Reducing Underwater Sounds with Air Bubble Curtains

Protecting Fish and Marine Mammals from Pile-Driving Noise

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Pile driving at large construction sites produces formidable noise. Marine pile driving similarly can produce high sound pressures underwater—but these can be lethal to fish and can harass marine mammals, including those protected by federal law. This problem has contributed to costly construction delays on major bridge projects. To protect marine life, engineers have designed air bubble curtains to reduce underwater sounds.

Problem

In 2000, the California Department of Transportation (Caltrans) undertook a demonstration project to install steel piles as part of the design to replace the eastern span of the San Francisco–Oakland Bay Bridge. The demonstration involved driving 8-foot-diameter steel piles that were more than 300 feet long. The new bridge would require more than 250 of the piles.

An unconfined air bubble curtain with two vertically stacked rings is deployed on a harbor project to reduce underwater sounds; oil-free compressors supply air to the system.

Caltrans also conducted tests on sound reduction methods that had been developed to protect marine mammals. The underwater sounds during this demonstration, however, fatally injured fish, which were observed floating on the surface and exposed to predation by seagulls. Because the sound reduction methods were not protecting the fish adequately, state and federal agencies raised concerns about the endangered fish species in the area.

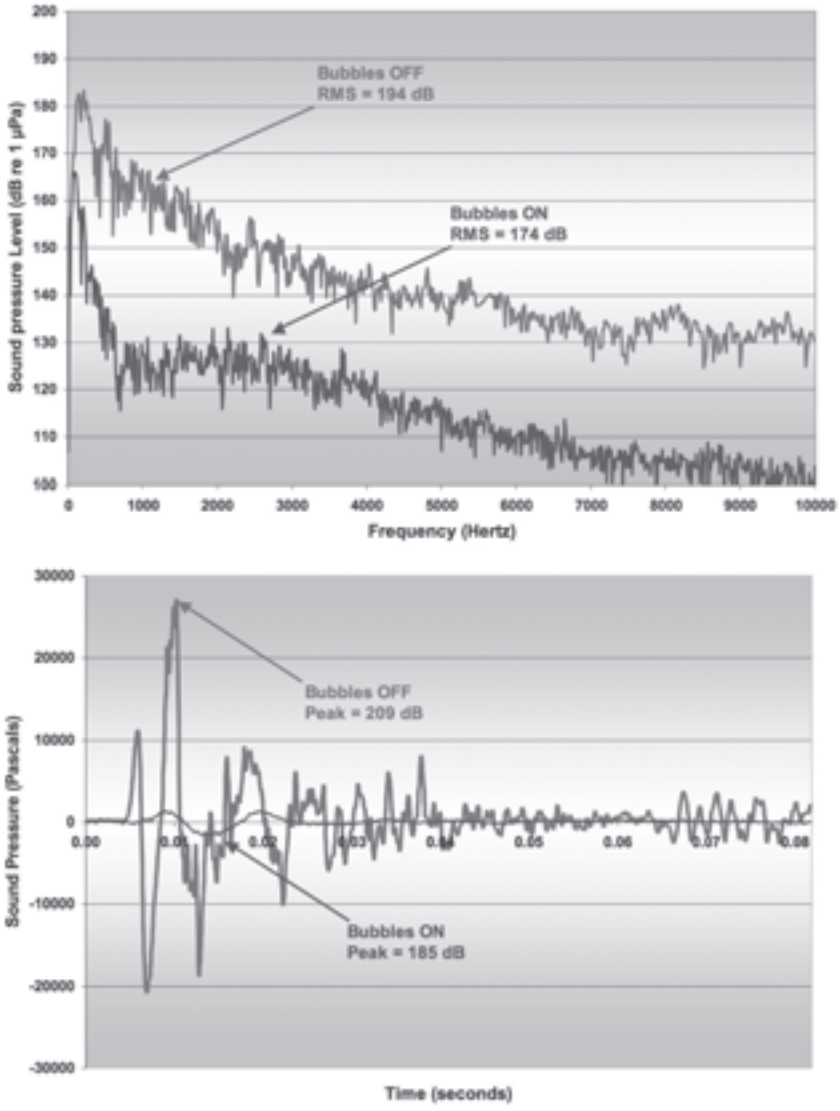
While the designers were working on developing an air bubble curtain that would effectively protect fish, pile driving began on the nearby Benicia-Martinez Bridge, located in the Carquinez Strait, a critical migration route for endangered fish in Northern California. Fish were fatally injured by the construction noise. This caused additional alarm and slowed the construction of the bridge.

The construction plans had not included methods to reduce underwater sounds. The pile driving had been restricted to slack tide conditions, when fish were least likely to be present, and was suspended when the endangered fish began their migration. The potential delay of 7 months threatened to stop the project permanently because of funding issues.

Solution and Application

Air provides an effective barrier to sound propagating through water, because of the difference in density between air and water. Air bubble curtain systems have been used to reduce underwater sound pressures from explosions or from other sources of high-amplitude sounds.

The first documented use of air bubble curtains on a marine pile-driving project was in Hong Kong; the curtains reduced the sounds by 3 to 5 decibels, protecting marine mammals (*1*). Engineers in Canada then reported favorable results with an air bubble curtain to protect fish at a wharf project. Caltrans, however, faced several complications: the sound levels were much higher, the water was



Example waveforms and frequency spectra for 2.4-m-diameter steel pile with and without bubble curtain: Benicia-Martinez Bridge, Carquinez Strait, California.

deeper, and the currents stronger. The curtain of air bubbles must be able to extend from the bottom of the pile to the water surface without any gaps.

Moreover, the driving templates that had been designed and fabricated for the project did not support the use of available air bubble curtains. Engineers therefore developed two types of curtains.

Design Variations

First, they placed a perforated tube at the bottom of a large cylinder that extended from just below the mud line to above the water surface, with the pile inside. The large cylinder would prevent currents from sweeping the air bubbles away from the pile.

Because many projects could not accommodate a large cylinder around the pile, multistage air-bubble curtains were developed. These systems place a series of rings around the pile at different depths. Although currents could sweep the bubbles away, the ring above would generate more bubbles, maintaining a uniform presence of air around the entire pile.

The prefabricated pile template for the Benicia-Martinez Bridge could not accommodate complete rings. The engineers therefore developed stacked quarter-rings that were placed at each quadrant of the piles. Because of the water depth, large compressors were required to deliver air to the bottom of the water column.

Underwater sound tests were conducted for these air bubble curtains with the air supplies turned on and off. The sound was reduced by 20 to 30 decibels close to the pile, where most of the fish injuries had occurred (2). Tests on other projects in shallower waters measured reductions of 10 to 20 decibels. In comparison, most highway noise barriers achieve reductions of only 5 to 10 decibels.

The key was that no fish injuries or mortality were observed with the air bubble curtains. Sound reductions from the pile driving were recorded out to 1 kilometer away. Areas with adverse effect on fish and marine mammals were estimated to decrease in size by up to 90 percent.

Research Group Formed

While the engineers were working on an effective design for the air bubble curtains against pile-driving sounds, researchers were trying to determine the effects of the noise on fish. Highway and resource agency officials, expert consultants, and university researchers formed the Fisheries Hydroacoustic Working Group (FHWG), which released the first research findings on the effects of sound on fish in 2005 (3). The group concluded that little was known and much additional research was needed.

In 2008, FHWG developed interim criteria to identify the potential effects of underwater sound on fish. All impact pile-driving activities exceeded the sound levels at which the onset of impacts to small fish occurs. On bridge projects that used larger steel-pipe piles, the impacts could extend 1 to 2 kilometers out into open water.

Benefits

Use of the air bubble curtains during pile driving has reduced sounds substantially. Biologists from Caltrans have not identified any injured fish with the air bubble curtains in use during pile driving. In San Francisco Bay, pile driving has been permitted during fish migration seasons, as long as the air bubble curtains reduce the sound levels sufficiently. In this way, pile driving that had been limited to seasonal windows can be completed before deadlines.

Projects now incorporate efforts to reduce underwater sounds from pile driving. In addition to air bubble curtains, options include dewatered cofferdams and other methods to install piles. Attenuation systems that use air to reduce underwater sounds are in routine use on the West Coast for marine pile-driving. Although the air bubble curtains can increase the time and cost of pile driving, proper planning can minimize the delays.

The FHWG continues to research the effects of sound on marine species and to develop more effective techniques to reduce underwater sound from marine construction. A National Cooperative Highway Research Program project is testing the effect of pile-driving sounds on fish in a laboratory setting (see box, below). A pooled-fund study will investigate changes to pile designs that could reduce sound pressures.

The Federal Highway Administration presented Caltrans and FHWG with a 2005 Environmental Excellence Award. Caltrans and the Washington State Department of Transportation (DOT) have developed guidance manuals for assessing the impacts of pile driving before design, so that the appropriate measures to reduce sound can be incorporated. Washington State DOT is investigating methods to reduce pile-driving sounds further, to allow pile driving year-round in waters with endangered or threatened species. For more information on this topic and for copies of research documents, see the Caltrans website, www.dot.ca.gov/hq/env/bio/fisheries_bioacoustics.htm.

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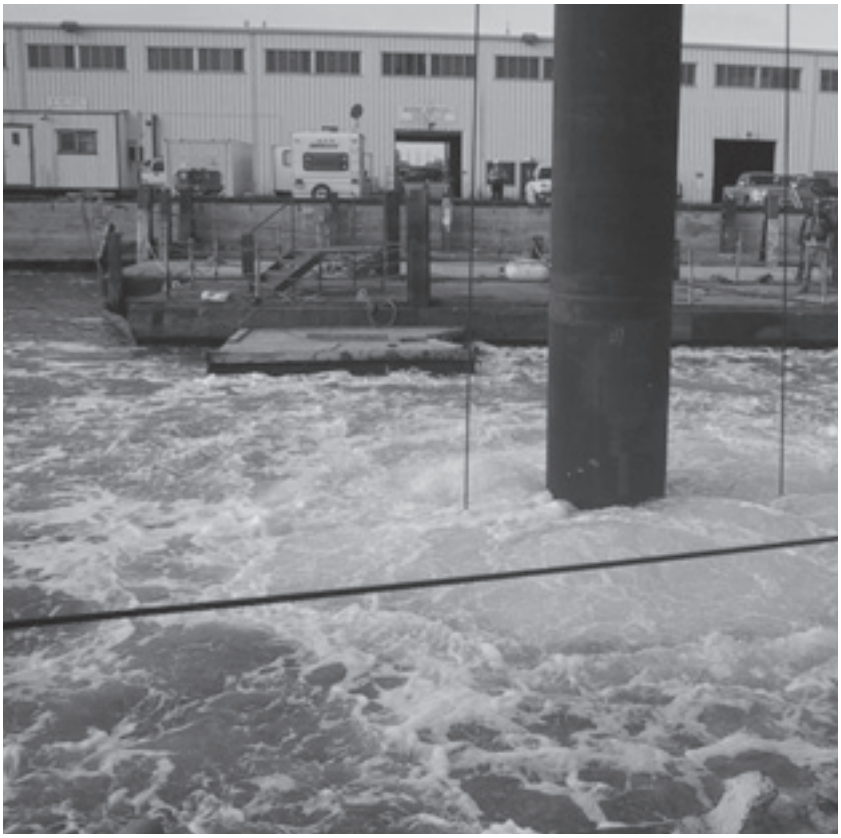
More Clues from the Lab

National Cooperative Highway Research Program Project 25-28, Predicting and Mitigating Hydroacoustic Impacts on Fish from Pile Installation, is studying the science behind aquatic pile driving and its impact on fish. The project team, led by Art Popper, University of Maryland, has developed a wave tube apparatus to study the effects on fish in a laboratory setting, using auditory signals that closely replicate those of pile driving. Variables include the intensity of the pile-driving signal, the number of strikes, and the intervals between strikes. Postexposure experiments assess the sample fish for hearing loss and tissue damage. Results of the study are expected this fall.



Air bubble curtain submerged and in action; the bubble curtain not only reduces the sound, but also keeps fish away from the pile.

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Suggestions for "Research Pays Off" topics are welcome. Contact G. P. Jayaprakash, Transportation Research Board, Keck 488, 500 Fifth Street, NW, Washington, DC 20001 (telephone 202-334-2952, e-mail gjayaprakash@nas.edu).