The Effect of Fines on Liquefaction of Sands

L'Effet des Grains Fins sur la Liquéfaction des Sables

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SYNOPSIS A laboratory investigation was carried out to study the effect of fines (passing #200 sieve) on liquefaction potential of isotropically consolidated Ottawa sands under cyclic triaxial loading. All specimens were statically compacted to a dry density of 1.70 g/cm^3. The proportions of sand the fines were varied from specimen to specimen. By fixing the dry density of all specimens, the void ratio of the "sand structure" of a specimen varies with the amount of fines. The results show that for a given void ratio of the sand structure, where sand to sand contact is possible, the presence of fines in the voids increases the resistance to liquefaction under cyclic loading.

INTRODUCTION

The fact that loosely deposited sandy silts and fine silty sands are highly susceptible to liquefaction under seismically induced ground motion has led to extensive laboratory studies on liquefaction potential of sands. However, most of the published information concerning this subject has dealt with pure sands contrary to many field conditions where liquefied soil deposits have indicated a presence of small percentages of silty and clayey fines (passing #200 sieve).

Lee and Fitton (1968) reported that grain size was a significant factor on soil strength under cyclic loading and that the effect of grain size distribution and grain shape were considerably less significant. They also reported that uniformly graded very fine sands and silty sands were weakest under cyclic loading. Based on shake table test, Murphy (1960) stated that a sand having a silt and clay content of 10% or more was not easily liquefied. On the other hand, Marsal (1961), in his investigation of the Jaltipan earthquake in 1959, showed that soil deposits containing a considerable amount of silt liquefied.

Ohsaki (1970) pointed out from his investigation of sites which liquefied during the 1964 Niigata earthquake that they contained uniform sand of medium grain size having a silt and/or clay content of less than 10%. This observation was generally in agreement with studies made by Kishida (1969, 1970) on various liquefied sites during earthquakes which took place in Japan.

More recently, Wong, Seed, and Chan (1975) conducted cyclic loading tests on gravelly soil and found that the cyclic deviator stress required to cause 2.5% strain was significantly lower for the well-graded gravelly material than for the uniformly graded material of the same mean grain size diameter (D_{50}).

The aforementioned literature provides information concerning the effect of gradation and qualitatively the effect of fines on the liquefaction potential of soils. Results of studies to specifically investigate quantitatively the effect of the presence of fines in sands are presently not available. This paper, as a part of a comprehensive study of the effect of fines on cyclic strength of sands, deals with two uniformly graded sands containing various amounts of fines.

LABORATORY INVESTIGATION

A laboratory investigation was carried out to study the effect of fines on the liquefaction potential of isotropically consolidated Ottawa sands under cyclic triaxial loading, Vrymoed (1973), Uyeno (1976). Two different sizes of uniform Ottawa sands, ASTM C 109 sand and ASTM C 190 sand, were chosen for separate testing programs. The physical properties of these sands are given in Table I. All cylindrical specimens (3.56 cm dia. and 7.65 cm long for C 190 sand; 6.35 cm dia. and 12.7 cm long for C 109 sand) were statically compacted to a dry density of 1.70 g/cm^3. The proportions of sand and fines were varied from specimen to specimen. The physical properties of the fines are shown in Table II. The amount of fines mixed with the sand varied from 0-25% of the total specimen weight. By fixing the dry density of all specimens, the void ratio of the "sand structure" of a specimen varies with the amount of fines. The more fines in a specimen, the higher is the void ratio of the sand structure. The computed void ratios of the various specimens tested are tabulated as shown in Table III.

Table I

Physical Properties of Ottawa Sand

ASTM No.	D_{50} (mm.)	Sp. Gr.	e_{max}	e_{min}
C 109	0.4	2.64	0.83	0.50
C 190	0.8	2.65	0.84	0.52

Table II

Physical Properties of the Fines
(passing #200 sieve)

Silt	81%	LL	35%
Clay	19%	PL	24%
Sp. Gr.	2.72	PI	11%

Table III

Void Ratio of Sand Structure
for Varying Amount of Fines
(Based on γ_d = 1.70 g/cm^3)

% Fines by Total Weight	Void Ratio e_s
25	1.03
20	0.92
17.5	0.87
15	0.82
12.5	0.77
10	0.72
5	0.63
0	0.52

A cyclic sinusoidal load with a frequency of 100 cycles per minute was applied to the specimen by a double-acting pneumatic loading system (1967). The C 109 sand specimens were tested using the modified version of the pneumatic loading system as described by Chan and Mulilis (1976). All specimens were backpressured and saturated prior to testing. In this study, the definition of failure and/or liquefaction of a specimen is the number of cycles required to cause a sudden loss in strength. This sudden loss of strength is accompanied by an equalization of pore water and confining pressure and a drastic increase in axial deformation.

TEST RESULTS AND DISCUSSION

Test results for specimens with different amounts of fines are shown in Figures 1 and 2. Both figures show the same basic pattern where specimens containing a relatively small percentage of fines are stronger against liquefaction under cyclic loading. This generalization appears to be only true for specimens having sand to sand contact. A maximum obtainable void ratio of 0.85 of the sand structure is reached when the amount of fines reaches 15~17.5% by weight. Beyond this void ratio, it is reasonable to assume that the resistance to liquefaction of the soil mass is no longer dominated by the packing of the sand particles. This is evidenced by the 20% and 25% fines curves in Figure 1 not following the same basic pattern. Consequently, the discussion will be limited to specimens with less than 20% fines.

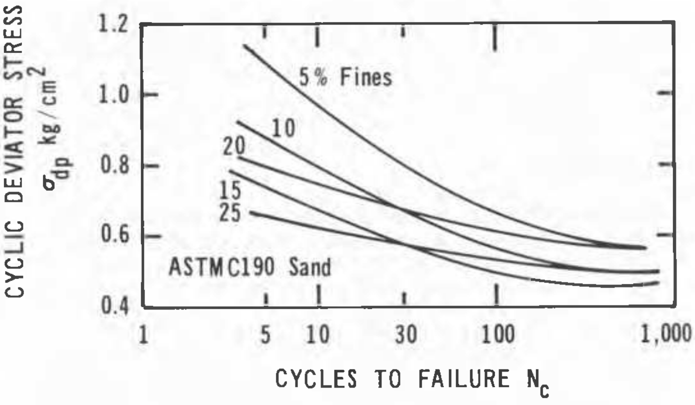

Fig. 1 Cyclic deviator stress vs. cycles to failure - ASTM C 190 sand with fines

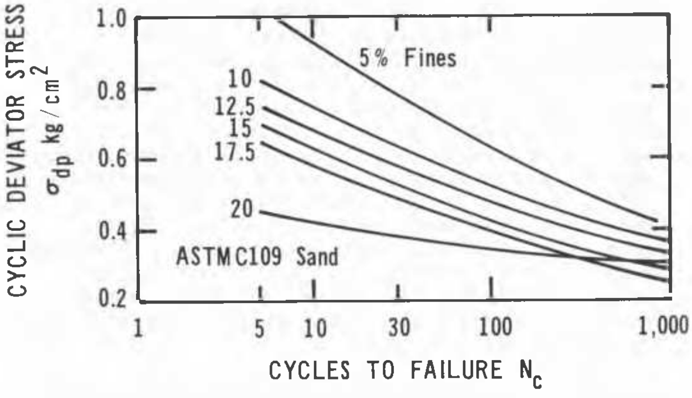

Fig. 2 Cyclic deviator stress vs. cycles to failure - ASTM C 109 sand with fines

Cyclic test results for the pure Ottawa sands are shown in Figures 3 and 4. Figure 4 is obtained using information given by Finn, Pickering and Bransby (1969). Comparisons made with pure sand specimens and specimens containing fines are shown on Figures 5 and 6 for C 190 and C 109 sands respectively. It can be seen from these figures that for a given void ratio of the sand structure, the specimens with fines are stronger than the corresponding pure sand specimens. It should be kept in mind, however, that the comparison is made on the void ratio of the sand structure alone. For specimens with the same sand structure void ratio, the one containing fines is always "denser" than the one without fines.

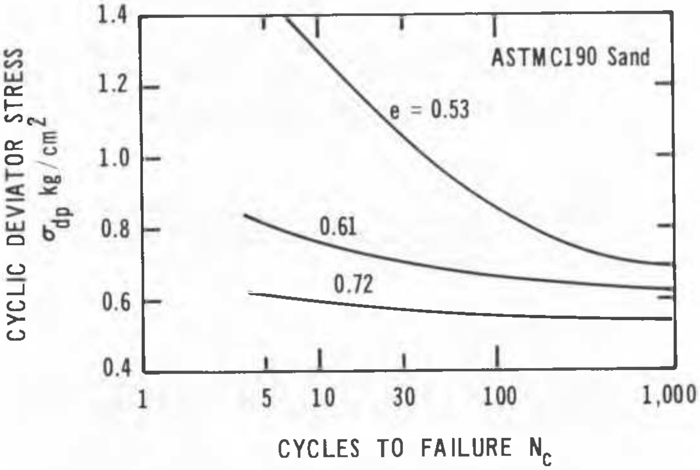

Fig. 3 Cyclic deviator stress vs. cycles to failure - ASTM C 190 sand

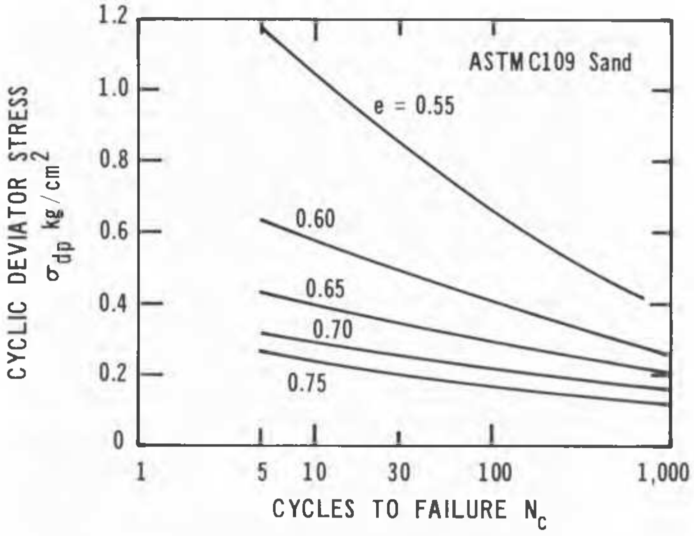

Fig. 4 Cyclic deviator stress vs. cycles to failure - ASTM C 109 sand (from Finn, et al. 1969)

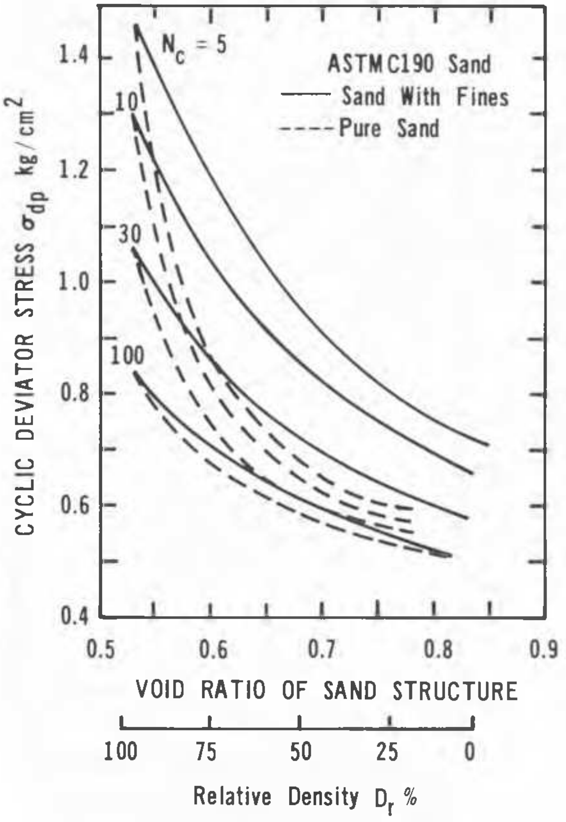

Fig. 5 Relationship of void ratio of sand and cyclic deviator stress - ASTM C 190 sand

Based on the cyclic strength of pure sand specimens $(\sigma_{dp})_s$, Figures 7 and 8 show the stress ratio, $\sigma_{dp}/(\sigma_{dp})_s$, where cyclic strength of specimens with and without fines are compared for a given relative density. The resistance to liquefaction increases for the C 190 sand (Figure 7) with a decrease in the number of cycles causing liquefaction. The relative density of the sand structure, however, does not appear to affect the increase in strength significantly. In the case of C 109 sand (Figure 8), the increase in cyclic resistance is affected by the relative density of the sand structure; the lower the relative density the greater is the strength increase. The difference in stress ratio vs. cycles to failure in Figures 7 and 8 may be attributed to such factors as the size of the voids, the ease of pore water movement in the voids, and the liquefaction potential of the pure sand itself. It can be assumed that the increase in resistance to liquefaction for specimens with fines is the result of longer time required to mobilize the pore water pressure within the specimen during cyclic loading. The presence of fines in the voids tends to retard the movement of water, requiring an increase in cycles to cause liquefaction at a given stress level. In addition, the size of the voids of a uniform rounded sand is controlled by its particle size. Since the C 190 sand is coarser than the C 109 sand it is reasonable to assume that the presence of fines in the voids in C 109 specimens, which are smaller in size but larger in number, could have a more significant effect on the movement of pore water.

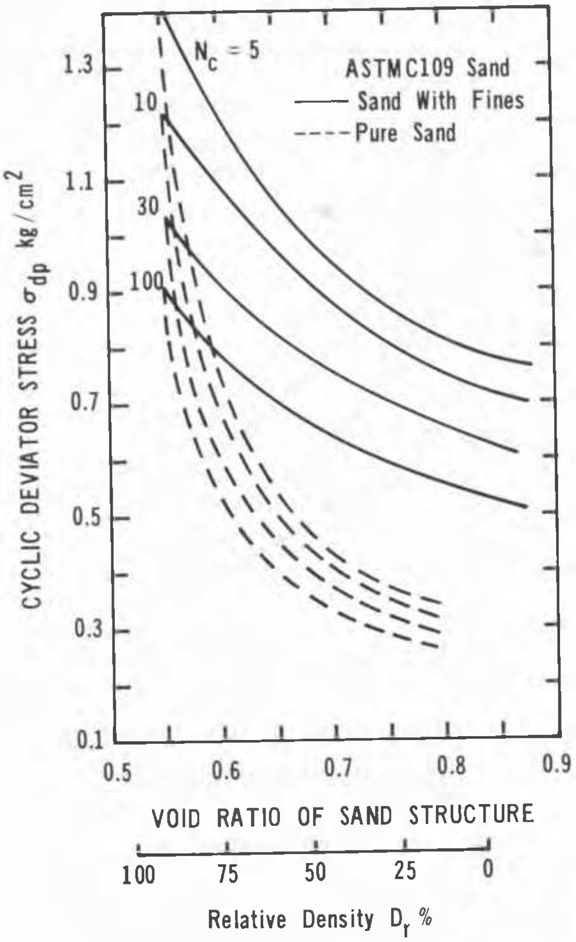

Fig. 6 Relationship of void ratio of sand and cyclic deviator stress - ASTM C 109 sand

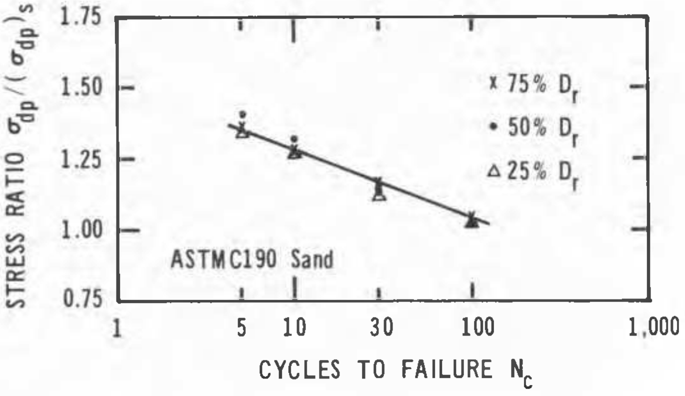

Fig. 7 Increase in cyclic strength for specimens with fines - ASTM C 190 sand

This is shown in Figures 7 and 8 where the percent increase in resistance to liquefaction is greater in C 109 specimens than in corresponding C 190 specimens.

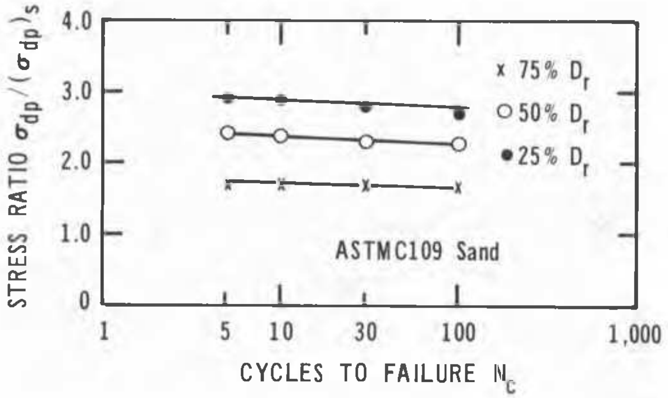

Fig. 8 Increase in cyclic strength for specimens with fines - ASTM C 109 sand

CONCLUSIONS

Based on the results of the study described above, the following general conclusions can be drawn:

1. For a given void ratio of the sand structure, where sand to sand contact is possible, the presence of fines in the voids would increase the resistance to liquefaction under cyclic loading.
2. The amount of increase in resistance to liquefaction relates to factors such as the amount of fines, the number of loading cycles causing liquefaction and the relative density of the sand structure. It is not clear, however, as to how the significance of these factors relates to the size of the voids, the liquefaction potential of the sands, etc.
3. When the amount of fines in the sand-fines mixture reaches a state where sand to sand contact is not a predominant feature (i.e., the void ratio of the sand structure is more than the maximum void ratio of the pure sand), the deformation characteristic of a specimen under cyclic loading is not controlled by the sand structure but rather by the types of fines and the relative compaction of the specimen.

It is important to note that the study reported in this paper dealt only with gap-graded sand-fines mixture; many other potentially significant factors such as size gradation, grain shape, types of fines, etc. were not considered in the investigation.

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