UNDERWATER DYNAMIC TESTING EXPERIENCE

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ABSTRACT

Underwater dynamic testing has been successfully performed during the construction of several offshore oil platforms. The tested piles for a recent example were approximately 113 m in length and were installed in approximately 110 m of water using a Menck underwater hydraulic hammer. Two of the eight piles which were tested during installation were also tested during restrike after a wait of approximately 24 hours.

A Pile Driving Analyzer, in conjunction with special underwater cables and gauges, was used to collect the data. Careful coordination was required between the contractor and the dynamic testing personnel in order to ensure a successful testing procedure. The dynamic testing data was analyzed with the CAPWAP program to determine the soil resistance to driving (SRD), which was then compared to preliminary wave equation analysis results obtained with the GRLWEAP software.

INTRODUCTION

When underwater hammers can be utilized in the construction of offshore installations, much time and money can be saved. Because the piles are shorter, less material is needed, and time required to splice the piles is generally eliminated as the piles are fabricated and delivered to the site in a continuous section. Therefore, many new platforms have been designed which use underwater hammers to install the piles.

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Although traditionally piles driven by conventional air/steam hammers for offshore oil installations have been dynamically tested to verify hammer performance, new underwater hammers have built-in sensors to monitor kinetic energy. However, dynamic testing is still required to monitor parameters such as driving stresses, pile integrity, pile capacity, and to confirm the energy delivered to the pile.

Early underwater dynamic pile testing projects were completed in 1989, followed by several subsequent underwater test programs for several platforms. A typical recent test is outlined below. The dynamic monitoring was made possible with the use of special underwater instrumentation and with careful coordination of the testing procedures. The measurements served as a quality control procedure for determining the adequacy of the piles.

DESCRIPTION OF EQUIPMENT

Due to the depth of the water at the project location, the relatively high cost of divers compared to the low cost of sensors meant that any instrumentation attached to the pile would be considered expendable. Therefore, because eight piles were to be dynamically monitored during installation, eight complete sets of instrumentation were required. Each set contains two strain transducers and two piezoelectric accelerometers which were placed at diametrically opposite locations approximately three pile diameters from the pile head and a 152 m main cable to bring the signals to the Pile Driving Analyzer (PDA) location on the crane vessel. In order to provide an efficient transfer of results, the PDA was located near the control center where blow counts could be monitored by remote underwater cameras.

The 152 m main cable connecting the strain and acceleration instrumentation to the PDA was designed to be retrievable, and if undamaged, to be reusable. The main cables consist of a cluster of wires to carry the sensor signals and a 6 mm wire rope strength member. The entire cable was encased in a heavy waterproof sheath of bright orange color to improve underwater visibility. The wire rope strength member provided a means of firmly anchoring the cable to the pile head for support, and to prevent the ocean currents from pulling the connections apart. Also, the main cables were to be retrieved, if possible, by pulling on the wire rope and thus breaking the "weak link" connections to the pile wall.

All of the sensors used with the PDA were standard strain transducers and piezoelectric accelerometers with special modifications to make them waterproof. The strain transducers were coated with polyurethane and the internal components of the piezoelectric accelerometers were protected with a waterproof sealer and O-rings to prevent water intrusion. Prior to being shipped to the site, all of the sensors passed a test in a pressure tank to an equivalent water pressure depth of 550 m as a quality inspection. Commercially available underwater connectors were used to connect the sensors to the main cable. Figure 1 contains a picture of the underwater testing instrumentation.

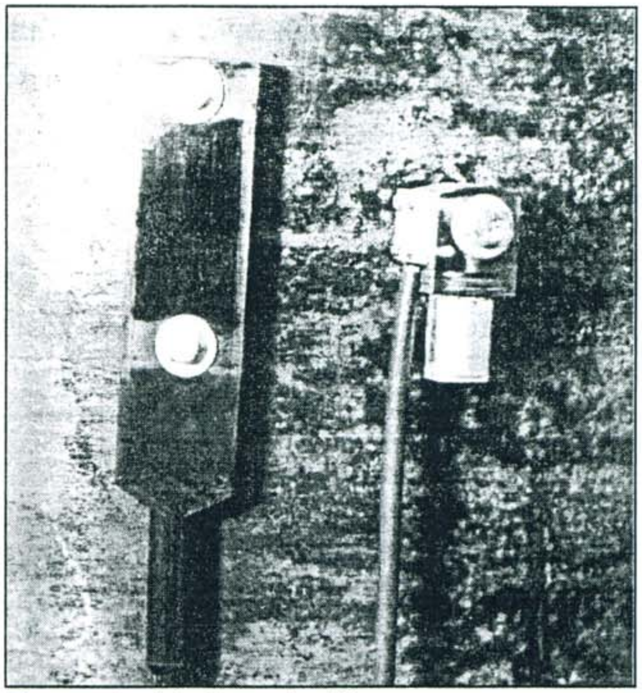
Figure 1: Underwater Sensors

DYNAMIC TESTING PROCEDURE

The subsurface conditions dictated that the piles should have a length of approximately 113 m and were to be installed at a location where the sea floor was approximately 110 m below the water surface. Subsurface conditions generally included layers of dense, silty sand and stiff, silty clay. The piles were open end pipes having nominal outside diameters of 1.8 m. While the piles were still at the fabrication yard, the pile heads were prepared by drilling and tapping holes partially into the pile wall for the attachment of strain transducers and accelerometers. These holes were drilled such that the strain and acceleration sensors would be bolted to diametrically opposite sides of the pile at a distance of approximately three diameters below the pile head. The piles were then loaded on a barge and towed to the project site.

On the crane vessel at the project site, careful coordination was necessary between the contractor and the dynamic testing personnel to prevent delays in the construction schedule. When the pile barge was brought to the site, the underwater sensors were quickly bolted to the pile head, the sensors were attached to the main cable, and the main cable strength member was attached to the pile wall. The remainder of the main cable was then laid out on the deck of the crane vessel such that the end connected to the pile could be easily lowered over the side of the crane vessel when necessary.

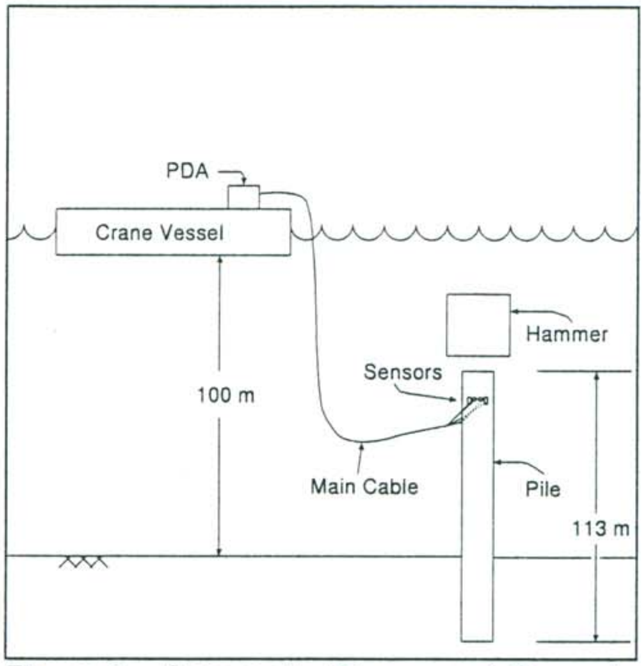

Figure 2: Schematic Diagram of Dynamic Testing Equipment

After positioning the platform jacket, a crane lifted the piles from the pile barge, and lowered the pile into a single sleeve (pile guide) at the bottom of the jacket leg. As is usually the case with underwater driving, the piles were installed vertically. During this time, the 152 m main cable was fed out as necessary, anchored to the side of the crane vessel, and connected by a series of conventional main cables to the PDA. Some caution was necessary to prevent the 152 m main cable from becoming tangled in the hammer and R.O.V. (Remotely Operated Vehicle) umbilical lines. Figure 2 contains a schematic diagram of the equipment in use.

After stabbing all of the piles through the jacket sleeves into the sea floor in this manner, a Menck underwater hydraulic hammer was lifted from the deck of the crane vessel, set on the first pile, and the dynamic testing program began. As the pile was driven continuously without further interruption, the PDA acquired data, then calculated and displayed results for every hammer blow. Two restrike tests were also obtained. One restrike was obtained at partial pile penetration after a hammer malfunction caused a one day construction delay. Also, because the blow counts were much lower than expected, the other restrike test was obtained one day after final installation of another pile.

Upon completion of the dynamic testing (after the needs for further restrike testing were eliminated), all eight 152 m main cables were successfully retrieved without damage by pulling on the wire rope strength member using a capstan system. The connections at the pile wall were broken by pulling apart the short wire "weak link" connecting the main cable to the pile. Further pulling then easily severed the sensor cables near the sensors, leaving the main cable and its connections intact.

RESULTS

During the dynamic testing, the main concern was the energy transferred by the hammer to the pile, the driving stresses in the pile, and the static resistance to driving (SRD). The hammer performance was evaluated from the equation:

$$E(t) = \int F(t)V(t)dt$$

where E is the measured transferred energy as a function of time, F is the measured force at the sensor location as a function of time, and V is the measured velocity from the integrated acceleration as a function of time. (Hannigan, 1990) The maximum transferred energy can then be compared to the manufacturer's maximum rated energy to obtain a hammer efficiency. In this case, an average hammer efficiency of approximately 80% was observed. This measured energy transfer matched very well with the energy transfer predicted in preliminary wave equation analyses.

The driving stress in each pile was determined with the PDA as the force measured at the sensor location divided by the pile cross-sectional area at the sensor location. CAPWAP analyses provided driving stress information at other locations along the pile length. The integrity of each pile was also evaluated by comparing the theoretical time (2L/c) at which a wave reflection from the pile toe is expected to the time observed during the data collection.

Typically, when constructing offshore platforms, dynamic capacity estimates are not of great concern. In this particular case, the blow counts were lower than expected, and the results of CAPWAP analyses at the end of driving (EOD) and the beginning of restrike (BOR) were used to determine the adequacy of the piles. Figure 3 shows typical force and velocity records obtained near final driving and near the beginning of restrike. Note the reflections caused by the changes in cross-section. Also notice the additional shaft friction and the smaller toe reflection in the restrike blow due to higher resistances. Case Method estimates of the pile capacity were not used because the Case Method assumes a uniform pile cross-section. CAPWAP analyses were used to more accurately determine the SRD values for these non-uniform piles which are commonly used in offshore installations. The CAPWAP results from the two restrike tests indicated that the SRD values more than doubled after a 24 hour wait.

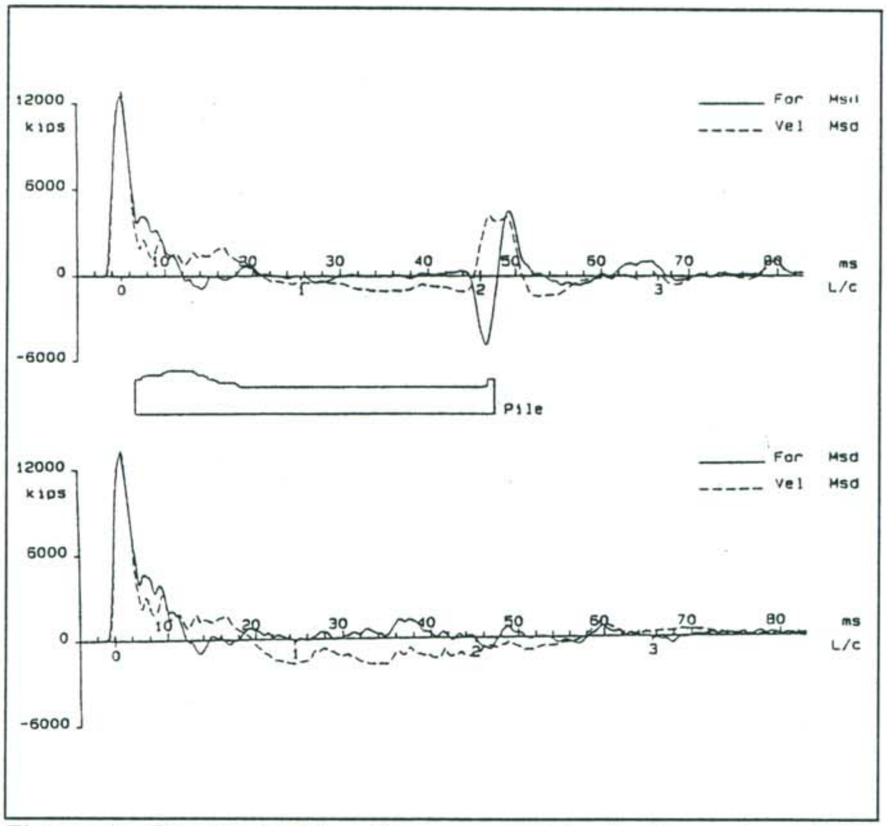

Figure 3: Representative Force and Velocity Records at EOD (Top) and BOR (Bottom)

CONCLUSIONS

The specially prepared underwater strain and acceleration sensors used for this project performed flawlessly for all eight piles monitored. Additionally, it has been proven that the underwater cables connecting the dynamic sensors to the PDA can be successfully retrieved for future use.

Underwater dynamic testing was an important tool for assessing the adequacy of piles. With a little advance planning and communication with the contractor's personnel, successful dynamic tests can smoothly fit into the construction schedule.

REFERENCE

Hannigan, Patrick J., 1990. Dynamic Monitoring and Analysis of Pile Foundation Installations. A continuing education short course text, Deep Foundations Institute, Sparta, New Jersey.