MASINDE MULIRO UNIVERSITY OF SCIENCE AND TECHNOLOGY

University Of Choice

UNIVERSITÀ DEGLI STUDI DI BARI ALDO MORO

Mitigation measures to prevent landslides

UNIVERSITÀ DI PARMA

Prof. Roberto Valentino, PhD

Earth Science Unit – Department of Chemistry, Life Sciences and and Environmental Sustainability

roberto.valentino@unipr.it

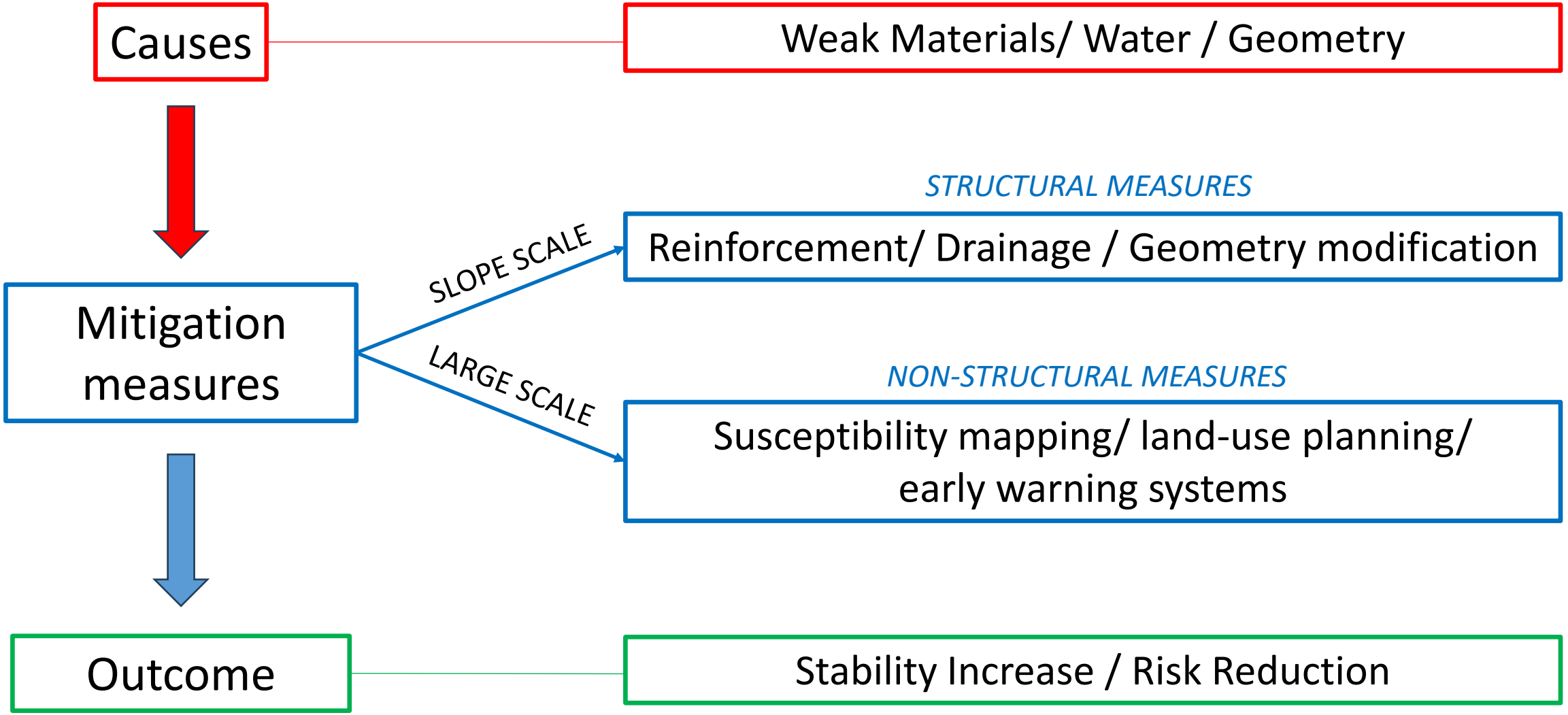
Instability drivers

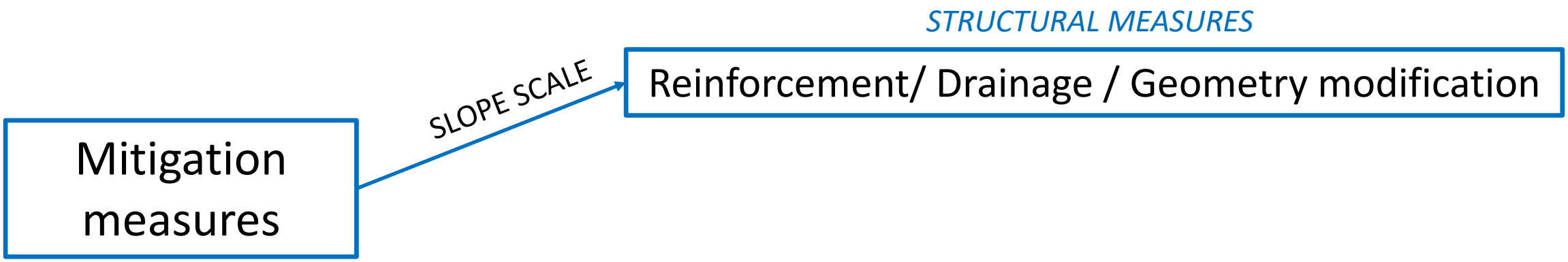
↓

Mitigation *(Structural vs Non-structural measures)*

↓

Stability & Risk Management

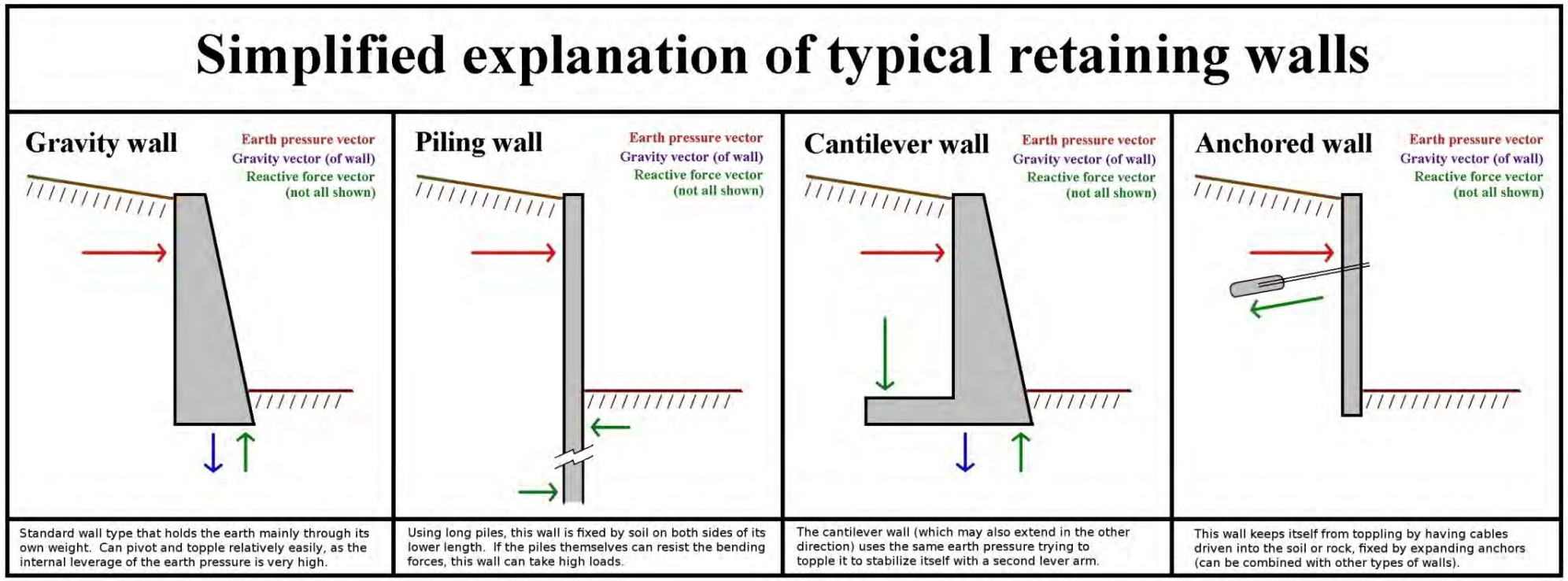

Causes
Weak Materials/ Water / Geometry
STRUCTURAL MEASURES
Mitigation measures
SLOPE SCALE
Reinforcement/ Drainage / Geometry modification
LARGE SCALE
NON-STRUCTURAL MEASURES
Susceptibility mapping/ land-use planning/ early warning systems
Outcome
Stability Increase / Risk Reduction



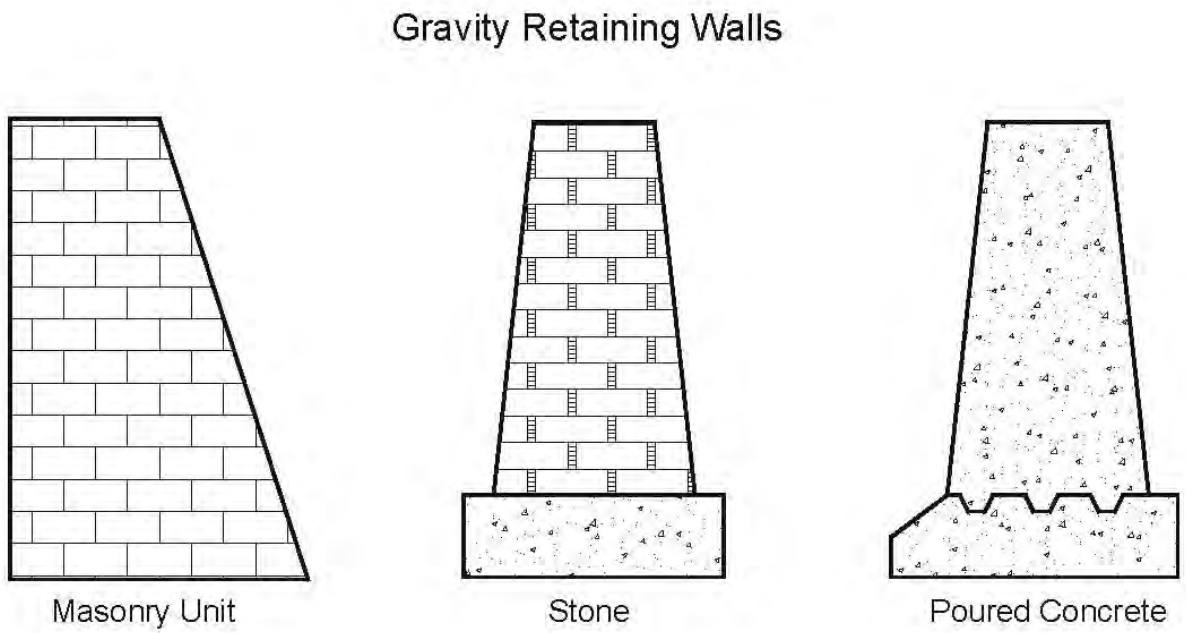
Reinforcement types:

- Retaining walls
- Piles
- Grouted tiebacks
- Geotextile

Retaining walls



Types of gravity walls



Types of gravity walls



Types of gravity walls

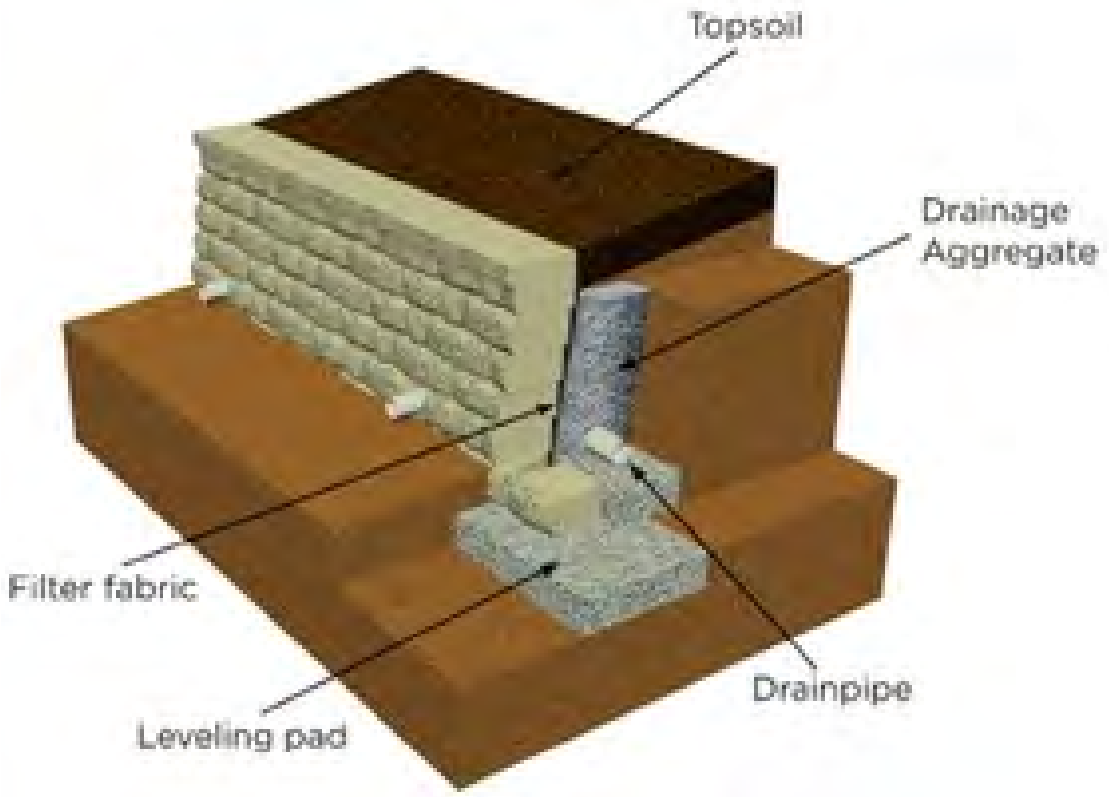






Masonry retaining wall

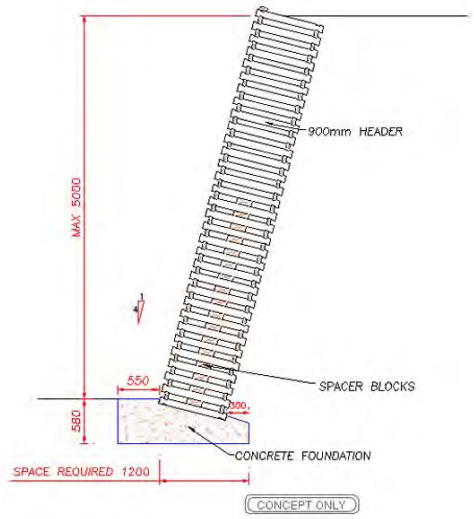




Crib walls (Semi-Gravity walls)





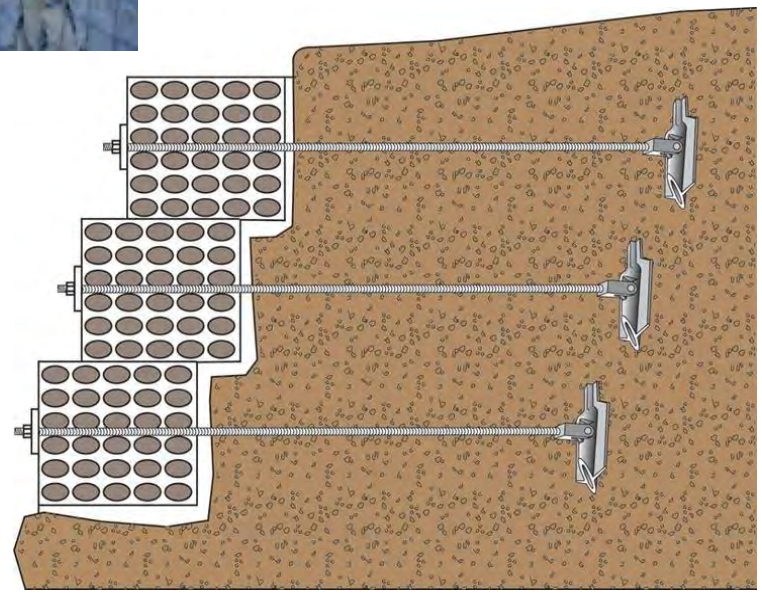




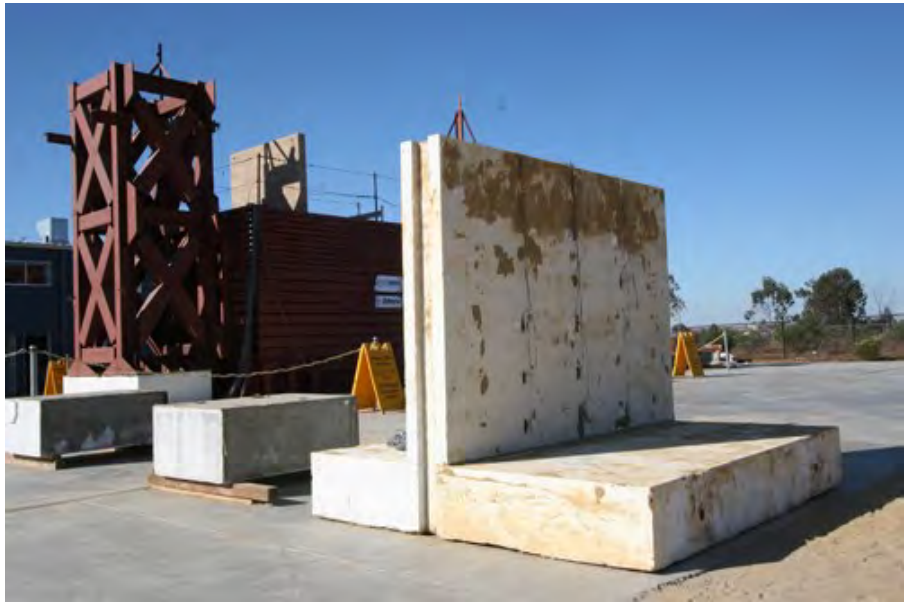
Gabion retaining walls







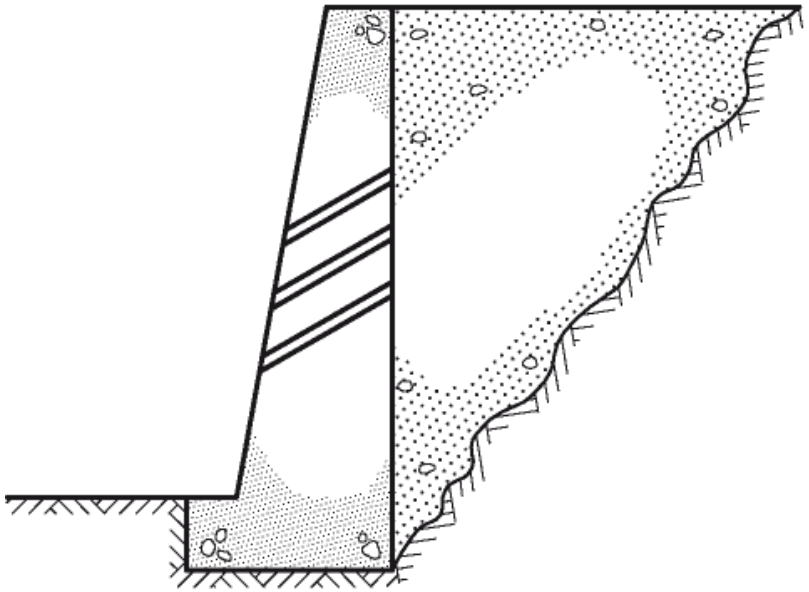
Cantilever retaining walls



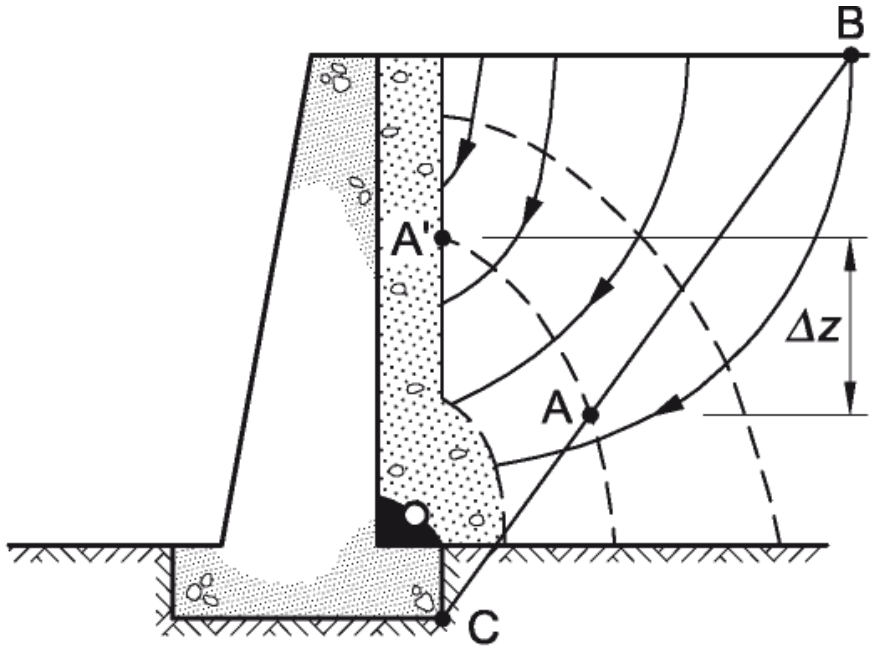




Water in the back of the wall



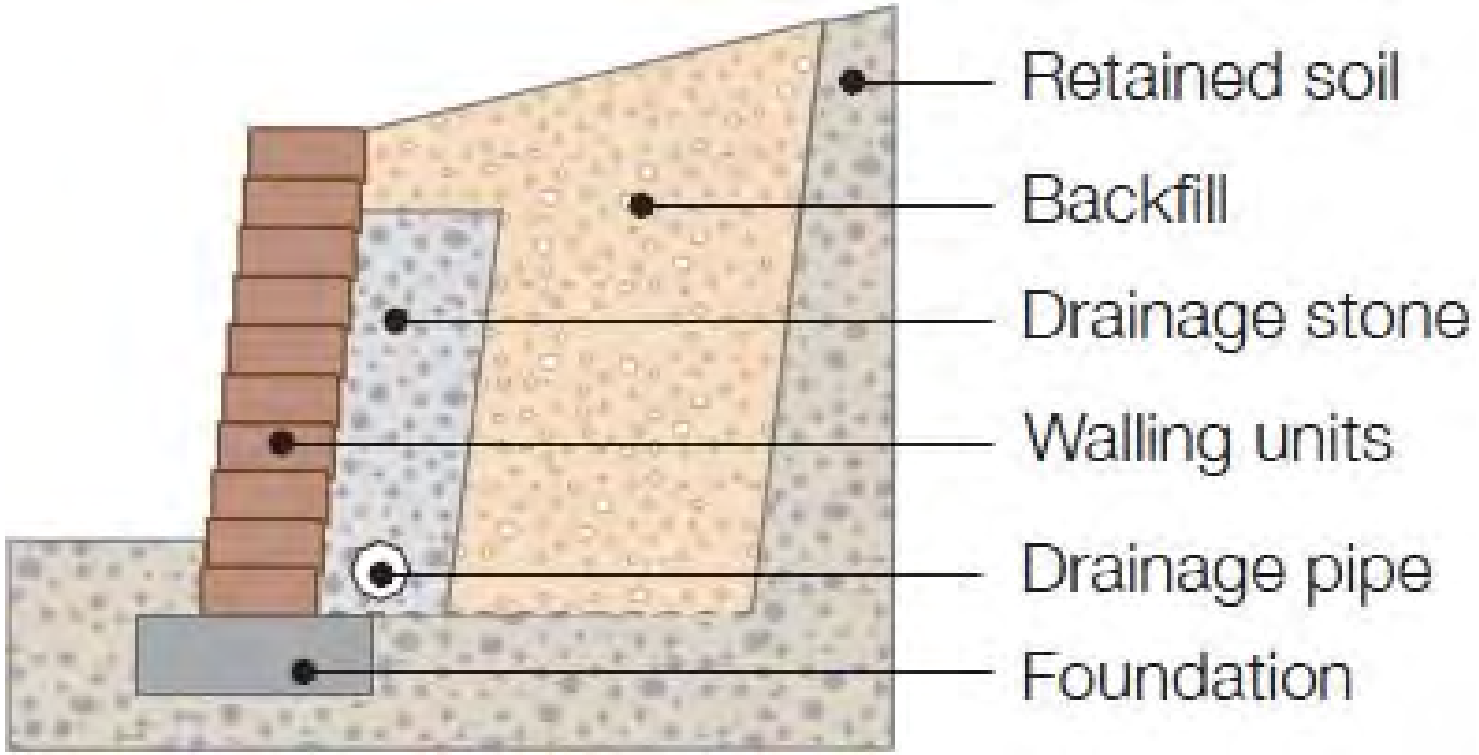
(a)



$$u_A = \Delta z \cdot \gamma_w$$

(b)

Drainage


Retained soil
Backfill
Drainage stone
Walling units
Drainage pipe
Foundation

Piles used as stabilising structures

Piles used as stabilising structures

- Easy to put in place
- Different possibilities of types and patterns
- Very good stabilising effect
- Widely used and tested in the past





Piles used as stabilising structures

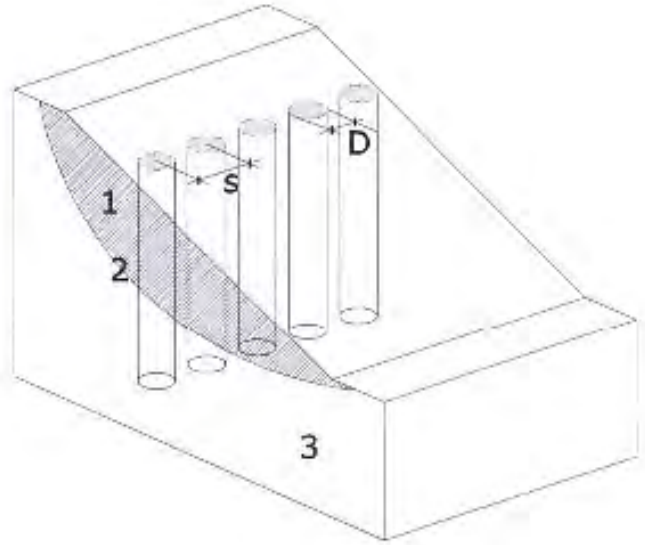




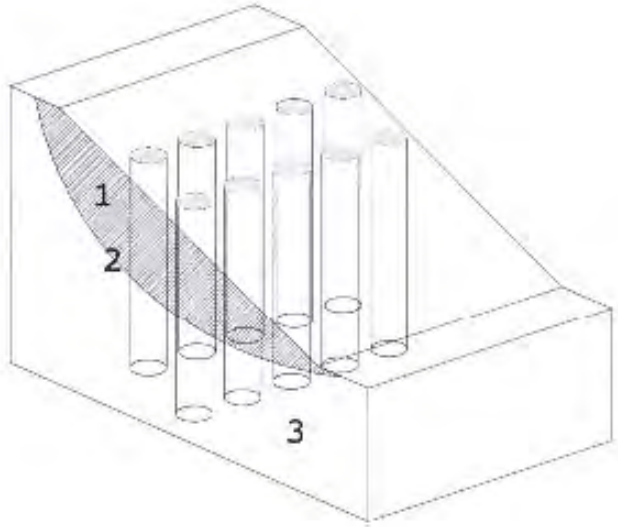
Piles used as stabilising structures

Generally, piles are put in place vertically, unless they are micopiles installed with a different angle with respect to the vertical axis

Along one row



Along 2 rows or more



s = distance between piles

D = pile diameter

1) Unstable soil
2) Failure surface
3) Stable soil

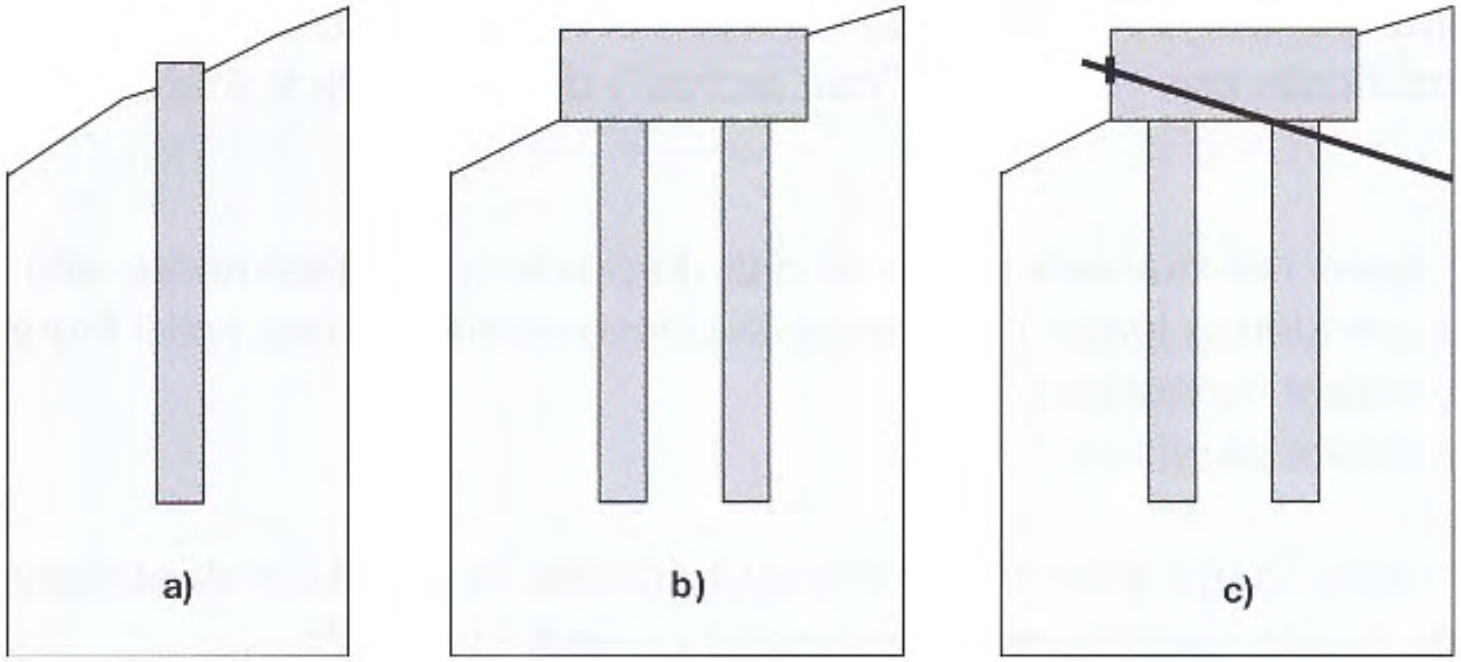
(from Froldi, 2020)

Piles used as stabilising structures

a) Simple sheet piles

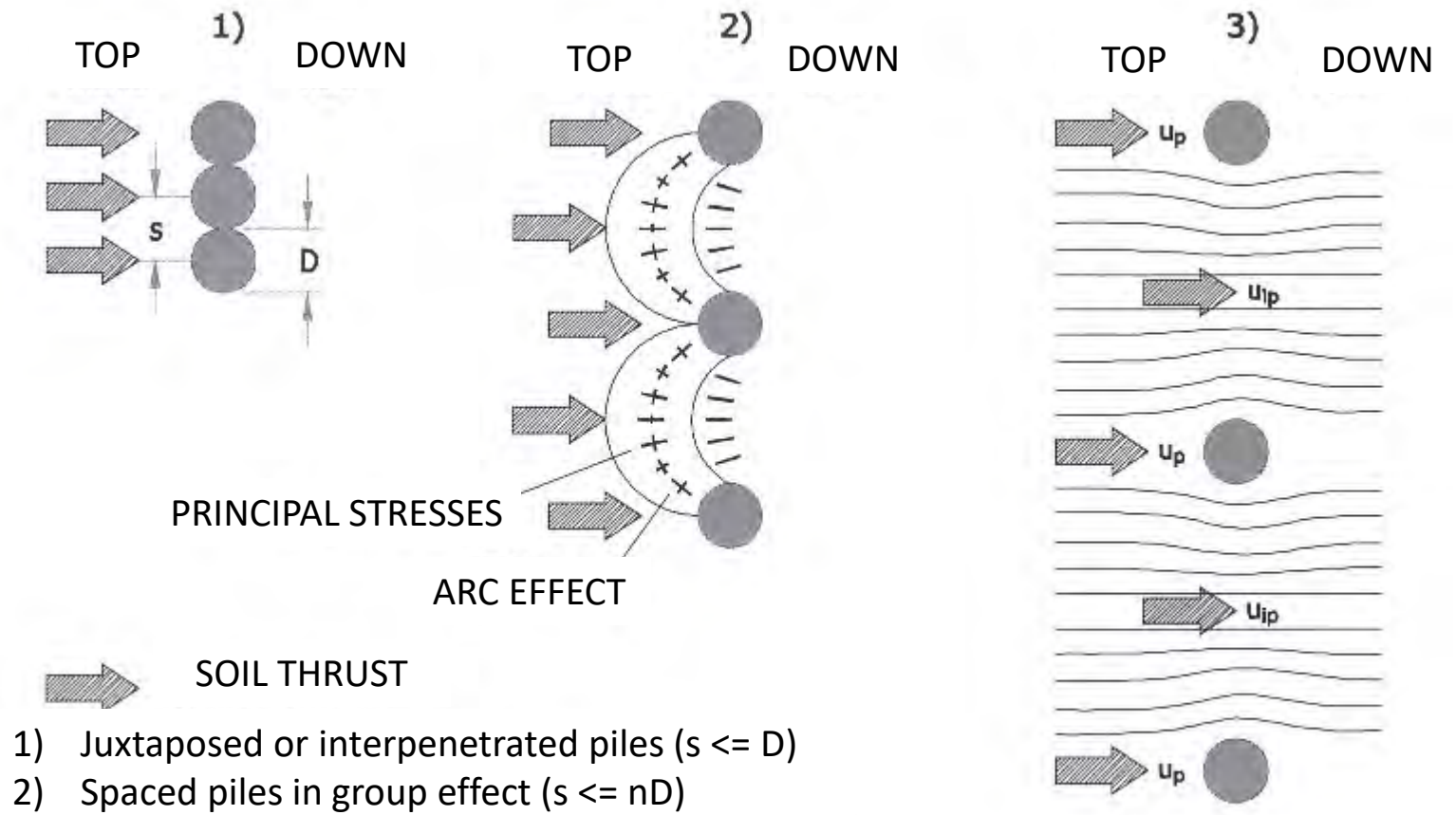
b) Double (complex) sheet piles with a cap

c) Double (complex) sheet piles + cap + tieback



(from Froldi, 2020)

Piles used as stabilising structures



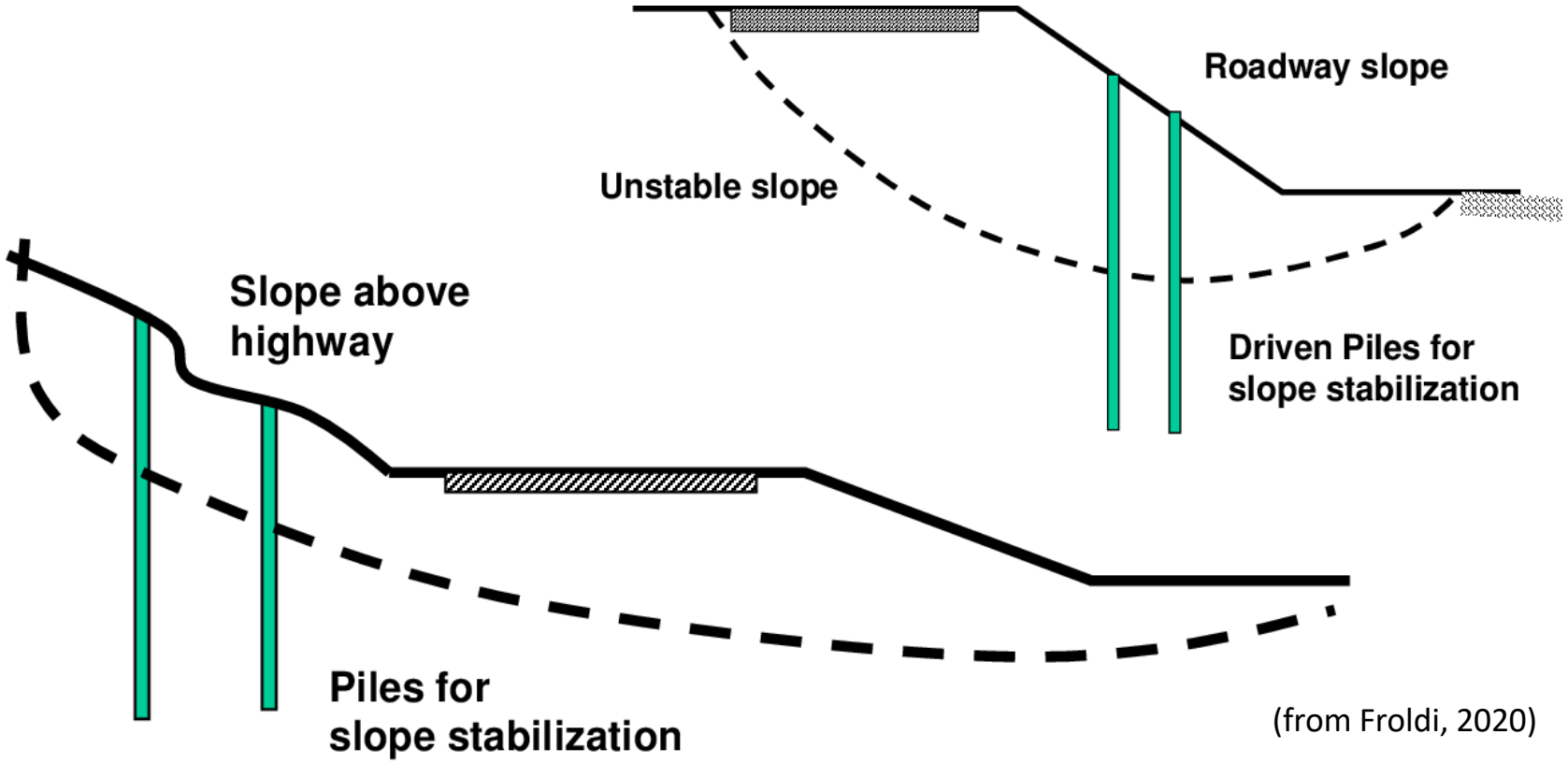
1) Juxtaposed or interpenetrated piles (s <= D)
2) Spaced piles in group effect (s <= nD)
3) Speced piles without group effect (s > nD)

s = distance between piles
D = pile diameter
n = critical distance factor (s/D)

(from Froldi, 2020)

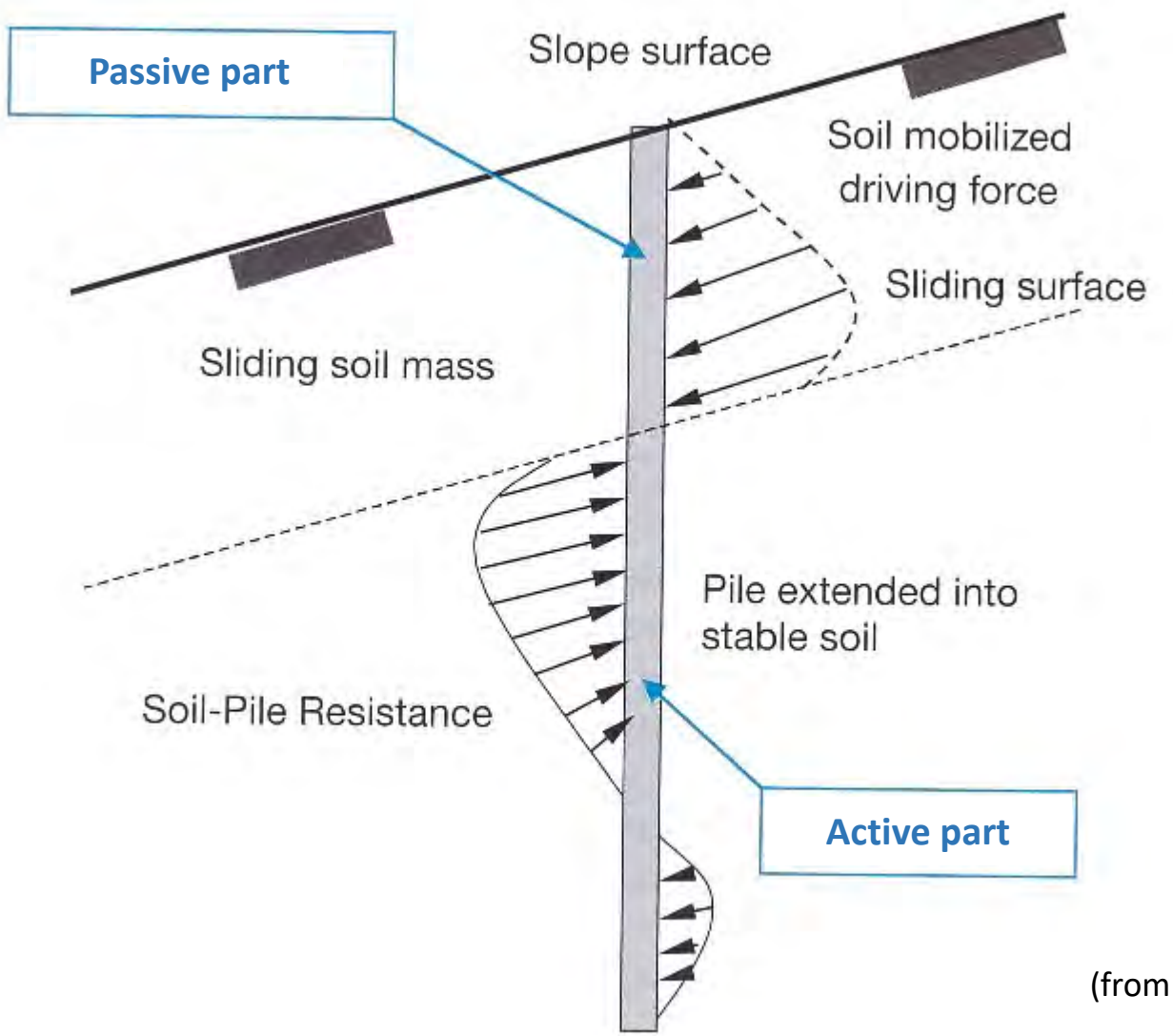
A good arc effect is obtained when 2 < s/D < 5 (optimum value n=4)

Piles used as stabilising structures



(from Froldi, 2020)

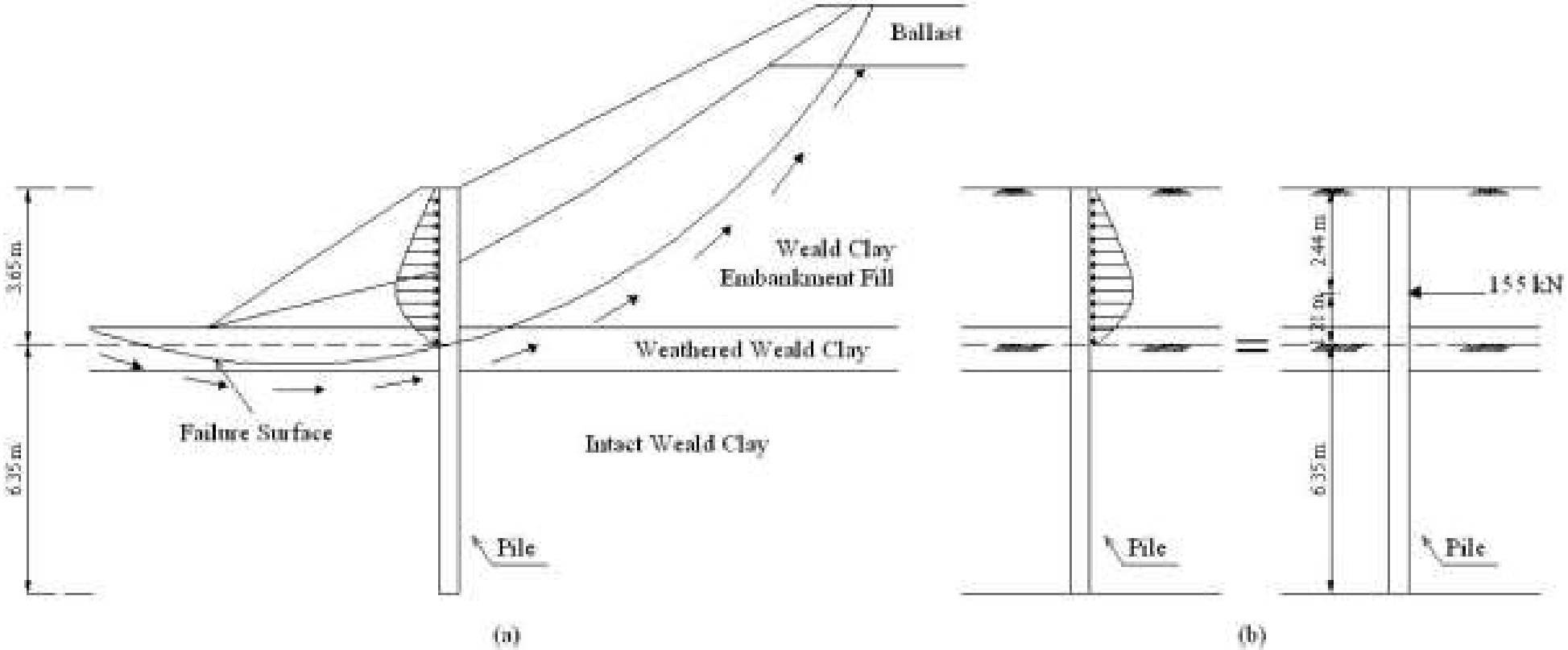
Piles used as stabilising structures



(from Froldi, 2020)

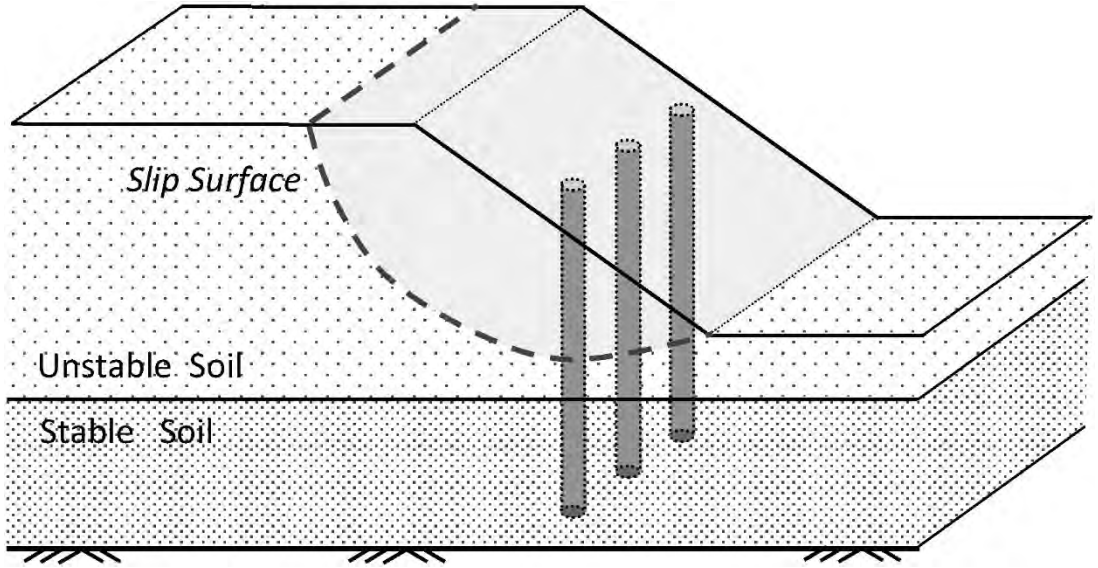
Piles used as stabilising structures

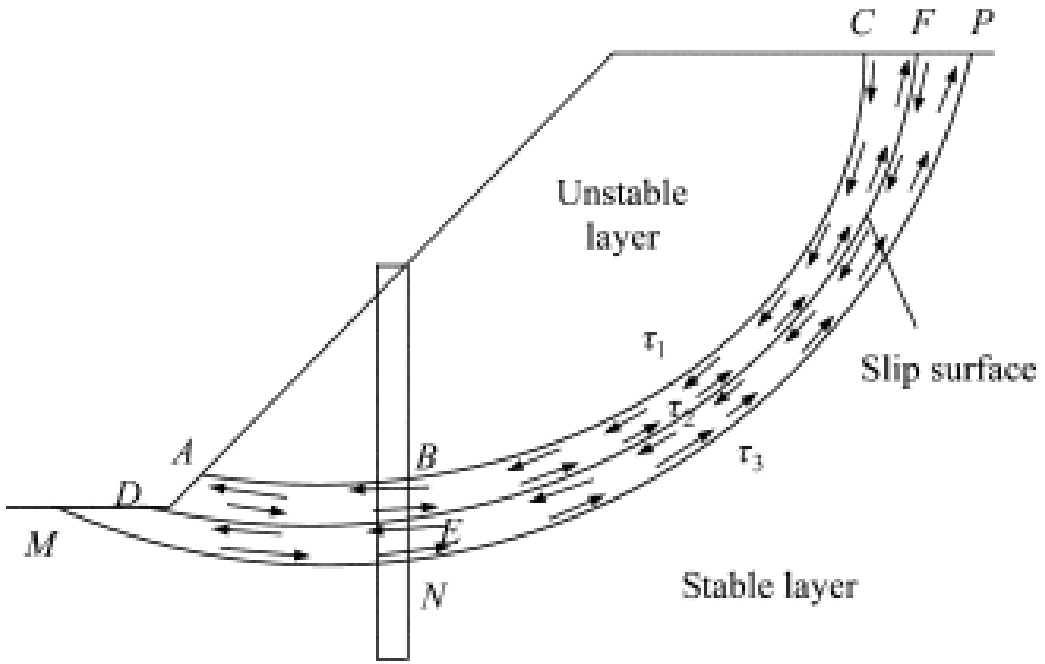
Example of simplified model



Piles used as stabilising structures

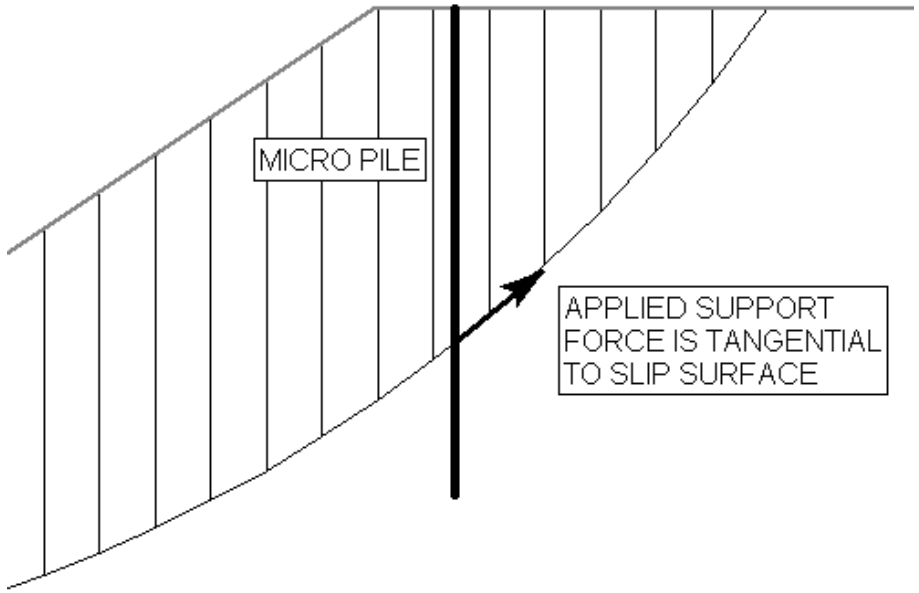
Example of simplified model

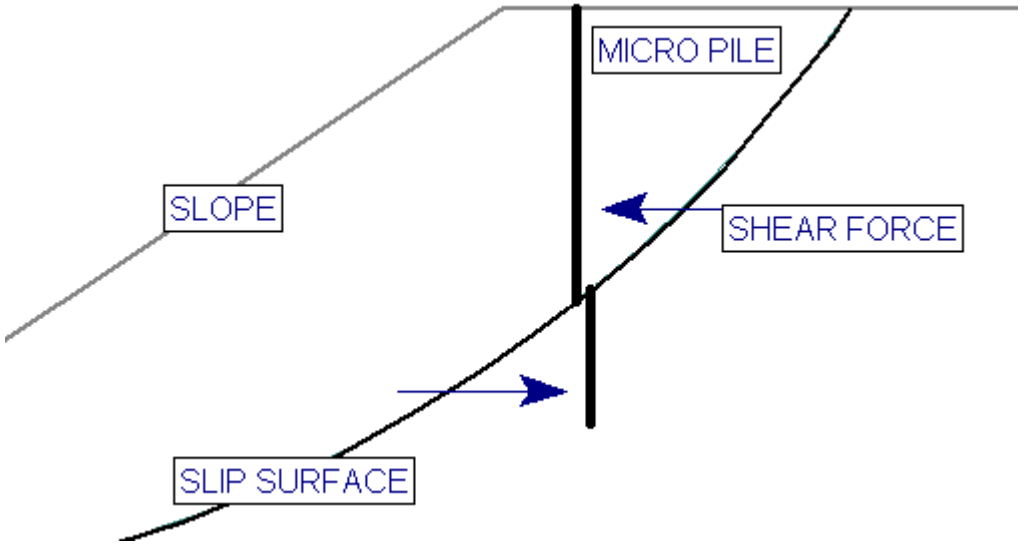




Piles used as stabilising structures

Simplified modelling of the resistence given by a pile as simulated in the Slide Software (Rocscience)





Piles used as stabilising structures

Simplified modelling of the resistence given by a pile as simulated in the Slide Software (Rocscience)

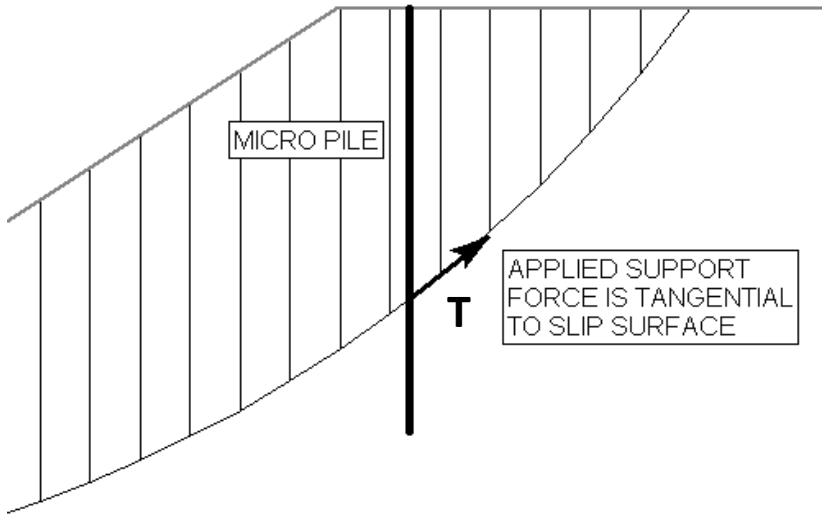
Total shear resistence T (pile cross section):

$$T = \tau_{CLS} \cdot \pi \cdot r^2$$

$\tau_{CLS} = 25000 \frac{kN}{m^2}$

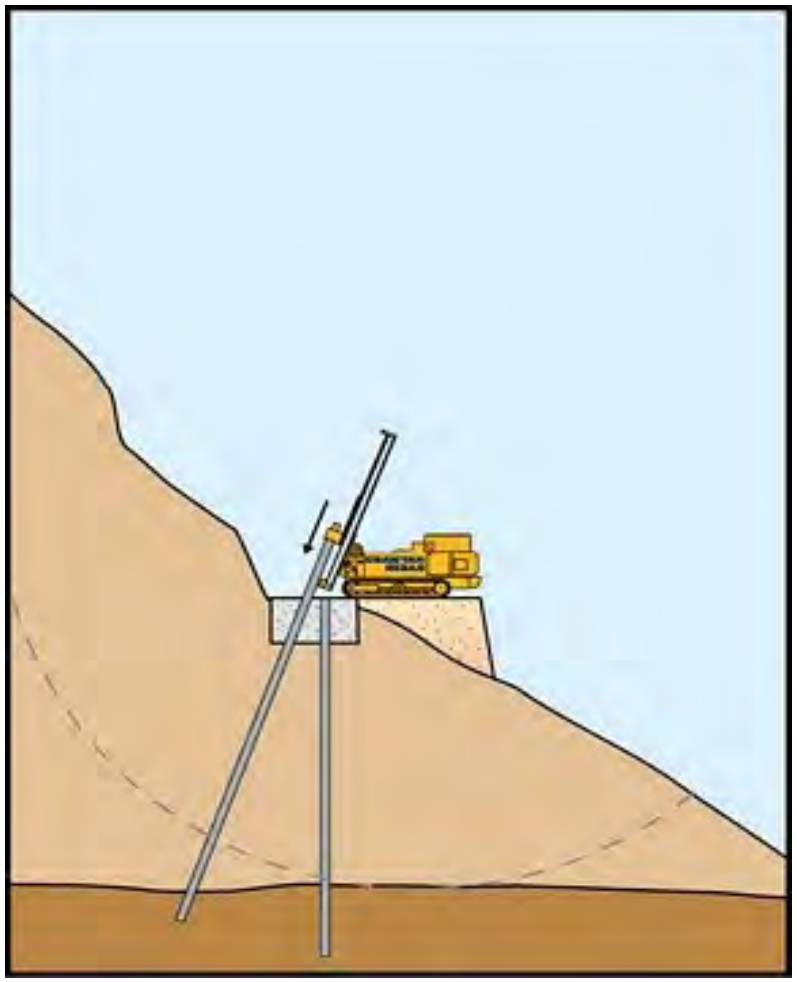
Pile diameter (2r):

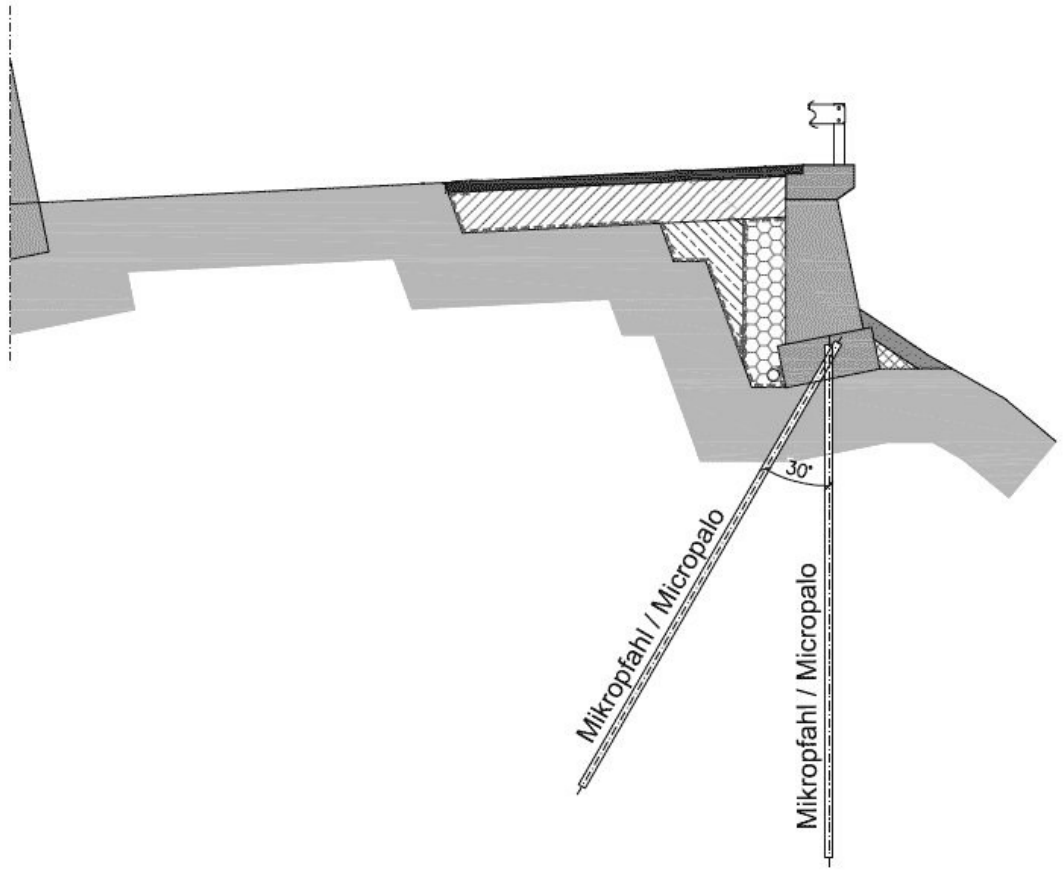
30cm	micropiles
30-80cm	medium diameter piles
>80cm	large diameter piles



Piles used as stabilising structures

MICROPILES (D < 30cm) – EASEL ARRANGEMENT

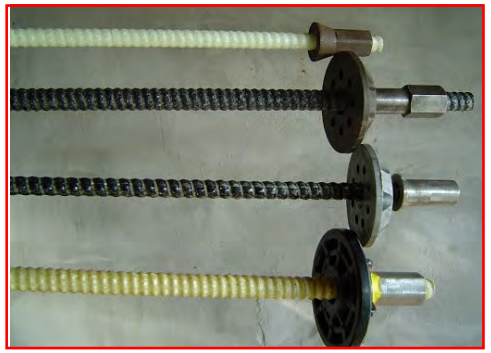




Piles used as stabilising structures

MICROPILES (D < 30cm) COMBINED WITH OTHER SUPPORT STRUCTURES

Self Drilling Anchors (SDA)



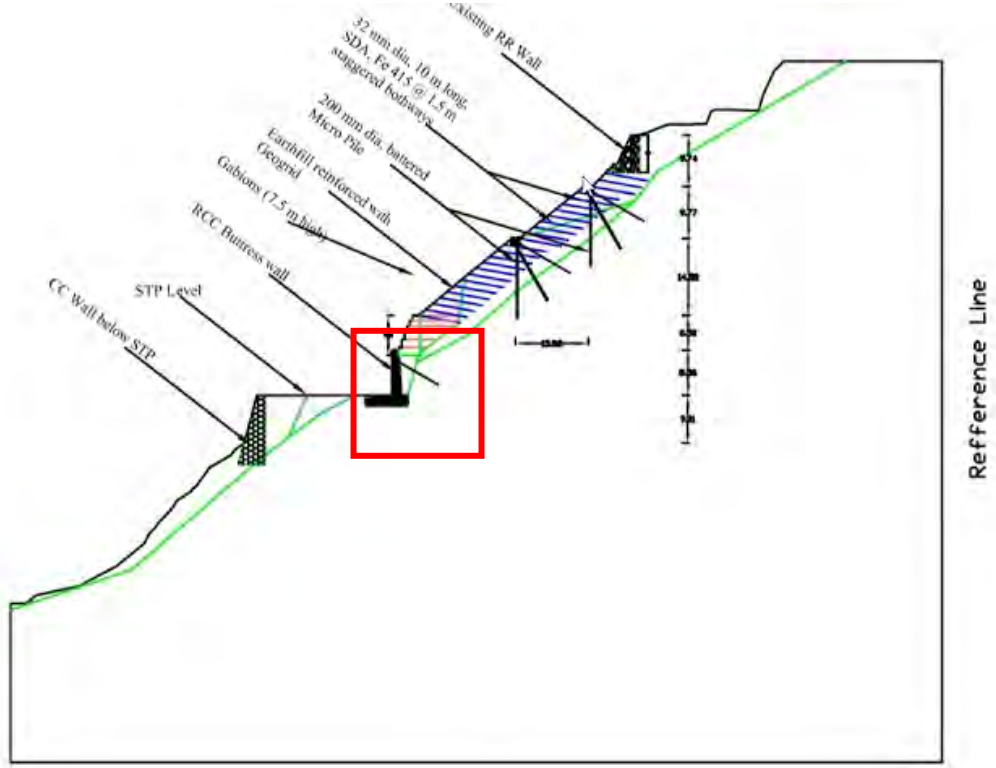


Figure1: Complete Section 0-0

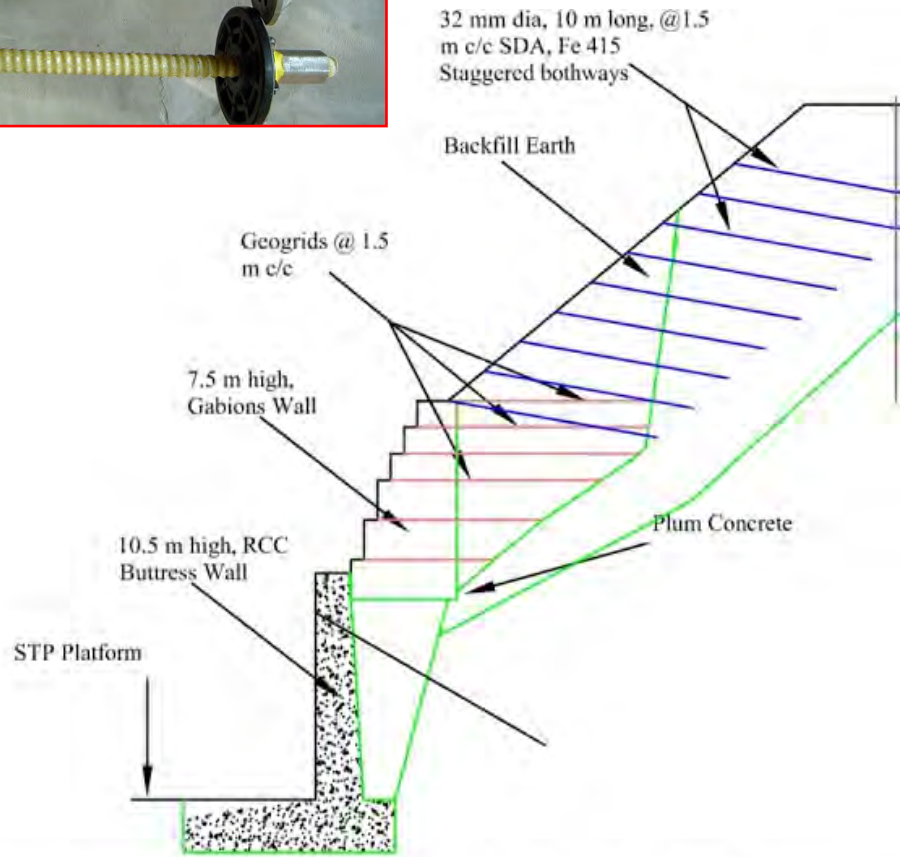
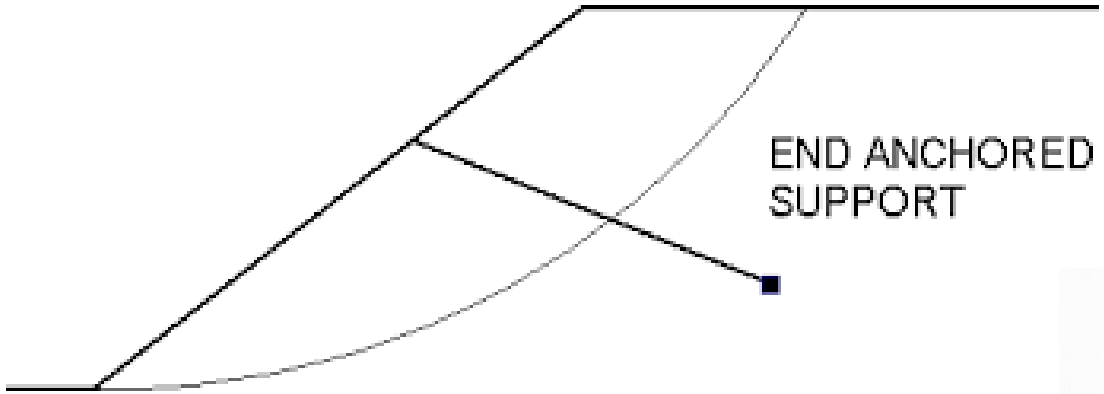
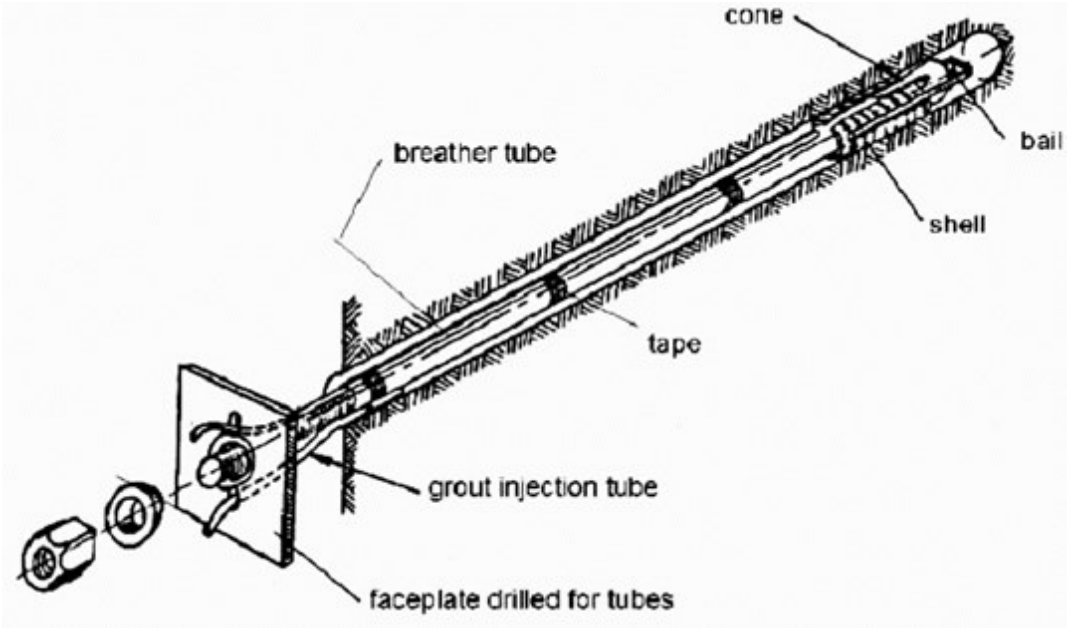


Figure2: Typical Details of Protection Works

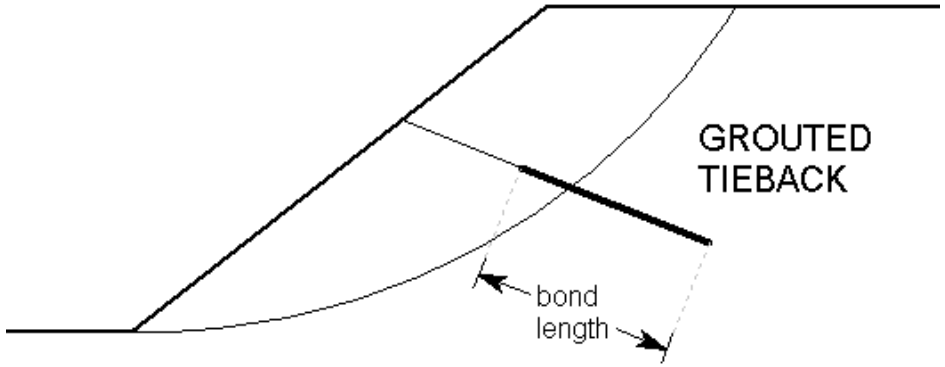
End anchored supports
and
tiebacks

END ANCHORED SUPPORT

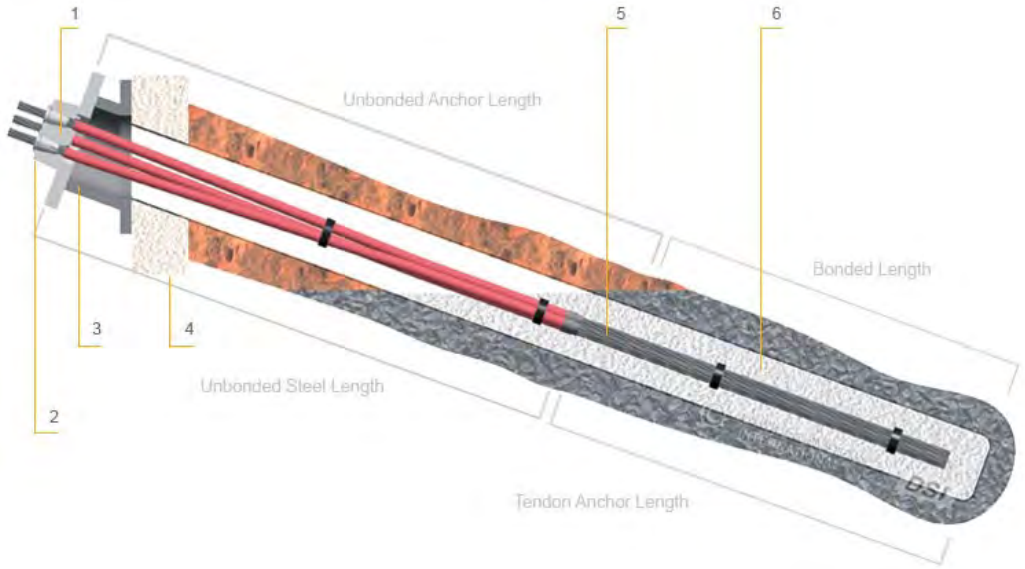




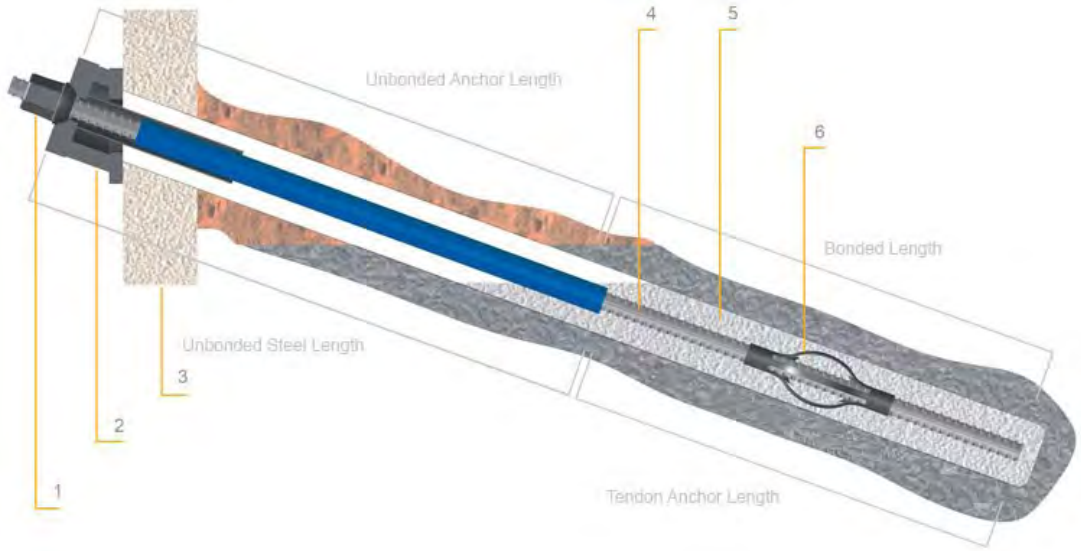
GROUTED TIEBACK



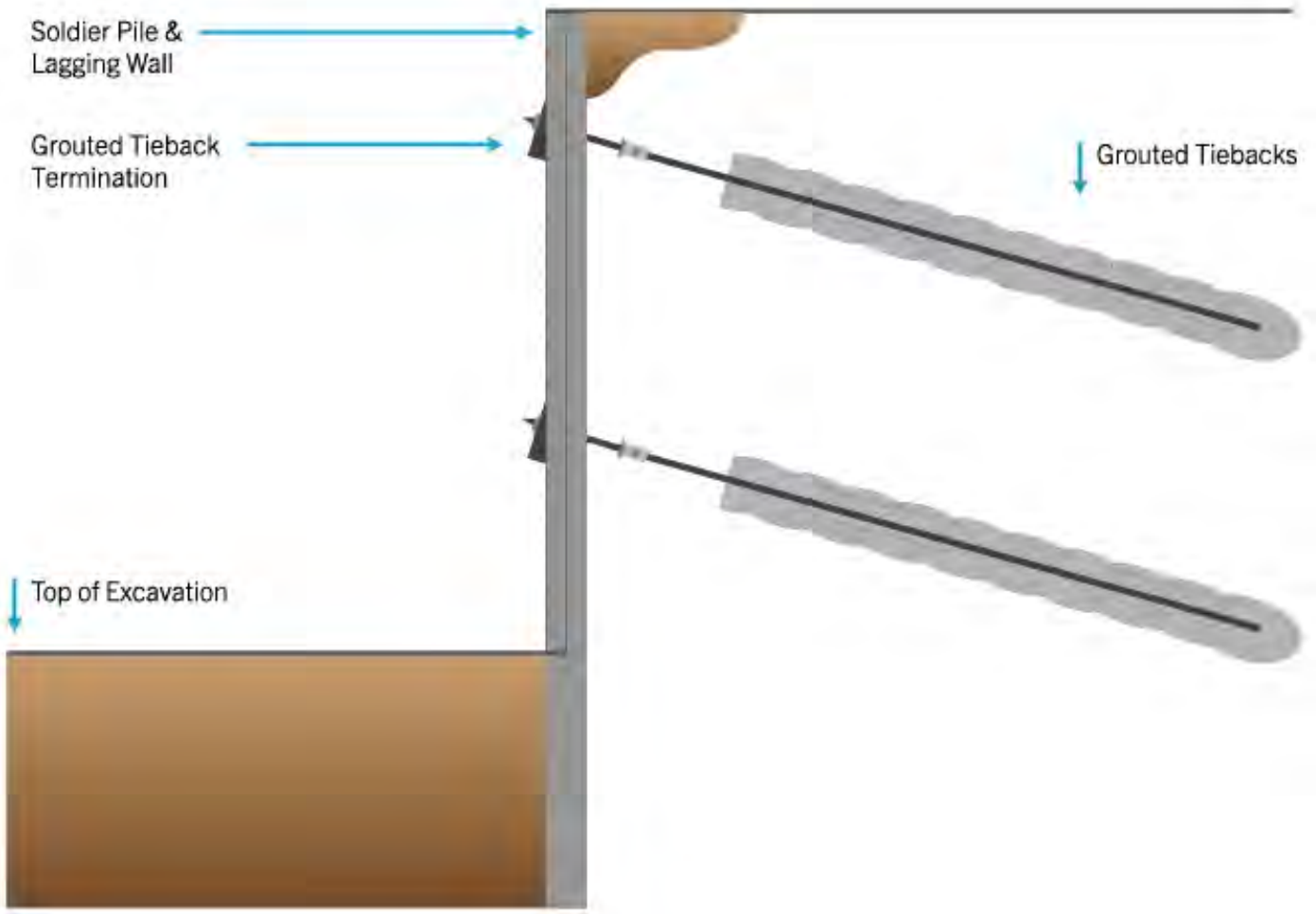
Steel strends



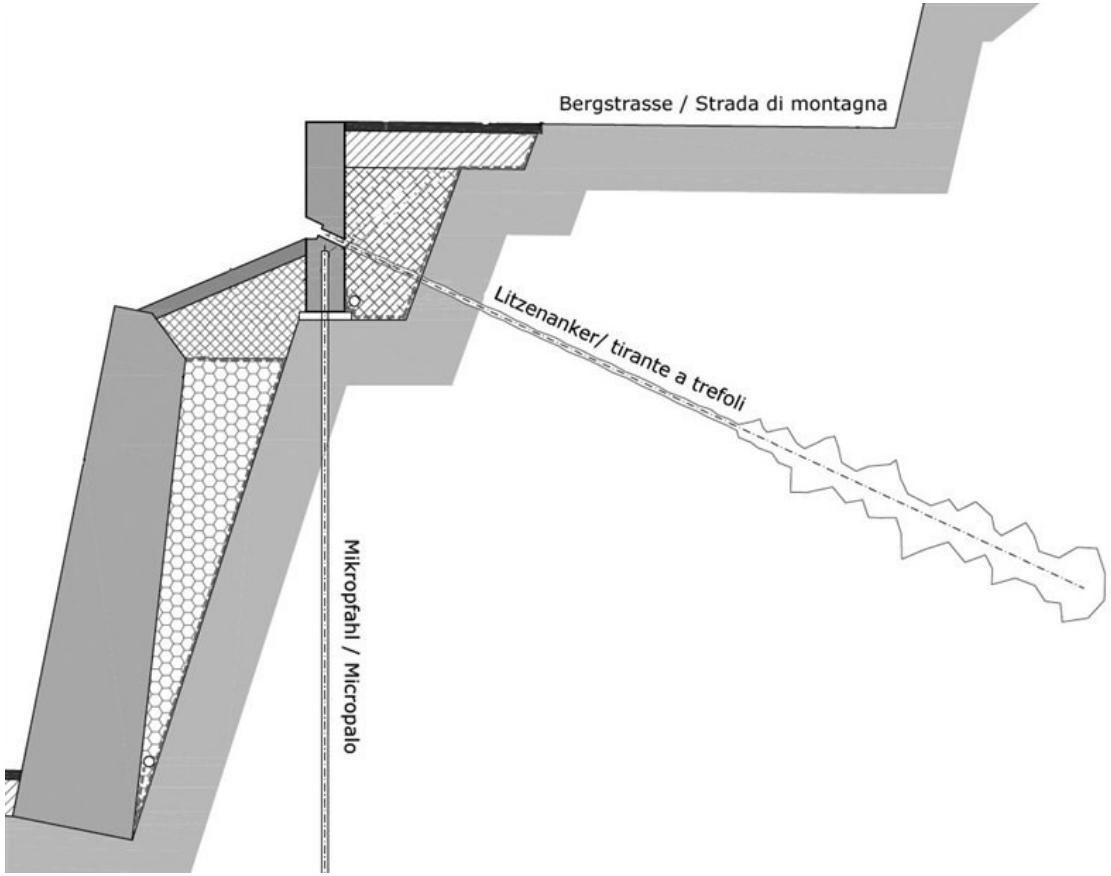
Steel bar

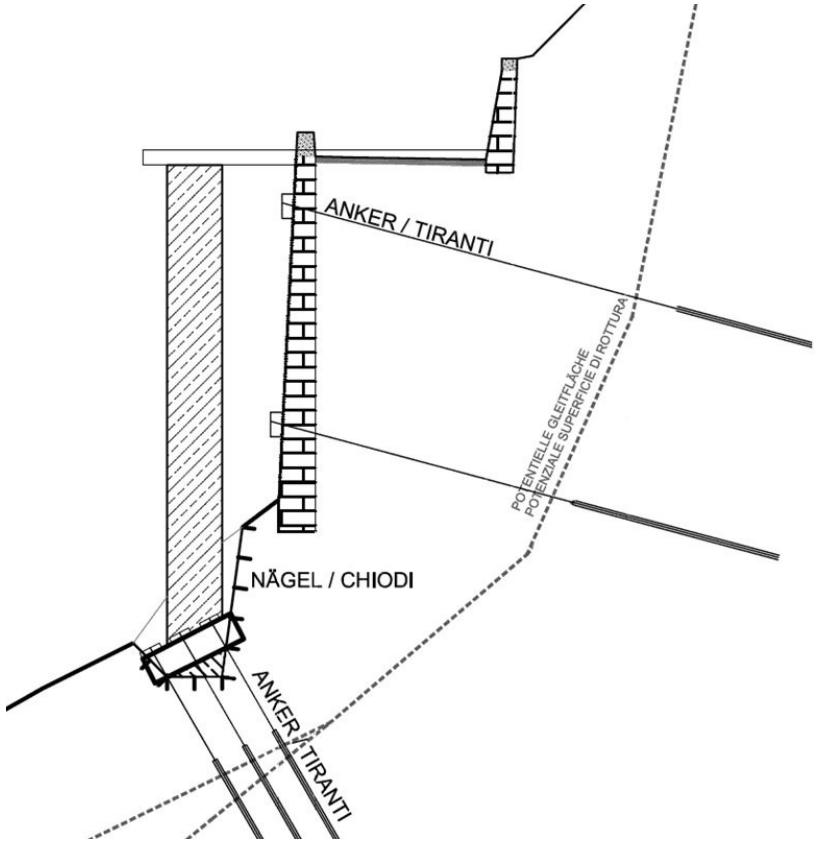


GROUTED TIEBACK

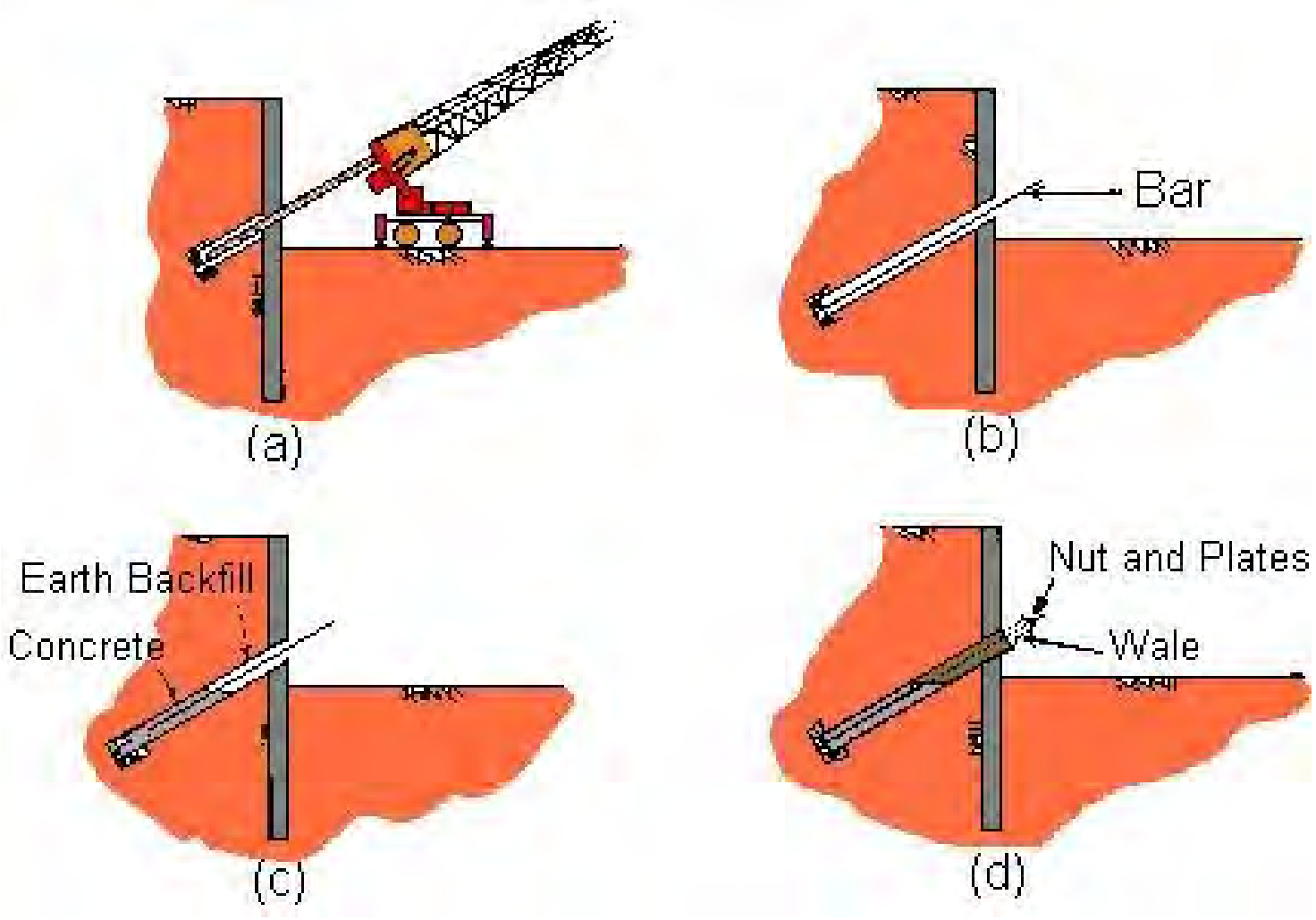


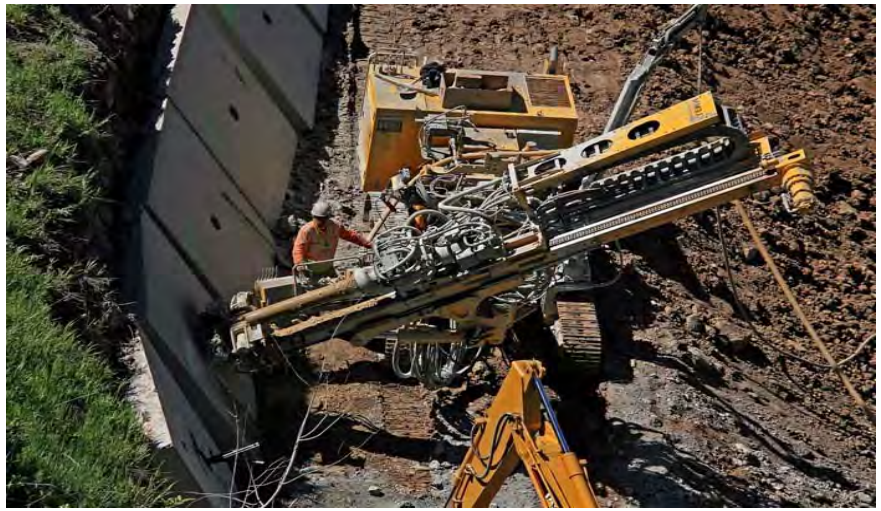
GROUTED TIEBACK





GROUTED TIEBACK – INSTALLATION STEPS





GROUTED TIEBACK

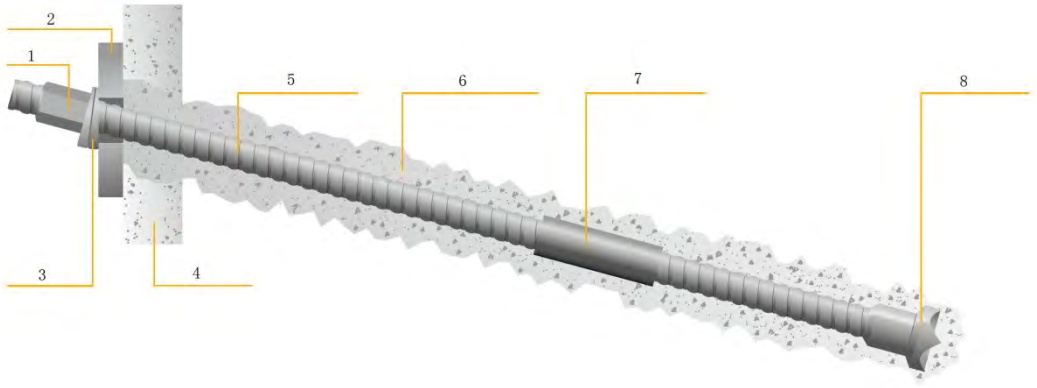


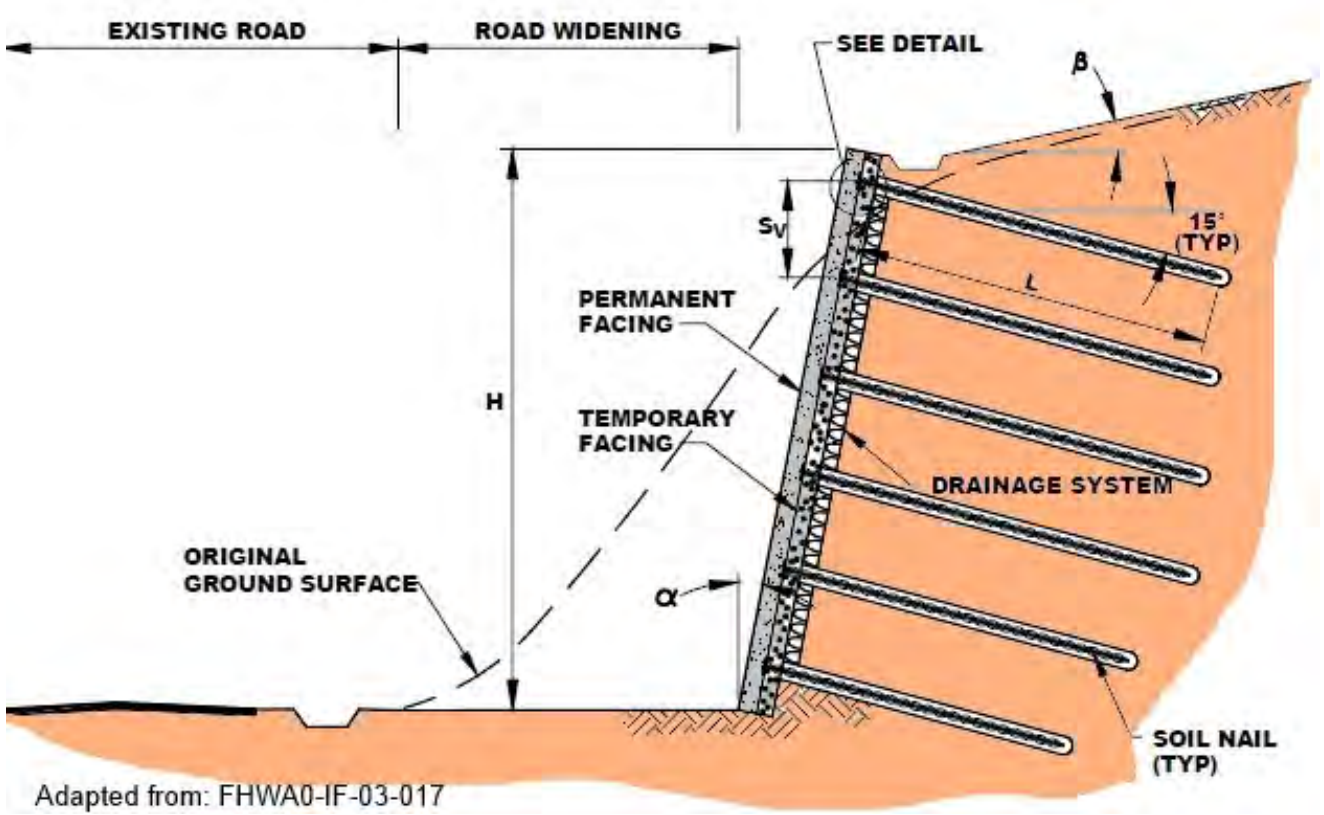






SOIL NAIL





Adapted from: FHWA0-IF-03-017

SOIL NAIL



SOIL NAIL

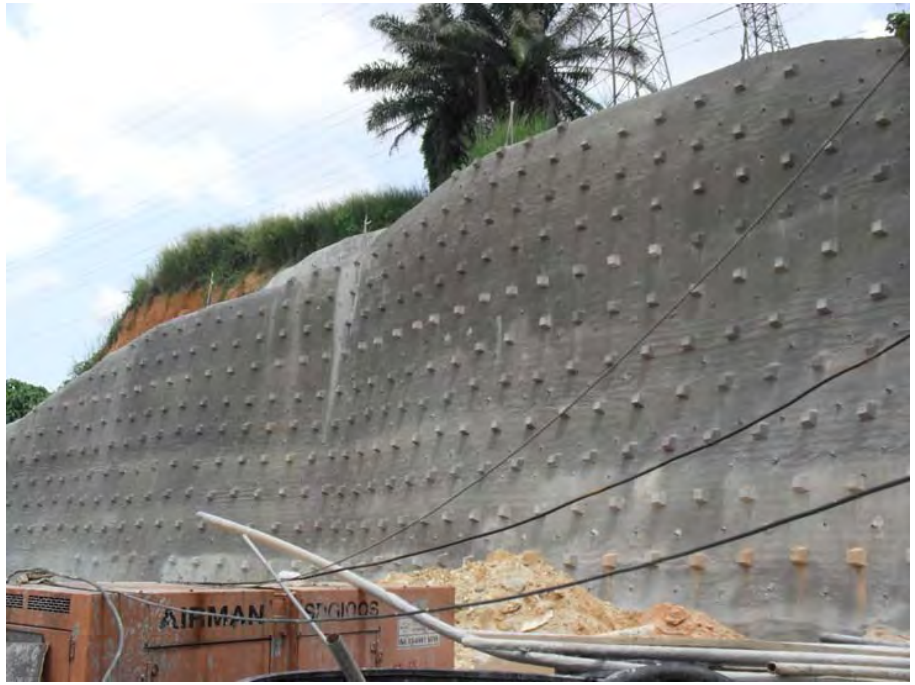


SOIL NAIL



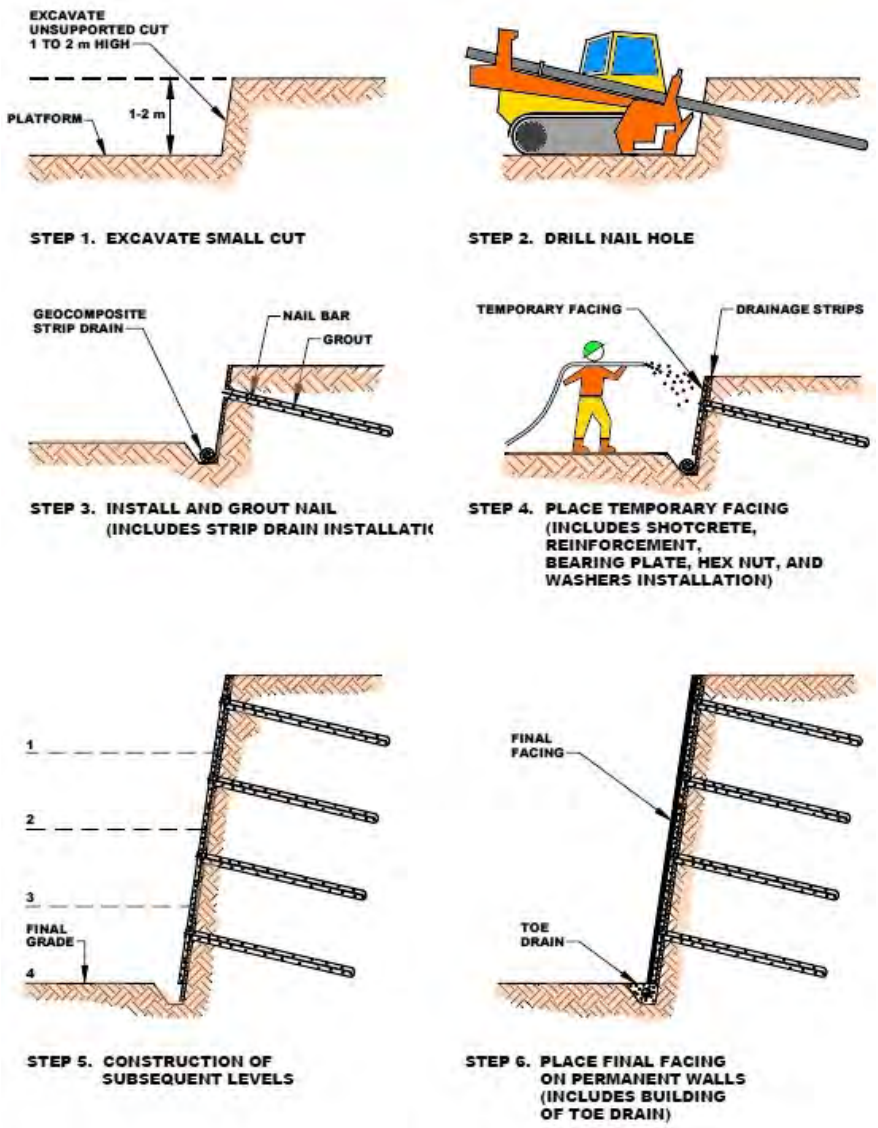


SOIL NAIL





SOIL NAIL


EXCAVATE
UNSUPPORTED CUT
1 TO 2 m HIGH
PLATFORM
1-2 m
STEP 1. EXCAVATE SMALL CUT
STEP 2. DRILL NAIL HOLE
GEOCOMPOSITE
STRIP DRAIN
NAIL BAR
GROUT
STEP 3. INSTALL AND GROUT NAIL
(INCLUDES STRIP DRAIN INSTALLATI
TEMPORARY FACING
DRAINAGE STRIPS
STEP 4. PLACE TEMPORARY FACING
(INCLUDES SHOTCRETE,
REINFORCEMENT,
BEARING PLATE, HEX NUT, AND
WASHERS INSTALLATION)
1
2
3
FINAL
GRADE
4
STEP 5. CONSTRUCTION OF
SUBSEQUENT LEVELS
FINAL
FACING
TOE
DRAIN
STEP 6. PLACE FINAL FACING
ON PERMANENT WALLS
(INCLUDES BUILDING
OF TOE DRAIN)



Geotextiles and Geogrids

What is Geotextile?

Geotextiles are permeable textile materials.

They can be woven, nonwoven, or knitted.

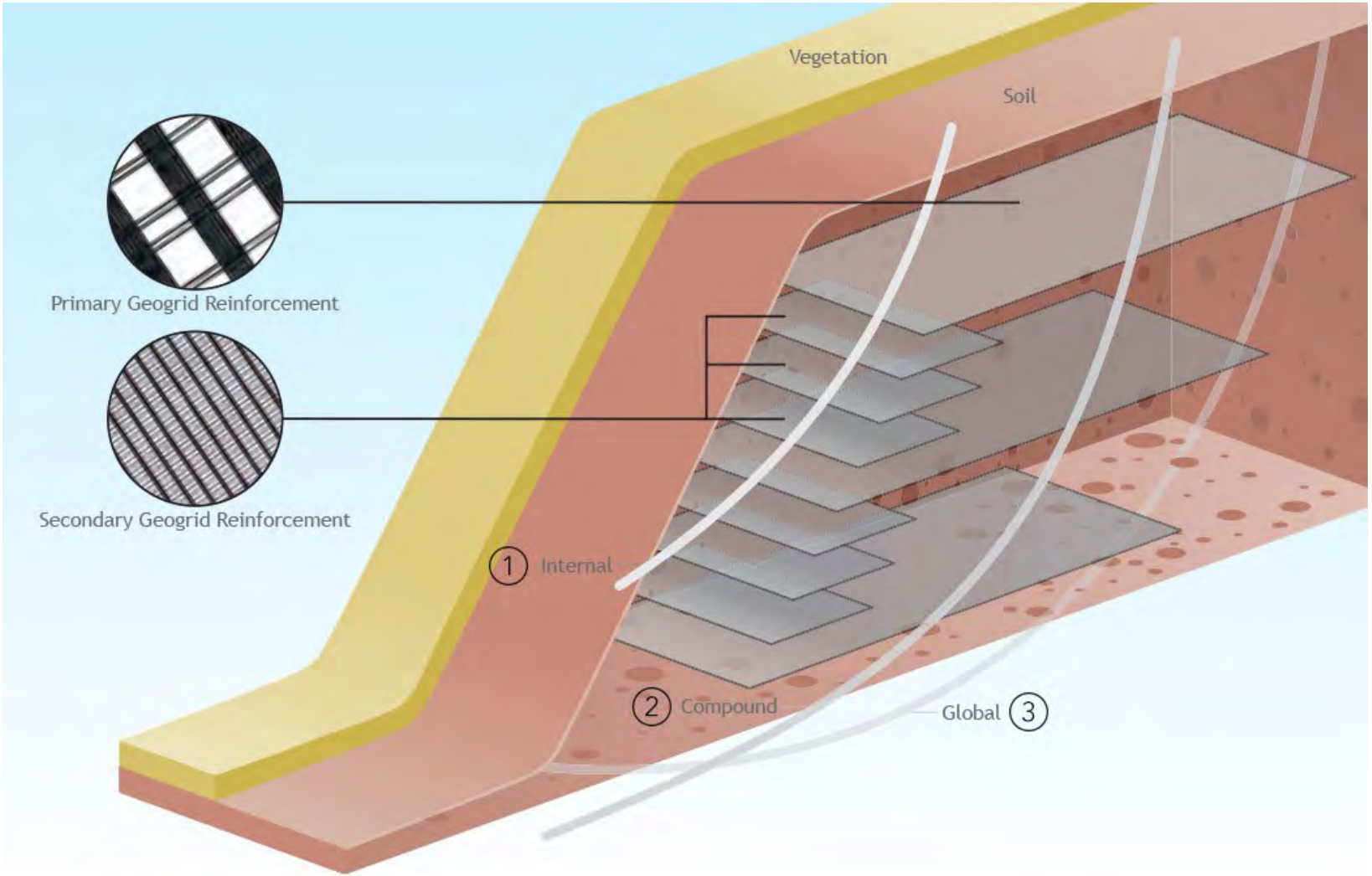
It’s a member of a larger family called *Geosynthetics*.

GeoTextiles and Geogrids

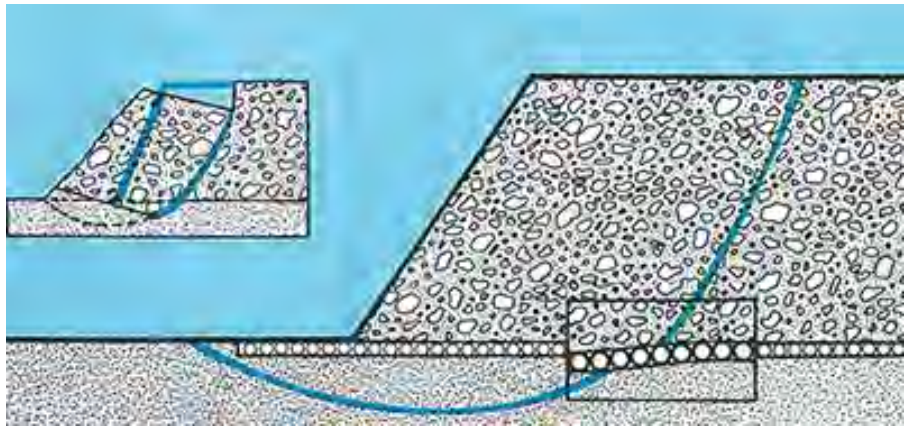


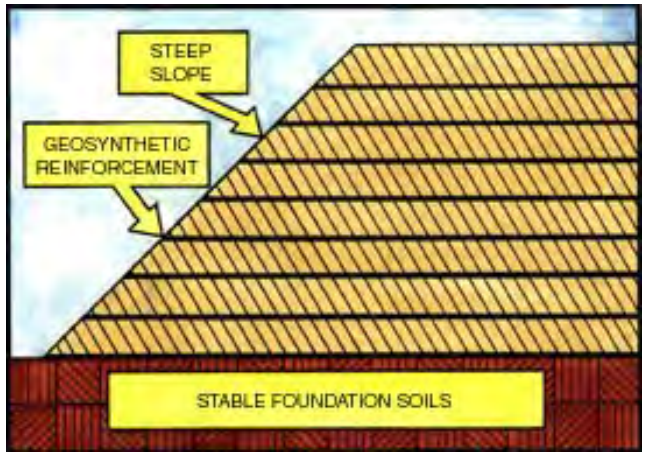


GeoTextiles and Geogrids

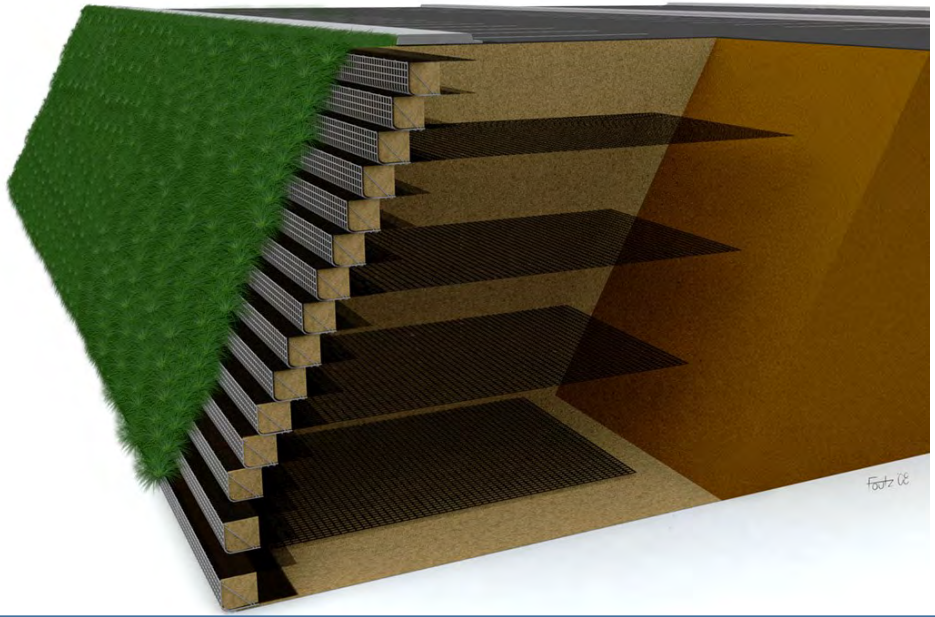


GeoTextiles and Geogrids

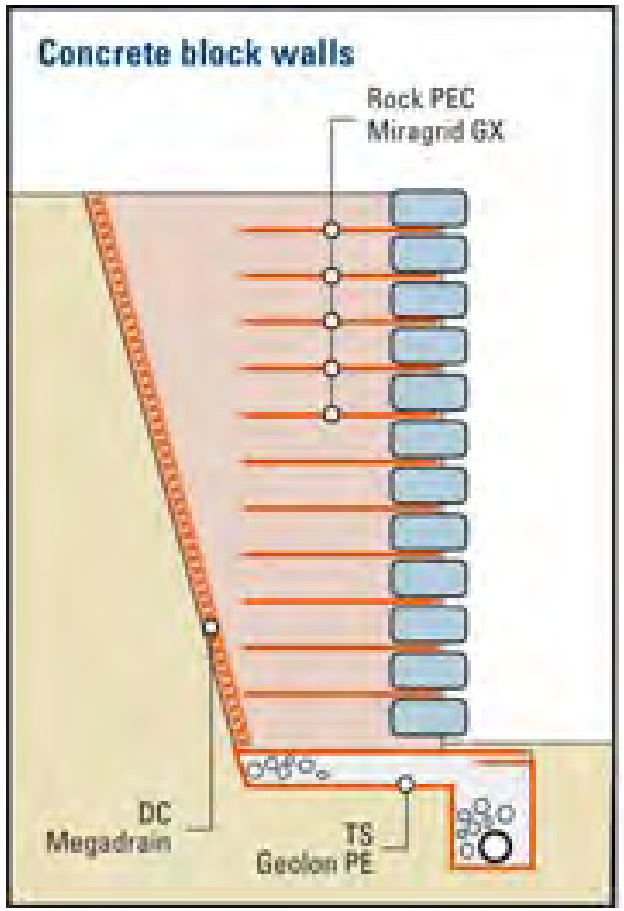


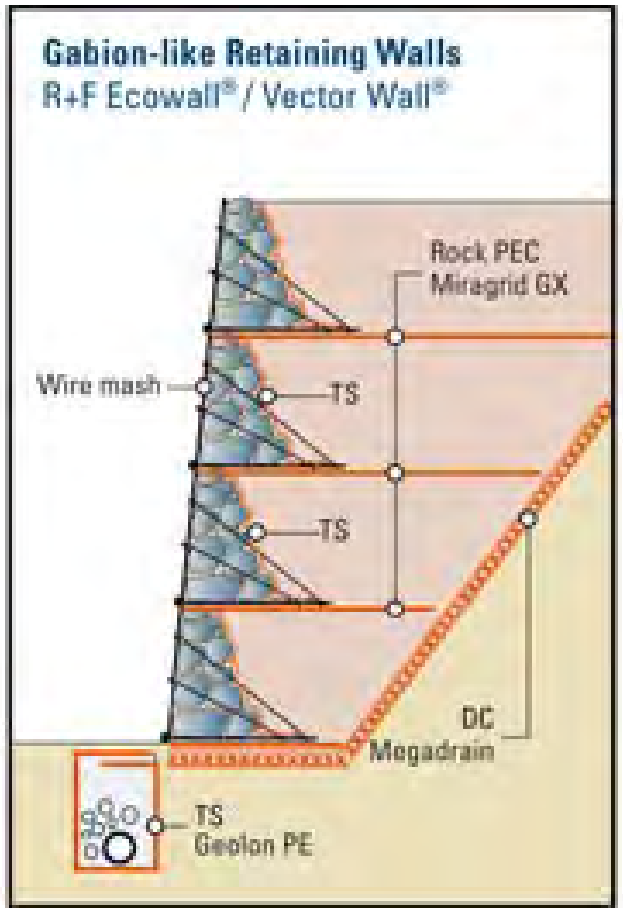


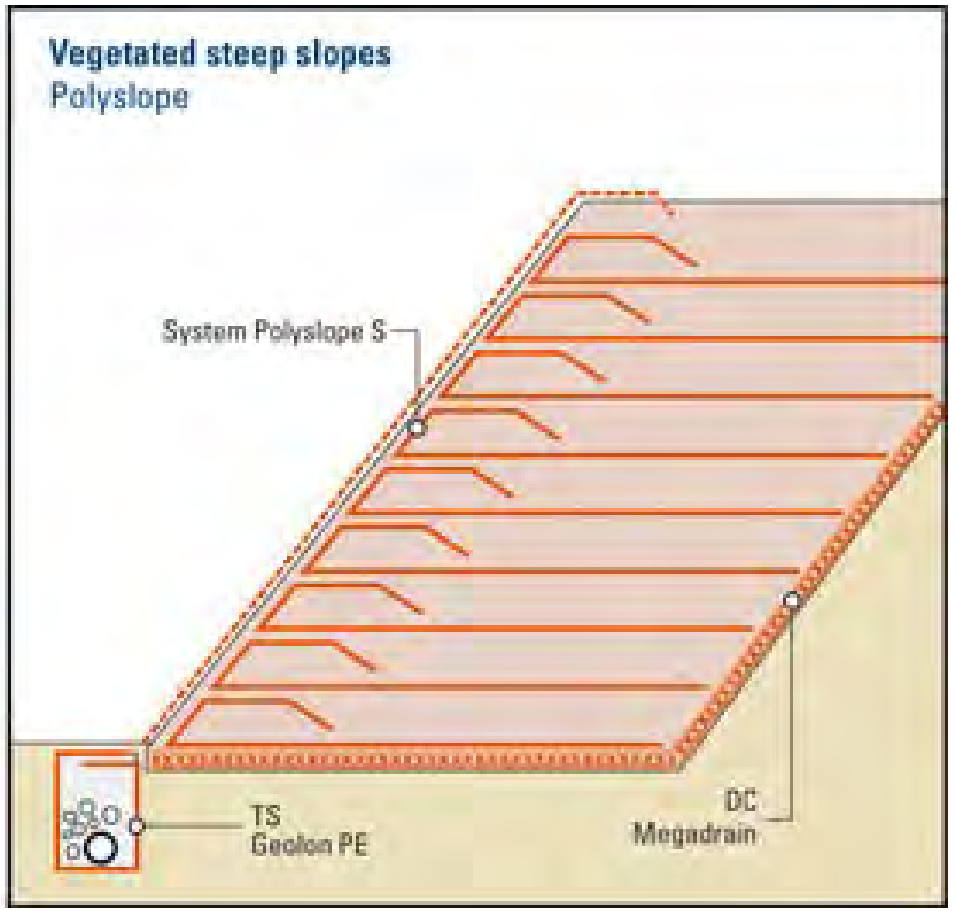




GeoTextiles and Geogrids







GeoTextiles and Geogrids



8. Soil Nail Wall –with Geo-Grid, Planted Masonry Block

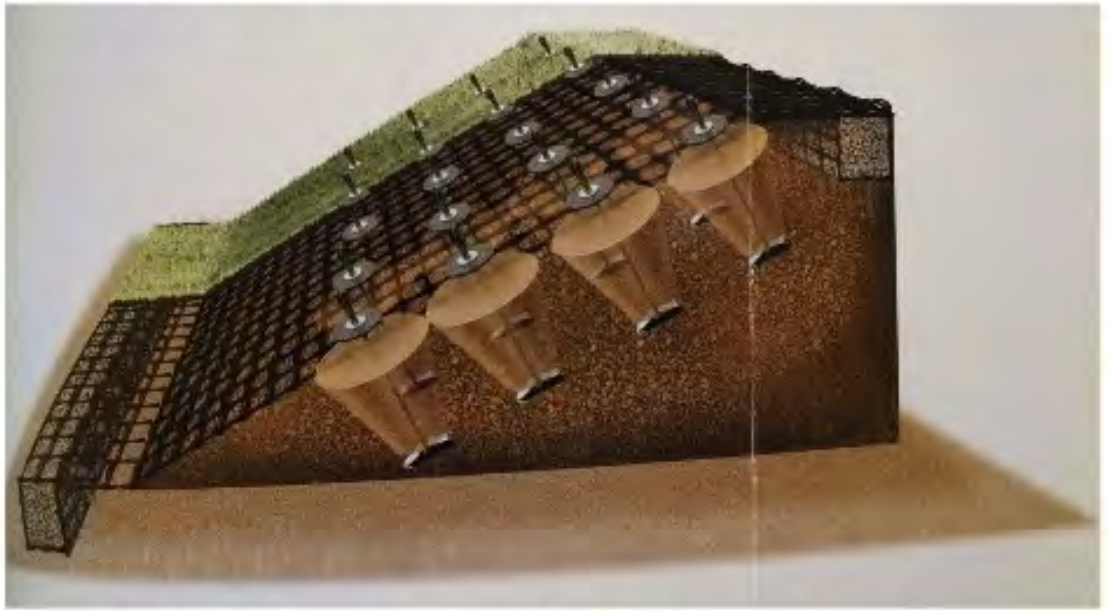
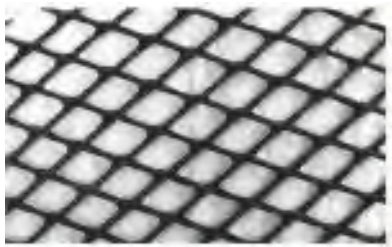


Figure 7. Soil Nail Reinforcing vegetated Geo-Grid (Source: Huesker)

GeoTextiles and Geogrids



Geotextile-geonets



Geotextile-geogrids



Geomembrane-geotextile



Geocell



Drainage geocomposite



Composite drain



Geocomposite for planar drainage

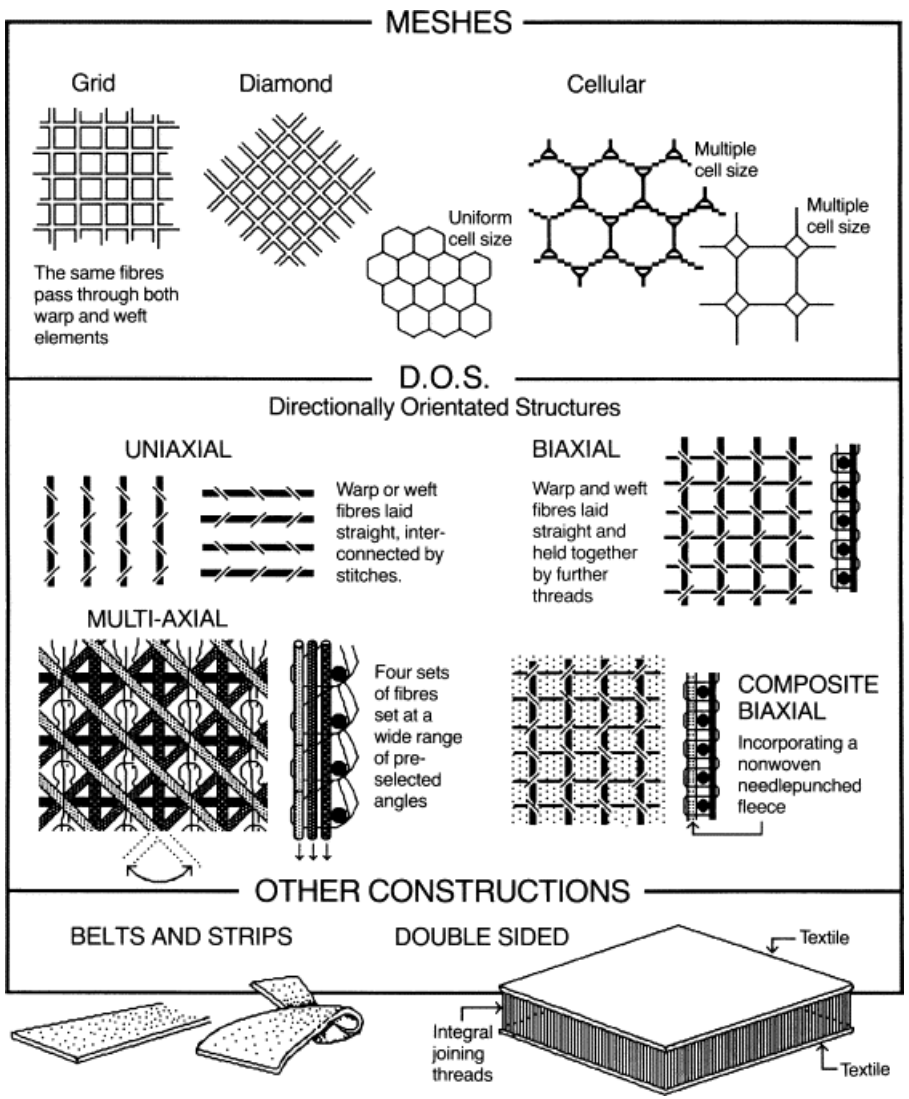


Glass filament reinforced geocomposite



Erosion control geocomposite

GeoTextiles and Geogrids





GeoTextiles and Geogrids



TerraMesh

GeoTextiles and Geogrids



TerraMesh

GeoTextiles and Geogrids

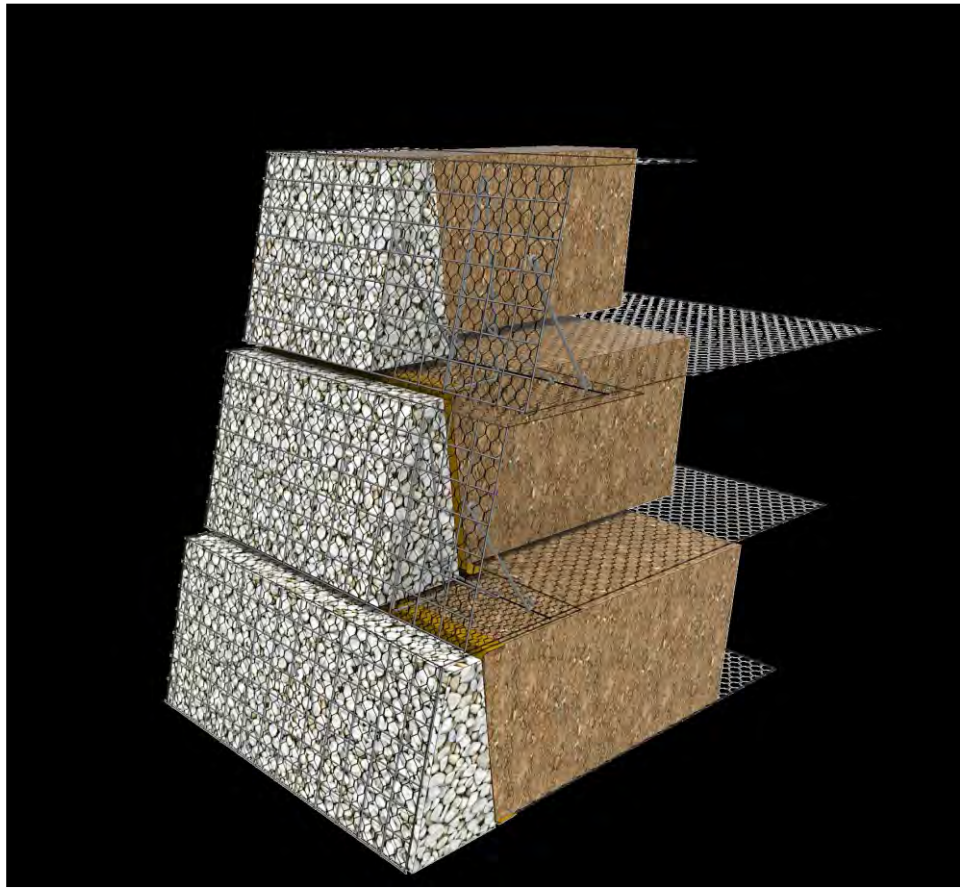


TerraMesh





GeoTextiles and Geogrids





TerraMesh



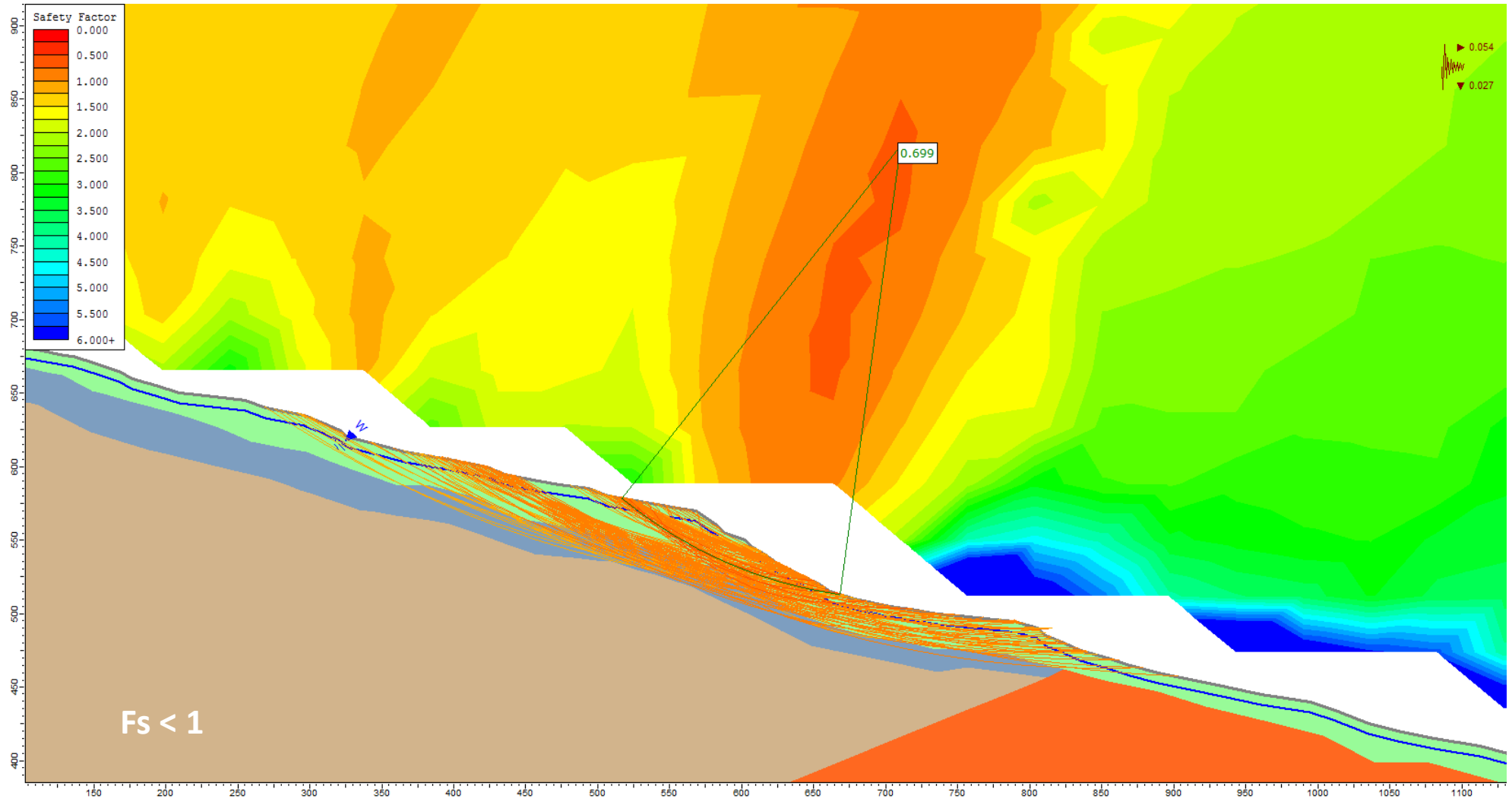


Boschetto landslide (Tizzano val Parma)

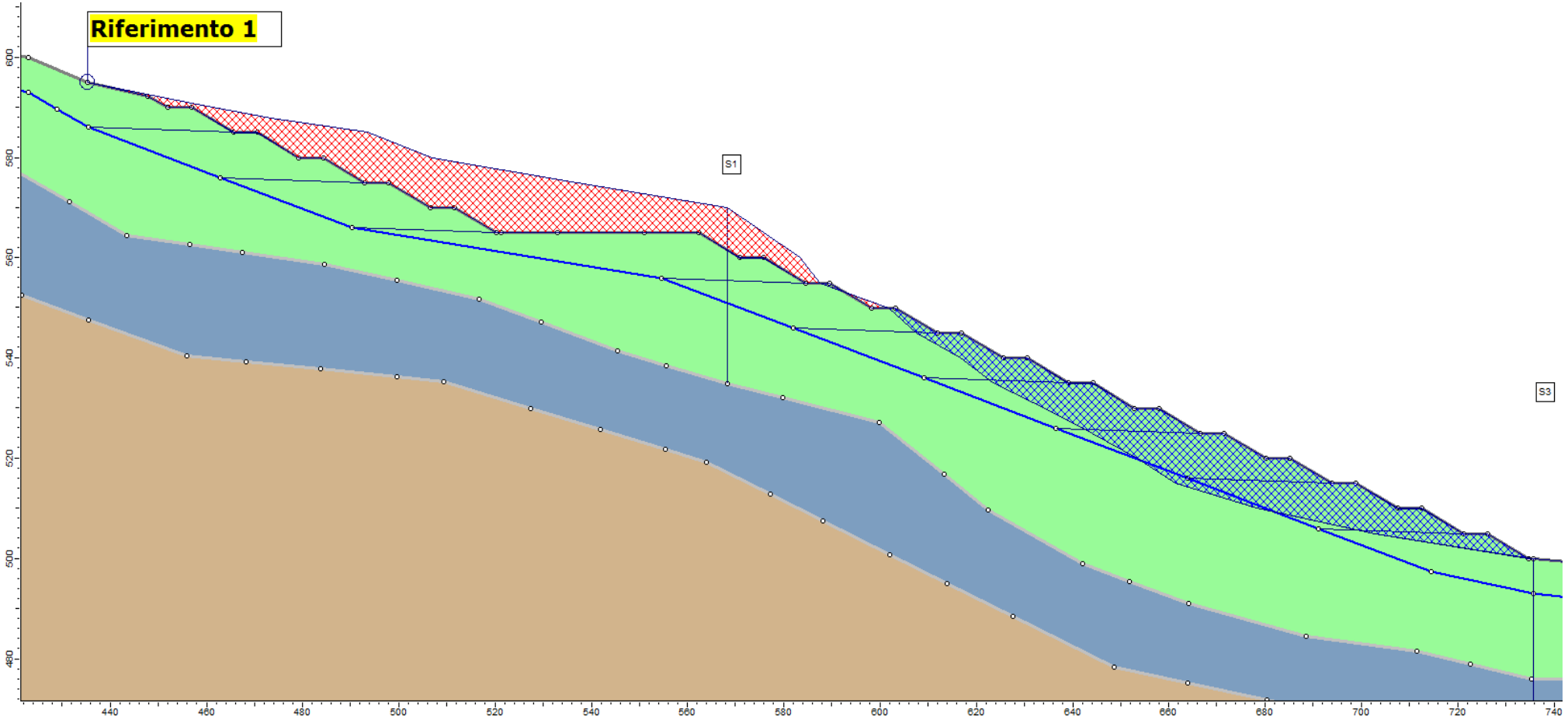




Case Pennetta Landslide (Solignano – Parma)



Geometry modification



Geometry modification

+

Piles

+

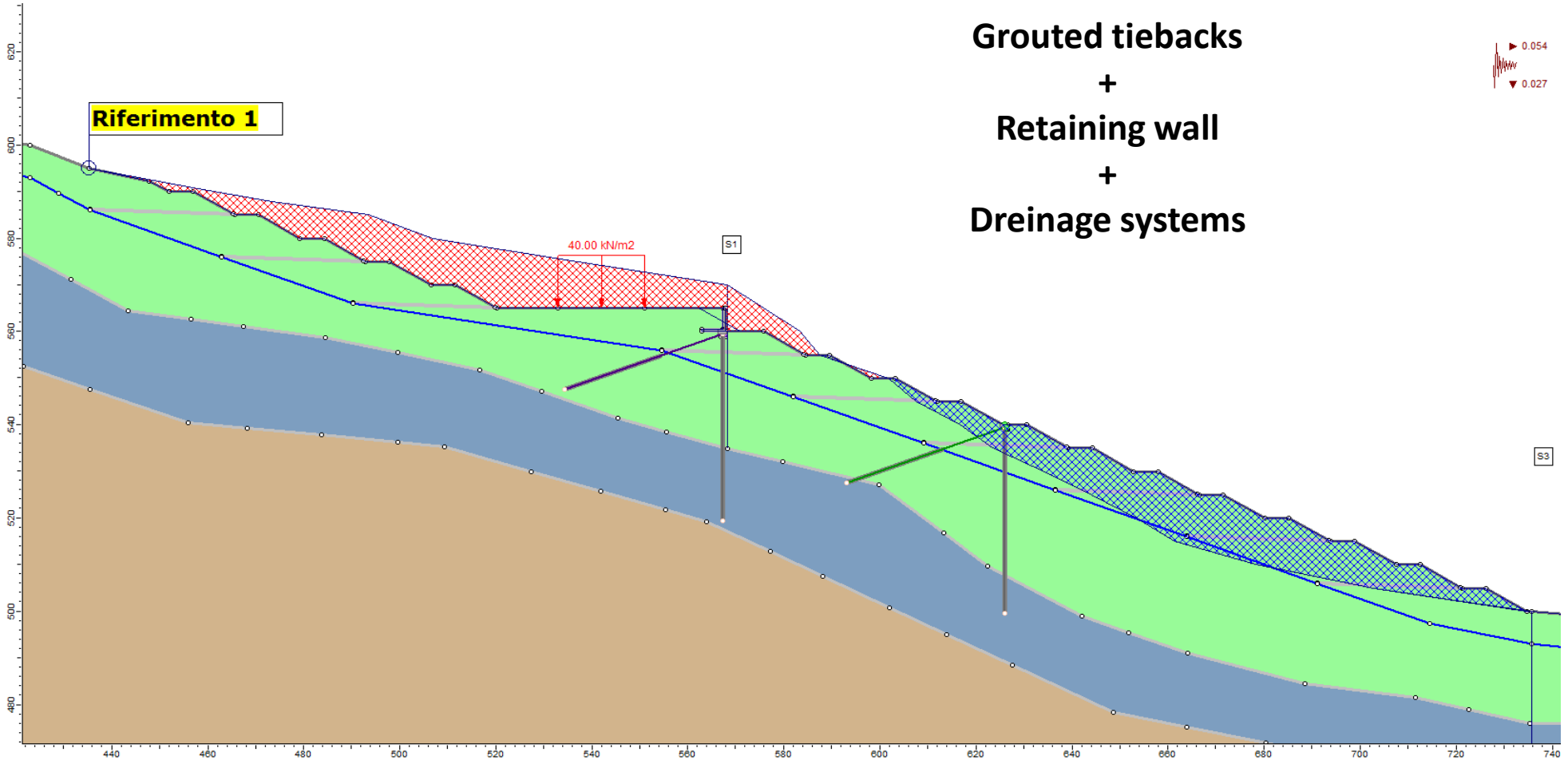
Grouted tiebacks

+

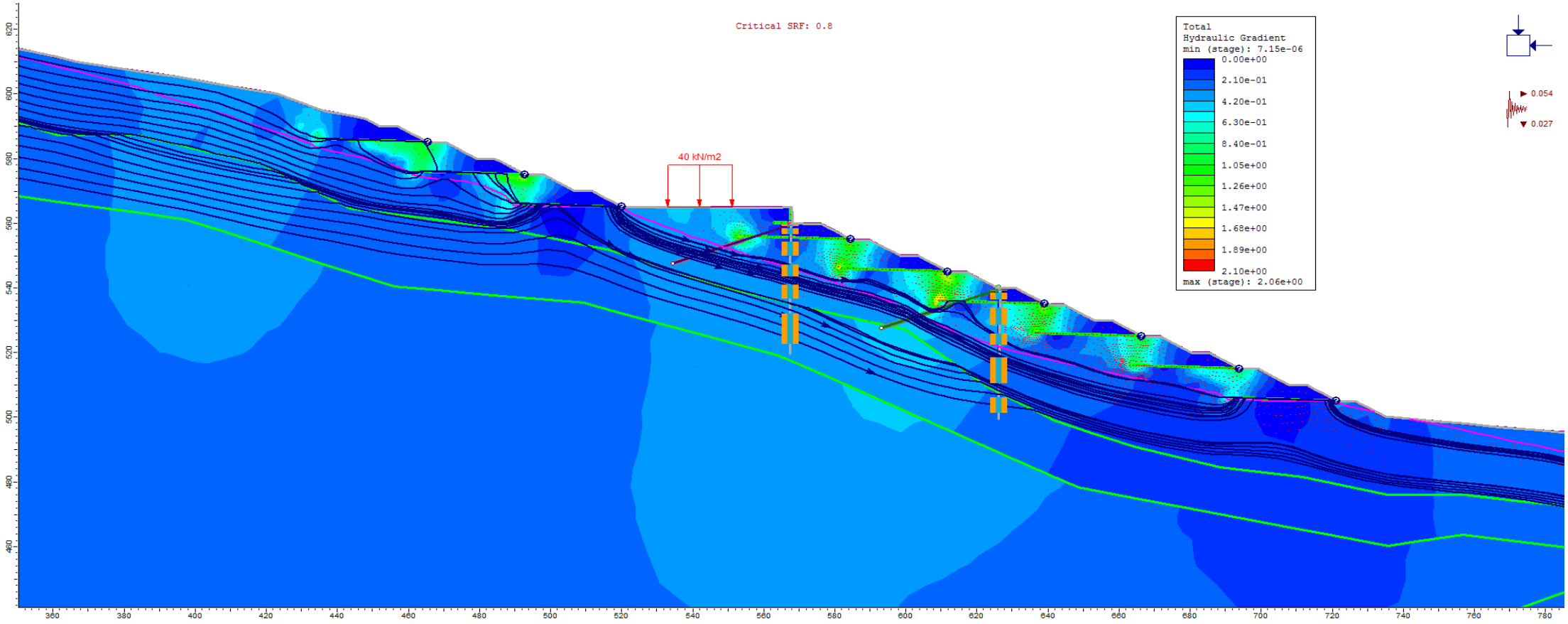
Retaining wall

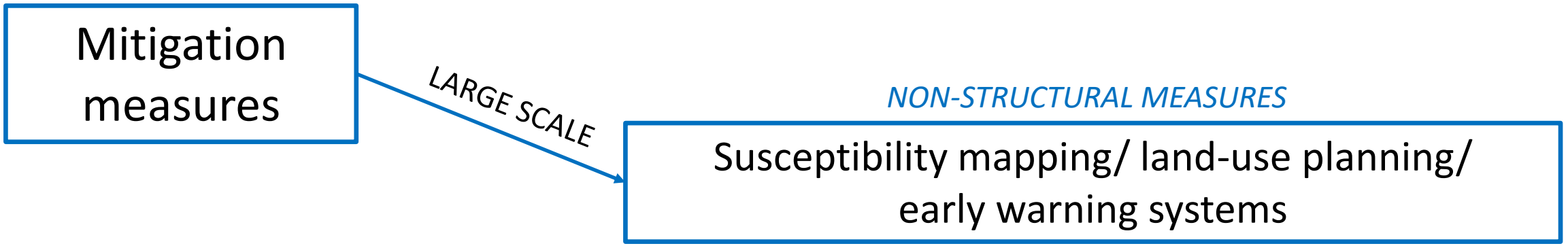
+

Dreinage systems

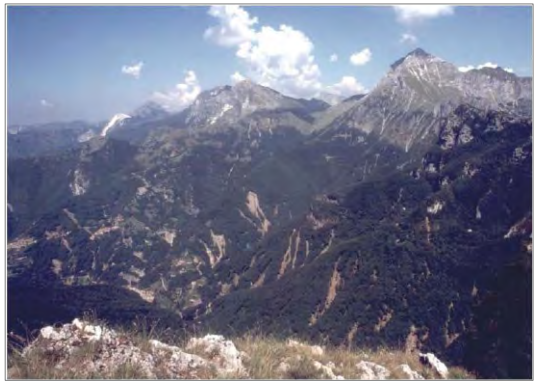


Effect of the drainage systems




Mitigation measures
LARGE SCALE
NON-STRUCTURAL MEASURES
Susceptibility mapping/ land-use planning/ early warning systems

TYPE OF LANDSLIDE: SHALLOW LANDSLIDES INDUCED BY RAINFALL



Alta Versilia – 19.06.1996 (*Tuscany*)



Sarno – 05.05.1998 (*Campania*)



Ceriana – 23.11.2000 (*Liguria*)



Oltrepo Pavese – 26.11.2002 (*Lombardy*)



App. Reggiano – 10.04.2005 (*Emilia Romagna*)



Giampilieri – 01.10.2009 (*Sicily*)



Casamicciola Terme – 10.11.2009 (*Campania*)

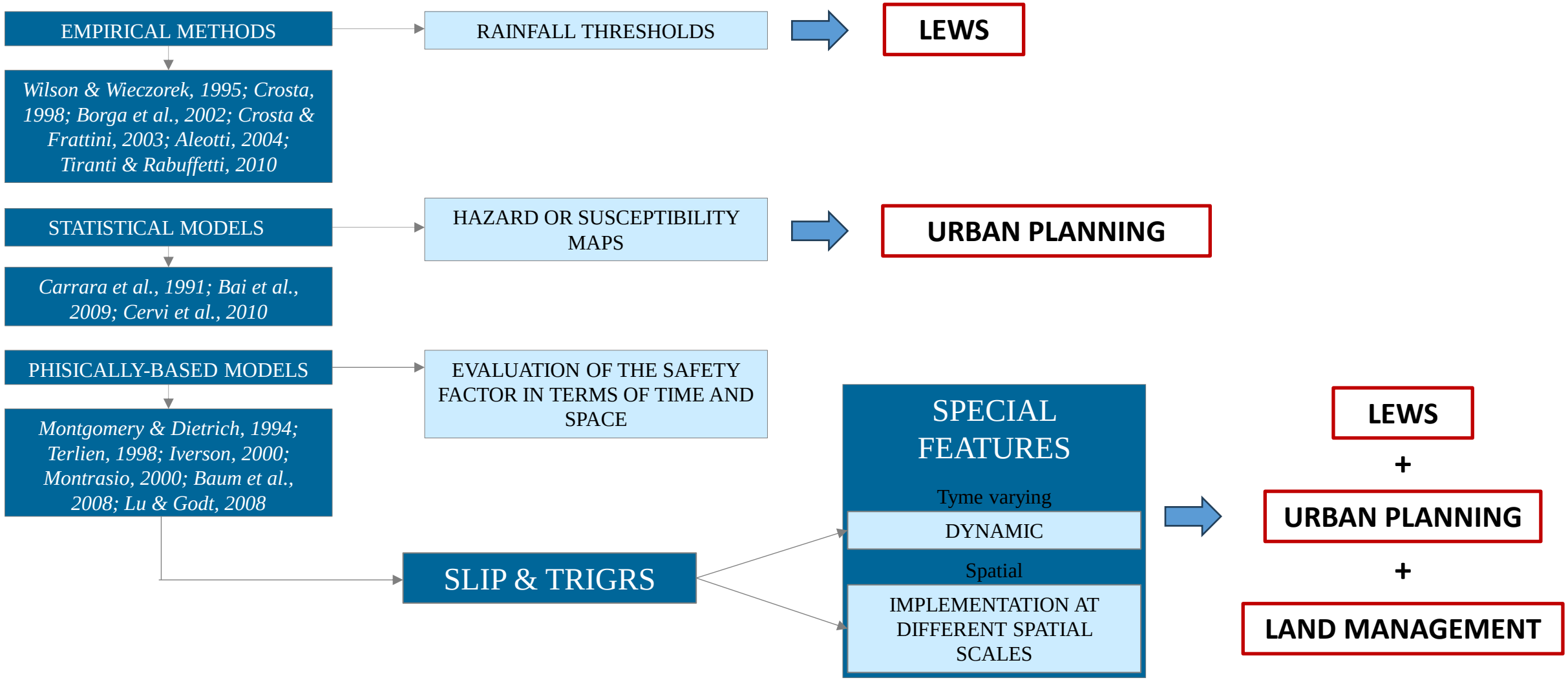


San Fratello – 14.02.2010 (*Sicily*)



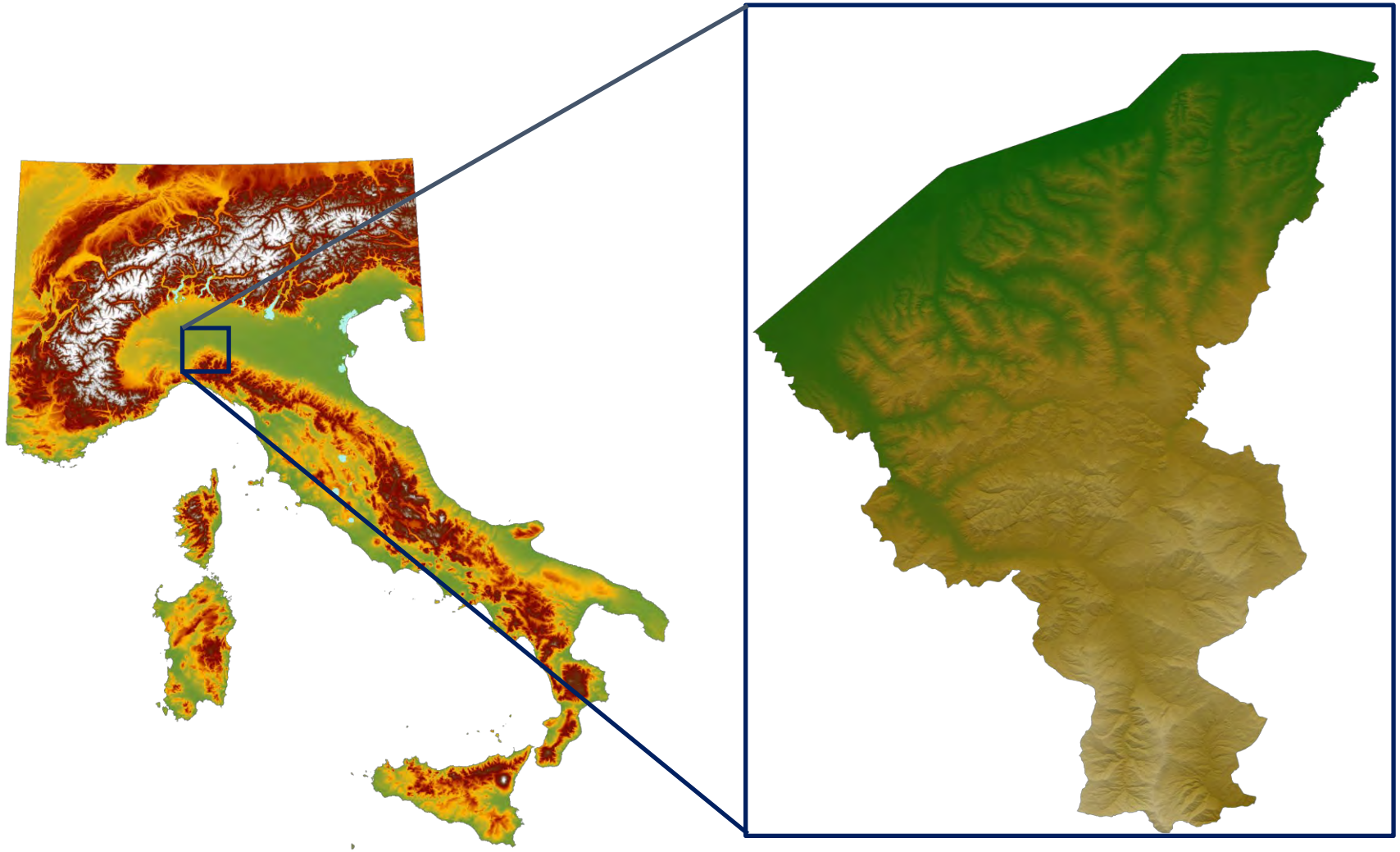
Massa Carrara – 01.11.2010 (*Tuscany)*

«DISTRIBUTED» SLOPE STABILITY ANALYSIS



Case study in Italy: Oltrepò Pavese, April 2009

Oltrepò Pavese is in the north-west of Italy and lies to the south of the Po river.

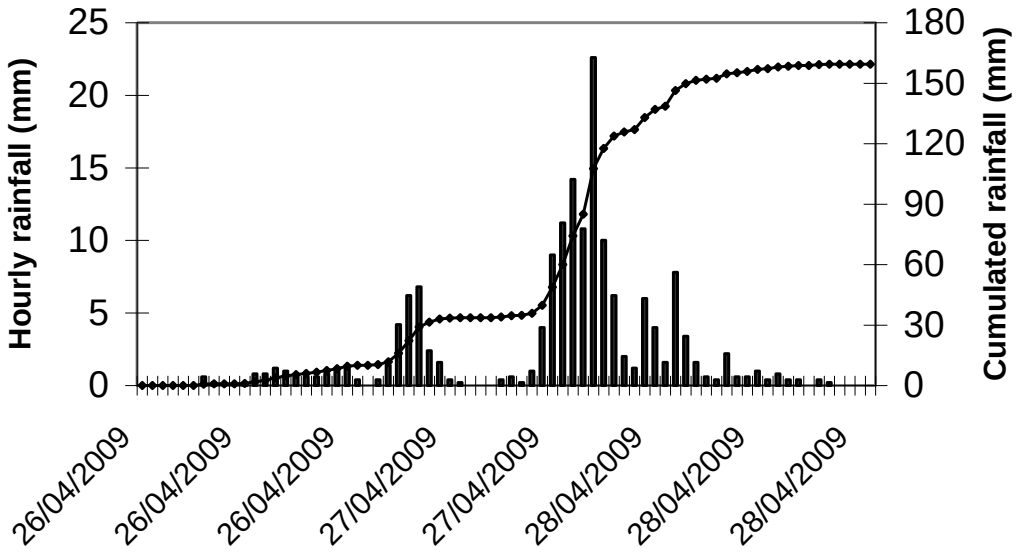


Case study in Italy: Oltrepò Pavese, April 2009

- On the 27 and 28 April 2009, the northeastern sector of Oltrepò Pavese experienced an extreme rainfall event. On the 28 April, the nearest rain-gauge station recorded 150mm of rain in 48 h (20% of the annual average amount), with a maximum rainfall intensity of 22mm per hour

- After this rainfall peak, several shallow landslides were triggered, causing one fatality and loss of agricultural land, as well as damaging/blocking roads in several places





Case study in Italy: Oltrepò Pavese, April 2009





Case study in Italy: Oltrepò Pavese, April 2009

The Recoaro Valley was the most affected area by this event

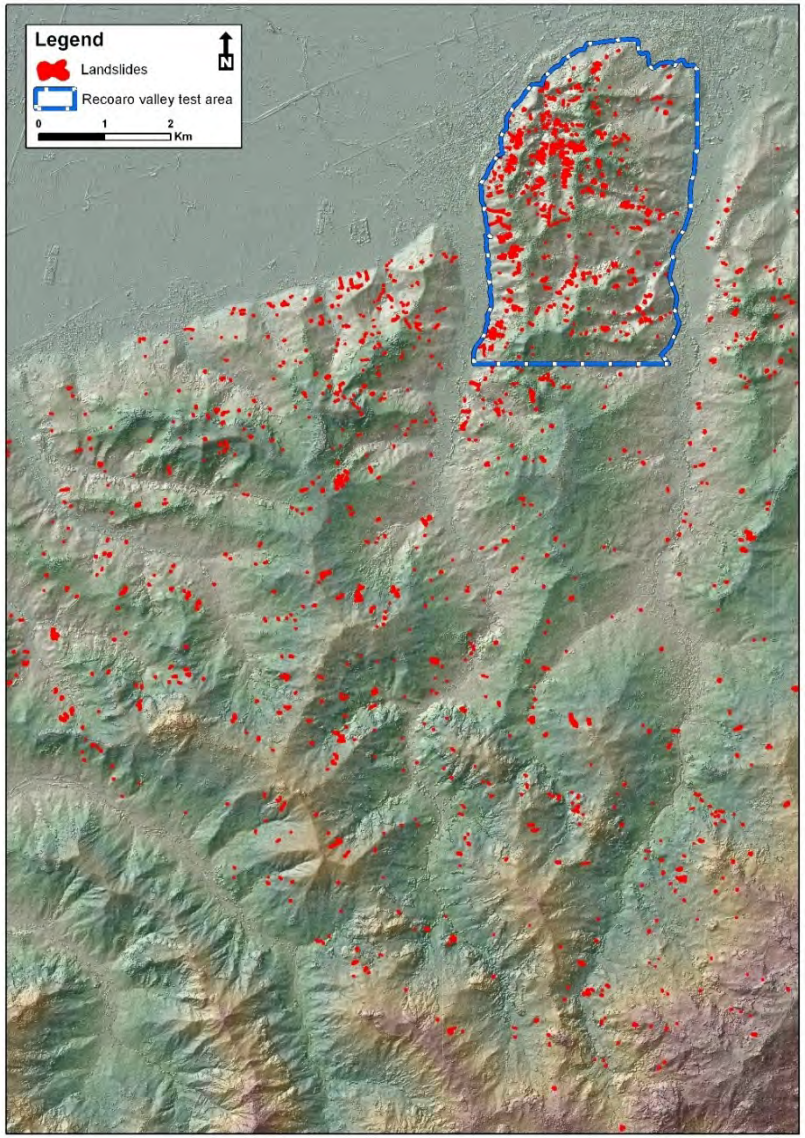


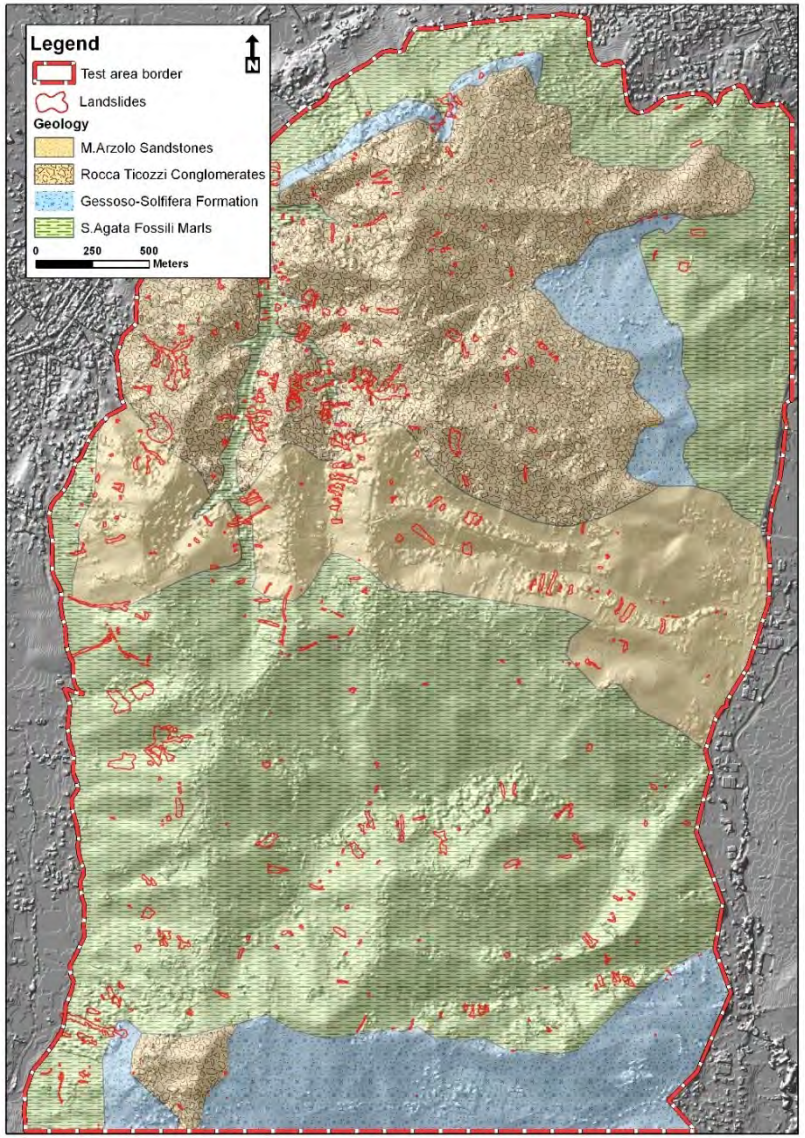


Case study in Italy: Oltrepò Pavese, April 2009

More than 1600 landslides in 180 km²

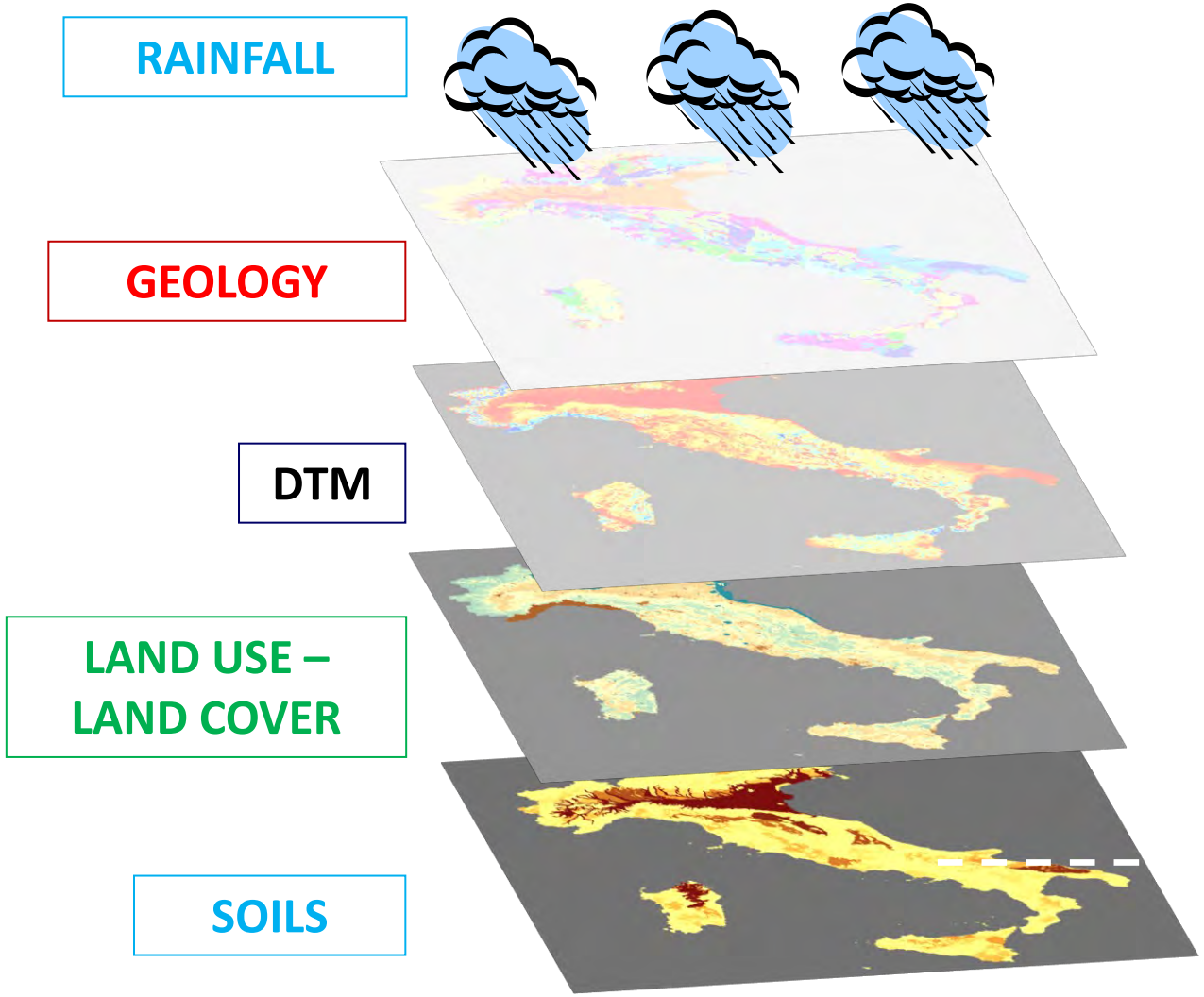
No. 491 landslides in 17 km²





Case study in Italy: Oltrepò Pavese, April 2009

Implementation of a distributed slope stability model at regional scale



Pre-Processing:

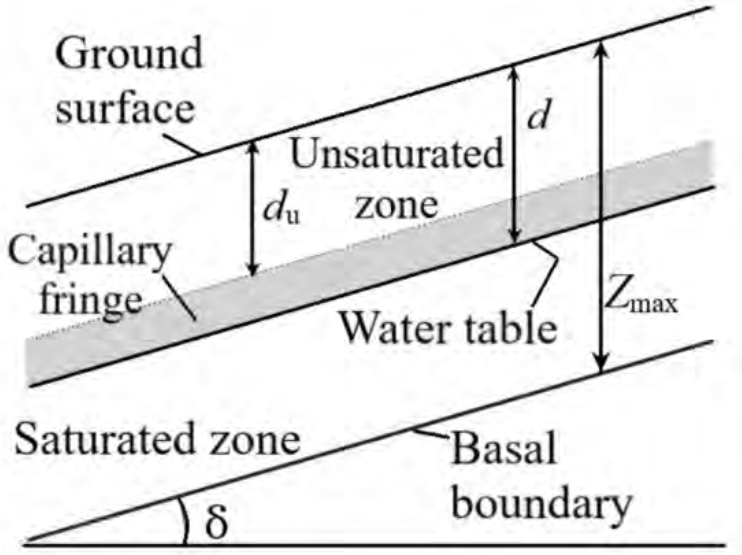
Data at large scale are acquired at the maximum available resolution.

Use of GIS

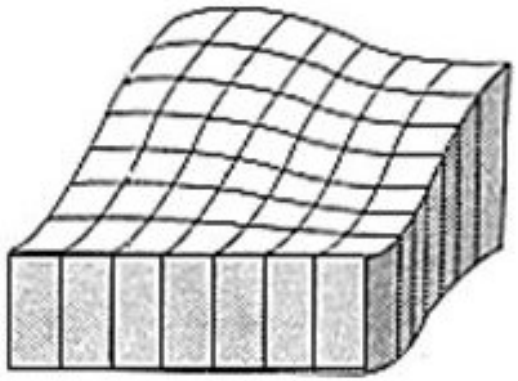
Case study in Italy: Oltrepò Pavese, April 2009

❑ TRIGRS uses an infinite-slope model to compute a factor of safety (FS) calculation ***for each grid cell***.

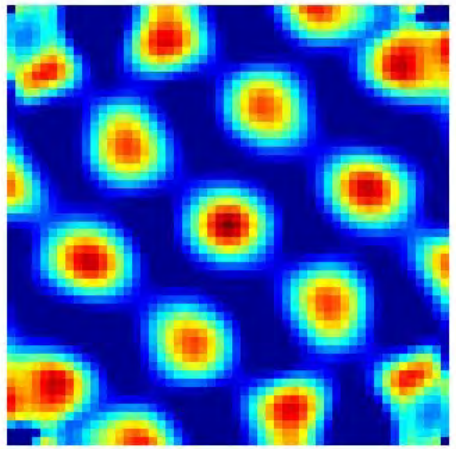
$$Fs(Z;t) = \frac{\tan\varphi'}{\tan\beta} + \frac{c' - \psi(Z;t)\gamma_w \tan\varphi'}{\gamma_s Z \sin\beta\cos\beta}$$



Elementary grid cell 10m x 10m

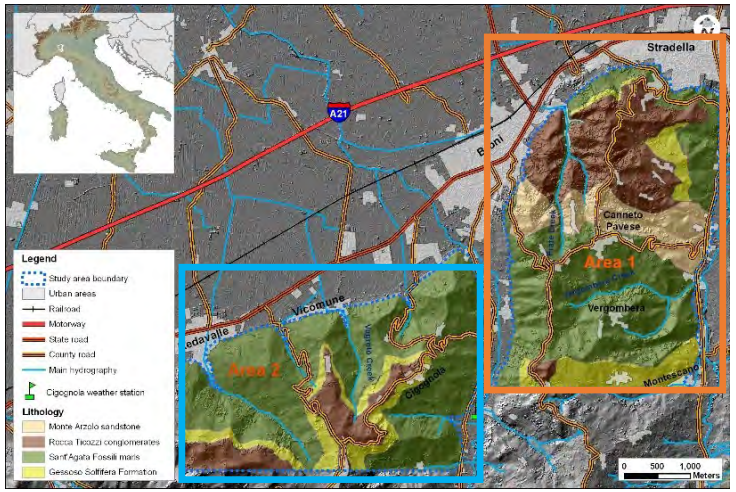


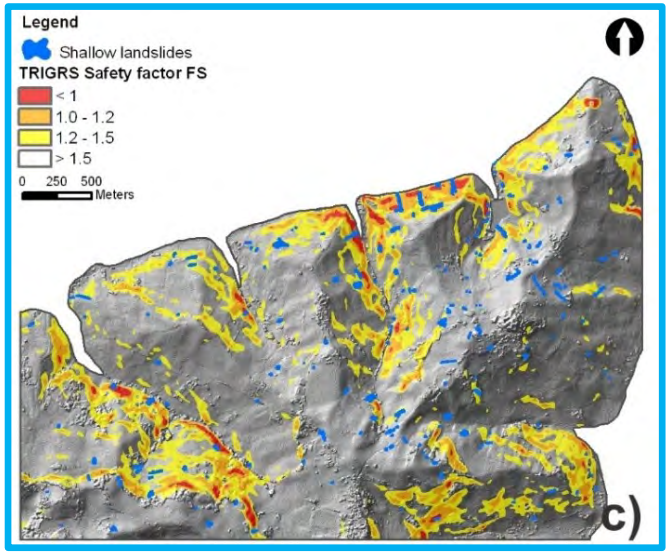
Fs map

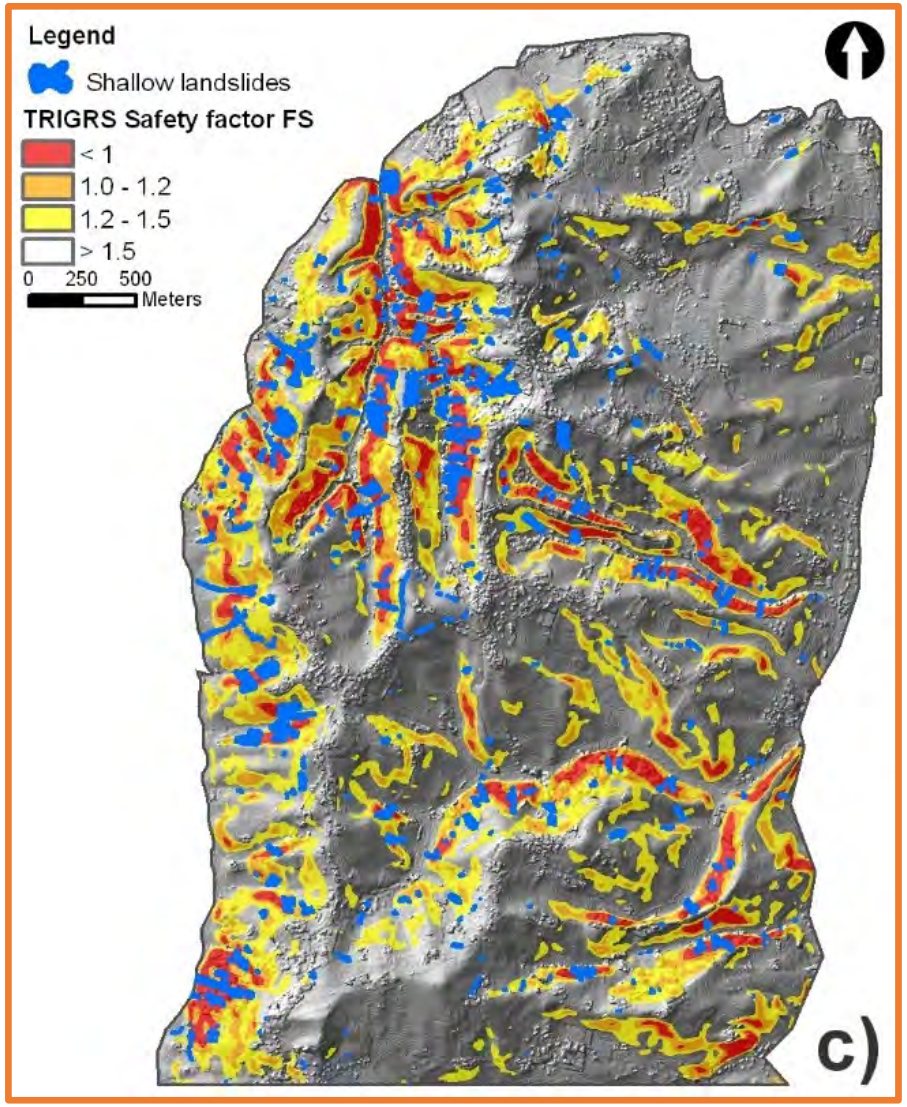


TRIGRS - Transient Rainfall Infiltration and Grid-Based Regional Slope-Stability Analysis (Baum et al., 2008)

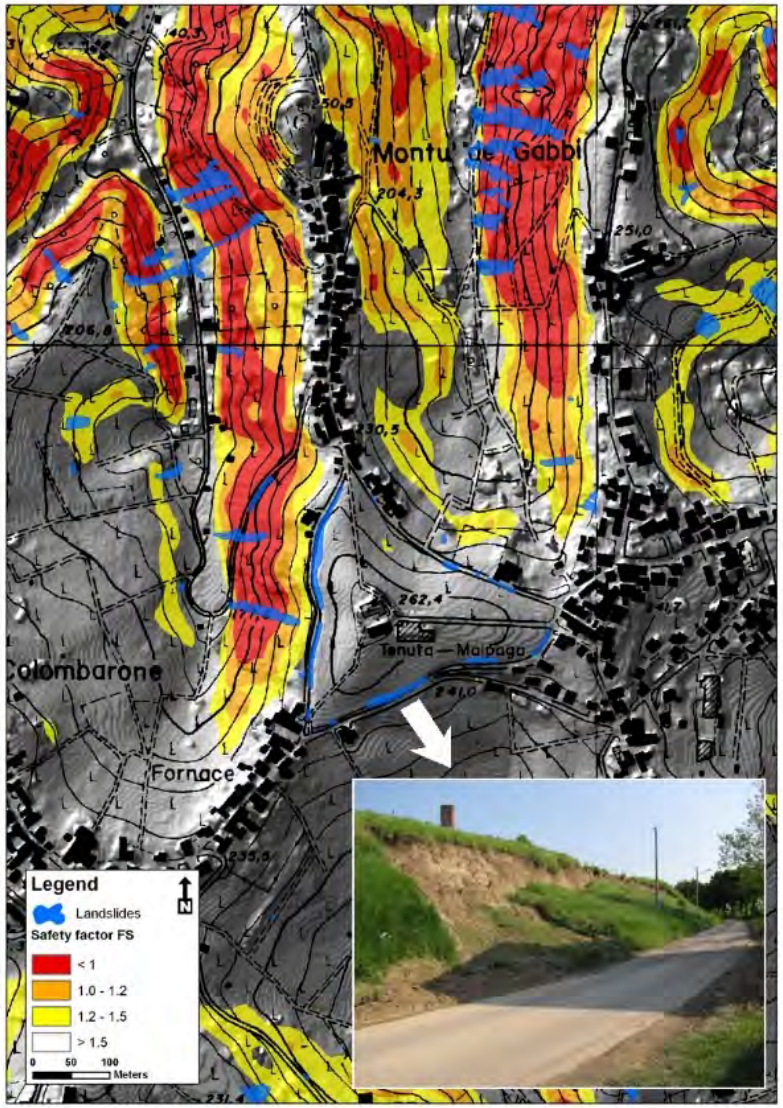
Case study in Italy: Oltrepò Pavese, April 2009

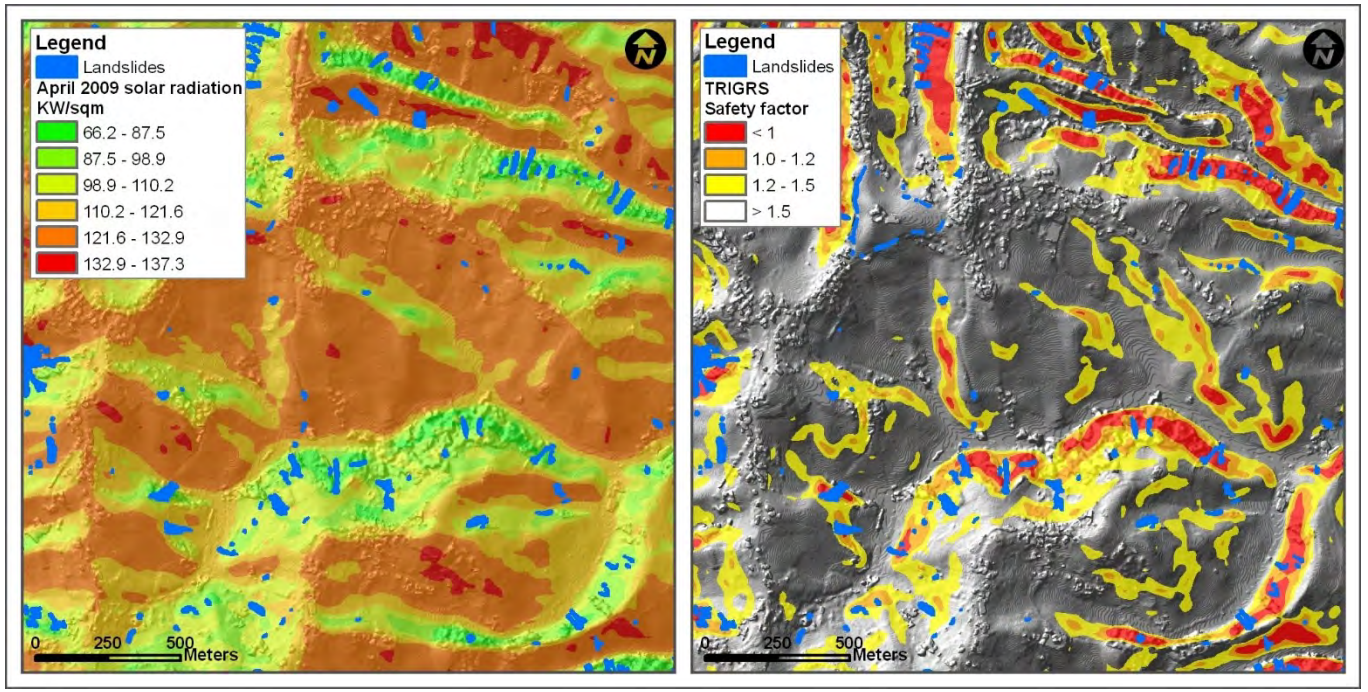






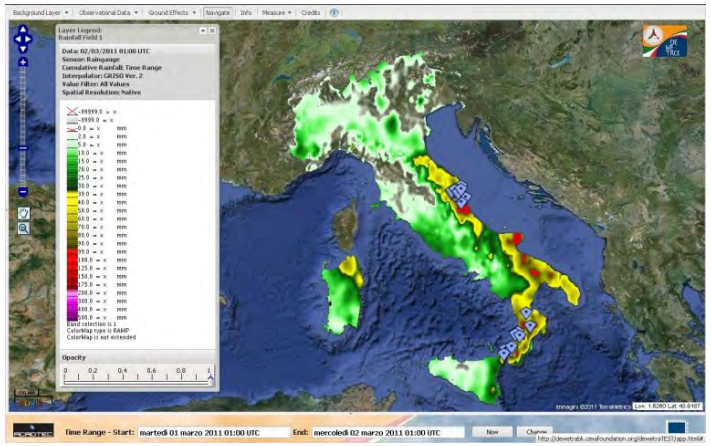
Case study in Italy: Oltrepò Pavese, April 2009





SLIP model at national scale in Italy

Rainfall map

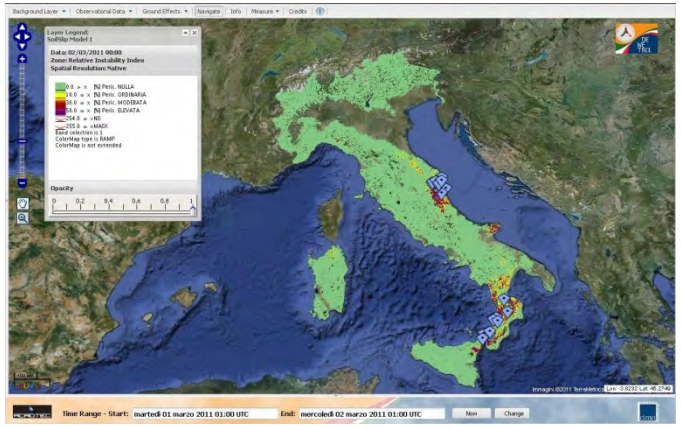


Geospatial data



SLIP model

Safety Factor (F_s) on elementary cells 20m x 20m



DEWETRA

reference operative system aimed to prevent, detect and mitigate potential weather related risks

NATIONAL CIVIL PROTECTION CENTRE

INSTABILITY INDEX

Ratio between number of elementary cells having Fs≤1 and total cells on areas

1km x 1km

ALERT LEVELS

Low

Ordinary

Moderate

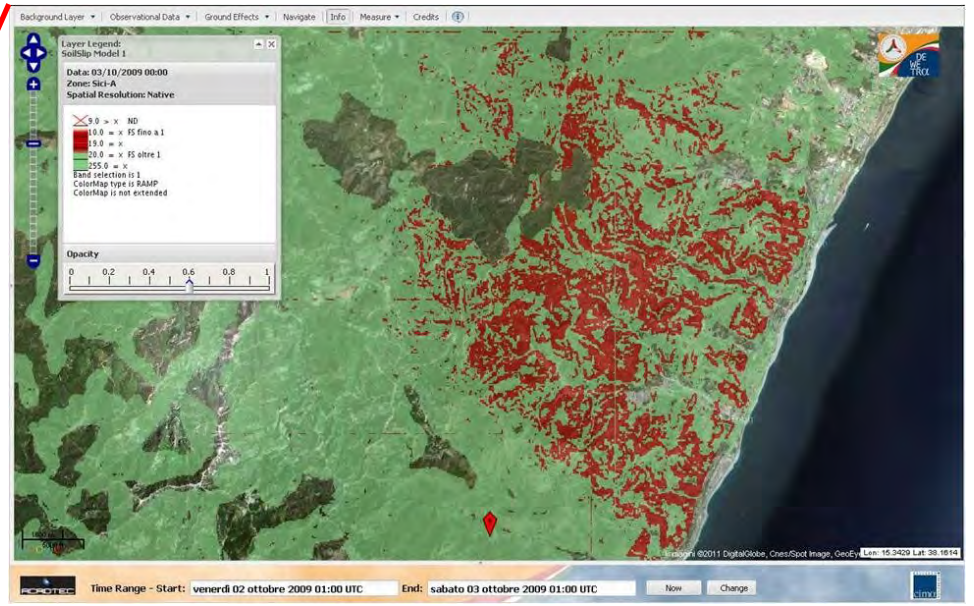
High

SLIP model at national scale in Italy

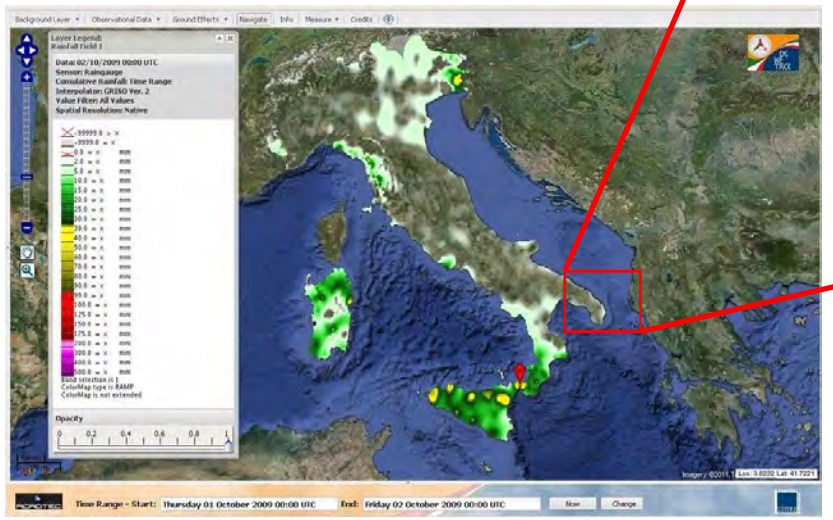
Event occurred at Giampilieri (ME) on the 1th of October 2009 (37 victims)

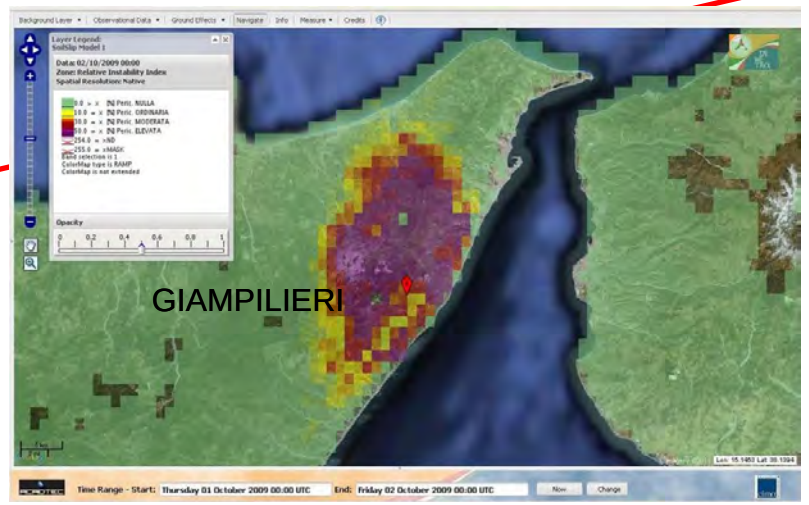


F_s map (20m x 20m)



Rainfall map





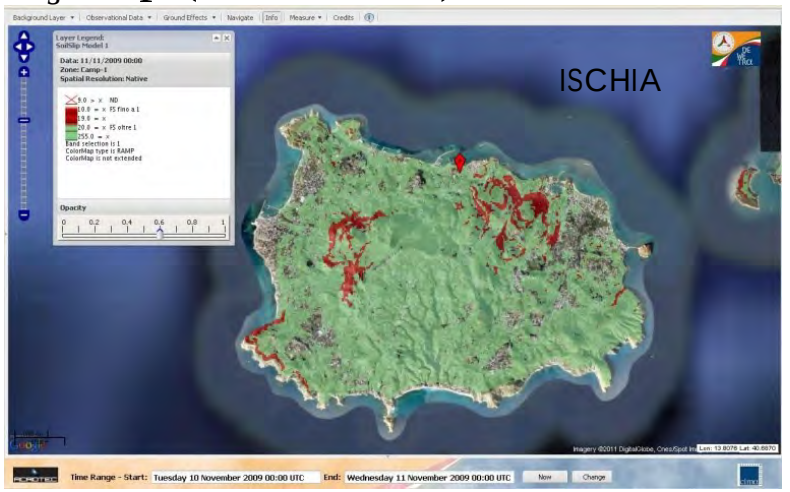
Instability index

SLIP model at national scale in Italy

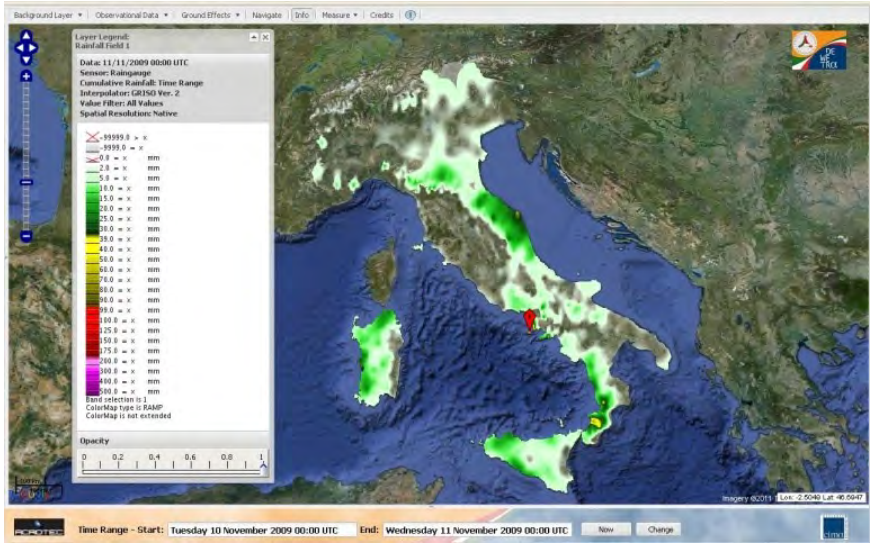
Event occurred at Casamicciola Terme (Isle of Ischia) on the 10th of November 2009 (1 victim)



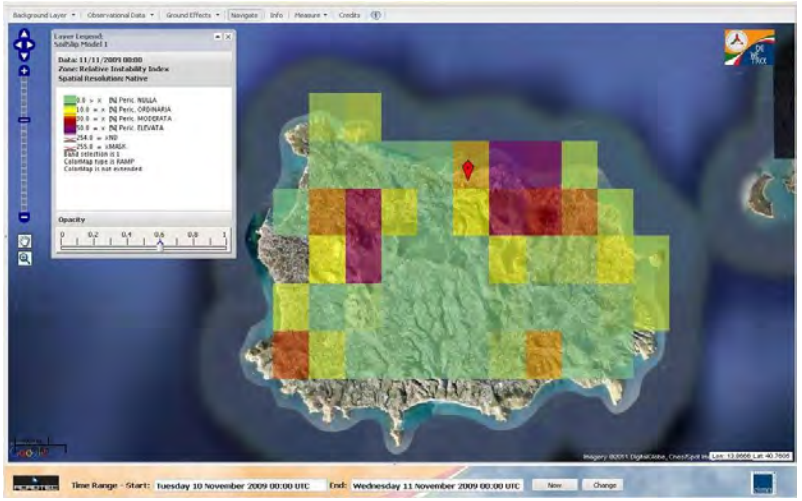
F_s map (20m x 20m)



Rainfall map



Instability index (1km x 1km)

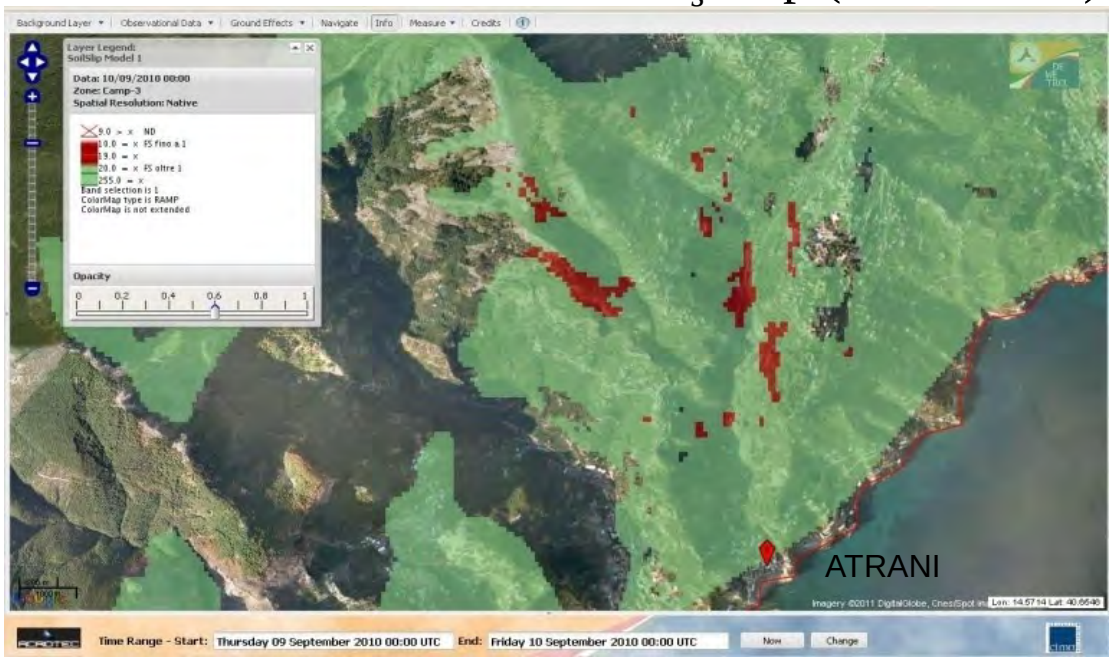


SLIP model at national scale in Italy

Event occurred at Atrani on 9th of September 2010 (1 victim)



F_s map (20m x 20m)



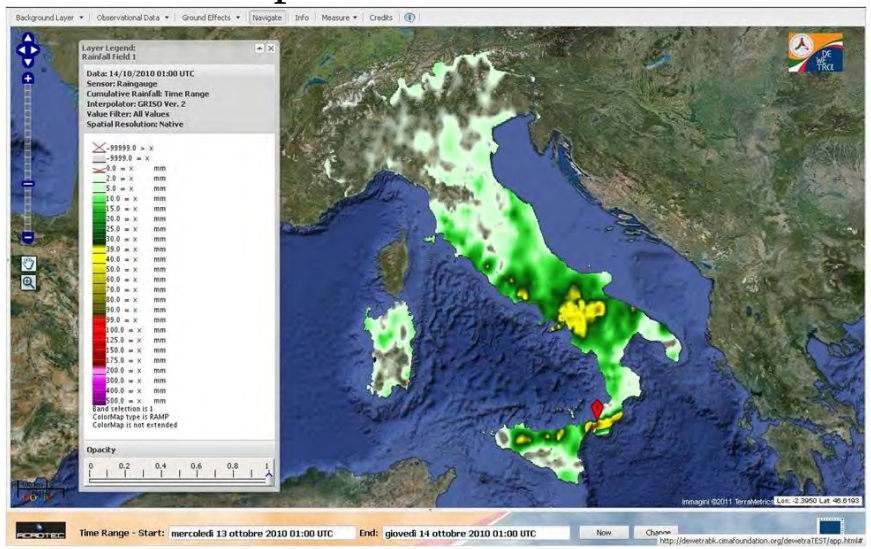


Zoom on the triggering areas

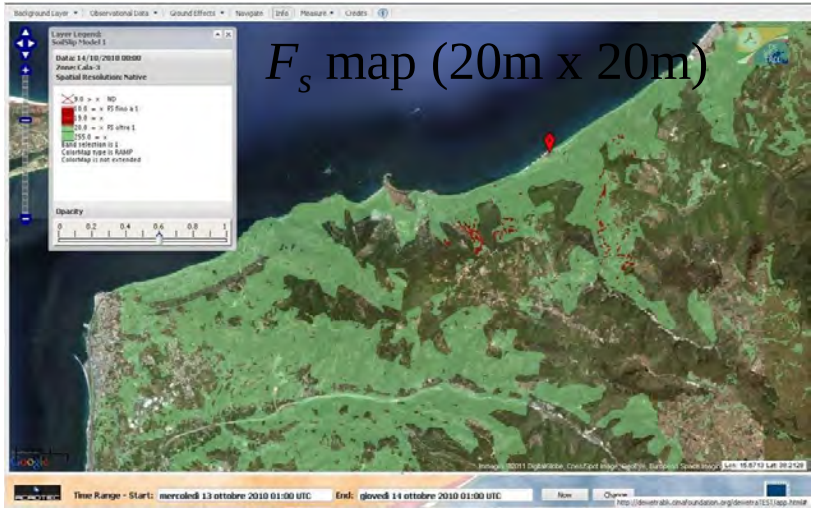
SLIP model at national scale in Italy

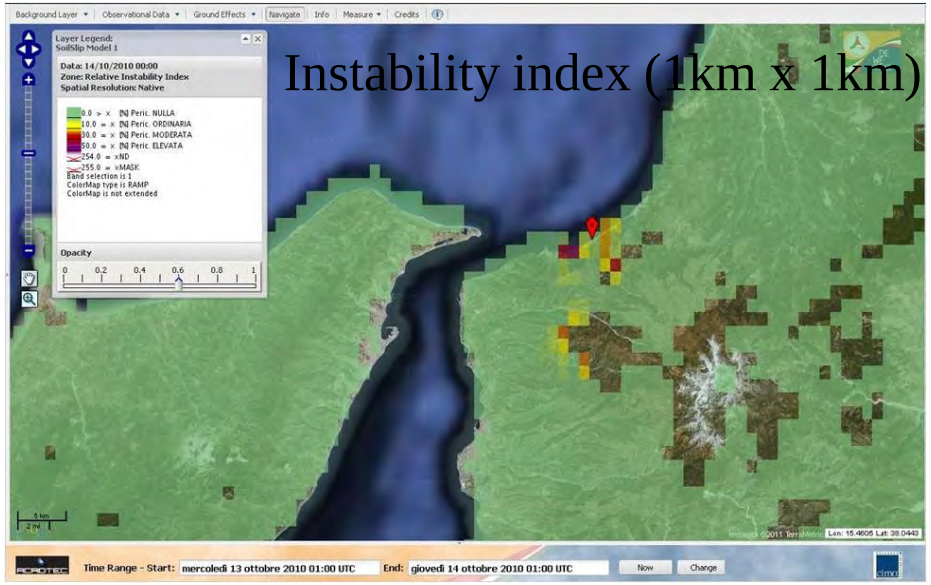
Event occurred at Reggio Calabria on the 13th of October 2010

Rainfall map







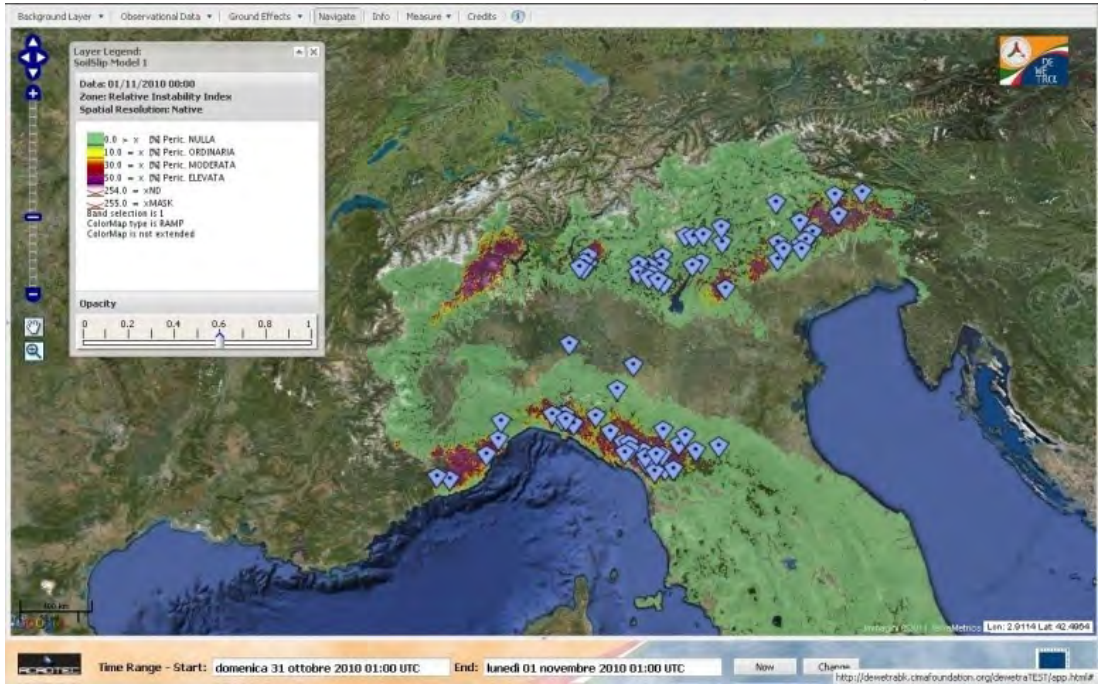


SLIP model at national scale in Italy

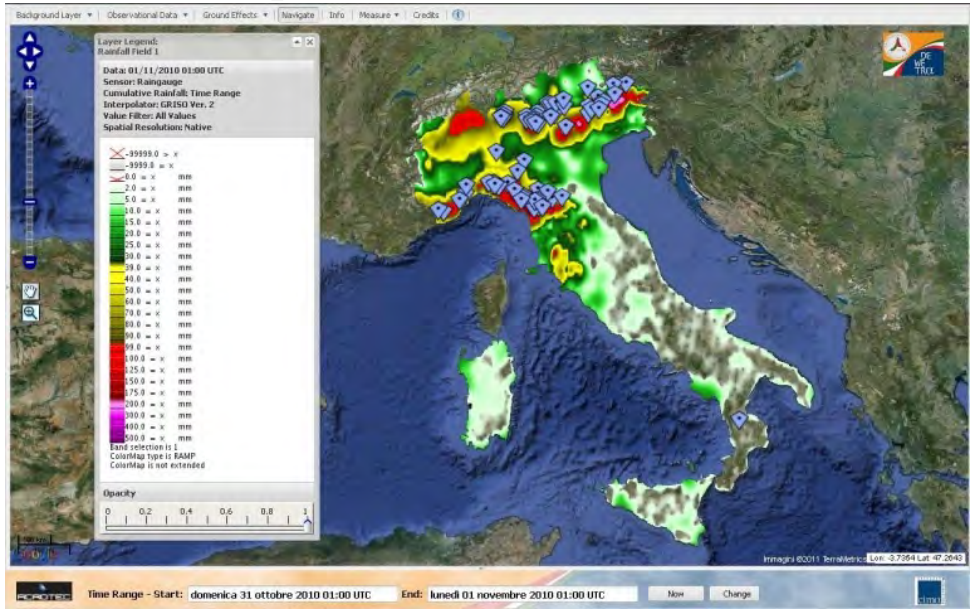
Event occurred in Northern Italy on the 31st of October 2010 (3 victims)



Map of instability index



Rainfall map

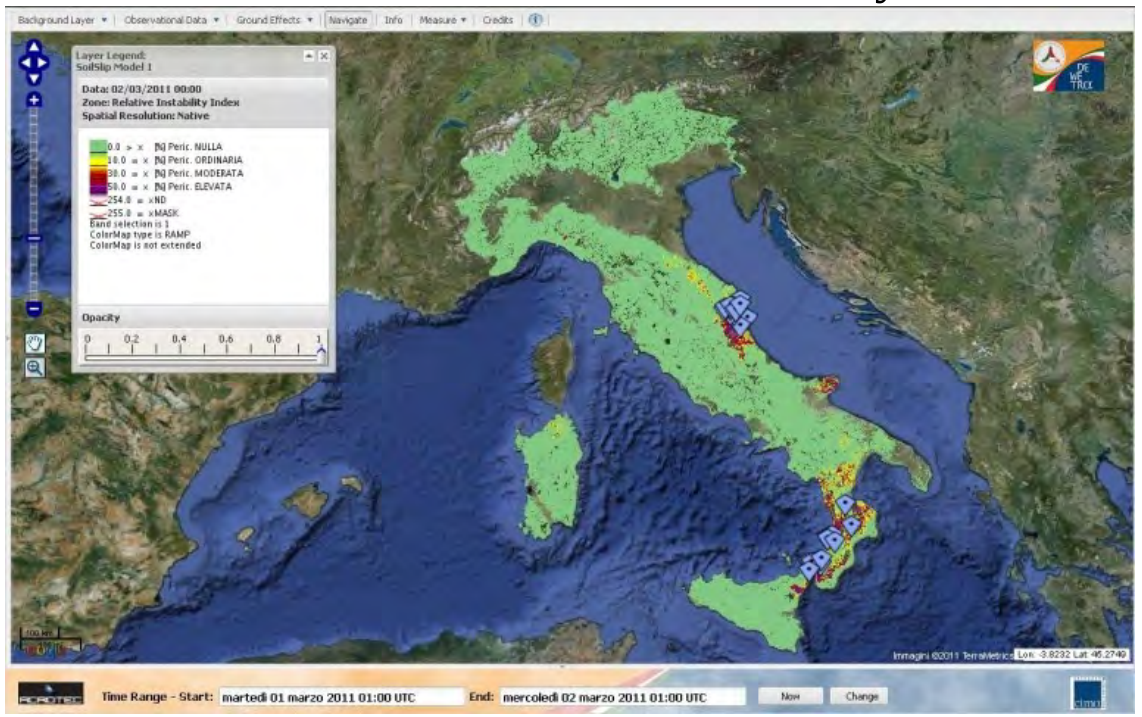


SLIP model at national scale in Italy

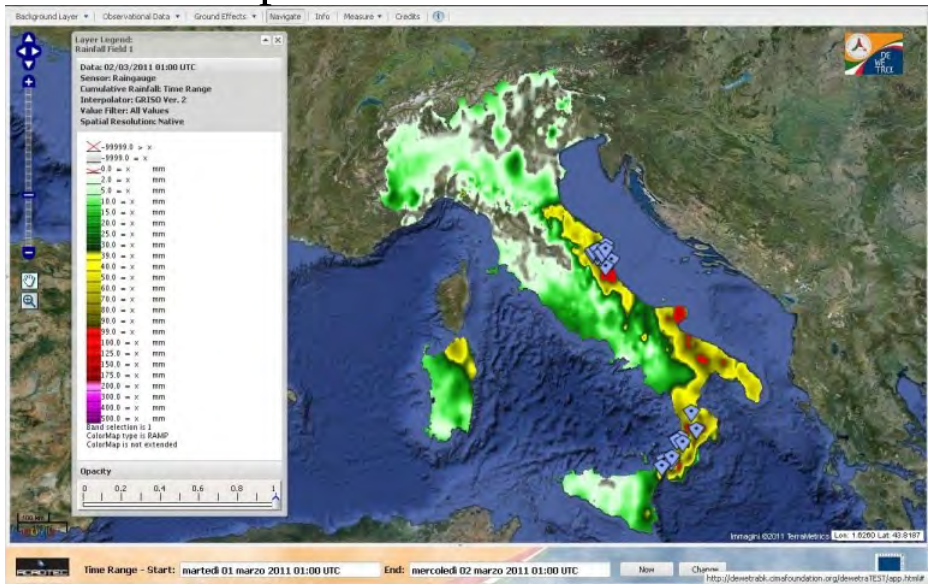
Events occurred on the 1st of March 2011 in Marche and Calabria



Instability index



Rainfall map



Summary

LEM

- **SINGLE SLOPE SCALE**

GeoWizard
Geo-Engineering Programs

HYRCAN 2.0
©2022 Roozbeh Geraili Mikola

rocscience

- **LARGE SCALE**

  TRIGRS
  SHALSTAB
  SINMAP
  SLIP

Landslide inventory (+ MAP):

- Date (day/month/year)
- Position (on the map)
- Shape (edge as polygon on the map)/2D profile
- Type
- Type of material (rock of soil)
- New or re-activated
- Land use
- Damage
- Photo

Data collection:

✓ Soil/rock samples
✓ Lab tests for classification and mechanical characterization

THANK YOU