



## STATE OF THE ART SLOPE AND ROCK FACE PROTECTION SYSTEMS TO SECURE RAILWAY LINES

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### Abstract

Flexible slope stabilization systems made from wire meshes in combination with nailing are widely used in practice 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 fissured and layered rock in which the bodies liable to break out are determined by fissure and layer surfaces. Critical boulders or large layers of stratified rock that cannot be cleared without posing a significant risk to people or infrastructure often have to be secured on excessively steep rock slopes. With the development of an innovative spiral rope net, combined with corresponding system spike plates, the transmission of force and the protection from corrosion have been significantly improved compared to ordinary cable nets. With these spiral rope nets it is possible to arrange the nails independent of panel size or shape. The design of the innovative rock protection system is based on laboratory and field tests, model experiments and standard tensile tests. It was possible to directly integrate the results and knowledge gained from the experiments conducted on the models as well as from the properties of deformation into the theoretical design model. Examples show the high suitability for the protection of railway lines of this new generation of slope and rock face protection systems due to their high cost effectiveness, quick installation time and low maintenance costs.

*Keywords: TECCO<sup>®</sup>, SPIDER<sup>®</sup>, high tensile steel, spiral rope net, flexible slope stabilization system*

### 1 Introduction

The use of flexible slope stabilization measures has proved its suitability in numerous cases and is often an alternative to massive concrete constructions. The success of this technology is decisively influenced by numerous laboratory and field tests as well as long-term experiences and practical applications worldwide. The open mesh structure permit the full-surface vegetation of slopes. Furthermore, the open structure has the effect that water pressure can't built up behind the system. Of course, to avoid any erosion problems, the surface needs to be revegetated and if there is noteworthy hillside water existing, corresponding drainage measures are required as well. In many cases low tensile wire meshes, based on a tensile strength of the individual wire of 400–500 N/mm<sup>2</sup>, are used for slope stabilization purposes.

Due to the low load capacity of these meshes, a narrow nail spacing is required, which causes uneconomically high drilling costs.

The development of a wire mesh made from high-tensile steel wire with a tensile strength of at least 1770 N/mm<sup>2</sup> 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.



Figure 1 High-tensile wire mesh for slope stabilization (left) and special spike plate to actively pressing the high-tensile steel wire mesh against the slope surface (right).

## 2 High-tensile steel wire meshes for active slope stabilization

A high-tensile steel wire mesh made out of a steel with a minimal tensile strength of 1770 N/mm<sup>2</sup> has been developed and is available on the market as TECCO®. In standard layout, it is made from a steel wire of 3mm diameter which has an aluminium-zinc coating as corrosion protection. The diamond-shaped meshes measuring 83 mm × 143 mm are produced by single twisting. The TECCO® steel wire mesh provides a tensile strength of 150 kN/m. This value represents a minimum guaranteed bearing capacity. Thanks to its three-dimensional structure, the mesh clings to the soil in an ideal manner and, additionally, serves to optimally secure sprayed-on greening.

The performance of this mesh is substantially higher than the one of traditional wire meshes. These usually offer a tensile strength of only 45 – 50 kN/m in longitudinal direction at comparable mesh sizes and wire diameters.

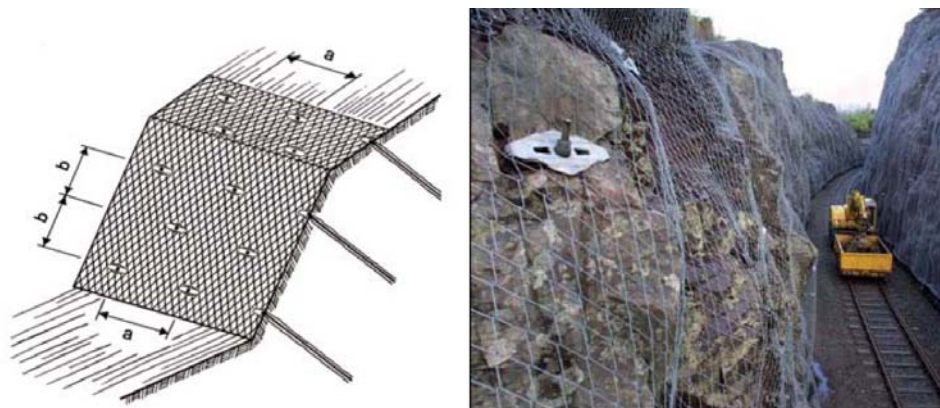


Figure 2 General profile with nail arrangement and example installation.

Special diamond-shaped system spike plates matching the TECCO® mesh serve to fix the mesh to soil or rock nails. By tightly pressing and if possible slightly impressing the spike plates in the ground to be stabilized, the mesh is tensioned against the slope in the best possible manner.

With the TECCO® slope stabilization system the rows of nails are offset to each other by half of the horizontal nail distance. This means that the maximum possible local body liable to break out between the individual nails is limited to a width  $a$  and a length of  $2 \times b$  (see Figure 2). The dimensioning concept RUVOLUM® has been specially developed for dimensioning of flexible slope stabilization systems against superficial instabilities. Basic requirement thereby is that the stabilization system consists of a flexible mesh cover with the possibility of variable nail arrangement.

### 3 High-tensile spiral rope nets for rockfall 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  $292 \times 500$  mm and its construction (spiral rope of  $1 \times 3$  wires, wire diameter of 4 mm), this rockfall protection system is especially suited to rock slopes with irregular surfaces and defined sliding mechanisms, with little susceptibility for weathering.



**Figure 3** Rock protection with high-tensile spiral rope nets combined with rock bolting (on the right under corner protection of a rock mass in Brzjet, Croatia).

The flexible SPIDER® rockfall protection system consists of the 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 ends of the spiral cables are tied to one another

to permit the full transmission of force to the adjoining panels. The basic dimensions of the net rolls are  $3.5 \times 20$  m; one roll weighs approx. 190 kg. The nails consist of commercial products (e.g. GEWI, DWIDAG, 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.

Ordinary cable nets have been used for this task so far. The sides of the square or rectangular panels were typically 3 to 4 meters long. A fixed nail pattern was the result. Moreover, the resistance to local force transmission and to corrosion was limited. With the development of the spiral rope net, the transmission of force and the protection from corrosion have been significantly improved. It is also possible now to arrange the nails independently of the netting size, so that project-specific requirements can be perfectly met. The design of the innovative rock protection system is based on the results of field tests, model experiments, on standard tensile tests, and on tests to determine the local force transmission.

#### 4 RUVOLUM® – The dimensioning concept for soil and decomposed rock slopes protection

The RUVOLUM® dimensioning concept serves to dimension surface slope stabilization systems which consist of a mesh cover in combination with nailing against superficial instabilities up to a depth of approx. 1.5 m in soil and superficially weathered, decomposed rock slopes. It is generally valid and also applicable to other surface stabilization systems which are comparable in a system technical manner. Thereby, the bearing resistances of the system as well as the system elements have to be known or determined by corresponding tests, respectively. The RUVOLUM® concept includes the investigation of superficial slope-parallel instabilities as well as the investigation of local instabilities between the individual nails. The influence of excess hydrostatic pressure, flow pressure and seismic forces are also considered.

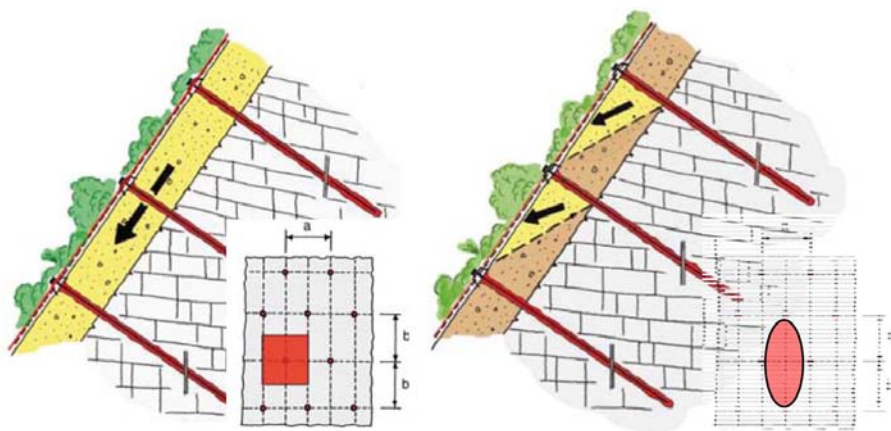


Figure 4 The RUVOLUM® concept is based on the investigation of superficial slope-parallel instabilities (on the left) and on the investigation of the local instabilities between single nails (on the right).

## 5 Investigation of the global stability

RUVOLUM® concept, the investigation of the overall stability with deep sliding surfaces must also be established depending on the prevailing subsoil and stability circumstances. The relevant calculations are carried out according to conventional methods of stability investigation, for example with curved sliding surfaces in soil or decomposed rock, respectively, or according to the sliding block method where sliding surfaces marked by stratification, fissures are concerned. For the investigation of the overall stability, the nails are generally introduced as tension elements. By checking the internal bearing resistances (steel crosssections and yield point under tensile load of the nails) and the external bearing resistances (friction forces that can be mobilized, pretension forces  $V$  or maximum head force  $V_{\max}$  that can be mobilized), the terrain's resistance against sliding  $n$  and the utilization factor  $1/f$  of the existing shear and system resistances are determined.

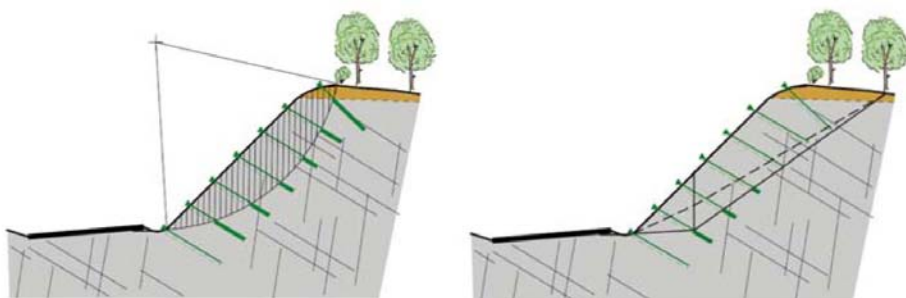


Figure 5 Investigation of the overall stability (on the left) and Sliding-block method (on the right).

## 6 Tests to determine the bearing resistances of the system

The following types of bearing resistances of the mesh must be known to permit establishing the proofs of bearing safety according to chapter preview, for soil and superficially highly weathered and loosened rock slopes:

- $Z_R$ : Bearing resistance of the mesh against selective tensile stress parallel to the slope
- $D_R$ : Bearing resistance of the mesh against puncturing in nail direction
- $P_R$ : Bearing resistance of the mesh against shearing-off at the edge of the spike plate due to a body sliding out of the slope

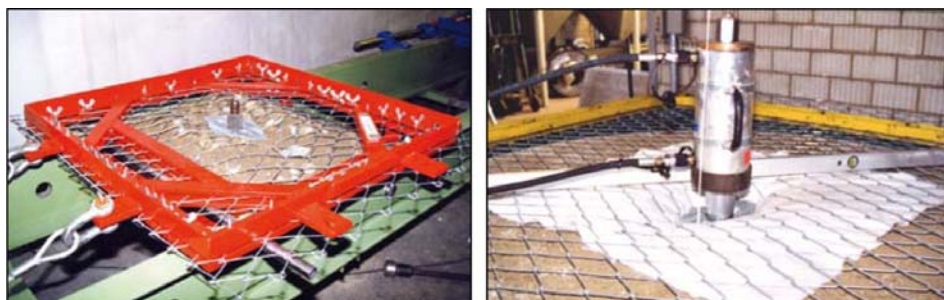


Figure 6 Test setup to determine the bearing resistance of the mesh against selective tensile stress parallel to the slope (on the left) and Test setup to determine the bearing resistance of the mesh against puncturing in nail direction (on the right).

The bearing resistances of the high-tensile TECCO® steel wire mesh have been determined under the supervision of the Landesgewerbeanstalt (LGA) Nürnberg, Germany with the aid of the testing devices shown in Figure 6.

## 7 Revegetation / Erosion protection with TECMAT®

The application of a vegetation layer is limited by the soil or rock properties and is also dependent on a certain amount of water supplied from rainfalls and groundwater following the slope layers. Furthermore the consideration of the regional micro climate is a very important factor for the selection of the seed to be applied.

The steeper the slope cuttings are the harder it is to raise up a durable vegetation. The system has to be flexible to be able to slightly move under frost effects. This is not possible with a shotcrete cover. Additionally water exist at the surface of the slope should be taken spreaded over the full surface and be guided back to the natural circular cause.

Based on the underground characteristic and the climate conditions, the organic mass has to be applied with high water restoring capacity. Because of the slope steepness, the erosion stability during strong rainfalls and frost is one of the most important points.

The seed mixture has to be specially adapted to the local conditions for getting a successful regreening. Aim of the first step is a fast surface covering greening, which is so planned that the used species can develop, during different steps of evolution, to a locally adapted dry biosphere.



**Figure 7** High-tensile steel wire mesh TECCO® and erosion control mat (on the left) and TECMAT® erosion control mat (on the right).

In steep slopes featuring fine-grained, non-cohesive loose rock or severely weathered rock there is a danger of erosion. Such fine material can be washed through the TECCO® mesh and flushed away underneath it. Hereby channels and hollows may be formed under the mesh. The cause is emerging hillside, layer or fissure water, or in otherwise dry slopes also drain water from heavy rainfalls. Emerging hillside, layer or fissure water must generally be captured and drained. Permanent water outflows will always lead to problems and must be coped with before the slope stabilization measure is started, since corrective action is hardly possible afterwards. Particular care must also be taken that no larger quantities of surface water from above flow over the slopes. If appropriate, drain channels must be provided above the edge of the slope so that the water is drained to the side in a controlled manner.

## 8 Conclusions

The TECCO® slope stabilization system and spiral rope nets for rockfall protection SPIDER® can be adapted to the site specific and static conditions in an optimal manner. It offers the possibility to arrange the nails in an economical way due to the capability of absorbing and transferring of high loads.

Unlike stabilization with concrete solutions, with TECCO® stabilized slopes regain a natural green appearance, which is well appreciated and more pleasant to the eye. Based on the RUVOLUM® concept, the TECCO® system can be dimensioned against superficial instabilities. Spiral rope nets, fabricated like mesh cover, provide new possibilities for securing unstable boulders prone to come loose on steep slopes due to their high longitudinal and transverse tensile strength and their high knot strength, which is important if the anchorage is subjected to a point force.

TECCO® and SPIDER® are flexible systems, where each part is optimized in their specific function to the others so that they are working as a real system together. Quick mobilization and installation time which means just a small influence to the traffic going on and low maintenance costs are the additional key factors for economical solutions.

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## 11 CROSSINGS & JUNCTIONS

