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AN ASSESSMENT ON SOIL DISTURBANCE OF BANGKOK CLAY SAMPLES IN RELATION WITH THE INTRINSIC COMPRESSION BEHAVIOR

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ABSTRACT: Recent researches have again stirred up the soil disturbance issue and clearly indicated how significantly it could affect on soil characterization, empirical relationship between different soil parameters and, finally, design calculations. In this study, analyses of sample quality were carried out for a large amount of the samples taken from a coastal site near the Gulf of Thailand. The results of the study on intrinsic compression suggested that Bangkok clay seems to be less cemented than some other clays known for being structured like Pusan or Louseville clays. By putting this finding next to the fact that Bangkok clay has not a big thickness, one can consider that the soil disturbance of Bangkok clay would not be so critical. On the other hand, the analyses have indicated that samples collected by the procedure of wash boring and Shelby sampling tube as commonly practiced in Bangkok plain were clearly subjected to soil disturbance. Consequently, quality of Bangkok clay samples to be tested should not be taken for granted as it has been for decades, and more studies on disturbance of Bangkok clay as well as an improvement in sampling procedure are therefore needed.

Key Words: Soil disturbance, Bangkok clay, intrinsic compression

INTRODUCTION

The need to assess the degree of sample disturbance prior to interpretation of parameters derived from laboratory tests on soils is now well accepted (Long, 2001). For investigation of Bangkok clays, it seems that quality of clay samples has been taken for granted for decades with the wash boring and the Shelby tube being used for the undisturbed sampling. But Bangkok clay is not free of soil disturbance as revealed in a recent work by Tanaka et al. (2002). Fig. 1a shows that quality of the samples taken by means of the Japanese and Shelby tube samplers was rated as “good” and “poor”, respectively, in the scale proposed by Andersen and Kolstad (1979), while Fig. 1b shows an excellent to good quality of samples taken by Japanese samplers based on the scale proposed by Lunne et al. (1997). One knows that Bangkok clay has been sampled mostly by Shelby tube. Is Bangkok clay easily disturbed during sampling, handling and testing processes? How we can identify it and then to assess the soil disturbance as well as its effect on geotechnical parameters determined from the laboratory geotechnical testing? Is there any need to review the sampling practice for Bangkok clay using the Shelby tube and to compare it with the practices for other soft clays using other types of sampler? This study addresses some of those questions with the following scopes:

1) to briefly review on the sampling practice of Bangkok clay;
2) to evaluate on soil disturbance of Bangkok clay based on some existing procedures such as Andersen and Kolstad (1979) and Lunne et al. (1997).
3) to assess the soil disturbance of Bangkok clay samples based on investigation of its intrinsic compression behavior.

SAMPLING PRACTICE AND SOIL DISTURBANCE OF BANGKOK CLAY

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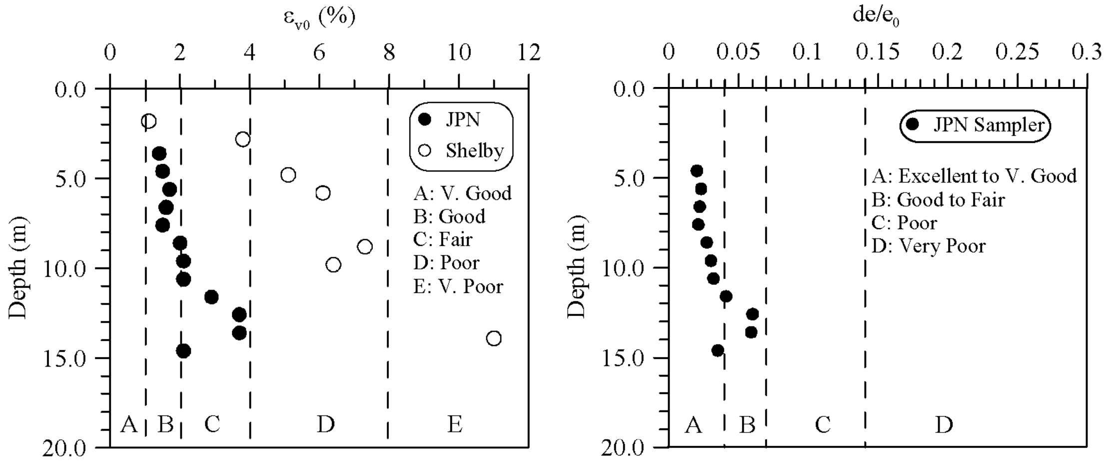


(a) Soil disturbance evaluation by the volumetric strain, ε_{v0}

(b) Soil disturbance evaluation by the normalized void ratio, de/e_0

Fig. 1 Assessed quality of Bangkok clay samples at Nong Ngu Hao Site (after Tanaka et al., 2002)

The common drilling technique for Bangkok clay is wash boring. In this method, a casing of about 2 to 3 m is driven into the ground. Soil that enters the casing at the bottom during driving is removed by pumping water through a small-diameter wash pipe, with a washing or chopping bit attached to its lower end. Water is forced through the drilling rod and it goes out at a very high velocity through the holes of the chopping bit. Cuttings of soil are carried upward by the wash water within the annulus between the casing and wash pipe (Fig. 2). The wash boring is slow, and therefore expensive, but for Bangkok clay deposit that is not thick it works satisfactorily.

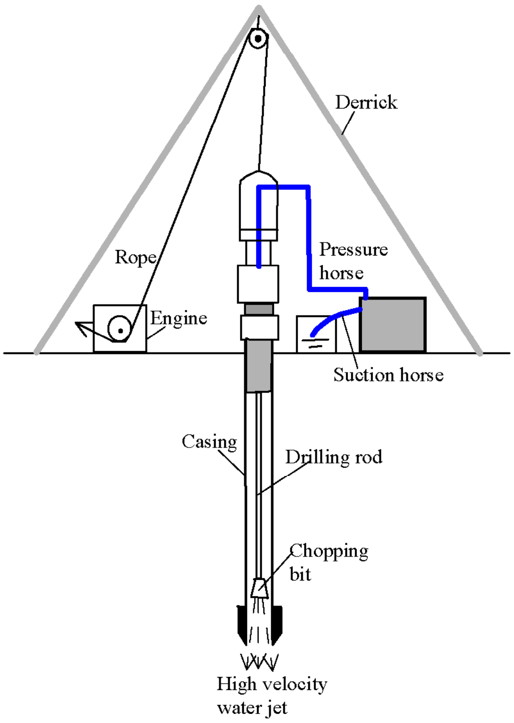


Fig. 2 Wash boring technique

From the sampling point of view, on one hand, wash boring ensures a clean stable borehole, which is an advantage, on the other hand, however, it tends to exercise significant impact at the bottom of the borehole due to chopping of the bit and high water pressure, causing disturbance to the soil at the top part of the sample tube, and this is of course a disadvantage. For undisturbed sampling of Bangkok clay, the thin-walled Shelby tube is commonly used. The sampling procedure follows the ASTM standard (D 1587-83). To collect sample at a given depth level, the drilling tools are first removed. The sampler is attached to a drilling rod and lowered to the bottom of the borehole; it is then pushed down without rotation by a continuous and relatively rapid motion.

Tanaka et al. (1996) have done a comparative study on sample quality using six samplers as seen in Table 1. Based on the UC tests, the Shelby tube sampler was found to give a lower quality sample, which exhibits lower strength and larger strain at failure.

Table 1 Samplers used by Tanaka et al. (1996)

Sampler	Inside diameter, Di (mm)	Sampler length, L (mm)	Thickness (mm)	Area ratio (%)	Piston
Japanese, JPN(P)	75	1000	1.5	7.5	Yes
Japanese, JPN(O)	75	1000	1.5	7.5	No
Laval	208	660	4.0	7.3	No
Shelby	72	610	1.65	8.6	No
NGI54	54	768	13.0	54.4	Yes
ELE100	101	500	1.7	6.4	Yes

GENERAL ON STUDY SITE

Study Location in the Bangkok Plain

Bangkok is situated on the Lower Central plain or the Bangkok plain having an area of about 13,800 km^2, which lies between Ayutthaya and the Gulf of Thailand. The low-lying Bangkok plain is near featureless with elevation ranging from 0 to 2 m above MSL. The Bangkok plain merges with a slightly higher alluvial plain at Ayutthaya. In general, the topography of the Lower Central plain reflects the fact that it was covered by a shallow marine sea from 5,000 to 3,000 years ago at which time a soft clay was deposited in shallow near-shore waters (see Fig. 3). Probably, during most of Mid to Late Holocene time the plain was a vast tidal flat that gradually subsided resulting in a thickness of the Bangkok clay ranging from 0 to 20 m. Subsequently, about 2,700 years ago, the sea withdrew and the soft clay was exposed at the surface. This soft clay has been little changed since its deposition and only the uppermost 2 m has been weathered (Nutalaya and Phien-wej, 2002). The Bangkok plain could be viewed, therefore, as a large bay, which was fed by estuaries emerging from both the western mountain belt (Kanchanaburi) and from the neck of the Lower Central plain (at or near Ayutthaya). The study area is located at a site in Samut Prakan as shown in Fig. 3.

Soil Profile and Geotechnical Properties at Study Location

The soil profile and geotechnical properties are shown in Fig. 4, in which UW, LI, PL, LL, Wc, Su, CR, σ'_y ,σ'_v stand for unit weight, liquid index, plastic limit, liquid limit, water content, undrained shear strength, yield stress and effective vertical stress, respectively. The clay layer is extended from the surface to about 24 m deep, the uppermost part of about 2 to 4 m thick is of weathered clay; the very soft to soft clay sublayer occurs from 2 to 18 m, overlying a medium clay sublayer from 18 to 24 m deep. The very soft to soft clay has very high water content and liquid limit, which are near each other and about 100% or slightly higher. The unit weight of the very soft clay is less than 14 kN/m$^{3;}$ the unit weight of the soft clay is around 15 kN/m^3, while that of the medium clay is exceeding 15 kN/m^3. As seen in Fig. 4, the yield stress or the preconsolidation pressure (σ'_y) is almost the same as the effective overburden (σ'_v), suggesting a normally consolidated clay that can be disturbed during sampling and testing processes.

ASSESSMENT OF SOIL DISTURBANCE OF BANGKOK CLAY SAMPLES USING THE EXISTING PROCEDURES

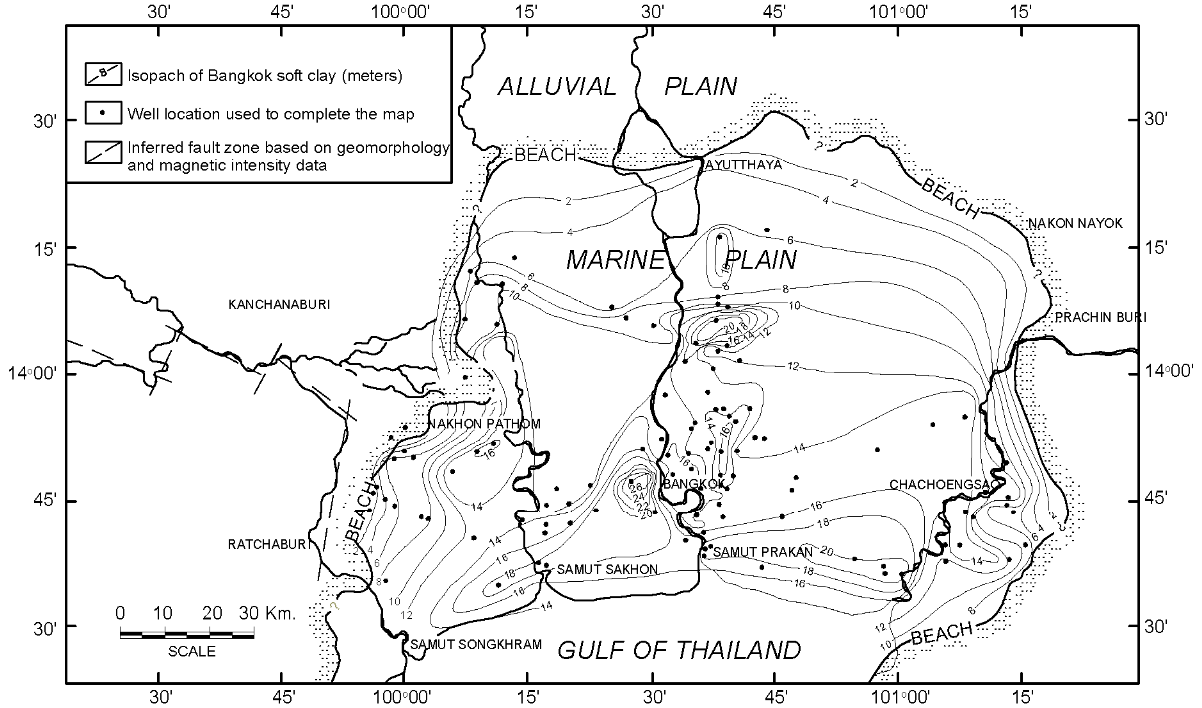


Fig. 3 Study location at Samut Prakan site (after Nutalaya and Rau, 1981)

Ladd and Lambe (1963), La Rochelle et al. (1981), Jamiokowski et al. (1985), Baligh (1985) have pointed out a number of causes to sample disturbance arising from sampling to laboratory testing. Other researches continued to highlight various factors such as sampling procedure and sampler type (Tanaka and Tanaka, 1999; Tanaka, 2000), structuration, aging and chemical bonding of clays (Leroueil, 1999; Nagaraj, 2000), plasticity index (Long, 2001), macro-heterogeneities found in soil mass (Chung et al., 2004), stress release (Watabe and Tsuchida, 2001). Despite the fact that many factors can cause soil disturbance of clay samples there are not many quantitative criteria to assess them. Most of the existing procedures make use of widely available oedometer test data and the assumption that a more disturbed sample would have a less void ratio for the same effective stress level. Two most frequently used techniques to evaluate quantitatively soil disturbance are those based on calculation of the volumetric strain (Andersen & Kolstad, 1979) and the normalized void ratio (Lunne et al., 1997), respectively. These techniques will be employed in this study as presented in the following parts.

Andersen and Kolstad (1979)'s Procedure

In this procedure, the volumetric strain (ε_{v0}) in an oedometer test is used for soil disturbance evaluation. The volumetric strain (ε_{v0}) is defined as follows:

$$\varepsilon_{vo} = \frac{e_0 - e_1}{1 + e_0} * 100(\%) \qquad (1)$$

where e_0 is the initial void ratio of the sample; e_1 is the void ratio corresponding to the in-situ effective

Table 2 Adersen and Kolstad (1979)'s criteria

Sample quality	Volumetric strains, ε_{v0} (%)	Classification
Very good	<1.0	A
Good	1.0 – 2.0	B
Fair	2.0 – 4.0	C
Poor	4.0 – 8.0	D
Very poor	> 8.0	E

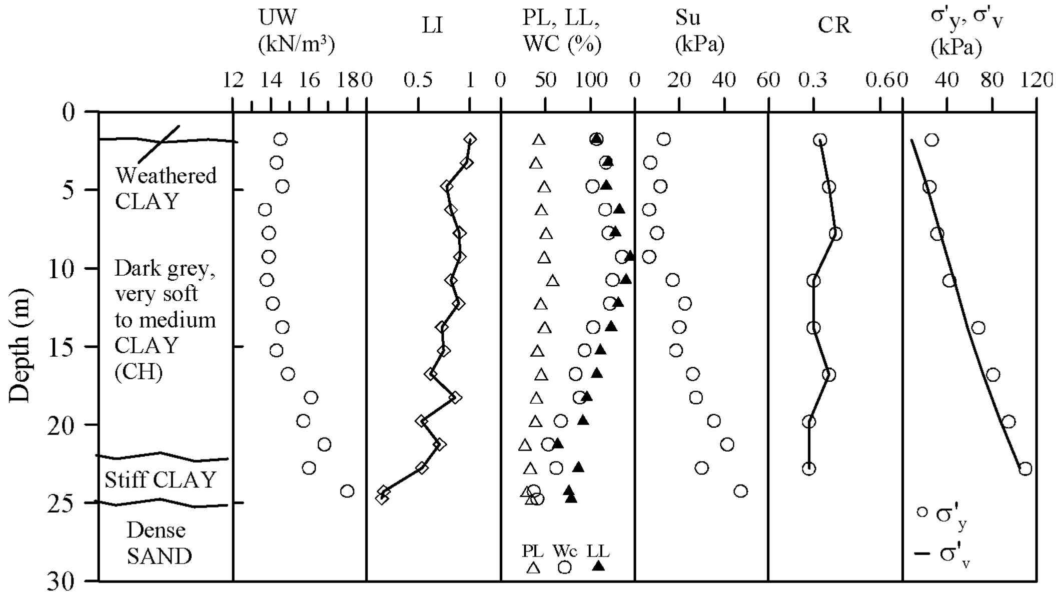


Fig. 4 Soil profile and geotechnical properties at the study site

stress. The quality of samples is estimated according to the following scale:

Lunne et al. (1997)'s Procedure

In this procedure, an index, de/e$_0$, named *the normalized void ratio change*, is used to evaluate soil disturbance as defined below:

$$\frac{de}{e_0} = \frac{e_0 - e_1}{e_0} \quad (2)$$

where e$_0$ is the initial void ratio, e$_1$ is the void ratio corresponding to the in-situ effective stress σ_{v0}'.

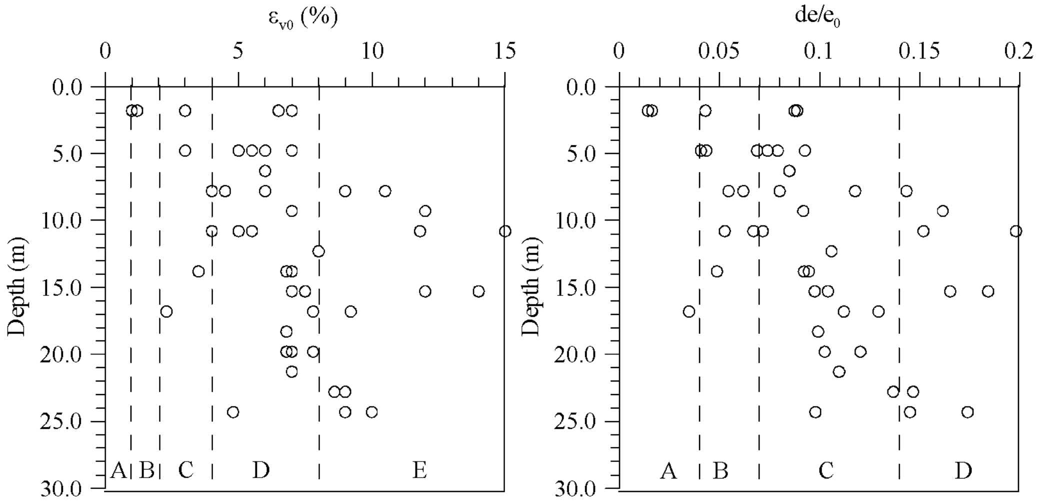
For the same in-situ effective stress e$_1$ would decrease if soil disturbance increases (Shogaki, 1996). According to Lunne et al. (1997), the normalized void ratio change is a measure of the change in pore volume, which would be increasingly detrimental to the particle skeleton as the initial pore volume decreases, and this would be better than the volumetric strain or the volume change, dV/V$_0$. In this procedure, the quality of sample is estimated as given below:

Table 3 Lunne et al. (1997)'s criteria

Sample quality	Normalized ratio, de/e$_0$ (OCR = 1-2)	Normalized ratio, de/e$_0$ (OCR = 2-4)	Classification
Very good to excellent	<0.04	<0.03	A
Good to fair	0.04 – 0.07	0.03 – 0.06	B
Poor	0.07 – 0.14	0.06 – 0.1	C
Very poor	> 0.14	> 0.1	D

Soil Disturbance Analysis Results

Fifty six consolidation tests were analyzed to assess degree of soil disturbance based on both methods of Andersen and Kolstad (1979) and Lunne et al. (1997), respectively. The analysis results are shown in Figs. 5a-b, respectively. In Fig. 5a, the volumetric strain, ε_{v0} (%), of the clay samples is mostly found larger than 4%, which indicated a poor to very poor quality. Similar trend can be depicted in Fig. 5b, where the normalized void ratio, de/e$_0$, is



(a) Soil disturbance evaluation by the volumetric strain

(b) Soil disturbance evaluation by the normlized void ratio

Fig. 5 Evaluation of sample quality at Samut Prakan

mainly found in the range higher than 0.4% with majority of samples having a fair to poor or very poor quality.

STUDY ON THE INTRINSIC COMPRESSION OF BANGKOK CLAYS WITH REFERENCE TO ASSESSMENT OF THEIR STRUCTURATION AND SOIL DISTURBANCE

The recent developments in soft clay engineering on intrinsic compression of soft clays allow to have more insights into *structuration* of soft clays, and hence their possibility of being disturbed. Leroueil et al (1985) indicated that a structured clay would have higher brittleness and sensitivity, and hence it would be easily destructured when subjected to any deformation or remoulding. The destructured state, therefore, can provide a basic frame of reference to study stress-strain characteristics of natural clays and has been defined as the *intrinsic state* of a natural clay by Burland (1990). Study on the structured state of natural soft clays has both theoretical and practical significance. Practically, a study on intrinsic compression would help to characterize better the insitu clay deposits regarding the use of appropriate methods to evaluate the engineering properties. One of most mentioned applications is the assessment and quantification of sampling disturbances. The concept by Burland (1990) will be used for this purpose as presented in the following.

General Framework proposed by Burland (1990)

According to Burland (1990), the term “intrinsic” was used to describe the compression properties of clays which have been reconstituted (after being thoroughly mixed) at a water content of from 1.0 to 1.5 times liquid limit (preferably 1.25), without any air-drying or oven-drying, and then consolidated. The intrinsic properties can be used as the reference to which natural properties of clays can be compared for their classifications. Burland (1990), by analysis of compressibility of natural clays, suggested a new soil parameter, the void index, I_v, defined by the following relation:

$$I_v = \frac{e - e^*_{100}}{e^*_{100} - e^*_{1000}} = \frac{e - e^*_{100}}{C^*_c} \qquad (3)$$

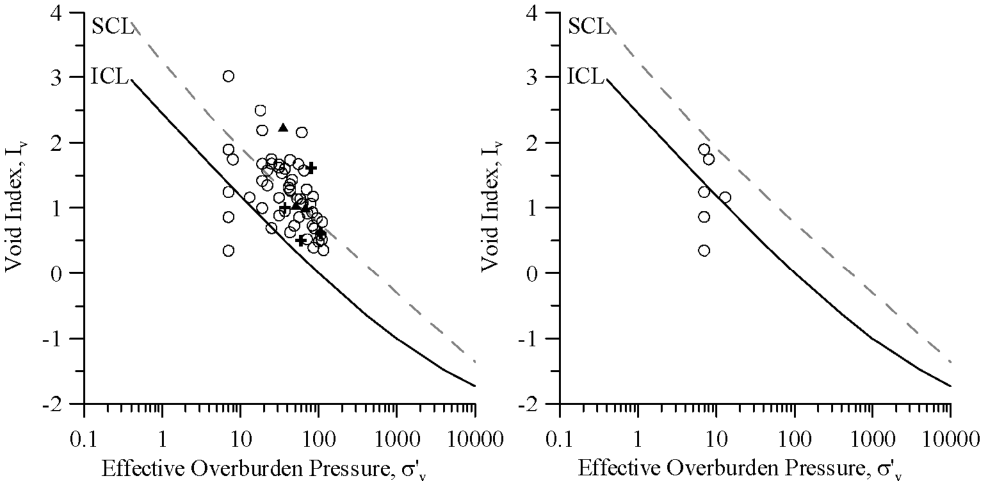
where e is void ratio of the reconstituted clay at a consolidation pressure, e^*_{100} and e^*_{1000} are void ratios at consolidation pressures of 100 and 1000 kPa, C^*_c is the intrinsic compression index being defined as $e^*_{100} - e^*_{1000}$.

The void index, I_v, is considered as a measure of the intrinsic compactness of a sediment. When I_v is less than zero the sediment is compact, and when I_v is greater than zero the sediment is loose. Based on study of a number of natural clays, the relationship between the void index and effective overburden stress, σ'_v in kPa, was found to be a reasonably unique line, whose equation can be approximated by the following (Burland, 1990):

$$I_v = 2.45 - 1.286(\log\sigma'_v) + 0.015(\log\sigma'_v)^3 \qquad (4)$$

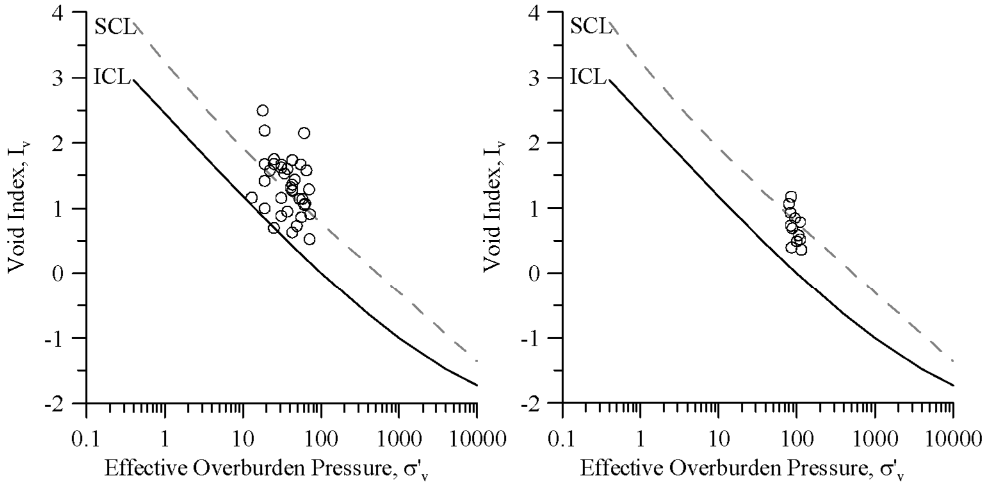
Eq. 4 is the Intrinsic Compression Line (ICL) as proposed by Burland (1990). The ICL is supposed to represent the compression curve when clays have no structuring due to aging. There are two ways recommended by Burland (1990) to construct the ICL, i.e., (i) to measure directly e^*_{100} and C^*_c ; (ii) to construct the ICL using Eq. 4.

Skempton (1970) had done a comprehensive study on gravitational compaction of twenty natural clay deposits all over the world and proposed a set of



(a) All depths for three sites

(b) Weathered clay (0 to 2m)



(c) Soft to medium clays (3 to 18 m)

(d) Stiff clays (more than 18m)

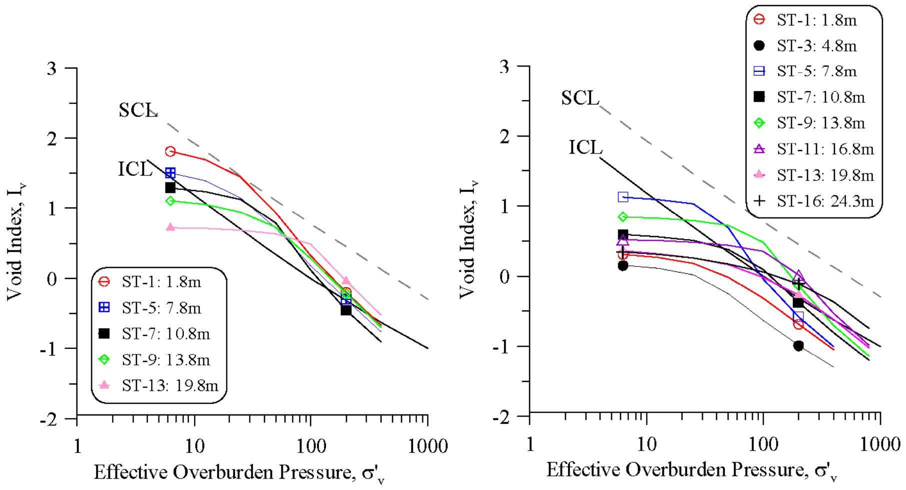
Fig. 6 ICL and SCL for Bangkok clays at Samut Prakan site sedimentation compression curves, which represent a relationship between the changes of void ratio against the effective overburden pressure. Burland (1990) reanalyzed these curves in the framework of intrinsic compression and transformed them into the so called *Sedimentation Compression Lines* (SCL) that represent a relationship between the insitu void index and the effective overburden for most of natural clays. To facilitate a fast construction of both ICL and SCL Burland (1990) recommended using the following relationships:

$$e^{*}_{100}=0.109+0.679e_{L}-0.089^{2}_{L}+0.016e^{3}_{L} \qquad (5a)$$

$$C^{*}_{c}=0.25e_{L}-0.04 \qquad (5b)$$

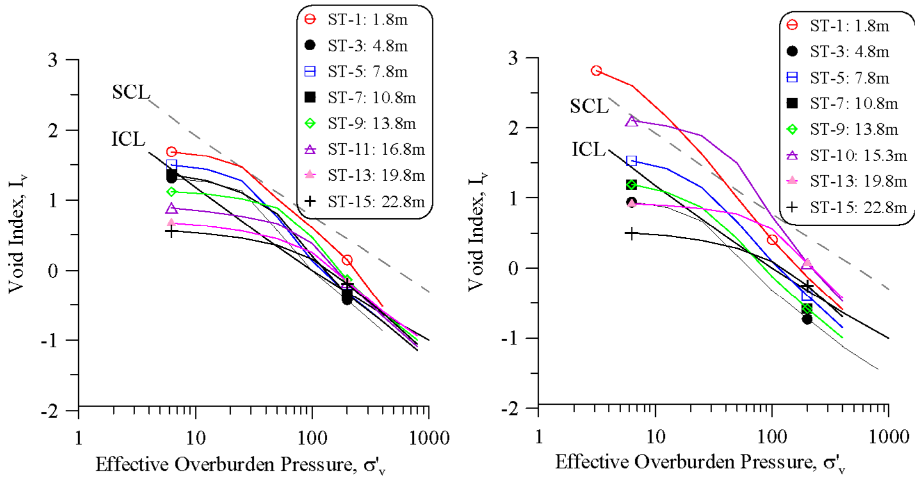
where e_L is the liquid limit void ratio.

Eqs. 5a-b are recommended to be used only for the soils having e_L from 0.6 to 4.5 (corresponding to w_L from 25 to 160%) and with Atterberg limits lying above the A line in the plasticity chart.



(a) Borehole WW-4

(b) Borehole WW-11



(c) Borehole WW-12

(d) Borehole WW-26

Fig. 7 Intrinsic compression behavior of consolidation curves with depth

Application of ICL and SCL for Bangkok Clay

The results are plotted in Fig. 6, where the intrinsic compression lines (ICL) and sedimentation compression lines (SCL) were also plotted. ICL represents a relationship between a parameter called the void index (I_v) and loading pressure (σ'_v) as obtained on reconstituted clays, while SCL represents a relationship between a parameter called the insitu void index (I_{v0}) and the effective overburden (σ'_v) as deduced from many natural soft clay deposits in the world as already mentioned above. These two curves can be used as references for evaluating the degree of structuration of natural clays. The points of (I_v, σ'_v) for Bangkok clays at Samut Prakarn site are also plotted in Fig. 6a-d. It can be seen that most of the points fall between ICL and SCL, suggesting that Bangkok clay do not behave very differently from most other natural clays or, in other words, cementation of Bangkok clay has not been developed that much.

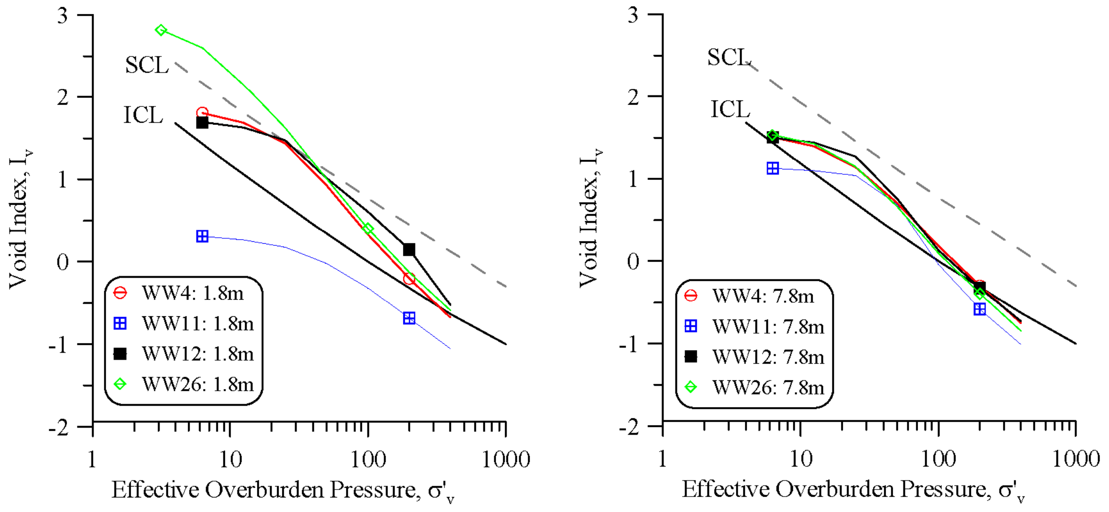
The technique proposed by Burland (1990) can also be used in interpretation of consolidation curves to get additional information on intrinsic compression behaviour of the clays. Data are plotted in Fig. 7a-d for 4 sets of consolidation curves performed on samples from four boreholes at Samut Prakarn site, WW-4, WW-11, WW-12 and WW-26, respectively.

Except the curves at borehole WW-11 in Fig. 7b, in which many of them lie below the ICL to indicate an overconsolidated state, the other curves in Figs. 7a, c and d suggest of a normally consolidated clay whose natural state is close to or above the SCL and their post-yield oedometer compression curve can be steeper than the SCL and it will cross the SCL to converge towards the ICL.

To investigate more in details intrinsic behaviour of each type of clay present in the Bangkok subsoil, i.e., weathered clay, soft clay, soft to medium clay and stiff clay, the consolidation curves from 1.8, 7.8, 13.8 and 19.8 m, are plotted in Fig. 8a-d, respectively. The weathered clays do not behave uniformly, they can be normally consolidated like in the case of WW4, WW12 and WW26 (Fig. 8a, c and d), or show some overconsolidated behavior as in the case of WW11 (Fig. 8b). The very soft clay at 7.8m, the soft to medium clay at 13.8m, and the stiff clay at 19.8m, however, represent normally consolidated uncemented clays.

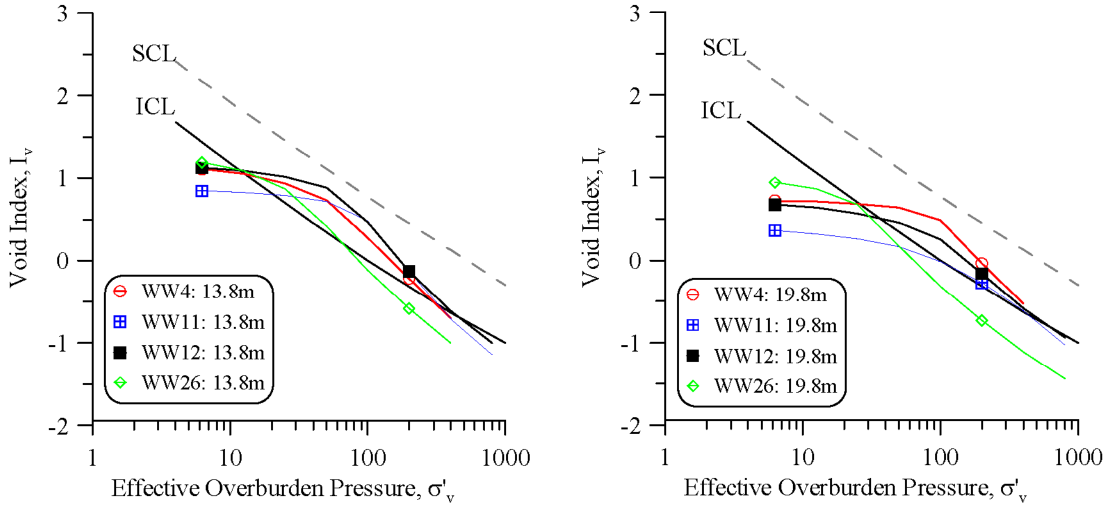
CONCLUDING REMARKS

1. A soil disturbance analysis of 56 consolidation curves indicated that quality of Bangkok clay samples taken by Shelby tube from the ground surface to more 20 m deep at a coastal site (Samut Prakan) varies from poor to very poor on both scales proposed by Andersen and Kolstad (1979) and Lunne et al. (1997), respectively (see Fig. 4a-b).
2. A study on intrinsic compression of Bangkok clays was carried out for the first time, using the concept of the intrinsic compression line (ICL) proposed by Burland (1990). The initial results indicated that the Bangkok clays essentially behave as a normally consolidated clay with little cementation.
3. The weathered clay of about 2 m on top does not behave uniformly, in some locations it is normally consolidated (the intrinsic compression points lie between ICL and SCL as seen in Fig. 6b), but in other locations it is overconsolidated (the intrinsic compression points lie below ICL as seen in Fig. 6b). The samples of weathered clay sample by wash boring and Shelby tube however show a good quality in most cases (see Fig. 5).
4. Bangkok soft to medium clay, about from 2 to 18m at the site, behaves as a typical normally consolidated clay. It also exhibits some structuration as a number of the intrinsic compression points are well above SCL (see Fig. 6c). Because cementation was found little developed, such a structuration would be mainly due to time (aging) and stress effect. As shown in Fig. 5, the soft clay samples have a poor to very poor quality on both scales by Andersen and Kolstad (1979) and by Lunne et al. (1997).
5. The stiff clay behaves as a normally consolidated clay as well with the intrinsic compression points lying mainly between ICL and SCL (see Fig. 6d). This is a little bit surprised because in general the Bangkok stiff clay has been considered overconsolidated. This remark is supported by the soil data shown in Fig. 4, where the effective stress and the yield stress or preconsolidation pressure profiles almost coincide at the study site. As indicated in Fig. 5, the stiff clay samples taken by Shelby tube have a poor to very poor quality on both scales by Andersen and Kolstad (1979) and by Lunne et al. (1997).



(a) Weathered clay

(b) Very soft clay



(c) Soft to medium clay

(d) Stiff clay

Fig. 8 Intrinsic Behavior of Consolidation Curves for Different Clay Types

6. More studies on soil disturbance related to Bangkok clay sampling need to be carried out. However, from the intrinsic compression point of view, Bangkok clay is less structured than some other clays, which are known of being structured such as Louseville clay (Tanaka et al., 1996) or Pusan clay (Giao et al., 2000; Chung et al., 2002), consequently possibility of soil disturbance should be less severe, especially the Bangkok clay is not very thick.

7. An investigation of soil disturbance of a certain clay, especially for a new study area would require a carefully designed testing program, which can be costly and time-consuming. It is therefore useful if one can assess qualitatively soil disturbance by studying the intrinsic compression behavior of that clay based on the existing consolidation data. It is also recommended that an assessment of soil disturbance be made for any site investigation project of Bangkok clays. As the Shelby tube and wash boring may cause the

sample quality to be poor as indicated in Tanaka et al. (2002) and especially in this study, the local engineer should consider better samplers whenever it deems necessary.

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