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In-situ Undisturbed Sand Sampling by Radial Freezing for Liquefaction Analysis

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SYNOPSIS. The authors experimented in laboratory that if radial freezing with free drainage is performed under an effective confining pressure of 100 kPa only an increase of the order of 0.5% of volumetric strain takes place going from the unfrozen to the frozen condition. The sample comes back to the original dimension after thawing. The displacements of the sample were measured by radiographs of a lead shot network properly built inside the sample. The technique suggested by Yoshimi and al. (1977) to freeze in situ a column of saturated sands was also verified and optimized in laboratory by simulating in a full scale test the site conditions. Finally 3.10 m length and 55 cm. diameter sample of saturated sand was frozen at a well studied site by radial freezing technique, then pulled out from the ground by a crane, sawed and stored in a freezer for future laboratory tests.

INTRODUCTION

Liquefaction of saturated sands during an earthquake is one of the most serious cause of damages for the structures founded on saturated sands. For siting of nuclear power plants liquefaction can be one of the most critical problem. At present two main lines are followed to assess liquefaction potential (Seed 1976). One is based on historical data regarding sites which underwent or not liquefaction during past earthquakes; the second one compares data from cyclic strengths on undisturbed or reconstituted samples with the dynamic stresses computed by site seismic response analysis. The first method is based on in situ tests (SPT) and on evaluation of the in situ seismic stresses occurred during past earthquakes, the other one defines a safety factor based on laboratory test data which are as good as the samples represent the in situ condition. That is true also for all laboratory test but is the main point for dynamic test on saturated sands. In fact undisturbed sampling of saturated sand or reconstitution of samples in laboratory with the in situ relative density, does not warrant that the in situ soil characteristic are fully represented. Recent laboratory investigation (Seed, Arango, Chan 1975) showed that other factors, such as soil structure, geologic history, preshaking, over consolidation ratio, sampling disturbance and preparation methods for reconstituted samples affect liquefaction potential. So the only way to overcome most of the above outlined problems is to test samples as much as possible undisturbed. Radial Freezing proposed by Yoshimi et al. (1977) is the most promising technique to get pratically undisturbed samples of saturated sand. CNEN, the Italian Committee for Nuclear Energy, within the research program for Nuclear Safety, is doing tests in situ and in laboratory to investigate the degree of disturbance induced by the freezing/thawing process and to optimize the technique to get frozen samples of saturated sands from any pratical depth.

RECENT INVESTIGATION ON SAMPLING BY FREEZING

Hvorslev (1949) reports the first attempt to use freezing to recover samples up to 91 cm in diameter with a sistem of freeze pipes driven all around a bore hole at Fort Peck Dam site. Recently Yoshimi, Hatanaka and Oh-Oka (1977) have presented the first example of in situ radial freezing to obtain sand samples. The sampling technique involves the driving of a buried freezing tube into the ground and removing the soil from inside with a cup auger. Reached a selected depth, the lower end of the tube is sealed and the water inside is pumped out. Through a vinyl tube 30 mm diameter inserted in the freezing tube, a mixture of ethanol and crushed dry ice is continuously circulated at -40°C to -60°C for at least 16 hours. A column of frozen sand can be obtained and pulled out of the ground. The authors showed through one dimensional freezing test with free drainage that under a minimum confining pressure of 10 kPa no measurable volume change is developed during the freezing. They showed also (Yoshimi et al. 1978) that freezing and thawing process does not affect static strenght and deformation characteristics of sands containing less than 5 percent fines. Recent laboratory investigation by Singh , Seed and Chan (1979) showed that if satured sand is frozen by radial freezing with free drainage and confining pressure conditions, the following coring of samples and thawing process do not affect the cyclic strenght characteristics and the increase of cyclic strenght due to preshaking is manteneid. Da Roit, Lojelo, Muzzi, Spat (1981) presented the results of direct measurements of intergranular movements due to freezing-thawing process applying radiographic techniques to detect the displacement of a lead shot network built into the sample. The authors decribe a triaxial cell capable of isotropically consolidating and freezing a 17.5 cm high and 7.2 cm diameter sample. The base of the cell allows circulation of liquid nitrogen so that the frozen front procedes from the bottom to the top of the sample while free drainage of water is allowed from the top of the cell. Under an effective confining pressure of 100 kPa a satured sample of clean sand was frozen in about 5 hours and 7% of the volume of water was drained; during the thawing phase, exactly the same amount of water entered into the sample. Three radiographs was taken on the sample to measure the displacements of the lead shot network in the soil mass. The first one before the freezing, the second one on the frozen sample and the last one after the thawing. The results of the measurements of the distances among The lead shots show a small dilation during the freezing phase which is pratically completely recovered when the sample is thawed. A volumetric strain of the order of 0.5% was computed which is well inside the elastic response of the sand sample. The above referred investigations all agree that if radial freezing technique is used and free drainage of water is allowed under a confining pressure, practically undisturbed samples of saturated sand can be get. Tsytowich (1975), studing the behaviour of frozen soils, showed that the fondamental process in freezing soils is the migration of pore water. In saturated sands with free drainage, at least in one direction, water does not migrate toward the freezing point but it is squeezed out and the increase of volume due to phase change from water to ice is pratically fully compensated by the water expelled still in the liquid phase .

LABORATORY FULL SCALE TEST TO SIMULATE SITE CONDITION

To investigate and optimize the in situ sampling technique proposed by Yoshimi et al. (1977) full scale laboratory tests was arranged. A large triaxial cell capable of isotropically and anisotropically consolidating and radially freezing 80 cm high and 40 cm diameter samples was built. Fig. 1 shows a cross section of the triaxial and freezing cell.

Massaciuccoli sand N. 6 was used for the test. This is a clean sand used for industrial purpose, it passes through the N. 30 sieve and is retained on the N.50 sieve with a uniformity coefficient of 1.5 and a mean grain size equal to 0.27 mm. The maximum and minimum void ratios are 0.85 and 0.61 according to the ASTM D 2049-69 procedure. The unit weight of solid particles is 26.0 KN/M^3. The sample was pre-

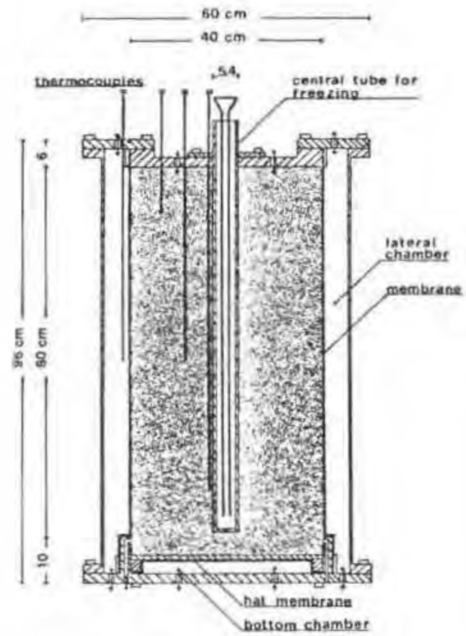

Fig. 1 - Triaxial cell for full scale laboratory freezig test. Cross section

parated at a relative density of 60%, using the wet tamping method, described by Mulilis, Chan and Seed (1976), depositing the sand in ten layers inside a mold in a CO_2 atmosphere to improve the saturation process. Preliminary investigation, reported by Da Roit et al. (1981), have shown how this method of sample preparation allow to obtain highly uniform sample. After saturation by slow circulation of disareated water from the bottom to the top, an effective confining pressure of 100 kPa was applied; saturation was obtained increasing the chamber pressure, checking the value of the Skempton's pore pressure parameter B and increasing the back pressure so that the desired effective pressure was maintained. A maximum value of B equal to 0.87 was obtained with a chamber pressure of 700 kPa and a back pressure of 600 kPa. The freezing of the sample was obtained by circulating vapours of liquid nitrogen for about 10 hours. Pore water squeezed by the freezing process through the top drainage entered into the back pressure line which included also the volume change device capable of measuring the amount of water and the verse of the water flow. During the freezing process 6.5 l of water were squeezed out (about 7% of the volume of water) and during the thawing process the same amount of water entered again into the sample. About 600 l of liquid nitrogen were consumed during freezing.

IN SITU SAMPLING BY RADIAL FREEZING

On the base of the results obtained from the full scale laboratory test an in situ experimental test was carried out. A well studied area was chosen where a considerable number of SPT tests were available indicating at depth of 2.5 m from the ground surface a sand layer 5m thick. The relative density of the sand, estimated by the SPT blow-counts and the Gibbs and Holtz (1975) correlations was about 60%. The ground water level was 1m below the ground surface. A thin SPT tube of 76 mm diameter was inserted in a hole predrilled without circulating water and its lower end was sealed. A 17 mm diameter freezing tube was inserted inside and liquid nitrogen circulated. After 12 hours a sample 3.10 m length and 55 cm diameter was pulled out. Figg. 2, 3, 4, 5 show the test area, the sample pul-

Fig. 2 - The test area

Fig. 3 - The sample is pulled out by the Crane

Fig. 4 - The sample is sawed

Fig. 5 - The sample is stored

led but by the crane, sawed and stored in a freezer. During the test about 4000 l. of liquid Nitrogen were consumed.

CONCLUSION

A freezing thecnique to get from the site undisturbed samples of saturated sand was investigated. Preliminary laboratory tests showed that radial freezing, if free drainage is allowed, does not develope measurable volume change during freezing-thawing process. A laboratory full scale test was carried out to reproduce the in situ conditions and to investigate and to optimize the sampling technique originally proposed by Yoshimi et al. (1977). Finally a 3.10 m lenght and 55 cm diameter sample of saturated sand was frozen in situ by the radial freezing technique and easyly pulled out from the ground.

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