The engineering properties of surface layer on very soft clay of the south coast in Korea

H.S. Jung & C.G. Cho & B.S. Chun
Hanyang University, Seoul, South Korea

ABSTRACT : Many researchers have actively studied on stiffness of soft clay in the south coast in Korea. However it is still insufficient to investigate clearly on the stiffness of very soft clay layer. Undrained shear strength of very soft clay layer in the south coast area were evaluated to investigate engineering characteristics of in-situ clay and dredged-reclaimed clay by various test methods. Results obtained by standard penetration test, field vane test, piezocone penetration test and dynamic cone penetrometer test were compared. Undrained shear strengths of clay layer near surface in south coast district are below 65kPa. Results of field vane tests were similar to those of piezocone penetration tests. The correlation between penetration depth and undrained shear strength produced a formula when dynamic cone penetration test made one blow in the field tests to apply dynamic cone penetrometer into very soft grounds.

1 INTRODUCTION

Recently dredged deposits and reclamations of public water area are increasing as one of the effective methods to use the wastelands more effectively. In addition, the cases to carry out constructions of civil engineering structures in very soft grounds also rapidly increase. Therefore, precise analyses of shear strength of the soft grounds have been required and then various soft ground improvement methods have been developed to stabilize soft grounds more economically in early stage of construction.

N-value is the most critical value for construction design on or in the ground. In spite that strength properties according to accumulation order of clay layers for very soft grounds were different, as the changes of N-values gained from Standard Penetration Test (SPT) were minimal, researchers had difficulties to precisely understand soil strength. In addition, as ground accessibility for sandy soils is easy, data are abundant and research results are good due to many researches, it is easy for many researchers to share. However in case of cohesive soils, as equipments entry is difficult in many cases, tests are quite difficult to be executed and data are in shortage. Moreover the data have many errors.

Accordingly in this research, in-situ tests such as standard penetration test, Field Vane Test (FV) and Cone Penetration Test (CPT) in five domestic fields were conducted to evaluate undrained shear strength of outer layers in the very soft ground. Contents to analyze undrained shear strength according to cone penetration depth in order to use Dynamic Cone Penetrometer Test (DCP) in very soft grounds are treated.

2 BACKGROUND

2.1 *Very soft ground*

The bases to judge soft grounds are depending on sorts, engineering methods and construction periods for structures to be constructed in the grounds. As soft grounds make instable behavior dynamically as their compressibility is high and bearing power is low, in case bankings (embankments) or digging works are executed in the grounds, ground subsidence and destruction occur. Accordingly counter-measuring engineering methods are required to be set up.

Soils in the ground are generally divided into clay and sand and the softness of soil can be estimated by experimental correlation. However for general judgement, softness of the grounds is expressed in soft/harness degree for clays and relative density for sands.

For clay soils, degree of is estimated by the test results of unconfined compressive strength (qu), cone penetration test, field vane test and/or standard penetration test. As shown in Table 1, clays of which unconfined compressive strength is less than 50kPa are soft clays and clays with 'less than 25kPa' are classified as very soft. If N-value in clay layer is less than 4 for SPT, it indicates soft clay, and very soft clay for N<2. However as N-values measured in clay layer provide rough estimate values only to judge shear strength and softness, they should be carefully considered when actual designs are applied.

Table 1. Judgement of Soft ground in Clay by SPT (Terzaghi & Peck, 1948)

Consistency	N values	Unconfined compression strength(qu, kPa)
Very Soft	< 2	< 25
Soft	2 ~ 4	25 ~ 50
Medium stiff	4 ~ 8	50 ~ 100
Stiff	8 ~ 15	100 ~ 200
Very stiff	15 ~ 30	200 ~ 400
Hard	> 30	> 400

On the other hand, softness of sandy grounds is judged by relative density. If relative density is less than 40%, it is considered as soft ground and if less than 20%, very loose ground (very soft ground).

Table 2. Relation between the corrected SPT N values and the internal angle of friction in Sand

N	Consistency	Relative Density Dr (%)	(Φ) Internal angle of friction	
			Peck	Meyerhof
0 ~ 4	Very loose	0 ~ 20	< 28.5	< 30
4 ~ 10	Loose	20 ~ 40	28.5 ~ 30.0	30 ~ 35
10 ~ 30	Medium	40 ~ 60	30.0 ~ 36.0	35 ~ 40
30 ~ 50	Dense	60 ~ 80	36.0 ~ 41.0	40 ~ 45
> 50	Very dense	80 ~ 100	> 41.0	>45

2.2 *In-situ test*

The standard penetration test has several advantages such as the easiness of the test procedure and the simplicity of the equipment employed. Representative but disturbed samples can be taken, which is used for the classification of layers. The test is carried out in various types of soils ranging from soft clay and loose sand to very stiff clay and dense sand.

In situ vane shear measurements are especially useful in very soft soil deposits which may have a strength disturbance during sampling. It should not be used in stiff clays or in soft soils containing gravel, shells, wood, etc. The main equipment components are the torque assembly, which includes a gear reduction device capable of producing constant angular rotation of 1 degree to 6 degrees per minute, a calibrated proving ring with a dial gage for torque measurement within 5%, a means of measuring angular rotation in degrees, and thrust bearings to support vane at ground surface (NAVAF, 1982).

The equipment for CPT consists of mechanical, electrical, electronic and hydraulic units and a coiling system. The length of the coil depends upon the required depth of sediment investigation. The tip of the coiling system, consisting of a cone with an apex angle of 60° and a diameter of 35.7mm, is pushed by the help of the hydraulic unit at a rate of 2cm/s into the sediment.

The dynamic cone penetrometer has been described by ASTM 6951-03 (2003). The typical dynamic cone penetrometer consists of an 8kg hammer that drops over a height of 575 mm, which yields a theoretical driving energy of 45J or 14.3J/cm^2, and drives a cone tip with 20mm base diameter vertically into the pavement or subgrade layer. The steel rod to which the cone is attached has a smaller diameter than the cone (16mm) to minimize the effect of skin friction. Depth of investigation of dynamic cone penetrometer is 1m to 2m. A number of blows measured during operation is recorded with depth of penetration. The slope of the curve defining the relationship between number of blows and depth of penetration (in millimeters per blow) at a given linear depth segment is recorded as the dynamic cone penetrometer penetration index (DPI).

3 FIELD TEST

3.1 *Methods*

The field test was executed to examine property of undrained shear strength in the very soft grounds of the south coast in Korea and use Dynamic cone penetrometer test (DCP) in very soft grounds.

Firstly, tests to examine property of undrained shear strength in the very soft ground of the south coast in Korea were executed in a total of 5 sites and the sites having very soft ground in the south coast for test places including Suncheon, Jeonnam (Site A), Gwangyang, Jeonnam (Site B), Mokpo, Jeonnam (Site C), Masan, Gyungnam (Site D) and Jinhae, Gyungnam (Site E) were selected. In the test methods, to determine whether the test area belongs to a very soft ground was based on standard penetration test (N<2). In case the area is very soft, cone penetration test and field vane test were executed and undrained shear strengths were compared and analyzed.

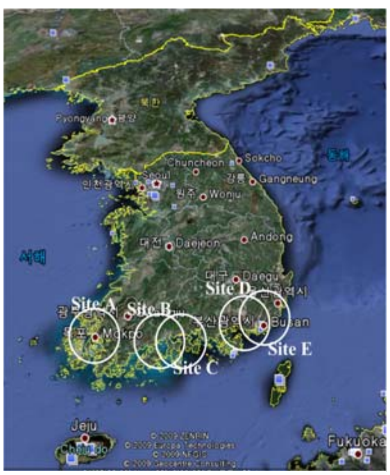


Figure 1. Locations of field tests

Secondly, in the field test executed to use dynamic cone penetrometer test in very soft grounds, analysis of undrained shear strength regarding penetration depth was executed when the dynamic cone penetrometer test made one blow. For the detailed test method, whether the test area is very soft was judged by Standard penetration test (N<2). The penetration depth when Dynamic cone penetrometer test made one blow was measured in the area corresponding to a very soft ground. As Field vane test (FV) was executed in the same position, undrained shear strength was secured and both data were mutually compared and analyzed.

Laboratory tests were composed of basic soil tests and the experiment materials gathered in GL(-)0.3m were used. The total six tests including unit weight test, moisture content test, special gravity test, particle-size test, liquid limit test, and plastic limit test were executed according to Korea Standard Test. Triaxial compression test was executed and then undrained shear strength was analyzed in the dynamics test (Table 3).

Table 3. Physical properties

Content	Site A	Site B	Site C	Site D	Site E
Unit weight	1.63g/㎤	1.54g/㎤	1.57g/㎤	1.52g/㎤	1.68g/㎤
Water content	35.07%	37.54%	35.02%	20.04%	36.02%
Specific gravity	2.63	2.70	2.73	2.69	2.65
Liquid limit	52.05%	55.44%	47.05%	-	43.75%
Plastic limit	36.50%	31.58%	25.48%	-	27.14%
USCS	MH	CH	CL	SP	OL
Undrained shear strength(UU test)	12.65kPa	27.42kPa	32.47kPa	34.38kPa	44.27kPa

3.2 *Results*

3.2.1 *Undrained shear strength of very soft clay layer in the South coast*

The clay layer in the site A was classified as a very soft ground because the penetration depths for one blow in the standard penetration test were ranging 28cm and 31cm. Results of the field vane test in the same place showed 'less than 36kPa' in the case 1 and 'less than 38kPa' in the case 2. Undrained shear strength converted from cone penetration resistance value were 'less than 37kPa' in the case 1 and 'less than 40kPa' in the case 2. When the results of field vane test and cone penetration test were mutually compared, the result of Field vane test showed relatively lower shear strength than that of Cone penetration test. In addition, both tests showed bigger undrained shear strength as gone to the surface layer.

As the Site B was the field where spoil was reclaimed, it was composed of very soft grounds of which N-values were generally less than 2 and the upper layer was classified as CH when it was classified by the two hundredth passed ratio, liquid limit and plasticity index under the unified classification rule. The penetration depths for one blow penetration when Standard penetration test was made were measured at 29cm, 43cm, and 60cm respectively. The result of field vane test showed 'less than 49kPa in the case 3, 'less than 47kPa in the case 4 and 'less than 23kPa in the case 5. In spite that the test was made after skimming the part of outer layer, the difference between undrained shear strengths for the outer layer and 50cm depth occurred more than other fields. When the cone penetration resistance value was converted to undrained shear strength by penetration depth and analyzed, the result showed 'less than 42kPa' in the case 3, 'less than 42kPa' in the case 4 and 'less than 20kPa in the case 5. When the results of field vane test and cone penetration test were mutually compared, the result of field vane test showed relatively lower shear strength than that of cone penetration test.

The site C is composed of silt clay mixed with fine grained sands down to GL(-)3m and high plastic clay(CH) mixed with a minute quantity of fine grained sands down to GL(-)7m. Dead load penetration by dead load of hammer occurs in the site, which is composed of very soft ground of which N-value is less than 2, generally down to GL(-)11m. The penetration depths for one blow penetration when Standard penetration test was made were measured at 25cm, 60cm, and 19cm respectively. The result of field vane test at that time showed 'less than 49kPa' in the case 6, 'less than 15kPa' in the case 7 and 'less than 45kPa in the case 8. When cone penetration resistance value was converted to undrained shear strength by penetration depth and analyzed, the result showed 'less than 35kPa' in the case 6, 'less than 11kPa' in the case 7 and 'less than 40kPa in the case 8.

The layer of the site D is composed of silt clay layer, sand gravel layer, weathering zone layer and sedimentary rock layer in turn. The silt clay layer was verified in the GL(-) 13.0~14.6m and upper altitude of sedimentary rock was verified in DL(-) 26.5~41.8m. The upper layer, which is composed of loose sandy soil, was classified as SP when it was classified by the two hundredth passed ratio, liquid limit and plasticity index under the unified classification rule. The penetration depths for one blow penetration when Standard penetration test was made were measured at 31cm, 27cm, and 30cm respectively. The result of field vane test showed 'less than 40kPa in the case 9, 'less than 50kPa in the case 10 and 'less than 28kPa in the case 11. The result of cone penetration test showed 'less than 20.5kPa in the case 9, 'less than 25kPa in the case 10 and 'less than 18kPa in the case 11. As this site is the ground mixed with loose sandy soil, whereas the other sites are composed of cohesive soil, it was analyzed that the difference between the result of field vane test and undrained shear strength by cone penetration test was about more than twice. As the penetration depth was getting deeper, the strength became larger not like the distribution of undrained shear strength of the site B and E, which is composed of dredging reclamation.

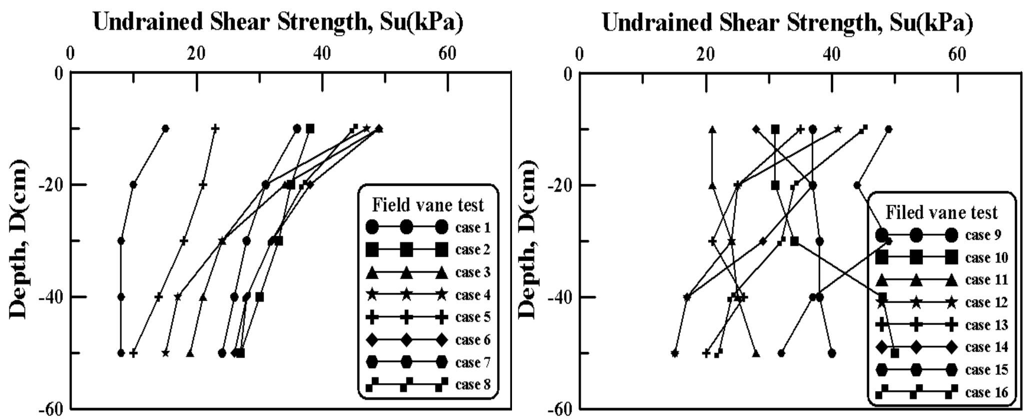
The site E is the place for dredging dumping and the case 12~16 in which the field tests were executed are the cohesive soil layer dredged and reclaimed. About 10~20 cm of its upper part is in state of consolidation and the lower part is composed of cohesive soil with high moisture ratio. It was classified as OL from the unified classification. The penetration depths for one blow penetration when standard penetration test was made were measured at 60cm, 60cm, 26cm, 16cm and 60cm respectively.

The result of field vane test showed 'less than 41kPa in the case 12, 'less than 35kPa in the case 13, 'less than 28kPa in the case 14, 'less than 49kPa in the case 15 and 'less than 45kPa in the case 16. The result of cone penetration test showed 'less than 39kPa in the case 12, 'less than 37kPa in the case 13, 'less than 41kPa in the case 14, 'less than 59kPa in the case 15 and 'less than 49kPa in the case 16.

When undrained shear strengths by penetration depth are analyzed, in case of very soft grounds (Site A, B, C, E) composed cohesive soil, the strength of the upper surface layer was verified to be higher than that of the lower part. The strength of lower part is greater than that of upper part in the very soft grounds (Site D) composed of loose sandy soil. Figures 2 and 3 show the result of undrained shear strength from field vane tests and cone penetration tests at the five fields respectively.

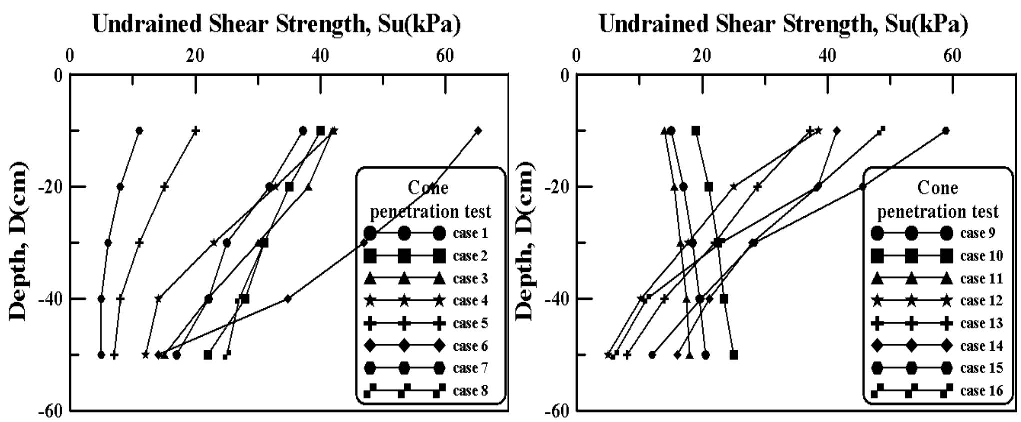
3.2.2 *Computation of undrained shear strength using dynamic cone penetrometer*

In order to use dynamic cone penetrometer in very soft grounds, undrained shear strength was computed using dynamic cone penetrometer. When one blow in the dynamic cone penetrometer was made, the undrained shear strength was analyzed by executing Field vane test at the same position of penetration depth.



(a) case 1~8 **(b) case 9~16**

Figure. 2 Field vane test result



(a) case 1~8 **(b) case 9~16**

Figure. 3 Cone penetration test result

The result of field vane test showed maximum undrained shear strength was less than 50kPa in very soft ground ($N<2$) and soft ground ($N\geq 2$). The penetration depth at one blow in the dynamic cone penetration test was analyzed to be 4cm. There are various strengths according to penetration depths from surface layer to 30cm penetration depth. However, in the surface layer below 30cm of penetration depth, as penetration is made by dead load of hammer, it is assumed that the undrained shear strength has no considerable meaning. The following equation was deduced from regression analysis of undrained shear strength by penetration depth when dynamic cone penetrometer made one blow. It is expected to be well used for computation of shear strength when dynamic cone penetrometer is used in very soft grounds.

$$\ln(Y)=-1.55\ln(X)+7.16 \quad (1)$$

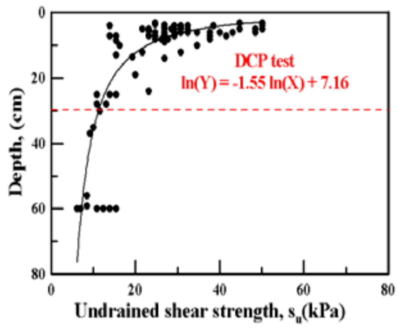


Figure. 4 Computation results of undrained shear strength using DCP test

4 CONCLUSIONS

1) The result of field vane tests in five fields of very soft ground showed that the undrained shear strength is about less than 50kPa in the border area to practically distinguish very soft ground and soft ground.
2) The undrained shear strength was verified to be 65kPa from the result of cone penetration test. This result indicates that the strength by cone penetration test is greater than undrained shear strength by field vane test.
3) When undrained shear strengths depth are analyzed compared with penetration depth, in case of very soft grounds composed of cohesive soil, the strength of the upper surface layer was verified to be higher than that of the lower part. The strength of lower part is greater than that of upper part in the very soft grounds (Site D) composed of loose sandy soil.
4) The formula ln(Y)=-1.55ln(X)+7.16 was derived by from regression analysis of undrained shear strength by penetration depth when the dynamic cone penetrometer made one blow and it is expected to be well used for computation of shear strength when dynamic cone penetrometer is used in very soft grounds.

5 REFERENCES

Sivrikaya, O. & Toğrol, E. 2006. *Determination of undrained strength of fine-grained soils by means of SPT and its application in Turkey*. Engineering Geology 86 : 53

DEPARTMENT OF THE NAVY NAVAL FACILITIES ENGINEERING COMMAND. 1982. SOIL MECHANICS. Design manual 7.1 : 97-100

Mohammadi, S.D. & M.R. Nikoudel, & H. Rahimi, & M. Khamehchiyan. 2008. *Application of the Dynamic Cone Penetrometer (DCP) for determination of the engineering parameters of sandy soils*. Engineering Geology 101 : 197

Edill, T.B. & Benson, C.H., 2005. *Investigation of the DCP and SSG as Alternative Methods to Determine Subgrade Stability*. Department of Civil and Environmental Engineering, University of Wisconsin-Madison. : 25-38

Girish Gopinath. 2009. *Determination of sediment characteristics through cone penetration test in shallow marine areas using electrical compression cones*. Current Science. VOL. 96, NO. 2 : 25

Rodin, S. 1965. *Ability of a clay fill to support construction plant*. Journal of Terramchanics 2 : 51-68.

Webster, S.L. & Grau, R.H. & William, T.P. 1992. *Description and Application of Dual Mass Dynamic Cone Penetration*. Instruction Report GL-92-3, U.S. Waterways Experimental Station : 50