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THE STRESS HISTORY OF SINGAPORE MARINE CLAY

M. F. Chang*

SYNOPSIS

The stress history, which is often measured by the state of consolidation of a soil in-situ, has a great influence on the engineering behavior of the soil. Although the geologic history of the Singapore marine clay is well-documented, current understanding of the stress history of the deposit is poor due to lack of detailed and reliable data from oedometer tests. Interpreted OCR-profiles from in-situ tests provide a basis for tracing the stress history of the clay, which normally consists of Upper and Lower Members separated by an intermediate layer. The stress history of the Singapore marine clay below the seabed appears to be different from that on-land. The Upper Member beneath the sea-bed is moderately to lightly overconsolidated primarily because of chemical bonding; whereas the Lower Member is lightly overconsolidated probably due to aging. In contrast, aging is probably the main cause of overconsolidation for both the Upper and the Lower Members on-land, although in some areas small scale groundwater level lowering or surface erosion could also have some effect. The intermediate layer is moderately overconsolidated primarily as a result of desiccation and oxidation.

INTRODUCTION

The Singapore marine clay dominates the Kallang Formation, a recent deposit in Singapore. In the past two decades, several major construction activities have been concentrated in areas underlain by Singapore marine clay. However, very little information has been published on the stress history or the overconsolidation ratio (OCR) of the clay (Lim, 1982 and Tan, 1983). Most constructions in the highly build-up areas involve high-rise buildings, which often sit on piles carried to an underlying hard stratum, deep excavations, and tunneling works. These types of construction require little information on the consolidation characteristics of the clay when using traditional methods of design. Consequently, very few high quality oedometer tests have been carried out in conjunction with these activities.

The works of Tan and Lee (1977) and Pitts (1983) cover extensively the geological history of the Kallang Formation which is directly related to the stress history of Singapore marine clay. However, a complete profile showing the variation of OCR with depth is important for detailed understanding of the stress

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* Associate Professor, Nanyang Technological Institute, Nanyang Avenue, Singapore 2263

history and the causes of overconsolidation of a soil deposit. One often has to resort to the estimation of OCR from other related soil properties that can be economically determined, as oedometer tests are both expensive and time consuming.

In-situ tests, in particular the field vane test, have been commonly used in routine site investigations in the Singapore marine clay. Results of these tests, which often provide continuous or nearly continuous profiles of soil characteristics, can be usefully correlated with the preconsolidation pressure or the OCR of the clay (e. g. Bjerrum, 1967). The correlations, such as those reported by Chang (1991), provide a basis for the interpretation of OCR. The interpreted OCR-profiles will be particularly useful for tracing the causes of overconsolidation of the clay, which are, like sedimentary clays elsewhere, closely related to the continuous geological activities in the past after deposition of clay.

SINGAPORE MARINE CLAY AND ITS GEOLOGIC HISTORY

The Kallang Formation consists of recent deposits of marine, alluvial, littoral, and estuarine origins. These deposits, which are widely distributed both on Singapore island and offshore, cover nearly 25% of the total land surface of the Singapore island, as shown in the geological map of Singapore in Fig. 1. The Singapore marine clay is the most distinctive and common deposit of the Kallang Formation. It generally consists of Upper and Lower Marine Members separated by a stiffer and usually more sandy intermediate layer. In some areas, organic soils of the Transition Member of the Kallang Formation are present at the base of the Upper Member (Pitts, 1983).

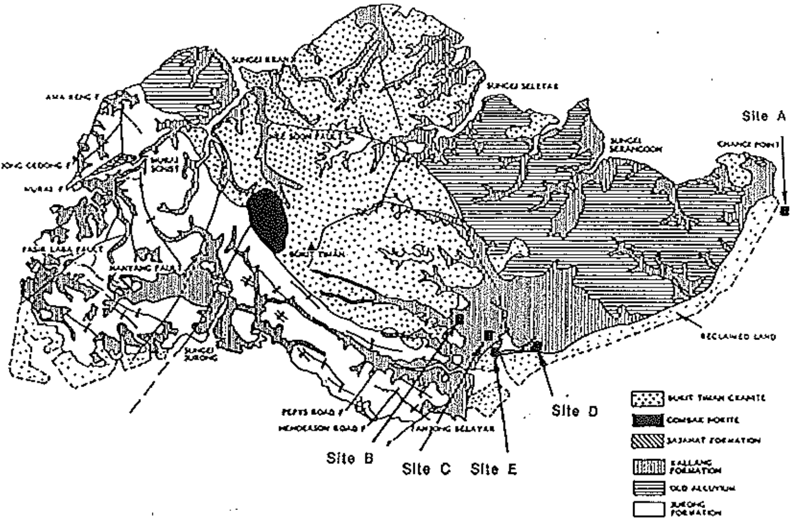

Fig. 1 Generalized geological map of Singapore and locations of testsites (modified from Pitts, 1984)

Fig. 2 shows the curves of the sea level change in the post-glacial period postulated by Fairbridge (1961) and Kenney (1964) and the depositional history of the Singapore marine clay presented by Pitts (1983). The Lower Marine Member was deposited unconformably over valley and plain floors or dense fluvial sediments some 12,000 years ago. Probably due to the exposure of the Lower Member to desiccation and the effect of weathering when the sea level dropped by 20 m to 25 m during two regressions between 10,000 and 12,000 years ago, a stiff weathered crust, which is locally known as the "intermediate layer", was formed on top of the Lower Member.

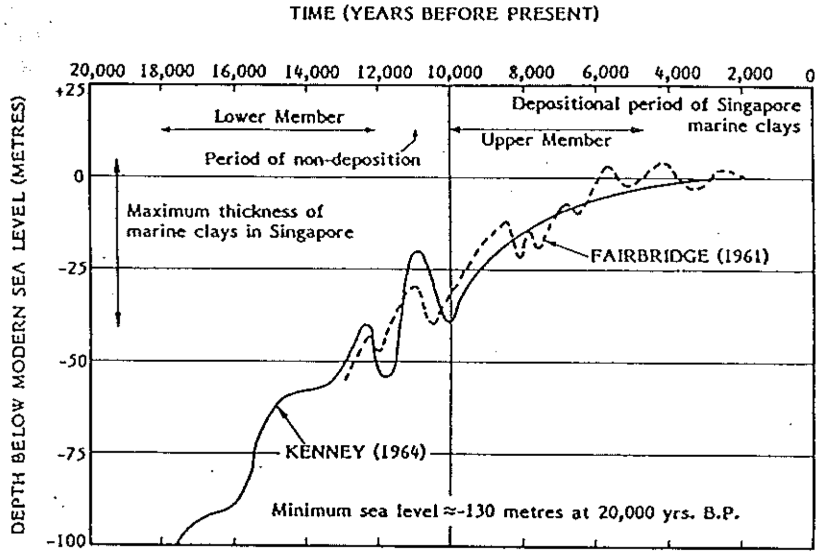

Fig. 2 Sea level changes and deposition of Singapore marine clay in the post-glacial period (after Pitts, 1983)

The Upper Marine Member was deposited during a period that stretched from 10,000 years ago, when the sea level began to rise from the elevation of approximately - 38 m after two major regressions, to between 6,000 and 5,000 years ago, when the sea level reached the recorded maximum elevation of +2 m during the post- glacial Climatic Optimum (Pitts, 1984).

According to Tan (1983), the marine deposit is essentially a weakly flocculated, kaolinite-rich clay with moderate contents of montmorillonite and illite. However, Lim (1982) noted that this mineralogical content could only be confirmed on an isolated sample. According to Cox (1968), the dominant clay mineral in the marine clay in the South East Asia is illite. The general observed plasticity characteristics, often indicated by the plasticity index (PI), of the Singapore clay seem to agree with that of a pure illite (PI = 58). The clay content is generally 55% to 65% and the activity is around 0.95 for the Upper Member based on Lim (1982). This finding further confirms that illite (activity = 0.90 ; Skempton, 1953) is probably the dominant mineral at least for the Upper Member of the Singapore marine clay. Typically, the specific gravity is 2.63 to 2.64 for both Members and the organic content is 3%, similar to the 3% to 5% reported by Cox (1968).

The general and index properties of the Singapore marine clay on and around the Singapore island were extensively reported by Lim (1982) and Tan (1983). The Lower Marine Member (or the lower marine clay) is normally pale grey to bluish grey in color. It is fairly homogeneous with occasional occurrences of shell fragments. The clay is highly plastic (typically LL = 65 – 85, PI = 38 – 55). The average bulk unit weight is 15.2 ± 0.6 kN/m^3. Its sensitivity ranges approximately from 2 to 4. With its natural moisture content at 50% to 69%, the corresponding liquidity index (LI) is approximately 0.39 to 0.75, indicating that the clay is overconsolidated to some extent.

The weathered crust of the lower marine clay (or the intermediate layer) has a composition that resembles the lower marine clay, although it is often slightly more sandy. The layer, typically 2.0 m to 4.0 m thick, is normally light grey with yellowish brown to reddish brown mottling. The natural moisture content of the clay (typically LL = 23 – 60, PI = 11 -22) varies from 16% to 28% depending primarily on the sand content. The liquidity index is generally 0.2 to 0.4 and the layer is much more heavily overconsolidated than the underlying lower marine clay.

The Upper Marine Member (or the upper marine clay) is normally grey to dark grey in color. It often consists of organic matters and shell fragments. The clay is highly plastic (typically LL = 76 – 101, PI = 45 – 69). Its moisture content is generally between 60% and 92% and its liquidity index is between 0.54 and 1.02. The average bulk unit weight is 16.3 ± 0.5 kN/m^3. The sensitivity of the clay usually ranges from 3 to 6. Occasionally, soils from the Transition Member, which are generally silty/sandy, shelly, and peaty, appear at the bottom of this Marine Member. They are sometimes considered as part of the intermediate layer.

CURRENT UNDERSTANDING OF STRESS HISTORY OF SINGAPORE MARINE CLAY

The recent marine clays in the Southeast Asian region have historically not been subjected to any pressure greater than the existing overburden pressure. In a classic sense, they may therefore be classified as normally consolidated clays. Nevertheless, as indicated by Bjerrum (1967), most natural deposits are actually lightly overconsolidated mainly due to delayed consolidation or aging. There are other processes of preconsolidation (Graham and Shields, 1985), among which the important ones are changes in groundwater levels, surface erosion, cementation and diagnesis bonding, and weathering or desiccation.

The detailed variation of the OCR-profile in a clay deposit is directly related to the post-depositional history of the clay (Hanzawa and Adachi, 1983). In the case of aging, the clay deposit is usually characterized by a constant OCR with depth (Bjerrum, 1967). Lowering of groundwater or surface erosion, and similary cementation, would introduce a constant change in vertical effective stress. Consequently, there would be a gradual decrease in OCR with depth. The effect of weathering due to downward leaching or desiccation would normally lessen as the depth increases and, as a result, the OCR would decrease, perhaps at a fairly rapid rate, with depth. The Singapore marine clay is generally considered to be slightly "aged" with the OCR ranging from 1.1 to 1.6 according to Lim (1982).

Fig. 3 shows a typical OCR-profile of the Singapore marine clay presented by Hanzawa and Adachi (1983) based on a comprehensive oedometer test program. The profile is representative of the natural Singapore marine clay beneath the sea-bed, which is traditionally believed to be normally consolidated based on the depositional history. However, Fig. 3 shows that the OCR-value is relatively high near the sea-bed, and is seen to decrease with depth approximately from between 4 and 8 just beneath the sea-bed to between 1.5 and 2 at the bottom of the upper marine clay. According to Hanzawa and Adachi (1983), the main cause of overconsolidation for the upper marine clay, as suggested by the probable shape of the OCR-profile, is chemical bonding, possibly as a result of ion exchange and development of cementation in the salt water environment.

For the lower marine clay, Fig. 3 shows that the OCR is approximately constant

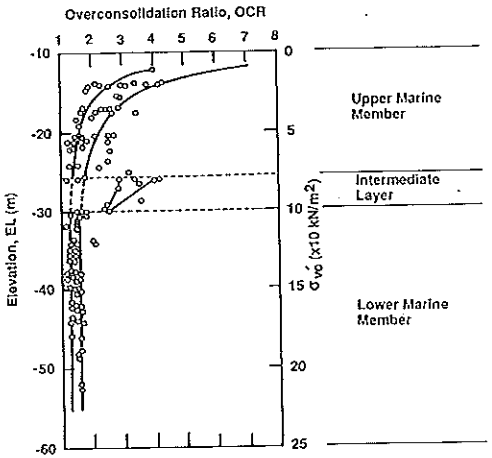

Fig. 3 Typical OCR-profile for Singapore marine clay below seabed (after Hanzawa and Adachi, 1983)

with depth, but the value is certainly higher than 1.0. The profile suggests that delayed consolidation or aging is probably responsible for the overconsolidation of the lower marine clay. It appears that this clay is one of the few casses in literature where Bjerrum's concept of constant OCR (Bjerrum, 1967) has been confidently identified. The value of OCR is generally between 1.3 and 1.6.

Data reported by Hanzawa and Adachi (1983) also suggest that the stiff clay of the intermediate layer is moderately overconsolidated (OCR = 2.5 to 4.0). Hanzawa and Adachi (1983) attributed the overconsolidation of this layer to oxidation or possibly laterization in addition to desiccation during exposure of the clay layer above the sea level prior to the deposition of the upper marine clay. According to Pitts (1983), the effects of desiccation and oxidation are frequently found offshore in the recent deposits in Southeast Asia. Leaching and the associated weathering effect as mentioned by Cox (1972) could also have contributed to the overconsolidation.

From a large collection of on-land oedometer test data gathered by the Public Works Department of Singapore, Tan (1983) concluded that the Singapore marine clay was lightly overconsolidated. He indicated that the OCR-value ranged from 1.0 to 1.5 for both the upper and the lower marine clays. In contrast to Hanzawa and Adachi (1983), Tan (1983) attributed the preconsolidation effect in both Marine Members to aging or delayed consolidation.

Chang (1988) related results of the piezocone test (CPTU) and the flat dilatometer test (DMT) to the stress history of the Singapore marine clay. Using a correlation between OCR and B_q (pore pressure ratio) deduced from the CPTU (Wroth, 1984), the OCR was found to be between 1.0 and 1.7 for the Upper Member and between 1.0 and 1.2 for the Lower Member at an on-land test site. The OCRs interpreted from DMT results using the original correlation of Marchetti (1980) were generally higher than commonly believed values of between 1.0 and 1.5.

Reclamation works carried out in the past twenty years have changed the overconsolidation ratio of Singapore marine clay in several areas (Fig. 1). Due to the low OCR of the natural Singapore marine clay and the high reclaimed sand fill, the clay in these areas could be either underconsolidated or close to a normally consolidated state, depending on the present degree of consolidation.

INTERPRETATION OF STRESS HISTORY FROM IN-SITU TESTS

The use of in-situ test for determining the overconsolidation ratio of clay has been an area of intensive research interest in the last few years (e.g. Wroth, 1984; Mayne, 1987; Konrad and Law, 1987; Chandler, 1987; Mayne and Holtz, 1988; Mayne and Mitchell, 1988; Mayne and Bachus, 1988; and Lacasse and Lunne, 1988). Recently Chang (1991) has studied the use of three common types of in-situ tests, the field vane test (FVT), the piezocone test (CPTU), and the dilatometer test (DMT), for profiling the OCR. Various correlations have been proposed for interpreting the OCR from the results of these tests. These correlations have been summarized and some have been applied to a series of sites in Singapore and Malaysia by Chang (1991).

According to Chang (1991), one can estimate the OCR of a clay from the field vane strength, $(s_u)_{FV}$, normalized by the corresponding effectives vertical stress, σ_v', based on the following two correlations:

$$OCR = 22\,(PI)^{-0.48}\,(s_u/\sigma_v')_{FV} \qquad (1)$$

$$OCR = [\,(s_u/\sigma_v')_{FV} / (s_u/\sigma_v')_{NC}\,]^{1.05} \qquad (2)$$

Equation (1), as proposed by Mayne and Mitchell (1988), was based on Larsson (1980) who reported that the $(s_u)_{FV}$-value could be related to the plasticity index (PI). Eq. (2) was proposed by Chandler (1987) on the basis of a large collection of field vane and oedometer test results. Chandler (1987) recommended that $(s_u/$

$\sigma_v')_{NC}$, the normalized undrained strength if the clay is normally consolidated, be estimated from Bjerrum's correlation for "young" clays (Bjerrum, 1972 & 1973). According to Chang (1991), Eq. (1) tends to produce a marginally lower value of OCR than Eq. (2). Both equations appear to provide reasonably or slightly conservative estimates of OCRs for the Singapore and the Malaysian marine clays.

Chang (1991) analyzed a large collection of published data obtained from CPTUs using piezocones with the filter element located at the base of the conical tip. He related the OCR to the pore pressure ratio $B_q = (u - u_o) / (q_t - \sigma_{vo})$, where u and u_o are the penetration and the initial pore pressures, respectively, q_t is the cone resistance corrected for the unequal end area effect (Jamiolkowski, et al., 1985), and σ_{vo} is the total overburden pressure, for clays of various sensitivity (S_t) ranges. He then proposed the following correlation for nonsensitive to highly sensitive clays ($S_t \leq 8$) with OCR less than 8:

$$OCR = 2.3\, B_q / (3.7\, B_q - 1) \tag{3}$$

This correlation was found to produce generally conservative estimates of OCRs for the Singapore and Malaysian marine clays (Chang, 1991).

The DMT results have also been used for estimating the OCR for clays. According to Marchetti (1980), the horizontal stress index, $K_D = (p_o - u_o) / (\sigma_{vo} - u_o)$, where p_o is the membrane lift-off pressure, is a measurement of the in-situ horizontal stress ratio. A common correlation between the OCR and the K_D is:

$$OCR = (0.5\, K_D)^{\lambda} \tag{4}$$

where $\lambda = 1.56$, recommended by Marchetti (1980) for uncemented natural clays, is most often used. However, Chang (1991) found that Marchetti's correlation led to OCR-values that were consistently larger than the oedometer values typically by 40% for the Singapore marine clay. A similar finding was reported by Powell and Uglow (1988) for some British clays which are younger than 70,000 years Before Present and by Lacasse and Lunne (1988) for some Norwegian clays. Chang (1991) proposed a λ - value of 0.84 for the Singapore marine clay.

INTERPRETED STRESS HISTORY AT SELECTED SITES

A total of five test sites, one (Site A) involving sedbed deposits, three (Sites B, C, and D) involving natural on-land deposits, and another one (Site E) involving reclaimed land, were investigated. The locations of these test sites are as shown in Fig. 1. Interpretation of the stress history and the causes of overconsolidation at these sites is mainly based on OCR-profiles interpreted from field vane, piezocone, and dilatometer test results. A limited number of OCR-values obtained directly from standard (24 hour load duration) oedometer tests on 63.5 mm diameter specimens prepared from 76.2 mm diameter "undisturbed" samples are used as reference values.

Site A (Seabed)

Fig. 4 shows the soil conditions and results of field vane shear tests at five locations at an offshore site (Site A) near Changi, located at the eastern tip of the Singapore island. At this site, the sedbed is generally less than 1.5 m below the low-tide level. The upper marine clay immediately below the seabed was rather thin, only around 8 meters. At most locations, the plasticity of the clay (LL = 69 – 80, PI = 40–58) is in the typical range of the Upper Member of the Singapore marine clay. The liquidity index of the clay is around 0.74. However, at one location (Location 3), the clay (LL = 57, PI = 29) seems to be different from the typical marine clay in Singapore. The liquidity index for this clay is fairly high, at around 1.72. All the tests were terminated in the underlying clayey silt or silty clay (LL = 50, PI = 25, LI = 0.2 – 0.4), the commonly known intermediate layer. At one location (Location 2), the lower marine clay (LL = 53 – 58, PI = 27 – 32, LI = 0.73 – 0.83), which is slightly less plastic than the Lower Member elsewhere, was found at a depth of around 11.5 m below the sedbed from a borehole record.

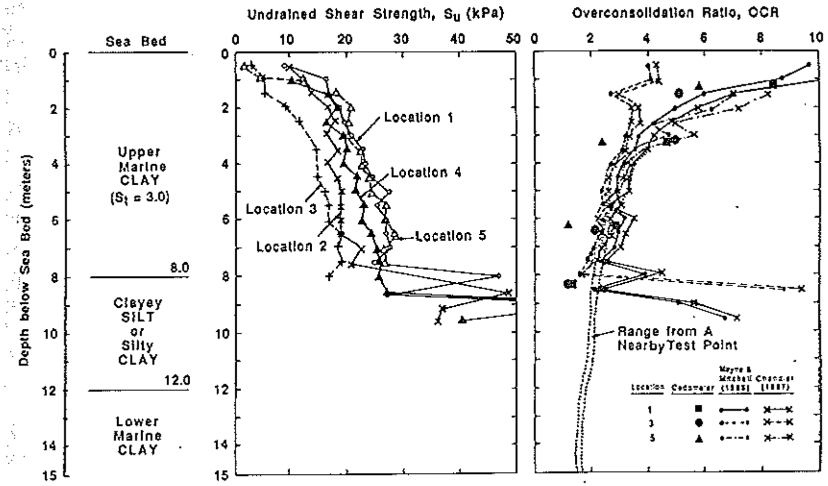

Fig. 4 Soil conditions and OCR-profiles at an offshore test site (Site A)

In Fig. 4, the vane strength profiles generally show a rapid increase in undrained strength within the first one meter or two below the seabed. This is likely to be an indication of chemical bonding or cementation effect. The measured strength at Location 3, where the clay is less plastic, is slightly lower than those at the other locations.

Fig. 4 also shows the OCR-profiles interpreted from the results of FVTs at Site A. The interpreted OCR-values in the upper marine clay range from 4 to 10 in the first three meters below the seabed to between 1.5 and 2.5 just above the stiffer clayey silt or silty clay layer. At Location 3, the corresponding OCR is lower. Also superimposed on these OCR-profiles is another OCR-profile based on FVTs for a nearby test point located possibly in an old drainage channel. The upper marine clay at this test point was underlain by 3 m of sand and it continued to a depth of around 20 m below the seabed. This OCR-profile compares reasonably well with the other profiles, with its lower portion resembling the extension of the OCR-profile at other locations. The interpreted OCR decreases gradually from 2.0 at a depth of 8 m to 1.5 at a depth of 15 m below the seabed. Note that the OCR-profiles interpreted by two different methods are only marginally different.

The interpreted OCR-profiles for the upper marine clay at Site A resemble the OCR-profile reported by Hanzawa and Adachi (1983) for an offshore site (near Marine Bay) in Singapore. Hanzawa and Adachi's profile in Fig. 3 shows that typically there is a rapid rate of decrease in OCR with depth for the upper marine clay and the OCR is fairly constant for the lower marine clay. A limited number of OCR-values from oedometer tests at Site A appear to confirm this trend. The OCR-profile seems to indicate that chemical bonding as suggested by Hanzawa and Adachi (1983) is responsible for the overconsolidation of the upper marine clay below the seabed. Other possible causes, such as lowering of groundwater level and weathering associated with leaching, can not be justified from the geologic history of the deposit if Kenney's curve in Fig. 2 is considered. Fig. 4 also shows that the OCR in the underlying intermediate layer is generally 4.0 or higher based on FVTs. Although the OCR values are interpreted, they are shown as points for clarity in Fig. 4 as they correspond to specific measured field vane strengths at different localities.

Site B (On-land and away from shoreline)

Fig. 5 shows the soil conditions and the results of FVTs and a CPTU at Site B. The test site located along the Central Expressway is an on-land site underlain by typical Singapore marine clay. The figure shows the comparison of OCR-profiles interpreted from results of the FVT, the CPTU, and the DMT. The range of OCR from the FVT is based on Eqs. (1) and (2), whereas the profile from the DMT is based on Eq. (4) and λ = 0.84. At this site, only two oedometer OCR-values are available for comparison. Both the FVT and the CPTU, which produce OCR-values of around 1.0 for both the Upper and the Lower Members, appear to have underestimated the OCR of the clay when the interpreted values are compared with the two reference values from oedometer tests. On the other hand, the OCR-profile interpreted from DMT seems reasonable; the two oedometer values fall right on the profile.

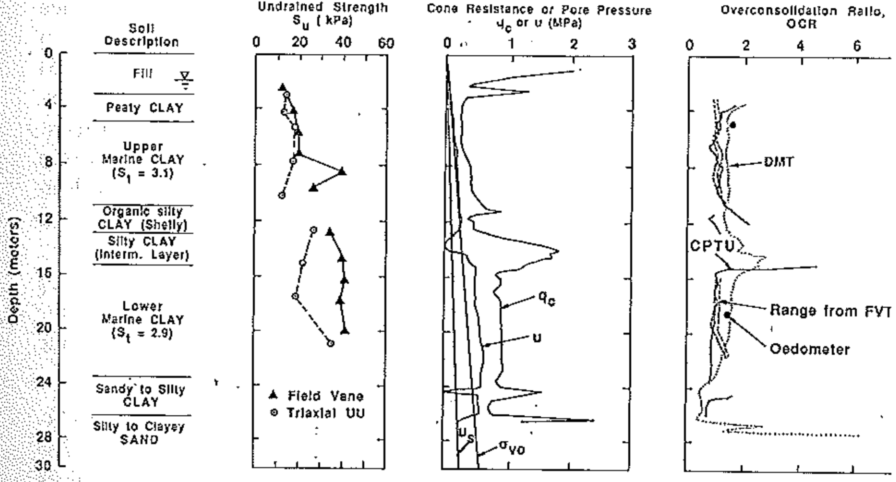

Fig. 5 Soil conditions and OCR-profiles at Site B

The OCR-profiles interpreted at this site consistently indicate a practically constant value of OCR in the upper marine clay (LL = 84, PI = 59, LI = 0.90), although the values obtained from the various methods are different. The probable OCR-value for this layer is around 1.5. Of particular interest is the difference in the OCR-profile of this clay layer from that of the seabed clay in Fig. 4, and also that reported by Hanzawa and Adachi (1983). The generally vertical OCR-profile may well indicate that aging as postulated by Tan (1983), instead of chemical bonding as suggested by Hanzawa and Adachi (1983), is more likely to be the cause of the overconsolidation for the on-land upper marine clay at this site, about 4 kilometers from the shoreline.

For the lower marine clay (LL = 71, PI = 47 LI = 0.68), the interpreted OCR-profiles indicate a very gradual decrease of OCR with depth. These profiles seem to suggest that a combination of aging and lowering of groundwater table or surface erosion during the period of regressions that caused the intermediate layer to become desiccated is probably responsible for the overconsolidation ($OCR \leq 1.5$) of the lower marine clay. As clearly indicated by the DMT, and less obviously by the q_t-profile from the CPTU (Fig. 5), there seems to be a meta-stable or underconsolidated layer near the bottom of this lower clay layer at the test site. The reason for the presence of this meta-stable layer in the Singapore marine clay is not clear.

Sites C and D (On-land and near shoreline)

Figs. 6 and 7, respectively, shows soil conditions and interpreted OCR-profiles for Singapore marine clay at two other on-land sites, Sites C and D, close to the original shoreline of Singapore. Site C is located along the Mass Rapid Transit route and Site D is located near Kallang Basin.

At Site C, which was originally occupied by a row of shophouses, the OCR-values interpreted from results of FVTs agree well with the oedometer values. The oedometer values are generally between 1.3 and 1.5, while the OCR-values interpreted from the DMT using $\lambda = 0.84$ are slightly higher. The upper bound of the oedometer OCR-values, most probably from samples of better quality among all the tests, seem to fall just to the left of the profile from the DMT. The OCR-values interpreted from the DMT result are between 1.5 and 1.6 for the Upper Member ($LL = 88$, $PI = 50$, $LI = 0.55$), except at shallow depths immediately below the fill and organic sand layer where the clay had been preconsolidated by the shophouses and was probably desiccated to some extent. The interpreted OCR-value based on the DMT is around 1.4 for the Lower Member ($LL=71$, $PI=38$, $LI=0.64$). These values agree with the most probable value of OCR for the Singapore marine clay at Site B.

At Site D, the OCR-profile interpreted from the DMT result using a λ-value of 0.84 compares very well with the oedometer results. The OCR-profile from the CPTU, which is seen to be parallel to that from the DMT in Fig. 7, suggests that Eq. (3) has resulted in underestimates of the probable field OCR-values based on oedometer tests. At this test site, the OCR-value seems to decrease very gradually with depth and the average is around 1.5 for the Upper Member ($LL = 70 - 87$, $PI = 42 - 56$, $LI = 0.57 - 0.73$). For the Lower Member ($LL = 61 - 75$, $PI = 36 - 48$, $LI = 0.49 - 0.63$), the OCR-value is marginally smaller and is seen to be fairly constant (based on the oedometer test and the CPTU) or decrease gradually with depth (based on the DMT); this is similar to those observed at Sites B and C. The average OCR-value is generally between 1.2 and 1.4 for the lower marine clay at this site.

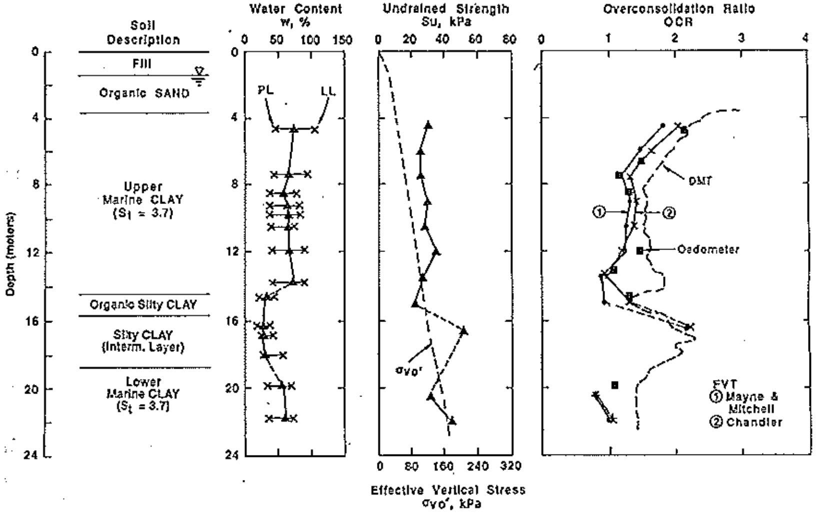

Fig. 6 Soil conditions and OCR-profiles at Site C

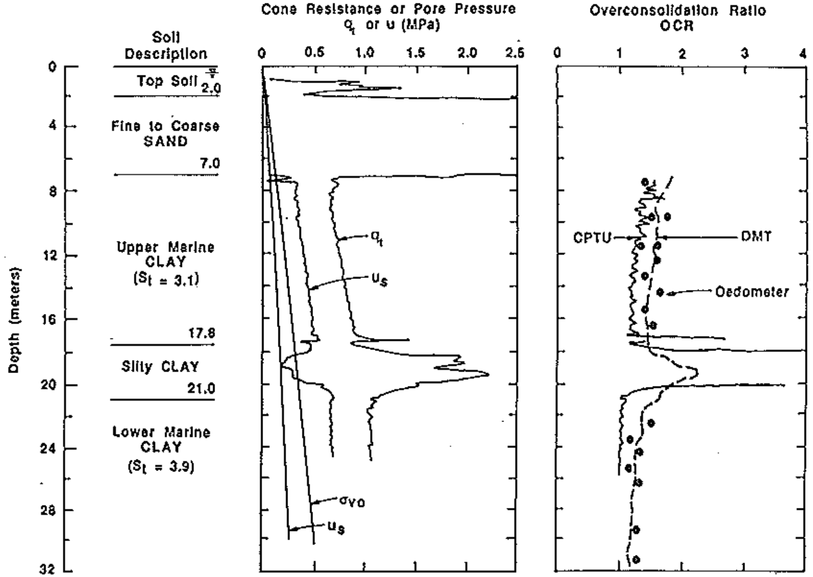

Fig. 7 Soil conditions and OCR-profiles at Site D

The OCR-profiles at both test sites suggest that the cause of overconsolidation for the upper clay layer is probably a combination of aging and small scale groundwater lowering. For the lower clay layer, it could be either aging alone, as suggested by Hanzawa and Adachi (1983), or a combination of aging and small scale groundwater level lowering or surface erosion that is responsible for the overconsolidation of the clay.

Site E (Reclaimed land)

Site E is reclaimed land near Marina Center in the Kallang Basin. The site was reclaimed some 15 to 20 years ago. Fig. 8 shows the soil conditions and the results of a CPTU at the test site where the marine clay (LL = 77, PI = 46, LI = 0.78 for the Upper Member and LL = 65, PI = 38, LI = 0.68 for the Lower Member) was still undergoing consolidation at the time of investigation (1986). Also shown on the same figure are the OCR-profiles interpreted by three different methods of in-situ tests. The three OCR-profiles are largely similar and practically vertical, although the profile based on the DMT appears to show a larger value as well as a larger variation of the OCR with depth than the others. The interpreted OCR-values are between 0.95 and 1.25, clearly reflecting the state of consolidation of the Singapore marine clay at this newly reclaimed site.

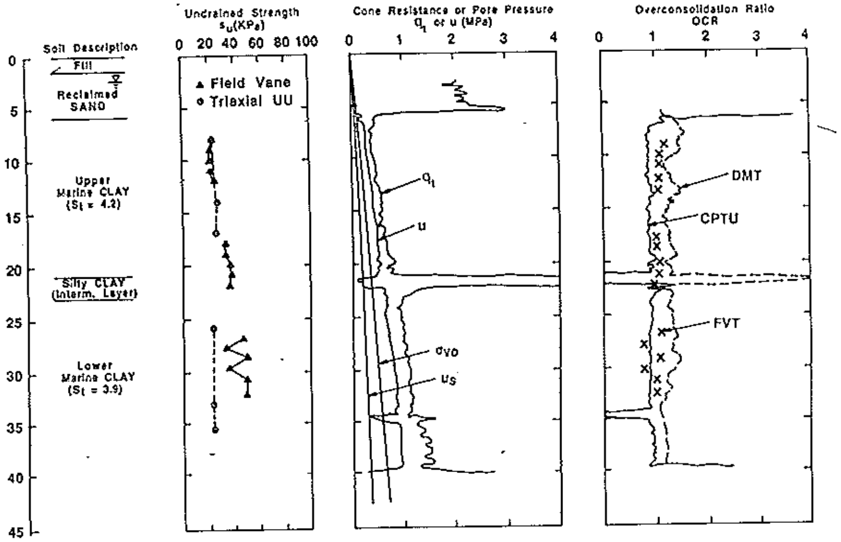

Fig. 8 Soil conditions and OCT-profiles at Site E

CONCLUSIONS

OCR-profiles interpreted from in-situ tests are useful for tracing the stress history of Singapore marine clay. Like other sedimentary clays, the OCR, profile of the Singapore marine clay is affected by the geological processes after deposition of the clay.

The stress history of the Singapore marine clay on-land is different from that of offshore based on OCR-profiles interpreted from in-situ tests. The sedbed clay deposit is generally more heavily overconsolidated than that on-land.

For the Upper Marine Member beneath the seabed, the overconsolidation ratio, especially that at shallow depths, decreases rapidly with depth, indicating that chemical bonding is most likely to be the main cause of its overconsolidation. The OCR-value in this upper layer varies widely from between 4 and 8 or higher immediately below the seabed to between 1.5 and 2 at the bottom of the layer. For the Lower Marine Member beneath the seabed, the preliminary indication is that the clay, with a practically constant OCR-value of between 1.3 and 1.6, is lightly overconsolidated, probably due to aging.

For the upper marine clay on-land, the OCR is fairly constant and the average is around 1.5 primarily as a result of aging, although at some areas small-scale lowering of groundwater level might also have contributed to the overconsolidation. The OCR of the lower marine clay on-land, on the other hand, appears to decrease gently with depth probably as a result of a combined effect of aging and small-scale groundwater lowering or surface erosion. The OCR-value is generally between 1.2 and 1.4 for the lower marine clay.

The intermediate layer is moderately overconsolidated and its OCR is 2 to 4 or larger. Desiccation and oxidation are mainly responsible for its overconsolidation, although weathering associated with leaching could also have an effect.

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