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GEOTECHNICAL PROPERTIES OF SOFT COHESIVE LOWLAND SOILS DEPOSITED IN SAGA AIRPORT HIGHWAY, JAPAN

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ABSTRAK

Studi ini menyajikan karakteristik dasar tanah lunak kohesif yang terdepositkan pada jalan akses ke Bandar Udara Saga, Jepang. Serangkaian seri pengujian telah dilakukan guna mengakses parameter dasar deposit dalam kaitan tipikal perilaku tanah tersebut; sensitivitas tinggi, kompressibilitas tinggi, dan daya dukung tanah rendah. Perilaku dasar deposit memiliki karakteristik menyerupai profil geologisnya yaitu deposisi endapan lunak dengan variasi ketebalan 20-25 m. Beberapa lapisan pasir tipis secara random terdepositkan dengan fungsional sebagai lapisan drainase. Lapisan atas pada kisaran tebal 6 m merupakan tanah lanau, dibawah lapisan tersebut adalah deposisi lanau - lempung lunak. Kadar air natural deposit lebih tinggi dibandingkan nilai batas cairnya, permeabilitas lapisan lanau kelempungan diaproksimasikan 3 – 5 kali nilai permeabilitas lempung Ariake pada umumnya. Struktur geoteknis yang dibangun diatas deposisi tersebut dilaporkan sarat dengan permasalahan penurunan dan keruntuhan pondasi akibat rumitnya perilaku deposisi tanah lunak tersebut. Tipikal kecendrungan kegiatan reklamasi dikawasan pantai telah meningkat secara signifikasi akibat keterbatasan lahan pengembangan infrastruktur, permintaan lahan rekrutan dilaut dangkal, dan lahan buatan tepi pantai. Besarnya penurunan pada badan jalan raya dan kerusakan berat bangunan lepas atau dekat pantai akibat aksi gempa, beban lalu lintas, dan gelombang badai adalah merupakan tipikal permasalahan geoteknis yang menjadi perhatian serius bagi birokrat, peneliti, dan praktisi di kawasan tersebut.

Kata kunci : *Lahan-landai, tanah sensitivitas tinggi, kompressibilitas tinggi, daya dukung tanah rendah, tanah kohesif lunak, lapisan drainase*

INTRODUCTION

Lowlands as the lands affected by a significantly fluctuating surface water level are commonly deposited in the coastal lands. Large tracts of coastal lands are below the mean sea level exist all over the world, most notably in the Netherlands, Japan, Bangladesh, India, Thailand, and Indonesia.
Natural lowlands are usually located in deltas or coastal plains and flood plains of rivers, just at or below mean sea level and are submerged during most or some part of the year.

In some of the developed countries, due to a shortage of land, new land is being created from the sea, such as in Japan, Singapore, and Hongkong. These artificial islands are usually founded on soft marine deposit and are subjected to tides and storm surges. Characteristic features of the soft cohesive deposit underlain this kind of lowland are associated with the geotchnical problems

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arising due to typical properties such as; very sensitive soft cohesive soils, high compressibility, and 10-30 m depth of the soft deposit.

From the standpoint of saving natural resources, low embankment highways constructed on soft deposit have therefore been prevalent throughout Japan. Yasuhara et al. (1983) performed field measurements and laboratory tests on a low embankment highway under moving of vehicles, and insisted that the settlement should be attributed to consolidation of the subground. Several highways around the Ariake plain have been reported to suffer from abnormal settlement after they were opened for traffics (Yamanouchi et al., 1975; Mori et al., 1994; Fujiwara et al., 1989). A case of the excessive differential settlement of a low embankment highway with lime improved-base materials was recently reported by Miura et al. (1993, 1995_b). The function of a polymer grid in base material (Miura et al., 1990_a) has been proved effectively in suppressing a non-uniform settlement due to traffic loading. This was clarified both in the model pavements and in the field tests.

In many other Asian countries, where coastal plains have been extensively reclaimed for the industrial activity, city expansion, transportation systems, etc., ground subsidence due to repeated changes in the ground water levels have become a common problem. For example, ground subsidence in Shanghai started in 1921, and reached about 2.7 m in 1966 with a maximum annual rate of 98 mm (Gu et al., 1991). The reclamation project in Korea was initiated on the Kangwha Island in Kyunggi Province in 1235 (Rhee, 1991). Since 1950, the scope of this project has been changed significantly to anticipate advanced construction techniques that use heavy equipment. Kim et al. (1992) reported that the geotechnical problems for the reclamation on the soft cohesive deposit mainly arose from the use of heavy equipment, which it is believed to induce vibration as well as significant settlement in the soft deposit.

In order to present the basic properties of soft cohesive lowland soils deposited in Ariake plain, a series investigation has been done along the access road to Saga Airport - Northern Kyushu, Japan. This paper discusses the basic characteristics of the soft cohesive deposit in associated with their typical properties such as; very sensitive soft cohesive soils, high compressibility, and low bearing capacity of the soft deposit. An investigation program is paid to several sections which it was identified to suffer from abnormal settlement after construction of embankment road. Basic soil parameters for evaluation of stability and settlement of embankment road are also presented.

BASIC CHARACTERISTICS OF SUBGROUND

In many cases lowland areas are commonly found around shore areas or estuarine areas, which are mainly composed of alluvial marine soft cohesive soils on the top layer. A typical example of this is the Saga plain (a lowland reclaimed from the Ariake Sea, Figure 1), where the sites of investigation (Saga airport and its access road) were situated. This is a peculiar case in which an airport has been constructed on this type of reclaimed lowland in Japan.

To mitigate the problems that can arise from these difficult conditions, a lot of laboratory and field investigations have been done under static conditions (Yoshioka et al., 1994; Miura et al., 1993). The following discussion presents the basic features of the subground in the investigation sites and compares them with the present test results.

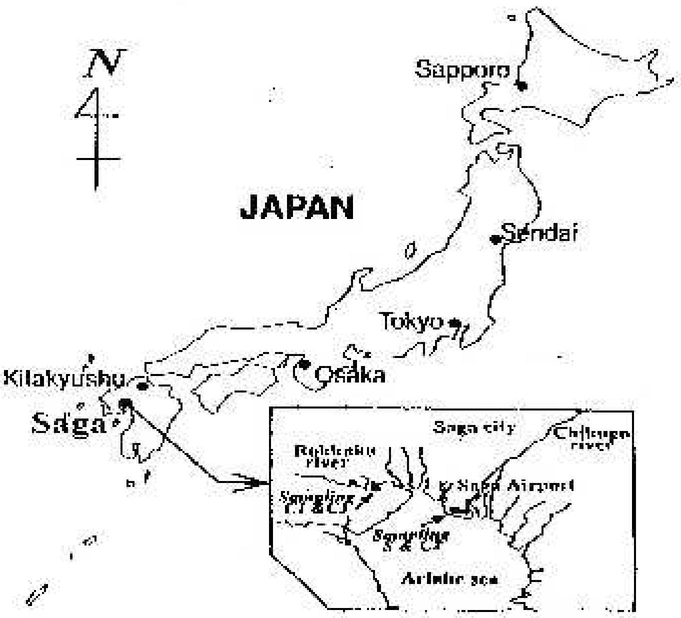


Figure 1. Map of Japan and location of Saga plain

Map and Site of Investigation

A map of the Saga plain, where the samplings and the field observations were made, is shown in Figure 2. Due to the fact that existing ground surface in this plain is almost lower than the mean sea level, a high concrete retaining wall was constructed in order to protect the site from daily tidal changes and storm wave action during the typhoon season. Adjacent to the Saga airport site, a number of high embankments were built on soft ground at the mouth of the Rokkaku River. The embankments were reported to undergo cyclic movements due to cyclic tidal action (Park et al., 1991).

Figure 3 shows the geotechnical and environmental profiles of the Saga plain. The structures founded in the coastal area of this plain are affected by 4 to 6 m daily tidal fluctuations of the Ariake Sea. Saga airport is located about 9 km south of the Saga City. The existing ground surface is +0.4 m, below the mean sea water level, and the highest water sea level can be as high as +5.0 m during the typhoon season (July-September). Saga Airport is one of an important infrastructure in this plain, which has been completed since the fiscal year of 1999.

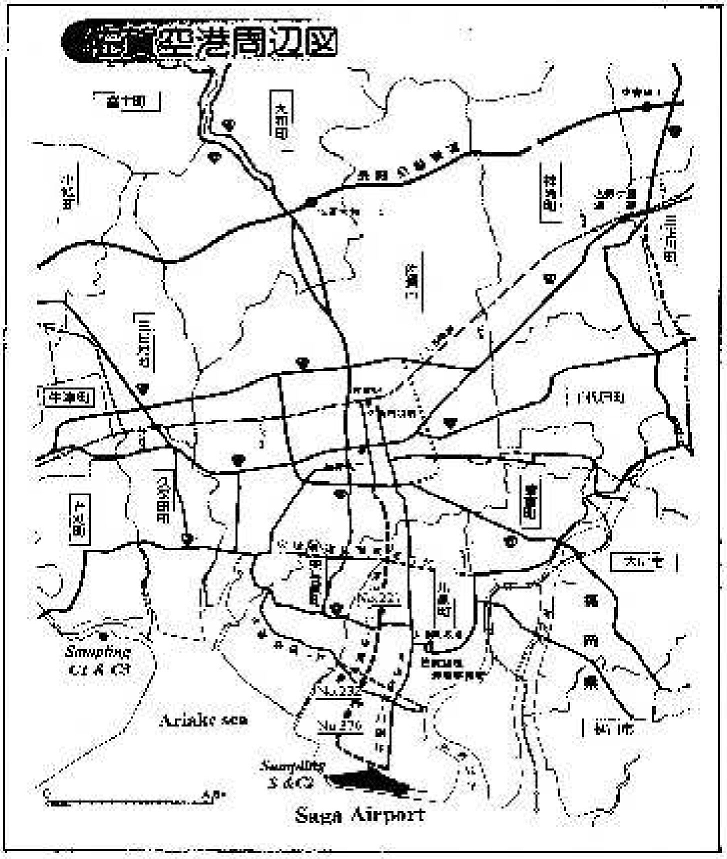


Figure 2. Map of Saga plain and site of investigation

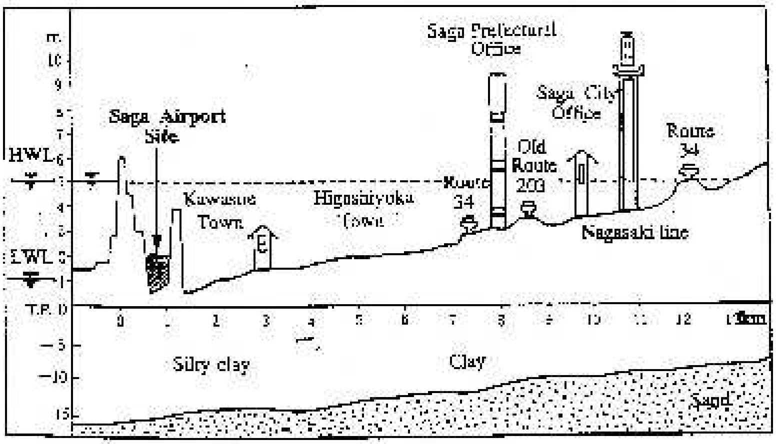


Figure 3. Geotechnical and environmental profile of Saga plain

To provide access to this site, the Saga airport highway has been completed and opened to traffic since 1992 as indicated by the dashed line (Fig. 2). Due to non-uniform settlement, the maintenance of road has been regularly performed by reoverlaying the pavement surface. The subground characteristics along the road were intensively investigated and reported by the Saga Prefectural Office, Division of Civil Engineering. Additional testing was also conducted in the Saga University, laboratory of geotechnical engineering.

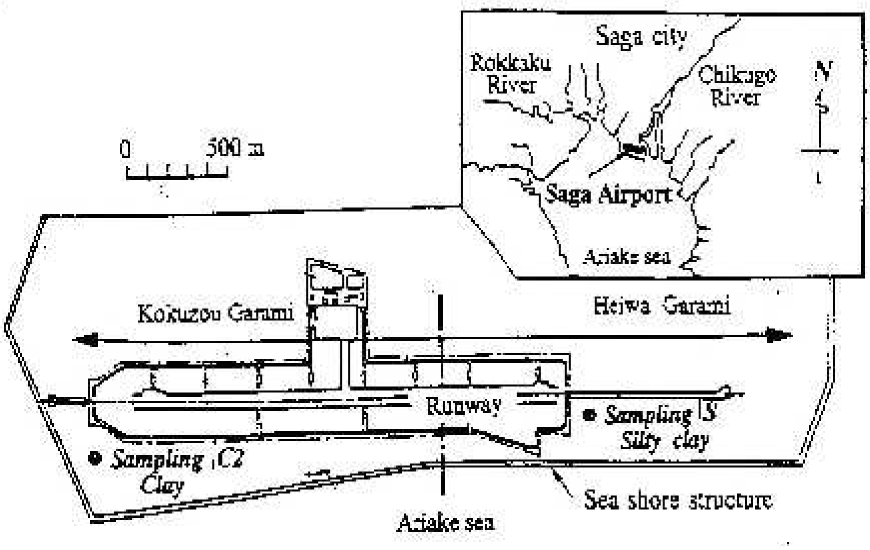


Figure 4. Layout of Saga airport runway and sampling site

Geological Profiles

The Saga airport covers two sections as shown in Figure 4, the Kokuzo Garami area (which was reclaimed during 1942-1964) and the Heiwa Garami area (which was reclaimed during 1963-1972). Figure 4 shows the geological stratum along the runway of the Saga airport. The alluvial deposit of three layers, A_{c1}, A_{c2}, and A_{c3} had almost zero SPT (Standard Penetration Test) values. Several layers of sand, A_{s1} and A_{s2}, are randomly deposited, below which a medium to dense diluvial sand D_s stratum exists. All of these layers act as drainage layers. The soft deposit varies in thickness from 20-25 m. The subground conditions are different in the two areas. The main deposition of Heiwa Garami area is silty clay and in the Kokuzou Garami area it is clay.

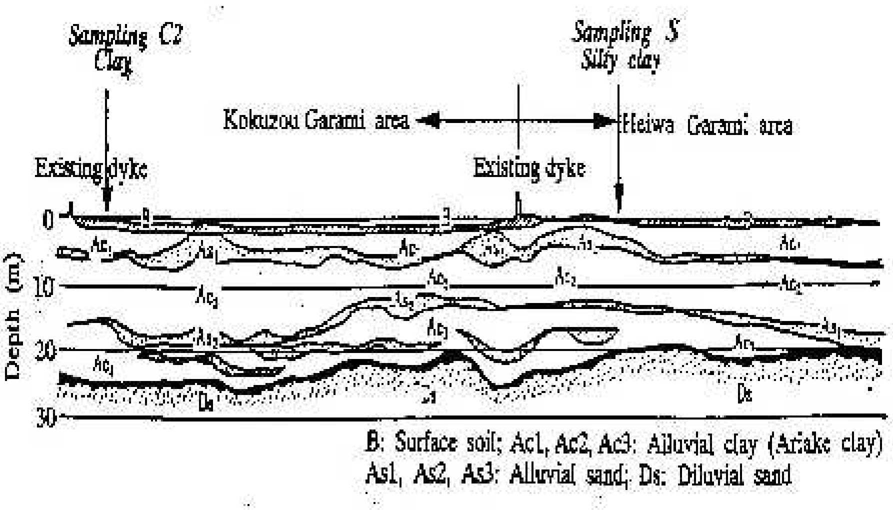


Figure 5. Geological profiles of Saga airport project (after Yoshioka et al., 1994)

The geological profiles along the Saga airport highway are presented in Figure 6 and show a geological stratum to be similar to that of the Saga airport (Fig. 5). Two or three alluvial sand layers intermediate the soft deposit. In order to evaluate part of the settlement induced by traffic loading, the typical geotechnical profiles (physical and engineering properties) of section A, station No. 221, are described in the following dsection.

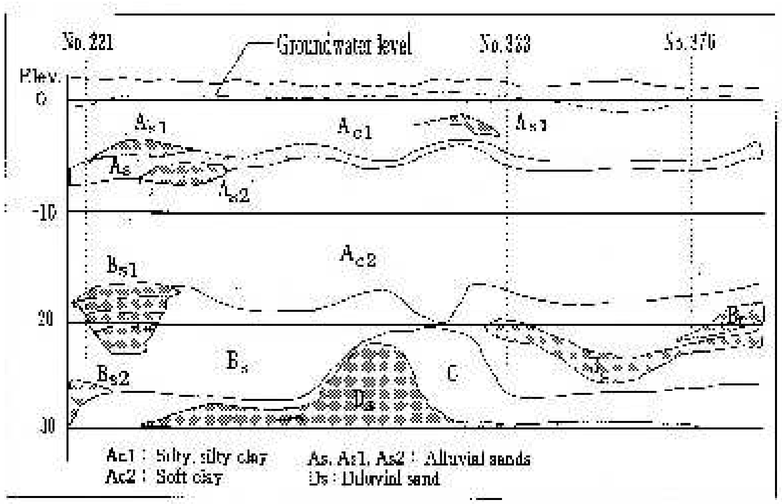


Figure 6. Geological profiles of Saga airport highway

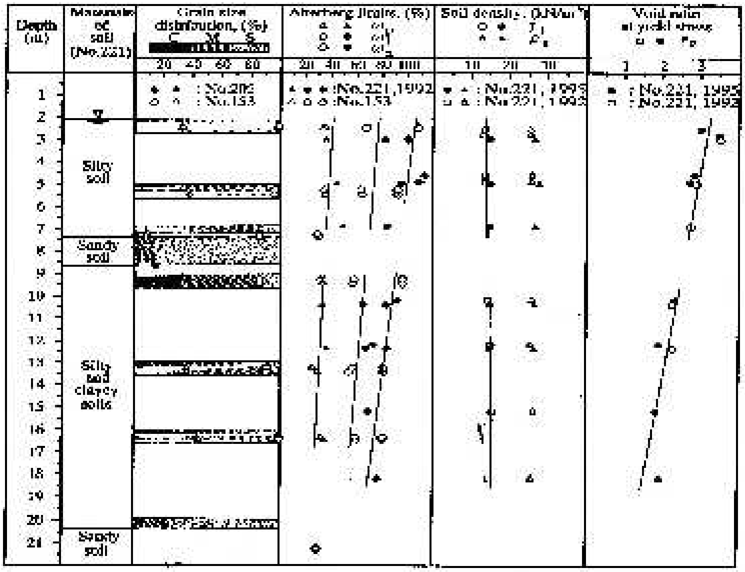


Figure 7. Physical properties of subground for various depths in section A, station No. 221

Subground Properties

The basic properties of the soft cohesive soils deposited along the Saga airport highway (section A, B, and C) are summarised in Table 1. Here, the general values of the physical and the mechanical properties of Ariake clay are also listed for comparison.

Table 1. Geotechnical properties of the soft cohesive deposit in the Saga airport highway

Soil properties	Ariake clay	Saga airport highway		
		No.221 (A)	No.323 (B)	No.376 (C)
Sampling depth, m	-	2.5-12.8	3.5-11.8	2.0-10.8
Physical properties:				
Natural water content, ω_n(%)	50-200	83-99	93-110	76-101
Density of soil particles, ρ_s(kN/m^3)	25.6-2.76	26.5-27.9	26.3-26.9	26.3-26.9
Wet density, γ_t (kN/m^3)	14.1-1.59	-	-	-
Initial void ratio, e_o	1.05-4.53	2.05-3.41	2.25-3.25	2.10-3.30
Liquid limit, ω_L(%)	28-112	67-105	70-83	63-105
Plastic limit, ω_P(%)	24-59	33-49	27-35	34-46
Plasticity index, I_p(%)	-	33-61	40-57	18-59
Clay contents (d<5μm), (%)	11-78	-	-	-
Mechanical properties:				
Friction angle, ϕ'(deg.)	-	-	27-33	33-37
Yield stress, σ_y'(kPa)	-	45-90	65-95	40-85
Compression index, C_c	0.37-1.86	0.77-1.80	0.83-1.14	0.97-1.56
Consolidation coefficient, c_v(10^{-4}m^2/sec)	40.5-172	8.1-92.6	11.6-80.9	8.1-104.1
Soil compressibility, m_v(10^{-3}m^2/kN)	-	0.7-2.5	1.0-2.0	0.8-2.5
Slope of Critical State Line, M	-	-	1.25-1.35	1.35-1.50
Soil elasticity, E_{50}(kPa)	-	-	10-55	12-50

a. Physical properties

The physical properties of the subground for various depths are shown in Figure 7. Grain size distribution reveals that the silt fraction is predominant instead of the clay fraction except at a depth of 7.5 to 8.5 m, where a thin sand layer exists. The plastic and liquid limits vary linearly with depth and their magnitudes decrease with depth. The natural water contents are much higher than their corresponding liquid limits and decrease with an increase in depth. This reflects one of the specific features of Ariake clay. The void ratio at yield stress decreases with depth and associated with changes in the natural water content of the deposit.

The plasticity chart for the Ariake clay in Kawasoe town near Saga airport is shown in Figure 8, the test results of present samples are depicted in this chart. The liquid limit and the plasticity index vary in the ranges of 30-125 and 15-80, respectively. These values are slightly higher than those observed in Fig. 7. It is clear from this figure that the soft cohesive soils deposited in this plain can be classified as mainly silty clay and clay with a medium to high plasticity index.

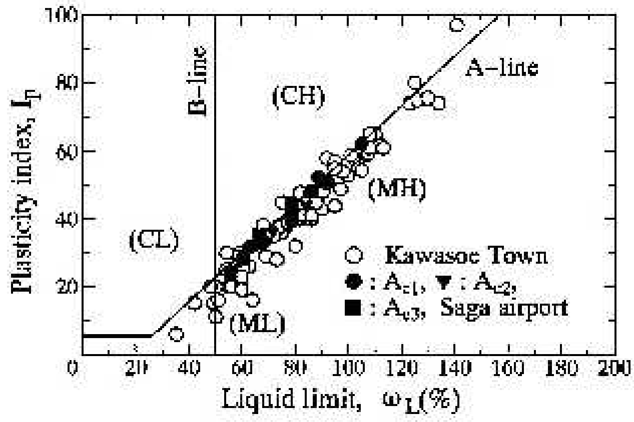


Figure 8. Plasticity chart of Ariake clay in Kawasoe town and Saga airport site

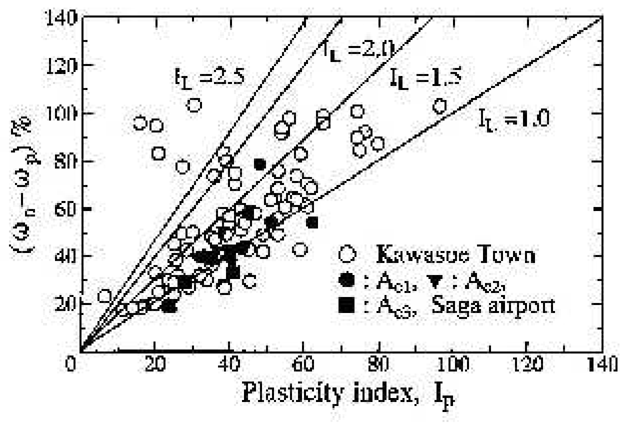


Figure 9. Liquidity index of Ariake clay in Kawasoe town and Saga airport site

Figure 9 shows variations of liquidity index in (ω_n-ω_p)-I_p plot, indicating that the value of liquidity index could be high as 2. ω_n and ω_p are the natural water content and the plastic limit of the deposit, respectively. I_p is the plasticity index of the deposit. Based on the fossil assemblages investigated, (Ohtsubo et al., 1988) stated that the layers in the top 10-11 m were deposited in a marine environment, while the lower layers were formed under brackish conditions. Smectite is the predominant mineral which exists along with vermiculite, illite, and kaolinite in the deposit.

As shown in Figure 10, the sensitivity of the deposit is less than 50 at a depth below 10 m (clay layers A_{c2} and A_{c3}) but could be as high as 200 or more at the top layer (A_{c1}). Therefore, this deposit can be classified as quick or extra quick according to Rosenquist's (1953) classification and salt leaching is the primary cause for the sensitivity of the soils. The salt concentration in the pore water is obtained between 3-9 gram/l NaCl for clay layers A_{c1}, A_{c2}, and A_{c3}, whereas the Saga airport samples repersents about 2-3 times to be higher. Based on the salt contents analysis of this deposit, a new classification of soft cohesive soils deposited in the Saga plain has been introduced by Miura et al. (1996).

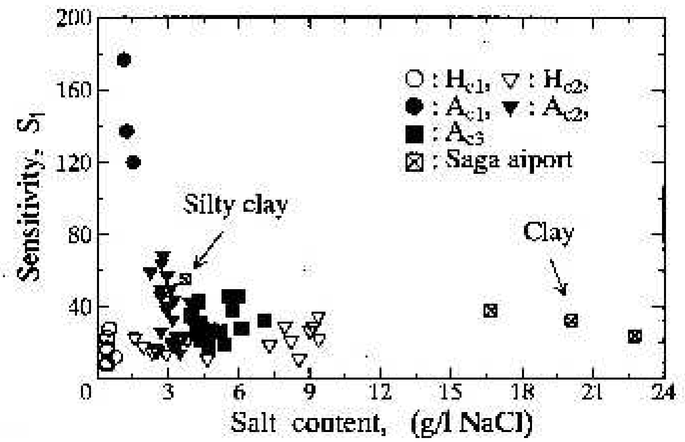


Figure 10. Characteristics of sensitivity against salt content of the soft deposit in Saga plain and Saga airport

b. Mechanical properties

The variations in the mechanical properties of the subground with depth are shown in Figure 11. From consolidation test results that show variations of yield stress σ_y' and effective overburden stress σ_{vo}' with depth, the upper soft deposit was found to be a slightly over consolidated state with OCR ranging from 1.5 to 2.5. A comparison of the test results observed before and after three years of the road was opened to traffics indicates that the OCR values increase depending on the depth of the deposit, i.e., they are higher at the adjacent view meter below the pavement. In this case, the effects of long-term traffic loading are considered to be attributed to the consolidation of the subground. This finding is similar to that reported by Fujikawa (1996).

Compression index C_c of the deposit was obtained in a range between 0.4 and 1.4 as shown Fig. 11. Its characteristic is that a linear variation decreases with depth. A similar tendency was also observed for the characteristics of soil compressibility in a range of $2.5x10^{-4}$ to $2.5x0^{-3}$ m^2/kN. The values of soil permeability have an opposite tendency that they slightly increase with depth and vary in a range of $3.5x10^{-9}$ to $9.5x10^{-9}$ m/sec. A comparison between the present values of soil permeability (silty clay) and the general values of soil permeability for Ariake clay reveals that the soil permeability of the silty clay is 3 to 5 times higher than that of the clay. Unconfined compressive strength and the elasticity of the deposit show a similar tendency, they increase linearly with depth. Most of the samples attained maximum shearing resistance at about 3% to 7% of axial strain.

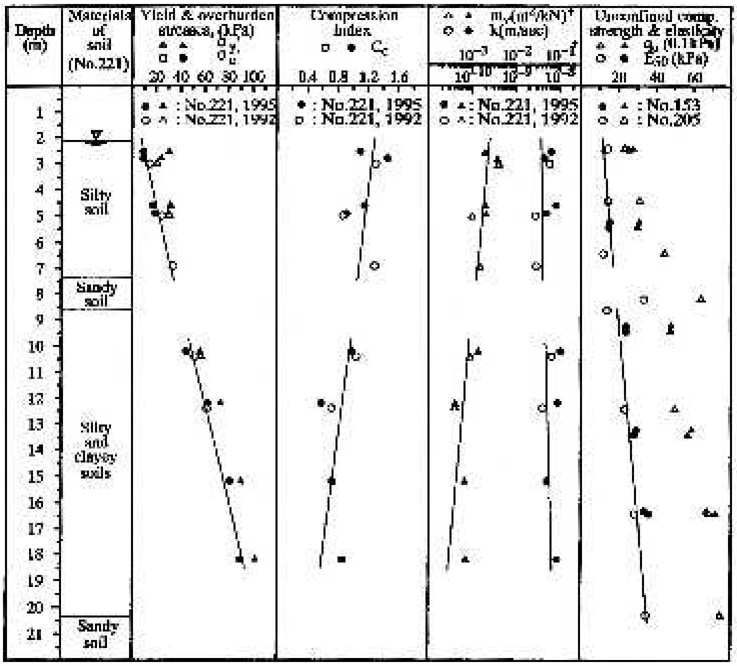


Figure 11. Engineering properties of subground for various depth in section A, station No. 221

TYPICAL COMPRESSIBILITY AND UNDRAINED STATIC CHARACTERISTICS

Typical responses of e-log(p′) curves obtained from oedometer tests for various sampling depths are shown in Figure 12(a). Specimens from a depth of 5 m show an e-log(p′) curve that is shifting downward with an initial void ratio of around 2. This appears to be due to specimens are dominated by sand fraction. In general, the specimens sampled from upper layers with depths of less than 7 m show e-log(p′) curves that are higher than those of the samples obtained from deeper layers. The characteristics of curves in e-log(p′) relationship are almost parallel each other.

The characteristics of soil compressibility m_v versus consolidation effective stress p′, in a logarithmic plot, as shown in Figure 12(b) reveal that the values of m_v vary in a wider range when p'<100 kPa. Figure 12(c) shows the relationship between the coefficient of consolidation c_v and consolidation effective stress p', indicating that the c_v values obtained from lower deposit (7m depth or higher) are almost constant for any applied pressure p' levels. Specimens sampled from upper deposit show a higher c_v values when applied pressure p' was less than 100 kPa.

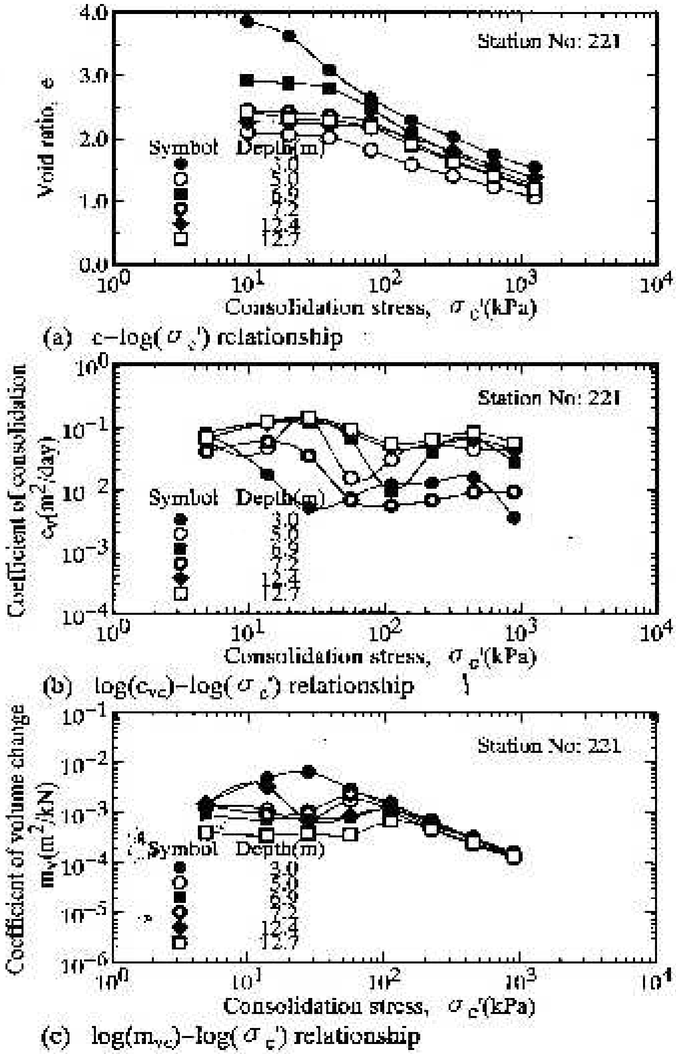
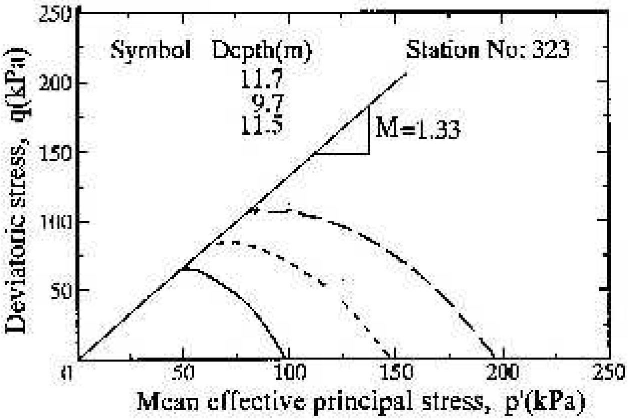
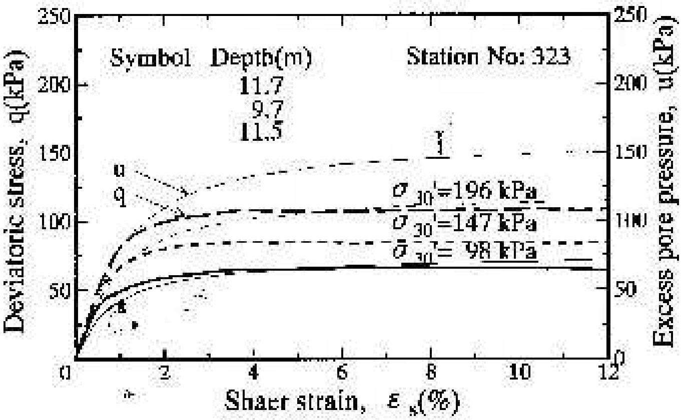


Figure 12. Typical responses of e-log(p), soil compressibility mv, and coefficient of consolidation cv in oedometer tests

As for the accuracy of consolidation settlement analysis due to the embankment weight by a modified cam clay model, the undrained static compression behaviour of the subground was also investigated. The test results are shown in Figure 13. The effective stress path is presented in Fig. 13(a), showing that the undrained paths shifted to the left lead to a failure envelope with critical state parameter M=1.33. Figure 13(b) shows the stress strain relationships and the curves that characterize hardening behaviour. The positive excess pore pressures gradually increase toward the static failure mode and their magnitudes are higher as compared to the static deviator stress q(=σ_1'-σ_3').



(a) Undrained static stress path



(b) Undrained static stress–strain path

Figure 13. Typical responses of undrained static behaviour of subground in triaxial compression tests

TYPICAL SOIL CHARACTERISTICS OF ASIAN LOWLANDS

The distributions of natural and created lowlands in Japan are shown in Figure 14. Soft cohesive soils deposited in the coastal plains of Southeast Asia are spread over most countries of the region: the Chao Phraya plains in Thailand, the Mekong deltas in Cambodia and Vietnam, the Malaysian coastal plains, the Philippine central plain, and the Indonesian plains. The largest plain is situated in the Tokyo area, the so-called Kanto plain, following the Nobi plain in the vicinity of Nagoya and the Saga plain in northern Kyushu. The vast tidelands exposed at the low tide of the Ariake Sea form part of the Saga plain with an area of about 400 km^2. Tidal fluctuations found in the sea are about 3 m at the entrance and 6 m in the interior. Many rivers such as the Chikukgo, Rokkaku, and Kase flow into the Ariake Sea bringing in substantial clay and sand deposit. Due to successive sedimentation and the wide range of tidal fluctuations, a beach emerges from the water at ebb tide some 5 to 7 km offshore. The original coastline of Ariake Bay is believed to be approximately 20 km inland from its present location (Watanabe et al., 1988).

Recently, in Japan, manmade coastal islands applications have increased significantly. More than a few thousand hectares of these artificial islands, which are mainly used for ports and airports created from the sea, are situated off Tokyo, Osaka, Kobe, etc. Kansai International Airport is the first iraport in the world built entirely on land reclaimed from the sea. It is about 5 km from the coast. The seabed properties of this huge artificial offshore island (Arai, 1991) are composed of 20 m thick soft alluvial clay and about 400 m thick diluvial stratum that consists of alternating layers of sand clay. As a result of the construction of the Kansai Airport, vertical stress increased by 450 kPa causing settlement of an order of 8.5 m.

Extensive lowlands exist along the lower parts of the Han, Kum, and Nakting Rivers, on the southern and western coasts of the Republic of Korea as shown in Figure 15. The Yellow Sea and its complex coastline cause one of the highest tidal ranges, 9 m, in the world at Inch'on, near Seoul. The Kyunggi plain in the estuary of the Han River, about 30 km from Seoul (Miura et al., 1990_a), is a lowland built up by reclamation to an elevation of 1.5 m to 6.0 m. More than 50% of this area is lower than the mean tide level of 4.7 m of Kyunggi Bay, therefore required the construction of polders. A very high 8 m macrotidal range and annual precipitation in excess of 1150 mm contribute to the complexity of this lowland development. The geotechnical profiles of the Kyunggi plain, as shown in Figure 16 and Figure 17, consist of 8-14 m thick layers of soft silt and clay underlain by 4 m thick gravelly sand containing diluvium and weathered rock. The liquidity index of the silty clay ranges from 0.7 to 3.0, with an average value of 2.0.

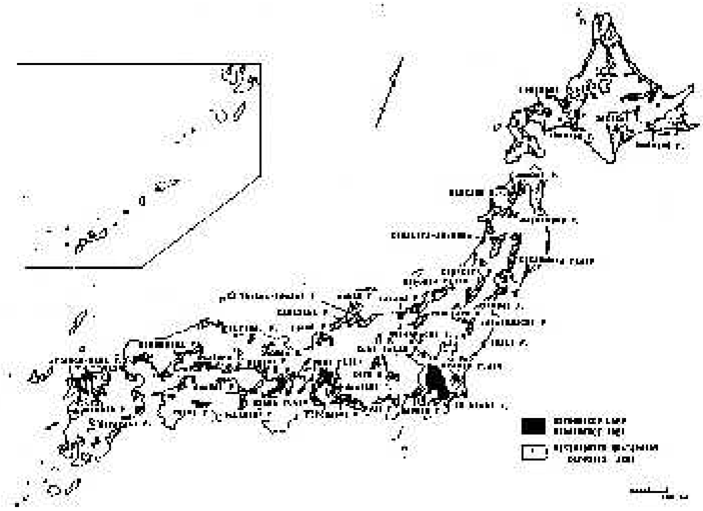


Figure 14. Distributions of natural and created lowlands in Japan (after Tohno, 1989)

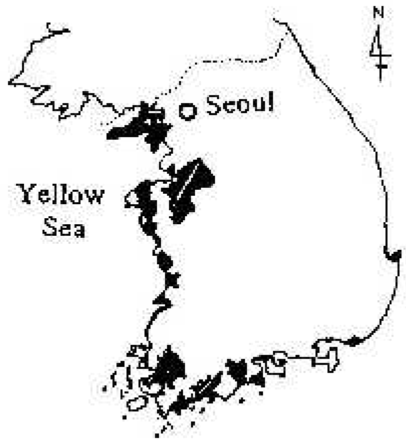


Figure 15. Lowland affected by tidal change in the Republic of Korea (South Korea)

Shanghai, China, is situated in the Changjiang (Yangtze) River delta. Alluvial sediments with 150-400 m thick were formed during the Quaternary period under alternating warm and cold climatic conditions, with the sea advancing and regressing, and through the interactions of rivers, lakes, and the sea (Bao et al., 1988). A highly compressible and soft clay layer 7-10 m thick exists at a depth of 10-12 m. The natural water content of this soil is greater that its liquid limit, implying that its liquidity index is greater than one and it has low shear strengths.

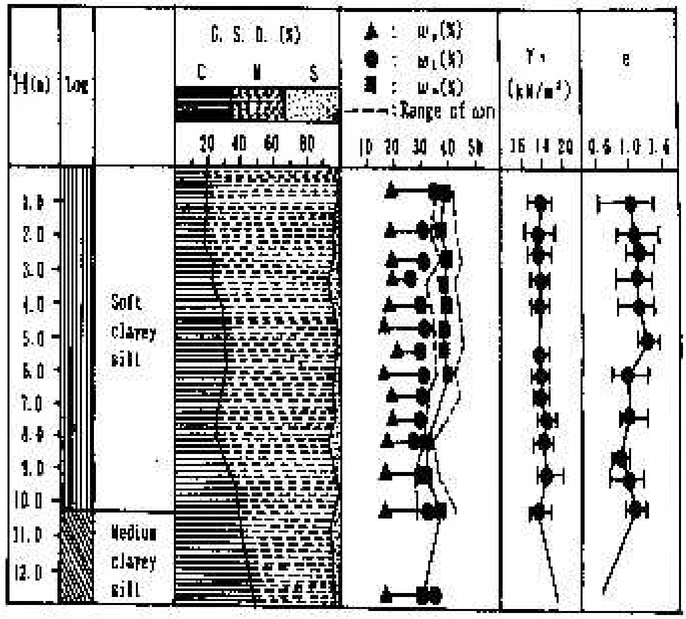


Figure 16. Typical physical properties of soft marine clay in the Kyunggi plain, South Korea

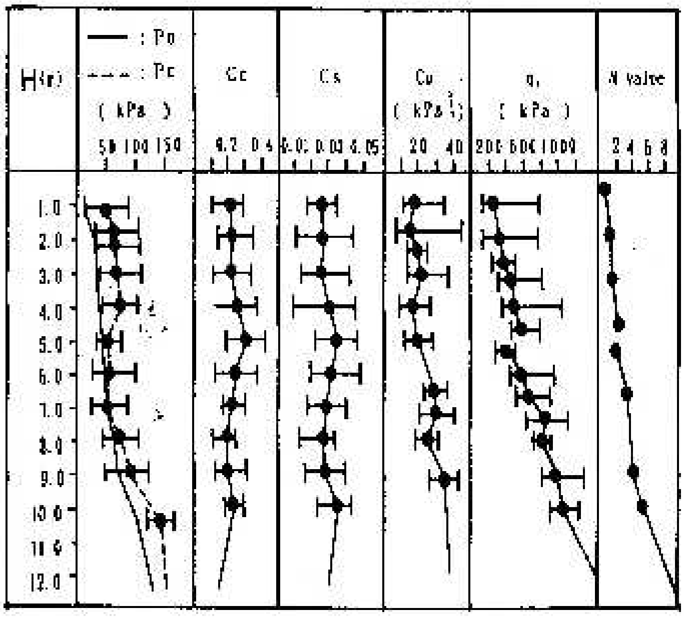


Figure 17. Typical physical properties of soft marine clay in the Kyunggi plain, South Korea

CONCLUSIONS

The results of field and laboratory investigation of the subground characteristics of the Saga airport highway were discussed in associated with the geotechnical problems arising due to their typical properties. The basic findings and characteristic features of the soft cohesive deposited in the investigation site are summarised as follows.

The soft cohesive soils deposited in the Saga airport and along the access road to the Saga airport are characterized by almost similar geological profiles, i.e., soft alluvial deposit of three layers varies in thickness from 20 to 25 m. Several thin sand layers were randomly deposited, all of these layers acted as drainage layers. The top layer of soft deposit around 6 m thick was deposited by silty soil, below which the soft silty to clayey soils existed.

These soft cohesive soils have difficult properties such as: very soft, highly sensitive, highly compressible, and low bearing capacity. The natural water contents are much higher than their corresponding liquid limits. The permeability of the silty clay is approximated 3 to 5 times that of the soil permeability of the Ariake clay in general.

The distribution of soft cohesive soils deposited in the coastal plains of Southeast Asia are spread over most countries of the region: the Chao Phraya plains in Thailand, the Mekong deltas in Cambodia and Vietnam, the Malaysian coastal plains, the Philippine central plain, and the Indonesian plains. In Japan, the largest lowlands are situated in the Kanto plain near Tokyo, the Nobi plain in the vicinity of Nagoya, and the Saga plain in northern Kyushu. Korean lowland is mainly situated in the Kyunggi plain, whereas in China it is deposited in the Changjiang delta (Shanghai).

Due to the paucity of land, especially in Asian countries such as in Japan, Singapore, and Hongkong, the demand for new lands created from the sea, man made coastal artificial lands, as well as and reclaimed from lowlands have been increasing significantly. The structures founded on such lowland have been reported to face many geotechnical problems due to the difficult properties of the soft cohesive deposit. Large settlement of low embankment highways and serious damage to offshore - near shore structures induced by cyclic loadings such as earthquakes, traffic loading, and storm wave action are the typical geotechnical problems faced on such lowland soils.

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