EXPERIMENTAL STYDY OF THE ANISOTROPIC BEHAVIOUR OF COHESIONLESS SOILS UNDER TORSIONAL SHEAR

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EXTENDED ABSTRACT

In this thesis the effect of anisotropic consolidation on undrained sand behaviour is investigated under monotonic and cyclic torsional shear in the hollow cylinder apparatus of the National Technical University of Athens. Emphasis was given on comparing the response between isotropically and anisotropically consolidated specimens during shearing at fixed directions of the major principal stress with respect to the vertical and during shearing with continuous rotation of the principal stress direction. The undrained response of the sand specimens was assessed at various densities, stress levels, cyclic stress levels and consolidation stress ratios. The experimental results in this thesis represent a useful dataset for researchers to use in advanced numerical modelling and practicing engineers to assess the influence of anisotropic consolidation on the response of development and infrastructure in or founded on sand deposits.

The results of the monotonic torsional shear tests showed that anisotropic consolidation does not alter the mobilised angle of shearing resistance at failure, phase transformation and peak shear stress. However, the stiffness characteristics and the stress paths of the sand specimens differ in a number of ways depending on the adopted consolidation path. Anisotropically consolidated specimens (AC), appear to be less stiff and exhibit higher shear stress and lower excess pore water pressure compared with isotropically consolidated specimens (IC). Most importantly, anisotropic consolidation greatly affects the response of loose sands; collapse was observed for anisotropically consolidated specimens in contrast with brittle behaviour exhibited by their isotropically consolidated

counterparts. Moreover the shear stress level reached at the end of various anisotropic consolidation paths has been found to affect significantly the shear stress increase under undrained conditions required to initiate unstable response; this observation highlights that should the in situ conditions be anisotropic, as will usually be the case, for engineered structures, in, or founded on, loose sand engineering design should take into account that such sand deposits may be prone to collapse even for small increases in shear stress under undrained loading conditions.

The results of the cyclic torsional shear tests showed that the cyclic resistance of sand specimens is strongly affected by anisotropic consolidation and it is less than half of the cyclic strength of isotropically consolidated material at the loose state; this trend reverses at the dense state. These experimental findings suggest that the consolidation conditions should not be ignored in geotechnical design while extra attention is required for the case of anisotropically consolidated loose to medium dense sand deposits which would exhibit lower earthquake resistance. Cyclic strength resistance increases with density irrespective of consolidation path while for loose sand specimens the cyclic strength resistance decreases with decreasing consolidation stress ratio. Moreover, it was found that AC specimens develop at all densities a terminal pore water pressure which is less than 40% of the initial effective stress and fail due to axial strain accumulation contrary to IC specimens which reach terminal pore pressure ratios higher than 70% and fail due to shear strain accumulation. Accordingly to these results, the problem of stability of engineering structures founded on or in sand deposits should not be approached solely by designing on the principle of keeping the induced pore pressure ratio below 100%. The ratio of the terminal excess pore water pressure to the initial mean effective stress is described as a function of consolidation stress ratio and density while the development of excess pore water pressure during cyclic loading is uniquely defined for all tests as a function of normalised shear work imparted to the sand during cyclic loading.

The comparison made between monotonic and cyclic torsional shear tests showed that the behaviour of anisotropically consolidated loose sand specimens under cyclic torsional loading can be interpreted in terms of a bounding line, namely the instability line defined in monotonic loading tests, in the vicinity of which a sudden increase in the rate of excess pore water pressure and strain accumulation is observed and the sand strain-softens. This pattern of cyclic behaviour is independent of the adopted consolidation path. However, for AC specimens this unstable response is arrested at phase transformation and the sand specimens show a stable or temporarily stable effective stress cycle at low and high consolidation stress ratios respectively while IC specimens exhibit initial liquefaction after strain-softening. For both IC and AC specimens at higher densities, the phase transformation line, PTL, defined under cyclic loading appears to coincide with the PTL defined under monotonic loading irrespective of the consolidation path followed. A common PTL was obtained for loose and medium density specimens; however for very dense specimens which show very small contractive tendency, $\Delta u/p_i' < 4\%$, the mobilised angle at phase transformation appears to decrease. The results of the cyclic tests also showed that the influence of anisotropic consolidation should not be neglected when defining the stiffness and damping ratio values of sand.

Finally, the results of undrained cyclic loading tests performed under torsional shear on four isotropically consolidated sands of various densities, initial stress levels, gradings and origins were used to establish the pattern of excess pore water pressure generation with cycles leading to initial liquefaction. Two equations are derived to predict this pattern. The first is based on the method introduced by Ishibashi et al. (1977) and incorporates density and effective stress level to the original equation. As a consequence a single constant reflecting material property has replaced the original four material constants. Moreover, the development of pore water pressure up to initial liquefaction has been expressed as a function of dissipated energy and an expression was derived including density, stress level, mean grain size and sphericity as variables. The proposed equations due to their simplicity can be readily implemented in numerical calculations related to liquefaction problems.