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available on **edesign.maccaferri.com**

Speaker:

LUCA GOBBIN *Corporate Rockfall Technical Specialist*

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SOIL NAILING AT A GLANCE

DESIGNING SOIL NAILING APPLICATIONS

Q&A SESSION

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SOIL NAILING AT A GLANCE

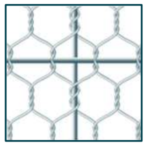
What it is

Soil nailing is a technique used **to stabilize slopes with low cohesion or purely frictional behavior**.

It is recommended for soil with no groundwater presence, partially saturated, with a miscellaneous granular matrix (from sandy gravel to clayey silt) and with a low to medium cementation grade, or for altered rocks (Cola et al., 2011)

Soil Nailing

Nails increasing the stability of the slope

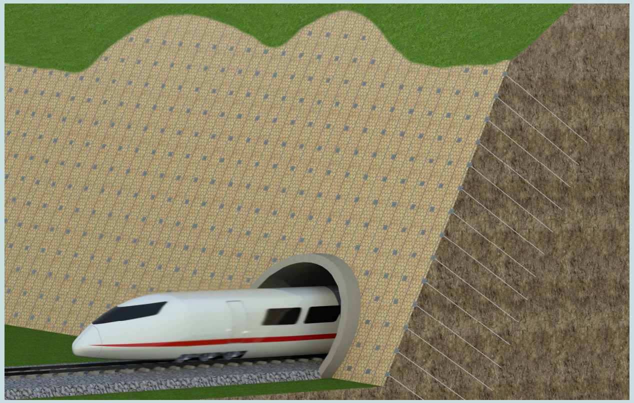


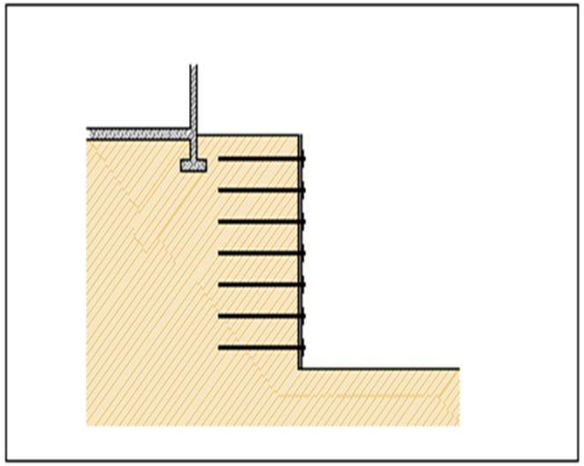
Facing contains the soil movement between nails

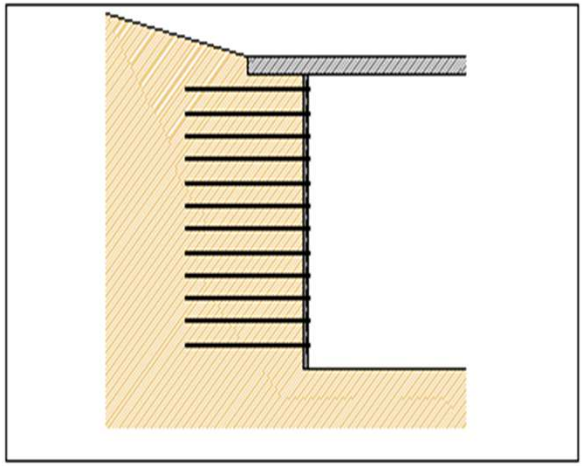
SOIL NAILING AT A GLANCE

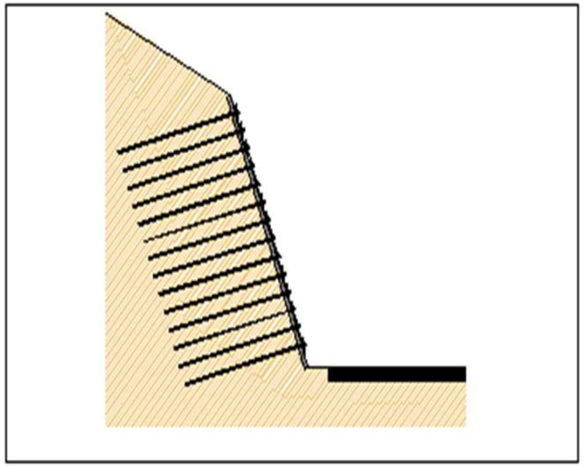
Where it is used and why

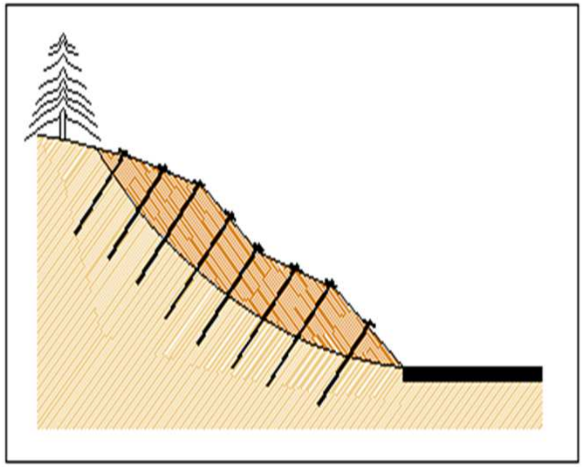
- Easy and fast to install
- Requiring limited excavations
- Environmentally friendly
- Can be applied on new excavated slopes/walls or on existing slopes











SOIL NAILING IN INTERNATIONAL STANDARDS

British Standard vs FHWA

BRITISH STANDARD 8006-2:2011+A1:2017

- It deals with **soil nailing** applications realized **with soft, flexible and hard facing**

FHWA-NHI-14-007

- It only deals with **long-term support soil nailing solutions**
- It includes a **final shotcrete or cast-in-place-concrete** (CIP) facing is installed.

FOR HARD FACING ONLY

SOIL NAILING AT A GLANCE

The nails in the British Standard

THE NAILS

BS EN 14490:2010

“Soil nail: reinforcing element installed into the ground, usually at a sub-horizontal angle, that mobilizes resistance with the soil along its entire length.”

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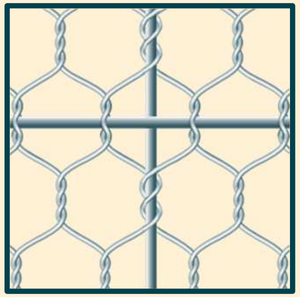
The Facing in the British Standard



THE FACING

bsi.

"Facing: covering to the exposed face of the reinforced ground that may provide a stabilizing function to retain the ground between soil nails, provide erosion protection and have an aesthetic function."

BS EN 14490:2010

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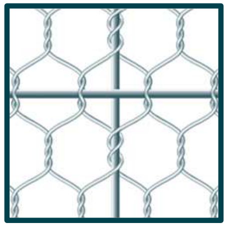
THE SOIL NAILING AT A GLANCE

The Facing in the British Standard



BS 8006-2:2011

The BS 8006-2:2011 identifies three different facing options: hard, flexible and soft facings

HARD FACING

FLEXIBLE FACING

SOFT FACING

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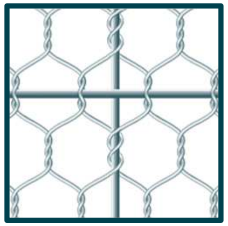
THE SOIL NAILING AT A GLANCE

The Facing in the British Standard



BS 8006-2:2011

The BS 8006-2:2011 identifies three different facing options: hard, flexible and soft facings

HARD FACING	FLEXIBLE FACING	SOFT FACING
		

The Design in the British Standard

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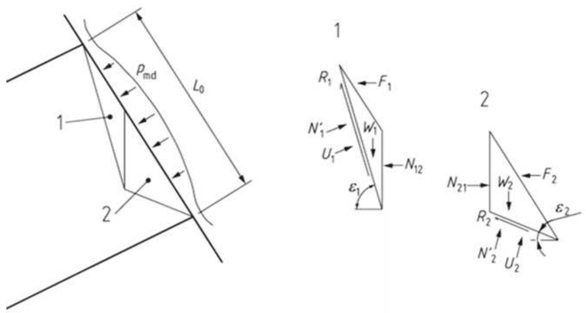
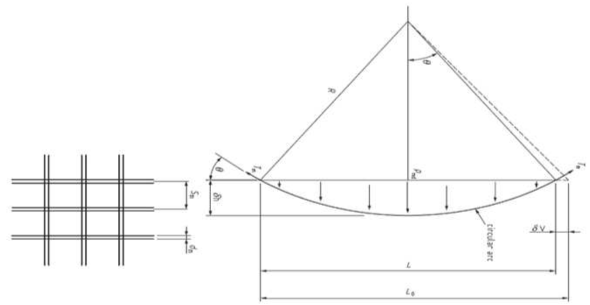
DESIGN OF SIMPLE FLEXIBLE FACING

BS 8006-2:2011 + A1:2017

"A simple flexible facing restrains the surface soil between the nail plate positions only. […] But the surface soil between the nail plates is not self supporting and the facing must be designed to restrain it. A method for calculating the loading to be resisted by the facing based on a two-part wedge failure mechanism forming between two rows of nails is given in the top figure.

The flexible facing may be designed to meet this loading by assuming that it acts as a tensioned catenary as shown in the bottom figure."





LEM ON UNDEFINED SLOPE

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SOIL NAILING AT A GLANCE

DESIGNING SOIL NAILING APPLICATIONS

Q&A SESSION

DEFINITION OF THE SOLUTION: MAC S-DESIGN

Maccaferri has a centre of excellence entirely dedicated to **research and development**, concentrating in a single place the capital of **knowledge** and **know-how**: in Bolzano (Italy) the Maccaferri Innovation Center (M.I.C.) is constantly working to innovate our products and solutions

Mac S-Design

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developed in collaboration with ***Politecnico di Milano***

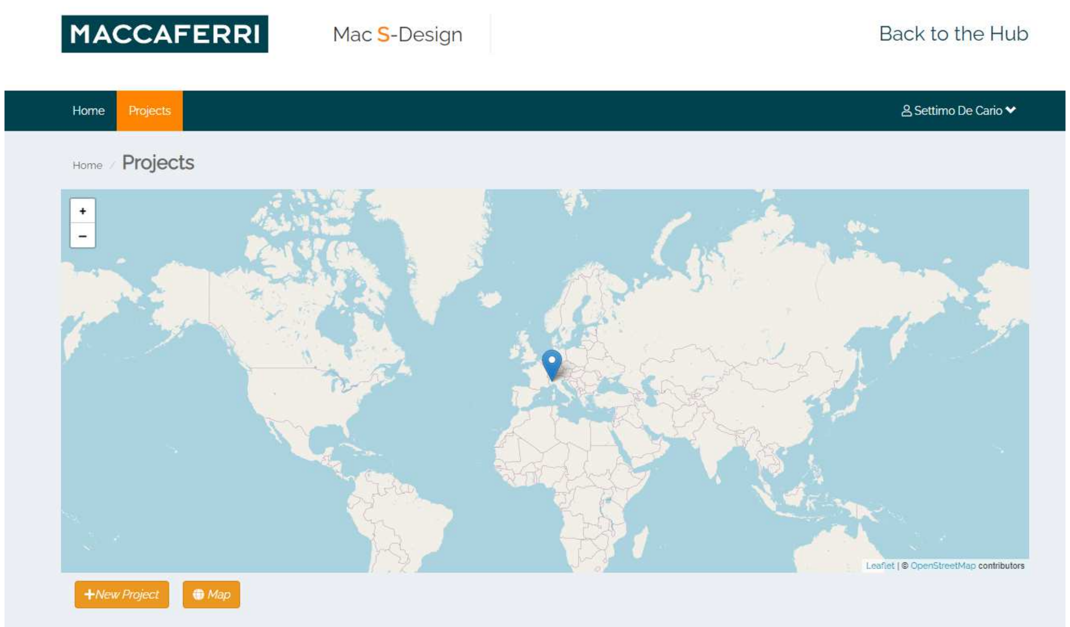
INNOVATION CENTER MACCAFERRI

DEFINITION OF THE SOLUTION: MAC S-DESIGN

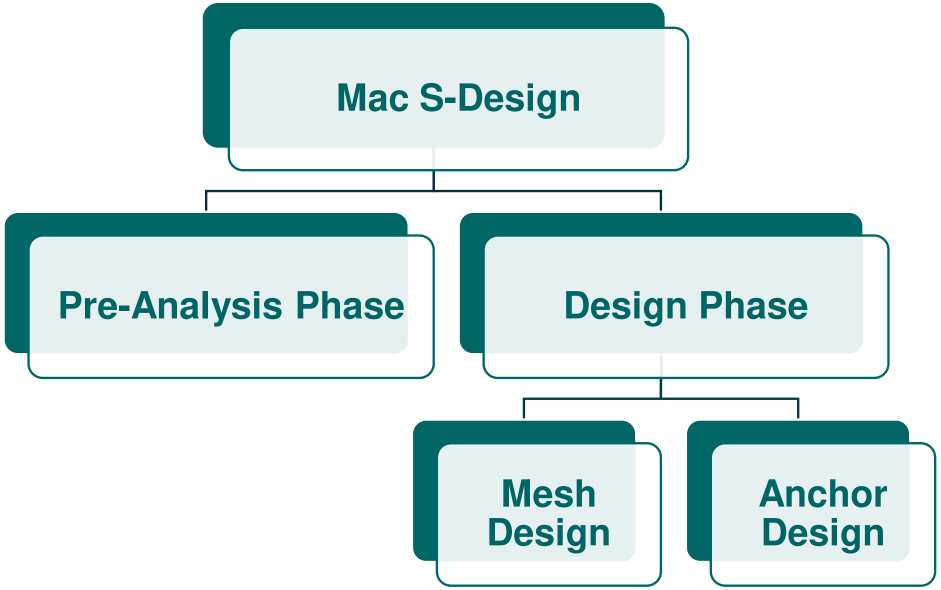
Mac S-Design

is a web-based tool accessible via

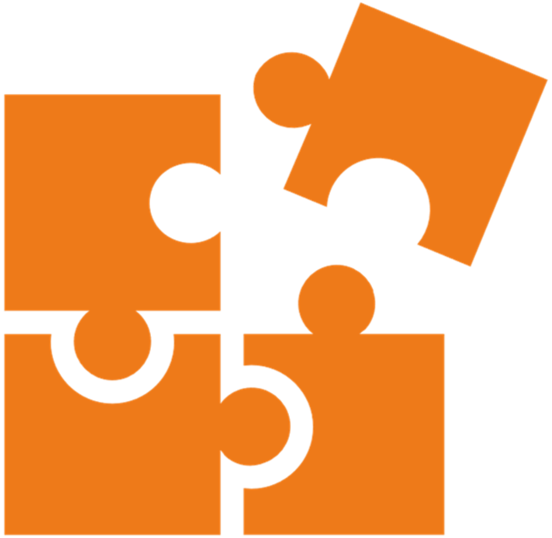
edesign.maccaferri.com



Mac S-Design has been developed with a modular approach:



MAC S-DESIGN APPROACH



Mac S-Design is based on a **hybrid approach**:

- the **stabilizing action** provided by the passive structural intervention is expressed as a **function of the relative soil-structure displacement**;
- the **equilibrium** of the **soil mass** is still analyzed by means of usual **LEM**.

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Which are the main characteristics of the "Hybrid Approach"?

- It is based on a **LEM approach** (Limit Equilibrium Method)

- It can be assumed as a **combination of both ULS and SLS**:
  i. ULS expresses the soil strength parameters (as described for instance in Eurocodes), while
  ii. SLS expresses the displacements condition;

- It is consistent with the **concept of "Mitigation & Prevention of Structures"**

- The design of both mesh and anchors is based on the **soil-mesh interaction** system through the use of a **Characteristic curve**

- The above hypotheses can be summarized in the following general equation:

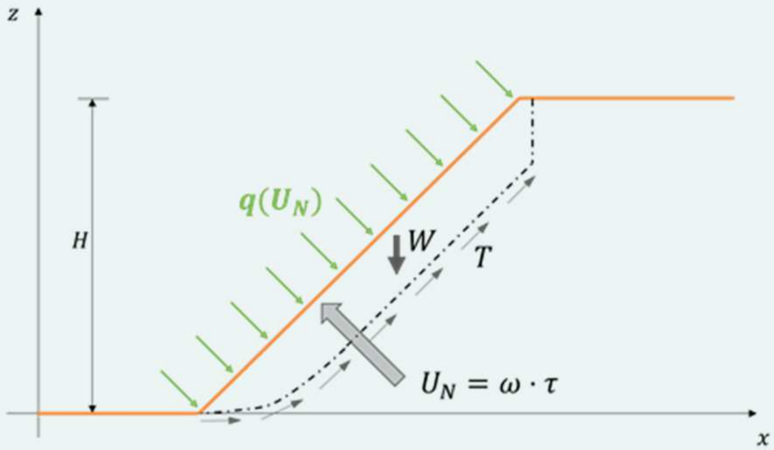
$$E_k^F = \frac{R_k^F}{F_S} + A_k^F(\boldsymbol{U})\ ^*$$

* Where the term E represents the driving forces (e.g. the weight W), R is the soil strength and A is the resulting stabilizing action provided by the mesh depending on the soil-mesh interaction

The problem of the stability of the surficial layer of a slope can be tackled through 3 subsequent phases of analysis:

Phase 1: Identification of the potential failure mechanism

- Identification of both the “failure surface” and of the related field of displacements **U(x,z)** of the soil
- Analysis in the frame of driving forces and resisting forces
- Instability due to: slope angle, unstable soil layer and soil strength parameters, tension crack, water table depth, etc.



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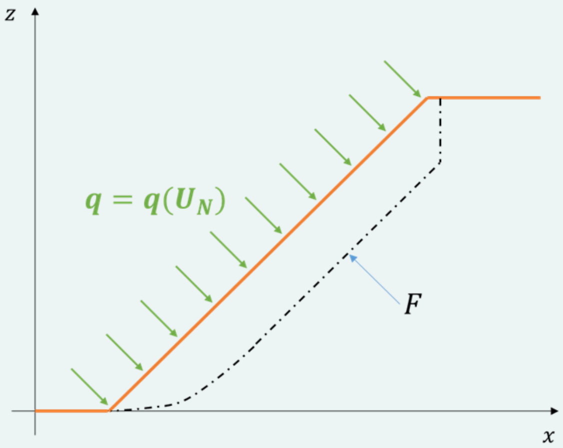
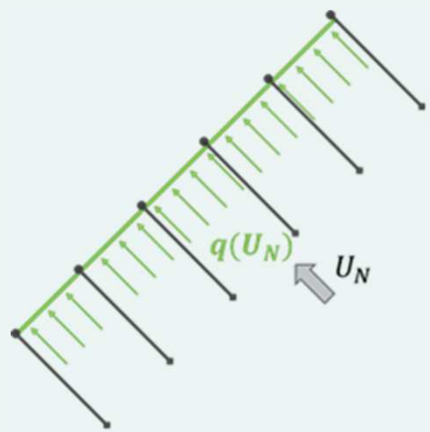
Phase 2: Analysis of Stability

- Definition of the required 'q' stabilizing pressure
- The mesh shall be able to bear the needed 'q' pressure, in case of soil movements



Phase 3: Definition of the Characteristic curve

- The Characteristic curve can be defined
- The pressure '**q**' that shall be withstood by the mesh is related to the Soil displacements **U(x,z)** and it also depends on the applied product
- The force acting on the anchor can be computed to guarantee the equilibrium of the system



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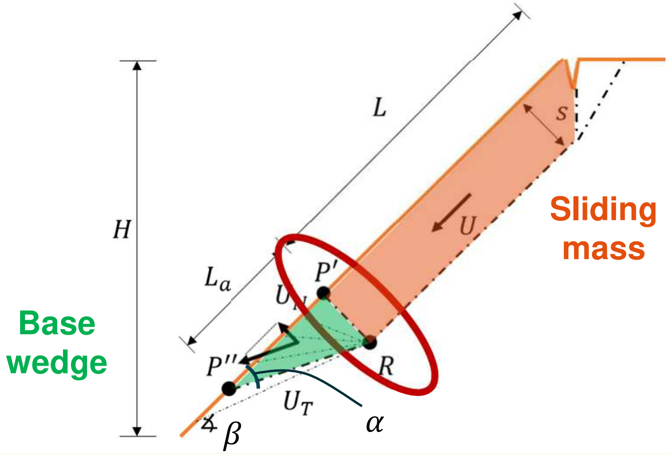
BASIC METHOD ASSUMPTIONS & SCHEMATIC APPROACH

Two approaches are included and they differ due to the geometry of the considered blocks

Method 1

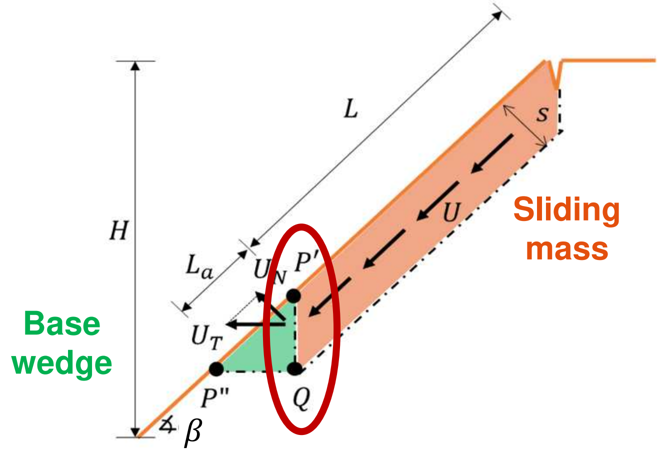


This method considers a stabilizing «soil wedge» where:

- the induced forces are transferred through an interface P'R orthogonal to the slope surface,
- Several wedge elements can be defined for each P' point and each one is defined by a different value of the α angle.

This method is rather compatible with steep slopes

Method 2



This method considers a stabilizing «soil wedge» where:

- the induced forces are transferred through a vertical interface P'Q,
- A single wedge element exists for each P' point.

This method is rather compatible with gentle slopes

THE DEFINITION OF THE CHARACTERISTIC CURVE

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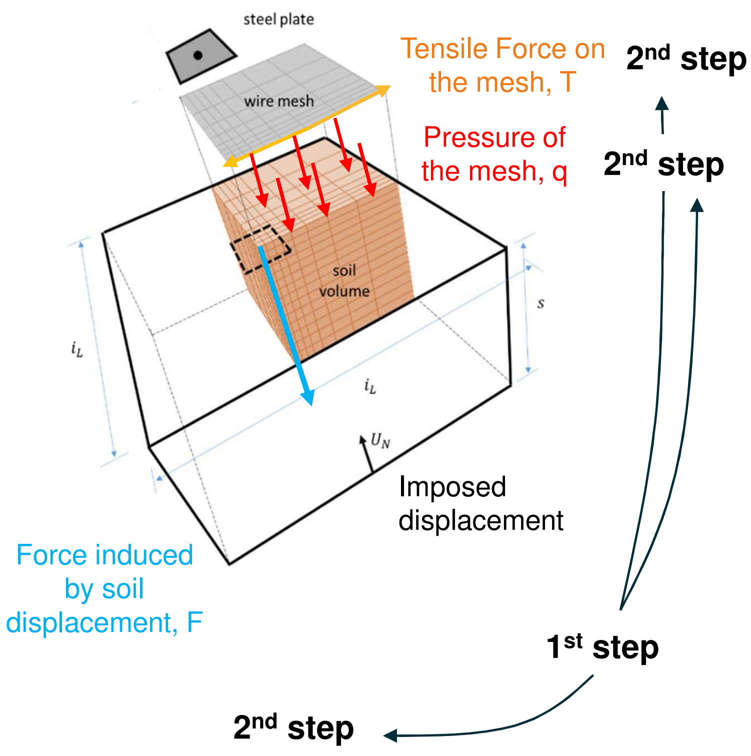
The characteristic curve describes the **interaction behavior between mesh and soil** through an equation. This equation is calibrated on FEM analyses and laboratory tests.

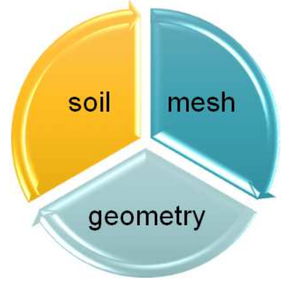


HP

- Isotropic / quasi-isotropic wire mesh

INPUT

- Mechanical properties of the soil
  (e. g. cohesion, Young modulus, Poisson ratio, etc.)
- Mechanical characteristics of the mesh
  (e. g. tensile strength, tensile stiffness)
- Anchor spacing



OUTPUT

The results of the calculation process are expressed in terms of:

- **Load - displacement curve «F-U_N»**
  Tensile force "F" on the anchor vs "U_N" soil displacement
- **Characteristic curve: Load - displacement curve «T-U_N»**
  Tensile force "T" on the mesh vs "U_N" soil displacement
- **Pressure "q"** provided by the mesh against the soil to reach the equilibrium of the system

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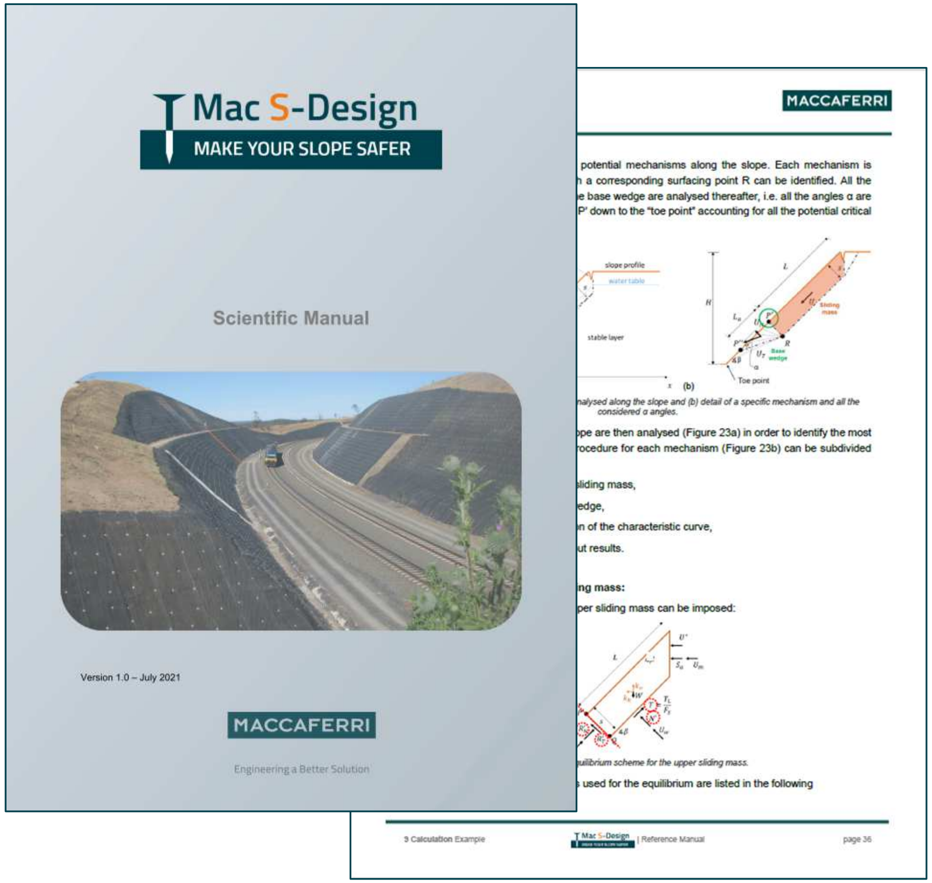

FOR A DETAILED EXPLAINATION OF THE SOFTWARE APPROACH, DOWNLOAD THE **SCIENTIFIC MANUAL** AND **USER GUIDE**

REAL SLOPE HEIGHT

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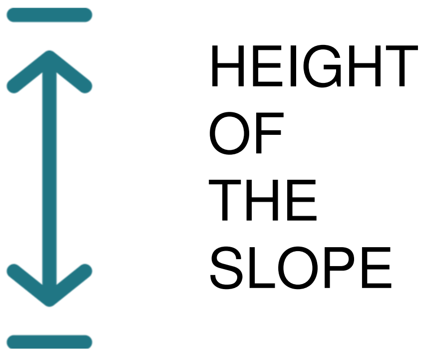

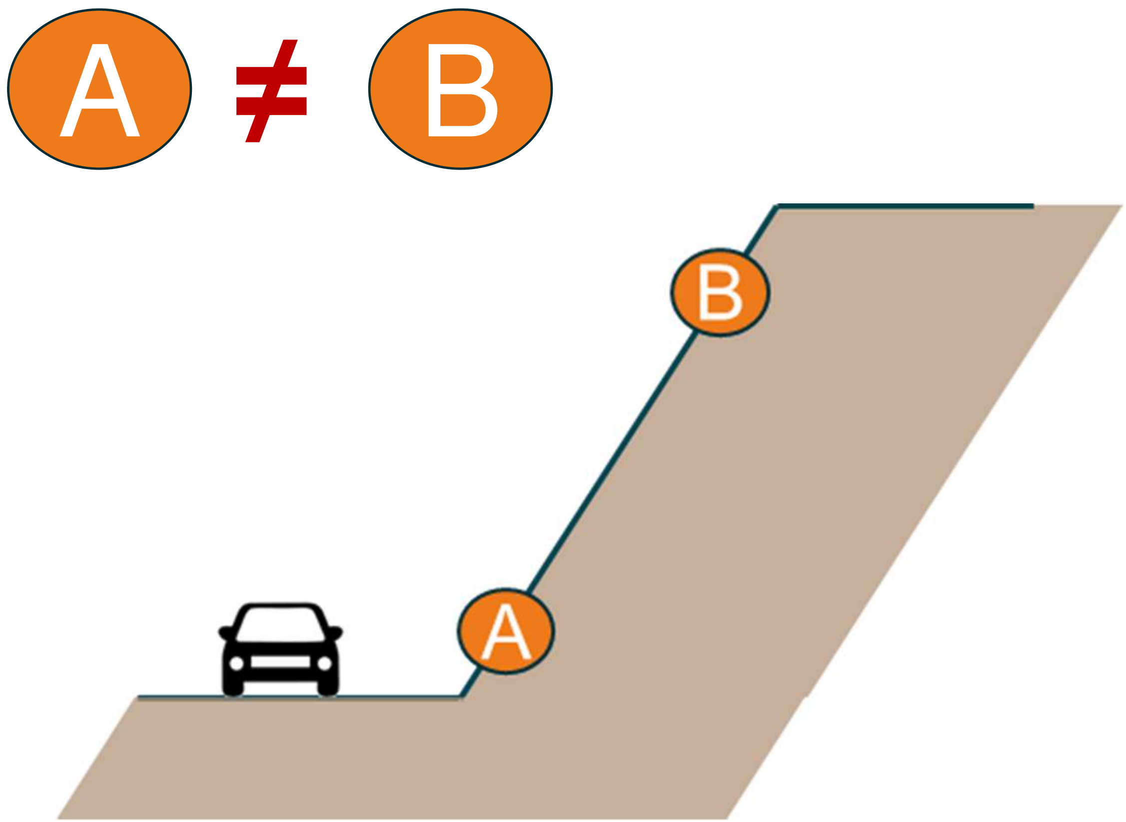

Mac S-Design considers the real height of the slope (defined slope approach). The load applied to the mesh varies along the slope.

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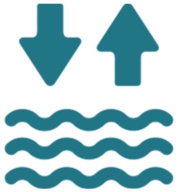
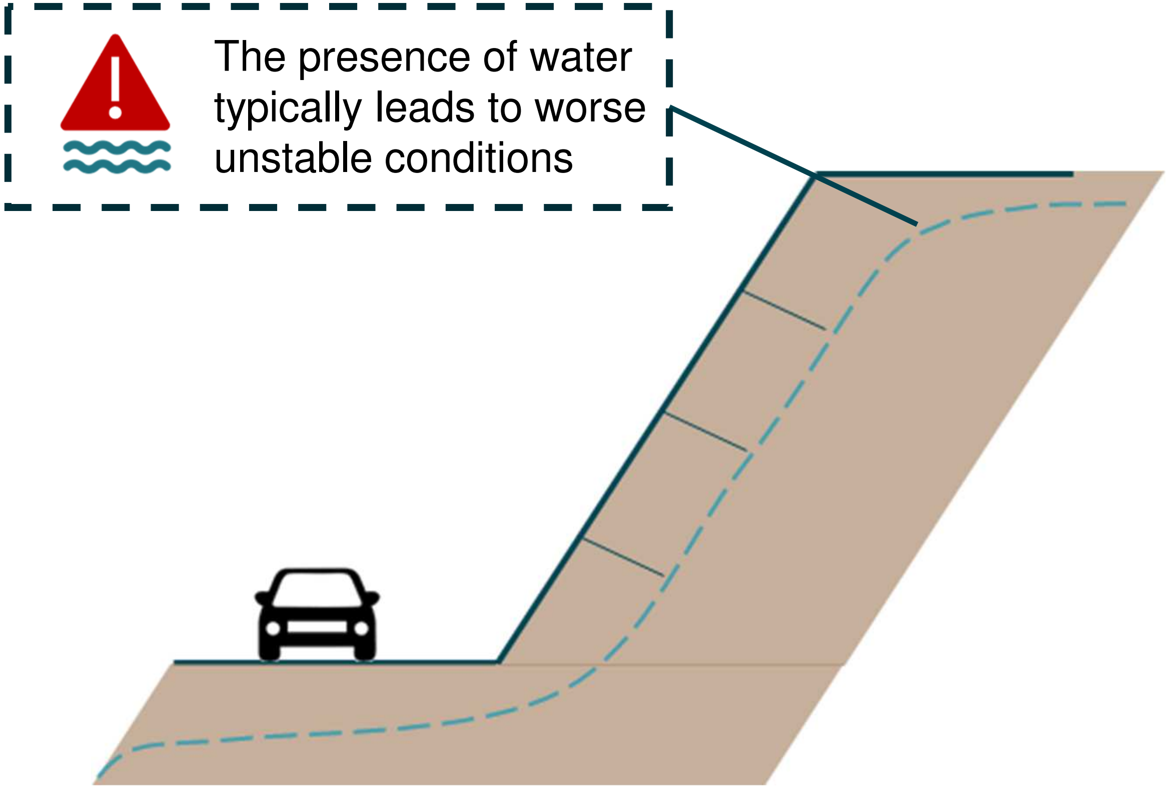
WATER TABLE LEVEL



WATER TABLE LEVEL CAN BE TAKEN INTO ACCOUNT

Mac S-Design enable designers to consider the water table level in their soil nailing calculation.



ANALYSIS OF THE UNSTABLE LAYER

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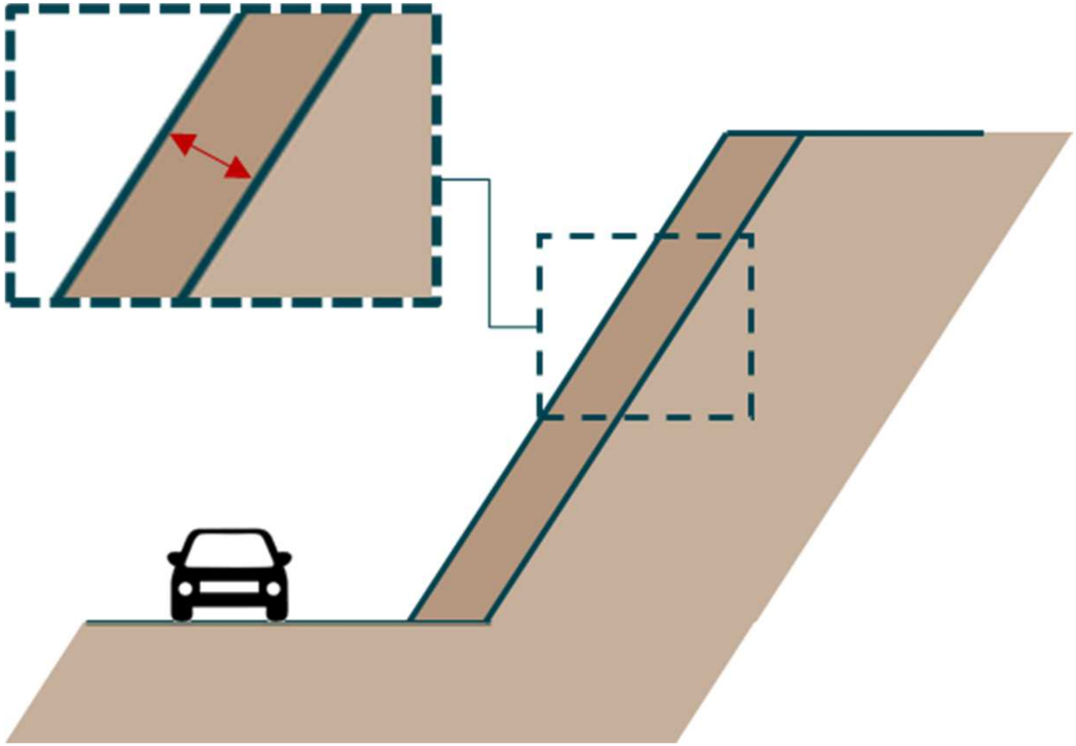
20% of SLOPE HEIGHT

THICKNESS OF THE UNSTABLE LAYER

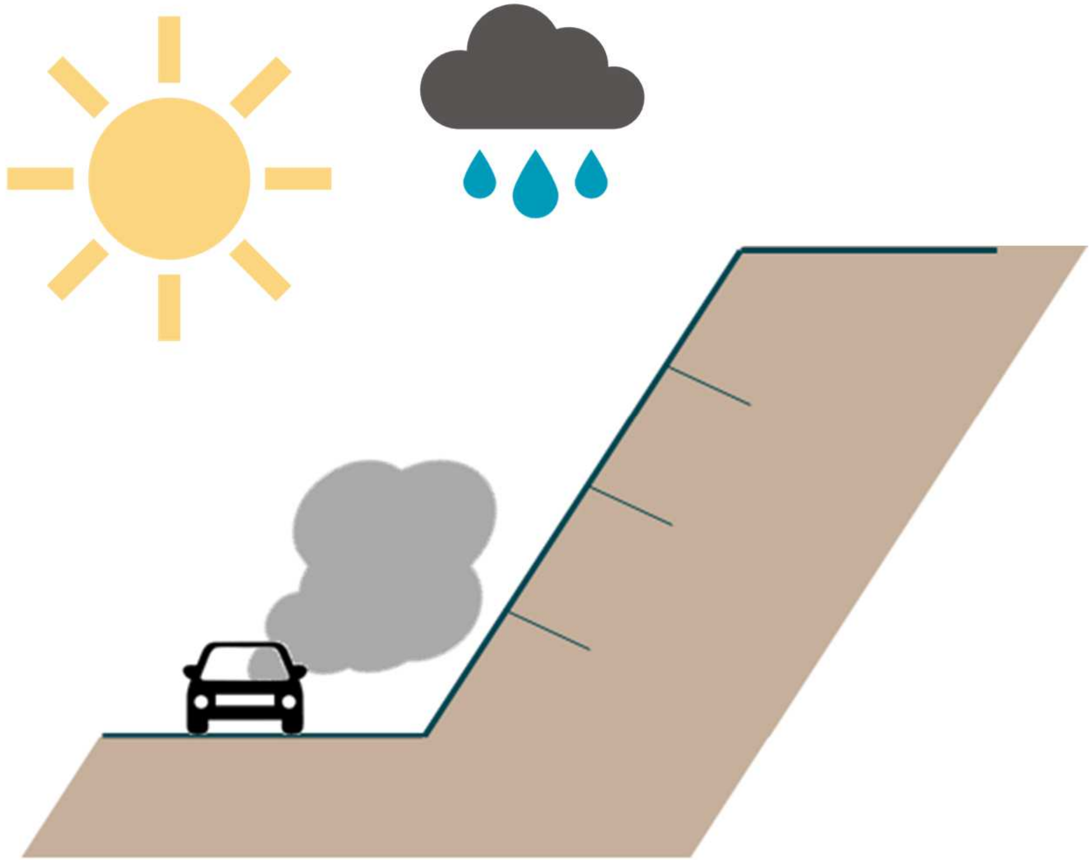
Mac S-Design allows to consider an unstable layer of soil up to a thickness of 20% of the slope height. This enables the analysis of a wide range of cases.



ENVIRONMENTAL EXPOSURE

ENVIRONMENTAL EXPOSURE
ACCORDING TO EN10223-3
AND EN10244-2.

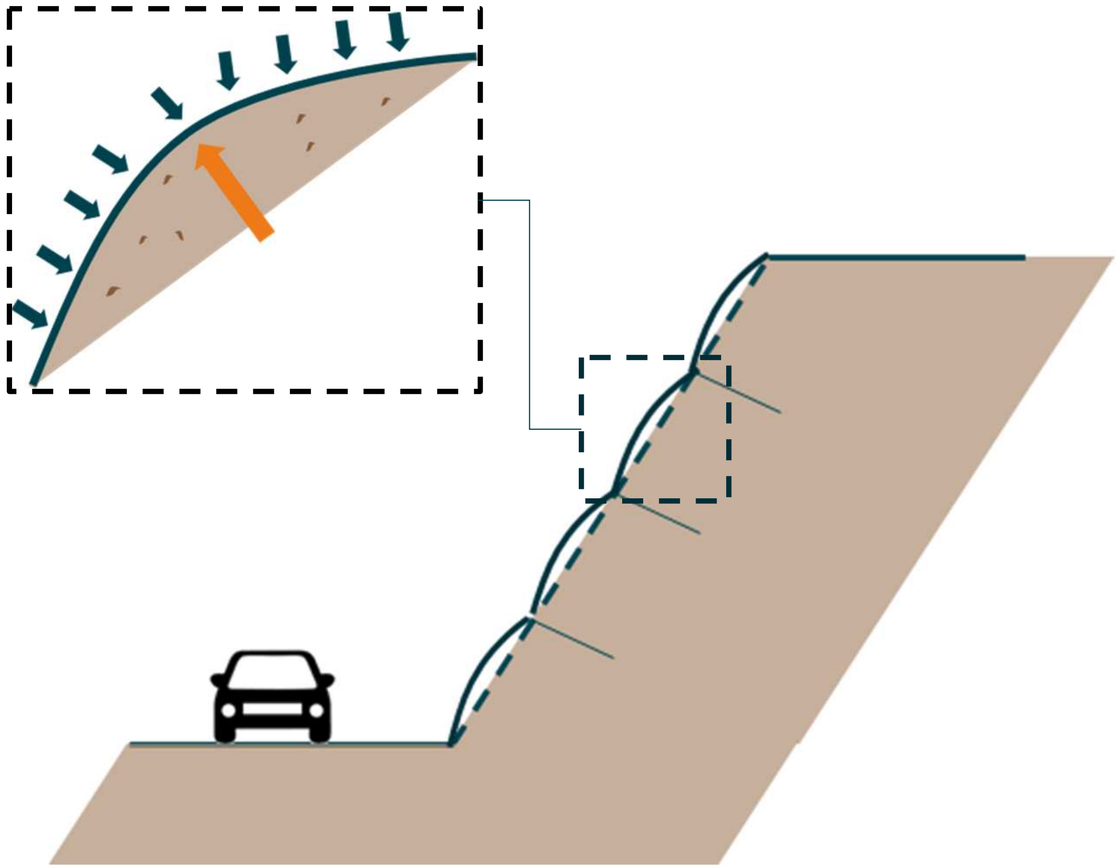
Mac S-Design enables designers to consider environmental exposure in their soil nailing calculation for both the mesh and the nails (corrosion crown).



STRESS-DISPLACEMENT

THE MESH DOES NOT EXERT ANY PRESSURE ON SOIL IF NOT DEFORMED

Mac S-Design is based on stress-displacement curves. There is no need of inputting arbitrary forces that might affect the reliability of the output



MESH WORKING RATIO

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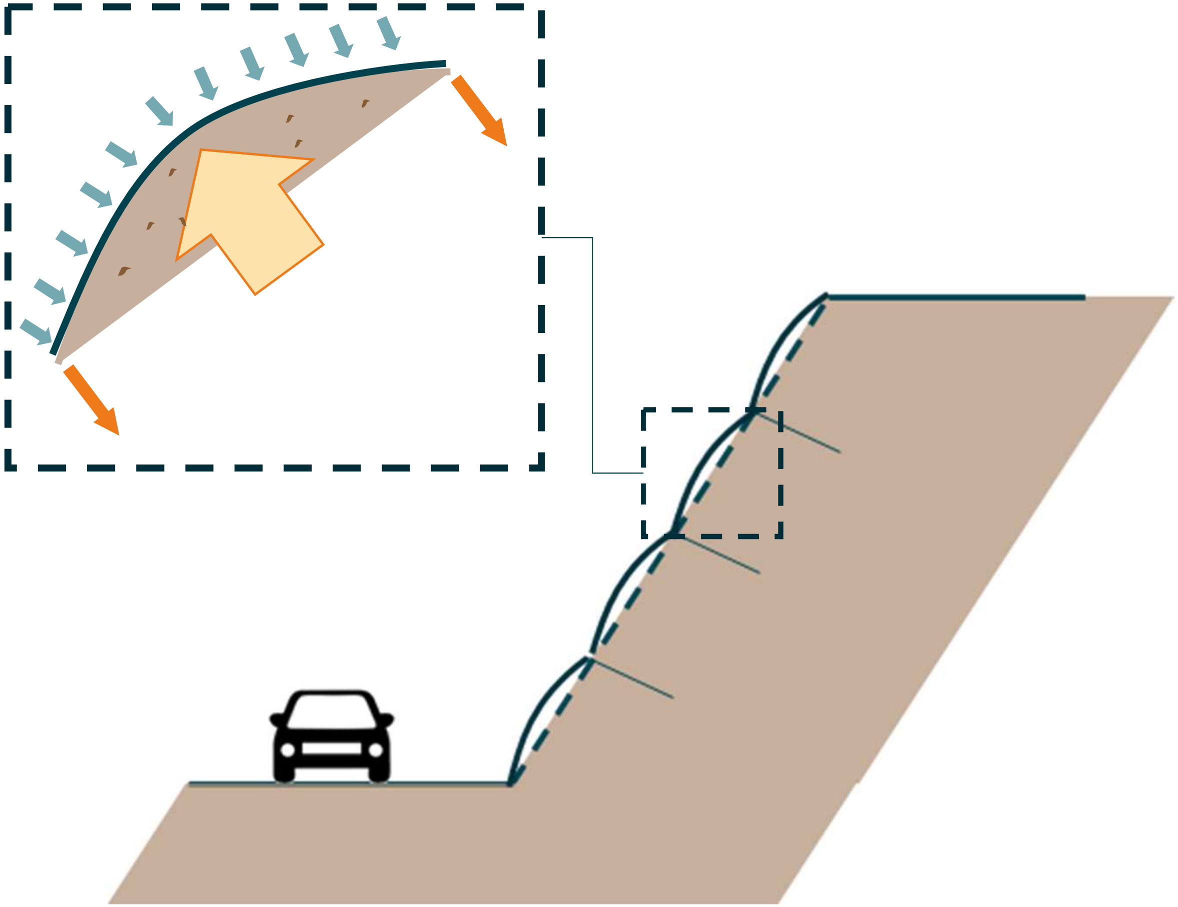
MESH WORKING RATIO



Mac S-Design optimizes the mesh design returning its working ratio.

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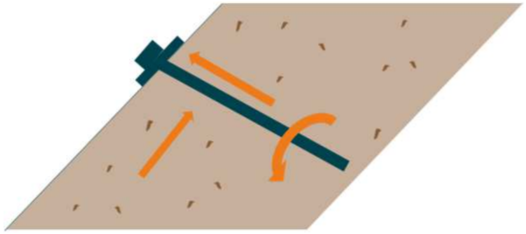
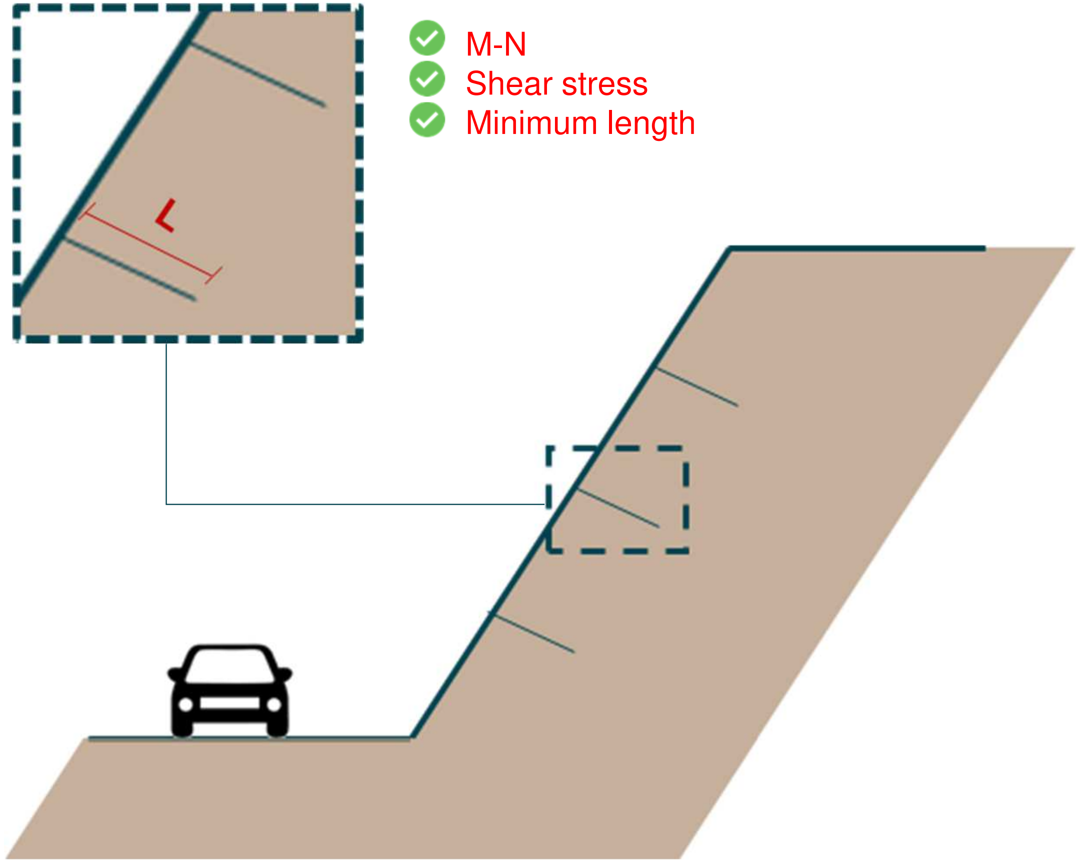
ANALYSIS OF SOIL NAILS



CHECK ON NAILS' STABILITY

Mac S-Design checks the nails for shear stress, bending moment and axial forces, and calculates their length.



BASIC METHOD ASSUMPTIONS & SCHEMATIC APPROACH

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The conceptual framework of Mac S-Design can be summarized as follows:

INPUT

- Geometry
  (height and angle of the slope, thickness of unstable layer, etc.)
- Geotechnical Parameters
  (friction angle, cohesion, specific weight, etc.)
- Water Table, Partial Coeff., Seismic Coeff., Safety Factor

PRE-ANALYSIS

- Analysis of all the potential sliding surfaces
- Stability analysis through “**Method 1**” and “**Method 2**”
- Identification of the most unstable mechanism (i.e. lowest FS)

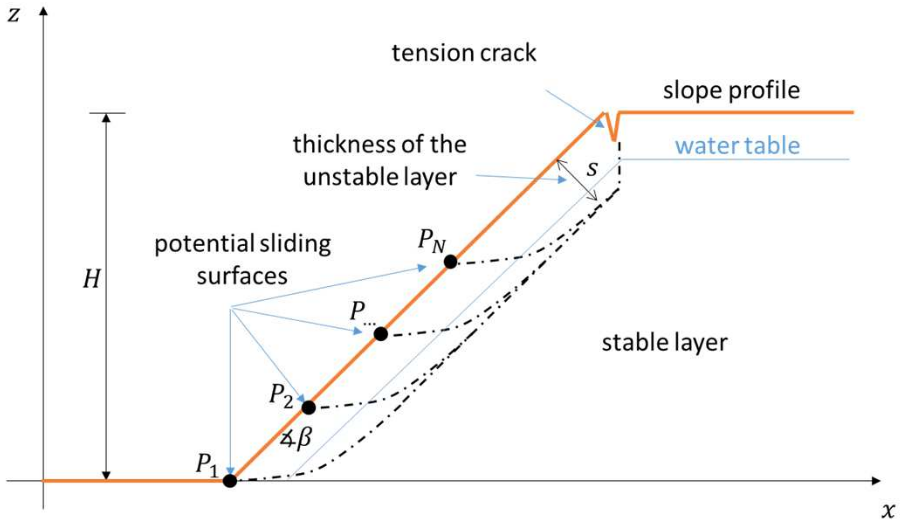
DESIGN

When FS < FS_{design}:

- Selection of the appropriate mesh to provide the needed ‘q’ stabilizing pressure
- Definition of the anchors characteristics

ANALYSIS

- Calculation of the **characteristic curve** of the selected mesh
- Stability analysis through “**Method 1**” and “**Method 2**”



OUTPUT

- Verification of the FS_{design}
- Mesh verification and Working Ratio
- Verification of nails

A REAL CASE WITH MAC S-DESIGN

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A REAL CASE EXAMPLE

Main Input Data

GEOMETRY:

Slope height: 25 m
Slope angle: 45°
Unstable soil thickness: 2.0 m

GEOTHECNICAL PARAMETERS:

Soil friction angle: 40°
Cohesion: 10 kPa
Unit weight: 21 kN/m^3
Saturated unit weight: 22 kN/m^3

WATER TABLE:

Water table depth: 1.5 m

SEISMIC COEFFICIENTS:

Horizontal seismic coefficient: 0.0
Vertical seismic coefficient: 0.0

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