Introducing Two Effective Modifications for Pastor-Zienkiewicz (PZ) Model for Improving the Dynamic Simulation Capability of Granular Soils

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1- Introduction

Analysis and design of geotechnical structures under dynamic and seismic loads have been among the challenges of engineers and researchers in recent decades. It has been shown that numerical methods are appropriate for dynamic simulation. Dynamic constitutive models that are embedded in numerical codes have a primary effect on problem results.

Dense sands show stiffness decrease or degradation during reloading stages of cyclic loading. The PZ model is unable to predict such behavior; so it is necessary to modify the PZ model to predict this behavior properly. The predicted deformations by the PZ model during cyclic loadings, especially with low loading cycles, are greater than the deformations observed in experiments. In other words, the PZ model cannot simulate ratcheting phenomenon properly; so it needs another modification.

First modification: Degradation effect. H_{DM} is used in the PZ model to apply the effect of stress history during cyclic loading. To apply the effect of dense sand degradation, the H_{DM} value should be in the range: $0.0 < H_{DM} \leq 1.0$. H_{DM} in the PZ model is defined as follows:

$$H_{DM} = \left(\frac{\zeta_{max}}{\zeta}\right)^{\gamma} \quad (1)$$

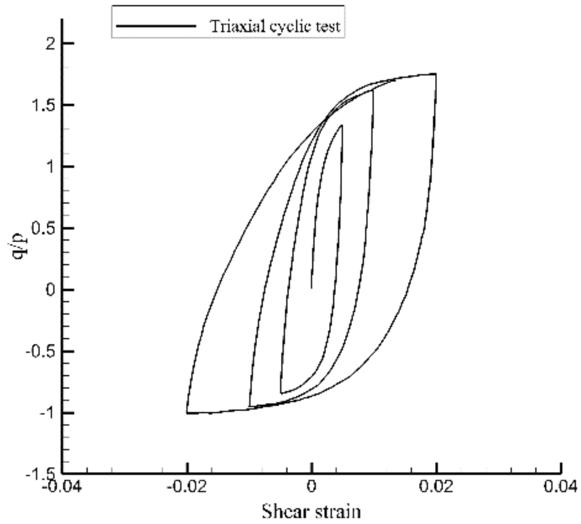
$$\zeta = p.\left(1 - \frac{\alpha}{1+\alpha}\frac{\eta}{M_f}\right)^{-1/\alpha} \quad (2)$$

Where γ is a model constant that has to be calibrated to provide the best prediction of loading–reloading experiments. ζ is a mobilized stress function. α is a model parameter and η is the stress ratio. M_f is a model constant.

γ is replaced with γ' in the modified PZ model. So, the Equation (1) is modified and re-defined as follows:

$$H_{DM} = \left(\frac{\zeta_{max}}{\zeta}\right)^{\gamma'(0.5-\frac{M_f}{M_g})} \quad (3)$$

Pradhan et al. test's simulation. Figure 1 shows the stress ratio – shear strain curve for a dense sand dynamic test and the predicted curves by the PZ and modified PZ model. It can be seen that the modified PZ model can predict the experiment better than the PZ model.



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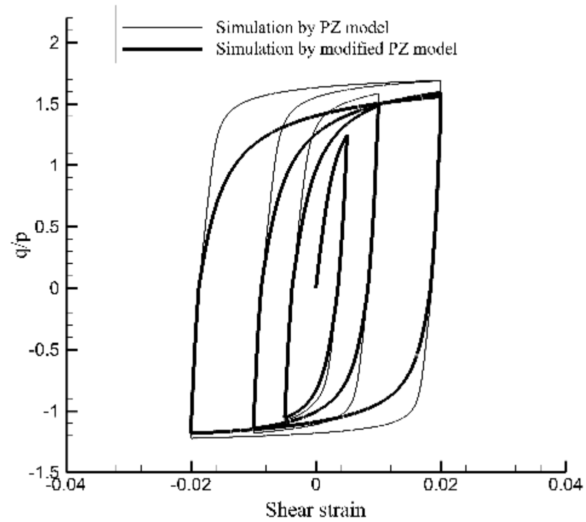

(b)

Fig. 1. Comparison between the results of the dynamic triaxial test and predicted results by PZ model and modified PZ model, stress ratio- shear strain curve a) experiment, b) simulation

Second modification: ratcheting effect. Earthquake acceleration amplitudes are usually low at the early stages of earthquakes. It can be concluded that geotechnical structures show lower deformation at the beginning of earthquakes. However, the PZ model shows high values for accumulated plastic strain and significant deformations during early stages of seismic loads which are usually greater than the observed deformations in the experiments.

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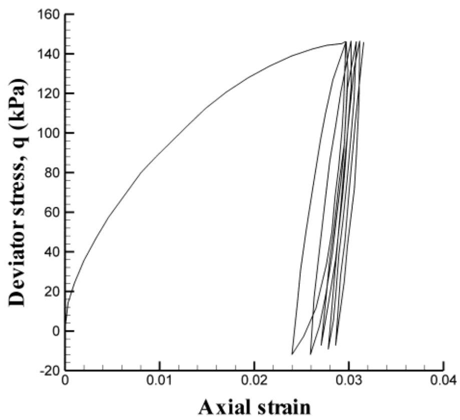

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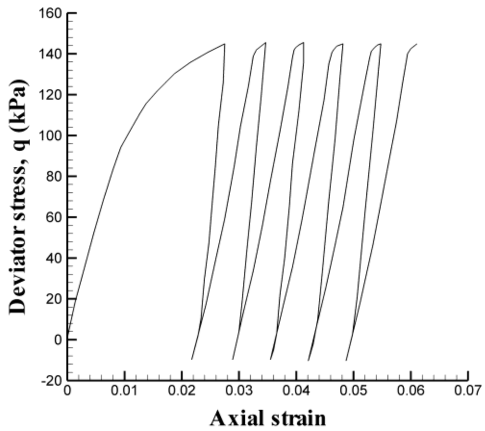

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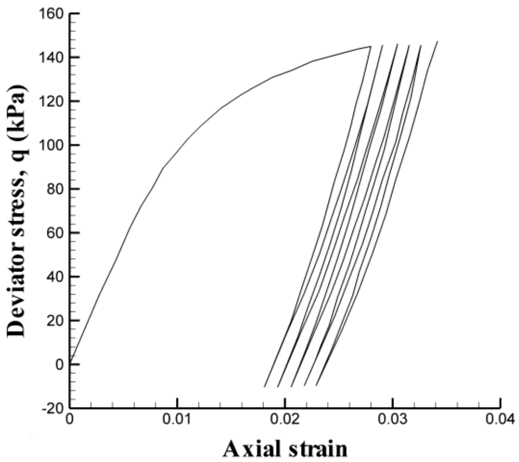

(c)

Fig. 2. Comparison between the results of the dynamic triaxial test and predicted results by PZ model and modified PZ model, deviatoric stress- axial strain curve a) experiment, b) simulation by the PZ model, and c) simulation by the modified PZ model

H_r is introduced here to employ the effect of ratcheting. This parameter is multiplied by H_L and H_u during re-loading and unloading, respectively.

$$\mathrm{H_r} = \beta_2 \exp(-\beta_3 \xi) + 1.0 \tag{4}$$

β_2 and β_3 are new model constants. ξ is the accumulated plastic deviatoric strain. Figure 2 shows the results for a dynamic triaxial test and the PZ model and the modified PZ model. The results showed that the predicted behavior by the modified PZ model is better than the behavior predicted by the PZ model.

2- Conclusion

Two effective modifications were introduced to predict degradation in dynamic behavior of dense sand and predict progressive plastic strains during dynamic loading (ratcheting). The first modification was validated using two dynamic triaxial tests on dense sand. A dynamic plane strain test and a dynamic triaxial test were used to validate the second modification. The modified PZ model can be used to simulate geotechnical structures under dynamic loading with granular materials and high relative densities. The modified model is also appropriate when the duration of the dynamic loading is relatively long and significant accumulated plastic strains are observed.