Geotextile tubes as containment dykes and breakwater structures

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ABSTRACT: Containment dykes and breakwater structures are essential structures that are required prior to the start of land reclamation works. Its function is to act as retaining structure and to protect reclamation areas from sea-wave erosion. In the vicinity of Ancol, located in the Northern area of Jakarta, the seabed consists of a thick soft soil layer, the bearing capacity is very low. This condition becomes one of the greatest challenges to construct a strong and durable containment dyke and breakwater structure. Other challenges to be considered are the sea waves, sea current, and extreme tidal conditions. To meet with these challenges, geotextile tubes were selected to serve as a containment dyke, as well as forming the core of the breakwater with A-Jack concrete blocks implemented as the armor layer. The advantage of using geotextile tube as a breakwater's core in contrast to the conventional method of using a rubble mound, is that it reduces the construction time whilst offering significant cost savings. When designing geotextile tubes as containment dykes and breakwaters, the data that needs to be addressed include the settlement analysis, especially for soft seabed soil, and sea depth, including the wave's height. Based on this data, a proper dimension, fabric type and strength of geotextile tube can be determined. The geotextile fabric used should have sufficient high-tensile strength with low elongation to withstand the water pressure during filling process. The design result of geotextile tube must meet the internal and external stability criteria, and required durability.

Keywords: Geotextile Tube, Reclamation, Breakwater, Dyke

1 INTRODUCTION

Breakwater and Containment Dykes are essential structures that required prior to commence a land reclamation work. “K Island”, is one of the 17 islands that will be created as part of the "Jakarta Water Front City Development Project" in Ancol, North Jakarta. The reclamation area is about 35 hectares. K island reclamation is planned to be part of an amusement park development of the Dunia Fantasy themed water ride.

Breakwater and Containment Dykes structures are very important because of its function as retaining structure and as protection of reclamation areas against abrasion from sea-wave. In the vicinity of Ancol, located in the Northern area of Jakarta, the seabed consists of a thick soft soil layer, hence the bearing capacity is very low. This poor seabed condition become one of the greatest challenges in construction of a strong and durable containment dyke as well as a breakwater structure. Other challenges to be considered are the sea waves, sea current, and extreme tidal conditions. To meet with these challenges, geotextile tube was selected to serve as a containment dyke, as well as forming the core of the breakwater with A-Jack concrete blocks implemented as the armor layer.

2 GEOTEXTILE TUBE

2.1 *Geotextile tube as breakwater structure*

With reference to GRI Test Method GT11, geotextile tube is a large tube (with a circumference of more than 2.3 m) is made from high strength, woven geotextile with a length of more than 6.1 m.

The advantages of geotextile tube for coastal protection:

- No significant environmental impact
- Strong and durable
- Effective retaining wall
- Practical and easy in application
- Filler material can be taken in the local area
- Efficient and effective

The advantage of using geotextile tube as a breakwater's core compared to the conventional method of using a rubble mound, is that it reduces the construction time whilst offering significant cost savings. The fabric used to make Geotextile Tube should have sufficient tensile strength with low elongation to withstand water pressure during the filling process and to reach expected tube height.

2.2 *Geotextile tube material*

To create geotextile tube, material woven and non woven can be used depends on its dimension and function. According to Lawson (2006), since 1980, large diameter tubes were developed using strong woven geotextiles as the tube skin (and with no impermeable inner liner). The major advantage of these later-developed tubes is that a large protected mass, tubular structure could be designed directly to meet many hydraulic and marine stability requirements. While for heavy weight nonwoven geotextiles were developed for small diameter (less than 1.5 m) geotextile tubes. Today, geotextile tubes ranging in equivalent diameters from 1.0 m to 5.5 m are used in many marine applications around the world.

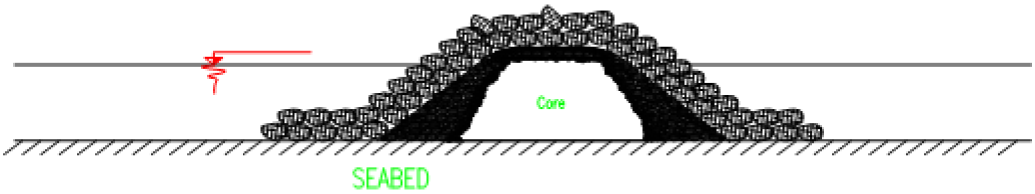
The main differences between woven and non woven geotextile tube are given in Table 1 as follows :

Table 1: Comparison Non Woven and Woven Geotextile Tube

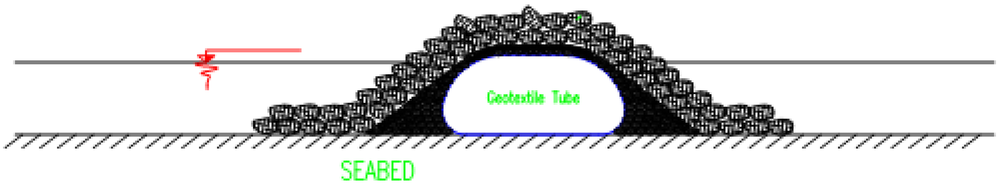
Comparison	Non Woven Geotextile Tube	Woven Geotextile Tube
Advantages	- More durable to sharp object disturbances	- High tensile strength - Smaller packaging for delivery - Less thickness and lighter weight - Need less sand for fill material to reach the same height compared to non woven tube
Disadvantages	- Less strength (only applicable for small tubes) - Much higher elongation - Thicker and heavier weight - Bigger packaging for delivery - More effort for mobilization	- Relatively less durable to sharp object disturbances
Price	- More expensive	- Less Expensive

2.3 *Geotextile tube design*

In general, the breakwater consists of two components, namely core and armor. Core for breakwater can be composed of rock material or sand (see Figure 1). Sand is used as core material for reclamation dyke of K Island, therefore, sand need to be placed into a container when used as marine structure. The core is protected by armor using a concrete armor units named A-Jack. In coastal engineering, an A-Jack consist of two concrete T-shaped pieces joined perpendicularly at the middle, forming six legs. A-Jack shape is designed to dissipate the force of incoming waves by allowing water to flow through rather than against it, and to reduce displacement by allowing a distribution of A-Jack to form a strong interlock. At the bottom of the breakwater geotextile tube mattress were placed to provide an even load distribution from the stacked Geotextile Tubes weight.



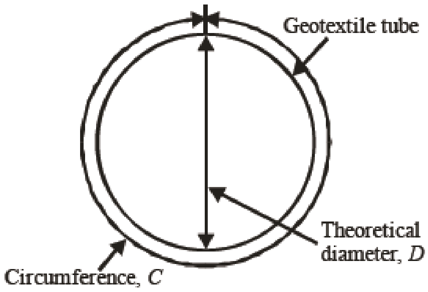
(a)



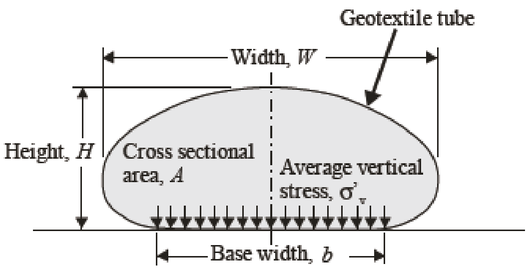
(b)

Figure 1 : a. Core of breakwater structure using rock material or sand,
b. Core of breakwater using geotextile tube

Parameters required to design a geotextile tube are the properties of fill material, expected dimension (tube circumference and height) and predicted external water height to determine the physical properties of geotextile tube material. Illustration of the parameters required to design a geotextile tube are shown in Figure 2.



a) Fundamental geotextile tube parameters



b) Engineering parameters of importance for filled geotextile tubes

Figure 2 : Geotextile Tube Dimension and Physical Properties (Lawson, 2006)

The dimensions and properties of geosynthetic material are determined by using a computer program. The GeoCops V.3.0 (Geosynthetic Confined Pressurized Slurry) from Adama Engineering was used for this project.

From a technical standpoint geotextile tube must meet geotechnical stability as shown in Figure 3. The stability requirements are as follow (Yee, 2002):

- Internal Stability
    - The geotextile material used to fabricate the tube, including seams and closure need to withstand the stresses that may be encountered during the placement and filling process.

  - The geotextile tubes should prevent excessive loss of fines, but be sufficiently permeable to prevent excessive build up of pressures during installation.
- External Stability
  - The geotextile tube should be hydraulically stable against waves and currents
  - The geotextile tube should be geotechnically stable against sliding, bearing, overturning and global slip failures.
- Durability
  - The geotextile should endure and perform the engineering functions over the lifespan o the design.

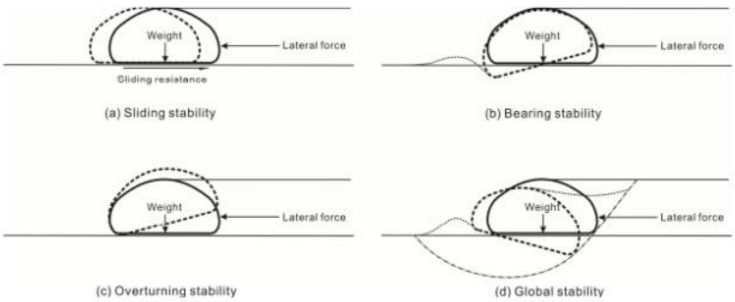


Figure 3 : Geotechnical Stability : sliding, bearing capacity, overturning, dan global (Yee, 2002)

Geotextile material used for geotextile tube must have a high tensile strength to receive high pumping pressure during tube filling process and lateral pressure of sand inside the tube. In addition, the geotextile material should have the suitable apparent opening size (AOS) based on the filling particle size available for the project. In Ancol project, the maximum AOS is 0.3mm.

Although the Geotextile Tube material is UV stabilized, the material is not resistant to UV rays, so it is necessary to give a UV protection layer in the form of non-woven geotextile as a sacrificed layer. In K Island, the non woven geotextile is applied to cover geotextile tube from UV exposure during construction and protection against puncture risk caused by armors as shown in Figure 4.

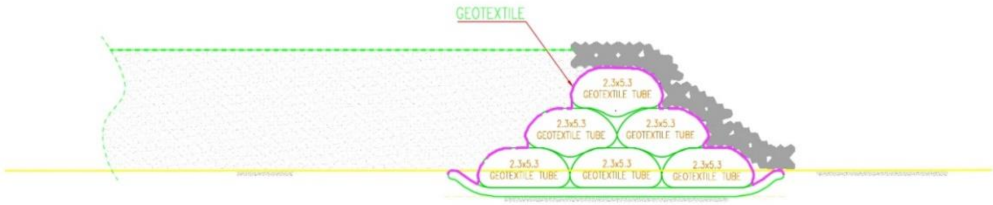


Figure 4 : K Island Breakwater Typical Cross Section

Since the seabed soil in Ancol project consists of very soft clay with 10 m of thickness, the consolidation settlement need to be considered. To prevent differential settlement, geotextile tube mattress was placed below geotextile tube system. The mattress act as a base to distribute the tube load evenly to the seabed and prevent differential settlement. Illustration of geotextile tube mattress are shown in Figure 5.

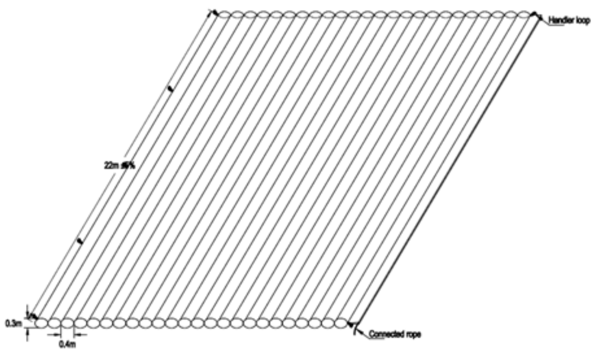


Figure 5 : Geotextile Tube Matress

Sand used to fill the geotextile tube for K Island should have a grain size of at least 0.35 mm with a medium or coarse qualifications. Tolerance for fine particles below 0.35 mm is up to 8%.

Specifications of the Geotextile Tube for K Island is as follows:
MD/CD tensile strength: ≥ 200 kN / m
Static puncture CBR: ≥ 23000 N
Aperture size: ≤ 0.297 mm
Filled Height (H) : 2.3 m - 2.4 m
Circumference (C) : 12.5 m - 12.9 m
Filled Width (W): 5.2 m - 5.3 m
Specfications of the Geotextile Tube Mattress for K Island is as follows:
MD/CD Tensile strength: ≥ 50 kN / m
Static puncture CBR: ≥ 4500 N
Aperture size: ≤ 0.354 mm
Length : 20 m
Filled Width : 7.2 m
Filled High: 0.4 m

2.4 *Settlement of geotextile tube*

The seabed in Ancol project is consist of very soft clay with 10 meters of thickness. This become one of the challenges to construct a breakwater structure. Geotextile tube was selected as the core of breakwater structure because its flexibility to suit soil surface conditions. Since the seabed is very soft clay layer, the consolidation settlement need to be considered. To prevent differential settlement, geotextile tube mattress was placed below geotextile tube system. The mattress act as a base that distribute the tube load evenly to the soil. Since the load are distributed evenly, it will prevent differential settlement and will reduced soil consolidation settlement.

Based on the consolidation settlement calculation using Terzaghi theory, the predicted total consolidation settlement are 3.2 m in 3.4 years. By using tube matress underneath the geotextile tube, the settlement can be reduced up to ± 19%. Thus the settlement is minimized to 2.6 m (See Figure 6 and Table 2).

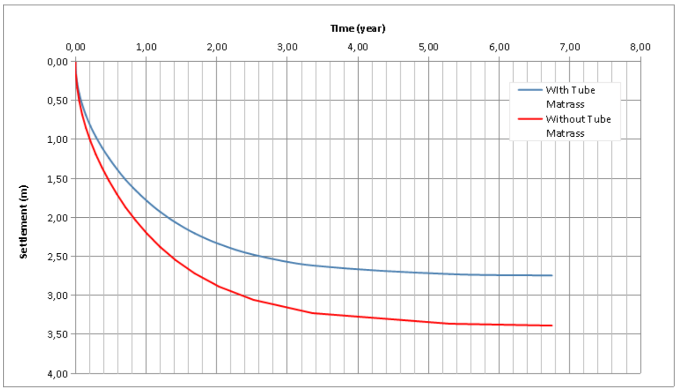


Figure 6 : Geotextile Tube Consolidation Settlement

Table 2: Consolidation Settlement Comparison

Uv (%)	t (years)	Settlement Without Matrass (m)	Settlement With Matrass (m)	Settlement Differences (m)	% of Settlement Reduced
0	0,00	0,00	0,00	0,00	0,00
5,00	0,01	0,17	0,14	0,03	18,95
10,00	0,02	0,34	0,28	0,06	18,95
15,00	0,05	0,51	0,41	0,10	18,95
20,00	0,09	0,68	0,55	0,13	18,95
25,00	0,15	0,85	0,69	0,16	18,95
30,00	0,21	1,02	0,83	0,19	18,95
35,00	0,29	1,19	0,96	0,23	18,95
40,00	0,37	1,36	1,10	0,26	18,95
45,00	0,47	1,53	1,24	0,29	18,95
50,00	0,58	1,70	1,38	0,32	18,95
55,00	0,71	1,87	1,51	0,35	18,95
60,00	0,85	2,04	1,65	0,39	18,95
65,00	1,01	2,21	1,79	0,42	18,95
70,00	1,20	2,38	1,93	0,45	18,95
75,00	1,42	2,55	2,07	0,48	18,95
80,00	1,69	2,72	2,20	0,52	18,95
85,00	2,03	2,89	2,34	0,55	18,95
90,00	2,52	3,06	2,48	0,58	18,95
95,00	3,36	3,23	2,62	0,61	18,95
99,00	5,29	3,36	2,73	0,64	18,95
99,70	6,74	3,39	2,75	0,64	18,95

Actual settlement was measured in 2014 right after geotextile tube dyke completed. Second measurement was taken in 2015 right before rubble mound installation started. For Actual settlement is shown in Figure 7.

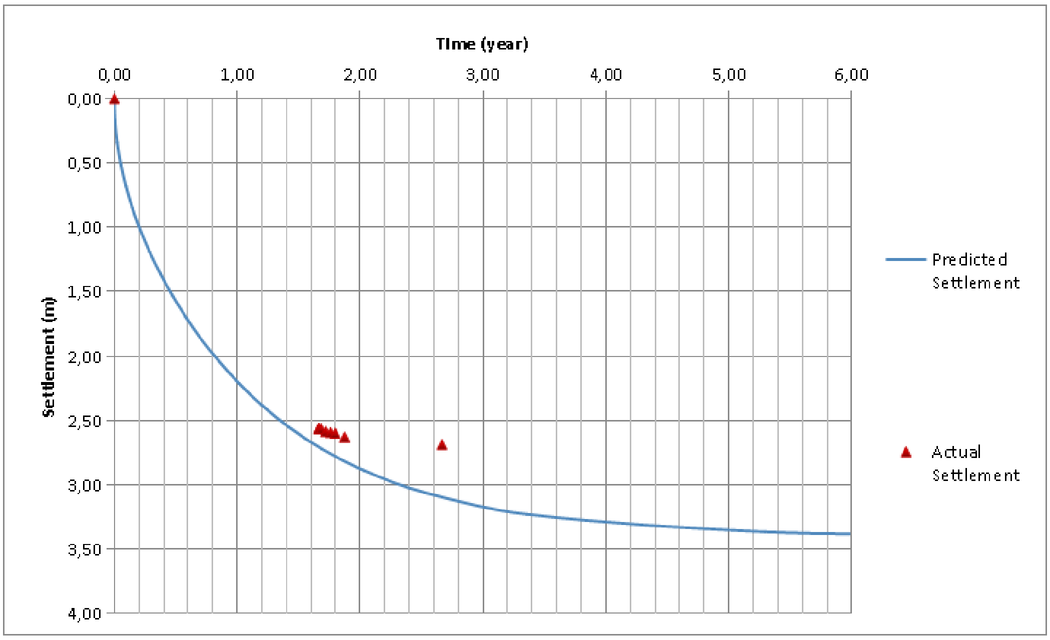


Figure 7 : Geotextile Tube Actual Consolidation Settlement

Although the actual measurement data is not enough to show actual settlement performance, the figure 7 may give an illustration about the actual settlement vs predicted settlement.

3 METHOD OF CONSTRUCTION

3.1 *Installation process*

One of the main challenges in the geotextile tube installation process for Ancol reclamation project is to find the suitable fill material. Not all kind of sand can be used as geotextile tube fill material. Geotextile tube filling material must be a medium or coarse sand, with a content of sludge and grains smaller than

0.35 mm not more than 8%. Since the sand with this specification could not be found in the area around the project site.

To optimize the use of barges, a temporary stockpile had created at the project site to accommodate the sand before it was pumped into geotextile tube, so when the barge arrived at the project site, granulated materials directly transferred into the stockpile as seen in Figure 8 and then the barge can directly returned to Banten to take new material. Sand was pumped from the stockpile using sand pump into the geotextile tube. Without this method, the barge must stand by at the project site until all the sand on the barge used, which it is certainly not an efficient way.

Figure 8 : Sand dumping from barge to stockpile

The geotextile tube and geotextile tube mattress are filled by pumping the sand into the geotextile tube and geotextile tube mattress as seen in Figure 9.

Figure 9 : Sand pumped to the first layer of geotextile tube

The pumping is done when the geotextile tube and geotextile tube mattress filled full with sand and consolidated. The sand pumped into geotextile tube and geotextile tube mattress will be retained inside the tube, while the water pumped into tube will go out through the pores of the fabric of geotextile tube and geotextile tube mattress (see Figure 10).

Figure 10 : Geotextile Tube filling process

This is why the opening size of geotextile material and grain size of the sand is very important in tube installation process. The apparent opening size (AOS) and the size of the granular materials need to be calculated in order to prevent sand going out through the geotextile pore during pumping and no blockage. The suitable AOS can be determined by using this formula (Bezuijen & Vastenburg, 2013):

$$O_{90} < 1.5\ D_{10}\ C_u^{1/2} \text{ and } O_{90} < D_{90}$$

where :
O_{90} = pore size of gotextile that corresponds to the average diameter of the sand fraction of which 90% remains on the geotextile
D_x = sieve size through which x% fraction of the sand material passes
C_u = uniformity coeeficient of the sand (D_{60}/D_{100})

If the opening size of geotextile is too large then there will be too much sand going through the pores that cause the tube filling process become ineffective. If the opening size of geotextile is too small, there will be a blockage in the geotextile pore hence water cannot go out easily from the geotextile material. This may cause over pressure inside the geotextile tube which may break the Tube fabric.

The next challenge after the geotextile tube has been filled with sand is the installation of thick non-woven geotextile as shown in Figure 11.

Figure 11 : Geotextile Tube after covered with non woven geotextile

Finally, rubble mound was placed on top of the non woven geotextile as protection to the geotextile tube against hard objects impact, and A-Jack concrete units to act as breakwater as seen in Figure 12.

Figure 72 : Geotextile tube condition after protected by armor

The construction of geotextile tube dyke and breakwater for Ancol project was commence in 2013 and finished in 2016. Until now, there are no damage has occurred on geotextile tube and it is in stable and steady condition, even though the seabed is a thick soft soil layer.

4 CONCLUSION

Geotextile tubes can be used as an alternative solution for Containment Dykes because of its strength and durability with relatively cost effective. Specification of geotextile as tube fabric and tube filler material are the main factors to be considered in designing geotextile tube. A High Strength Woven geotextile is preferable for large dimension geotextile tube. One of the successful key in construction depends on the method of construction and quality control performed during installation of geotextile tube.

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