Landmarks in Earth Reinforcement, Ochiai et al. (eds),
© 2001 Swets & Zeitlinger, ISBN 90 2651 863 3

Slope stabilization with high-performance steel wire meshes in combination with nails and anchors

R. Rüegger & D. Flum
Rüegger Systems Ltd, St. Gallen, Switzerland

B. Haller
Fatzer Ltd, GEOBRUGG Protective Systems, Romanshorn, Switzerland

ABSTRACT: Diagonally structured meshes of high-tensile steel wire provide new safety and economical possibilities for slope stabilizations in combination with soil and rock nailing. An adapted concept for dimensioning based on practical experience as well as special laboratory trials to determine the essential bearing capacities of tangential and axial force transmission from the mesh to the nails make this flexible facing system designable. This system with an open mesh permits full-surface greening and is often an economical alternative to rigid constructions of concrete.

1 INTRODUCTION

The use of wire mesh and wire rope nets as a flexible measure to protect surfaces has been proved worthwhile in many cases and is an accepted technology. Until now, wire mesh from wires of a tensile strength of approx. 500 N/mm^2 are mostly used for these protection measures. Ropes threaded into the mesh can be used as reinforcements. If the distances between nails are kept at an economical level, these simple meshes are often unable to absorb the occurring forces and to selectively transmit them onto the nails. Wire rope nets, while finally allowing larger spacing between nails, are comparatively expensive and therefore only used in particularly delicate cases with very high forces and a need for long nails.

The development of a wire mesh made from high-tensile steel wire with a tensile strength of more than 1,800 N/mm^2, produced in a special process, offers new possibilities for the efficient and also economical protection and stabilisation of slopes. The system lends itself for dimensioning by means of suitably adapted dimensioning models considering the statics of soil and rock. In the practical application these high-strength meshes are often able to replace the expensive wire rope nets.

2 HIGH-TENSILE WIRE MESH AS A SURFACE PROTECTION SYSTEM

The usual type of the new mesh for slope stabilization, named TECCO (cf. figure 1), has individual meshes measuring 83 mm x 143 mm. It is produced by single twisting of the wire with a diameter of 3 mm and a tensile strength of more than 1,800 N/mm^2. This TECCO mesh has a considerable tensile strength of approx. 150 kN/m in longitudinal and 75 kN/m in cross direction. The gentle deflection of the wire to form the individual meshes results in a three-dimensionality of the mesh which vastly improves the connection to the subsoil and possibly applied hydroseeding.

Substantially higher forces can be absorbed by this mesh in comparison with the wire mesh traditionally available on the market, offering a tensile strength in longitudinal direction of approx. 50 kN/m at comparable mesh size and similar wire diameter. Compared to wire rope nets, the high-tensile wire meshes with their special properties provide a statically virtually equivalent surface protection system which is, however, substantially more economical.

When using high-tensile wire mesh as a surface protection system, the slope of soil or rock to be protected is cut as suitable and level as possible to the profile and then covered with the high-tensile steel wire mesh which is fixed and often pretensioned to soil or rock nails.

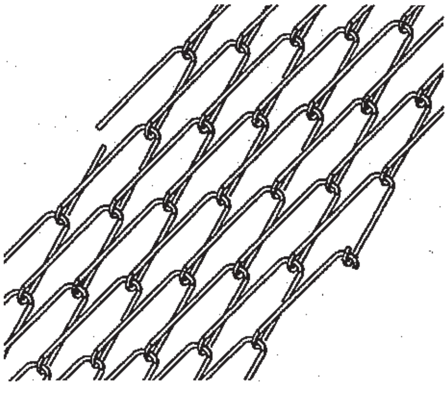


Figure 1. The TECCO mesh.

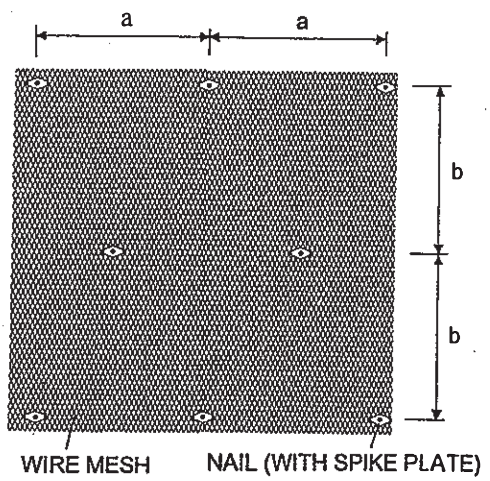


Figure 2. The TECCO mesh.

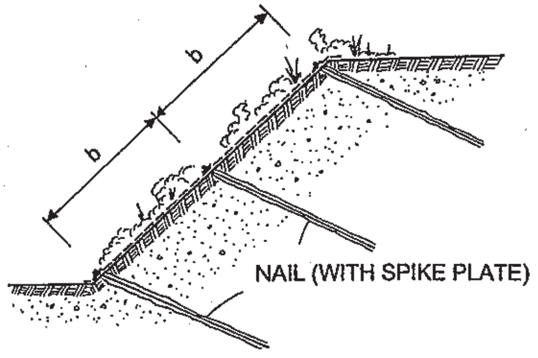


Figure 3. General profile.

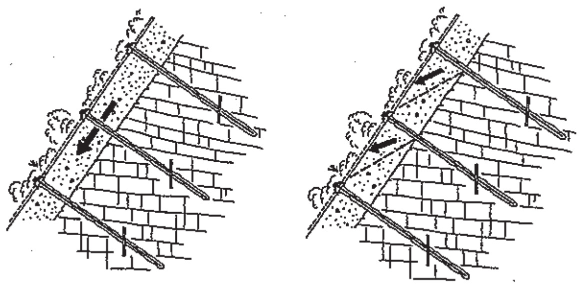


Figure 4. Instabilities, parallel to the slope, local.

For this system a nail pattern is to be selected on purpose in which the nails in the rows are offset by half a horizontal distance between nails (cf. figure 2). This means that the maximum possible bodies liable to break out are limited to a width a and a length of 2*b. The nail head is designed so that it can be pretensioned with the force V (cf. figure 5 or 7). This improves the static effectiveness of the system and limits the deformations in the area of the slope. To meet the high demands in respect of durability, the known anti-corrosion process of aluminium-zinc alloying is used to protect the wire surface what equals an enormous increase of corrosion protection in comparison with normal standard zinc coating.

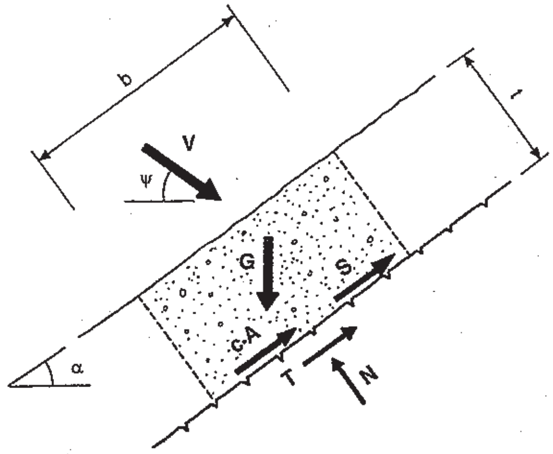
3 RUVOLUM, THE NEW DIMENSIONING CONCEPT

The new dimensioning concept RUVOLUM is applicable to all surface protection systems on the market which provide for nailing in combination with a mesh or a wire rope net (or a mixture of the two) as a surface protection system which permits any distance between nails in both horizontal and vertical direction. It is pointed out especially that RUVOLUM is not restricted to the dimensioning of protection systems using high-tensile mesh exclusively.

The new dimensioning concept comprises two investigations:

- Investigation of superficial instabilities parallel to the slope
- Investigation of local instabilities between single nails

RUVOLUM is a product of Rüegger Systems Ltd and has been established especially by Rudolf Rüegger and Daniel Flum in the context of the development of high-tensile mesh.



G	dead weight of the cubic body
S	shear force, to be absorbed by the nail
V	pretensioning force
t	thickness of the surface layer to be stabilized
c*A	cohesion of the cover layer * ground surface of the body liable to break out, whereby A = a * b
T, N	reaction forces from the subsoil
α	inclination of the slope front
Ψ	inclination of the nail to horizontal
φ	effective friction angle of the cover layer
F	safety factor

Figure 5. All forces acting on the cubic body.

3.1 *Investigation of superficial instabilities parallel to the slope*

The investigation of superficial instabilities parallel to a slope examines a cubic body of width a, length b and layer thickness t which threatens to slide off the firm subsoil. All forces considered and acting on the sliding body are marked in figure 5. Hereby it is assumed that no hydrostatic excess pressure and no flow pressure is effective on the sliding body. The force V signifies the pretensioning force of the surface protection system. The active application of this force V means that the spike plates and thereby the mesh are pressed onto or slightly into the subsoil. This outer pressure force acting on the surface of the steep terrain permits to mobilize additional friction forces along the sliding surfaces under examination. This has a positive effect above all on the overal stability.

From considerations of equilibrium concerning the cubic body shown in figure 5 and taking into account the rupture condition of Mohr-Coulomb, the general equation 1 can be formulated for the stabilizing shear force S in function of the geometrical and geotechnical parameters as well as of the pretensioning force V and safety factor F.

$$S\,[\mathrm{kN}] = 1 / F \cdot \{F \cdot G \cdot \sin\alpha - V \cdot F \cdot \cos(\Psi+\alpha) - c \cdot A - [G \cdot \cos\alpha + V \cdot \sin(\Psi+\alpha)] \cdot \tan\varphi\} \qquad (1)$$

The following three proofs of stability must be established in the investigation of global failures parallel to the slope:

- Proof against sliding off parallel to the slope
- Proof against puncture of the mesh due to pretensioning force
- Bearing safety of the nail (combined strains)

3.2 *Investigation of local instabilities between single nails*

When investigating bodies which might break out between single nails, the question is what sort of bodies become possible considering the selected nail arrangement.

Located above each nail is a field of width a and length 2*b which must be protected against local instabilities. The cross section of the maximum possible shape that may break out is influenced to a major extent by the protection concept itself: By tightening the nuts, the spike plates are firmly pressed onto the ground or slightly into it and the mesh is pretensioned against the nail head with the force V.

Due to the passing-on of forces in the area of the nail head, a truncated pressure cone occurs in the cover layer beneath the spike plate and the adjoining mesh (figure 7).

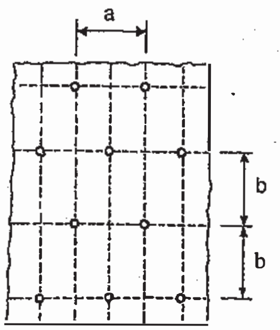


Figure 6. Overview of the general nail arrangement.

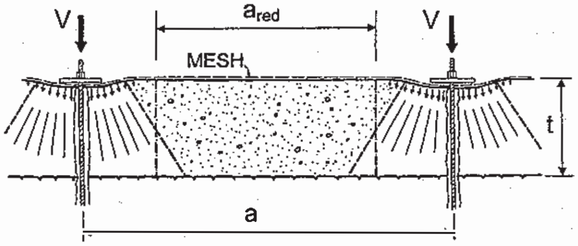


Figure 7. Cross-section of the maximum possible body (liable to break out) of the thickness t.

The dimensioning model is assuming that the pressure cones are located completely outside the body to be examined. The cross-section of the maximum possible body is therefore trapezoidal. Simplifying, the trapezoidal surface can be transformed into a rectangle of equal area of the width a_{red} and the thickness t.

The body to be considered now features a width of a_{red} and a maximum length of 2*b. For the proofs of bearing capacity in the context of the investigation of local instabilities by the dimensioning method described in this chapter it is mandatory to vary the thickness of the bodies to be examined over the entire interval 0 to t and to determine the decisive failure (break-out) mechanism in this way.

It must be pointed out that the selected geometry of the bodies to be examined is intended to approximately simulate the shell-like shapes which break out in reality. By means of the trapezoidal cross-section the actually curved cross-section is described as an approximation.

The failure mechanism in figure 8 shows a two-body sliding mechanism. Hereby the upper body I of trapezoidal cross-section presses onto the wedge-shaped lower body II via contact force X. The width of both bodies amounts to a_{red}. The force Z denotes the slope-parallel force which is to be transmitted selectively onto the upper nail. The force P is introduced as a general retaining force required in the context of the equilibrium considerations.

$$P\,[\mathrm{kN}] = \frac{G_{II} \cdot [F \cdot \sin\beta - \cos\beta \cdot \tan\varphi] + (X-Z) \cdot [F \cdot \cos(\alpha-\beta) - \sin(\alpha-\beta) \cdot \tan\varphi] - c \cdot A_{II}}{F \cdot \cos(\beta + \Psi) + \sin(\beta + \Psi) \cdot \tan\varphi} \tag{2}$$

$$X\,[\mathrm{kN}] = 1 / F \cdot \{ G_I \cdot (F \cdot \sin\alpha - \cos\alpha \cdot \tan\varphi) - c \cdot A_I \} \tag{3}$$

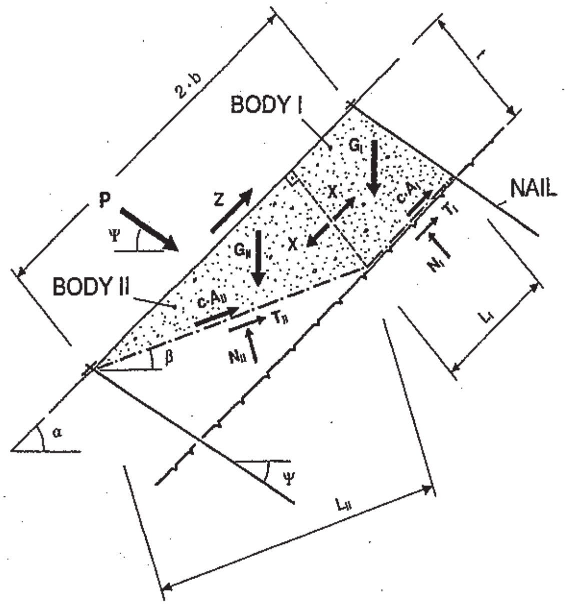
As a special case the body I does not exist and it remains body II as a one-body sliding mechanism.

The contact force X results from the equilibrium considerations at the upper body I, whereby the condition of Mohr-Coulomb as well as the safety factor F are again taken into account. The equilibrium conditions on body II are formulated to determine the maximum force P by variation of β. Hereby the contact force X from equation 3 and the slope-parallel force Z are used.

The following proofs of bearing safety must be established in the investigation of local instabilities taking into account the bearing capacities of the protection system (cf. chapter 4):

-Shearing-off of the mesh at the upslope edge of the spike plate at the lower nail (force P)

-Selective passing-on of the slope-parallel force Z from the mesh onto the upper nail



X	contact force
Z	slope-parallel force
$G_{I,II}$	dead weights of the individual sliding bodies
$c * A_{I,II}$	forces due to cohesion
$T_{I,II}$, $N_{I,II}$	reaction forces from the subsoil
α	inclination of the slope
Ψ	inclination of the force P

Figure 8. Two-body sliding mechanism (possible friction forces along the contact surface of the two bodies I and II are neglected).

3.3 *Additional proof of the terrain's resistance against sliding (deep sliding surfaces)*

This concerns the proofs of safety against rupture of the terrain, for which the nails are included in the stability caculations with the topographically and geologically adapted sliding surfaces, usually as tension elements with a stabilizing effect and in rarer cases as shear elements.

4 TRIALS FOR DETERMING THE BEARING CAPACITY FOR FORCE TANSFER MESH – NAIL

In the equilibrium considerations in paragraphs 3.1 and 3.2, the pretensioning force V, the retaining force P and the net force Z have been introduced as external forces. The question now arises how high these forces may be in the maximum so that they can still be absorbed by the used mesh, the applied spike plate and the nails, taking into account appropriate safeties.

Figures 11 and 12 show the test setups developed by Rüegger Systems Ltd, in one case to determine the bearing resistance of mesh against selective,

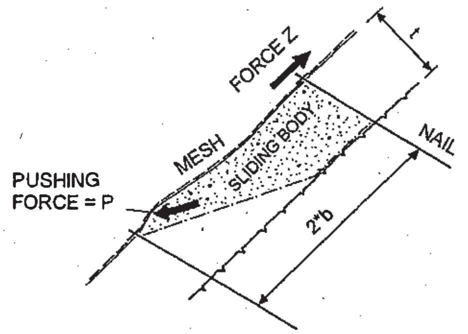


Figure 9. Pushing force P and tensile force Z.

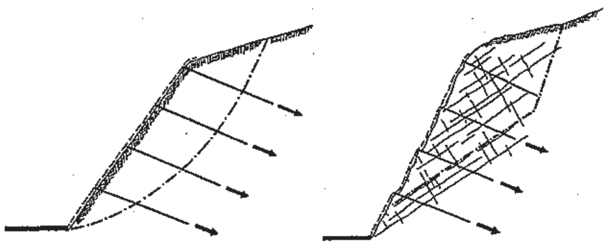


Figure 10. Global stability.

slope-parallel tensile strains, and in the other to determine the bearing resistance of mesh to pressure strain in nail direction.
The figures 13 and 14 show a graphic presentation of the test results. Laid off as abscissa are the deformations in mm and as ordinate the total tensile or total pressure forces in kN in each case. Hereby the different bearing capacities of a high-tensile wire mesh, of a common wire mesh and of a geogrid of PET become particularly evident.

To determine the curves I, II and III in figure 14, the meshes and the geogrid, respectively, were tensioned in a square frame. The hydraulic press is arranged centrally and presses against a nail of type GEWI D = 32 mm.

Curve IV describes the behaviour of the test soil (sandy gravel) without involvement of a mesh or geogrid.

The difference Δ in figure 14 corresponds for example to a high-tensile wire mesh of type TECCO, the bearing resistance of mesh to pressure strain in nail direction, whereby corresponding safety margins must be considered also. In the proof 'shearing-off of the mesh at the upslope edge of the spike plate at the lower nail', only half of Δ may be used in the calculation, while including corresponding safeties.

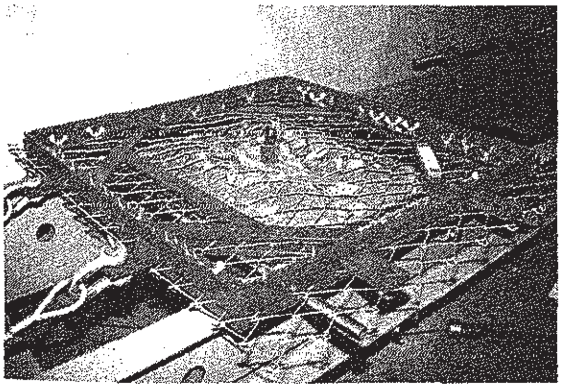


Figure 11. Test setup for determining the bearing resistance of mesh against selective, slope-parallel tensile strains.

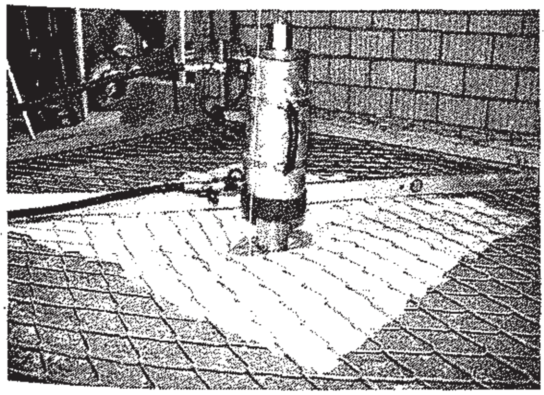
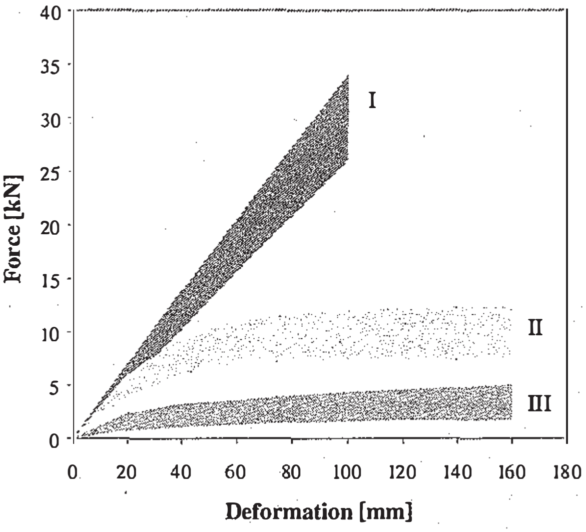
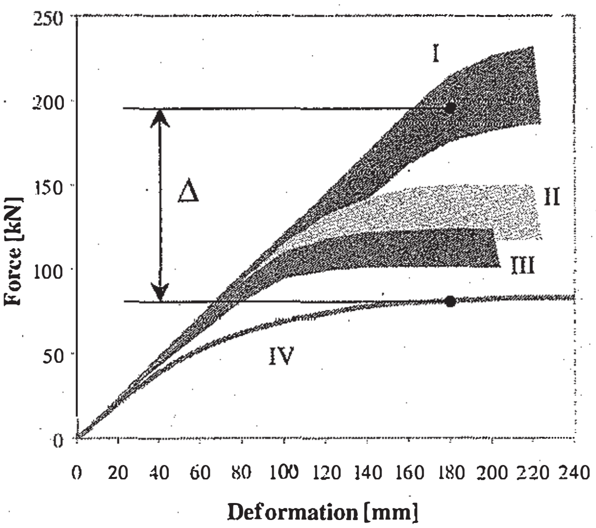


Figure 12. Test setup for determining the bearing resistance of mesh to pressure strain in nail direction.



I High-tensile wire mesh of a tensile strength of the mesh of approx. 150 kN/m
II Common wire mesh of a tensile strength of the mesh of approx. 50 kN/m
III Geogrid of PET of a tensile strength of the mesh of approx. 40 kN/m

Figure 13. Force-deformation relationships of three different products as result of tensile tests in tangential direction, using a round spike plate with a diameter of D = 220 mm.



I High-tensile wire mesh of a tensile strength of the mesh of approx. 150 kN/m
II Common wire mesh of a tensile strength of the mesh of approx. 50 kN/m
III Geogrid of PET of a tensile strength of the mesh of approx. 40 kN/m
IV Ground without involvement of a mesh

Figure 14. Force-deformation relationship as result of puncture tests in nail direction, using a round spike plate with a diameter of D = 220 mm.

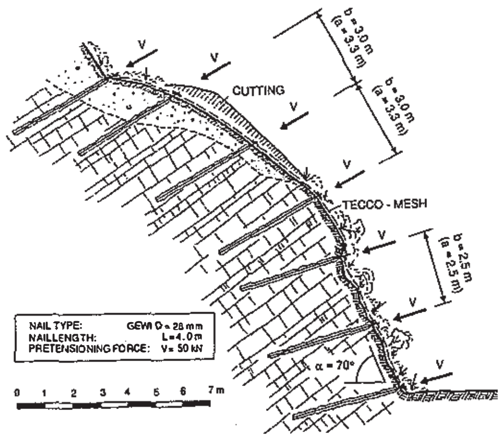


Figure 15. General cross-section.

Figure 16. Protected slope with mesh cover in combination with nailing.

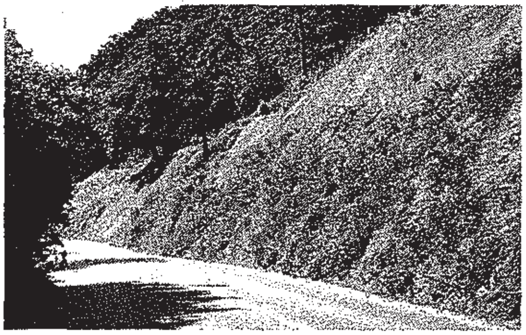


Figure 17. Protected slope.

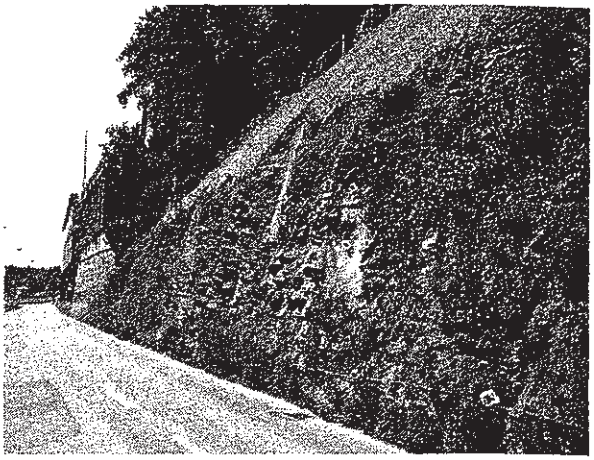


Figure 18. Protected slope (rocky section).

5 PROJECT IMPLEMENTED IN MÜLHEIM, GERMANY

In Mülheim, Germany, at the location Mendener Strasse, a rocky slope approx. 420 m long and on average approx. 12 m high is permanently protected against rockfalls and local instabilities by means of nailing in combination with a TECCO mesh cover.

The inclination of the slope front to the horizontal plane amounts to between 45 and 70°. Locally, above all in the upper areas, the rockface (sandstone, siltstone, mudstone) is covered by slope clay and slope scree. The rock is very prone to weathering. Based on the geotechnical situation, the overall stability of the slope is not endangered. The protection measures are limited to the section close to the surface.

The surface protection was dimensioned on the basis of the RUVOLUM concept. For the rocky section with a slope inclination of $\alpha = 70°$ and a long-term loosened, weathered layer of thickness $t = 0.50$ m to be protected, a nail pattern of $a = b = 2.5$ m resulted. In the area of the unconsolidated rock covers with a slope inclination of 45...50° and with $t = 0.80$ m, a nail pattern of $a = 3.3$ m and $b = 3.0$ m resulted. The slope was greened with the Fibrater system.