International Conference on Case Histories in Geotechnical Engineering

(1993) - Third International Conference on Case Histories in Geotechnical Engineering

02 Jun 1993, 2:30 pm - 5:00 pm

Case History of Soil Improvement for a Large-Scale Land Reclamation

Bang W. Shin
Chungbuk National University, Cheong-Ju, Korea

Eun C. Shin
Southern Illinois University, Carbondale, Illinois

Sun W. Kim
Hyundai Construction Company, Ltd., Seoul, Korea

Byung C. Yeo
Southern Illinois University, Carbondale, Illinois

Paghunath Dass
Southern Illinois University, Carbondale, Illinois

Proceedings: Third International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, June 1-4, 1993, Paper No. 7.06

Case History of Soil Improvement for a Large-Scale Land Reclamation

Bang W. Shin
Professor of Civil Engineering, Chungbuk National University, Cheong-Ju, Korea

Sun W. Kim
Chief Engineer, Hyundai Construction Company, Ltd., Seoul, Korea

Eun C. Shin
Research Assistant, Southern Illinois University, Carbondale, Illinois

Byung C. Yeo and Paghunath Dass
Research Assistants, Southern University, Carbondale, Illinois

SYNOPSIS: In recent years, land reclamation works have been extensively implemented along the coastal lines for a variety of purposes. This paper relates to the case history of a land reclamation project for a steel mill complex construction in Korea. Site improvement techniques used in this project include construction of sand drains and preloading. Construction procedures of sand drains are described as well as staged loading process along with field observations. Field measurement of settlement and theoretically estimated values are compared. The results of standard penetration tests and unconfined compression tests at various depths of soil, and time intervals are presented. Finally, the methods of construction quality assurance are discussed.

INTRODUCTION

With rapid pace of industrialization, many countries of the world are beginning to face a land shortage problem. Soil improvement techniques can help in reclaiming unfavorable ground for foundation construction. In the past 30 years, soil improvement works have been extensively implemented along the coastal areas where soft clay may generally be encountered. Most of these soil improvement works are for the construction of airport, industrial complex, storage tanks, breakwater system, port and harbor facilities, and so on.

There are a number of methods for improving poor soils which are not suitable to support foundations. Construction of sand drains with preloading can accelerate the consolidation process of clayey soil and hence increase its shear strength. Application of preloading contributes to reduction of the possible post construction settlement due to the future construction. Improved ground through these processes could prevent and/or reduce damages by earthquake. The present paper is a case history of the second consequent land reclamation project for Kwang-Yang steel mill complex in Korea. The project site and location is shown in Fig. 1, about 300 km south of Seoul, where the average depth of sea water is about 5 m. The reclaimed area was planned to be used for the hot strip mill (slab yard, water treament facilities, road & railroad, refinery yard) and cold rolling mill (machinery foundation, shipping yard, water treatment, road).

Site improvement techniques used in this project include sand drains as well as preloading. The diameter of sand drains was about 0.5 m and its center-to-center spacing ranged from 1.8 m to 2.5 m. The sand drains were laid out in square pattern with an average length of about 25 m. The total reclaimed area was about 469,700 m^2 and the volume of sand used for construction of sand drains as well as preloading was about 3,067,000 m^3.

SOIL CONDITIONS

The general nature of the in-situ soil along with field standard penetration resistance (N-values) are shown in Fig. 2. Average depth of sea water was above 5 m before backfilling with sand. The unit weight of backfill material was about 16.67 kN/m^3 with an average soil friction angle of 30°. The in-situ soil profile can be generally described as about 5 m of very loose alluvial sand and loose silty sand followed by very soft silty clay and clayey silt up to a depth of 20 m. Underlying this was a 5 m thick dark gray stiff clay. Bedrock and in someplaces, sandy gravel were located below the clay layer. Standard penetration resistance (N values) varied from 0 to 29, but more than 80% of the N values were below 10. Most of N values were between 0 and 2 in soft clayey soil and relatively higher N-values were encountered in stiff clay layer.

Sieve analysis showed that 24% of soil in upper sandy layer, and 88% of soil in middle clay layer passed No. 200 U.S. sieve. Average natural water content for the clayey soil was about 52%. The specific gravity, unit weight, and soil friction angle of upper sandy soil are approximately 2.65, 17.65 kN/m^3, and 32°, respectively. The average physical properties of the clayey soil were as follows: Specific gravity = 2.69; Liquid limit = 61.4%; plastic limit = 24.8%; plasticity Index = 36.6%; and sensitivity = 7.1. The average preconsolidation pressure P_c, compression index C_c, and coefficient of consolidation C_v were determined as 88.26 kN/m^2, 79.43 kN/m^2, and 1 x 10^{-3} cm^2/sec. The average void ratio for the clayey soil was about 1.52.

CONSTRUCTION OF SAND DRAINS

Site improvement method adopted for this project was construction of sand drains along with preloading. The diameter of sand drains was about 0.5 m with spacing ranging from 1.8 m to

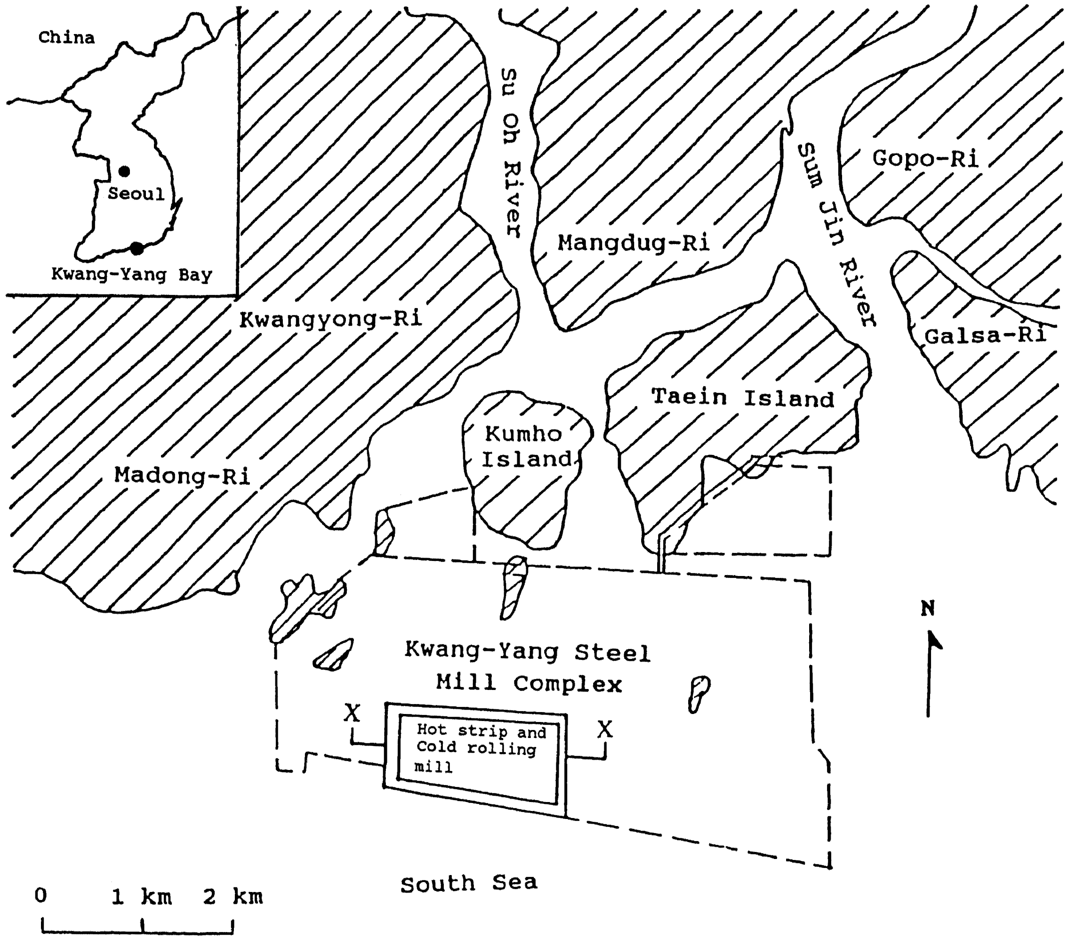

Fig. 1 Project site location of the Kwang-Yang Steel Mill Complex

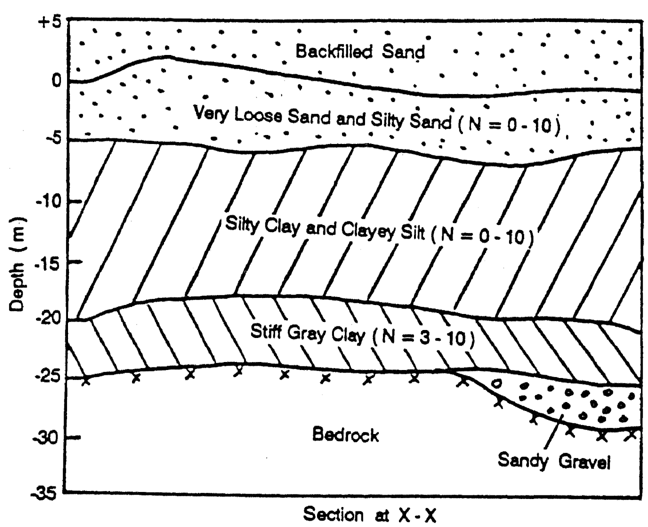

Fig. 2 Typical soil profiles with N-values along the cross section X-X in Fig. 1

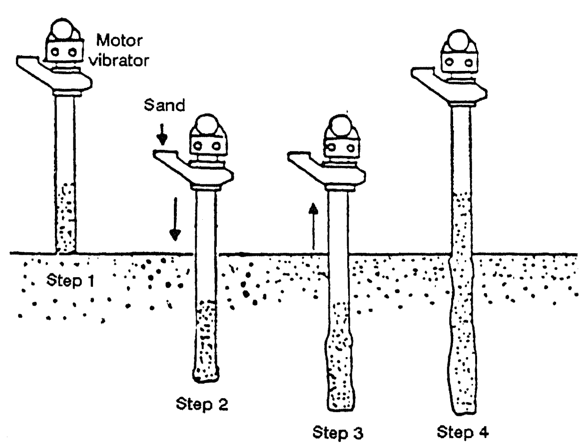

Fig. 3 Construction sequence for sand drains

2.5 m for hot strip mill site, and from 2.0 m to 2.5 m for cold rolling mill site. Typical construction pattern of sand drains was laid out in regular square pattern with an average sand drain length of 25 m. The sequence of the construction procedure for the sand drains are schematically shown in Fig. 3. They are as follows:

Step 1. Installing a casing pipe at the designated position on the ground with the help of 443 kN crawler crane with a less than 0.3 m horizontal deviation. The diameter of casing pipe was 0.4 m with an casing thickness of 16 mm.

Step 2. Driving the casing pipe into the ground with the aid of 54 kN vibrator which was attached at the top of the casing pipe. Sand backfill material was poured into the upper hopper during this process to reduce the time of sand drain construction.

Step 3. When the casing pipe reached the desired depth (i.e about 25 m), it was withdrawn with vibration to compact the sand in the casing pipe and also to apply the air pressure of 392 kN/m^2 to extrude compacted sand out from the lower end of the casing pipe. The casing pipe was withdrawn at the rate of about 9 m/min. Air pressure inside the casing, volume of sand supply, and withdrawal speed of the casing pipe were varied depending upon the soil properties and the desired unit weight of sand.

Step 4. Construction of sand drains was continued until it reached the ground level.

Construction of sand drains do not require redriving process like construction of sand compaction pile (Shin & Shin, and Das, 1992). Shin & Shin, and Das (1992) have reported the cases for which sand pile construction were not successful. An important design parameter in the design of sand drains is the area replacement ratio, a_s, which may be defined as

$$a_s = \frac{A_s}{A} \tag{1}$$

where A_s is the area of the completed sand drain ($A_s = \pi D^2/4$, D = sand drain diameter) and A is the total area tributary to the sand drain ($A = \sqrt{3}/2\ d^2$). The sand drain spacing, d, with a square pattern can be given as

$$d = 0.886D[\frac{1+e_i}{e_i-e_f}]^{\frac{1}{2}} \tag{2}$$

where e_i is the initial void ratio of loose sand before construction of sand drains and e_f is the final void ratio of sand after construction of sand drains.

PRELOADING

Preload was applied over the area where sand drains were constructed to accelerate the primary consolidation process of soft clay and to increase the shear strength of the clayey soil. Preloading proceeded through staged loading along with the monitoring of the pore water pressure dissipation and settlement. The overall stability against slope and base failure was also checked.

Preloading heights varied from 1.0 m to 13.0 m in the hot strip mill site, and from 2.0 m to 11.0 m in the cold rolling mill site. The unit weight of soil used for preloading was about 16.67 kN/m^3 with an average friction angle of about 30°. Twenty four surface settlement plates in the hot strip mill site and 48 surface settlement plates in the cold rolling mill site were installed to monitor the settlement along the staged loading process. Three ground water monitoring wells were also installed for each site.
Preloading height and layout of the field measurements in the hot strip mill site are given in detail in reference (1).

Observed settlement in the field and theoretically estimated settlement are tabulated in Table 1 for hot strip mill site. Observed and total settlements shown in Table 1 are also plotted in Fig. 4. They appear to have a very good agreement. Consolidation settlement of the sand drain improved ground in this project was calculated by assuming that the coefficient of consolidation in horizontal direction C_h is the same as the coefficient of consolidation in vertical direction C_v, that is, $C_h = C_v = 5.5 \times 10^{-4}$ to 9.0×10^{-4} cm^2/sec.

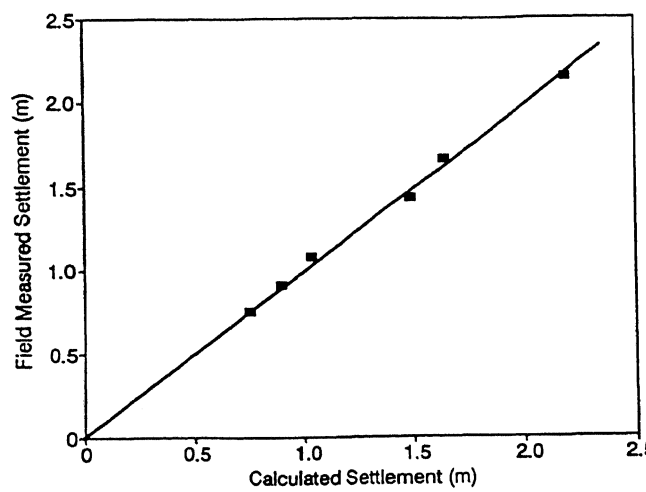

Fig. 4 Comparison between field measured and calculated total settlement

The field settlement as observed from settlement plate No. 5 (refinery yard in hot strip mill site) along the staged loading is shown in Fig. 5.

STABILITY CONTROL AGAINST BASE FAILURE

Stability control against base failure in the refinery yard area was carried out by monitoring the vertical settlement, s and lateral displacement, δ (Fig. 6a). These were plotted in the emprical chart, s vs δ/s, as proposed by Matsuo and Kawamura (1977) which is shown in Fig. 6b. In Fig. 6b, Q is the preload per unit area and Q_f is the load per unit area at failure. As shown in figure, most of the observed points for each staged loading fall within the control limit line and hence the constructed embankment for

TABLE 1. Results of the Field and Theoretically Calculated Settlements for Hot Strip Mill Site

Location	Field Measured Settlement (m)				Calculated Settlement (m)			
	S_i	S_c	S_r	S_t	S_i	S_c	S_r	S_t
Scarfing Yard	0.15	1.05	0.23	1.43	0.15	1.08	0.25	1.48
Press Equip.	0.08	0.69	0.14	0.91	0.08	0.70	0.11	0.89
Slab Yard	0.15	1.25	0.26	1.66	0.15	1.25	0.23	1.63
Refinery Yard	0.09	1.51	0.18	1.78	0.09	1.48	0.20	1.76
Water treat.	0.06	0.85	0.17	1.08	0.06	0.84	0.13	1.03
No. 104 Road	0.05	0.59	0.12	0.75	0.05	0.60	0.10	0.75

Note;
S_i = Immediate Settlement, S_c = Primary Consolidation Settlement
S_r = Secondary Consolidation Settlement, S_t = Total Settlement

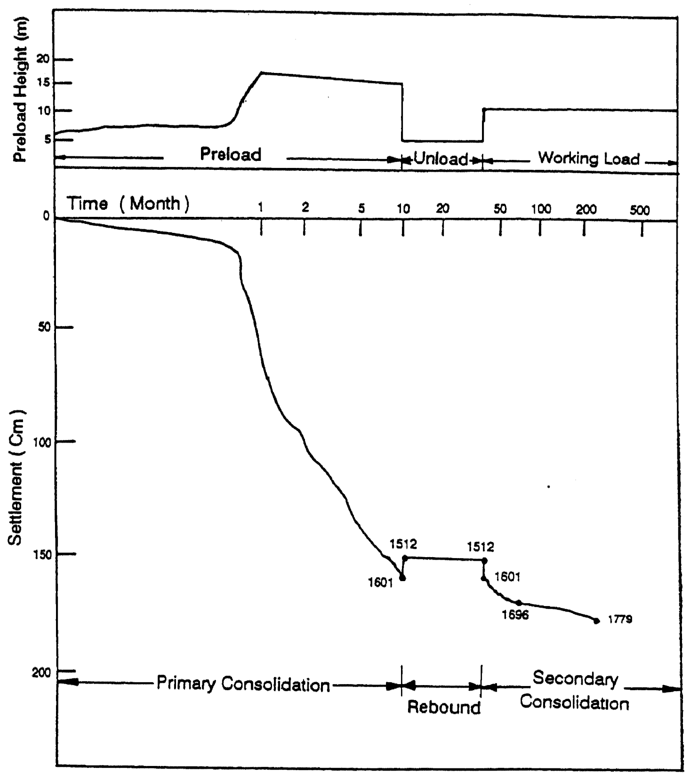

Fig. 5 Field settlement with time at the hot strip mill site

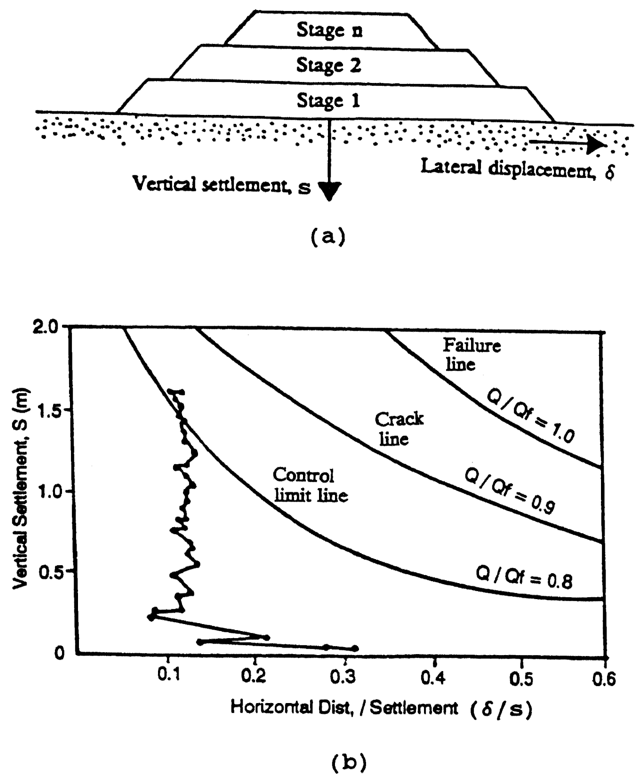

Fig. 6 Field observation of the settlement, (a) typical staged construction process for preloading, and (b) stability control method for the hot strip mill site

preloading was safe against stability failure. Slope stability analysis was also undertaken during the staged loading process in terms of total stress analysis ($\phi = 0$).

STANDARD PENETRATION TEST

Standard penetration tests were performed at various depths of soil profiles with consolidation time in the clay layer. The results of these are plotted in Fig. 7. The N-values increased in both sandy layer (upper zone) and clay layer (bottom zone) with depth. The N-values increased greatly immediately after sand drain construction in sandy soil while the N-values in clayey soil somewhat decreased due to the soil disturbance. Regaining original shear strength of clayey soil takes usually a month or more.

The N-values were also monitored before, and immediately after construction of sand drains; and also during the preloading at the constant time intervals (i.e 100, 150, 200, 250, 300 days). The average results of these measurements

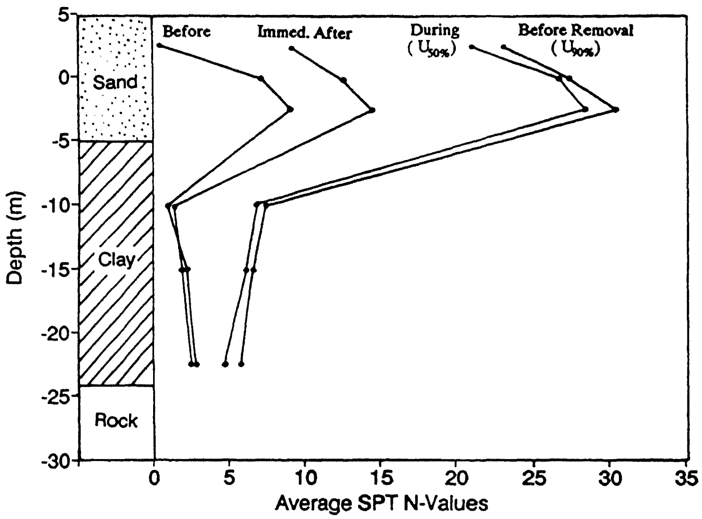

Fig. 7 Average SPT N-values at various depths with consolidation

for the upper sandy layer and middle clay layer (Figs. 2 & 7) are shown in Fig. 8. In an average, the N-values increased by about 300% at about 150 days after the sand drain construction as compared to that immedeately after construction. The N-values in sandy soil did not change too much after about 150 days of preloading. The N-values in clayey soil immediately, 100-250 days, and 300 days after construction of sand drains have an incremental factor of 1.0, 2.5-3.5, and 3.7, respectively. The maximum N-value in clayey soil occurred 3-5 month of preloading.

UNDRAINED SHEAR STRENGTH OF CLAY

Unconfined compression tests were performed to determine the degree of shear strength increase with the progress of the consolidation at various depths of clay layer. Undisturbed clay specimens were carefully retrieved from desired locations of the field using 71.12 mm diameter shelby tubes. Average undrained shear strength of clayey soil at various depths are tabulated in Table 2. The shear strength increase at elevations of -15 to -20 m was about 73.5% with inclusion of sand drains and preloading. The shear strength increase of clayey soil was about 22.2% where the area was not improved by the sand drains.

TABLE 2. Average Undrained Shear Strength at Various Depths of Clayey Soil

Depth (m)	Undrained shear strength (kN/m^2)			
	Before	Immed. after	During ($U_{50\%}$)	Pre-removal ($U_{90\%}$)
-15	36.3	-	-	41.2
-15- -20	29.4	39.7	48.5	51.0
-20*-	55.4	48.5	60.3	67.7

*Sand drains did not reach this level
Note; U = Average degree of consolidation

Fig. 9 shows the growth of average undrained shear strength with time. Undrained shear strength increased by about 20%-40% in 3-5 months after preloading with sand drains in place, and 80% about a year later.

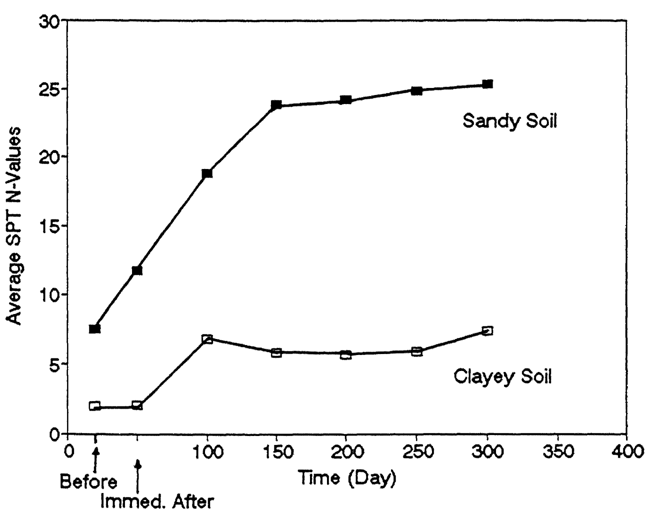

Fig. 8 Average SPT N-values for sandy and clayey soils

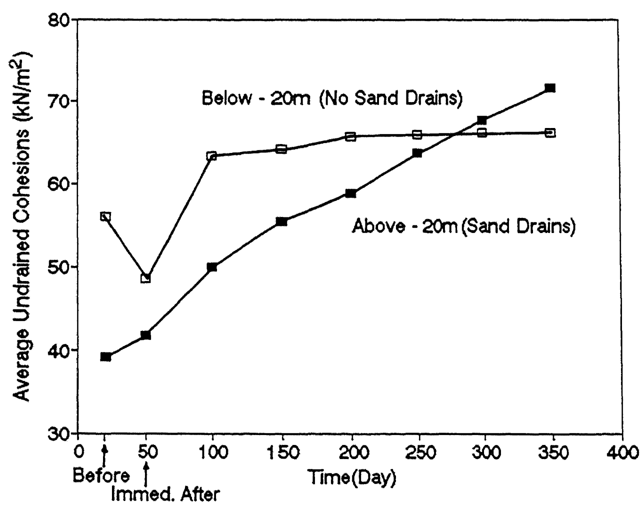

Fig. 9 Average undrained cohesion with various time intervals

CONSTRUCTION QUALITY ASSURANCE

Construction quality assurance was performed through the in-situ testing, laboratory test, evaluation of the engineering properties of backfill material which was used for sand drain construction. Usually, undrained cohesion of the clayey soil was determined to make sure that the clay can provide enough confinement to the sand columns. The clayey soil in the project site had, in general, an undrained cohesion of more than 29 kN/m^2 before construction of sand drains which is well above the normal requirement of 5-15 kN/m^2. Unconfined compression tests were also performed at various time intervals to verify the degree of the improvement of the shear strength of clayey soil. Standard penetration tests were performed before and after construction of sand drains to ascertain the quality of the completed sand drains.

Generally speaking, the gain size distribution of the backfill material is very important for it should be highly permeable. In order to achieve this, the backfill material should have D_{60} and D_{10} higher than 0.3 mm and 0.1 mm, respectively. The silt content of the backfill material should be less than 5%. If the grain size distribution is satisfied as aforementioned conditions, then the gradation curve should be fitted in the gradation range in Fig. 10. The backfill material used in this project was dredged from around the project site, and then kept for about 3 months to maintain the moisture content of 6% or less to facilitate the sand drain construction. The required permeability of the backfill material for this project with a dry unit weight of 15.7 kN/m^3 was about 1 x 10^{-2} cm/sec. Density tests were performed for every 5,000 m^3 of backfill material.

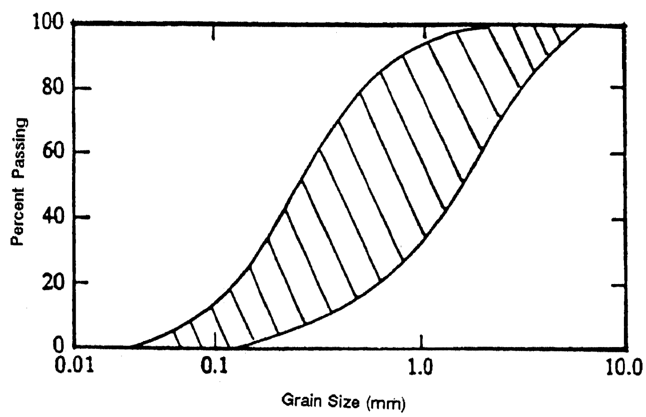

Fig. 10 Typical gradation range of the backfill material for sand drain construction

CONCLUSIONS

Sand drain technique has been effectively used in combination with preloading to improve the poor subsoils in a large-scale land reclamation project. Based on the experience of this construction project the following general conclusions can be drawn:

1. Sand drain technique is an efficient method to improve the loose sandy soil and soft clayey soil.

2. Field measurement of settlement is in very good agreement with the theoretically calculated values (Fig. 4).

3. The incremental factor of N-value for sandy and clayey soils was about 3.5 within a year due to sand drain construction and preloading. Large portion of this increment occurs in a 3-5 month period of preloading.

4. Increase of undrained cohesion of clayey soil was about 50%-80% with the inclusion of sand drains as well as preloading.

REFERENCES

(1) Pohang Iron & Steel Co., Ltd. (1990), "Report on Settlement Control", Soft Soil Improvement for Kwang Yang Steel Mill Complex (in Korean).

(2) Shin, E.C., Shin, B.W., & Das, B.M.(1992), "Site Improvement for a Steel Mill Complex", Speciality Conference on Grouting, Soil Improvement, and Geosynthetics, ASCE, Geotech. Engrg., Vol. 2, 816-828, New Orleans, LA, USA.

(3) Matsuo, M., and Kawamura, K. (1977),"Diagram for Construction Control of Embankment on Soft Ground", Soils and Foundations, JSSMFE, (17) 3, 37-52, September.