LARGE DROP HAMMER TESTING OF DRIVEN PILES IN DELAWARE

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ABSTRACT

Dynamic load testing requires enough impact energy to activate the specified test load or ultimate capacity. For driven piles, it is of course most economical and convenient to use the pile driving hammer to apply that impact load. However, frequently, a hammer that can safely and efficiently install a pile, may not be sufficient to generate the necessary dynamic load after the soil has set up. Thus, rather than restriking the driven pile with the installation hammer, large drop hammers apply test loads always more effectively and sometimes also more economically.

This paper presents a case study, describing tests with a 20-ton drop hammer on 508 mm square prestressed concrete piles for capacities up to almost 6000 kN. The paper describes details of test site, its soil properties and the soil setup behavior. General conclusions include recommendations for drop hammer sizes for restrike testing.

Keywords: Driven Piles, Bearing Capacity, Load Testing; Drop Hammer

1. INTRODUCTION

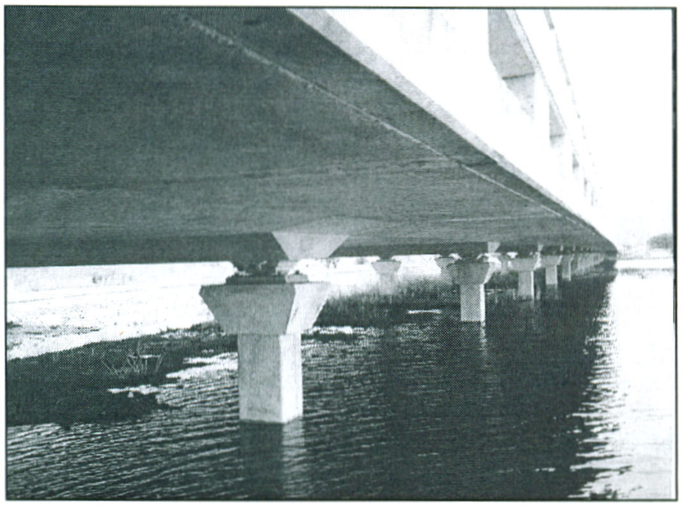

Figure 1. The Elevated Fenwick Island Highway

The SR-54 highway project in Fenwick Island, Delaware is an 820 m long stretch of elevated highway consisting of 2 precast segmental bridges spanning 487 m and 236 m, which was designed to allow for a safe escape route during flooding caused by major hurricanes or high ocean tides. The design of this bridge generally only required two driven piles as a support for each pier. Figure 1 shows the completed structure; two precisely driven concrete piles extend above the ground surface acting as columns to support each pier for the 12 m long spans. Lateral forces were carried by battered piles supporting the abutments and fixed piers located in the middle of each structure. Because of the lack of redundancy of this foundation system, validation of the ultimate capacity of a relatively large number of these piles was necessary.

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For economic reasons, static load tests can only be performed for a limited number of piles and do not lend themselves for routine testing of production piles. Dynamic load testing is therefore a logical alternative. However, as is common on most pile driving sites, the installation hammer often has insufficient energy to activate the full pile capacity. Another, higher energy hammer is therefore needed to perform a meaningful test.

Two pile sizes were installed at the SR-54 site: A smaller 350-mm square concrete pile, tested with the installation hammer achieved the required ultimate capacity of 2220 kN during restrike testing by the installation hammer. However, the larger 508-mm square concrete piles were designed for an ultimate capacity of 4300 kN. Using the installation hammer dynamic load testing typically mobilized not much more than 3200 kN. Another dynamic loading system was therefore needed to proof test this pile.

Because the installation hammer lacked the energy to fully activate the required capacity of the 508--mm pile, a 180-kN drop hammer referred to as APPLE-II (Advanced Pile Proof Loader/ Evaluator) was mobilized to the site. This system provided impacts by the 180 kN ram with drop heights adjustable in 0.1 m increments to a maximum of 2 m. The ram of this drop hammer consists of three segments. The guide-frame is 2.25 m square in plan and 7.3 m high (Figure 2).

2. DYNAMIC LOADING CONSIDERATIONS

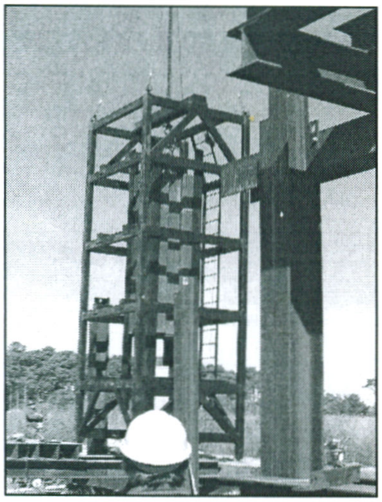

Figure 2. Apple-II Drop Hammer

At the Fenwick Island site, only proof tests were required. In fact, since it would have been very difficult and costly to replace a damaged pile, testing to ultimate capacity, which could have exceeded the structural strength of the piles, was not desired. Thus, if the dynamic load test capacity exceeded 4300 kN, the test would be considered successful. On the other hand if pile sets per impact would exceed 10 mm at calculated capacities less than 4300 kN, then the pile would have failed.

For piles with both friction and end bearing in a granular soil, a rule of thumb is that the ram should at least weigh 2% of the required capacity. This means that, in the present case, an 86 kN ram would have been satisfactory. However, it is even more desirable to work with a somewhat heavier weight and reduced drop heights, which provides an extra margin for higher test load activation at safe stress levels. Since the APPLE-II was available and no cost advantage existed for using a smaller drop weight, its relatively heavy, 180 kN ram was chosen for the job. The installation hammer only utilized a 40 kN ram.

Instead of using the rule of thumb for estimating an optimal combination of drop weight, drop height and cushion properties, a wave equation analysis can be performed. The process of rationally designing a dynamic load testing system has been described by Hussein et al. (1992) for the dynamic load testing of drilled shafts.

3. USE OF THE APPLE AND PDA SYSTEM

The advantage of the APPLE system over a basic drop hammer is its guide-frame which not only aligns the hammer and pile but also allows for supporting the drop weight prior to releasing it so that crane whipping is not an issue. The release mechanism employs a remotely operated hydraulic cutter that severs a wire loop resulting in a complete freefall of the drop weight.

While an accurate calculation of the dynamic capacity requires an analysis by CAPWAP, in the field the capacity is at first estimated by the simple Case Method (Rausche et al., 1985). If the Case Method does not indicate sufficient capacity and the pile set is also small (less than 2mm) then the drop height is increased until the required test load is activated. Additional cushioning may be necessary, if PDA calculated tension and/or compression stresses exceed allowable values.

4. SOIL DESCRIPTION

Boring logs at the test locations indicated saturated loose brown fine sand in the upper layer followed by silty fine sand with pockets of clay layers to a depth of 12.2 m (40 ft). Medium dense fine to coarse sand is indicated to approximately 21.3 m (70 ft) and very dense fine to coarse sand to a depth of approximately 24.4 m (80 ft). Sandy silt and medium dense fine sand and silty fine sand are indicated at the boring termination depth of approximately 24.4 m (80 ft). The SPT N-values at the minimum pile tip elevation at Pier 26 and Pier 38 were 25 and 21 blows/.3 m (1 ft), respectively. Higher N-values on the order of 75 blow/.3 m (1 ft) were indicated at the recommended tip elevation of the piles at Pier 26 and 38 locations.

5. DETAILS OF PILES AND INSTALLATION HAMMER

The test piles described here consisted of 508--mm square precast prestressed concrete sections. With a 45 MPa concrete strength and a 5.6 MPa prestress level, allowable compression and tension stresses were 32.7 and 7.3 MPa, respectively.

The hammer employed for installing this pile was a single acting diesel with a ram weight of 40 kN, a rated hammer stroke of 3.6 m and therefore a rated energy of 144 kJ. During either installation driving or restrike testing, the actual hammer stroke typically varied between 2.1 and 3.0 m.

The piles were initially driven to penetrations between 20.7 and 29.9 m and to final equivalent blow counts ranging from 98 to 168 blows/0.3 m by the installation hammer. Several restrike tests were attempted with the same hammer after waiting times of various durations, however, activated capacities generally remained below 3600 kN at blow counts in excess of 120 blow/0.3 m and therefore did not establish a valid proof test for the required minimum capacity of 4300 kN. As is often the case with restrike tests by standard pile driving hammers, as the restrike begins with low energies, setup capacity is already lost and a full mobilization of the available capacity is therefore never realized.

Through the course of testing it was determined that piles continued to gain capacity for up to 5 days after initial driving due to soil setup. This setup was estimated to be approximately 60% of the initial shaft resistance observed. It was determined that piles driven to an initial resistance of 3200 kN (75% of the required capacity) would result in an acceptable pile after setup has occurred. Because a PDA was not attached on all production piles, driving criteria for the project were 120 blows/ .3m with a maximum depth initiation. The maximum depth was added due to the potential for penetrating bearing strata and the large shaft friction resistance not being active during driving.

6. TEST PROCEDURE

Test setup and test procedures were performed following ASTM D-4945 specifications. Drop-in anchors, two strain transducers and two accelerometers were attached to opposite sides of each pile tested and connected to a Pile Driving Analyzer (PDA) located a safe distance away from the test piles.

Initial testing was done both at the end of pile installation and during restriking with the diesel hammer. If the pile capacity was still deemed insufficient, then a longer setup period was allowed before another restrike test was attempted.

For APPLE testing, the 180 kN ram was assembled on top of and aligned with the pile. Normally, three sheets of plywood with a total thickness of approximately 75 mm were placed between the ram and the top of the test pile. The ram was then dropped twice with drop heights between 0.56 and 0.81 m; a lower drop height was first applied and, after a review of stresses and activated capacity calculated by the PDA, a second, higher impact was selected.

7. ANALYSIS METHODS

The force and velocity data were processed in the field by the Case Method of analysis to compute transferred energy, pile top stresses and estimated pile capacity. Records from selected blows were then subjected to CAPWAP signal matching analysis (Rausche et al., 1985). From the APPLE generated records, always the second record was analyzed; the first blow usually generated negligible pile set. Matching the force and velocity records was first done with the automatic CAPWAP routine, followed by a careful review and adjustment of results by the analyzing engineer. The analysis that gave the best match quality was considered final. The results of the CAPWAP analysis included the mobilized capacity, the static soil resistance distribution and a static load versus pile top displacement curve. The latter is a simulated load-set curve and corresponds to a test loading of very short duration. For this reason, consolidation and/or creep effects are not included in this load-set curve.

8. RESULTS

In the context of this paper it is of particular interest to review the differences between test results obtained by the diesel hammer and the APPLE system. For the first pile tested, Table 1 shows results from a restrike conducted on January 14, 2002 with the diesel hammer. This was actually the fourth restrike test on the same pile. The pile again failed to show sufficient capacity. During the restrike the pile was driven from 21.3 to 22.7 m depth. At the beginning of the restrike the pile required 20 blows for the first 51 mm, and then 187 blows for 0.3 m. Because the PDA did not indicate the required restrike capacity driving was continued. During this driving sequence the blow count dropped to values as low as 75 blows/0.3 m before it increased to a final value of 98 blows/0.3 m. After a waiting period of 42 days, the APPLE test was conducted. Table 1 list the details of the last 3 restrikes; it is interesting to compare the potential energy applied by the diesel and APPLE hammers. The APPLE transferred more than three times the diesel hammer energy to the pile. Figure 3a shows force and velocity of the 21.3 m restrike test using the installation diesel hammer and Figure 3b the APPLE record from the 42 day restrike. Note the much wider force pulse generated by the APPLE while the diesel hammer maintained some compressive force over a longer time period. This is due to the pressure in the hammer's combustion chamber.

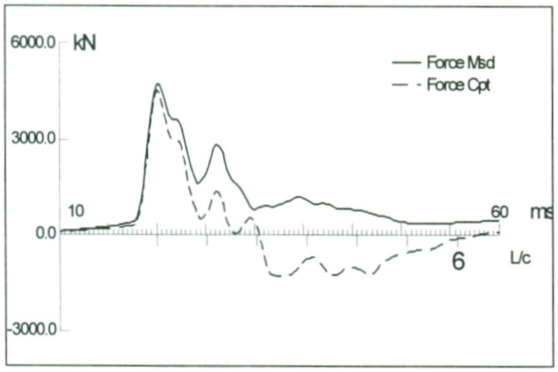

Figure 3a. Force Velocity Record for Diesel Hammer

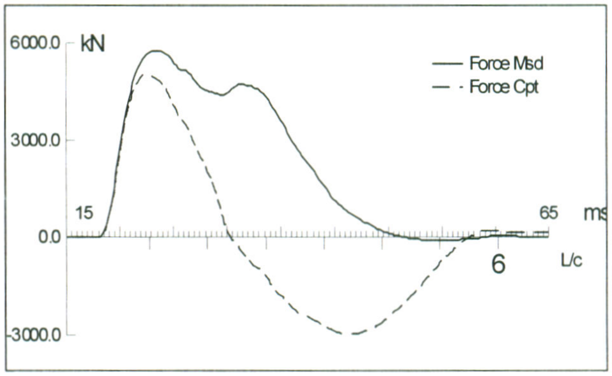

Figure 3b: Force Velocity Record for APPLE Drop Hammer

Table 1: Results from Diesel Hammer and APPLE System – Test Pile 2N

Date	Embedmt. m	Hammer	Stroke m	Potential Energy kJ	ENTHRU kJ	Equivalent Blow Count Blows/0.3m	CAPWAP Capacity kN
Jan. 14	21.3	Diesel	3.00	120	26	120	2674
Jan. 14	22.7	Diesel	2.80	112	23	98	2870
Feb. 25	22.7	APPLE	0.71	126	79	192	5780

The calculated load set curves for the three situations are summarized in Table 1 are shown in Figure 4.

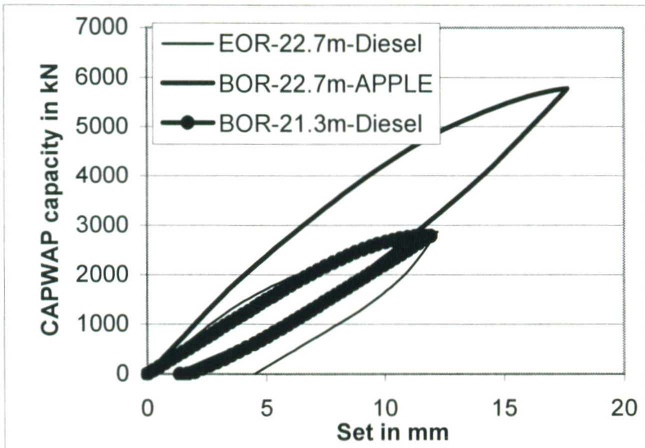

Figure 4. Load Set Curves

A summary of results for all piles tested by the APPLE at this site is presented in Table 2. The results include for the second test blow: ram drop height and pile set, calculated transferred energy, maximum pile compressive stress and CAPWAP capacity with end bearing component.

According to CAPWAP, the mobilized pile capacities of all the test piles ranged between 4850 and 5780 kN. Thus, all piles tested by the APPLE achieved capacities in excess of the required ultimate value of 4300 kN. The compressive stresses reached at most 28 MPa and were therefore less than the allowable

32.7 MPa. Final pile penetrations were typically within 1.5 m of the estimated tip calculated using static methods, however, the dynamic testing proved the pile actually had 12%-35% more capacity than estimated from static methods.

Table 2 Summary of APPLE Restrikes

Pile No.	Embedded Length m	Ram Drop Height mm	Pile Set mm	Transferred Energy kJ	Compr. Stress MPa	CAPWAP Total Capacity kN	CAPWAP End Bearing kN
2-N	22.7	711	1.6	79	25	5780	1930
2-S	22.7	762	3.2	100	28	5410	1400
26-S	20.9	787	3.2	101	26	6220	3140
38-N	21.5	762	6.4	107	28	4980	2040
6-S	29.9	0	3.2	118	28	5480	1080
1-N	20.7	0	6.4	110	28	4850	2070
12-N	21.6	813	4.8	88	26	4870	2690
17-S	21.8	813	6.4	92	26	4920	2630

9. CONCLUSIONS

Based on the experiences with the APPLE system at this and other sites, the following conclusions may be drawn.

Pile driving hammers are generally sufficient to install and activate required pile capacity during restrike if soil setup is not excessive.

At the Fenwick Island site, the ram weight was almost 3% of the activated capacities, however, very low drop heights were applied and stresses were well below allowable levels. Therefore, drop hammer weights in excess of 2% of desired capacity can safely be used with reduced drop heights.

Drop hammers with larger ram weights and therefore lower drop heights are much more effective in transferring energy to the pile when compared to conventional diesel hammers with equivalent energy. An additional advantage of the APPLE system is its free fall condition.

After a 2-hour system set up, APPLE load testing required typically one hour per pile.

REFERENCES

Rausche, F., Goble, G., and Likins, G.; (1985). "Dynamic determination of pile capacity." *Journal of Geotechnical Engineering*, ASCE, 1985, March Volume111, No.3, Pages 367-383.

Hussein, M., Rausche, F. and Likins, G.. (–1992).– "Dynamics of pile driving as a function of ram drop height." *Proc. Fourth International Conference on the Application of Stress-Wave Theory to Piles;*. The Hague, Holland.