DYNAMIC PILE MONITORING REPORT

PROPOSED SH 146 BRIDGE OVER

HOUSTON SHIP CHANNEL, HARRIS COUNTY, TEXAS

FHWA DEMONSTRATION PROJECTS dp

FHWA-DP-66-12

Federal Highway Administration

Office of Highway Operations

Demonstration Projects Program

Washington, D.C.

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SH 146 Bridge Over Houston Ship Channel, Harris County, Texas

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 test frame. The equipment and technical assistance are made available to a requesting State highway department.

A request for a field demonstration and use of the dynamic testing equipment was received from the Texas State Department of Highways and Public Transportation (SDHPT) in June 1985. SDHPT had decided to perform a comprehensive design stage pile load test program for the proposed SH 146 Bridge over Houston Ship Channel (Baytown Bridge). The Federal Highway Administration (FHWA) agreed to provide the dynamic monitoring equipment, and personnel and technical assistance. SDHPT's District 12 office obtained services of McClelland Engineers and Raymond International Builders, Inc. for the design and implementation of the load test program.

The purpose for the load test program was (1) to install and load test different pile types at two locations, (this was done in order to select the appropriate pile types), (2) to determine design pile load capacities, and (3) to assess pile performance during driving. Pile analyzer was used to demonstrate the use of newer and more accurate techniques for determining pile load capacity during driving, to measure driving stresses generated in the pile (pile damage control) and to assess the efficiency of the driving system.

The field work (pile driving and dynamic testing) for load test site number 1 - south side of ship channel) was performed during October-November 1985. The dynamic tests were performed by Mr. H. Clark, Civil Engineering Technician in the Demonstrations Projects Division, and Mr. S. Vanikar, Geotechnical Engineer in the Geotechnical and Materials Branch. McClelland Engineers designed the load test program and performed the wave equation analysis. Driven piles were installed by Raymond International Builders, Inc.

On October 31, 1985, after the dynamic testing of initial pile driving for the steel and concrete piles at load test site number 1 was completed, an informal presentation on the results of the dynamic testing was made to SDHPT and FHWA engineers. Also present at the meeting were representatives of McClelland Engineers Inc. and Raymond International Builders, Inc. The concrete and steel piles were retapped on November 8, 1985 and pile analyzer was used during retapping. A detailed description of the work performed, test results, and recommendations follow in this report.

Location and Structure Information

The two pile load test sites are located on North and South sides of the Houston Ship Channel on the proposed alignment of State Highway 146. The proposed bridge will replace the Baytown Tunnel across the Houston Ship Channel. The bridge proposed is a cable stayed structure with a 1200 ft. main span. The foundations for the structure will be either drilled shafts or driven piles (steel pipe or prestressed concrete).

Pile Data

Three pile types were installed and static load tested at each test site. The test piles were 24 inch O.D., 0.625-inch wall open end pipe, 20-inch square prestressed concrete and 36-inch diameter drilled shaft. Steel and concrete piles at the test site located on the south side of the channel were dynamically monitored by the pile analyzer.

The 140 foot long steel pile was driven in two sections. Driving of the first 70 feet section was not monitored with the pile analyzer. Another 70 foot section was welded to the driven section and the driving of 140 foot long section was monitored by using pile analyzer. Driving of steel pile was completed at the pile tip penetration of 132 feet below ground line. Prestressed concrete pile was 101.5 foot long and the driving was dynamically monitored for the entire penetration depth. The driving of prestressed concrete pile was terminated when the pile tip reached 98 feet below ground line.

Both test piles were retapped and dynamically monitored nine days after the initial driving was completed. The purpose for retapping was to determine whether there was any gain in the pile capacity due to setup.

Subsurface Conditions

Log of boring number 2 at the South test site location shows variable fill materials to a depth of 9 feet. Alternate layers of gray silty fine sand and stiff silty clay exit to a depth of 70 feet below ground. Standard penetration test (SPT) "N" values for silty sands vary from 4 to 29. Undrained shear strength estimates for silty clay layers (obtained from hand penetrometer) vary from 1 to 2 kips per square foot. Very stiff gray clay deposits exist from 70 foot to 115 foot depth. Typical undrained shear strength estimates (based on hand penetrometer) for very stiff clay are in excess of 2.5 KSF. Stiff gray clay with sandy silt and silty sand seams exist below 115 foot depth. Boring number 2 was terminated of 150 foot depth. The boring log does not indicate existence of water table but proximity of the test site to the ship channel suggests high water table.

Hammer Data

The following is the data for the hammer system selected by the contractor (Raymond International Builders, Inc.):

Raymond 5/0, Single Acting Air/Steam (Short & full stroke options)

Maximum Rated Energy = 58,900 Foot Pounds, Ram weight = 17,500 pounds

Hammer Cushion - alternate layers of micarta and aluminum,
total thickness = 11 inches

Pile Cushion - None for Steel Pile
Plywood (6 inches thick) for Concrete Pile

Dynamic Monitoring (Pile Analyzer) Results

The dynamic monitoring data and results shown in Tables 1 and 2 are self-explanatory. Table 1 shows the dynamic monitoring results for the 24 inch - O.D. steel pipe pile. Table 1 includes data obtained during initial driving and redriving after nine days. The compressive and tensile driving stresses did not exceed the limitations of 32.4 KSI. The large static pile capacity measured at 67 feet penetration was due to the setup of the first pile section driven on the previous day. The static pile capacity continued to increase with pile tip penetration. Initial driving was terminated at pile tip penetration to 133-foot depth. The analyzer predicted an ultimate capacity of 338 tons. The pile hammer performed well during initial driving. Transfer efficiencies in the range of 42 to 61 percent were recorded. The average transfer efficiencies of single acting air/steam hammers during steel pile driving are usually around forty five percent. The pile gained substantial additional static load capacity due to setup. The predicted ultimate capacity after nine days of setup was 417 tons. The estimated ultimate static pile load capacity based on static analysis computations was 325 tons. The hammer did not work well during redriving which is indicated by lower transfer efficiency value of 38.5 percent. The hammer and cushion system were well matched for the steel pipe pile driving.

Table 2 shows the dynamic monitoring results for the 20 inch-square prestressed concrete pile. The results of initial driving and redriving are included in the table. The pile hammer was operated at a shorter stroke until the pile developed adequate resistance. This was done in order to keep the tensile stresses in the pile within the specified limit of 1.2 KSI. The pile did not develop any static resistance until the pile tip reached 63 feet below ground. The compressive and tensile driving stresses were well within limits till the hammer stroke was changed to full stroke (39"). With full stroke, the tensile stresses practically reached the specified limitation and slight damage was observed on the oscilloscope when the pile reached 70 foot depth. The oscilloscope was used in conjunction with the pile analyzer to observe force and velocity wave forms and also to detect pile damage. This damage was confirmed by the computed output value "Beta" provided by the analyzer. The hammer stroke was reduced in order to keep the driving stresses low and to limit further pile damage. The driving was completed at pile tip penetration to 98 foot depth. The analyzer predicted 115 tons ultimate static pile load capacity. The hammer performed well throughout the initial driving of concrete pile. The pile gained substantial additional static load capacity due to setup. The predicted capacity after nine days of setup was 250 tons. The estimated ultimate static pile load capacity based on static analysis computations was 280 tons.

It should be noted that damping factor (J) was assumed to be 0.4 in making the ultimate pile capacity predictions for both piles (damping factor is used as one of the pile analyzer input values). This assumption was based on the fact that the boring shows stiff clay as the predominant soil type. After the static load tests are completed, a back analysis can be performed to determine the validity of this assumption.

Conclusions and Recommendations

1. The pile analyzer performed well in monitoring driving stresses, pile capacities and hammer performance. The analyzer detected slight pile damage in the prestressed concrete pile. The damage occurred when the pile tip reached 70 feet below existing ground. The cause of damage was probably the high level of tensile driving stresses in the pile. This demonstrates the tremendous advantages provided by the equipment.

2. The predicted ultimate pile load capacities by the analyzer should be compared with the static pile load test results. A back analysis based on static load test results can provide an assessment of "J" value assumed in using the pile analyzer.

3. Significant gain in pile capacities due to setup was measured for both pile types. This fact should be considered in developing the pile driving criteria for the production piles.

4. Based on the prestressed concrete pile performance during driving, it is recommended that the pile driving criteria developed for the production concrete piles should require the contractor to drive the pile with a reduced stroke until significant resistance is developed. This will avoid pile damage due to excessive tensile driving stresses. The driving criteria can be developed by performing wave equation analyses.

5. The single acting steam hammer (Raymond 5/0) for test pile driving performed reasonably well. The hammer and cushion systems used for the steel and concrete piles were well matched. The variable stroke feature of the hammer will be essential if prestressed concrete piles are selected for this project

6. It is strongly recommended that wave equation analysis for construction control be used for this project if driven piles are selected for foundations. The results of static load tests should be used in refining the wave equation analysis.

7. It is recommended that the Texas SDHPT acquire a pile analyzer and accessory equipment for the construction control on Houston Ship Channel bridge and future major pile foundation projects. Several consultants offer services for dynamic pile testing.

8. Dynamic pile testing by the analyzer is not necessary for all piles. Typically, 5 to 10 percent of the piles in a substructure unit should be tested dynamically. The remaining piles should be driven based on the wave equation criteria.

Suneel N. Vanikar

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Geotechnical Engineer

SH 146 BRIDGE OVER HOUSTON SHIP CHANNEL
(BAYTOWN BRIDGE, HARRIS COUNTY, TEXAS)

TABLE 1 SUMMARY OF DYNAMIC MONITORING RESULTS
(SOUTH PILE LOAD TEST SITE)

DATE October 29 & 30, 1985 and November 8, 1985 LENGTH (70'-0") + (70'-0") = 140'-0"

PILE TYPE 24" O.D., 5/8" wall Closed end pipe PILE NO. --

HAMMER TYPE Single Acting Steam HAMMER MODEL Raymond 5/0

HAMMER RATED ENERGY 58,900 Ft. Lbs. (Ram Weight = 17,500 Lbs.)

Depth,* Feet	Blow Count Per Foot: From Analyzer	Blow Count Per Foot: From Driving Record	RSP With J = 0.4 Kips	FMX Kips	Max. Comp. Stress Ksi	CTEN Kips	Max. Tensile Stress, Ksi	Maximum Transfer Energy Ft. Kips	Hammer Energy (Ram Wt. x Stroke) Ft. Kips	Transfer Efficiency Transfer Energy / Rated Hammer Energy %	Remarks
70'-0" Long Pile Section Was Driven on 10/29/85, Another 70'-0" Long Section Was Welded To Driven Section And Driving Was Resumed on 10/30/85. Dynamic Monitoring Was Not Performed For First 70' Section.											
67'	-	18	419	817	$\frac{817}{45.9}=17.8$	26	$\frac{26}{45.9}=0.6$	27.2	58.9	$\frac{27.2}{58.9}=46.2\%$	Full hammer stroke used from
70'	18	14	113	841	18.3	372	8.1	25.1		42.6%	beginning to end of driving.
80'	14	15	223	876	19.1	391	8.5	25.3		42.9%	Substantial static load capacity
90'	15	15	80	966	21.0	357	7.8	35.7		60.6%	at 67' due to set up of 70'
95'	18	20	306	932	20.3	280	6.1	32.9		55.9%	pile section overnight.
100'	23	22	290	925	20.2	210	4.6	34.8		59.1%	
105'	30	25	423	850	18.5	90	2.0	31.4		53.3%	
110'	50	47	657	857	18.7	0	0	32.2		54.7%	
115'	40	46	720	835	18.2	0	0	28.6		48.6%	
120'	-	32	538	852	18.6	0	0	32.2		54.7%	

*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

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)

SH 146 BRIDGE OVER HOUSTON SHIP CHANNEL
(BAYTOWN BRIDGE, HARRIS COUNTY, TEXAS)

TABLE 1 SUMMARY OF DYNAMIC MONITORING RESULTS
(SOUTH PILE LOAD TEST SITE)
Continued

DATE October 29 & 30, 1985 and November 8, 1985 LENGTH (70'-0") + (70'-0") = 140'-0"

PILE TYPE 24" O.D., 5/8" wall ~~Closed end pipe~~ PILE NO. --

HAMMER TYPE Single Acting Steam HAMMER MODEL Raymond 5/0

HAMMER RATED ENERGY 58,900 Ft. Lbs. (Ram Weight = 17,500 Lbs.)

Depth,* Feet	Blow Count Per Foot		RSP With J = 0.4 Kips	FMX Kips	Max. Comp. Stress Ksi	CTEN Kips	Max. Tensile Stress, Ksi	Maximum Transfer Energy Ft. Kips	Hammer Energy (Ram Wt. x Stroke) Ft. Kips	Transfer Efficiency Transfer Energy / Rated Hammer Energy %	Remarks
	From Analyzer	From Driving Record									
125'	31	30	537	831	18.1	0	0	28.7	58.9	48.7%	
130'	31	32	566	823	17.9	0	0	29.2	↓	49.6%	
132'	37	35	563	813	17.7	0	0	31.1	↓	52.8%	
133'	38	40	676	821	17.9	0	0	29.3	↓	49.7%	
Driving completed at 133'-0" on October 30, 1985. Predicted Ultimate Load Capacity = 676 Kips = 338 Tons. Retap (Redriving) of pile was performed on November 8, 1985.											
133'-1"	--	210/1"	834	653	14.2	0	0	22.7	58.9	38.5%	
Predicted Ultimate Pile Load Capacity After Setup = 834 Kips = 417 Tons											

*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

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)

SH 146 BRIDGE OVER HOUSTON SHIP CHANNEL
(BAYTOWN BRIDGE, HARRIS COUNTY, TEXAS)

TABLE 2 SUMMARY OF DYNAMIC MONITORING RESULTS
(SOUTH PILE LOAD TEST SITE)

DATE October 30, 1985 and November 8, 1985 LENGTH 101'-6"

PILE TYPE 20" Square Prestressed Concrete PILE NO. --

HAMMER TYPE Single Acting Steam HAMMER MODEL Raymond 5/0

HAMMER RATED ENERGY 58,900 Ft. Lbs. (Ram Weight = 17,500 Lbs.)

Depth,* Feet	Blow Count Per Foot		RSP With J = 0.4 Kips	FMX Kips	Max. Comp. Stress Ksi	CTEN Kips	Max. Tensile Stress, Ksi	Maximum Transfer Energy Ft. Kips	Hammer Energy (Ram Wt. x Stroke) Ft. Kips	Transfer Efficiency Transfer Energy / Rated Hammer Energy %	Remarks
	From Analyzer	From Driving Record									
101'-6" Long Pile Section, Driving Started on October 30, 1985											
20'	-	4	0	550	$\frac{550}{400} = 1.4$	290	$\frac{290}{400} = 0.7$	9.0	26.2	34.4%	18" Hammer stroke used until pile tip penetrated to 63'
30'	-	8	0	570	1.4	300	0.8	9.0	26.2	34.4%	below ground. 39" Hammer stroke from 63' to
40'	-	2	0	510	1.3	280	0.7	8.0	26.2	30.5%	81'. 33" to 36" Hammer stroke from
55'	-	7	0	510	1.3	330	0.8	8.0	26.2	30.5%	81' to end of driving.
65'	-	22	300	920	2.3	430	1.1	24.0	56.9	42.2%	
70'	25	16	270	940	2.4	440	1.1	24.0	56.9	42.2%	Slight damage to the pile was noted at 70'. (It was
79'	20	16	290	1030	2.6	430	1.1	27.0	56.9	47.5%	observed on oscilloscope and the output values of B were in
86'	-	29	190	570	1.4	270	0.7	41.0	52.5	78.1%	the range of 0.7 to 0.85 indicating damage). The
90'	23	25	170	560	1.4	260	0.7	39.0	52.5	74.3%	hammer stroke was slightly reduced.
95'	43	46	160	510	1.3	250	0.6	34.0	52.5	64.8%	

*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

Maximum Allowable Compressive Driving Stress = 0.85 x f'_c = 0.85 x 5000 = 4250 PSI = 4.3 KSI

Maximum Allowable Tensile Stress = 1000 + $3\sqrt{5000}$ = 1212 PSI = 1.2 KSI

J = Assumed Damping Parameter (Depends on soil type)

SH 146 BRIDGE OVER HOUSTON SHIP CHANNEL
(BAYTOWN BRIDGE, HARRIS COUNTY, TEXAS)

TABLE 2 SUMMARY OF DYNAMIC MONITORING RESULTS
(SOUTH PILE LOAD TEST SITE)
Continued

DATE October 30, 1985 and November 8, 1985 LENGTH 101'-6"

PILE TYPE 20" Square Prestressed Concrete PILE NO. --

HAMMER TYPE Single Acting Steam HAMMER MODEL Raymond 5/0

HAMMER RATED ENERGY 58,900 Ft. Lbs. (Ram Weight = 17,500 Lbs.)

Depth,* Feet	Blow Count Per Foot		RSP With J = 0.4 Kips	FMX Kips	Max. Comp. Stress Ksi	CTEN Kips	Max. Tensile Stress, Ksi	Maximum Transfer Energy Ft. Kips	Hammer Energy (Ram Wt. x Stroke) Ft. Kips	Transfer Efficiency Transfer Energy / Rated Hammer Energy %	Remarks
	From Analyzer	From Driving Record									
96'	-	44	270	860	2.2	420	1.1	19.0	52.5	36.2%	
98'	-	56	230	800	2.0	400	1.0	16.0	52.5	30.5%	
Driving Completed at 98'-0" on October 30, 1985. Predicted Ultimate Pile Load Capacity = 230 Kips = 115 Tons. Retap (redriving) of pile was performed on November 8, 1985											
98'-4"	-	113/4"	500	790	2.2	0	0	15.0	43.8	34.2%	30" Hammer stroke for retap
Predicted Ultimate Pile Load Capacity After Setup = 500 Kips = 250 Tons.											

*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

Maximum Allowable Compressive Driving Stress = 4.3 KSI

Maximum Allowable Tensile Driving Stress = 1.2 KSI

J = Assumed Damping Parameter (Depends on soil type)