SDG 13:

Friction Pile Load Tests

Chapter 13

Tennessee Department of Transportation August 22, 2022

Table of Contents

Table of Figures

Section 1 General

Friction piles are load tested to determine the maximum load carrying capacity of the pile. The maximum load capacity will be either the "maximum test load" or the "failure load" based on the method of interpretation of the load test. This document does not apply to point-bearing piles bearing on rock.

Standard Specification Article 606.08 (regarding Test Piles) establishes the procedures to be used in performing a load test. From these results, the designer shall determine the safe load capacity of the pile.

See the Standard Specifications (the “Specifications” hereafter) for additional information regarding load tests.

Section 2 Location of Load Tests

13-201.00 Determining Optimum Location

The cost of load tests can be significantly affected by their location. For instance, it is much easier to load test a test pile in an abutment fill or a pier in a shallow excavation on the bank than one inside a cofferdam or in a stream bed. The locations selected by the designer shall be, in his estimation, the most economical locations that will give reliable results. Due to the contractor's construction sequence or other unforeseen reasons, it may be beneficial to occasionally relocate a load test pile. If, in the opinion of the designer, the relocation will provide equally reliable results, the relocation can be allowed.

In some locations, such as in stream beds, it may be advantageous to the contractor to drive test piles through the overburden without excavating to the pile cut-off elevation. This procedure would be satisfactory for all test piles including those to be load tested, provided the additional pile length required to extend through the overburden is furnished at no cost to the project. When calculating pile capacity for this case, the designer shall deduct any frictional resistance from the soil above the bottom of footing elevation. It may be necessary to require that the contractor pre-drill a hole down to this elevation before driving the pile.

13-202.00 Load Tests at Cofferdams

When a different pile type is only being used in pier footings in deep cofferdams (for instance, steel piles at the piers and concrete piles at the abutments), it would be too difficult to perform the load test within the cofferdam. The designer shall designate the load test to be performed on the stream bank at ground elevation with a test pile which will be discarded after the load test or possibly included in a pier footing at that location.

13-203.00 Concrete Piles in Hard Driving Conditions

For concrete piles, to prevent driving in excess of fifteen (15) blows per inch which might damage the pile, jetting or pre-drilling may be necessary when a minimum pile tip elevation is required due to scour, liquefaction, or a soft stratum underlying a hard stratum. Steel piles may be a better pile type in this situation.

13-204.00 Economy of Load Tests

The number and length of piles shown on the plans is an estimate based on available soil data and is used to establish quantities and cost estimates. The length of the test piles shown on the plans shall be 10’ longer than the estimated length of the other piles at each substructure. The number and length of piles determined by the designer from test pile and load test results will usually be reasonably close to that shown on the plans. However, it may occasionally be necessary to make changes in the number or length of piles. Normally the load-carrying ability of the pile increases as it is driven. In cases where there is no significant increase in the load-carrying ability of the pile with an increase in pile length, it is more economical to add piles to the foundation than to drive longer piles. For instance, 10 piles 30 feet long would be more economical than 8 piles 50 feet long. If the solutions provide equivalent load-carrying capacity, the designer shall select the most economical alternative.

Changing the number of piles can usually be easily implemented in abutments. For pier footings, it may be more difficult to add piles because of the close spacing of the pile pattern. Also, displacement piles at close spacing may become difficult to drive as the material between the piles becomes compacted, especially in cofferdams. For these reasons, when possible, the designer should use a pile spacing greater than the minimum in pier footings. The spacing of the pile grid in a footing should be such that there will be a 5’ available dimension in the diagonals of the pile grid.

Section 3 Static Load Test Requirements

13-301.00 Load Test Apparatus

The vast majority of the time, load tests for friction piles will be static load tests. Dynamic testing is not a standard method used in the State of Tennessee yet, but it is expected that this method will become more common in the future.

The pile load test apparatus for applying loads and measuring movement shall meet the requirements of ASTM D1143, Standard Test Methods for Deep Foundation Elements Under Static Axial Compressive Load. The template for Bridge Plans Notes (No. 22 regarding Friction Piles) allows a reduction in the required clearances in the test setup if there is insufficient room within an excavation. To prevent this problem, the designer should avoid locating load tests in deep or confined excavations if at all possible.

The contractor selects the jacking method used in the load test. Normally, the load is applied by jacking against a reaction beam which is attached to hold-down piling. Hold-down piling should not be installed with vibratory hammers since only the frictional resistance of the soil develops their capacity to resist the test load. If there is some doubt about the ability of the hold-down piles to resist the total applied uplift force, it would be to the contractor's advantage to preload the test pile before beginning the load test. Preloading is not a requirement, but it could be beneficial to the contractor and even prevent a load test from being invalidated due to equipment malfunctions. When a preload has been applied, it shall be indicated on the load test report.

Details of a typical load test apparatus, showing the reaction beam, hold-down piles, jack, gauges, and calibration certificates are shown in Figures 2 through 5. At least two gauges capable of reading to one-hundredth of an inch shall be used to record the test pile settlement. Similar gauges are also required to monitor the hold-down pile movement. All gauges shall be attached to supports that are independent of the loading platform and test pile apparatus.

Should noticeable movement of the hold-down pile(s) occur, the load test shall be discontinued until the contractor can make the necessary corrections to insure support of the anticipated maximum applied load. Failure of the hold-down system invalidates the load test and requires the contractor to perform an additional load test at no extra cost to the project.

Unless specified otherwise on the Plans, a minimum waiting period of 3 days shall be observed between installing the last pile in the load test system and commencing the test.

13-302.00 Number of Load Tests

A test pile shall be required for each substructure for each bridge. If static load testing is specified, a minimum of one load test is required for each pile type and size used for each bridge or set of dual bridges. If the log of borings indicates a significant difference in subsurface conditions, or if a given substructure is more than 500 feet from a load test, an additional load test may be specified on the plans or added during construction by the designer.

The number of load tests and test piles shown on the plans is based on the assumption that all test piles are to be driven with the same make and model pile driver (hammer) as was used for the load test pile. Should the Contractor elect to drive some test piles with a different make or model hammer, he must furnish the necessary additional load tests at his cost.

13-303.00 Function of the Load Test

The purpose of a load test is to correlate the test pile driving resistance to the actual failing (ultimate) load established by the load test. Article 606.14 of the Specifications presents the formulas, called driving equations, to be used in determining the bearing value of a pile for different types of hammers. From the results of the load test, a "K factor" is calculated using Equation (1).

$$K = \frac{Safe\ Load}{Driven\ Load} \qquad (1)$$

The term "Safe Load" refers to what the designer determines to be the failing load from the load test. The term "Driven Load" refers to the bearing capacity of the load test pile calculated from the driving equation. The maximum value of the K factor shall be 1.5.

For example, if a test pile were driven to a bearing capacity from the driving equation of 100 tons and the failing load from the load test of that pile was 125 tons, the K factor would be 1.25. If 100 tons were the actual required bearing by design, the contractor would be instructed to drive piling to a minimum bearing of 100/1.25 = 80 tons by the driving equation. The adjusted driving equation has been correlated with the load test and may be applied to any pile of the same pile type and size driven near this location with the same make and model hammer. If for any reason the contractor elects to drive some test piles with a different make or model hammer, an additional test pile and load test shall be required, at the contractor's expense, to determine the K factor to be used in the driving equation for the second hammer. It is permissible by the Specifications to drive production piles with a different hammer. This is only allowed with the approval of the designer prior to the designer specifying production pile bearings and lengths based on the results of the test pile driving log.

The correlation between load test, test pile, and Specifications driving equation enables the designer to establish pile lengths with sufficient confidence to allow regular piles to be driven with a different hammer than that used to drive the test piles. There may be some specific cases where the designer will specify slightly longer piles when he knows that a hammer substitution will be made.

Section 4 Static Load Test Procedures

13-401.00 Methods for Performing Static Load Tests

The methods for performing two types of pile load tests are provided in the Specifications - the Quick Load Test and the Maintained Load Test. The Quick Load Test is preferred because it takes only 1 to 2 hours to complete. However, when the soil conditions are such that long term settlement is of concern (e.g., predominant presence of clay layers), then the Maintained Load Test should be performed. The Specifications direct the contractor to perform the Quick Load Test unless otherwise noted on the Plans.

13-402.00 Quick Load Test

The full test load shall be 200% of the pile design load shown on the plans. The load is applied in approximately equal increments of 10% to 20% of the pile design load, and at intervals of 5 minutes throughout the load test. Readings of time, load, and movement are taken and recorded immediately before and after the application of each load. Please note that deviating from this applied pile loading increment (loading other than 10%-20% of the design pile load) should be considered as grounds for rejecting the load test.

The load is applied until either a plunging failure occurs or the full test load is reached. Plunging failure occurs when continuous jacking is required to maintain the test load. After the final holding time, or immediately after plunging failure occurs, the applied load is removed in five approximately equal decrements with intervals of 5 minutes between decrements. Readings shall be taken after the removal of each decrement and five minutes after the complete removal of the test load.

Results from the Quick Load Test shall be analyzed in accordance with Davisson's failure criterion (see FHWA Manual on Design and Construction of Driven Pile Foundations Volume II, pages 16-18). The failing (ultimate) load is defined as that load which produces a settlement of the pile head (for piles 24" or less in diameter) equal to:

$$s_f = \Delta + \left(0.15 + \frac{b}{120}\right) \quad (2)$$

Where:

s_f = measured pile head movement at failure (inches)

Δ = elastic deformation of pile per Equation (3) (inches)

b = pile width or diameter (inches)

The elastic deformation, Δ, for a pile of uniform cross-section is computed from:

$$\Delta = \frac{QL}{AE} \tag{3}$$

Where:

Δ = elastic deformation of pile (inches)

Q = test load (kips)

L = pile length below dial gage or LVDT (linear variable differential transformer) measurement location (inches)

A = pile cross-sectional area (in^2)

E = modulus of elasticity of pile material (ksi)

The steps for the construction of a test plot are:

1) Calculate the elastic compression of the pile (Δ) when considered as a free column.

2) Determine the scales of the plot such that the slope of the pile elastic compression line is approximately 20°, and plot the line.

3) Plot the pile head movement versus the applied load observed during the load test.

4) Plot the failure criterion line (S_f) parallel to the elastic compression line. The interpreted failing (ultimate) load (Q_f) is the intersection of the failure criterion line with the observed load-movement curve.

5) If the load-movement curve does not intersect the failure criterion line, then the maximum applied test load will be assumed as the maximum capacity of the pile.

6) If plunging failure occurs, the failing (ultimate) load shall be the load applied just before the load at which the plunging failure occurred.

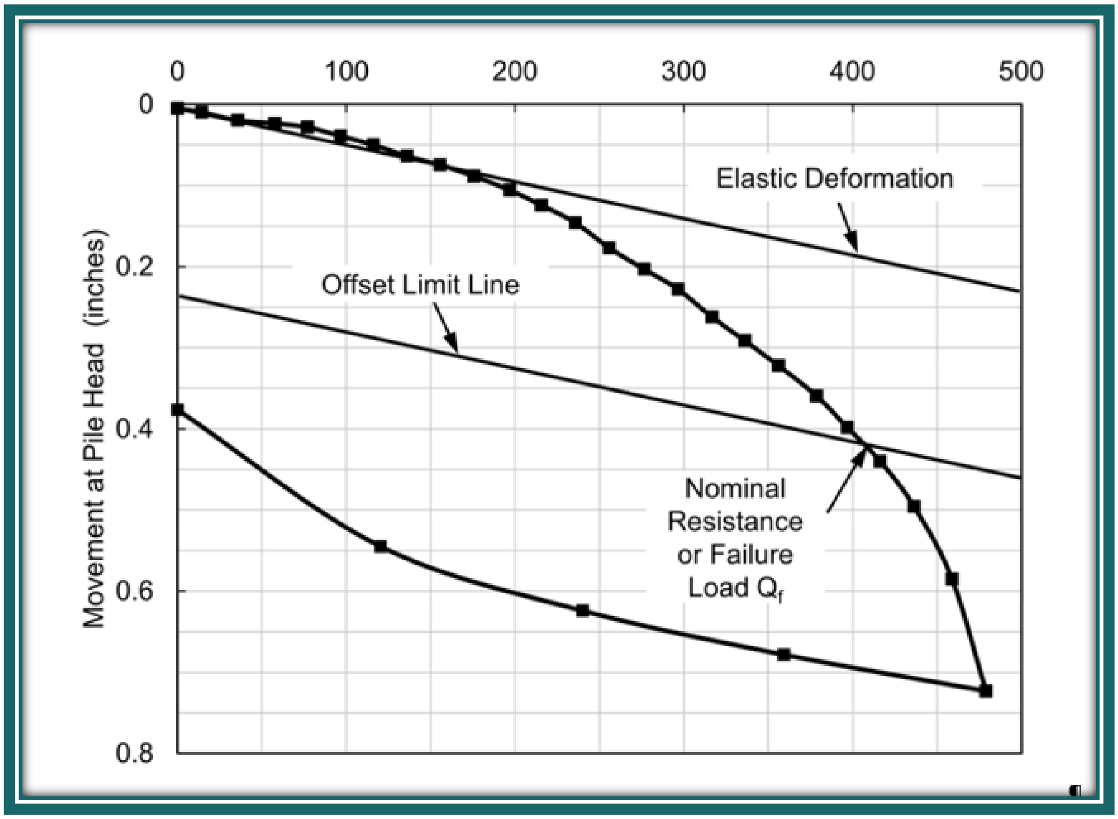


Figure 1. Typical Load Settlement Plot for Quick Load Test

For piles larger than 36" in diameter, additional pile tip movement is necessary to develop tip resistance. For these larger piles, the failure load can be defined as the load which produces movement at the pile head equal to:

$$s_f = \Delta + \frac{b}{30} \tag{4}$$

13-403.00 Maintained Load Test

The full test load shall be 150% of the pile load shown on the Plans. It shall be applied in maximum increments of 25% of the pile load as shown on the plans and at time intervals such that the rate of settlement does not exceed 0.120 inches per hour for a minimum interval of two hours. Similar to quick load tests, deviating from this applied pile loading increment (greater than 25% of the pile load as shown on the plans) shall be considered as grounds for rejecting the load test.

Each 25% increment load shall be gradually applied over about a five-minute interval to prevent driving. Gauge readings shall be recorded before and after application of the 25% increment loads. It is essential that jack and gauge readings be carefully monitored to control the rate of settlement.

The allowable rate of settlement can be proportioned and checked over thirty-minute intervals: 0.06 in. for thirty minutes, 0.12 in. for sixty minutes, 0.18 minutes for 90 minutes, and 0.24 in. for 120 minutes. If the allowable rate is not exceeded at the first thirty-minute interval, the contractor may apply the next load increment. If the rate of settlement is exceeded over a thirty-minute interval, then it must be checked at thirty-minute intervals until the rate of settlement has decreased to below the allowable limit or until the two-hour time period has elapsed.

If, over a two-hour period, beginning just prior to application of a load increment, the rate of settlement for the two-hour period exceeds allowable limits, the applied load shall be reduced until the rate of settlement is within allowable limits.

The failing load shall be defined as the minimum load that produces one of the following conditions:

1) Rate of settlement exceeding 0.12 inches per hour per load increment for a two-hour period
2) Settlement occurring during the last twelve hours of the full load test period
3) A permanent net settlement after rebound in excess of one-quarter (1/4) inch

The most common mode of failure under condition 1 is continual settlement at no increase in applied load. Settlements which just barely exceed the allowable limits should be carefully examined to ensure that the pile was not actually driven due to rapid application of the load.

Failure under condition 2 seldom occurs. However, even if the overall settlement is relatively small, but the settlement has not stabilized, ultimate failure could occur over a longer period of time.

Failure under condition 3 is easily recognized. By proportioning loads and settlements, the designer can determine the approximate load that will produce 1/4-inch net settlement. Most of the rebound which occurs when the test load is removed is due to relaxation of the compressive stresses in the loaded pile. See Equation (3) for the elastic deformation of a pile.

Should failure occur due to continual settlement at no increase in load or the total settlement over a two-hour period exceeds the allowable, the applied load shall be decreased until the settlement stabilizes. Gauge readings shall be recorded immediately after the load is decreased and at the end of the two-hour waiting period. The load shall then be removed and a final gauge reading taken.

A failing load test does not mean that a test pile has experienced structural failure. It means that the test pile has experienced settlement in excess of the allowable limits and is still capable of supporting a safe load capacity which will be determined by the designer.

If failure does not occur due to condition 1, the load test shall be carried to completion in accordance with the Specifications. The information from this portion of the test will be used by the designer to evaluate possible failure under conditions 2 and 3.

13-404.00 Adjusted Driving Equation

The example in Figures 7, 8, and 9 uses the following adjusted driving equation:

$$P = K\left(\frac{2WH}{S+0.1}\right) \tag{5}$$

This equation is applicable to single acting steam or air hammers and diesel hammers with unrestricted rebound. The applicable driving equations for various hammers are given in Specifications Article 606.14. It should be noted that K does not appear in the Specifications equations. To avoid misuse of the equations and possible errors in application, the adjusted driving equations, with appropriate K values, will be used only by Structures Division personnel. Construction personnel shall apply the driving equations exactly as they appear in the Specifications.

After reviewing the load test, the designer will determine the applicable K value and revise the required bearing accordingly. Past experience, based on the correlation of many load tests with test pile driving logs, indicates that K varies from about 0.40 to a maximum value of 1.50 depending on the soil conditions and the hammer. In the following example, the required bearing shown on the plans was 100 tons. The load test indicated that any pile driven near the location and with the same make and model hammer as was used for the load test pile would be capable of supporting 1.5 times the bearing value indicated by the non-adjusted Specifications driving equation. Using Equation (5):

$$P = 1.50\left(\frac{2WH}{S+0.1}\right)$$

$$\frac{2WH}{S+0.1} = \frac{P}{1.50} = \frac{100\ Tons}{1.50} = 67\ Tons$$

The Construction office was directed to instruct the contractor to drive 85’ piles to a minimum bearing of 67 tons as calculated using Equation (5). This pile length is longer than the pile length required for only bearing because the pile was required to reach a minimum tip elevation.

Figures 2 through 13 show various information related to load tests, including examples of both a Quick Load Test and a Maintained Load Test.

ALABAMA JACK
BEERMAN
INDUSTRIAL TOOL SPECIALISTS

1140 5th Avenue North
Birmingham, AL 35203
Phone: 205-251-8156 * Fax: 205-251-8157
Email: rental52@beerman.com

JACK CALIBRATION REPORT

CUSTOMER: FORD CONSTRUCTION PROJECT: SEMI ANNUAL

REPORT NO: 1583163 DATE: March 24, 2020

CYLINDER: ENERPAC CLRG3006 SERIAL NO: A0518E

GAUGE: ENERPAC 2-1/2" 10,000 PSI SERIAL NO: FCI

This report covers the results of Calibration for the above Hydraulic Cylinder. Calibration was performed utilizing our 1000-Ton Test Frame S/N 245017. The 1000-Ton Test Frame uses three 660 Kip Master Load Cells, S/Ns 58201, 58202, 60129, and GSE662 digital readout indicator, S/N 055826. The Master Load Cells were recently calibrated on June 21, 2019 in accordance with ASTM E4 and is within a 0.5% tolerance. Results of current calibration are shown on the following pages:

Temperature during test 70 Degrees Fahrenheit

By: [signature]

Date: March 24, 2020

ALABAMA JACK, DIVISION OF BEERMAN

F:\RENTAL\CUSTOMER CALIBTN & CERTS\MISCELLANEOUS CALIBRATIONS\FORD CONSTRUCTION ORD# 1567872 BAMA CLRG3006

Figure 2. Jack Calibration Certification Letter

ALABAMA JACK
BEERMAN
INDUSTRIAL TOOL SPECIALISTS

1140 5th Avenue North
Birmingham, AL 35203
Phone: 205-251-8156 * Fax: 205-251-8157
Email: rental52@beerman.com

PRESSURE GAUGE CERTIFICATION

CUSTOMER: FORD CONSTRUCTION — PROJECT: SEMI ANNUAL

REPORT NO: 1583163 — DATE: March 24, 2020

GAUGE: ENERPAC 2-1/2" 10,000 PSI — SERIAL NO: FCI

We certify the above hydraulic pressure gauge has been tested against our primary standard, an Ametek T-110 Dead Weight Tester, S/N 101479, and found to be within an accuracy of +/- 1/2% of full scale. The Ametek Tester was last certified on June 20, 2019 to 0.1% accuracy and traceable to the National Institute of Standards and Technology (NIST).

Standard Pressure (PSI)	Your Pressure Gauge (PSI)
0	0
500	500
1000	1000
1500	1500
2000	2000
2500	2500
3000	3000
3500	3500
4000	4000
4500	4500
5,000	5000

By:

Date: March 24, 2020

ALABAMA JACK DIV OF BEERMAN

Figure 3. Calibrated Gauge Readings for Actual Loads

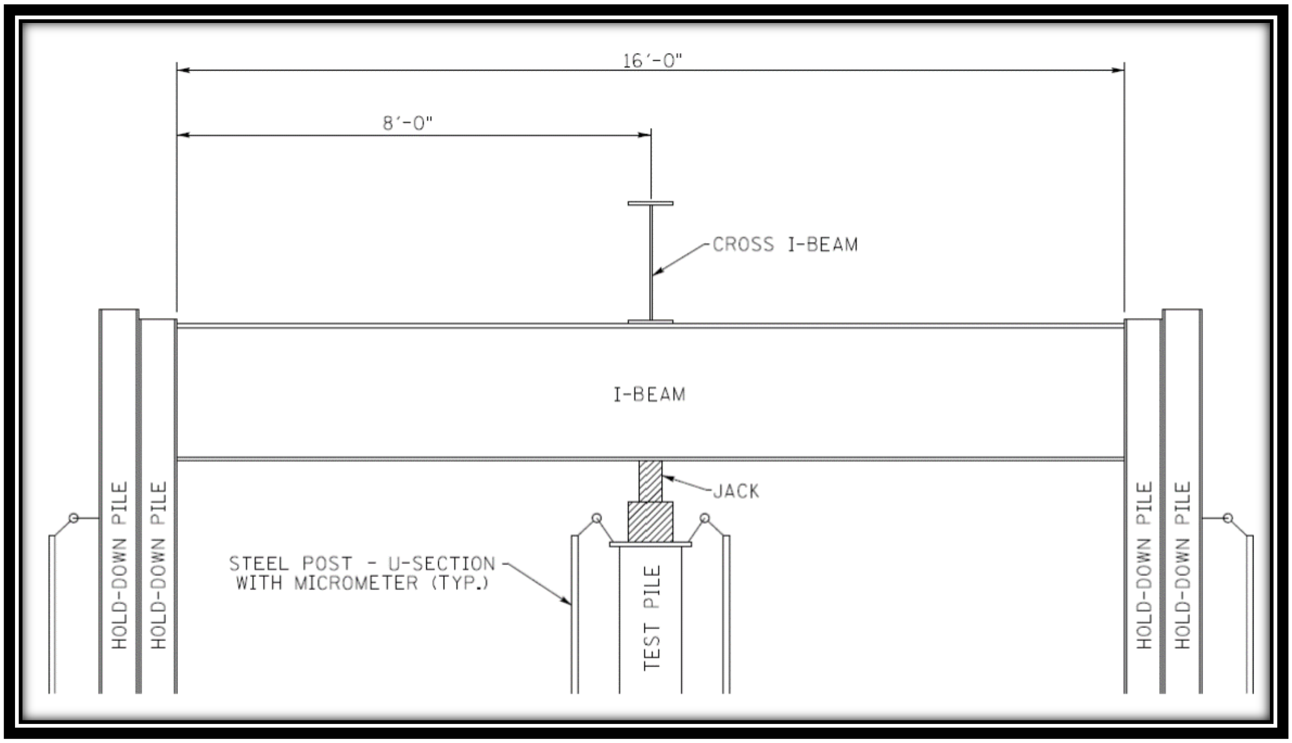


Figure 4. Cross-Section of Load Test Apparatus

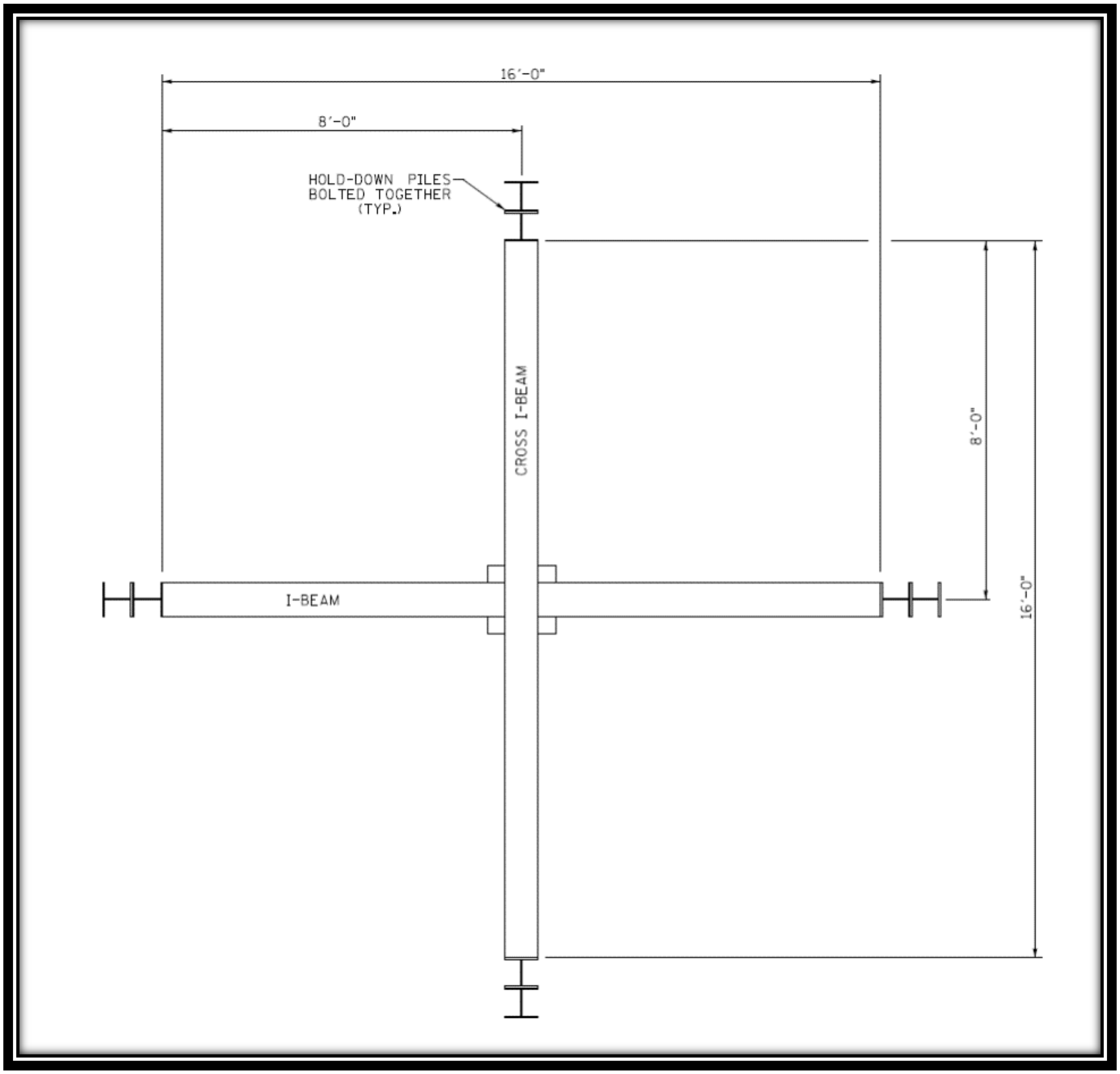
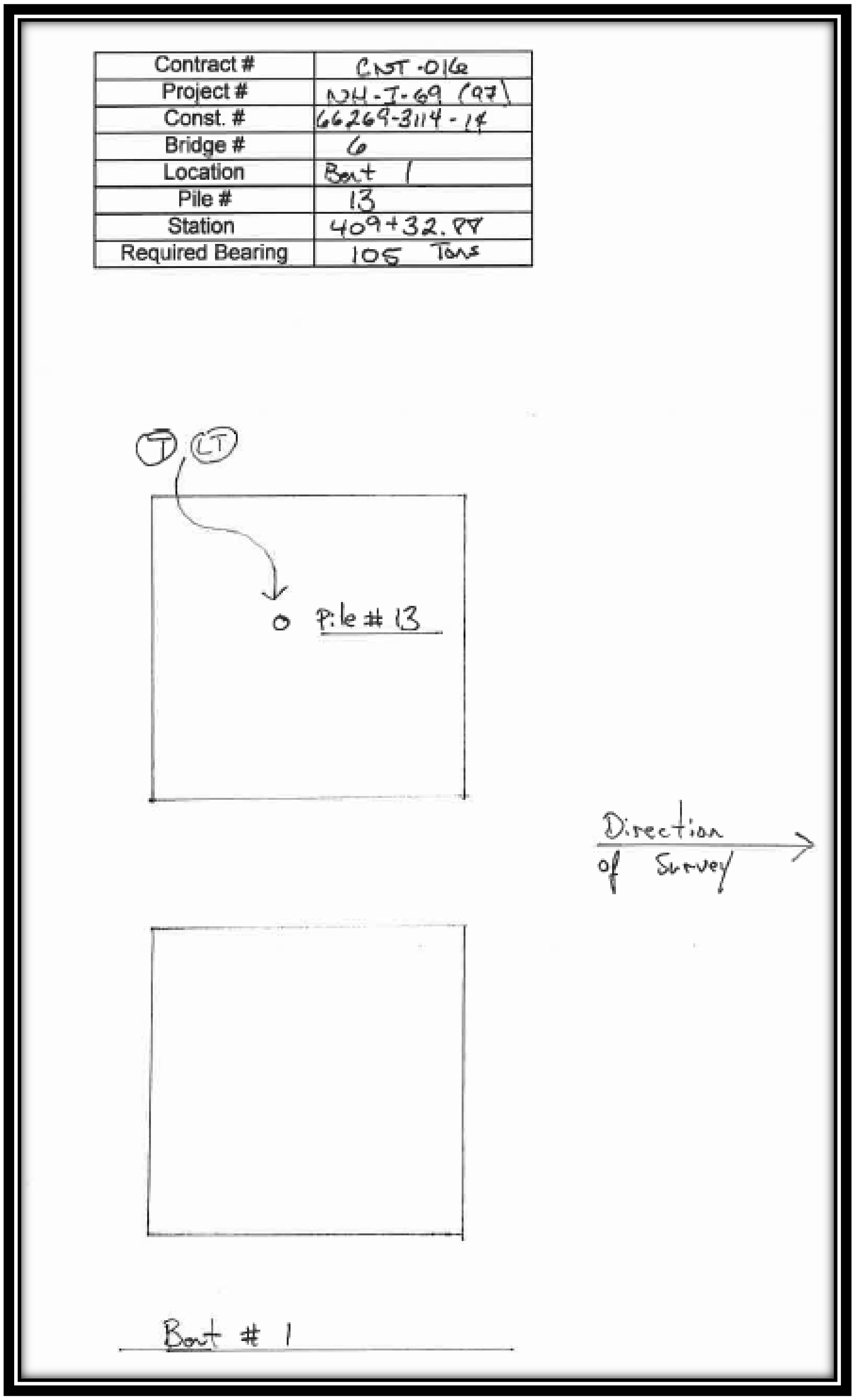


Figure 5. Plan of Load Test Apparatus



Contract #	CNT-016
Project #	NH-I-69 (97)
Const. #	66269-3114-14
Bridge #	6
Location	Bent 1
Pile #	13
Station	409+32.88
Required Bearing	105 Tons

Figure 6. Example Sketch Showing Location of Test Pile to Be Load Tested

Pile Data

Pile #	Feet (ft) (From PCO)	Hammer Height	# of Blows	Bearing
Abutment 2. Pile #10	0-44	W.O.H		
Test Pile	44-45	6	9	33
90' Pile	45-46	6.5	10	40
PCO 351.73	46-47	6.5	8	32
Date: 8-19-2020	47-48	7.8	21	95
	48-49	8.2	14	66
	49-50	8.3	18	83
	50-51	8.3	36	147
	51-52	8.1	31	130
	52-53	8	33	137
	53-54	7.9	26	113
	54-55	7.8	23	102
	55-56	7.8	21	95
	56-57	7.8	25	109
	57-58	7.6	17	74
	58-59	7.3	14	58
	59-60	7.1	9	39
	60-61	7.1	11	47
	61-62	6.9	10	43
	62-63	6.8	10	43
	63-64	6.7	11	47
	64-65	7.2	13	54
	65-66	7.7	19	87
	66-67	7.6	17	74
	67-68	7.7	21	89
	68-69	7.8	24	106
	69-70	7.8	25	109
	70-71	7.8	27	117
	71-72	7.9	30	127

Drive 85' piles full length to 67T. Must reach min. tip of 271. (Length includes 2' for stripping strands).

Figure 7. Tabulation of the Driving Log for a Quick Load Test Pile

QUICK LOAD TEST

CONTRACT CNS285 HAYWOOD CO.

Bridge 1 **Abut No. 2**

L =	72	FT
A =	196	SQ IN
E =	4060225	
D =	14	IN
DRIVEN LOAD	127	TONS

Sp=(QL/AE)*2000*12

Sf=Sp+(0.15+D/120)

LOAD Tons	GAUGE READING Ins.	TOTAL SETTLEMENT Ins.	Sp Ins.	Sf Ins.
0.0	0.0000	0.0000	0.0000	-0.2667
20.0	0.0175	-0.0175	-0.0434	-0.3101
20.0	0.0180	-0.0180	-0.0434	-0.3101
40.0	0.0450	-0.0450	-0.0869	-0.3535
40.0	0.0450	-0.0450	-0.0869	-0.3535
60.0	0.0695	-0.0695	-0.1303	-0.3969
60.0	0.0700	-0.0700	-0.1303	-0.3969
80.0	0.0975	-0.0975	-0.1737	-0.4404
80.0	0.0975	-0.0975	-0.1737	-0.4404
100.0	0.1325	-0.1325	-0.2171	-0.4838
100.0	0.1335	-0.1335	-0.2171	-0.4838
120.0	0.1685	-0.1685	-0.2606	-0.5272
120.0	0.1690	-0.1690	-0.2606	-0.5272
140.0	0.1985	-0.1985	-0.3040	-0.5707
140.0	0.1990	-0.1990	-0.3040	-0.5707
160.0	0.2280	-0.2280	-0.3474	-0.6141
160.0	0.2290	-0.2290	-0.3474	-0.6141
180.0	0.2580	-0.2580	-0.3908	-0.6575
180.0	0.2590	-0.2590	-0.3908	-0.6575
200.0	0.2920	-0.2920	-0.4343	-0.7009
200.0	0.2920	-0.2920	-0.4343	-0.7009
160.0	0.2760	-0.2760	-0.3474	-0.6141
160.0	0.2755	-0.2755	-0.3474	-0.6141
120.0	0.2300	-0.2300	-0.2606	-0.5272
120.0	0.2295	-0.2295	-0.2606	-0.5272
80.0	0.1690	-0.1690	-0.1737	-0.4404
80.0	0.1685	-0.1685	-0.1737	-0.4404
40.0	0.1115	-0.1115	-0.0869	-0.3535
40.0	0.1110	-0.1110	-0.0869	-0.3535
0.0	0.0295	-0.0295	0.0000	-0.2667
0.0	0.0275	-0.0275	0.0000	-0.2667

Qf =	**200.0**	*Safe Load*
K =	**1.50**	*K Factor = Safe Load / Driven Load (1.5 max)*
100 **/K =** (Pile Strength)	**66.7**	TONS

Figure 8. Tabulation of Quick Load Test Data

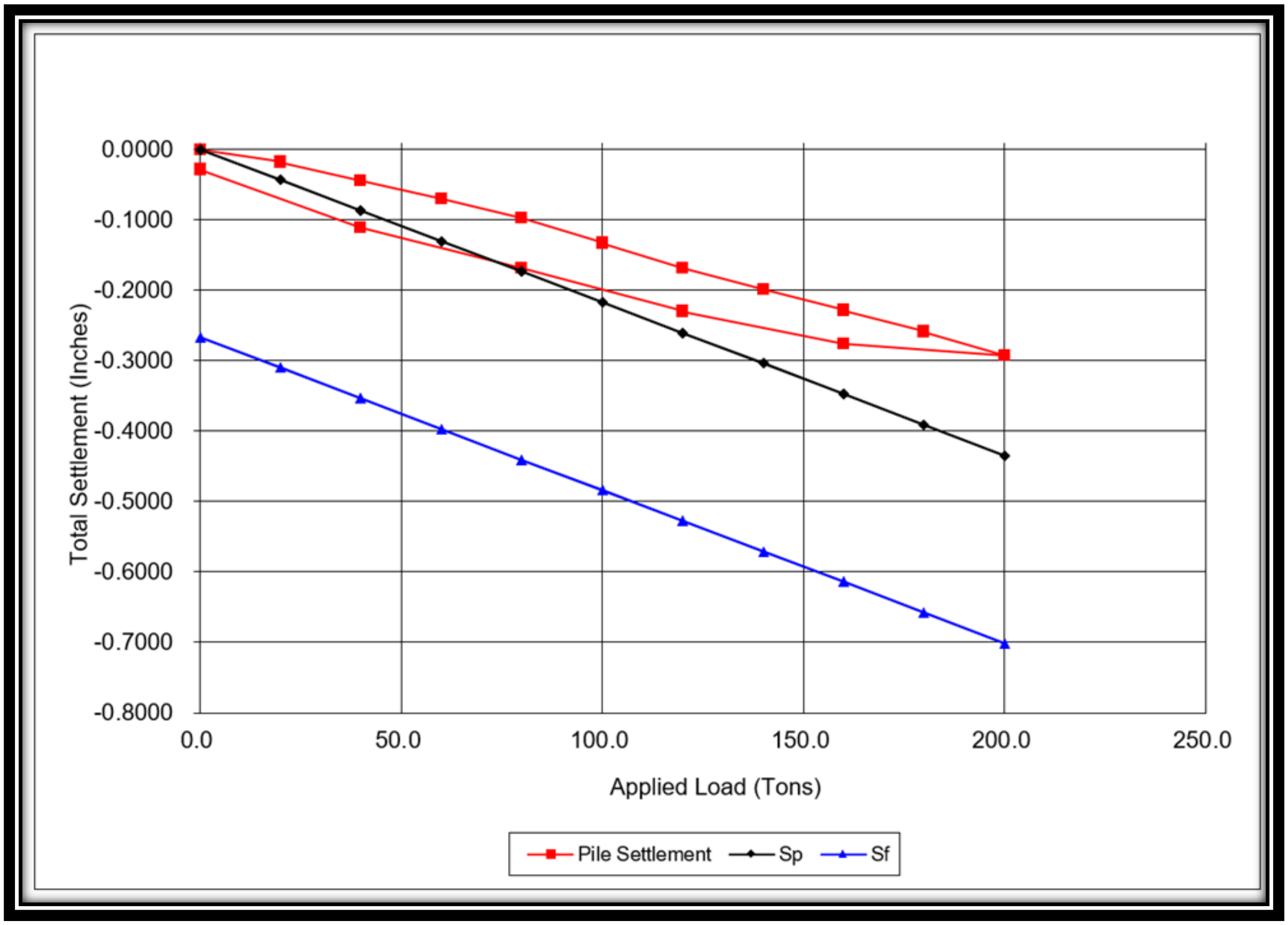


Figure 9. Graphical Plot of Quick Load Test Data

Height of Fall (ft.)	Penetration Below Pile Cut-Off	Penetration Below Observation Point	No. Blows Per Foot	Value S + 0.1	Bearing (Tons)
	0-1				
	1-2				
	2-3	W		H	
	3-4				
	4-5				
	5-6	E	O	A	
	6-7				
	7-8				
	8-9	I	F	M	
	9-10				
	10-11				
	11-12	G		M	
	12-13				
	13-14				
	14-15	H		E	
	15-16				
	16-17				
	17-18	T		R	
	18-19				
	19-20				
	20-21				
	21-22				
	22-23				
	23-24				
	24-25				
	25-26				
	26-27				
	27-28				
	28-29				
	29-30				
	30-31				
4.9	31-32		10	1.3000	24.93
4.8	32-33		10	1.3000	24.42
4.9	33-34		10	1.3000	24.93
5	34-35		10	1.3000	25.44
5	35-36		9	1.4333	23.08
5.1	36-37		11	1.1909	28.33
5.4	37-38		11	1.1909	29.99
5.5	38-39		13	1.0231	35.56
5.6	39-40		15	0.9000	41.16
5.9	40-41		12	1.1000	35.48
5.8	41-42		17	0.8059	47.61
5.9	42-43		16	0.8500	45.92
5.7	43-44		22	0.6455	58.42
6	44-45		20	0.7000	56.70
6	45-46		24	0.6000	66.15
6	46-47		26	0.5615	70.68
6.1	47-48		27	0.5444	74.12
6	48-49		33	0.4636	85.61
6.6	49-50		30	0.5000	87.32
6.3	50-51		26	0.5615	74.21
6.3	51-52		28	0.5286	78.84
6.4	52-53		28	0.5286	80.10
6.5	53-54		30	0.5000	86.00
6.7	54-55		32	0.4750	93.31
6.5	55-56		30	0.5000	86.00
6.7	56-57		30	0.5000	88.64
6.7	57-58		34	0.4529	97.85
6.9	58-59		37	0.4243	107.57

Figure 10. Tabulation of the Driving Load for a Maintained Load Test Pile

Load Test Data										
Gauge Reading PSI	Min. Time From Start of Test in Hours	% Req'd Test Load	Appl. Load in Tons	Ovserv. Time Hours	Indicator Reading in Inches					
					Test Pile			Hold Down Pile		
					Ind. #1	Ind. #2	Ave.	Ind. #1	Ind. #2	Ave.
0	0	0	0	4:00	0	0	0.000	0	0	0.000
705	0	25	25	4:00	0	0	0.000	0	0	0.000
705	2	25	25	6:00	0.002	0.002	0.002	0	0	0.000
1410	2	50	50	6:00	0.002	0.002	0.002	0	0	0.000
1410	4	50	50	8:00	0.002	0.001	0.002	0	0	0.000
2115	4	75	75	8:00	0.008	0.007	0.008	0	0	0.000
2115	6	75	75	10:00	0.01	0.064	0.037	0	0	0.000
2820	6	100	100	10:00	0.043	0.135	0.089	0.01	0.015	0.013
2820	8	100	100	12:00	0.043	0.133	0.088	0.02	0.015	0.018
3525	8	125	125	12:00	0.066	0.215	0.141	0.03	0.037	0.034
3525	10	125	125	14:00	0.066	0.215	0.141	0.038	0.052	0.045
4230	10	150	150	14:00	0.1	0.277	0.189	0.048	0.059	0.054
4230	12	150	150	16:00	0.104	0.281	0.193	0.056	0.069	0.063
4230	28	150	150	8:00	0.125	0.323	0.224	0.061	0.068	0.065
4230	36	150	150	16:00	0.124	0.318	0.221	0.069	0.082	0.076
4230	52	150	150	8:00	0.125	0.319	0.222	0.07	0.08	0.075
4230	60	150	150	16:00	0.127	0.32	0.224	0.07	0.075	0.073
3525	60	125	125	16:00	0.095	0.29	0.193	0.063	0.068	0.066
2820	61	100	100	17:00	0.096	0.29	0.193	0.062	0.068	0.065
2115	62	75	75	18:00	0.081	0.272	0.177	0.062	0.063	0.063
1410	63	50	50	19:00	0.03	0.26	0.145	0.05	0.048	0.049
705	64	25	25	20:00	0	0.258	0.129	0.048	0.04	0.044
0	65	0	0	21:00	-0.093	0.244	0.076	0.044	0.028	0.036
0	66	0	0	22:00	-0.097	0.237	0.070	0.042	0.02	0.031

Figure 11. Tabulation of Maintained Load Test Data

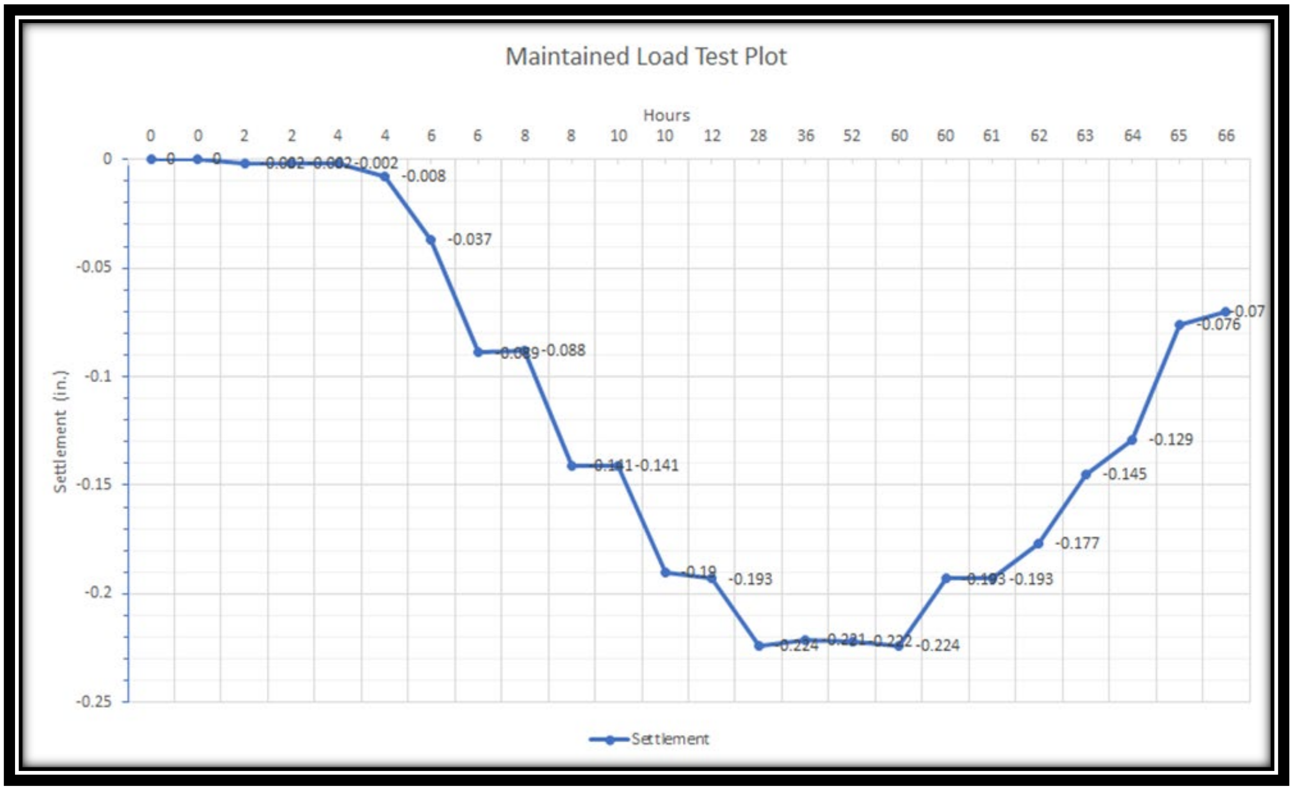
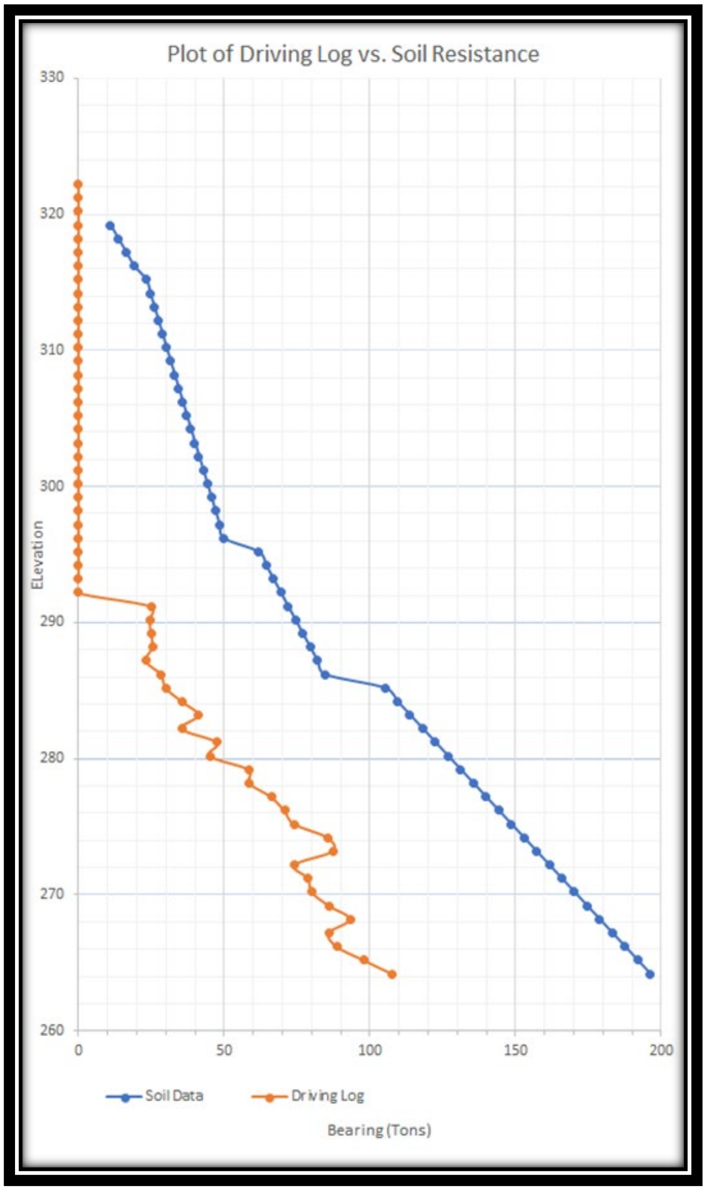


Figure 12. Graphical Plot of Maintained Load Test Data



Safe Load = 150T
Driven Load = 107T
K=150/107=1.4
100T/1.4=72T
Drive 60' piles to 71T
Includes 2' for stripping strands

Figure 13. Graphical Plot of Driving Log vs. Soil Resistance

Section 5 Setting Friction Pile Lengths

13-501.00 Setting Friction Pile Lengths for Bridge Plans

Setting lengths for friction piles on the bridge plans is based on analysis of the bore information from the foundation data provided by the Geotechnical Section.

Below is an example of the calculation of the estimated pile length at an abutment for a set of bridge plans.

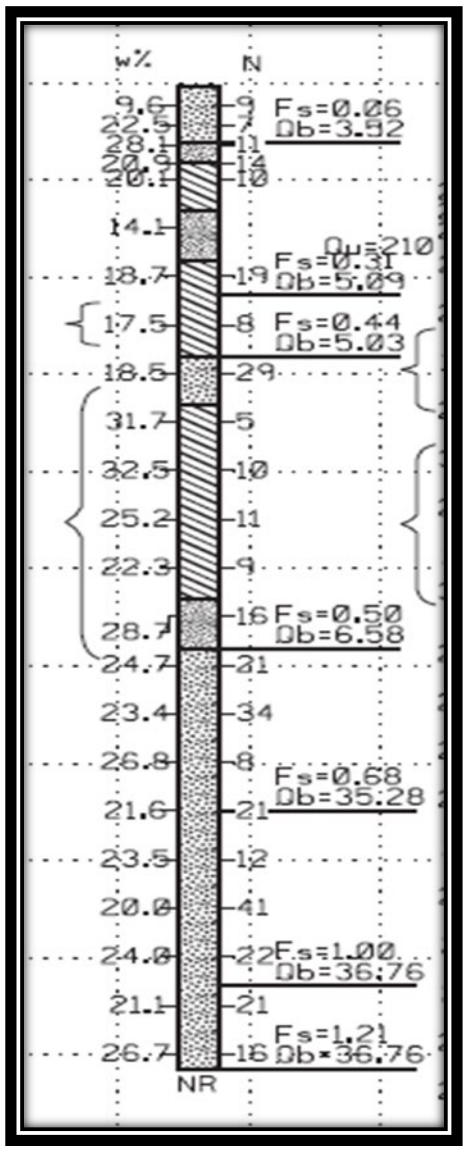


Figure 14. Skin Friction and End-Bearing Values Based on Pile Depth

There are two separate components to friction pile resistance – side friction and end bearing. These will both be given in the foundation report at each boring location. An example of how this information is reported is shown in Figure 14. The theoretical frictional pile resistance is calculated along the depth of the bore based on the skin friction resistance (Fs) and the end bearing resistance (Qb) for the specific soil material along the bore. For example, the top layer of the bore shown in Figure 14 specifies an Fs value of 0.06 Tons/ft^2 and a Qb value of 3.52 Tons/ft^2. Since this is a 14" prestressed concrete pile, the end area is (1.16 ft)^2 = 1.3611ft^2, and the perimeter area for a 1' deep section is 4 x 1.16 ft x 1ft = 4.66 ft^2. Thus, for the first 1' deep section the frictional bearing resistance would be 0.06 Tons/ft^2 x 4.66 ft^2 = 0.28 Tons. The end bearing resistance would be 3.52 Tons/ft^2 x 1.3611ft^2 = 4.79 Tons. Note that if this were a steel pile, the value of Fs would be reduced by 1/3 because steel/soil interfaces only have 2/3 of the frictional resistance of concrete/soil interfaces. Note that down the length of the pile, the skin friction resistance is cumulative, but the end bearing resistance is not. A spreadsheet is the usually the most efficient platform for estimated pile length and capacity calculations. An example of these calculations is shown in Figure 15.

PCO	Area	Perimeter	Bore #1			
354.48	1.361111	4.666667				
Elev.	Qb	Fs	Friction	End Bearing	Total	Pile Length
353.48			0	0	0	1
352.48			0	0	0	2
351.48			0	0	0	3
350.48			0	0	0	4
349.48			0	0	0	5
348.48			0	0	0	6
347.48			0	0	0	7
346.48			0	0	0	8
345.48			0	0	0	9
344.48			0	0	0	10
343.48			0	0	0	11
342.48			0	0	0	12
341.48			0	0	0	13
340.48			0	0	0	14
339.48	3.52	0.06	0.28	4.79111111	5.071111	15
338.48	3.52	0.06	0.56	4.79111111	5.351111	16
337.48	3.52	0.06	0.84	4.79111111	5.631111	17
336.48	3.52	0.06	1.12	4.79111111	5.911111	18
335.48	3.52	0.06	1.4	4.79111111	6.191111	19
334.48	3.52	0.06	1.68	4.79111111	6.471111	20
333.48	3.52	0.06	1.96	4.79111111	6.751111	21
332.48	5.09	0.31	3.406667	6.92805556	10.33472	22
331.48	5.09	0.31	4.853333	6.92805556	11.78139	23
330.48	5.09	0.31	6.3	6.92805556	13.22806	24
329.48	5.09	0.31	7.746667	6.92805556	14.67472	25
328.48	5.09	0.31	9.193333	6.92805556	16.12139	26
327.48	5.09	0.31	10.64	6.92805556	17.56806	27
326.48	5.09	0.31	12.08667	6.92805556	19.01472	28
325.48	5.09	0.31	13.53333	6.92805556	20.46139	29
324.48	5.09	0.31	14.98	6.92805556	21.90806	30
323.48	5.09	0.31	16.42667	6.92805556	23.35472	31
322.48	5.09	0.31	17.87333	6.92805556	24.80139	32
321.48	5.09	0.31	19.32	6.92805556	26.24806	33
320.48	5.09	0.31	20.76667	6.92805556	27.69472	34
319.48	5.09	0.31	22.21333	6.92805556	29.14139	35
318.48	5.09	0.31	23.66	6.92805556	30.58806	36
317.48	5.03	0.44	25.71333	6.84638889	32.55972	37
316.48	5.03	0.44	27.76667	6.84638889	34.61306	38
315.48	5.03	0.44	29.82	6.84638889	36.66639	39
314.48	5.03	0.44	31.87333	6.84638889	38.71972	40
313.48	5.03	0.44	33.92667	6.84638889	40.77306	41
312.48	5.03	0.44	35.98	6.84638889	42.82639	42
311.48	6.58	0.5	38.31333	8.95611111	47.26944	43
310.48	6.58	0.5	40.64667	8.95611111	49.60278	44
309.48	6.58	0.5	42.98	8.95611111	51.93611	45
308.48	6.58	0.5	45.31333	8.95611111	54.26944	46
307.48	6.58	0.5	47.64667	8.95611111	56.60278	47
306.48	6.58	0.5	49.98	8.95611111	58.93611	48
305.48	6.58	0.5	52.31333	8.95611111	61.26944	49
304.48	6.58	0.5	54.64667	8.95611111	63.60278	50
303.48	6.58	0.5	56.98	8.95611111	65.93611	51
302.48	6.58	0.5	59.31333	8.95611111	68.26944	52
301.48	6.58	0.5	61.64667	8.95611111	70.60278	53
300.48	6.58	0.5	63.98	8.95611111	72.93611	54
299.48	6.58	0.5	66.31333	8.95611111	75.26944	55
298.48	6.58	0.5	68.64667	8.95611111	77.60278	56
297.48	6.58	0.5	70.98	8.95611111	79.93611	57
296.48	6.58	0.5	73.31333	8.95611111	82.26944	58
295.48	6.58	0.5	75.64667	8.95611111	84.60278	59
294.48	6.58	0.5	77.98	8.95611111	86.93611	60
293.48	6.58	0.5	80.31333	8.95611111	89.26944	61
292.48	6.58	0.5	82.64667	8.95611111	91.60278	62
291.48	6.58	0.5	84.98	8.95611111	93.93611	63
290.48	6.58	0.5	87.31333	8.95611111	96.26944	64
289.48	6.58	0.5	89.64667	8.95611111	98.60278	65
288.48	6.58	0.5	91.98	8.95611111	100.9361	66

Figure 15. Example Pile Length Calculation Using a Spreadsheet

13-502.00 Setting Friction Pile Lengths for Bridge Plans to Account for Minimum Tip Elevations

Where the potential for scour exists at a substructure location, the minimum tip elevation of the pile shall be adjusted to provide adequate resistance for a scour event. Hydraulics shall identify a scour elevation on their hydraulic layout that shall also be included in the preliminary layout. Office policy is to set a minimum tip elevation such that the soil layers below the scour elevation (discounting all soil layers above) will provide a resistance equal to or greater than the maximum Service Limit State pile reaction. The aforementioned soil layers are defined in the bore information provided the Geotechnical Section (see Figure 14).

The potential for liquefaction around piles shall also be considered when determining minimum tip elevations. The boring information supplied by the Geotechnical Section shall identify layers in the bore that have the potential for liquefaction. When one or more liquefiable layers are present, office policy is to set the minimum tip elevation where the "good" (non-liquefiable) layers under the liquefiable layers provide a resistance equal to or greater than the sum of the downdrag force and the maximum Service Limit State pile reaction. The downdrag force on the pile is defined as the sum of the negative skin friction resistance along the length of the pile where the soil is moving downward relative to the pile. The designer shall specify pile lengths based on the Strength and Extreme Event Limit State requirements and the specified minimum tip elevation, whichever is deeper. Office policy is that the downdrag force will not increase the specified driving load up from what meets the Strength and Extreme Event Limit State requirements. Studies have been done that justify waiving the effect of downdrag forces on the driving load if the minimum tip elevation is set to provide a theoretical resistance of the "good" layers equal to or greater than the sum of the downdrag force and Service Limit State pile reaction.

13-503.00 Determining Length of Production Piles based on Test Pile Driving Logs

After receiving a test pile driving log from the construction office, determine the length of the production piles to be used at that particular substructure where the test pile was driven. The following steps shall be followed:

1. Look in the plans and verify the P.C.O. elevation for the test pile being reviewed.

2. Determine the actual required bearing. This is the design load on the plans (usually 100 tons) divided by the K factor you calculated when you analyzed the load test pile data (see Section 13-404.00). As office policy, K shall not be taken greater than 1.5,

which equates to a minimum actual required bearing of 2/3 the design load. This would be 67 tons for a design load of 100 tons.

3. Determine the depth below the P.C.O. elevation on the driving log that the test pile will achieve a bearing equal to or greater than the actual required bearing from step 2. Calculate the pile tip elevation at this depth. If a minimum tip elevation is specified on the plans, check that it has been reached. If it has not been reached, extend the pile tip to the minimum tip elevation. Also, if the pile tip is in a layer than is less than 5' from a layer beneath that has a smaller end bearing capacity, extend the pile into the weaker layer until the actual required bearing from Step 2 is reached.

The length of the production piles will also be affected by the type of seismic attachment that the contractor proposes to use. If the contractor is going to expose the prestressing strands in the top 2' of the piles, then this extra 2' shall be included in the production pile length. Lengths for production piles shall be given in 5' increments. Since the contractor is waiting on instructions for pile length and minimum bearing, the designer determining this information shall respond to the Construction Office as soon as possible.

13-504.00 Reviewing Reported Final Bearings of Driven Production Piles

The contractor (via the Construction Office) shall submit the final bearings and lengths for all the piles at a particular substructure to the Structures Division. If any of the driven piles do not achieve the bearing or length specified by the Structures Division based on the test pile, then the Structures Division will provide further instructions. The Structures Division may specify adding additional piles to the substructure if any of the final pile bearings are inadequate or if any of the pile tips do not reach the specified minimum tip elevation.

If additional piles are required in a pile footing, piles can be added in the diagonals of the pile grid if the grid spacing in either the transverse or longitudinal direction is less than 5'. However, the length along the diagonals of the pile grid must be at least 5' if piles are to be added in the diagonals.

When a contractor reports final pile bearings and lengths, review and submit either approval of the piles or further instructions for any piles back to the Construction Office. All piles in a substructure element shall be approved before the contractor can pour the concrete surrounding these piles (e.g., abutment beams, bent footings, or pile bent caps). Since the contractor is waiting on this approval, the designer reviewing the pile data shall respond to the Construction Office as soon as possible.

Works Cited

AASHTO, *LRFD Bridge Design Specifications.* 9th. Washington, D. C.: American Association of State Highway and Transportation Officials, 2020.

TDOT, *Standard Specifications for Road and Bridge Construction*, Tennessee Department of Transportation, 2021.

ASTM Standard D1143, *Standard Test Methods for Deep Foundation Elements Under Static Axial Compressive Load*, ASTM International, West Conshohocken, PA, 2020.

FHWA, *Design and Construction of Driven Pile Foundations*, Volumes I and II, Federal Highway Administration, U.S. Department of Transportation, 2016.

Boulanger, R. W. & Brandenburg S. J. (2004). "*Neutral Plane Solution for Liquefaction-Induced Down-Drag on Vertical Piles*" UC Davis. http://dx.doi.org/10.1061/40744(154)32 Retrieved from https://escholarship.org/uc/item/0hq9t1mb