Effect of large diameter sample testing for offshore site investigation

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ABSTRACT
In conjunction with a large future land development at the near shore off the East coast of Singapore, it is necessary to conduct a detailed soil investigation work to understand the in-situ geotechnical behaviour of the soft marine clay. Conventionally, a small size sample is used for determination of the strength and consolidation properties. However, such tests may suffer from the limitations of the small sample size as a small diameter sample may not truly represent the "fabric" and "structure" of the soils at the site. The in-situ soil is not as uniform or homogenous as represented by this small soil sample. Hence, in conjunction with this long-term mega near-shore development project, a large diameter sampling and testing research project is envisaged.

The results from the large diameter Triaxial and Oedometer sample tests were compared with the conventional small diameter Triaxial and Oedometer sample test. The results showed significant difference between the two tests. In addition to the mechanical tests, X-ray diffraction and SEM analysis tests were carried out to identify clay minerals and to study microstructure of undisturbed clay sample. XRD studies confirmed the presence of minerals quartz, kaolinite and illite. The microstructural studies indicated that the constituent particles were arranged in an open network, or flocculated structure.

RÉSUMÉ
En conjunction avec un grand aménagement du territoire près des rives de la côte Est de Singapour, il est nécessaire de procéder à un travail du sol détaillée enquête pour comprendre le comportement in situ géotechnique de l'argile marine. Classiquement, un petit échantillon est utilisé pour la détermination des propriétés de résistance et de compressibilité. Toutefois ces essais peuvent subir des limitations de la petite taille, qui ne peut vraiment représenter le 'tissue' et le 'structure' des sols sur le site. Le sol in-situ n'est pas aussi uniforme ou homogène représentée par cette petit taille de sol. Ainsi, en collaboration avec le méga projet près des côtes, un projet de recherche avec un grand échantillonnage est envisagé.

Les résultats de grand échantillon d'essais triaxiale et oedomètrique sont comparés avec les résultats des échantillons classiques de petit diamètre. Les résultats montrent une différence significative entre les deux. En plus des essais mécanique, les essais de diffraction de X-ray et les essais de SEM sont menées afin d'identifier les minéraux argileux et d'étudier les microstructures de l'argile non-perturbé. Études de diffraction de X-ray ont confirmé la présence de quartz, de kaolinite et de illite. Les études microstructurales indique que les particules constitutives sont disposées en un réseau ouvert, ou structure floculée.

1 INTRODUCTION

In conjunction with a large future land development at the near shore off the East coast of Singapore, it is necessary to conduct a detailed soil investigation work to understand the in-situ geotechnical behaviour of the soft marine clay. Conventionally, a small diameter sample is used for determination of the strength and consolidation properties. Conventional small diameter sampler is 102 mm diameter, and small diameter traixial sample is 38 mm or 50 mm diameter. However, such tests may suffer from the limitations of the small sample size as the in-situ soil is not as uniform or homogenous as represented by this small soil sample. The small diameter sample is also subjected to larger sample disturbance during sampling, transportation and sample testing. Furthermore, a small diameter sample may not truly represent the "fabric" and "structure" of the soils at the site. Hence, in conjunction with this long-term mega near-shore development project, a large diameter sampling and testing research project is envisaged. In this project, great effort has been made to design a large diameter sampler to collect high quality undisturbed soil sample of up to 250 mm diameter and up to 1000 mm height. The aim of this research is to study the effect of sample size on in-situ strength and consolidation properties of marine clay so that appropriate properties of marine clay can be used for design of foundation system for offshore structure. This is particularly important for soft soil at the incident river mouth when highly heterogeneous soil were expected. The corresponding large diameter sample extruder was also designed and fabricated in NUS geotechnical engineering laboratory. A large diameter triaxial test apparatus for 200 mm diameter sample size was designed and developed. In addition to the mechanical tests, X-ray diffraction and SEM analysis tests were carried out to identify clay minerals and to study microstructure of undisturbed clay sample.

2 LARGE DIAMETER TRIAXIAL TEST AND CONSOLIDATION TEST APPRATUS

The large diameter triaxial test apparatus used in this study is shown in Figure 1. The whole set-up consists of a strained-controlled triaxial cell with accessories, an autonomous data acquisition unit (ADU) and a host desktop. The key components include:

(a) Triaxial cell and loading frame: The triaxial cell allows the testing of sample up to 200 mm in diameter and 400 mm in hight. The cell is mounted on a 100 kN loading frame with strained controlled load application to the sample.

(b) Load cell and LVDT: The load cell is used to measure the load acting on the sample. The axial displacement of sample is measured with LVDT.

(c) Pressure transducers: Three pressure transducers are fitted to the base of triaxial cell for measurement of the cell pressure, back pressure and pore pressure separately.

(d) Volume change: A volume change transducer is used to measure the volume change of soil sample during the triaxial test.

(e) Autonomous data-acquisition unit (ADU): The ADU is a microcomputer-controlled device dedicated to intelligent data acquisition.

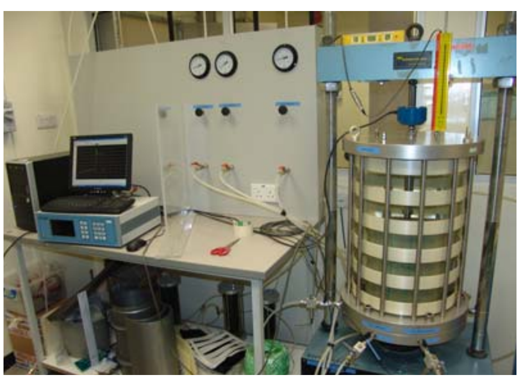

Figure 1. Large diameter Triaxial apparatus

The large diameter Oedometer test apparatus used in this study is a modified version of standard Cassagrande type Oedometer apparatus with diameter of 150 mm. Soil thicknesses of 19 mm or 38 mm can be tested. Set-up mainly consists of a consolidation cell, loading system, LVDT, an autonomous data acquisition unit (ADU) and a host desktop.

3 SAMPLE PREPRATION AND TEST METHOD

3.1 Triaxial and Oedometer test

The large diameter soil samples of diameter 200 mm and height 400 mm were prepared with the help of a specially made extruder. It was thus setup and tested in large diameter triaxial cell using similar procedure as UU test in standard triaxial test specified in British Standard BS 1377-7:1990 and Head (1986). Figure 2 & 3 show the large diameter sample before and after the test respectively. Three types of test samples (labeled L-L, L-S & S-S) were prepared to evaluate the effect of sample size and the soil fabric onto its strength and consolidation charecteristics. They are all obtained from same or near-by bore hole for fair comparison. They were listed in Table 1. The first letter of the sample code represents the testing size of sample & second letter for sampler size; and L represent large & S small.

Consolidation properties of these large diameter soil samples of size 150 mm in diameter and 19 mm in thickness were tested in modified large diameter Oedometer apparatus. The results were compared with standard Oedometer test results.

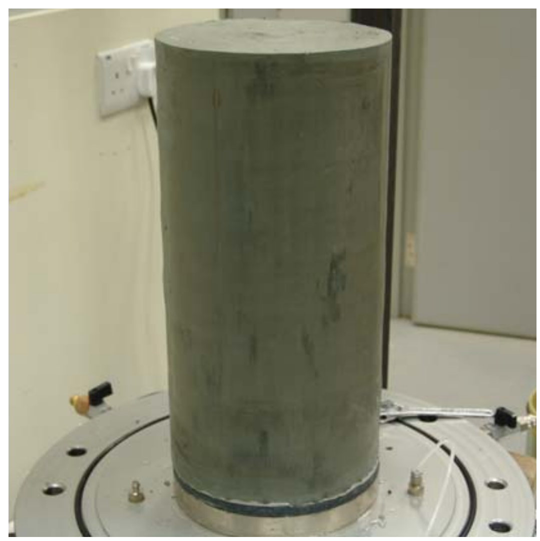

Figure 2. Triaxial sample before test

Table 1. Three type of sample for Triaxial and consolidation test

Code	Sampler	Size of Triaxial sample	Size of Oedometer sample
L-L	Large diameter sampler	200 mm Φ	150 mm Φ
S-L	250 mm Φ	38 mm Φ	70 mm Φ
S-S	Conventional small diameter sampler 102 mm Φ	38 mm Φ	--

3.2 XRD test

XRD analysis of marine clay was carried out by using Shimadzu XD-D1 X-ray diffractometer (Figure 4). For preparation of sample, about 200 g of in-situ soil was air-dried. The air-dried soil was powdered into small particles so that the particle should pass through 63 μm sieve. The soil sample less than 63μm was placed on a glass plate. The sample along with glass plate was then placed on the goniometer holder for XRD analysis. XRD patterns were then obtained using a Cu Kα (λ= I51.5148 Å) X-ray tube with input voltage of 30 kV and current of 30 mA. A continuous scan mode and scan rate of 2 deg./min was selected. Mineralogical analyses of XRD pattern of clay sample were carried out based on the characteristic Bragg angle from Brown (1960) and Mitchell (1992).

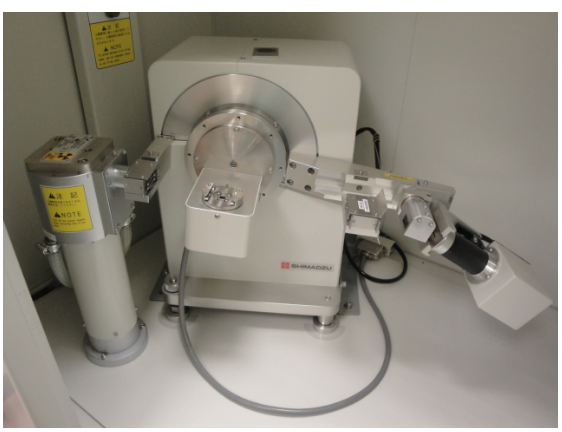

Figure 4. Shimadzu XD-D1 X-ray diffractometer

3.3 SEM test

SEM analysis was conducted by using Tabletop microscope TM-1000 (Figure 5). For sample preparation, the undisturbed samples were air dried and broken into small pieces of about 5 mm square and 3 mm thick with the help of knife. Care was taken to avoid the cutting of the face of observation surface by knife. The pieces of sample were then placed on stubs with observation surface facing upwards. The sample along with stub was then placed for gold coating to improve the conductivity to enhance the quality of microscopy. After gold coating the sample was fixed on aluminum stub by double side conductive tape and then placed in sample chamber of tabletop microscope for scanning. For scanning, the magnification level of 3.0 k was used.

Figure 5. Tabletop microscopes TM-1000

4 TEST RESULTS AND DISCUSSION

4.1 Comparison of strength of large diameter samples with small diameter samples

Figure 6 & 7 show the typical stress-strain behaviour of L-L and S-L respectively. These figures show clearly that the maximum deviator stress of L-L was attained faster than S-L. The strain of L-L and S-L at maximum deviator stress was about 4% and 10% respectively. The figures also show that L-L was stiffer than S-L for the strain range of 0 to 1%. However maximum deviator stress of L-L was noticeable lower than S-L.

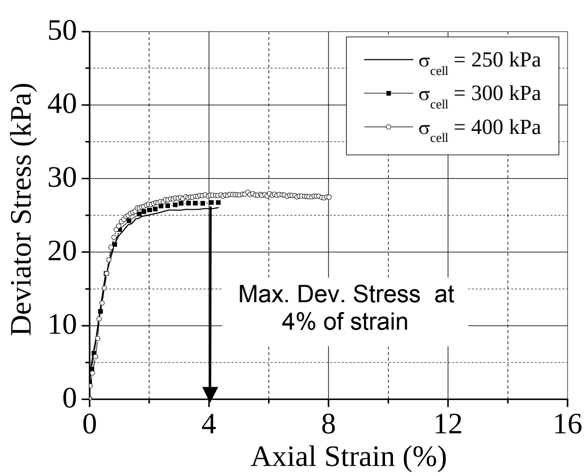

Figure 6. Stress-strain characteristic of L-L, large diameter triaxial sample from large diameter sampler

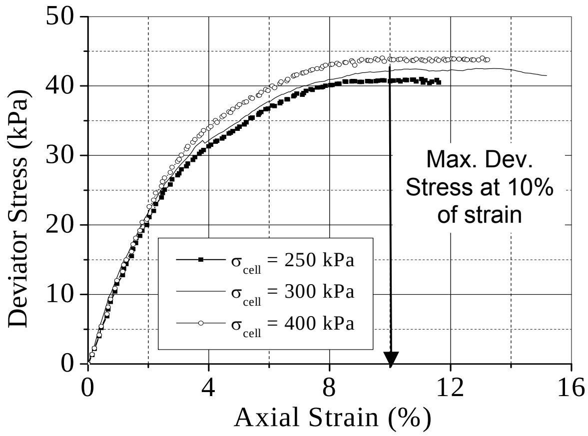

Figure 7. Stress-strain characteristic of S-L, small diameter triaxial sample from large diameter sampler

Figure 8 shows the summary of the undrained shear strength of L-L vs undrained shear strength of S-L at various undrained shear strength values. This clearly shows the effect of testing sample diameter, while both samples were obtained from the ground using large diameter sampler. In addition, the combined effect of sampler size and test sample size can be best illustrated by figure 9, which shows undrained shear strength of L-L and undrained shear strength of S-S.

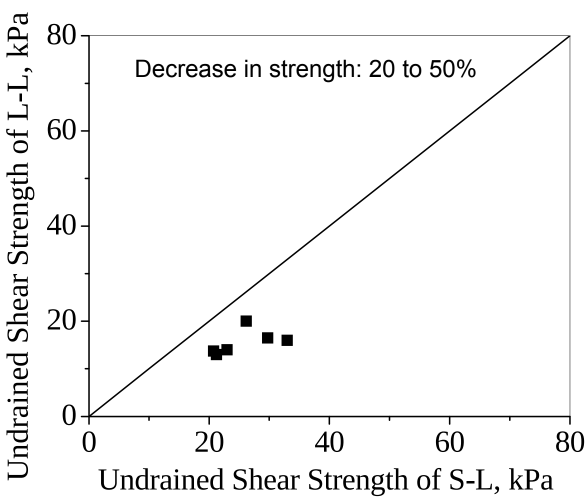

Figure 8. Undrained shear strength of L-L vs. undrained shear strength of S-L

For the sole effect of testing sample size, Figure 8 clearly shows that undrained shear strength of L-L was lower than S-L. The decrease in undrained shear strength of L-L was about 20% to 50% of S-L. This clearly indicates the effect on non-representativeness of small diameter soil sample which is not conservative in terms of strength. Further decrease in undrained shear strength was more pronounced (i.e. 20% to 70%) when undrained shear strength of L-L was compared with S-S indicating the combined effect (Figure 9). The reason for the strength of the large diameter sample being lower than that of small diameter sample is clearly seen from Figure 10, which shows clearly the non-homogeneity and non-uniformity of the soil sample; in this particular case, the presence of sand patches and holes within the clay matrix. Large testing sample size from large sampler can capture this while the small testing sample size can not. In addition, small diameter sampler is subjected to larger disturbance than large diameter sampler during extraction from ground, transportation and handling of sample. The S-S gives the result with highest disturbance.

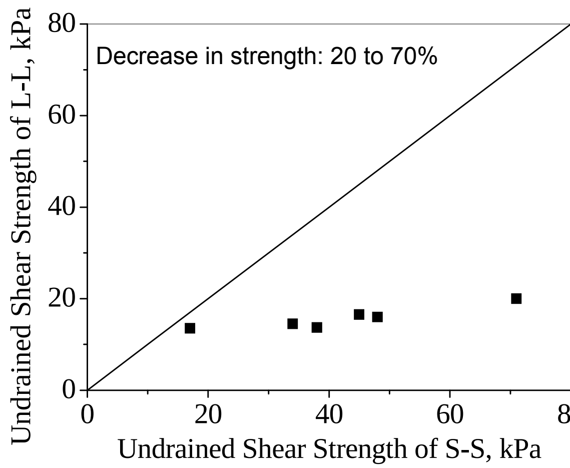

Figure 9. Undrained shear strength of L-L vs. undrained shear strength of S-S

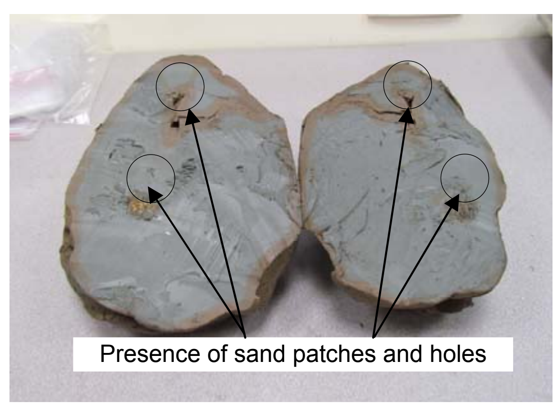

Figure 10. Section view of large diameter sample showing non-uniformity of sample

4.2 Comparison of Compressibility of L-L with S-L

Figure 11 shows the typical e-log P relationship of L-L and S-L samples. It shows clearly that the pre-consolidation pressure was about 100 kPa for both samples. However, the compression index, Cc of L-L was higher than S-L.

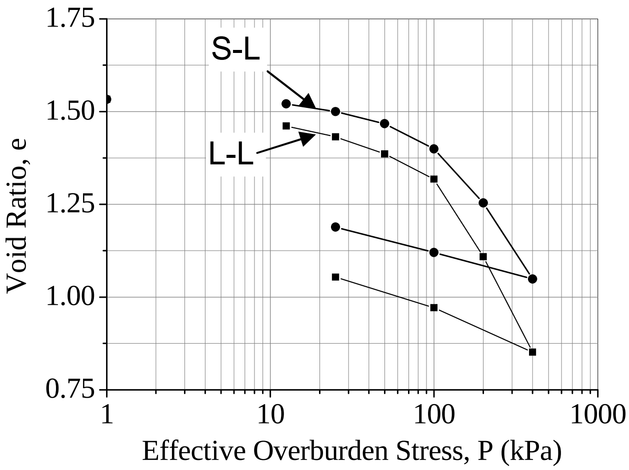

Figure 11. e-log p relationships of L-L and S-L

Figure 12 shows plot of compression index (Cc) of L-L vs compression index (Cc) of S-L. This figure clearly shows that most of compression index value of L-L was higher than that of S-L. This result implies that the S-L was unconservative in terms of compression charecteristics which has significant effect in design of foundation systems.

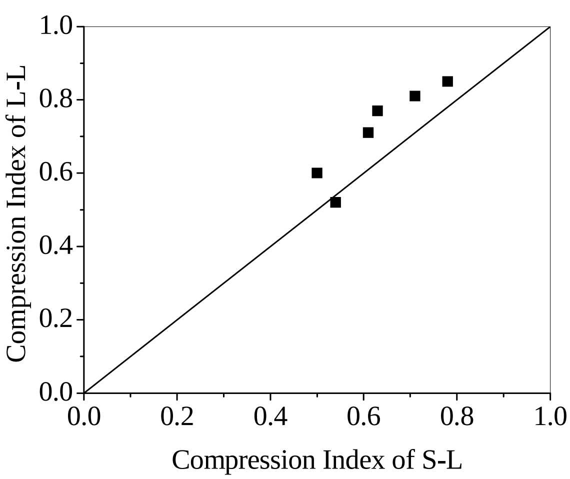

Figure 12. Compression index (Cc) of L-L Vs. compression index (Cc) of S-L

4.3 XRD analysis of marine clay sample

A number of XRD tests were carried out of marine clay. Figure 13 shows a typical XRD pattern of marine clay. As shown in this figure, minerals quartz, kaolinite and illite were detected in marine clay. This observation is consistent with Singapore marine clay reported by Chew et al. (2004).

Quartz composed of group of silica tetrahedral. Due to presence of tetrahedral structure, quartz is a stable mineral and has high hardness. Kaolinite is composed of alternate silica and alumina sheets held together with strong chemical bonds making kaolinite a stable mineral which does not expand appreciably when wetted. Whereas, illite is composed of one alumina sheet between two silica sheets bonded by potassium ions. The bond between the alumina sheet and silica sheet by potassium ions is weaker than the chemical bond present in kaolinite making illite slightly vulnerable to shrinkage and swelling when it is dried and wetted.

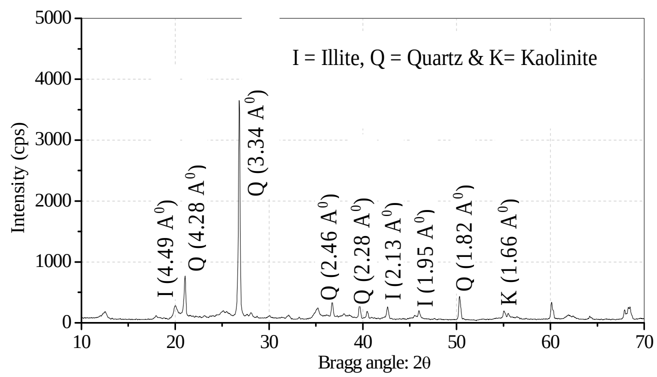

Figure 13. XRD analysis of marine clay

Montmorillonite mineral was not found in the marine clay which shows high shrinkage and swelling property when it is dried and wetted. So, it can be concluded that in-situ marine clay is not overly vulnerable to shrinkage and swelling when it is dried and wetted.

4.4 SEM analysis of in-situ marine clay sample

A number of SEM tests were carried on the undisturbed marine clay sample. Figure 14 shows typical SEM image of marine clay. It can be seen from figure that the structure of marine clay is flocculated, with aggregates formed by lumps of fine clay minerals such as kaolinite and illite. Similar observation for Singapore upper marine clay is found by Tan et al. (2003).

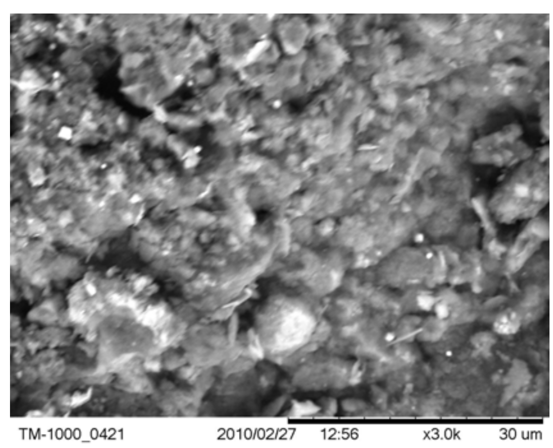

Figure 14. SEM image of in-situ marine clay

Soils with a flocculated structure are light in weight and have a high void ratio and water content. However these soils are very strong and can resist higher external forces than the soil having dispersed structure. In general, the soils in a flocculated structure have a low compressibility, a high permeability and high shear strength than the soil having dispersed structure. Thus it can be concluded that marine clay used in this study has high shear strength and low compressibility than the clay having dispersed structure.

5 CONCLUDING REMARKS

The following conclusions can be derived regarding testing of large diameter sample:

(1) The undrained shear strength obtained from large diameter triaxial sample (L-L) is lower than that obtained from small diameter sample (S-L), although both samples are obtained from large diameter sampler.

(2) The combined effect of sampler size and testing sample size is clearly seen by comparing undrained shear strength of L-L sample and conventional S-S sample results, which shows that L-L results are 20-70% lower than that of conventional S-S results. This indicates that the conventional small sample size result is not conservative.

(3) The reason for different results for L-L and S-S is mainly due to the presence of non-uniformity and non-homogeneity in the field which can be captured in large size sample but not in small size sample.

(4) Compression index value Cc of L-L is higher than that of S-L. This result implies that the S-L is unconservative in terms of compression charecteristics which has significant effect in design of foundation systems.

(5) The XRD analysis of marine clay confirms the presence of minerals quartz, kaolinite and illite and absence of montmorillonite mineral. So, the marine clay is not overly vulnerable to shrinkage and swelling when it is dried and wetted.

(6) The SEM image shows flocculated structure of undisturbed marine clay sample with aggregates formed by lumps of fine clay minerals such as kaolinite and illite.

(7) It should be noted that the conclusions reported here are based on limited test data due to time and budget constraint. It is planned to have more test data in due course to verify or amend the conclusions presented here.

REFERENCES

Brown, G. 1961. *The x-ray identification and crystal structures of clay mineral*, Mineralogical Society, (Clay Minerals Group), London.

Chew S.H., Kamruzzaman, A.H.M. and Lee, F.H. 2004. “Physico-chemical and engineering behaviour of cement-treated clays”, *Journal of Geotechnical and Geoenviromental Engineering,* 130(7), 696-706.

Head, K. H. 1986. *Manual of soil laboratory testing*, 1st Ed., ELE International Ltd., Pentech, London.

Mitchell, J. K. 1992. *Fundamentals of soil behavior*, 2nd Ed., Wiley, New York.

Tan, T. S., Phoon, K. K., Lee, F. H., Tanaka, H., Locat, J. and Chong, P.T. 2003. “A characterization study of Singapore lower marine clay”, *Swets & Zeitlinger, Lisse*, ISBN 90 5809 5371.