49

Louisiana Highway Research

TENSION PILE STUDY

Louisiana Department of Highways – Research & Development Section

TENSION PILE STUDY

by

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TABLE OF CONTENTS

List of Figures iii

Synopsis iv

Introduction 1

Purpose and Scope. 1

Methodology 2

Description of Activities 7

Discussion of Results 12

Findings and Conclusions 13

Appendix. 19

LIST OF FIGURES

Figure No.		Page
1	Design Drawing	3
2	Load Transfer Device, Pressure Cell, and Hydraulic Jack	4
3	Sketch of First Measuring Device	5
4	Level Used for Measuring Pile Movement	6
5	View of Level and Scales Glued to Piles	6
6	Logs of Borings Drill at Test Site	8
7	Bridge Maintenance Crew Cutting Test Pile	9
8	Grouted Test Pile.	9
9	I-Beam on Top of the Piles.	10
10	View of Bent Top Plate after Pressure was Released	14
11	Picture Illustrating Bent Bottom Plate.	14
12	Sketch of Test Pile with Description of Events.	15
13	Views of Cracks in Test Pile.	16 & 17
14	Failure of Tension Strands	17

SYNOPSIS

This report contains the results of a short term study of a pile in tension loads. The piles tested were driven on Louisiana Department of Highways' property in response to preceding research work entitled "Stability of Slender Prestressed Concrete Piling" by Professor H. Turner of Louisiana State University. When a depress raodway was to be built in the city of New Orleans where the water table is at or near the surface, the idea of "tension piles" was conceived. Piles were to be used to hold down the roadway - to counteract the hydrostatic uplift. But little information was available on the subject of tension piles, the idea was discarded. Since the piles, driven for the previous study, were available on the Department's property, it was decided to place one in tension just to see what would happen.

Four piles were driven; three were used in the study. Two were reaction piles, and one was the test pile. The test pile was placed in a tension load of 40 tons for a period of six months. Forty tons were approximately one fourth of the total bearing load computed from the pile driving formula. There was no movement.

At the completion of the six months the pile was loaded to failure in tension. Failure predictably occurred at approximately 98 tons. Four cracks appeared in the member at 89 tons, 90 tons, 97 tons, and 98 tons. Five of the eight prestressed cables used to place the pile in tension broke. Just prior to this, there appeared to be 0.17 inches of movement upward, but when the load was removed the pile returned to its original elevation and the cracks closed.

It is concluded that piles driven in stiff to very stiff clays and allowed to remain unloaded for several months will react favorably in tension.

TENSION PILE STUDY
FINAL REPORT

Introduction

The following is a final report of a research project completed in cooperation with the Federal Highway Administration, United States Department of Transportation and represents fulfillment of project contract number 68-4St(B). Permission to proceed with the work was received on October 1, 1968, however actual work did not begin until February after all equipment had been received and prepared for use. The study was for a period of 18 months from the approval date. The events of this project caused the investigators to change methodology on several occasions and, as a result, this will be a chronologic report of those events and findings obtained therefrom.

Purposes and Scope

As the name implies, this project was conceived to study the effect of long term tension applied to pile in Louisiana. After completion of this long term tension phase, the investigators were to endeavor to fail the pile or bring it to the limit of the stress capability within the scope of the project. The following section, methodology, will define that limit. The study was not meant to be an academically sophisticated one, but merely a short practical, and hopefully, useful investigation into the possible future use of tension piling in Louisiana.

The effects of hydraulic uplift were to be investigated along with tension dynamics. Several witness holes were drilled in an attempt to keep up with water table fluctuations, but the clay material which comprise most of the foundation soils slaked so badly that an open hole was difficult to maintain even cased. Luckily water table fluctuations created no measurable effects as will be shown.

The Department had driven four 70 foot by 12 inch square, prestressed, concrete piles to a depth of 65 feet 6 inches (±) in its back yard as a final requirement of a former research project entitled "Stability of Slender Prestressed Concrete Piling." Sinces there were so readily available and since the question of whether to hold down a depressed expressway through the City of New Orleans had been resolved to a means other than piles because there was no data available on the long term reaction of piling under tension, it was decided to do inexpensive, exploratory study into the problem. *

Methodology

The problem divided itself into parts: 1) Placement of a pile in tension and 2) Measurement of any displacement or elevation changes. Figure 1 is a diagram of the loading device and piles. A large hydraulic jack would furnish the upward force when jacked against a wide flanged I-beam supported at each end by two of the remaining piles. The detail at Section A-A describes all of the hardware used in fabricating the loading device with the exception of the measuring system.

The measuring system was somewhat more difficult to conceive. It was decided to use a pressure cell between the jack and the upper plate with the idea that any movement, no matter how slight, could be detected as a release of pressure on the cell. Figure 2 shows the entire system as originally built. In order to measure the movement of any of the three piles, a piano wire was strung across all three and attached to two short posts that had been driven into the ground. The post at each end of the I-beam were outside the influence of any active soil pressure created by the reaction piles. The wire was just touching or very close to three plastic, six inch scales glued to the piles at the three inch mark in each case so that any pile movement could be measured. Figure 3 illustrates this measuring system.

However, this proved unsatisfactory for reasons to be discussed later. A new measuring system was devised for the "failure phase" of the study. The pressure cell was removed not only because it proved unsatisfactory as previously stated but because it had an 80,000 pound capacity which was the "long term" tension load. To measure movement only, a small angle iron was securely fastened to the fourth pile. It served as an immovable platform upon which was placed a standard dumpy level used for surveying ground elevations (see Figure 4). Match marks were placed on both the level's base and on the angle iron platform so that the instrument could be removed when not in use and replaced in exactly the same additude for the next measurement. Again three, six inch scales were glued to each pile and zeroed at the three inch mark with the instrument's horizontal

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* For those interested: 1) The water table in New Orleans is at ground level so that a depressed roadway with concrete sidewalls would float, 2) the method decided upon to keep flotation from occurring was to add enough concrete to hold it down, and 3) the whole idea was abandoned because public opinion was that such an expressway would ruin the image of the French Quarters around which through traffic was to be diverted.

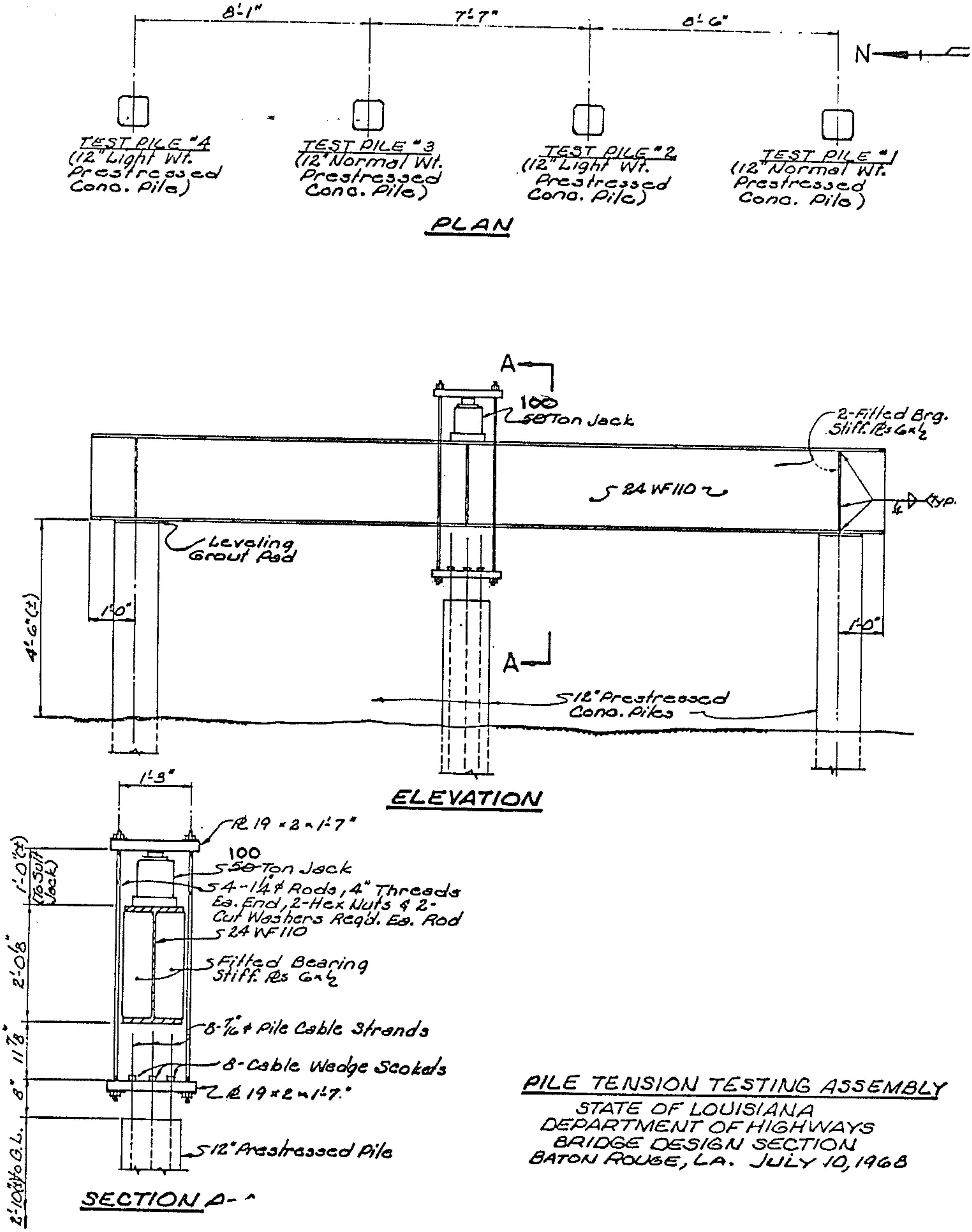


Figure 1 - Design drawing

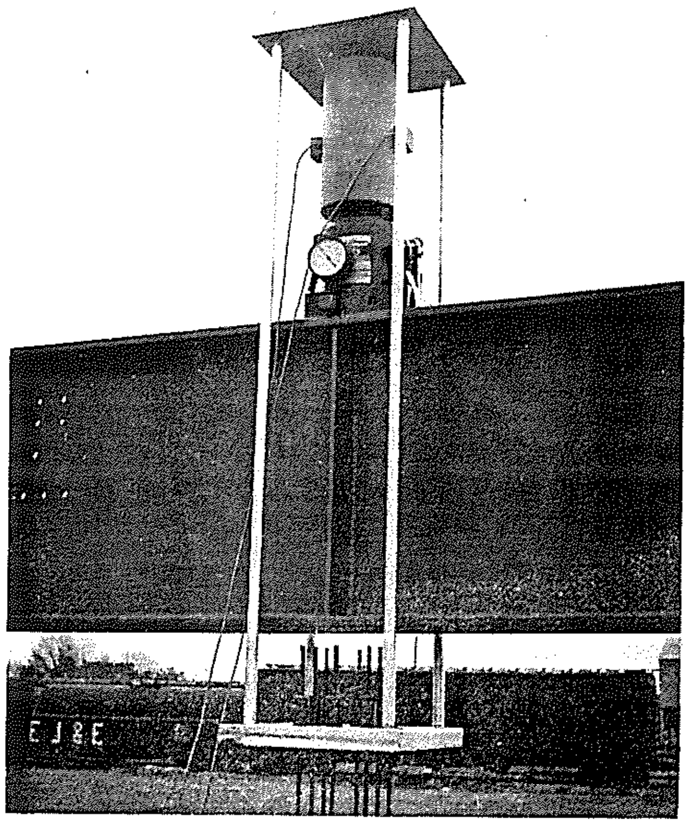


Figure 2

Load transfer device, pressure cell, and hydrolic jack

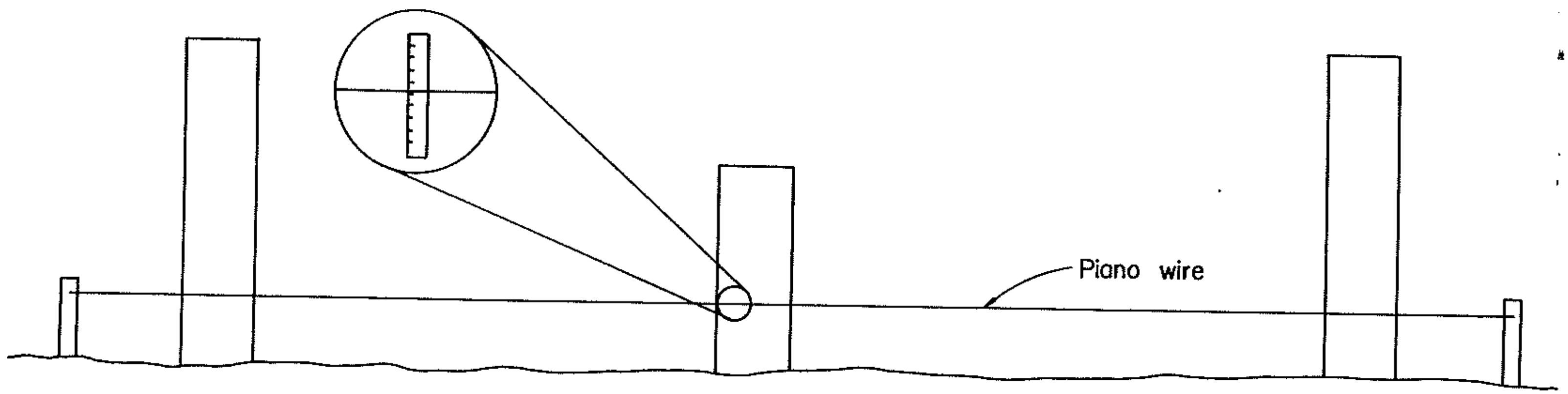


Figure 3 - Sketch of first measuring device

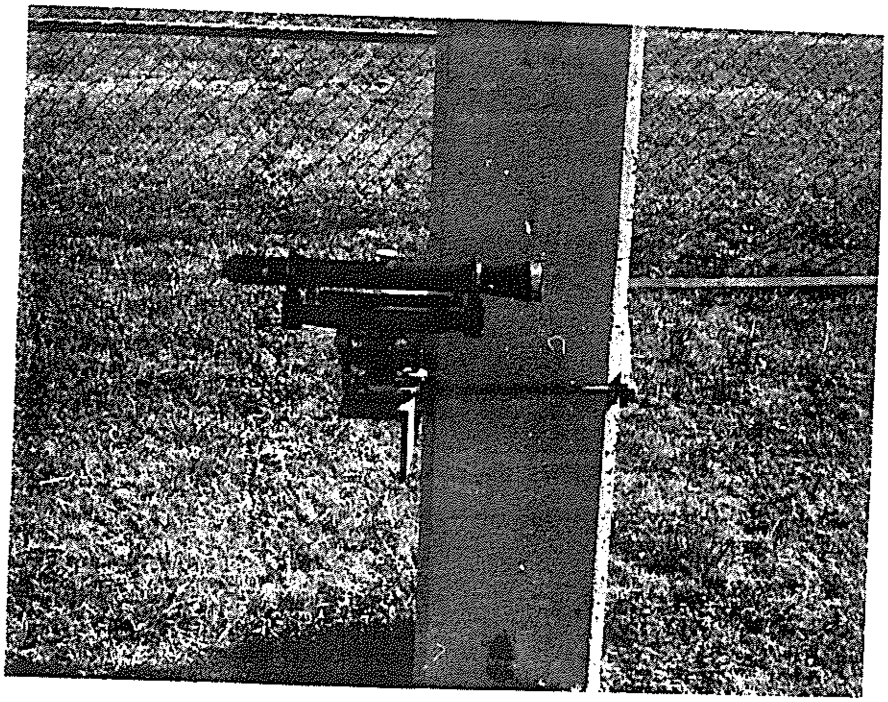
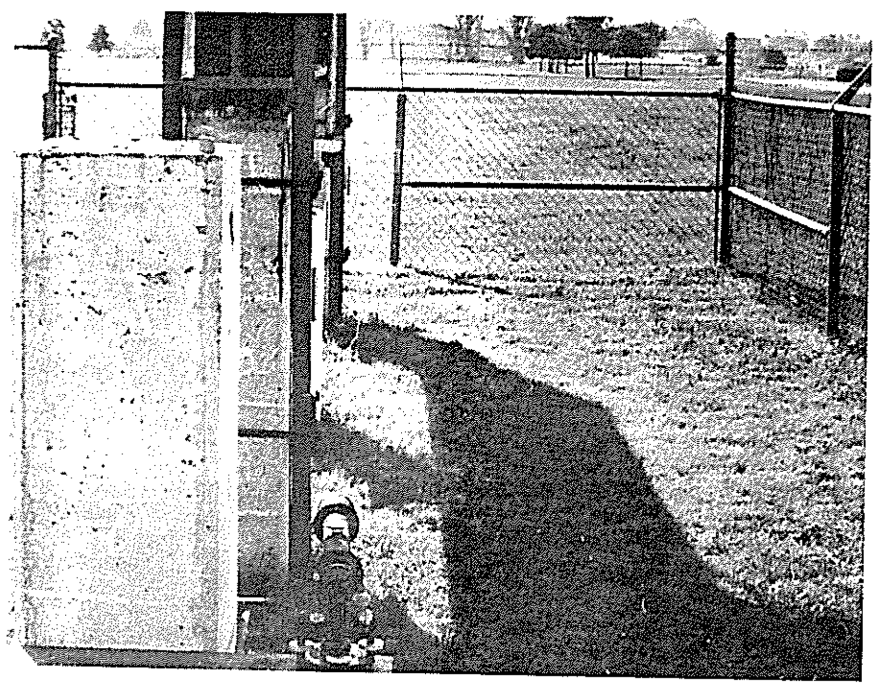


Figure 4

Level used for measuring pile movement

Figure 5

View of level and scales glued to test piles (note the reference scale on the fence post)



cross-hair, Figure 5. A fourth reference scale was glued to a nearby fence post, also zeroed at the three inch mark, to detect any movement of the angle iron platform between readings. This system proved very satisfactory both from the standpoint of convenience and accuracy.

Description of Activities

Realizing that the preceding section of this report can be construed as a "Description of Activities" as well as a methodology, the reasons of these activities and occurrences will be presented here and several others will also be described. At this juncture, the report must take on a chronologic aspect in order to maintain some semblance of organization.

Activities Prior to Project Approval

It should be recalled that this project was preceded by a study of slender prestressed concrete piles which furnished the main ingredient for this work, the piles. The predecessor also furnished pile driving data and foundation information from which initial tension loads were completed. Figure 6 presents the foundation information determined from undisturbed, shelly tube samples by the Department's Materials Laboratory. The hole locations are given at the bottom of each boring log. The extremely variable soils in the foundation can be recognized, nevertheless using the static formula, it was determined that the pile could be capable of sustaining 160 tons in compression. Originally the initial tension load was to be 50 tons or 5/16 of the maximum compression load just for a starting point. However, the pressure cell described in the preceding section restricted the initial load to 40 tons of uplift or 1/4 of the maximum.

The load transfer device shown in Figure 1 was designed by the Bridge Design Section of the Highway Department in July of 1968. It was planned to use a I-beam and the necessary steel for the device that was probably on hand. An I-beam suitable for use was on hand but the steel was not. As it turned out, the I-beam was a 33WF141 instead of the 24WF110 call for on the drawings.

The Construction Phase

The project was approved for initiation on October 1, 1968, and was to last 18 months. The jack was ordered along with the steel. Shortly thereafter a pile was cut off (see Figure 7) and the I-beam placed on top of the reaction piles. The top of these reaction piles were grouted to the same elevation with "Por-Rock," a "quick set" grout, which held up well throughout the entire loading schedule (see Figure 8). Placement of the I-beam was accomplished the same day and the welding of stiffiners and braces was accomplished on the site the next. Figure 9 shows the I-beam in place ready for the loading device.

Fabrication of the loading device was completed with little problem. The most difficult problem was the positioning of the eight holes in the bottom plate

TEST PILE N°	
TYPE OF PILE:	
TYPE OF HAMMER:	
ENERGY PER BLOW:	FT.LBS
DATE OF DRIVING:	
DATE OF LOADING:	
DESIGN LOAD:	TONS

CLASSIFICATION

SOIL TYPE & COLOR	qu	CONSISTENCY	MOISTURE CONTENT	LIQUID LIMIT	PLASTICITY INDEX	SAMPLE NUMBER	ASSUMED GROUND ELEVATION 0	STA.
BROWN SILTY CLAY LOAM		VERY STIFF	13	29	N=30 7	MC 1		
BR. & GR. SILTY CLAY LOAM & BR. & GR. SILTY CLAY		HARD	22	30	N=34 11	MC 2	-5	
GR. & BR. SILTY CLAY	2.44	VERY STIFF	21	33	16	C 3	-10	
BR. & GR. SILTY SANDY CLAY	4.31	HARD	19	44	27	C 5	-15	
GR. & BR. SILTY CLAY	1.75 S/S	STIFF	29	109	79	C 6		
GR. & BR. SILTY CLAY-TR. IRON ORE	1.40 S/S	STIFF	32	88	56	C 7	-20	
GR. & BR. SILTY CLAY	1.52 S/S	STIFF	33	90	62	C 8	-25	
BR. & GR. SANDY CLAY-LENSES SANDY LOAM	0.92	MED.	27	35	16	C 9		
GR. & BR. SILTY CLAY	0.92	MED.	29	40	20	C 10	-30	
GR. & BR. SILTY CLAY TR. IRON ORE	1.67	STIFF	34	80	53	C 11		
GR. & BR. SILTY CLAY	1.99	STIFF	30	106	79	C 13	-35 -40 -45	
GR. & BR. SILTY CLAY-LENSES GR. SANDY CLAY	2.68	VERY STIFF	26	68	49	C 16		
GR. & BR. SILTY SANDY CLAY	2.48	VERY STIFF	25	54	35	C 17	-50	
GR. & BR. SILTY CLAY	1.70	STIFF	29	57	38	C 18		
GR. & BR. SILTY SANDY CLAY	1.52	STIFF	29	52	33	C 19	-55	
BR. & GR. SANDY CL. & SD. CL. LM.	0.63	MED.	28	33	14	C20		
BR. SANDY CLAY LOAM	0.52	MED.	30	28	9	C 21	-60	
BR. SANDY CLAY & SANDY CLAY LOAM	0.81	MED.	28	30	8	C 22		
BR. SANDY LOAM-FINE & MED. SAND		MED.	23	N.	P.	C 23	-65	
BL. GR. SILTY CLAY	2.31	VERY STIFF	33	76	51	C 24		
BR. GR. SILTY CL.-TR. CONC. & SHELL	1.70	STIFF	41	94	70	C25	-70	
BL. GR. SILTY CLAY-TR. CONCRETIONS	1.90	STIFF	35	82	54	C26		
BL. GR. & BR. SILTY CLAY-CONCRETIONS	2.58 S/S	VERY STIFF	38	120	89	C 28	-75 -80	
							-85	

BORING N° 1 STA:
DATE MADE OCT. 27, 1967 LOCATION: 9' EAST OF PILE N° 1

DRIVING RESISTANCE
TONS

CLASSIFICATION

SOIL TYPE & COLOR	qu	CONSISTENCY	MOISTURE CONTENT	LIQUID LIMIT	PLASTICITY INDEX	SAMPLE NUMBER	ASSUMED GROUND ELEVATION 0	STA.
BR. & GR. SILTY LOAM		VERY STIFF	19	27	N=19 5	MC 30		
BR. & GR. SILTY SANDY CLAY-IRON ORE	1.10	STIFF	25	31	13	C 31	-5	
GR. & BR. SILTY CLAY-IRON ORE	0.99	MED.	24	26	4	C 32	WATER @ 9.6'	
GR. & BR. SILTY SANDY CLAY	1.00	MED.	23	47	33	C 33		
GR. & BR. SILTY SANDY CLAY	2.04	VERY STIFF	20	49	36	C 34	-15	
GR. & BR. SILTY SANDY CLAY	1.36 S/S	STIFF	29	69	44	C 35		
GR. & BR. SILTY CLAY	2.15	VERY STIFF	30	78	54	C 37	-20 -25	
GR. & BR. SILTY CLAY	1.98	STIFF	28	50	35	C39		
BR. & GR. SILTY CLAY	0.42	SOFT	32	41	22	C40	-30	
GR. & BR. SILTY CLAY	2.11	VERY STIFF	31	79	53	C 41		
BR. & GR. SILTY CLAY-LENSES SANDY CL. LOAM	0.81	MED.	29	44	26	C42	-35	
GR. & BR. SILTY CLAY	2.20	VERY STIFF	33	88	62	C 43	-40	
GR. & BR. SILTY SANDY CLAY	2.30	VERY STIFF	23	45	31	C 45	-45	
GR. & BR. SILTY CLAY	3.18	VERY STIFF	25	65	44	C 46		
GR. & BR. SILTY SANDY CLAY	2.27	VERY STIFF	25	45	26	C 47	-50	
BR. & GR. SILTY CLAY	2.10	VERY STIFF	29	54	36	C 48		
BR. SANDY LOAM & FINE SAND		MED.	28	N.	P.	C 49	-55	
BR. & GR. SILTY SANDY CLAY-LENSES SANDY LOAM	0.83	MED.	27	34	15	C 50	-60	
BR. SILTY SANDY CLAY-LENSES BR. SANDY LOAM & SAND	0.48	SOFT	29	29	7	C 51		
BR. SANDY LOAM		MED.	27	N.	P.	C52	-65	
BR. FINE & MED. SILTY SAND		DENSE	24	N.	N=42 P.	C 53		
BL. GR. SILTY CLAY-TR. SHELL	1.40	STIFF	58	84	53	C 54	-70	
BL. GR. & BR. SILTY CLAY-CONCRETIONS	2.52 S/S	VERY STIFF	35	106	78	C 56	-75 -80	

BORING N° 2 STA:
DATE MADE: OCT. 27, 1967 LOCATION: 8' EAST OF PILE N° 4

Figure 6

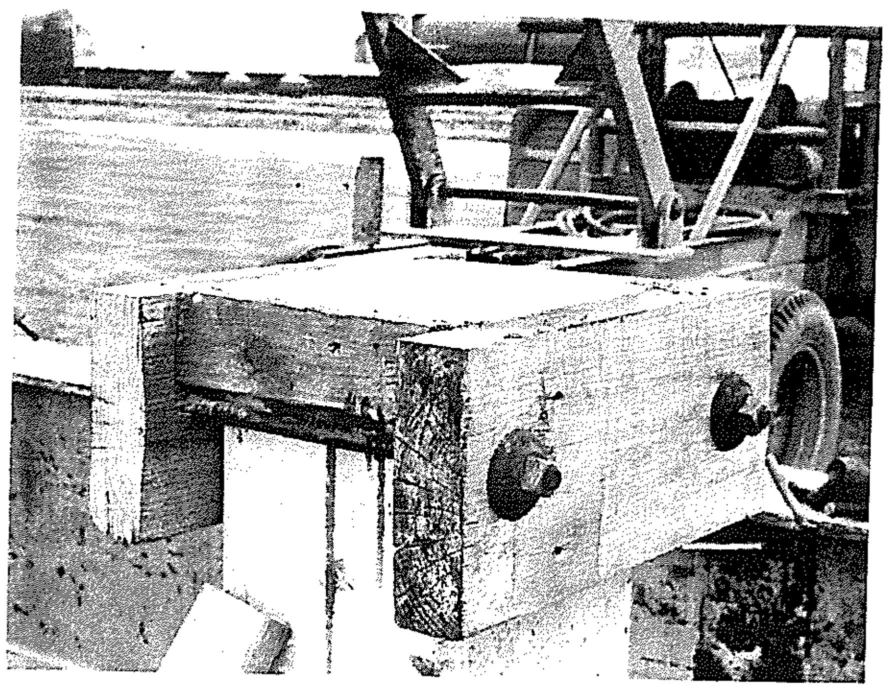
Log of boring drilled at test site

Figure 7

Bridge Maintenance crew cutting test pile

Figure 8

Grouted reaction pile



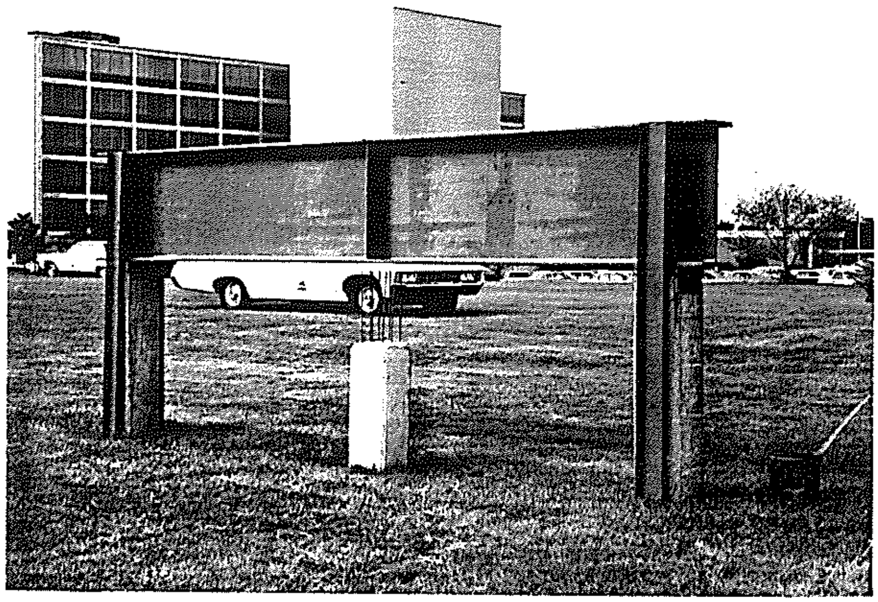


Figure 9

I-beam atop the piles

through which the tension strands were to be threaded and clamped. Obviously, each strand had to pass through the plate perpendicularly, otherwise undue stress at the flexure point would occur during loading. However, the hole positioning was accomplished rather simply. A piece of brown wrapping paper was impaled on the strands, removed and used as a guide to make a plywood templet. The plywood, 1/2 inch thick, was cut to the exact size of the plates, 19 inches square, and marked with the paper guide. One half inch diameter holes were drilled at each mark. This was then clamped to the 2" steel plate and the holes were drilled through the wooden templet. It worked without mishap.

Next the first elevation reading device described in the preceding section was installed. (See Figure 3) As a precaution, against vandalism or accident, level elevations were shot to each pile, so that pile movement could be determined should the wire be broken or damaged.

Both the jack and the pressure cell were calibrated at the Department's Materials Laboratory and set in place. As a matter of interest the pressure cell was borrowed from the Department of Civil Engineering, Louisiana State University. The pressure cell is read with a strain gauge indicator and a calibration curve of known loads.

"Long Term Load" Phase

Early in February a 40 ton tension load was applied to the system. Daily readings were made of 1)gauge on the jack, 2) pressure cell and 3) the wire stretched across the three six inch scales glued on the piling. This continued until August 1969. The readings on all these devices varied as can be seen in the table in the appendix. For this reason and the fact that it was the intention to increase the load to full jack capacity (100 tons, which was beyond the pressure cell capacity of 50 tons) or to failure, the load cell was removed. To verify the suspicion that the jack was losing pressure, it was replaced into the system and brought to 40 tons. During the months of September and October observations indicated that the jack was losing approximately 2,000 pounds per day.

Early in November the jack was removed for repairs. While this was being accomplished the new measuring system described earlier was installed. During mowing operations the wire system had been broken despite all the cautioning given to the yard maintenance crew. To determine whether there had been any movement since August, elevation shots were again made to the piles. For all intents and purposes none of the piles showed any elevation change. The center pile reading showed a variation of 0.01 feet upward which is explained as instrument operator's error, particularly in light of further findings to be discussed later.

By the middle of December 1969 the new measuring system was complete, the jack was back in place, and the original 40-ton load was set. Despite repairs, the jack did not seem to be able to hold the load, but it was decided to continue to failure or jack capacity anyway.

During the month of January the load was increased by 10 ton increments each week. Readings with the Dumpy Level and the scales were taken periodically. Slight movements were observed. By February 2, 1970, five of the eight tension cables on the center pile had failed and the project was terminated.

Discussion of Results

The previously mentioned table in the appendix presents an example of the data recorded during the long term phase of the study. It can be seen that the variations in the readings are extensive, and these variations render the data uninterpretable. Most of the pressure drop is explained by the inability of the 100 ton jack to hold the load. However, some of this drop may be attributed to the load cell and strain gage indicator. Several entries show a decrease in cell pressure without a corresponding decrease in jack gage pressure. The variation in Pile Elevation Readings from the wire can only be explained by a combination of temperature changes which might have caused wire tension variation and parallax. Loosening of the wire may have also occurred during the mowing since it was completely broken at one point.

The variations notwithstanding, if there was any movement of the piles at all during the six months while the 40 ton load was imposed it can be neglected. This is indicated by the fact that the elevation readings made with a surveyor's level were the same after the test period as they were before.

With the load removed, the jack in a state of semi repair, and the new measuring system in operation (see Figure 4) the short term or failure phase of the study was begun.

Nothing of significance occurred until a load of 70 tons was reached. At this point the center pile seem to be lifted 0.02 inches and the outside piles were apparently depressed 0.01 inches. Four days later the test pile reading was 2.95 inches or 0.05 inches higher that the original 3.00 inches set as zero. The two reaction piles remained at 3.01 and 0.01 inches lower then the original. Since there seemed to be some apparent movement, the 70-ton load was allowed to remain for a period of two weeks. At the end of the two weeks no further movement had occurred.

An 80-ton load was then imposed and the center pile displayed a reading of 2.93 inches while the outside reaction piles were seemingly depressed another 0.01 inches to a reading of 3.02 where they remained throughout the rest of the test. Daily readings were made at this load for a period of one week. No further change was observed. It should be mentioned that before each reading the height of the instrument was checked by means of the scale glued to a nearby fence post and each time the instrument was exactly on its mark.

Since there was no change over a week's time, the 90-ton load was imposed. At approximately 89 tons a crack developed in the test pile approximately 6 inches from the top. It occurred with a dull thump. Again at 90 tons a similiar report was heard and a second crack appeared at about 1 1/2 feet from the top. The elevation reading of the center pile was now 2.89 inches or 0.11 inch higher than originally. It was at this point that both the top and bottom plates of the loading transfer device showed flexure. The top plate seemed to deform symmetrically about the center (see Figure 10) whereas the bottom plate was noticably bent on one corner (Figure 11). Two days later the reading on the pile had increased to 2.88. Nevertheless it was decided to increase the load.

At 97 tons two failures occurred. The first was a third crack in the pile 2 feet 2 inches from the top. Shortly thereafter two of the strands in the tension cable at the corner mention above failed (Figure 11). At this point the increase in pressure was stopped. The pile elevation at this time read 2.83 inches or 0.17 inches above normal.

Two days later, again it was decided to increase the pressure. At 98 tons a fourth crack developed two feet six inches from the top and four more tension cables failed bringing the total to five of the eight. The cable failure caused a relaxation of the tension and consequent decrease in pile elevation. Since five of the cables failed, the jack was released. With this release, all the piles returned to their normal elevation of 3.00 inches. Thus it would appear that all movement is attributed to structural deformation.

Figure 12 is a diagrammatic sketch of the occurrence at the center pile. Figure 13 shows photographs of the cracks described above and Figure 14 depicts the broken tension cables.

Findings and Conclusions

The findings are as follows:

1. Based on long term test of 40 tons, no deformation was observed. The records indicate that decrease in load was observed daily, however; it is believed that the load cell and jack was losing this observed reduction.

2. Using the static formula it was computed that the pile would be capable of sustaining 160 tons as a bearing pile.

3. When the load was increased from 50 to 90 tons all the deformations observed were from the structural elements of the strands and concrete pile. The deformation of 0.12 inches observed can be computed to be the deformation received from stressing the 8 7/16 strands to 195,000 pounds over the length of 50 inches.

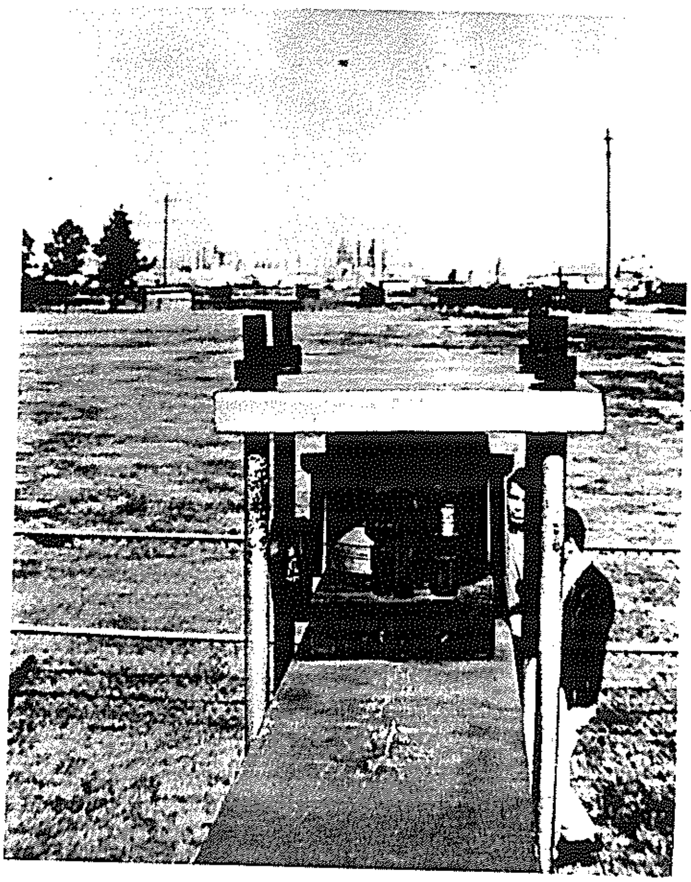


Figure 10

View of bent top plate after pressure was released

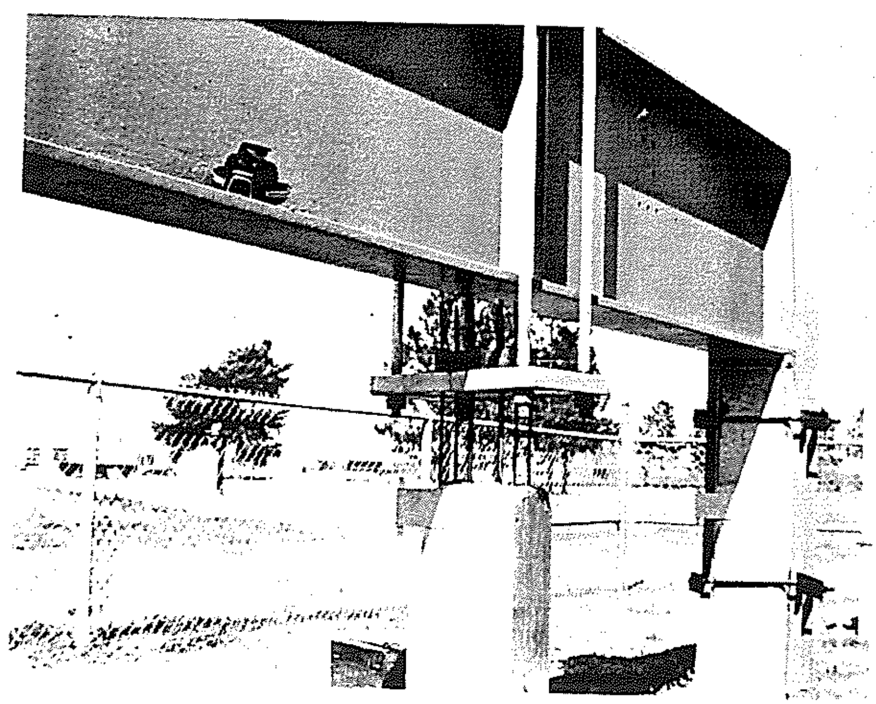


Figure 11

Picture illustrating bending in bottom plate

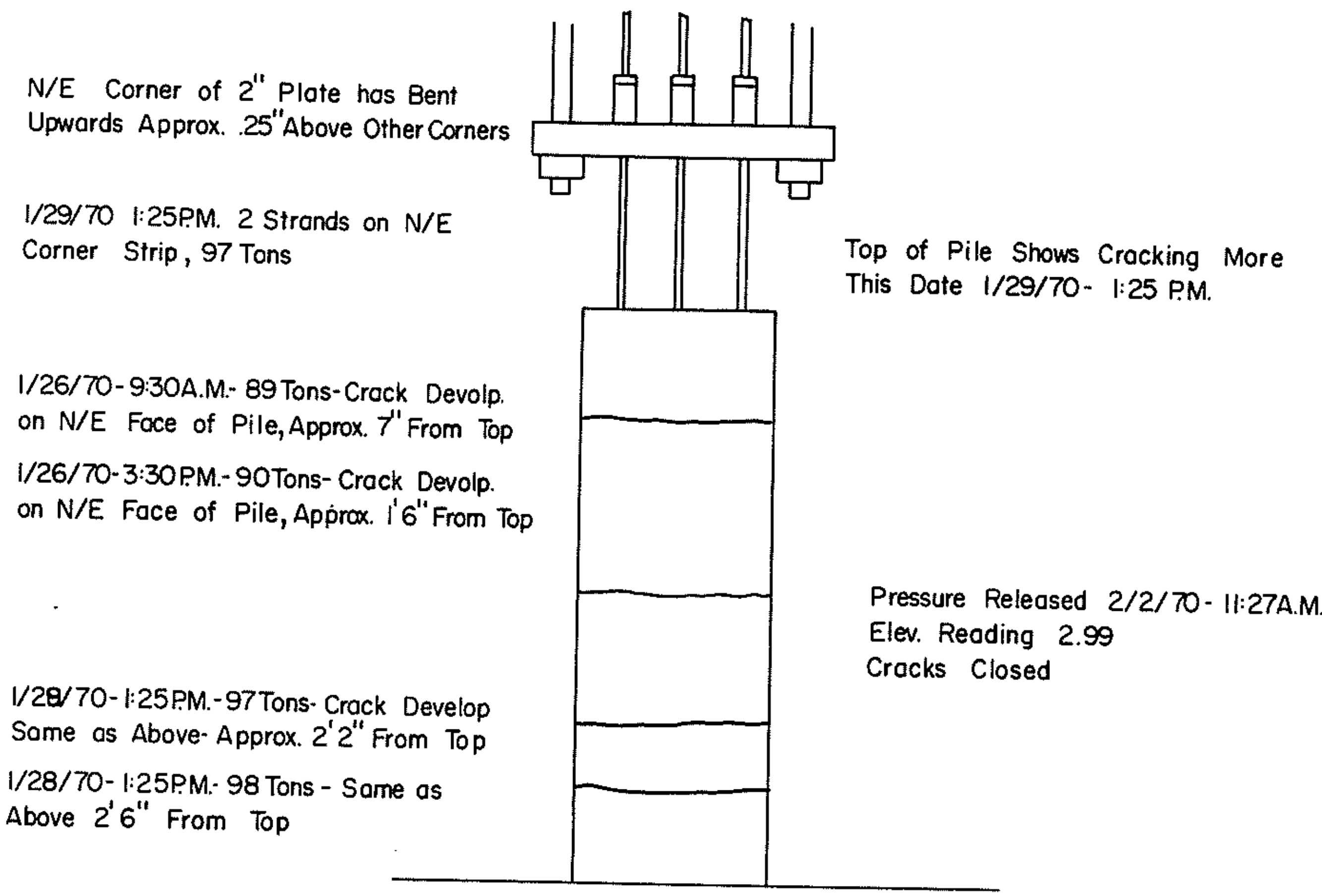


Figure 12

Sketch of the test pile with description of events

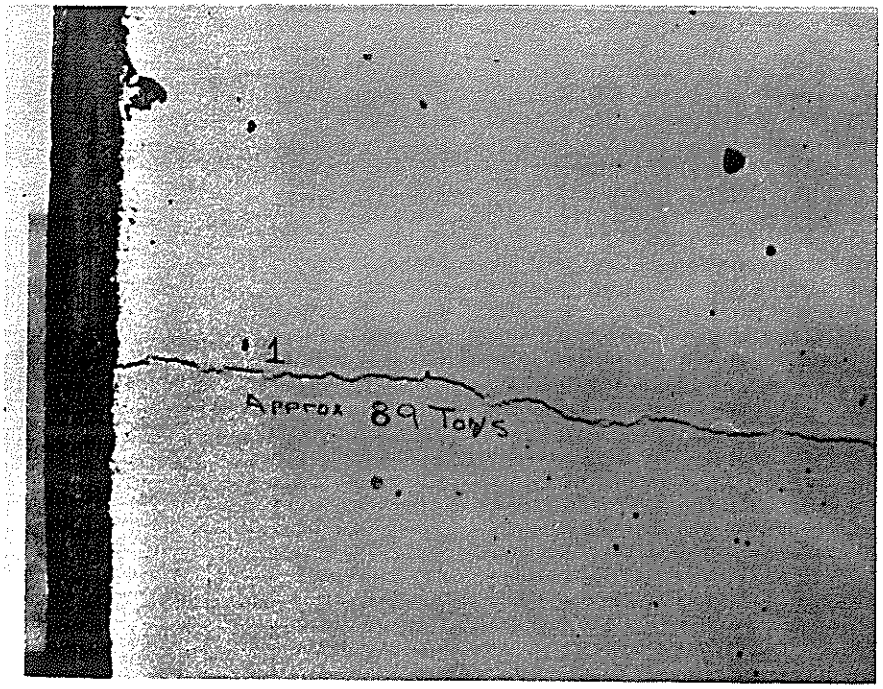
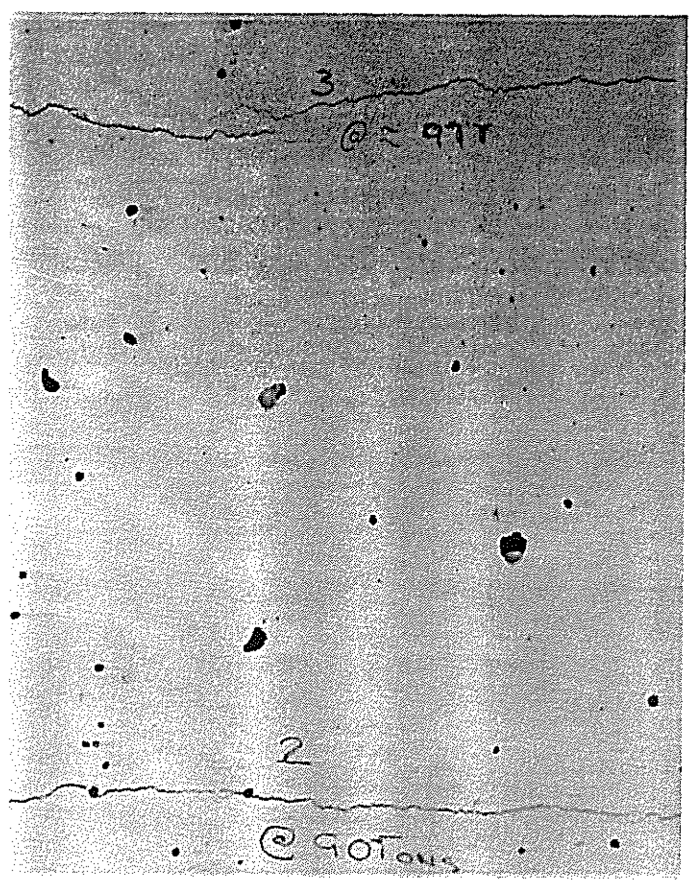


Figure 13 A

View of cracks in test pile

Figure 13 B



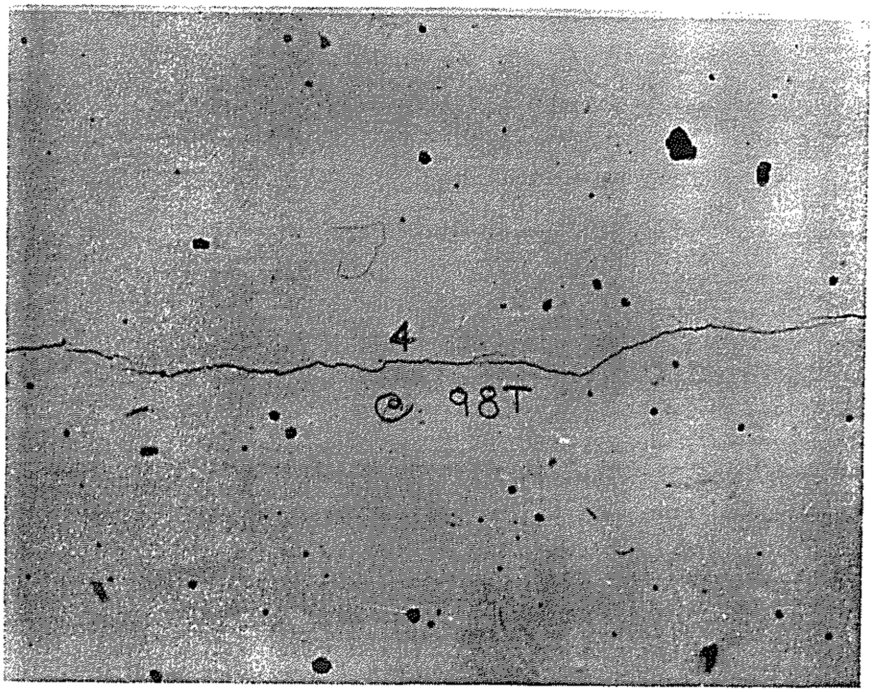


Figure 13 C

Crack developed at 98 tons

Figure 14

Failure of tension strands

Conclusions

It would appear that piles driven in stiff clays and allowed to remain in place for some months unloaded will react favorably in tension loads. However, much more work is necessary before piles can be used as tension members in structures.

APPENDIX

DATE	PRESSURE CELL READING (micro-in/in)	LOAD (lbs.)	JACK GAGE READ.	RELATIVE PILE ELEV. READING left	center	right	DEPTH TO WATER TABLE	WATER TABLE ELEV.	RIVER ELEV.	INITIAL	REMARKS
3/19/69	9550	8250	83500								Wire found loose Reset wire
3/19/69	9600	85000	84000	2 31/32	2 15/16	3 1/32	5'11"				Increased to 84000
3/20/69	9500	81200	84000	3"	2 15/16	3 1/32	5'4½"				
3/20/69	9600	85000	88000								Increased to 85000
3/21/69	9560	83500	88000	2 31/32	2 15/16	3 1/16	7'-1"				did not increase
3/21/69	"	"	"	"	"	"	"				
3/24/69	9470	80,500	80000	3	2 15/16	3 1/16	1'-11"				
"	"	"	"	"	"	"	"				
3/25/69	9325	75000	80,000	3	2 15/16	3 1/16	2'-6"				
3/26/69	9310	74,000	79,000	3 1/32	2 15/16	3 1/16	3'-11				Increased to 9425
3/26/69	9425	78,000	84,000	"	"	"	"				
3/27/69	9435	79,000	83,500	3	2 15/16	3 1/16	4'-7"				
"	"	"	"	"	"	"	"				
4/1/69	9265	72,500	76,000	3"	2 15/16	3"	6'-8½"				Increased to 9500
4/1/69	9500	81,200	85,000								
4/2/69	9430	75,500	84,000	3"	2 15/16	3"	6'-10"				No increase