Dredged-material filled geotextile tubes: Design and construction

Large tubes filled with dredged material have been utilized in a variety of coastal and inland projects. The tubes, manufactured of high-strength polyester or polypropylene geotextile, are hydraulically filled with a dredge or pump. The geotextile tubes are typically filled with on-site material; however, alternative materials can be imported and utilized. Typical applications would include sand dune restoration, dike construction, groin construction, artificial reefs, and simple waste (sludge) containment and dewatering. The tubes are filled in-place and installation is relatively simple and inexpensive.

System details
The envelope of the geotextile tube is prefabricated using a soil-tight geotextile. A tube with the desired diameter is made out of standard mill widths of geotextile seamed together. The length of the tube is only limited by practical weight limitations. The tube can be delivered to the site rolled up on a pipe, accordion folded, or alternately packaged. Inlets/outlets are regularly spaced along the length of the tube at intervals appropriate to the settling characteristics of the dredged fill. The inlet/outlet “sock” diameter is somewhat larger than the filling/discharge pipe.

Dredged-material filled geotextile tubes are commonly constructed by hydraulic filling of the envelope with a water/soil mixture using a cutter head and suction dredge delivery line. The geotextile tubes can be pre-filled and placed using a “cradle” bucket on a barge-mounted crane or, more commonly, they are installed using a continuous position-and-fill procedure.

Tube design
Sprague et al. (1996) presented basic design concepts for large, dredged-material filled geotextile tubes. The retention of fill and the structural integrity of a dredged-material filled tube is provided by the geotextile envelope. Functionally, fabric selection is based on the fabric’s opening characteristics, which must match the fill-particle size and permeability, and its having sufficient strength to resist filling pressures. A composite fabric shell is sometimes used, since it incorporates both an inner nonwoven fabric for filtration and an outer woven fabric for strength. Figure 1 provides an experimentally derived geometrical and tensile-strength design guide.

Leshchinsky et al. (1996) describe a more sophisticated tool—a computer program that is available to designers. The program can determine the required geotextile strength for a given geometry or, conversely, the maximum geometry safely attainable for a given allowable strength. Figure 2 provides an example output from this computer program.

The filled geotextile tube assumes a cross-section which is circular on the edges and flattened on top. Field experience has demonstrated that it is possible to fill geotextile tubes to 70% or 80% of their theoretical maximum circular diameter, though 50% to 60% is more commonly accomplished. The dredged-material filled geotextile tubes can be filled with any material capable of being transported hydraulically. Naturally occurring beach or river sand is the perfect choice for structural fill. However, clayey and silty dredged material has been used for containment-dike applications and waste sludges have been contained and dewatered. An assessment should be made of the fill material’s settling characteristics to assist in the determination of appropriate spacing and frequency of injection ports and relief ports in the geotextile tube. The following equation can be used to determine inlet/outlet spacing:

$$L = \frac{Q}{(W \times V_s)}$$

$L$ = inlet/outlet spacing

$Q$ = volumetric flow of material

$W$ = width of flow

$V_s$ = settling velocity of sediments

Current and wave forces
Achieving a relatively high unit weight for a filled unit is essential for stability under severe hydraulic conditions in...
which drag, lift and inertia effects can reduce the unit's stability. In order to assess the stability of the (filled) geotextile tube structure, current wave forces have to be estimated. Though a definitive analysis technique has not been established, a modified Minken approach, as outlined in the U.S. Army Corps of Engineers' Shoreline Protection Manual, may provide a reasonable approach to assessing the stability of filled units under wave loading. Model tests have shown that the percent of the geotextile tube that is filled with dredged material is an important parameter relating to stability. The internal stability of a "stacked" tube structure is also an important consideration.

Due to current and wave action, the presence of a structure built up by one or more units can lead to a scour hole directly adjacent to the structure, which can result in geotechnical instability of the structure. Therefore, a filter fabric apron must be provided for scour protection. The filter fabric apron (also known as a scour apron) is usually provided with a small tube (anchor tube) fabricated into the seaward edge of the apron or around the entire perimeter of the apron. (Figure 3) The anchor tube is then filled with dredged material to provide ballast for the scour apron. The apron must have filtration characteristics that are appropriate for both the foundation soil and the soil filling the anchor tube. The scour apron should extend in front of and behind the geotextile tube or tube structure to a distance sufficient to prevent scour of the foundation.

**Design example**
Given: A tube that is 1.2 m (3.9 ft.) high when filled is required. Fine sand will be used to fill the tube hydraulically. The slurry has a density of 1.2 times that of water. A dredge capable of supplying 0.13 m³/sec of slurry at 13.8 kPa (1.4 m head) will be used.

**Solution:** Regarding tube geometry and strength, assume two 3.8-m (12.5-ft.) wide panels will be used to fabricate the tube. This will provide a circumference, S, equal to approximately 7.3 m (24.0 ft.) (some fabric width is used in the seam).

From Figure 1, for \(\frac{H}{S} = \frac{1.2}{7.3} = 0.164\), \(21 / S^2 = 0.02\);

Therefore, \(T = 0.02(9.8)(7.3)2/2 = 5.2\) kN/m (360 lb./ft.).

A factor of safety of 3.0 for survivability, seam strength, and potential creep will bring this value up to 16 kN/m (1080 lb./ft.).

Inlet/outlet spacing: Particle size, d, for fine sand is approximately 0.1 mm (0.004 in.). A particle of this size has a settling velocity, Vs, of approximately 0.0061 m/s (0.02 ft./sec.).

Therefore, spacing \(L = 0.13(2.0 \times 0.0061) = 10\) m (33 ft.).

(Note: The filtration properties of the tube should be determined based on the fill soil. Also, stability of the tubes under wave and current forces should be evaluated.)

As Figure 2 shows, the computer program produces somewhat more precise results, which are very similar to the graphical method.

**Site preparation**
Before the geotextile tubes and scour aprons are deployed on site, the area is usually prepared using common grading equipment. The location in which the geotextile tubes are to be placed is usually marked off with grade stakes. Large stakes or anchors can also be utilized at predetermined spacing so that the geotextile tube can be fastened to them with straps to assure proper alignment during filling.

**Deploying the tube and scour apron**
The scour apron is deployed before the geotextile tube; in some cases, how-
ever, the scour apron may be attached to the bottom of the geotextile tube at the fabrication facility. Once the scour apron has been fully deployed, positioned and secured, the geotextile tube is then deployed. Deployment for both the scour apron and the geotextile tube is usually accomplished by unrolling them off of a core or pipe that is supplied by the manufacturer. The geotextile tube should be unrolled into position with the injection ports and relief ports facing upwards along the top centerline. Once the geotextile tube is deployed, it can be secured to the previously installed alignment stakes or anchors.

**Dredged material filling**

The small tube (anchor tube) located on the scour apron is usually filled first to provide ballast for the scour apron. The anchor tube is sometimes filled using the same dredging equipment as will be used to fill the geotextile tube; however, a smaller pump may also be utilized, since the anchor tubes are usually fairly small in diameter (2 ft, 0.61 m or less). Pump nozzle access into the anchor tubes is either by a simple slit in the geotextile or by prefabricated inlet ports.

After the scour apron has been secured by filling the anchor tubes with dredged material, the geotextile tube is filled. This process will take much longer and is much more complex than simply filling the scour apron anchor tubes. The discharge pipe (or injection nozzle) of the dredge must be placed inside the appropriate injection port of the geotextile tube (see Figure 4). The injection ports are fabricated of the same geotextile that makes up the tube itself. They are usually 5 ft (1.5 m) long and 18 in. (0.46 m) in diameter (however, the dredge pipe utilized should not be this large). Typically, an 8- to 12-in. (20.3- to 30.5-cm)-diameter pipe is used, depending on the specific job requirements. The pipe should be inserted approximately 2/3 of the way into the injection port and secured with tension strapping. The discharge nozzle and injection port connection should be elevated to a vertical position with a backhoe or by rigging.

Most geotextile tubes will contain several injection ports throughout the length of the tube. These ports are usually located at the top centerline, spaced no more than 50 ft (15.24 m) apart. These ports are utilized for filling and also for relief of excess water. The contractor and/or engineer must determine port spacing prior to fabrication of the geotextile tube. Several factors influence spacing, such as the overall size of the tube, the size of the dredge pipe, the discharge volume of the dredge, the type of fill material, and the amount of water to be utilized for transporting solids.

Depending upon the spacing of the injection ports, the composition of the dredged material, and the capabilities of the dredge, some of the injection ports will not be utilized at all. For example, a 200-ft.-long geotextile tube may contain 5 injection ports spaced throughout the length of tube; if conditions are ideal and the dredge is capable, it's likely that the entire 200-ft. (60.96-m)-long tube could be filled from one injection port located near one end of the tube. The injection port farthest from this port, at the opposite end of the tube, would be left open as a relief port to allow the expulsion of excess water. All of the ports in between would simply be tied or left unused. If, however, conditions are not ideal for this method of filling, then the filling operation would be performed sequentially down the entire length of the geotextile tube by utilizing one port at a time for injection and one (or more) port(s) for relief. The correct intervals in which to move the dredge pipe to fill the tube would be determined and, as the operation progresses, the port for each section of the tube should be closed as that section is filled in order to prevent the loss of materials from within the tube.

After the appropriate connections have been made between the injection ports on the geotextile tube and the discharge pipe of the dredge, and the other ports have been either closed or left open for relief of excess water, the filling process can commence. Prior to filling with any solid material, the geotextile tubes are first filled to their desired height only with water. Once the desired height has been achieved, the dredge operator can introduce solids into the geotextile tube. By first filling the tube with water, the solid material can be distributed within the tube more evenly. Newly introduced solids and vehicle water will simply push the existing water out through the relief port that was left open. The solids will settle, or “fall out,” to the bottom of the geotextile tube and gradually replace all of the existing water.

**Tube connection**

Most projects contain multiple geotextile tubes, which are usually filled in sequence; each tube is placed against the tube before it and filled. Every tube is completely filled before the next tube in the sequence is installed. This method of installation creates low areas between the tubes due to the rounded ends associated with this technology. If these low spots are undesirable, al-
ternative connection methods can be employed. The most common installation practiced to eliminate, or at least minimize, the amount of depression associated with tube-to-tube connection is the use of an overlap. With this type of connection, each subsequent geotextile tube (and usually the scour apron) is placed underneath the tail end of the previously deployed tube. The “underlapped” tube would not be fully deployed at this time. Just enough of the tube would be deployed to create the connection. Obviously, this overlapping procedure must be accomplished prior to filling either geotextile tube with water or solids. Once the connection has been made, the first geotextile tube is filled in the same way as previously described. Each subsequent tube is filled in this same manner. However, the section of the tube that has been placed beneath the already filled tube will not be filled. A fairly tight and “full height” connection should result.

Completion and backfilling

Upon completion of the installation, the injection ports must be secured properly to assure that they do not become torn during wave events. The correct procedure for securing the injection ports will be provided by the geotextile manufacturer. One commonly practiced method is simply to cut off the injection port, taking care to allow some excess fabric that can be rolled or folded down flush to the top surface of the tube. The folded material can then be fastened to the tube’s surface by use of corrosion-resistant lock rings or compression-type fittings.

Filled and closed geotextile tubes will continue to dewater, and solids will further consolidate for some time after the tubes have been filled. The duration of this dewatering and consolidation period will vary depending upon the type of geotextile utilized and the type of fill material that was pumped into the tube. Typically, coarse material will dewater much faster than fine material, such as silty clay. Once the expected amount of dewatering has taken place, the tubes can be buried, backfilled, etc.

Dewatering tubes

Water and waste treatment plants, as well as various manufacturing facilities worldwide, are faced with ponds loaded with sludge that is typically composed of less than 10% solids. In order to reuse or dispose of this sludge, it must first be dewatered—typically to at least 40% solids. Traditional dewatering is normally a very costly undertaking involving presses and polymers, or a lot of patience.

Recently published reports have detailed the development and results of successful attempts to dewater sludge dredged into long geotextile tubes and allowed to consolidate via gravity. The tubes were filled and have been monitored to document the progress of the dewatering process. Samples of the sludge are periodically retrieved from within the tubes to quantify the amount of dewatering achieved. Additionally, it is common to refill the tubes as consolidation and dewatering causes the tubes to flatten. Dewatering cost savings on the order of 50% and more have been estimated.

While the strength design of the tubes is the same as for tubes used for coastal structures, the hydraulic properties of the geotextile tube, i.e., opening size and permeability, must be carefully selected and perhaps tested on a sludge-specific basis.

Lessons learned

To date, dredged-material filled geotextile tubes have been used with modest success and have presented significant promise. Recently installed geotextile tubes have shown the following apparent deficiencies:

- Poorly designed and manufactured seams have failed under the pressures of filling, especially in and around the inlet.
- Tubes filled with coarse material have experienced premature settling and consequent uneven top elevation. More frequent inlets were necessary to minimize the impact of quick settling of sediment.
- Tubes filled with fine material have retained large quantities of water as a result of fine-grained soils “caking” on the inside of the tube and limiting the ability of dredged liquids to drain efficiently. Subsequent refilling of tubes is required to attain the desired long-term tube elevation. An associated problem involves the overfilling of these tubes, causing them to balloon and exert excessive stresses on the geotextile.
- Concerns over the durability or long-term performance of the geotextile shell have largely been ignored in the interest of demonstrating the filling process. Neglected concerns include the U.V., abrasion and vandalism resistance of the geotextile and the consequent effects of large losses of fill, as well as floating pieces of geotextile. Also, creep of the geotextile shell resulting in reduced elevation of the tube has yet to be studied.

In some cases, problems with filling tubes have resulted from insufficient or excessive dredged material supply. Clearly, a consistent dredged material supply with a valved diversion discharge near the tube inlet would allow for maximum control of the filling operation.

Summary

Large geotextile tubes filled with dredged material have been utilized for many years. More recently, the technology has gained attention as a result of many successful and high profile projects. The technology and the industry are still young, however, and newer and better protocols are being realized daily. Overall, the future looks bright for dredged-filled geotextile tubes.

Over the past year, geotextile tube manufacturing firms have joined together, along with the Geosynthetic Research Institute, to create an industry standard for geotextile-tube manufacturing and installation procedures. As a result, GRI has produced a document, “Test Methods, Properties and Frequencies for High Strength Geo-
The next Designer's Forum (April, 2001) will discuss the last decade of advancement in geotextile tube technology.

References


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