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MODERN FLEXIBLE SYSTEMS FOR SLOPE STABILIZATION MADE FROM HIGH-TENSILE STEEL WIRE MESHES / NETS IN COMBINATION WITH NAILING AND ANCHORING IN SOIL AND ROCK

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Abstract: Flexible slope stabilization systems made from steel wire meshes and spiral rope nets in combination with nailing are widely used to stabilize soil and rock slopes. They are economical solutions and a good alternative to measures based on rigid concrete liner walls or massive supporting structures. Apart from designs using conventional steel wire, meshes from high-tensile steel wire are now also available on the market. The latter can absorb substantially higher forces and transfer them onto the nailing. Special concepts have been developed for the dimensioning of flexible surface stabilization systems for use on steep slopes in more or less homogeneous soil or heavily weathered loosened rock, but also on jointed and layered rock in which the bodies liable to break out are determined by joint and layer planes. Stabilizations implemented in soil and rock, with and without vegetated face, confirm that these measures are suitable for practical application.

Key words: slope stabilization, nailing, anchoring, wire meshes, high-tensile spiral rope nets

1. INTRODUCTION

The use of steel wire meshes and spiral rope nets as a flexible slope stabilization measure has proved its suitability in numerous cases and is often an alternative to massive concrete constructions. The open structure of the meshes, furthermore, permits to realize a full-surface vegetation face. In most cases, wire meshes based on a tensile strength of the individual wires of approx. 500 N/mm^2 are used for slope stabilization purposes. If an economical spacing of the nails is aimed at, these simple meshes are often unable to absorb the occurring forces and to transmit them onto the nails.

The development of a steel wire mesh made from high-tensile steel wire of a tensile strength of the individual wire of at least 1770 N/mm^2 offers new possibilities for an efficient and economical stabilization of slopes. Adapted dimensioning models taking the statics of soil and rock into account serve to dimension these stabilizations.

2. HIGH-TENSILE STEEL WIRE MESHES FOR ACTIVE SLOPE STABILIZATION

High-tensile steel wire meshes have been developed which are available on the market under the name TECCO®. In standard layout, it is made from a steel wire of 3 mm diameter which has an aluminium-zinc coating for corrosion protection. The diamond-shaped meshes measuring 83 mm · 143 mm are produced by single twisting. The TECCO® standard steel wire mesh provides a tensile strength of 150 kN/m at least. Its three-dimensional structure causes an optimal force transmission from the subsoil to the mesh on the one hand and advantageous prerequisites for the fixation of sprayed-on greening on the other hand. In comparison with wire meshes traditionally available on the market with comparable mesh size and similar wire diameter, this high-tensile steel wire mesh with its special properties is able to absorb and to transmit approx. three times higher forces. Special diamond-shaped system spike plates matching the TECCO® mesh serve to fix the mesh to soil or rock nails. Thereby, the system allows a considerable pretensioning of the mesh against the nails and the subsoil. The dimensioning concept RUVOLUM® has been specially developed for dimensioning of flexible slope stabilization systems against superficial instabilities.

Fig. 1 Active stabilization of soil and rock slopes with high-tensile steel wire meshes in combination with soil nailing and rock bolting

3. HIGH-TENSILE SPIRAL ROPE NETS FOR ROCK PROTECTION

Depending on continuously increasing project specific requirements, high-tensile spiral rope nets in combination with rock bolting have been developed for securing rock slopes, spurs, overhangs or individual sections of loose rock. Thanks to the mesh size of 292 x 500 mm and its construction (spiral rope of 1 x 3 wires, wire diameter of 4 mm), this rock protection system is especially suited to rock slopes with irregular surfaces and defined sliding mechanisms, with little susceptibility for weathering.

The flexible SPIDER® rock protection system consists of the SPIDER® high tensile spiral rope net with a tensile strength of 220 kN/m which has an aluminium-zinc coating for corrosion protection and the associated system spike plates. The nails consist of commercial products (e.g. GEWI, DYWIDAG, TITAN, etc.). Type, diameter, bearing resistances as well as the lengths depend on the project-specific requirements.

Force-locked shackles are used to connect the net panels to one another. The net panels are mounted above, laterally and below on border ropes, which should be fastened laterally onto spiral rope anchors. Depending on project requirements, local conditions and the hazard potential for the problem area, a fine-meshed secondary mesh can be installed optionally under the spiral rope net to hold back stones and smaller blocks. The RUVOLUM® ROCK concept specially serves for dimensioning of such flexible rock protection systems in jointed and layered rock.

Fig. 2 Rock protection with high-tensile spiral rope nets combined with rock bolting

4. RUVOLUM® - THE CONCEPT FOR DIMENSIONING OF FLEXIBLE SLOPE STABILIZATION SYSTEMS IN SOIL AND STRONGLY WEATHERED ROCK

The RUVOLUM® dimensioning concept serves to dimension flexible slope stabilization systems which consist of a mesh or net cover in combination with nailing for soil and decomposed rock slopes. It includes the investigation of local instabilities between the individual nails as well as the investigation of superficial slope-parallel instabilities. Thereby, accelerations due to earthquake and streaming pressure in case of full saturation can be taken into account.

4.1 Investigation of local instabilities between the individual nails

The investigation of local instabilities regards bodies liable to break out locally between the individual nails. The surface stabilization system is to be dimensioned in such a manner that all possible local bodies liable to break out are retained, the maximum occurring forces absorbed and transmitted via the nails into the stable subsoil.

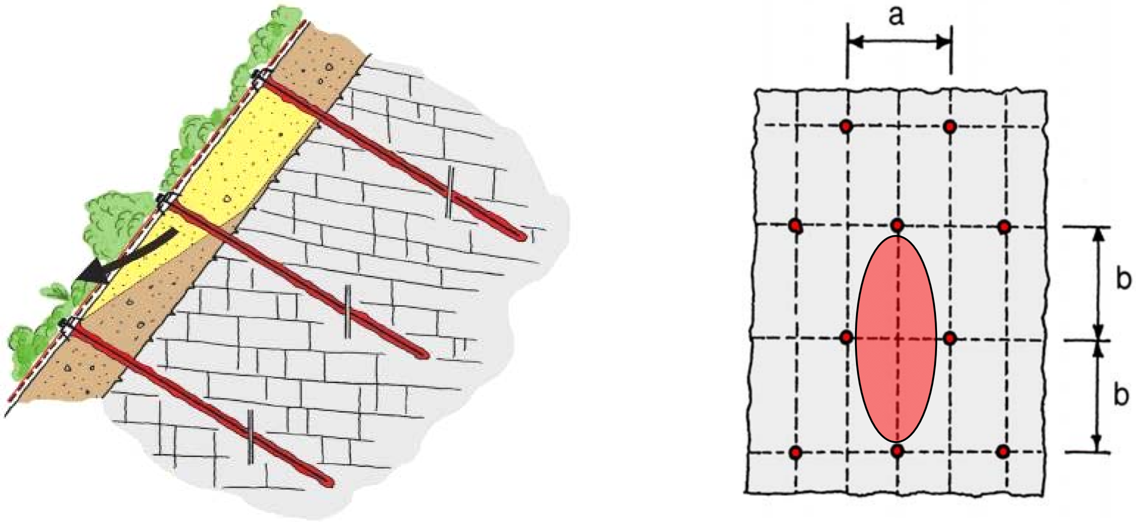

Fig. 3 Local instabilities between the individual nails

Above each nail is a field of width a and length 2·b which must be secured against local instabilities. Starting from this field, bodies liable to break out of a maximum length of 2·b can arise. The cross-section of the maximum possible wedge liable to break out is substantially influenced by the actual protection concept. The mesh is prestressed against the subsoil with the force V in that tightening of the nut causes the spike plate to be pressed firmly onto or even slightly into the ground. The superficial area of the subsoil immediately around the nail will be thereby stabilized. The dimensioning model takes that fact into account (fig. 4). It is assumed that lateral the stabilized truncated pressure cones in the cover layer below each spike plate and the adjoining mesh are located completely outside the sliding bodies to be investigated. The resulting theoretical trapezoidal cross-section can be transformed to a rectangle of equal area of the width a_{red} and thickness t for simplification.

The following relation (1) result from equilibrium considerations at the two-body-sliding mechanism taking into account the rupture condition of Mohr-Coulomb as well as the model uncertainty correction factor γ_{mod}. The maximum force P is to be determined by variation of the inclination of sliding surface β and the layer thickness t considering accelerations due to earthquake (ε_v, ε_h) as well as streaming pressure in case of full saturation (F_{SI}, F_{SII}).

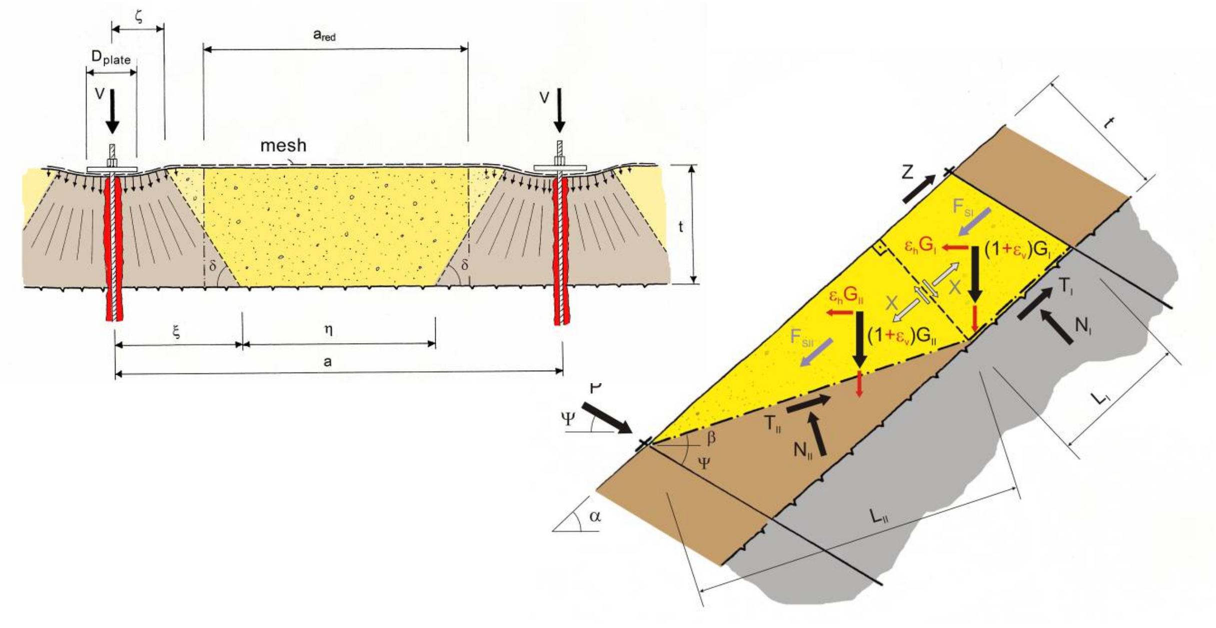

Fig. 4 Two-body sliding mechanism and maximum cross-section of thickness t of the body liable to break out taking into account pressure cones laterally

$$P\,[kN] = \frac{A+B+C}{D} \tag{1}$$

$$A\,[kN] = (1+\varepsilon_v)\cdot G_{II}\cdot[\gamma_{\mathrm{mod}}\cdot\sin\beta - \cos\beta\cdot\tan\varphi] \tag{2}$$

$$B\,[kN] = \varepsilon_h\cdot G_{II}\cdot(\gamma_{\mathrm{mod}}\cdot\cos\beta + \sin\beta\cdot\tan\varphi) \tag{3}$$

$$C\,[kN] = (X + F_{SII})\cdot[\gamma_{\mathrm{mod}}\cdot\cos(\alpha-\beta) - \sin(\alpha-\beta)\tan\varphi] - c\cdot A_{II} \tag{4}$$

$$D\,[kN] = \gamma_{\mathrm{mod}}\cdot\cos(\psi+\beta) + \sin(\psi+\beta)\tan\varphi \tag{5}$$

$$X\,[kN] = G_I\cdot[(1+\varepsilon_v)\sin\alpha + e_h\cdot\cos\alpha] - G_I/\gamma_{\mathrm{mod}}\cdot[(1+\varepsilon_v)\cos\alpha - \varepsilon_h\cdot\sin\alpha]\cdot\tan\varphi - (Z + c\cdot A_I)/\gamma_{\mathrm{mod}} + F_{SI} \tag{6}$$

The following two proofs of bearing safety must be submitted as far as the investigation of local instabilities between the individual nails is concerned:

1. Proof of the mesh against shearing-off at the upslope edge of the spike plate by the force P
2. Proof of the mesh to selective transmission of the slope-parallel force Z onto the upper nail

4.2 Investigation of superficial slope-parallel instabilities

The investigation of superficial slope-parallel instabilities concerns the cover layer which threatens to slide off the stable subsoil (as a combination of numerous instabilities between the nails). The nailing is intended to stabilize the unstable cover layer as a whole. Hereby a cubic body of width a, length b and thickness t is fixed per nail with a certain safety.

From equilibrium considerations at the illustrated cubic body and taking into account the rupture condition of Mohr-Coulomb, one can, in function of the geometrical and geotechnical parameters as well as the pretension force V and the model uncertainty correction factor γ_{mod}, formulate the general equation (7) for the stabilizing shear force S. Thereby, accelerations due to earthquake vertically and in horizontal direction (ε_v, ε_h) as well as streaming in slope-parallel direction in case of full saturation (F_S) can be considered furthermore.

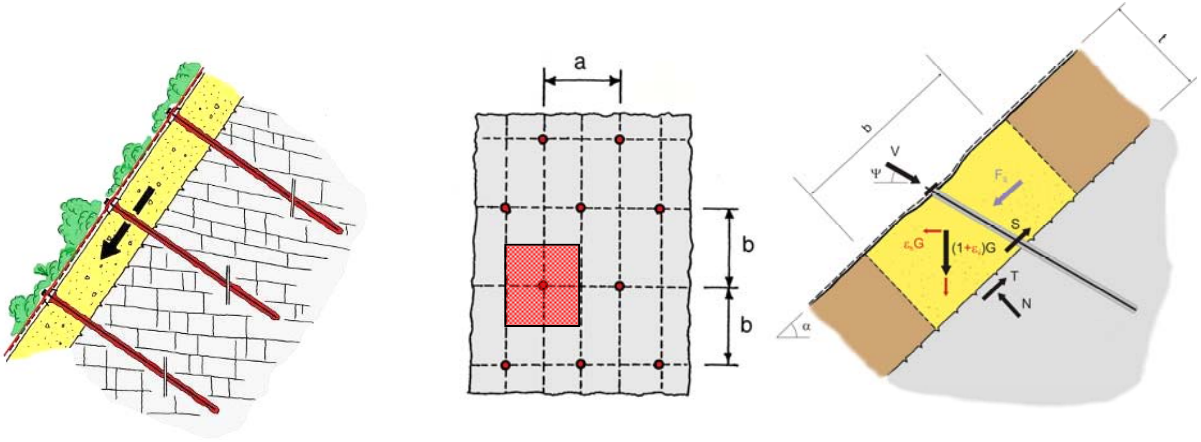

Fig. 5 Investigation of cubic shaped bodies liable to slide down slope-parallel

$$S\,[kN] = A + B - C + F_S \tag{7}$$

$$A\,[kN] = (1+\varepsilon_v)\cdot G\cdot(\sin\alpha - \cos\alpha\cdot\tan\varphi/\gamma_{\mathrm{mod}}) \tag{8}$$

$$B\,[kN] = \varepsilon_h\cdot G\cdot(\cos\alpha + \sin\alpha\cdot\tan\varphi/\gamma_{\mathrm{mod}}) \tag{9}$$

$$C\,[kN] = V\cdot[\cos(\psi+\alpha) + \sin(\psi+\alpha)\cdot\tan\varphi/\gamma_{\mathrm{mod}}] + c\cdot A/\gamma_{\mathrm{mod}} \tag{10}$$

The following three proofs of bearing safety must be established in the context of the investigation of superficial slope-parallel instabilities:

1. Proof against sliding-off of a superficial layer
2. Proof of the mesh against puncturing
3. Proof of the nail to combined stress

4. ROCK RUVOLUM® ROCK - THE CONCEPT FOR DIMENSIONING OF FLEXIBLE SLOPE STABILIZATION SYSTEMS IN ROCK

The dimensioning concept RUVOLUM® ROCK is intended for rock slopes and investigates bodies liable to break out that are limited by layer and fissure surfaces. While, in the traditional RUVOLUM® concept, the maximum stress on the system elements are determined by variation of the inclinations of the sliding surfaces in soil or very loosened and highly weathered rock, in the investigations according to the RUVOLUM® ROCK concept the alignment in space, i.e. the inclination and the position of the individual planes in the rock in relation to each other are preset.

The dimensioning concept RUVOLUM® ROCK comprises the investigation of wedge- as well as drawer-shaped bodies liable to break out.

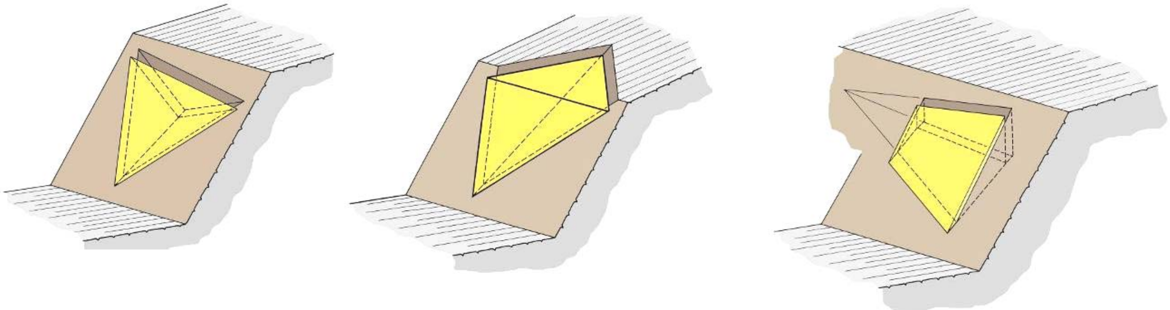

Fig. 6 Wedge-shaped and drawer-shaped body sliding down along the unfavourably forward-descending section edge or in the direction of the line of fall on the layer surface, respectively

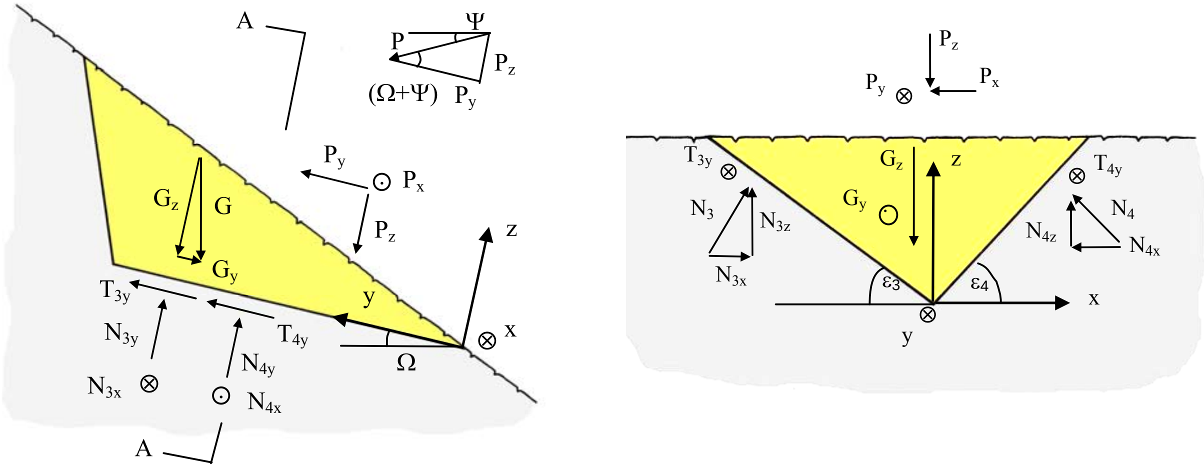

Fig. 7 Force components acting on the wedge-shaped body liable to break out in the y-z as well as x-z plane (water pressure, ice pressure, accelerations due to earthquake are neglected)

$$P\,[kN] = \frac{G \cdot [\gamma_{\text{mod}} \cdot \sin \Omega - \cos \Omega / \eta \cdot \tan \varphi_3 - \cos \Omega / \lambda \cdot \tan \varphi_4] - c_3 \cdot A_3 - c_4 \cdot A_4}{\gamma_{\text{mod}} \cdot \cos (\Omega + \Psi) + \sin (\Omega + \Psi) / \eta \cdot \tan \varphi_3 + \sin (\Omega + \Psi) / \lambda \cdot \tan \varphi_4} \tag{11}$$

$$1/\eta = \sin \varepsilon_4 \cdot \cos(\varepsilon_3 + \varepsilon_4) \tag{12}$$

$$1/\lambda = \sin \varepsilon_3 \cdot \cos(\varepsilon_3 + \varepsilon_4) \tag{13}$$

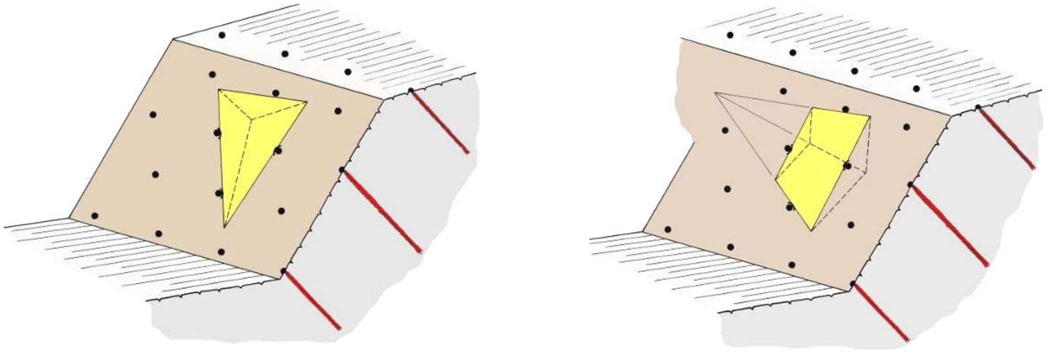

Fig. 8 Wedge-shaped as well as a drawer-shaped body fitted in maximum manner in the nail pattern

The figure above shows a wedge-shaped and a drawer-shaped body liable to break out which, in dependence on their geometry, are placed unfavourably between the individual nails. If these bodies slide out of the slope, they stress the slope stabilization system, particularly the mesh held by the spike plates, for shearing-off. In the proof of bearing safety, it must be proved that the net and the fixation to the nail are sufficiently strong to prevent a sliding out of the body liable to break out.

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