For pile no. 52, an adjustment of 63.7 feet (19.4 m) of the free-standing portion of the pile resulted in a substantially better performance. In conclusion, the free-length adjustment should be applied cautiously.

6.3 EXAMPLES

6.3.1 Overview

The proposed method is illustrated through the analysis of two cases chosen from the database. Both cases are analyzed step-by-step using both procedures of load and data ranges. The first example relates to a square concrete pile and the second example relates to a large-diameter round concrete pile.

6.3.2 Example No. 1 - Pile No. 4

(a) Analysis Based on Ranges of Data

- An 18-inch- (45.72-cm-) square pre-stressed concrete pile, driven to a depth of 75 feet (22.86 m) in Alabama. The pile was loaded until failure. The load test results are shown as a graph of load versus displacement in Figure 6. The presented axes were chosen such that the elastic compression line is inclined at about 20° from the horizontal.

- The displacements are divided by the corresponding load. The resulting values are then plotted versus displacement. The plot is shown in Figure 7. A regression analysis is then conducted on the data points to determine the coefficient of determination. The results of the regression analysis are shown in Figure 7. The coefficient of determination (r^2) is 0.99798, and hence, no elimination of data points at the beginning of the plot is necessary. This is considered the 100% of the data case. The slope (0.00144) and the y-intercept (0.00023) of the best-fit line through the data points are also provided in the figure.

Table 11
Extrapolated Pile Capacity by the Proposed Method (Method P) Using Actual and Adjusted Pile Length

Pile No.	% of Static Capacity	Length (ft)	Free Length (ft)	Unadjusted Method P	Adjusted Method P	Davisson	Method P/Dav. Unadjusted	Method P/Dav. Adjusted
12	100	48.4	20.9	593	603	610	0.97	0.99
	75			527	493		0.86	0.81
	50			448	373		0.73	0.61
	33			391	283		0.64	0.46
	25			348	233		0.57	0.38
23	100	94	30.6	884	902	958	0.92	0.94
	75			843	725		0.88	0.76
	50			814	494		0.85	0.52
	33			901	346		0.94	0.36
	25			1003	--		1.05	--
24	100	106	40.8	712	788	715	1.00	1.10
	75			692	618		0.97	0.86
	50			668	413		0.93	0.58
	33			913	296		1.28	0.41
	25			2931	240		4.10	0.34
26	100	91	39	493	590	524	0.94	1.13
	75			585	--		1.12	--
	50			--	--		--	--
	33			--	--		--	--
	25			--	--		--	--
27	100	88	26.2	694	788	812	0.86	0.97
	75			624	674		0.77	0.83
	50			522	496		0.64	0.61
	33			428	364		0.53	0.45
	25			363	282		0.45	0.35

Table 11
Extrapolated Pile Capacity by the Proposed Method (Method P) Using Actual and Adjusted Pile Length (continued)

Pile No.	% of Static Capacity	Length (ft)	Free Length (ft)	Unadjusted Method P	Adjusted Method P	Davisson	Method P/Dav. Unadjusted	Method P/Dav. Adjusted
29	100	132	29.1	896	411	976	0.92	0.42
	75			799	774		0.82	0.79
	50			615	528		0.63	0.54
	33			488	375		0.50	0.38
	25			415	291		0.43	0.30
36	100	102.3	37.6	1289	1405	1410	0.91	1.00
	75			1172	1084		0.83	0.77
	50			966	760		0.69	0.54
	33			791	500		0.56	0.35
	25			721	408		0.51	0.29
49	100	104	18.8	965	926	855	1.13	1.08
	75			1157	1032		1.35	1.21
	50			1201	1163		1.40	1.36
	33			847	833		0.99	0.97
	25			472	361		0.55	0.42
50	100	143.9	18.8	1001	989	1006	0.99	0.98
	75			930	831		0.92	0.83
	50			767	497		0.76	0.49
	33			559	351		0.56	0.35
	25			393	236		0.39	0.23
51	100	151.9	62.9	1142	1194	1162	0.98	1.03
	75			1105	929		0.95	0.80
	50			1057	585		0.91	0.50
	33			1231	--		1.06	--
	25			1133	--		0.97	--

Table 11
Extrapolated Pile Capacity by the Proposed Method (Method P) Using Actual and Adjusted Pile Length (continued)

Pile No.	% of Static Capacity	Length (ft)	Free Length (ft)	Unadjusted Method P	Adjusted Method P	Davisson	Method P/Dav. Unadjusted	Method P/Dav. Adjusted
52	100	143.9	63.7	1422	1156	1114	1.28	1.04
	75			1683	953		1.51	0.86
	50			1650	793		1.48	0.71
	33			1735	1179		1.56	1.06
	25			850	--		0.76	--
54	100	71	13.5	765	786	752	1.02	1.05
	75			755	708		1.00	0.94
	50			825	689		1.10	0.92
	33			773	575		1.03	0.76
	25			733	518		0.97	0.69

Length – Total length of pile.
Free length – Length of pile above ground surface.
Unadjusted Method P – Present method ultimate capacity, unadjusted for free length.
Adjusted Method P – Present method ultimate capacity, adjusted for free length.
Davisson's P – Ultimate pile capacity as determined by Davisson's criterion.
Meth. P/Dav. Unadjusted – Unadjusted Method P result divided by Davisson's P.
Meth. P/Dav. Adjusted – Adjusted Method P result divided by Davisson's P.

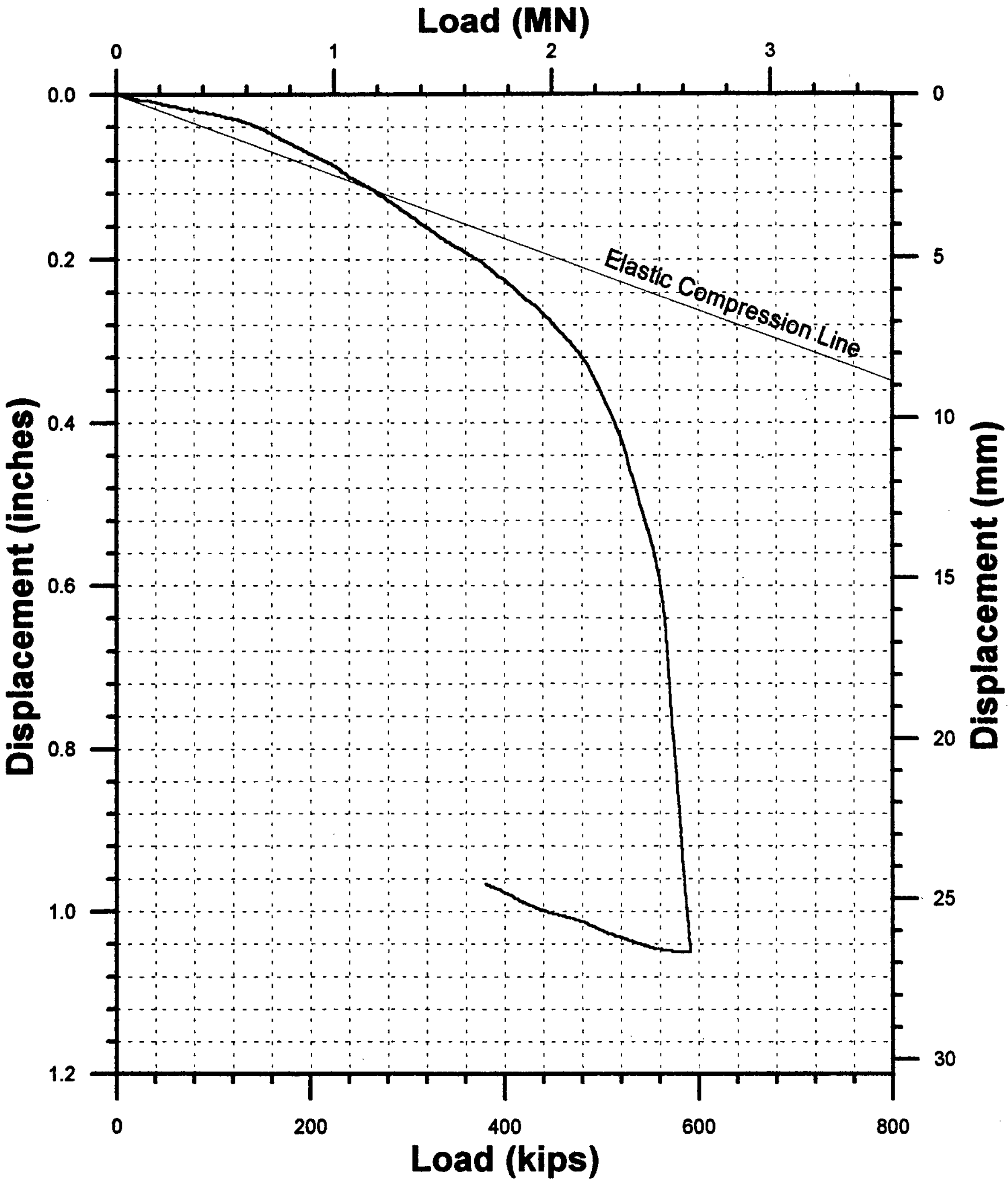

Figure 6. Load-Displacement Relationship for Pile Case No. 4 With Scaled Axes for Elastic Compression Line Inclined at Approximately 20 Degrees.

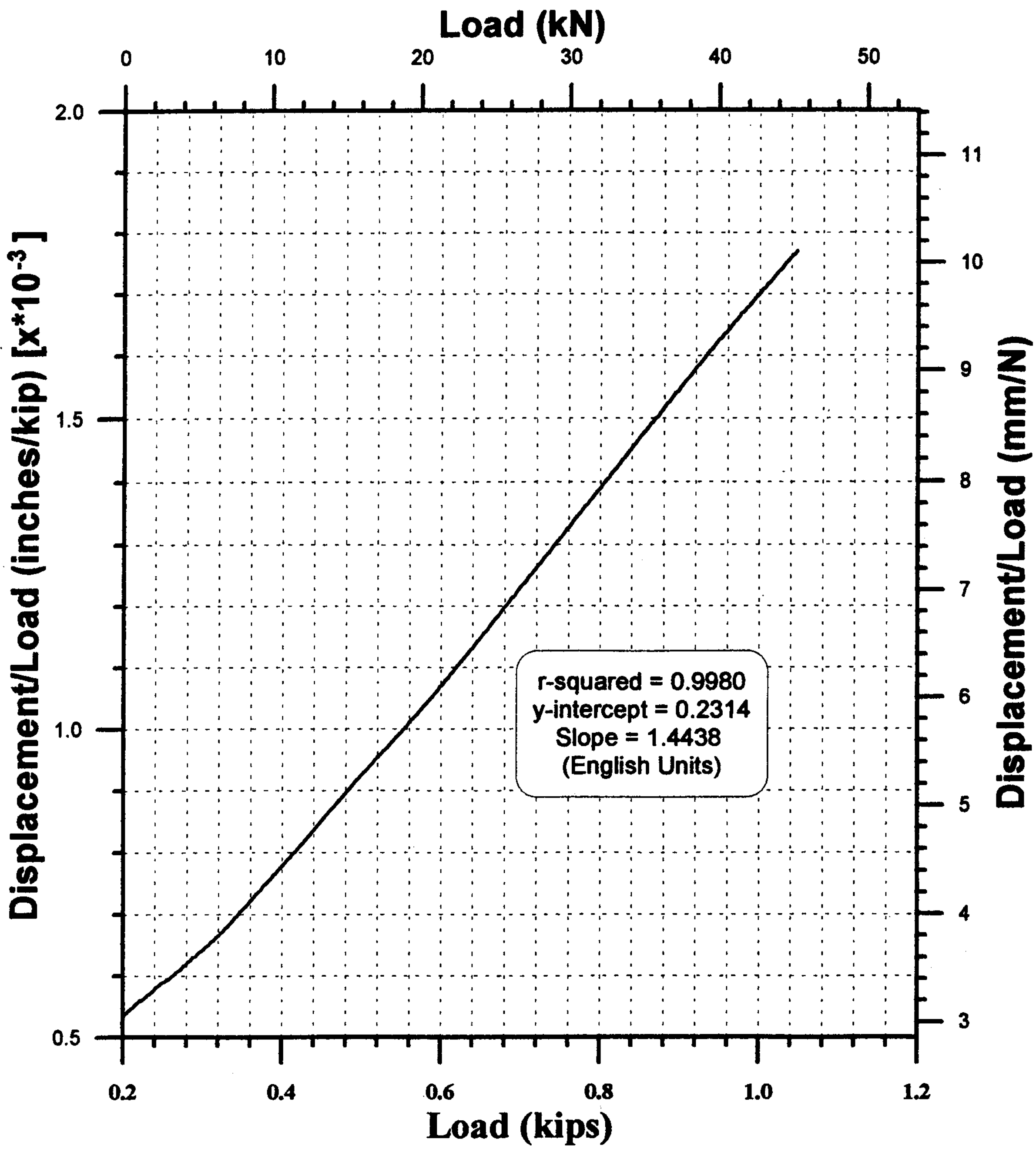

Figure 7. Plot of Displacement Over Load Versus Displacement for Pile Case No. 4.

- The variable (S) is calculated as L/EA (0.0004) using the modulus of elasticity, the pile area, and the pile length. Davisson's offset limit (X) is then calculated as the pile diameter divided by 120 added to a constant of 0.15, which equals 0.30 inches (7.62 mm).

- With the slope (a), the y-intercept (b), Davisson's offset limit, and (S) all known for 100% of the analyzed data, the variables A (0.0000006) and B (0.00023) are calculated and inserted into Equation 3.7.

- The proposed method's pile capacity is calculated as 532 kips (2365 kN). This capacity compares well to the designated pile capacity of 535 kips (2378 kN) or the Davisson's criterion capacity of 550 kips (2445 kN).

- To proceed, 25% of the data points from the end of the displacement divided by load versus displacement plot are eliminated. This is now the 75% of the data case. A regression analysis is conducted on 75% of the data, and the slope (0.00138) and y-intercept (0.00024) of the best-fit line through the data points are obtained. It should be noted that a coefficient of determination of 0.80 or greater is not necessary at this stage of the analysis. The pile area, pile length, Davisson's offset limit, and S all remain constant. The variables A (0.0000006) and B (0.00022) are recalculated with the new slope and y-intercept substituted into Equation 3.7 and the equation is solved for the proposed method's capacity of the pile, given 75% of the available data (546 kip [2427 kN]).

- Next, 25% of the data points from the end of the displacement divided by load versus displacement plot are eliminated from the previously analyzed 75% data case. This is now the 50% of the data case. A regression analysis is conducted on 50% of the data, and the slope (0.00165) and y-intercept (0.00022) are obtained. The variables A (0.0000007) and B (0.00028) are calculated (pile area, pile length, (S), and (X) do not change) and substituted into Equation 3.7. The equation is solved for the capacity of the pile, which is 479 kips (2129 kN). The process is continued for the 33% and 25% of the data cases, and the capacities are obtained (402 and 404 kips [1787 and 1796 kN], respectively).

- The extrapolated load-settlement relations for all five ranges of data percentage used in the analysis are shown graphically in Figure 8. Note on the graph that the load-settlement relations for the 25% and 33% of the data case fall on the same line. As can be seen from the plot, even in the 25% of the data case, the plot compares favorably with the actual load-test curve.

(b) Analysis Based on Ranges of Load

- This analysis uses the designated static capacity (failure) as the controlling factor. The static failure load was determined to be 535 kips (2378 kN). The 100% case analyzed included, therefore, all load-displacement data from 0 through 535 kips (0

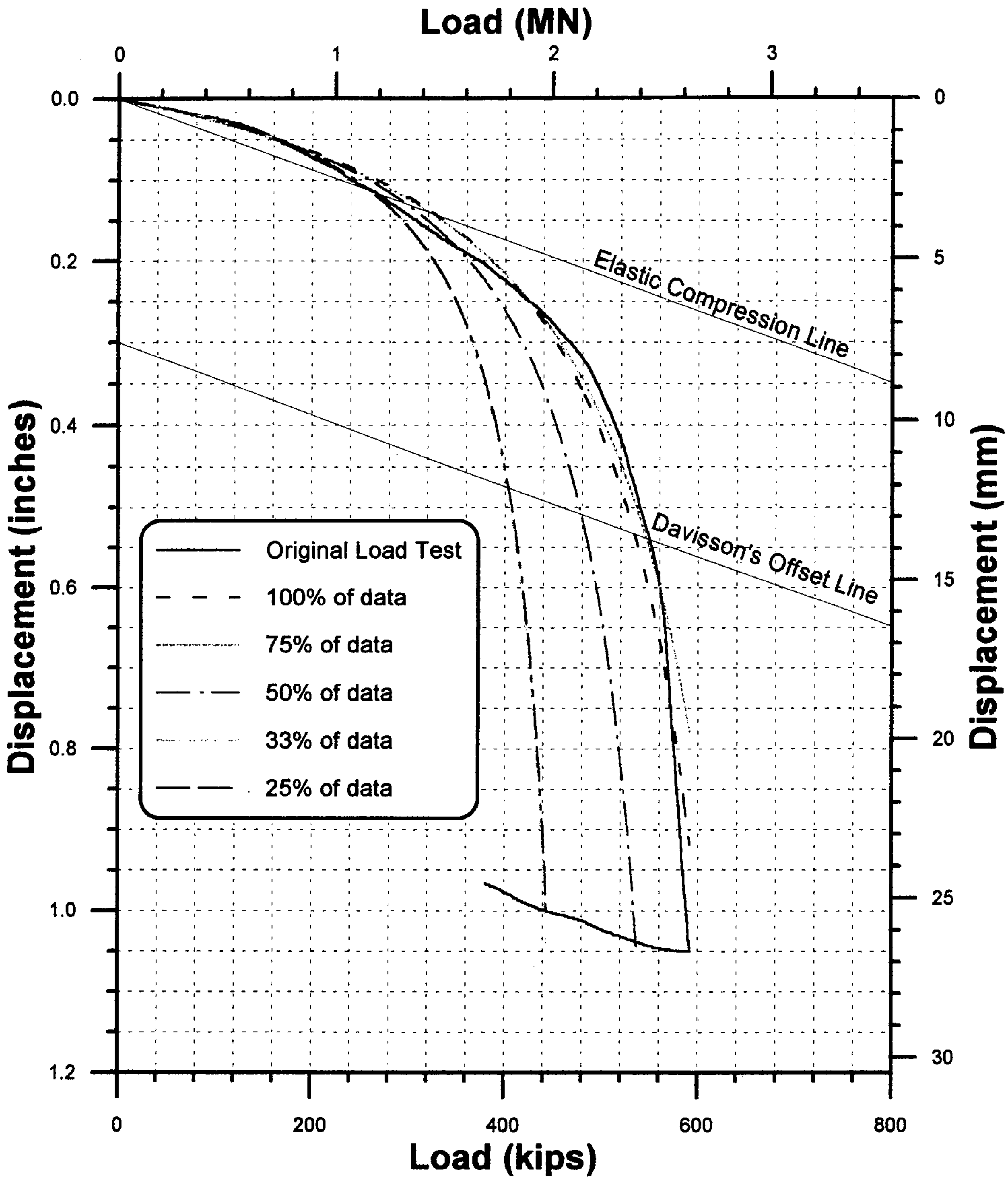

Figure 8. Actual and Extrapolated Load-Settlement Relations for Pile Case No. 4 Using Ranges of Load-Settlement Data.

through 2378 kN). Using this data range, the displacement is divided by its corresponding load and plotted as the calculated ratio versus displacement. As before, a regression analysis ensues and the coefficient of determination of the best-fit line through the data is obtained. Data are eliminated as needed to obtain a regression coefficient of 0.8 or greater. From the regression analysis, the slope (a) and y-intercept (b) of the best-fit line are obtained (0.00139 and 0.00024, respectively).

- The variables S and X, the pile area, and pile length, calculated or used during the 100% of the data case, do not change and are used, along with the new values of a and b to determine the variables A (0.0000006) and B (0.00023). With the variables a, b, S, A, and B known, the ultimate capacity of the pile is calculated as 542 kips (2409 kN).

- The analysis continued using 75% of the static capacity, which is equal to 401 kips (1783 kN). Using the data range of 0 through 401 kips (0 though 1738 kN), the displacement is divided by its corresponding load and plotted as the calculated ratio versus displacement. The slope (0.00170) and intercept (0.00022) of the best-fit line through the data are obtained, the variables A (0.0000007) and B (0.00030) are recalculated, and the ultimate capacity is determined to be 469 kips (1951 kN).

- Next, 50% of the static capacity, or 268 kips (1191 kN), is used in the analysis. For the data range of 0 through 268 kips (0 through 1191 kN), the displacement is divided by its corresponding load and plotted as the calculated ratio versus displacement. The slope (0.00207) and intercept (0.00020) of the best-fit line through the data are obtained, the variables A (0.0000009) and B (0.00039) are recalculated, and the ultimate capacity is determined to be 399 kips (1774 kN).

- The analysis continues similarly with data related to 33% and 25% of the static load, 177 and 134 kips (787 and 595 kN), respectively. Using the proposed method, the ultimate capacities for the 33% and 25% cases were 449 kips and 569 kips (1996 and 2530 kN), respectively.

- Figure 9 presents graphically the above extrapolation and analysis procedures related to the load ranges. The extrapolated curves show a very good agreement to the actual load-displacement relations even when the pile would have been loaded to a small portion (25%) of the designated bearing capacity. More so, the extrapolated relations produced consistently conservative results on the safe side.

6.3.3 Example No. 2 - Pile No. 14

(a) Analysis Based on Ranges of Data

- A 30-inch- (76.20-cm-) diameter pre-stressed concrete pile driven to a depth of 104 feet (31.70 m) in West Bay, Florida. The pile was loaded until failure. The load-test results are shown as a graph of load versus displacement in Figure 10. The

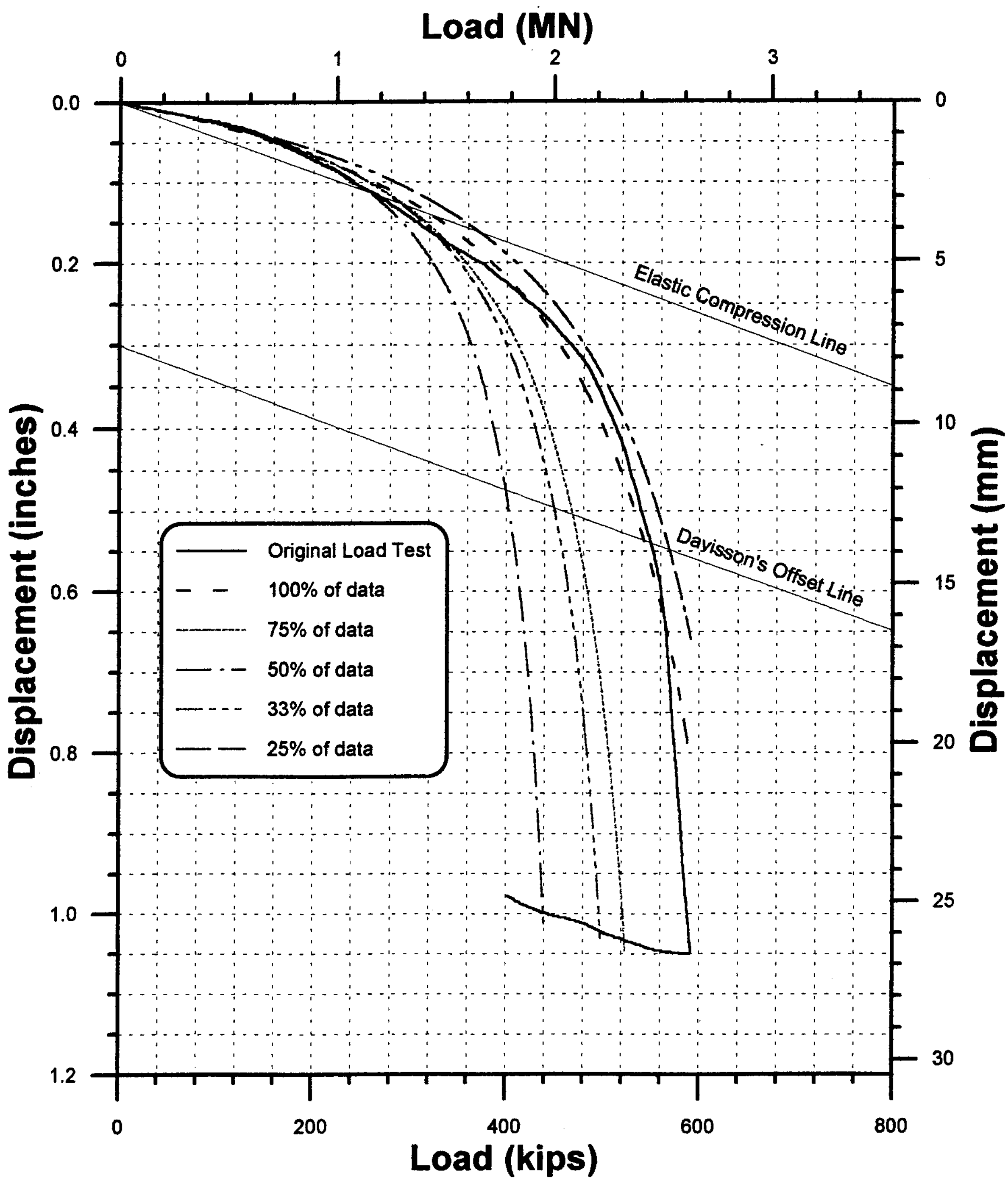

Figure 9. Actual and Extrapolated Load-Settlement Relations for Pile Case No. 4 Using Ranges of the Designated Static Capacity.

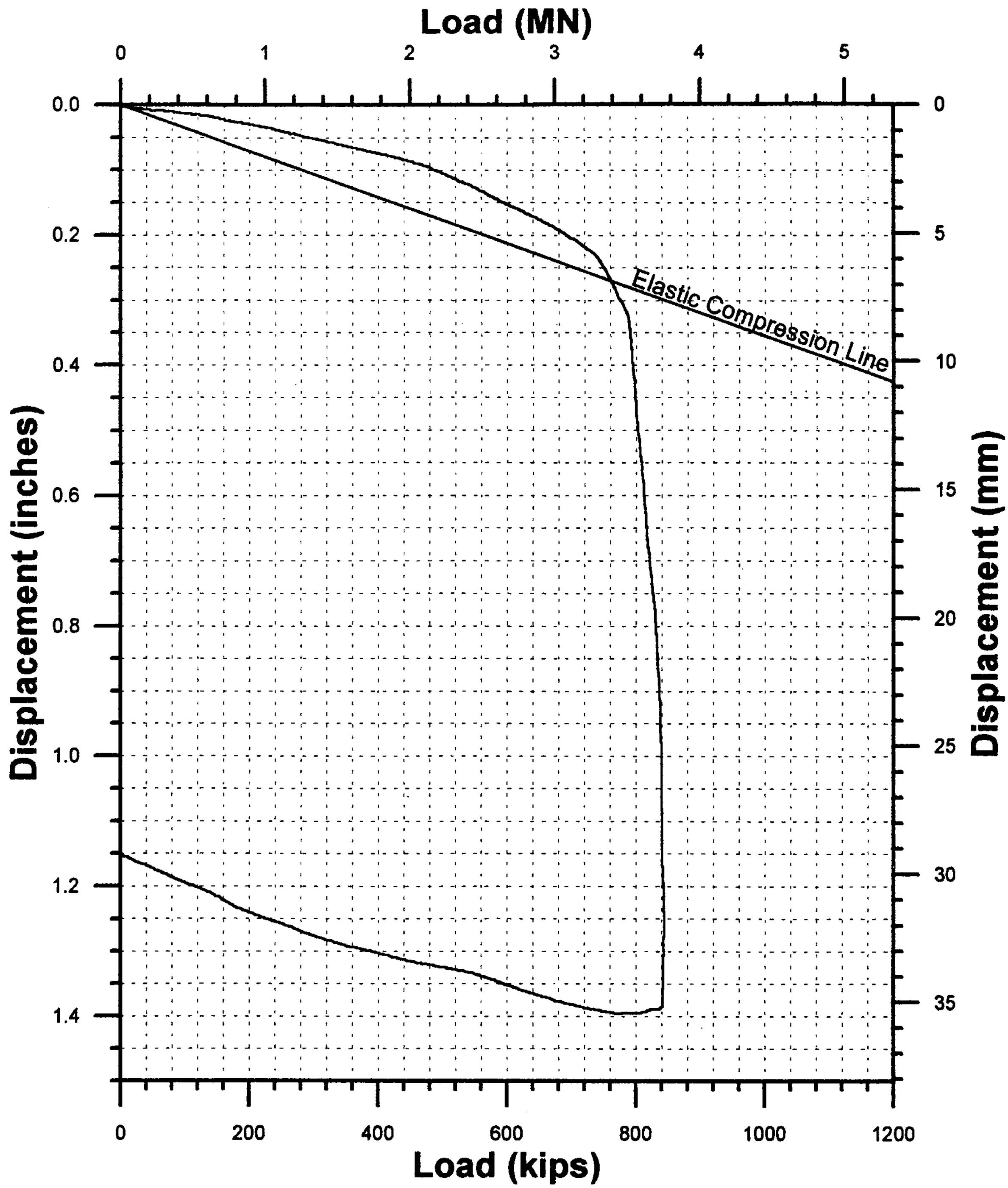

Figure 10. Load-Displacement Relationship for Pile Case No. 14 With Scaled Axes for Elastic Compression Line Inclined at Approximately 20 Degrees.

presented axis was chosen such that the elastic compression line is inclined at about 20° from the horizontal.

- The displacements are divided by the corresponding load and then plotted versus displacement. Figure 11 shows this plot, along with the coefficients of determination for each range of data analyzed. Since the coefficient of determination was 0.8 or greater, no elimination of data was necessary and the analysis could proceed. The regression analysis for all five ranges of data resulted in the slope and y-intercept for each case.

- Using the slope and y-intercept determined from the regression analysis, the capacity of the pile is evaluated based on Equation 3.7 for each case. The obtained capacities are:

Pile Capacity based on Davisson's criterion	=	820 kips (3646 kN)
P for 100% of the data	=	815 kips (3623 kN)
P for 75% of the data	=	853 kips (3792 kN)
P for 50% of the data	=	1074 kips (4775 kN)
P for 33% of the data	=	1251 kips (5562 kN)
P for 25% of the data	=	1871 kips (8319 kN)

- The extrapolated capacities for the 33% and 25% cases are approximately 1.5 and 2.3 times the capacity of the pile, respectively, based on Davisson's criterion. The erroneous values for the last two cases are believed to have been caused by a low coefficient of determination present in the 50%, 33%, and 25% of the data cases. A graphical representation of the results is shown in Figure 12. The extrapolated load settlement relations for the 50%, 33%, and 25% cases are above and extend farther than the actual load-settlement relation.

(b) Revised Analysis Based on Higher Quality Regression

- The pile was reanalyzed, with more data eliminated from the beginning of the displacement divided by load versus displacement graph to obtain a higher coefficient of determination. During the first analysis of this pile, 541 data points were analyzed in the 100% of the data case. During the subsequent analysis, 295 data points from the beginning of the plot were eliminated, and the remaining 246 data points were used in the 100% of the data regression analysis.

- Using this limited data, the following coefficients of determination were obtained:

100% of data	=	0.9999
75% of data	=	0.9998
50% of data	=	0.9998
33% of data	=	0.9998
25% of data	=	0.9998

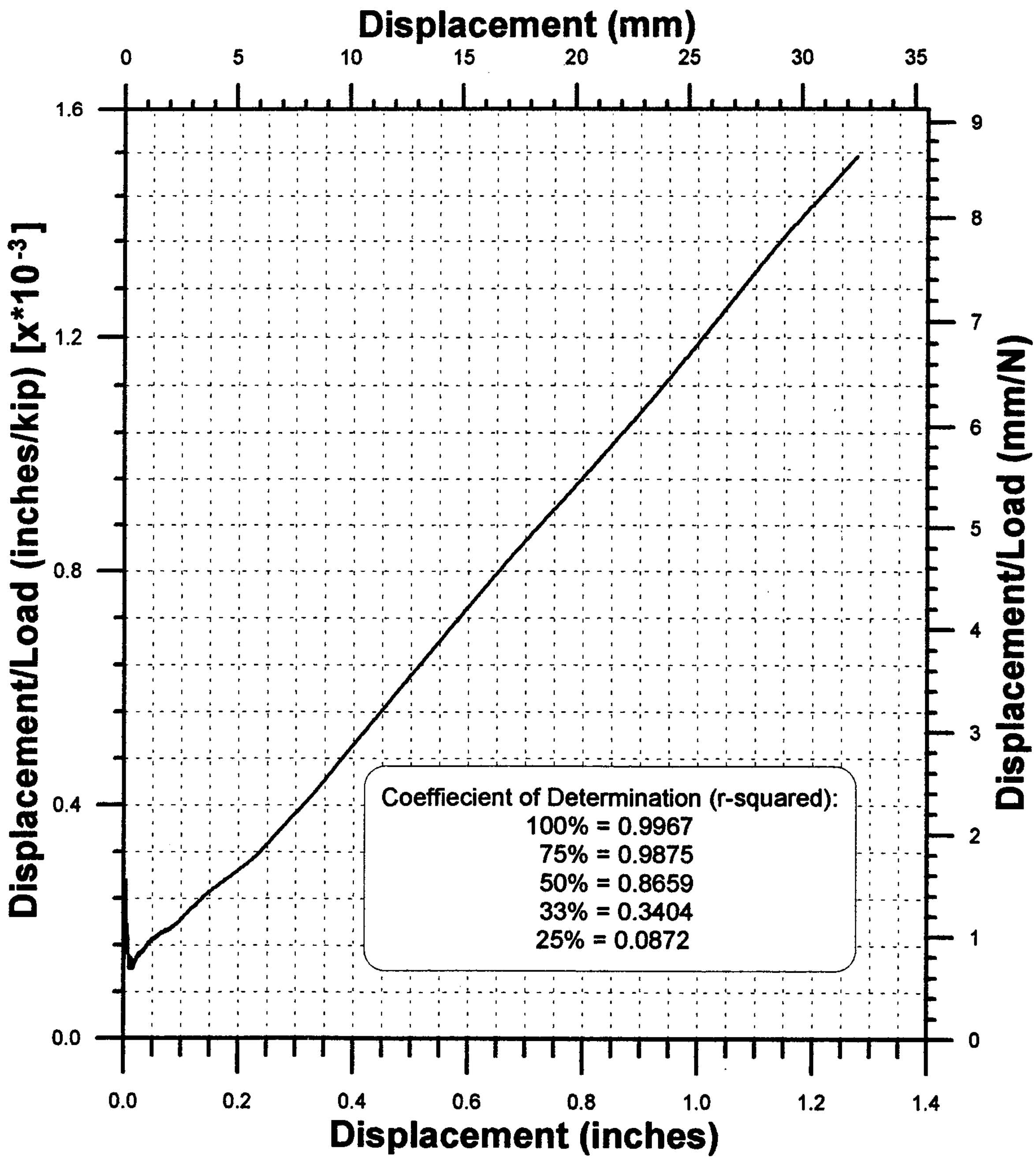

Figure 11. Plot of Displacement Over Load Versus Displacement for Pile Case No. 14 With the Statistical Details for Various Data Ranges.

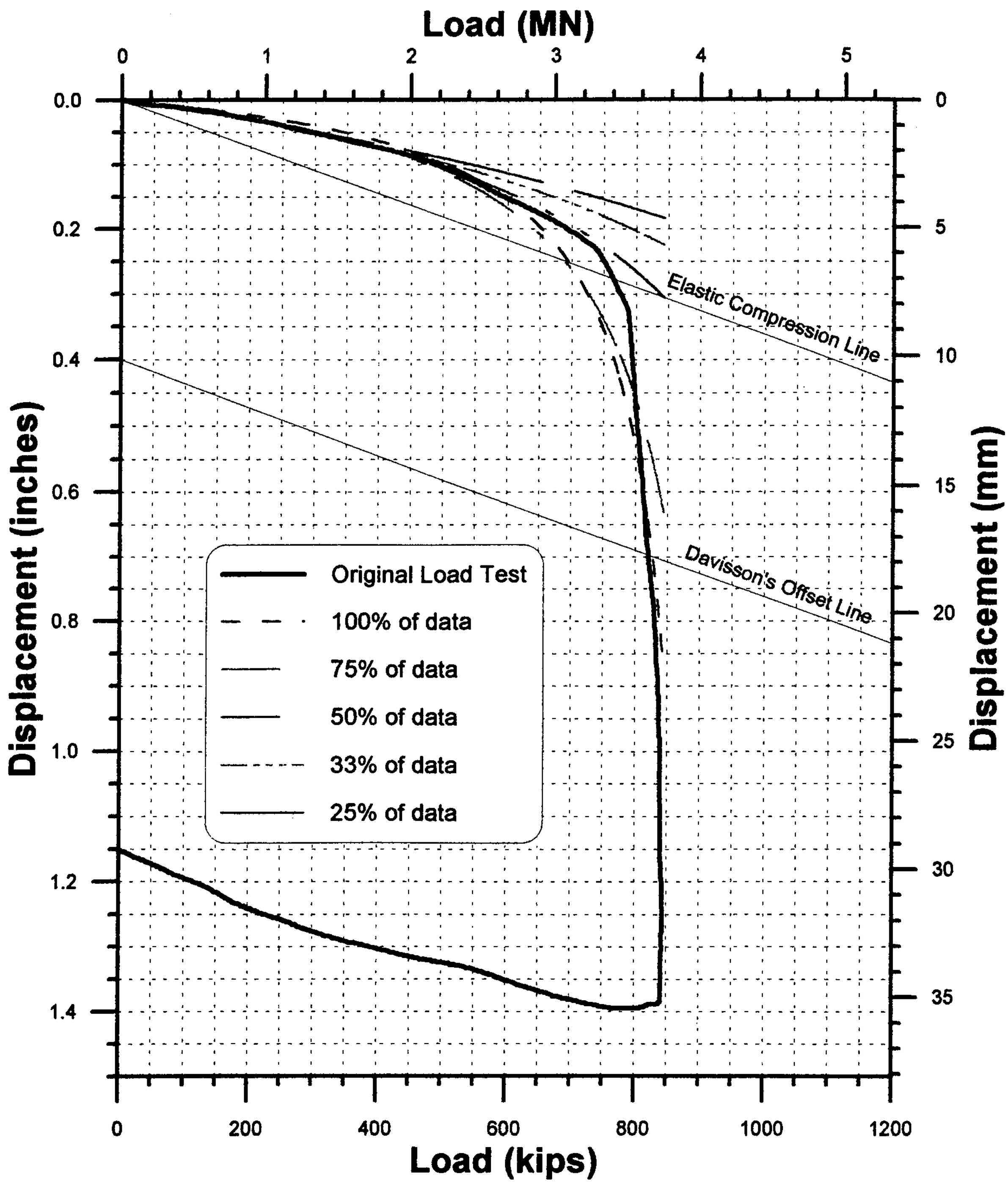

Figure 12. Actual and Extrapolated Load-Settlement Relations for Pile No. 14 Using Ranges of Load-Settlement Data.

- The capacities obtained using the slopes and y-intercepts generated from the above values are the following (see also pile no. 14 of Table 9):

Pile Capacity based on Davisson's criterion	=	820 kips (3646 kN)
P for 100% of the data	=	824 kips (3665 kN)
P for 75% of the data	=	825 kips (3669 kN)
P for 50% of the data	=	821 kips (3652 kN)
P for 33% of the data	=	816 kips (3630 kN)
P for 25% of the data	=	813 kips (3616 kN)

- As can be seen, the extrapolated capacities are in very good agreement with the actual measured static capacity. A graphical representation of the results of the re-analysis of pile no. 14 is shown in Figure 13. The extrapolated load-settlement relations are very similar to the actual load-settlement plot.

(c) Analysis Based on Ranges of Load

- This analysis used the designated static capacity (failure) of 766 kips (3407 kN) as the controlling factor. The 100% case analysis included, therefore, all load-displacement data from 0 to 766 kips (0 to 3407kN) and resulted in an extrapolated capacity of 1042 kips (4635 kN). The pile exhibited a general failure behavior, and hence, a clear change in the load-displacement response took place at the designated failure point. The extrapolations using 75% and 50% of the failure load resulted in predicted capacities of 1142 kips (5080 kN) and 1476 kips (6565 kN), respectively (see Table 10, pile no. 14). A smaller data segment related to less than 50% of the designated capacity could not be analyzed. A graphical representation of the obtained extrapolations is presented in Figure 14. The presented results suggest that using a small segment of the data resulted in extrapolation on the unsafe side. Observing the load-displacement relations of pile no. 14, it seems that the initial segment of the digitized curve is unreliable. The major conclusion of this example is that accurate data must be obtained, especially within the initial load-displacement relationship.

6.4 THE EXTRAPOLATED CAPACITY FOR THE DATABASE PILES

6.4.1 Detailed Results

The results of the proposed method were previously presented in Tables 9 and 10. The tables also list the static capacity of the pile as determined by the five load-test interpretation methods presented in Section 2.3, including the capacity according to the Davisson criterion. The last column in the tables provides the ratio of the proposed method capacity to the Davisson capacity. The Davisson method for determining the capacity of a pile can account for the pile size and it is an objective approach resulting in a unique value. The ratio of the proposed method capacity to the Davisson capacity is provided for all the ranges of the analyzed data. A ratio equal to 1 indicates perfect agreement between the proposed method and the Davisson criterion. A number less

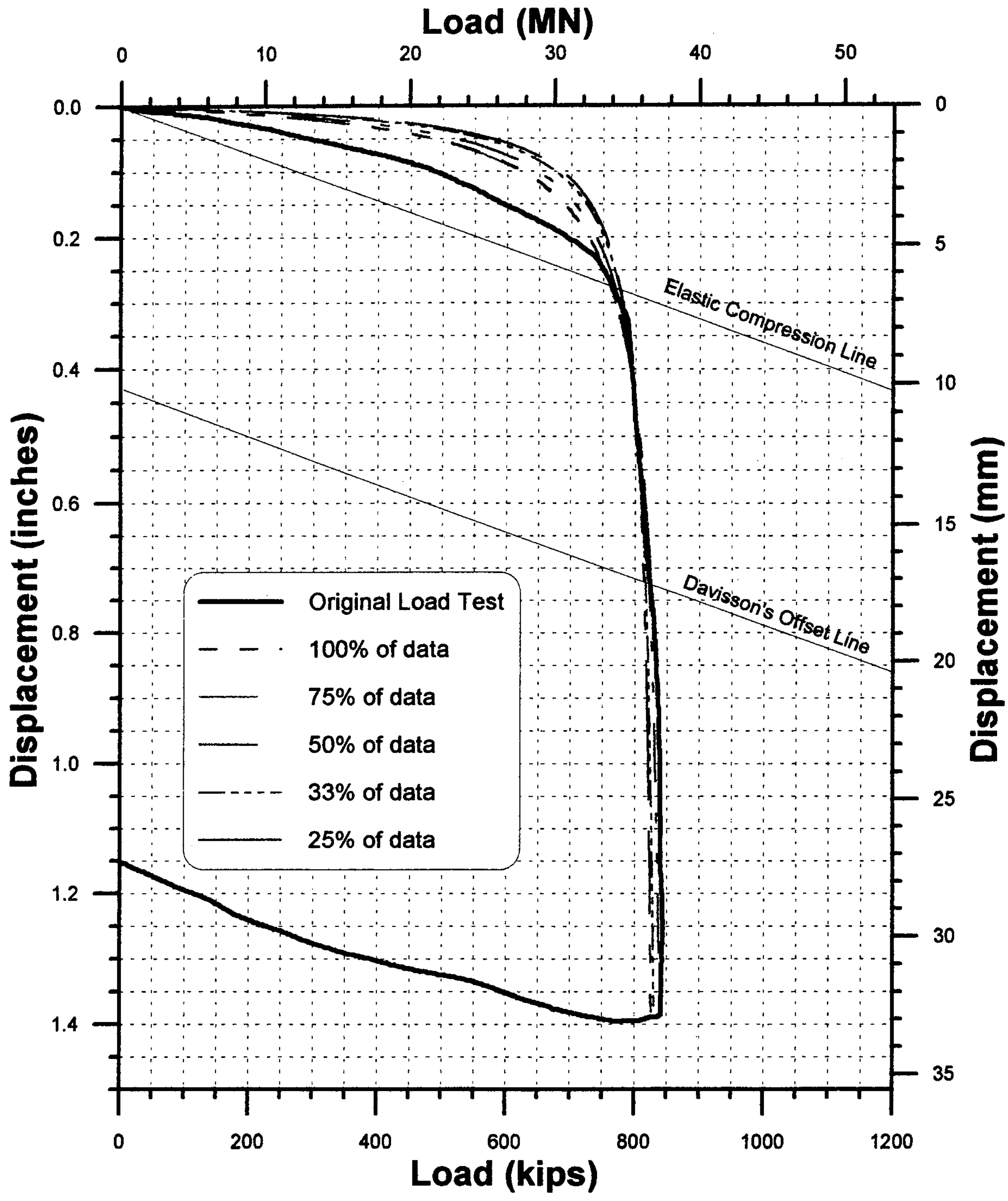

Figure 13. Actual and Extrapolated Load-Settlement Relations for the Re-Analysis of Pile Case No. 14 Using the Proposed Method.

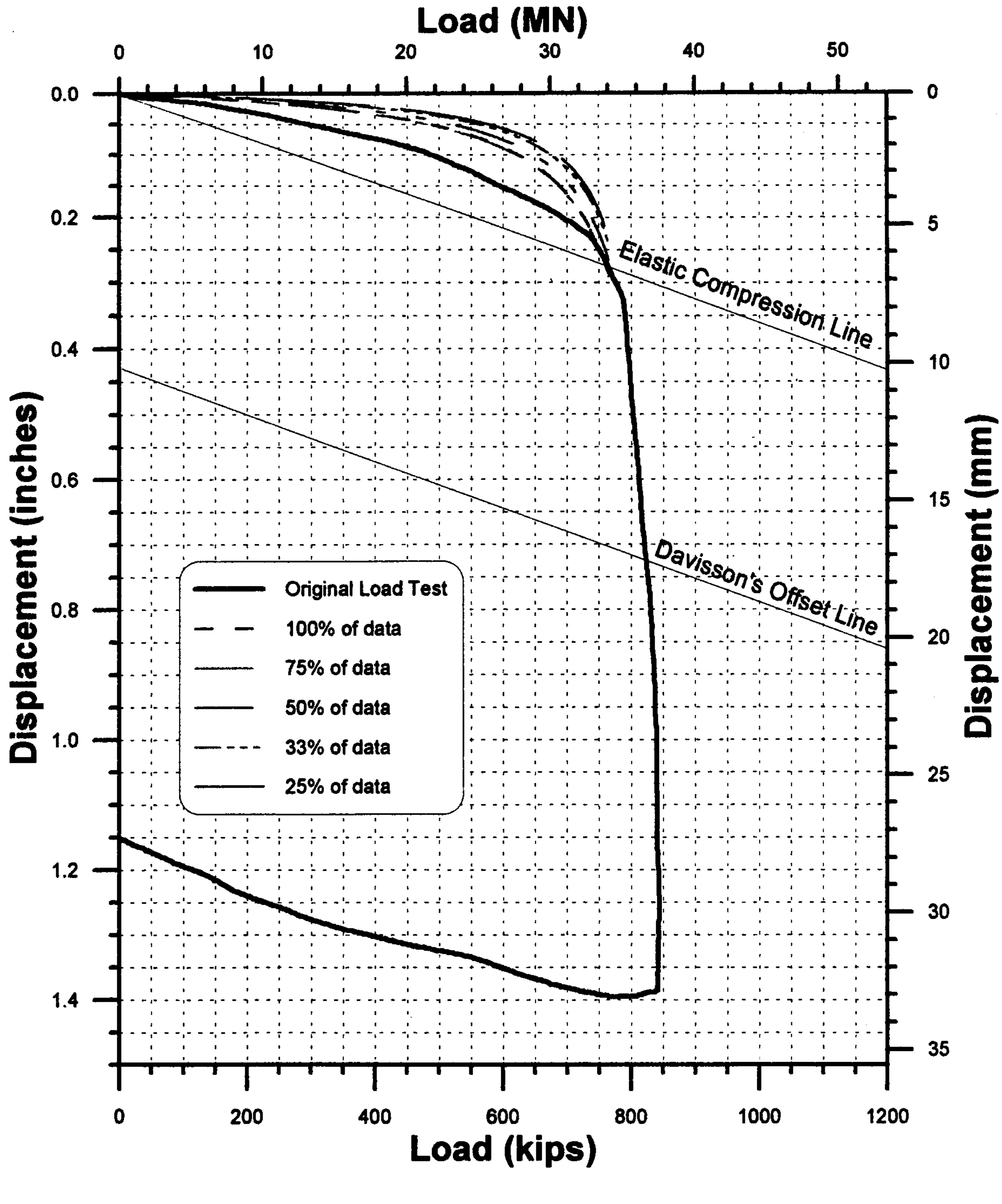

Figure 14. Actual and Extrapolated Load-Settlement Relations for the Analysis of Pile Case No. 14 Using Ranges of the Designated Static Capacity.

than 1 indicates that the proposed method has underpredicted the capacity (the conservative case), while a number greater than 1 indicates an overprediction of the capacity.

A statistical analysis of the obtained results was performed in order to quantify the accuracy of the proposed method. The range, mean, and standard deviation of the ratio between the extrapolated capacity based on the proposed method and the actual capacity (both determined using Davisson's criterion) were evaluated.

6.4.2 Statistical Analysis

Table 12 presents the results of the statistical analysis for the proposed method using ranges of load-displacement data points. Rows 4 and 5 list the mean and standard deviation for each range of data analyzed. The average values for the 100% to 75% cases are nearly 1.0, indicating almost perfect agreement with the actual load-test results. As expected, the 25% case was the least accurate, with an average value of 0.78. The standard deviation for all cases ranged from 0.21 for the 100% case to 0.33 for the 25% case. The mean values for the five ranges of data analyzed were all below 1.0, indicating that the proposed method is conservative in its results and, hence, consistently on the safe side.

Table 13 presents the results of the statistical analysis for the proposed method using ranges of the static capacity. Again, rows 4 and 5 list the mean and standard deviation for each range of analyzed load. The mean value for the 100% case is slightly greater than 1. The mean for the 75% case is nearly 1, with the mean values falling further from 1 as the percentages of static load decreases. The mean value is least in the 25% case. The standard deviations are similar to those obtained when analyzing ranges of load data.

Table 12
Mean and Standard Deviation of the Ratio Between the Extrapolated Capacity Based on the Proposed Method and the Actual Capacity (Both Determined by Davisson's Criterion) Using Ranges of Load-Settlement Data

Range of Data	100%	75%	50%	33%	25%
No. of Cases	63	63	63	62	60
Range	0.13 – 1.52	0.38 – 1.54	0.31 – 1.92	0.26 – 1.82	0.24 – 1.94
Mean	0.96	0.99	0.96	0.87	0.78
Standard Deviation	0.21	0.21	0.27	0.30	0.33

Table 13
Mean and Standard Deviation of the Ratio Between the Extrapolated Capacity Based on the Proposed Method and the Actual Capacity (Both Determined by Davisson's Criterion) Using Ranges of the Designated Static Capacity

Range of Data	100%	75%	50%	33%	25%
No. of Cases	63	62	61	54	48
Range	0.26 – 1.72	0.47 – 2.06	0.47 – 2.74	0.34 – 2.87	0.23 – 2.73
Mean	1.02	0.99	0.89	0.74	0.64
Standard Deviation	0.21	0.26	0.41	0.46	0.44

The initial statistical analyses presented in Tables 12 and 13 suggest the following:

- The proposed method is very accurate and can be used with any available data.
- The accuracy of the prediction decreases with a decrease in the available loading range compared to the failure load.
- The extrapolated values are conservative, and hence, even when predicting four times the tested load, these values can be used safely.

Additional insight into the method is presented in the following sections through a detailed statistical analysis and a correlation study.

6.4.3 Histograms

Figures 15 through 19 present the histograms and frequency distributions for each range set of data. This presentation allows visual inspection of the match between the actual distribution of the data and the normal distribution function related to the parameters presented in Table 12. The presented data suggests the following:

- The scatter of the extrapolated load is smaller compared to the normal distribution for the cases in which 50% to 100% of the data were used. The actual data matches reasonably well with the normal distribution for the cases in which 33% and 25% of the data were analyzed.
- As the data ranges become smaller, a greater number of cases of overprediction seem to take place. In no range did the overprediction exceed the ratio of 2, and the number of cases exceeding the ratio of 1.5 was in the worst case 2 (out of 60 cases).

6.5 INVESTIGATION OF CONTROLLING FACTORS

Two different types of possible correlations were investigated for the piles of data set PD/LT, examining the influence different factors may have on the performance of the proposed method. The two categories and their rationales are presented below.

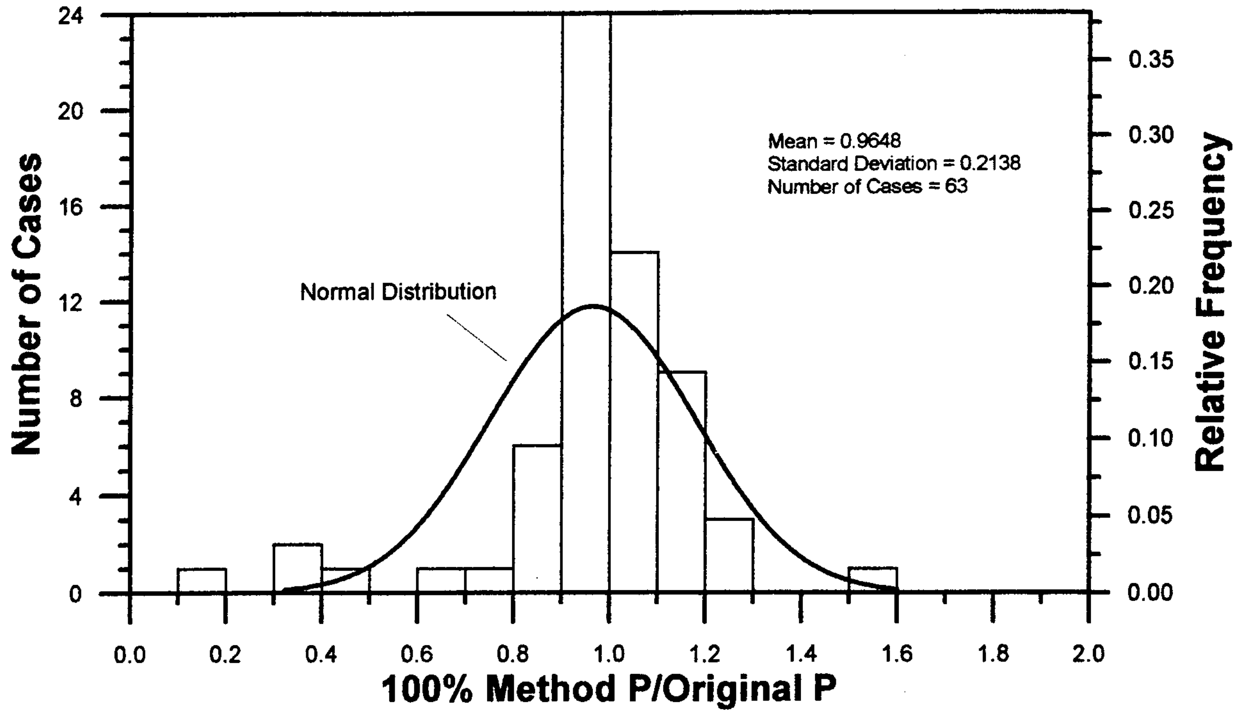

Figure 15. Histogram and Frequency Distribution for the Ratio Between Extrapolated Capacity Based on 100% of the Data Case and the Actual Capacity (Both Using Davisson's Failure Criterion).

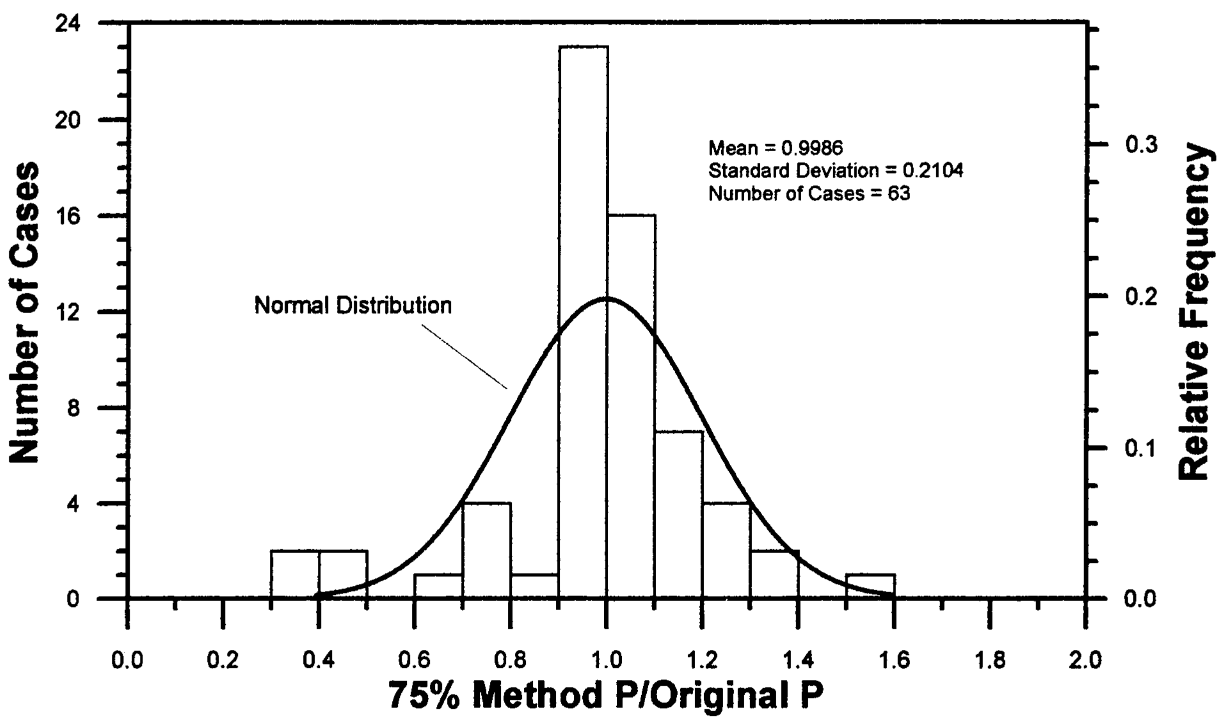

Figure 16. Histogram and Frequency Distribution for the Ratio Between Extrapolated Capacity Based on 75% of the Data Case and the Actual Capacity (Both Using Davisson's Failure Criterion).

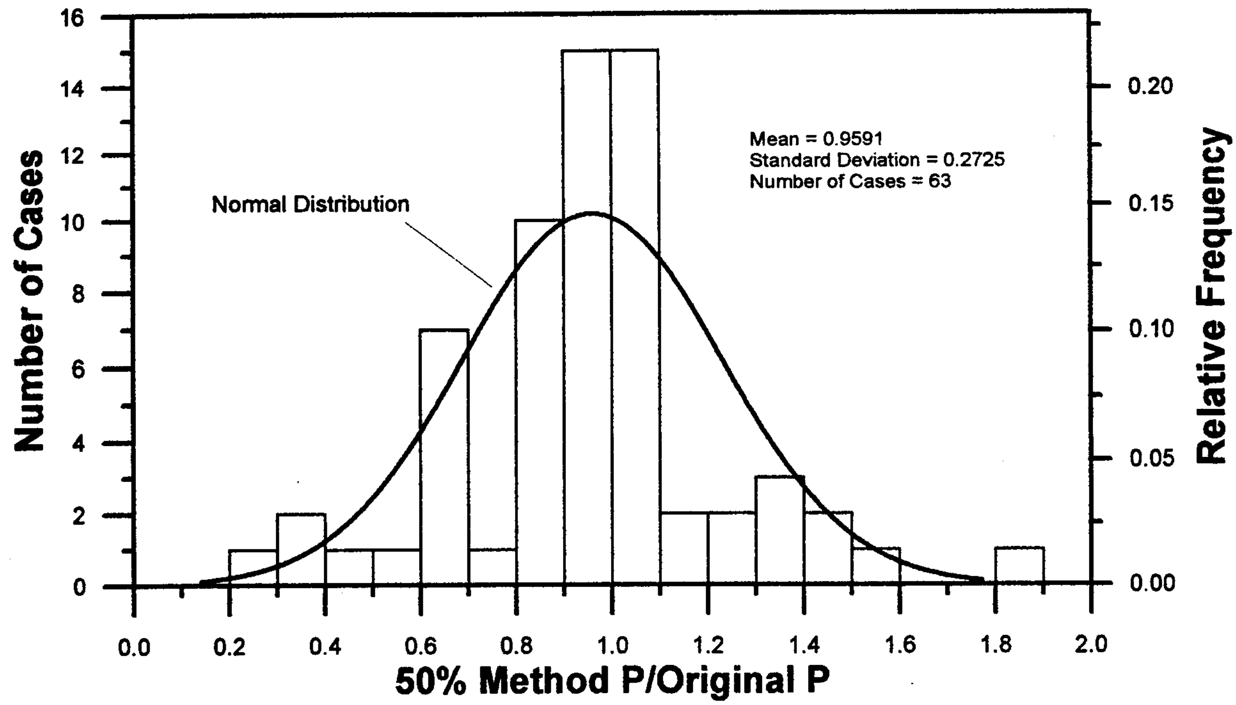

Figure 17. Histogram and Frequency Distribution for the Ratio Between Extrapolated Capacity Based on 50% of the Data Case and the Actual Capacity (Both Using Davisson's Failure Criterion).

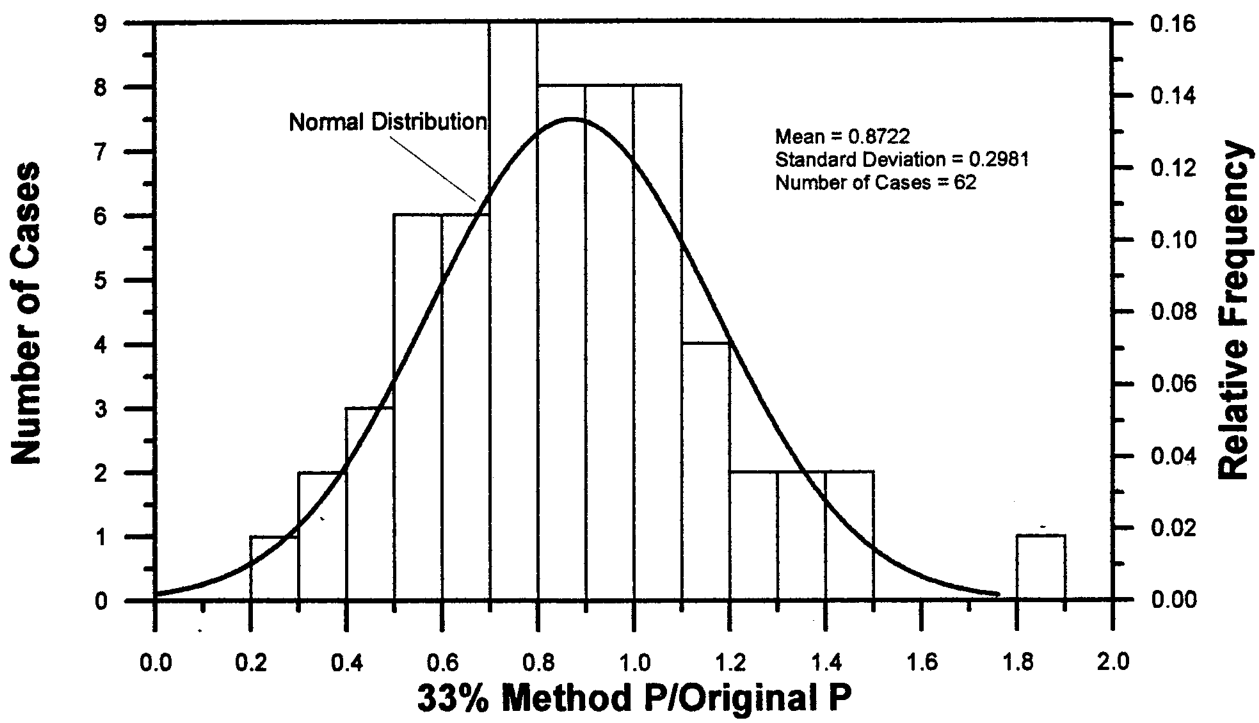

Figure 18. Histogram and Frequency Distribution for the Ratio Between Extrapolated Capacity Based on 33% of the Data Case and the Actual Capacity (Both Using Davisson's Failure Criterion).

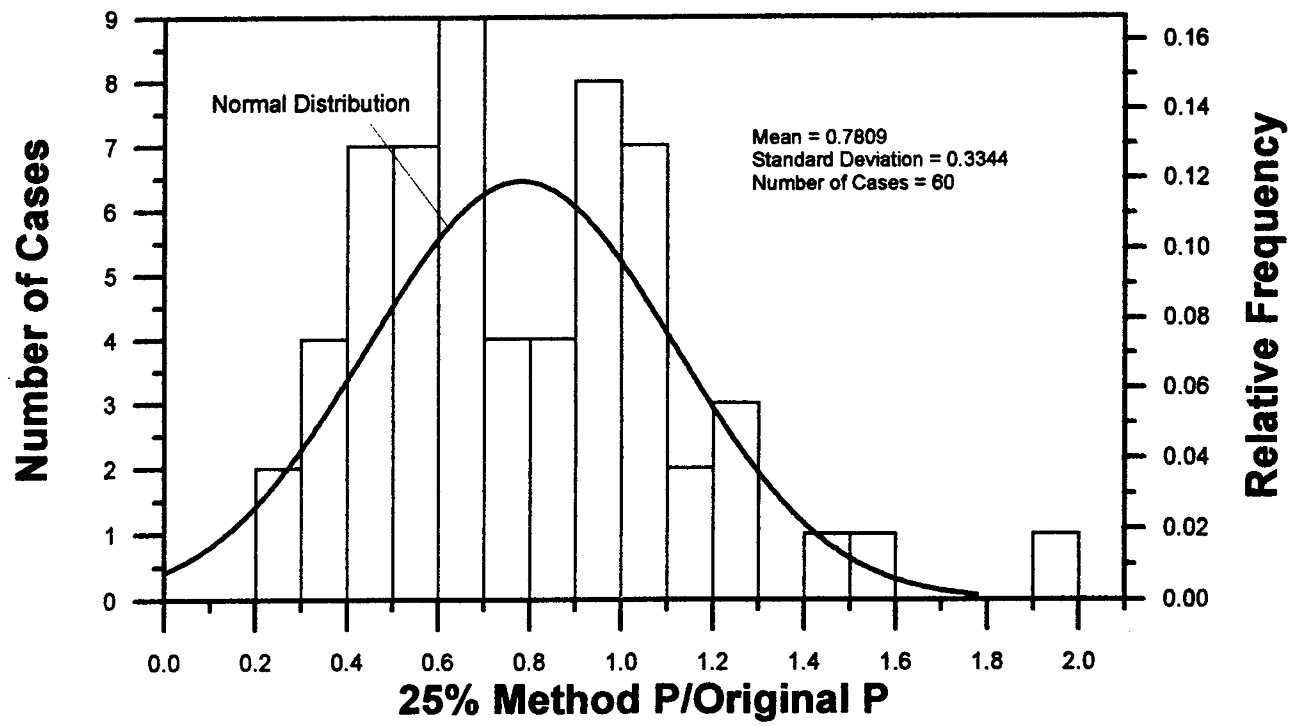

Figure 19. Histogram and Frequency Distribution for the Ratio Between Extrapolated Capacity Based on 25% of the Data Case and the Actual Capacity (Both Using Davisson's Failure Criterion).

6.5.1 Pile Stiffness

Pile stiffness is a measure of the compressibility of the pile material. Assuming uniform geometry and pile material, the stiffness is computed by calculating the elastic modules of the pile times the area of the pile, divided by the length of the pile (EA/L).

Figures 20 through 24 present the relationship between the ratio of the extrapolated capacity based on the proposed method and the actual capacity (both interpreted using Davisson's criterion), and the stiffness of the corresponding pile. Each figure corresponds to a range of data analyzed (100%, 75%, 50%, 33%, and 25%) for each pile.

Based on inspection of Figures 20 through 24, no clear correlation seems to exist between the accuracy of the proposed method and the pile stiffness.

6.5.2 Pile Slenderness

Pile slenderness can be defined as the ratio of pile length divided by pile diameter (L/B). Figures 25 through 29 present the relationship between the ratio of the extrapolated capacity based on the proposed method and the capacity based on Davisson's criterion

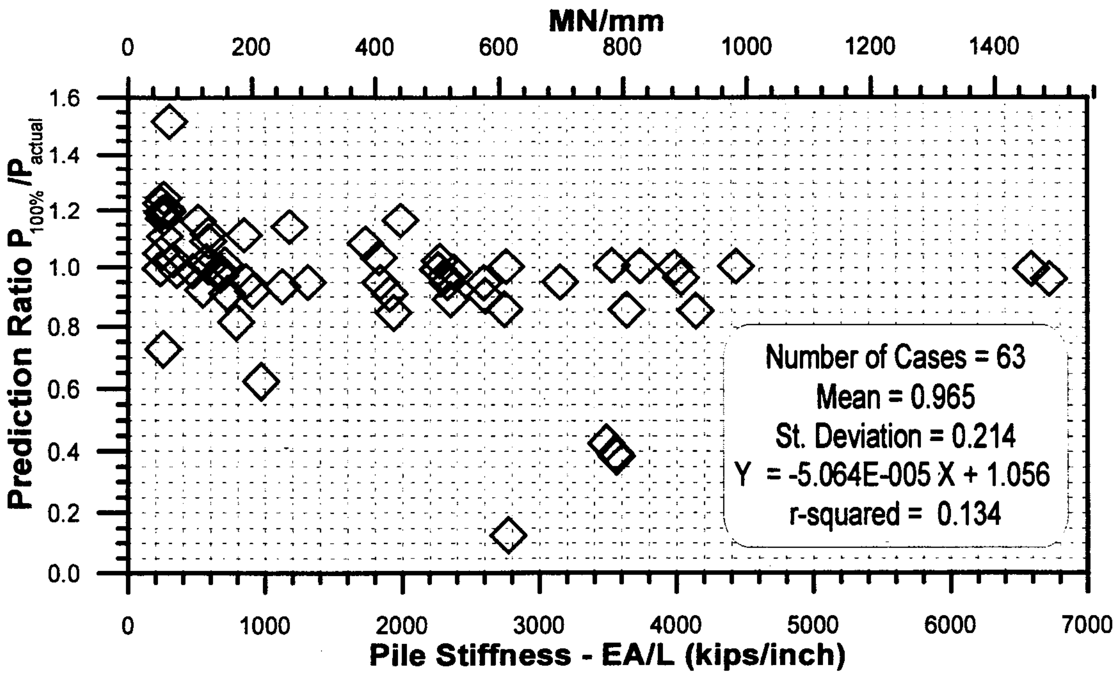

Figure 20. Ratio of Predicted Capacity Using 100% Data Over Actual Load-Test Results (Using Davisson's Criterion) vs. Pile Stiffness (Modulus of Elasticity Multiplied by Pile Area, Divided by Pile Length).

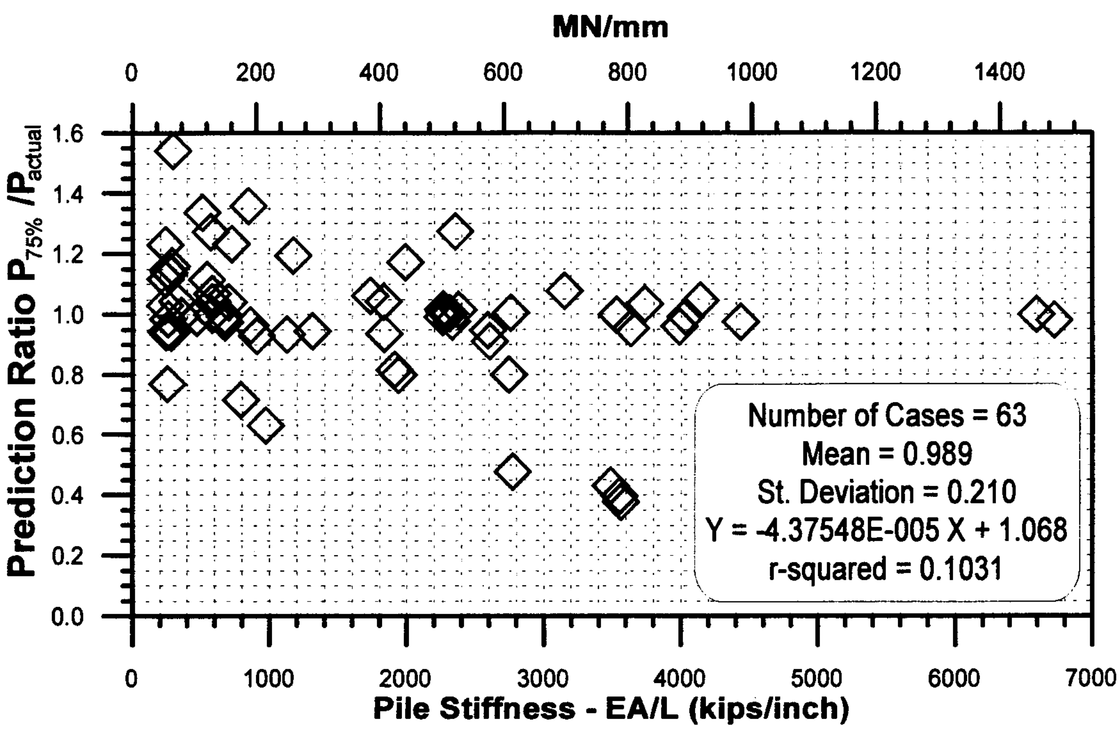

Figure 21. Ratio of Predicted Capacity Using 75% Data Over Actual Load-Test Results (Using Davisson's Criterion) vs. Pile Stiffness (Modulus of Elasticity Multiplied by Pile Area, Divided by Pile Length).

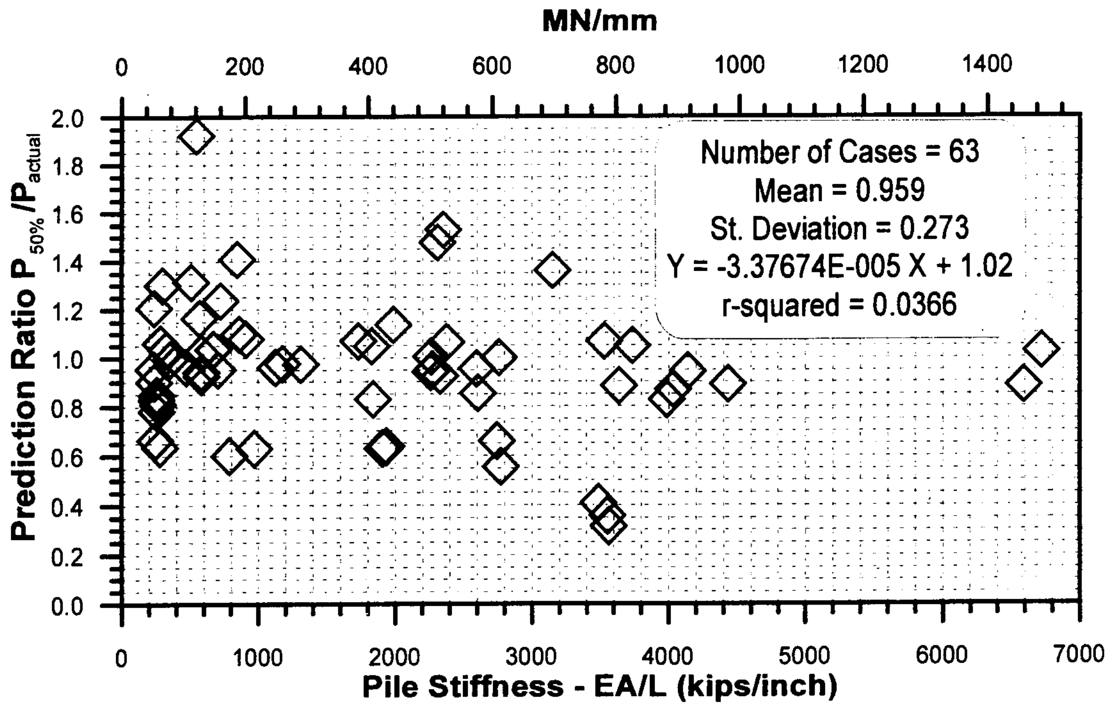

Figure 22. Ratio of Predicted Capacity Using 50% Data Over Actual Load-Test Results (Using Davisson's Criterion) vs. Pile Stiffness (Modulus of Elasticity Multiplied by Pile Area, Divided by Pile Length).

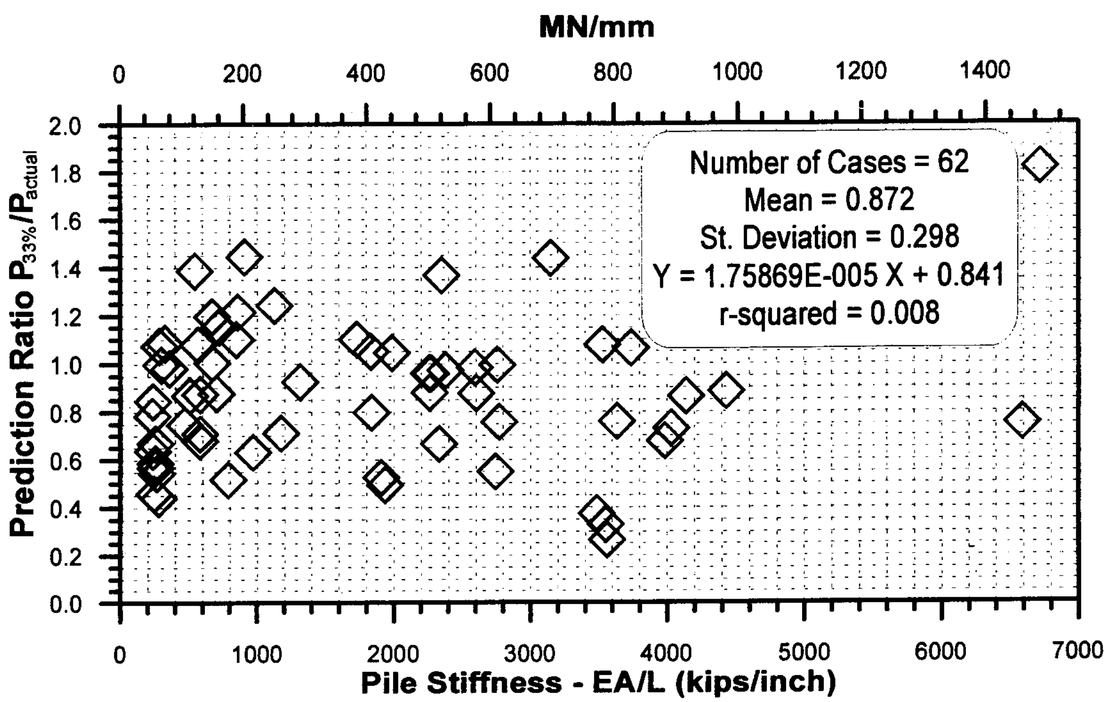

Figure 23. Ratio of Predicted Capacity Using 33% Data Over Actual Load-Test Results (Using Davisson's Criterion) vs. Pile Stiffness (Modulus of Elasticity Multiplied by Pile Area, Divided by Pile Length).

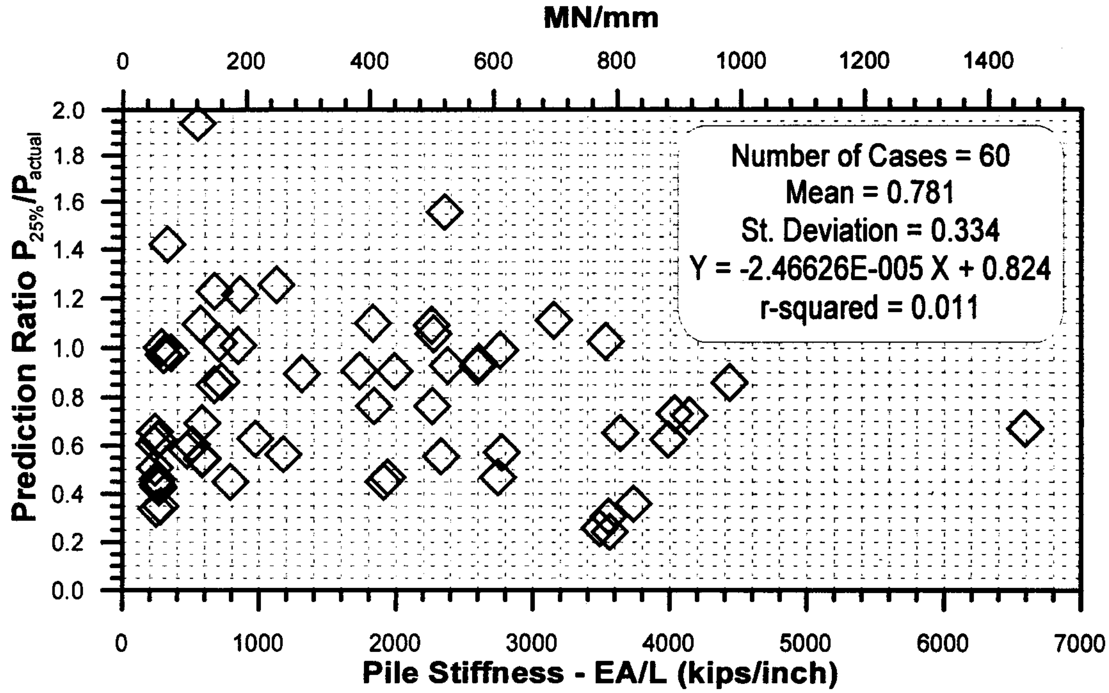

Figure 24. Ratio of Predicted Capacity Using 25% Data Over Actual Load-Test Results (Using Davisson's Criterion) vs. Pile Stiffness (Modulus of Elasticity Multiplied by Pile Area, Divided by Pile Length).

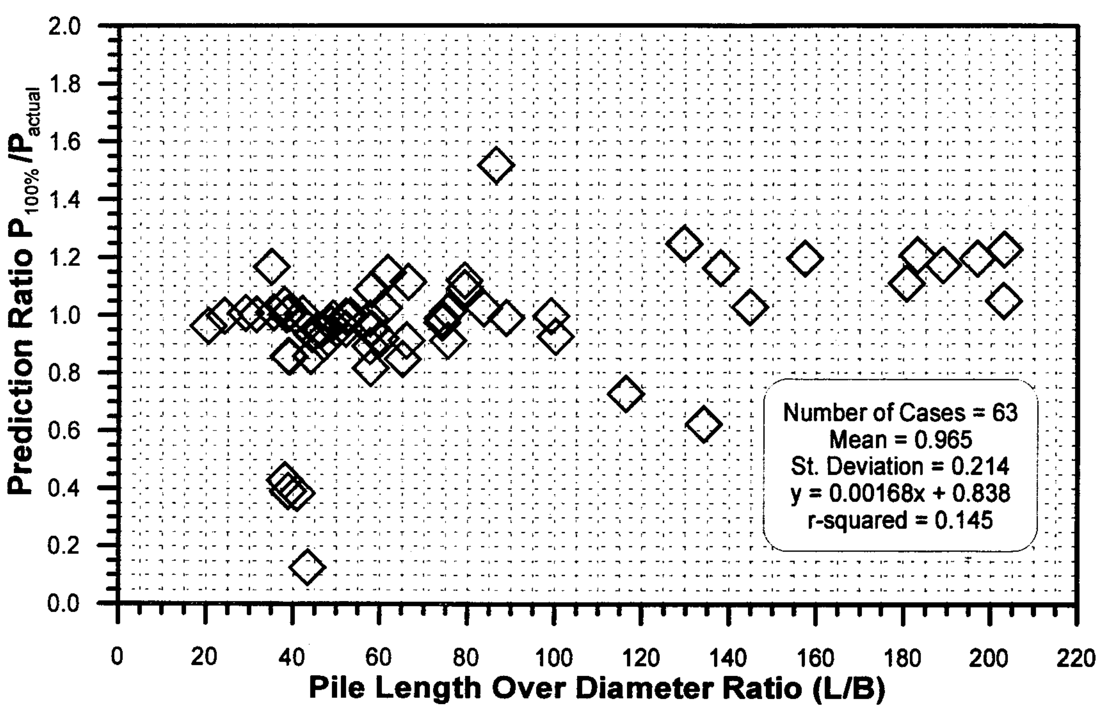

Figure 25. Ratio of Predicted Capacity (Using 100% Data) Over Actual Load-Test Results (Using Davisson's Criterion) vs. Pile Length Over Diameter Ratio.

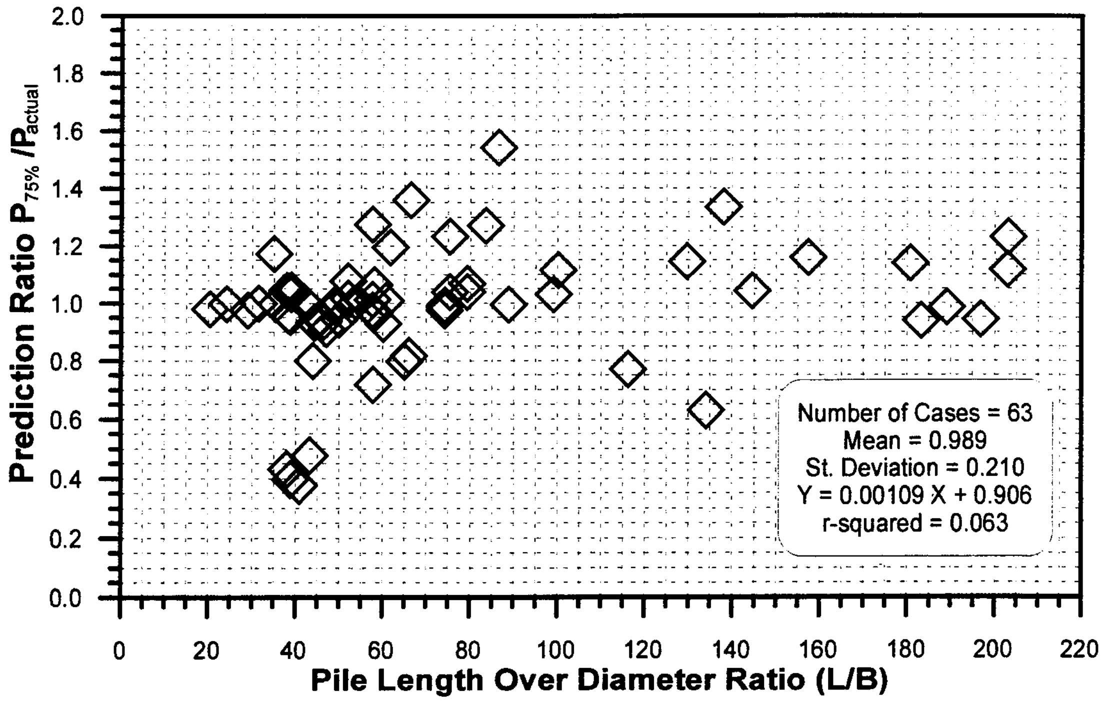

Figure 26. Ratio of Predicted Capacity (Using 75% Data) Over Actual Load-Test Results (Using Davisson's Criterion) vs. Pile Length Over Diameter Ratio.

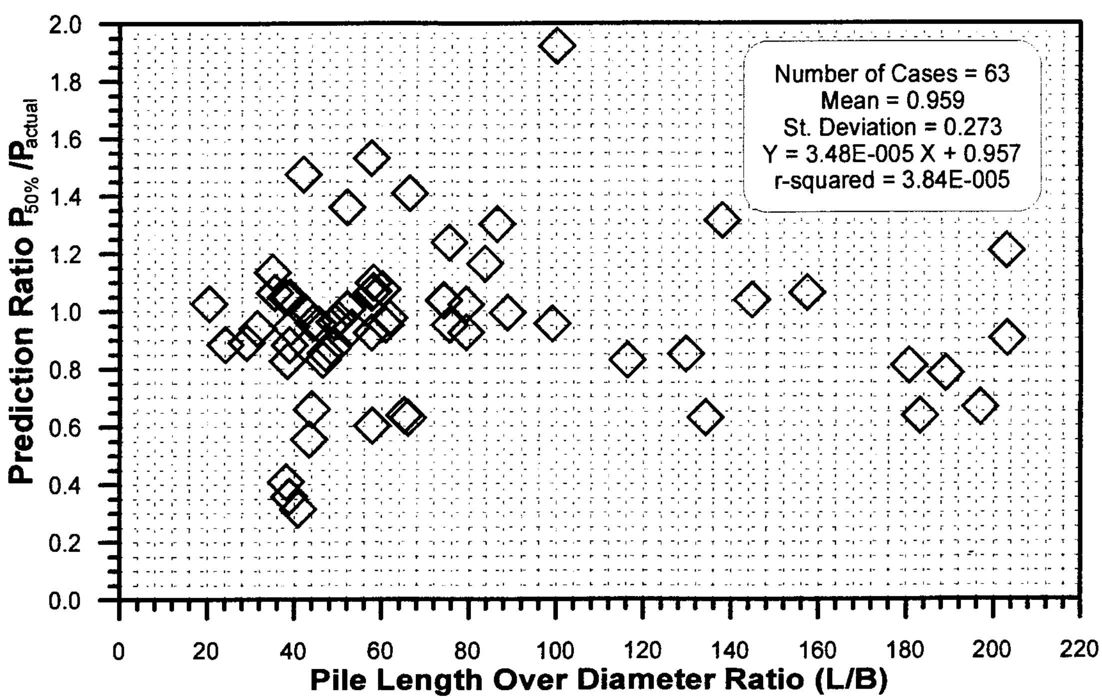

Figure 27. Ratio of Predicted Capacity (Using 50% Data) Over Actual Load-Test Results (Using Davisson's Criterion) vs. Pile Length Over Diameter Ratio.

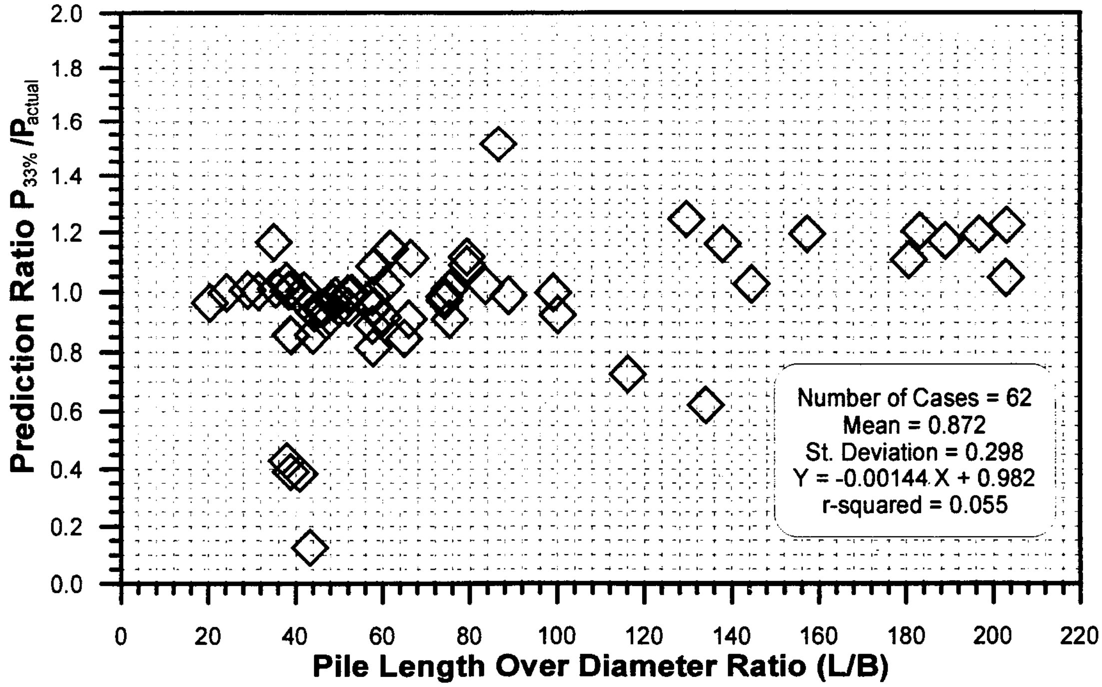

Figure 28. Ratio of Predicted Capacity (Using 33% Data) Over Actual Load-Test Results (Using Davisson's Criterion) vs. Pile Length Over Diameter Ratio.

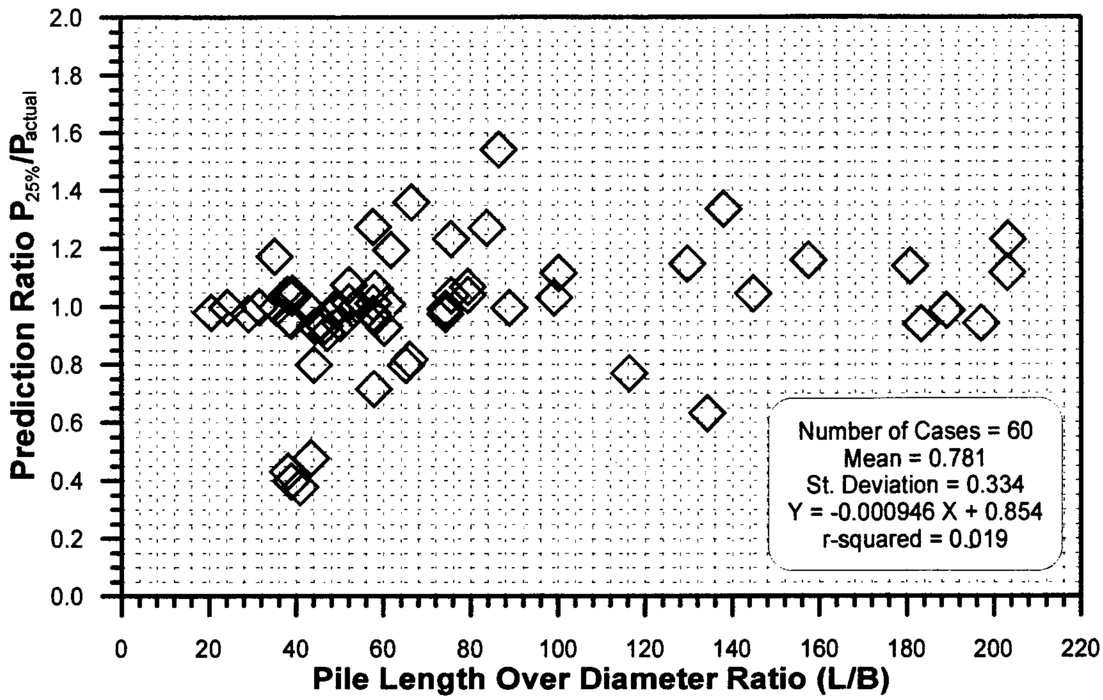

Figure 29. Ratio of Predicted Capacity (Using 25% Data) Over Actual Load-Test Results (Using Davisson's Criterion) vs. Pile Length Over Diameter Ratio.

to the corresponding pile slenderness. Each figure represents a range of the data analyzed.

A substantial scatter exists in each figure with no clear correlation between the accuracy of the proposed method and pile slenderness.

6.6 RISK ANALYSIS

Risk (R) is generally defined as the probability (P_{Prob}) that the proposed method predicted ultimate capacity (P) divided by the factor of safety (F.S.) exceeds the ultimate capacity determined by Davisson's criterion ($P_{Davisson}$) from the actual load test:

$$R = P_{Prob}(\{P/F.S.\} > P_{Davisson}) \qquad (6.4)$$

The factor of safety in current use is the factor applied to the predicted pile capacity such that the allowable load is free from meaningful risk.

The prediction ratio as presented throughout this research study is the ratio of the proposed method predicted capacity (for each range of data analyzed) to the capacity as determined by Davisson (from the actual load test). Equation 6.4 can be rewritten in the following format related to the associated risk:

$$R = P_{Prob}\{(P_{pred}/P_{Davisson}) \times F.S.\} \qquad (6.5)$$

As construction cost is directly related to the factor of safety, the following should be considered when determining an appropriate factor of safety:

- What is the minimum factor of safety that will allow absolute safety (zero risk)?
- What is the risk associated with each factor of safety?
- What is the actual factor of safety when considering the inaccuracy of the prediction method?

To address the above concerns, the following analysis was undertaken:

The data set was used to prepare the relationships between the applied factor of safety and its associated risk. The procedure was described by Briaud and Tucker (1988) and contains the following steps:

(1) Select an arbitrary Factor of Safety (F.S.).
(2) Calculate the risk of failure as the ratio between the number of piles in the data set for which the $P/P_{Davisson}$ ratio is greater than the F.S. over the total number of piles in the data set.
(3) Repeat steps 1 and 2 for different F.S. values.
(4) Plot the obtained relations between the applied F.S. and the associated risk.

This analysis was carried out for the proposed prediction method using the piles in data set PD/LT. Table 14 presents a summary of the results of the analysis for the ranges of data analyzed. The use of a factor of safety of 1.6 for example will be associated with an actual factor of safety of 3.11 and a risk of 1.69 percent. From the risk analysis, a factor of safety of 2.0 will allow absolute safety (zero risk) for data set PD/LT.

Table 14
Factor of Safety and Associated Risk Based on Ranges of Data

% of data	100%	75%	50%	33%	25%
FS=1					
Count	27.00	30.00	26.00	19.00	15.00
Risk (%)	42.86	47.62	41.27	30.65	25.42
Mean	1.11	1.13	1.18	1.21	1.21
Actual F.S.	1.11	1.13	1.18	1.21	1.21
FS=1.2					
Count	4.00	7.00	9.00	7.00	6.00
Risk (%)	6.35	11.11	14.29	11.29	10.17
Mean	1.30	1.32	1.42	1.42	1.44
Actual F.S.	1.56	1.59	1.70	1.70	1.72
FS=1.4					
Count	1.00	1.00	4.00	3.00	3.00
Risk (%)	1.59	1.59	6.35	4.84	5.08
Mean	1.52	1.54	1.59	1.57	1.64
Actual F.S.	2.13	2.16	2.22	2.19	2.30
FS=1.6					
Count	0.00	0.00	1.00	1.00	1.00
Risk (%)	0.00	0.00	1.59	1.61	1.69
Mean	NA	NA	1.92	1.82	1.94
Actual F.S.	NA	NA	3.08	2.91	3.11
FS=1.8					
Count	0.00	0.00	1.00	1.00	1.00
Risk (%)	0.00	0.00	1.59	1.61	1.69
Mean	NA	NA	1.92	1.82	1.94
Actual F.S.	NA	NA	3.46	3.27	3.50
FS=2.0					
Count	0.00	0.00	0.00	0.00	0.00
Risk (%)	0.00	0.00	0.00	0.00	0.00
Mean	NA	NA	NA	NA	NA
Actual F.S.	NA	NA	NA	NA	NA

Count - number of prediction ratios greater than F.S.
Prediction ratio - Ratio of proposed method capacity to actual capacity using Davisson's failure criterion.
Mean - the mean of all values greater than the initial F.S.
Actual F.S. - Initial F.S. multiplied by the mean.

Table 15 presents a summary of the results of analysis for the ranges of the designated static load.

Table 15
Factor of Safety and Associated Risk Based on Ranges of Static Load

% Static Load	100%	75%	50%	33%	25%
FS=1					
Count	37.00	23.00	17.00	8.00	6.00
Risk (%)	58.73	37.10	27.87	15.09	12.50
Mean	1.13	1.25	1.38	1.51	1.53
Actual F.S.	1.13	1.25	1.38	1.51	1.53
FS=1.2					
Count	8.00	14.00	9.00	3.00	4.00
Risk (%)	12.70	22.58	14.75	5.66	8.33
Mean	1.33	1.37	1.66	2.28	1.77
Actual F.S.	1.59	1.64	1.99	2.74	2.13
FS=1.4					
Count	1.00	4.00	4.00	3.00	2.00
Risk (%)	1.59	6.45	6.56	5.66	4.17
Mean	1.72	1.67	2.06	2.28	2.26
Actual F.S.	2.41	2.34	2.89	3.20	3.16
FS=1.6					
Count	1.00	2.00	4.00	2.00	2.00
Risk (%)	1.59	3.23	6.56	3.77	4.17
Mean	1.72	1.88	2.06	2.71	2.26
Actual F.S.	2.76	3.01	3.30	4.33	3.61
FS=1.8					
Count	0.00	1.00	2.00	2.00	1.00
Risk (%)	0.00	1.61	3.28	3.77	2.08
Mean	NA	2.06	2.39	2.71	2.73
Actual F.S.	NA	3.71	4.31	4.87	4.92
FS=2.0					
Count	0.00	1.00	2.00	2.00	1.00
Risk (%)	0.00	1.61	3.28	3.77	2.08
Mean	NA	2.06	2.39	2.71	2.73
Actual F.S.	NA	4.12	4.78	5.41	5.46

Table 15
Factor of Safety and Associated Risk Based on Ranges of Static Load (continued)

% Static Load	100%	75%	50%	33%	25%
FS=2.8					
Count	0.00	0.00	0.00	0.00	0.00
Risk (%)	0.00	0.00	0.00	0.00	0.00
Mean	NA	NA	NA	NA	NA
Actual F.S.	NA	NA	NA	NA	NA

Count - number of prediction ratios greater than F.S.
Prediction ratio - Ratio of proposed method capacity to actual capacity using Davisson's failure criterion.
Mean - the mean of all values greater than the initial F.S.
Actual F.S. - Initial F.S. multiplied by the mean.

CHAPTER 7: CASE HISTORIES

7.1 OVERVIEW

The Massachusetts Building Code (Massachusetts Building Code, 1998) and the Massachusetts Highway Department Specifications (Massachusetts Highway Department, 1995) call for a pile load test to at least twice the design load. The application of the proposed method to six recently completed pile load tests at two sites in the Boston area is demonstrated. All case histories were obtained from GeoSciences Testing and Research (GTR) Inc. of North Chelmsford, MA. Three different pile types in these cases were loaded beyond the necessary minimum of twice the design load. The analysis of these cases considered only the loads typically known in a project, i.e., up to and including twice the design load. The extrapolated pile behavior based on the analyses were then compared to the actual load-test results and conclusions were drawn. The presented cases are not part of the analyzed database, hence, they represent an independent examination of the method.

7.2 CASE HISTORY NO. 1

7.2.1 Overview

Case History No. 1 is comprised of three H-piles and two pipe piles. Details are provided in two reports, *Static Load Test Report, Steel H-Piles, Bridge N-10-15, Newbury, Massachusetts* (Geosciences Testing and Research, Inc., 1996a) and *Static Load Test Report, Steel Pipe Piles, Bridge N-10-15, Newbury, Massachusetts* (GeoSciences Testing and Research, Inc., 1996b). The site is located in northeastern Massachusetts in the Town of Newbury. A multi-span reinforced bridge was demolished prior to the pile driving. A new multi-span bridge was constructed on five bents (two piers each) and two abutments. Approximately 300 H-piles (vertical and batter) are supporting the abutments and piers. Three test piles, designated as TP2, TP3, and TP4, were installed to test the capacity of the H-piles utilized for the abutments and piers.

Five retaining walls at the site are used to support the new roadway approach embankments and ramp. Approximately 400 vertical and 3:1 batter pipe piles support these retaining walls. Two test piles, designated as TP1 and TP5, were driven to test the capacity of the pipe piles needed for the retaining walls.

The subsurface profile at the site generally consists of:

- 5 to 10 feet (1.5 to 3.0 m) of dense granular fill.
- 0 to 1 foot (0 to 0.3 m) of soft organic silt and peat.
- 30 to 40 feet (9.1 to 12.2 m) of soft Boston Blue Clay.
- 30 to 70 feet (9.1 to 21.3 m) of silt, fine sand, and silty clay.
- 5 to 20 feet (1.5 to 6.1 m) of glacial till.
- Bedrock.

Groundwater was observed approximately 15 feet (4.6 m) below grade.

7.2.2 Test Piles TP2, TP3, and TP4 (H-Piles)

The required ultimate capacity of the 12- by 74-inch (305- by 1880-mm) H-piles is 300 kips (150 tons, 1334 kN), based on a design load of 150 kips (75 tons, 667 kN) and a factor of safety of 2. Test pile TP4 was installed on June 24, 1996, while test piles TP2 and TP3 were driven the next day, on June 25. The driven lengths (depth below ground surface) for the three piles were TP2 = 112 feet (34.1 m), TP3 = 108.5 feet (33.1 m), and TP4 = 105.5 feet (32.2 m).

The static load tests for TP2, TP3, and TP4 were performed on July 3, 8, and 12, 1996, respectively. The tests were carried out in accordance with ASTM D1143-81, and Section 940.62 of the Massachusetts Highway Department's Standard Specifications for Highways and Bridges. The load-displacement relationship for different locations along the pile obtained from the static load tests are presented in Figures 30, 31, and 32 for TP2, TP3, and TP4, respectively. The presented load-settlement relations suggest that TP3 and TP4 were loaded mostly within the zone of the elastic response, while TP2 indicates a response closer toward failure.

7.2.3 Extrapolation Analyses

The load-displacement relationships for TP2, TP3, and TP4 for the 0- to 300-kip (0- to 1334-kN) range (twice the design load) were analyzed. The obtained relations for the displacement over the corresponding load versus the displacements are presented in Figures 33, 34, and 35 for TP2, TP3, and TP4, respectively. The plotted data indicates that in all three cases, questionable initial pile response exists within a zone for which the top displacement is smaller than 0.2 inches (5 mm). The load-displacement relationship within this zone represents initial loading, including the slack in the reaction and load application system. Hence, this zone is not reliable for representing the actual pile-soil response for loading and the extrapolation was carried out for the zone beyond a pile top displacement of 0.2 inches (5 mm).

The load tests were performed as short-duration tests where the load is being applied in 22.5-ton increments (25% of 90 tons) and maintained for approximately 30 minutes under each load increment. Such procedures result in a varied displacement (settlement) for a single load and, hence, the plotted relationships in Figures 33, 34, and 35 present a cluster of points around a single displacement value. The extrapolation analysis of the relevant information (e.g., displacement greater than 0.2 inches [5 mm]) can be carried out in this case in four ways:

(1) Find the best-fit line through all the available points.
(2) Refer to the final settlement under each loading, i.e., including all plastic deformation and, hence, extrapolate the load-settlement curve in the most conservative way.

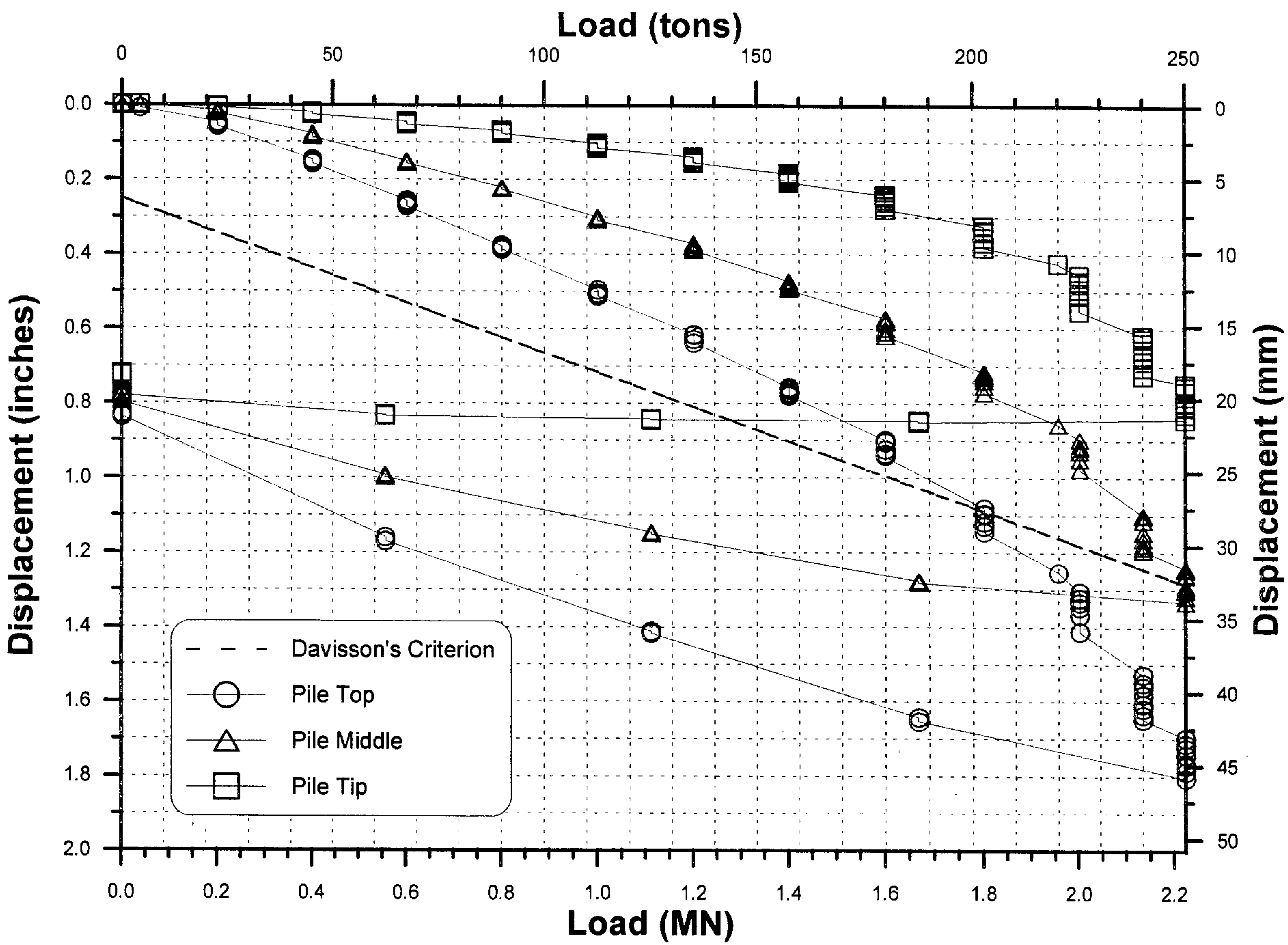

Figure 30. Load-Settlement Relationship for Test Pile TP2 (GTR Job No. 96-104, Newbury Bridge Project, July 1996).

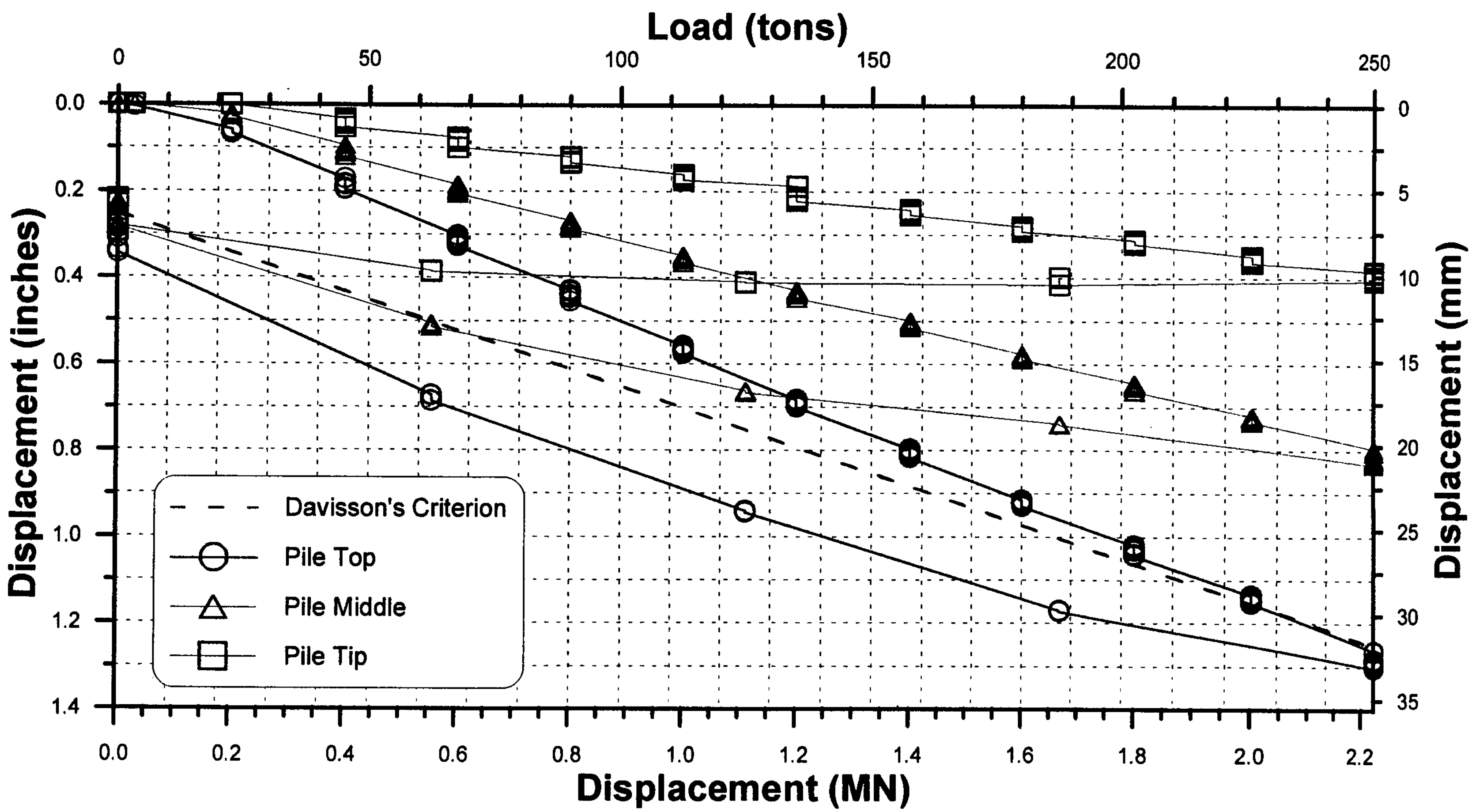

Figure 31. Load-Settlement Relationship for Test Pile TP3 (GTR Job No. 96-104, Newbury Bridge Project, July 1996).

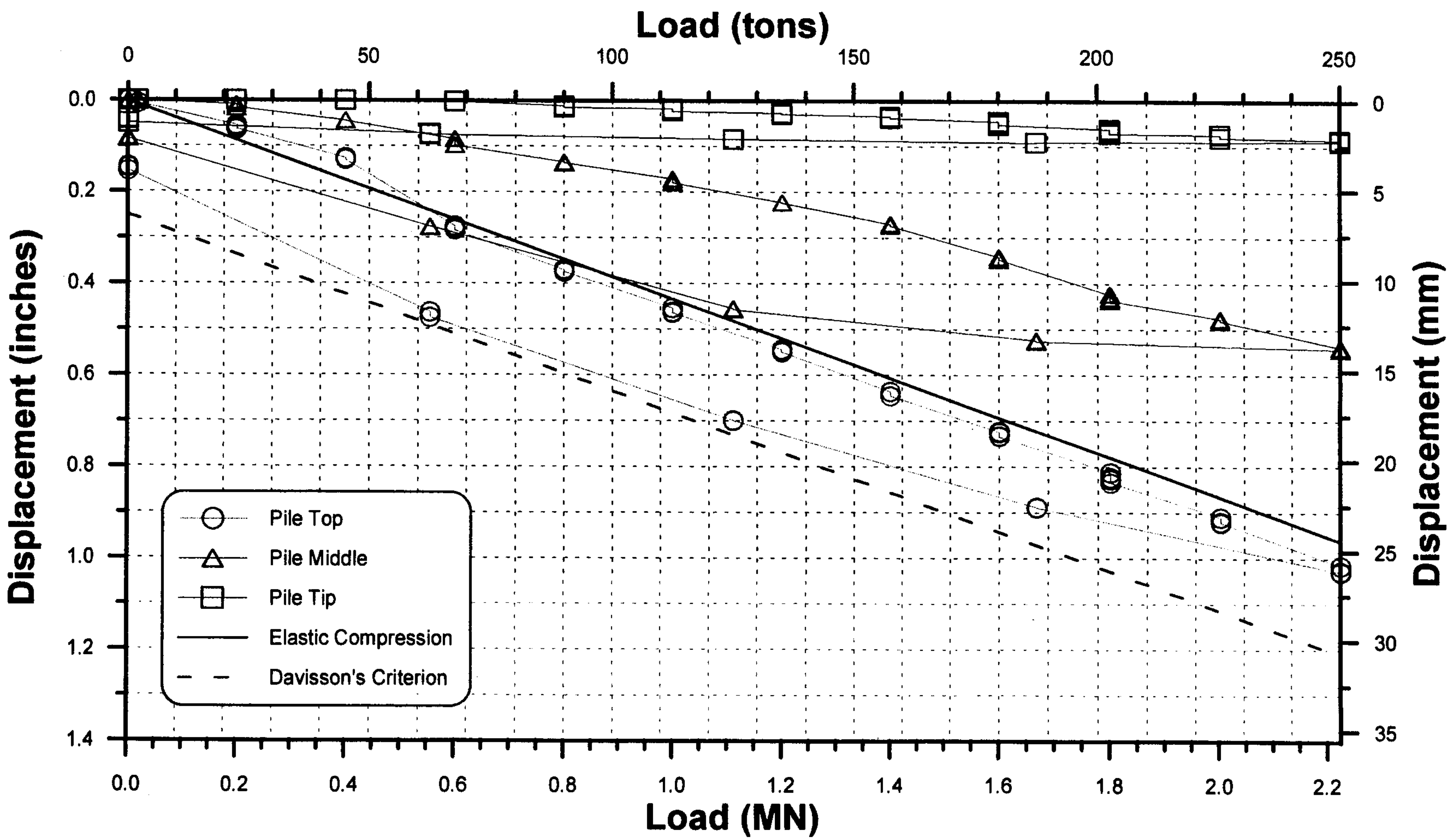

Figure 32. Load-Settlement Relationship for Test Pile TP4 (GTR Job No. 96-104, Newbury Bridge Project, July 1996).

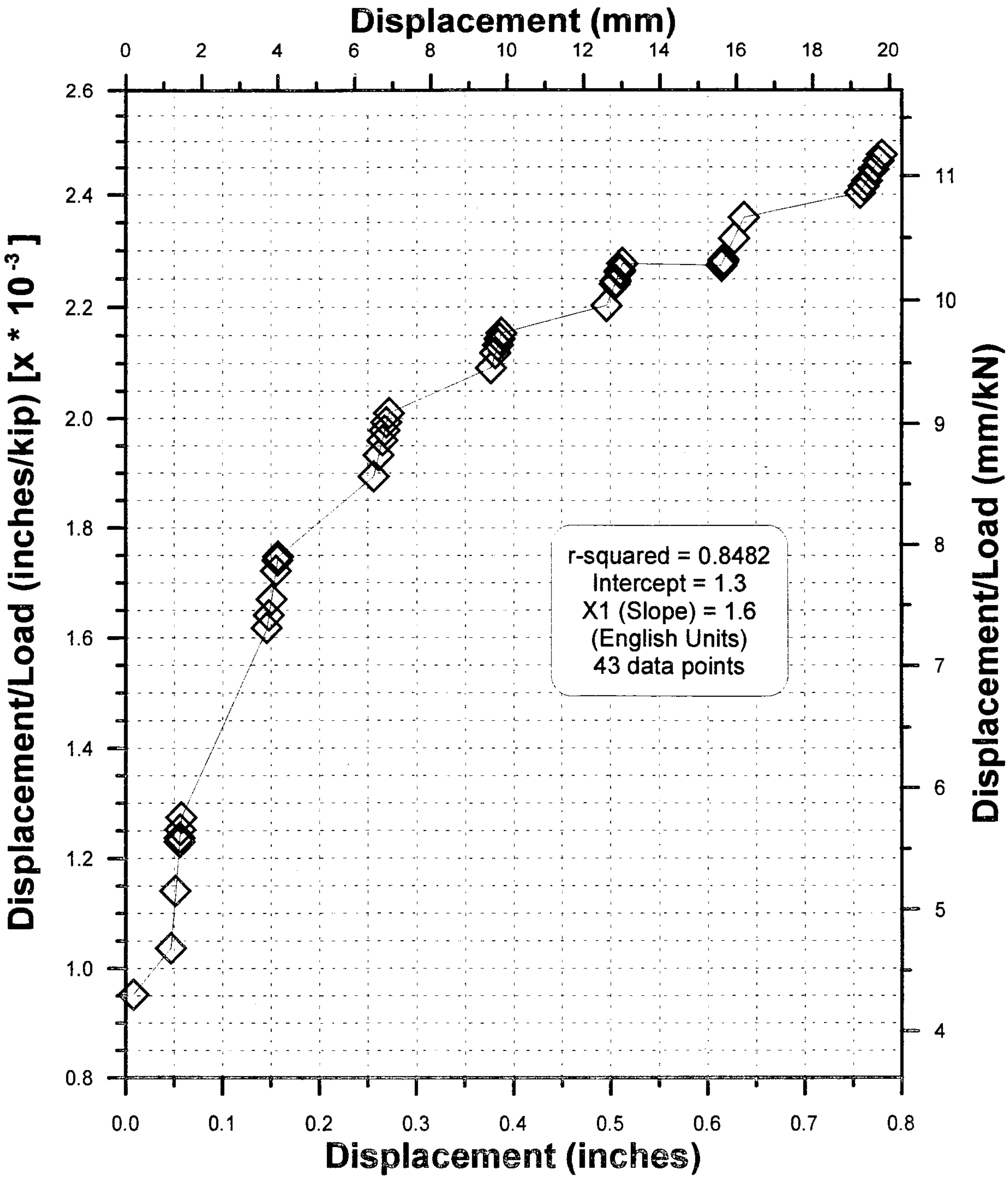

Figure 33. Relations Between Displacement Over Load Versus Displacement for Loads 0 to 300 kips (0 to 150 tons, 0 to 1334 kN) for Case History No. 1, Pile TP2.

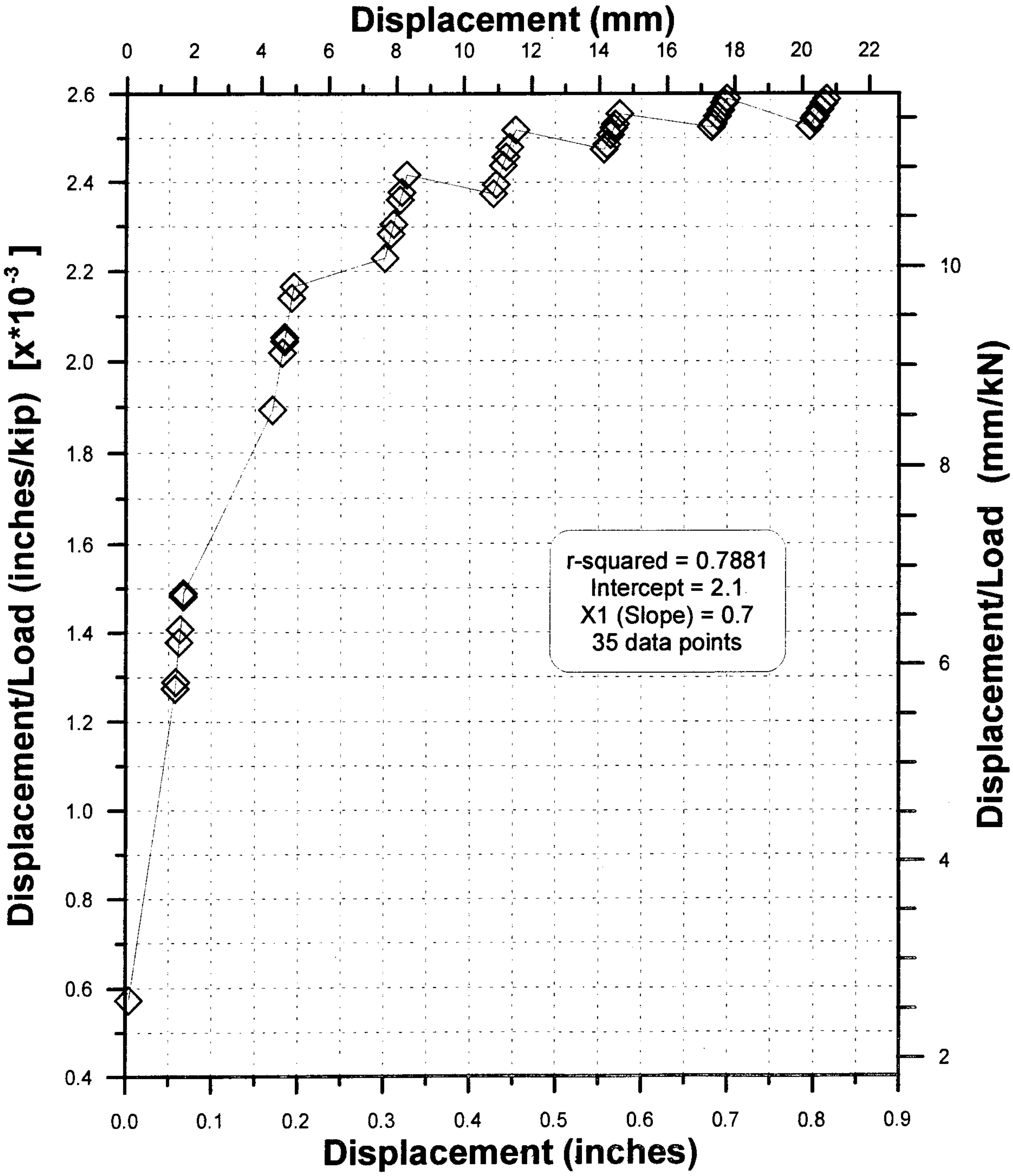

Figure 34. Relations Between Displacement Over Load Versus Displacement for Loads 0 to 300 kips (0 to 150 tons, 0 to 1334 kN) for Case History No. 1, Pile TP3.

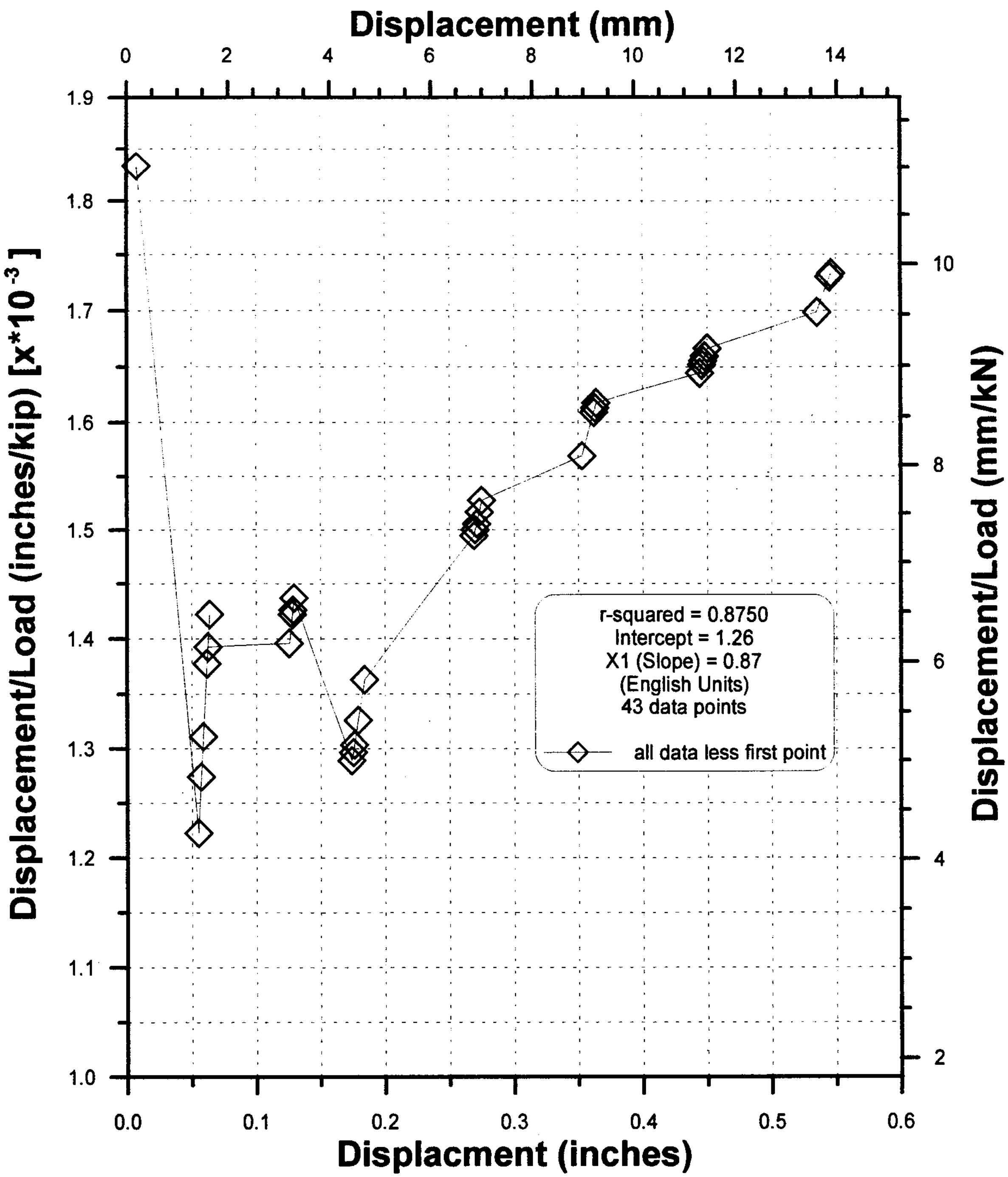

Figure 35. Relations Between Displacement Over Load Versus Displacement for Loads 0 to 300 kips (0 to 50 tons, 0 to 1334 kN) for Case History No. 1, Pile TP4.

(3) Refer to the initial settlement under each loading, i.e., including the plastic settlement of the previous points only, and refer to a load-settlement line through the initial loading.

(4) Refer to the initial settlement under each loading in a re-instituted curve subtracted for creep, i.e., the previous cumulative plastic deformation is reduced for any initial displacement under the applied load. This procedure results in the most unconservative extrapolation, analogous to a quick-loading procedure in which no time is provided for displacement as a result of creep.

Figures 36, 37, and 38 present the relations between displacement over load versus displacement for displacements greater than 0.2 inches (5 mm) for TP2, TP3, and TP4, respectively. The minimum square, first order, and best-fit lines of all four possibilities are presented in the figures as well. The obtained relations suggest a coefficient of determination well above 0.80, which is assumed to be the lowest for which the analysis can reliably be carried out. The obtained slope and intercept of the best-fit line were substituted in Equation 3.7 to calculate the predicted ultimate capacity of the pile based on Davisson's failure criterion.

Table 16 summarizes the extrapolation process and presents the intermediate calculated values as well as the final ultimate predicted capacity. Relatively small variations in predicted capacity exist between the different ways in which the method can be applied. For cases in which very little creep takes place within the loaded zones (e.g., TP2, TP3, and TP4), all ways of extrapolation will provide similar results as indicated in Table 16. Under different conditions, analyzing the two extremes (initial loading points reduced for creep and final loading point) should provide the entire possible range of extrapolation. The use of all points can be a simple and most efficient procedure to obtain representative extrapolation predictions. The designation "extrapolated load" in Table 16 was chosen as the average of the capacities obtained by the different procedures.

Table 16
Extrapolated Pile Capacities for Case History No. 1

Test Pile	Extrapolated Capacity in Relation to Data (Disp. >0.2 in load <300 kips)												Extrapolated Average Load (kips)
	All Points			Final Loading Points			Initial Loading Points			Initial Loading Points Reduced for Creep			
	# of pts	r^2	P kips	# of pts	r^2	P kips	# of pts	r^2	P kips	# of pts	r^2	P	
TP2	30	0.9541	386	5	0.9862	380	5	0.9668	387	4	0.9500	435	397
TP3	31	0.7752	345	6	0.7777	326	6	0.9313	345	5	0.9304	526	386
TP4	30	0.9226	485	5	0.9402	506	5	0.9249	488	5	0.9293	536	504

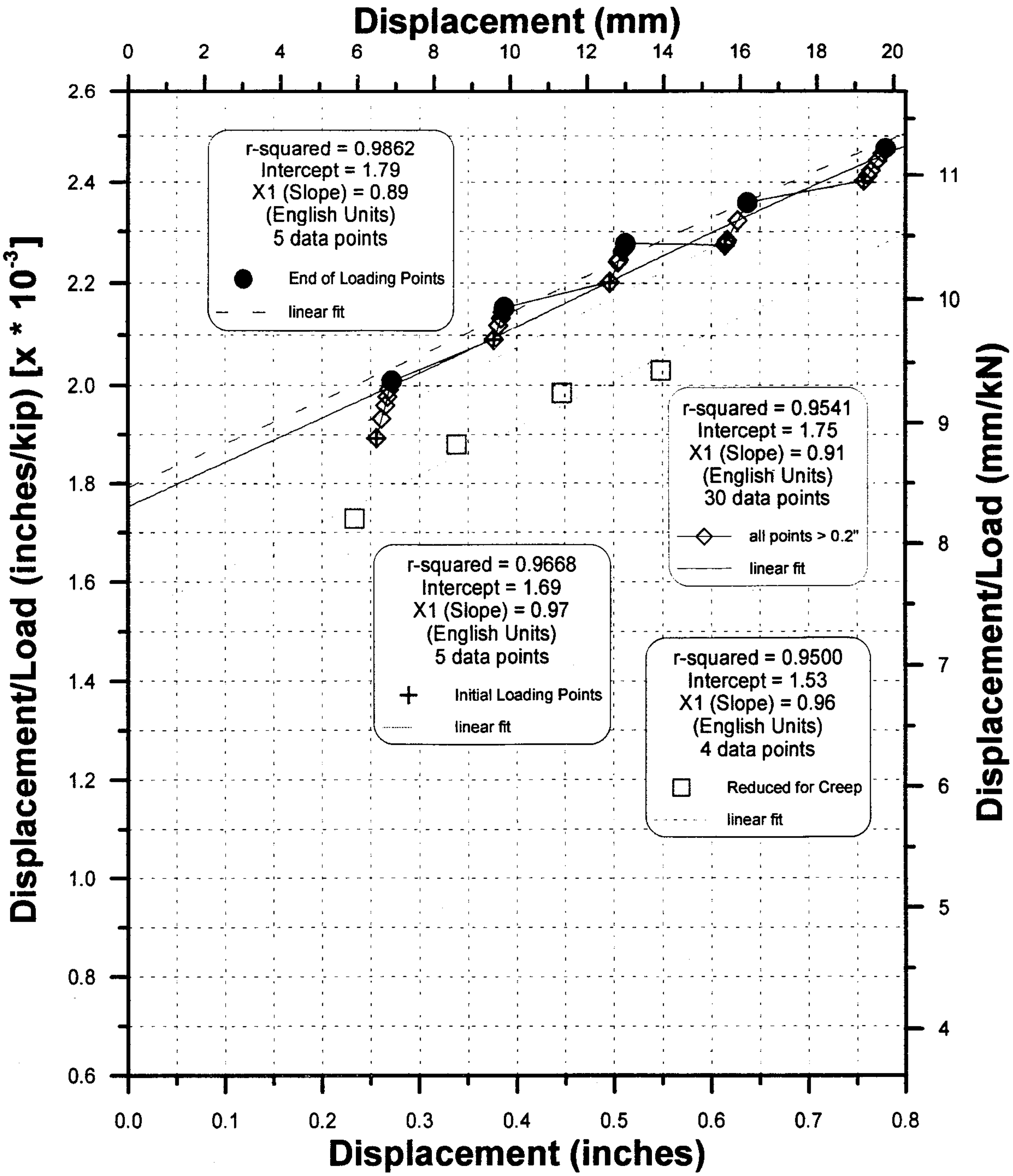

Figure 36. Relations Between Displacement Over Load Versus Displacement for Displacements Greater Than 0.2 inches (5 mm) and Loads Between 0 and 300 kips (0 and 150 tons, 0 and 1334 kN) for Case History No. 1, Pile TP2.

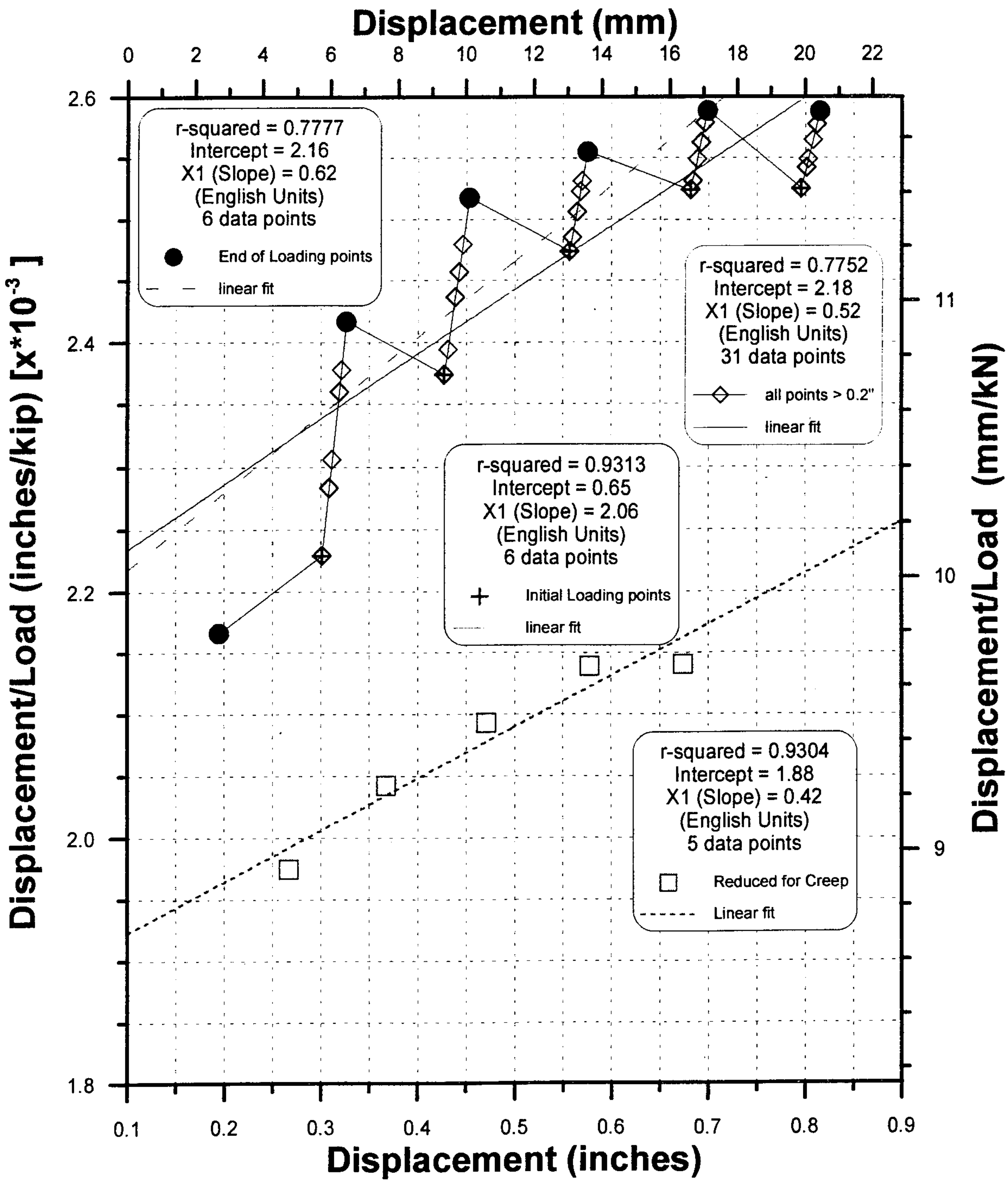

Figure 37. Relations Between Displacement Over Load Versus Displacement for Displacements Greater Than 0.2 inches (5 mm) and Loads Between 0 and 300 kips (0 and 150 tons, 0 and 1334 kN) for Case History No. 1, Pile TP3.

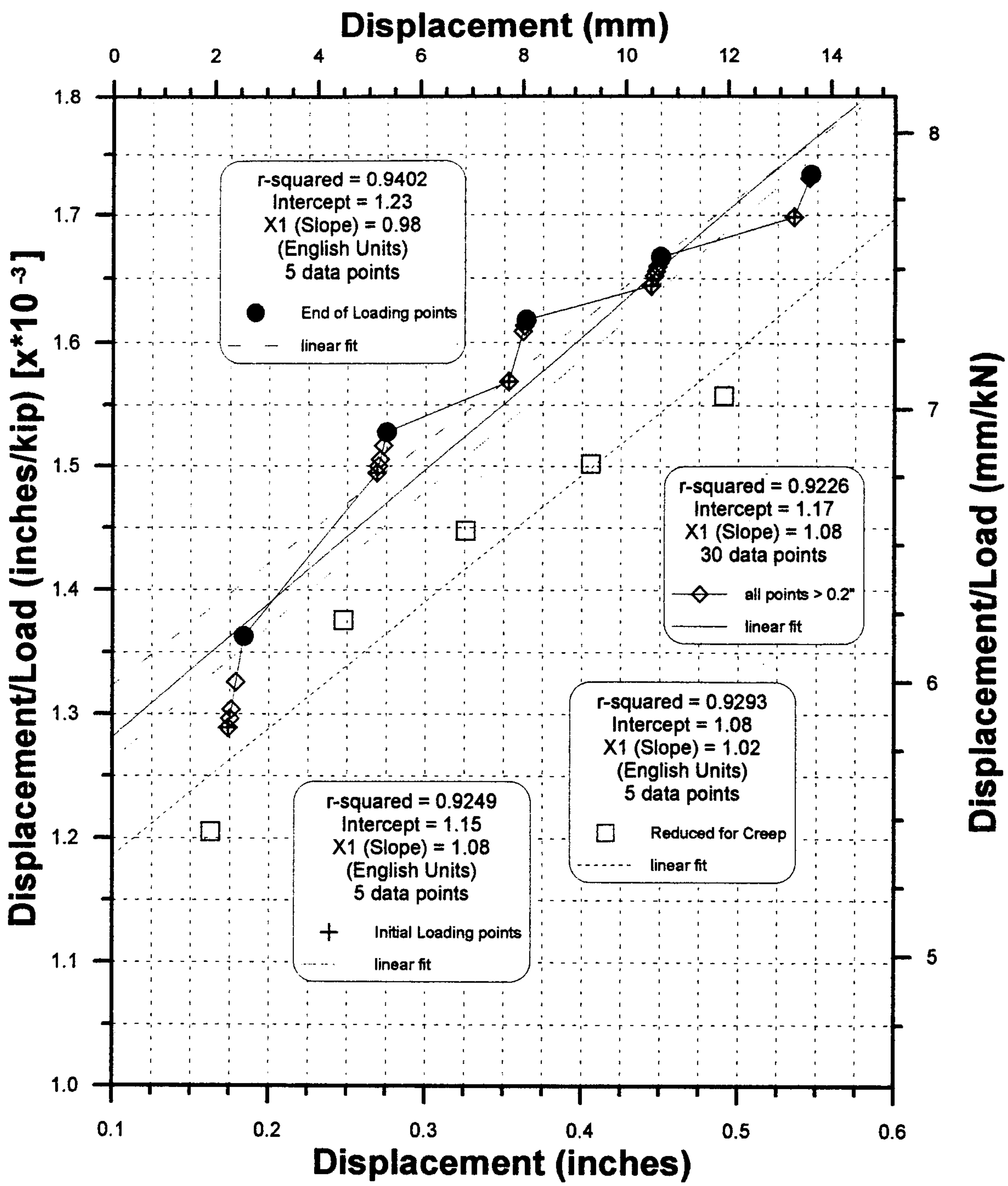

Figure 38. Relations Between Displacement Over Load Versus Displacement for Displacements Greater than 0.2 inches and Loads Up to 500 kips (250 tons, 2224 kN) for Case History No. 1, Pile TP4.

Table 17 presents the extrapolated values compared to the actual load-testing results. Table 17 also presents the predicted allowable capacity using a factor of safety of 2.0 when applied to the predicted ultimate capacity.

Table 17
Extrapolated and Actual Pile Capacities for Case History No. 1, Piles TP2, TP3, and TP4

	TP2	TP3	TP4
Ultimate Capacity Based on Actual Load Test (kips)	405	425	>500[4]
Predicted Ultimate Capacity (kips)[1]	397	386	504
Ratio of Predicted to Actual Capacity[2]	0.98	0.91	<1.01
Allowable Capacity Using F.S. = 2.0 (kips)[3]	199	193	252

Capacities determined using Davisson's criterion.
[1]Predicted Ultimate Capacity using only twice the design load data (300 kips).
[2]Ratio is determined by dividing the Predicted Ultimate Capacity by the Ultimate Capacity Based on Actual Load Test results.
[3]Allowable capacity was determined by dividing the Predicted Ultimate Capacity by a factor of 2.0.
[4]Load test not completed to failure, 500 kips represents maximum load tested.

Figures 39, 40, and 41 present the extrapolated load-displacement curves based on the described procedure in comparison with the actual load-settlement relations. The load-displacement relations beyond 300 kips (150 tons, 1334 kN) in Figures 39, 40, and 41 are the assumed unknown, indicating that a good conservative agreement exists between the extrapolated load-settlement relations and those observed in the zone beyond twice the design load.

7.2.4 Reliability of Results

The reliability of the predicted results was calculated using the risk analysis procedures outlined in Section 6.6. Since the ratios of assumed maximum applied load to the predicted ultimate capacity for TP2, TP3, and TP4 are between 0.60 to 0.78, the prediction method indicates that the ultimate capacities for the three piles are in the predicted zone of 50% to 75% and, hence, the 397, 386, and 504 kips (1766, 1717, and 2242 kN), respectively, are predicted with a risk of 1.6 to 3.2% (1 to 2 cases out of 63). Using a factor of safety (F.S.) of 2, as determined in Section 6.6 for all the tests in data set PD/LT, the allowable capacities of the three H-piles vary from 193 kips (858 kN) (TP3) to 252 kips (1121 kN) (TP4), in comparison with the 150-kip (667-kN) design load. The actual prediction accuracy for these piles is between 0.91 to 1.01, which suggests a very accurate performance.

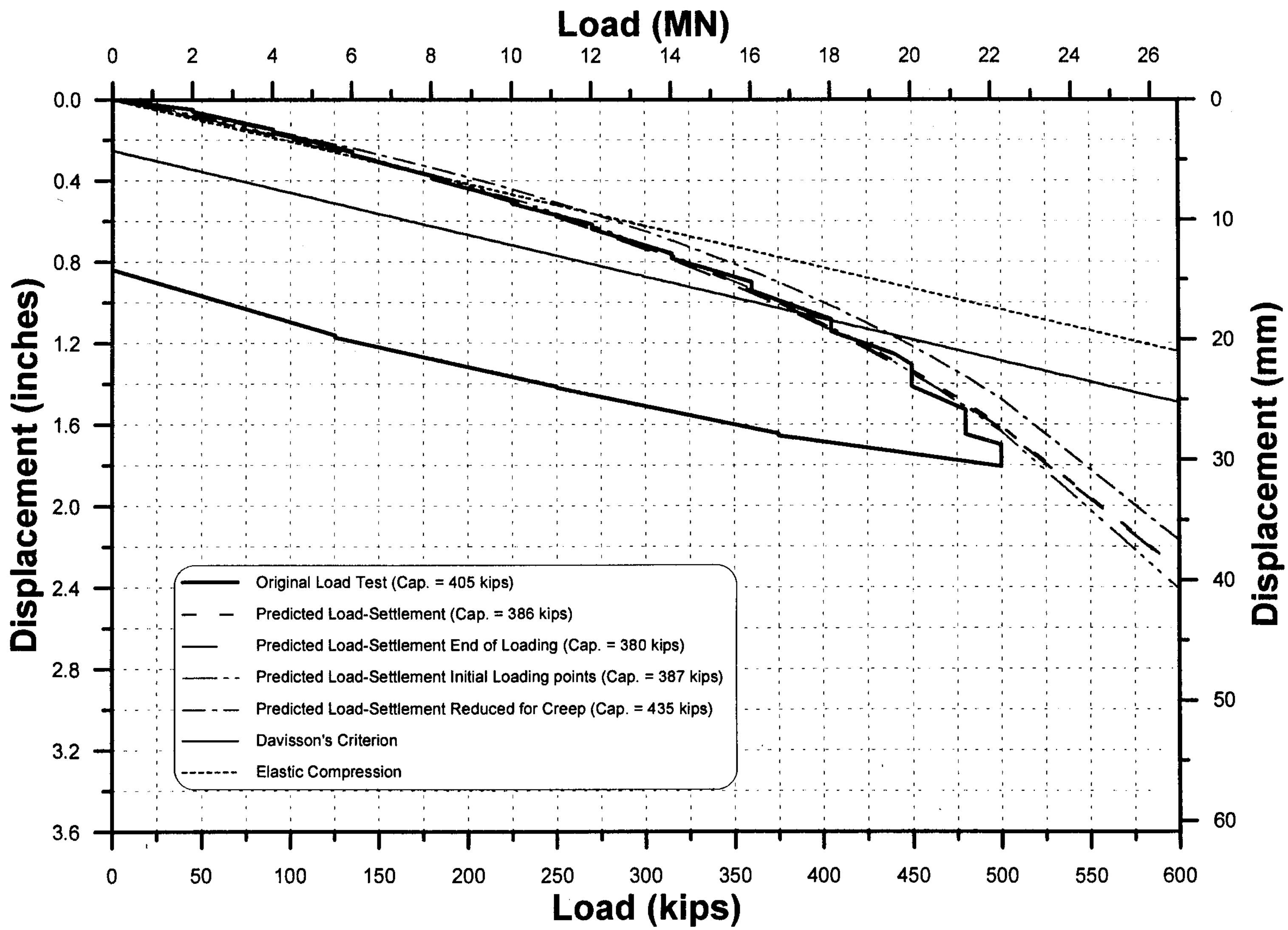

Figure 39. Predicted Load-Settlement Behavior for Case History No. 1, TP2.

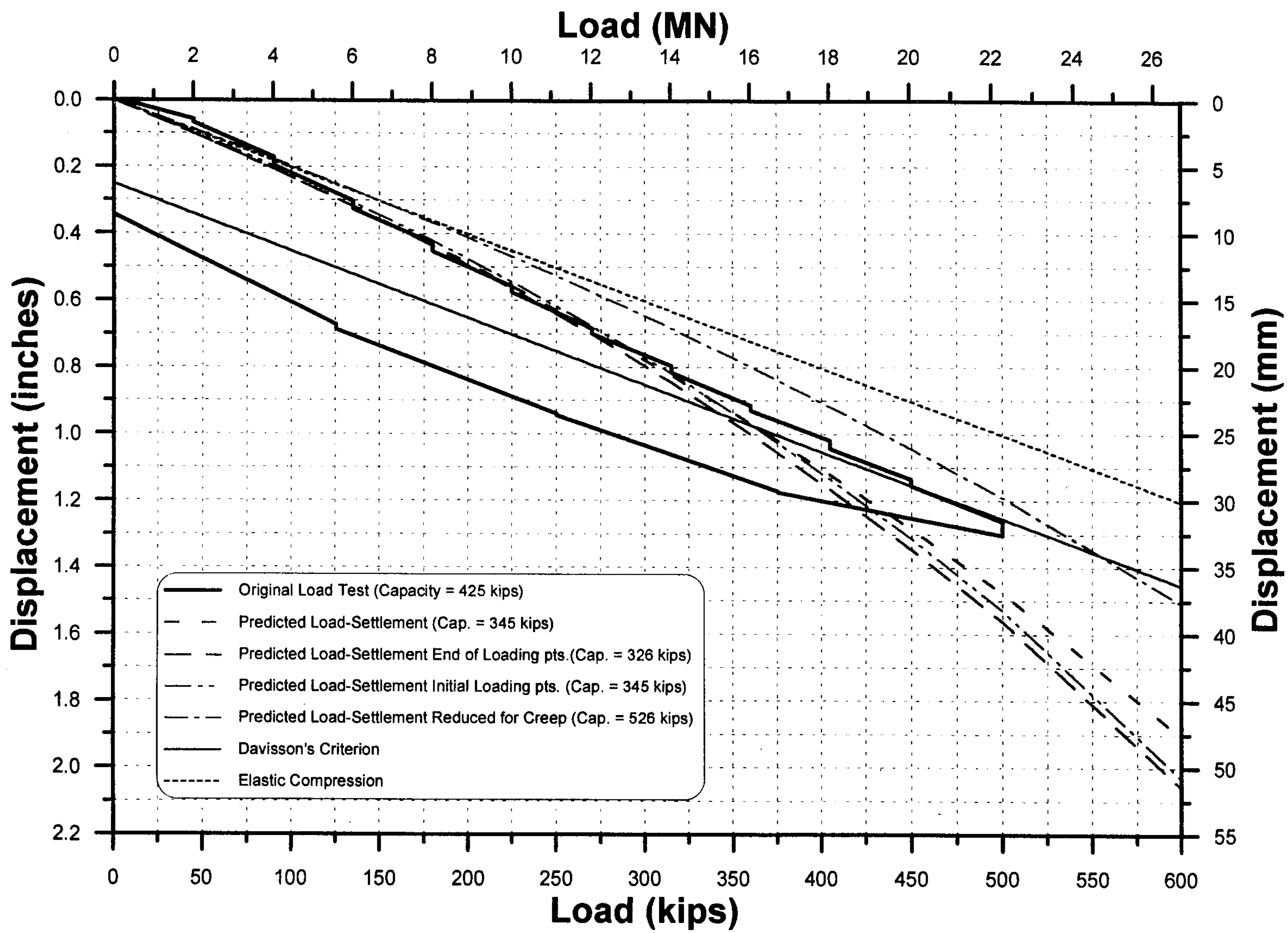

Figure 40. Predicted Load-Settlement Behavior for Case History No. 1, TP3.

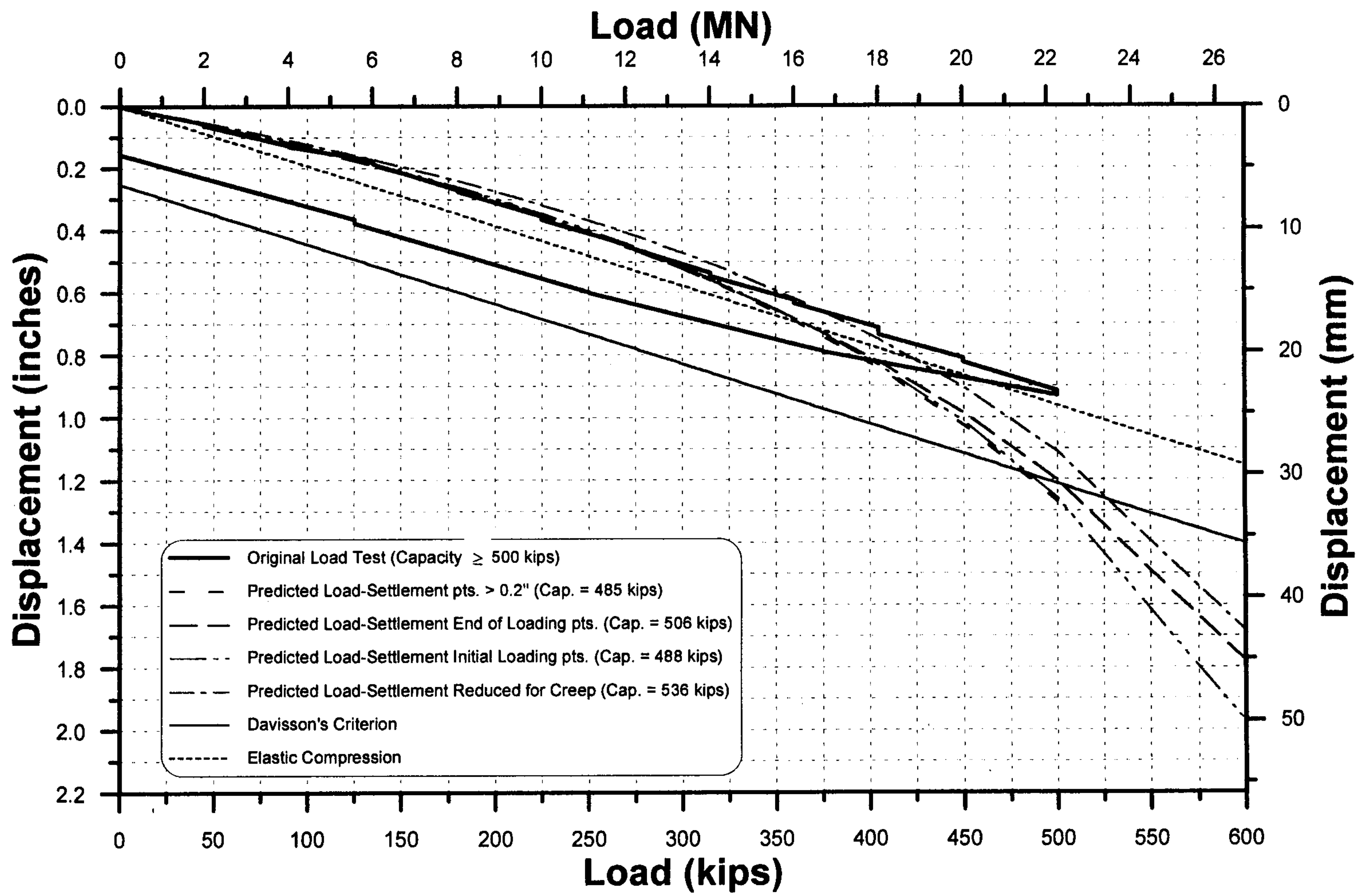

Figure 41. Predicted Load-Settlement Behavior for Case History No. 1, TP4.

7.2.5 Test Piles TP1 and TP5 (Pipe Piles)

The required ultimate capacity of the 12.75-inch (324-mm) outside diameter (3/8-inch wall thickness) pipe piles is 240 kips (120 tons or 1.07 MN), based on a design load of 120 kips (60 tons or 0.53 MN) and a factor of safety of 2.0. Test pile TP5 was installed on August 9, 1996 and test pile TP1 was installed on August 20, 1996. The driven lengths for TP1 and TP5 are 58 feet (17.68 m) and 111 feet (33.83 m), respectively. The static load tests were performed on September 16 and 19, 1996 for TP1 and TP5, respectively. The tests were carried out in accordance with ASTM D1143-81, and Section 940.62 of the Massachusetts Highway Department's Standard Specifications for Highways and Bridges. The static load test results are presented in Figures 42 and 43 for TP1 and TP5, respectively. The load-displacement relations for TP1 indicate a mostly elastic response, whereas those of TP5 suggest loading close to failure with substantially higher settlement under the same loads when compared to TP1.

7.2.6 Extrapolation Analyses

The load-displacement relationships for TP1 and TP5 for the 0- to 270-kip (0- to 1200-kN) range (twice the design load) were analyzed. The obtained relations for the displacement over the corresponding load versus the displacements are presented in Figures 44 and 45 for TP1 and TP5, respectively. The plotted data indicates once more the existence of a questionable initial pile response within a zone for which the top displacement is smaller than 0.01 inches (0.25 mm) for TP1 and 0.1 inches to 0.2 inches (2.5 to 5 mm) for TP5. Figures 46 and 47 present the relations between displacement over load versus displacement for displacements greater than 0.01 inches (0.25 mm) for TP1 and 0.2 inches (5 mm) for TP4, respectively. The minimum square, first order, and best-fit lines of all the aforementioned possibilities of data analyses are presented in the figures as well.

The obtained relations suggest a coefficient of determination well above 0.80, assumed to be the lowest for which the analysis can reliably be carried out. The obtained slope and intercept of the best-fit line were substituted in Equation 3.7 to calculate the predicted ultimate capacity of the pile based on Davisson's failure criterion.

Table 18 summarizes the extrapolation process and presents the intermediate calculated values as well as the final ultimate predicted capacities. Relatively small variations in the predicted capacity exist between the different ways in which the method can be applied in the case of test pile TP1. Very little creep takes place within the loaded zones of TP1, and the different ways in which the extrapolation can be applied lead to similar results as indicated in Table 18. TP5, for which substantially higher settlements took place, leads to varied results according to the application. The reduced-for-creep data results in an extrapolation typical of quick loading without settlement with time. The analysis based on the initial point loading, results in the lowest possible extrapolated load, similar to the analysis results using all data points. Again, very little variation exists between the different possible applications, with the exception of the reduced-for-creep analysis. As such, analysis of the two extremes, i.e., initial

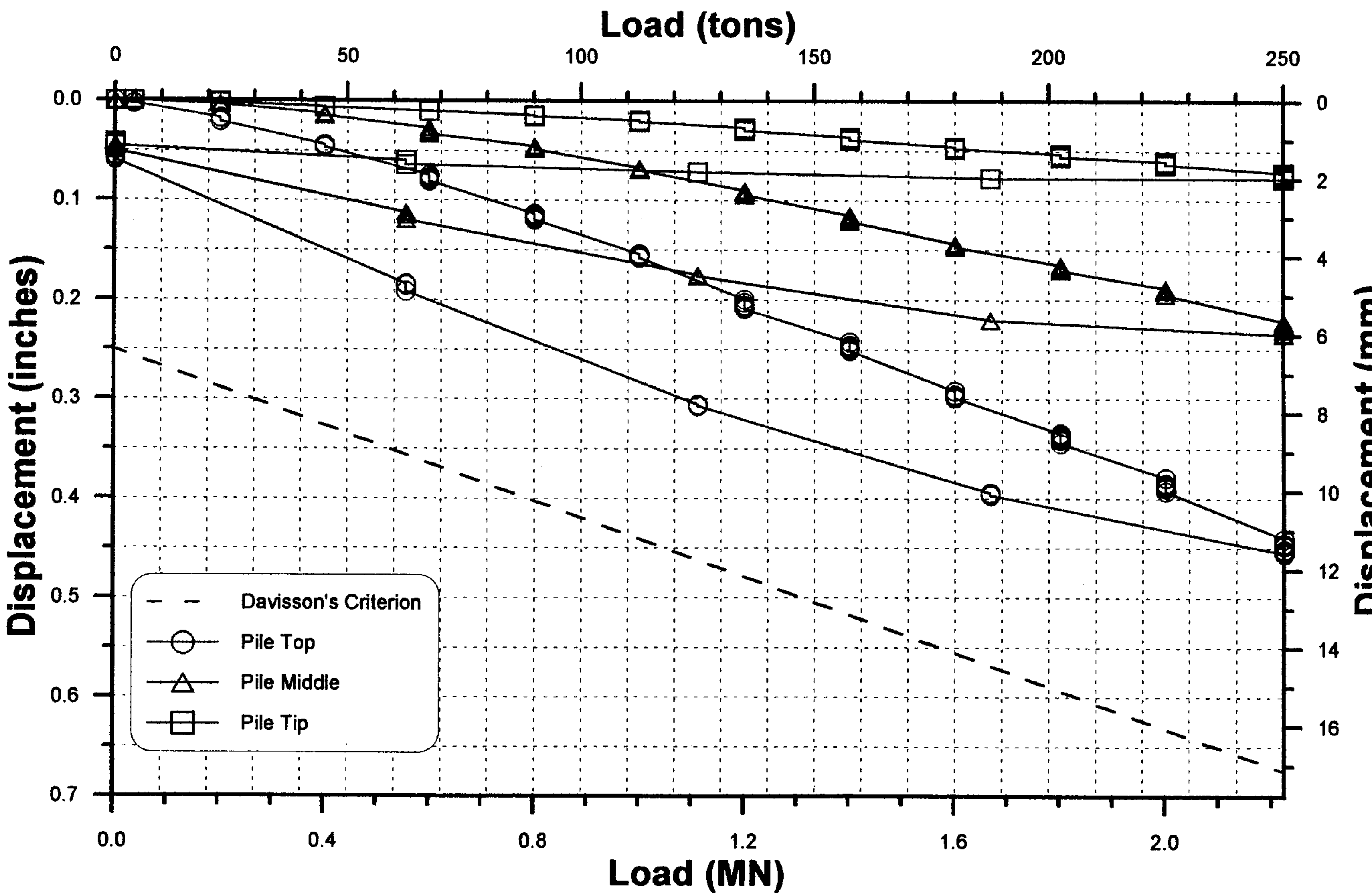

Figure 42. Load-Settlement Relationship for Test Pile TP1 (GTR Job No. 96-104, Newbury Bridge Project, Sept. 1996).

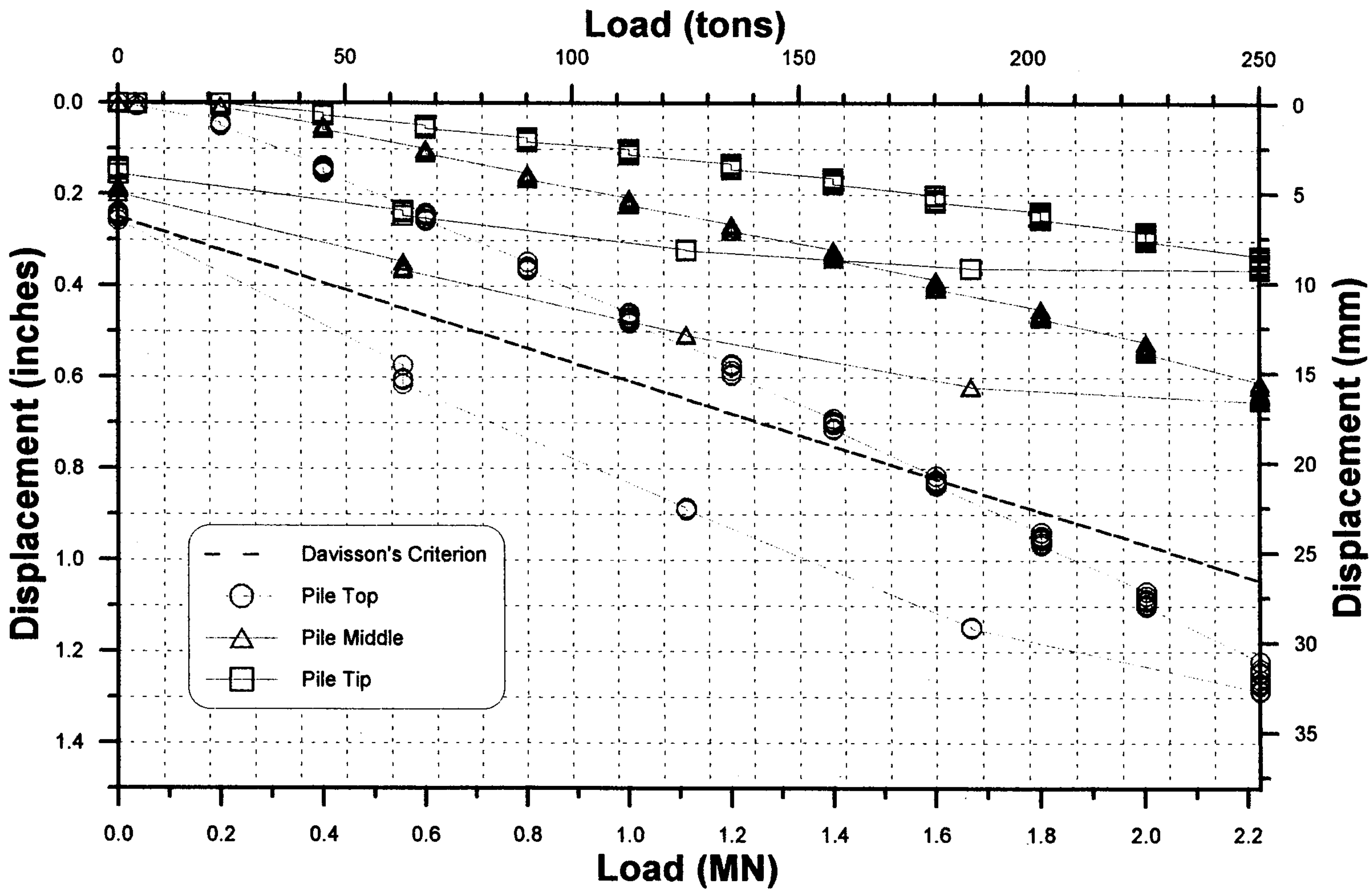

Figure 43. Load-Settlement Relationship for Test Pile TP5 (GTR Job No. 96-104, Newbury Bridge Project, Sept. 1996).

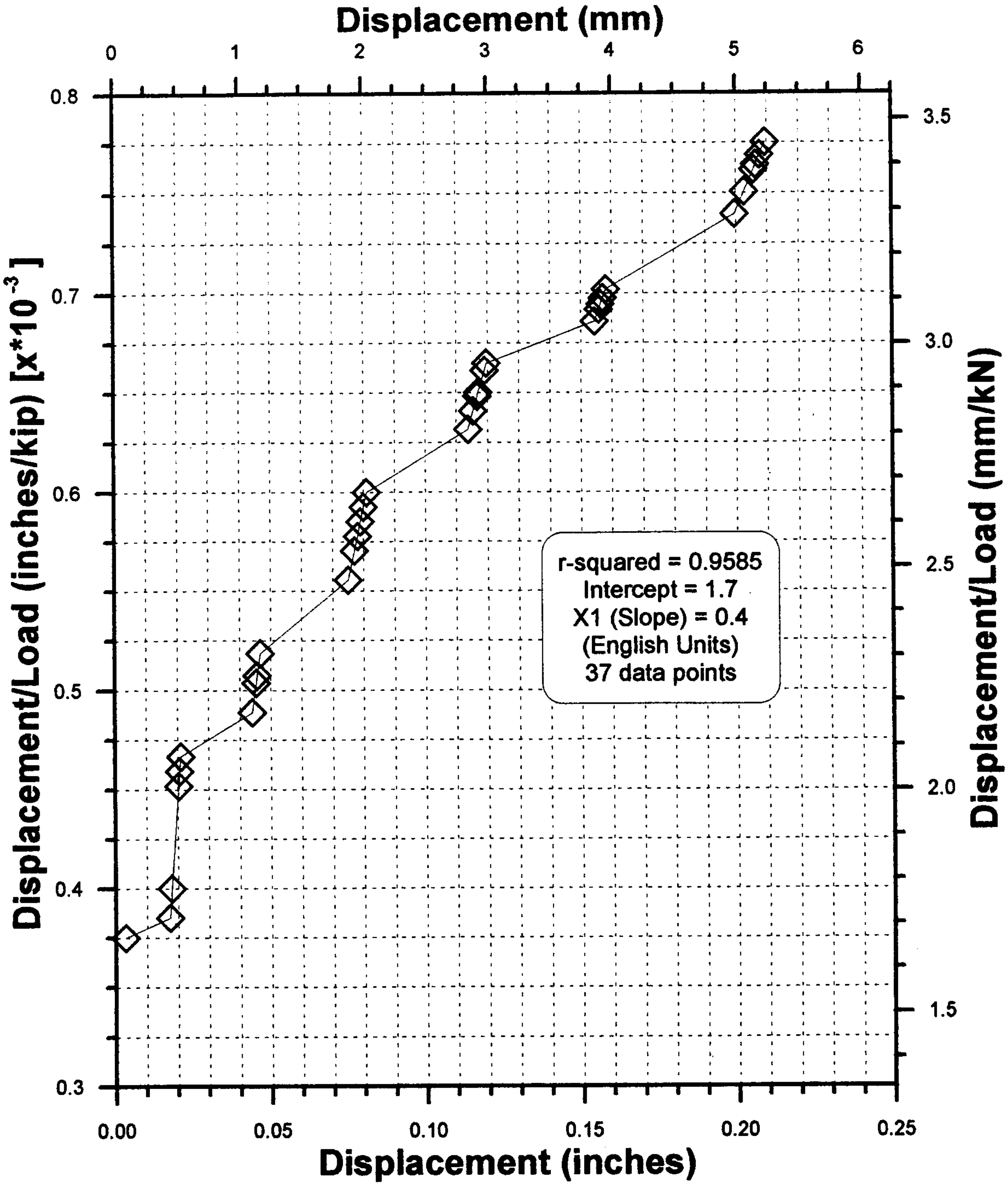

Figure 44. Relations Between Displacement Over Load Versus Displacement for Loads 0 to 300 kips (0 to 150 tons) for Case History No. 1, Pile TP1.

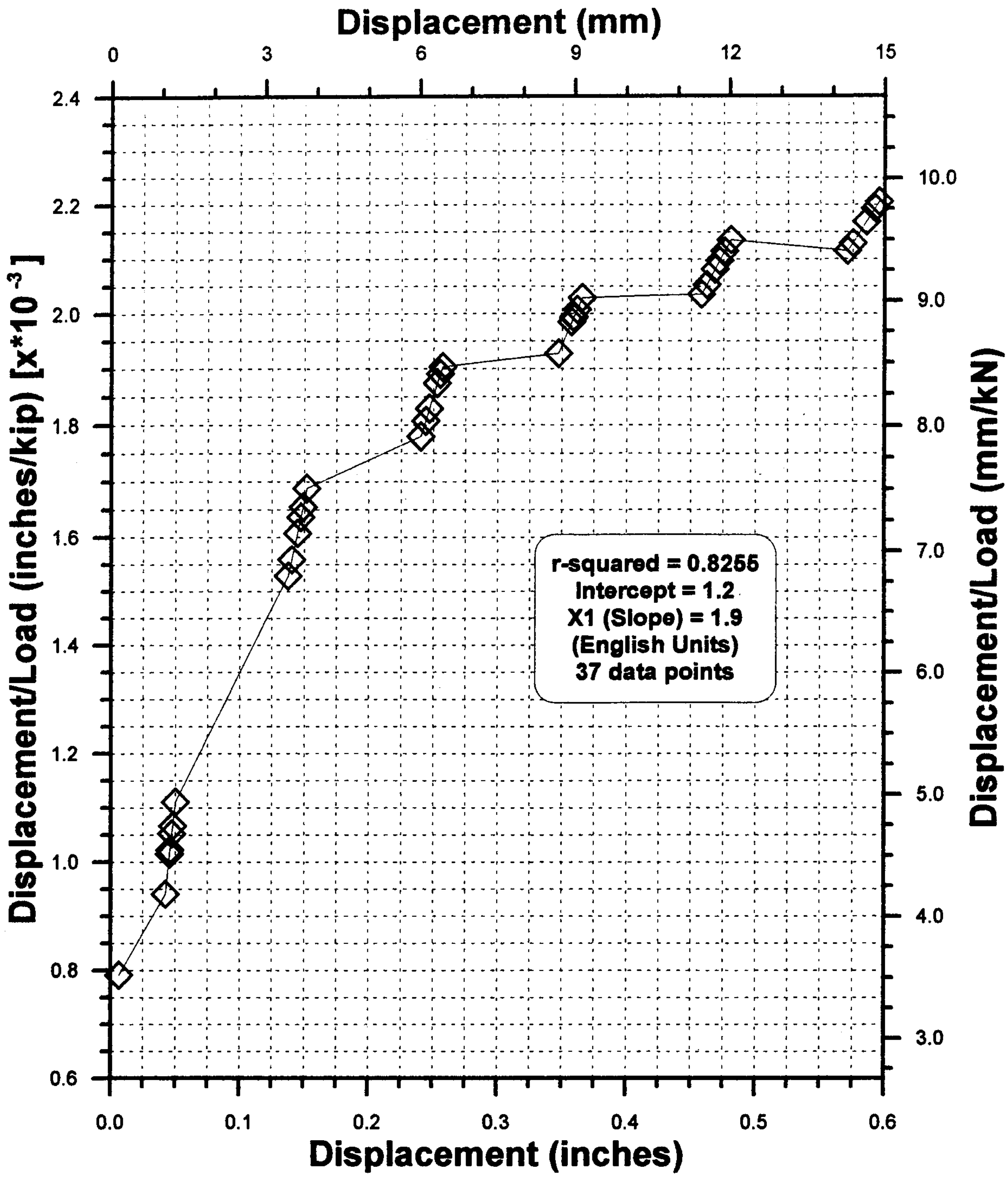

Figure 45. Relations Between Displacement Over Load Versus Displacement for Loads 0 to 300 kips (0 to 150 tons) for Case History No. 1, Pile TP5.

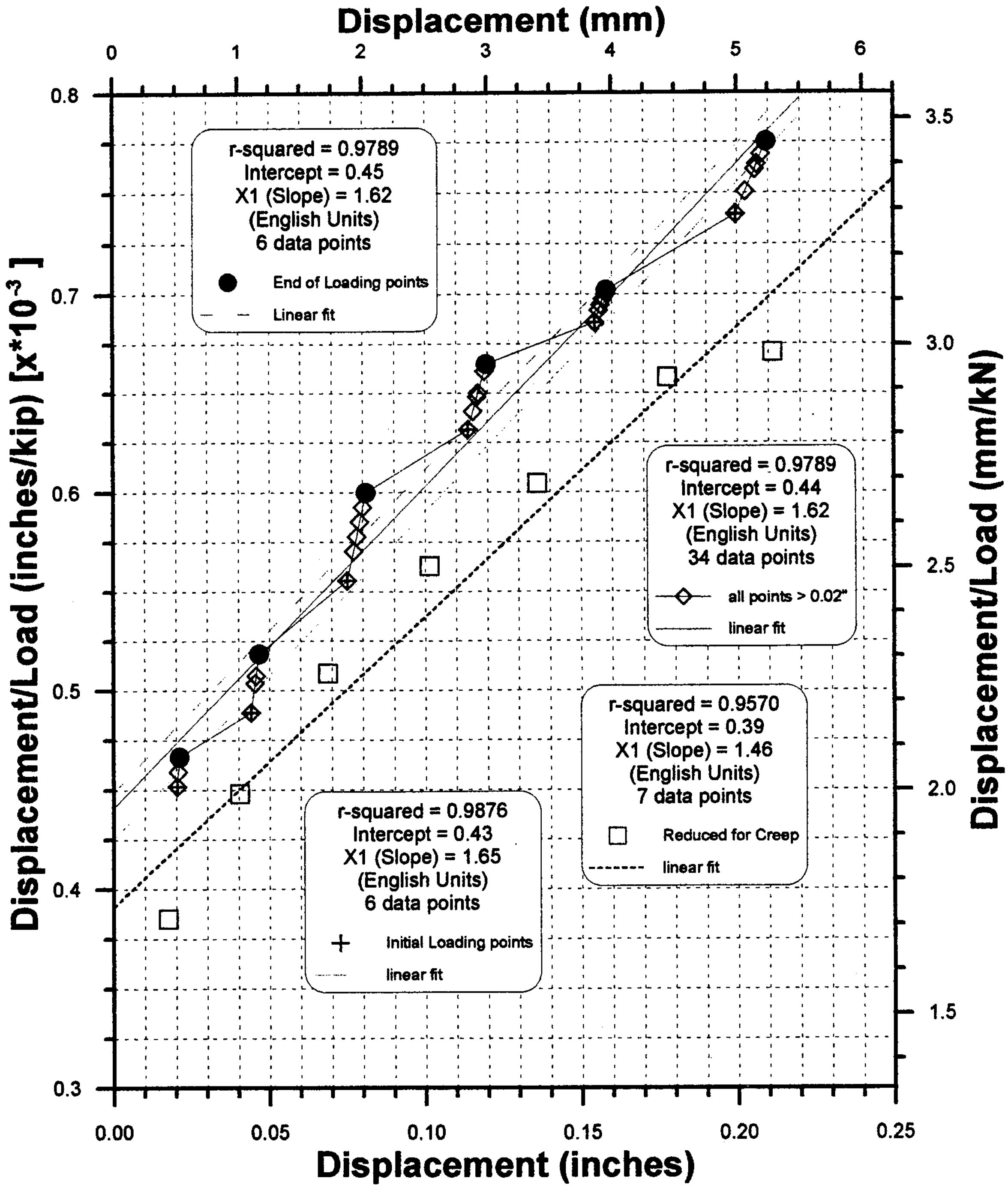

Figure 46. Relations Between Displacement Over Load Versus Displacement for Displacements Greater Than 0.02 inches (0.51 mm) and Loads Between 0 and 300 kips (0 and 150 tons) for Case History No. 1, Pile TP1.

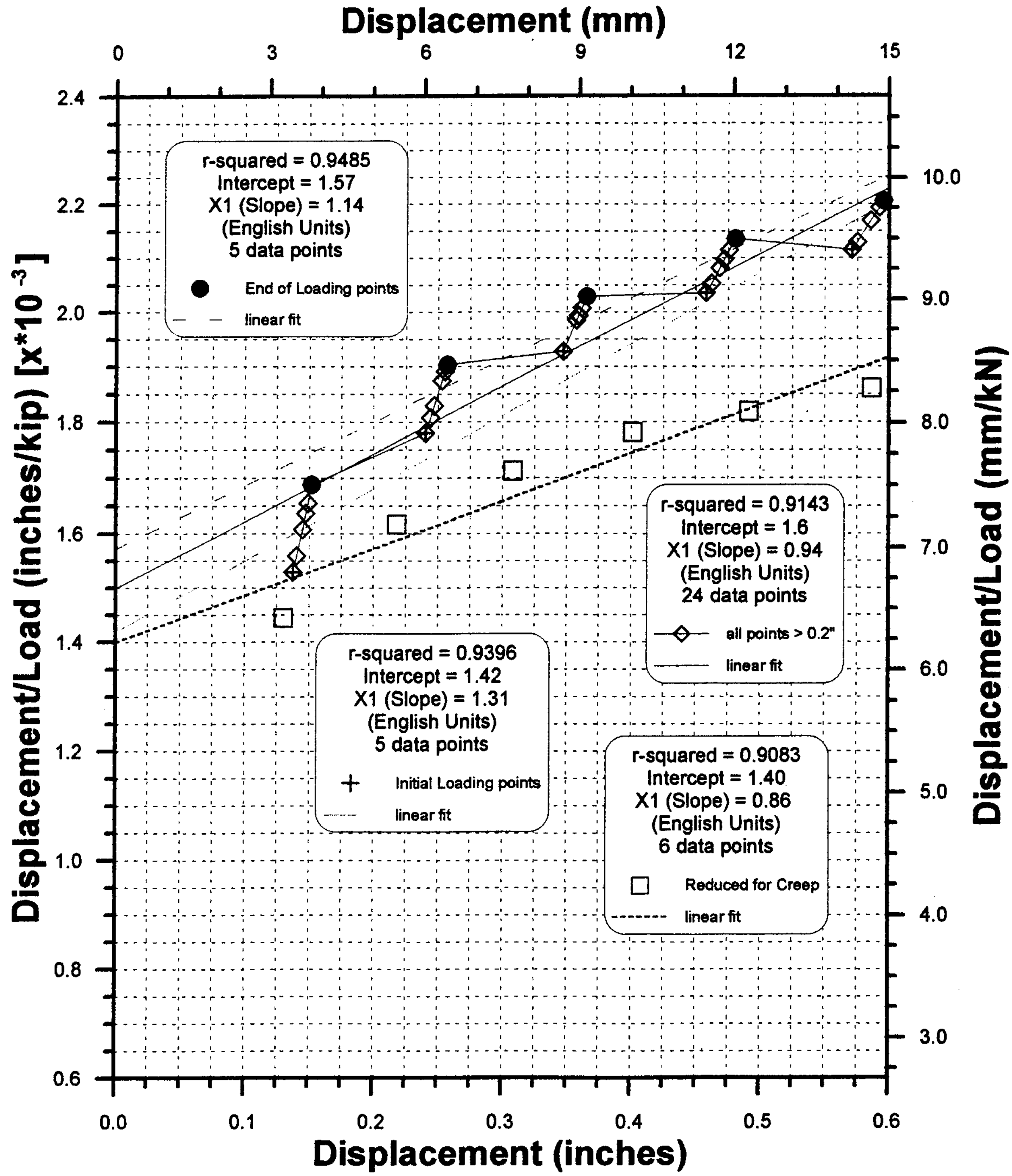

Figure 47. Relations Between Displacement Over Load Versus Displacement for Displacements Greater than 0.1inches (2.54 mm) and Loads Between 0 and 300 kips (0 and 150 tons) for Case History No. 1, Pile TP5.

loading points reduced for creep and final loading point, should provide the entire possible range of extrapolation as previously discussed in Section 7.2.3. The use of all points is demonstrated to be a simple and most efficient procedure to obtain representative extrapolation predictions for both cases TP1 and TP5. The designation "extrapolated load" in Table 18 was chosen as the average of the different procedures.

Table 18
Extrapolated Pile Capacities for Case History No. 1, TP1 and TP5

Test Pile	Extrapolated Capacity in Relation to Data (P<270 kips)												Extrapolated Load
	All Points			Final Loading Points			Initial Loading Points			Initial Loading Points reduced for creep			
	# of pts	r^2	P kips	# of pts	r^2	P kips	# of pts	r^2	P kips	# of pts	r^2	P kips	
TP1[1]	34	0.9789	427	6	0.9799	422	6	0.9876	426	7	0.9570	486	440
TP5[2]	30	0.9110	309	5	0.9485	307	5	0.9396	312	6	0.9083	418	337

[1]Analysis for displacements greater than 0.02 inches (0.51 mm).
[2]Analysis for displacements greater than 0.1 inches (2.54 mm).

Table 19 presents the extrapolated values compared to the actual load-testing results. The values presented in Table 19 also indicate the allowable capacity using a factor of safety of 2.0 compared to the extrapolated values.

Table 19
Extrapolated and Actual Pile Capacities for Case History No. 1, TP1 and TP5

	TP1	TP5
Ultimate Capacity Based on Actual Load Test (kips)	>500[4]	310
Predicted Ultimate Capacity (kips)[1]	440	337
Ratio of Predicted to Actual Capacity[2]	0.88	1.09
Allowable Capacity Using F.S. = 2.0 (kips)[3]	220	168

Capacities determined using Davisson's criterion.
[1]Predicted Ultimate Capacity using only twice the design load data.
[2]Ratio is determined by dividing the Predicted Ultimate Capacity by the Ultimate Capacity Based on Actual Load Test results.
[3]Allowable capacity was determined by dividing the Predicted Ultimate Capacity by a factor of 2.0.
[4]Load test not completed to failure, 500 kips (2224 kN) represents maximum load tested.

Figures 48 and 49 present the extrapolated load-settlement relations based on the presented analysis in comparison with the actual load-settlement relations observed during the tests. The presented relations convey graphically the data presented in Table 17 and discussed above.

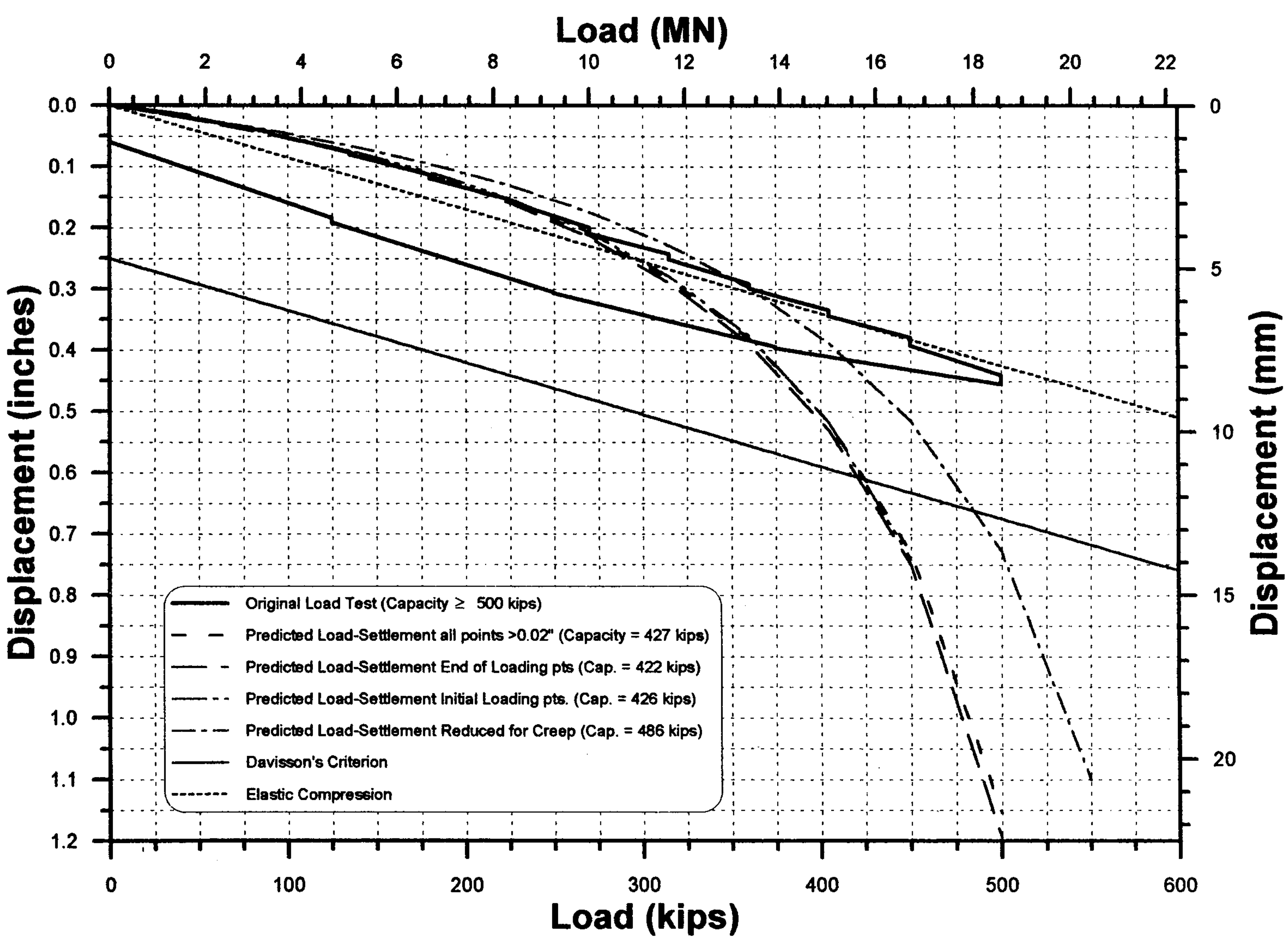

Figure 48. Predicted Load-Settlement Behavior for Case History No. 1, TP1.

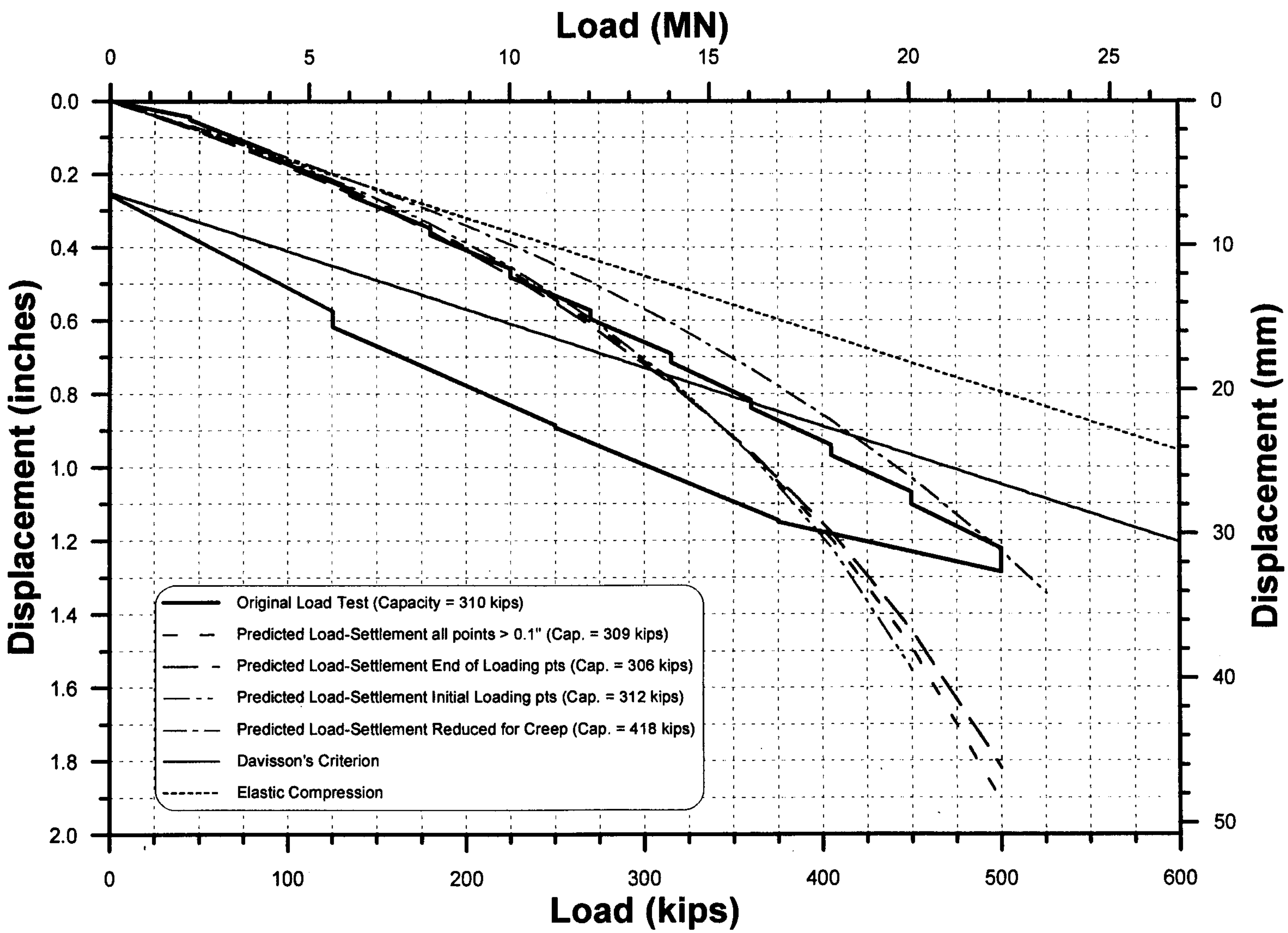

Figure 49. Predicted Load-Settlement Behavior for Case History No. 1, TP5.

7.2.7 Reliability of Results

The reliability of the predicted results was calculated using the risk analysis procedures outlined in Section 6.6. Since the ratios of the assumed maximum applied load to the predicted ultimate capacity for TP1 and TP5 are between 0.61 and 0.80, the prediction method indicates that the ultimate capacities for the three piles are in the prediction zone of 50% to 75% and, hence, the 440 and 337 kips (1957 and 1499 kN), respectively, are predicted with a risk of 1.6% to 3.2%. Using a factor of safety (F.S.) of 2, as determined in Section 6.6 for all the tests in data set PD/LT, the allowable capacities of the two pipe piles are 220 kips (979 kN) (TP1) and 168 kips (747 kN) (TP5). The actual prediction accuracy for these piles is 0.88 and 1.09, which suggests very accurate performance.

7.3 CASE HISTORY NO. 2

7.3.1 Overview

Case History No. 2 is comprised of one square 16-inch (406-mm) precast prestressed concrete (PPC) pipe pile, designated as Pile No. 375. Details are provided in a report entitled *Static Load Test Report, Pile 375, C07D2 Arrivals Tunnel, East Boston, Massachusetts* (GeoSciences Testing and Research, Inc., 1997). The site is located at Boston International Airport, in East Boston, Massachusetts. A mat foundation is planned to be installed and supported by an estimated 500 piles. Approximately 5 feet (1.5 m) of clay exist below grade. Glacial deposits consisting of various amounts of sand, gravel, silt, and clay underlie the clay.

Pile No. 375 was preaugured to a depth of 20 feet (6.1 m) and driven the remaining 32 feet (9.8 m) for a total penetration depth of 52 feet (15.8 m) below ground surface.

7.3.2 Pile No. 375 (Precast Concrete)

The required ultimate capacity of the 16-inch (406-mm) pile is 775 kips (387.5 tons or 3.4 MN), with a design capacity of 310 kips (1.4 MN) and a factor of safety of 2.5. The static load test was conducted in accordance with Section 940.62 of the Massachusetts Highway Department's Standard Specifications for Highways and Bridges. The static load-test results are presented in the form of load-settlement relations in Figure 50. The loading sequence was performed as follows:

1. Load was applied in increments of 77.5 kips (344.7 kN) to a maximum of 620 kips (2.8 MN).
2. An unload-reload cycle was performed at 310 kips (1.4 MN) (100% of design load) and 465 kips (2.1 MN) (150% of design load).
3. Load was removed in four increments of 155 kips (0.7 MN) (50% of design load) to complete unloading.
4. The pile was reloaded to 620 kips (2.8 MN) (200% of design load) in five equal increments of 31 kips (0.1 MN).

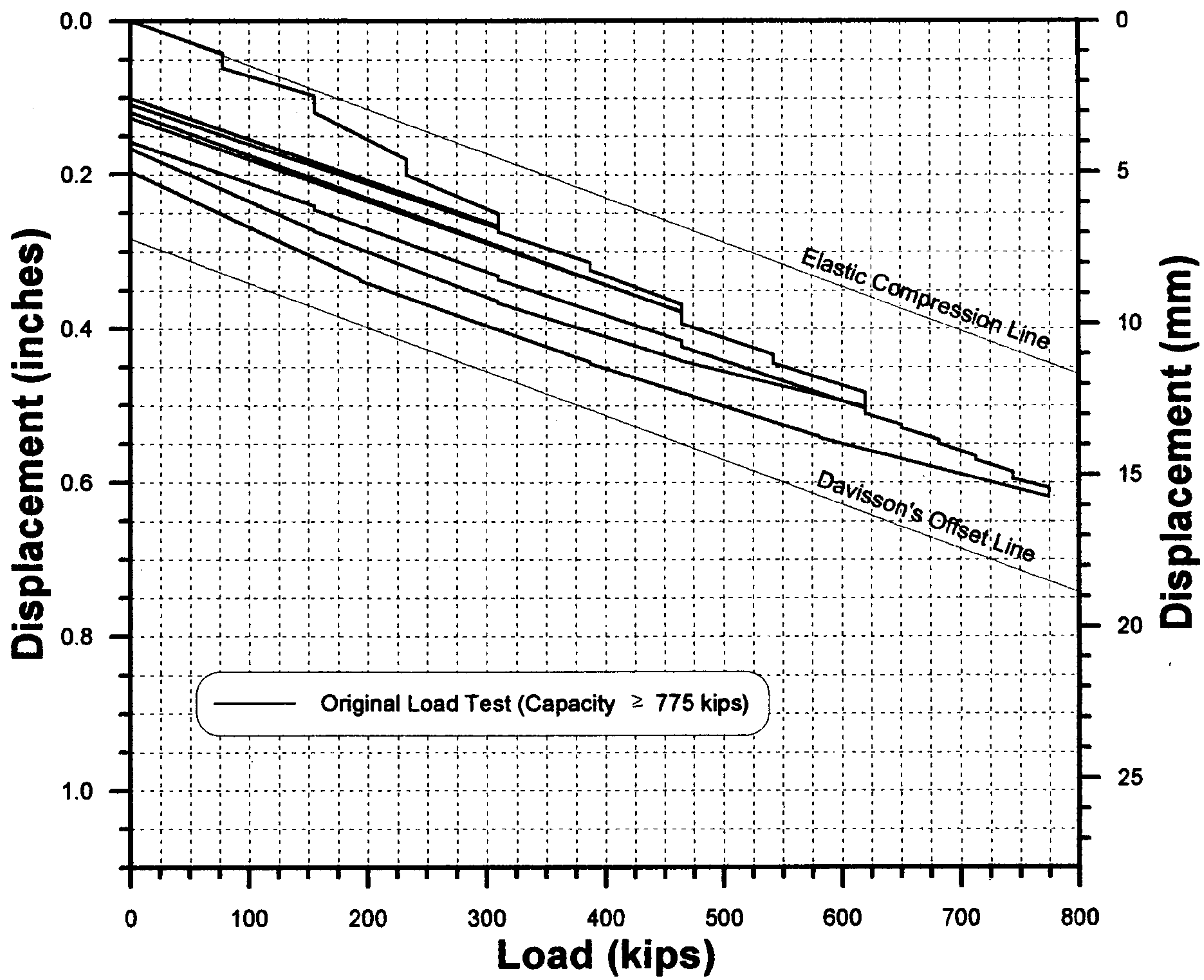

Figure 50. Load-Settlement Relationship for Case History No. 2, Pile No. 375.

5. Load was removed in four increments of 193.8 kips (0.9 MN) to complete unloading.

The extrapolation analysis utilized the first load cycle, which was applied to 310 kips (1.4 MN). The obtained relations for the displacement over the corresponding load versus the displacements are presented in Figure 51. The plotted data indicates once more on the existence of a questionable initial pile response within a zone for which the top displacement is smaller than 0.10 inches (2.54 mm). Figure 52 presents the relations between displacement over load versus displacement for displacements greater than 0.10 inches (2.54 mm) and loads smaller than 300 kips (150 tons or 1334 kN). The minimum square, first order, best-fit lines of all the interpretations are presented in Figure 52. When using individual data points (e.g., initial loading points), the obtained coefficient of determination is well above 0.80. However, when using all data points, the coefficient of determination is about 0.75 due to the relatively large settlement under constant loads resulting in "step"-type data point distributions. The obtained slope and intercept of the best-fit line were substituted in Equation 3.7 to calculate the predicted ultimate capacity of the pile based on Davisson's failure criterion. Table 20 summarizes the extrapolation process and presents the intermediate calculated values as well as the final average ultimate predicted capacity.

Large variations in the predicted capacity exist between the different ways in which the method can be applied in the case of pile no. 375. As large settlements takes place within the loaded zones, the different ways in which the extrapolation can be applied lead to extreme results as indicated in Table 20. The reduced for creep data and the final loading points resulted in high extrapolation values. The initial point loading similarly to the all points resulted in the lowest possible load. These unexpected results are probably the consequence of the untypical cyclic loading. The use of the last cycle as a typical representative load-test condition would have probably resulted in a more representative case. The designation "extrapolated load" in Table 20 was chosen as the average of the different procedures.

The results of the analysis are provided in Table 20.

Table 20
Extrapolated Pile Capacity for Case History No. 2.

Test Pile No.	Extrapolated Capacity in Relation to Data (Disp. > 0.1 inches)												Extrapolated Load
	All Points			Final Loading Points			Initial Loading Points			Initial Loading Points Reduced for Creep			
	# of pts	r^2	P	# of pts	r^2	P	# of pts	r^2	P	# of pts	r^2	P	
375	18	0.7496	490	3	0.9875	941	3	0.9125	464	4	0.6366	811	677

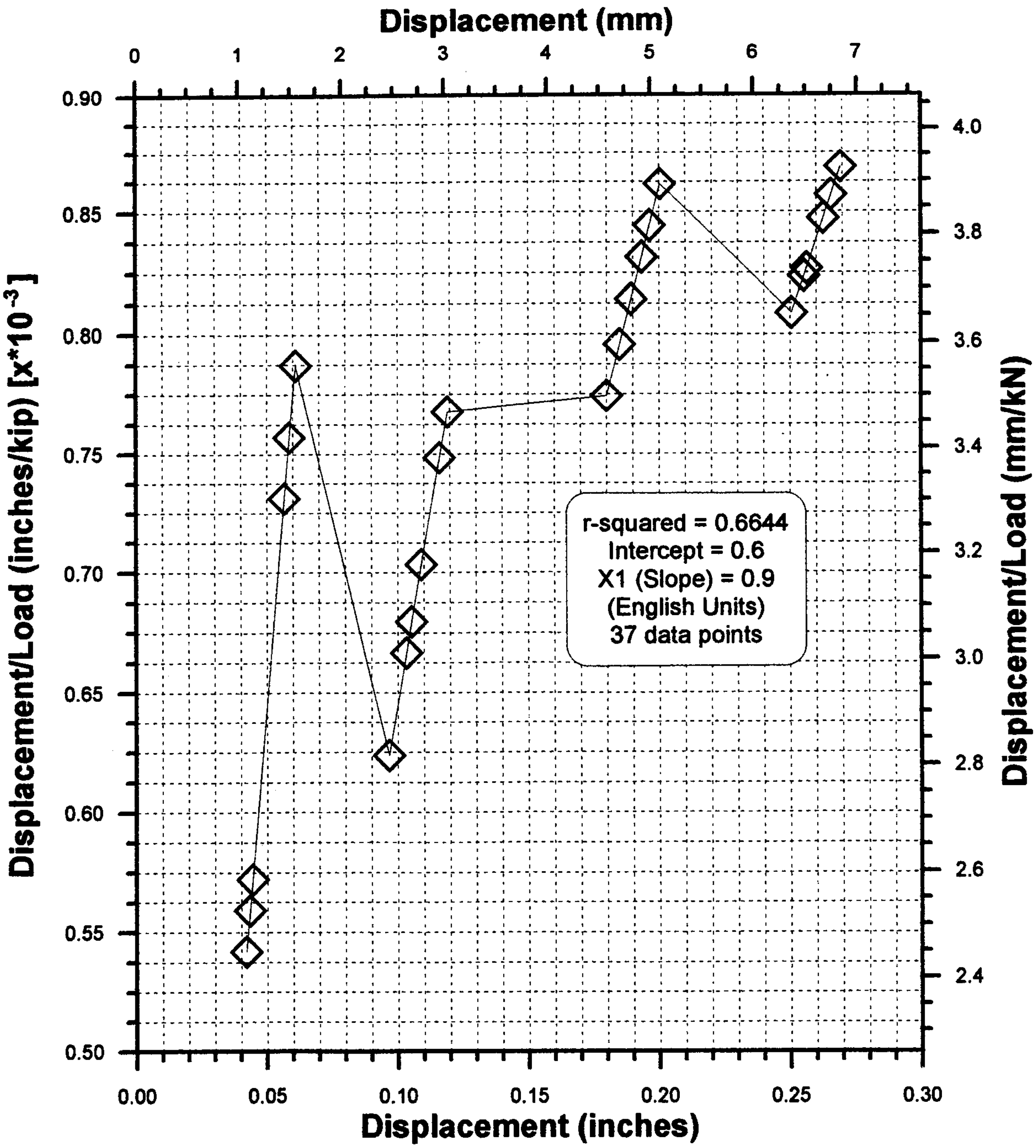

Figure 51. Relations Between Displacement Over Load Versus Displacement for Loads Between 0 and 300 kips (0 and 150 tons) for Case History No. 2, Pile No. 375.

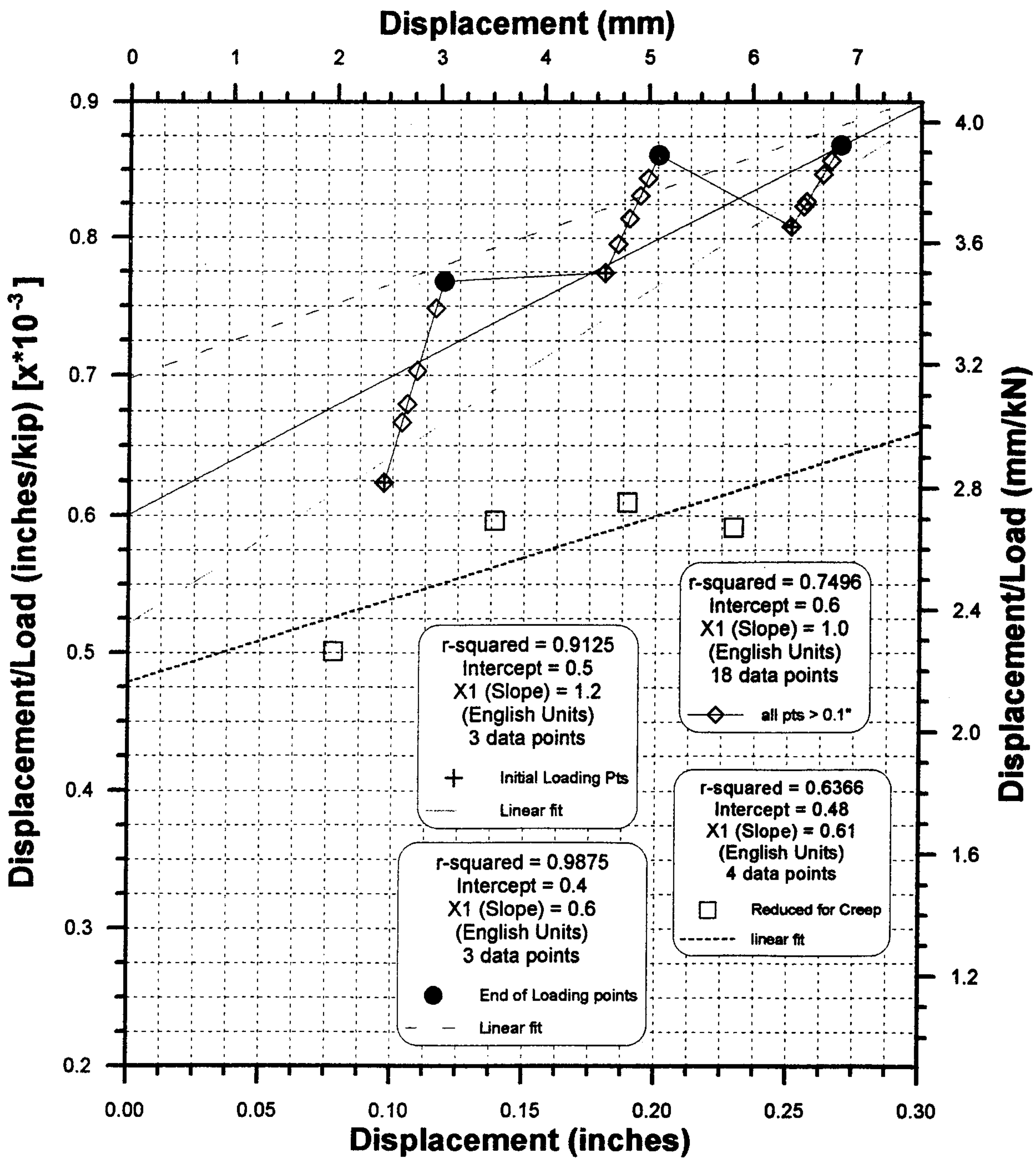

Figure 52. Relations Between Displacement Over Load Versus Displacement for Displacements Greater Than 0.1 inches (2.54 mm) and Loads Between 0 and 300 kips (0 and 150 tons) for Case History No. 2, Pile No. 375.

Table 21 presents the extrapolated values compared to the actual load-testing results. The values presented in Table 21 also indicate the allowable capacity using a factor of safety of 2.0 compared to the extrapolated values.

Table 21
Results of Prediction Analysis for Case History No. 2.

	Pile No. 375
Ultimate Capacity Based on Actual Load Test (kips)	>775[4]
Predicted Ultimate Capacity (kips)[1]	677
Ratio of Predicted to Actual Capacity[2]	0.87
Allowable Capacity Using F.S. = 2.0 (kips)[3]	338

Capacities determined using Davisson's criterion.
[1]Predicted Ultimate Capacity using only 0.5 times the design load data.
[2]Ratio is determined by dividing the Ultimate Capacity Based on Actual Load Test results by the Predicted Ultimate Capacity.
[3]Allowable capacity determined by dividing the Predicted Ultimate Capacity by a factor of 2.0.
[4]Load test not completed to failure, 775 kips (3.4 MN) represents maximum load tested.

The predicted allowable capacity (338 kips [1503 kN]) of the pile is higher than the required allowable capacity (310 kips [1379 kN]). The nature of the loading and unloading of this pile may have affected the accuracy of the prediction results. Figure 53 presents the extrapolated load-settlement curves compared to the actual load-testing results. The presented information elucidates the values presented for the case history and in Table 21.

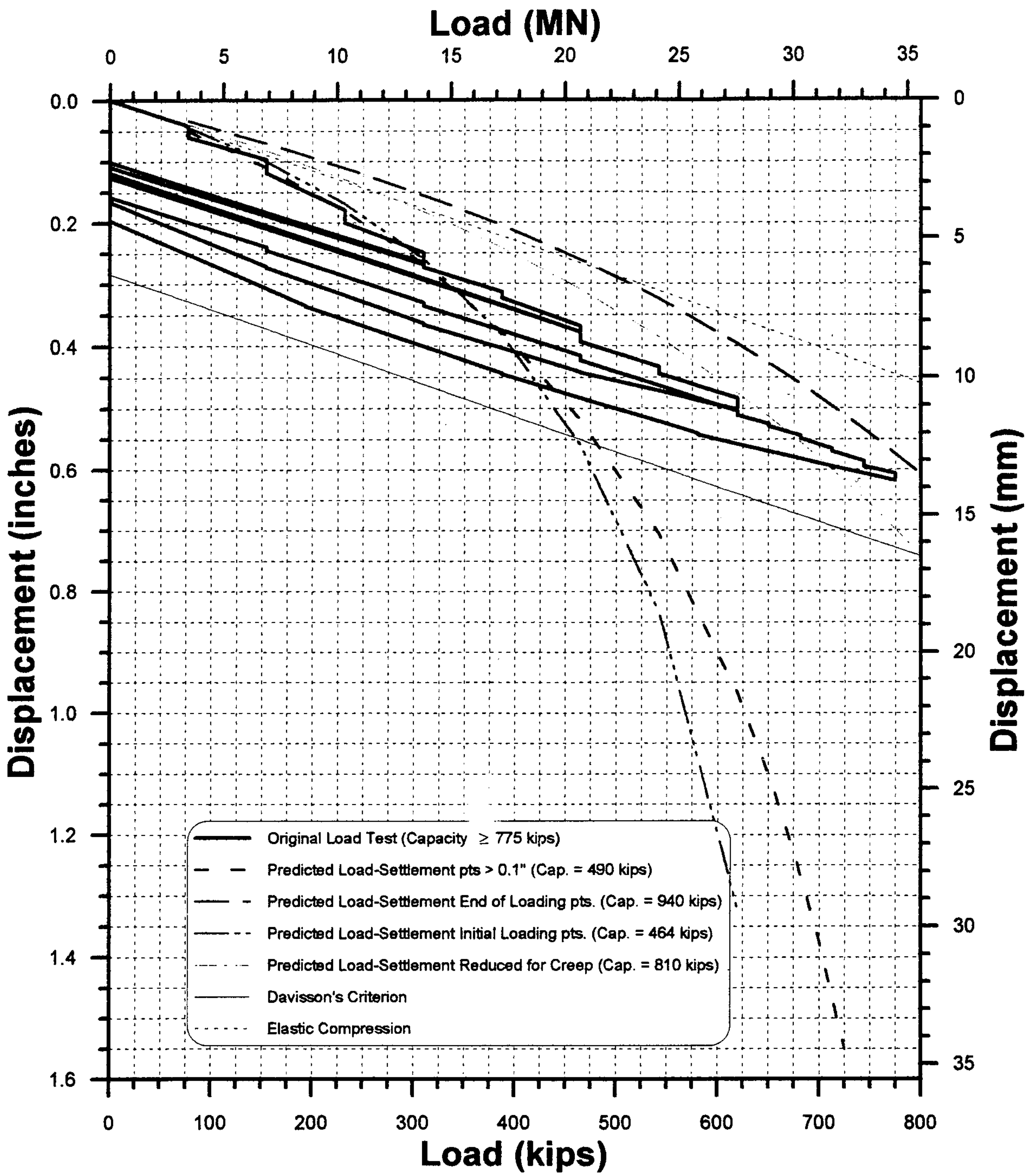

Figure 53. Predicted Load-Settlement Behavior for Case History No. 2, Pile No. 375.

CHAPTER 8: ENGINEERING SIGNIFICANCE

8.1 OVERVIEW

The current building codes and State highway specifications throughout the country (see Section 2.4) call for the application of a load test that is mostly limited to twice the contemplated design load. As a result, the actual factor of safety remains unknown. This chapter will examine the significance of the proposed method of evaluating pile capacity from non-failed load tests in relation to the prevailing engineering practice.

8.2 ENGINEERING SIGNIFICANCE

The ability to have a method in which the capacity can be assessed beyond the maximum carried load has an enormous importance from engineering and financial standpoints. The proposed method enables the user to both evaluate the ultimate capacity beyond the load for which the pile was tested and to assess the reliability of that evaluation. In other words, if a pile was loaded to 400 kips (1779 kN) (the design load being 200 kips [890 kN]), the method, for example, can indicate that the ultimate capacity is 500 kips (2224 kN) with a reliability of 87% or, with a reliability of 100%, the ultimate load is 450 kips (2002 kN). The result can be a load application of 225 kips (1001 kN) to the same pile, while maintaining a minimum factor of safety of 2.0.

For example, using the piles in Case History No. 1 and assuming that the load tests were terminated at the minimum required load (twice the design load), the savings ratio can be calculated as shown in Table 22.

Table 22
Savings Ratio for the Piles of Case History No. 1

Pile No.	Current Available Load[1] (kips)	Maximum Possible Load[2] (kips)	Extrapolated Predicted Capacity[3] (kips)	Recommended F.S.[4]	Maximum Allowable Loading[5] (kips)	Savings Ratio[6]
TP1	240	120	440	2.0	220	1.83
TP2	300	150	397	2.0	198	1.32
TP3	300	150	386	2.0	193	1.29
TP4	300	150	504	2.0	252	1.68
TP5	240	120	337	2.0	168	1.40
Avg.	276	138	412	--	206	1.50

[1]Current available load assumes that the load test was terminated at twice the design load.
[2]Maximum possible load is calculated as current available load divided by 2.0 (Mass Building Code).
[3]Predicted Capacities based on the proposed method presented in Chapter 7.
[4]Minimum Factor of Safety (F.S.) as determined in Chapter 6.
[5]Maximum allowable load determined by dividing the extrapolated predicted capacity by the recommended F.S.
[6]Savings Ratio is calculated as the maximum allowable load divided by the maximum possible load.

The data in Table 22 indicates that TP1 can be loaded an additional 83% above its previous maximum allowed load while other piles can be loaded between 29% and 68% while maintaining a factor of safety of 2.0.

As the construction cost is closely related to the factor of safety used, the above savings ratios have the potential for a significant cost-savings impact on many pile projects.

CHAPTER 9: RECOMMENDATIONS

9.1 RECOMMENDATIONS FOR IMPLEMENTATION

General

The simplicity of the proposed method, together with its high accuracy, make it an ideal method of analysis to extrapolate pile capacity from non-failed load tests. The details of the method's implementation are provided in Chapter 6. Chapter 7 provides analyses of six case histories. Discussions and examples are provided as to the influence of the chosen data points from the load test.

Factor of Safety

Based on the risk analysis presented in Section 6.6, the following factor of safety is recommended for use with the proposed method: F.S. = 2.0 for all piles in all cases.

Influencing Factors

No clear correlations were found between the pile stiffness and pile slenderness and the performance of the extrapolation method.

Pile-Length Adjustment

The present curve-fitting method is based on assumed hyperbolic load-deformation relations. Pile sections outside of the soil will experience elastic deformation, which is required to be subtracted prior to curve fitting. Analysis of such cases in Chapter 6 suggests that only extensive free length (on an order of greater than 20% of the pile embedment) affects the extrapolation prediction.

Coefficient of Determination

It is recommended that a coefficient of determination of 0.8 or greater be established for the plot of settlement divided by load versus displacement, prior to proceeding with the proposed method.

Initial Load-Settlement Relations

Due to various technical details associated with load-testing set-up, the initial load-settlement relations do not accurately represent the actual behavior and, hence, the relations appropriate for extrapolation. Inspection of the relations plotted as displacement over load versus displacement allow inspection and identification of these points that require omission prior to the data analysis.

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