DYNAMIC PILE MONITORING REPORT

EXIT GLACIER BRIDGE

KENAI FJORDS NATIONAL PARK, ALASKA

FHWA-DP-66-09

Federal Highway Administration

Office of Highway Operations

Demonstration Projects Division

Washington, D.C.

May 1985

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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 Direct Federal Divisions.

A request for performing dynamic pile tests on some of the production piles for the subject project was received from the Western Direct Federal Division (WDFD) in September 1984. Necessary specifications required for performing dynamic testing were provided to WDFD and were included in the contract documents.

The purpose for the dynamic pile testing was (1) to demonstrate the use of newer and more accurate techniques for determining pile load capacity during driving, (2) to determine the ultimate pile load capacities for the subject bridge, and (3) to compare load capacities of piles installed partially by the vibratory hammer and those installed exclusively, by the impact hammer. The contractor had requested the project engineer for an approval to install piles to a certain depth by using vibratory hammer before using an impact hammer to drive the piles. It was felt that the use of vibratory hammer may not allow the piles to develop necessary soil resistance. Therefore, dynamic pile testing was used to evaluate the load capacities of piles installed partially by a vibratory hammer and those installed by the impact hammer.

The field work was performed from April 18 to April 20, 1985. The dynamic tests were performed by Mr. H. Clark, Civil Engineering Technician, in the Demonstration Projects Division, and Mr. S. Vanikar, Geotechnical Engineer, in the Geotechnical and Materials Branch. The piling contractor was F. E. Ward Inc.

On April 20, 1985, after the dynamic testing was completed, results of the analysis and preliminary recommendations were discussed with Messrs. Monte Symons, Geotechnical Engineer, and James Crutchen, Project Engineer. A detailed description of the work performed, test results, data analysis, and recommendations follow in this report.

Location and Structure Information

The structure is located on Exit Glacier Road in the Kenai Fjords National Park. The two span superstructure will consist of a concrete box girder. Abutment number 1 will be supported on spread footings. The pier will be supported on vertical piles whereas abutment number 2 will be supported on vertical and batter piles.

The dynamic pile testing was performed on abutment piles. Originally it was intended to perform tests on the pier foundation piles also but scheduling difficulties made it impossible to test the pier foundation piles.

Pile Data

The foundation report prepared by the WDFD recommended the use of either 10 x 42 Steel H-piles or 10-inch diameter timber piles. The pier and abutment number 2 foundations are designed for 10 x 57 steel H-piles. The piles are to be fitted with proprietary pile points to provide protection against damage.

The piles tested at the abutment number 2 location are part of the foundation pile group. Each pile was driven in two sections. For each pile, a 30-foot long section was installed. Another 60-foot section was welded to the driven section with a full penetration butt weld and then driven.

Pile number 12 was installed to a depth of 69 feet by a vibratory hammer and then driven with an impart hammer until the pile reached a depth of 79 feet below the existing ground. Pile number 19 was driven with a vibratory hammer until the pile tip reached a depth of 70 feet below the ground and was then driven with an impact hammer to a depth of 80 feet. Pile numbers 12 and 19 were dynamically monitored during driving with impact hammer for the last 10 feet. Pile numbers 43 and 55 were installed to a depth of 15 feet with vibratory hammer. The remaining driving was performed with an impact hammer and was dynamically monitored.

Subsurface Conditions

The site is located in a glaciated valley. Borings were performed only at abutment number 1 and pier locations. The existing topography suggests that the subsurface conditions at abutment number 2 location are similar to those at the pier location. Therefore, the data from boring numbers 1 and 2 drilled at the pier location is used for describing subsurface conditions. These borings show the existence of deep glacial deposits of sand and gravel with traces of silt and many rock fragments. The Standard Penetration Test (SPT) "N" values for this material are variable ("N" values vary from 8 to 53). In general, the soil density is medium to dense.

Impact Hammer Data

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

Mitsubishi MH 15, open end diesel hammer

Rated Energy at 8.5 foot stroke = 28,100 foot pounds

Ram Weight = 3,310 pounds

Hammer Cushion = 2" thick ZELKOVA

Pile Cushion - none

Dynamic Monitoring (Pile Analyzer) Results

Four piles (10 x 57 - H) were driven at abutment number 2 location and were dynamically monitored. Monitoring was performed for each pile when they were driven by an impact hammer. Tables 1, 2, 3, and 4 in the Appendix summarize the results of dynamic monitoring.

Table 1 shows the summary of the dynamic test results obtained during driving of pile number 12. A 30-foot long section was driven with a vibratory hammer. A 60-foot long section was welded to the driven H-section and driving with the vibratory hammer continued until the pile tip reached a depth of 69 feet below the existing ground. Driving from 69 feet to 79 feet was accomplished by using an impact hammer and this portion of driving was monitored by using the pile analyzer. The impact hammer performed well as indicated by transfer efficiencies of up to 35 percent. The average transfer efficiencies for open end diesel hammers are usually in the range of 25 to 34 percent. Since the hammer stroke was not measured during driving, transfer efficiencies in Table 1 were computed based on rated hammer energy. Table 1 shows that the ultimate static load capacity did not vary significantly during the last 10 feet of driving. The analyzer predicted an ultimate static capacity of 55 tons at the end of the driving. The maximum measured compressive driving stress was 21.7 KSI and was within the limitation of 32.4 KSI. The maximum measured tensile driving stress was 8.2 KSI and was well within the limitation of 32.4 KSI. Since the pile design load indicated on plans is 52 tons, the ultimate pile capacity required is 130 tons (factor of safety = 2.5). The pile failed to develop the required ultimate load when the driving was terminated.

Table 2 summarizes the dynamic test results obtained during driving of pile number 19. Installation procedure similar to that used for pile number 12 was used. Driving from 70 feet to 80 feet below ground was performed by the impact hammer. The hammer performed extremely well as indicated by the transfer efficiencies of up to 43 percent. The maximum compressive and tensile driving stresses were well within the limitation of 32.4 KSI. The pile analyzer predicted an ultimate static capacity of 53 tons when driving was terminated at the pile tip penetration of 80 feet below ground. During driving, pile number 19 behaved very similar to pile number 12. This pile also failed to develop the required ultimate load of 130 tons when the driving was terminated.

Table 3 shows the dynamic test results for pile number 43. A 30-foot long section was driven first (15 feet) by the vibratory hammer and then by the impact hammer. A 60-foot long section was welded to the installed section and driving by the impact hammer was continued. The impact hammer performed well and transfer efficiencies of up to 51 percent were recorded. The pile analyzer predicted ultimate load capacities up to 67 tons until the pile tip reached a depth of 69 feet below ground. The capacity increased significantly to 102 tons at 72 feet penetration. A practical refusal was reached at 72 feet-6 inch penetrations (82 blows for 6 inch penetration). The refusal and high below count were possibly due to pile tip on a boulder or bedrock. The pile analyzer predicted an ultimate pile capacity of 247 tons at the end of driving which is significantly more than the required ultimate capacity of 130 tons. The maximum compressive and driving stresses were within the limitations of 32.4 KSI. A slight damage to the pile tip at the end of driving was detected by the pile analyzer (the wave patterns on the oscilloscope showed the damage).

Table 4 summarizes the dynamic test results for pile number 55. The installation procedure used was identical to the one used for pile number 43. The pile was installed by using a vibratory hammer to a depth of 15 feet. The remaining installation was performed with the impact hammer. The hammer performed well and the compressive and tensile driving stresses did not exceed the limitation of 32.4 KSI. An ultimate pile capacity equal to 35 tons was predicted when the pile tip reached 26 feet - 5 inches below the ground line. The capacity decreased rapidly to 0 when the pile tip reached 46 feet below the ground. The reason the for pile not developing any capacity is that the capacity developed for first 45 feet of penetration was probably due to end bearing only (no skin friction) and when the tip reached a loose soil deposit, there was no resistance at the tip. The analyzer predicted a capacity 62 ton capacity at 73 feet of penetration. An ultimate pile capacity of 90 tons was predicted when the driving was completed with the pile tip at 78 feet - 3 inches below ground. The pile failed to develop the required ultimate load capacity of 130 tons.

Conclusions

1. The dynamic monitoring equipment (pile analyzer) performed well in predicting ultimate pile load capacities and driving stresses. The equipment monitored the hammer performance by measuring the hammer energy transferred to the pile under each hammer below. The pile analyzer detected pile damage at the tip of pile number 43. This demonstrates the tremendous advantages provided by the equipment for construction control.

2. The ultimate load capacities of pile numbers 12 and 19 (driven with a vibratory hammer) for about 70 feet and with the impart hammer for the last 10 feet) were 55 and 53 tons, respectively. Significantly higher capacity of 90 tons was predicted for the pile number 55 which was driven with an impact hammer (except the first 15 feet of driving). Because the vibratory hammer reduces the skin friction along the pile length by loosening the soil around the pile, most of the developed pile capacity is only due to end bearing. The capacities of the impact driven piles such as pile numbers 55 and 43 are due to end bearing and skin friction and, therefore substantially higher than those predicted for pile numbers 12 and 19.

3. Extremely high ultimate pile load capacity for the pile number 43 at the end of driving may be due to the pile tip on a boulder or bedrock.

4. Pile numbers 12, 19, and 55 failed to develop the required ultimate load capacity of 130 tons.

Recommendations

1. Piles may be driven with a vibratory hammer to a depth of not more than 50 feet below the existing ground. The remaining 30 feet of driving must be performed by an impact hammer.

2. Three of the four tested failed fails to achieve the required ultimate load capacity of 130 tons. (Specified pile design load on plans = 52 tons. With a factor of safety of 2.5, the ultimate loud required is 130 tons.) Pile numbers 12 and 19 do not provide any safety factor at all. Pile number 55 provides a safety factor of 1.7. Longger piles and deeper penetration to refusal will be needed to achieve a reasonable factor of safety.

3. It is recommended that the pile driving criteria be based on the wave equation analysis. The information on the pile hammer and the test pile performance is now available and a wave equation analysis should be performed. The pile driving criteria should be provided for the project engineer's use.

4. A steel H-pile is usually a poor choice for use as a friction pile in sands and gravel. It is well known that H-piles have a tendency to "run" in sand and gravel deposits without developing the required resistance. A good choice of pile in such deposits is a displacement pile such as closed-end steel pipe pile. Prestressed concrete piles are also displacement piles and suitable for installations in sands and gravels.

Suneel N. Vanikar

Suneel N. Vanikar, P.E.
Geotechnical Engineer

EXIT GLACIER BRIDGE, KENAI FJORDS NATIONAL PARK ALASKA
TABLE 1 SUMMARY OF DYNAMIC MONITORING RESULTS

Dates April 20, 1985 Pile Length 30' + 60' = 90'
Pile Type 10 X 57 Steel H Pile No. 12 (Abutment No. 2)
Hammer Type Single-Acting Diesel Hammer Model Mitsubishi, MH-15
Hammer Rated Energy 28,100 Foot Pounds

Depth, Feet*	Blow Count Per Foot From Analyzer	Blow Count Per Foot From Driving Record	RS With J=0.15 Kips	FMax. Kips	Max. Comp. Stress KSI	CTEN Kips	Max. Tensile Stress K S I	Max. Transfer Energy FT. Kips	Hammer Energy (Ram Wt.) X Stroke FT. Kips	Transfer Efficiency (Transfer Energy / Rated Hammer Energy)	Remarks
30.0' long section was driven with a vibratory hammer. 60.0' section welded to the driven section and was driven with the vibratory hammer to a depth of 69.0' below the existing ground. Pile driving with diesel hammer started at 69.0' and driving was completed with pile tip at 79.0' below the existing ground.											
70'	15	--	91	312	312 / 16.8 = 18.6	105	105 / 16.8 = 6.3	7.4	RATED HAMMER ENERGY = 28.1 Foot Kips	26.3 percent	Hammer stroke was not measured during driving. Therefore, transfer efficiency is computed based on rated hammer energy rather than actual hammer energy.
71'	19	19	97	343	20.4	129	7.7	8.2		29.2 percent	
72'	20	21	113	358	21.3	119	7.1	9.3		33.1 percent	
73'	22	21	101	359	21.4	122	7.3	9.9		35.2 percent	
74'	19	19	105	352	21.0	121	7.2	9.0		32.0 percent	
75'	19	18	93	351	20.9	128	7.6	9.0		32.0 percent	
76'	19	17	89	347	20.7	137	8.2	8.9		31.7 percent	
77'	19	18	105	364	21.7	128	7.6	9.9		35.2 percent	
78'	20	19	129	357	21.3	111	6.6	8.7		31.0 percent	
79'	18	--	107	354	21.1	117	7.0	9.8		34.9 percent	
Driving completed at 79'-0" on April 20, 1985. Predicted ultimate static pile load capacity = 101 Kips = 55 tons.											

*Distance from the ground line to pile tip.
RS = Ultimate Static Resistance
FMAX = 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 Fy = 0.9 X 36 = 32.4 K S I
J = Damping parameter (depends on soil type)

EXIT GLACIER BRIDGE, KENAI FJORDS NATIONAL PARK ALASKA
TABLE 2 SUMMARY OF DYNAMIC MONITORING RESULTS

Dates April 20, 1985 **Pile Length** 30' + 60' = 90'
Pile Type 10 X 57 Steel H **Pile No.** 19 (Abutment No. 2)
Hammer Type Single-Acting Diesel **Hammer Model** Mitsubishi, MH-15
Hammer Rated Energy 28,100 Foot Pounds

Depth, Feet*	Blow Count Per Foot: From Analyzer	Blow Count Per Foot: From Driving Record	RS With J=0.15 Kips	FMax. Kips	Max. Comp. Stress KSI	CTEN Kips	Max. Tensile Stress K S I	Max. Transfer Energy FT. Kips	Hammer Energy (Ram Wt.) X Stroke FT. Kips	Transfer Efficiency (Transfer Energy / Rated Hammer Energy)	Remarks
30.0' long section was driven with a vibratory hammer. 60.0' long section welded to the driven section and was driven with a vibratory hammer to a depth of 70.0' below the existing ground. Pile driving with diesel hammer started at 70.0' and driving was completed with pile tip at 80.0' below existing ground.											
71'	16	18	76	315	$\frac{315}{16.8} = 18.8$	121	7.2	8.3	RATED HAMMER ENERGY = 28.1 Foot Kips	29.5 percent	Hammer stroke was not measured during driving. Therefore, transfer energy is computed based on rated hammer energy rather than the actual hammer energy.
72'	18	16	105	333	19.8	107	6.4	9.3		33.1 percent	
73'	19	17	87	370	22.0	143	8.5	12.1		43.1 percent	
74'	17	17	65	334	19.9	127	7.6	11.2		39.9 percent	
75'	18	14	41	325	19.3	148	8.8	9.8		34.9 percent	
76'	12	12	73	340	20.2	135	8.0	10.2		36.3 percent	
77'	12	13	100	346	20.6	123	7.3	10.5		37.4 percent	
78'	19	17	111	361	21.5	119	7.1	10.5		37.4 percent	
79'	27	--	103	364	21.7	132	7.9	10.9		38.8 percent	
80'	--	--	106	364	21.7	130	7.7	10.7		38.1 percent	
Driving completed at 80'-0" on April 20, 1985			Predicted ultimate static load capacity = 106 Kips = 53 tons.								

*Distance from the ground line to pile tip.
RS = Ultimate Static Resistance
FMAX = 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 Fy = 0.9 X 36 = 32.4 K S I
J = Damping parameter (depends on soil type)

EXIT GLACIER BRIDGE, KENAI FJORDS NATIONAL PARK ALASKA

TABLE 3 SUMMARY OF DYNAMIC MONITORING RESULTS

Dates April 19-20, 1985 Pile Length 30' + 60' = 90'

Pile Type 10 X 57 Steel H Pile No. 43 (Abutment No. 2)

Hammer Type Single-Acting Diesel Hammer Model Mitsubishi, MH-15

Hammer Rated Energy 28,100 Foot Pounds

Depth, Feet*	Blow Count Per Foot From Analyzer	Blow Count Per Foot From Driving Record	RS With J=0.15 Kips	FMax. Kips	Max. Comp. Stress KSI	CTEN Kips	Max. Tensile Stress K S I	Max. Transfer Energy FT. Kips	Hammer Energy (Ram Wt.) X Stroke FT. Kips	Transfer Efficiency (Transfer Energy / Rated Hammer Energy)	Remarks
30.0' long section driven first by diesel hammer on April 19, 1985. First 15.0' driven by vibratory hammer and, therefore, was not monitored dynamically.											
16'	7	--	50	169	10.1	17	1.0	3.0	RATED HAMMER ENERGY = 28.1 Foot Kips	10.7 percent	Hammer stroke was not measured during driving. Therefore, transfer efficiency is computed based on rated hammer energy rather than the actual hammer energy.
17'	16	15	52	364	21.7	107	6.4	10.7		38.1 percent	
18'	19	17	49	340	20.2	95	5.7	9.1		32.4 percent	
19'	14	15	68	358	21.3	79	4.7	10.0		35.6 percent	
20'	16	17	65	372	22.1	99	5.9	10.7		38.1 percent	
21'	19	17	79	348	20.7	64	3.8	9.2		32.7 percent	
22'	20	17	79	368	21.9	59	3.5	11.6		41.3 percent	
23'	16	18	83	385	22.9	60	3.6	11.8		42.0 percent	
24'	17	22	79	357	21.3	54	3.2	10.2		36.3 percent	
25'	18	15	76	350	20.8	48	2.9	10.8		38.4 percent	Driving completed at 26'-4" on April 19, 1985
26'	17	--	68	335	19.9	44	2.6	11.1		39.5 percent	
26'-4"	3	--	59	355	21.1	60	3.6	14.3		50.9 percent	

*Distance from the ground line to pile tip.
RS = Ultimate Static Resistance
FMAX = 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 Fy = 0.9 X 36 = 32.4 K S I
J = Damping parameter (depends on soil type)

EXIT GLACIER BRIDGE, KENAI FJORDS NATIONAL PARK ALASKA

TABLE 3 SUMMARY OF DYNAMIC MONITORING RESULTS

(continued)

Dates April 19-20, 1985 Pile Length 30' + 60' = 90'

Pile Type 10 X 57 Steel H Pile No. 43 (Abutment No. 2)

Hammer Type Single-Acting Diesel Hammer Model Mitsubishi, MH-15

Hammer Rated Energy 28,100 Foot Pounds

Depth, Feet*	Blow Count Per Foot: From Analyzer	Blow Count Per Foot: From Driving Record	RS With J=0.15 Kips	FMax. Kips	Max. Comp. Stress KSI	CTEN Kips	Max. Tensile Stress K S I	Max. Transfer Energy FT. Kips	Hammer Energy (Ram Wt.) X Stroke FT. Kips	Transfer Efficiency (Transfer Energy / Rated Hammer Energy)	Remarks
60.0' long section welded to the driven 30.0' long section and driven on April 20, 1985. Pile driving started at pile tip 26'-4" below the existing ground.											
27'	--	--									Hammer stroke was not measured during driving. Therefore, transfer efficiency is completed based on rated hammer energy rather than the actual hammer energy.
30'	17	16	67	266	15.8	79	4.7	6.9	RATED HAMMER ENERGY = 28.1 Foot Kips	24.6 percent	
33'	14	14	46	319	19.0	133	7.9	8.6		30.6 percent	
36'	15	15	67	330	19.6	133	7.9	7.8		27.8 percent	
40'	15	14	42	324	19.3	147	8.8	7.9		28.1 percent	
43'	14	13	40	319	19.0	147	8.8	8.3		29.5 percent	
46'	15	14	40	329	19.6	157	9.3	8.8		31.3 percent	
48'	12	11	12	314	18.7	165	9.8	8.2		29.2 percent	
50'	13	11	22	272	16.2	132	7.9	6.4		22.8 percent	
55'	9	9	30	287	17.1	131	7.8	7.2		25.6 percent	
60'	9	9	22	305	18.2	153	9.1	8.4		29.9 percent	
65'	10	11	49	274	16.3	107	6.4	6.6		23.5 percent	

*Distance from the ground line to pile tip.
RS = Ultimate Static Resistance
FMAX = 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 Fy = 0.9 X 36 = 32.4 K S I
J = Damping parameter (depends on soil type)

EXIT GLACIER BRIDGE, KENAI FJORDS NATIONAL PARK ALASKA

TABLE 3 SUMMARY OF DYNAMIC MONITORING RESULTS
(continued)

Dates April 19-20, 1985 Pile Length 30' + 60' = 90'

Pile Type 10 X 57 Steel H Pile No. 43 (Abutment No. 2)

Hammer Type Single-Acting Diesel Hammer Model Mitsubishi, MH-15

Hammer Rated Energy 28,100 Foot Pounds

Depth, Feet*	Blow Count Per Foot From Analyzer	Blow Count Per Foot From Driving Record	RS With J=0.15 Kips	FMax. Kips	Max. Comp. Stress KSI	CTEN Kips	Max. Tensile Stress K S I	Max. Transfer Energy FT. Kips	Hammer Energy (Ram Wt.) X Stroke FT. Kips	Transfer Efficiency (Transfer Energy / Rated Hammer Energy)	Remarks
68'	10	11	54	281	16.7	107	6.4	7.1	RATED HAMMER ENERGY =28.1 Foot Kips	25.3 percent	
69'	13	13	89	306	18.2	98	5.8	7.4		26.3 percent	
70'	21	19	138	348	20.7	93	5.5	8.5		30.2 percent	
71'	27	27	165	337	20.1	60	3.6	8.2		29.2 percent	
72'	34	32	203	360	21.4	41	2.4	8.9		31.7 percent	
72'-6"	82/6"	--	494	405	24.1	0	0	11.3		40.2 percent	

Driving completed at 72'-6" on April 20, 1985. Predicted ultimate static pile load capacity = 494 Kips = 247 tons.

Note: The high pile load capacity at 72'-6" penetration is possibly due to pile tip on a large boulder or bedrock.

*Distance from the ground line to pile tip.

RS = Ultimate Static Resistance

FMAX = 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 Fy = 0.9 X 36 = 32.4 K S I

J = Damping parameter (depends on soil type)

EXIT GLACIER BRIDGE, KENAI FJORDS NATIONAL PARK ALASKA

TABLE 4 SUMMARY OF DYNAMIC MONITORING RESULTS

Dates April 19-20, 1985 Pile Length 30' + 60' = 90'

Pile Type 10 X 57 Steel H Pile No. 55 (Abutment No. 2)

Hammer Type Single-Acting Diesel Hammer Model Mitsubishi, MH-15

Hammer Rated Energy 28,100 Foot Pounds

epth, Feet*	Blow Count Per Foot From Analyzer	Blow Count Per Foot From Driving Record	RS With J=0.15 Kips	FMax. Kips	Max. Comp. Stress KSI	CTEN Kips	Max. Tensile Stress K S I	Max. Transfer Energy FT. Kips	Hammer Energy (Ram Wt.) X Stroke FT. Kips	Transfer Efficiency (Transfer Energy / Rated Hammer Energy)	Remarks
30.0' long section driven first by diesel hammer on April 19, 1985. First 15.0' driven by the vibratory hammer and, therefore, was not monitored dynamically.											
16'	--	--	47	344	20.5	103	6.1	9.8	RATED HAMMER ENERGY = 28.1 Foot Kips	34.9 percent	Hammer stroke was not measured during driving. Therefore, transfer efficiency is computed based on rated hammer energy rather than the actual hammer energy.
17'	16	21	61	280	16.7	65	3.9	5.3		18.9 percent	
18'	17	18	52	330	19.6	98	5.8	7.7		27.4 percent	
19'	23	21	69	288	17.1	59	3.5	5.3		18.9 percent	
20'	18	17	42	367	21.8	101	6.0	12.4		44.1 percent	
22'	19	17	52	334	19.9	90	5.4	10.8		38.4 percent	
23'	22	16	48	309	18.4	83	4.9	8.0		28.5 percent	
24'	13	19	60	350	20.8	83	4.9	8.9		31.7 percent	Driving completed at 26'-5" on April 19, 1985.
25'	28	16	62	343	20.4	71	4.2	9.1		32.4 percent	
26'	21	14	63	360	21.4	68	4.0	10.6		37.7 percent	
26'-5"	--	--	70	364	21.7	71	4.2	10.1		35.9 percent	

Distance from the ground line to pile tip.

S = Ultimate Static Resistance

MAX = Maximum measured force in pile at the transducer location.

TEN = Maximum computed tensile force anywhere in the pile.

Maximum allowable compressive or tensile driving stress = 0.9 Fy = 0.9 X 36 = 32.4 K S I

J = Damping parameter (depends on soil type)

EXIT GLACIER BRIDGE, KENAI FJORDS NATIONAL PARK ALASKA

TABLE 4 SUMMARY OF DYNAMIC MONITORING RESULTS

(continued)

Dates April 19-20, 1985 Pile Length 30' + 60' = 90'

Pile Type 10 X 57 Steel H Pile No. 55 (Abutment No. 2)

Hammer Type Single-Acting Diesel Hammer Model Mitsubishi, MH-15

Hammer Rated Energy 28,100 Foot Pounds

Depth, Feet*	Blow Count Per Foot From Analyzer	Blow Count Per Foot From Driving Record	RS With J=0.15 Kips	FMax. Kips	Max. Comp. Stress KSI	CTEN Kips	Max. Tensile Stress K S I	Max. Transfer Energy FT. Kips	Hammer Energy (Ram Wt.) X Stroke FT. Kips	Transfer Efficiency (Transfer Energy / Rated Hammer Energy)	Remarks
60.0' long section welded to the driven 30.0' long section and driven on April 20, 1985. Pile driving started with pile tip at 26'-5" below the existing ground.											
27'	20	--	56	305	18.2	123	7.3	8.3	RATED HAMMER ENERGY = 28.1 Foot Kips	29.5 percent	Hammer stroke was not measured during driving. Therefore, transfer efficiency is computed based on the rated hammer energy rather than the actual hammer energy.
30'	21	14	60	312	18.6	117	7.0	8.8		35.6 percent	
35'	18	15	61	333	19.8	131	7.8	10.1		35.9 percent	
40'	18	16	35	337	20.1	162	9.6	9.4		33.5 percent	
45'	12	15	12	319	19.0	156	9.3	11.2		39.9 percent	
46'	12	13	0	289	17.2	148	8.8	12.4		44.1 percent	
50'	7	7	0	266	15.8	144	8.6	9.0		32.0 percent	
55'	11	10	4	253	15.1	133	7.9	6.8		24.2 percent	
60'	9	7	0	260	15.1	144	8.4	6.8		24.2 percent	
65'	9	9	22	276	16.4	130	7.7	6.9		24.6 percent	

*Distance from the ground line to pile tip.
RS = Ultimate Static Resistance
FMAX = 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 Fy = 0.9 X 36 = 32.4 K S I
J = Damping parameter (depends on soil type)

EXIT GLACIER BRIDGE, KENAI FJORDS NATIONAL PARK ALASKA
TABLE 4 SUMMARY OF DYNAMIC MONITORING RESULTS
(continued)

Dates April 19-20, 1985 Pile Length 30' + 60' = 90'
Pile Type 10 X 57 Steel H Pile No. 55 (Abutment No. 2)
Hammer Type Single-Acting Diesel Hammer Model Mitsubishi, MH-15
Hammer Rated Energy 28,100 Foot Pounds

Depth, Feet*	Blow Count Per Foot From Analyzer	Blow Count Per Foot From Driving Record	RS With J=0.15 Kips	FMax. Kips	Max. Comp. Stress KSI	CTEN Kips	Max. Tensile Stress K S I	Max. Transfer Energy FT. Kips	Hammer Energy (Ram Wt.) X Stroke FT. Kips	Transfer Efficiency (Transfer Energy / Rated Hammer Energy)	Remarks
70'	16	14	62	317	18.9	86	5.1	12.1	RATED HAMMER ENERGY = 28.1 Foot Kips	43.1 percent	Hammer stroke was not measured during driving. Therefore, transfer efficiency is computed based on the rated hammer energy rather than the actual hammer energy.
71'	17	15	105	326	19.4	93	5.5	9.2		32.7 percent	
72'	18	17	109	314	18.7	77	4.6	9.0		32.0 percent	
73'	22	19	124	324	19.3	83	4.9	9.1		32.4 percent	
74'	25	20	108	282	16.8	64	3.8	8.7		31.0 percent	
75'	20	23	90	308	18.3	98	5.8	8.5		30.2 percent	
76'	16	18	92	300	17.9	95	5.7	7.9		28.1 percent	
77'	23	17	129	293	17.4	45	2.7	8.7		31.0 percent	
78'	35	24	163	352	21.0	74	4.4	9.7		34.5 percent	
78'-3"	17/3"	--	181	346	20.6	55	3.3	9.3		33.1 percent	

Driving completed at 78'-3" on April 20, 1985. Predicted ultimate static pile load capacity = 181 Kips = 90 tons

*Distance from the ground line to pile tip.
RS = Ultimate Static Resistance
FMAX = 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 Fy = 0.9 X 36 = 32.4 K S I
J = Damping parameter (depends on soil type)