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Design Theory for Secured Drapery

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(2) Officine Maccaferri Italy

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Which is the right kind of mesh?

Which is the cooperation between nails and mesh?

Which is the right density of nails?

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Top Wire Rope Cable

Cable Anchor

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If the target is missed then the intervention is …

NOT feasible and

NOT safe

for the contractor and the client

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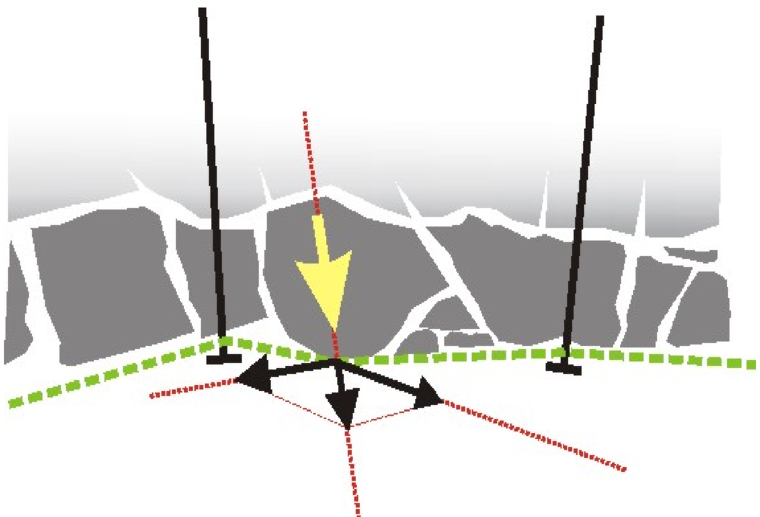
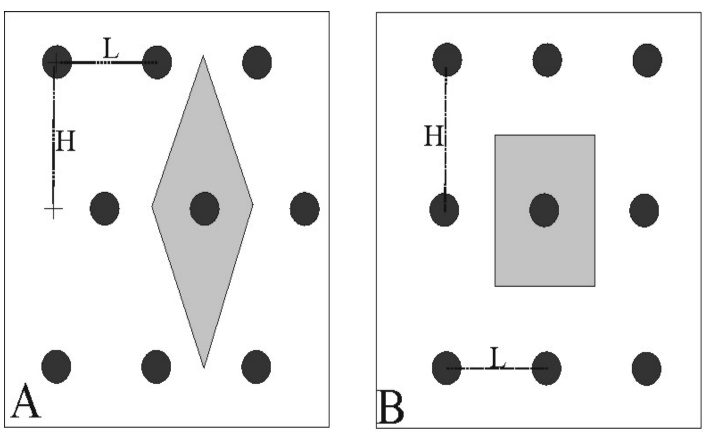
The superficial stability analysis is totally different for the rock than for the soil. This presentation is for the rock facing stability analysis.





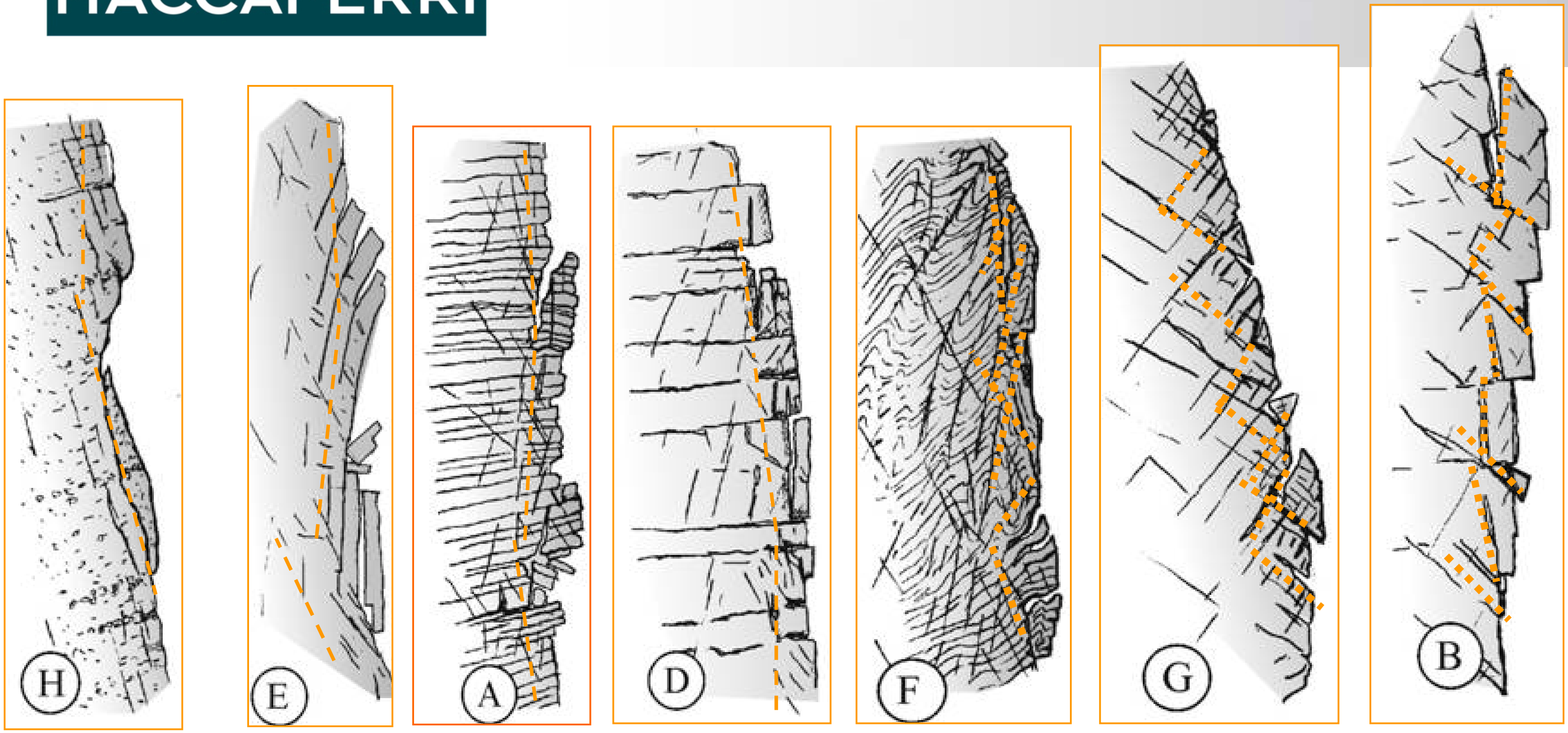
The stresses on the system must be controlled looking for the equilibrium between the stabilizing contribution offered from the various components of the system. This happens changing

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).



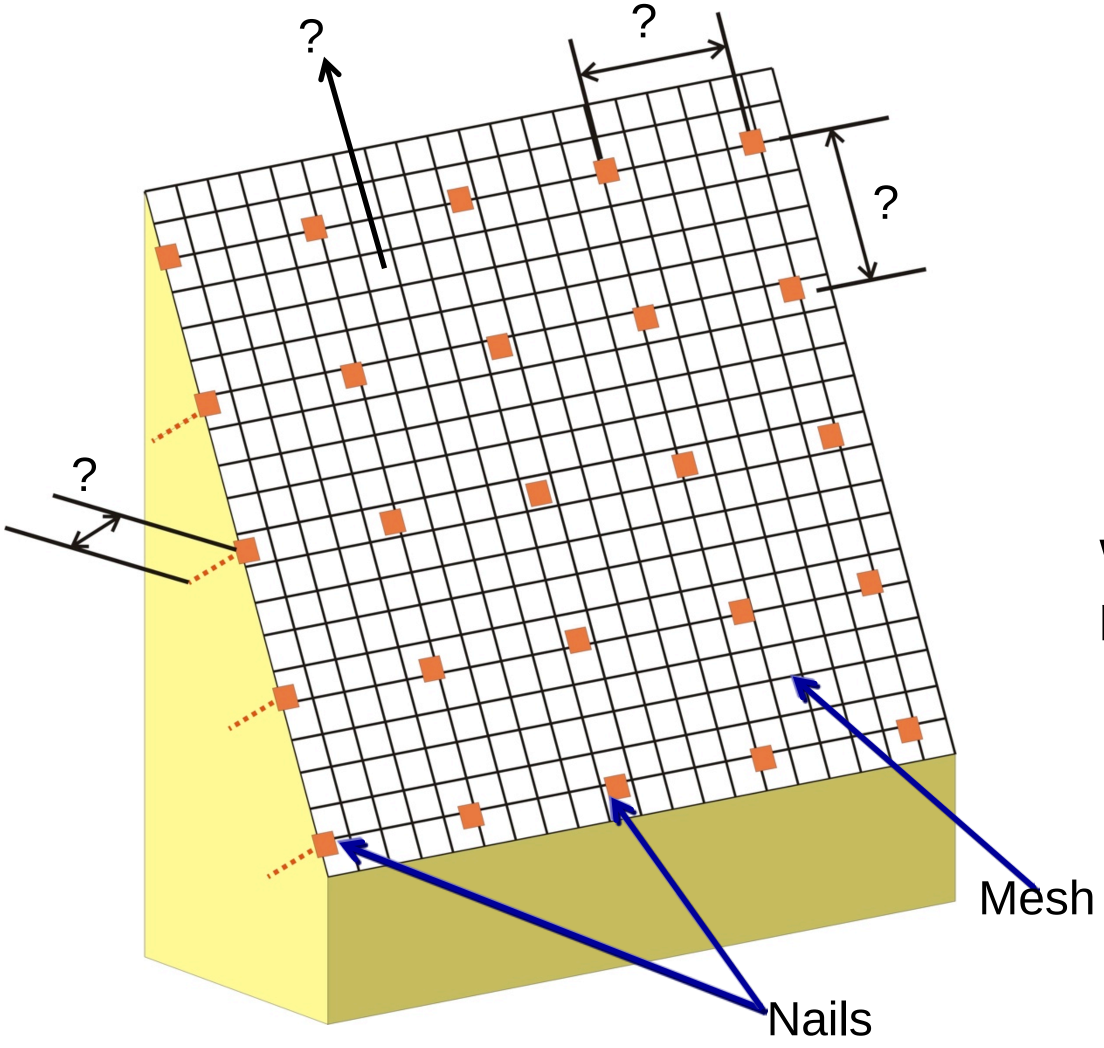
The surface of the rock mass is a loose zone of a certain thickness.

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).

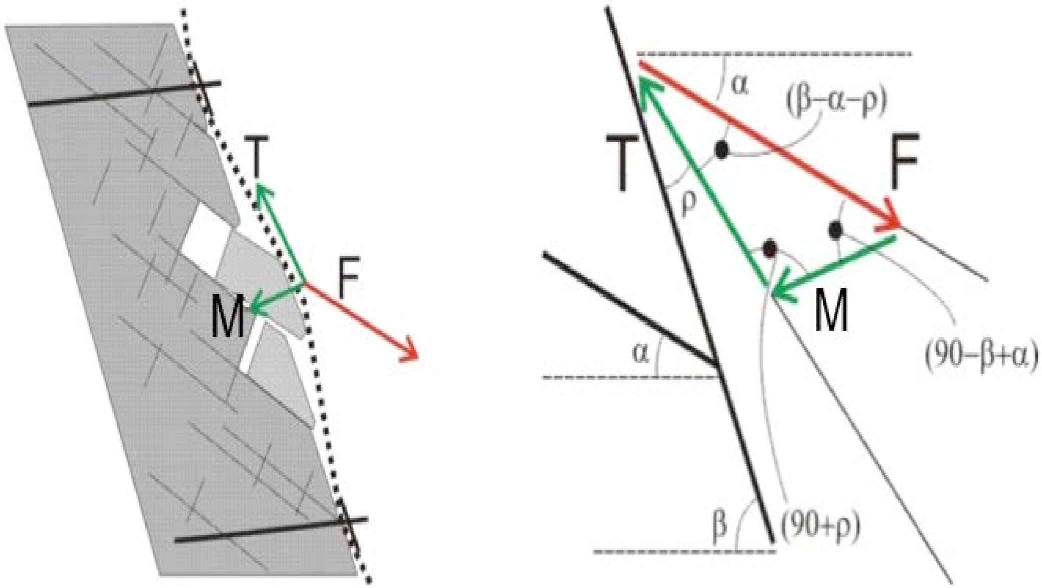
Design Concept



Secured drapery

Which is the calculation procedure for the nailing?
… and for the facing?

Design Concept



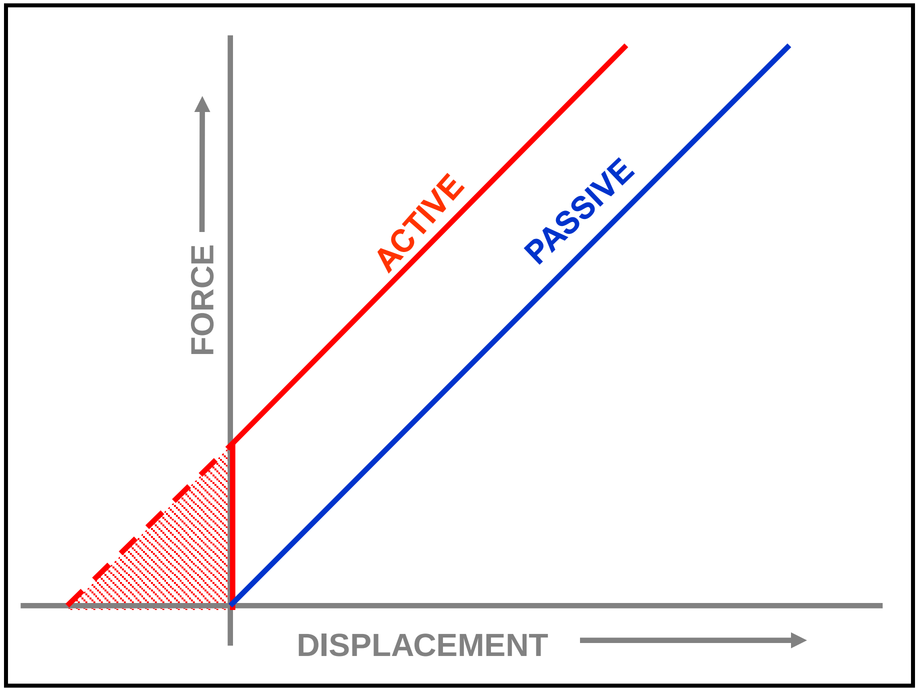
Equilibrium Design Theory

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

Secured drapery



Case (1) ACTIVE systems:

The force Rb acts before the driving forces overcome the resisting ones. *Rb acts against the driving forces:*

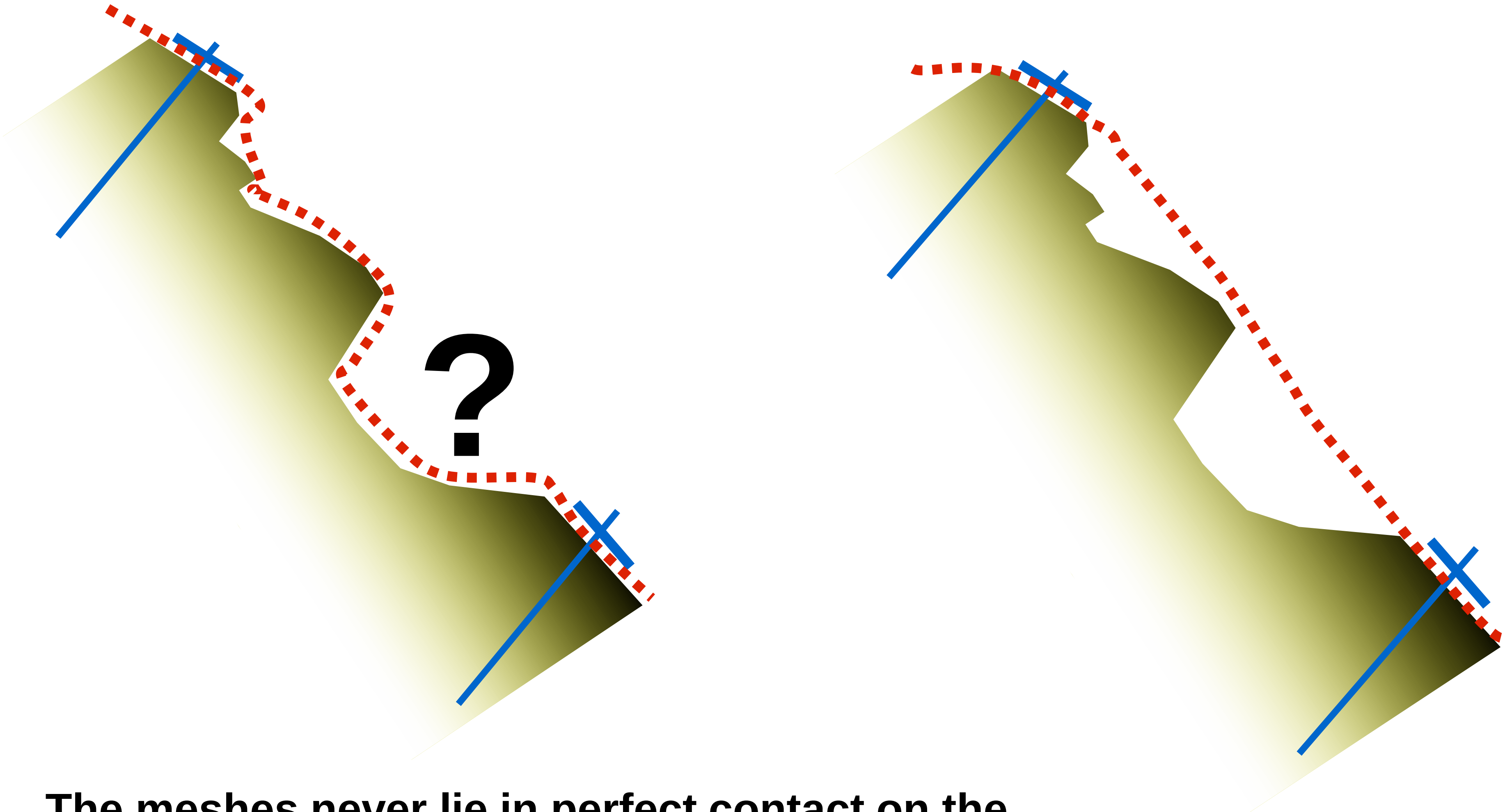
$$Fs = \frac{Resisting\ \ forces}{Driving\ \ Forces\ \ - Rb}$$

Case (2) PASSIVE systems:

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

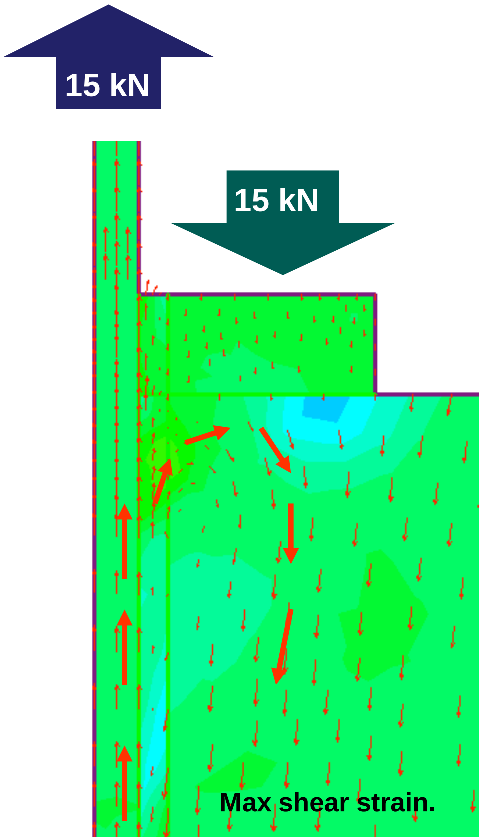
$$Fs = \frac{Resisting\ Forces + Rb}{Driving\ forces}$$

Design Concept



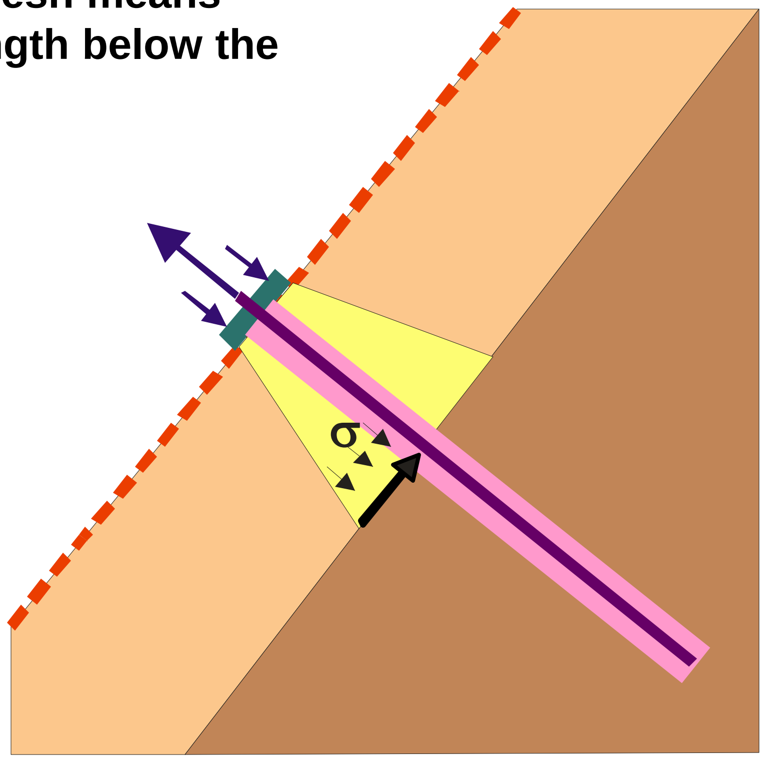
The meshes never lie in perfect contact on the ground surface

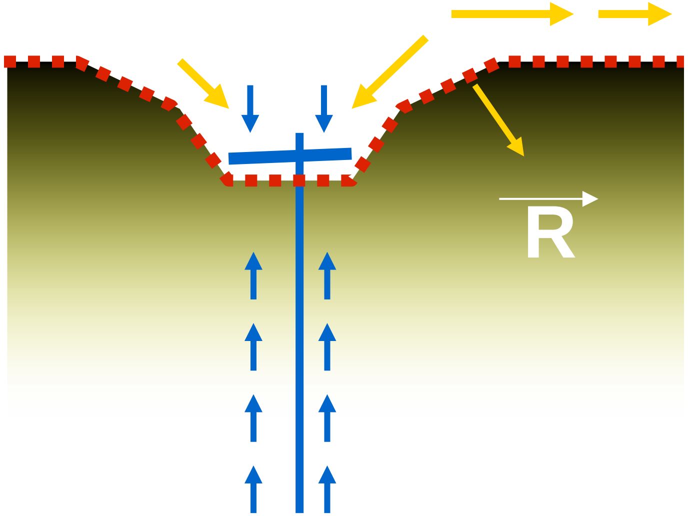
Design Concept



When using nails, pre-stressing down plate and mesh means short circuit strength below the plate.

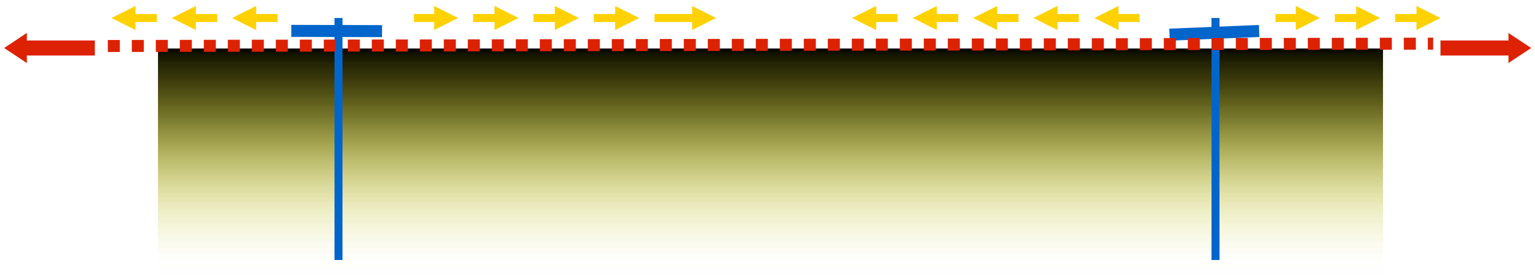
No pressure is developed on sliding plane





The meshes pushed down in the hollows can develop localized forces only (R).

The modulus of R is absolutely negligible

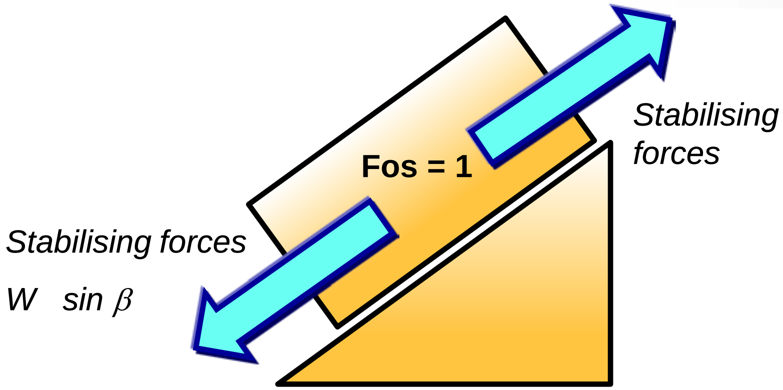


On planar surfaces the meshes can develop tangential forces only

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

Design Concept

Passive Design Concept



Conceptual solution:

$$\frac{\text{Stabilizing forces}}{\gamma_s} + R \quad > \quad \text{Driving forces} \ \gamma_d$$

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

$$((W \cdot sen\beta \cdot (1-c)/\gamma_{RW} + R) \geq (W \cdot \gamma_{DW} \cdot (sen\beta + c \cdot \cos\beta))$$

- Safety coefficient for driving forces

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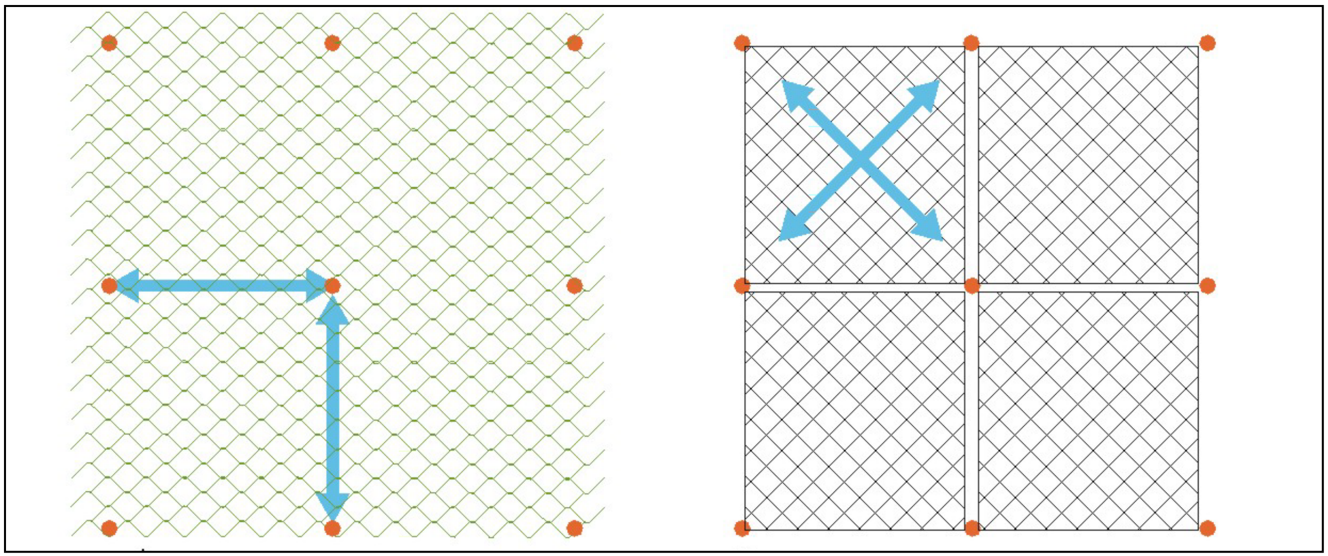
Load transfer

WIRE MESH PANELS

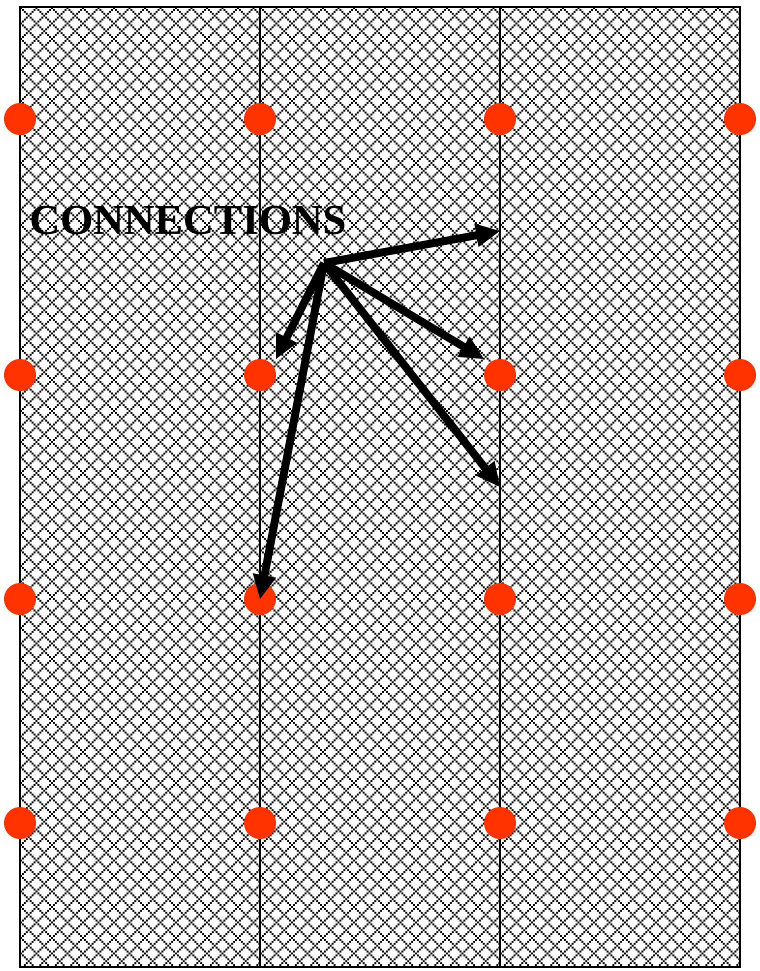
CABLE MESH PANELS



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

The load is transferred to the anchorings along diagonal directions

Border conditions

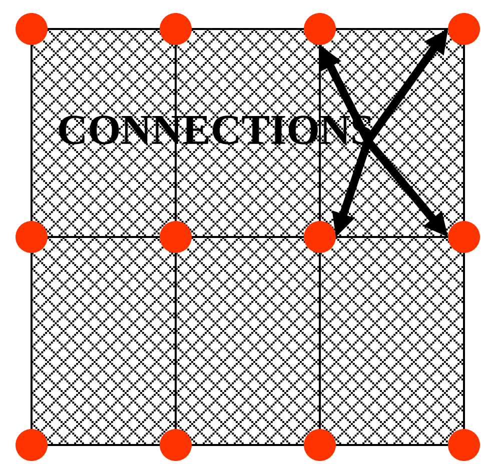


Wire mesh rolls: important the connection along the longitudinal borders

⇓

Importance of the benefit offered from RockMesh HR provided with longitudinal cables

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



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Testing is required to determine the behaviour of the mesh/panel with the action of the rocks.

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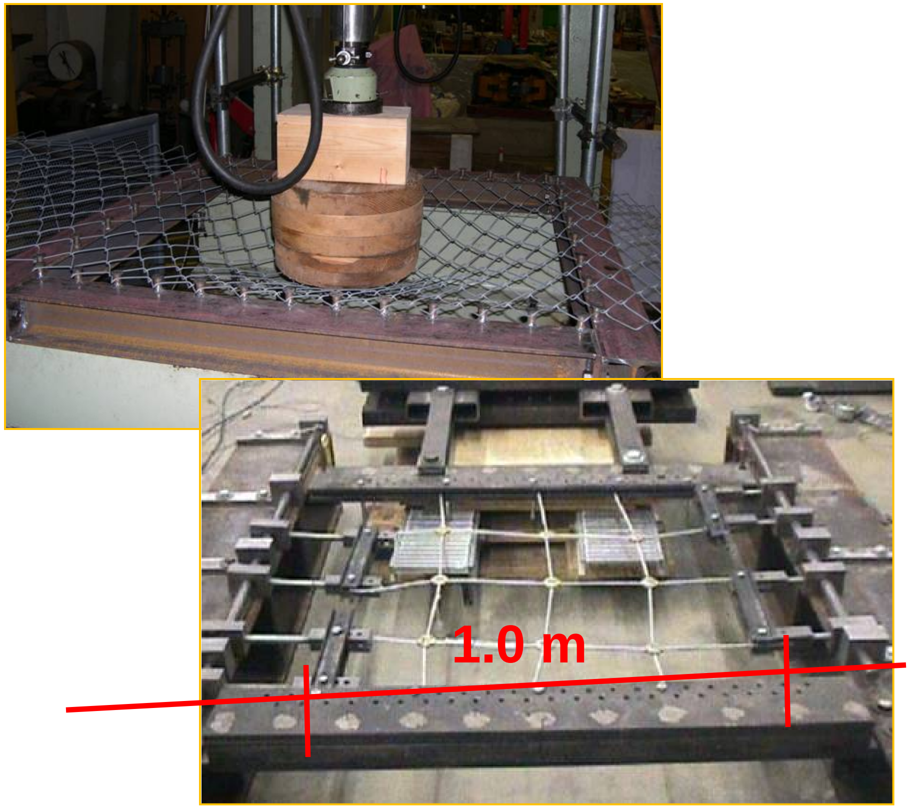
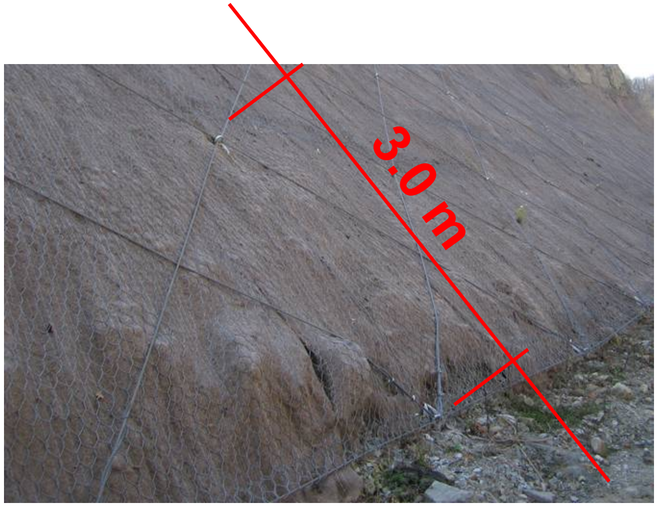
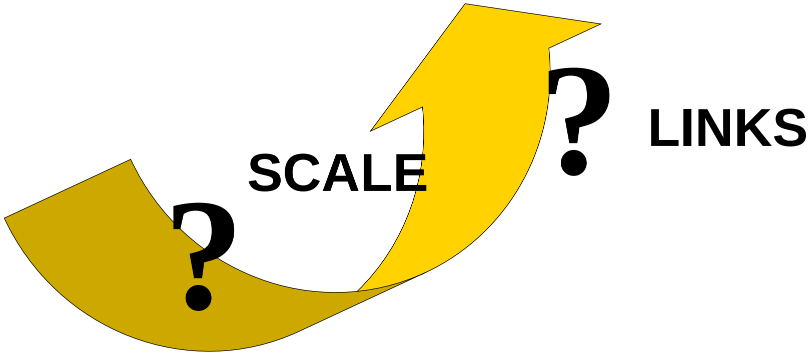
Scale Tests





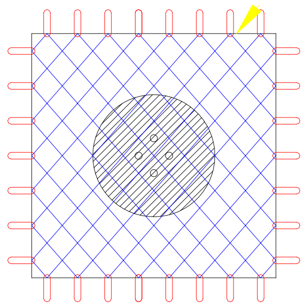


Large Scale Tests

Assessing the rigidity of deformity products

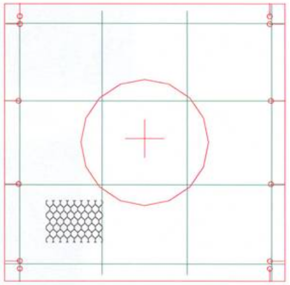
HEA Panel

wire Ø10, Mesh 400x400



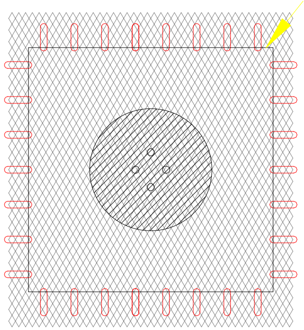
RockMesh

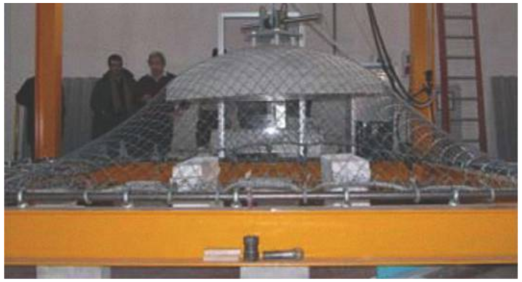
Mesh 8x10/Ø 3.00 Galfan



Chain-Link

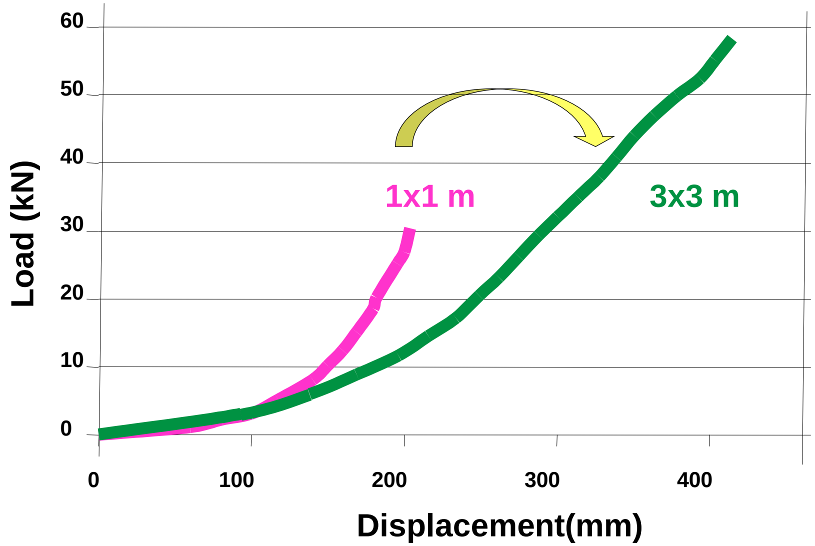
wire A.R., Ø 3.00





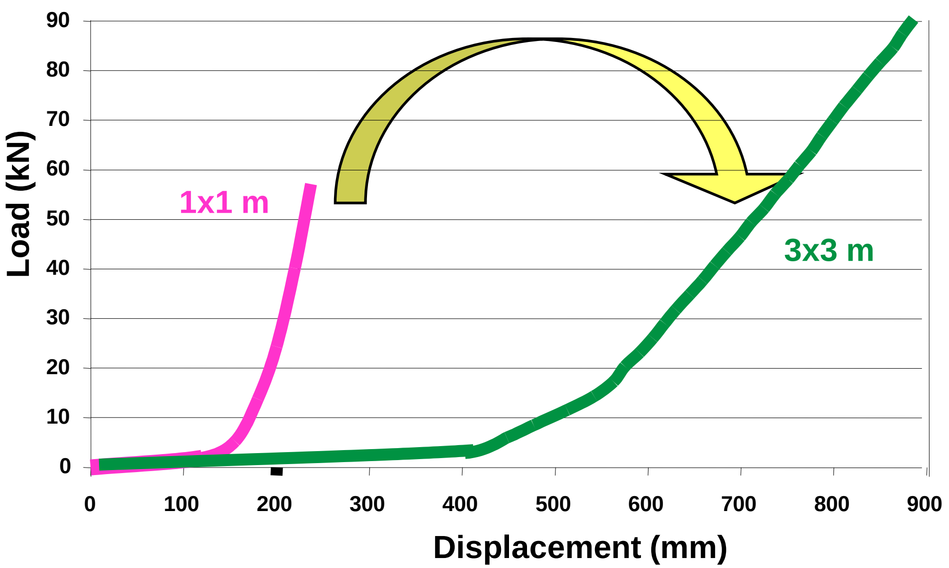
Large Scale Tests

Double Twisted Mesh - 3.00 mm



Importance of full scale tests.

Chain-Link Mesh - 3.00 mm



Comparison between

Scale tests (1x1 m)

Real Scale tests (3x3 m).

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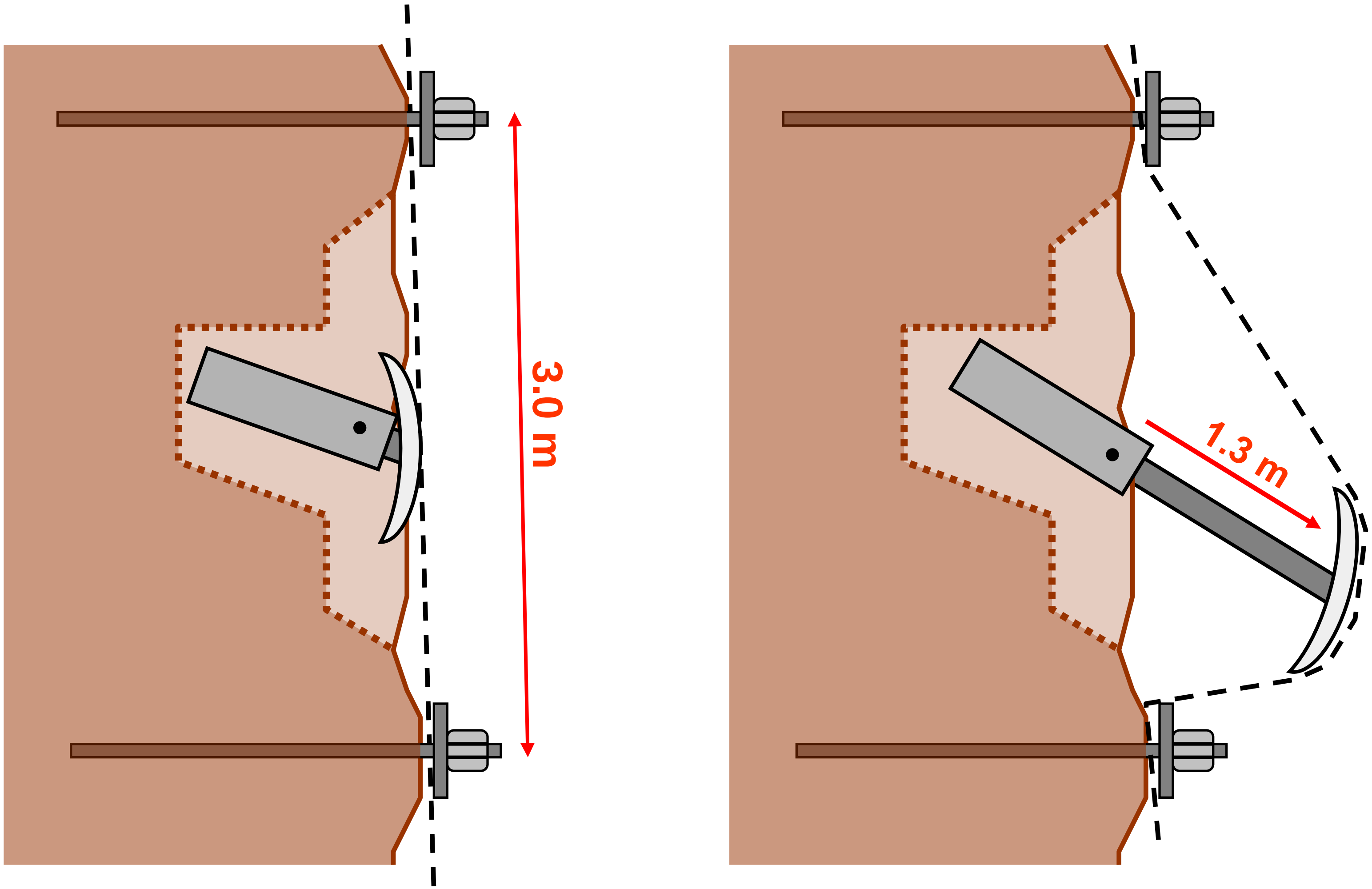
Pont Bozet (AO – Italy) - mesh field test



Large scale tests 3 x 3 m - Sample restrained on 4 points

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HEA Panel & DT mesh

Test in situ

Panel HEA with Knots

Pont Bozet (AO)

Test 21/02/2007

HEA Panel 300/10

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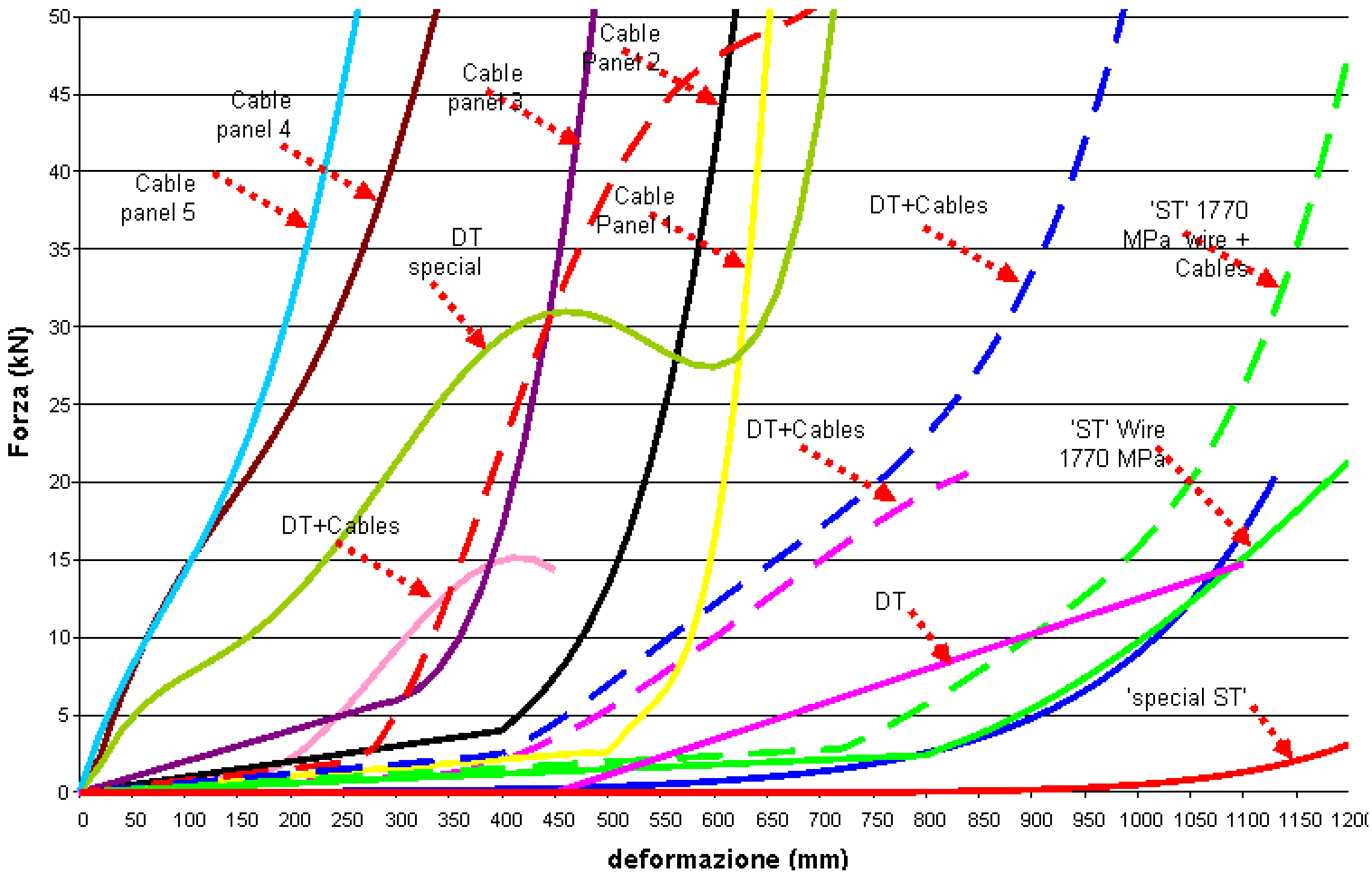

Forza (kN)
deformazione (mm)
0
5
10
15
20
25
30
35
40
45
50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1050
1100
1150
1200
Cable panel 5
Cable panel 4
Cable panel 3
Cable Panel 2
Cable Panel 1
DT special
DT+Cables
DT+Cables
DT+Cables
'ST' 1770 MPa 'wire + Cables'
'ST' Wire 1770 MPa
DT
'special ST'

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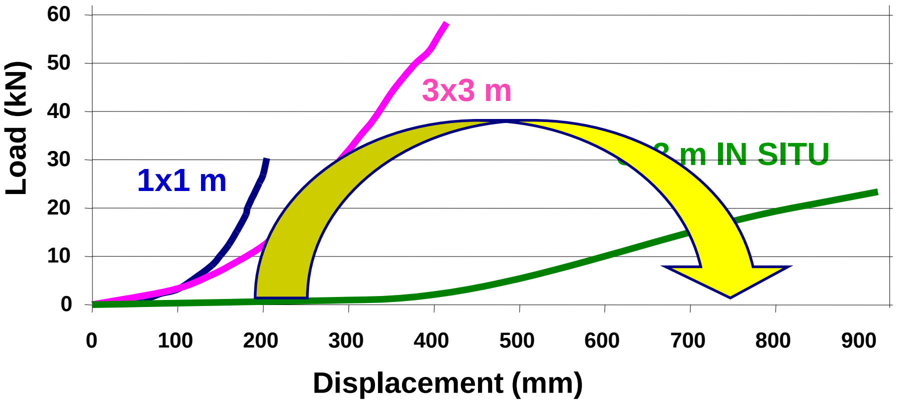
Behavior of the meshes

DT wire mesh - 3.00 mm



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

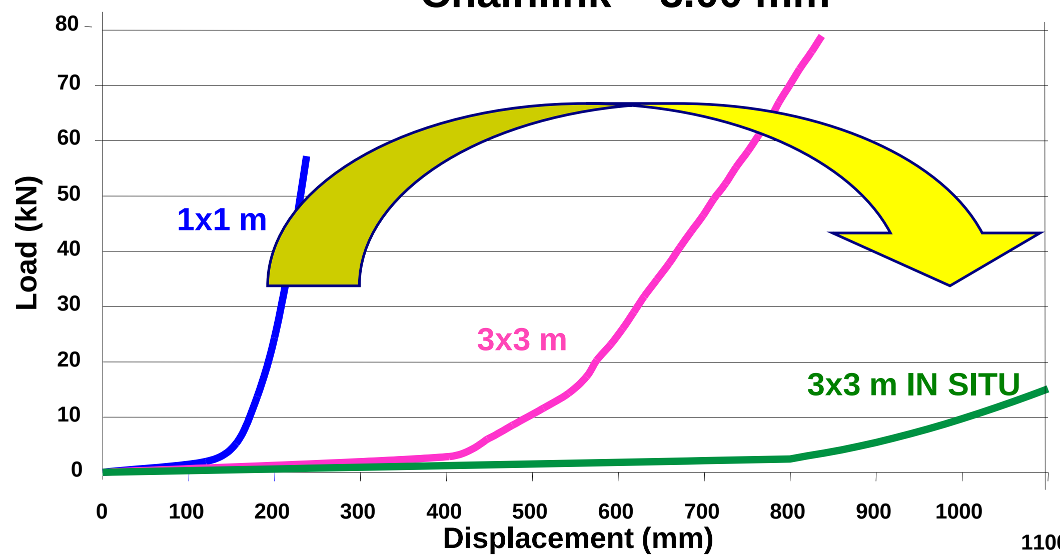
Comparation:

- Small size (1x1 m)

- Large Size (3x3 m) in Lab,

- Real Size (3x3 m) in situ

Chainlink – 3.00 mm



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Load cells

Tests have demonstrated that high stress is generated at anchor point and steel wire rope cable was the best solution for a strong connection.

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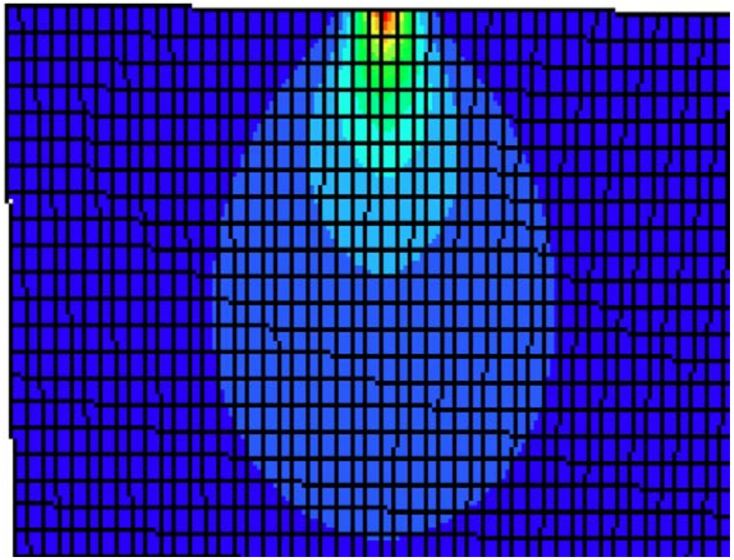

Modeling of the forces at the mesh anchor point.

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

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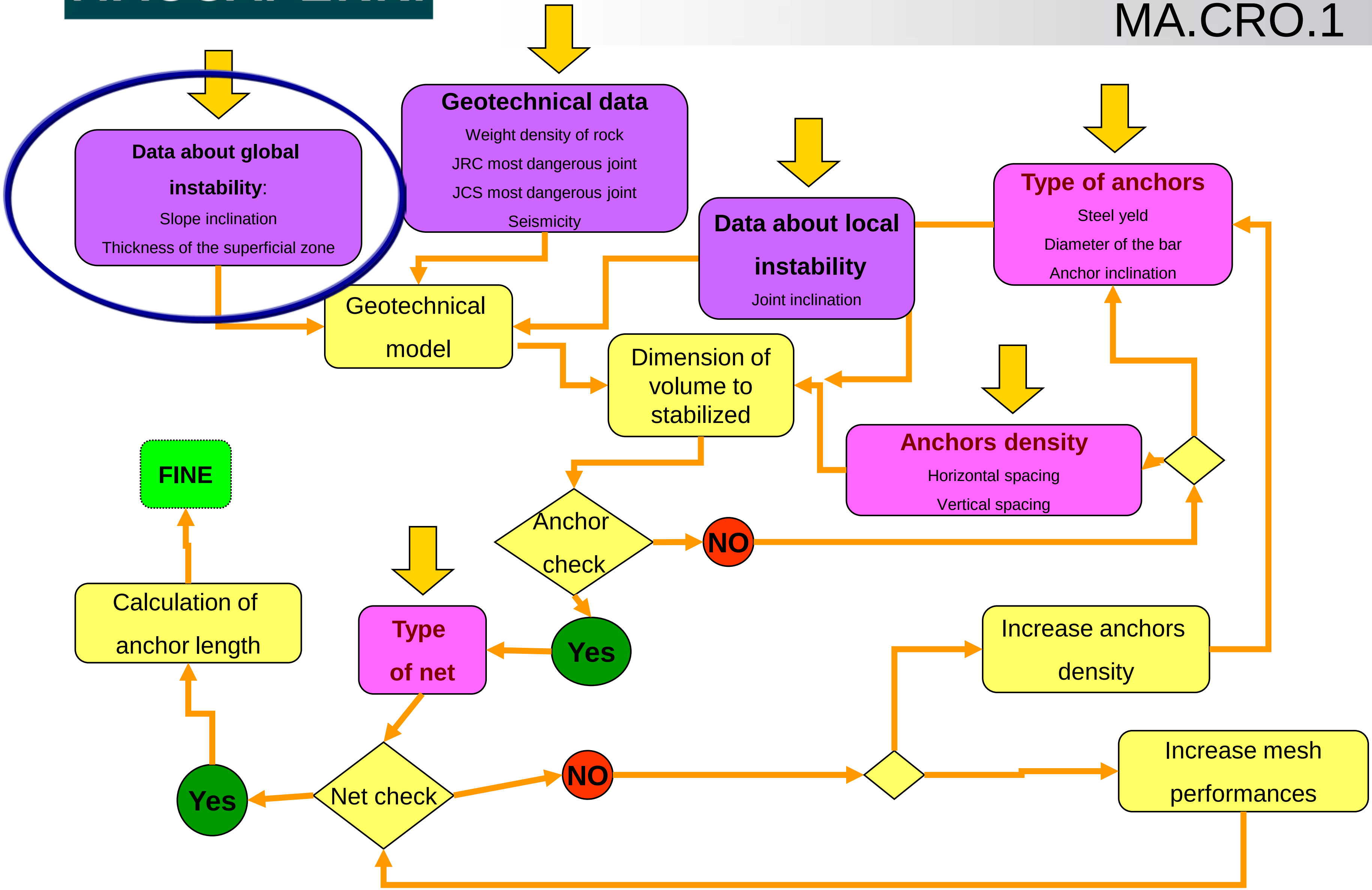
MA.CRO.1



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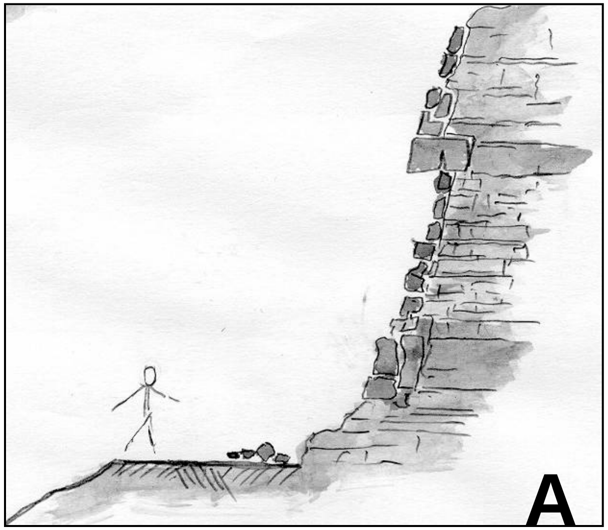
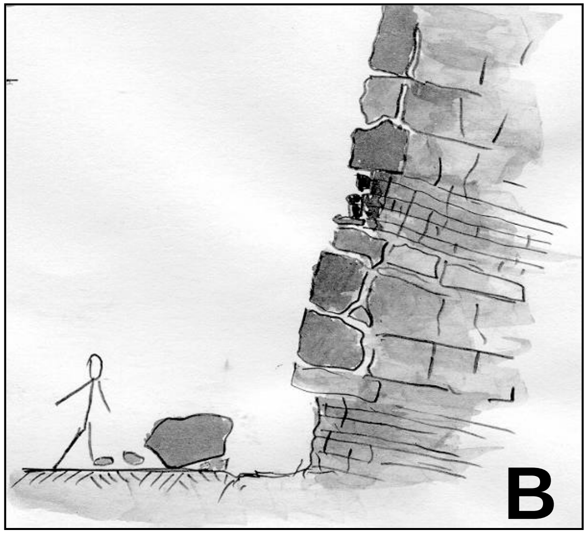
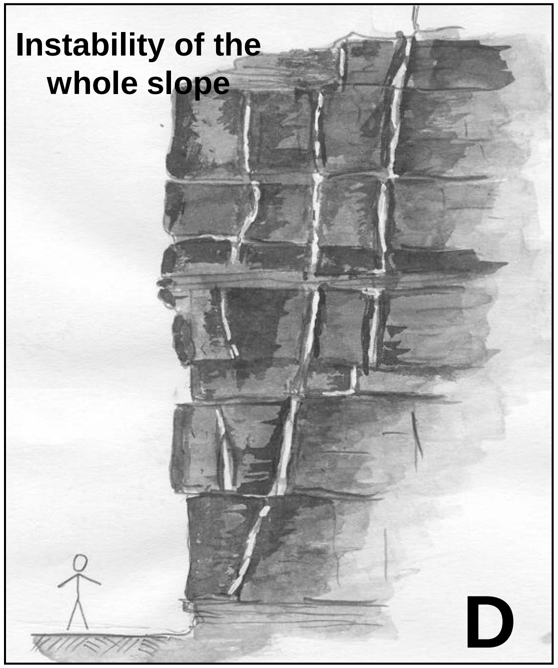


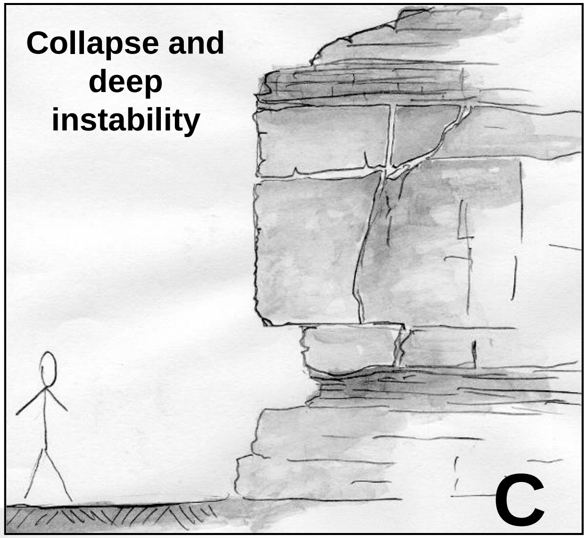


Global Instability.

It needs a geomechanical survey



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



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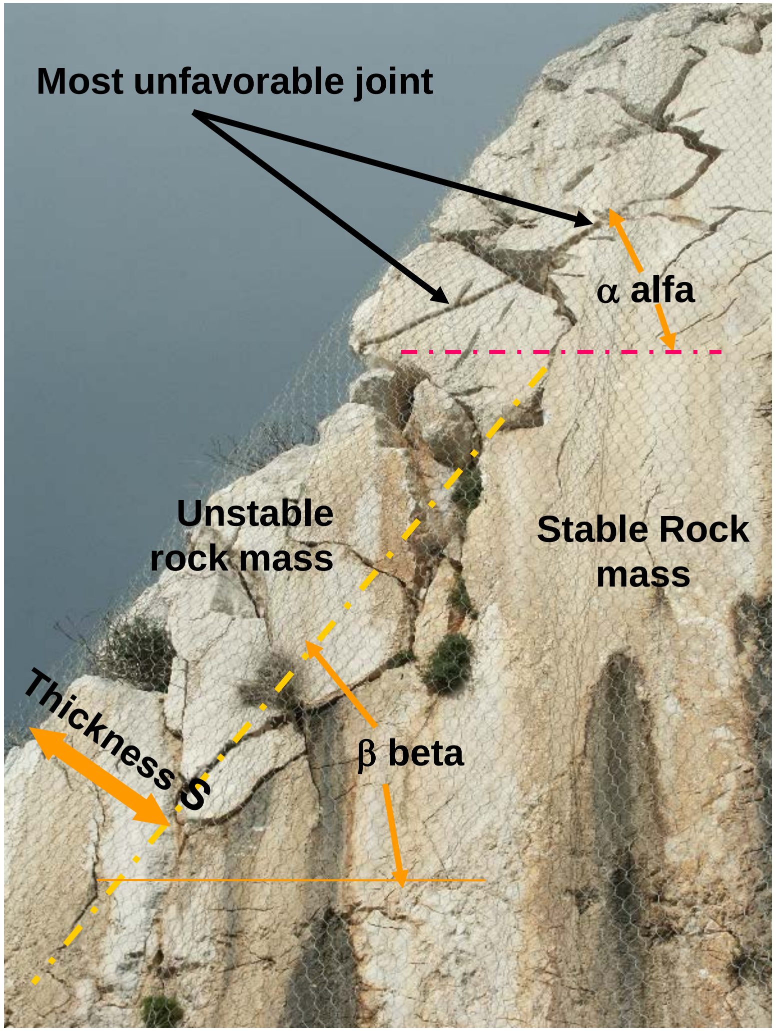
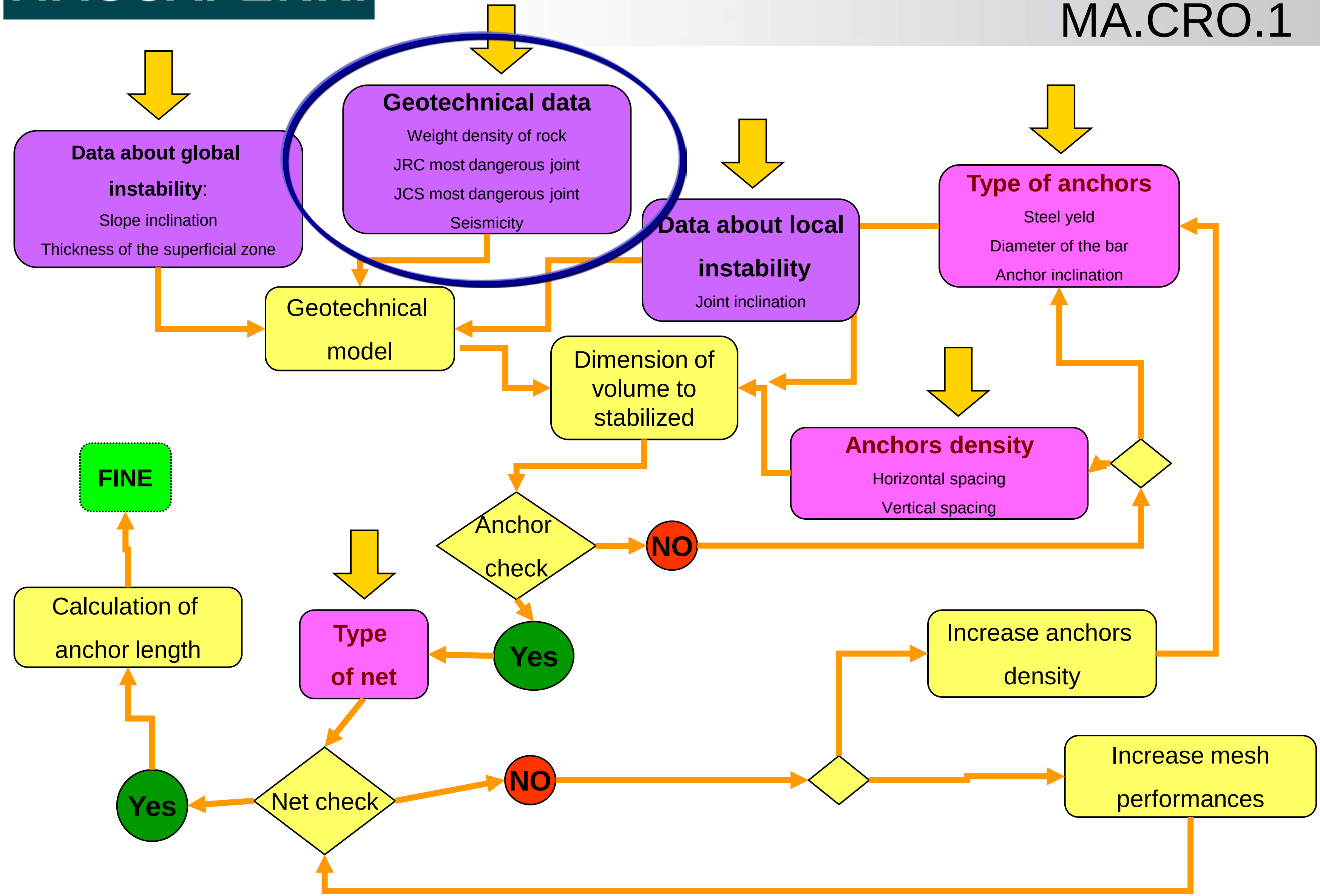
S = The average thickness of the loose rock mass

β = average inclination of slope surface

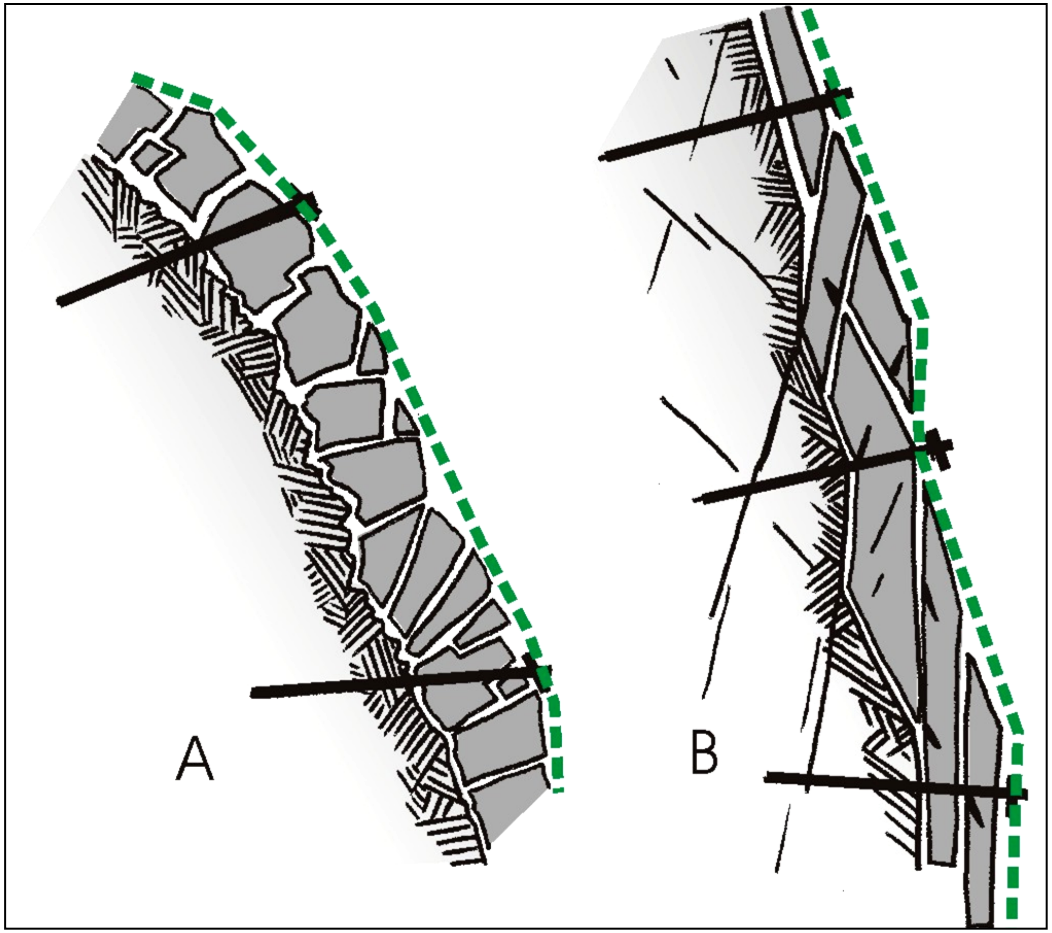


MA.CRO.1



Geotechnical data
Weight density of rock
JRC most dangerous joint
JCS most dangerous joint
Seismicity
Data about global instability:
Slope inclination
Thickness of the superficial zone
Data about local instability
Joint inclination
Type of anchors
Steel yeld
Diameter of the bar
Anchor inclination
Geotechnical model
Dimension of volume to stabilized
Anchors density
Horizontal spacing
Vertical spacing
FINE
Anchor check
NO
Yes
Type of net
Calculation of anchor length
Increase anchors density
Increase mesh performances
Net check
NO
Yes

Modelling of the surficial portion of the rock mass



Based on practical experiences, the surficial portion of the rock mass can be traced back.

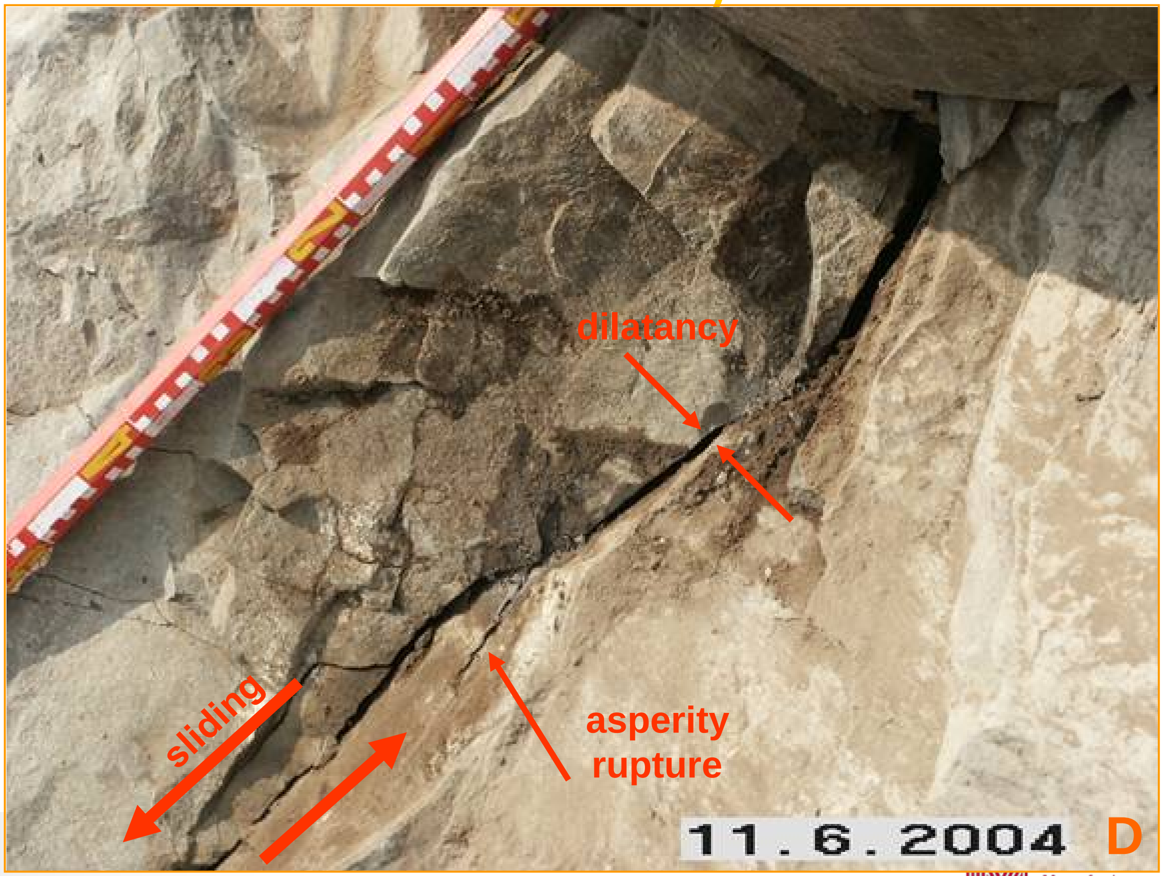
A) Pseudo-continous behavior: the surficial portion of the rock mass is highly divided. The wire mesh develops a relevant confinement action. The anchorings are only occasionally affected by shear stress.

B) Discontinous 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



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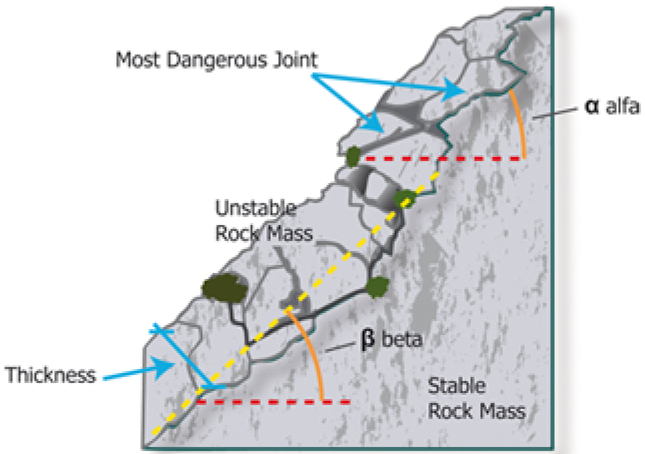
Compressive Strength (JCS)

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.



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

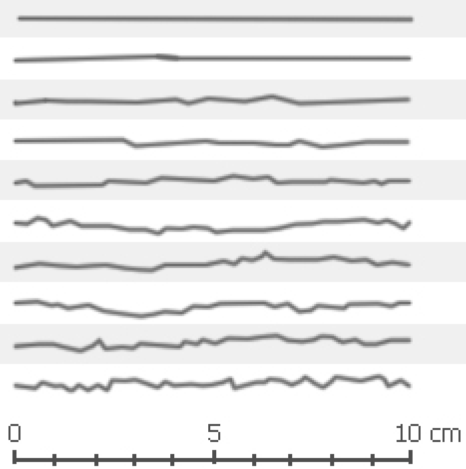
Compressive Strength (Minimum value) = 10

Ok

Roughness

Roughness of the Most Dangeorous Joint set is measured by Barton "comb". Its value range is between 0 t (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.



Profile	Roughness
	0 - 2
	2 - 4
	4 - 6
	6 - 8
	8 - 10
	10 - 12
	12 - 14
	14 - 16
	16 - 18
	18 - 20

Roughness = 0.1

Ok

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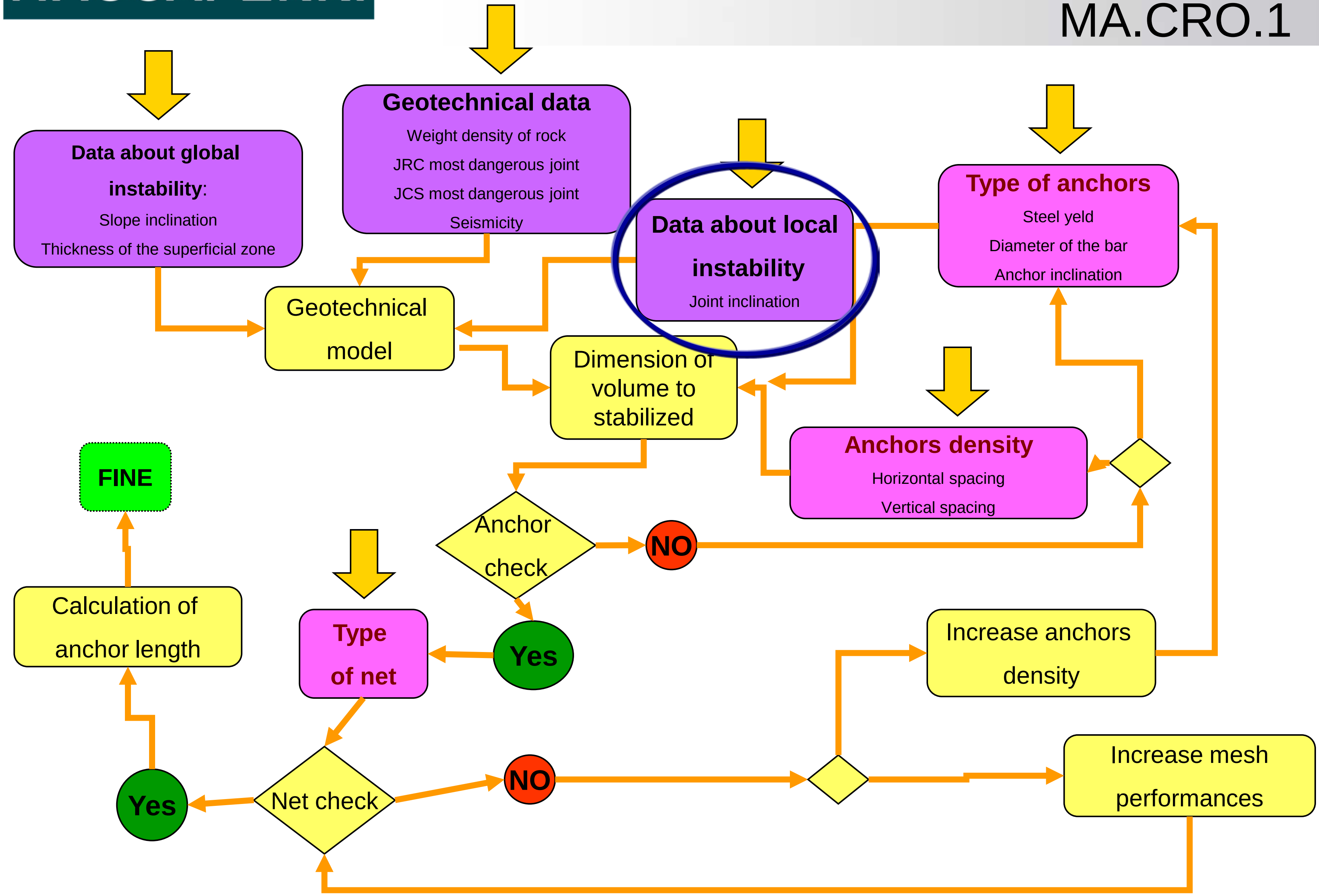
MA.CRO.1



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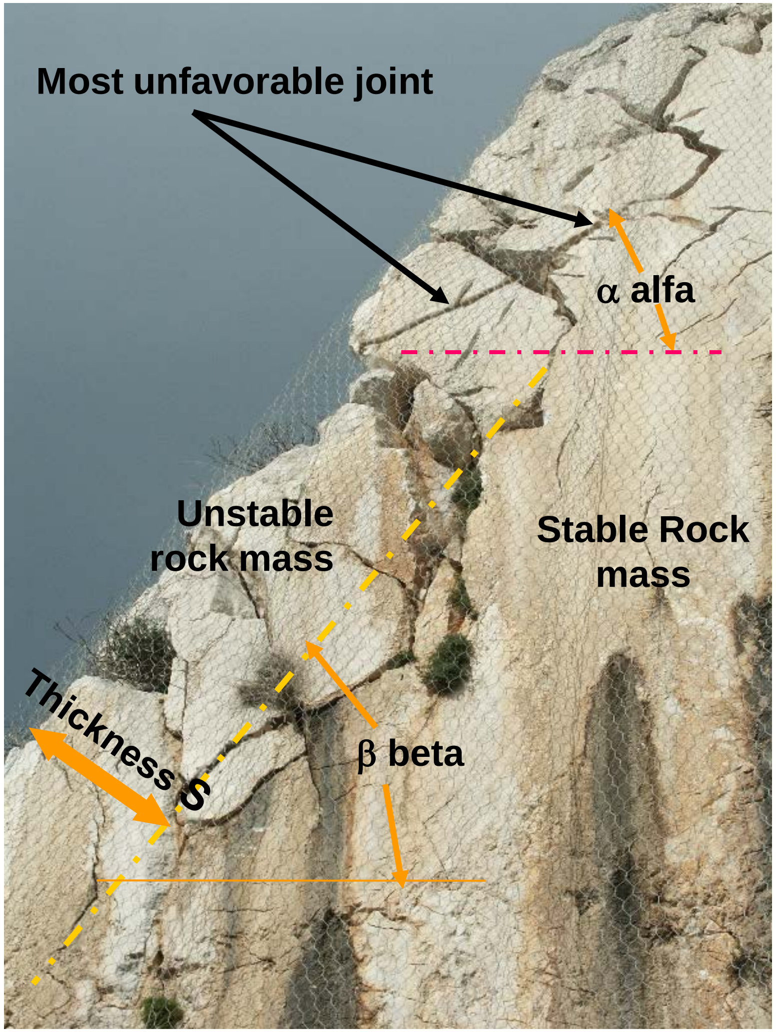
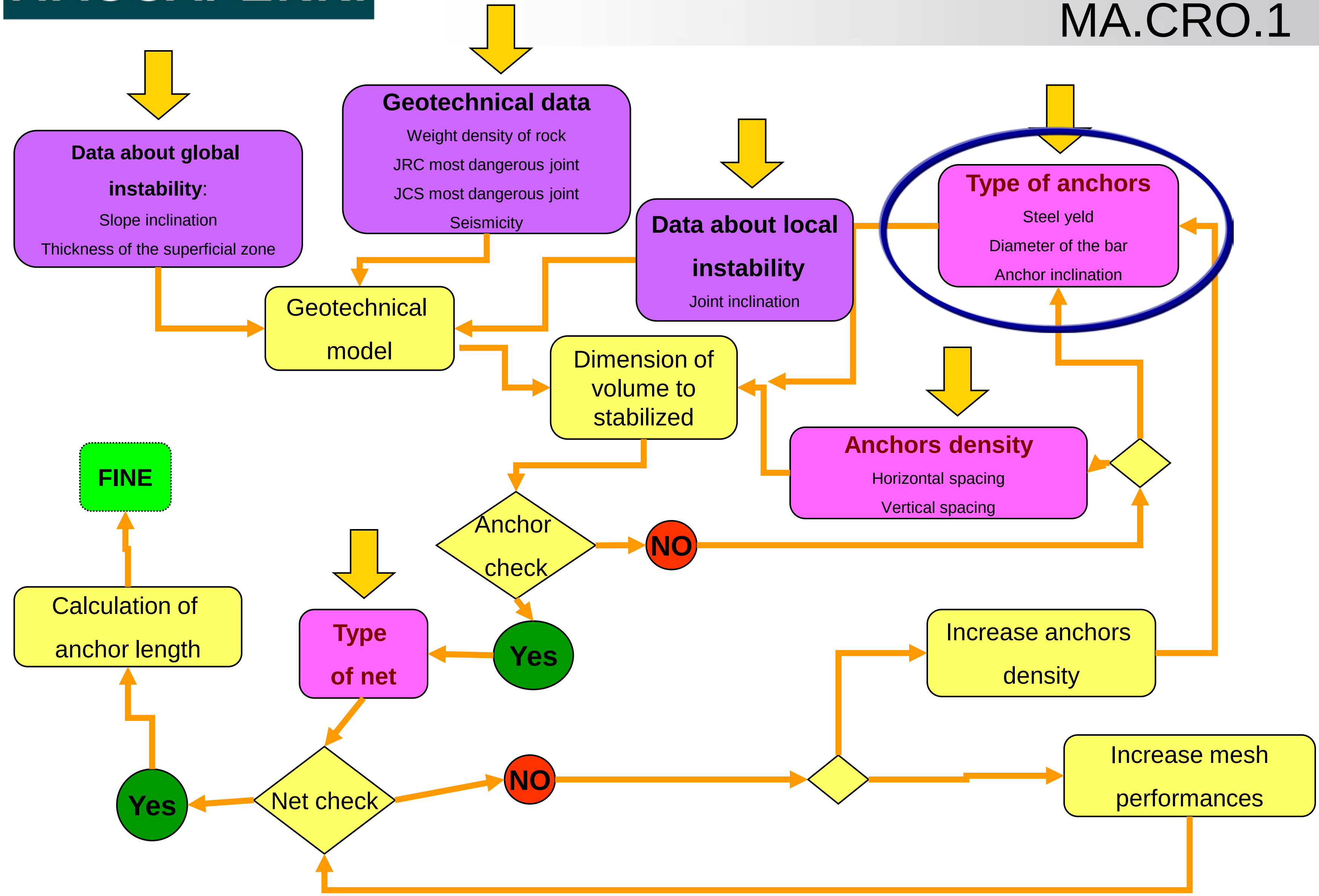
$\alpha =$ **Angle of the most unfavorable joint**



MA.CRO.1



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
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Joint inclination
Type of anchors
Steel yeld
Diameter of the bar
Anchor inclination
Geotechnical model
Dimension of volume to stabilized
Anchors density
Horizontal spacing
Vertical spacing
FINE
Anchor check
NO
Yes
Calculation of anchor length
Type of net
Increase anchors density
Increase mesh performances
Yes
Net check
NO

Nominal diameter of the anchorage bar.

Type of the bar with yield strength

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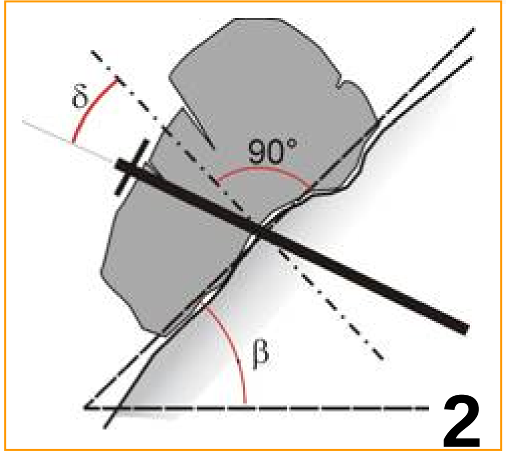
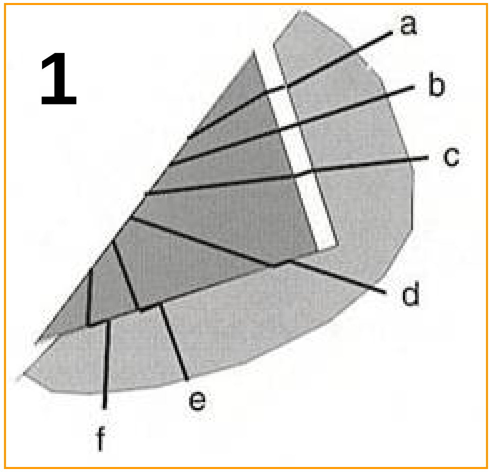
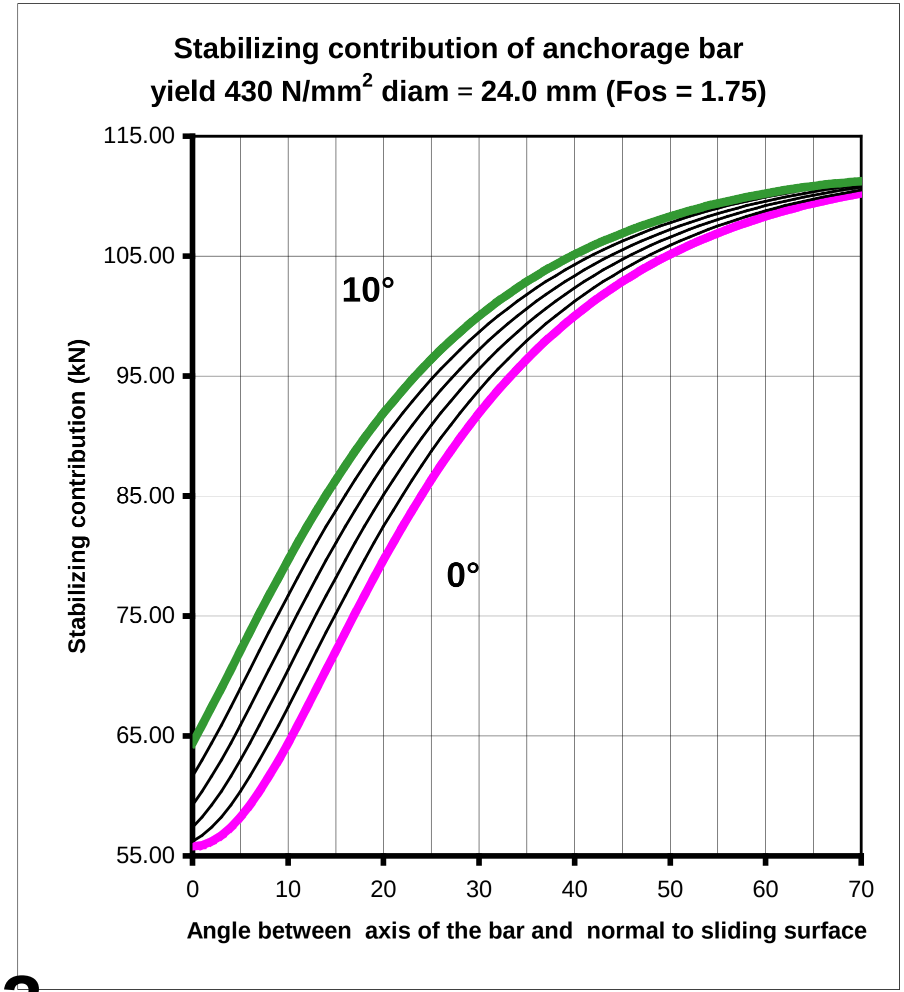


2

1

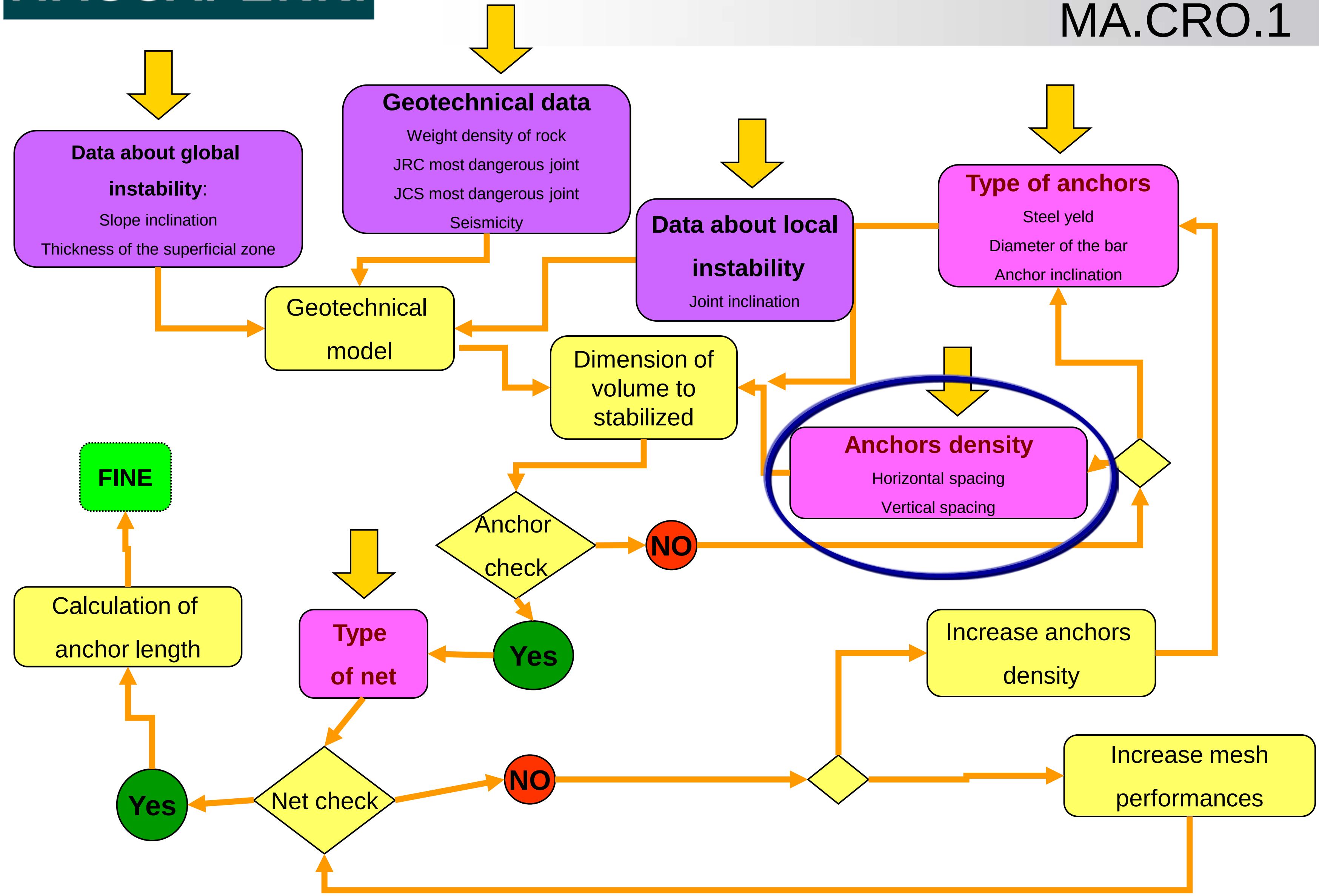


Bar subjected to pure traction (case “b”): the joint dilatency does not affect the resistance contribution due to the bar.



3

Bar subjected to pure shear (case “e”): the greater the joint dilatancy, the higher the resistance contribution of the bar.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Horizontal spacing
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FINE
Anchor check
NO
Yes
Type of net
Calculation of anchor length
Increase anchors density
Yes
Net check
NO
Increase mesh performances

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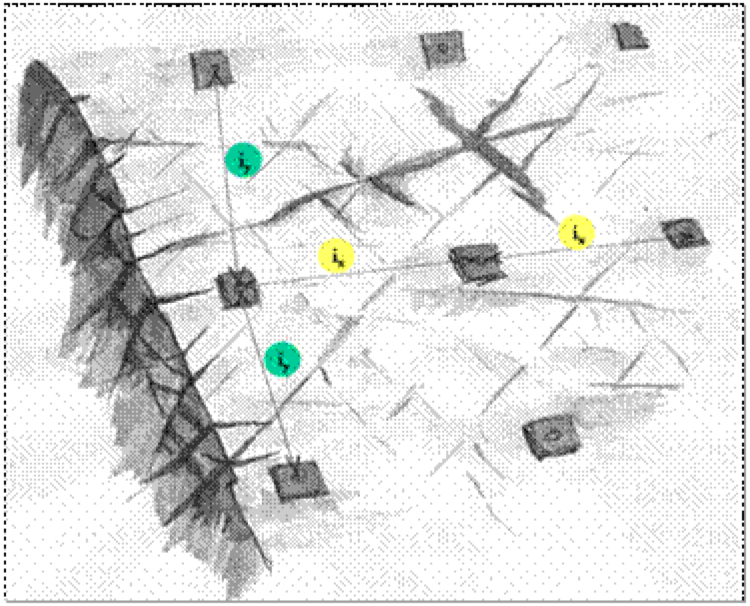
Spacing horizontal ix between the anchorages.

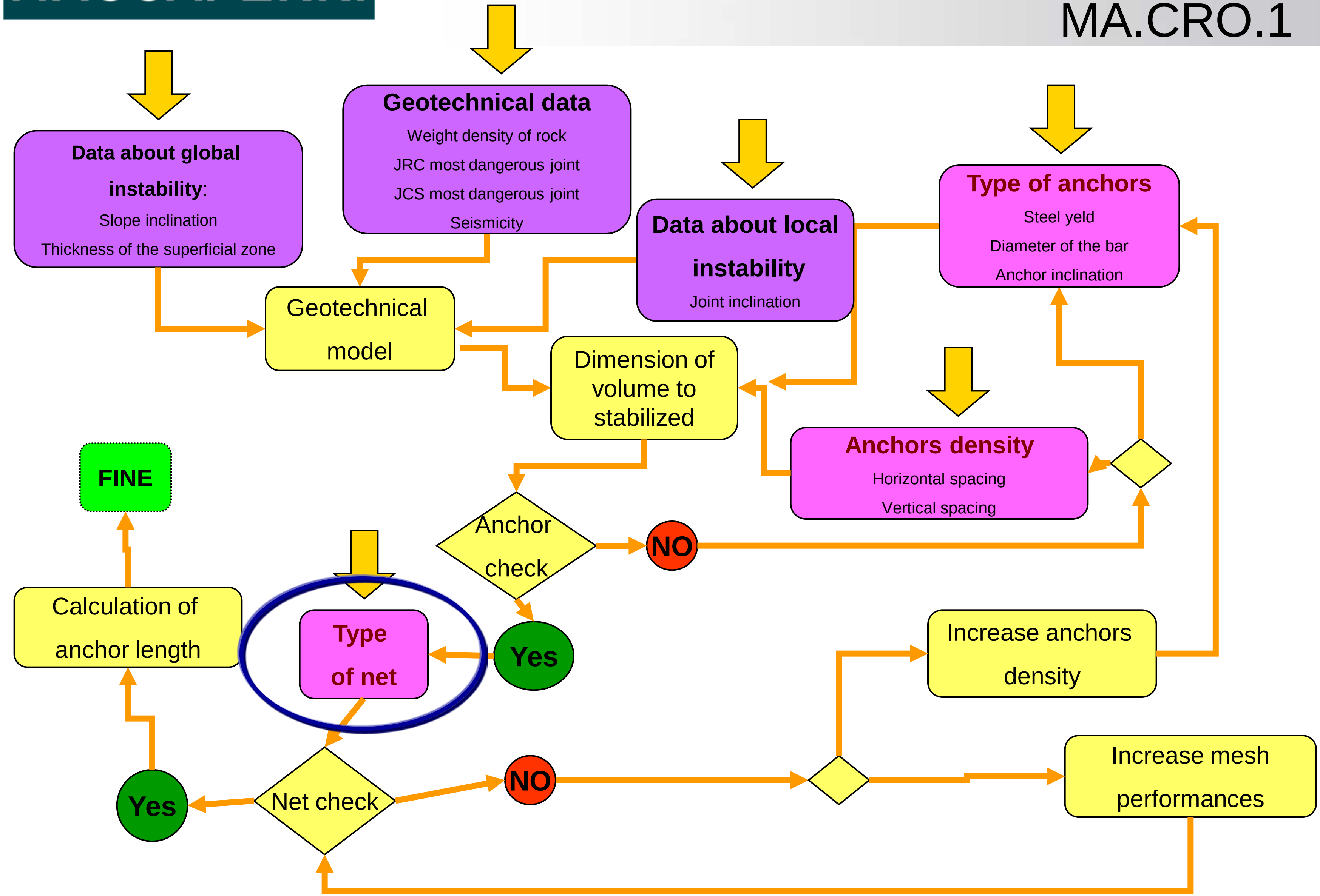
It is better than ix doesn’t differ too much from iy.

Vertical spacing iy between the anchorages.

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



MA.CRO.1


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 yeld
Diameter of the bar
Anchor inclination
Geotechnical model
Dimension of volume to stabilized
Anchors density
Horizontal spacing
Vertical spacing
FINE
Anchor check
NO
Yes
Type of net
Calculation of anchor length
Increase anchors density
Net check
Yes
NO
Increase mesh performances

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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

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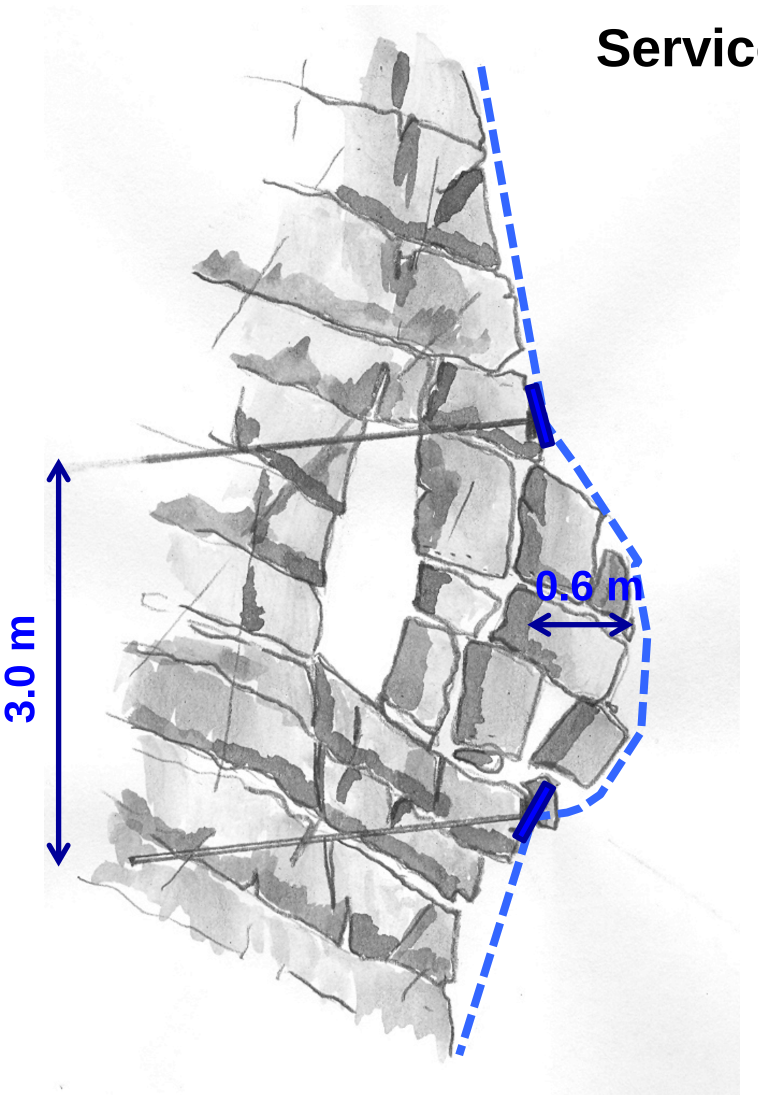
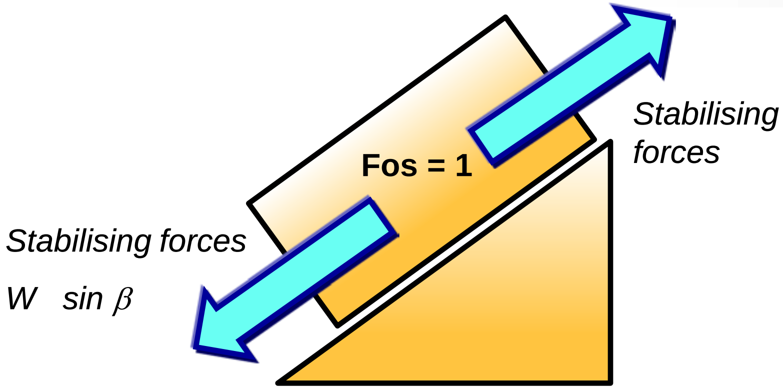
Serviceability Limit state



The acceptable maximum bulging must be assumed taking into account of maintenance problems & geotechnical conditions.

Design Calculation



Conceptual solution:

$$\frac{\text{Stabilizing forces}}{\gamma_s} + R > \text{Driving forces } \gamma_d$$

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

$$((W \cdot sen\beta \cdot (1-c)/\gamma_{RW} + R) \geq (W \cdot \gamma_{DW} \cdot (sen\beta + c \cdot \cos\beta))$$

- Safety coefficient for driving forces

Design Calculation

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

$$\gamma_{RW} = \gamma_{THI} \; \gamma_{WG} \; \gamma_{BH}$$

(for stabilizing forces)

uncertainties related to the slope morphology	1.10 - 1.30
uncertainties related overload applied on the facing system	1.00 - 1.20

$$\gamma_{DW} = \gamma_{MO} \; \gamma_{OL}$$

(for driving forces)

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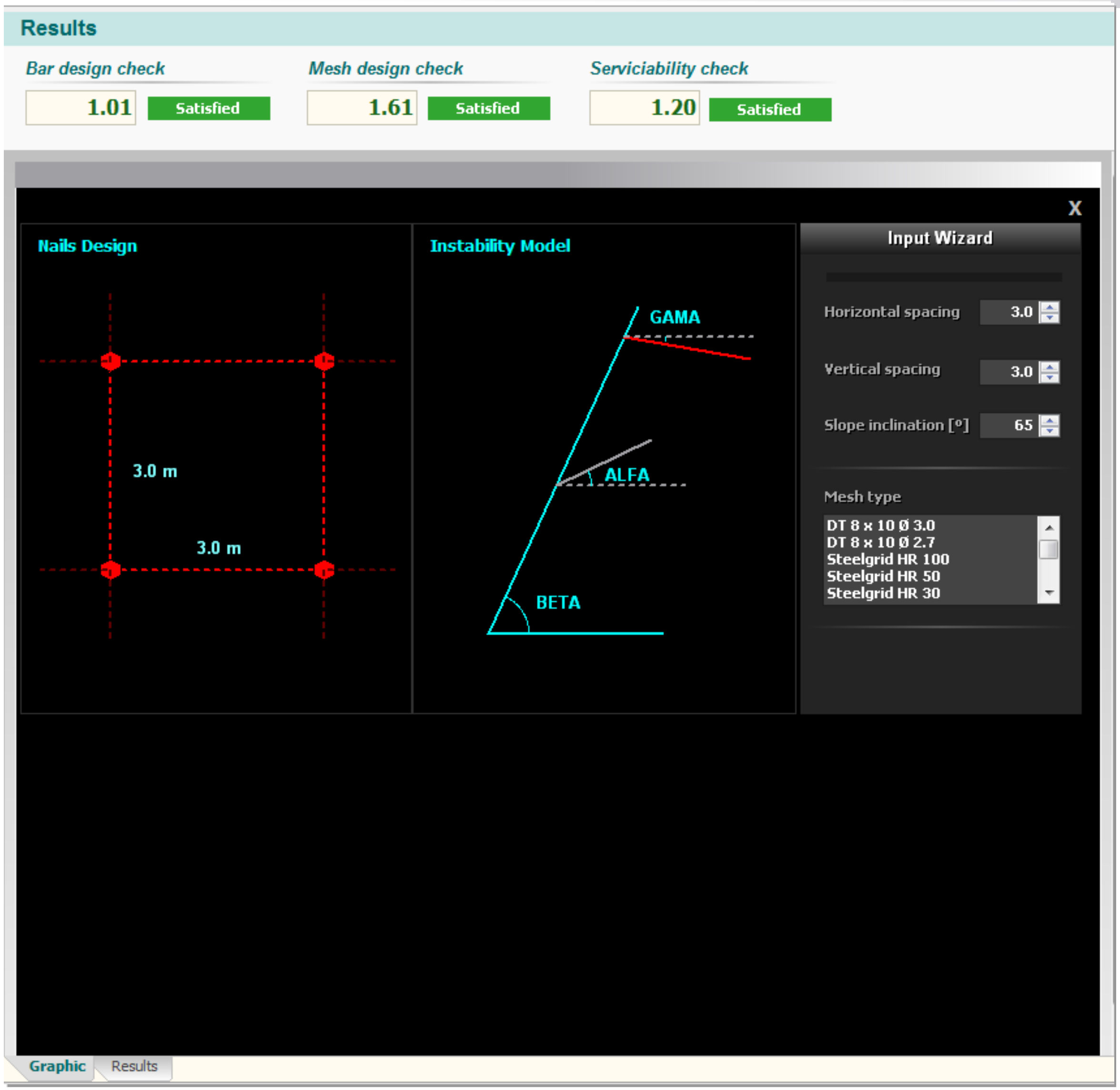

Results
Bar design check
1.01
Satisfied
Mesh design check
1.61
Satisfied
Serviciability check
1.20
Satisfied
X
Nails Design
3.0 m
3.0 m
Instability Model
GAMA
ALFA
BETA
Input Wizard
Horizontal spacing
3.0
Vertical spacing
3.0
Slope inclination [°]
65
Mesh type
DT 8 x 10 Ø 3.0
DT 8 x 10 Ø 2.7
Steelgrid HR 100
Steelgrid HR 50
Steelgrid HR 30
Graphic
Results

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Project Information

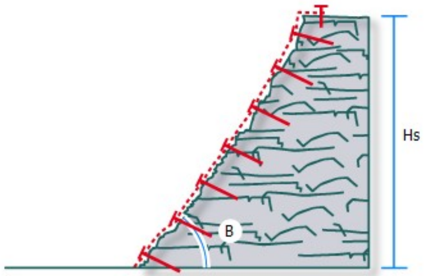
Title:
Number:
Client:
Designer:

Description:

Input

Rock Slope

Slope inclination [°]	B	65
Slope total height [m]		
Thickness of the surficial instability [m]		0.5
Density of the rock mass [kN/m3]		27
Assumed length os plasticization in the unstable rock mass [m]		0.3



Most Dangerous Joint

Inclination [°]	25
Compressive strength [MPa]	10
Roughness	0

Seismic Acceleration

Horizontal seismic coefficient	0.14

Mesh

Mesh Type	**DT 8 x 10 Ø 2.7**
Mesh ultimate tensile resistance [kN/m]	60
Maximum displacement acceptable [m]	0.6

Anchor Bars

Geometry

Horizontal anchor spacing [m]	3
Vertical anchor spacing [m]	3
Inclination of bar to the horiozntal [°]	10

Anchor Type

Bar type	**_bar**
Bar internal diameter [mm]	0
Bar external diameter [mm]	16
Thickness of corrosion crown [mm]	0
Bar yield stress (of steel) [MPa]	500
Rock-grout adhesion (bond stress) [MPa]	2.25

Safety Factor

Factors affecting the stabilizing forces

Uncertainty of the thickness of surficial instability	1.2
Uncertainty of the rock mass unit weight	1.01
Uncertainty of rock behavior and weathering	1.02
Control: Safety factor do 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

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www.maccaferri.com

Client: /

Results

Bar design check		Mesh design check		Serviceability design check	
1.01	Satisfied	1.61	Satisfied	1.20	Satisfied

Bar design

Stabilizing forces [kN]	132.36
Slidind plane driving force [kN]	131.38
Ratio strength stress	1.01

Bar inclination from horizontal [º]	15.00
Minimum acceptable steel yield stress [N/mm2]	431.03
Control: Effective cross section of bar [mm2]	201.06
Sliding plane stabilizing forces per acnhorage [kN]	55.99
Minimum driling diameter (Nominal) [mm]	38.00
Anchor pull-out force from load on the mesh [kN]	28.89
Anchor pull-out force due to global instability [kN]	14.24
Maximum pull-out force (total) [kN]	28.89
Minimum bar lenght in stable rock mass [m]	0.30
Minimum lenght (bar) in the unstable rock mass [m]	0.60
Minimum total bar lenght (Nominal) [m]	1.20

Serviceability

Stabilizing forces [kN]	0.30
Slidind plane driving force [kN]	0.25
Ratio strength stress	1.20

Mesh design

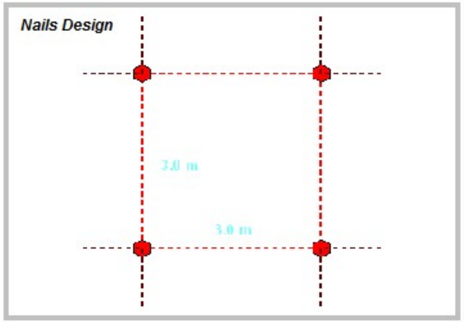
Maximum tensile force in the cable [kN]	24.00
Maximum tensile stress within the mesh [kN]	14.88
Force-strength ratio	1.61

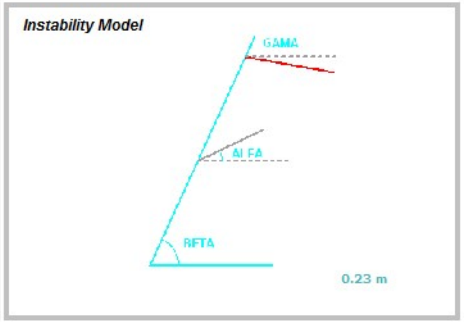
Potential unstable volume on joint - case A [m3/m]	0.00
Potential unstable volume on joint - case B [m3/m]	1.20
Potential unstable volume on joint - case C [m3/m]	0.15
Maximum rock vol that can slide between anchors [m3/m]	1.35
Maximum rock weight that can slide betweem anch [kN/m]	36.48
Sum of the driving forces acting on the sliding plane [kN/m]	22.45
Sum of stabilizing forces acting on the sliding plane [kN/m]	10.69
Punching forces acting on the mesh [kN/m]	22.67
Mesh deformation angle from horizontal [º]	9.46

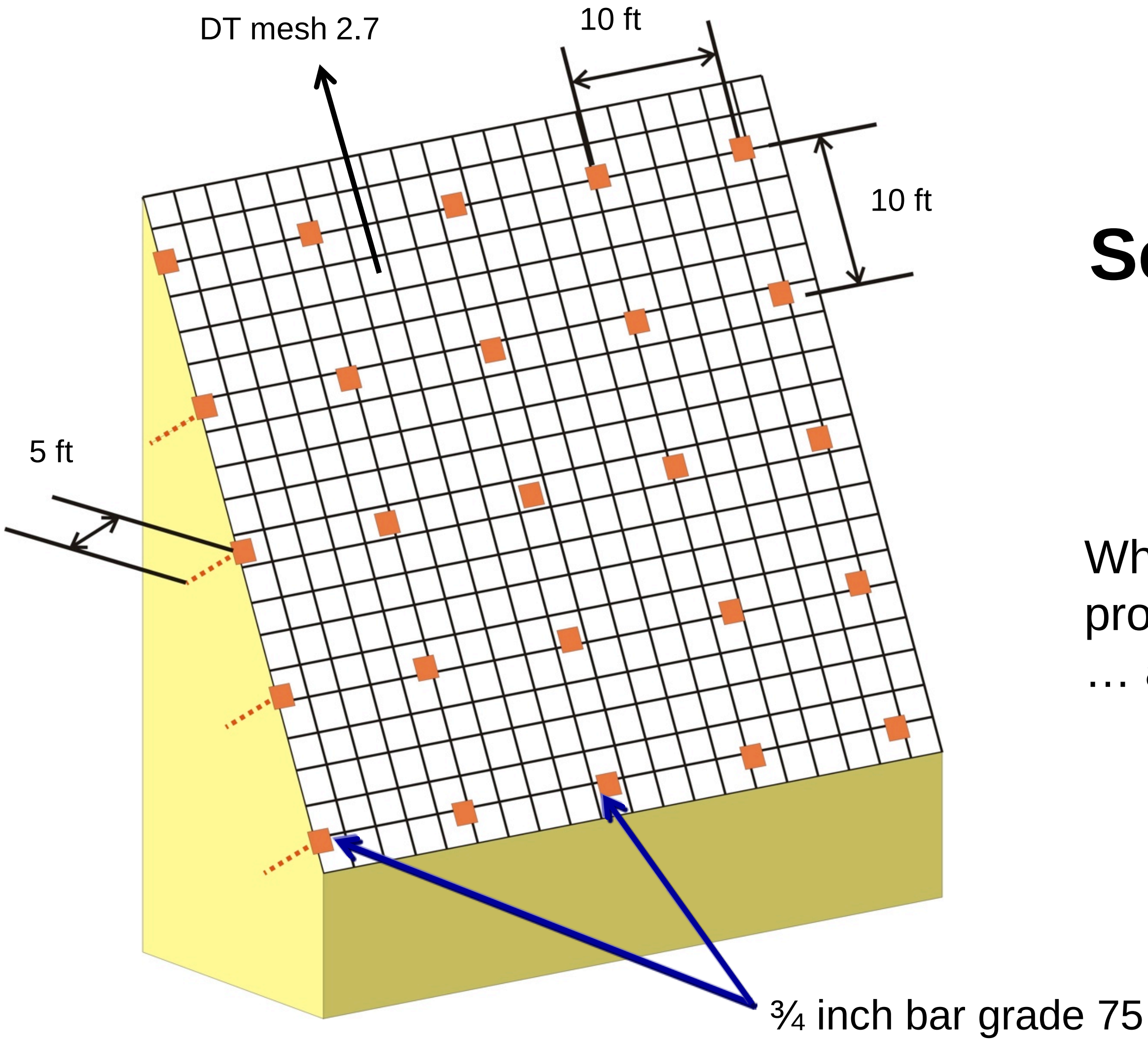
Features of the instability

Tension on the averege slip surface [MPa]	0.01
Initial dilatance of the most dangerous joint [º]	0.00
Total unstable vol controlled by each anchorage [m3]	4.50
Total unstable weight controlled by each anchorage [kN]	121.50

Geometry







Secured drapery

Which is the calculation procedure for the nailing?
… and for the facing?

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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.