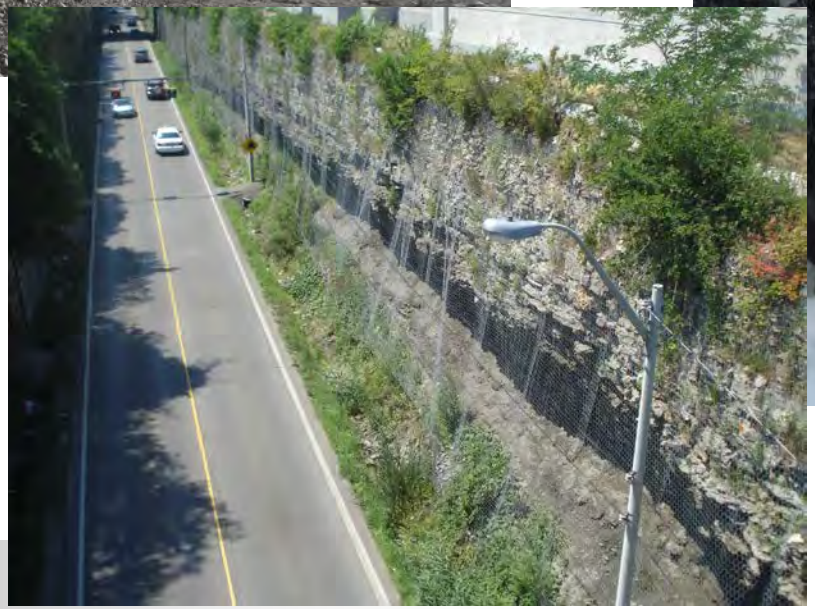
MACCAFERRI

Design of simple drapery systems to guide the rock falls along the slope

Maccaferri Industrial Group

MACCAFERRI

Simple drapery with the mesh opened at the bottom



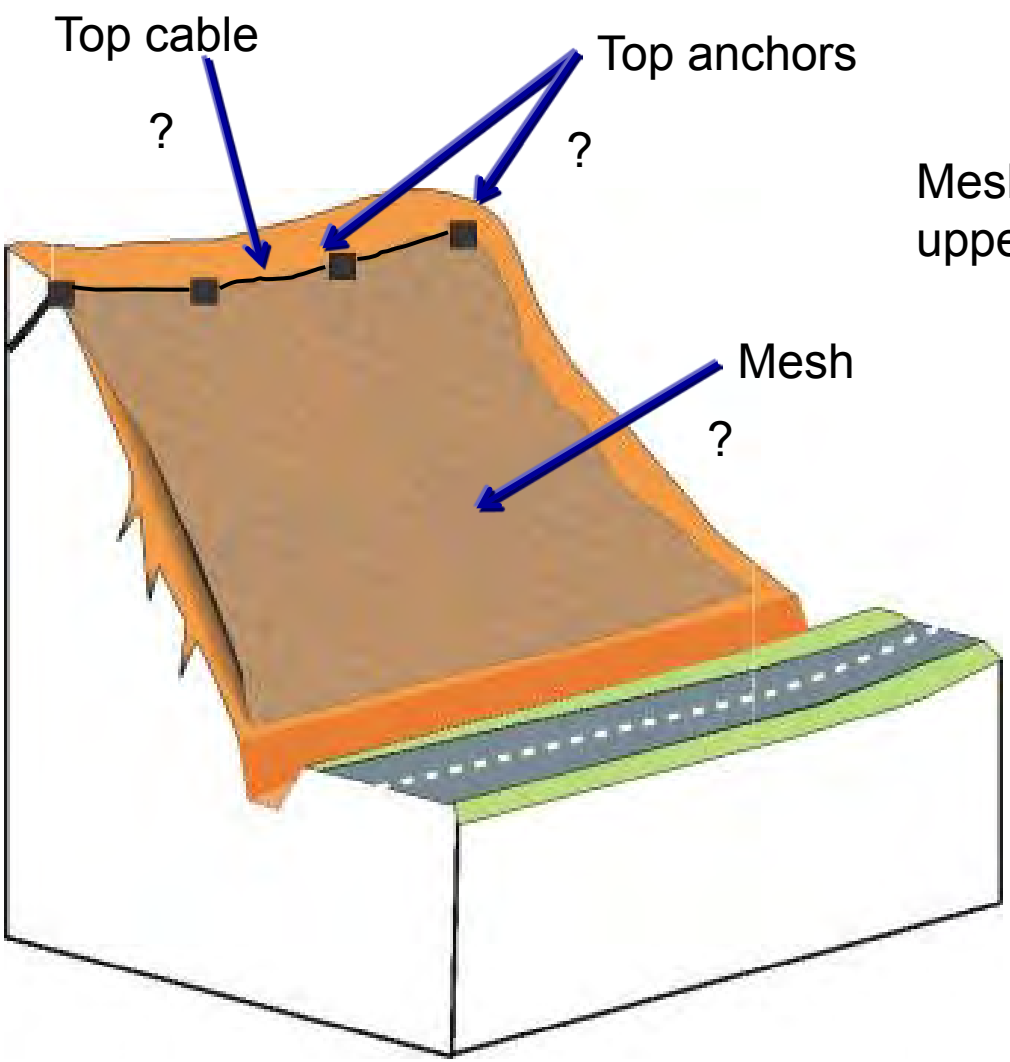
Maccaferri Industrial Group

MACCAFERRI

Simple drapery with the mesh fixed at the bottom

Maccaferri Industrial Group

MACCAFERRI



Simple Drapery

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

Goal:

- Drive the instable block at the toe of the slope
- Reduce the velocity and the energy of the blocks

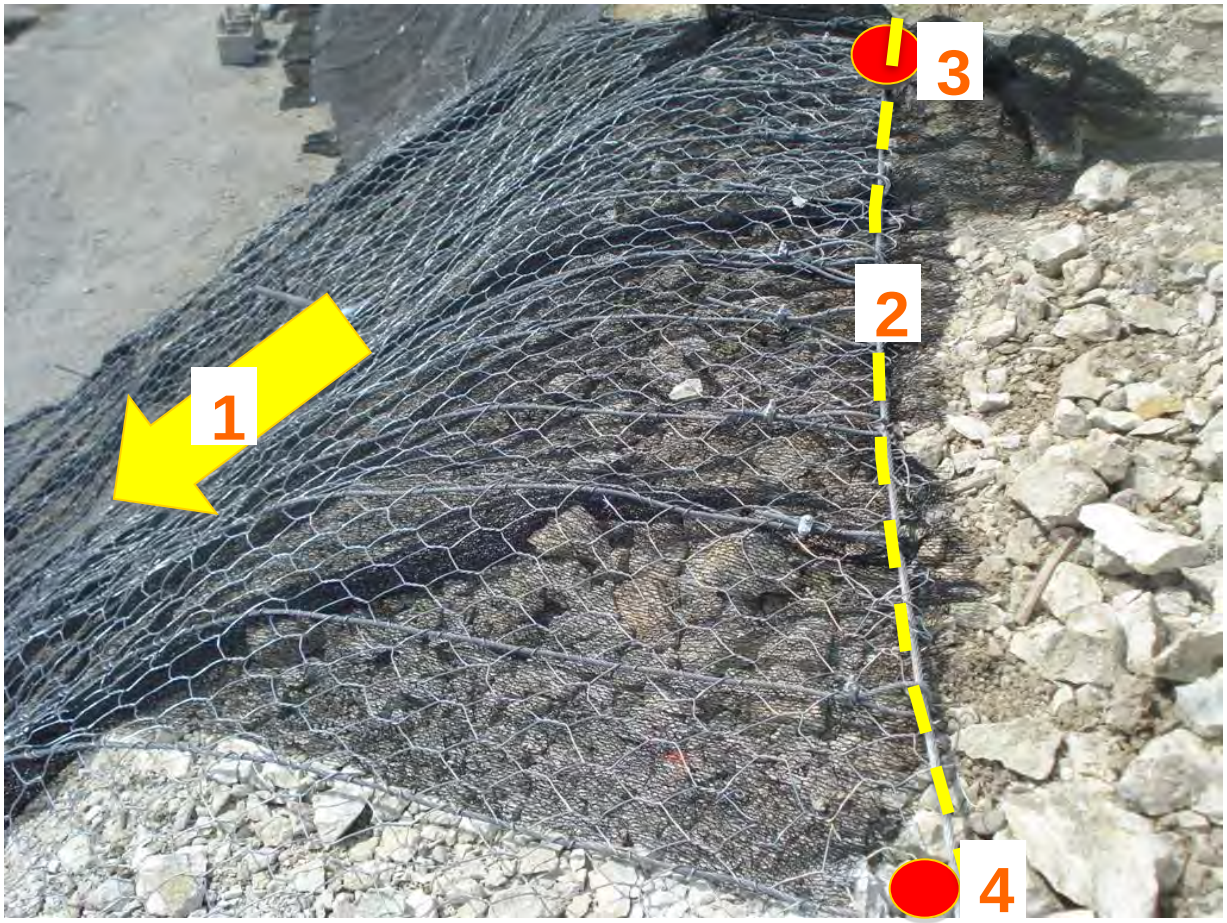
Main questions:

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

Simple drapery design

To verify:

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



MACCAFERRI

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

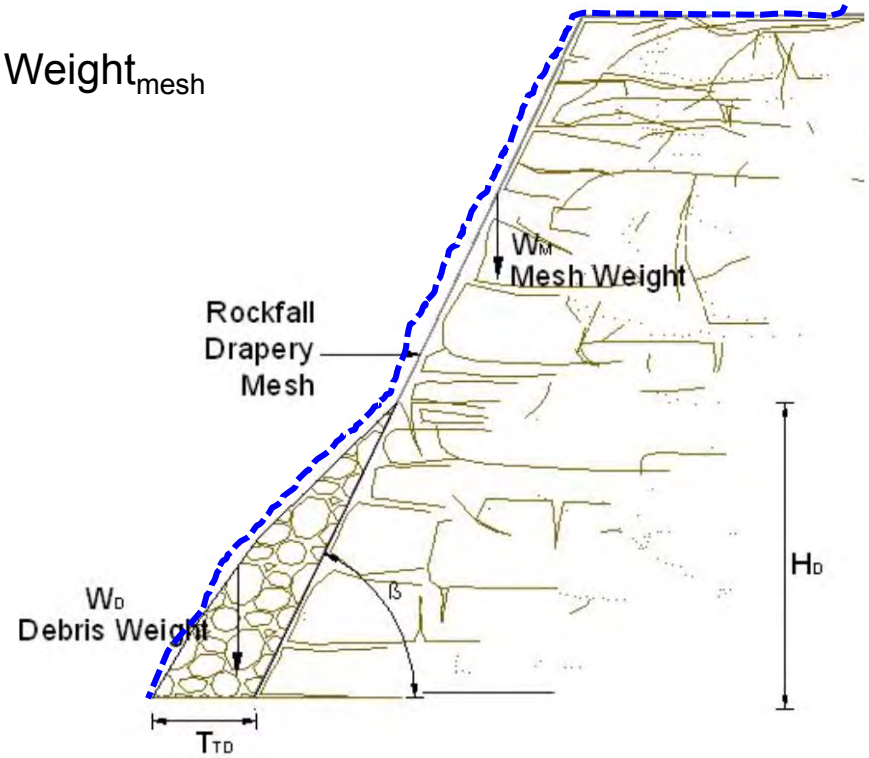
These three loads may be described by the following formulas, based on the researched of the U.S. Department of Transportation FHA.

Step 1: Mesh design

Design principle[1]

$$Mesh_{tensile\ resistance} \geq Load_{debris} + Load_{snow} + Weight_{mesh}$$

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



(1) Muhunthan B., Shu S., Sasiharan N., Hattamleh O.A., Badger T.C., Lowell S.M., Duffy J.D. (2005). "Analysis and design of wire mesh/cable net slope protection - Final Research Report WA-RD 612.1" Washington State Transportation Commission - Department of Transportation/U.S. Department of Transportation Federal Highway Administration.

MACCAFERRI

Total load due to the mesh (W_m)

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

Where:

- γ_m = steel mesh unit weight [ML^{-3}]
- H_s =total height of the slope [L]
- β = inclination of the slope [deg]
- δ = friction angle between mesh and slope [deg]
- g = acceleration of gravity [LT^{-2}]

MACCAFERRI

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:

- γ_d = debris unit weight [ML^{-3}]
- H_d =debris accumulation height [L]
- φ_d = debris friction angle [deg]
- B_d = debris external inclination value (Muhunthan equation) [deg]: = $\arctan[H_d / (T_d + H_d / \tan\beta)]$
- T_d = debris accumulation width [L]

MACCAFERRI

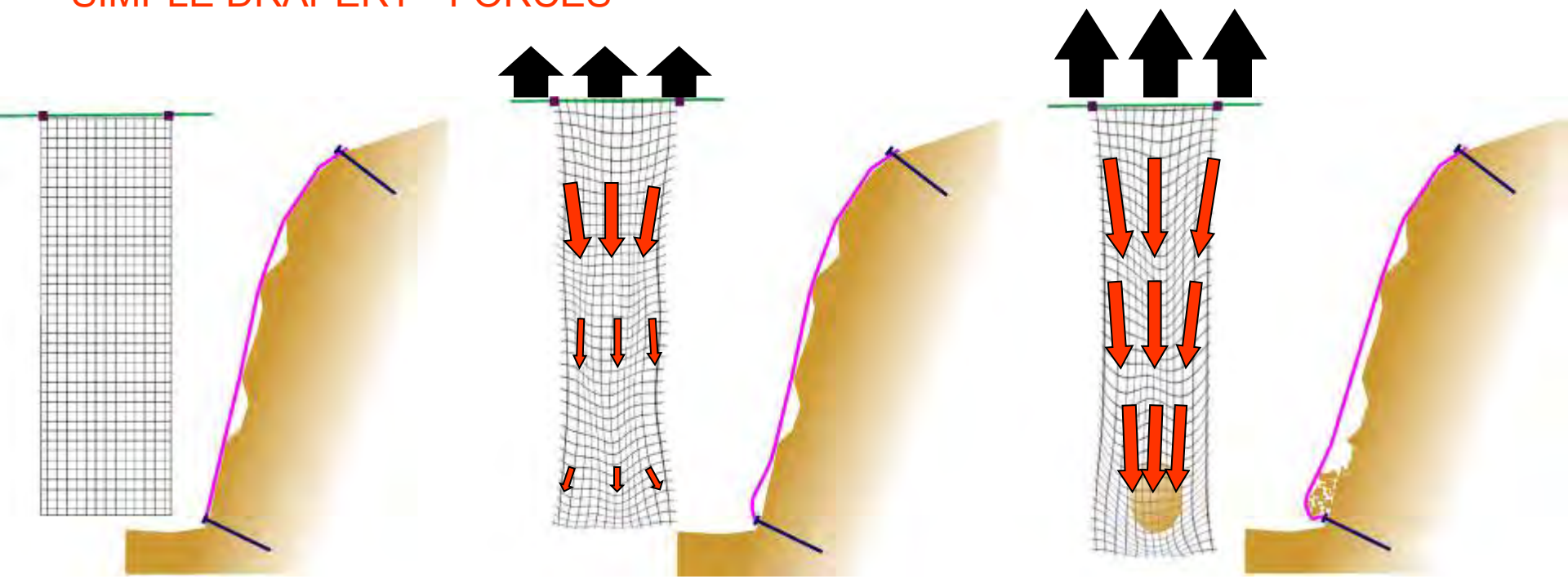
Total stress transmitted from the external loads (i.e. snow) (W_s)

$$W_s = \gamma_s \, t_s \, Hs \, / \, \sin\beta \, (\sin\beta - \cos\beta \, \tan\varphi_s) \, g$$

Where:

- γ_s = snow unit weight [ML^{-3}]
- t_s = snow thickness [L]
- φ_s = friction angle between soil and snow [deg]

SIMPLE DRAPERY - FORCES



1 – Theoretical case

2 – Mesh weight

3 – weight of the debris

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

Reaction of the top cable

Forces loading the mesh

MACCAFERRI

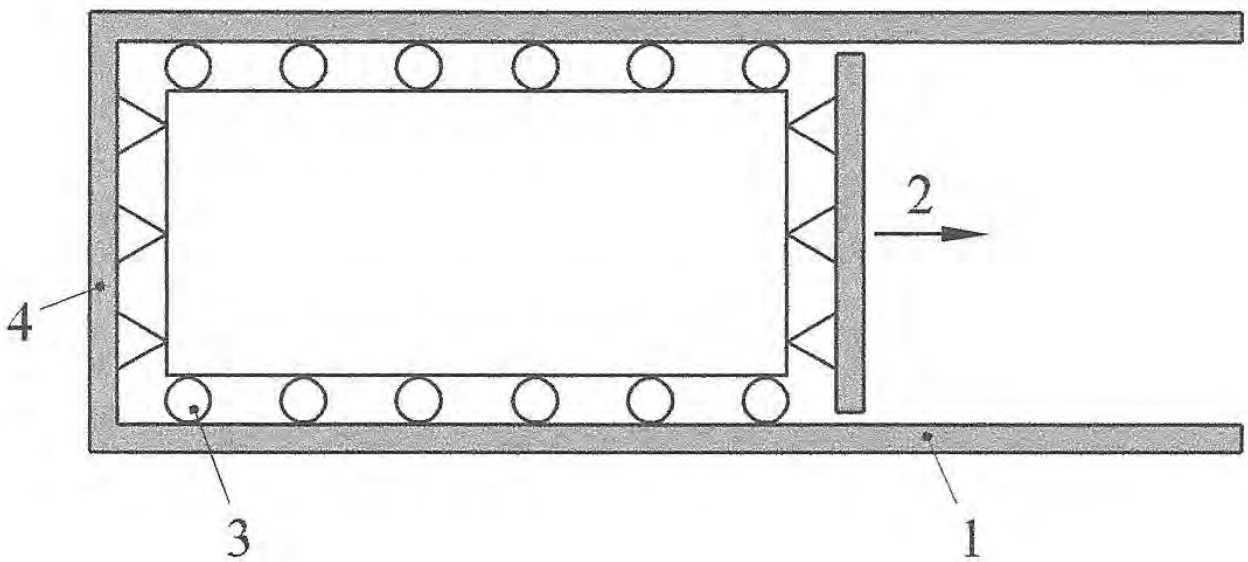
Tensile Strength

1- Fixed Frame

2- Moving Beam

3- Free Lateral Constrain

4- Side Beam



MACCAFERRI

Tensile Strength

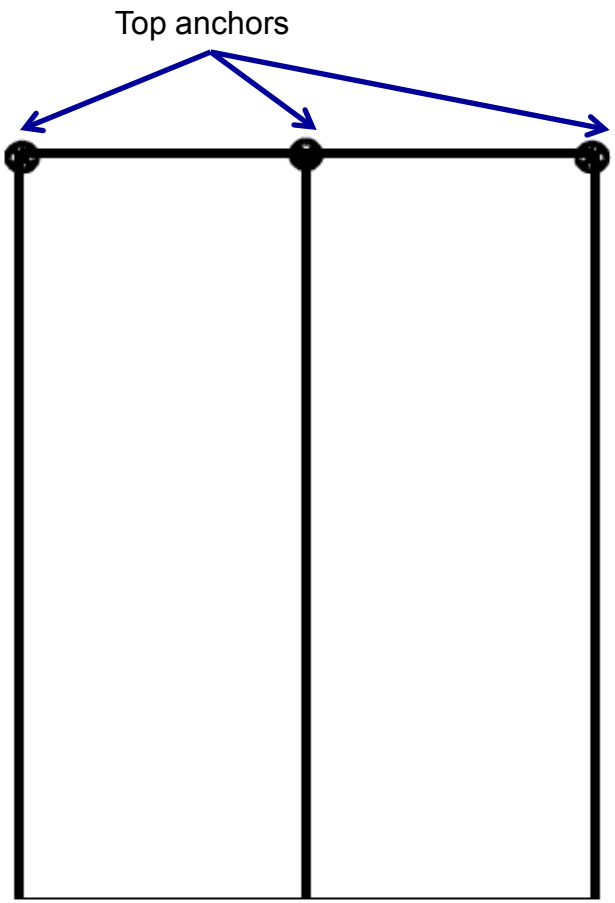
Maccaferri Industrial Group

MACCAFERRI

Tensile Strength - HEA Panel 300 mm with 8 mm Wire Rope

Sample Code	Tensile Force (kN)	Displacement (mm)	Side Reaction to Tensile Force (kN)			
			Local Cell 25	Local Cell 26	Local Cell 27	Local Cell 28
HEA 300 F8 (P1)	261.6	113	62.7	65.5	69.2	50.1
HEA 300 F8 (P2)	264.1	123	65.5	60.9	71.5	66.0
HEA 300 F8 (P3)	266.8	121	65.4	65.9	71.8	65.7
Average	264.2	119	65.6	64.1	70.8	60.6

MACCAFERRI



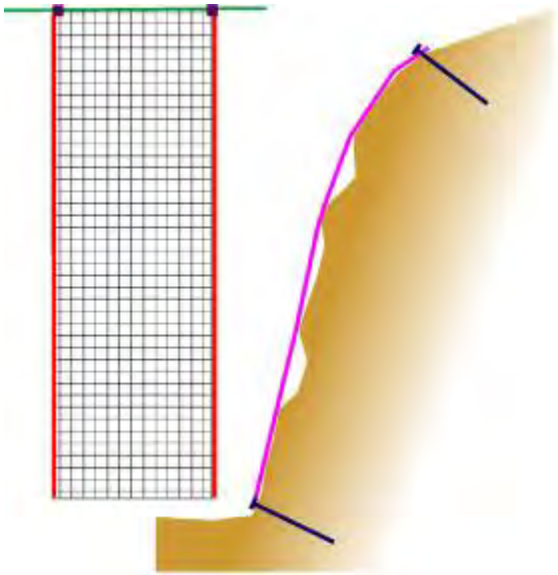
Mesh stress in the drapery with interwoven cables

Loading capacity without deformation

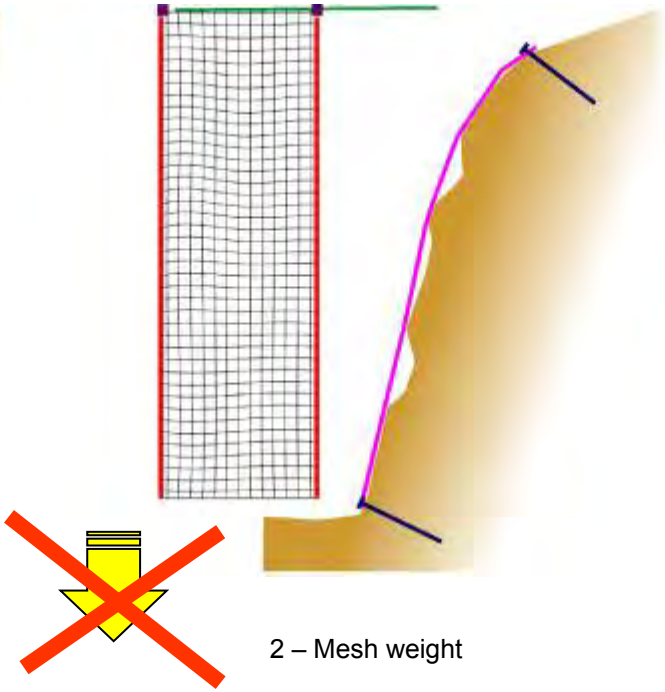
The inclusion of vertical ropes in addition to a top horizontal rope **reduces the stress concentration on the mesh**, as well as along the top horizontal rope **only if they are woven in the mesh and not applied on the mesh at the job site** (*)

(*) ANALYSIS AND DESIGN OF WIRE MESH/CABLE NET SLOPE Department of Transportation - U.S. Department of Transportation - Federal Highway Administration - April 2005

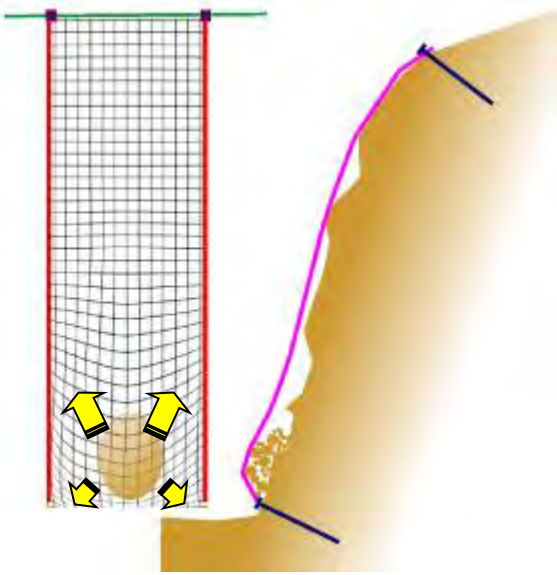
Steelgrid MO 400 - DEFORMATION



1 – Theoretical case



2 – Mesh weight

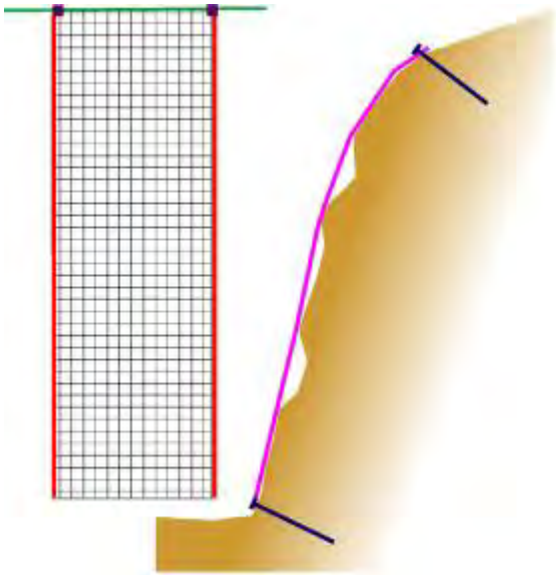


3 – Weight of debris

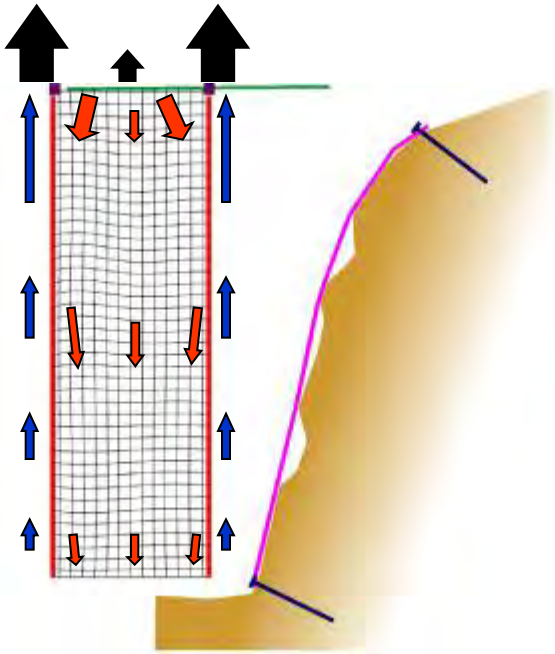
RockMesh does not strain due to its weight
Deformations due to the debris loads are localized

MACCAFERRI

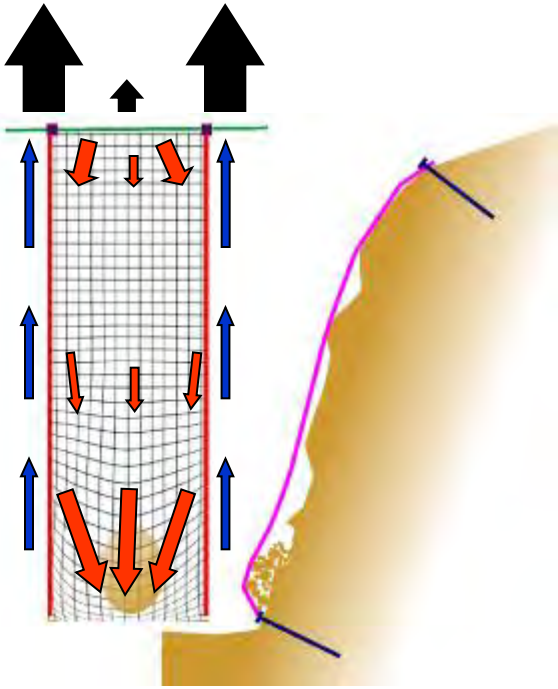
Steelgrid MO 400 - FORCES



1 – Theoretical case



2 – Mesh weight



3 – Weight of debris

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

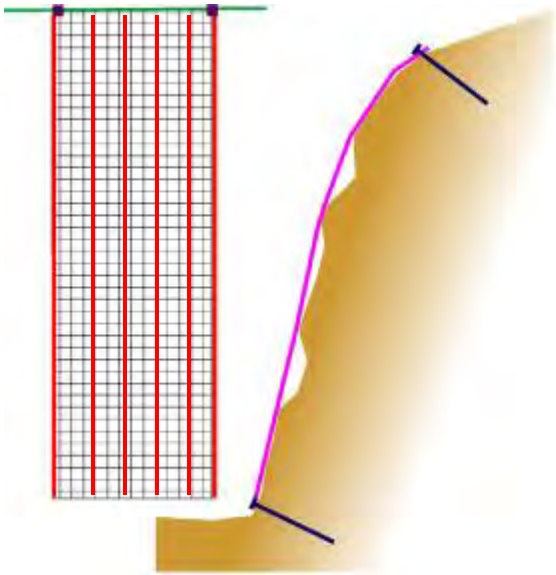
Reaction of the top cable

Forces loading the mesh

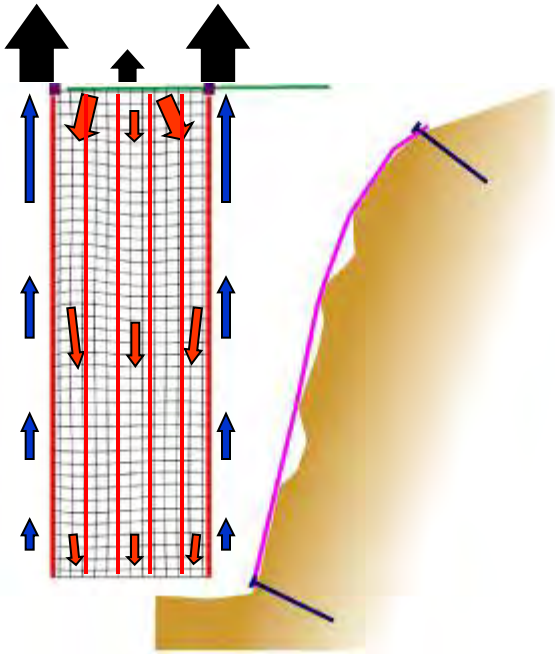
Reaction forces of the SteelGrid edge ropes

MACCAFERRI

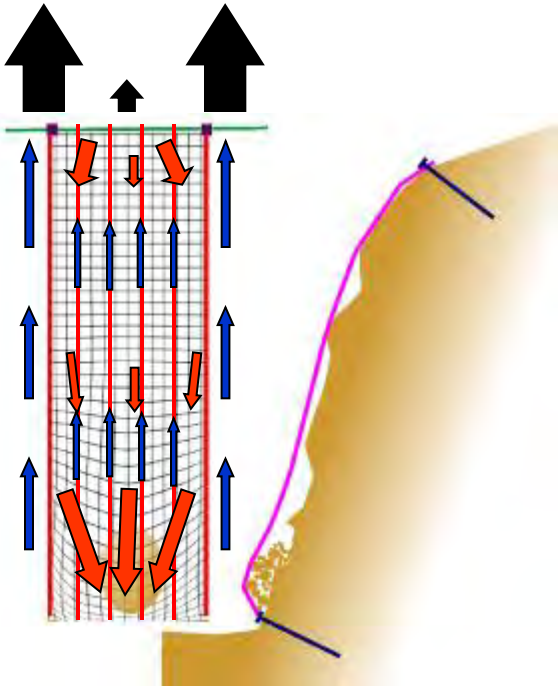
Steelgrid HR50 - FORCES



1 – Theoretical case



2 – Mesh weight



3 – Weight of debris

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

Reaction of the top cable

Forces loading the mesh

Reaction forces of the Rockmesh edge ropes

MACCAFERRI

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:

MACCAFERRI

Mesh Design

Resisting force: design tensile strength of the mesh

$$R_m = \frac{T_m}{\gamma_{mts}}$$

T_m: Ultimate tensile strength of the mesh (laboratory test)

γ_{mts}: Safety coefficient on the resisting forces (suggested > 2.0)

$$SF_{mesh} = \frac{R_m}{S_w} \geq 1.0$$

Acting force: design total stress on the mesh

$$S_w = (W_d + W_s)\gamma_{vl} + W_m \gamma_{pl}$$

W_s: Total load due to the snow

W_d: Total load due to the debris accumulation at the top

γ_{vl}: Safety coefficient for the variable load (suggested 1.5)

W_m: Total load due to the mesh

γ_{pl}: Safety coefficient for the permanent load (suggested 1.3)

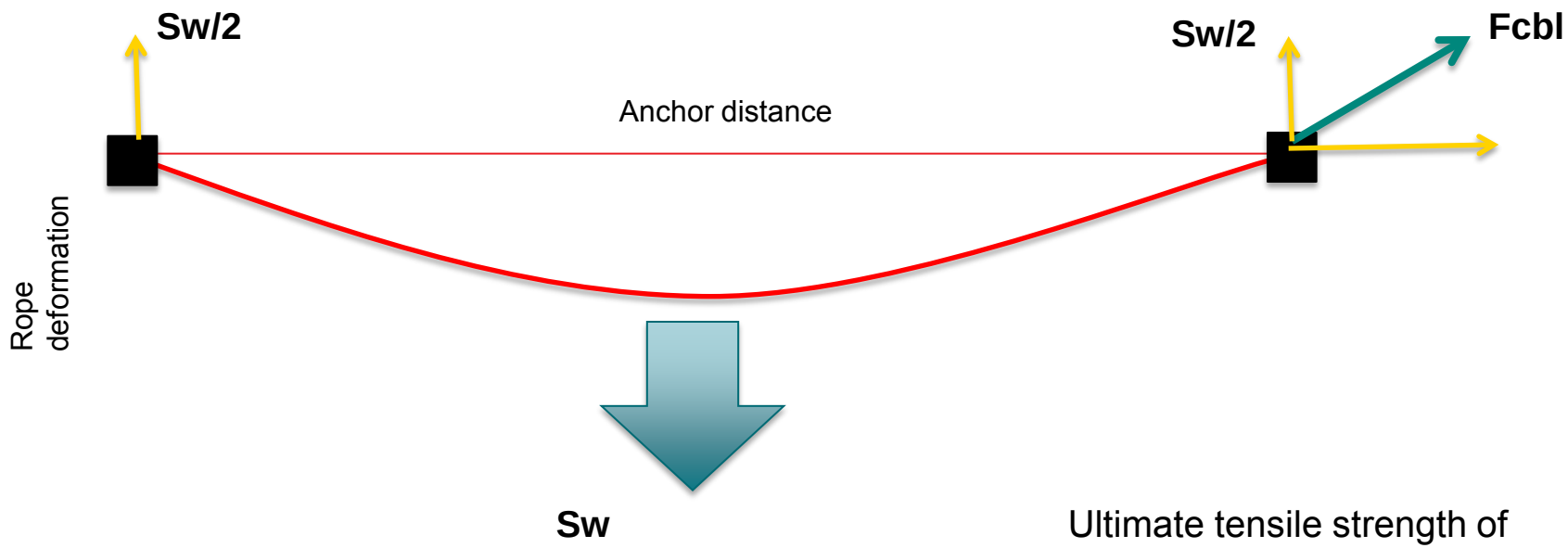
Maccaferri Industrial Group

MACCAFERRI

Suggested values for the partial and load factors

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

Cable Design



$$FS_{cbl} = \frac{T_{cbl}/\gamma_{cbl}}{F_{cbl}} \geq 1.0$$

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)

MACCAFERRI

Anchors design (1):

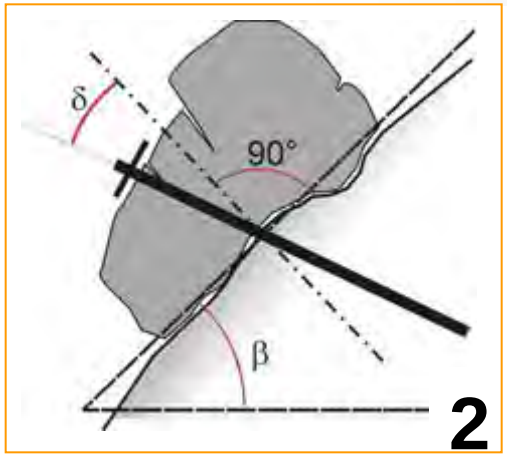
Working shear resistance of the anchor (j)

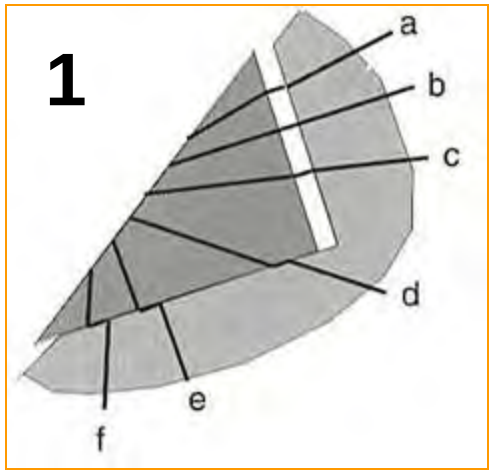
1. anchor diameter

$$FS_{anchor(j)} = \frac{S_{bar(j)}}{N_{(j)}} \geq 1.0$$

Force acting on the anchor (j), developed by the mesh and the cable (catenary solution)

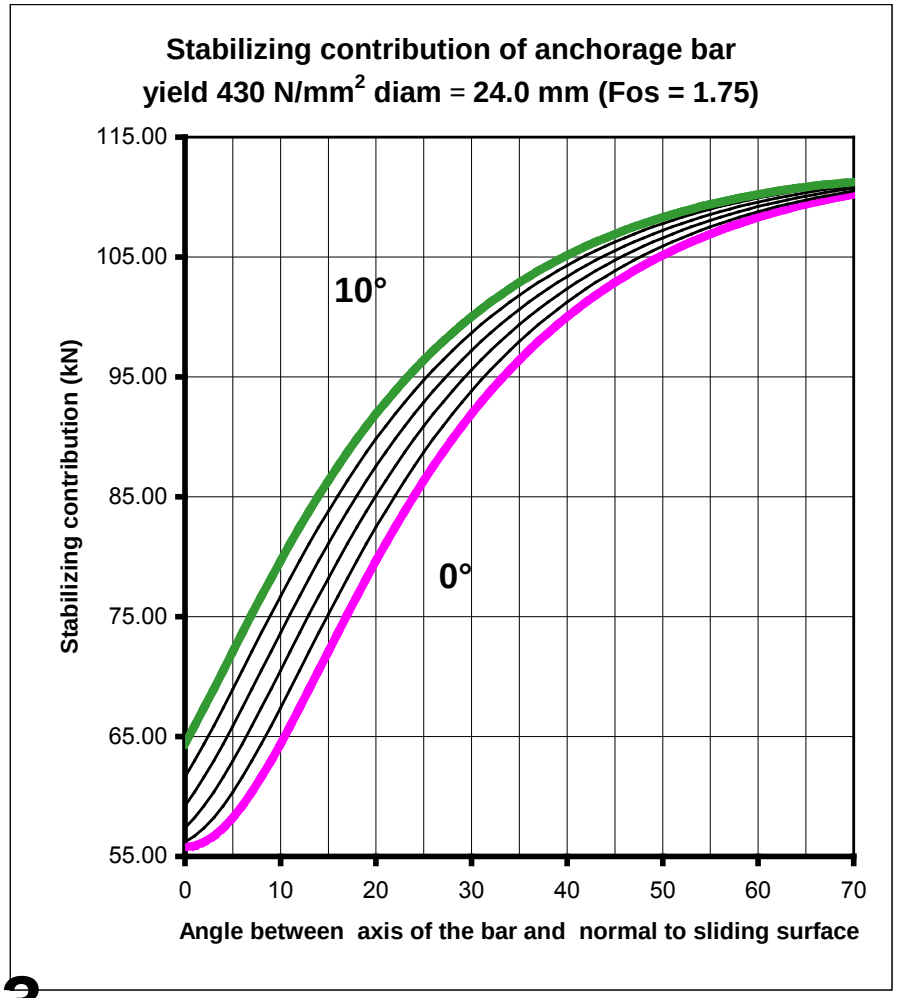
MACCAFERRI





Bar subjected to pure traction (case “b”): the joint dilatency 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.



MACCAFERRI

Anchors design (2):

2. anchor length

Minimum foundation length : calculated with Bustamante-Doix ($Ls = P / (\pi\ \phi_{drill}\ \ \tau_{lim} / \gamma_{gt})$)

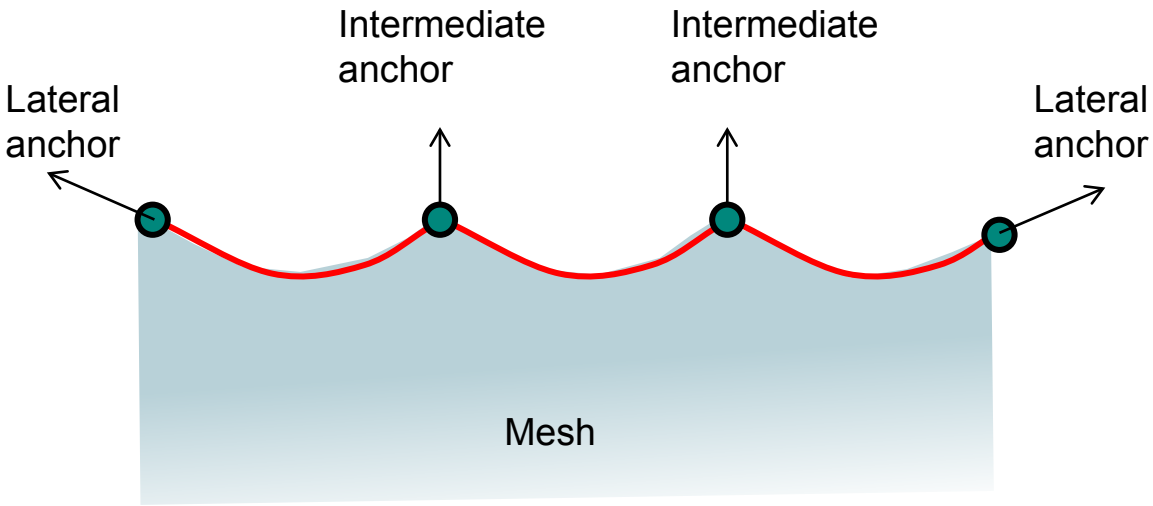
$$L_{anchor(j)} = Ls_{(j)} + Lp$$

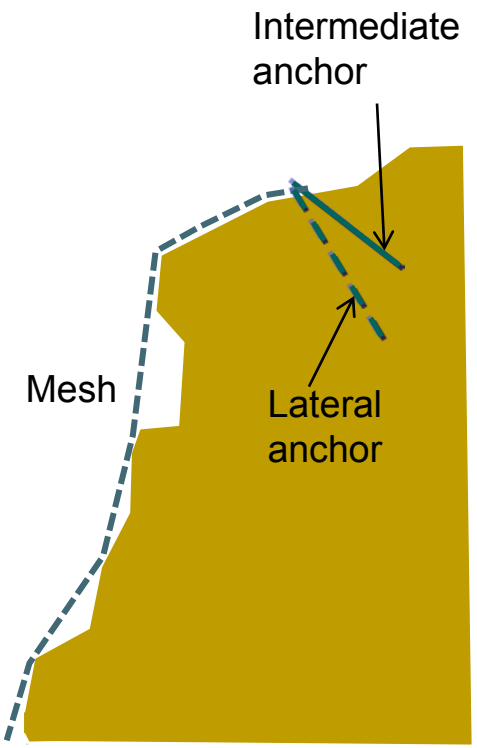
Length of hole with plasticity phenomena in firm part of the rock mass (generally 30-50 cm)

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.

MACCAFERRI

Superior structural system geometry





Anchors are frequently enough to the lateral and intermediate stability

Lateral steel cables are often required for high slope without significant friction

MACCAFERRI

Peerless Park, Missouri

MACCAFERRI

Upper Section

MACCAFERRI

Upper slope Input data

Input

Rock Slope

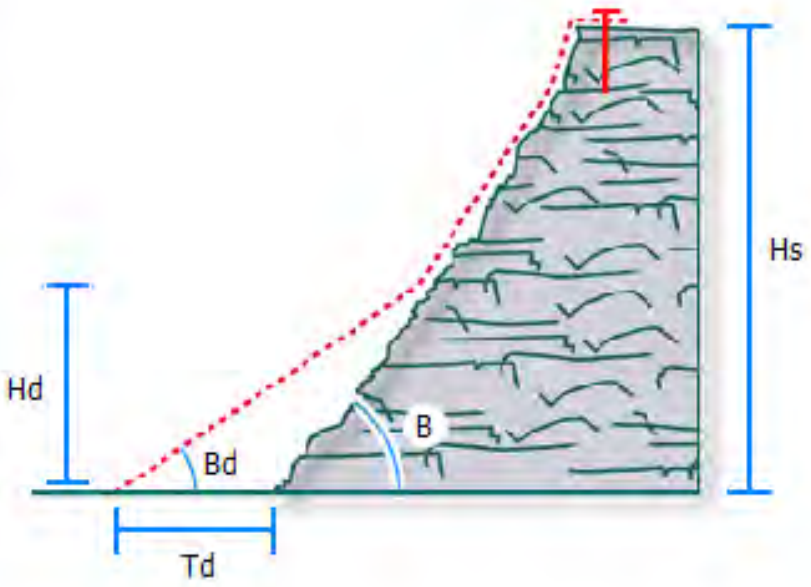
Slope inclination [º]	B	80
Slope total height [m]	Hs	10.00
Debris accumulation height [m]	Hd	1.00
Debris accumulation width [m]	Td	0.60
Debris accumulation angle [º]	Bd	52.18
Debris friction angle [º]		15.00
Debris unit weight [kN/m³]		20.00
Friction angle between mesh and slope [º]		18.00

Snow

Snow unit weight [kN/m³]	4
Snow thickness [m]	0

Mesh

Mesh type	**8X10 Ø 3.0**
Tensile resistance [kN/m]	65.00
Steel mesh unit weight [Kg/m²]	1.78



MACCAFERRI

Upper slope Input data

Crest Rope + Crest Anchorages

Layout of crest rope installation

Horizontal anchor spacing [m]	7.30
Vertical offset between crest anchors [m]	0.00

Crest Rope Specification

Rope diameter [mm]	**20**
Rope steel grade [MPa]	1770
Rope core type	Steel
Rope ultimate tensile strength [kN]	252

Crest Anchor Specification

Bar type	**Continuous threaded standard yield bar**
Anchor internal diameter (where hollow) [mm]	0
Anchor external diameter [mm]	25.0
Thickness of corrosion crown [mm]	0
Anchor yield stress (of steel) [MPa]	500
Rock-grout adhesion (bond stress) [MPa]	1.00

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	Crest Rope check	Intermediate anchor check	Lateral anchor check
5.03 Satisfied	1.94 Satisfied	3.01 Satisfied	1.63 Satisfied

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
Mesh	03.45

Maximum volume 1.67 m3 per m (59 ft3)

Cab

Maxin	86.72
Cable	68.00
Cable load force ratio	1.94

Maximum force on the intermediate anchorages [kN]	47.13
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

Top anchorages

Intermediate anchorages design

Maximum force on the intermediate anchorages [kN]	47.13
Working	141.70
Shear	3.01

Minimum Pullout was 19.3 Kips

Late

Maximum force on the lateral anchorages [kN]	86.72
Working shear resistance [kN]	141.70
Shear resistance ratio	1.63
Working section of steel [mm²]	490.87
Working tensile resistance of the anchorages [kN]	245.44
Minimum required tensile strength of cable anchors [kN]	86.72
Minimum drilling diameter [mm]	40.00
Minimum total bar length [m]	0.90
Anchors maximum debris weight [kN/m]	33.47

Maxim

Maximum a	7
Maximum a	1.67

Anchors were ¾ Wire rope cable 52 kips

Maccaferri Industrial Group

MACCAFERRI

CONCLUSION:

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.

MACCAFERRI

It is always better to design the System!!

Maccaferri Industrial Group