

Regional Report for Asia

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ABSTRACT: Asia is rather diverse in its geological conditions, economical/political developments and popularity in the use of CPT. It is fair to say, however, that CPT is relatively new to this region. When the CPT was introduced to the geotechnical community in Asia, it was well into the electric cone era. In countries with high population density, many large scale land reclamation projects have taken place. The unique capability of providing virtually continuous profiles of ground conditions has made the CPT a prime method in quality assurance for land reclamations in this area. Asia has its fair share of soft/loose soil deposits. Certain parts of Asia are located in areas with heavy seismic activities and under constant threats of strong earthquakes. The CPT is gaining popularity in its applications for the determination of monotonic undrained shear strengths for clays and cyclic strengths for sands. Direct applications of CPT results in routine foundation designs have also been included in geotechnical engineering practice. The regional report highlights the experience in the applications of CPT for land reclamations as well as determination of undrained/cyclic strength of soils in Asia.

1 INTRODUCTION

The level of sophistication in the application of the cone penetration test (CPT) is closely related to the economic developments in Asian countries. Japan has the longest history of CPT applications in this region. In addition to applying CPT locally, Japanese engineers/scholars have participated in the application and/or development of interpretation methods in other Asian countries as part of their engineering practice or research activities. With over a dozen CPT trucks, Taiwan has probably the highest density of CPT equipment in Asia. Because of the lack of a sizable and well distributed sample volume, this report will not describe the status of CPT applications in statistical terms. Instead, the report concentrates on experience that relates to the use of CPT in events that are of vital interests to Asian countries.

Due to high population density, land reclamation has been an important part of the industrial/economic developments in Hong Kong, Singapore, Taiwan and S. Korea. The classic paper by Lee et al. (1999) that dealt with CPT in sand for W. Kowloon land reclamation project has become an important documentation in the interpretation

of CPT in sand. CPT calibration tests were performed to provide interpretation methods for a clean silica sand used in the land reclamation in Busan, S. Korea. The 2400 hectare land reclamation in Mai Liao, Taiwan involved the use of relatively compressible, silty fine sand. CPT was used as a primary tool for quality assurance in ground improvement. Extensive studies that included chamber calibration tests have been performed for CPT in Mai Liao Sand. Large sized clay lumps from excavations in metropolitan areas have been used for land reclamation in Singapore. The unique capability of providing virtually continuous soil profiles made CPT an ideal tool to determine the status of inter-lump voids at different stages of consolidation after deposition.

CPT coupled with high quality sampling and laboratory shearing tests have been conducted for clays in many Asian countries. These studies provided correlations between cone tip resistance, q_c and undrained shear strength, s_u of clays in these areas. Determination of cyclic strength of granular soils for liquefaction potential assessment is another important aspect of the applications of CPT in certain parts of Asia. By directly comparing the cyclic resistance ratio (CRR) from laboratory cyclic shearing tests and field CPT or chamber calibration tests under similar states, it was possible to evaluate the effects of grain characteristics and fines contents on the CRR- q_c relationships. The report emphasizes the experience gained in these applications.

2 SUMMARY OF REGION

Asia is the world's largest and most populous continent, located in the eastern and northern hemispheres. It covers approximately 8% of the earth's total surface area (or 25% of its land area) and with more than 3 billion people, it hosts close to 50% of the world's current human population. Asia is traditionally defined as part of the landmass of Eurasia, with the western portion of the latter occupied by Europe, located to the east of the Suez Canal, east of the Ural Mountains and south of the Caucasus Mountains –and the Caspian and Black Seas.– It is bounded on the east by the Pacific Ocean, on the south by the Indian Ocean and on the north by the Arctic Ocean. Given its size and diversity, Asia, a toponym dating back to classical antiquity, is more a cultural concept incorporating a number of regions and peoples than a homogeneous physical entity. For this regional report, Asia is defined as the countries of Asia and southeast-Asia, that include over 30 countries, such as, China, India, Indonesia, Japan, North and South Korea, Taiwan, Philippines, Thailand, Vietnam and Malaysia. The countries of Russia and the Middle East are not included in the regional report.

The wealth of Asia differs very widely among and within its regions, due to its vast size and huge range of different cultures, environments, historical ties and government systems. In terms of nominal GDP, Japan has the largest economy on the continent and the second largest in the world. In purchasing power parity terms, however, China has the largest economy in Asia and the third largest in the world.

Given the size of the region it is not possible to summarize the geography and geology, other than to state that it is diverse.

Rapid economic growth in the past few decades has resulted in increased use and acceptance of the CPT. The mechanical cone is still common in parts of Asia (e.g. Indonesia) but the electric cone has become more common in major urban regions

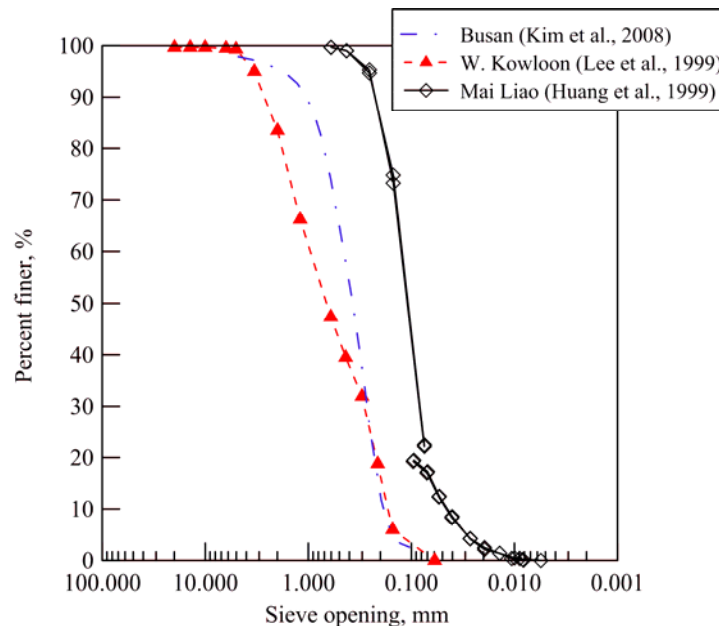
(e.g. Singapore, Malaysia, Taiwan and South Korea). Unfortunately, the SPT is still dominant in many parts of Asia (e.g. Japan, India, Thailand and Philippines).

3 APPLICATIONS OF CPT FOR LAND RECLAMATION

The so called four little dragons of Asia; Hong Kong, Singapore, S. Korea, and Taiwan have enjoyed significant economical growth in the past few decades. Land reclamation plays an important role to provide the desperately needed land for housing and industrial developments in these countries. CPT was used extensively as a means (but not limited to) for evaluating the properties of the materials used in land reclamation in these countries. This section compiles the experience gained from the use of CPT in some of the selected land reclamation projects.

3.1 CPT and Land Reclamations in Busan, W. Kowloon, and Mai Liao

Figure 1 shows the grain size distribution curves of sands from Busan (S. Korea), W. Kowloon (Hong Kong) and Mai Liao (Taiwan). Busan and W. Kowloon sand (WKS) can be classified as clean silica sand, with fines (particles passing #200 sieve) either close or less than 5%. The mineral content of Busan sand (BS) was mostly siliceous with high contents of crushed shell fragments (Kim et al., 2008). The grain shape of Busan sand was subangular. According to Lee et al. (1999), the W. Kowloon sand was mainly composed of siliceous materials derived from the weathering of granitic rocks. The grain shape is subangular to subrounded. W. Kowloon sand had some broken shells and calcite fossil fragments. The bulk of the Mail Liao sand (MLS) had approximately 18% of low plastic fines. MLS had its origin from weathered shale, slate and sandstone. In addition to siliceous materials MLS also contained significant amounts of muscovite. The grain shape of MLS was flaky. In comparison with typical clean quartz sand such as Ottawa sand, MLS was compressible and crushable (Huang et al., 1999).



Kim et al. (2008) reported a series of CPT chamber calibration tests in Busan sand. The calibration tests were conducted using the Korea University Calibration Chamber System, under stress controlled boundary conditions. The cone tip resistance, q_c was corrected for the boundary effects in chamber calibration tests according to the state parameter of the sand specimens. The procedure was developed by Been et al. (1986) based on CPT in Hokksund sand. CPT in W. Kowloon sand was calibrated using a chamber system at ENEL-CRIS in Italy (Lee et al., 1999). The q_c was corrected for boundary effects using a method proposed by Salgado et al. (1997). The Mai Liao sand CPT calibration tests were performed at the National Chiao Tung University calibration chamber laboratory in Hsin Chu, Taiwan. Test results showed that due to its high compressibility, CPT performed in MLS under stress controlled conditions had no need for boundary effect correction (Huang et al., 1999).

Figure 2 shows a comparison of the relationships between relative density (D_r) and q_c normalized with respect to effective overburden stress (σ'_v) for BU, WKS and MLS in contrast to the relationship compiled by Jamiolkowski et al. (1985) based on CPT in five types of clean quartz sands. According to Figure 2, BS can be placed in the group of average to low compressibility sand, while CPT in WKS and MLS demonstrated a behavior of high compressibility. The compressibility of MLS increases as the fines content (FC) changed from 0 to 15%.

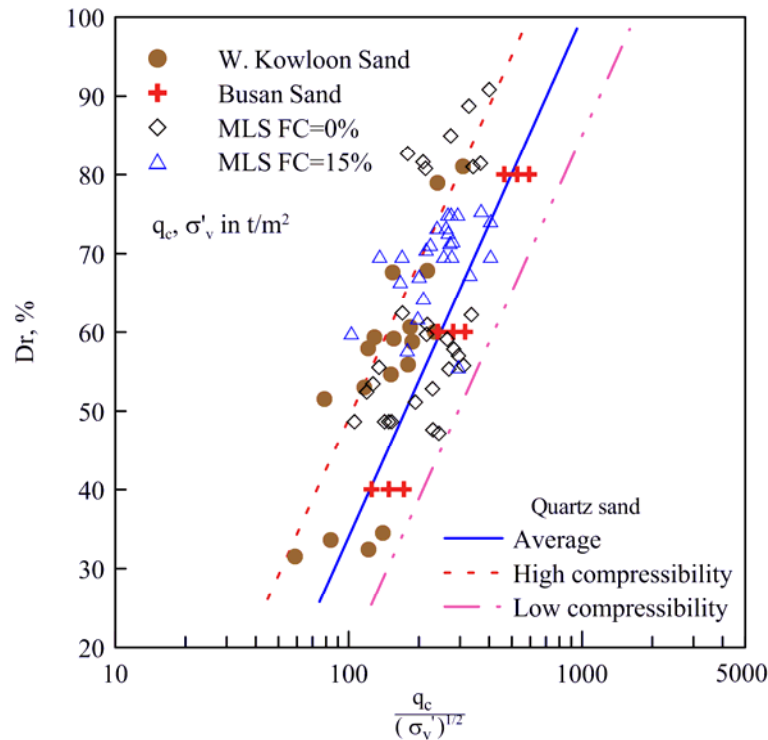


Figure 2. Relationship between D_r and normalized q_c .

Empirical rules that relate q_c to density and stress states have been proposed based on CPT calibration tests. A comparison of $q_c - \sigma'_v$ relationships for a few selected relative densities is shown in Figure 3. Among the three types of sands, q_c in MLS had the least sensitivity to density. This is likely due to a lack of dilatancy or high compressibility of MLS. For the two types of fines contents and relative densities asso-

ciated with MLS, the $q_c - \sigma'_v$ relationships clustered within a rather narrow range. For a given relative density and σ'_v , q_c in Busan sand was consistently higher than those from the other two types of sands. This is obviously related to the fact Busan sand had the lowest compressibility as indicated in Figure 2.

The methodology for using CPT to determine state parameter (Ψ) (Been et al., 1986) was well accepted in Asia. The value of q_c is normalized with respect to mean normal stress, p and effective mean normal stress, p' as:

$$Q_p = \frac{(q_c - p)}{p'} \quad (1)$$

Figure 4 shows a plot of Q_p against Ψ for the three types of sands, plus the relationship reported by Jefferies and Been (2006) for Chek Lap Kok sand (CLK) of Hong Kong. The data of CLK sand also came from CPT calibration tests for the land reclamation project of the Chek Lap Kok international airport. The $Q_p - \Psi$ correlations presented in Figure 4 also reflect the compressibility of the sands involved. MLS and WKS were compressible and thus had their $Q_p - \Psi$ correlations extended well into a territory where Ψ was positive. It should be noted that the MLS $Q_p - \Psi$ data had rather low coefficients of correlations at 0.29 and 0.35 for $FC = 0$ and 15%, respectively (Chu, 2009). The relatively weak correlation between Q_p and Ψ is believed to be related to the lack of dilatancy and crushable nature of MLS.

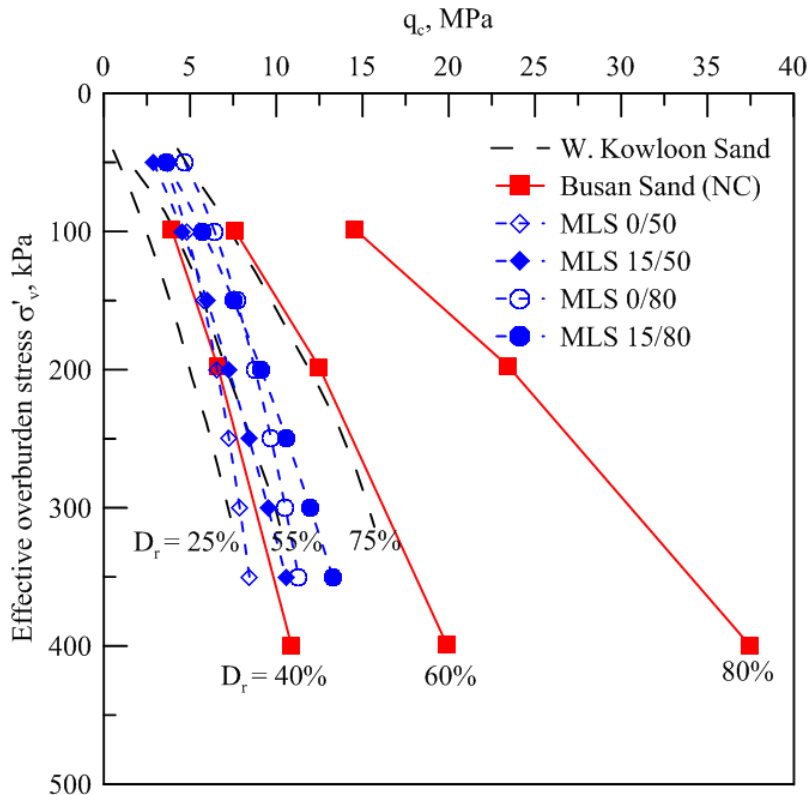


Figure 3. q_c versus effective overburden stress.

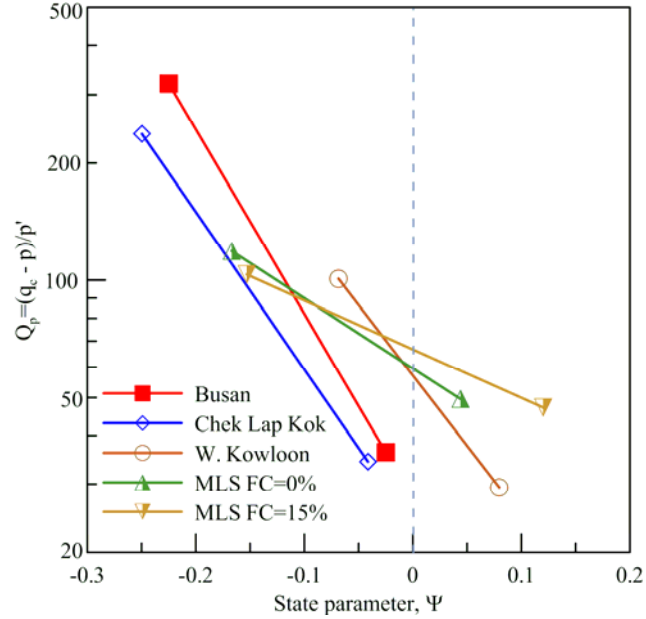


Figure 4. Correlations between Q_p and Ψ .

Been et al. (1987) proposed a simple exponential equation to describe the trend line between Q_p and Ψ as:

$$Q_p = \left(8 + \frac{0.55}{\lambda - 0.01} \right) \exp[-(8.1 - \ln \lambda) \Psi] \quad (2)$$

where

λ = slope of the critical state line

A plot of Q_p at $\Psi = 0$ against λ for the four types of Asian sands and other sands reported by Been et al. (1987) is shown in Figure 5. All the data included in Figure 5 had a reasonable fit with Equation 2.

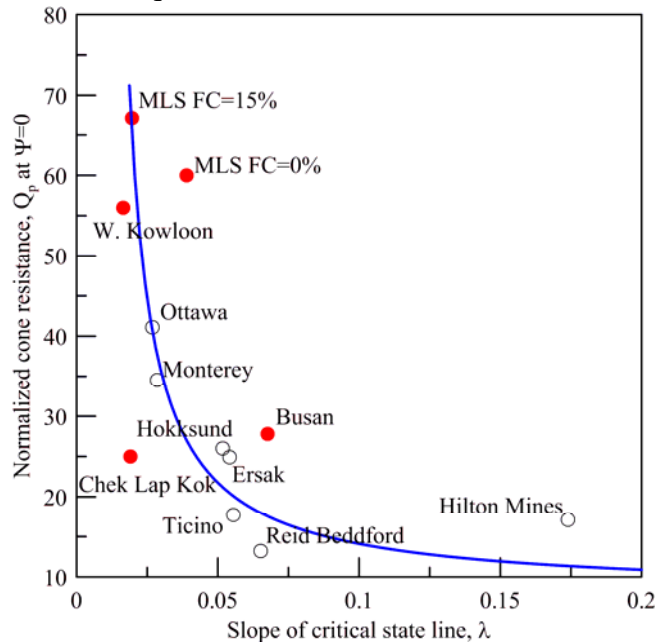


Figure 5. Correlation between Q_p at $\Psi = 0$ and λ . (after Been et al., 1987)

For the land reclamation project of Chek Lap Kok Airport, the concept of state parameter was taken one step further as a means for quality assurance using CPT (Shen and Lee, 1997). According to the CPT calibration tests, for a given state parameter, Ψ there was a consistent correlation between q_c and p' as shown in Figure 6. An empirical correlation between q_c and Ψ was established as:

$$\Psi = (0.8938 - \Gamma) - \left[0.0391 q_c^{0.25} \left(\frac{p_a}{p'} \right)^{0.125} - \lambda \left(\frac{p'}{p_a} \right)^{0.75} \right] \quad (3)$$

where

Γ = intercept of the steady state line at $p' = 0$

Taking $\Psi = 0$ as the maximum acceptable value to assure dilatancy of the sand deposit in the field, the corresponding minimum q_c can be derived from Equation 3 as:

$$q_{c(\min)} = \left[\frac{(0.8938 - \Gamma) \left(\frac{p'}{p_a} \right)^{1/8} + \frac{\lambda}{0.0391} \left(\frac{p'}{p_a} \right)^{7/8} \right]^4 (kPa) \quad (4)$$

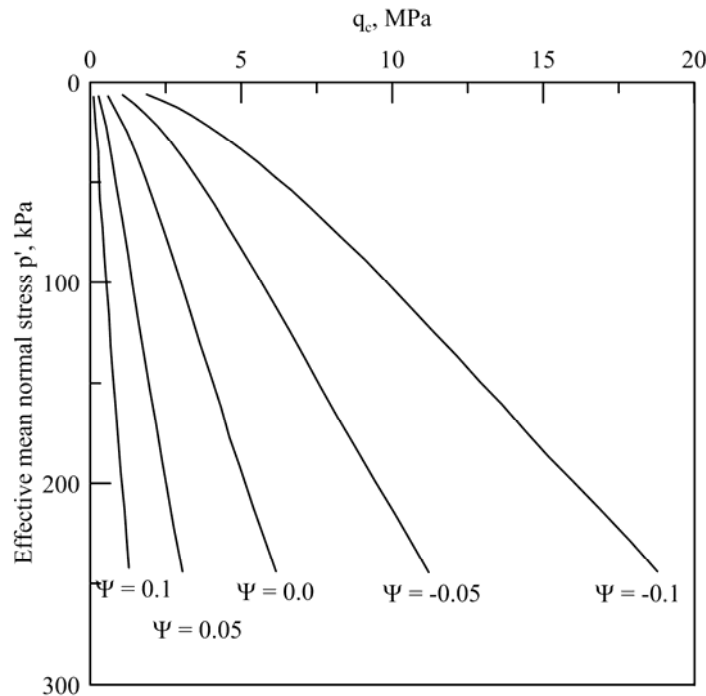


Figure 6. Correlation between q_c and p' for various state parameters. (after Shen & Lee, 1997)

3.2 Land reclamation in Singapore

Dredging works in the coastal areas and excavations in urban Singapore produce large quantities of clay lumps. Using the clay lumps for land reclamation can solve the problems of soil disposal and reduce the amount of material that would otherwise

be required. The typical volume of a clay lump ranged from 1 to 8 m³ (Karthikeyan et al., 2004). The clay lumps were placed directly on the seabed. The lumpy fill was then covered by a thick layer of sand. Initially, there could be large voids between the clay lumps (the inter-lump voids). As a result of consolidation and compression, the inter-lump voids reduce to the size of intra-lump voids (voids amongst particles within lumps), and the lumpy fill is considered to have been “homogenized”. Size of the inter-lump voids and strength/deformation characteristics of the lumpy fill are of major concerns. Karthikeyan et al. (2004) and Tan et al. (2004) reported the use of CPT to characterize the reclaimed land that involved the use of clay lumps. The conventional piezocone was modified by attaching a nuclear-density sensing device behind the cone tip. A penetration test using this modified device was referred to as the nuclear-density cone penetration test (ND-CPT).

Figure 7 shows two profiles of ND-CPT performed at the 1500 hectare Pulau Tekong land reclamation project in Singapore where the lumpy fill was used. In the first stage, clay lumps were placed directly on the seabed to elevation -3m chart datum (CD). Capping sand was then placed to a final grade of +4m CD. The time difference between the before and after sand fill ND-CPT was 6 to 8 months. The delineation between the sand and clay lumps was clearly identified by the drastic changes in the characteristics of q_c and u_2 readings. The cores of clay lumps were reflected by the spikes in q_c and wet density readings.

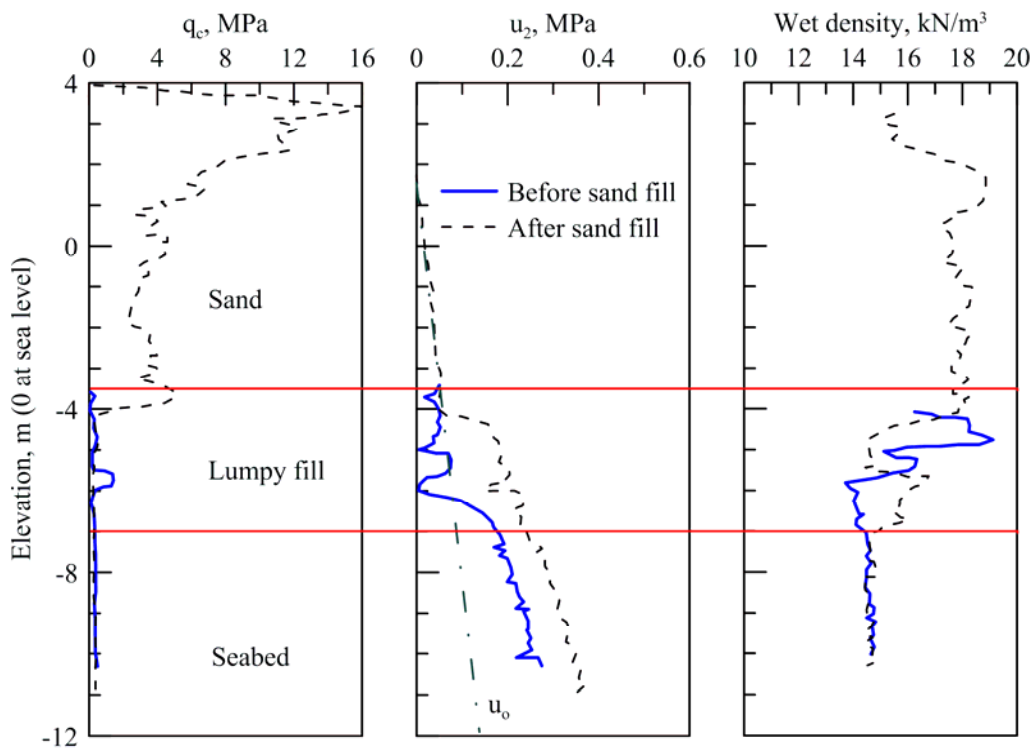


Figure 7. ND-CPT profiles from land reclaimed using clay lumps (after Tan et al., 2004)

4 DETERMINATION OF UNDRAINED SHEAR STRENGTH FROM CPT

CPT or piezocone penetration test (CPTU) has been used in Asia as an efficient in situ testing method to determine the undrained shear strength of soils. For clays, the undrained shear strength generally refers to that under monotonic loading conditions, s_u . For sands, it is the undrained cyclic resistance ratio, CRR that is of interest. Asia has its fair share of soft clays and sand deposits in areas of seismic activities, and thus the use of CPTU in both accounts. This section summarizes experience of using CPTU for characterizing undrained shear strengths for clays and sands.

4.1 Undrained Shear Strength of Clays

Tanaka and Tanaka (2004) took undisturbed clay samples and performed CPTU at six test sites in Asia that extended from Japan to Singapore. High quality undisturbed piston samples were taken using a Japanese sampler. The undrained shear strength, s_u of the clay samples was determined by unconfined compression tests. Liu et al. (2008) and Cai et al. (2008) reported their comprehensive studies on the engineering properties of the marine clays in Jiangsu province of China. These studies included CPTU and consolidated undrained triaxial tests on undisturbed soil samples taken with a piston sampler. As part of their studies on the performance of diaphragm wall construction, Ou et al. (1998) performed CPTU at a test site in Taipei. Elaborate triaxial tests on undisturbed piston samples taken from the test site and field vane shear tests were conducted to determine the undrained shear strength of the clay. The cities/countries where the above studies took place are compiled in Figure 8. The inference of s_u from CPTU followed the concept of a cone factor, N_{kt} as:

$$s_u = \frac{q_t - \sigma_v}{N_{kt}} \quad (5)$$

The cone tip resistance, q_c was corrected for the pore pressure effects and referred to as q_t . Table 1 shows the N_{kt} obtained from the test sites and information related to clay mineralogy, geological age and stress history.

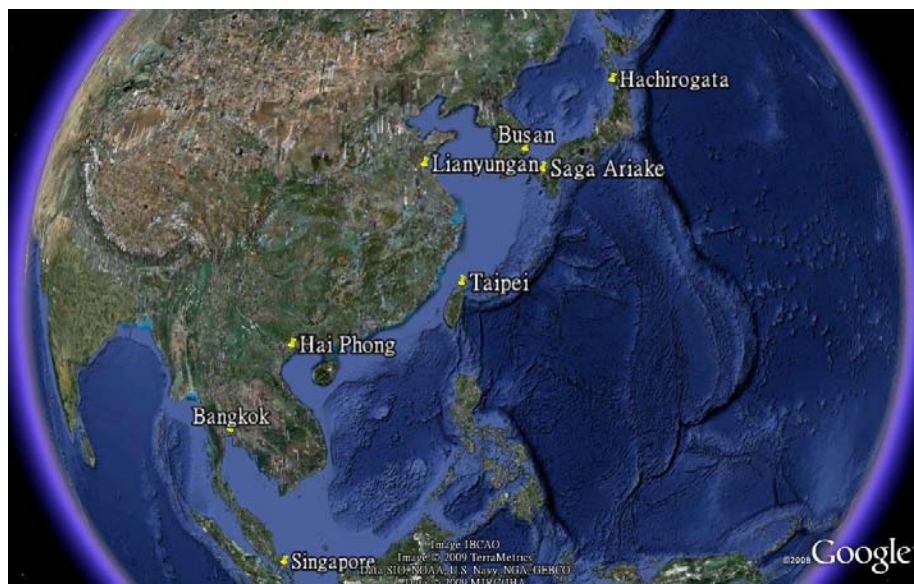


Figure 8. CPTU test sites in Asia.

Table 1. Characteristics of the clays from the test sites.

Site	Clay mineral	Geological epoch	OCR	N_{kt}	Reference
Saga Ariake	smectite	Holocene	1.0-1.3	10*	Tanaka & Tanaka, 2004
Hachirogata	smectite	Holocene	1.0-1.1	8*	Tanaka & Tanaka, 2004
Busan	smectite	Holocene	1.0-1.3	10*	Tanaka & Tanaka, 2004
Bangkok	kaolinite	Holocene	1.0-2.2	8*	Tanaka & Tanaka, 2004
Singapore upper	smectite	Holocene	3.7-5.8	12*	Tanaka & Tanaka, 2004
Singapore lower	kaolinite	Pleistocene	2.8-3.6	20*	Tanaka & Tanaka, 2004
Hai Phong	kaolinite	Pleistocene	2.0-2.5	16*	Tanaka & Tanaka, 2004
Lianyungan	--	Holocene	1.3	13#	Liu et al., 2008
Taipei	Illite	Holocene	1.1-1.3	15&	Ou et al., 1998

*: s_u from unconfined compression tests

#: s_u from consolidated undrained triaxial tests

&: s_u from unconfined compression, consolidated undrained triaxial and field vane shear tests

A plot of correlations between N_{kt} and plasticity index (I_p), based on data reported above is shown in Figure 9. The values of N_{kt} varies significantly. In general, for the Holocene clays, N_{kt} ranged from 5-15. For the more aged Pleistocene clays, most of the N_{kt} ranged from 15 to 25.

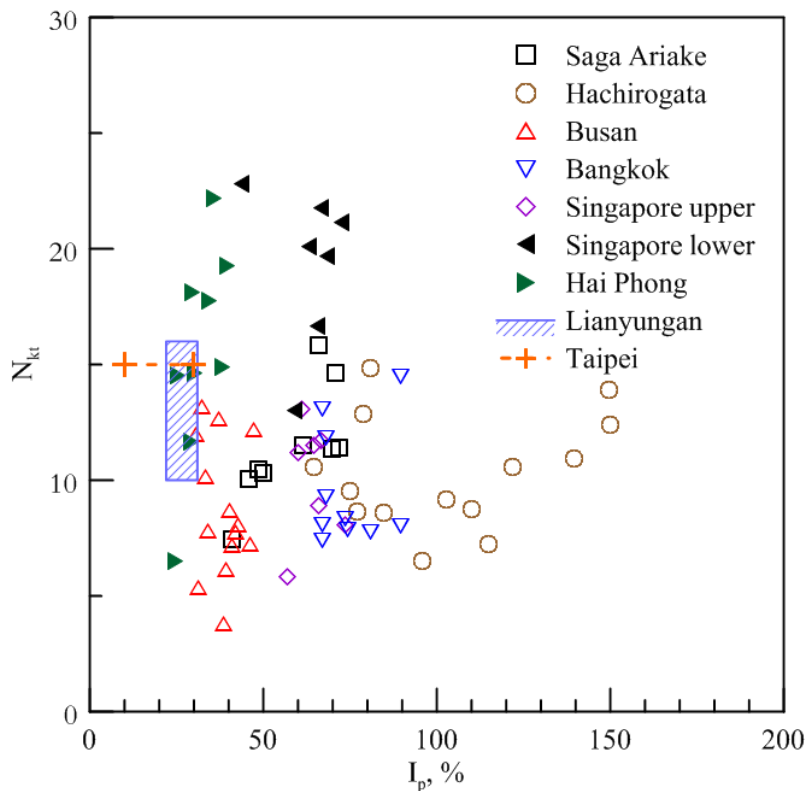


Figure 8. Correlations between N_{kt} and I_p . (modified from Tanaka and Tanaka, 2004)

4.2 Cyclic Strength of Sands

Earthquakes in this region are constantly reminding us of the need to enhance our capability to assess the soil liquefaction potential. CPT is gaining popularity and gradually replacing the SPT in Asia as the prime in situ testing method in assessing soil liquefaction potential. The use of CPT for the most part remains under the framework of the simplified procedure (Seed and Idriss, 1971). The criteria for liquefaction potential was empirically established based on field observations of the occurrence of soil liquefaction and normalized cone tip resistance (q_{c1N}). The experiences accumulated from decades of applications of CPT in liquefaction related studies in this region have provided a wealth of database. The database has been used in part to calibrate the boundary between the liquefiable and non-liquefiable (e.g., Juang et al., 2003; Roy, 2008) soils.

An increased interest in direct calibration between q_c and cyclic resistance ratio (CRR) has been reported recently. Ishihara and Harada (2008) analyzed the correlations between CPT results and their relationship with the ratio of effective horizontal stress to vertical stress (K). The CRR values were estimated from D_r . The penetration resistance values from CPT were based on calibration chamber tests. Figure 5.6 shows the comparison of the $CRR-q_{c1}$ correlations derived for three clean sands: Toyoura sand (average grain size, $D_{50} = 0.20\text{mm}$), Da Nang sand ($D_{50} = 1.13\text{mm}$) and Monterey sand ($D_{50} = 0.37\text{mm}$), for $K=0.5$. The correlations by Robertson & Wride (1998) and AIJ (2001) are also included for reference. For these three types of clean sands, the $CRR-q_{c1}$ correlations can deviate significantly from the published curves and among themselves.

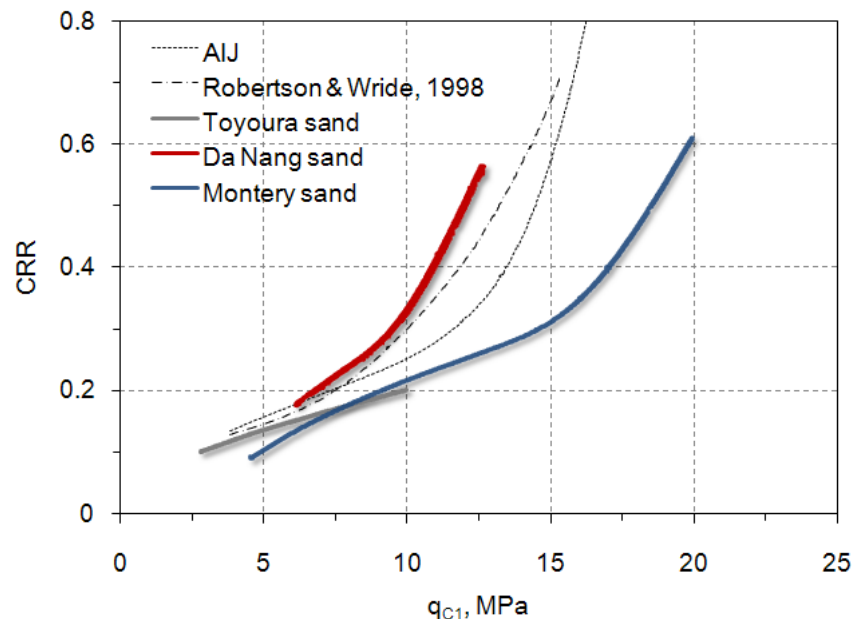


Figure 9 Comparison of the $CRR-q_{c1N}$ correlations derived for three clean sands (after Ishihara and Harada, 2008).

By compiling the CRR and q_t from CPT calibration tests in reconstituted specimens with comparable fines contents, density and stress states, it was possible to veri-

fy the CRR- q_{t1N} correlation by direct comparisons for MLS, as shown in Figure 10 (Huang et al., 2005). The effects of fines on the CRR- q_{t1N} correlations and the need for fines content adjustment can thus be readily evaluated. The results, as shown in Figure 10, indicate that the fines content adjustment becomes significant only when the fines start affecting the drainage conditions (i.e., when FC=30%) and thus result in a group of data points with distinctly lower q_{t1N} . The laboratory study in MLS seems to suggest that a more effective q_{t1N} adjustment scheme should be based on CPT drainage conditions rather than fines content. Additional CRR- q_{t1N} data points based on field CPTU and cyclic triaxial tests on undisturbed samples are also included in Figure 10. The data compiled by Tokimatsu et al. (1995) were collected from field CPT at 6 test sites in Niigata, Kanagawa and Chiba Prefectures of Japan, where soil samples were retrieved by ground freeze. The CRR values were determined from cyclic triaxial tests on undisturbed samples obtained by ground freezing. The fines contents varied from <1% to as much as 30%. According to Tokimatsu et al. (1995), there was a unique CRR- q_{t1N} correlation irrespective of fines content. For a given q_{t1N} , the dispersiveness in CRR was attributed to changes in permeability (K) and soil type.

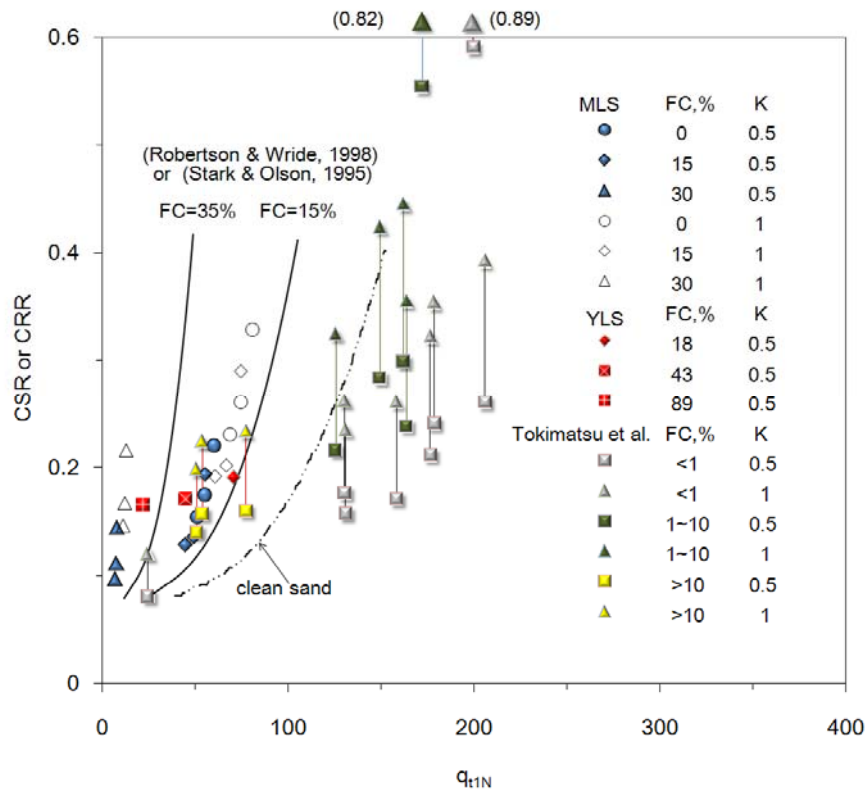


Figure 10 Laboratory and field calibrations of CRR- q_{t1N} correlations.

In light of the above findings, Huang et al. (2009) suggested that a pore pressure dissipation test during CPTU may be used as a reference to scale the amounts of fines content adjustment. In a dissipation test, the cone penetration was suspended and the dissipation of the excess pore pressure induced by cone penetration was monitored until its full dissipation. If the cone penetration were partially drained prior to pore pressure dissipation test, there was a distinct increase of q_t at the start of the subsequent push. This phenomenon referred to as the q_t setup was also reported by

McNeilan and Bugno (1984) in their experience of CPT in offshore California silts. The reason for setup is that partial drainage caused a lowered q_t due to pore pressure accumulation. The dissipation of pore pressure increases soil strength against cone penetration and generates the setup. For CPT in MLS, no obvious q_t setup was observed until FC reached 30%, as shown in Figure 11. This result was also reflected in the CRR- q_{tIN} correlations of MLS in Figure 10.

A series of CPTU using a standard cone (cone cross sectional area=10cm²) penetrating at 20mm/sec (the standard CPTU rate), a large cone (cone cross sectional area=15cm²) penetrating at 20mm/sec (the large CPTU), and a standard cone penetrating at 1mm/sec (the slow CPTU) were conducted at a test site in Yuan Lin in Central Taiwan. The rate of consolidation for soil surrounding a cone tip is inversely proportional to the square of the cone diameter (Robertson et al., 1992). Therefore, changing the cone diameter can also duplicate the effects of penetration rate. For cone penetration in partially drained conditions, reducing the penetration rate could induce higher q_c (Campanella et al., 1981). The pore pressure element was located immediately behind the cone tip, at the u_2 position. Profiles from CTPU results that include friction ratio, R_f ($=f_s/q_t \times 100\%$) from Yuan Lin are shown in Figure 12. The results indicated no significant differences in q_t among three types of CPTU, considering drastic differences in cone size and/or penetration rate. The slow CPTU was conducted at depth levels where Laval samples were also taken. The u_2 values from large CPTU were mostly identical to those from the standard CPTU. The u_2 in slow CPTU matched well with the hydrostatic pressure u_o , indicating that 1mm/sec was slow enough to allow the penetration induced pore pressure to fully dissipate and reach equilibrium in most parts with the surrounding hydrostatic pressure.

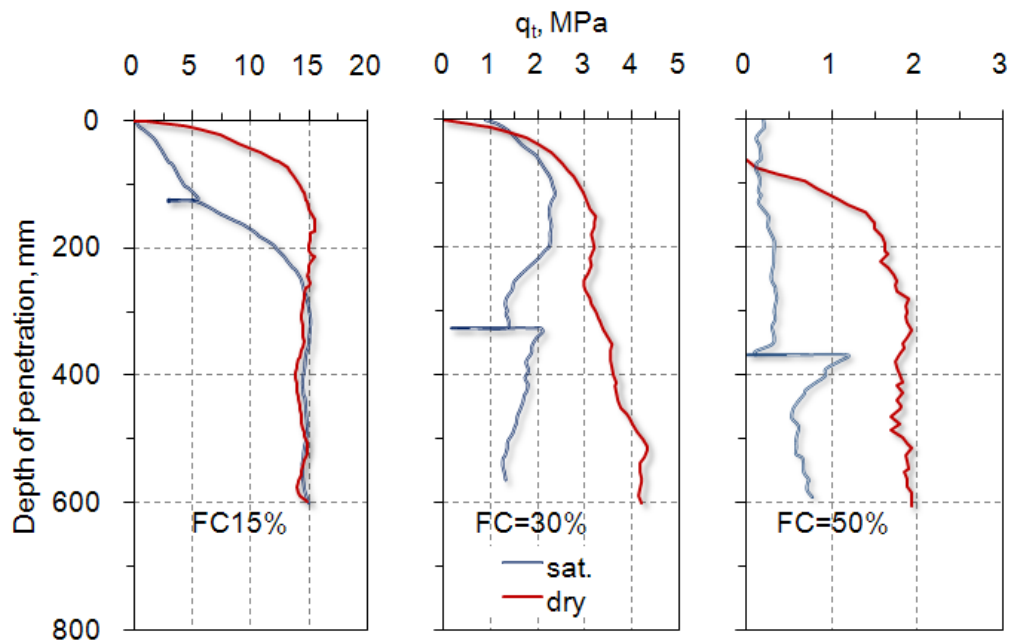


Figure 11 Measured q_t profiles from CPT calibration tests in MLS at different fines contents (after Huang et al., 2009).

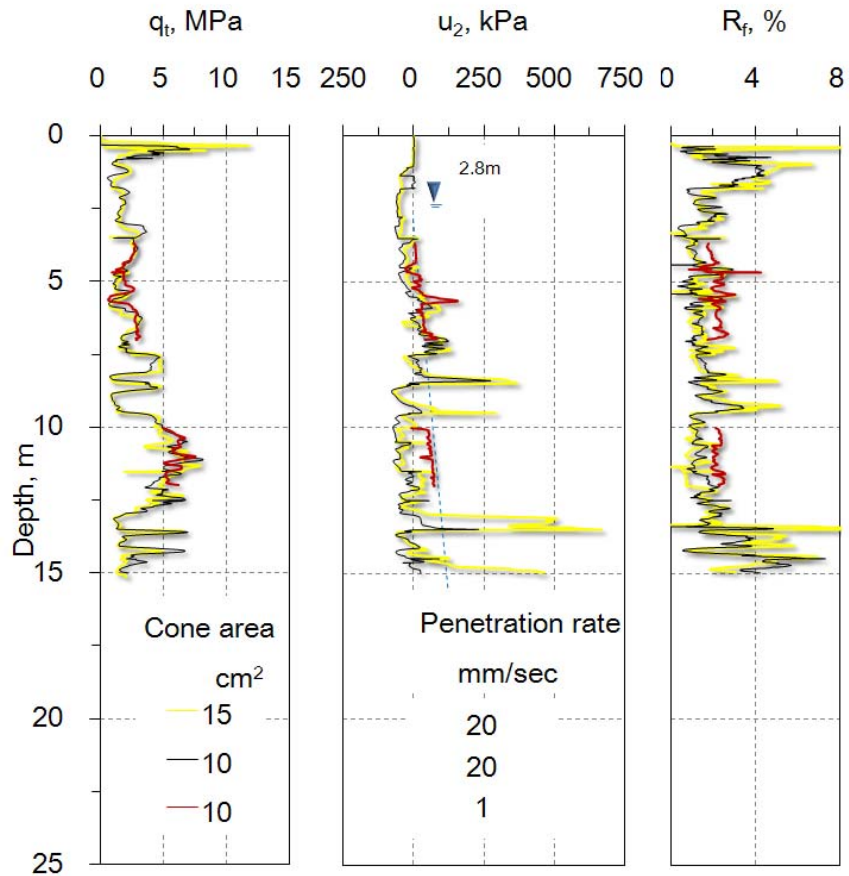


Figure 12 CPTU profiles from Yuan Lin, Taiwan (after Huang et al., 2009).

The standard CPTU in Figure 12 was coupled with dissipation tests. The results in terms of q_t profile are plotted in Figure 13 along with fines contents (from tests on soil samples). The comparison between Figures 12 and 13 allows the change in q_t and its relationship with pore pressure dissipation tests to be visualized. The field CPTU was close to drained conditions with essentially no signs of q_t setup, even when the fines contents reached as high as almost 100%. In contrast, the CPTU in MLS shown in Figure 11 was conducted in well mixed laboratory prepared specimens. The absence of setups for field CPTU in sands with high fines contents is likely due to the heterogeneity existed in natural soil. It is believed that the presence of closely-spaced free draining sand layers made the field CPTU behave as a drained test in a silty soil mass. At much wider range of fines contents, the lateral spread of $CRR-q_{tIN}$ data points based on tests in Yuan Lin Soil (YLS), shown in Figure 10, was less than those from tests using the reconstituted MLS specimens or suggested by the available $CRR-q_{tIN}$ correlations. The same reason may also explain a consistent $CRR-q_{tIN}$ correlation reported by Tokimatsu et al. (1995), as shown in Figure 10, where the sands had fines contents ranging from <1% to 30%.

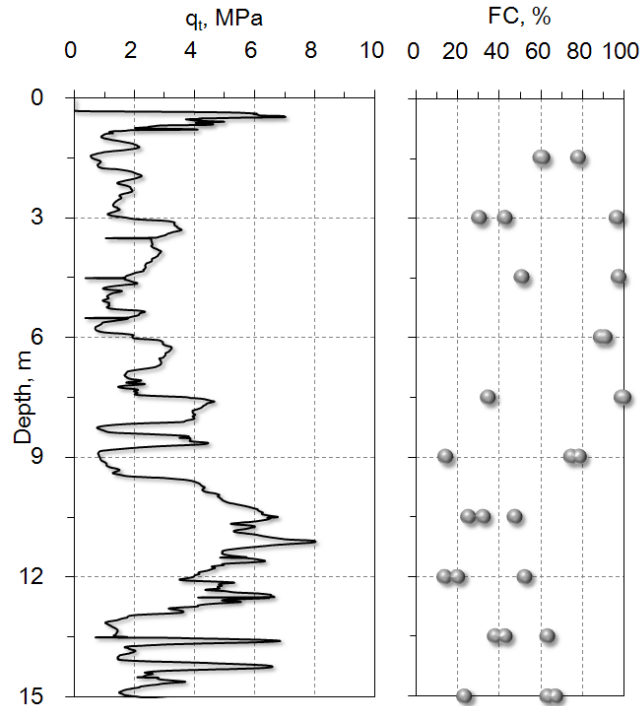


Figure 13 Enlarged q_t and fines content profiles from Yuan Lin site (after Huang et al., 2009).

5 CONCLUDING REMARKS

The experience described in this paper has provided sufficient evidence to show that the interpretation of CPT can be soil and site dependent. Proper usage of CPT and its results should be substantiated by sound theoretical understanding and thorough local calibration. For many countries in Asia, the use of CPT is still in its early stage. There is a great potential for further growth in quantitative scale and level of sophistication in the applications of CPT.

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