LOWLAND TECHNOLOGY INTERNATIONAL Vol.10, No. 1, 84-92, June 2008
International Association of Lowland Technology (IALT), ISSN 1344-9656

PERFORMANCE OF FULL SCALE TEST EMBANKMENT WITH REINFORCED LIGHTWEIGHT GEOMATERIALS ON SOFT GROUND

T. Tanchaisawat[1], P. Voottipruex[2], D. T. Bergado[3] and S. Hayashi[4]

ABSTRACT: Embankment construction using reinforced lightweight geomaterials over soft ground will alleviate problems of instability and large settlements. Backfills of retaining structures can also be constructed using lightweight materials resulting in lower vertical loads and, consequently, reduced settlements. The aim of this study is to investigate the behavior of lightweight geomaterials consisting of tire chip-sand mixture reinforced with geogrids for use as embankment construction on soft ground. The experimental results indicated that the mixing ratio of 30:70 % was the most suitable fill material. The full scale field test embankment was constructed at the campus of Asian Institute of Technology (AIT) in Bangkok, Thailand. The geogrid reinforced embankment system was extensively instrumented in the subsoil and within the embankment itself in order to observe its behavior during construction and post construction phases, and thereby evaluate its performance. The unit weight of rubber tire chip-sand mixtures is about 75% lighter than conventional sand. The total settlement at ground surface is 67.5% less when compared to the conventional backfill without foundation treatments. The maximum lateral wall movement observed at 13 months after construction at top of wall is 45% smaller when compared to conventional sand backfill on untreated ground. Finally, the geogrid reinforcements correspond well with the bilinear type of maximum tension line.

Keywords: Lightweight geomaterials, geogrid, soft ground, full scale test, reinforced embankment

INTRODUCTION

Generally, to improve the stability and performance of infrastructures on soft foundations two alternatives are available; one is to improve the strength and deformation characteristics of the foundation and the other is to reduce the weight of the structure on the foundation. The latter was first used in Oslo, Norway, where expanded polystyrene (EPS) was used in road embankments on soft ground (Freudelund and Aaboe 1993) called “The dawn of the lightweight geomaterial” (Yasuhara 2002). Several materials and methods have been proposed to produce lightweight geomaterials and are classified into three categories as follows: i) lightweight materials, ii) lightweight material with natural soil and cementing agent and iii) addition of air foam agent to reduce weight. The advantages of using lightweight geomaterials are not only the reduction of vertical pressures on foundations but also the decrease in lateral earth pressure, and a decrease in traffic induced vibration (Humphrey et al. 2000).

Construction of highway embankments on soft ground faces problems of high settlements and instability. Lightweight materials can be used as backfills in retaining structures and in the construction of embankments resulting in lower earth pressure and greater stability on soft ground. In recent years, however, there has been a growing emphasis on the use of industrial by-products and waste materials in construction. Used rubber tire is one of the waste materials that can be used as lightweight backfills of wall embankments and can reduce the environmental impact of waste tires.

Scrap tires can be used in several ways, whole, halved or shredded. They can be used alone as well as embedded in or mixed with soils. Geotechnical applications of shredded tires include embankment fills, retaining wall and bridge abutment backfills, insulation layer to limit frost penetration, vibration damping layer and drainage layer. Environmental applications of shredded tires include the use as reactive drainage layer in landfills, septic tank leach field aggregate and nutrient barrier in golf courses and athletic fields. Although use

[1] GTE Program, School of Engineering and Technology, Asian Institute of Technology, THAILAND
[2] King Mongkut’s University of Technology North Bangkok, THAILAND
[3] GTE Program, School of Engineering and Technology, Asian Institute of Technology, THAILAND
[4] IALT life member, Institute of Lowland Technology, Saga University, JAPAN
Note: Discussion on this paper is open until December 31, 2008

of scrap tires above groundwater table is widely accepted, use of tires under the groundwater table is still not permitted in some areas due to groundwater contamination (Edil 2007).

Due to the advantage of lightweight geomaterials for geotechnical application on soft ground, a full scale test embankment made of rubber tire-sand mixture reinforced with geogrid was constructed to study its behavior. The settlements of the embankment were observed and excess pore water pressures during and after construction were monitored to evaluate and analyze the consolidation process. Lateral wall movements and geogrid movements were measured using digitilt inclinometer and high strength extensometer wires respectively. Finally, the performance of lightweight embankment was evaluated for possible geotechnical applications on soft ground area.

LABORATORY INVESTIGATION

Experimental work was performed to investigate the interaction between tire chip-sand mixture and geogrid by pullout (Fig. 1) and large scale direct shear test. Two different geogrids were selected for testing. Geogrid A was made of the high tenacity polyester yarns with a mass of 840 g/m^2, opening size of 15 x 15 mm and with same direction tensile strength of 120 kN/m in the longitudinal and transverse. Geogrid B was made of high strength polyester yarns with a mass of 430 g/m^2, aperture size of 25 x 30 mm, with a longitudinal tensile strength of 100 kN/m and transverse member tensile strength of 30 kN/m. Laboratory results show that the specific gravity of sand is 2.65, while that of tire chips is 1.12. According to the Unified Soil Classification System (USCS), the sand can be classified as poorly graded (SP). For tire chips, most particle sizes ranged between 12 and 50 mm with irregular shape due to the random cutting process. Results of Standard Proctor compaction test on the tire chip-sand mixtures are shown in Fig. 2. The maximum dry unit weight and the optimum moisture content of the tire chip-sand mixtures vary depending on the mixing ratio from 9.5 to 13.6 kN/m^3 and from 5.7 to 8.8 % respectively (Prempramote 2005).

For the in-soil pullout tests, the pullout resistance increased while the displacement at the maximum pullout force tended to decrease as the normal stress increased. Moreover, the pullout resistance increased with the increasing sand content in the mixture. The mixing ratio of 30:70 % by weight yielded the highest pullout resistance for both geogrids as shown in Fig. 3.

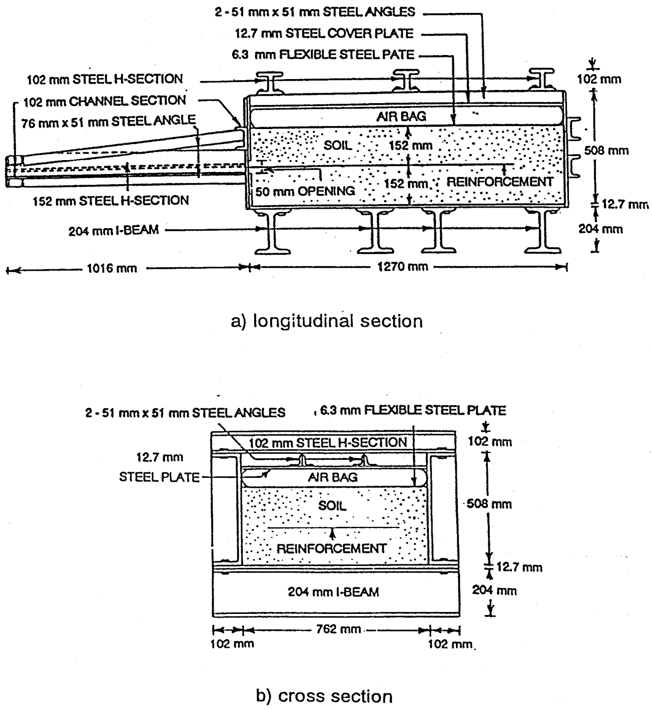

Fig. 1 Schematic pullout test apparatus

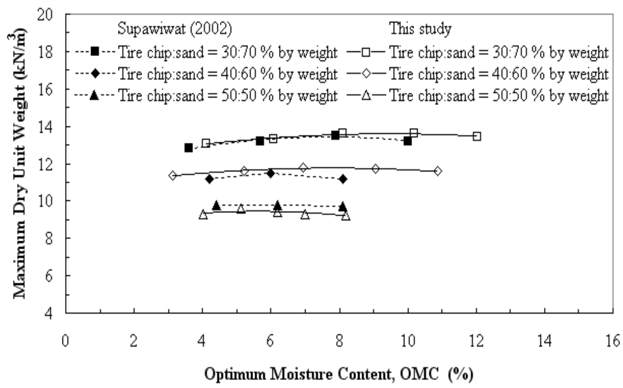

Fig. 2 Results of standard proctor tests on the mixture

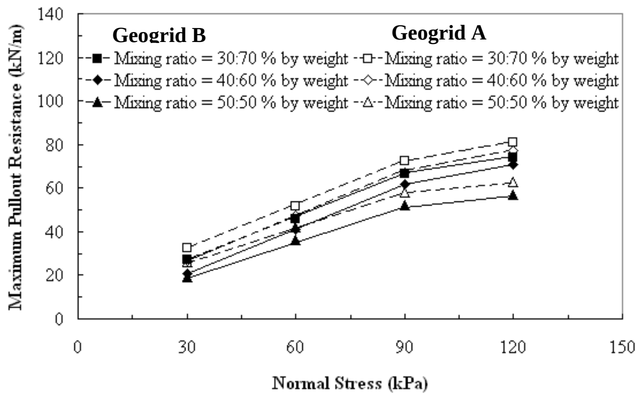

Fig. 3 Maximum pullout resistance of geogrid A and B at different mixing ratios

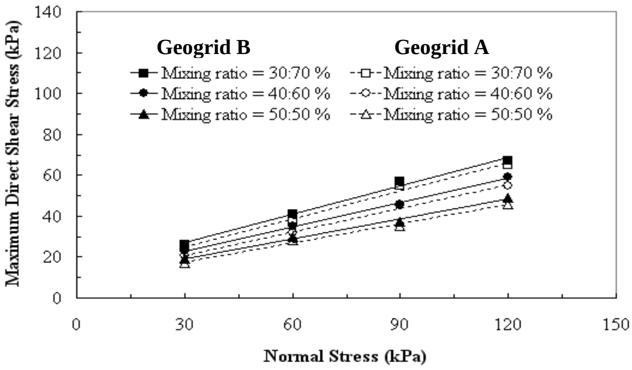

Fig. 4 Maximum direct shear stress of geogrid A and geogrid B at different mixing ratios

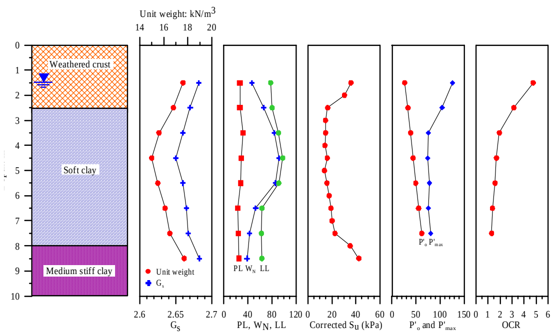

Fig. 5 Subsoil profile and relevant parameters

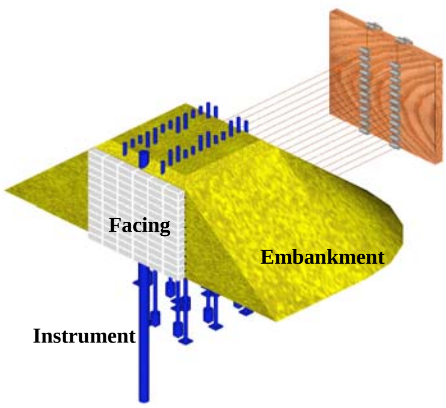

Fig. 6 Embankment drawing in 3D

The frictional resistance obtained from the sand governed the pullout resistance rather than that obtained from the tire chips. Pullout resistance of geogrid A was larger than geogrid B because tensile strength of geogrid A was more than geogrid B (Tanchaisawat et al. 2006).

The large scale direct shear test results are shown in Fig. 4. Under the same normal stresses and mixing ratios, both geogrids at mixing ratio of 30:70 yielded the highest direct shear stresses. The direct shear stresses obtained from Geogrid B were higher than those obtained from Geogrid A because Geogrid B had the bigger aperture size than that of Geogrid A

FULL SCALE EMBANKMENT TEST

The test embankment was constructed in the campus of Asian Institute of Technology (AIT). The general soil profile consists of weathered crust layer of heavily overconsolidated reddish brown clay over the top 2.5 m. This layer is underlain by soft grayish clay down to about 8.0 m depth. Medium stiff clay with silt seams and fine sand lenses were found at the depths of 8.0 to 10.5 m. Below this layer is the stiff clay layer. Figure 5 summarizes the subsoil profile and relevant parameters.

Instrumentation Program

The geogrid reinforcement embankment/wall system was extensively instrumented both in the subsoil and within the embankment itself. Since the embankment was founded on a highly compressible and thick layer of soft clay which dictates the behavior of the embankment to a great extent, several field instruments were installed in the soft soil layer. The 3D illustration of the full-scale field test embankment is shown in Fig. 6. The instrumentation in the subsoil were installed prior to the construction of the embankment and consisted of surface settlement plates, subsurface settlement gauges, open standpipes and inclinometer. (Fig. 7 and 8) (Tanchaisawat et al. 2007).

Construction of the reinforced embankment/wall involved the precast concrete block facing units with geogrid reinforcement. The vertical spacing of the geogrid reinforcement was 0.60 m. Rubber tire chips mixed with sand in the ratio of 30:70 by weight was the backfill. The backfill was compacted in layers of 0.15 m thickness to a dry density of about 95% of the Standard Proctor dry density. Compaction was carried out with a roller compactor and with a hand compactor near the instrumentation such as the settlement plates, the stand pipes and the inclinometer. The degree of compaction and the moisture content were checked regularly at several points with a nuclear density gage. Wherever the degree of compaction was found to be inadequate, addition compaction was done until the desired standard was met.

A sand layer was placed over the rubber tire chips-sand backfill as a surface cover for reducing the self-heating reaction. Hexagonal wire gabions were used on either side of the concrete facing at the front side slopes. Figure 9 illustrates the completed embankment construction (Kanjananak 2006).

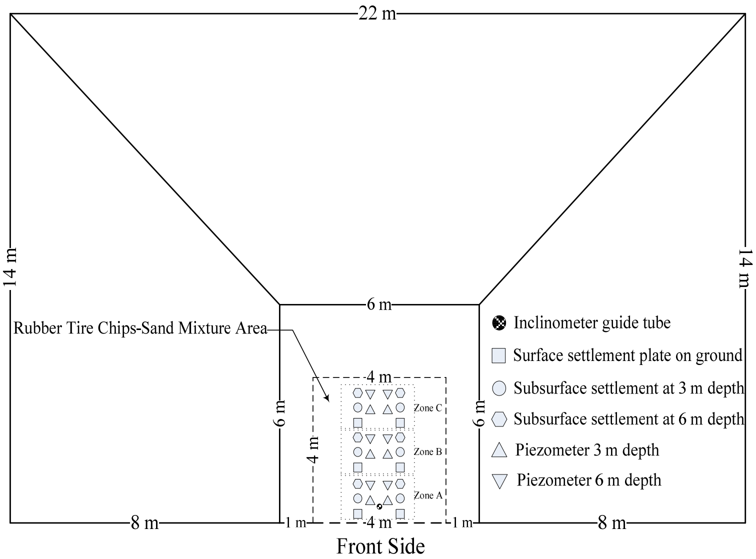

Fig. 7 Plan view of embankment with instrumentation

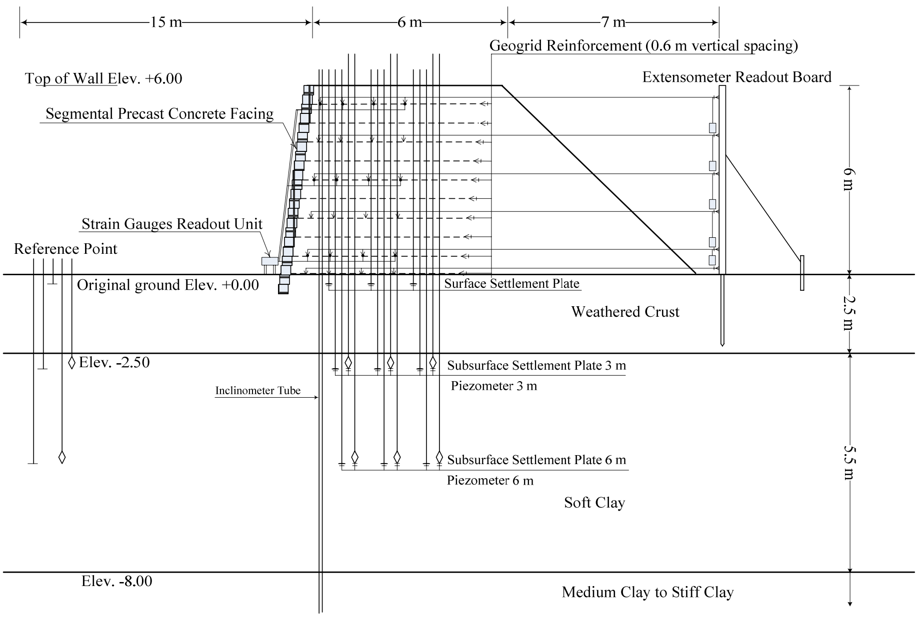

Fig. 8 Section view of embankment with instrumentation construction of Full Scale Test Embankment

Fig. 9 Completed full scale test embankment construction (Kanjananak 2006)

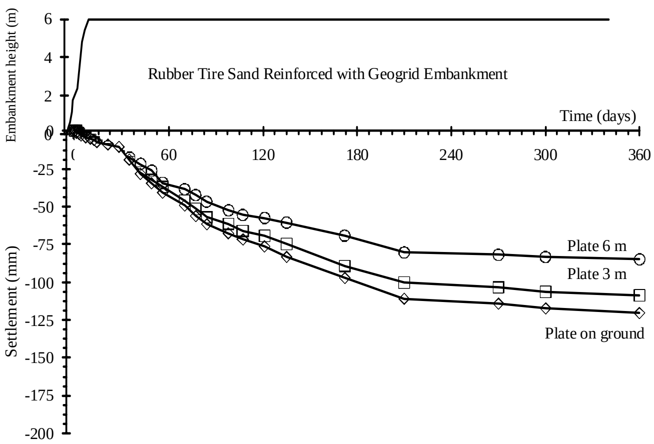

Fig. 10 Observed average settlements at different depths

Observed Behavior of Full Scale Test Embankment

Observed and predicted surface and subsurface settlements

The observed surface and subsurface settlements of the test embankment are shown in Fig. 10. The rate of settlement was low in all the surface and subsurface settlement plates during the construction period. After the construction, the rate of settlement increased. After 210 days from the end of construction, the maximum settlement was 122 mm as recorded in surface settlement plates near the facing. This is because the weight of the concrete facing is more than the lightweight embankment and the forward tilting of the embankment. Along the cross-section of the embankment, settlement decreased from front (122 mm) middle (112 mm) and back (104 mm). The average surface settlement on the ground after 210 days from the end of construction is about 111 mm. The settlements at 3 m and 6 m depths were lower than at ground surface, as expected.

The observed and predicted surface settlements of the test embankment are plotted together in Fig. 11. As expected, the predictions from Asaoka (1978) closely followed the observed data while the predictions from one-dimensional method were significantly higher than the measured.

Figure 12 demonstrates the comparison of the maximum settlements between conventional sand backfill reinforced with hexagonal wire mesh (Voottipruex 2000) and the lightweight embankment in this study. The maximum settlement of lightweight embankment was 130 mm compared to 400 mm for conventional backfill without foundation treatments. Settlement reduction amounted to 67.5%.

Observed and predicted excess pore water pressure at 3 m depth

The excess pore water pressure below the lightweight embankment was obtained from open stand pipe piezometer.

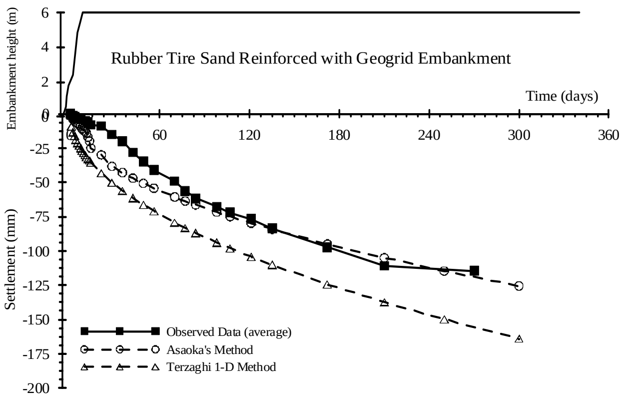

Fig. 11 Observed and predicted surface settlements at original ground level

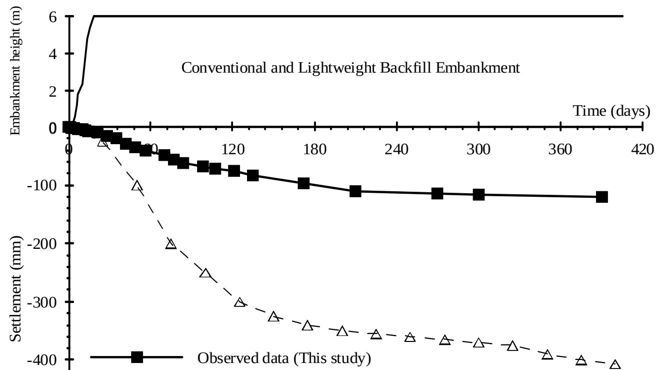

Fig. 12 Comparison of settlement between conventional and lightweight backfill

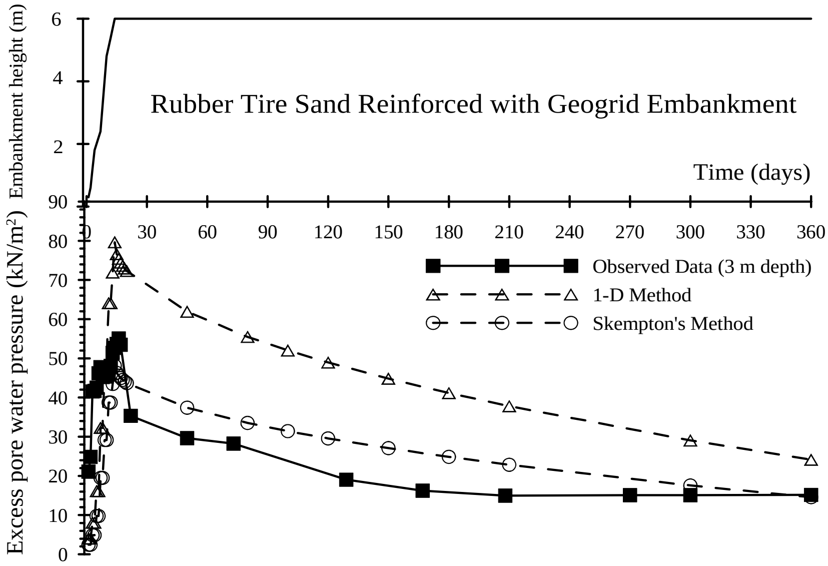

Fig. 13 Observed and predicted excess pore water pressure at 3 m depth

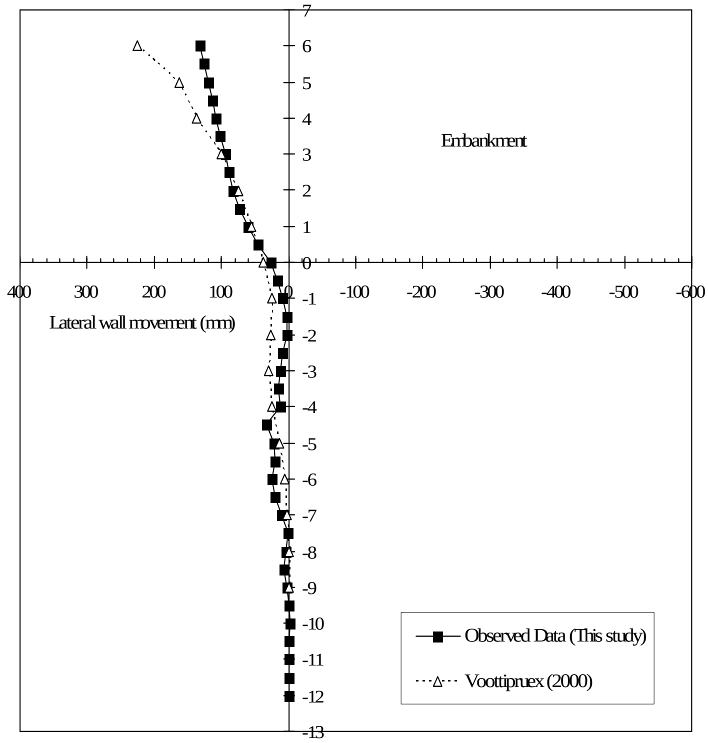

Fig. 14 Observed lateral wall movement

Figure 13 shows the excess pore water pressures during and after the construction at 3 m depth. The maximum pore water pressure of 57 kN/m^2 occurred at 15 days after full height of embankment. The trend of excess pore water pressure dissipation is an indication of consolidation of soft foundation subsoil in the over consolidation range when the load is below the maximum past pressure. After 50 days, the excess pore water pressure tends to dissipate very fast with time. The excess pore water pressure decreased to 18 kN/m^2 and 25 kN/m^2 at 3 m and 6 m depths, respectively. The excess pore water pressures become constant with time after 150 days from the end of construction. The predicted excess pore water pressures below the embankment are also plotted in Fig. 13. The 1-D method over predicted excess pore water pressure while the predictions from the Skempton and Bjerrum (1957) method agree well with the observed data (Tanchaisawat et al. 2007).

Observed lateral wall movement

The lateral wall movement was observed by digitilt inclinometer which was located near the embankment facing. The plots of lateral wall movement with depth from top of embankment to 12 m depth below original ground are shown in Fig. 14. The lateral wall movement was monitored once a week since the end of construction for first month and every month thereafter until 13 months. The lateral movement increased significantly for the first 4 months and decreased to negligible amounts at 13 months after embankment construction. The lateral movement occurred in a short period of time after construction. The total wall movement is quite small, 100 mm at top of embankment. The maximum lateral movement in the soft clay subsoil occurred at about 4.00 to 5.00 m depth below the ground surface, corresponding to the weakest zone of the subsoil.

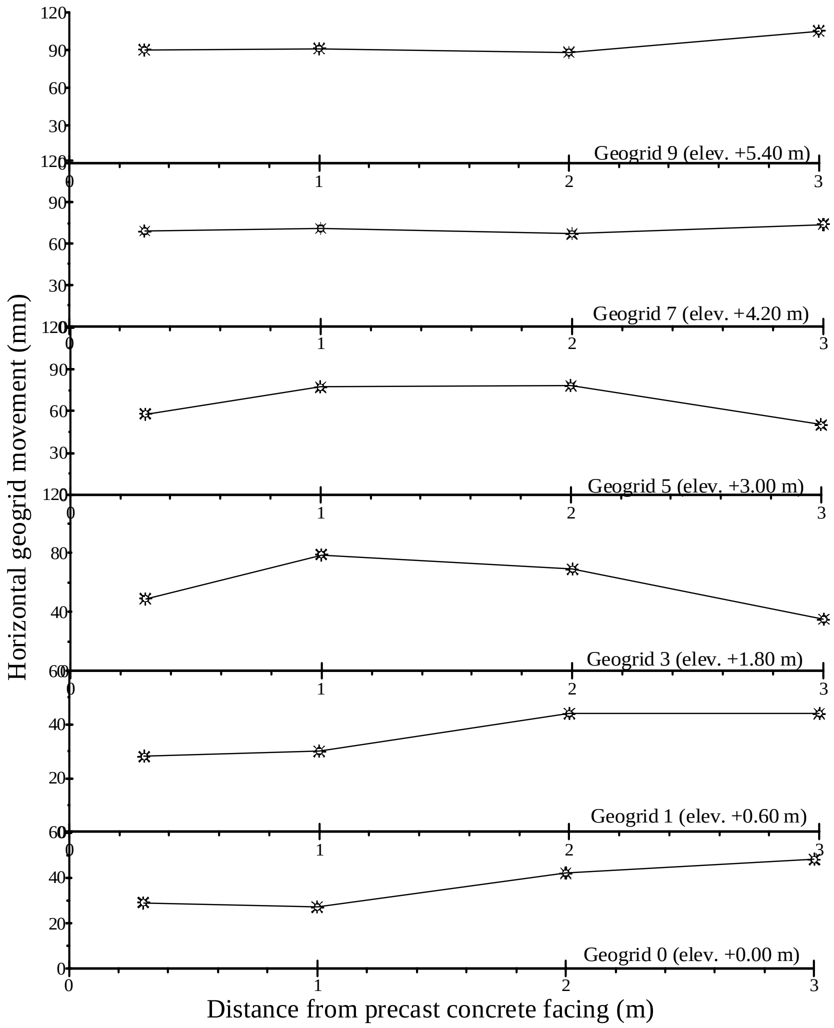

Fig. 15 Observed geogrid movement at 360 days

Compared to conventional sand backfill on untreated ground as reported by Voottipruex (2000), the lateral movement of the lightweight backfill was smaller by about 45%. This indicates that the use of lightweight backfill significantly reduced the lateral movement of the embankment.

Observed geogrid movement

High strength wire extensometers were used to measure the displacements of the geogrid reinforcement related to the surrounding soil. The measurement points were located at 0.3 m, 1.0 m, 2.0 m and 3.0 m from concrete facing to observe the geogrid movement in the rubber tire chips-sand backfill zone. The extensometers were installed at 6 layers of geogrid reinforcements. Geogrid movements were measured at the same time as the lateral wall movement. Figure 15 illustrates the geogrid movement observed from the end of construction until 360 days after embankment construction. At points near concrete facing geogrid movement was less than at other points

For the top geogrid, the maximum movement of about 90 - 100 mm was measured. This value agreed well with the lateral wall movement observed from the inclinometer.

Overall, the movement or deformation of the geogrid reinforcements corresponds to the bilinear type of maximum tension line.

CONCLUSIONS

The percentage of sand mixed in tire chip-sand mixtures was the most significant factor controlling the pullout and direct shear resistance of the mixtures. The pullout resistance increased with the increasing sand content in the mixture and increased with the increasing normal stresses. In direct shear test, the aperture sizes of geogrids significantly affected the direct shear resistance of geogrids. The tire chip-sand mixture with the mixing ratio of 30:70 % by weight yielded the higher results in the pullout and direct shear resistance compared to the other mixtures. Consequently, the mixing ratio of 30:70% was utilized as lightweight tire chip-sand backfill material.

The maximum settlement of the full scale test embankment was 122 mm as recorded in the surface settlement plates near the facing. The unit weight of lightweight backfill is lighter by about 75% when compared to the conventional sand embankment and resulted in settlement reduction of about 67.5%. The lateral movement increased significantly until 4 months after construction and decreased to negligible amounts 13 months after embankment construction. The maximum lateral wall movement of the lightweight embankment at the top was 45% lower when compared to the corresponding conventional sand embankment without foundation treatment. The movement or deformation of the geogrid reinforcements corresponded to the bilinear type of maximum tension line.

ACKNOWLEDGEMENTS

This work was derived mainly from a research project funded by the Royal Thai Government conducted at the Asian Institute of Technology. The facilities provided by the research project are gratefully acknowledged.

REFERENCES

Asaoka, A. (1978). Observation procedure of settlement prediction, Soils and Foundations, 18(4): 87-101.

Edil, T. B. (2007). A review of environmental impacts and environmental applications of shredded scrap tires, International Workshop on Scrap Tire Derived Geomaterials 2007, Yokosuka, Japan: 3-18.

Freudelund, T. E. and Aaboe, R. (1993). Expanpolystylene-A light way across soft ground. Proceedings 14th International Conference of Soil Mechanics and Geotechnical Engineering, New Delhi, India :1256-1261.

Humphrey, D. N., Whetten, N., Weaver, J. and Recker, K. (2000). Tire shreds as lightweight fill for construction on weak marine clay. Coastal Geotechnical Engineering in Practice, Rotterdam, A. A. Balkema Publishers: 611-616.

Kanjananak, T. (2006). Prediction and performance of reinforced rubber tire-sand test embankment, M. Eng. Thesis No. GE-05-7, Asian Institute of Technology, Bangkok, Thailand.

Prempramote, S. (2005). Interaction between geogrid reinforcement and tire chip-sand mixture, M.Eng. Thesis No. GE-04-12, Asian Institute of Technology, Thailand

Skempton, A. W. and Bjerrum, L. (1957). A contribution to the settlement analysis of foundations on clays, Geotechnique, 7(4): 168-178.

Tanchaisawat T., Bergado D. T. and Kanjananak T. (2007). Lightweight geomaterials for bridge approach utilization, Proceedings 16th Southeast Asian Geotechnical Conference 2007, Subang Jaya, Malaysia.: 877-882.

Tanchaisawat, T., Bergado, D. T., Prempramote, S., Ramana, G. V., Piyaboon, S. and Anujorn, P. (2006). Interaction between geogrid reinforcement and tire chips-sands mixture, Proceedings 8th International Conference on Geosynthetics, Yokohama, Japan: 1463-1466.

Voottipruex, P. (2000). Interaction of hexagonal wire reinforcement with silty sand backfill soil and behavior of full scale embankment reinforced with hexagonal wire, D. Eng. Dissertation No. GE-99-1, Asian Institute of Technology, Bangkok, Thailand.

Yasuhara, K. (2002). Recent Japanese experiences with lightweight geomaterials, Proceedings International Workshop on Lightweight Geomaterial: 32-59.