Composite Behaviour of Geotextile Reinforced Embankment on Soft Clay

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ABSTRACT: This paper presents some theoretical analyses of geotextile reinforced embankment constructed on soft soils. The results of the analyses were compared with the measured data obtained from the investigation of three full scale unreinforced and reinforced embankments constructed to failure on soft Bangkok clay. One of the reinforced embankments comprised four layers nonwoven geotextile of low stiffness modulus and the other a high strength nonwoven geotextile. Details, instrumentation and construction procedures of these embankments are given. The results and benefits of different geotextile reinforcement systems on the behaviour of the embankments are highlighted. The theoretical analysis provides good correlation with the observed results which can be used as the basis for evaluating the performance of geotextile reinforced base embankments constructed over highly compressible soft Asian clays.

1 INTRODUCTION

In South East Asia, large areas of soft highly compressive soils prevail. Due to rapid economic growth in this region, the development of infrastructure works particularly roads and highway constructions demand that the presence of these soils be stabilized. One of the most economical methods of stabilizing soft soils is the use of geosynthetics as reinforcement at the base of road embankments. However, it is necessary for the geosynthetic to perform other functions beside reinforcement to optimise performance in soft plastic clays. Geosynthetics such as high strength or multi-layer nonwoven needle-punched geotextiles with the capability to reinforce, separate and drain in soft saturated soils provide the most viable systems.

For these reasons, it was decided to investigate the performances of these geotextile reinforcement systems through the construction of full scale instrumented embankments on soft Bangkok clay which typically represents Asian regional soft soil conditions.

The results obtained were analysed theoretically to provide the basis for evaluating the performance of nonwoven geotextile reinforced base embankments constructed over highly compressible soft Asian clays.

2 EMBANKMENTS AND INSTRUMENTATION

Three full scale embankments were constructed rapidly to failure on soft Bangkok clay at the Asian Institute of Technology. Two of the embankments were reinforced and the other unreinforced which served as a control embankment (CE). One of the reinforced embankments comprised four layers nonwoven geotextile of low stiffness modulus (MGE) and the other a high strength nonwoven geotextile (HGE). Before construction of the embankments, a canal of about 2m deep and 7.5m wide at the bottom was excavated along the pre-determined failure side of the embankments. Figure 1 shows the plan and sections of the test embankments. The typical soil profile of the foundation is shown in Figure 2. Clayey sand was used as backfill which consisted about 30% clay, 15% silt and 55% fine to medium sand.

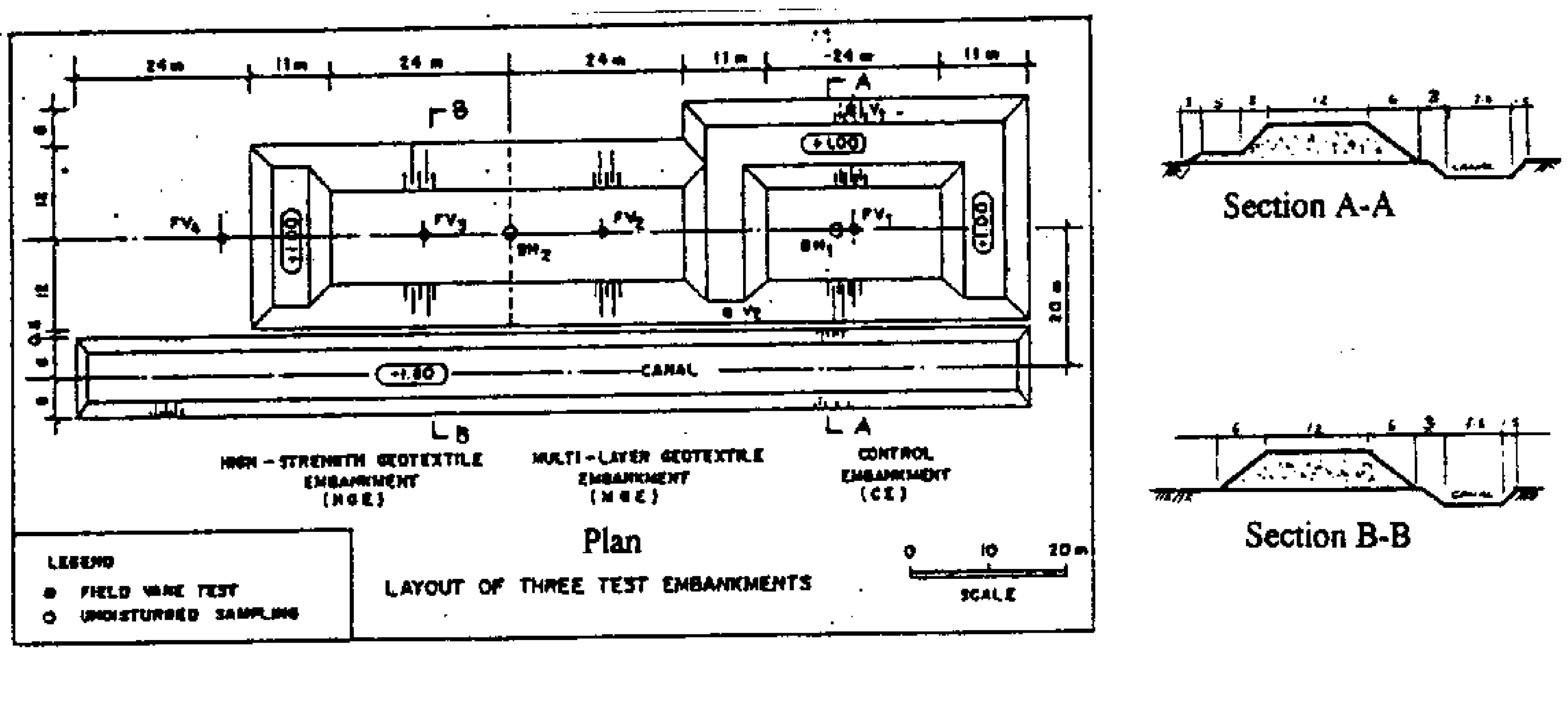


Figure 1. Plan and cross sections of the embankments.

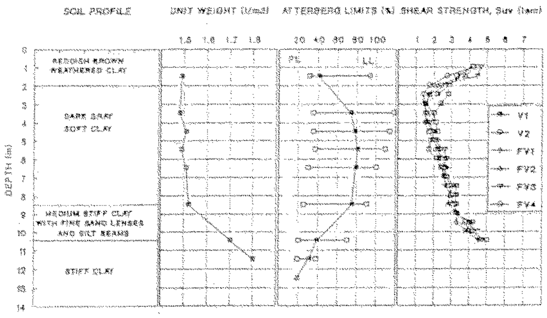


Figure 2. Vertical soil profile of foundation soil.

The foundation instrumentation consisted of settlement plates, piezometers, inclinometers and earth pressure cells. For geotextiles, wire extensometers, strain gauges and load cells were used to measure overall strains, local strains and loads in the geotextiles respectively. Wire extensometers were also installed in the soil near the geotextiles to determine the relative displacement between the geotextiles and surrounding soil.

2.1 Control embankment (CE)

Construction of the control embankment was carried out during the dry season. The embankment was constructed in layers with compaction lift about 300mm until the embankment failed completely at height 4m (Plate 1). Figure 3 shows the cross section of the CE embankment failure. During construction, the moisture content of the backfill was maintained at 9% and bulk density 1.85t/m^3. Large shear box tests showed that the apparent cohesion of the backfill was 15kPa and friction angle 30°.

2.2 Multi-layer nonwoven needle-punched geotextile reinforced embankment (MGE)

The MGE was constructed adjacent to the failed control embankment at same rate of filling. The embankment was reinforced with one layer 280g/m^2 geotextile (ultimate tensile strength 18kN/m) and three layers 130g/m^2 geotextile (ultimate tensile strength 8.3kN/m) at vertical spacing 0.3m. It was noted that during construction, the moisture content had increased to about 13% and bulk density 1.95t/m^3 due to the rainy season. Large shear box tests showed that the apparent cohesion of the backfill was 10kPa and friction angle 30°. The MGE failed at height 4.2m. Figure 3 shows the cross section of the MGE embankment failure.

2.3 High strength nonwoven needle-punched geotextile reinforced embankment (HGE)

The HGE was reinforced with one layer high strength geotextile with ultimate tensile strength 200kN/m. The embankment was constructed simultaneously with the MGE and therefore have similar field conditions as that of the MGE. Due to the nature of the construction, failure of the MGE, induced deformation to the HGE. However, geotextile instrumentation indicated that the reinforcement was still intact and subsequent filling operation was carried out 20 days later until the embankment failed completely at 6m (Figure 3).

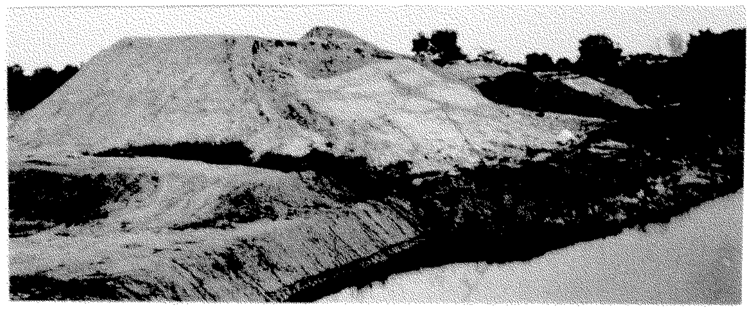


Plate 1. Failure of the CE at height 4m.

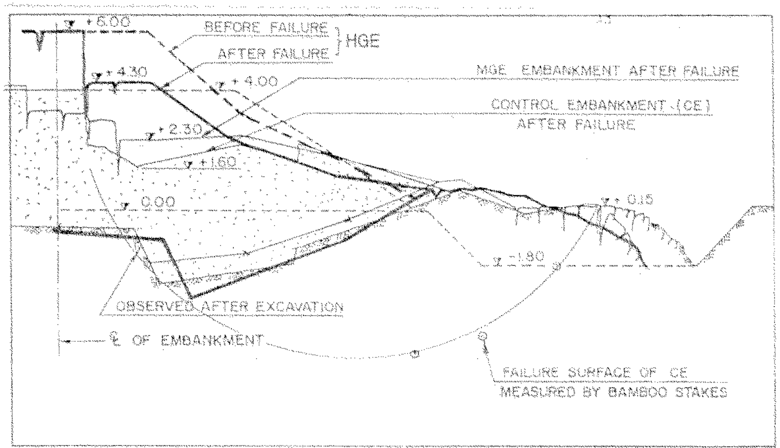


Figure 3. Cross sections after complete failure of CE, MGE and HGE.

3 RESULTS

3.1 Vertical and lateral displacement

The maximum vertical displacement of CE at failure height 4m was 320mm occuring at the centre of the embankment. For MGE and HGE, at height 4.2m, the maximum vertical displacements were 400mm and 280mm respectively. These maximum displacement also occurred near the centre line of the embankment. After failure of MGE, vertical displacement at the centre line of HGE was about 500mm and the maximum vertical displacement of 1100mm was recorded at 6m away from the centre line of the embankment. At height 6m, the maximum vertical displacement of the HGE was 1250mm occuring at the same location.

The maximum lateral displacement of CE at height 4m was 170mm which occurred at the ground surface. For MGE and HGE, at height 4.2m, the respective maximum lateral displacements of 165mm and 190mm were recorded at depth 2.5m and not at the ground surface.

This clearly indicates the effect of geotextile reinforcements near the region to restrain lateral deformation. Lateral displacements of MGE and HGE at ground surface were 90mm and 130mm respectively.

3.2 Total pore pressures

The development of total pore pressures at 3m, 5m and 7m in the foundation of the three embankments were recorded. The pore pressures were higher in both the MGE and HGE than the CE due to the rainy season. For HGE, during the period between induced deformation and subsequent filling operation, insignificant reduction of pore pressures were recorded at the centre of the embankment (Figure 4). This observation indicates that insignificant consolidation of the subsoil took place during that time.

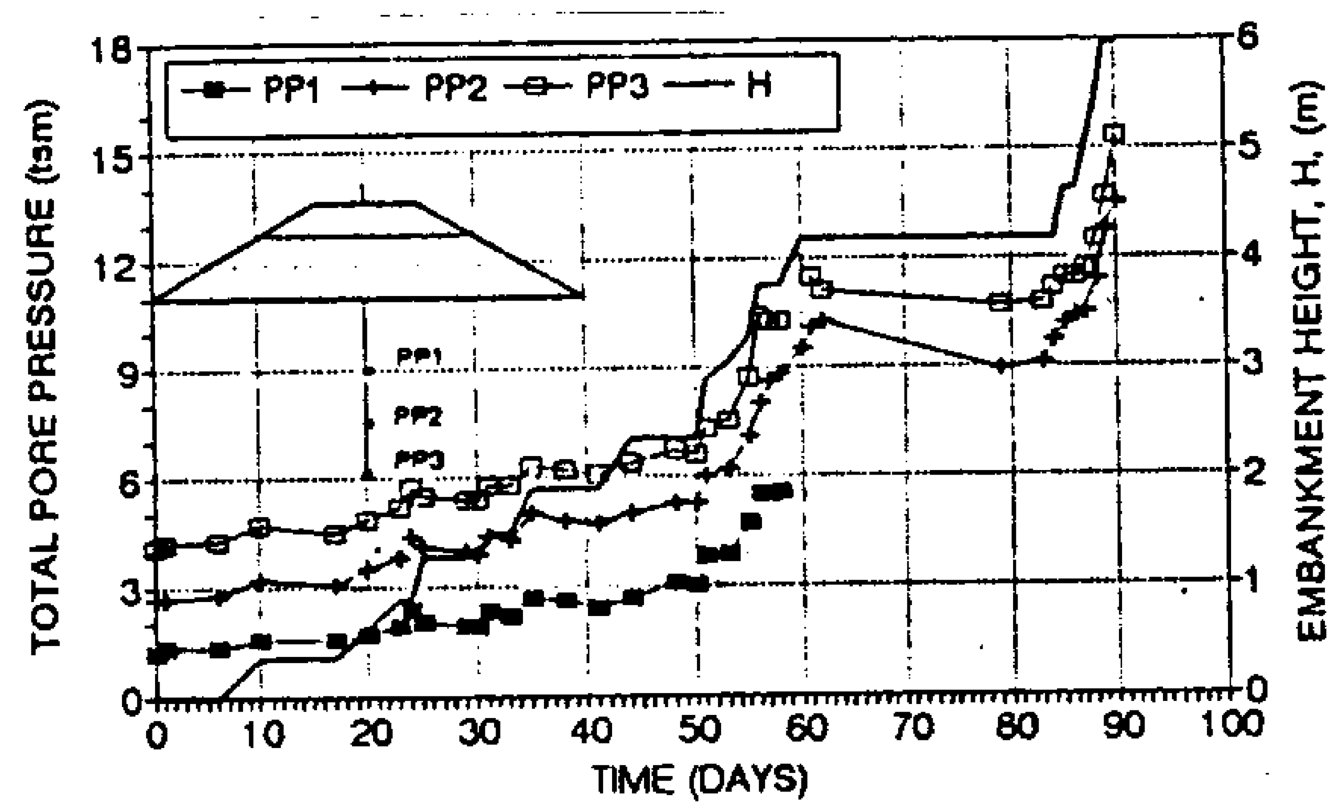


Figure 4. Total pore pressure development of HGE.

3.3 Strains in the geotextiles

For MGE, maximum strains of between 1.5% to 6% were measured in the 130g/m^2 geotextile prior to failure. For the 280g/m2 geotextile, the maximum strain prior to failure was about 3%.

Strains in geotextile of HGE are shown in Figure 5. There were no significant strains in the geotextile at the embankment height below 3m. Strains of about 2% to 3.5% were obtained at height 4m. A maximum strain of about 13% was recorded at failure height 6m.

In general, some compressions in the geotextiles were recorded similar to the observations made by Delmas et al (1992). The strains measured from the extensometers were comparable with the strain measurements obtained from strain gauges. While wire extensometers provide measurements at large strains, the strain gauges lost their effectiveness at strain level between 2% to 5% both in the field and in the laboratory calibration tests.

3.4 Relative displacement between geotextile and surrounding soil

Wire extensometers installed in the soil near the geotextiles at several locations in MGE and HGE indicated negligible relative displacement between the geotextile and surrounding soil at working condition. The results showed the intimate interaction between the geotextiles and the surrounding soil and confirmed soil/geotextile composite behaviour at working condition.

3.5 Loads in the geotextiles

Limited load measurements in the geotextiles were made to compare geotextile stress-strain relationship in-soil and in-air. For high strength nonwoven geotextile, the results indicated insignificant difference between the in-soil and in-air stress-strain behaviour. The in-soil/in-air relationship was also investigated on the 280g/m2 low stiffness modulus geotextile in MGE which showed a significant improvement in geotextile performance in the case of in-soil test (Figure 6).

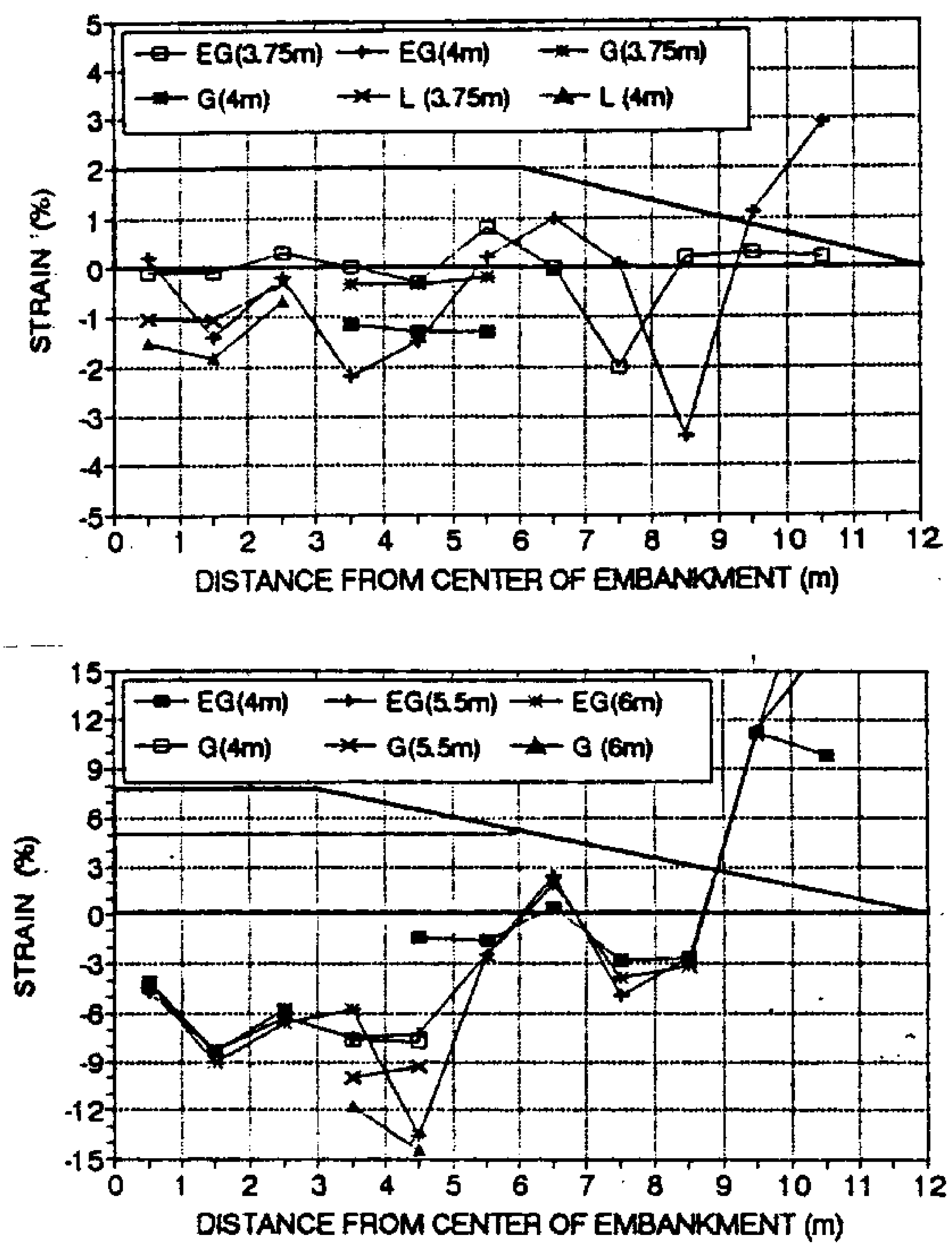


Figure 5. Strains in high strength geotextile of HGE.

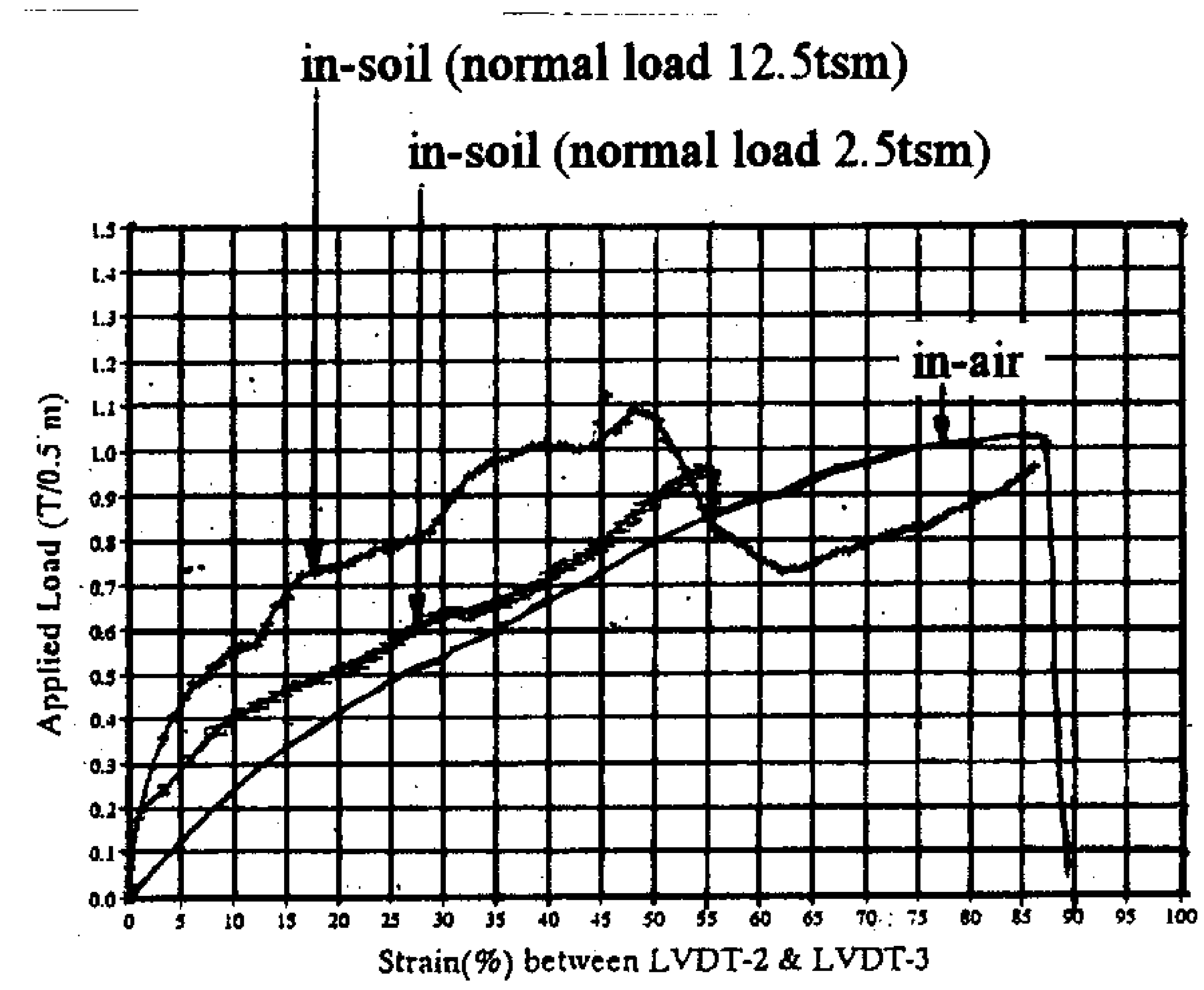


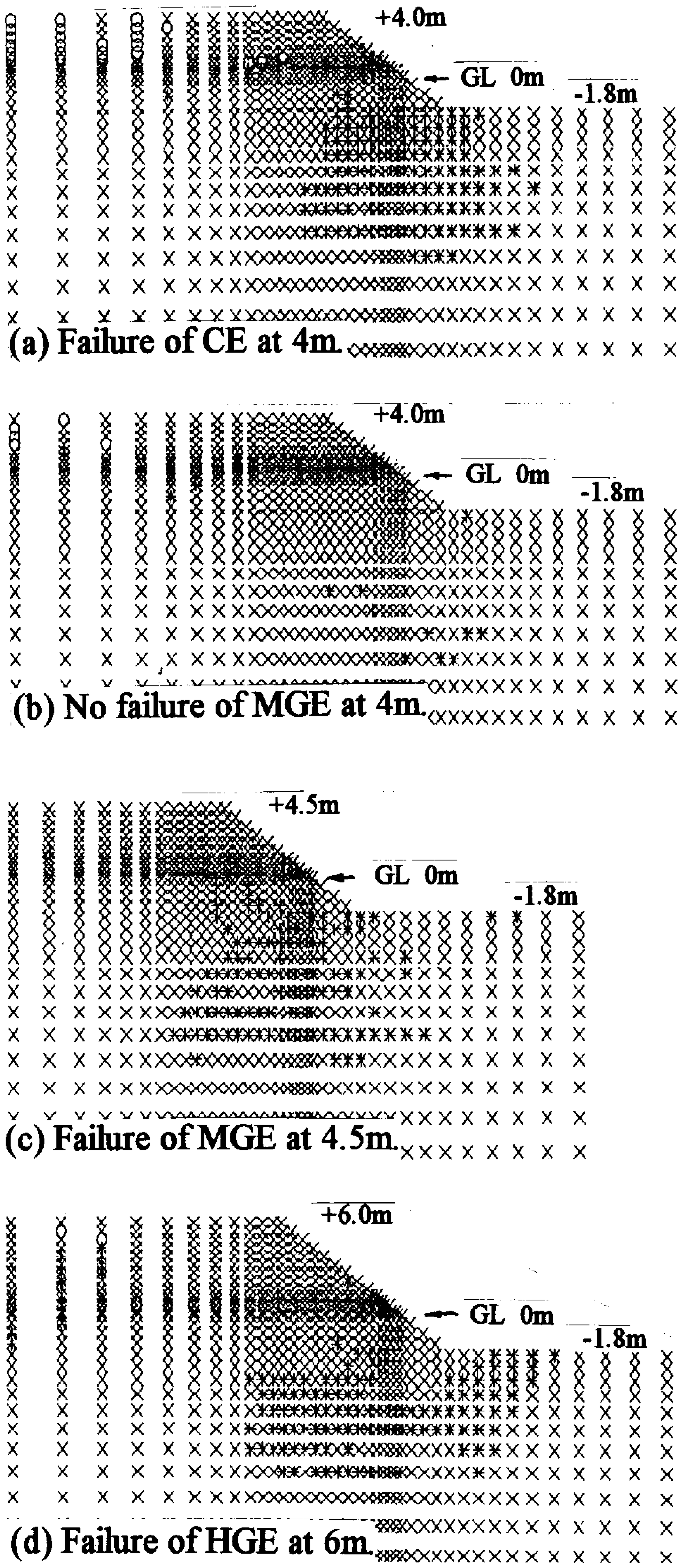
Figure 6. In-soil and in-air stress-strain relationships of 280g/m2 geotextile of MGE obtained from laboratory tests.

4 THEORETICAL ANALYSIS

Stability analyses, using finite difference method, were carried out on the embankments to determine the theoretical heights of failure.

For CE, the analysis confirmed the height of failure at 4m (Figure 7a). Using similar backfill parameters as that of the CE, the analysis showed that the MGE was stable at 4m (Figure 7b). However, at 4.5m failure occurred (Figure 7c). In-soil stress-strain properties of the geotextiles prior to failure were used (Figure 6) in the analysis and the geotextile layers were modelled as cable elements with zero flexural stiffness. Thus, it can be concluded that the multi layer reinforcements increased the height of embankments by at least 12.5%.

The analysis also confirmed the failure height of HGE at 6m where tensile force of 200kN/m (corresponding to 13% in-soil strain) was used (Figure 7d).



* - plastic zone failure
x - zone within ultimate strength
o - tension zone

Figure 7. Theoretical analysis on the stability of embankment heights.

5 CONCLUSIONS

The results highlight the effectiveness of the geotextile reinforcement systems under the conditions described.

The results confirm the presence of soil/geotextile composite behaviour particularly in the case of multi layer reinforced system at working condition. This behaviour increases the confining pressures of the soil between the reinforcements and consequently enhances the stability of the embankment.

Taking into consideration the confining stress due to the surrounding soil, the stiffness modulus of geotextile is improved. The effect of soil confining pressure is more significant on low strength nonwoven needle-punched geotextile than the high strength nonwoven geotextile used in this investigation.

The analysis confirmed the height of failure of CE at 4m. Using the same backfill parameters as that of CE and the enhanced in-soil geotextile stress-strain relationship of MGE, the analysis indicated that the multi layer reinforced system increased the height of embankment by at least 12.5%. The theoretical analysis also showed good correlation with the measured height of failure of HGE where an increased in height of embankment of 50% was recorded due to the single high strength nonwoven geotextile reinforcement. The theoretical analysis thus provides the basis for evaluating the performance of nonwoven geotextile reinforced road embankments constructed over soft clays.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

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