APPENDIX B
BUBBLE CURTAIN SPECIFICATIONS

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National Marine Fisheries Service (NMFS) and U.S. Fish and Wildlife Service (USFWS), Washington Fish and Wildlife Office
Impact Pile Driving Sound Attenuation Specification
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INTRODUCTION

Air bubbles can reduce sound pressure levels (SPLs) at some frequencies by as much as 30 dB (Gisiner et al. 1998). Bubble curtains are essentially perforated pipes or hoses, surrounding the pile being driven, that produce bubbles when air is pumped through the perforations. Bubble curtains can also reduce particle velocity levels (MacGillivray and Racca 2005).

Bubble curtain designs are highly variable, but can generally be grouped in two categories: unconfined and confined. Unconfined systems are simply a frame which allows for transmission of air bubbles around a pile being driven. Confined systems add a sleeve around the pile to contain the bubbles. The sleeve can consist of fabric, hard plastic, or a larger pile (casing). Spacing of the bubble manifolds, air pressure, tidal currents, and water depth are all factors influencing effectiveness. Improper installation or operation can decrease bubble curtain effectiveness (Pommerenck 2006; Visconty 2004).

Reyff et al. (2002) evaluated the effectiveness of a confined system which used a foam-filled casing and bubble curtain. The casing was 3.8 meters in diameter with the interior coated with 2.54 centimeter closed cell foam. The casing surrounded the pile being driven, and contained the bubble flow. This system dramatically reduced both peak pressure and rms levels. Peak pressure was reduced by 23 to 24 dB and rms levels were reduced by 22 to 28 dB.

A confined bubble curtain used in driving 24 inch octagonal concrete piles at the Port of Benicia in San Francisco Bay, California, attenuated SPLs between 20 and 30 dB (Rodkin, 2003). At the Benicia Martinez Bridge project in California, the project proponents used a casing that was either dewatered, or included an air bubble system. Both techniques yielded substantial reductions in SPLs. The sleeve with an air bubble curtain reduced peak SPLs by up to 34 dB, which the authors note, equates to a 99 percent reduction in the overall energy of the impulse (Reyff et al, 2002). A confined bubble curtain used in driving 30 inch steel piles at a Washington State Ferries facility in Eagle Harbor, Washington, attenuated SPLs by an average of 9.1 dB (MacGillivary and Racca, 2005).

During impact installation of steel piles in an embayment on the Columbia River an unconfined bubble curtain built using a design by Longmuir and Lively (2001) achieved a maximum reduction of 17 dB, although the results were variable (Laughlin 2006). Unconfined bubble curtains used in driving very large steel piles for bridges in San Francisco Bay, California, have attenuated SPLs by as much as 20 dB (Abbott and Reyff 2004). An unconfined bubble curtain used during installation of 24 inch steel piles in the City of Vancouver, British Columbia, reduced SPLs by 17 dB (Longmuir and Lively, 2001). At Friday Harbor, Washington, the Washington State Ferries monitored steel pile driving with and without a bubble curtain (Visconty 2004). Initially, the bubble curtain was improperly installed and no sound attenuation was observed. The bubble curtain was not placed firmly on the bottom; therefore, unattenuated sound escaped under the bubble curtain. After the bubble curtain was modified by adding weight and a canvas skirt to conform to the bottom contour of Puget Sound, the sound was reduced by up to 12 dB, with an average of 9 dB reduction. Vagle (2003) reported reductions of between 18 dB and 30 dB when using a properly designed bubble curtain.

In Washington, the effectiveness of both unconfined and confined systems has been variable and below that of other locations. This may be attributable to an incomplete understanding of design, deployment, and performance, and/or to site specific parameters such as substrate and driving depth. With a common set of design and performance specifications, variability should be minimized and limited to site specificity.

Unconfined Bubble Curtain Specifications:

1. General - An unconfined bubble curtain is composed of an air compressor(s), supply lines to deliver the air, distribution manifolds or headers, perforated aeration pipe, and a frame. The frame facilitates transport and placement of the system, keeps the aeration pipes stable, and provides ballast to counteract the buoyancy of the aeration pipes in operation.

2. The aeration pipe system shall consist of multiple layers of perforated pipe rings, stacked vertically in accordance with the following:

Water Depth (m)	No. of Layers
0 to less than 5	2
5 to less than 10	4
10 to less than 15	7
15 to less than 20	10
20 to less than 25	13

3. The pipes in all layers shall be arranged in a geometric pattern which shall allow for the pile being driven to be completely enclosed by bubbles for the full depth of the water column and with a radial dimension such that the rings are no more than 0.5 meters from the outside surface of the pile.

4. The lowest layer of perforated aeration pipe shall be designed to ensure contact with the substrate without burial and shall accommodate sloped conditions.

5. Air holes shall be 1.6 mm (1/16-inch) in diameter and shall be spaced approximately 20 mm (3/4 inch) apart. Air holes with this size and spacing shall be placed in four adjacent rows along the pipe to provide uniform bubble flux.

6. The system shall provide a bubble flux of 3.0 cubic meters per minute per linear meter of pipe in each layer (32.91 cubic feet per minute per linear foot of pipe in each layer). The total volume of air per layer is the product of the bubble flux and the circumference of the ring:

$V_t = 3.0\ m^3/min/m$ * Circum of the aeration ring in m

or

$V_t = 32.91\ ft^3/min/ft$ * Circum of the aeration ring in ft

7. Meters shall be provided as follows:

    a. Pressure meters shall be installed at all inlets to aeration pipelines and at points of lowest pressure in each branch of the aeration pipeline.

    b. Flow meters shall be installed in the main line at each compressor and at each branch of the aeration pipelines at each inlet. In applications where the feed line from the compressor is continuous from the compressor to the aeration pipe inlet the flow meter at the compressor can be eliminated.

    c. Flow meters shall be installed according to the manufactures recommendation based on either laminar flow or non-laminar flow.

Performance: In Washington, unconfined bubble curtains have achieved a maximum of 17 dB attenuation and more typically range between 9 to 12 dB. Should hydroacoustic monitoring reveal that an unconfined bubble curtain is not achieving (to be determined based on site and project specific considerations), the NMFS and/or USFWS staff person on the project should be contacted immediately regarding modifications to the proposed action. Should attenuation rates continue at less than (to be determined based on site and project specific considerations), re-initiation of consultation may be necessary.

Confined Bubble Curtain Specifications:

1. General - A confined bubble curtain is composed of an air compressor(s), supply lines to deliver the air, distribution manifolds or headers, perforated aeration pipe(s), and a means of confining the bubbles.

    a. The confinement (e.g. fabric, plastic or metal sleeve, or equivalent) shall extend from the substrate to a sufficient elevation above the maximum water level expected during pile installation such that when the air delivery system is adjusted properly, the bubble curtain does not act as a water pump (i.e., little or no water should be pumped out of the top of the confinement system).

b. The confinement shall contain resilient pile guides that prevent the pile and the confinement from coming into contact with each other and do not transmit vibrations to the confinement sleeve and into the water column (e.g. rubber spacers, air filled cushions).

2. In water less than 15 meters deep, the system shall have a single aeration ring at the substrate level. In waters greater than 15 meters deep, the system shall have at least two rings, one at the substrate level and the other at mid-depth.

3. The lowest layer of perforated aeration pipe shall be designed to ensure contact with the substrate without sinking into the substrate and shall accommodate for sloped conditions.

4. Air holes shall be 1.6 mm (1/16-inch) in diameter and shall be spaced approximately 20 mm (3/4 inch) apart. Air holes with this size and spacing shall be placed in four adjacent rows along the pipe to provide uniform bubble flux.

5. The system shall provide a bubble flux of 3.0 cubic meters per minute per linear meter of pipe in each layer (32.91 cubic feet per minute per linear foot of pipe in each layer). The total volume of air per layer is the product of the bubble flux and the circumference of the ring:

$V_t = 3.0\ m^3/min/m * \text{Circ of the aeration ring in m}$

or

$V_t = 32.91\ ft^3/min/ft * \text{Circ of the aeration ring in ft}$

6. Meters shall be provided as follows:

a. Pressure meters shall be installed at all inlets to aeration pipelines and at points of lowest pressure in each branch of the aeration pipeline.

b. Flow meters shall be installed in the main line at each compressor and at each branch of the aeration pipelines at each inlet. In applications where the feed line from the compressor is continuous from the compressor to the aeration pipe inlet the flow meter at the compressor can be eliminated.

c. Flow meters shall be installed according to the manufactures recommendation based on either laminar flow or non-laminar flow.

Performance: In Washington, few projects have used confined bubble curtains so there is a lack of data. Based on performance in other locations, the effectiveness of a confined system could range from 9 dB to 30 dB. Should hydroacoustic monitoring reveal that a confined bubble curtain is not achieving (to be determined based on site and project specific considerations), the NMFS and/or USFWS staff person on the project should be contacted immediately regarding modifications to the proposed action. Should attenuation rates continue at less than (to be determined based on site and project specific considerations), re-initiation of consultation may be necessary.

Terms and Conditions:

1. A bubble curtain meeting the above design specifications and performance requirements shall be used for all impact pile driving.

2. The bubble curtain design specifications shall be submitted to NMFS and/or the USFWS a minimum of 60 days prior to impact pile driving. The specification shall include, but not be limited to, details regarding hole size, hole spacing, hammer type and energy level, and air supply configuration and level. For confined systems the specification shall include details of the sleeve size, length, and guide system.

3. A hydroacoustic monitoring plan shall be submitted to NMFS and/or the USFWS for approval a minimum of 60 days prior to impact pile driving. The hydroacoustic monitoring plan must be prepared and implemented by someone with proven expertise in the field of underwater acoustics and data collection and shall include the name and qualifications of the biologist to be present during impact pile driving.

4. The contractor shall perform a performance test of the bubble curtain, prior to any impact pile driving, in order to confirm the calculated pressures and flow rates at each manifold ring. The contractor shall submit an inspection/performance report to NMFS and/or USFWS within 72 hours following the performance test.

5. Impact pile driving shall not take place between one hour after sunset and one hour before sunrise. (Note: Implementation of this condition will depend on site specific considerations)

6. A qualified biologist shall be present during all impact pile driving operations to observe and report any indications of dead, injured or distressed fishes, including direct observations of these fishes or increases in bird foraging activity.

7. If a barge is used to house the pile-driver, it shall be isolated from the noise-producing operations. This isolation shall be such that noise from the pile driving operation is not transmitted through the barge to the water column.

8. The agency shall document the effectiveness of the bubble curtain through hydroacoustic monitoring of a minimum of five piles, as early in the project as possible. Factors to consider in identifying the piles to be monitored include, but are not limited to: bathymetry of project site, total number of piles to be driven, sizes of piles, and distance from shore. Peak and rms SPLs, and sound exposure levels (SEL), with and without a bubble curtain, shall be monitored at a distance of 10 meters from each pile at mid-water depth.

9. If the hydroacoustic monitoring indicates that the SPLs will exceed the extent of take exempted in the Biological Opinion(s), the agency shall contact NMFS and/or the USFWS within 24 hours. The agency shall consult with the Service(s) regarding modifications to the proposed action in an effort to reduce the SPLs below the limits of take and continue hydroacoustic monitoring.

10. The agency shall submit a monitoring report to the consulting biologist(s) at NMFS and/or the USFWS within 60 days of completing hydroacoustic monitoring. The report shall include the following information:

    a. size and type of piles;
    b. a detailed description of the bubble curtain, including the design specifications identified above;
    c. the impact hammer force used to drive the piles;
    d. a description of the monitoring equipment;
    e. the distance between hydrophone and pile;
    f. the depth of the hydrophone;
    g. the distance from the pile to the wetted perimeter;
    h. the depth of water the pile was driven;
    i. the depth into the substrate the pile was driven;
    j. the physical characteristics of the bottom substrate into which the piles were driven; and
    k. the results of the hydroacoustic monitoring, including the frequency spectrum, peak and rms SPLs, and single-strike and cumulative SEL with and without the bubble curtain. The report must also include the ranges and means for peak, rms and SELs for each pile.

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