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The Control of Natural Disaster Caused by Slopes Sliding by Means of Stepped Buildings

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Abstract

The unstable slopes are one of the causes of natural disasters in Romania. A consolidation system, used only for the sliding slope, is, in most of the cases expensive, but as a part of the foundation system for a housing project might bring economic advantages. The analysis started from a practical case of an unstable slope in Cluj-Napoca city. A complex study was performed to establish the mechanical and physical soil properties and a slope stability analysis, with and without the consolidation system. The results obtained were compared in order to check the most valuable solution.

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Keywords: Slope stability; stepped buildings; FEM; consolidation solution.

1. Introduction

The landslides are the natural disasters, with the highest occurrence in Romania [1], due to erosional processes but also due to human activities generating negative effect to the stability of a slope. As a result of the frequent occurrence of landslides in Romania, it was settled a methodology for the elaboration of natural hazards maps for landslides [2], in 2003. The study of landslides in Romania, the landslides causes and consolidation solutions are important research topics for Romanian researchers, [3, 4,5,6,7], studying the landslides and consolidation solutions. Caused by the economic impact of the landslides, one of the general trends is to avoid housing projects on slopes with sliding potential. The consolidation systems are expensive, but the land cost is very low, this being one of the

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reasons why those sites are attractive for real estate developers. The management of risk due to landslides involves concepts in a simple, but technically-supported manner, which will contribute to reducing the vulnerability of the population, but also the vulnerability of economic assets, [8, 9, 10, 11, 12].

The site that we are referring to is on the western part of Cluj - Napoca city, in a hilly area, on the southern side of Hoia hill, along the Somesul Mic River. The Hoia hill, as well as other hills in the region, is well known as a site with sliding potential, due to the slope size and the soil geotechnical characteristics [13]. At the moment when the idea of the new building raised up on the site there were some gardens and few light buildings. During the rainy periods, because of the length of the slope, on the middle part of the site, a stream rise up, collecting all the water in the near area and conducting it towards downstream, trough Somesul Mic River. This stream was not visible because of the vegetation on the slope. The great view on the city recommended this site, even if it is a difficult site. Realizing a stepped building is one of the solutions that are very much used in the past ten years in Cluj - Napoca area, due to the fact that the city is expanding rapidly and the best sites, with great views are on slopes. This construction solution imposes sometimes important consolidation systems due to the fact that most of the sites are on slopes with high sliding probability [14]. The idea of stepped buildings is not a new one, being used in some beautiful places around the world, like Santorini, where the houses were built on volcanic rock.

A housing project was proposed for this site, a stepped building, having a waterfall aspect. Each step of the building is composed by three apartments, on the middle part of the construction having a spa area and on the inferior parts some technical spaces and a garage; the superior part has also a garage and a supplementary level. In order to develop a green project, each housing level was designed with its own terrace, see Fig. 1.

Fig. 1. The proposed building (courtesy to I. Andriescu & SIT).

Fig. 2. Broken draining pipes on the site.

2. Materials and methods

2.1. Geotechnical investigation

The studied site has a slope varying from 8 to 30^0 inclinations. The slope, according to Romanian norm NP 074 [15] indicates a high potential to sliding, this being one of the reasons why it was used mostly for agricultural purposes. Geologically, the slope is characterized by a relative homogeneous structure and texture, consisting of marly clay and sandy clay layers of soil, covered by a black marly clay layer. All these deposits have a quaternary age and a diluvia nature, specific to the slopes diluvia deposits.

In order to obtain the geotechnical characteristics of the soil a first geotechnical study was conducted, having seven low deep drillings, at approximately 4 m depth. This geotechnical study offered the initial information about the site. According to the drillings, a succession of layers was observed. A layer of brownish clay, having 0.90m thickness, downstream the site, which is not found upstream, where a layer of black silty clay it exist, having 1.40÷1.80m thickness. This layer covers a marly clay layer, found up to 4.00m. A lens on clayey sand (1.60÷2.00m thickness) was found on the middle part of the site and also upstream, the layer of marly clay disappears, having a layer of sandy marly clay, from 1.80m or 3.00m in one drilling. Ground water table was not found in any of the drillings. The main values of the soil characteristics offered by the geotechnical study, for the marly clay layer of soil are: I_c=0,7÷0,9, $\gamma\approx$19,70kN/m^3, $I_p\approx$31,18%, e=0,6÷0,7, φ=14÷16^0, c=30÷40kPa.

The initial foundation system for the building it was a continuous one, stepped continuous foundations, placed along the reinforced concrete diaphragm walls of the building. Because of some incertitude related to the stability of the slope, those soil characteristics had to be confirmed by in situ test, which is the subject of a second geotechnical study on the site. Therefore, one heavy dynamic penetration (DPH) and eight light dynamic penetrations (DPL) were performed on the site. The position of these penetrations was similar to the drillings position, in order to confirm the layers succession and characteristics. Correlating the number of blows necessary for the cone to penetrate into the soil with soil characteristics a succession of layers is determined. The first layer is brownish black clay, having 0.70÷1.90m thickness, with low consistency, consistency index I_c=0.25÷0.50. This layer is very compressible, loose, with voids ratio e>1.00. The mechanical parameters of the soil are: apparent cohesion c_u=15÷20kPa, effective friction angle φ'=5^0 and effective cohesion c'=10÷15kPa. The second layer is a marly clay, having 0.60÷2.10m thickness, consistent or stiff, with I_c=0.50÷0.75. The compressibility is high, with voids ratio e up to 1.10. Shearing strength characteristics are φ'=5^0 and c'=19kPa. The next layer is also a marly clay, having 0.60÷2.00m thickness, with different characteristics. The consistency index I_c=0.50÷0.75, e=0.6÷0.7 and φ'=11^0, c'=24kPa. In some areas there were found lenses of stiff soil, with φ'=15^0 and c'=30÷35kPa.The bedrock is a clayey marl, grey, identified at 2.50÷8.00m in DPH and DPL. The mechanical characteristics of this soil are φ'=17^0 and c'=55kPa. This soil layer has a low compressibility, with e<0.55. On the site when the penetrations were executed, downstream, there were identified some possible sliding surfaces at 0.60÷0.90m and 1.60÷2.00m.

Upstream, few springs were also found, which proves that water flowing in the soil occurs trough the soft and permeable layer of sandy clay. This fact invalidate the first geotechnical study, on which the water was not found on the site, but also confirm the fact that the site has a high sliding potential. The water flow in the soil is proved by the low consistency layers of soil, having great thickness, downstream (2.10m up to 4.10m), but also upstream (2.90m thickness). When the excavation was performed, it was discovered some draining pipes, having the role to transport the rain water from the slope trough the sewing system. But they were all filled with mud and broken, see Fig. 2.

2.2. Slope stability analysis

In order to estimate the possibility of a natural disaster caused by slopes sliding, the Romanian norm GT 019-98 [16] imposes the calculation of the instability factor.

The instability factor is calculated according to the equation (1) [16]:

$$K_m = 0{,}408\sqrt{K_a K_b \sum_{i=c}^{h} K_i} \tag{1}$$

The coefficient's K_a… K_h are evaluated according to the site conditions, considering lithology, geomorphology, structure, hydrological and climate conditions, hydrogeology, seismic activity, forests and anthropic factors. The calculated value of the coefficient is between K_m=0.41÷0.59, situating the slope, according to [16] into the category of slopes with medium – high sliding potential category and a medium – high probability of sliding.

The initial slope stability analysis was performed [17] using conventional methods. The Fellenius method used, considered an initial factor of safety F_S=1.5 and divided the sliding surface into 11 blocks corresponding to each foundation step. There were considered two possible sliding surfaces: one at the base of the marly clay and the second one which considers that all the covering layers are possible to slide on the clayey marl layer. The study concluded that the site has instability problems, when the building is placed on it, on both possible sliding surfaces, the sliding force determined having to be undertaken by a consolidation system. The consolidation solution proposed has micro piles, with 300mm diameter, disposed along the walls on foundation beams. The piles – raft system which undertakes the sliding force is placed every step of the building, on the section where a reinforced concrete diaphragm wall is in contact with the superior terrace. This consolidation system will stabilize the slope and the building, but also will increase the stability of the road and the surrounding area. The calculations performed at that time are the subject of the present complex study, involving complex software, able to consider in the calculation also the consolidation system.

The purpose of the slope stability analysis, with limit equilibrium methods and FEM using Geo Fine software is to determine if the initial stability analysis, realized by manual calculation, with medium soil parameters is verified by a more accurate calculation and if the solution realized is able to solve the stability problems found on the slope. When the slope stability analysis is performed, it is recommended to have two calculation stages. On the first stage, we obtain an overall safety factor for the slope. The purpose of this stage is to determine the most unfavorable sliding surface, having the smallest safety factor, using the characteristic soil parameters. The comparable experience it is recommended to be used. In the second stage, according to Romanian and European norms, the slope stability is performed, using limit equilibrium methods or FEM. The soil parameters used are affected by safety factors, corresponding to the design approach utilized.

In order to perform the stability analysis a succession of soil layers as in Table 1 is considered. The ground water table is not considered in the analysis, but the soil characteristics are calculated influenced by it.

Table 1. Soil characteristic parameters

Nr.	Soil type	$\gamma(kN/m^3)$	$\varphi(^0)$	$c(kN/m^2)$	E (*MPa*)	ν(-)
1	Brownish clay	19.5	5	10	3	0.40
2	Marly clay	19.5	5	19	5	0.40
3	Marly clay	19.7	11	24	7	0.40
4	Marly clay	19.7	15	30	10	0.40
5	Clayey marl	19.7	17	55	120	0.42

The analysis to find a stabile profile was performed using Slope Stability Module of the software, considering different probable situations, with and without the consolidation system. In this case the most suitable analysis uses Sarma [18] method, for slopes with probable polygonal sliding surfaces and the Fellenius - Petterson method [19] for slopes with probable circular sliding surface [20, 21]. The probable sliding surface was determined in the Sarma method, which is more suitable for layered soil and that surface was converted into a circular one, by the software, obtaining the safety factor in Fellenius – Petterson method. Due to the fact that a possible circular sliding surface passes through the stiff layer of soil, the slope stability is sometimes overestimated, see Fig. 10 and Fig. 18.

According to the Romanian similar experience for a slope, in order to be stable, the minimum factor of safety required is F_S=1.50, the study considering the safety factors methodology. The analysis using Geo 5 software indicated that on the initial state, the slope is stable, as it was before any building was erected, see Fig. 3 and Fig. 4. When the excavation will be performed and the building will be executed, without any consolidation system, the slope will be unstable, as seen in Fig. 5 and Fig. 6.

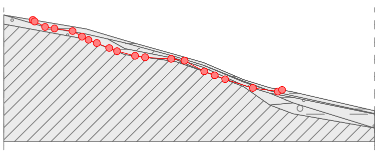

Fig. 3. Slope stability verification with Sarma method, for the initial slope. $F_S = 2.00 > 1.50$

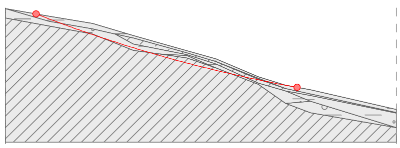

Fig. 4. Slope stability verification with Fellenius-Petterson method, for the initial slope. $F_S = 2.90 > 1.50$

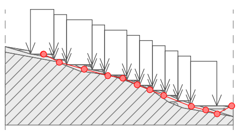

Fig. 5. Slope stability verification with Sarma method, for the initial slope, with the building. $F_S = 0.91 < 1.50$

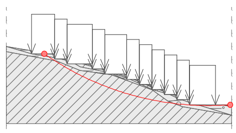

Fig. 6. Slope stability verification with Fellenius-Petterson method, for the initial slope, with the building. $F_S = 1.39 < 1.50$

Considering the recommendations of SR EN 1997[23] and the SR EN 1997 – NA[24], the stability analysis was also performed, verifying if the design effects of the actions, E_d do not exceed the corresponding resistance, R_d. In slope stability analysis the effect of the actions is the overturning moment, M_{Ed}, and the resistance is the resisting moment, the resistance to the effect, M_{Rd} [22]. The equation, which has to be verified, became (2). In terms of safety factors, the relation can be written as (3).

$$\frac{E_d}{R_d} = \frac{M_{Ed}}{M_{Rd}} \leq 1 \tag{2}$$

$$\frac{R_d}{E_d} = \frac{M_{Rd}}{M_{Ed}} \geq F_S \tag{3}$$

The design effect of the actions and the design resistance is obtained by applying safety factors to the actions, materials and resistances. The national annex of Eurocode 7 recommends for the slope stability analysis to use the safety factors corresponding to the design approach 1 combination 2 (DA1-2) and to the design approach 3 (DA3). Considering the values of the safety factors, for the analysis DA1-2 and DA3 are identical, therefore the calculus is performed for DA1-2. The same design situations were used in the slope stability analysis, the results being presented in Fig.7, Fig.8, Fig.9 and Fig.10. This analysis validates the initial calculation and in the same time indicates the fact that without a consolidation system, the construction activities might lead to disasters caused by slope sliding. The human activities are one of the causes of slope sliding. Because the soil parameters used have the design value, the safety factor value is significantly changed. By realizing the foundations for the building, a reinforced concrete raft foundation and foundation beams bearing on a row of micro piles, having 300mm diameter, embedded into the stiff clayey marl layer, these piles will act like a supporting system for the slope and the building, the entire slope being stabilized. In the Geo 5 software the pile row is considered as rigid regions, which stabilize the slope. According to the performed analyses if the consolidation system is realized, it stabilize the entire slope, Fig. 11 and Fig. 12. The design of the piles has as a mandatory requirement to be able to undertake the sliding fore. A similar analysis is performed also according to Eurocode 7 – DA1-2, Fig. 13 and Fig. 14. In our case the system is designed also to undertake the vertical load transmitted by the building (which is small compared to the sliding force), but even with realized construction the slope is still stable, Fig. 15 and Fig. 16. The analysis according to SR EN 1997 – DA1-2 is presented in Fig. 17 and Fig. 18. The limit equilibrium method analysis with software dedicated to geotechnical problems, indicated that the consolidation – foundation system proposed and realized is able to solve the stability problem and to fulfill the safety conditions in terms of bearing capacity and serviceability. This soil foundations-consolidation system has to be completed with an appropriate drainage system located around the foundations. Ground water table and the sprigs found on the site might influence significantly soil parameters and respectively soil active pressure and stability conditions.

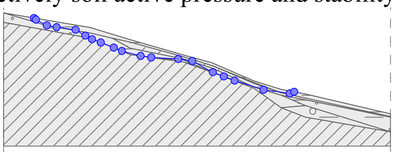

Fig. 7. Slope stability verification with Sarma method, for the initial slope, DA1-2. $E_d/R_d = 0.625 < 1.00$

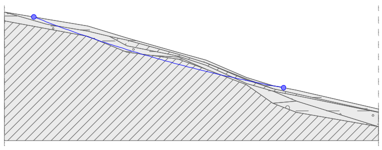

Fig. 8. Slope stability verification with Fellenius-Petterson method, for the initial slope. $E_d/R_d = 0.431 < 1.00$

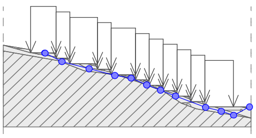

Fig. 9. Slope stability verification with Sarma method, for the initial slope, with the building. $E_d/R_d > 1.00$

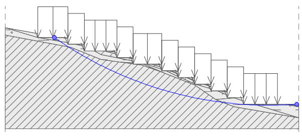

Fig. 10. Slope stability verification with Fellenius-Petterson method, for the initial slope, with the building. $E_d/R_d = 0.899 < 1.00$

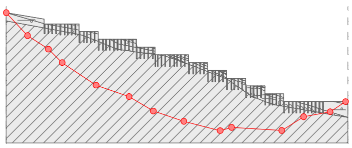

Fig.11. Slope stability verification with Sarma method, for the consolidated slope, without the building. $F_S = 1.84 > 1.50$

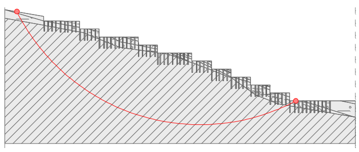

Fig. 12. Slope stability verification with Fellenius-Petterson method, for the consolidated slope, without the building. $F_S = 1.82 > 1.50$

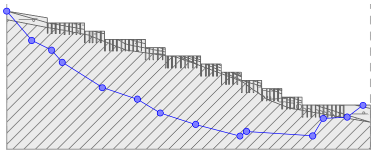

Fig. 13. Slope stability verification with Sarma method, for the consolidated slope, without the building. $E_d/R_d = 0.802 < 1.00$

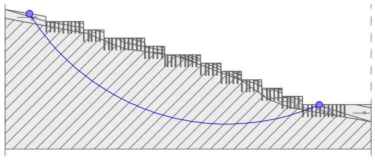

Fig. 14. Slope stability verification with Fellenius-Petterson method, for the consolidated slope, without the building. $E_d/R_d = 0.694 < 1.00$

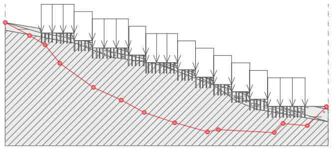

Fig. 15. Slope stability verification with Sarma method, for the consolidated slope, with the building. $F_S = 1.55 > 1.50$

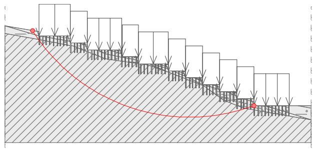

Fig. 16. Slope stability verification with Fellenius-Petterson method, for the consolidated slope, with the building. $F_S = 1.54 > 1.50$

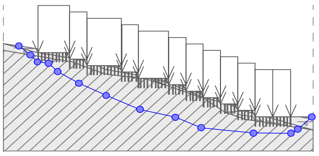

Fig. 17. Slope stability verification with Sarma method, for the consolidated slope, with the building. $E_d/R_d = 0.84 < 1.00$

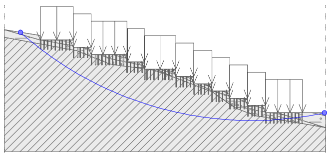

Fig. 18. Slope stability verification with Fellenius-Petterson method, for the consolidated slope, with the building. $E_d/R_d = 0.266 < 1.00$

Based on the finite element method (FEM) a different analysis of slope stability and of the effect of the proposed strengthening system has been conducted. The finite element method represents a powerful alternative approach for slope stability analysis which is accurate and requires fewer "a priori" assumptions regarding the failure mechanism [25]. The factor of safety (F_S) of a soil slope is defined as the factor by which the original shear strength parameters must be divided in order to bring the slope to the point of failure [26]. During the analysis the program gradually reduces the basic strength characteristics of the soil mass until failure occurs. For the soil in the analysis it has been adopted the Mohr – Coulomb failure criterion, which relates the shear strength of the material to the cohesion, normal stress and angle of internal friction of the material. The piles have been modeled as a single layer line, with elastic -plastic behavior [27].

The analysis used the same soil profile and parameters, having few calculation steps. In the first step the stability of the initial slope was verified, Fig. 19. This analysis provides a factor a safety, but also the plot of the displacement vectors, indicating the possible failure surface. In the following analysis step, the influence of the excavation and of the new building is considered. The results proved that the building will increase the instability of the slope. Very small safety factors are obtained locally, on each excavation step, as seen in Fig. 20.

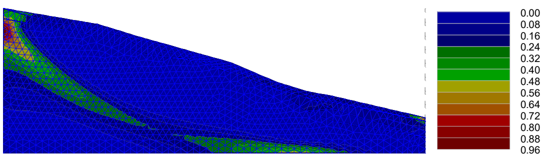

Fig. 19. Slope stability verification with FEM method, for the initial slope. $F_S = 1.76 > 1.50$

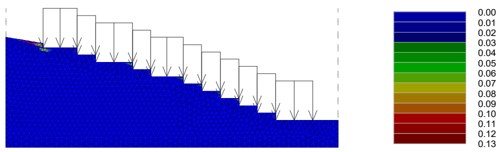

Fig. 20. Slope stability verification with FEM method, for the slope, with the excavation and the building. $F_S = 0.12 < 1.50$.

On the superior part of the slope the FEM analysis indicates high possibility of failure, Fig. 21. This local failure, indicated by the calculation occurred in 2011 on the slope. Fig. 22 taken on the site proves this soil failure, but also confirms the local instability of the slope. The overall stability is ensured by the consolidation system, but local, non-catastrophic hazards might occur on the sire and in the surrounding areas. The last calculation step refers to the consolidated slope, with the piles row, and the load transmitted by the building, see Fig. 23. There are still some areas with low safety factor, but they are caused by local distortions, see Fig. 24.

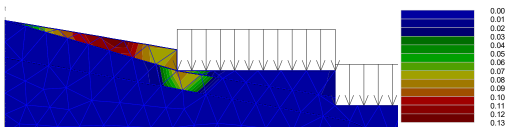

Fig. 21. Slope stability verification with FEM method, for the slope. Possible local failure.

Fig. 22. Slope local failure

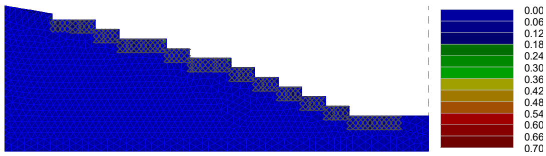

Fig. 23. Slope stability verification with FEM method, for the slope, with the consolidation system. $F_S = 0.12 < 1.50$.

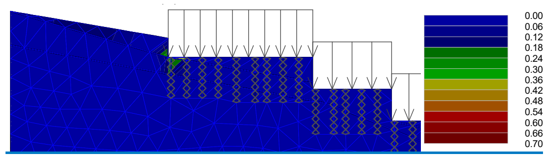

Fig. 24. Slope stability verification with FEM method, local distortions

3. Results and discussions

The slope limit equilibrium method and numerical FEM stability analysis proved that the empirical calculation, using average soil characteristics is close to the accurate calculation. The main difference is that the software is able to indicate calculated safety factor for slope stability, when in the empirical calculation this minimum safety factor is imposed and used to determine the sliding effect. The empirical calculation and comparable experience is an initial step into determining slope stability, but this step have to be followed by calculation using soil parameters affected by safety factors. Limit equilibrium method in slope stability analysis provide valuable information on the safety factor. For regular design it is a powerful tool which guides the designer into adopting the appropriate consolidation system. But also, it is a numerical tool for the geological and geotechnical engineers in order to establish the sliding potential of the slope. Using FEM in the study of slope stability and consolidation system leads to a new stage in the approach of geotechnical engineering problems. FEM-based analysis allows a qualitative emphasis of the development of the stability factor in different analysis stages (short term or long term), to manner that the deformations of the earth massive develop, the area of influence of the effect of reinforcing the slope etc. The FEM consider the effect of the consolidation system in terms of the deformations and stiffness, considering therefore the soil structure interaction.

In both calculations the significant element is the soil, the soil parameters. For an empirical calculation average soil parameters are used, which sometimes don't consider local soft layers of soil. The calculation, involving software, requires accurate soil parameters, resulting from extended laboratory works and site measurements. For the FEM analysis the soil parameters are more complex, requiring parameters related to the soil structure interaction and also the soil investigations are more complex. Considering all these aspects, when slope stability analysis is carried out, the input parameters (soil parameters, soil layers, ground water table, if it is the case, loads etc.) influence significantly the output, the safety factor describing the slope stability.

4. Conclusion

The results of this study are giving us the possibility to state that a stepped building, with an appropriate foundation system, consolidates the slopes with sliding potential. We consider that this foundation system reintegrates a site without housing potential, a site with a high potential of natural hazards occurrence, into the living space of the city. In the same time, two problems are solved: the problem of available space in a growing city, but also the important problem of slopes stabilization. As shown previously, the method used to calculate slope stability safety factor is important in obtaining real information about the stability of the site. The proposed methods to analyze the slope stability depend on the soil geotechnical parameters, obtained usually from a geotechnical report. Therefore, we underline the importance of an appropriate geotechnical report and mostly the accuracy of the determined parameters. The accuracy of the soil parameters is also an important factor in obtaining truthful safety factors on stability.

It can be concluded that the applied methods have a very good correlation with the real case, the consolidation system designed being able to stabilize the soil, without degradation due to landslide. Furthermore, the foundation system model may be adopted as an alternative for housing projects, but also as consolidation model for slopes with sliding potential. In conclusion, in our opinion, this foundation system might solve the lack of housing space inside crowded cities, in areas with sliding potential, but the most important aspect is that this foundation system improves the stability of the sites and it control the natural disasters caused by slope sliding.

References

[1] Surdeanu V. The Geography of the degraded lands (in Romanian), Presa Universitara Cujeana, Cluj Napoca, 1998

[2] Government order no. 447 since April, 10, 2003. The approval of the methodological rules related to the drafting and content of the natural hazards at floods and landslides maps (in Romanian), Monitorul Oficial, May 7,

[3] Marinescu C. Slopes and embankments stability protection (in Romanian), Editura Tehnica, Bucuresti, 1988

[4] Manea S. Evaluation of slopes sliding risk (in Romanian), Editura Conspress, Bucuresti, 1998

[5] Driga B, Popa A, Zaharia S, Surdeanu V. Natural risks in Satu Mare county (in Romanian), Editura Arvin Press, Bucuresti, 2007

[6] Roman F. Geotechnical engineering applications (in Romanian), Editura Papyrus Print, 2011

[7] Muresan O, Contributions regarding slope stability analysis, PhD thesis, Technical University of Cluj-Napoca, Romania, 2012

[8] Popa A, Tripa I, Study on the stability of a slope and consolidation solution, in: Proceedings of the 7th International Congress of the International Association of Engineering-Geology, (1994), 1481-1485

[9] Popa A, Fetea L. Risk factor monitoring for landslides, in: Proceedings of 7th International Symposium on Landslides, (1996), 337-338

[10] Lungu I, Implementation of monitoring technology on reducing landslide risk in: Proceedings of the 6th international Conference on the Management of Technological Changes, Vol 1, (2009), 517-520

[11] Muresan OC, Possible overview of landslide risk assessment, mitigation and management, in: Proceedings of 1st International Conference on Quality and Innovation in Engineering and Management (QIEM), (2011), 143-146

[12] Cobirzan N, Balog AA, Aciu C, Ilutiu-Varvara DA, Sustainable uses of zeolitic tuff as building materials, in: 7th International Conference on Interdisciplinarity in Engineering (INTER-ENG 2013), Procedia Technology 2014; 12: 542–547.

[13] Petrea D, Bilasco S, Rosca S, Vescan I, Fodorean I. The determination of the landslide occurrence probability by GIS spatial analysis of the land morphometric characteristics (case study: the Transylvanian plateau), Carpathian Journal of Earth and Environmental Sciences 2014; 9(2): 91-102.

[14] Liua SL, Dongb YH, Li AD, Liua Q, Wangc J, Zhangd XL. Effects of different terrace protection measures in a sloping land consolidation project targeting soil erosion at the slope scale, Ecological Engineering 2013; 53 :46-53

[15] NP 074-2007, Norm regarding geotechnical documentation for constructions

[16] GT 019-98: Guide to realize risk maps for slopes sliding, to ensure construction stability, 1998

[17] Popa A, Ilies N. Founding cascade building on unstable slope (in Romanian) In: Proceedings of the XI National conference of Geotechnics and Foundations, (2008), p. 49-59.

[18] Sarma SK. Stability analysis of embankments and slopes, Geotechnique 1973; 23: 423-433.

[19] Petterson KE. The early history of circular sliding surfaces, Geotechnique, 5, (1955), 275–296

[20] Alkasawneh W, Malkawi AH, Nusairat JH, Albataineh N. A comparative study of various commercially available programs in slope stability analysis, Computers and Geotechnics 2008; 35:428–435.

[21] Maula BH, Zhang L. Assessment of Embankment Factor Safety Using Two Commercially Available Programs in Slope Stability Analysis, Procedia Engineering 2014; 14:559–566

[22] Bond A, Harris A. Decoding Eurocode 7, Taylor & Francis, 2008

[23] SR EN 1997-1:2006, Eurocode 7: Geotechnical design – Part 1: General rules

[24] SR EN 1997-1/NB:2007, Eurocode 7: Geotechnical design – Part 1: General rules. National Annex

[25] Geo 5 – Engineering manuals. Part 3. Chapter 20. Finite Element Method (FEM) – Introduction, 2014

[26] Matsui T, San K. Finite element slope stability analysis by shear strength reduction technique, Soils and Foundations 32 (1), (1992), 59-70

[27] Griffiths DV, Lane PA. Slope stability analysis by finite elements, Geotechnique 1999; 49 (3):387-403.