PILOT SCALE FIELD TEST FOR NATURAL FIBER DRAIN

J. H. Kim[1] and S. D. Cho[2]

ABSTRACT: A pilot test using natural fiber drains was conducted to prove their effective discharge capacity in the field. The pilot test site was divided into 5 different areas, with various combinations of vertical and horizontal drains installed for evaluation. Conventional PDB and FDB, as well as the newly developed SDB, were used as vertical drains, while sand and fiber mats were used as horizontal drains. Based on the monitoring data obtained at the test site, the surface settlements which occurred at PDB, FDB and SDB installation fields were almost identical as well as laboratory model test results. The excess pore pressure measured in SDB was greater than that in PDB and FDB, while the dissipation rate of excess pore pressure in SDB was slower than that in PDB and FDB. The generation and dissipation rates of excess pore pressure measured in the ground from the installation of PDB, FDB and SDB were almost identical to the same extent as the surface settlements measured at the pilot test field. Based on the existing data, natural fiber drains represent a promising alternative material for the improvement of soft clay.

KEYWORDS: fiber drain board (FDB), straw drain board (SDB), plastic drain board (PDB), soil improvements

INTRODUCTION

An increasing number of huge construction projects, promoting national key industries, such as airports, expressways and ports etc., have been constructed on sites underlain by thick soft clay deposits over the past few decades. Vertical drain methods such as sand drains and plastic drain boards (PDB) have been widely used to accelerate consolidation of soft clay deposits. However, these technologies have faced difficulties in their application, such as high construction costs for sand drain due to the limited supply of sand, and long-term environmental disruption from PDB installation as a result of the nonperishable characteristics of plastic materials. Geotechnical researchers have performed numerous experiments to substitute eco-materials for geotextiles used in construction fields, made with various chemical materials such as plastics made with polypropylene or polyethylene. Because the amount of construction materials used for ground improvements or reinforcements is usually tremendous at construction field, construction cost is of great concern in addition to the quality of the materials. Therefore, many researchers are trying to use one of the most abundant and cheap eco-sources, natural fiber from plants, as construction materials. Eco-sound vertical and horizontal drains, made with coconut coir and jute filter, already have been used for eco-sound soft ground improvement in Japan and Southeastern countries. In addition, new types of environmentally friendly vertical drain, made with straw strands and jute filter, called straw drain board (SDB), have been recently developed in Korea. In this paper, results from a field pilot test as well as several laboratory tests for these natural fiber drains are discussed.

TYPES OF VERTICAL DRAINS

The main function of vertical drains is to accelerate the consolidation process by fast dissipation of the excess pore pressure induced by embankment load which usually lasts for 2 to 3 years. However, plastic drain board (PDB) which is nonperishable materials may become a source of pollutant after the completion of consolidation settlement. The idea of natural fiber drain board called fiber drain board (FDB) made with jute filter and coconut coir, which naturally decomposes with time, was first proposed by Professor Lee et al. (1987) of Singapore National University as an alternative method to replace nonperishable plastic drain board. In order to take advantage of agricultural residue, rice straw, which is abundantly produced in Korea, another natural fiber drain board called straw drain board (SDB) was also recently developed in Korea. The width and thickness of

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both drains were approximately 85—95 mm and 5—10 mm, respectively. The diameters of the coir of FDB and the straw strands of SDB were 5 and 8 mm respectively, with each strand enveloped by two layers of jute burlap. The jute burlap was manufactured from jute fibers, which are available in many parts of Southeast Asia. Three longitudinal stitches hold the coir or strands in separate flow channels within the jute burlap. Fig. 1a shows a fiber drain board (FDB) made with coconut coir and jute filter, while Fig. 1b shows a straw drain board (SDB) made with straw strands and jute filter. The plastic drain board (PDB) shown in Fig. 1c, which was also tested in this study to compare to natural fiber drains, was 10 cm-wide and 5 mm-thick.


(a) FDB (b) SDB (c) PDB

Fig. 1 Prefabricated vertical drains

TENSILE STRENGTH OF VERTICAL DRAINS

Tensile strength of plastic drain board (PDB) and natural fiber drain boards such as FDB and SDB are quite different. The strain on the PDB increased continuously after passing the point of inflection, with/without addition of small tensile force. However, the maximum tensile strength of the FDB and SDB deceased notably after reaching a maximum value, at approximately 10% strain. Despite such differences in strength behavior, the maximum tensile strengths of the FDB and SDB were 1 to 3 kN/width greater than that of the PDB, which proved to be acceptable for field installation.

DISCHARGE CAPACITY OF VERTICAL DRAINS

Fig. 2 shows the discharge capacity obtained from a model test called composite discharge capacity (CDC) test for the PDB, FDB and SDB. CDC apparatus is made with thin cylindrical steel which is 50 cm in diameter and 100 cm in height. With the CDC apparatus, a 65 cm-long drain is directly installed into the soft clay lump and confined by the surcharge load. The CDC test is more advantageous than the triaxial type apparatus in that the discharge capacity of the drain and the consolidation settlement can be monitored simultaneously. The initial discharge capacities of FDB and SDB by CDC test were relatively lower than that of PDB as shown in Fig. 2. The final discharge capacity of the SDB by CDC test was evaluated as 0.77 cm^3/sec under 250 kPa pressure, which was still lower than the 5.0 cm^3/sec of the PDB and 4.6 cm^3/sec of the FDB under the same condition. Moreover, the trend for a decreasing discharge capacity with time of the SDB was also more significant than those of the PDB and FDB. Despite its low discharge capacity, the final settlement from the installation of the SDB was identical to those from PDB and FDB as shown in Fig. 3. Such results of surface settlement from the installation of the SDB is significant, in that SDB has the potential to have the minimum discharge capacity required as a vertical drain.

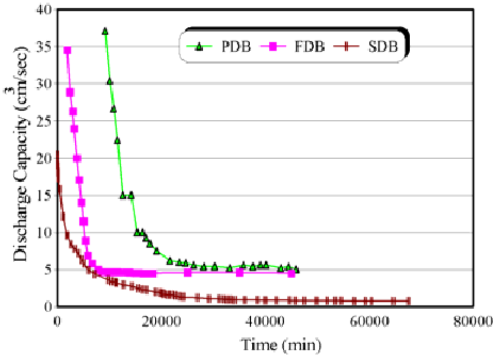

Fig. 2 Discharge capacity results by CDC test

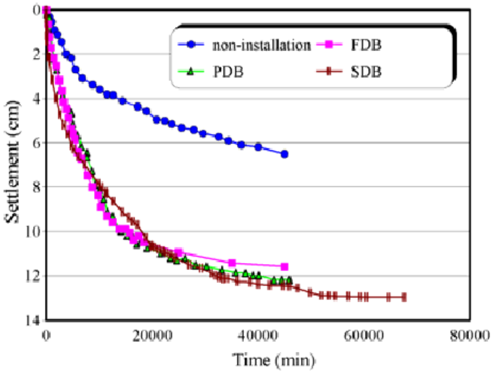

Fig. 3 Settlement curves by CDC test

Different deformation of vertical drain boards are partly explained why the discharge capacity of the PDB decreases drastically, while the settlement curves for the PDB, FDB and SDB are similar. The flexible PDB has a greater potential for reducing the discharge capacity factors, such as kinking or bending, than either the FDB or SDB. Therefore, PDB was found to be relatively more bent and kinked than either the FDB or SDB after the CDC test. These trends are expected to occur similarly or more significantly in the field.

DECOMPOSITION

FDB and SDB samples were embedded in distilled water, sea water and the Kwangyang clayey soil which was classified as typical low plasticity clay to evaluate decomposition of natural fiber drains as time goes on. Decomposition of FDB and SDB was evaluated by tensile strength test specified in ASTM D5035. Fig. 4 shows variation of tensile strength of FDB and SDB with embedded time. In the first 3 months, notable change in tensile strength of FDB was not identified. However, tensile strengths of FDB decreased drastically after 9 months of embedding in sea water and clayey soil. A similar trend of decrease in tensile strengths of FDB followed in the next 21 months; a period of small decrease after 18 months followed by a period of sharp decrease after 30 months of embedding in clayey soil. This decreasing trend of tensile strength of FDB can be partly explained by changes in temperature from seasonal variation. It was beginning of winter season when FDB samples were embedded in distilled water, sea water and clayey soil. Tensile strength of FDB decreased sharply after every summer season. It is assumed that bacteria multiplies in warm temperatures and accelerates the decomposition of textile structure. However, the tensile strength of FDB after 30 months of embedding in clayey soil is still above the required minimum tensile strength of PDB, which is 1-2kN/width. It is interesting that the tensile strength of SDB after 15 months of embedding in clayey soil decreased almost same amount compared to that of FDB. The study on decomposition of natural fiber materials will be performed continuously.

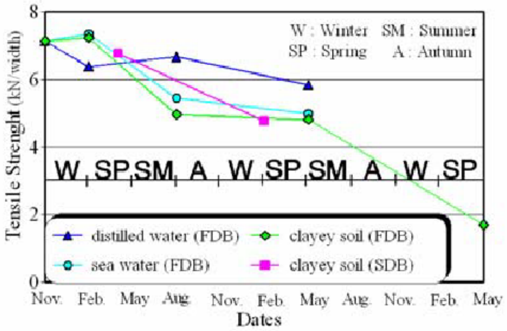

Fig. 4 Variation of tensile strength with time

PILOT SCALE FIELD TEST

Site Investigation

The overall purpose of this pilot scale field test is to evaluate field performance of each vertical drain which has already been verified by laboratory tests. The pilot test is conducted at a 4-lane road construction site connecting two main highways located in Mokpo of the southern coast of Korea. Mokpo is not far from Kwangyang area where the clay sample for CDC tests was collected. Cone penetration test (CPT), standard penetration test (SPT) and thin wall piston sampling in boreholes were carried out to evaluate the soil properties and geological profiles of the pilot test site. Fig. 5 shows the recorded N-values from SPT, cone resistance, q_c, from CPT, natural water content (w_n), liquid limit (LL), plastic limit (PL), compression index (Cc), coefficient of consolidation, (c_v) from oedometer tests and typical soil profile. Based on the results of site investigation, original strata can be classified into 5 soil layers. Two marine clay layers, Clay A and Clay C, were found to be separated by Clay B, which is a stiff clay layer with 3 m in thickness. The Clay A layer was expected to be very soft, for it had high natural water content ranging in between 60%－72%, which is greater than its liquid limit. Low N-value from SPT and low cone resistance from CPTU confirmed that the Clay A layer consists of very soft clayey soils. The liquid limit of relatively stiff Clay B layer is 33%－56%, which is greater than its natural water content ranging from 24% － 42%. Similarly, the liquid limit of Clay C layer is 34%－48%, which is greater than its natural water content ranging in between 33%－43%. The plastic limits of three clay layers are similar and found to be in the range of 21%－29%. Clay A is relatively high-plastic, whereas Clay B and Clay C are low-to-medium plastic based on plasticity chart. The compression index, Cc, of Clay A-layer from oedometer tests ranges in between 0.59 to 0.79 which is relatively greater than that of Clay C in the range of 0.2 to 0.52. The compression index of the intermediate Clay B could not be obtained because undisturbed samples contained small gravels which had made trimming of test sample difficult. Sudden increase in cone resistance at depth of between 6 m and 7 m of field ⑤ was also due to these small gravels contained in Clay B. The coefficient of consolidation of Clay A ranges from 1.7×10^{-4} cm^2/sec to 34.3×10^{-4} cm^2/sec which is greater than that of Clay C ranging from 2.5×10^{-4} cm^2/sec to 54.5×10^{-4} cm^2/sec.

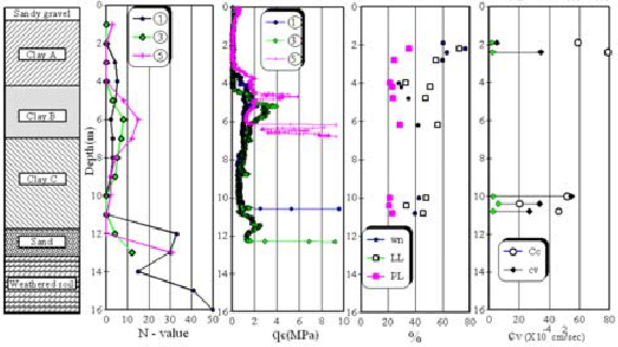

Fig. 5 Soil properties and geological profile of pilot test site

Geotechnical characteristics of the soil profile at the pilot test site can also be explained in terms of geology. Generally, the strata of the pilot test site, which are similar to those typically obtained in western coast of Korea, can be classified into four units. The four units consist of middle to late Holocene tidal deposit (Clay A), early Holocene siderite-containing stiff mud deposit (Clay B), late Pleistocene tidal deposits (Clay C) and late basal gravelly sand deposit (Sand and Weathered soils). Especially, stiffness of Clay B-layer, which is relatively much harder than the other clay strata can be explained in that Clay B-layer is paleosol formed by pedogenesis which had been exposed during the recent glacial age (Choi and Kim 2005,2006).

Test Plan and Present Field Condition

Three types of vertical drain, namely PDB, FDB and SDB, and two types of horizontal drain, sand mat and fiber mat, were installed at the pilot test site. The 170 m long and 50 m wide pilot test site was formerly a rice field. Originally, soil improvement methods involving sand drains and sand compaction piles as vertical drains and sand mat as horizontal drain were planned prior to road construction. However, PDB, FDB and SDB were installed as alternates of sand drain and sand compaction pile for this test. Both fiber mat and sand mat were also installed to compare their effectiveness in addition to their comparison with 3 types of vertical drains. Details of the combination of drain installation at the pilot test site are shown in Fig. 6. As shown in Fig. 6, the test site consists of 5 fields. Fields ① and ② have PDB installed as vertical drain in 1.4 m spacing, with sand mat and fiber mat as horizontal drain, respectively. In order to reinforce the high embankment slopes of field ① and ② from shear failure, 70 cm-diameter sand compaction piles were installed in 1.6 m spacing. For comparative study of PDB, field ④ and ⑤ had FDB as vertical drain in 1.4 m spacing, with sand mat and fiber mat as horizontal drain, respectively. New developed proto type SDB was installed at field ③ with 1.2 m spacing with sand mat.

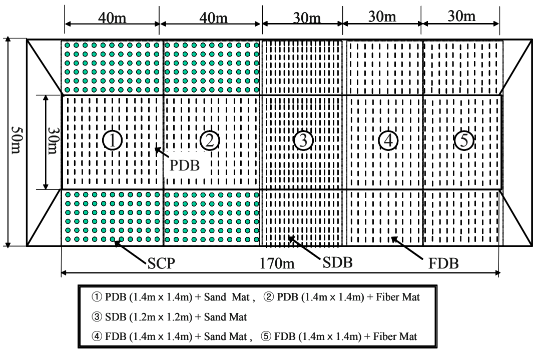

Fig. 6 Plane figure of the pilot test site (not scaled)

Several instruments such as settlement plate, vibrating wire type piezometers and inclinometers were installed to monitor the soil behavior during ground improvement. Particularly, two types of piezometer were installed; one which measures the variation of pore pressure in soft clay, and another which measures the variation of pore pressure in vertical drains. Most of the instruments were installed immediately after installation of the vertical drains.

Surface Settlements

Fig. 7 shows the surface settlements results from 19 months of monitoring from September, 2005 to April, 2007. Although the embankment height of the PDB installation field was relatively higher than those of the SDB and FDB, the amounts and rates of settlement of the PDB (P-2), SDB (S-3) and FDB (F4, F-5) installation sites were similar.

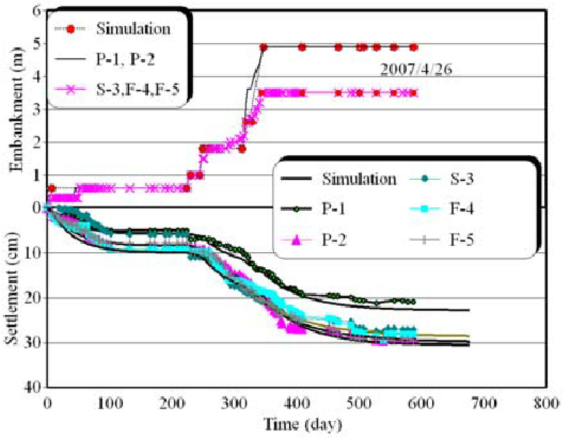

Fig. 7 Surface settlements measured at pilot test site

To more specifically analyze the soil improvement characteristics of the three types of vertical drain, the final settlement was predicted using a simulation method, based on conventional Terzaghi-Barron's consolidation theories, along with the ground investigation results, construction histories and monitored surface settlements. With the simulation method the monitored time-settlement curves were initially plotted, with the predicted time-settlement curves then superposed by applying proper soil properties via trial and error. This method was based on many assumptions and; therefore, a little complicated, but has been verified as very useful with respect to practical problems (Cho 1998). The monitored time-settlement curves obtained from the pilot test, as well as those predicted by the simulation method are shown in Fig. 7. The settlement rates, which is the percentage ratio of the monitored (A) to predicted (B) final settlement, for each test site are also shown in

Table 1. The settlement rates for sites P-1 and P-2, where PDBs were installed, were 91% and 94%, respectively, that for site S-3, where SDBs were installed, was 96% and those for sites F-4 and F-5, where FDBs were installed, were 96%－98%, respectively. Based on the results of the surface settlement, the consolidation processes at the pilot test sites were all similar, regardless the types of vertical drain.

Table 1 Settlement rates

Location	Monitored settlements (A) (cm)	Predicted final settlements(B) (cm)	Settlement rate (A/B) (%)
P-1	20.9	22.9	91
P-2	28.8	30.7	94
S-3	34.1	35.5	96
F-4	28.2	29.2	96
F-5	29.5	30.3	98

Pore Pressures

Generally, a pore pressure analysis is more difficult than that for settlement, in that there are many factors that influence the generation and dissipation of the pore pressure process, such as permeability, degree of saturation and stress history, and so on. In addition, with the exception of the quality of the piezometer itself, time lag, air bubble, clogging and variation measuring points due to settlement, temperature and atmospheric pressure, etc. also influence the observed pore pressure. Therefore, doubt still exists with regard to pore pressure analysis, even though many numerical and monitoring research trials have been performed. This is why a settlement analysis for the evaluation of a consolidation process is clearer than a pore pressure analysis in the field.

Figs. 8 and 9 show the excess pore pressures measured in the ground and vertical drains, respectively. Initially, the embankment construction was stopped after 50 days, but the excess pore pressure measured in the ground and vertical drains increased until 100 days. Therefore, it was found that the time lag phenomena occurred in the field. An additional embankment construction began in May 2006, where the excess pore pressure in the ground and vertical drains was found to gradually increase. The excess pore pressures measured in the vertical drains were relatively greater than those in the ground. This difference in the excess pore pressure between the ground and vertical drains was able to be partly explained by the different installation conditions. Piezometers for measurement of the pore pressure in the ground were installed by filling with sand around the piezometers, but those for measurement of the pore pressure inside the vertical drains were installed inside the thin filter of the vertical drains. Therefore, it was estimated that the piezometers for vertical drains were exposed to a greater clogging effects than those for ground.

In addition, the excess pore pressure measured inside the proto-type SDB and the ground was greater than that in the FDB and PDB, while the dissipation rate of the excess pore pressure in the SDB was slower than those in the PDB and FDB. These results related well with those from the Composite Discharge Capacity (CDC) test, as previously described. However, since the results of the excess pore pressure were quite different from those for the surface settlements, long term monitoring will be necessary.

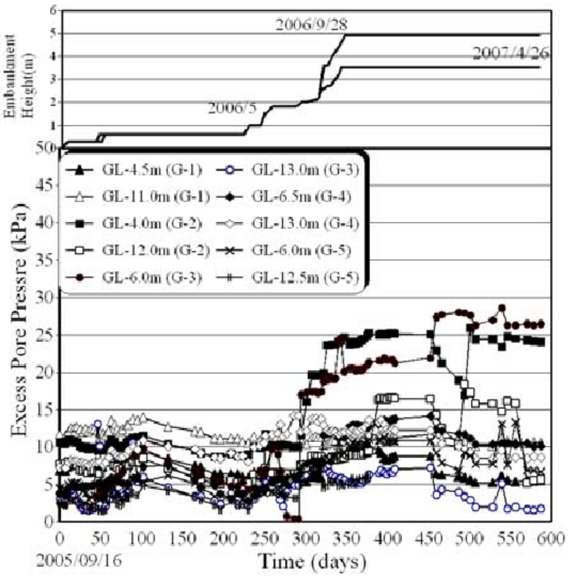

Fig. 8 Excess pore pressure measured in the ground

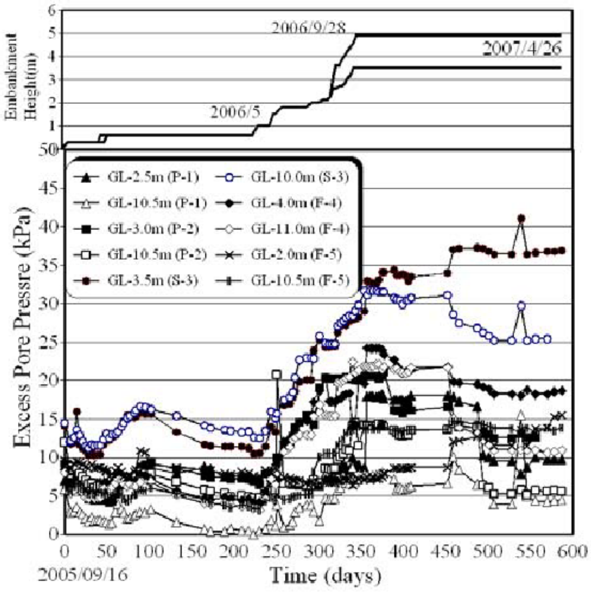

Fig. 9 Excess pore pressure measured in the vertical drain boards

CONCLUSION

In this study, a pilot scale field test for FDB, PDB and proto-type SDB were carried out to evaluate their practical applicability. Based on the monitoring data obtained at the pilot test site, the surface settlements which occurred at PDB, FDB and SDB installation fields were almost identical. The excess pore pressure measured in SDB was greater than that in PDB and FDB, while the dissipation rate of excess pore pressure in SDB was slower than that in PDB and FDB. The generation and dissipation rates of excess pore pressure measured in the ground from the installation of PDB, FDB and SDB were almost identical to the same extent as the surface settlements measured at the pilot test field. Based on the existing data, natural fiber drains represent a promising alternative material for the improvement of soft clay.

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REFERENCES

ASTM D5035. Standard Test Method for Breaking Force and Elongation of Textile Fabrics (Strip Method)

Choi KS, Kim JH (2006) Identifying late Quaternary coastal deposits in Kyonggi Bay, Korea, by their geotechnical properties, Geo Marin-letters, Springer-Verlag, 26: 77-89

Cho, SM (1998) Deformation Characteristics of Soft Clayey Deposits under the Embankment Loading in Korea, Ph.D Thesis, Seoul National University

Lee S L et al. (1987) Fibredrain for Consolidation of Soft Soils, Post-Vienna Conf. on Geotextiles, Singapore: 238-258

Korea Institute of Construction Technology (2006) Soft Ground Improvement Method for Road Construction using Environmentally Friendly Drains, Report of Construction Infra-structure Technology Research & Development Project. Ministry of Construction and Transportation: 399