GEOTECHNICAL ISSUES REGARDING THE CONCEPT OF MARGINAL STABILIZATION IN CASE OF LANDSLIDE

Anghel STANCIU[1], Irina LUNGU[2], Nicolae BOŢI[3], Jenel COPILĂU[4]

Rezumat. *Alunecările de teren sunt abordate în prezent, în sens anticipativ, printr-o analiză de stabilitate în condiţiile unor noi construcţii în zone potenţial alunecătoare sau prin intervenţiile necesare post-eveniment, pentru a reda construcţiilor avariate funcţiunea temporar anulată de instabilitate. Post-eveniment, deşi alunecarea induce o temporară stabilizare prin deplasarea nedirijată a maselor de pământ în zona aval, reabilitarea construcţiilor afectate, implică reconfigurarea zonelor de rambleu/debleu, lucrări de sprijinire însoţite de drenaje într-o abordare unitară, cu scopul de a crea o stabilitate dirijată pe zone de interes. Conceptul de stabilizare marginală prezentat în lucrare implică atât evaluări de parametri geotehnici prin calcul invers, cât şi elemente de dimensionare a lucrărilor geotehnice la acţiuni ale masivului de pământ identificate în urma reconfigurării geometrice, cerută de redarea în circuitul social/economic al construcţiei avariate.*

Abstract. *Landslides are presently approached as predictive processes, by slope stability analyses when building new constructions in zones prone to landsliding or through post-event interventions, to restore the temporary malfunction of the construction affected by the soil instability. Although sliding itself as post-event effect induces a temporary stabilization by random movement of the soil masses down the slope, rehabilitation of the affected constructions, involves retrofitting of the man/made slopes, retaining structures accompanied by drainage works in a unitary approach, to create intended stability on the zones of interest. The concept of marginal stabilization presented in this paper involves both evaluations of the geotechnical parameters by back calculations and the sizing of the geotechnical works for soil loads identified by the geometrical repointing, required by the damaged construction retrofit into the social/economical circuit.*

Keywords: landslide, slope rehabilitation, marginal stabilization, shear strength, landslide risk

1. Slope rehabilitation – general principles

It is necessary to provide the answer for two major questions in particular, to establish the slope rehabilitation measures and reduce the landslide risk [2]:

a. What are the causes that triggered or are about to trigger the soil instability?
b. What are the rehabilitation measures that will ensure the zone stability in predictable future conditions?

[1]Prof. Ph.D., Faculty of Civil Engineering and Building Services, Technical University "Gh. Asachi", Iaşi, Romania, member of the Academy of Romanian Scientists (anghel.stanciu@yahoo.com).
[2]Assoc. Prof. Ph.D., Faculty of Civil Engineering and Building Services, Technical University "Gheorghe Asachi", from Iaşi, Romania, (ilungu@ce.tuiasi.ro).
[3]Prof. Ph. D., Faculty of Civil Engineering and Building Services, Technical University "Gh. Asachi", from Iaşi, Romania, member of the Academy of Romanian Scientists (nicolae.boti@yahoo.com)
[4]Ph. D. Eng. S.C. COPER S.R.L. Slatina, Romania, (jenelcopilau@yahoo.com).

The competent answers to these questions will avoid the errors developed by the mentality based on which slope rehabilitation is approached in the sense that [2]:

- There is only one solution to solve a particular instability;
- The design of the rehabilitation works implies a safety factor of that work of 1.3 or 1.5, when the answer to the first question involves an engineering judgment over the safety factor value to be adopted in that specific design.

Natural slope rehabilitation provides a different approach on the stability and stabilization of man-made slopes, based on specific issues related to the natural slope stability analysis:

- the shape and location of the soil failure surface can be established based on inclinometric measurements recorded during a ground investigation program;
- the pore water pressure can be provided at the level of the failure surface by piesometric measurements;
- the safety factor when the landslide is triggered is about 1.00.

Thus, the landslide modeling can be made accurate enough by back calculation. The design of the intervention works and the stability computations are performed also along the same transversal profile and consequently, the stability analysis results (before and after the proposed stabilization) become comparable.

Any errors introduced by the back calculation to establish the calculus parameters involved in the stability analysis are transferred in designing the retaining work, which means that regardless the work suggested for rehabilitation, it will increase the stability reserve [1], [2].

It still remains to answer the question „How large should the safety reserve be ($F_{s,min}$ = 1. ...?) to ensure stability?" There are various opinions, as being difficult to establish which one of them are exaggerations as reducing or on the contrary, enhancing the costs of the necessary rehabilitation works.

Thus, there are the followings alternatives:

- some specifications recommend a single value $F_{s,min}$ = 1.30, to be enough as to ensure stability, regardless of the triggering causes for instability, the type and size of the landslide;
- the geotechnical specialists with significant experience in the field of landsliding consider that the safety factor should be accompanied by a (variable) value reflecting the direct influences of the causes specific to that particular area, as well as values ranging from little to high, increasing according to landslides from small to large.

To assess the size of the landslide, it can be considered the soil volume as an absolute value but also the projected/occupied area over the horizontal plan related to the sliding rock/soil volume – table 1 [2].

Table 1. The relative values regarding the size of the landslide

Size level	*Area of the lanslided soil mass on the ground surface (m^2)*
very small	< 200
small	200 ÷ 2.000
medium	2.000 ÷ 20.000
large	20.000 ÷ 200.000
very large	200.000 ÷ 2.000.000
gigantic	> 2.000.000

2. Estimation of the safety factor against landsliding

Although the variability of the minimum safety factors when designing rehabilitation works can be the subject of future research, it can be regarded relatively to F_s = 1.50 as the minimum value for man-made slope design, by qualitative and comparative estimations related to the above mentioned value – table 2 [2].

Table 2. Values of the recommended safety factors to design rehabilitation works for potential unstable natural slopes

The variable of the natural slope stability analysis	*Safety factor should be relatively:*	
	higher (> 1,5)	*less (1 ÷ 1,5)*
The type of movement	very fast ←→	very slow
The level of the performed analysis	preliminary ←→	detailed
The size of the landsliding (the amount of the soil volum)	small ←→	large
The potential consequences for human life and material losses	very high ←→	insignificant
The experience of the geotechnical engineer in the field of landsliding	limited ←→	very consistent

The instability/failure/landsliding is considered as triggered within a natural slope when the safety factor against landsliding F_s = 1.00, which makes the statement that the soil mass is at limit equilibrium, valid. This is also relevant to estimate that the variation of the stability factor related to the value of 1.00 measures the stability or the instability of the zone of interest.

As definition, although all the same, several formulations are accepted, among which the followings have a profound geotechnical significance, characteristic for the discrete medium as opposed to the continuous one [5]:

- *safety factor against landsliding* represents the ration between the available shear strength (mobilized at maximum) and the average shear strength necessary to be so that the soil to reach a limit equilibrium state along the potential failure surface ($F_s = F_{smed} = 1$);
- *safety factor against landsliding* is defined by the factor necessary to reduce the soil shear strength, along the potential failure surface, to provide a limit equilibrium state for the sliding.

3. Geotehnical issues when computing the safety factor against landsliding

There are two very important aspects when setting up the necessary computation for a slope analysis and they are interconnected:

- *total stress or effective stress analysis;*
- *short term or long term.*

The studies developed along these two aspects have reached an agreement over the following issues [2], [4], [5]:

- for normal consolidated clays and silts and for a short term analysis, a total stress analysis is considered appropriate;
- for overconsolidated clays and silts there is not a perfect agreement over a specific type of analysis due to the fact that the shear strength along the failure surface is altered quite fast; there are empirical rules established for particular situations and from this specific view point it is very significant the accumulated experience in studying the cohesive soils from that particular area.
- regarding the long term stability, the effective stress analysis is recommended for all the clays/cohesive soil types;
- there is this concept of *critical stability*, that develops mostly during the execution period of the rehabilitation works of the natural slope, when by removing important soil masses from specific zones “more critical” conditions are created than by the classical meaning of short term or long term slope analysis; the explanation comes with the fact that the pore water pressure can become positive (for normal consolidated soils) or negative (for overconsolidated soils) related to the increase of the active tangential stress along the failure surface; the increase of the soil mass movement that develops at the same time transfers the peak value of the

shear strength to the residual value of the shear strength, marking by this effect the concept of *progressive failure*.

The stability analysis can be performed, based on the same methods, using two different perspectives:

1. *by direct calculation* of the safety factor against F_s; the intended results is to establish the stability reserve available of the natural slope by zoning the area based on the F_s values computed for characteristics sections/soil profiles related also with the acknowledged zoning of the landslide potential, probability and risk;
2. *by back calculation*, when knowing that the safety factor F_s = 1,00 represents the limit equilibrium or the triggering of the instability / failure / landsliding, the soil characteristics along the failure surface can be established and later used in the design process of the rehabilitation works that will certainly develop the increase of the safety factor by comparison to the limit equilibrium.

It is worthwhile to mention that by the existing computer programs for slope stability, the back calculation could be avoided (with a certain degree of risk from the user), following the direct calculation, obtaining the values of the safety factors, selecting of the zones where these factors are equal or less than unitary, simulation within the model the presence of the rehabilitation work and adapted it to the necessity of the F_s increase by a new computing routine.

4. Solutions of marginal stabilization

The evaluation of the soil characteristics by back calculation has the advantage that, although the drifted zone is temporary stabilized as post-event effect, the stabilization works are needed when building new constructions in the same area, especially when developing access roads in new residential zones, at competitive costs.

Berms are considered mechanically viable solutions but with limitations regarding the materials in use and their permeability. Another solution of the classical berm involves a rock fill as a replacement of the natural soil mass using crushed stones [1], [3], with embedment under the failure surface – fig. 1.

This solution is surprisingly efficient in case of planar sliding of natural slopes, when the replaced volume consists of an extended previously drifted rock volume, with a residual shear strength of a reduced value and the benefit of added berm at the bottom of the drifted zone has little efficiency in increasing the stability reserve.

The limitations developed by the solution of the soil replaced berm with crushed stones are recorded for the following situations:

- the failure surface is located at high depth for which the berm solution is expensive and with risks during the execution because of the temporary stability issue of the excavation sides within the unstable natural slope;
- if the replacement is located within a flooding area or near a water source of high volume, it cannot provide gravitational drainage and the submerge effect over the crushed stone reduces the benefit of the self-weight as well as the shear strength compared to the situation when drainage works perfectly.

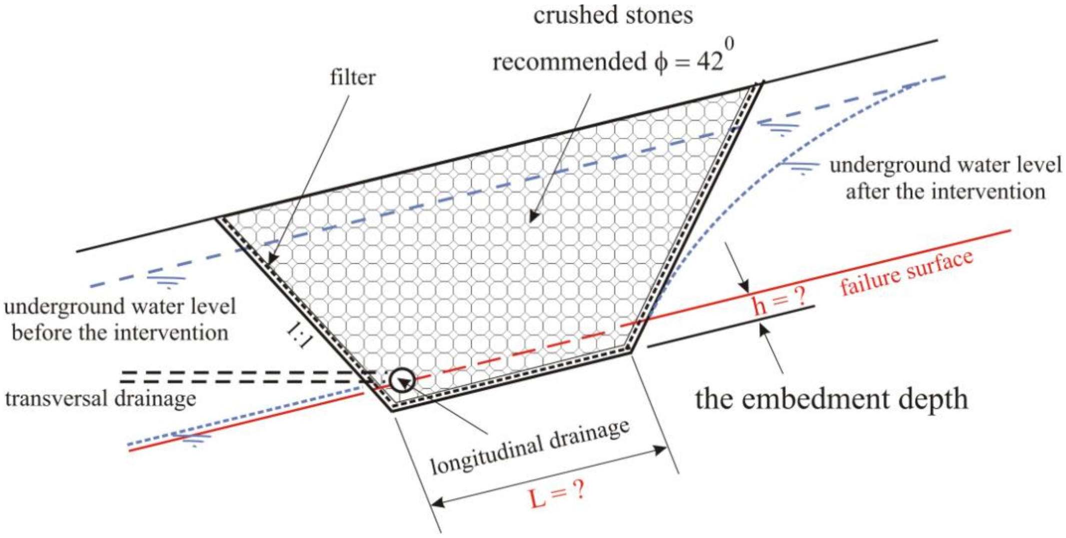

Fig. 1. Stabilization solution by partial inner filling of the soil sliding volume**.**

Repointing the soil profile and infill of berms can be combined in a unitary stabilizing solution (fig. 2), reducing as such the limitations for each individual stabilization measure.

This rehabilitation is correlated also with the repointing of the upward zone, and thus the new obtained geometry, combined with a higher average value of the shear strength along the failure surface compared to the initial one will induce the required value of the safety factor [1].

The marginal stabilization can be in this situation a soil improvement for the initial ground conditions in terms of new foundations for constructions delivering reduced to average loads, for which shallow foundations are the first economical option.

Foundation soil improvement can be valid in case of both soft/weak foundation soils, very deformable and reduced bearing capacity, and for foundation soils with special behavior: collapsible soils, soils sensitive to frost and thaw, soils with liquefaction potential, residual soils, recent unconsolidated earth fills.

The short term stability of the artificial slopes resulted during the berm excavation process requires a stability analysis sensitive to the selection of the soil parameters along the anticipated failure surface, especially for the upward slope, relative to the underground water condition.

The dependency is correlated to the soil permeability where the excavation is performed, but more to the extent of the time period when excavation is exposed to the weathering conditions until the berm is completed.

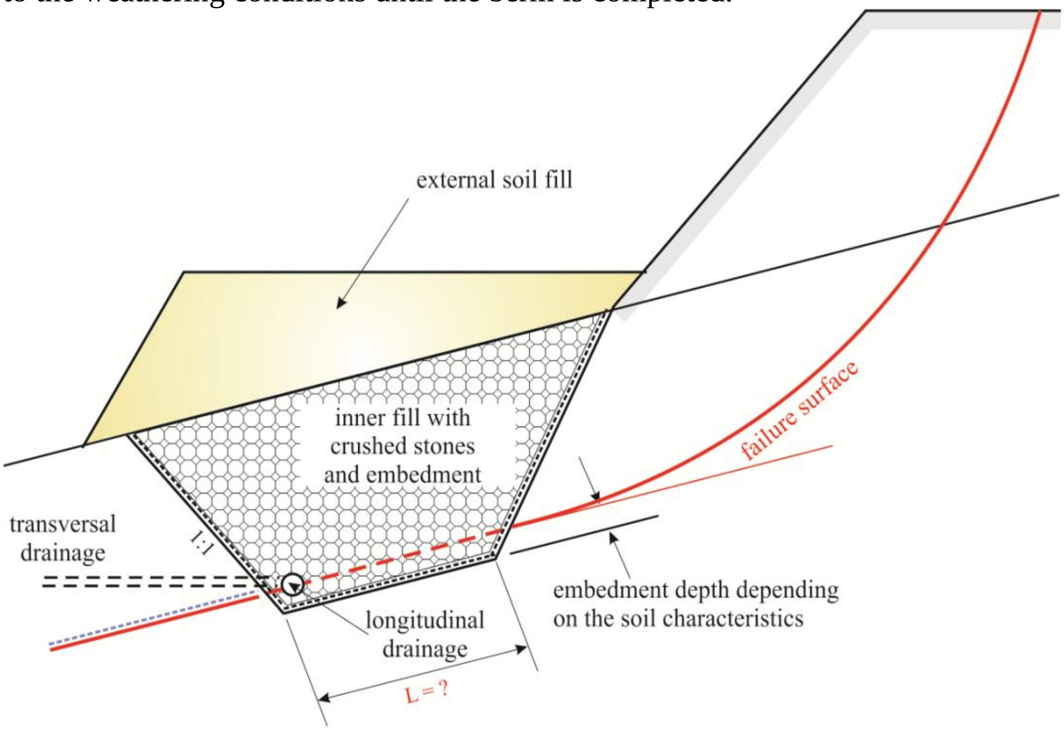

Fig. 2. Mixed solution for a natural slope rehabilitation.

5. Conclusions

Although there is a limited experience in Romania related to landslide management applied to the land developing projects / investment projects, international studies and publications in this field introduce the major management principles of the landslide risk [1], [6] that financially reveal extreme consequences:

- *accepting the risk* – where risk is considered *tolerable* by the local/regional authority (the net advantages of the project in the zone of interest compensate the shortcomings of the landslide risk);
- *avoiding the risk* – by project relocation, adaptation of the project or even the abandon of that particular project;

- *reducing the frequency of the landslide in the zone of interest* – by adopting and implementing of stabilization works that will control the circumstances that might trigger a landsliding;
- *reducing the consequences of landsliding in the area of interest*– by adopting and implementing protection works on the existing investments in that particular zone or improvement works related to the natural slope behavior in case of landsliding.

The marginal stabilization is related to the third principle from the above mentioned list, when considering the proposed rehabilitation works, as being accessible to medium and long term investment projects. It also has one of the components correlated to the fourth principle, which finally reflects on the accomplishment of the initial objective, as to reduce the landslide risk.

R E F E R E N C E S

[1] J. Copilău, *Teză de doctorat,* (Universitatea Tehnică "Gheorghe Asachi" din Iaşi, **2008**).

[2] D.H. Cornforth, *Landslides in practice,* (John Wiley & Sons, **2005**).

[3] I. Lungu, A. Stanciu, J. Copilău, *Landslide risk management in rehabilitation works for transportation infrastructure,* Proceedings of the PIARC International Seminar, (Iasi, Romania, **2009**).

[4] S. Manea, *Evaluarea riscului de alunecare a versanţilor*, (Conspress, Bucureşti, Romania, **1998**).

[5] A. Stanciu, I. Lungu, *Fundaţii – Fizica şi Mecanica Pământurilor*, (Editura Tehnică, Bucureşti, România, **2006**).

[6] *Landslides Risk Management – Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning,* Journal and News of the Australian Geomechanics Society, **42**, 1, (**2007**).