Chapter 1: Introduction and Literature Review

1.1 Overview

Geotextiles have recently become a new engineering material with numerous applications. One of these applications is the use of geosynthetic tubes filled with a slurry-mix, including sand, concrete, or mortar. These tubes have proven to be an economical alternative for the construction of breakwaters, groins, and temporary levees. They have also been used for slope protection along with many other engineering projects (Pilarczyk and Zeidler 1996).

Geotextiles are permeable fabrics which are able to hold back materials while water flows through. Geosynthetic tubes are large tubes consisting of a woven geotextile material filled with a slurry-mix. The mix usually consists of dredged material from the nearby area but can also be a mortar or concrete mix. These tubes are generally about 1 m to 2 m in diameter, though they can be sized for any application. The tubes can be used solely, or stacked to add greater height and usability. They can be constructed of any length depending on the use (den Adel et al. 1996).

This thesis studies the use of single and stacked geosynthetic tubes. An external water load and a deformable foundation are considered. Only a handful of researchers have carried out studies on these subjects.

1.2 Literature Review

A number of studies have been done on some of the applications for geosynthetic tubes, but mainly just on the analysis of single tubes. Recently, Delft Hydraulics and others have begun to look into the use of stacked tubes. Stacking tubes will create added height necessary for some breakwaters and levees, therefore increasing the usability of geosynthetic tubes (Breteler and van Wijhe 1994).

1.2.1 Geosynthetic description

A geosynthetic material, described in the overview, is very efficient for most of the applications discussed above. It is advantageous in a variety of ways. Geotextile fabrics have the ability to let water through while holding back the particles in the mix. They also tend to be very ductile and strong under tension, while remaining durable for a long period of time after installation. Generally the slurry-mix used is dredged from a location near the site. Little construction equipment is necessary for the placing of the tubes, keeping the cost down.

Though very advantageous, geosynthetic bags have a few drawbacks. They tend to corrode and fall apart if not protected from the sun's ultraviolet rays. The bags are also very susceptible to vandalism; e.g., they can easily be cut with a knife (Erchinger 1993; Koerner and Welsh 1980). According to Gadd (1988), the tubes are even susceptible to damage from ice impact, accidental bulldozing, and the passing of heavy machinery or barges across them.

Fabric types used today include nylon, polyester, polypropylene polyamide, and polyethylene. The type used depends on a variety of parameters. The viscosity of the mix and desired permeability of the fabric is one consideration when choosing the material. Flexibility and cost are other considerations (Koerner and Welsh 1980). Once the tubes are laid, the seam is sewn together in the field. The seam strength, which is an important aspect in design, should be at least 90% of the strength of the fabric (Gadd 1988).

Gadd (1988) recommends using a woven polypropylene with fibrillated yarns. This type of bag exerts high strength, while possessing good workability and physical toughness, and is relatively cheap. Though this material is excellent for projects of short duration, a high strength polyester fabric is available for projects of longer duration (Gadd 1988).

Once the tubes are placed in their desired position, a slurry-mix is pumped into the tubes using a suction dredged delivery line. Inlet openings in the tops of the tubes allow for the insertion of the mix. The slurry-mix needs to have a 100% slump so that vibrators will not be necessary to get the material to all sections of the bag (Silvester 1990). Depending on the viscosity of the mix, these inlets can range from 10 m to 150 m apart (Leshchinsky 1992).

These bags can either be filled with sand or concrete slurry-mix. Sand-filled bags are advantageous because they are very flexible and can be easily repaired if some of the bags get dislodged. However, sand-filled bags are susceptible to vandalism and have a very limited service life.

Concrete-filled bags, on the other hand, are very rigid and are only required to withstand the force of the slurry-mix initially and not the force of the waves or water. Once the mortar sets, the liners no longer serve any purpose (Silvester and Hsu 1993). Bags filled with concrete are normally not reinforced and simply rest upon one another. However, reinforcing dowels may be placed in the wet concrete to help stabilize the bags (Lamberton 1989). Though stable, complete failure may result if there is any differential movement in the soil (Koerner and Welsh 1980; Pilarczyk 1995).

1.2.2 Types of geosynthetics

In recent years, many companies have developed geosynthetic tubes and containers. Many of the brands listed below have been patented by their respective companies. A few of the products and their descriptions are given below.

Mexico has developed and patented three methods of controlling beach erosion in the last two decades. These include Bolsaroca, a sand-filled permeable bag; Bolsacreto, a concrete-filled waterproof geotextile; and Colchacreto, a mortar mat made up of geotextiles (Pilarczyk 1995;

Porraz 1976). The Bolsacreto system for breakwaters has been intensely tested and studied by a group of Mexican engineers (Porraz et al. 1979).

The Longard system, manufactured by the Adek Company of Denmark, is a combination of tubes of different sizes and lengths which are used for coastal protection. The Longard tubes consist of woven polyethylene tubes filled with sand when installed. These tubes are easy to place and are relatively cheap. Repairs to the fabric can be easily made (Armstrong and Kureth 1979; Leidersdorf 1981; Pilarczyk 1995).

Geotube, Geocontainer, and Geobag are geosynthetics developed by Nicolon GeoProducts Division (1994) which have many practical uses. Geocontainers are typically used for groins, underwater bank protection, or pipe protection. Geotubes can likewise be used for erosion protection and breakwaters, and a Geobag is typically used for the construction of flood protection banks. This material developed by Nicolon allows the water in the container to be filtered out while all the fill material stays in.

Other brands include Hydro-Linging, Fabricast, and Gobimat (Koerner and Welsh 1980) and Nicolon F570. Pilarczyk (1995), among others, mentions Dura Bag, an ultra-violet resistant bag, and Fabriform Nylon Bags developed by Construction Techniques USA.

1.2.3 Uses

Geosynthetic tubes have been used for many projects, but are mainly used for flood and water control. They are also used as a prevention against beach erosion (Plaut and Suherman 1998), for the protection of tunnels and underwater pipelines, and for the holding of contaminated materials and pollution (Plaut et al. 1998). Since use of the tubes has little environmental impact, they are very suitable for use in environmentally dangerous areas, such as wetlands (Leshchinsky and Leshchinsky 1996a; Leshchinsky 1992; Sprague and Fowler 1994).

Dikes and levees are one of the primary uses of geosynthetic tubes. Dikes can be constructed up to 4 ft tall to provide flood protection. By stacking the tubes, an even greater height can be achieved. These tubes can also be attached to the top of a floodwall to provide greater flood control (Perry and Meyers 1993). In Germany, a 15 km dike of sand-filled Geotubes was constructed in Leybucht. This system proved to be a very efficient and durable method of water control (de Bruin and Loos 1995).

The Army Corps of Engineers is looking into using geotextile tubes to raise the levees on 220 miles of the Mississippi River. The proposal involves dredging material from the river to fill the 20 in. tubes. The tubes will have little negative effect on the environment and could result in net savings of $368 million in comparison with other proposed techniques (Fowler 1997).

Groins can be very effective when used for shoreline protection. Sand-filled geosynthetic bags are a very reasonable alternative to other groin types. They are relatively inexpensive, only $20-$40 a foot, and can be removed with just a knife. Sand-filled bags can also be used for revetments or bulkhead protection (Gutman 1979).

Using geotextile tubes, it is possible to rehabilitate bridge foundations which have been damaged due to scour or the actual erosion of the soil and rock beneath them. The tubes can be fitted below the foundation and filled with concrete along with any other voids between the tube and foundation (Koerner and Koerner 1996; Koerner and Welsh 1980).

Delft Hydraulics (1994) has proposed stacking tubes for breakwaters. By setting the tubes away from shore, they will have the ability to break large waves before they reach shore, preventing possible destruction to marinas and piers.

Sprague and Fowler (1994) presented many different case histories for the use of geotextiles. To control rapid erosion in the Old Pass Lagoon near Destin, Florida, a system of three Geotubes was constructed. Geotubes were also used to increase the amount of dredged material that could be deposited on Gaillard Island in Alabama. Nicolon F570 bags were used to repair a dike which had been protecting a fresh water lagoon on Bull Island, South Carolina. In another application, six underwater groins were constructed from a geotextile material in the Mississippi River to maintain a site which was constantly in need of dredging to keep the channel open.

In other applications, geotextiles can also be used for landfill dikes, according to John (1987). Engineers in South Africa used geosynthetic tubes to support structures above abandoned mines (Koerner and Koerner 1996; Koerner and Soong 1997). Gadd (1989) discussed the use of geotextiles for slope protection of offshore islands for oil and gas exploration in the Arctic regions.

1.2.4 Analysis of single tubes

Some engineers and researchers have studied the use and behavior of these geosynthetic slurry-filled tubes. Before the tubes can become widespread in industry, professionals want to be confident with the performance of the tubes. The first step in the analysis is the study of the behavior of single tubes.

The analyses of geosynthetic tubes are usually based on a few assumptions. First, because the tube is very long compared to the diameter, it can be assumed that each cross-section is the same, and the problem becomes two-dimensional. The outer shell is also assumed to be very thin and lightweight, and does not resist bending. It is also assumed that no shear stress will be induced between the slurry and outer shell (Leshchinsky and Leshchinsky 1996a).

Leshchinsky and Leshchinsky (1996a) performed an analysis to solve for the circumference and axial tension based on the parameters of height and pressure. A program called GeoCoPS was developed to perform the analysis. They studied the effect of pumping pressure on the height of the tube. Required safety factors for choosing a geosynthetic material were also stated. They also formulated an equation for calculating the drop in height due to the solidifying of the slurry.

Since most analyses of geosynthetic tubes assume that the tubes rest on a flat, horizontal surface, Plaut and Suherman (1998) discuss the effect of the tubes resting on soil. The paper also analyzes tubes which have only one side loaded, such as a dike, and tubes placed completely under water. Approximate solutions for cross-sectional shapes and circumferential tension of the tube susceptible to hydrostatic pressure are also given.

Leshchinsky et al. (1996b) present further single tube analysis with equations which calculate the stresses in the geosynthetic material. They also determined that a large increase in pumping pressure would only produce a small increase in the tube's storage capacity. A guide to selecting a geosynthetic material is also presented, based on safety factors and filtration aspects.

Sand-sausages, large geosynthetic tubes filled with sand typically used for beach erosion or breakwaters, tend to take on a more noncircular shape as they become larger. Kazimierowicz (1994) determined exact deformations of sand-sausages. He determined that the final shape would be a factor of the tube's height, highest pressure, self-weight, tensile forces in the shell, and the circumference of the shell. Numerical methods were also used to determine the shape of the tube when the pressure at the highest point is zero.

An analysis of the height and size of single tubes with respect to a given pressure head, along with an equation for hoop tension of the tube, was also derived by Liu and Silvester (1977). From the input of circumference and pressure head, the values for height, width, cross-sectional area, contact width at base, and axial tension can be determined (Silvester 1986).

Bogossian et al. (1982) performed two tests with the use of continuous dikes and formulated mathematical equations for them. The tests performed in France and Brazil were to determine whether or not the geotextile tubes would work effectively. Due to the success of the first test, equations were developed to determine the different dimensions and pressures of the tube (Bogossian et al. 1982). Carroll (1994) derived an exact solution for the cylindrical shape for multiple combinations of interior and exterior pressures.

Szyszkowski and Glockner (1987) studied the use of long cylindrical membranes used as large floating containers. The tubes would allow for transport of large volumes of fluid over water. The analysis consisted of membrane theory to determine the cross-sectional profiles of the containers.

1.2.5 Analysis of stacked tubes

Stacked tubes are typically used for revetments, groins, and breakwaters. They can be placed parallel to a slope to form a revetment for erosion control. A limited number of authors have studied this topic. However, Breteler and van Wijhe (1994) have done extensive research on stacked tubes for Delft Hydraulics.

Delft Hydraulics (1973) first conducted experiments on the feasibility of stacked concrete-filled tubes used for breakwaters. They compared placing the tubes perpendicular and parallel to the breakwaters. Later, in a project funded by Nicolon, Delft Hydraulics performed an analysis on the collapse of stacked tubes in 4-3-2 and 3-2-1 formations. The experiment consisted of testing model tubes set up as groins and breakwaters to failure in a flume due to various wave heights and currents. Breteler and van Wijhe (1994) concluded that it is important to consider frictional contact between tubes when analyzing their behavior. Pilarczyk and Zeidler (1996) have described the research done by Delft Hydraulics.

Sprague and Koutsourais (1992) discuss the design of concrete bags for revetments. Stacking sand-filled bags can create an efficient breakwater. By stacking in a pyramid shape, they can become stable against the force of the waves. Only heavy bags should be used for this purpose to prevent movement. For short-term use, these stacked sand-filled bags can be used for groin construction (Pilarczyk 1995).

Geotubes can take on the shape of a box or pillow. They are often stacked upon one another and have been used for the construction of underwater berms. The “boxes” are placed in the field by barges and then sewn shut (den Adel et al. 1996; Koerner and Koerner 1996; Pilarczyk 1995).

Other authors have mentioned some other possible applications for stacked tubes. Koerner and Welsh (1980) discussed the process and analysis of using stacked tubes for pipeline protection on land and in water. Perrier (1986) illustrated the idea of stacking tubes in a proposed dike to reach a required height. Munday and Bricker (1987) and Kobayashi and Jacobs (1985) considered using stacked tubes for slope protection applications.

1.3 Objective

The objective of this thesis is to carry out a two-dimensional analysis of single and stacked geosynthetic tubes. The analysis will provide results for the circumferential tension and height of the tubes with a given nondimensional specific weight and internal pressure head of the fill. From the results obtained, a conclusion can be made about the usability of the structures with the given assumptions.

1.4 Scope

Single and stacked geosynthetic tubes are considered along with external water loads and deformable foundations. The program Mathematica was used to perform calculations. The solutions were transferred to Microsoft Excel, where cross-sectional profiles of the structures were created.

The assumptions and basic formulations used throughout the thesis are outlined in Chapter 2. Quantities throughout the thesis are nondimensional. A small discussion about the computer analysis and deformable foundation is given at the end of Chapter 2.

Chapter 3 looks into the use of a single geosynthetic tube. The chapter is divided into three sections. A rigid foundation, deformable foundation, and external water load are considered. The tube acts as a levee with regard to the external water. Various examples and charts follow the formulation of the problem.

In Chapter 4, the use of stacking a tube on top of another tube is studied. Both rigid and deformable foundations are considered. Structures with different fills, hence specific weights, in the top and bottom tubes are investigated. Also, tubes in the same structure with different perimeter lengths are examined.

The 2-1 stacked formation, where one tube is positioned on top of two lower tubes on a deformable foundation, is studied in Chapter 5. External water on one side of the structure at various heights is considered. Chapter 6 presents some general conclusions and recommendations for further work.