RIPRAP COVERED GEOTEXTILE TUBE EMBANKMENTS

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ABSTRACT

Riprap covered Geotextile tube embankments have been successfully constructed at Amwaj Island, Bahrain, the Naviduct Project in the Netherlands, and at the Nautical Club Stella Maris, Casa Blanca, Province of Esmeraldas, Ecuador.

Breakwater structures and the island perimeter wave protection were constructed using sand filled Geotextile tubes then covered with a soft limestone-calcite rock indigenous to the area of Bahrain. Approximately sixty kilometers of tubes were filled with sand and covered with rocks to protect Amwaj Island from waves and tidal effects from the Persian Gulf.

Geotextile tubes were used to construct the perimeter dikes for a confined dredged material disposal facility for maintenance dredged material from navigation channels on the Ijssel Meer on the North Sea in, The Netherlands. Limestone rocks were placed on the outer perimeter of the contained area that consisted of two parallel sand filled tubes.

A combination of river run and quarry rock was use to cover two parallel Geotextile tube jetties constructed to create an artificial navigational access channel and docking facilities for pleasure boats at Casa Blanca, Province of Esmeraldas, Ecuador. The use of riprap covered Geotextile tubes has become more readily accepted because of the large saving in riprap and the potential for protecting fabrics from damage. Other benefits from this methodology are reduced impacts on the environment and structural damage to roadways and bridges caused by repetitive loads from trucks loaded with rock.

Keywords: Riprap, limestone rock, Geotextile tubes, dredging, jetties, dredged material containment

INTRODUCTION

Background

For over two decades high strength woven polypropylene Geotextile tubes have been used to construct coastal protection structures. Earth covered tubes have also been successfully used for shoreline erosion protection from waves and currents. Several miles of these structures have served to protect coastal property form hurricane and tidal surges that cause flooding, floating debris, silt and sands onto streets and highways. Tubes have been used to construct dredged material containment structures for storage of maintenance dredged material and construction of islands. Tubes have been used to construct jetties, contraction dikes and control structures to prevent erosion and control depositions of sand and silts to minimize dredging cost. They have been use as sub-division dikes, spur dikes, underwater control dikes, current contraction dikes and thalweg control structures. Tubes have been used as bendway weirs, dikes, flood protection dikes and permanent and temporary structures (FEMA). They have also been used for dike repair. Several other coastal applications such as groins, off shore wave breakwaters, beach nourishment, shoreline structures, on shore and off shore stability berms, and coastal sand dune protection have

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utilized Geotextile tubes. Tubes have been used to protect wetland habitat, wetland creation, and to create wildlife habitat such as oyster and fishing reefs.

**Purpose**

Purpose of the paper is to report that sand filled Geotextile tubes can be technically and economically feasible when covered and protected with riprap without damage to the tubes in a coastal environment. Another purpose of the paper is to illustrate that riprap Geotextile tubes can be properly designed and constructed under various environmental constraints and conditions.

**Scope**

The scope of this paper will include the successful construction of three major Geotextile tube projects that were covered with riprap. The three riprap covered Geotextile tube embankment project have been successfully constructed and they are as follows: Amwaj Island, Bahrain; in the Netherlands; and the Nautical Club Stella Maris, Casa Blanca, and Province of Esmeraldas, Ecuador.

**AMWAJ ISLAND, BAHRAIN CASE HISTORY**

**Amwaj Island Description and Location**

One of the first Geotube applications in Bahrain was the construction of a dredged material containment island designated as Amwaj (Arabic for waves). The site (Figure 1) was strategically located 1.6 kilometers off shore at the northeastern end of Muharraq-Bahrain. Island construction consisted of dredging cohesion-less ocean sediments reclaimed from proposed navigation channels and marinas.

![Figure 1. Vicinity map of Bahrain Island](image)
The reclamation project provided new land for associated civil engineering infrastructures for the construction of five and four star hotels and restaurants, golf course, homes, condominiums and many other amenities. The island perimeter consists of various sizes of Geotextile tubes that were filled with ocean sand and positioned end to end to construct the containment area. The tubes were also stacked to achieve the necessary elevation required for protection from oceans tidal fluctuations of 1.5 meters and anticipated storm surges of 3.0 meters. Palm trees and various other plants and vegetation were planted on the island.

The development included land reclamation of 2.79 million square meters of submerged sea property northeast of Muharraq Island, Bahrain. Engineering, planning and design of the sand filled Geotube containment structures for the island perimeter and shoreline and foreshore protection systems were conducted prior to construction. Foreshore Geotextile tubes were filled with sand to form the segmented breakwaters along the island perimeter and that protected with a combination of riprap and articulating concrete blocks. Approximately 60 kilometers of 2.0 to 2.5 meter high Geotextile tubes were used to successfully construct this project. Infrastructure developments included access roads, bridges, marinas, communication systems, electrical power network, water supply, and sewage collection and treatment systems. A plan view of the island, breakwater reefs and Geotextile tube layout is shown in Figure 2.

![Figure 2. Amwaj Island and Geotextile tube breakwater reef layout](image)

**Geotextile Tube Construction**

Geotextile tubes were hydraulically filled with sandy materials from the proposed navigation channels leading into the Amwaj Island project. The geotechnical description for the dredged material to be used to fill the Geotextile tubes is primarily sand. The medium dense sand was slightly silty and fine to coarse grained, containing gravel size shell debris and fragments of calcarenite or carbonate sandstone. The contractor was able to locate his equipment and pump the materials that consist mostly of sand. Boring log information indicated that these materials were basically non-cohesive and settled out very rapidly.

The island perimeter consisted of two layers of sand filled Geotextile tubes that formed the island perimeter. Hydraulic fill was placed to construct the containment island and breakwater structures for the Amwaj Islands
During the filling of the tubes, excess dredge water was filtered by the close weave pattern of the Geotextile fabric. As the dredged material was pumped into the tubes, it formed its own filter medium that filtered fines less than 0.063 mm. This filter cake was formed on the inside of the tube very quickly allowing only clear water to exit. Minimum disturbance was caused by the dredging operation but this disturbance was mitigated by the application of the turbidity curtains.

**Geotextile Tubes in Island Perimeter**

![Geotextile Tubes in Island Perimeter](image)

**Figure 3. Geotextile tube placement in the island perimeter**

### Proposed Geotextile Tube Breakwater Design

Kristian Pilarczyk (2001) designed the Geotextile tube breakwater seaward defense system for Amwaj Island for storm surge conditions for a return period of 50 years (design frequency 1/50 per year for water levels and waves). A low crested structure was preferred because the landscape requirements were for an unobstructed view over the sea. This sea defense also functioned to preserve the artificial sand beach along the island perimeter. Access for boats to the island through the protective structure was also provided along the existing channel in a northern direction with a depth of -2.7 m (CD).

### Geotextile Tube Breakwater Reef Design

Geotextile tubes were used to create a broad crested breakwater reef design. The design was selected for both the shallow and deep water areas with a crest at MSL and the width of the crest equal to about 50.0 m (approximately equal to the local wave length). The design was based on representative wave transmission characteristic from past studies which were based on similar conditions. Studies have shown that the wave transmission coefficient will provided a reduction factor of about 60 percent of the wave height.

Geotextile tube breakwater protection was provided all around the island from the west to the east on the northern side. The northeastern part of the island is deeper than the western part; therefore it required more and heavier armor stone protection. The armor stone size and weight is shown in Figures 3 and 4.
The proposed breakwater layout was designed to reduce the erosion forces of the circulations during extremely large events and to provide proper beach protection, and to allow refreshing of the enclosed area between the breakwater and island during annual conditions, as previously shown in Figure 2. The length of the breakwaters, $L_r$ is 300 m; the gap between the breakwaters, $G$, is 0.25 times $L_r$ or about 75 m. The distance offshore is $X = L_r = 300$ m. The distance to the beach shoreline was about 340 m from the hard boundary of the island and the eleven segmented breakwater structures were 300 m long.

A layer of bedding stone and riprap was successfully placed on the Geotextile tubes to complete the breakwater structures. A protective sheet of Geotextile fabric was placed between the tubes prior to placement of the bedding stone and riprap. The rock obtained from the quarry consisted of calcarenite or carbonate sandstone. The design rock weight for deep and shallow water applications are shown in Figures 3 and 4.
Project Description and Location

The Naviduct lock, tunnel and dredged material disposal area are located near Markham on the Ijssel Meer in The Netherlands. The project consisted of the construction of a dredged material channel and double ship lock through one of the main flood protection levees on the North Sea. The project included a combination roadway tunnel underneath the lock, that was connected to the main levee system and roadway on either sided of the lock. The ship channel and lock complements an older and out dated lock system that had been used for smaller ships for over forty years. The new lock will be used as a navigation lock for large ocean going ships. Figure 5 shows a profile view of the lock and tunnel beneath the lock and a plan view of the dredged material disposal area.

![Diagram of Naviduct lock, tunnel, and disposal area](image)

Figure 5. Profile view of navigation lock and plan view of dredged material disposal area

Purpose of the Project

The purpose of the Naviduct project was to provide a modern port facility, a deeper navigation channel, and a maintenance dredged material disposal area. The Naviduct project consisted of dredging a 17 m deep ship channel out into the North Sea and constructing of a dredged material disposal area to accommodate the new work and maintenance dredged material from the channel and deepening of the new harbor area. Initially the disposal area will be used primarily for containment and disposal of new work dredged material. Once it has been filled to the desired elevation, this protected upland area will be developed as a ship container port and other industrial developments. The disposal area will also provide a partially enclosed safe harbor area from wind and waves.
Rock Covered Tube Protection

The perimeter of the dredged material disposal was constructed by filling two parallel sand filled tubes. Figure 6 shows a photograph of the two parallel sand filled tubes after they were filled with sand. The high strength polypropylene tubes were 13.7 m in circumference and filled to a height of about 2.0 m. The fill ports were tied and secured to the top of tube to prevent loss of fill material.

An aerial photograph of the banana shaped, dredged material containment, disposal area for the Naviduct project is shown under construction in Figure 7. The aerial view shows that placement of protective riprap cover on the tubes has begun and is about half complete along the southern side of the disposal area.
After the two parallel tubes had been filled to the required design height and the tube perimeter was enclosed for the disposal area, limestone riprap was placed to cover the outside face and top of the tubes as shown in Figure 8.
To protect the tubes from inadvertent damage from puncture and abrasion during placement of the rock, the tubes were protected with a thick non-woven polypropylene fabric (0.016 kg/m²). The limestone rock cover and non-woven fabric can be seen in Figure 8. Rock is very expensive because it has to be transported long distances to the Netherlands from faraway places like Germany, Norway, or Denmark. The project has been successfully completed and is functioning according to design. The project was designed to accommodate deposits of maintenance dredged material from the navigation channels for the next fifty years.

NAUTICAL CLUB STELLA MARIS, CASA BLANCA, ECUADOR

Project Description and Location

Nautical Club Stella Maris Marina is located about 160 kilometers northwest of Quito, Ecuador in the Esmeraldas Province. A vicinity map showing the location of the project is depicted in Figure 10. The marina is located within the Casa Blanca Club property. This beautiful warm weather tropical paradise with clean white sand beaches is primarily used as a vacation resort for Quito and surrounding residents. It currently has more than 600 luxury apartments built with a Mediterranean style that has exclusive use of the private beach front property. Esmeraldas is visited by tourists coming from Quito thanks to its geographical location, excellent weather conditions and closeness to the city.

![Figure 9. Vicinity map of Esmeraldas, Ecuador](image)

Purpose and Site Description

A plan view of the riprap covered jetties that were constructed to form a safe harbor environment for Stella Maris Nautical Club Marina is shown in Figure 10. The purpose of the project was to create a harbor and provide customers with all types of services relevant to marine activities. The facility would provide both nautical and social
areas to accommodate guests. The nautical area includes two jetties leading into the marina, and they consist of a north and south jetty.

Within the nautical area, which is our main interest, there are two parallel jetties 250 m in length which make up an artificial navigational channel that provides access to floating docks, with a capacity of 120 ships up to 100 ft in length. Upstream of this channel there is access to a 20,000m² natural lagoon, which is fed through a natural estuary, thus reducing the corrosive effect of marine water on all ships. There is a launching ramp, dry dock, covered parking, storage, repair shops, gas station, and radio communication services, among other amenities.

Jetty Construction

The construction of the Nautical Club Stella Maris Marina was divided into two stages. The first stage consisted filling the Geotextile tubes to form the core of the jetties and then placing rock to cover the tubes (Figure 11). The decision to use Geotextile tubes was made because it was more economical to fill the center portion of the jetties with sand filled tubes than with very expensive rock. Rock had to be blasted and excavated from the quarry and hauled from a distance of more than 70km to the project. Transportation over very poor roadways is not only very expensive but time consuming. Heavy dump trucks tend to haul their loads very slowly. This stage of construction and procurement of the rock was fully financed by the promoter of the project and members of the Coframar Company. The second stage of the project included everything related to construction of the social area of the club, which was financed by selling memberships in the marina.
The construction technique used for the construction of the jetties was to dredge the navigation channel and fill the tubes in the core of the jetties simultaneously. As the Geotextile tube core was advanced the rock cover was placed so that the construction could advance from the shore out into the Atlantic Ocean as shown in Figure 12.
The core of each jetty was constructed by installing and filling 71 tubes. The tubes were 22 m to 44 m in length and 13.70 m in circumference. More than 15,000 m³ of sand was dredged from the channel to fill the tubes 1.8 m to 2.0 m high.

Tube installation was carried out in several sections, beginning onshore with a single 2.0 m high tube and then working offshore to end of the jetty. The deepest cross section of the jetty consisted of 9 tubes, 6 m high stacked three high as shown in Figure 11. Prior to placement of the riprap the tubes were protected with a heavy non-woven polypropylene fabric to minimize construction damage and puncturing. The revetment rock was used to achieve the final design height and required geometry. Slope geometry was 1.5 H to 1 V on the inside of the jetties and 1.75 H to 1 V on the outside toward the ocean and wave action. Figure 13 show a photograph of equipment placing rock on the tubes in the south jetty.

![Figure 13. Photograph of riprap being placed on the south jetty tubes](image)

Construction of the two jetties took two months to complete. The construction workers worked two ten hour shifts six days per week. Placement of the riprap cover over the tubes continued for another month after the tubes were filled. It also required another month to hydraulic fill more than 20,000 m³ of sand in an area contained in the north jetty. Filling this area allowed the project owners to claim more than 5,000 m² of usable land to be used by the marina club members.

The first stage has been successfully built and membership sales began in October 2003 to fund the second stage. The project has under gone several storms and large waves and the jetties have not sustained any damage.
CONCLUSIONS

Conclusions
It has been shown that riprap covered Geotextile tube embankments have been successfully constructed at Amwaj Island, Bahrain, the Naviduct Project in the Netherlands, and at the Nautical Club Stella Maris, Casa Blanca, Province of Esmeraldas, Ecuador. It has been concluded that is economically and technically feasible to cover and protect sand filled Geotextile tube embankments with riprap in a coastal and estuarine environment. It has also been concluded that from a construction view point it is practical to place riprap on the tubes without damaging the fabric. It has been demonstrated that, use of Geotextile tubes in the core of dikes and jetties will save over half of the rock volume that is normally required in a dike that contains all rock. It has also been demonstrated that reducing the amount of rock needed also reduces the environmental impacts associated with quarrying large quantities of rock. It has also been concluded that reducing the required volumes and quantities used in conventional rock filled structures minimizes damage to roadways and bridges where material is transported by trucks.

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REFERENCES