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La susceptibilité à la liquéfaction de sables renforcés avec des géotextiles

Liquefaction susceptibility of sand reinforced with geotextiles

SOMMAIRE

Cet article decrit les resultats preliminaire d'un programme de recherche sur le comportement dynamique de sables satures renforces avec des inclusions de textiles et fibres. Le but de l'etude est d'examiner l'effet des geotextiles sur la susceptibilite a la liquefaction de remblais sous-marins.

Le plupart des remblais artificiels cotiers et en mer ont ete construits par dragage de sable marin et par mise en place sous l'eau sans compactage. Ce type de remblai est en general lache et susceptible de se liquefier dans les regions sismiques. Les resultats de cette etude indiquent que l'inclusion de geotextiles dans le remblai, sous la forme de toiles, peut ameliorer sa resistance a la liquefaction.

L'article decrit les resultats d'essais triaxiaux statiques et cycliques sur des sables satures renforces avec des textiles et des fibres. La susceptibilite a la liquefaction a ete etudiee en fonction de la densite du sol, du type et de la quantite d'inclusions, de la methode de compactage, et de la pression de confinement.

SUMMARY

This paper describes the preliminary results of a research program on the dynamic behavior of saturated sand with fabric and fiber inclusions. The objective of the study was to investigate the effect of geotextiles on the liquefaction susceptibility of underwater fills.

Most of the existing man-made coastal and offshore fills have been constructed by dredging sand from the sea floor and dumping under water without compaction. Such fills are usually loose and in seismic regions they are prone to liquefaction. The results of this study indicate that inclusion of geotextiles in the form of fabric in the fill can improve its resistance against liquefaction.

The paper describes the results of static and cyclic load triaxial tests on fabric and fiber-reinforced saturated sand. The liquefaction susceptibility as a function of soil density, type and amount of geotextile inclusions, method of compaction, and confining pressure was investigated.

INTRODUCTION

In California and other coastal regions, many coastal and some offshore fills have been constructed by dredging sand from the sea floor and dumping it under water without compaction. Such fills are typically weak, and in seismically active areas they are in danger of liquefaction by earthquakes. There are many cases of this type of failure in various coastal locations (Terzaghi[1], Morgenstern[2], Seed[3], among others).

At present, three different techniques can be used for densification of underwater fills: pile driving, vibroflotation, and dynamic compaction. These procedures are very expensive and must be carried out after fill construction has been completed and top of the fill has reached above water level. It would be desirable to find a new technique to be used during fill construction to produce a uniform and sufficiently strong fill that can withstand earthquakes without liquefaction.

The objective of this study was to explore the feasibility of using geofabric or geofiber inclusions to reinforce underwater sand fills and improve their resistance against liquefaction.

Various types of synthetic fabrics have been used as soil reinforcement on land (for example Koerner and Welsh[4], Giroud[5], and numerous papers in references 6 through 9. Although there is no published information on the use of geotextiles as a means of reducing soil liquefaction susceptibility, there have been some studies related to the strength behavior of fabric reinforced sand. These include studies by Yang[10], Schlosser and Long[11], Broms[12], McGowen et. al.[12] and Gray et. al.[14]. The common conclusion of these studies is that inclusion of layers of fabric in sand increases the soil's ultimate strength but does not seem to have a signficiant effect on its stress-strain behavior at low strains.

Regarding the use of fiber inclusions, Laflaive[15], and Gray and Ohashi[16] have studied the strength of fiber-reinforced dry or moist sand, and have found that synthetic fibers can increase the strength of sand under static loads. However, at present, there appear to be no published data regarding the behavior of fabric- or fiber-reinforced saturated sand subject to seismic loads.

LABORATORY TEST PROGRAM

An experimental program was carried out using both static and cyclic triaxial tests on sand samples with and without synthetic material inclusions. The static triaxial tests were performed on samples 7 cm in diameter and 18 cm in height, fully saturated by back-pressure technique and tested drained.

The triaxial tests were performed using the cyclic triaxial test apparatus developed at the University of California, Berkeley (Chan[17]). The samples had a diameter of 7 cm and a height of 18.7 cm. All samples were fully saturated using back-pressure technique until pore pressure coefficient B values of higher than 0.97 were measured. The loading pattern for dynamic triaxial tests was cyclic axial compression and extension under a constant stress amplitude with a frequency of 1 Hz. The variations of stress, strain and pore water pressure under cyclic load were recorded until liquefaction occurred. The number of stress applications necessary to initiate liquefaction was measured.

The sand used was Monterey No. 0 Sand, a uniform fine sand with 95 percent passing sieve No. 30 and 100 percent retained on sieve No. 100. The grain size distribution curve for the soil is shown in Figure 1. The sand has a coefficient of uniformity of about 1.5 and a mean particle diameter of about 0.4 mm. The sand grains are mainly quartz and feldspar with some mica. The particles are rounded to subrounded and have a specific gravity of 2.65.

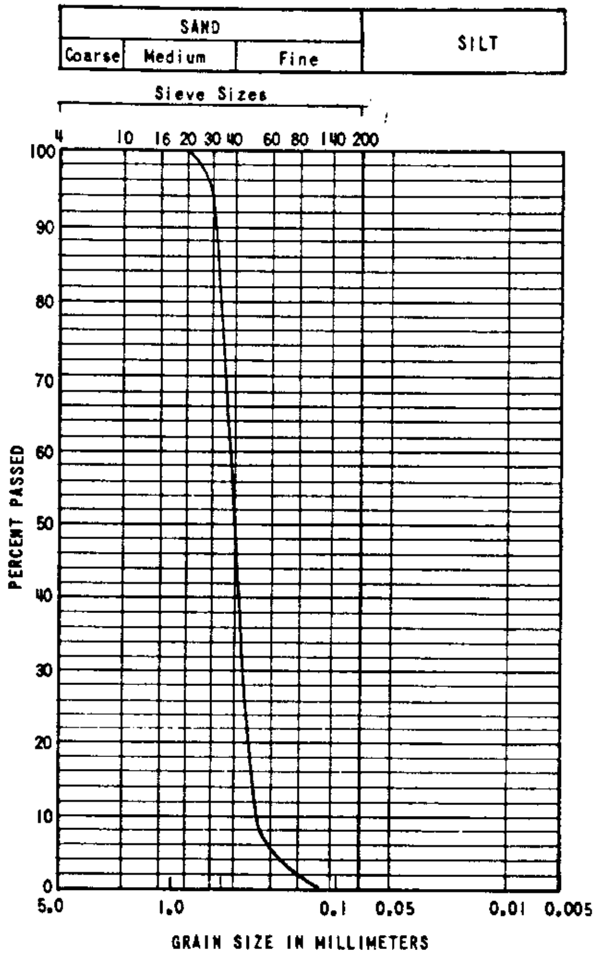

FIGURE 1 - GRAIN-SIZE DISTRIBUTION FOR MONTEREY NO. 0 SAND

Different soil densities were used to examine the effect of placement density on the dynamic behavior of fiber- and fabric-reinforced sand. Also, in order to explore the influence of placement method, some of the samples were prepared by pluviation of sand under water, and others were prepared by compacting moist sand and then saturating the sample by vacuum and back-pressure techniques.

The fabrics selected for the experiments consisted of three types of synthetic woven fabric, three types of synthetic nonwoven fabric, and one type of woven fiberglass fabric. The fabrics were cut into square or circular patches and were placed in seven horizontal layers within the cylindrical triaxial specimens. The fibers used were taken from the woven fabrics. Typically, 5 cm-long fibers were mixed uniformly with soil. In some tests fibers as long as 7 cm were used. The percentage of fiber and fabric used varied from 0.15 percent to 0.8 percent by weight of dry sand.

TEST RESULTS

The results of several series of static triaxial tests showed that the addition of synthetic fiber or fabric, in the amount of 0.2 percent to 0.8 percent by weight of sand, increased the soil strength. The increase in strength was significant (10 percent to 20 percent) at large strains. However, at small strains (up to 1 percent) the soil modulus did not appear to be affected by fiber or fabric inclusions. This is illustrated by typical test data shown in Figure 2. The results of static triaxial tests were in general agreement with the data obtained on fabric-reinforced dry sand by Yang[10], Schlosser and Long[11], Broms[12], McGowen et. al.[13], and Gray et. al.[14].

Five series of cyclic triaxial tests were performed to investigate the effect of synthetic fabric and fiber inclusions on the dynamic response of saturated sand. All tests were isotropically-consolidated undrained tests. Two different effective confining pressures of 49 kPa and 98 kPa were used.

The significant data from the cyclic triaxial tests are summarized in Table 1. The results of these tests are briefly discussed below:

- Test series 1 was performed on samples prepared by pluviation of sand under water. This method of sample preparation produced very low relative densities, D_r in the range of 25 percent to 36 percent. Addition of fiber or pieces of fabric to sand pluviated under water produced samples that had erratic relative densities. Furthermore, samples with inclusions had lower relative densities than those without inclusions. The reduction in relative density offset any significant beneficial effects that the presence of synthetic inclusions might have, and the results of all cyclic triaxial tests, with and without inclusions, fell within a relatively narrow band.

- Test series 2 and 3 were performed on samples compacted by tamping and then saturated by the back-pressure technique. The samples in these series were compacted to a relative density, D_r, in the range of 51 percent to 54 percent. This condition is representative of many underwater dredged sand fills after the fill has settled under its own weight and has further consolidated under repeated action of tides.

The reinforcing materials for series 2 and 3 tests consisted of threads of fiberglass, 4 cm to 7 cm long, or patches of nonwoven fabric. Data from test series 2, run under an initial effective confining pressure of 98 kPa, are shown in Figure 3. In this figure, the cyclic stress ratio, $\sigma_d/2\sigma'_c$ for each test is plotted against the number of cycles required to cause initial liquefaction. These tests indicated that inclusion of 0.8 percent (by weight of sand) fiberglass fibers or 0.6 percent nonwoven fabric did not have a noticeable beneficial effect on liquefaction susceptibility of the sand. The results of test series 3, at a lower confining pressure of 49 kPa were quite similar to those of test series 2.

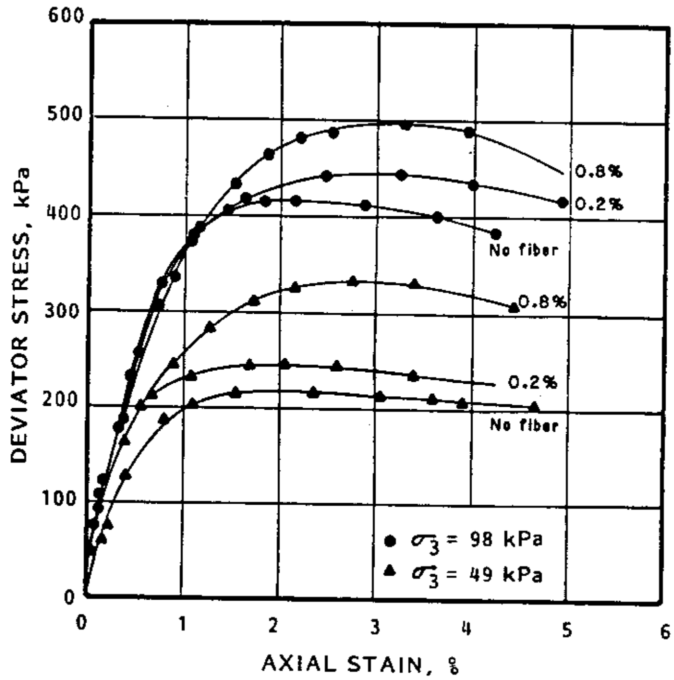

FIGURE 2 - RESULTS OF TRIAXIAL TESTS ON FIBER-REINFORCED SAND

Table 1. Summary of Cyclic Triaxial Tests

Test Series	Number of Tests	Method of Preparation	Relative Density	Confining Pressure	Inclusions
1	15	Pluviation Under Water	11 - 36%	98 kPa	° None ° 0.4% fiberglass fibers ° 0.4% woven fabric ° 0.4% nonwoven fabric
2	14	Moist Tamping	51 - 54%	98 kPa	° None ° 0.8% fiberglass fibers ° 0.6% nonwoven fabric
3	14	Moist Tamping	52 - 53%	49 kPa	° None ° 0.2% fiberglass fibers ° 0.5% fiberglass fibers ° 0.2% nonwoven fabric
4	10	Moist Tamping	49 - 52%	49 kPa	° None ° 0.5% woven fabric
5	13	Moist Tamping	52 - 53%	49 kPa	° None ° 0.15-0.3% woven fabric

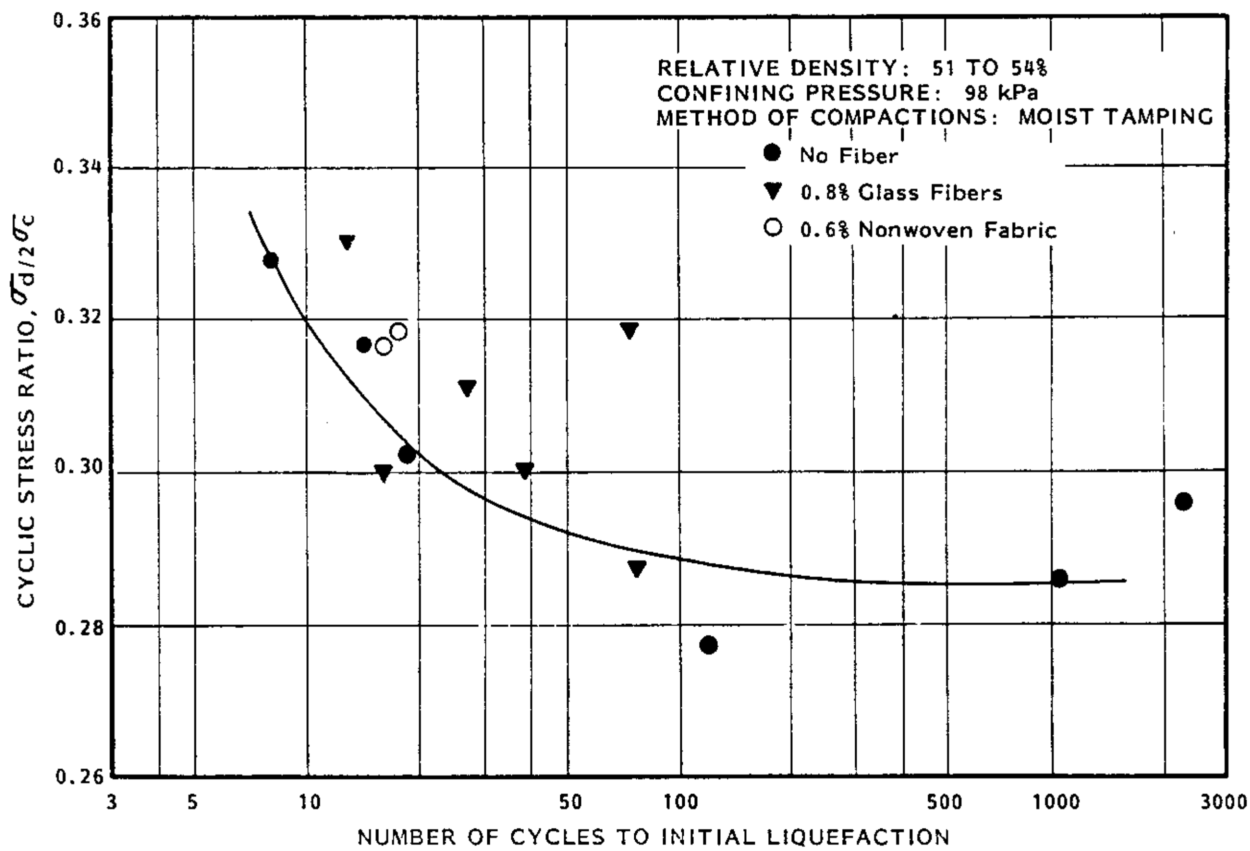

FIGURE 3 - RESULTS OF CYCLIC TRIAXIAL TESTS (SERIES 2) ON SAND WITH SYNTHETIC INCLUSIONS

- Test series 4 and 5 were run on samples prepared by tamping with relative densities in the range of 52 percent to 53 percent and tested under an initial effective confining pressure of 49 kPa. The reinforcing materials for these tests consisted of patches of strong woven fabrics with rough texture. The amount of woven fabric used in test series 4 was 0.5 percent (by weight of sand), and in test series 5 it varied from 0.15 percent to 0.3 percent. The results of these tests are shown in Figure 4. It can be seen that use of a strong woven fabric with a rough texture had a noticeable to significant beneficial effect on soil resistance against liquefaction.

- At present, more tests are being run using tough fibers with widths that are larger than the particle size of sand. The results of these tests are not conclusive yet.

CONCLUSIONS

The data presented in this paper are the results of the first phase of an on-going research project on the liquefaction susceptibility of fiber- or fabric-reinforced dredged fills. The static triaxial tests indicated that a relatively small amount of synthetic material, in the form of fiber or woven-fabric inclusions, can increas soil's ultimate strength under drained loading conditions. However, the soil stress-strain relationship at low strain does not seem to be significantly affected by the presence of inclusions. This seems to indicate that a certain amount of deformation is required to mobilize tensile stresses, and thereby the reinforcing effects, of fiber or fabric inclusions.

Under cyclic loads in undrained shear, the effect of inclusions depends on the type and amount of reinforcing material, soil density, and

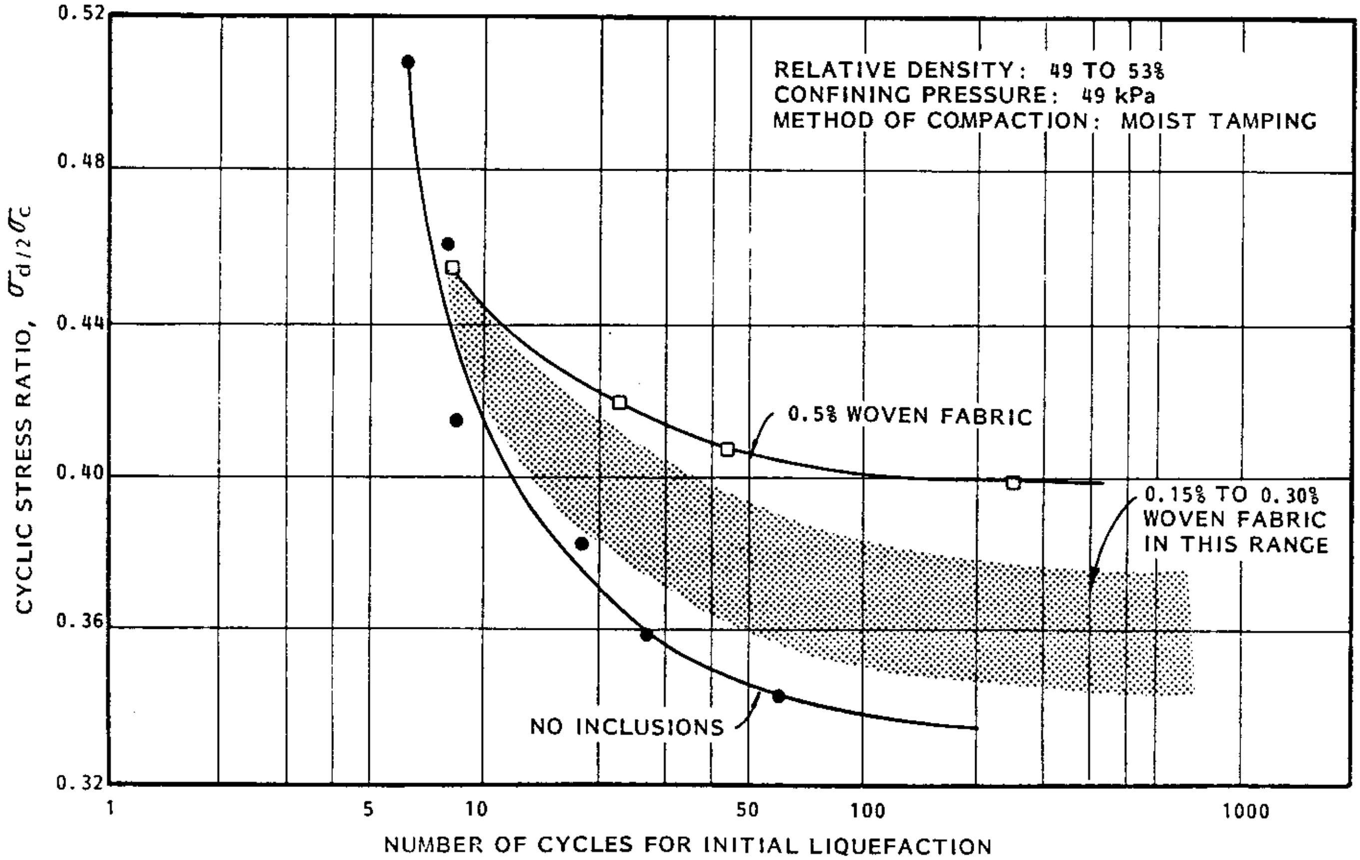

FIGURE 4 - RESULTS OF CYCLIC TRIAXIAL TESTS SERIES 4 AND 5

method of placement. If sand and reinforcing fiber or fabric materials are pluviated under water, undesirably low densities are produced. Under these conditions, the presence of synthetic materials can have adverse effects on the soil's liquefaction susceptibility. However, if treated and untreated soils can be densified to equal densities, inclusion of high modulus woven fabrics with coarse texture improves soil resistance against liquefaction. At present, we do not have conclusive evidence that this is also true for fibers. Smooth thin threads certainly do not have any beneficial effect, but tough fibers, in ribbons which are wider than soil grain size, might be useful. More dynamic tests are presently being run on this type of material.

Because the deposition of sand and fiber or pieces of fabric under water (pluviation method) does not appear to be a satisfactory technique for achieving sufficiently high relative densities, a new method of fill placement that will provide some degree of compaction control should be found. This constitutes an important challenge for the next phase of the research in progress at San Diego State University.

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