Evaluation of the fine contents of silty sands using CPTU results

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Abstract: The cone penetration test with measurement of pore pressure (CPTU) has been widely used in evaluation of liquefaction potential. Estimating the liquefaction resistance of non-clean sands using cone penetration resistance- based techniques can be accomplished by three methods: I) calculated equivalent clean sand (Ishihara, 1985; Seed & Dealba, 1986; Robertson & Wride, 1997). II) The chart-based solution in terms of a measured soil index (Olsen & Koester, 1995; Olsen, 1997). III) Direct correlation to field case histories (Shibata & Teparaksa, 1988; Stark & Olsen, 1995; Baziar & Ziaie-Moayed, 1998). It is important to note that the above approaches are sensitive to the amount of silt content.

The main object of this paper is to report on the new approach to evaluate the fines content based on CPTU results such as t_{50}. In this study, eleven cone penetration tests are performed in saturated silty sand samples with several different silt contents ranging from 1 to 50 percent in the calibration chamber. The standard piezocone is inserted into the chamber by a hydraulic system. Standard piezocone used in this investigation has 10 cm^2 projected tip area and a 150-cm^2 friction sleeve area. In this penetrometer friction sleeve is sited immediately behind the cone tip. The samples are consolidated at three overburden stresses including 100, 200 and 300 kPa. The pore pressure dissipation tests are also carried out in samples with different silt content and t_{50} parameters.

From the obtained results, it can be concluded that, as the t_{50} increases the fine content increases. At the end, the correlation between t_{50} and fine content is presented. The complete results will be presented in the main paper.

Résumé: L'essai de pénétration de cône avec la mesure de la pression de pore (CPTU) a été largement répandu dans l'évaluation du potentiel de liquéfaction. Estimer la résistance de liquéfaction des sables non-propres employant des techniques basées par résistance de pénétration de cône peut être accompli par trois méthodes : I) sable propre équivalent calculé (Ishihara, 1985 ; Seed et Dealba, 1986 ; Robertson et Wride, 1997). II) La solution diagramme-basée en termes d'index mesuré de sol (Olsen et Koester, 1995 ; Olsen, 1997). III) Corrélation directe avec des histoires de cas de champ (Shibata et Teparaksa, 1988 ; Stark et Olsen, 1995 ; Baziar et Ziaie-Moayed, 1998). Il est important de noter que les approches ci-dessus sont sensibles à la quantité de contenu de vase.

L'objet principal de cet article est de rendre compte à la nouvelle approche pour évaluer le contenu de fines basé sur des résultats de CPTU tels que t_{50}. Dans cette étude, onze les essais de pénétration de cône sont exécutés dans les échantillons silty saturés de sable avec plusieurs différent contenu de vase s'étendant de 1 à 50 pour cent dans la chambre de calibrage. Le piezocone standard est inséré dans la chambre par un circuit hydraulique. Le piezocone standard utilisé dans cette recherche a 10 cm^2 de secteur projeté de bout et un secteur de douille du frottement 150-cm^2. Dans ce frottement de pénétromètre la douille est située immédiatement derrière le bout de cône. Les échantillons sont consolidés à trois efforts de terrains de recouvrement comprenant le kPa 100, 200 et 300. Les essais de dissipation de pression de pore sont également effectués dans les échantillons avec différents contenu de vase et paramètres t_{50}.

Des résultats obtenus, il peut conclure que, à mesure que le t_{50} augmente les augmentations contentes fines. À l'extrémité, la corrélation entre t_{50} et contenu fin est présentée. Les résultats complets seront présentés dans le papier principal.

Keywords: calibration chamber, cone penetration chamber, pore pressure, silty sand, fine content, liquefaction

INTRODUCTION

During the past years, the liquefaction behaviour of clean sands has been the focus of most liquefaction studies. However, recent earthquake case histories indicated that natural soils and man-made sandy deposits that contain significant amount of fine-grains are also susceptible to liquefaction (Seed & Harder, 1990). Estimating the liquefaction resistance of non-clean sands using cone penetration resistance - based techniques can be accomplished by three methods: I) the calculated equivalent clean sand (Ishihara, 1985; Seed & DeAlba, 1986; Robertson & Wride, 1997). II) The chart-based solution in terms of a measured soil index (Olsen and Koester, 1995; Olsen, 1997). III) Direct correlation to field case histories (Shibata & Teparaksa, 1988; Stark & Olson, 1995, Baziar & Ziaie-Moayed, 1998).

It is important to note that the above approaches are sensitive to amount of silt content and its effect on cone penetration test (CPT) results. The purpose of this research is to evaluate the influence of silt content on cone penetration resistance in loose silty sand mixtures in a calibration chamber and then to verify the existing methods to determine liquefaction potential of loose silty sand soils.

The past investigation (Ziaie-Moayed, Naeini & Baziar, 2002) showed that the evaluation of fine content of loose silty sands only based on cone tip resistance (q_c) values causes some uncertainty especially for high silt content (fine content>30%). Therefore, there will be probably some errors in evaluation of liquefaction potential of loose silty sand using Robertson & Wride, (1997) method.

The purpose of this research is to correlate the pore water pressure dissipation test results (PPD test) with fine content (FC) in loose silty sand samples. For this purpose the eleven standard piezocone tests were performed at constant rate of 20 mm/s in silty sand samples containing 0, 5, 10, 20, 25, 30, 35, 40, 45 and 50 percent silt content and the time for 50% of pore water pressure dissipation (t_{50}) are also determined at midpoint of each sample. Then the PPD test results (t_{50} values) are correlated with silt percent.

TEST METHOD AND EQUIPMENT

Calibration Chamber

The testing chamber is consisted basically of a rigid thick walled steel cylinder of 0.76-m internal diameter and 1.50-m height, with removable top and bottom plates (Ziaie-Moayed, 2001).

Cone Penetrometer

The standard piezocone is inserted into the chamber by a hydraulic system. Standard piezocone used in this investigation has 10 cm^2 projected tip area and a 150-cm^2-friction sleeve area. In this penetrometer, friction sleeve is sited immediately behind the cone tip. The filter element to record pore water pressure is located immediately behind the cone tip. The piezocone is advanced through soil at a constant rate of 20 mm/sec. Three sets of data including cone tip resistance, friction resistance and pore water pressure can be recorded continuously during sounding in each 1 cm of depth.

Soil Sample

Approximately 60 tons of Tello clean fine sand was acquired for this research. This alluvial soil is a fine clean sand without any clay or silt particle and has specific gravity of 2.6. A typical grading curve of this material is shown in Figure 1. The sand is a rounded to sub-angular fine grained quartz sand with D_{50}=0.4 mm and C_u=3.0. In order to determine the silt content due to t_{50} measurement, pure silt was obtained from grinding of Tello fine sand. Approximately 10 tons of silt material was obtained enabling different mixtures of silt and sand to be made (between 0% to 50% silt). The properties of tested materials are reported in Table 1.

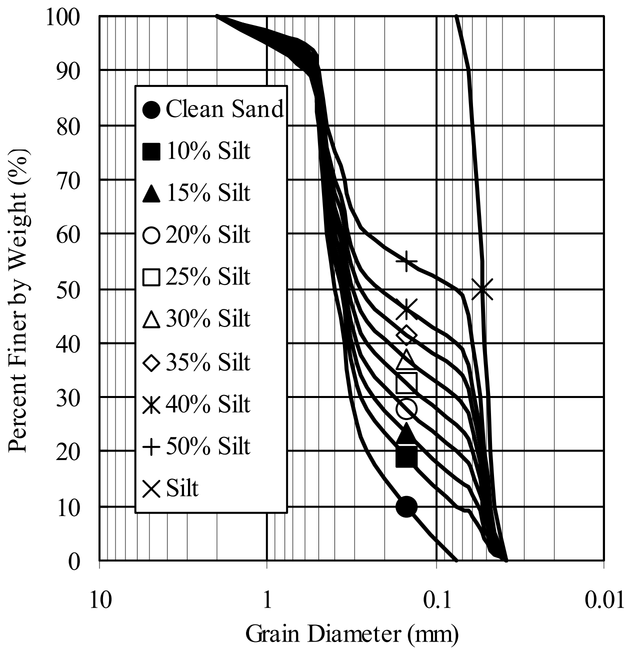

Figure 1. Grain distribution curves of tested materials

Experiment procedures

All the tests reported in this research were conducted in six stages including: sample preparation, saturation, consolidation, CPT sounding, pore water pressure dissipation test and evacuation (Ziaie-Moayed, 2001). Before filling the testing cylinder with dry sand, a soil filter grading from coarse sand to fine gravel was formed at the bottom. After the soil sample was setup, another filter layer was formed at the top of the soil. To saturate the soil specimen, the top plate was fixed on the chamber and vacuum was applied inside the chamber for 30 minutes. Then the bottom water supply was opened and as a result, the filter was flooded quickly, and a uniform slow upward flow was followed. The normal testing procedure consisted of sample consolidation were followed by cone penetration sounding. When the piezocone arrive at the midpoint of the pore water pressure readings during time expansion were determined.

PORE WATER PRESSURE DISSIPATION TEST RESULTS

A total of eleven pore water pressure dissipation tests were performed in calibration chamber including one clean sand and ten silty sand samples. Table 2 presents the summary of PPD test results. A typical pore water pressure dissipation curve is presented for 40 percent silt sample in Figure 2.

Table 1. Correction to SPT results

Material	D_{50} (mm)	C_U	FC (%)	e_{min}	e_{max}
TCS	0.4	30	0	0.746	1.05
Ts-10	0.38	5.6	10	0.625	1.0
Ts-15	0.35	7.1	15	0.608	0.99
Ts-20	0.34	7.5	20	0.594	0.97
Ts-25	0.33	7.45	25	0.584	0.94
Ts-30	0.32	7.4	30	0.592	0.92
Ts-35	0.28	7.14	35	0.535	0.91
Ts-40	0.24	6.88	40	0.52	0.90
Ts-50	0.075	5.53	50	0.485	0.88

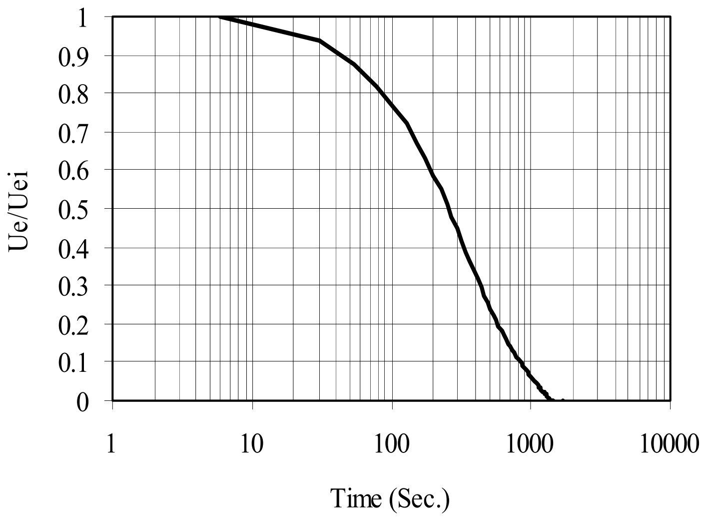

Figure 2. Typical pore water pressure dissipation curve (40% silt content)

Table 2. Pore water pressure dissipation test results

Sample No.	Silt Content (%)	t_{50} (s)
1	0	8.0
2	5	20.0
3	10	21.0
4	15	45.0
5	20	47.0
6	25	55.0
7	30	115.0
8	35	161.5
9	40	250.0
10	45	371.0
11	50	521.0

INTERPRETATION TEST RESULTS

The fines content of non-clean sand is an important ingredient for cone resistance-based techniques to estimate liquefaction resistance. Fines content can be either 1) measured from samples taken from nearby boreholes or 2) estimated using CPT based techniques. In recent years, new correlations have been proposed to determine fines contents directly from CPT data (Robertson & Wride, 1997; Olsen, 1997). Robertson & Wride (1997) suggested a method for estimating fines content based on CPT data. They presented the equation of FC based on only cone tip resistance and friction resistance. The results obtained by other researchers showed that the determination of FC of silty sands based on only cone tip resistance and friction resistance data may be cause some uncertainty (Finn 1993; Larsson, Lorforth & Moller, 1995). They recommended that excess pore water pressure parameters such as Δu (dynamic pore water pressure during CPT sounding) and t_{50} (rate of pore water pressure dissipation during a pause in the CPT sounding) are required to correctly clarify the soil behaviour type. In this research, the t_{50} parameter (rate of pore water pressure dissipation during a pause in the CPT sounding) is determined for each sample containing different silt content. The obtained results are presented in Table 2.

The relationships between t_{50} and FC values are presented in Figure 3. The results suggest that for t_{50}>115 s the fine content is greater than 30%. For t_{50} between 10 s and 115 s the cone penetration process is partially drained and there is a poor correlation between t_{50} and fine content. Otherwise for fine contents greater than 30%, the penetration process is partially undrained and there is a good correlation between t_{50} and fine content giving the following equation:

$$t_{50} = 10.235 * e^{0.079\,(F.C.)}$$

where t_{50} is the time taken for 50% of pore water pressure dissipation and FC is fine content

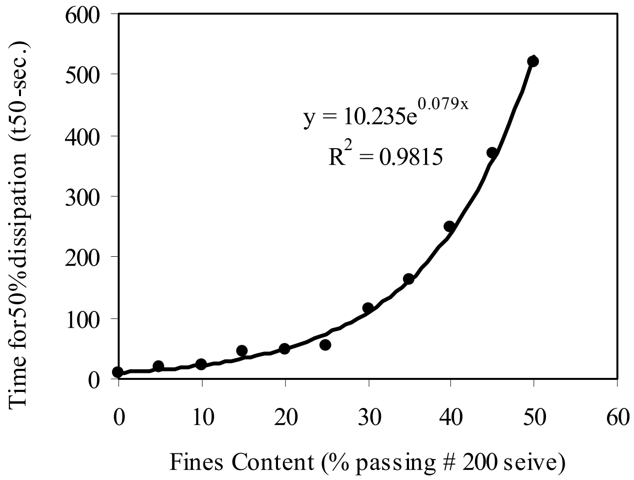

Figure 3. Correlation between t_{50} and Fine content

CONCLUSIONS

The fine content could be correlated with time for 50% dissipation of pore water pressure (t_{50}) in loose silty sand soils. As the fine contents increases the time for 50% of pore water pressure dissipation increases. The results suggest that for t_{50}>115 s the fine content is greater than 30%.

For the fine content smaller than 30%, the cone penetration process is partially drained and there is a poor correlation between t_{50} and fine content. For fine contents greater than 30%, the penetration process is partially undrained and there is a good correlation between t_{50} and fine content such as following equation:

$$t_{50} = 10.235 * e^{0.079\,(F.C.)}$$

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REFERENCES

BAZIAR, M. H. & ZIAIE-MOAYED, R. 1998. Evaluation of liquefaction potential and lateral deformation using CPT and field case histories. *In: Proceedings of the 1st International Conference on Site Characterization, ISC, 1998, Atlanta, USA,* 19-22

FINN, W.D.L. 1993. Evaluation of Liquefaction Potential. *In: Proceedings of Conference on Soil Dynamics and Geotechnical Earthquake Engineering, Lisbon*. Balkema, Rotterdam. 127-158

ISHIHARA, K. 1985. Stability of Natural Deposits During Earthquakes. *In: Proceedings of the 11th International Conference on Soil Mechanics and Foundation Engineering, San Francisco*. Balkema, Rotterdam, 321-376.

LARSSON, R., LORFORTH, B., MOLLER, B. 1995. Processing of Data From CPT Tests. *In: Proceedings of an International Symposium on Cone Penetration Testing, CPT'95, Linkoping, Sweden*, 201-207.

OLSEN, R. S., and KOESTER, J.P. 1995. Prediction of liquefaction resistance using the CPT. *In: Proceedings of an International Symposium on Cone Penetration Testing, CPT'95, Linkoping, Sweden*, 251-256

OLSEN, R. S. 1997. Cyclic Liquefaction Based on the Cone Penetrometer Test. *In: Proceedings of the NCEER Workshop on Evaluation of Liquefaction Resistance of Soils*. National Center for Earthquake Engineering Research. Technical Report NCEER-97-0022, 225-276.

ROBERTSON, P. K. & WRIDE, C. E. 1997. Cyclic Liquefaction and Its Evaluation Based on the SPT and CPT. *In: Proceedings of the NCEER Workshop on Evaluation of Liquefaction Resistance of Soils*. National Center for Earthquake Engineering Research. Technical Report NCEER-97-0022, 41–88.

SEED, H. B. & HARDER, L. F. 1990. SPT-based analysis of cyclic pore pressure generation and undrained residual strength. *In: Proceedings of H Bolton Seed Memorial Symposium, Berkeley,* **11**. Vancouver, BC, Bitech Publishers, 351-376

SEED, H. B. & De ALBA, P. 1986. Use of SPT and CPT Tests for Evaluating the Liquefaction Resistance of Sands. *In: Proceedings of the American Society of Civil Engineers Specialty Conference In-Situ'86: Use of In-Situ Tests in Geotechnical Engineering, Blacksburg*, 281-302.

SHIBATA, T. & TEPARAKSA, V. 1988. Evaluation of Liquefaction Potentials of Soils Using Cone Penetration Tests. *Soil and Foundations*, **28**(2), 49-60.

STARK, T. D. & OLSEN, S. M. 1995. Liquefaction Resistance Using CPT and Field Case Histories. *Journal of Geotechnical Engineering,* **121**(12), 856-869.

ZIAIE-MOAYED, R. 2001. *Evaluation of cone Penetration test results in loose silty sand*. PhD Thesis, Iran University of Science and Technology.

ZIAIE-MOAYED, R., NAEINI, S. A. & BAZIAR, M. H. 2002. Evaluation of liquefaction potential of loose silty sands based on CPTU results. *In: Proceedings of 55th Canadian Geotechnical Conference, October 2002, Niagara Falls, Ontario,* 95-100.