

INVESTIGATION ON THE LIQUEFACTION OF A CLAYEY-SANDY SOIL DURING CHANGUREH EARTHQUAKE

Abbas GHALANDARZADEH¹, Mahmoud GHAHREMANI², Kazuo KONAGAI³

ABSTRACT

An intense earthquake (MW = 6.4) occurred in western Iran, about 225 km west of Tehran at 7:28 local time, June 22, 2002. The affected region is located in the west of Takestan-Hamedan road along an east-west oriented valley in the west of the Abegarm village. Surface soil in this area is mostly clay; however, clear traces of sand boiling, softening of soil, and consequent deformations were observed particularly in Hesar village. Some soil samples were prepared throughout an excavated pit from a depth of 2 m, the depth of the liquefied layer. The preliminary tests showed that the soil has a liquid limit of 38, a plasticity index of 18, and a < No. 200 fraction of 44%. These index characteristics would indicate a nonliquefiable soil according to the commonly used criteria. Analysis of cyclic triaxial test data suggests that the clayey sand deposit likely developed high residual excess pore pressures and significant shear strains during the earthquake and thus likely contributed to the observed lateral deformations. This observation showed that the case of Changureh earthquake is one of the very rare evidences that liquefaction could occur in soils with this much high clay content. In this paper, different cases of observed liquefaction and consequent geotechnical phenomena are presented. Moreover, the results of laboratory tests on reconstituted samples are presented to prove how a soil with 44% of clay content could be liquefied. The field evidences and laboratory data show that commonly used criteria for identifying "liquefiable" clayey soils should be applied with caution and should not be indiscriminately viewed as a substitute for detailed laboratory and in situ testing of low plasticity fine-grained soils.

Keywords: Liquefaction, Fine grained soils, Clay content, Sandy clay soils.

INTRODUCTION

On June 22, 2002 at 7:28 local time, an intense earthquake hit a sparsely populated region of Qazvin province in northwest Iran, causing significant damage and casualties to small mountainous town and villages in the area. The earthquake -named the Changureh (Avaj) earthquake- was felt as far as Tehran, which is approximately 225 km east of the epicenter. Though the moderate moment magnitude of 6.4 (ERI, University of Tokyo) – 6.5 (USGS) calculated for this earthquake was not surprisingly large as contrasted with those major earthquakes that ever occurred in the country, seriously ravaged villages were found along east-west oriented valley in the west of Abegarm, and 261 people were reportedly killed and 1,300 injured. In addition, over 25000 people are estimated to be homeless as a result of this earthquake. Figure 1 shows the map of the region with the epicenter and major faults located.

¹ Assistant Professor, Department of Civil Engineering, University of Tehran, Tehran, Iran, Email: aghaland@ut.ac.ir

² Graduate Student, Department of Civil Engineering, University of Tehran, Iran, Email: mahmoud879@yahoo.com

³ Professor, Institute of Industrial Science, University of Tokyo, Tokyo, Japan, Email: konagai@iis-u-tokyo.ac.jp

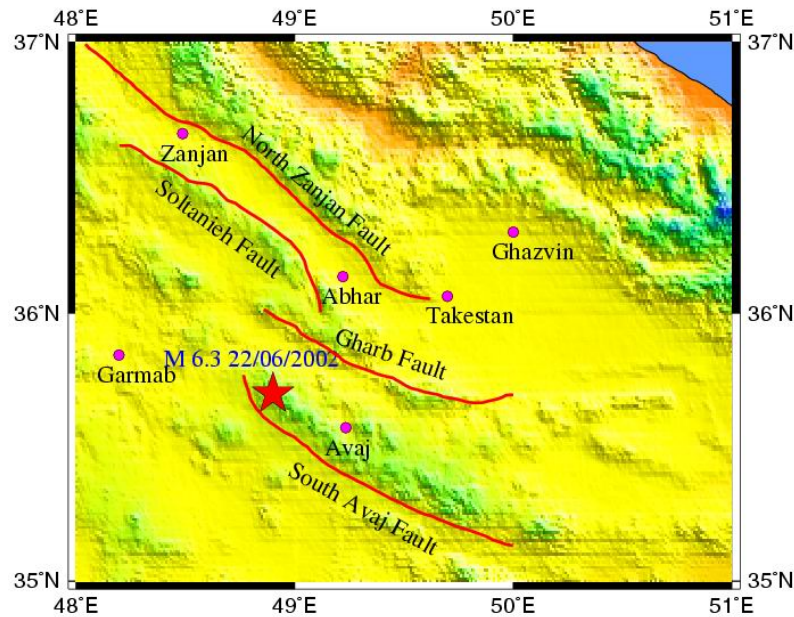


Figure 1. Site map showing the epicenter of the earthquake and faults around the affected area (Mansoori et al, 2002)

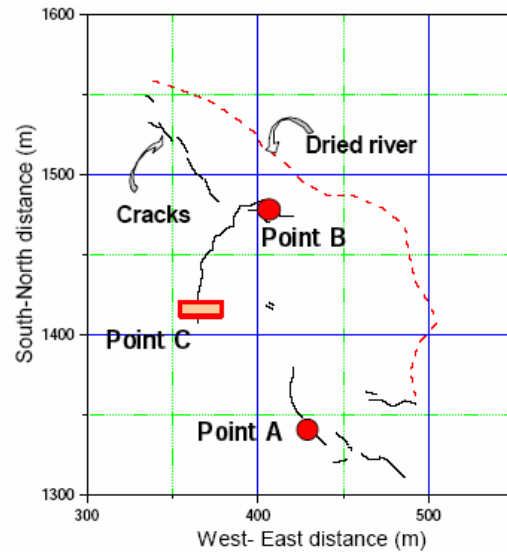
LIQUEFACTION

Hesar, about 5km north of Abdarreh, lies in the middle of a valley of about 15km wide extending in NW-SE direction. Liquefaction took place in a flat area of a little grassy land about 2 km northwest of Hesar (Fig.2a). Figure 2b shows the traces of liquefied sand. The bunch of cracks appearing across the area seems to be winding along a small river trace, which is dried up in hot weather. Soils along the crack at Point A are covered 5-10 cm thick with fine sand (about 0.5 mm in diameter, Fig.2a), while gravels were found at Point B (Fig.3). The flat mass of gravel stopped there was cut upright (Fig. 4) to discuss its possible sedimentation process. The bottom part was full of middle size grains of about 3-5 mm diameter, which was then covered thick with finer sand. And lastly, a number of bigger grains (5-15 mm) were found all over the sand mass. This fact suggests that the liquefied matter was forcibly spouted twice (Konagai and Ghalandarzadeh, 2003)

A trench was excavated at Point C, where the surface soil was covered thick with fine sand (0.5 mm in diameter). Several cracks were found almost upright on a stiff clay wall of the trench through which liquefied sands forced their ways up (Fig.5). There were several cracks appearing upright on the clay wall of the trench, through which liquefied sands forced their ways up. The clay layer was 2m thick lying over the completely wet sand layer.



(a)



(b)

Figure 2. (a) Liquefied area at point A , (b) Crack mat at the liquefied area, Hesar



Figure 3. Liquefied gravel at point B

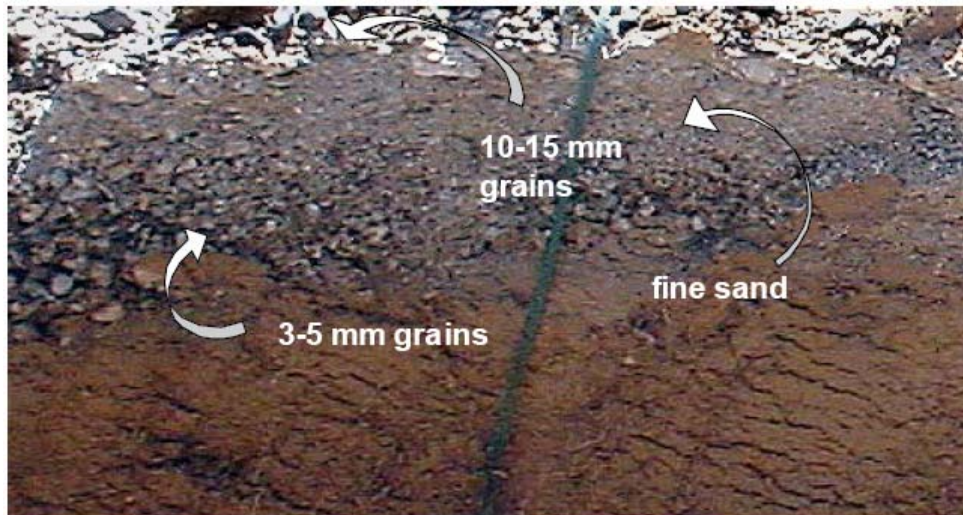


Figure 4. Cross section of flat mass of liquefied matters at point B

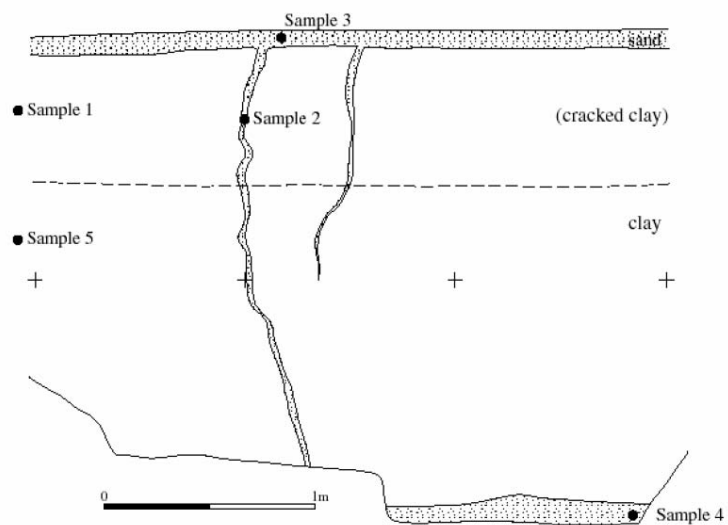
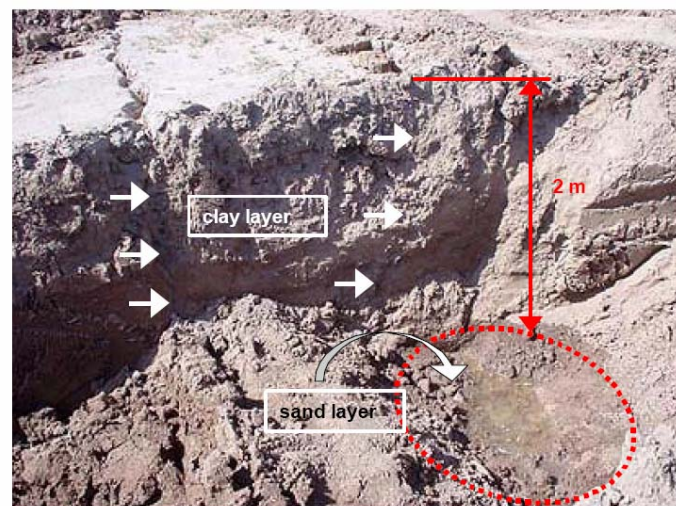


Figure 5. Liquefied sand channels through clay layer at point C

GRAIN SIZE DISTRIBUTION AND INDEX TESTS

Laboratory tests on samples from the liquefied clayey sand included gradation, index test and undrained cyclic triaxial tests in compression-extension mode. An amount of soil (sample 4 in figure 5) was sent to the laboratory for further investigations. The preliminary tests showed that the soil has a fine content (<0.075 mm) fraction of 44% mixed with subangular sand grains. Index tests revealed that the fines have a liquid limit of 38 and a plasticity index of 18. Figures 6a and 6b show the SEM image of clean sand and fines, respectively. Figure 7 presents the grain size distribution curve of clean sand and natural soil.

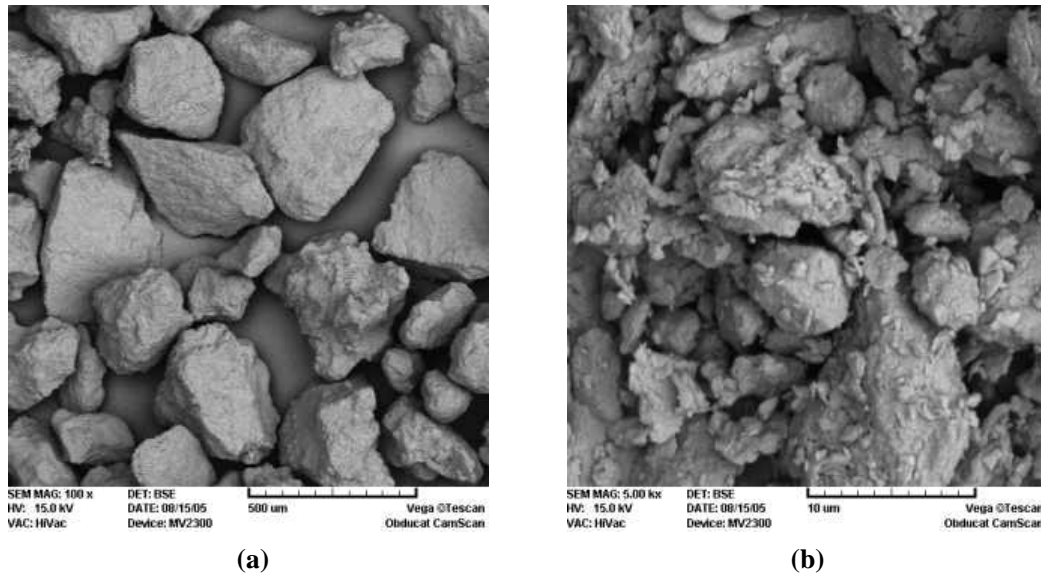


Figure 6. SEM image of (a) clean sand (b) fines of Changureh soil

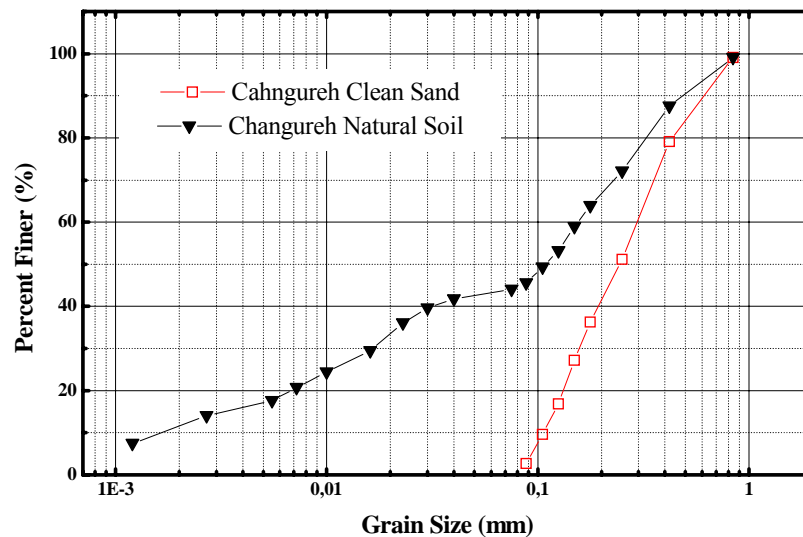


Figure 7. Grain size distribution of clean sand and natural soil of Changureh

CYCLIC TRIAXIAL TESTS

Due to some limitations in the field, it was not possible to take undisturbed sample from the site. Therefore, all cyclic triaxial tests were performed on reconstituted samples. Specimens were prepared by placing dried soil in a funnel that had a tube attached to the spout. The tube was placed in the bottom of a split mold and was then slowly raised along the centerline of the specimen. The diameter of specimen was measured after a slight vacuum was applied and the mold was removed. Both the diameter and height of the specimen was measured to the nearest 0.01 mm. The diameter was determined at three locations (top, middle and bottom) to ensure the specimen's quality which had a diameter of 38 mm and a height of 76 mm.

Saturation was performed by purging the dry specimen with CO_2 for approximately 30 minutes. De-aired water was then introduced into the specimen from the bottom drain line. B value measurements were made before cyclic loading and a B value greater than 0.96 was achieved in all cases, indicating satisfactory saturation. The saturated samples were consolidated isotropically with an effective confining stress of 200 kPa. Six isotropically consolidated, undrained triaxial tests were performed on reconstituted samples. Undrained cyclic tests were run using uniform cyclic loads in compression-extension mode at a frequency of 0.05 Hz for three tests, and 0.01 Hz for the other ones. Because of the inability of the water pressures to equilibrate throughout the sample and measurement system, such low frequencies were selected. A loading rate of 0.01 Hz was used in order to investigate the effect of the loading rate on pore water pressure and cyclic strength. The characteristics of tests as well as the test conditions and results for all tests are summarized in Table 1.

Table 1. Test conditions and results for cyclic triaxial tests

Test No.	CSR	Frequency	e	$N_L (\epsilon = 5\%)$	$N_L (P'=0)$
1	0.20	0.05	0.70	148	154
2	0.25	0.05	0.67	57	63
3	0.30	0.05	0.68	7	9
4	0.20	0.01	0.72	16	17
5	0.25	0.01	0.71	5	6
6	0.30	0.01	0.69	3	3

RESULTS AND DISCUSSION

The cyclic stress ratio versus the number of cycles to initial liquefaction ($u=\sigma_3$) and 5% double amplitude axial strain for both frequencies is plotted in Figure 8. The cyclic stress ratio was defined as $\text{CSR}=\Delta\sigma_d/2\sigma_{3c}'$, where $\Delta\sigma_d$ is the deviatoric load and σ_{3c}' is the isotropic consolidation stress. It is clearly seen that the failure defined by 5% axial strain occurs at relatively smaller cycles than those required to develop a state of initial liquefaction ($\text{EPWP}=200\text{kPa}$) for both frequencies. Therefore, it seems that criterion of 5% double-amplitude axial strain is more convenient than initial liquefaction to define liquefaction of soils with high fine contents in cyclic triaxial tests, as reliable pore pressure measurements are difficult in cyclic testing with relatively low permeabilities as stated by El Horsi et al. (1984) and Das et al (1999). Figure 9 presents the SEM image of the specimen. It is clearly seen that most of the sand grains have been fully confined by fine particles; hence, the specimen can be taken as a fine dominated one. It can be concluded that in the fine dominated soils, it is better not to rely on pore pressure measurements, because: 1) The conventional cyclic triaxial test apparatuses measure the water pressure at the top and bottom of the specimen; whereas, it is known that the water pressure cannot equilibrate throughout the sample and measurement system. 2) The specimen becomes more ductile when fine particles have separated sand grains. Therefore, cyclic failure in the form of cyclic deformation can be more likely to occur. The same behavior was observed for sand with high kaolin content (Ghahremani, 2005)

EFFECT OF FREQUENCY OF LOADING

The effect of frequency of loading on the cyclic resistance of mixture is shown in figure 10. It is demonstrated that by decreasing the frequency of loading, resulted cyclic strength is also decreased. This is in line with findings of Zergoun and Zaid (1994) who demonstrated that pore pressure measurements on clay samples can only reliably be obtained in slow cyclic tests and found that slow cyclic test resulted in lower cyclic strengths than fast ones.

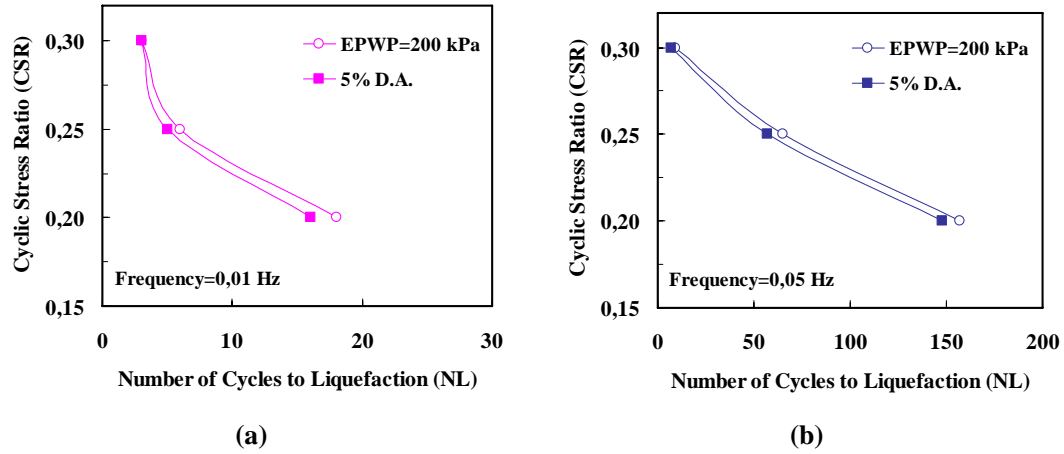


Figure 8. Comparison between number of cycles to initial liquefaction and number of cycles to 5% D.A. for (a) frequency of 0.01 Hz (b) frequency of 0.05 Hz

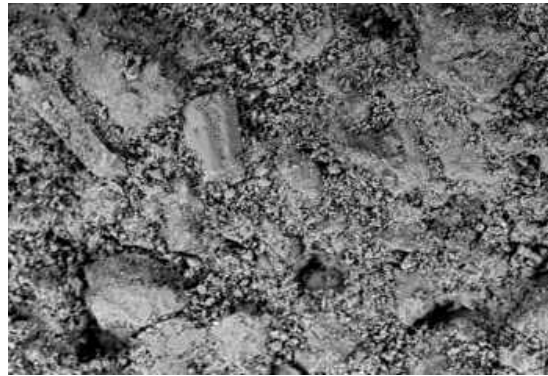


Figure 9. SEM image of natural soil of Changureh

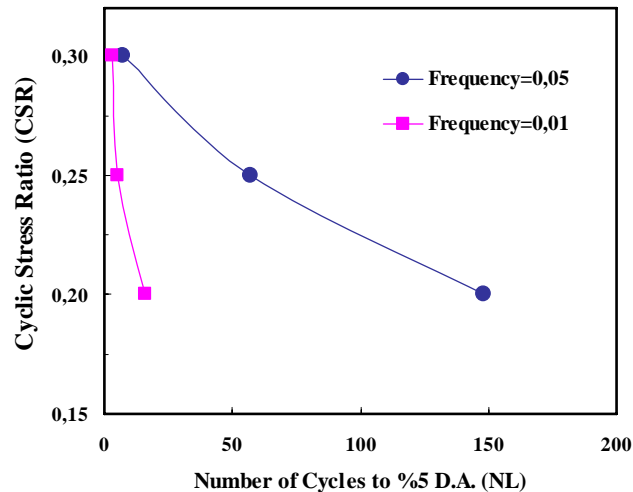


Figure 10. Effect of frequency of loading on cyclic resistance of mixture

CONCLUSION

The paper presented the reconnaissance report of Changureh earthquake including some geotechnical hazard such as liquefaction and damage to a small earth dam. The main focus of the paper was on the liquefaction of a clayey sandy soil which was assumed to be nonliquefiable according to commonly used criteria. It contained 44% plastic fines and yet liquefied during a moderate earthquake. The results of laboratory tests were in line with observed behavior in the field and suggest that the clayey sand deposit likely developed high residual excess pore pressures and significant shear strains during the earthquake and thus likely contributed to the observed lateral deformations. Moreover, it was found that when dealing with soils with high fine content, it is better to define liquefaction criterion as 5% double amplitude axial strain rather than state of initial liquefaction ($u=\sigma_3$). The effect of frequency of loading on cyclic resistance of soil was also studied. The results revealed that by decreasing the loading rate, the cyclic resistance is also decreased.

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