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Research article

Numerical Analysis of the phase differences in bidirectional seismic waves impacts on the granular soils liquefaction

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Keywords

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P2PSand model
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English Extended Abstract

Summary

In an actual earthquakes, the liquefaction of granular soils is generally due to seismic waves transmitted from hypocenter movement to near the field during the earthquakes. The vertical propagation of the shear wave towards the surface of the ground causes cyclic shear stress and reduces the cyclic resistance ratio (CRR) in granular soils and increases the probability of liquefaction. Large lateral deformations have been widely observed in liquefied environments during severe earthquakes, causing damage to surface structures as well as underground structures. The earthquake trigger is inherently multi-directional in nature and its amplitude and direction are always changing. This loading Characteristics creates complex patterns of stress-strain behavior when the resulting waves propagate through the soil layers. Laboratory experiments, shaking table (unit or centrifuge gravity acceleration) test and numerical methods are the proposed procedures for studying the liquefaction behavior of soil under multi-directional cyclic shear stress. In this study, a three-dimensional finite difference numerical simulation for a saturated sand column under bidirectional shear cyclic waves with different phase was performed and its results were analyzed. The numerical model was validated by comparing the results of the centrifugal shaking table experiment published by Su et al. Validation of the numerical model showed that the behavioral model and the selected numerical method are suitable for simulating the phenomenon of granular soils liquefaction created by bidirectional shear cyclic waves. The results of this study showed that the values of subsidence and excess pore water pressure in the sand column for bidirectional shaking depends on the difference in the shaking phase in the two directions, and with increasing the phase difference, the maximum amount of subsidence and excess pore water pressure decreases, and the maximum value of these parameters in the bidirectional shaking is higher than the unidirectional shaking.

Introduction

Large lateral deformations have been widely observed in liquefied environments during severe earthquakes, causing damage to surface structures as well as underground structures. The vertical propagation of the shear wave towards the surface of the ground causes cyclic shear stress and reduces the cyclic resistance ratio (CRR) in granular soils and increases the probability of liquefaction (Zhang & Wang, 2024). In 1979, Feng et al. investigated the field surveys and aerial maps of the Tangshan earthquake and confirmed the soil liquefaction due to surface waves (Fang, Wang, & Zao, 1979). Zhao and et al. introduced a coupled fluid-mechanical numerical analyses using a nonlinear constitutive model to analyze soil deformation and liquefaction caused by monotonic or cyclic loading. The new comprehensive constitutive model called P2PSand which was implemented in FLAC3D has internally calibrated parameters for the standard cyclic resistance field (SCRF) sand, which is compatible to cyclic resistance charts and empirical relations (Cheng &

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Detournay, 2021). The earthquake trigger is inherently multi-directional in nature and its amplitude and direction are always changing. This loading Characteristics creates complex patterns of stress-strain behavior when the resulting waves propagate through the soil layers (Reyes, Adinata, & Taiebat, 2019). In 2008, The impact of multidirectional shaking on the liquefaction of a level sand deposit was investigated experimentally, numerically and theoretically by Su and et al. A pair of shaking tests has been performed in a centrifuge. It was found that the peak excess pore water pressures developed under two-dimensional shaking were 0–20% greater than those developed under one-dimensional shaking, with the difference increasing with depth (SU & LI, 2008). In 2019, Andres and et al. carried out over 1000 simulations on homogeneous sand deposits with different densities and subjected to ground motions applied as unidirectional and bidirectional shearing. The dry models exhibited an 80% increase of surface settlement and in the saturated models depth averaged peak excess pore water pressure ratios were up to 60% higher. These outcomes highlight the need to account for bidirectional seismic shearing when predicting the shear-induced volumetric response of sand deposits and related damaging phenomena such as liquefaction or seismic-induced settlement, among others (Reyes, Adinata, & Taiebat, 2019). The effects of the phase difference in bidirectional seismic wave on the granular soils liquefaction behavior is studied using numerical method in this research.

Methodology and Approaches

The three dimensional numerical simulations are performed to determine the effects of phase differences in bidirectional seismic waves on liquefied granular soils behavior. The excess pore pressure, settlement of a liquefied saturated sand column under various phase differences of bidirectional seismic waves are investigated by finite difference numerical modelling. Also, the unidirectional and bidirectional seismic wave impacts on the excess pore pressure and settlement is compared by using FLAC3Dv9 software. P2PSand behavior model that is adequate to simulate the granular soil liquefaction phenomenon is utilized in this study. The numerical simulations are verified via laboratory shaking table test which was implemented by Su et al (SU & LI, 2008).

Results and Conclusions

The verification results showed that the P2PSand constitutive model and finite difference method is capable to simulate liquefaction under seismic waves in granular soils. The results of this study showed that the values of subsidence and excess pore water pressure in the sand column for bidirectional shaking depends on the difference in the shaking phase in the two directions, and with increasing the phase difference, the maximum amount of subsidence and excess pore water pressure decreases, and the maximum value of these parameters in the bidirectional shaking is higher than the unidirectional shaking.

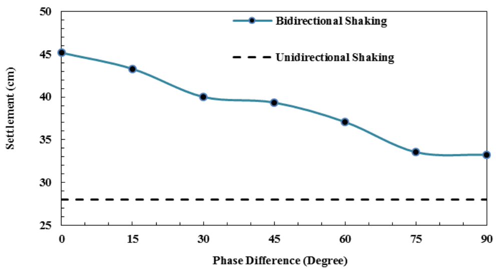

Fig. 1. Settlement vs Phase Difference of Bidirectional Shaking compared with Unidirectional Shaking

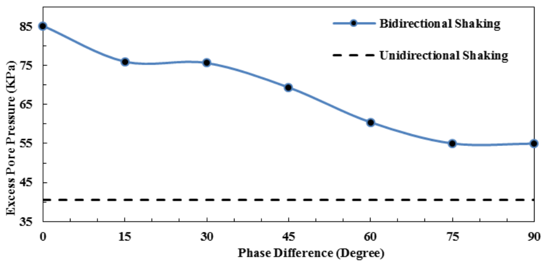

Fig.2. Excess Pore Water Pressure vs Phase Difference of Bidirectional Shaking compared with Unidirectional Shaking

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