SEACAMS2, Swansea University

Micro bubble curtains: impact on sediment dispersal

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1. EXECUTIVE SUMMARY

Background and objectives

Bubble Tubing® releases micro-bubbles from bubble curtains. These are utilised for a range of environmental protection purposes including oxygenation, the muffling of sound, and they restrict the dispersal of suspended sediments. SEACAMS Swansea studied the effectiveness of bubble curtains in restricting sediment movement in seawater under laboratory conditions on behalf of Frog Environmental Ltd. Specific objectives were:

(a) To quantify the effectiveness of a bubble curtain in obstructing sediment dispersal under controlled laboratory conditions.

(b) Quantify additional benefits of up to three parallel bubble curtains as effective controls for sediment movement.

(c) Determine how different sediment grain sizes behave in a controlled laboratory experiment with Bubble Tubing® and quantify sediment contained by or transferring through a bubble curtain.

Method and approach

A seawater tank was set up (274cm x 49cm; depth 24cm). Trials were conducted deploying up to 3 lines of 25mm 1" Bubble Tubing® supplied by Frog Environmental Ltd. Sediment of different grain size (medium 250-500 µm, fine 125-250 µm and very fine 63-125 µm) was inserted into laminar flowing water; the water was circulated through an overflow and sump back into the test-tank. Sediment settling out in front, between, and behind bubble curtains was retrieved and quantified.

Results

On average over 50% of sediment was restricted from dispersal by a single bubble curtain. Additional lines of bubble curtains trapped significant amounts of sand, and with every new curtain less material was dispersed in the tank. Greater amounts of coarser material settled out (70-80%) in front of the first curtain compared with finer sediment fractions (30-40%). Generally, the finer the sediment the more bubble curtains were necessary to retain the material. Also, larger quantities of finer sediment stayed in suspension in the experiment.

Three parallel bubble curtains retained 80-90% of sediment of all grain sizes. Overall, more than 90% of material settled out while the rest remained in suspension; in comparison significantly less of the finer than the coarser sediment fractions sedimented out.

Conclusion and application

Frog Environmental Ltd. uses Bubble Tubing® to manage sediment-related environmental risks, but so far their work focuses on freshwater systems. The product has shown to be effective, and experience in the field suggested that parallel lines of Bubble Tubing® may enhance the performance. Our laboratory trials confirm this observation and allow quantification of the effectiveness of Bubble Tubing® under different scenarios.

The transferability of the laboratory results to the field should be viewed with caution. The natural environment differs in many ways from laboratory conditions, for example in terms of the composition of sediments, hydrodynamic conditions or topography. However, the laboratory results indicated that bubble curtains could potentially be a tool to limit sediment dispersion in coastal environments. It seems crucial to understand the grain size composition of the sediments to be contained. All sediment management benefits from parallel lines of Bubble Tubing®, but the control of finer sediments in particular can be significantly improved by installing several bubble curtains.

The proliferation of coastal infrastructure including marine renewable energy devices will enhance the dispersion of sediments through construction and maintenance work. This may negatively impact the natural environment. Bubble Tubing® proved to be an effective product for sediment management and we recommend to trial and develop this further with the aspiration to develop a tool that limits excessive distribution of suspended sediments in the coastal environment.

2. INTRODUCTION

Construction, dredging and restoration activities create environmental risks for the coastal and marine environment. Risks range from sediment disturbance and dispersal to floating debris, noise pollution and vibration. These activities can negatively impact the ecological status of adjacent seafloor communities and water quality.

Frog Environmental Ltd. is a Welsh-based company specialising in water quality and sediment services and a supplier of the Canadian-made Bubble Tubing®. The product releases micro-bubbles which form bubble curtains. These can restrict the dispersal of suspended sediments. The company uses Bubble Tubing® to manage environmental risks in freshwater systems. Frog Environmental wishes to develop the product to market to the marine and coastal environment sectors. It could potentially be applied to improve mitigation of environmental impacts due to sediment mobilisation and dispersal associated with marine and coastal engineering projects.

With technological advancements in sustainable Marine Renewable Energy (MRE) devices across the world such as wave and tidal turbines including tidal lagoons, these developments could potentially considerably increase in large numbers along our coasts. Site planning, installation and construction, operation, maintenance dredging and de-commissioning may have negative effects on marine and coastal species, entire habitats and the wider environment. The company Frog Environmental Ltd. is exploring new ways and opportunities to develop Bubble Tubing® for marine environments that could mitigate such environmental impacts.

Frog Environmental Ltd. approached SEACAMS 2 at Swansea University to test the Bubble Tubing® product under varying laboratory-based experimental conditions. The main objective of this study was to undertake *in-situ* laboratory experiments testing Bubble Tubing® in seawater to determine its effectiveness as a form of sediment control in marine environments.

Specific objectives of the project were:

a) To quantify the effectiveness of a bubble curtain to hinder sediment dispersal in a controlled laboratory experiment.

b) Quantify additional benefits of up to three parallel bubble curtains as effective controls on sediment movement.

a) Determine how different sediment grain-sizes behave in a controlled laboratory experiment with Bubble Tubing® and quantify sediment contained by or transferring through a bubble curtain.

3. MATERIAL AND METHODS

Bubble Tubing®

The Canadian-made and designed Bubble Tubing® by 'Canadianpond.ca products Ltd.' is a flexible linear air diffusion system that creates fine or micro-bubbles (less than 1 mm in diameter) from perforations along its entire length when pumped with air. Bubble Tubing® can be placed on the seabed, river bed or along perimeters of aquatic environments in its weighted or non-weighted design to create a continuous screen of bubbles within the water column.

Due to a resistant PVC outer surface and a stainless-steel core Bubble Tubing® is flexible and resistant to varying environmental conditions and parameters such as chemicals, salinity and temperature. The design of the bubble curtains allows air to enter the tubing to create an inner pressure which is released as micro-bubbles uniformly across perforations along the tubing into the water column (Figure 1).

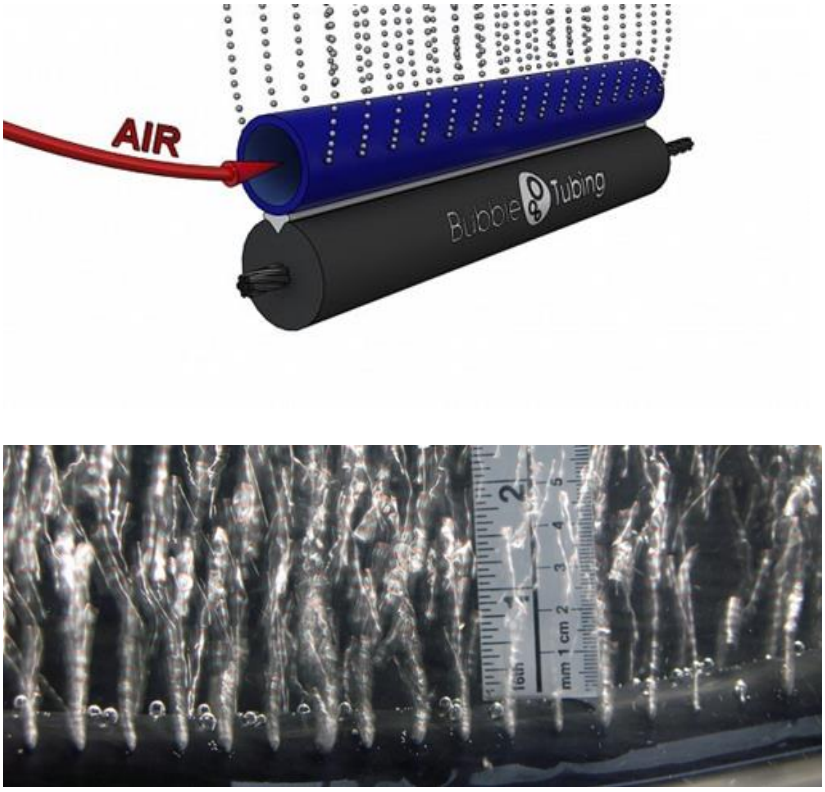

Figure 1: Bubble Tubing® schematic (top) and in-situ bubble barrier in operation.

Experimental set-up

Bubble Tubing® trials were tested *in-situ* under wet laboratory conditions within a controlled environment at Swansea University, Department of Biosciences, College of Science, Singleton Campus. The trials were conducted in July 2017 over the course of fourteen days.

The experiments were conducted in a 274cm (L) x 49cm (W) rectangular, smooth, flat-based marine tank with a depth of 24cm, which utilised the seawater supply from Swansea Bay, pumped directly to the aquatic laboratory at Swansea University through sand filters. Within all trials, the seawater pH and temperature remained constant at 7.8 and between 13-14.7°C, respectively, measured using a pH and temperature YSI probe.

Laminar water flow in the tank was generated through an inflow pipe with a series of holes. The water drained into a sump connected to the tank through an overflow pipe at the opposite end of the tank; the water in the sump was pumped back into the tank (Figure 2).

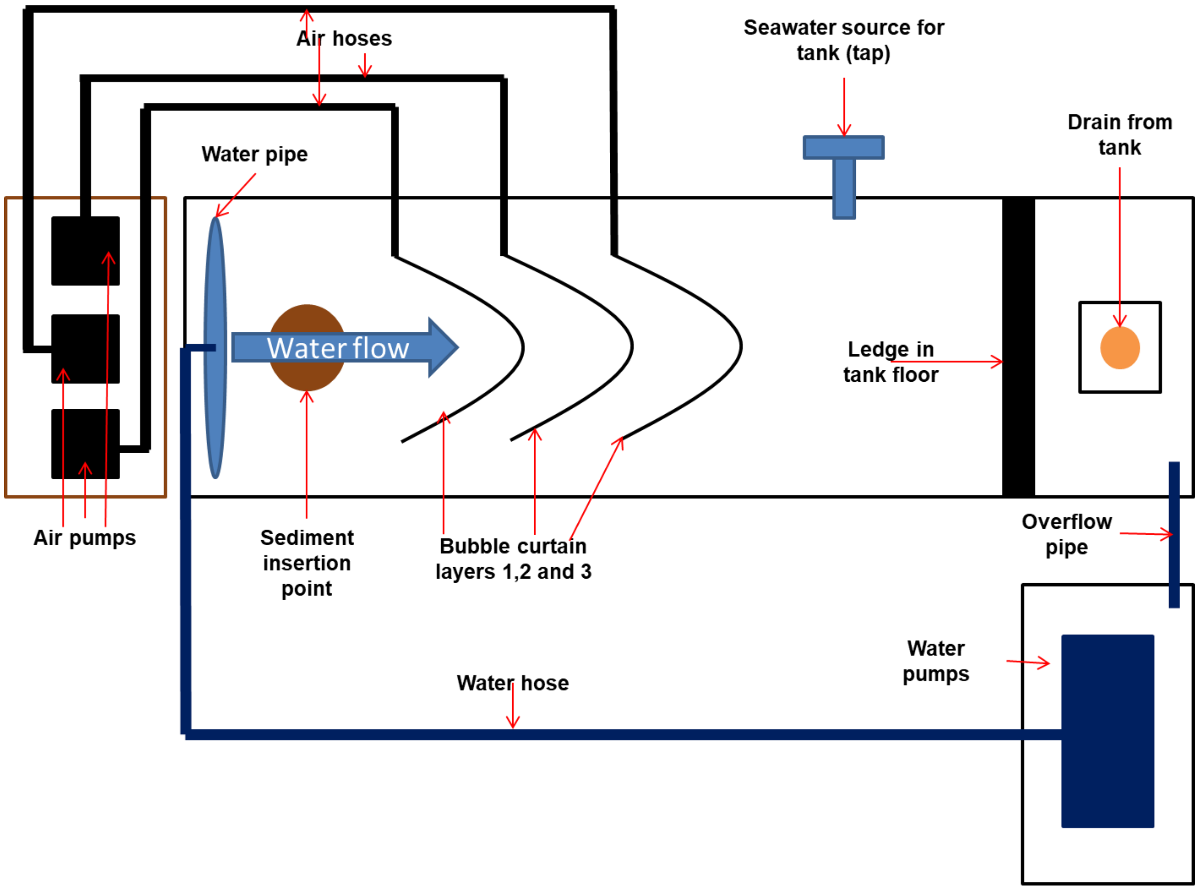

Figure 2. Schematic set-up of tank to test the effect of Bubble Tubing® on sediment dispersal.

We used 25 mm (1”) Bubble Tubing® for the experiment, supplied by Frog Environmental Ltd. Three identical Bubble Tubing® cuttings were used throughout the laboratory trials. Each length of Bubble Tubing® was connected to a Charles Austen ET100 air blower which regulated the pressure uniformly across the length of the tubing. Bubble Tubing® was placed on the bottom of the experimental tank in a semi-circular position so that the end of each tube reached the side of the tank creating a barrier (Figure3). The first bubble tube was situated 1m away from the water inflow pipe and additional bubble tubes installed in 30cm distance to each other.

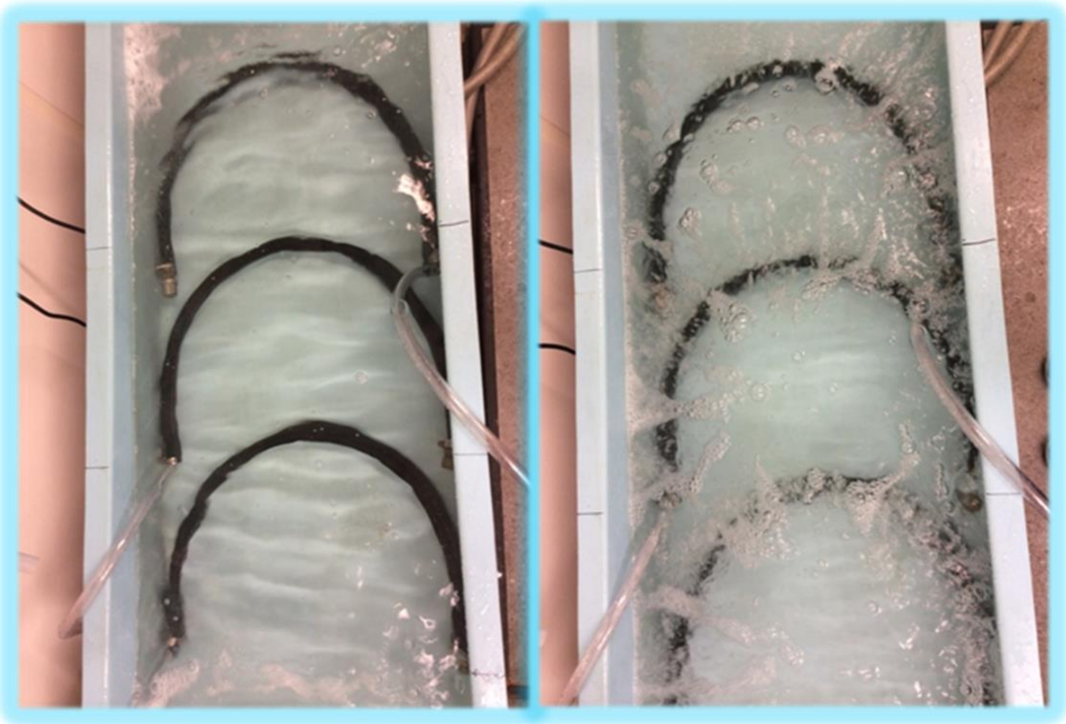

Figure 3: Experimental set-up image depicting 3 active Bubble Tubing® layers within the experimental tank.

Locally sourced sediment from Swansea Bay was retrieved and pre-sieved by hand through a nest of stainless steel sieves decreasing in mesh size. A fixed amount (100g) of dried sediment in three sediment grain-size fractions within the sand size class was produced for the experiments: medium sand (250-500µm), fine sand (125-250µm) and very fine sand (63-125µm).

A total of 27 Bubble Tubing® trials were conducted (Table 1). Each sediment grain-size class (medium, fine and very fine sand) was trialled each with 1, 2 and 3 lines of Bubble Tubing®, and each experiment was repeated three times (n=3). The experimental tank was flushed and cleaned following each trial to avoid cross-contamination.

Methodology

Once the tank was filled with saline water to a set height, the air pumps was switched on to create bubble curtains. Before each trial pumps ran for around 10 minutes, and the Bubble Tubing® was inspected for a constant stream of bubbles in the water column. This was to ensure that perforations along the tubing were blockage-free, and the orientation of the Bubble Tubing® was correctly positioned. It was necessary to clean the Bubble Tubing® in addition to the experimental tank between each replicate run.

Pre-weighed sediment (100g) was inserted into the tank at the same set position between the inflow pipe and the first bubble curtain (Figure 2.). The water pump was activated for the duration of each replicate experiment (10 minutes) to allow the sediment to distribute fully in the tank. After this time the pump was switched off to allow the sediment to settle. The tank was then drained and the sediment in front of, between and behind the Bubble Tubing® was retrieved. It was oven-dried at 30°C and weighed.

Table 1: Sediment testing regime of the Bubble Tubing® laboratory experiments.

Sediment-size fraction µm (mm)	Phi φ	Broad sediment classification*	No. of bubble curtains
500 - 250 µm (0.50 - 0.25 mm)	1.0 - 2.0	Medium sand	1 2 3
250 - 125 µm (0.25 - 0.125 mm)	2.0 - 3.0	Fine sand	1 2 3
125 - 63 µm (0.125 - 0.0625 mm)	3.0 - 4.0	Very fine sand	1 2 3

***According to the Wentworth-Udden grain-size classification scale (Wentworth, 1922)**

4. RESULTS

In laboratory trials and average of 92 ± 4g of 100g of sediment added into the test tank settled out and could be retrieved (n=27, mean ± sd); the remaining sediment stayed in suspension and could not be recovered. Significantly less very fine sediment settled out (88 ± 3g) than fine and medium sand (95 ± 1g and 92 ± 3g) (mean ± sd; ANOVA p<0.001), meaning that more very fine sand (63-125µm) stayed in suspension during the experiment than coarser sediments (125-500µm).

Overall, 48 ± 20g of sediment was retained in front of the first bubble curtain; 29 ± 24g passed through the line(s) of bubble curtain(s) (mean amount of sediment settling behind single or multiple lines of curtains plus sediment remaining in suspension). The amount of sediment passing through curtains (incl. sediment in suspension) was significantly reduced with every additional bubble curtain: from 50 ± 22g to 22 ± 12g and 13 ± 5g for one, two and three bubble lines (ANOVA, n=9, p< 0.0001; Figure 4).

Significantly larger amounts of coarse sediment settled out in front of the first bubble curtain: 75 ± 4g of medium sand sedimented out compared with 33 ± 2 and 36 ± 3g of fine and very fine sand (Table 2, Figures 5-8; ANOVA p <0.0001), or reversely, significantly less of the coarser sediments passed through bubble curtains, independent of the number of bubble lines (ANOVA, n=9, p=0.032). A single line of Bubble Tubing® was therefore more affective for the coarser sediment compared with finer particles.

The impact of additional bubble curtains was greatest on finer sediments: each extra line trapped significant amounts of the next finest particle size class. Adding a second bubble curtain triggered considerable sedimentation of fine and very fine sands, 46 ± 4g and 27 ± 3g. The almost 50% of fine sand settling out between the first and second curtain was significantly compared with the coarser and the finer sediments (ANOVA, n=6, p<0.0001).

Another 20% of the finest sediment was retained by the second and third bubble curtain (22 ± 2g), significantly more than moderate (3 ± 1g) and fine sand (9± 3g) (ANOVA, n=3, p<0.0001).

The amount of sediment passing through all three curtains and settling out behind them was significantly greater for fine and very fine sand (7± 4g and 8 ± 2g) than for moderate sand (0.6 ± 0.7g; ANOVA, n=3, p=0.0188). When adding the sediment remaining in suspension to the sediment settling out behind three bubble curtains, there was no significant difference between the different grain sizes (11 – 18g; ANOVA, n=3, p=0.108). Therefore, three bubble curtains retained 80-90% of sediment of all grain sizes.

Table 2. Amount of sediment held back and passing through 1, 2 and 3 bubble curtains (g sediment mean ± standard variation, n=3). A total of 100g of sediment was entered in each trial; medium sand 250-500µm, fine sand 125-250µm and very fine sand 63-125µm.

Number of bubble curtains	Grain size	In front of first curtain (g)	Between 1st and 2nd bubble curtain (g)	Between 2nd and 3rd bubble curtain (g)	Sedimentation behind curtain(s) (g)	Sediment staying in suspension (g)
1	**medium**	79.5 ± 2.6			**15.4 ± 2.8**	**5.1 ± 1.7**
	fine	32.0 ± 2.1			**63.2 ± 1.4**	**4.8 ± 1.3**
	very fine	38.3 ± 1.9			**47.9 ± 0.5**	**13.8 ± 1.6**
2	**medium**	72.7 ± 1.7	15.9 ± 2.4		**3.3 ± 0.6**	**8.1 ± 2.7**
	fine	34.7 ± 2.4	45.9 ± 3.5		**14.1 ± 1.1**	**5.3 ± 1.9**
	very fine	36.0 ± 4.3	27.6 ± 3.0		**23.4 ± 6.0**	**13.0 ± 4.1**
3	**medium**	73.7 ± 1.2	12.9 ± 1.2	2.8 ± 0.7	**0.6 ± 0.7**	**10.0 ± 2.3**
	fine	31.9 ± 1.8	47.4 ± 4.4	8.9 ± 2.6	**6.7 ± 3.8**	**5.1 ± 1.7**
	very fine	34.8 ± 2.2	25.6 ± 3.1	21.9 ± 2.2	**8.1 ±1.6**	**9.6 ± 0.8**

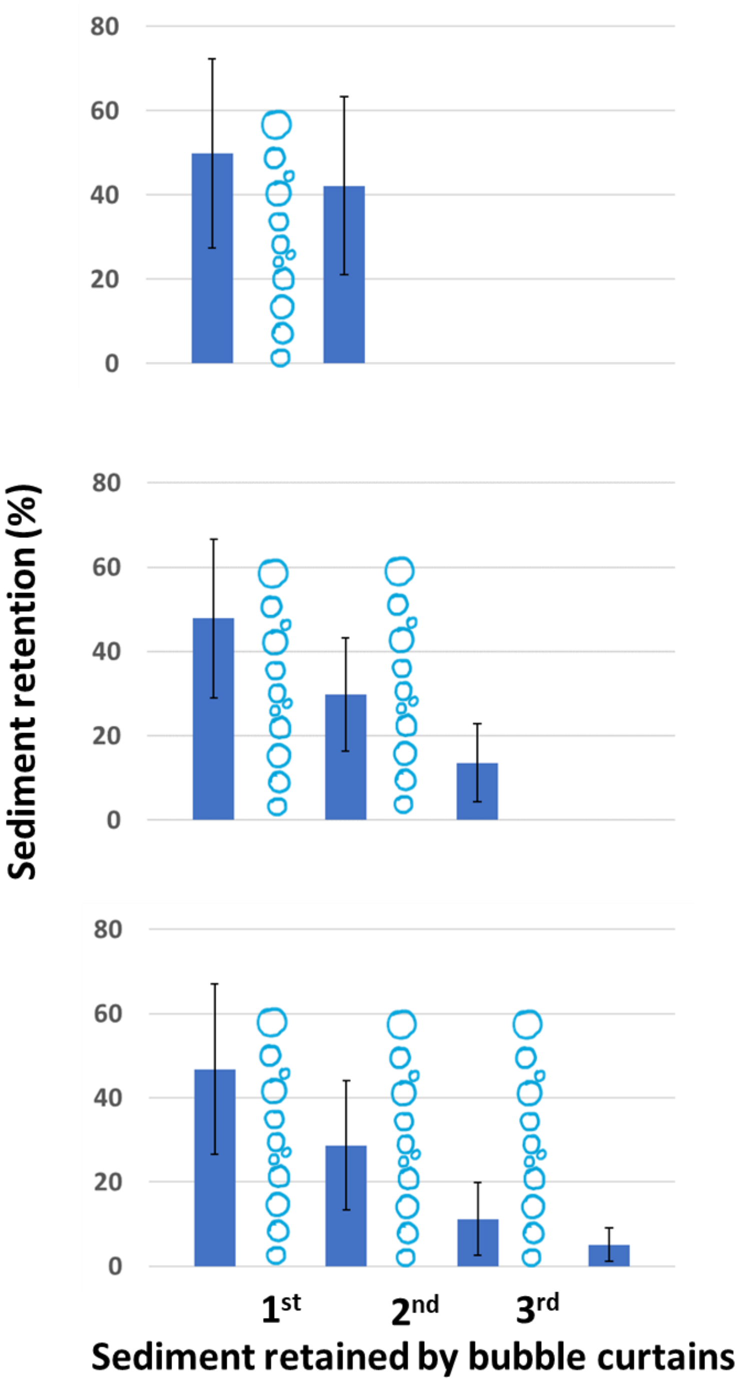

Figure 4. Sediment retained by different numbers of bubble curtains. Mean % values and standard variations (mean ± SD) are shown for combined values of different sized sediment (medium, fine, very fine, n=9) retained in front of 1st; between 1st and 2nd; and between 2nd and 3rd bubble curtain, and the sediment passing all bubble curtain(s).

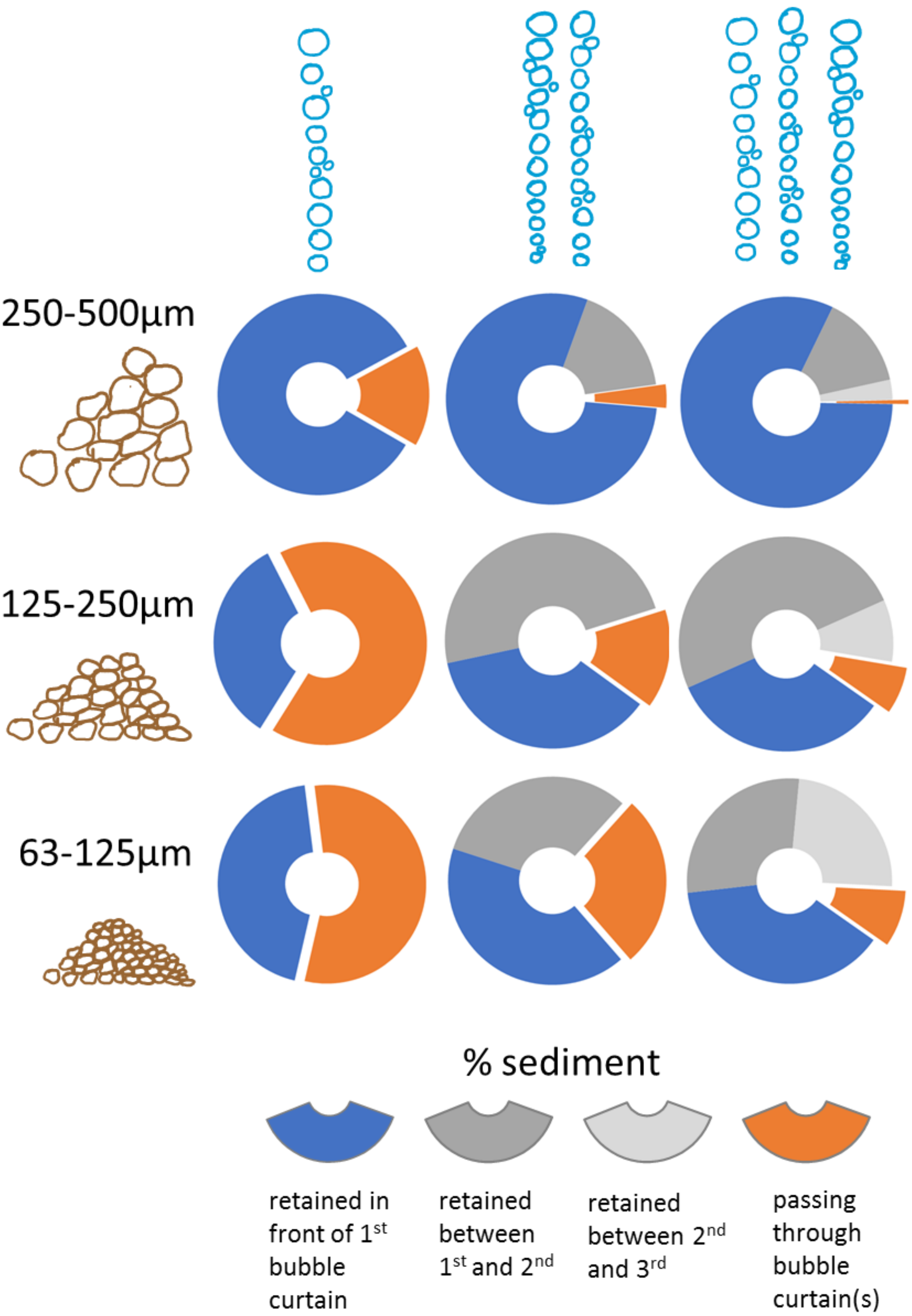

Figure 5. Percentages of different grain sizes retained by and passing through bubble curtains. 1, 2 and 3 parallel bubble curtains were tested with moderate, fine and very fine sand sediments. The amount of sediment retained in front of the 1st; between the 1st and 2nd; and 2nd and 3rd bubble curtain was quantified, as well the amount of sediment passing through all curtains.

Figure 6: Settled medium sand (500-250 μm) with one, two and three Bubble Tubing® layers.

Figure 7: Settled fine sand (250-125 μm) with one, two and three Bubble Tubing® layers.

Figure 8: Settled very-fine sand (125-63 μm) with one, two and three Bubble Tubing® layers.

5. DISCUSSION

The SEACAMS2 laboratory trials suggested that Bubble Tubing® technology is an effective measure to mitigate sediment dispersion in saline waters. A single bubble curtain limited the dispersal of over 50% of sediments. There were however significant differences between finer and coarser sediments, and between one or several layers of bubble curtains.

A single bubble curtain was significantly more effective for coarser than for finer sediments. The dispersion of 70-80% of medium sand (250-500µm) was restricted by a single curtain, while only 30-40% of fine (125-250µm) and very fine sands (63-125µm) were retained. A second and third bubble curtain was very effective in trapping large fractions of the finer sediments. Three parallel bubble curtains contained 80-90% of all sediment fractions.

Sediment suspension and bedload movement

The different effectiveness of bubble curtains for coarser and finer sediments in the tank experiment is most likely linked to the behaviour of particles in suspension and as bedload. Due to the lighter nature of fine sand it was more likely to be contained in suspension. As the finer sediments were released into the water column the flow transported particles further in the tank. Particles may collide with bubbles which transport them vertically through the water column, allowing them to be dispersed further. They were kept in suspension for longer until the particles lost velocity and deposited. The better suspension is also a plausible explanation for the larger amount of very fine sand not being recovered in this experiment. In contrast, the heavier particles of medium sands quickly lost velocity and settled in front of the first curtain. Further, the less cohesive nature of medium sands compared with finer sediments is likely to have contributed to less agglomeration with other particles. More cohesive particles are more prone to flocculation, causing varying rates of sedimentation along the tank. It was observed that very fine sediment readily stuck to Bubble Tubing® and the tank walls. When particles settled out and were part of the bed-load, finer ones required less flow and pressure to be transported further along the tank. This is likely to have contributed to less finer sediment being retained by the first curtain.

The seawater is likely to have influenced results. Salt ions bind themselves to suspended sediments and other flocculates, and as the weight increases the rate of settlement increases. The salinity of the water body does greatly affect the sediment deposition i.e. the more saline the water, the greater the particle deposition. This also influences the turbidity and therefore clarity of the water.

Application in the natural environment

While the laboratory trials showed clear results, their transferability to the natural environment has to be viewed with caution. This trial investigated the sediment transport capacity along a marine tank by applying constant water pressure and using sorted particle-size ranges. The trials did not investigate changes in pressure, salinity, sediment volume or any other variables that may be present in a natural scenario.

It seems likely that sediment retention would be lower in natural settings due to the influence of environmental factors not considered by this trial, i.e. tides, waves and nature of construction. In natural environments the sediment loading is carried out by different modes of entrainment i.e.

suspended, dissolved, wash or bed-load. The majority of the sediment in the medium sand fraction would be transported by bed-load, which is never truly suspended and therefore its movement is never truly continuous or uniform.

Additional observations and recommendations based on laboratory trials

- During the experiment, it was noticed that sediment was transported around the side of the curtain itself. When considering its placement within the field many environmental parameters must be taken into account e.g. when using in a riverine system, geomorphological conditions must be explored so that the movement of sediment around the bubble curtain does not artificially create any erosion to the river bank and accelerate morphological change if used consistently, particularly in an actively migrating fluvial system. When considering using in open water environment, especially those with a high tidal range, a spiral shape with multiple layers of curtain spiralling around itself should mitigate any sediment movement around the curtain.
- During laboratory testing it was noted that the fine-grained sediment fraction (63-125 µm) settled onto the bubble curtain including the perforations leading to blockages. Within aquatic environments where there is increased suspended sediment loading it is recommended that the curtain runs for a considerable time following in-water activities to mitigate this as a '*settling-out phase'*.
- Although the bubble curtain itself is weighted, in an applied setting it is recommended in high energy areas that further weights may be used to secure the bottom of the curtain to the sea floor in case of large wave and tidal velocities that could easily transport the tubing, particularly when large lengths of the tubing are required.
- Although the experiment focused on lateral movement of sediment dynamics in an aquatic environment *i.e.* bed-load, by using a series of laterally placed Bubble Tubbing cuttings along the floor, it may be necessary in deep, large volume areas such as estuaries and the sea, to adapt the Bubble Tubing® to account for the vertical movement of sediment re-suspended in the water column. This could be achieved by creating a series of vertical barriers of Bubble Tubing® at a set distance. This would mitigate any suspended sediments entrained higher into the water column and further currents displacing the sediment.
- A scaled-up field study is highly recommended to test sediment dynamics in the natural environment using a series of lateral and vertical Bubble Tubing® in areas such as river systems and in coastal environments.
- The limitation of Bubble Tubing® to consistently and uniformly maintain air pressure along its entire length at different depths could pose unique engineering challenges and must be approached on a site by site basis.

6. CONCLUSION

Our studies suggest that Bubble Tubing® technology could be an effective management tool to mitigate sediment transfer dispersion in aquatic marine environments. Bubble curtains could also be used in conjunction with other sediment management approaches during MRE phases. The type of substrate, nature of the construction work, depth of water, hydrodynamic conditions and salinity are key parameters that must be considered when using bubble curtains in a marine environment. Numerous Bubble Tubing® barrier system would provide better control of sediment transportation and retain a larger proportion of the sediment.

7. APPENDIX 1

Raw data from the laboratory experiment trials.

	Sediment size	Number of Bubble Tubing®	Run no.	Total mass of sediment (g)	Total mass of sediment out (g)	Mass of settled sediment in front of tubing 1 (g)	Mass of settled sediment behind tubing 1 (g)	Mass of settled sediment behind tubing 2 (g)	Mass of settled sediment behind tubing 3 (g)
Medium Sand	500-250 µm	1	1	100.00	92.94	79.46	13.48		
Medium Sand	500-250 µm	1	2	100.00	96.27	82.09	14.18		
Medium Sand	500-250 µm	1	3	100.00	95.44	76.82	18.62		
Medium Sand	500-250 µm	2	1	100.00	90.43	73.93	13.10	3.40	
Medium Sand	500-250 µm	2	2	100.00	90.28	70.77	16.86	2.65	
Medium Sand	500-250 µm	2	3	100.00	95.01	73.49	17.65	3.87	
Medium Sand	500-250 µm	3	1	100.00	88.06	72.39	12.58	2.69	0.40
Medium Sand	500-250 µm	3	2	100.00	92.45	74.67	14.30	3.48	0.00
Medium Sand	500-250 µm	3	3	100.00	89.37	73.91	11.96	2.17	1.33
Fine Sand	250-125 µm	1	1	100.00	93.66	30.47	63.19		
Fine Sand	250-125 µm	1	2	100.00	96.20	34.38	61.82		
Fine Sand	250-125 µm	1	3	100.00	95.68	31.07	64.61		
Fine Sand	250-125 µm	2	1	100.00	96.86	32.97	49.82	14.07	
Fine Sand	250-125 µm	2	2	100.00	93.58	37.48	43.11	12.99	
Fine Sand	250-125 µm	2	3	100.00	93.70	33.63	44.90	15.17	
Fine Sand	250-125 µm	3	1	100.00	96.68	31.27	50.13	11.19	4.09
Fine Sand	250-125 µm	3	2	100.00	93.38	33.91	42.36	6.08	11.03
Fine Sand	250-125 µm	3	3	100.00	94.63	30.52	49.85	9.32	4.94
Very Fine Sand	125-63 µm	1	1	100.00	87.25	39.93	47.32		
Very Fine Sand	125-63 µm	1	2	100.00	84.37	36.18	48.19		
Very Fine Sand	125-63 µm	1	3	100.00	86.94	38.72	48.22		
Very Fine Sand	125-63 µm	2	1	100.00	89.62	33.24	27.00	29.38	
Very Fine Sand	125-63 µm	2	2	100.00	82.24	33.87	24.91	23.46	
Very Fine Sand	125-63 µm	2	3	100.00	89.14	40.92	30.85	17.37	
Very Fine Sand	125-63 µm	3	1	100.00	89.50	34.19	24.46	21.93	8.92
Very Fine Sand	125-63 µm	3	2	100.00	90.91	37.21	23.27	24.18	6.25
Very Fine Sand	125-63 µm	3	3	100.00	90.70	32.86	29.11	19.72	9.01