# Big bubble curtain – Summary of the results of the project Borkum West II

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# 1 INTRODUCTION

Within the framework of the project HYDROSCHALL-OFF BW II a new noise mitigation system (Big Bubble Curtain) appropriate for series production was developed and tested during pile driving for the offshore wind farm Borkum West II, currently being constructed by company TRIANEL WINDKRAFTWERK BORKUM GmbH & Co. KG.

The wind farm, positioned 45 km north of Borkum Island, consists of 40 wind turbines (WEA) and a transformer station. During foundation work for the WEA (tripod constructions) 120 piles with a diameter of 2.5 m were driven into the sediment by a hydraulic hammer.

In order to reduce noise emission during pile driving a Big Bubble Curtain (BBC) was developed. This system could be layed out well before pile driving started and was tested and operated during construction process of the wind farm Borkum West II.

Noise mitigation regarding the Sound Exposure Level (SEL) ranged from 9 to 13 dB for the most suitable bubble curtain configuration BBC 2 (hose with small nozzles at short distances to each other) under full air supply. This proved to be very efficient since it reduced the noise-polluted area by 90 %. Acoustic monitoring of harbour porpoises approved a strongly reduced disturbance of animals by pile driving. Due to these findings the project is the worldwide first where a noise mitigation system was successfully operated under offshore conditions on a large scale, and in which its positive effect on an affected marine mammal species was demonstrated. The Big Bubble Curtain was proven to be suitable in principle as a noise mitigation system for pile driving.

Aim of the project was the development of a ready-for-production system for mitigation of noise emissions by pile driving during the construction of offshore wind farms. The Big Bubble Curtain, which was developed for operation in the wind farm Borkum West II, was successfully integrated into the construction process without causing delays at 31 (out of 40) foundations. In five cases technical problems (e.g., breaking of air-supply hoses, torn marker buoys), and in four cases time limitations prevented the operation of the Big Bubble Curtain.

## 1.1 Suitability of the Big Bubble Curtain under offshore conditions:

Within the scope of the project the basic offshore suitability of the Big Bubble Curtain during the construction process of a wind farm in water depths of 27-33 m, as well as the capability of this technology was demonstrated successfully.

Big Bubble Curtains were tested with different configurations, materials and deployment methods for the project. Endurance of materials and weather restrictions were evaluated. Materials and operational methods were suitable under the special conditions of Borkum West II. By means of modifications technical risks during operation of the noise mitigation system were reduced and economic efficiency was improved.

The operation of the Big Bubble Curtain jet nozzle hoses wound onto big winches was technically successful. The pre-laying principle, i.e. circular deployment of the nozzle hose around the planned position of the turbine foundation before arrival of the jack-up vessel, then connecting and operating the hose after positioning of the jack-up vessel, proved to be successful here.

Sustainable development of offshore wind energy will substantially benefit from the scientifical and technical knowledge gained during this project. The applicability of the systems operational methods to projects under different general conditions is considered to be basically given; however, applicability has to be evaluated on a case-by-case basis with the methods to be adjusted to each specific wind farm project.

## 1.2 Noise mitigation power of the Big Bubble Curtain:

In the context of the project several Big Bubble Curtain configurations (half-open linear bubble curtain (linBBC), circular bubble curtain with two nozzle configurations (BBC 1, BBC 2), and half-open double linear bubble curtain (DBBC)) were developed and tested.

Under configuration BBC 2, which represented the best combination of noise mitigation and practicability, and full air supply sound reduction amounted to 11 dBSEL (9-13 dBSEL) at Sound Exposure Level, and 14 dBLpeak (10 – 17 dBLpeak) at peak level.

It was shown that both nozzle hose configuration (nozzle size and distance) and quantity of compressed air determine the power of noise mitigation of a Big Bubble Curtain: Small nozzles (1.5 mm) at short distance to each other (0.3 m) reduced noise by 3 dB more than bigger nozzles (3.5 mm) at longer distance (1.5 m). With a maximum air flow of 0,32 m3/(min*m) noise mitigation was improved by 4 dBSEL when compared to 0,15 m3/(min*m). It is to be expected that the exact application of a certain configuration will result in similar noise mitigation even under different conditions.

# 2 COMPLIANCE WITH NOISE PROTECTION NORMS:

When operating configuration BBC 2 with full air supply the 5% percentile of the sound exposure level (SEL) undershot noise protection norms of 160 dBSEL5 in 750 m distance with 73% of the WEA foundations; the remaining 27% fell between 160 dBSEL5 and 163 dBSEL5 and never exceeded 163 dBSEL5. Both with BBC 1 and BBC 2 and full air supply the peak level always undercut the required 190 dBLpeak. In nine cases out of twelve the peak level even undercut 184 dBLpeak under BBC 2.

## 2.1 Additional hydro-acoustic results:

Evaluation of the half-open double linear bubble curtain (DBBC) yielded a reduction of noise immissions of up to 18 dBSEL and partly above 20 dBLpeak. Mitigation power depended on water depth and distance between the two bubble curtains (bubble curtains entirely separated or joining in the water column).

Measurements in various distances from pile driving (between several hundred metres and 30 kilometres) gave evidence that current models (partly half-empiric) on propagation loss of sound in water (Thiele formula, geometric propagation loss) overestimate sound levels by 10 dB and more as from a distance of several kilometres from a sound source, i.e. further apart from pile driving sound levels became more than 10 dB lower than predicted. A modified empirical model of propagation loss, based on additional data, showed much more congruence between predicted and measured values. However, considerable differences occurred between predicted values and those measured with and without a Big Bubble Curtain.

## 2.2 Response of harbour porpoises:

Within the project, extensive data from 26 C-POD positions and up to four hydro-acoustic points of measurement were available, adding up to a worldwide exceptional data pool for uncovering the response of harbour porpoises to underwater noise.

The limit of a disturbance effect of pile-driving noise emissions on harbour porpoises was at 144 dBSEL. On basis of the during this project established sound propagation function a distance to the sound source could be calculated. Thus, a distance of disturbance up to 15 km was calculated from the pile driving location during uninsulated pile drivings. During the use of configuration BBC 2 and full air supply the distance of disturbance was reduced to 4.8 km, and to 6.7 km during the use of configuration BBC 1 and full air supply.

Hence, the application of the Big Bubble Curtain (BBC 2) reduced the potential area of disturbance for harbour porpoises by 90 %. Under the assumption of an equal distribution of harbour porpoises in the study area the number of disturbed animals should similarily be reduced by 90 % when operating a Big Bubble Curtain (compared to pile driving without noise reduction).

A strong linear correlation of an increasing disturbance effect with increasing sound level (corresponding to shorter distances under similar conditions regarding noise mitigation) was found.

Lowest porpoise detection rates were recorded with >160 dBSEL, which is assumed to correspond to an almost total expulsion of these animals.

The duration of a significant expulsion effect did not correlate with sound level. Even at sound levels close to the detection limit of an effect it took up to 12 hours until detection rates became similar to those before pile driving.

On average (median) a significant expulsion effect was detectable until 9 to 12 hours after pile driving activity. Detection rates were lowest until four hours after pile driving and increased gradually afterwards.

No difference was found in harbour porpoise detection rates when equally sound levels were compared directly for pile driving with noise mitigation system (BBC 2) and without mitigation. Hence, no effect in different disturbance distances of harbor porpoises resulting from a change in frequencies by the Big Bubble Curtains was observed. However, since only few data were available for pile driving with noise mitigation for highest sound levels (>150 dBSEL) the latter result should not be generalised for now.

The targets of the project were fully met: during construction of the offshore wind farm Borkum West II a noise mitigation system was integrated into the construction process for the first time. Noise mitigation resulted in a strong reduction of spatial and temporal disturbance effects on harbour porpoises. This demonstrated that a positive effect for a species of public interest can be achieved by mitigation of noise immissions resulting from offshore pile driving.

# 3 OUTLOOK:

Experiences from the project HYDROSCHALL-OFF BW II form a sound basis regarding future application of noise mitigation systems as part of offshore wind development in Germany. However, findings of other projects gave evidence that the results of this project may only partly be applicable to other locations; under different conditions it was not always possible to reproduce noise mitigation rates yielded during this project. Besides further technical development of bubble curtains it is important to investigate their mode of action under different conditions, as well as to describe parameters relevant for BBC noise mitigation power. Ongoing discussions regarding the assessment of pile-driving noise clearly show that at the same time there is great public interest in description and evaluation of harbour porpoises response to noise pollution. The project provided new insights in this respect. However, against a backdrop of heterogeneous datasets for pile driving with and without noise mitigation other questions remain open, which should be addressed in future projects