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Evaluation of Engineering Properties of Soft Clay in the Daebul Reclaimed Area

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Abstract□To identify the soft marine clay of the Daebul reclaimed area, the south western part of Korea, and determine their engineering properties, a series of the laboratory and field tests are conducted. The main findings are summarized from laboratory and field investigations. It is also formulated the basic geotechnical characteristic data for the porject area. The established correlations for the engineering properties are reviewed and their applicabilities are studied.

Keywords□Reclaimed soil, marine clay, sensitivity, liquidity index, CPT.

I. Introduction

A clay is the result of a series of geolgical process of weathering, erosion, transport deposition and consolidation. The mineralogy, the grain-size distribution, the structure, and all mechanical properties of clay result from the combined effects of these processes. It must be therefore expected that all physical and mechanical properties of a clay should be related according to laws of correlation which reflect the geological history of the deposit. These laws of correlation must be also reflect the basic principles of soil mechanics and in particular the principles of yielding. They therefore form a valuable tool for the geotechnical study of any clay deposit.

In the construction and development of Daebul industrial area on the reclaimed area, the south western part of Korean Peninsular, wick drains (plastic drains) and preloadings are applied in order to accelerate the consolidation settlement and to ensure safety against shear failures. In order to determine the various effects of wick drains and preloadings on soft marine clay layer on the reclaimed area, the principal correlation between physical and mechanical properties can be defined and illustrated.

This paper handles the geotechnical and geological properties of the marine clay in the same reclaimed area. A comprehensive analysis of the data collected from instrumentations is done for better understanding physical and mechanical properties of reclaimed marine soft soils.

II. Outline of Soil Conditions and Clay Properties

The site is lain by alluvial clay about 13 to 23m thick(SPT N-values ranging 0 to 4). A residual soil substratum can be divided into an upper very

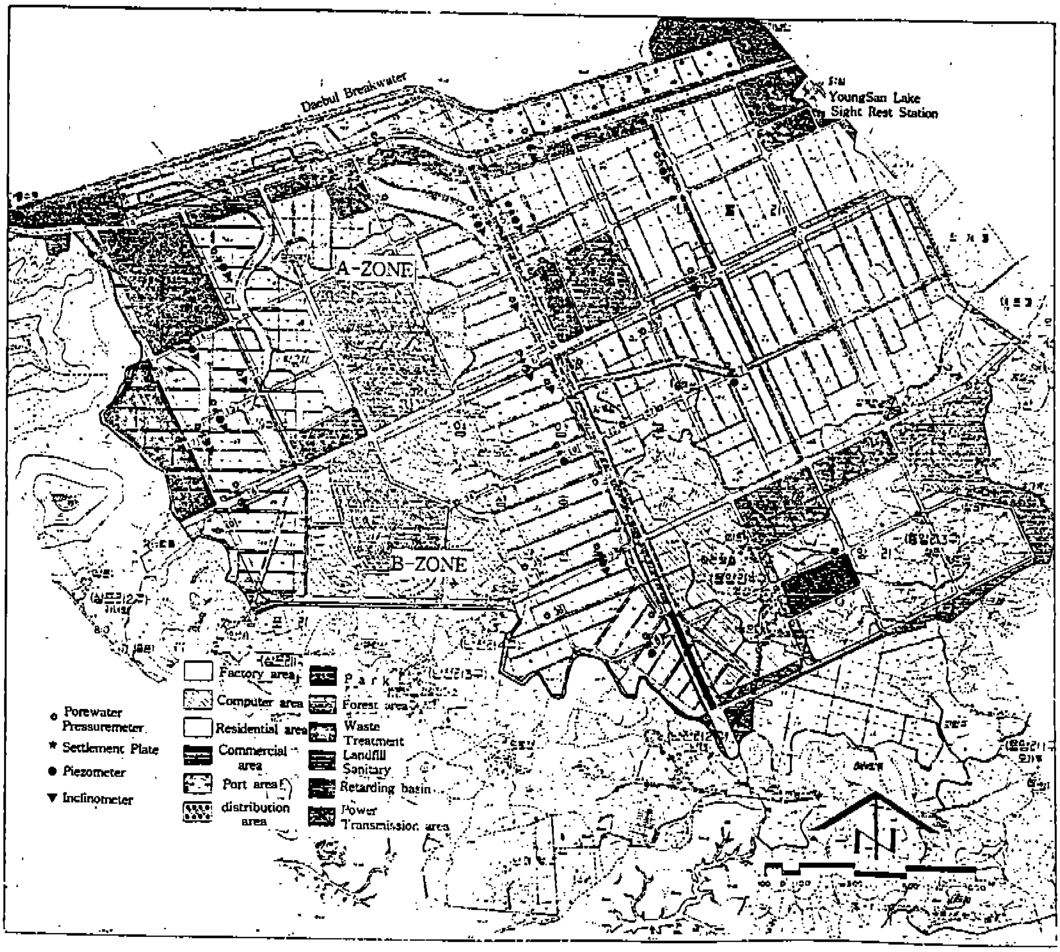

Fig. 1. Overview of the project area

soft marine clay with a little silt(CL). Immediately beneath this clay layer is followed by a residual soil, dense silty sand with trace of clay and gravels (classified as SM). According to the result of cone penetration test(CPT), layer thickness of the soft clay(q_c<10 Kg/cm^2) is about 5.0 to 19.8m. Fig. 1 shows an overview of the project area.

A conventional soil investigation consisting of undisturbed sampling, cone penetration tests (CPT), standard penetration tests(SPT), unconfining compression tests, triaxial compression tests and standard oedometer tests as well as physical tests is first carried out for all over the project area. Fig. 2 shows the depth profile of water content(ω_n), liquid limits(LL), and cone resistance(q_c). The average of water contents(ω_n) is varying from 35 to 65% with depth. The variation of liquid limit with depth is almost same as natural water content and ranging from 30 to 60%. It is certain that the soil is weak because the natural water contents are higher than the liquid limits.

Table 1 shows the soil properties obtained from laboratory and field tests.

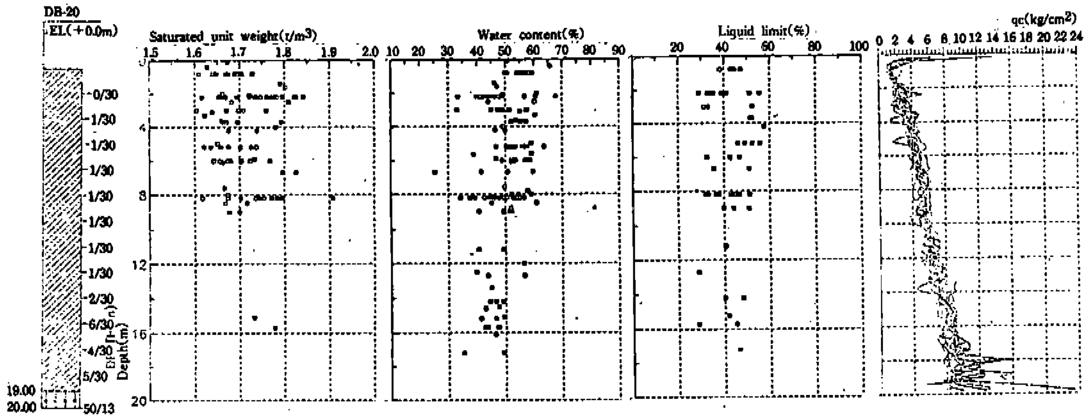

Fig. 2. Soil conditions

Table 1. Soil properties

Item	Zone A	Zone B
Thickness of soft layer(m)	26	16
Natural water content(%)	40~60(51.2)	50~70(58.4)
Liquid limit(%)	40~70(52.5)	50~70(60.8)
Plastic index	15~35(25.4)	25~40(31.5)
Void ratio(e_o)	1.3~1.4	1.6
Dry density(t/m^3)	1.6~1.8(1.69)	1.55~1.75(1.64)
Uniaxial strength(t/m^2)	2.5~3.5	2.2
Cohesion(t/m^2)	1.3~1.7(1.5)	1.2~1.7(1.5)
Compression index(C_c)	0.4~0.6(0.5)	0.55~0.7(0.6)
Coeff. of consolidation(cm^2/sec)	1×10^{-3}~5×10^{-3}(3×10^{-3})	1×10^{-3}~3×10^{-3}(2×10^{-3})

( ) denotes the average value

III. Strength Characteristics

The principal physical properties of a clay are the water content, the density characteristics which result from the water contents, the grain-size distributions, and the plasticity characteristics. All these are interrelated.

The plasticily characteristics, LL and PI(plasticity index) are also interrelated following lines in the Casagrande chart. As shown in Fig. 3, this soft clay lies in a zone parallel to and slightly above Casagrande's A-line. The mineralogy of the clay is reflected in the relationship between the PI and the clay content as shown in Fig. 4. The slope of the relationship is the activity(A). The clays of Daebul show a high activity, which corresponds to their high content of clay minerals and their formation from granite.

Clay samples from Deabul lose their strength after remolding and can not be easily tested without confining pressure, some vane shear tests are therefore performed for measuring the shear strength of remolded samples instead of unconfined compression test.

There would be a correlation between the unconfined compressive strength(q_u) or undrained

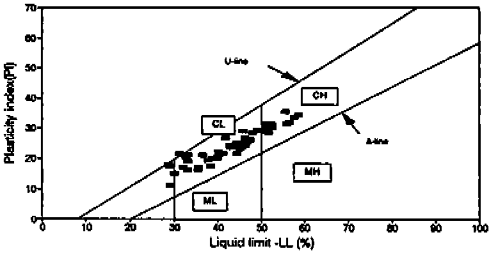

Fig. 3. Plasticity characteristics

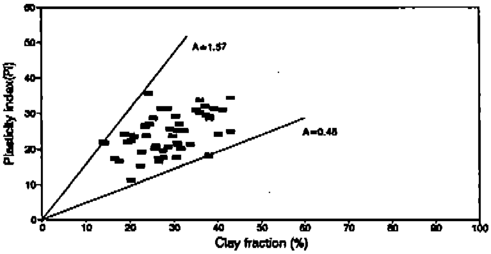

Fig. 4. Relationship between PI and clay content

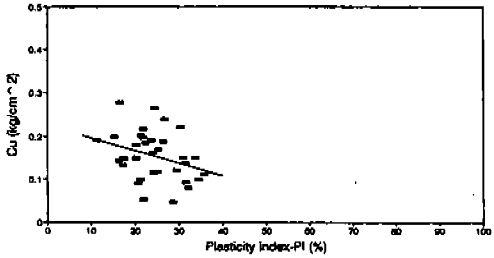

Fig. 5. Unconfined compression strength vs. plasticity index(q_u & PI)

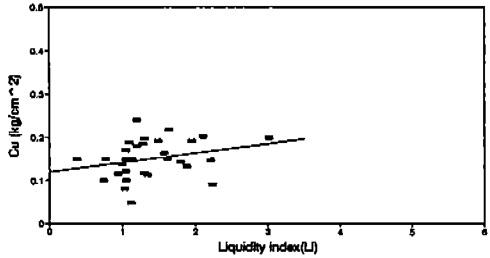

Fig. 6. Unconfined compression strength vs. liquidity index(q_u & LI)

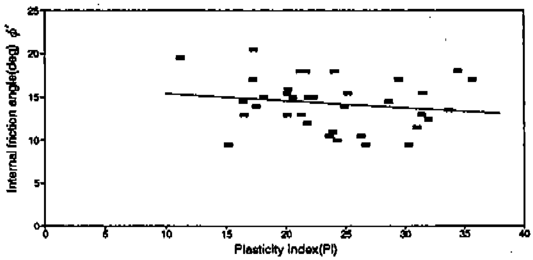

Fig. 7. Relation between ϕ′ and PI

shear strength($C_u = q_u/2$) and liquidity index(LI), which relates to the plasticity index and natural water contents(ω_n). When the value of Cu is plotted with PI and LI, there is a certain correlation between C_u and LI as showed in Figs. 5 and 6, respectively.

Since the undisturbed shear strength q_u and C_u are mainly controlled by both effective stress in the ground and soil structure, they should also be a reverse correlation to the plasticity index.

The angle of ϕ′ of friction reflects the nature and the shape of the clay particles. Fig. 7 shows the relation between ϕ′ measured on samples in a normally consolidated state, and plasticity index (PI). The relationship proposed by Bjerrum and Simons(1960) agrees with measurements made on different clays.

The compressibility charateristics of a clay reflect its initial structure. Fig. 8 shows relations between compression index C_c and initial void ratio e_o and Fig. 9 shows relations between compression index C_c and sensitivity S_t of the clay.

IV. Preconsolidation Pressure

Fig. 10 presents the variation of the preconsolidation pressure(p_c) with depth. The preconsolidation pressure of the soil increases as the overburden pressure increases with depth. The mean value of the preconsolidation pressure(p_c) was emp-

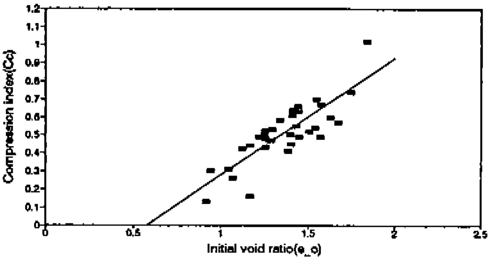

Fig. 8. Compression index(C_c) vs. initial void ratio(e_o)

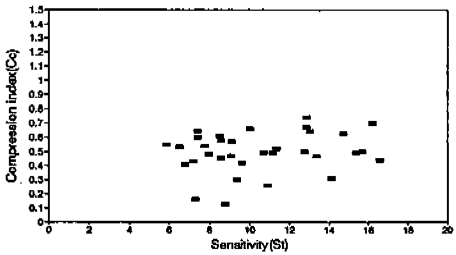

Fig. 9. Compression index(C_c) vs. sensitivity(S_t)

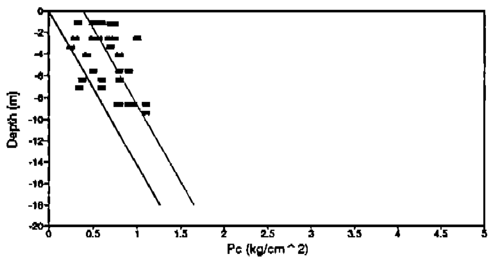

Fig. 10. The variation of preconsolidation stress(p_c) with depth

loyed as followed :

$$p_0 = 0.07D \qquad (kg/cm^2)$$
$$p_c = 0.07D + 0.39 \qquad (kg/cm^2) \qquad (1)$$

where, p_0 : the overburden pressure

p_c : the preconsolidation pressure

D : depth in meter

With respect to the geotechnical properties of the soil, the prime importance is often placed on the compression curve for settlement analysis and the effect of preloading. Fig. 11 presents a group of e-log p curves. From the analysis of the curves it can be seen that this clay layer shows the aging effect and the effect of cementation due to salt content. It may be told the fact that this area has been deposited for several thousand years and consolidated by the tidal changes.

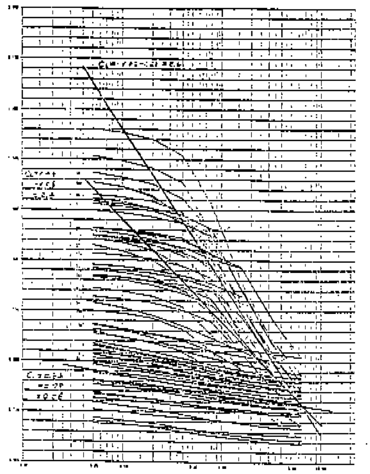

Fig. 11. A group of e-log p curves

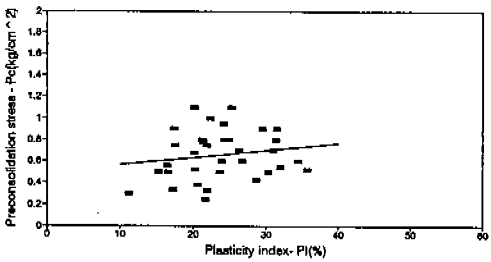

Fig. 12. The variation of p_c with PI

Fig. 12 shows the variation of p_c with PI. The higher the plasticity of soil is, the higher the preconsolidation pressure is, that is, the looser and more compressible the clay structure.

It can be found similar trend of the relationship between vane shear strength and the preconsolidation pressure in Fig. 13.

Fig. 14 shows the relationships between the un-

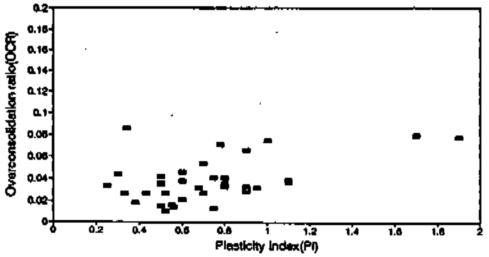

Fig. 13. The relationship between vane shear strength and preconsolidation pressure

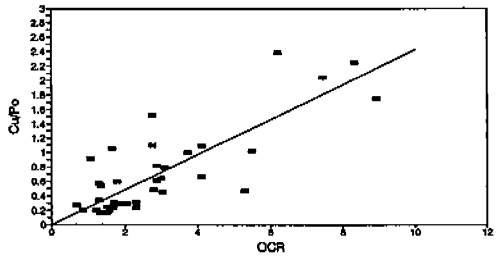

Fig. 14. The relationship between undrained strength ratio(C_u/σ'_p) and OCR

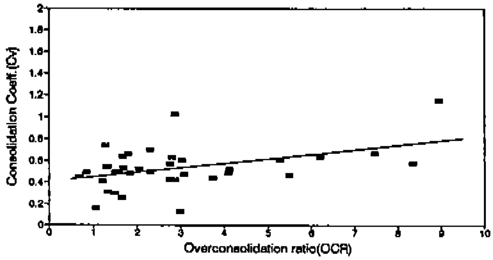

Fig. 15. The variation of consolidation coefficient(Cv) with OCR

drained strength ratio(C_u/σ'_p) and the OCR. The strength ratio was calculated from the unconfined compressive strength. The figure shows that a linear increase of the undrained shear strength ratio with OCR is prominent. Although there is some scatter, the average curve may be used for estimation of the undisturbed shear strength of overcon-

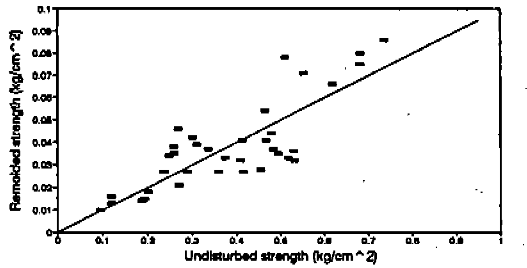

Fig. 16. The ratio of unconfined compression strength of undisturbed to remolded samples

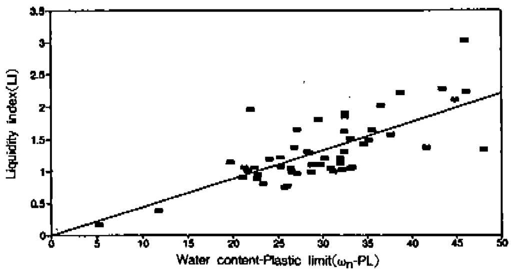

Fig. 17. The relationship between liquidity index and water content(ω_n-PL)

solidated clay. It is also said that one of the most dominant factor to control the undrained strength of this soft marine is the OCR.

It is found that clay in the area is in slightly to moderately overconsolidated state(OCR=1 to 8). Fig. 15 shows the variation of the consolidation coefficient(C_c) with the OCR. The values of C_c of the soil is slightly increased with increase in OCR.

V. Sensitivity and Liquidity Index

The sensitivity ratio(S_t) is calculated from the ratio of unconfined compression strength of undisturbed to remolded samples, q_u/q_{ur} as shown in Fig. 16. It is found that sensitivity gradually increases with the increase of clay-size fraction and a general validity of the fact. It is found that the S_t is greater than 6.0 in the figure. The solid line in the figure represents average value of sensitivity. It is, therefore, said that the soil is sensitive to extra sensitive. If the soil is disturbed, a significant strength reduction can be expected. Great care is required in using the site for any purpose.

The clay of sensitivity of $S_t>4$ and liquidity index LI>0.4 is classified as a sensitive clay where the clay of $S_t>8$ and LI>1.0 as an extra sensitive clay. The clay in this area should belong to sensitive to extra sensitive clay. The slight increase in sensitivity with liquidity index is shown in the figure.

The variation of the liquidity index with water contents(ω_n-PL) is plotted. Fig. 17 shows that most of the liquidity index is greater than 1 with some occasional values greater than 2. The variation of (ω_n-PL) vs. LI is approximately linear.

VI. Conclusions

The soil encountered should be classified from the profiles of water content, unit weight, Atterberg limits and grain size distributions, from visual examination of samples, and from observations of the site made at the time of boring. Then the strata and finally the substrata should be defined.

Having examined the mechanical characteristics such as vane shear strength, cone penetration test and preconsolidation pressure it should be recognized that these parameters are not independent but are all a reflection of the same soil structure. They are therefore related and one can check ratios such as C_u/σ'_p. The laws of correlation reflect the basic principles of soil mechanics and in particular the principles of yielding. They therefore form a valuable tool for the geotechnical study of any clay deposit. If the measured ratios are very different from the typical values, then the interpretation of the tests should be checked and if necessary, tests repeated with particular attention to the appropriate soil strata.

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References

1. Bjerrum, L. & Simons, N. E., 1960, Comparison of shearing strength characteristics of normally consolidated clays., Proc. ASCE Conf. on Shear Strength of Cohesive Soils, Boulder, Co, pp 711-726.
2. Bjerrum, L., 1973, Problems of soil mechanics and construction on soft clays and structurally unstable soils(collapsible, expansive and others)., Proc. 8th ICSMFE, Moscow, Vol 3, pp 111-159.
3. Leroueil, S., Magnan, S. P., & Tavern, F., 1990, Embankments on Soft clay, Ellis Horwood