Journal of Civil Engineering and Architecture 20 (2026) 66-73
doi: 10.17265/1934-7359/2026.02.004

# Rock Slopes Stability as a Function of Stress Concentration — Theory and Practice Overview

Chavdar Kolev
*University of Transport "Todor Kableshkov", Sofia 1584, Bulgaria*

**Abstract:** Problems with rocky slopes on roads and railways are most often caused by collapses and rolling stones - phenomena that are unacceptable for normal operation. The uneven surfaces of the slopes complicate the analysis of stability and are a prerequisite for faster weathering of the rock. The report looks for ways to achieve better quality and durability in the construction of rocky slopes. First, the theoretical and practical aspects of stress concentration along the uneven surfaces of rocky slopes are presented, and it is proved that they give rise to the process of destruction and destruction of rock blocks. Approaches for stress analysis on complex rough surfaces with the Mechanics apparatus are shown. The mathematical solution is based on the equations of Navier-Stokes et al. Examples of good practice for addressing it on Australia's roads is presented. The research is the result of a scientific expedition by the author. It has been proven that if the slopes are milled during construction, they will have great durability and will not need maintenance. A comparison has been made with the widely used approach in Europe to reinforce rock slopes with metal nets and its lower technical and economic efficiency has been demonstrated. The findings strongly prove that milled rock surfaces are much more effective than uneven ones. There are technical possibilities for widespread use of rock sloping in European practice.

**Key words:** rocky surfaces, stress, mills, cracks, efficiency.

## 1. Introduction

The stability of rocky slopes is a classic task in Rock Mechanics and always brings new and new problems to specialists in theory and practice. The application of this task is very wide all over the world and has its specific features depending on geological conditions and scale of construction. Problems with rocky slopes on roads and railways are most often caused by collapses and rolling stones — phenomena that are unacceptable for normal operation.

Almost everywhere the surfaces of the rocky slopes are uneven, fringed, have many in excavation. The uneven surface cracks, despite advances in blasting technology s of the slopes complicate the analysis of their stability and are a prerequisite for faster weathering of the rock. The question arises about the distribution of normal stresses on the surface of rock slopes and the role of concentrated stresses on stability. The report focuses on the theoretical and practical aspects of this problem and the good practice for solving it.

## 2. State of the Art

The concentration of stresses on arbitrary rough surfaces is a complex task for analytical solution, but it is of great importance for practice in many fields of technology, including rock mechanics. In fact, it is necessary to know how sites with anomalies in the form or in the qualities of the material turn into ulcers and their destruction begins.

Using the Navier-Stokes equations, Fick's Law of diffusion, and free-energy Gibbs equations, one can reach the mathematical model sought on very specific and simpler surfaces [1]. Knowledge of the most common solution to a problem is still accumulated

**Corresponding author**: Chavdar Kolev, Ph.D., professor, research fields: landslide stabilization, deep foundations, pile bearing capacity, and structural, geotechnical, and transport infrastructure engineering.

before reaching the solution. Much of the advancement on the fore-going topics has relied on the use of surface-stress-concentration distributions for the cases of sinusoidal surfaces, cycloid rough surfaces and some single-notch cases.

We are aware that rough surfaces are subject to transformations and deformations under the influence of stresses that flow around them and through them. The critical values of these stresses and strains are exactly in the folds of their shape. When the stresses and strains at these boundary sections reach critical values, destruction occurs. Even small random rough surfaces can increase the tension around them by 1.5 to 3 times [1].

It has been found that the presence of tensile stresses increase the electrostatic potential for oxygen molecules from water to bond to Si. Also, the stresses increase the hybridization of Si and O orbitals. This mechanism promotes the breaking of existing Si-O, thus creating more free Si sites exposed to the further attack of the environment. Additionally, it has been established that the so called “reaction-layer” process is initiated by high stress concentrations created at the bottom of notches [1].

## 3. Normal and Tangential Stresses in Rock Slope

### *3.1 Normal and Tangential Stresses in the Massifs and Influence on the Slope Stability*

Normal stresses increase as the depth increases. Tensions are concentrated in the heels of the slopes. The more gentle the slope, the lower the stress concentration. When the slope is vertical, the stress concentration in the heel is highest. High tangential stresses in the heel of the slope can plasticize the substrate if it is higher than its shear strength. When the slope is very steep, the tangential stresses remain unbalanced and form slippery surfaces. These are implications of the theory of boundary equilibrium.

The gentle slopes less concentrated tensions in its bottom and displace large normal stresses into the massif. Therefore, vertical slopes have the highest stresses. The ellipses of the principal normal stress around the slope and its heel can be calculated.

Deformations and sliding of slopes are possible due to unchecked steep slopes.

The areas around the slopes where slip or roll over of rock fragments and at the heels where the base is plasticized are the most vulnerable.

### *3.2 Slope Stability Against Sliding*

Sliding is the most common type of rock slope loss. The most common reasons for slipping are:

- rock weathering,
- hydrodynamic pressure,
- seismic effects,
- excavation works
- etc.

As a result of the above impacts on the rocks, new cracks appear and the friction forces in them decrease [2].

Weathering of rocks is a very long process and therefore to the durability of the slopes should always be treated with due care. The most commonly used measure in the past slopes are lined with stone masonry. Nowadays most often make networks attached to the rock anchors. The nets, although well insulated against corrosion, do not possess the durability and aesthetic appearance of stone masonry. However, networking is much faster. Both types of structures are preventive. The stone masonry prevents the rock from eroding and

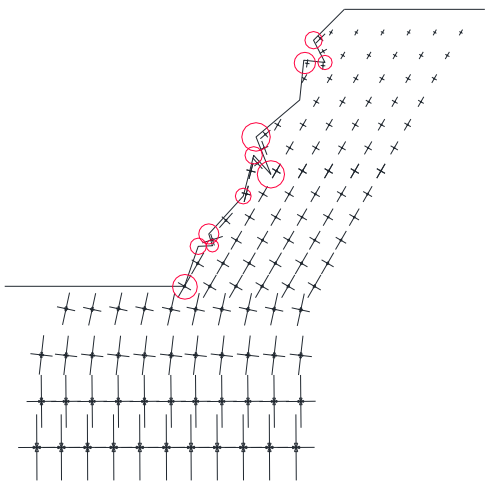


**Fig. 1 Rough slope surface.**



**Fig. 2 Sloping preparation for safety net cover — the most commonly used reinforcement measure.**



**Fig. 3 There are no more enough masters — craftsmen to perform stone masonry.**

thus maintains the stability of the slope. The cladding allows the groundwater to flow out.

## 4. Concentration Stress on Rock Slope — Theoretical Basic

### *4.1 Classic Case*

Alteration of the cross-section leads to disruption of the uniform distribution of stresses, i.e., give stress concentration. To quantify stress concentration ratio:

$$k = \sigma_{max}/\sigma_x$$

used what is called coefficient of stress concentration [3].

The more dramatic the change in cross-section, the greater is the coefficient of stress concentration.

The concentration of tension very quickly decreases when moving away from the hub. There may be internal stress concentration zones within the material that arise not only from heterogeneity in structure, but also from the crystals themselves with their anisotropic

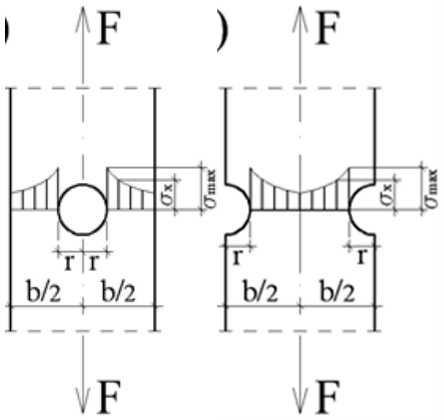



**Fig. 4 Concentration stress.**

properties, as well as from dislocations, inclusions, voids and external defects. All this causes a non-uniformity in the distribution of stresses and leads to the formation of internal zones of stress concentration.

The more plastic is the material, the greater the redistribution of stresses. For fragile materials strength sharply decreases around the hub due to increased local tensions. The concentration of stress in the vicinity of the hub substantially depends on the radius of curvature at the apex r, the depth t, as well as the angle of inclination. Of the three parameters affecting the value of stress concentration, the parameter r is the most important.

Concentration stress coefficient [1]

The first analytical solutions for stress concentration are from the beginning of the last century. After them, a number of empirical formulas have been proposed. For rough surfaces with small amplitudes for each function f(x) describing a two-dimensional surface, the stress concentration is given by the formula:

$$k_t(x) = 1 - 2\mathcal{H}(f'(x)) \quad (1)$$

where $\mathcal{H}$ stands for the general Hilbert transform, and $f'(x)$ is the first derivative with respect to the given independent variable $(x)$. Using this generating equation, well-known traditional results can be easily obtained.

Let's look at the profile of the $X$ axis on a rough surface $f(x)$ with small amplitudes, as shown in the Fig. 1. We assume that the material is elastic, homogeneous and isotropic. The material is characterized by Young modulus $E$ and *Poisson*' ratio $\upsilon$.




**Fig. 5 Surface profile on direction X [1]**

Roughness of this surface could be analyzed them subdivided into simple geometric lines described by *f (x)*: Cosine pulse notch (Fig. 2), Gaussian notch (Fig. 3), parabolic notch (Fig. 4), semi-elliptical profile (Fig. 5) and undulating surface (Fig. 6).

Thus, starting from the general equation (1) for a rough surface with small amplitudes, the following expressions are obtained for the stress concentration coefficients [1]:

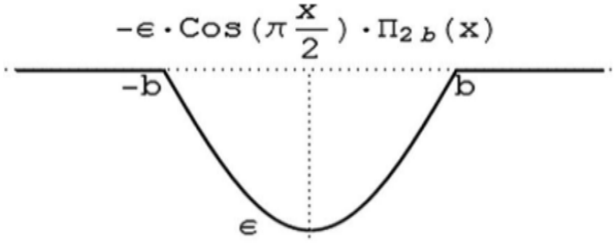



**Fig. 5 Cosine pulse notch [1].**

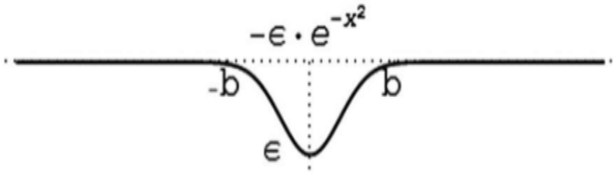



**Fig. 6 Gaussian notch [1].**

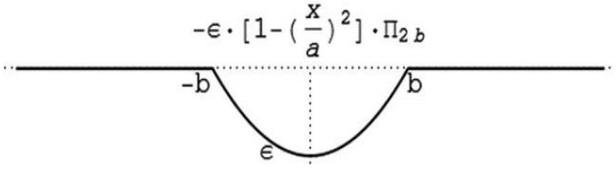



**Fig. 7 Parabolic notch [1].**

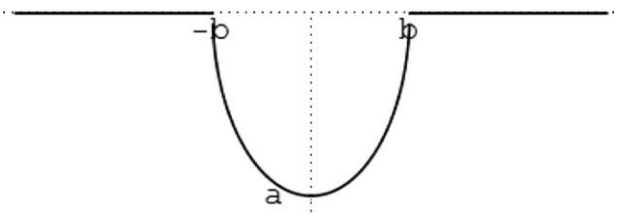



**Fig. 8 Semi-elliptical profile [1].**

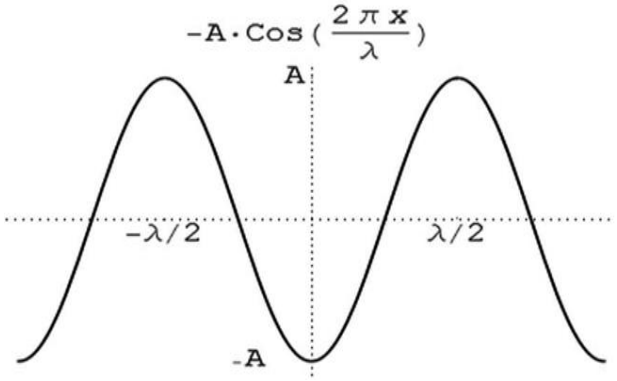



**Fig. 9 Undulating surface [1].**

- for semi-elliptical notch: $k_t = 1 + 2\frac{a}{b}$ ,
- where $a$ – notch depth;
- $b$ – notch width.

According [1] for a depth-to-width ratio, *a/2b*, equals to 0.1, the stress is magnified from the remote load by 40%.

- for undulating surfaces: $k_t(x) = 1 + 4\pi\frac{A}{\lambda}$ — $\cos(2\pi x/\lambda)$
- for Parabolic notch: $k_t(0) = SCF = 1 + \frac{8\epsilon}{\pi b}$
- for Gaussian notch: $k_t(0) = SCF = 1 + \frac{4\epsilon}{\sqrt{\pi}}$

While the first-order approximation shows $k_t$'s dependence only on the slope of the surface, the second-order approximation shows its dependence on both slope and curvature.

It has been found that the presence of tensile stresses increase the electrostatic potential for oxygen molecules from water to bond to *Si*. Also, the stresses increase the hybridization of *Si* and *O* orbitals [1]. This mechanism promotes the breaking of existing *Si-O*, thus creating more free *Si* sites exposed to the further attack of the environment. Additionally, it has been established that

the so called “reaction-layer” process is initiated by high stress concentrations created at the bottom of notches.

## 5. The Good Practice in Australia

The practical confirmation of the scientific hypothesis was found during my scientific expedition to Australia in 2013. I watched the old and new roads of all categories in New South Wales and Queensland. It turned out that without exception, they have perfect smooth surfaces on their rocky slopes, and no debris or erosion sand has fallen in the heels of the slopes. In practice, there are no cases of falling stones on the roads and railways.

The surfaces of the rocky slopes along Australia’s roads are perfectly smooth, as seen in Fig. 10 to Fig. 17. Thus, there is no stress concentration on the rock surface, no prerequisites for accelerated weathering and deformation. Obviously, after a masterful blow up the breach is particularly satisfied mechanical alignment of the rock surface. Thus, there is no stress concentration on the rock surface, no prerequisites for accelerated weathering and deformation. It is obvious that after the masterful blasting of the breakthrough, a specially mechanized alignment of the rock surface was performed.

Let’s not forget that Australia's mining industry has a long tradition of reaching a very high level of development. Obviously, blasting are performed masterfully with high precision. Directional controlled power blasts keep the rocky slope clear of large cracks. This is a prerequisite for achieving a smooth sloping surface.

All the rock mass-produced by the breakthrough is nested on the basis of the new road. The length of the road is 1000 km. This is the point of making a trench instead of a tunnel.

The slopes are made smooth, regardless of their height (Fig. 16). So they have durability and good aesthetic appearance.



**Fig. 10 Rocky slopes on the way from Sydney to the north.**

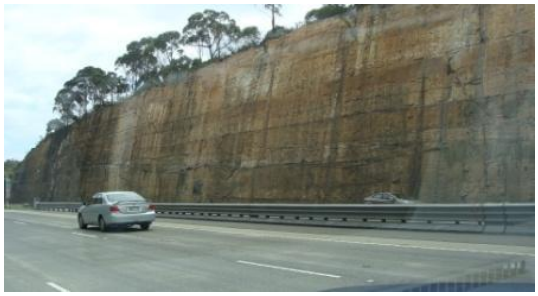


**Fig. 11 Smooth rock slopes about 10-12 m high.**



**Fig. 12 Rock excavation depth 20 m.**



**Fig. 13 Smooth rock slopes with blocky texture.**



**Fig. 14 Rock slope with height 25-30 m.**



**Fig. 15 Step slop There may also be a step slope if there is a higher degree of rock weathering.**



**Fig. 16 The lower slopes are also smooth.**



**Fig. 17 A rock wall left between the two lanes of the highway.**

*5.1 Technology of Shaping*

The question is what mechanization can effectively be shaped such smooth rocks? Generally, this can be achieved with mills (Figs. 18 and 19). Before that, however, the trench must be filled with skillfully controlled directed blasting. Explosions must be directed entirely inward to the trench and not outward to the slopes. In this way, the cracks caused by the explosion will be no larger than 10mm along the trench walls. The cutter will cut the cracked surface and turn it into a smooth undistorted plane.

Weathering does not create a dangerous situation where the walls are smooth.

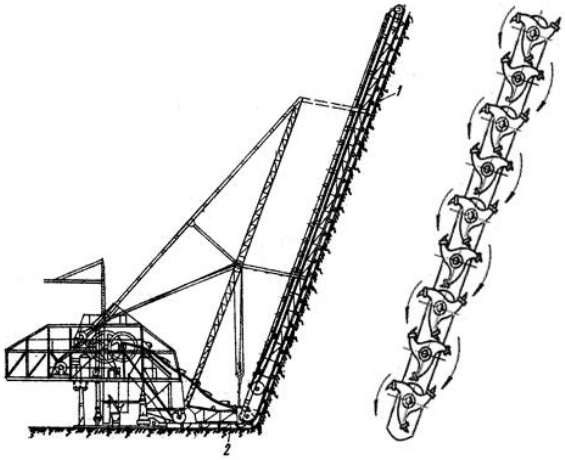




**Fig. 18 Mills for profile slopes - With machines like these can achieve a smooth surface of the rock slope.**







**Fig. 19 Sloping profiling machines.**



**Fig. 20 Occurring slopes with block texture and biological weathering.**



**Fig. 21 High road slopes, preferred to break Tunnel.**

Smooth rocks practically require no maintenance.

## 6. Comparison with Traditional Methods of Strengthening in Europe

There is no tradition in Europe to make such smooth slopes. The efforts of the builders come down to achieve good blow and sufficient slope to slope. The rough surface is offset by the protective metal mesh (Figs. 23 and 24). In this way, however, durability is not achieved and in the future time resources are needed to maintain and repair the slopes and nets. The aesthetic appearance of the nets is also not good enough for the eye (Fig. 25).

Often and blasting are not met precisely and thus constantly needs funds to maintain the slope, and the best aesthetic appearance just missing (Figs. 22 and 25).

### *6.1 Techno-Economic Comparison*

The difference in quality of the two approaches is obvious! Higher cost in construction (blasting excavation and milling) do not require expenditures for maintenance and repair. Conversely, lower construction costs with no milling required each year costs for maintenance, repair and strengthening (Figs. 26 and 27).



**Fig. 22 A rocky slope in the center of a small mining town in Bulgaria. It is as if the builders in Europe are not striving to reach the smooth surfaces of the rocky slopes at all.**



**Fig. 23 The most widely used method for reinforcing rock slopes.**



**Fig. 24 Installation of safety nets.**

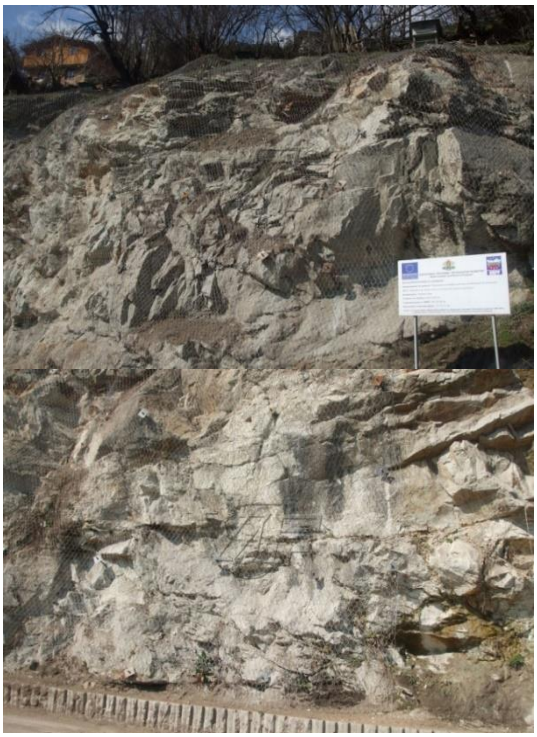


**Fig. 25 Safety net with anchors — no aesthetic appearance.**



**Fig. 26 Low cost of construction and permanent maintenance costs. There is a danger of rolling stones!**



**Fig. 27 Higher construction costs and no maintenance costs.**

## 7. Conclusions

It is clear that the concentration of stresses leads to cracking of rock slopes and loss of their stability.

The rough surfaces of the rocks require maintenance and reinforcement costs and also pose a risk to road safety.

Smooth slopes have a higher construction value but are completely safe and require no maintenance costs.

The analysis of concentrated stresses for complex uneven surfaces has not yet reached the point where it can be easily applied in construction practice.

## References

[1] Medina, H. 2015. "A Stress-Concentration-Formula Generating Equation for Arbitrary Shallow Surfaces." *International Journal of Solids and Structures* 69-70: 86-93.

[2] Totsev, A. 2009. "Rock Slope Calculation." In: *Proceedings of the International Conference UACEG2009*, Science & Practice, Sofia, 29-31 Oct. 2009.

[3] Neuber, H. 1961. "Theory of Stress Concentration for Shear-Strained Prismatical Bodies with Arbitrary Nonlinear Stress-Strain Law." *ASME Journal of Applied Mechanics* 28.