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ORIGINAL PAPER

Effective Stress Change and Cyclic Resistance of Saturated Sands Under Uniform and Irregular Cyclic Shears

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Abstract In this study, two marine sands collected from Vietnam (Nam O sand) and Japan (Toyoura sand) with similar grain size were tested under undrained uniform and irregular cyclic shears and the effective stress change and liquefaction resistance of the soils were then observed for different cyclic shear conditions. For the uniform cyclic shear, the tests were carried out with various cyclic shear directions, different number of cycles (n), and a wide range of shear strain amplitudes (γ). Meanwhile for the irregular one, the two-directional cyclic shear tests were performed with different amplitudes of maximum shear strain (γ_{max}). It is shown from the experimental results that firstly, the threshold number of cycles (n_{tp}) and cumulative shear strain (G^*_{tp}) for effective stress reduction in saturated specimen at $D_r = 50 \pm 5\%$ of Nam O sand are about n_{tp} = 0.1–0.7 cycle and G^*_{tp} = 0.1%–0.5%. For specimen at $D_r = 70 \pm 3\%$ of Toyoura sand, values of n_{tp} are about 0.03–0.3 cycle while those of G^*_{tp} is constant at 0.1%. Secondly, based on relationships between the cumulative shear strain G^* and γ at the occurrence of liquefaction, the threshold cumulative shear strain for liquefaction was obtained as $G^*_{tfU} = 15\%$ and $G^*_{tfM} = 11\%$ for Nam O sand and as $G^*_{tfU} = 24\%$ and $G^*_{tfM} = 19\%$ for Toyoura sand under uni-directional and two-directional cyclic shears, respectively. Thirdly, the results of G^*_{tp} and G^*_{tfM} obtained from uniform cyclic shear were applied to the earthquake-induced irregular cyclic shears, and practical applicability was confirmed for different amplitudes of the maximum shear strain.

Keywords Cyclic shear · Effective stress · Granular material · Liquefaction

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Introduction

When a saturated soil layers are subjected to cyclic shear under undrained condition, the pore water pressure is produced and accumulated. When sandy soil layers with lower relative density are subjected to strong cyclic shears, the pore water pressure rapidly increases and the initial liquefaction of the soils is often confirmed [1]. As the time proceeds after cyclic loading, the dissipation of the cyclic shear-induced pore water pressure results in the recompression of the soil layer, then the vertical settlement would be observed at the ground surface. Since sandy soils are easily liquefied under strong cyclic loading such as during earthquakes, the liquefaction resistance and the post-liquefaction settlement have been studied intensively on different types of sand with various testing conditions [2–10]. By using the triaxial cyclic shear tests under undrained condition, Tatsuoka et al. [11] indicated that the shear strength of Toyoura sand increases in proportion to the relative density (D_r) and that the cyclic shear resistance of the sand increases quickly when $D_r > 70\%$. Based on a combination of cyclic simple shear tests and triaxial cyclic shear tests on Fraser Delta sand, Vaid & Sivathayalan [12] indicated that the cyclic shear resistance of the sand increases with D_r for various conditions of lateral stress meanwhile for loose density, the influence of lateral stress condition becomes negligible. By using the multi-directional shaking table, Pyke et al. [6] concluded that the

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