New Hydro Sound Dampers to reduce piling underwater noise

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ABSTRACT

Underwater noise is a severe annoyance and danger to marine life. The innovative Hydro Sound Dampers (HSD) lead to an effective general method to reduce piling underwater noise. HSD were developed between 2007 and 2010 by K.-H. Elmer to reduce marine and offshore piling noise. The theory and the acoustical background of the new noise mitigation method will be presented.

HSD systems use nets with air filled elastic balloons and special PE-foam elements with high dissipative effects to reduce continuous and impact noise. The resonance frequency of the HSD-elements, the optimum damping rate for impact noise, the distribution and the effective frequency range can be fully controlled.

Offshore tests and serial applications in offshore wind farms in Germany and Great Britain demonstrate this new effective way to reduce the very high offshore piling noise. It is also intended to use systems of Hydro Sound Dampers in Australia to reduce high underwater piling noise levels in coastal ports and harbours. HSD-systems are very small systems and easy to handle. They are more effective than air-bubble curtains, independent of compressed air, not influenced by tidal currents, not expensive and easy adaptable to different applications.

Measured results of underwater noise reductions between 10dB (SEL) and more than 20dB (SEL) will be presented and discussed.

Keywords: Offshore windfarms, marine piling, transient or impulsive underwater noise, scattering, resonant absorbers, marine construction noise, piling underwater noise attenuation.

1. INTRODUCTION

Hydraulic impact hammers induce considerable underwater sound emissions. The construction noise of offshore wind turbines is potentially harmful to marine life, in particular to marine mammals. Different zones of underwater noise immissions can be defined in the surrounding of a source of acoustic noise. The ranges of zones depend on the hammer types and on possible noise mitigation methods.

Due to larger piles requiring higher driving energies, even higher underwater noise levels are expected in future offshore projects. This is also accompanied by an increasing number of erected offshore wind turbines. Effective noise reducing methods are in great demand, getting sound levels below recommended acoustic emission thresholds that are no longer harmful and disturbing to marine mammals and other protected animals.

2. UNDERWATER PILING NOISE

2.1 Radiation and propagation of piling noise

The generation, radiation and attenuation of underwater piling noise during the construction of foundations such as monopiles, tripods, tri-piles and jackets like the first offshore research platform in the North Sea FINO1 after Figure 1 are studied by numerical simulations and measurements. Most of the piling energy is driven into the sea ground. One part of the whole ram energy of Figure 1 is radiated

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directly from the wet surface of the pile into the surrounding water inducing very high underwater sound levels. Depending on the properties of the ground material one part of the impact energy is radiated indirectly from the sea ground into the water, resulting in additional underwater sound.

The short impact pulse of the hydraulic hammer induces an impact wave in the pile with small radial displacements of the pile surface due to the dilatational waves.. Numerical simulations and measurements of the impacts wave in the pile after Figure 1 and Figure 2 show that the resulting travelling wave is reflected up to several times at stepped cross sections of the pile and at both ends of the pile until all the kinetic energy is damped out and radiated into the ground.

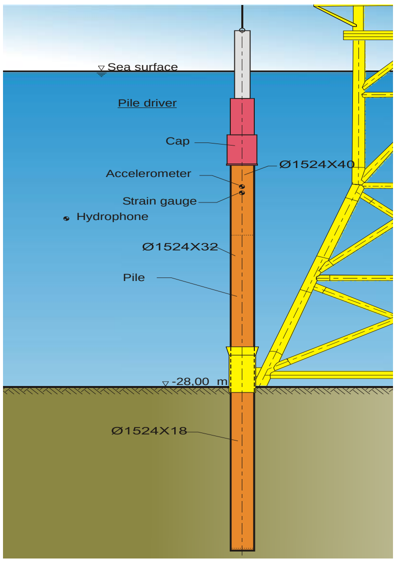

Figure 1. FINO1 foundation and impact energy.,Elmer et. al. (2007

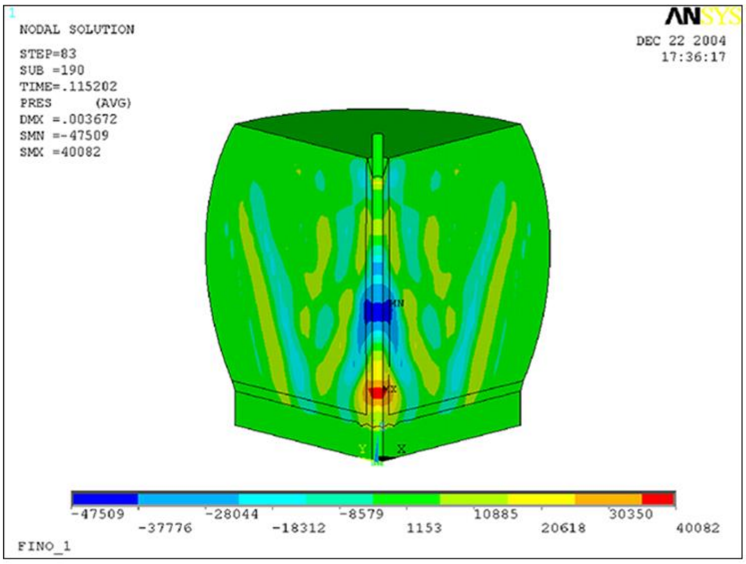

Figure 2. Travelling impact wave within the pile inducing uw-sound waves and reflections, Elmer et. al. (2007

These travelling waves induce sound waves in the surrounding water with an impact pressure of about 10-30 bar. This radiated underwater noise is propagating with the speed of sound of water of about 1500m/s into all directions of the shallow water, reflected at the free water surface and at the sea ground after [1], Elmer et. al. (2007).

The underwater piling noise is usually described by two sound levels. The first level is the peak Sound Pressure Level (peak SPL) in decibels (dB) of the maximum instantaneous positive or negative sound pressure $|p_{peak}|$ of the measured impact noise that is referred to the underwater sound pressure of $p_0 = 1\mu Pa$.

$$peak\ SPL = 20 \log \left(\frac{|p_{peak}|}{p_0} \right) \quad \text{in dB re:} 1\mu\text{Pa.} \qquad (1)$$

The second quantity for describing pile driving underwater noise is the Sound Exposure Level SEL in decibels (e.g. dB re:$1\mu Pa^2 s$), which is an equivalent energy level of the noise of a single pile driving impulse, based on $T_0 = 1s$.

$$SEL = 10 \log \left(\frac{1}{T_0} \int_{T1}^{T2} \frac{p(t)^2}{p_0^2} dt \right) \quad \text{in dB re:} 1\mu\text{Pa}^2\text{s.} \qquad (2)$$

The SEL is the level of a continuous sound with 1s duration and the same sound energy as the pile driving impulse.

Measurements of the underwater piling noise show peak levels of more than 210 dB (SPL) re $1\mu Pa$ and sound exposure levels of more than 180 dB (SEL) re $1\mu Pa^2 s$ at a distance of 750 m from pile driving sites, depending on ram energy and pile size.

2.2 Underwater noise mitigation

Spectral information of pile strokes are given by third-octave spectra of the sound exposure levels (SEL) of three different hydraulic hammers in Figure 3. The highest spectral levels of the measured underwater ram noise of the hammers are shown in the low frequency range from 100 to 300 Hz, responsible to the high broadband level of piling noise.

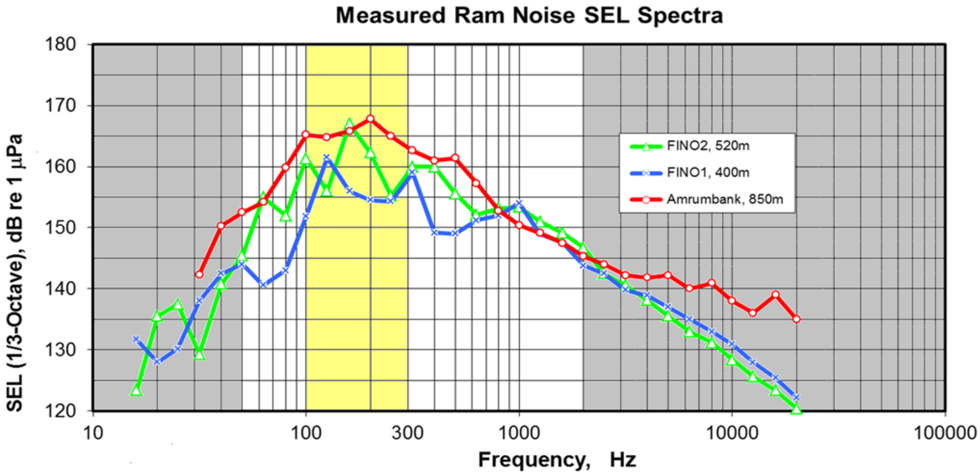

Figure 3: Third octave spectra of measured underwater noise of offshore projects, [2],Betke (2008)

First offshore applications of air bubble curtains achieved only small noise reductions during pile driving operations of the offshore platforms FINO3 as described by Betke (2008). The problems are sound leakage through the bubble curtain resulting from bubble drift with tidal currents. Therefore, the diameters of unconstrained bubble curtains around offshore piling sites are between 140m and 250m.

After Figure 4, the attenuation of air bubble curtains in the high frequency range above 1 kHz is very high. But the broadband sound level of the piling noise mainly depends on the lower frequency noise, far below 1 kHz, where the attenuation from bubble curtains is only poor.

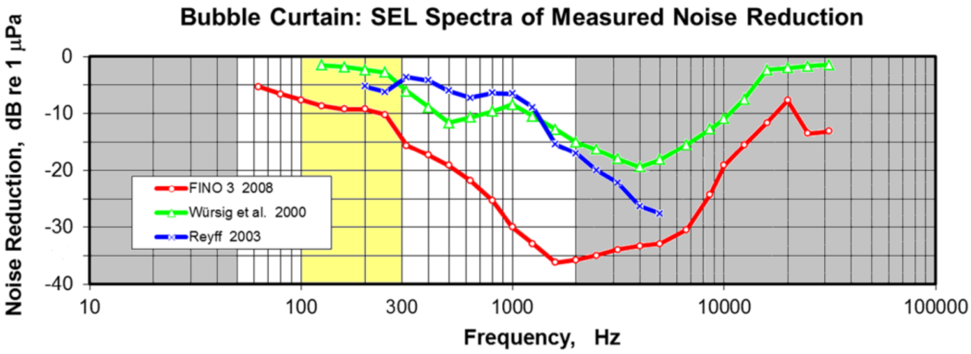

Figure 4: Noise reductions of bubble curtains, [2],Betke (2008).

The reasons for this are, that large air bubbles (several cm) with low resonant frequencies are uncontrolled, showing chaotic movements and dividing themselves when they are slowly arising to the surface of the water. The attenuation of air bubbles is only poor in the most important frequency range between 100 - 300Hz after Fig. 4. Modern hydraulic impact hammers even tend to most important frequency ranges between about 50 - 200Hz.

Offshore applications of air bubble curtains are very expensive at great water depth and currents. The main problems are the compressed air supply, the control of the bubble size, the installation of air pipes on the ground and the influence of water currents together with slow ascent rates of the bubbles.

The German Federal Maritime and Hydrographic Agency (BSH) has set the standard sound exposure level of 160 dB (SEL) and the peak level of 190 dB (SPL) at 750m distance from offshore pile driving sites as part of the building permission of offshore wind farms.

Effective noise reducing methods are necessary to achieve these standard levels.

3. HYDRO SOUND DAMPERS (HSD)

To overcome these problems, a new underwater noise reducing method is developed, as described by Elmer (2010) in [1], using gas filled envelope bodies and PE-foam elements as hydro sound dampers, instead of free natural air bubbles.

The size of the bodies, the effective frequency range, the damping rate, the number and distribution of the hydro sound dampers (HSD) and the influence from hydrostatic pressure can be fully controlled, if the envelope bodies are fixed to a pile surrounding fishing net or to stiff frames.

Figure 5 shows HSD offshore applications as staggered HSD-grids or large fishing nets with HSD-elements round a pile. Systems of hydro sound dampers can also be fixed to the hammer, a piling frame or a gripper after Figure 6. Covering the whole sea in the near of a pile to reduce the indirect noise, transmitted from the ground into the water is another HSD offshore application. The efficacy of HSD in reducing underwater noise depends on the frequency and the volume rate of the hydro sound dampers. Rates of about 1-2% of the HSD are sufficient to obtain good results. At these volume rates vertical forces from buoyancy and horizontal forces from tide currents are still small.

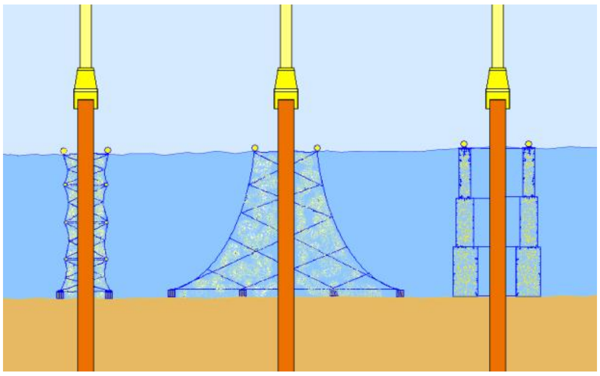

Figure 5: Staggered HSD-net, large fishing net and telescopic frames after [1], Elmer (2010).

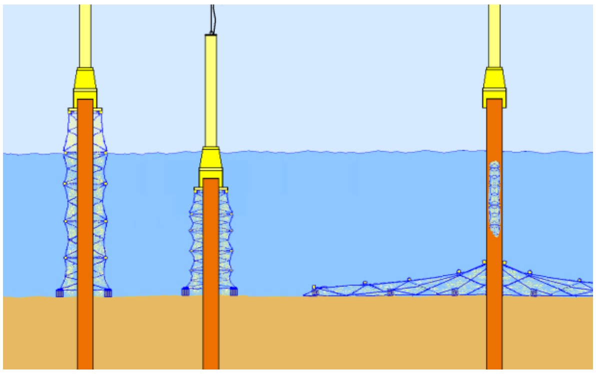

Figure 6: HSD-net fixed to a ram or piling frame or covering the ground after [1], Elmer (2010).

The HSD-system of Figure 7 is a donut-like container, enclosing the HSD-net. It can be fixed below a piling frame, or below the hydraulic ram, or it is swimming round the pile as shown in Figure 7.

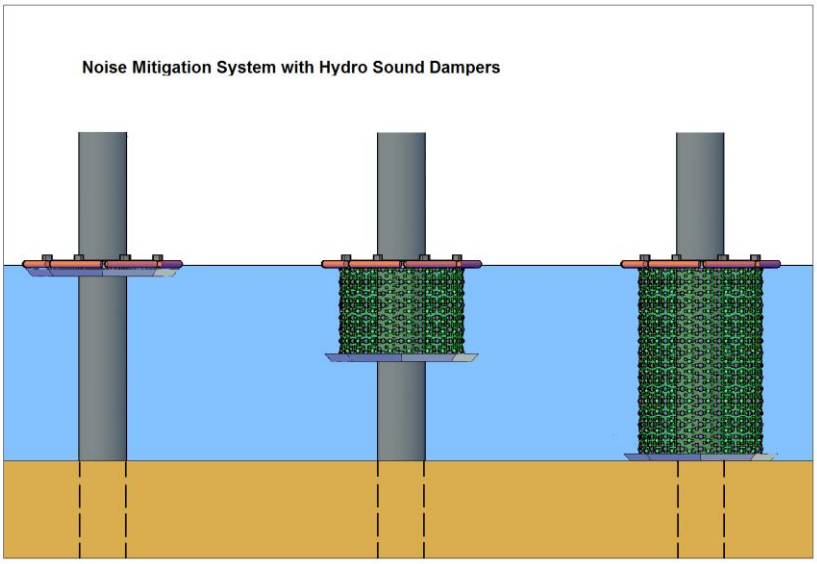

Figure 7. HSD-net enclosed in a donut-like container after Elmer et.el. (2011).

In contrast to free air bubbles of conventional air bubble curtains, hydro sound dampers allow to use three different physical reasons for effective underwater noise attenuation:

- Resonant effects of small air filled balloons and robust PE-foam elements in water can reduce underwater sound up to 35 dB and more as it is known from small air bubbles in water. But the resonance frequency of these HSD-elements is adjustable, even to very low frequency ranges below 100Hz, in contrast to free air bubbles. The resonance frequency is inversely proportional to the diameter of the elements. It is also depending on the gas pressure inside, the water depth and the stiffness of the envelope material.

- Dissipation and material damping effects according to the material damping potential of the envelope material and the filling material inside the HSD-elements. Maximum damping is obtained near the resonance frequency of a damped element, achieving noise reductions between 10 and 30 dB (SEL).

- Reflections of sound waves at impedance steps, as HSD-elements, like air bubbles in water, increase the compressibility of the mixed water-body, decrease the bulk modulus of the mixture and decrease the sound speed and the specific impedance of the mixture very much. These effects result in noise reductions between 5dB and 15dB (SEL).

The important resonant effect with high scattering, multiple reflections and effective absorption of sound waves in the water is to be seen in Figure 8. The very strong interaction of a vibrating HSD-element and the surrounding water is to be seen at the water surface in Figure 8. This interaction also takes place under water as shown in Figure 9, but it is not visible there.

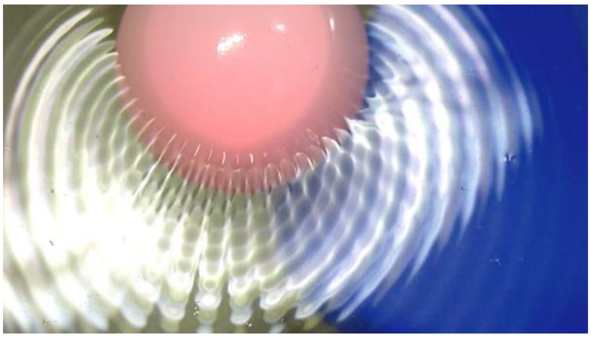

Figure 8. Scattering, radiation and strong interaction of a vibrating HSD, Elmer et.al. (2011).

Figure 9. HSD-net and elements under water.

Hydro sound dampers are used in the whole frequency range of pile driving noise from 50 - 5000 Hz. It is possible to control the damping rate, the size, the number and the distribution of the HSD around the pile. Finally, HSD-systems don’t need compressed air supply.

4. TESTS AND APPLICATIONS OF HSD-SYSTEMS

4.1 “ESRa” offshore test in the Baltic Sea, Germany

Offshore test results in the Baltic Sea confirm the high underwater sound attenuation of both, gas filled balloons and PE-foam elements. The first tested HSD-System is a self-swimming construction of 10t weight after [5], Bruns (2012). All elements are tuned to the resonance frequency of 120 Hz. The net layout with blue colored HSD-elements is to be seen in Figure 10. The radiated noise was measured at 4 m above the ground at a distance of 6 m from the pile to get most of the directly radiated sound and to avoid influences of reflections from the sea ground. Figure 11 shows the SEL spectrum of noise mitigation. There is a very broad noise reduction up to 23 dB (SEL) within the most important range of 100 - 600 Hz after Bruns et.al. (2012).

That means, 99.5% of the sound energy is damped out although the HSD-net is only covered by less than 10% of its surface. Higher frequencies and smaller elements are not tested.

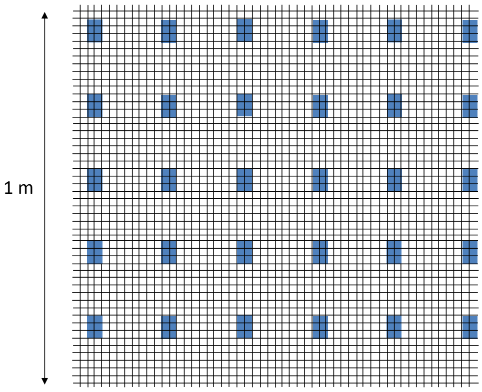

Figure10. HSD net-layout at ESRa-test in the Baltic Sea in 2011, [5].

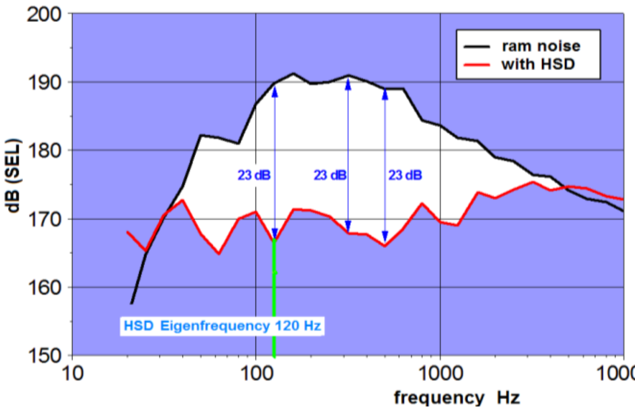

Figure 11. Third octave SEL spectra of underwater piling noise with and without HSD noise mitigation, [5].

4.2 Offshore test "London Array" (GB)

Another offshore test was done at the London Array (LA) wind farm in August 2012 in the North Sea nearby the coast of the United Kingdom. The designed HSD is a self-expanding system with a total weight of only 17t and a diameter of 9 m after Figures 12-14. There are three parts: the buoyancy ring at the water surface, the HSD net and the ballast box. The compressed HSD has a height of 1,8m and is applicable in variable water depth of up to 28m as described by Bruns et. al. (2012) in [5].

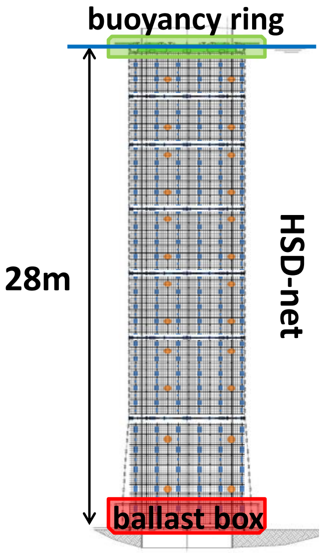

Figure12. HSD-net, LA test,[5].

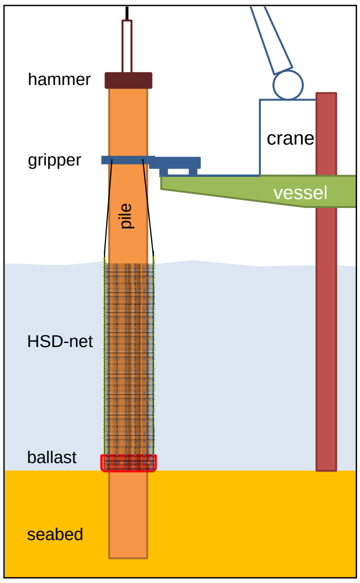

Figure 13. Net below the gripper,[5].

The net layout of LA in Figure 14 shows the same compilation of HSD elements as used before. In addition to that, smaller and larger elements are applied to get a better noise reduction in the frequency range below 100 Hz and higher than 1000 Hz. The underwater sound mitigation in Figure 15 was measured at 1 m above the seabed at a distance of 15 m. Figure 15 shows the 1/3 octave SEL spectrum of the original piling noise and reduced noise with HSD in use.

The impact of the additional applied HSD-elements causes increased reductions up to 21dB between 20-100 Hz and above 1kHz. Again there is a very broad noise reduction of up to 23 dB (SEL).

HSD-systems are already patented in Germany since 2010, international PCT patents are pending.

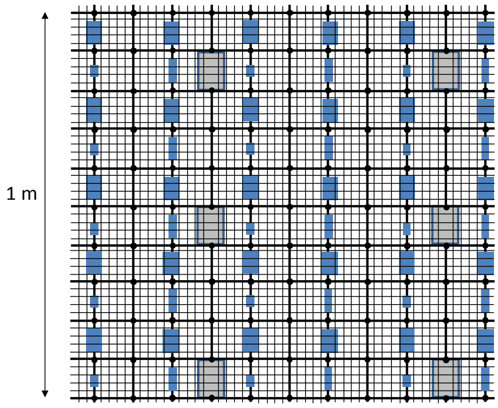

Figure14. HSD net-layout at London Array test in the North Sea in 2012after [5].

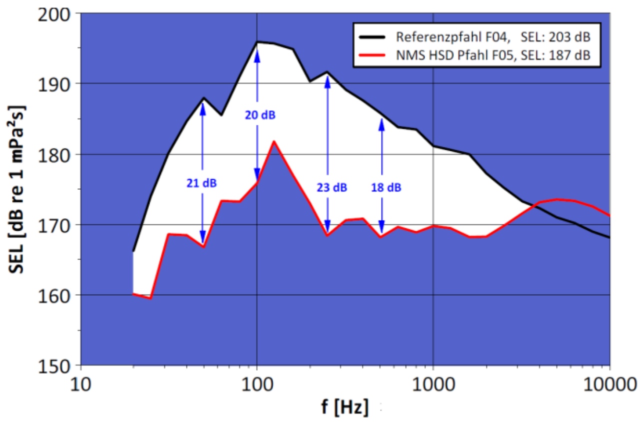

Figure 15. Third octave SEL spectra of underwater piling noise with and without HSD noise mitigation.

4.3 HSD application in offshore windfarm “Amrumbank-West”, North Sea

“Amrumbank West” is an offshore wind farm of the energy supplier E.ON in the German North Sea with 80 wind converters under construction. For the foundations of the wind farm monopoles with the diameter of 6.00m and a length of up to about 60m are used. The water depth is between about 19m and 26m. All monopoles are driven into the sea ground using a hydraulic hammer MENCK MHU 2100. It was necessary to divide the piling process into two phases: The first phase with reduced ram energy, using a gripper and a bubble curtain for noise mitigation. In the second piling phase, without a gripper, high ram energy was used together with a new HSD noise mitigation system around the piles. In most cases both noise mitigation systems are used together.

For this project a new HSD-system was developed together with the hammer supplier MENCK. The MHU 2100S hydraulic hammer and the HSD-system are hanging below the hammer as to be seen in Figure 16 over the pile and in Figure 17 around the pile.

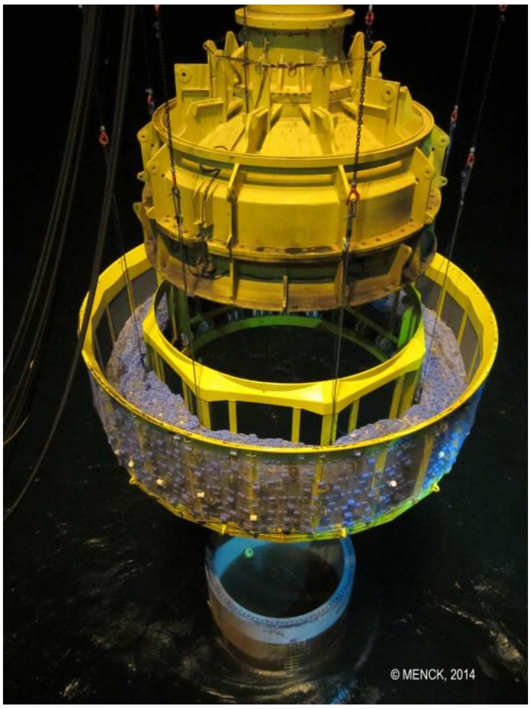

Figure16. HSD-box hanging below the hammer

Figure 17. HSD-box around the monopole

The HSD-box is filled with the folded HSD-net. After lowering the box to the sea ground the net with the HSD elements is rising up to the water surface, covering the wet surface of the monopile.

Figure 18 shows the HSD box with the folded HSD-net inside during a harbour test on the water surface. The HSD-box is hanging on 8 ropes below a winch frame to guarantee an even distribution of the net around the pile.

Fig. 18. HSD-box hanging on 8 ropes.

Fig. 19. HSD-box and HSD-net with 2 layers

The HSD-net of the Amrumbank-West application is similar to the HSD-net of the London Array test with PE-foam elements for the higher frequencies. In Figure 19 the HSD-net is to be seen with an additional second layer of large bladders for lower frequencies of excitation between 50 Hz and 150 Hz of the large hydraulic hammer. The surface of the box is also covered by a net with mixed HSD elements.

The HSD-system works very well and reliably without any disturbance. The first measured HSD noise mitigation results show very good effects of the HSD noise mitigation system of more than 20 dB noise reduction in the most important frequency range between 100 Hz - 800 Hz. All noise mitigation results of the first measuring campaign including measured vibrations of the sea ground are described after Bruns et al. (2014), in [6].

4.4 Application of HSD in coastal ports and harbours, Australia

Over the past ten years or so there has developed in Australia a greater awareness of the need to protect marine environments from the high levels of underwater noise resulting from marine piling[8][9]. Some regulatory authorities have responded by applying guidelines to marine piling[10] whilst other have applied development conditions in response to recommendations from EIS documents[11].

The increase in awareness has been accompanied by a significant expansion of ports and harbours around Australia to facilitate the increased shipping trade related to coal, iron ore, LNG and agricultural exports to Asia, Europe and elsewhere.

The marine piles utilized in ports and harbours are typically up to 2.1m in diameter and are generally driven by impact or vibratory methods.

The pile diameters are less than the offshore marine piles for which HSD was developed and initially field tested. The source levels and dominant frequencies are SPL 180-235 dB re 1μPa and

100Hz and 1kHz for impulsive impact piling and SPL 160-200 dB re 1µPa and 100Hz and 2kHz for continuous vibro-piling. In each instance HSD provides improved noise attenuation compared to air-bubble curtains, particularly for the low frequencies.

The standard approach used by Contractors during marine piling is generally to employ a *piling noise management plan* which specifies an observation and shut-down zone. The separation distances for each of these zones is based upon underwater noise modelling, based upon the source sound power level, the water depth profile, sea floor conditions, and a noise exposure threshold SEL which is based upon the species of cetaceans identified as potential inhabitants of that marine locality. For the proposed major Dudgeon Point coal terminal port in Queensland, the observation area required to protect cetaceans and turtles from the cumulative threshold SEL for 1.5m diameter steel piles and 300 pile strikes was predicted to be approximately 2kms [12].

In some instances the regulatory authorities have specified air bubble curtains to attenuate the underwater piling noise. In some of these cases the contractors have argued against this condition as being an unreasonable impost on the project costs. The condition is considered unreasonable due to the lack of piling contractors with expertise with air bubble curtains in Australia, and the expected ineffectiveness of an air bubble curtain in the presence of strong tidal currents which can occur in ports and harbours during the change of tides. In such cases the marine environment has been protected during marine piling by water-borne observers of the observation zone and shut-down zones around the piling sites. Observation zones may typically be 500m or more around a piling location for un-attenuated pilling.

The standard operational procedures using observers during piling may include pre-start procedure, softstart procedure, normal operation, stand-by operations and shut-down procedures [10]. In each procedure, the presence of marine mammals is visually monitored by a suitably trained observer with resultant actions for delaying or stopping piling if mammals are observed. The problem with this series of procedures is that the observation area can be large and successful implementation relies on the training and skill of the observers, the deployment of sufficient numbers of observers for the duration of the piling program, and the cost pressures caused by delays and stoppages to the piling program. The risk of adverse impacts upon marine life during marine piling can be therefore be much higher than desirable for major port and harbor projects.

The application of HSD has been reviewed by an international marine piling contracting company experienced in ports and harbours in Australia. The company has advised that HSD may be readily deployed using standard marine piling techniques used during piling operations for ports and harbours in Australia [13]. The HSD netting systems required to enclose piles up to 2.1m diameter will be quite small and easy to handle during installation and removal by the piling contractor. The effectiveness of HSD is not affected by tidal currents and the attenuation provided by HSD is not dependent upon maintaining a given separation distance between the HSD net and the pile under strong tidal current conditions.

Attenuation of underwater marine piling noise using HSD is more cost-effective than air-bubble curtains. The use of HSD will reduce underwater piling noise levels, by at least 10 dB and significantly reduce the observation area required during piling operations. The application of HSD to marine piling operations in ports and harbours will therefore provide improved protection of the marine environment from the adverse impacts of impulsive and cumulative underwater piling noise exposure.

5. CONCLUSIONS

The innovative Hydro Sound Dampers (HSD) have been demonstrated to be a cost-effective method of attenuating underwater piling noise in offshore marine piling projects. HSD is also applicable as an effective general method for reducing underwater piling noise in ports and harbours. HSD may achieve reductions of more than 10 dB in underwater piling noise, even in the presence of strong tidal currents. HSD systems are small and easy to handle by piling contractors for port and harbor applications.

The use of HSD will significantly reduce the observation area required during piling operations and provide improved protection of the marine environment from potential adverse impacts upon marine life from impulsive and cumulative underwater piling noise exposure.

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