An Underwater Geogrid Reinforced Slope in Singapore

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ABSTRACT:

Geogrids have been used in hundreds of reinforced slopes and wall projects in the world. The Keppel-Sentosa Road Link project in Singapore was the first time where geogrids were used to build a 11m high reinforced slope totally situated under the sea level. The slope, built with gravel and stones reinforced with HDPE mono-oriented geogrids, was aimed to provide easy access to water level in case of any need. To serve such a need effectively, the slope had to be rather steep. Therefore it was decided to reinforce the slope with HDPE geogrids, which are resistant to the aggressive environment of the sea. The paper describes the design principles used for this challenging project and the construction method, which involved the co-ordinated work of the contractor and of many scuba divers.

1. THE PROBLEM

The isle of Sentosa is one of the main tourist attractions in Singapore, featuring sand beaches, aquarium and a naturalistic museum among other things of interest. In June 1990, Sembawang-Obayashi-Toyo joint venture was awarded the prestigious contract to construct the road-link from Mainland Singapore to Pulau Brani and Sentosa Island by a combination of a 330m long Causeway and a 380m long Arch Bridge. The project was successfully completed in November 1992.

A granite platform had to be constructed at the western corner where the Causeway takes off from the former Keppel Wharf (**Fig 1**). It was slated to enhance the cosy-looking Causeway and mold into the ambiance of the newly completed Port of Singapore Authority Promenade fronting the Keppel Channel. The viewing platform at ground level is about 15m above the seabed level and 5m above the mean sea water level. Looking from the seabed, the rubble mound would appear as a mini-pyramid.

THE ALTERNATIVES

Originally, the platform was designed to have 1200 pieces of 2m x 2m x 1m concrete blocks forming its core while another 2000m^3 of crushed granite and armour stones had to be placed on the stacked blocks to make up the final shape.

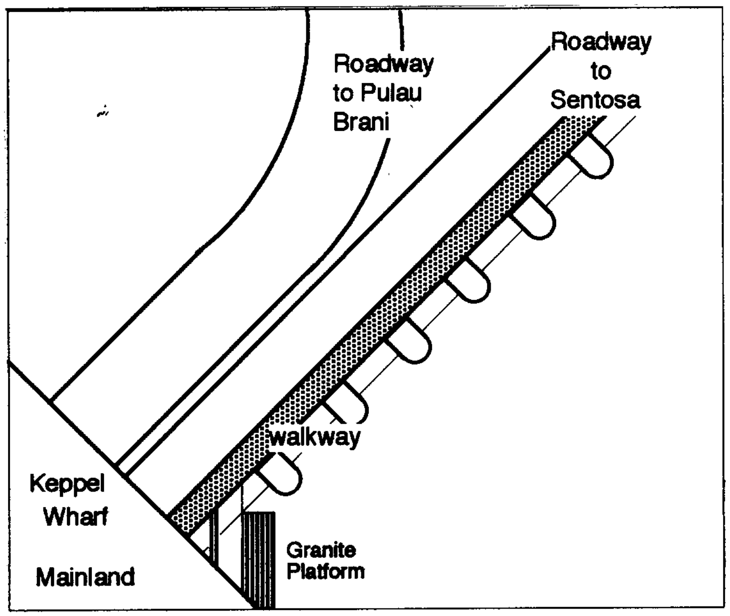

Fig.1 - Location of the Granite Platform

It was however anticipated, during the planning stage, that it was going to be a mammoth task to handle and place such a huge number of 10 ton giant blocks under

12m of water, given the limited time and with only space equivalent to two badminton courts for storage and handling. In addition, the cost of fabricating, delivering, storing and installing the concrete blocks was very expensive.

Gabions were considered not suitable because they are sensitive to corrosion in marine environment and moreover they would get easily deformed when lifted after stone filling. HDPE Gabions, on the other hand cannot be lifted as the plastic grid would not be strong enough to take the stress. Hence if they were used, they would have to be moved along an inclined plane, but it would then become extremely difficult and time consuming to re-position a plastic gabion if it slides into an incorrect position.

A search for a cost-effective and time efficient method was spearheaded thereon. Finally, the idea of a geogrid reinforced granite platform was mooted. As it was never anywhere used in an underwater structure before (to the authors' knowledge), a careful and in-depth study of its behavior was necessary to ensure that its intended performance and external dimensions were strictly adhered to. That is to say, the contractor was not allowed to decrease the side slope to take advantage of the angle of repose of granite stones. This was to prevent unnecessary encroachment into the adjacent wharf that serves passenger liners.

The study was carried out by Sembawang-Obayashi-Toyo Joint Venture in collaboration with RasWILL Representative Pte Ltd, the supplier of the selected geogrid (TENAX RT11030). This has led to a completely new section (Figure 2) with geogrid predominantly and strategically lining the stone mass to render the much needed shearing resistance.

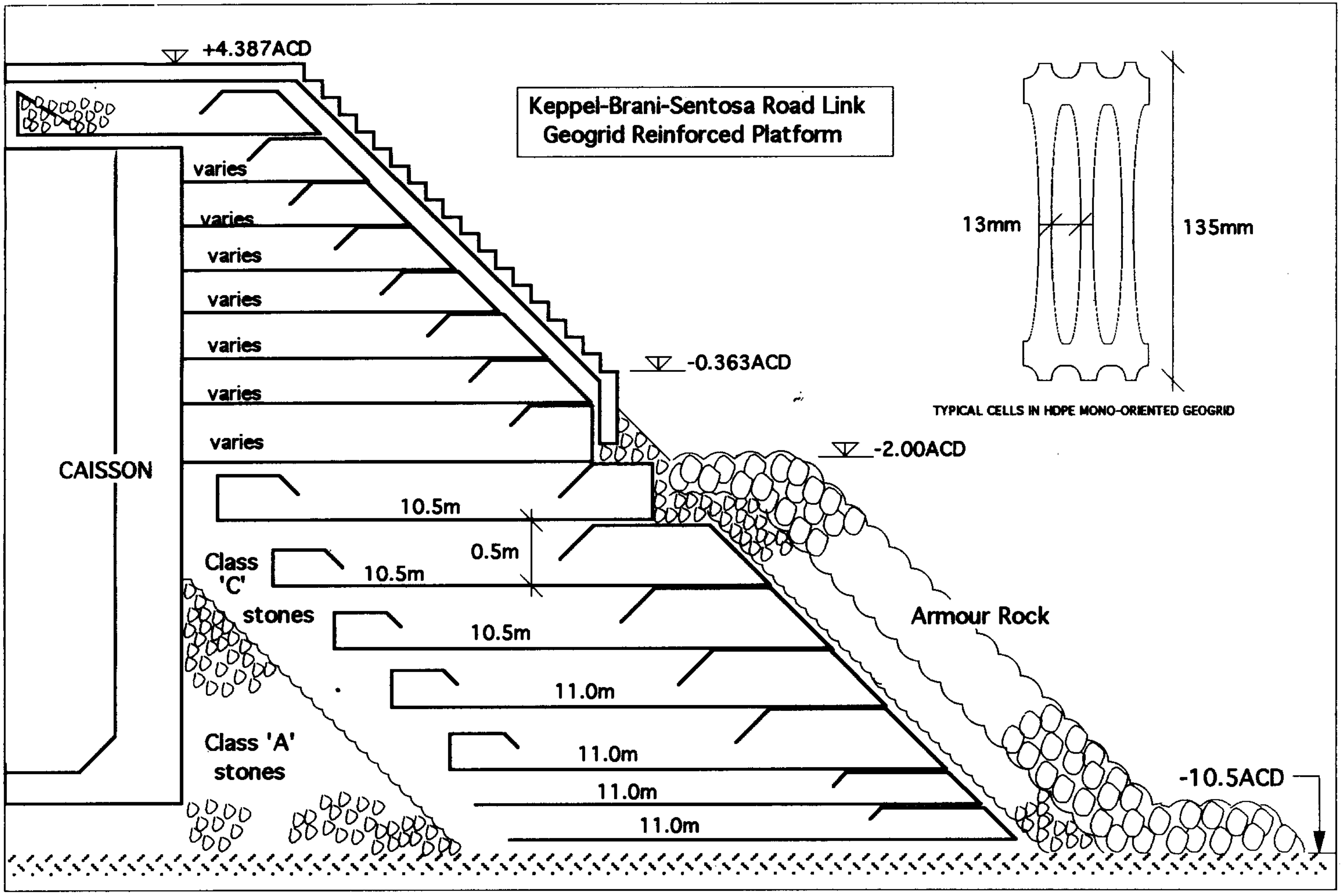

Fig. 2 - The Geogrid Reinforced Structure

2. THE GEOGRID REINFORCED STRUCTURE

Reinforced soil is a composite material, which combines the typical resistance of two different materials in such a way to minimize the weakness of each one (Jones, 1988). Particularly, a relatively large quantity of the cheapest and compression resistant material, the soil, is improved in its engineering characteristics by the combination with a relatively small quantity of a more expensive and tensile resistant material, the geogrids. The synergy between the tensile and compressive resistance of the two materials improves the global characteristics of the composite one, like with concrete and steel.

Geogrids are plastic products specially designed for earthworks: they appear like a sheet with a regular distribution of elliptical or rectangular holes, as shown inset in Fig. 2. Geogrids are made of polymers (High Density Polyethylene, Polypropylene, Polyester) and, through specific technological process, they gain a very high tensile resistance, of the order of 40~110kN/m-width (Koerner, 1986).

3. THE DESIGN

The design of the reinforced slope was carried out through a trial and error procedure. A preliminary design for the geogrids was selected based on past experience; then the reinforced slope was checked for stability with a Bishop modified method, taking into account the water level and therefore the submerged slope as well as the tensile force in the reinforcements; based on the results of the stability analysis, a second layout was selected and a new Bishop calculation was performed; and so on, until a satisfactory Factor of Safety was reached.

For the practical reason of fast installation, it was decided that the minimum vertical distance between the geogrid layers should be at least 0.8m. It was also decided to wrap the geogrids around the face of the slope and around the back end of the reinforcement soil block, to improve the anchorage of the geogrids.

The selected backfill is a coarse gravel, with a friction angle of 45 degrees from direct shear tests. The geogrid selected for this project was a HDPE Geogrid with a peak tensile strength of 110kN/m and a long term design strength (LTDS) of 42kN/m. For brevity, the complete characteristics of the geogrid used has been omitted in this paper. A partial Factor of Safety f_c for construction damages was included in the calculations, by decreasing the design strength with a factor $f_c = 1.5$:

$$T_a = LTDS/f_c = 28 \text{ kN/m}$$

where T_a is the allowable design strength of the geogrid.

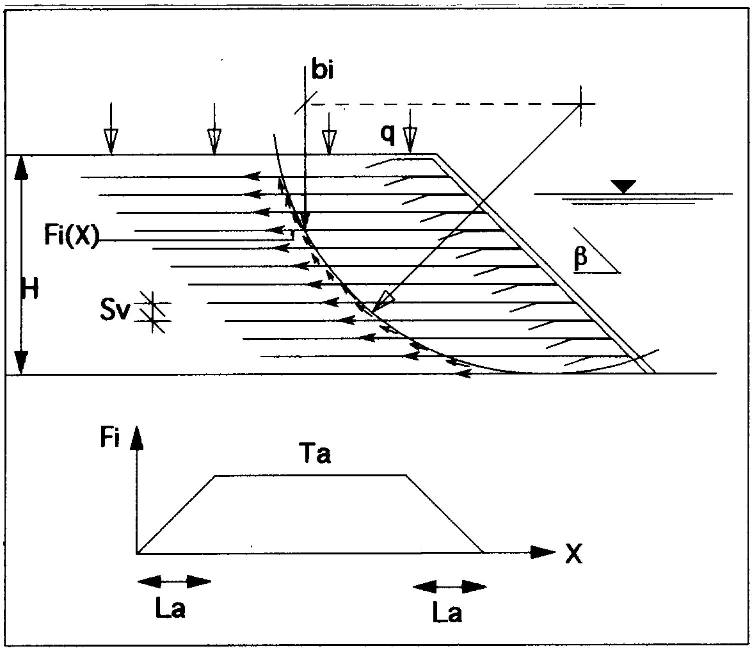

Fig. 3 - Schematic for stability analysis

With reference to Fig. 3, the Factor of Safety of the geogrid reinforced slope can be computed as:

$$FS = \frac{Ms + Mg}{Mo} = FSo + \frac{Mg}{Mo} \quad (2)$$

$$\left\{FSo = \frac{Ms}{Mo}\right\}$$

where

Ms = stabilizing moment due to soil shear resistance;

Mg = stabilizing moment due to geogrids tensile forces;

Mo = de-stabilizing moment;

FSo=Factor of Safety without geogrids.

Ms, Mo and FSo can be computed using a Bishop or Fellenius or Janbu method. The stabilizing moment due to geogrid tensile forces can be computed as:

$$Mg = \Sigma_i \{F_i(X).b_i\} \quad (3)$$

where:

$F_i(X)$ = tensile force in the "i"th geogrid layer, at the point where the failure surface intercepts the geogrid;

b_i = vertical distance between the failure circle centre and the "i"th geogrid layer (see Fig.3).

The envelope of available tensile force along each geogrid layer is assumed to be trapezoidal, as shown in Fig.3 with uniform tensile force at the medium portion equal to Ta. The anchorage length can be assumed to be in the range of 0.5 - 1.0m for the actual geogrids.

4. CONSTRUCTION METHOD

The construction work was started in early November 1991. A 70 ton crane barge equipped with $2m^3$ grab bucket was mobilized to place the different types of stone forming the platform and the geogrid layers. The amount of stone for each geogrid layer ranges from $80m^3$ - $400\ m^3$. Other parts (outside geogrid reinforcement) of the mass-placed stone accounted for about $1770m^3$. The average rate of placing was $150m^3$ - $200m^3$ per day.

Initially, the geogrid for all the layers were pre-assembled in mats on site and marked for identification purpose. The geogrids were supplied in 1m wide by 30m long rolls. In general, they were overlapped by 2 apertures and tied with HDPE rope into 5.5m wide pieces of different length. This greatly facilitated underwater handling. A schedule of sizes and location were made for every layer for ease of fabrication, storage, retrieval and later installation.

Every 1.0m, a knot was made along the rope; in this way if the rope breaks, during installation, it can unwire for only 1.0m, thus allowing the geogrids to remain connected even under such circumstances. Six rows of geogrids are connected into one mat, producing mats of about 15m(length) x 5.5m(width). Then each mat was rolled around a steel tube, 6m long and 100mm in diameter.

A group of 6 professional divers were hired to handle the following underwater works:

(i) help the surveyor to fix the line and level of each layer of stone;
(ii) manually level each layer of stone bed;
(iii) wrap around the geogrids left protruded from the last stone bed and pin them onto the newly built stone bed;
(iv) lay and tie up 5m wide mats of geogrids on the new stone bed; temporarily pin them onto the bed with steel hooks.

In addition to the routine stone placing work, the crane barge had also acted as a diving base for the divers. Apart from occasional berthing and unberthing of passenger liners at the adjacent wharf, the water was good and safe for diving work. Therefore, the divers were able to lay up to $570m^2$ of geogrids in a good day.

The location and level of each layer were controlled by a land surveyor and two chainmen. Basically, the open edge of each new layer was demarcated by sinkers dropped from a tensioned rope fixed at ground level. The level of that stone layer was then checked and measured by a long-staff method. While it is important that each stone layer was not over-placed with stone, an undulation of up to 6" was considered acceptable as it was deemed to enhance the anchorage effect of the geogrids.

5. RESULTS

The special application of geogrids to this project had made possible the following:

- The basic stone structure was completed in February 1992; much faster than the expected time under the original concrete block design. Twelve months after, the RC stairs and slab were built over it; no visible settlements or movement have been noticed.
- The construction of the submerged slope was completed in 2 months; faster than any other solution.
- The structure has demonstrated to have a very good resistance to the wave action of the sea: in fact when the water recedes back after a wave has beaten the slope, the gravel normally tends to move outward; but in this case the geogrid is put into tension, thus stopping any wash-off of the gravel.

6. CONCLUSION

Geogrids have proved to be an excellent engineering tool, this time underwater. It is hoped that the construction method described in this paper would help designers and builders to explore the use of geogrid in new frontiers such as an underwater environment, where construction difficulties with other methods are foreseen.

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