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# Field behavior of an instrumented geotextile reinforced piled-embankment for an expressway in Singapore

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ABSTRACT: A new 12 km-long expressway will be built to cater for the expanded traffic flow in northeast region of Singapore. The site for one of the sections of this project is situated in an old dumping ground for several decades, which consists of thick deposit of soft material, loose dumping material and occasionally peat. In addition, the expressway in this section has to be constructed across a numbers of existing buried sewer pipes protected on top by reinforced concrete (RC) slab that was supported by bored piles at both edges. In the design of this expressway, an intersection will be built on the right side of this RC slab. Hence, the destructive differential settlement between the road section and the reinforced concrete slab is the main concern. Geotextile reinforced piled embankment (GRPE) system has been proposed as a ground improvement method to minimize the differential settlement. The performance of the proposed system is monitored by soil pressure cells, strain gauges, deep settlement plates and piezometers at two instrumented sections. The field measurements show the satisfactory performance of this system in limiting the embankment settlement. Some of the results will be presented in this paper.

## 1 INTRODUCTION

The rapid expansion of housing estates in Kallang and Paya Lebar areas created an increased traffic demand that could not be fulfilled by the existing Tampines Road, Singapore. Therefore, a new expressway – Kallang/Paya Lebar Expressway (KPE) is part of the Land Transport Authority (LTA)'s plan to develop a comprehensive road network to cater for the expanded traffic flow. When completed, the KPE will help to relieve traffic congestion from the northeast region to the central business district.

Civil construction works are being carried out in six sections. C426 section is one of the sections that consist of a two-kilometres stretch, which connects Lorong Halus Interchange at TPE to the proposed interchange at Tampines Road. The site for this section is situated in an old dumping ground for several decades, which consists of thick deposit of soft material, loose dumping material and occasional peat. Hence, the expressway constructed over this kind of ground condition is expected to experience significant ground settlement in both short term and long term. In addition, at Chainages 11220 to 11250 of this C426 section, the expressway has to be constructed across a numbers of existing buried sewer pipes. Reinforced concrete (RC) slab supported by bored piles at two edges will be constructed to protect the sewer pipes. An intersection will be built on the right side of this RC slab (refer to Figure 1 and Figure 2 for details). In the design of the intersection of this expressway, geotextile reinforced piled embankment (GRPE) system has been proposed as a ground improvement method to minimize the differential settlement between the road section and the reinforced concrete slab (Figure 2).

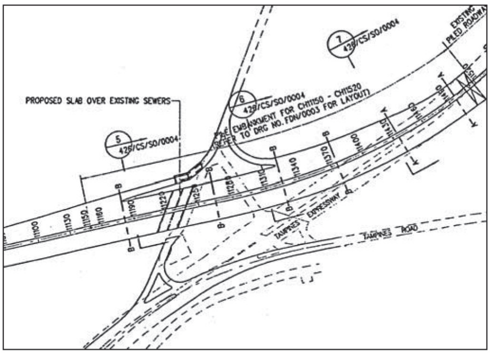


Figure 1. Site Plan of proposed GRPE section in KPE-C426 (obtained from LTA, Singapore).

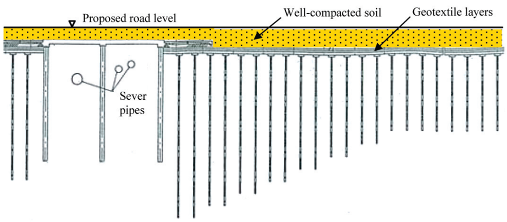

Figure 2. Cross sectional view of GRPE system.

This being the first geosynthetics reinforced piled embankment constructed for a major expressway in Singapore, the Land Transport Authority (LTA) of Singapore therefore required this system to be instrumented and monitored for validation and confirmation of the design concept and design parameters used. As a result, extensive instrumentation was designed, planned and implemented at two sections, in order to monitor the performance of the system for both short and long term observations.

## 2 GROUND CONDITIONS

Generally, the route of the whole KPE falls within the old alluvium formation and soft Kallang formation within the valleys. The proposed expressway construction site for C426 section is an old dumping ground for several decades. Several boreholes and soil testing were carried out to ascertain the stratigraphy. The original ground surface was at Reduced Level (RL) of 108 m. The simplified and idealized soil profile near the instrumentation sections is shown in Figure 3. The approximately 9 m-thick backfill layer on the top consists of dark grey fine-to-coarse sand, soft dredged material, plastic sheets, wood pieces, broken glass, organic matters and occasionally peat. The backfill is underlain by the Old Alluvium formation. The loose to medium dense clayey sand, silty clay, clayey silt and silty sand are characteristic soils of the Old Alluvium at this location. The ground water table is approximately 2-3 m below the ground surface.

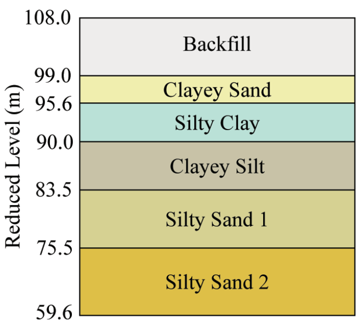

Figure 3. Simplified soil profile.

## 3 PROPOSED GRPE SYSTEM

Based on the original piled embankment design without geosynthetics (Swedish Road Board Design, obtained from Broms, 1979), the pile spacing has to be smaller than 1.7 m for 1.75 m fill height embankment with 1.0 m square reinforced concrete pile caps with well compacted sandy soil as back fill material. Study was conducted and it was shown that with the inclusion of geotextile as basal reinforcement right above the pile caps, the pile spacing can be confidently increased to 2.5 m for the same conditions.

Figure 2 shows the cross sectional view of GRPE system. This system was designed to minimize the differential settlement between the road section and the reinforced concrete slab that was constructed to protect those existing buried sewer pipes. It can be noticed that the piles that are located near the RC slab are longer. This is because those piles are designed to be end-bearing and expected to settle very minimal, as the full weight of the embankment will be transmitted to the hard stratum. While the piles located further away are shorter and expected to settle more. This will form a gradual transition from the RC slab to the embankment founded on highly compressible ground. In addition, the advantages of this system include cost and time saving as well as minimization of disturbance to the nearby existing road with heavy traffic flow.

Two layers of woven geotextile were perpendicularly cross-laid and separated by a thin layer of sand fill to provide reinforcements in two perpendicular directions. These geotextile reinforcements, which were placed within a sand blanket, were used to form a reinforced platform to effectively transfer the vertical load. The average ultimate tensile strength of geotextile in machine direction and cross machine direction are 150 kN/m (at 21% strain) and 134 kN/m (at 29% strain) respectively. The reinforced embankment was supported by square RC piles of 225 mm × 225 mm with 2.5 m spacing. The 1 m × 1 m individual square RC pile caps were cast on each pile. The pile caps only occupied 16% of the total area.

## 4 INSTRUMENTATIONS AND MONITORING

The two instrumentation sections, i.e. Section A and Section B, located approximately 13.5 m and 26 m away from the right edge of RC slab respectively. The instrumentations were planned to be placed across two lanes of the expressway, i.e. the slow lane and the medium lane, covering about 7.5 m width. The monitoring of the system started from construction stage until the defect liability period.

Figures 4 and 5 shows the plan and sectional view respectively of the instrumentation program for both

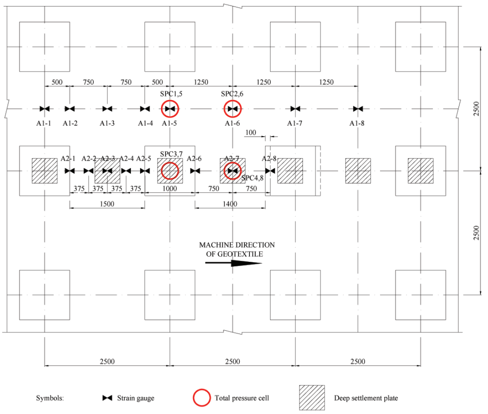


Figure 4. Plan of instruments installed.

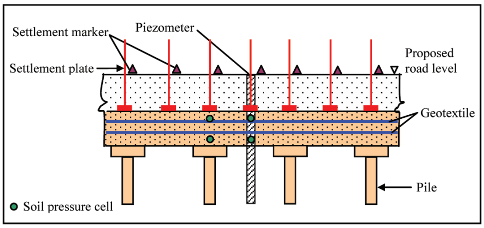


Figure 5. Sectional view of the instruments installed.

Sections A and B. The installation of sensors has taken the actual constructed locations of the piles into account. Four numbers of total soil pressure cells (SPCs) were installed at two different sub-layers, i.e. right above pile caps level and directly on top of the upper geotextile layer, to measure the total soil stress in the embankment fill at those locations. At every sub-layer, one TPC was placed directly above the pile cap and the other three were placed in-between the pile caps. Two arrays of strain gauges (SGs) were attached onto the lower geotextile sheet followed the method proposed by Chew et al. (2000), in order to measure the geotextile strain and tension induced throughout the construction and monitoring periods. One array is located in-between the pile caps region, while the other array is located across the pile caps. Deep settlement plates were installed to measure the settlement of the geotextile reinforcement platform.

## 5 RESULTS AND DISCUSSIONS

At the time of preparation of this paper, the construction of this reinforced embankment has reached the road base layer only, and the premix layers have not been laid yet. The results of Section A only will be discussed here, as the results of Section B is very similar to that of Section A till this time.

### 5.1 *Soil Stresses in embankment fill*

Figure 6 shows the soil stresses measured by SPC1 to SPC4. All these 4 SPCs were located at a level similar to the pile cap level. SPC3 that located right above one pile cap recorded much higher vertical soil stress than the static overburden pressure. SPC2 that located at the centre of 4 pile caps recorded the lowest vertical soil pressure compared to the other 3 SPCs. In addition, the recorded vertical soil stress were always lower than the static overburden pressure. The above observation validated the presence of soil arching effect.

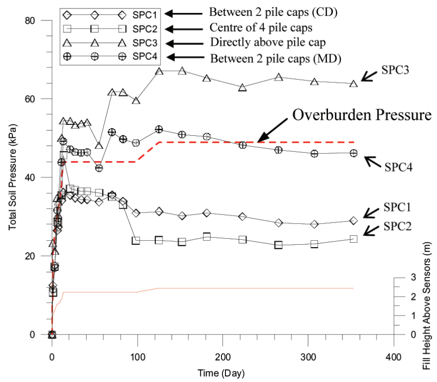


Figure 6. Soil stresses measured at various locations right above pile cap level.

SPC4 and SPC1 were located in-between two pile caps along the machine direction (MD) and cross-machine direction (CD) of the lower geotextile sheet, respectively. It can be noticed that the vertical soil stresses measured by SPC4 and SPC1 were between the soil stresses readings of SPC3 (i.e. directly above pile cap) and SPC2 (i.e. centre of 4 pile caps). However, SPC4's readings were always higher than SPC1's readings. This is because the stiffness modulus in CD direction is 1.55 times lower than that in MD direction. Therefore, the higher vertical deformation will be developed in CD. This will result in higher relief of vertical soil stress in CD compared to MD direction.

The similar trend was observed from the four SPCs that were placed right above the upper geotextile sheet. However, it can be seen that the degree of soil arching is lesser at this level. This resulted in the smaller difference between the recorded highest and lowest Fsoil stresses readings (Figure 7).

### 5.2 *Geotextile strain*

Figure 8 shows the recorded strains in lower geotextile sheet measured at various locations in-between pile caps during the construction of embankment. The results show that the strain distribution of each span

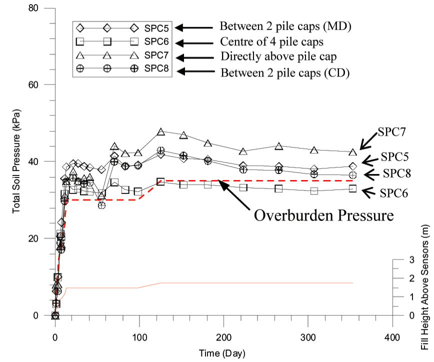


Figure 7. Soil stresses measured at various locations right above upper geotextile sheet.

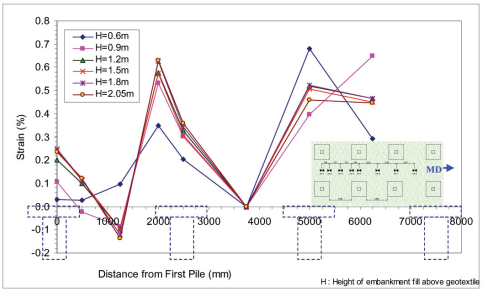


Figure 8. Strains in lower geotextile in-between pile caps.

between 2 pile caps is like a V-shape. The strain at the centre of the span is the lowest, and getting larger when closer to the pile cap on both sides.

The similar strain distribution profile can be observed from the strains measured by the other array of strain gauges that were placed across pile caps. For the two arrays of stain gauges, the maximum strain of about 0.6-0.7% took place at the edge of pile caps after the construction of 2.05 m embankment above the lower geotextile sheet. This shows the range of strain developed and the suitability of geotextile used. The results of strain gauges can be better exploited to indicate the extension of geotextile and its deformation, which is beyond the scope of this paper.

### 5.3 *Settlement of reinforcement platform*

Figure 9 shows the settlement of the geotextile reinforcement platform after 7.5 months of the construction of embankment up to road base level,

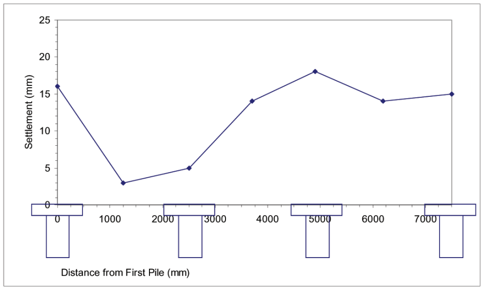


Figure 9. Settlement of geotextile reinforcement platform.

i.e. 2.05 m above lower geotextile sheet. It can be seen that the reinforcement platform only experienced a small settlement of less than 20 mm, which is closed to that was expected. This shows the success of GRPE system in reducing the settlement of the embankment constructed over compressible ground. The computation of settlement from the measured geotextile strain can be further studied in the future paper.

## 6 CONCLUSIONS

Extensive instrumentation was planned and installed to monitor both short term and long term performance of the first GRPE system for a major expressway in Singapore. Till now, the instruments have been performing very well and yielded reliable data for the evaluation of the performance of this GRPE system.

The results of soil stresses at various locations clearly show the presence of soil arching effect in the embankment fill. In addition, the use of a proper designed GRPE system has reduced the settlement to a satisfactory level. This helps in minimizing the differential settlement between the road section and the reinforced concrete slab, thus offer a gradual transition from the RC slab to the road section further away.

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