Slope stability analysis using conventional methods and FEM

Analyse sur la stabilite de la pente en utilisant des methodes conventionelles et FEM

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ABSTRACT
The paper presents the results of the comparison between two different directions in slope stability analysis for a particular example and the way these results can affect various parameters. Different methods were used to establish the slope stability of a 56.00 meter high slope. The calculations of the safety factor were made using the conventional methods of Bishop, Fellenius and Bell. The results of applying these conventional methods were compared with the calculations performed by the FEM analysis using shear resistance reduction (φ,c – reduction). The comparison, analysis and assessment of the results obtained when applying different methods for solving the same problem is an important factor in designing buildings on steep slopes.

RÉSUMÉ
Texte du résumé le papier présente les résultats de la comparaison entre deux directions différentes dans l'analyse sur la stabilité de la pentel'analyse de stabilité de pente. Différentes méthodes ont été employées pour établir la stabilité de pente d'une pente de 56.00 mètres d'hauteur. Les calculs du facteur de sûreté ont été effectués suivre les méthodes conventionnelles de Bishop, de Fellenius et de Bell. Les résultats d'appliquer ces méthodes conventionnelles ont été comparés aux calculs exécutés par l'analyse de marché des changes utilisant la réduction de résistance au cisaillement (φ, c - la réduction). La comparaison, l'analyse et l'évaluation des résultats obtenu en appliquant différentes méthodes pour résoudre le même problème est un facteur important en concevant des bâtiments sur les pentes raides.

Keywords : slope stability, FEM

1 INTRODUCTION

In connection with the construction of a hotel complex on the Black Sea shore in the vicinity of the town of Kavarna, Bulgaria, a numerical investigation was carried out to determine and prove the stability of the site slope (Fig. 1). The main aim was to observe the slope behavior during the construction and in operation so as to determine the safety factor with taking into account the anticipated seismic forces for the area.

Fig. 1. Slope view and situation

The slope is designed for construction as shown in the diagram and profile in Fig. 2. According to the Bulgarian regulations for designing structures in earthquake areas, the area concerned has a 9th degree seismic intensity, with a seismic coefficient of K_c=0,27. In compliance with the materials provided two approaches were used to model and study the problem. On the one hand, in conformity with the normative base of the Republic of Bulgaria the slope was investigated by the circular-cylindrical sliding surface method. The computations were performed using the specialized geotechnical software “Geostru Slope”. The results were obtained by the computational methods of Fellenius, Bishop, Janbu and Bell. A reliable design method is Fellenius’s method which has been adopted in the normative base of the country. Additional calculations were made using FEM by reducing the shear strength (φ,c – reduction). The problem was solved by the specialized geotechnical software Plaxis. The results obtained have been summarized and analyzed.

As can be seen from Fig. 2, calculations are required in different profiles in view of the non-homogeneous terrain relief and various architectural solutions. Of interest regarding the aims set in this paper is the analysis of the slope behavior in one particular profile. For the purpose, one of the most unfavorable profiles was selected – Profile 36 whose cross section is shown in Fig. 2. All subsequent analyses and calculations were carried out for Profile 36. A similar approach was used for solving all other profiles (for example Pr.44 - Fig.2).

2 SOIL MASS ENGINEERING GEOLOGY

According to the geological investigations carried out the slope is composed of almost horizontal interlayers with hard rock interbeds (highly jointed) alternating with varieous types of clay fill. Because of the high strength and deformation properties of the rock interbeds compared with those of the clay layers

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appearing as some sort of diluter between the rock interbeds, clays are hazardous with respect to the slope stability. The rock formations improve the slope behavior and increas its stability but due to their jointing they were not taken into account in the computations. Their influence is in favor of safety and ensures additgional reserve with regard to the slope stability in view of the structural safety. According to the engineering geological investigations no groundwater has been established.

The results of investigating the geological layers of the clay fill show high variation in the strength coefficients despite their highly homogeneous granulometric composition. In the results of the inverse calculations and analysis of the values of tested samples performed at different depths, the following averaged values of the slope soil parameters were assumed: γ = 19 kN/m^3; φ=25° и c=111 kPa. The values assumed are numerical, using the following partial safety factors: γ_G=1,1; γ_c=1,8 и γ_φ=1,2.

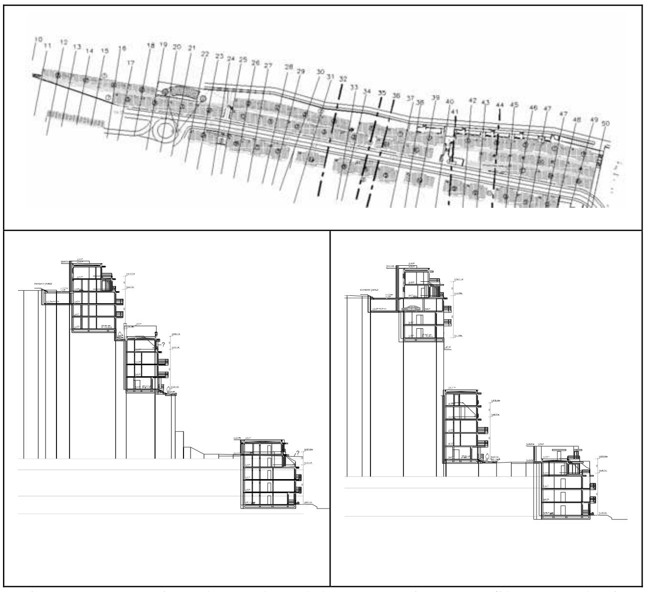


Fig. 2. Construction plan and model cross sections (Profiles 44 and 36).

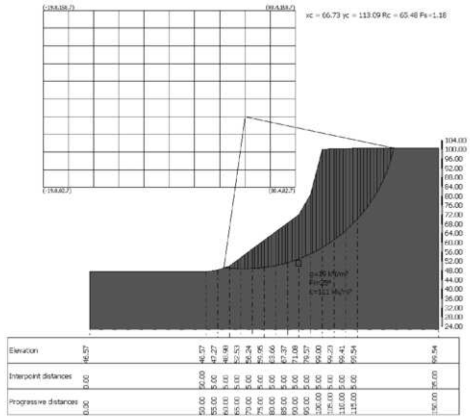
3 STABILITY INVESTIGATION

The computational parameters obtained (φ=25°; c=111kPa and γ=19kN/m^3) were used to assess the slope stability in operation with taking into account the seismic forces anticipated for the area.

The computations were made by using four versions of the method of slices (Fellenius, Bishop, Janbu and Bell) and the computational schemes are shown in Fig. 3. The results obtained on the minimum safety factor under operational conditions are summarized in Table 2. The results of investigating the total stability without taking into account local losses of stability show clearly that regardless of the method used, the stability coefficient values are close to the normative ones (F_s=1,25 – for basic combination of loads and 1.15– for special combination of loads and calculations made by the Bishop's method.

Along with the calculations using the method of slices, the slope was modeled in an finite element medium and its stability was determined by the „φ,c – reduction" method. The numerical model and the form of slope failure are shown in Fig. 4. The value obtained for the minimum allowable safety factor (Table 2) is more than twice as low as that for the method of slices.

The results obtained from the investigation of the slope stability by the method of slices were not confirmed by the FEM solution. For the first solution variant the slope stability was guaranteed whereas for the solution by the „φ,c –



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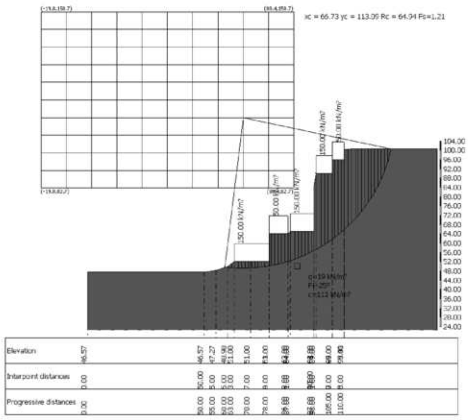

Fig. 3. Results of Geostru Slope 2008 according to Bishop's method: a) Natural slope; b) Operational conditions .

Table 2: Wichtigste Bodenkennwerte in kN/m^3, kPa und Grade

Method	Fs	
	without seismics	with seismics
Fellenius	1,50	1,21
Bishop	1,54	1,18
Janbu	1,50	1,25
Bell	1,56	1,28
fi, c- reduction	0,742	-

reduction" method the values obtained for the safety factor are far below the normative values. Therefore, it is necessary to plan support structures for proving and achieving the normative safety with respect to slope stability when investigations are performed using the two methods.

4 PILE SUPPORT

In view of ensuring the slope stability under operational conditions, when using a solution by the „φ,c – reduction" method, the slope support diagram shown in Fig. 6 was adopted. All buildings are founded on sheet pile walls taking the loads from the structure and transferring them in depth. At the same time the foundation of Building 3 (founded on level 89.55) is connected with the support wall of Building 2 (founded on level 63.10) by means of the continuous 0.80m thick reinforced concrete wall.

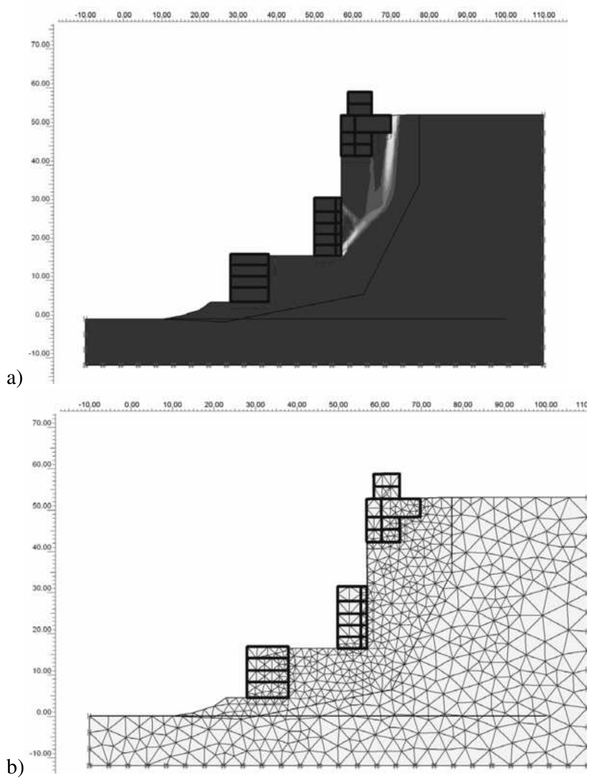

Fig. 4. Results from Plaxis (φ,c–reduction) a) Incremental shear strains; b) finite element network.

The lengths of the piles on which the buildings are founded are as follows:

- Building 1 (founded on approximate level 51.45) - L_{pile}=7.00м
- Building 2 (founded on approximate level 63.10) - L_{pile}=7.00м
- Building 3 (founded on approximate level 89.55) - L_{pile}=10.00м

The piles are of two types: cast-in-situ piles, reinforced concrete piles, diameter D=600mm. The pile lengths are 7m and 10m, respectively, for the different buildings (Fig. 5). In plan view they are positioned along the whole length of each building, axially at every 0.70m.

The variant thus obtained served to model and solve the slope by the „φ,c – reduction" method. The computational scheme and results obtained are shown in Fig. 5. The value of the safety factor sought is $F_{s(\varphi,c\,-\,reduction)}$=1. 368.

The slope failure pattern obtained is close to the assumed form of failure using the method of slices. The safety factor meets the normative requirements.

5 CONCLUSION

From the calculations performed it can be seen that the results obtained in determining the slope stability by using different computational methods vary within wide limits. As regards the difference in the safety factor values obtained by the method of slices and the "φ,c – reduction" method, it is of particular importance to have support structures in the slope. The results also show that when assessing the joint behavior structure-soil we have differences which can be measured in times.

Such differences create some feeling of insecurity in the designer or a feeling of over-security thus considerably raising the price of the engineering structure. The normative base of

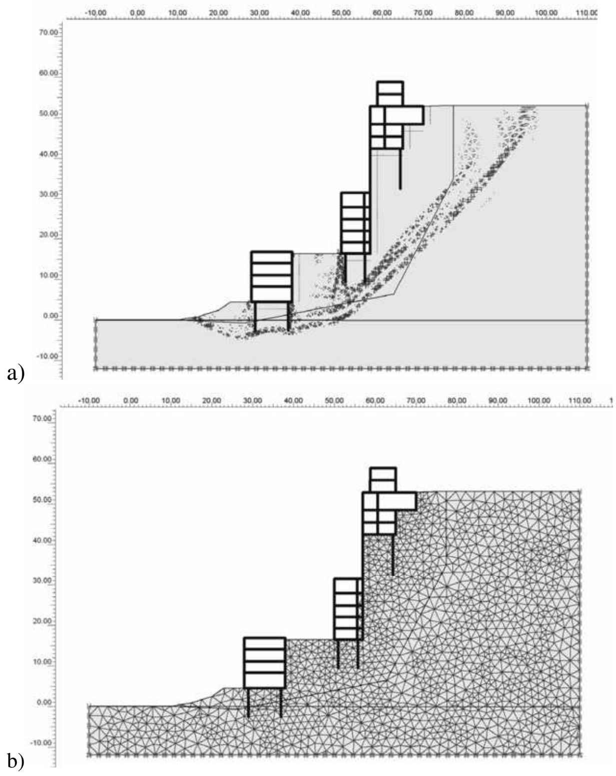

Fig. 5. Results from Plaxis (φ,c – reduction): a) Incremental shear strains ($F_{s(\varphi,c\,-\,reduction)}$=1.368); b) computational model.

Bulgaria does not specify the reliability of each method. The calculations by the FEM assess more precisely the soil behavior as a medium and its interaction with the structures but the results obtained are considerably more unfavorable as compared with those obtained by the method of slices.

When studying the problems related to slope stability, especially concerning safe buildings, in view of the results obtained we recommend that observations should be carried out on the structure during its construction so that the results of the observation method can serve to assess the accuracy and reliability of the difference calculation approaches.

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