SRS - Soil Reinforcement System 2.0

General Information

SRS is a design software for the dimensioning, in compliance with the current NTC 2018, of a cortical covering system for unstable soil layers, consisting of metal mesh connected to the ground by means of bar anchors.

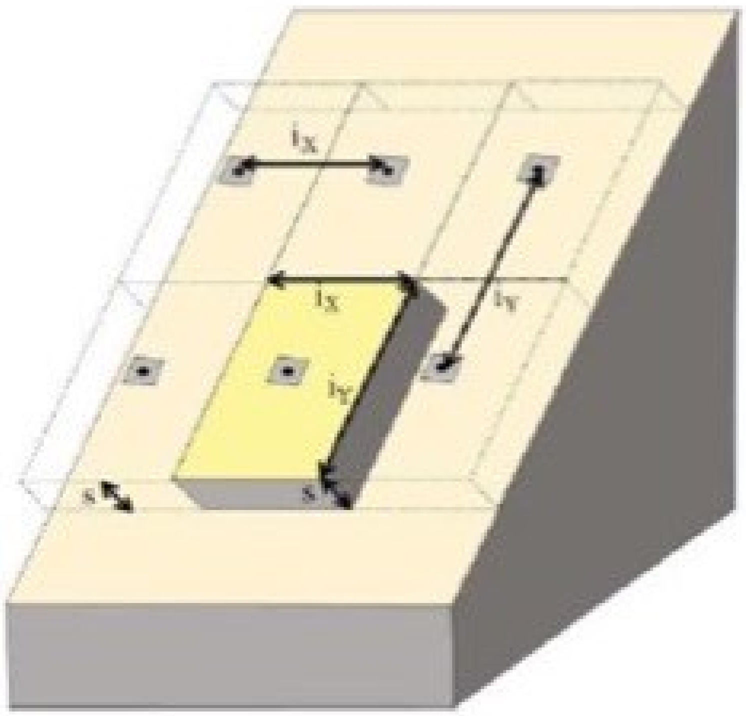
In **SRS**, reversing the usual design approach, the Designer sets the value of the design safety factor (**FS_{des}**) and the software determines the tensile force in each anchor required to achieve it.

Since the increase in the safety factor achieved following the implementation of the consolidation system is quantified, this can be considered as a "stabilization intervention" as prescribed in section 6.3.5 of NTC 2018.

Calculation Scheme

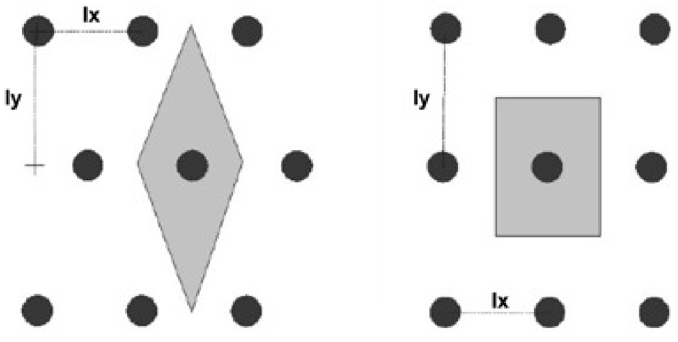
The scheme adopted in **SRS** provides for a stability analysis with respect to a translational kinematics of the soil volume represented planimetrically by the influence area of the single anchor and having a thickness equal to the thickness, measured perpendicularly to the sliding surface, of the layer to be stabilized (**S**).

It is assumed that sliding can occur on the contact surface between the layer and the underlying substrate, which can be composed of soil or rock, having the same angle of inclination α with respect to the horizontal of the topographic surface.



The analysis is also carried out under seismic conditions using the pseudo-static approach, as provided in section 7.11.3.5.2 of NTC 2018, considering such actions under the most unfavorable conditions.

For the definition of the soil volume, reference can be made to the following anchor arrangement schemes (rectangular or rhomboidal raster).

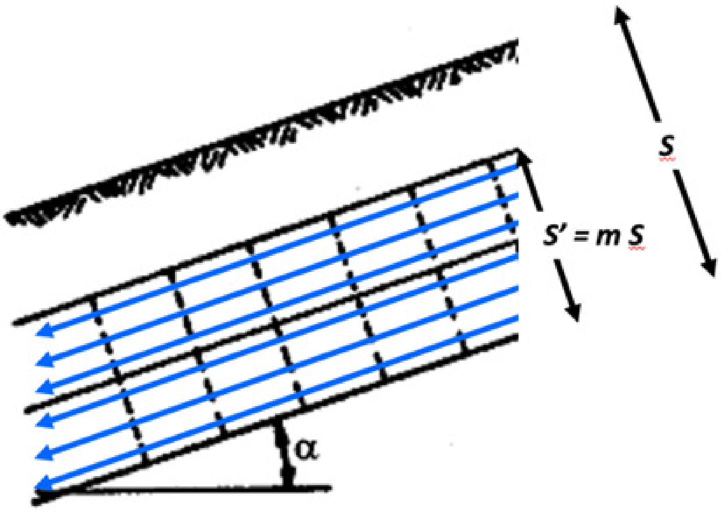


The volume, for both rhomboidal and rectangular rasters, is given by:

$$\mathbf{V = I_x\, I_y\, S\ (m^3)}$$

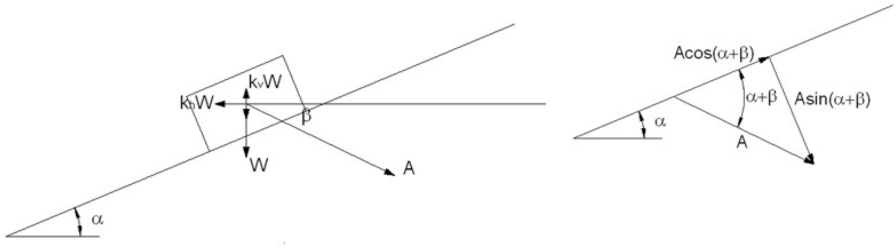
The stability analysis can also be carried out considering, in addition to seismic actions, the presence of a seepage flow with flow lines parallel to the slope affecting the layer for a thickness:

$$\mathbf{S' = m\ S}$$



In the absence of water table: **m = 0**; for water table at ground level: **m = 1**

The tensile force **A** to be transferred to each individual anchor to obtain the design safety factor (**FS_{des}**) is obtained by solving the following expression:



$$FSdes = \frac{\left[(W \pm F_V)\cos\alpha - F_h\sin\alpha + A\sin(\alpha+\beta)\right]\tan\varphi}{(W \pm F_V)\sin\alpha + F_h\cos\alpha - A\cos(\alpha+\beta)}$$

Once the tensile force acting on the anchor for achieving FS_{des} is known, the following verifications are carried out, applying the appropriate partial coefficients provided by NTC 2018:

1) Bar tensile strength verification;
2) Bar shear strength verification;
3) Bar/grout pull-out verification;
4) Foundation/soil pull-out verification;
5) Mesh punching resistance verification;
6) Mesh tensile strength verification.

The verifications are considered satisfied if the design loads E_d are lower than the design resistances R_d:

$$\mathbf{E_d < R_d}$$

The calculation approach used, according to NTC 2018, is Approach 2, which provides for the single combination (A1 + M1 + R3).

INPUT

Soil and Substrate Parameters

Soil layer

I.1. ***Slope inclination*** α: "average" angle (in sexagesimal degrees) of slope inclination with respect to the horizontal.

I.2. ***Thickness S***: thickness (in m) of the layer to be stabilized by the system, measured perpendicularly to the topographic surface.

I.3. ***Unit weight*** γ_{col}: unit weight (in kN/m^3) of the soil layer.

I.4. ***Friction angle*** ϕ_{col}: friction angle (in sexagesimal degrees) of the soil.

I.5. ***Drained cohesion*** c'_{col}: drained cohesion (in kPa) of the soil.

I.6. ***Dimensionless thickness affected by seepage flow m***: represents the ratio m = S' / S, where S' is the thickness, measured perpendicularly to the sliding surface, in which a seepage flow occurs with flow lines parallel to the surface (m = 0 for absent water table, m = 1 for water table at ground level, 0 < m < 1 for intermediate situations).

Substrate

I.7. ***1 = soil; 2 = rock***: enter the value "1" for soil substrate, "2" for rock substrate.

Case 1: Soil

I.8. ***Adhesion stress of the soil constituting the substrate*** ad_{soil} (in MPa), obtainable from pull-out tests or, in the absence of direct measurements, from reference tables.

TERRENO		Tensione di aderenza unitaria malta-terreno [Mpa] min	max
ROCCIA			
✔	Basalto	5.50	6.00
✔	Calcare	2.80	4.80
✔	Arenaria	1.50	1.70
✔	Dolomite	1.70	1.90
✔	Scisti	0.50	0.70
✔	Scisti alterati	0.30	0.50
✔	Gesso	0.60	0.80
✔	Ardesia	1.60	1.80
SCIOLTO			
✔	Limi argillosi	0.06	0.09
✔	Argilla satura	0.05	0.08
✔	Argilla sabbiosa compatta	0.20	0.40
✔	Sabbia medio fine compatta	0.20	0.60
✔	Argilla medio plastica dura	0.20	0.50
✔	Argilla medio plastica media	0.16	0.29
✔	Sabbia grossa e ghiaia compatta	0.29	0.60

E. Segre, *"Proposta di metodo di prove semplici per tiranti di ancoraggio"*
(Industria Italiana del Cemento 6/88)

I.9. ***Coefficient*** α_{inj}, which takes into account the injection modalities, obtainable from reference tables (Bustamante & Doix, 1985).

Case 2: Rock

I.10. ***Adhesion stress of the rock constituting the substrate*** ad_{rock} (in MPa), obtainable from pull-out tests or, in the absence of direct measurements, from reference tables.

	TERRENO	Tensione di aderenza unitaria malta-terreno [Mpa] min	max
ROCCIA			
✔	Basalto	5.50	6.00
✔	Calcare	2.80	4.80
✔	Arenaria	1.50	1.70
✔	Dolomite	1.70	1.90
✔	Scisti	0.50	0.70
✔	Scisti alterati	0.30	0.50
✔	Gesso	0.60	0.80
✔	Ardesia	1.60	1.80
SCIOLTO			
✔	Limi argillosi	0.06	0.09
✔	Argilla satura	0.05	0.08
✔	Argilla sabbiosa compatta	0.20	0.40
✔	Sabbia medio fine compatta	0.20	0.60
✔	Argilla medio plastica dura	0.20	0.50
✔	Argilla medio plastica media	0.16	0.29
✔	Sabbia grossa e ghiaia compatta	0.29	0.60

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Seismic Parameters

I.11. ***Horizontal seismic coefficient*** K_h: this coefficient represents the mass multiplier to obtain, using the pseudo-static approach, the horizontal and vertical seismic force. The coefficient value is obtained, according to the Standards, as a function of the maximum expected acceleration on a rigid reference site, dependent on the return period considered for the seismic action, appropriately amplified through the S_S (stratigraphic amplification) and S_T (topographic amplification) coefficients. Seismic forces are always considered in the most conservative direction (increase in loads, decrease in resistances).

Design Safety Factor

I.12. FS_{des}: value of the safety factor to be achieved post-intervention. Since partial amplification (for loads) or reduction (for resistances) coefficients are applied to all quantities according to the Standards, this variable can be assigned a value slightly above unity (e.g.: 1.05).

System Parameters

Anchors

I.13. ***Raster Y dimension I_y***: distance (in m) in the vertical direction between two anchors.

I.14. ***Raster X dimension I_x***: distance (in m) in the horizontal direction between two anchors.

I.15. ***Anchor inclination*** β: inclination (in degrees) of anchors with respect to the horizontal.

I.16. ***Anchor length L_a***: length of anchors, considering both the part that develops within the layer (non-contributing) and the part within the substrate (contributing).

I.17. ***Drilling diameter D_f***: diameter (in mm) of the anchor housing hole.

I.18. ***Bar diameter*** ϕ_b: diameter (in mm) of the anchor bar.

I.19. ***Bar yield strength f_{yk}***: characteristic yield strength (in N/mm^2) of the steel constituting the bar (data provided by the manufacturer).

I.20. ***Grout compressive strength R_{bk}***: characteristic compressive strength (in N/mm^2) of the injection grout.

I.21. ***Adhesion coefficient***: reduction coefficient for steel-concrete adhesion shear stress, as per section 4.1.2.1.1.4 of NTC 2018, equal to 1 for good adhesion and 0.7 for poor adhesion.

I.22. ***Number of investigation profiles for geotechnical parameter definition***: number based on which correlation factors are determined to derive characteristic resistance from geotechnical tests, according to Tab. 6.6.III of NTC 2018.

Mesh

I.23. ***Mesh unit tensile strength $R_{tr\_u\_mesh}$***: resistance (in kN/m) per meter width of the mesh chosen for consolidation (data provided by manufacturer).

I.24. ***Mesh punching resistance R_{punch}***: punching resistance (in kN) of the mesh chosen for consolidation (data provided by manufacturer).

I.25. ***Mesh resistance coefficient*** γ_{mesh}: coefficient (≥ 1) that the User can apply to reduce the tensile and punching resistance values of the mesh provided by the manufacturer (not required by NTC).

CALCULATIONS

E.1. ***Acting volume V***: volume (in m^3) identified by the influence area of the single anchor multiplied by the layer thickness:

$$\mathbf{V = S\ I_x\ I_y}$$

E.2. ***Volume weight W***: weight of the above-calculated volume (in kN):

$$\mathbf{W = \gamma_{col}\ V}$$

E.3. ***Hydraulic uplift U***: upward thrust (in kN) exerted at the base of the soil block in the presence of seepage flow in the layer, calculated as:

$$\mathbf{U = \gamma_w\ S'\ \cos\alpha\ I_x\ I_y}$$

E.4. ***Horizontal seismic force F_h***: seismic force (in kN) in the horizontal direction, obtained by multiplying the horizontal seismic coefficient K_h by the volume weight:

$$\mathbf{F_h = K_h\ W}$$

E.5. ***Vertical seismic force F_v***: seismic force (in kN) in the vertical direction, obtained by multiplying the horizontal seismic force by 0.5:

$$\mathbf{F_v = 0.5\ F_h}$$

E.6. ***Resisting tangential force T_{res0}***: resistance (in kN) along the sliding surface, obtained as:

$$\mathbf{T_{res0} = c'_{col}\ I_x\ I_y + [V\ (\gamma_{col} - m\gamma_w)\ \cos\alpha - F_h\ \sin\alpha - F_v\ \cos\alpha]\ \cos\alpha\ \tan\phi_{col}}$$

E.7. ***Acting tangential force T_{ag0}***: force (in kN) along the sliding surface, obtained as:

$$\mathbf{T_{ag0} = W\ \sin\alpha + F_h\ \cos\alpha + F_v\ \sin\alpha}$$

E.8. ***Pre-intervention safety factor FS_0***: obtained as:

$$\mathbf{FS_0 = T_{res0}\ /\ T_{ag0}}$$

E.9. ***Tensile force A***: tensile force in the anchor (in kN) necessary to reach the design safety factor FS_{des}, obtained as:

$$\mathbf{A = (FS_{des}\ T_{ag0} - T_{res0})\ /\ [\sin(\alpha + \beta)\ \tan\phi_{col} + FS_{des}\ \cos(\alpha + \beta)]}$$

E.10. ***Design tensile load in the anchor E_d***: obtained by multiplying the value of A by the partial coefficient γ_{Q1} = 1.5 (static case NTC 2018 A1 - 6.2.4.1.1) or 1.0 (seismic case - Tab. 6.2.I and 7.11.1):

$$\mathbf{E_d = \gamma_{Q1}\ A}$$

E.11. ***Design shear load T_d***: obtained by multiplying the value of T_{ag0} by the partial coefficient γ_{Q1} = 1.5 or 1.0 (NTC 2018 A1 - 6.2.4.1.1 - Tab. 6.2.I and 7.11.1):

$$\mathbf{T_d = \gamma_{Q1}\ T_{ag0}}$$

E.12. ***Maximum bar tensile resistance R_f***: maximum tensile force (in kN) supported by the bar according to the steel type and diameter chosen, applying the ultimate limit state amplification coefficient γ_f = 1.15 (NTC 2018 4.1.2.1.1.3):

$$\mathbf{R_f = [f_{yk}\ (\phi_b^2/4)\ /\ \gamma_f]/1000}$$

E.13. ***Maximum bar shear resistance T_f***: maximum shear force (in kN) supported by the bar as a "dowel" equal to:

$$\mathbf{T_f = R_f\ /\ (3)^{0.5}}$$

E.14. ***Grout cylindrical compressive strength f_{ck}***: resistance (in N/mm^2) referred to cylindrical specimens, obtained by multiplying the cubic resistance by 0.83 (NTC 2018 11.2.10.1).

E.15. ***Mean grout tensile strength f_{ctm}***: mean tensile resistance (in N/mm^2) of the grout, obtained as (NTC 2018 11.2.10.2):

$$\mathbf{f_{ctm} = 0.3\ (f_{ck})^{2/3}}$$

E.16. ***Characteristic grout tensile strength f_{ctk}***: characteristic tensile resistance (in N/mm^2) of the grout, obtained as (NTC 2018 11.2.10.2):

$$\mathbf{f_{ctk} = 0.7\ f_{ctm}}$$

E.17. ***Bar diameter coefficient*** η_2: coefficient defined in section 4.1.2.1.1.4 of NTC 2018 as a function of the anchor bar diameter, equal to 1.0 for bars with diameter $\phi_b \leq$ 32mm and $(132 - \phi_b)/100$ for bars with larger diameter.

E.18. ***Characteristic adhesion shear strength f_{bk}***: grout/bar shear resistance (in N/mm^2), given by (NTC 2018 4.1.2.1.1.4):

$$\mathbf{f_{bk} = 2.25\ \eta_1\ \eta_2\ f_{ctk}}$$

E.19. ***Design adhesion shear strength f_{bd}***: design shear resistance for grout/bar adhesion (in N/mm^2), given by (NTC 2018 4.1.2.1.1.4):

$$\mathbf{f_{bd} = f_{bk}\ /\ \gamma_c}$$

E.20. ***Bar/grout pull-out resistance R_{bm}***: maximum pull-out resistance (in kN) of the bar from the injection grout, obtained as:

$$\mathbf{R_{bm} = f_{bd}\ S_{lat\_bar}}$$

E.21. ***Non-contributing anchor length L_{nc}***: part of the anchor (in m) developing within the layer and not considered for the bulb/substrate pull-out verification:

$$\mathbf{L_{nc} = S\ /\ \cos\ (\alpha + \beta)}$$

E.22. ***Contributing anchor length (bulb) L_{bulb}***: part of the anchor (in m) developing in the substrate and considered for the bulb/substrate pull-out verification:

$$\mathbf{L_{bulb} = L_{tot} - L_{nc}}$$

E.23. ***Average bulb/substrate adhesion τ_{sub}***: value (in MPa) of adhesion between the bulb and the substrate. For soil substrate: $\tau_{sub} = \alpha_{inj}\ ad_{soil}$. For rock substrate: $\tau_{sub} = ad_{rock}$.

E.24. ***Investigated verticals reduction coefficient ξ_{a4}***: coefficient from Tab. 6.6.III of NTC 2018 as a function of the number of investigation profiles.

E.25. ***Permanent anchors reduction coefficient γ_{Rap}***: coefficient from Tab. 6.6.I of NTC 2018.

E.26. ***Bulb/substrate pull-out resistance R_{bulb}***: maximum pull-out resistance (in kN) of the foundation bulb from the substrate:

$$\mathbf{R_{bulb} = (\tau_{sub}\ L_{bulb}\ \pi\ D_f)\ /\ \xi_{a4}\ /\ \gamma_{Rap}}$$

E.27. ***Design mesh punching resistance R_{punch_des}***: (in kN) obtained by dividing the punching resistance value R_{punch} by the mesh resistance coefficient γ_{mesh}:

$$\mathbf{R_{punch\_des} = R_{punch}\ /\ \gamma_{mesh}}$$

E.28. ***Design mesh tensile resistance $R_{tr\_u\_mesh\_des}$***: (in kN) obtained by dividing the tensile resistance value $R_{tr\_u\_mesh}$ by the mesh resistance coefficient γ_{mesh}:

$$\mathbf{R_{tr\_u\_mesh\_des} = R_{tr\_u\_mesh}\ /\ \gamma_{mesh}}$$

OUTPUT

The increase in the safety factor value is provided and the safety verifications are carried out evaluating, for each mechanism, the condition:

$$E_d < R_d$$

Furthermore, for each analyzed mechanism, the value of the safety factor FS is provided, defined as:

$$FS = R_d / E_d$$

R.1. ***Safety factor increase ΔFS***: obtained as the difference between the pre-intervention safety factor FS_0 and the design safety factor FS_{des}:

$$\Delta FS = FS_{des} - FS_0$$

R.2. ***Bar tension***: the tensile load E_d is compared with the bar tensile resistance R_f.

R.3. ***Bar shear***: the shear load T_d is compared with the bar shear resistance T_f.

R.4. ***Bar/grout pull-out***: the tensile load E_d is compared with the bar/grout pull-out resistance R_{bm}.

R.5. ***Bulb/substrate pull-out***: the tensile load E_d is compared with the bulb/substrate pull-out resistance R_{bulb}.

R.6. ***Mesh punching***: the tensile load E_d is compared with the mesh punching resistance R_{punch}.

R.7. ***Mesh tension***: the shear load per meter width (T_d / I_x) is compared with the mesh unit tensile resistance $R_{tr\_u\_mesh\_des}$ (it is assumed that all shear load must be absorbed by the mesh through its own tensile resistance).

R.8. ***Number of anchors N_{tot}***: number of anchors per 100m^2 of mesh:

$$N_{tot} = 100 / (I_x \; I_y)$$

R.9. ***Total drilling length L_{tot}***: drilling length per 100m^2 of mesh:

$$L_{tot} = N_{tot} \; L_a$$