DESIGN AND CONSTRUCTION OF HIGH STRENGTH COMPOSITE GEOTEXTILE REINFORCED ROAD FOR THE TRANSPORTATION OF A SUBMARINE IN MALAYSIA

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ABSTRACT

The application of geosynthetics reinforcement to improve the bearing capacity and reduce differential settlement of loose or soft subgrade has increased significantly over the last decade. This paper presents a case study on the application of a high tenacity polyester composite geotextile as base reinforcement of a 1.6km access road from a temporary dock to a permanent foundation so that the transfer of a 1450 tons submarine was possible. As the ground which the road traverses comprises of 6m deep of very loose sand followed by 9m deep of very soft marine clay, the transportation of this submarine was almost impossible as the bearing pressure from the submarine and trailer exceeded the allowable bearing pressure of the soil. An innovative and cost effective solution which involved the replacement of 1.5m depth of the existing soil with well compacted granular material reinforced with 2 layers of high strength composite geotextile were employed. The design methodology, the construction sequence and the performance of this geotextile reinforced access road is discussed in this paper

Keywords: Base reinforcement, high strength composite geotextile, differential settlement, bearing capacity

INTRODUCTION

Due to the scarcity of land available for development, reclamation at coastal area is becoming a trend worldwide. In South East Asia the underlying soils commonly take the form of peat or very soft marine clay while the filling material normally used are sand obtained from the sea. Soft marine deposits are typically nearly saturated with low shear strength while the fill material used to raise the platform above the Highest Astronomical Tide (HAT) are sometimes not sufficiently compacted.

Geosynthetics are commonly used for base reinforcement and subgrade stabilization to reduce rutting, thereby improving roadway performance. Traffic loads produce a dynamic pore pressure increase in the subgrade that grows with traffic repetitions. Development of pore pressure reduces the effective stress in the subgrade and thereby reduces the subgrade stiffness and strength. The reduction of stiffness and strength can have a dramatic impact on the performance of the roadway as expressed in terms of rutting.

This paper pertains to the use of composite geotextile as a separator and reinforcement to enhance the bearing capacity and reduce differential settlement of an access road which alignment traverses through a reclamation area that comprises very loose sand underlain by very soft clay.

The composite geosynthetics (non-woven geotextile knitted with the high tenacity polyester yarn) was used to increase the performance of the road base by acting as a separator and reinforcement which reduced rutting and increase bearing capacity of the access road.

The design analysis using empirical bearing capacity theory and finite element method of a composite geotextile reinforced road is discussed in this paper. Plate bearing test results and maintained load test performed upon completion of the access road with geotextile reinforcement are also shown. Construction sequence and precautionary measures during construction are also highlighted in this paper.

PROJECT DESCRIPTION

The project site is located on a land reclamation area in Klebang, Malacca, at the west coast of Peninsular Malaysia. As Malacca used to be one of the main sea ports in the world and is currently a popular tourist destination, a maritime museum which will exhibit several sea vessels was proposed to at this site.

One of such vessel is a decommissioned submarine which was relocated from Brest, France. It was the first time in history a submarine of this size was transferred in one piece. The norm is to cut the vessel into several sections so that it would be much easier for relocation purposes.

The total load of the submarine, its saddle and the trailer with its power pack which was estimated to weigh 1450 tons need to be transferred from the sea shore to the homing ground at the museum site.

Due to the poor ground conditions observed at site (refer Fig. 1), the initial plan by the Malacca State Government was to build a very long jetty with extensive dredging work and a short access road built on piles. Considering the short construction period of 4 months and high sedimentation rate at the area, a makeshift dock and short canal, but with a much longer road, i.e. 1570m in length, was proposed instead. However, to make this proposal viable, an innovative and cost effective solution was required so that the road could satisfy the design criteria set forth by the transporter while keeping the project costs within the stipulated budget.

Fig. 1 The top soil comprises of very loose sand which is prone to extensive rutting

It was achieved by constructing a composite geotextile reinforced road to reduce the differential settlement and at the same time to increase the bearing capacity of the ground in order to cater for the bearing load from the submarine and trailer.

HIGH STRENGTH COMPOSITE REINFORCEMENT GEOTEXTILE

The composite geotextile used is made from high tenacity polyester yarns stitched onto a non-woven geotextile backing sheet. The high tenacity yarns provide the tensile strength required for the reinforcement while the non-woven geotextile provides separation function, facilitates in-plane drainage and optimum reinforcement/soil friction interface. Due to the composite nature of the geotextile, the reinforcement composite geotextile is suitable for the reinforcement of both poor draining and granular soils. The separation function of composite geotextile prevents granular base material from penetrating and mixing into the underlying loose sand or soft marine clay resulting deterioration of the base course. As a base reinforcement, the composite geotextile is designed to accelerate the release of pore water and consolidation of saturated soils without compromising the structural stability. It will increase the bearing capacity of the subgrade and stiffen the base layer, thus reduce the rutting.

To use reinforcement composite geotextile in long term soil reinforcement application an assessment of their load carrying capabilities is required. Several assessment procedures are in practice, each adopting the use of the partial factor approach to describe the behavior of the reinforcement material over time under specific load and environment regimes. The procedures adopted for reinforcement composite geotextile is compatible with the procedures adopted by various national codes of practice such as the US Federal Highway of Administration, the British Code of Practice BS 8006: 1995 and the Australian Standard. The procedure utilizes the following partial factor approach to determine the long term design strengths for the reinforcement materials at different design life:

$$Td = \frac{Tc}{fc.fd.fe.fm} \quad (1)$$

where:

- T_d= long term design strength of the reinforcement at the required design life,
- T_c = characteristic short term tensile strength of the reinforcement,
- f_c = partial factor relating to creep effects over the required design life of the reinforcement,
- f_d = partial factor relating to the installation damage of the reinforcement,
- f_e = partial factor relating to environmental effects on the reinforcement,
- f_m = the partial factor relating to consistency of manufacture of the reinforcement.

DESIGN AND ANALYSIS

Ground Conditions

The subsoil profile used for the geotechnical analysis was derived from deep borings conducted along the alignment of the access road. The subsurface conditions consist of 6.0m thick of fill material with SPT N-value that ranges from 1 to 11 blows with an average value of 4 blows. The fill material mainly consists of very loose to loose silty sand.

Beneath this fill lies 9m thick of very soft to soft clay with SPT N-value ranging from 0 to 2 blows followed by 6.0m thick of silty sand with average SPT N-value of 11 blows.

Underlying the silty sand layer is 10.5m thick of sandy silt layer with SPT N-value which ranges from 22 to 26 blows with an average value of 25 blows. Very dense sandy silt layer with SPT N-value of more than 50 blows/0.3m is found approximately 30m below the existing ground level.

The ground level of the proposed site is relatively flat with a reduced level of about 2.0m and its groundwater table greatly influenced by the tide. The HAT is 1.59m while the Mean Sea Level (MSL) is 0.17m from the land survey datum.

Submarine and Trailer Details

The submarine is 67.6m long, 6.8m width and 12.5m height. It is supported by two saddles and was transported on a modular trailer. The trailer was made up of 6 modules and this combination has 30 axles with 16 tyres per axle. The length of the trailer including its power pack was 48.45m.

For bearing pressure calculation, the outer edge of the tyres made a footprint of 6.3m width and 43.5m length. With a total load of submarine, saddle and trailer of 1450 tons and assuming that the load could be evenly distributed onto the whole footprint the average bearing pressure calculated was 52kPa. The pressure from each individual tyre, however, could range from 300-1000kPa.

Design Criteria

The design criteria for the access road given by the transporter to ensure safe relocation of the submarine are as follows:

Minimum Turning Radius:	19m
Maximum Gradient:	1%
Maximum Super-elevation:	3%
Design Pressure:	100kPa
Max differential settlement:	75mm

In the unlikely event of a bearing capacity failure of the access road, it would not be possible to lift the submarine using crawler cranes.

Ultimate and Allowable Bearing Capacity

The procedure for estimating the ultimate bearing capacity for sand overlying clay proposed by Meyerhof (1974) and described in Das (2011) was used to determine the Factor of Safety, SF against bearing capacity failure. Undrained shear strength, s_u of 22kPa just underneath the sand layer was obtained from Vane Shear Tests after applying the correction factor proposed by Bjerrum (1972). As for the friction angle ϕ' of the sand layer, the lowest SPT N-Value, corrected for depth, and the correlation proposed by Kulhawy and Mayne (1990) suggested a very low value of 19^0. Using these strength values, the SF against bearing capacity failure without any ground improvement is marginally 2.5.

The allowable bearing pressure based on settlement of foundation in sand could be estimated using the equation proposed by Bowles (1977). For foundation without a depth factor, the formula could be simplified as follows:

$$q_{all}\,(\text{kPa}) = N_{60}/0.08(B+0.3)/B(S_e/25) \qquad (2)$$

where:
N_{60} = corrected SPT N-value
B = width of foundation in metres
S_e = settlement in mm

By using the minimum SPT N-Value and a maximum settlement of 75mm, the allowable bearing pressure was only 30kPa, much less than the average bearing pressure from the submarine and trailer. Thus, it was necessary to improve the ground by compaction and geotextile reinforcement in the design.

Detail Design

The detail design, shown in Fig. 2, requires that the loose sand layer be excavated to about 1.5m depth and the exposed subgrade be well compacted with 8 passes of 25tons vibratory compactor. The sand was then reused as 0.75m fill material with a maximum lift thickness of 0.25m, well compacted to a dry density of $20.6kN/m^3$ and wrapped with high strength geotextile reinforcement, Tencate Polyfelt PEC 100/100. A 0.75m thick crusher run, with a maximum lift thickness of 0.25m was later compacted up to a dry density of $21.6kN/m^3$ and wrapped with the same high strength geotextile.

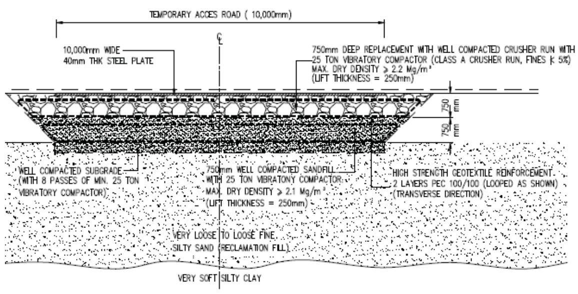

Fig. 2 Detail cross section of the access road with geotextile reinforcement

Finite Element Analysis

Finite Element Method is used to analyze the interaction between the soil and the high strength geotextile. This is to study the effects of the design load to the access road as well as to the surrounding ground after improving the soils with compaction and reinforcement with geotextile. The finite element program, PLAXIS V8 was used in the analyses of this soil-structure interaction. It was modeled using the 2-D plane strain analysis and the soils stress-strain behaviour was modeled using the elasto-plastic Hardening Soil Model proposed by Schanz and Vermeer (1999).

Based on the design and information from boreholes, the subsoil condition for soil layers S1, and S2 are predominantly composed of granular materials while the soil layer S3 is composed of cohesive material. Hence, drained condition is assumed for soil layers S1 and S3, whereas, for soil layer S3 (soft clay), undrained condition was assumed in the finite element analysis. The groundwater level was taken at 1m below existing ground level. A surcharge load of 100 kPa from the trailer was also taken into consideration. It was assumed that the load from the trailer could be evenly distributed to the ground using a 40mm thick steel plates. Tables 1 and 2 show the geotechnical model used in this finite element modeling.

Table 1 Physical and strength parameters used in the finite element analysis

Soil Layer	Unit Weight (kN/m3)	Cohesion c' (kPa)	Friction angle, ϕ'
S1- Crusher run	20	0	36
S2 - Sand	18	0	28
S3 - Clay	16	22	0

Table 2 Parameters for the hardening soil model

Soil Layer	E_{50} (MPa)	E_{oed} (MPa)	E_{ur} (MPa)
S1- Crusher run	55	-	-
S2 - Sand	8	8	24
S3 - Clay	6	4.5	18

In the typical finite element mesh, the left and right boundaries were assumed to be fixed horizontally but free to move vertically, whereas the bottom boundary was assumed to be fixed in both directions. The in-situ stresses were first generated based on the unit weight and the gravity, after which the in-situ hydrostatic pore pressures were generated by defining a phreatic line at the assumed water table level in the finite element mesh.

Result of the deformed finite element mesh is shown in figure 3 while the deformation contour is illustrated in Fig. 4. The maximum deformation predicted with 100kPa surcharge is 68mm, less than the maximum differential settlement allowed.

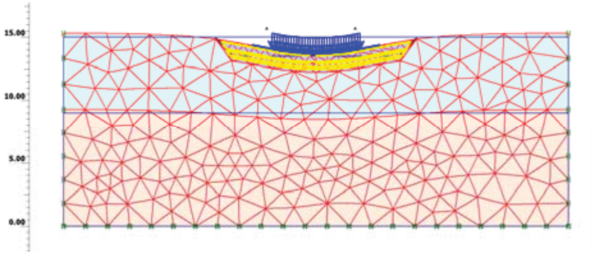

Fig. 3 Deformed finite element mesh

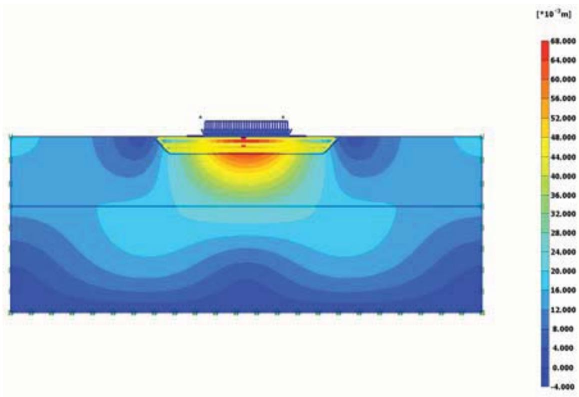

Fig. 4 Deformation contour

CONSTRUCTION SEQUENCES

The sequence of work during construction necessary to prepare a hard surface suitable for the trailer is shown in the following figures.

Fig. 5 Excavation of loose sand

A minimum of 1.5m of the sand layer was excavated below the existing ground level. The sloping surface was trimmed to about 1H:1V. All sharp objects which might puncture the geotextile must be removed during this stage.

Fig. 6 Laying of the first compacted layer reinforced with geotextile

Then, the first layer of reinforcement composite geotextile was laid on the excavated and trimmed surface. They were laid across the road with the machine direction perpendicular to the sloping surface. Each reinforcement composite geotextile panels were jointed with minimum 50-75mm overlapping distance and double stitched on the overlapped area by using "J-Seam" method. The sewing was done in the longitudinal direction by hand stitching machine.

Subsequently, the 750mm thick of sand was placed onto the reinforcement composite geotextile. The sand layer was properly compaction up to the specified dry density with lifts of 250mm

Fig. 7 Laying of second layer of reinforcement

The second layer of reinforcement composite geotextile was then laid on the well compacted sand fill layer. They were laid across the road with the machine direction perpendicular to the sloping surface.

Fig. 8 Laying of crusher run

A 750mm thick crusher run, compacted to the specified dry density, was then placed onto the reinforcement composite geotextile. The work needs to be supervised to ensure that the compaction adheres to specification and requirement. Well compacted soil is crucial for the road structure stability in order to mobilize the friction and tensile strength of the geotextile.

Fig. 9 Compaction of crusher run

Finally, the road was leveled using crusher run or quarry dust to achieve a smooth hard surface.

Fig. 10 Leveling the final layer of crusher run

ACTUAL PERFORMANCE

Although the design bearing pressure of the road was only 100kPa, plate bearing tests were conducted to simulate the pressure exerted by the trailer tyres onto the road surface which could be as high as 1000kPa. Figures 11 and 12 show the plate bearing tests conducted on the access road up to a pressure of 300kPa and 1000kPa, respectively using a 300mm square plate.

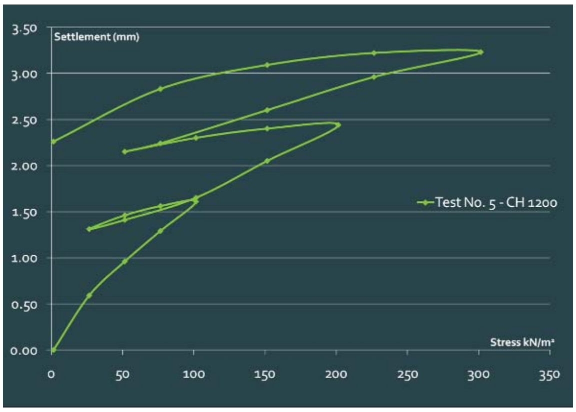

Fig. 11 Plate bearing test result - 300kPa

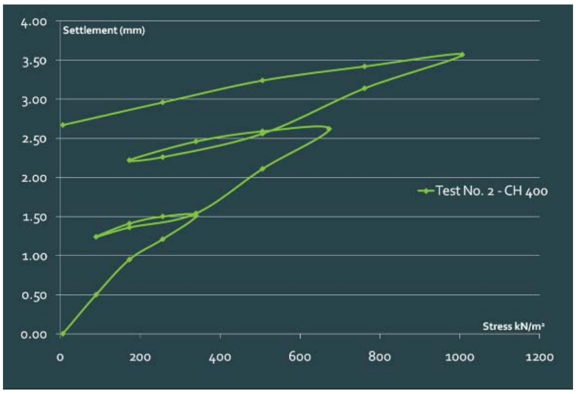

Fig. 12 Plate bearing test result - 1000kPa

Both tests show a strain hardening behavior but with very little settlement, i.e. less than 3.5mm. Due these results the steel plates were later omitted. This has saved costs and also shortened the relocation duration. It was initially estimated that the whole relocation would take 3 days to allow for the steel plates to be recycled during the process.

A 24hrs maintained load tests equal to the average bearing pressure exerted by the trailer and which resemble the base of the trailer were also conducted (refer Fig. 13). This was to ensure that a bearing capacity failure which cuts through the underlying very soft clay layer will not occur and to quantify the total settlement if the trailer were to park overnight. A typical result is shown in Fig. 14.

Fig. 13 Maintained load test

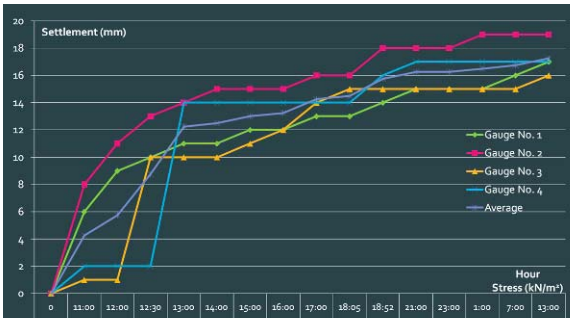

Fig. 14 Maintained load test result

The maintained load tests suggested immediate and consolidation settlement of about 25mm, still less than the maximum differential settlement allowed.

After the road was completed, a platform trailer was used to roll the submarine to its final destination. With the enhancement of stiffness and bearing capacity of the ground by compaction and composite geotextile reinforcement, the submarine was transported on the temporary road smoothly, without rutting and pumping effect as shown in Fig. 15.

Fig. 15 Access road being used for the relocation

CONCLUSIONS

Well compacted granular material reinforced with high strength composite geotextile was successfully employed to strengthen a road used to relocate a very heavy load.

For a very loose granular material, finite element and actual performance at site suggest that this method will drastically improve the stiffness of the soil, hence minimizing differential settlement and rutting. The actual deformation of the ground, showing a soil hardening trend, is much less than the results from finite element analysis.

Site supervision is crucial to ensure that the design was implemented at site. Soil need to be sufficiently compacted and the geotextile need to be properly installed to mobilize the friction and tensile strength of the geotextile.

ACKNOWLEDGEMENTS

The authors wish to thank the Malacca State Government for appointing Kumpulan Ikram Sdn Bhd as the project manager and technical advisor.

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