

CHAPTER 1: Introduction

1.1 Scope

Geotextile tubes are used in flood protection and erosion control. They can be used to construct dikes, groins, dunes, and similar structures. There are several advantages to using these tubes. They are quick and easy to construct, are cost-efficient, use readily-available materials, and do not require heavy machinery.

This thesis presents a three-dimensional study of geotextile tubes. In this chapter, the literature review provides general information about geotextile tubes along with past applications and analytical studies performed. Chapter 2 provides a detailed description of the model used in this study; the model consists of a geotextile tube, initially flat and rectangular in shape, resting on an elastic foundation. During the analysis, hydrostatic pressure is applied to the model to pump slurry into the tube. Also, in Chapter 2, a comparison is made with Celep (1988b).

Chapter 3 presents the results obtained from a model with an initially flat length-to-width ratio of 2:1, and Chapter 4 presents the results obtained from a model with an initially flat length-to-width ratio of 5:1. The results obtained consist of the three-dimensional shape of the tube, the amount of contact between the tube and its elastic foundation, the mid-surface stresses that form in the geotextile material, and the relationship between the tube height and the amount of applied hydrostatic pressure. Chapter 5 consists of conclusions and recommendations for further research.

1.2 Literature Review

1.2.1 Introduction

There has been an increase in the use of geotextile tubes in the past few decades. These tubes are comprised of geotextile sheets either glued, welded, or sewn together at their edges (Liu and Silvester 1977) and pumped full with slurry. The tubes usually can be rolled up, delivered to the site, unrolled at the desired location, and then filled with the slurry.

The geotextile sheets are permeable, yet soil-tight, so that any excess water is expelled from the tube. This will cause the tube height to decrease, so the tube may have to be pumped more than once in order to achieve the desired height (Leshchinsky 1993); as another option, the desired height may be obtained by stacking the tubes (Perry and Myers 1993; Pilarczyk and Zeidler 1996). The tubes are usually pumped using a hydraulic dredger or a hopper (Erchinger 1993).

There are inlets at the top of the tube where the pumping hose is inserted. The number of inlets is dependent upon the type of soil being used; the inlets will be spaced further apart for a clayey soil than for a sandy soil (Leshchinsky, et al. 1996). This is necessary for even distribution of the slurry. In some applications, a filter cloth is placed underneath the tube so that the foundation is not disrupted (Gutman 1979; Leidersdorf, et al. 1981; Pilarczyk 1995).

Ultraviolet rays can cause the strength of the geotextile fabric to decrease. To avoid this, the tube should either be covered (John 1987) or coated with acrylic or polyvinyl chloride (Gutman 1979). Tubes can also be damaged from vandalism and debris. To protect the tubes from abrasion, several geotextile sheets can be used (John 1987).

The seam at the edges is weaker than the geotextile fabric, so design must be based on seam strength rather than geotextile strength (Koerner and Koerner 1996). An additional inner layer can be used to add protection against a seam failure (Leshchinsky 1993).

There are several advantages to using geotextile tubes as opposed to more conventional methods. Geotextile tubes are relatively low in cost, materials are more readily available and obtainable, the tubes provide a means to get rid of unwanted fill, usually heavy machinery is not required, unskilled labor can be used, and labor time is decreased.

Mexican engineers have developed three geotextile forms: bolsaroca, bolsacreto, and colchacreto. Bolsaroca is a permeable bag filled with sand and water. Bolsacreto is a concrete-filled form. Colchacreto is a geotextile mat filled with mortar (Porraz 1976).

Some geotextile products that are currently being manufactured include Geobag, Geotube, and Geocontainer. They are manufactured by Nicolon B.V. The Geobag contains dredged material and is used in bank protection, such as for an artificial island, and other related projects. The Geotube is hydraulically pumped full of slurry and can be used as a breakwater or to stabilize and protect the shore from erosion (Nicolon GeoProducts Division 1994). The height of the Geotube is approximately 80% of the theoretical diameter (Ockels 1991). The Geocontainer is a large container filled with dredged material placed underwater for protection of pipes and to form groins and similar structures (Nicolon GeoProducts Division 1994). A study on the stability of Geotubes and Geocontainers is presented in Breteler and van Wijhe (1994). Geotubes and Geocontainers are described further in Ockels (1991), Pilarczyk (1995), and Pilarczyk and Zeidler (1996).

The Longard tube was a product of the Aldek Company of Denmark. The maximum possible dimensions of the Longard Tube were 2m in diameter and 150m long

(Sarti and Larsen 1983). It was lined with an inner liner to better retain the sand particles (Armstrong and Kureth 1979). The method of filling and placing Longard tubes is described in Sarti and Larsen (1983). These tubes have been used in many shore-protection projects, as described in Armstrong and Kureth (1979), including applications such as groins, dikes, and breakwaters (Sarti and Larsen 1983).

Another product is the Dura Bag. Its dimensions are 0.5m x 1.2m x 3.6m. They are pumped with concrete or sand and water and are resistant to the effects of sunlight (Pilarczyk 1995). Other manufactured bags include the “Sill Bag” and “Sand Pillow” (Gutman 1979).

Slurry-filled geotextile tubes have been used in many applications, for example, they have been used as breakwaters (Silvester 1990; Pilarczyk 1995; Plaut, et al. 1998), groins (Gutman 1979; Pilarczyk 1995), reefs (Koerner and Soong 1997), dikes (Perrier 1986; John 1987; Plaut, et al. 1998), revetments (Gutman 1979), levees (Perry and Myers 1993), floodwalls (Perry and Myers 1993), protection devices for bulkheads (Gutman 1979), and structures to improve surfing waves (Maldonado 1996).

Books written about geosynthetics include Koerner and Welsh (1980a), John (1987), Ingold (1994), Koerner (1994), and van Santvoort (1994, 1995).

1.2.2 Applications

Geotextile tubes were first known to be used in Egyptian times when they provided protection against flooding from the Nile River. These were only temporary and were constantly replaced or repaired. It was not until the 1960's, though, when these structures were used in permanent coastal projects, one being the Delta project in the Netherlands (Perrier 1986).

Erchinger (1993) described the uses of geotextile tubes along the North Sea coast of Germany. The first geotextile tube groin in this area was constructed in 1967 along the East Friesian coast. These types of tubes were also used to construct a retaining dike, stabilize a beach, and close a dike breach.

Delft Hydraulics (1975a) performed a two-dimensional comparative study and found that sand sausages offered more stable shore protection to artificial islands in the Beaufort Sea than gabions did. Sand sausages are tubes which have a very high length-to-width ratio. A three-dimensional study on the use of sand sausages for shore stability was also performed by Delft Hydraulics (1975b).

Porraz (1976) described several projects in Mexico which have been completed using Mexican textile forms. A number of projects in other countries have either been started or completed. Porraz and Czerniak (1983) described the use of these Mexican textile forms in the Arctic, and Porraz, et al. (1979) discussed the use of bolsacreto in laboratory and ocean tests.

Gutman (1979) discussed the effective use of sand-filled bags as groins, bulkhead toe protection, and revetments in Massachusetts. A study showed that these bags were not very effective in protecting banks when used for perched beach erosion control.

Leidersdorf, et al. (1981) described the use of geotextiles to protect two artificial islands northeast of Prudhoe Bay in the Beaufort Sea, Alaska. Sandbags with underlying filter cloths were used to protect the slope. In addition, some test sections were installed to hopefully provide further protection so that any damage would not spread; double Longard tubes were placed in the radial direction in some locations to act as groins and to stabilize the sandbags. An extra layer of sandbags was applied in the circumferential direction at the waterline to provide additional protection against ice and waves and to trap any fill that escaped from bags upslope. At the time the article by Leidersdorf, et al. (1981) was published, results of this intricate system were not yet known.

Bogossian, et al. (1982) described the use of geotextile tubes as dikes in Cubatao, Sao Paulo, Brazil. The project was completed in one-third of the time expected for conventional dikes to be constructed. Also described were similar tests carried out at the estuary of the Seine in France in 1977 and at Sao Luiz, Maranhao, Brazil.

Munday and Bricker (1987) described the need to protect the Endicott Oil Production Facility located on an artificial island near Prudhoe Bay in the Beaufort Sea. After studying possible alternatives, it was decided to use gravel-filled bags covered with gravel in sheltered areas. In unprotected areas, a combination of gravel-filled bags and linked concrete blocks was used.

Gadd (1988) discussed the successful use of sand-filled and gravel-filled bags to protect two artificial islands in the Arctic, Resolution Island and Seal Island, from erosion.

Geotextile tubes are currently being used as an inflatable barrier at the Jonesville Lock and Dam in the Vicksburg District, Mississippi (Perry and Myers 1993).

At Waikkal, Sri Lanka, 800 1.1m x 2.2m sandbags manufactured by Naue-Fasertechnik were used to protect a church from an eroding coast (Bishop, et al. 1993).

Leshchinsky (1993, 1996) described an experimental project at Gaillard Island, Theodore Ship Channel, Mobile Harbor, Alabama in which four 150m long clay-filled geotextile tubes were used. It was found that inner liners may not be necessary to avoid the loss of fine clay particles; the clay particles actually clog up the openings of the outer layer. An extra inner layer may be used for additional seam protection. The soil near the inlet had a lower water content than the soil away from the inlet. Also, after the first month, the heights of the tubes decreased by half. According to Leshchinsky, et al. (1996), it took two hours to fill the tubes through a single inlet; the filled height and

width were 1.5m and 3.6m, respectively. The design, construction, and subsequent observations were described in Sprague and Fowler (1994).

Bishop, et al. (1994) described the usage of 1 m³ nonwoven geotextile containers to stabilize the slopes at Eider Tidal Barrier, Germany. Each day a potential 700 containers could be filled.

De Bruin and Loos (1995) described the use of Geotubes as the toe on both the inland and sea sides of an embankment at Leybucht, Germany. The inland side acts as a foundation to a road next to a channel. The ratio of water to sand used in the slurry was 4:1. The operation proved to be successful.

At Smith Island, Maryland, the coast is eroding away so fast that 14% of the island has eroded away since the beginning of the 1900's. Six hundred seventy linear meters of geotextile tubes, each one 30.5m long x 13.7m wide when flat, manufactured by Bradley Industrial Textiles, Valparaiso, Florida, were planned to be installed to control the erosion (Anonymous 1997).

Fowler (1997) described the possible use of geotextile tubes to raise levees for flood protection along the Mississippi River. Not only would these tubes have a minimal effect on the environment, they would also be both lower in cost and quicker to construct.

At Sea Isle City, N.J., three geotextile tubes were used to create a 900 foot sand dune. This was necessary in order to protect nearby homes from erosion. A scour apron was also used to prevent the erosion of sand underneath the tube. Three years ago these tubes were used to construct sand dunes in Atlantic City, N.J. (Anonymous 1998).

Other applications of geotextile tubes are presented in Armstrong and Kureth (1979), Perrier (1986), Sprague and Fowler (1994), and Koerner and Soong (1997).

1.2.3 Concrete Forms

Geotextiles are often used as concrete forms. These fabric forms allow the concrete to take a wide range of shapes, be placed in hard to reach areas, and therefore be useful in a wide range of applications (Koerner and Welsh 1980b). Concrete forms are usually used for underwater purposes where there is no concern for the concrete to be aesthetically pleasing. The history of the use of geotextiles as concrete forms is discussed in Lamberton (1983,1989).

Once the geotextile is pumped full of concrete, most excess water will leave the permeable geotextile within 20-30 minutes (Lamberton 1989). This decrease in water content increases the strength of the concrete (Lamberton 1983).

Lamberton (1989) presented information on the amount of cement, sand, and water necessary to produce the concrete used in these forms. Koerner and Welsh (1980b) discussed the fibers which make up the geotextiles used in these forms: nylon, polyester, polypropylene, polyamide, polyethylene, and other fibers. Lamberton (1989) described the properties of some of these fibers. About half of the yarns should be treated to improve the geotextile's permeability (Lamberton 1989).

Concrete fabric forms have performed a variety of creative applications. These have been used in pile jacketing (Koerner and Welsh 1980b; Lamberton 1983, 1989; Koerner and Koerner 1996) and mine stabilization efforts (Koerner and Welsh 1980b; Sprague and Koutsourais 1992; Koerner and Koerner 1996). They have also been used to repair scouring bridge piers (Koerner and Welsh 1980b; Lamberton 1989; Sprague and Koutsourais 1992; Silvester and Hsu 1993; Koerner and Koerner 1996), protect tunnels and/or pipelines (Koerner and Welsh 1980b; Lamberton 1989; Sprague and Koutsourais 1992; Silvester and Hsu 1993), construct groins and/or breakwaters (Lamberton 1983, 1989; Sprague and Koutsourais 1992), repair jetties (Sprague and Koutsourais 1992), and control erosion (Koerner and Welsh 1980b; Koerner and Koerner 1996).

Lamberton (1983) discussed the difficulty of calculating the stress in the geotextile due to the geotextile's ability to elongate and the concrete inside not being a "true fluid." Also, more water is expelled from the geotextile as stress increases, thereby changing the properties of the concrete.

Sprague and Koutsourais (1992) discussed a method to calculate the circumference based upon the bag height and filled width. A graph was presented which relates the bag height, filled width, and flat width. This study was based upon the assumption that the cross section has cylindrical ends and is flat on the top and bottom, the fabric is inextensible, and buoyancy is negligible. Koerner and Welsh (1980b) estimated the height of the concrete fabric form to be one-half the width.

Delft Hydraulics (1973) performed a study on the use of piled concrete-filled hoses as a breakwater. The results indicate that such a structure, when exposed to wave impact, is not suited to act as a breakwater.

1.2.4 Analytical and Experimental Studies

Several analytical studies have been performed on geotextile tubes. Most of these studies were two-dimensional and assumed the outer geotextile layer to act as a membrane, internal fill to exert hydrostatic pressure on the membrane, the membrane self-weight to be negligible, and the membrane to be inextensible.

Liu and Silvester (1977) found a relationship between the circumference, pressure head, length of contact with soil, filled height, and filled width. Also studied was a method of determining hoop tension; hoop tension is constant around the cross section except where friction occurs between the tube and the ground. Experimental results agreed with theoretical results.

Liu (1981) performed a study on sand sausages and presented an equation to find the equilibrium shape of the tube and stresses in the geotextile. His theoretical study agreed with experimental results; any differences are assumed to be due to elongation of the material. An experimental study was also done on the impact of waves on sausages; based on the study, if the coefficient of friction between the sea bed and sausage is known, minimum recommended dimensions for the sausage can be found.

Kobayashi and Jacobs (1985) performed an experimental study on the stability of sandbags placed on non-uniform slopes.

Carroll (1994) studied cylindrical shapes that contained one or more fluids and were placed in one or more lighter fluids. Methods to find the constant circumferential tension, average axial tension, and shape properties were presented. Some examples were given. Also discussed was a cylinder with curved ends rather than flat ends.

Kazimierowicz (1994) performed a two-dimensional study on a cylindrical shell. The three cases studied were as follows: (1) internal pressure present at the top of the sausage was much greater than the hydrostatic pressure so that only the internal pressure was considered; (2) both internal pressure and hydrostatic pressure were considered; and (3) only hydrostatic pressure was considered so that the top of the cylinder had zero pressure acting on it. Relationships were developed to find the shape of the cylinder and the membrane tensile force, which is constant along the cross section. Also studied was the length of contact between the cylinder and the ground. Results were in agreement with Silvester (1986).

Den Adel, et al. (1996) studied the stability of Geotubes and Geocontainers. Also discussed were the forces which developed in Geocontainers due to waves, velocity of waves before impact, estimated height of Geocontainers, and recommended dimensions.

Leshchinsky, et al. (1996) studied the shape of a geotextile tube along with its circumferential and axial tensions. Results and an associated program GeoCoPS are in agreement with Silvester (1986), Liu (1981), and Kazimierowiz (1994). The computer program GeoCoPS is discussed further in Leshchinsky and Leshchinsky (1996). Recommended safety factors for the geotextile were also presented. An equation was also presented to determine the amount the geotextile tube will decrease in height due to consolidation.

Plaut and Suherman (1998) presented a method for determining the shape of geosynthetic tubes along with the membrane circumferential tension. The four cases studied were a tube with internal hydrostatic pressure on a rigid foundation, the tube fully submerged in fluid, the tube resting on a tensionless Winkler foundation, and fluid applied to the tube from one side. Results showed that tension increased when the tube rested on the Winkler foundation, and tension decreased when external fluid was applied to the tube.

1.2.5 Model Characteristics

A shell resting on a tensionless Winkler foundation will be modeled in this thesis. The uplift and contact region will be studied. Some related works involving plates include: Pu and Hussain (1970), Gladwell and Iyer (1974), Svec (1974), Gladwell (1975), Villaggio (1983), Ascione and Grimaldi (1984), Ascione and Olivito (1985), Celep (1988a, 1988b), Li and Dempsey (1988), Dempsey and Li (1989), Ascione and Bilotti (1990), Leonardi and Sacco (1991), Lewandowski and Switka (1991), Khathlan (1994), Khathlan and Waly (1994), Ang and Vy (1995), Auricchio and Sacco (1996), and Kocaturk and Akbarov (1996). A beam resting on a Winkler foundation is discussed in Hetenyi (1946).

Buckling of plates on a tensionless foundation has been considered; an example is Shahwan and Waas (1994). Some work has also been performed on uplifting of the

bottom plates of storage tanks during earthquakes; examples include Lau and Zeng (1996), Lu, et al. (1996), Malhotra (1995, 1997), and Natsiavas, et al. (1996).

Haber and Abel (1982) discussed methods to find the equilibrium shape of membrane structures.

The geotextile tube in this thesis will be modeled using finite element analysis. Wawa, et al. (1993) discussed the use of finite element analysis to model airbags in cars.