

## **EFFECT OF SILT CONTENT ON THE UNDRAINED ANISOTROPIC BEHAVIOUR OF SAND IN CYCLIC LOADING**

**Hadi BAHADORI<sup>1</sup>, Abbas GHALANDARZADEH<sup>2</sup>, Alireza AHMADI<sup>3</sup>, Mohamad ABADI<sup>4</sup>**

### **ABSTRACT**

The anisotropic behaviour of sand and the effect of adding different amounts of non plastic fines are studied in this paper. Stress anisotropy in clean sands has a considerable effect on the monotonic and cyclic behaviour of this kind of soils. The effect can be understood by comparing the behaviour in the compression and extensional modes in cyclic loading and two different approaches can be used to study.

In the first case, tests can be performed in different amounts of initial anisotropy ratio both in extension and compression but in the same amounts of cyclic stress ratio and initial consolidation stress. In this case the anisotropy effect can be evaluated either by the number of cycles causing liquefaction or the dissipated energy. On the other hand in an isotropic consolidated sample by consequently cyclic loading the anisotropy effect can be assessed by comparing the strains occurred in compression and extension sides.

17 stress control cyclic triaxial undrained tests have been conducted on Firoozkuh sand and silt mixtures. The effect of anisotropy has been investigated by considering the differences in the extensional and compression modes in a loading cycle.

Number of cycles causing liquefaction versus cyclic stress ratio in all of the tests is depicted. The results show that adding different amounts of silt changes the effect of anisotropy in sand and the amount of change is related to the non plastic fine content.

**Keywords:** Silt, Anisotropy, Firoozkuh sand, cyclic triaxial test, liquefaction

### **INTRODUCTION**

Saturated, loose granular deposits, when subjected to rapid shear loading, experience a rapid pore pressure increase and temporary loss of strength, which may lead to liquefaction, a stage, when soil loses almost all the strength and behaves like a liquid. Such a stage leads to lateral spreading of gently sloping ground, densification and vertical ground settlements, and slope instability.

The effect of fines on the cyclic liquefaction potential of sands has been studied extensively in geotechnical literature. Still, despite the amount of related research, results seem somewhat contradictory. Namely, mostly empirical correlations from in situ tests show that the presence of fines increases liquefaction resistance [5], while the majority of laboratory tests shows the opposite trend, at

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<sup>1</sup> Ph.D. Candidate, Department of Civil Engineering, University of Tehran, Iran, Email: [Bahadori@ut.ac.ir](mailto:Bahadori@ut.ac.ir)

<sup>2</sup> Assistant Professor, Department of Civil Engineering, University of Tehran, Iran Email: [Aghaland@ut.ac.ir](mailto:Aghaland@ut.ac.ir)

<sup>3</sup> Graduate student, Department of Civil Engineering, University of Tehran, Iran

<sup>4</sup> Graduate student, Department of Civil Engineering, University of Tehran, Iran

least for fines content less than about 30% of total weight [2,8]. The effect of plasticity of the included fines has also stirred contradiction. For example, Koester [2] claims that the plasticity index IP of fines is less important than the fines content itself, contrary to Refs.[1, 4] who claim that fines with high plasticity may fundamentally change the mechanism of excess pore pressure buildup.

Available interpretations for the effect of fines content on liquefaction resistance are based on mechanisms of deformation in the particle size level. Factors such as soil fabric and aging have been considered responsible for the increase of resistance of undisturbed specimens compared to reconstitute ones [11], and are used to explain why empirical correlations from in situ tests consider the presence of fines as beneficial for liquefaction resistance.

When the effect of aging is being removed, by using reconstituted specimens, micromechanical interpretations of laboratory test results suggest that fines in small percentages of, 30%  $P$  merely take up the space between sand particles without contributing to soil strength. This leads to a decrease of void ratio  $e$  without any particular change in soil behavior. In this manner, the decrease in liquefaction resistance with fines content  $f(\%)$  is considered an artifact of considering soils with the same  $e$  value, and not the same intergranular void ratio of the sand skeleton  $e_{sk}$ , a more representative index of behavior[ 3,6,7,9].

These micromechanical explanations provide insight to the phenomenon, but fail to draw the full picture. For example, laboratory results for tests on reconstituted specimens performed at relatively small mean effective stresses, similar to those expected in potentially liquefiable layers at generally shallow depth, show increase of liquefaction resistance with  $f(\%)$ , which cannot be attributed to aging [10]. This is an indication that the phenomenon is very complicated to be treated merely on the micromechanical level and that it should also be interpreted on the basis of an integrated framework of mechanical behavior.

Cyclic triaxial tests were conducted with different amount of stress reversal both in extension and compression modes in different amounts of silt content. Although in triaxial test it is not possible to control the direction of principal stresses between 0 and 90 degrees, the effect of anisotropy was investigated by means of stress reversal. As an important conclusion the effect of stress reversal from compression to extension mode on the liquefaction potential is introduced in several silt mixtures.

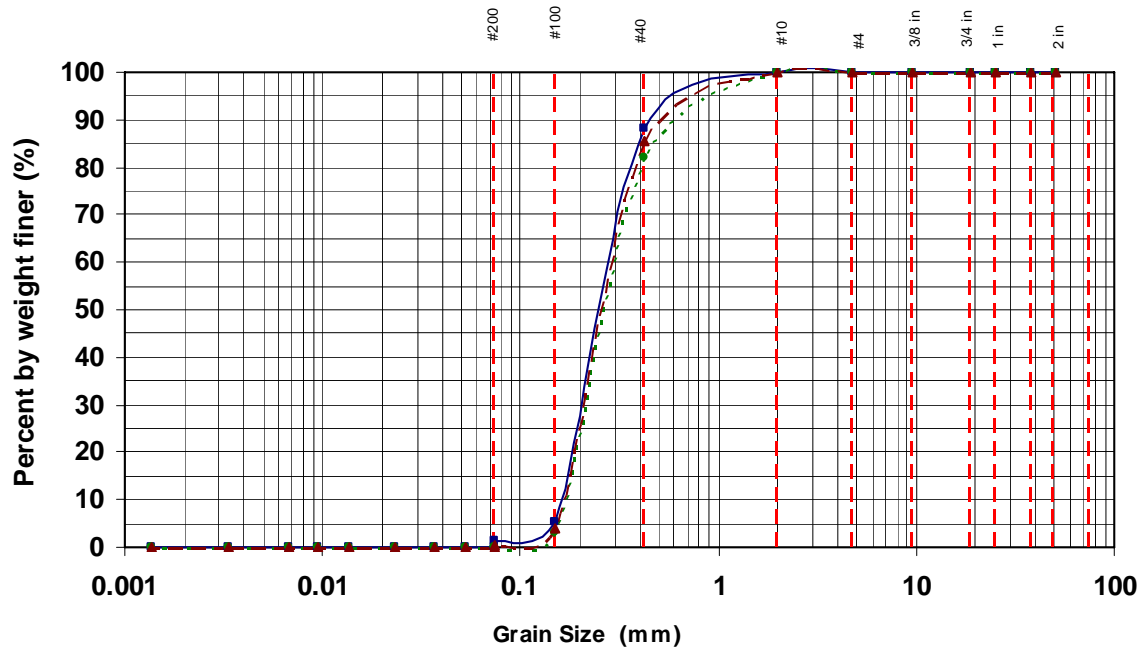
### Material properties, Test procedure and apparatus

**Material properties.** Firoozkuh sand and silt were used in the current study. Some of the physical properties of the sand are shown in Table 1 and the sand particle size distribution curve is depicted in Fig 1. As it is shown, the sand can be considered as fine sand. The silty soil contains less than fifteen percent of particles greater than No. 200 sieve. The plasticity index of silt is less than 5 percent and can be addressed as non-PI soil.

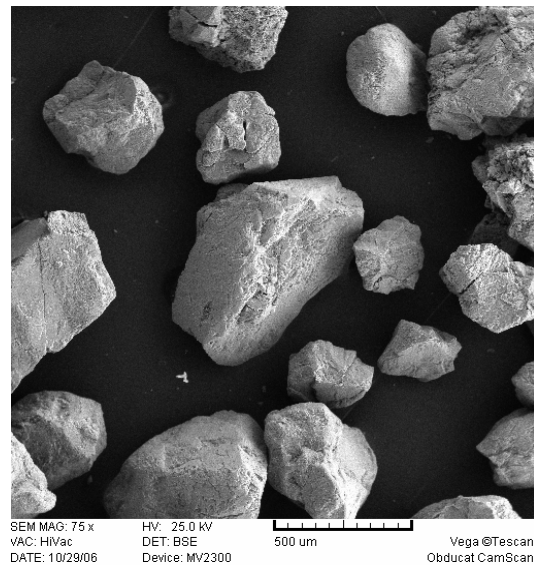
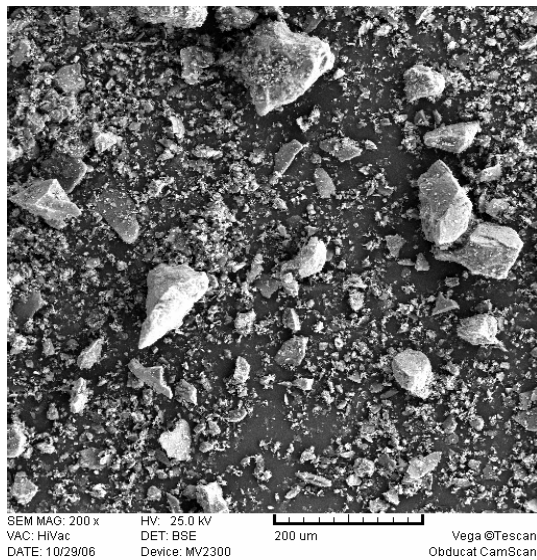
The microscopic SEM tests were taken from both silt and sand. The pictures can be seen in fig2. As it is clear by considering the pictures the sand particles are angular. The silt microscopic photo also shows the angular fabric of the soil like sand.

**Table 1. Physical properties of FiroozKuh sand**

Sand	Gs	$e_{max}$	$e_{min}$	$D_{50} (mm)$	%FC	Cu	Cc
FiroozKuh	2.65	0.874	0.548	0.27	1	1.87	0.88



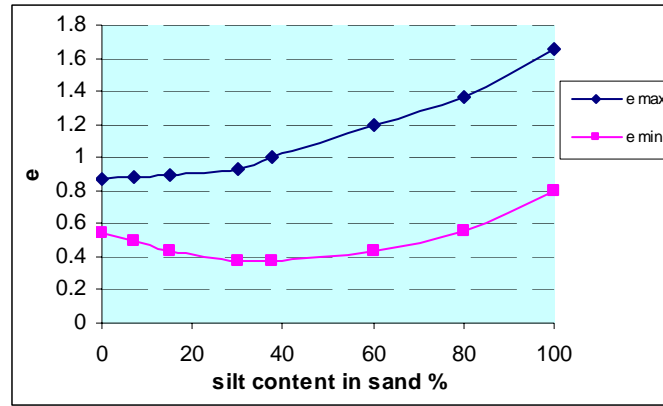
**Fig 1. FiroozKuh sand particle size distribution curve**



**Fig 2. FiroozKuh silt and sand microscopic photos**

**Soil mixture.** Various silt percentage were added to the sand skeleton to define the mixture mechanical properties. The main mixture ratio was 15 percent silt and 85 percent sand. Also some tests with higher silt content were conducted in 30 and 70 percentages.

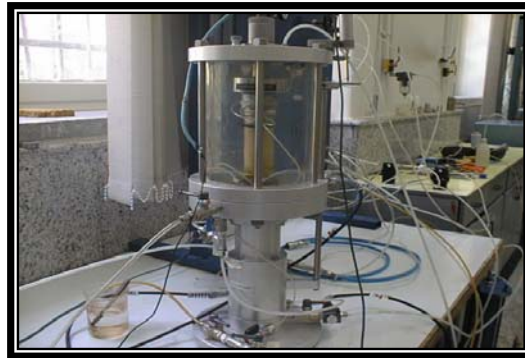
The mixture's void ratio decrease till about 35 percent of silt and then increase again in greater silt content. The minimum and maximum void ratio of sand-silt mixtures is depicted in Fig3.



**Fig 3. FiroozKuh silt and sand mixture's void ratio**

**Sample preparation and test procedure.** Sample preparation method used in this study was dry deposition method. After the sample was prepared the saturation stage continued till reaching a value of  $B=0.95$ . The consolidation can be performed either isotropic or anisotropic.  $K$  value can be smaller and larger than unity. Then finally a cyclic deviator stress was applied in both compression and extension side. The frequency was about 0.05 Hz.

**Apparatus.** A cyclic triaxial device was used. The apparatus was modified in such way that enables performing a fully computer controlled stress path. Cyclic tests were performed at Soil Dynamics Laboratory of University of Tehran. Fig 4 shows this device.



**Figure 4. A view of the apparatus used in this study**

A closed loop control could be applied to the machine to handle any type desired stress history including compression and extension cyclic loads.[12]

### Test results

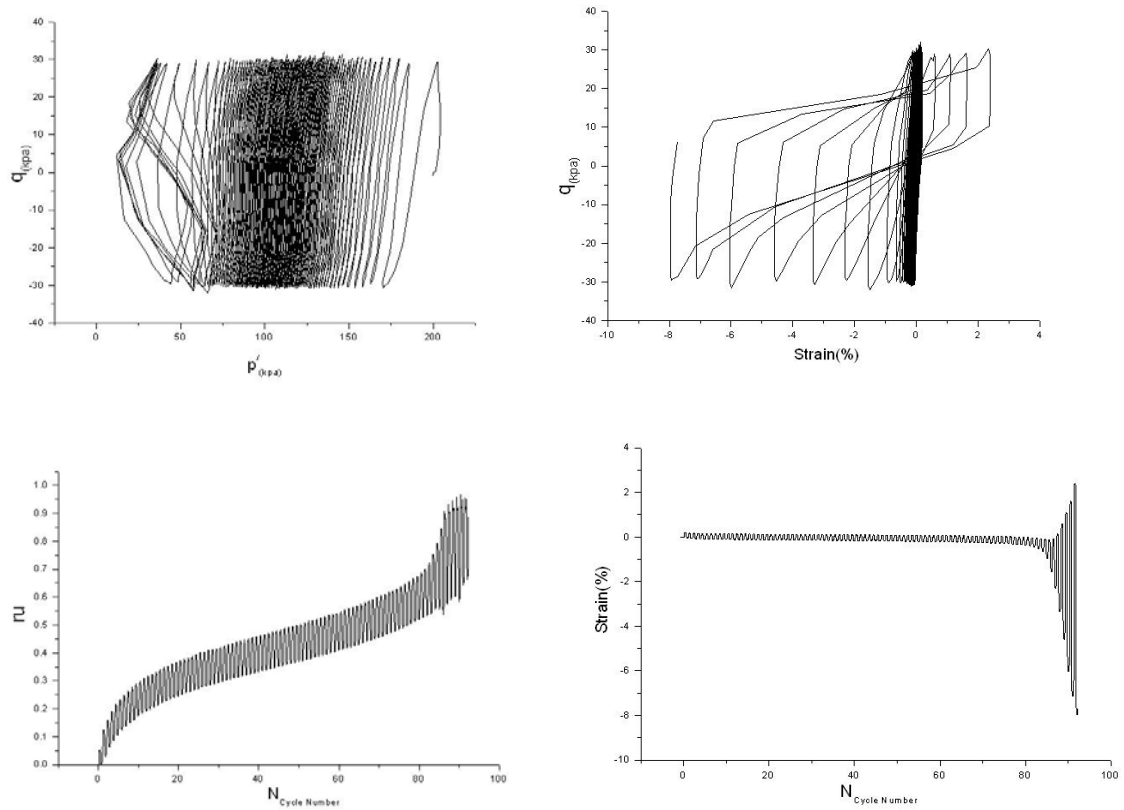
Table 2 summarizes the general characteristics of the tests. Cyclic stress was applied in both fully compression and also reversed to extension side. The main objective was to investigate the effect of extension and also direction of principal stresses on the cyclic liquefaction behavior of sands with adding silt. Figure 5 and 6 shows a typical result of cyclic triaxial tests in sand and silty sand samples. Regarding to Figure 5 although the amplitude of cyclic stress is the same both in compression and extension sides, soil exhibits softer behavior in extension side. Axial deformation in extension side is also considerably larger and this effect is related to anisotropy. On the other hand in silty sample (fig6) the anisotropy effect cannot be seen easily. Because of the huge tendency for dilation in silt the sample tends to exhibit compression strain rather than extension and the sample's height decreases

continuously. This pattern can be seen in higher silt contents as well. In fig 7 the results in 70 percent silt content is depicted. The strength of the sandy soil dramatically decreases when silt content is about 30 percent. In this critical ratio the soil does not show any resistance due to monotonic or cyclic loads and liquefaction occurs in the first or second cycles even in dense samples. But in greater silt percentage the strength increases and the silt behavior dominates. The complicated response of adding non-plastic fines in sands has confused many researchers in the past years but now there is a good understanding of the phenomenon.

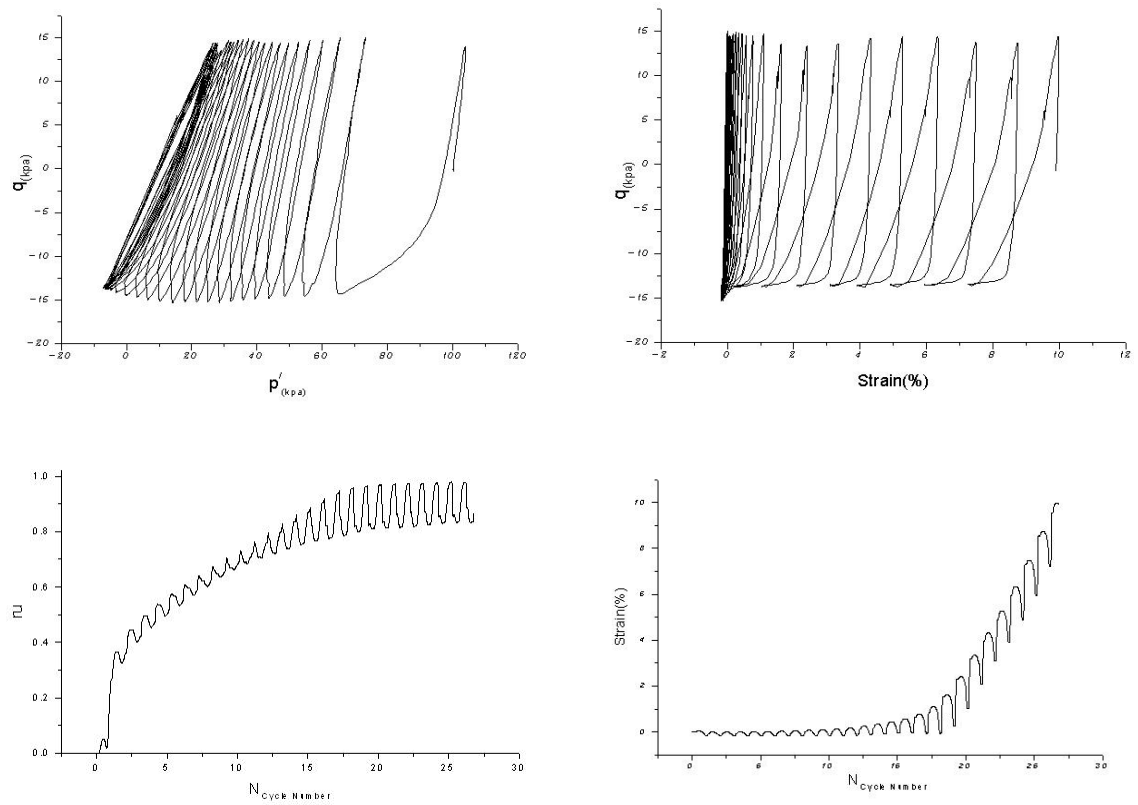
The liquefaction resistance curve that is often shown in CSR-N curve is depicted in the different silt contents in fig8. As it is obvious from the diagram adding 15 percent silt to the sand decreases the soil resistance due to liquefaction in the almost same relative densities. Even in much denser samples by 30 percent silt content the cyclic strength is much lower than clean sand samples. But the 70 percent silt content point takes place above the pure sand graph that means the strength of soil against liquefaction increases in that content comparing pure sand.

**Table2. General characteristics of the tests**

No	Silt Percent	P'0	K'	CSR	(N)	E	Dr
1	15	100	0.8	0.15	7	0.663	0.492
2	0	100	1	0.15	10	0.695	0.56
3	0	100	1	0.15	2	0.707	0.51
4	0	100	1	0.18	48	0.663	0.65
5	0	100	1	0.12	800	0.707	0.51
6	0	200	1	0.15	90	0.688	0.57
7	15	100	1	0.1	336	0.665	0.5
8	15	100	1	0.15	19	0.6	0.646
9	15	100	1	0.15	1	0.674	0.483
10	15	100	1	0.15	53	0.62	0.601
11	15	100	1	0.18	1	0.636	0.636
12	15	100	1	0.12	2	0.636	0.568
13	15	200	1	0.18	1	0.688	0.453
14	30	100	1	0.15	1	0.52	0.731
15	30	100	0.8	0.15	1	0.532	0.72
16	70	100	1	0.15	129	0.61	0.73
17	30	100	0.75	0.15	1	0.509	0.752



**Figure 5. A typical isotropic cyclic triaxial test (silt=0)**



**Figure 6. A typical isotropic cyclic triaxial test (silt=15)**

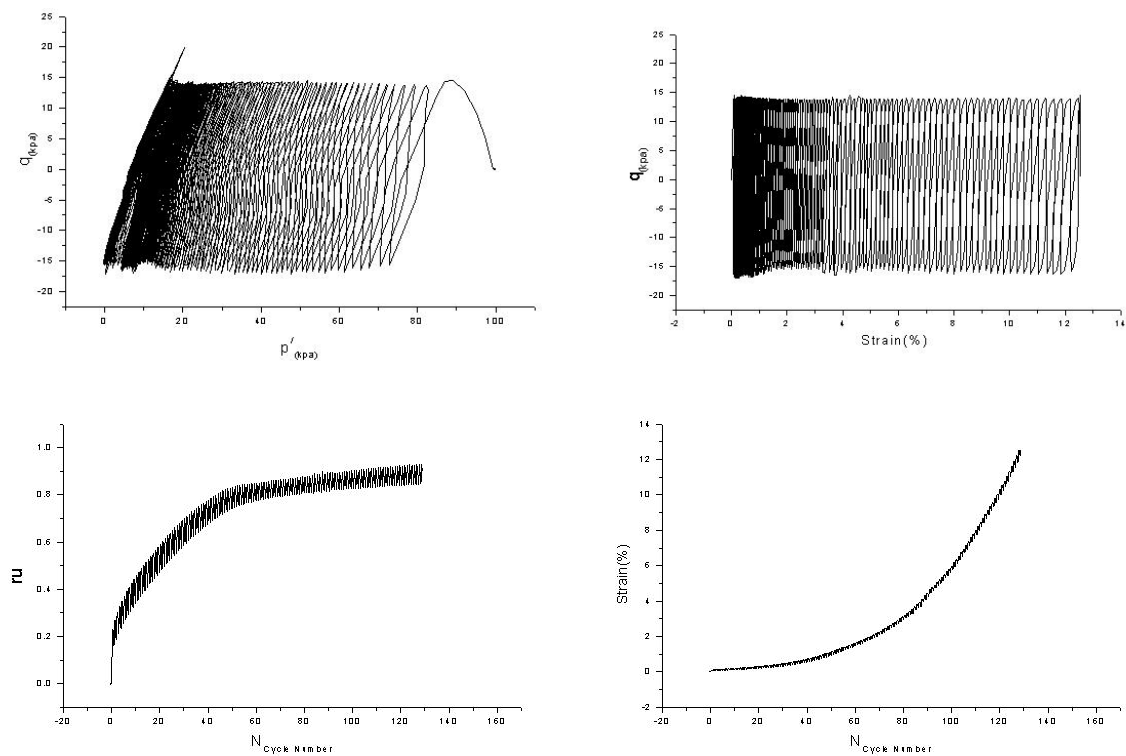


Figure 7. A typical isotropic cyclic triaxial test (silt=70)

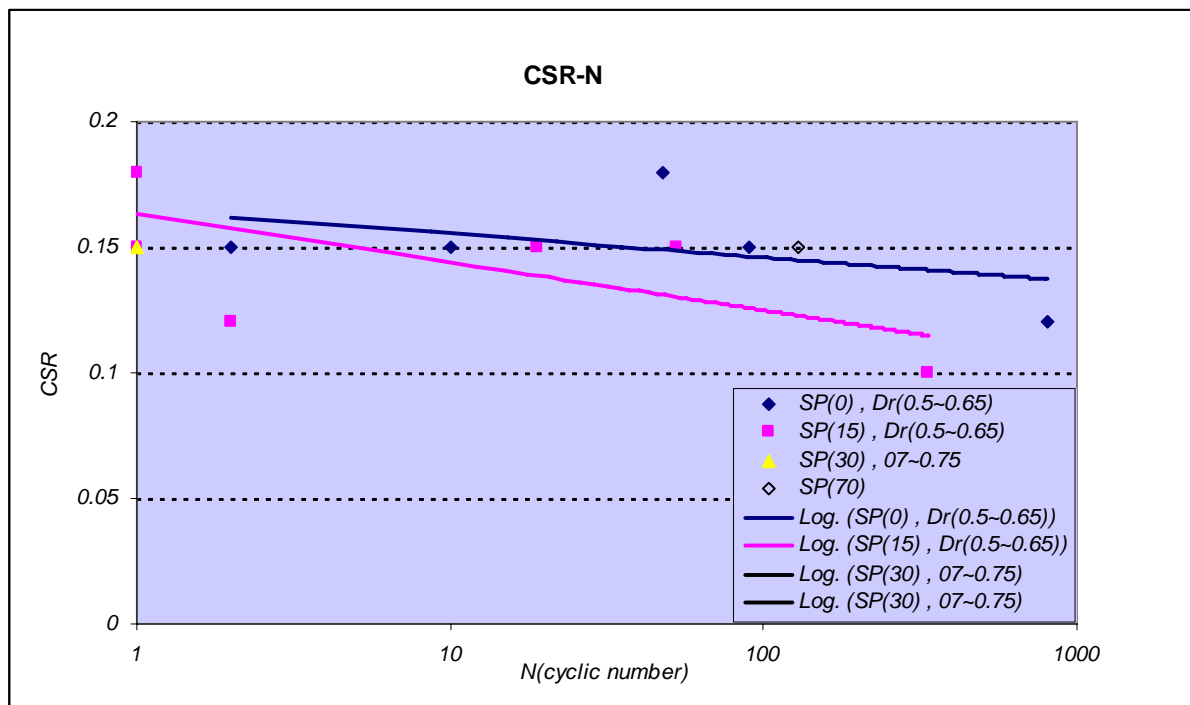


Figure 8. Liquefaction resistance curve

## SUMMARY

Experimental work in the laboratory on Iranian Firoozkuh sand and silt mixtures shows the different behavior of this soil in the various ratios. Adding about 15 percent silt to the sand makes it weaker and more susceptible to liquefaction. Furthermore adding much more silt up to 30 percent makes the mixture so much weak that can not suffer any load and liquefies by a very small trigger. But in higher values of silt ratio the strength recovers itself and in 70 percent the liquefaction resistance becomes equal to the pure sand. The effect of anisotropy in the sandy samples can be well observed in the compressional and extensional sides of strain loop but in silty sands the inherent dilatancy of silt do not let see this effect.

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