$$D_r = D_{r0} + \alpha\sqrt{\frac{\sigma_v'}{P_a}} \qquad (1)$$

The liner element was used for modeling of aluminum pipeline. The liner element has the capability of elesto-plastic behavior. This type of element is used for the modeling of nonlinear materials such as tunnel liner and/or deformable materials such as steel.

The interface element was used for modeling of the interaction between soil and the pipeline. The interface element allows soil element to move relative to the tunnel. The schematic view of the interface element is given in Fig.3. Normal stiffness and shear stiffness were considered to be 120 MPa/m. The friction angle was considered to be 23.5^{o} at the interface of the buried pipeline and soil.

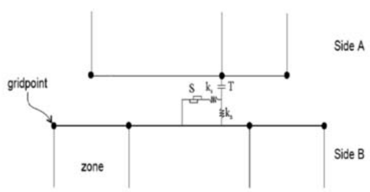

Fig. 3. Schematic view of interface element

3- Comparing the numerical results with experimental data

The modeling results are compared with the measurements of centrifuge experiment and the capabilities of the model to predict the liquefaction of soil around tunnels are assessed. In addition to uplift of structure, the pore pressure build up was assessed for verification purposes.

Fig. 4 depicts the uplift of pipeline versus time which is measured during centrifuge experiment and the corresponding numerical simulations of UBCSAND model using finite difference method. The final displacement obtained from UBCSAND is in good agreement with the experimental results based on centrifuge test.

The excess pore water pressures at piezometer P2 which is located at the left of the pipeline are shown in Fig. 5. The simulation results of this study are in good agreement with the measured ones. Particularly, the final excess pore pressure is precisely predicted. In contrast there is a notable difference between the predictions of Pastor Zienkewicz model, obtained from the literature, and the measured experimental excess pore pressure. The results in other piezometers are similar and it could be stated that UBCSAND model has effectively modeled the soil behavior of liquefied soil around a tunnel.

The displacement vectors at the end of seismic excitations are shown in Fig. 6. Although the soil movement towards the tunnel underneath has been considered as the major reason of tunnel uplift in liquefied soils, it is clear from Fig. 6 that such pattern of displacement is not the case in this research. Therefore, in this case the uplift of tunnel is attributed to excess pore water pressure.

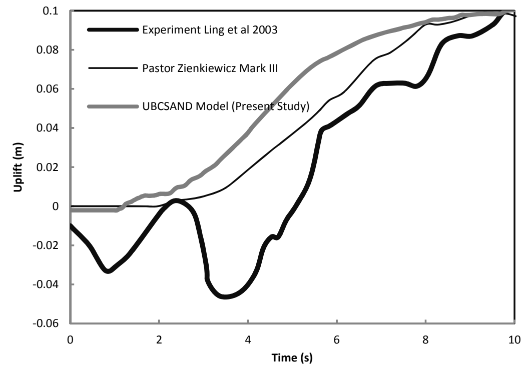

Fig. 4 Tunnel uplift observed in experiments and simulation results

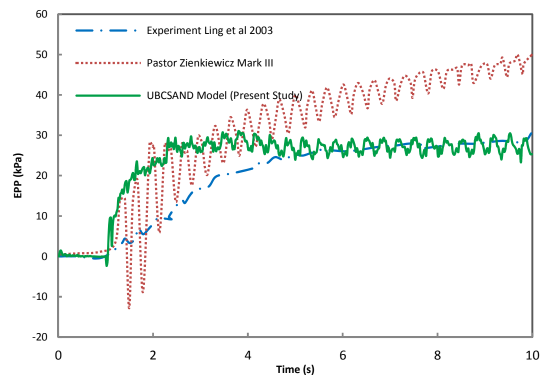

Fig. 5 Measured and predicted excess pore pressures at the left of the pipeline (P2)

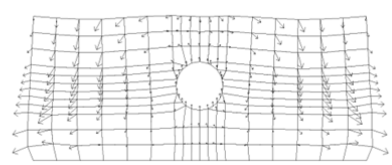

Fig. 6 Displacement vectors at the end of seismic excitations

4-Conclusions

This paper presents a successful numerical modeling of liquefied soil around a tunnel. The stress induced compaction has a considerable effect on the performance of the numerical simulation of liquefied soils and it was carefully implemented in this research. Furthermore, the dependence of pore fluid bulk modulus and its influence on the results of modeling were analyzed in this paper. The outcomes of the research revealed the advantages of employing UBCSAND constitutive model for liquefaction modeling

Numerical Modeling of Tunnels and Lifelines in Liquefiable Grounds under Seismic Loading

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Amirhossein Bagherieh[2]

1-Introduction

Earthquakes could have catastrophic impacts on tunnels and buried structures. Liquefaction phenomenon is one of the most destructive effects of earthquakes. Liquefaction results in decreasing the effective stress and this consequently lead to a decrease in shear strength of the soil. As a result, large deformation in both the soil and the structure buried in the soil occurs. Moreover, liquefaction causes soil boiling, lateral spreading, structure settlement and the uplift of buried structure. Lifelines, as their name implies, are extremely important because any disconnection or malfunction of them can potentially cause severe problems in every day's life. With the development of urban areas in recent years, development of the public transportation systems has evolved. As a result, use of subway and underground tunnels for transportation has been increased.

Granular materials are prone to be compacted under seismic loading. In saturated soil masses, the tendency for contraction will be hindered. Thus, the pore pressure will be increased and this would result in decrease in effective stress and decreases in shear strength. This phenomenon is termed liquefaction.

In many earthquake cases, uplift of the buried structure due to liquefaction has been reported as one of the major damaging factors.

This research seeks to model earthquake induced uplift of buried structures including tunnels in the soil susceptible to liquefaction under seismic loading.

2-Numerical modeling of lifelines uplift in centrifuge test

Two dimensional finite difference modeling is employed to simulate centrifuge experiments. The experiments are brought from published literature. The experimental data consist of several tests for investigating uplift and behavior of pipelines with large diameters under seismic loading. The centrifugal acceleration of 30g was applied in these experiments. Nevada sand with relative density of 38% and average grain size of 0.15 mm was used. The maximum and minimum densities of this sand were 13.7 and 17.38 KN/m^3. The pipeline used for modeling was made of aluminum alloy. The pipeline was 28 cm length with internal diameter 9 cm and external diameter of 10 cm. Fig.1 shows the schematic view of centrifuge experiments.

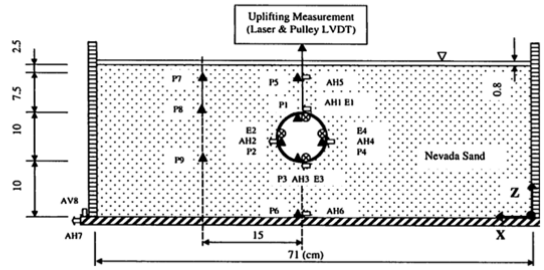

Fig.1 Schematic view of centrifuge test

FLAC2D software was used to simulate centrifuge tests. The UBCSAND model was adopted as constitutive model in numerical simulations. The properties of Nevada sand were assigned to the soil surrounding pipelines. The UBCSAND model is an effective stress based plasticity model that is used for advanced stress-deformation analyses. In this model stress-strain behavior is defined in hyperbolic from. Plastic strains are controlled by yield surface and flow rule. In this model, yield surface in stress space is similar to Mohr- Coulomb model for cohesionless materials. The yield plane will move due to hardening. In order to verify the input parameters, the input parameters of UBCSAND model should be calibrated based on laboratory tests results. In this research, the cyclic undrained simple shear test was simulated to calibrate input parameters. Fig.2 depicts the results of prediction of liquefaction simple shear test and numerical modeling. The results of numerical modeling are in good agreement with laboratory results Thus, it can be concluded that input parameters are calibrated.

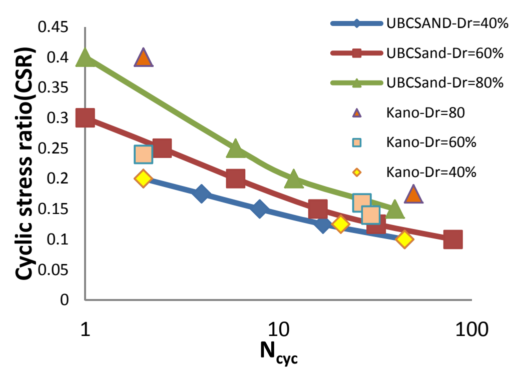

Fig. 2 Prediction of liquefaction for Nevada sand

The relative density is one of the most important parameters of sand. Because of stress difference in upper and lower parts of the centrifuge box, the relative density at the surface of soil becomes lower than the lower parts of the model after applying the centrifugal acceleration. In this research it is assumed that stress induced compaction is expressed by equation (1):

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