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Design of a piezovibrocone and calibration chamber

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Abstract. This paper presents the details of indigenous development of the piezovibrocone and calibration chamber. The developed cone has a cylindrical friction sleeve of 150 cm^2 surface area, capped with a 60^0 apex angle conical tip of 15 cm^2 cross sectional area. It has a hydraulic shaker, coupled to the cone penetrometer with a linear displacement unit. The hydraulic shaker can produce cyclic load in different types of wave forms (sine, Hover sine, triangular, rectangular and external wave) at a range of frequency 1-10 Hz with maximum amplitude of 10 cm. The piezovibrocone can be driven at the standard rate of 2 cm/sec using a loading unit of 10 ton capacity. The calibration chamber is of size 2m×2m×2m. The sides of the chamber and the top as well as the bottom portions are rigid. It has a provision to apply confining pressure (to a maximum value of 4 kg/cm^2) through the flexible rubber membrane inlined with the side walls of the calibration chamber. The preliminary static as well as dynamic cone penetration tests have been done sand in the calibration chamber. From the experimental results, an attempt has been made to classify the soil based on friction ratio (f_R) and the cone tip resistance (q_c).

Keywords: calibration chamber; cone penetration test; piezovibrocone; site characterization; sand.

1. Introduction

Liquefaction evaluation of sandy and silty soils using laboratory methods consist of cyclic triaxial or cyclic simple shear testing, while in-situ tests consist of the standard penetration test (SPT), cone penetration test (CPT), flat plate dilatometer test (DMT), or shear wave velocity technique. In case of laboratory methods, effects of aging, sampling disturbances, inherent fabric, and re-establishment of the in-situ stress state are difficult to take into account. Whereas, in-situ tests can handle some of the above aspects in in-situ conditions. Among the vast number of in-situ devices, the CPT and the piezocone represent most versatile tools for soil exploration. In order to provide a direct and more rational approach to site- specific liquefaction susceptibility analysis, a very advanced hydraulic-type piezovibrocone has been developed at Indian Institute of Science, Bangalore jointly with M/S HEICO, New Delhi. This is basically a piezocone with provision for measuring tip resistance, skin resistance and pore pressure at any depth during static penetration. In addition, the cone can be vibrated at a selected frequency range and amplitudes at any specified depth. The summary of different piezovibrocone has been given in literatures (Sasaki and Koga 1982, Teparaksa 1987, Moore 1987, Mitchel 1988, Piccoli 1993, Wise *et al.* 1999, Schneider *et al.* 1999, Mitchell *et al.*

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Table 1 Large calibration chamber used in geotechnical investigations (Ghionna and Jamiolkowski 1992)

Test cell owner/location	Specimen diameter (m)	Specimen height (m)	Boundary condition		
			Radial	Bottom	Top
Country road board, Australia	0.76	0.91	Flexible	Cushion	Rigid
University of Florida, USA	1.2	1.2	Flexible	Cushion	Rigid
Monash university, Australia	1.2	1.8	Flexible	Cushion	Rigid
Norwegian geotechnical society	1.2	1.50	Flexible	Cushion	Rigid
ENEL CRIS, Milano, Italy	1.2	1.50	Flexible	Cushion	Rigid
ISEMS, Bergamo, Italy	1.2	1.50	Flexible	Cushion	Rigid
University California, Berkeley, USA	0.76	0.80	Flexible	Rigid	Rigid
University of Texas, Austin, USA	Cube 2.1×2.1×2.1 m		All flexible		
University of Houston, Texas, USA	0.76	2.54	Flexible	Cushion	Cushion
North Carolina state University, USA	0.94	1.00	Flexible	Rigid	Rigid
Louisiana state university, USA	0.55	0.80	Flexible	Flexible	Rigid
Golder associates, Calgary, Canada	1.40	1.00	Flexible	Rigid	Cushion
Virgina polytechnic institute and state university, Blackburg, USA	1.5	1.5	Flexible	Rigid	Rigid
University of Grenoble, France	1.2	1.5	Flexible	Cushion	Cushion
Oxford university, UK	0.90	1.10	Flexible	Cushion	Rigid
University of Tokyo, Japan	0.90	1.10	Flexible	Rigid	Rigid

1999).

In case of sandy soils, the problems of sample disturbances normally prevent laboratory tests on undisturbed soil samples being used. Cone penetration test in calibration chamber can be used as the most efficient means of verifying interpretation theories and establishing engineering correlations for sands. Table 2 shows the review of existing large-scale calibration chamber in the world (Kurup *et al.* 1994, Salgado *et al.* 1997, 1998, Konrad 1998, Wesley 2002, Huang and Hsu 2005). Also for evaluating the piezovibrocone developed at IISc, a series of calibration chamber studies are being planned. In this paper, the details of indigenous development of the piezovibrocone and calibration chamber testing facility along with testing procedure and preliminary test results from the piezovibrocone have been presented.

2. Piezovibrocone design

The basic concept of a piezovibrocone consist of cone penetrometer with piezo pore pressure sensor at the tip along with tailing vibrator unit. The development of a piezovibrocone has been initiated in IISc, Bangalore to study the in-situ liquefaction potential of sandy soils. The developed piezovibrocone (Fig. 1) has a cylindrical friction sleeve of 150 cm^2 surface area, capped with a 60^0 apex angle conical tip of 15 cm^2 cross section nal area. It has one hydraulic shaker, coupled to the cone penetrometer with a linear displacement unit. The hydraulic shaker can produce cyclic load in different types of wave forms (sine, Hover sine, triangular, rectangular and external wave) at a range of frequency 1-10 Hz with maximum amplitude of 10 cm. The piezocone can be driven at the standard rate of 2 cm/sec using a loading unit (Fig. 2) of 10ton capacity. Key resistance parameters,

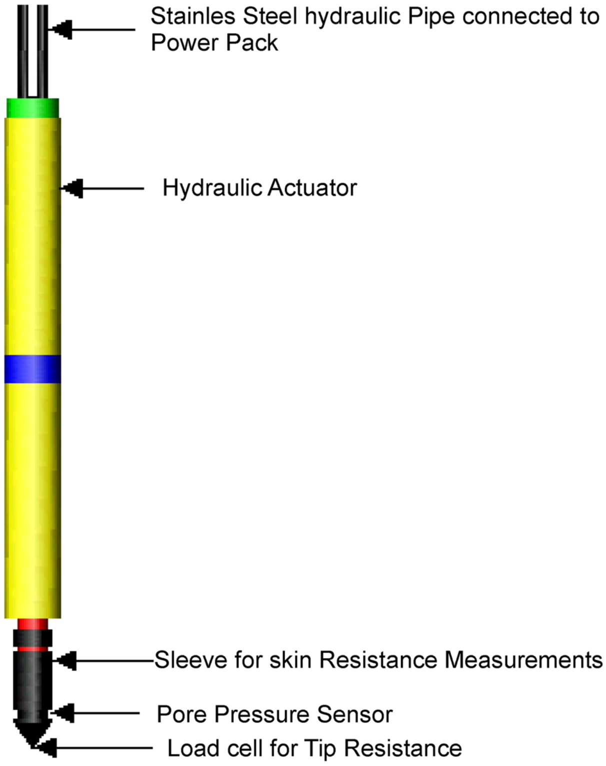

Fig. 1 Developed piezovobrocone

Fig. 2 Loading unit

which are measured during tests, include tip resistance (q_c), sleeve friction (f_s), porewater pressure (u) at the tip and displacement of excitation.

3. Calibration chamber

The calibration chamber (Fig. 3) of 2m×2m×2m was designed to allow lateral pressures (to a maximum value of 4 kg/cm^2) to be applied independently on the soil sample. Fig. 3 shows the placement of the calibration chamber in the soil mechanics lab at Indian Institute of Science. The pressure is applied through the rubber membrane (Fig. 4) inlined with the walls of the calibration chamber. The sides of the calibration chamber are flexible, whereas top as well as bottom portions are rigid. There are 4 holes on every sides of the calibration chamber to pressurize the calibration chamber through the air pressure. In each hole, one white colour pipe (Fig. 5) (BSP, 4 mm (inner dia)×6 mm (outer dia)) is connected. The pipes are attached to the air compressors machine. The top plate of the calibration is removable. It is attached with the calibration chamber by 44 nuts and bolts (1/2 inch dia & 2 inch length). There are nine holes (dia-62 mm) through the top plate (see Fig. 6). This allows for multiple tests penetration, as the influence zone of the penetrated cone is small and also the loading unit to push the cone into the soil through the insertion ports provided in the top cap of the calibration chamber. There is no vertical stress control on the chamber specimen.

Fig. 3 Calibration chamber

Fig. 4 Inner portion of the calibration chamber

Fig. 5 Pipe connected with air compressor machine

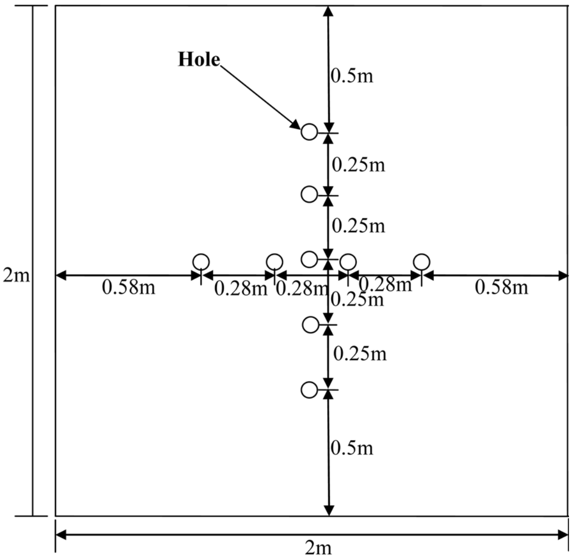

Fig. 6 Position of holes in the calibration chamber

4. Calibration chamber testing

There are three major steps in calibration chamber testing. Typical arrangement of cone penetration test in calibration chamber is shown in Fig. 9. After the initial learning period, a complete chamber testing was accomplished in three-day period. The first step is to open the top plate and the top plate is tightened by the chain. Then the calibration chamber is filled with sand by raining technique. Next, the top plate covers the calibration chamber. Prior to insertion, the loading unit is placed on the top plate (Fig. 7). After assembling the cone, the small caps that cover the cone penetration holes are removed. In the next step, the data acquisition system is prepared. The cone is then pushed at 2 cm/s insertion rate by loading unit, which is driven by power pack mounted on

Fig. 7 Placing the loading unit on the calibration chamber

Fig. 8 Power Pack

tractors (Fig. 8). This unit can be carried as a trailer unit to field for field test. After pushing the cone upto one meter in the tank, then stop the loading unit by hand controller and join one meter pipe to the cone. Again start the loading unit by hand controller to push the cone into the tank. At the time of joining the pipe to the cone the data acquisition system was stopped. Then after a test, the cone is removed from the sand sample and the loading unit is moved over the next testing hole. Testing in a new hole requires reorienting the loading unit on the top plate. After all cone penetration tests are performed, the loading unit is removed from the top plate. The top plate is unbolted and removed from the chamber. Totally 9 tests will be carried out a different location of the testing tank. Fig. 9 shows the placement of the calibration chamber and also the loading unit to push the cone into the soil through the insertion ports provided in the top cap of the calibration chamber. In this study, cone penetration tests have been performed in "dry" as well as "saturated" condition. The lateral pressure has been applied up to 2 kg/cm^2.

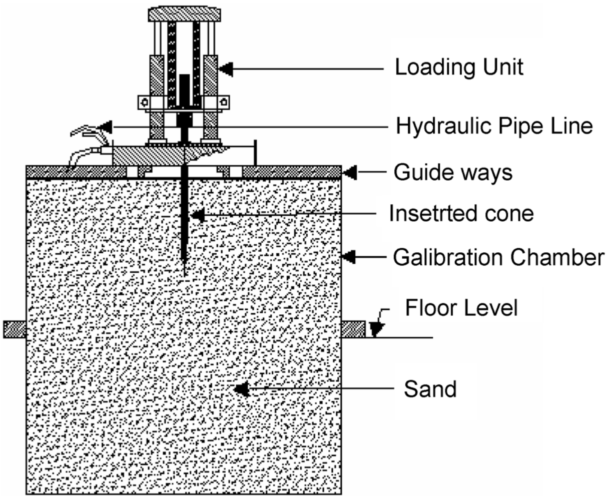

Fig. 9 Assembly view off the experimental set up, showing calibration chamber and CPT

Table 2 Index properties of sand

Medium grain size (D_{50})	0.6 mm
Effective grain size (D_{10})	0.22 mm
Maximum void ratio (e_{max})	0.816
Minimum void ratio (e_{min})	0.534
Specific gravity of particles (G)	2.67
Uniformly coefficient (c_u)	3.31
Coefficient of curvature (c_c)	1.046

5. Test results

A series of verification experiments using cone penetrometer have been conducted in the calibration chamber to evaluate the performance of the cone developed. The index properties of the sand used in calibration chamber validation tests is shown in the Table 2. The value of tip resistance, q_c (Fig. 10), and sleeve resistance, f_s (Fig. 11) are recorded from the calibration chamber experiment with sand in dry condition. A plot (Fig. 12) has been made between q_c and friction ratio, ($f_R\%=f_s/q_c\times 100$) to classify the sand used in calibration chamber experiment from the CPT results. The resulting classification showed reasonable agreement with the available soil classification chart (Robertson and Campanella 1983) as shown in Fig. 12. In another test, the sand specimen of calibration chamber is saturated with water. For saturated sand condition, the cone penetrometer tests have been done with applying lateral pressure of 0 kg/cm^2, 1 kg/cm^2 and 2 kg/cm^2. The value of q_c, f_s and pore water pressure (u) were recorded from the calibration chamber experiment with saturated condition of sand. The values of q_c, f_s and u with depth corresponding to lateral pressure of 0 kg/cm^2 are shown in Figs. 13, 14 and 15 respectively. Figs. 16, 17 and 18 show the value of q_c, f_s and u with depth corresponding to lateral pressure of 1 kg/cm^2 respectively. The variation of q_c, f_s and u with depth corresponding to lateral pressure of 2 kg/cm^2 are shown in Figs. 19, 20 and 21

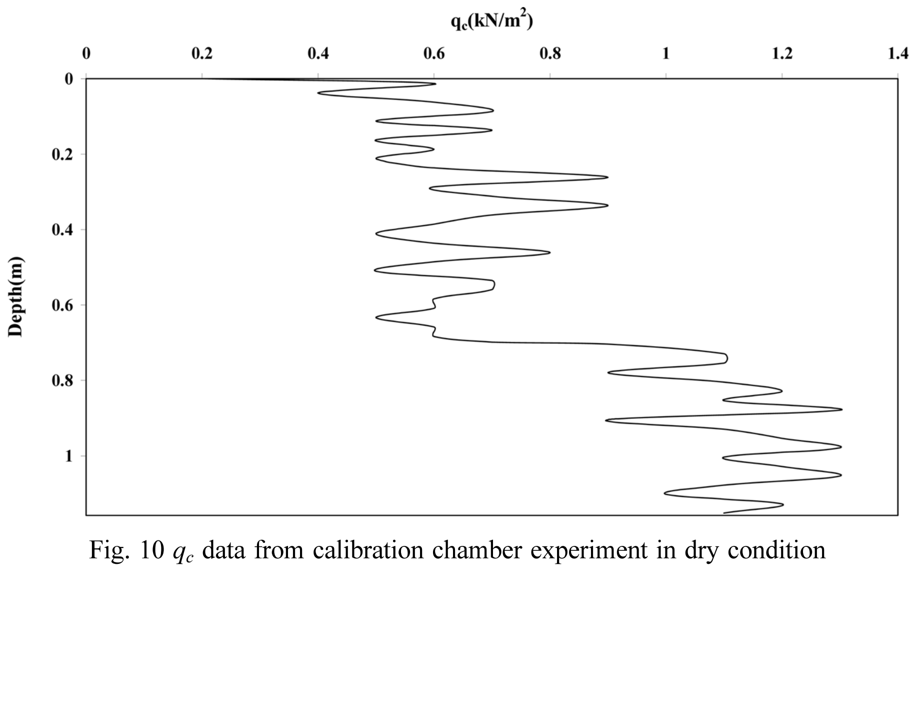

Fig. 10 q_c data from calibration chamber experiment in dry condition

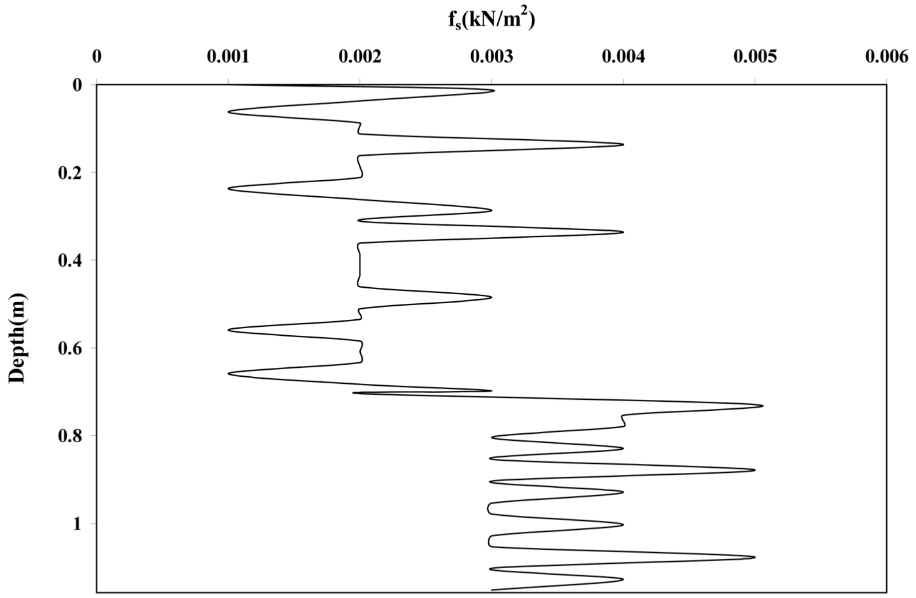

Fig. 11 f_s data from calibration chamber experiment in dry condition

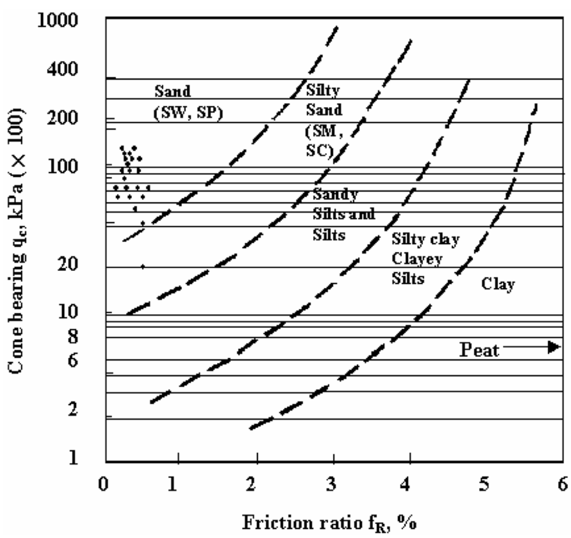

Fig. 12 Plot between the cone resistances (q_c) and friction ratio (f_R%) to classify the soil

respectively. It is clear from these figures that as the lateral pressure is increased, the values of q_c, f_s and u are also increased. The dynamic tests have been performed at a depth of 1 meter using a Sine wave (frequency=2 HZ and amplitude=4 cm). The results of dynamic test have been shown in Figs. 22, 23 and 24.

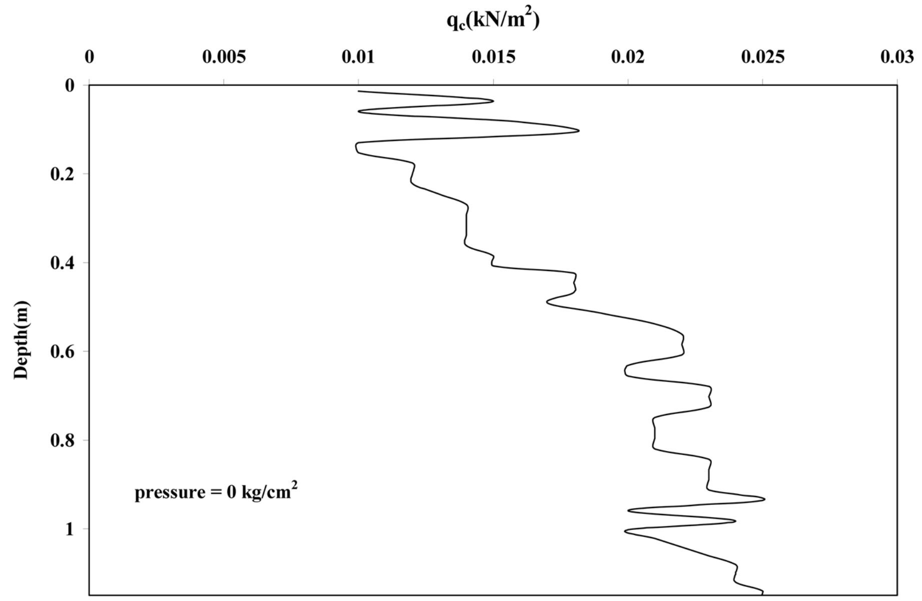

Fig. 13 q_c data from calibration chamber experiment in saturated condition under applying pressure of 0 kg/cm^2

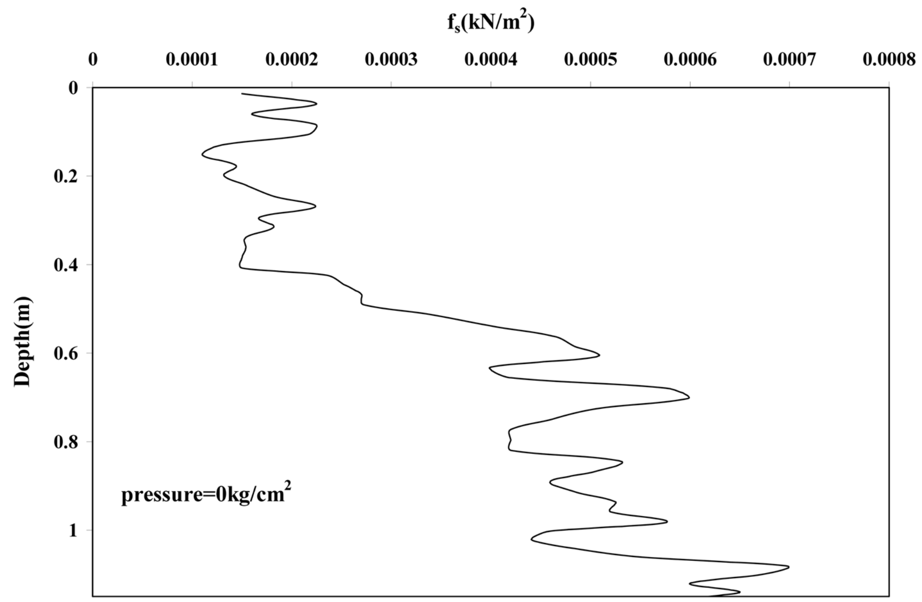

Fig. 14 f_s data from calibration chamber experiment in saturated condition under applying pressure of 0 kg/cm^2

5. Conclusions

A specialized in-situ tool, termed the piezovibrocone, has been developed for the direct evaluation of soil liquefaction potential on site-specific projects. A large-scale calibration chamber was

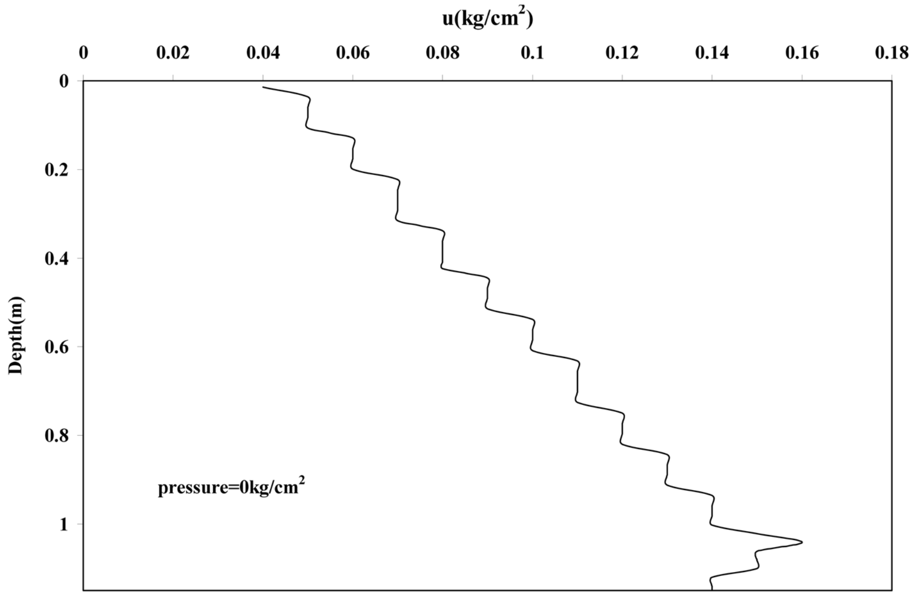

Fig. 15 u data from calibration chamber experiment in saturated condition under applying pressure of 0 kg/cm^2

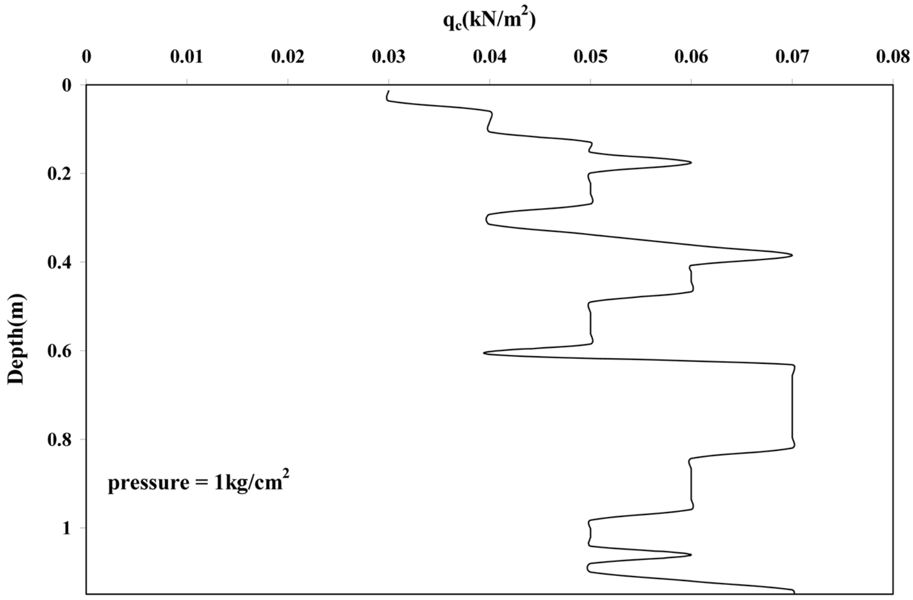

Fig. 16 q_c data from calibration chamber experiment in saturated condition under applying pressure of 0 kg/cm^2

designed and fabricated to test piezovibrocone and other in situ devices under controlled conditions. The major components are loading unit, power pack, air compressor and data acquisition system. The calibration chamber has a provision for multiple penetrations with the in-situ testing probe. It contains a large soil specimen (2m×2m×2m). The chamber permits testing application over a range

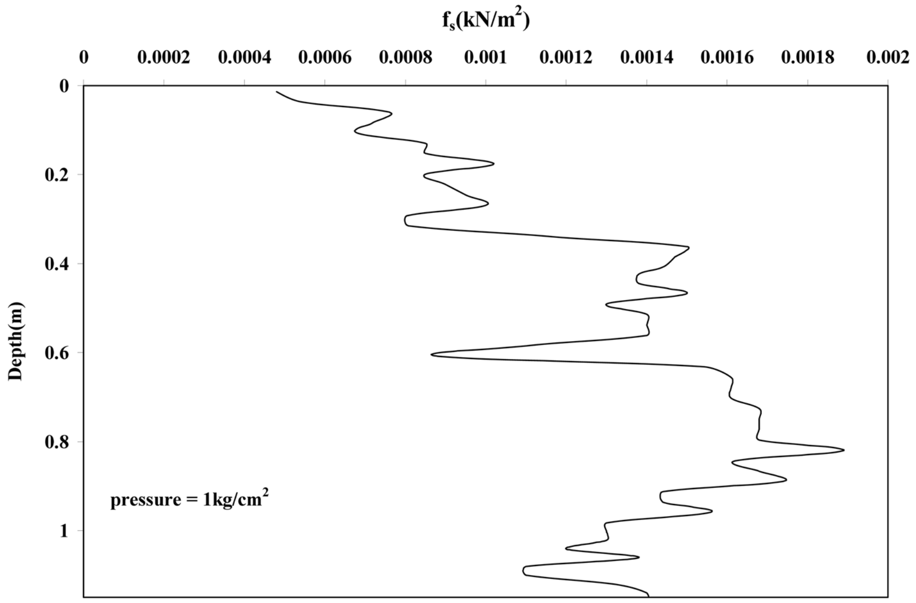

Fig. 17 f_s data from calibration chamber experiment in saturated condition under applying pressure of 1 kg/cm^2

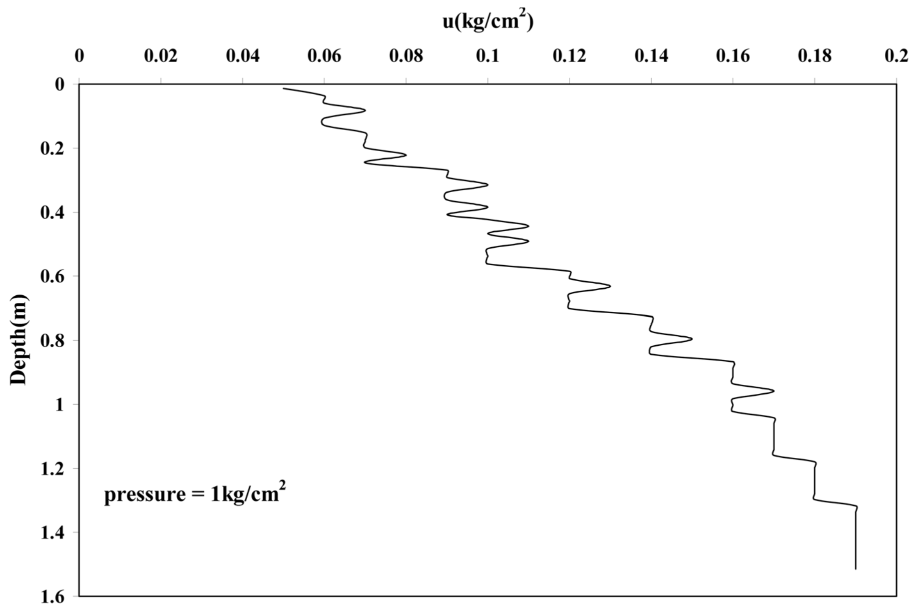

Fig. 18 u data from calibration chamber experiment in saturated condition under applying pressure of 1 kg/cm^2

of 0 kg/cm^2-4 kg/cm^2 lateral stress. The calibration chamber testing program is shown to produce high quality data and useful information. The preliminary results indicate a good trend and the values clearly able to classify the sand used within the classification chart as presented by Robertson and Campanella (1983). The results of calibration chamber tests clearly show the effect

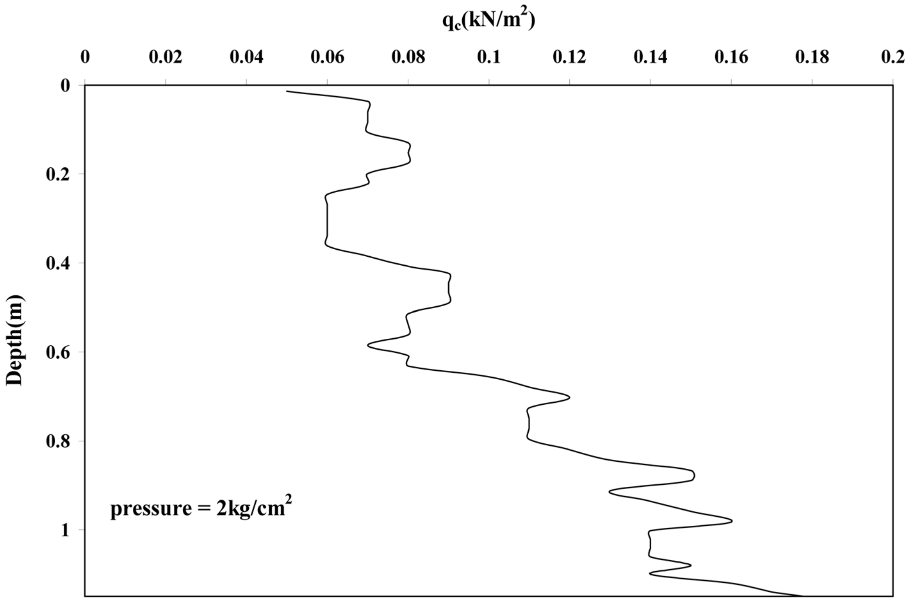

Fig. 19 q_c data from calibration chamber experiment in saturated condition under applying pressure of 2 kg/cm^2

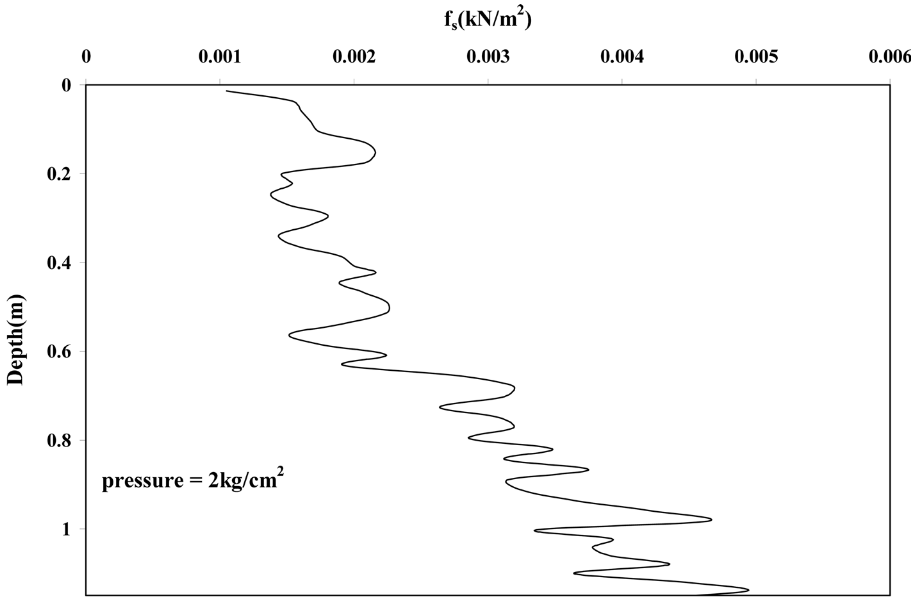

Fig. 20 f_s data from calibration chamber experiment in saturated condition under applying pressure of 2 kg/cm^2

of lateral stress. Generally, the pore pressure increases with depth. Dynamic tests clearly show that the developed cone has the ability to measure the pore pressure.

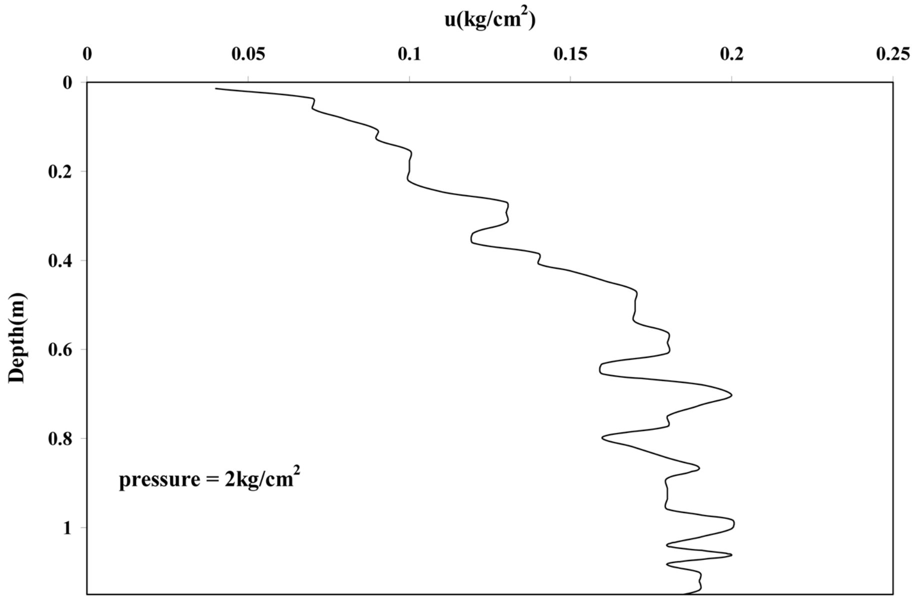

Fig. 21 u data from calibration chamber experiment in saturated condition under applying pressure of 2 kg/cm^2

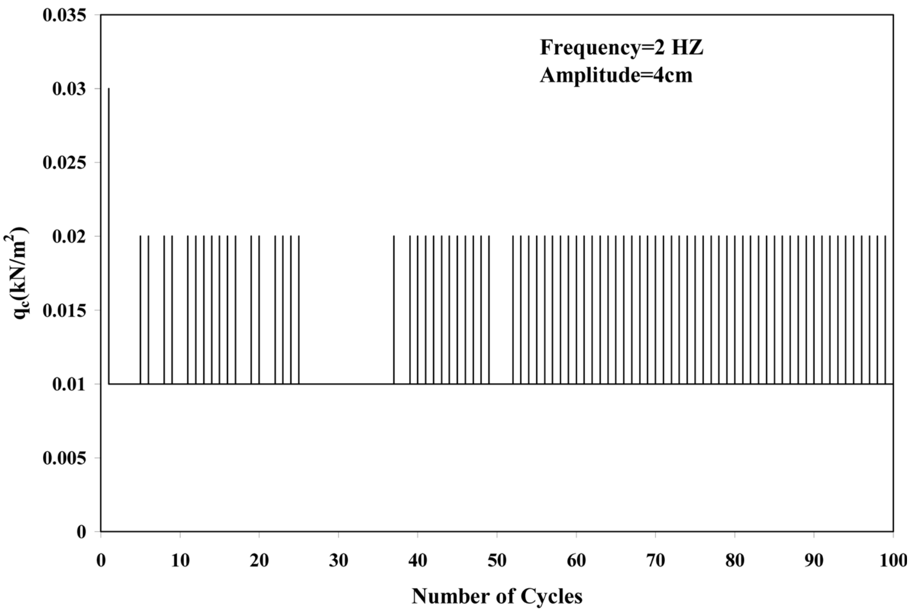

Fig. 22 Variation of q_c with number of cycles

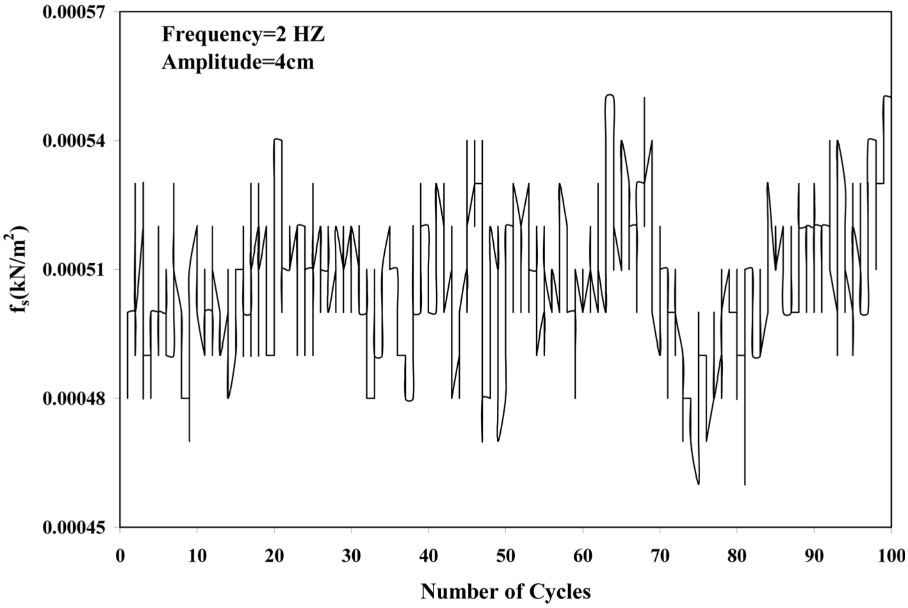

Fig. 23 Variation of f_s with number of cycles

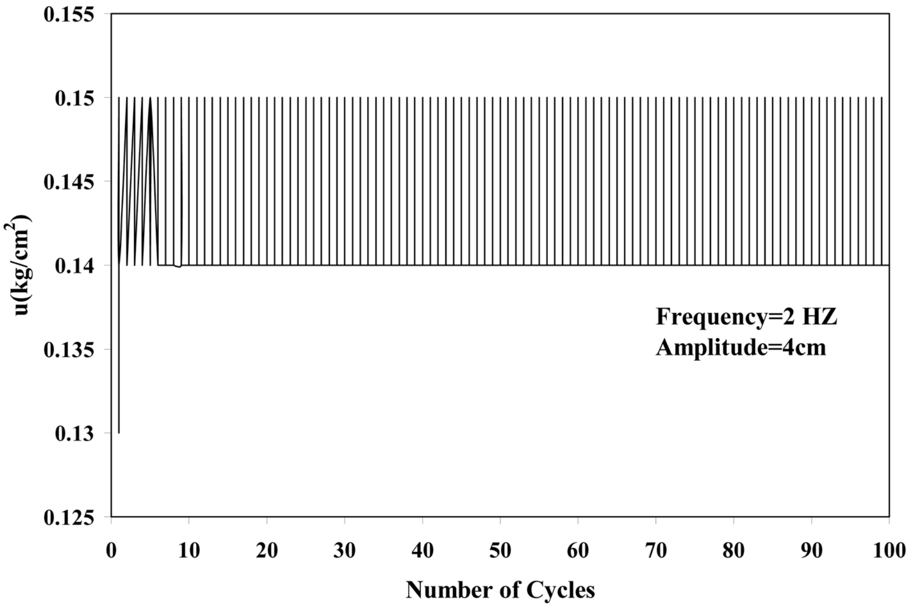

Fig. 24 Variation of u with number of cycles

References

Huang, A.B. and Hsu, H.H. (2005), "Cone penetration tests under simulated field conditions", *Geotechnique*, **55**(5), 345-354.

Ghionna, V.N. and Jamiolkowsi, M. (1992), "A critical appraisal of calibration chamber testing of sands. Proceedings of the international symposium on calibration chamber testing", Potsdam, New York, 1991, 13-40, Balkema Pub., Rotterdom.

Konrad, J.M. (1998), "Sand state from cone penetrometer tests: a framework considering grain crushing stress", *Geotechnique*, **48**(7), 201-215.

Kurup, P.U., Voyiadjis, G.Z. and Tumay, M.T. (1994), "Calibration chamber studies of piezocone test in cohesive soils", *J. Geotech. Eng.*, **120**(1), 81-107.

Mitchell, J.K., Bonita, J.A. and Brandon, T.L. (1999), Development of a piezovibrocone penetrometer for in-situ evaluation of soil liquefaction potential, summary report presented to the United States Geologic Survey, July, pp.7.

Moore, D.M. (1987), "Evaluation of the cone penetrometer and its effect on cone bearing and pore pressure", BS thesis, Civil Engineering, University of British Columbia, Vancouver, pp. 73.

Robertson, P.K. and Campanella, R.E. (1983), "Interpretation of cone penetration tests. Part I: Sand", *CGJ*, **20**(4), Nov, 718-733.

Salgado, R., Mitchell, J.K. and Jamiolkowski, M. (1997), "Cavity expansion and penetration resistance in sand", *J. Geotech. Geoenviron. Eng.*, **123**(4), 344-354.

Salgado, R., Mitchell, J.K. and Jamiolkowski, M. (1998), "Calibration chamber size effects on penetration resistance in sand", *J. Geotech. Geoenviron. Eng.*, **124**(9), 878-888.

Sasaki, Y. and Koga, Y. (1982), "Vibratory cone penetrometer to assess liquefaction potential of the ground", *Proceedings, 14th U.S-Japan Panel on Wind and Seismic Effect*, Washington D.C., NBS Special Pub. 651, pp. 541-555.

Schneider, J.A., Mayne, P.W., Hendren, T.L. and Wise, C.M. (1999), "Initial development of an impulse piezovibrocone for liquefaction evaluation", Physics and Mechanics of Soil Liquefaction, Balkema, Rotterdam, pp. 341-354.

Teparaksa, W. (1987), "Use and applications of penetration tests to assess liquefaction potential of soils", PhD dissertation, Department of Civil Engineering, Kyto University, Japan, December.

Wesley, L.D. (2002), "Interpretation of calibration chamber tests involving cone penetrometers in sands", *Geotechnique*, **52**(4), 289-293.

Wise, C.M., Mayne, P.W. and Schneider, J.A. (1999), "Prototype piezovibrocone for evaluating soil liquefaction susceptibility", *2nd international conference on Earthquake Geotechnical Engineering*, Lisbon, Portugal, pp. 6.

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