Project Number	TEHE119024
Project Title	Bubbles JIP
Applicant	Stichting Maritiem Research Instituut Nederland
Additional applicant	Boskalis (D1), Heerema Marine Contractors (D2), IHC IQIP (D3), Seaway Heavy lifting (D4), TNO (D5), TU Delft (D6), Van Oord (D7), Wageningen Marine Research (D8)
Project Period	1 April 2020 - 31 March 2023
RVO Tender	HER + tender
Date of this report	July 2023
Type of report	Public report
Publication date report	30-6-2023

1. Summary of principles, objective's and project partners

During installation of monopiles and jackets with driven pile foundations at sea, the noise generated by high-energy piling may harm the marine environment. To reduce the risk of piling sound for marine life, governments have set noise limits for pile-driving operations in their permits for offshore construction projects. For this purpose, various noise mitigation methods exist of which air bubble curtains are most commonly used. These bubble curtains are generated by using one, two or sometimes three loop hose(s) with nozzles on the seabed enclosing the pile driving location, pressurized by air compressors on a support vessel. An example is shown in Figure 1. Bubble curtains are frequently used in German seawaters to comply with noise level limitations. German experiments have evaluated the noise reductions of different bubble screen configurations of which an example is shown in Figure 1 below.

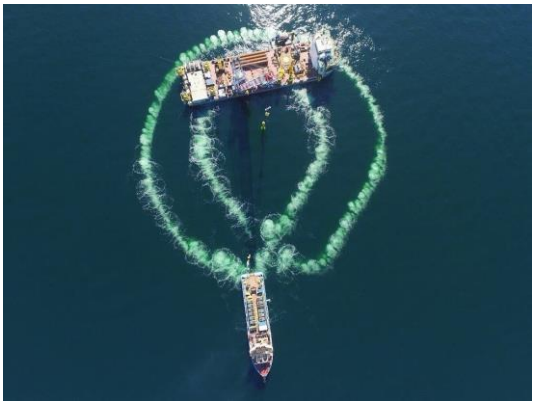


Figure 1-1: example of double bubble curtain *(Boskalis)*

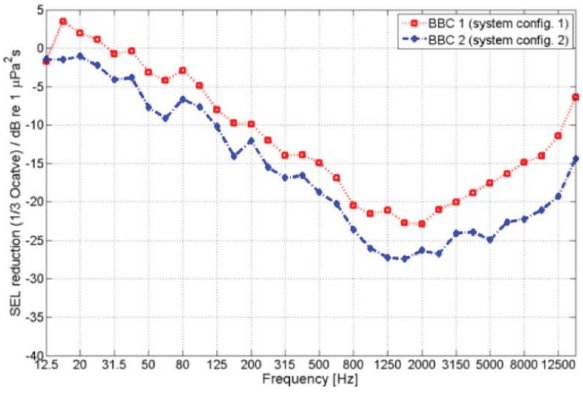
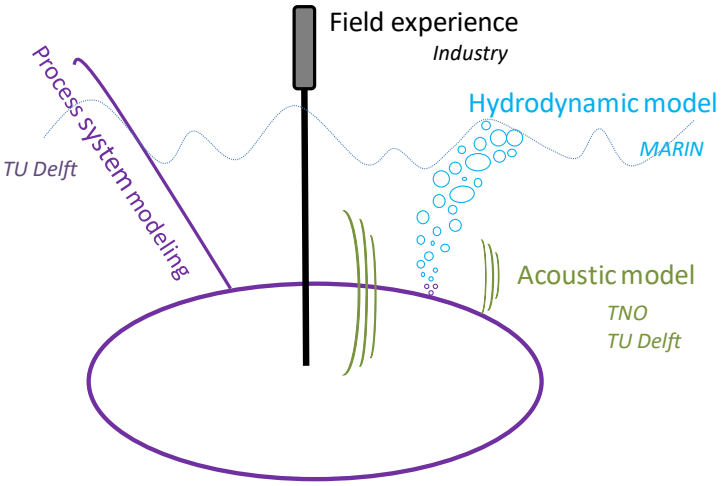


Figure 1-2:. Noise attenuation of bubble curtains *(Bellmann)*

The practical experience of applying bubble curtains is currently available at a limited number of companies that offer this service. The cost of the (subcontracting of) bubble curtains is a considerable amount of the total cost of the installation of an offshore wind farm (up to 15%).
There are large variations in the current performance of bubble curtains resulting in a need to improve the understanding on how to reduce the variability in practical application. This would enable better engineering of the curtains, leading to reduced costs of the curtains and reduced sound levels for the local environment.

For improved understanding of bubble curtains various expertises are required. The figure below illustrates that this expertise is divided in modelling of the bubble generation, bubble development, acoustics modelling and field experience. This is all available within this JIP consortium.
At present the integration between the different fields of expertise as well as the availability of appropriate models for this specific application in bubble curtains is limited, which hinders optimization. Optimization is, however, necessary to increase the efficiency of the bubble curtains and reduce the uncertainties involved. On forehand a better prediction can be made of the configuration of the hose and the needed pressure if validated integrated models would be available. It is expected that the curtain can be installed more quickly to an optimum situation with less need for extra overpower. This can also reduce the number of compressors and fuel use (and consequently reduce the CO_2 footprint).



1.1. Project partners

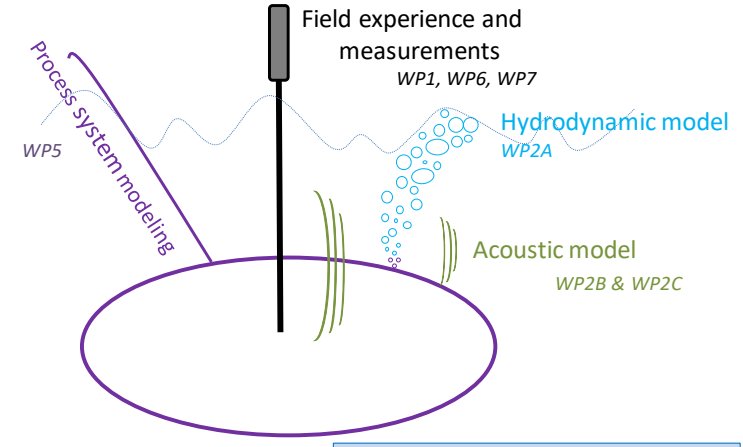
The Bubbles JIP consortium consisted of the following project partners:

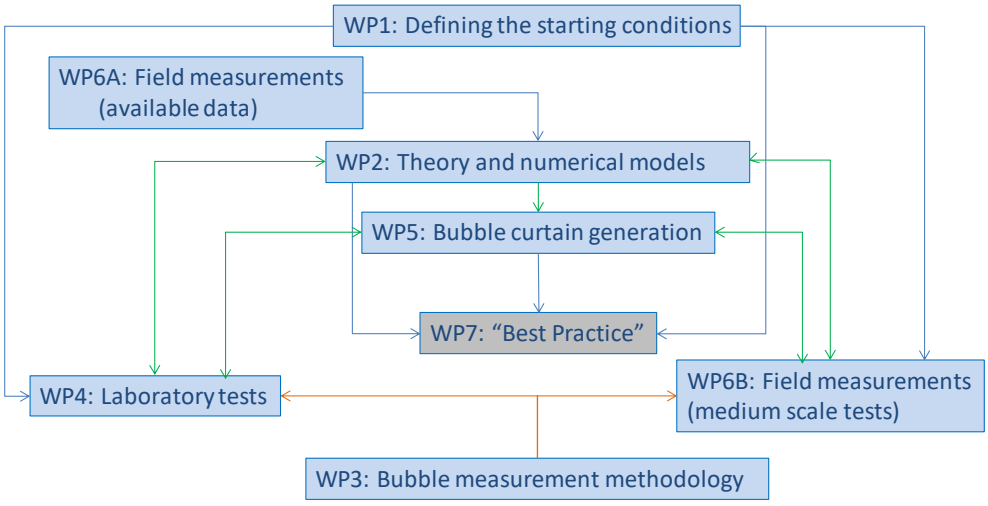
Figure 1-3:The Bubbles JIP consortium

The strong point of this team of project partners is that it covers a wide range of expertise which is all required to bring the use of bubble screens to a next level. End users with industrial experience as well as a multidisciplinary team of acoustic experts, hydrodynamic experts are involved. Furthermore the marine life is represented by WMR.

1.2. Approach

In combination with (existing) numerical models, and laboratory and medium-scale tests, improved knowledge of the bubble curtain generation, bubble curtain development over the water depth and bubble curtain noise reduction mechanisms was obtained. Furthermore, the tests provided validation material for the numerical models. The findings were summarized in a "Best Practice" reference document. To make sure that the "Best Practice" document has a direct link to the marine life for which it has been developed, it also contained an overview of typical thresholds on noise levels and frequency ranges for which marine life is sensitive and the overview of present regulations which are a result from the literature review.
The work has been divided in 8 work packages. An overview of the work packages is given in below table. The background, objective, work package leader, involved partners, indicative scope, defined tasks and interfaces with other workpackages is described per work. The relation between the work packages is illustrated in the figure and flow diagram below.





2. Description of the results achieved, the bottlenecks and the perspective for application

The objective of the Bubbles JIP was to investigate the noise migration of Bubble curtains during installation of offshore wind pile driving to mitigate the risk of marine life. The objective of the Bubbles JIP project was:

To achieve more efficient and effective use of bubble curtains for noise mitigation in offshore installation projects by improved engineering of the bubble screen. In that way the noise levels can be better controlled and the risk not to comply with the specific noise requirements per piling project is reduced in a cost-effective manner.

The following sub objectives were defined and reached as follows:

- To understand the current practice of bubble curtain generation; This objective was reached by WP1 where the starting conditions are defined and WP6A, where datasets of previous partners were analysed.
- To understand the sound propagation of piling noise through water and soil; This objective was covered by theory and numerical work as performed in WP2 and laboratory tests of WP4. In various numerical and experimental setups more knowledge is gained about noise propagation and mitigation by various bubble screen setups.
- To understand the physical mechanism of noise attenuation by air bubbles. This objective was covered by theory and numerical work as performed in WP2 and laboratory tests of WP4. A large amount of data is generated about bubble size distributions, void fractions and bubble rise velocities with the measurement setup as developed in WP3.
- To determine the parameters influencing the noise attenuation by air bubbles; In a combination of the numerical models and the laboratory data (WP2 & 4), it is found that the void fraction is one of the main parameters to influence the level of noise attenuation of the bubble curtain.
- To develop the technology to measure the bubble size distribution and concentration; Two measurement setups (optical and electrical) are developed to measure bubble curtain characteristics in laboratory environments.
- To understand the bubble generation and bubble growth over the water depth, also under the influence of waves and current. This objective is reached in the WP5 and WP6B on the bubble curtain generation and WP2 and 4 on the development of the bubbles over the waterdepth, including the influence of environmental conditions like current and waves.
- To develop a practical numerical model which can be used to calculate the noise reduction of piling noise for realistic air bubble curtain configurations; In WP2 a lot of effort is spend to develop numerical models that include the bubble curtain, noise mitigation. The combination of these models for practical application is a recommended for future work.
- To develop a guideline for bubble curtain design based on physical understanding that can be adjusted to the local system. The main findings, lessons learned and recommendations are collected in a 'Towards best practice document', which can be used by partners for application in future developments or research projects.

Figure 2-1: Bubble measurements during Laboratory tests in MARIN's Offshore Basin.

3. Description of the contribution of the project to the objectives of the tender (sustainable energy management, strengthening of the knowledge position)

Offshore wind has enormous potential: globally, in Europe and in the Netherlands. Large-scale application of offshore wind for the production of electricity can make an important contribution to the far-reaching reduction of CO2 emissions and to increasing security of supply.

Thanks to the Bubbles JIP project, improved knowledge in the field of noise mitigation for under water noise is generated. With this knowledge, the project partners can use this knowledge in future offshore wind farm installations.

4. Spin off inside and outside the sector

Within the offshore wind industry, the spin-off is clear. The knowledge developed will provide more efficient and improved knowledge in the field underwater noise mitigation by means of bubbles screens. The size of the consortium, will ensure a good dissemination of the developed knowledge in new offshore wind projects. The results of the Bubbles JIP can also be used in other sectors such as the Civil and offshore Oil & Gas industry

5. Overview of public publications about the project and where to find or obtain them

During the project several publications are submitted with a relation to the Bubbles JIP:

- Beelen, S., van Rijsbergen, M., & Birvalski, M. (2023). In situ measurement of void fractions and bubble size distributions in bubble curtains. *Experiments in Fluids, 64*(31).
- Peng, Y., Laguna, A.J., Tsouvalas, A. (tbp). A Muti-physics Model for Modelling Noise Mitigation using an Air-bubble curtain in Impact Pile Driving

Furthermore, dissemination on other platforms is done as well:

- GROW-to-go podcast & article
- MARIN Report article & video
- Presentation of bubble measurement systems at Multphase 2022 workshop

6. More copies of this report

More copies of this report can be obtained digitally from the contact listed below.

7. Contact for more information.

More information about this project can be obtained from:

- Erik-Jan de Ridder, MARIN, e.d.ridder@marin.nl

8. Subsidy

The project was carried out with a subsidy from the Ministry of Economic Affairs, for the HER tender conducted by RVO.