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LIQUEFACTION RESISTANCE OF SILTYSAND BASED ON LABORATORY UNDISTURBED SAMPLE AND CPT RESULTS

Mehdi ESNA-ASHARI[1], Mohammad Hassan BAZIAR[2]

SUMMARY

Liquefaction resistance of loose silty sand utilizing laboratory techniques are investigated. Many researchers have investigated relationship between cone penetration tip resistance and susceptibility of soils to liquefaction. They have often focused on uniform clean sands using field data. However, little study has been done using laboratory tests such as calibration chamber and cyclic triaxial tests particularly in loose silty sands.

In this study, correlation between cone penetration resistance and cyclic strength of undisturbed silty sand samples are examined using CPT calibration chamber and cyclic triaxial tests. The cone penetration tests were performed on silty sand samples with fines contents ranging from 0% to 30% and overburden stresses in the range of 100-300 kPa . Then the soil sample in calibration chamber, in the same way that soil samples were prepared during CPT sounding, was frozen and undisturbed soil specimen retrieved from frozen soil sample were tested using cyclic triaxial tests

Using data obtained in this research, relationship between cone tip resistance and cyclic resistance ratio (CRR) for loose silty sand soils will be presented. These correlations are in relatively good agreement with field case history data. Also increasing confining pressure in silty sand material increases the cone tip resistance and cyclic resistance ratio increases by increasing silt content.

INTRODUCTION

Liquefaction can be a major cause of failures of dams, earth structures, slopes, and foundations. Liquefaction is defined as the transformation of a granular material from a solid to a liquefied states as a consequence of increased in pore-water pressure and reduced effective stress Marcuson [1]. Various empirical procedures have been proposed to evaluate liquefaction resistance of sand deposits Robertson [2,3], Youd [4]. To do so , estimation of two variables is required: equivalent cyclic stress ratio acted on a soil layer, expressed in terms of CSR, and cyclic stress ratio that causes cyclic liquefaction, termed cyclic resistance ratio, CRR. The equation formulated by seed and Idriss (1971) is usually used to calculate of the cyclic stress

[1] Ph..D. Candidate, Iran University of Science and Technology
[2] Associate Professor, Iran University of Science and Technology

ratio Seed [5]. Currently, the most popular simple method to estimate CRR, is the use of cone penetration (CPT) and the standard penetration tests(SPT). However, due to the facts that CPT provides a continuous record with depth and also it has greater repeatability, CPT has become more popular. However, a plausible method for evaluating CRR is to test undisturbed soil specimen in the laboratory. Unfortunately , drilling and sampling techniques are too disturbed to yield meaningful results. Only through specialized sampling techniques, such as ground freezing,undisturbed specimen can sufficiently be obtained Youd [4]. Although, in situ frozen samples are valuable for assessing the liquefaction potential of a sand deposit , this method is fairly expensive and difficult to apply. Recently, the CPT calibration chamber testing has attracted the attention for its advantages such as repeatability of the specimen results, uniformity of the specimen and controlled and known boundary condition. Furthermore, obtaining undisturbed sample from calibration chamber is much more feasible than from the field. Therefore, to simulate the field conditions calibration chamber can be useful. The object of this paper is to present a set of data showing the relationship between liquefaction resistance and CPT tip resistance for loose silty sands based on laboratory tests including cyclic triaxial tests and cone penetration tests in calibration chamber.

EXPERIMENTAL PROGRAM AND EQIPMENTS

Testing program

The testing program is included 12 cone penetration tests in the calibration chamber and 12 cyclic triaxial test on undisturbed silty sand samples. To accomplish the objectives of this study, soils with fine contents ranging from 0 to 30% and overburden stresses ranging from 100 to 300 kPa were frozen in the calibration chamber and cyclic triaxial tests were conducted on specimens retrieved from frozen soils.

Calibration chamber

Since its early development in late 1960s, the calibration chamber has been an important research tool in establishing interpretation procedures for cone penetration tests in sand. Some of the most significant advantages of CPT calibration chamber testing includes: (1) repeatability of the specimen and test results, (2) uniformity of the specimen, and (3) controlled and known boundary conditions, as well as stress history.

The calibration chamber system used in this study has been described by Baziar and Ziaie[6]. This chamber consists of a rigid thin walled steel cylinder of 0.76 m internal diameter and 1.5m height, with removable top and bottom plates. A rubber membrane cap, forming a flexible diaphragm is used to apply load to the top of the sample, simulating a big odeometer device and producing samples with different stress histories. The chamber is capable of housing a 0.76 diameter by 1.0 m height soil sample. The main part of the chamber is a 1.0 cm thin cylindrical shell bolted to circular top and bottom plates of 2 cm thin.

Soil Freezing and Coring Apparatus

There is not a best or unique system for conducting in situ freezing and drilling and sampling operations, and design of a suitable freeze plant system depends on various parameters such as site condition. In this research, to freeze soil sample in the calibration chamber a conventional freezing system was used . This apparatus consists of a motor, compressor ,condenser and evaporator. Using this system, the sample gets slowly frozen from bottom to top .Also ,coring of the frozen soil was under taken utilizing a modified core barrel sampler.

Piezocone

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 situated immediately behind the cone tip. Also, the filter element for reading pore water pressure is located immediately behind the cone tip. The standard piezocone is inserted into the chamber by a hydraulic system at a constant rate of 20 mm/sec.

Triaxial test

To perform the stress – controlled cyclic triaxial tests, the automated triaxial testing system, located at the International Institute of Earthquake Engineering & Seismology (IIEES of IRAN) was used.

Soil Sample

To accomplish the objectives of this study, the specimens with varing fines content were prepared by mixing appropriate amounts of Tello sand with pure silt that was obtained from grinding this soil. This alluvial soil is a fine clean sand without any clay or silt particle. The typical gradation curves of these material are shown in Figure 1.

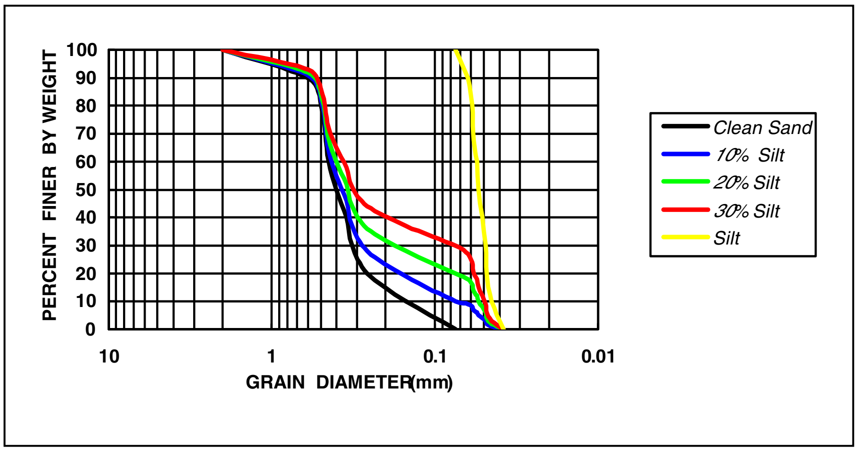


Figure 1 : Grain distribution curve of materials

TESTING PROSIDURE

Calibration chamber tests

At first , the testing cylinder is filled with dry soil . However, a soil filter, grading from coarse sand to fine gravel ,is formed at the bottom of the chamber .Using dry depositional method the soil specimen is set up. The same soil filter as used in the bottom, is also formed at the top of the tested soil . To saturate the sample, the top plate is fixed on the chamber and vacuum is applied inside the chamber through the top connection for 30 minutes. Then the bottom water supply is opened and a uniform slow upward flow is followed. The second phase of testing is the consolidate of the sample. To consolidate the specimen a rubber membrane cap, forming a flexible diaphragm is used simulating a big odiometer device to apply load to the top of the sample.The final phase is to conduct cone penetration test at the center of the specimen. The cone is pushed into the specimen at a rate of 2 cm/s. A total of 12 cone penetration tests were performed in 12 calibration chamber specimens. The samples were prepared with four different silt contents including 0, 10, 20 and 30% and were consolidated to several different effective confining stresses including, 100, 200, 300 kpa prior to testing.

Soil freezing in the calibration chamber

It has been shown that the in situ liquefaction resistance of saturated sandy soils can be evaluated by running undrained cyclic tests on high-quality undisturbed samples obtained by in situ ground freezing Yoshimi [7]. In the last 15 years, Japanese and north American researches have demonstrated the technique of carrying out in situ ground freezing to be a superior method for obtaining undisturbed samples of sand Hofmann [8]. It has been also shown, undisturbed samples of saturated sandy soils can be obtained by freezing if an adequate confining pressure is maintained. Efforts in recent years have been directed towards the development of field and laboratory equipment whereby specimens could be frozen in this way.

In this research at first soil specimen is prepared in the calibration chamber as done for cone penetration test. After saturating and consolidating the specimen, the freezing system is turned on and the consolidated soil sample is frozen from bottom to top with maintained overburden pressure. The rate of freezing is sufficiently slow compared with the conductivity of the sample to allow for pore water explosion in advance of the freezing front. Coring from frozen sample with tow inches in diameter was undertaken utilizing a modified core barell sampler. Then the cylindrical frozen sample was trimmed and prepared for cyclic triaxial test. To evaluate sample disturbance, the void ratio of samples before and after freezing were measured. Results of this investigation indicated the frozen samples were of high quality.

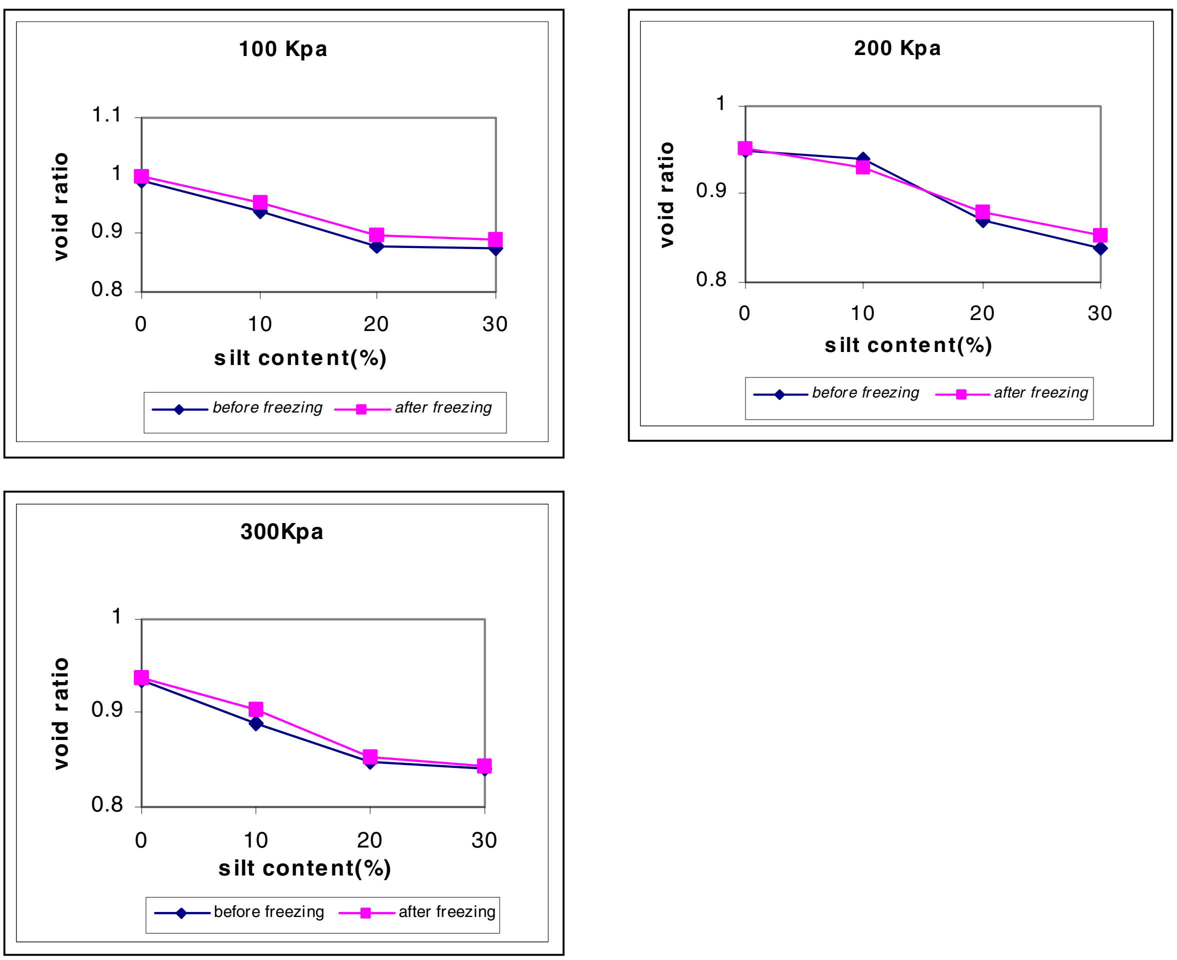


Figure 2: Comparison of void ratio measured from frozen soil samples before and after freezing

Cyclic triaxial tests

Undrained cyclic triaxial tests were conducted on specimens with effective confining pressures of 100, 200, 300 kPa using triaxial test apparatus for which the cyclic loads were applied pneumatically. All of the undrained cyclic tests were performed by applying sinusoidal loading of constant axial amplitude at a frequency of 0.1 Hz. At first, cylindrical frozen specimen was weighted and its diameter and length were measured exactly. Then the specimen was covered with a rubber membrane and set on the pedstal of the triaxial cell and also sealed with O-rings, the cell was filled with water to a level somewhat higher than the top of the specimen cap. Then the specimen was allowed to thaw at room temperature under an isotropic stress of 30 kPa. After the specimen thawed completely after about 12 hours, it was saturated with the help of carbon dioxide and de – aired water. All samples exhibited the B parameter of 0.96 or greater. Then the triaxial tests specimen were isotropicaly consolidated to the desired effective confining pressure prior to cyclic loading

RESULTS AND ANALYSES

Calibration chamber tests

As stated before, a total of 12 cone penetration tests were preformed and cone penetration resistance, sleeve frictions and excess pore water pressures, through the height of specimens at every 1 cm intervals, were recorded by a data acquisition system. Fig 2 shows typical tip – resistance profiles for specimens tested at 100, 200, 300 kPa of vertical overburden stresses and 10% silt contents.

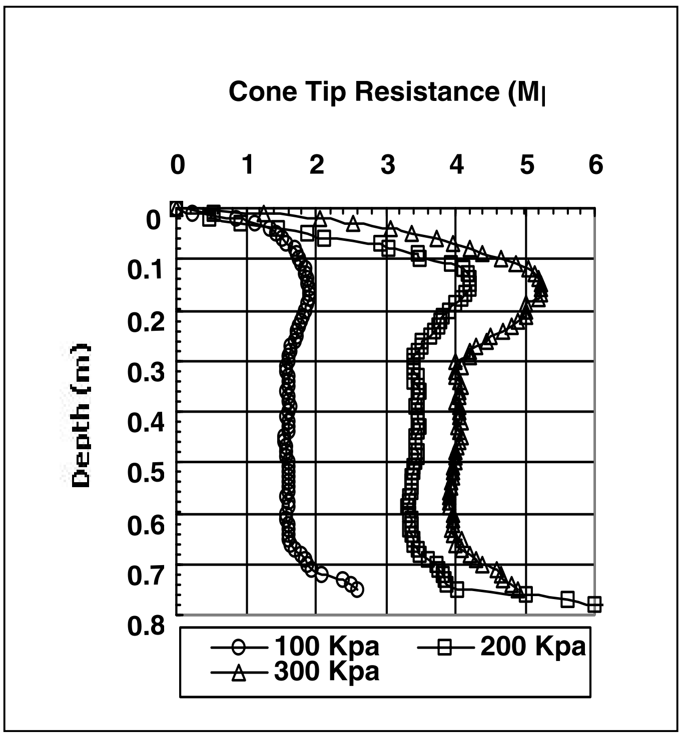


Figure 2 : Typical result of piezocone tests in silty sand (clean sand)

It should be noted that for all samples, there is a 20 cm top filter and 80 cm bottom filter and the total length of soil sample is about 50 cm. It can be seen that, tip – resistance values in the first 20 cm of the penetration, increase sharply and then reduce and remain constant along the soil sample and then start to increase by reaching the bottom filter. This pattern is shown in both clean sand and silty sand samples. Table 1 presents the summary and results of the calibration chamber tests [12].

TABLE 1

RESULTS OF CPT SOUNDING

Series (1)	Fines content (%) (2)	Type of material (3)	Consolidation stress kpa (4)	Cone tip resistance qc (Mpa) (5)
1	0	Clean Sand	100 200 300	1.6 3.5 4
2	10	Siltysand	100 200 300	1.4 3 3.4
3	20		100 200 300	1.2 2.8 3.2
4	30		100 200 300	1 2.6 3.6

Cyclic triaxial tests

In this study cyclic triaxial testing has been conducted on loose saturates specimens of Tello sand with several different silt contents. In order to investigate the correlation between results of cone penetration tests and cyclic resistance ratio (CRR), cyclic triaxial tests were conducted on undisturbed samples .To obtain undisturbed sample, at first the calibration chamber is filled with the same soil and identical condition as the CPT was prepared. Then this sample was frozen and undisturbed soil specimen was retrieved from the calibration chamber . Similar to chamber calibration tests, twelve cyclic triaxial tests were performed on four sets of samples with 0, 10,20 and % 30 silt content . For each silt content , three specimens were tested with confining pressures equal to 100, 200, 300 kPa .The results of these tests are summarized in Table 2 and a typical test result is shown in Fig 3.

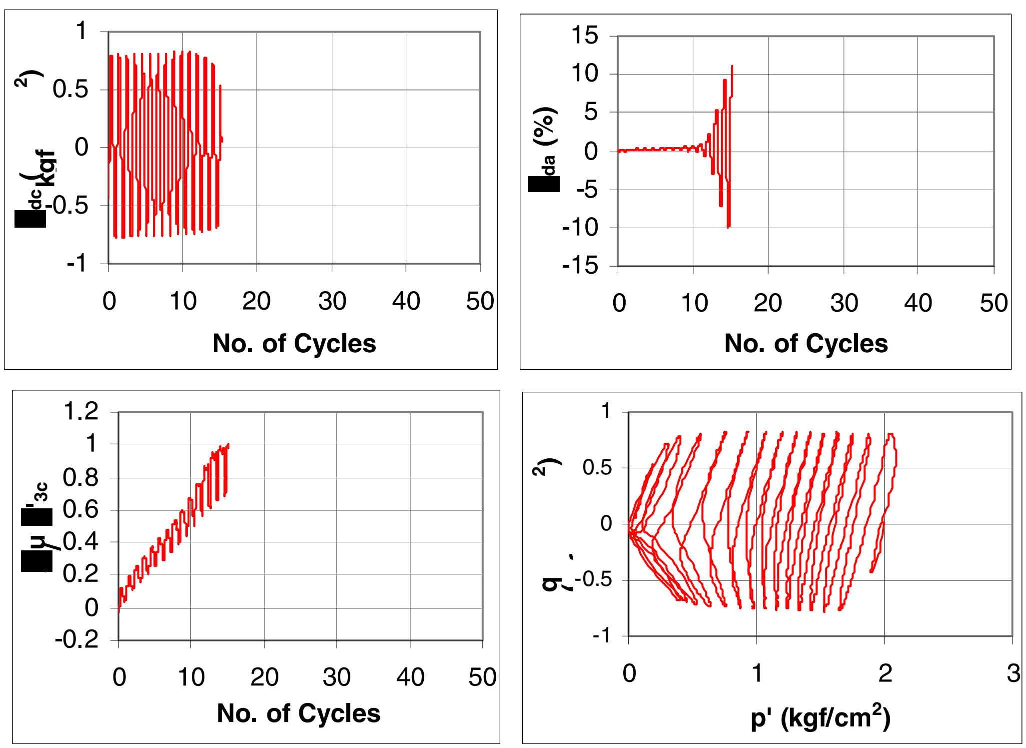
TABLE 2

SAMPLE SUMMARY FOR CYCLIC TRIAXIAL TESTS

Sample No.	**Confining pressure (kpa)**	**Fine contents (%)**	**CRR_{tx}**	**$(CRR_{7.5})_{tx}$**	**$(CRR_{7.5})_{ss}$**
1 2 3	100 200 300	0	0.195 0.221 0.205	0135 0.14 0.17	0.094 0.097 0.12
4 5 6	100 200 300	10	0.214 0.201 0.210	0.105 0.22 0.22	0.073 0.153 0.153
7 8 9	100 200 300	20	0.205 0.217 0.216	0.15 0.206 0.183	0.104 0.143 0.127
10 11 12	100 200 300	30	0.214 0.185 0.161	0.17 0.201 0.214	0.118 0.14 0.149

When subjected to cyclic loading, the saturated specimens developed excess pore water pressure, which resulted in a decrease in effective confining pressure. All samples reached approximately zero effective confining pressure and failure was sudden and can be classified as cyclic liquefaction. The fourth column of Table 2 represents the cyclic resistance ratio which is obtained using cyclic triaxial test . In this test ,

(CRR) $_{tx}$ is defined as the cyclic shear stress σ'_d divided by two times the effective confining pressure σ'_3 , i. e. , $(CRR)_{tx} = \sigma'_d / 2\sigma'_3$. The cyclic resistance ratio is typically taken at about 15 cycles of uniform loading to represent an equivalent earthquake loading of magnitude (M) 7.5 , i. e., $CRR_{7.5}$ .Based on the work of seed et al. (1985), laboratory tests can be normalized to an earthquake magnitude of 7.5 by multiplying the CRR by a magnitude scaling factor (MSF) which is dependent upon the measured number of cycles to failure ,N. In this research to calculate $(CRR)_{7.5}$ the recommendations of the 1996 NCEER regarding the scaling factor have been used . Also , to estimate the cyclic resistance ratio based on simple shear test, i. e., $(CRR_{7.5})_{ss}$, the correction factors that developed by Ishihara [9] were used . Based on results the of cyclic triaxial test shown in Fig 4, it can be concluded that in general, increase in silt content causes the liquefaction resistance of silty sands to increase. Relationship between stress ratios causing liquefaction and cone resistance , obtained in this research, is shown in Fig 5 . It should be noted that in this Figure, CPT tip resistance Values q_c , is corrected with a vertical overburden stress of approximately 100 kPa. The corrected CPT tip resistance q_{c1} , is obtained using the following relation : $q_{c1} = c_q \cdot q_c$
Where c_q= correction factor of effective overburden stress **.**



Figure(3) : Typical cyclic triaxial test results

To estimate the correction factor of effective overburden stress, Kayan et al (1992) proposed the following equation. This equation originally was developed by Seed et al (1983) and later was confirmed by Mitchell and Tseng [10].

$$c_q = \frac{1.8}{0.8 + (\sigma'_{v0} / \sigma'_{ref})} \tag{1}$$

where σ'_{ref} = a reference stress equal to one atmosphere (approximately 100 kPa)

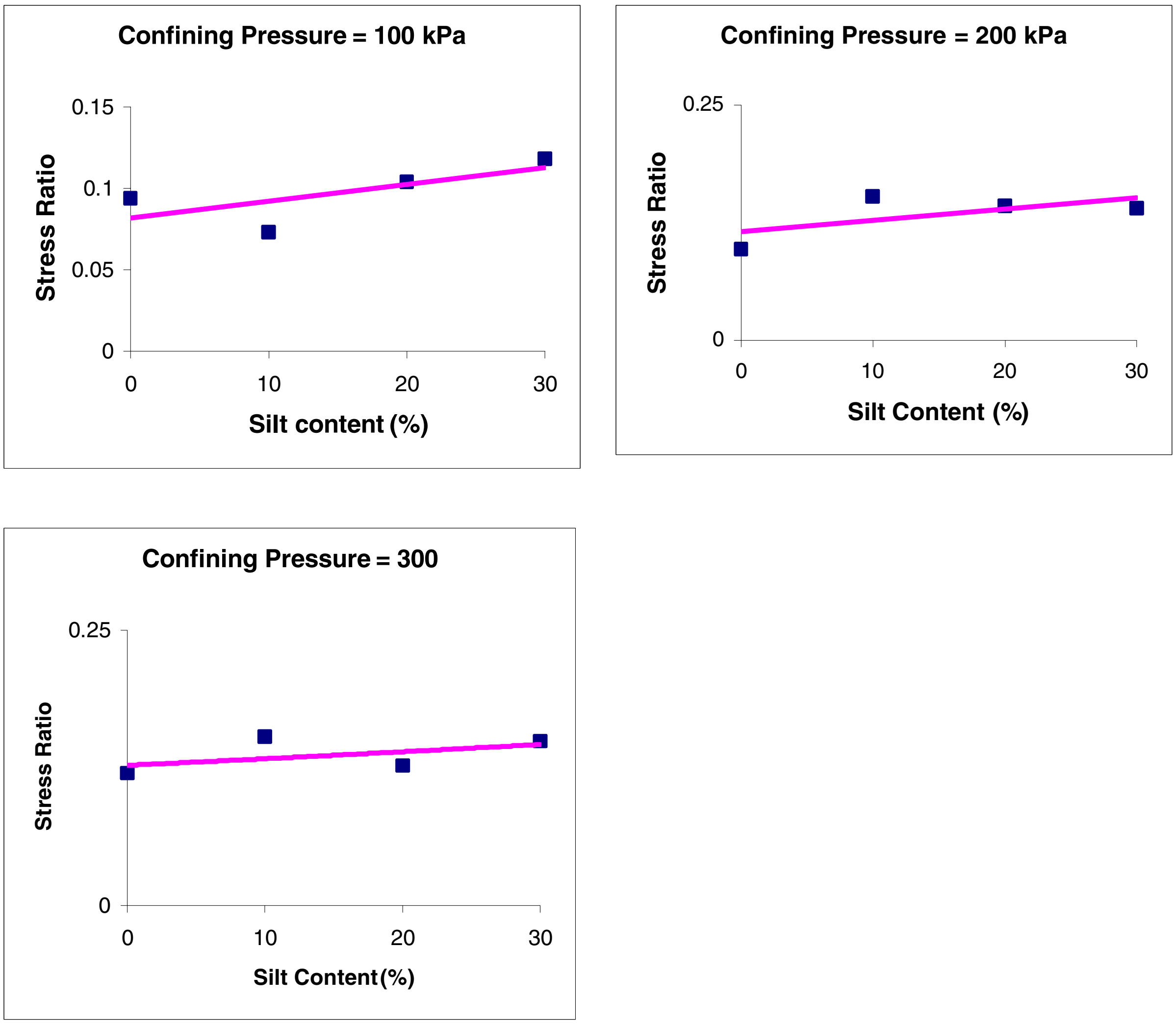
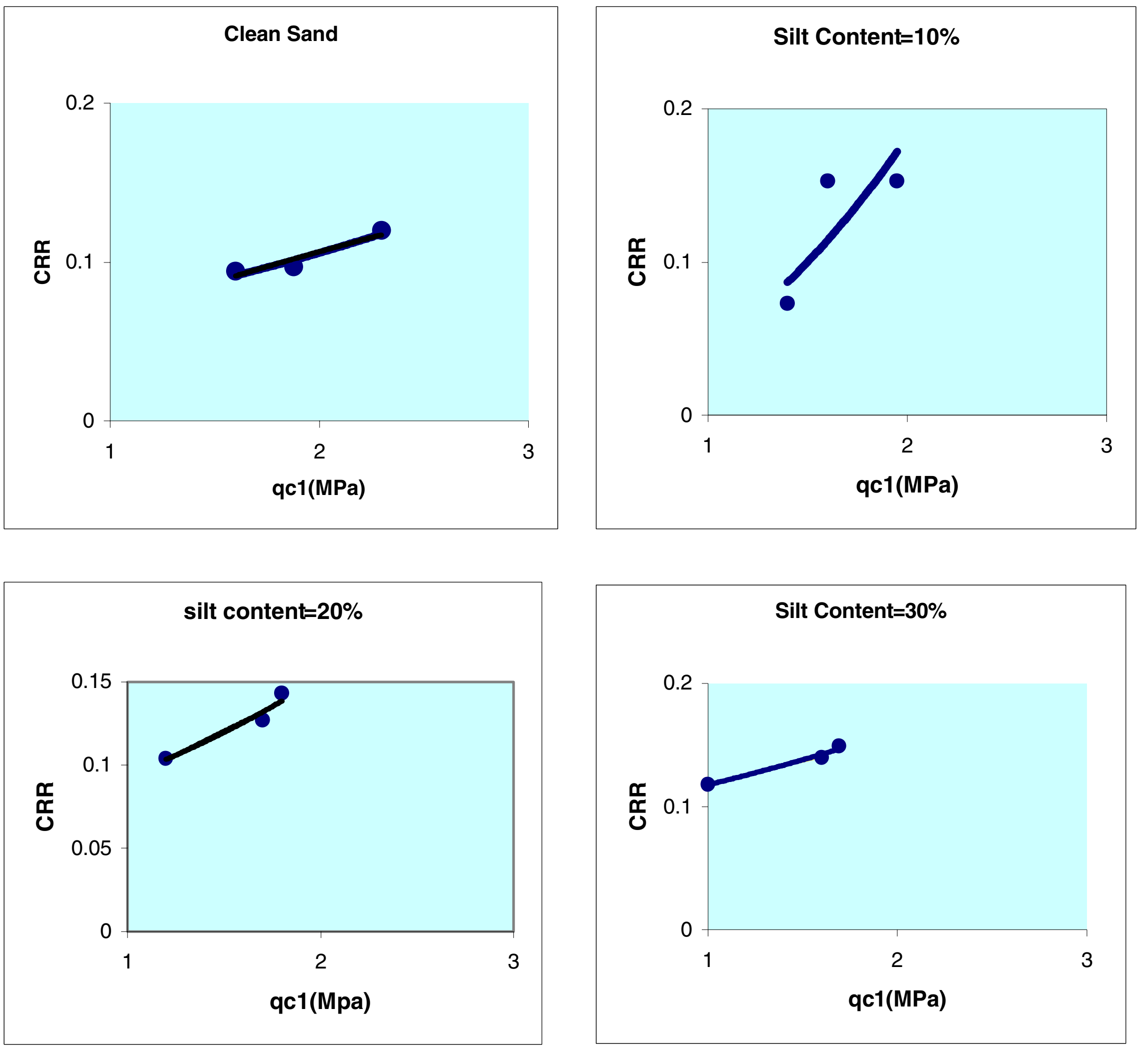


Figure (4) : stress ratio as function of silt content for various confining pressures

CONCLUSIONS

An experimental study on loose silty sand with different fines content was conducted .Cone penetration test in a calibration chamber and undrained cyclic triaxial tests on undisturbed specimens with fines content of 0, 10,20 30% under confining pressures of 100, 200, 300 kPa were performed . Relationship between corrected cone tip resistance , q_{c1} and cyclic resistance ratio , CRR, using four boundary curves were presented . Each of these boundary curves represents a bound of the liquefied data in silty sand with low q_c . Although these boundary curves are in a relatively good agreement with some charts that proposed by others, to verify this correlation , field – case – history data is required . As can be seen , the curves corresponding to the silty sands are at the left and top of the curve of clean sand which is in a good agreement with the field – case – history data .



(5) : Relationship between cyclic resistance ratio and q_{c1}- values for various silt contents and M=7.5 Earthquakes

Based on the results of cone penetration tests in the calibration chamber in this study the following conclusions can be drawn :

The cone tip resistance increases with increasing overburden stresses.

In general , the cone tip resistance decreases with increasing the fines content . This is due to the facts that increases of silt percent , decreases the contact between sand particles and q_c decreases .

Also, as a results of cyclic triaxial tests , the liquefaction resistance of silty sands generally is increased with increasing silt content . As explained above, when the silt content increases , sand particles are increasingly surrounded by silt and the sand – grain to sand – grain contact decreases . Thus, the specimen behavior becomes similar to silty soils. This result is , in general , in agreement with results obtained in previous studies Amini [12] .

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