LONG TERM FIELD MONITORING OF CHEMICALLY STABILIZED SAND WITH GROUTING

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Abstract: Chemical grouting method is employed frequently within an urban area to improve the strength and permeability characteristics of soft ground. In order to ensure the long term performance of chemically stabilized sand with grouting, the systematic field measurement of the mechanical characteristics of the chemical grouted sandy soil has been carried out by the Japanese Grouting Association for the period of five years, from 2000 to 2005. The test field soil condition consisted mainly of comparatively dense sand with gravel and the ground water table was around 6 m below the ground surface. Four types of silicate grouting materials were employed. Standard penetration tests (SPT), lateral loading tests (LLT), in-situ permeability tests and flow meter tests within a bored hole were conducted to obtain the strength and permeability characteristics of the grouted sand. The SPT-N value and LLT deformation modulus of the grouted sand with a silicate material of an organic hardener has increased for the initial two years and then decreased for the next year. However, its N-value was still the triple times the initial one. It has been concluded that silicate grouted materials have demonstrated the satisfactory performance during the period of three years.

Keywords: Soil stabilization; chemical grouting; site investigation.

1. INTRODUCTION

The purpose of employing chemical grouting method as a supplementary method for underground construction in urban area is to achieve the short-term effects. Hence, there are few case studies on its long-term performance. As a result, the duration at which the injected chemical grout material maintained its performance within the soil is not fully understood, since there were no follow-up surveys. From the laboratory experimental results, several researchers reported that there was no long-term durability of small sand specimens stabilized with common types of water glass material. On the other hand, the durability of the soil mass stabilized with chemical grouting has been qualitatively reported from the field observation results, where the excavation of chemically stabilized soil mass has been fortunately conducted after the completion of the project. Currently, the application of chemical grouting method is increasingly demanded in cases, where the long term durability of chemically stabilized soil is anticipated to be a countermeasure against the liquefaction.

In order to ensure the long term performance of chemically stabilized sand with grouting, the systematic field measurement of the mechanical characteristics of the chemical grouted sandy soil has been carried out by the Japanese Grouting Association for the period of five years, from 2000 to 2005. This paper summarizes the field monitoring test program and the results for the initial three year period of the long term performance with chemically stabilized sand with grouting.

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2. PRELIMINARY SURVEY AND TESTING PROGRAM

The soil layer profile, the soil grading and the N-value measurement results are indicated in Fig. 1. The sandy soil layer prevails over the whole test field zone. Small gravel grain is mixed with the sand layer and a large amount of gravel is partly found. According to the grain-size analysis results, the soil composition is mainly that of sandy soil and fine grained material content is less than 10 %, but in certain parts of the layer, the gravel content is between 25 and 50 %. The N value ranges within 14 $\sim$ 17 down to GL-5.0 m and is found to be comparatively loose. Below GL-5.0 m, N value is increased to be 20 $\sim$ 40, 50 and the soil is at dense condition. The underground water level is GL-5.7 $\sim$ 5.8 m and the seasonal fluctuation of the depth is 5.0 $\sim$ 6.1 m. The hydraulic conductivity is 1.2×10^{-2} (cm/s) on average and is an almost homogeneous layer.

Three types of silicate grouting materials, "Type A: inorganic alkaline material", "Type B: organic alkaline material" and "Type C: neutral and acid material" were employed. In addition, a small amount of "Type D: silica colloid material" assumed to be durable was injected for the lateral loading test in the final year, for comparison. The injecting method

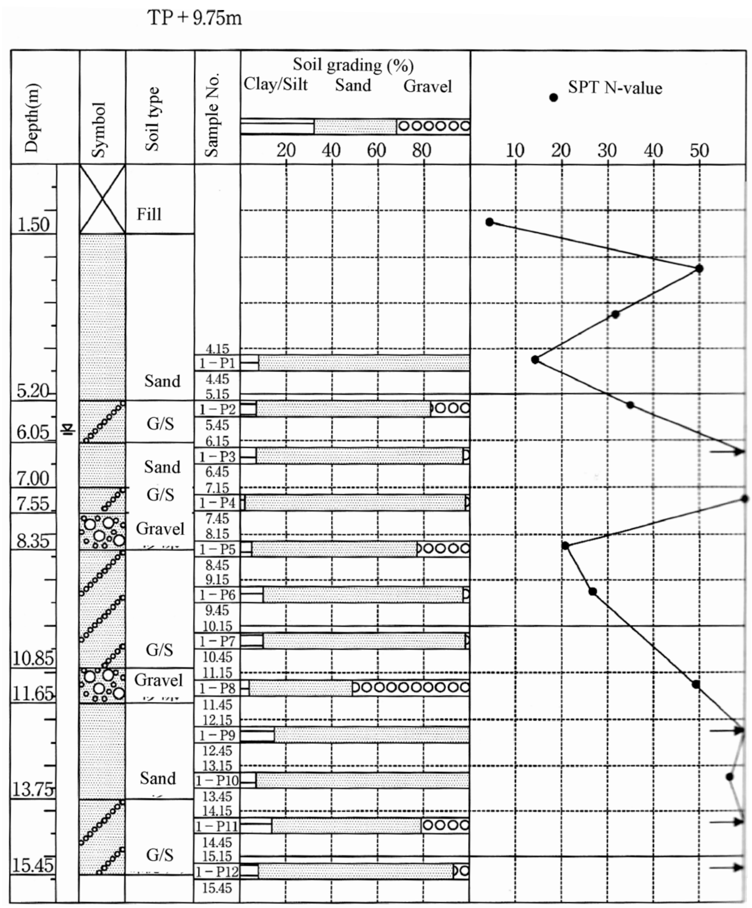


Figure 1. Soil profile, soil composition and SPT N-value of test field.

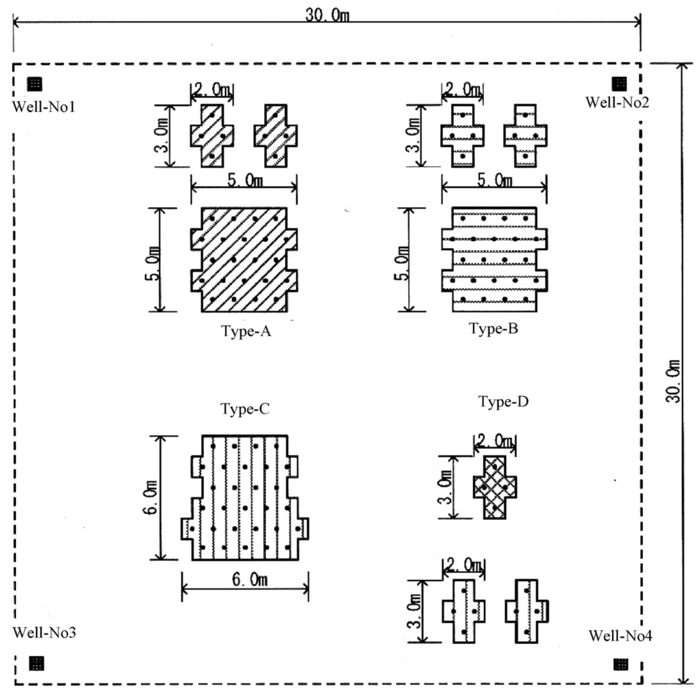


Fig.2 Plan of the field test site

Figure 2. Plan of the field test site.

adopted was a "double-packer method", which guarantees a high quality outcome that ensures the uniform improvement of the target sand layer as much as possible. However, the commonly used CB (Cement Bentonite material) grouting was omitted.

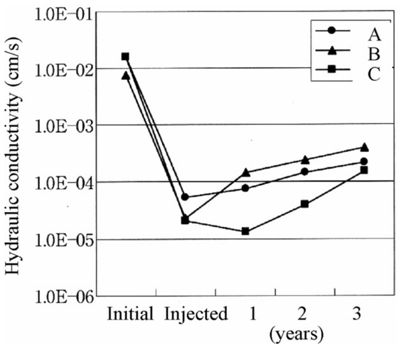
The chemical injection for each material was basically conducted on a test field site soil mass plan of 5 m×5 m, as shown Fig. 2. The grouting depth was selected to be GL-6.0m ~ 11.0 m. This depth was determined because the water table level was about GL-5.8 m and the upper end of the injection area had to be deeper than the water table. The ratio of the grouting material volume against the soil volume was 43%. The spacing between the injection holes adopted was 1.0 m pitch, injection step length: 33 cm, injection rate: 12 l/min, gel time: 30 ~ 50 min, the injection pressure: 1 ~ 1.5 MPa on average and the injection was controlled at a fixed injection rate of 144 l/step length.

Standard penetration tests (SPT), lateral loading tests (LLT), in-situ permeability tests and flow meter tests within a bored hole were conducted to obtain the strength and permeability characteristics of the grouted sand. These measurements have been performed once a year for this period.

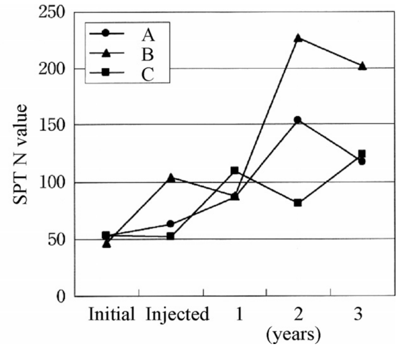
3. FIELD MONITORING RESULTS

The monitoring results for the period of initial three years are shown as follows.

Figures 3(a) and 3(b) indicate the variation of hydraulic conductivity and SPT-N values. Many of the previous laboratory-based reports have indicated no change in strength immediately after the grouting. However, the SPT N-value increases greatly over time more than the value obtained at just after the injection. The hydraulic conductivity increases each year.



(a) Hydraulic conductivity



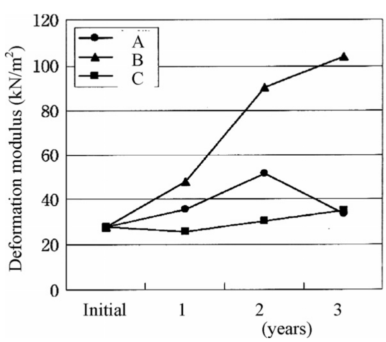
(b) SPT-N value

Figure 3. Variation of hydraulic conductivity and SPT-N value.

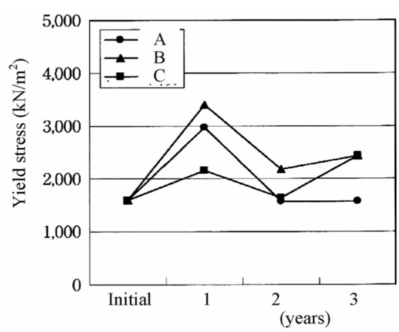
But the hydraulic conductivity value is around 1.5,3.8$\times10^{-4}$ (cm/s) and the cutoff capacity of the injected soil mass remains to be kept. As for the Type B organic alkaline material, the results indicate twice the value of N compared with other injected materials immediately after grouting and has been proven to have high strength characteristics. The SPT-N value for Type C neutral and acid material increases every year.

Figures 4(a) and (b) demonstrate the time dependent change of the deformation coefficient and the yield stress values obtained from LLT tests within a bore hole. The deformation modulus of the chemical injected materials experienced a small change after the third year except for the Type B: organic alkaline material. In the case of Type B material, the deformation modulus increases up to three times of the initial value particularly for the period from the first year to second year due to the development of chemical reaction, as is the same as in the SPT-N value. The yield stresses increase more than their initial values during the first year. However, in the second and third year, the Type A material values were decreased to almost the same as the initial value, while both of the Type B and Type C material values increase their yield stress values to about 1.5 times of the initial values.

Sulphate radical is a constituent of chemical injected material for Type C: neutral and acid material. Hence, it can potentially decompose the cement concrete material. Therefore,



(a) Deformation modulus



(b) Yield stress

Figure 4. Variation of deformation modulus and Yield stress from LLT.

a concrete pile was embedded within the injected soil mass using the Type C material. The inspection results show that no decomposition of cement concrete material is observed even in the case of Type C material for the initial three years.

4. CONCLUSION

In order to ensure the long term performance of chemically stabilized sand with grouting, the systematic field measurement of the mechanical characteristics of the chemical grouted sandy soil has been carried out by the Japanese Grouting Association for the period of five years, from 2000 to 2005. This paper summarizes the field monitoring test program and the results for the initial three year period of the long term performance with chemically stabilized sand with grouting.

The major findings from the field monitoring of chemically injected soil mass are summarized as follows.

(1) The SPT-N value and LLT deformation modulus of the chemically stabilized sand with a silicate material of an organic hardener has increased for the initial two years and then decreased for the next year. However, its N-value was still the triple times the initial one.
(2) The hydraulic conductivity just after the grouting have decreased to around 10^{-5}(cm/s) and then gradually increased to the value of around 10^{-4}(cm/s). The significant water leakage from the grouted zones has not been observed by the flow meter tests.
(3) No decomposition of cement concrete material has been observed even in the case of Type C: neutral and acid material for the initial three years.

Consequently, silicate grouted materials have demonstrated the satisfactory performance during the period of initial three years. The final field observation of the grouted sand is planned to be carried out by the end of this year, 2009.

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