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AGING EFFECTS ON CYCLIC SHEAR STRENGTH OF TAILINGS MATERIALS

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ABSTRACT

With an aim to clarify the effects of aging of tailings materials, a series of cyclic triaxial tests was conducted on undisturbed more or less cemented sand samples with different ages of deposition which were recovered from two tailings dam sites at El Cobre in Chile. The outcome of the study revealed that the sand with an age of 30, 5, and one years of deposition possesses about 3.5 times, 2.4 times and 2.0 times stronger resistance to cyclic stress application, respectively, as compared to the sample freshly reconstituted sample.

INTRODUCTION

It has been generally recognized that the resistance of sand to liquefaction tends to increase with increasing age of deposition, probably because of the cementation or welding developing at points of grain contact over a prolonged period of time. Mori et al. (1978) indicated the possibility of increase in liquefaction resistance of aged sand deposits, of the order of 100%, over the resistance to liquefaction of freshly deposited laboratory samples. Kokusho et al. (1983) showed about 80% increase in cyclic resistance of intact Narita sand over the cyclic strength of freshly reconstituted specimen in the laboratory. The Narita sand is of diluvial origin possessing a history of deposition over tens of thousands years. Mitchell et al. (1984) reported that freshly deposited sands are likely to develop increased stiffness and strength, as measured by resistance to penetration, over periods up to several months. In this study, the influence of aging on the cyclic strength of sand is investigated more systematically by testing undisturbed samples with known period of deposition in the laboratory.

SAMPLING SITES

El Cobre mine is located about 100 km northeast of Santiago, Chile. The tailings derived from this copper mine had been deposited since 1930 in an old pond constructed in a valley until its operation was terminated around 1960. This pond will be referred to as El Cobre No. 1 dam. Afterwards, this dam suffered catastrophic failure at the time of March 28, 1965 earthquake (M = 7.6) which took place with its epicenter located about 20 km north of El Cobre (Dobry and Alvarez, 1968). After the impoundment of the No. 1 dam had been terminated, a new pond was provided in a nearby valley and has been in operation since then. The dike retaining this new pond will be referred to as No. 4 dam.

Blocks of moderately cemented sand were procured from the exposed surface of deposits at the No. 1 dam site which had been formed as a result of sedimentation of tailings. In the No.4 dam, sampling from within the pond was a difficult task and, therefore, block samples were carefully recovered from pits excavated on the downstream slope of the dam. The material in the downslope had been placed by pouring cyclone-separated sand-size tailings over the already-existing dry surface of the slope. Since the ground water level in the downstream slope was far below the surface, the sample taken there should be considered as being an as-placed sand, in contrast to the sample taken from the No. 1 dam site which is deemed as being under-water sedimented sand. However, as mentioned below, the gradation characteristics of the sand from these two different sites was almost identical.

RECOVERY OF BLOCK SAMPLES

As a result of the collapse at the time of the 1965 earthquake, many scarps with a maximum height of about 15 m were formed at the edge of the exposed horizontal sliding surface. Gullies have been formed thereafter by erosion due to rainfalls. It was an easy task to walk down the gully and to expose a slab-like intact sand by removing the overlying more or less disturbed soil layers. Chunks of the plate-like samples about 15 cm thick were recovered and transported to the Geotechnical Engineering Laboratory at the Catholic University of Chile. The sand was moderately cemented and by no chance any disturbance appeared to have been incurred to the block sample during the handling and transportation. The sample had been in place there for the last 30 years since 1955.

The younger-age samples were recovered from deposits near the downslope surface of the No. 4 dam by means of two methods. At the beginning of 1985, a deep pit was excavated to a depth of about 8 m on the downstream slope. Undisturbed chunks of sand samples were taken by carefully carving the sand deposit into about 30 cm x 30 cm x 30 cm cubes and by enclosing the chunk into a wooden box. In view of an annual rate of dike-height raising of 1.5 m, the sample procured from a depth of 8 m was regarded as having been there over a period of 5 years. The samples were lightly cemented and no disturbance appeared to have been incurred during handling and transportation.

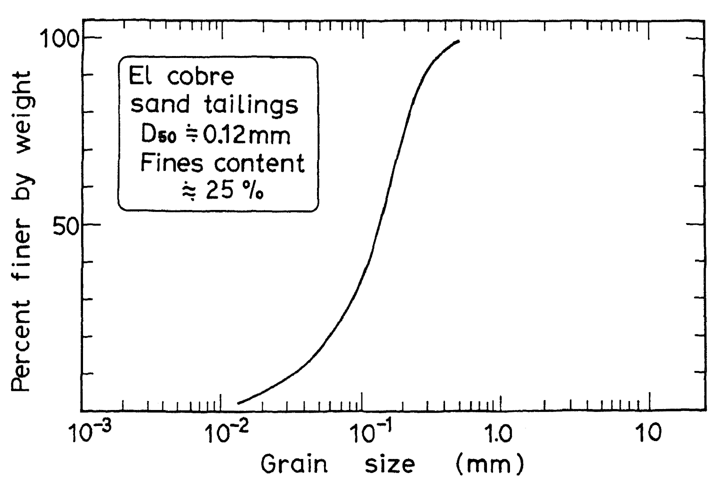

Fig. 1

Gradation curve of sand tailings

The newest samples were obtained from a shallow pit about 1.5 m deep dug on the downslope surface of the No. 4 dam. Special care was taken to prevent any disturbance during handling and transportation. The sample had been placed there about a year ago.

The analysis of grain size characteristics showed that all the samples from the three sites have fines content passing # 200 ranging between 15 and 30%. An average grain size distribution curve is shown in Fig. 1. Since these samples are all from the same concentration plant, the cyclic strength obtained from the tests is deemed to reflect only the effects of aging under otherwise identical conditions.

CYCLIC TRIAXIAL TESTS IN THE LABORATORY

All the blocks of sand samples transported to the laboratory were tested by means of the cyclic triaxial test apparatus. The block of sand was trimmed into solid cylindrical specimen 5 cm in diameter and 10 cm in height, and after put in place in the triaxial cell, it was saturated with a back pressure of about 100 kN/m^2 whereby a B-value of 0.95 was attained. The samples were consolidated under a confining stress of 50 kN/m^2 or 100 kN/m^2 which are considered slightly in excess of the in-situ overburden pressure. In addition to the undisturbed samples, the sample reconstituted to possess the same density as in-situ was also tested to provide data for comparison. Then, the cyclic axial stress was applied under undrained conditions until the sample deformed to a double-amplitude axial strain of 5%.

TEST RESULTS AND DISCUSSIONS

The results of cyclic triaxial tests on the 30 year-old undisturbed samples from El Cobre No. 1 dam are presented in Fig. 2 in terms of the cyclic stress ratio versus the number of cycles required to cause 5% double-amplitude axial strain, where the cyclic stress ratio is defined as the ratio of amplitude of cyclic axial stress to twice the initial applied confining stress. The samples were identified to contain about 25% fines passing # 200 mesh and to have a void ratio of about e = 0.91. The outcome of the tests shown in Fig. 2 indicates that the cyclic stress ratio needed to soften the sample producing 5% double amplitude axial strain in the course of 20 cycles is about 0.5 on the average.

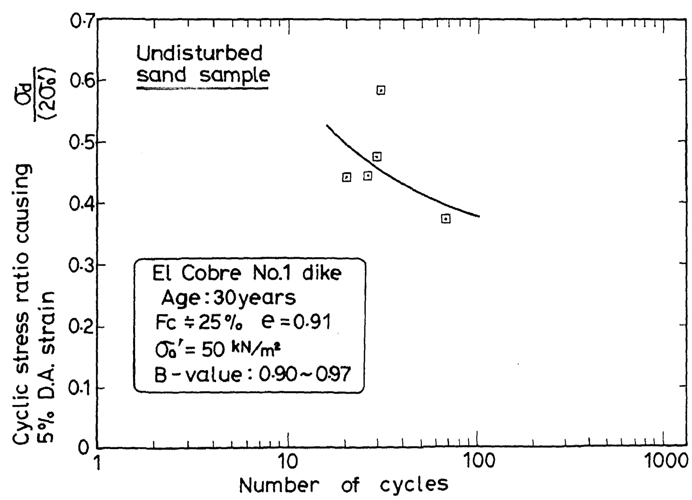

Fig.2

Cyclic stress ratio versus number of cycles for 30 year-old samples

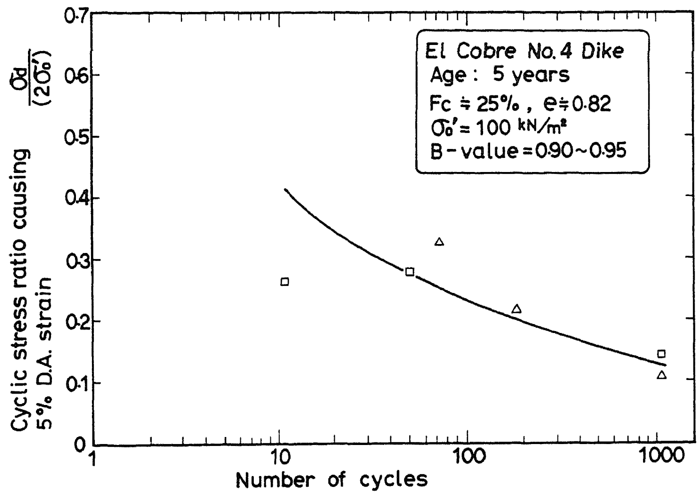

Fig.3

Cyclic stress ratio versus number of cycles for 5 year-old samples

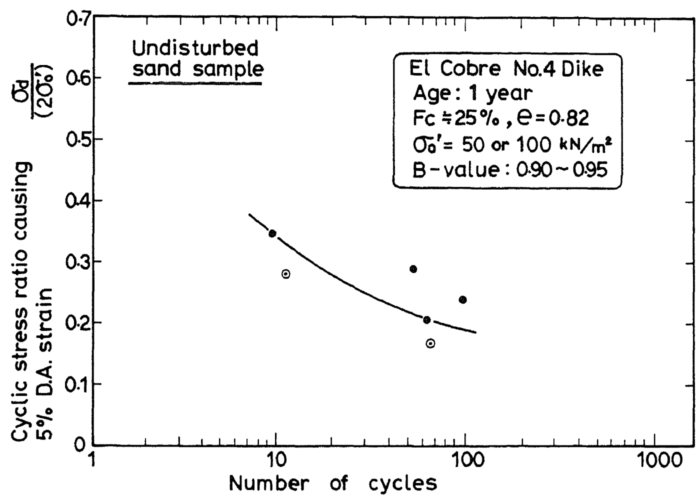

Fig.4

Cyclic stress ratio versus number of cycles for one-year old sample

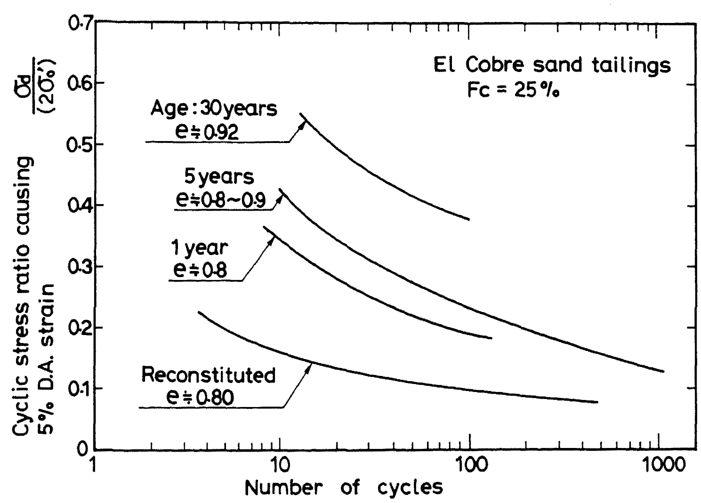

Fig.5

Summary plots of all the test results

The test results on the 5 year-old intact samples from El Cobre No. 4 dam are shown in Fig. 3, where it may be seen that the sample with a void ratio of about 0.82 requires a cyclic stress ratio of about 0.35 to produce a state of softening under 20 cycles of load application.

The results of cyclic triaxial tests on the one-year old samples are presented in Fig. 4, where it may be observed that the samples with a void ratio of about e = 0.82 should undergo 20 cycles of load application with a cyclic stress ratio of about 0.28 in order to produce a state of softening accompanied by a 5% double-amplitude axial strain.

The average curves shown in the above figures correlating the cyclic stress ratio and the number of cycles are displayed together in Fig. 5 for comparison sake. Also shown in Fig. 5 is a curve obtained from the samples reconstituted to approximately the same void ratio as those of the intact samples. It may be seen that the cyclic strength curves are located gradually upwards with increasing age of sample deposition, with a curve for the reconstituted samples specially located utmost down. It can thus be mentioned that the tailings sand at El Cobre containing about 25% fines tends to gain cyclic shear strength as the length of depositional time increases. It may also be mentioned that even one-year old samples hydraulically placed on the dry downslope surface shows almost twice as much cyclic strength as that of the laboratory samples reconstituted by the method of pulviation under water.

In order to visualize the influence of sustained period of deposition, the cyclic stress ratio required to spawn 5% double amplitude axial strain in 20 cycles of load application was read off from the test data shown in Fig. 5 and plotted versus the number of cycles in Fig. 6. It may be seen that the cyclic resistance as defined above tends to increase from a value of 0.27 for the one-year old sample through a value of 0.33 for the 5-year old sample up to a value of 0.50 for the sample deposited over a prolonged period of 30 years. The cyclic stress ratio shown in Fig. 6 for each period of deposition is normalized to the cyclic stress ratio for the freshly reconstituted sample, as shown in Fig. 7. It may be mentioned that the cyclic strength of the 30-year old sample is 3.5 times greater than the cyclic strength of freshly deposited sample. It is also of interest to note that the substantial increase in cyclic strength takes place within a few years, as noticed by Mitchell and Solymar (1984).

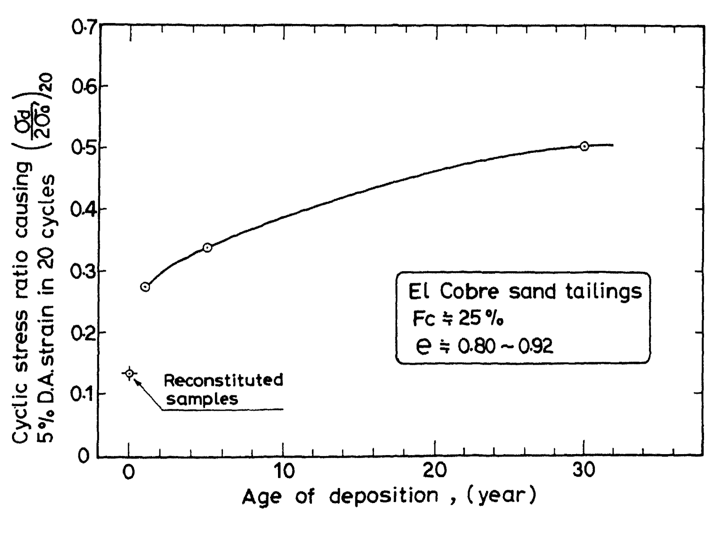

Fig.6

Cyclic shear strength versus age of deposition

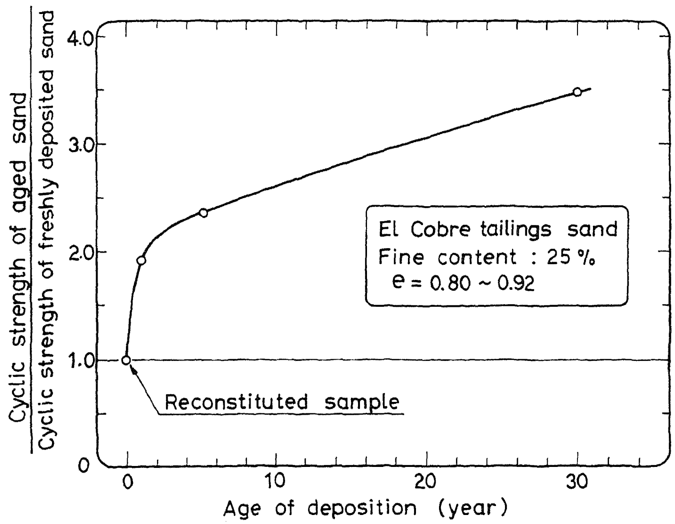

Fig.7

Increase in cyclic strength over the one-year old samples

CONCLUSIONS

To evaluate the degree of gain in cyclic resistance of sand due to prolonged period of deposition, three batches of undisturbed samples of sand were recovered from two sites of tailings dam at El Cobre, Chile. A series of cyclic triaxial tests were performed on each batch of these specimens. The result of tests disclosed that the cyclic stress ratio required to produce a state of softening with 5% double-amplitude strain tended to increase by a factor of 3.5, 2.4 and 2.0 for the samples of 30, 5 and one years of sustained deposition, respectively, as compared to the cyclic strength of freshly deposited samples. It was also known that even one-year period of deposition tends to produce almost two fold increase in the cyclic strength for the tailings sand containing about 25% fines.

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