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EXPERIMENTAL OBSERVATION OF THE FAILURE PROCESS IN A DYNAMIC BEARING CAPACITY TEST IN SUBMERGED SAND

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1. INTRODUCTION

Aseismic design procedures for foundations emphasize mostly on the effects of horizontal seismic forces. However, if the epicentral distance to a foundation is short, the vertical component and its rate of loading will be of significant importance for the stability of the foundation. Nevertheless, the effects of high-rate vertical loading on the bearing capacity of a footing on sand is little understood.

The scope of this report is to present experimental results from dynamic bearing capacity tests in submerged sand under different vertical loading rates by using both the conventional and a new experimental techniques.

The recent major earthquakes in Northridge, California and Kobe, Japan, where significant vertical accelerations were recorded justify the need for research on this topic.

2. EXPERIMENTAL METHOD

The Laser-Aided Tomography [1], LAT, is a new experimental method which enables the visualization of all particles interlocking one another in a three-dimensional coarse granular model. Its enhancement [2], allowing the observation of the inner deformation process in a fine-grained assemblage, is a very powerful tool for studying the behavior of submerged sand models.

In both the conventional and LAT bearing capacity tests, the same sample size, W300 x D150 x H170 and a footing diameter, D = 70 mm, were chosen. The footing was driven at a constant speed of settlement during one experiment. Onahama sand, D_{50}= 0.176 mm, was used in the conventional tests and crushed optical glass, D_{50}= 0.47 mm, in the LAT tests, respectively.

3. TEST RESULTS

Ten tests with submerged Onahama sand at three different rates of footing settlement - 1, 10 and 100 mm/min were conducted. The variation of the bearing capacity factor with the loading rate is presented in **Fig.1**. The full curve in this figure is the average relation of the experimental data by Vesic [3]. As in this test result with submerged sand, the experimental data with Onahama sand also considerably scattered. The scatter is believed to be a result of the sensitivity of the bearing capacity of submerged sand to small changes in degree of saturation and sand density (cf.: **Fig.2**). This phenomenon should be more pronounced in fine-grained sands with lower permeability coefficients.

Two main factors is believed to cause the increase in bearing capacity in dense saturated sand at high loading rates: (1) the development of negative pore water pressure in the sand; (2) the change in shape of the triangular active wedge formed beneath the footing. With increasing loading speed, the angles between the footing base and each rupture surface of the wedge decreases, resulting in an increase in the bearing capacity of the ground.

The pore-pressure was measured in a series of 9 tests with Onahama sand, permeability

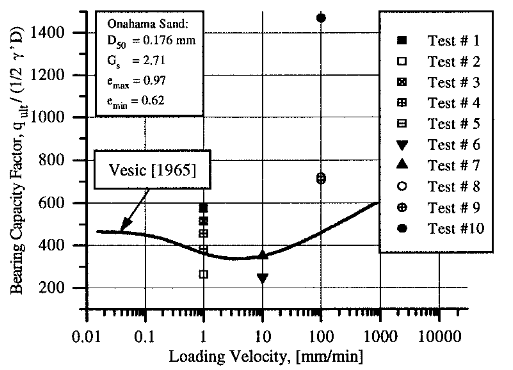

Fig.1 Bearing capacity factor versus loading velocity for submerged sand.

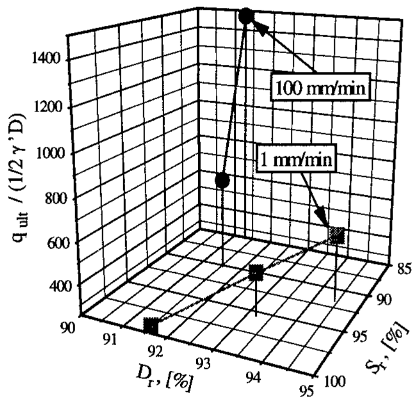

Fig. 2 Bearing capacity factor versus relative density and degree of saturation.

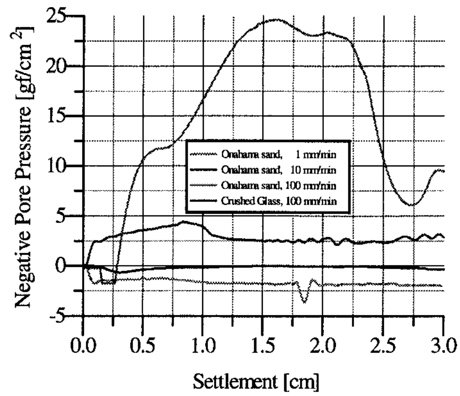

Fig. 3 Change in pore pressure with increasing settlement at three different loading speeds.

coefficient, $k=196\times10^{-3}$ mm/s. **Fig.3** represents the results from these tests, confirming the hypothesis of the increase in negative pore-pressure with loading speed and hence temporary increase in sand's shear strength.

To study the time effect on the displacement of the sand grains beneath the footing, more than 10 LAT tests were performed, at three different speeds: 1, 10 and 100 mm/min. The bearing capacity changed with the same tendency as in the conventional tests with sand. The effect of negative pore pressure development at the high loading speed of 100 mm/min have been found to be negligible due to the high permeability coefficient, $k=878\times10^{-3}$ mm/s, of the crushed glass, cf. **Fig.3**. **Fig.4** shows a result typical of LAT. It depicts an image of the model's middle cross-section at the residual state, as observed in a general shear failure. Due to technical difficulties of taking photographs at high loading speed and limited available time, the LAT tests could not yield a clear proof for the change in the failure wedge's angle with loading rate yet. Another series of LAT tests is being conducted, which should provide more detailed explanation of the phenomenon.

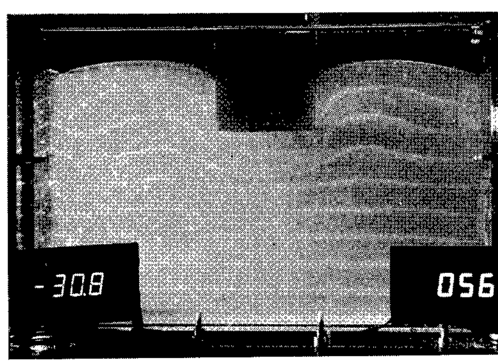

Fig. 4 Deformed middle cross-section. Settlement = 30.8 mm; Load = 56 kgf.

4. CONCLUSIONS

The bearing capacity of submerged granular material at three different loading rates was studied by means of both the conventional and a new experimental method, namely Laser-Aided Tomogrphy. Two factors are believed to cause the increase in bearing capacity in dense saturated sand with increase in loading rate: (1) the development of negative pore water pressure; (2) the change in shape of the triangular failure wedge formed beneath the footing.

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