Design of simple drapery systems to guide the rock falls along the slope
Simple drapery with the mesh opened at the bottom
Simple drapery with the mesh fixed at the bottom
Main questions:
- Which is the calculation procedure for the top supporting system: cable and anchors?
- … and for the facing?

Simple Drapery

Mesh facing + anchors at the top (bottom) + upper longitudinal cable

Goal:
- Drive the unstable block at the toe of the slope
- Reduce the velocity and the energy of the blocks

Main questions:
- Which is the calculation procedure for the top supporting system: cable and anchors?
- … and for the facing?
To verify:

1. Mesh resistance
2. Top cable resistance under mesh load
3. Intermediate anchors resistance
4. Lateral anchors resistance
Mesh Design

The simple drapery system is a passive system capable to contain the debris at the bottom of the slope. It has to be designed by taking into account all the weights able to transmit a stress on the mesh per linear meter:

1. The **proper weight of the chosen mesh**
2. The **weight of the debris accumulated at the toe of the mesh**
3. **External weight like the snow** or ice accumulation on the drapery

These three loads may be described by the following formulas, based on the researched of the U.S. Department of Transportation FHA.
Step 1: Mesh design

Design principle

\[ \text{Mesh}_{\text{tensile resistance}} \geq \text{Load}_{\text{debris}} + \text{Load}_{\text{snow}} + \text{Weight}_{\text{mesh}} \]

Security factors: reduction of resistance forces, increase of destabilizing forces.

Total load due to the mesh ($W_m$)

\[ W_m = \gamma_m H_s / \sin\beta (\sin\beta - \cos\beta \tan\delta) \ g \]

Where:

- $\gamma_m =$ steel mesh unit weight [ML$^{-3}$]
- $H_s =$ total height of the slope [L]
- $\beta =$ inclination of the slope [deg]
- $\delta =$ friction angle between mesh and slope [deg]
- $g =$ acceleration of gravity [LT$^{-2}$]
Total stress transmitted from the debris to the mesh ($W_d$)

$$W_d = \frac{1}{2} \gamma_d H_d^2 (1/\tan B_d - 1/\tan \beta) (\sin \beta - \cos \beta \tan \varphi_d) \ g$$

Where:

- $\gamma_d = \text{debris unit weight \ [ML^{-3}]}$
- $H_d = \text{debris accumulation height \ [L]}$
- $\varphi_d = \text{debris friction angle \ [deg]}$
- $B_d = \text{debris external inclination value (Muhunthan equation) \ [deg]}: = \arctan[H_d / (T_d + H_d / \tan \beta)]$
- $T_d = \text{debris accumulation width \ [L]}$
Total stress transmitted from the external loads (i.e. snow) ($W_s$)

\[ W_s = \gamma_s \, t_s \, H_s / \sin\beta \, (\sin\beta - \cos\beta \, \tan\varphi_s) \, g \]

Where:
- $\gamma_s$ = snow unit weight [ML$^{-3}$]
- $t_s$ = snow thickness [L]
- $\varphi_s$ = friction angle between soil and snow [deg]
SIMPLE DRAPERY - FORCES

Under load (weight, debris, snow)
The top horizontal rope is uniformly loaded
The wire mesh is uniformly tensioned

1 – Theoretical case
2 – Mesh weight
3 – weight of the debris

Reaction of the top cable
Forces loading the mesh
Tensile Strength

1- Fixed Frame
2- Moving Beam
3- Free Lateral Constrain
4- Side Beam
Tensile Strength
# Tensile Strength - HEA Panel 300 mm with 8 mm Wire Rope

<table>
<thead>
<tr>
<th>Sample Code</th>
<th>Tensile Force (kN)</th>
<th>Displacement (mm)</th>
<th>Side Reaction to Tensile Force (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Local Cell 25</td>
</tr>
<tr>
<td>HEA 300 F8 (P1)</td>
<td>261.6</td>
<td>113</td>
<td>62.7</td>
</tr>
<tr>
<td>HEA 300 F8 (P2)</td>
<td>264.1</td>
<td>123</td>
<td>65.5</td>
</tr>
<tr>
<td>HEA 300 F8 (P3)</td>
<td>266.8</td>
<td>121</td>
<td>65.4</td>
</tr>
<tr>
<td>Average</td>
<td>264.2</td>
<td>119</td>
<td>65.6</td>
</tr>
</tbody>
</table>
The inclusion of vertical ropes in addition to a top horizontal rope reduces the stress concentration on the mesh, as well as along the top horizontal rope only if they are woven in the mesh and not applied on the mesh at the job site (*)

(*) ANALYSIS AND DESIGN OF WIRE MESH/CABLE NET SLOPE Department of Transportation - U.S. Department of Transportation - Federal Highway Administration - April 2005
RockMesh does not strain due to its weight
Deformations due to the debris loads are localized
RockMesh transfers forces from the mesh to the edge ropes
- The edge ropes transfer forces on top anchors
- The horizontal top cable is only partially loaded
- The wire mesh is only partially loaded on top
RockMesh transfers forces from the mesh to the steel ropes:
- The ropes transfer forces on top anchors.
- The horizontal top cable is only partially loaded.
- The wire mesh is only partially loaded on top.

1 – Theoretical case
2 – Mesh weight
3 – Weight of debris

Reaction of the top cable
Forces loading the mesh
Reaction forces of the Rockmesh edge ropes
MACRO 2 Software:

The calculation is done using the Limit State Design (LSD) approach. This method provides margin of safety, against attaining the limit state of collapse by introducing some safety factors:

- Partial Factors: resisting forces are decreased to produce the design strength (Rd);
- Load factors: permanent and variable loads are increased to produce the design load acting on the system (Ed).

The equation at the base of the LSD calculation method is described with the following formula:
Mesh Design

Resisting force: design tensile strength of the mesh

\[ SF_{mesh} = \frac{R_m}{S_w} \geq 1.0 \]

\[ R_m = \frac{T_m}{\gamma_{mts}} \]

Ultimate tensile strength of the mesh (laboratory test)

Safety coefficient on the resisting forces (suggested > 2.0)

Acting force: design total stress on the mesh

Total load due to the snow

\[ S_W = (W_d + W_s)\gamma_{vl} + W_m\gamma_{pl} \]

Safety coefficient for the permanent load (suggested 1.3)

Safety coefficient for the variable load (suggested 1.5)

Total load due to the debris accumulation at the top

Total load due to the mesh
<table>
<thead>
<tr>
<th>Partial/Load Factor</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>γ_T</td>
<td>If the superficial instability thickness is defined by:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- geomechanical survey:</td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td>- rough/visual estimation:</td>
<td>1.30</td>
</tr>
<tr>
<td>γ_W</td>
<td>If the rock unit weight is:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- homogeneous:</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>- not-homogeneous (i.e. flysch):</td>
<td>1.05</td>
</tr>
<tr>
<td>γ_B</td>
<td>If the rock:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- does not present any anomalous behavior:</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>- is subjected to erosion and/or environmental condition that can create weakness of the rock mass:</td>
<td>1.05</td>
</tr>
<tr>
<td>γ_Mo</td>
<td>If the morphology of the rock is:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- regular (the mesh lies in better contact with the slope, thus the rock movement are limited):</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>- rough (the mesh cannot be in adherence with the slope, thus the unstable block can easily move):</td>
<td>1.30</td>
</tr>
<tr>
<td>γ_OL</td>
<td>If there are/are not external loads acting on the system:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- not significant loads are applied:</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>- additional external loads are applied (i.e. snow, ice, vegetation, etc.):</td>
<td>1.20</td>
</tr>
</tbody>
</table>

Suggested values for the partial and load factors
Cable Design

- **Sw/2**
- **Sw/2**
- **Sw**
- **Fcbl**

**Anchor distance**

Rope deformation

**FS_{cbl} = \frac{T_{cbl}}{\gamma_{cbl}} \geq 1.0**

Ultimate tensile strength of the cable divided by a safety coefficient (suggested 1.5)

Maximum tensile strength acting on the cable (Catenary theory, function of Sw)
Anchors design (1):

1. anchor diameter

\[ FS_{\text{anchor}(j)} = \frac{S_{\text{bar}(j)}}{N(j)} \geq 1.0 \]

- Working shear resistance of the anchor \((j)\)
- Force acting on the anchor \((j)\), developed by the mesh and the cable (catenary solution)
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.
Anchors design (2):

2. anchor length

\[ L_{anchor(j)} = L_{s(j)} + L_p \]

Minimum foundation length: calculated with Bustamante-Doix ( \( L_s = P / (\pi \phi_{drill} \frac{\tau_{lim}}{\gamma_t}) \))

Length of hole with plasticity phenomena in firm part of the rock mass (generally 30-50 cm)

NOTE: the final suitable length of the anchor has to be evaluated during the drilling in order to verify the exact nature of the soil and confirmed with pull-out tests.
Anchors are frequently enough to the lateral and intermediate stability.

Lateral steel cables are often required for high slope without significant friction.
Peerless Park, Missouri
Upper Section
### Upper slope Input data

#### Input

**Rock Slope**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope inclination [°]</td>
<td>B</td>
</tr>
<tr>
<td>Slope total height [m]</td>
<td>Hs</td>
</tr>
<tr>
<td>Debris accumulation height [m]</td>
<td>Hd</td>
</tr>
<tr>
<td>Debris accumulation width [m]</td>
<td>Td</td>
</tr>
<tr>
<td>Debris accumulation angle [°]</td>
<td>Bd</td>
</tr>
<tr>
<td>Debris friction angle [°]</td>
<td></td>
</tr>
<tr>
<td>Debris unit weight [kN/m³]</td>
<td></td>
</tr>
<tr>
<td>Friction angle between mesh and slope [°]</td>
<td></td>
</tr>
</tbody>
</table>

**Snow**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snow unit weight [kN/m³]</td>
<td></td>
</tr>
<tr>
<td>Snow thickness [m]</td>
<td></td>
</tr>
</tbody>
</table>

**Mesh**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesh type</td>
<td>8X10 Ø 3.0</td>
</tr>
<tr>
<td>Tensile resistance [kN/m]</td>
<td></td>
</tr>
<tr>
<td>Steel mesh unit weight [Kg/m²]</td>
<td></td>
</tr>
</tbody>
</table>
### Upper slope Input data

#### Crest Rope + Crest Anchorages

<table>
<thead>
<tr>
<th>Layout of crest rope installation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal anchor spacing [m]</td>
</tr>
<tr>
<td>Vertical offset between crest anchors [m]</td>
</tr>
</tbody>
</table>

#### Crest Rope Specification

<table>
<thead>
<tr>
<th>Rope diameter [mm]</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rope steel grade [MPa]</td>
<td>1770</td>
</tr>
<tr>
<td>Rope core type</td>
<td>Steel</td>
</tr>
<tr>
<td>Rope ultimate tensile strength [kN]</td>
<td>252</td>
</tr>
</tbody>
</table>

#### Crest Anchor Specification

<table>
<thead>
<tr>
<th>Bar type</th>
<th>Continuous threaded standard yield bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchor internal diameter (where hollow) [mm]</td>
<td>0</td>
</tr>
<tr>
<td>Anchor external diameter [mm]</td>
<td>25.0</td>
</tr>
<tr>
<td>Thickness of corrosion crown [mm]</td>
<td>0</td>
</tr>
<tr>
<td>Anchor yield stress (of steel) [MPa]</td>
<td>500</td>
</tr>
<tr>
<td>Rock-grout adhesion (bond stress) [MPa]</td>
<td>1.00</td>
</tr>
</tbody>
</table>

#### Safety Coefficients

**Rock Slope**
- Safety coefficient for variable loads (snow or debris) | 1.50 |
- Safety coefficient for permanent loads                  | 1.00 |

**Mesh**
- Safety reduction for mesh resistance                    | 1.50 |

**Geometry of the top longitudinal cable**
- Safety reduction on X spacing                           | 1.10 |
- Safety reduction on Y vertical gradient                 | 1.05 |

**Cable type**
- Safety reduction for cable resistance                   | 1.50 |

**Anchor type**
- Coefficient for the steel bar yield stress              | 1.00 |
- Coefficient for rock-grout adhesion (bound stress)      | 1.30 |
## Results

### Mesh capacity check

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mesh design</strong></td>
<td><strong>Crest Rope check</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Intermediate anchor check</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Lateral anchor check</strong></td>
</tr>
<tr>
<td><strong>Mesh capacity check</strong></td>
<td><strong>Satisfied</strong></td>
</tr>
<tr>
<td><strong>Mesh capacity check</strong></td>
<td><strong>Satisfied</strong></td>
</tr>
</tbody>
</table>

### Mesh design

- **Design total stress [kN/m]**: 8.61
- **Admissible tensile resistance [kN/m]**: 43.33
- **Ratio strength stress**: 5.03
- **Debris total load [kN/m]**: 5.63
- **Snow total load [kN/m]**: 0.00
- **Mesh total load [kN/m]**: 0.16
- **Resultant stress on the drapery [kN/m]**: 5.79

### Intermediate anchorages design

- **Maximum force on the intermediate anchorages [kN]**: 47.13
- **Working shear resistance [kN]**: 141.70
- **Shear resistance [kN]**: 3.01

### Top anchorages

- **Maximum force on the lateral anchorages [kN]**: 86.72
- **Working shear resistance [kN]**: 141.70
- **Shear resistance ratio**: 1.63

### Anchors maximum debris weight [kN/m]

- **Minimum required tensile strength of cable anchors [kN]**: 86.72
- **Minimum drilling diameter [mm]**: 40.00
- **Minimum total bar length [m]**: 0.90

### Maximum force on the intermediate anchorages [kN]

- **Maximum force on the lateral anchorages [kN]**: 86.72
- **Maximum admitted distance between anchorages [m]**: 8.03
- **Length of the rope (total) between anchorages [m]**: 8.13
- **Maximum sag between adjacent anchorages [m]**: 0.56
- **Cable maximum debris weight [kN/m]**: 39.71

### Maximum volume

- **1.67 m³ per m (59 ft³)**

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- **Minimum Pullout was 19.3 Kips**
- **Anchors were ¾ Wire rope cable 52 kips**
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.
It is always better to design the System!!