Jörg Rustemeier, Tanja Grießmann, Klaus Betke, Joachim Gabriel, Thomas Neumann,
Michael Küchenmeister

Final report on the research project

Research into the noise reduction measure "Graduated "Little Bubble Curtain" in the alpha ventus test field („Schall alpha ventus")

Network partner (part A) and project management:

Institute for Statics and Dynamics (ISD)

Project manager:
Prof. Dr.-Ing. habil. Raimund Rolfes
Institute for Statics and Dynamics
Gottfried Wilhelm Leibniz University PO
Box 6009
D-30060 Hanover

Association partners (Part B):

MENCK GmbH

Dipl.- Ing. Michael Küchenmeister
MENCK GmbH Am
Springmoor 5a
D-24568 Kaltenkirchen

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German Wind Energy Institute GmbH (DEWI)
Ebertstr.
96, D-26382 Wilhelmshaven

Institute for Technical and Applied Physics GmbH (ITAP)
Marie-Curie-Str. 8,
D-26129 Oldenburg

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0 Summary

by Tanja Grießmann (ISD)

The measurement results for underwater sound levels as a consequence of pile driving activities in the North Sea and the Baltic Sea show that the limit values (160 dB (SEL) / 190 dB (LPeak)) established by the German Federal Maritime and Hydrographic Agency (BSH) in accordance with the Federal Environmental Agency (UBA) and the Federal Agency for Nature Conservation (BfN) are exceeded. In this regard it is necessarily required to provide effective sound reduction techniques to reduce impact on the marine environment as far as possible. However, the application of noise mitigation measures has to be cost-effective and must not considerably disturb the installation procedures of the offshore wind turbines' foundations.

Within the framework of the workshops arranged by the Foundation Offshore Wind Energy it was decided December 2008 to test a prototypic layered bubble curtain close to the foundation of an offshore wind turbine of type Areva/Multibrid M5000 at alpha ventus. The conceptional design and construction of the bubble curtain was developed by MENCK in cooperation with the company Hydrotechnik Lübeck. The testing of the prototype took place during the erection of the test field alpha ventus in the German AWZ, about 45 km north-west of the island Borkum. In this location the water depth is about 29 m; the diameter of the piles fixing the tripod to the seabed averages 2.50 m. The maximum ram energy, which was needed to drive the piles to the final depth, amounted to 375 kJ

By the end of May 2009 the required hydro sound measurements during the installation of an offshore wind turbine of type were carried out under the coordination of ISD together with the contractors DEWI and itap. During the measurements the bubble curtain was mounted at two of the three pile sleeves of the tripod foundation for the wind turbine AV9. In order to avoid dangers to marine mammals caused by piling noise, Seal scarer and pinger measures had been applied in the run-up to piling, which, additionally, started

The name "bubble curtain" comprises the whole concept, consisting of the tube system and the actual bubble curtain, which arises, when the air bubbles escape from the nozzles of the tubes at status "filled with compressed air". As the bubbles rise to the surface they form a dense curtain.

Gas bubbles change the acoustic properties of the medium water. Due to the different impedances of the two media acoustical scattering occurs at the border between both.

In addition to this effect the single bubble reacts like an acoustical resonator when insonified by an incident wave close to its resonance frequency. The result is a very high ratio of effective acoustical to geometrical cross section at resonance. In total the two effects lead to a significant reduction of the hydro sound immission "behind" the bubble and at greater distances, which is the main reason for the efficiency of the system.

Since the bubble curtain is no rigid construction, but consists of freely moving air bubbles, it is vulnerable to sea current and waves. A further challenge poses the immediate vicinity to the piling activities. To minimize disturbance of the installation procedure the bubble curtain was split up in an upper and a lower part (see Figure 'Bild 2-1'). The lower parts could be mounted at two pile sleeves (of the north- and south-eastern pile) in Ee

When the tripod foundation for the wind turbine AV9 was being installed offshore the lower bubble curtains could be put into operation as planned. Although the upper mobile systems were ready for operation on board the vessel, they weren't applied due to weather restrictions and the risk to delay the installation process. In this regard the construction site management made a short-term decision on May, 31th in the morning.

The subsequent hydro sound measurements took place during pile driving activities at AV9. At this time the lower systems were in use. Goal of the measurements was to investigate the bubble curtain's mitigation effect and its dependence on relevant parameters. To reach this, measurement positions were placed at distance 500 m from the source of sound on the western and the eastern side of AV9. In addition to this, autarkic hydrophone systems were placed at distance 2.4 and 17.5 km.

To quantify the bubble curtain's effect two situations are compared: piling with and without bubble curtain in operation. For that purpose the bubble curtain had to be switched off and on twice. Due to the omission of the mobile upper systems and the associated reduction of the compressed air flow, a variation of the latter was impossible.

The results show that the bubble curtain's mitigation effect is strongly dependent from the tide and the related flow speed and direction. The reason is, that a bubble curtain at the same very close to the pile and subjected to current and waves, isn't able to wrap the pile entirely – consequently the good reduction effect can only be unfolded at "one side" of the pile. Only during slack water at turn of tide the good mitigation effect would be available in every direction (see Figure 'Bild 5-27').

To reliably detect the reduction effect of the bubble curtain, two instants of time – about 09:21 pm and about 10:13 pm - with constant ram energy and different state of bubble curtain (on and off) have been evaluated. At the first time the according pile was half driven into the seabed. The identified reduction of the sound pressure level was about 13 dB (ÿSEL) and 14 dB (ÿLpeak) with the current and at the same time 2 (ÿSEL) and 0 dB (ÿLpeak) against the current. At the second time the pile had nearly reached its final depth. At this state the reduction could be quantified by 10 dB (ÿSEL) and 12 dB (ÿLpeak) at position "with the current" and at the same time 4 dB (ÿSEL) and 5 dB (ÿLpeal The limit value for the SEL was complied only at position "with the current."

Furthermore it could be shown that the difference of the measured sound pressure levels at position "with the current" compared to the ones "against the current" are strongly dependent from the absolute value of the flow speed. With increasing flow speed the difference between the measured sound pressure levels at position "with the current" compared to the ones "against the current" is increasing too.

For future applications there is a strong need, to eliminate the drawback of the detected anisotropic mitigation effect. To reach this goal the bubbles have to be directed in such way that their lateral drift is minimized.

With regard to short installation times offshore, the pre-installation of the lower systems onshore has proved to be very advantageous. Therefore this result should be taken into consideration while developing future concepts.

1 Introduction

At this point we would like to thank our contractors DEWI and itap for the good cooperation in the project.

The application, planning and execution of the test of a stepped bubble curtain close to the foundation structure of an Areva/Multibrid M5000 offshore wind turbine were under great time pressure right from the start, which weighed particularly heavily on project part B of the MENCK company. In this context, we would like to express our thanks to the MENCK company and the companies involved in the project on behalf of MENCK, in particular the companies Hydrotechnik Lübeck and Prokon Nord, who played a key role in ensuring that the tight schedule could be met, and the bubble curtain, consisting of two modules, fully assembled on April 17th, 2009 at the quay edge in Eemshaven.

Last but not least, we would like to thank the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety and the project management agency Jülich for the financial support and the intensive support and project supervision.

Hanover, June 2012

Dr.-Ing. Tanja Grießmann **Prof. Dr.-Ing. habil. Raimund Rolfes**

2 Introduction, Summary and Outlook

by Tanja Grießmann, Jörg Rustemeier (ISD)

Measurements in connection with piling work for the construction of offshore wind turbines (OWEA) in the North Sea and Baltic Sea have resulted in hydro noise levels that are defined by the Federal Maritime and Hydrographic Agency (BSH) in consultation with the Federal Environment Agency (UBA) and the Federal Agency for Nature Conservation (BfN). Exceed **the limit values for piling noise (160 dB re 1** µPa **for the SEL and 190 dB re 1** µPa **for the LPeak) . This result shows that there is a need for effective noise reduction measures during pile driving to protect marine life. However, such measures must be cost-effective and be able to be implemented without significantly influencing the construction process.**

As part of the regular working meetings of the Offshore Wind Energy Foundation, it was decided in December 2008 to test a prototype of a stepped bubble curtain close to the foundation structure of an Areva/Multibrid M5000 offshore wind turbine as a noise-reducing measure in the test field. MENCK, in cooperation with Hydrotechnik Lübeck GmbH, took on the design and construction of the bubble curtain. The test of the prototype system took place in the course of the construction of the German offshore test field alpha ventus in the German EEZ approx. 45 km northwest of the North Sea island of Borkum. At this location, the water depth is around 29 m and the mean diameter of the driven piles is around 2.50 m. The maximum driving energy required to bring the two piles, which were equipped with bubble curtains, to the final depth was 375 kJ (Northeast and Southeast poles).

The accompanying hydro noise measurements were coordinated by the ISD at the end of May 2009 during the piling work on the AV9 and carried out together with the contractors DEWI and itap. In order to prevent marine mammals from being harmed by pile driving noise, acoustic signaling devices were used prior to pile driving as a deterrent and pile driving began with reduced piling energy ("soft start").

The term "bubble curtain" includes the entire noise protection concept, consisting of the nozzle pipe rings and the actual bubble curtain, which only arises when the horizontal pipe systems are filled with compressed air, the air bubbles emerge from the nozzle openings and rise to the water surface in the form of a veil. Air or gas bubbles change the hydroacoustic properties of the medium water. There is a significant jump in impedance between water and air due to the large difference in density. The sound excitation of air bubbles close to their natural frequency leads to a strong reduction in sound amplitudes, with both scattering and absorption effects being effective. In the vicinity of the resonance frequency, the acoustic surface of the individual gas bubbles is many times its geometric surface, which explains the particular effectiveness of bubble curtains. However, arranging a bubble curtain close to the foundation structure poses a particular challenge due to the close proximity to the piling equipment, pile and foundation. In order to keep disruptions to the piling process to a minimum, the bubble curtain was divided into a pre-assemblable lower and a mobile upper one (Fig -1) Partial system disassembled. Two posts of the tripod (NE and SE post) were equipped with bubble curtains.

On the day the AV9 was erected, the lower pre-assembled systems could be put into operation as planned during the piling work. The mobile upper systems were

ready in good time before the start of piling on the AV9 on the transport ship, but were not used due to the narrow weather window and the risk of delaying the erection of the foundations too much due to the uncertain time required for their assembly offshore. This decision was made at short notice on the morning of May 31, 2009 by the construction site management, taking into account the current weather conditions, and supported by everyone involved.

Fig. 2-1 (left:) Lower subsystem of the Bubble Curtain pre-assembled on the AV9, Eemshaven, The Netherlands, (Source: Hydrotechnik Lübeck GmbH); (right:) Upper mobile subsystem of the bubble curtain in the transport frame with buoyancy bodies, Eemshaven, Netherlands (Source: Hydrotechnik Lübeck GmbH)

The subsequent hydro noise measurements, which were carried out during the piling work on the AV9 and during operation of the lower subsystems, served the purpose of mapping the effect of the bubble curtain and the dependence on relevant influencing parameters. Measurements were carried out in and against the flow direction at a distance of approx. 500 m from the sound source. In addition, measuring buoys recorded sound pressure levels at a distance of 2.4 and 17.5 km.

The effect of the bubble curtain was quantified by comparing ramming times with and without bubble curtain operation. To do this, the bubble curtain was switched off and on again twice.

Due to the omission of the mobile system and the associated reduced amount of compressed air, no variation of this parameter could be carried out.

The result showed that the effect of the bubble curtain is strongly dependent on the flow of the surrounding water, since the air bubbles produced are expelled in such a way that the driven pile is not enveloped with air bubbles all around and over the full water depth. The reason lies in the spatial proximity of the bubble curtain to the driven pile. This results in a strongly direction-dependent and time-varying reduction effect in the area. Only in the vicinity of the backwater point (compare Fig. 5-27) does the bubble curtain develop its noise-reducing effect equally well in all directions.

The noise-reducing effect of the bubble curtain could be determined in the periods around 9:21 p.m. and 10:13 p.m., since the sound levels were then determined with and without the bubble curtain. At the first point in time, the corresponding pile had been driven about halfway into the seabed. The noise reduction determined was around 13 dB (ÿSEL) or 14 dB (ÿLpeak) in the direction of flow and 2 dB (ÿSEL) or 0 dB (ÿLpeak) against the direction of flow. At the second point in time, the driven pile had almost reached its final depth. Here the noise reduction was about 10 dB (ÿSEL) or 12 dB

(ÿLpeak) in the direction of flow and 4 dB (ÿSEL) or 5 dB (ÿLpeak) against the direction of flow. The limit value of 160 dB re 1 μPa at a distance of 750 m could only be maintained in the direction of flow.

Furthermore, at different points in time at the beginning of the individual piling, it could be shown that the difference between the sound pressure levels measured in and against the direction of flow depends significantly on the magnitude of the flow. With increasing flow velocity, the difference between the sound pressure levels measured in the flow direction and the sound pressure levels measured against the flow direction increases.

Since it was not possible to vary the amount of compressed air as part of this project, the connection between the amount of compressed air and the reduction effect could not be researched. Knowledge of this relationship is a necessary prerequisite for optimizing the physical effect of the concept. For future applications, there is also a need to remedy the weakness of the direction-dependent and temporally variable reduction effect identified here. This is possible if e.g. B. manages to guide the bubbles in such a way that lateral drift is reduced to a minimum. The pre-assembly of the underwater noise reduction measures on the foundation structures on land has proven to be very advantageous in terms of short installation times in offshore use and should be considered in future concepts for noise reduction measures.

3 Cooperation in the project

by Tanja Grießmann (ISD)

The joint project is divided into parts A and B. *Sub-project A* was coordinated by the ITS. There was close cooperation with the contractors DEWI and itap. The aim of the cooperation was the scientific monitoring of the project, the joint implementation of the hydronoise measurements as well as their evaluation and the final evaluation of the effectiveness of the tested bubble curtain. Table 3-1 provides an overview of the partners and contractors involved in the project and their tasks in the project.

The **applicant for *sub-project B* is MENCK. The main contractors are Hydrotechnik Lübeck and Pieter van Luipen Consulting. The main goals of this part of the project were the development of a design, the construction, the manufacture as well as the assembly and disassembly of the bubble curtain.**

Table 3-1: Distribution of tasks in sub-project A

	Institution / Pursue	Tasks	contractor
1	Institute for Statics and dynamics	- Project coordination - Scientific support - Measurements, evaluations	- DEWI GmbH (line 2) - itap (line 3) - PN, PNOI (Zeilen 5, 6) - Shipping companies (line 4) - Company Hydrotechnik (line 10)
2	DEWI GmbH	- Measurements, evaluations	no
3	steps	- Measurements, evaluations	no
4	shipping companies NN	- Provision of ocean-going vessels	no
5	PROKON Nord Energy Systems Ltd (PN)	- coordination - Engineering Installation (Procedures) - Logistics Engineering	- OWT - Bode & Wrede (line 8) - Karl Wrede Stahl- u. mechanical engineering (line 9)
6	PN Offshore Installations GmbH (PNOI)	- Provision of the required Installation units (ships, platforms etc.)	- div. Schiffsreeder etc.
7	OWT	- Design of the connection to the pile sleeve - Control of the profile for the connection of the Cantilevers and the connection to the Pileguide (weld) Approval of the overall design Bode & Wrede for the connection to the Pileguide - Confirmation of the verifiability of the cantilever connection in the OWT defined Area - Ensuring the project certification of QUALITIES	no
8	Bode and Wrede Organisation for; society for; party for construction and Calculation Ltd	- Design, engineering and construction of all Fixings and brackets on the tripod	no
9	Karl Wrede Steel and mechanical engineering	- Manufacture of all fasteners and Brackets on the tripod	no
10	Fa. Hydrotechnik	- Provision of compressors, supply air lines, fittings, distributors, - Operation of the offshore bubble curtain	no

4 Conception, construction and use of the stepped Bubble Curtain (LBC)

by Michael Küchenmeister (MENCK)

As part of the "Little Bubble Curtain" (LBC) noise reduction measure, the MENCK company created a design and operating concept for underwater noise protection that can be used safely and is economically justifiable for ramming offshore wind turbines. In the period from February 15, 2009 to April 17, 2009, the MENCK company realized the design (including the operating concept), the construction, the manufacture and the assembly of the underwater noise reduction measure LBC for the installation of a tripod foundation structure for a wind turbine (AV9) from the manufacturer Multibrid in the test field alpha ventus.

4.1 Concept, Design and Manufacture

MENCK's LBC concept for the noise-reduced installation of a tripod is based on a modular structure. Figure 4-1 shows the bubble curtain system, which consists of a lower and an upper bubble curtain. Both bubble curtains are arranged around the pile to be driven, which fixes the foundation structure on the seabed. The LBC, powered by compressed air, is designed to create a noise-reducing bubble curtain by escaping the gas through vertically stacked perforated toroidal components and ideally rising vertically (concentrically) around the center of the pole to the water surface.

The lower bubble curtain consists of two modules. The modules are installed concentrically around two of the three feet of the tripod foundation structure already on land. The lower bubble curtains each consist of four nozzle pipes that are fixed to cantilever arms and cables in the area of the tripod sleeves. Due to the tripod construction, the toroidal components taper radially in the vertical direction towards the sea floor and have the shape of an open truncated cone shell.

The upper, mobile bubble curtain is to be assembled or disassembled around the pile and to the lower bubble curtain for each individual pile penetration on the open sea, while the pile is located in the pile holder of the foundation structure. In order to minimize the additional time involved in piling and not having to wait for the disassembly and reassembly of the upper bladder curtain to drive the next pile, two copies of the upper bladder curtain should be used. Since the MENCK piling hammer is guided vertically through the bubble curtain, the decreasing distance between the upper end of the pile and the seabed during pile penetration does not play an important role in this concept. In use, the upper bubble curtain takes the form of an open (octagonal) cylinder shell. A ring-shaped octagonal buoyancy body, which is not shown in Figure 4-1 and is under water during the pile penetration, ideally pulls five perforated ring-shaped air ducts vertically upwards and offers sufficient space for the use of the MENCK hammer up to a critical strength of the sea current including pole guide. A sixth nozzle tube is integrated into the buoyancy body.

The air supply consists of two compressors, a distributor and the The air supply consists of two compressors, a distributor and
[illegible]
compressed air hoses are already on land between the top edge of the pole and tripods the compressed air hoses are already mounted on the sleeve on land between the top edge of the pole and the cantilever level. Cantilever level fully assembled on the sleeve.

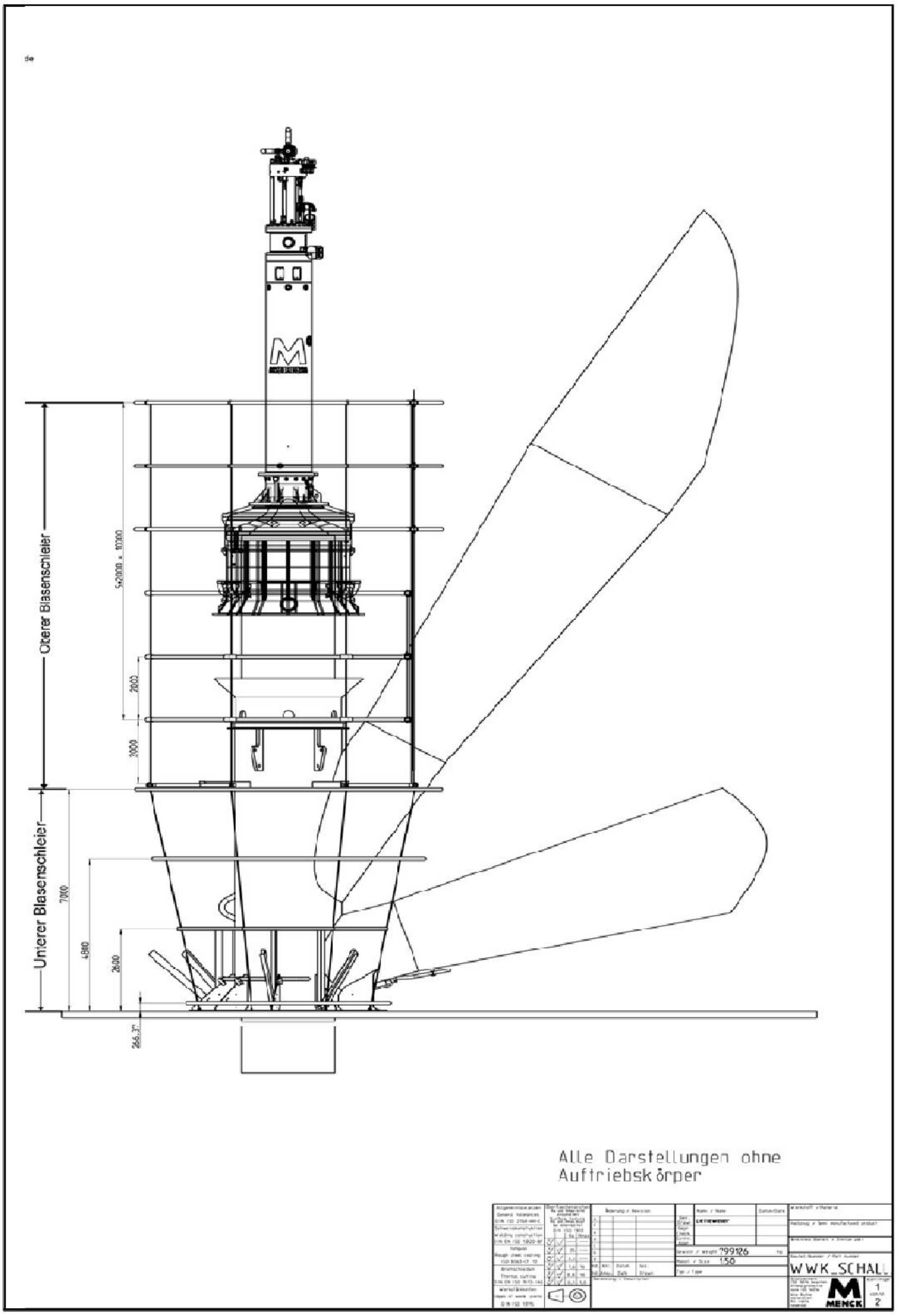

Image 4-1: Technical drawing of the tiered “Little Bubble Curtain” (lower and upper bubble curtain at the foot of a tripod foundation structure)

The upper bubble curtain can be folded along its vertical axis of the cylinder shell (between the seabed and the water surface) for transport purposes according to the accordion principle. A lifting beam was designed, built and delivered for safe and speedy offshore assembly.

Fig. 4-2: Lifting traverse for offshore assembly of the upper bubble curtain

4.2 Transport and assembly of the stepped bubble curtain (LBC)

On April 3rd, 2009, the transport of the material required for the bubble curtains to Eemshaven was completed, so that assembly of the upper and lower bubble curtains could begin and be completed by April 17th, 2009. Compliance with this project milestone, which was set for April 22, 2009 at that time, had absolute priority and was also observed by MENCK.

The lower bubble curtain, which initially consisted of only two modules for the test purposes of the research project, was already pre-assembled on land in Eemshaven on two of the three feet of the Tripod-AV9 foundation structure in order to avoid delays caused by the noise reduction measures during the construction phase and the associated costs minimize.

The two upper bubble curtains were assembled in Eemshaven. For use, the two upper bubble curtains were shipped to the offshore installation site with a transport ship in a storage and transport frame specially designed for this purpose.

The detailed assembly process can be found in Appendix No. I-III ("Installation procedure for noise reduction for multibrid OWT alpha ventus tripod AV9").

Figure 4-3: AV9 tripod foundation structure with two pre-assembled lower bubble curtain modules

Picture 4-4: Upper bubble curtain on its storage and transport frame

4.3 Use of the graduated bubble curtain (LBC)

MENCK GmbH has achieved the goal of developing a design and operating concept for underwater noise protection that can be used safely and is cost-effective. This construction and operating concept was used when installing a tripod in the alpha ventus test field. However, the operation of the upper bubble curtain on a tripod in the alpha ventus test field could not be tested under real conditions due to a project decision (early project termination due to bad weather, which would have endangered safety). Figure 4-5 shows the use of the LBC during the installation of a tripod in the alpha ventus test field.

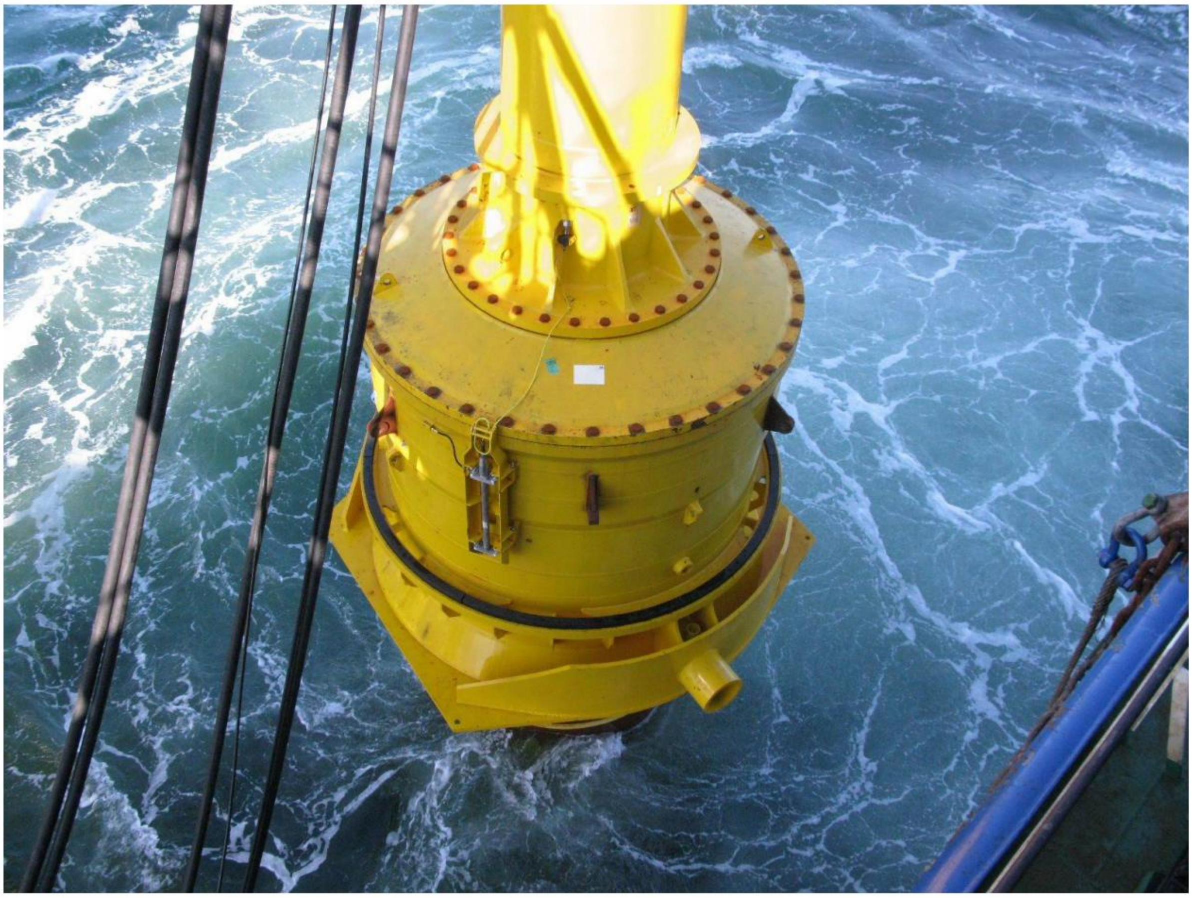

Fig. 4-5: Use of the "Little Bubble Curtain" noise reduction measure during the installation of a tripod in the alpha ventus test field

The detailed assembly process can be found in Appendix IV-VI ("Installation procedure for noise reduction for Multibrid-OWEA alpha ventus-Tripod AV9").

A total of six Multibrid Tripods were installed in the Alpha Ventus offshore field. The most important data of the tripods and their poles are given in Table 4-1.

The experiments with the LBC were carried out on the tripod AV9.

After placing the tripod on the seabed, the 3 stakes were inserted into the respective "sleeve" at the foot of the tripod and installed with a vibrating hammer. After that, the piles were first pre-rammed a little with the MENCK hydraulic hammer MHU 500T and then rammed to the final penetration depth. Table 4-2 contains the most important driving data from the three piles of Tripod AV9. These are: the timing of the ramming, the number of impacts and the average energy over the respective ramming distance. The chronological sequence is shown in Figure 5-22, upper graphic, which also shows when the driving energy (and to what value) was changed.

The respective driving results are shown in Figures 4-6, 4-7, 4-8 for the SE, W and NE piles. These show the impacts per penetration (in impacts/m) and ramming energy/impact (in kJ) versus distance driven (in m). These original documents show the results recorded on board. The designations are: blowcount and av energy/bl versus penetration.

Table 4-1: General data tripods and piles - offshore field alpha ventus

Tripod	
Base (distance between sleeves)	**24,2 m**
overall height	**44,6 m**
Height Above Water (SKN)	**7,1 m**
Number	**6 -**
Water depth (related to SKN)	**27,5 m**
piles	
Number (per tripod)	3
total number	**18 -**
Outer diameter	**2480 mm**
Tilt	**vertical**
Wall thickness	**32 - 50 mm**
Long	**47 - 55 m**
penetration	**35 - 43 m**
Pilehead Underwater (SKN)	**-15,5 m**

Table 4-2: Driving data SE, W, NE piles - Tripod AV9

stake no. of	date Time	until date Time	blow no from ... to		medium Energy kJ	piling distance from	until	in total punches
pile SO	05/31/09 16:18:27	05/31/09 16:28:59	0	337	209	0,00	3,00	
pile W	05/31/09 16:40:20	05/31/09 16:50:44	0	459	224	0,00	2,00	
pile NO	05/31/09 17:00:51	05/31/09 17:23:00	0	950	215	0,00	4,25	
pile SO	05/31/09 17:38:00	05/31/09 17:53:37	337	1007	283	3,00	5,75	
pile W	05/31/09 18:11:34	05/31/09 19:42:30	459	4171	326	2,00	10,50	
pile W	05/31/09 20:00:42	05/31/09 20:28:42	4171	5396	478	10,50	13,75	5211
pile NO	05/31/09 20:44:28	05/31/09 22:22:30	950	5034	368	4,25	15,50	4902
pile SO	05/31/09 22:39:16	06/01/09 00:19:43	1007	5566	289	5,75	17,50	5450
							Tripod In total	15563

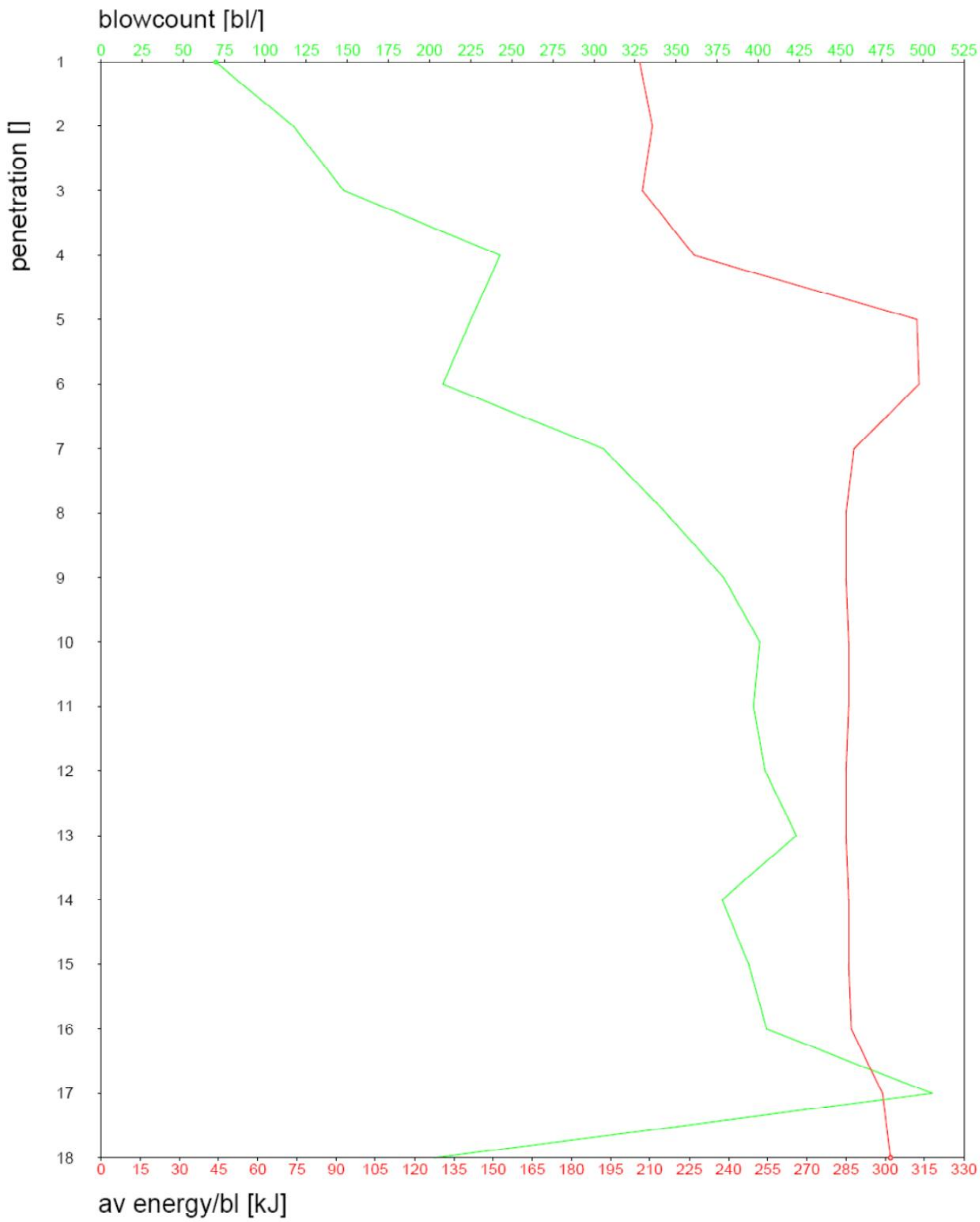

Figure 4-6: Post SO - Blowcount & Energy versus Penetration Curve

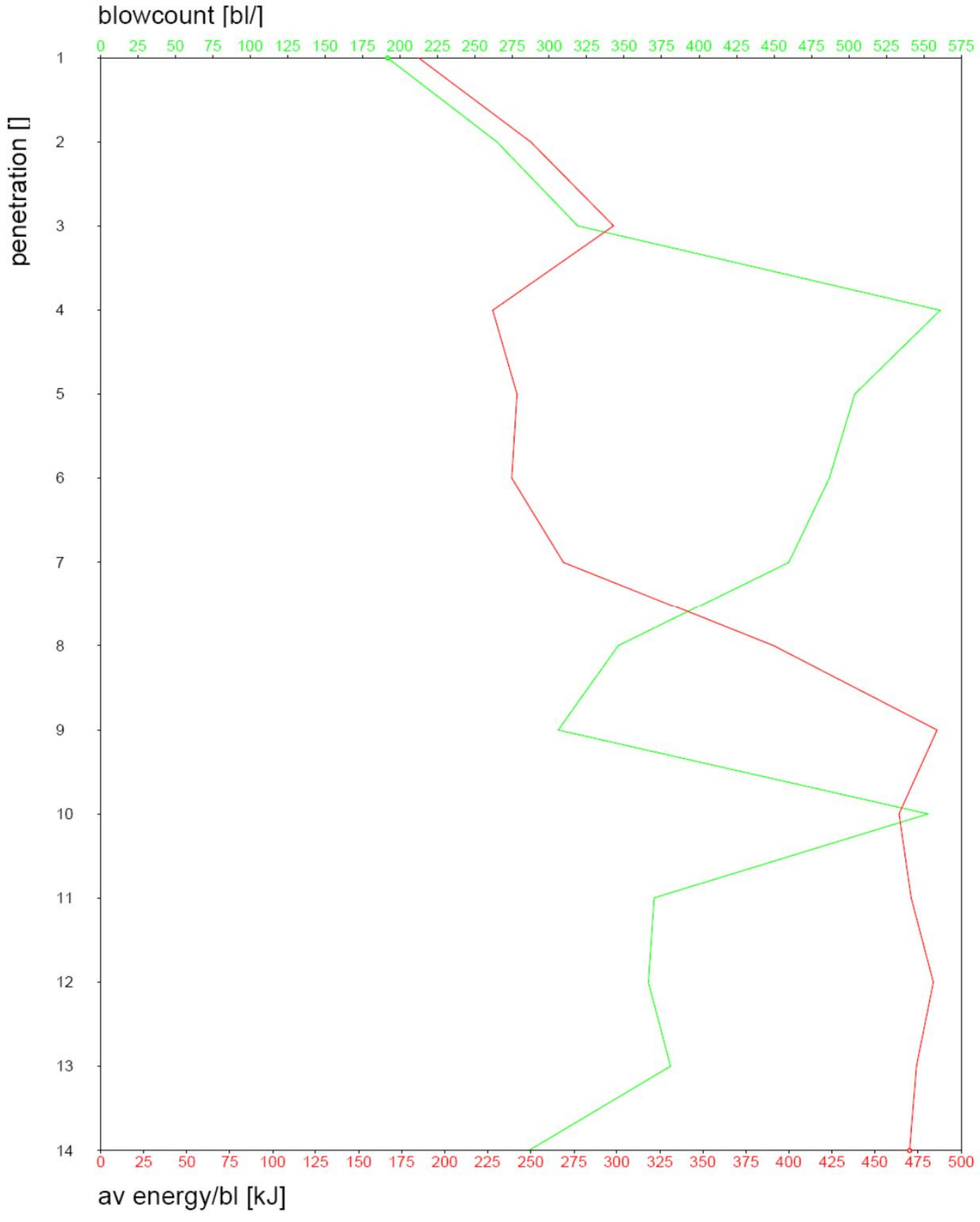

Figure 4-7: Pile W - Blowcount & Energy versus Penetration Curve

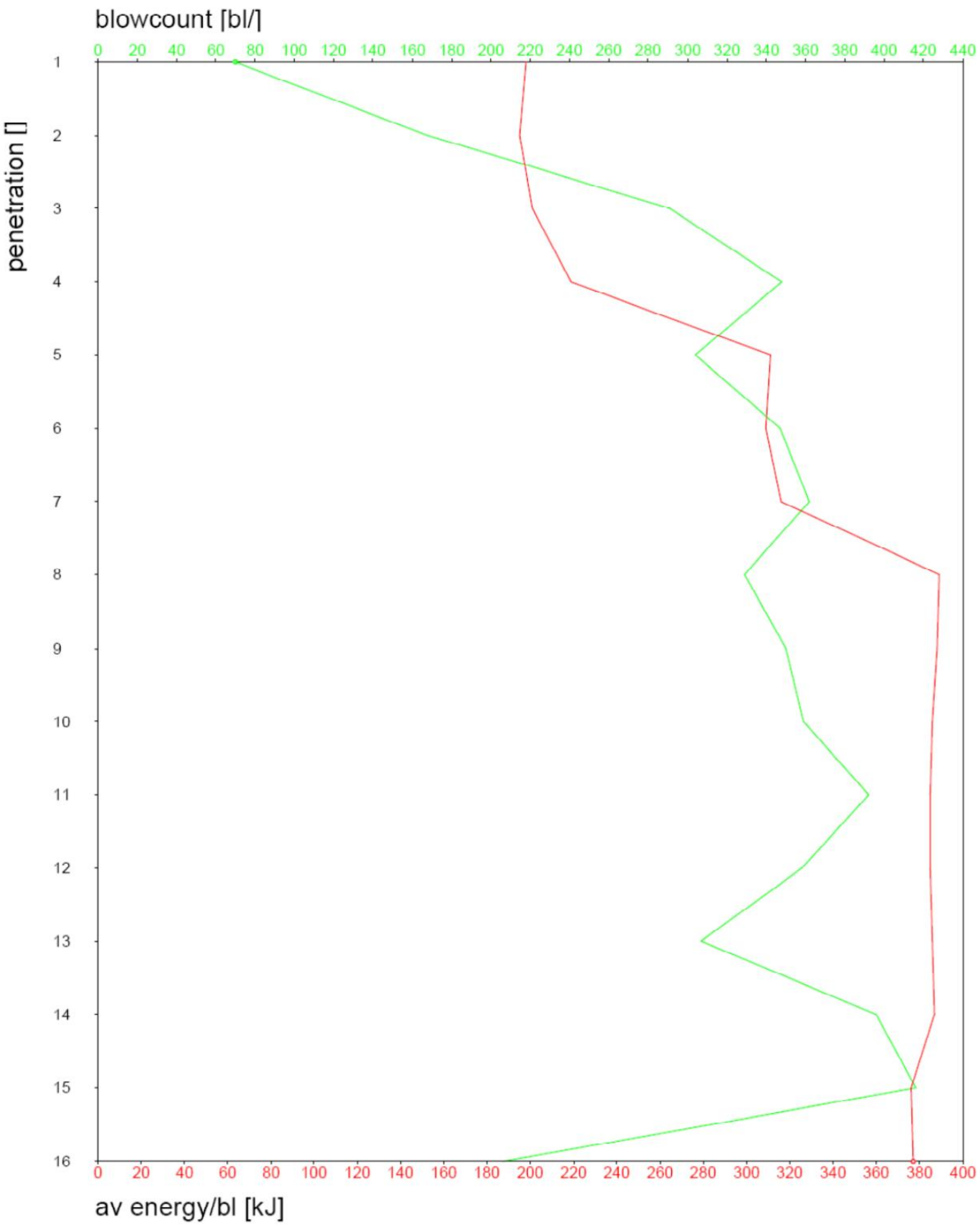

Figure 4-8: Post NO - Blowcount & Energy versus Penetration Curve.

The description of the main events when using the LBC follows in the form of a log.

date Time		activity	Involved	from
28. May. 20:00		Discussion on board ODIN: whether 1 or 2 upper bubble curtains was not decided at the discussion on 27 May with the BMU. PvL: Practice (="loss of time") will specify this. decision whether upper bubble curtain at all decided shortly before; depending on forecast how long good weather, tripod installation must not be jeopardized. Procedures discussed (PvL: for the first time) and optimized.	Herren Klingele, Mettbach, Nanninga, Andreas .. (Taucher Supervisor), Grunau, Mku, PvL	PvL
29. May.	15:00	Leaving ODIN	Mku, PvL	PvL
29. May.	15:30 Start	loading Tripod by Taklift	Mku, PvL	PvL
29. May.	16:00	Taklift alongside the quay with tripod. Tugger Lines tight to leg W	Mku, PvL	PvL
29. May.	19:30	Arrival foreman WR, SK, Mr. Knoll (from BAM) and Mr. van Leest (from BAM)		Mr
29. May. 22:00		Leaving Kottzov		Mr
30. May. 5:00		Odin jacketed in the field at position AV9 (statement Mr Mandelsloh, Kamaraman)		Mr
30. May. 9:00		Call Mr. Klingele by radio from the Odin. Time window for installation Tripod AV9 has shortened. Cannot deploy 2nd Upper Bubble Curtain, so 2nd Upper Bubble Curtain remains in Eemshaven. Mr. Mandelsloh and Mr. Nanninga are to be picked up with Alisa to the Odin. Reminder from Mr. Grunau of preparatory work on the Odin for the use of the compressors. Answer from Mr. Klingele, he would like to be ready for the crew change at 7:00 p.m. today.	Herr Grunau, sir Mandelsloh, Herr Nanninga, PVL, Mr	Mr
30. May.	9:45 - 10:45	Discussion about the use of bubble curtains and influence on ramming with Mr. Grunau, supervisor WR, SK, Mr. Knoll (from BAM) and Mr. van Leest (from BAM), PvL and Mku.	see left	Mr
30. May.	12:00	Sighting of TakLift 4 with Tripod AV9 from the west tug support		Mr
30. May.	14:50	Mr. Nanninga with RIB from Balticdiver to Kottzov to get his luggage. After a short stay on to the Odin. Mr. Nanninga: -Alisa went to Eemshaven around 1:00 p.m. to load an Upper Bubble Curtain. Expected back at AV9 tonight. -When and who should go from the Kottzov to the Odin will be radioed by the Odin. -Mr. Nanninga is staying on the Odin tonight.	Herr Nanninga, Mr	Mr
30. May.	14:55 Lowe	ring of tripod on AV9 has started.		Mr
30. May.	17:30	Tripod lowered into position, Taklift remains in field under its own power		Mr

Machine Translated by Google

date Time		activity	Involved	from
30. May.	19:00	Mr. Klingele:- the third post is coming to Odin today at 10:00 p.m. -Plan ramming start tomorrow noon -Ready to translate for ramming and bubble curtain tomorrow morning 07:00. -Tug Bankert fetches second Upper Bubble Veil	Mr. Klingele	Mr
30. May.	19:30	First post, NO, is lifted and set with a vibrator		Mr
30. May. 20:00		Lifted the vibrator off the first post.		Mr
30. May. 21:20		Second stake, SO, placed and vibrated		Mr
30. May. 23:00		Crane boom Odin discarded		Mr
30th May. 23:30		Odin jacketed off, moved to a new position with a tugboat.		Mr
May 31. 6:00		ODIN is 3rd post when picking up. Taklift still in the field. Alisa is here with upper bubble curtain and traverse. ODIN is SW (not NW) of Tripod. Waves from O		PvL
May 31. 7:00		Alisa with diver/rigger and Willem/bam, Stefan, Grunau, Mku, PvL to ODIN.		PvL
May 31. 7:40		Meeting on board ODIN. Mettbach, Klingele, Grunau, Mku, PvL. Mettbach explains the current situation: "Piles are pre-vibrated, 3rd pile is hanging in the crane. Both lids at the top and bottom still have to be burned out. The weather is already bad, according to the weather forecast it will be even worse. Currently Hs 1.5 m. Weather report: Wind will remain, worsening on Monday/Tuesday. On Monday 15:00 must be ready, ODIN jacked down into the water and departure to Eemshaven. Calculating backwards: 18 hours for grouting and remaining work on the tripod, including replacing the cover hoses, so be ready to ram on Sunday at 9:00 p.m. That actually means you should start ramming at 09:00 (in an hour!). But you still need to prepare for 3rd stake, set, shake 1 or 2 x row around 6 hours. So you can only start ramming at 14:00 (5 hours late). So there is no time for upper bubble curtains.	bell, Mettbach, Grunau, Mku, PvL	PvL
May 31. 7:41 a.m		Klingele wants to send both upper bubble curtains back to Eemshaven. Especially no. 1 with Alisa, because Alisa is needed for work in the field (including translating staff). At our request that at least the 2 lower bubble curtains are used, we can prepare distributors and hoses, be prepared for laying over to the tripod, there are only 2 hoses. Decision whether possible falls at the last moment.	bell, Mettbach, Grunau, Mku, PvL	PvL
May 31. 9:00		Distributor was placed on deck next to compressor. 1 x short hose connected to the compressor. We should also connect upper compressor for safety. (was not made by us)	Gru, Stefan, Willem, Mk	PvL
May 31. 9:30 am		dropped the post. Beginning burn out top lid post.		PvL

date Time		activity	Involved	from
May 31.	11:00	Compressor run to test.	Gru	PvL
May 31.	11:15	Proposal for a rough protocol for ISD, itap, Dewi, MENCK: General: post number, such as intrusion. In addition: time, such as penetration, energy, air NE, SO, bar & m3/min.		PvL
May 31.	11:30	The third post arrived at 05:00 this morning, not yesterday at 22:00 as planned, as the tug had to fight against a strong current.	Nanninga	MKu
May 31.	11:45 Crane	lifts vibrator + 3rd pole		PvL
May 31.	12:20	3. Stake (=W) placed and vibrated. 2 men on top of tripod		PvL
May 31.	12:31	Vibrate NO early, only ~1 min.		PvL
May 31.	13:00	2 jumper hoses ready connected to the tripod. Connection by Mr. Klingele to 2A3 (NO) and 3A3 (SO). After 5 - 10 minutes strong bubble formation on the surface, but displaced by the current in an easterly direction at the NE and SE poles		PvL
May 31.	13:10	Air bubbles visible on water surface, both lower bubble curtains okay. NO and SO 7/7 bar. Slight drift to the east, only a few meters (5m from depth 25m), but it is backwater.		PvL
May 31.	13:40	Mr. Rustemeier on board		PvL
May 31.	13:55 Strike	hammer, swing up and forward.		PvL
May 31.	14:15	1 pair of hoses laid over the left roller		PvL
May 31.	14:45	Set hammer to SO. Small leak HP hose from BAM winch, therefore hammer lifted off pole and in front of winches.		PvL
May 31.	16:18	1 x single blow.		PvL
May 31.	16:21	Start driving SO. Compr. 7/7 bar, 1600/1900 m3/min. 210 kJ, 42 bl./min.		PvL
May 31.	16:28	Stop SO.		PvL
May 31.	16:38	Anvil on pile W		PvL
May 31.	16:40	Start 40%		PvL
May 31.	16:50	Stop W		PvL
May 31.	17:00	Start NO		PvL
May 31.	17:23	Stop NO		PvL

date Time		activity	Involved	from
May 31.	17:37	Start SUN. 7/7, ../1939. Bubbles ~ 4 m away. backwater is coming.		PvL
May 31.	17:53	Stop SO.		PvL
May 31.	18:11	Start W. Blow 2 m away from pole.		PvL
May 31.	18:18	Initiation Mr. Mettbach ROV for bubble curtain to SO. Good shots of ROV. Picture by Mr. Rustemeier: Bubbles right around the post		PvL
May 31.	19:42	Stop W. Stop compressor, let ROV in. Bubbles are gone quickly (< 5 min.)		PvL
May 31.	19:50	Sketch of Stefan with pole numbering: Seen from ODIN: left = P2 / A 13 = W, right = P1 / A 14 = SE, back = P3 / A 12 = NE.	Stefan	PvL
30. May.	19:55	Stefan and Willem on board, Wilke and Henry on board		PvL
May 31. 20:00		Start W (next).		PvL
May 31. 20:28		Stop W by Shackle (set for last meter ramming to end penetration), Done!		PvL
May 31. 20:35		air active again. 6.5 / 6.5 1340 / 1400.		PvL
May 31. 20:43		Start NO		PvL
May 31. 21:05		Turn off air, request measuring vessel for reference.		PvL
31. May. 21:15 Air take-off again				
May 31. 9:45 p.m		Rustemeier: Have enough measurements, on board.		PvL
May 31. 21:46		Rustemeier: had already informed Klingele so. PvL definitely try to measure up to the end after all the effort and no use of upper bubble curtains.		PvL
May 31. 22:00		Compressor stopped to refuel.		PvL
May 31. 10:05	p.m	Stop NO.		PvL
May 31. 10:08	p.m	Start for last stretch NO		PvL
May 31. 10:10	p.m	Compressor refueling complete. Start compressor.		PvL
May 31. 22:22		shackle stops hammer = end NO.		PvL
May 31. 10:38	p.m	Start SO		PvL
May 31. 11:15	p.m	Test reduction delivery quantity Compr. control valve compr. Turn NO on ("pinch") first. Should be SO because it is rammed.		PvL

date Time		activity	Involved	from
May 31. 23:25		Turn down SO 7.8 / 4.0 .. / 740. 8.0 / 4.0 1885 / 2500. 6.3 / 5.3 1630 / 1228. Blowing NE normal, SE less.		PvL
1. Jun.	0:00	Open SO, close NO. 3.0 / 9.1 .. / 2076. Compr. 9.8 2.9 / 9.5 .. / 2350. Blowing NE less, SE significantly more.		PvL
1. Jun.	0:19	Stop ramming SO. Stop bubble curtain		PvL
1. Jun.	0:35	ROV watched, Mettbach okay, 0.5 m before end penetration.		PvL
1. Jun.	1:15	All distributor connections cleared, all air hoses on deck cleared away.		PvL
1. Jun.	2:00	2 men on tripod, jumper hoses to tripod to ODIN pulled and put away.		PvL
1. Jun.	3:30	Alisa von ODIN zu Kotzov with Wilke, Henry, Grunau, Mku, PvL		PvL
1. Jun.	17:00	ODIN already jacked down, in the field, but away from Tripod AV9.		PvL
1. Jun.	17:05	Info Nanninga: Man cover (top in tripod with 6 +1 hoses) was not replaced.		PvL
1. Jun.	18:30	Kotzov starts to drive to Eemshaven. ODIN has been on the road for a while.		PvL
1. Jun.	19:00	Doti > PvL: ODIN limit to down jackets is 1.2m. We had over 1.0 m, so it was on the limit, especially with the heavy load. PvL: so the weather forecast was good, because now it's going to be worse than predicted. DOTI: yes, we have 3 weather reports, take the average.		PvL
		MENCK employees:		
		PvL: Pieter van Luipen		
		Mku: Michael Küchenmeister		
		WR: Wilke Remmers		
		SK: Stefan Kürschner		

4.4 Dismantling, return transport and dismantling of the stepped bubble curtain (LBC)

The two lower bubble curtains remained on the AV9 tripod as planned. The detailed dismantling and return transport process can be found in Appendix No. VII (“Installation procedure for noise reduction for multibrid OWT alpha ventus tripod AV9”). The two upper bubble curtains and the lifting traverse have meanwhile been stored in the outdoor storage area on our company premises. From the point of view of MENCK, the further use of one or both upper bubble curtains would be desirable, but no specific application is currently seen.

4.5 Summary

MENCK has successfully designed, constructed, manufactured, assembled and provided for test purposes an economically viable noise reduction measure for ramming offshore wind turbines. The use of the lower bubble curtain led to the expected significant reduction in noise in the direction of flow. The many vertically stacked air loops of the lower and upper bubble curtains were intended to counteract the blowing away of the bubbles by the sea currents, which had already been anticipated in the design phase of the LBC. Therefore, as expected, the noise-reducing effect against the direction of flow was low, since the upper bubble curtain could not be used due to a weather-related, safety-related project decision.

Nevertheless, as expected, the measurement results of the noise reduction measure underpinned the strong reduction in pile driving noise and confirmed the fundamental success of the "Little Bubble Curtain".

Figure 4-9 shows the bubbles emerging concentrically around pile A14 during operation of the lower bubble curtain. The pre-assembly of the underwater noise reduction measures on the foundation structures on land has proven to be very advantageous in terms of short installation times in offshore use and should be considered in future concepts for noise reduction measures.

Fig. 4-9: Bubble formation on the water surface at post A14 in the alpha ventus test field

4.6 Outlook

Another possibility for testing the upper bubble curtain is seen on a foundation structure in the offshore wind farm area. Experiences from this project could be incorporated here. Furthermore, an application in port and bridge construction is conceivable, since underwater noise emissions also occur here due to piling or sheet pile driving.

A proven noise protection concept as a mature series model would be further optimized in terms of handling and efficiency during installation. For example, a modified upper bubble curtain is conceivable as an overall underwater noise reduction operating system. Similar to the above-water noise protection solutions operated by MENCK (see Fig. 4-10), integrative noise protection concepts could be pre-installed directly on the hammer prior to the piling activities and reduce the assembly and disassembly time to a minimum. In addition, it would be conceivable to allow the air bubbles to rise within a cylindrical bellows in order to escape the effects of the ocean currents. A monopile foundation or a test pile would be suitable for testing.

Fig. 4-10: MENCK bellows as surface noise protection system

5 Measurement of hydronoise levels

5.1 Objective

The measurements should efficiently depict the effect of the bubble curtain and the dependency on relevant influencing parameters. The main external influencing parameter is the sea current, as this potentially drives the air bubbles out of the sound path. Therefore, measurement positions were defined in relation to the dominant flow direction, which runs in an east-west direction in the area of alpha ventus.

The main goals of sub-project A can be summarized as follows:

- Measurement of the sound pressure curves in different directions and distances
- Evaluation of the effectiveness of the tiered bubble curtain offshore Conditions.
- Determination of the influence of the flow on the noise reduction effect of the bubble curtain in operation.
- Investigation of the impact of ramming energy on the sound pressure level.

The effect of the bubble curtain is quantified by comparing ramming times with and without bubble curtain operation. These operating states were set during the ramming action by switching the air supply on and off. During the ramming period documented here, continuous operation of the bubble curtain was interrupted three times.

Measurements on variations in the air volume and the "connection" of the bubble curtain stages were also on the measurement plan. However, these could not be implemented due to the already explained weather-related limitations in the implementation of the reduction measure.

The measurements and evaluations documented here do not include the sound propagation and parameter studies, e.g. on the water depth dependency of the sound emissions and immissions and the influence of the structure of the construction platform (reflections and shadowing) on the sound radiation.

5.2 Acoustic measurement parameters

by Klaus Betke (ITAP)

Sound is a rapid, often periodic fluctuation in pressure that is additively superimposed on the ambient pressure (i.e. the hydrostatic pressure in water). This is associated with a "back and forth movement" of the water particles, which is usually described by their speed, the particle velocity. Confusing the speed of sound with the speed of propagation of sound, which is about 1500 m/s in water, but much smaller is not the speed of sound c, also

Sound pressure p and sound velocity v are linked via the characteristic acoustic impedance Z of the medium:

$$Z = p / v \qquad (5.2.1)$$

In the far field, ie at some distance from the sound source, the impedance is given by

$$Z = ÿ c \qquad (5.2.2)$$

Here ÿ is **the density of the medium. For example, for a sound pressure amplitude of 1 Pa (corresponds to a sound level of 117 dB re 1 μPa for a sinusoidal signal or a peak level of 120 dB re 1 μPa, see below), this results in a value of approx. 0.7 μm for the sound velocity in water /s.**

In sound engineering, noises are usually not described directly by the size of sound pressure (or speed of sound), but by the ***level*** in dB (decibels) **known from communications engineering . There are different sound levels; The following are important for the present question:**

- **Equivalent continuous noise level Leq**
- **Single Event Level LE (identical to Sound Exposure Level SEL)**
- **Spitzenpegel Lpeak**

The Leq and the LE can be specified both frequency-independently, ie as broadband values, and frequency-resolved, eg in 1/3 octave bands. The precautionary value specified by the BSH and UBA for piling work of 160 dB re 1 μPa at a distance of 750 m means the broadband single event level LE of a single piling blow. The second criterion of the BSH/UBA value concerns the peak level Lpeak (see below), which must not exceed 190 dB re 1μPa at a distance of 750 m.

Equivalent Continuous Noise Level, Leq

The Leq is the most common measurement in sonic engineering and is defined as

$$L_{eq} = 10 \log \left(\frac{1}{T} \int_0^T \frac{p(t)^2}{p_0^2} \, dt \right) \text{ dB} \qquad 5.2.3$$

Here p(t) is the sound pressure, p0 is the reference sound pressure 1 μPa and T is the averaging time. The observed sound pressures p are to be squared, the mean value of the squares is to be formed over the time T and this mean value divided by $p0^2$. The logarithm of this value multiplied by 10 is the result in dB.

single event level, SEL

The **Leq alone is not a sufficient measure to characterize ramming noises ,** because it not only depends on the strength of the ramming impacts, but also on the averaging time and the pauses between the impulses. The single event level (sound exposure level, SEL, also abbreviated to **LE** in German-speaking countries) **is more suitable and** is defined somewhat differently than the **Leq:**

$$L_{AND} = 10 \log \left(\frac{1}{T_0} \int_{T_1}^{T_2} \frac{p(t)^2}{p_0^2} \, dt \right) \qquad 5.2.4$$

Start time T1 and end time T2 of the averaging are to be selected in such a way that the sound event lies between T1 and T2. T0 has the value 1 second. The single event level of a sound pulse is thus the level (Leq) of a continuous sound of 1 s duration and the same sound energy as the pulse.

In the following, the "sound event" is mainly understood to be the individual ramming blow. With regard to the biological or medical effect of the noise, it can make sense to also consider the consequences of several blows up to the entire process of driving a driven pile as a noise event. Sometimes there is talk of "cumulative SEL". 10 equally strong impacts would then have an SEL that is 10 dB higher than the single impact SEL, with 100 impacts the difference would be 20 dB, and so on.

The LE can **be calculated from the Leq :**

$$L_{AND} = 10 \log 10 \left(10^{Leq/10} - 10^{Lhg/10} \right) - 10 \log \frac{n T_0}{T} \qquad 5.2.5$$

Here n is the number of sound events, i.e. piling impacts, within the time T. As before, T0 = 1 s. The application of equation 5.2.5 to a Leq measurement thus provides the mean LE of n sound events. Lhg is the interference or background level between the

sound events. If the level of the background noise is significantly lower (e.g. 10 dB) than the piling noise, a simplification of Equation 5.2.5 can be calculated with good accuracy:

$$THE \; ÿ \; L_{eq} \; ÿ \; 10\log \frac{nT_0}{T} \qquad 5.2.6$$

Spitzenpegel, Lpeak

This size is a measure of sound pressure peaks. Unlike Leq and LE, there is no averaging:

$$L_{peak} = 20 \log (|p_{peak}| / p_0) \qquad 5.2.7$$

Here ppeak is the maximum detected positive or negative sound pressure, i.e. the maximum of pmax and |pmin|, when pmax is the highest and pmin is the maximum negative sound pressure. The peak level Lpeak is always higher than the single event level LE, with pile driving noise this difference is 20 to 25 dB. Some authors prefer the specification of a peak-to-peak value, which is less common in sound measurement technology

$$L_{pp} = 20 \log ((p_{max} - p_{min}) / p_0) \qquad 5.2.8$$

From Equation 5.2.8 it follows that Lpp can be a maximum of 6 dB greater than Lpeak. In practice, there is a difference of 5 to 6 dB in ramming noises.

frequency weights

In order to be able to calculate single-number level values that also take into account the hearing ability of the respective species, frequency weightings were proposed - analogous to the well-known A and C weighting for airborne noise (Southall et al. (2007). These "M weightings" are slightly different for different marine mammals. For example, the curve given for "HF cetaceans" attenuates signal components below 300 Hz and above 100 kHz. HF cetaceans refers to toothed whales whose hearing ability roughly covers the frequency range from 200 Hz to 180 kHz, which includes also the porpoise.

5.3 Boundary conditions at the site, measurement program and individual evaluations

boundary conditions at the site

The test of the prototype system took place in the course of the construction of the German offshore test field alpha ventus in the German EEZ approx. 45 km northwest of the North Sea island of Borkum. The table below summarizes key data useful for comparability with other Bubble Curtain trials.

Table 5-1: Site boundary conditions (Areva/Multibrid M5000, Annex AV9)

water depth in m	pole diameter in m	Type impact ram	Maximum, applied Ram energy in kJ	Number beats per stake	Air volume used in m³/min (atm. condition)
29	2.5	MENCK MHU500T	475 (West stake)	that. 5000	that. 45

Two air compressors with a suction volume of 45 m³/min each were kept on board the jack-up platform. This volume of air was designed to operate the two tiered bubble curtains on the north-east and south-east poles of the AV9 tripod. Since the two upper parts of the bubble curtain could not be used due to the weather, the number of bubble curtain levels was reduced from ten to four (see Fig. 4-1).
As a result, only one compressor could be used, which supplied the two lower bubble curtains with compressed air. It was therefore no longer possible to partially switch off the bubble curtain or to reduce the amount of air. To determine the effectiveness of the two lower bubble curtains, the compressor was turned off.

measurement positions

The anchor positions for the two ships ***Baltic Taucher 2*** (DEWI) and ***Arne Tiselius*** (ISD, itap) were chosen to be as close as possible to the sound source in order to be able to compare the results more easily. The desired distance of 500 m is outside the vicinity of the sound source, where impairments of the measurements due to local effects (e.g. reflections and shadowing by the construction platform, directional characteristics of the sound radiation and excited secondary sound sources) are to be expected. The selected position at approx. 500 m is still close enough to the construction site to be able to measure sound pressure levels relevant to the long-distance effect of noise emissions, but at the same time to be able to follow and log the work process. While the ship ***Baltic Taucher 2*** (DEWI) anchored continuously east of the tripod of the AV9, the ***Arne Tiselius*** (ISD, itap) changed its anchor position during ramming from initially 240° (approximately perpendicular to the current) to 300° (roughly the opposite direction to the *Baltic Taucher* 2). In detail, the positions resulted from the coordination with the construction management and the current requirements in the construction area. The position of a ship lying at anchor in the current naturally fluctuates due to the length of the anchor chain that is inserted. Because of the ship's wobble, the s

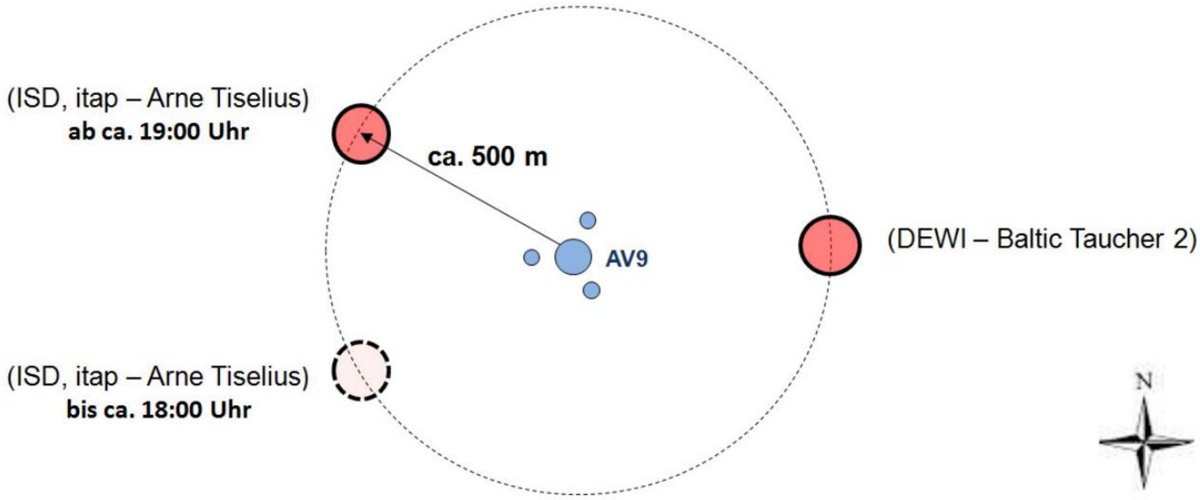

Figure 5-1: Sketch of the measurement positions

5.3.1 Measurement 500 m east of the point of emission

by Joachim Gabriel, Thomas Neumann (DEWI)

The DEWI measurements at the measuring position to the east of the construction site were carried out on May 31, 2009 between 4:20 p.m. and 12:20 a.m. on June 1, 2009.

The measurements were carried out by DEWI employees Hauke Decker and Joachim Gabriel on board the *Baltic Taucher 2 .* The ship was anchored at the position to the east of the construction site. The anchor position (eastern direction and target construction site distance of 500 m) was determined using the ship's radar. The position fluctuated due to the sway caused by the current, wind and length of the anchor chain. The ship's position (GPS data) was recorded and the distances to the construction site were determined on the basis of this data.

Fig. 5-2: Construction site seen from Baltic Taucher 2 (DEWI)

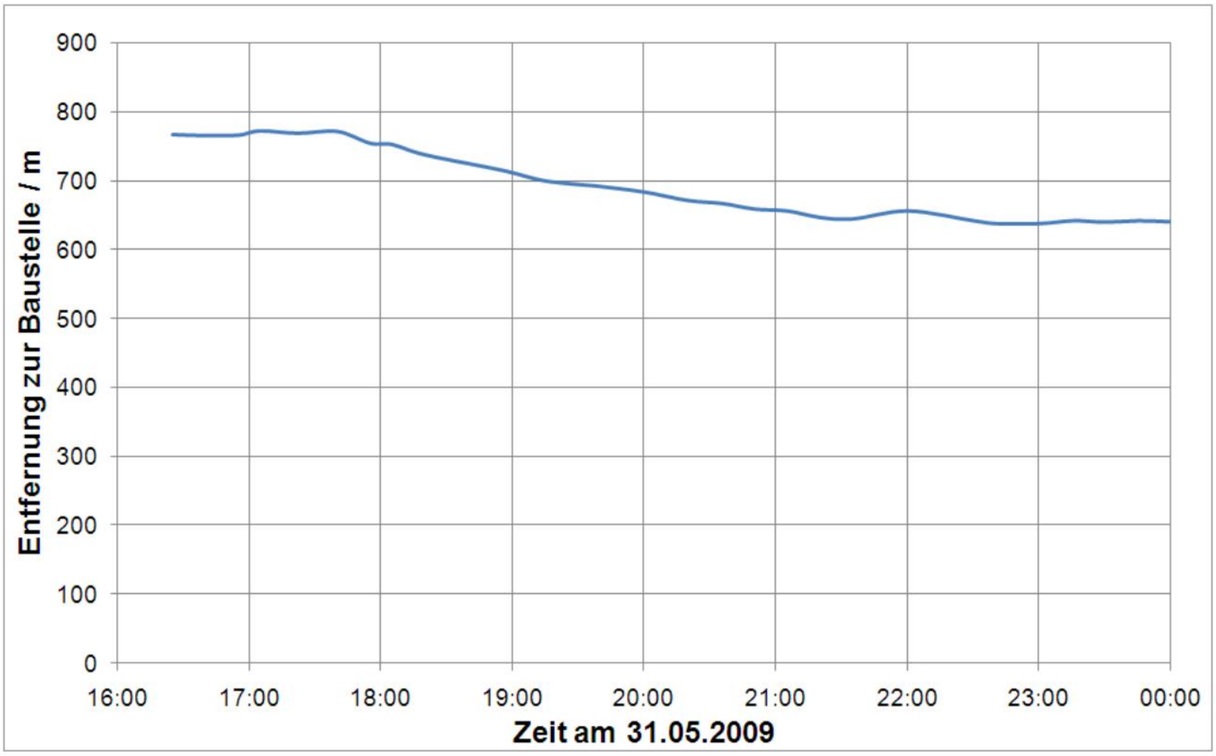

Figure 5-3: Distance from Baltic Taucher 2 to the construction site (from GPS data, DEWI)

Measuring devices used

Audio recorder:	**Fostex FR-2**
Hydrophon:	**Brüel & Kjaer 8105**
Hydrophonkalibrator:	**Brüel & Kjaer 4229**
charge amplifier:	**Brüel & Kjaer NEXUS 2692**
anchor position:	**ship radar**
positioning:	**Garmin GPS 72**
Sound level meter:	**Brüel & Kjaer 2236 DEWI No.2, calibrated**
Frequenzanalysator:	**Brüel & Kjaer 2143**

measurement setup

For the DEWI measurements at the measuring position to the east of the construction site, weighted hydrophones were lowered into the water on the sides of the ship.
The measured values of the hydrophone on the port side were evaluated and documented below. The following picture shows a sketch of the arrangement.

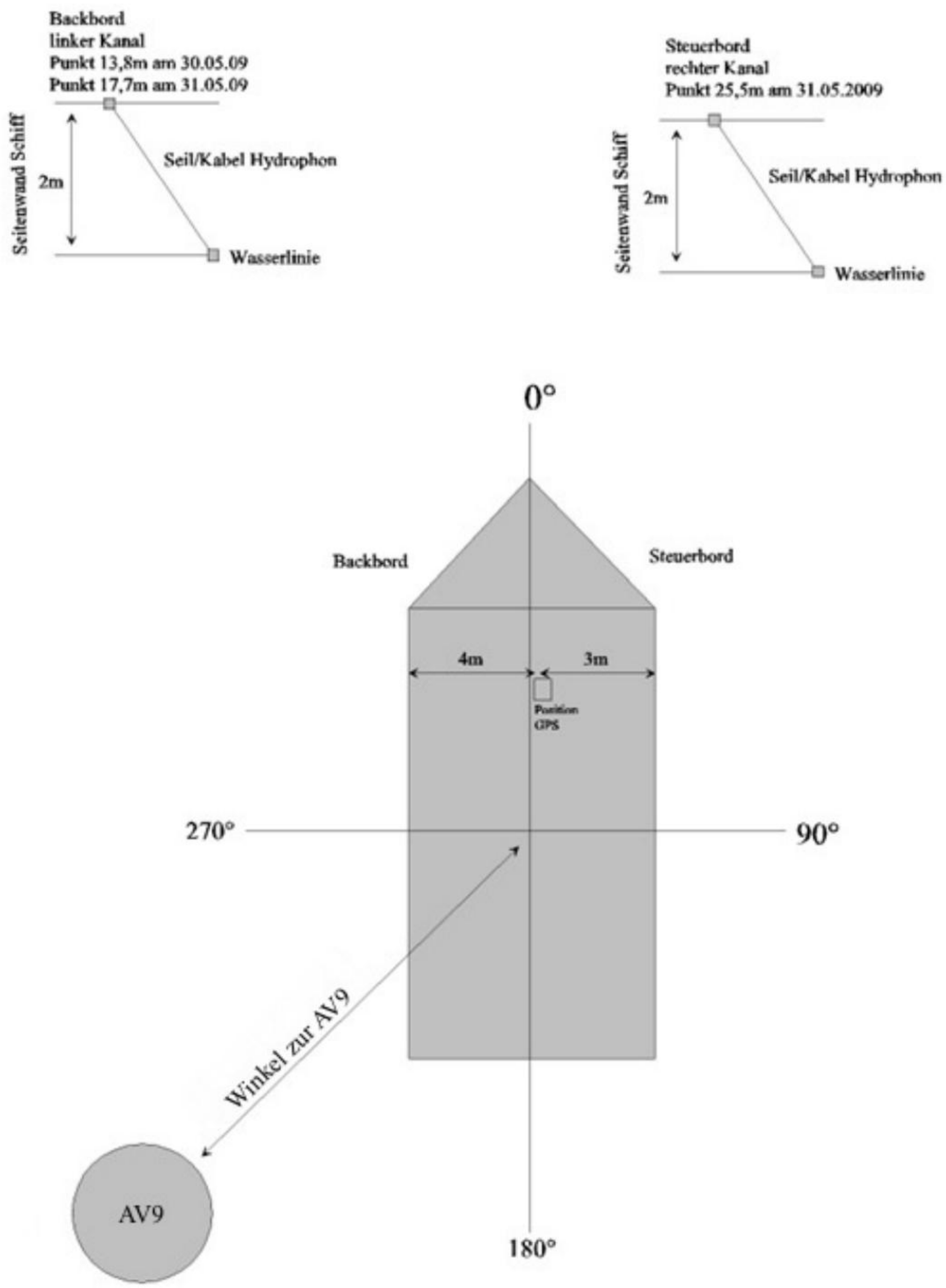

Fig. 5-4: Sketch of the measurement geometry (without scale, DEWI)

The depth of immersion of the hydrophone was approximated from the logged angle of immersion of the hydrophone cable. Depending on the current, the vertical immersion depth varied in the range of approx. 10 to 16 m.

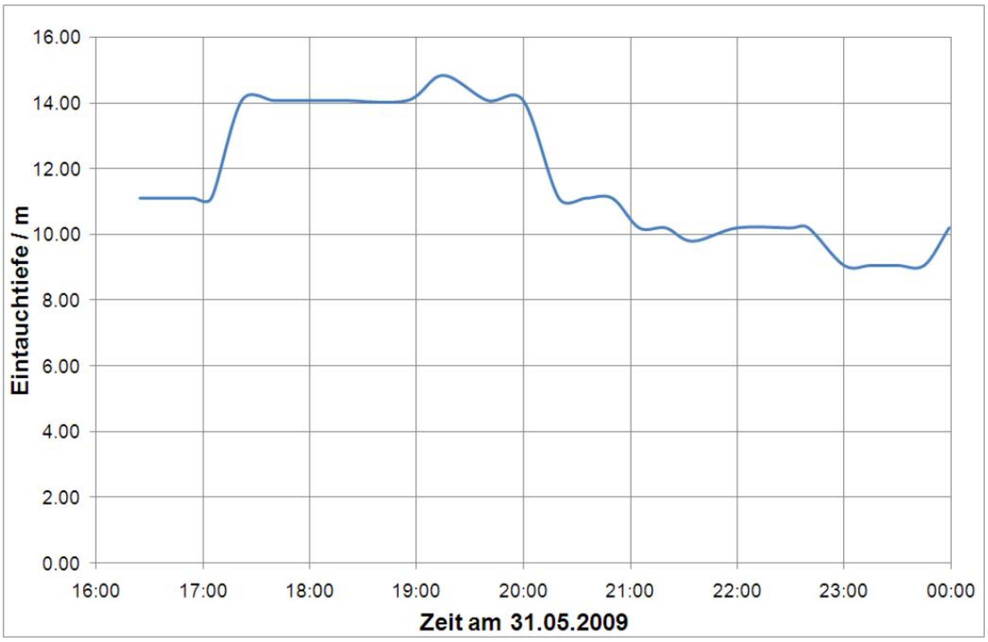

Fig. 5-5: Depth of immersion of the hydrophone (DEWI)

Figure 5-6: Hydrophone with protective cage and weight (DEWI)

Figure 5-7: Hydrophone cable on the ship's side (DEWI)

The hydrophone signal was recorded with an audio recorder for laboratory evaluation. The signal from the hydrophone calibrator (250 Hz) was also recorded for each measurement setup. At the same time, the currently measured levels were recorded as 1-second mean values of the equivalent continuous sound level by a class 1 calibrated sound level meter and the instantaneous values were displayed.

With the exception of 5 minutes (10:04 p.m. to 10:09 p.m.), the entire ramming action was continuously recorded and documented. The impact frequency varied in the course of the construction work in the range of approx. 34 to 44 impacts per minute (counted).

The following diagrams show the results of the level evaluations for the time ranges 4:20 p.m. to 5:30 p.m. (east current) and 8:55 p.m. to 9:36 p.m. (west current).

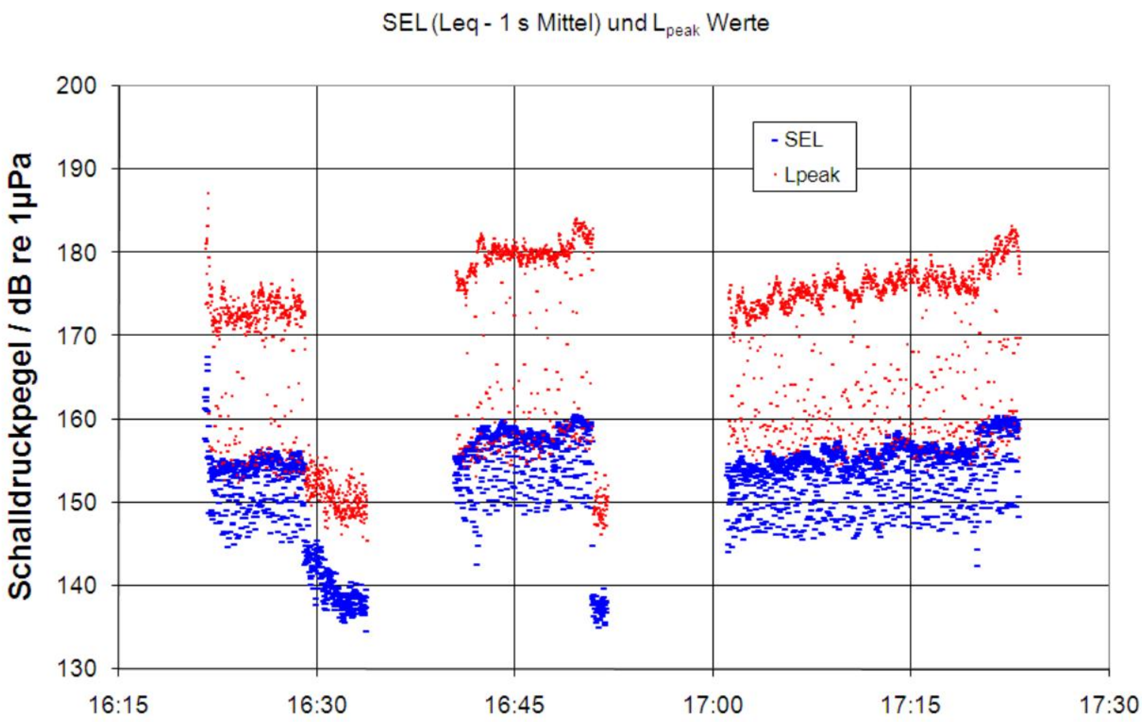

Fig. 5-8: 1-second mean values of the measured sound pressure levels at 4:20 p.m. - 5:30 p.m. (DEWI)

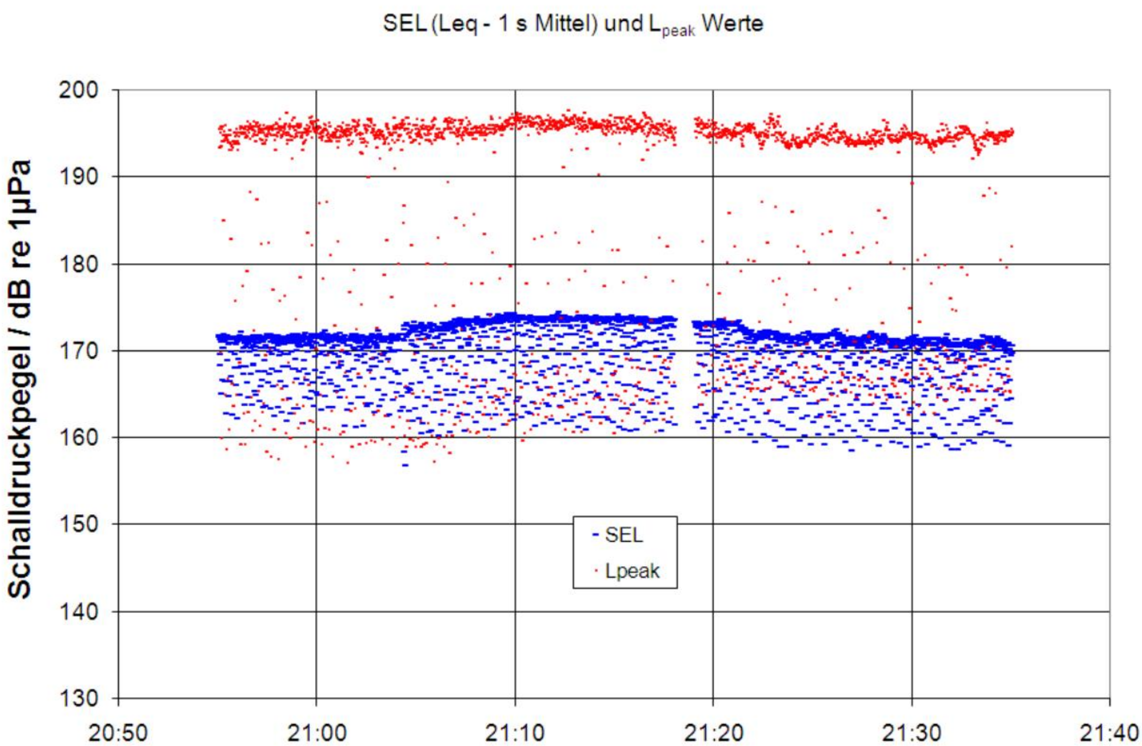

Fig. 5-9: 1-second mean values of the measured sound pressure levels at 8:55 p.m - 21:36 Uhr (DEWI)

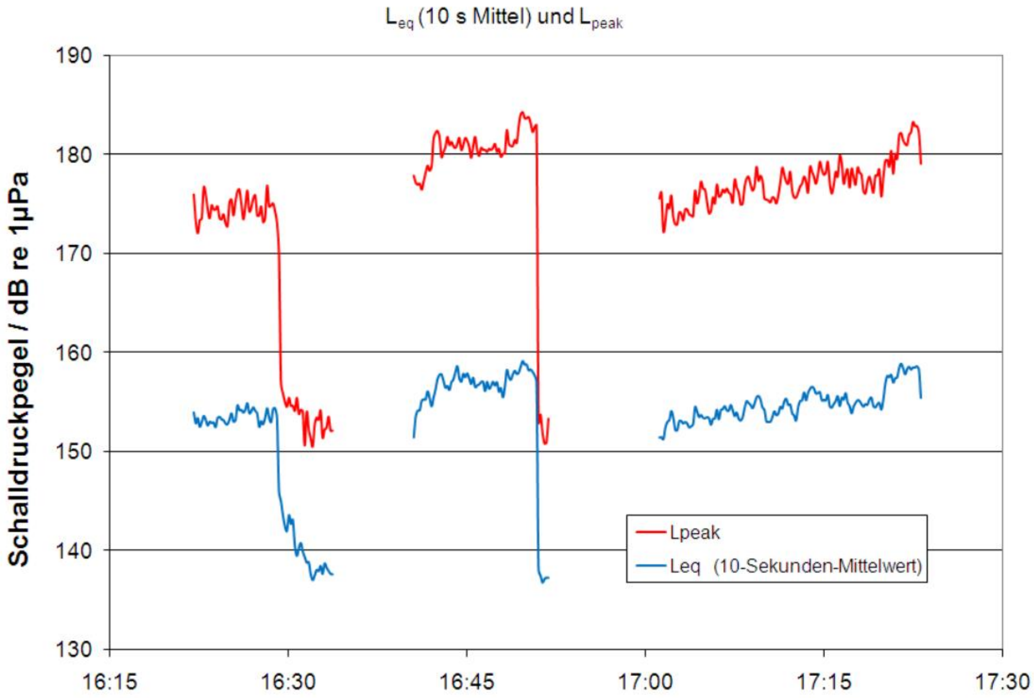

Figure 5-10: 10-second mean values of the equivalent continuous noise level and peak values (Measurement time: 4:20 p.m. to 5:30 p.m., DEWI)

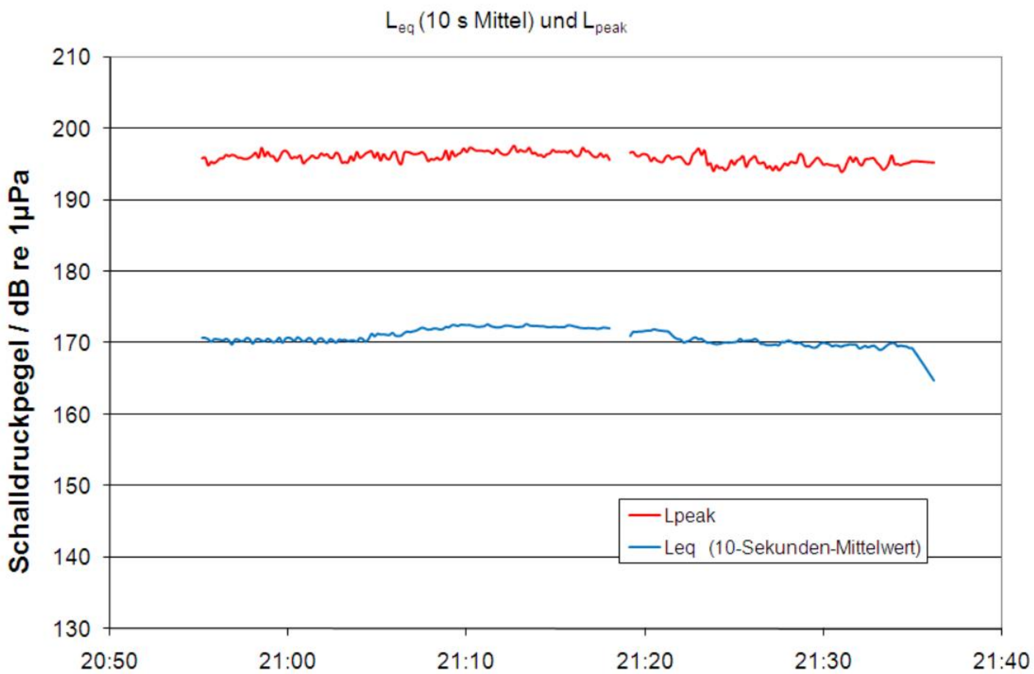

Figure 5-11: 10-second mean values of the equivalent continuous noise level and peak values (Measurement time: 8:55 p.m. to 9:36 p.m., DEWI)

frequency analyses

The following images show frequency analyzes of the piling noise measured east of the emission site. Three significant periods of time are considered as examples, which are characterized by the following flow conditions and operating states of the bubble curtain:

1. **From 4:25 p.m**

   West-East flow (many bubbles in the sound propagation path)
   OS operational

2. **From 21:00 east-**

   west flow (few bubbles in the sound propagation path)
   OS operational

3. **From 21:16 east-**

   west flow (few bubbles in the sound propagation path)
   OS out of order

Figures 5-12 to 5-14 show narrowband spectra for these three time ranges.

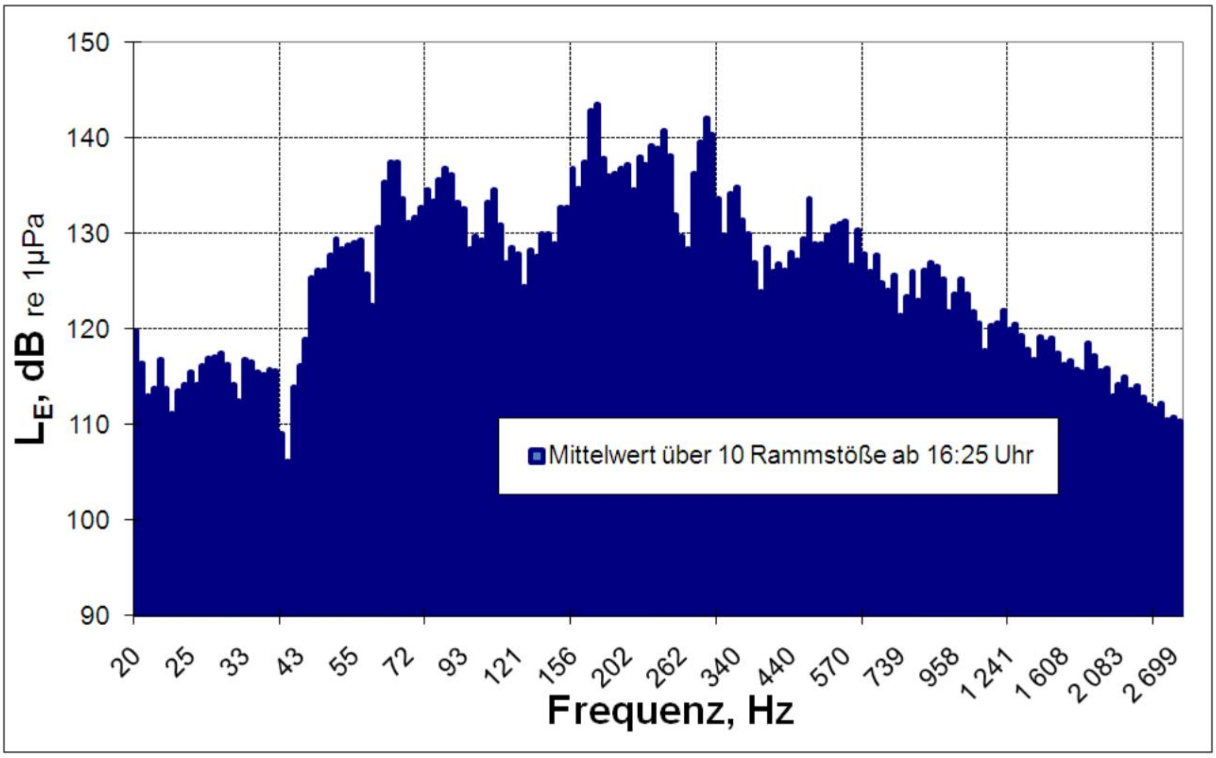

Fig. 5-12: 1/24 octave spectrum of the ramming noise from 16:25 (WO, BS on, DEWI)

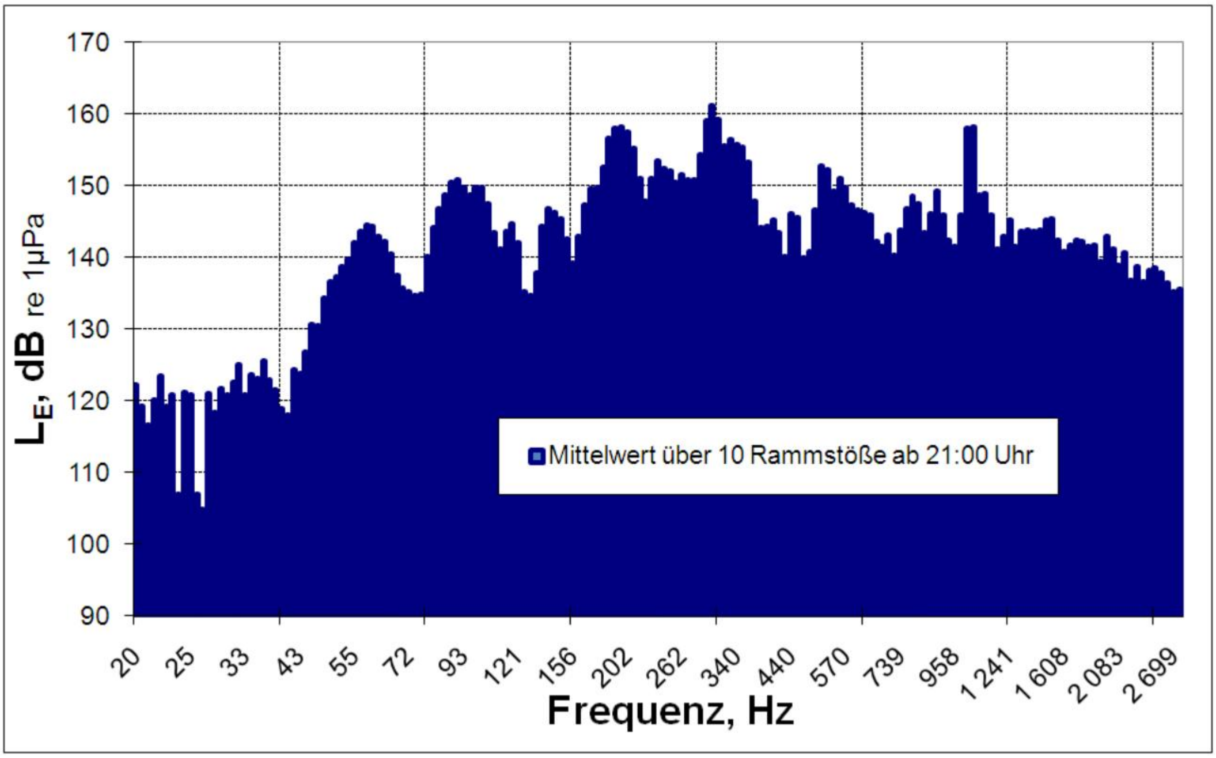

Fig. 5-13: 1/24 octave spectrum of the pile driving noise from 9 p.m. (OW, BS on, DEWI)

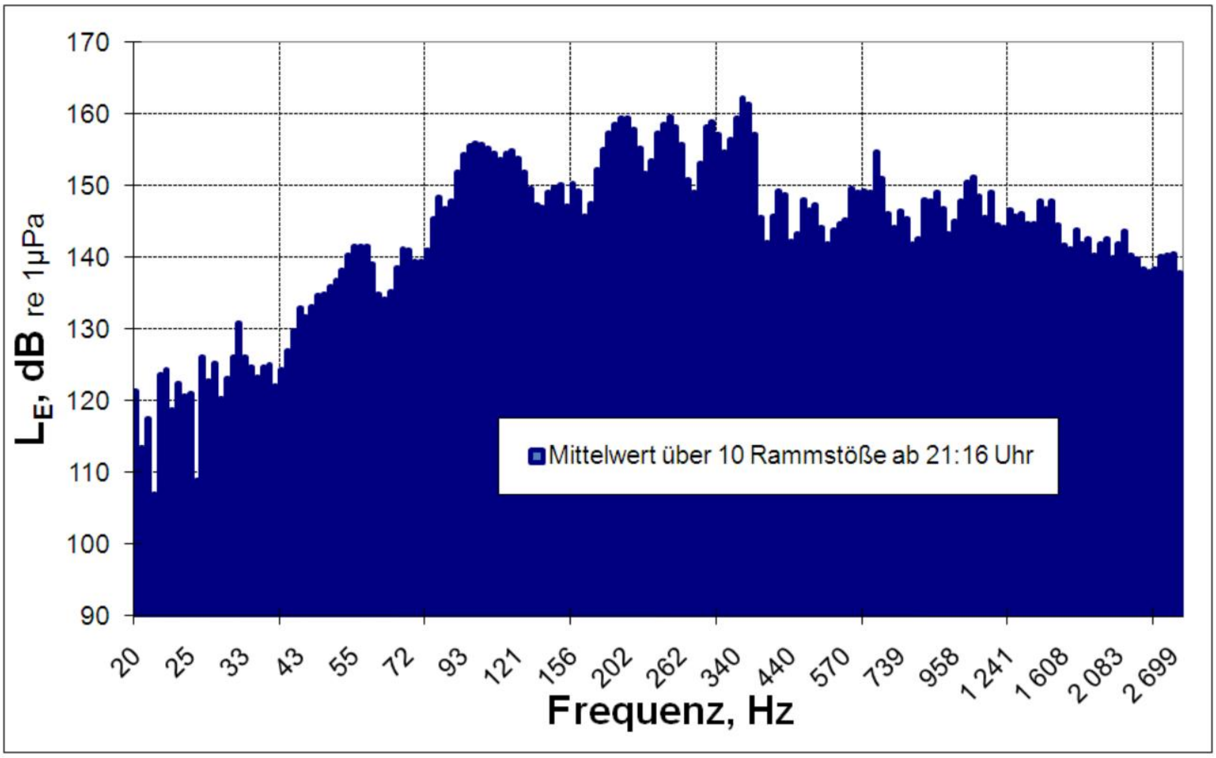

Fig. 5-14: 1/24 octave spectrum of the pile driving noise from 9.16 p.m. (OW, BS off, DEWI)

The tonal component at approx. 1 kHz, which can be seen in Fig. 5-13, is an anomaly. The corresponding spectral lines emerge when the bubble curtain is in operation and are inconspicuous when the compressors are switched off. This effect can also be seen in the third-octave spectra shown in Fig. 5-16. The bubbles were driven out of the sound path by the east-west flow that prevailed in this time period. In the 1 kHz third-octave band, the operation of the bubble curtain even leads to a level increase of approx. 5 dB. However, the 1kHz frequency band does not determine the level of the total level of the piling noise and is in any case not relevant for the damping behavior of the bubble curtain without the influence of sea currents.

Figure 5-15 shows the mean value (thick line) and the third-octave spectra of the individual impacts (thin lines) of the pile-driving noise measured from 1625 onwards. Due to the tidal flow direction, the bubble entry in the sound propagation path was significant in the analyzed time range. For these flow conditions, there is no comparative measurement data for the ramming noise without bubble curtain, since the compressors were operated continuously in the corresponding time range. A comparison with the other measurement positions is given in the corresponding chapters of this report.

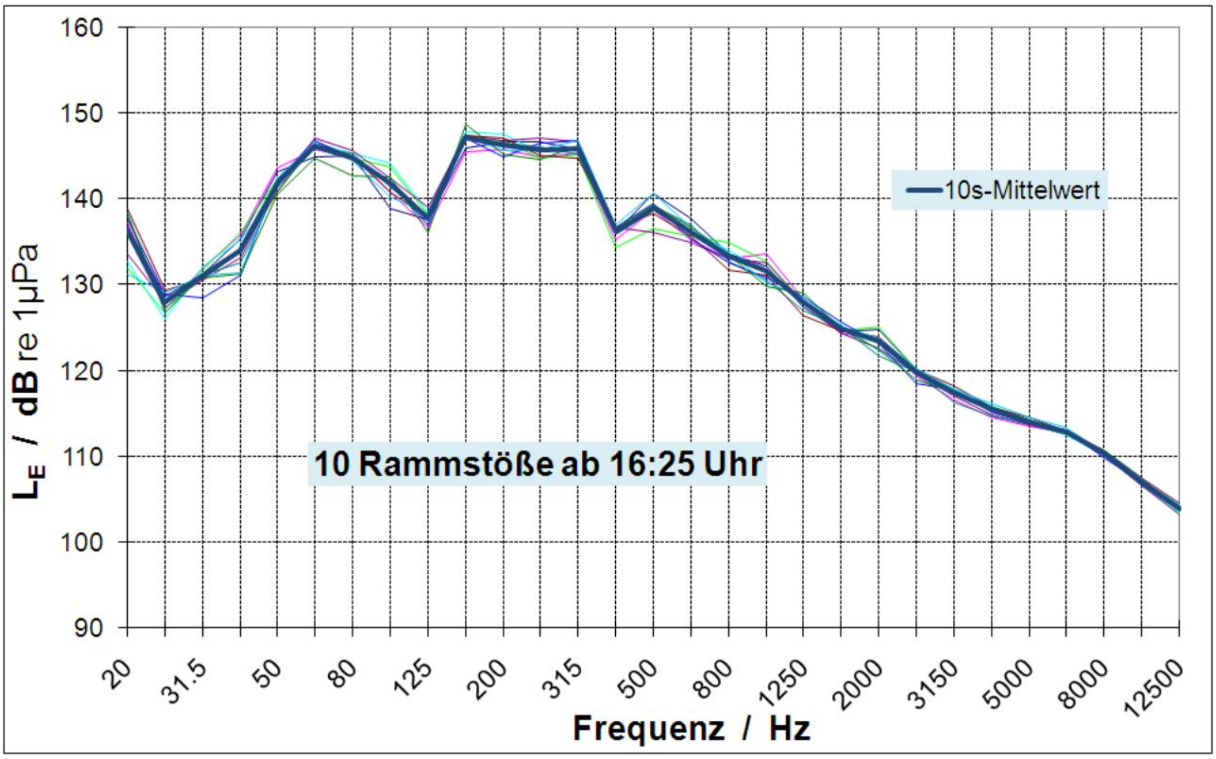

Fig. 5-15: Third-octave spectra of the piling noise from 4:25 p.m. (WO, BS on, DEWI)

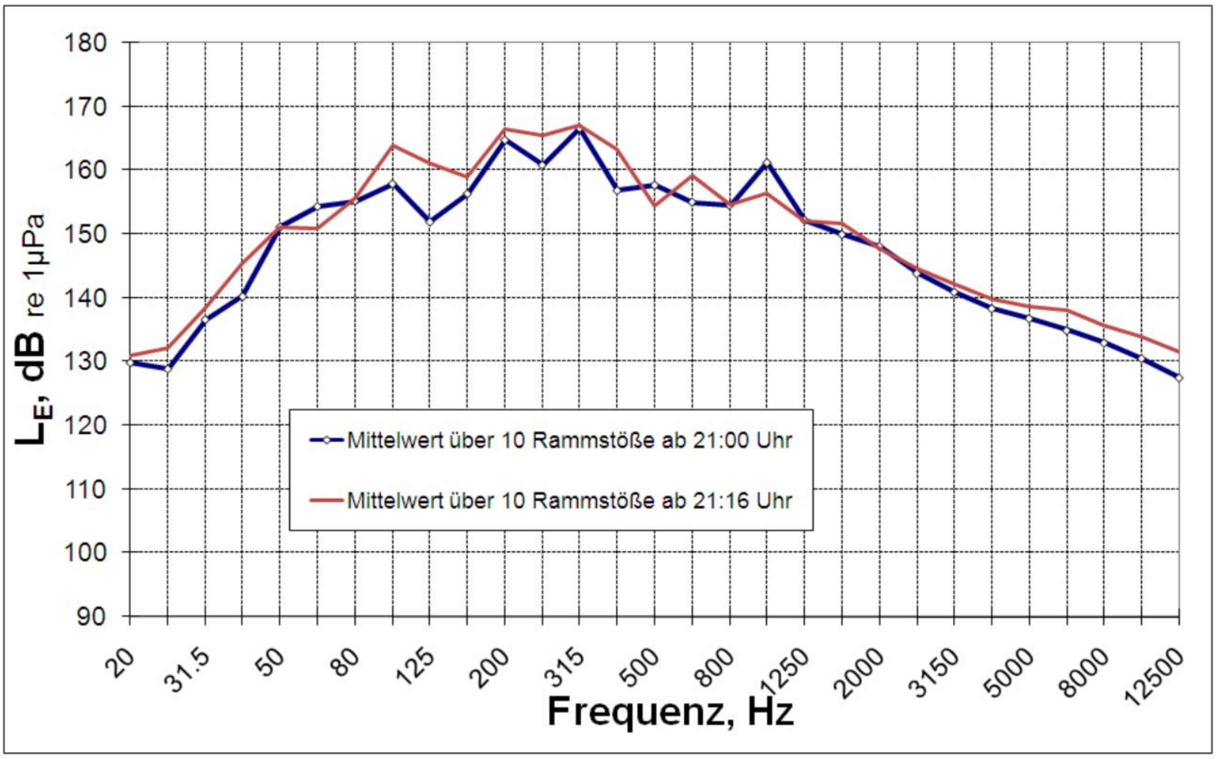

Fig. 5-16: Third-octave spectra of the ramming noise from 9:00 p.m. (LBC "on") and 9:16 p.m. (LBC "off") (DEWI)

5.3.2 Measurement 500 m west of the point of emission

by Klaus Betke (ITAP)

The ship ***Arne Tiselius*** **was deployed at this position with measurement teams from ISD and itap. First, a position about 500 m west-southwest of the construction site was assigned, from which an undisturbed measurement should be possible during the entire piling work and which** ***Arne Tiselius*** **therefore anchored. However, this position had to be cleared on May 31, 2009 at 6 p.m. CEST to allow** the cable-laying vessel ***Stemat 82*** to pass through. **Due to the change to the new position about 500 m west-northwest of the construction site, the measurement had to be interrupted for about an hour (Fig. 5-17).**

Due to the change of location and the effect of the tidal current on the anchored ship, the distance to tripod AV9 fluctuated between 460 m and 560 m. From 2000, when a stable westward current had developed, the distance was constant at around 550 m.

When measuring itap, a Reson TC4033 hydrophone was used at a depth of 10 m with a Brüel & Kjaer 2635 measuring amplifier. The signal was recorded with a Tascam HD-P2 recorder with a sampling frequency of 96 kHz. The usable frequency range was about 10 Hz to 40 kHz. A second measuring system was operated at the same time as redundancy, with a hydrophone Reson TC4033 at a depth of 6 m. The further measuring chain consisted of a measuring amplifier Metra M68D1 and a recorder Marantz PMD670. The recording bandwidth was 10 Hz to 22 kHz.

A program written in MATLAB was used for the evaluation. The signals were divided into sections of 30 s duration and for each section Lpeak, Leq and

SEL calculated. The SEL was **determined from the Leq** according to Equation 5.2.5, with the number of piling blows in each 30-second interval being counted by the program using a simple threshold detector. **For adjustment, the signals were checked visually in a wave editor (Adobe Audition 1.5) and a suitable threshold value was read off.**

A 1/3 octave spectrum was also calculated for each interval. Figure 5-18 shows the spectra determined when driving the north-east pile. At the time of the recording, the tidal current was moving in a westerly direction, so that there was a lot of bubbled water between the ramming pile and the measuring position and a clear level difference between ramming with and without air bubbles.

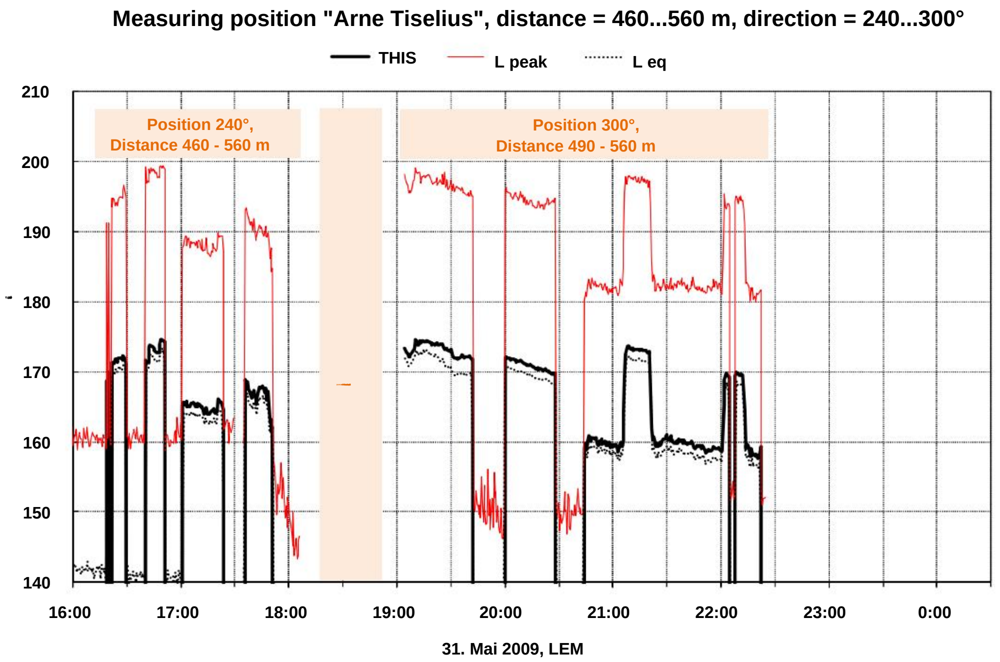

Fig. 5-17: Level course (itap) measured about 500 m west of the construction site

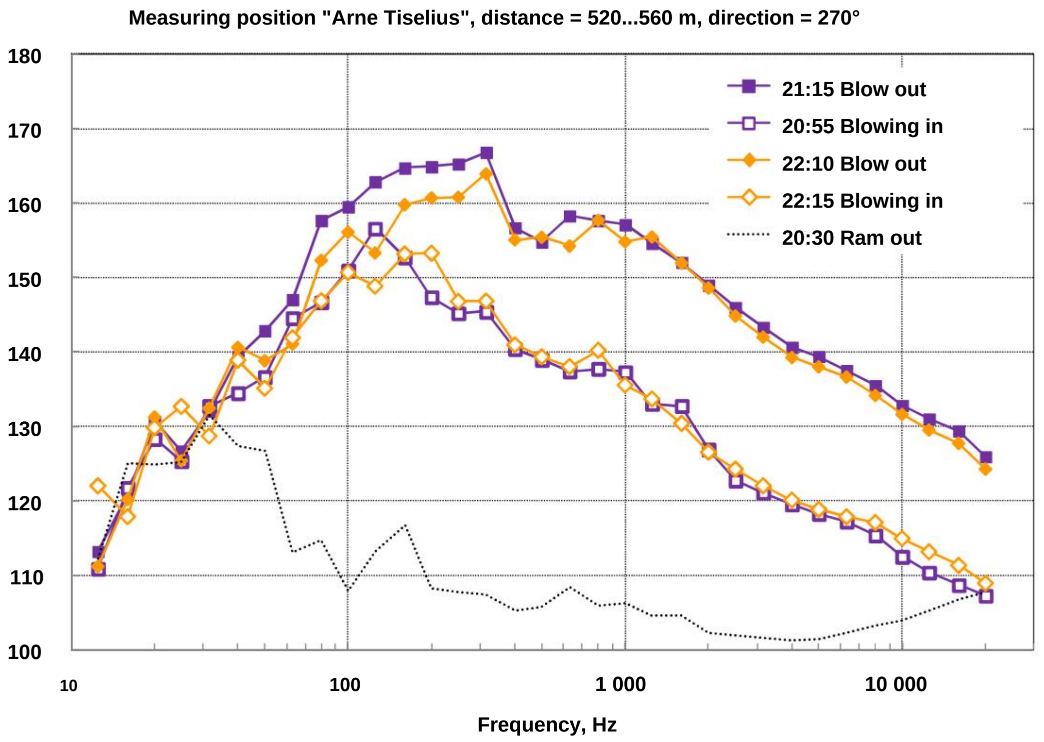

Fig. 5-18: Spectra of the sound signal when ramming the southeast pile of AV9 (itap).

In Fig. 5-18, the "ram off" curve shows the state during a pause in ramming with the bubble curtain switched on, ie the background noise caused by ships and aggregates in the construction site area. Inherent noise from the bubble curtain could not be identified in this environment.

5.3.3 Other measuring points

by Klaus Betke (ITAP)

Underwater noise was measured at various points during the construction phase as part of the ecological studies accompanying alpha ventus. For this purpose, autonomous recording devices were used (Betke & Matuschek 2010). The devices were installed at the positions of porpoise detectors (PODs) at their moorings laid out in the sea area (Diederichs et al. 2009).

Such measurement buoys were in operation at two locations to the west of the construction site during the piling work on AV9:

- POD T4, 54°00.23'n 06°35.00'e, distance to AV9 = 2400 m, direction = 260° - POD T10, 53°59.25'n 06°21.60'e, distance to AV9 = 17.5 km, direction = 263°

Another measurement buoy was placed at POD position T3, 54°00.25'n 06°37.78'e, about 800 m southeast of AV9. Apparently, however, a few days before the work at AV9 began, the system was struck by an anchor from a construction vehicle and damaged. Among other things, the cable with the hydrophone was torn off and the POD system, together with the anchor stone weighing around 800 kg, was pulled several hundred meters from the target position.

The hydrophone was about 1.5 m above the sea floor. The devices continuously recorded time signals (divided into 2-hour sections for better manageability). The procedure described in section 0 was used for the evaluation. The level-time curve for the measuring point T4, 2400 m away, is shown in Figure 5-19. At measuring point T10 (Fig. 5-20), 17 km away, the SEL was not evaluated because the sound level with the bubble curtain was not high enough above the background level for reliable automatic detection and counting of the piling blows, especially from around 9 p.m. Of course, at this measuring point the numerical difference between SEL and Leq is the same as at the other positions, ie about 1.5 dB on average.

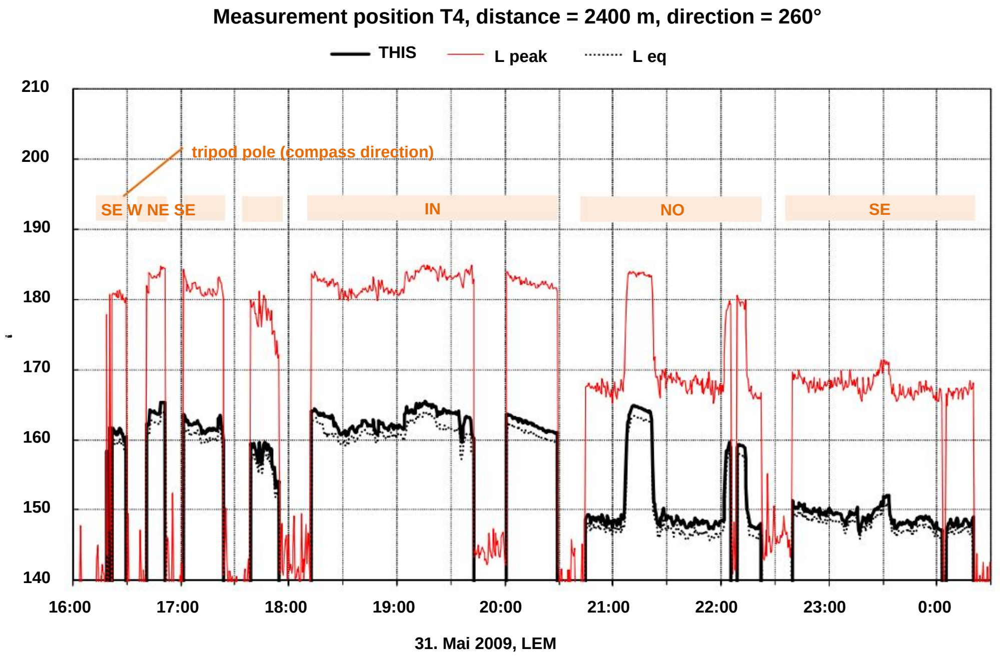

Fig. 5-19: Level course at a distance of 2.4 km from the construction site (itap)

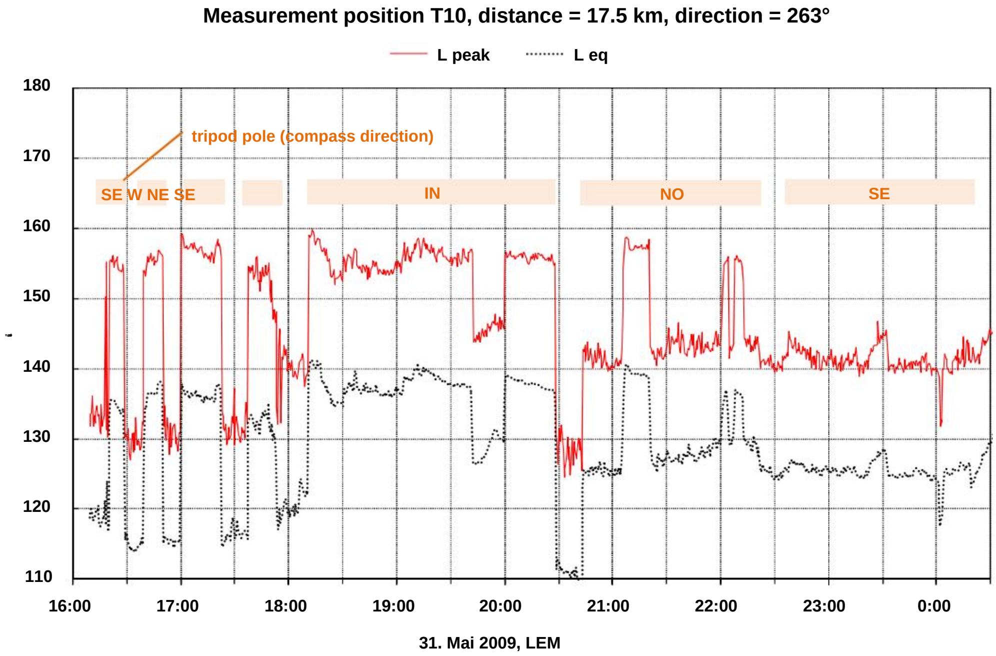

Fig. 5-20: Level course at a distance of 17.5 km from the construction site (itap)

In addition, the periods in which the south-east pile was rammed (marked "SE" in Figure 5-19) were extracted from the level-time curve for the 2400 m to the west measuring point T4, and a level statics were drawn up (Figure 5-21). For the SEL, there is an accumulation at 150 dB and a smaller local maximum at 160 dB. The first maximum can be assigned to the ramming after 10:30 p.m. local time and west current, the smaller maximum to the period between 4 p.m. and 6 p.m. when the bubble curtain drifted away due to the east current.

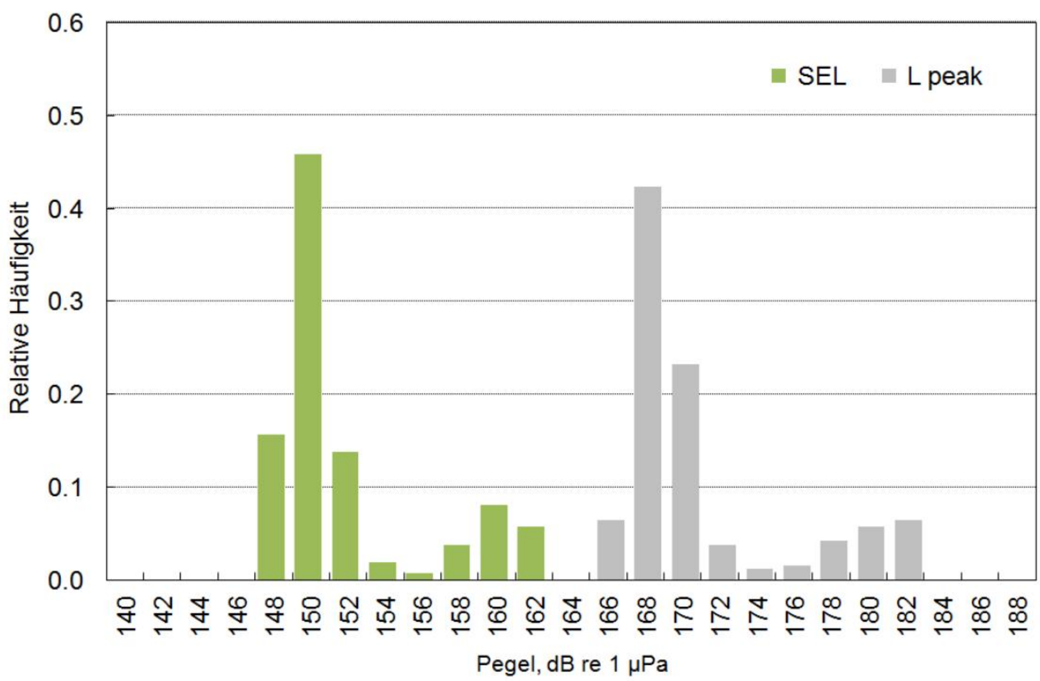

Fig. 5-21: Frequency distribution of single event level (SEL) and peak level (Lpeak) when driving the southeast pile, measuring point T4 at a distance of 2.4 km, data from Fig. 5-19 (itap)

5.4 Results

by Jörg Rustemeier (ISD)

In order to be able to record the different influences such as ramming energy, current and operating status of the bubble curtain on the sound pressure level, the data were displayed on a common time basis (CEST) (Fig. 5-22).

Frame energy

The ramming energy and its allocation to the three piles of the tripod could be taken from the MENCK company's ramming report. The course of the ramming energy over time is shown in Figure 5-22 (above). The three driven piles are colour-coded, of which piles no. 2 and 3 (northeast and south-east piles) are provided with the pre-installed bubble curtain. The west pole (pole 1) does not have a bubble curtain installed (red dashed line).

Between 1620 and 1800 (CEST) the tripod was aligned with four impact groups, with only ramming above the waterline. From around 6:10 p.m. to 8:30 p.m. the west pile (pile 1) was driven down to the final depth. During the break in driving at 19:45, the penetration depth of the pile was determined with the help of an underwater robot. Furthermore, from about 8:40 p.m. the northeast pile (pile 2) and from about 10:40 p.m. the southeast pile (pile 3) were driven down to the final depth.

Operating status of the bubble curtain

Since the two mobile subsystems of the bubble curtain could not be installed due to the weather, only the two subsystems pre-installed on the pilesleeves were put into operation. These are four nozzle pipe rings each with a maximum diameter of eight meters, which are located in the lower quarter of the water column. Because only about a third of the nozzle pipe length had to be supplied with compressed air due to the omission of the mobile systems, only one of the two compressors (flow rate approx. 45 m^3/min) could be used. Since no intermediate states could be set, it was not possible to vary the amount of compressed air.

The operating status of the bubble curtain is shown in Figure 5-22 (centre). The associated ordinate is on the right. The compressor was switched off three times during pile driving:

- **At approx. 19:45 (measurement of the penetration using an underwater robot)**
- **At approx. 21:06 (evaluation of the effect of the bubble curtain)**
- **At approx. 22:01 (refueling the compressor)**

Evaluated sound pressure level

The sound pressure curves were recorded by the ISD (western position, see Fig. 5-1) and by the DEWI (eastern position) with hydrophones (see Section 5.3). The individual ramming impacts were detected in these sound pressure curves. The peak sound pressure level (Lpeak) and the single-event sound pressure level (Sound exposure level, SEL) were calculated according to Formula 5.2.4 for each ramming blow according to Formula 5.2.7. In Fig. 5-22 (centre) the peak and individual event levels of the ISD and DEWI are shown as a point for all pile driving impacts evaluated.

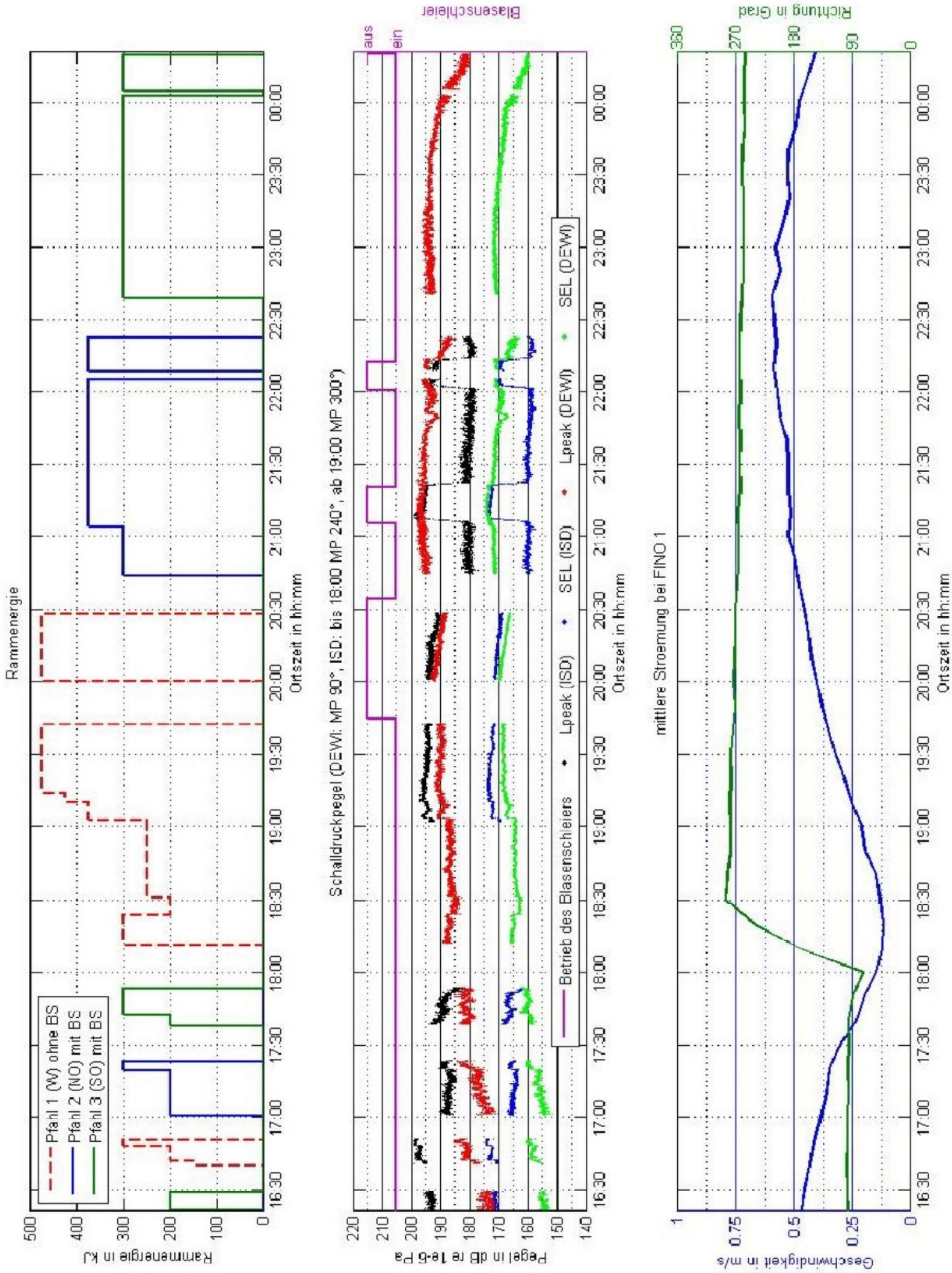

Fig. 5-22: Representation of the ramming energy over time (top), the operating status of the bubble curtain and the evaluated sound pressure level (middle) as well as the mean current at FINO1 (bottom) (ISD)

Influence of the distance from the sound source on the sound pressure levels

When comparing the sound pressure levels evaluated by ISD/itap and DEWI, the different distance from the sound source must be taken into account. The level difference due to different distances can be simplified with the formula

$$ÿ L = k \log10(RW/RO) \quad 5.4.1$$

(from Elmer, Betke and Neumann (2007), page 37) can be estimated. At around 17:00, the measurement distances to the sound source were approximately RW = 490 m in the west and RO = 770 m in the east. With k = 15, a level difference of about -3 dB is obtained. So, to account for the range error, the ISD/itap sound levels must be reduced by 3 dB or the DEWI sound levels increased by 3 dB. From around 9:00 p.m. the measurement distances were around RW = 550 m and RO = 650 m. The level difference due to different distances is then around -1 dB. Other influences of local conditions such as the influence of the location of the jack-up platform, the tripod construction, the water depth or the seabed cannot be taken into account when comparing the noise levels.

Medium flow at FINO1

The current data were collected by the Federal Maritime and Hydrographic Agency (BSH) near the research platform *FINO1* (research platforms in the North Sea and Baltic Sea). The amount and direction of the current were recorded at different depths, each one meter apart, with a time resolution of ten minutes.
The data was averaged over water depth and plotted over time in Figure 5-22 (below). The flow velocity ordinate is on the left edge and the flow direction ordinate is on the right edge. A flow direction of z. B.
90 degrees means that the bubble curtain's air bubbles are blown off to the east.

5.4.1 Impact of ramming energy on the level of the sound pressure level

The influence of the ramming energy can be seen most clearly during the ramming of the west pile between 4:40 p.m. and 4:51 p.m., since the measured values here show a comparatively small scatter. During this period, an only slightly decreasing easterly flow of about 4 m/s was measured at FINO1 (see Fig. 5-22). The air bubbles generated at the two east poles are therefore expelled to the east (see Fig. 5-23). It can therefore be assumed that there are no air bubbles from the bubble curtain between the west pile that was driven in and the measuring position in the west (ISD/itap). Figure 5-24 shows the course of the ramming energy and the sound pressure level recorded and evaluated by the ISD at the western measuring position.

The ramming energy was increased in two stages from 150 kJ to 200 kJ to 300 kJ. Assuming that the course of the sound energy is proportional to the course of the piling energy, the expected sound pressure level difference satisfies the equation

$$ÿ L = 10 \log10(E2/E1) . \quad 5.4.2$$

Fig. 5-23: Drift of the bubble curtain at 16:43 (CEST), on the left edge of the picture the northeast pole behind the yellow painted ladder of the tripod, on the lower edge of the picture the Southeast Stake (ISD)

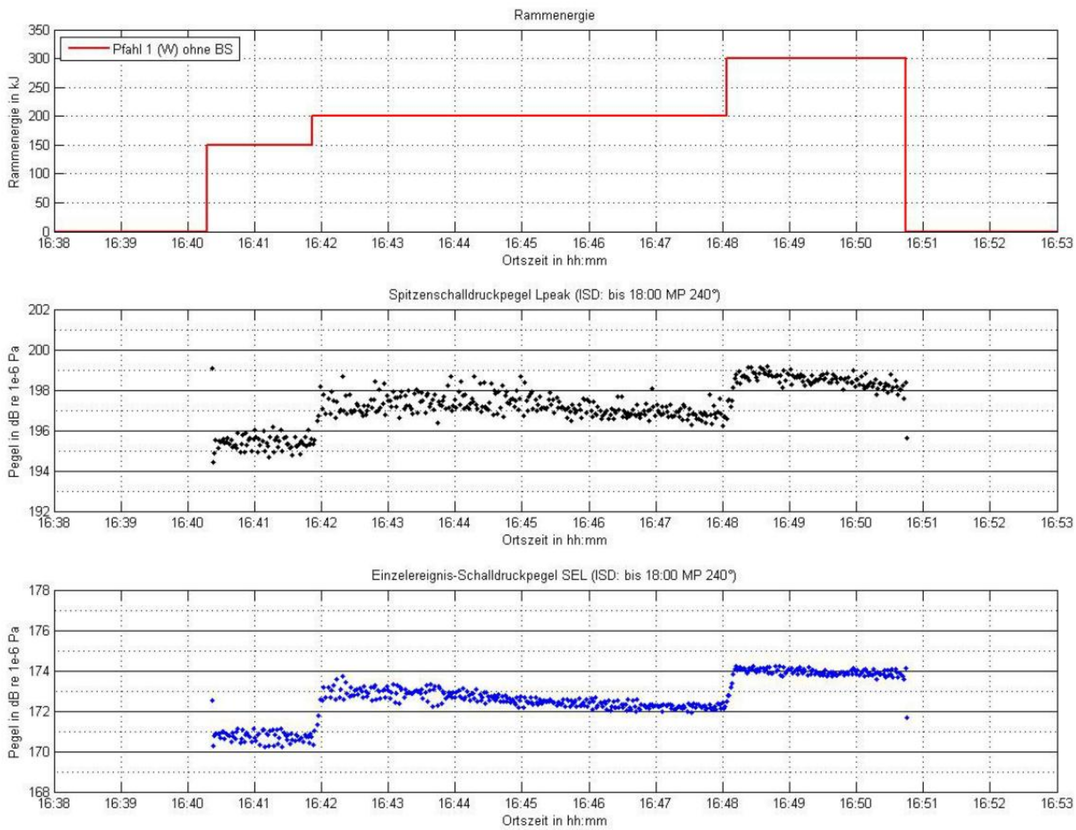

Fig. 5-24: Course of the driving energy when driving the west pile (top), recorded and evaluated sound pressure levels Lpeak (middle) and SEL (bottom) (ISD) in the west

From this follows an expected sound pressure level difference of 1.25 dB for the jump from 150 kJ to 200 kJ in the course of the piling energy and a sound pressure level difference of 1.76 dB for the jump from 200 kJ to 300 kJ.

From the measurement data obtained, 20 ramming blows before and after each jump were averaged. At 1642, the mean single-event sound pressure level (SEL) increased from 170.7 dB to 173.0 dB (see Figure 5-24). The difference is therefore 2.3 dB and is therefore above the expected difference of 1.25 dB. It should be noted that the measured values at this point in time are still relatively widely scattered.

During the second increase in ramming energy at around 1648, the mean SEL increased from 172.2 dB to 174.0 dB with a significantly lower scatter (see Fig. 5-24). The difference of 1.8 dB corresponds to the expected sound pressure level difference.

5.4.2 Noise-reducing effect of the bubble curtain

After switching off the compressors, it takes a while for the small air bubbles to rise to the surface of the water. During this time, the sound pressure levels scatter relatively strongly. Therefore, the noise-reducing effect of the bubble curtain can be determined most reliably when the bubble curtain is switched on at around 9:21 p.m. and 10:13 p.m. At these times, the ramming energy remains constant at 375 kJ. The flow measured at FINO1 is between 0.5 and 0.6 m/s with a slightly increasing trend (see Fig. 5-22). The current runs in a westerly direction (Fig. 5-25).

Fig. 5-25: Drift of the bubble curtain at 21:28 (CEST), on the right edge of the picture the main tube of the tripod, behind it the ram driving the northeast pile (ISD)

Other influences on the hydronoise level include the penetration depth of the driven pile and the fluctuating measurement distance due to the swaying of the research vessels. In order to minimize these influences, two temporally adjacent points in time are evaluated at which the bubble curtain was switched on and off. Figure 5-26 shows the operating status of the bubble curtain and the sound pressure levels **Lpeak** and SEL **evaluated in the measuring positions east (DEWI) and west (ISD) between 20:42 and 22:25. For the evaluation of the sound-reducing effect of the bubble curtain were to the**

80 ramming blows were averaged at 9:19 p.m., 9:24 p.m., 10:11 p.m. and 10:15 p.m. The averaged levels are listed in Table 5-2. Table 5-3 shows the differences in the respective sound levels between switched off and switched on bubble curtain.

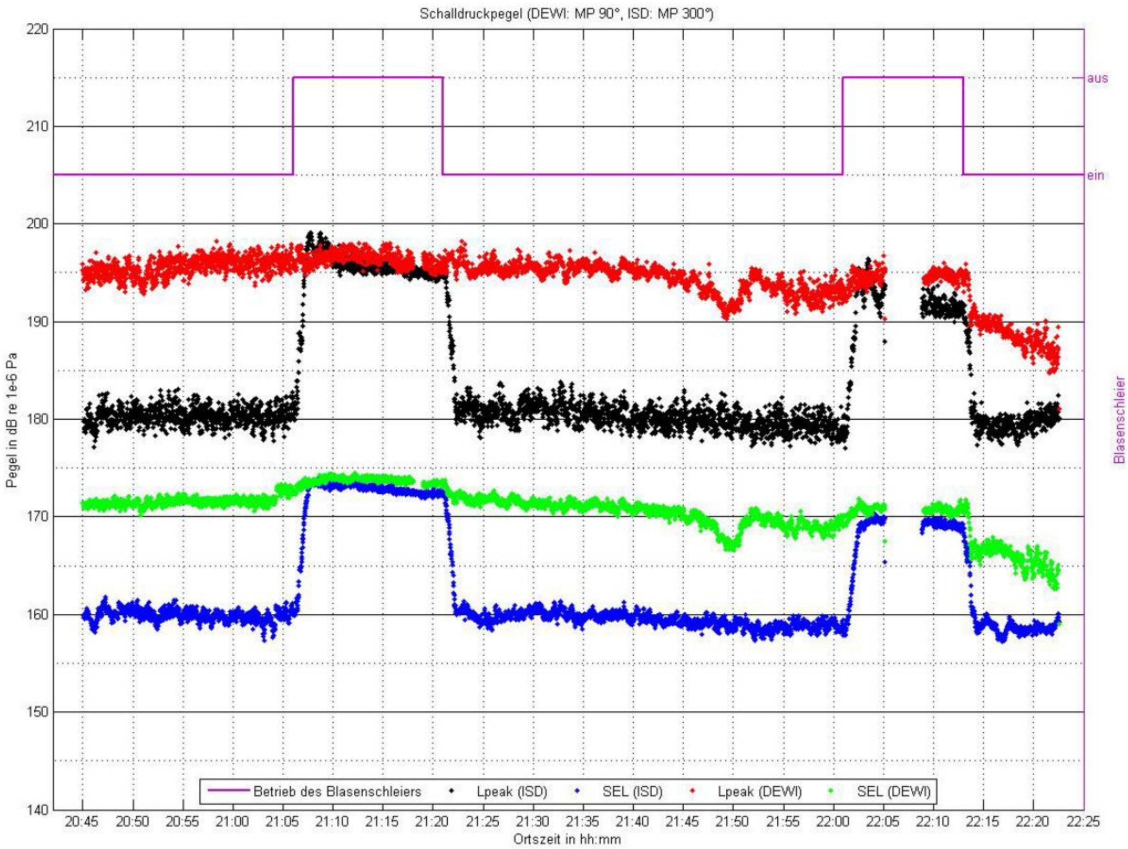

Fig. 5-26: Operating status of the bubble curtain and evaluated sound pressure level (ISD)

Table 5-2: Mean values from 80 ramming blows before and after the bubble curtain was switched on again

time	operating status of bubble curtain	Lpeak (West) in dB re 1 μPa	SEL (West) in dB re 1 μPa	Lpeak (Ost) in dB re 1 μPa	SEL (Ost) in dB re 1 μPa
9:19 p.m	Out of	194.8	172.4	195.8	173.4
9:24 p.m	A	180.7	159.4	195.5	171.8
10:11 p.m	Out of	191.3	169.1	194.7	170.6
10:15 p.m	a	179.2	158.7	189.8	166.9

Table 5-3: Level difference between switched off and switched on bubble curtain

Time of switching on the bubble curtain	ÿLpeak (West) in dB	ÿSEL (West) in dB	ÿLpeak (Ost) in dB	ÿSEL (Ost) in dB
approximately 9:21 p.m	14.1	13.0	0.3	1.6
about 10:13 p.m	12.1	10.4	4.9	3.7

It can be seen that the level reduction in the west is significantly greater than in the east. This can be explained by the westerly current. The air bubbles of the bubble curtain are driven westwards and form a closed bubble curtain over the water depth, which reduces the hydronoise radiated in this direction.

Due to the flow, only the air bubbles that are generated in the lowest quarter of the water column at the Pilesleeve are between the driven pile and the eastern measuring point. Shortly after leaving the nozzle pipes, the air bubbles are driven past the driven pile and are therefore unable to reduce the noise radiated against the flow direction.
The bubble veil therefore only protects the lower part of the water column in an easterly direction.

While the noise reduction in an easterly direction at 2121 can hardly be detected when the bubble curtain is switched on again, it is clearly recognizable at 2213. Here, the penetration depth of the driven pile must be taken into account. At 10:13 p.m. the driven pile almost reached its final depth. The length of the pile unprotected by the bubble curtain is therefore significantly less than before. Therefore, when the bubble curtain is switched on again, a reduction in level can be determined (see Table 5-3).

5.4.3 Effect of flow on sound pressure levels

While the effect of the bubble curtain can only be evaluated under approximately the same conditions with the compressor switched on and off, the sound pressure levels in the east and west are to be compared here with different flow speeds and directions. The level difference due to different measurement distances from the sound source must be taken into account. Other influences of the local conditions such as the influence of the location of the jack-up platform, the tripod construction, the water depth or the seabed cannot be quantified when comparing the sound levels, so that the sound level differences calculated here are subject to uncertainties.

The calculation of the level differences between the western and eastern measuring point is carried out taking into account the distance error (according to formula 5.4.1) with the equation

$$ÿ\, LW\text{-}O = LW - LO + 15 \log10(RW/ RO) \qquad 5.4.3$$

At the start of the piling work, there was a current in an easterly direction with an average current speed of around 0.45 m/s measured at FINO1 (see Fig. 5-22).

If the flow direction remains the same, the flow speed decreases monotonously until the backwater time at around 18:15. The range error over this period is approximately -3 dB (see above).

At the time of the backwater (Fig. 5-27), the west pile was rammed without a pre-installed bubble curtain. Therefore, no measurement results are available when driving a pile completely covered with air bubbles.

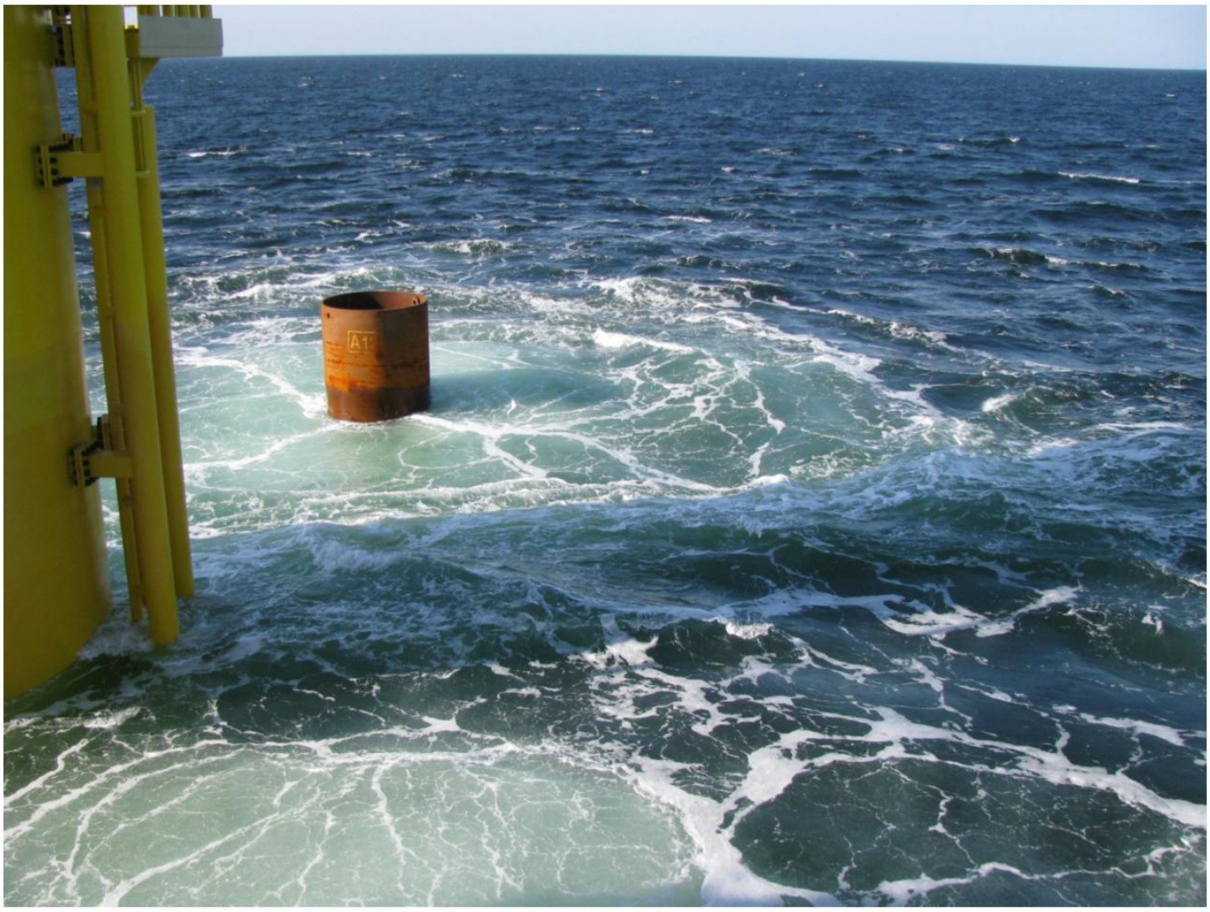

Fig. 5-27: Drift of the bubble curtain at 18:18 (CEST), on the left edge of the picture the main tube of the tripod, in the middle the northeast pole with bubble curtain, on the bottom Image edge of the Southeast Stake (ISD) bubble curtains

After the backwater point, the current changed to a westerly direction. The flow velocity increases up to the apex at around 22:30 and then decreases again (see Fig. 5-22). The range error is approximately -1 dB from 21:00 (see above).

The level differences according to formula 5.4.3 for different points in time can be found in Table 5-4. At all of these times, the bubble curtain was in operation on the north-east and south-east poles. Due to the early stages of the piling process, the length of the pile radiating noise in the water was approximately the same.

Table 5-4: Level difference depending on the flow speed and direction measured at FINO1

averaging period (CEST)	pile designation	flow speed and direction	Level difference ÿLpeak,WO	Level difference ÿSELW-O
16:22 - 16:29	southeast pole	0.45 m/s, Ost	16 dB	13 dB
16:42 - 16:48	Westpfahl	0.42 m/s, Ost	13 dB	11 dB
17:02 - 17:07	northeast pole	0.38 m/s, Ost	10 dB	8 dB
17:14 - 17:19	northeast pole	0.34 m/s, Ost	6 dB	5 dB
17:43 - 17:47	southeast pole	0.21 m/s, Ost	4 dB	3 dB
17:49 - 17:53	southeast pole	0.19 m/s, Ost	2 dB	2 dB
21:00 - 21:04	northeast pole	0.52 m/s, West	-17 dB	-13 dB

Table 5-4 makes it clear that the difference in the sound pressure level between the westerly and easterly direction of radiation decreases as the flow velocity decreases.
This can be explained by the more or less strong drifting of the bubble curtain as a result of the current. At a lower flow rate, fewer air bubbles drift past the driven pile than at a higher flow rate. If the entire driven pile is evenly enveloped in air bubbles at the time of backwater (see Fig. 5-27), it can be assumed that the effect of the bubble curtain is the same in all directions, i.e. the level difference is zero.

As stated in Section 5.4.2, the more air bubbles there are between the driven pile and the hydrophone, the lower the sound pressure levels. When the flow is in an easterly direction, the air bubbles are blown off to the east, so that the sound pressure levels are greater in the west than in the east. As Table 5-4 confirms, the level difference ÿLW-O is greater than zero in this case. On the other hand, if the air bubbles are driven west in a westerly flow, the sound pressure levels in the west will be lower than in the east. Then the level difference ÿLW-O is less than zero (see Table 5-4).

Overall, it can be stated that the noise reduction is greater the more air bubbles there are between the point of emission and immission.

5.5 Comparison with literature data and reference values

by Klaus Betke (ITAP)

5.5.1 Comparison with literature data

Table 5-5 and Figure 5-28 summarize data from some known implementations of bubble curtains.

Table 5-5: A comparison of some implementations of bubble curtains

construction	Diameter, m	Air supply, m³/ minute per m bubble veil	water depth, m	broadband reduction of Rammschall, dB	authors
1 Ring	50	0.25	6 - 8	3 - 5	Würsig et al. 2000
1 Ring	ÿ4	3.6	7 - 9	0 - 2	Illingsworth & Rodkin 2001
1 Ring, Blasen in textile sleeve				5-10	
2 rings, more vertical Distance 5m	ÿ6	14	7 - 9	3 - 10 (Leq) 9 - 17 (Lpeak)	reyff 2003
5 rings stacked vertically	Unknown. Pfahlø = 2.4 m	Unknown	Unknown	25 - 30	Rodkin & Reyff 2007
1 Ring	140	0.2 - 0.4	23	7 - 12	Griessmann et al. 2010 (FINO3)
4 rings on top of each other near the ground			27	1 - 15	alpha ventus "Little bubble curtain"

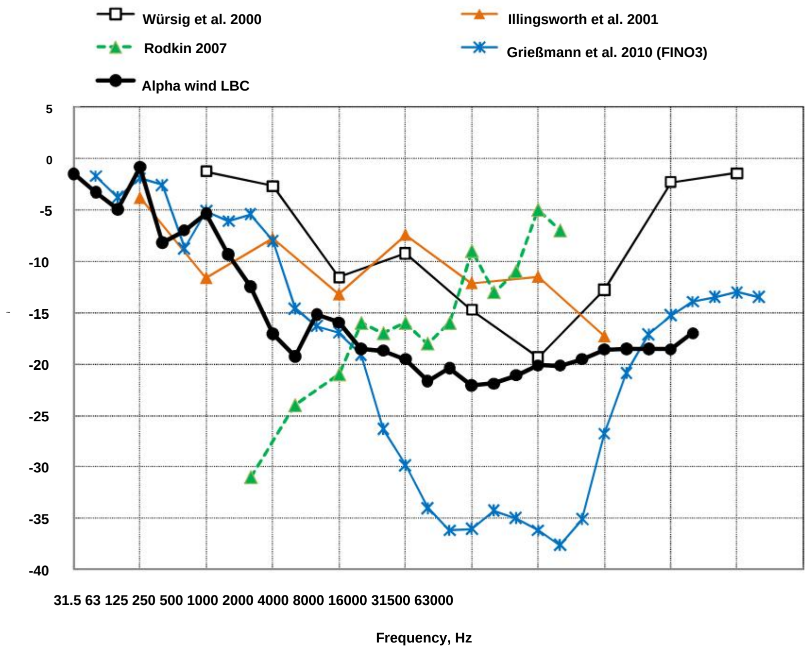

Fig. 5-28: Frequency-dependent effect of some bubble curtains compared to the stepped bubble curtain at alpha ventus.
FINO3 (Grießmann et al. 2010): Result of the measurement at a distance of 270 m. Alpha ventus LBC: Average curve from the measurements at 21:15 and 22:10, measurement location approx. 500 m west of the construction site

5.5.2 Comparison with UBA precautionary value

In order to prevent damage to harbor porpoises in the area of the construction site, the Federal Environment Agency (UBA) proposed a precautionary value. Accordingly, the broadband SEL of a single ramming blow should not exceed 160 dB re 1 µPa and the peak level 190 dB re 1 µPa at distances of more than 750 m. The UBA is of the opinion that damage is already the occurrence of a temporary increase in hearing threshold (temporary threshold shift, TTS). Figure 5-29 shows a statistical distribution of the SEL values. It was obtained from all recordings available from the two measurement positions "ship 500 m west" and T4, i.e. at position T4 for the ramming of all three piles, for the "ship" position as well, except for the final ramming of the south-east pile. The levels scatter over a fairly wide range; the UBA value is both significantly exceeded and undercut. The scatter is due, among other things, to the fact that the air bubbles temporarily had a shielding effect in the measuring direction, but not at other times. This can be seen from the level distribution when driving the south-east pile (open symbols in Figure 5-29, when the bubble curtain showed a good effect in the westerly direction. Table 5-6 shows the SEL values from Figure 5-29 together with the associated peak levels are listed.

"25%" means, for example, that the levels in this line are exceeded by 25% of all measured values.

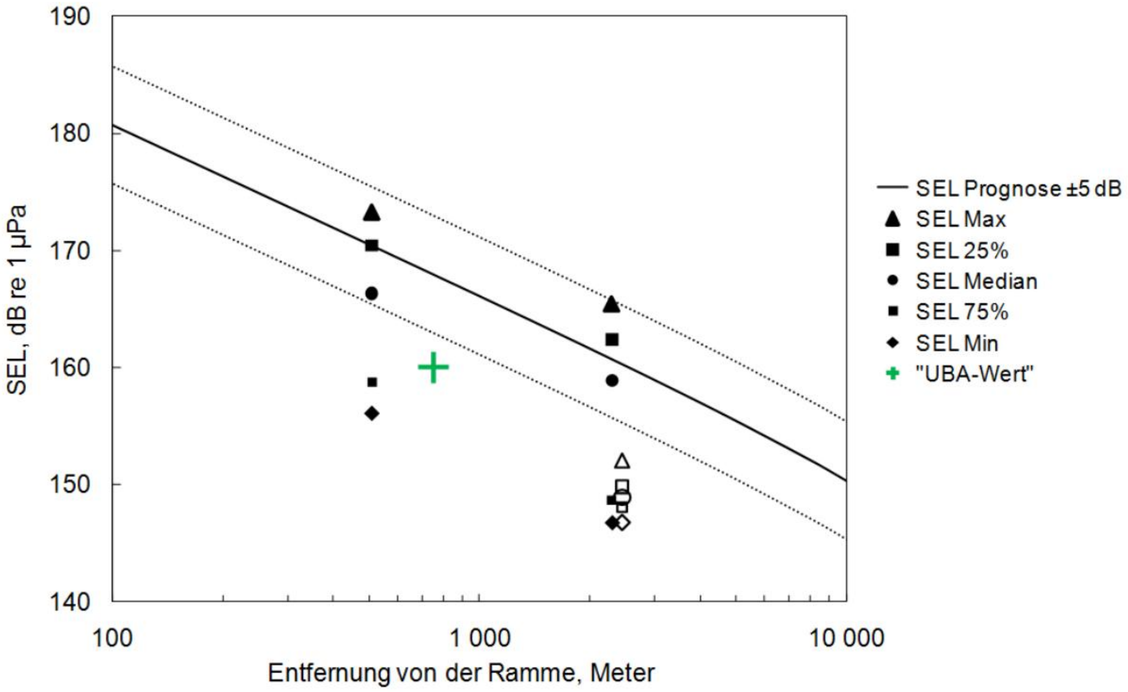

Fig. 5-29: Distribution of the individual event levels measured during the piling work on AV9 (Betke & Matuschek 2010) in comparison to the UBA precautionary value and a forecast made before the start of construction (Betke & Schultz-von Glahn 2008). Measurement from the ship at a distance of approx. 500 m and at position T4 at 2400 Open symbols: Southeast pole only (shifted horizontally a little for the sake of illustration).

Table 5-6: Distribution of broadband single event level (SEL) and peak level Lpeak in dB re 1 μPa

measuring point	Schiff, ca. 500 m		T4, 2400 m		T10, 17.5 km	
level size	Peak	THIS	Peak	THIS	Peak	THIS
Maximum	199	173	185	165	160	not evaluated, see section 5.3.3
25 %	196	170	182	162	156	
Median	193	166	179	159	153	
75 %	183	159	168	149	142	
Minimum	180	156	165	147	139	

5.6 Literature

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Attachment

No.	Other	MENCK	activity	Technical specifications Remarks	Security
I.			INSTALLATION AIR SUPPLY Completed in IM TRIPOD	mid-April 2009.	
0.	M, crane, climber M (HT)		Install air lines in/on the tripod - Connection at the manhole - Load transfer on the crossbar - Transition to the bracings - Installation of the air ducts Bracings	Usage of manhole – special design for the cover with possibility of connection for pipes from jack-up platform ODIN connection for pipes from jack-up platform on top platform. A total of 6+2 lines, for each sleeve 3+1, for upper and lower bubble curtains 2 and 1 respectively, plus 1 for buoyancy. Fasten the air line to the grout line bracket (bracings).	
			PRELIMINARY INSTALLATION LOWER BUBBLE VEIL	Shipyard Eemshaven	
1.	shipyard		build scaffolding	For 2 sleeves	
2.	Faucet SW	M (HT)	Fix holder for two times 8 ropes - Cantilever arms with eyelets - Weld eyelets on the mudmat of the sleeve - Weld the steel bracket to the Mudmat	Caution: leveling tool, measuring cable, U-profiles, etc.	
II.			INSTALLATION OF THE BOTTOM BUBBLE VEIL (2x) AM TRIPOD	Done mid-April 2009.	
0. 0	Procon		Working area on shipyard site provide	Access to the shipyard, name contact person, Space required~30x20m	
1.		2 M (HT) 1 ST	Fasten ropes between cantilevers and mudmat		
2.		2 M (HT) 1 ST	Tension locks	preload	
3.		2 M (HT) 1 ST	Attachment of the nozzle pipe at the top The collar arm des Tripod	Planned without a crane, with rope hoists	

No.	Other MENCK		activity	Technical specifications Remarks	Security
4.		2 M (HT) 1 ST	Attachment of the two nozzle pipes to the 8 ropes	Pay attention to bracings (nozzle pipes - ring or segments)!	
5.		2 M (HT) 1 ST	Attachment of the lowest nozzle pipe with Bells on Mudmat	Screw clamps onto welded L-profiles	
6.		2 M (HT) 1 ST	Run the air line up on ropes and connect it to the respective nozzle pipes		
7.		2 M (HT) 1 ST	Connection of air supply lines from bracings to air line (lower bubble curtain)	connect couplings.	
8.		2 M (HT) 1 ST	2 air inlets for upper Guide the bubble curtain up the steel cable and attach it to the cantilever arms		
			REPEAT FOR SECOND LOWER BUBBLE VEIL		
III.			ASSEMBLY UPPER BLASENSCHLEIER (2x)	Done mid-April 2009.	
0.	Procon		Working area on shipyard site provide	Access to the shipyard, name contact person, Space required~30x20m	
1.		2 M (HT) 1 ST	provide bucks	crane necessary	
2. 0		2 M (HT) 1 ST	Assemble segments for lower nozzle pipe	Open to bracing! Align for later assembly of the ropes 8 pairs	
3. 0		2 M (HT) 1 ST	Attach weights to nozzle tube and Lay the nozzle pipe down on stands	per nozzle pipe, weight pair ~17 kg	
			PROCESS 2 AND 3 FOR THE TWO FURTHER LOWER REPEAT NOZZLE PIPES		
4. 0		3 M (HT) 1 ST	Bend fourth nozzle pipe, attach weights and place on stands	Align for later installation of the ropes	
			PROCESS 4 FOR FIFTH NOZZLE PIPE		
5. 0	SW	3 M (HT) 1 ST	Mount/weld steel ring	Dpipe~0.2m, Dring~8m, weight~1 t	
6. 0	Faucet	3 M (HT) 1 ST	Place the steel ring above the 5 nozzle pipes		

No.	Other	MENCK	activity	Technical specifications Remarks	Security
7. 0	GS	3 M (HT) 1 ST	Mount buoyancy body on steel ring 16 pieces	, D~0.7m, length~1.5m, body weight~66kg	
8. 0		3 M (HT) 1 ST	Measure and mark attachment points for nozzle pipes on the 8 ropes	ropes of equal length	
9. 0		3 M (HT) 1 ST	Fasten all nozzle pipes (5 plastic, 1 steel) on the 8 ropes	>HT: without crane	
10. 0		3 M (HT) 1 ST	air lines and valve(s). Mount/connect nozzle pipes	3 above, 3 below 2 air connections at the very bottom >HT: Additional attachment to ropes or sufficient connection to	
11. 0	Faucet	3 M (HT) 1 ST	nozzle pipes Crane picks up the traverse and traverse over the bubble curtain, shackles m ropes (length~27m) on eyelets on the Attentio ring Test	lifts these 4 lifting ropes (length ~8m) to lift the easuring ~8x8 m , Weight~2 t 8 n: hook height~50m Steel	
12. 0	Faucet	3 M (HT) 1 ST	lifting of the entire upper bubble curtain Place	Test if everything is correct.	
13. 0	Faucet	3 M (HT) 1 ST	the upper bubble curtain back on the trestles	When folding, make sure that the ropes are not "knotted"!	
14. 0		3 M (HT) 1 ST	Remove the assembly ropes, replace with deployment	IF NECESSARY!	
15. 0		3 M (HT) 1 ST	ropes Upper bubble curtain including crossbeam ready for loading and sea		
16. 0	Faucet	3 M (HT) 1 ST	transport Remove the traverse from the first bubble curtain and lay it ready for		
			the second REPEAT PROCESSES 1 TO 16 FOR THE SECOND UPPER BUBBLE GUARD Place the		
17.	Faucet	3 M (HT) 1 ST	traverse on the trestle		

No.	Other MENCK		activity	Technical specifications Remarks	Security
IV.			PROCEDURE OF THE PREPARATORY WORK		
0.			The control: - availabilities, - Fit shackles, strops, SIKA swivel hook		
1.	ODIN		ODIN loaded with: 2 compressors, - spare parts, lattice boxes, - distributors, - air hoses, - possibly measuring instruments - Seefasten.	Note: if compressors cannot be loaded on ODIN in port, offshore loading must be clarified, risk: failure of lifting eyes Compr. for (note: offshore frames are not available).	example compr. on flat and/or very good weather
2.	ODIN	1 SV (HT) 2 ST	Prepare equipment for Bubble curtain system	Install distributors, prepare air lines, lay on deck.	
3.	ODIN	1 SV (HT) 2 ST	Prepare equipment for Bubble curtain system	Set up and prepare compressors, connect air lines.	
4.			Preparation and installation of measuring instruments		
5.	Crane		In Eemshaven: - Loading the Multicat with: 2 upper bubble curtains on transport frame, 1 traverse. Upper bubble curtain: D~9.5m, H~2.6m, G~6 t. - Detach short slings, attach traverse: LxW~7.5x Seefasten (Prokon).	Multibrid / Prokon supplies 4 slings of the same length, min. 6.7 m and Green Pin standard shackles 32 t for above the traverse. Lift the upper bubble curtain using the traverse Info: Afterwards: 7.2m, H~1.1m, G~5d. 28m slings.	
6.	Multicat		Transit Multicat from Eemshaven to the place of use		
7.	An offer		Tripod is brought into position by floating crane Taklift and set down in position, Taklift moves away	Departure Tide dependent	

No.	Other	MENCK	activity	Technical data Remarks Post OD 2.48 m,	Security
8.	Faucet		Set first and second stake with Hubinsel ODIN	length 45 m. Either first W, NE or SE, depending on the current, as this is to be used for threading in the pole (stop apron on the upper edge of the cone). Caution: Write down the crane slewing angle and boom tilt.	
9.	crane, Ranks		shake 2 piles.		
10.	ODIN		Implement the ODIN parallel to the W piles measured.	Info: for noise reduction, piles and NE (or W and SE) should be NE and SUN. Pole W can be measured for reference.	
11.	Faucet		Third post from the jack-up platform ODIN set		
12.	crane, Ranks		3. Shake pole		
13.	crane, MK	SV (HT), 1 ST	Connection of the air lines (per sleeve: 1 3+1) from ODIN to the tripod platform. protection tubing over tripod rim.	As soon as possible (preferably via a gangway (bridge), otherwise with a man basket on the truck-mounted crane)! Info: Construction hoses with Storz A coupling. Info: connect only 3+1 lines to the distributor for a planned post.	
IN.			INSTALLING BUBBLE VEIL		General: Divers only work when the current is acceptable (backwater).
0.	MK Multicat	1 ST	Translate ST to Multicat		
1.	Faucet	1 ST	Attach crane 4 slings to traverse of upper bubble curtain	4 equally long slings min. 6.7 m and 4 Green Pin standard shackles 32 t (Multibrid / Prokon).	
2.	Multicat	1 ST	Release the Seafasten of the upper Bubble curtain and traverse		
3.		1 ST/ 1 ST (HT)	Open flaps topside floats buoyancy body		

No.	Other	MENCK	activity	Technical specifications Remarks	Security
4.	crane, Multicat		Note: if possible in the overall schedule, i.e. shortly before backwater: lifting the curtain with the crane of the Multicat ODIN Note: in the meantime Attention: gap hammer (this gap is in the lower 3 (octagonal) nozzle tubes.	air lines are unrolled with the lifting of the upper bubble bubble curtain and at the bottom of the Multicat. Bubble curtain attached. bubble curtain for bracing could already be rammed, then reset on board ODIN.	Attention: Pay attention to the correct unfolding of the upper bubble curtain! Risk: get stuck. Risk: too much movement Bubble curtain in wind and waves.
5.	Faucet		Raise the upper bubble curtain over one of the two piles planned for sound measurements		
6.	Faucet		Upper bubble veil up to release end position	The buoyancy bodies fill with water. Caution: Write down the crane swivel angle and boom tilt (for later dismantling).	Risk: filling takes a few minutes, but this phase is critical due to wave loads on the upper part of the bubble curtain.
7.	Diver		Connect the upper bubble curtain to 8 eyelets on cantilevers on the tripod. After connecting, the crane should pull something tight.	connections with SIKA 13-8 swivel hooks. See drawing Discuss Attachment point “S” for one silver hook, other possible corresponding parts on site are red. view.	Safety for divers in particular: all activities beforehand and HT:
8.	Diver		Connection of the 1 x air line for filling the buoyancy body and 2 air lines of the upper bladder curtain		
9.	Diver		Close vent flaps Ventilation control air line	Note: according to instruction HAT.	
10.	Compr. 1	SV (HT)	Filling the buoyancy chambers with air	The air for filling is directed from the ODIN into the supply air hose according to the diver's instructions. Info: 8 separate chambers.	
11.	crane, Diver		When filled with air (air escapes from the bottom of the buoyancy body): Crane lowers a little.		
12.	Diver		Release the connection between the traverse and the bubble curtain.	8 SIKA swivel hooks 13-8.	
13.	crane, Diver		removing the traverse		Diver in safe position.
14.	Diver		Checking the position of bubble curtain		

No.	Other	MENCK	activity	Technical specifications Remarks	Security
15.	Faucet	1 ST	Traverse at second upper Mount bubble curtain		
0.- 15.			ABOVE OPERATIONS FOR INSTALLATION OF THE SECOND UPPER BUBBLE VEIL REPEAT	The first upper bubble curtain will be transported on the Multicat “Alisa”, the second will be transported on the tugboat “Bankert”. The procedures would have to be changed accordingly. This includes: - Translate staff from ODIN to Multicat or Tug to instruct the crew of the "Alisa" or "Banker". - Traverse can probably only be stored on Multicat become.	
16.	Faucet Multicat	1 ST	depositing the traverse on Multicat		
17.	Kran, M.K., Multicat		Retrieving the ST from the Multicat ODIN		

No.	Other MENCK		activity	Technical specifications Remarks	Security
WE.			RAM		
0. 0			Limits of use: Current 0.5 m/s, significant wave height 1.0 m. Wind Beaufort 5.	Estimates were made for a deflection of 1.5 m. Info: At ~ 1.6 m deflection, buoyancy occurs. Info: buoyancy from bubble curtain comes against hammer case at hor. Movement ~ 3.4m. This is an additional estimated wind limit for handling upper soundproofing over water. Decision by OCM in consultation with MENCK and HydroTechnik.	Risk: These are the best available benchmarks. An exact calculation of forces and movements noise protection during use was not made. Risk: if the buoyancy bodies are deflected too much by current and waves, the underside of the pile guide on the hammer for driving the last ~ 10 m pile cannot dip into the bubble curtain without risk of damage. Possible measures: - observation under water, - accepting damage to the bubble curtain, - accepting the risk of damage to the hammer system, - Previously Bubble Veil for this one remove the last meter of ramming.
1. 1	Faucet MK	ST	operating lines on the hammer: visible, these should be available above the letter "M" if possible. Therefore (possibly held in a simple MENCK on the hammer housing, i.e. to be on the safe side, a constant the engine accordingly (3.0 m under the top observation of the loop of the opera. Lines hammer	If the operating lines are under water, that is no longer. Note: good hose saddle) must be attached to the top of attach. hammer case). This requires contact with the buoyancy body. ramming at the end by the sound system.	2. Crane hook is not available for the 20 m jumper opera. Lines prevented from
2. 2	Faucet MK	2 ST	Mount the deflector (against noise protection when the hammer is pulled up) on the hammer.	Similar to sketch S000-06081, but hemp ropes (as many as possible (8 – 12), more like 4 holes + 2 pins) and/or tension belts.	
3. 3	ODIN		scaring away the porpoises.		
4. 4	ODIN		Remove Seafastening Hammer.		

No.	Other MENCK		activity	Technical specifications Remarks	Security
5. 5	Faucet		Raise hammer, swing forward, connect operating lines on deck: 20m jumper on hammer to opera. Lines on winches.	Hammer position: Hoses (support) towards the crane.	
6. 6	Crane, ROV.		Pick up hammer and place it on pole (above water).	Caution: Write down the crane slewing angle and boom tilt. Attention: on loop in opera. Pay attention to lines between deck and hammer, no pull!	
7. 7	Crane, ROV.		When the hammer sits correctly on the post, the crane hook should move away from the ODIN to the other side (not towards the hydr. hoses) and let it down loop in strop.		
8.	Activate 8 bubble curtains (air from compr. 1 SV (HT) compressor)			Operating pressure approx. 7 bar, air volume approx. 90 m3/ min (division between 2+1 supply lines for upper and lower bubble curtain)	
9. 9	REV		Check the hose for leaks and check that the bubbles escape evenly		ROV is designed to stay away from bubbles.
10. 0	Faucet	1 ST, MHU 500T	start ramming, single shots	Air is continuously fed through the compressor via the bubble curtain directed	
11. 1	1 Faucet	1 ST, MHU 500T	The framework	Air is continuously fed through the compressor via the bubble curtain directed	Risk: contact hammer closed Bubble Veil (see dates at beginning)
12. 1	2		Control under water	on loop in opera. Pay attention to lines between deck ODIN and no pull!	between / on the buoyancy device Hammer, Risk: Opera. Lines get caught Attention: bubble veil
13. 1	3 ISD		Recording and measuring the settings noise reduction		
14. 1	stop, 4 decisions		checking a possible tilting of the tripod	Depending on the inclination of the tripod, decide how far and which post to drive next. Both upper bubble curtains remain installed	

No.	Other	MENCK	activity	Technical specifications Remarks	Security
15. 15	ODIN		Abortion of the ramming process of the first Pfahls	When tilted!	
16. 16		1 SV (HT)	Disable bubble curtain		
17. 17	Crane, ROV.	1 ST, MHU 500T	raise hammer.	Warning: before lifting the crane, bring the swivel angle and tilt of the boom into the same position as when placing the hammer on the post. Attention: ROV checks whether contact between sound system and hammer.	Avoid the risk of undesired swinging out of the hammer. Risk: Hammer contact with bubble curtain and breaks it.
18. 18	Faucet	1 ST, Measurement	no noise reduction at the west pole. Place hammer on corresponding post MHU 500T possible on second sound post.		
19. 19	Faucet	1 ST, MHU 500T	The frame Westpfahl / Ram "Sonic" Stake	Without noise reduction! / With noise reduction as described above	
20. 20	Faucet	1 ST, MHU 500T	Ramming the three piles up to desired depth		
21. 21	ISD		ISD suggestion: after reaching end penetration, ram with 10% energy and measurements with different air settings (see ISD suggestion).	MENCK comment: if done, then: - if possible, stop at the end of the normal ramming, in the upper tolerance range of the penetration. - continuous mode, normal stroke frequency (30 - 40 BPM), limited time (¼ - 1 min.). Check post penetration.	Risk: additional number of ramming blows and additional penetration over tolerance range.
22. 2	Faucet	1 ST, MHU 500T	Raise hammer and place on ODIN		

No.	Other	MENCK	activity	Technical specifications Remarks	Security
VII.			UNINSTALL THE UPPER BUBBLE VEIL		
0. .	Kran, MK Multicat	1 ST	Translate ST to Multicat		
1.	Faucet		Traverse (with 28 m ropes below) from Pick up Multicat, into the water	Caution: Crane swivel angle and boom tilt in the same position as when touching down.	Risk: hooked 8 x Sail 28 m.
2. .	crane, Diver		Attach ropes to top of bubble curtain	Connections with SIKA swivel hooks 13-8.	
3. .	crane, Diver		Lower crane slightly for loose bottom.		
4. .	Diver		Open the flaps on the top of the float (instruction HT)	The buoyancy body fills with water!	
5. .	Diver		Disconnect the 2+1 air supply lines of the upper bubble curtains and for buoyancy devices	one	
6. .	Diver		Loosen the connection above Blasenschleier - Collar arm	8 connections with SIKA swivel hooks 13-8.	
7. .	crane, Multicat		Raising the first upper Bubble Curtain and on Multicat "Alisa" or tugboat tugboat Discard Bankert	Put in frame.	Diver to safe position.
8. .	Faucet Multicat	1 ST	loosening the connection traverse - upper bubble veil		
9. .	Multicat	1 ST	Secure the upper bubble curtain Table there Multicat		
10. 1	Faucet, MK, 1 Multicat		Retrieving the ST from the Multicat ODIN		
0. -10.			ABOVE OPERATIONS FOR SECOND UPPER BUBBLE VEIL REPEAT	Place second bubble curtain on Multicat "Alisa" or Tug "Bankert"	
11. 12	crane, Bridge	1 SV (HT), platform.	dismantling of air lines on Tripod 1 ST		

No.	Other MENCK		activity	Technical specifications Remarks	Security
12. 1	3 crane, Bridge		Replacing the manhole cover		
13. 1	4	1 SV (HT), 1 ST	Dismantling the air lines from the The compressor		
14. 1	5	1 SV (HT), 1 ST	Prepare demo		
15. 1	6 ODIN		Remaining work tripod		
16. 1	7		RETURN TO EEMSHAVEN Unloading in the port		

report sheet

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18. Summary The
overarching goal of the "Schall alpha ventus" project was research and offshore testing of the "stepped bubble curtain" noise reduction measure for the foundation of a wind turbine in the offshore test field alpha ventus in the North Sea. Also referred to as the "Canadian model", the noise reduction concept consists of several nozzle pipe rings that are installed at different levels in the water column around the driven pile. When the nozzle pipes are filled with compressed air, a curtain of bubbles is created which envelops the driven pile and thus dampens the noise emitted.

After a brief description of the cooperation between the various institutions in the research project, the conception and implementation of the "stepped bubble curtain" noise reduction measure is explained in detail. The concept envisaged pre-installing the lower part of the system (4 levels each) on two of the three pile guides of the tripod in Eemshaven.
The upper part of the system (6 levels each) was designed as a mobile system, which was brought to the test field independently of the tripod in specially built transport frames. In a backwater phase, the mobile systems with divers should be connected to the pre-installed system parts. Due to a weather-related, safety-related project decision, the mobile systems were not used. The pre-installation of the lower levels of the "stepped bubble curtain" on land has proven to be very advantageous and should be considered in future concepts for noise reduction measures.

After the description of the most important acoustic parameters and the conditions at the testing site, the individual sound pressure measurements at the different measurement positions are described. Due to the strong directional dependency of the noise reduction effect on the tidal flow, measurements were carried out at a distance of 500 m to the west and east. Further measurements took place at a distance of 2.4 km and 17.5 km. In order to determine the damping effect of the two lower subsystems, the compressed air supply was switched off and on again. The result was that the noise-reducing effect was 13 dB (SEL) or 14 dB (Lpeak) in the flow direction and 1.6 dB (SEL) or 0.3 dB (Lpeak) against the flow. Shortly before reaching the final ramming depth, the compressed air supply was switched off again. At this time, the noise reduction in flow direction was 10.4 dB (SEL) or 12 dB (Lpeak) and against the flow 3.7 dB (SEL) or 4.9 dB (Lpeak). Overall, it can be stated that the noise reduction is greater the more air bubbles there are between the point of emission and immission.

Finally, the effect of the "stepped bubble curtain" is compared with other bubble curtain realizations from the literature and the limit values for piling noise defined by the Federal Environment Agency (UBA) and the Federal Agency for Nature Conservation (BfN) (160 dB re 1 μPa for the SEL and 190 dB re 1 μPa for compared to the Lpeak at a distance of 750 m).

19. Keywords
underwater noise, noise protection, noise reduction, testing, piling work, offshore wind farm, alpha ventus

20. Verlag	21st prize