Design Theory for Secured Drapery

Ghislain Brunet (1)
Giorgio Giacchetti (2)

(1) Maccaferri USA
(2) Officine Maccaferri Italy
Which is the right kind of mesh?
Which is the cooperation between nails and mesh?
Which is the right density of nails?
If the target is missed then the intervention is ... 

NOT feasible and NOT safe for the contractor and the client
The superficial stability analysis is totally different for the rock than for the soil. This presentation is for the rock facing stability analysis.
The stresses on the system must be controlled looking for the equilibrium between the stabilizing contribution offered from the various components of the system. This happens changing

1) Spacing and resistance of the anchorings

2) Tensile strength and stiffness of the wire/cable mesh

It is evident that the mesh can cooperate with the anchorings only if reacts to the pressure with the minimum deformation (high stiffness).
The surface of the rock mass is a loose zone of a certain thickness. On this zone there are sets of joints dipping towards the slope which create unstable conditions.
MACRO 1 software is a simple design approach for secured drapery system, which combines the field experience of geologists and engineers on one hand, and the results of full scale drapery field tests on the other.

The calculation procedure allows for determining both the ultimate limit state (verification of breaking loads of the system components), and serviceability limit state (maximum permissible deformation of the facing).
Which is the calculation procedure for the nailing? … and for the facing?
Equilibrium Design Theory

F = Forces developed by the block sliding

T = Mesh tensile resistance from secured by the upper anchors

M = Punch resistance from the mesh under the block sliding
Case (1) **ACTIVE** systems:

The force $R_b$ acts before the driving forces overcome the resisting ones. $R_b$ acts against the driving forces:

$$Fs = \frac{\text{Resisting forces}}{\text{Driving Forces}} - R_b$$

Case (2) **PASSIVE** systems:

The force $R_b$ acts after the rock mass becomes unstable. $R_b$ acts with the resisting forces and not against the driving forces:

$$Fs = \frac{\text{Resisting Forces} + R_b}{\text{Driving forces}}$$
The meshes never lie in perfect contact on the ground surface
When using nails, pre-stressing down plate and mesh means short circuit strength below the plate.

No pressure is developed on sliding plane.
The meshes pushed down in the hollows can develop localized forces only (\( R \)).

The modulus of \( R \) is absolutely negligible.
On planar surfaces the meshes can develop tangential forces only.

That is why, even if the mesh is pre-tensioned, no one pressure acts on the ground.
Conceptual solution:

\[ \frac{\text{Stabilizing forces}}{\gamma_s} + R \geq \gamma_d \text{ Driving forces} \]

\[ \left( \frac{W \cdot \sin \beta \cdot (1 - c)}{\gamma_{RW}} + R \right) \geq \left( W \cdot \gamma_{DW} \cdot (\sin \beta + c \cdot \cos \beta) \right) \]
Load transfer

**WIRE MESH PANELS**

The load is transferred as per the mesh fabrication pattern to the closest anchorings.

**CABLE MESH PANELS**

The load is transferred to the anchorings along diagonal directions.
Border conditions

Wire mesh rolls:
- Important the connection along the longitudinal borders

Cable mesh panels: the load is transferred along the “diagonal directions” and the border cable doesn’t improve the system behaviors

Importance of the benefit offered from RockMesh HR provided with longitudinal cables
Testing is required to determine the behaviour of the mesh/panel with the action of the rocks.
Scale Tests

1.0 m

3.0 m

SCALE

LINKS
Assessing the rigidity of deformity products

**HEA Panel**
wire Ø10, Mesh 400x400

**RockMesh**
Mesh 8x10/Ø 3.00 Galfan

**Chain-Link**
wire A.R., Ø 3.00
Importance of full scale tests.

Comparison between Scale tests (1x1 m) and Real Scale tests (3x3 m).
Pont Bozet (AO – Italy) - mesh field test

Large scale tests 3 x 3 m - Sample restrained on 4 points
HEA Panel & DT mesh
Panel
HEA with Knots

Pont Bozet (AO)
Test 21/02/2007
HEA Panel 300/10
Behavior of the meshes

The importance of the test in the real size with real connections.

Comparison:
- Small size (1x1 m)
- Large Size (3x3 m) in Lab,
- Real Size (3x3 m) in situ
Tests have demonstrated that high stress is generated at anchor point and steel wire rope cable was the best solution for a strong connection.
Modeling of the forces at the mesh anchor point.

The highest stress is below the anchors which are stiff restrain. Between the anchors the stress is low even if the mesh has a high tensile resistance (i.e. 170 kN/m). Actually the tensile strength has no importance if the mesh is not stiff.
MACRO 1

a simple design approach for secured drapery
Data about global instability:
- Slope inclination
- Thickness of the superficial zone

Geotechnical data:
- Weight density of rock
- JRC most dangerous joint
- JCS most dangerous joint
- Seismicity

Data about local instability:
- Joint inclination

Type of anchors:
- Steel yield
- Diameter of the bar
- Anchor inclination

Dimension of volume to stabilized

Anchor check

Type of net

Yes

Net check

Yes

Increase anchors density

Increase mesh performances

Geotechnical model

Dimensions of volume to stabilized

Anchors density

Horizontal spacing
- Vertical spacing

Calculation of anchor length

FINE

Increase mesh performances
The surface instability is relates to external and weathered rock surfaces. The superficial instability doesn’t affect the overall stability of the slope.

Global Instability.

It needs a geomechanical survey
S = The average thickness of the loose rock mass

\[ \beta = \text{average inclination of slope surface} \]
Data about global instability:
- Slope inclination
- Thickness of the superficial zone

Geotechnical data:
- Weight density of rock
- JRC most dangerous joint
- JCS most dangerous joint
- Seismicity

Geotechnical model

Data about local instability:
- Joint inclination

Type of anchors:
- Steel yield
- Diameter of the bar
- Anchor inclination

Dimension of volume to stabilized:

Anchors density:
- Horizontal spacing
- Vertical spacing

Increase anchors density

Increase mesh performances

Calculation of anchor length

Type of net:
- Yes
- NO

Net check:
- Yes
- NO

Anchor check:
- NO
- Yes
Based on practical experiences, the surficial portion of the rock mass can be traced back.

A) Pseudo-continuous behavior: the surficial portion of the rock mass is highly divided. The wire mesh develops a relevant confinement action. The anchorings are only occasionally affected by shear stress.

B) Discontinuous behavior: the surficial portion of the soil mass is lightly divided. The wire mesh develops a local confinement action. Anchorings are frequently subjected to shear stress.
The importance of natural joints in the rock mass

JRC most dangerous joint
JCS most dangerous joint
**Compressive Strength (JCS)**

JCS is the Unconfined Compressive Strength of the most dangerous joint set. JCS is measured by Schmidt hammer. In a rough way we can take that: JCS = 1/3 UCS (Unconfined Compressive Strength).

JCS increases the resistance of the anchorage under shear stress. The software corrects the JCS in order to take into account the scale factor.

<table>
<thead>
<tr>
<th>Rock</th>
<th>Compressive Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cementing conglomerate</td>
<td>70 - 100</td>
</tr>
<tr>
<td>Cementing sandstone</td>
<td>75 - 160</td>
</tr>
<tr>
<td>Siltite</td>
<td>50 - 180</td>
</tr>
<tr>
<td>Mudstone</td>
<td>50 - 180</td>
</tr>
<tr>
<td>Sandstone</td>
<td>2 - 150</td>
</tr>
<tr>
<td>Marl – marlstone</td>
<td>25 - 90</td>
</tr>
<tr>
<td>Dolomite</td>
<td>60 - 300</td>
</tr>
<tr>
<td>Chalk</td>
<td>15 - 30</td>
</tr>
<tr>
<td>Granite</td>
<td>95 - 230</td>
</tr>
<tr>
<td>Porphyry</td>
<td>100 - 230</td>
</tr>
<tr>
<td>Dolerite</td>
<td>220 - 320</td>
</tr>
<tr>
<td>Tuff</td>
<td>3 - 100</td>
</tr>
<tr>
<td>Andesite</td>
<td>75 - 300</td>
</tr>
<tr>
<td>Basalt</td>
<td>100 - 350</td>
</tr>
<tr>
<td>Gneiss</td>
<td>80 - 160</td>
</tr>
<tr>
<td>Marble</td>
<td>60 - 230</td>
</tr>
<tr>
<td>Serpentine</td>
<td>20 - 130</td>
</tr>
<tr>
<td>Phyllite</td>
<td>20 - 80</td>
</tr>
</tbody>
</table>

**Compressive Strength (Minimum value) =**

![Map of joint sets and rock mass](image)
Roughness

Roughness of the Most Dangerous Joint set is measured by Barton "comb". Its value range is between 0 (smooth) to 20 (very rough joint). If the joint is weathered or clay covered, it's better to take low values of Roughness.

Roughness increases the resistance of the anchorage under shear stress.

<table>
<thead>
<tr>
<th>Profile</th>
<th>Roughness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 - 2</td>
</tr>
<tr>
<td></td>
<td>2 - 4</td>
</tr>
<tr>
<td></td>
<td>4 - 6</td>
</tr>
<tr>
<td></td>
<td>6 - 8</td>
</tr>
<tr>
<td></td>
<td>8 - 10</td>
</tr>
<tr>
<td></td>
<td>10 - 12</td>
</tr>
<tr>
<td></td>
<td>12 - 14</td>
</tr>
<tr>
<td></td>
<td>14 - 16</td>
</tr>
<tr>
<td></td>
<td>16 - 18</td>
</tr>
<tr>
<td></td>
<td>18 - 20</td>
</tr>
</tbody>
</table>

Roughness = 0.1

Ok
Data about global instability:
- Slope inclination
- Thickness of the superficial zone

Geotechnical data:
- Weight density of rock
- JRC most dangerous joint
- JCS most dangerous joint
- Seismicity

Data about local instability:
- Joint inclination

Type of anchors:
- Steel yield
- Diameter of the bar
- Anchor inclination

Geotechnical model:

Dimension of volume to stabilized:

Anchors density:
- Horizontal spacing
- Vertical spacing

Increase anchors density:

Increase mesh performances:

Calculation of anchor length:

Net check:
- Yes
- NO

Type of net:
- Yes
- NO

Fine:

Anchor check:
- NO
- Yes

NO
$\alpha = \text{Angle of the most unfavorable joint}$
Data about global instability:
- Slope inclination
- Thickness of the superficial zone

Geotechnical data:
- Weight density of rock
- JRC most dangerous joint
- JCS most dangerous joint
- Seismicity

Data about local instability:
- Joint inclination

Type of anchors:
- Steel yield
- Diameter of the bar
- Anchor inclination

Geotechnical model:

Dimension of volume to stabilized

Anchors density:
- Horizontal spacing
- Vertical spacing

Calculation of anchor length

Type of net:
- Yes
- No

Net check:
- Yes
- No

Increase anchors density

Increase mesh performances

FINE

Joint inclination
Nominal diameter of the anchorage bar.

Type of the bar with yield strength
Bar subjected to pure traction (case “b”): the joint dilatancy does not affect the resistance contribution due to the bar.

Bar subjected to pure shear (case “e”): the greater the joint dilatancy, the higher the resistance contribution of the bar.
Data about global instability:
- Slope inclination
- Thickness of the superficial zone

Geotechnical data:
- Weight density of rock
- JRC most dangerous joint
- JCS most dangerous joint
- Seismicity

Data about local instability:
- Joint inclination

Geotechnical model:

Type of anchors:
- Steel yield
- Diameter of the bar
- Anchor inclination

Dimension of volume to stabilized:

Anchors density:
- Horizontal spacing
- Vertical spacing

Calculation of anchor length:

Type of net:
- Yes
- No

Anchor check:
- No

Net check:
- Yes
- No

Increase anchors density:

Increase mesh performances:
Spacing horizontal ix between the anchorages.

It is better than ix doesn’t differ too much from iy.

Vertical spacing iy between the anchorages.

It is better than iy doesn’t differ too much from ix.
Data about global instability:
- Slope inclination
- Thickness of the superficial zone

Geotechnical data
- Weight density of rock
- JRC most dangerous joint
- JCS most dangerous joint
- Seismicity

Geotechnical model

Data about local instability
- Joint inclination

Type of anchors
- Steel yield
- Diameter of the bar
- Anchor inclination

Dimension of volume to stabilized

Anchors density
- Horizontal spacing
- Vertical spacing

Increase anchors density

Increase mesh performances

Type of net
- NO
- Yes

Calculation of anchor length

NO

Anchor check

FINE

Net check

Increase mesh performances

Calculation of anchor length
Mesh DT PVC 8x10 / 2.7 mm
Mesh DT 8x10 / 3.00 mm
RockMesh HR 30
RockMesh B600
RockMesh B900
HEA panel 300 mm / 10 mm
HEA panel 400 mm / 10 mm
HEA panel 300 mm / 8 mm
The acceptable maximum bulging must be assumed taking into account of maintenance problems & geotechnical conditions.
Conceptual solution:

\[
\text{Stabilizing forces} + R > \frac{\text{Driving forces}}{\gamma_s}
\]

\[
((W \cdot \sin \beta \cdot (1 - c) / \gamma_{RW} + R) \geq (W \cdot \gamma_{DW} \cdot (\sin \beta + c \cdot \cos \beta))
\]

- Weight
- Slide surface inclination
- Seismic coefficient
- Safety coefficient for stabilizing forces
- Stabilizing contribution (nails or mesh)
- Safety coefficient for driving forces
Design Calculation

\[ \gamma_{RW} = \gamma_{THI} \gamma_{WG} \gamma_{BH} \]

uncertainties while determining the surficial instability thickness \( s \); 1.20 – 1.30

uncertainties in the unitary weight; 1.00 - 1.05

uncertainties related to the rock mass weathering and erodibility; 1.00 - 1.05

(For stabilizing forces)

\[ \gamma_{DW} = \gamma_{MO} \gamma_{OL} \]

uncertainties related to the slope morphology 1.10 - 1.30

uncertainties related overload applied on the facing system 1.00 - 1.20

(For driving forces)
MACRO 1 Reinforced System
Rock and Soil Slope Protection Design Software

Project Information

<table>
<thead>
<tr>
<th>Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number</th>
<th>Client</th>
<th>Designer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Input

Rock Slope

<table>
<thead>
<tr>
<th>Slope inclination [°]</th>
<th>65</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope total height [m]</td>
<td></td>
</tr>
<tr>
<td>Thickness of the surfiical instability [m]</td>
<td>0.5</td>
</tr>
<tr>
<td>Density of the rock mass [kN/m³]</td>
<td>27</td>
</tr>
<tr>
<td>Assumed length of plastification in the unstable rock mass [m]</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Most Dangerous Joint

<table>
<thead>
<tr>
<th>Inclination [°]</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength [MPa]</td>
<td>10</td>
</tr>
<tr>
<td>Roughness</td>
<td></td>
</tr>
</tbody>
</table>

Seismic Acceleration

<table>
<thead>
<tr>
<th>Horizontal seismic coefficient</th>
<th>0.14</th>
</tr>
</thead>
</table>

Mesh

<table>
<thead>
<tr>
<th>Mesh Type</th>
<th>DT 8 x 10 Ø 2.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesh ultimate tensile resistance [kN/m²]</td>
<td>60</td>
</tr>
<tr>
<td>Maximum displacement acceptable [m]</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Anchor Bars

Geometry

| Horizontal anchor spacing [m] | 3 |
| Vertical anchor spacing [m] | 3 |
| Indication of bar to the horizontal [°] | 10 |

Anchor Type

<table>
<thead>
<tr>
<th>Bar Type</th>
<th>bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bar internal diameter [mm]</td>
<td>0</td>
</tr>
<tr>
<td>Bar external diameter [mm]</td>
<td>16</td>
</tr>
<tr>
<td>Thickness of corrosion crown [mm]</td>
<td>0</td>
</tr>
<tr>
<td>Bar yield stress (of steel) [MPa]</td>
<td>500</td>
</tr>
<tr>
<td>Rock-grout adhesion (bond stress) [MPa]</td>
<td>2.25</td>
</tr>
</tbody>
</table>

Safety Factor

Factors affecting the stabilizing forces

| Uncertainty of the thickness of surfiical instability | 1.2 |
| Uncertainty of the rock mass unit weight | 1.01 |
| Uncertainty of rock behavior and weathering | 1.02 |
| Control: Safety factor to reduce stabilizing forces | 1.24 |

Factors affecting the driving forces

| Slope surface morphology | 1.1 |
| External loads | 1.02 |
| Safety coefficient to increase the driving forces | 1.12 |
| Global factor applied to the geomechanical model | 1.39 |

Mesh

| Safety reduction for mesh resistance | 2.5 |
| Safety reduction for maximum displacement | 2 |

Anchor type

| Safety reduction for steel resistance | 1.16 |
| Safety reduction for rock-grout adhesion | 2 |
**MACRO 1 Reinforced System**

**Rock and Soil Slope Protection Design Software**

---

### Results

<table>
<thead>
<tr>
<th>Bar design check</th>
<th>Mesh design check</th>
<th>Serviability design check</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1.01</strong> Satisfied</td>
<td><strong>1.61</strong> Satisfied</td>
<td><strong>1.20</strong> Satisfied</td>
</tr>
</tbody>
</table>

#### Bar design

- Stabilizing forces (kN) 132.36
- Sliding plane driving force (kN) 131.30
- Ratio strength stress 1.01

#### Mesh design

- Maximum tensile force in the cable (kN) 24.00
- Maximum tensile stress within the mesh (kN) 14.88
- Force-strength ratio 1.01

#### Serviability

- Potential unstable volume on joint - case A (m³/m) 0.00
- Potential unstable volume on joint - case B (m³/m) 2.00
- Maximum rock vol that can slide between anchors (m³/m) 0.15
- Maximum rock weight that can slide between anch [kN/m] 36.46

#### Features of the instability

- Sum of the driving forces acting on the sliding plane (kN/m) 22.45
- Sum of stabilizing forces acting on the sliding plane (kN/m) 10.59
- Prying forces acting on the mesh (kN/m) 2.07
- Favorable deformation angle from horizontal [%] 9.46

#### Serviability

- Stabilizing forces (kN) 0.30
- Sliding plane driving force [kN] 0.25
- Ratio strength stress 1.20

### Geometry

- **Nails Design**

- **Instability Model**

---

MACRO Studio beta | Copyright © Maccaferri 2011-2012 | v8.20.01 | 2012.12.10 | Notice: Maccaferri is not responsible for the drawings and the calculations transmitted, since these should be intended as general design outlines and advice, serving only for the best use of the products.
Which is the calculation procedure for the nailing? … and for the facing?

Secured drapery

DT mesh 2.7

10 ft

10 ft

5 ft

3/4 inch bar grade 75
Even if the software allows a quick and simple calculation approach, onsite observations are always recommended to achieve a good design, with the ultimate goal of protecting property and the public.