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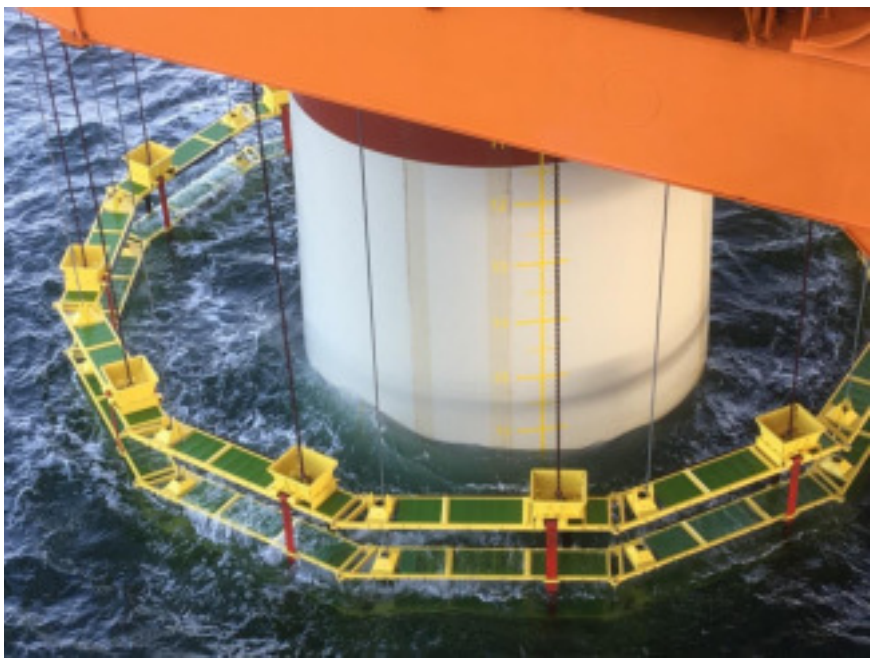
# AdBm Noise Mitigation System 2018 Demonstration Results

Mark S Wochner, PhD



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# Executive Summary

The underwater noise mitigation system produced by AdBm Technologies was demonstrated in late 2018 during pile driving operations in the Belgian North Sea, in cooperation with, and supported by Van Oord Offshore Wind BV who designed and built the deployment system and secured the test site. The Helmholtz resonance-based noise abatement system was deployed and recovered quickly and without incident on five monopiles piles. Data was collected by itap GmbH at nine locations during each pile driving sequence and showed consistent results at all locations.

Significant results from the 2018 demonstration:

1) Attenuation of up to 20 dB $L_{p,pk}$ was measured when coupled with a single big bubble curtain
2) Attenuation of 8 dB was measured from the AdBm system alone, and many places of improvement have been identified for future use
3) Noise was reduced to as little as 161 dB $SEL_{05}$ when used with the single big bubble curtain
4) All known regulations, with the exception of current German regulations, were met with a single bubble curtain
5) Van Oord announced they would be using the AdBm system on Borssele OWF Plots 3, 4 and 5

Although the results were good for a first application of the system, lower than expected performance was seen from both systems and has been attributed to the significant amount of clay found in the soil at the testing locations, and this was verified by computational modeling.

Additional testing was performed in June 2019 at the University of Texas at Austin's Applied Research Laboratories studying various methods of improving system performance. In particular, refilling the resonators with air at their deployment depth, and keeping that system running during testing was studied.

Significant results from the 2019 laboratory testing:

1) Doubling the air in the resonators by refilling them at 10 m depth nearly doubled performance
2) Keeping the air system running during testing greatly increases the system performance at high frequencies and does not affect the low-frequency performance of the resonators

The void fraction of the system, defined as the amount of air trapped in the cups around the pile, may be increased by either increasing the number of resonators around the pile, or by refilling the resonators at depth. It is up to the installation contractor to decide which method best suits their needs.

Based on the demonstration results and laboratory testing, it is reasonable to predict that the modified system should produce at least an additional 6 dB of overall reduction. This modified system will be implemented soon in the field and noise mitigation data will be made available as soon as possible.

## Introduction

The AdBm Noise Mitigation System was tested on a full-scale monopile installation for the first time at an offshore wind farm installation site in late 2018. The test set out to prove both the operational robustness and the acoustical performance of the noise mitigation system. The WTG foundations driven during this test were monopiles ranging from 7.2 m to 7.8 m diameter, which were installed using impact pile driving.

## AdBm System Configuration

The system was designed and built with 36 levels of slat rings, and each slat contained a single radial layer of AdBm resonators. The rings were twelve sided, with a metal framework housing the acoustic resonator blocks. For the results shared below, a slat separation of 0.67 m was used.

Hydraulic winches were utilized for deploying and recovering the system. A control system synchronized the movement of all winches to ensure the system stayed level during deployment, although it should be noted that the system can tilt considerably without it affecting acoustical performance. Winches employed on this project deployed and recovered at a rate of 4 meters per minute. Under normal circumstances it is reasonable to expect 10 minutes for deployment and recovery in 40 m water depths.

Three different sizes of AdBm noise mitigation resonators were used on this project, each designed for a different portion of the water column. The smallest resonators, colored green, are used in shallowest depths, the mid-sized resonators, colored white, are used for the middle of the water column, and the largest resonators, colored yellow, are used at the deepest depths.

## Deployment

The AdBm noise abatement system was deployed and recovered without incident. As can be seen in the photos included in this report, during some deployments there were slats above the water. Normally the system is deployed so that the top slat is positioned approximately one meter below the water surface at the highest tide expected during pile driving.

The maximum current measured during the demonstration was 0.5 m/s. The framework showed minimal motion throughout, and it was concluded that these sea states had no effect on the deployment or performance of the system. Based on these observations, there is little concern of the system contacting monopiles during operations in sea states within vessel operational limitations.

***AdBm noise mitigation system deployed during foundation installation (left) and AdBm system in retracted position, prior to deployment (right)***

## Project Specifics

The water depths ranged from 19 m to 27 m. In situations where the water depth was less than full deployment depth of the system, the extra slats simply stayed stacked at the bottom. The pile diameter for the five piles installed ranged from 7.2 m to 7.8 m.

A single big bubble curtain was employed for this test. The bubble curtain's flow rate was 0.4 $m^3$/m/min. The hose had a total length of 660 m and was deployed circularly around the foundations.

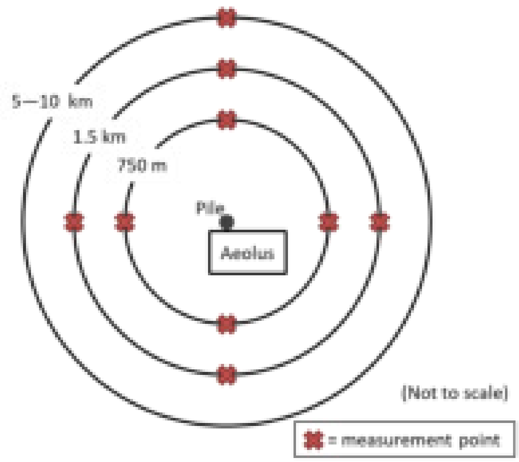
The testing sequence was as follows:

1. Pile driven to pre-defined depth, depending on pile location
2. Pile driven 2 m with no noise mitigation
3. Pile driven 2 m with AdBm System deployed
4. Pile driven 2 m with AdBm System and Big Bubble Curtain deployed
5. Pile driven 2 m with Big Bubble Curtain deployed

The hammer energies were kept constant throughout the test.

## Data Collection

A brief overview of the data collection protocol designed by itap GmbH is provided here. Hydrophones were located in all four cardinal directions at 750 m and 1500 m from the monopile being driven, and a single measurement location was also set approximately 5 km from the monopile.




***Data collection locations for the itap measurements***

At each measurement location there were two hydrophones: one at a depth of 2 m above the seafloor, and one 10 m above the seafloor. The data was collected at 24-bit resolution and a 44.1 kHz sampling rate compliant with ISO 18406 and DIN SPEC 45653, stored with lossless compression.

## Acoustic Results

| Noise mitigation configuration | Slat spacing [m] | Effective noise reduction of the SEL [dB] | Effective noise reduction of the $L_{p,pk}$ [dB] |
|---|---|---|---|
| AdBm | 0.67 | 7 ≤ 7 ≤ 8 | 7 ≤ 7 ≤ 8 |
| AdBm + BBC | 0.67 | 14 ≤ 15 ≤ 15 | 18 ≤ 18 ≤ 20 |
| BBC | 0.67 | 10 ≤ 10 ≤ 11 | 12 ≤ 13 ≤ 15 |

Increasing the void fraction (number of resonators per volume) of the system has consistently shown to be beneficial to system performance, so for future systems it is suggested that void fraction is further increased. In this testing, a maximum reduction of 20 dB $L_{p,pk}$ was measured, and the measured levels at 750 m were 161.5 dB $SEL_{05}$. With these results, it is reasonable to predict that the AdBm system used in conjunction with a double big bubble curtain would meet the German BSH regulations of 160 dB $SEL_{05}$.

## Lessons Learned & Future Improvements

Increasing Void Fraction

Theory and experiment have shown that increasing the void fraction has a positive effect on the overall noise reduction. In order to continue the improvement of this system, it is suggested that the void fraction be increased wherever operationally feasible. For future systems, rather than decreasing the slat spacing it is suggested that the radial thickness of the system be doubled. This would double the absorbing layer of the system, which will significantly increase performance without affecting the stack height of the system.

Refilling Resonators at Depth

Refilling the resonators once they are at depth is another way to increase the void fraction of the AdBm system. Ensuring the resonators are full of air would increase the void fraction by at least 200%, improving the performance of the system significantly. In addition, if the air continues to run near the AdBm system during pile driving, it should further increase the high frequency reduction of the system.

## Laboratory Testing

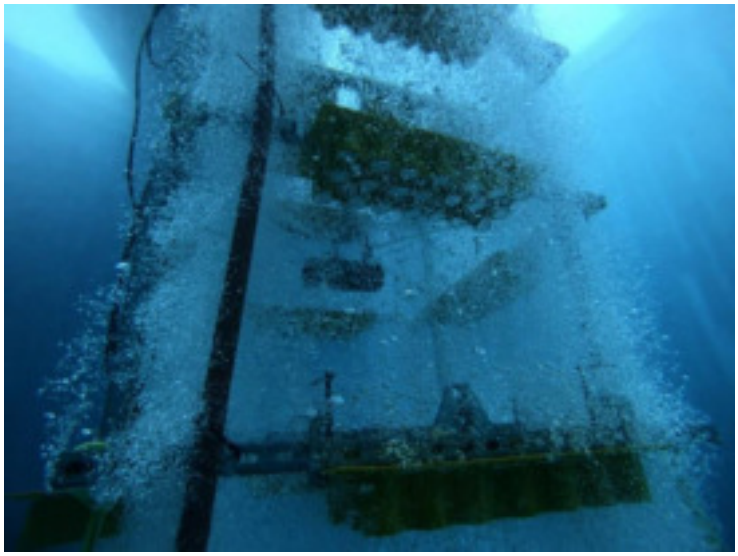
Because of hydrostatic pressure, when the resonators are deployed the air bubble captured inside of them gets increasingly compressed as depths increase. This is taken into account when systems are designed, and for most projects the system is completely passive by default. If however it is desired to keep the system under a certain weight or size, the void fraction can also be increased by refilling the resonators at depth.

In the test, the three resonator models were lowered to approximately a 10 m water depth, where each resonator bubble is about half the volume it would be at the surface. Three scenarios were compared: 1) naturally-compressed resonators; 2) filled resonators; 3) filled resonators and compressed air running.

The test produced the expected results: the filled resonators work better than the naturally-compressed resonators, and leaving the compressed air running does indeed increase the high-frequency reduction. This is very promising, so this methodology will be verified in the field on the next project. The laboratory results are below:

| Level Reduction over Whole Frequency Band (40 Hz to 5 kHz) | Increased Performance when Filled at Depth | Increased Performance with Air Supply Running |
|---|---|---|
| Small Resonators (Green) | 167% | 261% |
| Medium Resonators (White) | 174% | 262% |
| Large Resonators (Yellow) | 187% | 206% |

It should be noted that since this is laboratory testing, the absolute improvements are not going to be the same as in the field for a number of reasons, not least of which is the presence of ground-borne vibration. However, it should also be noted that the increased performance due to filling the resonators may actually be greater than that shown in in the laboratory data because the amount of air in the resonators deployed at greater depths will be more than doubled. For example, at 40 m depth, the air bubble would naturally be 20% the volume of the cup, so filling it would increase the volume by a factor of five rather than a factor of two seen at 10 m deployment depth.



***Photograph of the resonators being filled with air during testing. The results showed the resonators can be filled with compressed air and that the compressed air increases the performance of the system***

Compressed air may not be the preferred method for some installation contractors since the void fraction of the system can be increased simply by increasing the number of resonators. It is however an option that is being offered to customers to provide the greatest flexibility in the use of the system.

## Conclusions

The testing of the AdBm system in the North Sea, in cooperation with Van Oord, has shown very positive results. Combined with only a single bubble curtain, all but the German noise regulations were able to be met. A maximum noise reduction of 20 dB was observed from both the AdBm system and the single bubble curtain, and a maximum noise reduction of 8 dB was observed from the AdBm system alone.

Laboratory testing has shown that doubling the amount of air in the resonators by filling them at depth nearly doubles the reduction, and adding compressed air during pile driving increases the performance further. Since the field testing showed levels around 161—164 dB $SEL_{05}$ with just a single bubble curtain and a low void fraction, it is reasonable to predict that the AdBm system coupled with a double bubble curtain should reliably get noise levels below 160 dB $SEL_{05}$ at 750 m. This new configuration will be implemented soon and data from its use will be made available as soon as possible.

## Acknowledgements

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