A REPORT

ON

STRESSES IN LONG PRESTRESSED CONCRETE PILES DURING DRIVING

By

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Prepared for the Bridge Division
of the
Texas Highway Department
Research Project RP-27

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II. INTRODUCTION

For several decades engineers have been seeking a method of analyzing the stresses produced in piles by the impact of the driving hammer. In August, 1960, Mr. Edward A. Smith* published a numerical method of solving this problem in the ASCE Soil Mechanics and Foundations Journal (7)**. Prior to this mathematical development, engineers had to rely strictly on past experience and judgment in designing piles and in evaluating the effect of various types of driving equipment on these piles. Since Smith's solution involves rather extensive mathematical computations, it is necessary for practical purposes to use high-speed electronic computers to perform the calculations. It has been estimated that a single engineer using an ordinary desk calculator would have to work for about eight months to solve only one simple problem of this type.

During the year 1960-61, engineers of the Texas Highway Department Bridge Division engaged the staff personnel at Texas A. & M. College to develop a computer program to accomplish the rigorous mathematical calculations for this pile stress analysis. With the aid of Mr. Edward A. Smith as a special consultant, a functioning computer program was developed and used successfully on several pile problems (4). This program for the IBM 709 Computer at the A. & M. College Data Processing Center

*Formerly Chief Mechanical Engineer for Raymond International.

**Numbers thus (7) refer to corresponding references in the Selected Bibliography.

now accomplishes in about one minute what would have required about eight months of manual computations by a single engineer. The computer solution to this complex problem now makes it practical to investigate theoretically the behavior of various type piles when driven by different equipment under different foundation conditions.

In order to properly use this theoretical solution, it was considered necessary to conduct field tests to obtain actual stress and displacement data to correlate with the theory. During this 1961-62 year, Research Project RP-27 was initiated to conduct such a field study of the internal stresses in prestressed concrete piles used on the Nueces Bay Causeway at Corpus Christi, Texas. This particular site was selected because the pile type, driving equipment, and foundation conditions were very similar to those used on the Lavaca Bay Causeway where considerable pile breakage was experienced.

IV. FIELD TESTS

General

To accomplish the objectives of this project, some rather unusual strain-gage techniques were required, since it was necessary that the tests be performed under field construction conditions in a manner such that the contractor would not be unduly delayed. Three precast prestressed concrete piles 95 feet long and two precast prestressed concrete piles 92 feet long were strain gaged and tested. These piles were 18 inches square and weighed approximately 13½ tons each. The stress and displacement data were recorded by a high-speed recording oscillograph.

Two series of tests were performed. In the first series, three strain gages were installed in each of three different piles 95 feet long. One gage was cast near the head of the pile, one at mid-length, and one near the tip as shown by Figure 1. As can be seen, these gages were not at the center of gravity of the pile and consequently would pick up flexual stresses if they were present. In addition to obtaining dynamic stress data, the purpose of this first series of tests was to find out if the embedded strain gages, embedded lead wires, and the recording oscillograph would perform as intended under the field conditions imposed.

The second series of tests were performed on two strain-gaged piles. Since only eight channels of strain recording system were available, seven strain gages were cast in each of these two piles. The eighth recording channel was used to record dynamic pile displacement data. Test Pile 5 had gages placed on opposite sides of the pile in order that the axial stresses as well as the magnitude of the flexural stresses could be determined from the stress records. Test Pile 4 had gages placed at intervals down the length of the pile so that the magnitude of stresses could be measured at

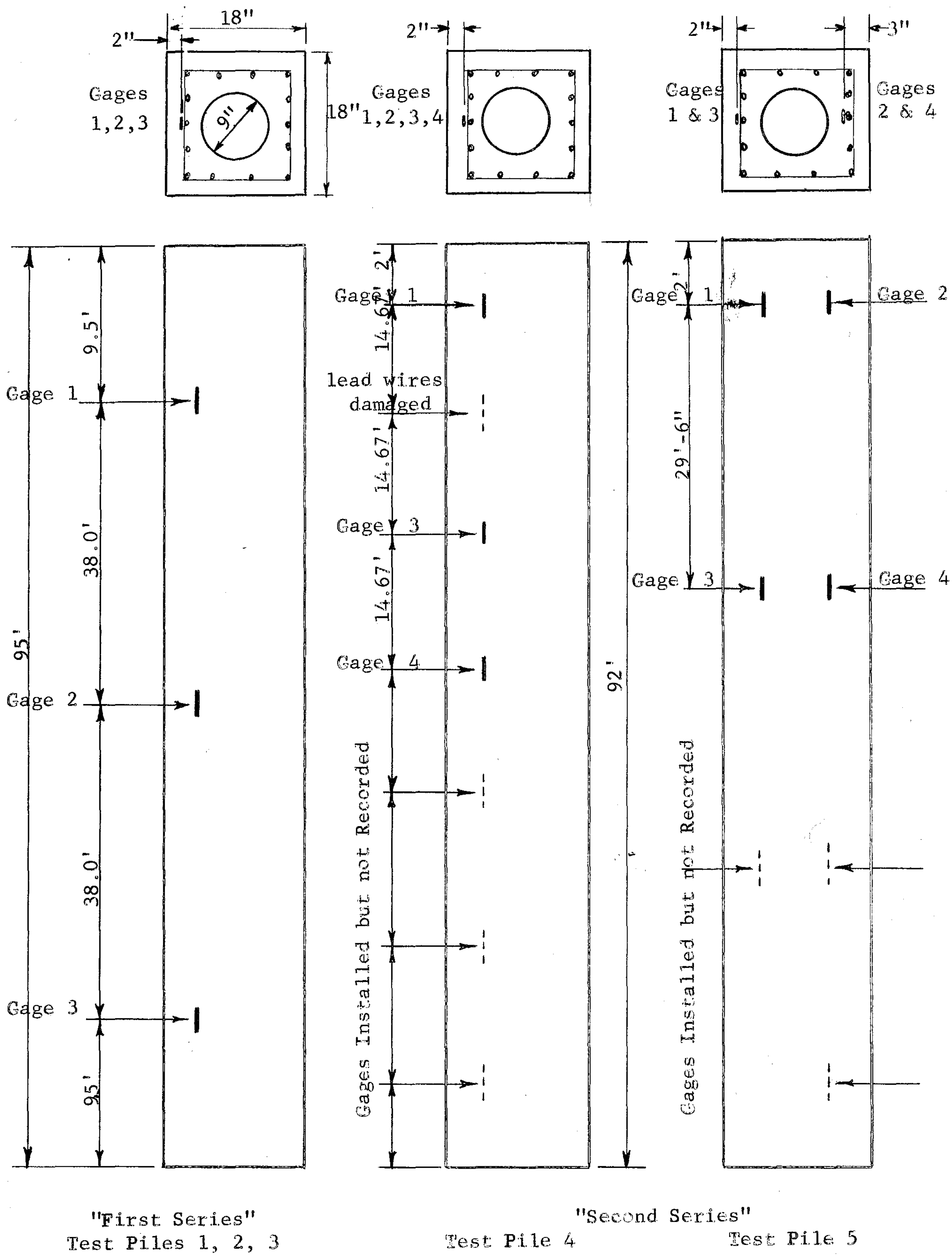


Figure 1: Drawing of Test Piles Showing Strain Gage Locations.

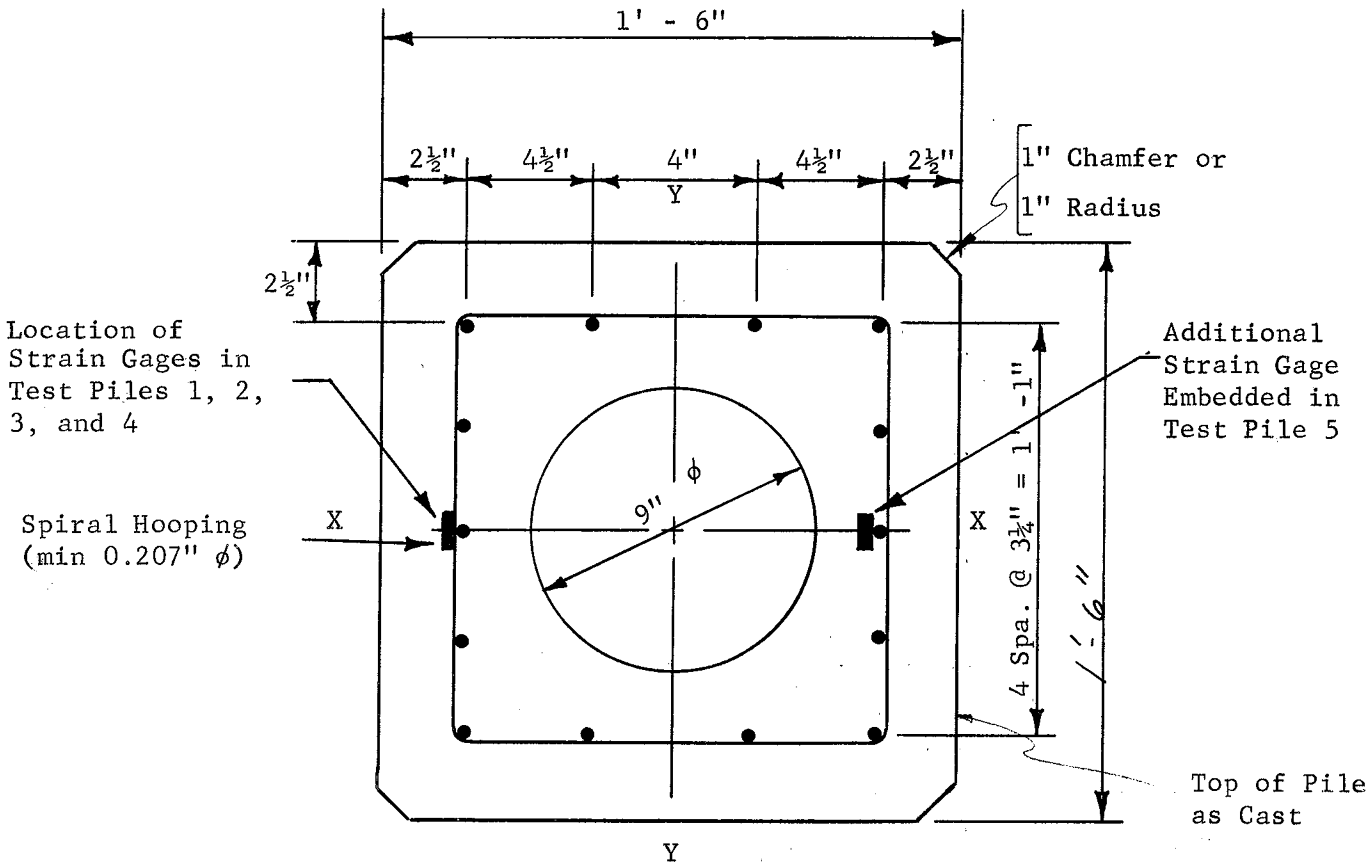
these various points. It was desired to see how the stress wave diminished along the pile as a result of soil friction and pile damping characteristics.

Unfortunately only four of the seven strain gages in each of these piles could be recorded because of technical difficulties with the two different power supplies of the two 4-channel strain-gage amplifiers. "Cross-talk" between gages on the two different power supplies prevented the simultaneous operation of these two units. Many useful data from the four recorded gages were obtained, however.

Strain Gages

Baldwin AS9 constantan wire grid, Valore type brass foil envelope, strain gages were embedded parallel to the longitudinal axis of the prestressed concrete piles during the placing of the concrete. This was done about three or four weeks prior to the driving of these piles. The lead wire from the gages was Belden No. 8525, American wire gage No. 24, vinyl plastic insulated. The lead wires were run the length of the pile embedded in the concrete and were brought out about 15 feet from the pile head. In this manner the gages and leads were protected from being stripped from the pile as it was driven into the ground. Shielded cable extensions were connected to the lead wires at the head of the pile and these cables were connected to the strain-gage amplifiers and recording oscillograph (Belden No. 8424 cable).

Figure 2 shows a typical cross section of the test piles. The strain gages were embedded parallel to one of the central 7/16 inch steel strands as shown in Figure 2. Test Piles 1, 2, 3, and 5 had only one strain gage at each desired cross-section. Test Pile 4 had two gages at each cross-section near opposing steel strands in order that the flexural strains and more precise axial strains could be determined.



Number of Strands = 14 - 7/16" φ
Initial Prestress Force = 264.6 Kips
Final Prestress (20% loss) = 786.6 p.s.i.
Gross Area = 258.4 in.^{2}
Metallic Area of One 7/16"φ Strand = 0.1089 in.^{2}
Transformed Area (n = 8) = 269.1 in.^{2}
I_{xx} (transformed) = 8565.6 in.^{4}, I_{yy} (transformed) = 8610.0 in.^{4}
Concrete Tensile Capacity (Ultimate) = 370 p.s.i. est.
Weight of Pile = 269 lb/ft. est.
Max. allowable tensile load = 311.2 Kips @ 1,156.6 p.s.i. est.
Length = 95' (Test Piles 1,2 and 3) and 92' (Test Piles 4 and 5)

Figure 2. Typical Cross-Section of Test Piles.

Strain Gage Amplifiers and Recording Oscillograph

A Consolidated Electrodynamics Corporation Type 5-116 Recording Oscillograph and two CEC Type 1-118 Carrier Amplifiers were used to amplify and record the dynamic strains and displacements. The oscillograph was equipped with CEC Type 7-323 Galvonometers with a flat frequency response to 600 cycles per second. DuPont photorecording paper Lino-Write 4 was used to record the data. This record paper required dark room developing with a wet process similar to regular camera film. The 110 volt, 60 cycle, electrical power was supplied by a portable generator.

Test Pile Properties

Concrete specimens were obtained from the ready mixed concrete trucks as the test piles were cast. Standard 6" diameter x 12" length cylinder specimens and 3" x 4" x 16" prism specimens were cast in order to determine the static and dynamic modulus of elasticity, modulus of rupture, compressive strength, and unit weight of the concrete. Prism specimens 3" x 3" x 22" were cast in order to determine the direct tensile strength of the concrete. A summary of the concrete properties is given in Table 1.

The modulus of elasticity of the concrete was required to transform the strain-gage readings into stress. The modulus of elasticity and unit weight values were used in setting up these pile problems for the digital computer solution. The strength properties were very useful in interpreting the significance of the measured dynamic stresses.

Soil Properties

In order to simulate the test piles for the theoretical computer solution, it was necessary to know the shear strength properties and other factors about the soil in which the pile was being driven. To assist in determining some of these soil variables, three test holes were drilled

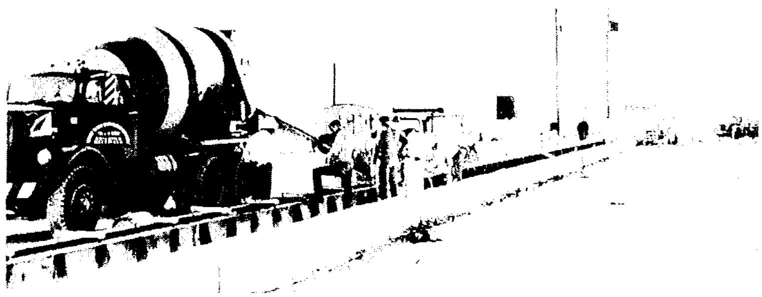


Figure 3. Placing concrete in forms of 18"x18" precast, prestressed concrete piles 95' in length. Prestressed bed 500' in length. Ross Anglin and Son, General Contractors, San Antonio, Texas.

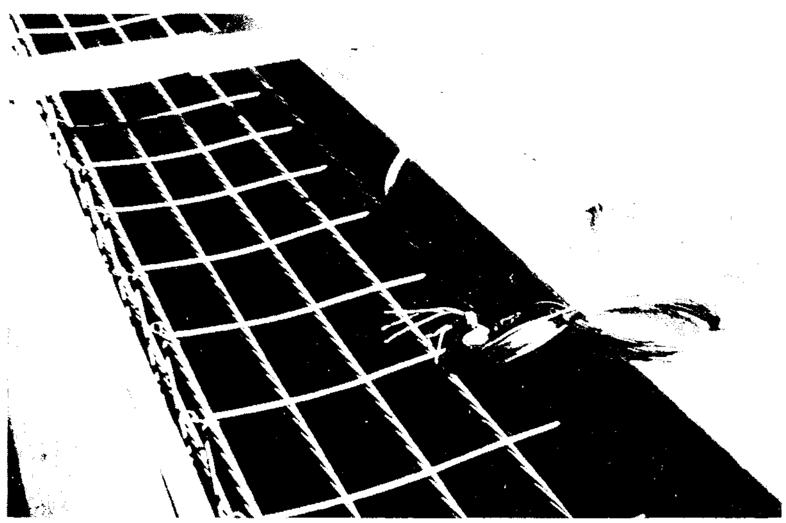


Figure 4. Strain gage lead wires and steel reinforcement inside 18" square steel forms.

near the sites where the test piles were driven. The foundation exploration crews of the Texas Highway Department Bridge Division drilled these holes and located, identified, described, and determined the shear strength, density, and moisture content of the various soil strata.

TABLE 1. Properties of Concrete in Test Piles

	Test Piles No. 1, 2, 3	Test Piles No. 4, 5
Unit Weight, lb./cu.ft.	158	154
Compressive Strength, psi		
2 day, 6" x 12" cyl.	4540	4800
7 day, 6" x 12" cyl.	7230	7120
42 day, 3" x 4" x 16" prism	8490	8060
Tensile Strength, psi		
42 day	455	465
Modulus of Rupture, psi		
42 day, center point	925	790
Modulus of Elasticity, psi		
42 day, Static	8.18×10^6	6.95×10^6
42 day, Dynamic	8.32×10^6	7.71×10^6
Poisson's Ratio		
42 day, Dynamic	.15	.16

To determine the shear strength of the soil, four different methods of tests were conducted. They were the "in place" vane shear test, the THD standard penetrometer test, the triaxial shear test, and the "miniature" vane shear test. In general, the "in place" vane shear test and the standard penetrometer test were the most practical tests for the Nueces Bay area. Very frequently the undisturbed samples required for a triaxial or "miniature" vane tests could not be recovered from the sampling tube, particularly when muck or loose granular materials were encountered. These various methods of tests appeared to yield values in reasonable agreement with each other.

Figures 5, 6, and 7 present a summary of the ultimate shear strength of the soil versus depth. The shear strength is given in kips per linear

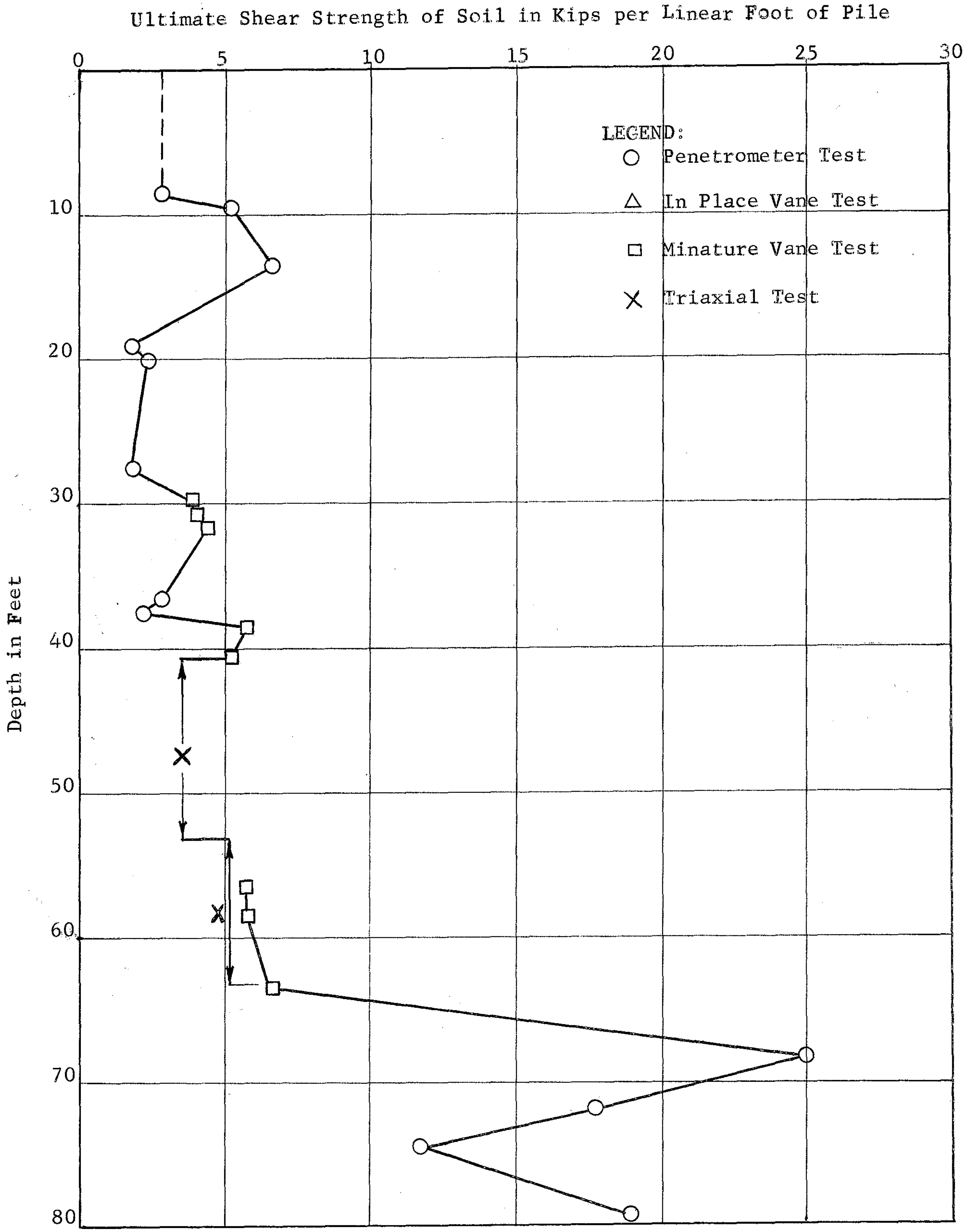


Figure 5. Ultimate Shear Strength of Soil at Various Depths
Test Hole No. 1 Near Test Piles 1, 2, and 3 (Bent No. 58)

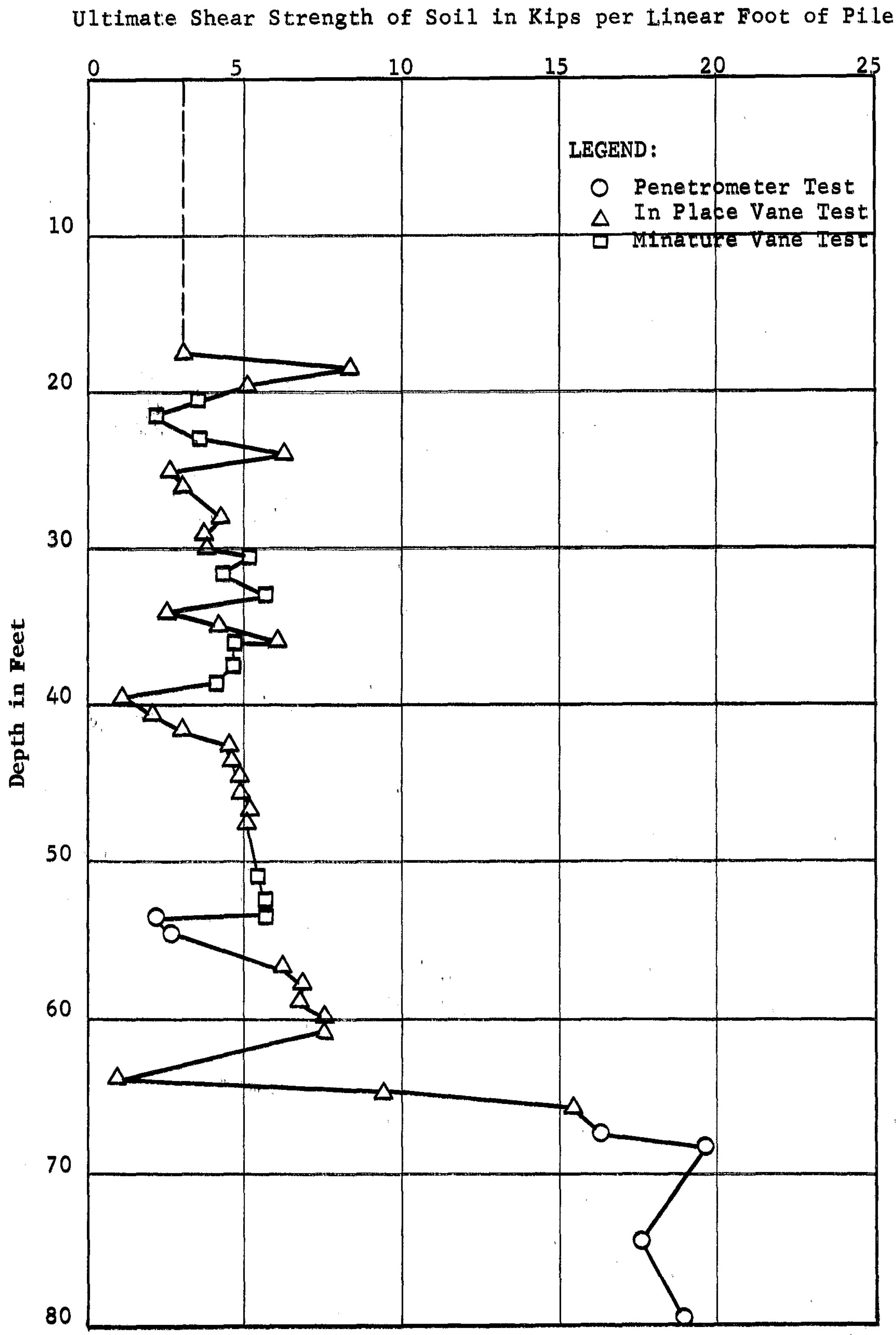


Figure 6. Ultimate Shear Strength of Soil at Various Depths
Test Hole No. 2 Near Test Pile No. 1, 2, and 3 (Bent No. 58)

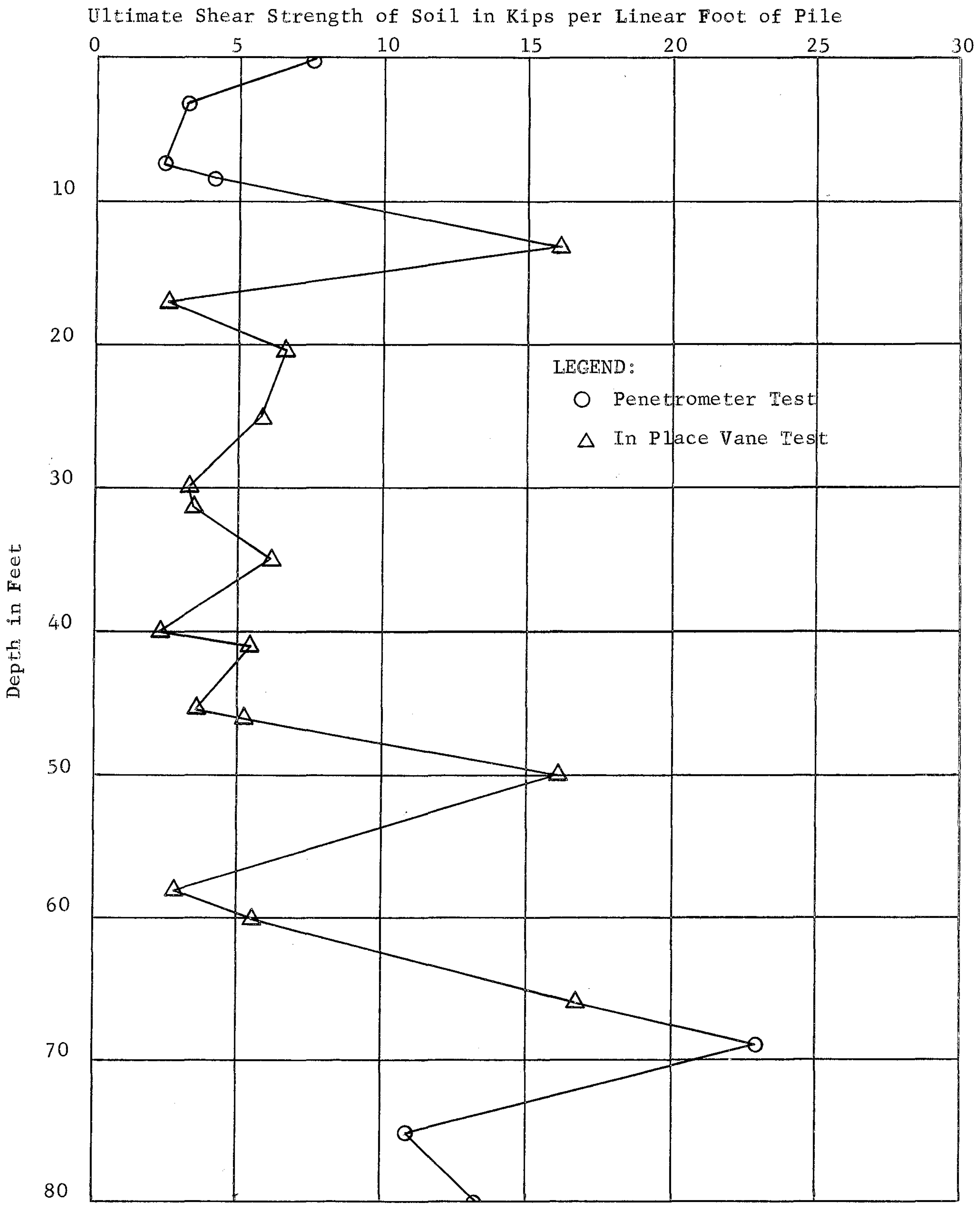


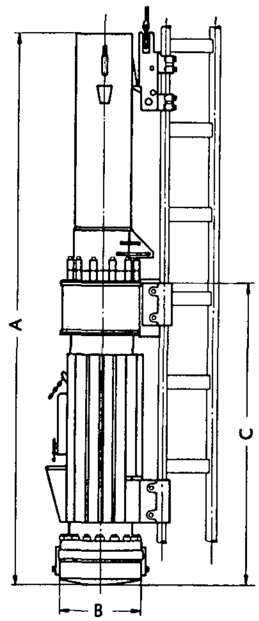
Figure 7. Ultimate shear Strength of Soil at Various Depths
Test Hole No. 3 Near Test Pile No. 5 and 6 (Bent No. 148)

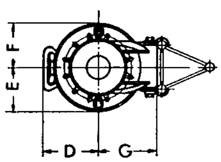
TECHNICAL DATA

Piston weight, lbs. 4850

Measures in inches

A	154 1/2
B	22 53/64
C	83 17/64
D	14 3/8
E	11 13/16
F	12 33/64
G	15 5/8 (on GF-22 G-112)

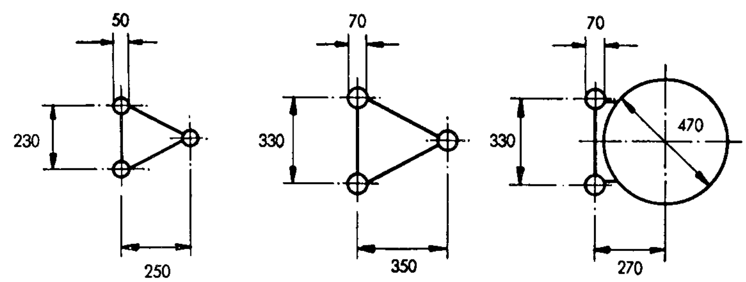




Example of detail measurements for Hammer Lead

g	2 3/4
h	13
i	10 5/8
k	18 1/2

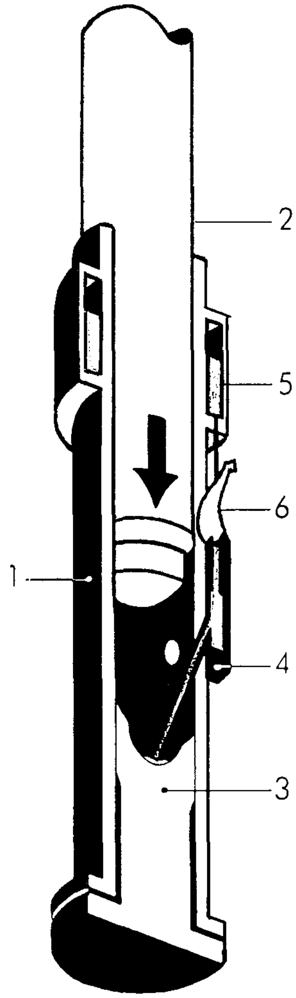
Measures in inches



Piston weight	4,850	lbs.
Weight of hammer (without accessories)	9,768	lbs.
Accessories: tripping device	286	lbs.
transport slide	375	lbs.
tool-kit	326	lbs.
Shipping weight net (hammer + accessories	10,755	lbs.
Shipping weight gross	11,964	lbs.
Storage space	230	cu. ft.
Weight of anvil	1,147	lbs.
Number of blows	42-60	per min.
Energy output per blow	39,800	ft. lbs.
Maximum explosion pressure on pile	158,700	lbs.
Fuel consumption, continuous working	3.44	U.S. gal. per hour
Oil consumption, continuous working	0.39	U.S. gal.
Fuel tank capacity	10.2	U.S. gal.
Oil chamber capacity	7.0	U.S. qts.

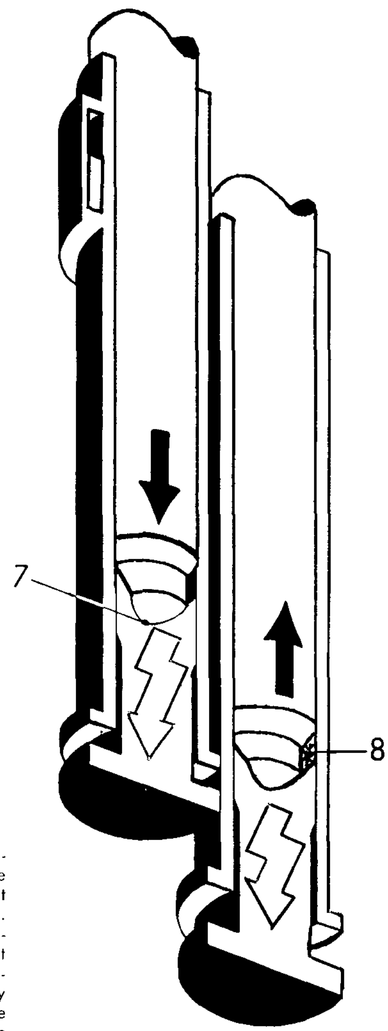
Figure 8. Technical Data for Delmag Diesel Hammer Model D22

Free fall



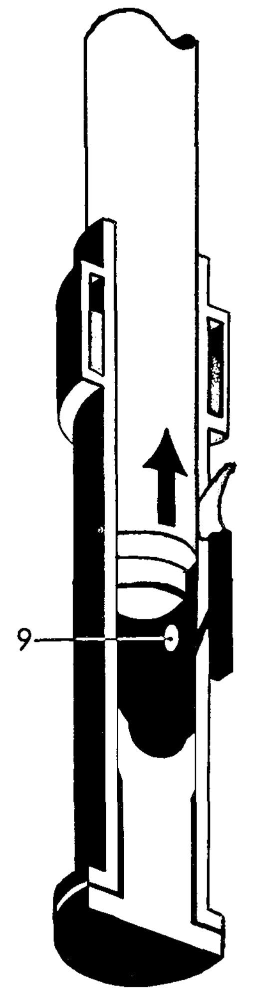
1. The long cylinder (1) accommodates in its upper half the piston (2) and the impact block (3) in its lower part. The piston is the actual working part, whereas the impact block rests on the pile to impart the energy, produced by the falling piston and the explosion, to the pile. The impact block also serves to seal off the combustion chamber at the lower end. The fuel pump (4) and the fuel tank (5) are attached to the cylinder. To start the hammer the piston (2) is lifted and, when reaching a certain height, is automatically released. During the downward fall of the piston (2) a pump lever (6) on the fuel pump (4) is activated injecting a fixed amount of Diesel Fuel into the combustion chamber at a pressure of 1,5 atmospheres.

Blow plus Explosion



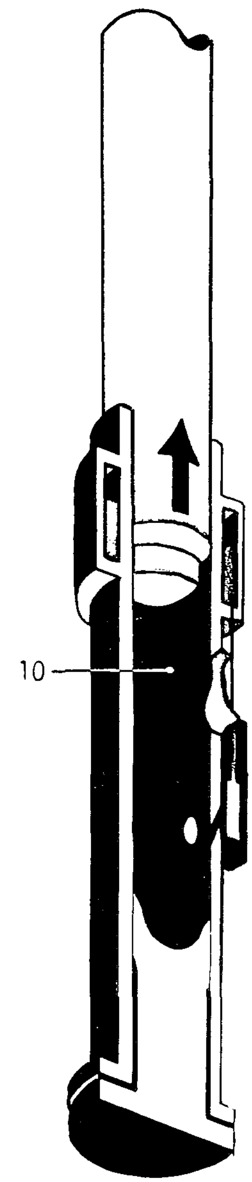
2. As the piston (2) continues to fall it closes the exhaust ports, compresses the remaining air in the cylinder and hits the concave ball pan of the impact block. The impact of the falling piston (2) atomizes the Diesel fuel lying in the ball pan, and the highly compressed air causes these atomized fuel particles to ignite. The combustion pressure thus created exerts an additional force onto the pile, which is already travelling downward under the compression force developed by the falling piston, and the blow from the piston further serves to throw the piston (2) up for the next working cycle.

Exhaust



3. As the piston clears the exhaust ports (9) in its upward motion the internal and external pressures are equalized.

Scavenging



4. As the piston continues its upward motion fresh air is drawn into the cylinder (10), which is thus being scavenged. The pump lever (6) is now released, allowing a new charge of Diesel fuel to enter the fuel pump (4).

Figure 9. Working Principal of Delmag Diesel Pile Hammers

The above information is approximate because detailed drawings of the hammer were not available. It is considered to be sufficiently accurate for setting up the computer program for the theoretical analysis, however.

The working principles of this diesel pile hammer are shown in Figure 9. The driving force delivered to the pile results from two events; (1) the impact of the ram on the anvil, and (2) the explosion of the diesel fuel. By far the greater of these two forces is the impact of the ram on the anvil. This force depends on the weight of the ram and its velocity at impact. In order to determine this velocity at impact, it was necessary to know the height of fall of the ram.

Pile Driving and Test Procedure

When the test piles arrived at the driving site by truck, the gages had been previously cast in them and several feet of lead wire was protruding from the concrete near the pile head. Shielded cable extensions were connected to these wires at the head of the pile, and then the pile was raised into position in the leads of the pile driver rig. The pile was usually raised and dropped several times to obtain some penetration (it varied from 5 feet to 40 feet) for stabilization before it was plumbed and the diesel hammer placed on top.

The strain-gage extension cables were then connected to the recording oscillograph. Each strain-gage channel was then balanced and calibrated prior to the driving of the pile.

The piles had been previously measured and marked off every foot so that the penetration of the pile in the ground could be determined by inspection. As the pile was driven continuously into the ground, the recording oscillograph was turned on intermittently at different depths of penetration. In

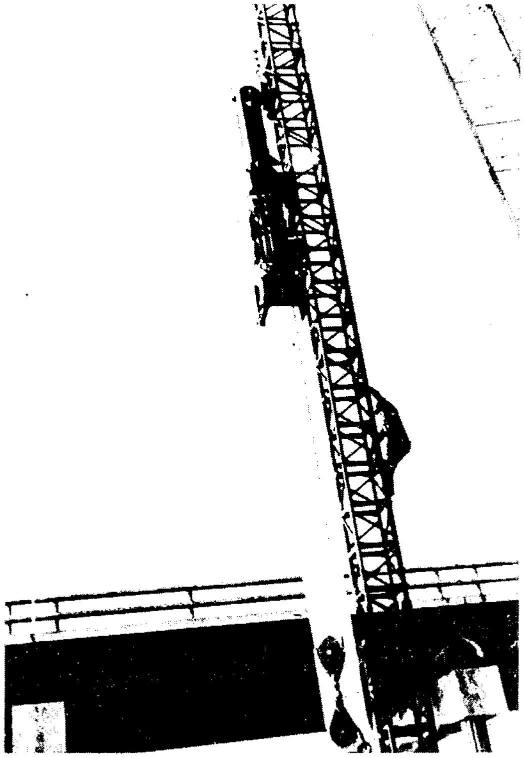


Figure 10. Delmag D-22 diesel hammer driving prestressed concrete pile.

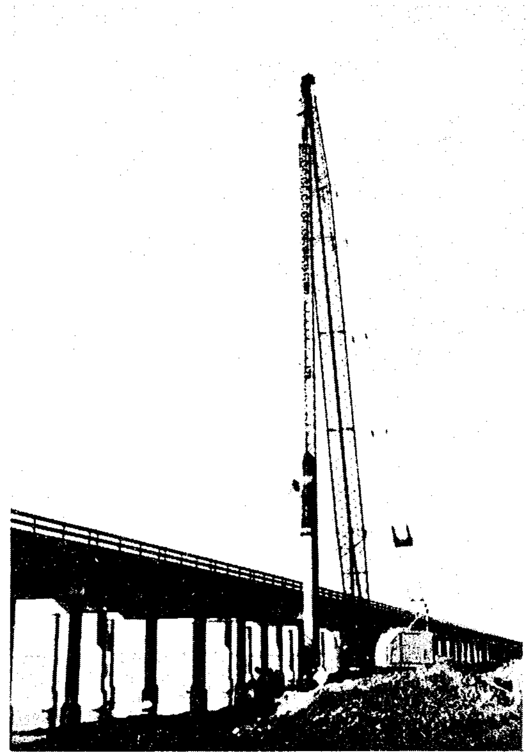


Figure 11. View of 95' pile leads used to drive piles up to 115' in length.

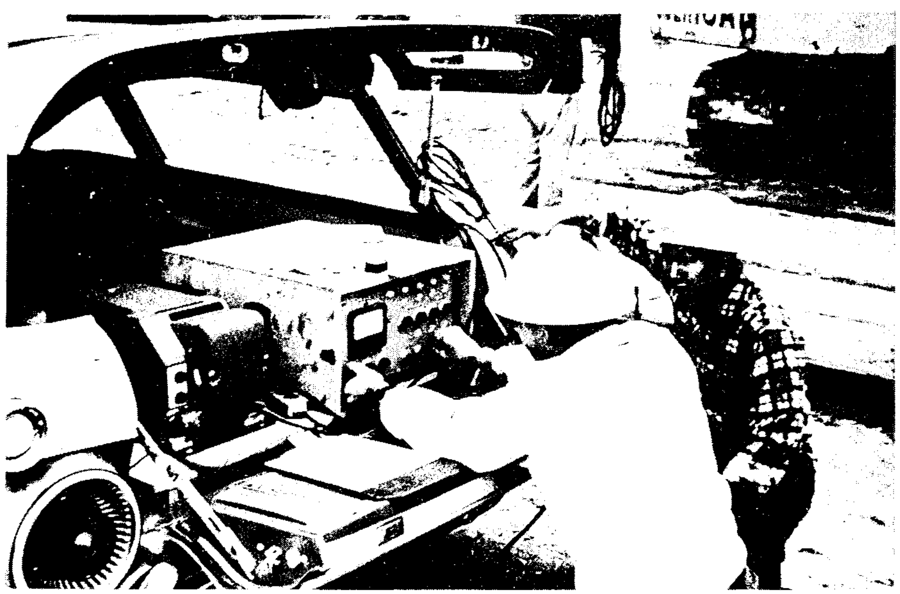


Figure 12. Recording oscillograph and strain gage amplifier unit recording strains from gages embedded in concrete piles during driving on Nueces Bay Causeway, near Corpus Christi, Texas.

general, the recorder was run for periods of 3 to 5 seconds. By doing this the stresses from 3 to 5 consecutive blows could be recorded along with the time interval between blows. This time interval was desired, because the height of ram fall could be more accurately determined from it than from direct visual observation.

In addition to these data, a survey crew of the Texas Highway Department took level readings on the pile and made a log of the average penetration per blow as the pile was driven into the ground.

The entire field procedure was designed such that the maximum amount of data could be obtained in a manner such that the pile driving contractor would not be unduly delayed. This was necessary since the contractor received no monetary compensation for his cooperating in this pile research.

During the driving of test piles 4 and 5, two devices were hooked up to the pile to measure dynamic displacements. Both these devices consisted of cantilever beams equipped with strain gages. They were designed so that the strain reading from the dynamically deflected beam would be proportional to the deflection. Both devices seemed to work but the accuracy of the data was questionable since both did not yield exactly the same results while operating simultaneously. The average penetration per blow as determined from the level reading is the value reported with the stress data from the piles.

Test Data

Figure 13 (a) is a typical example of the oscillograph record of the dynamic strains in Test Pile No. 3. This pile had penetrated 45 feet into the ground. Gage 1 was located near the head of the pile, gage 2 at mid-length of the pile, and gage 3 near the tip of the pile. The maximum compressive stress occured at gage 1 and is about 2270 psi. The maximum tensile stress is 860 psi and occurred at gage 2. The vertical lines on the figure are time lines and are spaced at 1/100 second intervals. From these time lines, the time period for the initial compressive wave to travel from gage 1 to gage 3 can be determined. It is also interesting to note the decrease in the initial compressive wave as it travels down the length of the pile and into the ground. This compressive wave is seen to be reflected from the pile tip as a tension wave because very little point bearing was present. It is this reflected tension wave which can cause tensile breakage in such prestressed concrete piles being driven in soils which offer little point resistance.

Figure 13 (b) is also an oscillograph strain record from Test Pile 3. However, in this case the pile had penetrated 74 feet into the ground. In comparing this record with that of Figure 13 (a), it is interesting to note how little tensile stress occurred when the pile was 74 feet in the ground. It is apparent that the damping effect of the soil friction greatly reduced the reflected tension wave. In general, the larger tensile stresses under these conditions occurred when the pile had only slightly penetrated into the ground and had little soil resistance. The theoretical computer solution which is presented later supports this conclusion.

These particular piles had a final prestress of about 800 psi and the concrete had an additional tensile strength of about 460 psi. This means these piles should withstand a measured tensile stress of about 1260 psi without failure. Keeping this in mind, it is interesting to look at Table 2 which is a summary of the maximum tensile and compressive stresses recorded in all 5 of the test piles. The maximum tension recorded was 1350 psi in Test Pile 2, however, values of around 900 to 1000 psi were common.

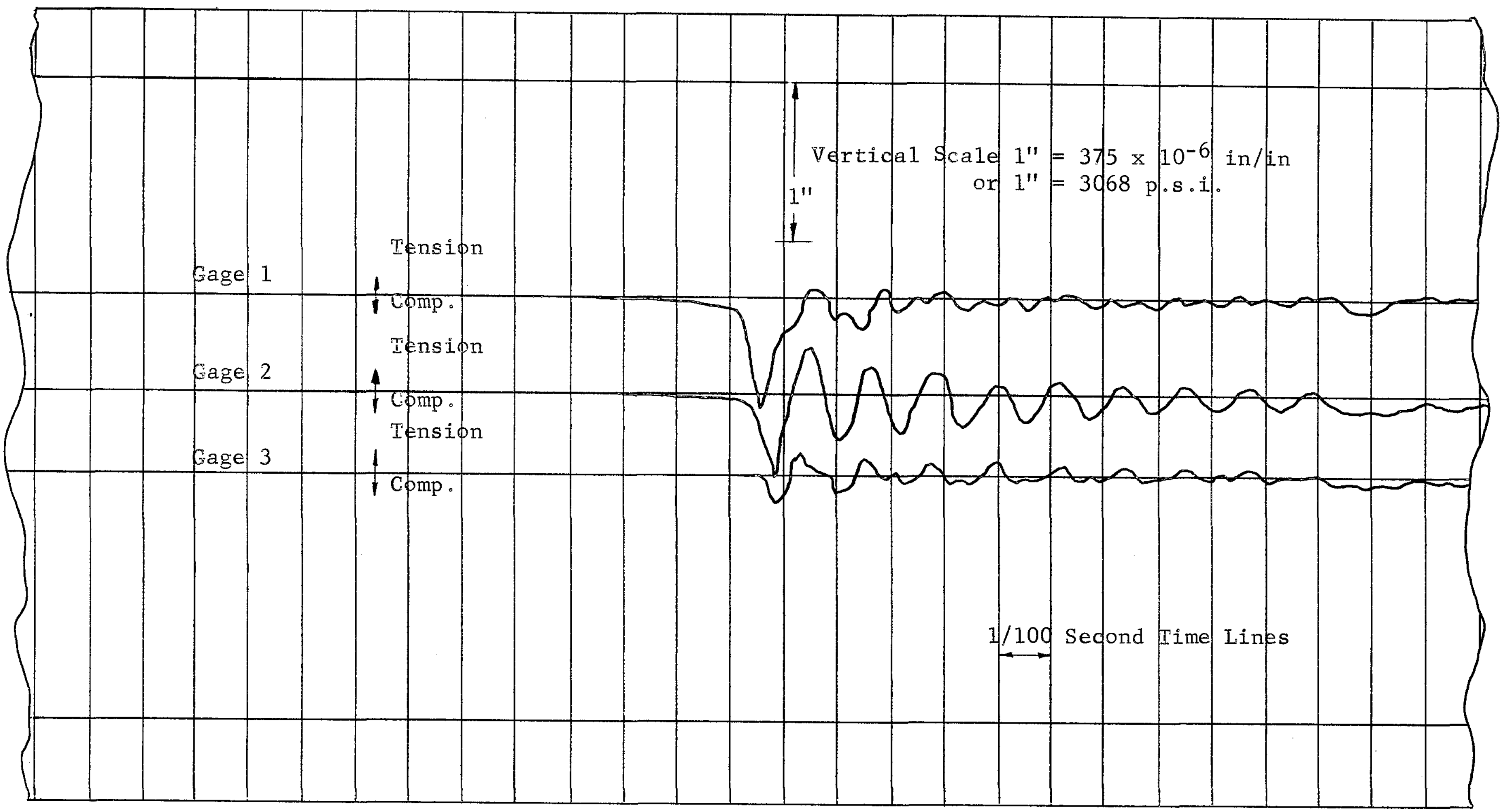


Figure 13(a). Oscillograph Strain Record from Test Pile 3. Pile Penetration is 45' in Ground.

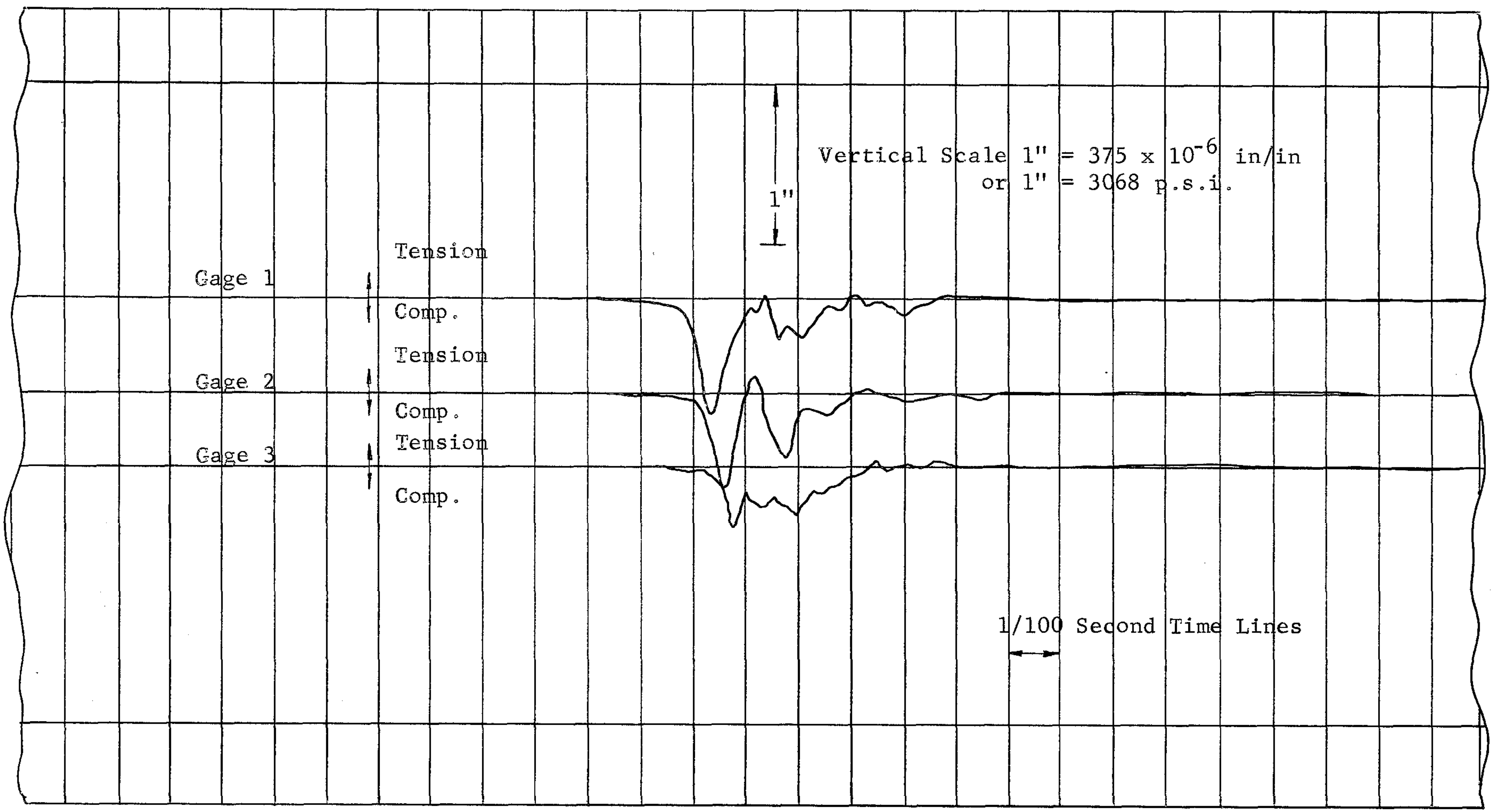


Figure 13(b). Oscillograph Strain Record from Test Pile No. 3. Pile Penetration is 74' in Ground.

TABLE 2. Maximum Measured Compression and Tensile Stresses in Prestressed Concrete Piles

Depth of Pile in Ground Feet	Computed Hammer Drop Feet	Average Penetration per Blow Inches	Maximum Stresses* Compression psi	Maximum Stresses* Tension psi
Test Pile No. 1 Bent No. 53				
48-	4.55		2045	982
48	3.95		1922	982
48-51	4.15		1840	1145
51	4.45		2086	1063
55	4.48	1.57	2086	982
55+	5.14	1.57	2086	1022
59	4.74	1.03	1963	1022
63	4.61	1.188	1963	1022
64+	4.87	1.18	1677	1022
68	4.66	.781	1759	614
68.5	4.96	.638	1759	245
69	5.18	.495	1800	123(head)
69.7	5.38	.298	1840	123(head)
71	4.78	.075	1513	0
73.5-	4.96	.064	2127	409
73.5	5.05	.064	2209	450
74.8	5.14	.079	2413	654
Test Pile No. 2 Bent No. 53				
34	4.35		1840	1350
42	3.82		1513	1186
49	3.48	2.77	1268	900
55	3.37	1.77	1227(Cen.)	818
58	3.68	1.41	1267(Cen.)	900
63-	3.63	1.34	1391	859
63	3.81	1.34	1432(Cen.)	982
67	3.94	1.28	1513	941
68	4.40	1.04	1718(Cen.)	982
Test Pile No. 3 Bent No. 58				
7	5.40		2147	828
8	5.12		2209	736
10	4.92		2270	767
12	4.74		2393	798
17	4.25	1.338	2239	982

*Maximum compressive stress occurred at head of pile unless noted otherwise. Maximum tensile stress occurred at center of pile unless noted otherwise.

TABLE 2. (Continued)

Depth of Pile in Ground Feet	Computed Hammer Drop Feet	Average Penetration per Blow Inches	Maximum Stresses* Compression psi	Maximum Stresses* Tension psi
Test Pile No. 3 (Continued)				
35	3.94	4.99	1932	920
40	3.48	2.90	1564	675
45	4.19	2.81	2178	890
50	3.78	2.34	2239	828
55	4.19	1.91	2117	859
60	4.09	1.60	2147	859
65	4.18	1.61	2178	920
67	4.02	.89	2147	828
68	4.14	.46	2209	736
68+	4.42	.46	2179	644
69	4.36	.233	2270	614
70-	5.12	.135	2883	644
70	5.42	.135	3006	644
70+	4.48	.135	2362	460
74	4.48	.055	2239	338
74+	4.39	.055	2178	276
Test Pile No. 4 Bent No. 148				
20	4.18	.923	1642	599
23	3.78	12.0	1798	964
46	4.18	2.40	2007	834
50	4.26	.308	2007	782
52	4.26	.154	2033	599
53	4.43	.138	2059	495
54	4.43	.10	2007	521
55	4.02	.247	1772	704
56	4.18	.308	1824	782
57	4.18	.353	1824	964
65	3.63	.571	1147	521
66	4.78	.364	2007	443
69	4.78	.104	1981	443
Test Pile No. 5 Bent No. 148				
5	3.94		1876	1053
10	3.78	1.00	1826	1091
15	3.70	3.00	1849	1294
20	4.02	.705	1852	1-53

*Maximum compressive stress occurred at head of pile unless noted otherwise. Maximum tensile stress occurred at center of pile unless noted otherwise.

TABLE 2. (Continued)

Depth of Pile in Ground Feet	Computed Hammer Drop Feet	Average Penetration per Blow Inches	Maximum Stresses* Compression psi	Tension psi
Test Pile No. 5	(Continued)			
25-35	3.94	7.50	2016	1192
40	3.94	2.00	1806	891
45	3.86	2.40	1832	911
50	4.52	.364	2060	775
54	4.26	.174	2168	728
55	4.26	.292	2071	722
57	4.18	.48	1988	921
58	4.10	.667	1982	1005
61		.75	1797	735
65	4.26	.75	2102	1087
67	4.60	.4	2354	965
68	4.69	.15	2380	824
69	4.69	.074	2342	668
69.5	4.52	.06	2206	494
70	4.60	.052	2136	436

*Maximum compressive stress occurred at head of pile unless noted otherwise. Maximum tensile stress occurred at center of pile unless noted otherwise.

The measurements are very interesting in view of the fact that two piles did fail in tension while being driven at Bent 57. This was within 200 feet of the location of Test Piles 1, 2, and 3. Figures 15 and 16 are pictures of these two broken piles. All the tensile cracks were located in the lower half of the pile. Some cracks were also at the mid-length of the pile. These observations will be referred to later when discussing the theoretical computer analysis of this problem.

A complete tabulation of the maximum tensile and compressive stress recorded at each gage from each blow of the hammer is presented in the Appendix.

Figure 14 shows a typical oscillograph strain record taken from Test Pile 5. This record shows the presence of bending in the pile. Gages 1 and 2 were located at the head of the pile but on opposite sides. Gages 3 and 4 were located about 32 feet from the head of the pile but on opposite sides also. These flexural stresses were on the order of $\pm$ 300 psi as an average. They may be attributed to several factors as follows:

(1) hammer not centered on top of pile,

(2) crooked pile,

(3) pile not vertical, and

(4) top of pile out of square.

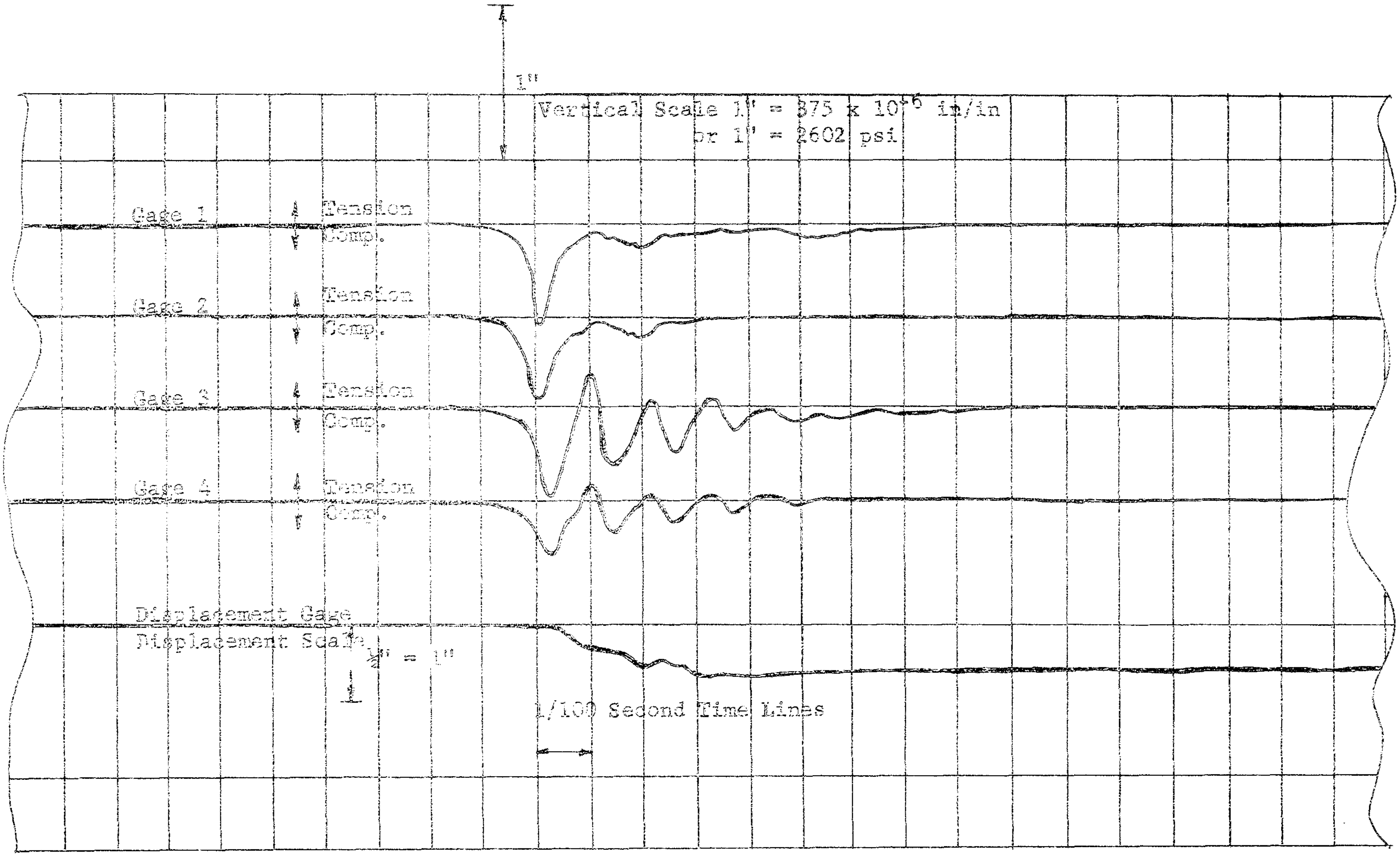


Figure 14. Oscillograph Strain Record from Test Pile 5. Pile Penetration is 57' in ground.

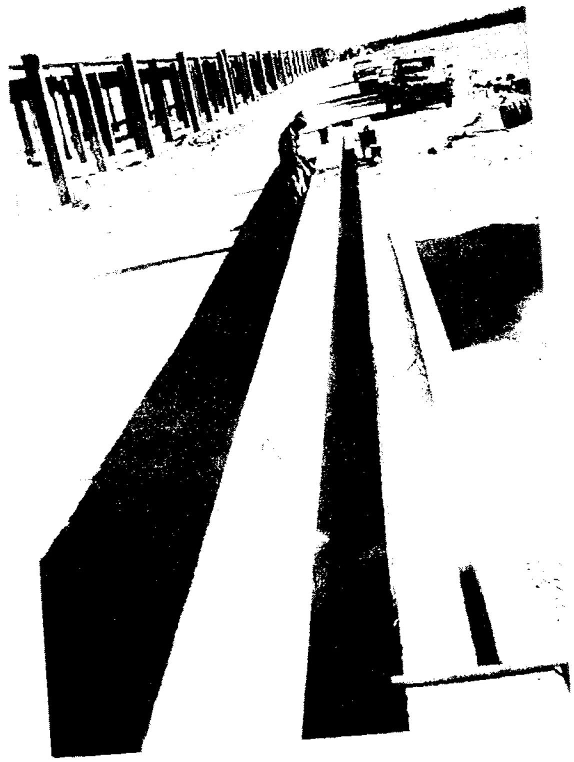


Figure 15. Two 95' prestressed concrete piles which broke in tension while being driven. Workman is applying paint to cracks which were perpendicular to longitudinal axis of pile. All cracks occurred in lower half of piles.

Figure 16. View of lower half of broken pile.

V. COMPUTER CORRELATION

Problem Setup

For the digital computer solution of these pile problems, the actual pile is simulated as shown in Figure 17. In order to accomplish this simulation (7), various physical data concerning the ram, anvil, capblock, etc. were obtained from either the pile driver manufacturer, observed in the field, determined from laboratory tests, or estimated using engineering judgment.

Ram

The weight of the steel ram, W(1), was 4850 pounds. It was about 15 inches in diameter and about 8.45 feet high. Its stiffness was calculated to be

$$K(ram) = \frac{AE}{L} = 50 \times 10^6 \text{ lb./in.}$$

where

K = stiffness in lb./in.,

A = cross-sectional area in square inches,

L = length in inches, and

E = modulus of elasticity in psi (30×10^6 psi for steel).

Its coefficient of restitution was assumed to be e = 1.0.

The velocity of the ram at impact with the anvil was computed from its height of fall in the following manner. Referring to Figure 9, it can be seen that the ram is free falling until it passes the exhaust ports on the side of the diesel cylinder. After a mathematical investigation into the effect of the compressed diesel fuel on the ram velocity, it was concluded that the velocity of the ram at impact was essentially the same as the free-fall velocity at the instant it passed the exhaust

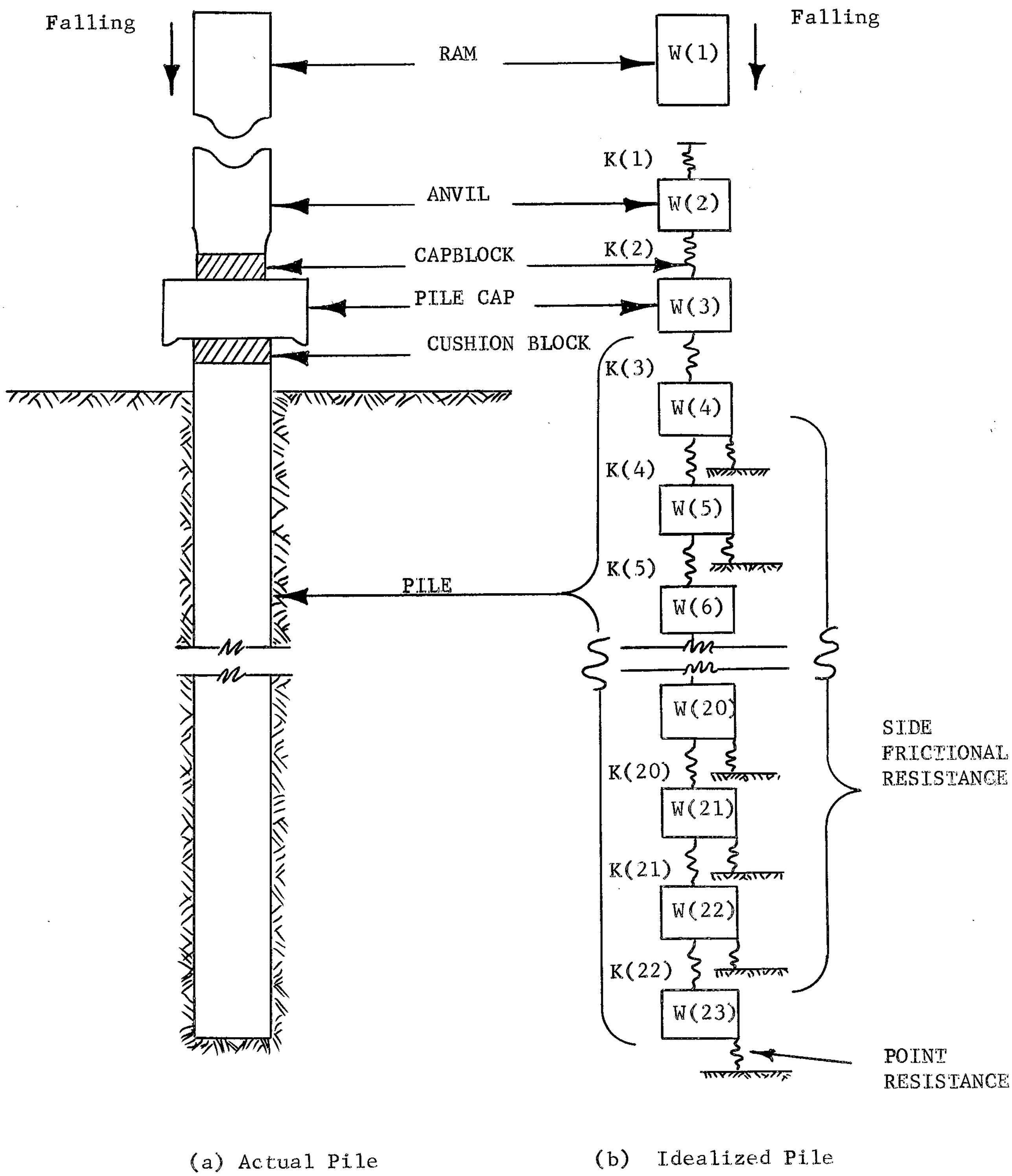


Figure 17. Method of Idealizing a Pile for Purpose of Analysis. This pile was divided into twenty segments of equal lengths. Segment 1 is the ram, 2 is the anvil, 3 is the helmet, and 4 is the first segment of the pile.

ports. Therefore the ram velocity at impact was found by

$$V = \sqrt{2g\ (h-1.25)}$$

where

V = ram velocity in ft./sec.,

g = acceleration due to gravity (32.2 ft./sec^2.),

h = total fall of ram in feet, and

1.25 = distance from center of exhaust port to anvil striker face in feet.

In addition to the energy transmitted to the pile by the falling ram, the explosion pressure from the diesel fuel was also included. This was accomplished by holding the maximum explosion pressure of 158,700 pounds (see D-22 technical data page 16) on top of the anvil for a period of 1/100 second after the ram impact.

Anvil

The weight of the steel anvil, W(2), was 1150 pounds. It was about 15 inches in diameter and about 24 inches high. Its stiffness is calculated to be

$$K(\text{anvil}) = \frac{AE}{L} = 210 \times 10^6 \text{ lb./in.}$$

In this problem the spring stiffness K(1) was assigned a composite stiffness of both the ram and the anvil. Thus

$$K(1) = \frac{K(\text{ram})\ .\ K(\text{anvil})}{K(\text{ram}) + K(\text{anvil})} = 40.5 \times 10^6 \text{ lb./in.}$$

and

$$e(1) = 1.0.$$

Capblock

The capblock originally was a 1 inch thick plywood disk with a contact diameter of 19.74 inches. The driving force which was applied perpendicular to the grain of the wood compressed it to a thickness of 1/2 inch and laboratory tests indicated its modulus of elasticity was about 40,000 psi. Its spring stiffness K(2) was calculated to be

$$K(2) = \frac{AE}{L} = 24.5 \times 10^6 \text{ lb./in.}$$

The coefficient of restitution of this well-compressed wood was assumed to be

$$e(2) = 0.5 \ .$$

Pile Cap (Helmet)

The weight of the helmet, W(3), was estimated to be 1200 pounds.

Cushion Block

The cushion block was 18 inches square and 6 1/2 inches thick. It was made of green oak and the driving force was applied perpendicular to its grain. After several hundred hammer blows its thickness was compressed to about 4 1/2 inches and laboratory tests indicated its modulus of elasticity was about 40,000 psi. Its contact area with the pile was equal to the cross-sectional area of the pile, 258.4 square inches. Its spring stiffness was

$$K(\text{cushion}) = \frac{AE}{L} = 2.3 \times 10^6 \text{ lb./in.}$$

The coefficient of restitution of the oak cushioning material is assumed to be 0.5.

Concrete Pile

Test Piles 1, 2, and 3 were 95 feet long and had a cross-sectional area of 258.4 square inches. The concrete weighed 158 pounds per cubic foot and had a modulus of elasticity of 8.18×10^6 psi. For computer simulation it was divided into twenty segments of equal lengths, 4.75 feet each. The weights of the segments, W(4) through W(23), were 1350 pounds each. The spring stiffnesses of the pile segments were

$$K(\text{pile}) = \frac{AE}{L} = 37.1 \times 10^6 \text{ lbs./in.}$$

Laboratory static stress-strain tests on the concrete material indicated that it had a coefficient of restitution of about 0.92, so this value was used in the program.

Referring to Figure 17, it can be seen that spring K(3) should have a composite stiffness of both the cushion block and the first concrete pile segment. Thus

$$K(3) = \frac{K(\text{cushion}) \quad K(\text{pile})}{K(\text{cushion}) + K(\text{pile})} = 2.16 \times 10^6 \text{ lb./in.}$$

and

$$e(3) = \sqrt{\frac{e^2(\text{cushion})\ K(\text{pile}) + e^2(\text{pile})\ K(\text{cushion})}{K(\text{pile}) + K(\text{cushion})}}$$

$$e(3) = 0.54.$$

All other springs, K(4) through K(22), have stiffnesses equal to that of the pile segments, 37.1×10^6 lb./in., and a coefficient of restitution of 0.92.

Test Piles 4 and 5 were similar to the previous ones except they were 92 feet long. The concrete weighed 154 pounds per cubic foot and had a modulus of elasticity of 6.95×10^6 psi. For computer simulation they too, were divided into twenty segments of equal length, 4.6 feet each. The weights of the segments, W(4) through W(23), were 1272 pounds each. The spring stiffness of the segments was 32.5×10^6 lb./in. The coefficient of restitution of the concrete was also assumed to be e = 0.92. Similarly,

$$K(3) = 2.16 \times 10^6 \text{ lb./in.}$$

and

$$e(3) = 0.55.$$

All other springs, K(4) through K(22), have stiffnesses equal to that of the pile segments, 32.5×10^6 lb /in.

Soil Resistance

In order to complete the simulation of this pile problem, certain values must be assigned to certain constants that describe the soil resistance on the pile during driving. The values presently defined are (1) the ultimate static soil resistance, Ru, (2) the damping or instantaneous soil resistance, J or J', and (3) the soil "quake" or elastic deformability. Up to the present time no experiments have been performed to determine these last two constants, damping and "quake", accurately. In view of this and other unknown variables, the soil shear-strength data from Figures 5, 6, and 7 have been simplified to the average skin-friction values shown on Figures 18 and 19. Although these were predominantly skin-friction piles, some point resistance was also present and the dashed lines on these figures indicate the estimates as to its magnitude at various depths. These estimates were made using the formula of Terzaghi (9).

Since no tests have been developed for determining the damping constants or "quake" for soils (4, 7), the following values were assumed:

"quake"	Q = 0.02 inches
friction damping constant	J' = 0.05 (7)
point damping constant	J = 0.15 (7)

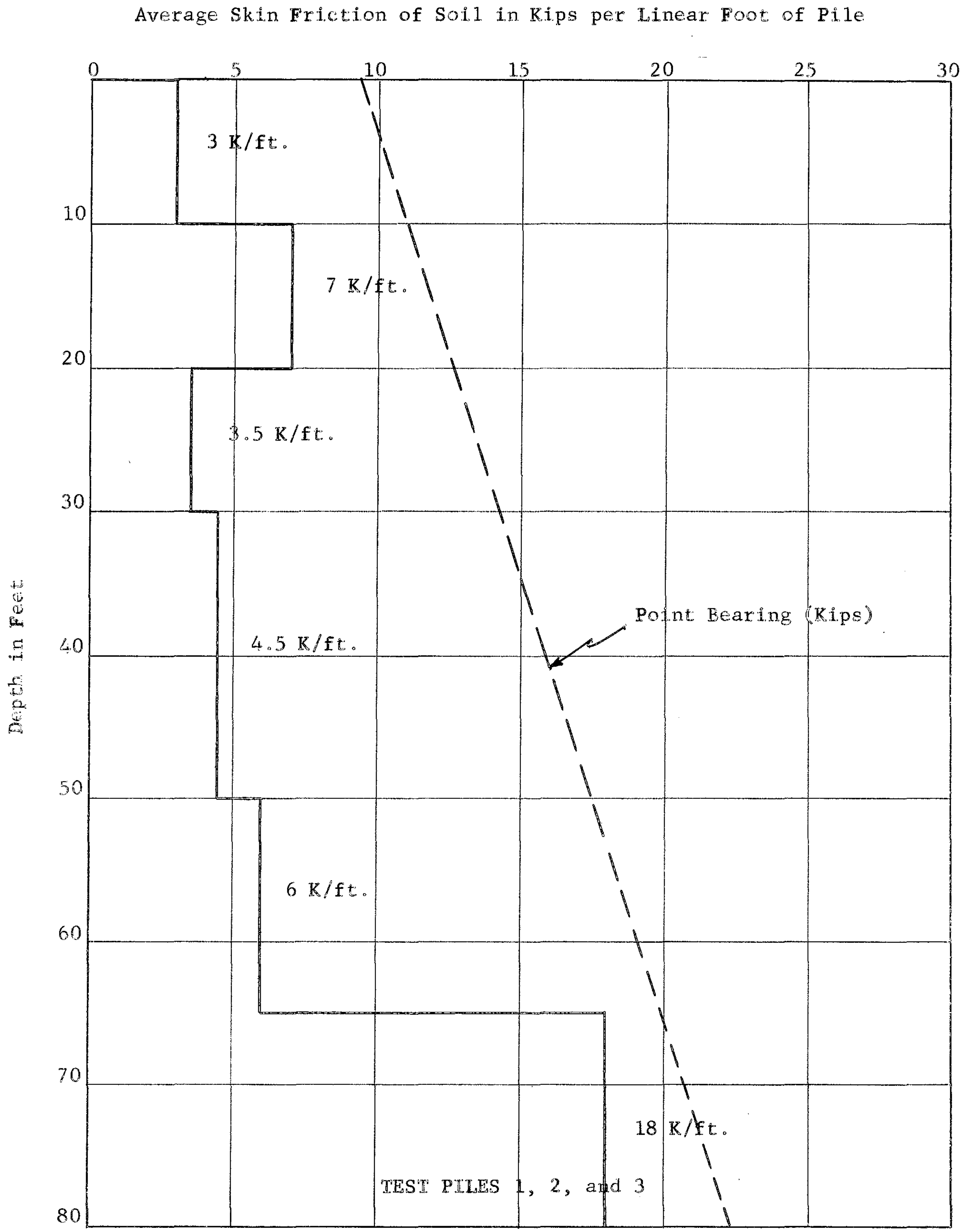


Figure 18. Average Skin Friction of Soil at Various Depths in the Ground

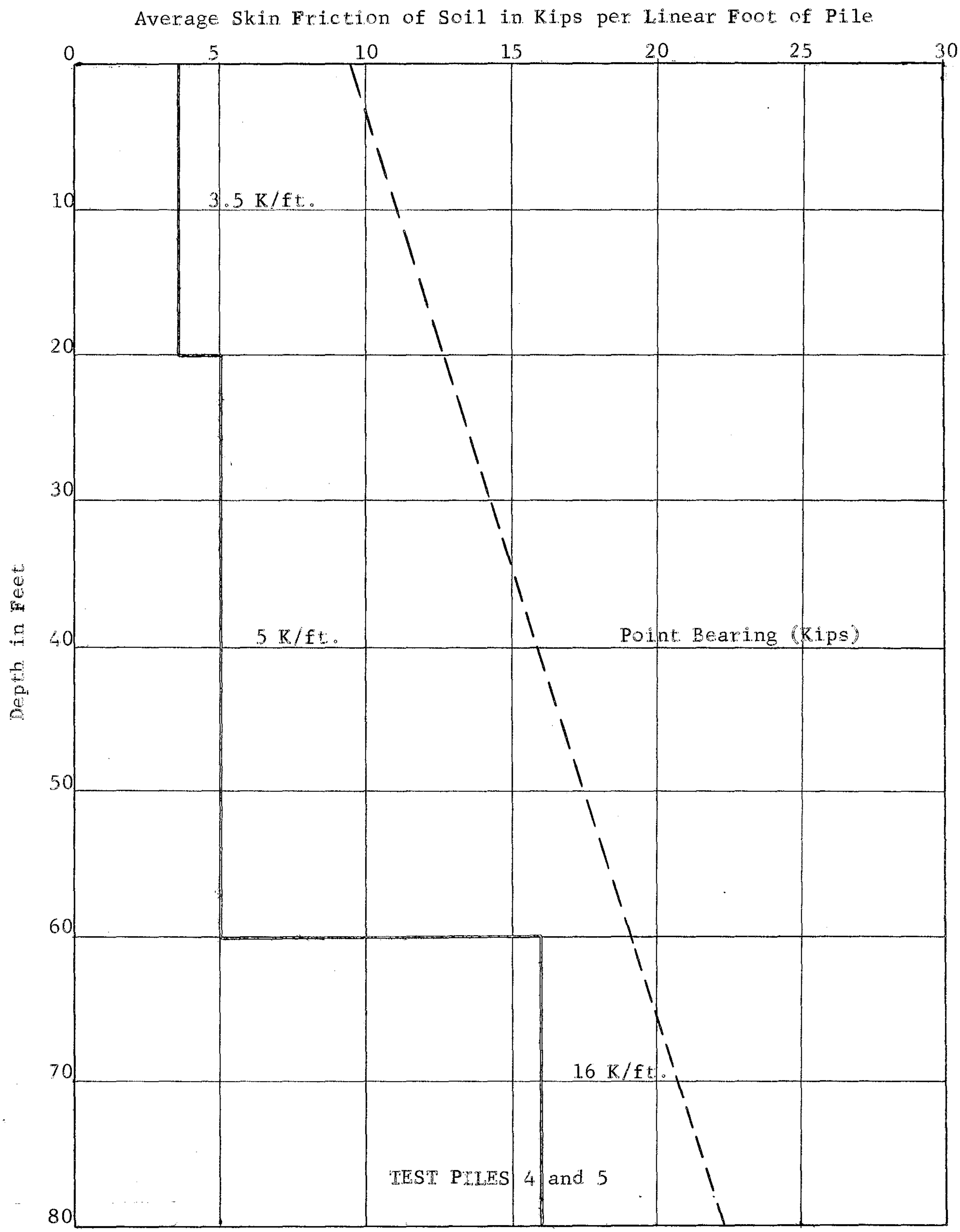


Figure 19. Average Skin Friction of Soil at Various Depths in the ground

Computer Results

In this investigation approximately 48 problems were run on the IBM 709 Computer. A comparison of the computed stresses with those measured in the field test is given by Table 3. Since the strain gages were located at various points along the length of the pile, the computed stress shown was taken from the corresponding segments of the pile. The compressive stresses tabulated were taken from the gage nearest the head of the pile and the tensile stresses tabulated were taken at the gage nearest the mid-length of the pile unless noted otherwise. For the exact location of these gages, reference is made to Figure 1. This was done because, in general, the maximum measured compressive stress was near the head of the pile and the maximum measured tensile stress was near the mid-length of the pile. This is not to be construed to mean that these were the maximum stresses present in the pile. The computer analysis indicated that the absolute maximum tensile stresses in these particular piles were located in the lower half of these piles (see Table 5).

In view of the unknown dynamic properties of the soil, concrete, and wood materials involved in the problem and also the variable nature of the foundation, the quantitative comparisons made in Table 3 are considered very encouraging.

To illustrate the computer out-put of the theoretical stresses, Table 4 shows the computer listing of the compressive and tensile stresses in certain segments of Test Pile 3 at 45 feet penetration into the ground. The time shown is in 1/10,000 of a second. Referring back to Figure 17, it can be seen that segment 5 is the second segment down from the head of the pile. Segment 13 is at the mid-length of the pile and segment 21

TABLE 3. (Continued)

Depth of Pile in Ground Feet	Computed Hammer Drop Feet	Average Penetration per Blow Inches		Comparison of Computed Stresses with Average Measured Stresses			
				- Compression* psi		+ Tension* psi	
		Computed	Measured	Computed	Measured	Computed	Measured
Test Pile No. 4 (92 feet long)							
20	3.96	.574	.923	-2209	-1460	+ 923	+ 526
23	3.73	.465	12.0	-2111	-1746	+ 751	+ 938
46	4.14	.218	2.40	-2251	-1972	+ 732	+ 825
50	4.22	.202	.308	-2349	-1939	+ 725	+ 678
52	4.23	.181	.154	-2279	-1981	+ 720	+ 554
53	4.39	.182	.138	-2335	-1997	+ 705	+ 427
54	4.38	.174	.190	-2293	-1961	+ 698	+ 456
55	4.02	.168	.247	-2279	-1645	+ 685	+ 668
56	4.02	.158	.308	-2209	-1672	+ 647	+ 719
57	4.20	.157	.353	-2237	-1759	+ 627	+ 916
66	4.69	.124	.364	-2419	-1850	+ 282	+ 417
69	4.74	.108	.104	-2391	-1912	+ 331	+ 399
Tesp Pile No. 5 (92 feet long)							
5	3.88	.946		-2181	-1565	+ 896	+ 734
10	3.74	.622	1.00	-2111	-1578	+ 660	+ 762
15	3.70	.640	3.00	-2097	-1557	+ 660	+ 795
20	3.90	.574	.705	-2209	-1638	+ 667	+ 726
25	3.90	.415	4.00	-2167	-1700	+ 541	+ 802
40	3.94	.258	2.00	-2181	-1632	+ 502	+ 632
50	4.43	.202	.364	-2349	-1809	+ 462	+ 543
55	4.90	.168	.292	-2279	-1741	+ 601	+ 368
57	4.10	.157	.480	-2237	-1695	+ 627	+ 532
58	4.10	.153	.667	-2237	-1720	+ 640	+ 645
65	4.13	.116	.750	-2251	-1547	+ 474	+ 495
67	4.66	.119	.400	-2419	-1910	+ 479	+ 530
68	4.69	.113	.150	-2405	-1925	+ 491	+ 426
69	4.60	.108	.074	-2391	-1829	+ 492	+ 279

*Compressive Stresses were taken at head of pile.
Tension Stresses were taken at mid-length of pile unless noted otherwise.

THE A. AND M. COLLEGE OF TEXAS

PILE DRIVING ANALYSIS

CASE NUMBER RP2795

PROBLEM NUMBER 45

INPUT DATA

OPTIONS	1	2	3	4	5	6	7	8	9	10
	1	1	2	2	-0	1	-0	-0	-0	-0

1/(DEL T)	=	10000.0000	RU(TOTAL)	=	-0.
Ru(POINT)	=	-0.	IVEL(1)	=	13.80000
P	=	23	Q	=	0.02000
J	=	0.15000	JPRIME	=	0.05000
ERES(1)	=	1.00000	ERES(2)	=	0.50000
GAMMA 1	=	158700.00	GAMMA 2	=	0.
N1	=	360	N2	=	360
MO	=	-1			

M	K(M)	B(M)	ERES(M)	GAMMA(M)
1	40500000.0	0.	1.00000	158700.00
2	24500000.0	0.	0.50000	0.
3	2160000.0	0.	0.54000	0.
4	37100000.0	0.	0.92000	-1.00
5	37100000.0	0.	0.92000	-1.00
6	37100000.0	0.	0.92000	-1.00
7	37100000.0	0.	0.92000	-1.00
8	37100000.0	0.	0.92000	-1.00
9	37100000.0	0.	0.92000	-1.00
10	37100000.0	0.	0.92000	-1.00
11	37100000.0	0.	0.92000	-1.00
12	37100000.0	0.	0.92000	-1.00
13	37100000.0	0.	0.92000	-1.00
14	37100000.0	0.	0.92000	-1.00
15	37100000.0	0.	0.92000	-1.00
16	37100000.0	0.	0.92000	-1.00
17	37100000.0	0.	0.92000	-1.00
18	37100000.0	0.	0.92000	-1.00
19	37100000.0	0.	0.92000	-1.00
20	37100000.0	0.	0.92000	-1.00
21	37100000.0	0.	0.92000	-1.00
22	37100000.0	0.	0.92000	-1.00

THE A. AND M. COLLEGE OF TEXAS

PILE DRIVING ANALYSIS

CASE NUMBER RP2795

PROBLEM NUMBER 45

INPUT DATA

M	W(M)	RU(M)	IVEL(M)
1	4850.0	-0.	13.80000
2	1150.0	-0.	0.
3	1200.0	-0.	0.
4	1350.0	-0.	0.
5	1350.0	-0.	0.
6	1350.0	-0.	0.
7	1350.0	-0.	0.
8	1350.0	-0.	0.
9	1350.0	-0.	0.
10	1350.0	-0.	0.
11	1350.0	-0.	0.
12	1350.0	-0.	0.
13	1350.0	-0.	0.
14	1350.0	6750.0	0.
15	1350.0	14250.0	0.
16	1350.0	21200.0	0.
17	1350.0	33250.0	0.
18	1350.0	28870.0	0.
19	1350.0	16650.0	0.
20	1350.0	17380.0	0.
21	1350.0	21380.0	0.
22	1350.0	21380.0	0.
23	1350.0	37980.0	0.

TABLE 4

THE A. AND M. COLLEGE OF TEXAS

PILE DRIVING ANALYSIS

CASE NUMBER RP2795

PROBLEM NUMBER 45

STRESSES IN PSI (-COMPRESSION, +TENSION) FOR SEGMENTS 5, 11, 13, 15, 21

TIME	SEGMENT 5	SEGMENT 11	SEGMENT 13	SEGMENT 15	SEGMENT 21
6	-0.	-0.	-0.	-0.	-0.
12	-80.	-0.	-0.	-0.	-0.
18	-819.	-0.	-0.	-0.	-0.
24	-1632.	-3.	-0.	-0.	-0.
30	-2009.	-94.	-4.	-0.	-0.
36	-2250.	-683.	-96.	-5.	-0.
42	-2025.	-1621.	-652.	-96.	-0.
48	-1616.	-1981.	-1607.	-616.	-0.
54	-698.	-2235.	-2022.	-1553.	-7.
60	-359.	-2025.	-2283.	-2042.	-91.
66	-20.	-1542.	-2113.	-2288.	-486.
72	-77.	-764.	-1631.	-2134.	-1143.
78	-170.	-572.	-859.	-1582.	-1314.
84	-342.	-213.	-582.	-809.	-877.
90	-523.	-383.	-273.	-443.	-265.
96	-739.	-410.	-326.	165.	460.
102	-881.	-515.	-49.	513.	835.
108	-1006.	-312.	203.	826.	672.
114	-1061.	-45.	493.	739.	274.
120	-965.	228.	377.	415.	-110.
126	-413.	183.	27.	-335.	-252.
132	297.	-76.	-552.	-853.	-313.
138	670.	-551.	-1046.	-1229.	-259.
144	345.	-820.	-1321.	-1297.	-324.
150	-207.	-881.	-1140.	-1218.	-257.
156	-647.	-788.	-853.	-770.	-323.
162	-904.	-1092.	-508.	-589.	-290.
168	-773.	-1146.	-900.	-272.	-267.
174	-311.	-1213.	-995.	-681.	16.
180	67.	-753.	-1096.	-897.	166.
186	240.	-361.	-697.	-948.	13.
192	179.	162.	-303.	-587.	-387.
198	110.	352.	170.	-239.	-772.
204	94.	421.	317.	28.	-534.
210	45.	209.	195.	57.	87.
216	-18.	-38.	-57.	126.	430.
222	63.	-233.	-43.	271.	436.
228	-92.	-101.	128.	428.	160.
234	-153.	28.	449.	352.	-46.
240	-241.	431.	320.	86.	-190.
246	28.	290.	118.	-195.	-122.
252	318.	92.	-110.	-155.	-1.
258	481.	-42.	-93.	-103.	78.

STRESSES IN PSI (-COMPRESSION, +TENSION) FOR SEGMENTS 5, 11, 13, 15, 21

TIME	SEGMENT 5	SEGMENT 11	SEGMENT 13	SEGMENT 15	SEGMENT 21
264	247.	65.	47.	183.	93.
270	-256.	237.	415.	381.	113.
276	-405.	386.	626.	601.	139.
282	-113.	315.	677.	665.	92.
288	94.	241.	398.	563.	131.
294	312.	194.	192.	243.	205.
300	388.	430.	91.	13.	157.
306	246.	448.	267.	-101.	-22.
312	86.	395.	271.	118.	-246.
318	-50.	128.	248.	123.	-200.
324	-114.	-83.	-42.	80.	-27.
330	-117.	-352.	-205.	-91.	300.
336	-193.	-455.	-375.	-50.	258.
342	-118.	-419.	-288.	-139.	-4.
348	-131.	-242.	-189.	-152.	-158.
354	-143.	-75.	-133.	-287.	-214.
360	13.	17.	-227.	-426.	-171.

TABLE 5

MAXIMUM COMPRESSIVE AND TENSILE STRESSES (PSI) IN THE SEGMENTS

SEGMENT	TIME	STRESS	TIME	STRESS
1	3	-6605.	359	-0.
2	7	-5687.	359	-0.
3	30	-2278.	359	-0.
4	33	-2272.	135	377.
5	36	-2261.	137	670.
6	39	-2253.	138	797.
7	42	-2248.	139	686.
8	45	-2246.	300	608.
9	48	-2245.	303	579.
10	51	-2244.	299	537.
11	54	-2252.	302	475.
12	58	-2277.	278	577.
13	61	-2321.	279	698.
14	64	-2349.	277	703.
15	67	-2342.	109	883.
16	70	-2281.	103	997.
17	74	-2151.	104	1299.
18	76	-2028.	106	1412.
19	76	-1894.	106	1248.
20	75	-1701.	102	1220.
21	76	-1336.	103	884.
22	76	-795.	107	379.

PERMANENT SET OF PILE = 0.21403740 INCHES

NUMBER OF BLOWS PER INCH = 4.67208064

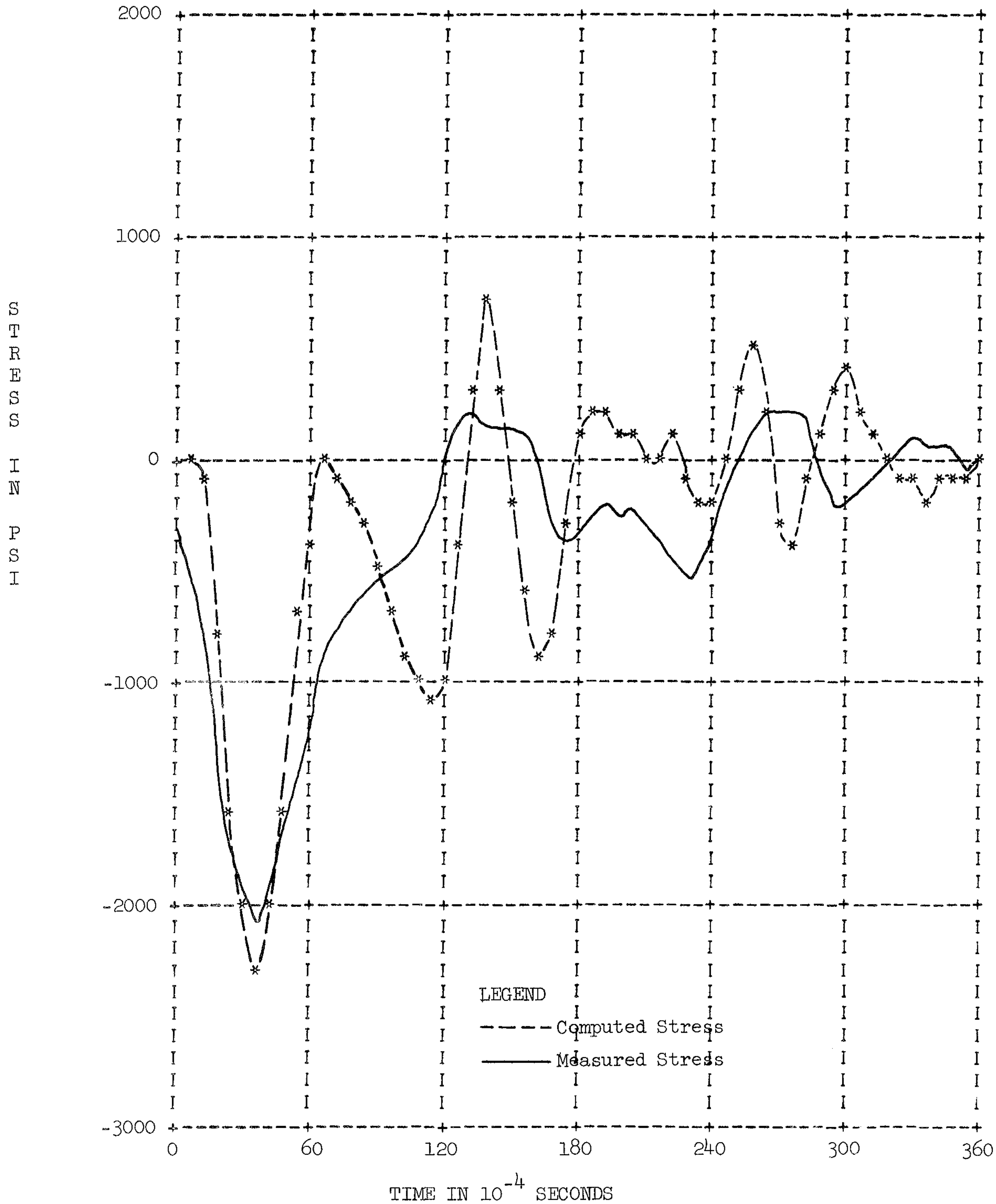


FIGURE 20. Stress in Pile Head vs Time
Test Pile 3, 45' Penetration in Ground

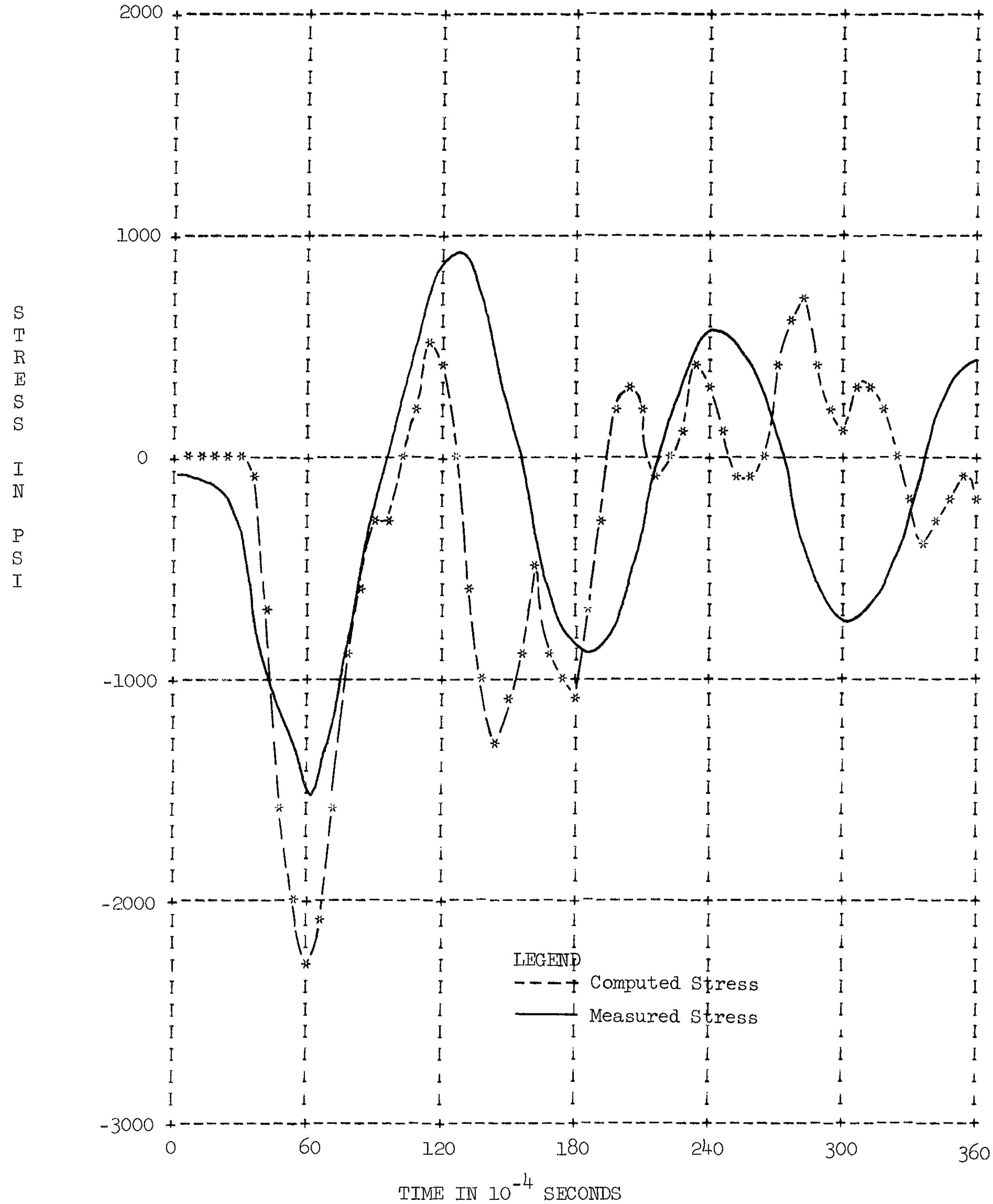


FIGURE 21. Stress at Mid-Length of Pile vs Time
Test Pile 3, 45' Penetration in Ground

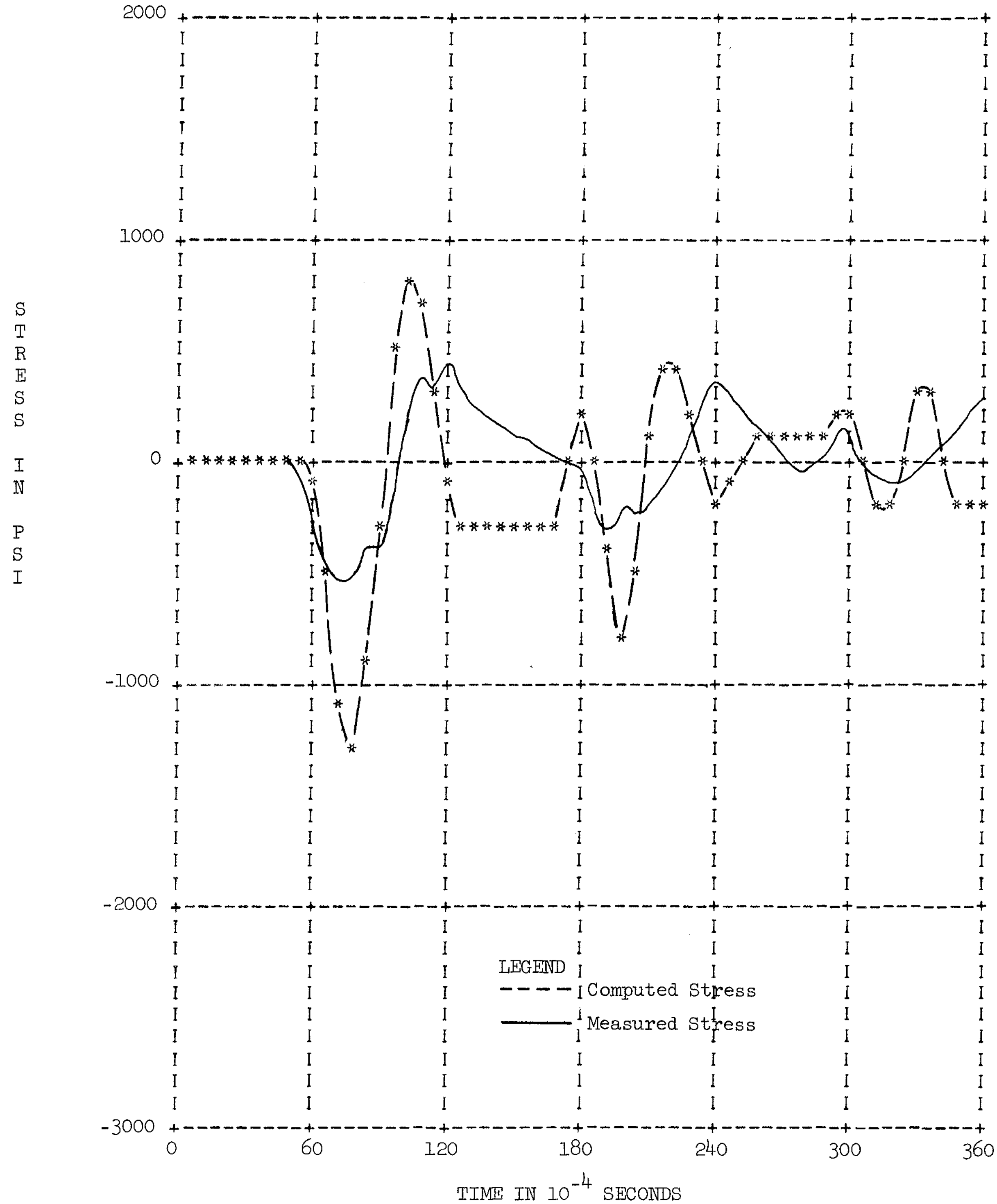


FIGURE 22. Stress in Tip of Pile $\frac{vs}{}$ Time

Test Pile 3, 45' Penetration in Ground

CONCLUSIONS

As a result of this field study of the internal stresses in long prestressed concrete piles during driving and the comparison of this field data with values from the computer program, the following conclusions are offered:

1. Maximum compressive stresses occurred at the head of these piles when a great resistance to penetration was encountered. Measured values ranged from 2000 to 3000 psi.

2. Maximum tensile stresses were found to occur in the lower half of these piles when the piles had little soil resistance. Measured values ranged from 900 to 1350 psi. The actual tensile stress in the concrete is obtained by subtracting the prestressing force of about 800 psi from these measured values.

3. In view of the large number of unknown variables such as the dynamic properties of the soil, concrete, and wood materials which influence the theoretical calculations, the computer correlation with the field data was considered very encouraging. In general, the computed stresses were in good agreement with the measured values.

4. By using judicious engineering estimates of the dynamic properties of the materials involved, the computer program can be used to perdict the maximum compressive and tensile stresses to be expected during driving.

5. Additional research is needed to fully develop the use of the wave equation for analyzing a variety of pile problems. Little is known about the true energy outputs of various pile hammers and about the dynamic properties of various foundation media.

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APPENDIX "A"

TEST PILE STRESS DATA

Test Pile 1

Depth of Pile in Ground Feet	Average Penetration per Blow Inches	Computed Hammer Drop Feet	(-) Compression and (+) Tension Stresses in Prestressed Concrete Pile Head	Center	Tip
			-1922	-1513	- 777
48-			+ 573	+941	+ 286
			-2044	-1513	- 859
		4.69	+ 654	+ 982	+ 368
			-1840	-1350	- 777
		4.35	+ 450	+ 900	+ 327
			-2045	-1472	- 818
		4.52	+ 573	+ 900	+ 286
			-2045	-1595	- 818
		4.61	+ 450	+ 900	+ 368
			-2004	-1472	- 818
		4.44	+ 450	+ 900	+ 368
			-2045	-1472	- 859
		4.69	+ 491	+ 982	+ 409
			-1992 Avg.	-1484 Avg.	- 818 Avg.
		4.55 Avg.	+ 520 Avg.	+ 929 Avg.	+ 344 Avg.
			-1922	-1350	- 736
48			+ 573	+ 982	+ 491
			-1922	-1432	- 859
		4.27	+ 532	+ 941	+ 368
			-1595	-1104	- 573
		3.63	+ 368	+ 695	+ 327
			-1813 Avg.	-1295 Avg.	- 723 Avg.
		3.95 Avg.	+ 491 Avg.	+ 873 Avg.	+ 395 Avg.
			-1759	-1391	- 654
48-51			+ 573	+ 818	+ 450
			-1840	-1350	- 654
		4.44	+ 695	+1145	+ 450
			-1800	-1350	- 818
		4.19	+ 654	+ 859	+ 450

Test Pile 1 (Continued)

Depth of Pile in Ground Feet	Average Penetration per Blow Inches	Computed Hammer Drop Feet	(-) Compression and (+) Tension Stresses in Prestressed Concrete Pile Head	Center	Tip
48-51 (Cont.)		3.82	-1718 + 490	-1432 + 695	- 818 + 204
		4.15 Avg.	-1779 Avg. + 603 Avg.	-1381 Avg. + 879 Avg.	- 736 Avg. + 388 Avg.
51			-2045 + 777	-1472 +1022	- 532 + 450
		5.27	-2086 + 573	-1759 + 859	- 532 + 409
		4.44	-1963 + 491	-1391 + 859	- 736 + 409
		4.27	-1800 + 409	-1472 + 818	- 777 + 409
		4.44	-2045 + 450	-1413 + 859	- 777 + 368
		4.11	-1881 + 450	-1432 + 777	- 695 + 409
		4.44	-1881 + 532	-1472 + 941	- 777 + 450
		4.27	-1840 + 491	-1350 + 859	- 736 + 368
		4.27	-1881 + 654	-1513 +1063	- 818 + 491
		4.61	-2085 + 491	-1636 +941	- 818 + 450
		4.35	-1881 + 532	-1472 + 859	- 695 + 409
		4.45 Avg.	-1944 Avg. + 532 Avg.	-1498 Avg. + 896 Avg.	- 718 Avg. + 420 Avg.
55	1.57		-1881 + 736	-1309 + 982	- 818 + 368
		4.61	-1881 + 573	-1391 + 982	- 777 + 286

Test Pile 1 (Continued)

Depth of Pile in Ground Feet	Average Penetration per Blow Inches	Computed Hammer Drop Feet	(-) Compression and (+) Tension Stresses in Prestressed Concrete Pile Head	Center	Tip
55 (Cont.)	1.57	4.61	-1963 + 573	-1472 + 982	- 818 + 368
		4.52	-1963 + 573	-1513 + 982	- 859 + 409
		4.70	-2086 + 491	-1677 + 859	- 818 + 327
		4.19	-1800 + 573	-1391 + 700	- 777 + 327
		4.27	-1800 + 573	-1391 + 982	- 736 + 409
		4.44	-2004 + 491	-1595 + 982	- 859 + 286
		4.48 Avg.	-1922 Avg. + 573 Avg.	-1467 Avg. + 931 Avg.	- 808 Avg. + 348 Avg.
55	1.57		-2045 ----	-1718 + 982	- 900 + 368
		5.05	-1963 + 409	-1636 +1022	- 900 + 409
		5.23	-2086 + 327	-1800 + 982	- 900 + 532
		5.14 Avg.	-2031 Avg. + 368 Avg.	-1718 Avg. + 995 Avg.	- 900 Avg. + 436 Avg.
59	1.03		-1963 + 368	-1636 + 941	- 859 + 409
		4.70	-1800 + 327	-1513 + 900	- 777 + 368
		4.78	-1963 + 409	-1595 +1022	- 859 + 368
		4.74 Avg.	-1909 Avg. + 368 Avg.	-1581 Avg. + 954 Avg.	- 832 Avg. + 382 Avg.

Test Pile 1 (Continued)

Depth of Pile in Ground Feet	Average Penetration per Blow Inches	Computed Hammer Drop Feet	(-) Compression and (+) Tension Stresses in Prestressed Concrete Pile Psi Head	Center	Tip
			-1922	-1636	- 736
63	1.18		+ 409	+1022	+ 409
			-1718	-1391	- 613
		4.35	+ 163	+ 818	+ 368
			-1963	-1595	- 695
		4.87	+ 368	+ 941	+ 409
			-1868 Avg.	-1541 Avg.	- 681 Avg.
		4.61 Avg.	+ 313 Avg.	+ 927 Avg.	+ 395 Avg.
			-1595	-1472	- 654
63+	1.18		+ 368	+ 900	+ 327
			-1677	-1432	- 614
		4.87	+ 409	+1022	+ 409
			-1636 Avg.	-1452 Avg.	- 634 Avg.
		4.87 Avg.	+ 388 Avg.	+ 961 Avg.	+ 368 Avg.
			-1636	-1432	- 695
68	.781		+ 204	+ 613	+ 41
			-1636	-1432	+ 614
		4.35	+ 164	+ 550	+ 41
			-1759	-1595	- 736
		4.96	+ 245	+ 614	+ 41
			-1677 Avg.	-1486 Avg.	- 682 Avg.
		4.66 Avg.	+ 204 Avg.	+ 592 Avg.	+ 41 Avg.
			-1677	-1431	- 859
68.5	.638		+ 41	+ 245	+ 450
			-1759	-1472	- 941
		5.14	+ 82	+ 245	+ 450
			-1718	-1472	- 941
		4.78	+ 123	+ 245	+ 532
			-1718 Avg.	-1458 Avg.	- 914 Avg.
		4.96 Avg.	+ 82 Avg.	+ 245 Avg.	+ 477 Avg.

Test Pile 1 (Continued)

Depth of Pile in Ground Feet	Average Penetration per Blow Inches	Computed Hammer Drop Feet	(-) Compression and (+) Tension Stresses in Prestressed Concrete Pile Psi Head	Center	Tip
			-1718	-1472	- 941
69	.495		+ 82	+ 0	+ 450
			-1800	-1413	- 900
		5.23	+ 123	+ 41	+ 450
			-1759	-1513	- 859
		5.14	+ 123	+ 82	+ 532
			-1759 Avg.	-1499 Avg.	- 900 Avg.
		5.18 Avg.	+ 109 Avg.	+ 41 Avg.	+ 477 Avg.
			-1840	-1636	-1022
69.7	.298		+ 409	+ 0	+ 736
			-1840	-1636	-1022
		5.51	+ 123	+ 0	+ 736
			-1718	-1554	- 941
		5.23	+ 41	+ 41	+ 695
			-1799 Avg.	-1609 Avg.	- 995 Avg.
		5.38 Avg.	+ 191 Avg.	+ 14 Avg.	+ 722 Avg.
			-1513	-1432	- 941
71	.075		+ 41	+ 41	+ 573
			-1432	-1350	- 859
		4.61	+ 0	+ 0	+ 532
			-1513	-1432	- 982
		4.96	+ 0	+ 0	+ 614
			-1486 Avg.	-1405 Avg.	- 927 Avg.
		4.78 Avg.	+ 14 Avg.	+ 14 Avg.	+ 573 Avg.
			-2127	-1963	No Record
73.5-	.064		+ 204	+ 409	" "
			-2045	-1922	No Record
		4.96	+ 204	+ 409	" "
			-2086 Avg.	-1942 Avg.	No Record
		4.96 Avg.	+ 204 Avg.	+ 409 Avg.	" "

Test Pile 1 (Continued)

Depth of Pile in Ground Feet	Average Penetration per Blow Inches	Computed Hammer Drop Feet	(-) Compression and (+) Tension Stresses in Prestressed Concrete Pile Psi Head	Center	Tip
			-2168	-2045	-1391
73.5	.064		+ 245	+ 450	+ 614
			-2004	-1881	-1350
		4.96	+ 204	+ 409	+ 654
			-2209	-2045	-1391
		5.14	+ 204	+ 450	+ 573
			-2127 Avg.	-1990 Avg.	-1377 Avg.
		5.05 Avg.	+ 204 Avg.	+ 436 Avg.	+ 614 Avg.
			-2413	-2168	-1432
74.8	.079		+ 245	+ 614	+ 491
			-2413	-2127	-1432
		5.23	+ 286	+ 654	+ 532
			-2290	-2086	-1350
		5.05	+ 246	+ 614	+ 450
			-2372 Avg.	-2127 Avg.	-1405 Avg.
		5.14 Avg.	+ 259 Avg.	+ 627 Avg.	+ 491 Avg.

Test Pile 2

Depth of Pile in Ground Feet	Average Penetration per Blow Inches	Computed Hammer Drop Feet	(-) Compression and (+) Tension Stresses in Prestressed Concrete Pile Psi Head	Center	Tip
			-1840	-1840	- 695
34			+ 286	+ 982	+ 409
			-1595	-1472	- 695
		4.44	+ 409	+1350	+ 409
			-1432	-1677	- 695
		4.44	+ 409	+ 941	+ 368
			-1595	-1595	- 654
		4.19	+ 368	+1104	+ 409
			-1636	-1636	- 654
		4.34	+ 409	+1104	+ 614
			-1620 Avg.	-1644 Avg.	- 679 Avg.
		4.35 Avg.	+ 376 Avg.	+1096 Avg.	+ 442 Avg.
			-1309	-1309	- 409
42			+ 286	+ 900	+ 409
			-1513	-1391	- 572
		3.95	+ 286	+1186	+ 409
			-1391	-1432	- 654
		4.106	+ 286	+1022	+ 286
			-1350	-1350	- 532
		3.95	+ 286	+ 982	+ 368
			-1022	-1486	- 532
		3.26	+ 123	+ 532	+ 0
			-1317 Avg.	-1334 Avg.	- 540 Avg.
		3.82 Avg.	+ 253 Avg.	+ 924 Avg.	+ 294 Avg.
			-1104	-1145	- 573
49	2.77		+ 163	+ 900	+ 163
			-982	- 982	- 450
		3.19	+163	- 654	+ 0
			-1186	-1145	- 409
		3.56	+ 163	+ 859	+ 245
			-1227	-1227	- 450
		3.56	+ 204	+ 818	+ 245

Test Pile 2 (Continued)

Depth of Pile in Ground Feet	Average Penetration per Blow Inches	Computed Hammer Drop Feet	(-) Compression and (+) Tension Stresses in Prestressed Concrete Pile Psi Head	Center	Tip
49 (Continued)		3.63	-1267 + 164	-1268 + 818	- 409 + 245
		3.48 Avg.	-1353 Avg. + 171 Avg.	-1153 Avg. + 810 Avg.	- 458 Avg. + 180 Avg.
55	1.77		-1068 + 164	-1145 + 777	- 368 + 245
		3.48	-1145 + 245	-1227 + 818	- 491 + 286
		3.26	-1063 + 164	-1145 + 695	- 449 + 286
		3.37 Avg.	-1092 Avg. + 191 Avg.	-1172 Avg. + 763 Avg.	- 436 Avg. + 272 Avg.
58	1.41		-1145 + 204	-1268 + 858	- 573 + 164
		3.56	-1186 + 245	-1268 + 900	- 450 + 204
		3.79	-1268 + 204	-1268 + 900	- 532 + 204
		3.68 Avg.	-1200 Avg. + 218 Avg.	-1268 Avg. + 886 Avg.	- 518 Avg. + 191 Avg.
63-	1.34		-1227 + 245	-1390 + 818	No Record " "
		3.63	-1186 + 204	-1268 + 859	No Record " "
		3.63 Avg.	-1206 Avg. + 224 Avg.	-1329 Avg. + 838 Avg.	No Record " "
63	1.34		-1309 + 164	-1432 + 900	- 695 + 164
		3.94	-1350 + 245	-1432 + 982	- 654 + 245
		3.63	-1268 + 164	- 1268 + 941	- 500 + 327
		3.87	-1350 + 164	-1432 + 982	- 614 + 245
		3.81 Avg.	-1319 Avg. + 184 Avg.	-1391 Avg. + 951 Avg.	- 616 Avg. + 245 Avg.

Test Pile 2 (Continued)

Depth of Pile in Ground Feet	Average Penetration per Blow Inches	Computed Hammer Drop Feet	(-) Compression and(+) Tension Stresses in Prestressed Concrete Pile Psi Head	Center	Tip
			-1513	-1432	- 491
67	1.28		+ 327	+ 859	+ 327
			-1350	-1432	- 450
		4.02	+ 327	+ 859	+ 368
			-1350	-1432	- 532
		3.94	+ 327	+ 941	+ 204
			-1350	-1432	- 450
		3.87	+ 286	+ 859	+ 164
			-1391 Avg.	-1432 Avg.	- 481 Avg.
		3.94 Avg.	+ 317 Avg.	+ 880 Avg.	+ 266 Avg.
			-1350	-1513	- 777
68	1.04		+ 286	+ 818	+ 0
			-1554	-1718	- 736
		4.44	+ 327	+ 982	+ 123
			-1554	-1595	- 695
		4.35	+ 327	+ 941	+ 0
			-1486 Avg.	-1609 Avg.	- 736 Avg.
		4.40 Avg.	+ 313 Avg.	+ 914 Avg.	+ 41 Avg.

Test Pile 3

Depth of Pile in Ground Feet	Average Penetration per Blow Inches	Computed Hammer Drop Feet	(-)Compression and (+) Tension Stresses in Prestressed Concrete Pile Head	Center	Tip
			-1196	- 736	- 337
7			+ 215	+ 153	+ 61
			-1810	-1350	- 706
		5.46	+ 0	+ 429	+ 215
			-1779	-1319	- 708
		5.60	+ 92	+ 552	+ 276
			-2086	-1538	- 859
		5.41	+ 185	+ 552	+ 123
			-2147	-1564	- 828
		4.87	+ 276	+ 828	+ 276
			-2024	-1508	- 767
		4.35	+ 123	+ 644	+ 184
			-1840 Avg.	-1336 Avg.	- 700 Avg.
		5.14 Avg.	+ 148 Avg.	+ 526 Avg.	+ 189 Avg.
			-2055	-1656	- 859
			+ 123	+ 675	+ 184
			-2209	-2237	-828
		4.96	+ 245	+ 736	+ 276
			-1994	-1595	- 798
		5.27	+ 123	+ 675	+ 245
			-2086 Avg.	-1829 Avg.	- 828 Avg.
		5.12 Avg.	+ 164 Avg.	+ 695 Avg.	+ 235 Avg.
			-2270	-1595	- 920
10			+ 215	+ 767	+ 153
			-2178	-1718	- 920
		4.96	+ 153	+ 644	+ 153
			-2116	-1656	- 831
		4.87	+ 123	+ 644	+ 153
			-2188 Avg.	-1656 Avg.	- 890 Avg.
		4.92 Avg.	+ 164 Avg.	+ 685 Avg.	+ 153 Avg.

Test Pile 3 (Continued)

Depth of Pile in Ground Feet	Average Penetration per Blow Inches	Computed Hammer Drop Feet	(-) Compression and (+) Tension Stresses in Prestressed Concrete Pile Psi Head	Center	Tip
			-2209	-1718	- 767
12			+ 154	+ 736	+ 163
			-2055	-1595	- 736
		4.52	+ 0	+ 644	+ 61
			-2395	-1810	- 890
		4.96	+ 184	+ 798	+ 245
			-2220 Avg.	-1708 Avg.	- 798 Avg.
		4.74 Avg.	+ 113 Avg.	+ 726 Avg.	+ 156 Avg.
			-1840	-1380	- 521
17	1.338		+ 184	+ 828	+ 215
			-2055	-1503	- 552
		4.96	+ 245	+ 982	+ 368
			-2239	-1656	- 583
		4.27	+ 307	+ 920	+ 429
			-2209	-1595	- 644
		4.44	+ 307	+ 920	+ 521
			-1963	-1442	- 491
		3.79	+ 184	+ 890	+ 307
			-1871	-1380	- 491
		3.79	+ 215	+ 951	+ 307
			-2030 Avg.	-1493 Avg.	- 547 Avg.
		4.25 Avg.	+ 240 Avg.	+ 915 Avg.	+ 358 Avg.
			-1932	-1442	- 491
35	4.99		+ 154	+ 920	+ 337
			-1932	-1442	- 521
		3.94	+ 184	+ 920	+ 307
			-1932 Avg.	-1442 Avg.	- 506 Avg.
		3.94 Avg.	+ 169 Avg.	+ 920 Avg.	+ 322 Avg.
			-1411	-1043	- 399
40	2.90		+ 31	+ 614	+ 215
			-1350	- 982	- 368
		3.33	+ 0	+ 585	+ 215

Test Pile 3 (Continued)

Depth of Pile in Ground Feet	Average Penetration per Blow Inches	Computed Hammer Drop Feet	(-) Compression and (+) Tension Stresses in Prestressed Concrete Pile Psi Head	Center	Tip
			-1411	-1043	- 368
40 (Cont.)	2.90	3.33	+ 0	+ 552	+ 215
			-1565	-1166	- 429
		3.78	+ 0	+ 675	+ 245
			-1434 Avg.	-1058 Avg.	- 391 Avg.
		3.48 Avg.	+ 8 Avg.	+ 606 Avg.	+ 222 Avg.
			-2178	-1626	- 583
45	2.81		+ 153	+ 859	+ 399
			-2117	-1564	- 583
		4.19	+ 153	+ 859	+ 368
			-2178	-1656	- 583
		4.19	+ 153	+ 859	+ 429
			-2086	-1595	- 614
		4.27	+ 153	+ 859	+ 399
			-2177	-1595	- 552
		4.11	+ 215	+ 890	+ 368
			-2147	-1595	- 521
		4.19	+ 153	+ 890	+ 398
			-2147 Avg.	-1605 Avg.	- 573 Avg.
		4.19	+ 163 Avg.	+ 869 Avg.	+ 394 Avg.
			-2239	-1596	- 583
50	2.34		+ 184	+ 951	+ 368
			-1810	-1288	- 491
		3.94	+ 123	+ 828	+ 276
			-1748	-1258	- 429
		3.63	+ 123	+ 706	+ 245
			-1932 Avg.	-1380 Avg.	- 501 Avg.
		3.78 Avg.	+ 143 Avg.	+ 828 Avg.	+ 296 Avg.
			-1748	-1258	- 337
55	1.91		+ 244	+ 736	+ 368
			-2117	-1595	- 552
		4.27	+ 123	+ 798	+ 368

Test Pile 3 (Continued)

Depth of Pile in Ground Feet	Average Penetration per Blow Inches	Computed Hammer Drop Feet	(-) Compression and (+) Tension Stresses In Prestressed Concrete Pile Psi Head	Center	Tip
			-2055	-1539	- 460
55		4.11	+ 153	+ 859	+ 429
(Cont.)			-1973 Avg.	-1463 Avg.	- 450 Avg.
		4.19 Avg.	+ 173 Avg.	+ 807 Avg.	+ 388 Avg.
			-2147	-1626	- 552
60	1.60		+ 123	+ 859	+ 276
			-2086	-1564	- 521
		4.02	+ 92	+ 767	+ 337
			-2123	-1534	- 491
		4.16	+ 153	+ 828	+ 337
			-2119 Avg.	-1575 Avg.	- 521 Avg.
		4.09 Avg.	+ 123 Avg.	+ 818 Avg.	+ 317
			-2178	-1595	- 523
65	1.61		+ 61	+ 800	+ 307
			-2178	-1564	- 521
		4.35	+ 61	+ 923	+ 339
			-2055	-1503	- 461
		4.02	+ 92	+ 828	+ 307
			-2137 Avg.	-1554 Avg.	- 502 Avg.
		4.18 Avg.	+ 71 Avg.	+ 850 Avg.	+ 318 Avg.
			-2147	-1595	- 491
67	.89		+ 123	+ 828	+ 337
			-2055	-1534	- 491
		4.11	+ 123	+ 828	+ 307
			-1994	-1503	- 460
		3.94	+ 123	+ 767	+ 307
			-2065 Avg.	-1544 Avg.	- 480 Avg.
		4.02 Avg.	+ 123 Avg.	+ 808 Avg.	+ 317 Avg.
			-2117	-1564	- 583
68	.46		+ 61	+ 675	+ 92
			-2209	-1656	- 644
		4.27	+ 61	+ 736	+ 92

Test Pile 3 (Continued)

Depth of Pile in Ground Feet	Average Penetration per Blow Inches	Computed Hammer Drop Feet	(-) Compression and (+) Tension Stresses in Prestressed Concrete Pile Psi Head	Center	Tip
			-1994	-1534	- 583
68 (Cont.)		4.35	+ 61	+ 675	+ 61
			-1718	-1319	- 521
		3.79	+ 31	+ 491	+ 31
			-2010 Avg.	-1518 Avg.	- 583 Avg.
		4.14	+ 54 Avg.	+ 644 Avg.	+ 69 Avg.
			-1994	-1503	- 399
68	.46		+ 31	+ 521	+ 61
			-2178	-1656	- 767
		4.65	+ 0	+ 644	+ 61
			-2806	-1595	- 828
		4.19	+ 0	+ 491	+ 92
			-2326 Avg.	-1585 Avg.	- 665 Avg.
		4.42 Avg.	+ 10 Avg.	+ 552 Avg.	+ 71 Avg.
			-2270	-1687	- 890
69	.233		+ 0	+ 614	+ 123
			-2147	-1626	+ 828
		4.52	+ 0	+ 552	+ 153
			-2031	-1534	- 800
		4.19	+ 0	+ 429	+ 153
			-2149 Avg.	-1616 Avg.	- 839 Avg.
		4.36 Avg.	+ 0 Avg.	+ 532 Avg.	+ 143 Avg.
			-2883	-2117	-1104
70	.135		+ 0	+ 644	+ 276
			-2822	-2055	-1166
		5.14	+ 0	+ 644	+ 276
			-2577	-1871	- 982
		5.23	+ 0	+ 521	+ 368
			-2761 Avg.	-2014 Avg.	-1084 Avg.
		5.12 Avg.	+ 0 Avg.	+ 603 Avg.	+ 307 Avg.

Test Pile 3 (Continued)

Depth of Pile in Ground Feet	Average Penetration per Blow Inches	Computed Hammer Drop Feet	(-) Compression and (+) Tension Stresses in Prestressed Concrete Pile Psi Head	Center	Tip
			-2853	-2086	-1104
70	.135		+ 31	+ 583	+ 368
			-3006	-2178	-1196
		5.42	+ 0	+ 644	+ 307
			-2930 Avg.	-2132 Avg.	-1150 Avg.
		5.42 Avg.	+ 16 Avg.	+ 614 Avg.	+ 338 Avg.
			-2239	-1877	-1105
70	.135		+ 92	+ 429	+ 429
			-2362	-1748	-1012
		4.52	+ 0	+ 307	+ 429
			-2178	-1656	- 951
		4.44	+ 31	+ 307	+ 460
			-2260 Avg.	-1760 Avg.	-1022 Avg.
		4.48 Avg.	+ 41 Avg.	+ 348 Avg.	+ 439 Avg.
			-2209	-1779	-1196
74	.055		+ 61	+ 337	522
			-2055	-1687	-1043
		4.44	+ 31	+ 276	+ 521
			-2239	-1840	-1196
		4.52	+ 31	+ 276	+ 583
			-2168 Avg.	-1769 Avg.	-1145 Avg.
		4.48 Avg.	+ 41 Avg.	+ 296 Avg.	+ 542 Avg.
			-3116		
74	.055			+ 409	
			-2178	-1779	-1166
74	.055		- 61	+ 276	+ 552
			-2147	-1779	-1166
		4.39	+ 153	+ 154	+ 644
			-2163 Avg.	-1779 Avg.	-1166 Avg.
		4.39 Avg.	+ 107 Avg.	+ 215 Avg.	+ 598 Avg.

Test Pile No. 4

Depth of Pile in Ground Feet	Computed Hammer Drop Feet	Average Penetration per Blow Inches	(-) Compression and (+) Tension Stress in Concrete Pile		
			Gage 1	Gage 2	Gage 4
			-1642	-1486	-1381
20		.923	+ 0	+ 469	+ 573
			-1173	-1512	-1460
	4.18		+ 0	+ 443	+ 599
			-1590	-1407	-1355
	3.86		+ 0	+ 391	+ 521
			-1564	-1355	-1329
	3.94		+ 0	+ 339	+443
			-1329	-1381	-1355
	3.86		+ 0	+ 365	+ 495
			-1460 Avg.	-1428 Avg.	-1376 Avg.
	3.96 Avg.		+ 0 Avg.	+ 401 Avg.	+ 526 Avg.
			-1798	-1433	-1538
23		12.0	+ 0	+ 339	+ 964
			-1746	-1007	-1512
	3.78		+ 0	+ 365	+ 938
			-1694	-1329	-1459
	3.55		+ 0	+ 313	+ 886
			-1746	-1381	-1512
	3.86		+ 0	+ 313	+ 964
			-1746 Avg.	-1288 Avg.	-1505 Avg.
	3.73 Avg.		+ 0 Avg.	+ 333 Avg.	+ 938 Avg.
			-1955	-1642	-1694
46		2.40	+ 0	+ 287	+ 834
			-2007	-1590	-1720
	4.18		+ 0	+ 261	+ 834
			-1954	-1538	-1694
	4.10		+ 0	+ 235	+ 808
			-1972 Avg.	-1590 Avg.	-1703 Avg.
	4.14 Avg.		+ 0 Avg.	+ 261 Avg.	+ 825 Avg.

Test Pile No. 4 (Continued)

Depth of Pile in Ground Feet	Computed Hammer Drop Feet	Average Penetration per Blow Inches	(-) Compression and (+) Tension Stress in Concrete Pile Gage 1	Gage 2	Gage 4
			-1929	-1486	-1642
50		.308	+ 0	+ 261	+ 782
			-2007	-1512	-1694
	4.26		+ 0	+ 182	+ 626
			-1928	-1511	-1642
	4.18		+ 0	+ 182	+ 678
			-1824	-1381	-1564
	4.18		+ 0	+ 313	+ 678
			-2007	-1564	-1694
	4.26		+ 0	+ 156	+ 626
			-1939 Avg.	-1491 Avg.	-1647 Avg.
	4.22 Avg.		+ 0 Avg.	+ 219 Avg.	+ 678 Avg.
			-1955	-1460	-1668
52		.154	+ 0	+ 130	+ 521
			-1981	-1538	-1668
	4.18		+ 0	+ 130	+ 547
			-1955	-1512	-1668
	4.26		+ 0	+ 104	+ 547
			-2033	-1512	-1720
	4.26		+ 0	+ 182	+ 599
			-1981 Avg.	-1506 Avg.	-1681 Avg.
	4.23 Avg.		+ 0 Avg.	+ 137 Avg.	+ 554 Avg.
			-2033	-1460	-1694
53		.138	+ 0	+ 104	+ 391
			-1981	-1512	-1694
	4.43		+ 0	+ 130	+ 495
			-1981	-1538	-1642
	4.43		+ 0	+ 26	+ 391
			-1929	-1433	-1668
	4.26		+ 0	+ 104	+ 391

Test Pile No. 4 (Continued)

Depth of Pile in Ground Feet	Computed Hammer Drop Feet	Average Penetration per Blow Inches	(-) Compression and (+) Tension Stress in Concrete Pile Gage 1	 Gage 2	 Gage 4
53 (Cont.)			-2059	-1564	-1772
	4.43		+ 0	+ 130	+ 469
			-1997 Avg.	-1501 Avg.	-1694 Avg.
	4.39 Avg.		+ 0 Avg.	+ 99 Avg.	+ 427 Avg.
			-1981	-1590	-1746
54		.190	+ 0	+ 208	+ 443
			-2007	-1590	-1772
	4.43		+ 0	+ 208	+ 443
			-1928	-1512	-1772
	4.35		+ 0	+ 208	+ 417
			-1929	-1564	-1720
	4.35		+ 0	+ 313	+ 521
			-1961 Avg.	-1564 Avg.	-1753 Avg.
	4.38 Avg.		+ 0 Avg.	+ 234 Avg.	+ 456 Avg.
			-1668	-1668	-1720
55		.247	+ 0	+ 235	+ 678
			-1668	-1668	-1772
	4.10		+ 0	+ 261	+ 704
			-1590	-1668	-1668
	4.02		+ 0	+ 417	+ 626
			-1694	-1772	-1772
	4.02		+ 0	+ 443	+ 626
			-1642	-1642	-1720
	3.94		+ 0	+ 469	+ 678
			-1590	-1564	-1668
	4.02		+ 0	+ 469	+ 652
			-1668	-1668	-1720
	4.02		+ 0	+ 495	+ 704
			-1645 Avg.	-1664 Avg.	-1720 Avg.
	4.02 Avg.		+ 0 Avg.	+ 398 Avg.	+ 668 Avg.

Test Pile No. 4 (Continued)

Depth of Pile in Ground Feet	Computed Hammer Drop Feet	Average Penetration per Blow Inches	(-) Compression and (+) Tension Stress in Concrete Pile Gage 1	Gage 2	Gage 4
56		.308	-1642 + 0	-1642 + 469	-1694 + 704
	4.10		-1642 + 0	-1642 + 521	-1668 + 704
	3.94		-1642 + 0	-1642 + 573	-1772 + 704
	3.78		-1616 + 0	-1668 + 495	-1720 + 626
	3.86		-1564 + 0	-1564 + 521	-1668 + 678
	4.26		-1772 + 0	-1772 + 573	-1824 + 834
	4.18		-1824 + 0	-1824 + 573	-1876 + 782
	4.02 Avg.		-1672 Avg. + 0 Avg.	-1679 Avg. + 532 Avg.	-1746 Avg. + 719 Avg.
57		.353	-1746 + 0	-1668 + 521	-1694 + 886
	4.10		-1746 + 0	-1668 + 521	-1694 + 886
	4.18		-1720 + 0	-1642 + 469	-1720 + 886
	4.18		-1694 + 0	-1694 + 521	-1694 + 938
	4.18		-1824 + 0	-1772 + 521	-1746 + 964
	4.35		-1824 + 0	-1824 + 521	-1746 + 938
	4.20 Avg.		-1759 Avg. + 0 Avg.	-1711 Avg. + 512 Avg.	-1716 Avg. + 916 Avg.

Test Pile No. 4 (Continued)

Depth of Pile in Ground Feet	Computed Hammer Drop Feet	Average Penetration per Blow Inches	(-) Compression and (+) Tension Stress in Concrete Pile		
			Gage 1	Gage 1	Gage 4
			- 938	- 990	- 886
65		.571	+ 0	+ 156	+ 261
			-1042	-1042	- 990
	3.48		+ 0	+ 182	+ 261
			-1121	-1147	-1042
	3.63		+ 0	+ 261	+ 417
			-1016	-1095	- 064
	3.40		+ 0	+ 156	+ 521
			-1029 Avg.	-1069 Avg.	-0745 Avg.
	3.50 Avg.		+ 0 Avg.	+ 189 Avg.	+ 365 Avg.
			-1876	-1955	-2007
66		.364	+ 0	+ 443	+ 417
			-1824	-1876	-1929
	4.78		+ 0	+ 313	+ 417
			-1850	-1929	-1981
	4.60		+ 0	+ 339	+ 417
			-1850 Avg.	-1920 Avg.	-1972 Avg.
	4.69 Avg.		+ 0 Avg.	+ 365 Avg.	+ 417 Avg.
			-1903	-1929	-1981
69		.104	+ 0	+ 313	+ 365
			-1903	-1981	-2085
	4.69		+ 0	+ 417	+ 417
			-1929	-1981	-2085
	4.78		+ 0	+ 443	+ 417
			-1912 Avg.	-1964 Avg.	-2050 Avg.
	4.74 Avg.		+ 0 Avg.	+ 391 Avg.	+ 399 Avg.

Test Pile No. 5

Depth of Pile in Ground	Computed Hammer Drop	Average Penetration per Blow	(-) Compression and (+) Tension Stress in Concrete Pile			
			P/A Stress		Mc/I Stress	
			Gages 1 and 2	Gages 3 and 4	Gages 1 and 2	Gages 3 and 4
Feet	Feet	Inches				
			-1442	-1215	- 180	- 289
5			+ 0	+ 665	+ 0	+ 306
			-1537	-1279		
	3.86		+ 0	+ 719		
			-1577	-1293	- 252	- 288
	3.78		+ 0	+ 719	+ 0	+ 288
			-1628	-1373	- 216	- 324
	3.94		+ 0	+ 783	+ 0	+ 270
			-1642	-1361	- 234	- 342
	3.94		+ 0	+ 783	+ 0	+ 270
			-1565 Avg.	-1304 Avg.	- 221 Avg.	- 311 Avg.
	3.88 Avg.		+ 0 Avg.	+ 734 Avg.	+ 0 Avg.	+ 284 Avg.
			-1628	-1375	- 198	- 343
10		1.00	+ 0	+ 785	+ 0	+ 306
			-1547	-1299	- 180	- 397
	3.70		+ 0	+ 731	+ 0	+ 270
			-1559	-1363	- 162	- 378
	3.78		+ 0	+ 769	+ 0	+ 252
			-1578 Avg.	-1346 Avg.	- 180 Avg.	- 373 Avg.
	3.74 Avg.		+ 0 Avg.	+ 762 Avg.	+ 0 Avg.	+ 276 Avg.
			-1509	-1205	- 198	- 343
15		3.00	+ 0	+ 733	+ 0	+ 306
			-1509	-1219	- 198	- 361
	3.70		+ 0	+ 773	+ 0	+ 273
			-1535	-1245	- 162	- 378
	3.63		+ 0	+ 747	+ 0	+ 252
			-1615	-1337	- 234	- 379
	3.78		+ 0	+ 933	+ 0	+ 361
			-1615	-1335	- 234	- 342
	3.70		+ 0	+ 787	+ 0	+ 342
			-1557 Avg.	-1268 Avg.	- 205 Avg.	- 360 Avg.
	3.70 Avg.		+ 0 Avg.	+ 795 Avg.	+ 0 Avg.	+ 307 Avg.

Test Pile No. 5 (Continued)

Depth of Pile in Ground	Computed Hammer Drop	Average Penetration per Blow	(-) Compression and (+) Tension Stress in Concrete Pile			
			P/A Stress		Mc/I Stress	
			Gages 1 and 2	Gages 3 and 4	Gages 1 and 2	Gages 3 and 4
Feet	Feet	Inches				
			-1690	-1391	- 162	- 414
20		.705	+ 0	+ 731	+ 0	+ 270
			-1664	-1351	- 162	- 397
	4.02		+ 0	+ 783	+ 0	+ 270
			-1559	-1299	- 162	- 397
	3.78		+ 0	+ 665	+ 0	+ 252
			-1638 Avg.	-1347 Avg.	- 162 Avg.	- 403 Avg.
	3.90 Avg.		+ 0 Avg.	+ 726 Avg.	+ 0 Avg.	+ 264 Avg.
			-1612	-1327	- 162	- 433
25-35		4.00	+ 0	+ 769	+ 0	+ 252
		to	-1785	-1457	- 217	- 432
	4.10	8.00	+ 0	+ 903	+ 0	+ 289
			-1747	-1407	- 235	- 469
	3.94		+ 0	+ 871	+ 0	+ 315
			-1835	-1497	- 181	- 450
	3.94		+ 0	+ 862	+ 0	+ 270
			-1718	-1405	- 198	- 432
	3.94		+ 0	+ 836	+ 0	+ 270
			-1656	-1339	- 252	- 415
	3.86		+ 0	+ 719	+ 0	+ 288
			-1547	-1310	- 180	- 445
	3.63		+ 0	+ 653	+ 0	+ 270
			-1700 Avg.	-1392 Avg.	- 204 Avg.	- 439 Avg.
	3.90 Avg.		+ 0 Avg.	+ 802 Avg.	+ 0 Avg.	+ 279 Avg.
			-1626	-1367	- 180	- 451
40		2.00	+ 0	+ 639	+ 0	+ 252
			-1638	-1379	- 162	- 433
	3.94		+ 0	+ 625	+ 0	+ 234
			-1632 Avg.	-1373 Avg.	- 171 Avg.	- 442 Avg.
	3.94 Avg.		+ 0 Avg.	+ 632 Avg.	+ 0 Avg.	+ 243 Avg.

Test Pile No. 5 (Continued)

Depth of Pile in Ground	Computed Hammer Drop	Average Penetration per Blow	(-) Compression and (+) Tension Stress in Concrete Pile			
			P/A Stress		Mc/I Stress	
			Gages 1 and 2	Gages 3 and 4	Gages 1 and 2	Gages 3 and 4
Feet	Feet	Inches				
			-1628	-1365	- 216	- 415
45		2.40	+ 0	+ 573	+ 0	+ 234
			-1572	-1365	- 144	- 415
	3.78		+ 0	+ 677	+ 0	+ 234
			-1652	-1365	- 180	- 415
	3.86		+ 0	+ 667	+ 0	+ 234
			-1617 Avg.	-1365 Avg.	- 180 Avg.	- 415 Avg.
	3.82 Avg.		+ 0 Avg.	+ 639 Avg.	+ 0 Avg.	+ 234 Avg.
			-1799	-1525	- 235	- 486
50		.364	+ 0	+ 519	+ 0	+ 198
			-1785	-1445	- 217	- 450
	4.43		+ 0	+ 547	+ 0	+ 234
			-1825	-1563	- 235	- 468
	4.52		+ 0	+ 559	+ 0	+ 216
			-1825	-1523	- 235	- 450
	4.35		+ 0	+ 545	+ 0	+ 198
			-1809 Avg.	-1514 Avg.	- 231 Avg.	- 464 Avg.
	4.43 Avg.		+ 0 Avg.	+ 543 Avg.	+ 0 Avg.	+ 212 Avg.
			-1737	-1405	- 289	- 432
54		.174	+ 0	+ 324	+ 0	+ 216
			-1843	-1549	- 325	- 450
	4.26		+ 0	+ 421	+ 0	+ 307
			-1789	-1483	- 289	- 432
	4.26		+ 0	+ 368	+ 0	+ 306
			-1790 Avg.	-1479 Avg.	- 301 Avg.	- 438 Avg.
	4.26 Avg.		+ 0 Avg.	+ 371 Avg.	+ 0 Avg.	+ 276 Avg.
			-1747	-1471	- 269	- 450
55		.292	+ 0	+ 352	+ 0	+ 252
			-1706	-1417	- 216	- 414
	4.10		+ 0	+ 364	+ 0	+ 234

Test Pile No. 5 (Continued)

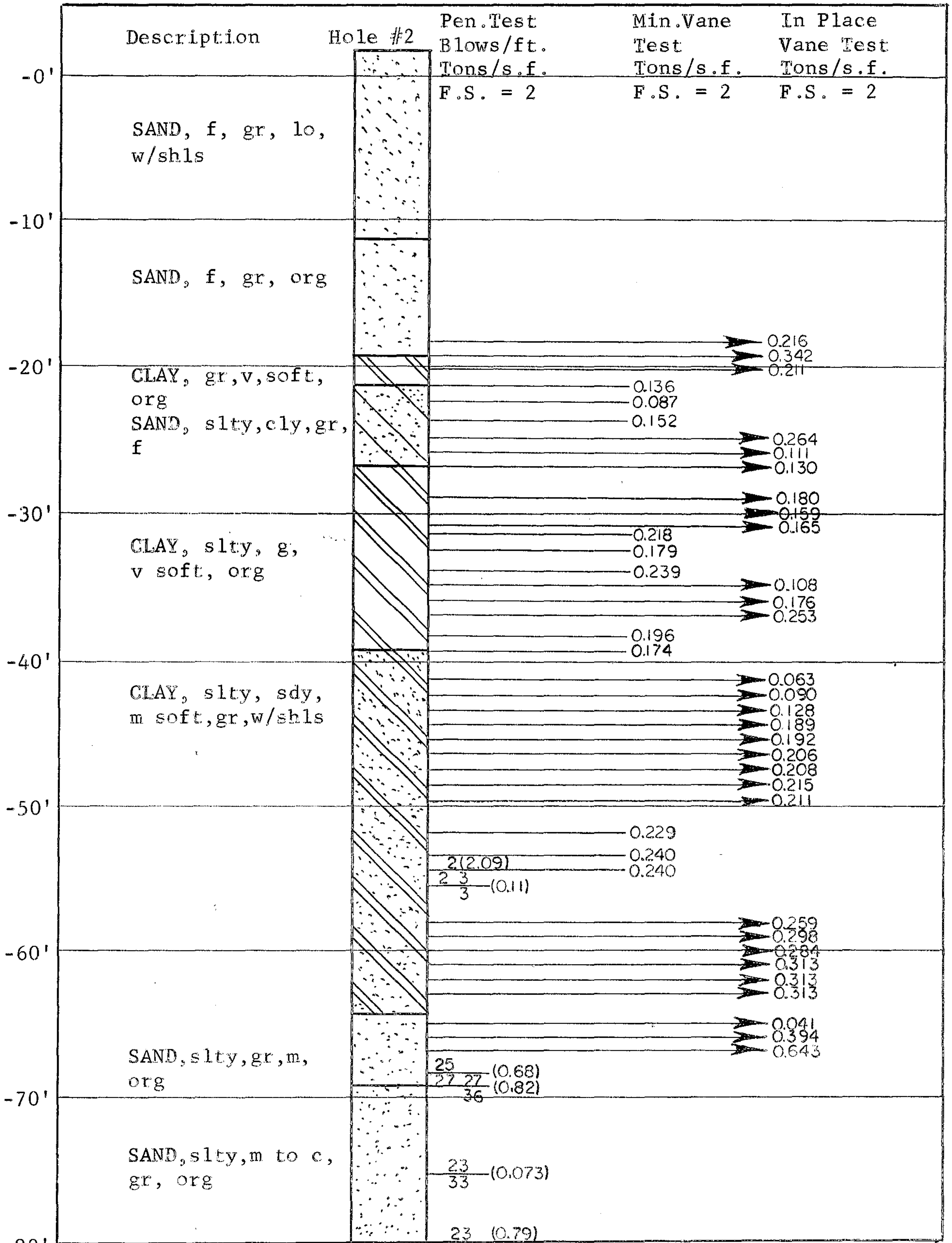
Depth of Pile in Ground	Computed Hammer Drop	Average Penetration per Blow	(-) Compression and (+) Tension Stress in Concrete Pile			
			P/A Stress		Mc/I Stress	
			Gages 1 and 2	Gages 3 and 4	Gages 1 and 2	Gages 3 and 4
Feet	Feet	Inches				
65 (Cont.)			-1403	-1167	- 262	- 361
	4.18		+ 0	+ 406	+ 0	+ 288
			-1527	-1219	- 288	- 361
	4.10		+ 0	+ 461	+ 0	+ 325
			-1741	-1419	- 361	- 450
	4.26		+ 0	+ 637	+ 0	+ 450
			-1555	-1283	- 324	- 343
	4.10		+ 0	+ 489	+ 0	+ 361
			-1555	-1299	- 324	- 397
	4.02		+ 0	+ 513	+ 0	+ 324
			-1547 Avg.	-1263 Avg.	- 314 Avg.	- 373 Avg.
	4.13 Avg.		+ 0 Avg.	+ 495 Avg.	+ 0 Avg.	+ 346 Avg.
			-1873	-1563	- 397	- 364
67		.400	+ 0	+ 503	+ 0	+ 379
			-1927	-1614	- 337	- 467
	4.78		+ 0	+ 529	+ 0	+ 378
			-1939	-1630	- 415	- 487
	4.60		+ 0	+ 517	+ 0	+ 397
			-1901	-1590	- 433	- 503
	4.60		+ 0	+ 569	+ 0	+ 396
			-1910 Avg.	-1599 Avg.	- 396 Avg.	- 455 Avg.
	4.66 Avg.		+ 0 Avg.	+ 530 Avg.	+ 0 Avg.	+ 388 Avg.
			-1951	-1592	- 397	- 505
68		.150	+ 0	+ 449	+ 0	+ 343
			-1965	-1644	- 415	- 505
			+ 0	+ 451	+ 0	+ 379
			-1821	-1487	- 397	- 504
			+ 0	+ 342	+ 0	+ 306
			-1963	-1630	- 379	- 487
	4.69		+ 0	+ 463	+ 0	+ 361
			-1925 Avg.	-1588 Avg.	- 397 Avg.	- 500 Avg.
	4.69 Avg.		+ 0 Avg.	+ 426 Avg.	+ 0 Avg.	+ 347 Avg.

Test Pile No. 5 (Continued)

Depth of Pile in Ground	Computed Hammer Drop	Average Penetration per Blow	(-) Compression and (+) Tension Stress in Concrete Pile			
			P/A Stress		Mc/I Stress	
			Gages 1 and 2	Gages 3 and 4	Gages 1 and 2	Gages 3 and 4
Feet	Feet	Inches				
			-1713	-1405	- 325	- 432
69		.074	+ 0	+ 168	+ 0	+ 216
			-1739	-1471	- 325	- 450
	4.43		+ 0	+ 196	+ 0	+ 252
			-1788	-1563	- 523	- 468
	4.69		+ 0	+ 288	+ 0	+ 270
			-1857	-1511	- 343	- 468
	4.52		+ 0	+ 300	+ 0	+ 252
			-1963	-1604	- 379	- 487
	4.69		+ 0	+ 380	+ 0	+ 288
			-1911	-1616	- 379	- 469
	4.69		+ 0	+ 340	+ 0	+ 141
			-1829 Avg.	-1528 Avg.	- 379 Avg.	- 462 Avg.
	4.60 Avg.		+ 0 Avg.	+ 279 Avg.	+ 0 Avg.	+ 237 Avg.
			-1817	-1499	- 325	- 486
69.5		.059	+ 0	+ 272	+ 0	+ 215
			-1855	-1539	- 307	- 504
	4.69		+ 0	+ 260	+ 0	+ 234
			-1831	-1526	- 343	- 486
	4.78		+ 0	+ 220	+ 0	+ 216
			-1845	-1526	- 361	- 486
	4.52		+ 0	+ 234	+ 0	+ 216
			-1837 Avg.	-1523 Avg.	- 334 Avg.	- 491 Avg.
	4.66 Avg.		+ 0 Avg.	+ 247 Avg.	+ 0 Avg.	+ 220 Avg.
			-1789	-1537	- 289	- 468
70		.052	+ 0	+ 206	+ 0	+ 198
			-1829	-1551	- 307	- 486
	4.60		+ 0	+ 220	+ 0	+ 216
			-1809 Avg.	-1544 Avg.	- 298 Avg.	- 477 Avg.
	4.60 Avg.		+ 0 Avg.	+ 213 Avg.	+ 0 Avg.	+ 207 Avg.

TEST PILE RESISTANCE TO PENETRATION (Continued)

Depth of Pile in Ground Feet	Number of Blows	Hammer Drop Feet	Total Pene-tration Inches	Average Pene-tration Inches	Depth of Pile in Ground Feet	Number of Blows	Hammer Drop Feet	Total Pene-tration Inches	Average Pene-tration Inches
TEST PILE NO. 5 (Continued)									
39	5	4.0	12	2.40					
40	6	4.25	12	2.00					
41	6	4.25	12	2.00					
42	6	4.25	12	2.00					
43	4	4.0	12	3.00					
44	4	4.0	12	3.00					
45	5	4.25	12	2.40					
46	6	4.5	12	2.00					
47	5	4.5	12	2.40					
48	6	4.5	12	2.00					
49	19	4.5	12	.631					
50	33	4.75	12	.364					
52	80	4.75	12	.150					
53	113	4.75	12	.106					
54	69	4.75	12	.174					
55	41	4.75	12	.292					
56	29	4.75	12	.414					
57	25	5.0	12	.480					
58	18	5.0	12	.667					
59	16	5.0	12	.750					
60	16	4.75	12	.750					
61	16	4.75	12	.750					
62	14	4.5	12	.857					
63	14	4.5	12	.857					
64	13	4.75	12	.923					
65	16	4.75	12	.750					
66	19	4.75	12	.633					
66.5	10	4.75	6	.600					
67	15	4.75	6	.400					
67.5	26	4.75	6	.231					
68	40	5.0	6	.150					
68.5	63	5.0	6	.0952					
69	81	5.0	6	.0741					
69.5	102	5.0	6	.0588					
70	116	5.0	6	.0517					
70.5	162	5.25	6	.0371					



APPENDIX "C" DRILLING LOG
Nueces Cty, Nueces Bay Causeway
Control 101-6-36, U204(13); US 181
Bent #58 @ Sta. 930 + 65
Test Hole #2 @ Sta. 930 + 70