[Konni, 3(7): July 2016] ISSN 2348 – 8034
DOI-10.5281/zenodo.58248 Impact Factor- 4.022

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

RELATIONSHIP BETWEEN GEOLOGICAL AND GEOTECHNICAL CHARACTERISTICS OF SOFT MARINE CLAYS AT HOWAJON SITE, PUSAN

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ABSTRACT

Despite a number of geotechnical investigations that have been carried out on soft clay deposits at Pusan,South Korea, the local practicing engineers have been unable to deduce successfully the geotechnical properties of the clays due to their spatial variation and influence from geological depositional environments. In the area, clay deposits, so-called Pusan clays, are unusually thick, varying from 20m to 70 m in thickness. For this study, reclaimed land along the Nakdong river deltaic plain, which is called as “Hwajeon site” has been considered and an attempt has been made to characterize the Pusan clay in terms of both geotechnical and geological, furthermore dependency of geotechnical properties on geological depositional environment was also studied. In this study, a comprehensive geotechnical investigation was carried out with sophisticated sampling techniques, in situ and laboratory tests as well as geological analyses at an additional three locations. As a result of the investigations, it was found that depositional environments are closely related to the relative changes in sea level and have different features depending on location and depth. The clays consist of soft and stiff clays in the upper and the lower layers, respectively, which are classified as normally consolidated and cemented clay. Moreover, most of the geotechnical properties undergo changes due to their depositional environment.

***Keywords**: Pusan Clays, reclamation land, Characterization, geological depositional environment, geotechnical properties.*

1. INTRODUCTION

South Korean government proposed a plan of new land development in the deltaic plain of the Nakdong river for Pusan city and its vicinity and reclamation works have been started since the early 1990s. Some of the reclamation areas are Myungji, Shinho, Noksan, Gadukdo, Pusan New Port and Kimhae, as shown in Fig 1 below. Since there is further demand for developing new industrial and residential complexes along the Nakdong river plain area, further land development has been carried out along the Nakdong river deltaic plain, which is named as “Hwajeon” (hereafter called as study area) and shown in Fig 1 below, which is larger in size of about 2.45km^2. At the study area, there is top 10 – 15m of sand layer followed by soft clay of thickness varies from 20m to up to maximum of 40m thick, which is called as “Pusan Clay”. The soil below this Pusan clay is gravel. Despite the detailed geotechnical investigations were carried out at other sites along the Nakdong River, it has been very much required to have site specific geotechnical study due to the special variation in the soils along the Nakdong river estuary. Furthermore, geotechnical engineers are unable to deduce the design geotechnical properties of Pusan clays, may be due to the significant variation in geotechnical properties across the any specific site(s). In this study an attempt has been made to evaluate geological characteristics and their related geotechnical properties for the Pusan Clays at the study area. Hence, comprehensive geotechnical investigation includes both laboratory and in-situ, and also detailed geological investigation was carried out for the study area. In this study, the geotechnical characterization of Pusan clays in association with geological depositional environment were discussed.

 ISSN 2348 – 8034
Impact Factor- 4.022

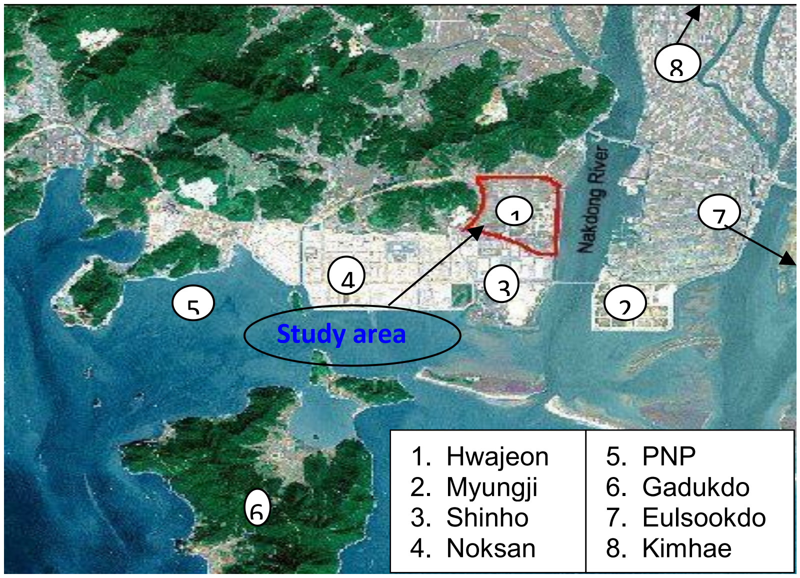

Fig 1 Location of study area

2. SITE INVESTIGATION

In order to characterize the Pusan clays at study area, a comprehensive investigation plan consisting of both in-situ and laboratory testing has been proposed. Total 5 locations were selected for in-situ tests as shown in Fig. 2 for geotechnical study. The details of the in-situ tests are presented in table-1 below. Laboratory tests have been performed on undisturbed samples from all the 5 locations for both physical and mechanical properties. Larger size undisturbed samples have been collected from 3 additional boreholes exclusively for geological study. In order to compare the geological and geotechnical properties from both laboratory and in-situ tests, locations for geological study, CPTs, and field vane shear tests are selected quite close to the BH locations conducted for geotechnical study.

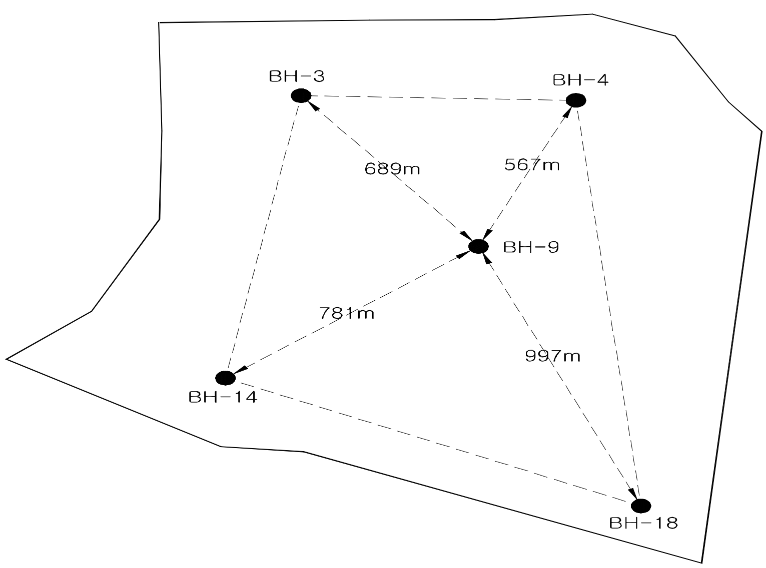

Fig 2 Site investigation layout at study area

Table-1: Details of in-situ tests conducted at study area

Study	Test Type	Quantity (nos)	Remarks
Geotechnical	Boreholes Field vanes CPT	5 (BH-3, 4, 9, 14 & 18) 5 5	Field Vane and CPTs are conducted close to the Borehole locations
Geological	Boreholes	3 (BH-3,9 & 18)	Separate boreholes are done and undisturbed samples were collected

3. GEOLOGICAL BACKGROUND OF PUSAN AREA

Pusan clays are deposited widely in the Nakdong River plain (or also called the Kimhae plain) that is surrounded by mountain ranges. The plain consists of a lozenge-shaped delta and flat areas with elevations varying around 2 to 3m above the mean sea level. The major channel marks with a longitudinal drainage pattern parallel to a major geological structure known as the Yangsan fault (running in the NNE-SSW direction), and the minor channels are connected to the major to form a dendritic pattern as shown in the Fig. 3.

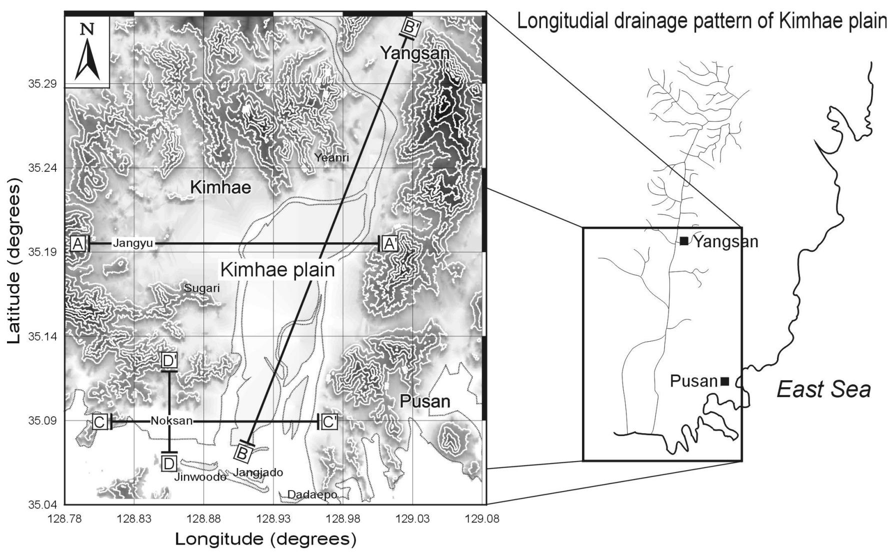

Fig 3 Topography and drainage pattern in the Nakdong river Plain

4. GEOLOGICAL CHARACTERIZAION AND DEPOSITIONAL ENVIRONMENTS(GDE)

According to physiography (Kwon 1973; Kim 1988), th deltaic areas are generally divided into four categories; namely upper and lower delta plains, floodplain, and delta-front or pro-delta . As per this study, the study area is situated in the floodplain (i.e., marginal basin) which is in the west and middle of the plain.

In order to evaluate the geological characteristics of the Pusan clay at the study area, comprehensive laboratory geological investigation has been carried out, on undisturbed samples recovered from three exclusive boreholes for this specific study. . A mechanical analysis has been carried out to analyze the type of deposit and structure of the sedimentary deposit. As a result, the sedimentary facies has been found to be muddy (silty clay) sedimentary layer at the study area.

Based on the results from the study, it is found that the Pusan clay at the study area has been deposited into two major sedimentary facies (hereafter referred as Geological Depositional Environments (GDE)); namely Lower sedimentary facies (SF 1) and upper sedimentary facies (SF 2), which were classified based on the sedimentary types and primary structure of the clay deposits. Each of these two sedimentary facies further sub-deposited as SF 1.1 (upper tidal flat) and SF 1.2 (lower tidal flat); SF 2.1(near shore), SF 2.2(inner shelf), and SF 2.3(pro-delta) as shown in Fig. 4. showing a typical geological cross section profile across the site...

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As shown in Fig. 4 the thickness of each sedimentary layer varies across the study area and it can also be noticed that lower sedimentary layer does not exist everywhere as indicated by, borehole location 3 and thickness of upper and lower sedimentary layers varies significantly across the site.

These major two geological depositional environments (SF1 & SF2) are conveniently named as "lower clay" and "upper clay" respectively.

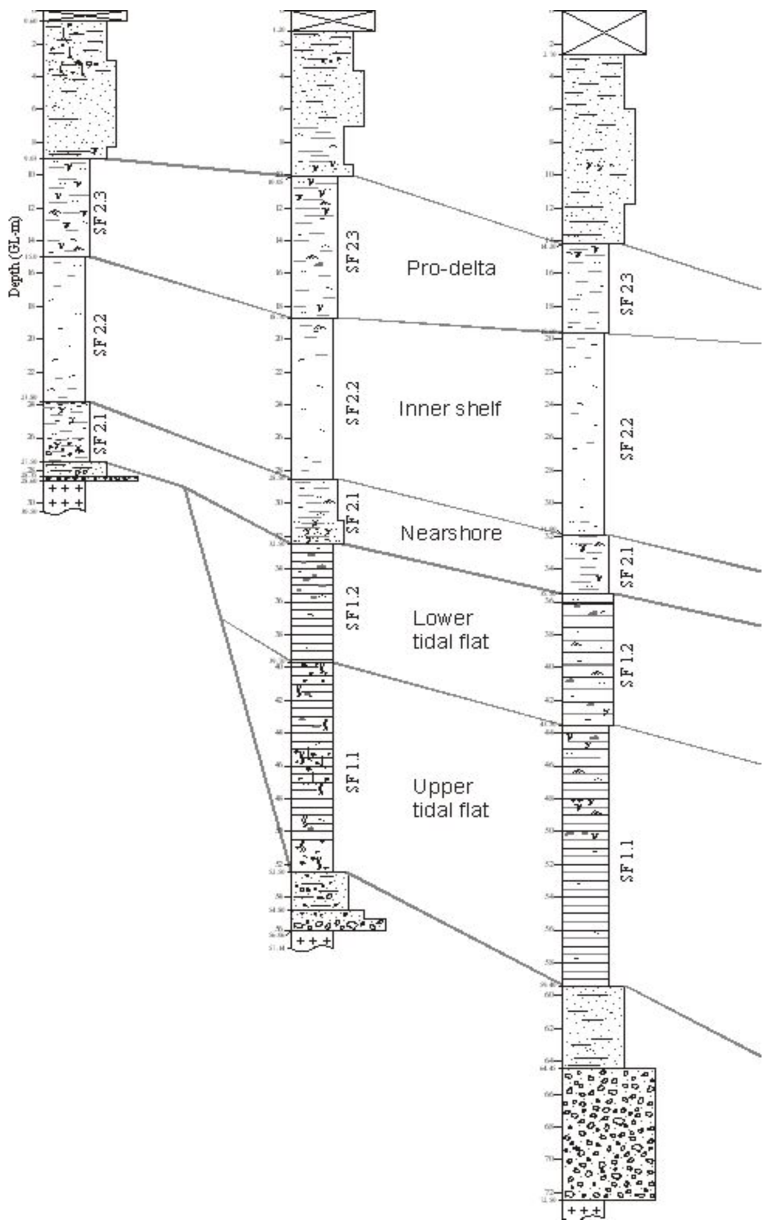

Fig 4 Typical geological profile cross section across the site
V

4.1 Comparison of Geological and Geotechnical Soil Profiles

In order to study the relationship between the geotechnical and geological characteristics, field investigation for both geological and geotechnical have been carried out as closely as possible so as to avoid the possible influence of soil variation on the relationship. Geotechnical parameters such as cone tip resistance (q_t) from CPT test, as it is continuous profile, and natural moisture (Wn) content, as it is sensitive parameter for soft marine clays, from laboratory tests are compared with a typical geological profile in Fig.5. It is found that even these geotechnical parameters also showing the soil stratification indicating the two different layers as upper and lower clays as indicated by geological profile. It would be unable to differentiate the sub-sedimentary facies by CPT and water content. It is quite interesting to note that the sensitivity in the variation of these geotechnical parameters even indicating the transition zone between two GDEs, which confirms that geotechnical parameters are closely related to the geological depositional environments of Pusan clays. Therefore it is strongly recommended to perform the detailed geological investigation, besides geotechnical investigation, as it plays critical role in characterization and arriving geotechnical design parameters for soft marine clays. The variation of other geotechnical parameters with GDE are discussed in the following sections.

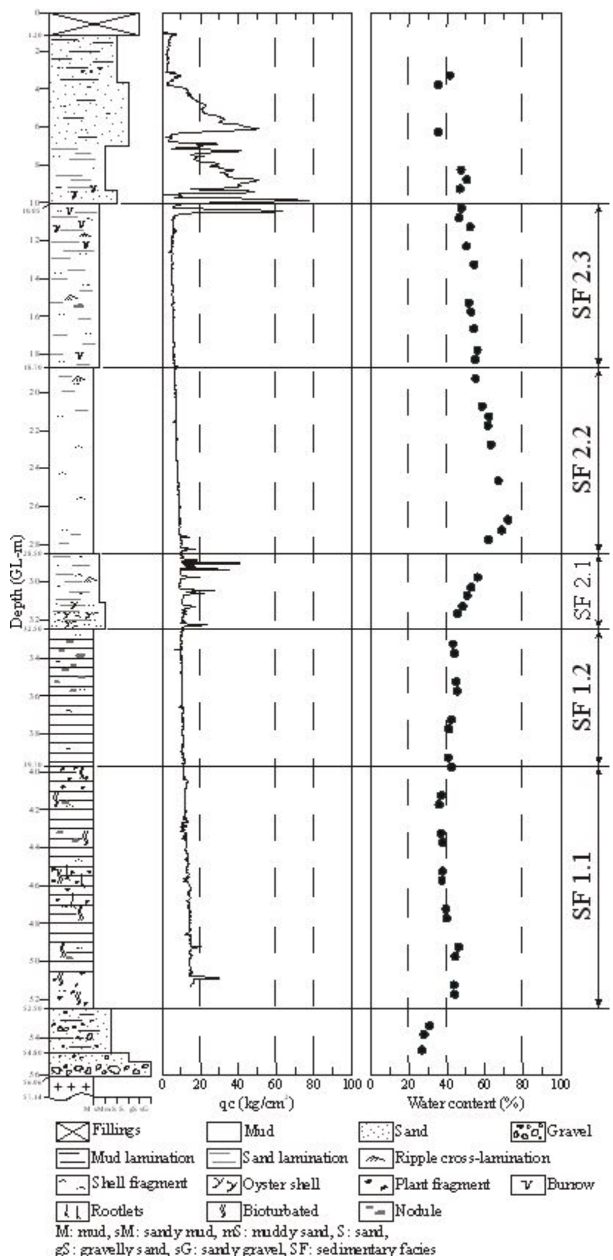

Fig 5 A typical combined profile showing both geological and geotechnical parameters for BH-9

[Konni, 3(7): July 2016] ISSN 2348 – 8034
DOI-10.5281/zenodo.58248 Impact Factor- 4.022

5. GEOTECHNICAL PROPERTIES WITH GDE's

5.1 *Soil Composition*

In order to evaluate the continuous soil composition profile, CPT-Pclass software program (Zang and Tumay (2003)) has been used, which classifies the soil composition using CPT data. In this paper, a typical soil composition profiles from three locations (output from CPT-Pclass software) are shown in Fig.6, wherein it can be noticed that clay content is higher in the upper clay (between 10m and 30m) and relatively lower in the lower clay (below 30m). t. As it can be seen from Fig.6 that the Pusan clay at the study area consists predominantly silty and clay (together about 80% – 95%) with relatively less sand content (about 5% – 20%). The CPT-Pclass results from all other locations have also shown almost similar observation, which indicates that the Pusan clay deposit at the study area is quite uniform in nature. Furthermore, in order to evaluate the mineral composition of the soil from the study area, the activity (Ac) of the soil (clay fraction (≤2mm) Vs Plasticity Index(Ip)) is plotted in Fig 7, where it can be clearly seen that the predominant minerals in the clay are Kaolinite and illite. It can be further noticed from the same figure that the upper clay constitutes more illite in nature while lower clay predominant in kaolinite.

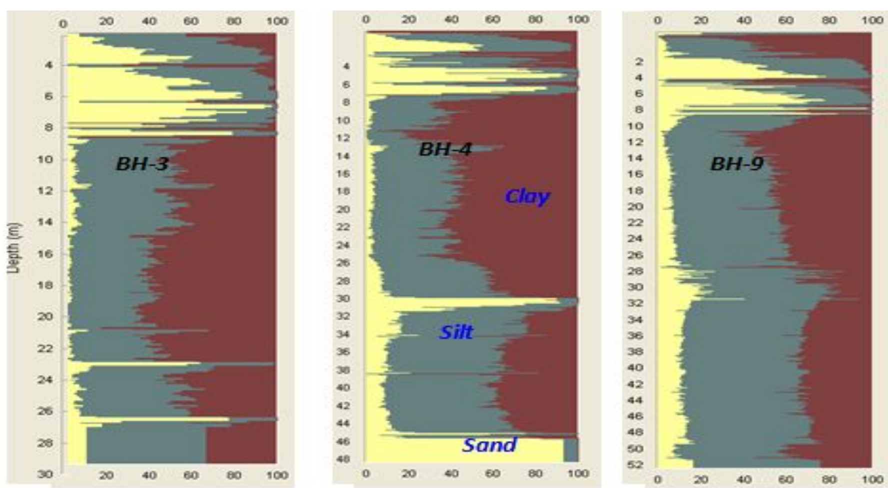

Fig 6 A typical soil composition profiles from CPT-Pclass program

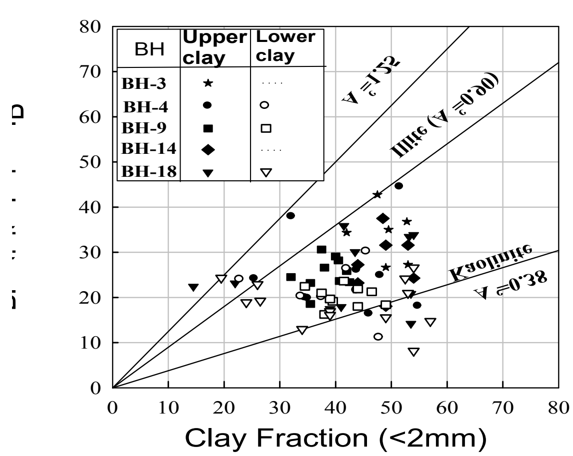

Fig 7 Mineral composition of Pusan clay from study area

[Konni, 3(7): July 2016] ISSN 2348 – 8034
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5.2 ***Index Properties***

Total 95 samples from all borehole locations were tested in laboratory for index properties. These index properties are used to study their relationship with geological depositional environments at the study area. The relationship ofeach index parameter with GDE has been studied in this section. Moisture content (Water content (Wn) and atterberg limits (Plastic limit (PL) & Liquid Limit(LL)) profiles for all the boreholes is presented in the Fig. 8, which clearly shows that all the water content parameters are relatively higher in the upper clay compare to those in lower clay. The water content profiles also show clear transition between upper and lower clays. The PL is ranging from 18 to 35% and LL is ranging from 30 to 70% across the site. It is quite interesting to note that the water content (Wn, PL and LL) has consistent trend with constant or slight increase with depth in upper clay and then, it falls suddenly at boundary between two major GDEs, indicating the strong relationship with geological depositional environments

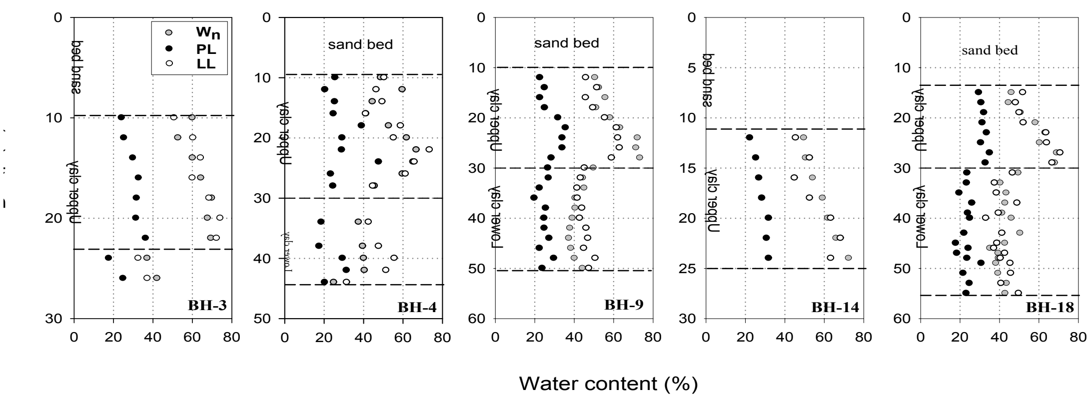

Fig 8 Variation of water content at the study area

Fig. 9 shows the plasticity chart for the Pusan clay at the study area, wherein it can be noted that the plasticity index is higher for upper clay compare to the lower clay, which could be due to the fact that upper clay has more fine content.It can be seen that the soil from the study area falls under CL – CH type; more interestingly, majority of lower clay falls under CL type whereas majority of upper clay falls under CH type,which is indicating the clear distinction between the two major GDEs and strong relationship between the geological and geotechnical properties of Pusan clay at the study area.

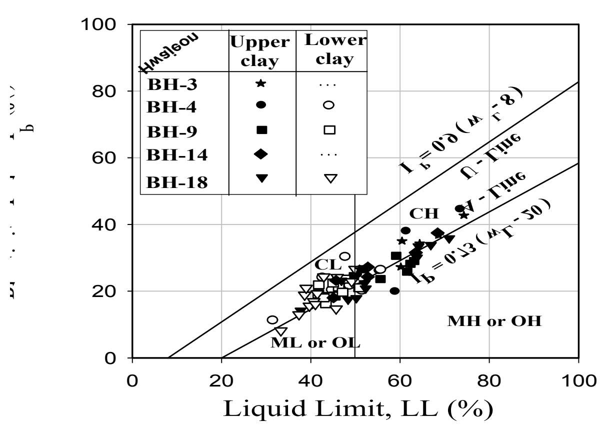

Fig 9 Plasticity chart for the Pusan Clay from study area

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Fig. 10 shows the variation of specific gravity (Gs) from all the boreholes with depth for the Pusan clay at the study area. It can be seen from this figure that the GDE has a noticeable effect on the specific gravity as well. Gs values varies between 2.63 and 2.74 in upper clay while it varies between 2.6 and 2.7 in the lower clay.

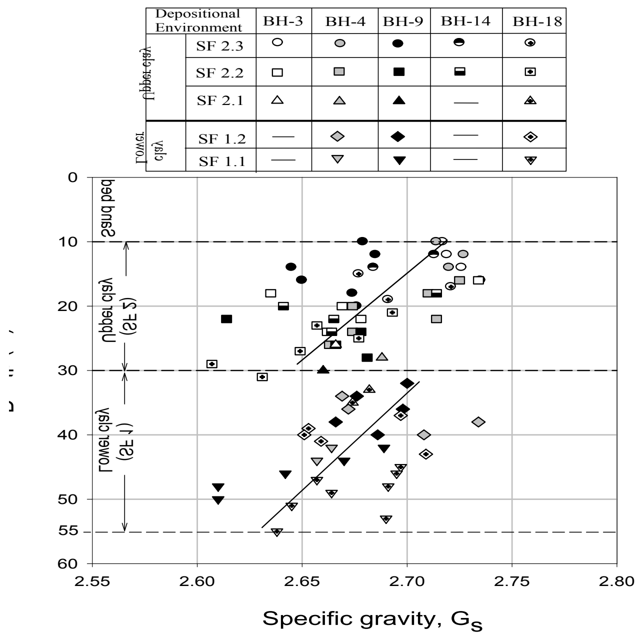

Fig 10 Variation of specific gravity (Gs) for Pusan Clay from study area

Fig. 11 shows the variation of unit weight from all the locations with depth for the Pusan Clay at study area. It is very interesting to see that very clear distinction between the two GDEs. The unit weights decreases with depth from 1.8t/m3 to 1.55t/m3 in the upper clay while it remains almost constant (ranging between 1.7t/m3 and 1.8t/m3) with depth in lower clay with very clear indication of boundary between upper and lower clays. The unit weight is slightly higher in lower clay compare to upper clay due to the fact that lower clay has less fine content and slightly higher sand component.

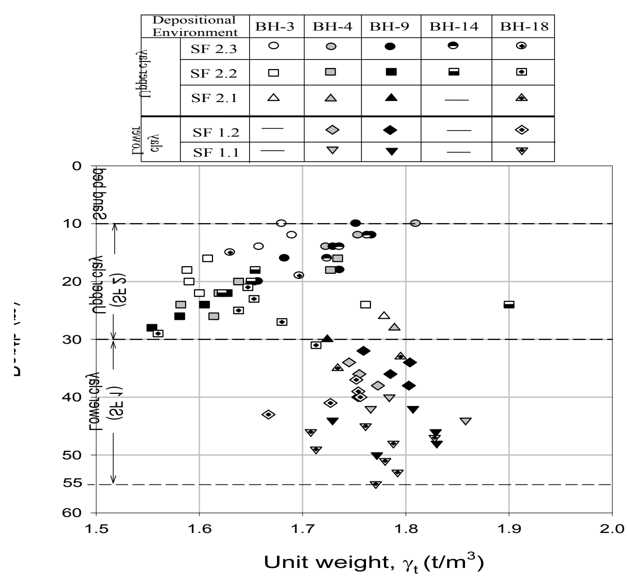

Fig 11 Variation of unit weight for Pusan Clay from study area

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The salinity tests were performed on samples from different depths of the Pusan clay from study area and the results are plotted in Fig. 12, which shows the upper clay is more saline in nature compare to the lower clay, which may be due to the reason that the upper clay is more exposed to saline environment compare to lower clay. It can be seen that it increases with depth from 10g/l to 19g/l in the upper clay while it decreases with depth in lower clay. Therefore it can be inferred that salinity of soil reduces with depth. Hence, salinity also shows very strong relation with geological depositional environments.

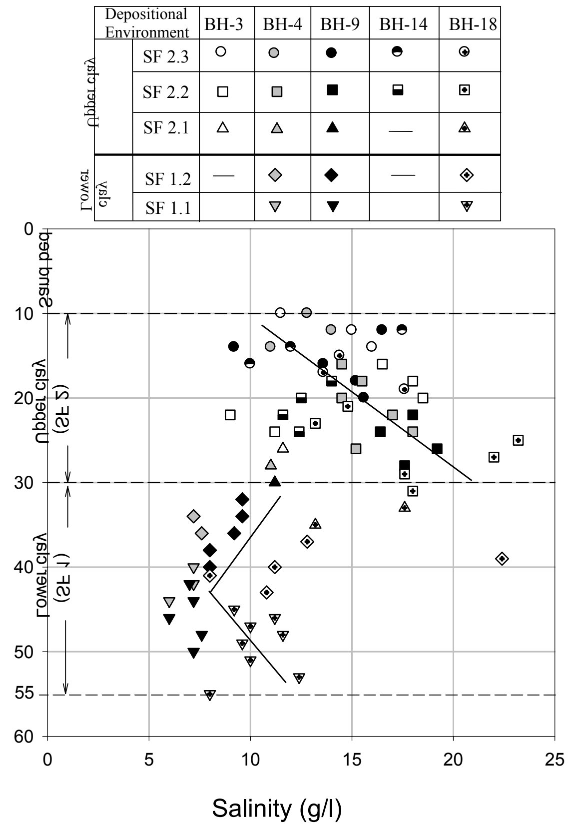

Fig 12 Variation of salinity for Pusan Clay from study area

5.3 Mechanical Properties

5.3.1 Undrained shear strength

It is fact that undrained shear strength measured from laboratory tests are significantly affected by inevitable sample disturbance, which may cause to disappear the relationship between the undrained shear strength and GDE. Therefore shear strengths from field vane shear tests are used in the current study. . In this study, the Geonor type four blade apparatus was used and applied at a rotation rate of 1%/s. The apparatus is 110mm high, 55mm wide, and 2mm thick. The measured undrained shear strength (u) from five locations at the study area are presented in Fig.13a. It shows that the variation of u with depth from all the locations indicate the similar trend, while the u values from BH-18 are relatively less compared to those from other four locations, which may be due to the reason that the upper clay at this location has large quantity of clay rather than silt at other locations; it is fact that the silt mobilizes relatively more frictional resistance than clay does.

Furthermore, laboratory tests such as; unconfined compressive (UC) test, Unconsolidated Undrained (UU) test, an-isotropically Consolidated undrained (CAU) test; were also performed on the undisturbed samples recovered from different depths from the study area. Such data for one location (BH-9) is compared with mobilized undrained shear strength (u, mob) from the Field vane tests and also with estimated u based on the Mesri (1957) recommendation (u = 0.22 σ'vo) and combined data is presented in Fig. 13b. It can be seen that u values increasing with depth. An interesting finding is that u from CAU tests on lower clay are significantly more than those from other laboratory

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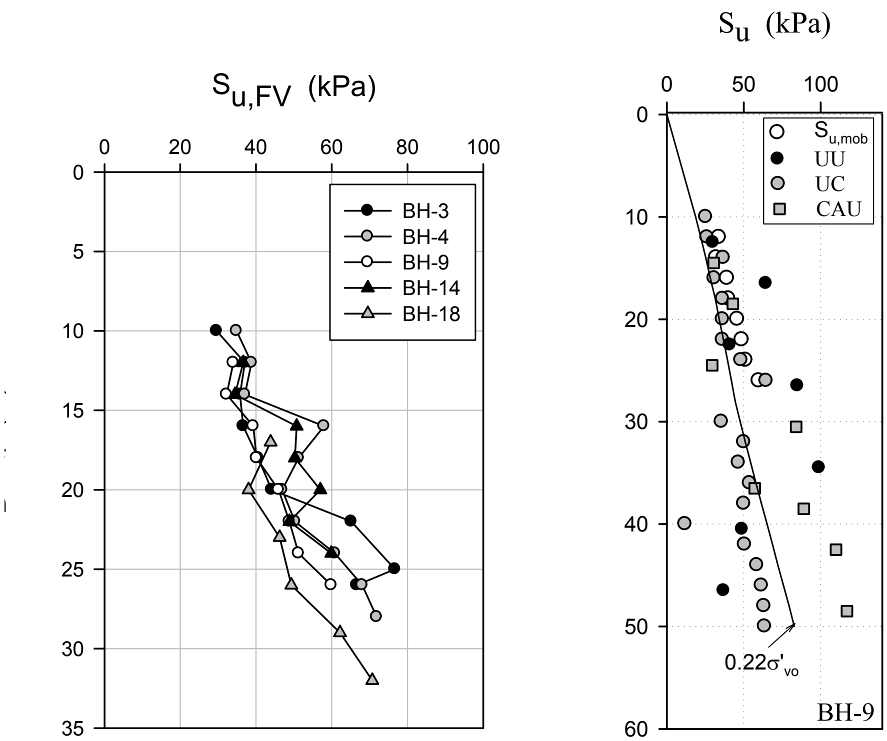
tests, this could be due to the reason that sample disturbance effects on u might have been reduced during anisotropic consolidation under in-situ effective stress.



(a) Results from Field Vane(FV)tests ***(b) Laboratory results comparing with FV results***

5.3.2 Compressibility

The compressibility characteristics of clay reflect its initial structure (Leroueil *et al.*, 1990). The values vary significantly depending on sample disturbance and testing methods. In this study, data from the conventional oedometer test (the load increment ratio is 1.0 and the duration is 24 hr at each load) were obtained. Specimens were 60 mm in diameter and 20 mm in height.

Fig.14 shows the variations in compression index (Cc) with depth for the study area, where it can be clearly seen that upper clay is found to be more compressible than lower clay due to fact that the upper clay has more fine content; Also Cc value increases with depth in upper clay form about 0.5 to 1.0 while it is ranging between 0.4 and 0.75 in lower clay. Very interesting to note that Cc variation with depth shows the clear transition zone between two GDEs and strong relation can be seen between DGE and Cc.

ISSN 2348 – 8034
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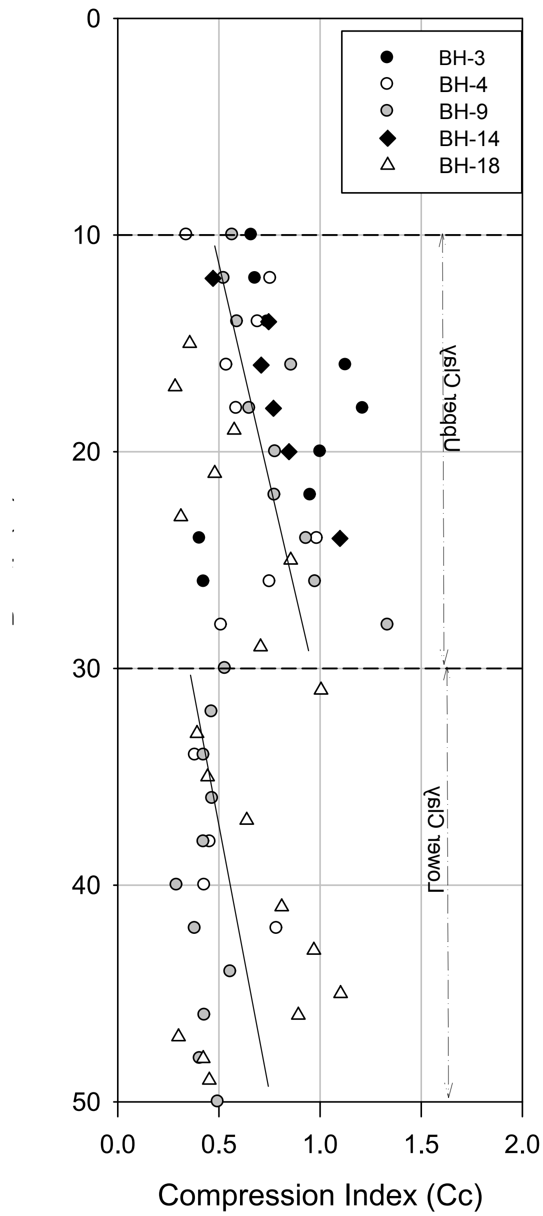

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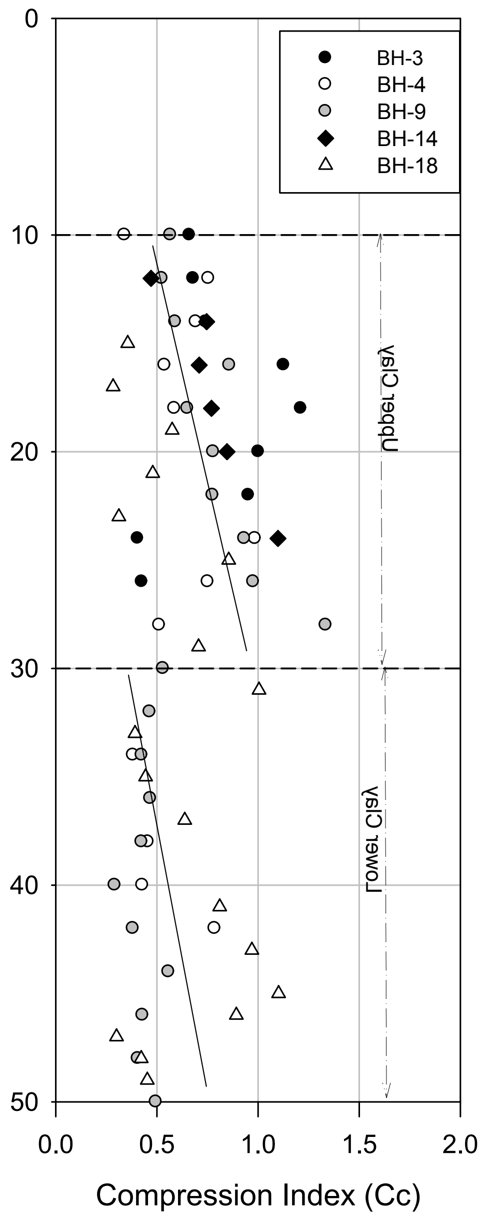

Fig 14 Variation of compression index for Pusan Clay from study area

6. CONCLUSIONS

From the soil investigation carried at the study area and subsequent analysis, the following conclusions can be drawn

6.1 The study area is situated in the floodplain and the Pusan clay at the study areahas higher fine content and deposited into two major geological depositional Environments.

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6.2 It is found that all geotechnical properties clearly shows their dependence on the geological depositional environments of the same soil

6.3 Both index and mechanical properties of the soil have strong relationship with geological depositional environments of the Pusan Clay at the study area.

6.4 The Geotechnical properties, especially CPT data can be used for preliminary geological stratification just to understand major sedimentary facies in the absence of geological investigation.

6.5 It is recommended to carry out a comprehensive geological as well as geotechnical investigation in order to characterize the soil and deduce the more representative geotechnical design parameters for the design use.

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