AN EXPERIMENTAL PARAMETRIC STUDY ON BUBBLE SCREEN PERFORMANCE

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Abstract: *Offshore engineering activities such as pile driving produce extremely high amplitude noise that is harmful to marine life. To help mitigate the impact of such activities, bubble screens may be used to reduce the acoustic environmental impact. This consists of supplying compressed air through a perforated pipe on the seabed to create a curtain of bubbles. This screen acts as an impedance barrier, preventing transmission of some portion an incident acoustic waves.*

The performance of these designs, as noted in the literature, can be very variable, raising questions around how best to design and operate them. To address this issue, a controlled parametric experiment has been performed in the UCL towing tank. This study has been conducted by supplying a series of individual pipes fastened along a rail across the bottom of the tank with the same pressure applied to each. This setup enables a high degree of flexibility for the bubble screen configuration and ensures a reliable and repeatable performance. An underwater emitter and hydrophone were then used to generate and measure the sound, including the self-noise of the curtain.

Initial studies show positive repeatable results demonstrating how varying parameters such as pressure, mass flow rate, and hole separation influence attenuation performance at a range of frequencies. Furthermore, the results show that a high mass flow rate at low pressure yields the most effective results as this generates a more stable bubble screen with a higher void fraction.

Future studies are planned to consider a broader range of parameters and include environmental conditions such as waves. The noise generating mechanisms of the curtain itself will also be considered with a view to reducing the self-noise.

Keywords: Bubble curtain, experimentation, underwater acoustics

1. INTRODUCTION

The advent of marine infrastructure projects, including the development of offshore wind turbine farms, has caused an increased anthropogenic noise level in the ocean environment [1]. In line with the seventh United Nations Sustainable Development Goal (UNSDG) [2], clean and affordable energy, offshore wind energy capacity increased by 121% from 5.1 GW to 11.3 GW between 2016 and 2021 in the UK alone. Over 2300 turbines have been installed, with a further 800 under construction [3].

These and other projects, including building bridges over seas and rivers, require the construction of foundations, a process which includes driving steel piles into the seabed. A method often used is impact piling which generates impulses of high amplitude low-frequency sound in the 20Hz to 1000Hz range [4] with measured sound levels of over 200 dB 500 m from the source [5]. Low-frequency noise is of special concern due to the longer propagation distances.

Such noise has been established to have adverse effects on marine life, including injuring animals, interrupting communication, and causing avoidance of regions around the source, decreasing the area of accessible habitat [6-7].

To meet the UNSDG 14, life underwater [2], regulations have been introduced around this noise, including target reductions of noise propagation; underwater noise has been classed as a pollutant in the EU as outlined by the Marine Strategy Framework Directive [8] and German regulations require sound levels for any construction site to not exceed 190 dB 750 m from the site [9].

To achieve this, the implementation of bubble curtains around piling sites has become a common feature of such projects due to the ease of deployment and efficacy in noise reduction [10].

2. PROBLEM DEFINITION

While the physical principles of bubble curtain sound attenuation are well understood theoretically, understanding of operations towards optimisation is still the subject of ongoing research [11].

The primary aim of this paper is to develop a fully parametric experimental setup to collect experimental data on the efficacy of bubble curtain designs in mitigating underwater noise propagation. This will serve to aid in the understanding of the relationship between curtain parameters and sound attenuation.

3. EXPERIMENTAL SETUP

Figure 1 shows a schematic of the experimental setup used to record a bubble screen's effectiveness at reducing underwater sound propagation. A bubble curtain was installed at the tank bottom having a underwater hydrophone and underwater speaker placed 3m away on either side of the curtain. The bubble curtain was positioned on the towing tanks centreline.

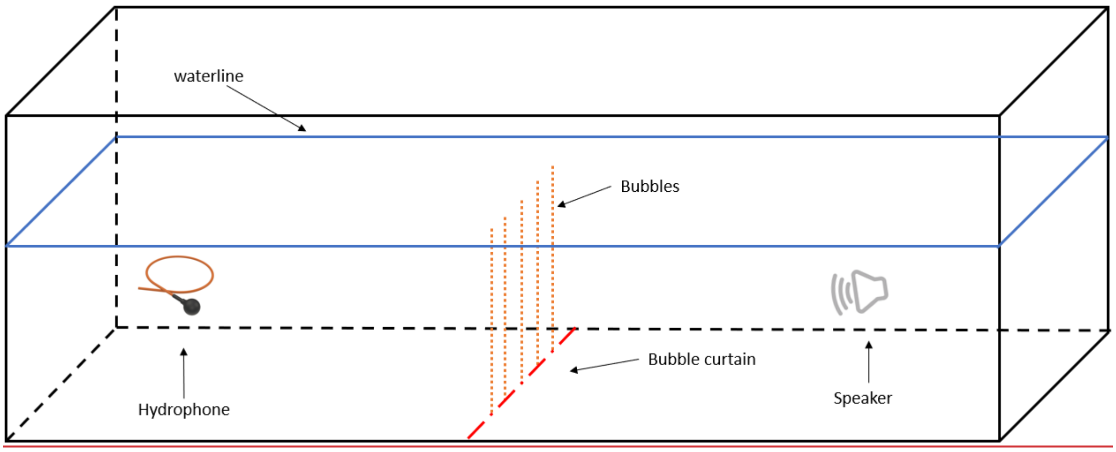


Figure 1 - Schematic of the experimental setup

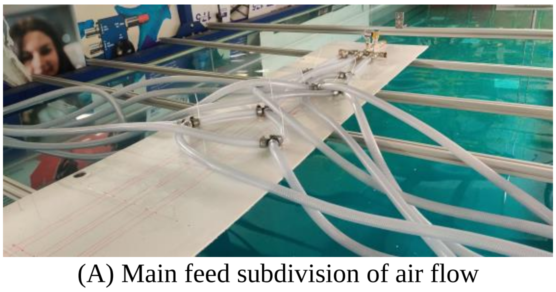
A fully parametric experiment setup was developed making it possible to control and vary a large number of variables. Following initial studies conducted at UCL, it was determined that mimicking the design of conventional bubble curtains did not make it possible to confirm with confidence, observations and results from the tests conducted. For this reason, the experimental setup considered a novel approach to ensure that the air flow is as equal as possible across the whole of the curtain at each orifice.

UCL Towing Tank

The UCL towing is 20m long, 2.5m wide and has an operating water depth of 1m. The tank is filled with regular tap water While the towing tank has the ability to generate waves, this experiment considered calm water conditions. The speaker was positioned facing the tank's parabolic beach.

Parametric Bubble Curtain

Figure 2 shows the experimental setup used to facilitate the parametric study. A series of manifolds and Y splitters were used to subdivide the air supply to a maximum of 96 orifices. All pipework was secured in place to avoid small pipe radiuses and inconsistent pipe flows throughout the duration of the experiment. To reduce the chance of a pressure bias forming along the length of the bubble curtain, each half of the lower level Y splitters supplied air to the opposite end of the bubble curtain. 27mm pipe was used to construct the main branches of the air distribution system while 8mm pipework was used to plumb between each nozzle and an 8 way manifold. Each outlet on the 8 way manifold has a valve installed, making it possible to stop or reduce air from flowing to a specific nozzle.



(A) Main feed subdivision of air flow

(B) 8 way manifolds to feed each of the 96 nozzles

(C) 3d printed nozzles fitted to linear rail

(D) Parametric bubble curtain under operation

Figure 2 - Experimental setup for a 96 nozzle experimental setup

The nozzles used in this study were 3d printed using PLA and the set up allows for different nozzle geometries to be considered. In this work, each nozzle had the same internal profile, leading to an orifice having a 2mm diameter. The interface between the 8mm pipe and 3d printed nozzle was made by using threaded inserts in the nozzle and tube-to-thread pneumatic fittings to make the final connection. A seal was created by a rubber O-ring between the threaded insert and the tube-to-thread connector. A key benefit of this set up is that is allows for the effect of the nozzle geometries on the attenuation performance and also the bubble screen self noise to be investigated.

Instrumentation and Equipment

A Neptune Sonar D/70/H hydrophone connected to a Neptune Sonar T400 surface receiver unit was used to conduct this experiment. It has a frequency range of 5Hz to 100kHz and a sensitivity of -171dB re 1V/μPa. A National Instruments data acquisition (DAQ) device was used to collect the hydrophone data. The position of the hydrophone remained constant throughout the whole experimental campaign. An underwater speaker connected to an ADS 35DF mixer amplifier and laptop was used to generate the incident soundwaves.

Experimental Matrix

The experimental campaign consisted of varying the incident frequency, supply pressure and bubble curtain configuration in calm water. The frequencies considered for this study were 1kHz, 3kHz, 7kHz, 9kHz, 11kHz, 13kHz and 17kHz for pulses lasting 8s each while the supply pressure was tested at 1bar and 1.5bar respectively. Each of these combinations where tested using four bubble curtain configurations as described below:

1. 96 nozzles, equally spaced in the same plane
2. 48 nozzles, equally spaced in the same plane
3. 32 nozzle, equally spaced in the same plane
4. 96 nozzles, equally spaced, alternatively offset by 0.04m

Procedure

Once the main elements of the experiment and bubble curtain configuration were set, the air supply was opened to produce the required pressure, leaving it to settle for 1min.

The hydrophone and speaker were then initiated to produce sound and record data taking repeated readings. 5 minutes were allocated between tests to let the system settle before testing the next experiment.

4. RESULTS & DISCUSSION

Bubble Curtain Performance

Figure 3 shows the acoustic reduction for each configuration considered in this parametric study. The values plotted show the mean reduction in sound over the three repeated readings.

The figures clearly indicate that the bubble curtain's performance is highly dependent on the incident frequency, its configuration and air supply pressure. Based on the experimental matrix considered, some observations can be made. These include:

- When the air supply pressure was set to 1 bar, the peak performance was recorded at 7kHz and 11kHz with a 30db and 35db reduction
- All configurations performed similarly at 1kHz with increasing variability at higher frequencies.
- When the air supply pressure was set to 1.5 bar, higher attenuation was recorded at higher frequencies
- For all configurations considered, the maximum attenuation was recorded at 11kHz
- In general, configuration 4 at 1.5 bar, there is a marked improvement in performance implying that for a fixed airflow, a wider screen may be preferrable

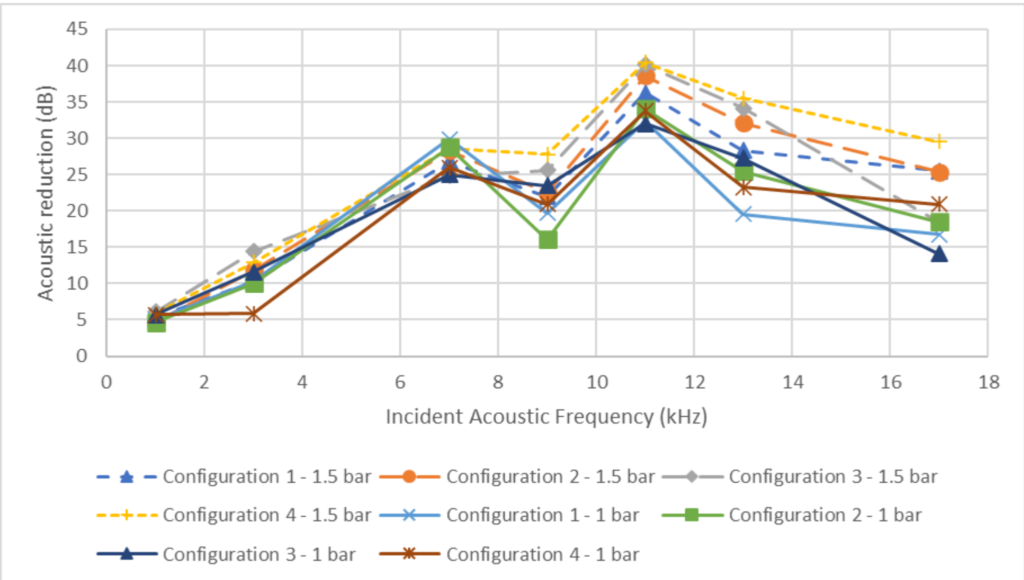


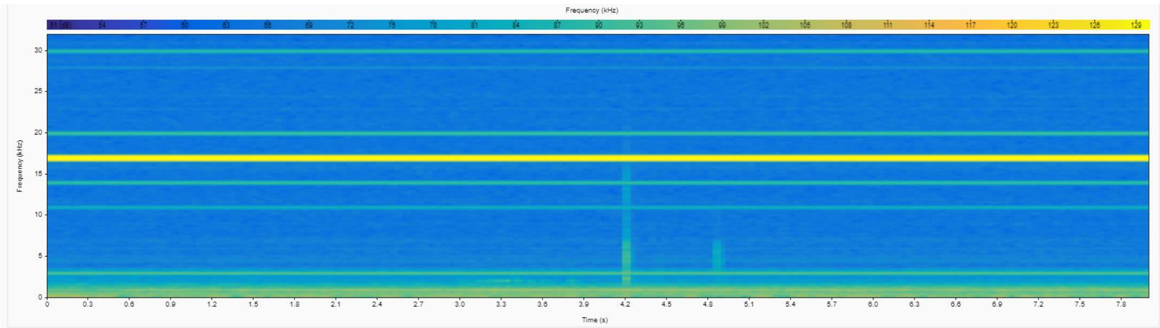
Figure 3 - Acoustic reduction for each bubble curtain configuration with a supply pressure of 1bar and 1.5 bar

Self Noise

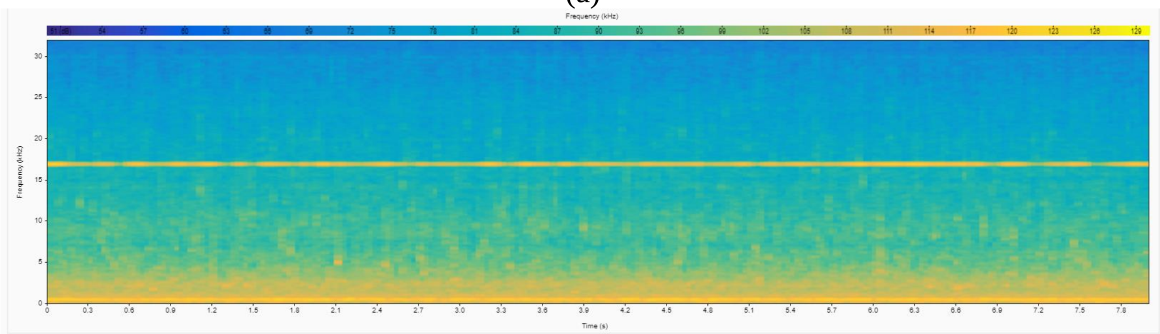
The self noise of each curtain configuration and air supply pressure was also recorded. Each of the configurations registered a similar noise and peak frequency of approximately 119dB and 0.55kHz respectively. Configurations 1 and 4 did consistently record a marginally lower level at both supply pressures.

Variation in readings

One interesting result from the experiments is the high variability in attenuation of the incident wave when the curtain is switched on. Figure 4 shows this for a single experiment with a 17kHz soundwave. Whilst the amplitude of the tone remains constant with the curtain switched off there is significant variability with the curtain on. Over an 8s duration, the reduction in SPL at 17kHz varies from 18.5 to 33.5dB. This variability can be partly explained by random variations in the bubble screen that lead to local regions of higher and lower void fractions. Changes in the distribution of bubbles in the column can have a significant impact on the transmission of the incident wave [12].



(a)



(b)

Figure 4 - Spectograms of (a) the curtain off and (b) the curtain on for configuration 4

These variations confirm that the interaction between the bubbles and acoustic waves are complex and not constant. The level of attenuation over a period of time in discrete timesteps should be considered.

5. CONCLUSIONS & FUTURE WORK

A fully parametric experimental setup was designed and built that can be reconfigured to consider different pressures, nozzles, nozzle positions and incident frequencies together with other variables.

The experimental campaign conducted showed how the attenuation of each bubble curtain was not constant across the complete frequency range considered. It also showed that the level of attenuation was not constant over the complete time period.

Future work will involve considering different configurations, nozzles and parametric studies to develop a repository of underwater acoustic data for bubble curtains.

Further investigation is needed to understand why the peak performance of the curtains considered was 11kHz. Additional work is needed to quantify the bubble size distribution.

REFERENCES

[1] **Robinson, S. P., Theobald, P. D., & Lepper, P. A.**, Underwater noise generated from marine piling, 2013.

[2] **United Nations**, The 17 goals. https://sdgs.un.org/goals, 2022.

[3] **The Crown Estate**, Offshore Wind Report, 2021

[4] Lepper, P. A., Robinson, S. P., & Theobald, P. D., Underwater radiated noise and impact assessment of marine piling operations during offshore windfarm construction, The Journal of the Acoustical Society of America, 2012

[5] Nedwell J R , Parvin S J, Edwards B, Workman R , Brooker A G and Kynoch J E, Measurement and interpretation of underwater noise during construction and operation of offshore windfarms in UK waters, 2003

[6] Simmonds, M. P. , D. S. J. , J. M. , P. E. C. M. , W. L. , W. A. J. , & L. R., Marine noise pollution--increasing recognition but need for more practical action. Journal of Ocean Technology, 9(1), 71–90, 2014

[7] Richardson, W. J., Greene, C. R. J., Malme, C. I. and Thomson D. D., Marine mammals and noise. San Diego: Academic Press, 1995

[8] European Union, European Union framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive), 19, 2018

[9] Bellmann, M.; May, A.; Wendt, T.; Gerlach, S.; Remmers, P.; Brinkmann, J., Underwater noise during percussive pile driving: Influencing factors on pile-driving noise and technical possibilities to comply with noise mitigation values, 2020

[10] Tsouvalas, A., & Metrikine, A. V.. Noise reduction by the application of an airbubble curtain in offshore pile driving. Journal of Sound and Vibration, 371, 150–170 (2016)

[11] Kemp, Linda, MARIN.). Bubbles JIP . https://www.marin.nl/en/jips/bubbles, 2022

[12] T. A. Smith, N. Bempedelis, and A. Grech La Rosa, "Numerical modelling of acoustic wave propagation through a bubble column," 7th Underwater Acoustics Conference, Jun. 2023