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A DRILLED DISPLACEMENT PILE LOAD TEST PROGRAM: MACARTHUR PLACE LAKE SITE TOWERS – SANTA ANA, CA

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Berkel & Company Contractors Inc. (Berkel) completed a drilled displacement pile load test program as part of a foundation design-build contract for the proposed MacArthur Place Lake Site Towers in Santa Ana CA. A significant issue was the proposed 30 ft excavation in the tower footprint and the potential to complete foundation design and performance testing services prior to the start of this excavation. To address these issues, the test program consisted of four test piles instrumented with multiple strain gages. The program successfully enabled Berkel to evaluate the allowable load of piles installed from final surface elevations down to 30 ft below the test pile installation elevation.

INTRODUCTION

Berkel & Company Contractors Inc. (Berkel) was engaged to provide foundation design and construction services for a proposed multi-purpose facility termed the MacArthur Place Lake Site Towers in Santa Ana CA. A general site location plan is presented on Figure 1.

One of the primary issues surrounding the final design of foundations was a planned 30 ft excavation of the building footprint below the existing ground surface in the area. Final design of the foundation system, including performance testing of any proposed test foundations, was to be completed prior to any excavation at the site.

This paper includes the following project details:

- a brief description of the subject project
- in situ soil test results provided to Berkel prior to the load test program and comments regarding the use of these results
- brief details of Berkel's drilled displacement piling method

Regarding the test program for the selected foundation system, details presented in this report include the following:

- foundation installation records from the data acquisition systems installed on Berkel's drilling platforms
- load test results and evaluation
- final recommendations for foundation design and installation

All Figures referenced herein follow the text of this paper.

PROJECT DESCRIPTION

Figure 2 is an architectural rendition of the proposed facilities at the MacArthur Place Lake Site Towers site. The towers are each 27 floors and are connected at their bases by a smaller structure (two to three stories above the surrounding site grade). The entire site has 3 underground parking levels. Proposed compressive loads are largest at the core of the towers which will require in excess of 300 piles each. The areas not under the towers are subject to net static uplift due to hydrostatic pressure.

IN SITU SOIL TEST DATA AND ANALYSIS

In situ soils data made available to Berkel prior to the pile load test program consisted of the results of ten Cone Penetration Tests (CPT) performed as part of the geotechnical site characterization of Geotechnical Professionals, Inc. (GPI) for this site. The general locations of the CPTs were provided to Berkel for preliminary analysis and are shown on Figure 3 after the text of this paper.

The data from the CPTs indicated a 25 ft to 30 ft zone of predominantly fine-grained material from the ground surface. This was underlain by an approximately 5 ft to 10 ft thick zone of dense coarse-grained material. From a depth of approximately 35 ft to 40 ft below the ground surface, the encountered materials consisted of inter-bedded layers of fine- and coarse-grained materials of varying consistencies/densities. A composite plot of the CPT data provided to Berkel is shown on Figure 4.

Berkel was informed that the entirety of the site would be subject to excavations of about 30 ft below the existing ground surface. This material was not considered for the preliminary capacity analyses. These analyses, performed according to NeSmith (2002a), indicated that installing 16-inch diameter Berkel displacement piles to the predominantly coarse-grained zones existing at about 70 ft to 85 ft below the ground surface would provide the appropriate capacities as required for this project.

BERKEL DISPLACEMENT PILES

General Statement of Method

Berkel drilled displacement piles are Auger Pressure Grouted Displacement (APGD) piles. APGD piles are constructed by drilling a displacement auger into the ground utilizing a track-mounted, fixed-mast, hydraulic drilling machine. Once the required penetration is achieved, fluid grout is pressure injected through a grout pipe located centrally within the drill stem and out a port located at the tip of the displacement auger as the displacement auger is slowly retracted. Once the displacement auger is fully retracted, reinforcing steel is inserted into the fluid grout column prior to initial set. The Berkel Displacement Pile Tool and installation platform are shown in Figure 5 and Figure 6 respectively.

Drilling Operation

The forward auger flights and ramp located below the displacement element on the tool displaces soils laterally as the auger is advanced. Soil packed between the forward auger flights upon reaching the final drill depth is retained upon auger retraction and removed to the surface.

Grouting Operation

Once the final drill depth is achieved, injection is initiated through the grout pipe located centrally within the drill stem and out of the port located at the tip of the displacement auger. Grout injection pressure is monitored continuously during the grouting process by means of a pressure transducer located at the top of the drill stem. Once the target “liftoff pressure” is achieved, retraction of the auger begins. The rate of auger withdrawal is coordinated with the grouting pressure such that target grouting pressures are maintained. Positive (clockwise) rotation of the auger is maintained continuously throughout the grouting process. The reverse auger flights and displacement ramp capture and re-displace any material which may have entered the annular space between the drill stem and the pile wall. The pressure within the fluid grout column resulting from the pressure injection process during the grouting operation and later from gravity following full auger retraction maintains the integrity of the shaft similarly to a heavyweight drilling slurry.

Steel Placement

Steel inserts are lowered into the fluid grout column following full retraction of the displacement auger. Placement of a full-length center bar is followed by placement of the reinforcing cage. The center bar and reinforcing cage are centralized within the pile by means of prefabricated spacers.

TEST PILE INSTALLATION

A total of four 16-inch diameter test piles and their accompanying 16-inch diameter reaction piles were installed at the proposed Lake Site Tower site. The piles were installed at CPT locations C-5, C-6, C-7 and C-8 (see Figure 3).

Berkel’s pile installation platforms include an on-board data acquisition system to record depth, grout pressure (measured at the top of the tools), KDK pressure (fluid pressure of the motors driving the turntable), and rotation rate versus time during pile installation. This data is gathered at 1-second intervals and stored in a computer on the installation platform. Further details on the data acquisition system on Berkel’s displacement pile drilling platforms are presented in NeSmith & NeSmith (2006).

Plots of test pile installation data are presented on Figures 7 to 10. Grout volumes for each test pile were determined by counting the number of pump strokes required to complete casting and multiplying that number by the pump calibration

($0.57\ ft^3$/stroke) as determined by Berkel prior to installation of any test piles. A summary of installation details for the test piles is presented in Table 1 below. Pile names correspond to the CPT location at which they were installed.

Strain gages for the test piles were provided by GeoDAQ, Inc. (GeoDAQ) of Sacramento CA. Gages were typically attached to the center bar inserted into each pile at depths such that the gages would sit almost at the pile toe, at about 10 ft above the toe, at about the proposed depth of excavation (about 30 ft below the ground surface) and at about 5 ft below the top of the pile.

Table 1 – Test Pile Installation Details

Pile Name	Maximum Depth [ft]	Grout Overage [%]
TP-C5	70.1	123
TP-C6	69.5	124
TP-C7	80.3	120
TP-C8	69.1	118

EVALUATION OF TEST PILE PERFORMANCE

A total of four compression load tests were performed; one each on every test pile. Load tests were performed by Berkel under the supervision of GeoDAQ. Piles were tested in accordance with ASTM D 1143. Load distributions throughout the pile were derived by GeoDAQ from the available strain gage data. Pile head load-displacement relationships and load distributions throughout the piles are presented on Figures 11 to 18.

Berkel derived compressive capacities from interpretation of the load vs. pile-head deflection data obtained during pile testing. Shaft and toe components of the total capacity were derived from the available strain gage data and the interpretation of the pile head load-displacement relationships. Derived capacities are presented in the Table 2.

Table 2 – Derived Test Pile Capacities

Pile Name	Total Cap. [tons]	Shaft Cap. [tons]	Toe Cap. [tons]
C-5	350	285	65
C-6	350	280	70
C-7	390	340	50
C-8	410	310	100

ADJUSTMENT OF PILE CAPACITY DUE TO REDUCTION OF OVERBURDEN

General

As discussed, earthworks at the project site will include removal of about 30 ft of material present at the time of test pile installation testing. We have performed an evaluation of the effect of the cuts with respect to the potential impact on pile lengths and capacities. Removal of material below the level at which the piles were tested will have the following effects:

- First, shaft resistance that contributed to the capacity of the test pile will no longer be active through the length of the cut
- Second, the removal of overburden may reduce the effective vertical stress (and thus the effective horizontal stress) acting on the piles below the cut

With regard to the second point above, reduction in the vertical, and thus horizontal, stresses acting on a pile will result in a reduction in both shaft and toe resistance. This effect is most pronounced in normally consolidated sands where the density of the sand at any given level is related only to the thickness and weight of the material above that level, and the depth of the groundwater.

Given the CPT results at this site, the lower sand is somewhat over-consolidated and/or slightly cemented. Thus, the horizontal stresses will not respond to changes in overburden in the same way as normally consolidated sands. Additionally, the area of the proposed excavation is bounded on all sides by unchanged final grades and some stresses lost due to excavation will be replaced by the construction of the proposed structure and foundations system. Thus it was considered that there will not be significant changes to the horizontal stresses acting on the piles due to the proposed excavation.

Shaft Resistance in Material to be Excavated

To estimate the amount of shaft resistance that was developed in the material that will potentially be removed prior to construction, strain gauges were installed in all three test piles. Instrumentation was placed on the reinforcing steel cages for the test piles so that they would sit at 3 ft and about 25 ft below the top of the pile and about 3 ft and about 15 ft above the pile tip after installation. Due to an electrical communication error, data from TP-C5 is not considered reliable. Data from the remaining test piles indicated the transfer of 25 tons to 85 tons in the upper 25 ft to 30 ft of material.

Allowable Pile Loads

The test pile with the lowest estimated capacity, TP-C6, has a compressive capacity of about 350 tons. The apparent capacity of the upper 30 ft at this location is approximately 85 tons. This would leave a capacity of 265 tons after excavation. The results from the other load tests indicates that 265 tons is the lowest expected capacity for a similarly installed pile with an excavation of up to 30 ft below the ground surface at the time of the test pile program.

As a result, Berkel recommended an allowable compressive load of 135 tons be applied to 16-inch diameter Berkel displacement piles installed as described herein.

PRODUCTION PILE INSTALLATION CRITERIA

A review of the test pile installation records indicated a spike in the measured torque of the rig from about 66 ft to 70 ft below the ground surface at the time of the test pile installations. In 3 cases; C5, C6 and C8; this coarse-grained zone was considered thick enough for pile termination. At C7, this zone was not as thick and the pile was extended to about 85 ft below the ground surface (80 ft below the excavated surface of the test pile area).

As such Berkel recommended that 16-inch diameter production piles be installed to the following criteria:

- A minimum depth of 65 ft below the ground surface at the time of the test pile program; and
- Termination in a minimum of three ft of embedment in material which requires an applied torque of greater than 120 kip*ft to penetrate; or
- Termination when the penetration rate of the drill stem is less than 1 ft per minute and the applied torque is greater than 150 kip*ft; or
- A maximum depth of 85 ft below the ground surface at the time of the test pile program

Summary

Upon review of the completed foundation performance test program, the Client considered that the basic approach to pile support for the proposed construction at this site was sound and the results validate the position that displacement piles will provide safe, efficient foundation support. As such, Berkel's recommendations for final foundation design and construction were accepted.

Reference List

CHIN, F. K., (1970), "Estimation of Ultimate Load of Piles Not Carried to Failure", *Proceedings of the 2nd Southeast Asian Conference on Soil Engineering*, pp. 81 – 90.

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NESMITH. W. (2002a), "Static Capacity Analysis of Augered, Pressure-Injected Displacement Piles", *Proceedings of the International Deep Foundations Congress 2002*, ASCE Geotechnical Special Publication No. 116, American Society of Civil Engineers, February 2002, pp. 1174-1186.

NESMITH, W. (2002b), "Design and Installation of Pressure-Grouted Displacement Piles", *Proceedings of the Ninth International Conference on Piling and Deep Foundations*, Nice, France, June 2002, pp 561-567.

NESMITH, W. M. and NESMITH, W.M. (2006). "Anatomy of a Data Acquisition System for Drilled Displacement Piles". *Proceedings of the the American Society of Civil Engineers GeoCongress 2006*. Atlanta GA USA. 26 February – 01 March 2006.

Figure 1 – Site Location

Figure 2 – Architectural Rendition of Proposed Development at MacArthur Place Lake Site – Santa Ana CA

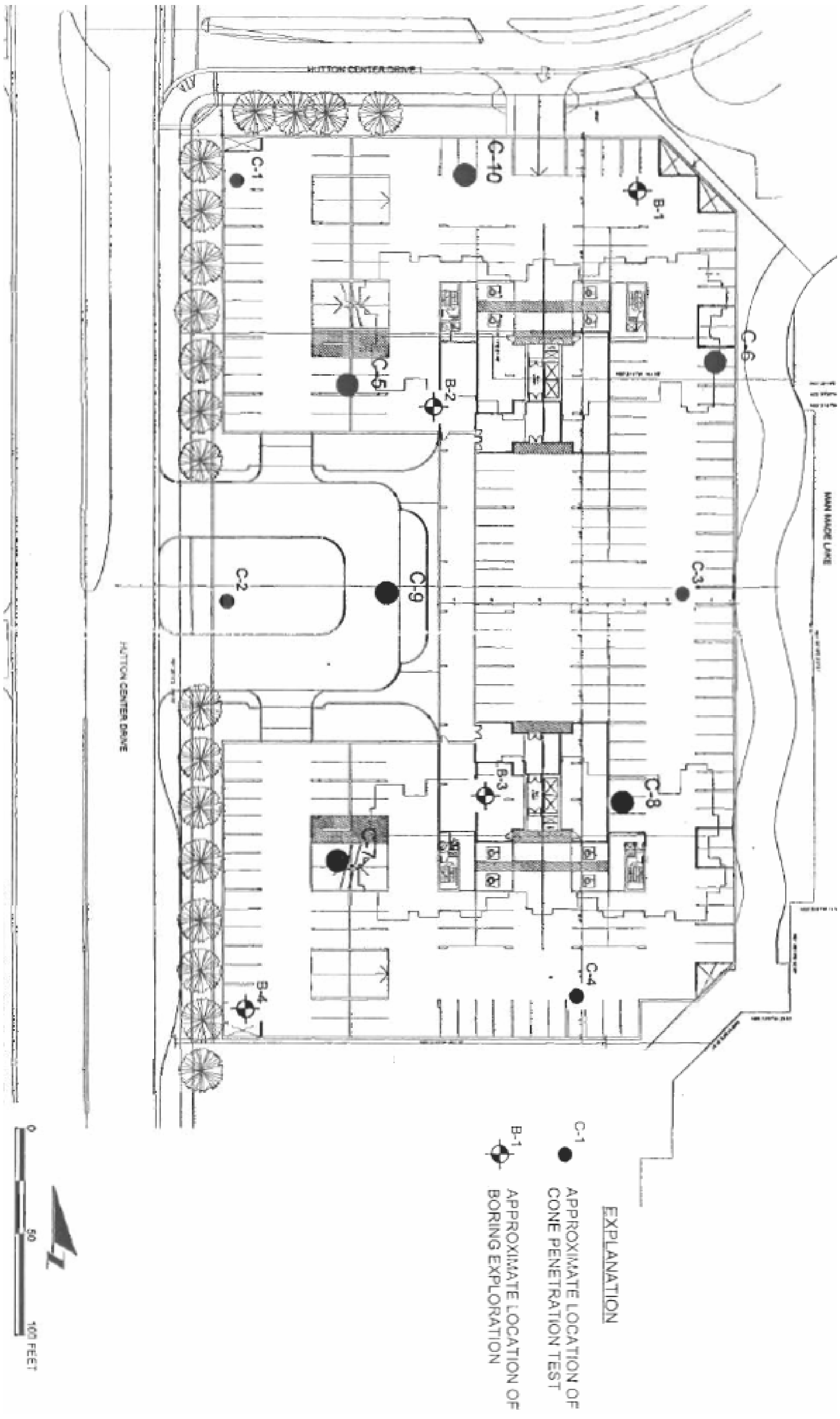

Figure 3 – In Situ Test Locations

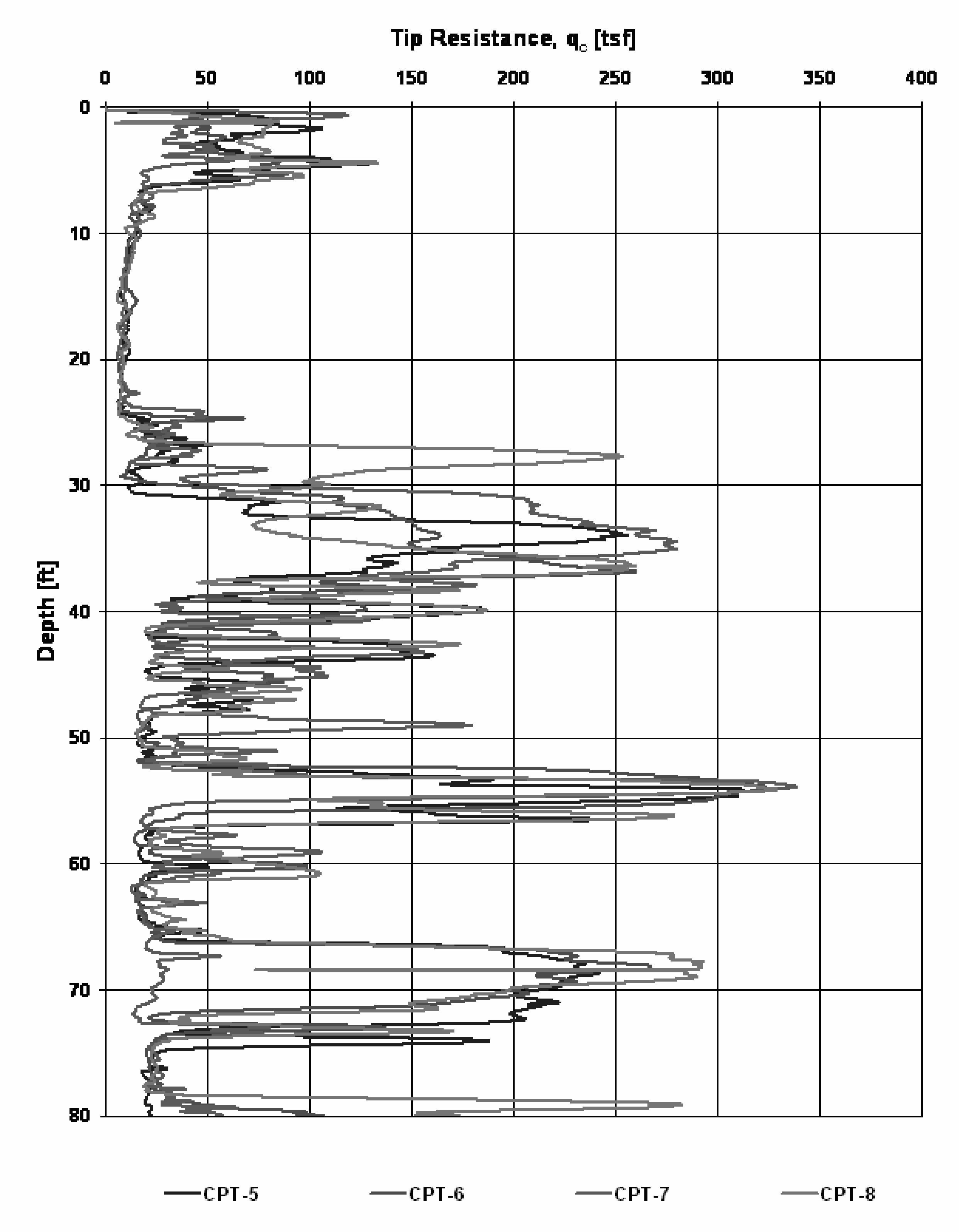

Figure 4 – Composite Plot of CPT Results

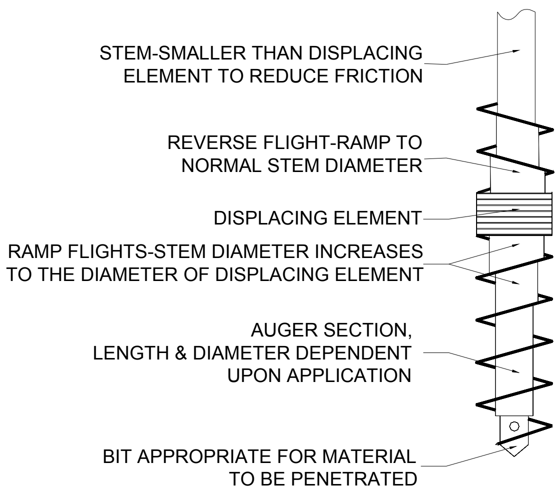

Figure 5: Berkel Displacement Tool

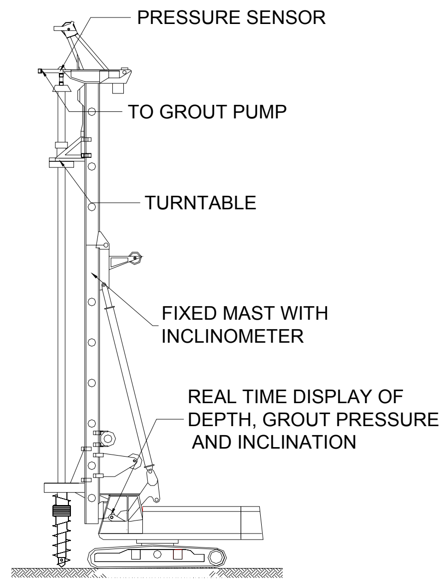

Figure 6: Installation Platform

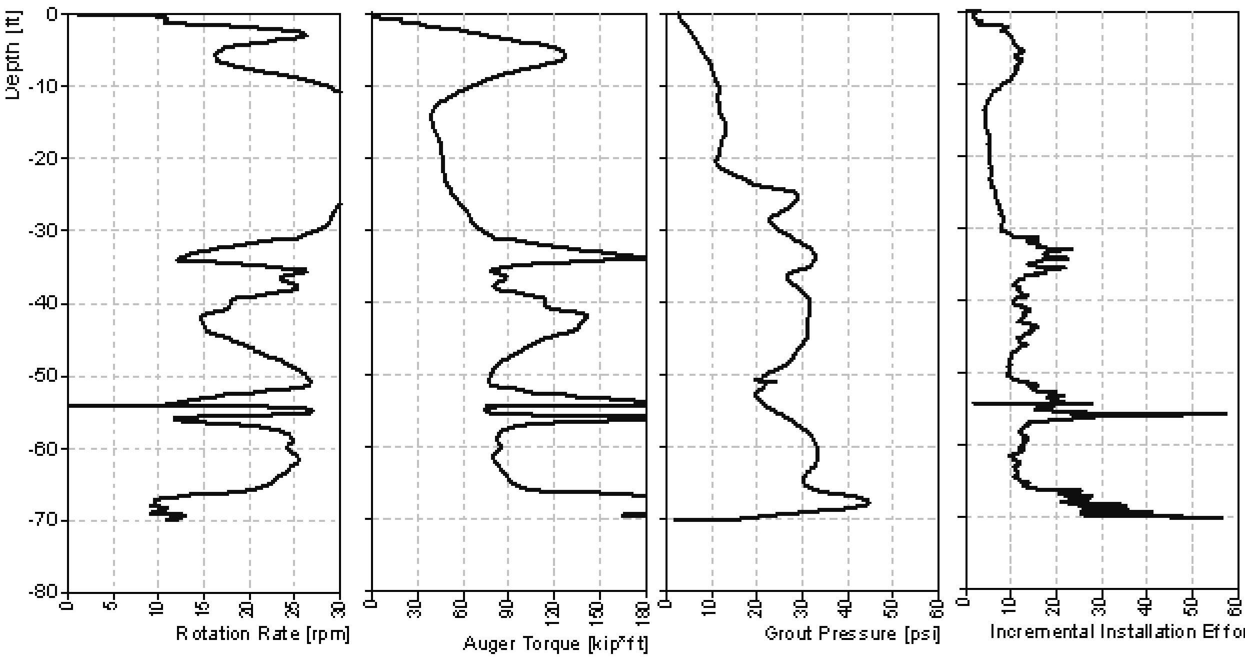

Figure 7: Test Pile Installation Details for TP-C5

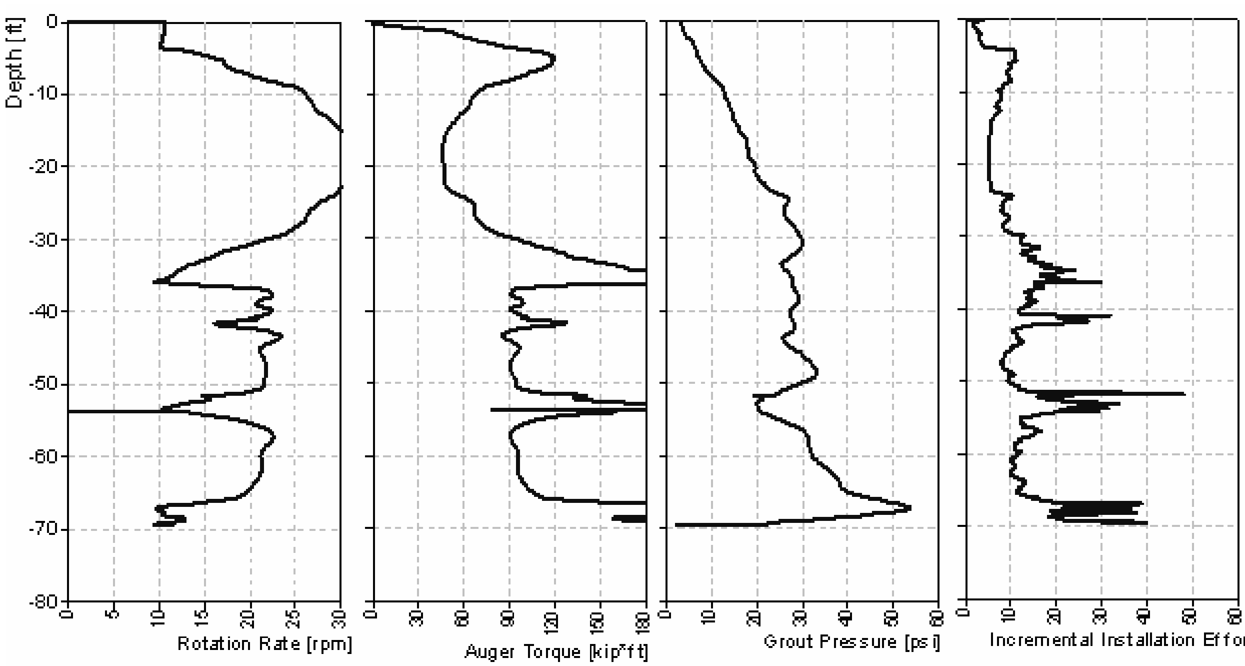

Figure 8: Test Pile Installation Details for TP-C6

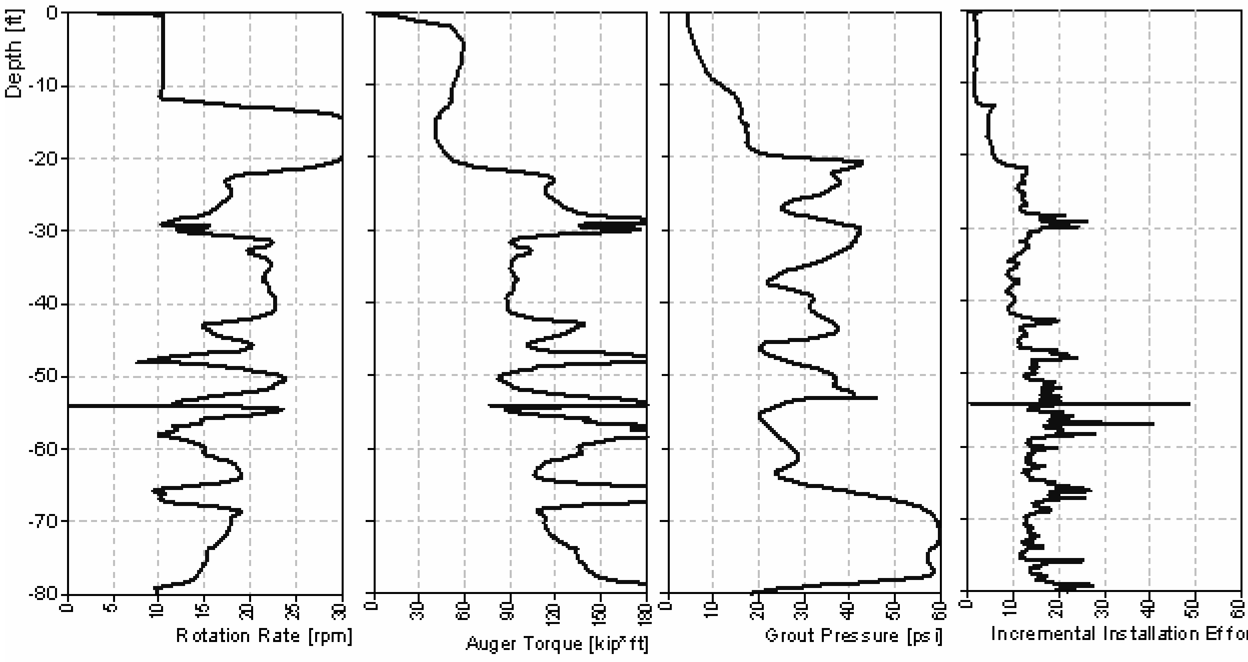

Figure 9: Test Pile Installation Details for TP-C7

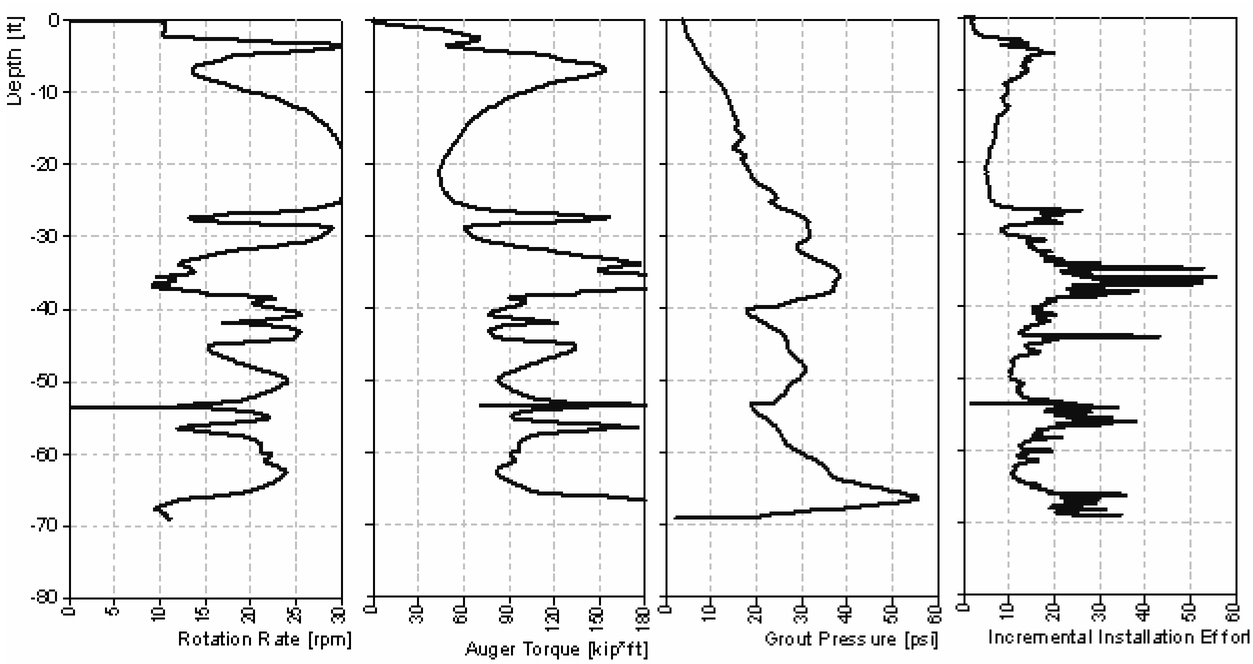

Figure 10: Test Pile Installation Details for TP-C8

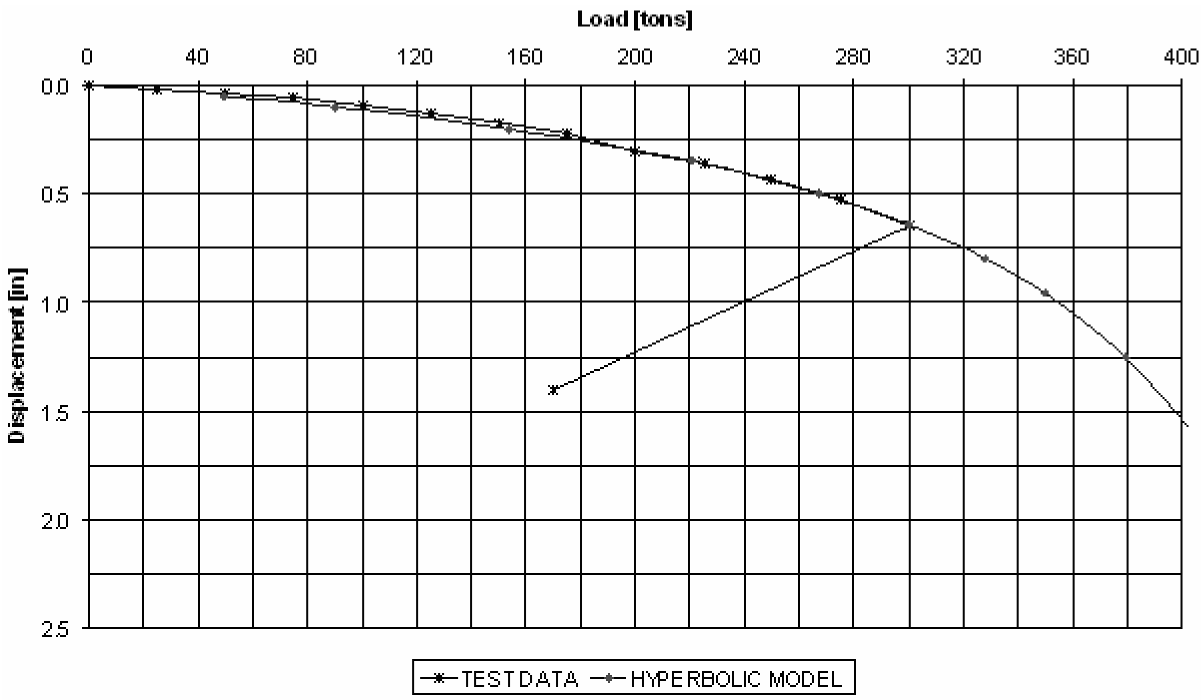

Figure 11: Pile Head Load-Displacement Relationship for TP-C5

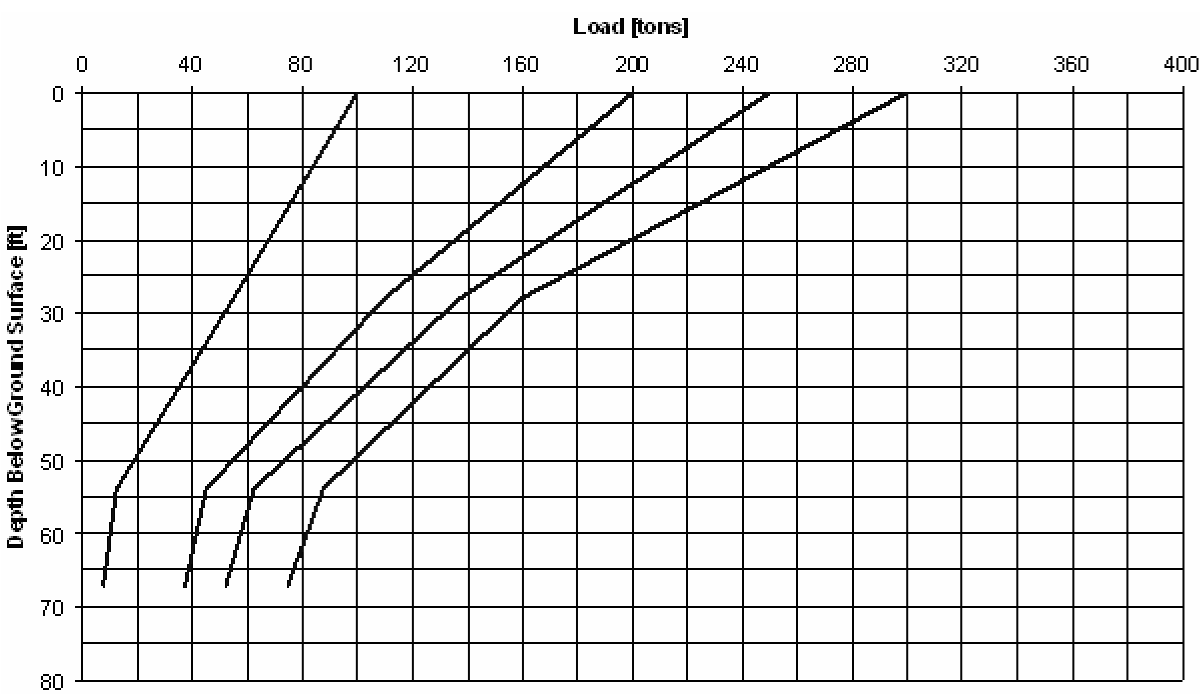

Figure 12: Load Distribution Along Test Pile TP-C5

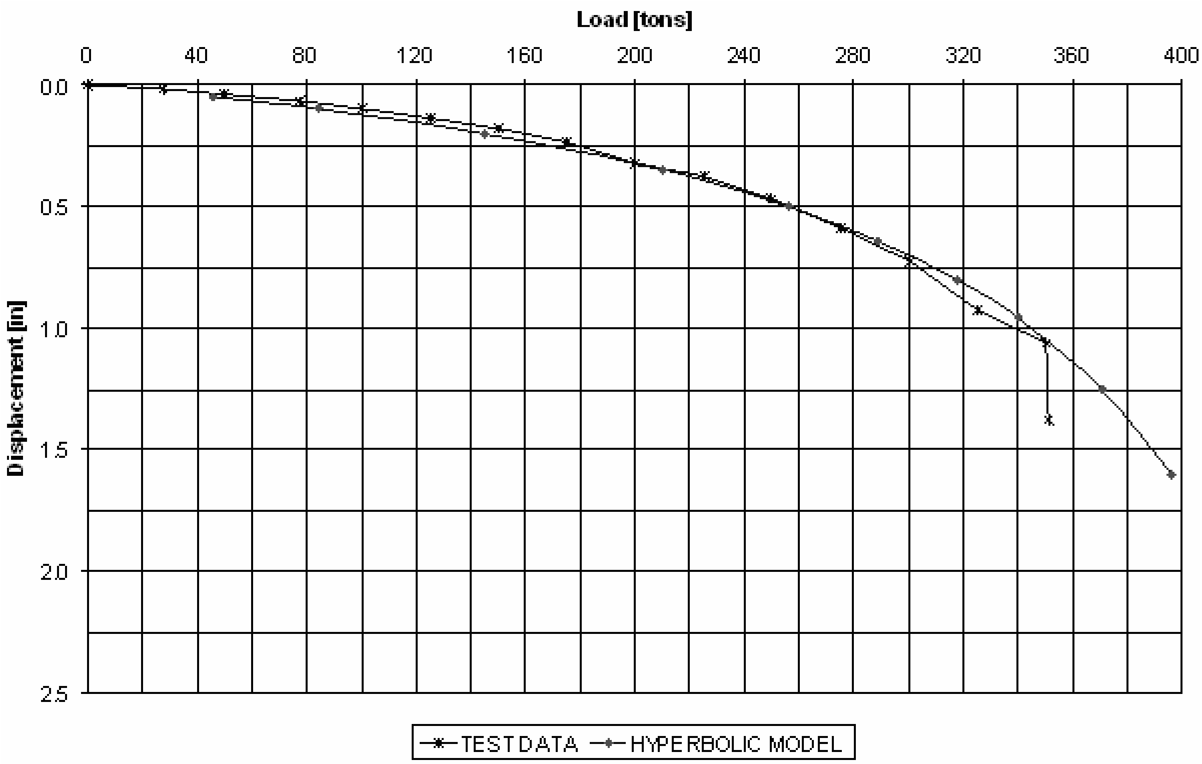

Figure 13: Pile Head Load-Displacement Relationship for TP-C6

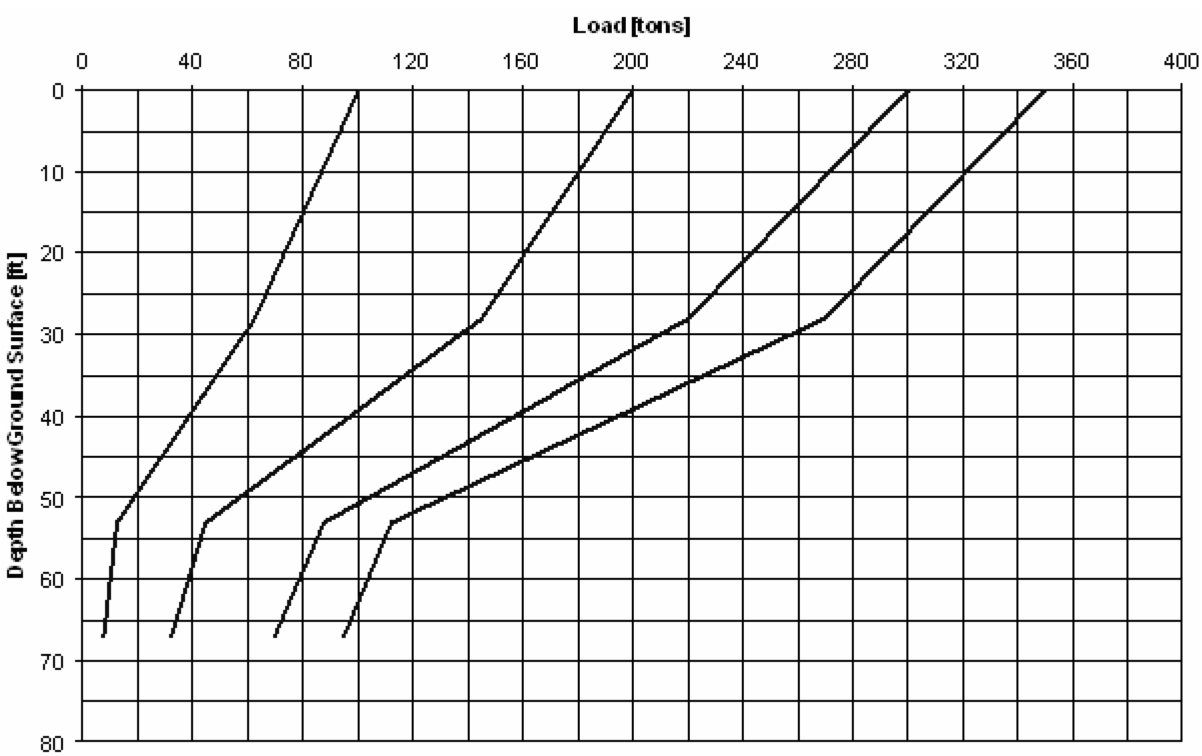

Figure 14: Load Distribution Along Test Pile TP-C6

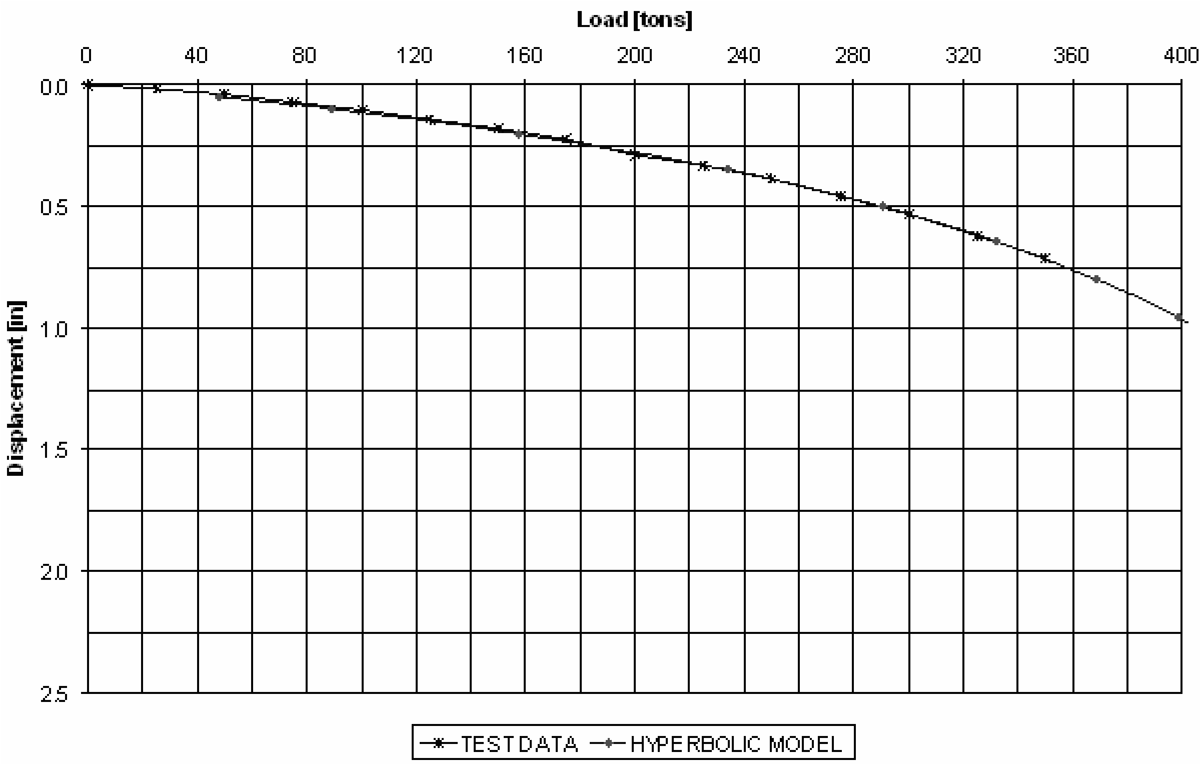

Figure 15: Pile Head Load-Displacement Relationship for TP-C7

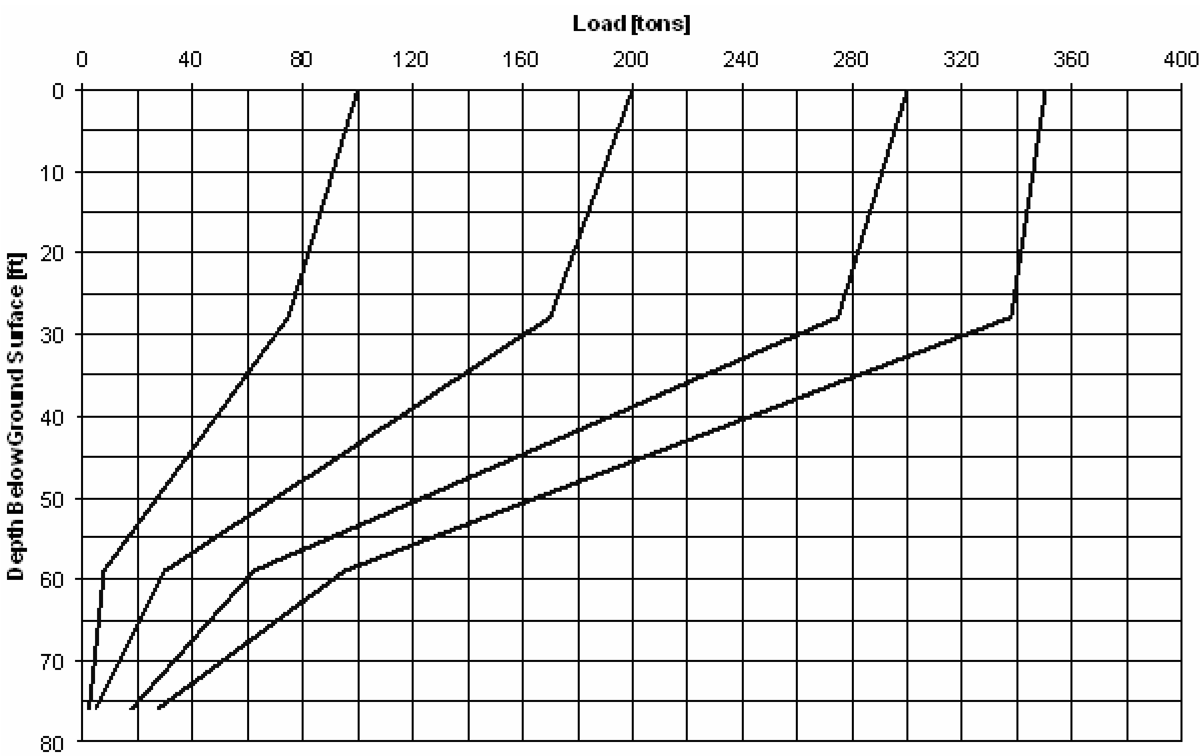

Figure 16: Load Distribution Along Test Pile TP-C7

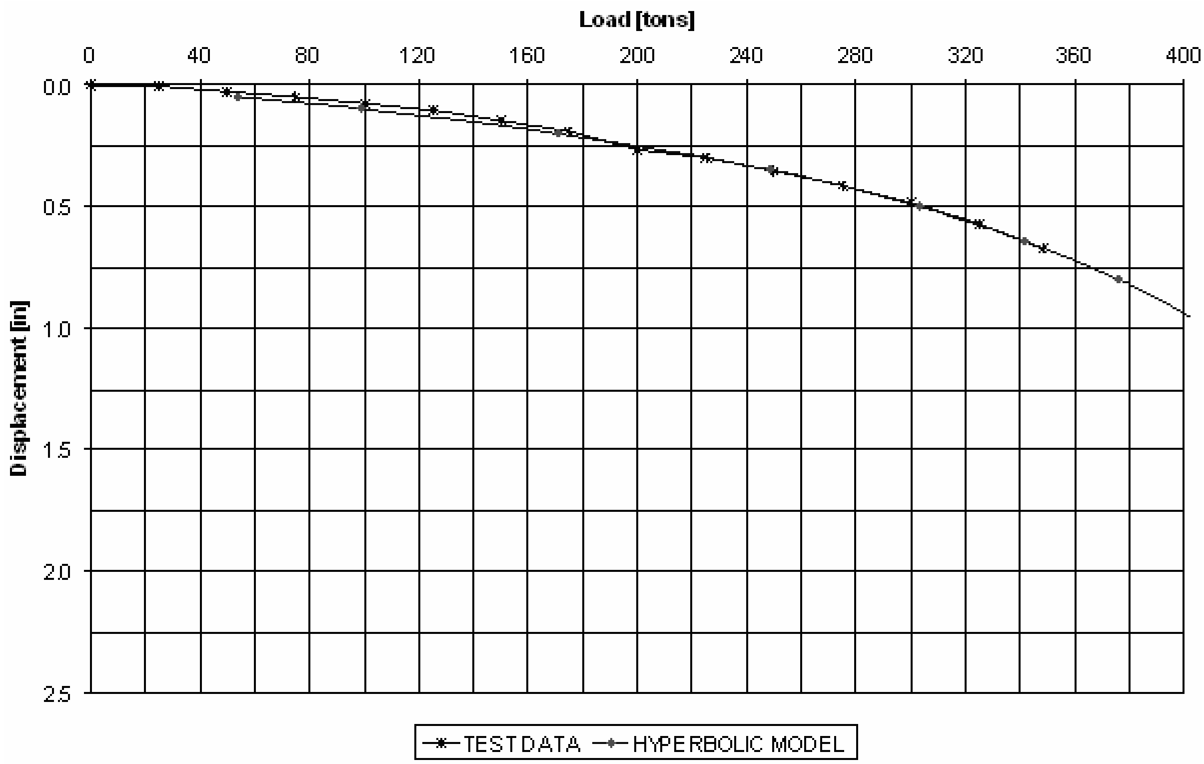

Figure 17: Pile Head Load-Displacement Relationship for TP-C8

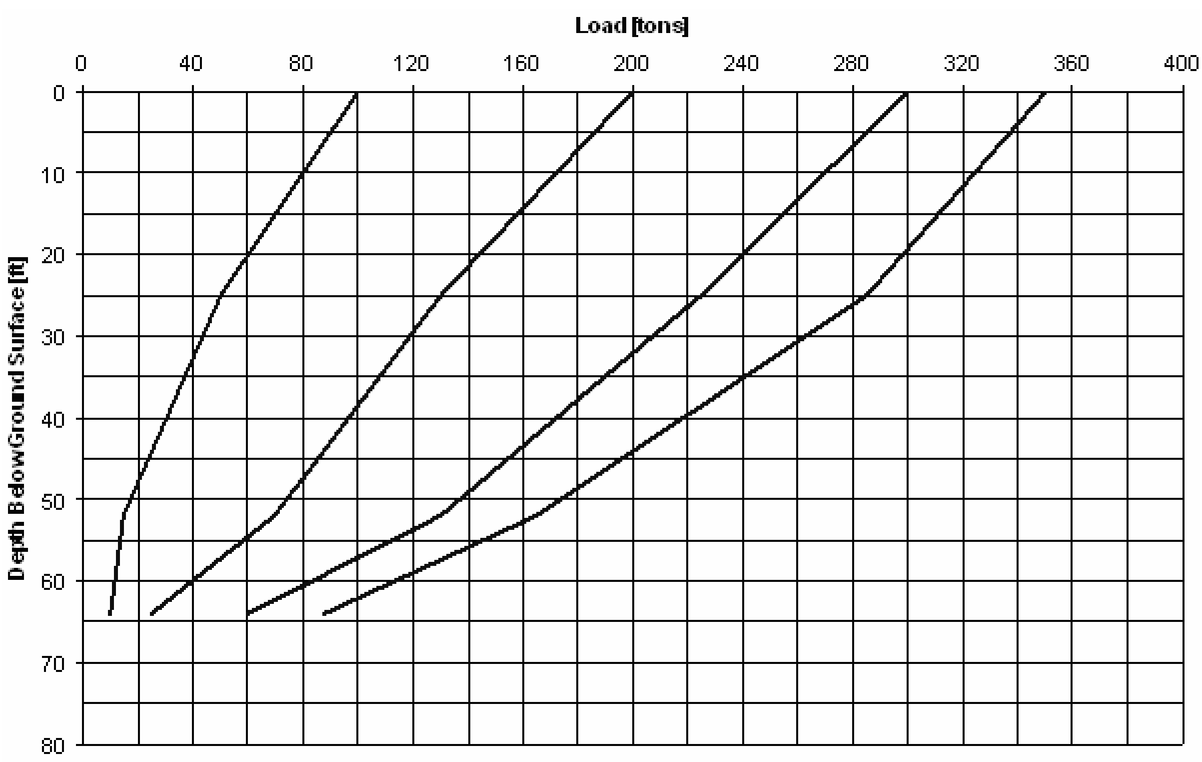

Figure 18: Load Distribution Along Test Pile TP-C8