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# Evaluation of Constitutive Soil Models in Soil Nail Wall Using Centrifuge Model

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**ABSTRACT:** Numerical modeling is a strong tool for soil deformation in deep excavations. There is some kind of methods such as finite element, finite difference and etc. Finite element method helps to select the appropriate constitutive soil model with high accuracy. The controversy between simplicity and accuracy is an important issue always has been interested in by the researchers. By using physical modeling, the accuracy of each constitutive soil modeling could be an asset. In this paper, four models of geotechnical centrifuges were used to investigate the effect of the overburden distance from the edge of the excavation and the results of various constitutive soil modeled in the soil nailing wall. The results showed that the overburden distance from the edge of the wall was so effective on the value and pattern of wall deformation. By increasing the overburden distance from the edge of the excavation, the greatest amount of horizontal deformation of the wall led to the bottom of the excavation. However, the basis of the numerical solution, without the overburden distance from the edge of the excavations, this deformation always occurs in the top of the excavation. Also, based on the comparison of the results of centrifuge models and the results obtained from different behavioral models, in order to predict the vertical deformation of the top of the excavation, the result of hardening soil small strain model (HSS) was closer to reality than other investigated constitutive soil model.

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## 1. INTRODUCTION

In order to reduce the building damages nearby excavation, it is necessary to predict the changes in the ground and the excavation wall, by using empirical methods or numerical analyzes. The use of numerical methods has been considered by researchers as a quick and inexpensive way to solve geotechnical problems. Validation is necessary to determine the accuracy of numerical methods. The results of numerical modeling could be validated by using physical modeling. Physical modeling is an important and effective tool in geotechnical engineering [1]. The centrifuge modeling method, as one of the most successful modeling methods in soil issues, has been widely used to study the behavior of soil nailing walls [2].

Many studies have focused on the field deformations of the ground adjacent excavation by using numerical methods. Brinkgreve studied the choice of constitutive soil models and soil parameters in various geotechnical applications [3]. Obrzud and Eng have studied the use of the hardening soil small strain model in geotechnical practice [4]. Lim et al. have evaluated the clay constitutive soil models in deep excavation analysis in undrained conditions using a case study. Teo and Wong have described the applications of the hardening soil model in deep excavation analysis [5]. Hsiung and Dao studied on constitutive soil models of hardening soil, Mohr-Coulomb model, hardening soil small strain in-wall stabilized by diaphragm wall [6].

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In this paper, the effect of choosing constitutive soil models of hardening soil (HS), Mohr-Coulomb (MC), hardening soil small strain (HSS) and the overburden distance from the top of excavation in predicting the deformation of the soil nailing wall was investigated using the centrifuge models.

## 2. METHODOLOGY

Four different centrifuge models were used to validate the different constitutive soil models in a soil nailing wall. The goal acceleration in this research was 50 g. These tests were carried out at the Geotechnical Research Center of the University of Science and Technology of Iran. The soil materials used in these tests were silica sand 161 Firoozkooh. The elastic modulus of this soil at a relative density of 70% was 40 MPa. In centrifuge tests, a 0.8 mm diameter copper-nail was used as an anchor, which was carried out by performing a dimensional analysis equivalent to $\phi$30 bars. Translucent PVC was used for shotcrete modeling in centrifuge tests. By dimensional analysis the bending hardness and considering 5 cm for the shotcrete, the target acceleration was $N$ = 50 g, the modulus of elasticity of concrete $Ep$ = 18.5×10$^6$ KN/m$^2$, the elasticity modulus of PVC $Em$ = 2.5×10$^6$ KN/m$^2$ which is based on the test on PVC, The thickness of the PVC equivalent in the centrifuge modeling was 0.6 mm.

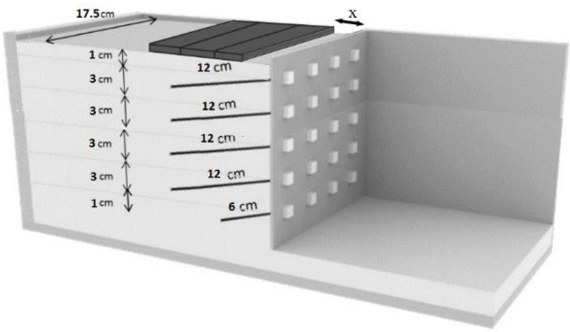


**Fig. 1. Schematic image of the box test at the centrifuge device.**

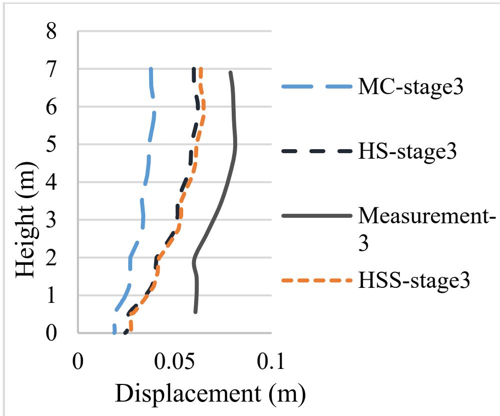


**Fig. 2. Deformation of the excavation in the third phase of excavation of model 1.**

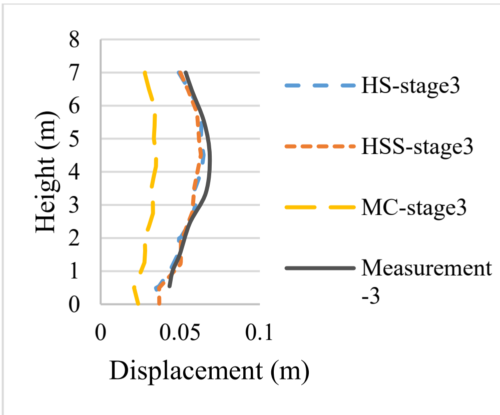


**Fig. 3. Deformation of the excavation in the third phase of excavation of model 2.**

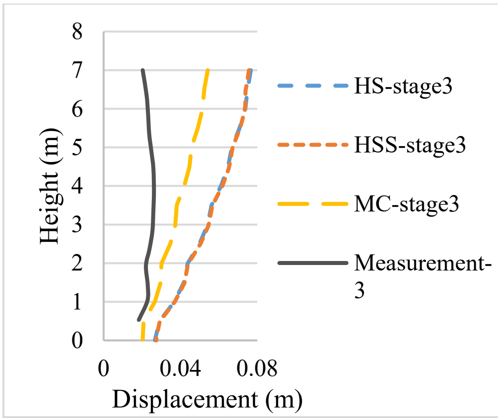


**Fig. 4. Deformation of the excavation in the third phase of excavation of model 4.**

In the centrifuge tests, the wall height of the models was 14 cm ($h$=14cm) and five rows of nails were used as shown in Figure 1. The horizontal distance between the nails was 3 cm. In figure 5, $x$ is the horizontal distance of the surcharge edge of the excavation, and in models, all models are 0, $h$/4, $h$/2, and 3$h$/4, respectively [7].

Dry precipitation was used for sampling. Three pieces of steel rectangular cubes with dimensions of 17.5×5×2.6 cm were used as surcharge load. Due to the specific gravity of the steel and the dimensional analysis, the stress caused by these plates in the actual model was 100 kPa. To simulate the excavation used PVC-filled water bags. The deformations obtained by a digital camera were taken and the numerical values were obtained by processing the image [7].

According to the dimensional analysis, models 1 to 4 were modeled in real dimensions in finite element software. The specification of the rebar was $EA$= 14.83×10$^4$ kN. Soil parameters were introduced to form of $\varphi$=35° (Friction angle), $c$=0 (cohesion), $\psi$=5° (Angle of Dilation), $\gamma_{unsat}$=15.5 kN/m$^3$ (Unsaturated Specific Weight), $E$=40000 kN/m$^2$ (elastic Young's modulus), $E_{50}$=24000 kN/m$^2$ (triaxial compression), $E_{ur}$=72000 kN/m$^2$ (triaxial unloading/reloading), $E_{oed}$=16800 kN/m$^2$ (oedometer loading), $\upsilon_{ur}$=0.2 (unloading / reloading Poisson's ratio), $K_0$=0.427 primary one-dimensional compression, $R_f$=0.9 (failure ratio), $m$=0.5 (power parameter), $ã_{0/7} = 0^{-5}$ (shear strain) and $G_0$=83000 kN/m$^2$ (shear modulus at small strain).

## 3. DISCUSSION AND RESULTS

In Figures 2 to 6, the values obtained by centrifuge models 1, 2 and 4 were compared with results of numerical analyses for different constitutive soil models in the last step. Each step was equal to $h$/3 of the excavate. The point (0,0) was the heel of excavate.

The horizontal deformation of the wall was highly influenced by the overburden position. In the centrifuge model 1 (where the overburden is located at the edge of the excavate), the predicted value of the numerical solution was less than the measured value of the centrifuge model. That is the reason why the back analysis was done. By back analysis and reduced Young's modulus by multiplying by 0.7, the measured and predicted values of the numerical solution were equal in this model.

## 4. CONCLUSIONS

Based on the results of centrifuge models, the MC model was highly inefficient in predicting the vertical deformation of the back wall, While the values obtained from the HS and HSS models were closer to the measured value. The vertical deformation of the back wall in model 1 centrifuge was approximately equal to the predicted value of the HSS behavioral models, as a general conclusion based on all the results of this study, the use of the HSS model to obtain the vertical deformation of the back wall with considering $\gamma_{0.7}$ equal to $10^{-5}$ has the results closer to reality. In model 2 centrifuge ($x = h/4$), the results of the HS and HSS behavioral model in the last phase were well suited to the measured values, and there was no need to change the soil parameters. According to models 3 and 4, centrifuges (in the cases of $x \geq h/2$) in final phase of excavation, the predicted horizontal deformation of the MC model had the smallest difference with the values measured by centrifuge model, and as a result, this model was more suitable for use in numerical solutions to predict wall horizontal deformation in $x \geq h/2$.

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