DRILLED SHAFT TESTING AT WASHINGTON COUNTY SEGMENTAL BRIDGE AND HAMILTON-50 TEST SITE

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Submitted to

The Ohio Department of Transportation
and
The U.S. Department of Transportation, Federal Highway Administration

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December, 2000

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/OH-2000/008		

4. Title and Subtitle	5. Report Date
DRILLED SHAFT TESTING AT WASHINGTON COUNTY SEGMENTAL BRIDGE AND HAMILTON-50 TEST SITE	June, 2000
	6. Performing Organization Code
7. Author(s) Robert Y. Liang	8. Performing Organization Report No.
9. Performing Organization Name and Address The University of Akron Department of Civil Engineering Akron, OH 44325	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. State Job No. 14707(0)
	13. Type of Report and Period Covered Final Report
12. Sponsoring Agency Name and Address Ohio Department of Transportation 1600 West Broad Street Columbus, OH 43223	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

A total of four lateral load tests on eight fully instrumented drilled shafts have been successfully carried out. The test data and analysis results have been submitted to ODOT structure office in a timely manner to allow ODOT engineers to implement these test results into design. Specifically, two load tests have been conducted at Putnam bridge site with the shafts diameter of 1.22-m (48-inch) and shaft length of 14-m and 9-m respectively. Also, two lateral load tests have been conducted at CLE-50 site with the shafts diameter of 1.067-m (42-inch) and shaft length of 5.48-m (18-ft), and 9.62-m (26-ft) respectively. Test results included the load-displacement relationship at the shaft head, and strains and deflections along shaft length at different load levels. In addition to lateral load testing a new back-analysis method was employed to demonstrate the benefits of deriving the *p-y* relationship from the curve-fitting back-analysis techniques.

The research results have allowed ODOT engineers to adopt the design changes of the drilled shaft foundations. As a rough estimate, a saving of 1.5 million dollars of construction cost have been realized. The test results also formed a part of on-going efforts of developing pertinent data base of the behavior of laterally loaded drilled shafts. The large data base could be used for further development of an improved analysis method.

17. Key Words	18. Distribution Statement
Drilled Shafts, Lateral Load, Testing Instrumentation	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		

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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February 2000

EXECUTIVE SUMMARY

Drilled shafts have often been used as deep foundations for bridges, retaining walls and noise barrier walls that are subjected to lateral loads and overturning moments, in addition to axial loads. The analysis of the response of laterally loaded drilled shafts involves considerations of soil-structure interaction. The current state-of-the-art practice on the design and analysis of laterally loaded drilled shafts relies primarily on the computer program COM624. One of the key ingredients of the program is the need to characterize the relationship between the shaft deflection and the soil resistance along the shaft length. This relationship is referred to as the *p-y* curves, where *p* stands for the net soil resistance force per unit length of the shaft and *y* represents the shaft deflection. While criteria for establishing p-y curves exist, they often are misused or have resulted in inconsistent design. As a case in point, two Ohio Department of Transportation (ODOT) projects, when reviewed by ODOT engineers, have shown either over conservative or unconservative design by the consultants. Due to concerns over these inconsistent designs, ODOT has engaged the principal investigator to conduct a total of four lateral load tests at these two project sites: WAS-Putnam St. project and Ham/Cle-50 project.

The main objectives of the research project include the following: (i) to plan and execute instrumentation and load testing of a total of four drilled shafts at the WAS-Putnam St. and Ham-50 project sites, and (ii) to analyze the load test data and submit the results with analysis to ODOT structure office for finalizing the design shaft dimensions (diameter, length, and reinforcements).

A total of four lateral load tests on eight fully instrumented drilled shafts have been successfully carried out. The test data and analysis results have been submitted to ODOT structure office in a timely manner to allow ODOT engineers to implement these test results into design. Specifically, two load tests have been conducted at Putnam bridge site with the shafts diameter of 1.22-m (48-inch) and shaft length of 14-m and 9-m respectively. Also, two lateral load tests have been conducted at CLE-50 site with the shafts diameter of 1.067-m (42-inch) and shaft length of 5.48-m (18-ft), and 9.62-m (26-ft) respectively. Test results included the load-displacement relationship at the shaft head, and strains and deflections along shaft length at different load levels. In addition to lateral load testing a new back-analysis method was employed to demonstrate the benefits of deriving the *p-y* relationship from the curve-fitting back-analysis techniques.

The research results have allowed ODOT engineers to adopt the design changes of the drilled shaft foundations. As a rough estimate, a saving of 1.5 million dollars of construction cost have been realized. The test results also formed a part of on-going efforts of developing pertinent data base of the behavior of laterally loaded drilled shafts. The large data base could be used for further development of an improved analysis method.

TABLE OF CONTENTS

APPENDIX

LIST OF FIGURES

CHAPTER I

INTRODUCTION

I.1 STATEMENT OF THE PROBLEM

Drilled shafts have often been used as foundations for bridges, retaining walls and noise barrier walls that are subjected to lateral loads in addition to the axial loads. Additionally, drilled shafts have also been increasingly used to stabilize manmade embankments as well as natural slopes. In most instances for such foundations, significant lateral loads are transferred from the superstructure down to the drilled shafts. The drilled shafts subject to such lateral loads should not only satisfy the equations of static equilibrium but should also maintain the displacement compatibility. Thus, the analysis of the response of laterally loaded drilled shafts has become a complicated soil-structure interaction problem. The solution of the problem requires that the relationships between the shaft deflections and the soil reactions be known. Technological advances in instrumentation have allowed better understanding of the soil shaft interactions; namely, instrumentation embedded in the shafts enables strains and deflections to be read during testing of full-scale drilled shafts. From these measurements, the soil-shaft interaction can be deduced and quantified.

The current state-of-the-art practice of designing the drilled shafts subjected to lateral loads relies primarily on the computer program COM624 (Reese, 1984). One of the key features of the program is the need to characterize the relationship between the shaft deflection and the soil resistance along the shaft length. This relationship is commonly referred to as *p-y* curves, where p stands for the net soil resistance force per unit length of the shaft, and y represents the shaft deflection. The accuracy of the analysis results using COM624 program is largely dependant on the accuracy of the p-y curves used to represent the in-situ soil and shaft interaction mechanisms. While researchers realize the importance of characterizing the p-y curves accurately, the existing p-y criteria seem to have resulted in inconsistent design. These inconsistencies becoming even more critical as they lead to designs which could be on the unconservative side. A fact, which was recently, evidenced in two ODOT projects, namely WAS-PUTNAM St. and HAM50.

During the design review stage, being performed by ODOT structural engineers, it was established that the design for the drilled shafts for the WAS-PUTNAM St. project was inadequate.

The concerns, being mainly centered on inadequate design length of the drilled shafts and lack of socket in the rock. Consequently, an "Item Special" for drilled shafts instrumentation and lateral load test has been included in the plan to verify the safety and adequacy of the design. The second project site is HAM/CLE-50-36.29/0/00, where the consultant has suggested an over conservative drilled shaft length. According to ODOT review, almost 40% reduction in total drilled shaft volume could be realized with a more efficient design. As a check for the validity of this revised design, lateral load testing was suggested.

The job of conducting these lateral load tests at the aforementioned two sites, was assigned to the University of Akron, based upon its expertise and experience in the specific area.

I.2 OBJECTIVES OF THE STUDY

The main objectives, which were planned to be achieved from conducting the lateral load tests at the two sites, were:

(1) To plan and execute instrumentation and load testing of the drilled shafts at the WAS-PUTNAM St. and the HAM/CLE-50 project sites.

(2) To analyze the load tests data and submit the results with the analysis to ODOT structural office for possible implementation to produce a more cost efficient and structurally safe design.

I.3 ORGANIZATION OF THE REPORT

This report is organized as follows. Chapter II provides details of work previously conducted in the area of lateral load testing and deals with the various analytical approaches that are in use to determine the lateral load capacity of drilled shafts. It also provides a problem statement for the work that has been conducted and presented in this report.

Chapter III deals with the lateral load tests performed at the WAS-Putnam Street Bridge, Marietta, Ohio on the 14m deep and 9m deep drilled shafts. The chapter includes details of the tested shafts, such as their cross-sectional dimensions, reinforcement details, and the construction sequence followed. It also provides details of the test set-up and the instrumentation used for observing deflections and strains. Also included in the chapter are the experimental observations, made during the test.

Chapter IV provides information regarding the lateral load tests conducted on the HAM50 test site. The information included in this chapter is similar to the information provided in Chapter III.

Results achieved through analysis of the various drilled shafts using a constant EI, a nonlinear EI and a finite element analysis have been presented in Chapter V. Comparisons between these calculated values and the observed values are also included in this chapter.

Chapter VI summarizes the work conducted and provides conclusions on the observed results and observed behavior of the drilled shafts. Also included are the recommendations for implementation for safer and economical designs.

CHAPTER II

BACKGROUND AND LITERATURE REVIEW

II.1 ANALYSIS TOOLS FOR LATERALLY LOADED DRILLED SHAFTS / PILES

Lateral loads on drilled shafts could arise because of any or all of wind, earthquake, water pressure, earth pressure and live loads. A properly designed and adequately detailed laterally loaded drilled shaft must be able to withstand such forces without failing (i.e. without reaching the ultimate limit state) and without deflecting excessively (i.e. without reaching the serviceability limit state). The governing criterion in the design of laterally loaded drilled shafts is almost always the maximum tolerable deflection or the structural capacity of the drilled shaft itself. The condition of ultimate failure of the surrounding soil does not seem to control the design because the mobilization of the ultimate lateral capacity of the surrounding soil requires such large displacements that it is not a realistic possibility. In designing drilled shafts to resist lateral loads, both lateral deflection and structural capacity should be considered and controlled.

One of the design objectives is to insure that the lateral deflection of the drilled shaft or group of drilled shafts does not exceed the tolerable limit. The lateral deflection of a group of drilled shafts can be related to the lateral deflection of a single drilled shaft. The behavior of deep foundations under lateral load can be analyzed using any of the following methods (Poulos and Davis, 1980); (1) elastic analysis in which the pile is modeled as an elastic inclusion in an elastic half-space; (2) subgrade reaction analysis in which the pile is modeled as a beam on a Winkler or a two-parameter foundation; and (3) *p-y* analysis. Elastic analyses and subgrade reaction analyses are based on the assumption that the soil behaves as a linear material; and *p-y* analyses model nonlinear behavior, but require the use of computer programs and involves considerable engineering time.

In the subgrade reaction method, laterally loaded drilled shaft behavior is modeled by assuming the shaft to act as a beam-column supported on a nonlinear foundation. In the most complete subgrade reaction model, the pile is represented as a beam on a nonlinear two-parameter foundation. The soil is defined in terms of a lateral stiffness parameter, K, and a parameter, S, for describing shear coupling between the infinitesimal horizontal layers into which the soil is assumed to be divided. Drilled shaft behavior is obtained by solving the governing differential equation for the problem,

$$EI\frac{d^4y}{dx^4} + (Q_x - S)\frac{d^2y}{dx^2} + Ky = 0 \qquad (1)$$

where

EI = drilled shaft bending stiffness,

Q_x = shaft axial force, and

y = shaft deflection at depth x.

The two-parameter foundation model has been of little use in practice because of difficulty in evaluating both K and S from results of a single shaft test. Normally a simplified subgrade reaction method model is used, in which the foundation is considered to act as a Winkler medium. In such a model, the soil response at a given point along the shaft is assumed to be a function only of the shaft displacement at that point. The nonlinear foundation behavior is represented using p-y relations. Shaft behavior is calculated by solving the governing differential equation for a beam on a Winkler foundation,

$$EI\frac{d^4y}{dx^4}+Q_x\frac{d^2y}{dx^2}+K_hy=0 \qquad (2)$$

where

K_h = modulus of subgrade reaction at depth *x*, defined as *-p/y*, with *p* and *y* being compatible values from the *p-y* curve for depth *x*.

The governing differential equation is usually solved using either finite deference (Reese and Sullivan, 1980) or discrete element (Bogard and Matlock, 1977) methods. The accuracy of this approach largely hinges on the accuracy of the p-y curves used in the analysis. However, caution must be exercised when developing p-y curves for shaft analysis for a site where soil conditions may differ significantly from those at the former experimental test sites used in developing current p-y criteria. Most of the published p-y data were obtained from a limited number of lateral load tests on 10 - 24 in. diameter steel pipe piles and on drilled shafts (Brown, et. Al., 1994; Bhowmik and Long, 1991; Brown and Shie, 1990; Brown and Shie, 1989; Dunnavant and O'Neil, 1989; Baguelin, et. Al., 1977; Reese, et. Al., 1974). Therefore, additional uncertainties may be introduced when extrapolating this p-y curve criteria to larger shaft diameters or different soil types. Full-scale tests would be especially useful in addressing the uncertainties in these situations.

The condition of restraint against rotation at the top of the drilled shaft has a strong effect on the magnitude of its lateral deflection under load. Drilled shafts that are embedded in reinforced concrete caps are effectively restrained from rotation at the top. On the other hand, some drilled shafts are connected directly to the structure without a cap; in which case, they are free to rotate and translate at the top. The lateral deflection of a fixed-head shaft is about one-fourth of the deflection of a free-head shaft subjected to the same load.

The capacity and load-movement performance of drilled shafts is critically dependent upon construction details. Current design methods for drilled shafts do not normally take explicit account of these details, which include production of borehole roughness, geomaterial smearing, depressurizing of geomaterials during drilling, repressurizing of geomaterials due to concrete placement, residual drilling fluid and other similar factors. A conservative approach to design is therefore adopted by most designers. However, most of these effects can be quantified, to a large extent, by full-scale field tests.

II.2 REVIEW OF EXISTING TEST DATA BASE

This portion of the report discusses the details of lateral load tests on fully instrumented drilled shafts that have been previously conducted. A total of four project sites have been included in this study. They are: (i) LOR.6 bridge project, (ii) LAK.91 bridge project, (iii) I-90 noise wall project, and (iv) I-270 noise wall project. At LOR.6 site, four load tests were carried out. At LAK.91 site, two load tests were completed. At the I-90 noise wall project site, two load tests were conducted. Finally, at I-270 noise wall project site, one load test was performed.

Presented hereunder are brief summaries of the lateral load tests conducted at the above mentioned sites together with a brief description of the soil conditions encountered at the test sites. Detailed results of the tests can be found in the report produced by the Department of civil Engineering, University of Akron and submitted to Ohio Department of Transportation, titled “Pressuremeter to Predict Lateral Load Capacity of Drilled Shafts on Slope”.

II.2.1 ODOT PROJECT 493 (49) LORAIN COUNTY, BRIDGE LOR-6-0080, VE ION, OHIO

As part of Ohio Department of Transportation (ODOT) sponsored research project entitled "Pressuremeter to Predict Lateral Load Capacity of Drilled Shafts on Slopes", lateral load tests on heavily instrumented prototype drilled shafts at ODOT Project 493(49) Lorain County, Bridge LOR-6-0080, Vermilion, Ohio, were carried out on April 25&27, 1995, and May 25&27, 1995. National Engineering and Contracting Company was the foundation contractor who installed the tested drilled shafts. H.C. Nutting Company provided engineering service to National Engineering and Contracting Company to help set up load test frames and to monitor and record test results in accordance with ASTM D3966-90. The principal investigator and his graduate assistants from The University of Akron installed instruments, which include inclinometer casing and vibrating-wire strain gages. Also, The University of Akron personnel performed inclinometer readings as well as data acquisition of strain readings during the lateral load tests. ODOT District 3 project engineers supervised the load tests. The lateral load tests being completed on April 25, 1995 for shafts 19&20, April 27, 1995 for shafts 22&23, May 25, 1995 for shafts 88&89, and May 27, 1995 for shafts 91&92.

According to the report on soil investigation carried out by R&R International, Inc., the project site was located on the glacial, relatively flat lake plain physiographic province at an approximate elevation of 615 ft. The existing structure overlies the Northfolk and Western railway. Lake Erie is located just to the north of the site while the Vermilion river is located to the south. This area was glaciated by both the Illinois and Wisconsin ice sheets. Locally, the glacial drift material was thin, average not more than 30 ft to the bedrock surface. The glacial material at the site consisted of lacustrine deposits. These deposits were composed primarily of silt and fine sand with varying quantities of clay and gravel. Soil samples obtained during this investigation and subsequently tested were classified primarily as sandy silt (A-4A) which appeared to verify the presence of the Lacustrine deposits. Bedrock in this vicinity consists of shales belonging to the Devonian age Ohio formation.

A subsurface exploration program was performed by R&R International, Inc. between April and June 1988. It consisted of two Roadway and eight structural test borings. The test borings disclosed intervals of stiff to very stiff sandy silt (A-A4) and silt and clay (A-A6) with some relatively limited layers of loose to very dense sand (A-A3). These soil units are underlain by gray clay shale which was found to be extremely to moderately altered at those test locations where rock core samples were secured.

II.2.2 LAKE - 91 - 0423 PROJECT OVER CORNEAL AND NORFOLK AND WESTERN RAILROADS IN EASTLAKE, OHIO

The lateral load tests on heavily instrumented prototype drilled shafts at the Project LAK-91-0423 site were carried out on July 19, 1994, and December 27, 1994. McKinney Drilling Company was the foundation contractor who installed the tested drilled shafts. GRL and Associates provided engineering service to McKinney Drilling Company to help set up load test frames and to monitor and record test results in accordance with ASTM D3966. The principal investigator and his graduate assistants from The University of Akron installed instruments, which included inclinometer casings and vibrating-wire, rebar strain-meters in the south abutment shafts, and full-bridge strain gages in the north abutment shafts. Also, The University of Akron personnel performed inclinometer readings as well as data acquisition of strain readings during the lateral load test. ODOT District 12 project engineers and engineers from the Bureau of Bridge and Bureau of Research and Development supervised the load tests. The lateral load tests being completed on July 19, 1994, for shafts 5 and 8 and December 27, 1994, for shafts 67 and 70.

The original ground elevation (prior to bridge construction) was at 644+- feet. According to the revised report of soil investigation and slope monitoring prepared by Solar Testing Laboratories, Inc. for Burgess & Niple, limited, the roadway embankment material consisted of brown and gray silt and clay along with varying amounts of sand, gravel, rock fragments, shale fragments, organics, and wood. Below the original ground surface (Elev. 644) the soil material consisted of silt clay and other materials including organics.

Four soil borings with sampling were conducted at the proposed site in 1987, to determine the subsurface conditions and to install slope indicators. In the boring taken on the east side of the northbound lane, a five foot thick layer of very stiff silty clay was encountered below the fill material. Underlying these soils was highly weathered gray shale at 38.5' below existing ground surface. It was stated by Burgess & Niples report that the soil beneath the original ground surface was much less permeable than the embankment material, which was considered to be fairly permeable.

ODOT testing lab crew performed two soil borings on November, 1991. In addition, unconfined compression tests were conducted on core samples taken from the boreholes.

II.2.3 ODOT PROJECT 939 (93) I-90 SOUND BARRIERS LOAD TESTS, CUYAHOGA COUNTY, OHIO

A total of two lateral load tests on instrumented sound barriers drilled shafts at the Project 939(93) site were carried out on November 2, 1994, and November 3, 1994. National Engineering and Contracting Company was the foundation contractor who installed the tested drilled shafts. The principal investigator and his graduate assistants from The University of Akron installed instruments, which included inclinometer casings and vibrating-wire, rebar strain-meters in the shafts, and helped set up load test frames and monitor and record test results in accordance with ASTM D3966. Also, The University of Akron personnel performed inclinometer readings as well as data acquisition of strain readings during the lateral load tests. ODOT District 12 project engineers and engineers from the Bureau of Bridge and Bureau of Research and Development supervised the load tests.

According to Ridgeway Engineering Company Limited test boring log, the top layer of material consisted of brown sand with brick and concrete fill. The second layer consisted of wet brown very fine sand with some silt, underneath which is a layer of brown fine sandy silt with a trace of clay, and the bottom layer terminated at 12 feet deep consists of brown changing to gray silt clay with some small rock fragments.

II.2.4 ODOT PROJECT T-701 LATERAL LOAD TEST ON NOISE BARRIER WALL AT I-70 WEST, COL US, OHIO

A lateral load test was carried out on February 2, 1994 on drilled shafts at the ODOT Project T-701 site along I-70 West. These shafts were installed along the north side of I-70 approximately five miles west of I-270, near Hilliard-Rome Road in Columbus, Ohio. Parks Drilling Company was the foundation contractor who installed the tested drilled shafts, and supplied the equipment and had personnel on site to perform the lateral load test. BBC&M Engineering Inc. from Dublin, Ohio was geotechnical consultant who provided technical help to Parks Drilling Company. The principal investigator and his graduate assistants from The University of Akron were present to install the slope inclinometer tubings, and helped set up load test frames and monitor and record test results in accordance with ASTM D3966-90. Also, The University of Akron personnel performed inclinometer readings. BBC&M Engineering, Inc. provided the dial gages and recorded the lateral displacement at the drilled shaft head.

According to the soil boring that was performed by ODOT crew, the soil consists of a fill material up to a depth of 3 feet, then a layer of clay up to 9.5 feet. Two boreholes were bored at stations 235 and 227. The unconfined compressive strength for the samples retrieved from fill material at station 235 was about 60 psi, and 80 psi for sample retrieved at depth 6-8 feet at station 235. At station 227 the unconfined compressive strength for soil retrieved at depth 2-3 feet was about 18 psi.

II.3 SUMMARY OF CRITICAL ISSUES TO BE RESOLVED

The main idea behind conducting the lateral load tests on the drilled shafts at the two sites was to establish certain parameters with regards to the strength and load resistance of the originally designed shafts, which would benefit the engineer in terms of

1. Providing the designer with proof tests for an accurate and structurally safe design of the drilled shafts at each of the two project sites, or verify the adequacy of the original design.

2. Provide pertinent data to improve the existing design methodology for drilled shafts subjected to lateral loads. Thereby resulting in drilled shaft designs which are safer and economical at the same time.

CHAPTER III

LATERAL LOAD TESTS AT WAS – PUTNAM ST. BRIDGE

The planned field work for the project is documented in the Item Special (524 95200 Drilled Shafts Instrumentation and Lateral Load Tests) specified in the inter-office communication from the Administrator of the Office of Structural Engineering to the District 10 Deputy Director dated November 24, 1997.

This chapter deals with the details of the drilled shafts and their construction, the lateral load tests (instrumentation and testing) and finally the test results. Two drilled shafts were tested in accordance with ASTM D3966-90: "Standard Test Method for Piles Under Lateral Loads". The location of these shafts, which were of 14m and 9m length, is given in Fig. III.1. Also presented are the site conditions and the soil boring information. The instrumentation details and the load test results are given in detail. The measured data presented includes the load~deflection curve at the shaft head, the shaft deflection along the shaft length for each load increment, as well as the measured strains (on the compression and tension face of the shaft) and deduced moments along the shaft.

III.1 SITE CONDITIONS / SOIL INFORMATION

A subsurface exploration was performed by H. C. Nutting Company on the subject site and four test borings (two each for the 14m and 9m drilled shafts) were carried out. The location of these bores is presented in Fig. III.1, while the bore logs giving specific conditions at various depths are included as Fig. III.2 to III.5.

III.2 TESTED SHAFTS DESCRIPTION

Lateral load tests were carried out on four drilled shafts. The shafts, which were 14m and 9m in length, had the same cross-sectional dimensions and reinforcement details. The drilled shafts for both lengths had an outer diameter of 48-in. They were reinforced with 24-#11 bars for the longitudinal reinforcement and ties were made up of #3 bars placed at 6 in center-to-center. The outer diameter of the reinforcement cage was 42-in.

III.3 CONSTRUCTION METHOD

The drilled shafts were cast in situ, and the construction sequence for both of them is detailed below.

III.3.1 14M Deep Shafts

Two number shafts were drilled for the lateral load tests. The first of the shafts, referred to as Shaft#1, was poured in place on September 18, 1998. Prior to the pouring of concrete the boring for the shaft was carried out, and the reinforcement cage was assembled. All required instrumentation was done on the reinforcement cage, which was then lowered into the bored hole. The total depth of the borehole being 16.1m, which took it into the bed rock. Prior to pouring of the structural concrete, a 5ft-7in deep layer of lean concrete was poured at the bottom of the hole. Once the concrete pour inside the borehole was completed, the portion of the drilled shaft, protruding above the natural ground level was formed into a 1.2-meter square and poured monolithically with the previously poured concrete. The whole process of concreting was completed within a 6-hour period and without any construction joints. The total depth of the shaft (including the lean concrete at the bottom) was 18.1-m. Figures III.8 to III.18 show the construction and instrumentation process.

The second of the 14m deep shafts, referred to as Shaft#2, was poured on September 21, 1998. The construction sequence was similar to that of Shaft#1. As for the first shaft, 5ft-7in deep layer of lean concrete was poured at the bottom of the borehole, and the remaining was then filled in with structural concrete. The portion of the shaft extending above ground level (2m) was formed into a 1.2 meter square shape, as for the first case. The total depth of this shaft being 18.7m, while the depth of the borehole was 16.7m.

III.3.2 9M Deep Shafts

The first of the two shafts having 9m depth, was poured on September 23, 1998. The instrumentation done and the construction sequence for the 9m deep, drilled shaft was similar to the 14m deep shafts. These shafts were also having an outer diameter of 48-in and were reinforced with 24-#11 bars. The ties provided were once again #3 bars placed at 6-in on centers. Upon fabrication of the reinforcement cages and completion of the instrumentation, the cages were lowered in the borehole. Before pouring the structural concrete the bottom 5ft-7in of the borehole was filled with lean concrete and an additional 3ft-6in deep layer of sand was placed on top of the lean concrete. The remaining 9.1m deep borehole was filled with structural concrete. Similar to the 14m deep shafts, the 2m portion of the shaft protruding above the ground was formed into a 1.2m square cross-section. The entire concreting process was completed without any breaks and any construction joints. Figures III.36 to III.46 provide details of the drilling, casting, and instrumentation operation.

The second of the 9m deep test shafts was cast on September 24, 1998. The only difference between the construction sequence for this and the first shaft being, that there was a 3m deep layer of lean concrete at the bottom, on top of which there was a 1m deep layer of sand. The 9.1m deep structural concrete was poured over the sand and the lean concrete.

III.4 INSTRUMENTATION

This portion includes the detail of the instrumentation carried out for the 14-m and 9-m deep drilled shafts. It includes the type of strain gages, inclinometer and dial gages used.

III.4.1 Instrumentation for 14M Deep Drilled Shafts

Each of the 14m deep drilled shafts were instrumented with 14 vibrating wire strain meters also referred to as "Sister Bars" (Geokon model 4911), an inclinometer tube (Geokon model 6501) to measure the lateral movement with depth, associated with each load increment. The inclinometer tube extending 4m below the bottom of the shaft. Three dial gages were located at the top of the shaft as well, to measure the deflection of the shaft head. Figures III.12 to III.14 give the location of the strain gages, the inclinometer and the dial gages. Also given is the test frame assembly.

III.4.2 Instrumentation for 9M Deep Drilled Shafts

The instrumentation for the 9m deep shaft was quite similar to that of the 14m deep shaft. This shaft was instrumented with 10 Nos. vibrating wire strain meters (Geokon model 4911), an inclinometer tube (Geokon model 6501), again extending 4m below the bottom of the drilled shaft, for measuring the lateral movement with depth associated with each load increment, and three dial gages placed at the top of the shaft head for monitoring deflections at the shaft head. Figures III.40 to III.42 provide details for the instrumentation, mentioned above and the test set-up including the loading frame.

III.5 TEST REACTION FRAME SET-UP

Figure III.20 to III.23 give the details of the test set-up and the loading frame used for the 14-M deep shafts, while Figs. III.47 to III.49 give similar details for the 9-M deep shafts, for conducting the test in accordance with ASTM standard D3966-90. The test frame was designed and manufactured by the University of Akron. The test frame was made up of 14x14x1/2-in tubular sections and was assembled as indicated through schematic diagrams in Fig. III.24(a,b,c) and Fig. III.50.

III.6 LATERAL LOAD TEST RESULTS

III.6.1 Load Test results From 14-M Deep Shafts 1 and 2

Lateral load tests on the two shafts were carried out on October 28, 1998. The observed deflection of the shaft head versus the class A predicted deflection for the two 14m drilled shafts are plotted out and presented in Figures III.25 and III.26. The comparisons have been made between the observed values from the dial gages and the inclinometer readings and for values calculated for constant EI considerations and secondly, assuming a non-linear relationship for EI. Figures III.27 to III.30 give the observed values of deflection along the depth of the drilled shaft for the various load stages, as observed from the inclinometer readings. The lateral movement in the two directions has been plotted out for two feet intervals and for the specific load increments of 25-k in which the test was conducted. Tables included in Appendix A provide the dial gage readings at the shaft head for the various load increments, while the detailed inclinometer readings are also given in the same Appendix.

Also presented, in Figs. III.31 to III.34 are the strain measurements along the length of the shaft, at the different load stages, for the compression and the tension face of the drilled shaft. Tables provided in Appendix A give the detailed strain readings at locations of the instrumented gages for the various load stages.

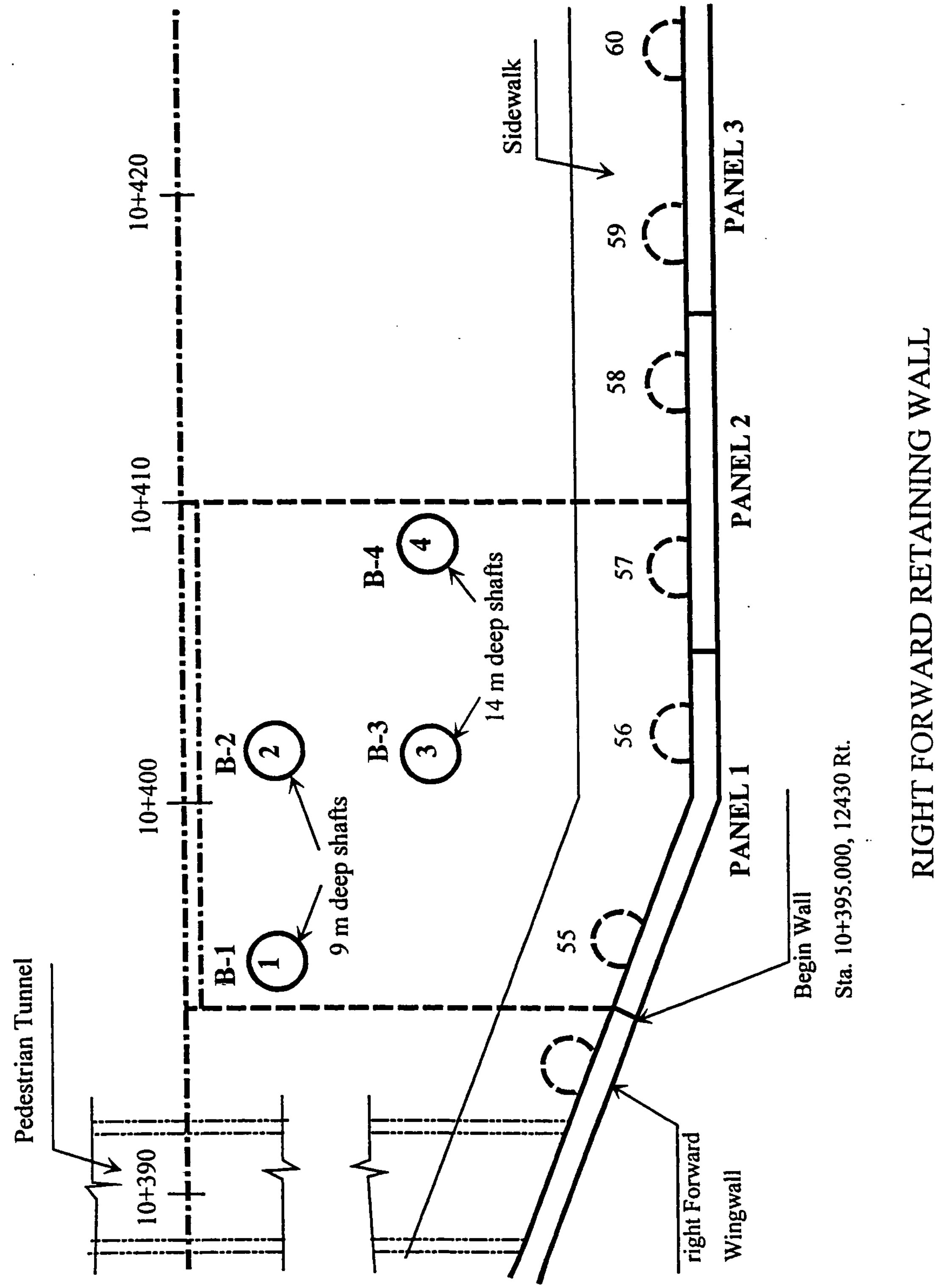
It was observed during the testing that at a load of around 90-kips appreciable cracks appeared in the soil surrounding the drilled shafts and this field observation is presented in Fig. III.35.

III.6.2 Load Test results From 9M Deep Shafts 1 and 2

Lateral load tests on the two shafts were carried out on October 21, 1998. The observed deflection of the shaft head versus the calculated deflection for the two 9m drilled shafts are plotted out and presented in Figures III.51 and III.52. The comparisons have been made between the observed values from the dial gages and the inclinometer readings and for values calculated for constant EI considerations and secondly, assuming a non-linear relationship for EI. Figures III.53 to III.56 give the observed values of deflection along the depth of the drilled shaft for the various load stages, as observed from the inclinometer readings. The lateral movement in the two directions has been plotted out for two feet intervals and for the specific load increments of 25-k in which the test was conducted. Tables included in Appendix A provide the dial gage readings at the shaft head for the various load increments, while the detailed inclinometer readings are given in Tables attached as Appendix A.

Also presented, in Figures III.57 to III.60 are the strain measurements along the length of the shaft, at the different load stages, for the compression and the tension face of the drilled shaft. Tables III.25 to III.28 give the detailed strain readings at locations of the instrumented gages for the various load stages.

Furthermore, appreciable movement of the shaft head, for one of the shafts, was observed at a load of around 75-kips.



III.1 Location of bore holes and drilled shafts used in lateral load tests at Was-Putnam St. Bridge

H. C. NUTTING COMPANY

CORPORATE CENTER - 4120 AIRPORT ROAD
CINCINNATI, OH 45226 (513) 321-5816
FAX: (513) 321-0294

EMPLOYEE OWNED

GEOTECHNICAL, ENVIRONMENTAL AND TESTING ENGINEERS SINCE 1921

FIELD LOG OF TEST BORING

APPALACHIAN REGION — CHARLESTON, WV | CENTRAL OHIO REGION — COLUMBUS, OH | INDIANA REGION — WALNUT STREET, LAWRENCEBURG, IN | BLUEGRASS REGION — COVINGTON, KY

CLIENT:	National Engineering	BORING NO.:	B-1
PROJECT:	Putnam Street Bridge - Marietta, Ohio	DATE STARTED:	9-2-98
BORING LOCATION:	As Marked	DATE COMPLETED:	9-3-98
ELEVATION REFERENCE:		WORK ORDER NO.:	60171.002

ELEV	DEPTH (meters)		DESCRIPTION OF MATERIALS	SAMPLE #	SAMPLE TYPE	SAMPLE DEPTH (meters)	SAMPLE BLOW PER 6 INCHES	SAMPLE RECOVERY	SOIL PROPERTIES W (%)	SOIL PROPERTIES PENN	SOIL PROPERTIES RQD
	0.0	0.27	Asphalt and gravel								
	0.27	1.0	Reddish Brown lean clay (FILL), moist-stiff	1	SS	0-0.45	25-8-6	0.28			
	1.27	1.77	Gray lean clay, with fine gravel (FILL), stiff, moist to very moist	2	SS	1.52-1.97	5-9-3	0.16			
	3.04	1.52	Gray lean clay with fine gravel (FILL), soft very moist	3	SS	3.04-3.49	1-2-1	0.36			
	4.56	4.14	Brown lean CLAY, stiff to firm to soft-wet	4 5 6	SS SS SS	4.56-5.01 6.08-6.53 7.60-8.05	3-5-6 3-3-4 1-2-2	0.45 0.45 0.45			
	8.70	1.52	Gray lean CLAY with fine sand lenses, soft	7	SS	9.12-9.57	0-0-3	0.40			
	10.22	1.52	Fine gravel with silty fine to coarse SAND, firm-wet	8	SS	10.64-11.09	4-7-11	0.21			
	11.74	4.53	Brown fine SAND with fine gravel, firm-wet	9 10 11	SS SS SS	12.16-12.61 13.68-14.13 15.20-15.65	4-9-9 4-9-15 5-9-12	0.18 0.32 0.06			
	16.27	0.15	Auger refusal - cased in rock								
	16.42	0.37	Gray sandy SHALE, medium hard	1 2	core core	16.42-18.59 18.59-20.59	PENN-2.17 PENN-2.00	2.17 2.00			95% 95%
	16.79	2.20	Reddish brown and greenish - soft gray SHALE, some gray sandy shale, medium hard								
	18.99	1.60	Gray sandy SHALE, medium hard alternating with reddish brown shale, soft								
	20.59		TEST BORING COMPLETED								

* Pocket Penetrometer Reading - Unconfined Compressive Strength, Tons/Sq. Ft.

General Notes		Remarks	Water Level Observations		
Driller	K.MULLINS		Immediate	4.56	m
Rig No.	48		At Completion	4.12	m
Rig Type	CME-55		After Hours		m
Method	3-1/4 HSA	* ADD AT 4.56	Water Used in drilling	*	m
	NQ CORE		(Measured from ground surface)		

III.2 Log of test bore used in subsurface investigation for 14-m deep shaft

H. C. NUTTING COMPANY FIELD **LOG OF TEST BORING**

CORPORATE CENTER - 4120 AIRPORT ROAD
CINCINNATI, OH 45226 (513) 321-5816
FAX: (513) 321-0294

EMPLOYEE OWNED

GEOTECHNICAL, ENVIRONMENTAL AND TESTING ENGINEERS SINCE 1921

APPALACHIAN REGION	CENTRAL OHIO REGION	INDIANA REGION	BLUEGRASS REGION
912 MORRIS STREET	780 MORRISON ROAD	340 WALNUT STREET, STE 8	50 E. RIVERCENTER BLVD., STE 400
CHARLESTON, WV 25301	COLUMBUS, OH 43230	LAWRENCEBURG, IN 47025	COVINGTON, KY 41011
[illegible]	(614) 863-3113	[illegible]	[illegible]
FAX: [illegible]	FAX: [illegible]	FAX: [illegible]	FAX: [illegible]

CLIENT:	National Engineering	BORING NO.:	B-2
PROJECT:	Putnam Street Bridge - Marietta, Ohio	DATE STARTED:	9-1-98
BORING LOCATION:	As Marked	DATE COMPLETED:	9-2-98
ELEVATION REFERENCE:		WORK ORDER NO.:	60171.002

ELEV	DEPTH (meters)		DESCRIPTION OF MATERIALS	SAMPLE #	TYPE	DEPTH (meters)	BLOW PER 6 INCHES	RECOVERY *	W (%)	LL/PL (%)	RQD
	0.0										
		0.22	Asphalt and gravel	1	SS	0-0.45	22-8-7	0.40			
	0.22										
		1.30	Reddish brown lean clay with sandstone fragments (FILL), moist-stiff								
	1.52			2	SS	1.52-1.97	3-2-3	0.00			
		1.52	Gray lean clay with fine gravel (FILL), firm moist								
	3.04			3	SS	3.04-3.49	5-6-10	0.45			
		1.52	Brown mottle with gray lean CLAY, moist-very stiff								
	4.56			4	SS	4.56-5.01	2-3-5	0.45			
		3.04	Brown lean CLAY, firm wet	5	SS	6.08-6.53	2-3-4	0.45			
	7.60			6	SS	7.60-8.05	2-3-2	0.45			
		1.52	Gray lean CLAY, firm moist								
	9.12			7	SS	9.12-9.57	2-2-1	0.40			
		1.52	Gray lean CLAY with fine sand lenses, soft wet								
	10.64			8	SS	10-64-11.09	2-3-2	0.15			
		1.52	Fine gravel with some fine to coarse SAND, loose wet								
	12.16			9	SS	12.16-12.61	3-4-8	0.17			
		4.11	Brown fine SAND with some fine gravel, firm to loose to dense-wet	10	SS	13-68-14.13	3-5-5	0.25			
				11	SS	15.20-15.65	8-18-22	0.26			
	16.27										
		0.15	Reddish brown and greenish gray SHALE, soft, auger refusal								
	16.42			12	SS	16-42-16.57	50/0.15	0.15			
		0.15	Same split spoon refusal								
	16.57			1	core	16.57-18.43	PENN. 1.86	1.86			90%
		2.69	Reddish brown and greenish gray SHALE, soft	2	core	18.43-20.59	PENN. 2.16	2.16			90%
	19.26										
		0.22	Gray sandy SHALE, medium hard								
	19.48										
		0.60	Reddish brown SHALE, soft								
	20.08										
		0.22	Gray sandy SHALE, medium hard								
	20.30										
		0.29	Reddish brown, SHALE, soft								
	20.59										
			TEST BORING COMPLETED								

* Pocket Penetrometer Reading - Unconfined Compressive Strength, Tons/Sq. Ft.

General Notes		Remarks	Water Level Observations		
Driller	K.MULLINS		Immediate	4.56	m
Rig No.	48		At Completion	3.90	m
Rig Type	CME-55		After Hours		m
Method	3-1/4 HSA	* ADD AT 4.56 meters	Water Used in drilling	*	m
	NQ CORE		(Measured from ground surface)		

III.3 Log of test bore used in subsurface investigation for 14-m deep shaft

H. C. NUTTING COMPANY
CORPORATE CENTER - 4120 AIRPORT ROAD
CINCINNATI, OH 45226 (513) 321-5816
FAX: (513) 321-0294
EMPLOYEE OWNED
GEOTECHNICAL, ENVIRONMENTAL AND TESTING ENGINEERS SINCE 1921

APPALACHIAN REGION [illegible] CHARLESTON, WV [illegible]
CENTRAL OHIO REGION [illegible] COLUMBUS, OH [illegible]
INDIANA REGION [illegible] LAWRENCEBURG, IN [illegible]
BLUEGRASS REGION [illegible] COVINGTON, KY [illegible]

FIELD LOG OF TEST BORING

CLIENT:	National Engineering	BORING NO.:	B-3
PROJECT:	Putnam Street Bridge, Marietta, Ohio	DATE STARTED:	9-1-98
BORING LOCATION:	As Marked	DATE COMPLETED:	9-1-98
ELEVATION REFERENCE:		WORK ORDER NO.:	60171.002

ELEV	DEPTH (meters)		DESCRIPTION OF MATERIALS	SAMPLE #	TYPE	DEPTH (meters)	BLOW PER 6 INCHES	RECOVERY	SOIL PROPERTIES W (%)	LL/PL (%)	PP* (tsf)
	0.0										
	0.13	0.13	Asphalt								
	0.25	0.12	Gravel								
		1.27	Reddish brown lean CLAY with sandstone fragments (FILL), moist-stiff	1	SS	0-0.45	17-5-7	0.30			
	1.52			2	SS	1.52-1.97	2-3-6	0.34			
		1.52	Gray lean clay with brick fragments (FILL), moist-stiff								
	3.04			3	SS	3.04-3.49	3-7-9	0.45			
		1.52	Brown mottle with gray lean CLAY, moist-very stiff								
	4.56			4	SS	4.56-5.01	2-3-4	0.45			
		4.86	Brown lean CLAY, firm to soft to very soft, moist to wet	5	SS	6.08-6.53	2-2-2	0.45			
				6	SS	7.60-8.05	2-2-1	0.45			
				7	SS	9.12-9.57	1-3-3	0.32			
	9.42										
		1.22	Brown fine to coarse gravel, loose wet								
	10.64			8	SS	10-64-11.09	17-8-6	0.09			
		1.52	Fine to coarse gravel with fine sand, firm wet								
	12.16			9	SS	12.16-12.61	3-3-7	0.27			
		0.45	Fine SAND AND GRAVEL, loose wet								
	12.61										
			TEST BORING COMPLETED								

* Pocket Penetrometer Reading - Unconfined Compressive Strength, Tons/Sq. Ft.

General Notes		Remarks	Water Level Observations		
Driller	K.MULLINS		Immediate	7.60	m
Rig No.	48		At Completion	6.72	m
Rig Type	CME-55		After 24 Hours	3.52	m
Method	3-1/4 HSA	* ADD AT 7.60 meters	Water Used in drilling	*	m
			(Measured from ground surface)		

III.4 Log of test bore used in subsurface investigation for 9-m deep shaft

H. C. NUTTING COMPANY
CORPORATE CENTER - 4120 AIRPORT ROAD
CINCINNATI, OH 45226 (513) 321-5816
FAX: (513) 321-0294
EMPLOYEE OWNED
GEOTECHNICAL, ENVIRONMENTAL AND TESTING ENGINEERS SINCE 1921

FIELD LOG OF TEST BORING

APPALACHIAN REGION | CENTRAL OHIO REGION | INDIANA REGION | BLUEGRASS REGION

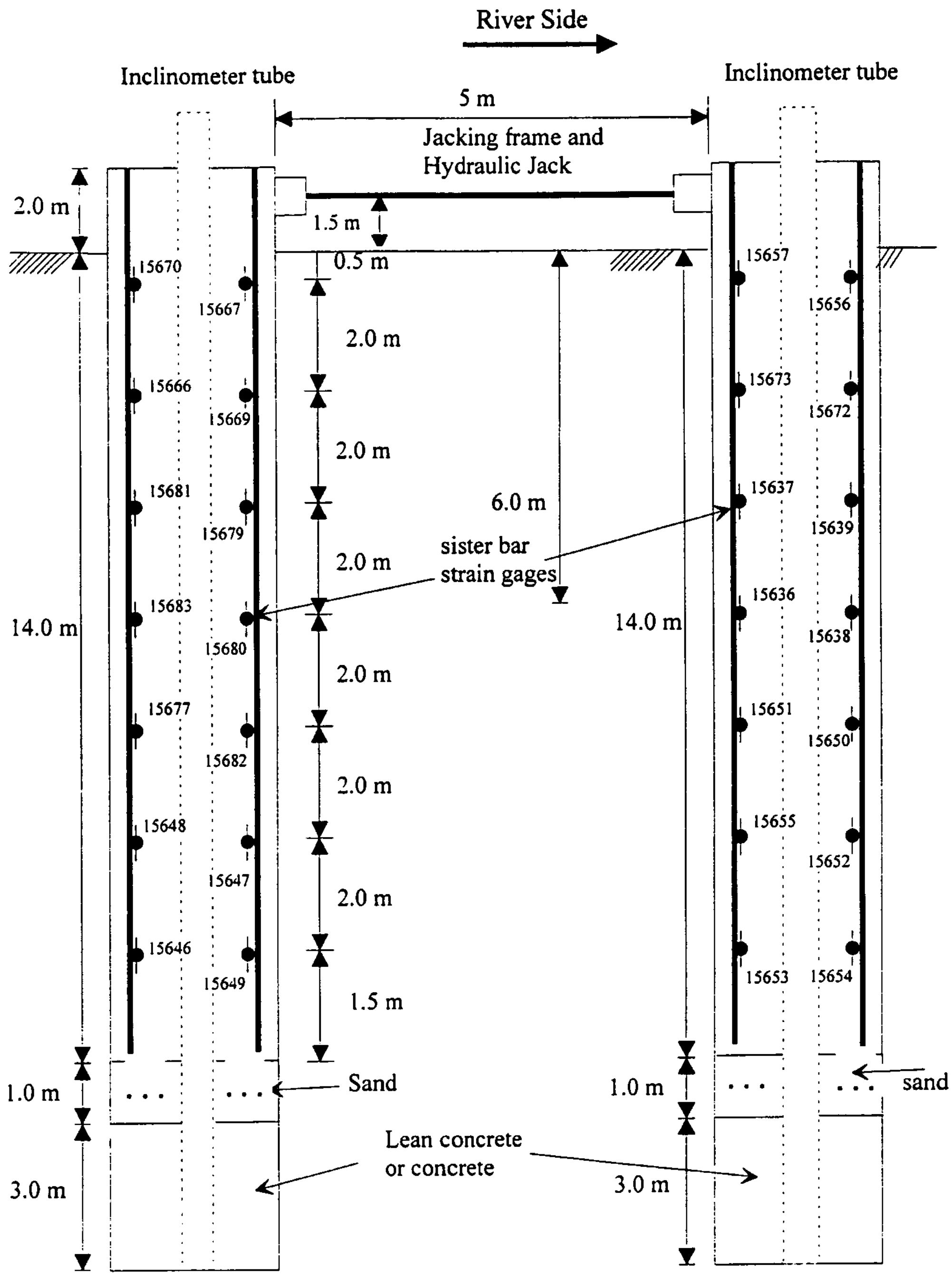
CLIENT:	National Engineering	BORING NO.:	B-4
PROJECT:	Putnam Street Bridge, Marietta, Ohio	DATE STARTED:	9-1-98
BORING LOCATION:	As Marked	DATE COMPLETED:	9-1-98
ELEVATION REFERENCE:		WORK ORDER NO.:	60171.002

				SAMPLE					SOIL PROPERTIES		
ELEV	DEPTH (meters)		DESCRIPTION OF MATERIALS	#	TYPE	DEPTH (meters)	BLOW PER 6 INCHES	RECOVERY	W (%)	LL/PL (%)	PP* (tsf)
	0.0										
		0.12	Asphalt								
	0.12										
		0.15	Gravel								
	0.27										
		1.25	Reddish brown lean CLAY (FILL), firm moist	1	SS	0-0.45	16-5-3	0			
	1.52			2	SS	1.52-1.97	2-2-6	0.30			
		0.60	Brown and gray lean CLAY, with fine sand and gravel (FILL), firm moist								
	2.12										
		0.90	Sandstone boulders, hard								
	3.02										
		1.52	Brown lean CLAY, moist-very stiff	3	SS	3.04-3.49	4-7-9	0.0			
	4.56			4	SS	4.56-5.01	2-3-4	0.07			
		1.52	Brown lean CLAY with some sandstone fragments, firm moist								
	6.08			5	SS	6.08-6.53	3-3-4	0.45			
		1.52	Brown lean CLAY, firm moist								
	7.60			6	SS	7.60-8.05	2-2-3	0.45			
		1.52	Brown lean CLAY, with some fine sand, firm moist								
	9.12			7	SS	9.12-9.57	3-3-4	0.31			
		3.04	Brown fine SAND with some fine gravel, loose wet	8	SS	10-64-11.09	4-3-3	0.08			
	12.16			9	SS	12.16-12.61	2-3-5	0.10			
		0.45	Fine gravel with fine SAND, loose wet								
	12.61										
			TEST BORING COMPLETED								

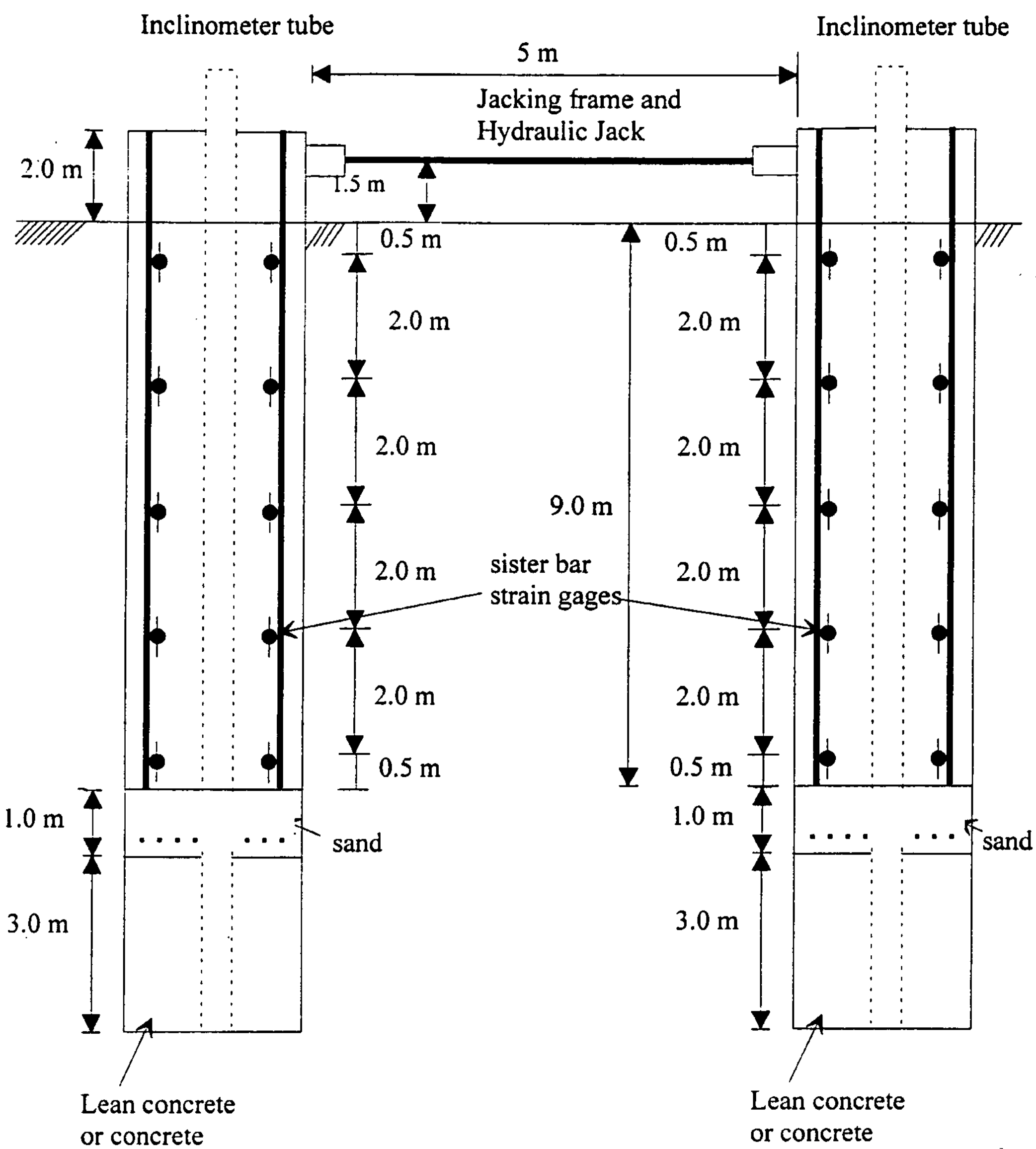
* Pocket Penetrometer Reading - Unconfined Compressive Strength, Tons/Sq. Ft.

General Notes		Remarks	Water Level Observations		
Driller	K.MULLINS		Immediate	8.35	m
Rig No.	48		At Completion	5.80	m
Rig Type	CME-55		After 24 Hours	4.45	m
Method	3-1/4 HSA	* ADD AT 9.12 meters	Water Used in drilling	*	m
			(Measured from ground surface)		

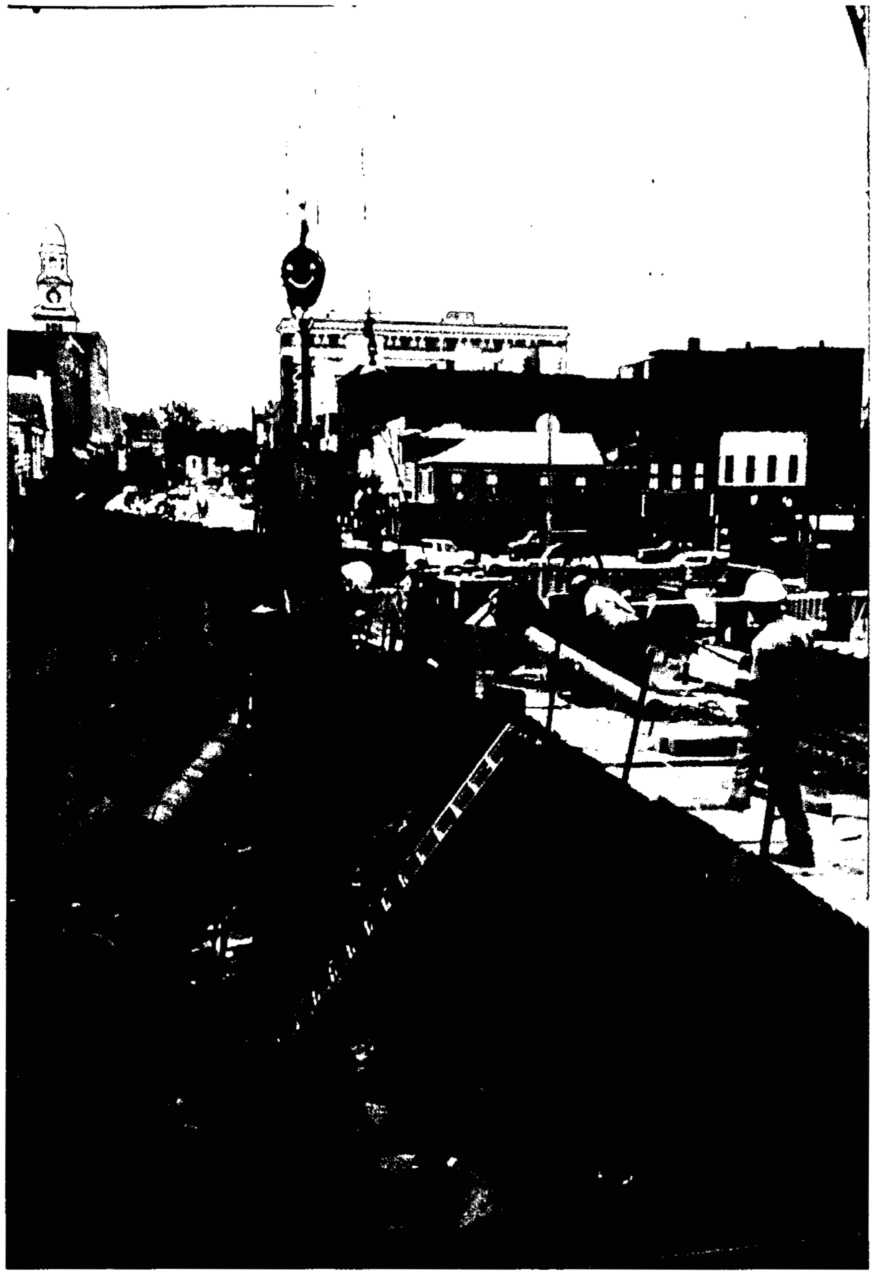
III.5 Log of test bore used in subsurface investigation for 9-m deep shaft



III.6 Instrumentation details for lateral load test –14-m deep shaft

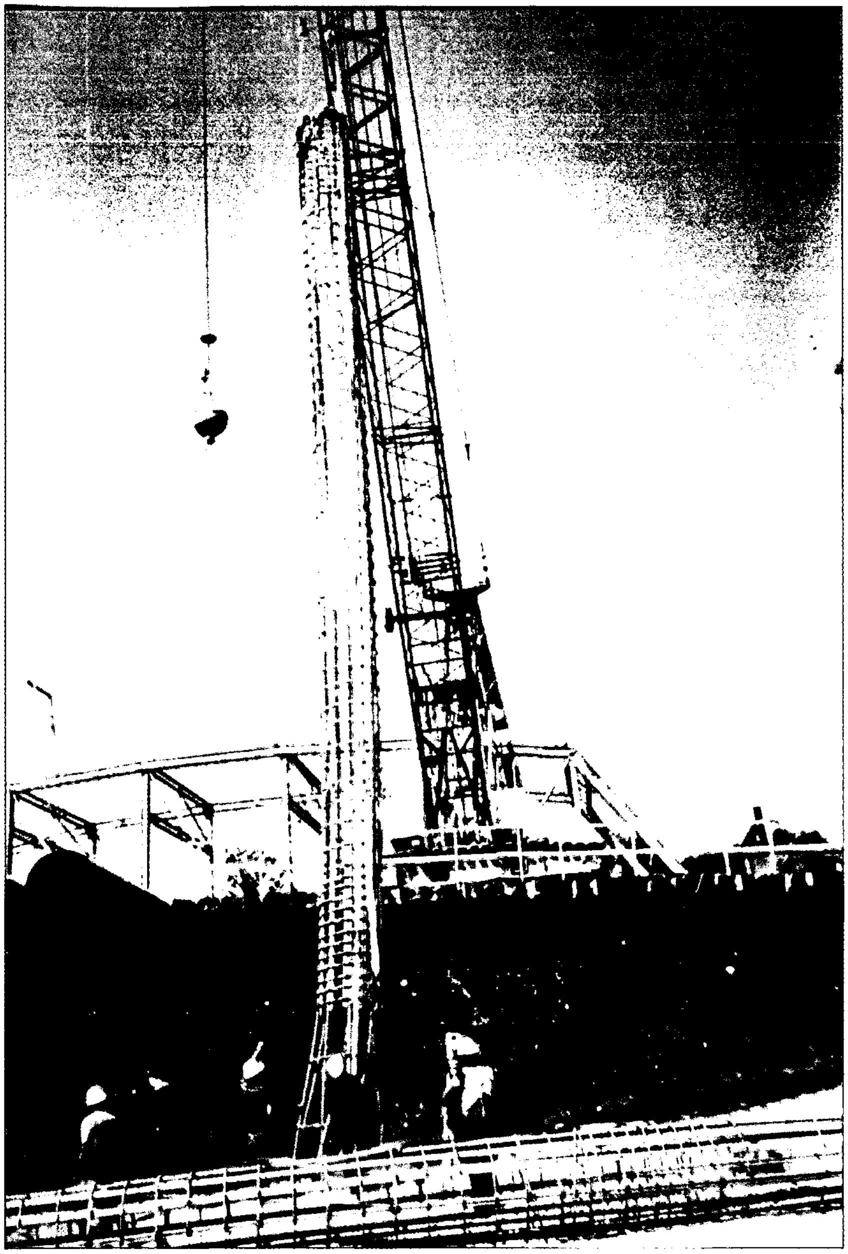


III.7 Instrumentation details for lateral load test – 9-m deep shaft

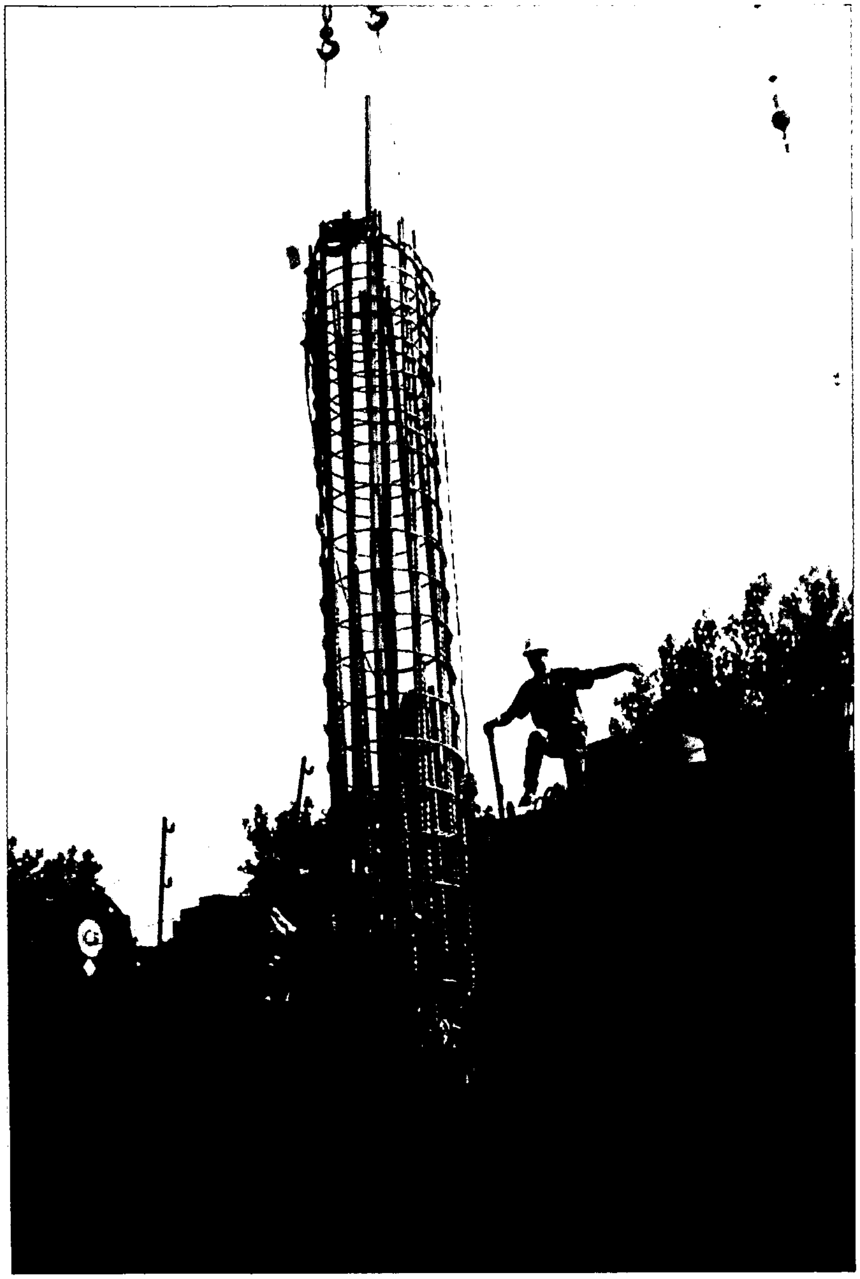


III.8 Drilling of the 14-m deep shaft in progress

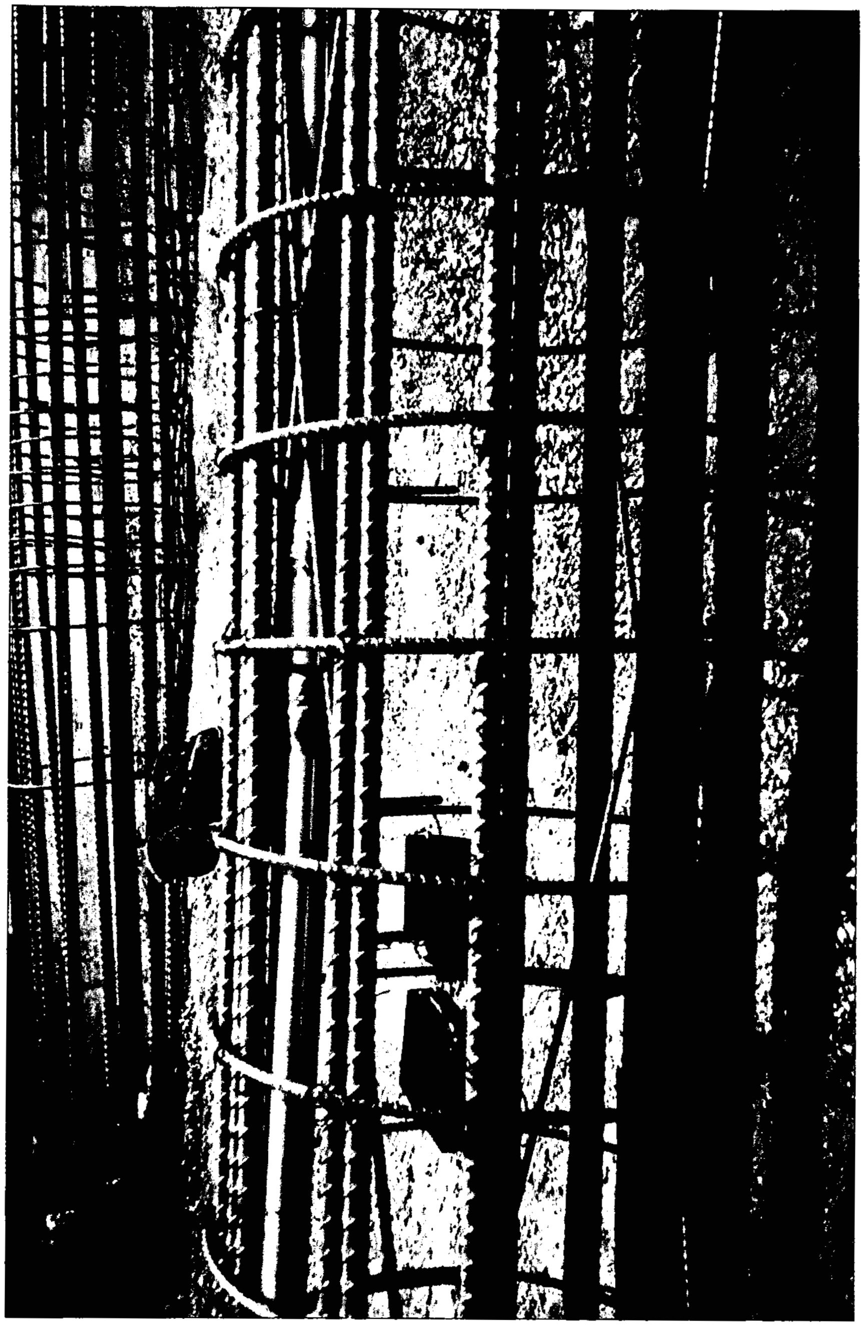
III.9 Drilling of the 14-m shaft in progress



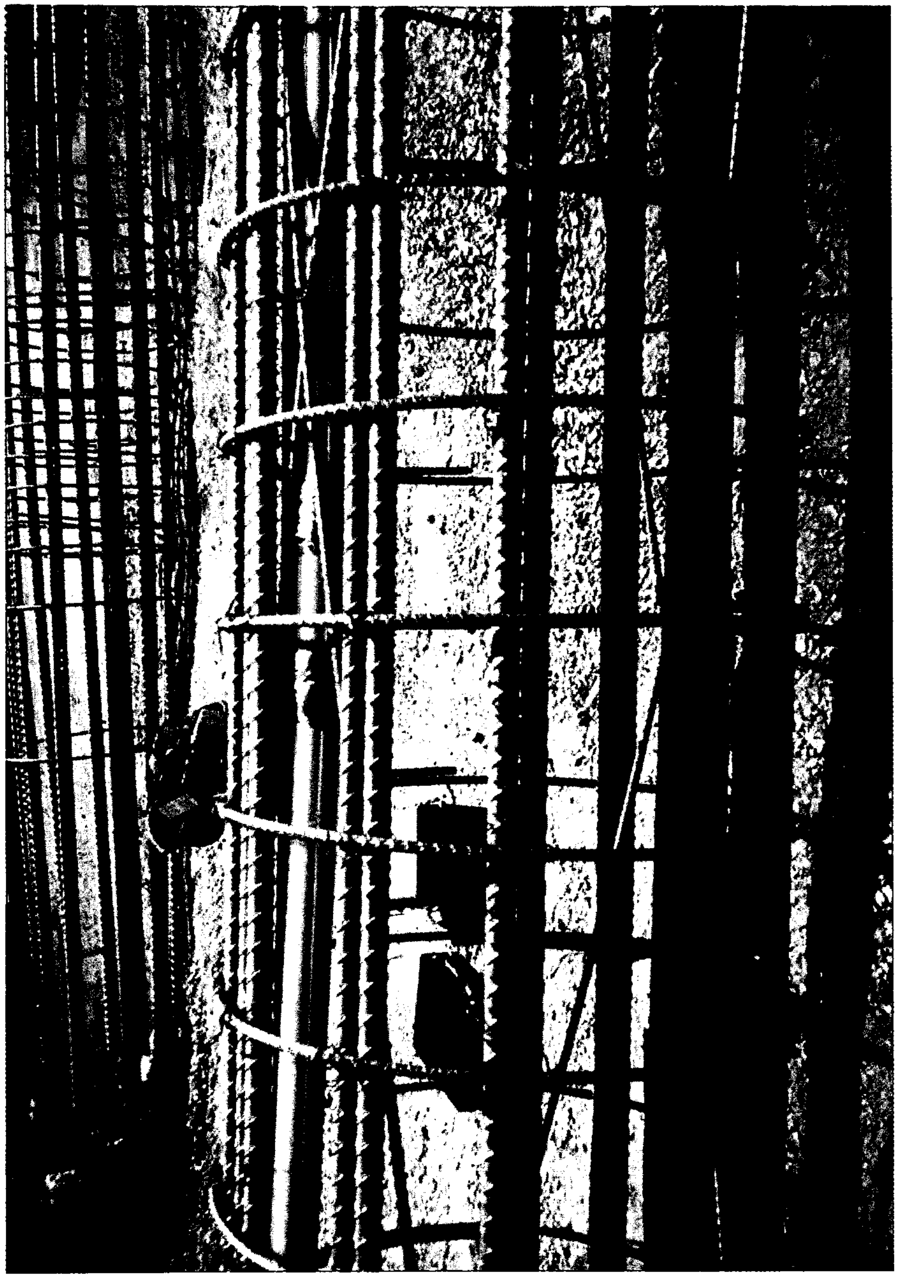
III.10 Lowering the cage for the 14-m deep shaft in progress



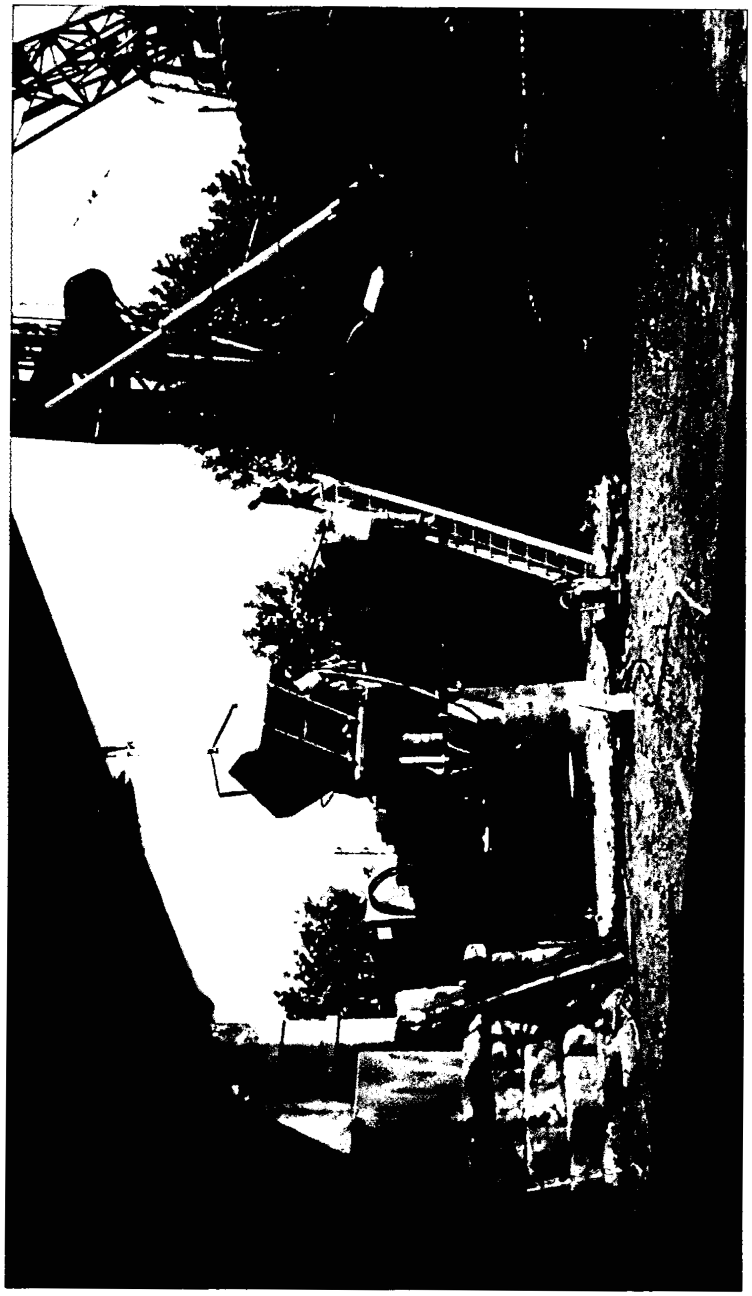
III.11 Lowering of the cage for the 14-m deep shaft in progress



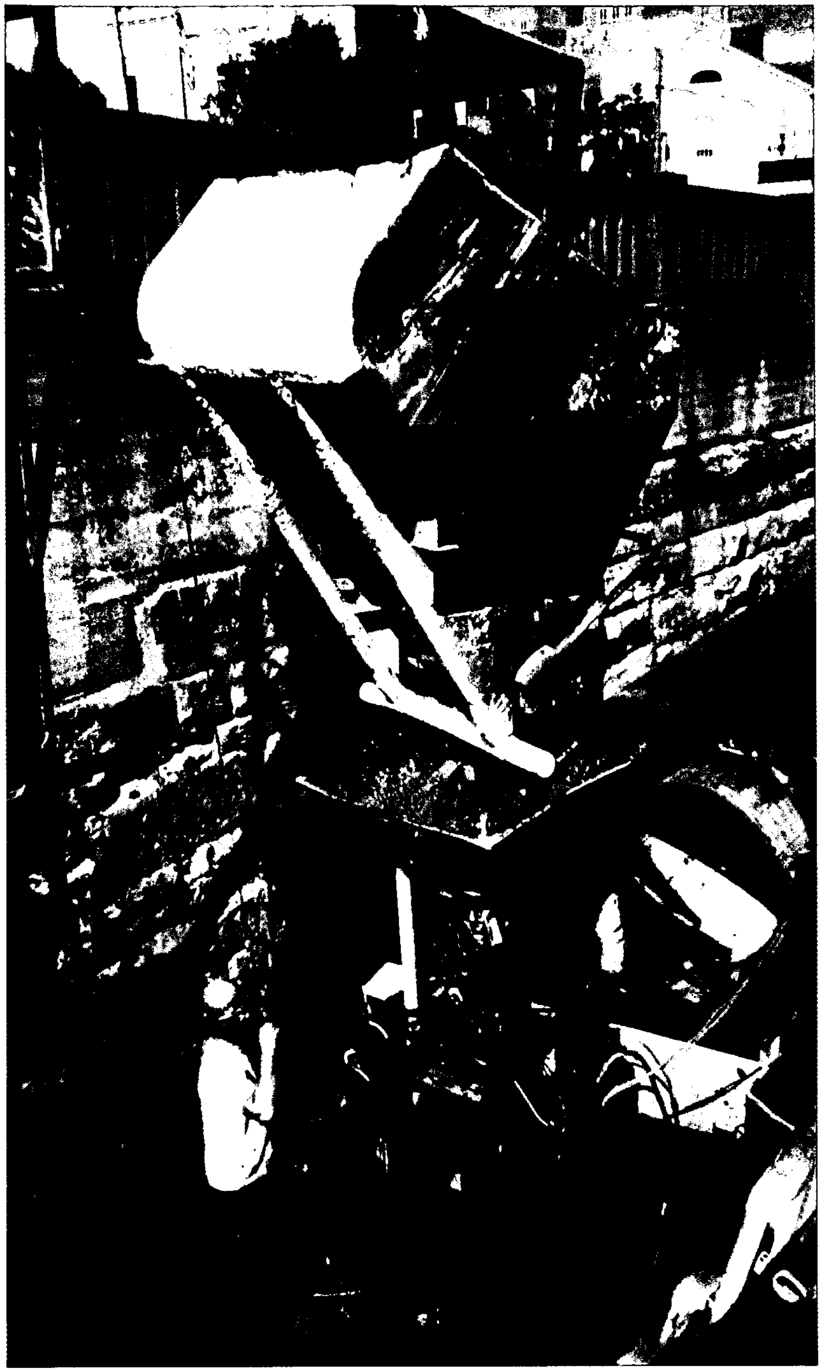
III.12 Instrumentation details for the 14-m deep shafts



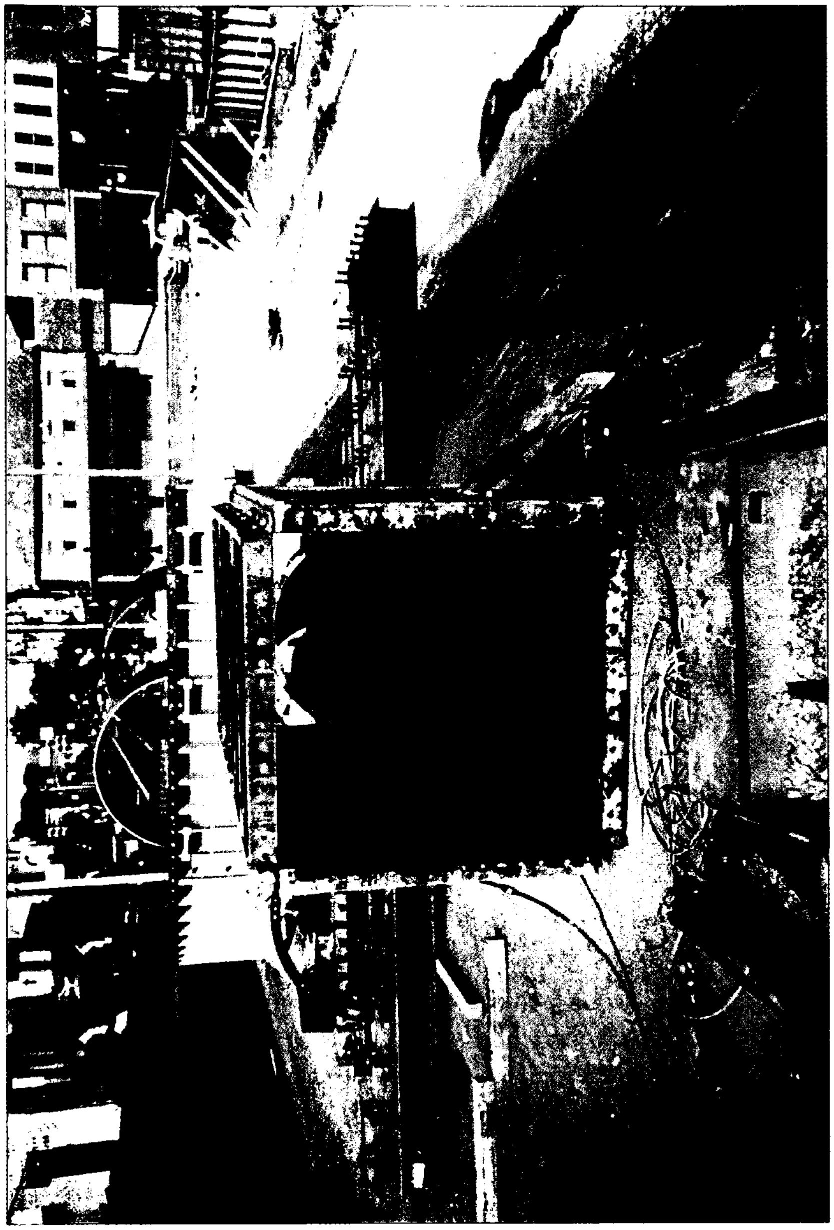
III.13 Instrumentation details for the 14-m deep shafts



III.14 Concreting of the 14-m deep shaft in progress



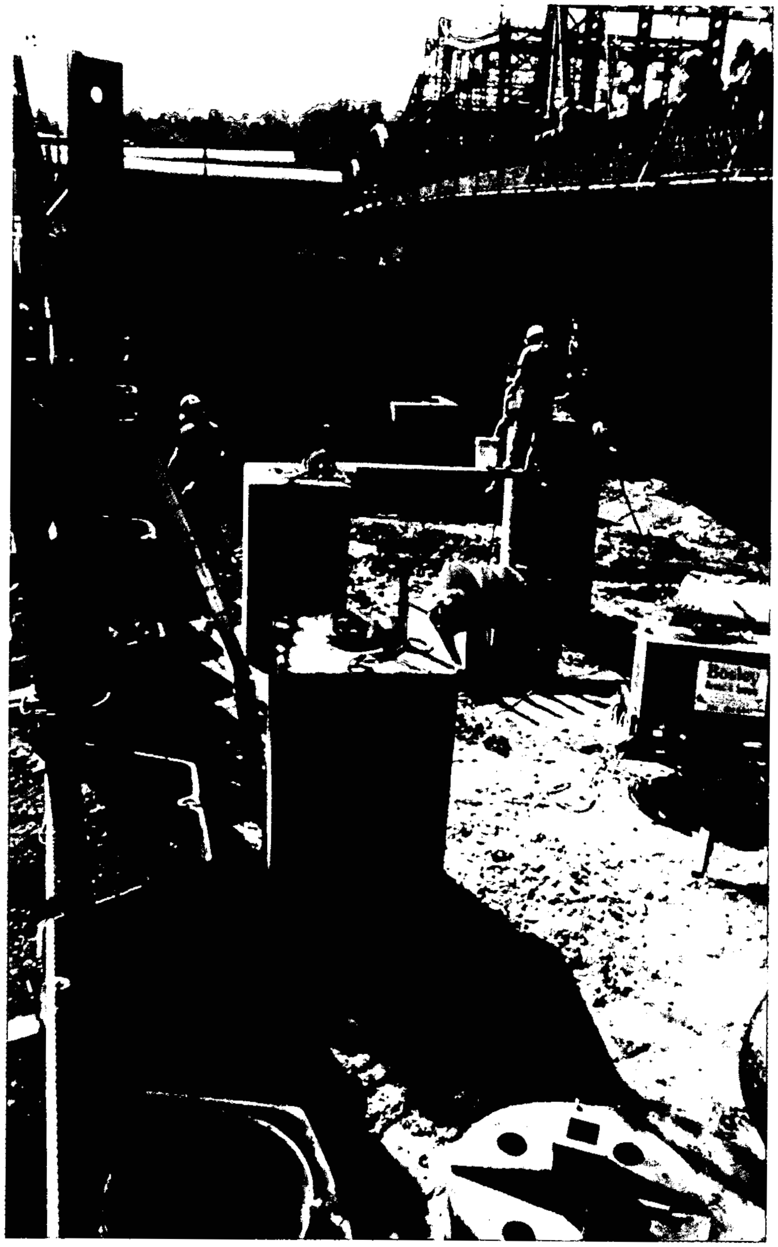
III.15 Concreting of the 14-m deep shaft in progress



III.16 Formwork details for the top 2-m portion of the drilled shaft

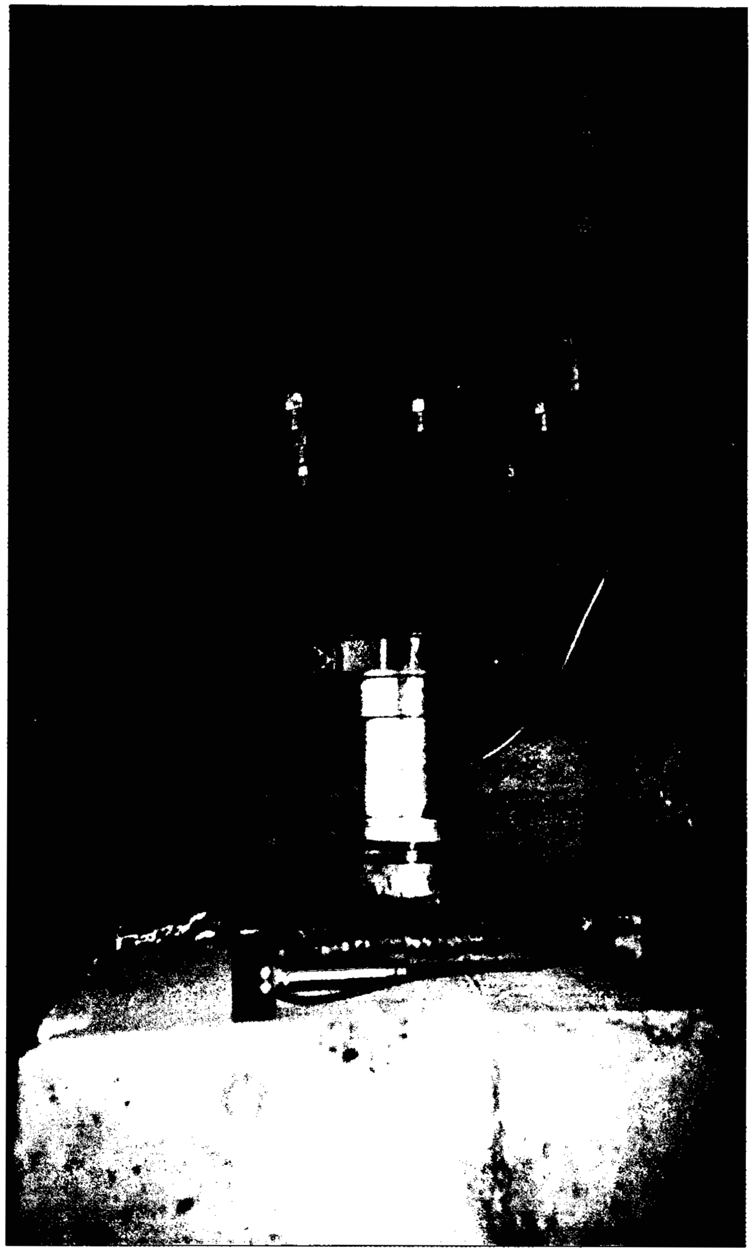
III. 18 Finishing of the top 2-m od the drilled shaft

III.18 Finishing of the top 2-m of the drilled shaft

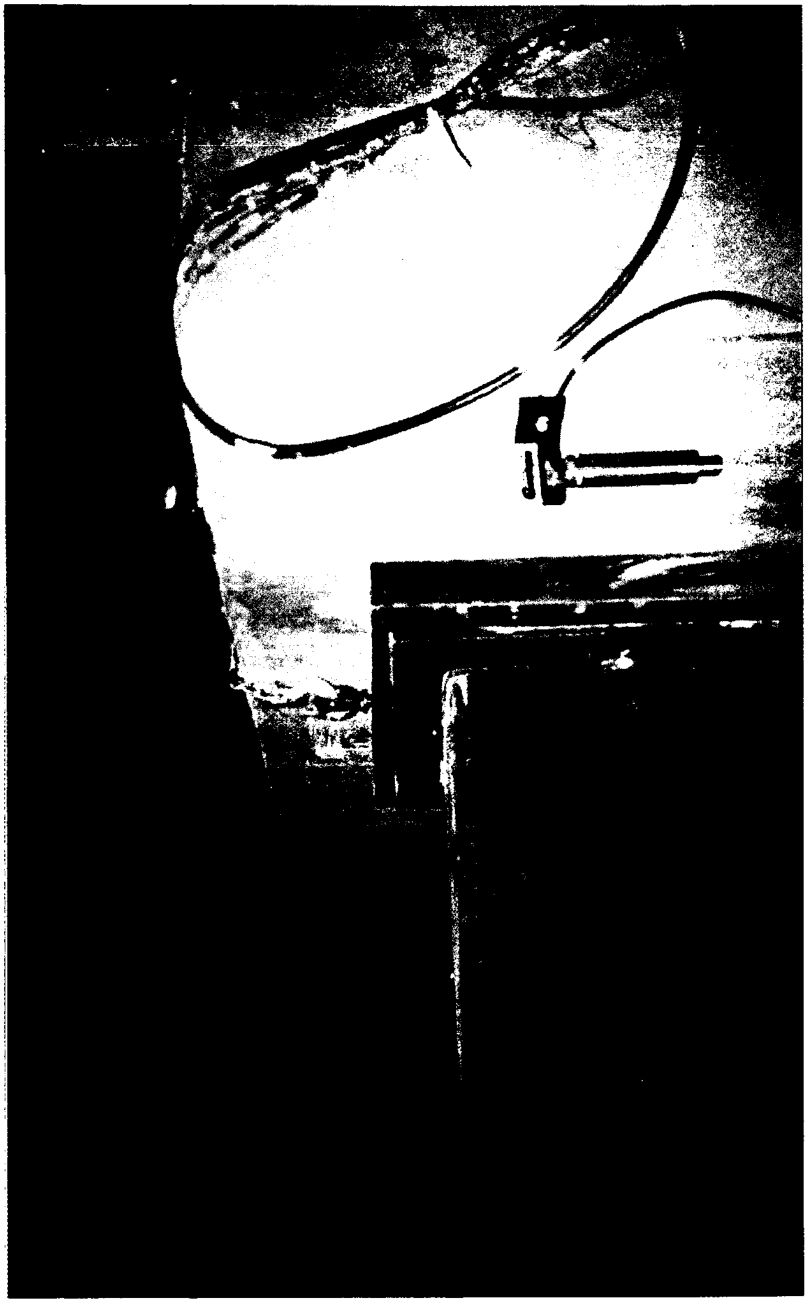


III.19 Finishing shafts

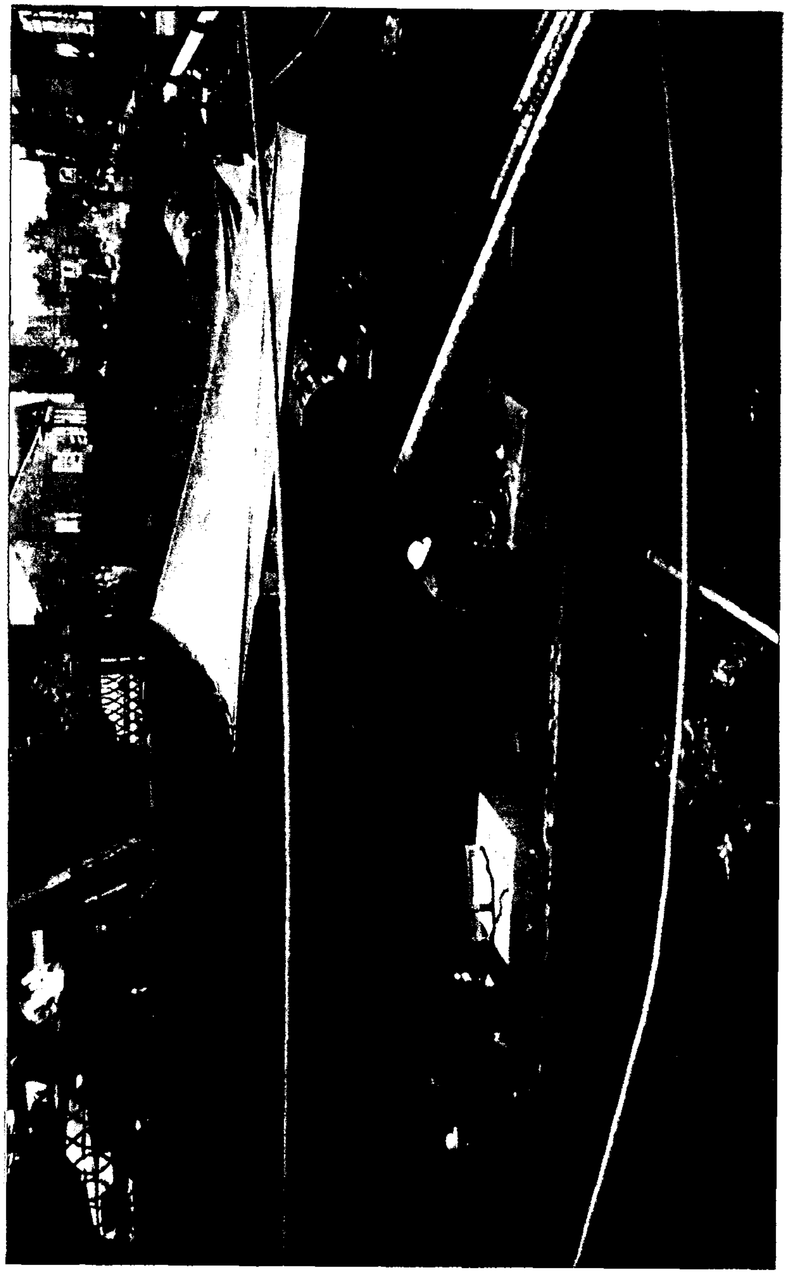
III.20 Test set-up



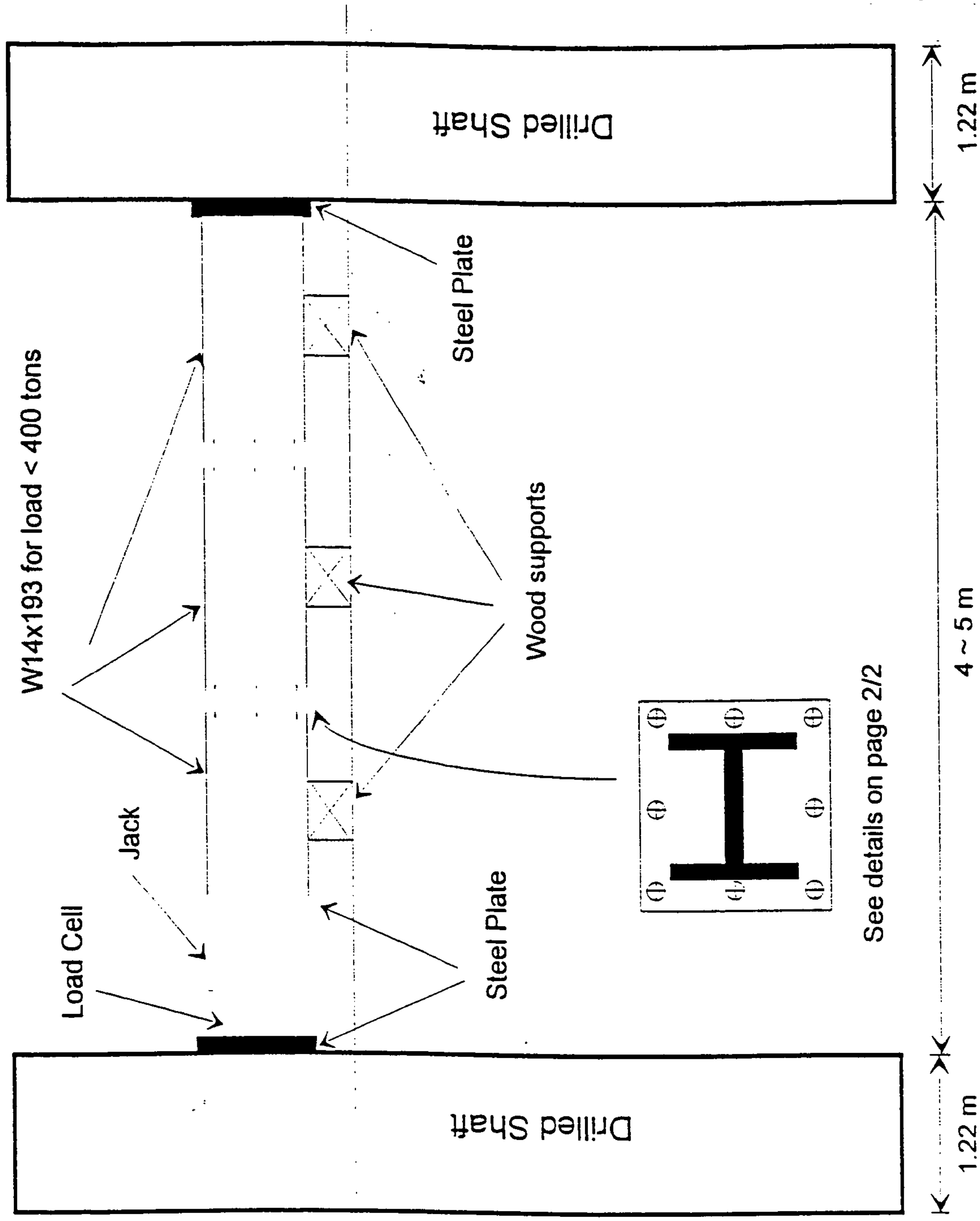
III.21 Details of the jacking end of the test frame



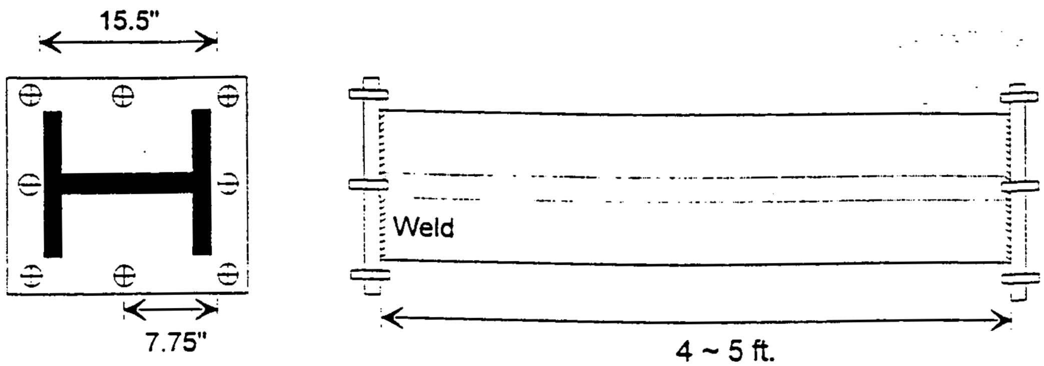
III.22 Details of the loading end of the test frame



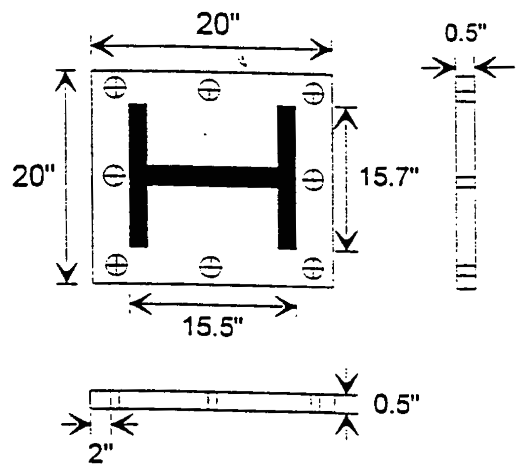
III.23 Test in progress



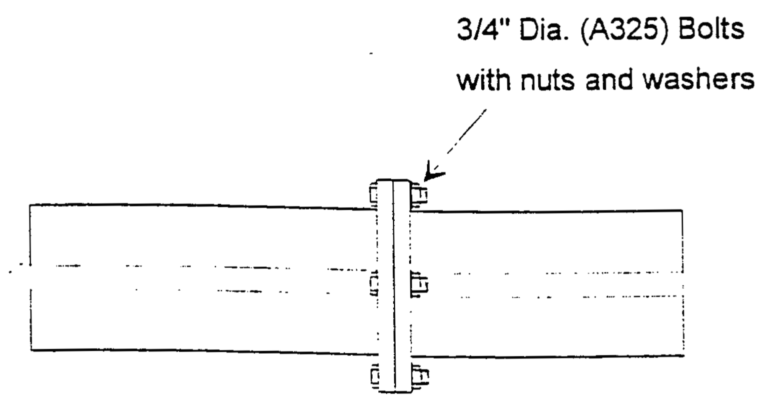
III.24 (a) Schematic details of the jacking system used in the load test



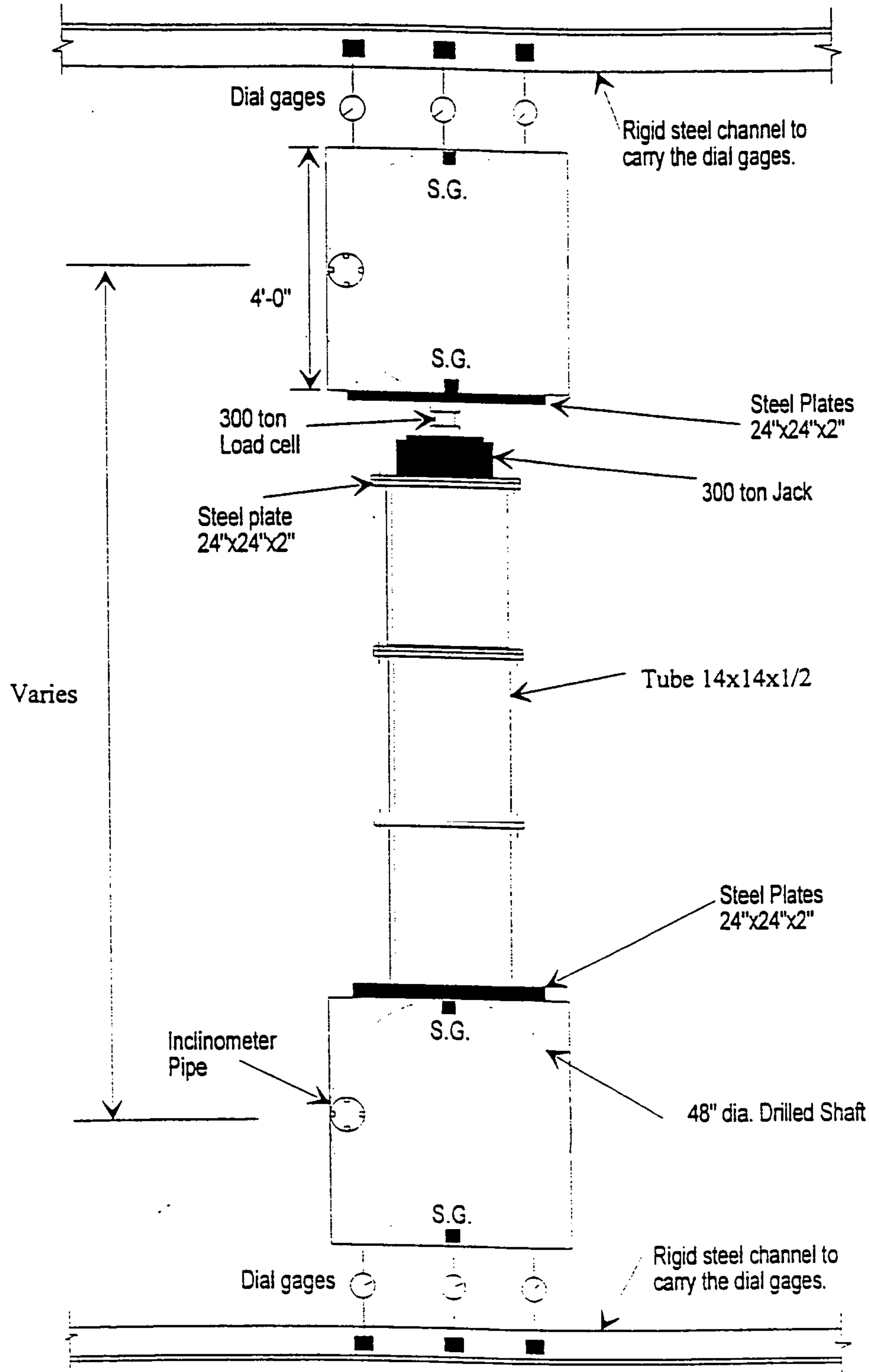
Detail of one piece of the reaction beam



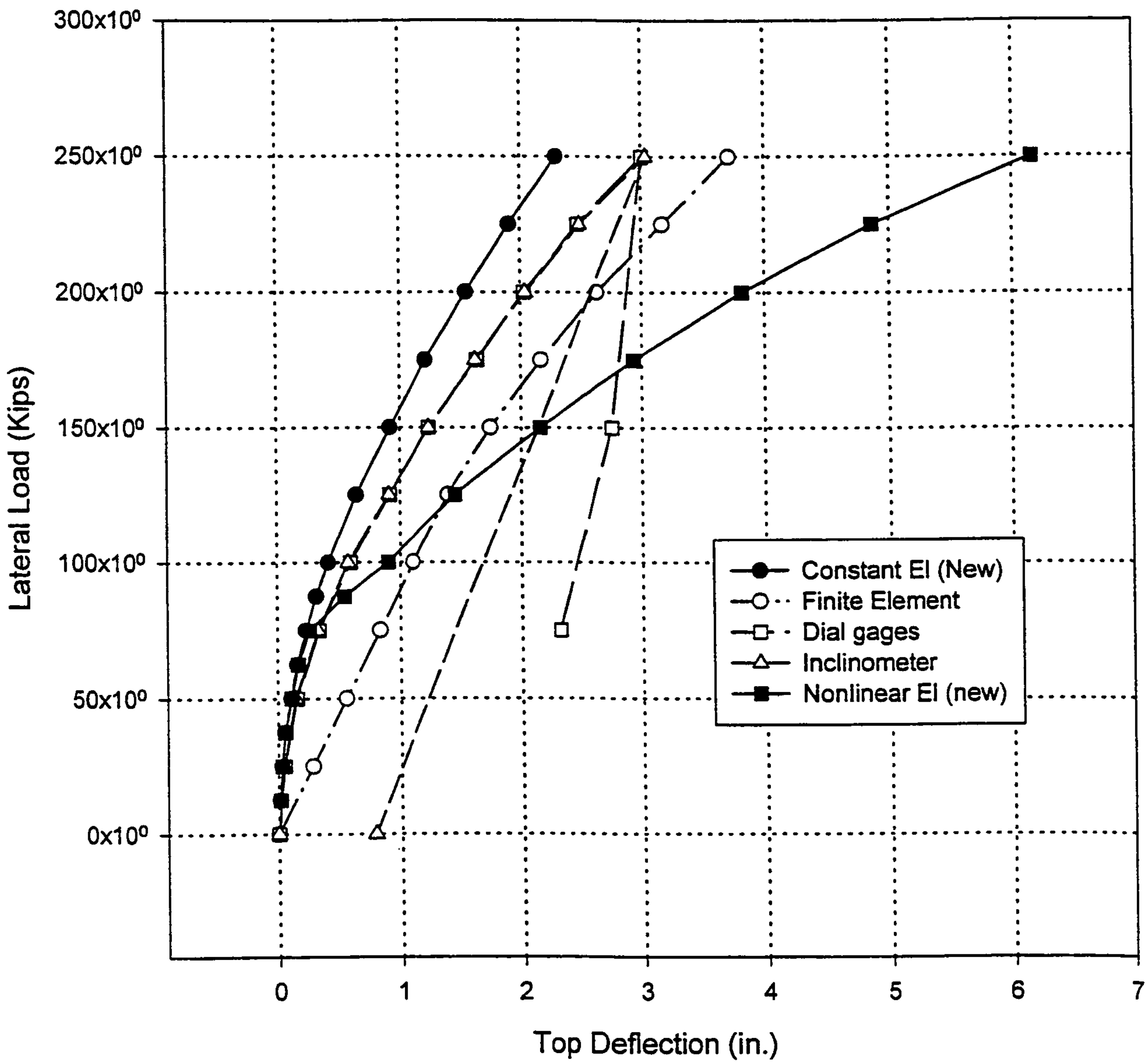
Details of the plate welded to W14x193



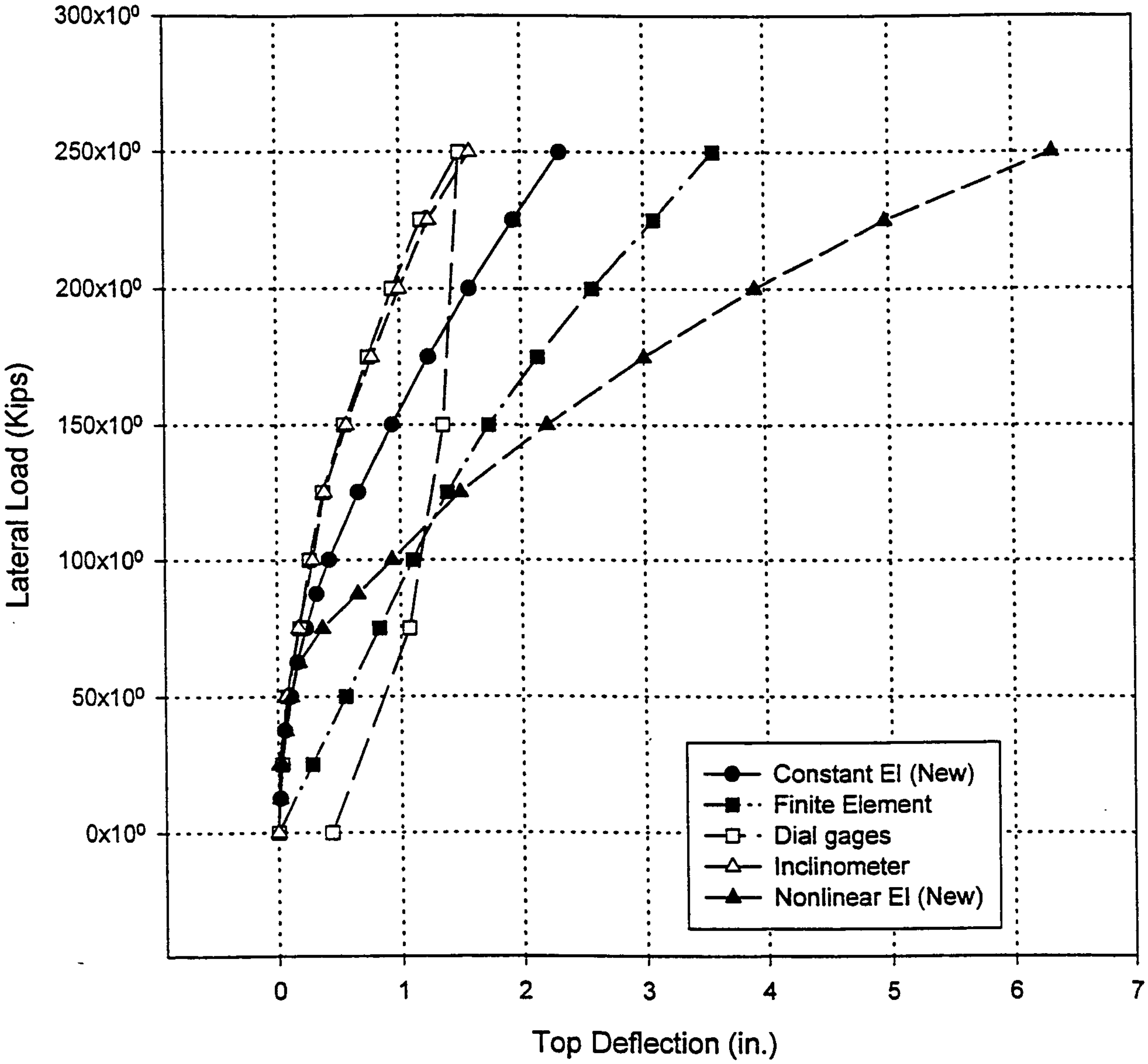
III.24 (b) Schematic details of the jacking system used in the load test (continued)



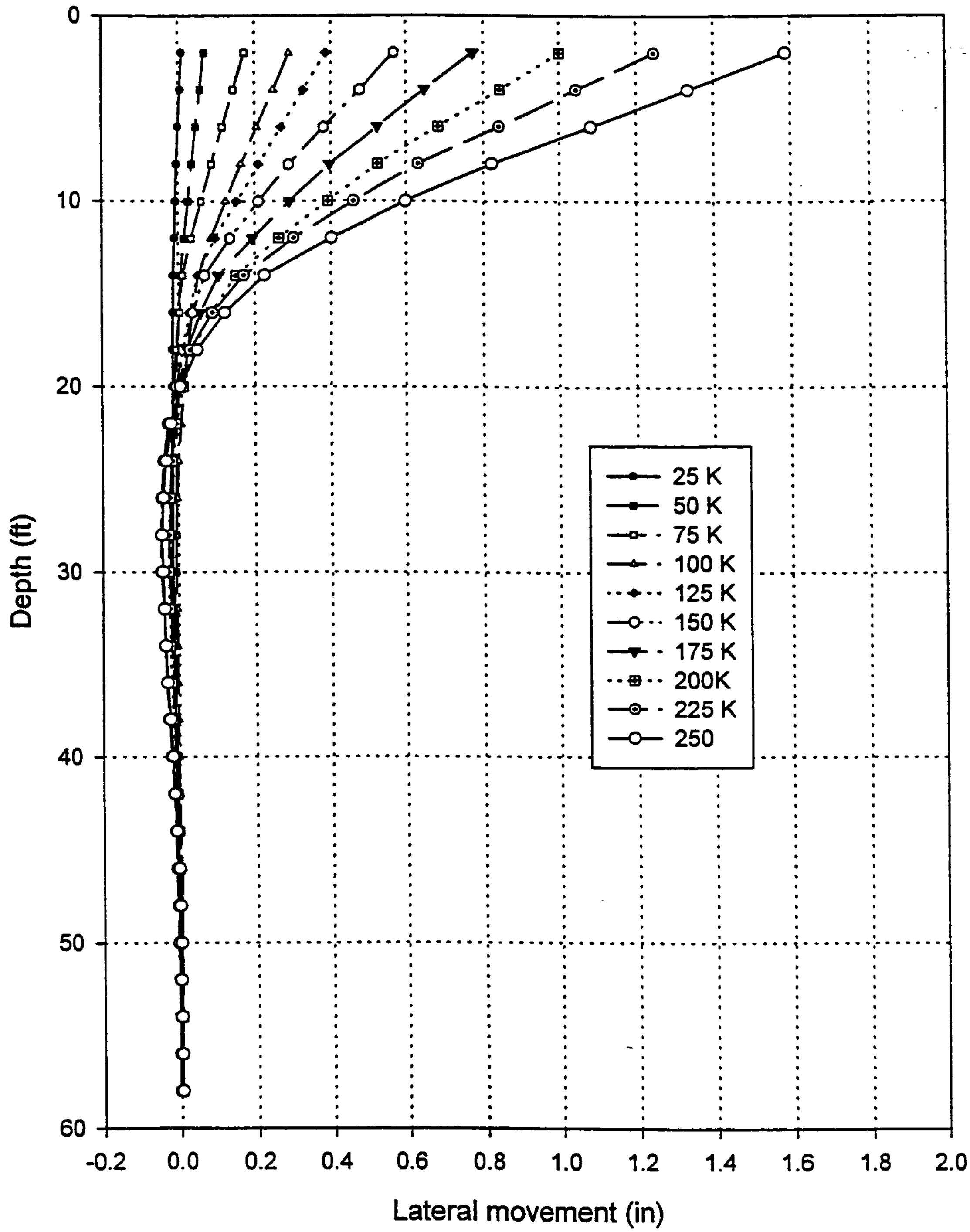
III.24 (c) Plan view of the lateral load test assembly



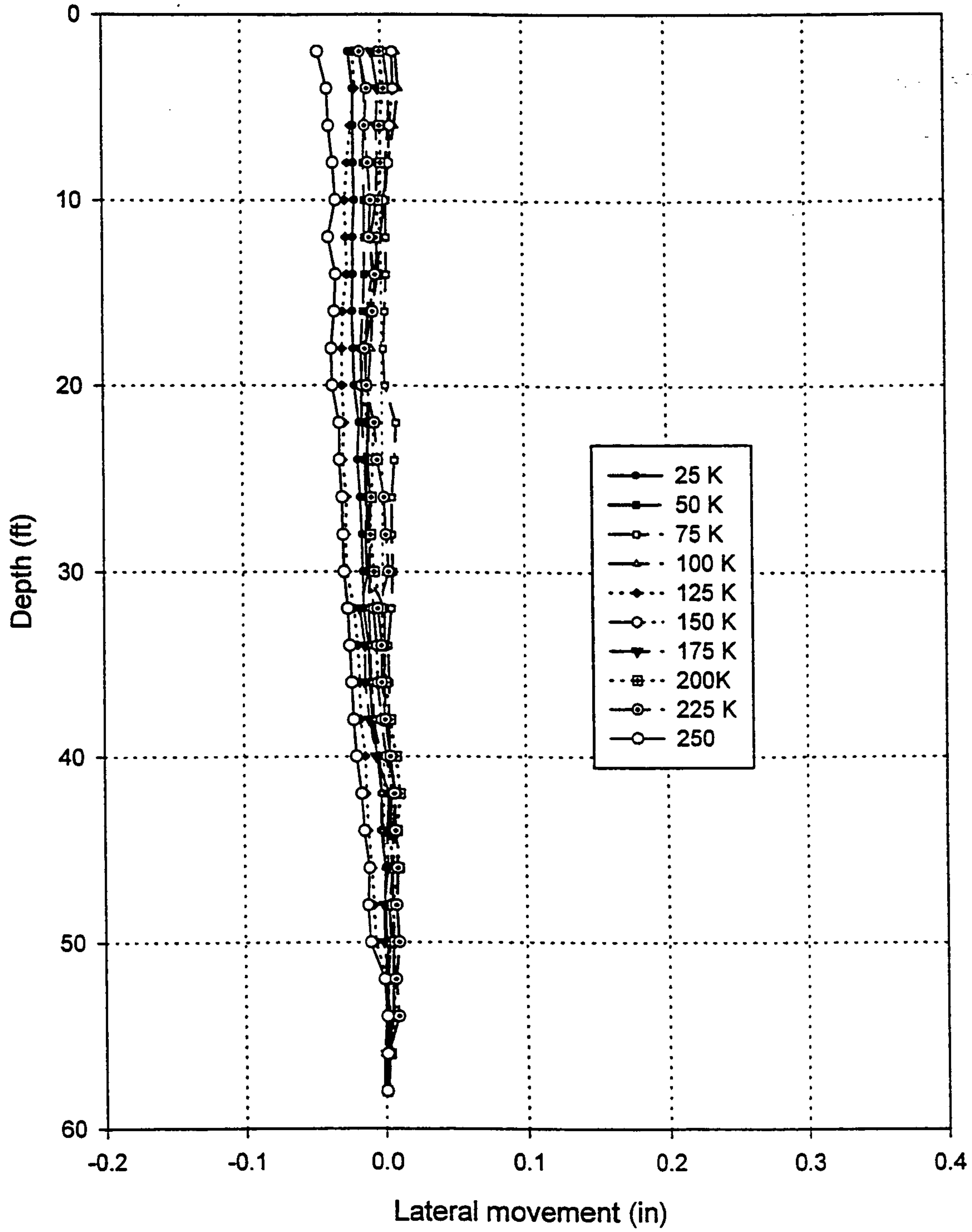
III.25 Deflection versus lateral load at jack level for 14-m deep shaft (Putnam street Bridge)



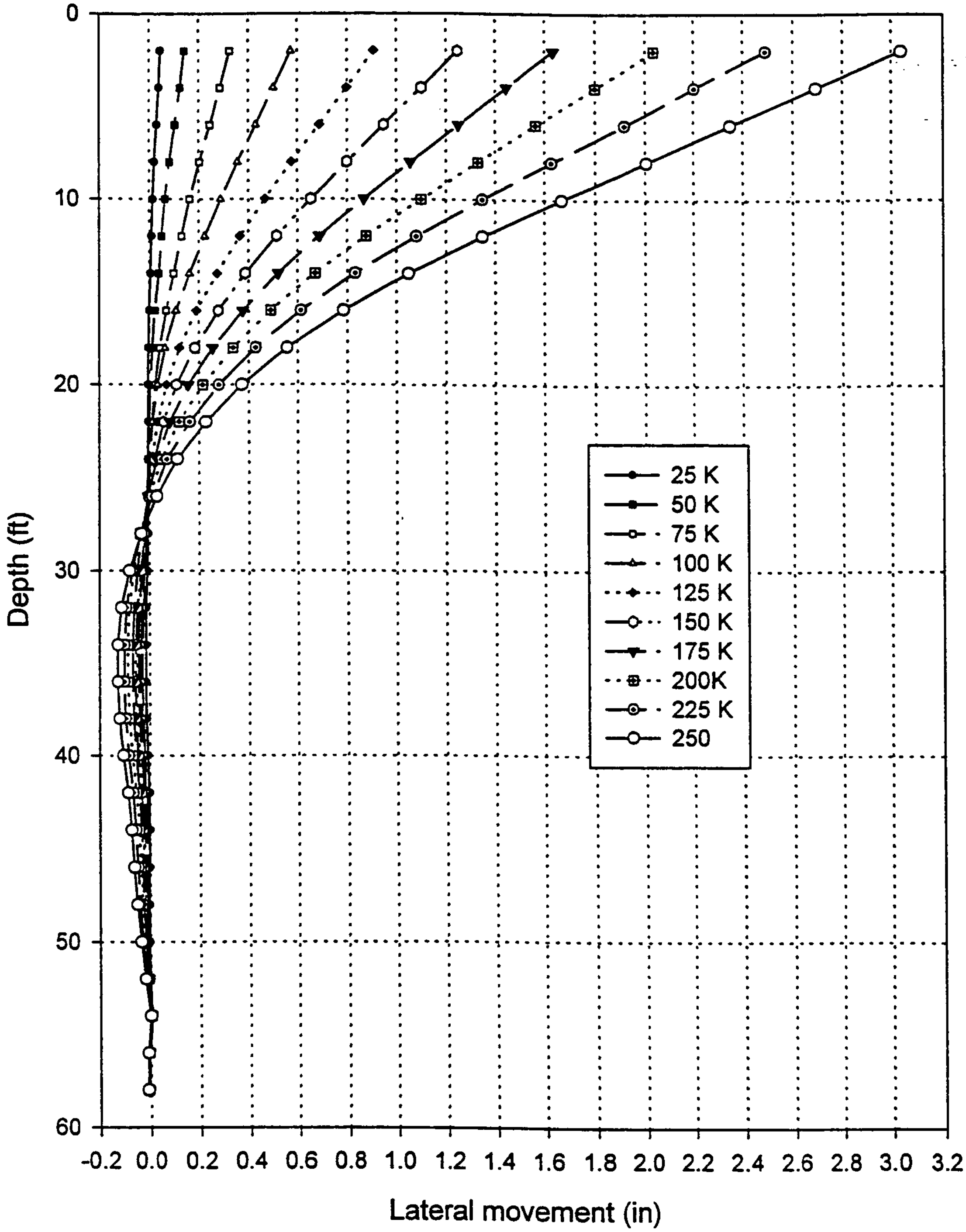
III.26 Deflection versus lateral load at jack level for 14-m deep shaft (Putnam Street Bridge)



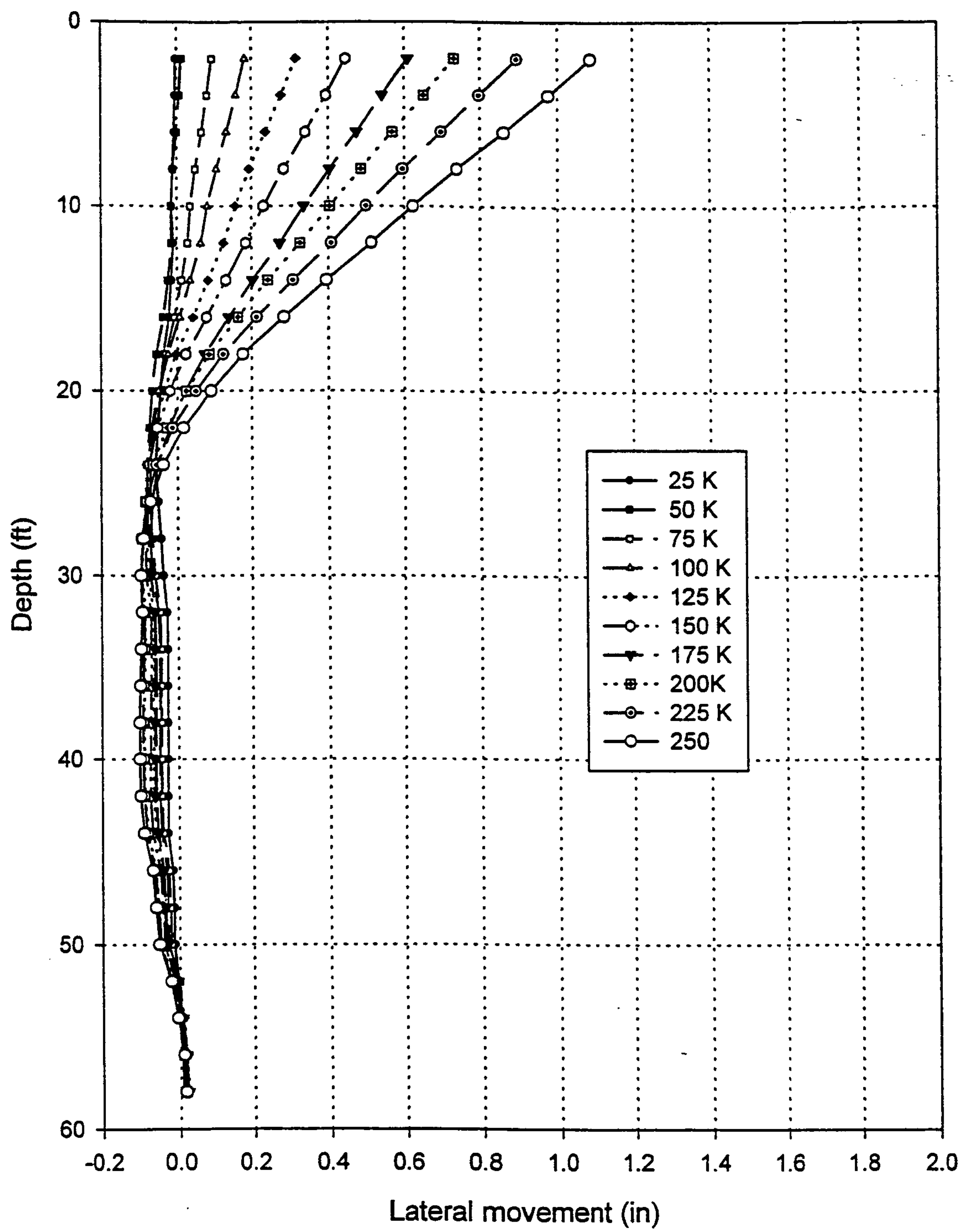
III.27 Observed deflection along the length of the 14-m deep shaft (Shaft #1 – A-direction)



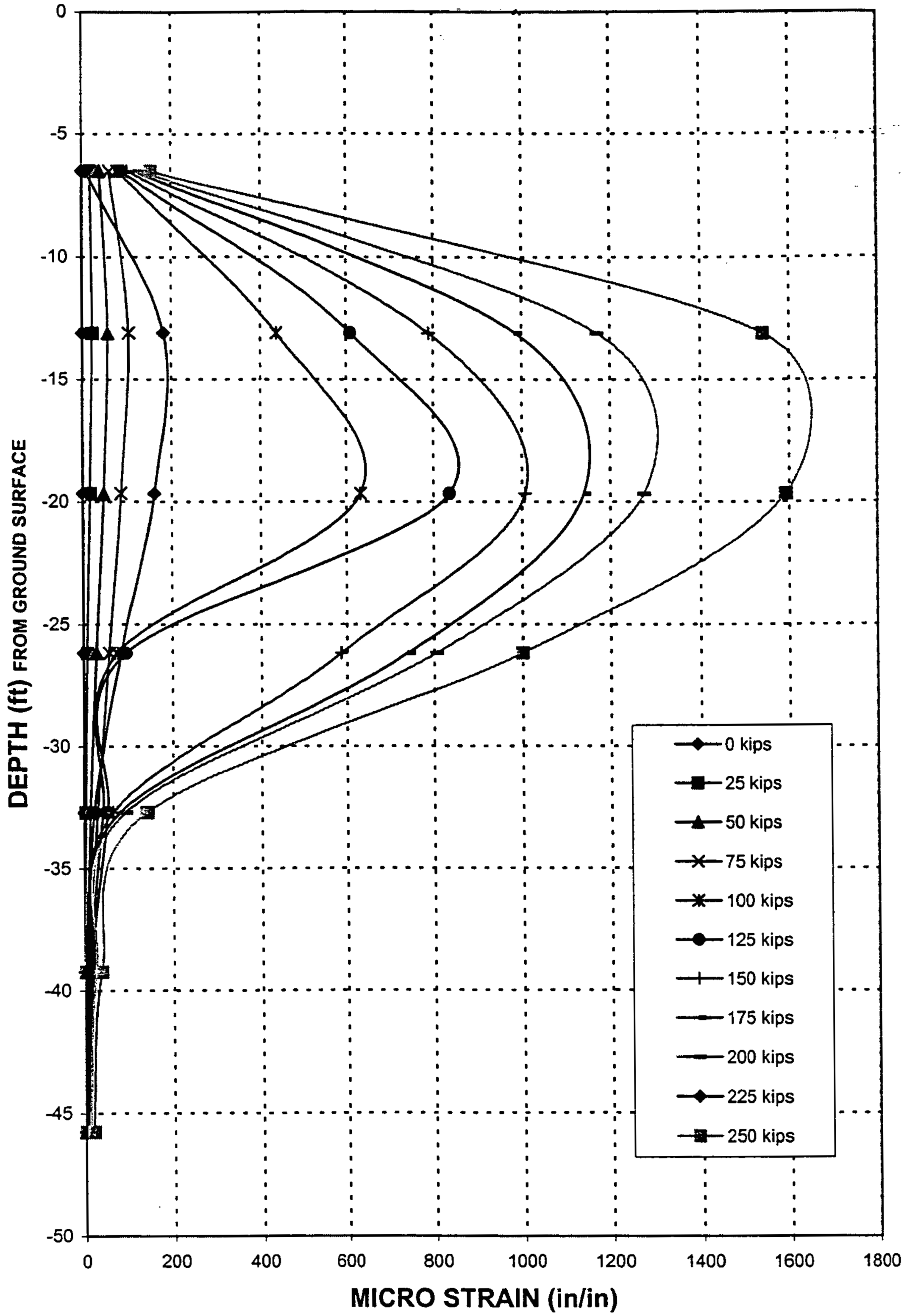
III.28 Observed deflection along the length of the 14-m deep shaft (Shaft #1 – B-direction)



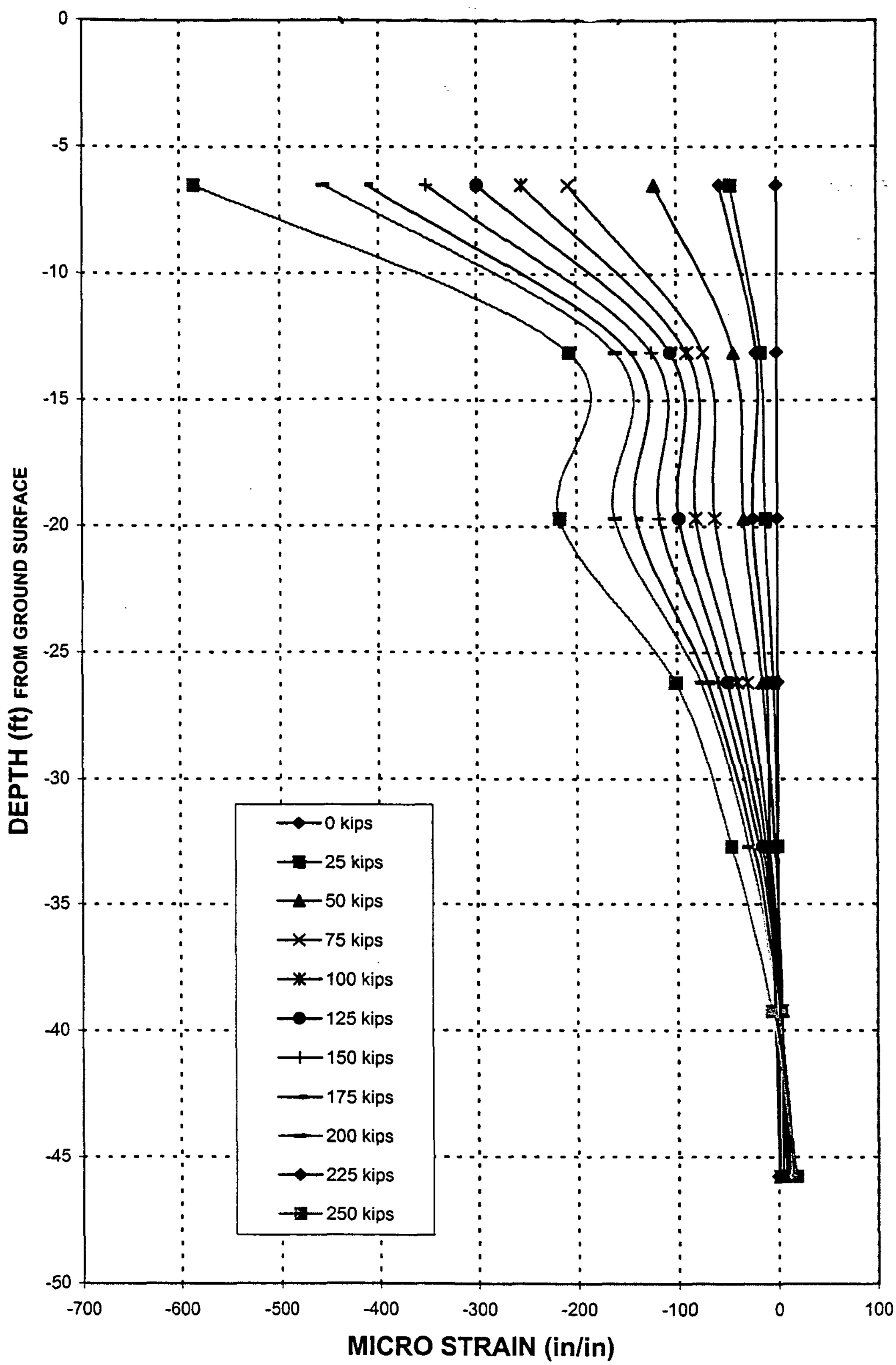
III.29 Observed deflection along the length of the 14-m deep shaft (Shaft #2 – A-direction)



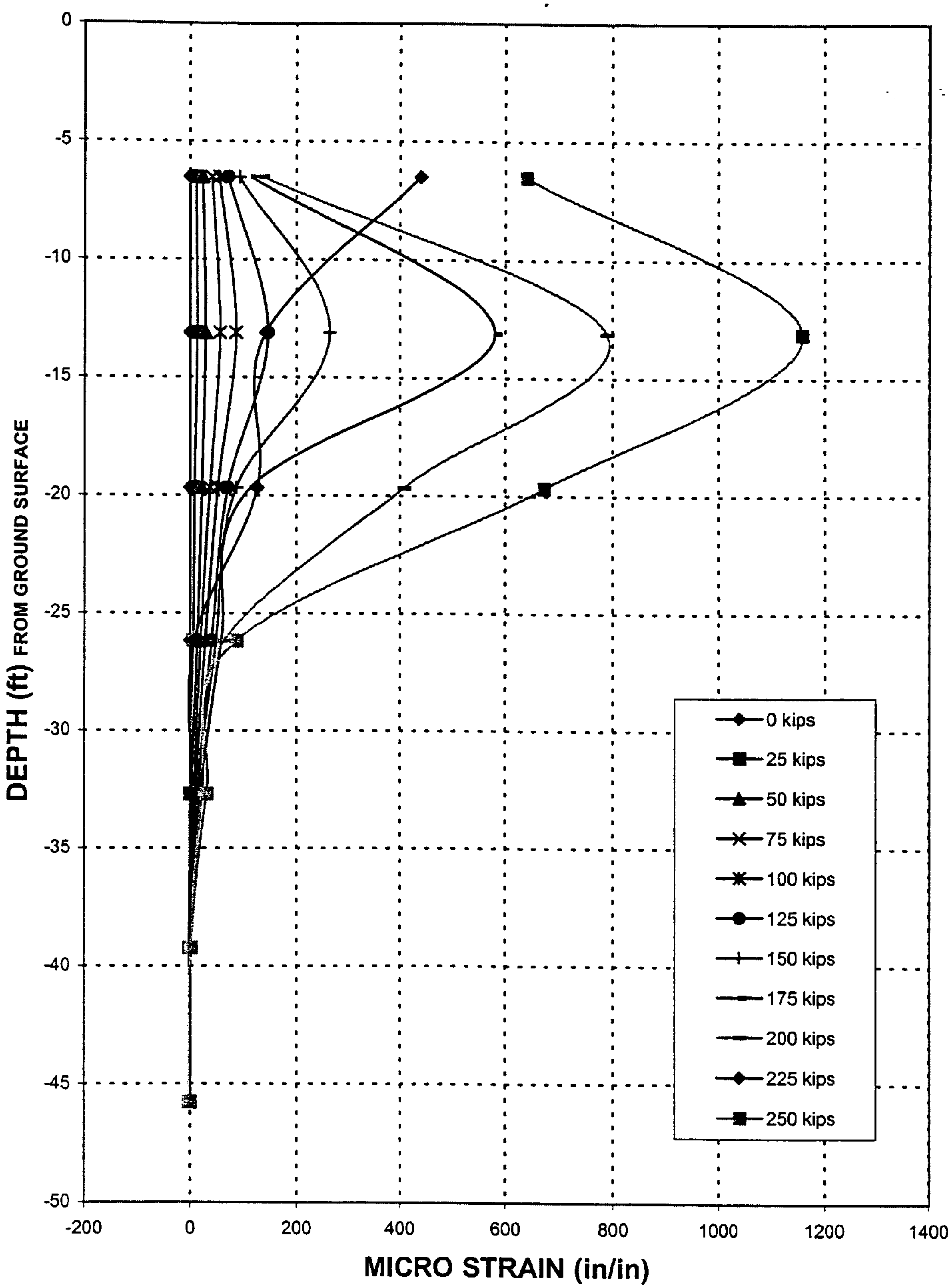
III.30 Observed deflection along the length of the 14-m deep shaft (Shaft #2 – B-direction)



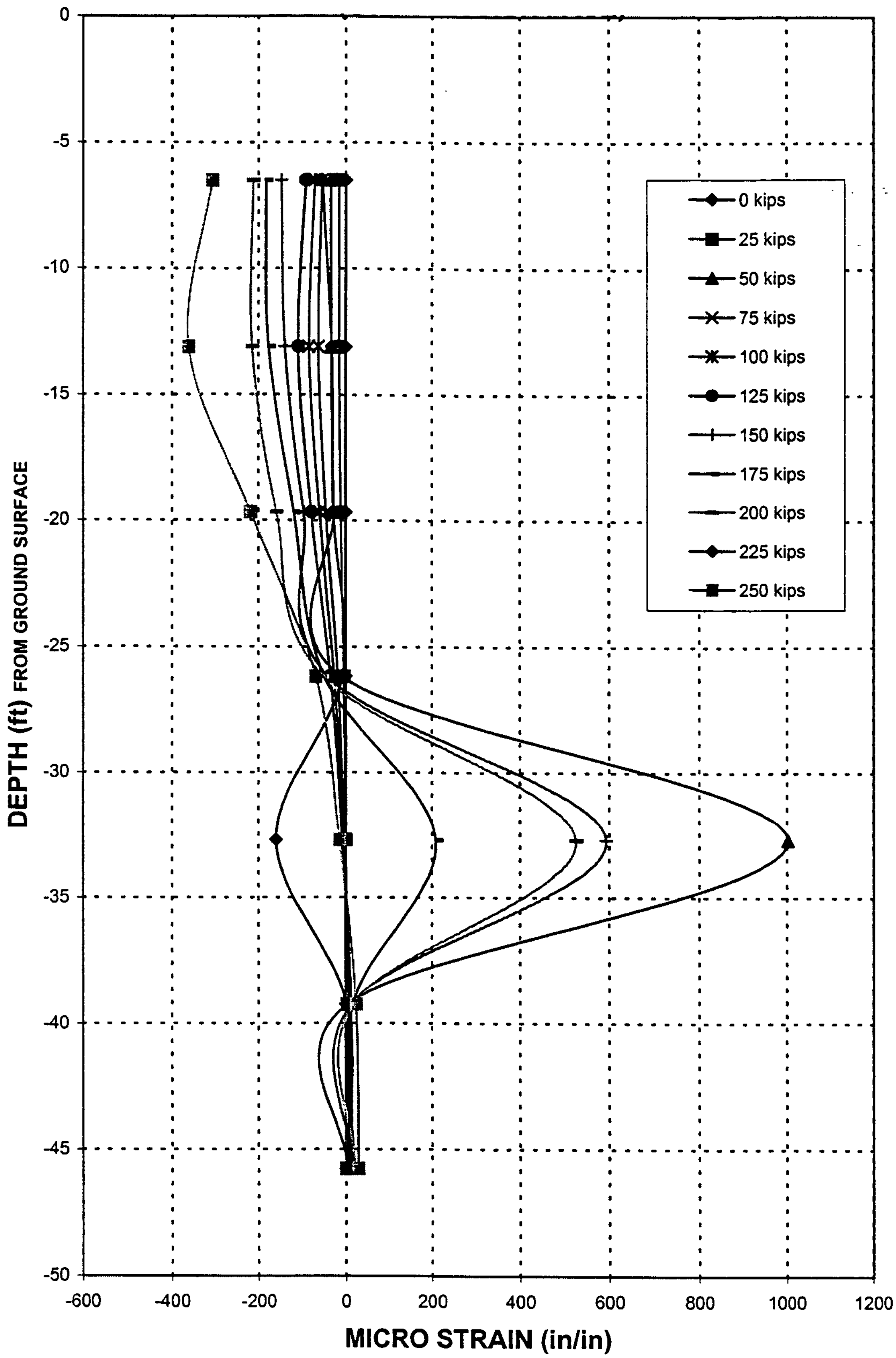
III.31 Observed strain along the length of the 14-m deep shaft #1 (Tension Face)



III.32 Observed strain along the length of the 14-m deep shaft #1 (Compression Face)

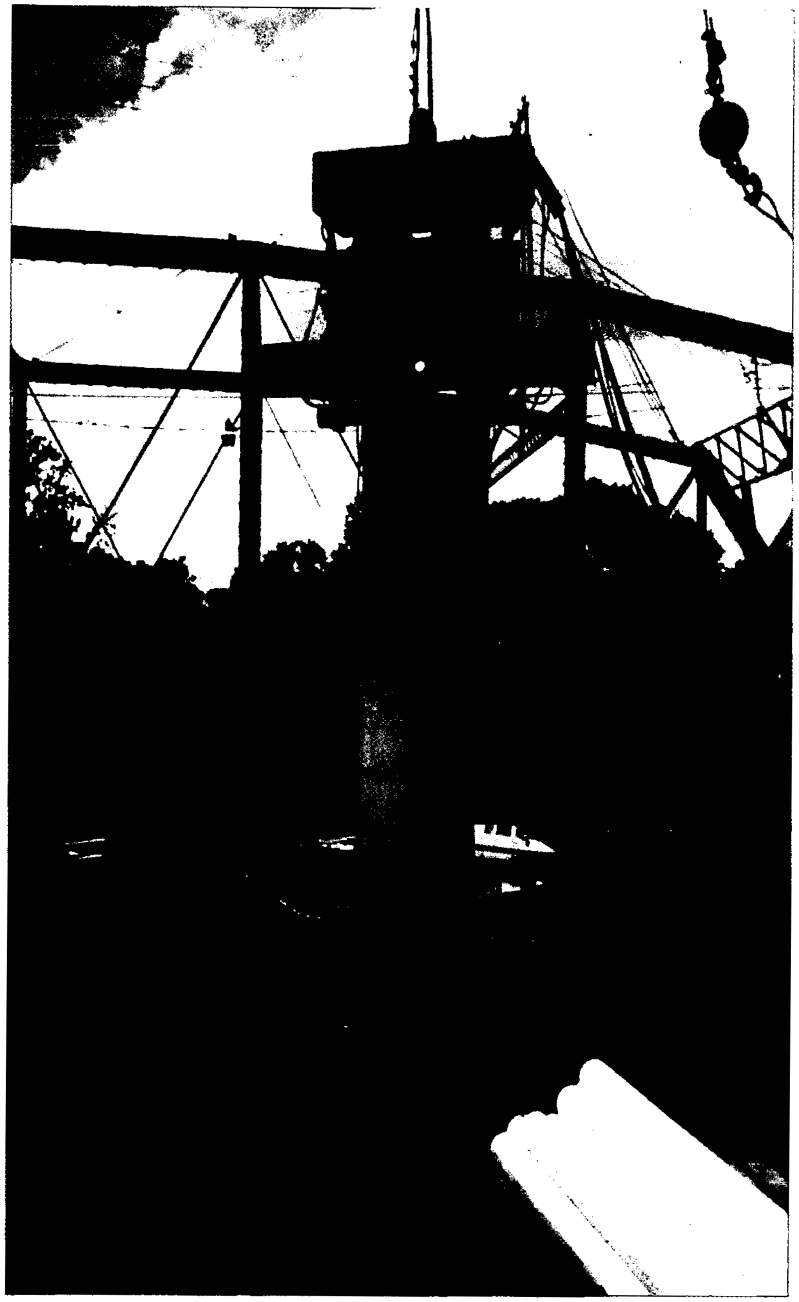


III.33 Observed strain along the length of the 14-m deep shaft #2 (Tension Face)

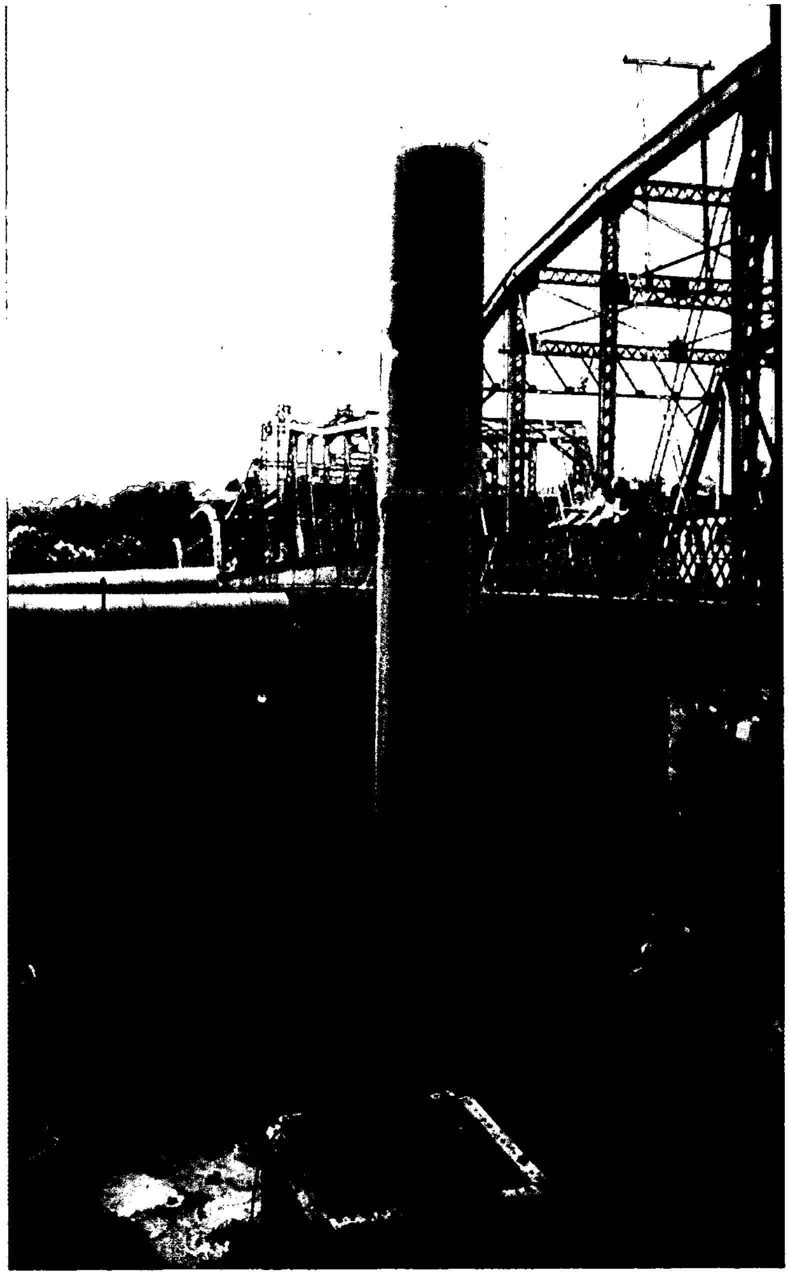


III.34 Observed strain along the length of the 14-m deep shaft #2 (Compression Face)

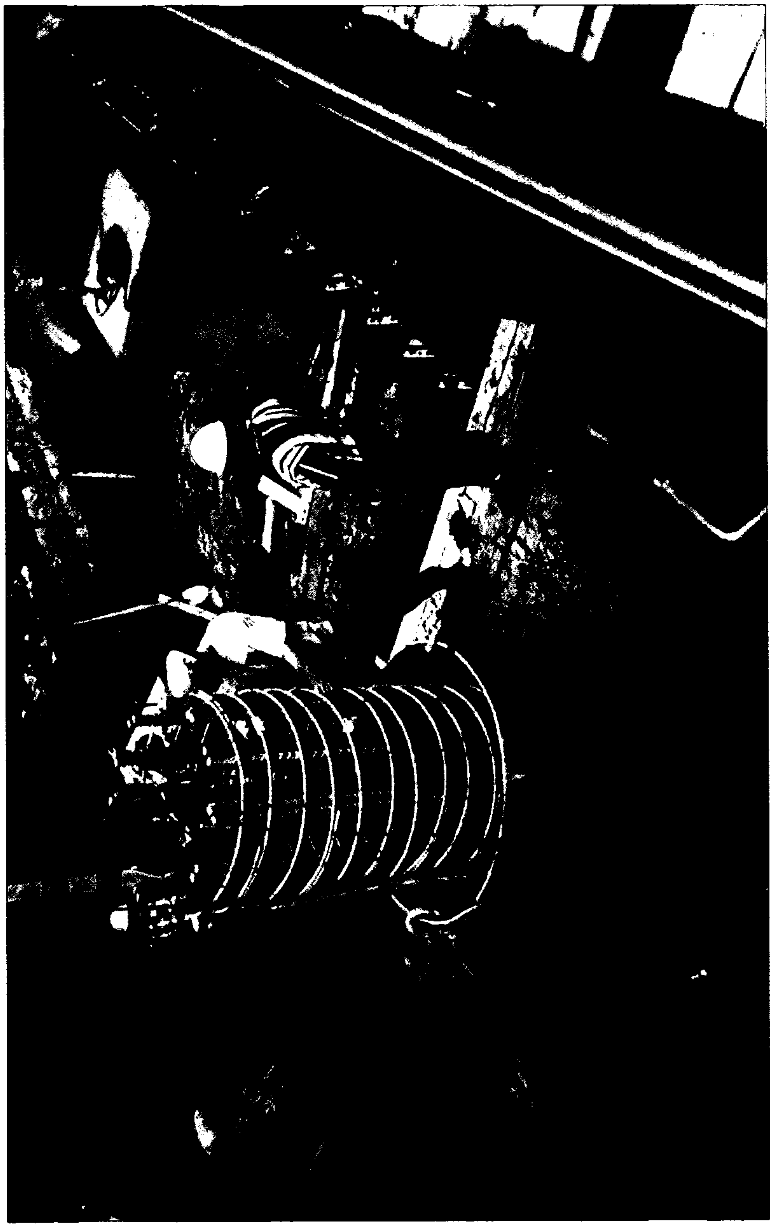
III.35 Observed ground movement around the 14-m deep shaft



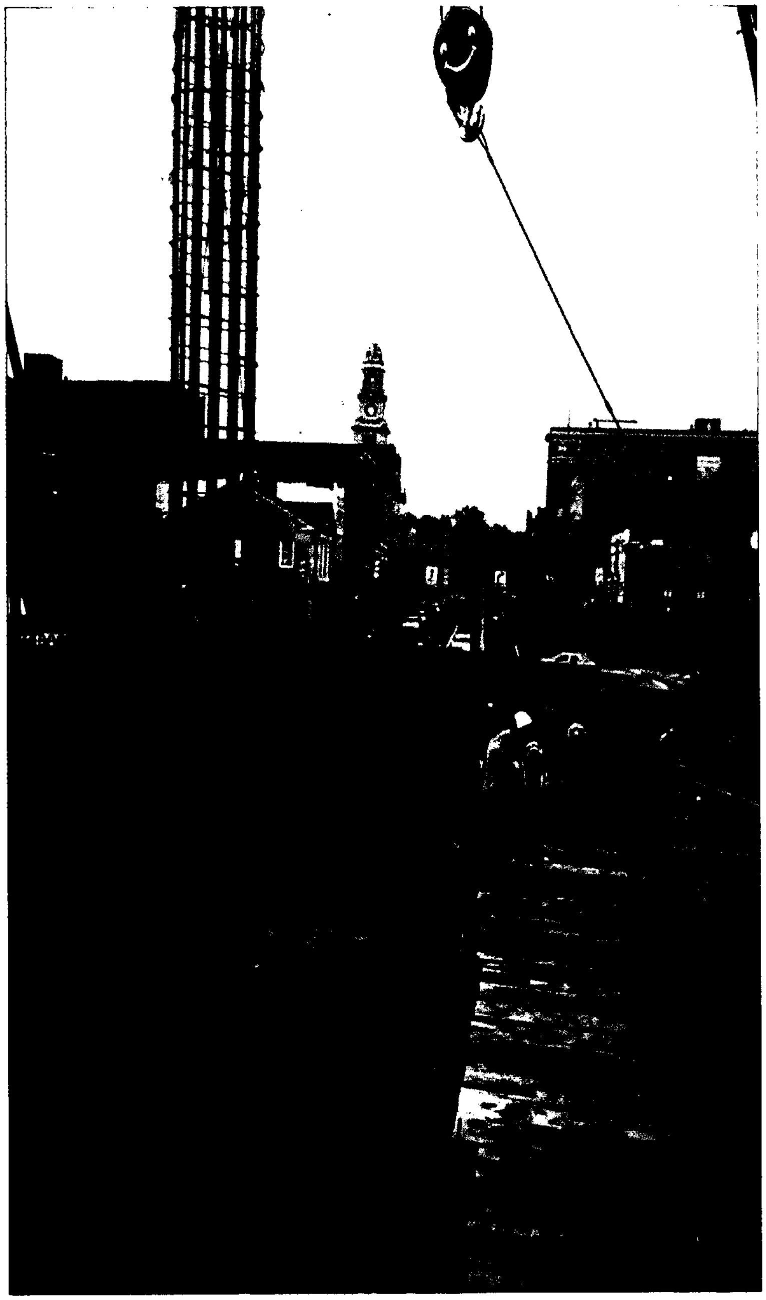
III.36 Drilling of the 9-m deep shaft in progress



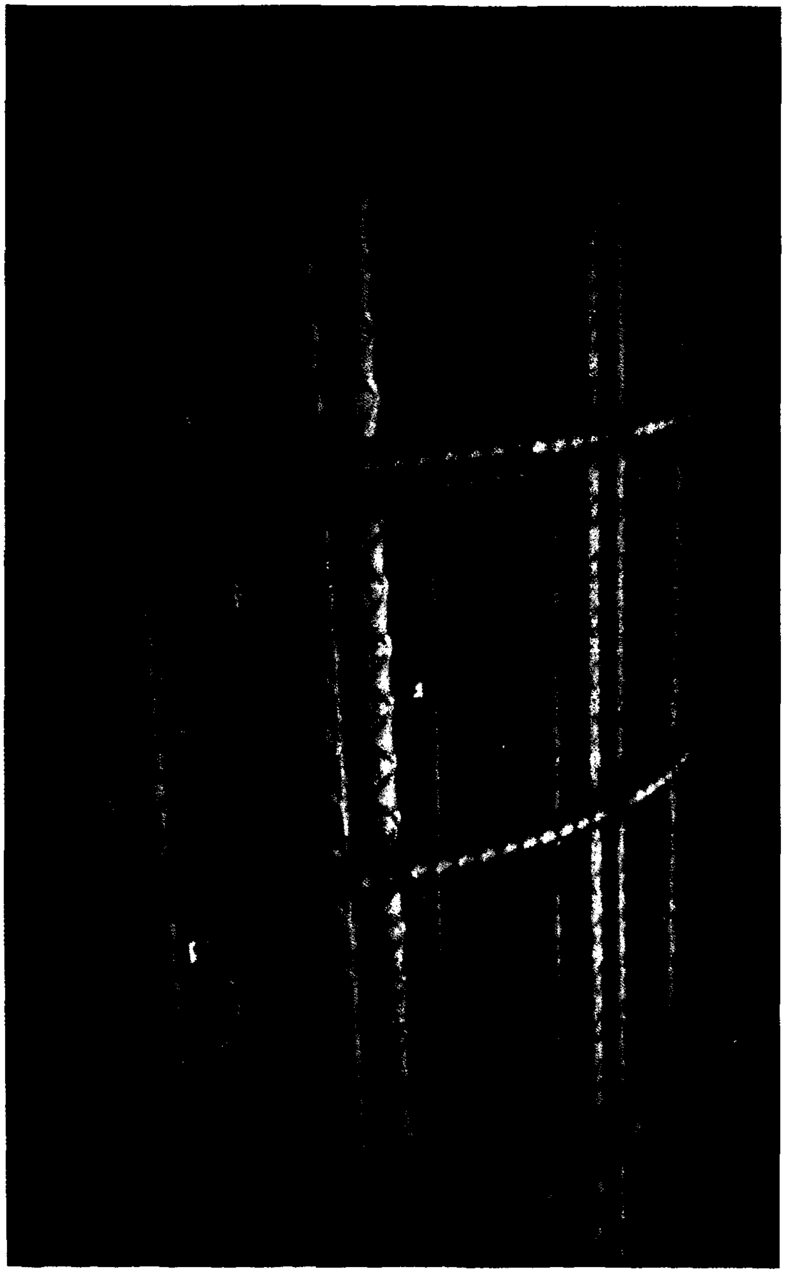
III.37 Drilling of the 9-m deep shaft in progress



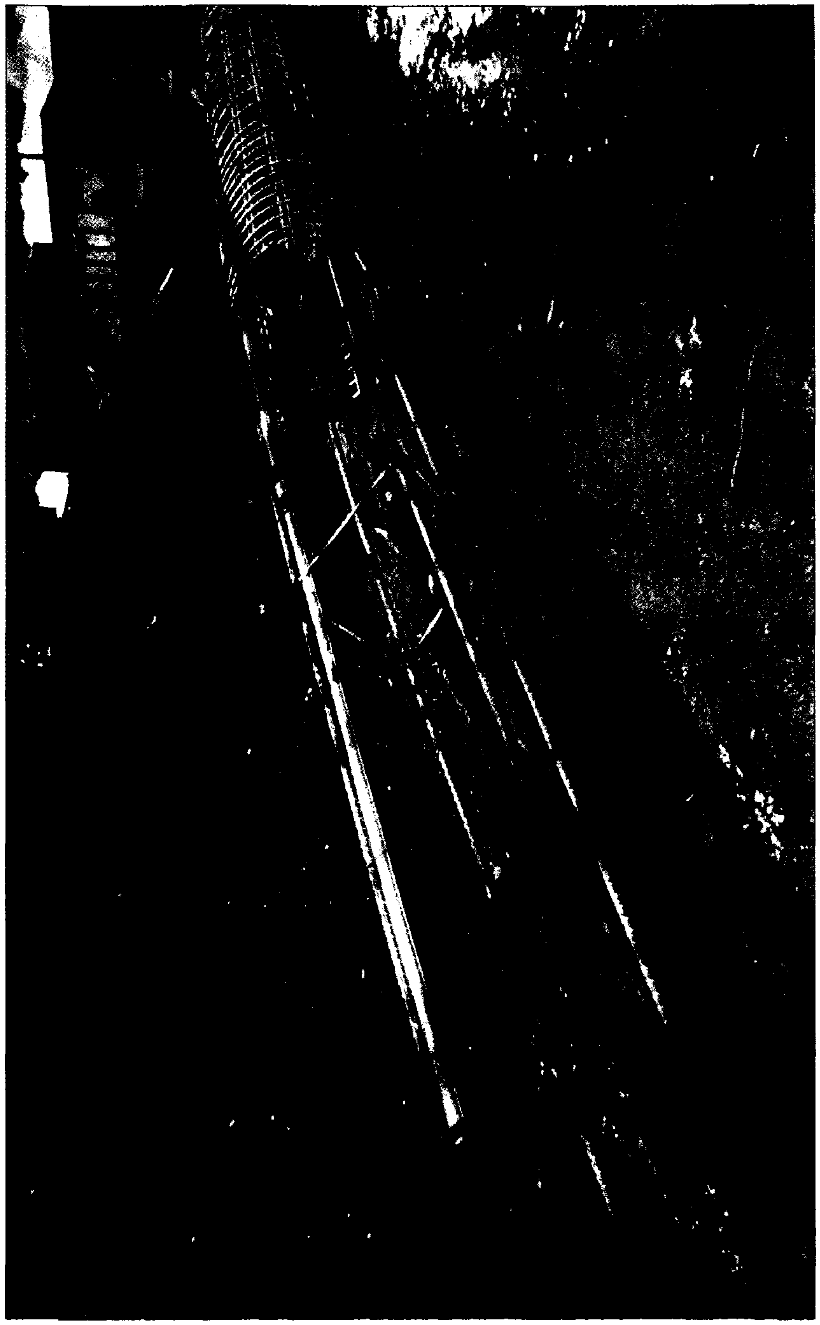
III.38 Lowering of the cage for the 9-m deep shaft in progress



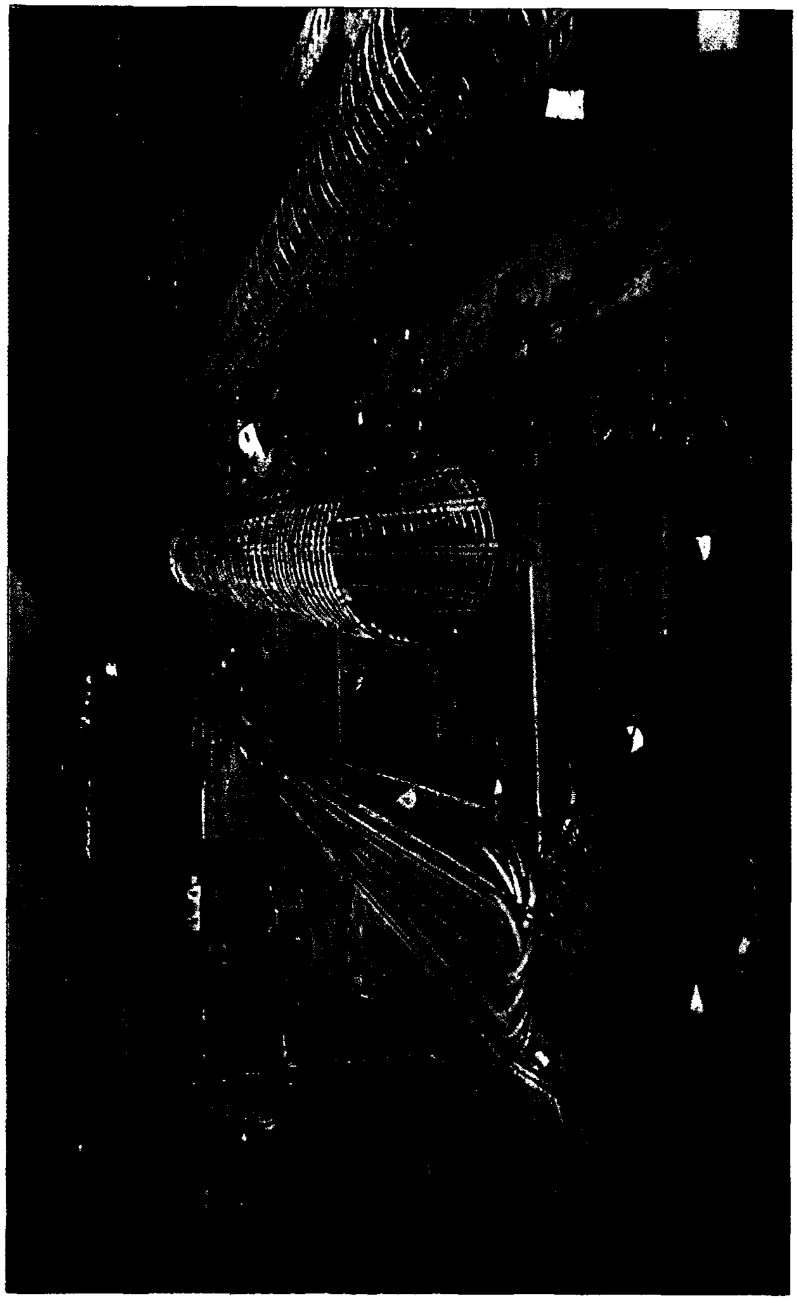
III.39 Lowering of the cage for the 9-m deep shaft in progress



III.40 Instrumentation details for the 9-m deep shafts

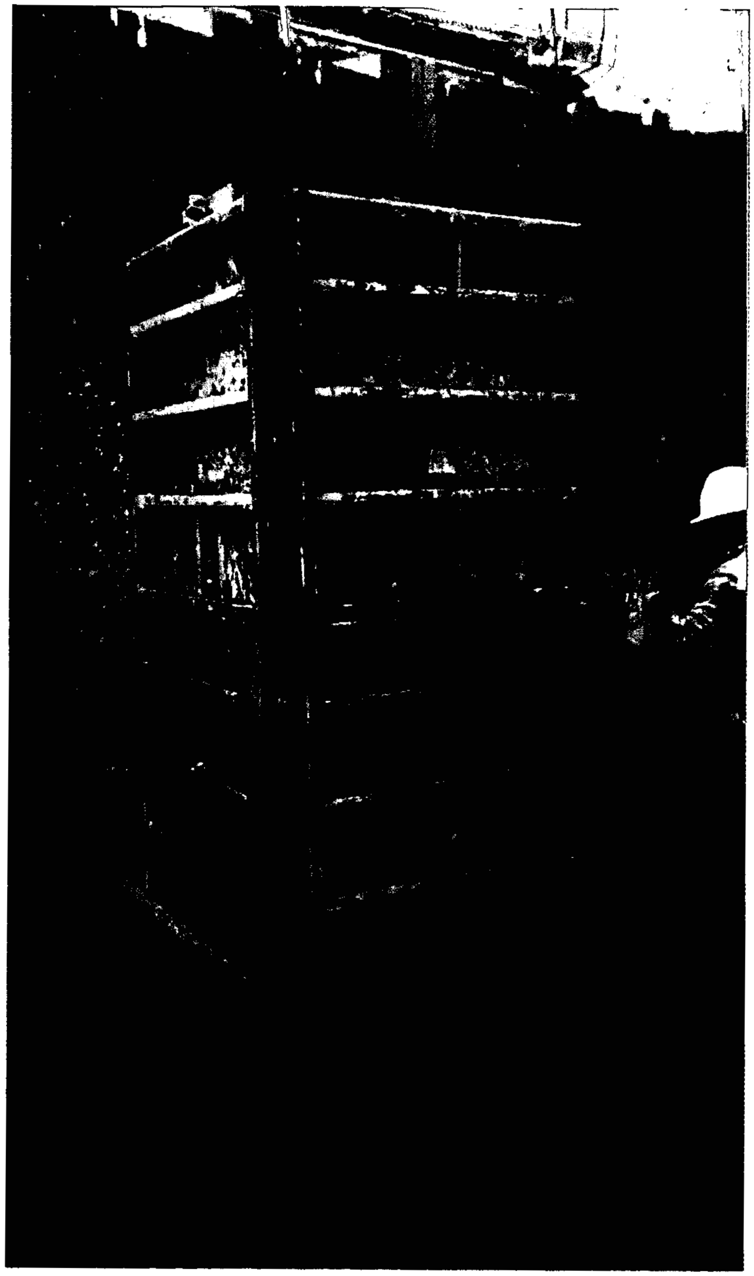


III.41 Instrumentation details for the 9-m deep shafts

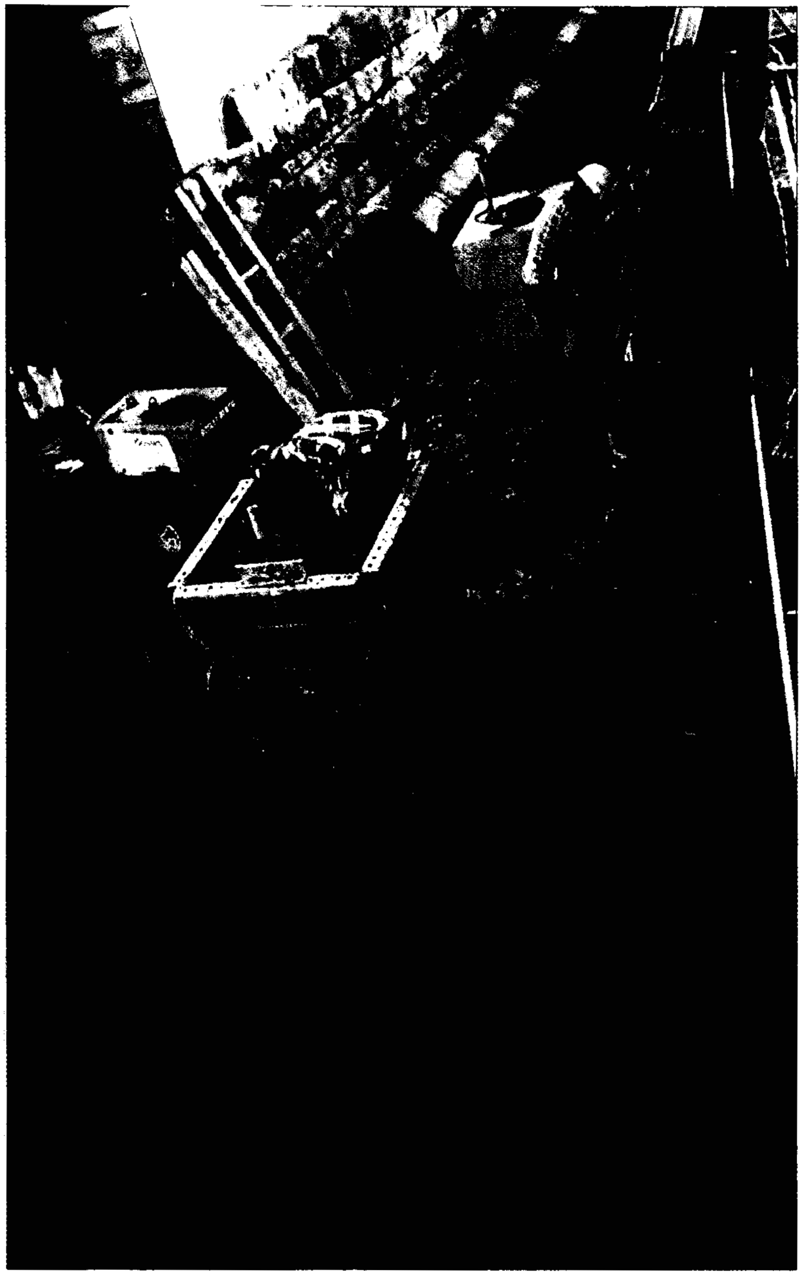


III.42 Instrumentation details for the 9-m deep shafts

III.43 Concreting of the 9-m deep shaft in progress



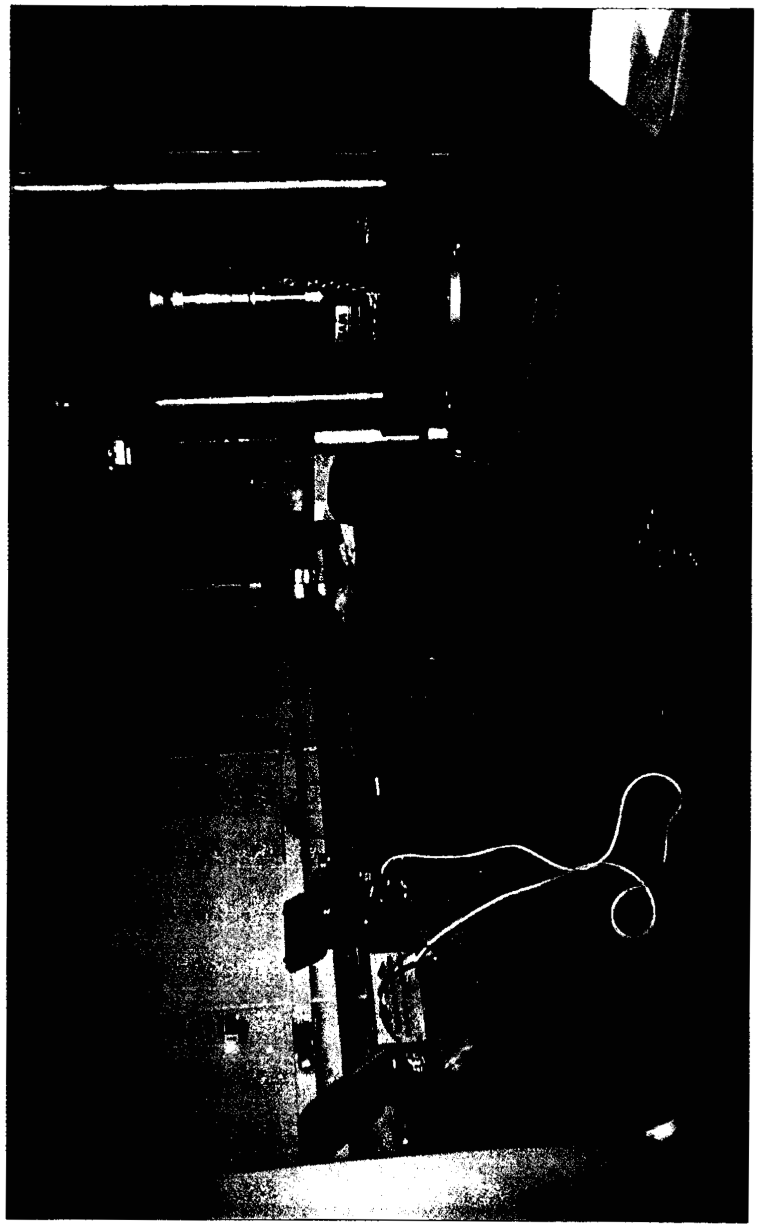
III.44 Placing of forms for the top 2-m portion of the shaft



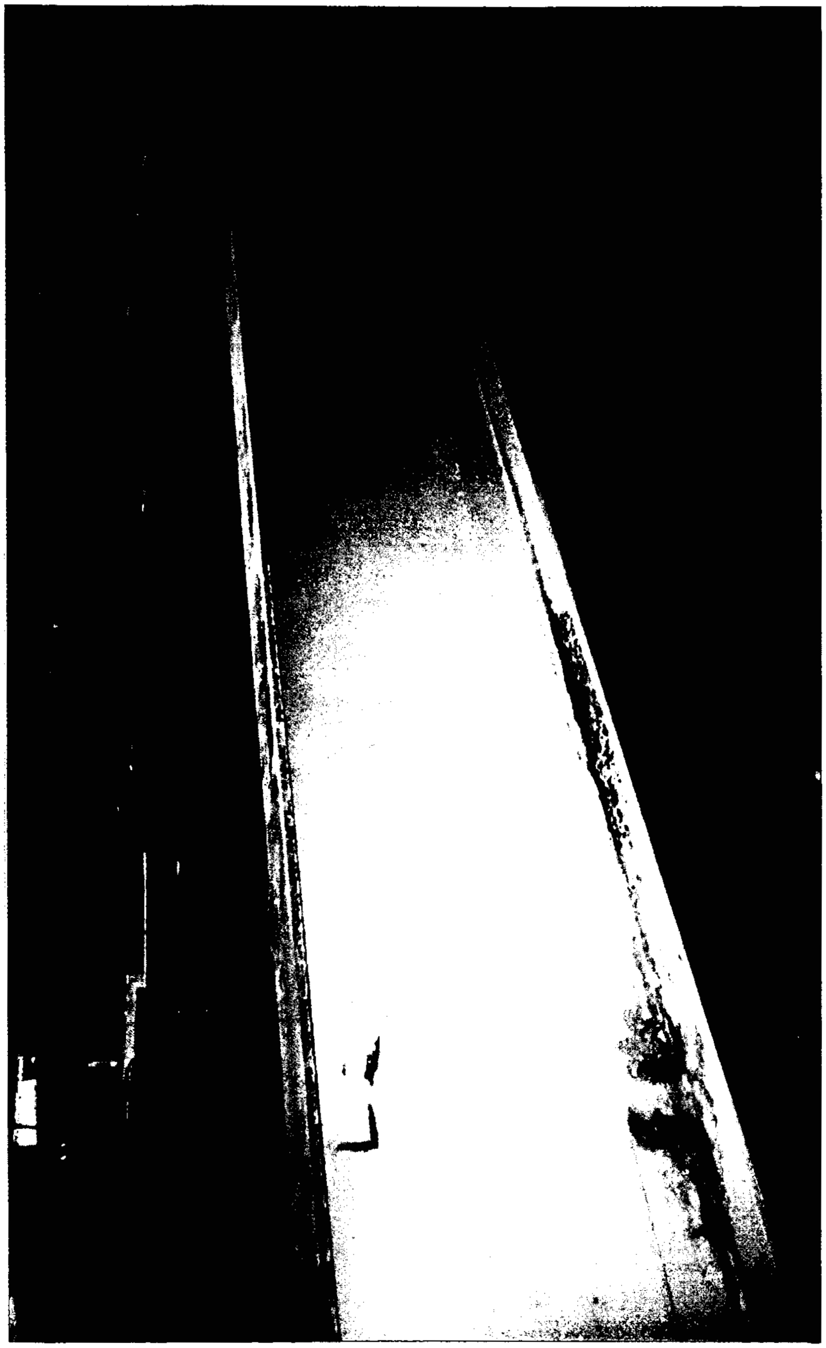
III.45 Finishing of the top 2-m portion of the drilled shaft

III.46 Finished shafts

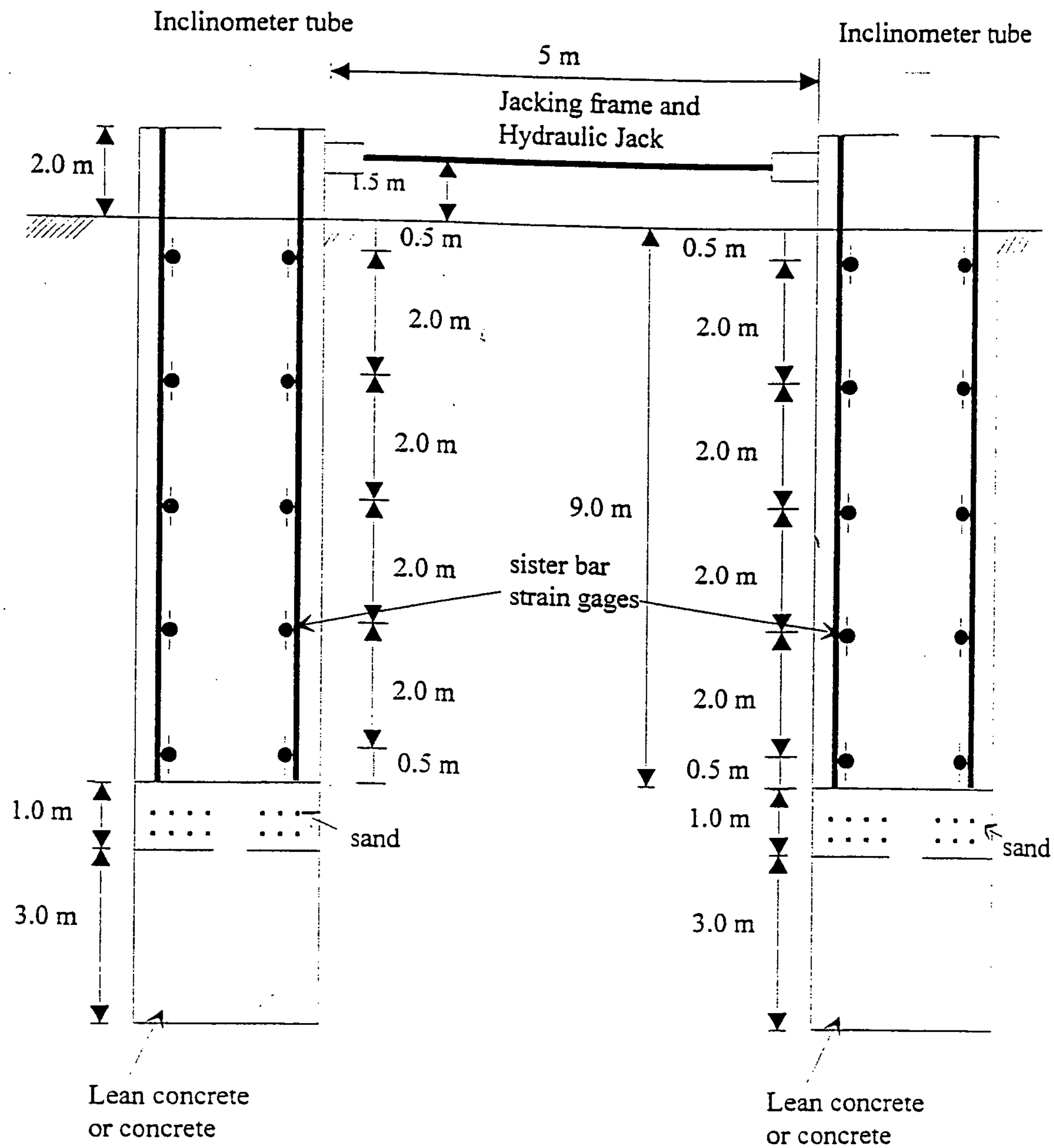
III.47 Details of the test set-up



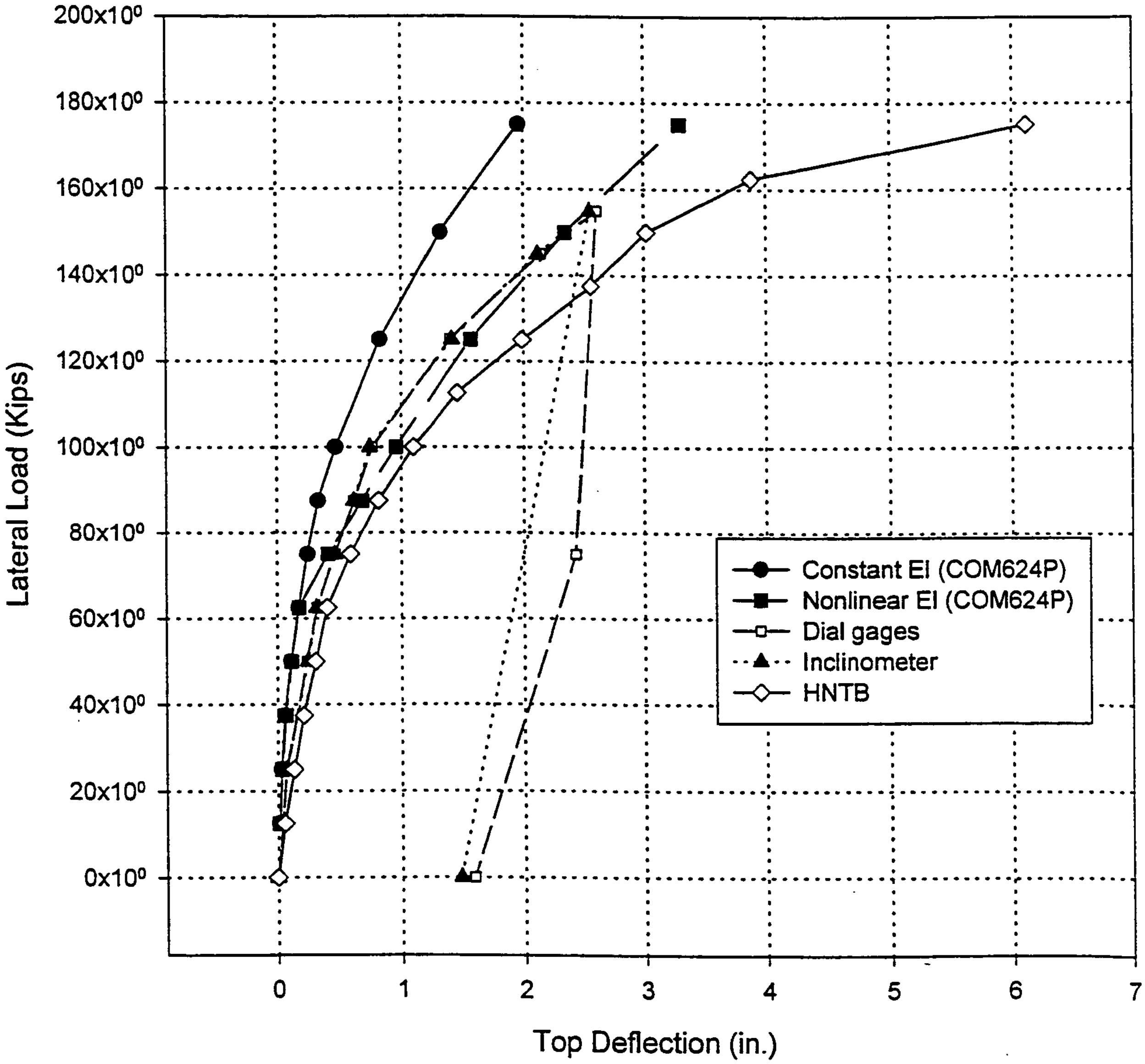
III.48 Calibration of the load cell in progress



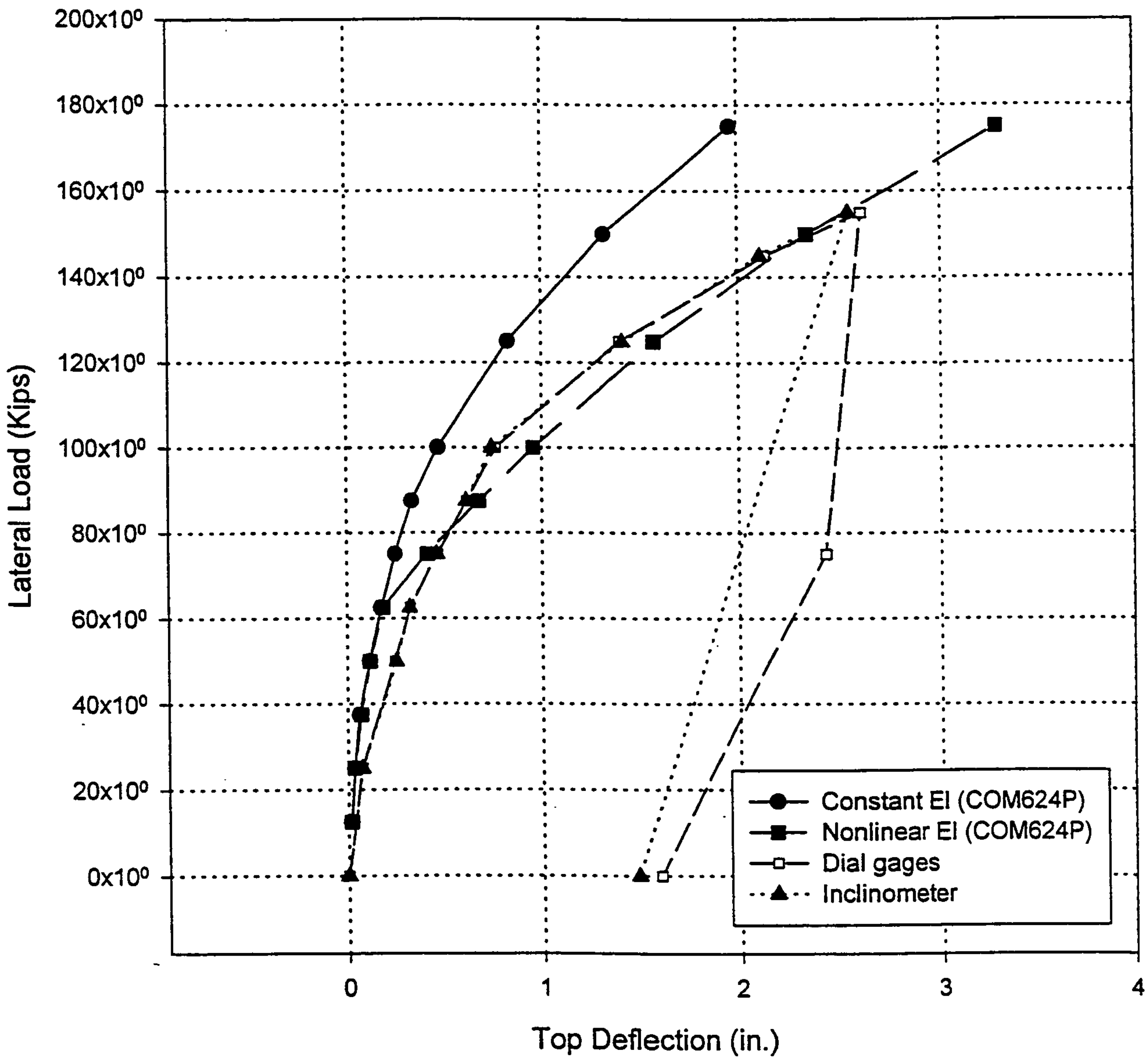
III.49 Location of the dial gages for monitoring deflection



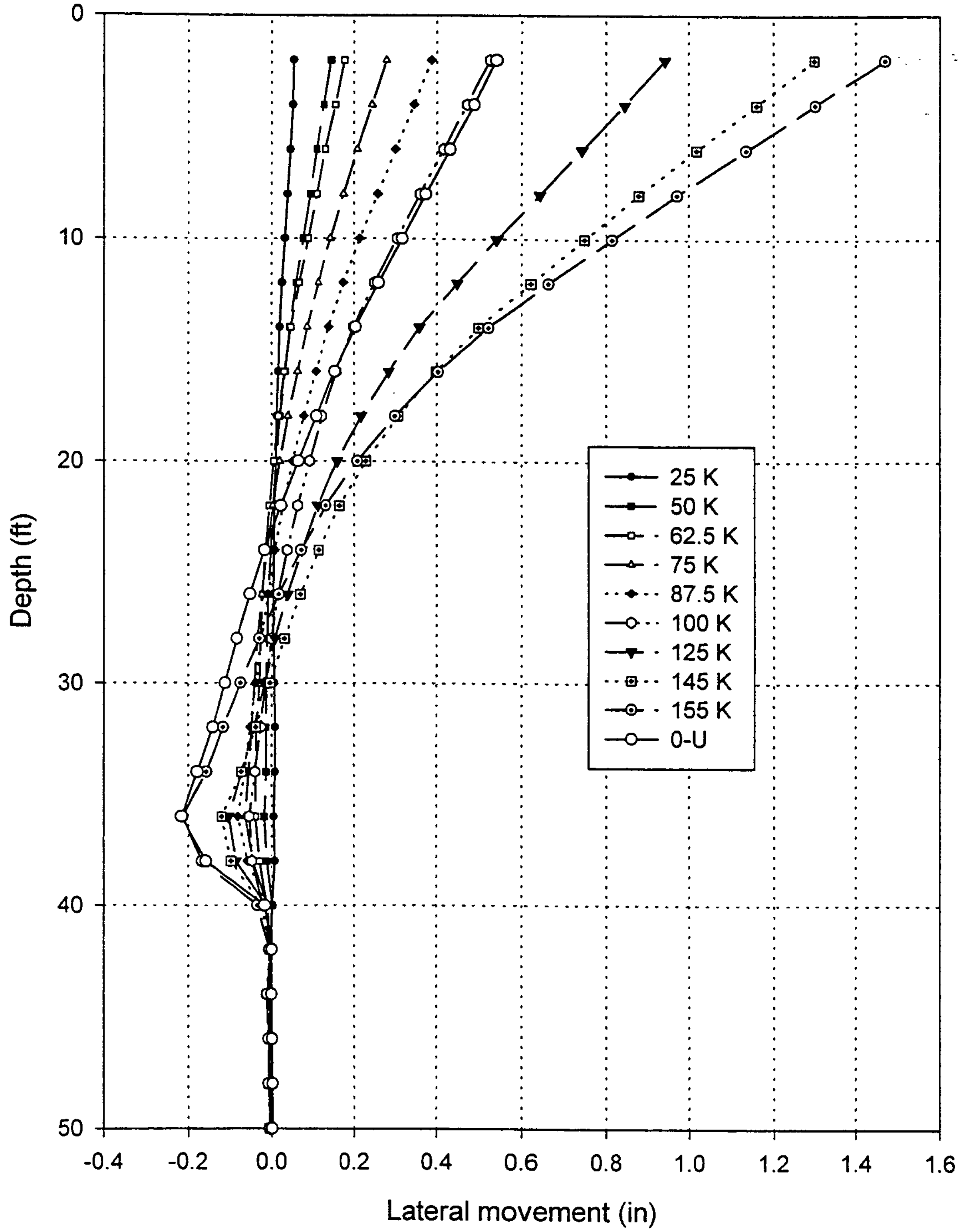
III.50 Instrumentation details for the 9-m deep drilled shafts (Putnam Street Bridge)



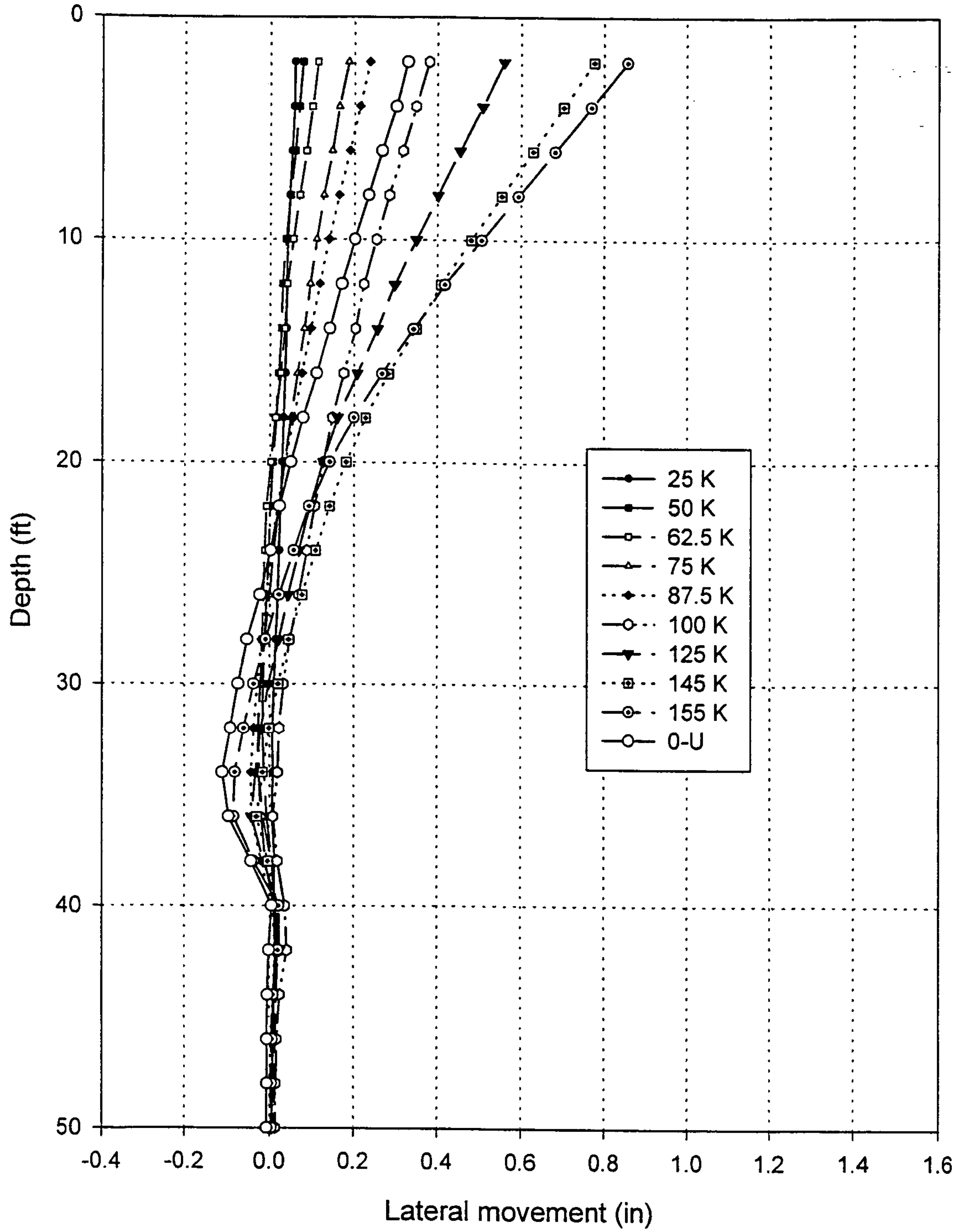
III.51 Deflection versus lateral load at jack level for 9-m deep shaft (Putnam Street Bridge)



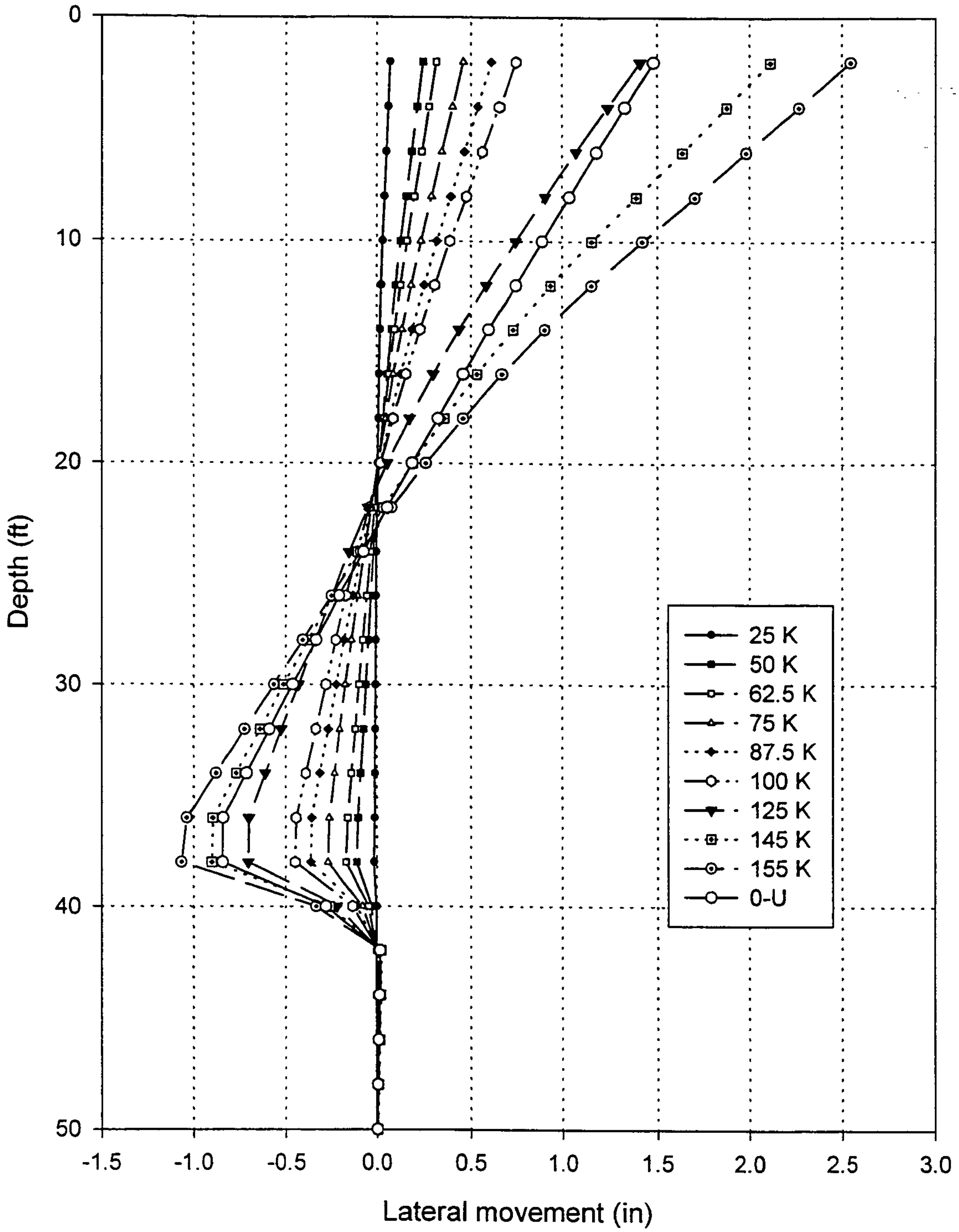
III.52 Deflection versus lateral load at jack level for 9-m deep shaft (Putnam Street Bridge)



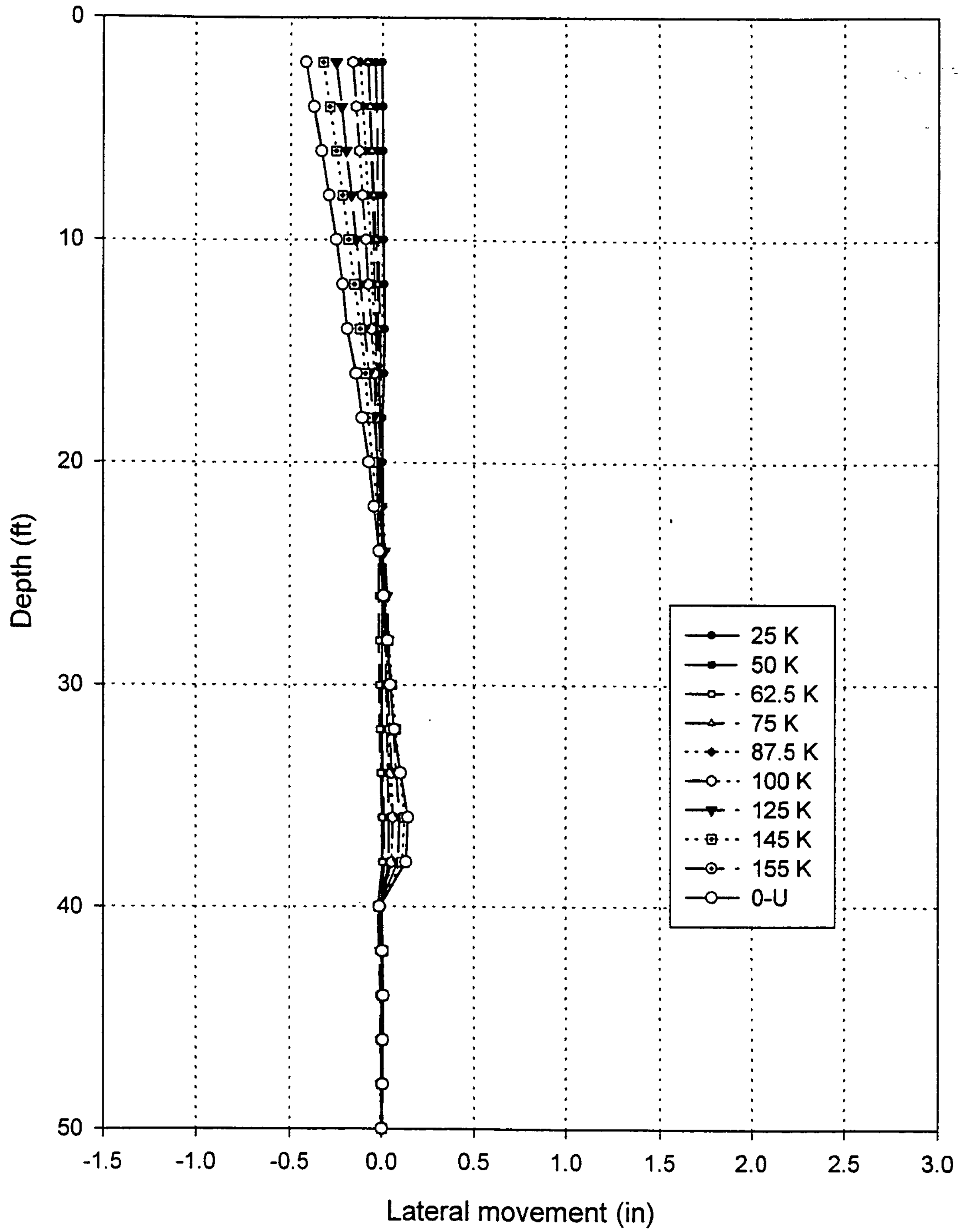
III.53 Observed deflection along the length of the 9-m deep shaft (Shaft #1 – A-direction)



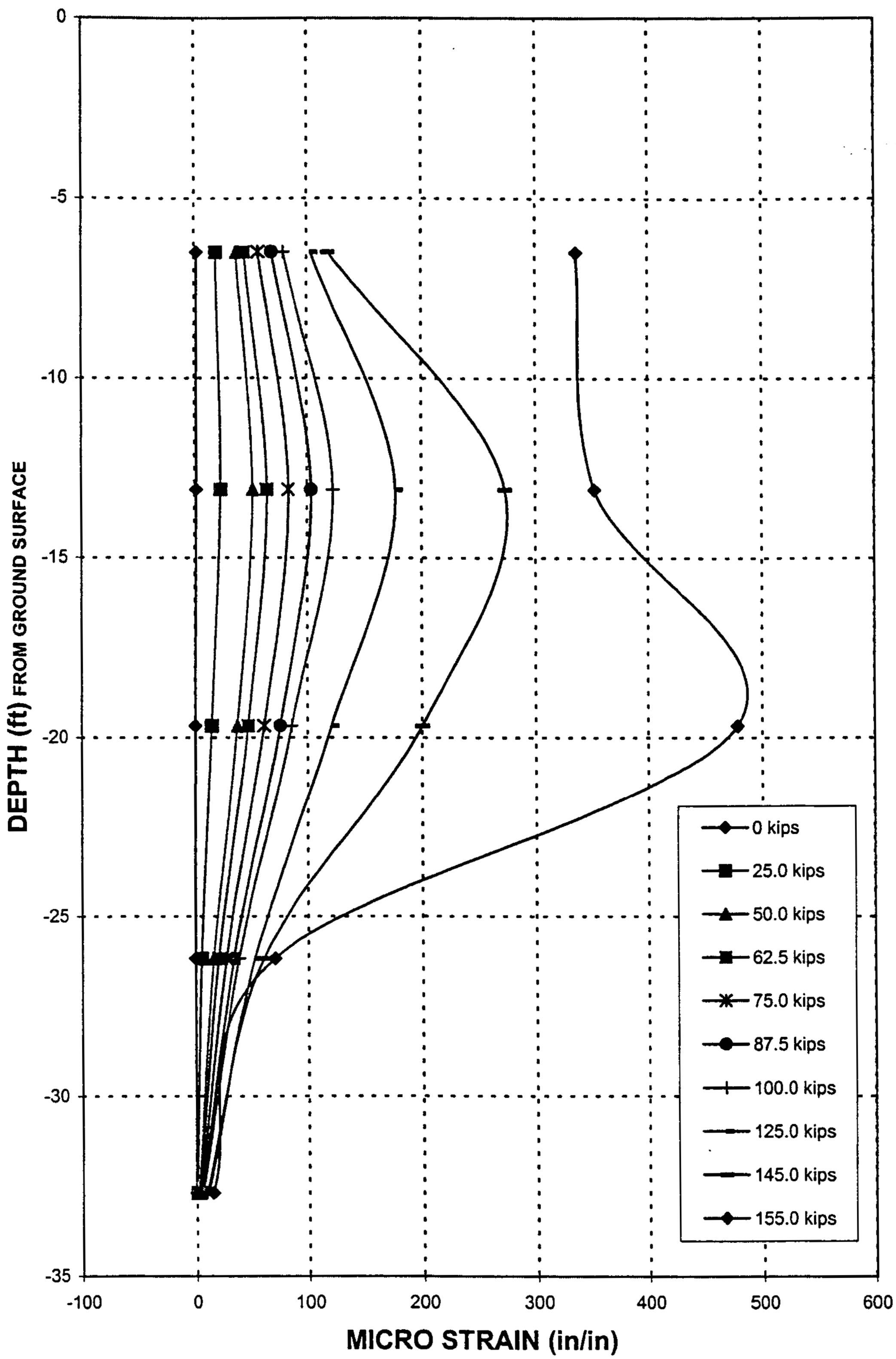
III.54 Observed deflection along the length of the 9-m deep shaft (Shaft #1 – B-direction)



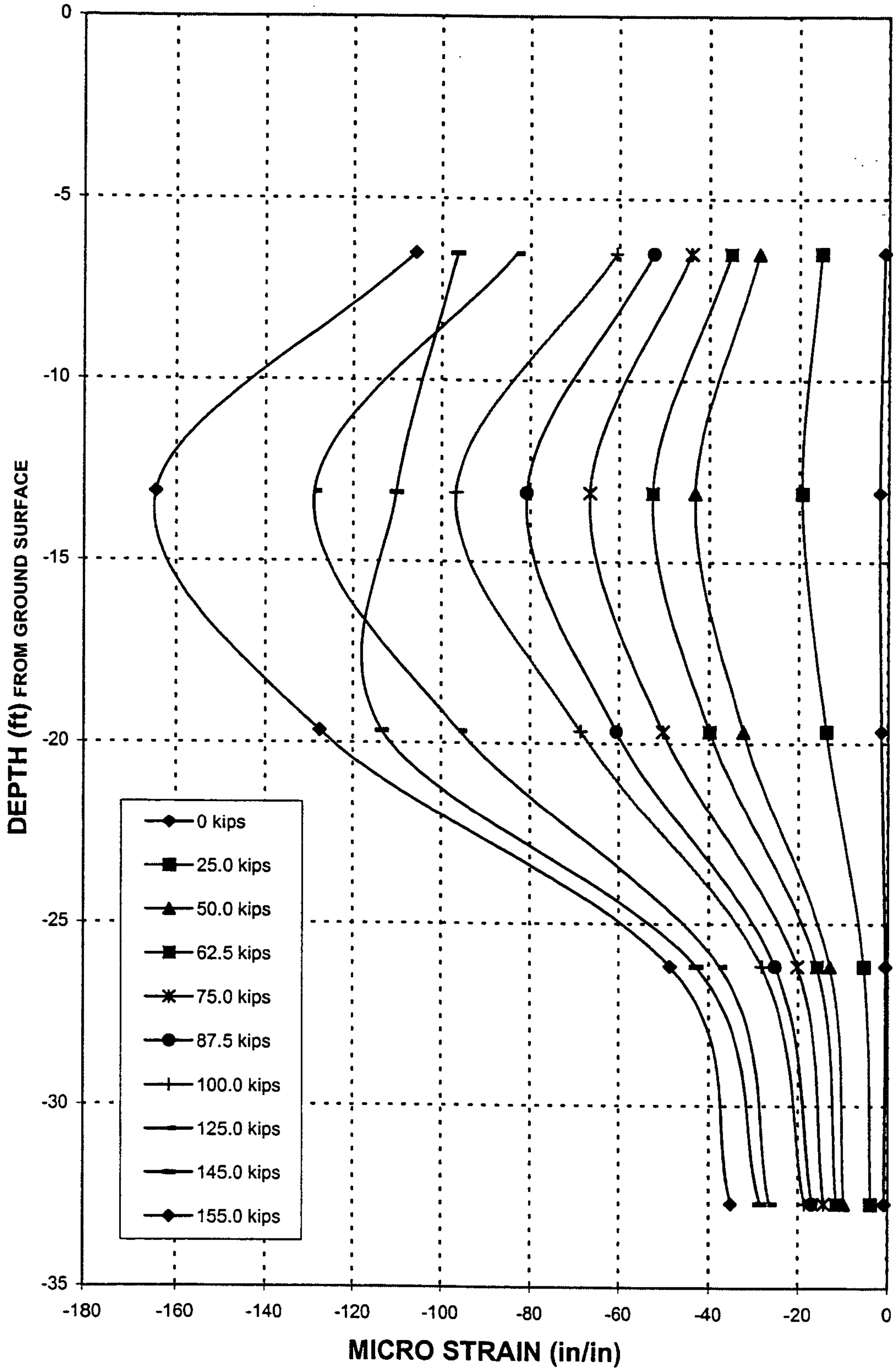
III.55 Observed deflection along the length of the 9-m deep shaft (Shaft #2 – A-direction)



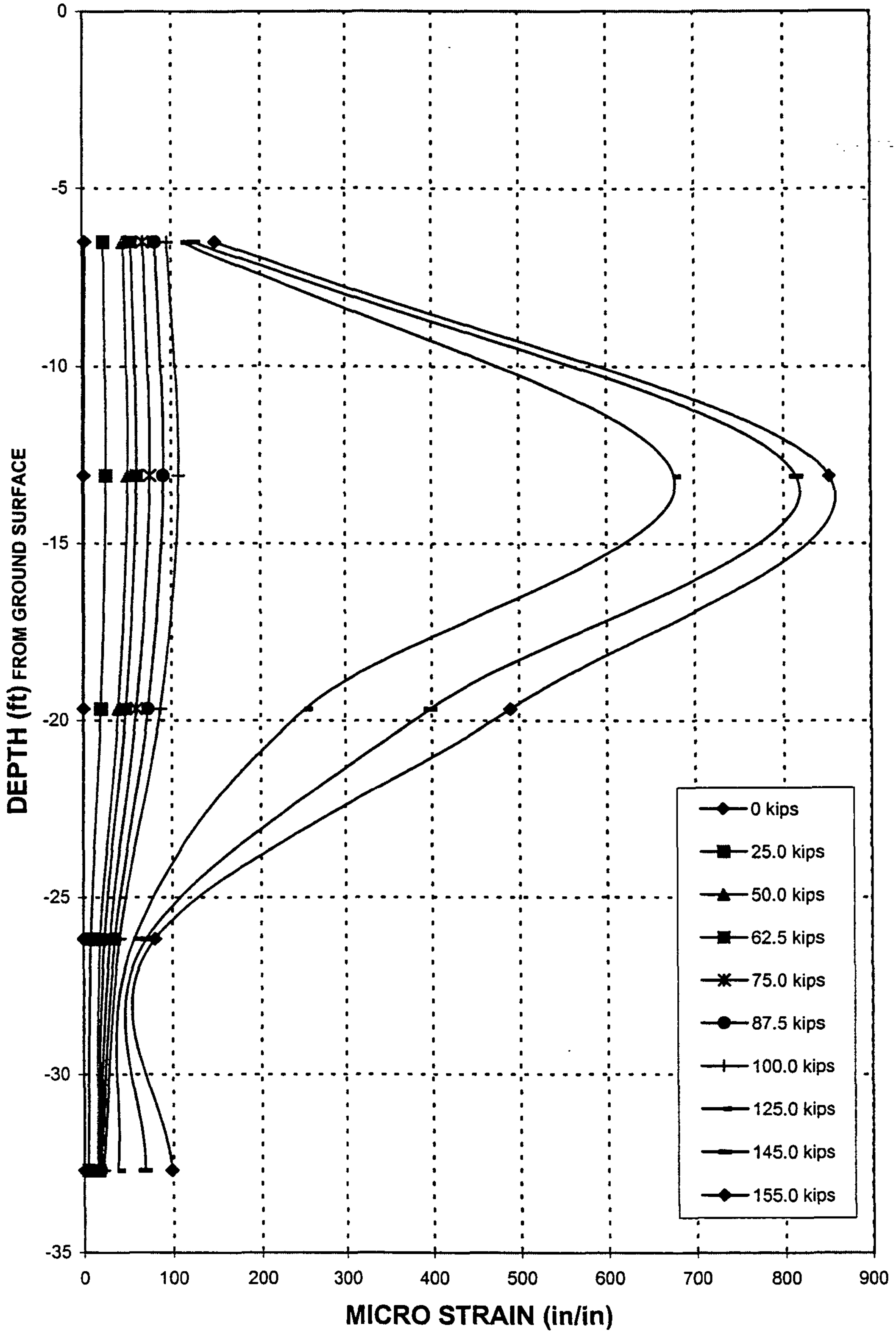
III.56 Observed deflection along the length of the 9-m deep shaft (Shaft #2 – B-direction)



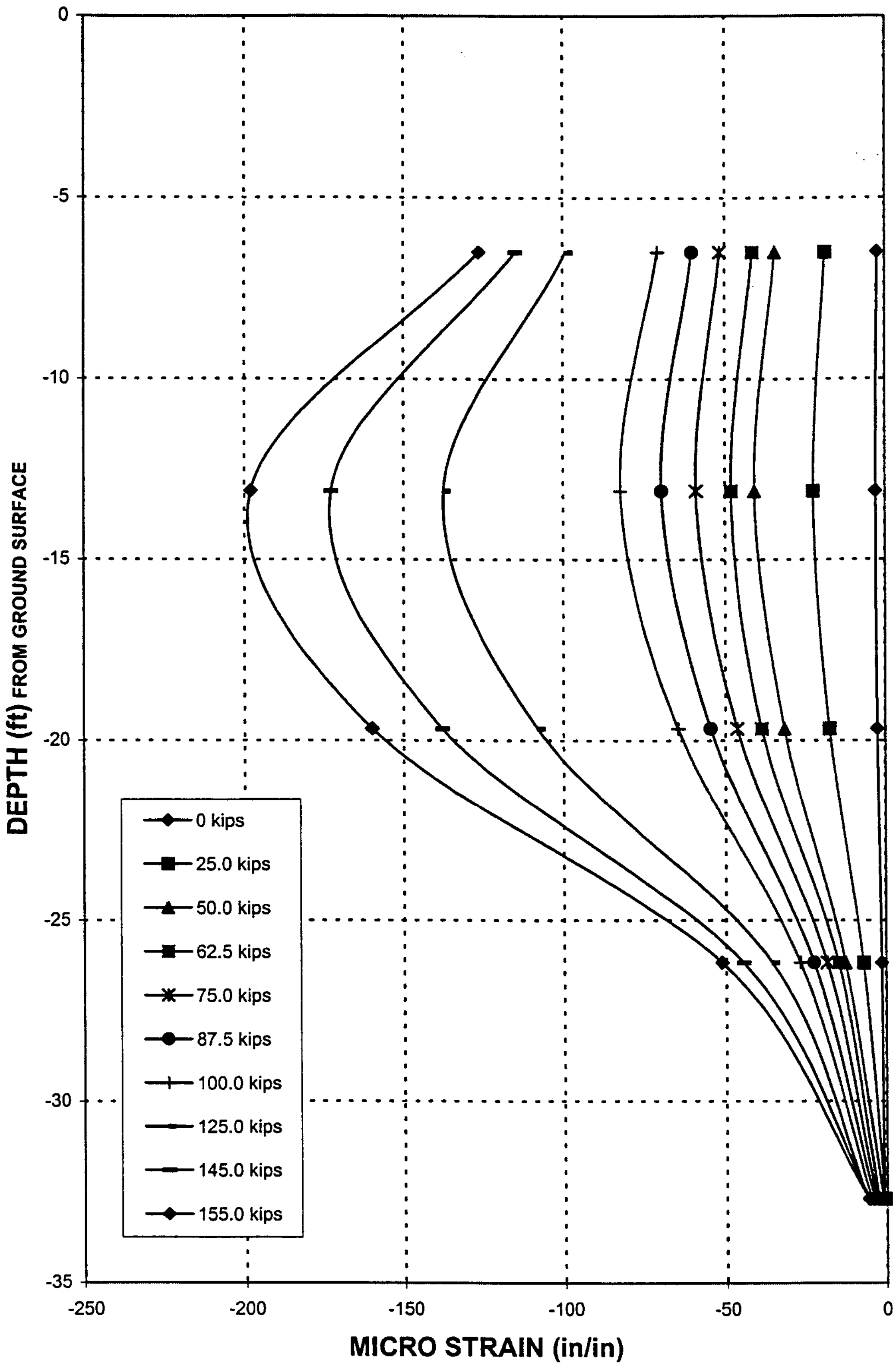
III.57 Observed strain along the length of the 9-m deep shaft #1 (Tension Face)



III.58 Observed strain along the length of the 9-m deep shaft #1 (Compression Face)



III.59 Observed strain along the length of the 9-m deep shaft #2 (Tension Face)



III.60 Observed strain along the length of the 9-m deep shaft #2 (Compression Face)

CHAPTER IV

LATERAL LOAD TEST AT HAMILTON 50

Lateral load tests were conducted on drilled shafts that were 26-ft and 18-ft deep. The tests were performed to measure the lateral load capacity of the shafts and establish parameters to economize the shaft design.

This chapter deals with the details of the drilled shafts and their construction, the lateral load tests (instrumentation and testing) and finally the test results. The two drilled shafts were tested in accordance with ASTM D3966-90: "Standard Test Method for Piles Under Lateral Loads". The site location of these shafts, which were of 26-ft and 18-ft length, as mentioned above, is given in Fig. IV.1. Also presented are the site conditions and the soil boring information. The instrumentation details and the load test results are given in detail. The measured data presented includes the load~deflection curve at the shaft head, the shaft deflection along the shaft length for each load increment, as well as the measured strains (on the compression and tension face of the shaft), deduced moments along the shaft and the field observations.

IV.1 SITE CONDITIONS / SOIL INFORMATION

H. C. Nutting performed a subsurface exploration on the subject site and five test borings along the proposed retaining wall axis were carried out. The locations of these boreholes are presented in Fig. IV.2, while the bore logs giving specific conditions at various depths are included as Fig. IV.3 to IV.7.

All of the test borings performed revealed existing fill, with the fill depths ranging from 2.5-ft to 12-ft. The fill encountered was primarily granular in nature, consisting of silty sand with varying amounts gravel, cinders and rock fragments. The SPT values for this fill layer being between 6 and 40.

Below the fill layer, there are layers of glacial tills ranging from 5-ft to 12.5-ft in depth. The layer being extremely stiff with N-values as determined from the Standard Penetration Test being in the mid twenties.

The soils underlying the glacial deposits were residual in nature. The residual clay underlying the above and overlying the bedrock were very stiff to hard, brown to brown with some gray clays to fat clay containing rock fragments and noted shale fragments to layers. The Standard Penetration test results being generally in the upper twenties.

The overburden soils showed a gradual transition into highly weathered bedrock, primarily consisting of gray calcareous Shale with thin Limestone interbeds. The Limestone layers measuring between ¼-in to 8-in in thickness and being well distributed. The Shale occupying nearly 90% of the bedrock matrix. The Shale layers being soft and broken at the surface and becoming medium tough to tough with increasing depth.

IV.2 TESTED SHAFTS DESCRIPTION

Two lateral load tests were carried out on four drilled shafts. The drilled shafts, which were 26-ft and 18-ft in length, had overall diameters of 48-in and 42-in, respectively.

The main reinforcement for both the drilled shafts consisted of 6#11 bars on one face and 3#5 bars on the other face. These bars were placed in a rectangular core measuring 14-in by 30-in, which was tied by #5 bars @ 18-in c/c. The details of the reinforcement are provided in Figure IV.8 and IV.9.

The details of the reinforcement for the column placed at the head of the pile is also given in the above two figures.

IV.3 CONSTRUCTION METHOD

The drilled shafts were cast-in-situ, and the construction sequence for both of them is detailed below.

IV.3.1 26-FT Deep Shafts (T-21 and T-23)

The constructed shafts were 48-inch in diameter. The bore holes for the shafts were drilled on 7/20/99 and 7/21/99. Upon completion of the boring, the steel cage for shaft T-21 was lowered in the hole and aligned, and the column section was attached to it. The concreting of the shaft was carried out on 7/21/99.

For shaft T-23, the bore hole was drilled, the cage lowered, column part installed, and concreting was carried out on 7/21/99.

The Column parts for shafts T-21 and T-23 were formed and concrete was poured on 7/23/99.

IV.3.2 18-FT Deep Shafts (T-25 and T-27)

The shafts were 42-inch in diameter. The bore holes for the shafts were drilled on 7/19/99. The cages were lowered and concrete was poured on 7/20/99.

The column parts were formed and poured on 7/21/99.

Before concreting any shaft, the air content and slump were tested. Two cylinders were taken from the mix for each shaft and were tested for their 7-day compressive strength. The results obtained from the testing are given hereunder.

SHAFT NO.	AVERAGE COMPRESSIVE STRENGTH (psi)
T-21	2,956
T-23	2,956
T-25	3,055
T-27	3,055

IV.4 INSTRUMENTATION

This portion of the chapter includes the details of the instrumentation carried out for the 26-ft and 18-ft deep drilled shafts. It includes details of the type of strain gages, inclinometer and dial gages used.

IV.4.1 Instrumentation For 26-FT Deep Shafts (T-21 and T-23)

Each of the 26-ft deep drilled shafts were instrumented with 14 vibrating wire strain meters also referred to as "Sister Bars" (Geokon model 4911), and an inclinometer tube (Geokon model 6501) to measure the lateral movement with depth, associated with each load increment. The inclinometer tube had an overall length of 36-ft and extended 5-ft below the bottom of the shaft. Three dial gages were used as well, to measure the deflection of the shaft head and the point of application of the load on the column. These dial gages were placed at the top of the shaft head and on the column at the point of application of the lateral load. Figures IV.10 and IV.11 give the location of the strain gages, the inclinometer and the dial gages. Also given is the test frame assembly. While Figs. IV.12 to IV.14 provide details of the actual instrumentation carried out at the subject site.

IV.4.2 Instrumentation For 18-FT Deep Shafts (T-25 and T-27)

As for the 26-ft deep drilled shafts, each of the 18-ft deep drilled shafts were also instrumented with 14 vibrating wire strain meters also referred to as "Sister Bars" (Geokon model 4911), and an inclinometer tube (Geokon model 6501) to measure the lateral movement with depth, associated with each load increment. The inclinometer tube had an overall length of 28-ft and extended 5-ft below the bottom of the shaft. Three dial gages were used as well, to measure the deflection of the shaft head and the point of application of the load on the column. These dial gages were placed at the top of the shaft head and on the column at the point of application of the lateral load. Figures IV.15 and IV.16 give the location of the strain gages, the inclinometer and the dial gages. Also given is the test frame assembly.

IV.5 TEST REACTION FRAME SET-UP

Figures IV.17 and IV.18 give details of the test set-up and the loading frame used for conducting the test in accordance with ASTM standard D3966-90. The test frame, which was designed and manufactured by the University of Akron, was made up of 14x14x1/2-in tubular sections and was assembled as indicated in Figure IV.18.

IV.6 LATERAL LOAD TEST RESULTS

This portion of the chapter deals with the results obtained from the lateral load tests performed. It includes the field observations, the analysis of the obtained data and the conclusions derived from it.

IV.6.1 Load Test results From 26-Ft Deep Shafts (T-21 &T-23)

Lateral load tests on the 26-ft deep shafts, T-21 and T-23 were carried out on ??????. The observed deflection at the top of the shaft and at the jacking point for shaft T-21 and T-23, for the different load stages, are plotted out and presented in Figures IV.24 to IV.27. Comparisons have been made between the observed values from the dial gages and the inclinometer readings and for values computed from constant EI considerations. Figures IV.28 and IV.29 give the observed values of deflection along the length of the drilled shaft for the various load stages, as observed from the inclinometer readings. The lateral movement in the two directions has been plotted out for two feet increments along the depth and for the specific load increments 25-k in which the test was conducted.

Also presented, in Figs. IV.30 to IV.33 are the observed strain measurements along the length of the shaft, at the different load stages, for the compression and tension faces of the drilled shaft. Tables IV.3 to IV.6 give the detailed strain readings at locations of the instrumented gages for the various load stages.

IV.6.1.1 Field Observations

Lateral load tests were conducted on the two test shafts, T-21 and T-23, to determine their load carrying capacity and overall response. The tests were carried out to establish the parameters for design and determine the required size and depth of the pile shafts.

Crack Pattern

The crack pattern that was observed for the two shafts (T-21 & T-23), as the load was applied in accordance with ASTM D 3966, is given in Figures IV.34 and IV.39.

Test Shaft T-23:

Cracks first appeared in the columns during the application of the second load stage, that is, as the load was increased from 25 kips to 50 kips. These cracks which were flexure and shear, from this point onwards progressively increased in length, width and numbers through the subsequent load stages. Towards the ultimate load stage the cracks were fairly uniformly spread over the maximum flexure-shear zone and the widths of the major cracks were around 1 mm.

The junction of the column and shaft also indicated good resistance against the applied load of 200 kips at the ultimate stage.

As for the shaft itself, cracks initially appeared as the load was increased from 50 kips to 75 kips. The crack which has been labeled 1 in Fig. IV.40(a), progressively increased in length and width during the successive load stages, finally running across the entire section and having a width of around 3 mm at a load of 200 kips.

Additional cracks appeared over the entire cross-section, as indicated in the figure. The crack widths being extremely high at the higher loads as shown through notes 1 to 3.

Test Shaft T-21:

The behavior of the column of the shaft was quite similar to that of Shaft T-23. First cracks appeared as the load was increased from 25 kips to 50 kips, and progressively increased with additional loads. As for Shaft T-23, the cracks were quite uniformly spread in the maximum flexure-shear zone at the higher load stages.

The shaft itself exhibited first signs of cracking as the load was increased from 100 kips to 125 kips. The crack which ran horizontally about 10 in from the top of the shaft, first appeared on the loading face side of the column, as indicated in Figure IV.40(b).

This crack which had a width of around 1 mm at a load of 125 kips increased progressively in width and as the load was increased from 175 kips to 200 kips, extended right through the section of the shaft, shearing the top of the shaft and causing failure.

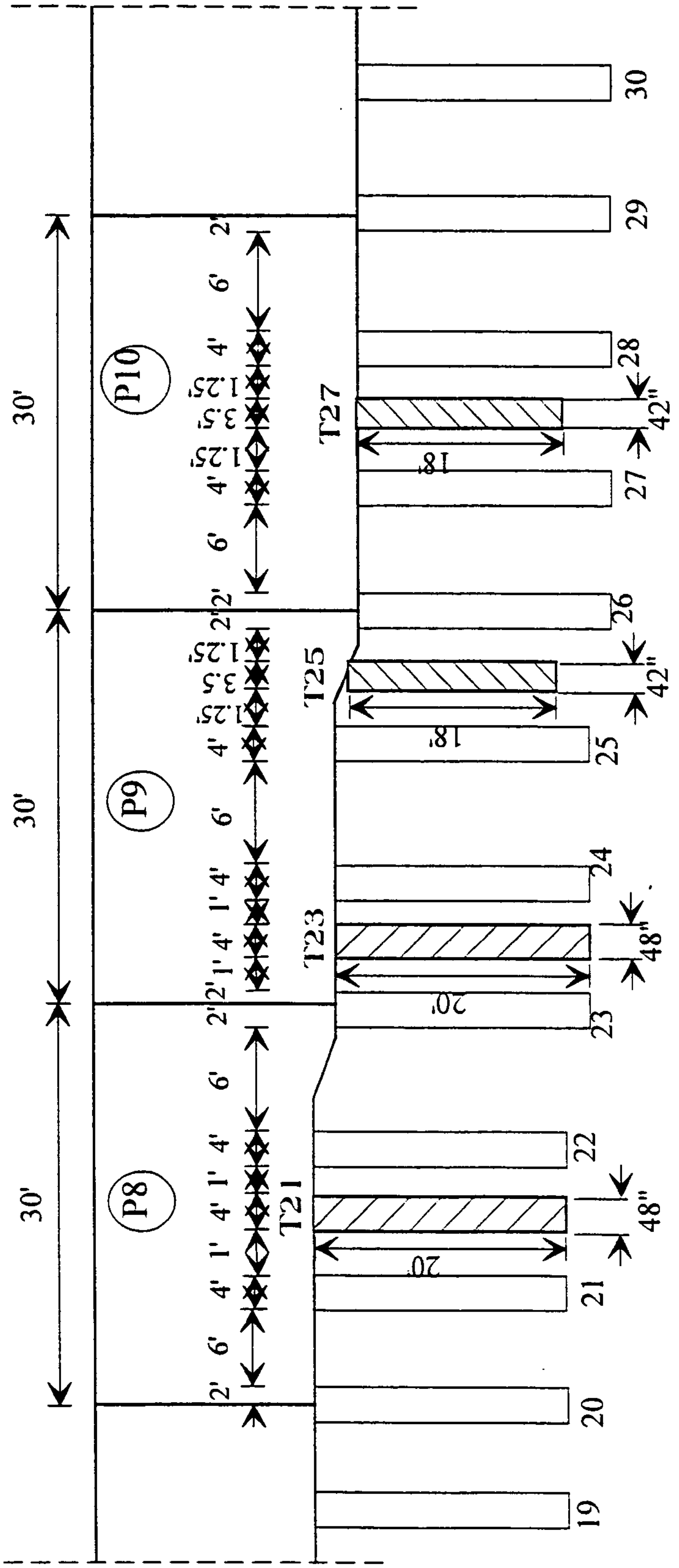
IV.6.2 Load Test results From 18-Ft Deep Shafts (T-25 &T-27)

Lateral load tests on the 18-ft deep shafts, T-25 and T-27 were carried out on ??????. The observed deflection at the top of the shaft and at the jacking point for shaft T-25 and T-27, for the different load stages, are plotted out and presented in Figures IV.41 to IV.44. Comparisons have been made between the observed values from the dial gages and the inclinometer readings and for values computed from constant EI considerations. Figures IV.45 and IV.46 give the observed values of deflection along the length of the drilled shaft for the various load stages, as observed from the inclinometer readings. The lateral movement in the two directions has been plotted out for two feet increments along the depth and for the specific load increments 25-k in which the test was conducted.

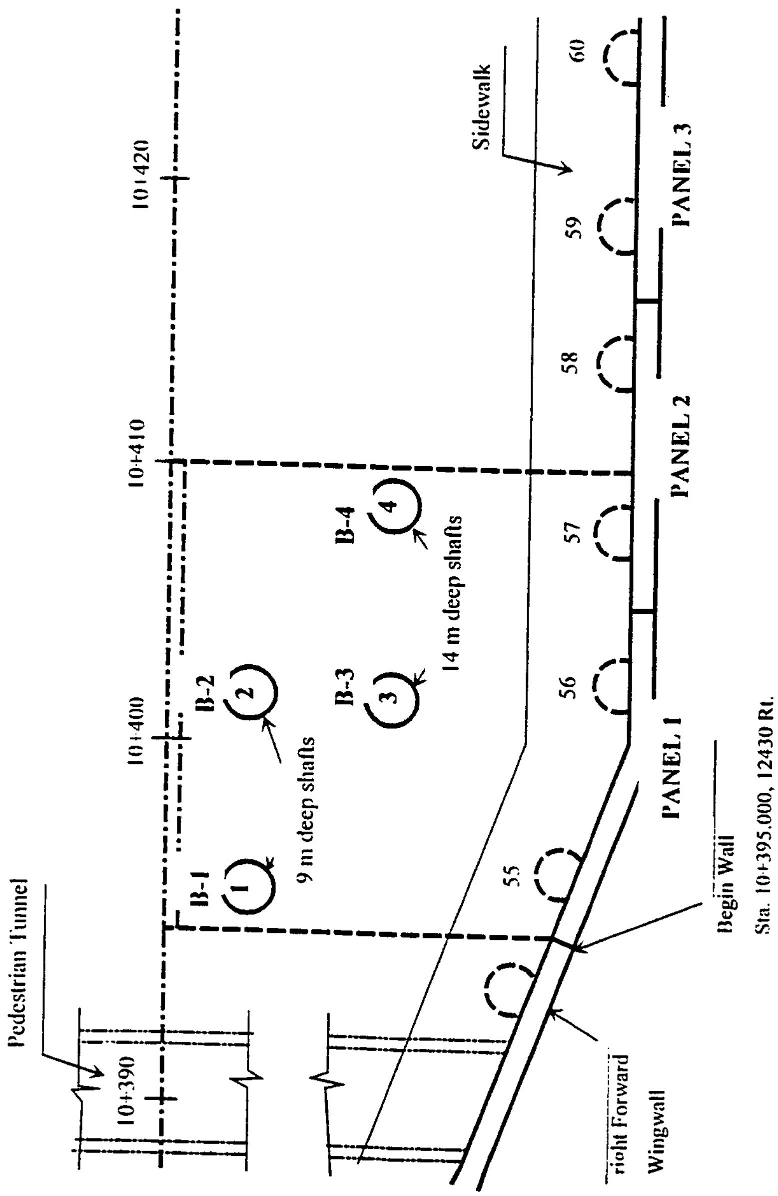
Also presented, in Figs. IV.47 to IV.50 are the observed strain measurements along the length of the shaft, at the different load stages, for the compression and tension faces of the drilled shaft. Tables IV.9 to IV.10 give the detailed strain readings at locations of the instrumented gages for the various load stages.

Also presented are the strain measurements along the length of the shaft, at the different load stages, for the compression and tension faces of the drilled shaft.

IV.1 Site location of the test shafts



IV.2 Location of bore holes and drilled shafts used in lateral load tests at Hamilton 50



IV.3 Log of test bore used in subsurface investigation for 26-ft deep shaft

H. C. NUTTING COMPANY
CORPORATE CENTER - 4120 AIRPORT ROAD
CINCINNATI, OH 45226 (513) 321-5816
FAX: (513) 321-0294
EMPLOYEE OWNED
GEOTECHNICAL, ENVIRONMENTAL AND TESTING ENGINEERS SINCE 1921

FIELD LOG OF TEST BORING

APPALACHIAN REGION, 812 MORRIS STREET, CHARLESTON, WV [illegible], (304) 344-0821, FAX: (304) 342-4711
CENTRAL OHIO REGION, 7[illegible] MORRISON ROAD, COLUMBUS, OH [illegible], (614) [illegible]-3113, FAX: (614) [illegible]-0475
INDIANA REGION, [illegible] WALNUT STREET, STE [illegible], LAWRENCEBURG, IN 47025, (812) 53[illegible], FAX: (812) 53[illegible]
BLUEGRASS REGION, 50 E. RIVERCENTER BLVD., STE 4[illegible], COVINGTON, KY 41011, ([illegible]) 2[illegible]-2575, FAX: ([illegible]) 2[illegible]-5415

CLIENT:	National Engineering	BORING NO.:	B-1
PROJECT:	Putnam Street Bridge - Marietta, Ohio	DATE STARTED:	9-2-98
BORING LOCATION:	As Marked	DATE COMPLETED:	9-3-98
ELEVATION REFERENCE:		WORK ORDER NO.:	60171.002

ELEV	DEPTH (meters)		DESCRIPTION OF MATERIALS	SAMPLE #	TYPE	DEPTH (meters)	BLOW PER 6 INCHES	RECOVERY	SOIL PROPERTIES W (%)	PENN	RQD
	0.0										
		0.27	Asphalt and gravel								
	0.27										
		1.0	Reddish Brown lean clay (FILL), moist-stiff	1	SS	0-0.45	25-8-6	0.28			
	1.27										
		1.77	Gray lean clay, with fine gravel (FILL), stiff, moist to very moist	2	SS	1.52-1.97	5-9-3	0.16			
	3.04			3	SS	3.04-3.49	1-2-1	0.36			
		1.52	Gray lean clay with fine gravel (FILL), soft very moist								
	4.56			4	SS	4.56-5.01	3-5-6	0.45			
		4.14	Brown lean CLAY, stiff to firm to soft-wet	5	SS	6.08-6.53	3-3-4	0.45			
				6	SS	7.60-8.05	1-2-2	0.45			
	8.70										
		1.52	Gray lean CLAY with fine sand lenses, soft	7	SS	9.12-9.57	0-0-3	0.40			
	10.22										
		1.52	Fine gravel with silty fine to coarse SAND, firm-wet	8	SS	10.64-11.09	4-7-11	0.21			
	11.74										
		4.53	Brown fine SAND with fine gravel, firm-wet	9	SS	12.16-12.61	4-9-9	0.18			
				10	SS	13.68-14.13	4-9-15	0.32			
				11	SS	15.20-15.65	5-9-12	0.06			
	16.27										
		0.15	Auger refusal - cased in rock								
	16.42			1	core	16.42-18.59	PENN-2.17	2.17			95%
		0.37	Gray sandy SHALE, medium hard	2	core	18.59-20.59	PENN-2.00	2.00			95%
	16.79										
		2.20	Reddish brown and greenish - soft gray SHALE, some gray sandy shale, medium hard								
	18.99										
		1.60	Gray sandy SHALE, medium hard alternating with reddish brown shale, soft								
	20.59										
			TEST BORING COMPLETED								

* Pocket Penetrometer Reading - Unconfined Compressive Strength, Tons/Sq. Ft.

General Notes		Remarks	Water Level Observations		
Driller	K.MULLINS		Immediate	4.56	m
Rig No.	48		At Completion	4.12	m
Rig Type	CME-55		After Hours		m
Method	3-1/4 HSA	* ADD AT 4.56	Water Used in drilling	*	m
	NQ CORE				
			(Measured from ground surface)		

IV.4 Log of test bore used in subsurface investigation for 26-ft deep shaft

H. C. NUTTING COMPANY

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CINCINNATI, OH 45226 (513) 321-5816
FAX: (513) 321-0294

EMPLOYEE OWNED

GEOTECHNICAL, ENVIRONMENTAL AND TESTING ENGINEERS SINCE 1921

APPALACHIAN REGION, [illegible] MORRIS STREET, CHARLESTON, WV [illegible] — CENTRAL OHIO REGION, [illegible] MORRISON ROAD, COLUMBUS, OH [illegible], (614) [illegible] — INDIANA REGION, [illegible] WALNUT STREET, STE [illegible], LAWRENCEBURG, IN 47025, (812) [illegible] — BLUEGRASS REGION, 50 E. RIVERCENTER BLVD., STE [illegible], COVINGTON, KY 41011, [illegible]

FIELD LOG OF TEST BORING

CLIENT:	National Engineering	BORING NO.:	B-2
PROJECT:	Putnam Street Bridge - Marietta, Ohio	DATE STARTED:	9-1-98
BORING LOCATION:	As Marked	DATE COMPLETED:	9-2-98
ELEVATION REFERENCE:		WORK ORDER NO.:	60171.002

ELEV	DEPTH (meters)		DESCRIPTION OF MATERIALS	SAMPLE #	TYPE	DEPTH (meters)	BLOW PER 6 INCHES	RECOVERY	SOIL PROPERTIES W (%)	LL/PL (%)	RQD
	0.0										
		0.22	Asphalt and gravel	1	SS	0-0.45	22-8-7	0.40			
	0.22										
		1.30	Reddish brown lean clay with sandstone fragments (FILL), moist-stiff								
	1.52			2	SS	1.52-1.97	3-2-3	0.00			
		1.52	Gray lean clay with fine gravel (FILL), firm moist								
	3.04			3	SS	3.04-3.49	5-6-10	0.45			
		1.52	Brown mottle with gray lean CLAY, moist-very stiff								
	4.56			4	SS	4.56-5.01	2-3-5	0.45			
		3.04	Brown lean CLAY, firm wet	5	SS	6.08-6.53	2-3-4	0.45			
	7.60			6	SS	7.60-8.05	2-3-2	0.45			
		1.52	Gray lean CLAY, firm moist								
	9.12			7	SS	9.12-9.57	2-2-1	0.40			
		1.52	Gray lean CLAY with fine sand lenses, soft wet								
	10.64			8	SS	10-64-11.09	2-3-2	0.15			
		1.52	Fine gravel with some fine to coarse SAND, loose wet								
	12.16			9	SS	12.16-12.61	3-4-8	0.17			
		4.11	Brown fine SAND with some fine gravel, firm to loose to dense-wet	10	SS	13-68-14.13	3-5-5	0.25			
				11	SS	15.20-15.65	8-18-22	0.26			
	16.27										
		0.15	Reddish brown and greenish gray SHALE, soft, auger refusal								
	16.42			12	SS	16-42-16.57	50/0.15	0.15			
		0.15	Same split spoon refusal								
	16.57			1	core	16.57-18.43	PENN. 1.86	1.86			90%
		2.69	Reddish brown and greenish gray SHALE, soft	2	core	18.43-20.59	PENN. 2.16	2.16			90%
	19.26										
		0.22	Gray sandy SHALE, medium hard								
	19.48										
		0.60	Reddish brown SHALE, soft								
	20.08										
		0.22	Gray sandy SHALE, medium hard								
	20.30										
		0.29	Reddish brown, SHALE, soft								
	20.59										
			TEST BORING COMPLETED								

* Pocket Penetrometer Reading - Unconfined Compressive Strength, Tons/Sq. Ft.

General Notes		Remarks	Water Level Observations		
Driller	K.MULLINS		Immediate	4.56	m
Rig No.	48		At Completion	3.90	m
Rig Type	CME-55		After Hours		m
Method	3-1/4 HSA	* ADD AT 4.56 meters	Water Used in drilling	*	m
	NQ CORE				
			(Measured from ground surface)		

IV.5 Log of test bore used in subsurface investigation for 18-ft deep shaft

H. C. NUTTING COMPANY
CORPORATE CENTER - 4120 AIRPORT ROAD
CINCINNATI, OH 45226 (513) 321-5816
FAX: (513) 321-0294
EMPLOYEE OWNED
GEOTECHNICAL, ENVIRONMENTAL AND TESTING ENGINEERS SINCE 1921

FIELD LOG OF TEST BORING

APPALACHIAN REGION, 112 MORRIS STREET, CHARLESTON, WV 25301, [illegible]
CENTRAL OHIO REGION, 708 MORRISON ROAD, COLUMBUS, OH 43230, [illegible]
INDIANA REGION, 340 WALNUT STREET, STE 8, LAWRENCEBURG, IN 47025, [illegible]
BLUEGRASS REGION, 50 E. RIVERCENTER BLVD., STE 400, COVINGTON, KY 41011, [illegible]

CLIENT:	National Engineering	BORING NO.:	B-3
PROJECT:	Putnam Street Bridge, Marietta, Ohio	DATE STARTED:	9-1-98
BORING LOCATION:	As Marked	DATE COMPLETED:	9-1-98
ELEVATION REFERENCE:		WORK ORDER NO.:	60171.002

ELEV	DEPTH (meters)		DESCRIPTION OF MATERIALS	SAMPLE #	TYPE	DEPTH (meters)	BLOW PER 6 INCHES	RECOVERY	SOIL PROPERTIES W (%)	LL/PL (%)	PP* (tsf)
	0.0										
		0.13	Asphalt								
	0.13										
		0.12	Gravel								
	0.25										
		1.27	Reddish brown lean CLAY with sandstone fragments (FILL), moist-stiff	1	SS	0-0.45	17-5-7	0.30			
	1.52			2	SS	1.52-1.97	2-3-6	0.34			
		1.52	Gray lean clay with brick fragments (FILL), moist-stiff								
	3.04			3	SS	3.04-3.49	3-7-9	0.45			
		1.52	Brown mottle with gray lean CLAY, moist-very stiff								
	4.56			4	SS	4.56-5.01	2-3-4	0.45			
		4.86	Brown lean CLAY, firm to soft to very soft, moist to wet	5	SS	6.08-6.53	2-2-2	0.45			
				6	SS	7.60-8.05	2-2-1	0.45			
				7	SS	9.12-9.57	1-3-3	0.32			
	9.42										
		1.22	Brown fine to coarse gravel, loose wet								
	10.64			8	SS	10-64-11.09	17-8-6	0.09			
		1.52	Fine to coarse gravel with fine sand, firm wet								
	12.16			9	SS	12.16-12.61	3-3-7	0.27			
		0.45	Fine SAND AND GRAVEL, loose wet								
	12.61										
			TEST BORING COMPLETED								

* Pocket Penetrometer Reading - Unconfined Compressive Strength, Tons/Sq. Ft.

General Notes

Driller	K.MULLINS
Rig No.	48
Rig Type	CME-55
Method	3-1/4 HSA

Remarks

* ADD AT 7.60 meters

Water Level Observations

Immediate	7.60	m
At Completion	5.72	m
After 24 Hours	3.52	m
Water Used in drilling	*	m

(Measured from ground surface)

IV.6 Log of test bore used in subsurface investigation for 18-ft deep shaft

H. C. NUTTING COMPANY
CORPORATE CENTER - 4120 AIRPORT ROAD
CINCINNATI, OH 45226 (513) 321-5816
FAX: (513) 321-0294
EMPLOYEE OWNED
GEOTECHNICAL, ENVIRONMENTAL AND TESTING ENGINEERS SINCE 1921

APPALACHIAN REGION, 812 MORRIS STREET, CHARLESTON, WV 25301 — CENTRAL OHIO REGION, 780 MORRISON ROAD, COLUMBUS, OH 43230 — INDIANA REGION, 340 WALNUT STREET, STE 8, LAWRENCEBURG, IN 47025 — BLUEGRASS REGION, 50 E. RIVERCENTER BLVD, STE 400, COVINGTON, KY 41011

FIELD LOG OF TEST BORING

CLIENT:	National Engineering	BORING NO.:	B-4
PROJECT:	Putnam Street Bridge, Marietta, Ohio	DATE STARTED:	9-1-98
BORING LOCATION:	As Marked	DATE COMPLETED:	9-1-98
ELEVATION REFERENCE:		WORK ORDER NO.:	60171.002

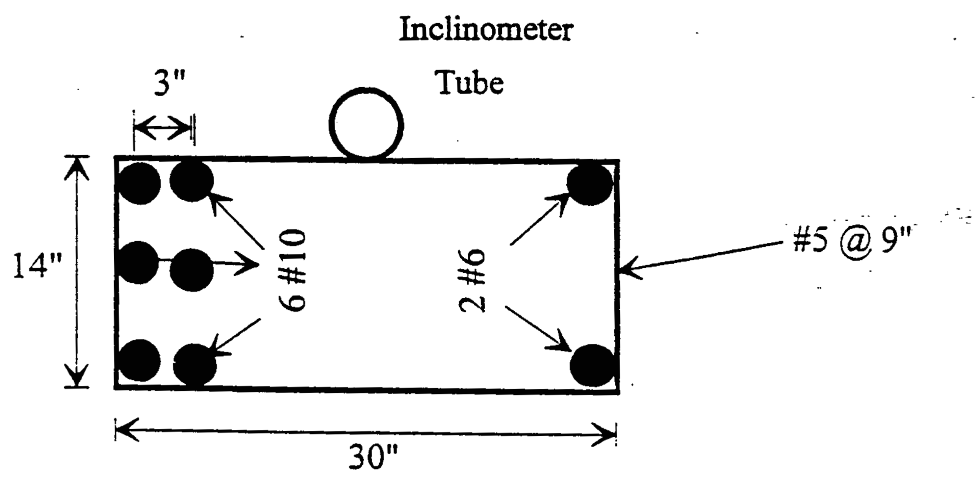
ELEV	DEPTH (meters)		DESCRIPTION OF MATERIALS	SAMPLE #	SAMPLE TYPE	SAMPLE DEPTH (meters)	BLOW PER 6 INCHES	RECOVERY	SOIL PROPERTIES W (%)	LL/PL (%)	PP* (tsf)
	0.0	0.12	Asphalt								
	0.12	0.15	Gravel								
	0.27	1.25	Reddish brown lean CLAY (FILL), firm moist	1	SS	0-0.45	16-5-3	0			
	1.52	0.60	Brown and gray lean CLAY, with fine sand and gravel (FILL), firm moist	2	SS	1.52-1.97	2-2-6	0.30			
	2.12	0.90	Sandstone boulders, hard								
	3.02	1.52	Brown lean CLAY, moist-very stiff	3	SS	3.04-3.49	4-7-9	0.0			
	4.56	1.52	Brown lean CLAY with some sandstone fragments, firm moist	4	SS	4.56-5.01	2-3-4	0.07			
	6.08	1.52	Brown lean CLAY, firm moist	5	SS	6.08-6.53	3-3-4	0.45			
	7.60	1.52	Brown lean CLAY, with some fine sand, firm moist	6	SS	7.60-8.05	2-2-3	0.45			
	9.12	3.04	Brown fine SAND with some fine gravel, loose wet	7	SS	9.12-9.57	3-3-4	0.31			
				8	SS	10-64-11.09	4-3-3	0.08			
	12.16	0.45	Fine gravel with fine SAND, loose wet	9	SS	12.16-12.61	2-3-5	0.10			
	12.61		TEST BORING COMPLETED								

* Pocket Penetrometer Reading - Unconfined Compressive Strength, Tons/Sq. Ft.

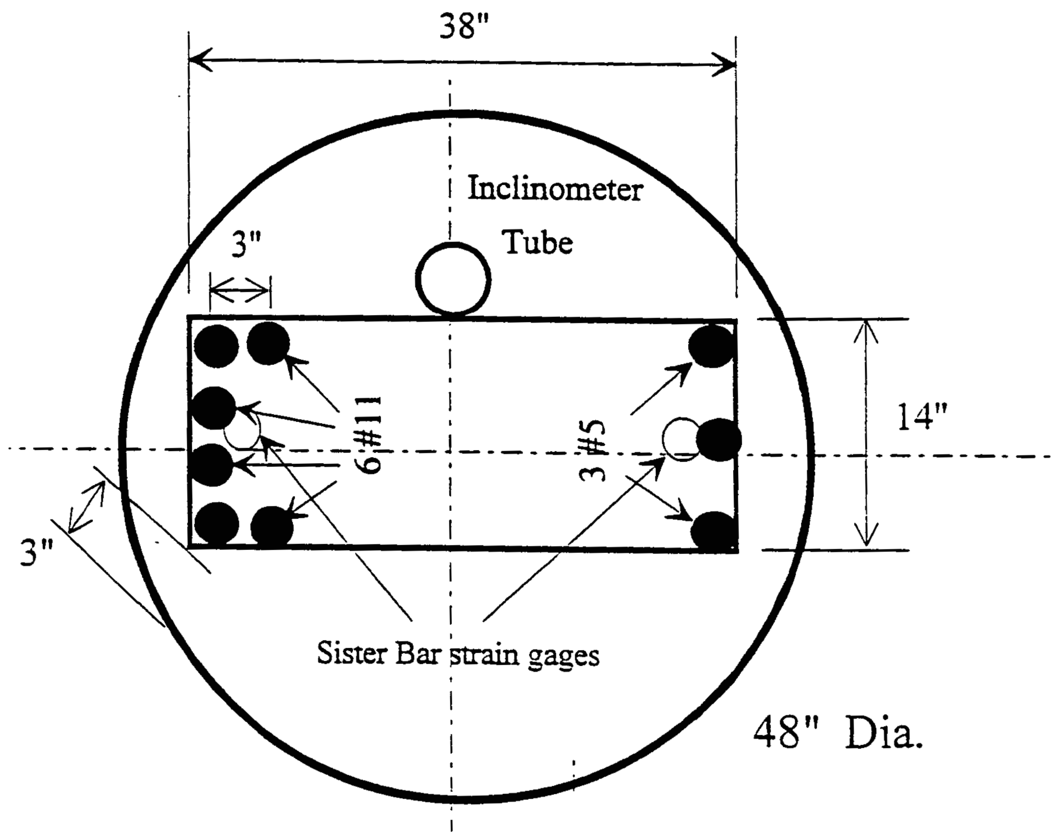
General Notes		Remarks	Water Level Observations		
Driller	K.MULLINS		Immediate	3.35	m
Rig No.	48		At Completion	5.80	m
Rig Type	CME-55		After 24 Hours	4.45	m
Method	3-1/4 HSA	* ADD AT 9.12 meters	Water Used in drilling	*	m

(Measured from ground surface)

IV.7 Log of test bore used in subsurface investigation for 18-ft deep shaft

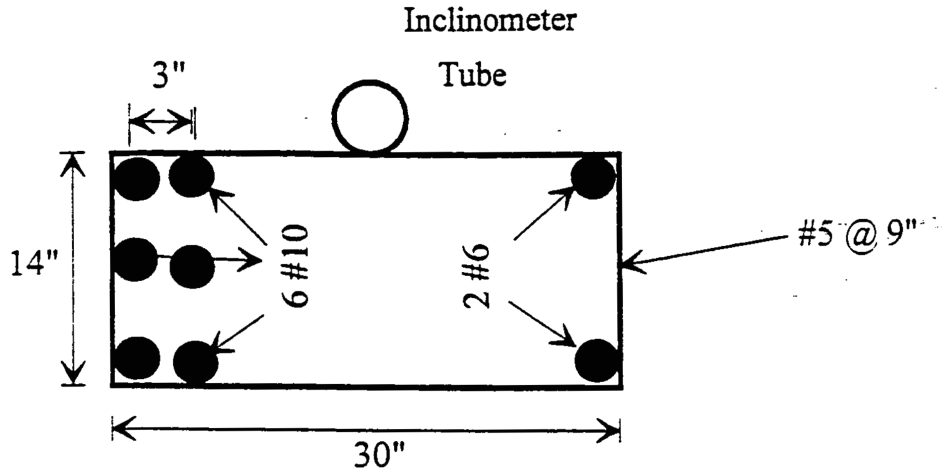


Cross-section A-A in Shafts T21 and T23

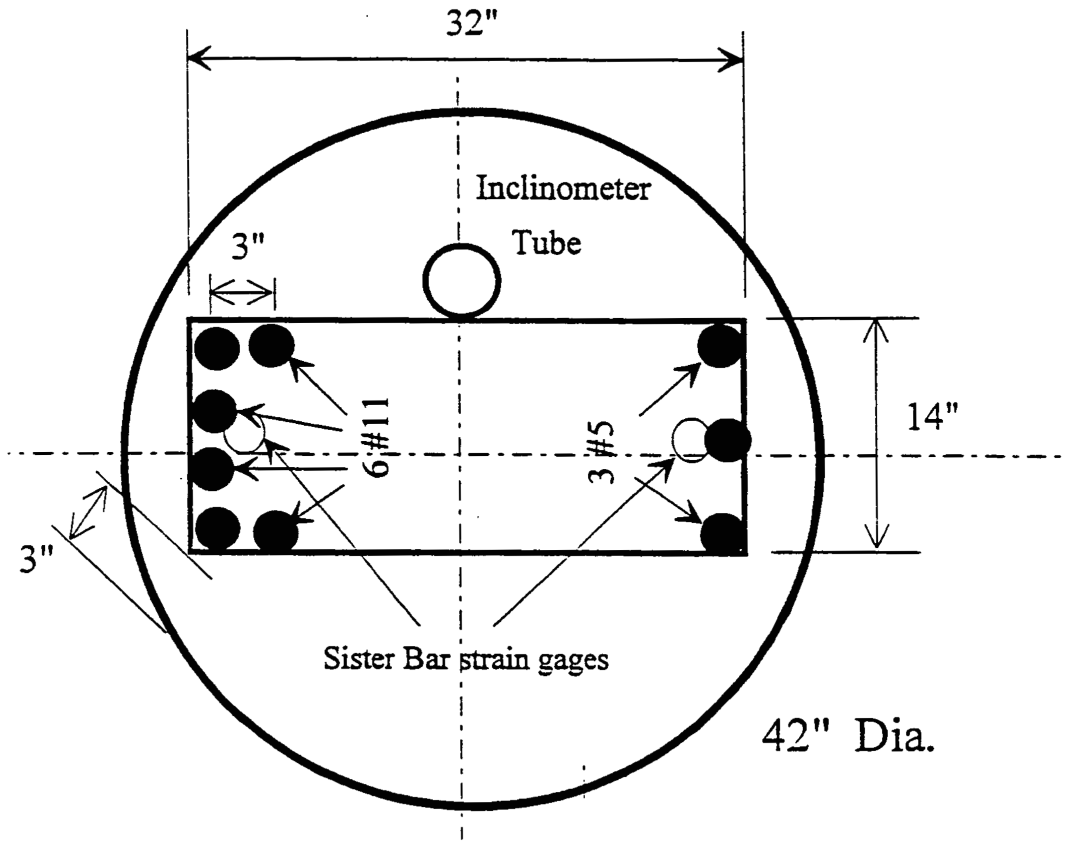


Cross-section B-B in Shafts T21 and T23

IV.8 Reinforcement details of the 26-ft deep shaft

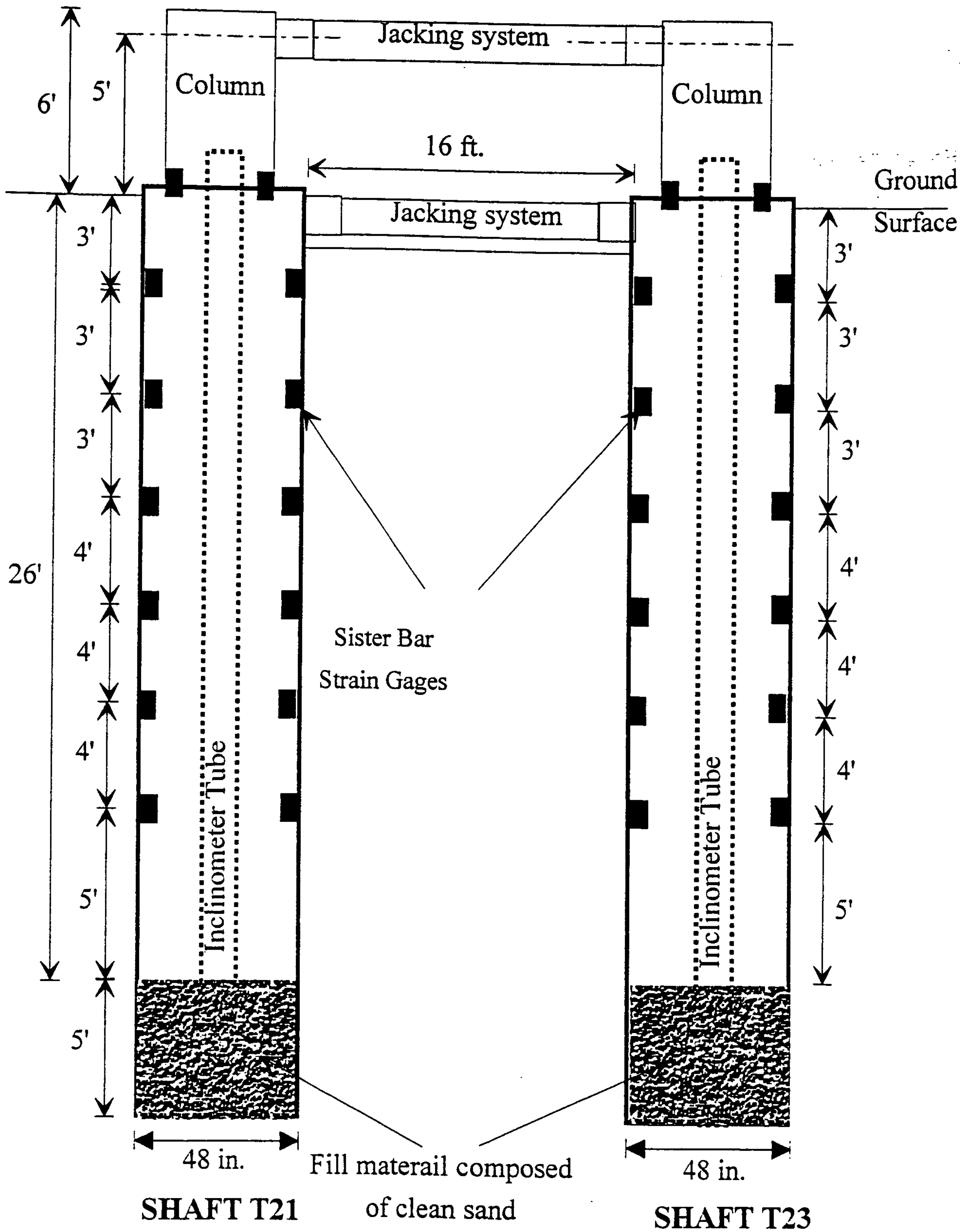


Cross-section A-A in Shafts T25 and T27

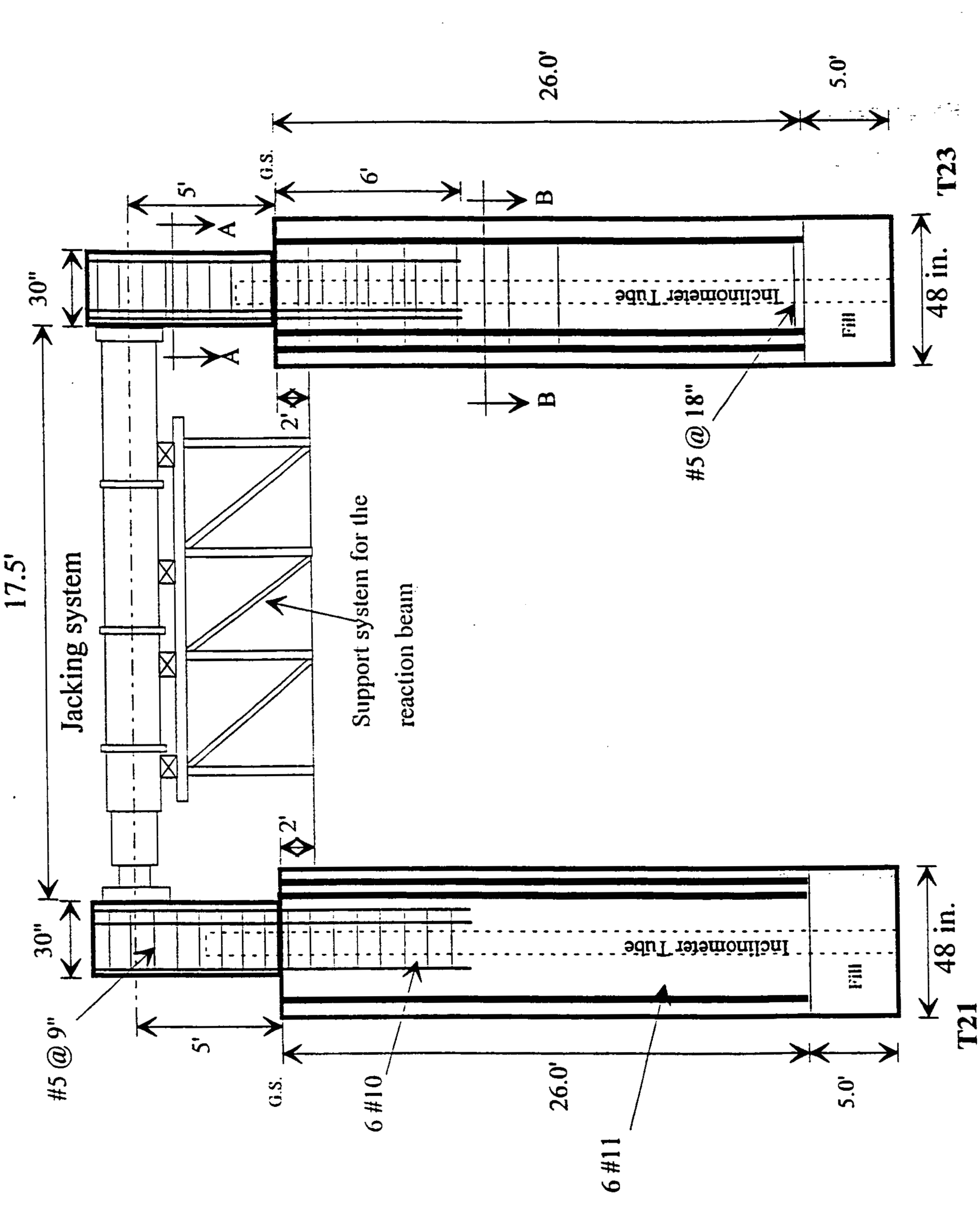


Cross-section B-B in Shafts T25 and T27

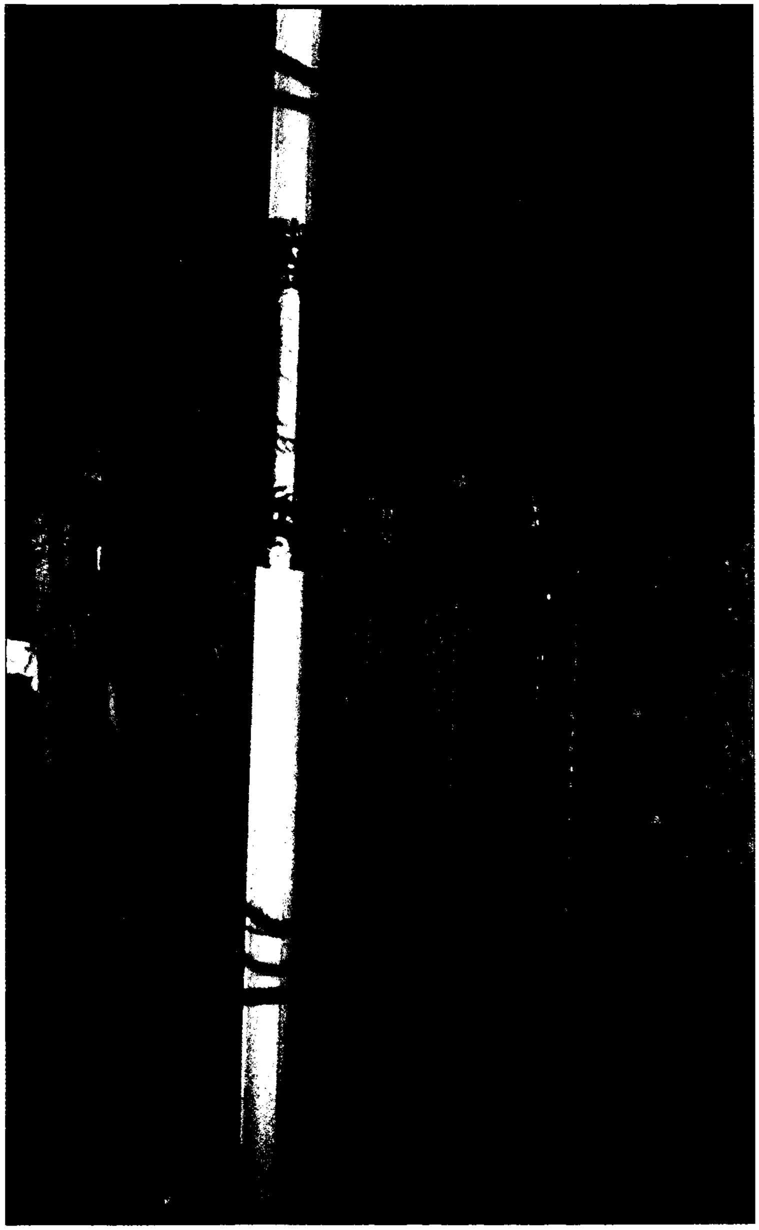
IV.9 Reinforcement details of the 18-ft deep shaft



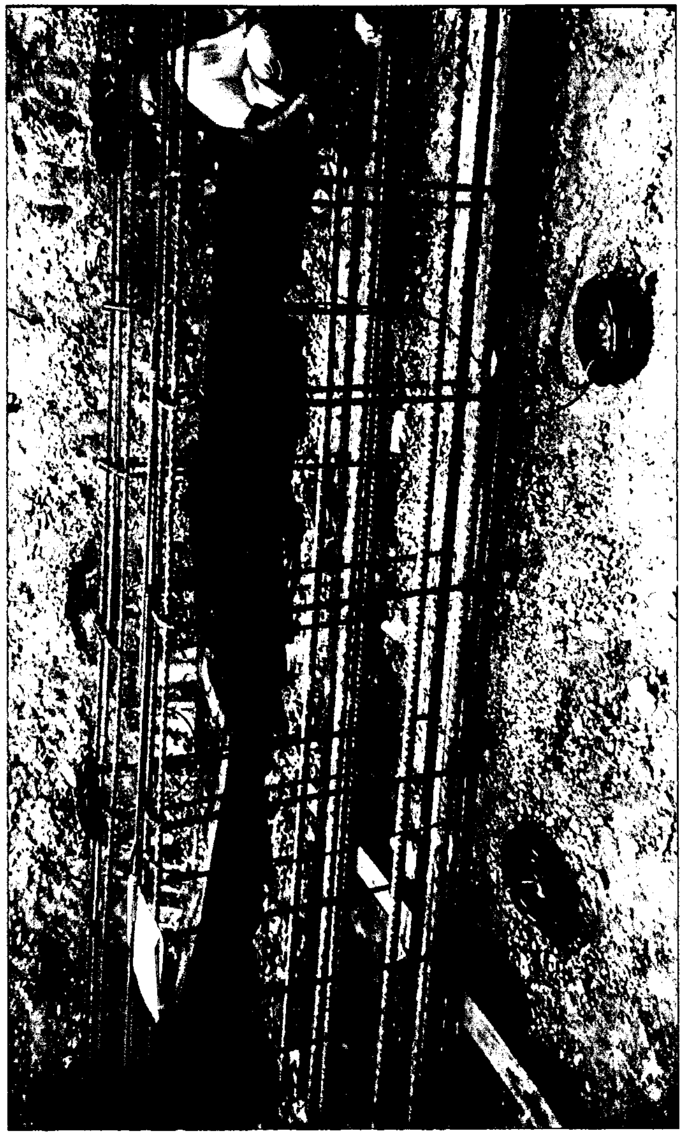
IV.10 Instrumentation details of 26-ft deep shafts (T-21 and T-23)



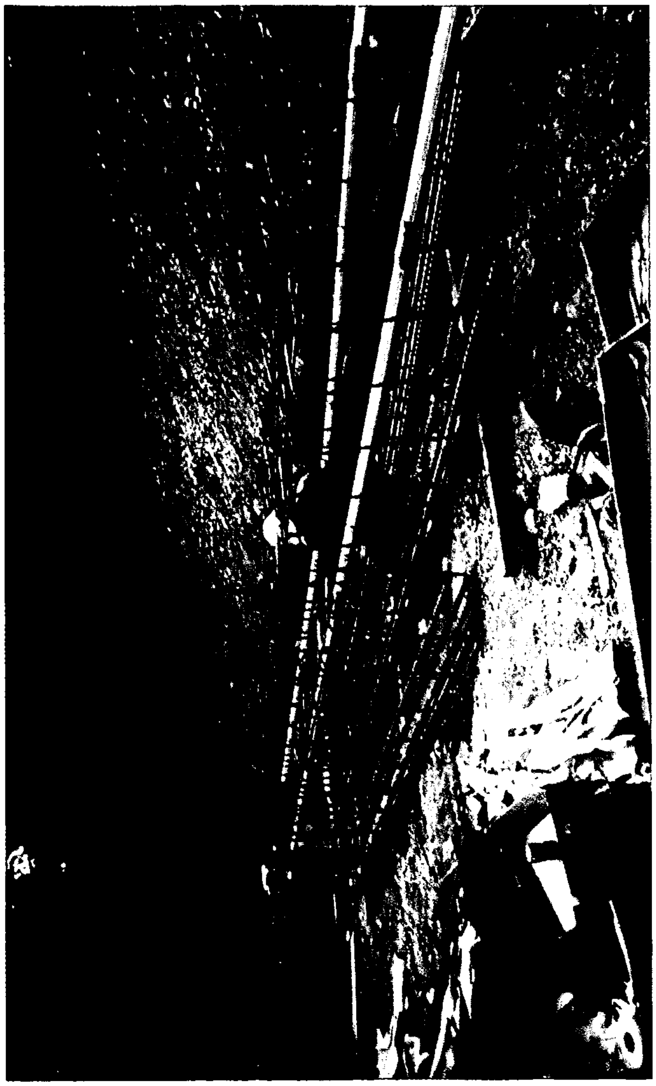
IV.11 Longitudinal section of 26-ft deep shafts (T-21 and T-23)



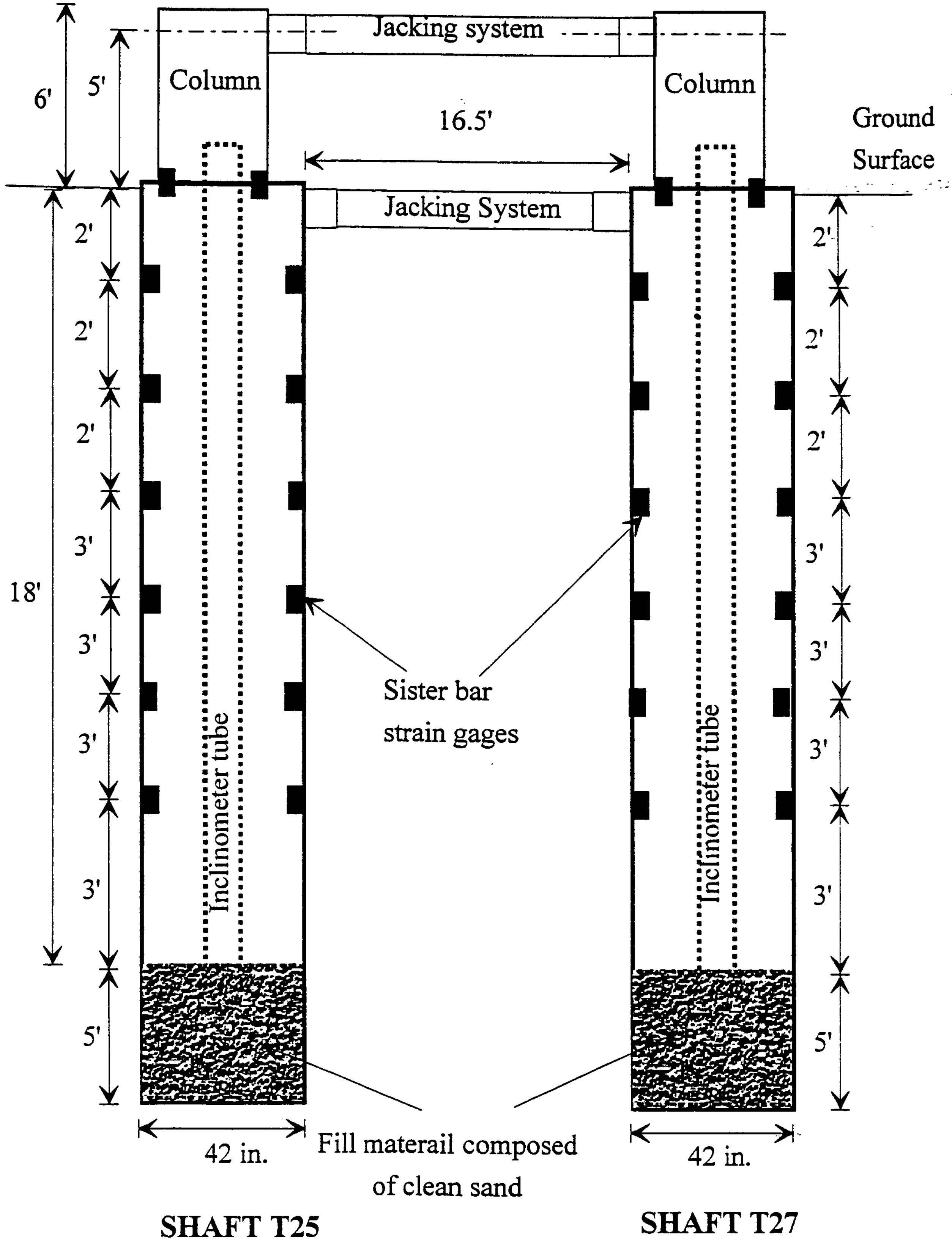
IV. 12 Instrumentation details for the shafts



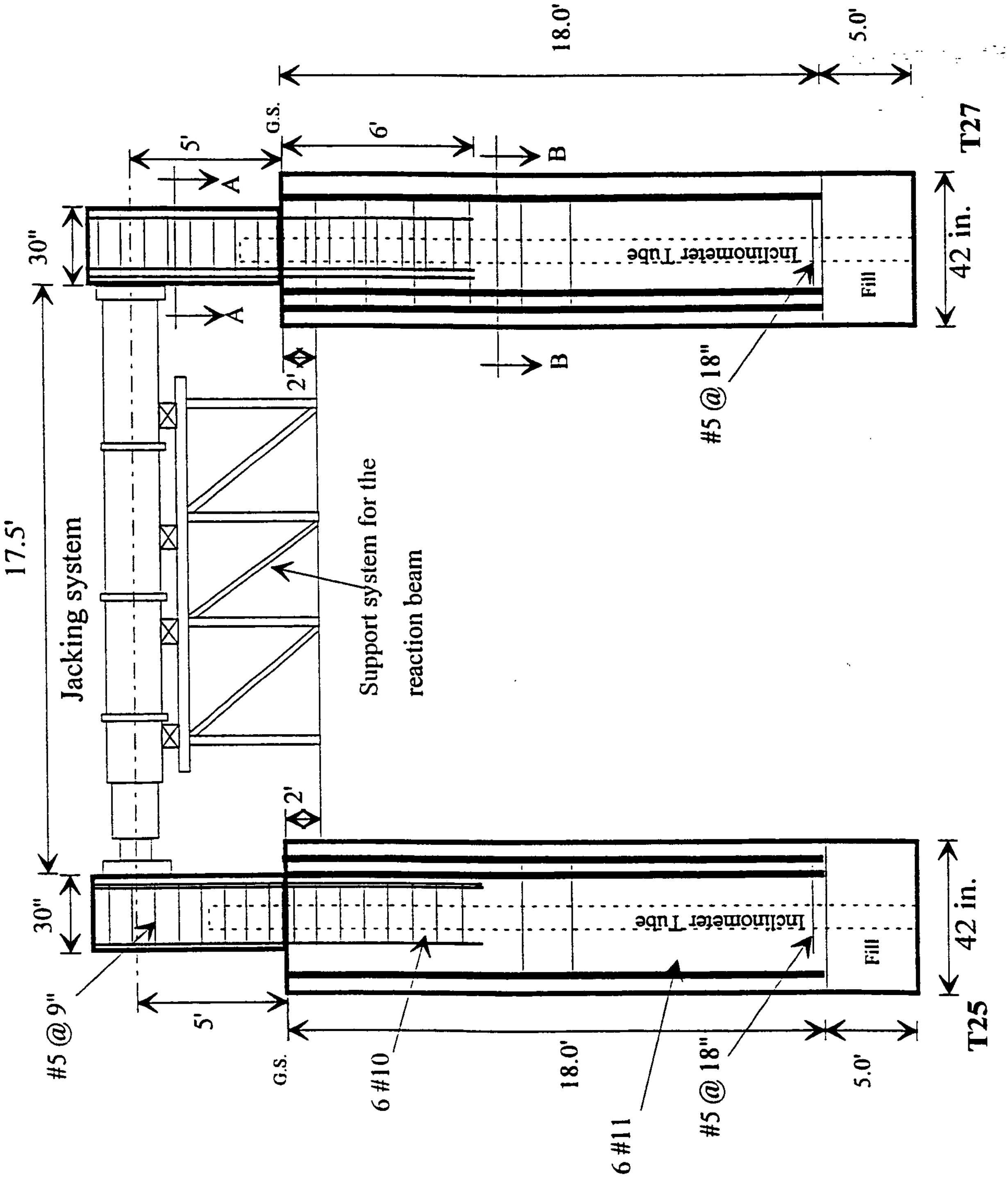
IV.13 Instrumentation details for the shafts



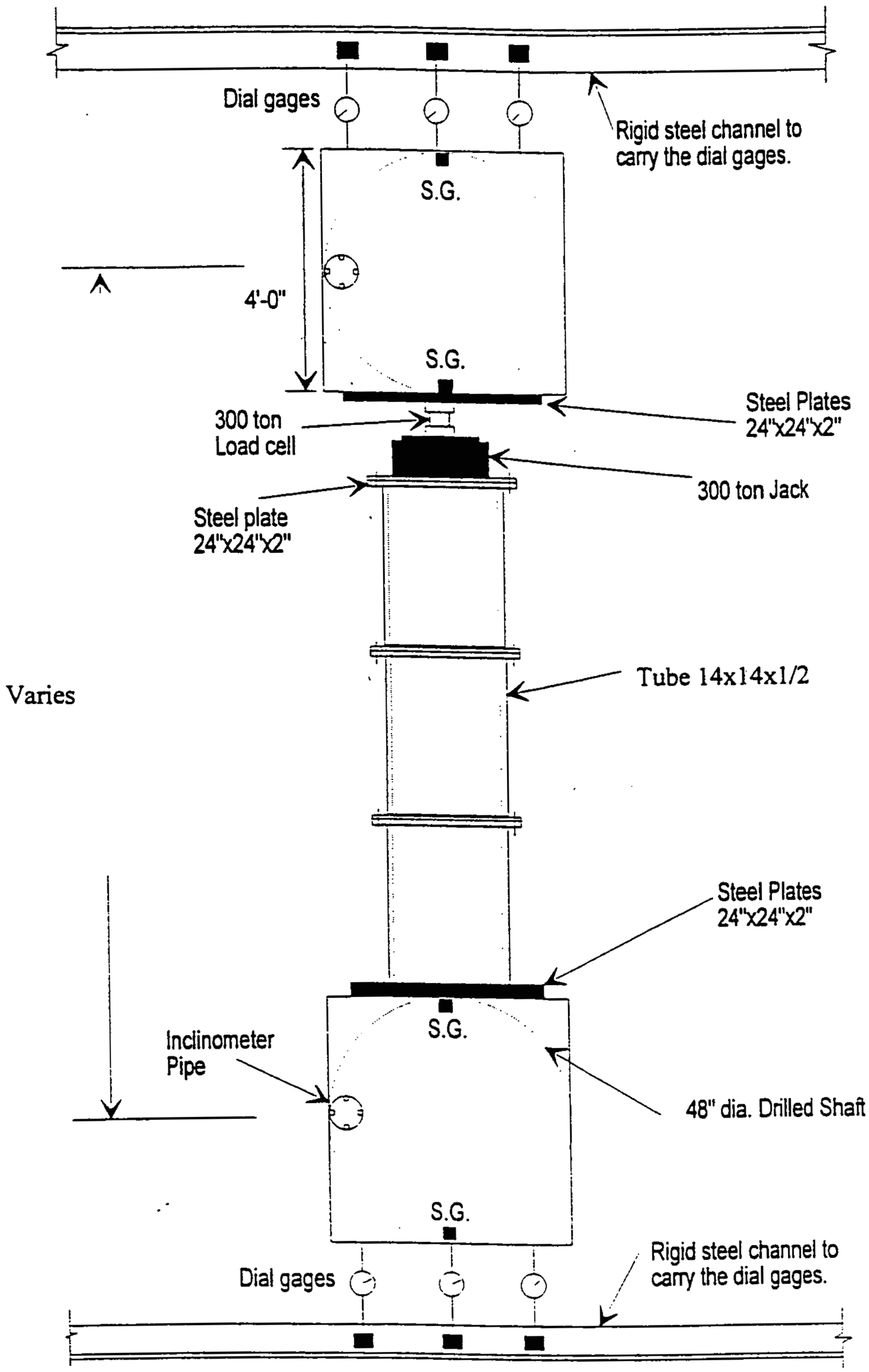
IV. 14 Instrumentation details for the shafts



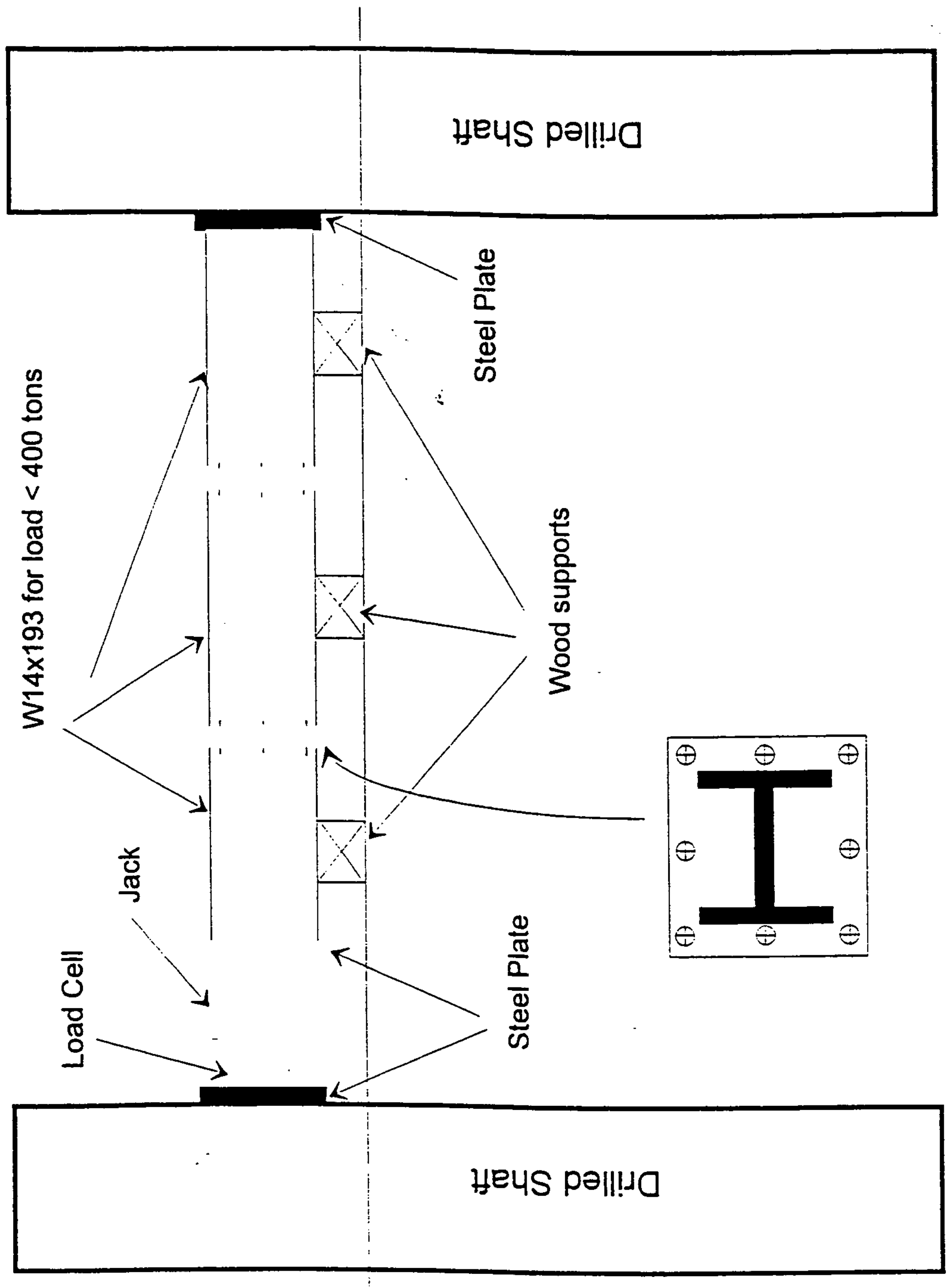
IV.15 Instrumentation details of 18-ft deep shafts (T-25 and T-27)



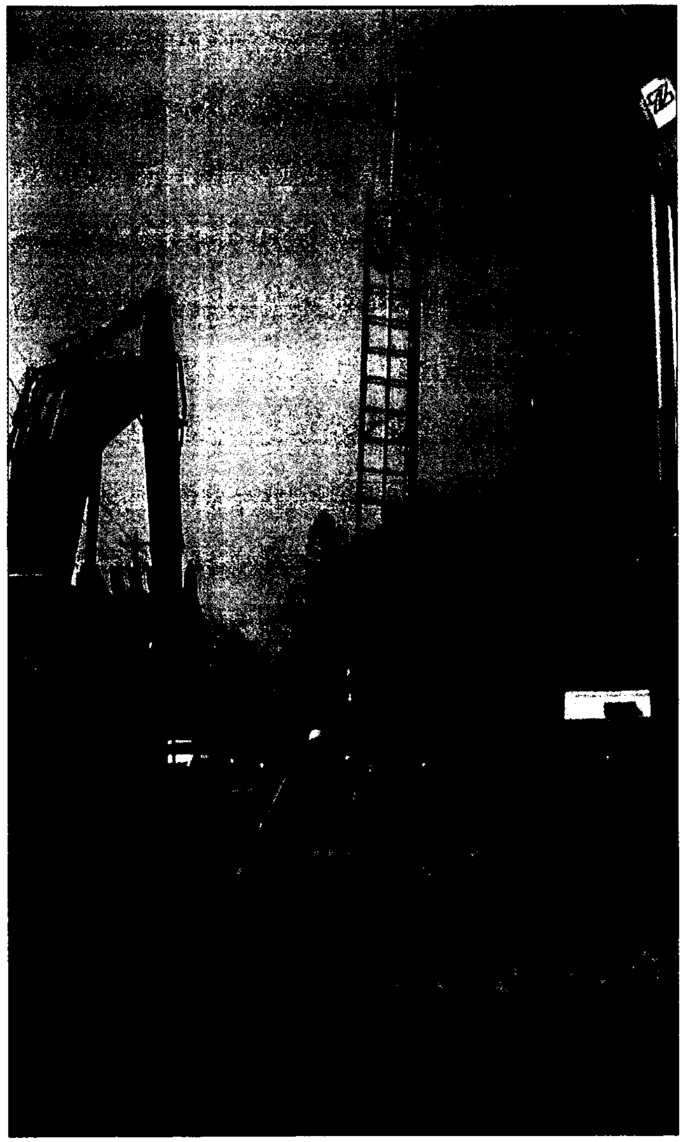
IV.16 Longitudinal section of 18-ft deep shafts (T-25 and T-27)



IV.17 Test set-up



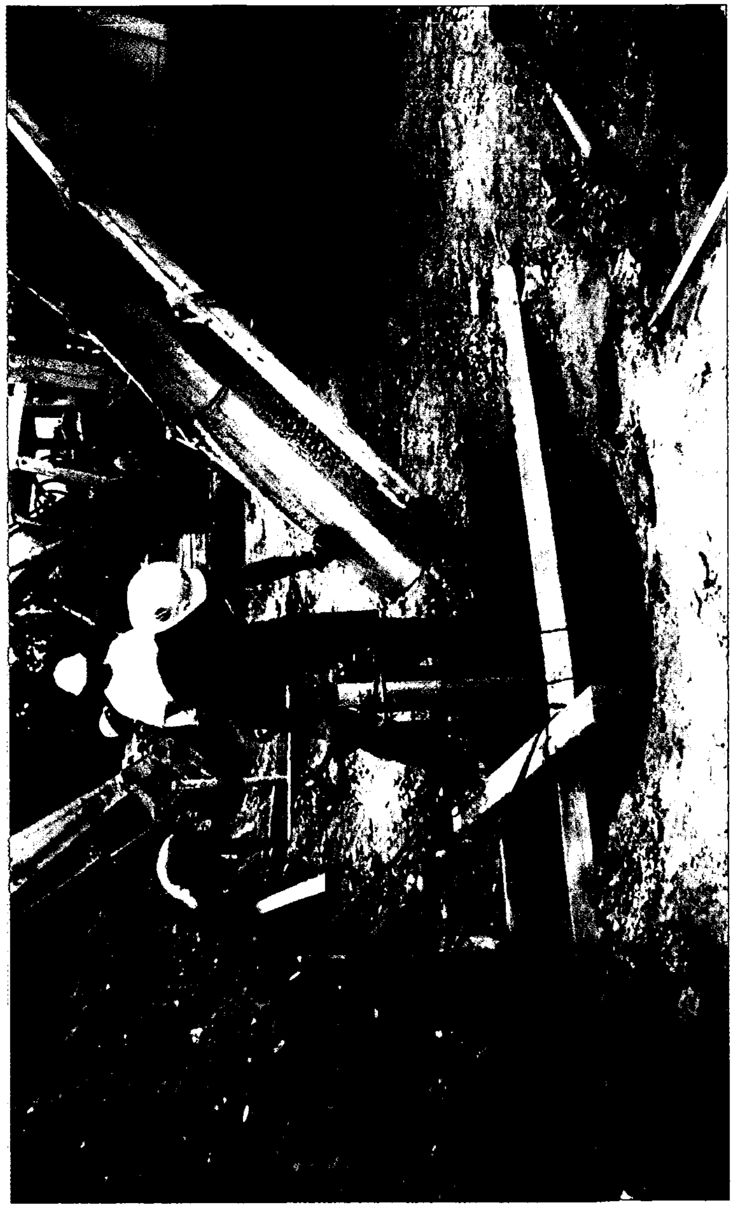
IV.18 Schematic details of the test frame



IV.19 Lowering of the cage for the shafts in progress

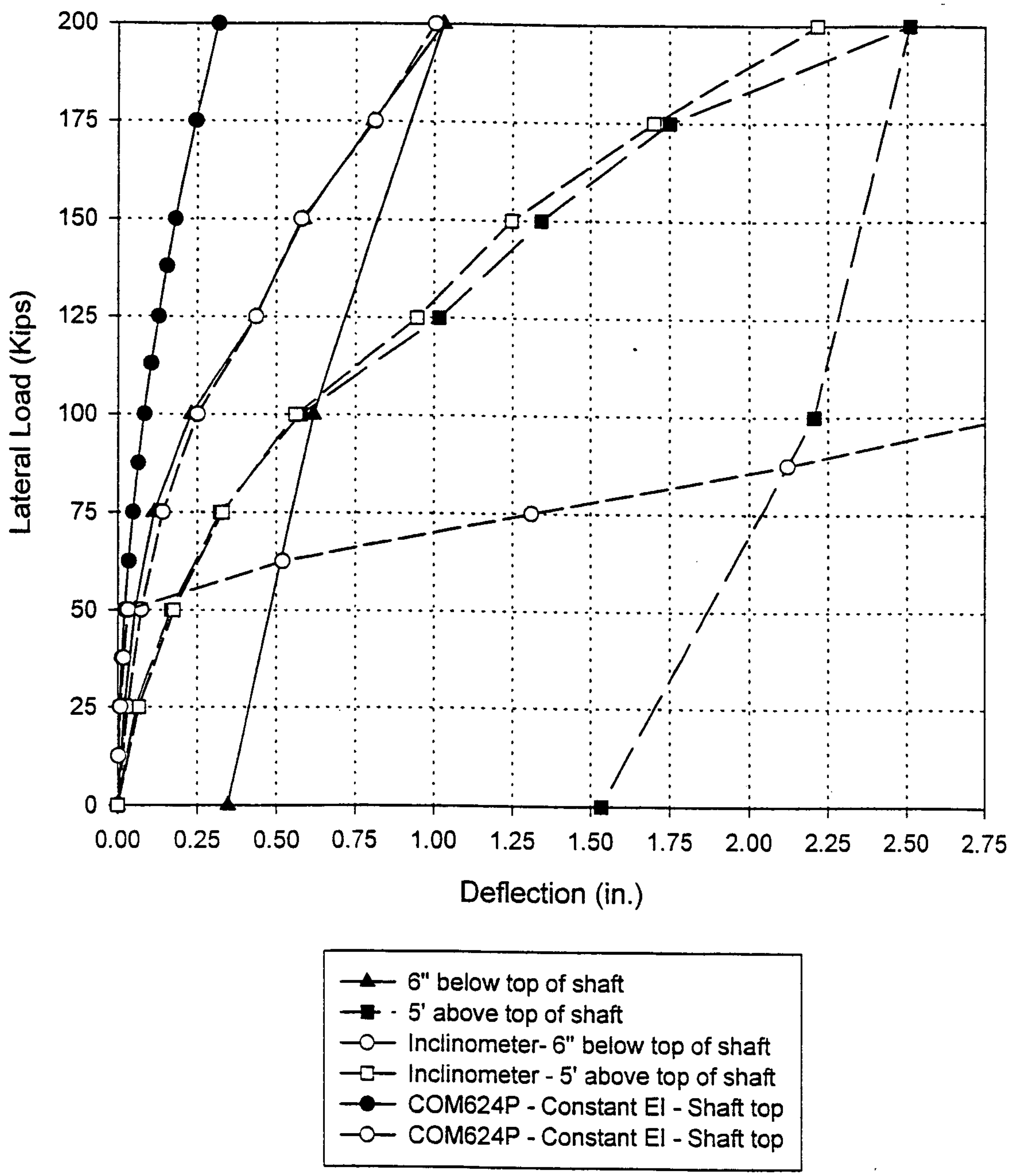
IV. 20 Lowering of the cage for the shafts in progress

IV.21 Backfilling for the bottom of the shafts in progress

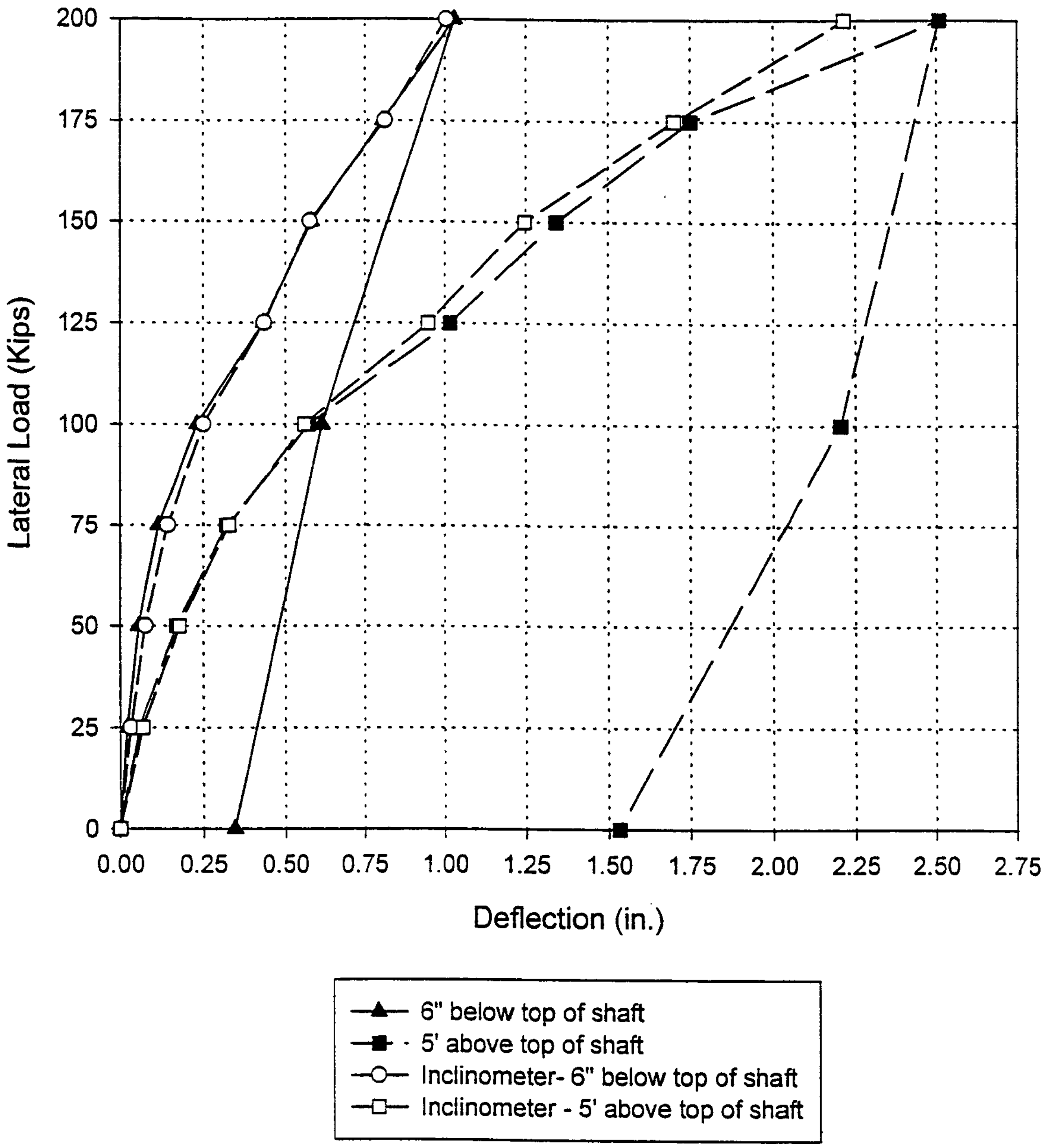


IV.22 Concreting of the shafts in progress

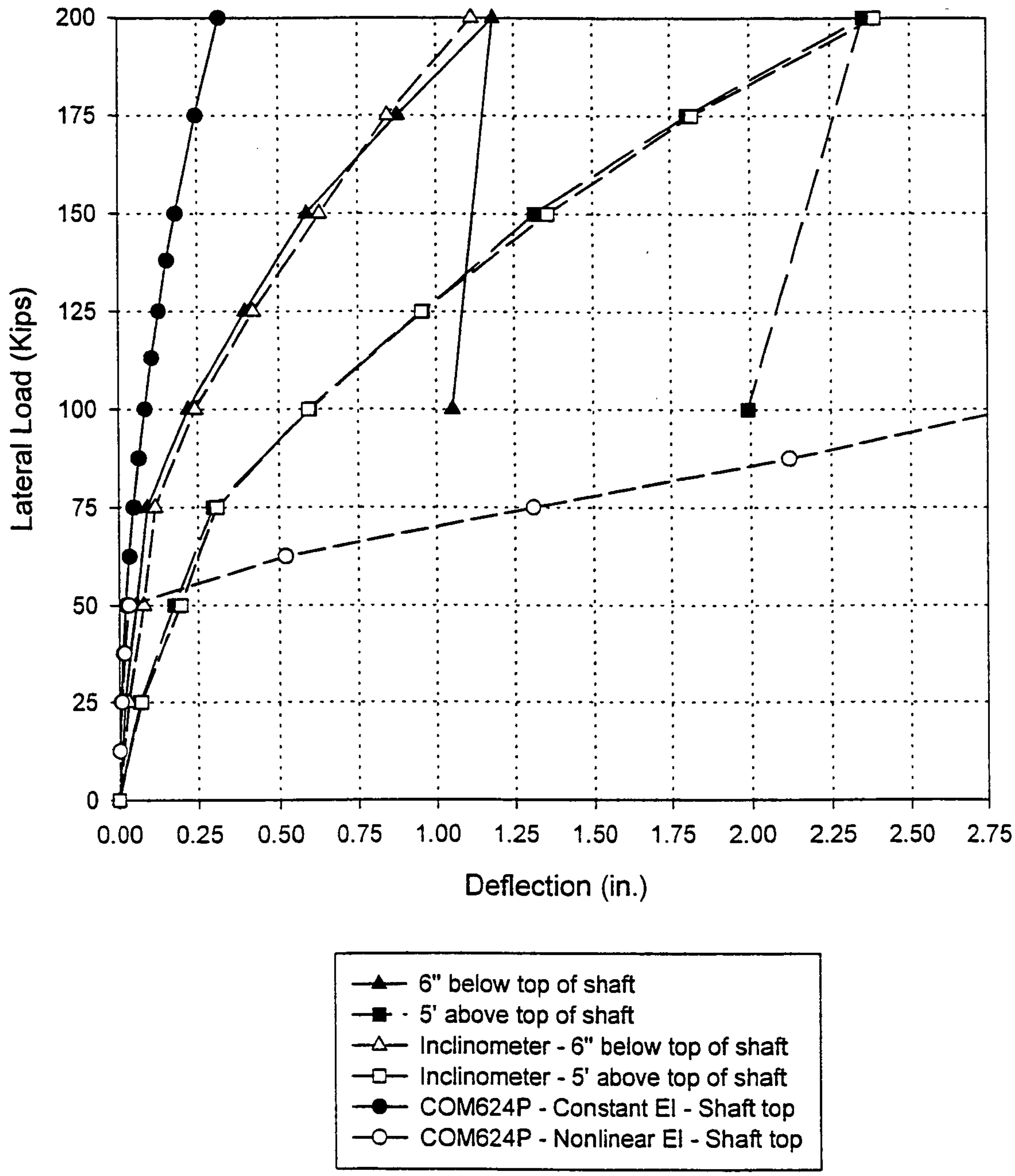
IV.23 Concreting of the shafts in progress



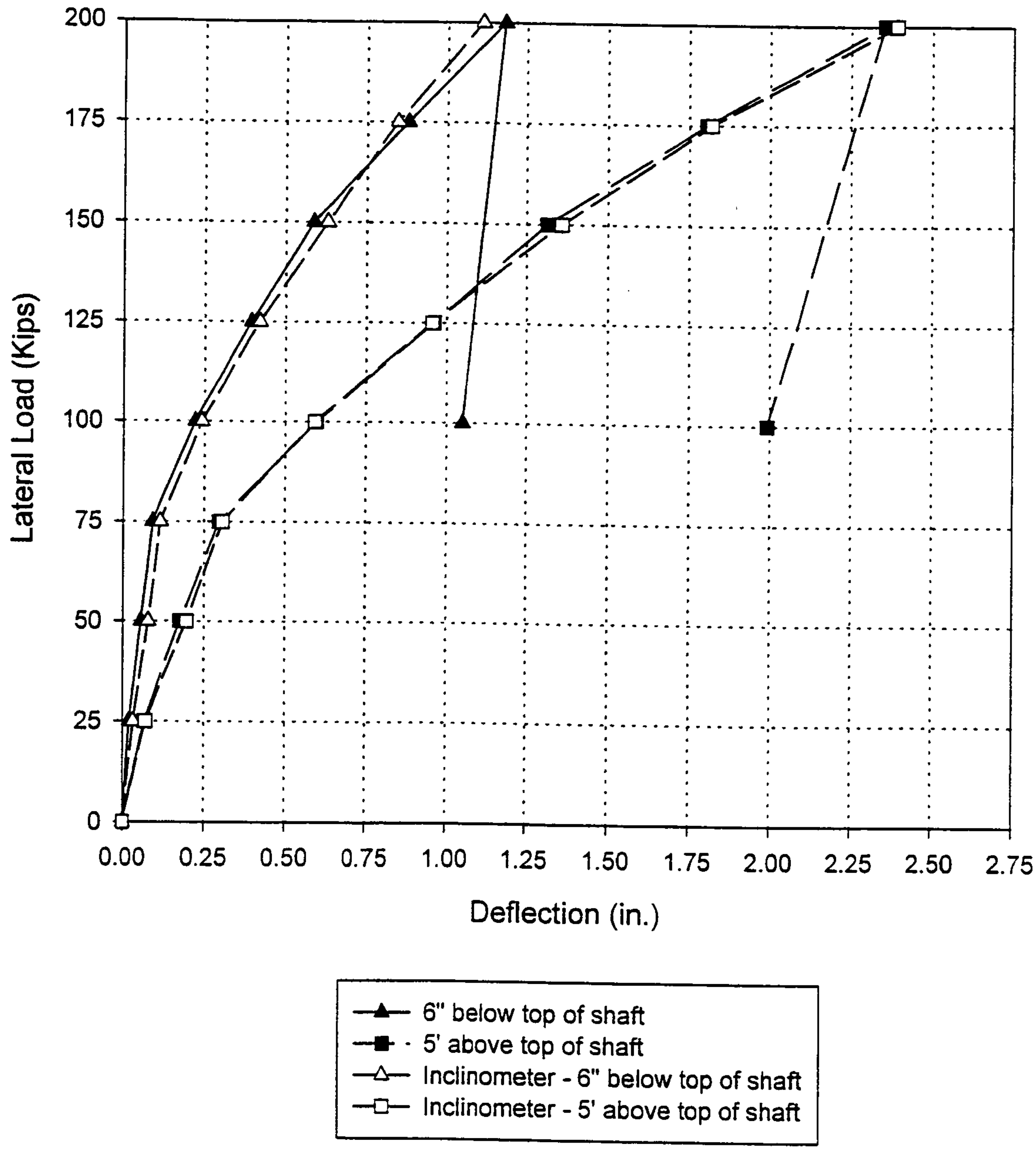
IV.24 Deflection versus lateral load at jack level and top of shaft for 26-ft deep shaft (T-21)



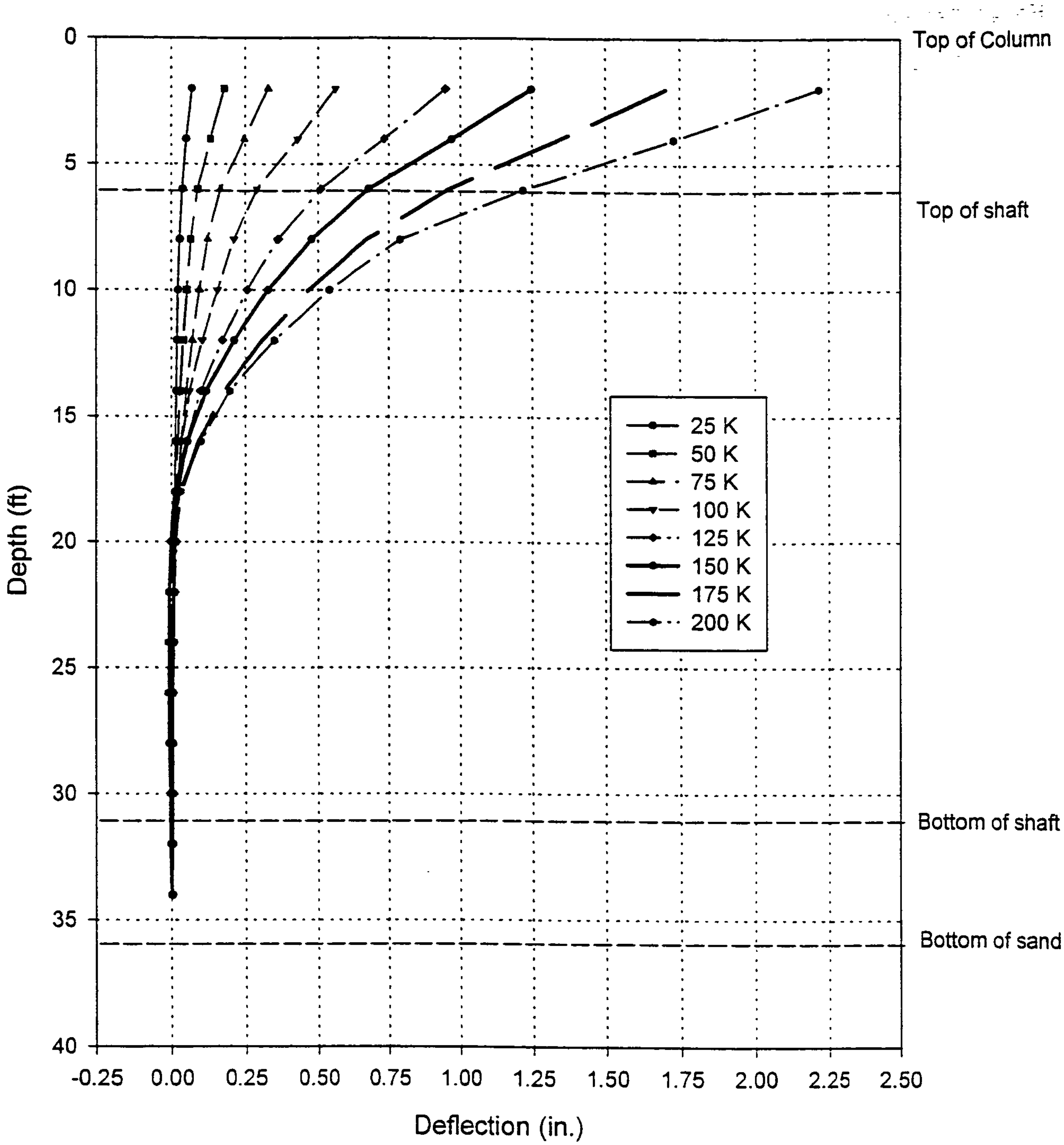
IV.25 Deflection versus lateral load at jack level and top of shaft for 26-ft deep shaft (T-21)



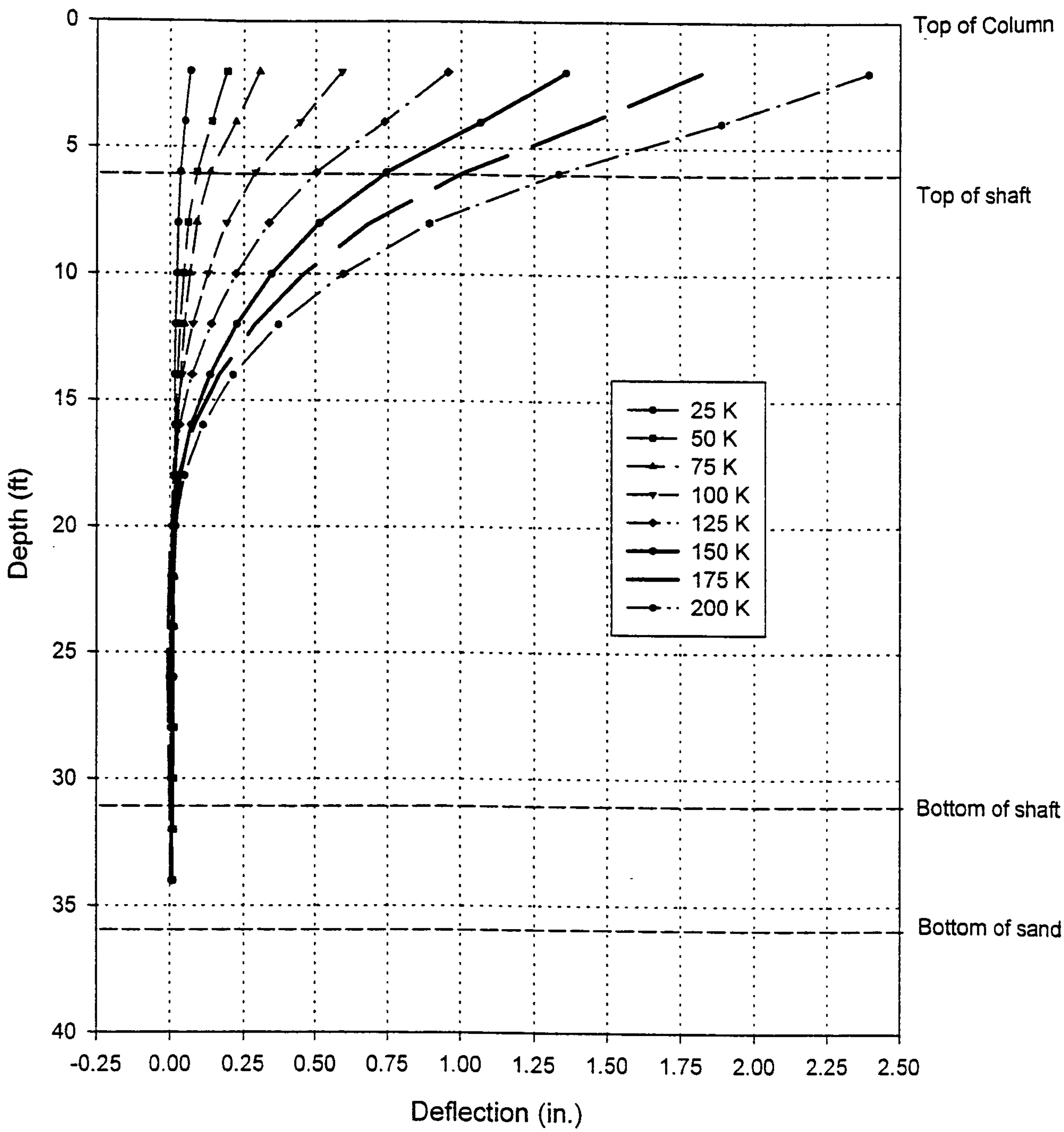
IV.26 Deflection versus lateral load at jack level and top of shaft for 26-ft deep shaft (T-23)



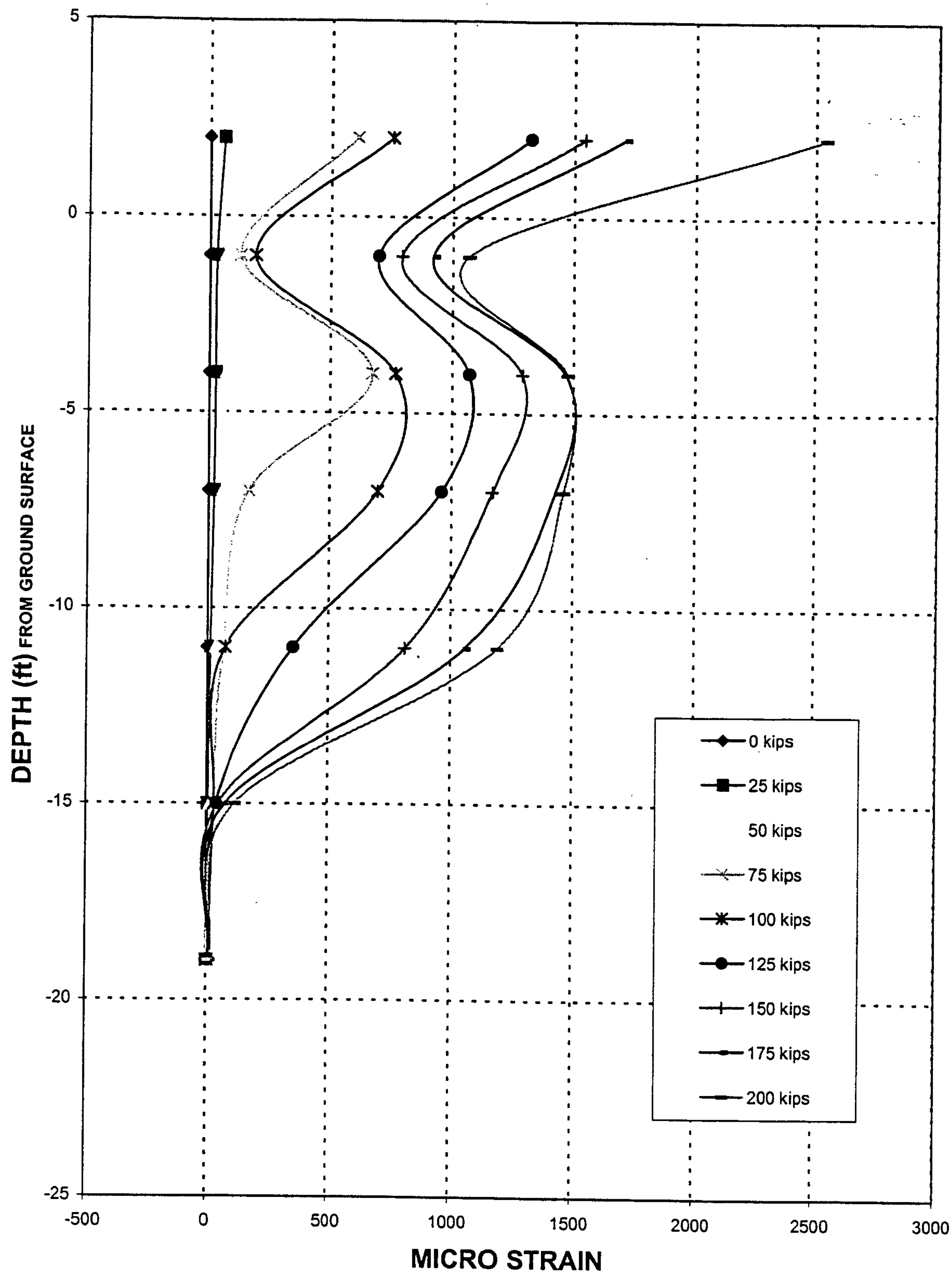
IV.27 Deflection versus lateral load at jack level and top of shaft for 26-ft deep shaft (T-23)



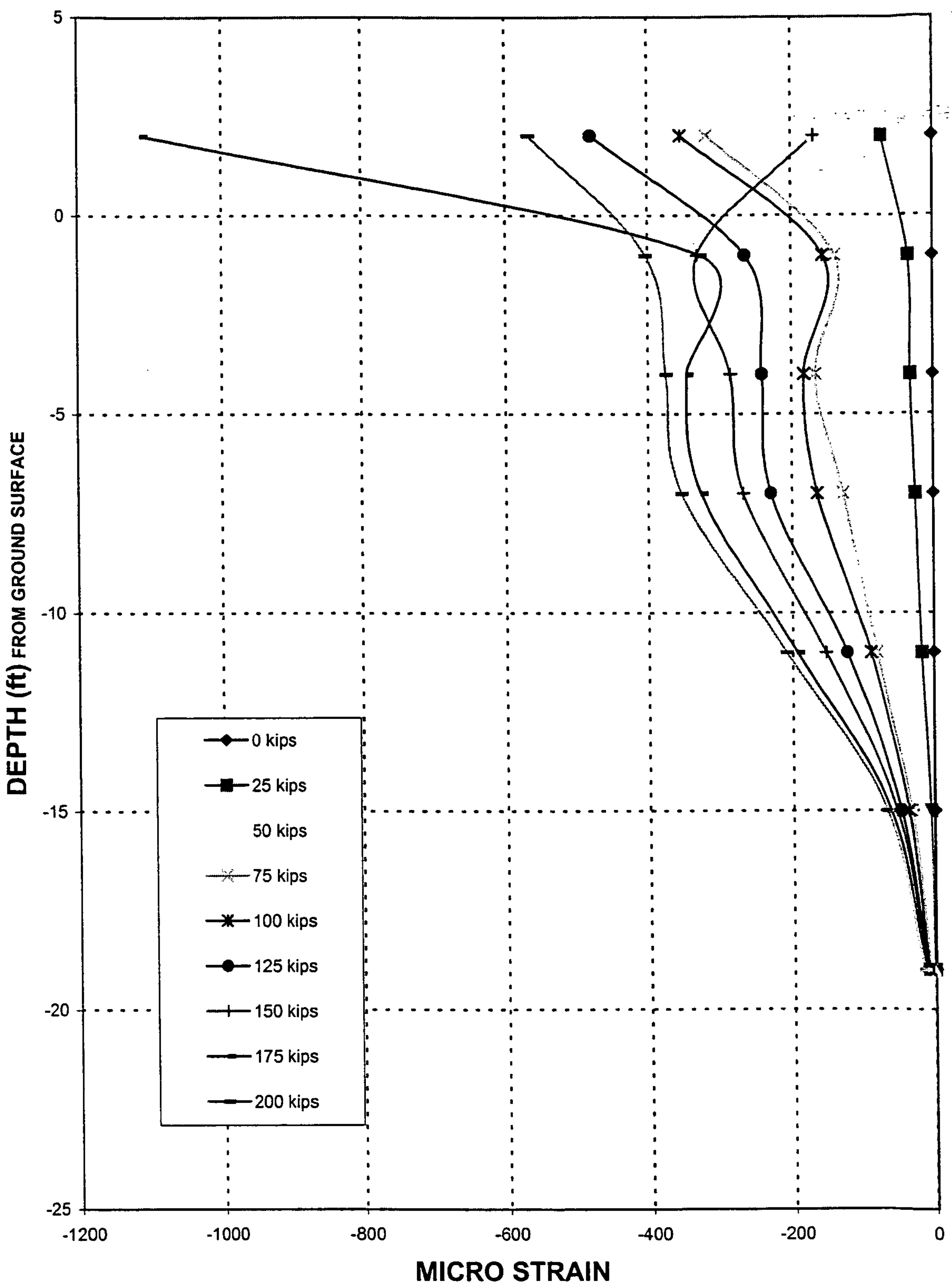
IV.28 Deflection along the length of the 26-ft deep shaft (T-21)



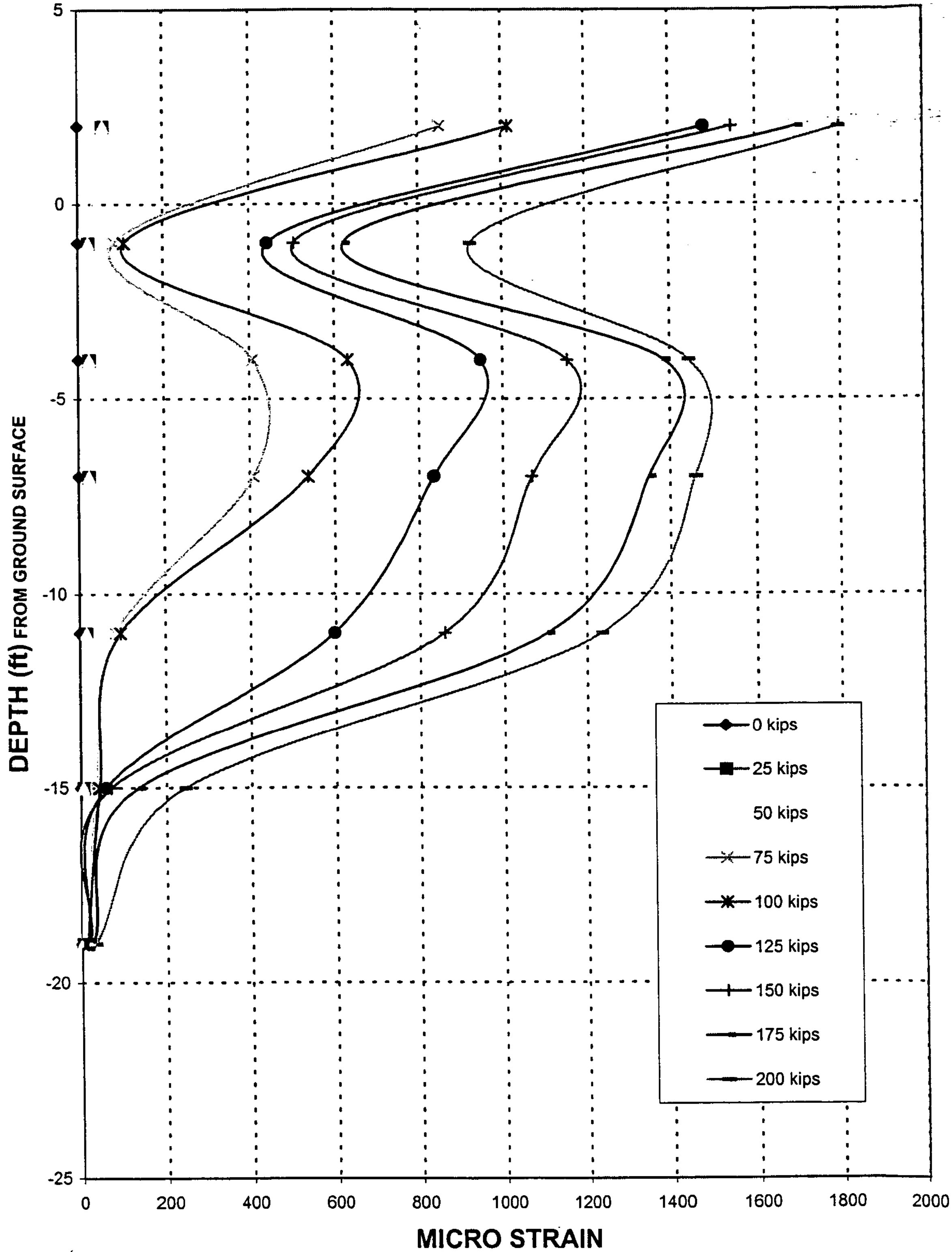
IV.29 Deflection along the length of the 26-ft deep shaft (T-23)



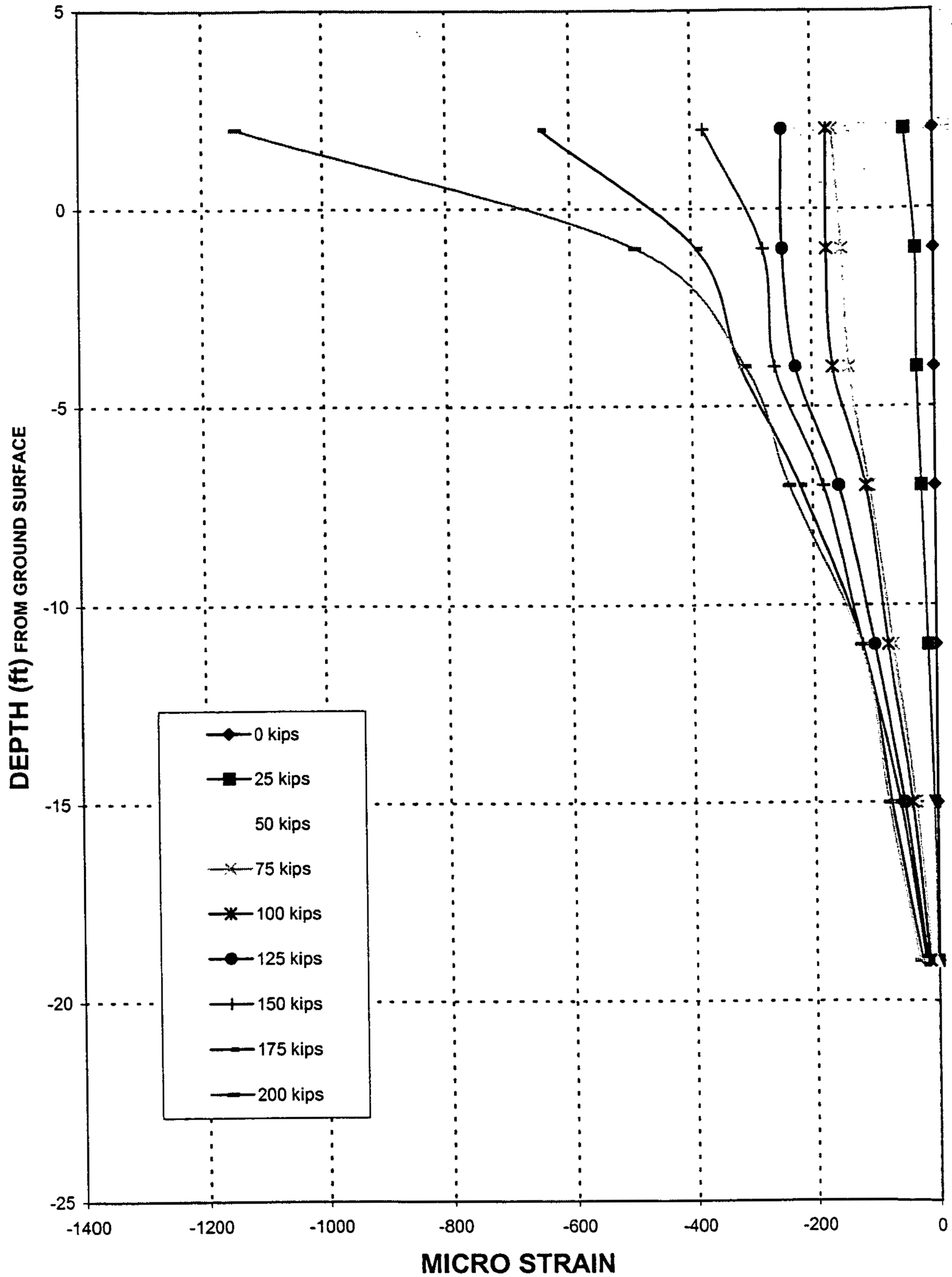
IV.30 Observed strain along the length of the 26-ft deep shaft (T-21 – tension face)



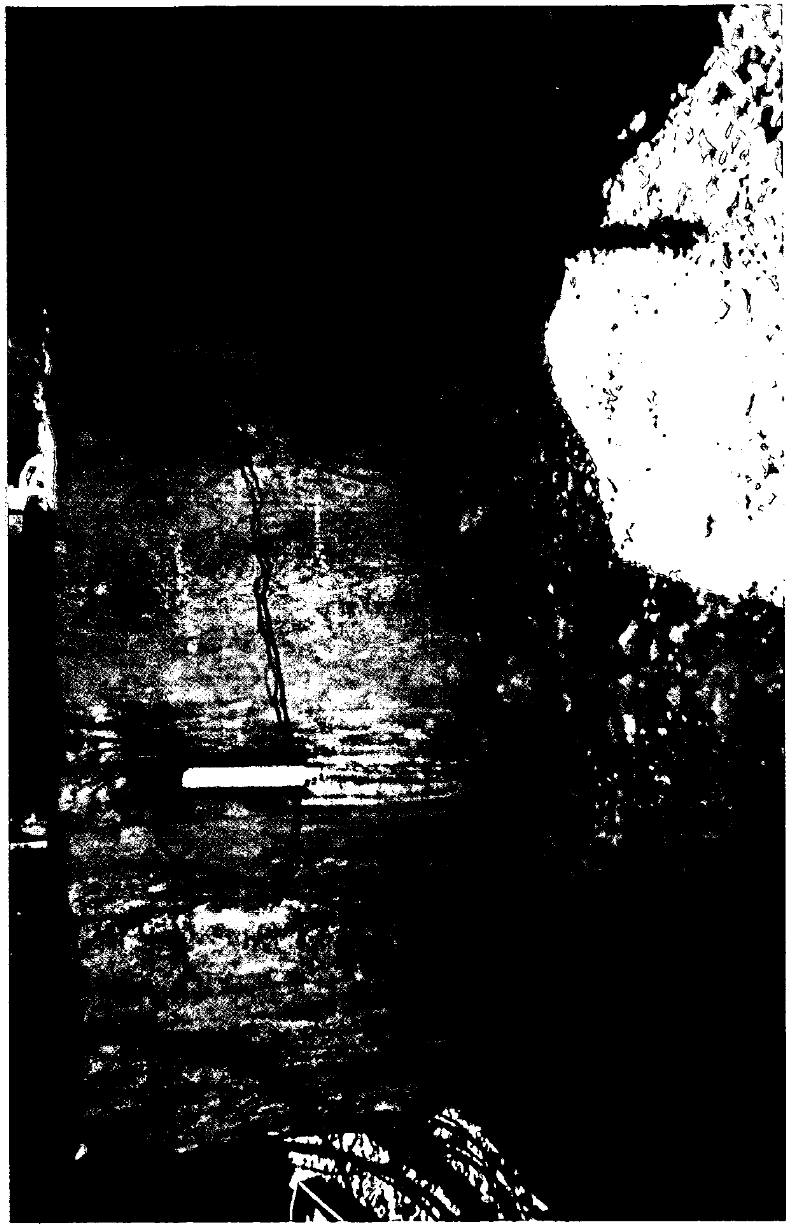
IV.31 Observed strain along the length of the 26-ft deep shaft (T-21 – compression face)



IV.32 Observed strain along the length of the 26-ft deep shaft (T-23 – tension face)



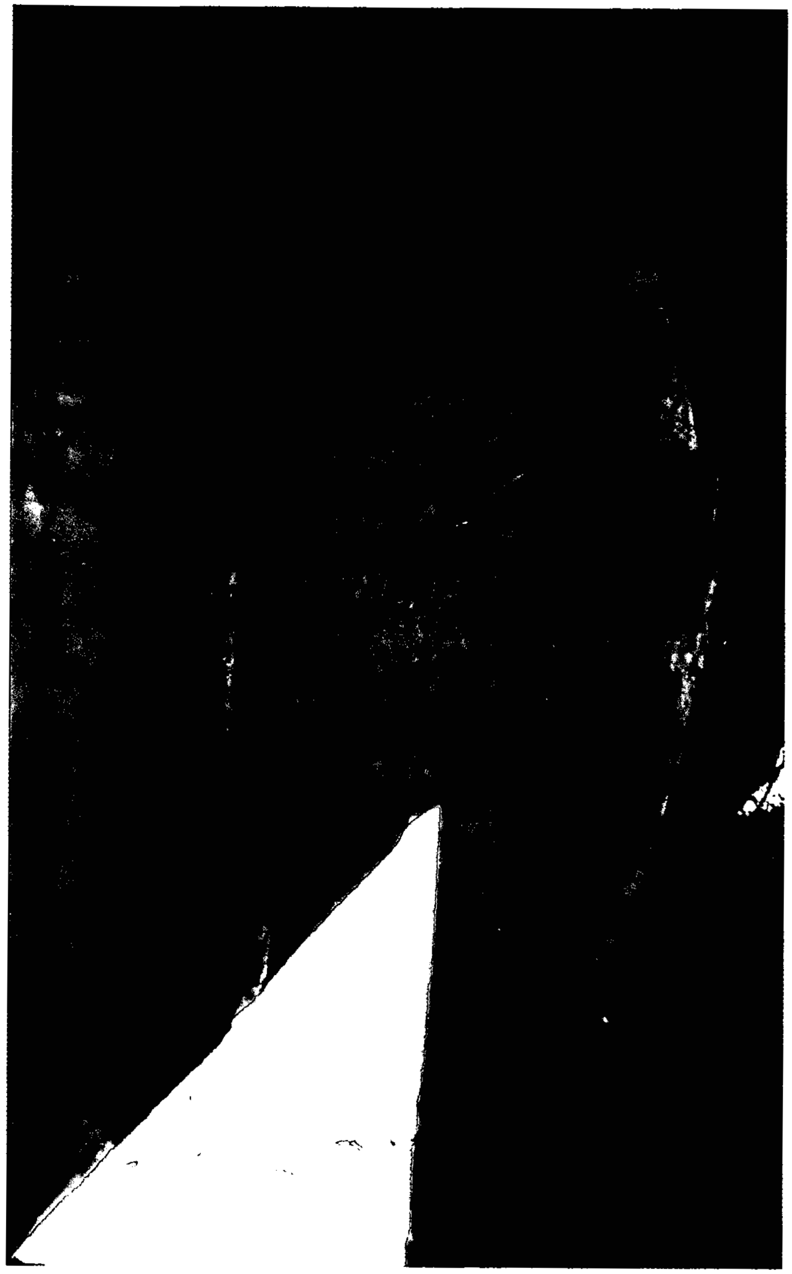
IV.33 Observed strain along the length of the 26-ft deep shaft (T-23 – compression face)



IV.34 Crack pattern of test shaft T-21

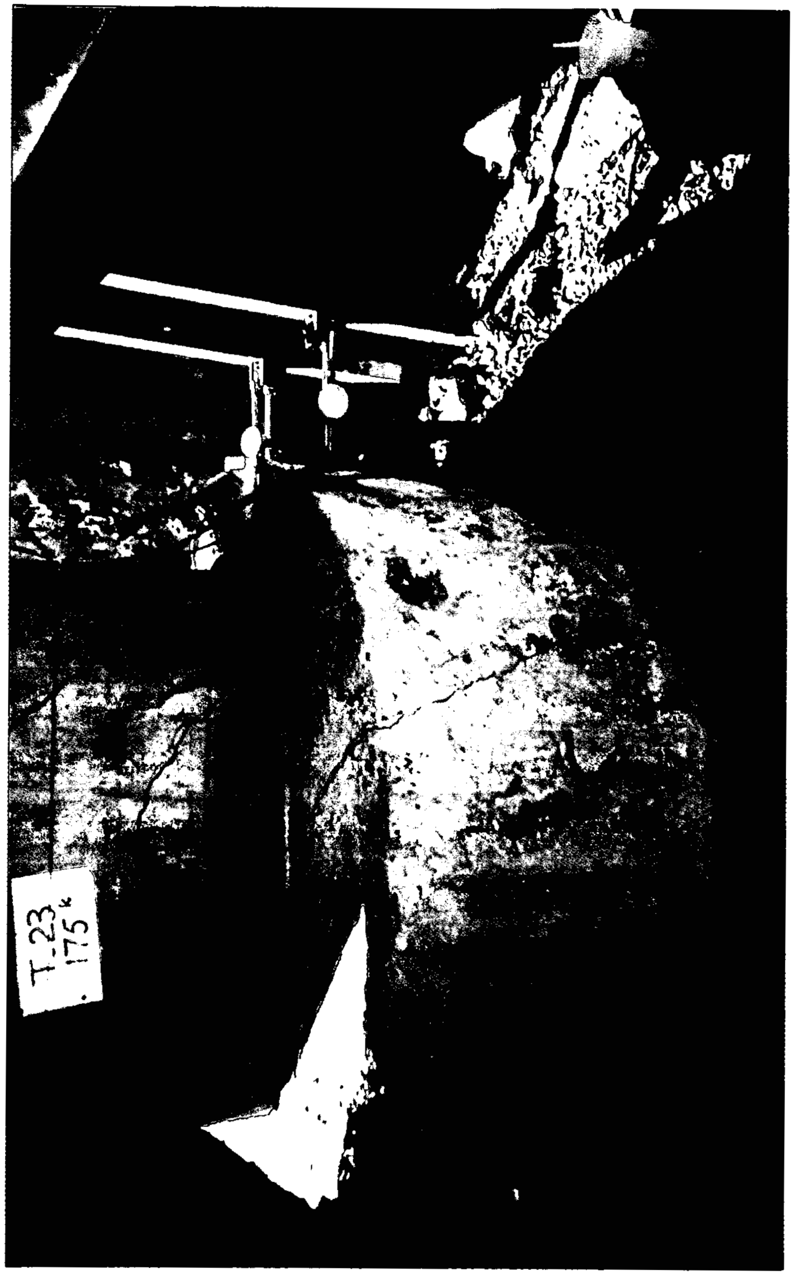
IV. 35 Crack pattern of test shaft T- 21

IV..36 Crack pattern of test shaft T – 21

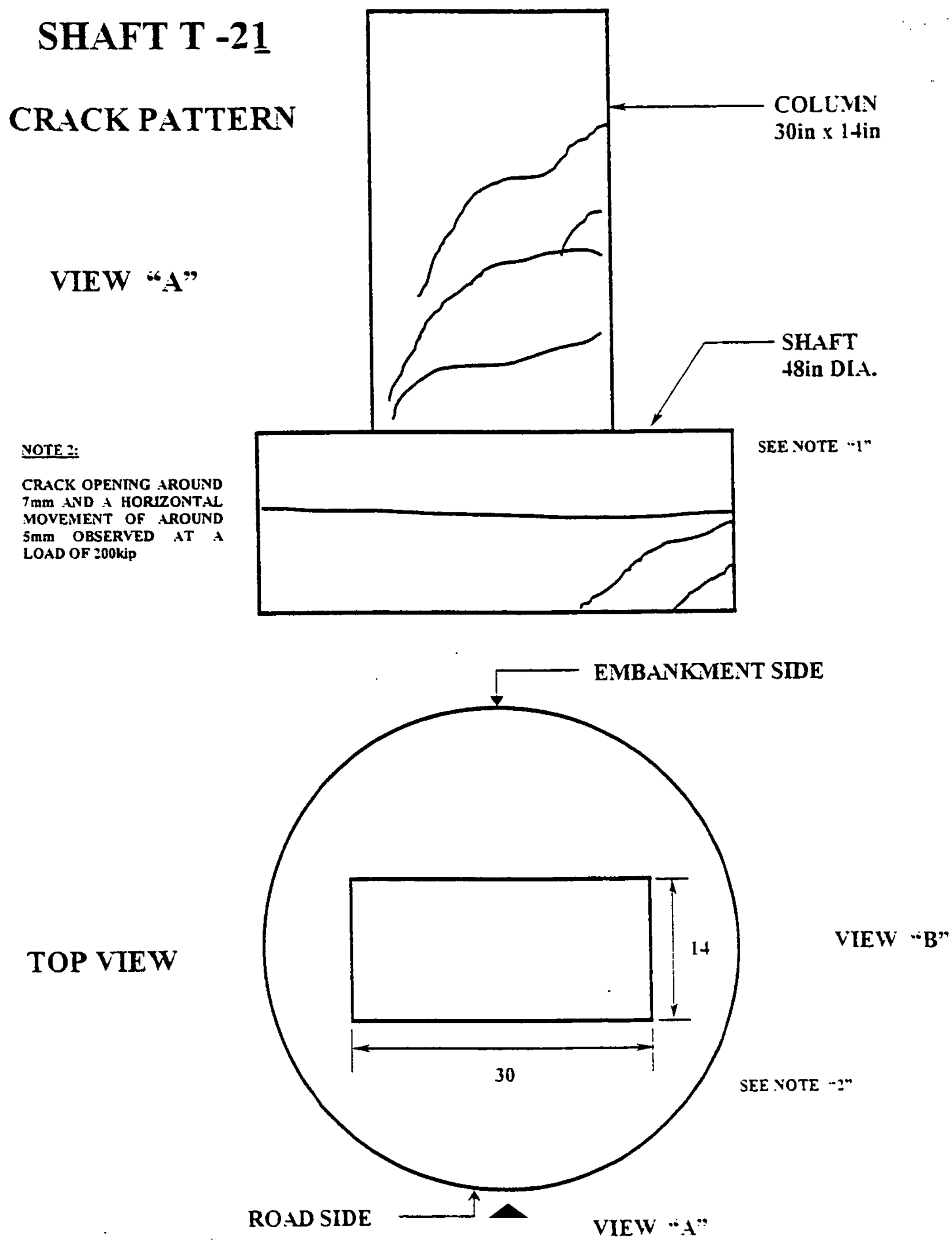


IV.37 Crack pattern of test shaft T-23

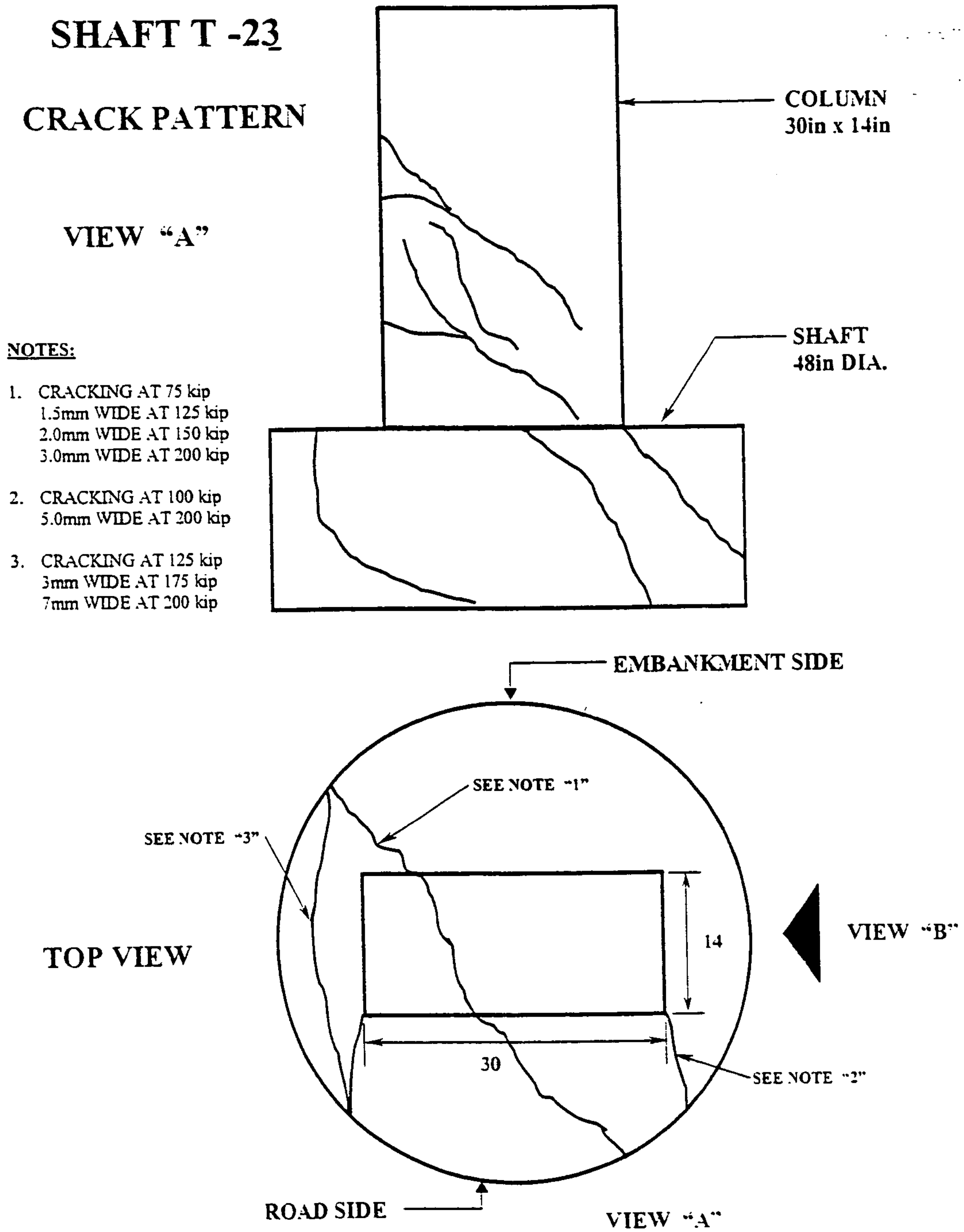
IV.38 Crack pattern of test shaft T – 23



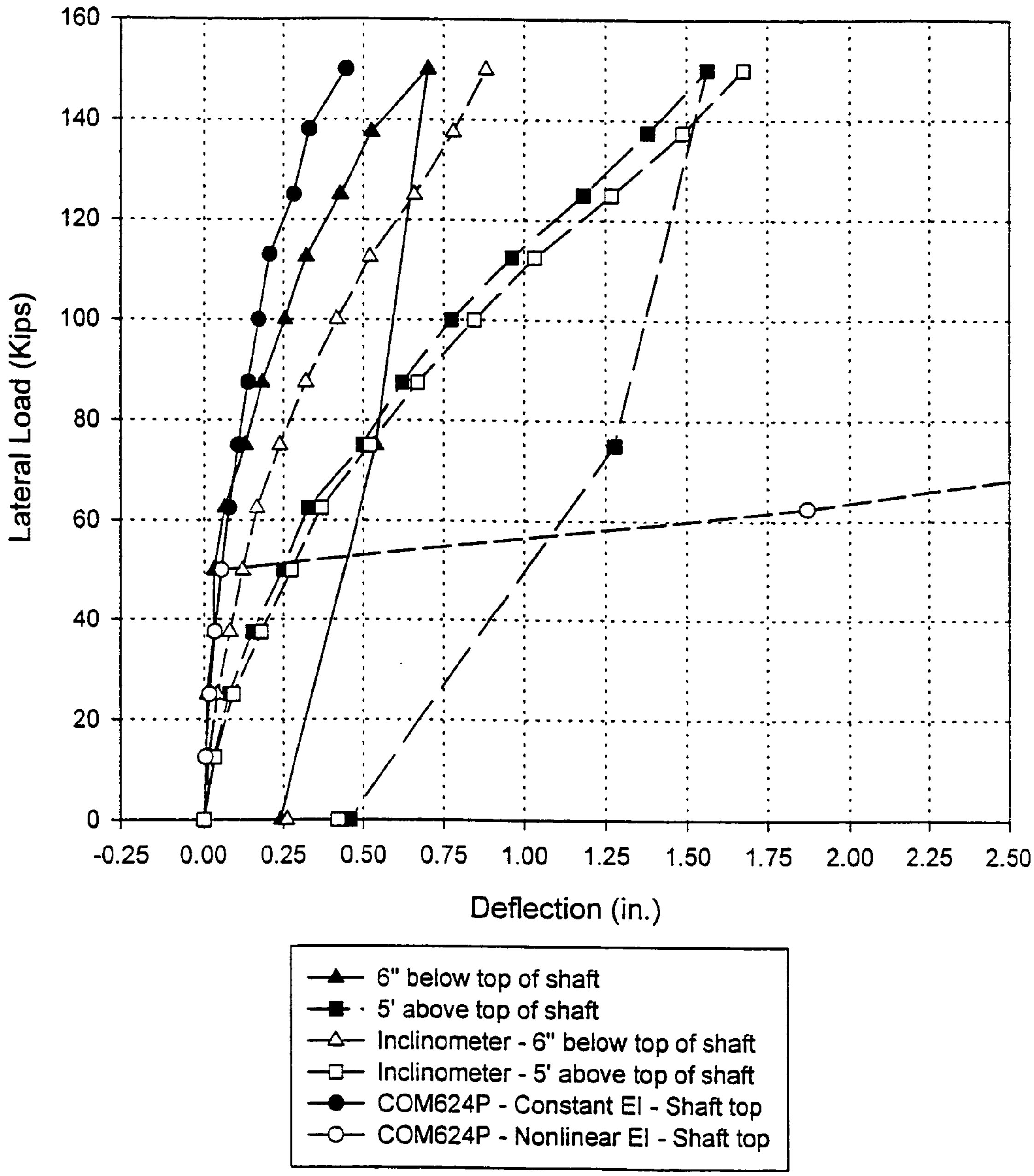
IV.39 Crack pattern of test shaft T – 23



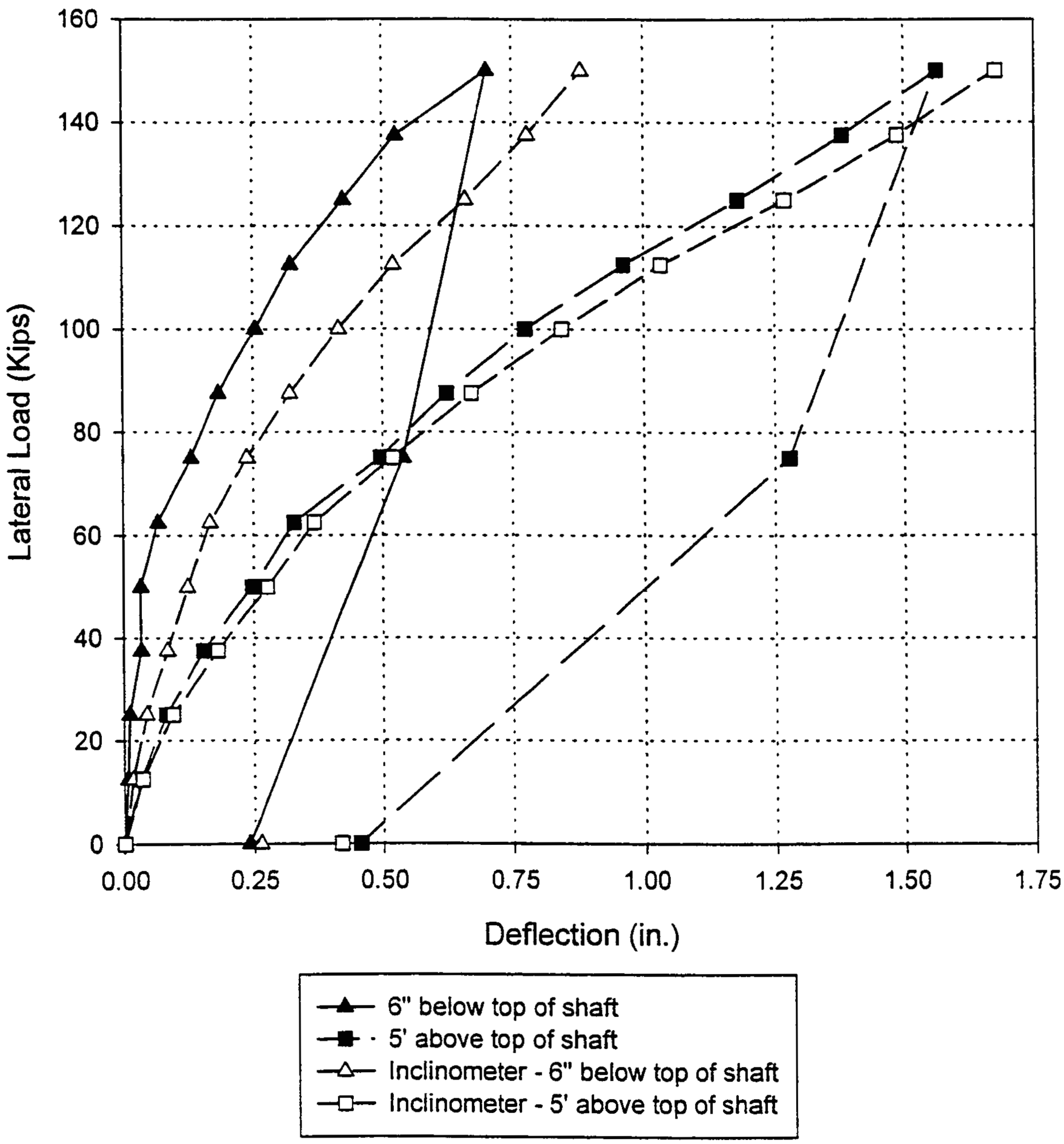
IV.40(a) Observed crack pattern of Shaft T-21 at various load stages



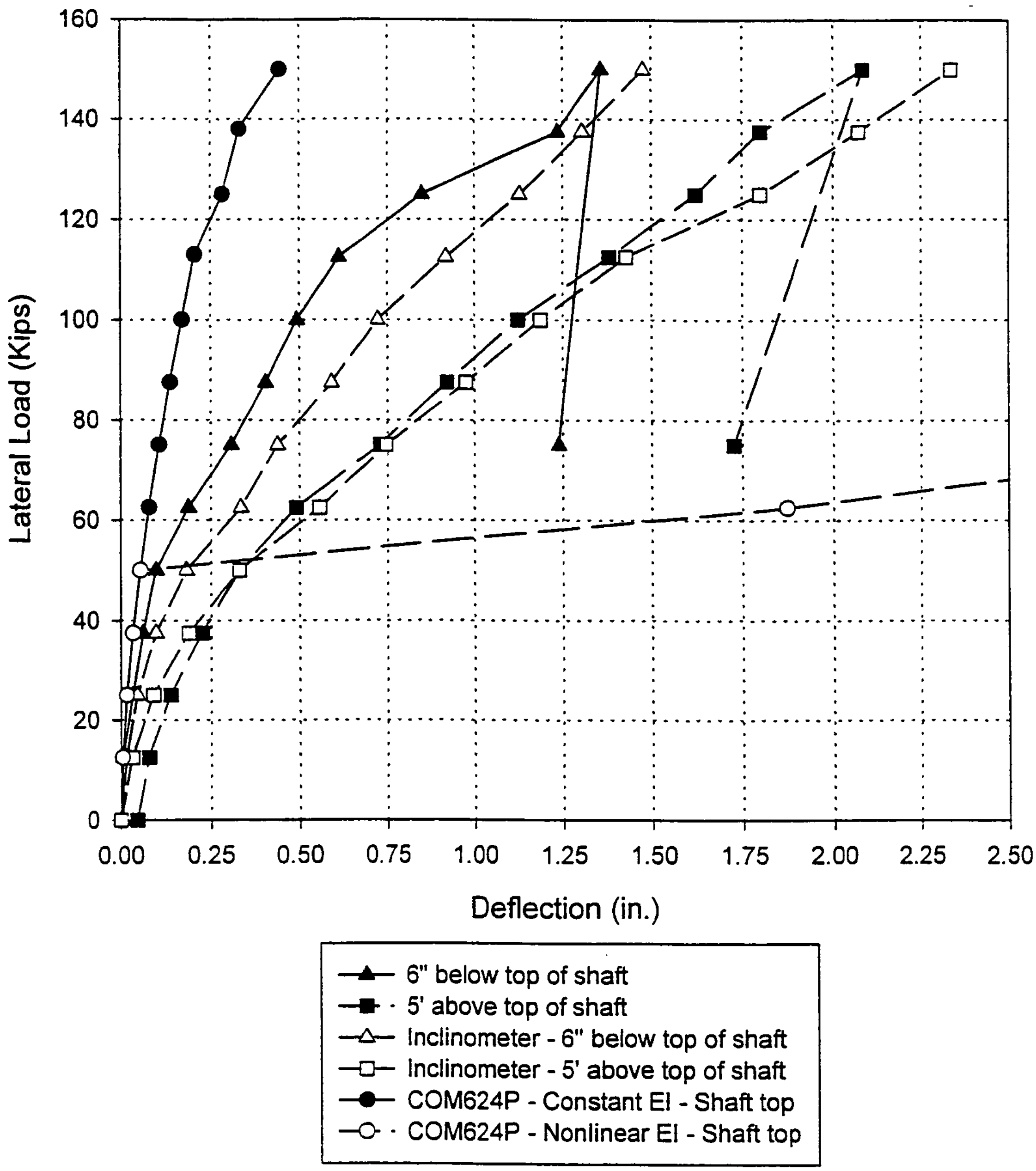
IV.40(b) Observed crack pattern of Shaft T-23 at various load stages



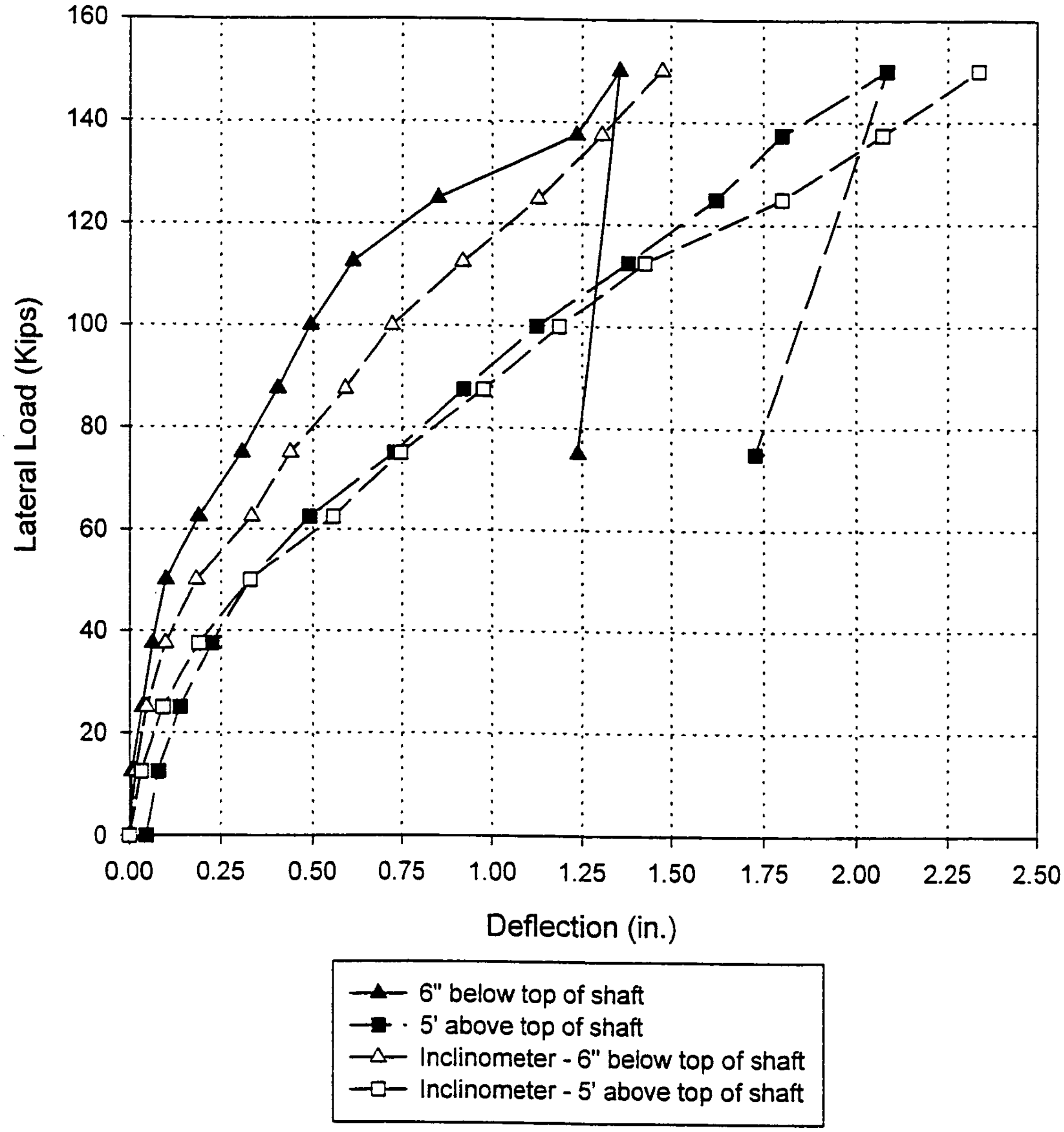
IV.41 Deflection versus lateral load at jack level and top of shaft for 18-ft deep shaft (T-25)



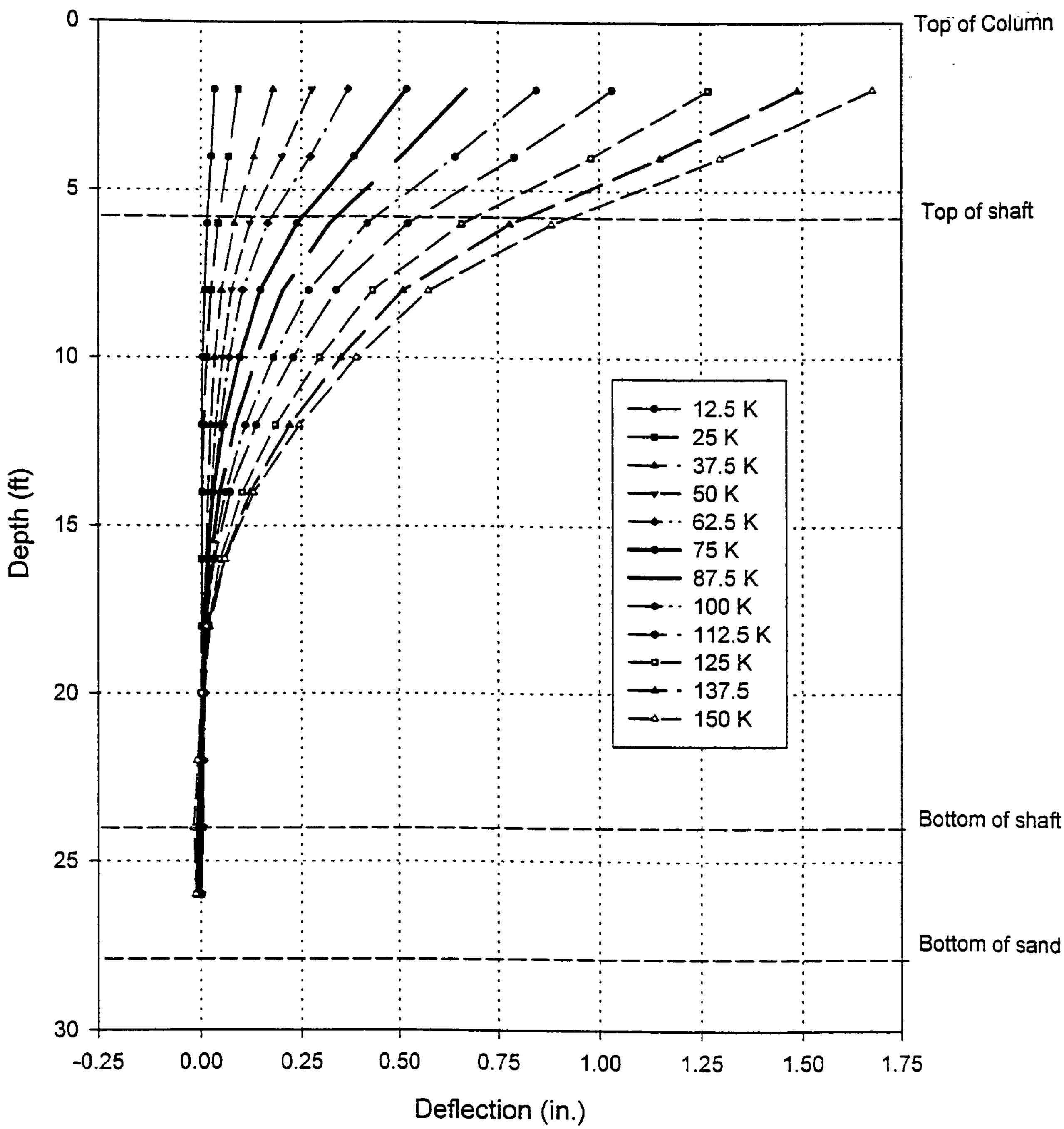
IV.42 Deflection versus lateral load at jack level and top of shaft for 18-ft deep shaft (T-25)



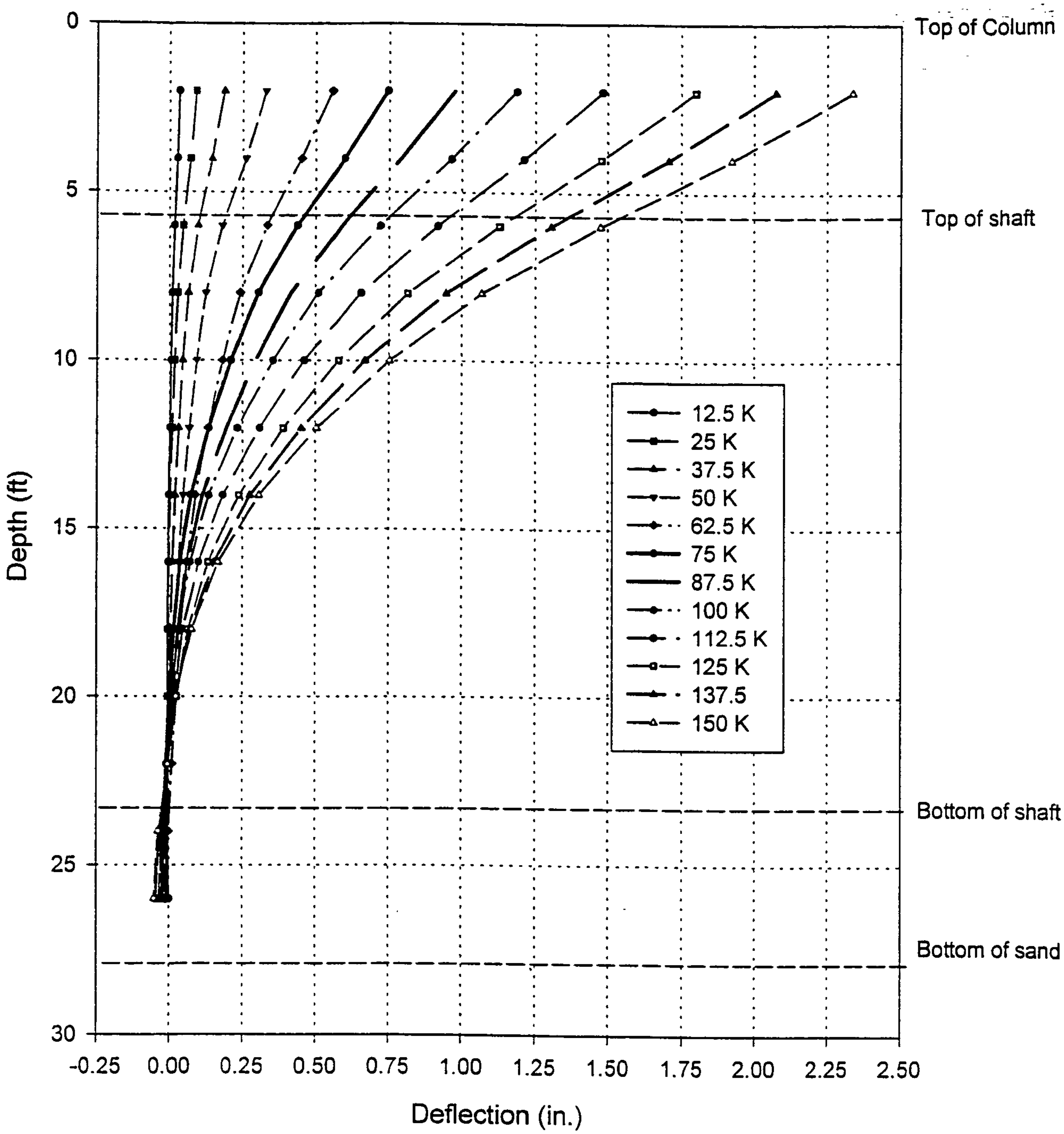
IV.43 Deflection versus lateral load at jack level and top of shaft for 18-ft deep shaft (T-27)



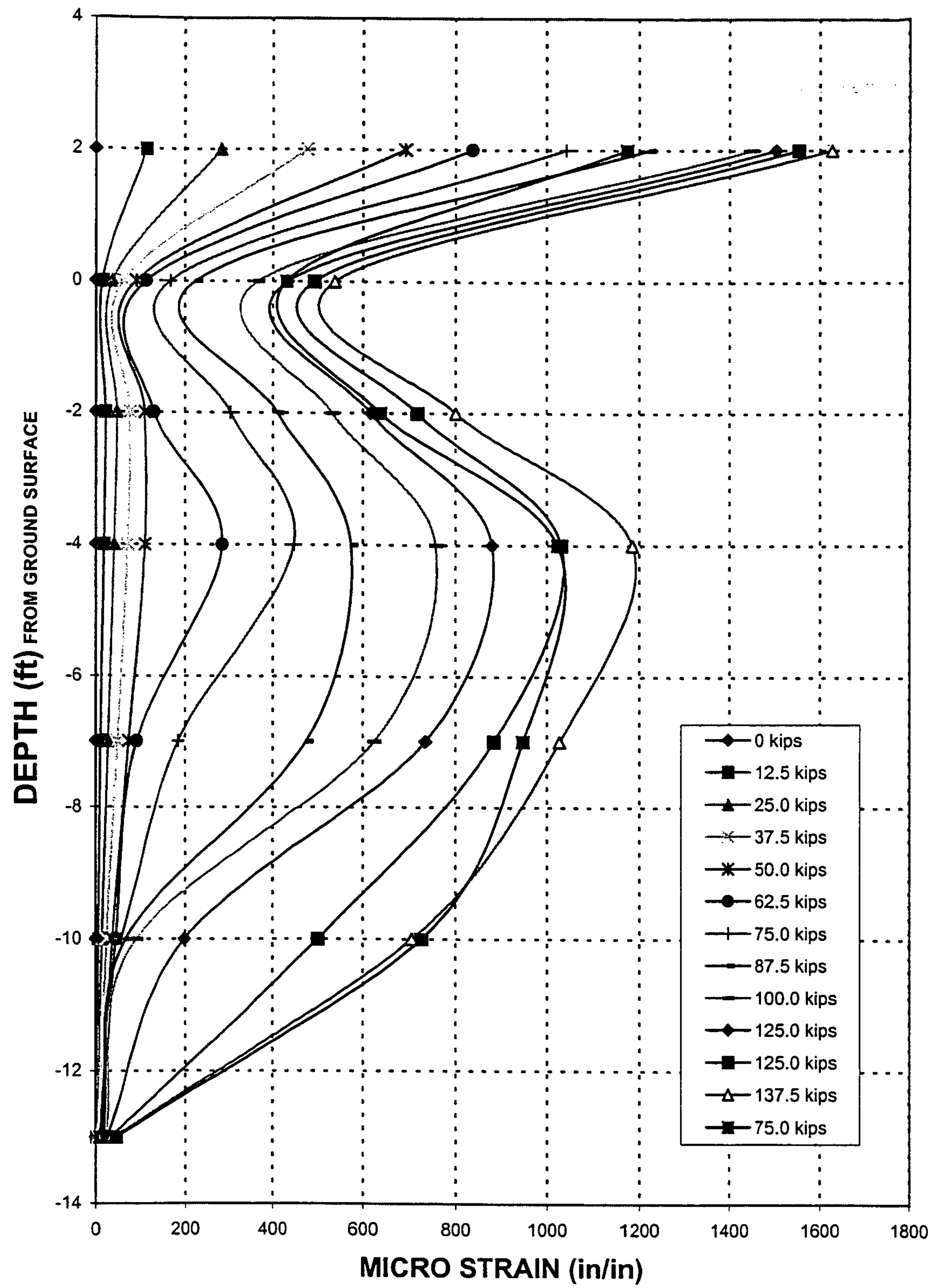
IV.44 Deflection versus lateral load at jack level and top of shaft for 18-ft deep shaft (T-27)



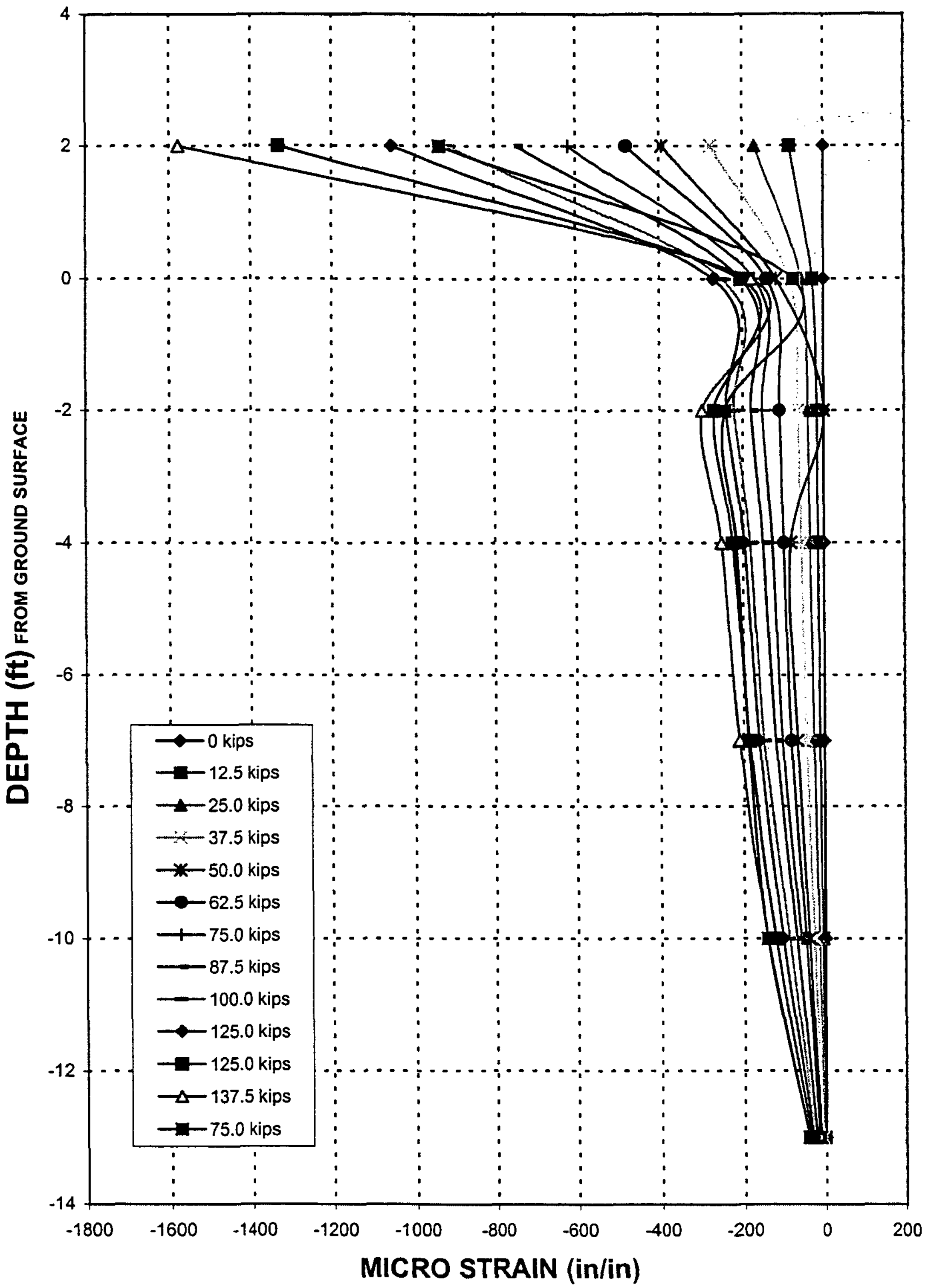
IV.45 Deflection along the length of the 18-ft deep shaft (T-25)



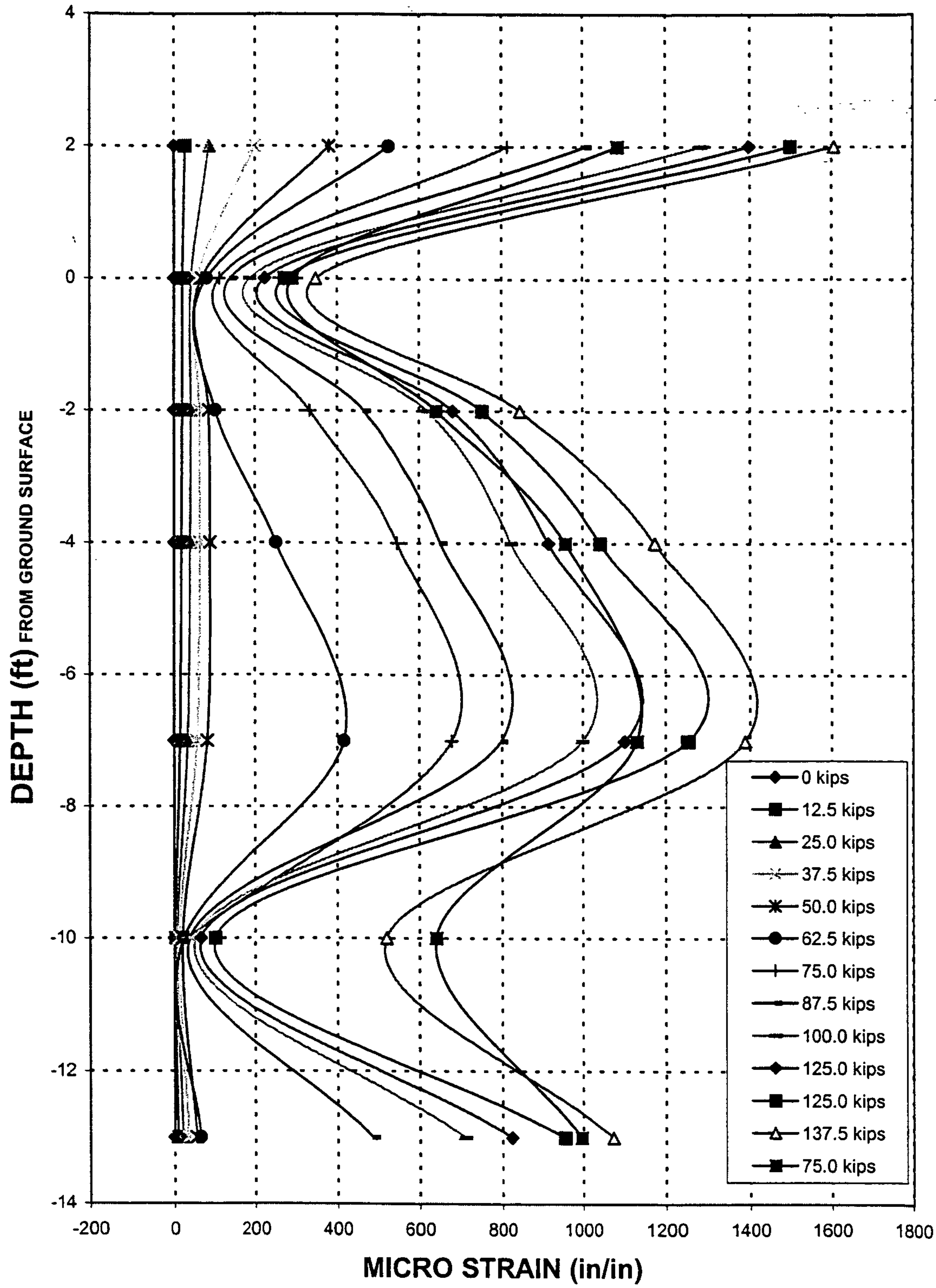
IV.46 Deflection along the length of the 18-ft deep shaft (T-27)



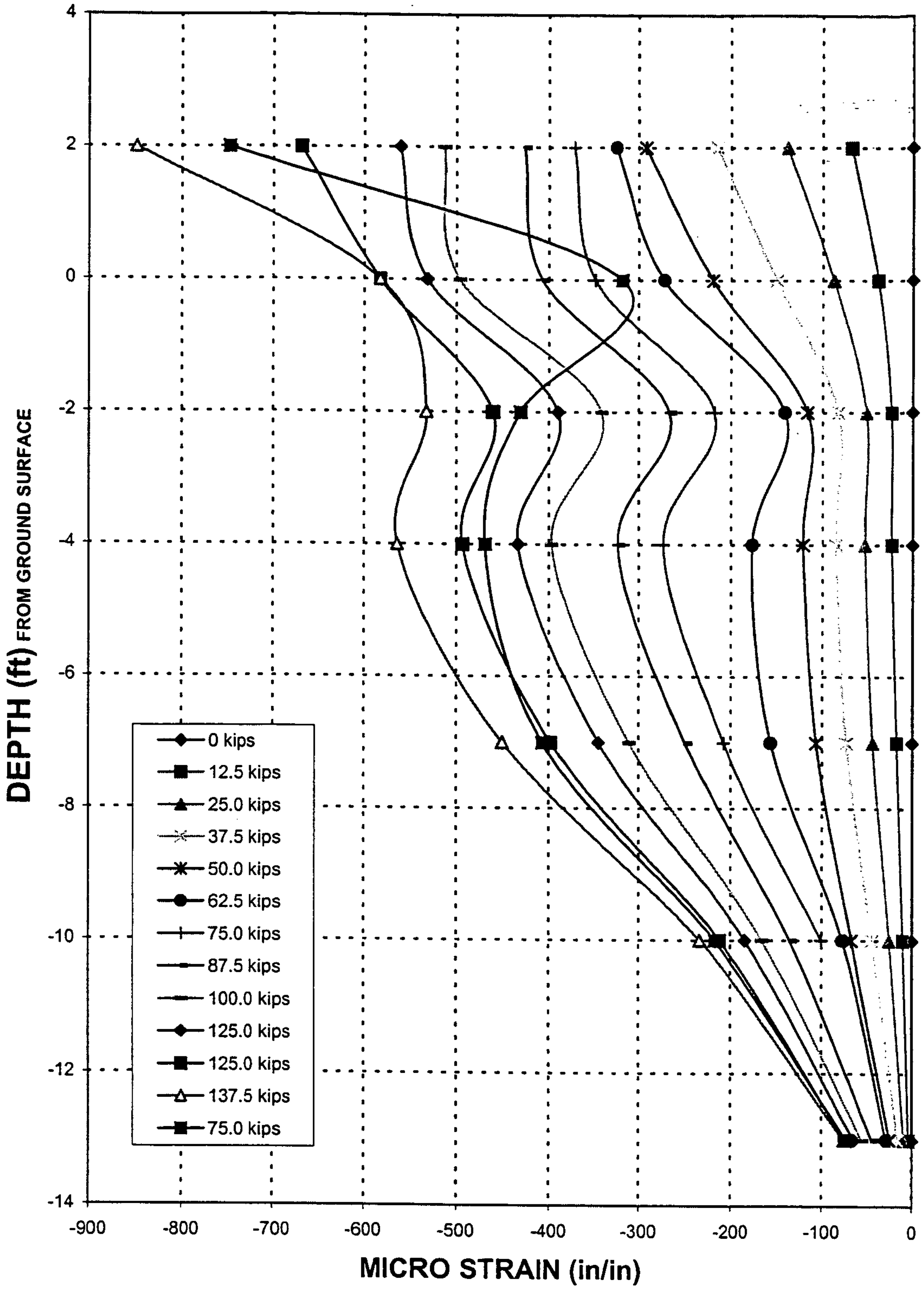
IV.47 Observed strain along the length of the 18-ft deep shaft (T-25 – tension face)



IV.48 Observed strain along the length of the 18-ft deep shaft (T-25 – compression face)



IV.49 Observed strain along the length of the 18-ft deep shaft (T-27 – tension face)



IV.50 Observed strain along the length of the 18-ft deep shaft (T-27 – compression face)

CHAPTER V

BACK CALCULATION OF P-Y CURVES USING INCLINOMETER DATA

V.1 INTRODUCTION

The determination of the load-displacement relationship for an unconstrained, laterally loaded drilled shaft is a highly nonlinear problem. The most common method of analysis for the laterally loaded drilled shafts is the p-y curve method. The p-y curves provide simple and reasonable approach to capture the essential aspects of soil-shaft interaction behavior, including the nonlinear soil resistance as well as variable soil and drilled shaft properties.

The existing p-y curves for design are largely based upon interpretation and empirical evaluation of relatively few, well-instrumented lateral load tests. Clearly, these analytical expressions include a considerable degree of empiricism. Furthermore, there could be inherent uncertainties in extending these empirical p-y criteria to sites of different soil conditions.

The use of existing p-y criteria is no guarantee of the accuracy of the analysis results. The reason is that these p-y criteria were derived only from a limited number of load tests on fully instrumented drilled shafts at various sites with different soil types: cohesionless soil, stiff clay and soft clay. The principle of soil mechanics was used to a large extent to generalize the equations of the p-y curves. However, some significant shortcomings of existing p-y curves still exist:

1) The nonlinearity of reinforced concrete shaft under bending (flexural) stresses was not accounted for in the original data deduction.
2) Generalization of p-y curves for soils other than those at the test sites results in the requirements of certain soil parameters, such as ε_{50}, undrained shear strength S_u, and friction angle φ, among others. Sometimes it may be difficult to determine these parameters accurately.
3) It has been observed that the construction details can affect the p-y curves, in addition to soil properties, dimension and stiffness of the drilled shafts. In addition, time duration of hole opening before casting concrete, the use of slurry in drilling, and the method of drilling will also affect the in-situ soil stress and soil properties to a large extent, and thus affecting the p-y curves. These construction effects on the p-y curves can not be accounted for by the existing p-y criteria.

Therefore, full-scale load tests are usually needed in order to obtain more accurate p-y curves. In carrying out lateral load tests, full instrumentation such as the incorporation of strain gages along the entire length of the drilled shaft may be too expensive to be done routinely. However, inclinometer data could be obtained within a reasonable cost. As demonstrated by Brown, et al. (1994), the inclinometer data obtained during lateral load tests can be used to derive the site-specific p-y curves.

V.2 BACK CALCULATION OF P-Y CURVES FROM INCLINOMETER DATA

V.2.1 General Principle

The method outlined below is a means of deriving p-y curves from the measured deflections by making a "best-fit" to the data using a pre-selected analytical functions for the p-y relationship and using a least squares technique. The variation of the shape of the p-y curves and the variations of p-y curves with depth are defined using several variables, which are the subject of the fitting process. For the simple case of using existing analytical p-y curves to fit for a specific site, these variables can simply be taken as the input soil strength and stiffness parameters (e.g., S_u, ε_{50} for clay, φ, k for sand). When used to develop or evaluate more general form of analytical p-y curves, other empirical parameters could be used as the unknown for the fitting purpose. The former case may be most useful for evaluating test data at a specific site so that alternative boundary conditions, pile or shaft lengths, etc. could be evaluated. The latter case may be more useful to the development of more reliable analytical p-y curves for a particular type of soils. In either case, the "best-fit" technique would be the same; however, the actual variables to be determined would be different. In the method and case study outlined below, soil strength and stiffness parameters are used as unknowns.

V.2.2 Governing Equation for Soil-Shaft Interaction

The differential equation to be solved is derived on the assumption that the shaft is a linearly elastic beam and that the soil reaction may be represented as a line load

$$EI\frac{d^4y}{dx^4}+P_x\frac{d^2y}{dx^2}-p=0 \qquad \text{V-1}$$

in which P_x = axial load applied on drilled shaft; y = lateral deflection of the drilled shaft at point x along the shaft length; p = soil reaction per unit length; and EI is the flexural rigidity of the drilled shaft.

VI.2.3 Definition of the Problem

Suppose a drilled shaft is divided into i-1 intervals, so that there are i nodes along the length. Additionally, the shaft deflections are determined at each of j sets of boundary conditions (for a load test, the values of shaft head shear use the boundary conditions). Thus, there are a total of $i \times j = m$ nodes for which the deflection measurements are obtained. The horizontal deflections, y, are represented as

$$\mathbf{y}(\mathbf{u})=\begin{Bmatrix} y_1(\mathbf{u}) \\ y_2(\mathbf{u}) \\ \vdots \\ y_m(\mathbf{u}) \end{Bmatrix} \qquad \text{V-2}$$

where

$$\mathbf{u}=\begin{Bmatrix} u_1 \\ u_2 \\ \vdots \\ u_n \end{Bmatrix} \qquad \text{V-3}$$

and

u = soil parameters affecting the analytical p-y curves

n = number of soil parameters used to define analytical p-y curves and their distribution with depth.

The measured deflections during load test are represented as

$$\mathbf{b} = \begin{Bmatrix} b_1 \\ b_2 \\ \vdots \\ b_m \end{Bmatrix} \qquad \text{V-4}$$

The purpose of back-calculation is to determine a set of unknown soil parameters, u, by using the measured deflections. Since m>>n, there is not an exact solution for u. The best estimate of the soil parameters, **u**, is by using a least squares "inversion" technique; that is, the best estimate of the soil parameters, **u**, is found by minimizing

$$\mathrm{Y}(\mathbf{u}) = [\mathrm{y}(\mathbf{u}) - \mathbf{b}]^{\mathrm{T}} [\mathrm{y}(\mathbf{u}) - \mathbf{b}] \qquad \text{V-5}$$

V.2.4 Method of solution

Using the Taylor series expansion technique and selecting the first term only, the following equation can be obtained

$$\mathbf{y}(\mathbf{u} + \Delta\mathbf{u}) - \mathbf{y}(\mathbf{u}) = \mathbf{J}\ \Delta\mathbf{u} \qquad \text{V-6}$$

where **J** is the Jacobian matrix describing the effect of changes in **u** on **y**. The above equation can be re-written as

$$\mathbf{J}\ \Delta\mathbf{u}_k = \Delta\mathbf{y}_k \qquad \text{V-7}$$

where

$$\Delta \mathbf{y}_k = \mathbf{y}(\mathbf{u} + \Delta \mathbf{u}) - \mathbf{y}(\mathbf{u}) = \mathbf{b} - \mathbf{y}(\mathbf{u}) \qquad \text{V-8}$$

Equation (V-7) is considered as a linear least squares problem, for which the computed changes in the unknowns, $\Delta \mathbf{u}_k$, can be solved. The solution involves an iterative process in which the difference at point $\mathbf{u}_k$ is used to estimate the next point, $\mathbf{u}_{k+1}$. The singular value decomposition (SVD) technique is used to solve Eq. V-7. In order to obtain a stable converged solution, a damping coefficient which reduces the changes in the unknowns during iteration is applied.

V.3 APPLICATIONS TO LOAD TEST RESULTS

V.3.1 Project at Putnam Street Bridge

Back calculation of P-Y curves for drilled 9-m deep shaft #1, 9-m deep shaft #2 and 14-m deep shaft #2 at Putnam St. Bridge were preformed. The stiff clay p-y criterion for stiff clay developed by Reese et al. (1975) was selected to determine the back calculated soil resistance from the test results. The initial iteration parameters for each soil layer are summarized below.

Soil layer #1 (0 ft. ~ 10 ft.): $S_u = 10$ psi, $\gamma = 0.064$ pci, $\varepsilon_{50} = 0.005$

Soil layer #2 (10 ft. ~ 20 ft.): $S_u = 10$ psi, $\gamma = 0.067$ pci, $\varepsilon_{50} = 0.005$

Soil layer #3 (20 ft. ~ 53 ft.): $S_u = 5$ psi, $\gamma = 0.067$ pci, $\varepsilon_{50} = 0.01$

Soil layer #4 (53 ft. ~ 83 ft.): $S_u = 20$ psi, $\gamma = 0.067$ pci, $\varepsilon_{50} = 0.005$

The knowledge of site soil conditions is important in determining the initial parameters. It should be pointed out that the back calculated soil strength values from this analysis do not represent the actual strengths; rather, the parameter values are only used for producing p-y curves.

- 9-m deep shaft #1

Eight locations where the p-y curves were to be the output from the back calculation include the following: 4 in., 116 in., 124 in., 236 in., 244 in., 632 in., 640 in., 996 in. below the ground surface. A total of nine sets of inclinometer data corresponding to the lateral load from 25 kips to 155 kips were used to back calculate p-y curves.

The back calculated p-y curves are shown in Fig. V.1 for the depths at 116 in., 236 in., and 632 in. It can be seen that the soil resistance at depth of 236 in. is larger than that at depth of 632 in. This phenomenon is consistent with the result of site investigation. The back calculated p-y curves were then used in the COM624P program to predict the drilled shaft displacement under various lateral loads. Presented in Fig. V.2 and Fig. V.3 are measured and predicted deflections. Basically the predicted deflections capture the general trends in the data. Also it can be seen that the agreement of deflection at low load level is not good as that at high load level, due to the fact that the deflections at low load level usually make small contribution to the optimization process.

- 9-m deep shaft #2

Eight locations where the p-y curves were to be the output from the back calculation include the following: 4 in., 116 in., 124 in., 236 in., 244 in., 632 in., 640 in., 996 in. below the ground surface. A total of nine sets of inclinometer data corresponding to the lateral load from 25 kips to 155 kips were used to back calculate p-y curves.

The back calculated p-y curves are shown in Fig. V.4 for the depths at 116 in., 236 in., and 632 in. Also the soil resistance at depth of 236 in. is larger than that at depth of 632 in. The back calculated p-y curves were then used in the COM624P program to predict the drilled shaft displacement under various lateral loads. The measured and the predicted deflections are shown in Fig. V.5 and Fig. V.6. It can be seen that the agreement of deflection is not good, especially in the middle part of the shaft. Since there is no concrete but sand from depth of 9 meter to 10 meter in the shaft, the deformation near this area is relatively large and irregular. The back analysis procedure does not work well for such a case.

- 14-m deep shaft #2

Eight locations where the p-y curves were to be the output from the back calculation include the following: 4 in., 116 in., 124 in., 236 in., 244 in., 632 in., 640 in., 996 in. below the ground surface. A total of ten sets of inclinometer data corresponding to the lateral load from 25 kips to 250 kips were used to back calculate p-y curves.

The back calculated p-y curves are shown in Fig. V.7 for the depths at 116 in., 236 in., 632 in., and 640 in. The back calculated p-y curves were then used in the COM624P program to predict the drilled shaft displacement under various lateral loads. The measured and the predicted deflections shown in Fig. V.8 and Fig. V.9 indicate that a very good agreement exists.

V.3.2 Project at Hamilton-50

Back calculation of P-Y curves for drilled shaft #T-23, shaft #T-25 and shaft #T-27 at Hamilton-50 were preformed. The stiff clay p-y criterion for stiff clay developed by Reese et al. (1975) was selected to determine the back calculated soil resistance from the test results. The initial iteration parameters for each soil layer are summarized below.

Soil layer #1 (0 ft. ~ 2 ft.): $S_u = 50$ psi, $\gamma = 0.06$ pci, $\varepsilon_{50} = 0.005$

Soil layer #2 (2 ft. ~ 5 ft.): $S_u = 50$ psi, $\gamma = 0.06$ pci, $\varepsilon_{50} = 0.005$

Soil layer #3 (5 ft. ~ 14 ft.): $S_u = 50$ psi, $\gamma = 0.06$ pci, $\varepsilon_{50} = 0.005$

Soil layer #4 (14 ft. ~ 26 ft.): $S_u = 100$ psi, $\gamma = 0.06$ pci, $\varepsilon_{50} = 0.005$

Again, it should be pointed out that the back calculated soil strength values from this analysis do not represent the actual strengths; rather, the parameter values are only used for producing p-y curves.

- Shaft #T-23

Eight locations where the p-y curves were to be the output from the back calculation include the following: 4 in., 20 in., 28 in., 56 in., 64 in., 164 in., 172 in., 308 in. below the ground surface. A total of eight sets of inclinometer data corresponding to the lateral load from 25 kips to 200 kips were used to back calculate p-y curves.

The back calculated p-y curves are shown in Fig. V.10 for the depths at 20 in., 56 in., 164 in., and 308 in. The back calculated p-y curves were then used in the COM624P program to predict the drilled shaft displacement under various lateral loads. The measured and the predicted deflections are shown in Fig. V.11 and Fig. V.12. Basically the predicted deflections capture the general trends in the data.

- Shaft #T-25

Eight locations where the p-y curves were to be the output from the back calculation include the following: 4 in., 20 in., 28 in., 56 in., 64 in., 164 in., 172 in., 308 in. below the ground surface. A total of twelve sets of inclinometer data corresponding to the lateral load from 12.5 kips to 150 kips were used to back calculate p-y curves.

The back calculated p-y curves are shown in Fig. V.13 for the depths at 20 in., 56 in., 164 in., and 308 in. The back calculated p-y curves were then used in the COM624P program to predict the drilled shaft displacement under various lateral loads. Presented in Fig. V.14 and Fig. V.15 are measured and predicted deflections. Basically the predicted deflections capture the general trends in the data.

- Shaft #T-27

Eight locations where the p-y curves were to be the output from the back calculation include the following: 4 in., 20 in., 28 in., 56 in., 64 in., 164 in., 172 in., 308 in. below the ground surface. A total of eleven sets of inclinometer data corresponding to the lateral load from 12.5 kips to 150 kips were used to back calculate p-y curves.

The back calculated p-y curves are shown in Fig. V.16 for the depths at 20 in., 56 in., 164 in., and 308 in. The back calculated p-y curves were then used in the COM624P program to predict the drilled shaft displacement under various lateral loads. The measured and the predicted deflections are shown in Fig. V.17 and Fig. V.18. Basically the predicted deflections capture the general trends in the data.

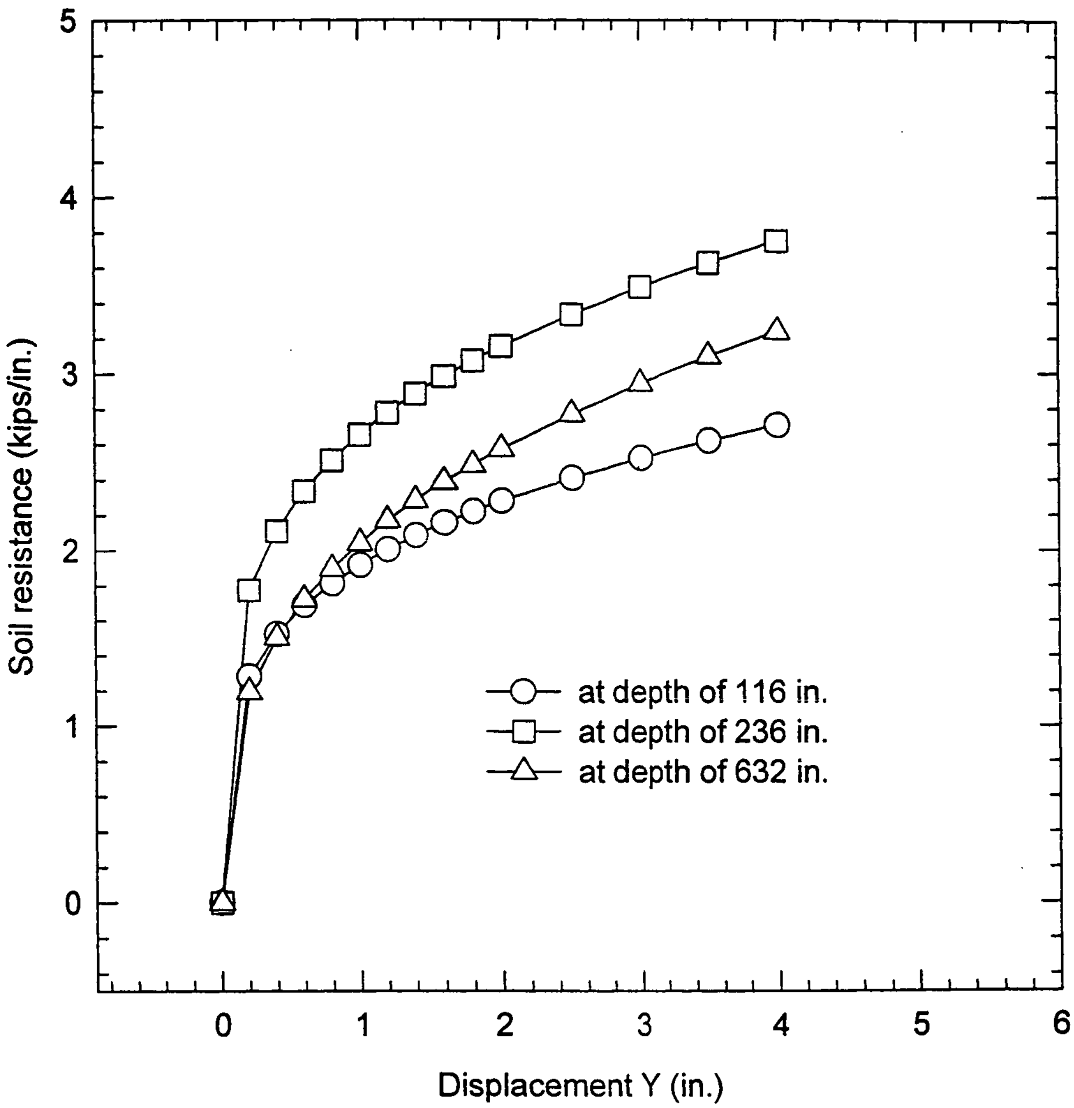


Fig. V.1: Back calculated P-Y curves (9-m deep shaft #1)

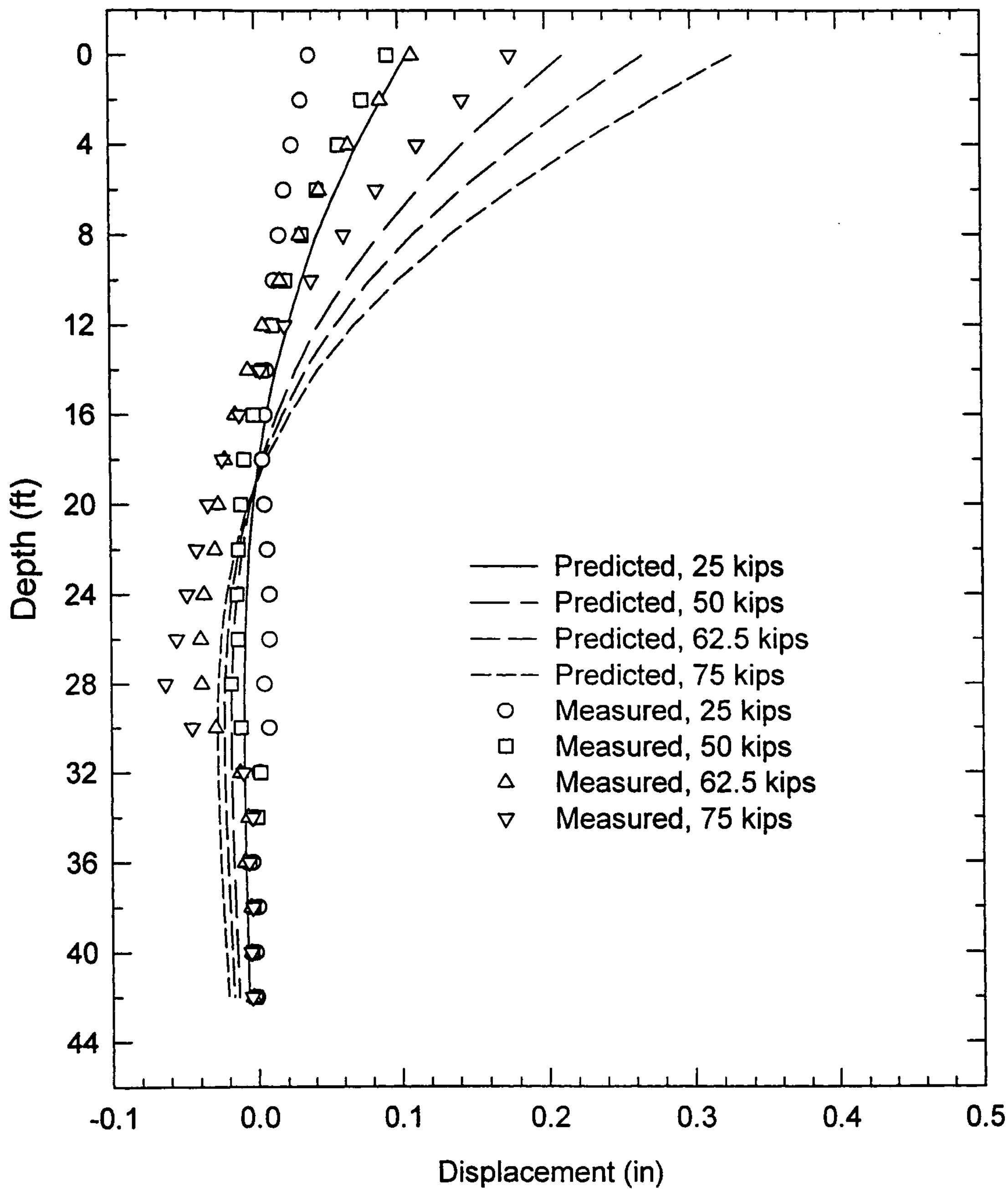


Fig. V.2: Comparison of deflections (9-m deep shaft #1, 25 kips, 50 kips, 62.5 kips, 75 kips)

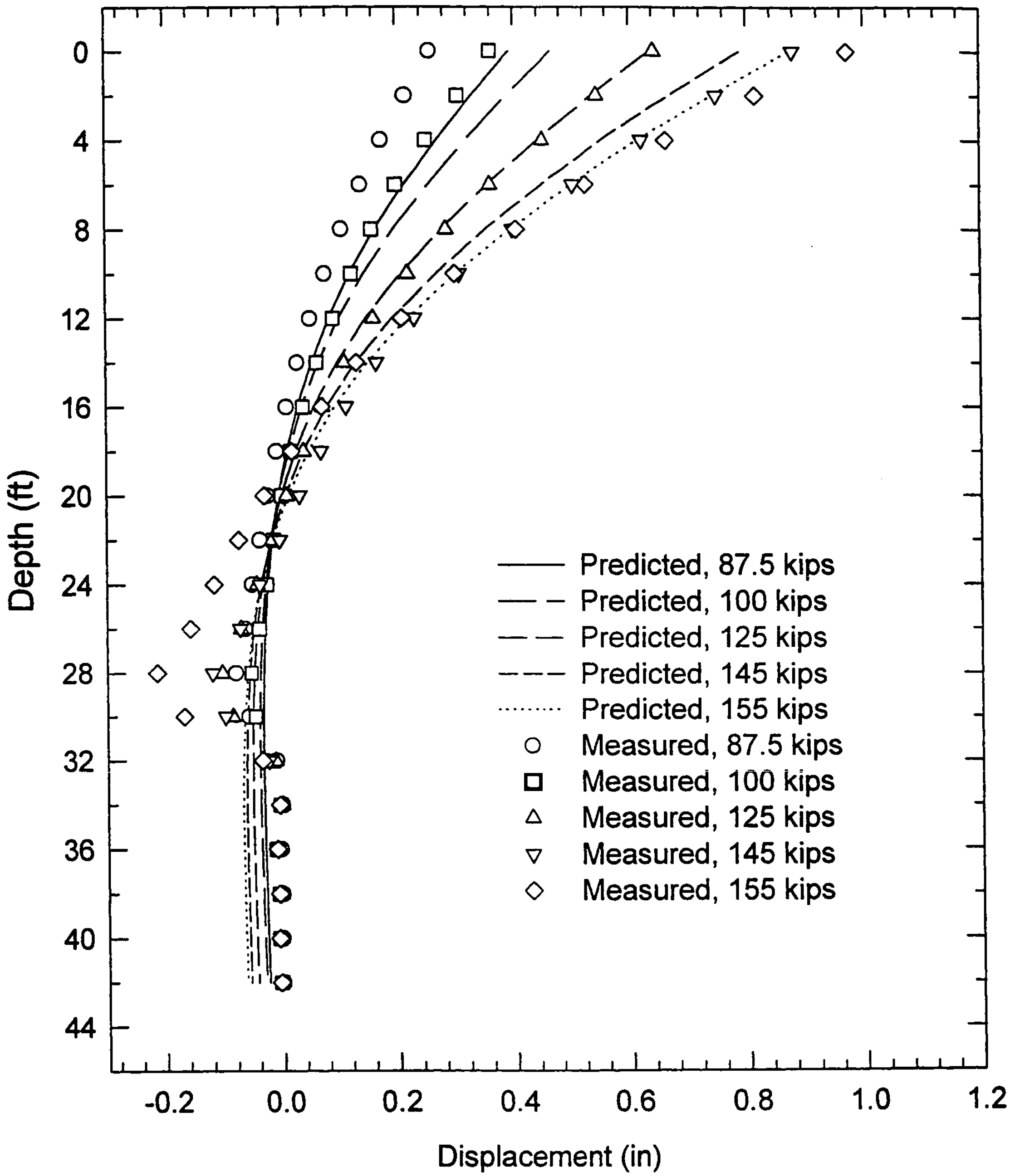


Fig. V.3: Comparison of deflections (9-m deep shaft #1, 87.5 kips, 100 kips, 125 kips, 145 kips, 155 kips)

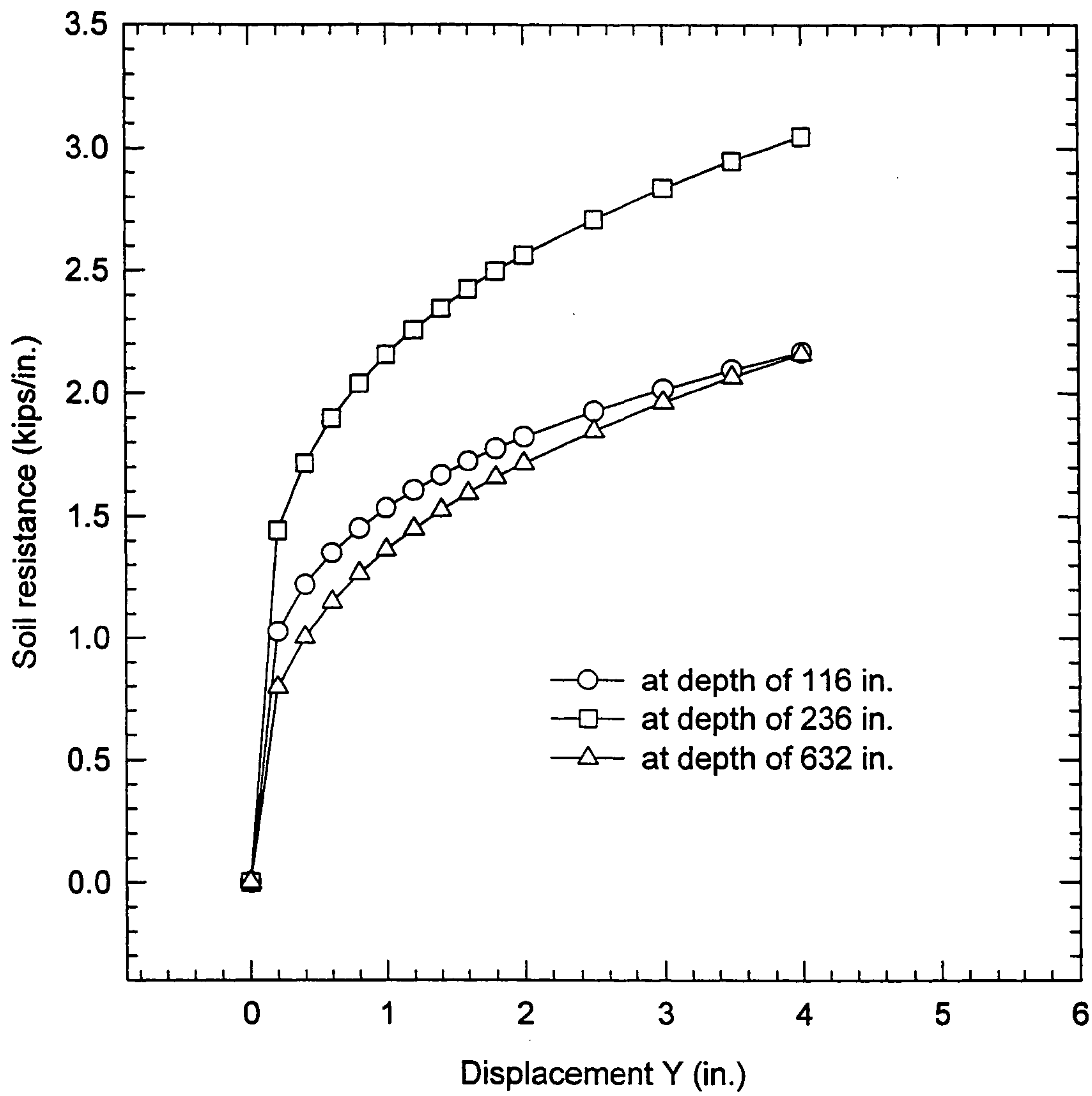


Fig. V.4: Back calculated P-Y curves (9-m deep shaft #2)

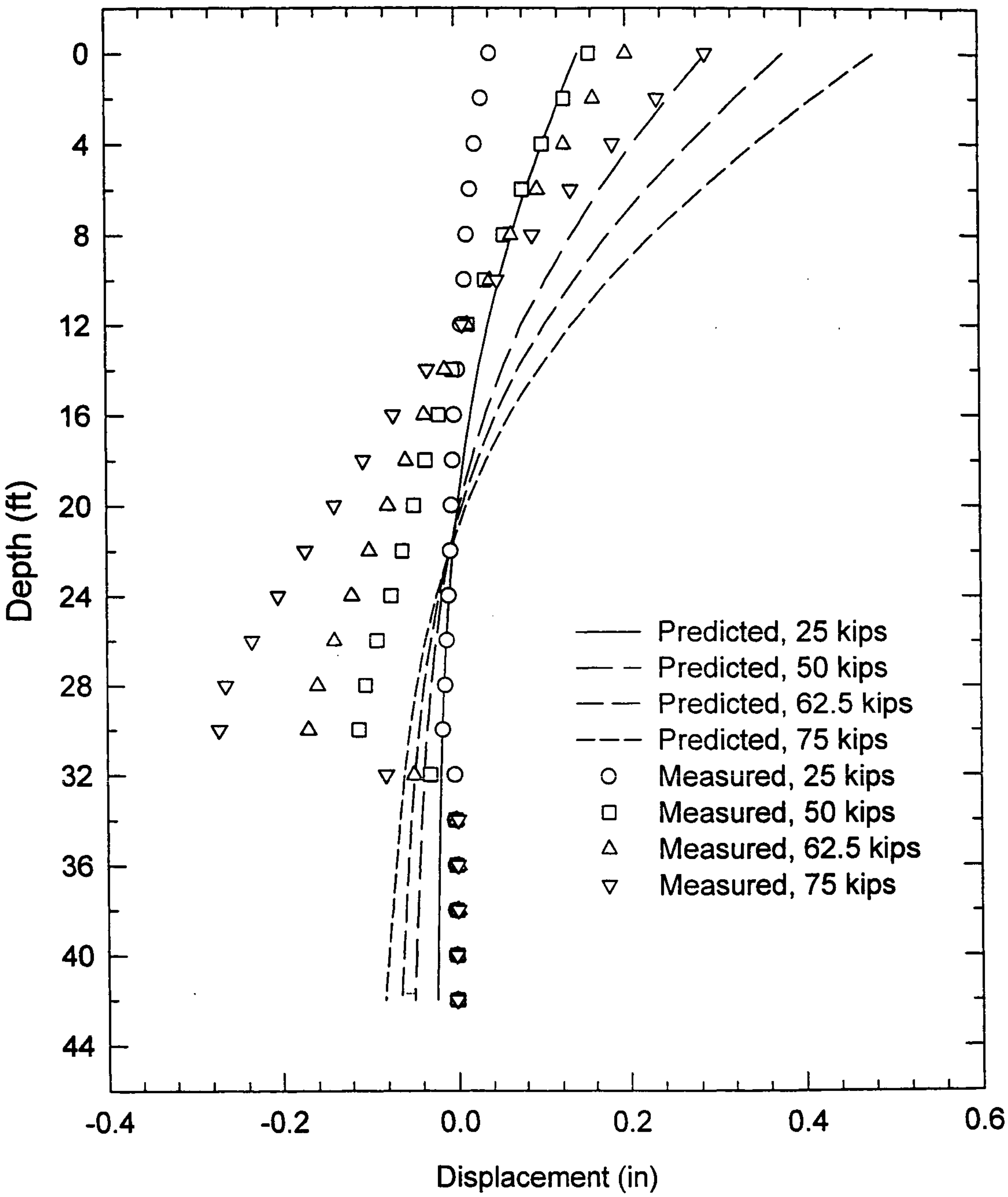


Fig. V.5: Comparison of deflections (9-m deep shaft #2, 25 kips, 50 kips, 62.5 kips, 75 kips)

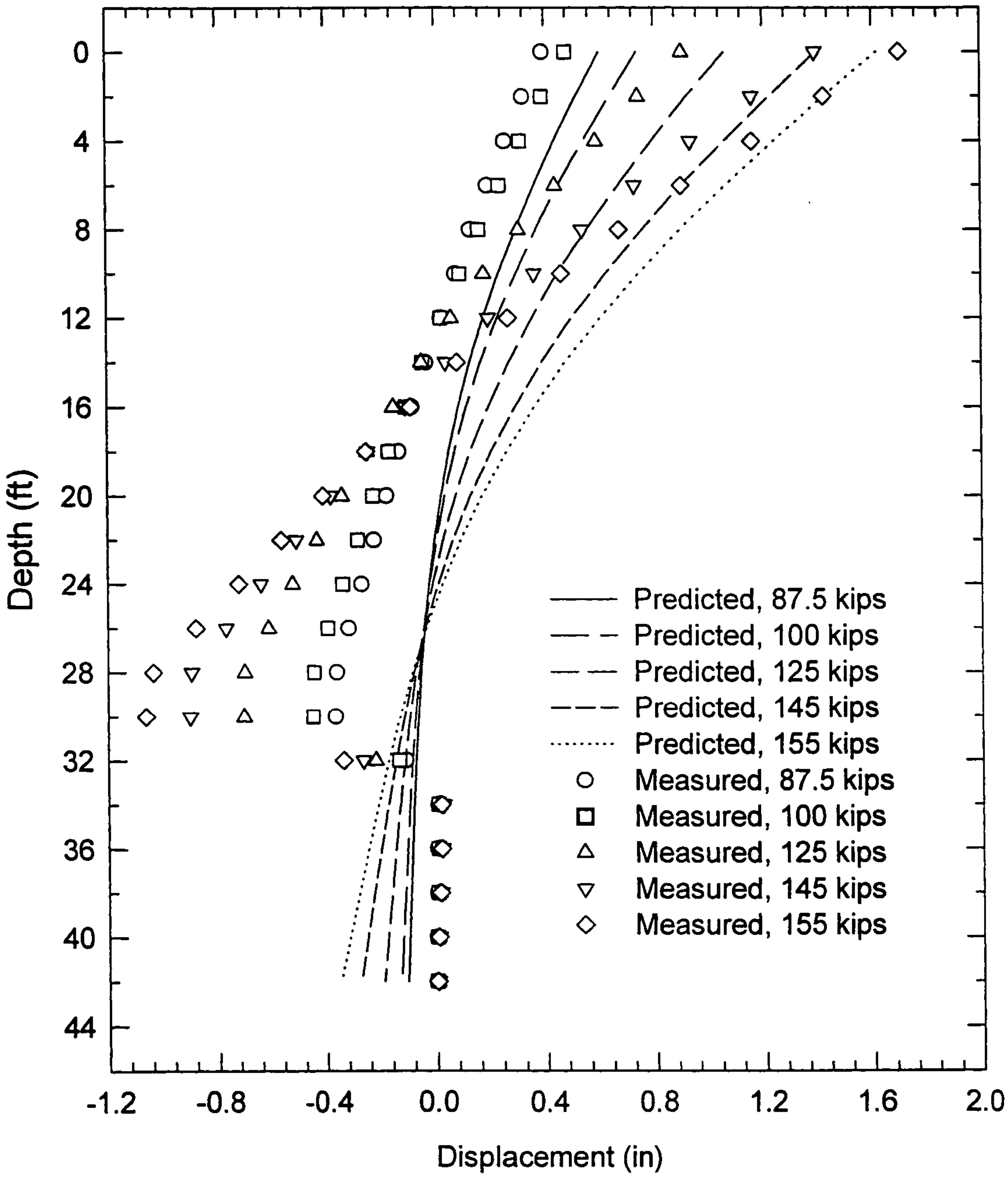


Fig. V.6: Comparison of deflections (9-m deep shaft #2, 87.5 kips, 100 kips, 125 kips, 145 kips, 155 kips)

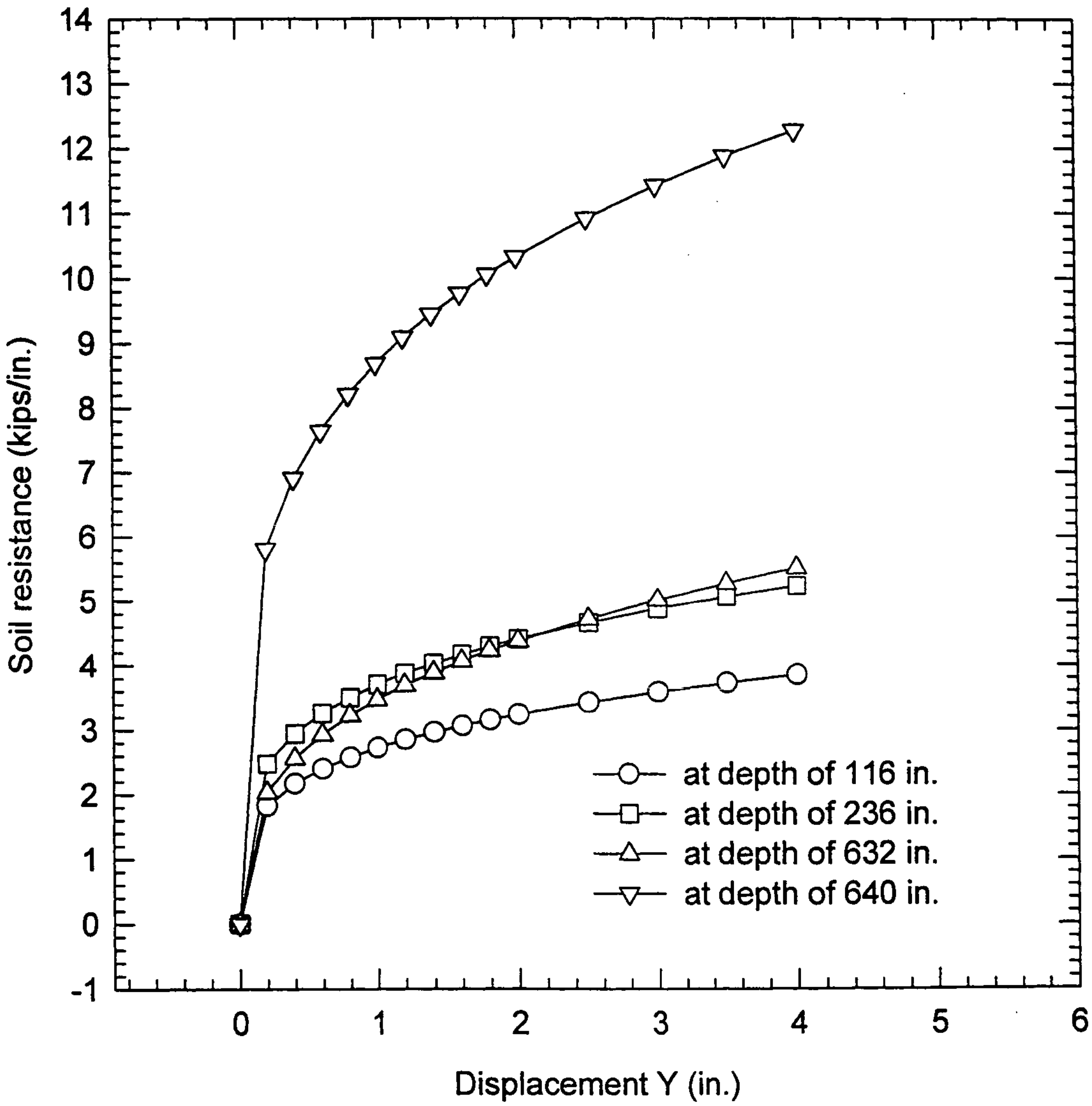


Fig. V.7: Back calculated P-Y curves (14-m deep shaft #2)

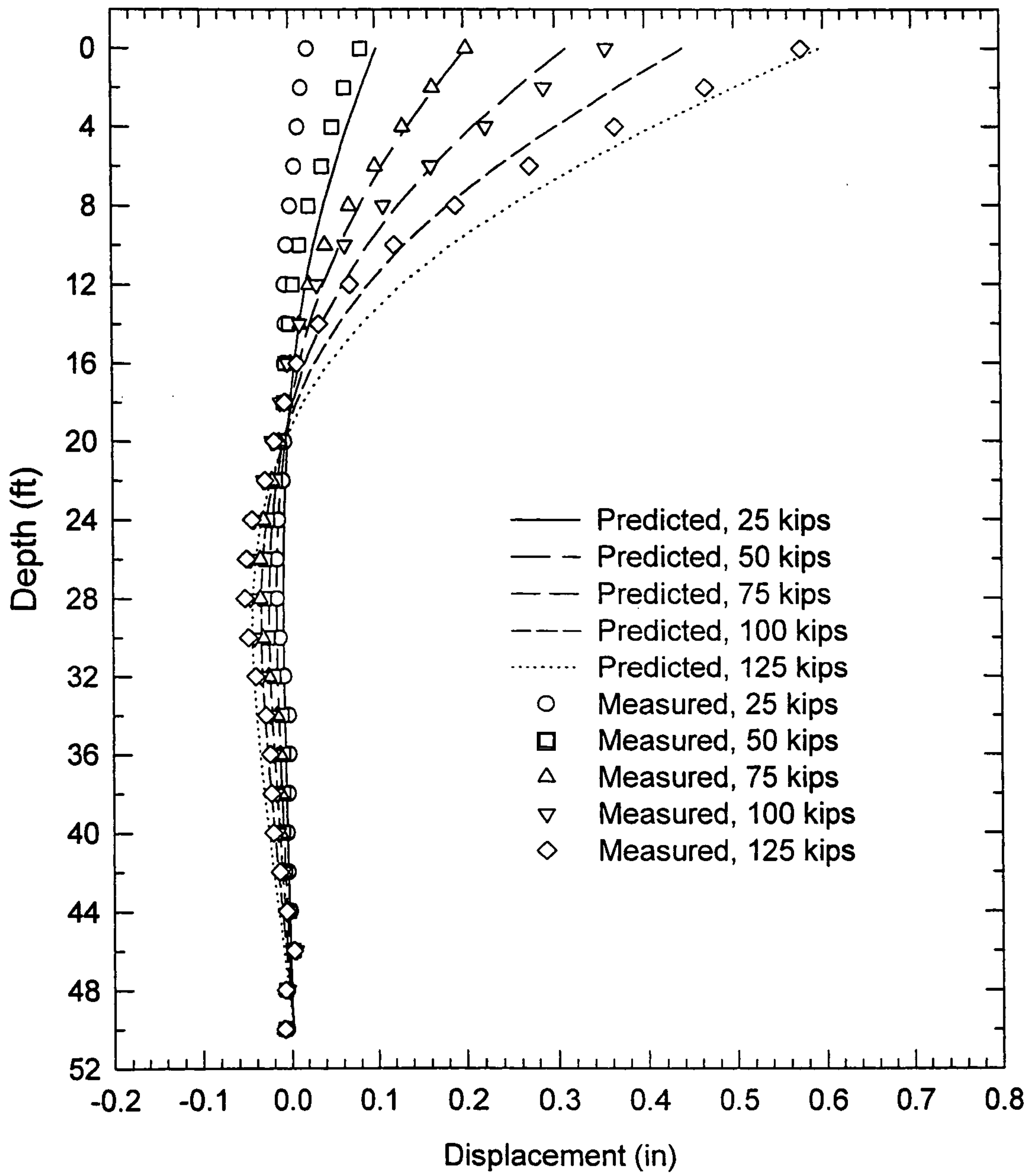


Fig. V.8: Comparison of deflections (14-m deep shaft #2, 25 kips, 50 kips, 75 kips, 100 kips, 125 kips)

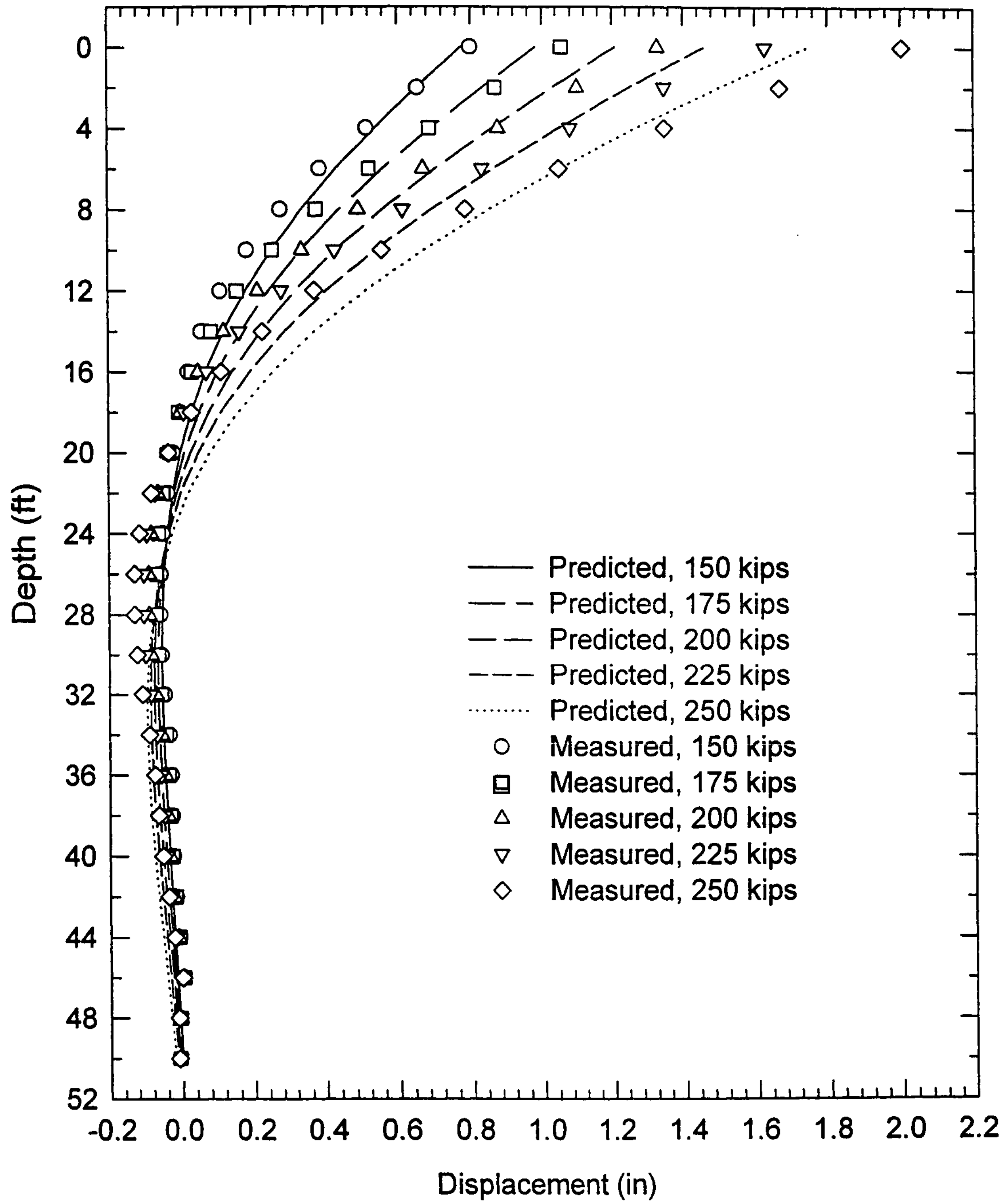


Fig. V.9: Comparison of deflections (14-m deep shaft #2, 150 kips, 175 kips, 200 kips, 225 kips, 250 kips)

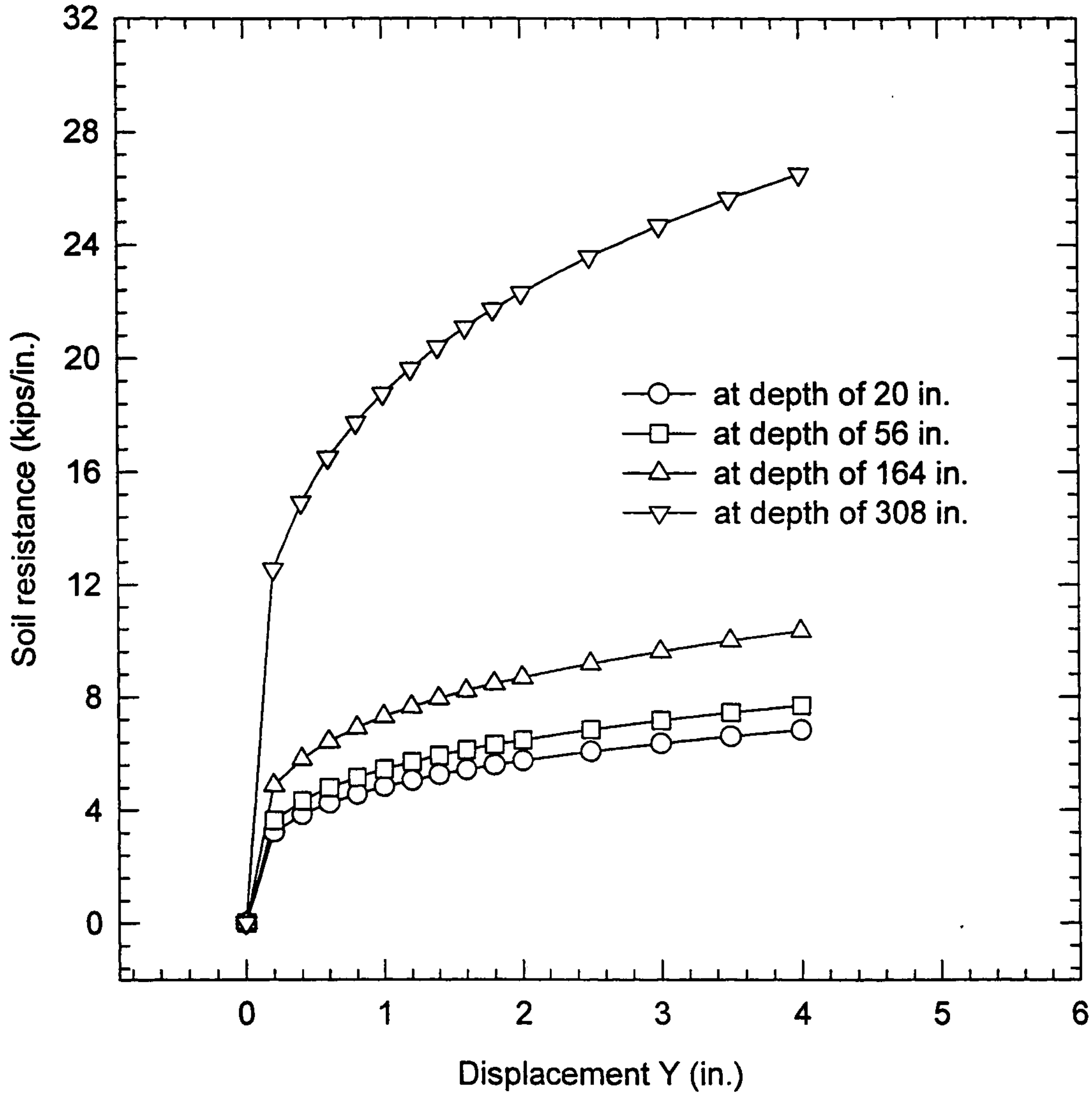


Fig. V.10: Back calculated P-Y curves (Shaft #T-23)

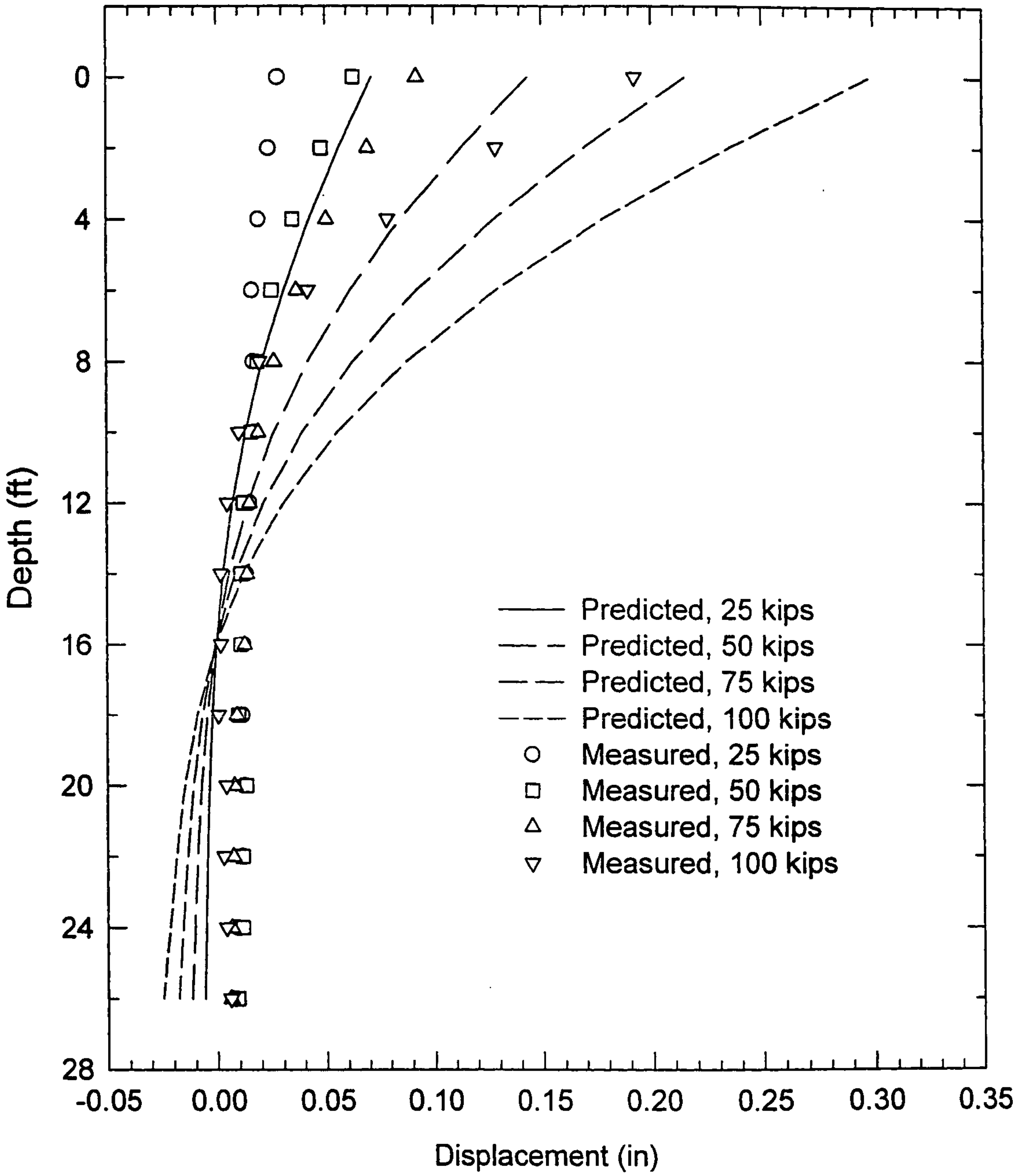


Fig. V.11: Comparison of deflections (Shaft #T-23, 25 kips, 50 kips, 75 kips, 100 kips)

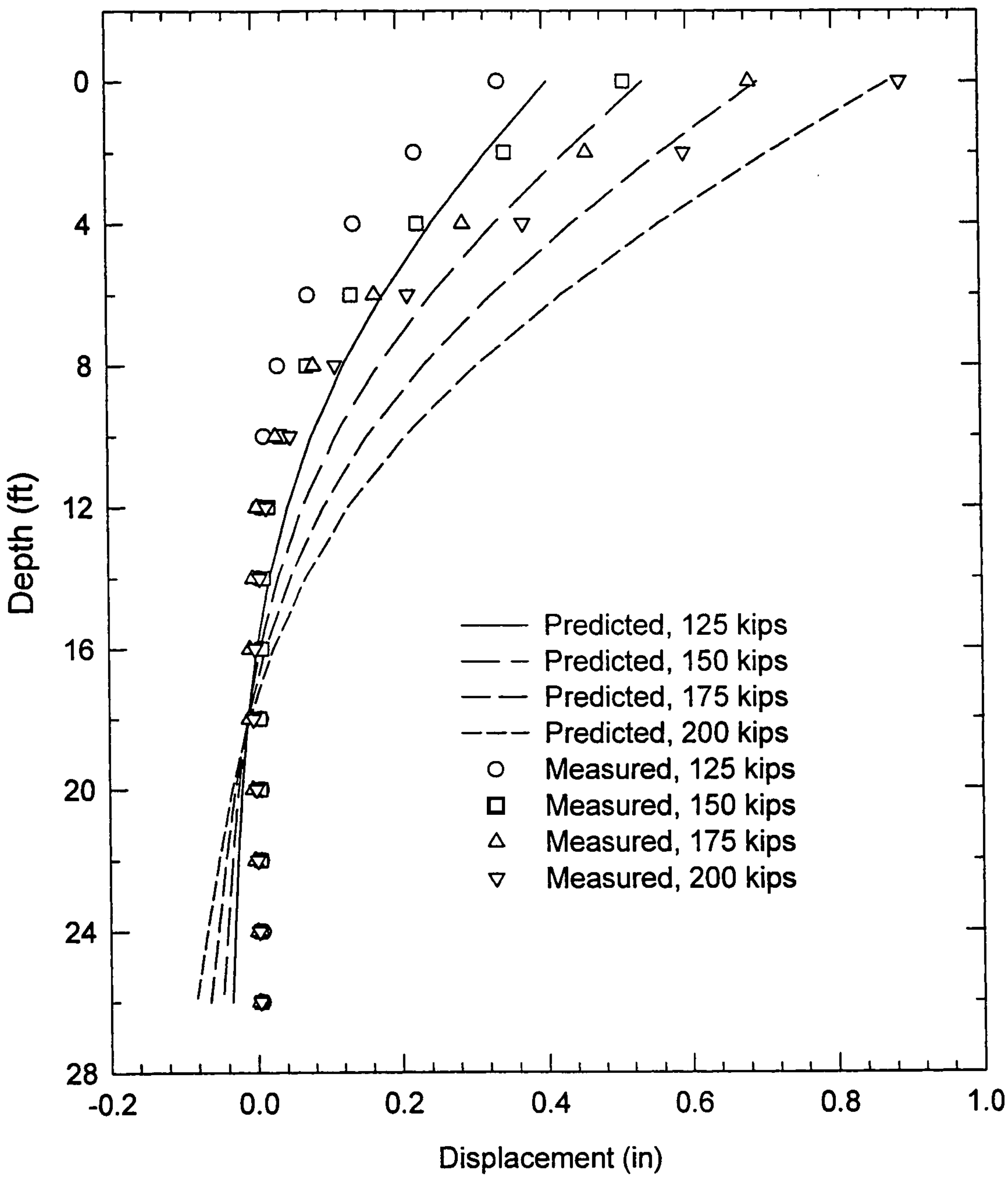


Fig. V.12: Comparison of deflections (Shaft #T23, 125 kips, 150 kips, 175 kips, 200 kips)

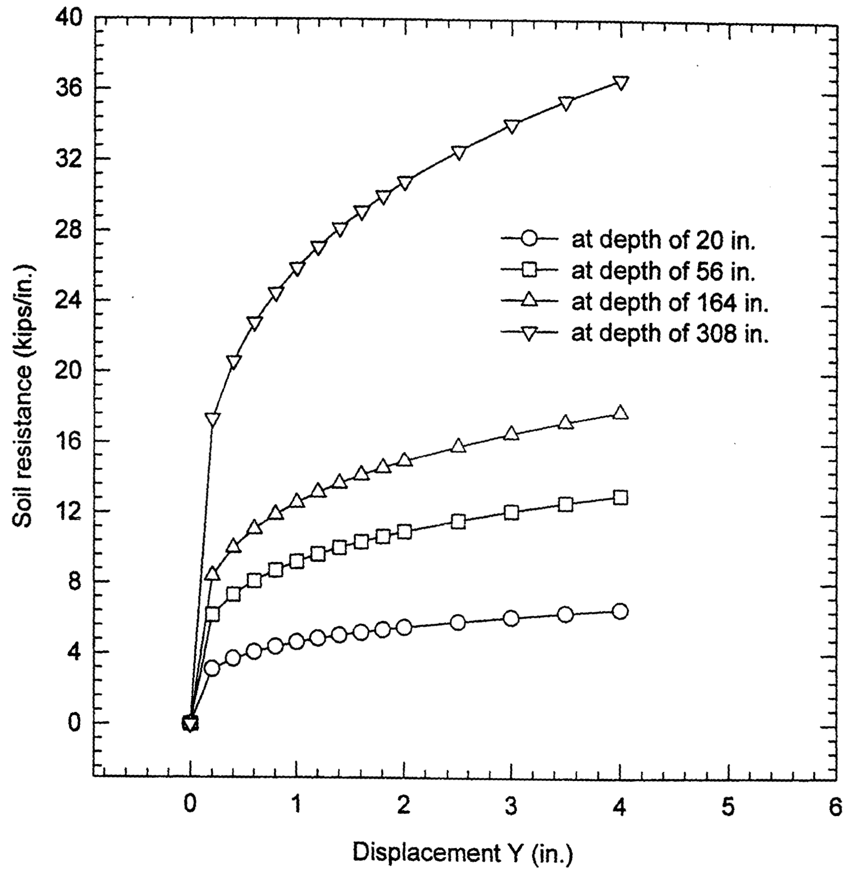


Fig. V.13: Back calculated P-Y curves (Shaft #T-25)

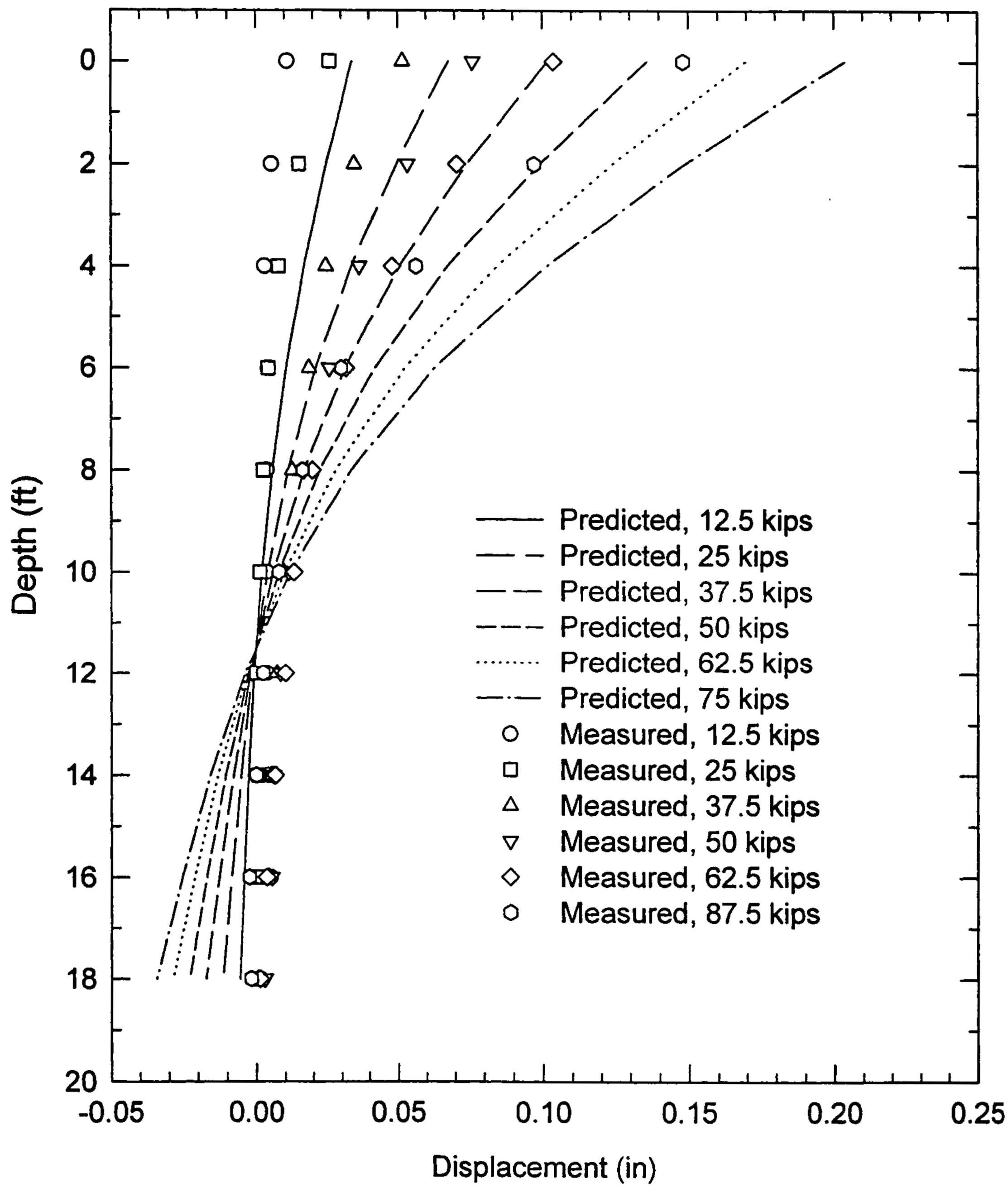


Fig. V.14: Comparison of deflections (Shaft #T-25, 12.5 kips, 25 kips, 37.5 kips, 50 kips, 62.5 kips, 75 kips)

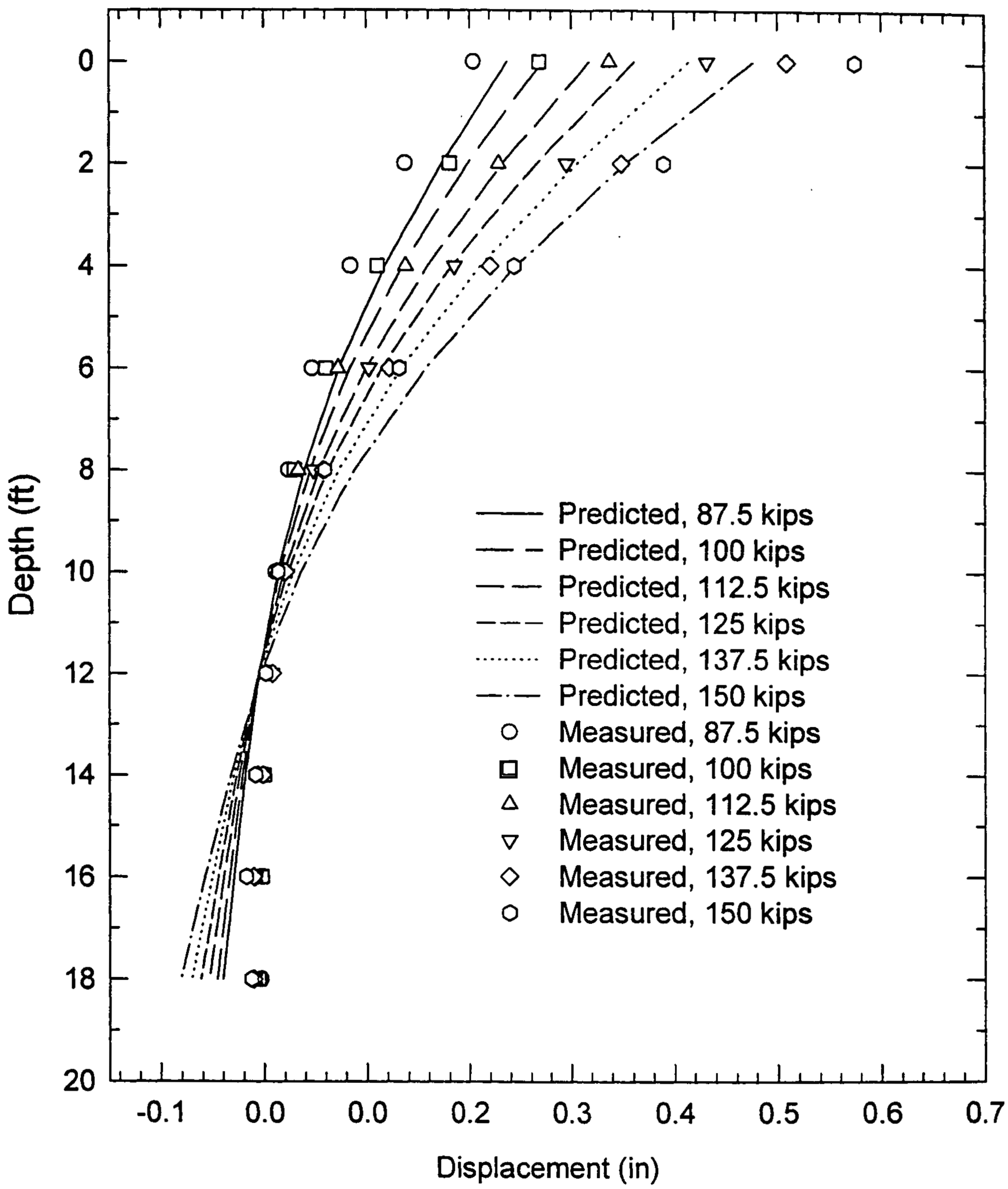


Fig. V.15: Comparison of deflections (Shaft #T-25, 87.5 kips, 100 kips, 112.5 kips, 125 kips, 137.5 kips, 150 kips)

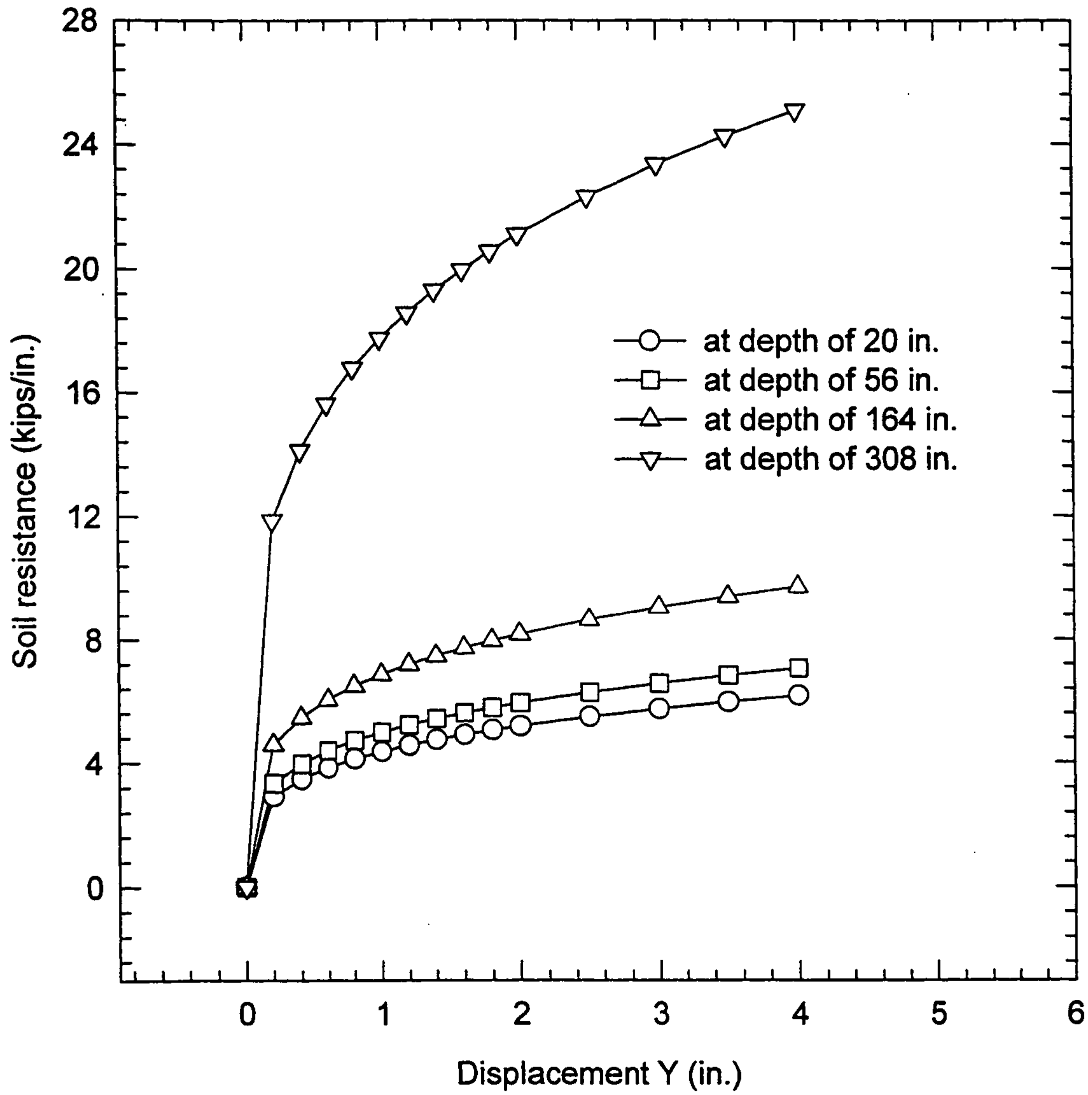


Fig. V.16: Back calculated P-Y curves (Shaft #T-27)

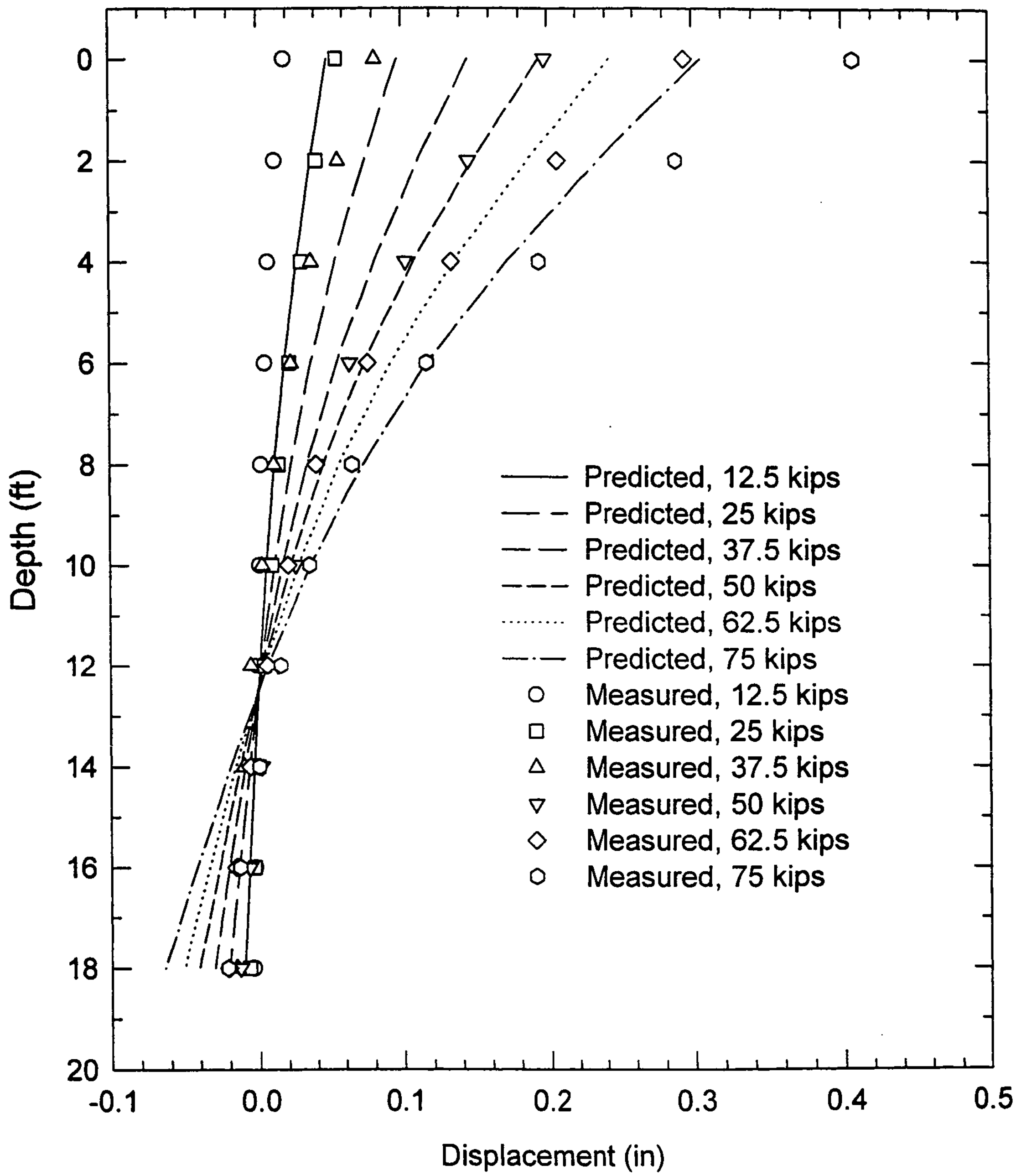


Fig. V.17: Comparison of deflections (Shaft #T-27, 12.5 kips, 25 kips, 37.5 kips, 50 kips, 62.5 kips, 75 kips)

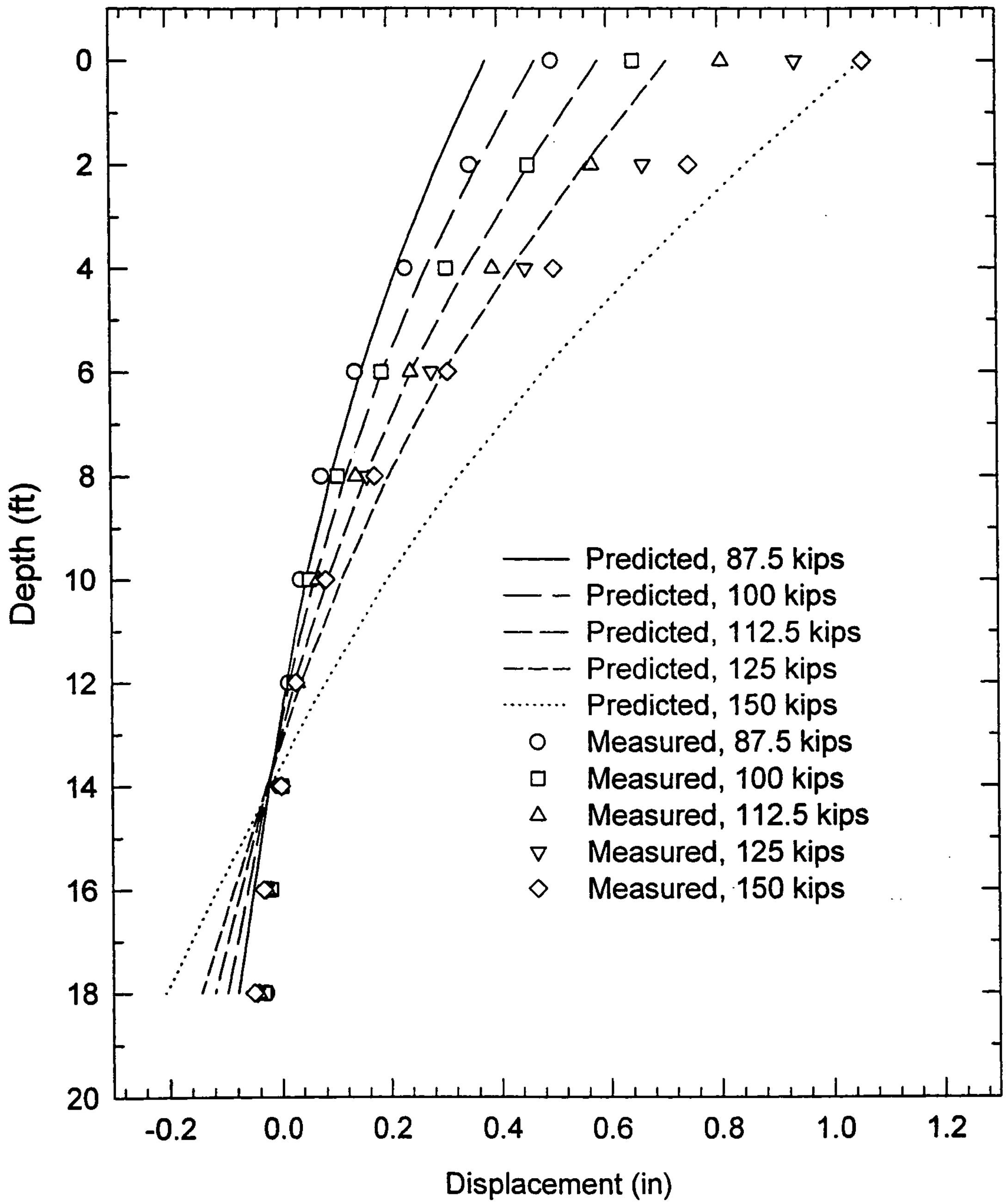


Fig. V.18: Comparison of deflections (Shaft #T-27, 87.5 kips, 100 kips, 112.5 kips, 125 kips, 150 kips)

CHAPTER VI

SUMMARY AND CONCLUSIONS

VI.1 SUMMARY OF WORK ACCOMPLISHED

During the course of the project, the following work has been successfully accomplished.

a) A total of four lateral load tests on 8 fully instrumented drilled shafts have been successfully conducted at the Putnam St. Bridge project and the Hamilton 50 project, respectively.

At the Putnam St. Bridge site, the drilled shafts tested were 14-m and 9-m in length and 1.067-m (42-inch) in diameter. The soil condition at the site is primarily clay with sand lenses and trace of gravel. The SPT blow count is in the range of 12 to 14 with layers of weak soil with SPT blow count in the range of 3 to 5. The soil conditions at the Hamilton 50 site is primarily clay with sand in top 20-ft with SPT blow count ranging from 30 to over 45. The instrumentation installed in the drilled shafts includes sister-bar type vibrating-wire strain gages, and inclinometer casing for deflection measurements. The load tests were carried out by the University of Akron research team.

(b) Pre-test analysis has been carried out to assist ODOT engineers in revising the designs submitted by the consultants. In the case of Putnam St. Bridge, the main concern of the ODOT engineer was the possibility of under-design of the drilled shaft foundation. The load tests conducted at the Putnam Bridge site, however, have confirmed that the design of the drilled shafts (both diameter and length) is sufficient to support the design lateral earth pressure. Thus, the load tests have resulted in avoiding the costly redesign of the drilled shaft foundation. A cost saving of half a million dollars is realized. In the case of the Hamilton 50 project, the main concern of the ODOT engineers was the possibility of over-design of the drilled shaft foundations. Pre-analysis by the principal investigator and the subsequent field load tests have verified that reduced drilled shaft dimensions (both the diameter and length of shaft) are warranted without undermining the factor of safety. As a result, a saving of 300 cubic yard of shaft construction was realized. The actual construction cost saving is about 1 million dollars.

VI.2 CONCLUSIONS

1. The four lateral load tests conducted for this research project have served well the intended purpose: (a) validate the adequacy or inadequacy of the original design by the consultants, and (b) document high-quality test data for development of improved analysis methods.
2. The instrumentation techniques for measuring strains and deflections of the drilled shafts subjected to lateral loads have been proven very successful. The measured data are considered to be of high quality and could be incorporated in a data base for subsequent research to develop an improved analysis method.
3. Significant construction cost saving have been realized for both construction projects. For the Putnam St. Bridge project, the proposed lengthening of the drilled shafts foundations into rock formation was found unnecessary due to the proof from the load tests conducted in this research project. It is estimated that roughly one-half million dollars have been saved from the construction. For the Hamilton 50 project, the original proposed foundation length was considered to be over conservative. As a result of reanalysis by the principal investigator and the proof load tests conducted in this research project, ODOT engineers were able to reduce the total amount of drilled shaft volume by about 300 cubic yard. A one million dollars of cost saving was realized.
4. The back-analysis technique documented in Chapter V has shown that site-specific *p-y* curves can be obtained via lateral load test results with shaft deflection

measurements only. The developed method should be widely used for other projects involving the lateral load tesing of drilled shafts.

VI.3 RECOMMENDATION FOR IMPLEMENTATION

This research project has clearly shown the economic benefits of specifying lateral load tests for construction projects involving a large amount of drilled shafts. The lateral load test results can be used in the developed back-analysis procedure to obtain site-*specific p-y* curves. These relevant *p-y* curves can then be used in the COM624 computer analysis to optimize the drilled shaft dimensions (diameter, length, and reinforcement requirements). As documented in this research, the cost savings derived from the lateral load tests are at least ten times of the cost for conducting the load tests. It is therefore highly recommended that ODOT specify the lateral load tests for construction projects that involve a large amount of drilled shaft construction.

CHAPTER VII

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APPENDIX A: DEFLECTION AND STRAIN DATA FOR TESTED DRILLED SHAFTS

A.1: WAS-PUTNAM STREET B GE

A.2: LTON 50

A.1

WAS-PUTNAM STREET B GE

A.1.1: 14-M DEEP SHAFT #1 – DIAL GAGES

Load (Kips)	Pressure(psi)	Time	SH-1-1	Δ-1-1	SH-1-2	Δ-1-2
0	50	12:50	0		0	
25	550	12:54	0.029		0.026	
		12:59	0.033	0.004	0.029	0.003
		1:04	0.034	0.001	0.03	0.001
		1:09	0.035	0.001	0.03	0
50	1050	1:14	0.071	0.036	0.068	0.038
		1:19	0.079	0.006	0.073	0.005
		1:24	0.081	0.002	0.075	0.002
		1:29	0.082	0.001	0.077	0.002
		1:34	0.084	0.002	0.078	0.001
75	1550	1:37	0.125	0.041	0.123	0.055
		1:42	0.168	0.043	0.161	0.038
		1:47	0.178	0.01	0.17	0.009
		1:52	0.182	0.004	0.173	0.003
		1:57	0.184	0.002	0.176	0.002
100	1950	1:59	0.232	0.048	0.226	0.05
		2:04	0.252	0.02	0.241	0.015
		2:09	0.258	0.006	0.246	0.005
		2:14	0.261	0.003	0.249	0.003
		2:19	0.265	0.004	0.253	0.004
		2:24	0.269	0.004	0.256	0.003
125	2400	2:31	0.34	0.071	0.326	0.07
		2:36	0.361	0.021	0.347	0.021
		2:41	0.369	0.008	0.353	0.006
		2:46	0.374	0.005	0.359	0.006
		2:51	0.378	0.004	0.363	0.004
		2:56	0.382	0.004	0.367	0.004
150	2850	3:00	0.478	0.096	0.46	0.093
		3:05	0.525	0.047	0.508	0.048
		3:10	0.538	0.013	0.519	0.011
		3:15	0.545	0.007	0.526	0.007
		3:20	0.552	0.007	0.532	0.006
		3:25	0.558	0.006	0.537	0.005
175	3300	3:29	0.644	0.086	0.625	0.088
		3:34	0.685	0.041	0.664	0.039
		3:39	0.7	0.015	0.678	0.014
		3:44	0.715	0.015	0.689	0.011
		3:49	0.728	0.013	0.7	0.011
		3:54	0.736	0.008	0.71	0.01
		3:59	0.744	0.008	0.718	0.008
		4:04	0.754	0.01	0.728	0.01
200	3750	4:07	0.84	0.086	0.825	0.097
		4:12	0.883	0.043	0.858	0.033
		4:19	0.912	0.0029	0.883	0.025
		4:23	0.924	0.012	0.894	0.011
		4:28	0.936	0.012	0.906	0.012
		4:33	0.944	0.008	0.913	0.007
		4:38	0.951	0.007	0.919	0.006
		4:43	0.954	0.003	0.923	0.004
225	4200	4:47	1.057	0.103	1.03	0.107
		4:52	1.102	0.045	1.07	0.04
		4:57	1.13	0.028	1.095	0.025
		5:02	1.152	0.022	1.132	0.037
		5:07	1.183	0.031	1.142	0.01
		5:12	1.198	0.015	1.152	0.01
		5:17	1.205	0.007	1.164	0.012
250	4650	5:22	1.3	0.095	1.26	0.096
		5:27	1.366	0.068	1.33	0.07
		5:32	1.404	0.036	1.358	0.028
		5:37	1.434	0.03	1.388	0.03
		5:42	1.46	0.026	1.41	0.022
		5:47	1.475	0.015	1.423	0.013
		5:52	1.49	0.015	1.437	0.014
		5:57	1.498	0.008	1.446	0.009
		6:02	1.51	0.012	1.455	0.009
		6:07	1.518	0.008	1.466	0.011
		6:12	1.522	0.004	1.472	0.006
150	2950	6:15	1.386	-0.136	1.333	-0.139
		6:25	1.384	-0.002	1.332	-0.001
75	1550	6:25	1.1	-0.284	1.053	-0.279
		6:35	1.095	-0.006	1.05	-0.003
0	50	6:37	0.485	-0.61	0.45	-0.06
		6:47	0.445	-0.04	0.418	-0.027

Load (Kips)	SH-1-1	SH-1-2	Average
0	0	0	0
25	0.029	0.026	0.0275
	0.033	0.029	0.031
	0.034	0.03	0.032
	0.035	0.03	0.0325
50	0.071	0.068	0.0695
	0.079	0.073	0.076
	0.081	0.075	0.078
	0.082	0.077	0.0795
	0.084	0.078	0.081
75	0.125	0.123	0.124
	0.168	0.161	0.1645
	0.178	0.17	0.174
	0.182	0.173	0.1775
	0.184	0.176	0.18
100	0.232	0.226	0.229
	0.252	0.241	0.2465
	0.258	0.246	0.252
	0.261	0.249	0.255
	0.265	0.253	0.259
	0.269	0.256	0.2625
125	0.34	0.326	0.333
	0.361	0.347	0.354
	0.369	0.353	0.361
	0.374	0.359	0.3665
	0.378	0.363	0.3705
	0.382	0.367	0.3745
150	0.478	0.46	0.469
	0.525	0.508	0.5165
	0.538	0.519	0.5285
	0.545	0.526	0.5355
	0.552	0.532	0.542
	0.558	0.537	0.5475
175	0.644	0.625	0.6345
	0.685	0.664	0.6745
	0.7	0.678	0.689
	0.715	0.689	0.702
	0.728	0.7	0.714
	0.736	0.71	0.723
	0.744	0.718	0.731
	0.754	0.728	0.741
200	0.84	0.825	0.8325
	0.883	0.858	0.8705
	0.912	0.883	0.8975
	0.924	0.894	0.909
	0.936	0.906	0.921
	0.944	0.913	0.9285
	0.951	0.919	0.935
	0.954	0.923	0.9385
225	1.057	1.03	1.0435
	1.102	1.07	1.086
	1.13	1.095	1.1125
	1.152	1.132	1.142
	1.183	1.142	1.1625
	1.198	1.152	1.175
	1.205	1.164	1.1845
250	1.3	1.26	1.28
	1.368	1.33	1.349
	1.404	1.358	1.381
	1.434	1.388	1.411
	1.46	1.41	1.435
	1.475	1.423	1.449
	1.49	1.437	1.4635
	1.498	1.446	1.472
	1.51	1.455	1.4825
	1.518	1.466	1.492
	1.522	1.472	1.497
150	1.386	1.333	1.3595
	1.384	1.332	1.358
75	1.1	1.053	1.0765
	1.095	1.05	1.0725
0	0.485	0.45	0.4675
	0.445	0.418	0.4315

A.1.2: 14-M DEEP SHAFT #2 – DIAL GAGES

Load (Kips)	Pressure(psi)	Time	SH-2-1	Δ-2-1	SH-2-2	Δ-2-2
0	0	12:50	0	0	0	0
25	550	12:54	0.04	0.04	0.04	0.04
		12:59	0.048	0.008	0.048	0.008
		1:04	0.049	0.001	0.049	0.001
		1:09	0.05	0.001	0.05	0.001
50	1050	1:14	0.12	0.07	0.127	0.077
		1:19	0.14	0.02	0.141	0.02
		1:24	0.147	0.007	0.145	0.004
		1:29	0.15	0.003	0.149	0.004
		1:34	0.153	0.003	0.152	0.003
75	1550	1:37	0.248	0.095	0.254	0.102
		1:42	0.309	0.061	0.306	0.052
		1:47	0.321	0.012	0.32	0.014
		1:52	0.329	0.008	0.326	0.006
		1:57	0.333	0.004	0.331	0.005
100	1950	1:59	0.462	0.129	0.482	0.151
		2:04	0.539	0.077	0.543	0.061
		2:09	0.568	0.029	0.564	0.021
		2:14	0.577	0.009	0.574	0.01
		2:19	0.586	0.009	0.584	0.01
		2:24	0.594	0.008	0.591	0.007
125	2400	2:31	0.77	0.176	0.777	0.186
		2:36	0.867	0.097	0.862	0.085
		2:41	0.884	0.074	0.881	0.019
		2:46	0.895	0.011	0.893	0.012
		2:51	0.905	0.01	0.902	0.009
		2:56	0.915	0.01	0.91	0.008
150	2850	3:00	1.1	0.185	1.101	0.191
		3:05	1.182	0.082	1.178	0.077
		3:10	1.211	0.029	1.204	0.026
		3:15	1.227	0.016	1.219	0.015
		3:20	1.241	0.014	1.232	0.013
		3:25	1.25	0.009	1.241	0.009
175	3300	3:29	1.44	0.19	1.448	0.216
		3:34	1.53	0.09	1.524	0.076
		3:39	1.565	0.035	1.557	0.033
		3:44	1.585	0.02	1.578	0.021
		3:49	1.612	0.017	1.604	0.026
		3:54	1.625	0.013	1.617	0.013
		3:59	1.635	0.01	1.626	0.009
		4:04	1.65	0.015	1.641	0.015
200	3750	4:07	1.835	0.185	1.845	0.204
		4:12	1.917	0.082	1.91	0.065
		4:14	1.923	0.006	1.922	0.012
		4:19	1.963	0.04	1.954	0.032
		4:23	1.984	0.021	1.972	0.018
		4:28	2.002	0.018	1.992	0.02
		4:33	2.018	0.016	2.009	0.017
		4:38	2.025	0.007	2.016	0.007
		4:43	2.03	0.005	2.023	0.007
225	4200	4:47	2.274	0.244	2.264	0.241
		4:52	2.361	0.087	2.352	0.088
		4:57	2.405	0.044	2.396	0.044
		5:02	2.427	0.022	2.422	0.026
		5:07	2.445	0.018	2.433	0.011
		5:12	2.461	0.016	2.451	0.018
		5:17	2.476	0.015	2.467	0.016
250	4650	5:22	2.688	0.212	2.687	0.022
		5:27	2.811	0.123	2.811	0.124
		5:32	2.86	0.049	2.854	0.043
		5:37	2.875	0.035	2.887	0.033
		5:42	2.923	0.028	2.916	0.029
		5:47	2.943	0.02	2.936	0.02
		5:52	2.963	0.02	2.954	0.018
		5:57	2.974	0.011	2.965	0.011
		6:02	2.987	0.013	2.979	0.014
		6:07	3.001	0.014	2.991	0.012
		6:12	3.011	0.01	3.002	0.011
150	2950	6:15	2.758	-0.253	2.745	-0.257
		6:25	2.758	0	2.744	-0.1
75	1550	6:25	2.218	-0.54	2.407	-0.337
		6:25	2.218	0	2.406	-0.1
0	50	6:34				

A.1.2: 14-M DEEP SHAFT #2 – DIAL GAGES (CONTINUED)

Load (Kips)	SH-2-1	SH-2-2	Average
0	0	0	0
25	0.04	0.04	0.04
	0.048	0.048	0.048
	0.049	0.049	0.049
	0.05	0.05	0.05
50	0.12	0.127	0.1235
	0.14	0.141	0.1405
	0.147	0.145	0.146
	0.15	0.149	0.1495
	0.153	0.152	0.1525
75	0.248	0.254	0.251
	0.309	0.306	0.3075
	0.321	0.32	0.3205
	0.329	0.326	0.3275
	0.333	0.331	0.332
100	0.462	0.482	0.472
	0.539	0.543	0.541
	0.568	0.564	0.566
	0.577	0.574	0.5755
	0.586	0.584	0.585
	0.594	0.591	0.5925
125	0.77	0.777	0.7735
	0.867	0.862	0.8645
	0.884	0.881	0.8825
	0.895	0.893	0.894
	0.905	0.902	0.9035
	0.915	0.91	0.9125
150	1.1	1.101	1.1005
	1.182	1.178	1.18
	1.211	1.204	1.2075
	1.227	1.219	1.223
	1.241	1.232	1.2365
	1.25	1.241	1.2455
175	1.44	1.448	1.444
	1.53	1.524	1.527
	1.565	1.557	1.561
	1.585	1.578	1.5815
	1.612	1.604	1.608
	1.625	1.617	1.621
	1.635	1.626	1.6305
	1.65	1.641	1.6455
200	1.835	1.845	1.84
	1.917	1.91	1.9135
	1.923	1.922	1.9225
	1.963	1.954	1.9585
	1.984	1.972	1.978
	2.002	1.992	1.997
	2.018	2.009	2.0135
	2.025	2.016	2.0205
	2.03	2.023	2.0265
225	2.274	2.264	2.269
	2.361	2.352	2.3565
	2.405	2.396	2.4005
	2.427	2.422	2.4245
	2.445	2.433	2.439
	2.461	2.451	2.456
	2.476	2.467	2.4715
250	2.688	2.687	2.6875
	2.811	2.811	2.811
	2.86	2.854	2.857
	2.875	2.887	2.881
	2.923	2.916	2.9195
	2.943	2.936	2.9395
	2.963	2.954	2.9585
	2.974	2.965	2.9695
	2.987	2.979	2.983
	3.001	2.991	2.996
	3.011	3.002	3.0065
150	2.758	2.745	2.7515
	2.758	2.744	2.751
75	2.218	2.407	2.3125
	2.218	2.406	2.312
0			[illegible]

PUTNAM STREET BRIDGE PROJECT : Lateral load test on 14 m deep shaft - 1
Deflection vs. depth using inclinometer - A-direction (Load application direction)

Time	14:00	14:24	14:46	15:18	15:46	16:16	16:54	17:34	18:09	19:04	19:43
load (K)	25K	50 K	75 K	100 K	125 K	150 K	175 K	200 K	225 K	250 K	0U
Depth (ft)	Deflection (inch)										
2	0.0102	0.0696	0.1728	0.2898	0.3864	0.5676	0.7728	1.0002	1.2468	1.587	0.414
4	0.006	0.0588	0.1458	0.2484	0.3276	0.4746	0.648	0.8424	1.0434	1.335	0.3594
6	0	0.0468	0.1164	0.2052	0.2682	0.3804	0.5226	0.684	0.8406	1.0818	0.3024
8	-0.0036	0.036	0.0882	0.1644	0.21	0.2886	0.396	0.5232	0.6318	0.8214	0.2406
10	-0.0072	0.0264	0.0612	0.1254	0.1536	0.2094	0.2904	0.3918	0.4584	0.5982	0.1866
12	-0.0096	0.0162	0.0342	0.087	0.0978	0.1362	0.1938	0.2622	0.3018	0.4008	0.1326
14	-0.0126	0.0072	0.012	0.0534	0.0516	0.0702	0.1062	0.1518	0.171	0.225	0.0828
16	-0.0138	0.0024	0.0036	0.0372	0.0294	0.0384	0.0594	0.087	0.0906	0.1224	0.0516
18	-0.0156	-0.0036	-0.006	0.0246	0.012	0.012	0.0234	0.0402	0.0306	0.0504	0.027
20	-0.0156	-0.0054	-0.0114	0.0156	0	-0.0042	0.0048	0.0126	-0.0048	0.0054	0.0102
22	-0.0162	-0.0054	-0.018	0.0066	-0.0084	-0.0126	-0.009	-0.006	-0.027	-0.0198	0.0012
24	-0.0156	-0.0066	-0.0204	0	-0.0126	-0.0192	-0.0186	-0.0168	-0.0384	-0.0324	-0.0072
26	-0.0162	-0.0066	-0.021	-0.0042	-0.0168	-0.0228	-0.024	-0.0234	-0.0444	-0.0402	-0.0138
28	-0.0162	-0.0066	-0.0204	-0.0066	-0.018	-0.0228	-0.0252	-0.0258	-0.0468	-0.0438	-0.0162
30	-0.0162	-0.0084	-0.0186	-0.0078	-0.018	-0.0222	-0.0276	-0.027	-0.0462	-0.042	-0.0174
32	-0.0138	-0.0126	-0.015	-0.0054	-0.0174	-0.021	-0.0198	-0.0258	-0.0384	-0.0384	-0.0174
34	-0.0138	-0.012	-0.0138	-0.0054	-0.0168	-0.0192	-0.0192	-0.024	-0.036	-0.0354	-0.0186
36	-0.0126	-0.0108	-0.0132	-0.0042	-0.015	-0.0156	-0.0168	-0.0216	-0.0324	-0.0312	-0.0174
38	-0.0114	-0.009	-0.0108	-0.0036	-0.012	-0.0144	-0.0144	-0.0174	-0.0276	-0.0246	-0.0144
40	-0.0096	-0.0072	-0.0078	-0.0018	-0.0078	-0.0114	-0.0102	-0.0114	-0.0222	-0.0186	-0.0114
42	-0.009	-0.0036	-0.006	-0.0006	-0.0036	-0.0078	-0.0078	-0.0072	-0.0162	-0.0144	-0.0114
44	-0.0084	-0.0036	-0.0042	0	-0.0018	-0.006	-0.0054	-0.0048	-0.012	-0.0096	-0.0072
46	-0.006	-0.0012	-0.0024	0.0042	0.0012	-0.0042	-0.0036	-0.003	-0.0096	-0.003	-0.006
48	-0.0048	0.0006	-0.003	0.0042	0.0042	-0.003	-0.003	-0.0036	-0.0072	-0.0006	-0.0042
50	-0.0036	0.0024	-0.0036	0.003	0.0036	-0.0018	-0.0024	-0.0012	-0.006	0.0018	-0.0048
52	-0.003	0.003	-0.0012	0.0036	0.0006	0.0006	-0.0036	0	-0.0036	0	-0.0066
54	-0.003	0.0012	-0.0018	0.003	0.0018	0.0012	-0.0036	0.0018	-0.0018	0.0012	-0.0048
56	-0.0024	0	-0.0018	0.0018	0.0024	-0.0012	-0.0024	0.0018	-0.003	0.0024	-0.0036
58	-0.003	0	-0.0006	0.0006	0.0018	-0.0012	-0.0012	0.0012	-0.0018	0.003	-0.0024

PUTNAM STREET BRIDGE PROJECT : Lateral load test on 14 m deep shaft - 1

Deflection vs. depth using inclinometer - B-direction (90 degrees from load application direction)

Time	14:00	14:24	14:46	15:18	15:46	16:16	16:54	8:09	18:09	19:04	19:43
load (K)	25K	50 K	75 K	100 K	125 K	150 K	175 K	200 K	225 K	250 K	0U
Depth (ft)	Deflection (inch)										
2	-0.0228	-0.015	0.0024	0.0108	-0.0198	0.0084	-0.006	-0.0006	-0.015	-0.045	-0.0648
4	-0.0198	-0.0114	0.006	0.0126	-0.0186	0.009	-0.0018	0.0024	-0.0096	-0.0384	-0.057
6	-0.0198	-0.012	0.0054	0.0096	-0.0216	0.0066	-0.003	-0.0006	-0.0114	-0.0372	-0.0546
8	-0.0198	-0.0126	0.0036	0.0054	-0.024	0.0054	-0.0024	0	-0.009	-0.0342	-0.0516
10	-0.0192	-0.012	0.0036	0.003	-0.0258	0.0018	-0.003	-0.0018	-0.0072	-0.0324	-0.048
12	-0.0204	-0.012	0.0036	-0.0006	-0.0252	-0.0024	-0.0072	-0.0036	-0.0084	-0.0378	-0.0456
14	-0.0204	-0.012	0.0036	-0.0024	-0.0246	-0.0036	-0.006	-0.0024	-0.0042	-0.0324	-0.0438
16	-0.021	-0.0132	0.0024	-0.006	-0.0276	-0.0084	-0.0102	-0.0066	-0.006	-0.0336	-0.0438
18	-0.0204	-0.015	0.0012	-0.0072	-0.0282	-0.0132	-0.0108	-0.012	-0.012	-0.036	-0.0402
20	-0.0198	-0.015	0.0024	-0.0096	-0.0282	-0.015	-0.0114	-0.0108	-0.0108	-0.0354	-0.0396
22	-0.0168	-0.0144	0.0096	-0.009	-0.027	-0.0102	-0.0096	-0.006	-0.0054	-0.0306	-0.0336
24	-0.018	-0.0126	0.0084	-0.0102	-0.0282	-0.0108	-0.0114	-0.0066	-0.0036	-0.0306	-0.0348
26	-0.0162	-0.012	0.0066	-0.009	-0.0258	-0.0084	-0.0114	-0.0078	0.0012	-0.0288	-0.0318
28	-0.015	-0.012	0.0066	-0.0096	-0.0264	-0.009	-0.0108	-0.0084	0.0024	-0.0282	-0.0294
30	-0.0144	-0.0114	0.0072	-0.009	-0.0258	-0.009	-0.0102	-0.006	0.0042	-0.0276	-0.0276
32	-0.0138	0.0012	0.006	-0.0102	-0.021	-0.0066	-0.0168	-0.0012	-0.0036	-0.0252	-0.0276
34	-0.0102	0.0012	0.0036	-0.009	-0.0186	-0.0048	-0.0132	0.0006	-0.0012	-0.024	-0.0258
36	-0.0096	0.0006	0.0042	-0.0084	-0.0174	-0.0042	-0.0132	0.0018	-0.0012	-0.0228	-0.0246
38	-0.0078	0.0018	0.0036	-0.0066	-0.0168	-0.0018	-0.0102	0.0048	0.0012	-0.0216	-0.0228
40	-0.0048	0.0048	0.0048	-0.003	-0.0132	0.0018	-0.0054	0.0084	0.0048	-0.0198	-0.021
42	-0.0018	0.003	0.0078	-0.0018	-0.0126	0.0054	0.0036	0.0108	0.0072	-0.0162	-0.015
44	-0.0024	0.003	0.006	-0.0012	-0.0114	0.0042	0.0018	0.0084	0.0078	-0.0144	-0.0144
46	0.0006	0.0054	0.006	0.0006	-0.009	0.0054	0.0024	0.0096	0.009	-0.0108	-0.0126
48	0	0.0054	0.003	0.0006	-0.0078	0.0036	-0.0006	0.0054	0.0078	-0.012	-0.0132
50	0.0018	0.006	0.0042	0.0012	-0.0066	0.0042	-0.0006	0.0066	0.0096	-0.0102	-0.0126
52	0.0012	0.0054	0.0018	0	0.0006	0.0006	0.0018	0.0054	0.0072	-0.0006	-0.006
54	0.0024	0.0054	0.0024	0.0006	0.0024	0.003	0.003	0.0066	0.009	0.0012	-0.003
56	0.003	0.0012	0	-0.0012	0.0024	0.0024	0	0.003	0.0018	0.0012	-0.0006
58	0.0018	0.0012	0.0006	-0.0012	0.0018	0.0012	0.0006	0.0006	0.0006	0.0006	0.0006

A.1.4: 14-M DEEP SHAFT #2 – INCLINOMETER

PUTNAM STREET BRIDGE PROJECT : Lateral load test on 14 m deep shaft - 2
Deflection vs. depth using inclinometer - A-direction (Load application direction)

Time	14:00	14:24	14:46	15:18	15:46	16:16	16:54	17:34	18:09	19:04	19:43
load (K)	25K	50 K	75 K	100 K	125 K	150 K	175 K	200 K	225 K	250 K	0U
Depth (ft)	Deflection (inch)										
2	0.0462	0.1434	0.3252	0.5736	0.9078	1.2462	1.6344	2.0352	2.4894	3.0372	0.783
4	0.0402	0.1254	0.2862	0.5034	0.7986	1.0992	1.4436	1.8012	2.2038	2.694	0.7062
6	0.0318	0.105	0.2448	0.4302	0.687	0.9492	1.2492	1.5648	1.9158	2.349	0.6276
8	0.0222	0.0834	0.2028	0.357	0.5754	0.7992	1.0554	1.3284	1.6278	2.0046	0.5472
10	0.015	0.0648	0.165	0.2886	0.468	0.6546	0.8676	1.0986	1.347	1.668	0.4668
12	0.0108	0.051	0.1314	0.2238	0.3666	0.5154	0.687	0.876	1.0794	1.3476	0.3954
14	0.0066	0.039	0.1002	0.1632	0.273	0.3882	0.522	0.6702	0.831	1.0482	0.324
16	0.0012	0.0234	0.0696	0.1092	0.1908	0.2778	0.3774	0.4914	0.6138	0.7842	0.255
18	-0.003	0.0126	0.0426	0.0648	0.1218	0.1836	0.2544	0.3378	0.429	0.5574	0.1932
20	-0.0054	0.0042	0.024	0.033	0.0702	0.1104	0.1566	0.2142	0.2796	0.3726	0.141
22	-0.0048	-0.0006	0.0126	0.0126	0.0348	0.0582	0.084	0.1206	0.1626	0.2268	0.099
24	-0.006	-0.0054	0.0018	-0.0024	0.009	0.0216	0.0306	0.0498	0.0726	0.1134	0.0612
26	-0.0042	-0.0072	-0.0042	-0.0108	-0.006	-0.0024	-0.006	-0.0006	0.0102	0.03	0.0318
28	-0.006	-0.012	-0.012	-0.0204	-0.018	-0.0204	-0.0312	-0.0372	-0.036	-0.0336	0.0036
30	-0.0084	-0.0168	-0.0204	-0.0306	-0.0288	-0.0354	-0.0492	-0.0636	-0.0702	-0.081	-0.0216
32	-0.0138	-0.0258	-0.0306	-0.0414	-0.0438	-0.0498	-0.0624	-0.0828	-0.0942	-0.1146	-0.048
34	-0.0156	-0.0294	-0.0348	-0.0456	-0.0498	-0.0564	-0.0684	-0.0894	-0.1026	-0.129	-0.0594
36	-0.0156	-0.03	-0.0348	-0.0456	-0.0516	-0.0582	-0.069	-0.0888	-0.1032	-0.1296	-0.0642
38	-0.0126	-0.0258	-0.0318	-0.0414	-0.048	-0.0546	-0.0636	-0.0828	-0.0978	-0.1224	-0.0624
40	-0.0078	-0.0198	-0.0252	-0.0336	-0.0402	-0.0468	-0.0558	-0.0702	-0.0852	-0.1074	-0.054
42	-0.0024	-0.0108	-0.0162	-0.0234	-0.0288	-0.0336	-0.0426	-0.0546	-0.0672	-0.0882	-0.0414
44	-0.0018	-0.009	-0.0126	-0.0192	-0.024	-0.0282	-0.036	-0.045	-0.057	-0.0744	-0.0372
46	-0.003	-0.009	-0.012	-0.0168	-0.0228	-0.0264	-0.0312	-0.0384	-0.0492	-0.0642	-0.036
48	-0.0048	-0.0096	-0.0126	-0.015	-0.0204	-0.024	-0.0264	-0.0318	-0.042	-0.0528	-0.0324
50	-0.0036	-0.0072	-0.009	-0.009	-0.0138	-0.0168	-0.018	-0.0216	-0.0294	-0.0372	-0.0216
52	-0.0012	-0.003	-0.0036	-0.0024	-0.006	-0.0078	-0.0084	-0.0102	-0.015	-0.021	-0.012
54	0.0024	0.0024	0.0018	0.0054	0.003	0.0024	0.0024	0.003	0.0024	0	0.003
56	-0.0054	-0.0072	-0.0078	-0.0042	-0.0078	-0.0084	-0.0072	-0.0072	-0.0078	-0.0102	-0.0108
58	-0.0054	-0.0084	-0.0096	-0.0078	-0.0084	-0.0084	-0.0084	-0.009	-0.0084	-0.0096	-0.0108

PUTNAM STREET BRIDGE PROJECT : Lateral load test on 14 m deep shaft - 2

Deflection vs. depth using inclinometer - B-direction (90 degrees from load application direction)

Time	14:00	14:24	14:46	15:18	15:46	16:16	16:54	17:34	18:09	19:04	19:43
load (K)	25K	50 K	75 K	100 K	125 K	150 K	175 K	200 K	225 K	250 K	0U
Depth (ft)	Deflection (inch)										
2	-0.003	0.0114	0.0924	0.1824	0.3156	0.4452	0.609	0.732	0.8934	1.0878	0.24
4	-0.0042	0.006	0.0786	0.1578	0.2772	0.3936	0.5424	0.6522	0.7974	0.9756	0.2172
6	-0.0072	-0.0012	0.0636	0.132	0.2364	0.3396	0.4734	0.5694	0.6978	0.8592	0.1914
8	-0.012	-0.0108	0.0468	0.1044	0.1944	0.2838	0.4026	0.4848	0.5958	0.7392	0.1626
10	-0.0144	-0.0168	0.0336	0.0798	0.156	0.231	0.3354	0.4032	0.4986	0.6228	0.1368
12	-0.0096	-0.0156	0.027	0.0618	0.1236	0.1848	0.2736	0.3258	0.4068	0.5136	0.1182
14	-0.015	-0.0246	0.0108	0.0336	0.0816	0.1302	0.2028	0.2418	0.3072	0.3942	0.087
16	-0.0216	-0.0366	-0.006	0.0066	0.0408	0.0774	0.138	0.1638	0.2136	0.2838	0.0528
18	-0.0366	-0.0546	-0.03	-0.024	-0.003	0.0222	0.072	0.084	0.1224	0.1764	0.0096
20	-0.0438	-0.066	-0.0474	-0.0486	-0.0348	-0.0192	0.0204	0.0228	0.048	0.0894	-0.0252
22	-0.0516	-0.0738	-0.0624	-0.0678	-0.063	-0.0528	-0.0222	-0.0288	-0.0126	0.0156	-0.0588
24	-0.0564	-0.0804	-0.0714	-0.0798	-0.0804	-0.075	-0.0516	-0.0648	-0.0552	-0.0378	-0.0756
26	-0.0516	-0.0774	-0.0714	-0.081	-0.0852	-0.084	-0.066	-0.084	-0.0804	-0.0708	-0.084
28	-0.045	-0.072	-0.0666	-0.078	-0.0828	-0.0852	-0.0714	-0.093	-0.0942	-0.09	-0.0858
30	-0.039	-0.0642	-0.0594	-0.0708	-0.0762	-0.0828	-0.0696	-0.0936	-0.096	-0.0966	-0.0804
32	-0.0294	-0.0516	-0.0486	-0.06	-0.0648	-0.0714	-0.0612	-0.0864	-0.0888	-0.0936	-0.0684
34	-0.0276	-0.0486	-0.0456	-0.0582	-0.0642	-0.0702	-0.0606	-0.087	-0.0894	-0.0966	-0.0696
36	-0.0276	-0.0492	-0.0456	-0.0582	-0.0654	-0.0714	-0.0618	-0.0894	-0.0918	-0.0996	-0.0732
38	-0.0276	-0.0498	-0.0462	-0.0588	-0.0654	-0.0726	-0.0624	-0.09	-0.0936	-0.1014	-0.0768
40	-0.0276	-0.0498	-0.0462	-0.0588	-0.0648	-0.0738	-0.0618	-0.09	-0.0924	-0.1014	-0.0798
42	-0.0288	-0.0498	-0.0468	-0.0594	-0.0666	-0.0744	-0.0612	-0.0888	-0.0906	-0.0996	-0.0816
44	-0.0288	-0.0468	-0.042	-0.054	-0.0594	-0.0684	-0.0552	-0.0798	-0.0834	-0.0912	-0.0756
46	-0.0168	-0.0324	-0.0258	-0.0444	-0.042	-0.0504	-0.0414	-0.0618	-0.063	-0.0696	-0.0558
48	-0.0138	-0.0294	-0.0228	-0.0408	-0.0372	-0.0444	-0.036	-0.0552	-0.0558	-0.0612	-0.0516
50	-0.0126	-0.027	-0.0204	-0.0366	-0.0324	-0.0402	-0.0306	-0.0486	-0.0498	-0.0534	-0.0468
52	-0.0036	-0.003	-0.0006	-0.0132	-0.0036	-0.0108	-0.006	-0.0162	-0.0204	-0.0228	-0.018
54	0.0018	0.0054	0.0084	-0.003	0.0096	0.0018	0.006	-0.0024	-0.0036	-0.0054	-0.0024
56	0.0066	0.0114	0.0162	0.0054	0.0174	0.0102	0.0156	0.009	0.0096	0.0102	0.0132
58	0.0084	0.0138	0.0198	0.0162	0.0216	0.015	0.0198	0.0138	0.0138	0.015	0.0186

A.1.5: 9-M DEEP SHAFT #1 – DIAL GAGES

Load (Kips)	Pressure(psi)	Time	SH-1-1	Δ-1-1	SH-1-2	Δ-1-2
0	150	3:38	0		0	
25	650	3:39	0.044	0.044	0.049	0.049
		3:44	0.051	0.007	0.054	0.005
		3:49	0.054	0.003	0.057	0.003
		3:54	0.055	0.001	0.058	0.001
		3:59	0.058	0.003	0.06	0.002
50	1130	4:05	0.121	0.063	0.131	0.071
		4:10	0.142	0.021	0.149	0.018
		4:15	0.151	0.009	0.158	0.009
		4:20	0.155	0.004	0.165	0.007
		4:25	0.162	0.007	0.17	0.005
		4:30	0.164	0.002	0.173	0.003
		4:35	0.168	0.004	0.177	0.004
		4:42	0.169	0.001	0.179	0.002
62.5	1350	4:46	0.201	0.032	0.211	0.032
		4:51	0.215	0.014	0.226	0.015
		4:56	0.22	0.005	0.231	0.005
		5:01	0.226	0.006	0.237	0.006
		5:06	0.232	0.006	0.244	0.007
75	1600	5:12	0.27	0.038	0.29	0.046
		5:17	0.298	0.028	0.314	0.024
		5:22	0.312	0.014	0.327	0.013
		5:27	0.318	0.006	0.334	0.007
		5:32	0.329	0.011	0.344	0.01
		5:37	0.337	0.008	0.353	0.009
		5:42	0.341	0.004	0.358	0.005
		5:45	0.343	0.002	0.359	0.001
		5:50	0.346	0.003	0.362	0.003
87.5	1850	5:58	0.385	0.039	0.415	0.053
		6:03	0.418	0.033	0.438	0.023
		6:08	0.429	0.011	0.451	0.013
		6:13	0.44	0.011	0.461	0.01
		6:18	0.45	0.01	0.47	0.009
		6:23	0.456	0.006	0.476	0.006
		6:28	0.461	0.005	0.483	0.007
		6:33	0.467	0.006	0.49	0.007
100	2100	6:37	0.508	0.041	0.535	0.045
		6:42	0.56	0.052	0.59	0.055
		6:47	0.575	0.015	0.602	0.012
		6:52	0.585	0.01	0.611	0.009
		6:57	0.608	0.019	0.63	0.019
		7:02	0.719	0.011	0.646	0.015
		7:07	0.728	0.009	0.655	0.009
125	2600	7:14	0.975	0.247	0.902	0.247
		7:19	1.04	0.065	1.075	0.173
		7:24	1.068	0.028	1.05	-0.025
		7:29	1.095	0.027	1.138	0.088
		7:37	1.004	-0.091	1.148	0.01
		7:42	1.12	0.116	1.061	-0.087
		7:52	1.134	0.014	1.08	0.019
		8:02	1.151	0.017	1.1	0.02
		8:12	1.158	0.007	1.007	-0.093
		8:20	1.165	0.007	1.014	0.007
145	3000	8:26	1.345	0.18	1.287	0.273
		8:36	1.419	0.074	1.37	0.083
		8:48	1.498	0.079	1.458	0.088
		9:01	1.534	0.036	1.496	0.038
155	3200	9:06	1.644	0.11	1.583	0.087
		9:16	1.716	0.072	1.683	0.1
		9:26	1.758	0.042	1.723	0.04
		9:36	1.791	0.033	1.763	0.04
75	1600	9:48	1.565	-0.226	1.529	-0.234
		10:00	1.562	-0.003	1.527	-0.002
0		10:15	0.824	-0.738	0.856	-0.671

A.1.5: 9-M DEEP SHAFT #1 – DIAL GAGES (CONTINUED)

Load (Kips)	SH-1-1	SH-1-2	Average - 2
0	0	0	0
25	0.044	0.049	0.0465
	0.051	0.054	0.0525
	0.054	0.057	0.0555
	0.055	0.058	0.0565
	0.058	0.06	0.059
50	0.121	0.131	0.126
	0.142	0.149	0.1455
	0.151	0.158	0.1545
	0.155	0.165	0.16
	0.162	0.17	0.166
	0.164	0.173	0.1685
	0.168	0.177	0.1725
	0.169	0.179	0.174
62.5	0.201	0.211	0.206
	0.215	0.226	0.2205
	0.22	0.231	0.2255
	0.226	0.237	0.2315
	0.232	0.244	0.238
75	0.27	0.29	0.28
	0.298	0.314	0.306
	0.312	0.327	0.3195
	0.318	0.334	0.326
	0.329	0.344	0.3365
	0.337	0.353	0.345
	0.341	0.358	0.3495
	0.343	0.359	0.351
	0.346	0.362	0.354
87.5	0.385	0.415	0.4
	0.418	0.438	0.428
	0.429	0.451	0.44
	0.44	0.461	0.4505
	0.45	0.47	0.46
	0.456	0.476	0.466
	0.461	0.483	0.472
	0.467	0.49	0.4785
100	0.508	0.535	0.5215
	0.56	0.59	0.575
	0.575	0.602	0.5885
	0.585	0.611	0.598
	0.608	0.63	0.619
	0.719	0.646	0.6825
	0.728	0.655	0.6915
125	0.975	0.902	0.9385
	1.04	1.075	1.0575
	1.068	1.05	1.059
	1.095	1.138	1.1165
	1.004	1.148	1.076
	1.12	1.061	1.0905
	1.134	1.08	1.107
	1.151	1.1	1.1255
	1.158	1.007	1.0825
	1.165	1.014	1.0895
145	1.345	1.287	1.316
	1.419	1.37	1.3945
	1.498	1.458	1.478
	1.534	1.496	1.515
155	1.644	1.583	1.6135
	1.716	1.683	1.6995
	1.758	1.723	1.7405
	1.791	1.763	1.777
75	1.565	1.529	1.547
	1.562	1.527	1.5445
0	0.824	0.856	0.84

A.1.6: 9-M DEEP SHAFT #2 – DIAL GAGES

Load (Kips)	Pressure(psi)	Time	SH-2-1	Δ-2-1	SH-2-2	Δ-2-2
0	150	3:38	0		0	
25	650	3:39	0.051		0.045	
		3:44	0.062	0.011	0.06	0.015
		3:49	0.067	0.005	0.065	0.005
		3:54	0.07	0.003	0.068	0.003
		3:59	0.073	0.003	0.07	0.002
50	1130	4:05	0.162	0.099	0.152	0.081
		4:10	0.192	0.03	0.182	0.031
		4:15	0.207	0.015	0.195	0.013
		4:20	0.219	0.012	0.206	0.011
		4:25	0.227	0.012	0.215	0.011
		4:30	0.232	0.015	0.221	0.006
		4:35	0.239	0.007	0.227	0.006
		4:42	0.243	0.004	0.231	0.005
62.5	1350	4:46	0.282	0.039	0.266	0.035
		4:51	0.303	0.011	0.285	0.019
		4:56	0.311	0.008	0.299	0.014
		5:01	0.32	0.009	0.303	0.004
		5:06	0.329	0.009	0.309	0.006
75	1600	5:12	0.373	0.044	0.351	0.042
		5:17	0.406	0.033	0.382	0.031
		5.22	0.424	0.018	0.399	0.017
		5.27	0.435	0.011	0.409	0.01
		5.32	0.448	0.013	0.422	0.012
		5.37	0.46	0.012	0.433	0.011
		5.42	0.468	0.008	0.441	0.008
		5.47	0.472	0.004	0.444	0.003
		5.52	0.479	0.007	0.45	0.006
87.5	1850	5.58	0.528	0.049	0.49	0.04
		6.03	0.557	0.029	0.524	0.034
		6.08	0.573	0.016	0.539	0.015
		6.13	0.585	0.012	0.55	0.011
		6.18	0.597	0.012	0.562	0.012
		6.23	0.607	0.01	0.572	0.01
		6.28	0.619	0.012	0.589	0.012
		6.33	0.629	0.01	0.6	0.011
100	2100	6.37	0.671	0.042	0.645	0.045
		6.42	0.719	0.048	0.675	0.03
		6.47	0.732	0.013	0.695	0.02
		6.52	0.744	0.012	0.704	0.009
		6.57	0.766	0.022	0.724	0.02
		7.02	0.774	0.008	0.735	0.011
		7.07	0.786	0.012	0.742	0.007
125	2600	7.14	0.94	0.154	0.961	0.219
		7.19	1.112	0.172	1.04	0.079
		7.24	1.164	0.052	1.094	0.054
		7.29	1.234	0.07	1.138	0.044
		7.37	1.26	0.026	1.184	0.046
		7.42	1.296	0.036	1.219	0.035
		7.52	1.238	0.032	1.25	0.031
		8.02	1.37	0.042	1.293	0.043
		8.12	1.411	0.041	1.33	0.037
		8.2	1.44	0.029	1.359	0.029
145	3000	8.26	1.622	0.182	1.505	0.146
		8.36	1.81	0.188	1.797	0.292
		8.38	1.892	0.082	1.862	0.065
		8.48	1.999	0.107	2.083	0.221
		9.01	2.095	0.096	2.182	0.099
155	3200	9.06	2.206	0.111	2.275	0.093
		9.16	2.45	0.244	2.435	0.16
		9.26	2.542	0.092	2.53	0.095
		9.36	2.613	0.071	2.602	0.072
75	1600	9.48	2.472	-0.141	2.43	-0.172
		10	2.426	-0.046	2.426	-0.004
	0	10.15	1.56	-0.866	1.623	-0.803

A.1.6: 9-M DEEP SHAFT #2 – DIAL GAGES (CONTINUED)

Load (Kips)	SH-2-1	SH-2-2	Average- 2
0	0	0	0
25	0.051	0.045	0.048
	0.062	0.06	0.061
	0.067	0.065	0.066
	0.07	0.068	0.069
	0.073	0.07	0.0715
50	0.162	0.152	0.157
	0.192	0.182	0.187
	0.207	0.195	0.201
	0.219	0.206	0.2125
	0.227	0.215	0.221
	0.232	0.221	0.2265
	0.239	0.227	0.233
	0.243	0.231	0.237
62.5	0.282	0.266	0.274
	0.303	0.285	0.294
	0.311	0.299	0.305
	0.32	0.303	0.3115
	0.329	0.309	0.319
75	0.373	0.351	0.362
	0.406	0.382	0.394
	0.424	0.399	0.4115
	0.435	0.409	0.422
	0.448	0.422	0.435
	0.46	0.433	0.4465
	0.468	0.441	0.4545
	0.472	0.444	0.458
	0.479	0.45	0.4645
87.5	0.528	0.49	0.509
	0.557	0.524	0.5405
	0.573	0.539	0.556
	0.585	0.55	0.5675
	0.597	0.562	0.5795
	0.607	0.572	0.5895
	0.619	0.589	0.604
	0.629	0.6	0.6145
100	0.671	0.645	0.658
	0.719	0.675	0.697
	0.732	0.695	0.7135
	0.744	0.704	0.724
	0.766	0.724	0.745
	0.774	0.735	0.7545
	0.786	0.742	0.764
125	0.94	0.961	0.9505
	1.112	1.04	1.076
	1.164	1.094	1.129
	1.234	1.138	1.186
	1.26	1.184	1.222
	1.296	1.219	1.2575
	1.238	1.25	1.244
	1.37	1.293	1.3315
	1.411	1.33	1.3705
	1.44	1.359	1.3995
145	1.622	1.505	1.5635
	1.81	1.797	1.8035
	1.892	1.862	1.877
	1.999	2.083	2.041
	2.095	2.182	2.1385
155	2.206	2.275	2.2405
	2.45	2.435	2.4425
	2.542	2.53	2.536
	2.613	2.602	2.6075
75	2.472	2.43	2.451
	2.426	2.426	2.426
0	1.56	1.623	1.5915

A.1.7: 9-M DEEP SHAFT #1 – INCLINOMETER

PUTNAM STREET BRIDGE PROJECT : Lateral load test on 9 m deep shaft - 1

Deflection vs. depth using inclinometer - A-direction (Load application direction)

Time	15:49	16:31	16:58	17:43	18:24	18:55	20:10	20:53	21:31	22:06
load (K)	25K	50 K	62.5 K	75 K	87.5 K	100 K	125 K	145 K	155 K	0U
Depth (ft)	Deflection (inch)									
2	0.0522	0.1458	0.1782	0.2784	0.3876	0.5286	0.9426	1.2996	1.4688	0.5436
4	0.0504	0.1278	0.156	0.2436	0.3456	0.474	0.8454	1.1598	1.302	0.4914
6	0.0444	0.1092	0.1314	0.2088	0.3006	0.4164	0.7428	1.0176	1.1346	0.4332
8	0.0378	0.0924	0.1092	0.1758	0.2568	0.36	0.6426	0.8796	0.9714	0.3744
10	0.0318	0.075	0.0876	0.144	0.2148	0.3042	0.5448	0.7488	0.8148	0.3168
12	0.0252	0.0582	0.0654	0.1128	0.1752	0.2496	0.45	0.6216	0.663	0.2592
14	0.0198	0.0432	0.045	0.0846	0.1392	0.1992	0.3594	0.5016	0.525	0.2046
16	0.0162	0.0324	0.0306	0.0618	0.1062	0.1584	0.2838	0.399	0.4038	0.1548
18	0.0126	0.0204	0.0168	0.039	0.0762	0.1224	0.2178	0.3066	0.2988	0.1074
20	0.0102	0.0114	0.0048	0.0198	0.0504	0.0906	0.1608	0.2292	0.2088	0.0636
22	0.0072	0.0042	-0.0054	0.003	0.0276	0.0618	0.1104	0.1656	0.1314	0.0222
24	0.006	-0.0018	-0.0144	-0.0114	0.0084	0.0372	0.072	0.1128	0.0702	-0.0174
26	0.0042	-0.0084	-0.0216	-0.0234	-0.009	0.0162	0.0384	0.0684	0.0174	-0.0516
28	0.0054	-0.0108	-0.0264	-0.0336	-0.0246	-0.0006	0.0084	0.0312	-0.0294	-0.0834
30	0.0072	-0.0126	-0.0288	-0.0414	-0.0378	-0.0144	-0.0162	-0.0042	-0.0744	-0.1122
32	0.0084	-0.0138	-0.0366	-0.048	-0.0516	-0.0264	-0.0426	-0.0378	-0.117	-0.1422
34	0.0084	-0.0132	-0.039	-0.0552	-0.0642	-0.0396	-0.0714	-0.0726	-0.1572	-0.1788
36	0.0048	-0.018	-0.0384	-0.063	-0.0804	-0.0534	-0.1032	-0.12	-0.2142	-0.216
38	0.0078	-0.0114	-0.0288	-0.045	-0.0582	-0.0468	-0.0858	-0.0978	-0.168	-0.1584
40	0.0012	0.0018	-0.012	-0.0096	-0.0114	-0.021	-0.0132	-0.024	-0.0348	-0.0168
42	-0.0024	-0.0006	-0.0066	-0.0036	-0.0018	-0.0054	-0.0018	-0.0048	-0.006	0
44	-0.0036	-0.006	-0.009	-0.006	-0.0048	-0.0132	-0.0096	-0.0096	-0.0108	-0.0006
46	0	-0.0036	-0.0048	-0.0036	-0.003	-0.0084	-0.0042	-0.0054	-0.0078	0.0006
48	-0.0018	-0.0042	-0.0048	-0.0048	-0.0036	-0.0078	-0.006	-0.0072	-0.0078	0.0018
50	-0.0012	-0.0024	-0.0036	-0.0042	-0.0024	-0.0054	-0.0042	-0.0054	-0.0054	0.0012

PUTNAM STREET BRIDGE PROJECT : Lateral load test on 9 m deep shaft - 1

Deflection vs. depth using inclinometer - B-direction (90 degrees from load application direction)

Time	15:49	16:31	16:58	17:43	18:24	18:55	20:10	20:53	21:31	22:06
load (K)	25K	50 K	62.5 K	75 K	87.5 K	100 K	125 K	145 K	155 K	0U
Depth (ft)	Deflection (inch)									
2	0.0576	0.0762	0.1116	0.186	0.2382	0.3798	0.5592	0.7764	0.8586	0.3288
4	0.0558	0.0672	0.0978	0.1644	0.2148	0.348	0.5076	0.7026	0.7698	0.3018
6	0.051	0.0582	0.0846	0.147	0.189	0.3174	0.4548	0.6288	0.6822	0.2682
8	0.0456	0.0474	0.069	0.1272	0.1638	0.2856	0.402	0.5532	0.5928	0.2358
10	0.0414	0.0366	0.054	0.1092	0.1398	0.255	0.3492	0.4812	0.5058	0.2016
12	0.0378	0.0288	0.0402	0.0942	0.117	0.2244	0.2994	0.4104	0.4194	0.171
14	0.0384	0.0264	0.0342	0.081	0.0954	0.204	0.258	0.3492	0.3432	0.1416
16	0.0354	0.0204	0.0246	0.0642	0.075	0.1758	0.2088	0.2844	0.2688	0.1098
18	0.0318	0.0144	0.0126	0.0492	0.0552	0.1488	0.1614	0.2292	0.1998	0.078
20	0.0282	0.0072	0.0024	0.0348	0.0354	0.1266	0.1254	0.1818	0.1422	0.0492
22	0.0246	0.0006	-0.0084	0.021	0.0174	0.105	0.0948	0.1416	0.0924	0.0222
24	0.0216	-0.0024	-0.0126	0.0096	0.0036	0.0876	0.0684	0.108	0.0558	0.0018
26	0.0192	-0.0072	-0.0156	-0.0006	-0.0084	0.0684	0.0432	0.0762	0.0216	-0.0228
28	0.0144	-0.0126	-0.0186	-0.0126	-0.0192	0.0468	0.021	0.0444	-0.0102	-0.0528
30	0.0102	-0.0156	-0.0222	-0.0222	-0.0294	0.0318	-0.003	0.0198	-0.0378	-0.0732
32	0.0066	-0.0174	-0.0264	-0.0282	-0.0372	0.0222	-0.021	-0.0012	-0.0612	-0.0912
34	0.0078	-0.0138	-0.0258	-0.027	-0.0438	0.0186	-0.033	-0.0168	-0.0804	-0.111
36	0.006	-0.0066	-0.0192	-0.0162	-0.0426	0.0078	-0.042	-0.0306	-0.084	-0.096
38	0.0126	0.0054	-0.0102	0.0042	-0.0204	0.0186	-0.0144	-0.0042	-0.0378	-0.0432
40	0.0102	0.0132	0.0102	0.0138	0.0066	0.036	0.0216	0.0192	0.0216	0.0048
42	0.0132	0.0198	0.0162	0.0192	0.012	0.0408	0.024	0.0204	0.0198	-0.0018
44	0.0108	0.0096	0.0102	0.0156	0.0084	0.0234	0.0084	0.0084	0.0084	-0.0048
46	0.009	0.0048	0.0054	0.0132	0.0078	0.0168	0.0042	0.003	0.006	-0.0066
48	0.006	0.0048	0.0048	0.0114	0.0066	0.0138	0.0024	-0.0006	0.0042	-0.0066
50	0.0054	0.0054	0.0054	0.0102	0.006	0.0126	0.0048	0	0.003	-0.0078

A.1.10: 9-M DEEP SHAFT #2 – INCLINOMETER

PUTNAM STREET BRIDGE PROJECT : Lateral load test on 9 m deep shaft - 2
Deflection vs. depth using inclinometer - A-direction (Load application direction)

Time	15:49	16:31	16:58	17:43	18:24	18:55	20:10	20:53	21:31	22:06
load (K)	25K	50 K	62.5 K	75 K	87.5 K	100 K	125 K	145 K	155 K	0U
Depth (ft)	Deflection (inch)									
2	0.072	0.2454	0.3168	0.4608	0.6138	0.744	1.413	2.1126	2.5458	1.482
4	0.0618	0.216	0.2784	0.4038	0.5394	0.6546	1.2438	1.8732	2.2632	1.3338
6	0.0522	0.1866	0.24	0.3474	0.4662	0.5652	1.074	1.6326	1.9812	1.1862
8	0.0414	0.1572	0.2004	0.2904	0.3936	0.477	0.9048	1.3926	1.6992	1.038
10	0.0312	0.1272	0.162	0.2358	0.3198	0.39	0.7416	1.1592	1.4244	0.8886
12	0.0234	0.1014	0.1272	0.1848	0.2532	0.3078	0.5856	0.9354	1.1592	0.7428
14	0.018	0.0792	0.096	0.135	0.1902	0.2316	0.438	0.7278	0.9018	0.6
16	0.0132	0.057	0.066	0.0906	0.1296	0.1578	0.3018	0.5352	0.6696	0.4608
18	0.0108	0.0342	0.0408	0.0492	0.0744	0.09	0.1764	0.3594	0.4596	0.3264
20	0.0066	0.0144	0.0138	0.0078	0.0204	0.021	0.0588	0.1926	0.2628	0.1902
22	0.0024	-0.0036	-0.012	-0.0318	-0.0336	-0.045	-0.0498	0.0378	0.0804	0.0576
24	-0.0018	-0.0192	-0.0354	-0.0708	-0.0852	-0.108	-0.1512	-0.1068	-0.0888	-0.0738
26	-0.0036	-0.0348	-0.0564	-0.105	-0.1314	-0.168	-0.2472	-0.2448	-0.2502	-0.2052
28	-0.0054	-0.0474	-0.0774	-0.1386	-0.177	-0.2256	-0.3396	-0.3798	-0.4092	-0.3348
30	-0.0066	-0.0612	-0.0984	-0.1722	-0.2226	-0.282	-0.432	-0.5112	-0.5646	-0.4632
32	-0.009	-0.0744	-0.1188	-0.2034	-0.2688	-0.3378	-0.5244	-0.6402	-0.7224	-0.5898
34	-0.0114	-0.09	-0.1392	-0.234	-0.3162	-0.393	-0.612	-0.7692	-0.8796	-0.7128
36	-0.0132	-0.1038	-0.159	-0.264	-0.36	-0.4458	-0.7002	-0.8958	-1.035	-0.8394
38	-0.0162	-0.111	-0.1692	-0.2712	-0.366	-0.45	-0.7038	-0.9012	-1.0632	-0.8436
40	-0.003	-0.0306	-0.0486	-0.0804	-0.1098	-0.1344	-0.2184	-0.2634	-0.336	-0.282
42	-0.003	-0.0024	-0.0018	0.0006	0.0042	0.0042	0.0096	0.0246	0.0168	0.0174
44	-0.0024	-0.0018	0.0006	0	0.003	0.0042	0.0102	0.021	0.018	0.0144
46	-0.003	-0.0018	0	0	0.0012	0.0024	0.0072	0.0156	0.0126	0.009
48	-0.0024	-0.0018	-0.0018	-0.0018	-0.0012	0	0.0024	0.009	0.0066	0.0048
50	-0.0018	-0.0018	-0.0018	-0.0018	-0.0018	-0.0006	0.0006	0.0048	0.0018	0.0018

PUTNAM STREET BRIDGE PROJECT : Lateral load test on 9 m deep shaft - 2

Deflection vs. depth using inclinometer - B-direction (90 degrees from load application direction)

Time	15:49	16:31	16:58	17:43	18:24	18:55	20:10	20:53	21:31	22:06
load (K)	25K	50 K	62.5 K	75 K	87.5 K	100 K	125 K	145 K	155 K	0U
Depth (ft)	Deflection (inch)									
2	-0.003	-0.0384	-0.0798	-0.0822	-0.1236	-0.1632	-0.2502	-0.3204	-0.4152	-0.4152
4	0.0018	-0.0324	-0.072	-0.0696	-0.1092	-0.1458	-0.2214	-0.285	-0.3708	-0.3708
6	0.0036	-0.027	-0.0642	-0.0594	-0.0942	-0.1278	-0.1956	-0.2496	-0.3288	-0.3288
8	0.0048	-0.027	-0.0552	-0.048	-0.0828	-0.1116	-0.1674	-0.2148	-0.2886	-0.2886
10	0.009	-0.0204	-0.0486	-0.0342	-0.0648	-0.0924	-0.1422	-0.1806	-0.2484	-0.2484
12	0.0114	-0.0162	-0.0426	-0.0258	-0.0564	-0.078	-0.1188	-0.15	-0.213	-0.213
14	0.0144	-0.0108	-0.0354	-0.0204	-0.0438	-0.0606	-0.0972	-0.12	-0.1872	-0.1872
16	0.0114	-0.0066	-0.03	-0.0162	-0.033	-0.0438	-0.0726	-0.0924	-0.1404	-0.1404
18	0.0024	-0.0114	-0.0342	-0.0168	-0.0216	-0.0372	-0.0468	-0.0774	-0.1086	-0.1086
20	0.003	-0.0084	-0.03	-0.0096	-0.0054	-0.0258	-0.0216	-0.0528	-0.0726	-0.0726
22	0.0036	-0.0042	-0.0246	-0.0024	0.0042	-0.0138	-0.0036	-0.03	-0.045	-0.045
24	0.0066	0	-0.018	0.009	0.0162	0.0024	0.015	-0.0042	-0.0168	-0.0168
26	0.0054	0.0024	-0.0186	0.0144	0.021	0.0132	0.0294	0.0156	0.0078	0.0078
28	0.0024	-0.0006	-0.0162	0.0174	0.0246	0.0222	0.0366	0.0366	0.0312	0.0312
30	0.0012	-0.0018	-0.015	0.0234	0.024	0.0336	0.0504	0.0558	0.0456	0.0456
32	0.0006	0.0006	-0.0108	0.0288	0.0312	0.0444	0.066	0.0774	0.069	0.069
34	0.0018	0.0048	-0.0048	0.0336	0.042	0.0528	0.0798	0.0996	0.1026	0.1026
36	0.0012	0.0102	0.0018	0.0378	0.0564	0.06	0.0984	0.1242	0.1416	0.1416
38	0.003	0.012	0.0048	0.036	0.0534	0.0528	0.0882	0.111	0.1326	0.1326
40	0.0012	-0.0018	-0.0198	-0.0036	-0.0012	-0.0132	-0.015	-0.015	-0.012	-0.012
42	0.0066	0.0024	-0.0126	0.003	0.0066	0	-0.0048	0.0084	0.0036	0.0036
44	0.0042	0.0048	-0.0054	0.0036	0.0042	-0.0012	0.0006	0.006	0.009	0.009
46	0.0036	0.0042	-0.0054	0.0036	0.0036	-0.0018	-0.0006	0.0036	0.0066	0.0066
48	0.0048	0.0036	-0.0036	0.0036	0.0018	-0.0018	-0.0006	0.0018	0.0054	0.0054
50	0	-0.0018	-0.003	0.0024	0.0018	-0.0012	-0.0018	0.0012	0	0

A.1.11: 9-M DEEP SHAFT #1 – STRAINS

Tension

Load (K) / Depth (ft)	-6.5	-13.1	-19.67	-26.17	-32.7
0	2.185438	1.734698	0.251391	-0.389466	-0.459641
25	18.787717	22.65728	14.508852	5.063058	0.35357
50	36.976201	51.474508	37.134042	15.40161	1.979992
62.5	44.307993	63.7236	46.902378	19.933578	2.439633
75	56.821388	82.805278	60.908448	26.519094	3.323558
87.5	68.136317	103.72786	74.950431	33.317046	4.702481
100	78.675768	122.66793	85.508853	37.955232	5.551049
125	103.491064	177.647236	121.02681	52.22385	9.122106
145	118.471889	273.091028	200.322714	59.942358	9.970674
155	335.887721	352.462312	478.00203	69.537384	14.248871

Compression

Load (K) / Depth (ft)	-6.5	-13.1	-19.67	-26.17	-32.7
0	-0.88345	-1.889503	-1.38111	-0.432744	-0.684247
25	-15.01865	-19.394144	-13.774755	-5.301114	-3.709339
50	-28.871146	-43.173361	-32.34705	-12.946258	-9.687497
62.5	-35.302662	-52.442621	-39.870465	-15.86728	-11.452134
75	-43.99581	-66.66737	-50.08341	-20.230782	-14.261148
87.5	-52.229564	-80.856468	-60.587115	-25.171276	-16.962123
100	-60.640008	-96.649861	-68.655705	-28.236546	-18.618721
125	-83.150314	-129.05662	-95.80542	-37.648728	-26.397529
145	-96.366726	-110.125939	-113.32371	-42.805594	-28.594322
155	-105.731296	-164.493714	-127.71633	-48.539452	-35.184701

A.1.12: 9-M DEEP SHAFT #2 – STRAINS

Tension

Load (K) / Depth (ft)	6.5	13.1	19.67	26.17	32.7
0	3.1676	1.8744	1.316	0.143184	0.250383
25	23.75972	26.48913	20.36058	8.340468	4.506894
50	46.363956	51.351432	40.57494	18.936084	14.808366
62.5	55.318988	61.466108	48.945806	23.374788	15.702591
75	68.787645	76.319828	61.118288	29.853864	16.81143
87.5	81.895212	91.385744	73.912188	35.509632	18.59988
100	95.183324	108.75045	87.510276	40.879032	21.604476
125	113.418369	677.011338	252.661248	57.524172	38.058216
145	126.525936	814.12532	398.07306	71.162448	68.640711
155	150.466203	851.96694	490.335356	80.791572	98.293212

Compression

Load (K) / Depth (ft)	6.5	13.1	19.67	26.17	32.7
0	-2.40656	-2.91098	-2.5344	-1.28405	-0.79015
25	-18.9243	-22.6409	-17.6	-6.88392	-0.50282
50	-34.63985	-40.96932	-31.6448	-12.697808	-0.933816
62.5	-41.531357	-48.228796	-38.7904	-14.944892	-2.298624
75	-51.595145	-58.902382	-46.464	-18.476024	-3.016944
87.5	-60.16395	-69.396278	-54.6304	-22.577844	-3.735264
100	-70.482979	-82.262082	-64.592	-26.822336	-4.561332
125	-99.142897	-137.319098	-108.24	-35.739336	-5.56698
145	-115.004302	-172.68209	-137.8432	-44.727672	-5.100072
155	-126.234906	-198.162132	-159.808	-51.36192	-5.315568

A.1.13: 14-M DEEP SHAFT #1 – STRAINS

Tension

Load (K) / Depth (ft)	6.5	13.1	19.67	26.17	32.7	39.23	45.76
0	0	0	0	0	0	0	0
25	18.339903	22.349096	16.081236	7.951584	3.515985	0.510426	0.036786
50	39.294744	57.795633	46.396539	28.534224	13.815335	3.135474	0.846078
75	61.769076	104.997214	85.875249	57.87768	29.939145	7.145964	2.648592
100	81.133752	435.154314	633.723843	76.912224	41.69461	11.010618	6.25362
125	88.130478	610.681792	835.717206	95.806032	52.881835	14.036715	7.688274
150	102.088593	789.728527	1006.960638	587.39688	65.027965	17.463861	9.01257
175	118.626309	985.682208	1140.862281	742.73424	80.796625	21.911859	11.0358
200	134.139252	1170.388779	1272.482127	805.678416	93.19136	25.083792	11.21973
225	8.48088	182.348306	160.81236	84.336048	22.58754	5.395932	4.23039
250	154.033983	1540.672665	1592.658087	999.75336	140.959035	37.261098	18.061926

Compression

Load (K) / Depth (ft)	6.5	13.1	19.67	26.17	32.7	39.23	45.76
0	0	0	0	0	0	0	0
25	-45.7	-16.166832	-11.733712	-4.190416	-0.384032	1.11093	1.65946
50	-121.7	-43.052592	-33.084612	-14.879528	-2.688224	3.962317	4.563515
75	-207.8	-73.511328	-62.1961	-29.617008	-8.064672	3.406852	8.033295
100	-254.5	-90.03192	-81.393344	-39.986512	-11.276576	1.999674	8.82531
125	-299.5	-105.95112	-97.731424	-49.89436	-14.66304	3.110604	10.10762
150	-351.8	-124.452768	-117.448516	-59.234016	-18.3288	2.147798	11.804795
175	-411.9	-145.713744	-140.507488	-69.887616	-23.460864	0.814682	15.23686
200	-455.2	-161.031552	-161.561332	-76.812456	-28.62784	0.444372	16.89632
225	-56.7	-20.058192	-23.541688	-10.29848	-7.715552	-2.96248	0.641155
250	-585.9	-207.267984	-217.03654	-101.990464	-45.874368	-5.92496	18.32949

A.1.14: 14-M DEEP SHAFT #2 – STRAINS

Tension

Load (K) / Depth (ft)	-6.5	-13.1	-19.67	-26.17	-32.7	-39.23	-45.76
0	0	0	0	0	0	0	0
25	11.572868	13.621125	8.924322	6.554443	0.393668	-1.205127	-0.299784
50	24.867017	30.184413	23.069196	14.170779	3.543012	-0.986013	-0.449676
75	41.310744	55.901097	37.778454	20.798456	8.267028	-0.511266	-0.487149
100	55.044369	85.72228	52.346616	29.623153	11.022704	0.146076	-0.637041
125	71.011997	145.764199	70.72437	41.157508	15.782508	0.547785	-0.599568
150	92.106845	266.065975	86.174382	48.883695	15.639356	0.912975	-0.786933
175	114.227137	580.187279	112.982622	59.136455	20.649676	1.570317	-1.161663
200	135.651592	789.698343	407.837988	64.116367	23.763232	0.912975	-1.386501
225	440.831051	142.059253	125.892906	8.824697	3.543012	0.292152	-0.487149
250	640.975746	1158.122532	673.7334	86.818907	32.137624	1.789431	-2.360799

Compression

Load (K) / Depth (ft)	-6.5	-13.1	-19.67	-26.17	-32.7	-39.23	-45.76
0	0	0	0	0	0	0	0
25	-16.00965	-14.3075	-10.97105	-3.324498	0.109065	2.722608	0.891525
50	-33.833727	-32.560625	-26.81399	-9.584457	1002.707255	4.512816	3.173829
75	-53.756847	-62.02375	-44.2561	-17.860335	-2.03588	7.123536	6.133692
100	-70.691499	-84.14875	-59.42962	-26.030112	-3.817275	9.69696	8.237691
125	-91.504044	-108.33875	-78.8428	-34.235256	-6.943805	11.972016	11.732469
150	-147.182049	-139.055625	-96.13615	-41.167188	593.349955	13.575744	13.943451
175	-183.22155	-177	-118.15263	-48.700359	208.786765	16.59672	18.008805
200	-212.821614	-215.2025	-158.98725	-52.307793	524.82078	18.983664	20.719041
225	-53.00973	-31.970625	-28.15283	-7.108767	-159.780225	2.498832	3.316473
250	-306.602586	-361.965	-218.41687	-68.399778	-14.10574	23.272704	28.921071

A.2

HAMILTON 50

A.2.1: HAM 50 – SHAFT T-21

Depth	Load							
(ft)	25 K	50 K	75 K	100 K	125 K	150 K	175 K	200 K
2	0.0672	0.1764	0.3288	0.5598	0.9474	1.2462	1.701	2.2158
4	0.048	0.129	0.2466	0.4278	0.7326	0.969	1.3368	1.728
6	0.036	0.0864	0.1626	0.2904	0.5088	0.6774	0.9552	1.2174
8	0.0276	0.063	0.12	0.2094	0.3612	0.477	0.6714	0.7878
10	0.0222	0.0498	0.0924	0.1536	0.2568	0.3276	0.4674	0.5394
12	0.0186	0.0378	0.0684	0.102	0.1698	0.2106	0.3078	0.3486
14	0.0162	0.0282	0.048	0.0588	0.096	0.1146	0.1752	0.1944
16	0.0132	0.021	0.0324	0.033	0.0492	0.0516	0.0888	0.096
18	0.0114	0.0156	0.021	0.0192	0.024	0.0108	0.03	0.0282
20	0.009	0.012	0.0132	0.012	0.0156	-0.0024	0.0084	0.0018
22	0.0084	0.0078	0.0054	0.0072	0.0096	-0.0078	-0.0036	-0.0096
24	0.0078	0.0054	0.003	0.0036	0.006	-0.0084	-0.006	-0.0126
26	0.0048	0.0024	0	0.0024	0.0036	-0.0096	-0.0072	-0.0126
28	0.0042	0.0012	0.003	0.0024	0.0012	-0.0084	-0.006	-0.0102
30	0.0048	0	0.003	0.003	0.0006	-0.006	-0.0048	-0.0072
32	0.0036	-0.0006	0.0012	0.0024	0.0012	-0.0036	-0.0036	-0.0042
34	0.0024	0	0.0012	0.0018	0.0018	-0.0006	-0.0018	-0.0006

A.2.2: HAM 50 – SHAFT T-23

Depth	Load							
(ft)	25 K	50 K	75 K	100 K	125 K	150 K	175 K	200 K
2	0.0702	0.1944	0.306	0.5904	0.9546	1.359	1.8204	2.391
4	0.051	0.1422	0.2238	0.4458	0.7374	1.0662	1.434	1.8864
6	0.036	0.0924	0.1374	0.291	0.5028	0.7434	1.0068	1.3332
8	0.0282	0.063	0.0924	0.1926	0.3384	0.513	0.6864	0.8922
10	0.024	0.048	0.0696	0.129	0.2244	0.3474	0.4596	0.5958
12	0.0192	0.0348	0.0504	0.0792	0.1404	0.2268	0.2898	0.372
14	0.0162	0.0252	0.0366	0.042	0.0756	0.1362	0.168	0.2136
16	0.0168	0.0186	0.0264	0.0198	0.033	0.0732	0.0828	0.1128
18	0.0174	0.0156	0.0192	0.0102	0.0132	0.0354	0.0294	0.0498
20	0.015	0.012	0.015	0.0048	0.006	0.0186	0.003	0.0162
22	0.0132	0.0108	0.0138	0.0018	0.0042	0.0114	-0.003	0.0066
24	0.012	0.0108	0.0126	0.0018	0.006	0.0084	-0.0078	-0.0006
26	0.0114	0.0096	0.009	0.0006	0.006	0.0048	-0.0096	-0.0036
28	0.012	0.0132	0.0078	0.0042	0.0066	0.0054	-0.0048	0
30	0.0114	0.0114	0.0072	0.003	0.006	0.0048	-0.0024	0.0012
32	0.009	0.0114	0.0066	0.0042	0.0072	0.0042	0.0006	0.003
34	0.0078	0.009	0.006	0.006	0.0066	0.0042	0.0024	0.0042

A.2.3: HAM 50 – SHAFT T-25

Depth	Load											
(ft.)	12.5 K	25 K	37.5 K	50 K	62.5 K	75 K	87.5 K	100 K	112.5 K	125 K	137.5 K	150 K	0u
2	0.0342	0.093	0.18	0.276	0.3684	0.5184	0.6696	0.8442	1.0326	1.269	1.4874	1.6764	0.423
4	0.0258	0.0684	0.132	0.2016	0.2718	0.3852	0.504	0.642	0.7908	0.9792	1.1508	1.2978	0.3516
6	0.0162	0.0426	0.0828	0.1212	0.1662	0.2388	0.321	0.417	0.5214	0.6594	0.7794	0.8814	0.2622
8	0.0108	0.0258	0.0516	0.0762	0.1038	0.1482	0.204	0.2682	0.3378	0.432	0.5094	0.5748	0.1932
10	0.0054	0.015	0.0348	0.0534	0.0708	0.0972	0.1374	0.1806	0.2292	0.2958	0.3498	0.3906	0.1446
12	0.003	0.0078	0.0246	0.0366	0.048	0.0564	0.0846	0.1104	0.138	0.1854	0.2208	0.2448	0.1068
14	0.0042	0.0042	0.0186	0.0258	0.0318	0.03	0.0468	0.0606	0.0726	0.1026	0.1224	0.132	0.075
16	0.0036	0.0024	0.0126	0.0168	0.0198	0.0162	0.024	0.0294	0.033	0.048	0.0576	0.0594	0.0486
18	0.0036	0.0012	0.0096	0.0114	0.0132	0.0078	0.0114	0.0138	0.012	0.0186	0.021	0.0138	0.0282
20	0.0036	0	0.0072	0.0084	0.0102	0.0024	0.0042	0.0048	0.0018	0.0078	0.0084	0.0018	0.018
22	0.0042	0.0006	0.0054	0.006	0.0066	0	0	0	-0.006	-0.0012	-0.0012	-0.0084	0.0078
24	0.0048	0.0006	0.0042	0.0054	0.0036	-0.0024	-0.0024	-0.0024	-0.0096	-0.0084	-0.0102	-0.0174	-0.0018
26	0.0012	0	0.0006	0.003	0.0012	-0.0018	-0.003	-0.0054	-0.0096	-0.0096	-0.0102	-0.0126	-0.006

A.2.4: HAM 50 – SHAFT T-27

Depth	Load												
(ft.)	12.5 K	25 K	37.5 K	50 K	62.5 K	75 K	87.5 K	100 K	112.5 K	125 K	137.5 K	150 K	0u
2	0.033	0.0912	0.1884	0.33	0.5556	0.7458	0.975	1.1868	1.4826	1.8	2.073	2.337	0.6144
4	0.0264	0.0708	0.1464	0.2616	0.4512	0.5988	0.7908	0.9636	1.212	1.4784	1.7046	1.923	0.5304
6	0.0168	0.0468	0.099	0.1824	0.3348	0.4386	0.5904	0.7212	0.918	1.1286	1.3062	1.476	0.4302
8	0.0096	0.0282	0.0648	0.126	0.2424	0.3042	0.417	0.5088	0.6564	0.816	0.9468	1.0686	0.3348
10	0.0054	0.0174	0.0462	0.0942	0.1836	0.2118	0.294	0.3552	0.4608	0.5778	0.6696	0.7536	0.2562
12	0.0018	0.009	0.0318	0.0684	0.1338	0.1356	0.1956	0.234	0.3084	0.3912	0.4518	0.504	0.192
14	-0.0024	0.0024	0.0192	0.048	0.0894	0.0738	0.1146	0.1356	0.1848	0.2388	0.2766	0.3066	0.1374
16	-0.0036	-0.0018	0.0102	0.0312	0.0606	0.0366	0.0618	0.0714	0.1014	0.135	0.1554	0.1698	0.0924
18	-0.0054	-0.0048	0.0036	0.0162	0.0396	0.015	0.03	0.0312	0.048	0.0642	0.072	0.0768	0.0534
20	-0.0048	-0.006	-0.0012	0.0042	0.0228	0.0012	0.0102	0.0078	0.018	0.0258	0.0228	0.0228	0.0234
22	-0.0048	-0.0078	-0.0054	-0.003	0.009	-0.0108	-0.0048	-0.0096	-0.0054	-0.006	-0.0054	-0.0054	-0.0018
24	-0.0054	-0.0084	-0.009	-0.0108	-0.003	-0.021	-0.0186	-0.0264	-0.0264	-0.033	-0.0348	-0.0384	-0.0288
26	-0.0018	-0.006	-0.009	-0.0138	-0.0114	-0.0228	-0.0234	-0.0312	-0.0348	-0.0444	-0.0474	-0.0522	-0.0402

Final Strain (micro)	Shaft T-21- Tension						
Gage #	17041	17062	17061	17056	17055	17054	17053
Depth (ft) from ground Surface	2	-1	-4	-7	-11	-15	-19
0K	0	0	0	0	0	0	0
25.0 K	61.652144	30.45504	28.652	24.002669	12.644339	4.329969	0.427428
50.0 K	203.86922	67.871232	71.55837	60.762247	34.692685	13.834779	2.457711
75.0 K	608.67352	130.37658	672.42663	169.14326	65.370176	26.930295	4.452375
100.0 K	752.26928	192.12054	766.79915	696.95598	75.971697	30.97864	5.485326
125.0 K	1319.1226	695.28131	1071.0476	957.82247	353.12575	40.83548	7.586847
150.0 K	1541.8339	791.21469	1286.9762	1166.5719	812.16104	47.911283	9.118464
175.0 K	1705.509	918.65453	1468.9164	1425.5758	1056.947	78.397081	10.365129
200.0 K	2539.7926	1066.3977	1474.2887	1459.3131	1188.11	116.80355	12.324174

A.2.5: SHAFT T-21 – STRAINS (CONTINUED)

Final Strain (micro)	Shaft T-21 - Compression						
Gage #	17046	17063	17065	17066	17076	17075	17074
Depth (ft) from ground Surface	-2	1	4	7	11	15	19
0K	0	0	0	0	0	0	0
25.0 K	-73.62411	-34.56258	-31.87107	-25.44025	-17.57894	-5.479598	-0.391523
50.0 K	-168.3038	-74.12259	-72.68464	-64.42524	-44.63984	-16.6122	-3.132184
75.0 K	-318.0519	-139.8229	-166.9744	-129.5172	-81.89298	-32.25333	-7.047414
100.0 K	-354.0366	-156.4577	-182.9636	-165.2739	-90.91328	-36.34569	-9.25418
125.0 K	-480.5109	-265.737	-242.8783	-230.5764	-124.7927	-47.23552	-10.82027
150.0 K	-168.8672	-331.0879	-285.9454	-269.2807	-154.1264	-53.20065	-11.74569
175.0 K	-1112.178	-327.3136	-346.2894	-326.723	-193.972	-62.00963	-14.34398
200.0 K	-567.5852	-403.0088	-375.2273	-354.0932	-209.1716	-67.66263	-15.19821

A.2.6: SHAFT T-23 – STRAINS

Final Strain (micro)	Shaft T-23- Tension						
Gage #	17039	17064	17092	17090	17088	17086	17078
Depth (ft) from ground Surfa	-2	1	4	7	11	15	19
0K	0	0	0	0	0	0	0
25.0 K	59.148915	25.053314	26.82218	24.901954	16.190766	5.922321	1.196018
50.0 K	248.26281	52.40378	63.641718	61.356724	42.540444	18.689001	5.382081
75.0 K	851.03021	84.599801	407.59263	408.8922	82.646982	37.23615	11.467702
100.0 K	1015.3956	107.78668	632.27193	537.94561	94.393224	43.158471	13.507968
125.0 K	1479.9249	443.67337	947.65897	834.37396	597.82375	57.662838	18.116155
150.0 K	1544.271	506.41434	1156.245	1070.0444	857.33457	70.110351	20.965492
175.0 K	1699.1259	622.88712	1385.1043	1350.6933	1106.369	133.87283	27.297352
200.0 K	1799.5341	924.06529	1442.9288	1457.7681	1236.3537	244.76563	30.815052

A.2.6: SHAFT T-23 – STRAINS (CONTINUED)

Final Strain (micro)	Shaft T-23 - Compression						
Gage #	17045	17073	17091	17089	17087	17077	17079
Depth (ft) from ground Surfa	-2	1	4	7	11	15	19
0K	0	0	0	0	0	0	0
25.0 K	-47.56616	-30.23336	-29.00024	-22.9643	-13.9325	-5.67552	-1.478419
50.0 K	-99.69727	-67.50194	-65.29416	-55.67528	-36.73762	-17.27486	-5.192496
75.0 K	-165.8717	-151.3833	-140.4993	-109.8079	-71.3729	-36.1105	-12.4043
100.0 K	-174.5835	-175.4112	-166.2541	-114.6111	-80.17425	-41.50224	-14.96449
125.0 K	-248.5637	-248.6135	-227.8141	-158.0505	-102.6587	-54.80424	-19.07521
150.0 K	-378.8914	-280.6868	-262.2934	-182.6626	-122.1499	-61.40203	-21.8157
175.0 K	-648.7466	-391.6988	-318.8979	-221.2286	-122.043	-75.94555	-27.58514
200.0 K	-1144.794	-491.7792	-311.011	-239.4949	-124.0385	-80.87616	-30.90256

A.2.7: SHAFT T-25 – STRAINS

Final Strain (Micro)	Shaft T-25 - Tension						
Gage #	17042	17038	17037	17085	17057	17058	17084
Depth (ft) from ground surf	2	0	-2	-4	-7	-10	-13
0 K	0	0	0	0	0	0	0
12.5 K	111.63678	14.556654	20.654808	17.415225	10.218751	5.742668	1.43796
25.0 K	281.45956	37.094855	46.436696	40.90635	27.049635	13.011868	3.127563
37.5 K	477.5055	61.250462	74.818746	69.837525	47.628573	23.406824	5.895636
50.0 K	691.73906	88.95733	107.26584	108.16515	72.309155	36.236962	9.490536
62.5 K	837.27582	111.53069	129.64188	282.8826	89.705783	43.506162	11.467731
75.0 K	1042.7564	166.90927	301.39906	448.94543	184.25575	55.500342	14.235804
87.5 K	1221.8344	223.79977	410.8256	574.03125	475.47247	66.004336	16.141101
100 K	1451.0629	367.39729	532.15428	756.59085	624.4753	89.0477	21.713196
125 K	1503.0787	435.08221	616.82435	881.04083	734.05284	198.26743	24.696963
125 K	1552.5834	493.02754	716.6193	1031.5253	884.54074	500.92057	31.599171
137.5 K	1626.8406	538.35007	800.41043	1184.8712	1027.3204	705.33048	38.788971
75.0 K U	1173.1547	432.12869	638.28484	1024.0718	947.40905	725.5752	44.612709

A.2.7: SHAFT T-25 – STRAINS (CONTINUED)

Final Strain (Micro)	Shaft T-25 - Compression						
Gage #	17043	17083	17059	17081	17049	17071	17080
Depth (ft) from ground surf	2	0	-2	-4	-7	-10	-13
0 K	0	0	0	0	0	0	0
12.5 K	-86.02283	-28.68153	-17.2921	-15.05138	-11.09331	-5.776152	-1.722497
25.0 K	-170.828	-56.48649	-40.44234	-35.34106	-25.79017	-14.5312	-3.796524
37.5 K	-276.2973	-86.67574	-65.85114	-58.07529	-44.86783	-26.22882	-7.171212
50.0 K	-393.9072	-118.8636	0.42348	-83.91757	-67.79635	-39.63385	-12.05748
62.5 K	-478.8556	-141.5844	-111.2694	-101.2738	-83.1998	-48.20726	-14.79941
75.0 K	-619.0277	-172.0191	-152.6998	-129.3162	-105.3511	-61.32166	-18.91231
87.5 K	-745.5908	-202.8044	-179.4144	-151.5615	-121.8497	-71.71147	-21.37302
100 K	-916.3114	-248.3512	-219.4332	-182.7817	-149.7596	-89.69383	-27.41934
125 K	-1055.445	-269.9851	-238.9133	-197.2045	-161.5242	-106.0051	-30.75888
125 K	-1332.065	-202.9446	-268.0276	-223.8151	-185.3713	-124.0601	-35.99667
137.5 K	-1579.103	-178.681	-297.9888	-250.8098	-209.0064	-142.2968	-41.97268
75.0 K U	-939.0169	-78.01518	-241.9835	-215.6434	-187.5263	-143.314	-42.1836

A.2.8: SHAFT T-27 – STRAINS

Final Strain (Micro)	Shaft T-27 - Tension						
Gage #	17042	17038	17037	17085	17057	17058	17084
Depth (ft) from ground surfa	-2	0	2	4	7	10	13
0 K	0	0	0	0	0	0	0
12.5 K	25.7549	19.838763	18.865252	17.033611	13.81107	2.44209	7.7495
25.0 K	84.795788	41.28702	40.000008	38.243907	32.438308	6.244773	19.620325
37.5 K	198.7923	55.912422	60.815615	61.124877	54.394368	11.51271	34.626175
50.0 K	379.89366	66.898968	84.04257	86.947686	79.891728	19.327398	53.18975
62.5 K	524.79605	79.005162	100.31917	250.71006	416.10275	22.537002	63.017525
75.0 K	815.80866	109.93544	333.29794	546.41936	677.41528	29.514402	99.440175
87.5 K	1006.8212	137.82167	464.3618	651.27231	798.10278	37.294203	485.22438
100 K	1281.7059	187.82095	620.00012	823.82388	997.90293	50.551263	708.79745
125 K	1396.8037	224.41945	680.56751	915.63831	1102.6192	64.261854	824.44113
125 K	1497.6918	271.82954	752.65973	1043.118	1250.256	99.462837	954.56228
137.5 K	1606.3953	347.6507	846.66684	1173.8664	1387.6584	519.39766	1073.5171
75.0 K U	1086.1108	290.47868	641.17034	956.67878	1130.7725	640.00202	995.35283

A.2.8: SHAFT T-27 – STRAINS (CONTINUED)

Final Strain (Micro)	Shaft T-27 - Compression						
Gage #	17043	17083	17059	17081	17049	17071	17080
Depth (ft) from ground surfa	-2	0	2	4	7	10	13
0 K	0	0	0	0	0	0	0
12.5 K	-68.86207	-39.69805	-24.39688	-24.18948	-18.25936	-10.69497	-3.7401
25.0 K	-137.909	-88.01546	-52.44977	-53.87025	-45.27173	-26.43134	-9.47492
37.5 K	-215.0138	-149.9276	-83.13921	-85.91436	-74.04187	-45.98477	-16.67016
50.0 K	-292.0077	-220.1087	-116.5004	-121.1212	-106.5069	-68.31097	-26.03822
62.5 K	-324.2394	-272.4205	-140.8972	-176.4859	-155.9041	-77.99766	-30.06328
75.0 K	-371.3673	-348.1726	-218.5524	-273.4176	-208.2786	-100.756	-38.79018
87.5 K	-427.1444	-407.562	-266.9946	-322.9782	-250.2859	-134.8935	-45.52236
100 K	-513.1204	-496.4534	-341.4156	-397.0064	-310.8037	-165.3939	-56.56456
125 K	-559.6198	-530.9308	-389.8579	-433.9162	-344.6319	-184.0831	-65.39832
125 K	-668.8824	-582.2264	-460.9392	-493.4167	-398.262	-212.351	-74.90886
137.5 K	-849.2249	-582.0863	-531.7746	-562.6139	-450.9236	-234.2451	-76.36928
75.0 K U	-748.279	-318.2852	-431.4802	-469.2968	-407.7325	-217.9685	-73.30596