Geotextile containment

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ABSTRACT: Geotextile containment provides novel solutions for hydraulic and marine engineering applications, and for environmental engineering applications. The three geotextile containment unit types – geotextile tubes, geotextile bags and geotextile containers – are used as mass-gravity elements for hydraulic and marine engineering structures. These same unit types are also used for the dewatering of waste and for the safe contained disposal of waste in marine environments.

1 INTRODUCTION

Geotextile containment is used for an increasing range of applications in the fields of hydraulic and marine engineering, and in environmental engineering. Here, the geotextile encapsulates soil or waste, resulting in a specific geometrical shape. The function of the geotextile is to contain the fill material thus preventing its erosion and loss, and to allow drainage of the fill material.

Where geotextile containment is used for hydraulic and marine applications the containers prevent the erosion of the sand fill from the containers, thus preserving a specific shape and volume of fill. This enables these structures to be used as erosion-resistant, mass-gravity structures. Where geotextile containment is used for environmental applications the containers enable accelerated dewatering of contained waste and/or the prevention of loss of the contained waste.

Geotextile containment units are produced in a range of shapes and volumes. These may be divided into three overall types – geotextile tubes, geotextile containers and geotextile bags.

Geotextile tubes, fig. 1a, are tubular containers that are formed insitu on land or in water. The tubes are filled by hydraulically pumping fill into the tube. Geotextile tubes range in size from 1 m to 10 m in diameter, and up to 200 m in length.

Geotextile containers, fig. 1b, are large-volume containers that are filled in barges above water and then deposited into submarine environments. The volumes of these containers more commonly range from 100 m^3 to 700 m^3, although containers as large as 1,000 m^3 have been installed. To facilitate the installation of geotextile containers of this magnitude an efficient and practical installation system must be utilized. To date, this has been accomplished by means of split-bottom barges.

Geotextile bags, fig. 1c, are small-volume containers that are filled on land or above water and then pattern-placed either near water or below water level. Geotextile bags range in volume from 0.05 m^3 to around 5 m^3, and may be pillow-shaped, box-shaped or mattress-shaped depending on the required application.

When considering geotextile containment, distinction must be made between those applications where the geotextile containment is required for only temporary or expedient use and those applications that require long-term performance. For example, for temporary or expedient works the requirements of the geotextile container is fairly basic as it only has a short life expectancy over which it has to perform; however, for long-term applications the performance requirements of the geotextile container are more severe. With regard to long-term performance, distinction also must be made according to the type of hydraulic environment acting on the geotextile container. For instance, the action of still, or slowly moving, water will have a different effect on the geotextile container than the action of breaking waves.

a) Geotextile tubes

b) Geotextile containers

c) Geotextile bags

Figure 1. Types of geotextile containment units (Lawson 2008, 2006)

2 GEOTEXTILE TUBES FOR HYDRAULIC AND MARINE APPLICATIONS

2.1 *Applications for geotextile tubes*

Geotextile tubes are used for a range of hydraulic and marine applications where mass-gravity barrier-type structures are required. These applications are shown in fig. 2 and described briefly below.

2.1.1 *Revetments, fig. 2a*

Geotextile tubes are used for revetment structures where their contained fill is used to provide mass-gravity stability. They are used for both submerged as well as exposed revetments. For submerged revetments the geotextile tube is covered by local soil and is only required to provide protection when the soil cover has been eroded during periods of intermittent storm activity. Once the storm is over the revetment is covered by soil again either naturally or by maintenance filling. For exposed revetments the geotextile tube is exposed throughout its required design life.

To prevent erosion of the foundation soil in the vicinity of the geotextile tube it is common practice to install a scour apron (see fig. 2a). This scour apron usually consists of a geotextile filter layer that passes beneath the geotextile tube and is anchored at the extremity by a smaller, filled, geotextile tube.

Revetments are also constructed using multiple-height geotextile tubes. Here the geotextile tubes are staggered horizontally to achieve required stability. Considerable care should be exercised during construction of these types of revetments to ensure the water emanating from the hydraulic filling of the upper geotextile tubes does not erode the soil and undermine the lower geotextile tubes in the multiple-height revetment structure.

2.1.2 *Offshore breakwaters, fig. 2b*

Geotextile tubes are used for offshore breakwaters to prevent the erosion of shoreline developments. Here the filled geotextile tube is located a certain distance offshore in order to dissipate wave forces before they can reach the shoreline. Again, scour aprons are used beneath the geotextile tube breakwater to ensure local erosion does not undermine the breakwater structure.

In many instances the geotextile tube is left exposed which consequently affects its design life. Additional techniques or treatments may be applied to the geotextile tube breakwater to increase its exposed design life.

2.1.3 *Protection dykes, fig. 2c*

Geotextile tubes are used for protection dykes where they prevent flood and storm damage to valuable structures and real estate. Protection dykes also may be used for river, lake or stream training works.

Where geotextile tube protection dykes are constructed it is common to cover the geotextile tube with local soil. The geotextile tube is only required to function intermittently during storm or flood periods when the soil cover is eroded. The use of the soil cover provides a number of advantages to the

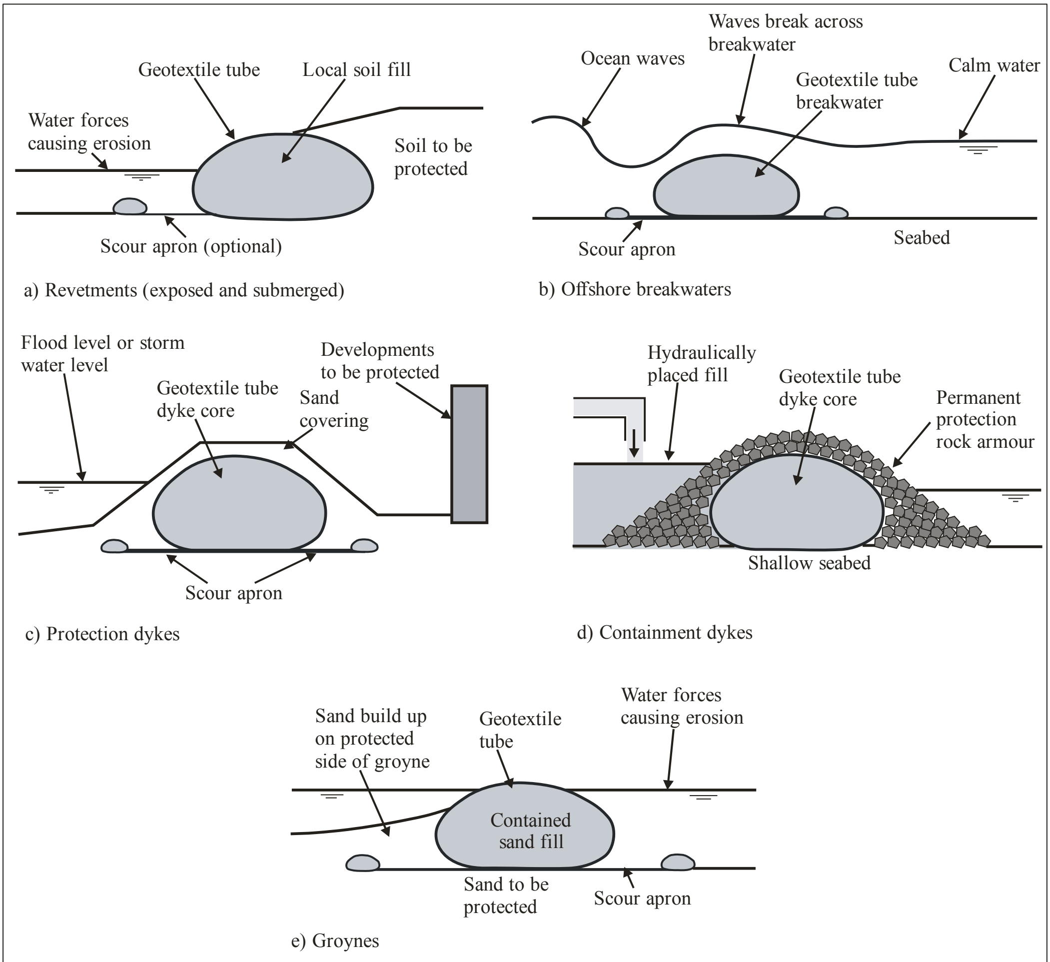


Figure 2. Hydraulic and marine applications for geotextile tubes (Lawson 2008, 2006)

geotextile tube core. First, the soil cover hides the geotextile tube core thereby providing an aesthetic environment and ensuring no damage due to vandalism. Second, the soil cover protects the geotextile tube from long-term exposure to direct sunlight (UV degradation).

Where geotextile tubes are used for river, lake or stream training works it is common to leave the tube exposed except for major structures where rock armour layers may be placed over the geotextile tube to dissipate hydraulic forces. Where the tubes are left exposed a geotextile shroud may be used across the top of the tube, or a coating applied, to enhance its longevity in an exposed environment.

2.1.4 *Containment dykes, fig. 2d*

Geotextile tubes are used for the cores of containment dykes where water depths are relatively shallow. Here, the tube structure contains a filled reclamation area - the reclamation fill being dry dumped or placed hydraulically. The advantage of this approach is that the same hydraulic fill used in the reclamation can also be used inside the geotextile tubes for the containment dykes thus avoiding the need to import rock fill for the dykes. Containment dykes constructed from geotextile tubes provide an economic alternative to other forms of construction, e.g. sheet piled walls, especially where the foundation soil is soft. Where water forces dictate, and where longevity is required, rock armouring can be placed around the geotextile tube core, e.g. fig.2d.

2.1.5 *Groynes, fig. 2e*

Geotextile tubes can be used as groynes to prevent the littoral movement of sediment. In most cases the geotextile tubes are left exposed, but coatings or a rock covering may be applied depending on the circumstances and the required life expectancy.

2.2 *Design of geotextile tube structures*

Geotextile tubes act as mass-gravity structural units and may be designed on the basis of assessing the various potential failure modes. The various external and internal potential failure modes are shown in fig. 3. Lawson (2006, 2008) provides a detailed description of each potential failure mode.

2.3 *Tensions generated in geotextile tubes*

During the filling process, and through the design life, the geotextile tube must resist the tensions generated in the geotextile skin to prevent tube rupture. Tensions are generated in three directions/locations in the filled tube. These are tensions around the circumference of the tube, tensions along the length of the tube and tensions generated at the connection of the filling port with the tube during the filling process.

The analysis of tensions generated in geotextile tubes is complex because of the influence of tube geometry, which changes during the filling process (and may also change over the life of the tube). The nature of the fill, which starts as a liquid during initial filling, and then quickly reverts to a solid, also complicates the analysis of tensions. Various techniques have been used to analyze tensions ranging from the use of membrane theory to continuum methods. Lawson (2006, 2008) provide a discussion of the merits of each approach.

2.4 *Required hydraulic properties of geotextile tubes*

Geotextile tubes are constructed to perform in a variety of hydraulic environments ranging from still or slow moving water, to fast moving currents, to wave environments. In many of these applications the geotextile tube skin is exposed directly to the hydraulic environment. Two aspects of the hydraulic environment should be taken into account when considering the use of geotextile tubes. These are the type of hydraulic regime acting on the geotextile tube and the time period of exposure to this hydraulic regime. The severity of these hydraulic regimes governs the hydraulic properties of the geotextile skin as well as whether the geotextile tube can perform suitably in an unprotected manner (i.e. with the geotextile skin exposed directly to the hydraulic regime).

The time period of exposure can also have an effect on the severity of the hydraulic environment, for example, exposure to intermittent storm activity will not have the same effect as continual exposure to the same types of waves. Lawson (2006, 2008) provides guidance for suitable geotextile hydraulic properties for a variety of hydraulic conditions.

2.5 *Protection measures applied to geotextile tubes*

External protection measures are applied to geotextile tubes for a variety of reasons, namely;

- to reduce the impact of the hydraulic forces acting directly on the geotextile tube;
- to enhance the design life of the geotextile tube in

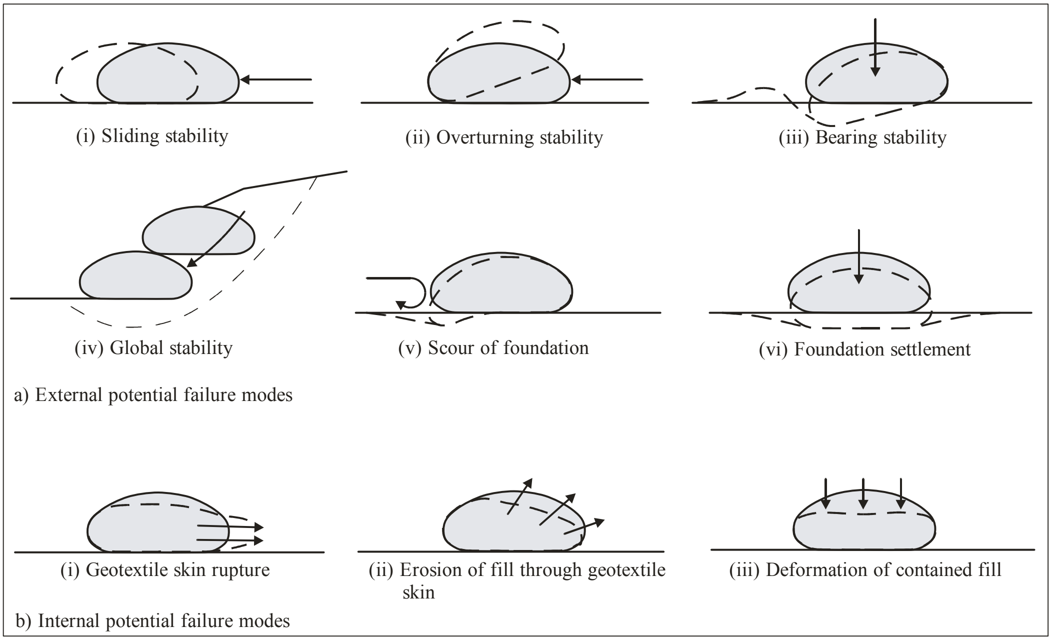


Figure 3. Potential failure modes for geotextile tubes (Lawson 2008, 2006)

an exposed environment;

- to protect from extreme natural occurrences, e.g. ice flows, etc;
- to protect from vandalism.

In many instances geotextile tubes are required to perform over a relatively long design life in an exposed environment. In this environment UV degradation can occur, with the geotextile tube design life dependent on the level of UV radiation and the resistance of the geotextile tube skin to this radiation. If the geotextile tube is located in a marine environment, marine growth generally occurs quickly on the outer surface and this tends to mask the geotextile skin somewhat from the effects of UV radiation. However, for good long term performance, in an exposed environment, additional protection measures are normally required for the geotextile tube skin. These measures are listed below in order of providing longer term performance.

- Additional stabilizer packages in the geotextile tube skin – where the enhanced performance of the stabilizer package improves the performance of the geotextile tube skin over time.
- More robust, or multi-layer geotextile skin – where extra design life is achieved by the use of more robust or multi-layer geotextile skins that degrade over a longer period of time.
- Geotextile shrouds - where the outer geotextile shroud provides protection for the inner geotextile tube skin. The geotextile shroud becomes sacrificial over the design life of the geotextile tube structure. These are used where the geotextile tube structure is continually exposed to the environment and where the hydraulic forces are not severe.
- Geotextile coating – where a robust coating is applied to the geotextile tube to protect it. Coatings can be applied in a variety of colours.
- Soil covering – where the geotextile tube is covered by soil or sand to prevent long term UV exposure. Here the geotextile tube structure performs intermittently during periods of storm activity and is then covered over again by soil or sand.
- Armour covering – where a flexible armour covering is used around the geotextile tube structure to prevent long term exposure to UV light. This is normally used in hydraulic and marine applications where severe hydraulic forces occur.

Extreme natural occurrences can also affect the long term performance of exposed geotextile tubes. Examples include the damaging effects of ice flows, and trees carried in water during floods, on the exposed surface of geotextile tubes. Where this is known to be a problem then the geotextile tube structure must be protected. The form of protection from this type of exposure is normally armour covering.

Vandalism can also affect the long term performance of geotextile tubes. This type of damage is normally in the form of localized cuts and tears. The best way of protecting against this likelihood is to cover the geotextile tube so it is out of sight. Alternatively, robust coatings can be applied which prevent vandalism. Failing this, a good maintenance scheme should be put in place to correct any acts of vandalism.

2.6 *Artificial island construction using geotextile tubes, Incheon, Korea*

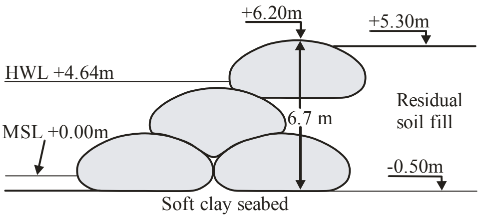
This project has been reported on by others, the most recent being Lawson (2008), and is summarized here to demonstrate the sophisticated type of hydraulic and marine application where geotextile tubes can be used.

The Incheon Grand Bridge Project consists of the construction of a freeway connecting the island containing the new Incheon International Airport to the mainland of Korea to the South East. In the area close to the mainland it was planned to construct an artificial island in order to construct the freeway viaduct and associated toll gate facilities in the dry. This artificial island is to be left in place once the freeway viaduct is completed as the area will later be enveloped by a large land reclamation scheme to build a new high technology city – Songdo City.

The foundation conditions where the artificial island is located consist of very soft marine clay to an approximate depth of 20 m. Further, in this area the tide range is very high, with a maximum difference in level of 9.3 m. This results in the exposure of the soft clay foundation at low tide and inundation to around +4.64 m at high tide. As a result of this it was decided to construct the containment dyke for the artificial island out of geotextile tubes as it was considered that the alternative of using sheet pile walls would not be feasible considering the low shear strength of the soft foundation and the height to which the artificial island would have to be raised above high tide level.

Fig. 4a shows a view of the artificial island under construction. The sand fill for the geotextile tubes was brought to the site by barge, mixed with water, and then pumped hydraulically into the geotextile tubes. Fig. 4b shows the cross-section through the geotextile tube wall of the artificial island. The base of the wall has two tubes side-by-side, with a third tube placed on top. Later, a fourth tube is then placed to bring the island up to the required design height. Locally available residual soil has been used for the fill material for the island. Fig. 4c shows the completed island with construction equipment

a) Artificial island using geotextile tubes



b) Cross-section through geotextile tube dyke

c) Geotextile tube protection

Figure 4. Use of geotextile tubes to construct artificial island, Incheon, Korea (Lawson, 2008)

present starting the construction of the freeway viaduct and associated toll gate facilities.

3 GEOTEXTILE CONTAINERS FOR HYDRAULIC AND MARINE APPLICATIONS

3.1 *Applications for geotextile containers*

Geotextile containers are used for a range of hydraulic and marine applications where submarine mass-gravity support or barrier type structures are required. These are shown in fig. 5 and described briefly below.

3.1.1 *Offshore breakwaters, fig. 5a*

Geotextile containers are used as part of offshore breakwaters to prevent the erosion of the shoreline. The technique here is the same as that for geotextile tube offshore breakwaters except that geotextile containers are used at greater water depth and a rock covering is normally placed across the top of the containers to raise the breakwater to its required height.

3.1.2 *Containment dykes, fig. 5b*

Geotextile containers are used for containment dykes where the water depth facilitates the placement of the containers. The technique is the same as that for geotextile tubes except that the geotextile containers are used at greater water depth. A rock covering is normally placed across the top and down the outer face of the geotextile containers to raise the containment dyke above water level. Where the dyke is to remain submerged geotextile containers may be the sole units.

3.1.3 *Artificial reefs, fig. 5c*

Geotextile containers can be used to construct artificial reefs. Here, the containers provide a raised platform (a reef) that forces waves to break over the top of the reef. This prevents erosion of the protected shoreline.

As well as dissipating wave energy artificial reefs also can be used to refract waves and alter the normal waveform. However, to do this successfully requires the reef to be constructed to a specific plan geometry with specific side slopes and platform height. This level of placement accuracy is normally outside the limits of large-volume geotextile container placement, and is more suited to the application of smaller-volume geotextile bags.

Further, the nature of geotextile containers makes it difficult to fill them to maximum volume and density. Consequently, it is to be expected that if the filled geotextile containers are to be exposed to continual wave activity then liquefaction of the sand fill will cause a change in shape of the exposed containers and a subsequent lowering of the surface level of the artificial reef. This then alters the shape of the waveform across the top of the reef, and thus the structure may require periodic maintenance to maintain the existing waveform.

3.1.4 *Slope buttressing, fig. 5d*

Geotextile containers are used for the underwater buttressing of unstable slopes. Here, the weight of the geotextile containers is utilized to provide a counter-weight to a potentially unstable slope. The advantage of using geotextile containers is that a "soft" buttress structure is provided that won't damage shipping.

3.2 *Tensions generated in geotextile containers*

The tensions generated in a geotextile container vary throughout the installation stages. These stages are;

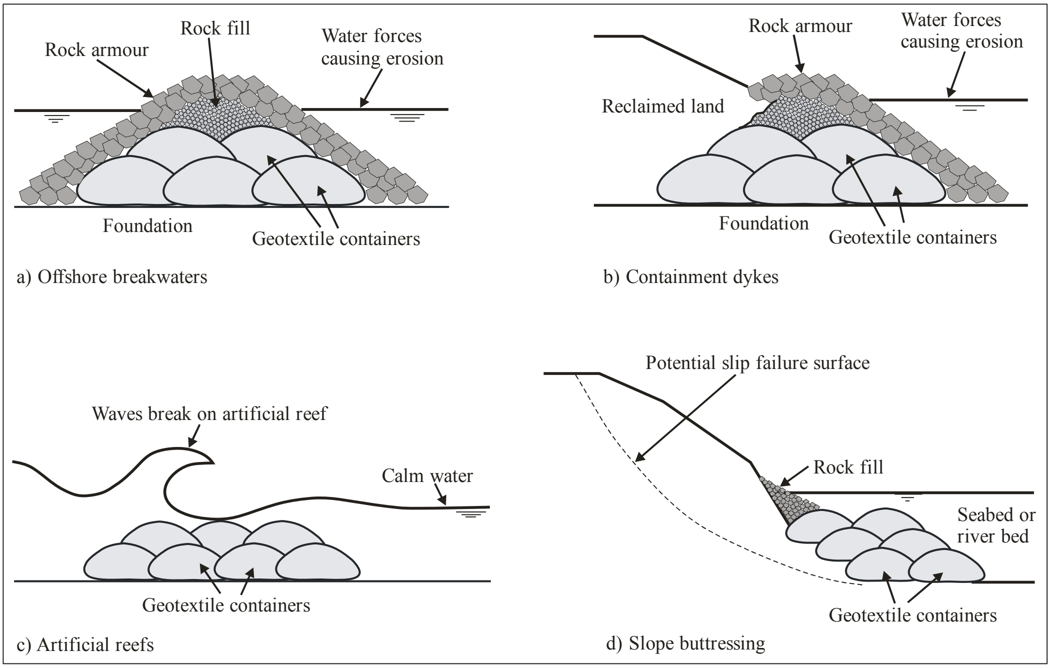


Figure 5. Hydraulic and marine applications for geotextile containers (Lawson 2008, 2006)

filling of the geotextile container in the barge; re-shaping of the geotextile container to exit the barge; free-fall of the geotextile container through the water; impact of the geotextile container on the seabed; and the final installed shape of the geotextile container on the seabed. All five installation stages generate different tensions in the geotextile container and these must be properly assessed in order to accurately determine the tensile strength requirements of the geotextile container. The tensions developed in geotextile containers are complex and are dependent on many factors, see Lawson (2006, 2008).

4 GEOTEXTILE BAGS FOR HYDRAULIC AND MARINE APPLICATIONS

4.1 *Applications for geotextile bags*

Geotextile bags are used for a range of hydraulic and marine applications. These are shown in fig. 6 and described briefly below.

4.1.1 *Revetments, fig. 6a*

Geotextile bags are used for revetments where their contained fill is used to provide stability and prevent erosion. Geotextile bags have been used for both submerged as well as exposed revetments, the same as with geotextile tubes. Much of the details concerning geotextile tube revetments also apply to geotextile bag revetments.

To prevent erosion of the foundation soil at the toe of the revetment it is common practice to extend the bottom layer of geotextile bags so the main revetment cannot be undermined.

4.1.2 *Groynes, fig. 6b*

Geotextile bags may be used as groynes to prevent the shoreline movement of sediment. Here, the same conditions apply for geotextile bags as for geotextile tubes.

4.1.3 *Artificial reefs, fig. 6c*

Geotextile bags can be used to construct artificial reefs. Here, the same conditions apply for geotextile bags as for geotextile containers. A major advantage of geotextile bags is that they can be installed to better geometric tolerances than relatively large-volume geotextile containers. Also, being relatively small in volume and having considerably better fill density, the geotextile bags are less prone to liquefaction from waves (or its effects) than the relatively large-volume geotextile containers.

Artificial reefs are normally required to dissipate wave energy and thus prevent erosion of the protected shoreline. Here, the reef has only to have basic geometrical requirements of height and area, with the geotextile bags providing a mass-gravity structure. However, artificial reefs have been used more recently to also refract waves and alter their shape to make them better suited for surfing. For this

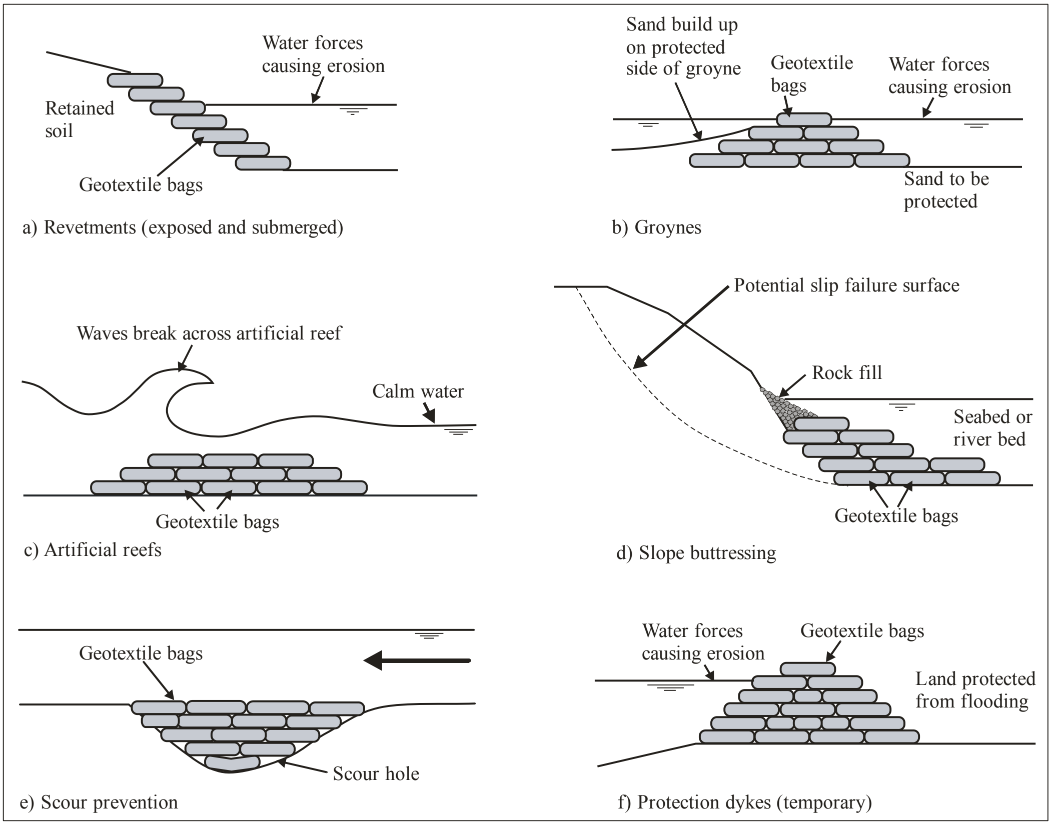


Figure 6. Hydraulic and marine applications for geotextile bags (Lawson 2008, 2006)

application the reef has to be constructed to good geometrical tolerances of height and shape as well as side-slope tolerances, and these tolerances have to be maintained throughout the design life of the reef. For this application geotextile bags have to be of a specific geometry and have to be installed carefully in order to meet the required geometrical tolerances of the reef.

4.1.4 *Slope buttressing, fig. 6d*

As with geotextile containers, geotextile bags can be used to provide buttress support to an unstable slope in a hydraulic environment. Here, the geotextile bags act as a mass-gravity structure providing additional restraint to the toe of the unstable slope.

One advantage of geotextile bags for this application is that installation can be carried out by simple lifting equipment; thus geotextile bags can be installed at shallow water depths if necessary, unlike geotextile containers, which have to be installed at relatively greater water depth.

4.1.5 *Scour prevention, fig. 6e*

Geotextile bags are used as expedient means of scour prevention to prevent undermining of nearby structures. This is the original application for these units. Geotextile bags can be easily installed using simple machinery. The bags conform to the shape of the scour hole and thus provide good sealing qualities.

4.1.6 *Protection dykes, fig. 6f*

Protection dykes are one of the original applications for geotextile bags. These bags, in the form of small sand bags, can be seen the world over shoring flood defences during times of natural calamity. This expedient use of geotextile bags comprises the most basic, and common, form of geotextile containment application.

However, geotextile bags may be used for more sophisticated and substantial protection dyke structures where they may be required to perform over long periods of time. Here, the geotextile bags are required to perform in the same manner as geotextile tubes for this same application. The pattern-placement of geotextile bags forms a stable mass-gravity structure that is resistant to erosion when subjected to hydraulic forces.

4.2 *Design of geotextile bag structures*

As with geotextile tubes, packed geotextile bags behave as mass-gravity structures, and the approach to design may follow an identical process to other structural-type applications where the various stability and deformation modes are assessed and rendered safe. Lawson (2006, 2008) discusses in some detail the various stability and deformation modes for geotextile bags.

5 GEOTEXTILE CONTAINMENT FOR DEWATERING OF SLURRY WASTE AND CONTAMINATED SEDIMENTS

5.1 *Fundamentals of geotextile container dewatering*

Many industries utilize water for the processing, moving and storing of by-products and waste. This results in large volumes of liquid or slurry-like materials being stored in containment areas, or being treated before discharge into lakes, rivers and streams. In the past many industry by-products were discharged directly into water courses where they have settled, and over time, have contaminated the sediments of these water courses.

The removal and disposal of sludge and waste from lagoons and ponds, and contaminated sediments from mines, lakes, rivers and streams presents a major environmental problem because of the large volumes involved and the fact that these wastes are in liquid form which presents problems in handling, transportation and disposal. Landfilling has become the disposal facility of choice, however, with the huge volumes of slurry-like wastes and contaminated sediments produced; direct landfilling is not practical. Further, these wastes, in their natural state, are in liquid form which makes their handling, transport and disposal difficult. Thus, a preliminary treatment stage has to be employed in order to significantly reduce the volume of the slurry waste prior to disposal by landfilling, and to render it manageable for handling, transport and disposal. Dewatering is commonly applied as this preliminary treatment.

Dewatering accomplishes the two primary objectives with regard to treatment and disposal of slurry-like waste and contaminated sediments. These are a large reduction in the volume of the slurry-like waste (by the removal of water) and the rendering of the waste into a semi-solid, solid form for easy handling. Also, if done in a controlled manner dewatering can also retain solids and contaminants within the containment medium.

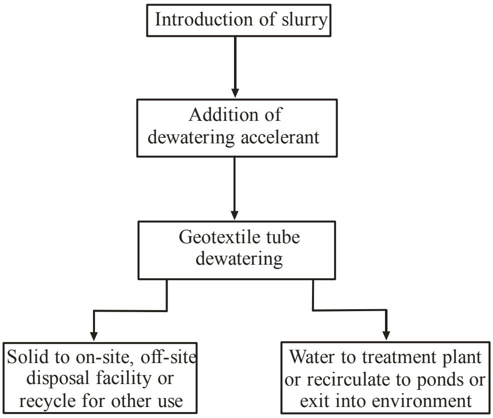
Geotextile tubes and bags provide an ideal medium for the dewatering of slurry-like waste streams and contaminated sediments because of the following. First, they provide a large contact surface area with the slurry to enable efficient dewatering. Second, they utilize geotextiles that enable efficient dewatering of the slurry. Third, they can be fabricated in sizes, and used in numbers, that fit into the scale of required dewatering operations. Fourth, they are relatively simple to employ and utilize unlike other, more complex, mechanical dewatering technologies, and therefore cheaper. Geotextile tubes are used where the volume of slurry waste to be dewatered is large, while geotextile bags are used where the volume of slurry waste to be dewatered is small.

In many respects the use of geotextile tubes to dewater waste streams and contaminated sediments is still developing with new applications arising frequently. For example, industries that produce significant quantities of slurry waste and where geotextile tubes have been successfully utilized for dewatering, are municipal waste treatment, agriculture waste treatment, food and food processing waste treatment, industrial and mining waste treatment, construction industry waste treatment and the treatment of contaminated sediments.

Geotextile tubes are used as a component in the overall dewatering system. Fig. 7a shows the overall dewatering process, which begins with the extraction of the slurry waste from its natural location. The slurry waste is then normally dosed with an appropriate amount of the correct dewatering accelerant to ensure the dewatering occurs within a suitable time period. The slurry waste, along with the dewatering accelerant, is pumped into the geotextile tubes where the dewatering occurs. The free-draining water passes out through the skin of the geotextile where it is collected in a base drainage system where it is then passed on for further treatment or allowed to flow back into the natural environment. Following dewatering, the geotextile tubes are cut open and the dewatered waste is extracted and taken to a suitable storage facility. Alternatively, the dewatered waste may be recycled, or left in place.

Fig. 7b shows the components of the geotextile tube dewatering facility. Normally, the dewatering tubes are contained within an impermeable or lined facility to prevent loss of the effluent water into the ground. A drainage blanket across the base of the facility collects the effluent water from the geotextile tubes and drains it to a drainage point where it is transported for further treatment or allowed to pass back into the natural environment. The facility is sized according to the quantity of waste to be dewatered. Geotextile tubes are placed within the containment facility in the sizes and numbers required to dewater the waste in the required time period.

During the dewatering process the solids concentration of the contained waste increases and at the same time the contained volume decreases. This is shown in fig. 8a. Over time, the rate of increase of solids concentration slows, with the rate of decrease in contained volume also slowing. Both solids



a) Overall dewatering process using geotextile tubes

b) Photograph of the geotextile tube dewatering component

Figure 7. Geotextile tube dewatering process

concentration and contained volume are interrelated. Lawson (2006, 2008) provides relationships between solids concentration and contained volume.

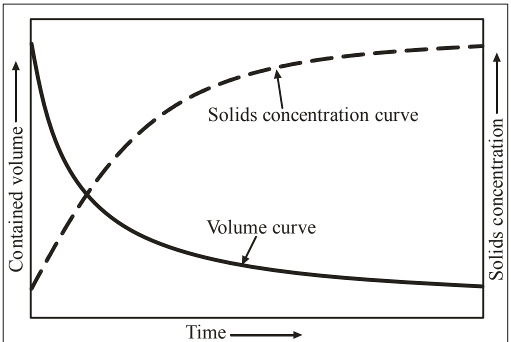
Fig. 8b shows the geotextile tube dewatering of sewage sludge from a particular site. The change in solids concentration and contained volume over time closely reflects the curves presented in fig. 8a. The sludge starts off at 4% solids concentration in the geotextile tube (which corresponds to 100% contained volume), and after 2 months dewatering the solids concentration has increased to 12.5%, with the contained volume reducing to around 30% (70% volume reduction). After 6 months dewatering the solids concentration has increased to 17% with the contained volume reducing to 20%. Thus, after 6 months dewatering the contained volume has reduced by 80%.

To effectively perform the dewatering procedure the geotextile tubes undergo several filling and dewatering cycles. This makes the process more efficient inasmuch as maximum use is made of the available geotextile tube volume for dewatering.

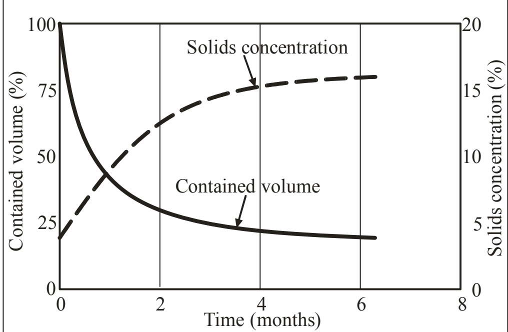
Table 1. Typical initial and final solids concentrations for various waste streams

Waste material	Initial solids concentration	Final solids concentration
Biosolids	1% - 4%	15% - 25%
Agriculture	2% - 4%	20% - 25%
Mineral processing	3% - 10%	40% - 70%
Industrial by-products	4% - 10%	25% - 75%
Contaminated sediments	10% - 14%	35% - 70%

Following completion of the filling and dewatering cycles the geotextile tubes are left to undergo the final dewatering stage, and consolidation. The aim of this final stage is to render the contained waste into a semi-solid, or solid form, so it can be handled and removed (if required). Table 1 shows typical final solids concentration values for various waste streams where the dewatered material may be considered semi-solid or solid. Also, shown in table 1 is the typical initial solids concentration that the waste streams are pumped into the geotextile tubes. It should be noted that there is a wide range of solids concentration values not only for the various waste streams but also within the same waste stream. The more inorganic particulate wastes (e.g. mineral



a) Increase in solids concentration and decrease in contained volume versus time during dewatering



b) Change in solids concentration and contained volume for sewage sludge undergoing dewatering

Figure 8. Dewatering fundamentals using geotextile tubes

processing, some industrial by-products, and contaminated sediments) exhibit higher final solids concentrations than the more organic and colloidal wastes.

5.2 *Use of dewatering accelerants*

Slurry wastes and contaminated sediments consist of little intact solid matter, but are comprised of large amounts of suspended solids, colloids and (maybe) suspended organic matter. Also present can be significant quantities of inorganic and/or organic contaminants. To dewater efficiently, the geotextile tube must retain much of the solids and organic matter and control the passage of any inorganic and organic contaminants; and at the same time allow the water to pass. Further, for practical purposes, the loss of water must occur in a relatively short time period. Meeting these two conflicting requirements has lead to the common use of dewatering accelerants in the dewatering process.

Chemical flocculating agents have been used for many years in the water treatment industry to separate suspended solids, colloids and organic matter from water. These chemical agents neutralize the inter-particle charges and consequently collapse the suspended solids and organic matter. The collapse of the slurry structure also traps heavy metals and organic contaminants within the collapsed structure, and produces relatively large amounts of free water.

Flocculating agents can be used in geotextile tube dewatering to accelerate the dewatering rate and enable effective dewatering over a relatively short period of time. The chemical accelerant is introduced into, and mixed with, the waste prior to its entry into the geotextile tubes. The type of accelerant used and its dosage rate is critical to the dewatering performance of the chemical accelerant, and this is highly dependent on the type of waste being treated.

Water-soluble organic polymers known as polyelectrolytes are very effective chemical dewatering accelerants. They usually have ion exchange sites, which gives the molecule an ionic charge. Those with a positive charge are cationic; those with a negative charge are anionic; others that are neutral are non-ionic. These molecules react with colloidal material in the slurry by neutralizing the charge and bridging individual particles to form flocs.

Cationic polyelectrolytes are either polyamines or acrylamides and are generally most effective at higher pH. Anionic polyelectrolytes are acrylates and are most effective at lower pH. Non-ionic polyelectrolytes are typically polyacrylamides. By tailoring structures and molecular weights it is possible to design a polymer dewatering accelerant for most coagulation and flocculation problems.

The chemical dewatering accelerant that works best in any system can be determined only through experimental screening by small-scale filtering or hanging bag tests or geotextile tube dewatering tests. Waste streams are highly variable, not only across different waste streams, but also within specific waste groups. Chemical accelerant addition is highly specific not only from the type of accelerant used but also its dosage rate. Consequently, the only way of arriving at an optimal specific waste/chemical accelerant combination is by way of small-scale filtration testing.

An important secondary consideration in the use of chemical dewatering accelerants concerns the ability of the treated waste to trap and contain contaminants within the geotextile tube and not allow them to pass out with the effluent water. This has major implications when considering effluent quality. Examples exist of the ability of appropriate chemical dewatering accelerants to contain heavy metals, e.g. mercury, lead, zinc, cadmium and arsenic, and non-soluble organic compounds, e.g. polychlorinated biphenyls (PCB's), polycyclic aromatic hydrocarbons (PAH's), pesticides and dioxins. The ability of the accelerant to enable these heavy metals and non-soluble compounds to be trapped depends on how the accelerant reacts with the waste stream overall. If the accelerant can collapse the waste stream structure effectively then high percentages of these contaminants can be contained within the geotextile tube.

5.3 *Filling heights, and tensions generated in geotextile tubes during dewatering*

The design of geotextile tube dewatering units involves a two stage procedure. First, the units have to be designed hydraulically to enable them to handle the volume of slurry present. Second, the units have to be designed structurally to ensure there is no tube failure during operation.

The structural design of dewatering tubes entails assessing the tensions generated in the geotextile tubes during the filling and dewatering stages. The tensions generated in geotextile tubes for dewatering are similar to those for hydraulic and marine applications, section 2.3. During filling, tensions are generated in three locations in the tube units - around the circumference of the tubes, along the length of the tubes, and at the connection of the filling ports with the tubes.

Figure 9 shows the generation of maximum circumferential tension in the geotextile tube during filling. As the ratio of filling height to tube diameter (H_T/D_T) increases the magnitude of maximum circumferential tension increases. Also, larger diameter tubes generate larger circumferential tensions. For practical purposes the maximum filling height should be around $H_T/D_T = 0.6$. Design checks should be made to ensure the geotextile tubes can withstand the resulting tensions generated in the circumferential and longitudinal directions.

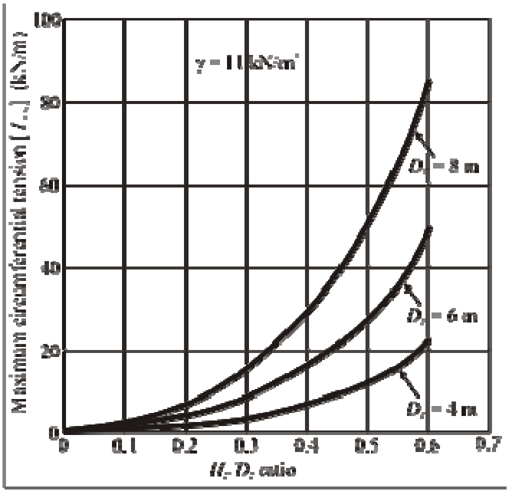


Figure 9. Maximum circumferential tensions in geotextile dewatering tubes (Lawson 2008, 2006)

The magnitude of the port connection tensions can be significant especially if the dewatering tubes are filled to maximum filling heights. To prevent rupture at the ports, and to enable greater filling heights, special polymeric port connections have been developed to resist the high stresses in these locations.

To maximise dewatering capacity it is important for the geotextile tubes to be filled to a maximum safe height in order to maximise the volume throughput. Safety is important here in order to ensure the tubes do not rupture and discharge the waste in an uncontrolled manner. Good control over pumping during the filling stages is very important to ensure the tubes are not overstressed.

5.4 *Dewatering contaminated sediments using geotextile tubes, Porto Marghera, Veneto Region, Italy*

This project has been reported on recently by Lawson (2008), and is reproduced here to demonstrate the effective use of geotextile tube dewatering.

Porto Marghera is one of the most important industrial and commercial ports in Italy, and is located on the Western side of the Venetian lagoon, near the City of Venice, in North East Italy, fig. 10a. The port began to be developed in the early twentieth century, and many chemical and petrochemical industries were established here between the 1950's and the 1980's. As a consequence of this heavy industrial development high levels of heavy metals, e.g. mercury, cadmium, lead, arsenic and caesium, and non-soluble organic compounds, e.g. PAH's, HCB's, PCB's, PCDD's and PCDF's, are found in the ground and sediments of the area. The highest concentrations of these contaminants occur in the

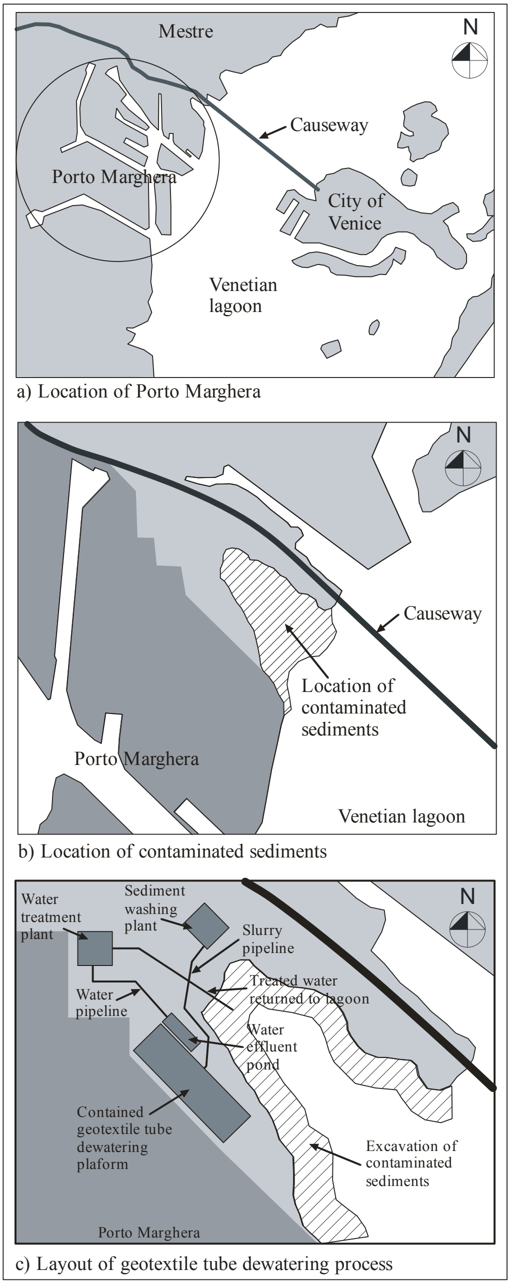


Figure 10. Details of geotextile tube dewatering site at Porto Marghera (Lawson, 2008)

sediments within the Porto Marghera area itself, and in its immediate vicinity, while within the Venetian lagoon in general lower concentrations are observed. These levels of contamination have made Porto Marghera one of the most polluted sites in Europe.

a) Removal of contaminated sediments

b) Separation of clean aggregates at washing plant

c) Maintaining contaminated fines in suspension before pumping to geotextile tubes

d) Geomembrane-lined drainage basin

e) Geotextile tubes dewatering contaminated sediments

f) Water effluent containment pond prior to transfer to water treatment plant

Figure 11. Various stages of the dewatering process at Porto Marghera (Lawson, 2008)

As part of the ongoing remedial works at Porto Marghera, the area immediately to the North of the port, and adjacent to the Venice causeway, was to undergo remediation and development. This location, known as “Pili”, consists of a low-lying, tidal inlet area, which had become a site for the dumping of industrial waste from Porto Marghera, and over time had become polluted with rainfall run-off and seepage through these waste deposits. The whole site covers an area of around 52 ha with industrial waste deposits approximating 800,000 m^3. Contaminants present include heavy metals (cadmium, mercury), organic compounds (benzo-pirene, PCB’s) and radio-active substances (radon 222). These contaminants were being leached from the industrial waste deposits into the sediments of the tidal inlet, and then on into the Venetian lagoon, contaminating benthic and bird life. Part of the Pili remediation involved the removal of 80,000 m^3 of contaminated sediments from a 50 m wide strip around the edge of the tidal inlet, fig. 10b. Following removal, these sediments were dewatered, and then disposed of in a local landfill.

The layout of the contaminated sediment dewatering process is shown in fig. 10c. Here, the excavated sediments are transported to the washing plant, where the aggregates are separated out, and the resulting slurry is pumped by pipeline the geotextile tube dewatering area. Before entering the geotextile tubes the slurry is dosed with a chemical dewatering accelerant. The geotextile tubes dewater the slurry, with the effluent water draining to an effluent pond adjacent to the dewatering platform. The effluent water then passes to a water treatment plant for further treatment, and then is returned to the Venetian lagoon. The dewatered solids in the geotextile tubes will be removed and disposed of in a landfill.

The contaminated sediment was excavated and transported by truck to the sediment washing plant, fig. 11a. Excavation proceeded at a rate of approximately 400 m^3/day. At the washing plant the contaminated sediment was washed, with the cleaned aggregate fraction separated out for alternative use, fig. 11b. The remaining fines slurry was maintained in suspension by agitation in a holding tank (fig. 11c) until it could be pumped through a pipeline to the geotextile tube dewatering area at a rate of around 1,200 m^3/day.

The geotextile tube drainage platform consisted of a compacted clay containment area, with a HDPE geomembrane liner on top, fig. 11d. In the base of this containment area a 300 mm thick gravel drainage blanket was placed to enable the effluent water from the tubes to travel to side-drains where it was then piped to an external water containment pond, fig. 11f. Before entering the geotextile tubes the contaminated slurry was dosed with a chemical dewatering accelerant. The geotextile tubes were filled with the slurry and allowed to dewater over a number of cycles, fig. 11e. Around 7,200 linear metres of 5.8 m theoretical diameter tubes were used for the dewatering project. Once the tubes had dewatered, they were cut open, and the contained waste was transported and disposed of in a nearby landfill site.

The effluent water from the dewatering process was captured in an effluent pond adjacent to the drainage platform, fig. 11f. From here, the water was pumped to a water treatment plant located on site for further treatment. Following this, the treated water was returned to the Venetian lagoon.

6 CONCLUSIONS

Geotextile containment presents very interesting possibilities in the fields of hydraulic and environmental engineering.

Geotextile tubes, containers and bags provide “soft” mass-gravity solutions for hydraulic and marine engineering applications. They enable the use of sand fill to be used in erosion resistant, mass gravity units. The various geotextile containment units available can be adapted to suit a wide range of geometrical situations.

Geotextile tubes and bags provide an ideal medium for the dewatering of slurry waste. Their large surface contact area, engineered hydraulic properties, and tensile strengths make them a low cost solution for many dewatering problems. Further, the ability to scale the sizes and numbers of tubes enables them to be used for most dewatering projects.

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