FLEXIBLE SLOPE STABILIZATION SYSTEMS MADE FROM HIGH-TENSILE STEEL WIRE

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ABSTRACT

Flexible slope stabilization systems made from wire mesh 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, mesh from high-tensile steel wire is now also available on the market. The latter can absorb substantially higher forces and transfer them into the nailing. Special concepts have been developed for the dimensioning of flexible slope stabilization systems for use on steep slopes in more or less homogeneous soil or heavily weathered loosened rock, as well as fissured and layered rock. Critical boulders or 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. Up to now, traditional wire rope nets made from stranded ropes have with a diameter of normally 8 – 10 mm, joined at the crossing points with cross clamps or wire coils have been used for this purpose. The development of a new kind of spiral rope net enables a significant improvement in load transmission, handling during installation and corrosion protection. 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.

1. INTRODUCTION

The use of flexible slope stabilization measures has proved its suitability in numerous cases around the world including Switzerland, Germany, Italy, Spain, Poland, North America, South America and South Africa. The open structure of the mesh permits development of a full-surface vegetation face. In most cases for slope stabilization purposes the wire mesh is based on a tensile strength of the individual wires of 400–500 N/mm^2. In this case if a nail spacing of say 2.75 m by 2.75 m is used, the mesh is often unable to absorb the driving forces and to transmit them into the nails.

Fig. 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)

The development of a 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. Taking the statics of soil and rock into account serves to dimension the proposed stabilization.

2. HIGH-TENSILE STEEL WIRE MESH FOR ACTIV SLOPE STABILIZAITON

A high-tensile steel wire mesh made out of a steel with a tensile strength of 1770 N/mm^2 at least has been developed which is 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 protection against corrosion. The diamond-shaped mesh measuring 83 mm x 143 mm is produced by single twisting. The steel wire mesh provides a tensile strength of 150 kN/m. This value represents a minimum guaranteed load or bearing capacity. As a result of its three-dimensional structure, the mesh clings to the soil and serves to secure sprayed-on greening. Substantially higher forces can be absorbed by this mesh in comparison with the wire mesh traditionally available and offering a tensile strength in longitudinal direction of approximately 45–50 kN/m at comparable mesh size and similar wire diameter.

Special diamond-shaped system spike plates matching the mesh serve to fix the mesh to soil or rock nails. By tensioning the nail and if possible slightly impressing the spike plates into the ground to be stabilized, the mesh follows the surface contour and is tensioned in the best possible manner.

With the slope stabilization system the rows of nails are offset to each other by half a 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 x b” (see Figure 2). The staggered layout is shown in Figure 3 for a project in Polymilou, Greece. 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.

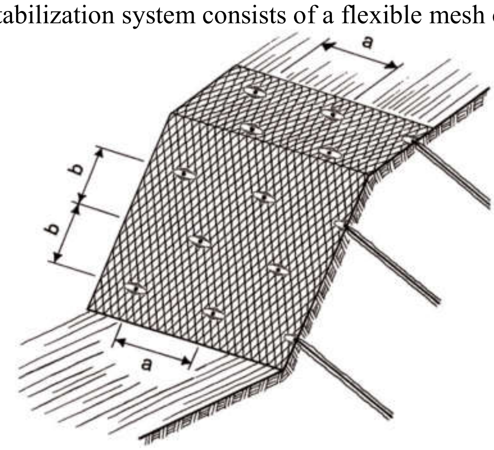


Fig. 2 – General profile with nail arrangement

Fig. 3 – Staggered pattern of nail installation – Z-Morh Tunnel, J&K, India

3. DIMENSIONING CONCEPT FOR SOIL AND DECOMPOSED ROCK SLOPES

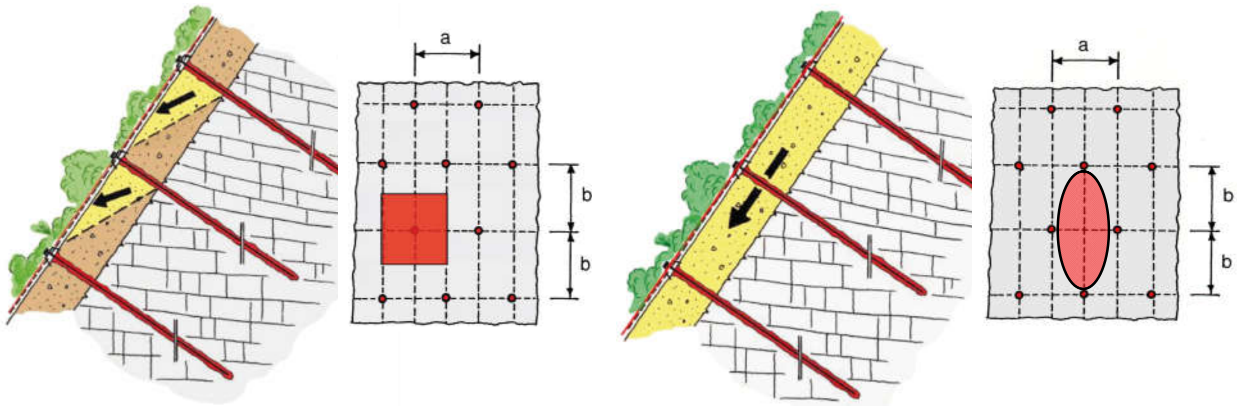


Fig. 4 – The dimensioning concept is based on the investigation of superficial slope-parallel instabilities (typically less than 2m) (on the left) and on the investigation of the local instabilities between single nails (on the right)

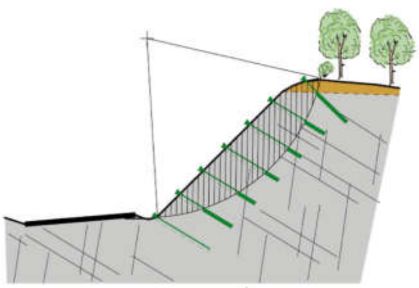
The RUVOLUM® dimensioning concept serves to dimension surface slope stabilization systems which consist of a mesh cover in combination with nailing against superficial instabilities up to a depth of max. 2.0 m in soil and superficially weathered, decomposed rock slopes. It is generally valid and also 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.

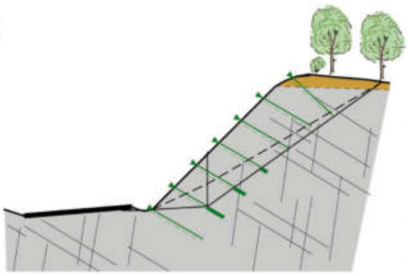
The dimensioning concept includes the investigation of superficial slope-parallel instabilities as well as the investigation of local instabilities between the individual nails. The influence of excess hydrostatic pressure, flow pressure and seismic forces are also considered.

4. INVESTIGATION OF THE GLOBAL STABILITY

In addition to the investigations of instability near the surface using the RUVOLUM® concept, the investigation of the overall stability with deep sliding surfaces must also be investigated 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 (Figure 5), respectively, or according to the sliding-block method where sliding surfaces marked by stratification, fissures are concerned (Figure 6).

For the investigation of the overall stability, the nails can be introduced as tension elements or as effective cohesion. By checking the internal bearing resistance (steel cross-sections and yield point under tensile load of the nails) and the external bearing resistance (friction forces that can be mobilized, pretension forces V or maximum head force V_{max} that can be mobilized), the soil or rock's resistance to sliding η and the utilization factor 1/f of the existing shear and system resistances are determined.





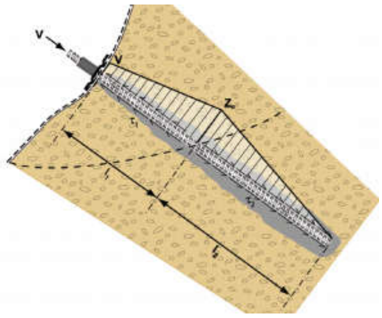


Fig. 5 – Investigation of the overall stability, Fig. 6 – Sliding-block method and Fig. 7 – Load distribution over the nail length in shear

5. TESTS TO DETERMINE THE BEARING RESISTANCES OF THE SYSTEM

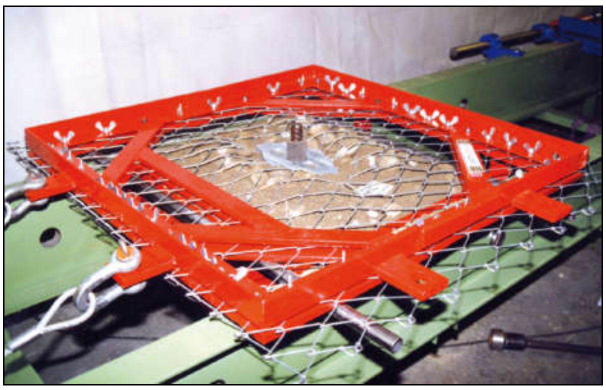


Fig. 8 – Test setup to determine the bearing resistance of the mesh against selective tensile stress parallel to the slope

Fig. 9 – Test setup to determine the bearing resistance of the mesh against puncturing in nail direction

The following load carrying capacity or bearing resistances of the mesh must be known or established to use the above equations for design of support 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

The bearing resistances of the high-tensile steel wire mesh have been determined under the supervision of the Landesgewerbeanstalt (LGA) Nürnberg, Germany (Brändlein, 2004) with the aid of the testing devices shown in Figure 8 and Figure 9. These devices have been developed by Rüegger and Flum AG (Rüegger, et al (2006)) in cooperation with Geobrugg AG.

6. REVEGETATION / EROSION PROTECTION WITH EROSION CONTROL MAT

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 high tensile mesh and flushed away underneath it resulting in channels and hollows under the mesh.

The cause is groundwater emerging from the hillside, layer or fissures, or in otherwise dry slopes surface water from heavy rainfalls. Groundwater depressurisation 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.

What remains is the rainwater falling directly onto the protected slope. In case of a high intensity and long duration rainfall this can also lead to erosion problems. The impact of the rain drops and the draining of the surface water may lead to soil movements, degradation and general erosion. The problem can often be coped with by means of a full-surface vegetation face. The roots stabilize the surface layer and a substantial quantity of water is stored in the vegetation layer before it starts to flow off.

However, it takes time for an effective vegetation to form and for stable subsoil circumstances to result. No vegetation can develop in a slope subject to movements and erosion. Immediate spraying of erosion-resistant vegetation material and seeding are not always possible directly after laying of the mesh. It is often necessary, therefore, to provide an erosion protection together with the mesh so that erosion and washing-out are prevented for the time being and optimal prerequisites achieved for successful greening later on.

Fig. 10 – High-tensile steel wire mesh and erosion control mat

Fig. 11 – Erosion control mat

Regrettably it is not always possible to achieve the goal with the known erosion protection mats of natural fibres (jute, coir) because the often irregular surfaces prevent an uninterrupted ground contact of the mats. The mats in question are normally too tight for spraying-through of vegetation material and seeds. The results are undesirable and in the long run critical bare patches which expose the free surfaces to erosion again as soon as the mats have rotted away.

What was sought, therefore, was a flexible mat of a three-dimensional open structure which provides a comparatively good protection against erosion despite relatively large openings. The mat must also be suitable as an adhesion and stabilization layer for the vegetation for as long as the latter is unable to perform this function. Of importance is also that the mat is optically inconspicuous, i.e. adapted in its colour to the substrate.

After various suitability tests with different products, with dry and wet greening also in extreme locations , a 3-dimensional mat of a loop structure, a so-called random-laid nonwoven fabric of polypropylene was eventually found which meets the partly opposing requirements of erosion protection and vegetation face in an optimum manner. The erosion protection mat, developed especially for use in combination with the TECCO® stabilization system and available under the trade name of TECMAT® is shown in Figure 11.

7. HIGH-TENSILE STEEL WIRE ROPE NET FOR ROCK FACE 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 width of 230 mm (diagonal openings 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 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 x 20 m; one roll weighs approx. 190 kg. 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.

Ordinary cable nets have often 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.

8. EXAMPLES OF IMPLEMENTED PROJECTS

The following projects present some examples of how the spiral rope net rock protection system has been used as active measure.

Fig. 12 – Taubenloch Canyon near Biel, Switzerland, rock protection of overhang above a hiking trail with secondary mesh

Fig. 13 – Slope Stabilization at Kiratpur-NerChowk Expressway, Himachal Pradesh

Fig. 14 – Rock protection project in Imin Tanout, Morocco

Fig. 15 – Ajdovscina, Slovenia, protection of road and residences from unstable rocks or boulders.

9. ADVANTAGES OF THE WIRE ROPE NETS COMPARED TO ORDINARY CABLE NETS

The advancement of ordinary and customary cable nets to spiral rope net application has yielded several advantages for the client, project manager and the contractor. Compared to ordinary cable net systems, which works with individual 3.3 x 3.3 m panels, the spiral rope net is delivered in 3.5 x 20 m rolls. Rather than spending the time sewing together the individual panels, two shackles per meter are used to connect the panels in a force-locked manner which takes very little time. The reduced number and the optimized quality of joints allow for an efficient installation of the spiral rope net.

In terms of static loads, one of the decisive advantages lies in the fact that the arrangement of nails no longer depends on the size of the individual cable net panels, but can be perfectly adapted to match the project-specific requirements. The advanced system of spike plates ensures that the system is braced against the ground as securely as possible.

Fig. 16 – Ordinary cable net system with cross-clip

Fig. 17 – Spiral rope net corrosion protection compared to ordinary cable net system

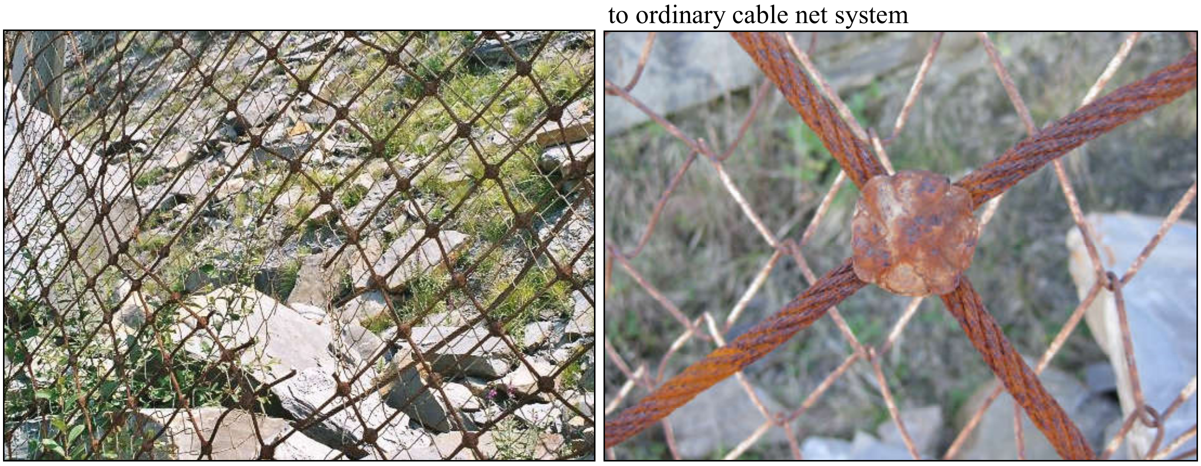


Fig. 18 – Ordinary galvanized cable net near the coast

The corrosion protection was further enhanced by no longer needing cross-clips and by using the significantly larger wire diameter of 4 mm, compared to the 0.9 mm diameter of twisted wire, in conjunction with an aluminum/zinc coating (see Figure 16 - 18).

10. MODEL EXPERIMENTS

10.1 Objectives

The model experiments for the protection of a boulder with the SPIDER® system were conducted on a scale of 1:3.5. Objectives included the implementation of the theoretical basic considerations described in the previous chapter, the comparison under real-life conditions, and the determination of the distribution of forces in a three-dimensional system.

10.2 Test setup

The test setup basically consisted of a blue steel frame to which the rope and the model net were fastened and a slide face red colored in between. The frame was 1.5 m wide and 2.5 m long. The angle between the slide face and the frame was kept constant at 36°. Strain gauges were used to measure the forces acting on the rope, net and directly on the sliding body. A potentiometer was used to measure the displacement of the block-shaped boulder. A wooden block that weighed 58 kg was used as a sliding body.

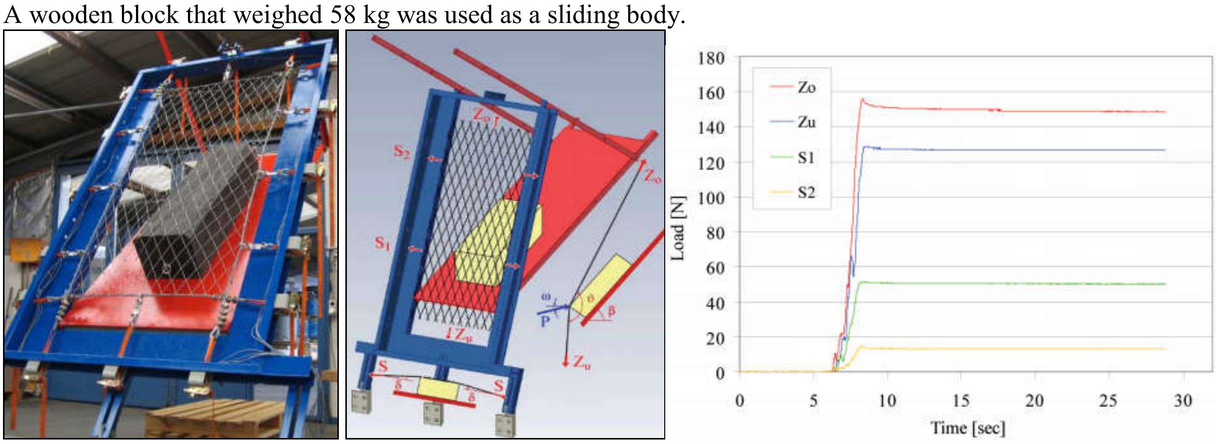


Fig. 19 – Test setup, force measurement arrangement and test results with an inclination of the sliding plane of 45 degrees to horizontal

10.3 Findings from model experiments

The forces calculated by means of the two-dimensional model were in general congruent with those measured as a result of the experiments. For the purpose of practical application this means that the two-dimensional model can be applied with satisfactory accuracy to determine the forces in the main direction. The opening angle (ϑ) from the directions of the restraint in longitudinal direction exerts the decisive influence on the forces. The influence of friction between the net and the block is small in comparison. The influence of the lateral restraints on the retention force depends on the position of the restraint and the forces themselves depend on the angle (δ) from the directions of the lateral restraints to horizontal. Based on the model experiments, the factors $\eta = Z_u / Z_o$ and $\zeta = S / Z_o$ can be determined.

11. LARGE SCALE FIELD TESTS

11.1 Objectives

The aims of these large scale field experiments were as follows: the investigation of the load bearing behavior of the total rock protection system, the load transfer over the net to the anchorage points in scale 1:1, forces acting in the boundary ropes as well as the confirmation of its practicability. Moreover, the corresponding design concept was to be validated, based on the results from the experiments and the rock protection system optimized.

11.2 Test setup

The test side in Felsberg (Grisons, Switzerland) was at a 55° inclined rock slope with a downwards opened break-out niche. For fixation of the spiral rope net were several nails and rope anchors installed to allow test arrangements with different geometries. Strain gauges were used to measure the forces acting on the boundary rope, net and directly on the sliding body. A potentiometer was used to measure the displacement of the boulder. As a sliding body was a 1160 kg heavy rock boulder used.

11.3 Findings from large scale field tests

The measured static forces from the field tests correspond with those determined based on the theoretical model considering a static equilibrium. As shown from the tests, the forces from the dynamic influence exceed the statically determined forces by a factor of 1.5 – 2.5 or more. In principle the forces are more likely to be transferred upwards. The size of the relationship of the upward forces to the downward forces depends on the nature of the meshing of the boulder with the rope net and whether boundary ropes are installed. The large scale field tests have shown that when using a large mesh net for securing individual boulders, boundary ropes are to be fitted to the top and bottom and where possible also at the sides. This can essentially improve the supporting behavior of the system. The dimensioning of flexible rock protection systems can be carried out using a simple model based on the equilibrium consideration. It is obligatory for the individual relationship factors and above all the dynamic effects to be adapted to the local and project specific circumstances.

Fig. 20 – Overall view of the test system before the test (left) and at the end of the test (right)

12. CONCLUSIONS

The TECCO® slope stabilization system and spiral rope nets for rock 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 the high tensile steel wire mesh stabilized slopes regain a natural green appearance, which is well appreciated and more pleasant to the eye. Based on the RUVOLUM® concept, the 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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Christophe Balg graduated in Geography, Geology and Meteorology from the University of Freiburg, Germany and obtained his Master of Science (MSc) in 2007. His research focused on the effects of global climate change on morphological structures in the Swiss Alps. Until 2008 he worked for Meteomedia AG and developed a flood warning system. Now at GEOBRUGG AG he is a Regional Manager and in charge of Project management and Business development in India, The Middle East and Africa.

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