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FRASER RIVER PILE & DREDGE LTD.

BUBBLE CURTAIN SYSTEMS FOR USE DURING MARINE PILE DRIVING

Authors: Craig Longmuir, AScT
Tom Lively, P.Eng.

1.0 Purpose/Scope

High underwater shock wave overpressures are detrimental to the health of fish which exist in the aquatic environment directly adjacent to pile driving which is being completed using an impact style hammer. In recent years, environmental agencies worldwide have been given more power and have started introducing extremely stringent environmental protection regulations applicable to marine construction activities. Contractors, Consultants and Owners have been required to begin searching for a cost effective method of mitigating high underwater shock wave overpressures in order to obtain permission to complete projects which include marine pile driving. This report provides these organizations with an additional resource which may be consulted during the overpressure mitigation process. It describes one method of mitigating underwater shock wave overpressures which are created during the driving of steel pipe piles with an impact style hammer.

2.0 Background

The work discussed in this report 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 (refer to sketch-1 for general arrangement). 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. The project was tendered on a lump sum competitive price basis. 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" dia. x 0.75" 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 impacts to the marine environment were recorded.

Phase II pile driving started immediately with the installation of 36" dia. x 0.75" wall open ended steel pipe piles along the interface between the existing dock and it's 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 impacts to the marine environment were recorded.

Phase III pile driving began immediately with the installation of 36" dia. x 0.75" 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 23/00 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.

3.0 Development of the Bubble Curtain System

Measures to mitigate the fish mortalities began immediately with deployment of a simple prototype bubble curtain on May 24/00 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 Fisheries and Oceans (DFO) was monitoring pile driving activities on a full time basis at this site. Work continued throughout phase III with DFO shutting down the Work on an intermittent weekly and sometimes daily basis whenever a fish kill was recorded. FRPD continually made adjustments and refinements to the bubble curtain system. A testing period followed each refinement to the system. 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 towards the development of a cost effective mechanical system which would successfully mitigate fish mortalities due to high underwater overpressures created during pile driving. This was the first time that 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 20/00.

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" dia. x 0.75" 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 also driven through overburden and into glacial till using the D80 hammer. One third of the phase IV piles were battered 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.

Expectations of all parties were that the driving of closed ended piling (as opposed to open ended as driven until this point) would have a 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 testing completed to date and to construct new, improved physical components. FRPD initially utilized a recorded dive inspection of the bubble curtain system as deployed on the first pile of phase IV. The results of this inspection were disappointing in that 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 identified. The combination of 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 mitigation system. Experts from across North America and the United Kingdom were consulted and numerous proposals were investigated such as an acoustic and/or strobe light fish deterrent systems, temporary fixed and/or floating physical barriers, rubber and/or foam bladders 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 and/or cushion material between the hammer and pile, large coverage area bubble mats installed on the seafloor and an improved design (utilizing new information obtained during dive inspections) of the original prototype small manifold bubble curtain system deployed around each piling during driving. Several of these proposals worked well in theory and were likely to perform well in the field 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 cost, 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 which 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 regard to shock wave overpressure mitigation, effectiveness monitoring and consistency of deployment. FRPD received permission to conduct testing on July 14/00. Initial testing was successful in identifying minor flaws with the new system. Adjustments were made accordingly and a

second round of testing was conducted on July 17/00. These tests showed that the new system functioned well and performed up to the full potential of it's 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 until completion on October 14/00 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" dia. x 0.75" 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 overpressures and no negative impacts to fish were 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.

4.0 Details of the Small Manifold Bubble Curtain System

An effective bubble curtain system must distribute air bubbles around 100% 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 battered piles installed in areas where there are substantial currents.

4.1 Components (refer to sketch-2 for schematic)

- high volume air compressor and primary feed line
- primary distribution manifold
- medium volume secondary feed lines
- secondary distribution manifolds (refer to sketch-3 for details)
- pressure gauges, flow meters and deployment hardware

4.2 Selection of Equipment/Materials

The secondary distribution manifolds are the key component of the system and therefore should be the first component 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" diameter air release holes every ¾" along their length.

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

Battered piles present a new difficulty since bubbles, once released, rise only vertically. Larger manifolds and/or additional levels of manifolds are required to maintain 100% coverage on batter 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 which are capable of carrying a sufficient volume of air at an appropriate pressure to the secondary distribution manifolds. When sizing these lines, allowances must be made for backpressure at the exit point, in-line friction losses and losses through fittings. If a 0.75" inside diameter line is used and the manifold release holes are as above then there must be at least one supply line for each 144 holes (9 lineal feet of manifold). Since they are the part of the system most vulnerable to wear and their failure results in down time 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 down 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' or if there are other special site conditions. Consider excess supply volume to overcome unforeseen losses.

Size the primary feed line so that 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 actual pile driving work. This is the center point of the system where airflow 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 are underwater during driving the operator must rely on these gauges and meters to monitor the system's effectiveness. They should report the pressure as well as the flow in both the primary feed line and each of the secondary feed lines.

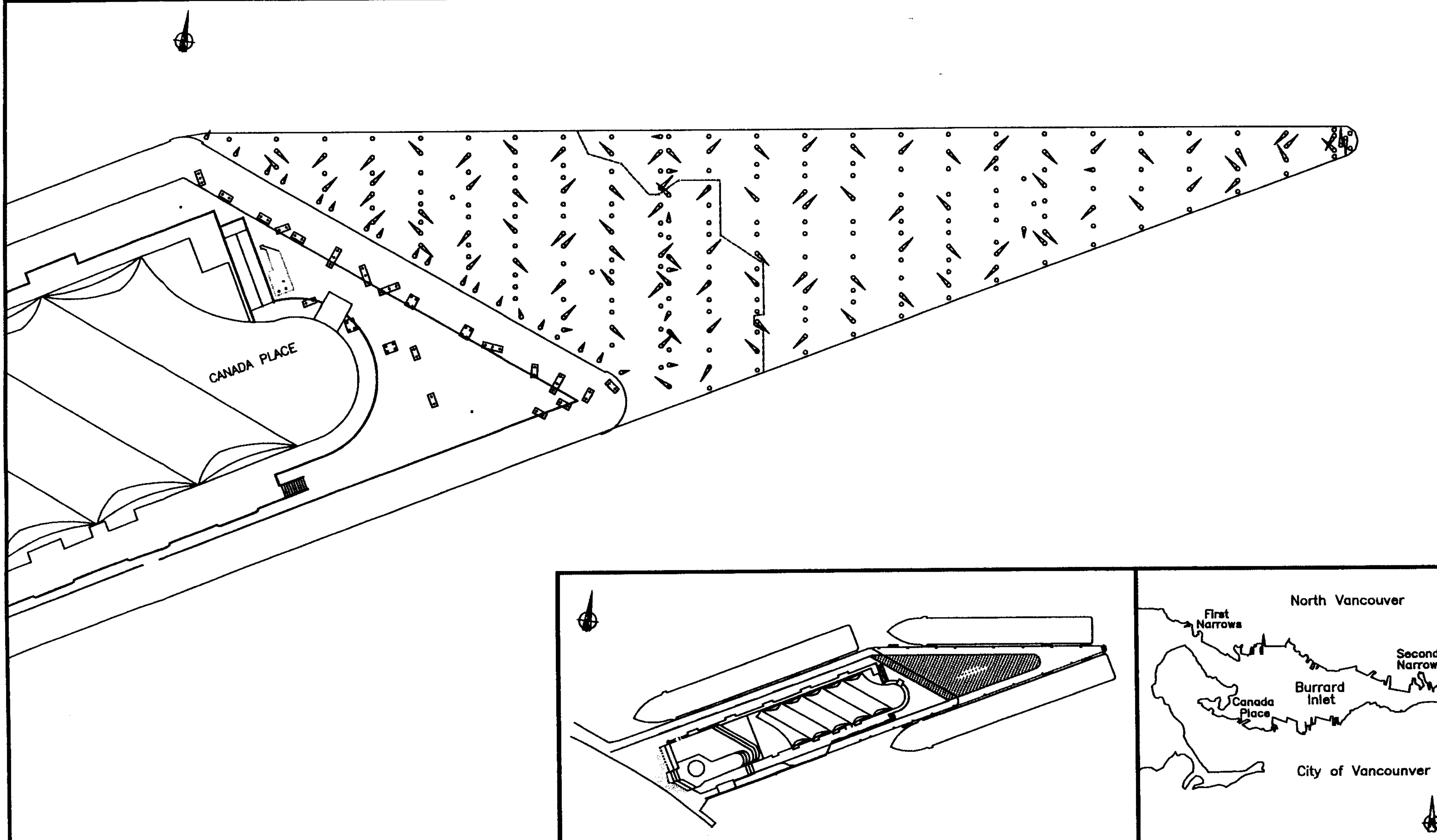
The deployment hardware must be specifically designed to suit individual applications. It must be capable of setting and maintaining the secondary manifolds in position around the pile to be driven so that no gaps in coverage are present. It should be power driven and easy to use in order to minimize operating costs. Inspection and troubleshooting are made easier if the deployment system can be completely removed from the water at any time with relative ease. Pile driving equipment to be used, type and size of piling to be driven, water depth, pile orientation and project schedules will all be factors to be considered when designing the deployment hardware. It can be as basic or as intricate as required to get the job done while remaining within project budget and scheduling constraints.

5.0 Performance

A properly designed, constructed and deployed small manifold bubble curtain which provides complete coverage can reduce underwater overpressures by at least 85%. Hydrophone test data taken during the Canada Place Pier Extension Project by FRPD and VPA showed that the bubble curtain reduced underwater overpressures during pile driving from in excess of 22 psi with no mitigation to less than 3 psi using the bubble curtain.

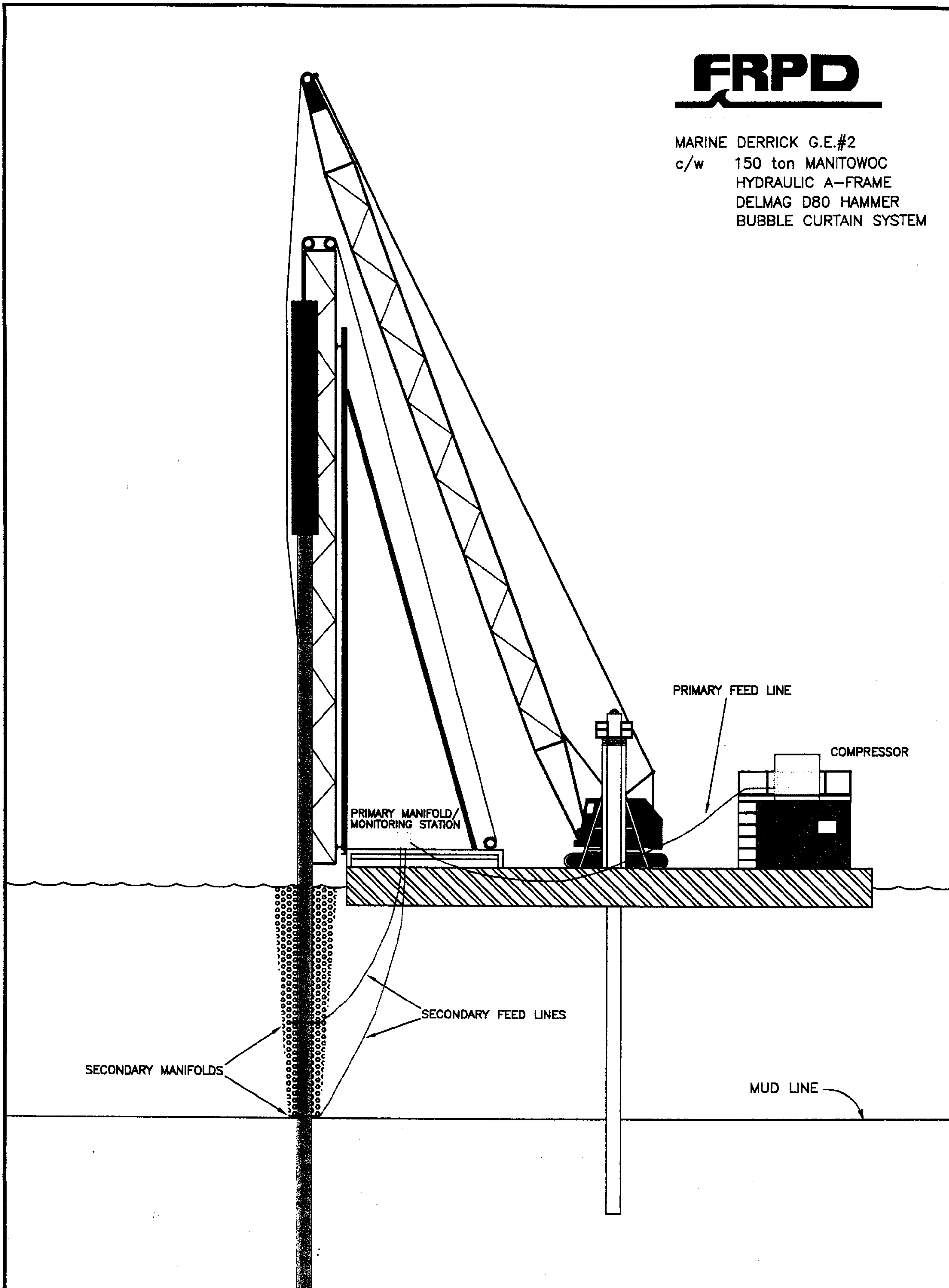
The overpressure level which is damaging to a particular marine environment will of course vary with the size, maturity and species of fish in the area. It is difficult to recommend a safe overpressure level without conducting testing in the immediate work area to determine the type of fish present and to obtain a measure of their resilience to overpressure waves. Canadian DFO guidelines limit overpressures created by blasting operations to 14.5 psi. Blasting typically consists of only a few, single shock waves and this limit was proven in Vancouver to be less than adequate to mitigate the effects of the multiple, high pressure shock waves created over an extended period of time during the driving of large diameter steel piles. At Canada Place small fish were found to be resilient up to at least 4.5 psi which then became the accepted maximum for this particular project. A higher level may be acceptable (or a lower level required) in other areas. In the absence of existing government regulations, testing which considers the resident marine life should be conducted to establish a safe overpressure level for individual sites.

Though there may be other systems which, after further development and testing, may rival this system, the small manifold bubble curtain system is certainly an extremely effective method of mitigation which can cost effectively protect marine life from the high underwater shock wave overpressures created during pile driving.



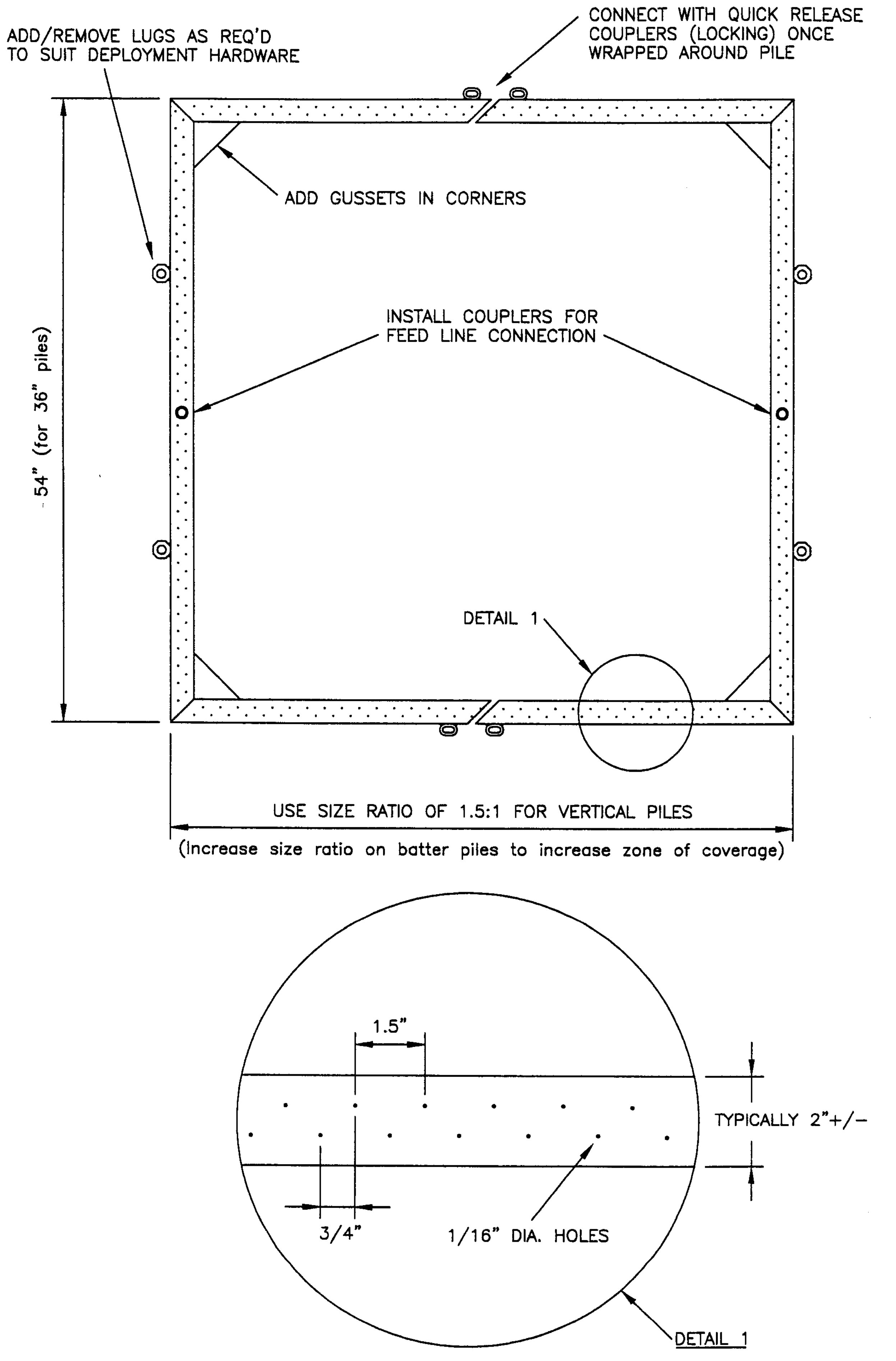
FRPD – BUBBLE CURTAINS FOR USE IN MARINE PILE DRIVING

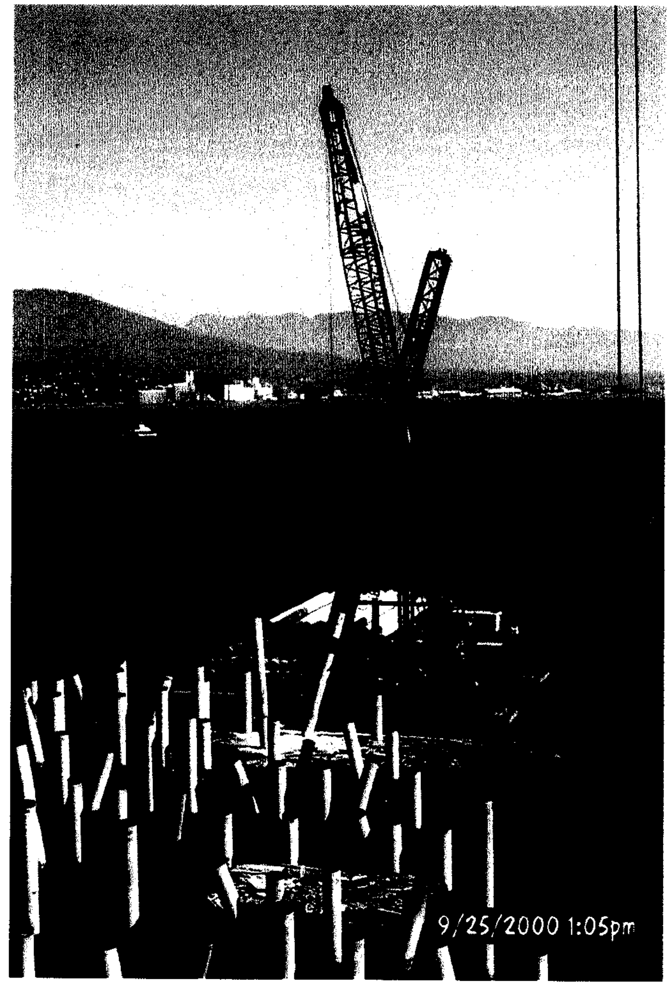
SKETCH – 1



FRPD – BUBBLE CURTAINS FOR USE IN MARINE PILE DRIVING

SKETCH – 2


ADD/REMOVE LUGS AS REQ'D
TO SUIT DEPLOYMENT HARDWARE
CONNECT WITH QUICK RELEASE
COUPLERS (LOCKING) ONCE
WRAPPED AROUND PILE
ADD GUSSETS IN CORNERS
INSTALL COUPLERS FOR
FEED LINE CONNECTION
54" (for 36" piles)
DETAIL 1
USE SIZE RATIO OF 1.5:1 FOR VERTICAL PILES
(Increase size ratio on batter piles to increase zone of coverage)
1.5"
TYPICALLY 2"+/−
3/4"
1/16" DIA. HOLES
DETAIL 1



Marine Derrick G.E. II driving

36" Pipe Piles with a Bubble Curtain