

Geotextile Tube Installation at Deep Waters using Innovative Methods

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ABSTRACT

Geotextile tubes are commonly used in revetments and breakwaters in coastal protection structures. Most of these are in relatively shallow waters with water depths less than 15m. If the water is very shallow (<5 m), empty geotextile tubes can be laid on the seabed before being filled. For slightly deeper waters (5 – 15 m+), one common installation method involves dropping the filled geotextile tubes from split bottom hopper barges onto the seabed in a free-fall manner. However, this method may not be suitable in deeper waters because of the lack of accuracy in its placement due to harsh waves and current conditions in deep waters. Research on geotextile tube installation in deep waters was conducted, with the objective of finding an optimal installation method that promises adequate placement accuracy, speedy installation, and cost effectiveness. Two innovative methods were studied. The first innovative method makes use of a floating barge equipped with a high-capacity crane to facilitate the lowering of a fully filled geotextile tube onto the seabed. A lifting and holding system (consists of load spreader, geogrid holding net, GPS sensors etc.) was designed to assist in the lifting of a 25m long filled geotextile tube and subsequent lowering onto the seabed using the high-capacity crane. A field trial of this method was conducted in Singapore to construct an underwater geotextile tube bund consisting of 6 tubes stacked in 3 layers. Monitoring sensors (e.g., strain gauges, pore pressure transducers etc.) were installed on or inside the geotextile tubes to monitor the effectiveness of this installation process. In addition, shape accelerometer arrays (SAA) were installed beneath and above the bottom layer of geotextile tube to monitor the ground settlement, and the settlement of the bottom layer geotextile tubes. The exact location of the tubes can also be inferred from this settlement information obtained from SAA. Results from instrumentation data and observations showed that the high-capacity crane barge option is an effective method for the installation of geotextile tubes in deeper waters of more than 15 m. Taking the lessons learnt from the first method, a second innovative method was developed, called the “N-H Geotextile Tube Deep Water Installation Method”. This method makes use of a pair of mid-size conventional flat top barges, modified with the addition of a series of winches on two banks of the barges. The geotextile tube is first filled when it is placed on a flat floater, between the two barges. Upon the completion of filling, the tube will then be lowered using the series of winches after removing the floater. The specially designed lifting and holding system used in the “high-capacity crane barge method” was also further modified to fit into the system here. Model tests are in progress. A detailed analysis and comparison of both methods were done. It was concluded that the “N-H Geotextile Tube Deep Water Installation Method” has a better overall score than the “high-capacity crane method”, and especially excels in terms of its high adaptability, cost-efficiency and scalability.

Keywords: Geotextile Bund, Woven, Installation, Deep Waters, Cost Effectiveness.

1 INTRODUCTION

Geotextile tubes are commonly used in revetments and breakwaters in coastal protection structures. Most of these are in relatively shallow waters with water depths less than 15m. In these shallow depths, there are several common methods of installing geotextile tubes. At very

shallow depths (<5 m), empty geotextile tubes can be laid on the seabed before being filled. For slightly deeper waters (5 – 15 m+), one common installation method involves dropping the filled geotextile tubes from split bottom hopper barges onto the seabed in a free-fall manner (Figure 1(a)). However, at greater depths, the significant

influence of underwater currents will affect placement accuracy, thus making these methods unsuitable for use in depths $>20\text{m}$. Custom-made designs such as NEREIS were created to specially install geotextile tubes in deep waters (Figure 1(b)). However, the scale and complexity of these systems can add significant costs to the project.

Thus, research on geotextile tube installation at deep waters (20-40m) was conducted, with the objective of finding an optimal installation method that promises adequate placement accuracy, speedy installation, and cost effectiveness. Two innovative methods were studied, and a field trial was conducted.

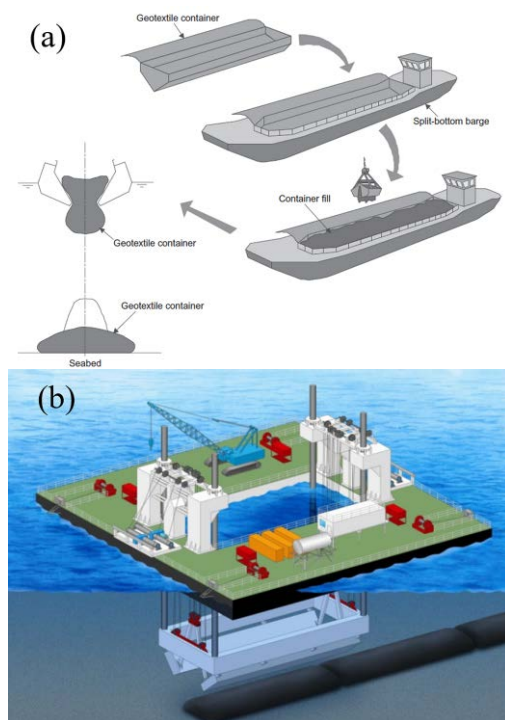


Fig 1. Installation methods: (a) "Free-fall" dropping of filled geotextile tube (Pilarczyk, 2000); (b) NEREIS custom designed geotextile tube installation barge (Kamada, 2010).

2 METHODOLOGY OF INSTALLATION METHODS

2.1 High-Capacity Crane Barge Method

This innovative method makes use of a floating barge equipped with a high-capacity crane to facilitate the lowering of a fully filled geotextile tube onto the seabed. There are 2 key components of this method (shown in Figure 2): (1) High-capacity crane barge; and (2) Geotextile tube lifting and holding system. The lifting and holding system ensure that the lifting force from the crane barge is uniformly distributed along the fully filled geotextile tube using a custom lifting frame and a specially designed sacrificial geogrid. This will minimize the bending or uneven lifting of the geotextile tube in

the longitudinal direction during lifting and lowering onto the seabed. Once the geotextile tube is lowered onto the seabed, the geogrid sheet will be cut by divers. To ensure accuracy of placement, GPS sensors are installed at two ends of the lifting frame. An illustration of this installation process of the High-Capacity Crane Barge Method is shown in Figure 3.

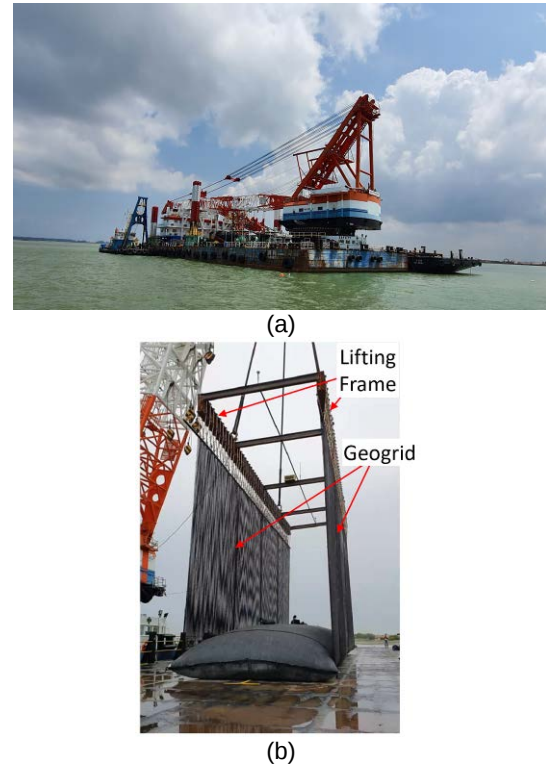


Fig 2. (a) High-Capacity Crane Barge; (b) Geotextile tube lifting and holding system.

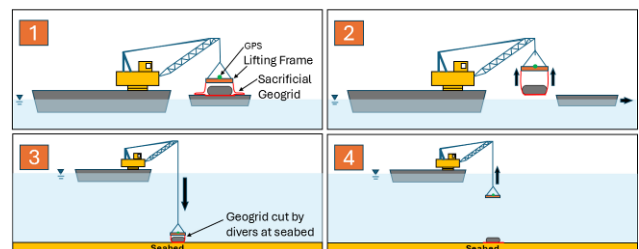


Fig. 3. Installation Process using High-Capacity Crane Barge

2.2 Field Trial Setup of High-Capacity Crane Barge Method

A full-scale field trial using the High-Capacity Crane Barge Method was conducted to investigate two key factors: (1) Effectiveness of the lifting frame in ensuring uniform distribution of forces across the length of fully filled geotextile tube during lifting and lowering; and (2) Accuracy of placement of geotextile tubes in water. Six (6) members of fully filled geotextile tubes will be progressively lowered onto the seabed using a 600-ton high-capacity crane barge. They will be

stacked together to form a bund. The fully filled geotextile tubes measure approximately 20-22 m along its length and 6.5 m in width. The geotextile tubes were made from high strength polypropylene geotextiles with an ultimate tensile strength of 200 kN/m in both Machine Direction and Cross-Machine Direction.

The whole process of the installation method was monitored using sensors placed in three geotextile tubes. Its effectiveness will then be evaluated. Strain Gauges were installed in the Longitudinal Direction (LD), Circumferential Direction (CD) and Diagonal Directions (DD) at multiple locations on the tube, as illustrated in Figure 4(a). In addition, two lines of Shape Accelerometers Arrays (SAA) were also installed at different locations in the bund (shown in Figure 4(b)) to monitor the settlement beneath each layer of geotextile tubes, and to confirm the accuracy of placement. Figure 5 shows the lifting and lowering process of the fully filled geotextile tube during the field trial.

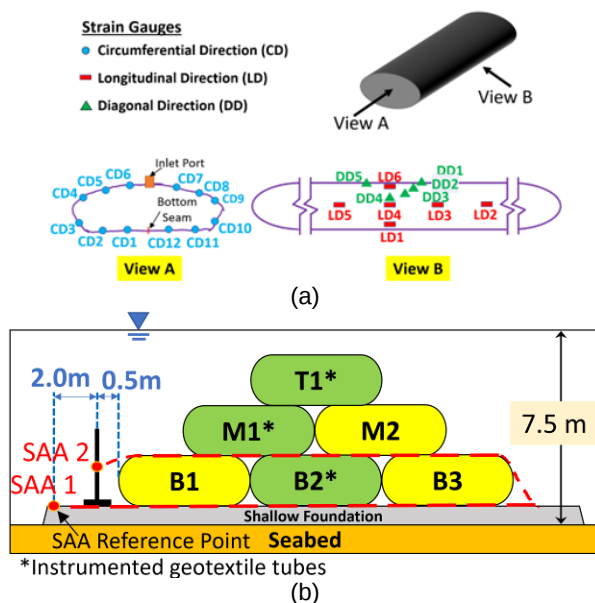


Fig 4. (a) Strain gauge arrangement in geotextile tube; (b) Positions of Shape Accelerometer Arrays (SAA) for settlement measurement.

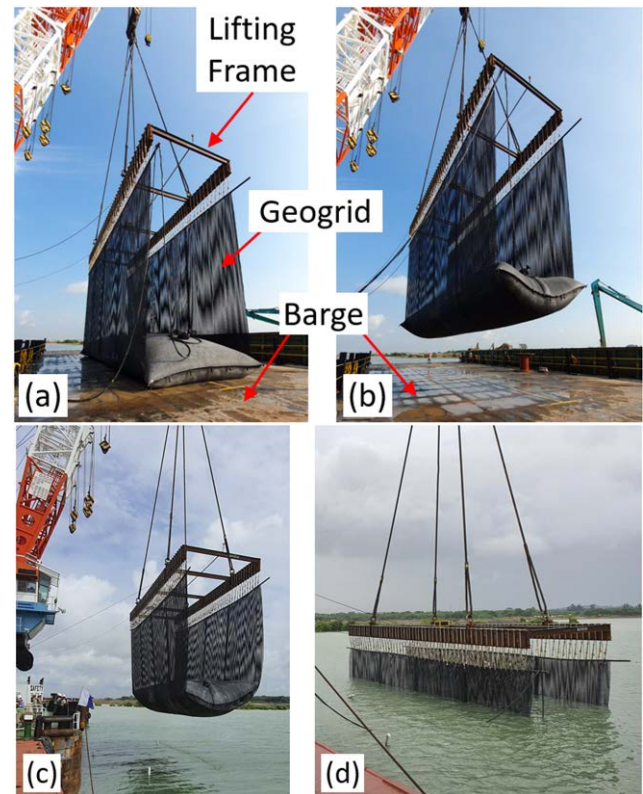


Fig 5. Lifting and lowering process: (a) Lifting frame and geogrid is set up; (b) Geotextile tube is lifted off the barge; (c) Barge is shifted away from the bottom of the geotextile tube; (d) Geotextile tube is lowered into the water.

2.3 N-H Deep Water Installation Method

The N-H Deep Water Installation Method was designed after the lessons learned from the field trial of the High-Capacity Crane Field Trial. Figure 6 illustrates the design of the system used in the N-H method. This method makes use of a pair of normal conventional flat top barges joined by a series of rectangular frame structures. A pair of winches are installed on each rectangular barge frame, with the ropes from the winches linked to the geotextile tube lifting frame (modified version of the system used in the High-Capacity Crane Method). The geotextile tube is connected to the lifting frame using a sacrificial geogrid. GPS sensors are also installed at both ends of the lifting frame to ensure installation accuracy.

The installation process of the N-H Method is illustrated in Figure 7. The geotextile tube is first filled on a flat floating platform, then lowered using the series of winches with the floating platform removed. Once the tube is lowered into position on the seabed, the sacrificial geogrid is disconnected from the lifting frame using a remote locking system. The lifting platform is raised to prepare for installation of the next tube.

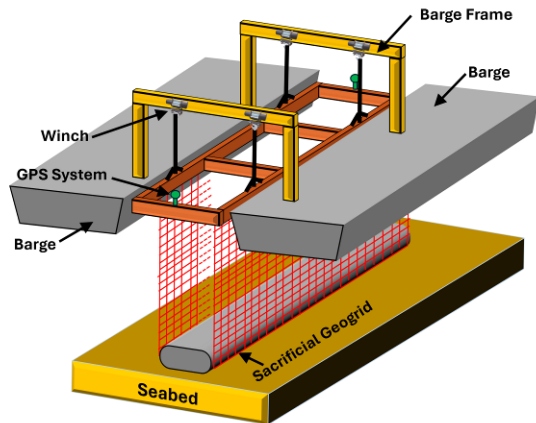


Fig 6. Conceptual diagram of Barge System of N-H Method

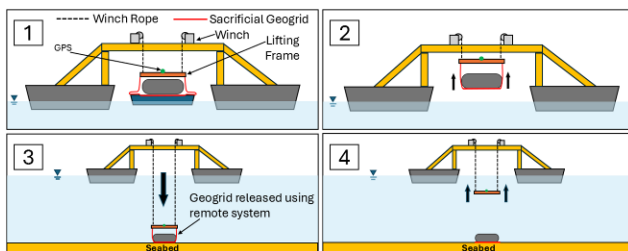


Fig 7. Installation process of N-H Method.

3 RESULTS AND DISCUSSION OF FIELD TRIAL (HIGH-CAPACITY CRANE BARGE METHOD)

Figure 8 shows the strain gauge readings from instrumented geotextile tube B2 during the lifting and lowering process, with strain converted to tensile force (kN/m) using the tensile force-strain relationship of the geotextiles. The initial values of tensile forces here were tensile forces induced during the infilling stage of geotextile tubes prior to the lifting operation. It can be observed that the tensile forces experienced by geotextile tube start to change as the tube was lifted off the ground. Tension forces remained constant during the whole process when the tube was in the air, as well as the whole lowering process. When the tube touches the seabed, tension forces start to change again until the tube was fully settled on the seabed.

The largest change in tensile force during lifting operation was observed to occur in the Circumferential Direction (CD) of the tube, with values ranging from 5 to 20 kN/m at various locations. Tensile forces in the LD and DD direction experienced very minor changes of only up to 8 kN/m. This is likely because deformation of the geotextile tube took place in its cross-section of the tube which is the CD direction of geotextile during lifting. It can also be observed that some CD readings decreased (e.g., CD5 experienced a 20 kN/m decrease in tension), while others increased (CD1 experienced an increase of 15 kN/m). This was likely due to the difference in positions of the

strain gauges on the geotextile, with respect to the cross-section of the tube, during the lifting process. As illustrated in Figure 9, the CD strain gauges at the top of the geotextile tube (e.g., CD5) experiences a decrease in tension force because the geotextile tube “compressed” upwards during lifting, while the strain gauges at the bottom (e.g., CD1) experiences additional tension as it is on the stretching side of the geotextile tube during lifting.

Strain gauges in LD direction experienced minimal changes in tensile forces during lifting and lowering, which indicates that the lifting frame was able to ensure the geotextile tube to maintain uniform tension in the longitudinal direction, preventing any sagging behavior of the tube. Similar trends were also observed in instrumented geotextile tubes M2 and T1. Overall, the lifting frame has been shown to be effective in ensuring sufficiently uniform distribution of forces throughout the geotextile tube during the lifting and lowering process.

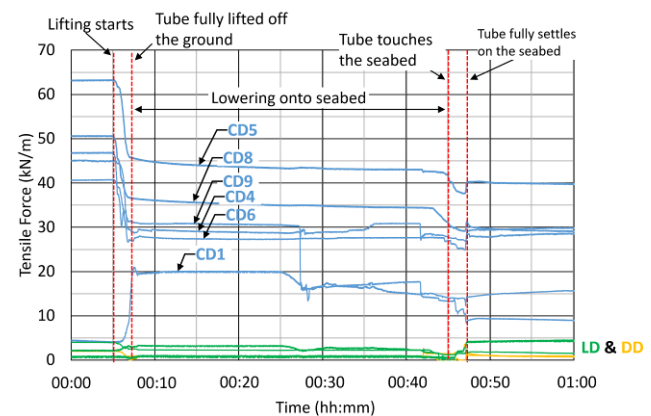


Fig 8. Selected strain gauge readings of tube B2 during lifting and lowering process

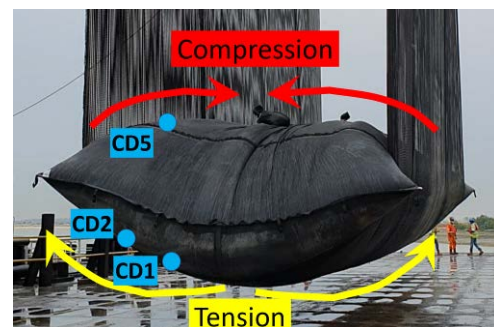


Fig 9. Deformation of geotextile tube during lifting

Wireless sensors attached to the exterior of geotextile tubes were used to monitor its movement when it was lowered into the water. Figure 10 clearly shows the physical maneuvering of the geotextile tube: after the geotextile tube was first lowered onto the top of middle layer tubes, it was then re-lifted, and its position adjusted before it is lowered again into the water to its final position.

This demonstrates an advantage of the crane system, where the GPS combined with the flexibility of the crane allows for adjustment of the tube position until it is in the desired position.

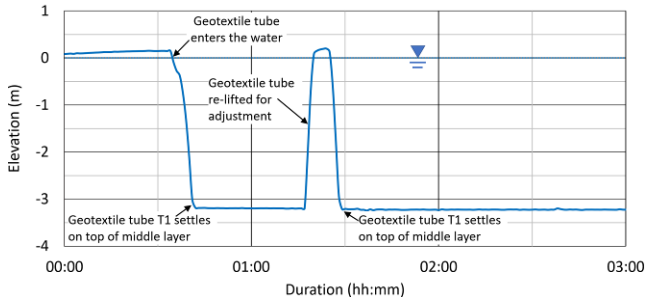


Fig 10. Lowering of Geotextile Tube T1 into the water as recorded by wireless sensor mounted on the tube

Bathymetry surveys were also conducted after various construction milestones to verify the accuracy of placement. Figure 11(a) shows bathymetry survey (plan view) of the bottom layer tubes after they were installed, and results show good agreement the target geotextile tubes position as shown in Figure 4(a).. Figure 11(b) shows the 3D bathymetry survey results after the completion of the geotextile tube bund, and the geotextile tubes were well aligned in the longitudinal direction.

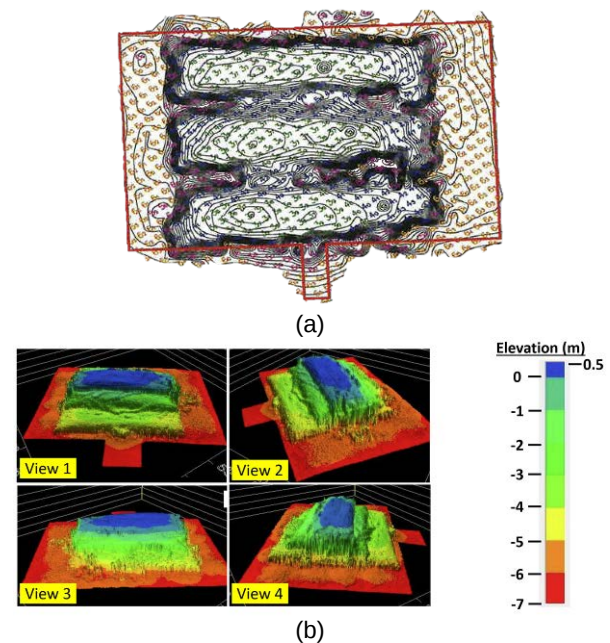


Fig 11. (a) Plan view result from bathymetry survey after installation of bottom layer tubes; (b) 3D result from bathymetry survey after geotextile tube bund has been completed.

4 COMPARISON OF METHODS

An analysis and comparison of each installation method was conducted, and the findings summarized in Table 1. The installation methods were evaluated based on 3 main categories: (1) Scalability; (2) Cost-Effectiveness; & (3) Placement Accuracy.

Table 1. Analysis and Comparison of Installation Methods

Category	High-Capacity Crane Barge Method	N-H Deep Water Installation Method
Scalability	The high-capacity crane barge is a specialized equipment, and in a large-scale project there may be constraints in mobilising multiple high-capacity crane barges in a single project.	As the modified winch barge system is designed to be less complex than the high-capacity crane barge, it will likely be easier (and cheaper) to mobilise multiple sets of winch barge systems for large scale projects.
Cost Effectiveness	As the equipment is more specialized, the cost to build, or to rent and maintain each system will be higher than a modified winch barge.	The modified winch barge is less complex and thus likely to be cheaper to build (per unit) when compared to a high-capacity crane barge. As a larger number of modified winch barges can be deployed (due to ease of scalability and lower cost per system), the deployment of geotextile tubes will be carried out at a faster pace, improving the method's cost effectiveness.

Placement Accuracy	The GPS in the lifting and holding system allows the operator to accurately place the geotextile tube to its target position during lowering operations. This has been verified in a field trial, where the High-Capacity Crane Barge Method was able to accurately install fully filled geotextile tubes at the desired locations.	As the N-H method has the same lifting and holding system as the High-Capacity Crane Barge Method, it can be expected to have a similar level of placement accuracy.
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Analysis and comparison of the two methods has shown that the N-H method is a promising improvement over the high-capacity crane barge method, addressing some of the issues associated with the cost and scalability of the system in large scale projects.

4 CONCLUSION

The field trial of the high-capacity crane barge has confirmed several key findings. Firstly, the lifting and holding system is able to lift and lower geotextile tubes in a uniform manner, without any significant bending or deformation to the filled geotextile tubes in the longitudinal direction. This was verified with strain gauge data, supplemented by visual observations of the lifting operations at site. The high-capacity crane was also able to lower the geotextile tubes with good accuracy with the help of the GPS system mounted on the two ends of the lifting frame. This was verified with hydrographic surveys done at various stages of construction of the geotextile tube bund.

Following the completion of the field trial, the N-H Deep Water Installation Method was developed by drawing on the lessons learnt from the field trial using the high-capacity crane barge. The N-H method addresses the limitations of the high-capacity crane barge method e.g., expensive lifting system, while incorporating and adapting key features such as the lifting and holding system.

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