Noise mitigation during pile-driving on a jacket
Description of the Company:
Heerema Marine Contractors (HMC) brings more than 50 years of specialized skills to the offshore oil and gas industry. Oil and gas companies rely on Heerema Marine Contractors for full offshore field development in the toughest of environments in all the seas of the world. We build long-term client relationships by solving what looks like impossible challenges and by delivering on our promises. Innovation and ingenuity are key to our success.

Services
Heerema Marine Contractors transports, installs, and removes all types of offshore facilities, including fixed and floating structures, and subsea pipelines and infrastructures in shallow, deep, and ultra-deep waters. From its headquarters in Leiden, HMC commands the entire supply chain of offshore construction, from design through to completion. Our services include engineering, planning, logistics, project management, and execution of projects all over the world. We are proud of our top expertise in project management and engineering, our passionate workforce, and a fleet that includes formidable heavy-lift and deep-water construction vessels.

QASHE policy
Heerema Marine Contractors values high standards in Quality Assurance, Safety, Health and Environment (QASHE) as much as technical excellence. QASHE is aimed at preventing harm to people and the environment they work in. Being careful is an essential aspect of our business operations both onshore and offshore.

HMC’s approach to QASHE is based on an integrated management system. Our employees can access QASHE manuals and tools online and apply them in their daily work. This management system allows us to offer our clients the reliable service they expect and assures them that compliance with QASHE standards is an integral part of the tender and project phases of our work. We guarantee that our suppliers meet our QASHE standards.

We expect all our employees to show commitment and demonstrate visible personal leadership in QASHE.

Environment
We measure the environmental impact created by our assets and activities and set annual targets for the continuous improvement of our environmental performance and prevention of pollution. To achieve this, we pay special attention to:
- minimizing physical damage to the environment and disturbance to flora and fauna;
- minimizing exposure of the environment to harmful materials;
- using environmentally friendly materials where available and reasonably practicable;
- optimizing energy usage by developing and implementing efficient procedures and equipment;
- eliminating or reducing waste at the source;
- optimizing waste recycling.
Background of the environmental issue

Man-made or anthropogenic noise in the marine environment has increased over the years, due to an increase in shipping and other human activities that involve sound producing equipment, like windmills, pile-driving hammers, seismic surveying, etc. Until recently, it was assumed that the effect of man-made sound at sea was negligible, and, if produced occasionally and locally, would not affect the marine environment significantly. But growing knowledge on communication and localisation methods of marine life, and recordings of anthropogenic noise sources at sea, have led to a better understanding of the adverse effects on marine mammals, and resulted in an EU directive on acoustic pollution allowed in its marine environments.

Legislative frameworks are being developed throughout the EU, regulating the allowable ‘acoustic pollution’ by offshore pile-driving operations. At present, the German Sector of the North Sea has the most concrete and stringent guidelines on allowable broadband sound levels, which are defined at a distance of 750 m from the source (i.e. pile driving location):

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\begin{align*}
\text{SEL (Sound Exposure Level)} & \text{ max. } 160 \text{ dB re } 1 \mu\text{Pa}^2\text{s} \\
\text{SPL}_{\text{peak}} \text{ (Sound Pressure Level)} & \text{ max. } 190 \text{ dB re } 1 \mu\text{Pa}^2
\end{align*}
\]

These levels are defined by the German Umweltbundesamt (UBA, Federal Environment Ministry) and Bundesamt für Seeschifffahrt und Hydrografie (BSH, Federal Ministry for Shipping and Hydrography). In addition the UBA advises to ensure that no marine mammals are present within that 750m radius from the piling.

HMC became aware it was a contributor to potential harmful sound at sea in 2009. On this project it was first acknowledged that pile driving had an adverse effect on marine life and company had mammal observations scheduled from an airplane before pile-driving could start.
A mammal observer came on board to scan the sea surface for marine mammals and to listen to underwater communications. The latter has been a regular visitor to all our vessels since then.

*Description of the initiative*

Although regulations oblige our Clients to reduce their impact to the environment, HMC considers it beneficial to actively cooperate in developing sound reduction measures during offshore installations. It is in the interest of the transport and installation contractor to develop installation methods that minimize impact to the environment, while remaining operationally viable and commercially attractive to our Clients. Pile-driving has been considered to have significant environmental impact and was therefore chosen to be the main focus of our noise mitigation program.

In the offshore industry, constructions are designed under specific technical and economical requirements. In relatively shallow water, the majority of the platform designs comprise of piled platforms, either main pile or skirt pile jackets. Heerema Marine Contractors was aware it had to concentrate its noise mitigation efforts on the standard designs of skirt and main pile jackets, to be able to effectively contribute to reducing sound at sea. Then, when able to indicate how best to reduce sound during pile driving, design houses may use this knowledge to further develop jacket pile design to allow the noise mitigation measures on a larger scale.

Figure 2 – Main pile jacket (left) and skirt pile jacket (right) during pile-driving
The technical problem at hand

To reduce sound produced by pile-driving, it is important to first understand how sound is produced by the pile in its environment. In the figure below, a sketch shows the shock wave going through a pile after the hammer anvil hits the top. A local expansion of the pile surface produces lateral vibrations, which are transmitted into the water volume around the pile. It is this vibration that is propagating through the sea over a large distance that is potentially harmful to marine life. A second wave effect takes place as the pile is penetrating into the seabed and produces vibrations that are being re-transmitted into the water volume around the place where the pile is driven. This seabed-borne sound can enter the water at various distances from the pile, being the effect of reflections on deeper sediment layers in the seafloor. This is believed to propagate less far, as the transmission of vibrations from pile to seafloor, reflecting on a sediment layer and being transmitted back through the seabed into the water absorbs part of the energy. But it is sound that is propagated ahead of the direct shock wave depicted below, as sound travels easier through sediment than through water.

HMC has concentrated on technical measures that can be taken to reduce sound produced by the pile deformation as the hammer’s anvil hits on it.
Solution to the problem

Knowledge of sound and its propagation in media quickly triggered the idea of shielding this shock wave with a gaseous layer, as a lower density layer would absorb more energy from sound transmission.

A vacuum between source of sound and the environment would completely hush the source, but is very hard to achieve, especially in a subsea environment, where hydrostatic pressure will work against the subsistence of a vacuum.

HMC thought of trying the easiest technical application to achieve this: a double walled sleeve around the pile, filled with air. For skirt pile installations a sleeve would need to be added to the piling construction, since it does not contain a natural casing around the pile that can be filled with air. Since a pile-driving operation under water demands close monitoring, remotely operated vehicles (ROV’s) are used that follow the hammer sleeve as it moves over the pile under water. Anything built around the pile could hamper this monitoring task that is crucial to a safe installation.

The best installation project to try out the principle would therefore be a main-pile jacket, since it does not require underwater monitoring, and the leg would provide the enclosed casing in which the air layer could be built. This has been implemented on the Dolwin Alpha platform that HMC installed in October 2012 in the North Sea.

Implementation of the sound reduction experiment

The implementation of the sound reduction experiment is shown in Figure 4. The jacket leg is being blown empty by air supplied by the installation vessel. By constantly pumping air in the gap between pile and jacket leg, and sealing the top end, the air layer is maintained. At seabed level, a vent in the jacket leg lets the water flow out under the pump’s pressure. As soon as bubbles come out of the leg, Contractor knows that the leg is empty of water.

There is a choice to pump out water at seabed level, or to pump in air at the surface. HMC chose for the latter, because it is easier to implement, and does not bring the risk of sucking soil into the jacket leg. The foundation of the jacket needs to remain intact and suction just above the mudmat could bring the risk of sediment lift.

The pile is usually centred inside the jacket leg by using steel guide plates. These can transfer vibrations into the jacket, so had to be mounted with Teflon blocks on them. The seals at the top of the leg were doubled to ensure that if upon pile stabbing one would get damaged, there would be a secondary seal.
Figure 4 – Schematic representation of the pipe-in-pipe pile-driving concept

The design and fabrication of the jacket was awarded to Heerema Fabrication Group by ABB Sweden, while the installation was awarded to Heerema Marine Contractors. The noise mitigation offshore work scope was developed by HMC and implemented by the project team on board. Thereto, HMC arranged Dutch Research Institute TNO to take noise measurements subsea, to assess the performance of the method. TNO has reported their measurements in an official open source document (see list of references for title).

Offshore results

The technical implementation worked very well, one or two legs out of six had issues getting emptied. This was hard to discover, since the weather did not allow ROV’s to be deployed. The airflow coming out of the vent at the mud line could therefore not be monitored subsea, but had to be checked at the surface. There, however, it was very clear when air bubbles would start coming up, and failure of one of the air compressors was at one instance even noticed due to bubbles disappearing.
Figure 5 - Dolwin Alpha jacket during installation. Air expelled from jacket leg clearly visible on surface.

To measure the effect of the method, Client had arranged noise measurements from other vessels. Due to the weather, these have failed. They involved the deployment of a hydrophone over the side, but to have comparable measurements the vessel needs to anchor out, which was impossible due to wind and currents. HMC’s project team organized independent measurements.
It considered it too risky to work with a vessel-based set-up, as all noise reduction measures would have been foregone without measurements. The Client’s interest was to be allowed to pile-drive, HMC’s interest was to evaluate the effect of the noise reduction method. TNO’s measurements with a seabed-based buoy were not dependent on weather and surface vessels, nor human operators, so were consistent due to the fixed location of hydrophone.

Figure 6 – Sound measurement buoy being deployed from the SSCV Thialf during Dolwin

During the pile-driving, the compressors were switched off temporarily during two pile-driving sessions. On these occasions, the sound exposure level increased by 6 and 10 dB respectively. An increase that clearly disappeared after switching compressors on again.
Although more details are described in the TNO report, the following figure shows the sound exposure level increase very clearly. The black dashed line delineates the time in between which the compressors were shut down, allowing the water to enter the jacket leg again, so removing the noise reduction effect provided by the air layer. As you can see in Figure 7, the effect is clearly present, and also allowed our Client to remain slightly below the limit for admissible sound produced at sea.

Figure 7 - Acoustic energy during driving session of two piles (the black vertical dashes delimits the time that no air was blown in the leg – the red horizontal line delimits the maximum level that was allowed according to regulations)

Since different species of marine life are expected to be affected by different parts of the sound spectrum in pile-driving noise, TNO investigated the frequency content of the pile-driving noise, and the contribution of sound reduction in each of the frequency bins. The research company was pleased to discover that the method effectively reduces in the entire range of frequencies contained in the produced sound. This spectrum analysis is displayed in Figure 8.
Recapitulating, the offshore experiment was a success:
1. The technical implementation worked out according to plan.
2. The set-up allowed us to experiment with both situations: noise mitigation on / off, while other parameters that could influence sound levels remained fixed.
3. The noise measurements succeeded.
4. The effect was measurable and made the difference to our Client, and,
5. The effect measured was shown to be broadband in frequency, showing it is an all-round effective reduction method of sound.
Achievement

The German authorities have called this the most successful way of reducing sound produced by pile-driving since their legislation took effect. The 6 to 10 dB SEL reduction measured account for a reduction of up to 8 times in acoustic energy absorbed by introducing the air layer.

HMC believes that the result of this initiative deserves an environmental award, for the following reasons:

- It is an effective sound reduction method as it reduces level substantially, and over the entire frequency range of the produced sound by pile-driving;
- It does not involve complicated implementation, but instead can be accomplished with equipment readily available on board, such as air compressors;
- It is cost-effective, since the implementation offshore comes with a restrained amount of extra operations on top of the regular activities, and the preparation onshore involves little extra appurtenances to be fabricated on the jacket;
- It demonstrates HMC’s innovative curiosity and the passion to improve on our operations, without losing the sense of practicality that is needed to perform our installations safely;
- It is evidence of a committed project team, where Client, project manager, engineers and offshore fleet personnel must all be fully aligned to achieve the results described in this document.

The method presented in this initiative is only part of the whole noise mitigation package that was adopted by HMC on Dolwin Alpha. Other measures involved a slow start of the pile-driving procedure to chase marine life, the use of mammal deterrent devices, and acoustic monitoring of marine communication before starting to pile-drive. Those measures are already widely applied by installation contractors.

Obviously, achieving a comparable result on other types of structures will bring the difficulty of designing an enclosed casing around the pile to retain the air layer, but the effect has now shown to be worthwhile. It is therefore encouraged to continue looking for comparable applications of air layers to reduce sound, whether it be for pile-driving in shallow waters on different kinds of jackets or subsea pile-driving in deeper waters.

In the meantime, HMC has used this method again on another jacket, for which results will come out soon.
REFERENCES
Multiple external references have been used by HMC, that are non-essential to understanding the initiative, therefore they are not referred to directly in the text. They are named below.