CAPWAPC CORRELATION - A CASE STUDY

By

C. Michael Morgano

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Cleveland, Ohio

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INTRODUCTION

This year's Deep Foundation Institute (DFI) seminar, performed jointly with North Carolina State University and the North Carolina section of the American Society of Civil Engineers, was held in Raleigh, North Carolina on March 7 through 9, 1988. Included in the seminar was a full-scale pile load test of a 54 ft long, 12 inch square prestressed concrete pile.

The pile was tested both dynamically and statically. The dynamic test involved restriking the pile three days after its initial drive and then performing a CAPWAPC analysis. The static load test which was performed following the dynamic test consisted of a quick load test.

DRIVING DETAILS

The test pile was originally driven using a Conmaco 65E5 on March 4, 1988, at the site of the proposed N.C. State University towers. The pile was driven using 6-3/4 inch plywood sheets for pile top cushioning. At a penetration of 39 ft, the pile was significantly damaged near the pile top. After cutting a portion off the pile top, four additional 3/4" plywood sheets were added and driving continued to a penetration of 44.5 Ft. At the end of initial drive, the driving resistance was reported to be 5 blows/inch. After the final cut-off, the pile had a total length of 45.5 ft.

On Monday, March 7, the test pile was dynamically monitored during a restrike test. A total of 5 blows were delivered resulting in approximately 1/2 inch of penetration.

The pile was then statically tested that afternoon making use of the "quick" load test. The pile was loaded in increments of 40 kips at 10 minute intervals. At a maximum applied load of 414 kips, the pile apparently had failed. The pile was then unloaded in 80 kip increments again at 10 minute intervals.

SOIL CONDITIONS

The subsurface soil conditions consisted of residual soils composed of sandy and clayey silts overlying a layer of partially weathered rock. It was not evident whether or not the pile tip reached the rock. The pile was designed to support a load of 160 kips. With a safety factor of 2, the required ultimate capacity is therefore 320 kips.

DYNAMIC ANALYSIS AND RESULTS

The dynamic analysis included performing a Wave Equation Analysis, field testing during a restrike using the Pile Driving Analyzer and finally performing a CAPWAPC analysis on the restrike data.

Wave Equation Analysis

A Wave Equation Analysis was performed prior to field testing. The soil parameters (ie., damping, quakes, resistance distribution) were input using the standard values recommended in the WEAP manual. These values have been summarized in Figure 1. The final results in the form of a bearing graph are also shown in Figure 1. Note that to obtain the required 320 kips ultimate capacity, the pile would have to be driven to 6 blows/inch (based on a 5 ft ram stroke).

PDA Field Results

The Case Method results have been summarized in Table 1. The results showed that the ultimate capacity is in the 400 to 500 kips range, depending on the chosen damping factor. The field evaluations of ultimate capacity was reported as 450 kips (RMX with a damping constant of J=0.5)

CAPWAPC Analysis Results

A CAPWAPC analysis on data representing the third blow of the restrike was performed that afternoon. The results of the static test results were not revealed until the following day. The complete results have been summarized in Tables 2 through 5. Table 1 summarizes the calculated soil parameters (i.e., capacity, damping, quakes, resistance distribution). The pile profile and model are described in Table 3. Table 4 tabulates various maximum quantities vs pile depth. Quantities include maximum force, stress, transferred energy, velocity and displacement. Table 5 contains the results of the simulated static load test. The original force and velocity record along with the match plots of force and velocity and a plot of the resistance distribution are shown in Figure 2. A plot of applied load vs pile top and tip displacement obtained from the CAPWAPC simulated static load test is shown in Figure 3.

The CAPWAPC total ultimate capacity was calculated as 420 kips; distributed as 340 kips skin friction and 80 kips as end bearing. The Smith Damping factors for the skin and toe were calculated as 0.18 and 0.12 s/ft, respectively. Quakes were calculated as 0.1 and 0.26 inches for the skin and toe, respectively.

STATIC TEST RESULTS

A plot of applied load vs pile top displacement is shown in Figure 4. The ultimate static capacity as determined from the static load test, by four distinguished panelists using various methods, ranged from 380 to 410 kips. The 410 kips capacity was determined from Davisson's failure criterion.

CORRELATION OF STATIC VS DYNAMIC METHODS

Static vs CAPWAPC

The load vs pile top set curves from the CAPWAPC simulated static analysis and from the actual static load test have been plotted together and shown in Figure 5. Both curves indicate that the pile was indeed loaded to failure. Note that the ultimate capacity obtained from the CAPWAPC analysis is within 10 percent of any prediction obtained from the static load test (within 2.5 percent if compared to capacity obtained from Davisson's failure criterion). This excellent correlation is also reflected on the load vs. pile top displacement curves shown in Figure 5.

Static vs WEAP

A plot of blow count vs capacity is shown in the bearing graph of Figure 1. Note that the analysis predicted an ultimate capacity of 390 kips at a blow count of 120 bl/ft (equivalent to 5 bl/.5 in as obtained during the restrike test). This prediction also correlates well with the capacity obtained from the static load test.

Static vs Case Method

Table 1 summarizes the Case Method results for the same data set that was analyzed with CAPWAPC. Note that in order to match the capacity obtained from the static load test (Davisson's method), a damping factor of 0.68 with the RMX method must be utilized (or 0.55 using the RS1 method). Though these damping factors are somewhat larger than one would expect from the existing soil conditions, they are still realistic.

All three dynamic methods described above correlated very well with the static load test. Unlike the Case Method and CAPWAPC, WEAP is independent of time for static load test capacity correlation. The Case Method capacity (and of course the capacity obtained by CAPWAPC) is always at the time of testing. In order to obtain a good correlation, it is imperative that the dynamic testing be performed at a time which best simulates the soil conditions which exist during the static load test. Since it is physically impossible to perform both the dynamic and static test simultaneously, at least on the same pile, one must perform them sequentially. Because static testing generally results in less soil disturbance, it is recommended that it be performed prior to the dynamic test.

SUMMARY

A case study for a prestress concrete pile in residual soils which discussed the correlation between various dynamic methods and a static load test was presented. Correlation between these methods was found to be very good. The ultimate capacity obtained by the CAPWAPC program was within 2.5 percent of the ultimate capacity obtained by the Davisson limit on the static load test. Since soil strength and therefore soil resistance generally changes with time, a good correlation can only be obtained if dynamic tests are performed within the same time frame as the static load test.

TABLE 1: Case Method Results

DFI NC STATE, CONCRETE TEST PILE, BOR

Case Method Capacity Results

	J=0.0	J=0.1	J=0.2	J=0.3	J=0.4	J=0.5	J=0.6	J=0.7	J=0.8	J=0.9
Rs	631.	591.	551.	511.	471.	431.	391.	351.	311.	270.
Rx	631.	591.	551.	514.	482.	450.	425.	406.	388.	385.
Ru	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Ra Ra2	110.	492.								

TABLE 2: CAPWAPC Results

CAPWAPC - GRL & Associates, Inc.

DFI NC STATE, CONCRETE TEST PILE, BOR   Blow No 3   07-Mar-88

Final CAPWAPC Capacity: Ru 420.0, Skin 339.8, Toe 80.2 Kips

Soil Sgmnt No.	Depth Below Gages ft	Depth Below Grade ft	Quake in	Soil Damping Case Kips/ft/s	Soil Damping Viscs Kips/ft/s	Soil Damping Smith s/ft	Ru Kips	Sum of Ru Kips	Unit Skin Frctn Kips/ft2
								420.0	
1	10.0	6.7	.100	.068	4.4	.175	25.0	395.0	.94
2	16.7	13.4	.100	.109	7.0	.175	40.1	354.9	1.50
3	23.4	20.1	.100	.191	12.3	.175	70.1	284.8	2.62
4	30.1	26.8	.100	.213	13.7	.175	78.3	206.4	2.93
5	36.8	33.5	.100	.175	11.2	.175	64.1	142.3	2.40
6	43.5	40.2	.100	.169	10.9	.175	62.1	80.2	2.32
Sum				.926	59.5		339.8		
Avrge			.100			.175	56.6		2.12
Toe			.260	.149	9.6	.120	80.2		80.20

Soil Model Extensions		Skin	Toe
Unloading Quake	(% of loading quake)	50	100
Unloading Level	(% of Ru)	5	
Soil Plug Weight	(Kips)		.30

TABLE 3: Pile Model and Profile

CAPWAPC - GRL & Associates, Inc.

DFI NC STATE, CONCRETE TEST PILE, BOR Blow No 3 07-Mar-88

PILE PROFILE AND PILE MODEL

	Depth ft	Area in2	E-Modulus Kips/in2	Spec. Weight Kips/ft3
1	.00	144.00	6150.0	.150
2	43.50	144.00	6150.0	.150

Segmnt No.	Depth B.G. ft	Impedance Kips/ft/s	Tensn Slack inch	Compr. Slack inch
1	3.35	64.2	.0000	.0000
13	43.50	64.2	.0000	.0000

Pile Damping (%) .0, Time Incr (ms) .243, Wave Speed 13784.8

TABLE 4: Table of Extrema

CAPWAPC - GRL & Associates, Inc.

DFI NC STATE, CONCRETE TEST PILE, BOR Blow No 3 07-Mar-88

EXTREMA TABLE

Pile Sgmnt No.	Depth below Gages ft	max. Force Kips	min. Force Kips	max. Comp. Stress Kips/in2	max. Tension Stress Kips/in2	max. trnsfd. Energy Kips-ft	max. Veloc. ft/s	max. Displ. in
1	3.3	558.6	-9.3	3.88	-.06	15.01	7.8	.392
2	6.7	611.5	-35.1	4.25	-.24	14.61	7.8	.360
3	10.0	636.2	-38.8	4.42	-.27	14.41	7.6	.350
5	16.7	630.6	-38.9	4.38	-.27	13.00	7.0	.320
6	20.1	569.8	-33.5	3.96	-.23	11.25	6.6	.310
7	23.4	566.3	-37.2	3.93	-.26	11.13	6.2	.300
8	26.8	444.6	-23.9	3.09	-.17	8.53	5.9	.290
10	33.5	383.6	-6.0	2.66	-.04	5.82	5.3	.280
11	36.8	388.8	-2.3	2.70	-.02	5.76	5.2	.270
12	40.2	275.3	.0	1.91	.00	3.76	5.9	.260
13	43.5	219.5	.0	1.52	.00	1.72	6.7	.261
Absolute	10.0			4.42		(T=	23.8 ms)	
	10.0				-.27	(T=	37.1 ms)	

TABLE 5: CAPWAPC Simulated Static Analysis Results

STATIC ANALYSIS

CAPWAPC - GRL & Associates, Inc.

DFI NC STATE, CONCRETE TEST PILE, BOR
Blow 3 Date 07-Mar-88

DYNAMIC D-TOE, E-P R-TOE

I	Top Load Kips	Top Set IN	Bot. Load Kips	Bot. Set IN
10	27.9	.016	1.8	.006
11	57.6	.034	3.6	.012
12	108.2	.063	6.8	.022
13	181.4	.106	11.5	.037
14	265.9	.158	17.1	.056
15	329.2	.206	23.1	.075
16	363.8	.242	28.6	.093
22	387.5	.318	47.7	.155
28	408.5	.399	68.7	.223
37	420.0	.443	80.2	.260
44	373.9	.424	79.0	.257
45	337.4	.408	78.0	.254
46	295.6	.390	76.9	.251
47	251.9	.371	75.8	.247
48	212.9	.352	74.6	.243
49	177.8	.334	73.4	.239
50	146.1	.316	72.1	.235
51	120.2	.300	70.9	.231
52	98.7	.286	69.6	.227
54	68.1	.262	67.1	.219
58	46.6	.238	63.6	.208
80	25.0	.155	42.0	.137
100	48.0	.144	36.2	.119
106	69.1	.156	37.5	.123

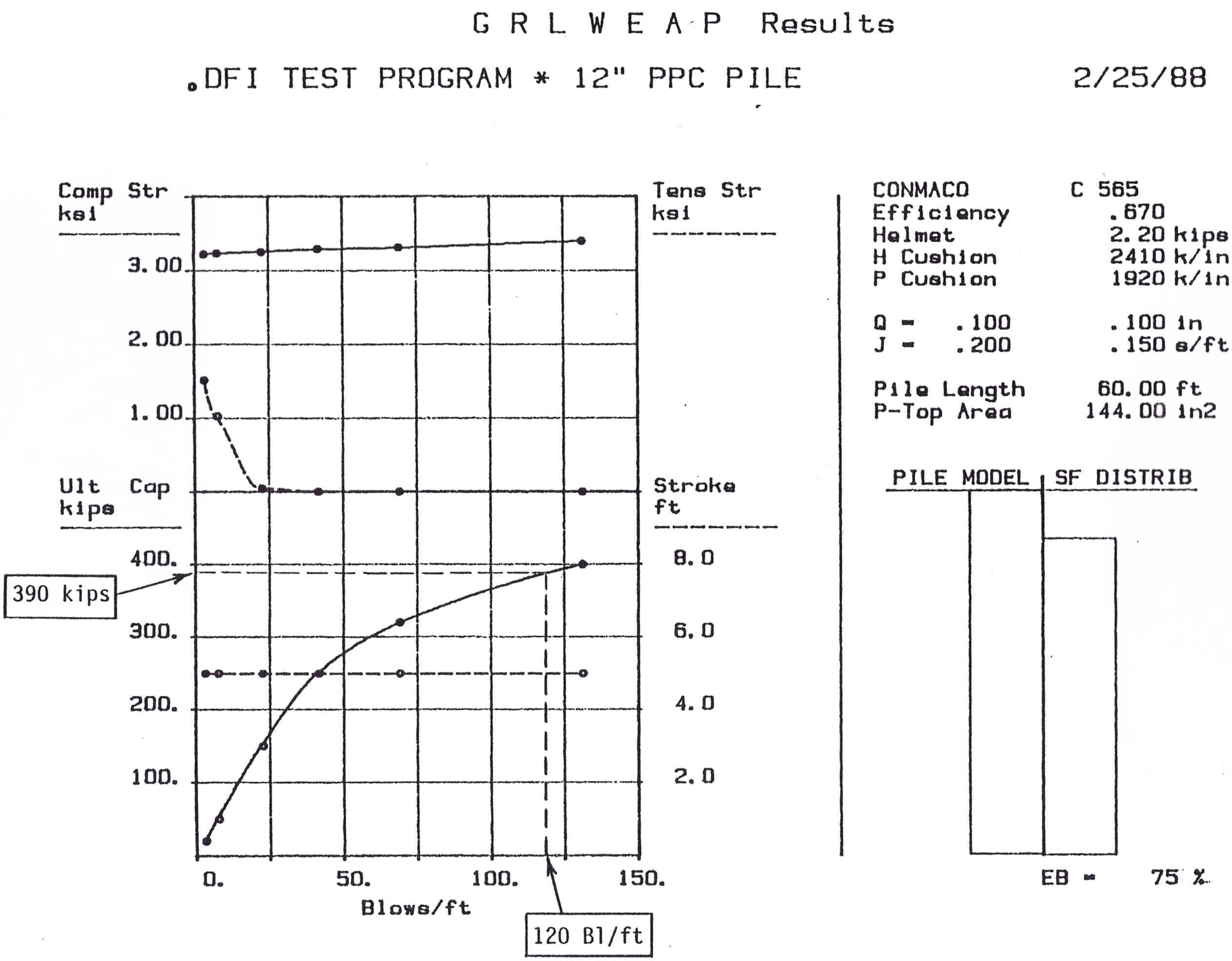

G R L W E A P Results
DFI TEST PROGRAM * 12" PPC PILE
2/25/88
Comp Str ksi
Tens Str ksi
3.00
2.00
1.00
Ult Cap kips
Stroke ft
400.
300.
200.
100.
8.0
6.0
4.0
2.0
390 kips
0.
50.
100.
150.
Blows/ft
120 Bl/ft
CONMACO C 565
Efficiency .670
Helmet 2.20 kips
H Cushion 2410 k/in
P Cushion 1920 k/in
Q = .100 .100 in
J = .200 .150 s/ft
Pile Length 60.00 ft
P-Top Area 144.00 in2
PILE MODEL
SF DISTRIB
EB = 75 %

FIGURE 1

CAPWAPC - GRL & Associates, Inc.

DFI NC STATE, CONCRETE TEST PILE, BOR

Blow 3 07-Mar-88

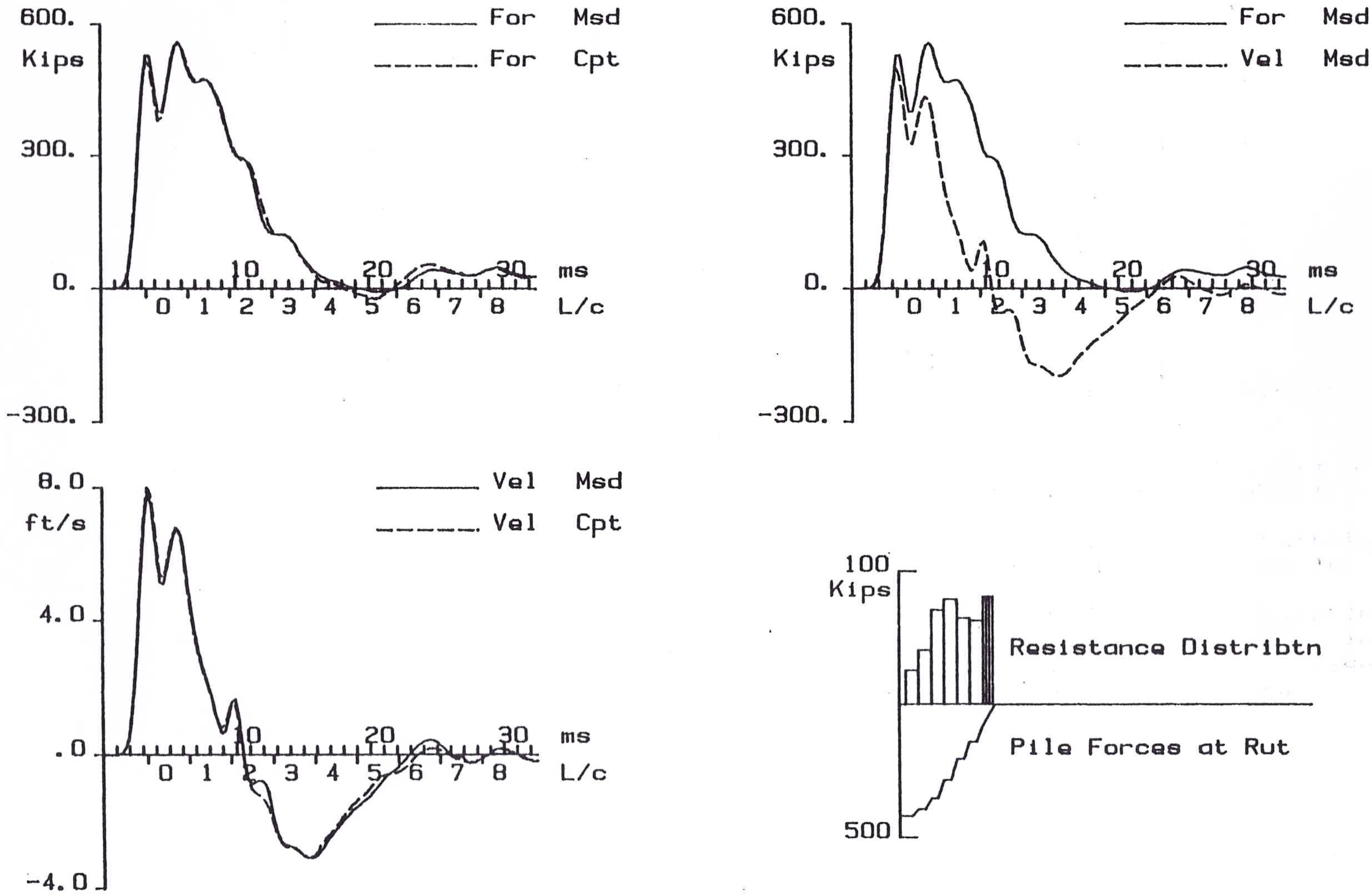


FIGURE 2

CAPWAPC - GRL & Associates, Inc.

DFI NC STATE, CONCRETE TEST PILE, BOR

Blow 3 DYNAMIC D-TOE, E-P R-TOE

——— Pile Top - - - - - - Pile Bottom

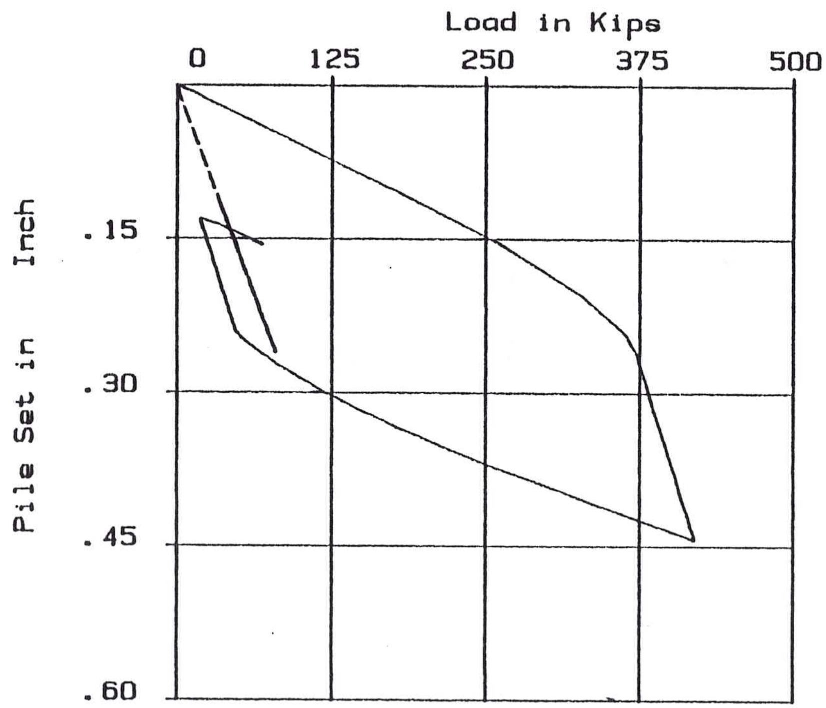
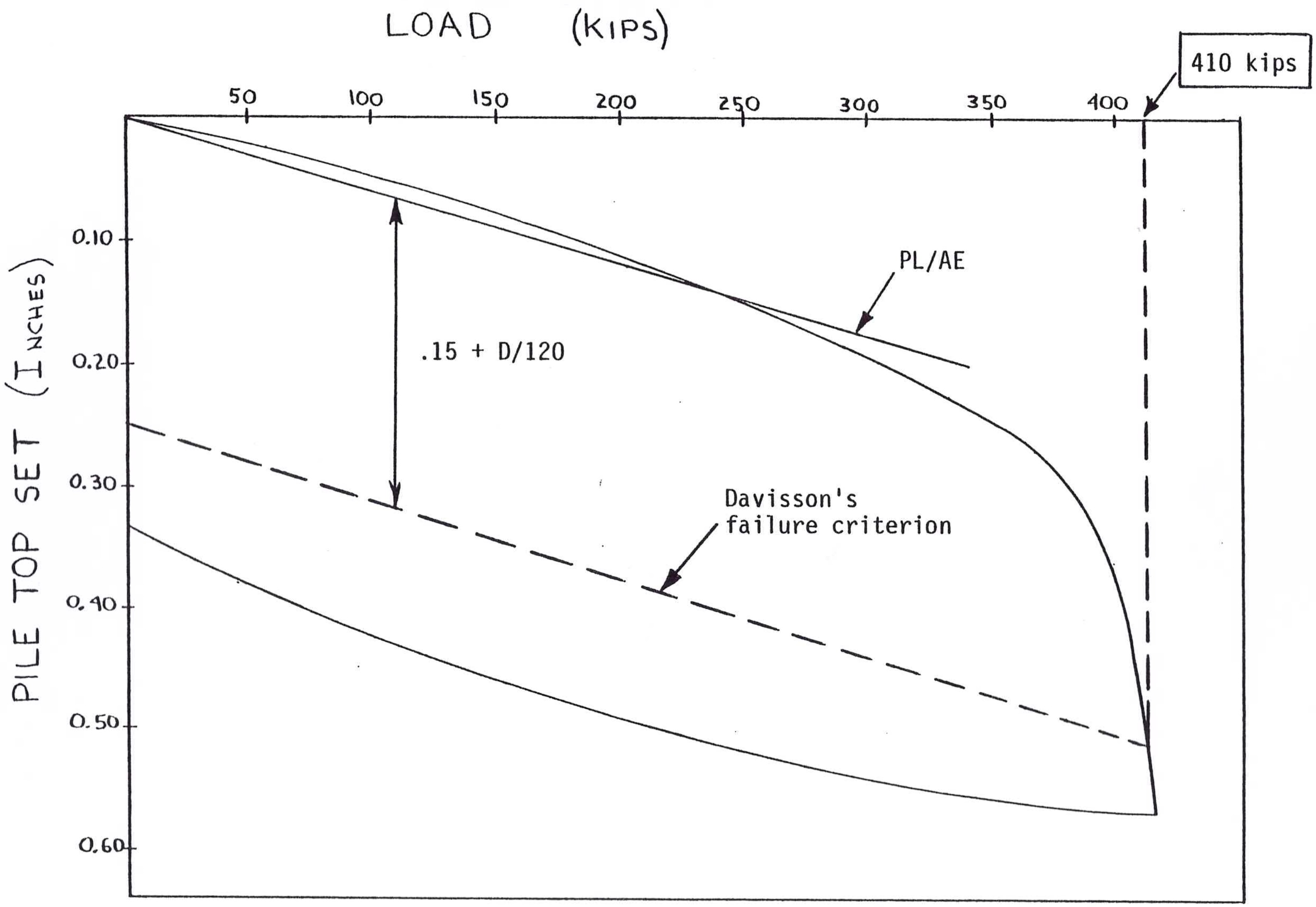
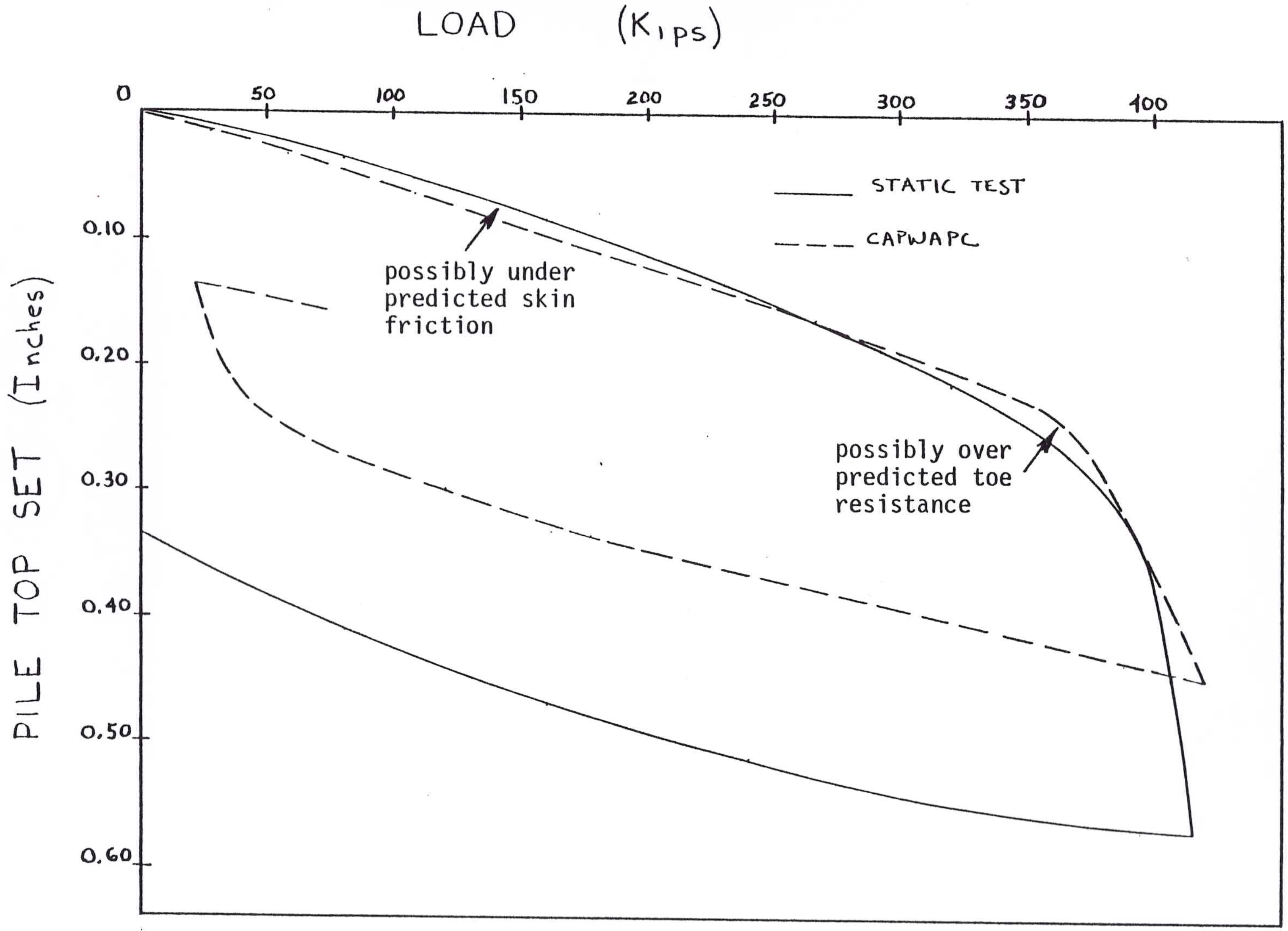


FIGURE 3



LOAD (KIPS)
410 kips
50
100
150
200
250
300
350
400
PILE TOP SET (INCHES)
0.10
0.20
0.30
0.40
0.50
0.60
PL/AE
.15 + D/120
Davisson's
failure criterion

FIGURE 4



Ultimate Capacity :

- Static Test → 410 kips
- WEAP (120 Bl/ft) → 390 kips
- Case Method RMX (J=0.5) → 450 kips
- CAPWAPC Analysis → 420 kips

FIGURE 5

APPENDIX

Soil & Driving Information

DFI/NCSU/ASCE SEMINAR

DEMONSTRATION
OF
PILE DRIVING & DYNAMIC PILE ANALYSIS

FOUNDATION SERVICES INC
CONMACO INC
GRL, INC

AVAILABLE INFORMATION

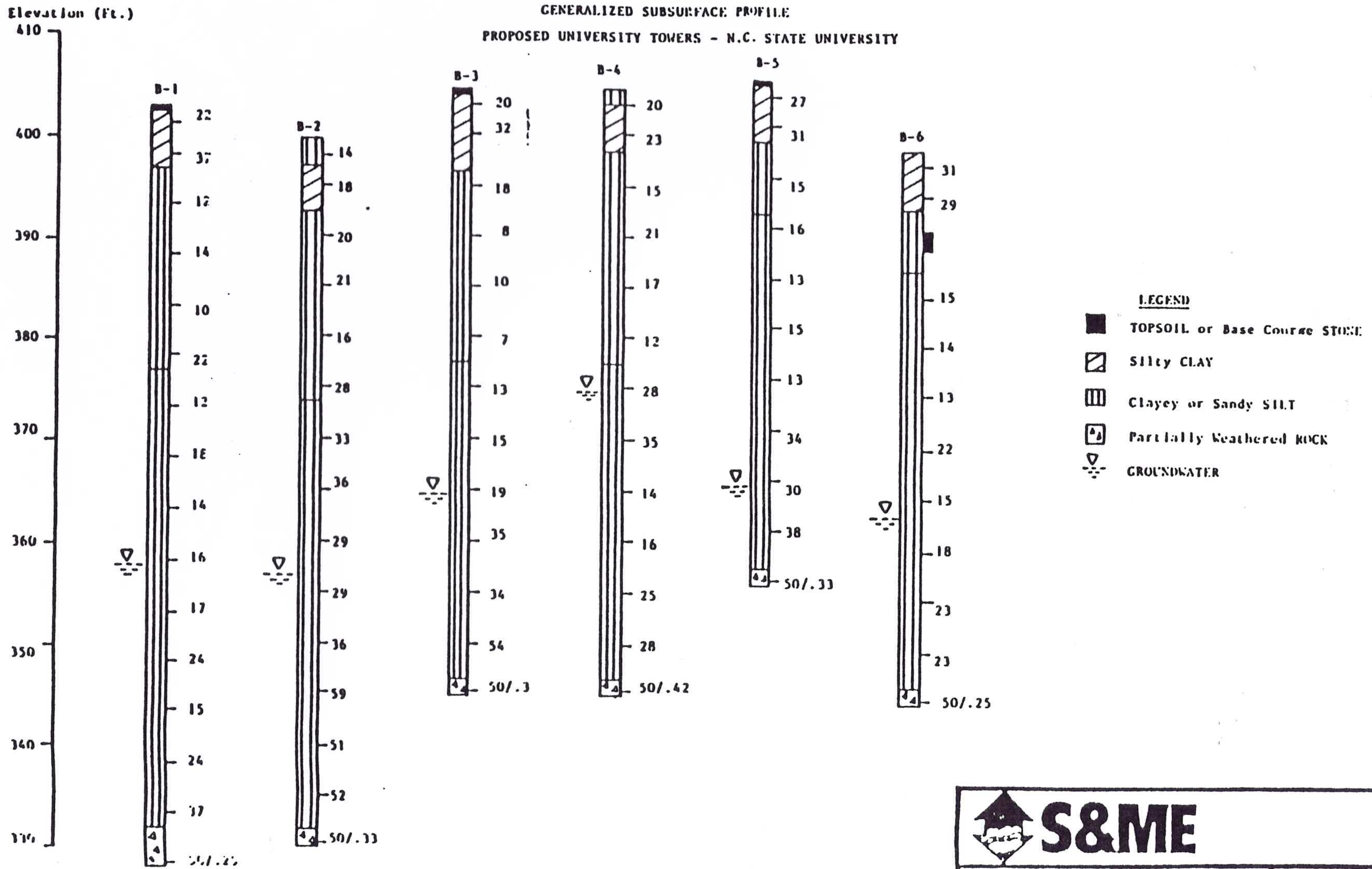
PROJECT: UNIVERSITY TOWERS, RALEIGH, NC

GENERAL CONTRACTOR:
METRIC CONSTRUCTORS, INC., CARY, NC

March 1988

GENERALIZED SUBSURFACE PROFILE

PROPOSED UNIVERSITY TOWERS - N.C. STATE UNIVERSITY



S&ME

N.C. State University Towers
Raleigh, North Carolina

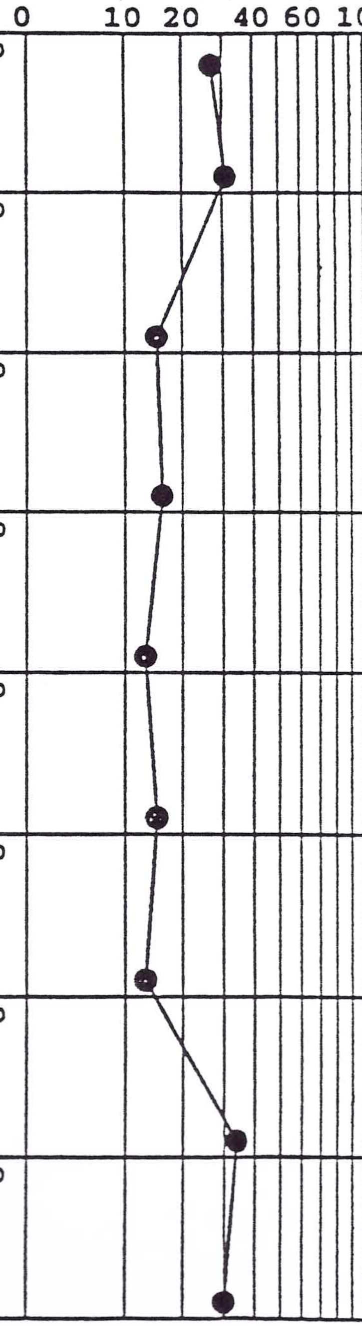
DRWN BY:	CHKD BY:
JOB NO:	DATE:
SCALE: NTS	SHEET OF

2

TEST BORING RECORD

DEPTH (FT.)	DESCRIPTION		ELEVATION (FT.)
0.0	TOPSOIL	CL	406.0
0.3	Very Stiff to Hard Red-Brown Silty CLAY		
			401.0
6.0	Stiff & Very Stiff Red-Brown Clayey SILT	ML	
			396.0
13.0	Stiff to Hard Tan Slightly Micaceous Fine Sandy SILT	ML	
			391.0
			386.0
			381.0
			376.0
			371.0
40.0			

PENETRATION (BLOWS/FT.)



BLOWS PER SIX IN.
12-13-14
10-14-17
7-6-9
6-7-9
4-6-7
6-7-8
5-5-8
10-14-20
11-12-18

REFER TO ATTACHED SHEET FOR EXPLANATIONS AND SYMBOLS

JOB NUMBER 051-87-288
BORING NUMBER B-5
DATE 06-03-87

S&ME

TEST BORING RECORD

DEPTH (FT.)	DESCRIPTION		ELEVATION (FT.)	PENETRATION (BLOWS/FT.) 0 10 20 40 60 100	BLOWS PER SIX IN.
40.0	Stiff to Hard Tan Slightly Micaceous Fine Sandy SILT	ML	366.0		9-18-20
			361.0		43-50/0.3"
48.0	Partially Weathered Rock				
50.0	Boring Terminated @ 50.0'		356.0		

REFER TO ATTACHED SHEET FOR EXPLANATIONS AND SYMBOLS

JOB NUMBER 051-87-288
BORING NUMBER B-5
DATE 06-03-87

S&ME

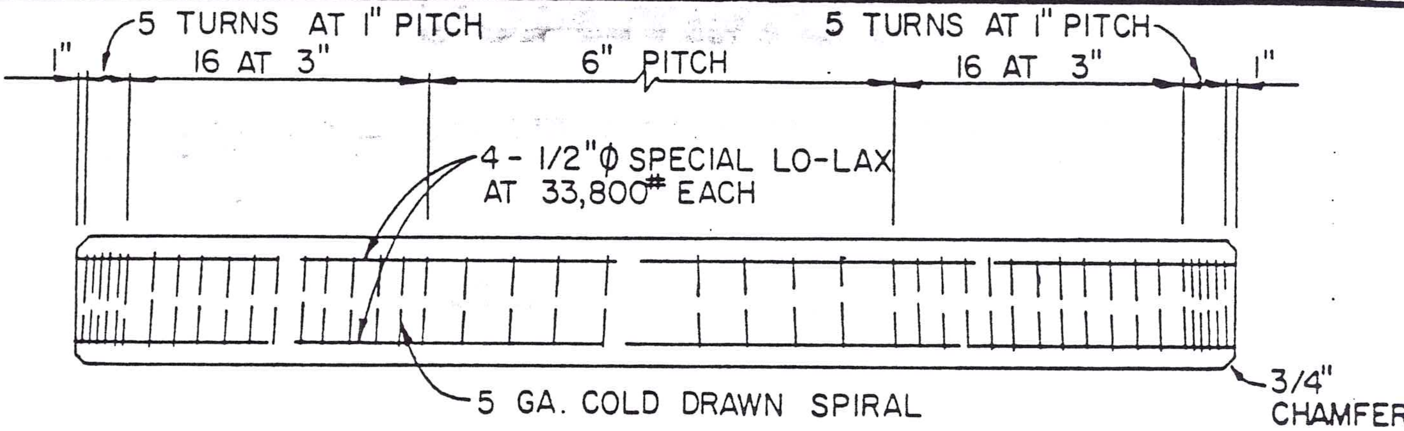
CONMACO

SINGLE-ACTING AIR/STEAM HAMMERS

MODEL 65E5

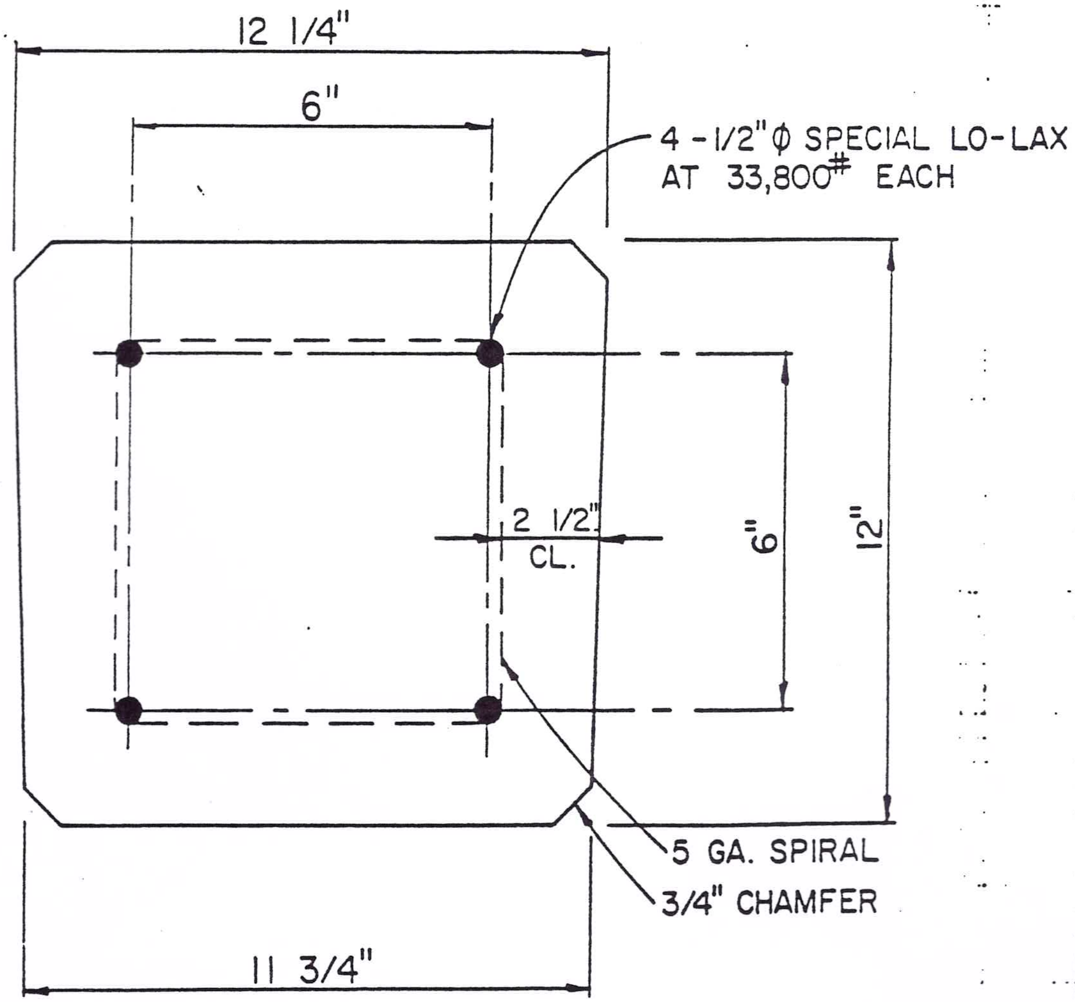
OPERATING DATA				
RATED STRIKING ENERGY - ft. lbs.	32,500	26,000	19,500	13,000
BLOWS PER MINUTE AT REFUSAL	50	52	60	70
NOMINAL STROKE LENGTH - ft.	5	4	3	2
OPERATING PRESSURE AT HAMMER - p.s.i.	95	95	95	95
STEAM CONSUMPTION @ 212 F. - lbs./hr.	2584	2067	1548	1033
ADIABATIC AIR CONSUMPTION - CFM	700	630	565	490
$\sqrt{EW}$ RATING @ENERGY RATING	14,534	13,000	11,258	9,192
DIMENSIONAL DATA				
DIAMETER BY PISTON - in.	13.5	13.5	13.5	13.5
NET AREA OF PISTON - sq. in.	143	143	143	143
LENGTH OF HAMMER - ft.,in.	16',10"	16',10"	16',10"	16',10"
DISTANCE BETWEEN JAWS - in.	20	20	20	20
WIDTH OF JAWS -in.	8.25	8.25	8.25	8.25
SIZE OF HOSE - in.	2.5	2.5	2	2
WEIGHT DATA				
WEIGHT OF STRIKING PARTS - lbs.	6500	6500	6500	6500
WEIGHT OF HAMMER - lbs.	12,500	12,500	12,500	12,500

DESIGN	CHECK		SHEET 1 OF 3
MCN		PRE-STRESS CONCRETE CO., INC. P.O. Box 32055, Charleston, South Carolina 29407 • Phone (803) 571-3460	
PROJECT 12" x 12" PRESTRESSED PILES FOR UNIVERSITY TOWERS			DATE 2-26-88



TYPICAL ELEVATION

f'c = 5000 psi
f'ci 3500 psi
MIX: G-7 TYPE I



TYPICAL SECTION

DFI/NCSU/ASCE Seminar – TEST PILE

PILE DRIVING RECORD

Job No. ____________ Pile Location ____________

Job Name & Location UNIVERSITY TOWERS, RALEIGH NC

Client METRIC CONSTRUCTORS Contractor ____________

GENERAL INFORMATION

Type of Hammer CONMACO 65

Hammer Weight ____________ lbs.

Hammer Energy Rating ____________ ft-lb.

Type of Pile 12"x12" Prestress Concrete

Design Load ____________ tons

Required Penetration ____________

Date Driven 3/4/88

Pile Length 54'

Butt Diam ____________ Tip Diam ____________

Cut-off Elevation ____________

Cut-off Lenght ____________

Cut-off to tip Length ____________

Out of Plumb. Allow. ____________ Act. ____________

Out of Align. Allow. ____________ Act. ____________

Heave or Settlement ____________

Driving Time: Start ____________ Fin. ____________

Splice ____________

Remarks

1. Cushion – 6 Pieces of 3/4" Plywood
2. DOT PDA monitors when tip is 25' to 34' deep.
3. Top cracked at 39'. 24" cut off & 4 piece of 3/4" Plywood added to cushion
4. Driving continued to 44.5' DOT PDA remounted for final 5 blows.

Inspector Don Johnson

Ft.	Blows	Ft	Blows	Ft.	Blows
1	↑	31	17	61	
2		32	17	62	
3		33	18	63	
4	D	34	17	64	
5	E	35	19	65	
6	R	36	17	66	
7	E	37	19	67	
8	G	38	18	68	
9	U	39	21	69	
10	A ↓	40	26	70	
11	8	41	29	71	
12	11	42	35	72	
13	12	43	30	73	
14	13	44	44	74	
15	14	~~45~~	4/1"	75	
16	13	~~46~~	5/1"	76	
17	14	~~47~~	6/1"	77	
18	14	~~48~~	5/1"	78	
19	12	49		79	
20	13	50		80	
21	12	51		81	
22	13	52		82	
23	14	53		83	
24	13	54		84	
25	14	55		85	
26	13	56		86	
27	13	57		87	
28	13	58		88	
29	16	59		89	
30	17	60		90	