

LIQUEFACTION CHARACTERISTICS OF SILTY CLAY

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SUMMARY

The paper presents the results obtained from undrained cyclic triaxial tests carried out on undisturbed samples in order to investigate the effects of some factors on the liquefaction characteristics of natural soil deposits. The type of the studied soils is sandy silt and silty clay containing some strips of silt or fine sand. The experiments that have been carried out during this study prove that the silty clay specimens containing about 20% of particles finer than 2 microns and having a plasticity index lower than 10 are vulnerable to liquefaction. In this case, the liquefaction is localized in the zone of strips. It is also shown that the cyclic strength increases with the decrease of the void ratio and with the increase of D_{50} .

INTRODUCTION

The past twenty years, considerable laboratory study have been carried out concerning the liquefaction resistance of sand, as described in Refs. 4 and 5. Most of these studies have been limited to granular materials such as clean sands or gravels. In the field, the natural soils deposits containing some fines are much more frequently encountered than clean sand or gravels. If a particular soil contains fines, it is often considered as clayey soil with high plasticity index and therefore it's not vulnerable to liquefaction when it is subjected to cyclic loading. On the other hand, speaking in terms of grain size, the rock flours are classified as clayey soil, but their mechanical characteristics being similar to those of the sand make them vulnerable to liquefaction (Ref. 2).

Hence, there are good reasons to believe that, an appropriate method to identify the potentially liquefiable soils should be based on both the quality of the fine particles, prescribed by a plasticity index, and the percentage of fines contained in the soils.

In order to study the influence of the percentage of fines contained in natural soils on the liquefaction potential, two series of cyclic triaxial tests were performed on undisturbed samples consisting of sandy silt and silty clay with strips of silt or fine sand.

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TEST MATERIALS

The soils used for tests program were obtained from two different sites at depths from 20 to 40m. The grain size of these soils are shown in figs. 1 and 2. The samples of silty clay and clayey silt contain several inclined strips of silt and fine sand of some millimetres thickness, but the specimens were homogeneous in the same tube sample.

The mineralogy analyse of the particles smaller than 2microns using X-ray diffraction reveals that the particles constitutes from a chlorite very little thirsty and a powder of rocks such as quartz and feldspar.

In the first site, one sample constitute from fine sand with 17% finer than 0.074mm, the relative density of 90%. The other sample of the same site were either clayey silt or silty clay containing fines about 20% finer than 2 microns and with a low plasticity index. In the second site, one sample is constituted from clayey silt containing fines of about 28% smaller than 2 microns, with a liquid limit of 50% and plasticity index of 15%. The other samples of this site were consisted of silty clay with about 15 percent of fines smaller than 2 microns and a low plasticity index.

TESTING EQUIPMENT AND PROCEDURE

The experimental study was conducted by cyclic triaxial tests on undisturbed specimens of 70mm diameter and 150mm hight. The cyclic loads are monitored by a load cell and controlled by a servohydraulic closed-loop system machine.

The sample was first extraced from the tube (100mm diameter) by pushing or sawing longitudinally. It was pushed into a tube sample (70mm diameter) which had a sharp cutting edge and then extracted. The specimen ends were trimmed and smoothened. After that, the specimen was placed in the triaxial appartus and surrounded with a single rubber membrane with O-rings. To ensure the saturation of the specimen, Skempton's pore pressure parameter "B" value was checked at several stages by increasing back pressures and cell pressures until "B" value exceeds 0.98. The back pressures required to obtain this value of "B" were between 200 and 300KPa. Then the specimens were consolidated isotropically under an effective confining pressure between 150 and 300 KPa, which corresponde to normally consolidated state of the soil in the field.

Once the specimen was consolidated, the drainage valves were closed and sine wave cyclic loading applied at frequency of 0.2Hz, until the excess pore water pressure becomes equal to the initial effective confining pressure or when the axial strain of the specimen "peak-to-peak" exceeds 5%.

The hysteresis loops of the axial stress versus the axial strain, and the axial stress versus the change of pore water pressure were drawn on a chart of X-Y recorders.

After completing cyclic triaxial test on the specimen, the drainage valves were then opened to reconsolidate the specimen under the initial effective confining pressure and the volume change was measured.

TEST RESULTS AND DISCUSSIONS

The results of the cyclic triaxial tests are presented in Table I in which the values of physical properties of the specimens used are shown

together with the consolidation conditions. The values of cyclic stress ratio employed in each test are also shown, as well as, the number of cycles required to cause initial liquefaction (where the pore water pressure becomes equal to the initial effective confining pressure), or to cause 5% of the double amplitude axial strain. The cyclic stress ratio is defined as the ratio of the single amplitude cyclic deviator stress, σ_{dc} , to twice the initial effective confining pressure, $2\sigma'_v$.

The results of the tests on the specimens of site I and II are plotted in Figs. 3 and 4 respectively, where the cyclic stress ratio is drawn versus the number of cycles required to cause initial liquefaction or 5% axial strain. Fig. 3 shows the results of cyclic triaxial tests on samples of site I. It may be seen that the cyclic strength of sample A (at a relative density about 90% and having a mean grain diameter $D_{50}=0.132\text{mm}$) is higher than that of sample C ($D_{50}=0.009\text{mm}$), but it is slightly less than the cyclic strength of sample B ($D_{50}=0.069\text{mm}$). This appears more clearly by the comparison of the values of the cyclic stress ratio required to cause initial liquefaction or 5% axial strain under 20 cycles of load application; it is equal to 0.295 for sample A, 0.315 for sample B and 0.255 for sample C. The higher value of the cyclic strength of sample B may be due to the high density of the specimens of this sample (void ratio is about 0.48) and to the plasticity index value which is relatively small.

Fig. 4 shows the results of cyclic triaxial tests on samples of site II. It is interesting to note that the pore water pressure during cyclic load application on the specimen of sample E (containing 28% finer than 2 microns and having a plasticity index 15) does not fully build up to become equal to the initial effective confining pressure; the maximum pore pressure developed was 85 percent of the initial effective confining pressure. The specimens of samples D and F had approximately the same percentage of fines finer than 2 microns but the void ratio and plasticity index values of sample F were smaller than obtained for sample D. This can be possibly the reason for a higher cyclic strength of sample F.

The relationship between the excess pore pressure ratio, $\Delta U/\sigma'_v$, and cycle ratio, N/N_L , is presented in Fig. 5; where N is the number of cycles required to develop the excess pore water pressure ΔU , N_L is the number of cycles required to cause the initial liquefaction, and σ'_v is the initial confining effective pressure. Fig. 5 shows that the excess pore pressure ratio increases rapidly at the beginning of cyclic load application on the silty clay specimens ($\Delta U/\sigma'_v$ equals between 0.55 and 0.75 when cycle ratio equal to 0.25 and equals 0.80 to 0.90 when $N/N_L=0.50$). This increasing is more quick than that observed for sand specimens (sample A) where the excess pore pressure ratio is equal to 0.25 when cycle ratio equal to 0.25 and 0.35 when $N/N_L=0.50$. Fig. 5 also shows that the curve presenting the excess pore pressure ratio versus the cycle ratio obtained for sand specimens is placed within the envelope of curves obtained from tests on Sacramento Sand by LEE and ALBAISA (Ref. 3).

This difference in the excess pore water pressure measured in laboratory tests between the sand and silty clay specimens during cyclic loading is clearly illustrated by recording the cyclic axial stress versus the change of pore pressure (or effective confining pressure), as presented in Fig. 6 for the sand and Fig. 7 for the silty clay. Fig. 6 shows that the initial liquefaction is reached on sand specimens when the cyclic deviator stress is equal to zero at loading state, but on the specimens of silty clay

the initial liquefaction is reached when the cyclic deviator stress is equal to its maximum value at loading compression state as shown in Fig.7 .

CONCLUSIONS

The results obtained from undrained cyclic triaxial tests performed on undisturbed specimens of sand and silty clay indicate the following:

- The silty clay specimens with strips of silt or fine sand containing about 20% of particles finer than 2 microns and having a plasticity index lower than 10 are vulnerable to liquefaction .
- The mineralogy constitution of the particles finer than 2 microns may influence the susceptibility to liquefaction of the silty clay .
- The cyclic strength of silty clay specimens increases with the decrease of the void ratio and with the increase of the mean grain diameter D_{50} .
- The excess pore pressure ratio increases rapidly at the beginning of cyclic loading on the specimens of silty clay, this increase is more quick than that observed on sand specimens .

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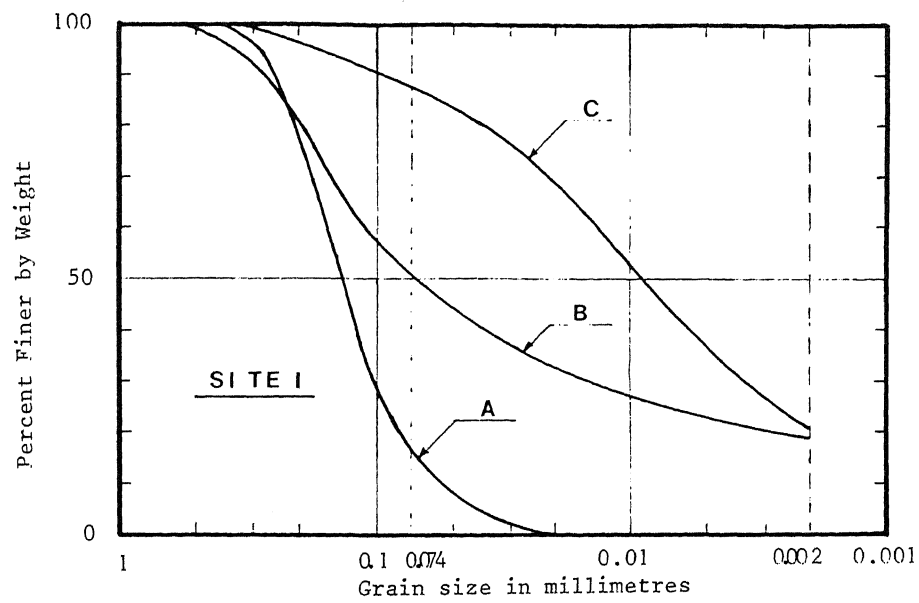


Fig.1- Grain size distribution curves for samples I

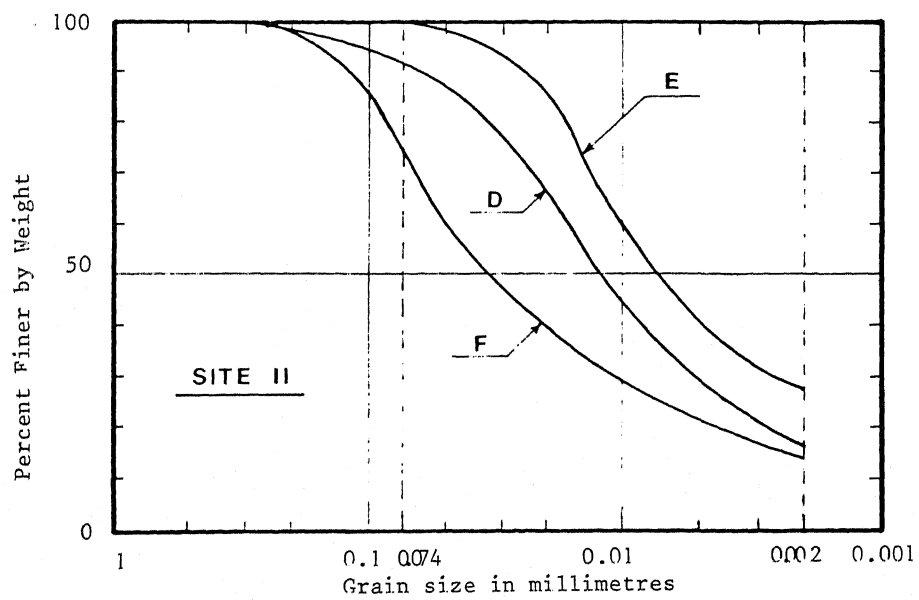


Fig.2- Grain size distribution curves for samples II

TABLE I- Characteristics of the specimens and test results

	sample N°	Depth (m)	Gradation		ω natural %	Consistency Index		Consolidation Conditions		σ_{dc} $\frac{\sigma_1}{2\sigma_2}$	N° of cycles for		Δe After Liquef action
			D_{50} (mm)	$<2\mu m$ %		LL %	PI %	σ'_1 kPa	U_0 kPa		$\Delta U = \sigma'_1$	$\epsilon = 5\%$	
SITE (I)	A	18.5	0.132	0	24.5	—	—	150	200	0.25	155	154	-0.037
					25.8	—	—	150	200	0.30	18	14	-0.035
					25.6	—	—	150	200	0.40	6	4	-0.033
	B	39.0	0.069	19	18.7	22	5	200	300	0.30	28	37	-0.031
					18.9	22	5	200	300	0.35	12	15	-0.034
					23.4	32	8	300	200	0.20	100	77	-0.033
SITE (I)	C	40.5	0.009	21	21.8	32	8	300	200	0.25	22	10	-0.031
					22.0	32	8	300	200	0.30	13	6	-0.031
					28.5	34	9	200	250	0.25	74	56	-0.042
	D	22	0.012	17	28.0	34	9	200	250	0.35	9	3	-0.046
					41.6	50	15	200	250	0.30	(2)	45	-0.050
					30.5	30	6.5	200	250	0.25	265	275	-0.040
SITE (I)	E	27.5	0.007	28	30.2	30	6.5	200	250	0.30	43	60	-0.042
					30.2	30	6.5	200	250	0.30	43	60	-0.042

(1) the relative density of the specimens after consolidation $Dr = 90\%$

(2) $\Delta U_{max} / \sigma'_1 = 85\%$
 $e_{min} = 0.592$
 $e_{max} = 1.108$

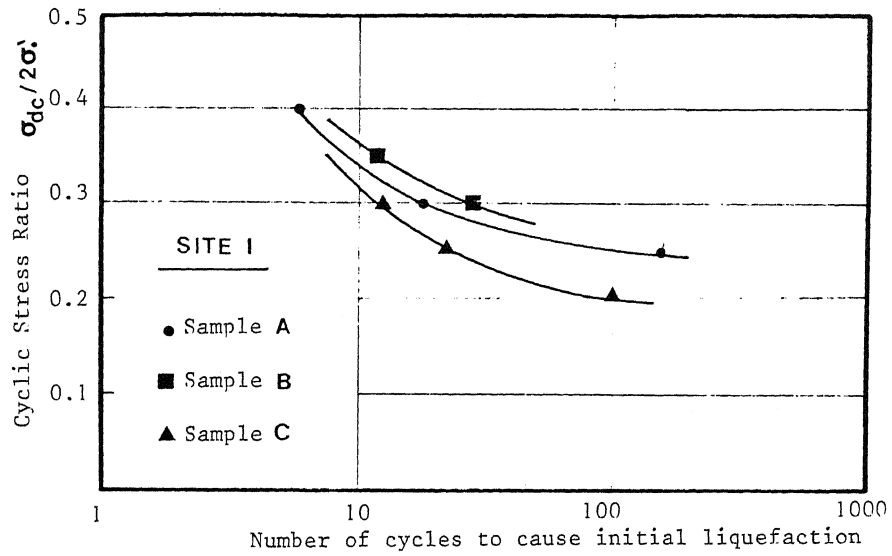


Fig.3- Cyclic stress ratio versus number of cycles

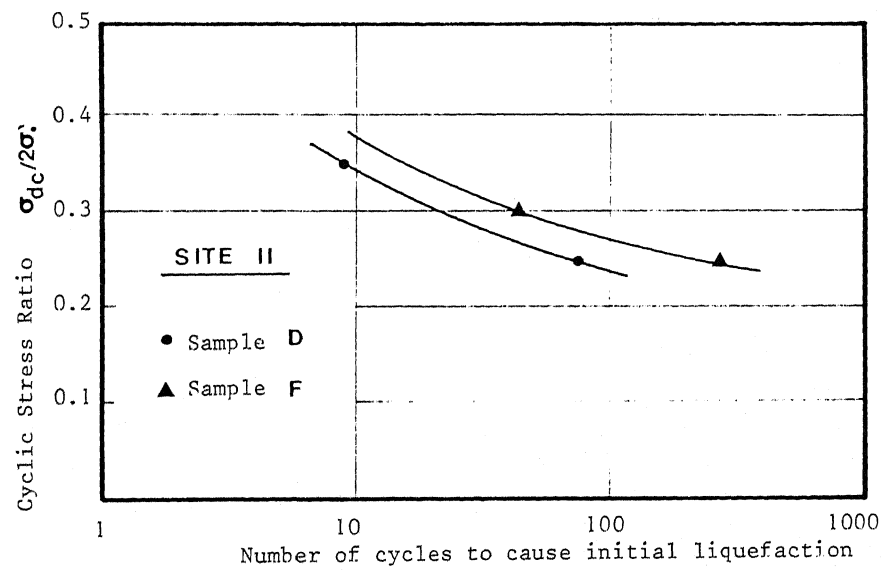


Fig.4- Cyclic stress ratio versus number of cycles

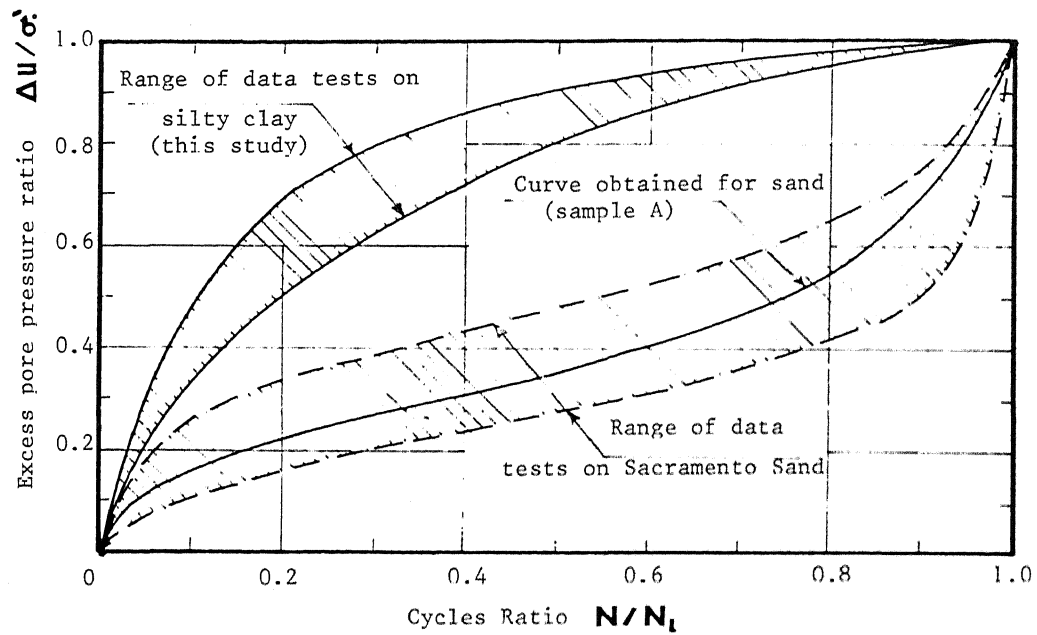


Fig.5- Rate of pore water pressure buildup in cyclic triaxial tests

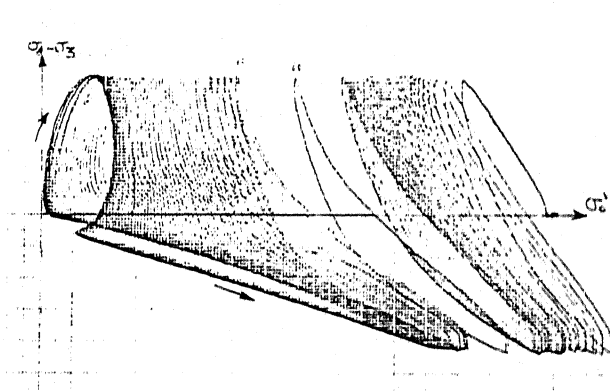


Fig.6- Cyclic axial stress versus the change of effective confining pressure records for sand specimen

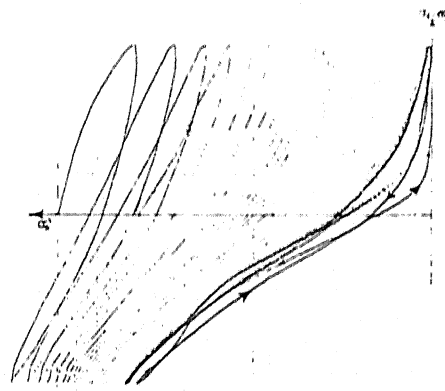


Fig.7- Cyclic axial stress versus the change of effective confining pressure records for silty clay specimen