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Construction of underwater dykes using geotextile containment systems

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ABSTRACT: Rock is the conventional building block for construction of underwater dykes. Recently, geotextiles have been used to contain soils to form units that replace rock as the building blocks of hydraulic structures. Such systems, which include geobags, geomattresses, geotubes and geocontainers, can be economical alternatives to rock. The economics further improve when marine excavations within project sites are used as infill material. Design may be divided into two parts, i.e. internal stability and external stability. Internal stability design involves ensuring each unit remains intact over the design life e.g. the geotextile and seams are strong enough to prevent rupture and soil loss through geotextile is limited. The external stability design concerns the response of the units to external influences e.g. ability to withstand impacting hydrodynamic forces, geotechnical forces, etc. The application of geotextile containment systems to construct underwater dykes is discussed. Two recent projects in Asia are presented.

1 INTRODUCTION

Dykes are hydraulic structures used typically for flood protection, land reclamation, shoreline profile management, etc. A conventional dyke structure usually consists of a core (constructed of soil or rock fill) and an outer armour protection layer to resist wave and current attacks. The scope for using soil as core fill material is significantly limited for portions of dyke below water level. In areas where source of rock may not be found within practical or economical haulage alternative solutions that allow use of soil for construction below water level would be a great asset.

The use of soil filled bags to build temporary dykes in emergency situations to prevent rising waters from flooding areas has been a common practice. In the past, bag sizes tended to be small to enable man handling on site.

Recent developments in geotextile containment systems involve engineered application of geotextiles to form soil contained structural units of various shapes and sizes, in replacement of rock, to construct both temporary and permanent hydraulic structures.

2 GEOTEXTILE CONTAINMENT SYSTEMS

2.1 *Classification*

Geotextile containment systems may be classified under the form it takes (Yee et al. 1999). This includes geobag, geomattress, geotube, geocontainer, etc. Geobags, geotubes and geocontainers may be used for construction of underwater dykes.

2.2 *Geobags*

Geobags take the form of an ordinary bag. The quantity of fill per bag is relatively small and may be between 1 to $10m^3$. The bags are tailored with a filling port or end to allow filling with soil. The filling port may be closed or the end seamed after filling with soil.

If the filling is done off site, the geobags may be transported to site to be dropped or lifted into position.

Geobags can be dropped into water as easily as dropping rocks.

2.3 *Geotubes*

Geotubes are close-ended tubular formed geotextile units with regularly spaced filling ports. The filling ports allow hydraulic filling to be carried out on site. Each linear meter of geotube may contain from 1 to more than $10m^3$ of fill, depending on the size of the tube. The geotube may be tailored to any desired length but for practical purposes chosen based on site handling limitations and target to complete filling within a working shift.

Geotubes are filled at intended locations. As a result installation difficulty increases with water depth.

2.4 *Geocontainers*

A geocontainer is essentially a very large pillow shaped bag. The geocontainer is designed to contain material using a split bottom barge as filling form and dropped into water through the gradual opening of the split bottom.

The bag is tailored into a shape that resembles an envelope that will be fitted into the hopper of the barge. The envelope is then closed after filling with soil. Closure is usually done with seaming but may also include use of rope knots.

The quantity of fill in a geocontainer is governed by the size of the split bottom barge used but may be anywhere between 100 to $1,000m^3$ per geocontainer.

Geocontainers are only feasible when water depth is sufficient (typically 4 to 5m) to facilitate installation.

3 APPLICATIONS

3.1 *Geometry and function*

The choice of geobag, geotube or geocontainer as the building block to replace rock depends on economics, available equipment for installation, desired geometry of structure and site conditions. Sometimes the structure may include the use of more than one type of building block.

A dyke may function as a retaining structure, reef structure or training structure.

3.2 *Retaining dykes*

The primary function of a retaining dyke is to withhold material behind the structure. Examples include reclamation dykes, dredged material containment dykes, dykes to retain perched beaches, etc. The Naviduct project in the Netherlands used geotubes as dykes to retain dredged material (Fig 1).

Figure 1. Geotube retaining dyke at Naviduct project

3.3 *Reef dykes*

A reef structure is a submerged structure with wide crown (Hsu et al. 1999). The key goals of a reef dyke are beach enhancement and improvement in surfing conditions.

3.4 *Training dykes*

Training dykes are structures detailed to 'train' a river or coastline to result in long term beneficial responses. In many instances it may mean encouraging accretion in areas to be protected against bank or shoreline erosion. In some cases, it may mean encouraging erosion or inducing higher current velocities for beneficial engineering purposes.

The Mississippi River Red Eye Crossing training dykes constructed using geobags and geocontainers is an example (Fig 2).

Figure 2. Training dykes using geobags and geocontainers

4 DESIGN

4.1 *Concepts*

From a technical standpoint, the geotextile containment unit needs to fulfill the following:

- Internal stability
  - the geotextile used to fabricate the unit, including seams and closure, need to withstand the stresses that may be encountered during placement and filling process
  - the geotextile should prevent excessive loss of fines but be sufficiently permeable to prevent excessive build up of pressures during installation
- External stability
  - the dyke structure should be hydraulically stable against waves and currents
  - the dyke structure should be geotechnically stable
- Durability
  - the geotextile should be durable enough to perform its engineering functions over the life span of the design

4.2 *Internal stability - strength requirement of geotextile*

The geotextile containment unit may be stressed during filling, placement and impact with bottom. Geotextile overstressing during filling is rarely an issue with geobags and geocontainers but may be critical with geotubes.

The selection of geotextile for geobags is generally based on past experience.

The analysis of stresses during the filling of geotube has been studied in some detail and design software (GeoCoPS, SOFFTWIN) is available. Numerical analysis is based on the equilibrium of an encapsulating flexible shell filled with pressurized slurry.

The analysis of geotextile stresses for geocontainer installation has been discussed before (Den Adel et al. 1996, Pilarczyk 2000). The stress analysis covers different phases e.g. laying of geocontainer onto barge hopper, filling of material into geocontainer, geocontainer leaving split bottom barge, geocontainer falling through water and impact with bottom.

4.3 *Internal stability - hydraulic requirement of geotextile*

The selection of hydraulic performance properties of geotextile has been well documented. The selection is usually based on equating the apparent opening size of the geotextile and the particle size of the contained material.

Additionally, a minimum permittivity is required of the geotextile.

4.4 *External stability - hydraulic stability of dyke*

Pilarczyk et al. 1998 have discussed and proposed hydraulic stability design criteria for geotextile containment systems. Stability is rarely an issue with the bigger unit geotubes and geocontainers.

4.5 *External stability – geotechnical stability of dyke*

The dyke structure should be designed for sliding, overturning, bearing and global stability (Fig 3). Potential weakness planes along contact boundaries of geotextile containment units should also be investigated. Settlements should be within acceptable limits of design.

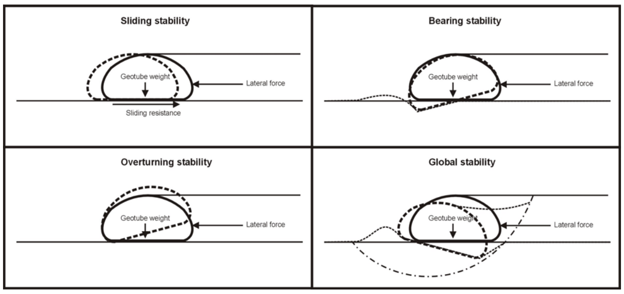

Figure 3. External stability checks

4.6 *Durability requirement of geotextile*

Most geotextiles manufactured today are generally from stable polymers or additive enhanced to satisfy durability requirements. When covered, they are anticipated to last a very long time. Geotextile containment units exposed directly to ultraviolet light, however, have a durability issue. The effect is however significantly reduced if the geotextile containment units are situated substantially or permanently underwater. Marine growth e.g. algae, barnacles, etc. further act to shield the geotextile.

If desired, the exposed areas may be covered with a protective layer that could come in the form of sacrificial geotextile, geomat, sand, riprap, etc.

5 PROJECTS

5.1 *Wack Wack Golf Course, Manila, the Philippines*

Wack Wack Golf Course, located in Metro Manila, is the oldest golf course in the Philippines. It was rather unusual but a municipal drainage channel actually runs through part of the course. At a particular location, the channel flow mingles with a lake. The water from the channel emitted a persistent foul smell and was rather unpleasant. The golf course management decided to call for proposals to solve the problem. Construction restrictions laid down by the management were as follows:

- the course must remain open during normal golfing hours
- heavy machinery will not permitted on site
- equipment and materials can only be transported using light vehicles that the buggy tracks can support
- transportation would only be allowed at night as a curfew would be imposed on movement of vehicles during normal golfing hours
- construction noise should be kept to a minimum
- temporary dewatering of the lake to facilitate construction works would not be permitted
- a green solution was desired

The winning proposal involved the construction of an underwater geotube dyke structure to separate the lake and the drainage channel. The geotube dyke acted as a mini dam to retain water in the lake when the water level in the drainage channel was subsequently lowered. This allowed rapid flush through of the municipal drainage channel to rid the area of the foul smell. The cross section of the dyke structure consisted of two bottom geotube units filled to approximately 1.5m in height (Fig 4). A wire mesh mattress and a 1m x 1m gabion were then placed centrally above the geotubes.

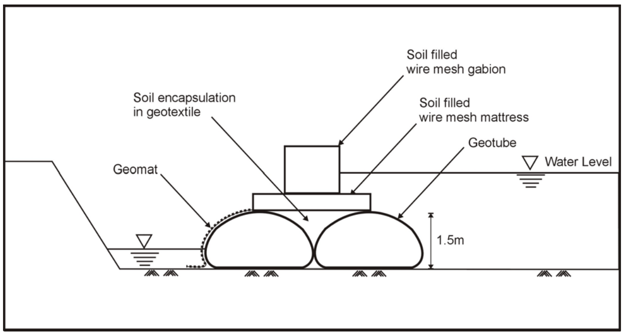

Figure 4. Cross section of geotube dyke

Fabric stresses were analysed using the SOFFTWIN programme. The circumferential and axial tensions during pumping were determined to be 37.6 kN/m and 27.2 kN/m respectively (Fig 5). The dyke structure was checked for sliding, overturning, bearing and global stabilities and found to be adequate.

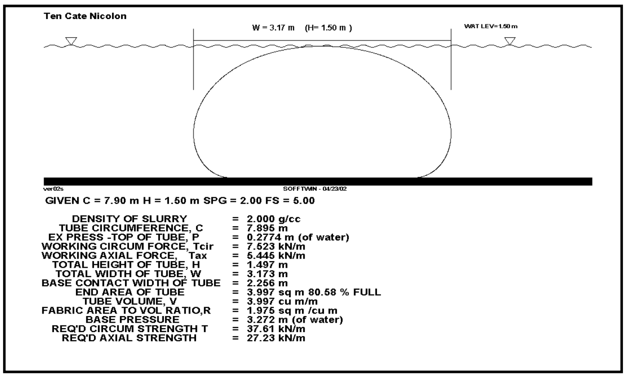

Figure 5. SOFFTWIN programme analysis output

Construction began in early 1999. The lake was man-made and had been carved out of a sandstone formation. The water depth was approximately 2m. The dyke was about 85 m long. The geotube had a diameter of 2.5m and was made using woven polypropylene geotextile with tensile strength of 80kN/m, apparent opening size of 0.425mm and permittivity of $0.26s^{-1}$. The geotube was pumped up with sand slurry to a height of about 60% of the diameter, using a submersible sand pump.

The construction sequence was as follows:

- the position of the dyke was set out
- the first geotube was floated into position
- the first geotube was pumped to the required height
- the second geotube was floated into position
- the second geotube was pumped to the required height, beside the first geotube
- the top of installed geotubes was leveled using soil filled bags
- a layer of wire mesh mattress (lined with geotextile and filled with soil) was placed on top of the leveled platform
- a unit of wire mesh gabion (lined with geotextile and filled with soil) was placed on top of the mattress
- a geomembrane was placed behind the dyke on the lake side
- the water level of the channel in front of the dyke was lowered by partially removing the concrete wall which had acted as a control weir
- a geomat was placed on top of the exposed geotube at the front of the dyke
- the exposed mattress and gabion at the front of the dyke was vegetated

The construction was completed within three months (Fig 6). The geomat was fully vegetated by natural process (without prior seeding) within two months of completion of construction. The dyke has performed satisfactorily until today.

Figure 6. Completed geotube dyke

5.2 *Southern Islands Reclamation, Singapore*

Singapore is an island country located at the southern tip of Peninsular Malaysia, approximately latitude 1.5^{O} north of the equator. With a land area of only $660km^2$, land reclamation from the sea is being constantly carried out to meet current and future development demands.

The Southern Islands reclamation project involved linking four islands through reclamation of 34 hectares of land from the sea. Spoils from excavations to prepare foundation for dykes and revetments were taken to an underwater dumping ground near Pulau Tekong, located off the eastern tip of Singapore. A $420,000m^3$ capacity dumping ground was required.

As the dumping ground is located underwater, sand dykes instead of rock dykes were the conventional retaining structures. Underwater rock structures would pose a far greater risk to passing boats and ships. Compared with the conventional sand dyke that was typically constructed to side slopes of 1:8, the geocontainer alternative solution proposed by the contractor had several important advantages (Wei et al. 2001):

- geocontainers could be filled with material as they are being excavated at project site
- sand dykes are subject to erosion and run the risk of breaching while geocontainer dyke integrity is assured
- unlike sand dykes, geocontainer dykes can be constructed relatively accurately regardless of weather conditions, current velocities, tides and water depths
- geocontainer dykes could be constructed to steeper side slopes, thereby increasing dumping ground capacity

As the geocontainer alternative solution resulted in relatively steeper side slopes, the length of the geocontainer dyke could be shorter than the conventional sand dyke without sacrificing on capacity of the dumping ground. The alternative layout was a 1.6km long, roughly U-shaped retaining geocontainer dyke (Fig 7). The bottom line was savings in both time and cost.

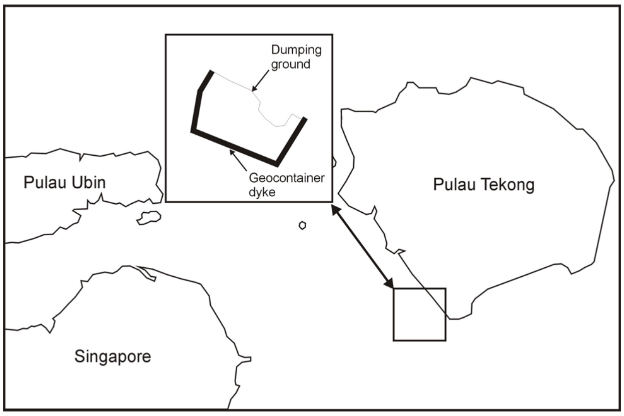

Figure 7. Layout of geocontainer dyke

At the peak of installation, two basically identical split bottom barges were employed. The barge hopper length was 34 m while the width was 7.6m. The depth of the vertical and sloping faces were 2.78m and 2.19m respectively. The radius of rotation was 4.8m while the maximum hopper split opening width was 2.8m. The hold capacity of the hopper was about 1,000m^3. The geocontainer was made up using woven polypropylene geotextile with ultimate tensile strength of 120kN/m in both warp and weft directions, apparent opening size of 0.2mm and permittivity of 0.4s^{-1}. The cross section of the dyke is shown in Figure 8.

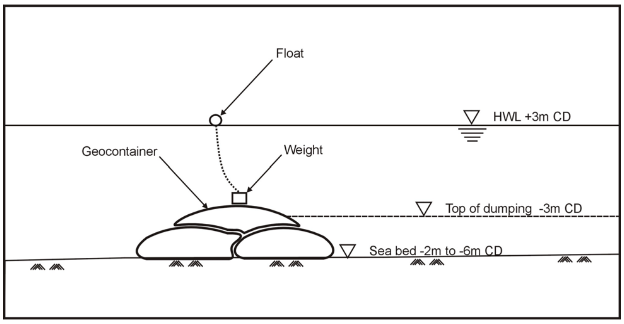

Figure 8. Cross section of geocontainer dyke

The 1.6 km dyke was formed using 108 geocontainers over a period of 85 days. This was despite initial teething problems at site and that the barges had to shuttle 4 to 5 hours each way between project site and dumping ground.

The intended fill for the geocontainer was selective excavated material. It became apparent from the start of works that it would not be practical to be selective on the fill. What was excavated for the day was used instead. The variety of material excavated included marine clay, residual soils, weathered rock and boulders. The first geocontainer was put to severe test when the excavated material of the day consisted of sharp edged boulders ranging up to 0.5 m in diameter (Figure 9). During an extreme low tide event one geocontainer remained stuck in the split bottom barge. The barge had to wait for the tide to rise sufficiently before the geocontainer could exit the barge completely.

Figure 9. Geocontainer filled with sharp edged boulders

6 DISCUSSIONS

The development and application of geotextile containment systems for underwater dyke construction is relatively recent. More research is required to better understand the mechanics involved in the installation processes. Currently, there is no analytical method that can reasonably predict the stresses in the geotextile during impact with bottom. Factors that may determine induced geotextile stresses at impact include geotextile used, depth of fall through water, fill material and foundation type. When a geotextile containment unit is released, potential energy is gradually converted to kinetic energy. At impact, kinetic energy dissipation occurs until the unit comes to rest (Den Adel, 1996). The energy dissipation is expensed by work done in deforming the foundation, in remoulding of contained material, in straining of geotextile and in expelling of excess pore pressures through the geotextile. How the geotextile stiffness and permeability affect the stressing need to be understood more clearly. .

Issues remain concerning stresses from unusual loads on exposed units e.g. impacting debris, etc. and vandalism. Development of practical and cost effective protective covers will further widen the application scope. The protective benefits of marine growth on exposed units may be better quantified.

Despite remaining issues and skepticisms, geotextile containment systems are proving to be viable and economical alternatives to conventional underwater dyke constructions.

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