Slopes stabilized by retaining panels – a new dimensioning method based on 3D Finite Element calculations

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ABSTRACT
Different techniques exist for stabilizing ground slopes. This paper deals with slope stabilization by means of retaining panels. Retaining panels are classified according to their bearing behaviour. The stability of slopes stabilized by retaining panels can only be determined realistically by spatial stability calculations using the Finite Element Method. The achievable stabilizing effect is mainly influenced by the distance between the panels and the panel geometry in the slope cross section. The failure mechanisms, the bearing behaviour and the effects of the influence parameters are considered. Suggestions are made for dimensioning panel distances and panel geometry.

RÉSUMÉ
Il existe plusieurs techniques de stabilisation des pentes. Cette publication ne concerne que la méthode de stabilisation de pente par panneaux de retenue. Une classification essentielle des panneaux de retenue est réalisée selon leur comportement porteur. Seuls des calculs de stabilité dans l'espace selon la méthode des éléments finis permettent d'analyser des pentes stabilisées avec panneaux. L'effet stabilisateur à obtenir dépend principalement de la distance séparant les panneaux et de leur géométrie. Le mécanisme de rupture, le comportement porteur et les paramètres d'influence sont pris en compte. Des mesures de la distance entre les panneaux et de leur géométrie sont également proposées.

1 INTRODUCTION

Various technical methods exist for the stabilization and/or reinforcement of slopes. Slope flattening, soil nailing, massive retaining constructions or geotextile retaining wall constructions are some examples that could be mentioned. Another method of slope stabilization is the use of retaining panels made of lean concrete. This method uses lean concrete retaining bodies arranged at defined intervals along the length of the slope (see figure 1). The width of the retaining elements is typically 2 metres. The distance between the panels varies from 2 metres to 10 metres. The panels are manufactured using the so-called “hydro-cementation” technique. In comparison to other methods, slope stabilization by retaining panels is a good alternative both technically and economically. This method is well established for the reinforcement of railroad embankments in particular. Slope-stabilizing retaining panels are quite flexible and adaptable to the existing local conditions in each case. They can be used to increase slope stability in slopes without a defined slip surface, or used to plug slopes possessing defined weak zones. When used together with infiltration ditches, the static effect of the retaining panels can be combined with the drainage effect of the infiltration ditches. The stabilizing effect achievable by retaining panels is influenced mainly by the distance between the panels longitudinally along the slope and by the geometric shape of the panels in the slope cross section.

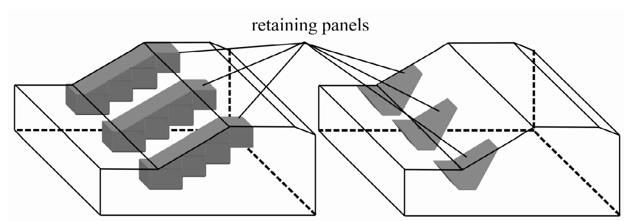

Figure 1. Retaining panels for slope stabilization

2 FABRICATION OF THE PANELS

The retaining panels are manufactured using a method called “hydro-cementation”. The retaining body is produced by adding water and cement to the soil. The trench for the retaining panels is excavated using backhoe excavators for low slopes and using special walking excavators for higher slopes. The soil material is excavated and temporarily stored off to one side. The cement suspension is poured through a hose line into the trench as the excavated soil is back-filled, where the soil and the cement suspension are mixed by the excavator bucket in the trench. This method achieves a soil improvement without soil replacement (in-situ soil conditioning). The amount of cement added usually ranges from 5 to 20 mass percent in relation to the soil mass. The water/cement ratio usually varies between 0.5 and 1.0 depending on the soil.

3 PROPERTIES AND SOIL MECHANICAL PARAMETERS OF THE PANELS

After setting, the properties of the retaining body are comparable to those of lean concrete. Depending on the in-situ soil, a uniaxial compression strength between 5 and 10 MPa is reached. Regarding the soil mechanical shear parameters: the internal friction angle is between 40 and 50 degrees and the cohesion is approximately 300 to 700 kPa.

4 SLOPE STABILITY CALCULATIONS BASED ON 3D FINITE ELEMENT CALCULATIONS

The stability of slopes stabilized by retaining panels cannot be adequately determined using analytical calculation methods (for instance slip circle methods or wedge methods). In particular, the correct geometrical shape of the failure body between the panels cannot be determined optimally using conventional analytical methods. To calculate the correct bearing behaviour of the panels, one can instead use spatial numerical calculations. The slope stability calculations for slopes stabilized by retaining panels presented in this paper were therefore carried out three-dimensionally using the Finite Element Method. The key advantage this presents over analytical calculation methods is that the location and the shape of the critical slip surface is automatically calculated during the calculation process. That means it is not necessary to predefine a geometrical slip surface shape. Any failure mode develops naturally.

For calculating the stability (factor of safety), the strength reduction method (φ-c-reduction) was employed. Using this method, the slope stability is based on a comparison of the shear strength in limit state with the existing shear strength (shear strength based on the existing soil shear parameters). Within the shear strength reduction method, the factor of safety is defined as the number by which the existing shear strength parameters have to be divided in order to bring the slope to the limit state (failure state).

By employing the Finite Element Method for slope stability calculations, the result of the calculation (primarily the factor of safety) is exclusively based on the soil shear parameters friction angle φ and cohesion c. Due to this fact, the single requirement for the constitutive law is that the limit state condition for the shear failure be based on these parameters. Therefore, the elastoplastic Mohr-Coulomb constitutive law is employed for the numerical calculations.

Due to the fact that the slope stability exclusively refers to the soil elements within this method, the shear resistance of structural elements (e. g. anchors, nails) is not influenced by the strength reduction technique. That means that by employing the strength reduction technique, only the shear strength of soil elements is reduced. To work around this disadvantage of the method, the material of the retaining bodies (lean concrete) is also defined as a Mohr-Coulomb material. This means that, when employing the shear parameter reduction method, the shear strength of the panel material is reduced in the same way as the shear strength of the soil.

5 DEFINITION OF SPECIFIC PARAMETERS, FACTORS AND DESIGNATIONS

The stability of slopes stabilized by retaining panels is mainly influenced by the following input parameters:

- slope inclination / slope angle β_{slope},
- slope height h_{slope},
- unit weight of the soil γ_{soil},
- friction angle φ_{soil} and cohesion c_{soil} of the soil,
- panel width b_{panel}
- distance between the panels a_{panel}.

In order to derive a dimensioning method, it was necessary to combine the input parameters and define suitable factors and parameters without scale units.

To eliminate the panel distance as a single parameter, the panel distance is linked with the slope height. The distance/height ratio a_{panel} / h_{slope} defines the ratio of the clear distance between the panels to the height of the slope. Furthermore, the panel distance is linked with the panel width to obtain the distance/width ratio a_{panel} / b_{panel}.

The degree of slope reinforcement that can be achieved by employing retaining panels is expressed as the factor of improvement FOI. This factor is defined as the ratio between the factor of safety FS_1 of the slope stabilized by retaining panels and the factor of safety FS_0 of the original slope without any reinforcement.

$$FOI = FS_1 / FS_0 \qquad [1]$$

$$FOI = f(a_{panel}, b_{panel}, \gamma_{soil}, \varphi_{soil}, c_{soil}, h_{slope}, \beta_{slope}) \qquad [2]$$

The dimensionless factor $f_{\varphi c}$ combines the parameters γ_{soil}, φ_{soil}, h_{slope} and c_{soil}.

$$f_{\varphi c} = \gamma_{soil} \cdot h_{slope} \cdot \tan\varphi_{soil} / c_{soil} \qquad [3]$$

$f_{\varphi c}$ fundamentally represents the ratio between the friction rate and the cohesion rate on the total shear strength of a soil. For instance, if $f_{\varphi c}$ decreases and slope height as well as unit soil weight remain constant, then the stress dependent rate on the total shear strength increases (the amount of friction on the total shear strength increases). In the context of the dimensioning methods developed, the factor $f_{\varphi c}$ represents the main input parameter.

The stability number N* includes the input parameters γ_{soil}, h_{slope} and c_{soil} as well as the slope stability (factor of safety FS).

$$N^* = FS \cdot \gamma_{soil} \cdot h_{slope} / c_{soil} \qquad [4]$$

The combination of the defined dimensionless factors proved to be the best method for expressing the connection between the input and the result parameters of a spatial numerical stability calculation of slopes stabilized by retaining panels. By implementing these factors, it is possible to express the relations of input and result parameters through elementary mathematical relations.

6 EMPLOYMENT OF RETAINING PANELS TO INCREASE SLOPE STABILITY BY MOBILIZATION OF A SPATIAL BEARING ARCH BETWEEN THE PANELS (CASE A1)

6.1 Case A1 – bearing behaviour / failure mechanism

6.1.1 Basic principle

The basic principle of case A1 is to manipulate the critical slip surface of the slope in such a way as to produce a slip surface located exclusively between the panels. In the limit state, a spatial failure body develops between the panels (see figure 2). The failure body is shell-shaped. The position of the retaining panels is unaffected by the failure body in the case of failure (limit state). This is ensured by the geometrical dimensions of the panels.

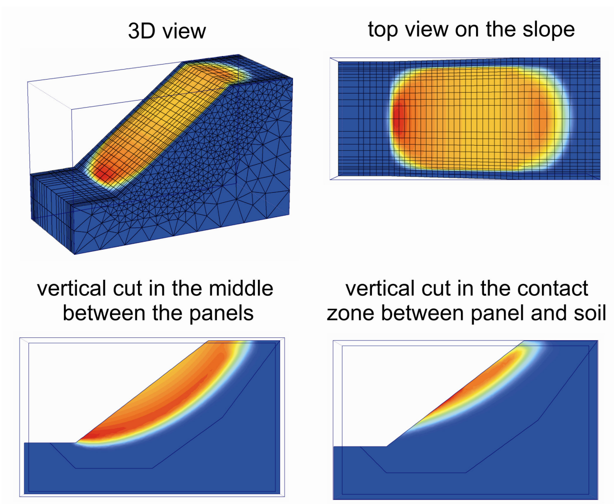

Figure 2. Case A1 – failure body / location of the critical slip surface in limit state

The stabilizing effect concerning the slope stability in case A1 is based on an arching effect / rearrangement of stresses among the panels as well as the transmission of lateral shear forces between the failure body and the retaining bodies.

In a condition close to the limit state, a spatial bearing arch develops between the panels. The retaining panels exhibit essentially greater stiffness and shear strength than the soil.

The bearing arch redistributes the stresses from regions in a limit state to regions that are less stressed and accordingly able to withstand a greater load. Stresses are redistributed from regions between the panels to the contact regions of the panel surfaces and to the panels themselves. Figure 3 illustrates this displacement of stresses by the example of a horizontal cut through a slope stabilized by retaining panels in limit state. The figure shows the shape of the failure body due to the deformations, the direction of the principal effective strains and the directions of the principal effective stresses. The principal effective stresses decrease in the middle between the panels and increase in the panel–soil contact regions. A three-dimensional rotation of the principal effective stresses is induced around the spatial failure body.

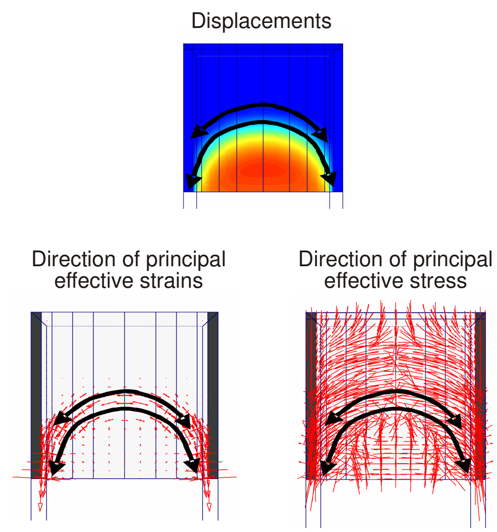

Figure 3. Case A1 – horizontal cut through a slope stabilized by retaining panels in limit state, total displacements, direction of principal effective strains and principal effective stresses

Shear forces are activated on a defined contact surface between the spatial failure body and the panels. The failure body, which develops between the panels, suspends itself laterally on the panels (see figure 2). The failure body transmits shear forces through the lateral contact surface to the retaining panels. The panels absorb these shear forces and transmit them further to the subsoil. This in turn leads to an increase in slope stability. Consequently, the panels have to be designed in such a way that they are able to transmit the shear forces to the subsoil. Should the geometrical dimensions of the panels be too small, the lateral shear forces would cause the panels to fail along with the failure body between them. In such a case, the panels would be pushed or toppled out of the slope.

There is another effect directly associated with the arching effect between the panels, which also influences the shear forces in the contact region between the panels and the failure body. In limit state, the arching effect causes a displacement of stresses from regions between the panels to the regions of contact with the panels. The regions in the middle between the panels are relieved, whereas regions bounding the panels are stressed. This displacement of stresses results in an increase in normal forces on the contact surface between retaining panels and failure body. Associated with this is an increase in supporting forces resulting from friction in the contact surface.

6.1.2 Effects of the influencing parameters

To understand the effect of retaining panels for slope stability and especially the bearing behaviour of the panels, the effects of the input parameters on the stability of slopes stabilized by retaining panels are dealt with below.

The basis for deriving the dimensioning method is an evaluation of the influence of the input parameters on the stabilization effect as well as the influence of the input parameters on bearing behaviour.

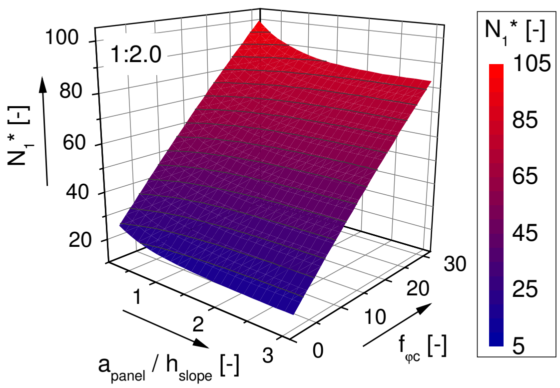

Figure 4. Case A1 – influence of the input parameters $f_{\varphi c}$ and a/h on the stability number (exemplary for the slope inclination of 1:2.0)

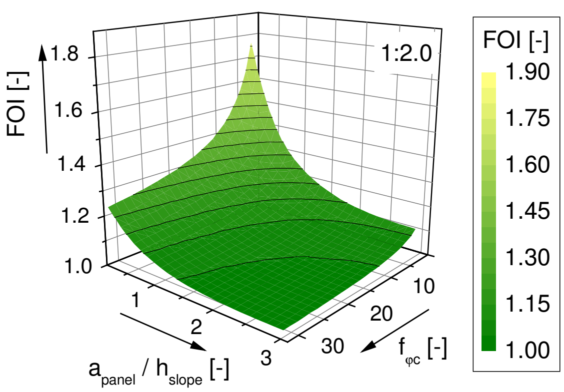

Figure 5. Case A1 – influence of the input parameters $f_{\varphi c}$ and a/h on the factor of improvement FOI (exemplary for the slope inclination of 1:2.0)

To determine the effects of the input parameters, a large number of three-dimensional slope stability calculations were carried out using the Finite Element Method. The input parameters were each varied and optimized on the basis of a statistical experiment design. The charts illustrated in this paper are based on approximately 1,600 calculations.

Figures 4 and 5 illustrate the influence of the factor $f_{\varphi c}$ and the distance/height ratio on the stability number N_1^* and the factor of improvement FOI for a slope inclination of 1:2.0. The influences of the input parameters on the stabilization effect in case A1 can be summarized as follows:

The achievable stabilizing effect increases disproportionately as the distance/height ratio decreases. If the distance/height ratio is less than 1.5, then the stabilizing effect of the panels is particularly high. If the distance/height ratio is greater than 2, then the panels loose their stabilizing effect (limit panel distance). If the limit panel distance is exceeded, then the distance becomes too large to achieve a stabilizing effect. The three-dimensional failure mechanism changes into a two-dimensional failure mechanism. In this case, the stability is equal to the stability of the original slope without reinforcement.

The achievable stabilizing effect, expressed by the factor of improvement FOI, increases disproportionately as the values of factor $f_{\varphi c}$ decrease. Thus, the stabilizing effect increases with an increasing influence of the cohesion rate and a decreasing influence of the friction rate on the total shear strength of the soil.

In case A1, a minimum cohesion in the soil is required to achieve a stabilizing effect. The application of case A1 is not practicable in soils without cohesion. In soils without cohesion, the critical failure mechanism is characterized by slip surfaces close to the slope surface. In this case, it is not possible to form a sufficient spatial bearing arch to achieve a noticeable stabilizing effect. It is recommended to avoid case A1 and therefore apply case A2 in soils without cohesion.

Furthermore, the attainable stabilizing effect increases with decreasing slope height, flattening slope inclination and decreasing unit soil weight.

$$FOI\uparrow = f(a_{panel}\downarrow, \gamma_{soil}\downarrow, \varphi_{soil}\downarrow, h_{slope}\downarrow, \beta_{slope}\downarrow, c_{soil}\uparrow) \quad [5]$$

6.2 Case A1 – dimensioning the panel dimensions

6.2.1 Basic principle

The dimensioning of the panels regarding case A1 is completed in two steps. The first step is to dimension the distance between the panels. The second step is to dimension the geometrical design of the panels in the panel plane. The input parameter is always the dimensionless factor $f_{\varphi c}$.

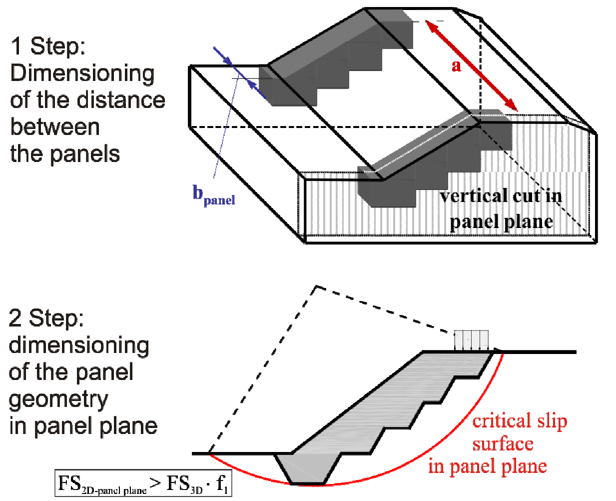

Figure 6. Case A1 – basic principle of the geometrical panel dimensioning

6.2.2 Dimensioning the panel distance

The distance between the panels can be dimensioned using charts as illustrated in figure 7. The diagram shows an example chart for a slope inclination of 1:2.0. Such dimensioning charts can be used flexibly depending on the particular problem at hand.

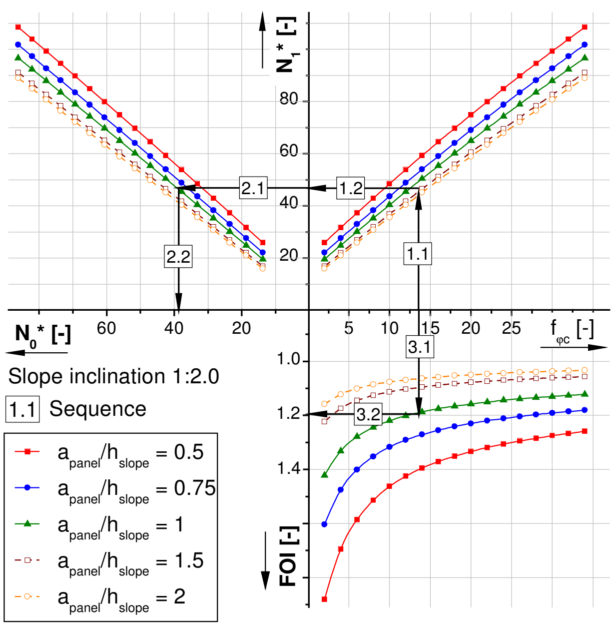

Figure 7. Case A1 – dimensioning chart for dimensioning the panel distance (example for slope inclination 1:2.0)

Starting with the input parameter $f_{\varphi c}$ and a defined distance/height ratio, the factor of safety for a slope stabilized by retaining panels can be determined using the stability number $N_1^*(f_{\varphi c};\ a_{panel} / h_{slope})$ from the first quadrant of the chart (sequence 1.1 to 1.2). Inversely, it is possible to calculate the stability number $N_1^*{}_{req}$ for a required factor of safety FS_{req}, and directly read off the associated optimal distance/height ratio from the first quadrant of the chart for a specific factor $f_{\varphi c}$ (sequence 1.1 to 1.2 in reverse). The related stabilizing effect, expressed by the factor of improvement FOI, can be determined from the fourth quadrant of the dimensioning chart as a factor of the distance/height ratio (sequence 3.1 to 3.2).

6.2.3 Dimensioning the panel geometry in the panel plane

Next, the dimensions of the panels in the panel plane have to be defined in such a way as any failure is enforced exclusively to between the panels. Accordingly, the geometrical dimensions of the panels must be calculated such that the panels do not change their positions in the case of failure. Employing two-dimensional slope stability calculation methods, the panel geometry is adjusted iteratively until all slip lines that arise in the panel plane exhibit a factor of safety $FS_{2D\text{-}panel\ plane}$ that is larger than the factor of safety FS_{3D} calculated from dimensioning the distance between the panels multiplied by an increase factor f_1 (equation 6).

$$FS_{2D\text{-}panel\ plane} = FS_{3D} \cdot f_1 \qquad [6]$$

The increase factor f_1 indirectly accounts for the arching forces transmitted by the spatial bearing arch between the panels through the lateral contact surfaces into the panels in the limit state.

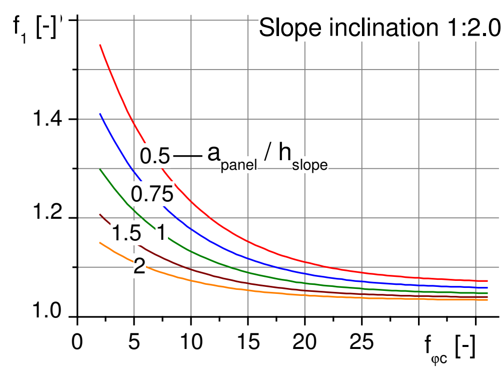

Figure 8. Case A1 – dimensioning chart for determining the increase factor f_1 for dimensioning the panel geometry in the panel plane (example for slope inclination 1:2.0)

This means that the value of the increase factor is mainly influenced by the formation of the spatial bearing arch between the panels. The increase factor depends on the input parameter $f_{\varphi c}$, the distance/height ratio determined within the first dimensioning step and the slope inclination. The increase factor f_1 can be deduced from charts such as the one illustrated in figure 8. The chart in figure 8 provides an example for a slope inclination of 1:2.0. Also, the chart in figure 8 is only valid for a panel width of 2 metres.

The following recommendations should be taken into consideration for the initial design of the panel geometry (see figure 9).

A) Interlocking of panels and subsoil: To obtain a good interlocking connection of the retaining panels with the subsoil, the shape of the panels should be built in a cascaded form.

B) Considering the critical slip surface of the original, unreinforced slope: The panels should be designed such that the panel cross sections cover at least the bulk of the critical slip surface of the original, unreinforced slope.

C) Embedment length of the panels behind the slope shoulder: The embedment length behind the slope shoulder should extend at least to the access point of the critical slip surface of the original slope. Employing retaining panels of case A1 in slopes with concentrated loads on the crest of the slope (e. g. traffic loads on a railroad embankment), the panel's embedment length behind the shoulder should preferably extend all the way up to the loads.

D) Embedment depth of the panels at the foot of the slope: Experience shows that embedment depths at the foot of the slope of between 0.25 h_{slope} and 0.5 h_{slope} are sufficient for homogeneous slopes. If there is a sturdy load-bearing layer beneath the slope (e. g. bedrock), then the panel should be embedded within this layer.

E) Width of the panels: A minimum width of 2 metres is recommended. This empirically determined minimum width is due to panel fabrication aspects.

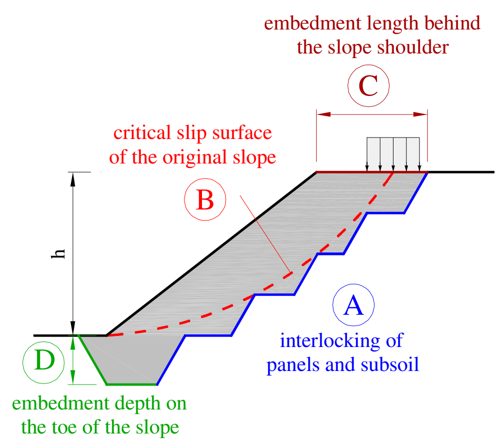

Figure 9. Case A1 – recommendations for the initial design of panel geometry in the panel plane

7 EMPLOYMENT OF RETAINING PANELS TO INCREASE SLOPE STABILITY BY MANIPULATION OF THE CRITICAL SLIP SURFACE IN THE PANEL PLANE (CASE A2)

7.1 Bearing behaviour / failure mechanism – basic principle

The basic principle of case A2 is to influence the location of the critical slip surface in such a way that the slip surface is forced to exist either above or beneath the panels. This slip surface then exhibits sufficient stability. The retaining panels are adjusted such that the critical slip surface of the original slope cuts the panels (see figure 10 A). By installing the retaining panels, the stability of the critical slip surface of the original slope increases significantly due to the high shear resistance in the panel region (see figure 10 B). Due to the fact that the retaining panels have an essentially higher shear resistance than the soil, this is valid for all slip surfaces cutting the retaining panels. This results in a relocation of the slip surface of lowest factor of safety (critical slip surface) (see figure 10 C). This means there are two different cases to distinguish between in case A2. First, a critical slip surface can be forced to exist above the retaining panel (high-lying slip surface). Second, a slip surface can be forced to run beneath the retaining panels (deep-lying slip surface).

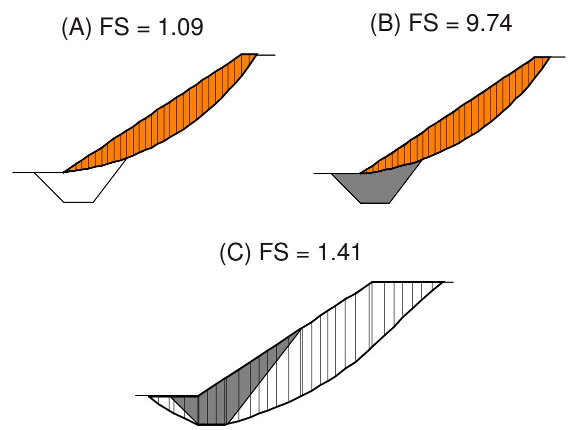

Figure 10. Case A2 – bearing behaviour / failure mechanism – basic principle

7.2 Determining the panel dimensions

7.2.1 Dimensioning the panel geometry in the panel plane

The first step is to determine the required panel geometry in the panel plane. This is done by iterative adjustment of the panel geometry using plane slope stability calculation methods. When doing so, the panel geometry has to be optimized regarding the slope stability (factor of safety). The stability of all slip surfaces in the panel plane must be higher than the required stability. (The factor of safety of all slip surfaces in the panel plane must be higher than the required factor of safety.) In the ideal case, the panel geometry will be optimized in such a way that the critical slip surfaces above and beneath the panels just reach the required stability level.

7.2.2 Dimensioning the panel distance in longitudinal direction of the slope

Next, the lengthwise panel distance in the slope has to be determined such that case A2, which was assumed in the first dimensioning step (panel geometry in the panel plane), also applies in the longitudinal direction of the slope. That means that the critical slip surface determined in the first dimensioning step must also exist in the lengthwise direction of the slope. This must be ensured by sufficiently small panel distance. If the panel distance becomes too large, then the critical slip surface will shift to between the retaining bodies and, consequently, the spatial slope stability will decrease. Figure 11 shows an example of the slope stability (factor of safety FS) as a factor of the distance/height ratio and the distance/width ratio. It is clear from the graphs in figure 11 that the spatial slope stability decreases if the permissible panel distance to ensure case A2 is exceeded. Figure 12 demonstrates the associated failure mechanisms for select panel distances. It is also noticeable that the influence of the panel width decreases with increasing panel distance.

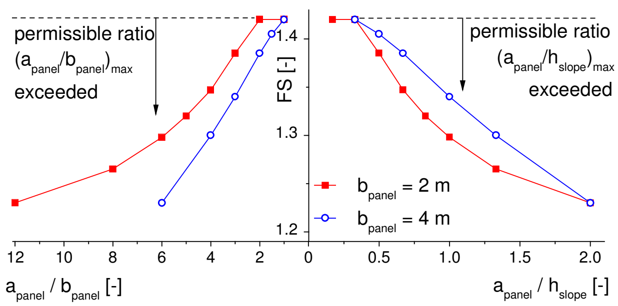

Figure 11. Case A2 – slope stability factor in dependence of a/h and a/b

The next step could then be to adjust the panels continuously along the length of the slope, to be on the safe side. In practical applications, this is often the case (so-called friction feeds). In such cases, the retaining bodies are only interrupted by infiltration ditches to drain the water out of the slope. Regarding slope stability, however, it is not always necessary to make the retaining panels continuous along the length of the slope. For economical optimization purposes, the panels can be placed in defined distances along the length of the slope. The following dimensioning method is suggested for doing this. Firstly, the width of the panels has to be defined. With regard to the fabrication of the retaining bodies, a panel width of at least two metres is recommended. The permissible panel distance to ensure case A2 is determined by the ratio panel distance to slope height (distance/height ratio a_{panel} / h_{slope}) and panel distance to panel width (distance/width ratio a_{panel} / b_{panel}). The permissible panel distance can be deduced from the charts illustrated in figure 13 and 14 depending on the factor $f_{\varphi c}$. The permissible panel distance finally results from the lowest value from the distance/height ratio and the distance/width ratio. It has to be noted that the charts in figure 13 and 14 are merely examples. They are only valid for slope inclinations from 1:1.3 to 1:2.0.

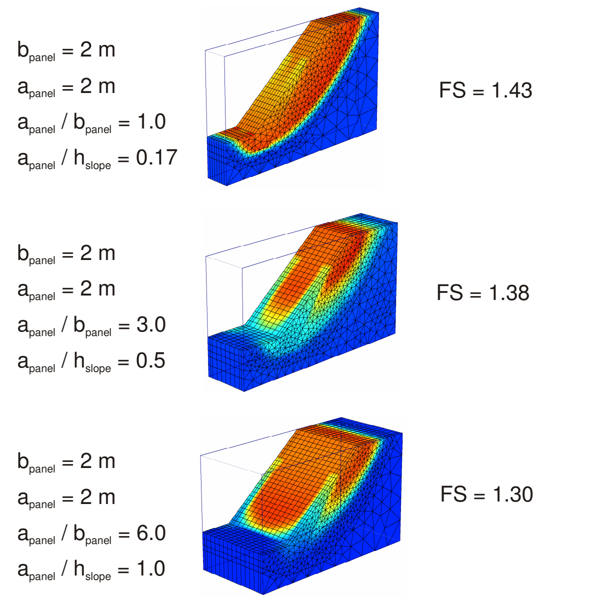

Figure 12. Case A2 – failure mechanism and factors of safety FS depending on a_{panel} / h_{slope} and a_{panel} / b_{panel}

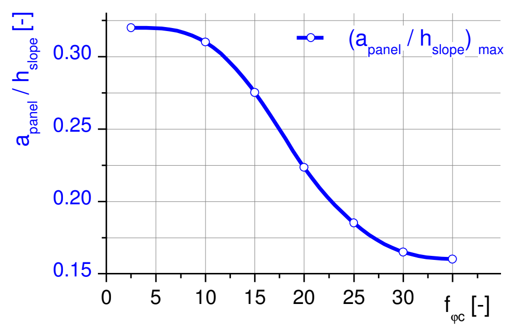

Figure 13. Case A2 – dimensioning charts for determining maximum panel distance – chart $(a_{panel} / h_{slope})_{max}$

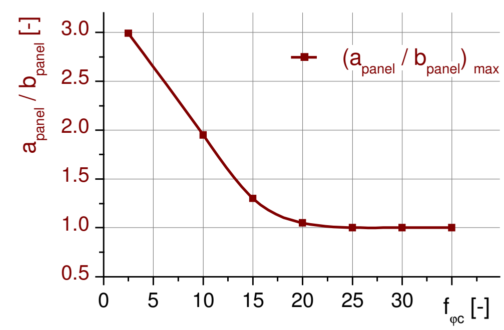

Figure 14. Case A2 – dimensioning charts determining maximum panel distance – chart $(a_{panel} / b_{panel})_{max}$

8 EMPLOYMENT OF RETAINING PANELS TO INCREASE SLOPE STABILITY BY COMBINATION OF CASE A1 AND A2 (CASE A3)

Compared to cases A1 and A2, case A3 is the most complex case with respect to the slope stability calculations and the dimensioning of the panels. In case A3, the panels are pushed or toppled / rotated out of the slope in limit state. The installation of retaining panels produces a combined failure mechanism of case A1 and A2.

Depending on the panel distance, cases A2 and A3 merge. Applying the same panel geometry in the panel plane, case A2 develops at small panel distances and case A3 develops as panel distances increase (see figure 12). Since the panels in case A2 are dimensioned in such a way as to ensure the required slope stability is achieved in that specific case, the required stability is no longer achieved in the transition from case A2 to A3 (see figure 11).

In case A3, failure occurs primarily between the panels. The failure body partly hangs on the panels sideways through a spatial arching effect. Since the panels are not dimensioned to sustain these arching forces as in case A1, the panels are pushed or toppled out of the slope in limit state.

The stabilizing effect achievable by applying case A3 is typically lower than applying case A1 or A2.

The use of retaining panels as conceived in case A3 can only be recommended to a limited extent. At the moment, it is not possible to adequately determine the failure mechanism. There is also no explicit dimensioning method by which to calculate case A3 at present. Given these limitations, if retaining panels are to be used for slope stabilization, it is recommended to dimension the panels according to case A1 and A2 in slopes without predefined slip surfaces.

9 EMPLOYMENT OF RETAINING PANELS TO INCREASE SLOPE STABILITY BY DOWELING GEOLOGICAL WEAK ZONES (PREDEFINED SLIP SURFACES) (CASE B)

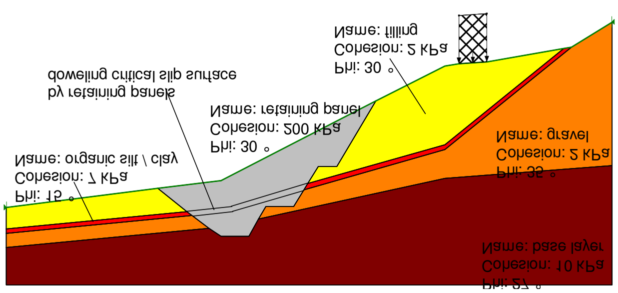

Figure 15. Case B - Example application of retaining panels for doweling predefined geological slip surfaces

If there are predefined geological weak zones (predefined slip surfaces) inside the slope, then the critical slip surface and thus the minimal stability ratio (factor of safety) will normally be located within these weak zones. Such weak zones can be doweled by installing retaining panels. This means that the shear resistance on the critical slip surface and consequently the slope stability increases (see example in figure 15).

10 INFILTRATION DITCHES TO INCREASE SLOPE STABILITY

An alternative and/or addition to lean concrete retaining panels are infiltration ditches made with gravel. Infiltration ditches are usually applied for drainage purposes. The adjustment of infiltration ditches is analogous to the adjustment of retaining panels. There are cases in which retaining panels and infiltration ditches are used in combination. Given the high permeability of infiltration ditches, water inside the slope accumulates inside the infiltration ditches to be drained away from the slope. Such slope drainage increases the slope stability. Infiltration ditches perform a second task that further increases slope stability. Typically, infiltration ditches are made using coarse grained crushed gravel. This material has a rather high friction angle. It is the use of such a material of high shear resistance that attains the additional stabilizing effect.

11 SUMMARY

Retaining panels for slope stabilization are retaining elements made of lean concrete to be positioned inside the slope at defined distances along the length of the slope. Such panels are manufactured using the hydro-cementation technique, a form of in-situ soil improvement that requires no soil replacement. The retaining bodies can be adjusted quite flexibly to the existing local situation in each case. To increase slope stability, retaining panels can be used either in slopes with geological weak zones as a way to dowel predefined slip surfaces, or in slopes without predefined slip surfaces. Given their flexible application, there is no uniform dimensioning method for calculating the geometry of such panels. Therefore, the retaining panels have to be classified according to their bearing behaviour. This paper presents the various kinds of bearing behaviours of slopes stabilized by retaining panels. The failure mechanism, the bearing behaviour and the effects of the influence parameters are analyzed. Since the retaining panels are placed at defined distances along the length of the slope, one of the dimensioning problems is to determine the required panel distance. This dimensioning problem demands three-dimensional methods for slope stability calculation. The calculation results presented in this paper are based on spatial stability calculations using the Finite Element Method. Suggestions for dimensioning panel distances and panel geometry are given for various applications.