DYNAMIC PILE MONITORING AND PILE LOAD TEST REPORT

I-90, THIRD LAKE WASHINGTON BRIDGE

SEATTLE, WASHINGTON

FHWA DEMONSTRATION PROJECTS dp

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Federal Highway Administration

Office of Highway Operations

Demonstration Projects Program

Washington, D.C.

April 1984

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April 1984

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

FIELD TRIP REPORT
(See instructions on reverse)

DATE: APR 25 1984

Mr. P. E. Cunningham, Chief
Construction and Maintenance Division
Thru: Mr. Gary L. Klinedinst, Chief
Geotechnical and Materials Branch

FROM: Suneel N. Vanikar
Highway Engineer
Geotechnical and Materials Branch

INCLUSIVE DATES: From February 27-March 10, 1984 To March 19-30, 1984

ITINERARY: Washington, D.C., to Seattle, Washington, and return.

PURPOSE: (1) To dynamically monitor pile driving at two pile load test sites for the proposed Third Lake Washington Bridge (I-90), Seattle, Washington. (2) To conduct compression and tension load tests at both test sites. The FHWA owned equipment was used for this work which is a part of the Demonstration Project 910, "Design and Construction of Driven Pile Foundations."

PRINCIPAL CONTACTS: Messrs. Ron Chassie, FHWA Region 9 Geotechnical Engineer; John Coffee and Dick Kay, FHWA Washington Division Office; and LeRoy Wilson, Washington State Department of Transportation Assistant Foundation Engineer.

ACCOMPLISHMENTS OR RESULTS

See attached "Pile Load Test Report."

SUBSEQUENT ACTIONS TAKEN

See attached "Pile Load Test Report."

RECOMMENDATIONS

See attached "Pile Load Test Report."

OTHER PERTINENT ITEMS

Federal Highway Administration
HHO-33:SVanikar:ad:60436:04/25/84
Copies to: D. Bernard HHO-40
S. Vanikar HHO-33
Official File HHO-33
Reader File HHO-30
R. Chassie HST-010.2
HRA-010, HDA-WA(2)
Reader File HHO-1
Chron File HHO-33
Pending File HHO-33

"DYNAMIC PILE MONITORING AND LOAD TEST REPORT"
(Third Lake Washington Bridge, I-90, Seattle, Washington)

Introduction and Background

The Demonstration Project 910, "Design and Construction of Driven Pile Foundations," equipment includes the demonstration of a dynamic pile testing system which uses a field computer and a mobile pile load testing frame. Even though the project is yet to be announced, the equipment and personnel are made available to a requesting State highway department.

A request for the demonstration and use of equipment for the subject project was received from the Washington State Department of Transportation (WashDOT). The request came through the FHWA division and regional offices in November 1983.

The field work was performed by Mr. H. Clark, Civil Engineering Technician, in the Demonstration Projects Division, and Mr. S. Vanikar, Highway Engineer. The mobile load frame was used for the first time on a construction project and Mr. Rex Cocroft provided services as a consultant during the load tests. Mr. Cocroft is the designer of the load frame and the load frame modifications were performed under his supervision during the last year.

After the dynamic pile testing was completed, an informal presentation on the results of the analysis was made to the WashDOT geotechnical engineers on March 26, 1983. The data recorded on the magnetic tapes has been forwarded to Pile Dynamics, Incorporated, Cleveland, Ohio, for further analysis including "CAPWAP" analysis.

The results of the "CAPWAP" analysis will be provided to the WashDOT as soon as they are received. A detailed description of the work performed, results, and analysis follow in this report.

Location and Structure Information

The bridge site is located on proposed I-90 in Seattle, Washington and will be the Third Floating Bridge across Lake Washington. Several piers for the west and east approach structures will be supported on pile foundations because of the excessive water depths (up to 90 feet at some locations). Preliminary reports by two consultants show that pile groups at each pier will consist of mostly batter piles.

Precast segmental and steel girder alternates are being designed. The pile load tests were conducted at locations for the proposed Pier No. 7 (Site A, Station L^L 117+83, west approach) and Pier No. 9 (Site B, Station L^L 178+99, east approach).

Pile Data

Two pile types were considered during the design of load test program. Prestressed concrete cylinder piles (54-inch O.D. and 5-inch wall thickness) and steel pipe piles (48-inch O.D. and several different wall thicknesses) were considered. Based on the structural and cost considerations, it was decided to test the 48-inch O.D. steel pipe pile. Wave equation analyses were performed by the FHWA Geotechnical and Materials Branch for selecting compression and reaction pile wall thicknesses and for specifying minimum pile hammer energy requirements. Based on the analyses, it was decided to specify 3/4-inch wall thickness for the compression and reaction piles.

The following is the pile data at each test site:

Test Site A

Test Pile - 48-inch O.D., 3/4-inch wall, and 160-foot long pipe (length included 10-foot long fabricated H-shaped tip).

Reaction Piles - four reaction piles, each 36-inch O.D., 3/4-inch wall, and 168-foot long open ended pipe.

Test Site B

Test Pile - 48-inch O.D., 3/4-inch wall, and 158-foot long pipe. The pile was closed by an end plate 10 feet above the pile tip.

Reaction Piles - four reaction piles, each 36-inch O.D., 3/4-inch wall, and 169-foot long open ended pipe.

Subsurface Conditions

Test Site A - Boring No. HX-11 (℄, Station L^L 117+82) represents subsurface conditions at this site. The boring log shows shallow loose silty fine to coarse sand (average SPT N=8) deposit underlain by 12-foot thick dense deposits of sandy silt (average SPT N=35). Very dense sandy gravel (glacial till) deposits (average SPT N=80 to 100) exists below the sandy silt deposits. Existence of artesian water conditions at 44 feet below the mudline is noted on the boring log. It was the intent not to penetrate the artesian layer during test pile driving.

Test Site B - Boring No. HX-3(L, Station 179+09) represents subsurface conditions at this site. The boring log shows 10 feet of loose to medium dense fine sandy silt (SPT N=3 to 17). Very dense, gravelly fine to coarse sand deposits (glacial till) (SPT N=100) exist below the sandy silt deposits.

Hammer Data

Conmaco 300, single acting steam hammer
Rated energy at 36 inches (full) stroke = 90,000 ft./lbs.
Ram Weight = 30,000 pounds
Hammer Cushion - Alternate layers of micarta and aluminum, total thickness = 9 inches
Pile Cushion - None
(Note: Same hammer was used for driving 36-inch O.D. and 48-inch O.D. piles.)

Dynamic Monitoring Results for Piles at Load Test Site A

One compression pile (48-inch O.D.) and four reaction piles (36-inch O.D.) were driven at this site. The compression pile was monitored during the initial driving and during retapping after 16 hours. Two of the four reaction piles were monitored during initial driving.

Attached Tables 1 and 2 show the summaries of the results obtained during initial driving and retapping of 48-inch O.D. pile. The results show that the tensile and compressive driving stresses induced in the pile were well within the specified limitations. The hammer performance during initial driving was good (transfer efficiencies up to 62 percent were recorded) but the transfer efficiencies never exceeded 44 percent during the retap. The inefficient hammer performance during the retap may be attributed to the lack of sufficient steam pressure. Recent research data on single acting air-steam hammers shows that average transfer energy transmitted into steel piles is 48 percent. The analyzer predicted pile static load capacities of 750 tons at the end of initial driving and 785 tons during retapping showing no significant change.

Table 3 summarizes the dynamic monitoring data obtained during initial driving of the 36-inch O.D. reaction Pile No. 1 (SW corner). The hammer transfer efficiencies recorded were between 42 to 57 percent. The analyzer predicted a static load capacity of 600 tons for this pile. The pile was not monitored during the retap because the experience with the 48-inch O.D. pile showed that there was no significant change in capacity after a time period.

Table 4 summarizes the dynamic monitoring data obtained during initial driving of the 36-inch O.D. reaction Pile No. 3 (NE corner). Note that between 123 feet and 125 feet pile penetration below the template, the hammer imparted higher energy into the pile than its maximum rated energy. This was due to very high steam pressure which caused the hammer and its assembly to lift off the pile. The driving was discontinued temporarily and the steam pressure was adjusted. The hammer operated reasonably well after the adjustment. The analyzer predicted a static load capacity of 650 tons for this pile.

Dymanic Monitoring Results for Piles at Load Test Site B

One compression pile (48-inch O.D.) and four reaction piles (36-inch O.D.) were driven at this site. The compression pile and one reaction pile were monitored during the initial driving and during retapping. One reaction pile was monitored only during initial driving.

Tables 5 and 6 show the summaries of the results obtained during initial driving and retapping of 48-inch O.D pile. The tables show that the hammer operated consistently during initial driving but not during retapping. High transfer efficiencies were recorded during initial driving and retapping. The maximum compressive and tensile stresses generated during driving were within limits. At the end of initial driving, the analyzer predicted a static pile load capacity of 945 tons. Table 6 shows that a reduced capacity of 785 tons was predicted during retapping. The reduction in capacity may have occurred due to soil relaxation. The pile driving operations in the very dense granular material may have generated negative pore pressures which temporarily exhibit higher soil strength but the strength reduction occurs as the negative pore water pressures are dissipated.

Table 7 summarizes the dynamic monitoring data obtained during initial driving of reaction Pile No. 5 (SE corner). The monitoring was discontinued at 34-feet pile penetration below the mudline because of the failure of the dynamic monitoring instrumentation attached to the pile. The erratic hammer performance may be the primary cause of instrumentation failure. The analyzer predicted a pile load capacity of 870 tons when the monitoring was discontinued. The dynamic monitoring was not performed during the retap.

Tables 8 and 9 summarize the dynamic monitoring results obtained during intial driving and retapping of reaction Pile No. 6 (SW corner). The predicted static pile load capacity at the end of initial driving was 925 tons. The retapping data in Table 9 shows that the pile capacity did not change significantly.

Pile Load Tests at Sites A and B

The FHWA provided the load test frame and accessory equipment including the precision load measuring equipment. The FHWA personnel provided the technical assistance for conducting the load test. The piles were instrumented with vibrating wire strain gages and "tell-tale rods" to determine the load-transfer distribution. The deflections of the compression pile top was measured with a "LVDT." The load frame deflections and reaction pile pullout were accounted for by survey measurements. At test Site B, the compression and reaction pile movements were checked by a survey instrument located on the shore. The compression load test on each pile was succeeded by a tension test. The tension tests were conducted by using the contractor provided jacks and gauges.

Figure 1 shows the load-settlement curve for the compression load test at Site A. The scale is chosen as per Professor Davisson's recommendations for estimating failure loads. It should be noted that the load-settlement curve is adjusted at the first load increment (125 tons). It is the opinion that the deflection measurement at the first load increment include substantial movements in connections and does not truly reflect the pile deflection. Three methods for estimating the failure loads from the load-settlement curve were used and the results are shown in Figure 1 and Table 10. Table 10 also shows the prediction by the pile analyzer. The "Davisson Criteria" and the analyzer prediction (analyzer uses the same criteria) compare well. The "D/30 Criteria" (recommended by the Canadian Foundation Engineering Manual) is frequently used for large diameter piles particularly steel pipes and provides a failure load estimate of 975 tons. The "Double Tangent Criteria" (recommended in the FHWA publication on "Texas Quick Load Test") provides a failure load estimate of 960 tons. The tension test data for the test pile at Site A showed that the pile failed at about 250 tons.

Figure 2 shows the load-settlement curve for the compression load test at Site B. The load-settlement curve has been adjusted at the first load increment (125 tons) for the same reasoning as given for Site A. Figure 2 and Table 11 show the failure load estimates provided by previously discussed criteria. The estimate provided by "Davisson Criteria" compares well with the pile analyzer prediction. The "D/30 Criteria" provides the estimate failure load of 1,000 tons and matches with the estimate provided by the "Double Target Criteria."

The tension test for this pile was discontinued after two load increments of 25 tons each (total load 50 tons) because of the pile failure. This pile was extracted after the test was completed. It was discovered that the bottom 10-foot pile section below the end enclosure plate was sheared off at the plate and remained in the ground. The damage may have occurred due to the inability of welds to sustain high compressive forces generated during driving.

Table 10
Estimated Pile Failure Loads, Test Site A

Failure Criteria	Failure Load Estimate (See Figure 1)
"Davisson" Criteria	700 tons
Prediction by "Pile Analyzer"	780 tons
"D/30" Criteria (Canadian Foundation Engineering Manual)	975 tons
"Double Tangent" Criteria	960 tons

Table 11
Estimated Pile Failure Loads, Test Site B

Failure Criteria	Failure Load Estimate (See Figure 2)
"Davisson" Criteria	750 tons
Prediction by "Pile Analyzer"	785 tons
"D/30" Criteria (Canadian Foundation Engineering Manual)	1,000 tons
"Double Tangent" Criteria	1,000 tons

Conclusions and Recommendations

1. The dynamic monitoring equipment performed well in monitoring driving stresses and hammer performance. The predicted ultimate pile capacities by the analyzer compare well with load test interpretation by "Davisson Criteria." But the predicted ultimate loads by the analyzer were 20 to 25 percent lower than those predicted by the "D/30" and "Double Tangent" Criteria.

2. The revised analysis of dynamic data including "CAPWAP" is being performed by the Pile Dynamics, Incorproated, and may show different pile load capacities than those predicted by the analyzer in the field. The "CAPWAP" data.will be furnished to the WashDOT.

3. The steam hammer used for the pile driving operations often operated erractically. The inconsistent hammer performance was due to too much or too little steam pressure. There were instances when due to excessive steam pressure, the entire hammer assembly tended to lift off the pile and induced very high dynamic stresses in the pile. This was readily detected by the dynamic equipment. This demonstrated the tremendous advantages provided by the dynamic equipment in pile damage control and hammer performance monitoring.

4. The blow count estimates provided by the "Wave Equation Analysis" did not match with the field driving records and load test results, primarily because the hammer operated substantially below the 80 percent efficiency assumed by the "WEAP Program." This can be readily determined by comparing the measured energy at the pile top by the pile analyzer (provided in Tables 1 through 9) with the energy shown in the summary of "WEAP" program output. This demonstrates another advantage provided by the dynamic equipment for the construction control. We recommend

that for the production pile driving, the assumed hammer efficiency be between 65 percent to 70 percent if a steam hammer is used. The other wave equation input parameters such as load transfer distribution, damping parameters, and quakes should be those provided by the "CAPWAP" analysis. Revised wave equation analysis should be used for production pile driving.

5. We recommend that a 48-inch O.D., 3/4-inch thick wall, closed end pile be designed using an ultimate axial compression load capacity of 1,000 ton (soil capacity).

6. We strongly recommend that the State consider using dynamic monitoring equipment and the wave equation analysis for the construction control of pile driving on this project.

I-90, SEATTLE, 3RD LAKE WASHINGTON BRIDGE, DYNAMIC PILE MONITORING

TABLE 1 PILE LOAD TEST PROGRAM - SITE A, 48" O.D. - 3/4" WALL, INITIAL DRIVING

DEPTH BELOW TEMPLATE	DEPTH *	BLOW COUNT PER FOOT	RSTC WITH J=0.20 KIPS	RSTC WITH J=0.1 KIPS	F. MAX. KIPS	MAX. COMP. STRESS K.S.I.	CTEN KIPS	MAX. TEN. STRESS K.S.I.	MAX. TRANSFER ENERGY FT. KIPS	STROKE FT.	HAMMER ENERGY (RAM WT. X STROKE) FT. KIPS	TRANSFER EFFICIENCY (TRANSFER ENERGY / ACTUAL HAMMER ENERGY)	REMARKS
97'-0"	(97'-0") -(91'-0") = 6'-0"	DRIVING STARTED											Blow Count by Analyzer compared with Washington D.O.T. records
105'-0"	(105'-0") -(91'-0") =14'-0"	12	430	750	1,650	14.8	740	6.6	40	CONSTANT STROKE = 3'-0"	30,000 lbs. X 3.0 ft. = 90,000 ft. lbs. = 90 ft. kips	44.4 percent	
115'-0"	24'-0"	29	610	920	1,890	17.0	710	6.4	47			52.2 percent	
118'-0"	27'-0"	60	720	1,070	1,890	17.0	590	5.3	49			54.4 percent	
121'-0"	30'-0"	100	820	1,120	1,950	17.5	600	5.4	50			55.5 percent	
122'-0"	31'-0"	108 (122)	830	1,190	1,970	17.7	600	5.4	54			60.0 percent	(122) Blows Recorded by Washington Dept. of Trans.
123'-0"	32'-0"	126	850	1,120	2,020	18.1	630	5.7	53			58.8 percent	
124'-0"	33'-0"	147	850	1,150	1,980	17.8	610	5.5	56			62.2 percent	
125'-1"	34'-1"	(236)	1,220	Ave. 1,500	1,860	16.7	190	1.7	50			55.5 percent	(236) Blows Recorded by Washington Dept. of Trans.

Driving Completed at 125'-1"

Predicted Static Load Capacity = 75.0 Tons

*Distance from the mudline to pile tip.
RSTC = Ultimate Static Resistance
FMAX = Maximum measured force in pile at the transducer location
CTEN = Maximum computed tensile force anywhere in pile
Maximum allowable compressive or tensile stress = 0.85 fy
(Drivin[illegible]ess) = 0.85 X 36,000/1,000
= 30.6 k.s

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TABLE 2 PILE LOAD TEST PROGRAM - SITE A, 48" O.D. - 3/4" WALL, RETAP ANALYSIS (AFTER 16 HOURS)

DEPTH BELOW TEMPLATE	DEPTH *	BLOW COUNT PER FOOT	RSTC WITH J=0.2 KIPS	RSTC WITH J=0.1 KIPS	F. MAX. KIPS	MAX. COMP. STRESS K.S.I.	C TEN KIPS	MAX. TEN. STRESS K.S.I.	MAX. TRANSFER ENERGY FT. KIPS	STROKE FT.	HAMMER ENERGY (RAM WT. X STROKE) FT. KIPS	TRANSFER EFFICIENCY (TRANSFER ENERGY / ACTUAL HAMMER ENERGY)	REMARKS
125'-1"	34'-1"	RETAPPING STARTED AFTER 16 HOURS											
125'-2"	34'-2"	16/inch (7)	---	1540	1,670	15.0	0	0	36			40.0 percent	
125'-3"	34'-3"	16/inch (10)	---	1520	1,720	15.4	60	0.5	39	3'-0"	90.0	43.3 percent	Hammer did not work at full stroke because of lack of sufficient steam pressure.
125'-4"	34'-4"	22/inch (22)	---	1540	1,750	15.7	50	0.4	40			44.4 percent	
125'-5"	34'-5"	(22)	---	1560	1,750	15.7	40	0.3	39			43.3 percent	( ) Washington D.O.T. Blow Count

PREDICTED STATIC LOAD CAPACITY OF PILE = 780 TONS

*Distance fr(n the mudline to pile tip.
RSTC = Ultim te Static Resistance
FMAX = Maxim m measured force in pile at the transducer location
CTEN = Maxim n computed tensile force anywhere in pile
Maximum allc able compressive or tensile stress = 0.85 fy
(Drivi :r ss) = 0.85 X 36,000/1,000
= 30.6 k.s.i.

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TABLE 3 PILE LOAD TEST PROGRAM - SITE A, 36" O.D. - 3/4" WALL REACTION PILE NO. 1 (SW CORNER), INITIAL DRIVING

DEPTH BELOW TEMPLATE	DEPTH *	BLOW COUNT PER FOOT	RSTC WITH J=0.1 KIPS	F. MAX. KIPS	MAX. COMP. STRESS K.S.I.	C'TEN KIPS	MAX. TEN. STRESS K.S.I.	MAX. TRANSFER ENERGY FT. KIPS	STROKE FT.	HAMMER ENERGY (RAM WT. X STROKE) FT. KIPS	TRANSFER EFFICIENCY (TRANSFER ENERGY / ACTUAL HAMMER ENERGY)	REMARKS
96"-0"	(96.0)-(91.0) = 5'-0"	DRIVING STARTED							CONSTANT STROKE = 3'-0"	30,000 lbs. X 3.0 ft. = 90,000 ft. lbs. = 90 ft. kips		
115'-0"	24'-0"	15	590	1,730	20.8	660	7.9	41			45.6 percent	
122'-0"	31'-0"	31	870	1,680	20.2	410	4.9	39			43.3 percent	Hammer did not work at full efficiency because of lack of sufficient steam pressure
132'-0"	41'-0"	32	1,030	1,530	18.4	250	3.0	40			44.4 percent	
145'-0"	54'-0"	20	890	1,740	21.0	460	5.5	51			56.6 percent	
155'-0"	64'-0"	29	990	1,440	17.3	190	2.3	41			45.6 percent	Blow Counts compared with Washington D.O.T. records
158'-0"	67'-0"	49	1,280	1,340	16.1	0	0	40			44.4 percent	
160'-0"	69'-0"	57	1,260	1,380	16.6	0	0	42			46.7 percent	
161'-0"	70'-0"	71	1,460	1,500	18.1	0	0	46			51.1 percent	
162'-0"	71'-0"	49	1,150	1,290	15.5	8	0.1	38			42.2 percent	Driving (monitoring) completed at 162'-3"
162'-3"	71'-3"	12/3"	1,170	1,320	15.9	6	0.1	38			42.2 percent	

PREDICTED STATIC PILE LOAD CAPACITY = 600 TONS

*Distance from the mudline to pile tip.
RSTC = Ultimate Static Resistance
FMAX = Maximum measured force in pile at the transducer location
CTEN = Maximum computed tensile force anywhere in pile
Maximum allowable compressive or tensile stress = 0.85 fy
(Driving stress) = 0.85 X 36,000/1,000
= 30.6 k.

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TABLE 9 PILE LOAD TEST PROGRAM - SITE B, 36" O.D. - 3/4" WALL PILE NO. 6 (SW CORNER) (RETAPPING)

DEPTH BELOW TEMPLATE	DEPTH*	BLOW COUNT PER FOOT	RSTC WITH J=0.1 KIPS	F. MAX. KIPS	MAX. COMP. STRESS K.S.I.	C TEN KIPS	MAX. TEN. STRESS K.S.I.	MAX. TRANSFER ENERGY FT. KIPS	STROKE FT.	HAMMER ENERGY (RAM WT. X STROKE) FT. KIPS	TRANSFER EFFICIENCY (TRANSFER ENERGY / ACTUAL HAMMER ENERGY)	REMARKS
127'-3"	(127'-3") -(93'-0") = 34'-3"		RETAPPING STARTED AFTER 16 HOURS									Blow count by analyzer compared with Wash. D.O.T. blow count.
127'-4"	34'-4"	45/inch	1,810	1,410	17.0	0	0	42	CONSTANT STRIKE = 3'-0"	30,000 lbs. X 3.0 ft. = 90,000 ft. lbs. = 90 ft. kips	46.7 percent	
127'-5"	34'-5"	27/inch	1,810	1,390	16.7	0	0	40			44.4 percent	
127'-6"	34'-6"	23/inch	1,800	1,390	16.7	0	0	40			44.4 percent	
127'-7"	34'-7"	21/inch	1,770	1,380	16.6	0	0	40			44.4 percent	
127'-8"	34'-8"	19/inch	1,770	1,390	16.7	0	0	43			47.8 percent	
127'-9"	34'-9"	24/inch	1,780	1,400	16.9	0	0	43			47.8 percent	
	RETAPPING COMPLETED AT 127'-9"											
		PREDICTED STATIC PILE LOAD CAPACITY = 1,800 kips = 900 TONS										

*Distance from the mudline to pile tip.
RSTC = Ultimate Static Resistance
FMAX = Maximum measured force in pile at the transducer location
CTEN = Maximum computed tensile force anywhere in pile
Maximum allowable compressive or tensile stress = 0.85 fy
(Drivi[illegible]ress) = 0.85 X 36,000/1,000
= 30.6 k.[illegible]

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TABLE 8 PILE LOAD TEST PROGRAM - SITE B, 36" O.D. - 3/4" WALL PILE NO. 6 (SW CORNER) (INITIAL DRIVING)

DEPTH BELOW TEMPLATE	DEPTH *	BLOW COUNT PER FOOT	RSTC WITH J=0.1 KIPS	F. MAX. KIPS	MAX. COMP. STRESS K.S.I.	CTEN KIPS	MAX. TEN. STRESS K.S.I.	MAX. TRANSFER ENERGY FT. KIPS	STROKE FT.	HAMMER ENERGY (RAM WT. X STROKE) FT. KIPS	TRANSFER EFFICIENCY (TRANSFER ENERGY / ACTUAL HAMMER ENERGY)	REMARKS
103'-0"	(103'-0") (93'-0") = 10'-0"											( ) Wash. D.O.T. Blow count. Blow count by analyzer compared with Wash. D.O.T. records.
122'-0"	29'-0"	93	1,470	1,570	18.9	0	0	51	CONSTANT STROKE = 3'-0"	30,000 lbs. X 3'-0" ft. = 90,000 ft. lbs. = 90 ft. kips	56.7 percent	
123'-0"	30'-0"	85	1,600	1,610	19.4	0	0	53			58.8 percent	
124'-0"	31'-0"	108	1,640	1,580	19.0	0	0	52			57.8 percent	
125'-0"	32'-0"	120	1,790	1,570	18.9	0	0	54			60.0 percent	
126'-0"	33'-0"	187	1,800	1,510	18.2	0	0	50			55.6 percent	
127'-0"	34'-0"	(215)	1,880	1,540	18.5	0	0	54			60.0 percent	
127'-1"	34'-1"	(17)/inch	1,940	1,570	18.9	0	0	55			61.1 percent	
127'-2"	34'-2"	(21)/inch	1,940	1,560	18.8	0	0	54			60.0 percent	
127'-3"	34'-3"	(24)/inch	1,850	1,360	16.4	0	0	48			53.3 percent	
		PREDICTED STATIC PILE LOAD CAPACITY = 925 TONS										

*Distance from the mudline to pile tip.
RSTC = Ultimate Static Resistance
FMAX = Maximum measured force in pile at the transducer location
CTEN = Maximum computed tensile force anywhere in pile
Maximum allowable compressive or tensile stress = 0.85 fy
(Driving Stress) = 0.85 X 36.000/1,000
= 30.6 k.s.i.

I-90, SEATTLE, 3RD LAKE WASHINGTON BRIDGE, DYNAMIC PILE MONITORING

TABLE 7 PILE LOAD TEST PROGRAM - SITE B, 36" O.D. - 3/4" WALL PILE NO. 5 (SE CORNER), INITIAL DRIVING

DEPTH BELOW TEMPLATE	DEPTH *	BLOW COUNT PER FOOT	RSTC WITH J=0.1 KIPS	F. MAX. KIPS	MAX. COMP. STRESS K.S.I.	CTEN KIPS	MAX. TEN. STRESS K.S.I.	MAX. TRANSFER ENERGY FT. KIPS	STROKE FT.	HAMMER ENERGY (RAM WT. X STROKE) FT. KIPS	TRANSFER EFFICIENCY (TRANSFER ENERGY / ACTUAL HAMMER ENERGY)	REMARKS
104'-0"	(104'-0") -(93'-0") = 11'-0"	PILE DRIVING STARTED										Blow count by analyzer compared with Wash. D.O.T. records.
110'-0"	17'-0"	24	550	1,240	14.9	460	5.5	39	CONSTANT STROKE = 3'-0"	30,000 lbs. X 3.0 ft. = 90,000 ft. lbs. = 90 ft. kips	43.3 percent	
114'-0"	21'-0"	47	930	1,380	16.6	210	2.5	44			48.9 percent	
118'-0"	25'-0"	58	1,300	1,450	17.5	0	0	50			55.6 percent	
123'-0"	30'-0"	(69)	1,340	1,190	14.3	0	0	42			46.7 percent	( ) Blows recorded by Wash. D.O.T.
124'-0"	31'-0"	109	1,400	1,210	14.6	0	0	43			47.8 percent	
125'-0"	32'-0"	120	1,620	1,450	17.5	0	0	51			56.7 percent	
126'-0"	33'-0"	133	1,790	1,650	19.9	0	0	55			61.1 percent	Instruments attached to the pile became inoperable.
127'-0"	34'-0"	142	1,740	1,430	17.2	0	0	51			56.7 percent	Dynamic monitoring discontinued at 127'-0" penetration. Retapping was not monitored.
		PREDICTED STATIC LOAD CAPACITY AT 34' EMBEDMENT = 1,740 kips = 870 TONS										

*Distance from the mudline to pile tip.

RSTC = Ultimate Static Resistance

FMAX = Maximum measured force in pile at the transducer location

CTEN = Maximum computed tensile force anywhere in pile

Maximum allowable compressive or tensile stress = 0.85 fy
(Driv' 'tress) = 0.85 X 36,000/1,000
= 30.6 k.

I-90, SEATTLE, 3RD LAKE WASHINGTON BRIDGE, DYNAMIC PILE MONITORING

TABLE 6 PILE LOAD TEST PROGRAM - SITE B, 48" O.D. - 3/4" WALL PILE, RETAPPING ANALYSIS (AFTER 24 HOURS)

DEPTH BELOW TEMPLATE	DEPTH*	BLOW COUNT PER FOOT	RSTC WITH J=0.1 KIPS	F. MAX. KIPS	MAX. COMP. STRESS K.S.I.	C TEN KIPS	MAX. TEN. STRESS K.S.I.	MAX. TRANSFER ENERGY FT. KIPS	STROKE FT.	HAMMER ENERGY (RAM WT. X STROKE) FT. KIPS	TRANSFER EFFICIENCY (TRANSFER ENERGY / ACTUAL HAMMER ENERGY)	REMARKS
109'-0"	(109'-0") -(93'-0") = 16'-0"	PILE RETAPPING STARTED							CONSTANT STROKE = 3'-0"	30,000 lbs. X 3.0 ft. = 90,000 ft. lbs. = 90 ft. kips		
109'-1"	16'-1"	17	1,470	1,870	16.8	450	4.0	58			64.4 percent	Hammer did not operate consistently.
109'-2"	16'-2"	25	1,680	1,940	17.4	40	0.4	67			74.4 percent	
109'-3"	16'-3"	56	1,530	1,800	16.2	210	1.9	63			70.0 percent	Blow counts compared with Wash. D.O.T. records
109'-4"	16'-4"	50	1,570	1,840	16.5	60	0.5	54			60.0 percent	

PREDICTED STATIC LOAD CAPACITY = 785 TONS

NOTE: The pile was extracted after the loat test. The bottom 10' section below the end plate was damaged and remained in the ground. The extraction was performed by the crane pulling the pile and was easy.

*Distance from the mudline to pile tip.
RSTC = Ultimate Static Resistance
FMAX = Maximum measured force in pile at the transducer location
CTEN = Maximum computed tensile force anywhere in pile
Maximum allowable compressive or tensile stress = 0.85 fy
(Driving stress) = 0.85 X 36,000/1,000
= 30.6 k

I-90, SEATTLE, 3RD LAKE WASHINGTON BRIDGE, DYNAMIC PILE MONITORING

TABLE 5 PILE LOAD TEST PROGRAM - SITE B, 48" O.D. - 3/4" WALL PILE, INITIAL DRIVING

DEPTH BELOW TEMPLATE	DEPTH*	BLOW COUNT PER FOOT	RSTC WITH J=0.1 KIPS	F. MAX. KIPS	MAX. COMP. STRESS K.S.I.	CTEN KIPS	MAX. TEN. STRESS K.S.I.	MAX. TRANSFER ENERGY FT. KIPS	STROKE FT.	HAMMER ENERGY (RAM WT. X STROKE) FT. KIPS	TRANSFER EFFICIENCY (TRANSFER ENERGY / ACTUAL HAMMER ENERGY)	REMARKS
103'-0"	(103'-0") -(93'-0") =10'-0"	PILE DRIVING STARTED										
104'-0"	11'-0"	31	1,440	1,880	16.9	110	1.0	55	CONSTANT STROKE = 3'-0"	30,000 lbs. X 3.0 ft. = 90,000 ft. lbs. = 90 ft. kips	61.1 percent	Blow counts by analyzer compared with Wash. D.O.T. records.
105'-0"	12'-0"	28	1,560	1,870	16.8	0	0	53			58.9 percent	
106'-0"	13'-0"	64	1,580	2,000	18.0	0	0	56			62.2 percent	
107'-0"	14'-0"	197	1,590	1,810	16.3	290	2.6	52			62.2 percent	Wash. D.O.T. blow count = 104
107'-6"	14'-6"	206/6"	1,710	1,840	16.5	90	0.8	53			57.8 percent	
108'-0"	15'-0"	90/6"	1,780	1,820	16.3	0	0	51			56.7 percent	
109'-0"	16'-0"	(321)	1,890	1,820	16.3	0	0	53			58.9 percent	(321) Blows recorded by Washington D.O.T.
		DRIVING COMPLETED AT 109'-0" PREDICTED STATIC LOAD CAPACITY = 1,890 kips = 945 TONS										

*Distance fr the mudline to pile tip.
RSTC = Ultimate Static Resistance
FMAX = Maximum measured force in pile at the transducer location
CTEN = Maximum computed tensile force anywhere in pile
Maximum allowable compressive or tensile stress = 0.85 fy
(Drivi tress) = 0.85 X 36,000/1,000
= 30.6 k.

I-90, SEATTLE, 3RD LAKE WASHINGTON BRIDGE, DYNAMIC PILE MONITORING

<u>TABLE 4</u> PILE LOAD TEST PROGRAM - SITE A, 36" O.D. REACTION PILE NO. 3 (NE CORNER), INITIAL DRIVING

DEPTH BELOW TEMPLATE	DEPTH *	BLOW COUNT PER FOOT	RSTC WITH J=0.1 KIPS	F. MAX. KIPS	MAX. COMP. STRESS K.S.I.	CTEN KIPS	MAX. TEN. STRESS K.S.I.	MAX. TRANSFER ENERGY FT. KIPS	STROKE FT.	HAMMER ENERGY (RAM WT. X STROKE) FT. KIPS	TRANSFER EFFICIENCY (TRANSFER ENERGY / ACTUAL HAMMER ENERGY)	REMARKS
99'-0"	(99'-0") -(91'-0") = 8'-0"	DRIVING STARTED										
111'-0"	20'-0"	8	450	1,540	18.5	780	9.4	40	CONSTANT STROKE = 3'-0"	30,000 lbs. X 3'-0" ft. = 90,000 ft. lbs. = 90.0 ft. kips	44.4 percent	Between 123' and 125' penetration, hammer provided more energy than rated energy because very high steam pressure caused the assembly to lift off the pile.
120'-0"	29'-0"	23	740	1,610	19.4	560	6.7	49			54.4 percent	
124'-0"	33'-0"	28	1,780	2,840	34.2	0	0	99			110.0 percent	
132'-0"	41'-0"	18	720	1,620	19.5	480	5.8	49			54.4 percent	
145'-0"	54'-0"	18	810	1,640	19.7	440	5.3	54			60.0 percent	
153'-0"	62'-0"	29	1,010	1,590	19.1	300	3.6	50			55.6 percent	Blow count by analyzer compared with Wash. D.O.T. records.
157'-0"	66'-0"	35	1,320	1,690	20.3	0	0	56			62.2 percent	
158'-0"	67'-0"	35	1,320	1,670	20.1	3	0.04	55			61.1 percent	
160'-0"	69'-0"	48	1,340	1,630	19.6	0	0	55			61.1 percent	
161'-0"	70'-0"	41	1,280	1,620	19.5	6	0.1	53			58.9 percent	Driving (monitoring) completed at 161'-10"
161'-10"	70'-10"	30/10"	1,260	1,610	19.4	7	0.1	53			58.9 percent	

<u>PREDICTED STATIC LOAD CAPACITY = 650 TONS</u>

*Distance from the mudline to pile tip.
RSTC = Ultimate Static Resistance
FMAX = Maximum measured force in pile at the transducer location
CTEN = Maximum computed tensile force anywhere in pile
Maximum allowable compressive or tensile stress = 0.85 fy
(Driving Stress) = 0.85 X 36,000/1,000
= 30.6 ksi

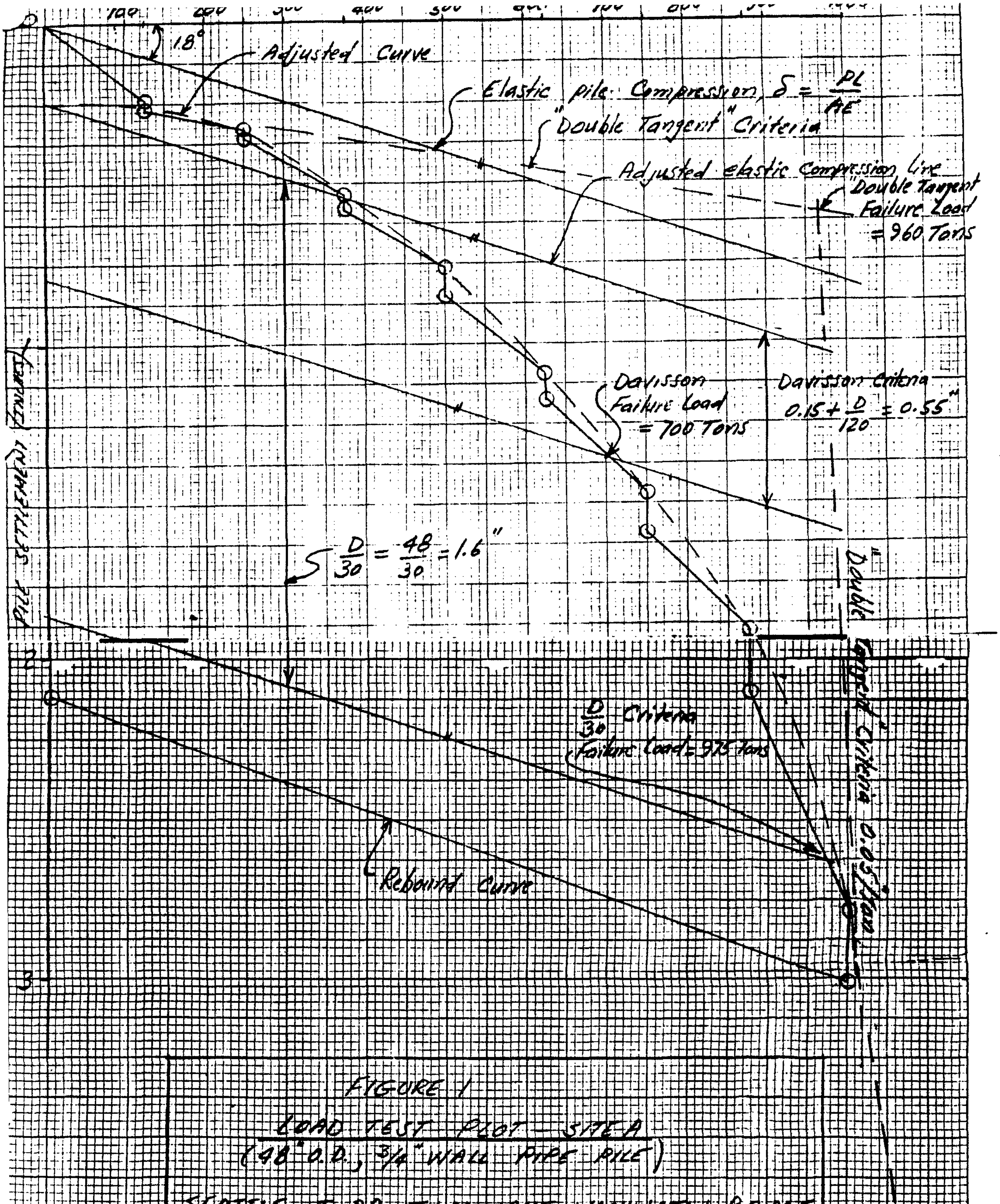

FIGURE 1

LOAD TEST PLOT – SITE A

(48" O.D., 3/4" WALL PIPE PILE)

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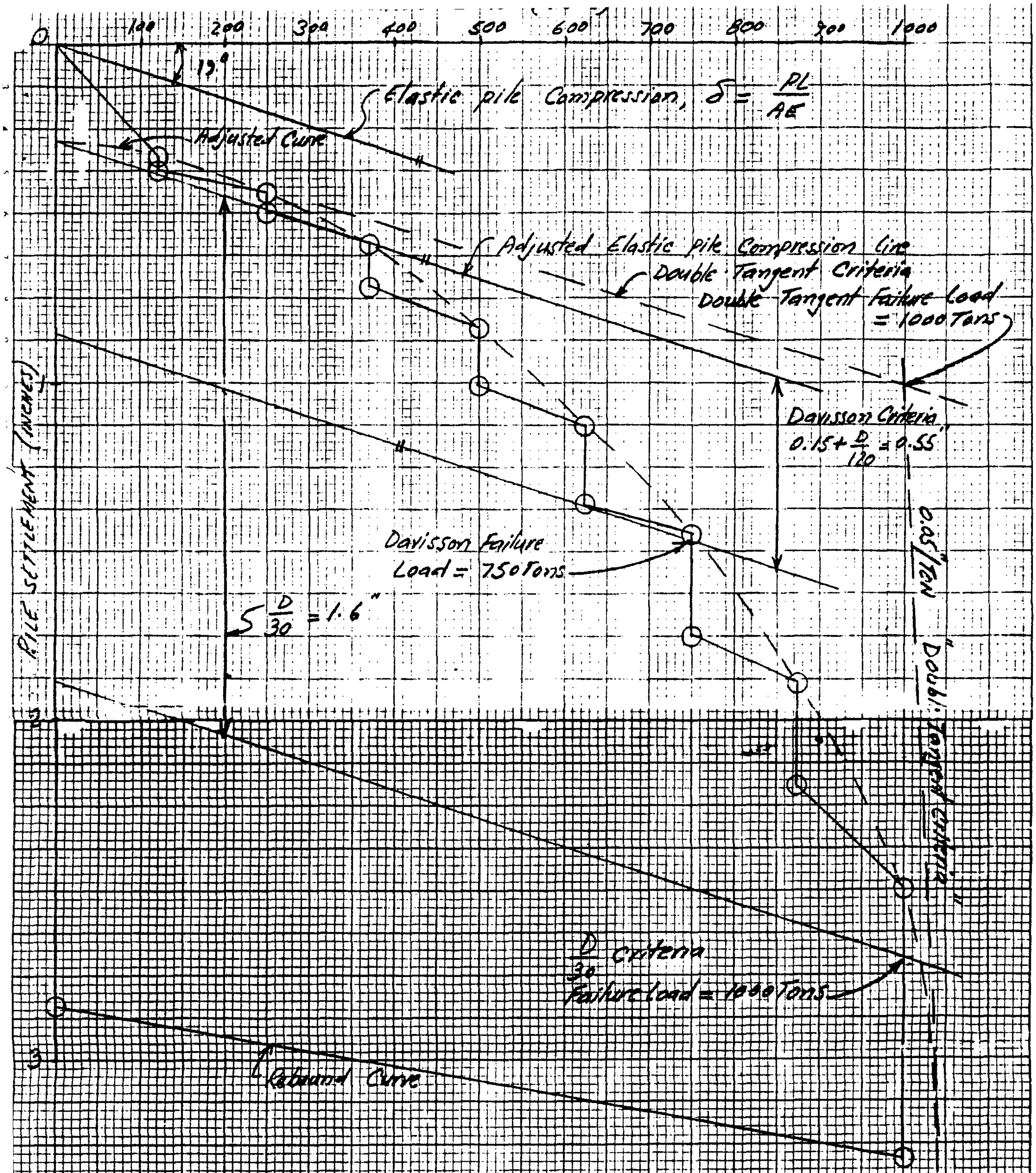

FIGURE 2

LOAD TEST PLOT – SITE B

(48" O.D., 3/4" WALL PIPE PILE)

SEATTLE, I-90, THIRD LAKE WASHINGTON BRIDGE