Behaviour of Water Saturated Sand Subjected to Cyclic Axial Loading With Initial Shear

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1. Introduction

During the Hyogoken-Namby earthquake in 1995, the substantial lateral displacement occurs in the harbour quay walls. Also, large distortion and subsidence of important facility developed during the seismic shaking. Usually, the foundation soils under those structures are loose water saturated sands. The shaking table tests on quay wall, shows that large deformation in the foundation of the wall occurred although the effective stress path did not reach the state of zero effective stress, which point that the displacement occur as combined effect of shaking and pore water pressure development. Axial cyclic stress state near to the failure line was observed with the experiments (Figure 1).

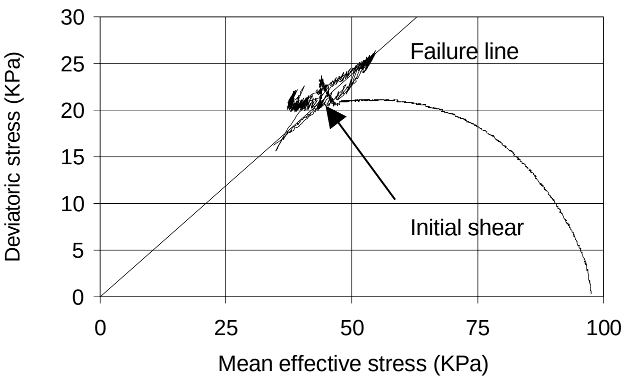

Fig. 1. Stress state near to the failure line during cyclic axial loading with initial shear

2. Stress state in the foundation soil

The stress state in the foundation soil under the waterfront quay walls is very complex. Efforts are made to learn the behaviour of the foundation soil during the seismic shaking. The stress state in the foundation soil under the toe of the quay wall is characterized with cyclic forces which acting perpendicular on the shearing plane, where horizontal (sliding) forces induce constant shear stress and rocking forces cause axial cyclic loading (Figure 2 and 3).

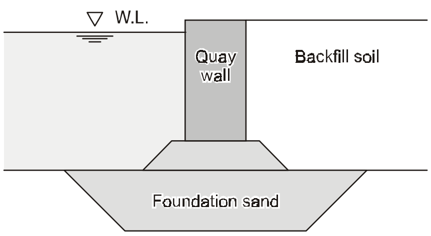

Fig. 2. Typical cross section of gravity quay walls

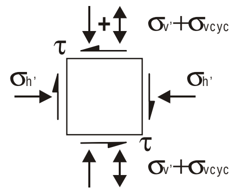

Fig. 3. Forces acting on the soil element

3. Experimental procedure

Hollow cylindrical specimen of Toyoura sand with the height of 19.5cm, outer diameter of 10.0cm and inner diameter of 6.0cm were used. The densities of 40% and 56% were used during testing. The specimens were isotropically and anisotropically ($\sigma_v'/\sigma_h'=2$) consolidated to considered confining pressure. During the test 98Kpa, 196Kpa and 294Kpa confining pressures were used.

The specimen, first were monotonically sheared to 1% shear strain state under constant volume. Then cyclic axial loading was applied under constant volume. The ratio of cyclic load was in range of 0.05, 0.10, 0.20 and 0.40 from the starting confining pressure, dependable on confining pressure. Vertical cyclic force was with sinusoidal shape and period of 600 seconds. During applying the cyclic force shear stress was kept constant as at 1% shear strain.

4. Test results

Experimental data shows that cyclic axial loading has influence on the development of shear strain during constant shear stress. Cyclic axial loading, generate an increasing of the shear strain. Significant increasing of the shear strain increment occurs during the first cycle, and decrease with increasing of the number of cycles (Figure 4 and 5).

Relationship between mean effective stress and deviatoric stress shows that the stress state is near or on a failure line (Figure 4 and 5).

Test results on the relationship between vertical stress versus vertical strain show two types of behaviour. In case of isotropic consolidation, the vertical strain in sand shows extension behaviour, while in case of anisotropic consolidation, the vertical strain in sand show compressive behaviour (Figure 4 and 5).

Keywords: Axial cyclic loading, loose sand, quay wall, torsional hollow cylinder.

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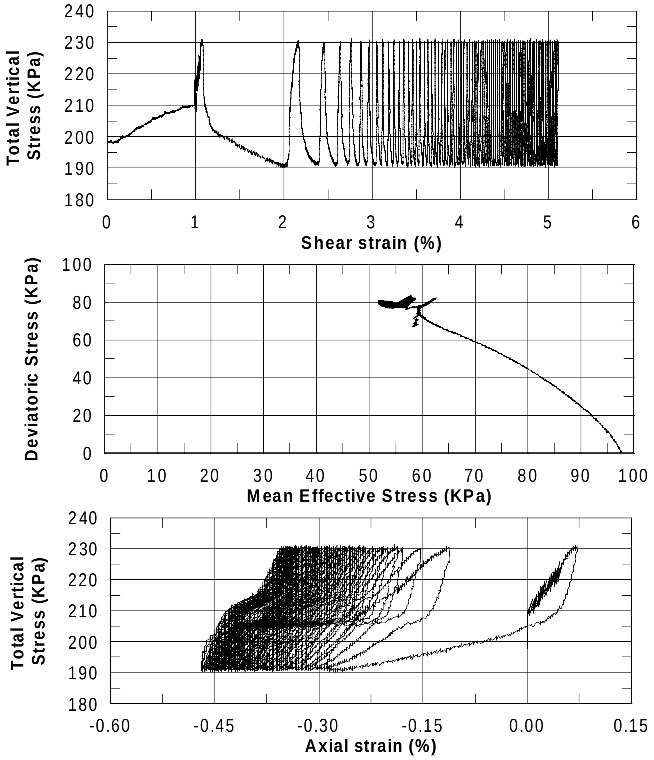


Fig. 4. The relationship between shear strain, total vertical stress, mean effective stress and vertical strain for specimens with relative density Dr=41%(e=0.888) and isotropic consolidation with 98Kpa mean confining pressure and $\delta\sigma_{cyc}/\ \sigma_c^{'}$=0.2.

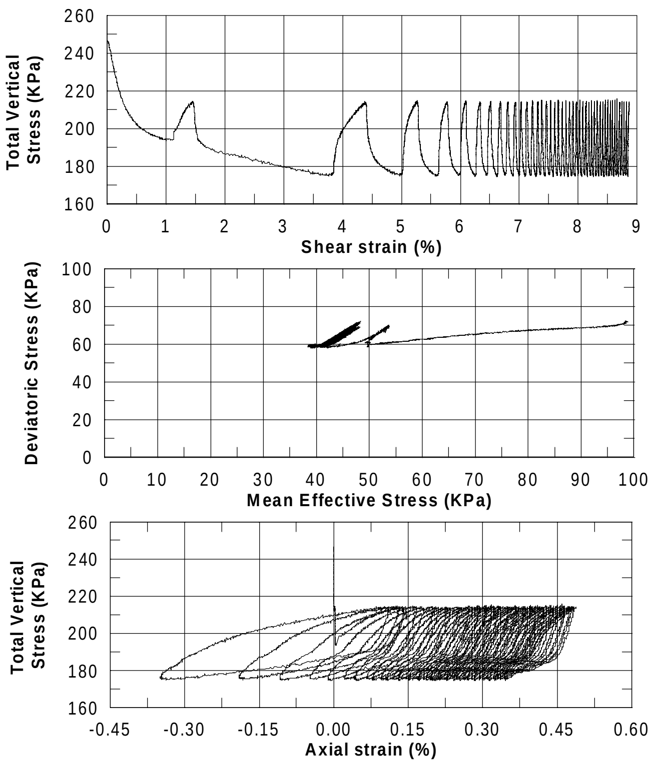


Fig. 5. The relationship between shear strain, total vertical stress, mean effective stress and vertical strain for specimen with relative density Dr=41%(e=0.888) and anisotropic consolidation K=2, with 98Kpa mean confining pressure and $\delta\sigma_{cyc}/\ \sigma_c^{'}$=0.2.

5. Conclusion

The summarized data on torsional shear strain increment after first cycle (Figure 6), shows that the confining pressure, relative density and ratio of cyclic loading introduce different behaviour of the strain increment. The number of cycles for stabilizing the shear strain was varying, however in some cases it was not possible to achieve steady state. Data shows that increase of confining pressure and axial cyclic load lead to increase of the first cycle strain increment. Also, looser sands shows large first cycle shear increment with no stabilizing the shear increment.

The data from the recent experiments are showing the importance of the problem of lateral displacement. Prediction of permanent lateral displacement and vertical settlement is extremely important for waterfront structure as well as for the offshore structures. Large displacement of the waterfront structures will induce damage and no usability of the offshore structures. During design of such structures, not just allowable stresses and factor of safety, but also and the level of residual displacement should be taken in to account, as the factor which shows the usability and repair ability of the structure.

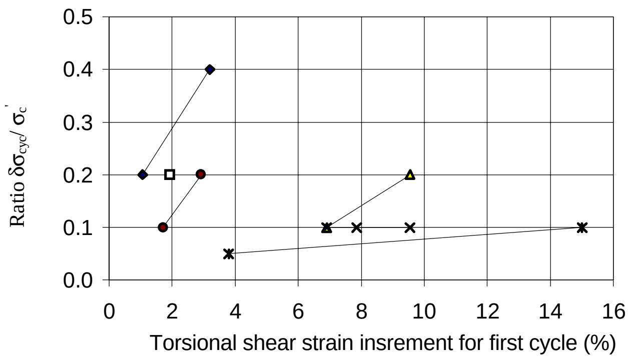
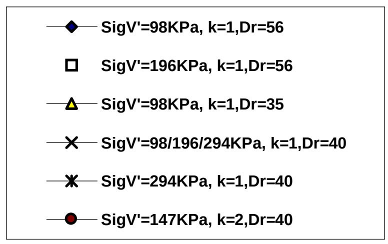


Fig. 6. Torsional shear strain increment after first cycle (lines does not represent the shear strain increment for the range between observed results)

Legend:



6. References

Ghalandarzadeh, Abbas et Al, (1998) *Shakin Table Tests on Seismic Deformation of Gravity Quay Walls*, Soil and Foundation, Special Issue on Geotechnical Aspects of the January 15, 1995 Hyogoken-Namby Earthquake, pp. 115-132.