Bubble Curtain Systems Help Protect The Marine Environment

High underwater shock wave overpressures created by pile driving with an impact style hammer are detrimental to the health of fish. In recent years, environmental agencies worldwide have been given more power to introduce stringent environmental protection regulations applicable to marine construction activities. Contractors, consultants and owners have been required to begin searching for a cost-effective way to mitigate high underwater shock wave overpressure to obtain permission to complete projects that include marine pile driving.

Background

The work discussed in this article was completed at the Canada Place Cruise Ship Terminal in the city of Vancouver, Province of British Columbia, Canada.

In 1999 the Vancouver Port Authority (VPA) began a revitalization project at Canada Place, the central cruise ship port in Vancouver. The marine work was to include modifications and seismic upgrades to the existing pier, an extension of the existing pier creating a third cruise ship berth and a new fender system. Fraser River Pile and Dredge Ltd. (FRPD) secured the prime contract for the marine portion of the work.

Work on-site began in March 2000 with densification of the seabed in the offshore area adjacent to and north of the existing pier. Simultaneously, FRPD began phase I pile driving, which included the installation of 24-inch diameter, .75-inch wall closed-ended steel pipe piles driven through the north apron area of the existing pier. These piles would support the refurbished terminal superstructure and were driven through previously imported fill and into glacial till using both an ICE 80S diesel impact hammer and an ICE 115 hydraulic impact hammer. This portion of the work was completed in early May 2000 and no negative impact to the marine environment was recorded.

Phase II pile driving started immediately with the installation of 36-inch diameter x .75-inch wall open-ended steel pipe piles along the interface between the existing dock and its new extension. These piles were driven through the previously densified overburden and down to glacial till using an ICE 66-80 vibratory hammer and then seated with the ICE 80S. This portion of the work was completed by mid-May 2000 and no negative impact to the marine environment was recorded.

Phase III pile driving began immediately with the installation of 36-inch diameter x .75-inch wall open-ended steel pipe piles driven in the offshore area immediately adjacent to and north of the existing pier. These piles were driven through previously densified overburden and into glacial till using a Delmag D80 diesel impact hammer. Native material was subsequently cleaned out from the inside of these piles and a tremmie plug was cast in place to provide additional bearing capacity. This phase continued

for 10 days, with no recorded impact to the marine environment until May 23, 2000, when the first fish mortalities on the Canada Place project were observed and recorded. The fish mortalities were attributed to extremely high underwater shock wave overpressures created during pile driving.

The Bubble Curtain System

Measures to mitigate the fish mortalities began immediately with deployment of a simple prototype bubble curtain on May 24, 2000, while pile driving continued. The initial design of the prototype bubble curtain was based on an extension of the theory behind the documented successful use of air curtains to reduce shock wave overpressures created by underwater blasting.

The prototype bubble curtain consisted of a circular or square shaped air distribution manifold made of rubber, plastic or steel tubing, which encircled the piling at various points below the water surface level. The Canadian government's Department of *(Continued On Page 12)*

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Fisheries and Oceans (DFO) monitored pile driving activities full-time at the site. Work continued throughout phase III, with DFO shutting down the work intermittently whenever a fish kill was recorded. FRPD continually made adjustments and refinements to the bubble curtain system, and a testing period followed each refinement. Work was allowed to proceed cautiously and the effects of each improvement were ascertained under close scrutiny and constant monitoring by DFO. FRPD was continually working toward the development of a cost-effective mechanical system that would successfully mitigate fish mortalities due to high underwater overpressures created during pile driving. This was the first time negative impacts on fish due to pile driving had been documented in British Columbia. DFO, in conjunction with FRPD and VPA, quickly recognized the significance of developing the bubble curtain system and exercised as much latitude as possible within the regulations to allow testing during pile driving to continue. Phase III continued in this manner and was completed by June 20, 2000.

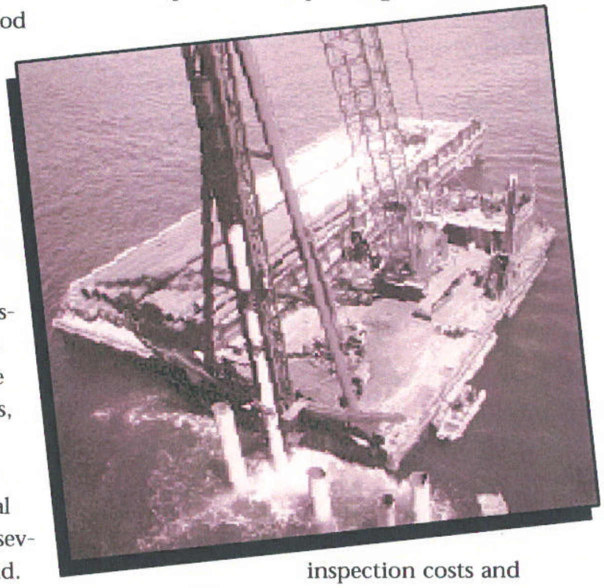
There was a scheduled three-week break from pile driving between the end of phase III and the beginning of phase IV. Phase IV pile driving included the installation of 36-inch diameter x .75-inch wall closed-ended steel pipe piles in the offshore area to the east of the phase III piles. A double bent separated the phase III and phase IV portions of the pier, with a seismic expansion joint being the only link between them.

These piles were driven through overburden and into glacial till using the D80 hammer. One third of the phase IV piles were inclined at 1h:3v and had a custom tip designed to keep native material from entering the pile while still allowing the installation and post-tensioning of drilled anchors installed through the piling and into the glacial till below after completion of the entire pier.

All parties thought driving closed-ended piling (as opposed to open-ended, as driven until this point) would have substantially greater negative impact on the marine environment. The testing and development period was now over and the project was required to refine the means of mitigating shock waves created by pile driving, as well as develop a means of testing the effectiveness of the mitigation without using fish as the indicator. FRPD utilized the scheduled break period between phases to refine the bubble curtain design based on tests completed so far and to construct new, improved physical components. FRPD initially used a recorded dive inspection of the bubble curtain system on the first pile of phase IV. The results of this inspection were disappointing because there was an obvious lack of air flow from the secondary distribution manifolds, there was less than complete air bubble coverage around the pile perimeter throughout the vertical depth of the water column and several deployment flaws were found. These factors rendered the existing semi-developed bubble curtain ineffective. All pile driving activity was immediately shut down pending redesign of the bubble curtain system or implementation of an alternate mitigation system.

FRPD channeled all available resources into searching for a more effective system. Experts from across North America and the United Kingdom were consulted and numerous proposals were investigated, such as acoustic or strobe light fish deterrent systems, temporary fixed or floating barriers, rubber or foam bladder wrapped around piling, changing the frequency of the shock wave generated during pile driving by filling the piling with dense material, use of an alternate hammer or cushion material between the hammer and pile, large-coverage-area bubble mats installed on the sea floor and an improved design (utilizing new information obtained during dive inspections) of the original bubble curtain. Several of these proposals worked well in theory, but the modified version of the original small manifold bubble curtain system continued to emerge at the top of the list of options when both performance and cost-effectiveness were considered.

Key factors used to assess the viability of a mitigation system were depth of coverage required (varying with tides), local currents, speed, ease and consistency of deployment, performance monitoring, capital costs, operating costs,



inspection costs and effectiveness.

FRPD decided to proceed with further development of the small manifold bubble curtain system, hoping to develop a mechanical device to mitigate underwater overpressure that was superior to any used before during the installation of marine piling.

The new bubble curtain system was designed in-house by FRPD staff and was constructed specifically to suit the equipment and materials being used on the Canada Place project. The design of the new system addressed all DFO concerns, with great regard to shock wave overpressure mitigation, effectiveness monitoring and consistency of deployment. FRPD received permission to conduct testing on July 14, 2000, which found minor flaws in the new system. Adjustments were made accordingly and a second round of testing was conducted on July 17, 2000. These tests showed that the new system functioned well and performed up to the full potential of its design expectations.

DFO gave permission for pile driving activities to proceed with full-time hydrophone monitoring and stringent reporting guidelines. Phase IV pile driving continued (Continued On Page 13)

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until completion on Oct. 14, 2000, with only minor adjustments and repairs made periodically to the new system.

Phase V pile driving began at the end of September with the installation of 24-inch diameter x .75-inch wall closed-ended pipe piles driven through the existing pier under the existing building using an APE 7.5A super-low headroom hydraulic impact hammer. A scaled down version (for the smaller piles) of the new bubble curtain system was utilized to mitigate underwater overpressure, and no negative impact to fish was recorded. All pile driving was completed on the project by the first week of December.

A successful overpressure mitigation system had been developed and had become the new standard by which to measure protection of aquatic life during marine pile driving activities in Canada.

The Details

An effective bubble curtain system must distribute air bubbles around 100 percent of the perimeter of a pile over the full depth of the water column while it is being driven. Many small bubbles are preferable to fewer larger bubbles. Distribution manifolds must be deployed so that there are no gaps in the coverage area. This can be very difficult on inclined piles installed in areas where there are substantial currents.

The components of the system include:

✘ high volume air compressor and primary feed line;

✘ primary distribution manifold;

✘ medium volume secondary feed lines;

✘ secondary distribution manifolds;

✘ pressure gauges, flow meters and deployment hardware.

Selection Of Equipment/Materials

The secondary distribution manifolds are the key component of the system and therefore should be the first component of the system designed. These manifolds should:

✘ completely surround the piling to be driven;

✘ have sufficient self weight or be weighted appropriately so that they are negatively buoyant once charged with air (consider any attached air lines);

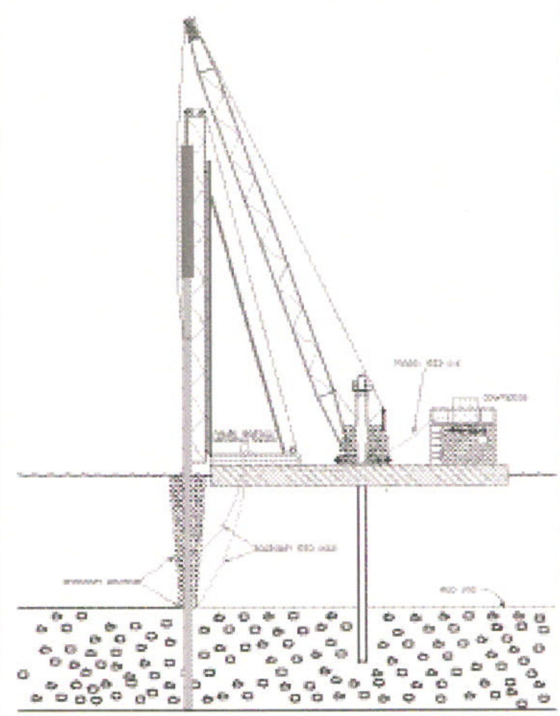
✘ have 1/16-inch diameter air release holes every 3/4-inch along their length.

If the pile is to be driven vertically in shallow water, one level of secondary distribution manifolds is sufficient. If the water is deeper than 35 feet, a second level is required. Similarly, add a third level if depth exceeds 70 feet, and so on.

Inclined piles present a new difficulty since bubbles, once released, rise only vertically. Larger manifolds or additional levels of manifolds are required to maintain 100 percent coverage on inclined piles. Secondary manifolds should be simple and light enough to be deployed and recovered cost-effectively multiple times within a single shift, yet durable enough to survive repeated use and abuse during pile driving.

The next step is to select secondary feed lines that are capable of carrying a sufficient volume of air at an appropriate pressure to the secondary distribution manifolds. When sizing these lines, allow for back pressure at the exit point, in-line friction losses and losses through fittings. If a .75-inch inside diameter line is used and the manifold release holes are as above, there must be at least one supply line for each 144 holes (nine lineal feet of manifold). Since they are the part of the system most vulnerable to wear and their failure results in downtime from pile driving, these feed lines should be of the highest quality available. They must be deployed and recovered numerous times while maintaining their resistance to twisting, kinking and stretching. Keep hose lengths to the minimum possible to reduce the likelihood of snagging and kinking during deployment and recovery.

Now that the number and size of secondary feed lines is known, the compressor and primary feed line can be selected. A 100+psi compressor, which supplies 150 cfm per each secondary feed line required, will be sufficient for most applications. Consider a higher supply pressure if water depth exceeds 100 feet or if there are other special site conditions. Consider excess supply volume to overcome unforeseen losses.



The components of a small manifold bubble curtain system.

Size the primary feed line so it can carry the full volume capacity of the compressor to the primary distribution manifold. Allow for line losses if the compressor is to be located a long distance away from the primary distribution manifold.

Design the primary distribution manifold so that it accepts air from the primary feed line and redirects it into the secondary feed lines. Set up this manifold at an easily accessible location near the pile driving work. This is the center point of the system where air flow to individual secondary manifolds is controlled and system operating status is monitored. Include valves for each feed line so that they can be controlled and adjusted individually.

Flow gauges and pressure meters must report system status at all times to the operator. Since the majority of the system components (Continued On Page 16)