Rockfall Protection

Rockfall protection systems are a key element in the design and maintenance of infrastructure networks and have a direct impact on safety. For this reason, such systems need a new approach that encompasses the overall analysis of the structural system, and not just the individual components. The word “system” is the best description, as it embraces the different structural components which interact with one another.

A key distinction must be made between active and passive protection systems.

“Passive” systems are those which do not affect the process of the rock detaching, but rather focus on containing falling debris, thereby averting danger for the infrastructure and its users.

Passive systems include:
- drapery wire mesh
- rockfall protection barriers
- rockfall protection embankments

The “active” systems are those which act on the rock-detachment process:
- secured drapery, where different kinds of steel wire and cables form a mesh which is then anchored to the rock slope.

The planning, construction and maintenance of these structures must take into account their durability. In accordance with these concepts, Maccaferri’s long-lived experience in this field, coupled with its corporate orientation towards research and innovation, yielded the development of the MACRO.™ System (MACcaferri ROckfall protection systems), which provides a flexible response to different problems, and combines industrial innovation, advanced research and project design.
The MAC.RO. System

The concept behind a protection system is the combination of good planning and the right choice of system components, which must be made as a function of the actual stress the system will have to withstand, compared with the stress capacity of the various component materials.

Just as for other soil stabilization activities, the basic concept to comply with is the "minimum energy level", i.e. a response commensurate with the problem, thereby avoiding overdesign and unnecessary costs.

Aspects related to the durability of the systems are regulated by the guideline, “Durability and Construction Products Directive” 89/106/EEC. The concept of useful design life of a system, i.e. the period of time during which the system performs as expected, is strictly linked with the durability of the system components, and, of course, with the level of maintenance.

Rockfall protection barriers and facings must be conceived as "non-easily-replaceable systems", and therefore must have a durability of around 25 years, while structural works such as reinforced earth embankments for rockfall protection must last for 50 years.

**Durability of facings and systems**

**Very aggressive environment (industrial, road and marine)**

<table>
<thead>
<tr>
<th>Rockfall protection - required life-span</th>
<th>Reinforced rockfall protection embankments - required life-span</th>
<th>Class A EN 10244</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn-Al (5%) MM</td>
<td></td>
<td></td>
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<tr>
<td>Zn</td>
<td></td>
<td></td>
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<tr>
<td>Zn-Al (5%) MM polymer-sheathed</td>
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<td>Loss of Fixing (g/m²)</td>
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<tr>
<td>Steel</td>
<td></td>
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<tr>
<td>Galfan Zn-Al 5% MM Alloy</td>
<td></td>
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<tr>
<td>Zinc</td>
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<tr>
<td>Polymer sheathing</td>
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</tbody>
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LA.T.I.F. Trento - Italy
The MAC.RO.™ system includes:
- surface facings / protection
- rockfall barriers
- reinforced earth rockfall protection embankments

Choosing between the available options, and between the various solutions within each option, must be in proportion to the actual scale of the containment problem being addressed.

The solutions provided by the MAC.RO.™ system have been developed in collaboration with distinguished research centers. This way, Maccaferri not only provides products, but also the fundamental technical assessments which are needed in order to achieve the optimum action planning.
Drapery wire mesh system

This system is typically applied to rock masses whose surface can break down into fragments not smaller than the apertures in the mesh, and in any case not larger than 0.5 meters (2 ft) in diameter. On moderately steep slopes, or those where some vegetation may grow, the mesh should be kept as close to the slope as possible. On very steep and/or near vertical slopes, the net must be anchored at the top of the cliff, and left unanchored on the rockwall, thereby allowing rocks to fall to the foot of the cliff, and be contained between the rockwall and the mesh. A key factor here is to have a safe and continuous anchorage at the top, from which space has to be allowed for debris to fall down. Our double-twist wire mesh is the ideal solution, both due to its flexibility in all directions, and to the fact that it will not unravel, even in the event of some of its wires accidentally breaking. This problem used to be unsolvable, with old single-twist mesh, as it cannot provide the same level of safety, irrespective of the kind of wire used.

Italy

Australia
Fixed facing systems

An overall drapery mesh system must be sized after a realistic assessment of the problem to be addressed, and in accordance with general planning concepts laid out in design codes. The main stress factors to be taken into account are:

- permanent stress factors:
  weight of the whole netting, with a recommended factor of safety of 1.35

- variable stress factors:
  weight of debris piled up at the foot and weight of snow (for slopes of less than 60°), with a recommended factor of safety of 3.

In general, the dynamic stress produced by a rock during its fall should not be taken into account, except in very peculiar situations.

Apart from cases in which system planning and application have been inadequate, the main mechanical stress comes from the debris piled up at the foot of the slope.
Volume of debris at the foot

The volume of debris must be calculated, not only in order to design the anchoring system, but also to decide whether and to what extent of rockfall is acceptable. It is important to assess what the likely amount of accumulated debris will be, and the acceptable amount in accordance with the distance between the foot of the slope and the adjacent road surface. In other words, the designer should have a sensible idea of the acceptable level of debris, and correctly refrain from drawing catastrophic scenarios only to justify the presumed requirement of a higher resistance system.

The figure below shows the volume of debris for a foot width of 1.00 meter (3.28 ft), and a possible max pile-up height of 3.00 meters (9.84 ft).

Tensile Strength

The tensile strength experienced by the steel mesh is a function of the slope angle, and must be calculated using limit state conditions, taking into account the friction between the debris and the previously mentioned factors of safety.
Secured Drapery System

Secured drapery systems are those actions aimed at consolidating the surface of the rock mass and at containing possible rock detachments (typically those of up to 1-1.5 m$^3$ [1.3 - 2 CUY]). This intervention falls under the 'active' category rather than 'passive', although it could be argued as combining the two. To be clear, a "surface revetment" is different from a whole "rock surface" or slope stability solution.

The latter must be addressed - if it presents problems - with deep-reaching overall stability solutions (e.g. soil nailing), which may then be combined with a facing, (also made with a series of anchorages, mesh and cables) to address the surface stability.

The overall system made of anchorages, steel cable panels, steel cables and mesh netting, is illustrated below, in which the basic cell is a unit enclosed between 4 anchorage points. In order to determine the right size of the overall system, one must assess:

- the required rigidity of the structure
- the strain experienced by the anchorage points

In order to limit movement of the rock mass, it is crucial that the surface facing provides a high resistance with minimum deformation. The rigidity against deformation of the system is the resistance that is applied when a deforming action occurs perpendicular to the plane of the system.
HEA cable panels

HEA panels are made of twisted steel wire cables and high-resistance 3 mm wire “knots”, for which the following forces have been measured:
- resistance to tear and untwisting / unravelling
- resistance to the opening of one single mesh in static conditions
- deformation under static load
- stress dissipation to the frame and anchorage points

Comparison with the same measurements taken on traditional cable mesh panels connected with “studs” shows that Maccaferri HEA panels are more reliable, in terms of performance and quality.

With the knotted connection, when the limit resistance is overcome, the knot progressively unties itself until the breaking point is reached. However, with traditional stud connection systems, the connection fails suddenly when the resistance limit is exceeded. This produces immediate unravelling of the panel.

Knot resistance

<table>
<thead>
<tr>
<th>Type of knot</th>
<th>Resistance to tear (kN)</th>
<th>Resistance to untwisting (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEA Panel</td>
<td>24.4</td>
<td>11.9</td>
</tr>
<tr>
<td>High resistance stud</td>
<td>13.5</td>
<td>8.0</td>
</tr>
<tr>
<td>Low resistance stud</td>
<td>4.6</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Resistance to mesh opening

![Resistance to mesh opening graph]
Facing types

For slope reinforcement applications, a steel cable, or steel cable reinforced panel is a lot more effective than woven wire mesh alone, without taking into account the mechanical properties of the wire. (In any case, double-twist mesh has higher rigidity than single twist mesh, and is therefore more effective.)

Maccaferri therefore has developed Rock Mesh, a new double-twist woven mesh into which steel cables are woven.

The resulting product is midway between a cable-reinforced mesh and a cable-panel surface revetment. However, the great economic bonus of Rock Mesh comes from the fact that two different products can be installed at the same time (mesh and steel cables). The following graphs and pictures show how the cables woven into the mesh enable the facing to distribute strain to the outer frame and anchorage points.
Strain on anchorage points

Material Stiffness
Rockfall protection barriers and embankments

These passive systems are an ideal solution when it is not possible to intercept falling rocks or prevent them detaching, due to the whole slope being too large, or inaccessible.

These days, embankments are increasingly made with reinforced earth, enabling builders to use local material, reduce the footprint of the structure, and create a vegetated embankment face, which minimizes the system’s environmental impact.

Maccaferri Terramesh® solves many of these situations, in which system effectiveness goes hand-in-hand with rapid construction time. The double-twist mesh fascia unit and soil reinforcement structural element are pre-assembled during the manufacturing process, thereby dramatically reducing the number of operations to be performed on site.

Rockfall protection barriers are widely used, in different configurations according to the impact they have to withstand, to the location, and to the interaction with other containment and support structures, if present.
Variable geometry barriers are made of a complex system of metal cable and double-twist wire mesh panels for the containment of small boulders. The metal cables connect to structural elements, dissipation cables and anchorage lines with a high deformation capacity enabling the system to withstand great energy (normally in the range of 250-3000 kJ).

Maccaferri has developed a barrier system (OM 250 to OM 3000) covering a wide energy absorption spectrum. These systems were developed through the combination of planning and on-site tests, as required by the strictest regulations.