Deformation analysis of a construction pit in high-plasticity clay

R Bulko and J Mihálik
Geotechnics Department, Faculty of Civil Engineering, University of Žilina
E-mail address: roman.bulko@uniza.sk

Abstract. In Slovakia, construction process already begins in less suitable locations. Such a location is also situated in Podhorie, small village near the city of Žilina. The subsoil is formed by high-plasticity clay with claystone in lower position. This article deals with the analysis of the influence of various input parameters as well as $R_{inter}$ mesh discretization on the determination of safety factor $M_{SF}$. The Mohr-Coulomb constitutive model was used in numerical model with respect to availability of input parameters. The ability to identify the parameter with the biggest impact on the resulting value of safety factor is an indisputable benefit. Various studies have been published on this topic. In our case, cohesion $c$ had the biggest influence on the $M_{SF}$ parameter when reducing shear parameters. In the future, the authors will compare the achieved results of numerical modelling with the actual deformations of the structure.

1. Introduction
Nowadays there is a high demand for building land in Slovakia. Nice flat sites are missing, having become the property of developers, or at high prices. Therefore, construction process already begins in localities that are less attractive and suitable for various reasons. Such a location is situated in Podhorie, small village near the city of Žilina, where the subsoil is formed by high-plasticity clay with claystone in lower position. In the past, high-plasticity clay was mined there for the production of solid fired bricks. Today, few people remember that there was a brickyard here and the construction of family houses began on the site in difficult geological conditions. The terrain is sloping 12-17° with frequent slope deformations. Therefore, the subsoil properties had to be verified. For this purpose, three static penetration tests were performed.

2. Geological conditions of area
The geological structure of the area consists mainly of claystone, which predominates over sandstones. In the past, several landslides have been documented in the area, mostly of a translational type [7]. These landslides have almost been occurred after high precipitation periods, or initiated by inappropriate human activities. The subsoil is formed by three main types of rocks as shown in figure 1.
Figure 1. Results of penetration tests [1, 2, 3, 8].

3. Numerical model

The program PLAXIS 2D version 8.5 was used for numerical analysis. The construction pit is located in the cadastre of Podhorie, in Žilina district. Two types of rocks, clay and claystone, were included in the calculation. No groundwater level was indicated during the geological survey works. The main goal of deformation analysis by the help of numerical analysis was to determine how various factors may affect final safety factor of the construction pit. The construction pit consists of a soldier pile wall 7.0 m long, an IPE 220 profile with an axial distance of 2.0 m, and intermediate wooden profiles.

| Rock type     | γ  [kN/m³] | E_{ref} [kPa] | ν  [-] | φ  [°] | c  [kPa] |
|---------------|------------|---------------|--------|--------|----------|
| Clay          | 20         | 3700          | 0,46   | 19.2   | 12       |
| Claystone     | 20         | 43600         | 0,3    | 32.3   | 5        |

The final form of the model geometry is presented in Figure 2. We chose Mohr-Coulomb constitutinal model with respect to the available input parameters. The input parameters to the constitutinal model are listed in table 1. In the numerical model, the soldier pile wall is modelled by the structural element – plate with the values of stiffness as follows: \( EA = 9.555 \times 10^5 \) kN/m, \( EI = 8.55 \times 10^3 \) kNm²/m. The individual phases of construction process are summarized in table 2.
Due to the inclination of the individual layers, the gravity loading method was chosen instead of the K0-procedure in phase 1 as a plastic analysis [5, 6]. In the second phase, the wall was activated and the soil was excavated into the final phase. The $M_{SF}$ safety factor was calculated in the last phase by the method of phi-c reduction, when the strength parameters are reduced until the collapse of the structure.

**Table 2. Individual construction phases.**

| Construction phases | Phase function                              | Phase type          |
|---------------------|---------------------------------------------|---------------------|
| 1                   | Calculation of geostatic stress using gravity loading | Plastic             |
| 2                   | Activated support structure and excavation   | Plastic             |
| 3                   | $M_{SF}$ calculation                        | Phi-c reduction     |

### 4. Results of analysis

**Figure 3a.** Dependence between $M_{SF}$ safety factor and parameter $R_{\text{inter}}$.  
**Figure 3b.** Calculated horizontal deformations due to a change in the $R_{\text{inter}}$ parameter.

In the parametric study we changed various parameters and determined their effect on the resulting safety factor. First, we analysed the effect of $R_{\text{inter}}$ on the safety factor $M_{SF}$ at mesh with discretisation into 1228 elements. We created six models in total. The parameter $R_{\text{inter}}$ was entered in the range 0.5 - 1.0, while simulating a certain degree of discontinuity, respectively reducing the strength parameters at the soil-structure contact.
From the graph in figure 3 we can see a linear dependence between the examined parameters. Secondly, we also examined the horizontal deformations on the structure. The reduction of strength parameters due to smaller $R_{\text{inter}}$ caused an increase in horizontal deformations. The appropriate choice of the $R_{\text{inter}}$ parameter depends on the type of structure that is in contact with the soil. This issue has been addressed by several authors [4, 5]. Based on literature review of the articles published so far and our results, we decided to further use only $R_{\text{inter}} = 0.7$.

Figure 4a. Dependence between $M_{\text{SF}}$ and mesh discretization.

Figure 4b. Calculated horizontal deformations due to a mesh discretization.

Another parameter we analysed was the mesh density in our model, with the same input parameters. We created five models in total, choosing the number of 81, 139, 292, 614, 1228 elements. The results of our analysis are represented in the following graphs (figure 4a). A nonlinear dependence applies to these determined parameters. As the mesh discretization increases, the safety factor decreases. Respectively, with a higher number of elements, there should be a better approximation of the results. A sufficient degree of mesh discretization to obtain relevant results is presented in graph in figure 4a. From a certain number of elements, the $M_{\text{SF}}$ safety factor does not change significantly as the number of elements in the network increases. If we look at the graph, we find that with some discretization of the mesh, the addition of other elements does not have a significant effect on the calculation. That is why we decided to keep $R_{\text{inter}} = 0.7$ and the number of 1228 elements in further analyses.

Figure 5. Dependence between safety factor and parameters values.
The next step of our analysis was to examine the influence of other input parameters on $M_{SF}$. We have created five models in total. We changed the deformation parameter $E_{ref}$ and the parameters of shear strength $\phi$ and $c$. We entered 50 %, 75 %, 100 %, 125 % and 150 % of the parameter value into the calculation (figure 5).

By a parametric study for the Mohr-Coulomb constitutive model, we found that for our geotechnical problem, the value of cohesion $c$ has the most significant impact and not the friction angle $\phi$ as we assumed. We assume that this is due to the higher value of $c$ compared to $\phi$. The mutual ratio of these two parameters is in favour of parameter $c$. In the case of the Mohr-Coulomb constitutive model for the final level of $M_{SF}$ safety factor, we confirmed that the change in $E_{ref}$ has no effect on our results.

Figure 6 shows the resulting slip surface, which is mostly present near to the surface. This is due to the lower rigidity of the soldier pile wall, which has the biggest displacement at the surface. For this reason, in these places there is also the least support of soil stability from pile wall and the software evaluates the slip surface at the surface behind the pile structure.

![Image](image_url)

**Figure 2.** Slip surface.

**5. Conclusions**

The ability to identify the parameter with the biggest impact on the resulting value of safety factor in geotechnics is an indisputable benefit. This analysis contributes to better safety. This paper analyses the influence of individual parameters on the value of $M_{SF}$. Discretization of mesh had the least effect on $M_{SF}$, but only from a certain number of elements. $R_{inter}$ has a significant impact on $M_{SF}$ in terms of reduction of shear parameters at the soil-structure contact. Various studies have been published on this topic. In our case, cohesion $c$ had the biggest influence on the $M_{SF}$ parameter when reducing shear parameters. Before our parametric study, we thought that the friction angle would have a bigger effect than cohesion. We assume that this is caused by a small difference between the input parameters $\phi$ and $c$. To determine parameters for more advanced constitutional models such as e.g. Hardening soil, laboratory analysis and tests of high-plasticity clay are important. In future, authors will compare the results of numerical modelling with the actual deformations of the structure.
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