Geotextile Tube Structures for Wetlands Restoration and Protection

PURPOSE: This technical note provides information for determining appropriate applications for geotextile tube structures in wetland restoration and protection and other coastal engineering applications.

BACKGROUND: In the early 1990s, some U.S. Army Corps of Engineers Districts began using and evaluating custom-made geotextile tubes with fabric tensile strengths ranging between 400 and 1,000 lb/in. (70,000-175,000 N/m). The tubes have been used as containment dikes for dredged material placed in shallow water to intertidal elevations. Wetlands have been restored on the dredged material with the tubes acting as erosion protection. The tubes have also been used as nearshore, low-crested breakwaters to limit erosion. Individual tubes have ranged between 20 and 45 ft (6-14 m) in circumference and between 200 and 2,000 ft (61-610 m) in length. During the planning of these projects, many questions have been asked regarding the best techniques for designing, deploying, filling, and handling the tubes.

After responding to a number of individual requests for assistance in designing and constructing geotextile tube structures and realizing that limited information was available, the U.S. Army Engineer Waterways Experiment Station (WES) held a workshop to document the experiences of people who have used geotextile tubes. The discussions at the workshop focused on specific case studies, experiences with deployment and filling tubes, hydrodynamic and geotechnical engineering design, geotextile fabric characteristics, and risk and contingency planning. The 50 participants in the workshop were from Corps of Engineers headquarters, district, and laboratory offices; the Port of Houston Authority (PHA); academia; engineering consulting firms; material suppliers; and dredging contractors.

The workshop was held in Galveston, TX, and was hosted by the U.S. Army Engineer District, Galveston (SWG). Field trips associated with the workshop were hosted by SWG, PHA, Gahagan and Bryant Associates, Inc. (Houston, TX), and Turner Collie Braden, Inc. (Houston, TX). The workshop was co-sponsored by the U.S. Army Corps of Engineers' Wetlands Research Program, Dredging Research Program, and Dredging Operations Technical Support Program, all of which are managed at WES.

For reference, the geotextile tube structures considered in this technical note are nearshore, low-crested breakwaters and dredged material containment dikes that are not stacked. Figure 1 shows a schematic of a representative tube cross section. Geotextile tubes are made from two pieces of geotextile fabric (polypropylene or polyester) laid over one another and sewed along the edges and ends. Factory-installed filling ports are made by cutting 18-in. (46-cm) holes in the top piece of fabric and then sewing a 3-ft (0.9-m) sleeve of fabric into the hole. A dredge discharge pipe is used to fill the tube by placing the end through the sleeve. The sleeve and pipe are strapped together with rope or other material.

For the geotextile tubes described in this technical note, it is assumed that the fill material is sand. When available, sand is the best fill material because it is easily pumped and, after settling in the tube, further consolidation is minor. Sand also has a higher density than finer materials and thus lends more mass to the tube. Short tubes (approximately 200 ft long) (<60 m) would be placed end to end to create a longer structure.

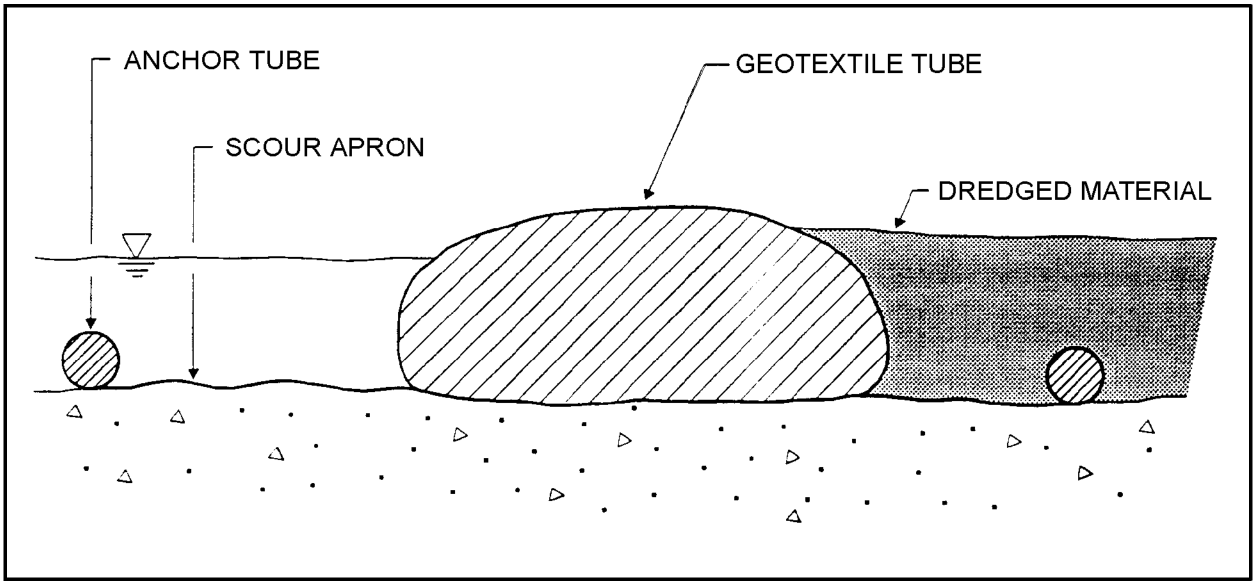

Figure 1. Schematic cross-sectional view of a geotextile tube retaining and protecting dredged material

The discussion below summarizes the information gathered from workshop participants in several areas of concern: limitations of geotextile fabric, criteria for determining appropriate applications for geotextile tubes, and based on these considerations, why the tubes have worked well for wetland restoration and protection.

LIMITATIONS OF GEOTEXTILE TUBES: The concerns raised at the workshop were the same as those raised by Pilarczyk (1995) in his thorough review of “novel” systems for coastal engineering. Participants were concerned about fabric resistance to puncture and abrasion, fabric degradation in the environment, especially under exposure to ultraviolet (UV) light, the difficulty in placing a tube precisely on a given alignment and in achieving a consistent crest height along the length of the tube, and the lack of hydraulic, hydrodynamic, and geotechnical design guidance. Each of these concerns is addressed below.

The resistance to geotextile fabrics to punctures and abrasion is low. Puncturing the materials with a blunt object is not easy. However, it takes no effort to puncture even the highest strength material with a pointed object, such as a knife. Consequently, in areas where the public has access to the tubes, vandalism often results in damage. Debris (for example, a stump with sharp roots) that is forced against the tube by waves or currents can puncture and abrade the material. The workshop participants also suspected that ice could abrade or puncture the fabric. The material can be abraded during shipping and handling, or during deployment. Tubes may be damaged by placing equipment (pipes, flanges, cables, and connectors) on the tubes. Participants also indicated that tubes that are cut or torn will lose sediments within only a few feet to either side of the cut. That is, most of the tube beyond the damaged area will remain intact.

Fabric degradation in UV light is uncertain. Laboratory tests that have exposed the fabrics to intense UV radiation have been conducted. The results suggest that the fabric is resistant, but the results cannot be extrapolated to actual field applications. Some workshop participants suggested that tubes could last several decades (20 to 50 years) in the field; others suggested that, without data, those values cannot be relied upon. It should be noted that exposure to UV light is significantly blocked when the tube is submerged or covered by sediments or marine growth such as algae and barnacles.

The constructed quality of the tubes depends on the skill of the construction contractors and the environmental conditions under which the deployment and filling takes place. The skill and experience of some contractors is increasing within the dredging industry, but no method has yet been widely accepted or documented as the best approach to deploying and filling tubes. Given that the overall average height of the tube depends on the length and circumference of the tube, the permeability of the fabric, the pressure and flow rate inside the tube during filling, sediment characteristics, and other factors, it has been difficult to determine whether it is these factors or the techniques of the contractor that affect the quality of the final tube shape. Ultimately, the experience of the contractor and the available equipment seem to dictate the construction methods chosen.

Some variations of height cannot be avoided. If the contractor stops filling a tube prematurely, because of weather for example, sand in the tube will stabilize and flatten the tube out. Once that happens it is very difficult to pump the tube higher. Also, low spots always occur near the filling ports, with other random undulations elsewhere. It is not surprising to find variations of 0.5 ft (0.15 m) or more along the length of the tube. Based on the results reported at the workshop, the maximum tube height that can be achieved is 5 ft (1.5 m), regardless of the circumference of the tube used. Greater final tube height might be possible, but it has not been the general experience.

Not only does the height of the tube vary, but the elevation of the bed upon which it rests may vary. Hence, if the tube is not placed directly on a given bed elevation, the variations in the bed itself result in variations of the crest elevation. Geotextile tubes are hard to position and hold in place in waves and tidal or wind-driven currents prior to filling. Occasionally, a tube may roll to one side during filling. When this occurs, the tube moves off alignment, it puts the filling ports to the side of the tube instead of on top, and it increases the stress in the fabric.

Existing guidance is limited for designing and predicting the stability of tube structures. Some techniques modified from other structure design techniques were discussed at the workshop. It was suggested that the methods described in the “Shore Protection Manual” (U.S. Army Corps of Engineers 1984) or Minikin (1983) be used for loading on vertically faced structures. Similarly, the methods outlined in Goda (1985) or Walton and others (1989) could be used.

Once the forces are estimated for the tube, one can assume that the cross section of the tube is a rigid, roughly oval object and calculate its tendency to slide or overturn. The recommended friction angles are 18 deg for fabric on fabric and 25 deg for fabric on sand. The WES maintains a discrete-element model that can be used to simulate the deformation of a tube in two-dimensional cross section under loading. A graphical technique to estimate the strength of fabric needed for an application has been developed.* Most workshop participants agreed that, if there is concern about the strength of the fabric, the strongest available fabric should be used. Sprague* also presents a technique for selecting the spacing for filling ports along the crest of the tube. Each of these methods is likely conservative, and all the methods disregard the three-dimensional nature of the tubes.

* J. C. Sprague. (1995). “P.E.T. geotextile tubes and containers for beneficial use of dredged material,” draft contract report prepared for Bradley Industrial Textiles, Inc., Valparaiso, FL, and Hoechst Celanese Corporation, Spunbond Business Group, Spartanburg, SC.

CRITERIA FOR GEOTEXTILE TUBE APPLICATIONS: Based partially on the limitations discussed above, a list of general criteria was compiled for use in determining appropriate applications for geotextile tubes. Pilarczyk (1995) also identifies several of these criteria. The greater the number of criteria satisfied, the more successful the implementation is likely to be.

The listing of criteria given below probably is incomplete, but it can serve as a good guide. The criteria are not listed in order or priority. Priority might be set based on project characteristics.

- Shallow water, low tidal range, and low wave energy. The region in which the tubes are placed should be shallow (0-3 ft, <1 m) and where the tidal range is small (0-3 ft, <1 m). Several Corps of Engineers projects have been stable and have performed successfully in such environments. These criteria limit the size of the waves that will impact the project such that the tubes are inherently stable. Further, tubes placed at low crest elevations as assumed here are usually inundated by surge during large wave events. Larger waves, which might occur with meteorologically induced surges, pass over the tubes with reduced force. The propagation of such waves over the tubes is not problematic, because the area in the lee of the tube is low-elevation marsh.

- Temporary, maintained, and hidden. An appropriate geotextile tube application is one in which the tube is a temporary structure. Obviously, a tube that is used until another approach can be found is just temporary. However, a less obvious temporary application would be a tube that is maintained. For example, a tube used to contain and protect dredged material that is needed only until the next dredging cycle (3-5 years) would be temporary. During the next cycle, the tube may no longer be needed, or it may be maintained or replaced. A hidden tube is one that is covered over, by sediment for example, and serves only as protection when erosion exposes it. This is a useful approach when vandalism or debris is a concern. It also blends the tube into the environment. Once the tube is exposed, however, maintenance is required to repair and rebury it. Material suppliers have indicated that holes in tubes might be patched in situ using marine adhesives. However, if the damage is significant, new tubes can be placed in front of or behind the failed tube. Workshop participants noted that they had little success placing one tube on top of another.

- No threat to life or property. An appropriate geotextile tube application is one where there is no risk of life or property if it fails. Geotextile tubes are effective structures as long as they remain intact. However, since their durability is uncertain, depending on them to protect life or property for long periods of time (without maintenance) is not recommended.

- Flexible height and alignment requirements. Since aligning tubes during placement and achieving consistent crest elevation along the length of tube is difficult, projects where variation in these parameters can be tolerated are best.

- Associated with an existing dredging project. A final criterion is that the tube construction be associated with an existing dredging project. The growing popularity of geotextile tubes is due to several factors, the main one being that they are usually less expensive than other protection or containment alternatives. Geotextile tubes are most cost effective when used in conjunction with a dredging project because the cost of mobilizing a dredge to fill the tubes is minimized. The cost of tube construction is maximized when a dredge has to be mobilized on short notice to fill a small section of tube.

SUCCESS IN WETLAND RESTORATION AND PROTECTION: The first application of geotextile fabrics in wetlands and habitat development was in the early 1970s in Galveston Bay, Texas (Knutson, Allen, and Webb 1990). Large nylon bags (12 by 4 by 3 ft)(3.5 by 1.2 by 0.9 m) were filled hydraulically with sandy dredged material to form a stacked breakwater. The crest of the breakwater was very low, with the marsh built to an intertidal elevation. The bay is broad but shallow, such that wave energy is limited. At the time, it was assumed that the bags would eventually fail, leaving behind established habitat that could maintain itself. In 1995, a visit to the site in Galveston Bay showed that the upper portions of the nylon bags had deteriorated, but the marsh in the lee was prospering.

The successful project in Galveston Bay and the more recent projects that have applied geotextile tubes satisfy several of the criteria established in the preceding section, which would indicate that geotextile tubes are an appropriate alternative structure. The most recent wetlands applications have been monitored for less than 5 years, so long-term performance (10-20 years) is still uncertain. The remainder of this section discusses how these projects fit the criteria listed above.

The Corps of Engineers has constructed wetland restoration projects on dredged material using geotextile tubes as containment dikes and erosion protection in the Chesapeake Bay near Smith Island, Barren Island, the Pokomoke River, and Eastern Neck National Wildlife Refuge (Blama et al. 1995) and along the Gulf Intracoastal Waterway in West Bay north of Galveston Island and near the Aransas National Wildlife Refuge in Texas (McCormick and Davis 1992). These wetland restoration projects were initiated in areas where wetlands once existed. The areas are generally in shallow water with low tidal ranges, and consequently, low wave energies. Because the area in the lee of the structures is intertidal marsh, the tubes are built to low elevation so that they are sufficient to protect the root mat of the marsh from erosion. The naturally low and wide cross-sectional shape of a geotextile tube makes it stable and suitable for this application.

Also, the low wave-energy conditions limit the amount of toe scour that occurs at the tube. As shown in Figure 1, a tube should have a geotextile scour apron to prevent toe erosion. The aprons placed at some Corps of Engineers structures have performed well, suffering little or no damage after several years of service. Some have silted over. However, it is likely that in higher wave energy environments, the apron would not be as effective except perhaps as a temporary measure. Any other type of apron (for example, stone or concrete) would increase the cost of the project and may damage the tube fabric.

The tubes used in the Corps of Engineers projects are not necessarily temporary, maintained, or hidden. At the West Bay site, the Corps of Engineers expects to return to the area in 3 to 5 years (the next dredging cycle) to create additional wetlands, and at that time would correct or modify the project. Therefore, the opportunity for maintenance is present. All of the projects mentioned are in remote areas of bays where the risk of vandalism is very low, since public access is difficult. However, the potential for damage due to debris is always present.

The remoteness of the projects inherently satisfies the criterion that no life or property be at risk in the event of tube failure. The only thing at risk if the geotextile tube is damaged is potential erosion of a portion of the wetland that was restored. However, such erosion may be ecologically desirable. After the wetlands have developed behind the geotextile tubes, it is often desirable to open up the area to the ingress and egress of marine organisms. Removal of a tube is an option. Furthermore, when part of the wetland is eroded, it often remains as shallow, open water or as a mudflat, either of which provides diversity of habitat.

The random height variations along the length of a geotextile tube cause a varying amount of wave transmission into the marsh along the tube. The varying wave energy results in a more random and natural-looking plant growth and propagation in the lee of the tubes.

Finally, all of the Corps of Engineers projects have been associated with existing maintenance dredging where the maintenance material was to be used beneficially. Geotextile tubes provided a means for containing the material and protecting the marsh from erosion in a cost-effective manner. If the projects had been developed separately from maintenance dredging, the costs for the projects would have been relatively excessive.

CONCLUSIONS: Within the Corps of Engineers, geotextile tubes are being considered for alternative structure designs in many applications. They are being considered for sills, low-crested breakwaters, the cores of dunes or rubble mound structures, containment dikes, groins, and compartmentalization structures that limit movement of sand along a beach. Many of these uses challenge designers because of the limitations of geotextile tubes. They are punctured and abraded easily by vandals, debris and ice; their life expectancy after prolonged exposure to UV light is unknown; and they are difficult to construct to precise alignment and crest elevations. Yet, if they are used as temporary structures, hidden components of structures, in shallow water with low wave energy and tidal regimes, in projects where there is no risk to life or property in the event of failure, in projects where inspection and maintenance will be established, or in projects where sand is being dredged, they can be used effectively.

Wetland restoration projects, developed on dredged material placed to intertidal elevations, satisfy many of these criteria. Funds usually available for developing a marsh habitat are limited; therefore, the potential low cost of geotextile tubes makes them an attractive alternative for erosion protection and dredged material containment. Roughly, the cost for placement of geotextile tubes in the Texas projects was $50 to $100 per foot ($150 to $300 per meter). In projects where a dredge was mobilized to fill a short tube, costs approached or exceeded $200 per foot ($650 per meter). The tube containment dikes were generally more expensive than unprotected earthen dikes, but less expensive than an equivalent riprap structure.

Pilarczyk (1995) notes that some worthwhile applications for geotextile tubes exist, but that they should not be generally considered for coastal engineering applications. The criteria identified above, though not all- encompassing, may serve as a reasonable guide because they avoid or minimize the effects of the limitations of geotextiles. The more criteria that are satisfied, the more successful the application is likely to be. Finally, while the construction of geotextile tubes is conceptually easy to understand, one must remember that careful attention must be given to the massive structure and its critical features—the foundation, scour, overtopping, and flanking protection—to develop a successful project.

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