Construction and Performance of Containment Bund Using Geotextile Tubes Filled With Cement Mixed Soil in Singapore

La construction et la performance de la digue de confinement utilisant des tubes géotextiles remplis de terre mélangée au ciment à Singapour

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ABSTRACT: In a major port development project in Singapore, a containment bund using modified geotextile tubes (M-GT) filled with cement mixed soil has been constructed. The main purpose of this bund is to create a containment area to contain any sediment plumes due to construction activities (i.e. dredging activities, dumping activities and sand-filling activities). The containment bund also serves as a retaining structure to retain dredged materials during the sand-key construction and other port expansion works. This paper presents the key consideration in the innovative design and construction of a geotextile containment bund. In addition, instead of usual sand fill, the dredged soil mixed with cement was used as the fill material in this bund. Among the challenges faced in this project were the great water depth of this containment bund location (>25m) and high traffic volume in Singapore water course as the site is next to the existing operating port terminal. Extensive field instrumentation and monitoring were carried out during and post construction phase to verify the design, as well as ascertain the performance of the geotextiles containment bund system.

RÉSUMÉ : Dans un important projet de développement portuaire à Singapour, une digue de confinement utilisant des tubes géotextiles modifiés (M-GT) et remplis de terre mélangée au ciment, a été construite. Le but principal de cette digue est de créer une zone de confinement afin de contenir les déblais de sédiments provenant des travaux de construction (c'est-à-dire travaux de dragage, de déversement et de remplissage au sable). La digue de confinement sert également de structure de retenue pour retenir les matériaux de dragage lors de la construction de la tranchée d'étanchéité et d'autres travaux d'extension de port. Cette étude présente le facteur clé dans la conception innovatrice et la construction d'une digue de confinement en géotextiles. En outre, au lieu du remplissage au sable habituel, le sol dragué est mélangé avec du ciment avant d'être utilisé comme matière de remplissage dans cette digue. Parmi les défis relevés durant ce projet étaient la grande profondeur des eaux à l'emplacement de la digue de confinement (> 25m) et le volume du trafic maritime dans les eaux de Singapour vue que le site se trouve à proximité du terminal portuaire existant. Des instrumentations et mesures approfondies ont été menées pendant et après la phase de construction pour vérifier la conception, de même que la performance du système de digue de confinement en géotextiles.

KEYWORDS: Geotextile tubes, containment bund, cement mixed soil.

1 INTRODUCTION

A containment bund consisting of modified geotextile tubes (M-GT) filled with cement mixed soil has been constructed for a major port development project in Singapore. This containment bund forms part of the Pasir Panjang Terminal Phase 3 & 4 Expansion Project, which is located at the Southern part of Singapore water (Figure 1). During the project construction phase, this bund serves as a retaining structure to retain dredged materials and at the same time contains any sediment plumes arises from construction activities from being transported towards the nearby forest reserve area by currents. This containment bund, termed as a geotextile containment bund, is being constructed by systematically stacking of modified geotextile tubes (M-GT) and filling of cement mixed dredged soil. A typical cross section of the geotextile containment bund is shown in Figure 2.

A "geotextile tube" is a tubular container (diameter 1m to 10m) that is formed in-situ, on land or in water, by hydraulically filling the tube with sand or dredged material (Pilarcyzk, 2000) and Lawson, 2006). On the other hand, "geotextile container" is made of geotextile sheet laid onto a split-bottom barge, filled mechanically with sand or other fill material, and sewn the top opening to form into a closed "container". The barge will then move to the desired position, and the bottom of the barge will open allowing the containers to sink into the sea at the intended location. The volume of these containers can range from 100m^3 to 800m^3.

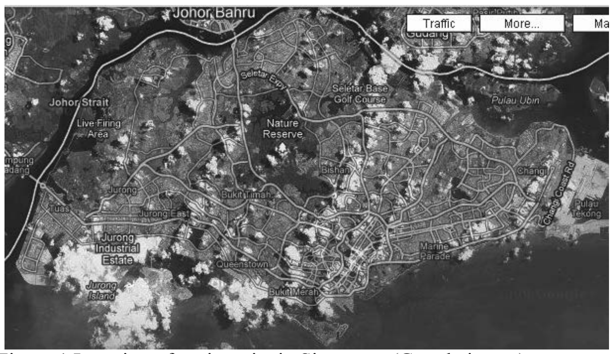

Figure 1 Location of project site in Singapore (Google image)

The modified geotextile tube (M-GT) introduced in this paper is an innovative application, which combines the structure / shape of a "geotextile tube" and the method of installation of a "geotextile container". The diameter of M-GT is 5m and the length is 25m (limited by barge length). The theoretical maximum volume of M-GT is 490m3. However, for practical reasons, the filled volume is only about 290m3 or 60% filled in this project.

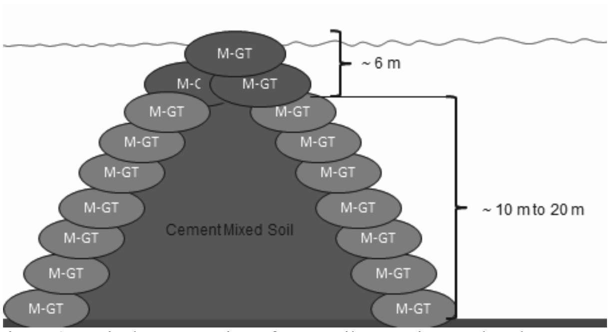

Figure 2 Typical cross section of geotextile containment bund

Two geotextile containment bunds were constructed in this project. The length of bund 1 is 500 m and bund 2 is 1800 m. Bund 1 was constructed first in order to provide a staging ground for other construction activities at the site. The layout and length of the bunds are shown in Figure 3.

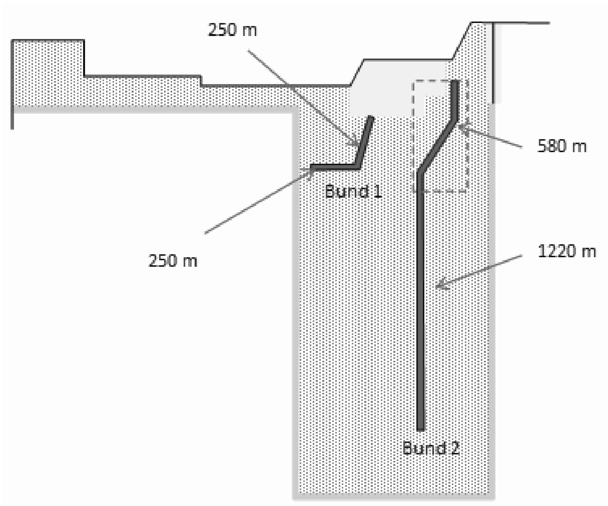

Figure 3 Length of geotextile containment bund 1 and 2 (Plan view)

2 DESIGN AND CONSTRUCTION OF GEOTEXTILE CONTAINMENT BUND

In the design of this bund, there are a few stability criteria that have to be fulfilled: Stability against hydraulic force of waves and current, local stability against sliding failure, local stability against slip failure, settlement and deformation. The tensile strength of the geotextile material is one of the major design parameters. This is because the installation of the tubes at water depth of 25m is deemed to be 'extreme' in the field installation of geotextile tubes and containers.

The installation process of the M-GT consists of five (5) main phases, namely:-

1) Filling of the M-GT − The dredged material mixed with cement, known as cement mixed soil, is being pumped into the modified geotextile tube via the inlet ports that are available at the top face of the M-GTs.

2) Opening of split-hopper barge − the bottom of the split-hopper barge opens slowly to allow the exit of the filled M-GTs through its opening. High tension in geotextile is expected to be experienced at this stage.

3) Free-falling of M-GTs onto the seabed − Air pockets inside the tube or container during free-falling would exert certain forces onto the geotextile and cause higher strain (Pilarcyzk 2000). Tensions are generated in the tube due to the balancing of these forces, fill weight, buoyancy, drag, etc. (Lawson, 2006).

4) Impacting onto the seabed − At the point of impact, the kinetic energy of the falling tube is converted to elastic energy, which will reshape the tube, from a cone shape into a transitional cylindrical shape and eventually into a semi-oval shape or rectangular shape (Pilarcyzk, 2000).

5) Stabilized phase of the M-GTs − The final shape of the tube attained depends on a number of interrelated factors such as the volume of fill, internal shear resistance of the fill material and the stiffness of the geotextile material (Lawson, 2006).

There are a number of equations and formulas available for the determination of the tension development in some of the stages mentioned above. The equations used in the design of M-GT in this project can be found in Chew et al. (2010).

The construction sequence of the bund is illustrated in five steps (Figure 4(a) to (e)).

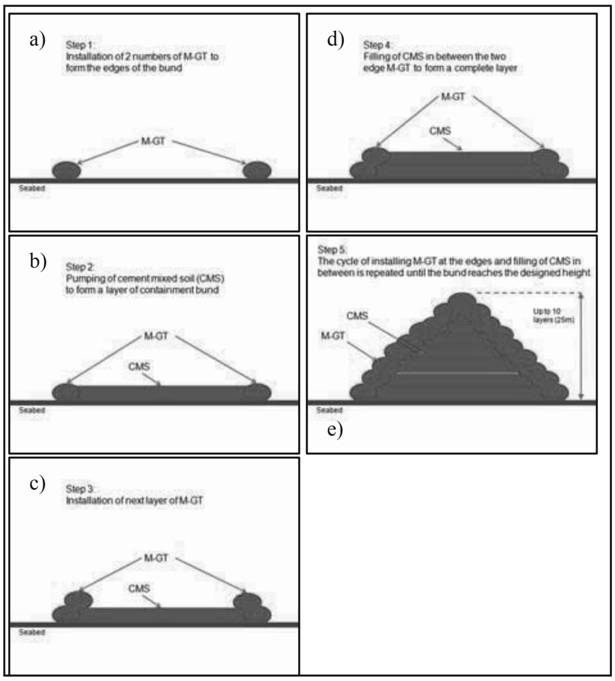

Figure 4 (a) to (e) Construction sequence of geotextile containment bund (cross-section view)

3 USE OF CEMENT MIXED SOIL (CMS) AS IN-FILL MATERIAL

Discarded soil from other excavation projects on land or sea in Singapore, and dredged materials from port extension works have been mixed with cement to form into Cement Mixed Soil (CMS), and was used as in-fill material in the M-GTs and as the core of the geotextile containment bund as shown in Figure 2. In order to satisfy the stability criteria of the geotextile containment bund, the cement mixed soil has to achieve a design value of unconfined compressive strength q_u of 200kN/m^2. After taking into account of soil variability and the factor between the laboratory test result and in-situ achieved results, the targeted in-situ unconfined compressive strength is state as 1.3x200, which is 260kN/m^2.

4 PERFORMANCE OF CONTAINMENT BUND

The performance of the bund has been monitored during and after the construction through an extensive instrumentation plan.

A total of 28 numbers of M-GTs were instrumented and monitoring at various stages of the installation process. One of the key parameters was that monitored closely is the strain development of the M-GT at different stages. The results of the monitoring during the installation process were presented by Chew et al. (2011) and it showed that high tensile forces of about 180kN/m were recorded at the bottom of M-GT during the impact onto the seabed.

Hydrographic survey was used to monitor the shape of the installed M-GTs, which is one of the performance indicators of this design. The accuracy of the installation was determined by using survey results conducted before and after the dumping of the instrumented M-GTs. The overall construction progress of the bund was also tracked using hydrographic surveys that were conducted every 5 days. The profile of the bund can be plotted using the survey results as shown in Figure 5, which shows one of the completed bund.

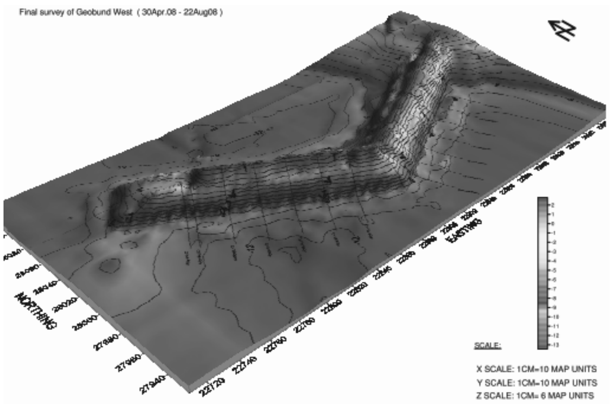

Figure 5 Profile of completed bund 1

After the completion of the bund, a total of 11 instrument clusters have been installed to monitor the performance of the containment bund during other construction activities such as the filling of dredged soil behind the containment bund and soil improvement works for the dumped material within the containment bund.

Out of the 11 instrumented clusters, 6 of them were placed at the top of the bund and the remaining was installed to monitor the slope of the bund by using a staging. The cross section of the instrument clusters is given in Figure 6.

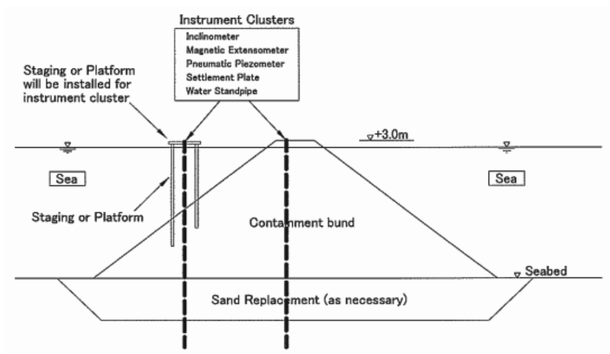

Figure 6 Instrumentation cluster installed in the containment bund

The results from the inclinometers installed at the top and side faces of the bund are discussed here. The location of the inclinometer is at CH. 1370 (Figure 7). The lateral deformation in the section perpendicular to the centre line of the bund is plotted in Figure 8 for both top and side inclinometer.

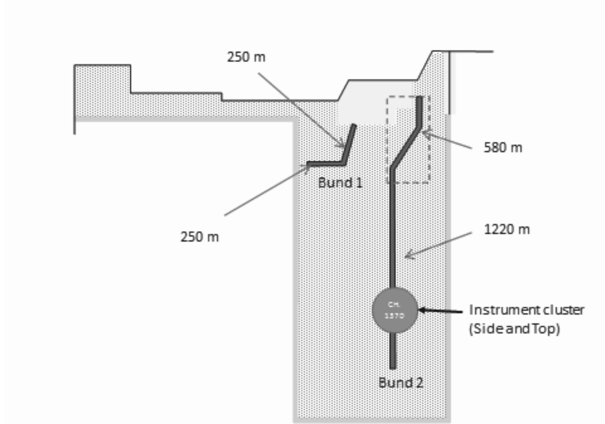

Figure 7 Location of inclinometers at CH. 1370 of the bund (Plan view)

The inclinometer readings show that the maximum deformation of the bund centre is 10mm at elevation of -8.5m (Figure 8a). The measurement was taken at 911 days after the completion of the bund at that location. This shows that the containment bund has remained stable throughout the period of other construction activities that occurred during this period.

Figure 8b shows the lateral deformation at the sides of the bund, which was also found to be within 10mm, where the maximum deflection occurred close to the bottom of the bund. Higher lateral deformation of up to 30mm was also recorded by the inclinometer at elevation above the bund (i.e. -5m to +10m). The lateral movement above the surface of the bund (side inclinometer) indicates that the dredged filled material has been placed onto the sides of the bund and at the same time being treated.

The settlement measured by extensometers installed on the top and side instrumentation clusters and settlement plates at the top of the bund are given in Table 1. The settlement readings showed that the geotextile containment bund filled with cement mixed soil has remained stable and performed as expected throughout the construction period of this project.

Table 1 Settlement of containment bund

	Settlement (mm)		
Elevation	Extensometer (Center)	Extensometer (Side)	Settlement plate
Top	---	---	11
-3.0 CD	24	---	---
-6.0 CD	26	40	---
-9.0 CD	25	29	---
-12.0 CD	17	23	---
-15.0 CD	18	8	---

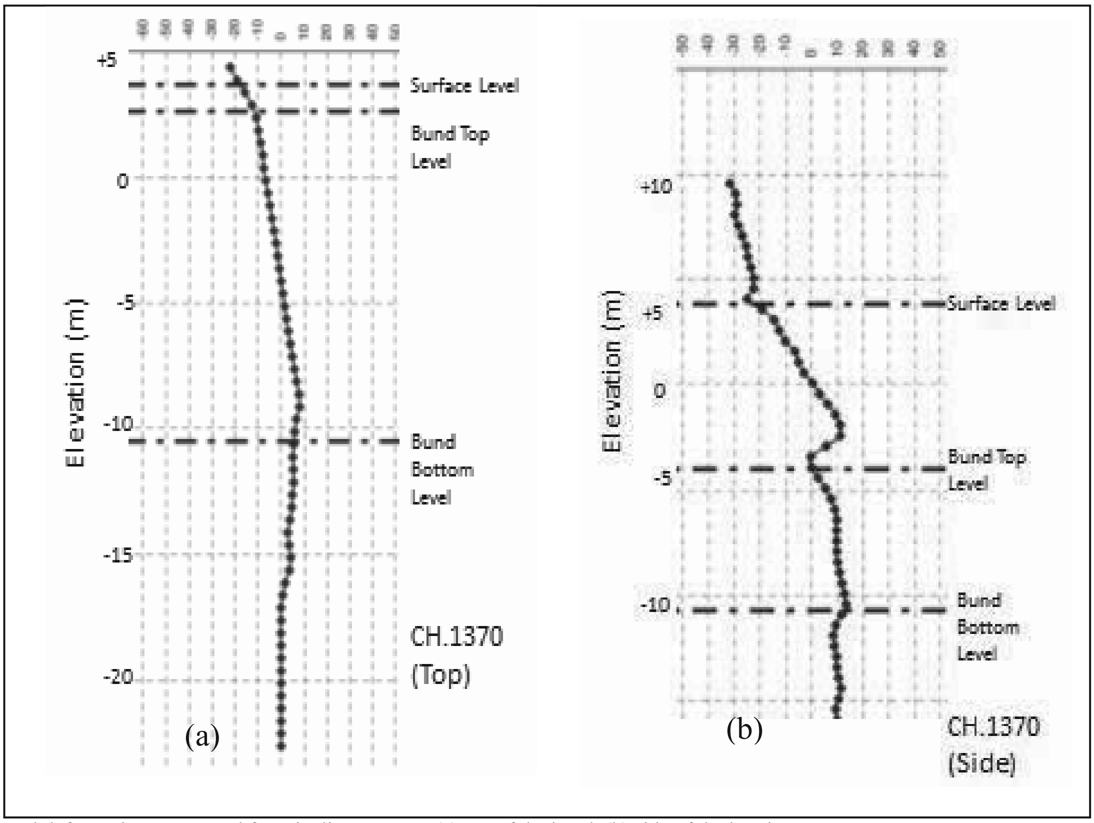

Figure 8 Lateral deformations measured from inclinometer at: (a) top of the bund. (b) side of the bund

5 CONCLUSION

The construction of the geotextile containment bund using modified geotextile tubes (M-GT) filled with cement mixed soil (CMS) has been completed successfully over a total length of 2.3 kilometres in Singapore. Field measurements of lateral deformations and settlements showed that the bund has performed well within the design limits and expectations. The innovative use of discarded soil from other excavation projects on land or sea via mixing with cement is proven to be a good fill material. This CMS material was shown to be able to achieve highly uniform and well controlled properties, and deemed to be suitable as in-fill material for geotextile tubes and the core portion of a containment bund.

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