Experimental Study on Liquefaction of Saturated Sand contained a little Clay

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Abstract

Experiments on the liquefaction of the saturated sand contained a little clay, were carried out by the simple shear test, in order to clarify the effect of the cohesion and clay contents on liquefaction. As seen the record of the test (Fig. 2), sinusoidal shearing stress applied to a sample in the apparatus, utilizing two double action air cylinder.

Soils used in the experiment are Shingu sand contained clay at the rate of about 5~15%.

Introduction

The experimental studies on the liquefaction of the saturated sands have been carried out at laboratories

We also complete the experiments on the saturated sands up to the present. In order to investigate the effects of cohesion on the liquefaction, we now are carrying out the experiment on the liquefaction of the saturated sand contained a little clay continuously.

Soils used in this experiments, were the mixture of Shingu sand and clay in various ratios and the dynamic simple shear test apparatus was used in this experiment.

In this paper, these findings followed with discussion are described.

Soils

The samples used in this experiment are the mixture of Shingu sand and clay in the

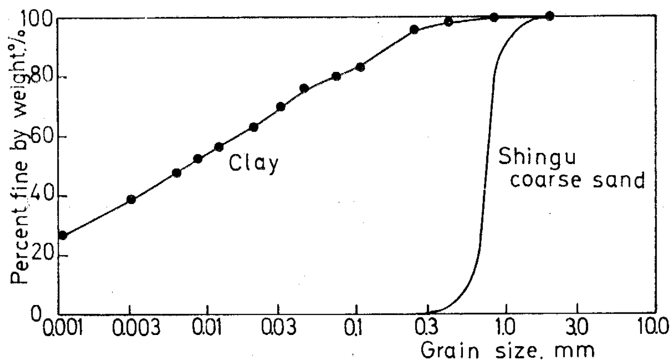

Fig. 1 Grain size distribution curve.

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weight ratio of about 100: 5, 100: 10 and 100: 15 respectively. The grain size distribution curves of Shingu sand and clay are shown in Fig. 1.

A 50% grain size (D_{50}) of Shingu sand and clay are 0.82 mm and 0.0072 mm, respectively.

To saturate soil, the following procedure was adapted, soil is placed in a beaker filled with water, which is then boiled for about one hour to remove completely air from the soil.

Experimental apparatus and proɔedure

The apparatus used in this experiments is a dynamic simple shear test apparatus that was prepared in the author's laboratory. It's shearing box is of the same type as Kjellman's.

The sample of 75 mm in diameter and about 20 mm high, is then to be formed in the rubber sleeve and more over, the stacked 12 to 14 acryl rings (each of 75.2 mm in inner and 96.0 mm in outer diameter and 2.0 mm thick) are positioned at the outside of the rubber sleeve.

The top cap is fastened to horizontal direction and the pedestal is fixed on the horizontal carriage. Shearing force can thus be applied to the sample by moving the carriage horizontally left and right repeatedly.

In the apparatus, to give the load of shearing force in sinusoidal wave, two double action air cylinders are utilized. The detailed explanation of the mechanism was abbreviated in this paper, because it has been described in the previous report[1].

The present experiments were carried out under the initial effective pressure $\sigma'_v=$ 0.3 kg/cm^2 and 0.5 kg/cm^2. The frequency was 0.5 c/s.

To mold the saturated sample, soil which is prepared as described above, is poured gently into a rubber sleeve formed shear box and then, soil is compacted by a tamper.

A density of the sample was changed in three steps by a adjustment of the compaction. But it was difficult to make the sample with same density from respective soil with different clay content, because the relative volume of clay particles in sand void become gradually large as a clay content increase.

The samples were consolidated under normal pressure 0.3 kg/cm^2 and 0.5 kg/cm^2 after the samples were molded. The completion of consolidation was recognized by a measurement of pore pressure of the sample. For measurement of the pore pressure, the pore water through the porous metal sheet on top of the pedestal is led to a pore pressure gauge through polyethylene pipe. The pressure gauge used is of the wire strain gauge type and of diaphragm 6 cm in diameter.

After completion of the consolidation, Shearing stress is repeatedly applied to the sample until liquefaction occurs in the sample.

The various quantities such as shearing force, shearing displacement and pore pressure were recorded in pen-written oscillograph.

Experimental results and the discussion

Fig. 2 shows the experimental results for the sample with 14.4% clay content, consolidated at void ratio $e=0.50$ with the initial, effective confining pressure $\sigma'_v=0.3\ \mathrm{kg/cm^2}$.

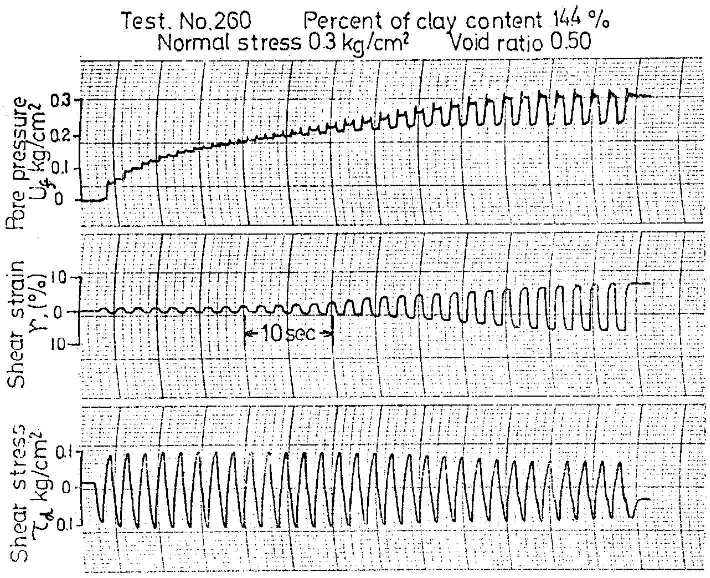

Fig. 2 Record of dynamic simple shear test.

As seen in the figure, there is no appreciable differences between it and the results for sand.

In summarizing the such results thus obtained, Fig. 3 shows the relations between the stress ratio τ_d/σ'_v, the maximum shearing stress and the initial effective pressure respectively, and the number of pulses n_L, initiating liquefaction in the sample. Fig. 3 (a), Fig. 3(b) and Fig. 3(c) are the results for clay content 5.6%, 10.4% and 14.4% respectively.

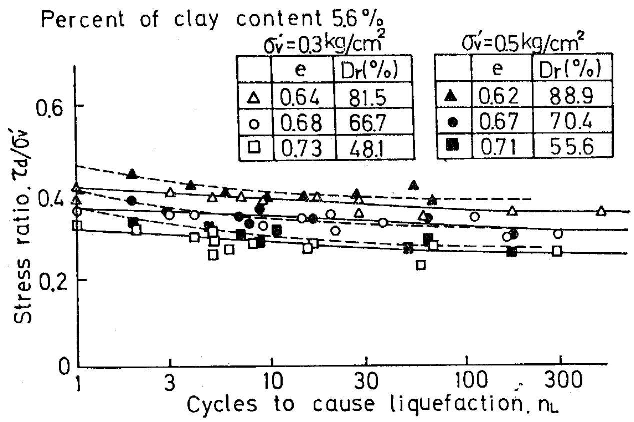

Fig. 3 (a) Stress ratio τ_d/σ'_v required to cause liquefaction.

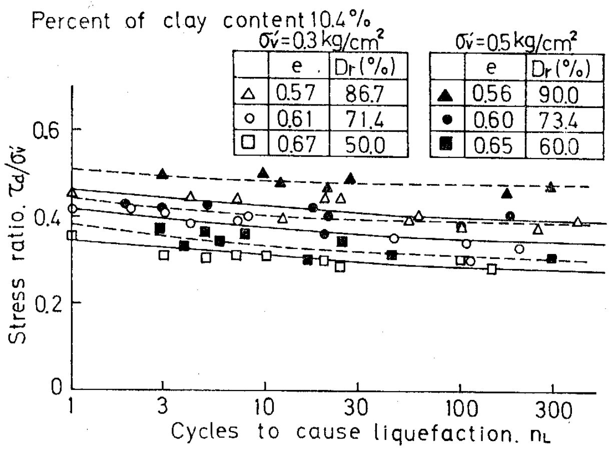

Fig. 3 (b) Stress ratio τ_d/σ_v' required to cause liquefaction.

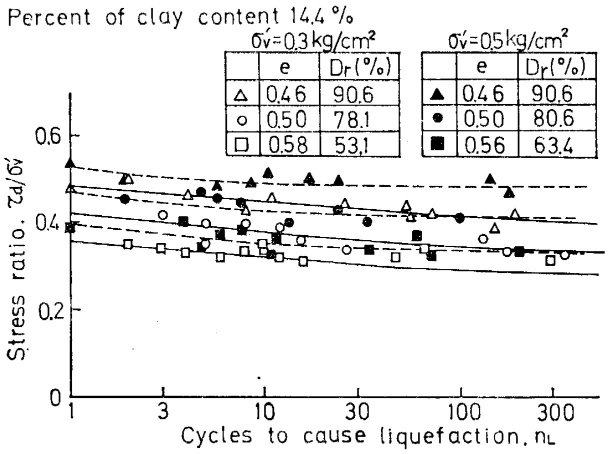

Fig. 3 (c) Stress ratio τ_d/σ_v' required to cause liquefaction.

In comparison with these three results, it may be plainly seen that the stress ratio τ_d/σ_v' required to cause initial liquefaction, increase in value in proportion to the increment of clay content.

We considered that the major cause is cohesion. So the effective pressure and shearing stress just before initial liquefaction was calculated from the experimental results shown in Fig. 2 and thus Fig. 4 which is considered to be Mohr-Coulomb's failure envelope, was obtained.

Accordingly, cohesion and angle of internal friction for respective clay content, are obtained from three figures.

It is clear naturally that a cohesion increase whereas angle of internal friction decrease as the clay content increase.

Now, considering that the formula which shows the condition of the initial liquefaction of saturated cohesive soil is

$$\tau_d = c + (\sigma_v' - u_f)\tan\phi \qquad (1)$$

Here τ_d : Repeated shearing stress

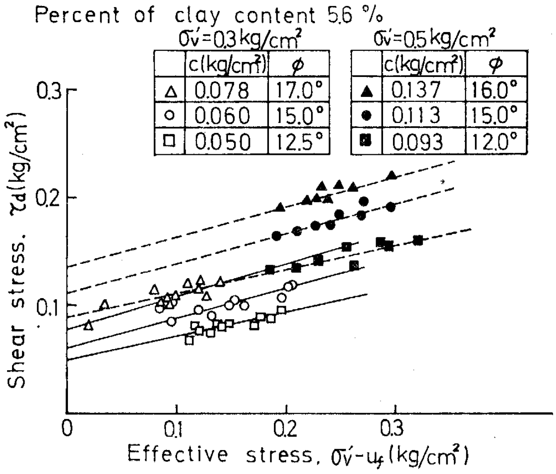

Fig. 4 (a) Relationships between effective stress and shear stress.

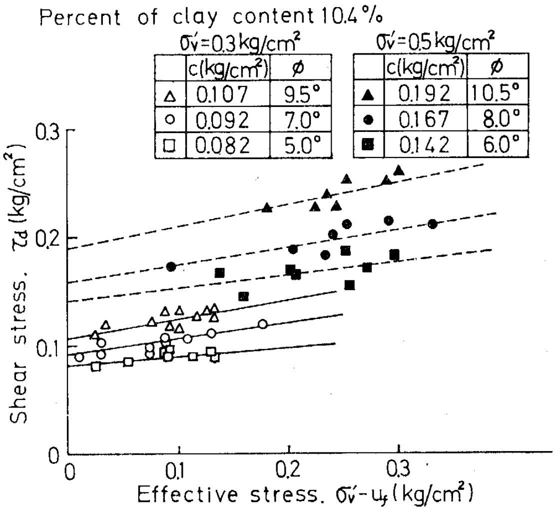

Fig. 4 (b) Relationships betwen effective stress and shear stress.

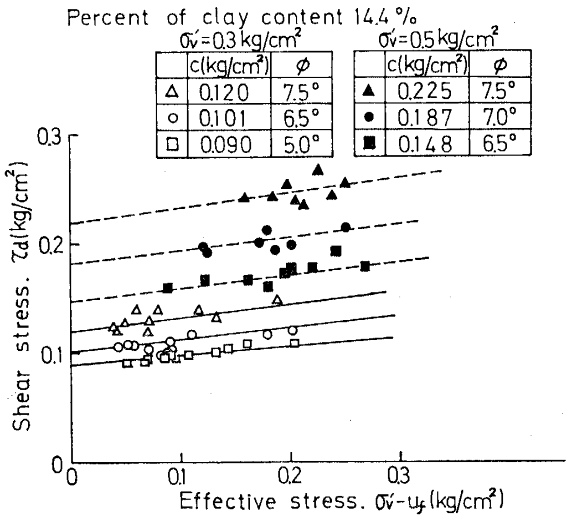

Fig. 4 (c) Relationships between effective stress and shear stress

c : Cohesion
σ'_v : Initial, effective normal pressure
u_f : Pore pressure just before occurrence of the liquefaction
ϕ : The angle of internal friction

The following equation (2) is deduced from the equation (1).

$$(\tau_d - c)/\sigma'_v = (1 - u_f/\sigma'_v)\tan\phi \qquad (2)$$

The experimental results shown in Fig. 3 was arrenged over, considering the equation (2), with respect to a parameter $(\tau_d - c)/\sigma'_v$ and thus Fig. 5 could be obtained.

As seen these figures, it was thus confirmed that for the given clay content, occurrence of the liquefaction of cohesive soil is determined by the ratio $(\tau_d - c)/\sigma'_v$ and is independent of the relative density.

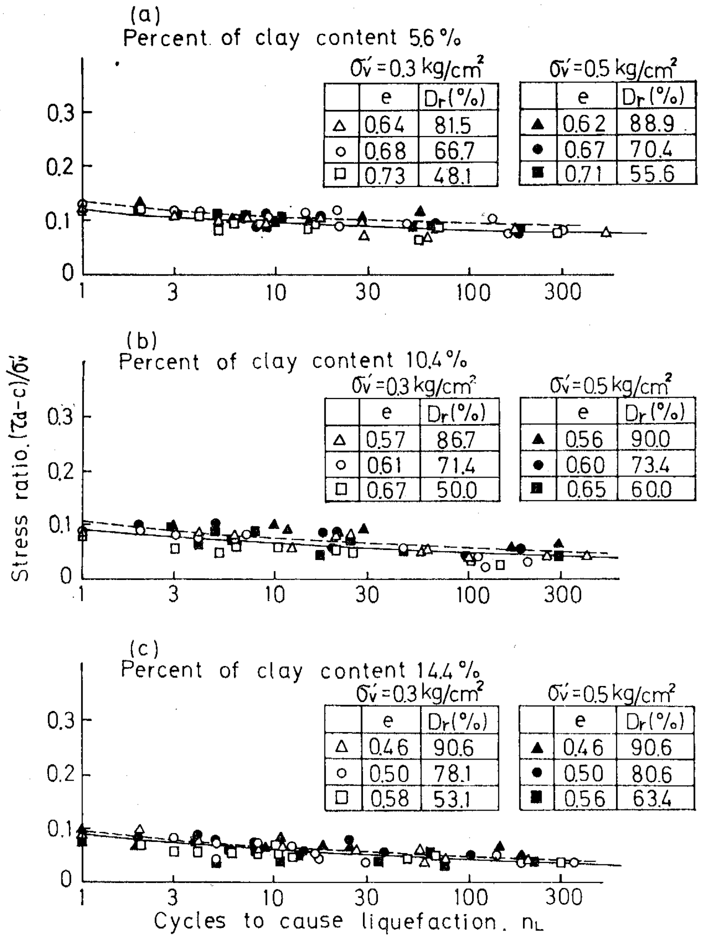

Fig. 5 Stress ratio $(\tau d-c)/\sigma_v'$ required to cause liquefaction

Whereas, in previous paper, it was confirmed that occurrence of the liquefaction of pure sand is dependent of the relative density. We considered that the difference between cohesive sand and pure sand is caused of whether there is the change of angle of internal friction due to relative density.

In previous experiments of Shingu sand, angle of internal friction changed from 24° to 39.5° for change of relative density 45.2% to 77.4%. But in this experiment, the change of relative density of the sample produced only a little change of angle of internal friction.

Table 1 shows a range of the change of angle of internal friction with relative density.

Table 1

Clay content (%)	Relative density (%)	Angle of internal friction (Degrees)
5.6	50.0∼85.7	12.5∼17.0
10.4	50.0∼86.7	5.0∼9.5
14.4	53.1∼90.5	5.0∼7.5

As seen Table 1, the change of internal friction with relative density is a little. This fact back up that the effect of relative density on the occurrence of the liquefaction did not appeared in this experiment. What is evident on comparing the three curves shown in Fig. 5, is that the stress ratio $(\tau_d - c)/\sigma'_v$ somewhat decrease in proportion to clay content. It is considered that the cause is a little change of the angle of internal friction due to clay content.

Next, let us discuss a point about the effect of clay content on the occurrence of liquefaction. According to the experimental results, it became evident that the liquefaction of sample with clay content 20% over is difficult to occurrence.

This result is shown in Fig. 6(a) (the relative density $D_r = 80.0\%$) and Fig. 6(b) (the relative density $D_r = 65.0\%$).

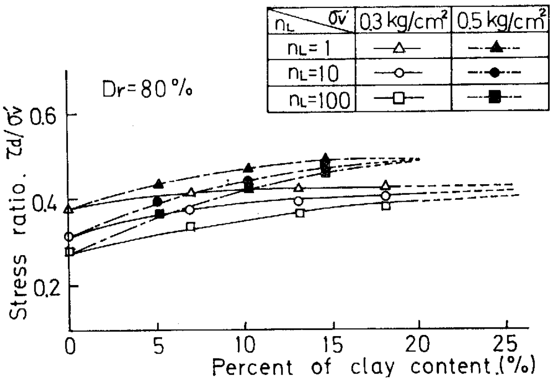

Fig. 6 (a) Relationships between stress ratio τ_d / σ'_v required to cause initial liquefaction and percent of clay content.

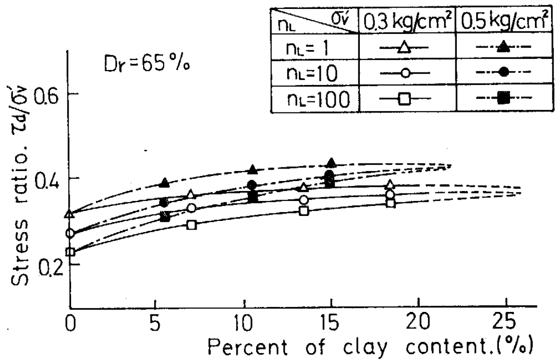

Fig. 6 (b) Relationships between stress ratio τ_d / σ'_v required to cause initial liquefaction and percent of caly content.

As seen these figures, the stress ratio τ_d/σ'_v required to cause initial liquefaction gradually increase in proportion to the clay content, moreover, the differences of the stress ratio between the three curves decrease in proportion to clay content and the three curves converge at clay content 20% over.

Conclusion

In order to clarify the effects of cohesion and clay content in sand on the liquefaction, the experimental studies were carried out by the simple shear test. Sample used in this experiment is Shingu coarse sand contained clay at the rate of 5~15%.

The following are concluded: —

(1) In the cohesive sand, the occurrence of liquefaction determined simply by the stress ratio $(\tau_d - c)/\sigma'_v$ (τ_d: repeated shearing stress, c: cohesion, σ'_v: initial confining pressure).

(2) In this experiments, the liquefaction of sand contained clay at the rate of 20% over, is difficult to occurrence.

Symbols used in the paper

e : Void ratio

D_r : Relative density

n_L : The number of pulse coarsing initial liquefaction

u_f : Pore pressure in initial liquefaction

ϕ : The angle of internal friction

τ_d : Repeated shearing stress

σ'_v : Initial effective normal pressure

References

1) O-hara Sukeo: "The results of Experiment on the Liquefaction of Saturated Sand with a Shaking Box: Comparison with Other Methods" Technology Reports of the Yamaguch University, 1, 121 139 (1972).