PERIODICA POLYTECHNICA SER. CIV. ENG. VOL. 43, NO. 2, PP. 153–161 (1999)

ROCK SLOPES AS ENGINEERING CONSTRUCTIONS

Miklós GÁLOS

Department of Engineering Geology
Technical University of Budapest
H-1521 Budapest, Hungary

Received: December 20, 1997

Abstract

The civil engineer and the geologist are very much concerned with rock slopes because they may be called upon to build and maintain safe, economical and useful structures even on hasardous ground. Such a task requires not only proficiency and a thorough understanding of the factors involved, but also intuition and experience. It should not be thought, however, that there is always a feasible solution or if there is one it should be pushed through at all cost.

Keywords: engineering geology, rock engineering.

1. Introduction

During the performance of construction engineering activities in a consolidated surrounding rock, the question of the solidity of rock slopes very often emerges. Generally speaking, rock slopes appear as a necessary evil beside our constructions causing additional troubles in the periods of design, construction and, later on, operation as well. This additional trouble manifests itself in additional expenses.

Basically, rock slopes can be classified into two groups. From the point of view of their formation, they can be either

– natural rock slopes, formed as a result of tectonic (geological) processes or
– artificial ones.

This grouping is well represented by *Table 1*.

Table 1. Classification of rock slopes

Rock slopes		
Natural	Artifical	
Motive: structural strength deformation glacier erosion	quarry bench open pit	railway, road, etc. cut ground recultivation

A rock slope may become an engineering construction in either group if their solidity is provided for by conscious engineering activities. They differ from other engineering constructions in their structural material because the engineering material is not chosen by the engineer here, but he has to accept the block of rock formed as a result of tectonic processes as structural material. In the case of concrete, reinforced concrete and steel structures, the engineer can influence the characteristics of the engineering material to a great extent (by choosing the category of solidity, the method of reinforcing, the thickness of structures and supporting walls, etc.). However, in the case of rock slopes, modification possibilities are restricted (to injection, solidification, placement of supporting structures).

The first step of dealing with rock slopes is already a task requiring engineering work: from the surrounding rock, the block of rock has to be marked to which its effect extends. This activity has a decisive and determining effect on the entire subsequent work. Marking the block of rock must be based on preliminary design work and the results of surveys provided for by different methods of excavation.

In itself, the block of rock is still a very heterogeneous space element. For this reason, the block of rock has to be divided into bodies of rock, having the same geological structure and/or joint system. The heterogeneity of the geological composition would generally require the isolation of quite a lot of smaller bodies of rock. On the contrary, the local nature of preparatory work (may be tied to drilling) results in a greater extent of generalisation. Therefore, at the marking of bodies of rock, an engineering geological approach structure taking technical aims into consideration is necessary. This approach creates an optimal balance between the two opposing trends from the point of view of the construction.

Within the body of rock, the featureless blocks of rock and fissure are equivalent space elements. We mention slopes of rock using their geological name: e.g. limestone or dolomite slope. On the other hand, slopes of rock are also characterised by their fissuration, as well as their fissuration system and its direction: e.g. a strongly mashed and banked slope of rock.

The process of the construction of geological engineering models, the interaction of model elements and the issues concerning homogeneity and isotropy are dealt with in GÁLOS – KERTÉSZ (1981). *Fig. 1* summarises the usual names for the sake of quick and easy survey.

2. Deterioration of Rock Slopes

In the case of surface forms, deterioration manifests itself in mass restructuring attached to different forms of movement. Forms of surface movements are grouped by the engineering literature in different ways. Basically, there are three forms of movement (SZILÁGYI – HORVÁTH, 1980):

– avalanche,
– foundering and
– flowing.

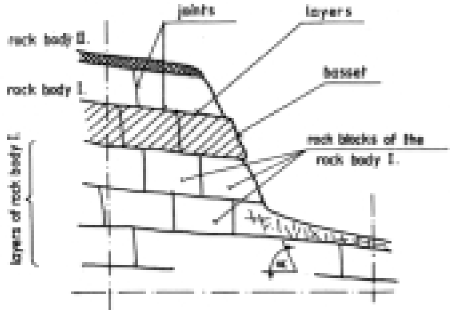

Fig. 1. Discontinuities in rocks

In the case of rock slopes, only the first two forms of deterioration occur (*Fig. 2*). We can speak about rock avalanche and peeling when rock masses or bodies of rock having lost their toughness disintegrate, as well as sliding and slumping belonging to the second category. Although they are the characteristic forms of deterioration friable rock, but they can also be interpreted to rock slopes as well.

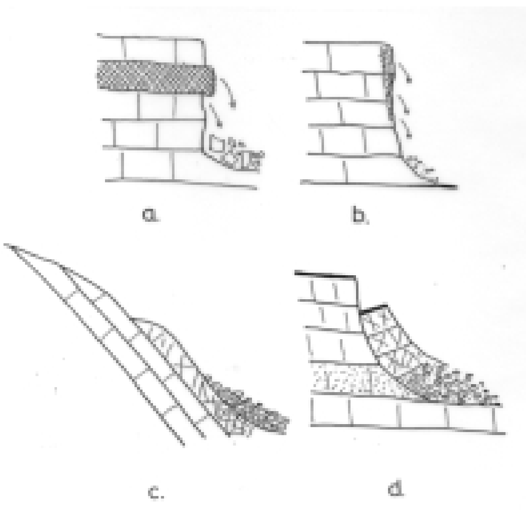

Fig. 2. Damaged types

Sliding is the rapid movement of bodies of rock having lost their toughness on a surface possible to determine in advance. Slumping is the large-scale rock avalanche along the surface of deterioration when bodies of rock having lost their toughness cause the movement of the block of rock.

Slow deformation, belonging to the category of foundering, may indirectly cause deterioration if the surfaces of articulation of bodies of rock open wide as a result of the loose sediment under the consolidated block of rock, susceptible to slow deformation (*Fig. 3*).

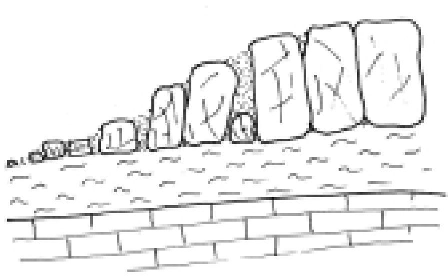

Fig. 3. Instability in creeping

The deterioration of rock slopes results in a large-scale mass movement, deserving increased attention from the point of view of both personal and property safety. It can be prevented only if tectonic (geological) conditions are known.

3. Natural Rock Slopes (Rock Splays)

Concerning the slopes consisting of a single type of rock, VENDL (1953) states, referring to Cholnoky, that they are concave on the bottom and convex on the top and it is on the inflexion line that slope is the most steep. As a result of weathering processes, the concave top is continuously deteriorating and the convex bottom is filled with pelt and fallen pieces of rock.

Depending on whether the concave or convex part is the larger, we talk about concave and convex slopes.

If weathering products are transported rapidly from the bottom of the slope, a straight slope will be formed. This is the steepest slope that can be formed from the given rock (*Fig. 4*).

Different geological and geological engineering handbooks (VENDL, 1953; MOSONYI – PAPP, 1959) tell slope angle values based on empirical data, summarised for individual rock groups by *Fig. 5*.

It can already be seen from the outline of *Fig. 5* that this grouping is strongly informative and cannot be used in engineering work. Its danger is that creates a basis for considering friction angle in the case of rock slopes as well, resulting in erroneous conclusions in this case.

Fissuration has a determining role already in the formation of a single-type rock slope. This statement is increasingly valid if the rock material of the slope is not homogeneous, that is made heterogeneous by the settlement of other types of rock or layers of the same rock with different quality.

Basic cases are shown in *Fig. 6*.

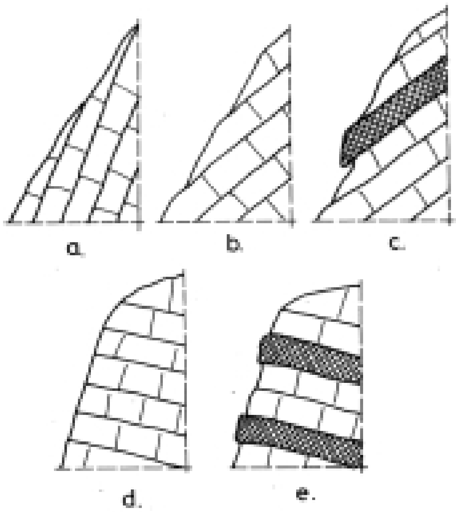

Fig. 4. Types of rock slopes

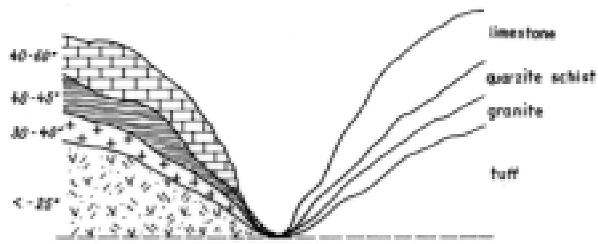

Fig. 5. Natural rock slopes

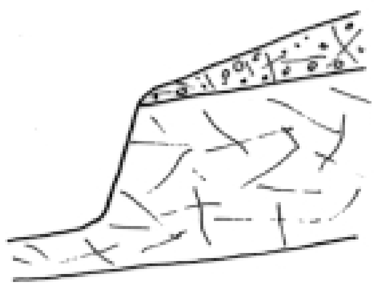

Fig. 6. Variations in rock stability

If the direction of the slope is at an oblique angle with the strike, humps and hollows appear on the surface of the slope depending on local rock quality (*Fig. 7*).

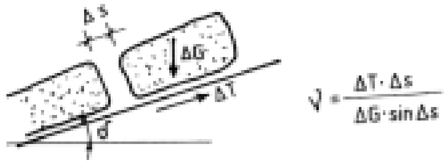

Fig. 7. Stability of jointed rock

Natural rock slopes become the indirect subject of engineering activities, since their deterioration should be dealt with only if they threaten the stability of other establishments, as well as personal or material safety.

Beginning from their formation, rock slopes are continuously exposed to deterioration. When the need for intervention arises that is to be regarded as the basic state of our survey, that is our activities connected to the given stage of the development of rock slopes. Its purpose is to restore the stability of rock mass with our modest means compared to the forces of nature.

4. Artificial Rock Slopes (Rock Cuttings)

Compared to natural rock splays, artificial rock slopes are engineering constructions regarding the entire process of their formation. From the construction need to the operation, they are under engineering supervision both from technological and economical aspects.

We differentiate artificial rock slopes as constructions from the point of view of their planned lifetime. Their formation and method of protection depend on whether they are temporary or final constructions.

Temporary rock slopes are the walls of productive mine plants, continuously changing during the course of production, as well as the side walls of excavation pits and working areas necessary for the construction of other establishments, bordering the area during the time of construction.

Final rock slopes are the accompanying cuttings of linear establishments and the ones bordering the area of establishments settled among variable ground configuration conditions.

A natural rock slope can become an artificial one if its solidity is to be protected, that is dealing with it goes beyond the scope of solidity survey.

Natural rock slopes become the indirect subject of engineering activities, since their deterioration should be dealt with only if they threaten the stability of other establishments, as well as personal or material safety.

Beginning from their formation, rock slopes are continuously exposed to deterioration. When the need for intervention arises that is to be regarded as the basic state of our survey, that is our activities connected to the given stage of the development of rock slopes. Its purpose is to restore the stability of rock mass with our modest means compared to the forces of nature.

5. Artificial Rock Slopes (Rock Cuttings)

Compared to natural rock splays, artificial rock slopes are engineering constructions regarding the entire process of their formation. From the construction need to the operation, they are under engineering supervision both from technological and economical aspects.

We differentiate artificial rock slopes as constructions from the point of view of their planned lifetime. Their formation and method of protection depend on whether they are temporary or final constructions.

Temporary rock slopes are the walls of productive mine plants, continuously changing during the course of production, as well as the side walls of excavation pits and working areas necessary for the construction of other establishments, bordering the area during the time of construction.

Final rock slopes are the accompanying cuttings of linear establishments and the ones bordering the area of establishments settled among variable ground configuration conditions.

A natural rock slope can become an artificial one if its solidity is to be protected, that is dealing with it goes beyond the scope of solidity survey.

Natural rock slopes become the indirect subject of engineering activities, since their deterioration should be dealt with only if they threaten the stability of other establishments, as well as personal or material safety.

Beginning from their formation, rock slopes are continuously exposed to deterioration. When the need for intervention arises that is to be regarded as the basic state of our survey, that is our activities connected to the given stage of the development of rock slopes. Its purpose is to restore the stability of rock mass with our modest means compared to the forces of nature.

6. Artificial Rock Slopes (Rock Cuttings)

Compared to natural rock splays, artificial rock slopes are engineering constructions regarding the entire process of their formation. From the construction need to the operation, they are under engineering supervision both from technological and economical aspects.

We differentiate artificial rock slopes as constructions from the point of view of their planned lifetime. Their formation and method of protection depend on whether they are temporary or final constructions.

Temporary rock slopes are the walls of productive mine plants, continuously changing during the course of production, as well as the side walls of excavation pits and working areas necessary for the construction of other establishments, bordering the area during the time of construction.

Final rock slopes are the accompanying cuttings of linear establishments and the ones bordering the area of establishments settled among variable ground configuration conditions.

A natural rock slope can become an artificial one if its solidity is to be protected, that is dealing with it goes beyond the scope of solidity survey.

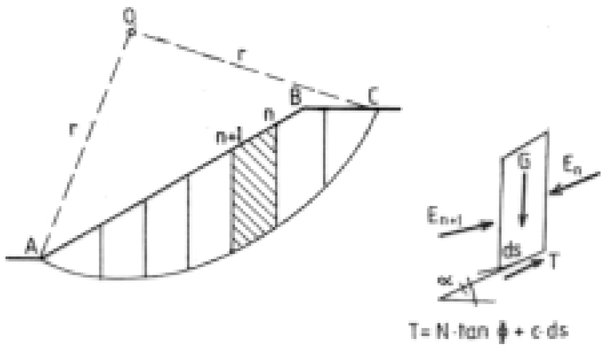

Fig. 8. Stability of hard rock

If the cutting to be formed in a consolidated surrounding rock were made in an heterogeneous surrounding rock, that is block of rock, our business would be very simple. In this case, rock mechanics characteristics determined by laboratory surveys would be the determining factors of the structural formation and geometrical dimensions of the cutting. The cutting could be constructed with high vertical walls. This geological situation is approximated by the bordering walls of the quarry of Fertőrákos stone pit, formed in a Miocene limestone.

The situation is more complicated if the surrounding rock consists of bodies of discontinuous rock but having the same structure. Cases to be considered are by *Fig. 9*.

Fissure may be undirected, having a so-colled homogeneous joint system, where surfaces of sliding might be formed through the fusion of articulation surfaces (*Fig. 9a*). The hazard of peeling is the largest in this geological situation.

In the case of directional joint systems, i.e. where there is bedding, there are three basic cases, each of which can be subdivided into two parts depending on whether the internal fissure of layers are of the same degree or not. Bedding can be horizontal or nearly horizontal and it can have the same or the opposite dip direction as the slope.

In the case of horizontal bedding (*Fig. 9b*), steep slopes can be formed, the solidity of which is determined by the internal joint system of the layers. More strongly articulated intermediate layers can make this situation critical (*Fig. 9c*). Their unfavourable solidity and strain characteristics might make them places causing deterioration, since their primary state of stress changes with the formation of the slope.

The worst case is when the layers are of the same dip direction as the slope to be formed (*Figs 9d* and *9e*). When identifying the blocks of rock with a movement hazard, it is on the one hand the relationship of the layers and the angle of the

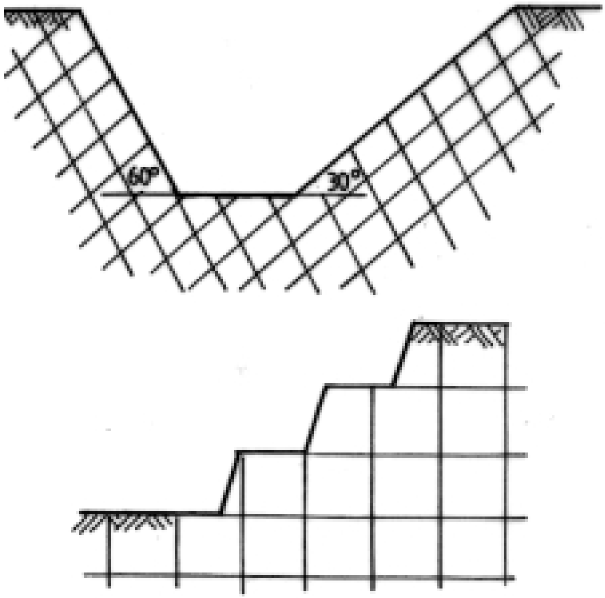

Fig. 9. Artificial cuts

slope and on the other hand the internal joint system which has to be taken into consideration. The angle of the slope might be lower, higher than and equal to the dip direction of the layers.

If the dip direction of the layers is opposite to the angle of the slope (*Figs 9f* and *9g*), a steep slope can be formed so long as sharp intersections, already susceptible to movement, do not occur in the case of possible steep slopes.

Unworthy of detailing is the series of cases when the geological environment consists of layers or bodies of rock with different lithological structure. Being dangerous it must, however, be stressed especially when they have a low solidity, are susceptible to compression and sensitive against water, etc. Preparatory phases before starting planning work have a definitive importance here.

References

[1] GÁLOS, M. – KERTÉSZ, P. (1981): A mérnöki munkák környezetének modellezése – a mérnökgeológiai kőzetmodell. *Mélyépítéstudományi Szemle,* Vol. XXXI. No. 12. pp. 540–545.
[2] MOSONYI, E. – PAPP, F. (1959): Műszaki Földtan. Műszaki Könyvkiadó, Budapest, p. 534.
[3] SZILVÁGYI, I. – HORVÁTH, ZS. (1980): Magyarország csúszásveszélyes területeinek katasztere. *Előtervezés-Mélyépítés,* FTV Kiadvány, pp. 252–256.
[4] VENDL, A. (1953): Geológia I. Tankönyvkiadó, Budapest, p. 655.