ANALYSIS OF DEEP EXCAVATION: A COMPARISON BETWEEN THE HARDENING SOIL MODEL AND THE MOHR-COULOMB SOIL MODEL

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1. BACKGROUND

The selection of an appropriate soil model is critical for accurately simulating the behavior of soils under various loading conditions. The Mohr-Coulomb soil model is the most common model used to describe the stress-strain behavior of soil and rock. It assumes that the soil or rock behaves like an elasto-perfectly plastic material. The Mohr-Coulomb model uses a failure criterion in which shear strength changes depending on confining pressure of soil or rock, and linear elastic deformation occurs due to unloading with a set of constant Young's modulus and Poisson's ratio. On the other hand, the stress-strain relation in the Hardening soil model is used to describe the non-linear behavior of soils where the soil stiffness changes due to the effect of unloading/reloading during deep excavation. The Hardening soil model assumes that soil begins to exhibit plastic deformation after a certain applied stress[1].

According to the previous research done by El-Kassas et.al (2020), the wall deformation in small-strain Hardening soil model shows the best representation of the inclinometer results compared to the Hardening soil model and the Mohr-Coulomb model. Moreover, the deformation of the diaphragm wall in top-down construction is significantly lesser than the bottom-up construction [2]. On the other hand, according to Phien-wej et.al (2012), the horizontal wall deformation using the Hardening soil model shows good alignment to the field data for the deeper part of earth retaining wall although the shallow part of the wall does not align well with the model results [3].

In this study, the excavation sequence was simulated with Mohr-Coulomb and Hardening soil model using PLAXIS 2D and comparisons of the vertical displacement of soil at ground level and the horizontal displacement of the diaphragm wall were made.

2. METHODOLOGY

The geometry of the analyzed finite element model was selected from an under-construction subway project. The analyzed cross-section is shown in the Figure 1. The total depth of excavation is 26.1m and the excavation was carried out in five steps; named as, 1st excavation, 2nd excavation, 3rd excavation, 4th excavation and final excavation. The plan dimensions of the station are 382.9m in length and 36.22m in width. The thickness of the reinforced-concrete diaphragm wall is 1.2m.

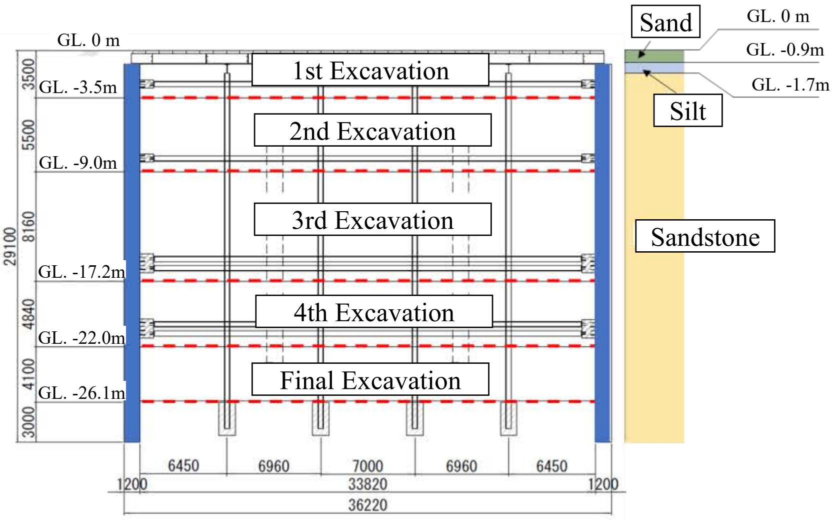

Figure 1 Cross-sectional view of analyzed section

Table 1 Geotechnical parameters

Soil classification	Unit weight γt (kN/m³)	Cohesion c (kN/m²)	Friction Angle (°)	Young's Modulus E_{50}(kN/m²)
Sand	18.0	0	47	102,500
Silt	17.0	310	0	125,000
Sandstone	17.5	365	36	240,000

The geotechnical investigation shows that the on-site soil strata are composed of three soil layers. The top two layers are sand and silt representing the shallower part (GL. 0 ~ -1.7m) while the third layer is composed of sandstone. Material properties of each soil layer are given in Table 1.

For Mohr-Coulomb model, three values of soil stiffnesses represented as E1 (E_{50}), E2 ($2E_{50}$), and E3 ($3E_{50}$) have also been checked.

Keywords: Deep excavation, Hardening soil model, Mohr-Coulomb soil model, FEM analysis
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3. RESULTS AND DISCUSSIONS

The analysis results in the final excavation step are represented in Figure 2. The plotted data in Figure 2(a) shows that the diaphragm wall of both the Hardening soil model and the Mohr-Coulomb soil model exhibit a similar behavior of horizontal deformation where the wall deflects towards the excavation side. In addition, the wall deflection shown by both models is a close representation of the actual field data. The Hardening soil model exhibits slight underestimation until a wall depth of 12m, whereas the Mohr-Coulomb soil model presents overestimation up to that depth. Beyond the wall depth of 12m, the Hardening soil model displays a slight overestimation, while the Mohr-Coulomb model closely matches the actual field data.

Figure 2(b) shows the horizontal displacement of the diaphragm wall due to increase in soil stiffness in Mohr-Coulomb model. By considering soil stiffness of E2 and E3, it shows lesser deflection as compared to the observed data.

Figure 2(c) shows the results of vertical ground displacement of 5m from the edge of the diaphragm wall. The Hardening soil model estimated around 3mm of ground settlement which gives almost similar representation to the field data. However, Mohr-Coulomb model with stiffness E1 shows heaving of 11mm. Therefore, Mohr-Coulomb models with increase soil stiffness (E2, E3) were also compared to evaluate the effect of soil stiffness on the ground deformation. From the results, with the increase of soil stiffness, the heaving of the ground decreases but still showing positive vertical ground displacements as illustrated by the bar charts.

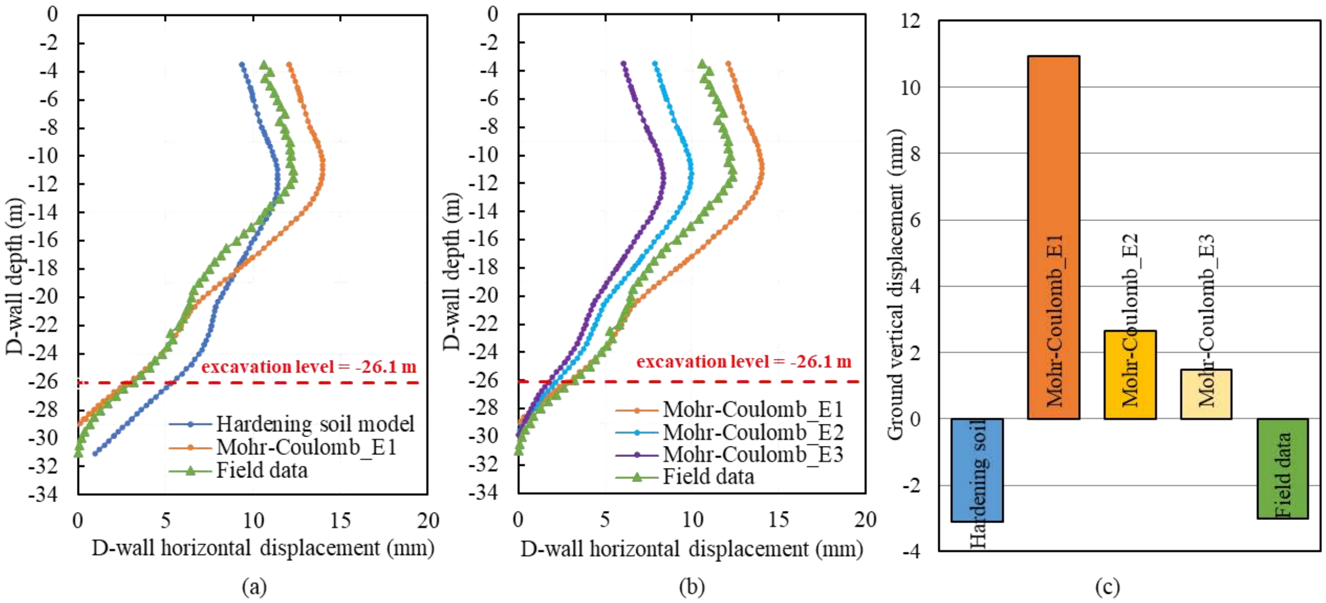

Figure 2 Comparison of (a) soil models and field data in terms of horizontal displacement, (b) different soil stiffnesses using Mohr Coulomb model in terms of horizontal displacement, (c) soil models and field data in terms of vertical displacement

4. CONCLUSION

From the above-mentioned results, it is concluded that the Hardening soil model and the Mohr-Coulomb soil model give good representation of the observed horizontal deformation of the diaphragm wall in the final excavation step. However, the heaving of the ground was observed in case of Mohr-Coulomb soil model which does not show a true reflection of the field data. In contrast, Hardening soil model gives a closer replication of the observed data. The reason seems to be due to more accurate consideration of the nonlinear behavior of soil with the Hardening soil model which could more thoroughly represent the deformation of the soil in a complex stress state. Advanced soil model like the Hardening soil model proves a better representation of the actual site than the Mohr-Coulomb soil model. However, it should be noted that depending upon the actual geology, the conclusions might be different and due to simplicity, the Mohr-Coulomb soil model is always preferred for initial estimation of the ground behavior.

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