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DYNAMIC PILE MONITORING AND PILE LOAD TEST REPORT

PROPOSED DEEP RIVER BRIDGE (WASHINGTON STATE HIGHWAY)

DEEP RIVER, WASHINGTON

FHWA

DEMONSTRATION PROJECTS

FEDERAL HIGHWAY ADMINISTRATION

BRIDGE AND DEMONSTRATION PROJECTS DIVISIONS

WASHINGTON, D.C.

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Federal Highway Administration

Bridge and Demonstration Projects Divisions

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September 1988

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Introduction and Background

Field demonstrations for Demonstration Project 66, "Design and Construction of Driven Pile Foundations," include:

(1) Dynamic pile monitoring by pile analyzer (field computer); and

(2) Static pile load testing using a mobile pile load testing frame.

The equipment and technical assistance are made available to requesting State highway departments and Federal Highway Administration (FHWA) Direct Federal Divisions.

The Washington State Department of Transportation (WSDOT) requested the use of the pile analyzer for the construction stage load test program for the subject project. The static load test was conducted by WSDOT personnel and did not use the Demonstration Project 66 mobile pile load testing frame.

The purpose of the load test program was:

(1) To confirm the design load on the timber and steel pipe composite piles;

(2) to confirm the drivability of these piles; and

(3) to demonstrate the use of newer and more accurate techniques for pile driving construction control.

The load test program will reduce the uncertainties involved in driving piles and may reduce the total length of pile driven. Pile foundation cost savings and increased certainty of pile capacity were the main purposes for this load test program.

The field work was performed over a six week period during June and July 1988. The dynamic load tests were performed by Mr. Herbert Clark, Civil Engineering Technician in the Demonstrations Projects Division of the FHWA. The static load tests were performed by Mr. T. Harrison, Geotechnical Engineer with WSDOT. Mr. Barry Siel, FHWA Highway Engineer Trainee provided assistance in conducting dynamic and static load tests. WSDOT personnel performed wave equation analysis and structural design of the load frame and dead load used as the reaction system. The piling contractor, Quigg Brothers, for the load tests was also the construction piling contractor as the load tests were a part of the main construction contract.

During field testing, informal presentation of dynamic test results and analysis were made to WSDOT engineers. A detailed description of the work performed, test results, data analysis, and recommendations follow in this report. "CAPWAP" (Case Pile Wave Analysis Program) analysis of dynamic test data was performed by Pile Dynamics, Inc. of Cleveland, Ohio and the results are included in this report.

LOCATION AND STRUCTURE INFORMATION

The pile load test sites were located near the west bank of the Deep River at Station 140+86 near boring H-1, between piers 12 and 13 (Site A) and approximately 250 feet east of the east bank of the Deep River at Station 146+42 near boring H-8, between piers 24 and 25 (Site B). The new bridge is to be a 32-span structure providing two, 12-foot lanes and two, 6-foot shoulders. Driven pile foundations will be used to support the structure because of the existence of loose sandy silt and very silty sand deposits to depths in excess of 100 feet below the existing ground surface. The total length of the new bridge will be 1,388 feet between abutments with approach embankments requiring fills up to 20 feet in height.

PILE DATA AND INSTALLATION DETAILS

The pile type to be used to support the structure, and so used in the pile load tests, was a composite pile consisting of an 18-inch diameter, 0.25 inch wall steel pipe pile with a timber tip designed for an allowable load of 100 kips. The timber section was 60 feet long. The splice was fabricated by welding a steel plate onto the bottom of the steel pipe pile and then welding a 14-inch diameter, 3-foot long section of pipe pile onto the steel plate. A wave equation analysis was performed to confirm the drive-ability of the selected pile type and size and to determine the minimum size of pile hammer required. The load frame system consisted of four timber piles driven at a 1H:12V batter to a minimum allowable bearing capacity of 25 tons each. The load frame supported 320 kips of concrete dead weights which supplied the reaction for the load test via a jacking system.

Two composite timber/steel pipe test piles (compression piles) were driven with an impact hammer for their entire lengths. The timber section was spliced to the steel pipe section by wedging the top of the timber pipe into the splice section of the steel pipe pile after the timber section had been driven approximately 57 feet. Driving was then continued until both driving criteria were satisfied. That is, a minimum toe depth and a minimum blow count. Both test piles were dynamically monitored during initial driving and during retap. The retap was conducted after a waiting period of approximately 16 hours to provide a prediction of any gain in capacity due to soil "setup" or a prediction of any loss in capacity due to soil "relaxation."

SUBSURFACE CONDITIONS

Deep River Bridge spans the tidally-influenced Deep River approximately 2 miles north of Grays Bay near the mouth of the Columbia River. The bedrock in this area is early to middle Miocene bathyal sediments of the Astoria Formation. This quiet shelf environment gathered thick argillaceous silt to fine sand sediment, mostly consisting of quartz with some micas. The rich biologic environment, evident from molluck shells and organics in core samples, left the rock void of bedding surfaces, except for some severely contorted lenses still visible. The sediment lithified and was uplifted several million years ago, with the structure believed to be slightly dipping to the south. The rock is very poorly indurated, and consequently, forms poor outcrops. In the area of Deep River, the bedrock is unconformably overlain by poorly stratified Quanternary alluvium ranging in composition from argillaceous silt to silty fine sand with minor amounts of wood and organics.

The field investigation consisted of drilling 15 test holes to determine the type of foundation support required. Borings H-1 (Figure 1) and H-8 (Figure 2) represent subsurface conditions at test sites A and B, respectively. In general, the foundation material at the site consists of up to 125 feet of alternating discontinuous layers of very loose to loose very silty fine sand and fine sandy silt containing varying amounts of wood, clay and organic material, which is underlain by 6 to 133 feet of similar material ranging from medium dense to dense, which is in turn underlain by bedrock consisting of silty sandstone and fine sandy siltstone containing some clay and gravel interbeds. For specific conditions at the test sites, refer to the boring logs, Figures 1 and 2.

HAMMER DATA

The following is the data for the impact hammer driving system selected by the contractor:

MKT MS-500 Single Acting Air/Steam

Maximum rated energy at 4.0 foot stroke + 46,350 foot pounds (BPM = 40)

Ram Weight = 11,300 pounds

Hammer cushion - blue nylon, 2¼ inches thick and aluminum, 2¼ inches thick.

Pile cap weight = 2025 pounds

DYNAMIC MONITORING (PILE ANALYZER) RESULTS

Figure 3 shows the details of the test piles and reaction piles. The test piles were dynamically monitored during initial driving and retap. The load frame (reaction) piles were also dynamically monitored. Tables 1 and 2 summerize the dynamic monitoring results for the test piles.

SITE A - DYNAMIC TEST

Table 1 shows the summary of dynamic test results for the timber and steel pipe composite pile. A 60-foot long section of Douglas Fir timber pile was driven into the ground and then a 73-foot long section of steel pipe pile was spliced on and driven for a total driven length of 126.8 feet. Retap resulted in an additional penetration of 1 foot for a total of 127.8 feet.

Dynamic monitoring was started when the pile tip was 122 feet below the existing ground. Table 1 shows the hammer blow count, maximum compressive stress at the pile top, maximum tensile stress anywhere in the pile, maximum transferred energy at the pile top, and static pile load capacity. Hammer stroke was measured by visual observations. The measurements are shown at various pile tip penetration depths. The static pile load capacity increased until the pile tip reached a 126-foot depth and then decreased slightly as the pile reached the end of critical driving at 126.8 foot depth with a predicted static pile load capacity of 192 kips (by Pile Analyzer). The air hammer performed well and the good performance is indicated by transfer efficiency values ranging from 42 percent to 64 percent. Based on recent research work completed for FHWA, it has been observed that the average transfer efficiency value for steel piles driven with single acting air hammers is 45 percent. The compressive and tensile driving stresses did not exceed the limitations of 32.4 ksi. The pile was "retapped" the next day to determine the setup capacity. The analyzer estimated ultimate capacity determined after soil "setup" was 361 kips, therefore, the net setup capacity was 169 kips.

The "setup" or "freeze" occurs because of the decrease in pore water pressure which increases the skin friction and end bearing after the pile has been driven in soils containing silt and clay. The pile driving causes compression and disturbance in the soil which in turn generates excess hydrostatic pressures (pore pressures). The excess hydrostatic pressures reduce the soil shear strength and static pile load capacity during and immediately after driving. The gradient resulting from the excess hydrostatic pressure starts a consolidation process which provides a regain of shear strength over a period of time. Since the soil deposits at this location are predominantly sandy silts and silty sands along the pile length and at the pile tip, a large amount of setup was expected and confirmed by the measurements.

SITE B DYNAMIC TEST

Table 2 shows the summary of dynamic test results for the timber and steel pipe composite pile. A 60-foot long section of Douglas Fir timber pile was driven into the ground and then a 60-foot long section of steel pipe pile was spliced on and driven to a total depth of 114 feet. An additional 20-foot long section was spliced onto the pile and driving continued until a total depth of 118.5 feet was reached. Retap resulted in no additional penetration.

Dynamic monitoring was begun at the beginning of the drive. Table 2 shows the hammer blow count, maximum compressive stress at the pile top, maximum tensile stress anywhere in the pile, maximum transferred energy at the pile top, and static pile load capacity. Hammer stroke was measured by visual observations. The measurements are shown at various pile tip penetration depths. The static pile load capacity reached a maximum at a depth of 114 feet of 253 kips and then dropped off at the end of driving to 237 kips, (by Pile Analyzer). Hammer performance was satisfactory as indicated by the transfer energy values ranging from 41 percent to 47 percent although not as good as during the driving of the pile at Site A. The compressive and tensile driving stresses did not exceed the limitations of 32.4 ksi. The pile was "retapped" the next day to determine the setup capacity. The analyzer estimated ultimate capacity determined after soil "setup" was 316 kips, therefore the net setup capacity was 79 kips.

STATIC PILE LOAD TESTS

The load frames consisted of driving four timber piles around each test pile to an estimated design capacity of 50 kips each and constructing the load frames on them. The frames were then loaded with 320 kips of concrete slabs for dead weight. Jacks were placed between the dead weight and the test piles to apply the static test loads. The load frame details are shown in Figure 3.

The load applied was measured by an electronic load cell and also by a jack pressure gage. The pile top settlement was measured by two LVDTs. The load versus settlement curves were plotted by using load cell measurement as the axial load and the average pile settlement computed from the two LVDTs. Both test piles were instrumented just above the timber/pipe splice for determining load transfer data. The quick load test procedure as per ASTM D 1143-81 was used for both load tests (applied loads were increased at up to 60-minute intervals rather than at 2½ minute intervals specified in ASTM D 1143-81). Tables 3 and 4 provide the load test data.

Figures 4 and 5 show the load-settlement curves for the load test piles at sites A and B respectively. Both test piles were loaded to a maximum of 300 kips with neither pile approaching failure. The load-settlement curves in both cases remained above the elastic pile compression line which suggests that most of the imposed load was transferred to the soil by pile skin friction. The residual pile top settlements for sites A and B respectively were 0.31 inches and 0.10 inches after all the applied load was released. Interpretation of ultimate pile capacities cannot be made for either pile since the maximum applied loads were less than the failure loads.

COMPARISON OF WAVE EQUATION AND DYNAMIC MONITORING (PILE ANALYZER) PREDICTIONS WITH STATIC LOAD TESTS

There is a good comparison between the wave equation analysis prediction and the ultimate load based on the pile analyzer results. The static load tests indicate that both analyses underpredicted the ultimate capacity. The ultimate pile capacities cannot be predicted from the static load test results.

Table 5 shows a comparison of wave equation, dynamic monitoring and static load test ultimate loads for the test piles. Neither test pile failed at the maximum applied load of 300 kips. The Engineering News Formula predicted 428 kips design load, which may be too high.

CAPWAP ANALYSES

The purpose of performing a "CAPWAP" analysis is to determine the load transfer distribution along the pile and the soil damping parameters. These two items must be assumed when performing a wave equation analysis. When using the pile analyzer, the damping constant, "J", is estimated based on the soil type. These assumptions introduce some uncertainties in the results obtained from the wave equation and the pile analyzer. The CAPWAP analysis is based on force and acceleration data recorded on magnetic tape during pile driving. A reasonable assumption is made regarding soil parameters and then the motion of the pile is assumed, using the measured pile top acceleration as a boundary value. The output results are pile element motions, soil resistance forces and computed pile top forces are compared and, if they differ, appropriate changes are made to the soil model assumptions. Finally, a computed pile top force will be obtained which cannot be further improved.

Four CAPWAP analyses were performed, two each on the two load test piles. The analyses were performed for FHWA by Goble, Rausche, Likins and Associates, Inc. of Cleveland, Ohio. The hammer blows selected represent the end of driving (EoD) of both piles, the beginning of restrike (BoR) at Site A and the end of restrike (EoR) at Site B. Results of the analyses are summarized in Table 6. At the connection between pipe and timber pile, an additional impedance was added for a good match in the corresponding record portion. For the timber pile it was assumed that cross sectional areas changed linearly from top to bottom.

CAPWAP capacity predictions of 197 kips for Site A and 282 kips for Site B were made using a case damping value of 0.4, which is on the high end of what might be expected for the existing soil conditions (typical values of 0.25 to 0.40 might be expected).

CONCLUSIONS

1. The dynamic monitoring equipment (pile analyzer) performed well in monitoring driving stresses and hammer performance. The predicted ultimate pile load capacities by the pile analyzer were substantially smaller than the ultimate loads that can be inferred from the static load tests.

2. Poor correlation of ultimate pile capacity was obtained between the pile analyzer and CAPWAP results at Site A. The correlation was much better at Site B. The high values of case damping cannot be completely explained, but may, in part, be due to the unusual pile geometry.

3. Although there was poor correlation between the pile analyzer and CAPWAP analyses in terms of setup, it is evident that setup is a major factor in the ultimate capacity of the piles. Additional setup is a possible explanation for the much higher capacities observed during the static load tests as they occurred 2 to 4 days after the retap.

4. Damping factors (CAPWAP) were high on the shaft and low at the toe at the end of driving. The reverse was true for restriking on both piles. This shows that the damping factors were really not a good measure of the soil's viscous damping potential.

5. End bearing values (CAPWAP) decreased sharply from end of driving to restriking. Although it is conceivable that relaxation occurred, it is more likely that the full toe bearing was not activated during the restrike. This could partially account for lack of correlation with the static load test results.

6. No pile damage was observed (steel pipe piles) nor predicted (pile analyzer) during the load test program. Driving stresses did not exceed the limitation of 32.4 ksi.

7. The results of the test program show that there is more than an adequate factor of safety for the pile design load of 100 kips.

8. Because of the large setup, the piles can be driven to design depth and stopped, even if desired blow count is not reached.

ATTACHMENTS

DEEP RIVER BRIDGE
DEEP RIVER, WASHINGTON
TABLE 1 SUMMARY OF DYNAMIC MONITORING RESULTS
SITE " A " TEST PILE 2

DATE .... JULY 25-26 1988

PILE TYPE ...... DOUGHLAS FIR / 16" OD 1/4" WALL PIPE PILE

PILE NO. .... SITE " A " PILE 2

LENGTHS .... 60' DOUGLAS FIR + 99' PIPE PILE

PILE AREA ...... 13.9 sq. in.

HAMMER MODEL .... M K T AIR HAMMER

HAMMER TYPE .... M S 500

HAMMER RATED ENERGY .. 46,350 FT. LBS

RAM WEIGHT .... 11.3 KIPS

DEPTH FEET *	BLOW COUNT PER FOOT ANALYZER	BLOW COUNT PER FOOT DRIVING RECORD	RSP WITH J = .40 KIPS	RSU J = .40 KIPS	SFT KIPS	FMX KIPS	MAX. COMP. STRESS KSI	CTEN KIPS	MAX. TENSILE STRESS, KSI	EMX FT. KIPS	STROKE FEET	HAMMER ENERGY (RAM WT. x STROKE) FT. KIPS.	TRANSFER EFFICIENCY TRANSFER ENERGY / APPLIED HAMMER ENERGY %	REMARKS
58	3	--	109	109	--	447	32.2	--	--	21.7	4.0	45.2	48.0	PILE AREA TAKEN AT LOCATION OF INSTRUMENTATION.
59	2	--	36	36	--	450	32.4	--	--	22.9	4.0	45.2	50.7	INITIAL DRIVING STARTED AT 58'. 1 HOUR SET DUE TO
75	5	--	72	72	--	457	32.9	--	--	23.1	4.0	45.2	51.1	SPLICE 16" OD 1/4" WALL PIPE PILE TO DOGULAS FIR PILE.
80	2	--	64	64	--	468	33.7	--	--	24.3	4.0	45.2	53.8	
90	4	--	59	59	--	452	32.5	--	--	25.8	4.0	45.2	57.1	
100	4	--	91	91	--	476	34.2	--	--	25.0	4.0	45.2	55.3	
110	2	--	111	111	--	431	31.0	--	--	21.3	4.0	45.2	47.1	
115	6	--	83	83	--	433	31.2	95	6.8	23.4	4.0	45.2	51.8	
120	5	--	92	92	--	441	31.7	--	--	23.7	4.0	45.2	52.4	TAPE RECORDER NOT TURNED ON FOR MONITORING TILL 122'.
122	4	--	118	118	--	376	27.1	--	--	19.3	4.0	45.2	42.7	
124	10	--	116	116	--	423	30.4	--	--	23.8	4.0	45.2	52.7	
125	12	--	132	132	--	372	26.8	--	--	23.2	4.0	45.2	51.3	STOPPED FOR HAMMER REPAIR.
126	15	--	198	198	--	566	40.7	--	--	29.3	4.0	45.2	64.8	
126.8	9	--	192	192	--	560	40.3	10	0.7	29.3	4.0	45.2	64.8	END INITIAL DRIVING AT 127' PENETRATION FROM
						R E T A P	J U L Y 2 6 , 1 9 8 8							EXISTING GROUND.
127.8	1	--	361	361	--	383	27.6	--	--	14.2	3.0	33.9	41.9	END RETAP AT 3". HAMMER NOT HITTING AT FULL STROKE.

* DISTANCE FROM THE GROUND LINE TO PILE TIP
RSP = ULTIMATE STATIC RESISTANCE USING DAMPING J
FMX = MAXIMUM MEASURED FORCE IN PILE AT THE TRANSDUCER LOCATION
CTEN = MAXIMUM COMPUTED TENSILE FORCE ANYWHERE IN THE PILE
RSU = CAPACITY INCLUDING UNLOADING WITH DAMPING J
BTA = INTEGRITY FACTOR (% DAMAGE)

MAXIMUM ALLOWABLE COMPRESSIVE OR TENSILE DRIVING STRESS = 0.9 x Fy = 0.9 x 36 = 32.4 KSI
J = ASSUMED DAMPING PARAMETER (DEPENDS ON SOIL TYPE)
EMX = MAXIMUM TRANSFERRED ENERGY AT TRANSDUCER LOCATION
SFT = SKIN FRICTION TOTAL (NOT REDUCED FOR DAMPING)
RMX = MAXIMUM CASE - GOBLE CAPACITY (KIPS)

DEEP RIVER BRIDGE
DEEP RIVER, WASHINGTON.
TABLE 2 SUMMARY OF DYNAMIC MONITORING RESULTS
SITE " B " TEST PILE 2

DATE .... JUNE 23-24,1988

PILE TYPE ...... DOUGLAS FIR AND 18"OD 1/4"WALL PIPE PILE

PILE NO. .... 1 "

LENGTHS .... 60' DOUGHLAS FIR + 80' PIPE PILE

PILE AREA ...... 13.9 sq. in.

HAMMER MODEL .... M K T AIR HAMMER

HAMMER TYPE .... M S 500

HAMMER RATED ENERGY .. 46,350 FT. LBS

RAM WEIGHT .... 11.3 KIPS

DEPTH FEET. *	BLOW COUNT PER FOOT ANALYZER	BLOW COUNT PER FOOT DRIVING RECORD	RSP WITH J = .40 KIPS	RSU J = .40 KIPS	SFT KIPS	FMX KIPS	MAX. COMP. STRESS KSI	CTEN KIPS	MAX. TENSILE STRESS, KSI	EMX FT. KIPS	STROKE FEET	HAMMER ENERGY (RAM WT. x STROKE) FT. KIPS.	TRANSFER EFFICIENCY TRANSFER ENERGY / APPLIED HAMMER ENERGY %	REMARKS
21	1	---	0	0	---	215	15.5		0.00	5.6	2.0	22.6	24.8	DOUGLAS FIR.21' TO 57'. INITIAL DRIVING BEGIAN AT 21'.
57	1	---	0	0	--	314	22.6	--	0.00	5.6	4.0	45.2	12.4	PIPE PILE SPLICED, DOWN TIME APPX: 1 HOUR 30 MINUTES.
57	6	---	197	197	--	372	26.8	--	0.00	16.4	4.0	45.2	36.3	
60	3	---	34	34	--	366	26.3	--	0.00	15.6	4.0	45.2	34.5	
75	4	---	0	0	--	364	26.2	74	5.32	20.4	4.0	45.2	45.1	
85	4	---	0	0	--	374	26.9	123	8.85	20.4	4.0	45.2	45.1	
95	5	---	9	9	--	376	27.1	112	8.06	21.6	4.0	45.2	47.8	
100	4	---	27	17	--	389	28.0	111	7.99	21.0	4.0	45.2	46.5	
105	5	---	23	12	--	378	27.2	89	6.40	20.4	4.0	45.2	45.1	
110	5	---	46	45	--	369	26.5	80	5.76	20.5	4.0	45.2	45.4	
112	7	---	56	56	--	366	26.3	51	3.67	19.7	4.0	45.2	43.6	
114	10	---	253	257	--	353	25.4	38	2.73	20.2	4.0	45.2	44.7	SLICED ON 20'PIPE PILE SECTION, DOWN TIME
117	18	---	236	225	--	360	25.9	--	0.00	20.1	4.0	45.2	44.5	1 HOUR 20 MINUTES.
118.5	12	---	237	227	--	349	25.1	--	0.00	18.7	4.0	45.2	41.4	END INITIAL DRIVING AT 118.5'.
R E T A P J U N E 2 4, 1 9 8 8														CONTRACTOR CHANGED STROKE WITHOUT NOTICE. RETAP IS
118.5	1	---	316	326	--	302	21.7	49	3.53	11.2	2.5	28.3	39.6	AT 2.5' STROKE.

* DISTANCE FROM THE GROUND LINE TO PILE TIP
RSP = ULTIMATE STATIC RESISTANCE USING DAMPING J
FMX = MAXIMUM MEASURED FORCE IN PILE AT THE TRANSDUCER LOCATION
CTEN = MAXIMUM COMPUTED TENSILE FORCE ANYWHERE IN THE PILE
RSU = CAPACITY INCLUDING UNLOADING WITH DAMPING J
BTA = INTEGRITY FACTOR (% DAMAGE)

MAXIMUM ALLOWABLE COMPRESSIVE OR TENSILE DRIVING STRESS = 0.9 x Fy = 0.9 x 36 = 32.4 KSI
J = ASSUMED DAMPING PARAMETER (DEPENDS ON SOIL TYPE)
EMX = MAXIMUM TRANSFERRED ENERGY AT TRANSDUCER LOCATION
SFT = SKIN FRICTION TOTAL (NOT REDUCED FOR DAMPING)
RMX = MAXIMUM CASE - GOBLE CAPACITY (KIPS)

TABLE 3

STATIC LOAD TEST - SITE A

Increment Load (kips)	Gauge Reading (Actual load-kips)	Reading	LVDT's Settlement - Inches Left	Right	Avg.
0	2570	1	0	0	0
	(0)	2	0	0	0
50	2221	1	.072	.084	.078
	(48)	2	.088	.099	.094
100	1864	1	.192	.203	.198
	(99)	2	.242	.246	.244
150	1510	1	.364	.349	.357
	(149.6)	2	.418	.402	.410
200	1154	1	.546	.542	.544
	(200.2)	2	.613	.622	.618
250	778	1	.761	.754	.758
	(254)	2	.841	.825	.833
300	407	1	1.002	.949	.976
	(303.6)	1	1.045	.988	1.017
250	771	1	.996	.921	.944
	(252.6)	2	.996	.921	.944
200	1119	1	.858	.841	.850
	(103.8)	2	.850	.836	.843
150	1491	1	.728	.839	.734
	(151.4)	2	.703	.713	.708
100	1828	1	.581	.599	.590
	(104.2)	2	.572	.590	.581
50	2174	1	.467	.477	.472
	(55.6)	2	.452	.466	.459
0	2570	1	.311	.348	.330
	(0)	2	.294	.333	.314

TABLE 4

STATIC LOAD TEST - SITE B

Increment Load (kips)	Gauge Reading (Actual load-kips)	Reading	LVDT's Settlement - Inches Left	Right	Avg.
0	700	1	0	0	0
	(0)	2	0	0	0
50	540	1	.056	.054	.055
	(50)	2	.051	.052	.052
100	380	1	.130	.132	.131
	(400)	2	.142	.150	.146
150	220	1	.238	.253	.246
	(150)	2	.250	.267	.259
200	60	1	.352	.375	.364
	(200)	2	.370	.397	.384
250	-100	2	.481	.502	.492
	(250)	2	.515	.535	.525
300	-260	1	.632	.648	.640
	(300)	2	.675	.702	.689
250	-100	1	.617	.643	.630
	(250)	2	.607	.636	.622
200	60	1	.521	.551	.536
	(200)	2	.517	.549	.533
150	220	1	.421	.459	.440
	(150)	2	.415	.453	.434
100	380	1	.321	.357	.339
	(100)	2	.311	.349	.330
50	540	1	.213	.243	.228
	(50)	2	.201	.230	.216
0	700	1	.091	.113	.103
	(0)	2	.091	.113	.103

TABLE 5

COMPARISON OF WAVE EQUATION, DYNAMIC
MONITORING AND STATIC LOAD TESTS

Method Used for Determining Ultimate Pile Capacity	Ultimate (Failure) Load EOD	BOR/EOR
Wave Equation	300 kips	330 kips
*Dynamic Monitoring	215 kips	340 kips
Static Load Test		>>300 kips

*Average of PDA results from Site A and Site B.

Table 6 Summary of CAPWAPC Results

Pile	Data Set	Max. Top Force	Max. Transf. Energy	Capacity			Damping		Quakes	
				Skin	Toe	Total	Skin	Toe	Skin	Toe
		kips	kip-ft	kips	kips	kips	s/ft	s/ft	in	in
Site A	EoD	349	19.3	45	66	111	.32	.02	.10	.30
	BoR	320	14.5	187	10	197	.12	.36	.15	.15
Site B	EoD	317	18.3	65	46	111	.24	.05	.10	.40
	EoR	308	17.9	262	20	282	.10	.31	.10	.05

S.H. ____ S.R. 4 SECTION Deep River Bridge 4/102 Replacement Job No. L-4515

Hole No. H-1 Sub Section Deep River Bridge 4/102 Replacement Cont. Sec. 3501

Station K 141+30 Offset 12' Rt. Ground El. 7 Contour on Layout

Type of Boring Jet & Drive; Tircone; Core Casing 4" to 25', 3" to 154' W.T. El. River level

Inspector ____ Date April 15, 1986 Sheet 1 of 11

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
			B C D U-1	
	1		1/12" 1/12" STD PEN 2	OL, M.C.=97.4% Very loose, gray-brown, saturated, fine sandy organic SILT. Retained 15".
5				
10			A B C D U-3	
	2		1/12" 1 1 STD PEN 4	OL, M.C.=80.6% Very loose, gray, saturated, fine sandy, organic SILT. Retained 16".
15				
20				

DOT FORM 351-003 REVISED 12/79

Figure 1

Original to Materials Engineer
Copy to Bridge Engineer
Copy to District Administrator
Copy to ____

Y Form 351-005-o (H. F. 26.66-A).
Revised 5-67.

Hole No. H-1 Sub Section Deep River Bridge 4/102 Replacement Sheet 2 of 11

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.		DESCRIPTION OF MATERIAL
			A B	U- 5	
			C D		
			1/ 12"	STD PEN	OL, M.C.=102.1% Very loose, gray, saturated, fine sandy, organic SILT. Retained 13".
	2		1 1	6	
25					
30					
			A B	U-7	
			C D		
	2		1 1	STD PEN	ML, M.C.=62.6% Very loose, gray, wet, fine sandy, SILT. Retained 19".
			1 1	8	
35					
40					
			A B	U-9	
			C D		
	2		1 1	STD PEN	Very loose, gray, wet, fine sandy SILT. Retained 18".
			1	10	
45					

Form 351-003-a (H. F. 26.66-A).
Revised 5-67.

Hole No. H-1 Sub Section Deep River Bridge 4/102 Replacement Sheet 3 of 11

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
50				
			A B U-11	
			C D	
			1 STD	ML, M.C.=56.7%
	2		1 PEN	Very loose, gray, wet, fine sandy, slightly clayey, SILT. Retained 18".
			1 12	
55				
60				
			A B U-13	
			C D	
			1 STD	
	4		2 PEN	Very loose, gray, wet, fine sandy, slightly clayey, SILT. Retained 23".
			2 14 2	
65				
70				

Form 351-003-a (H. F. 26.66-A).
Revised 5-67.

Hole No. H-1 Sub Section Deep River Bridge 4/102 Replacement Sheet 4 of 11

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
			A B C D U-15	
	3		1 1 2 2 STD PEN 16	ML, M.C.=58.5% Very loose, gray, wet, fine sandy SILT with traces of organic material. Retained 24".
75				
80				
			A B C D U-17	
	8		2 4 4 3 STD PEN 18	ML, M.C.=51.9% Loose, gray, wet, fine sandy SILT. Retained 23".
85				
90				
			A B C D U-19	
	6		2 3 3 4 STD PEN 20	Loose, gray, wet, fine sandy SILT. Retained 21".
95				

Hole No. H-1 Sub Section Deep River Bridge 4/102 Replacement Sheet 5 of 11

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
100			A B C D U-21	
	6		2 3 3 4 STD PEN 22	ML, M.C.=48.3% Loose, brown-gray, wet, fine sandy, slightly clayey SILT. Retained 20".
105				
110			A B C D U-23	
	10		3 4 6 6 STD PEN 24	SM, M.C.=69.5% Loose, gray, wet, slightly clayey, very silty, fine SAND with organic material. Retained 18".
115				
120				

Y Form 351-003-o (H. F. 26.66-A).
Revised 5-67.

Hole No. H-1 Sub Section Deep River Bridge 4/102 Replacement Sheet 6 of 11

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.		DESCRIPTION OF MATERIAL
			B		
			C	U-25	
			D		
			4	STD	MH, M.C.=64.2%
	10		5	PEN	Loose, brown and gray, wet, fine sandy, clayey, SILT. Retained 18".
			5	26	
			6		
125					
130					
			B		
			C	U-27	
			D		
			6	STD	
	15		7	PEN	Medium dense, brown and gray, wet, fine sandy, clayey SILT.
			8	28	Retained 15".
			12		
135					
140					
			B		
			C	U=29	
			D		
			6	STD	SM, M.C.=35.8%
	19		9	PEN	Medium dense, brown and gray, wet, gravelly, slightly clayey, very silty,
			10	30	fine SAND. Retained 12".
			11		
145					

Y Form 351-003-o (H. F. 26.66-A)
Revised 5-67.

Hole No. H-1 Sub Section Deep River Bridge 4/102 Replacement Sheet 7 of 11

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
150				
			B C U-31 D	
	24		8 STD 12 PEN 12 32 15	Medium dense, brown and gray, wet, gravelly, slightly clayey, very silty, fine SAND. Retained 15".
155				
160				
			C D U-33	
	22		5 STD 9 PEN 13 34 16	Medium dense, brown and gray, wet, gravelly, slightly clayey, very silty, fine SAND. Retained 16".
165				
170				

Hole No. H-1 Sub Section Deep River Bridge 4/102 Replacement Sheet 8 of 11

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
			C D U-35	
			8 STD	
			11 PEN	Dense, brown and gray, wet, gravelly, slightly clayey, very silty,
	27		11 36	fine SAND. Retained 13".
			17	
175				
180				
			C D U-37	
			11 STD	
			14 PEN	Dense, brown and gray, wet, gravelly, slightly clayey, very silty,
	31		17 38	fine SAND. Retained 1".
			18	
185				
190				
			C D U-39	
			9 STD	
			11 PEN	No Recovery.
	25		14 40	
195				

Form 351-003-a (H. F. 26.66-A).
Revised 5-67.

Hole No. H-1 Sub Section Deep River Bridge 4/102 Replacement Sheet 9 of 11

Depth	Blows per ft.	Profile	Sample tube nos.	Description of material
200				
			U-41	
			25 STD	SC, M.C.=27.9%
	61		34 PEN 27 42	Very dense, gray, moist, very silty, clayey, fine SAND. Retained 16".
205				
210				
	59		18 STD 24 PEN 35 43	Very dense, gray, moist, very silty, clayey, fine SAND. Retained 16".
215				
			STD	ML, M.C.=23.4%
	100/4"		69 PEN 100/4" 44	Very dense, gray, moist, fine, sandy SILT. Retained 9.5".
			C-45	Dark gray, very soft, slightly fine sandy SILTSTONE; massive;near horizontal fracture. RQD=72%.
220			69% Rec.	

Y Form 351-003-a (H. F. 26.66-A).
Revised 5-67.

Hole No. H-1 Sub Section Deep River Bridge 4/102 Replacement Sheet 10 of 11

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
			C-46 100% Rec.	Dark gray, very soft, slightly fine sandy SILTSTONE; massive; trace distorted bedding. RΩD=40% Highly fractured from 223.5' to 226.0' below ground elevation.
225				
			C-47 100% Rec.	Dark gray, very soft, fine sandy SILTSTONE; massive;near horizontal fracture. RQD=64%.
			C-48 100% Rec.	Dark gray, very soft, fine sandy SILTSTONE; massive;near horizontal fracture. RQD=48%.
230				
			C-49 100% Rec.	Dark gray, very soft, fine sandy SILTSTONE; massive;near horizontal fracture. RQD=100%
			C-50 100% Rec.	Dark gray, very soft, fine sandy SILTSTONE; massive;near horizontal fracture. RQD=100%.
235				
			C-51 100% Rec.	Dark gray, very soft, fine sandy SILTSTONE; massive;near horizontal fracture. RQD=74%
240				
			C-52 100% Rec.	Dark gray, very soft, fine sandy SILTSTONE; massive;near horizontal fracture. RQD=100%.
245				

Form 351-003-o (H. F. 26.66-A). Revised 5-67.

Hole No. H-1 Sub Section Deep River Bridge 4/102 Replacement Sheet 11 of 11

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
			C-53	Dark gray, very soft, fine sandy SILTSTONE; massive;near horizontal
			100% Rec.	fracture. RQD=100%
250				
				Test boring stopped at ~~1~~ 2 48.0' below ground elevation.
				This is a summary Log of Test Boring. Soil/Rock descriptions are derived from visual field identifications and laboratory test data.

LOG OF TEST BORING

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

____ S.H. ______ S.R. 4 SECTION Deep River Bridge 4/102 Replacement Job No. L-4515

Hole No. H-8 Sub Section Deep River Bridge 4/102 Replacement Cont. Sec. 3501

Station K 146+53 Offset 4' Lt. Ground El. 4' Contour on Layout

Type of Boring Rotate & Drive; Tricone; Core Casing 4" to 10' W.T. El. 4' below ground elevation

Inspector ________ Date May 12, 1986 Sheet 1 of 11

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
5				
			A B U-1	
			C D	
			1/ STD 12" PEN	SM, M.C.=86.0% Very loose, gray-brown, saturated, very silty, fine SAND with organic
	2		1 2 1	material. Retained 14".
10				
15				
20				

DOT FORM 351-003 REVISED 12/79

Original to Materials Engineer
Copy to Bridge Engineer
Copy to District Administrator

Figure 2

Copy to ________

Form 351-003-a (H. F. 26.66-A)
Revised 5-67.

Hole No. H-8 Sub Section Deep River Bridge 4/102 Replacement Sheet 2 of 11

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
25				
30				
			C D U-3	
	4		2 2 2 2 STD PEN 4	ML, M.C.=60.1% Very loose, gray-brown, wet, fine sandy SILT with organic material. Retained 7".
35				
40				
45				

Hole No. H-8 Sub Section Deep River Bridge 4/102 Replacement Sheet 3 of 11

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
50				
55				
60				
			A B U-5	
			C D	
			1 STD	ML, M.C.=48.8%
	4		2 PEN	Very loose, gray-brown, wet, fine sandy SILT. Retained 23".
			2 6 2	
65				
70				

Form 351-003-c (n. F. 26.66-A).
Revised 5-67.

Hole No. H-8 Sub Section Deep River Bridge 4/102 Replacement Sheet 4 of 11

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
75				
80				
85				
90				
			A B C D U-7	
	12		4 5 7 8 STD PEN 8	SM, M.C.=34.6% Medium dense, gray-brown, wet, very silty, fine SAND with organic material. Retained 24".
95				

Form 351-003-a (H. F. 2a.66-A).
Revised 5-67.

Hole No. H-8 Sub Section Deep River Bridge 4/102 Replacement Sheet 5 of 11

EPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
100				
105				
110				
115				
120				

Y Form 351-003-a (H. F. 26.66-A).
Revised 5-67.

Hole No. H-8 Sub Section Deep River Bridge 4/102 Replacement Sheet 6 of 11

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
	14		5 7 7 8 STd PEN 9	MH, M.C.=51.4% Medium dense, gray-brown, wet, fine sandy, slightly clayey SILT. Retained 24".
125				
130				
135				
140				
145				

Form 351-003-a (H. F. 26.66-A).
Revised 5-67.

Hole No. H-8 Sub Section Deep River Bridge 4/102 Replacement Sheet 7 of 11

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
150				
	18		6 8 10 10 STD PEN 10	MH, M.C.=36.6% Medium dense, gray-brown, wet, fine sandy, clayey SILT. Retained 22".
155				
160				
165				
170				

Form 351-003-a (H. F. 26.66-A).
Revised 5-67.

Hole No. H-8 Sub Section Deep River Bridge 4/102 Replacement Sheet 8 of 11

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
175				
180				
	22		8 / 10 / 12 / 13 STD PEN 11	Medium dense, gray-brown, wet, fine sandy, clayey SILT. Retained 23".
185				
190				
195				

Y Form 351-003-a (H. F. 26.66-A).
Revised 5-67.

Hole No. H-8 Sub Section Deep River Bridge 4/102 Replacement Sheet 9 of 11

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
200				
205				
210				
	24		9 10 14 STD PEN 12	Medium dense, gray-brown, wet, fine sandy, clayey SILT. Retained 16"
215				
220				

Y Form 351-003-o (H. F. 26.66-A).
Revised 5-67.

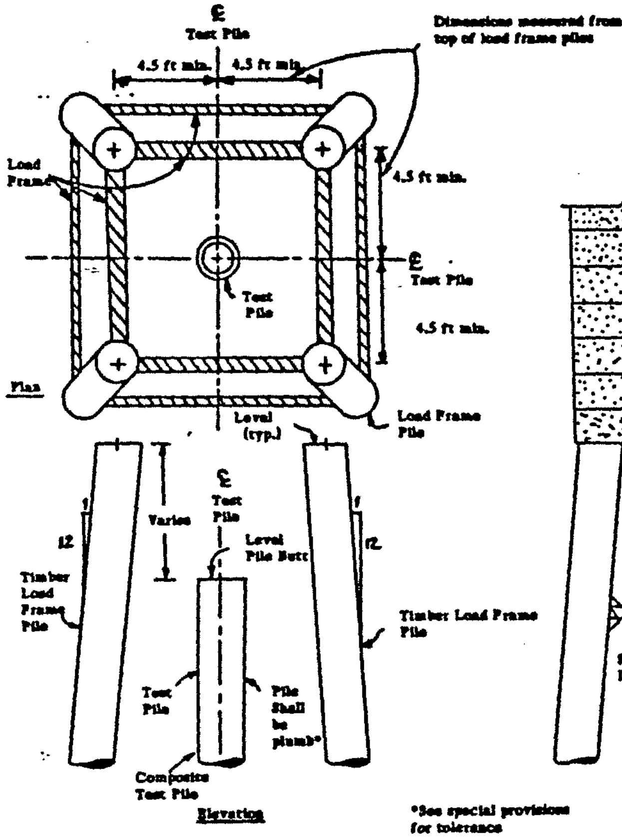
Hole No. H-8 Sub Section Deep River Bridge 4/102 Replacement Sheet 10 of 11

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
			C-13	Very soft, brown-gray, silty, fine SANDSTONE with trace of black
225			100% Rec.	organics and shells. RQD=92%
			C-14	
			100% Rec.	Very soft, brown-gray, silty, fine SANDSTONE with trace of black organics and shells.
230			60% Rec. C-15	Very soft, brown-gray, silty, fine SANDSTONE with trace of black
			C-16	organics and shells. Very soft, brown-gray, silty, fine SANDSTONE with trace of black
			100% Rec.	organics and shells.
			C-17	Very soft, brown-gray, very silty, fine SANDSTONE with trace of black
235			100% Rec.	organics and shells. RQD=73%.
			C-18	Very soft, brown-gray, very silty, fine SANDSTONE with trace of black
240			100% Rec.	organics and shells. RQD=95%.
			C-19	Very soft, brown-gray, very silty, fine SANDSTONE with trace of black
			100% Rec.	organics and shells. RQD=100%.
245				

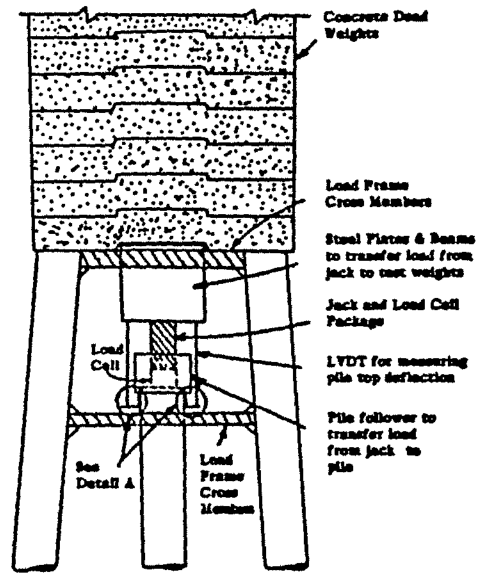
Form 351-003-a (H. F. 26.66-A).
Revised 5-67.

Hole No. H-8 Sub Section Deep River Bridge 4/102 Replacement Sheet 11 of 11

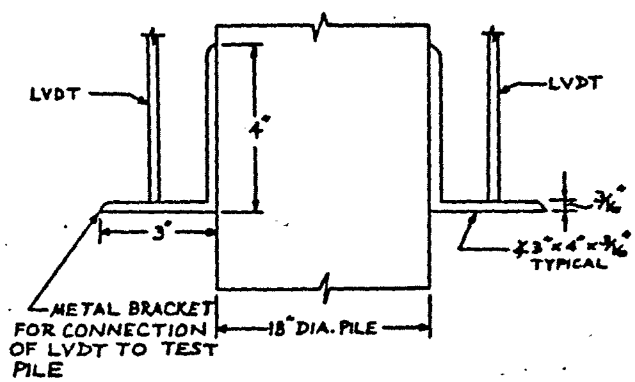
DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.		DESCRIPTION OF MATERIAL
				C-20	Very soft, brown-gray, very silty, fine SANDSTONE with trace of black organics and shells. RQD=50%.
			100% Rec.		
				C-21	
250			100% Rec.		Very soft, brown-gray, very silty, fine SANDSTONE with trace of black organics and shells. RQD=78%.
				C-22	Very soft, brown-gray, very silty, fine SANDSTONE with trace of black organics and shells. RQD=100%.
			100% Rec.		
255					
					Test boring stopped at 255.0' below ground elevation.
					This is a summary Log of Test Boring. Soil/Rock descriptions are derived from visual field identifications and laboratory test data.

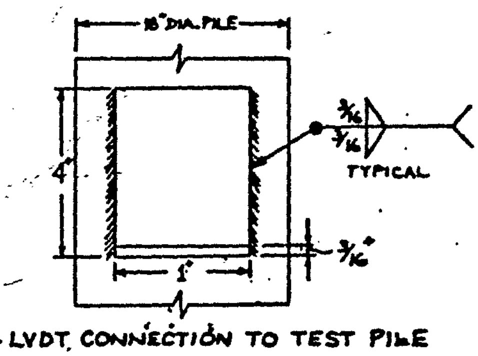


TEST FRAME FOR PILE LOAD TEST



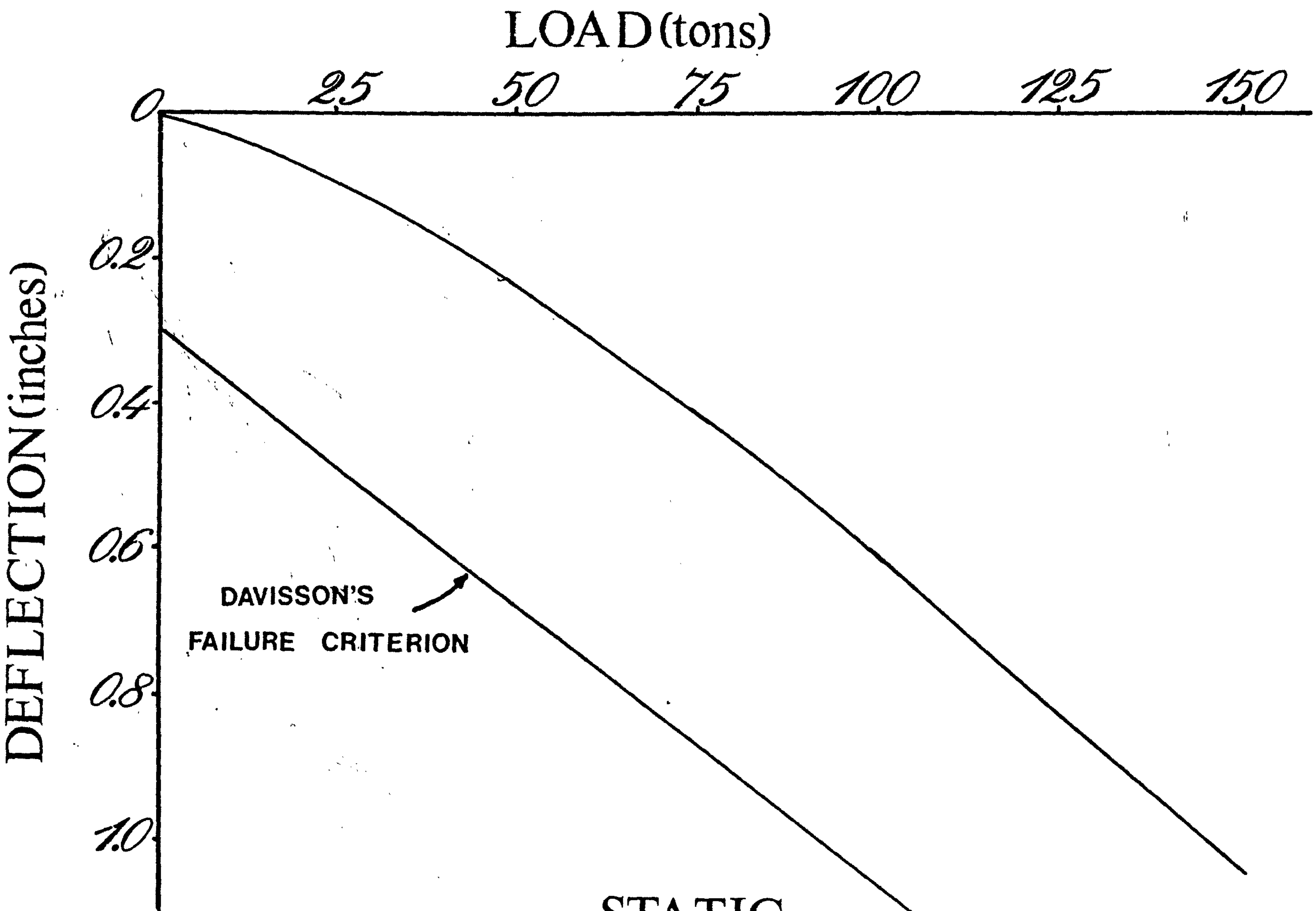
COMPRESSION TEST SET-UP





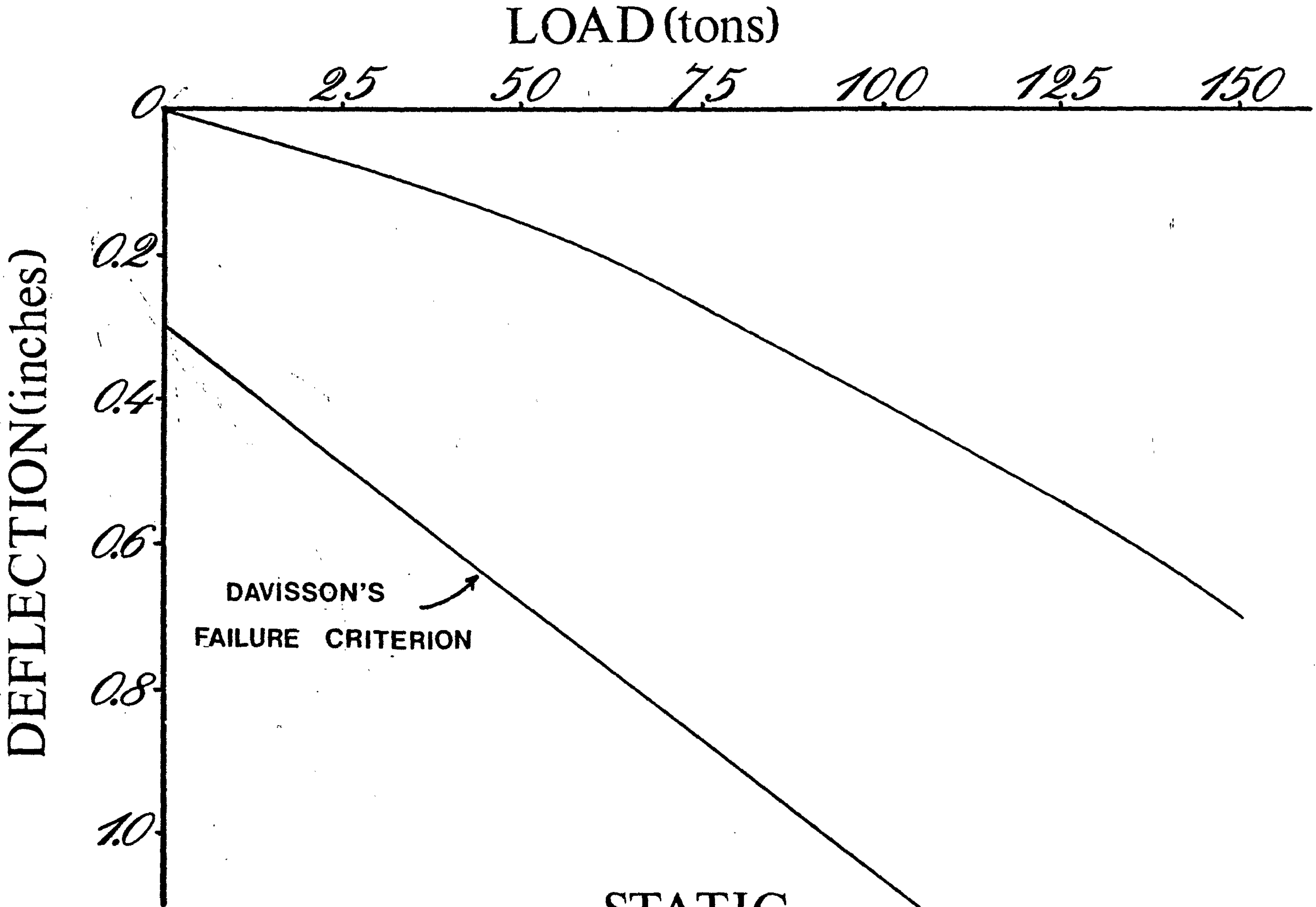
DETAIL 'A'- LVDT CONNECTION TO TEST PILE

Figure 3



STATIC
PILE LOAD TEST
SITE 'A'

Figure 4



STATIC
PILE LOAD TEST
SITE 'B'

Figure 5