Spider Rock Protection System for Rock Slope Stabilization

Joseph C. Bigger, P.E.
Geobrugg North America, LLC., New London, Connecticut USA

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ABSTRACT
Stabilizing rock formations or blocks has been a combination of engineering and art and common techniques include rock bolts with or without cable lashing and/or nets. The recent development of SPIDER Nets lead to the SPIDER Rock Protection System for stabilizing rock formations. Further, the Ruvolum Rock Dimensioning program was changed for the SPIDER System and it is now a tool for engineers and designers to use. The program is used on-line and it allows the user to analyze sliding and toppling mechanisms. The program is based on Mohr-Coulomb Equilibrium theory and it establishes the relationship between driving and stabilizing forces. The program allows the user to input various site conditions, select anchor spacing and size and the result is an optimized arrangement for the given conditions. As part of the program development, the concept was modeled and tested under laboratory conditions. Field evaluation was completed in 2009 to further verify the program. The program has been successfully used for applications in place in Europe and Asia.

RÉSUMÉ
Formations rocheuses de stabilisation ou de blocs a été une combinaison de l'ingénierie et de l'art et les techniques communes comprennent des boulons d'ancrage, avec ou sans amarrage de câble et / ou des filets. Le développement récent des filets de SPIDER entraîner le système SPIDER Rock protection pour la stabilisation de formations rocheuses. En outre, le Ruvolum Rock Dimensionnement programme a été changé pour le système SPIDER et il est maintenant un outil pour les ingénieurs et les concepteurs à utiliser. Le programme est utilisé en ligne et il permet à l'utilisateur d'analyser les mécanismes de glissement et de renversement. Le programme est basé sur Mohr-Coulomb Théorie de l'équilibre et il établit la relation entre la conduite et la stabilisation de forces. Le programme permet à l'utilisateur des conditions d'entrée différents sites, sélectionnez ancrage espacement et la taille et le résultat est un arrangement optimisé pour les conditions données. Dans le cadre de l'élaboration du programme, le concept a été modélisée et testée en conditions de laboratoire. Evaluation sur le terrain a été achevé en 2009 pour vérifier le programme. Le programme a été utilisé avec succès pour des applications en place en Europe et en Asie.

1 BACKGROUND

Over the years, conventional solutions were developed and implemented to hold rock ledges or overhangs or individual loose rocks in place and they included:

- Anchor beams
- Shotcrete
- Cable lashing
- Wire rope nets with and without rope restraints

The various conventional solutions are outlined in the following paragraphs:

1.1 Anchor beams

This method involved the placement of beams with anchors on the slope to hold the rock in place. It often required comprehensive, difficult and intensive construction to place anchor beams directly on the rock slope. The installed anchor beams were highly visibility, subject to weathering and did not enhance the natural scenery of the slope.

1.2 Shotcrete

In order to achieve sufficient strength to hold rock in place, anchors are placed in a tight grid along with a rigid wire mesh and whalers. The shotcrete layer needed to have a minimum thickness. The installation of anchors and shotcrete in area with difficult access makes this an expensive solution. Shotcrete is often not very aesthetically pleasing and it can be damaged by water and weather. A newer technique is sculpting the shotcrete which also leads to additional cost.

1.3 Cable lashing

The placement of cables to lash rock formations in place were often used but had their limitations. Due to the given geometry of the formation, the placement of the cables was not always ideal and would require over dimensioning. This meant the placement of the anchors for the cables was also not ideal. The cables can only work locally and, over time the rope tension is reduced.

1.4 Wire rope nets with or without cable lashing

The use of wire rope nets to cover and hold rock formations was used but had its limitations. The nets were square or rectangular and the nail grid was usually based on net shape. The combination did not adapt well to local rock shapes or configurations. A further disadvantage was each individual net could only cover a few square meters and connect the nets together to cover a larger area was time consuming. Wire net ropes were generally made using 8mm diameter, 7x7 or 7x19 construction, galvanized wire rope. The individual wires in the wire ropes are galvanized before the ropes are made and the small diameter of individual wires do not have a large coating of zinc galvanizing. The result is a reduced life expectancy of the rope.

The addition of wire rope nets had only have a limited effect on improving system capabilities. The two components are not coordinated and the stability of each utilized part is not equally distributed. Adequate protective methods are difficult to properly dimension. This is especially problematic for rock areas with irregular surfaces.

2 TECCO® SLOPE STABILIZATION SYSTEM

Geobrugg AG developed TECCO® Mesh several years ago, which is a high-tensile steel wire mesh featuring elongated diamond shape openings, for the TECCO Slope Stabilization system. The mesh provided the strength of a wire rope net and it was easier to handle. This innovation opened up new possibilities including:

• nail pattern optimized to meet the local conditions (slope, ground, topography)
• offsetting of nails in horizontal rows to avoid the crossing of pathways in the slope line
• tensioning of the system against the ground using spike plates

In the process of development, it became clear the transmission of force to the nails or anchors played an important role in improving the bearing resistance of the slope stabilization system. Because of this, the further advancement of flexible slope stabilization systems required that spike plates be adapted and optimized in terms of size, geometrical layout and bending resistance.

This brought about the development of the Ruvolum Dimensioning program for soil and highly weathered rock slopes and Ruvolum Rock Dimensioning program for rock slopes.

3 THE SPIDER® NET INNOVATION

The development of the SPIDER® net followed the TECCO® mesh and the net is made with 1x3 strand and high-tensile steel wire is used for the strand. Plus, the net has elongated diamond shape openings, the nets replaced TECCO® mesh and lead to the SPIDER® rock protection system to secure rock slopes where the rock is not prone to decomposition or weathering, where the surface is irregular and where rocks that come loose tend to be large.

There are currently two concepts regarding the potential risks and maintenance requirements:

• Concept (I): If the critical area is to be secured in a proactive manner and deformation and maintenance work is to be kept to a minimum, the solution is to utilize nailing in the critical area with a net cover system including spike plates. The type and arrangement of nails as well as its lengths are to be adapted to meet the requirements for static loads.

• Concept (II): Should it not be possible to drill through the critical areas or should the requirements regarding deformation and maintenance be less, the nails could be arranged around the critical area (e.g. around an unstable boulder). The protective measure in this instance is rather passive. Larger deformations must be anticipated should pieces of rocks or even a mass come loose under the protection of the net drapery. The concept is applied to limited areas only.

3.1 System Components

The innovative rock protection system consists of the following components:

1. SPIDER® net
2. Anchors nails
3. Spike plates
4. Shackles, boundary ropes and wire rope anchors
5. Secondary mesh (optional) - shown in Figure 1.

The SPIDER® net openings have the elongated diamond shape and the openings are 500mm x 292mm. The strand used to make the nets consists of three (3) 4mm diameter high-tensile strength galvanized wires twisted together. The wires have a minimum tensile strength of 1,770 N/mm^2.

Similar to the TECCO® mesh, the construction is single twist to form the openings and the ends of the strands are knotted together to permit the full transmission of force to the adjoining panels. Nets are connected together with shackles. The wire is galvanized with a coating that is 95% zinc and 5% aluminum for corrosion protection. The standard net is 3.5 meters x 20 meters and supplied as a roll which weighs approximately 190 kilograms.

Commercially available anchors are used to anchor the nets in place and the anchors need to fulfill the static requirements. Plain or galvanized or epoxy coated nails can be used and these are drilled and grouted anchors in typically 100mm diameter holes using a cement grout. Contrary to earlier cable net covers where so-called anchor heads with eyes were placed on the anchors and utilized for fastening the wire rope nets to the anchors, elongated diamond shaped spike plates are now used to simply tension the nets against the rock. The shape, size and bending resistance of the plates have been optimized based on various puncturing and bending tests and adapted to the system requirements. For the connection of the net panels, 3/8 inch shackles are normally used.

In order to achieve ideal load transfer in adjoining areas and to reinforce the edges, 14mm diameter boundary ropes are placed all the nets and attached to wire rope anchors that are installed laterally. The boundary ropes can be pulled directly through the mesh openings from the top, bottom or sides. Seam ropes or shackles or compression claws are not needed to attach the net to the boundary ropes. In the event of overhangs, additional cables can be installed under the overhangs to optimize the bearing behavior of the system.

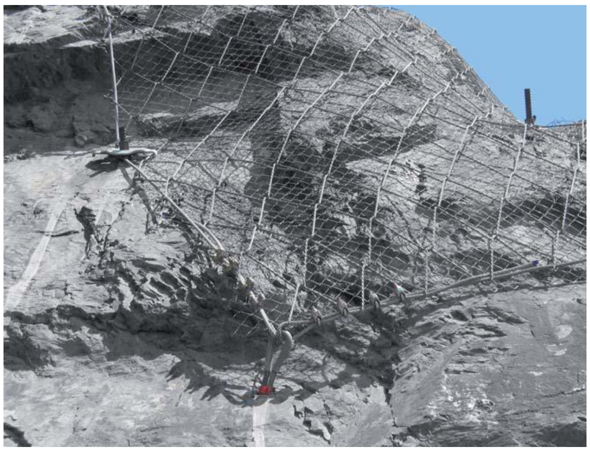

Figure 1: SPIDER® Net Installation

As an option, a secondary steel wire mesh is placed underneath the SPIDER® net if there is a risk of smaller rocks coming loose and possibly falling through the mesh openings. Intermediate nails or pins can be provided to ensure the net is adequately pinned against the rock using a simple spike plate to do the job.

4 Design Approach

In order to secure an individual block, an external stabilizing force (P) is required to hold the block against the stable ground. This force depends predominantly on the following components shown in figure 2:

- dead weight (G) of the block
- inclination of the sliding surface to horizontal (β)
- friction angle (ϕ) between the stable ground and the block
- cohesion (c) or interlocking force along the slide plane and its size (A)
- direction (ϑ_o) and (ϑ_u) of the forces (Z_o) and (Z_u) in the net cover

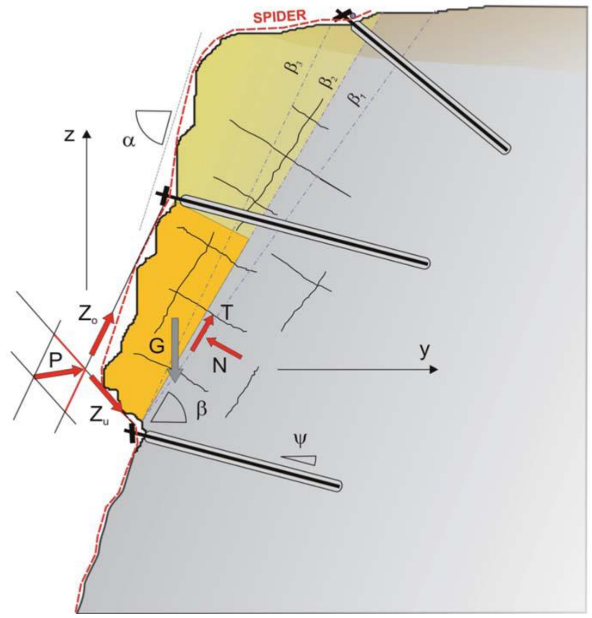

Figure 2: Retention Forces

The external stabilizing force (P) can be calculated as follows (equation 1) and takes into account the stabilization issues relevant to an individual block as well as the model uncertainty correction value (γ_{mod}).

$$P\ [kN] = [G \cdot (\gamma_{mod} \cdot \sin\beta - \cos\beta \cdot \tan\phi) - c \cdot A] / [\gamma_{mod} \cdot \cos(\beta - \omega) + \sin(\beta - \omega) \cdot \tan\phi] \quad [1]$$

The force (P) is a vector and can be applied in a two-dimensional model where it is divided into the vectors Z_o and Z_u. These are the forces which will be transferred from the net to the nails and into the stable subsurface. The direction (ω) of the force (P) to horizontal (upwards = positive) or the relation factor η, respectively, depends on various factors such as the interlocking action and/or friction between the surface of the block and the net restraint and the surface irregularities/roughness of the block. Figure 3a outlines these forces and their relationship.

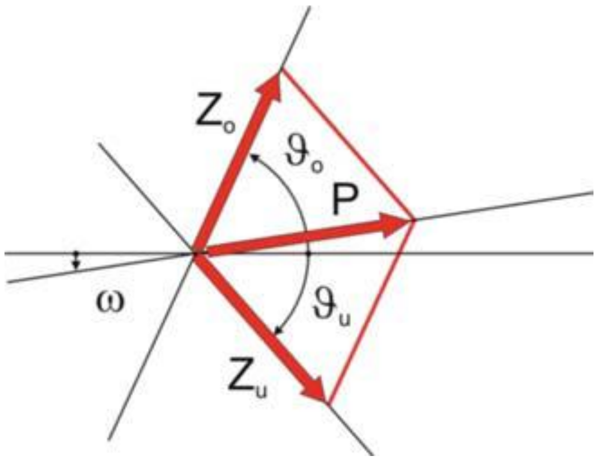

Figure 3a.

The stronger the interlocking action between the net cover and the boulder, the more favorable is the direction of action of the force (P) and the tensile force on the lower restraint is smaller. In general, the force at the lower restraint is always smaller than or equal to the force at the upper restraint as shown in figure 3b.

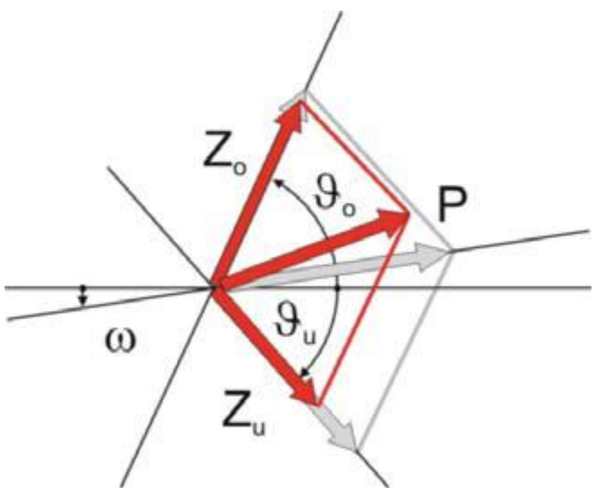

Figure 3b.

The forces (Z_o) and (Z_u) significantly depend on their orientation to each other. If the opening angle ($\vartheta = \vartheta_o + \vartheta_u$) tends towards 180 degrees, the forces (Z_o) and (Z_u) tends theoretically towards infinite when keeping force (P) constant and not equal to 0 as shown in Figure 3c. The result is the arrangement of the SPIDER® net on the slope plays an important role in securing a boulder.

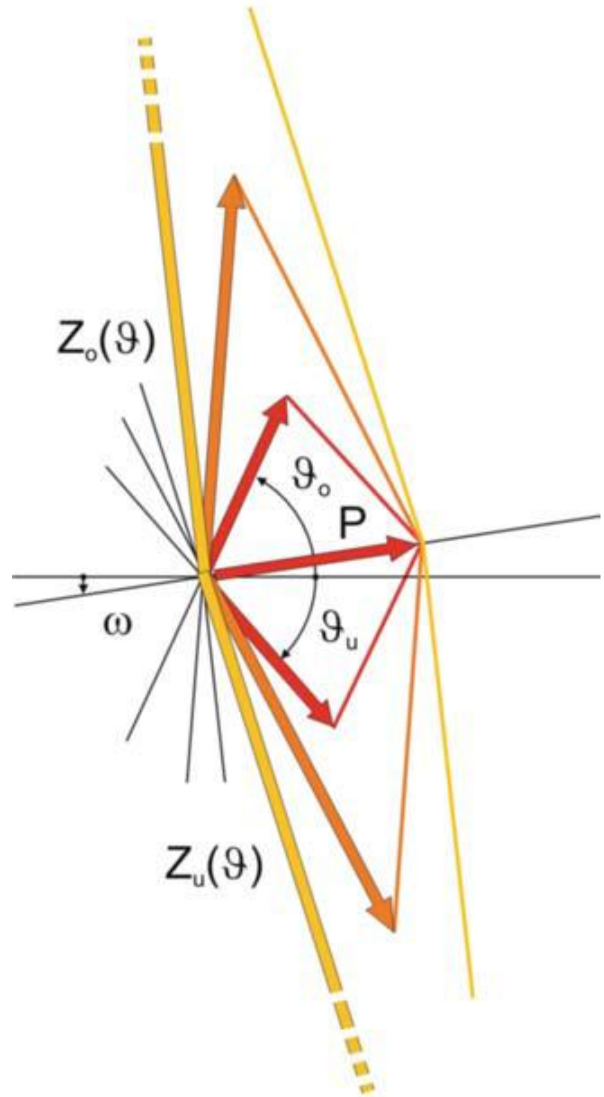

Figure 3c.

Since the SPIDER® protection system has a certain degree of elasticity, it is unavoidable for the boulder to be displaced along the slide face in the event of a failure. The forces (Z_o) and (Z_u) are reduced as a result of this boulder movement. The opening angle ($\vartheta = \vartheta_o + \vartheta_u$) becomes smaller with an increasing displacement and the upper and lower retention forces will consequently decrease. Figure 4 is a qualitative presentation of the parameter interdependence.

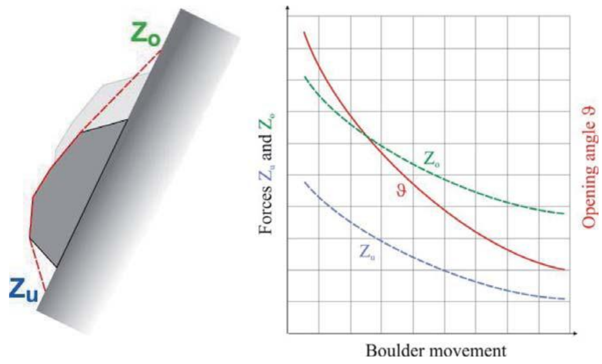

Figure 4: Parameter Interdependence

5 PROCEDURE FOR DIMENSIONING

In order to dimension the systems, the following input quantities have to be determined through field investigation:

- Weight, geometrical dimension of the block-shaped boulder
- Inclination of the sliding surface (β)
- Shear parameters along the sliding surface (friction angle and possibly cohesion)
- Angle of the net restraint to horizontal (ϑ_o) on top of the boulder
- Angle of the net restraint to horizontal (ϑ_u) at the bottom of the boulder
- Angle of the lateral net restraint to horizontal (δ)
- Accelerations due to earthquake horizontal (ε_h) and vertical (ε_v)

Experiments conducted on 1:3.5 models allow the following qualitative conclusions related to the distribution of forces. These conclusions will have to be refined by means of different anchorage arrangements and by utilizing different block-shaped boulders.

- The friction between the net and the block-shaped boulder can increase the calculated upper retention force by 10% - 20 % and reduce the lower retention force accordingly.

- The influence of the lateral retention forces may reduce the longitudinal retention forces by approx. 15% - 30 %.

- The lateral retention forces may exceed 50% of the upper retention force, depending on the arrangement and deflection of the net in the restrained section.

5.1 Ruvolum Rock Program

The program was originally developed for applications involving the TECCO Mesh G65/3. With the development of the SPIDER® net, the program was revised and is now used as online application.

When the program is opened, preset default values are already in place and the determined input quantities are entered in their place as shown in figure 5.

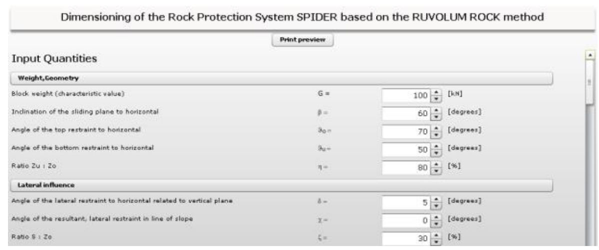

Figure 5: Program Input Quantities

As the input quantities are changed, a graphical presentation of the forces is shown and it shows the relationship between Pd, Z_{od}, Z_{ud} and S_d as shown in figure 6.

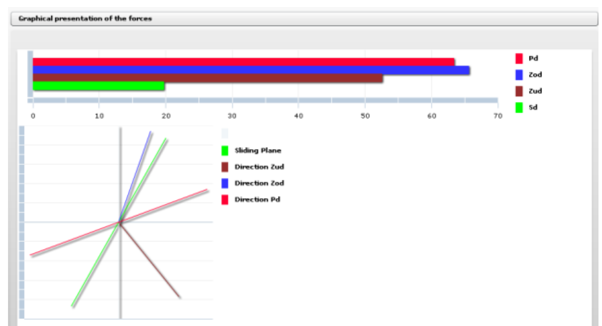

Figure 6: Graphical Presentation of Forces

Additional parameters may be changed and they include geotechnical parameters, safety factors, number of anchors, earthquake and water pressure acting on the block shown in figure 7.

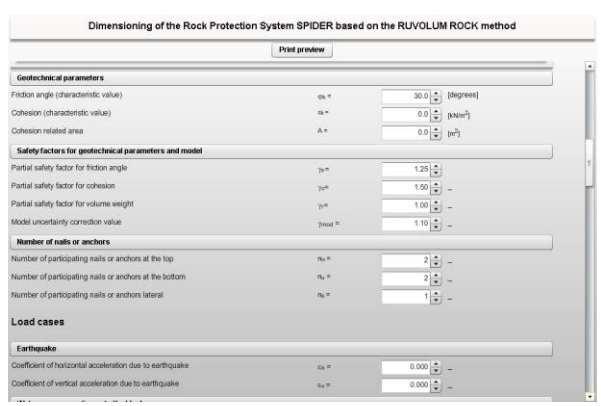

Figure 7: Additional Input Parameters

In additional to balancing the load, a key consideration is to fulfill (1) Proofs of bearing resistance of the net and (2) Proofs of bearing safety of the nails. There are a total of 7 individual proofs that need to be fulfilled and they are listed below:

1. Proof of local force transmission in the net to the top nails
2. Proof of local force transmission in the net to the bottom nails
3. Proof of local force transmission laterally in the net to the nails
4. Proof of shear stress in nails at the top
5. Proof of combined stress in the nails at the top
6. Proof of shear stress in nails at the bottom
7. Proof of combined stress in the nails at the bottom

The key is to optimize the anchors arrangement so all the forces are in equilibrium and forces at the anchors are not unbalanced.

6. KNOWLEDGE GAINED AND CONCLUSIONS FROM LARGE SCALE FIELD TESTS

Spiral rope nets 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.

The forces measured in earlier model experiments scaled 1:3.5 were consistent with the results derived from the simple two-dimensional theoretical model.

The large scale field tests showed the practical suitability of rope nets such as the SPIDER® rock protection nets. Figure 8 shows a large scale test up. A range of tests enabled the direction and amount of the force vectors to be determined dependent on the arrangement of the anchorages. The acceleration distance of the boulder played an important role. The tests yielded the following information and conclusions for practice:

- If a critical boulder is calculated purely statically on the basis of an equilibrium consideration, the forces in the anchorages can sometimes be massively underestimated. 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. Consequently a dynamic factor κ_D is to be taken into account when dimensioning flexible rock protection systems. The dynamic factor is the relationship between the dynamic forces and static forces.

- In principle the forces are more likely to be transferred upwards. The size of the relationship η 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.

Figure 8: Large Scale Test Set-Up

7 SUMMARY

The SPIDER® net along with the SPIDER® rock protection system was developed specifically for rock slopes where it is not practical to remove loose rock. The net is supplied in 3.5 meter wide x 20 meter long rolls which facilitates an easier and faster installation.

The two dimensional theoretical model was used to develop the concept and model testing in a laboratory confirmed the validity of the two dimensional theoretical model. Full scale field testing tested different anchor arrangements and added to our knowledge about rock behavior which has lead to improvements in the program such as adding the dynamic factor.

It is now possible to optimize the net and anchors so the loads are balanced which was not possible using other techniques. The updated Ruvloum Rock Dimensioning Program is a new tool designers and engineers can use to optimize their applications.

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