Project details

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Project Information

Summary

As a response to the increasing concerns regarding underwater noise during offshore operations, especially pile driving, noise restrictions are set by multiple governments.

The industry needs to develop technology to reduce the underwater noise.

The goal of this project was to demonstrate a novel Noise Mitigation System (NMS) with technology developed by AdBm. This new technology should contribute to a reduction in costs in the construction of offshore windfarms relative to existing systems. Furthermore a numerical model was made and validated in order to forecast performance and optimise the system.

The project has been delayed with 3 years but has given very good results:

1. Predictable noise reduction performance of the AdBm system.
2. Noise prediction model that gives an indication of the relative performance of near and far field noise mitigation systems.
3. Useful data and modelling results on the performance of air bubble curtains.
4. A robust design of the deployment system for future use under offshore conditions.

The initial hope was that the noise reduction would be sufficient to eliminate the use of a big air bubble curtain next to the NMS. Modelling by TNO has however shown that the energy travelling subsurface (passing the NMS through the soil) is very significant and that a far field noise barrier will be needed to comply with imposed noise limitations.

Introduction

Until 2018 the piling season in the Netherlands was restricted to 6 months and only one park could be installed per piling season putting a significant restriction on the amount of GWs that can be installed in the coming years in Dutch waters. The recent Dutch permits for the Borssele concessions incorporate maximum noise levels that are subject to both piling intensity and timing.

AdBm has developed a new Noise Mitigation System (NMS). The system consists of hollow chambers containing trapped air that act as Helmholtz resonators. Helmholtz resonance is a resonance phenomenon that is dependent on factors such as the volume and the area of the opening of the resonating cavity.

These resonators are attached to slats which are interconnected by tension wires. The whole system lowers down to the seabed level similar to a Venetian blind system.

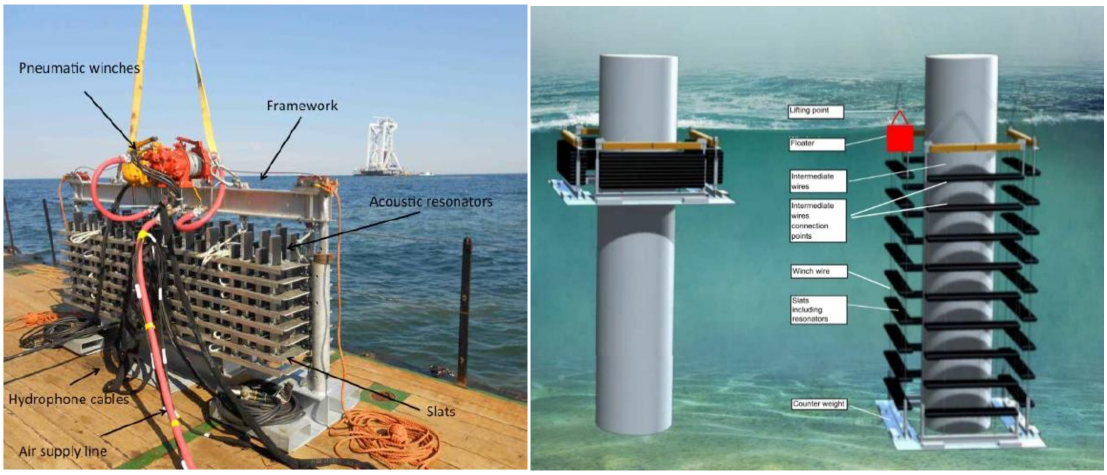
Small sized tests had already been executed in Texas to test the effectiveness. Measurements during a test with a small size (demonstration panel) of the screen developed by AdBm and deployed in offshore wind projects Butendiek and Luchterduinen were promising.

However, the system needed to be tested in full scale for the following reasons:

- In the demonstration panel test the pile noise is mitigated at distance and not at the source

- In the demonstration panel test noise was measured within the screen

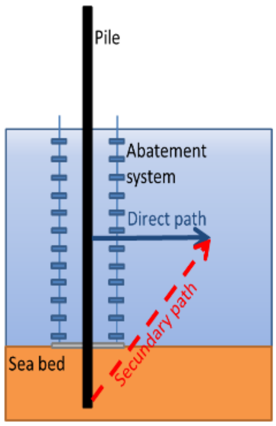
- The effect of sound emission through the soil is not fully understood



Demonstration version of the NMS (as applied on Butendiek and Luchterduinen) The full scale system as it was anticipated to be used in this project is shown on the right.

For optimal use of the NMS, the system should be tuned for the situation under interest, making sure that the mitigation effect is strongest for those frequencies at which most sound is produced. This depends on not only on parameters of the monopile, but also on the environment in which the pile driving will take place.

Besides the configuration and design of the hollow chambers, the mitigation effect of the screen also depends on leakage of sound energy through the seafloor back into the water column. The presence of the NMS only reduces the direct sound transfer path through the water. The sound path through the sediment is not attenuated (see figure below). Both for creating the optimum configuration for the screen as well as for estimating the total mitigating effect, a numerical model is needed.



Schematic overview of the direct sound transfer path through the water and the secondary path through the sea bed.

Objectives

The project objectives were the following:

- To test the NMS in a full scale environment. This should confirm that the screen is able to meet the required noise level as set in Germany and potentially used for Dutch offshore wind farms. (With or without combination with an air bubble screen)
- To develop a numerical model with which an optimum configuration for the screen can be found, depending on the frequency dependent underwater noise emission from the pile during pile driving.
- To validate the numerical model in combination with a source model for the underwater noise emission of the pile.
- To get certainty on the deployment method of the NMS.

Approach

Numerical Model

TNO has developed a numerical noise prediction model for offshore piling noise in an earlier research project for the Ministry of the Environment and Transport. This model consists of two parts. The first is a detailed model of the underwater sound generated by a pile driving blow and the propagation of this sound through the water and sediment relatively close to the pile (< 750m). The second part models the propagation of sound in the water and in the sediment at larger distances from the pile. With the combined model the absolute underwater noise levels at various distances from the pile driving site can be predicted, given a certain blow energy for each pile driving blow.

In order to carry out a feasibility study of the NMS, the TNO model for offshore piling noise needed to be extended with a model of the noise abatement measure. By predicting the noise reduction that can be obtained with such abatement systems it becomes possible to assess beforehand if the resulting noise levels are likely to comply with governing legislation. Or, alternatively, if the abatement measure can be adapted to comply with future legislation, for instance by altering parameter settings like tuning frequency of the absorbers of the noise abatement system.

An important aspect in assessing the optimal performance of abatement measures in the water column, is that they only mitigate the direct sound transfer path through the water. The sound path through the sediment is not attenuated. This limits the maximal effect that can be obtained with the abatement measure. As the acoustic model can also be used to estimate the amount of sound propagating through the water column versus that in the sediment, a realistic prediction of the attenuation through the abatement measure can be made.

In the current TNO model for marine pile driving the soil is modelled as a fluid, which means that shear effects are neglected. This seems a good assumption for very soft soils like in the North Sea. To make the model more generic and compliant with regulations of the German Bundesamt für Seeschifffahrt und Hydrographie (BSH), elasticity effects of a solid soil were also modelled up to 750m distance from the pile. It was verified that coupling the detailed model including elasticity of the sediment with a propagation model for larger distances that does not include elasticity at an appropriate range yielded satisfactory results.

A numerical model of the NMS system was constructed and coupled to the existing TNO pile driving noise model. The effect of a big bubble curtain has also been implemented in the model assuming an approximation that is suitable below bubble resonance. This is desired since the BSH uses the piling noise emitted by pile driving with big bubble curtains as a reference situation to assess the performance of the noise mitigation measures.

After the measurements, the expected noise levels and spectra of the reference pile driving (without any mitigation measures) and with mitigation measures (both NMS and big bubble curtain) were predicted for the test-site. Also, the flow of acoustic energy through the water column and the water/sediment interface were predicted.

Acoustic Resonators

The AdBm system uses Helmholtz resonators which are tuned to absorb sound in a chosen frequency band. The resonance frequency of these resonators can be tuned by modifying the shape, size, and materials used to produce the resonators, allowing the system to be tailored to the specific needs of a project. For most current offshore wind farm projects, peak noise levels occur around the 100-300 Hz band of frequencies, so if regulations use unweighted sound exposure levels as their metric, it is desirable to produce resonators which optimally reduce noise in that frequency band. If in the future regulations target particular frequency bands to protect specific animals, the resonator design can be modified to accommodate this type of regulation. These properties make the use of Helmholtz resonators very desirable for offshore applications.

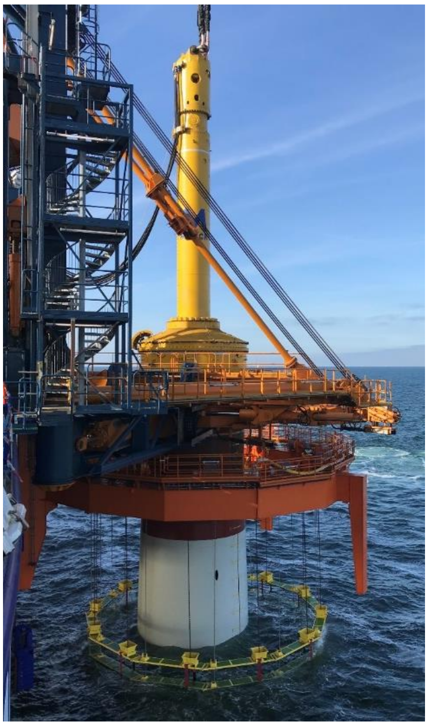
For this demonstration project, the Helmholtz resonators in the system were produced by AdBm Technologies using injection-molded high-density polyethylene (HDPE), making them fast to produce and very durable. Each resonator block consists of many Helmholtz resonator cups which go into the water with their open side facing downward so that air is trapped inside each cup as the system is submerged. Once they are in place around the noise source, the resonators passively absorb noise. For pile driving applications the system is designed to be supported underneath a pile gripper or template and kept there for the duration of the installation process. For destructive applications in which the resonators may be damaged or destroyed, it is also possible to manufacture sacrificial Helmholtz resonators out of metal alloys which quickly corrode in seawater.

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. Due to the fact that this deployment was from a jack-up vessel, “transition zones” were created in order to account for tidal variations which can change the deployment depth of the slats during a single pile driving session. These transition zones were simply a mix of two different sizes, installed in an alternating pattern. A photograph of the three different resonator blocks is shown below.

Design and construction of the deployment system

Van Oord designed and built the deployment system for the AdBm resonators.

The system was deployed offshore from the Offshore Installation Vessel Aeolus. The design of the NMS and the lifting frame was done in such a way that the vessel can operate independently of smaller auxiliary vessels, which was beneficial for the workability.



Impressions of the deployment of the system mounted on the Jack-Up vessel Aeolus

Project results

Generic results relative to project objectives

To test the acoustic insertion loss of the NMS a total of five monopile locations were selected at a wind park under construction. To ensure the tests were executed to the highest scientific and industry standards, all tested scenarios were performed under the DIN SPEC 456532017-04 standard. The standard stipulates a methodology for ‘direct’ and ‘indirect’ testing. Indirect testing consists of the selection of one monopile location as a baseline which is then compared to numerous scenarios tested at different monopile locations. This is often preferred from an operational perspective as one test per location minimizes the chance of operational down time. A ‘direct’ testing method entails testing several test variables on a single location.

All tests in the current study were executed under the ‘direct’ testing regime. The ‘direct’ method was chosen to eliminate influence of unwanted variables as much as possible. For instance, the monopile diameter and wall thickness (as a function of depth), which have a large influence on the radiated underwater sound, may vary per test location, but here are guaranteed to be constant through the application of the ‘direct’ test method. Piling energy, another major factor that characterizes the radiated sound, was kept constant during the test for each test location.

The penetration depth of the pile during measurement was determined for each location by the availability of an 8 m stretch of constant soil properties through which the pile tip penetrates during the test. Using this criterion, the influence of different soil layers on the underwater sound was eliminated as much as possible. To avoid sound interference of small air bubbles remaining in suspension after BBC activation, the BBC was not activated while piling to the test penetration depth. An additional advantage of the 'direct' method is that it yields a performance indication per measured pile location. Compared to the 'indirect method' which requires measuring at multiple pile locations for a single performance indication, this leads to a much larger scenario sample size, and helps to assess the spread in the expected performance of a mitigating measure.

A total of four scenarios were tested on each pile and each scenario was tested for a penetration depth of 2 meters. This penetration depth typically results in around 200–250 blows per scenario. This amount is sufficient to reliably assess the underwater sound resultant resulting from each scenario. The four scenarios were set up as follows:

- **Scenario 1 – Benchmark test: No Noise Mitigation**
  The benchmark test was used to determine an unmitigated baseline measurement. At each test location this scenario functioned as a benchmark to determine the insertion loss of the other three scenarios.

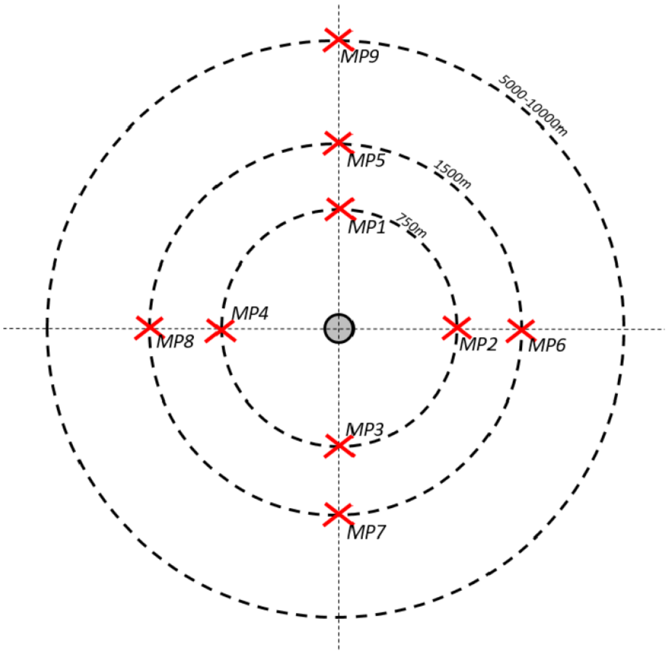
- **Scenario 2 – NMS: NMS only**
  The NMS was lowered to establish the mitigation compared to the benchmark scenario.

- **Scenario 3 – NMS & BBC: Both NMS & BBC system active**
  This scenario tested the mutual effect of the NMS system when deployed together with a BBC.

- **Scenario 4 – BBC system active**
  Scenario was used to test the BBC by itself in order to determine any differences in frequency-dependent insertion loss. The NMS was retrieved prior to this test scenario.

Initially three test monopiles were planned with a slat spacing of 1 m on the NMS. However, due to the availability of time and additional slats, the decision was made to increase the void fraction of the system and test it on an additional two monopiles with a slat spacing of 0.67 m. As a result a total of 5 monopile locations were tested under the NMS test program.

Monitoring of the underwater sound produced during the tests was also executed under the guidance of the DIN SPEC 456532017-04 standard. Sound measurements were executed in four cardinal directions from the piling locations. Every directional spread consisted of a measurement location at distances of 750 m and 1500 m from the monopile. Each measurement location features two hydrophones: one hydrophone 2–3 m above the seabed and one hydrophone at 10 m above the seabed. An additional measurement was also executed from a stationary measurement buoy located between 5,000 m and 10,000 m from the piling location (for the first three piles only). This measurement set up is schematically indicated in the figure below.



Schematic overview of the NMS measurement set-up around a monopile

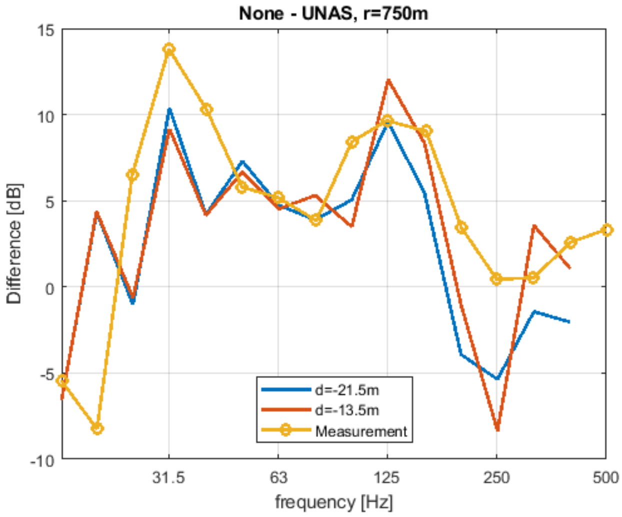
The test results are summarised in the table below which shows the insertion loss results, which is the actual noise mitigation compared to the baseline test.

Insertion loss results

Test phase	Test Scenario	Slat spacing	Effective noise reduction of the SEL [dB]	Effective noise reduction of the $L_{p,pk}$ [dB]
1	AdBm	1.00 m	5 ≤ 5 ≤ 6	5 ≤ 6 ≤ 6
	AdBm + BBC		10 ≤ 11 ≤ 11	12 ≤ 12 ≤ 13
	BBC		7 ≤ 8 ≤ 8	9 ≤ 9 ≤ 10
2	AdBm	0.67 m	7 ≤ 7 ≤ 8	7 ≤ 7 ≤ 8
	AdBm + BBC		14 ≤ 15 ≤ 15	18 ≤ 18 ≤ 20
	BBC		10 ≤ 10 ≤ 11	12 ≤ 13 ≤ 15

Noise prediction model

With the combined numerical model of the pile drive noise generation and propagation and noise mitigation measures (NMS and big bubble curtain) the noise levels were modelled up to a distance of 5 km from the piling site. The modelled insertion loss of NMS has compared to the measured insertion loss, see Figure 1. The increase in measured insertion loss around frequencies of 125 Hz effect is the target tuning frequency of the resonators is predicted well. Also the additional low frequency peak in the insertion loss a observed from the measurement results is predicted by the model.

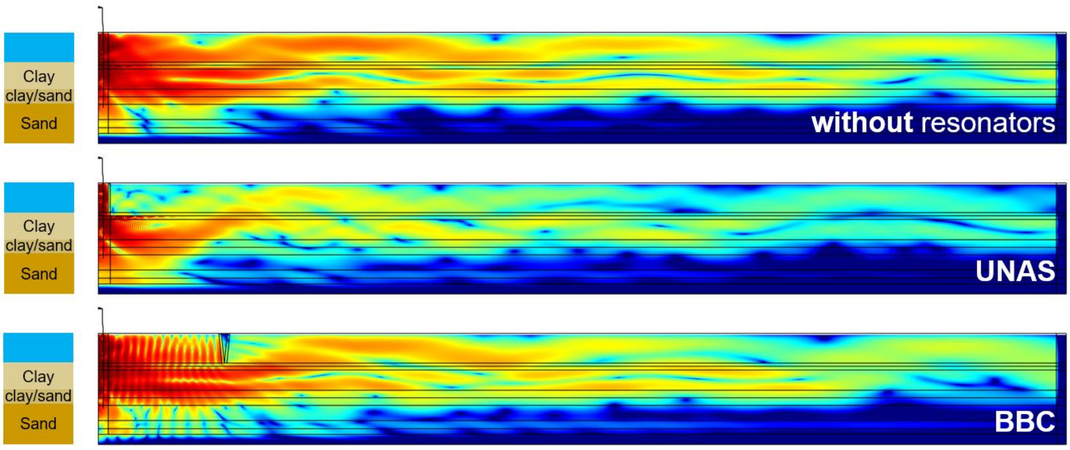


Measured and calculated insertion loss of NMS at 750m distance in deci-decade bands. Yellow lines and markers indicate measured insertion losses, blue and red modelled losses (blue line: at 21.5 m depth, red: at 13.5m depth).

The sediment has been modelled as various layers of clay and sand, each with their own acoustic properties. This allowed to study the sound travelling through the sediment, which cannot be mitigated by either NMS or the bubble curtain, as they mitigate in the water column. The figure below shows that the model indicates that on the selected test site the presence of soft clay layers result in leakage of piling sound through the sediment underneath NMS and BBC, limiting the observed performance.

The simulations show:

- Acoustic performance of near-pile noise mitigation systems may be limited by sound that travels underneath the system through the sediment and back into the water at a distance;
- There is less reflection of sound by ‘softer’ soils such as clay, when compared to ‘harder’ soils such as sand;
- This leads to more prolific ground-borne sound dispersal in ‘soft’ soils compared to ‘hard’ soils;
- Ground borne noise is almost impossible to mitigate using the current NMS systems which are dedicated solely to the water-borne path.



Calculated radiated underwater noise in the water column and sediment layers, up to 750m range.

Discussion

Thorough preparation resulted in a smooth offshore test operation with no unforeseen issues or delays for the first deployment of the system. The 'direct' test methodology has resulted in the desired comparability between the different scenarios and has minimized bias from soil characteristics, pile diameter, or driving force between scenarios. Some points of improvement in the NMS configuration were identified after the first test set. An increase in the concentration of resonators in the NMS increases the void fraction of the system. Laboratory testing has shown that this would lead to greater insertion loss and this hypothesis was confirmed by the results of the second test set. In fact, the second test set yielded an increase in average insertion loss of 3 dB SEL_1 and $L_{p,pk}$. This change is particularly visible in the 125 Hz frequency band for which the resonators were designed. Modification of the BBC configuration also generally resulted in an increased sound insertion loss. The changes made to both the NMS and BBC led to a final insertion loss capacity of 14 to 15 dB SEL and 18 to 20 dB $L_{p,pk}$ when both systems were deployed simultaneously.

The sound reduction observed for the NMS + BBC scenario during the second test set demonstrates that the combination of systems are an adequate option for sound mitigation for the studied Offshore Wind Park (OWP). The underwater sound limits at certain Dutch OWP, where the sound limit varies between 159 and 172 dB SEL_1 re 1 μPa^2s at 750 m dependent on season and development size, may be met depending on the actual applicable limit value. On the selected test site, the German limit cannot be met using the current NMS + BBC configuration, although the addition of a second BBC, which typically reduces 3 dB SEL and 3 dB $L_{p,pk}$, may lead to a reduction where the sound limit of 160 dB SEL_{05} can be met. Further modifications to the system and additional field tests are required in order to demonstrate that these more stringent limits can be met consistently. The current NMS + BBC scenario is also likely to comply with limits currently in place in other countries such as Denmark and Belgium, although this conclusion is based on some extrapolation of our data and out of the scope of this research.

It must also be noted that these assessments of the compliance of the NMS and NMS + BBC configuration as discussed above are based on a maximum driving force of 2250 kJ. With driving forces of large monopiles in hard soil conditions upwards of 3500 kJ the baseline sound level is likely to be higher, and the resulting acoustic energy spectrum at 750 m is likely to be different than for the blows considered in this study. The current tests cannot be used to show what the performance of the NMS will be for the acoustic energy spectra produced by these driving forces. Driving forces of 2800 kJ were envisaged for Location 2 however due to weaker soil conditions than anticipated this was brought down to 2250 kJ. As it stands, the insertion loss observed for the NMS and NMS + BBC configurations during the second test set approaches the insertion loss of most currently available established noise mitigation systems. However, in light of increasing monopile diameters and required driving forces, further optimization and performance increase is required to comply with the most stringent current regulations. In order to assess acoustic performance and reproducibility of the performance, additional deployment and performance monitoring of the NMS system at future projects is desirable and recommended.

The modelling results show the sediment layer properties strongly affect the propagation of sound through the water and sediment. At the selected test site, the top layers consist of clay. Since the model suggests that clay and water layers do not differ much acoustically, these layers behave mostly as a single medium. As a result, much of the acoustic energy is carried by the clay layer and not attenuated by both NMS and BBC.

For a sediment setup where the top layers are more reflective, the observed overall acoustic performance for both NMS and BBC would have been higher. However, the baseline noise levels would also have been higher in this case.

Conclusion and recommendations

While this first full-scale field test already establishes the NMS system as an operationally mature system which is ready for deployment, a number of further development steps can be taken for the future. From an acoustical perspective the simplest way to improve the performance of the NMS is to increase the void fraction. This can be done by doubling the radial width of the system by using slats with two resonators per slat width rather than just one. From an operational perspective, the advantage of this approach is that it will not increase the stack height of the system but substantially increase the performance of the system. Filling the resonators with air so that they are completely full of air at depth is another potential improvement. Full resonators at depth would approximately triple the void fraction with no modifications to the system required other than providing a source of compressed air. Filling the resonators can potentially increase the overall dB SEL reduction by 5 dB or more according to recent effective medium modeling. The compressed air source on deck required to fill the resonators could also be used to supply a near-pile bubble curtain. Near-pile bubble curtains have shown a positive effect on the overall performance of the system in laboratory settings. The resulting insertion loss and effect on the mitigation bandwidth of the system is to be confirmed through additional field testing. The inference that for the selected test site a large part of the acoustic energy travels underneath the NMS system through the sediment layer shows that there is an urgent need for better knowledge of acoustic sediment parameters in order to consult on how to employ mitigating measures successfully. The strategy leading to optimal mitigation can be different for each site, depending on the sediment composition and properties.

Expected spin off and future activities

Future smaller scale tests under lab conditions will be helpful to test the effect of for example void ratio or resonator size and to validate modelled performance. This will result in improved performance of the system on future projects. Some of these additional tests are presently being performed by AdBm and the results will be used to improve the system for use at the projects Borssele 3, 4, and 5.

As a spin-off of the prototype deployment system developed for the demonstration Van Oord has been able to build a full scale deployment system which, with a few modifications, is very suitable for full operational use in large projects.

With respect to noise propagation modelling it is expected that future research will include research on the effects of soil stratigraphy and acoustic sediment parameters in order to better design the near and far field mitigating measures successfully.

The demonstration has provided increased understanding of the noise mitigation performance of air bubble curtains which will lead to further research with sector partners to predict and improve the performance of air bubble curtains.

Publications in the public domain.

The results of the test have been published in a paper for the Offshore Technology Conference (OTC) in Houston.

Manuscript Title: Installing Offshore Wind Turbine Foundations Quieter: A Performance Overview of the First Full-Scale Demonstration of the AdBm Underwater Noise Abatement System.

By: Jesper Elzinga Van Oord Offshore Wind, Arjen Mesu Van Oord Offshore Wind, Erik van Eekelen Van Oord Offshore Wind, Mark Wochner AdBm Technologies, Erwin Jansen TNO Netherlands Organization for Applied Scientific Research, Marten Nijhof TNO Netherlands Organization for Applied Scientific Research

The paper was presented at the OTC in May of this year and can be procured through the following portal: https://www.onepetro.org

Other presentations were given at:

Windforce 2019 conference in Bremerhaven on the 21st of May

Winddays 2019 conference in Rotterdam on 12 June

Elaboration on the contribution to the targets of the Nationale Regeling EZ-subsidies

In the coming 10 years about 35 to 40 GW of windpower is planned to be installed in Europe. That is approximately 7,000 foundations of which the majority will need pile driving for installation.

Permits in most countries require noise mitigations systems to reduce underwater noise from pile driving.

The benefit for society of developing effective noise abatement systems:

a) A sufficiently high rate of installation can be achieved within acceptable underwater noise levels, for the Netherlands this means that more power can be installed in a shorter period.
b) A system that is effective and that can be easily deployed will have limited effect on Levelized Cost of Energy (LCOE) whilst limiting negative environmental effects.

The results of this project in the light of a) and b) is that the tested system has proven to be robust and predictable and will contribute to lowering of underwater noise levels. The performance of the system is comparable to those of other systems.

The deployment of the system under relatively adverse sea states is a big advantage over some of the other available systems. Further improvements of the system are likely to be achieved.

It is therefore expected that reduction of LCOE by using this system can be achieved in the near future.

The cooperation with TNO has resulted in better fundamental understanding on the effectiveness of underwater noise mitigation systems. The know how developed by TNO on how to model near and far field noise mitigation and the propagation of noise through the subsurface and water column can be used to further develop improved modelling software for the entire sector subject to the restrictions of IP owned by TNO. This will also contribute to a further reduction of the costs of noise mitigation (and LCOE) in future wind parks.