XIV Convegno Nazionale GIT
17-19 Giugno 2019
Melfi (Pz)

The Cimaganda landslide (SO): hydro-mechanical numerical modelling

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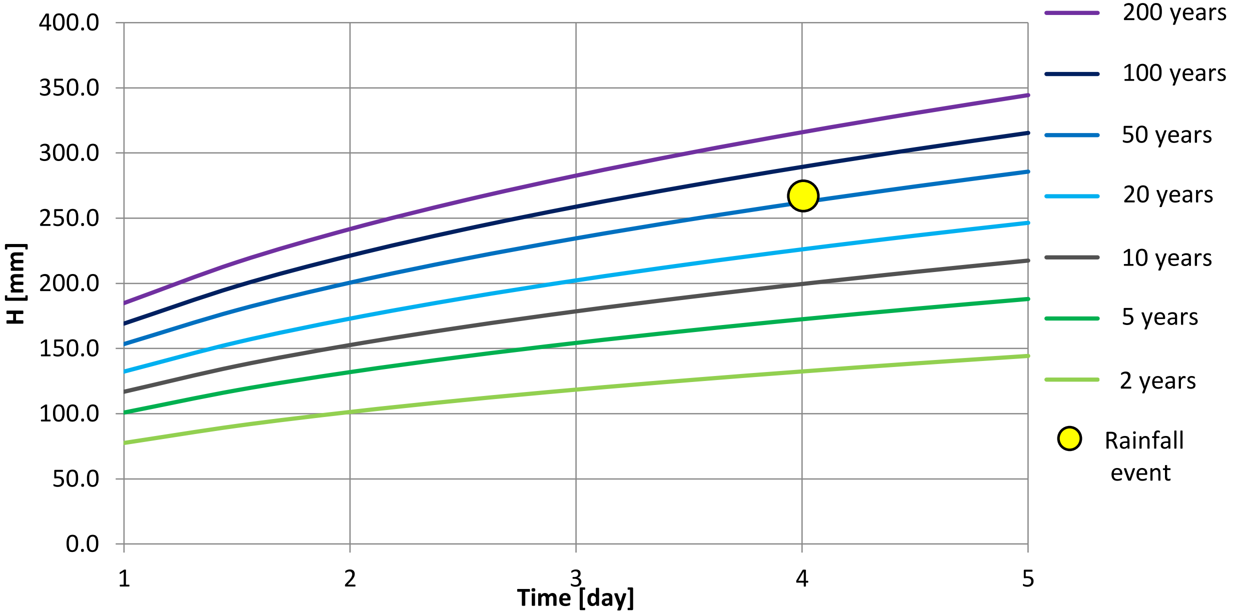
Cimaganda landslide

27th September 2012

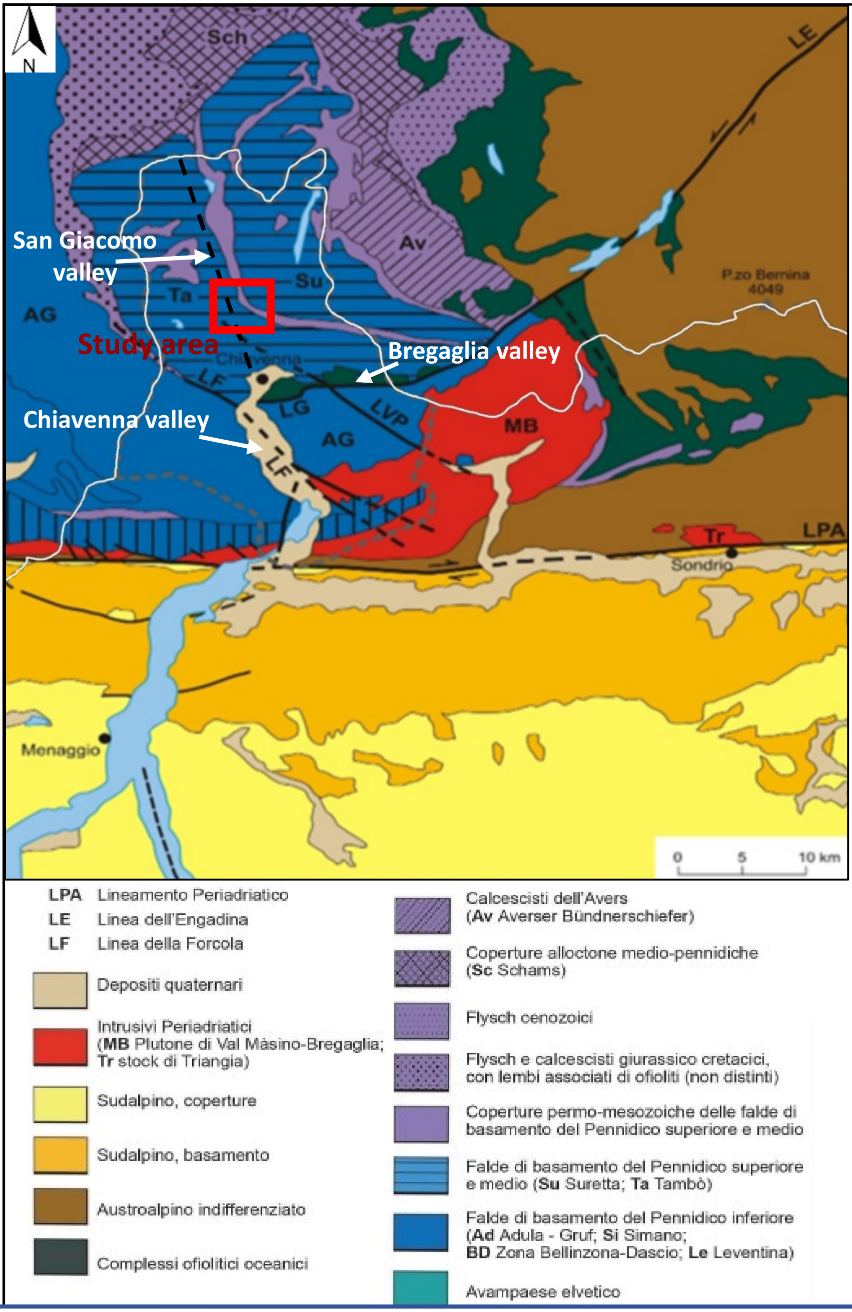
Rock volume involved: 20.000 m^3

Triggering factor:

DDF CURVES – 'Cimaganda'



Total amount of water cumulated in 4 days: 267,8 mm



Cimaganda landslide

Geological framework

- <u>Suretta nappe (Upper Pennidic unit)</u>

''Complesso stella timun''

Permo-mesozoic cover unit

- <u>Tambò nappe (Middle Pennidic unit)</u>

''Zona del Corbet superiore''

<u>Main structural elements</u>:

- *Engadina line (NE-SW)*
- *Forcola line (NW-SE)*
- *San Giacomo Valley allignment (N-S)*
- *Tambò-Suretta contact (N-S/ NW-SE)*

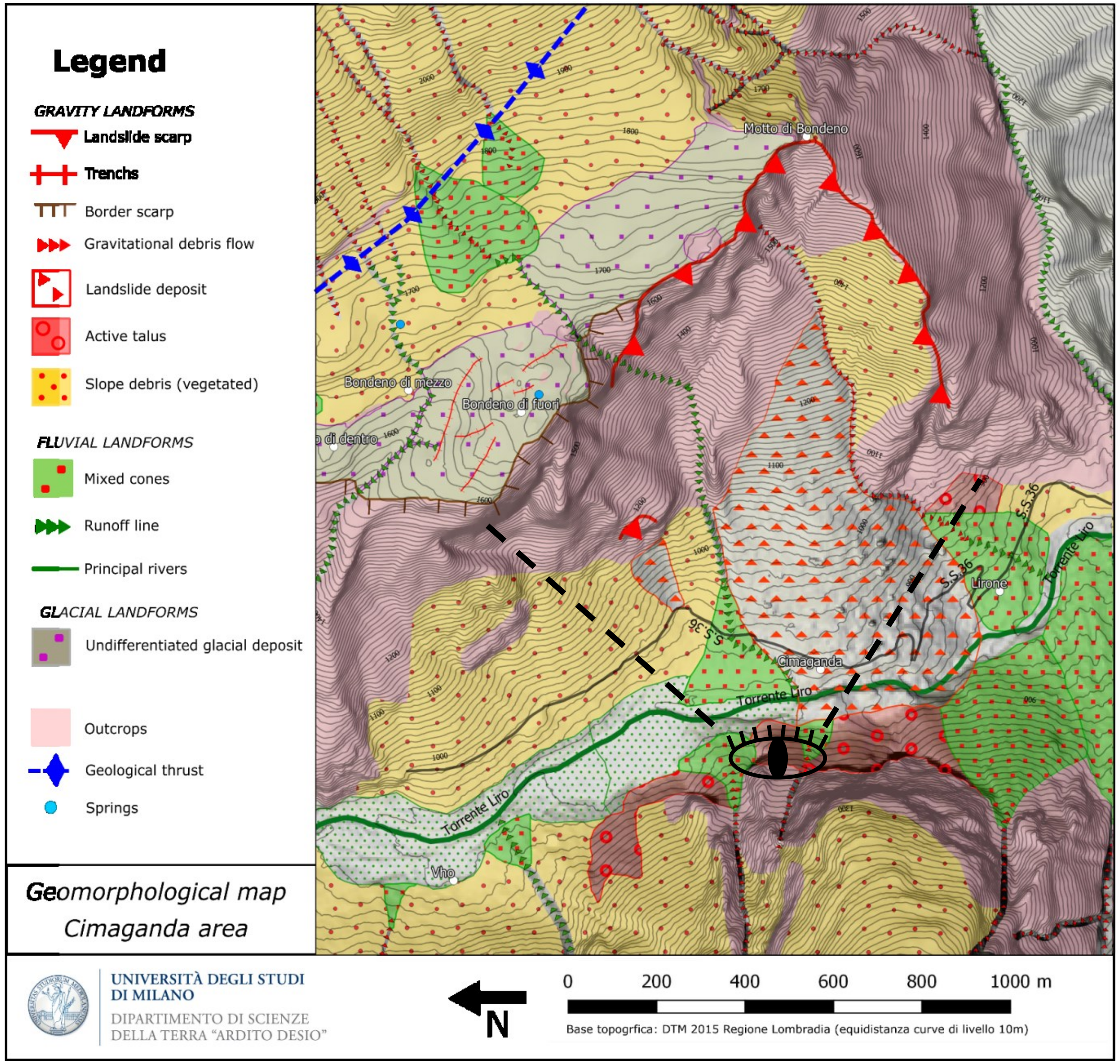
Ortogneiss – Tambò nappe

Paragneiss – Tambò nappe

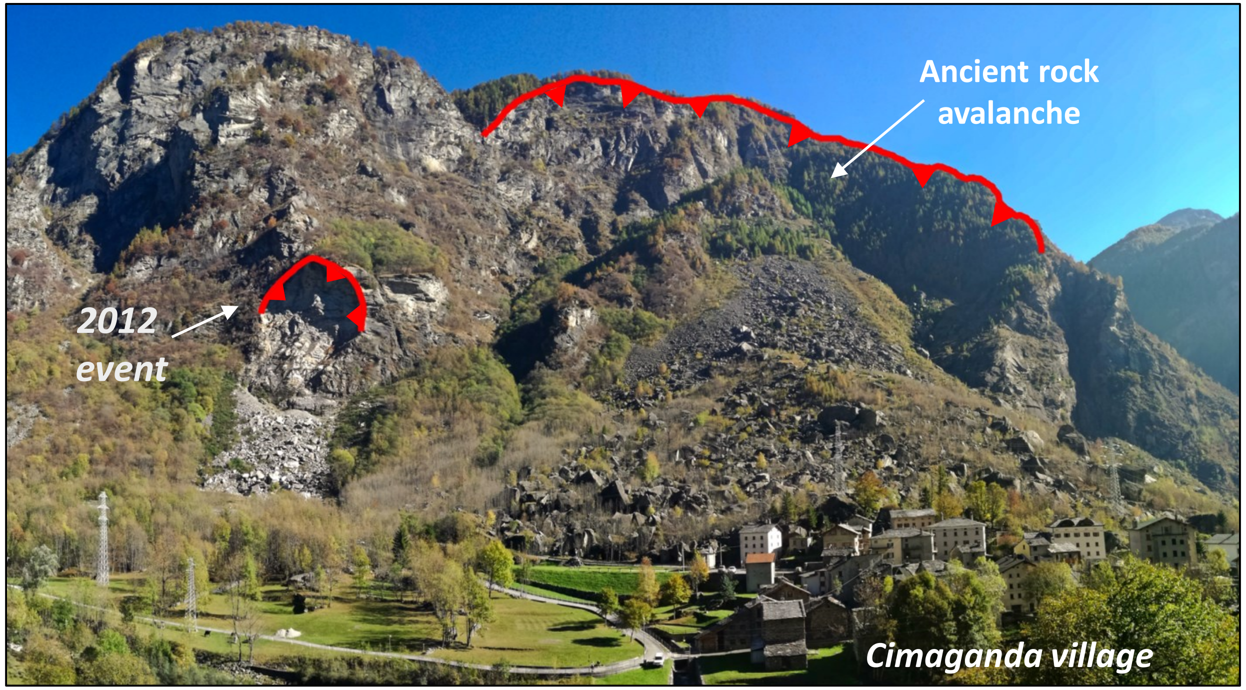
Schists – cover unit

Cimaganda landslide

Geomorphological features



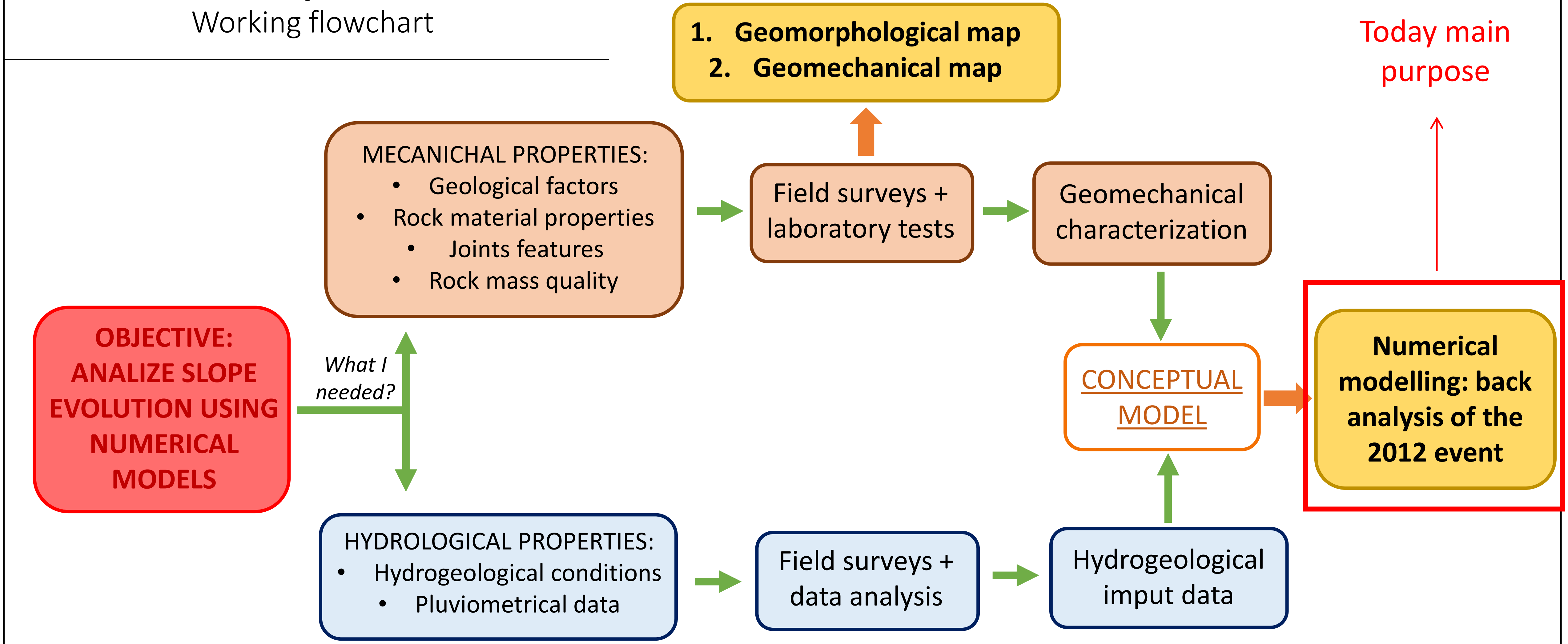
The 2012 event represent the recent evolution of the historical Cimaganda rock avalanche which mobilized about 7.5 Mm^3 of material



- Steep slopes with high sub-vertical rock cliffs
- Frequent rockfalls and instability events

Case study approach

Working flowchart



1. **Geomorphological map**
2. **Geomechanical map**

Today main purpose

MECANICHAL PROPERTIES:

- Geological factors
- Rock material properties
- Joints features
- Rock mass quality

Field surveys + laboratory tests

Geomechanical characterization

OBJECTIVE: ANALIZE SLOPE EVOLUTION USING NUMERICAL MODELS

What I needed?

CONCEPTUAL MODEL

Numerical modelling: back analysis of the 2012 event

HYDROLOGICAL PROPERTIES:

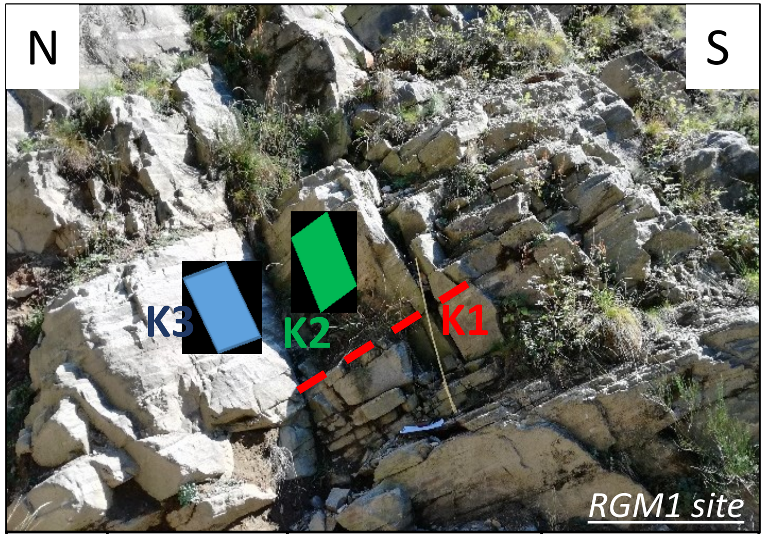
- Hydrogeological conditions
- Pluviometrical data

Field surveys + data analysis

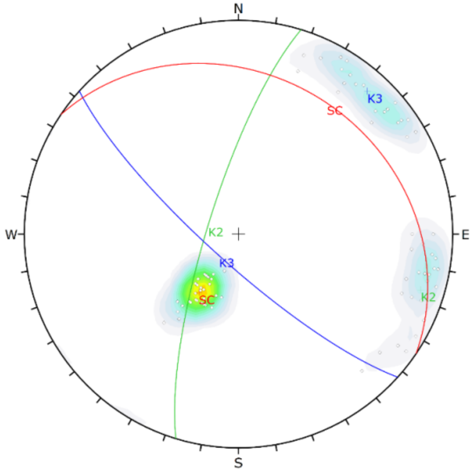
Hydrogeological imput data

Data collection: Geomechanical surveys

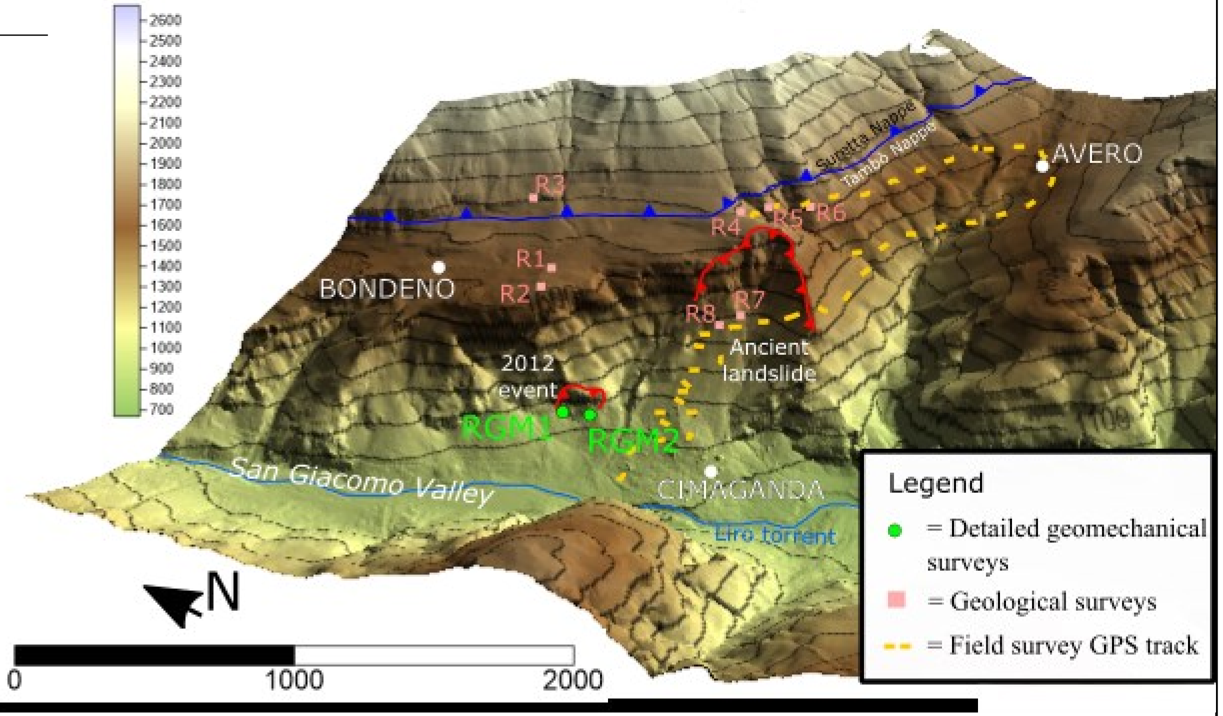
1. Joints distribution



SET	Type	Dip direction [°]	Dip [°]
K1	Schistosity	34	27
K2	Joint	287	78
K3	joint	222	79



Main discontinuity sets



2. Geomechanical rock mass classifications

Variability in geomechanical properties:

- ○ Intact rock strength (Due to different txtural features and weathering degree)
- ○ Intesity of fracturing — **$1m^3 < VRU < 10m^3$**
- ○ Persistency, aperture and rugosity of discontinuity — **$2 < JRC < 12$**

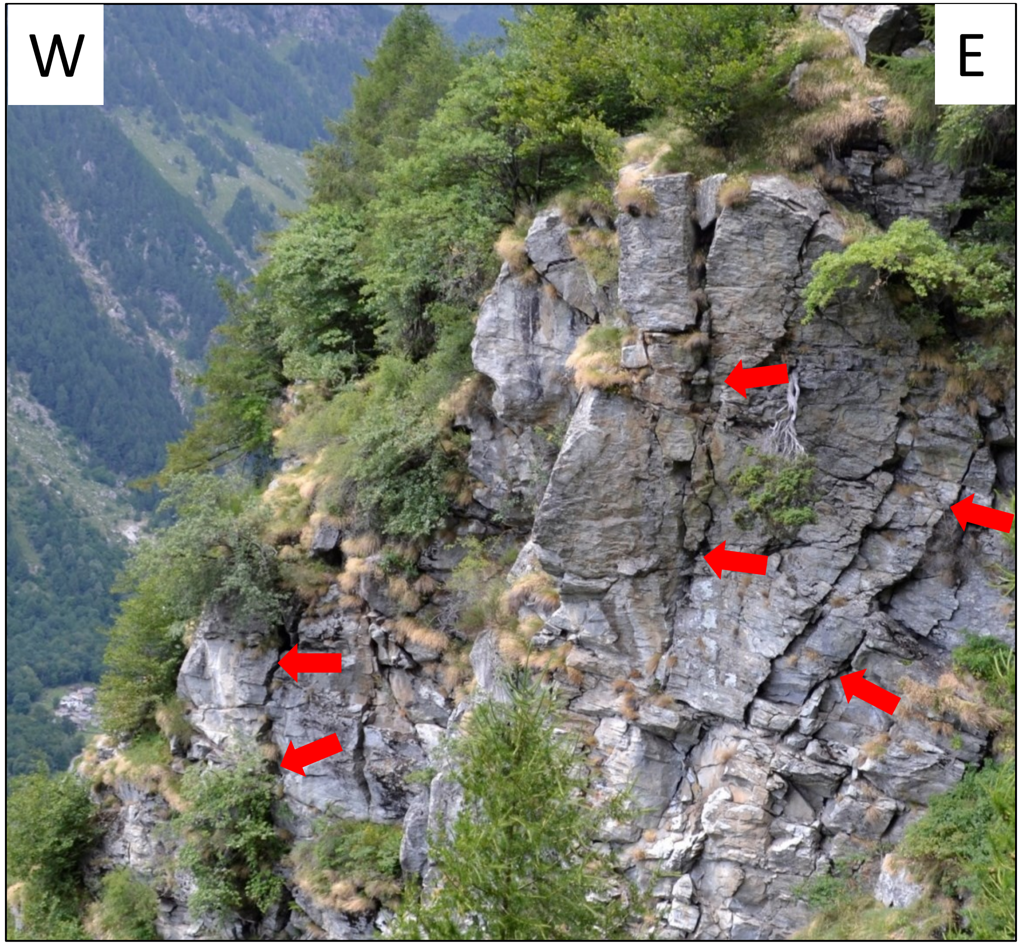
Rock mass quality indexes

- RMR: 75
- GSI: 50-65

Hoek&Brown

Surveys | Laboratory | Modelling

Predisposition elements to rockfalls and slope instability events



K3 set:

1. Joint orientation parallel to the main valley axis
2. High degree of linear and areal persistency
3. Apertures even greater than 10 centimeters

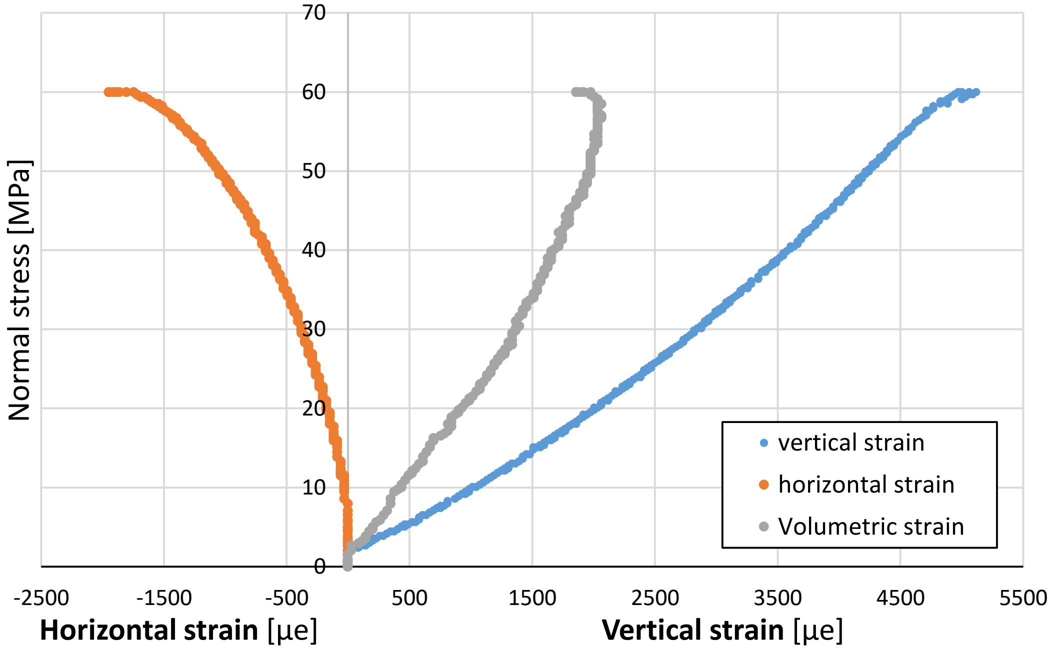
Data collection: Intact rock strength

Uniaxial compression tests (ASTM D4543-08)

5 tests contucted on specimen from ancient landslide crowning (SC1 and SC2 sites)

- Compressive strength (σ_c) of **61 MPa** and elastic module (E_{t50}) of **19.7 GPa**.
- Different strength behaviour due to textural rock features and micro preexisting fractures
- Previous tests conducted on the material of the landslide deposith had shown an higer compressive strength and stiffness (σ_c = **175 MPa** and E= **35 GPa**) due to different degree of weathering and textural features

Parametr	***SC1_M1***	***SC1_M2***	***SC1_M3***	***SC2_M1***	***SC2_M2***
σ_f	60.26	75.30	36.61*	60.00	49.00
$E_{t50\%}$	14.50	26.40	10.50	13.40	22.80
ν	0.30	0.22	0.22	0.33	0.24



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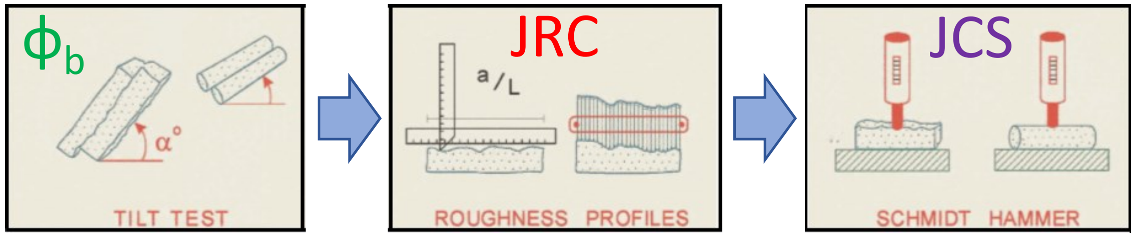
Data collection: Joint shear strength

Shear tests (ASTM D5607-08)

1. Field geological sampling (3 joints → 6+3 samples)

2. Laboratory analysis of joint surfaces (Barton N., 2002)



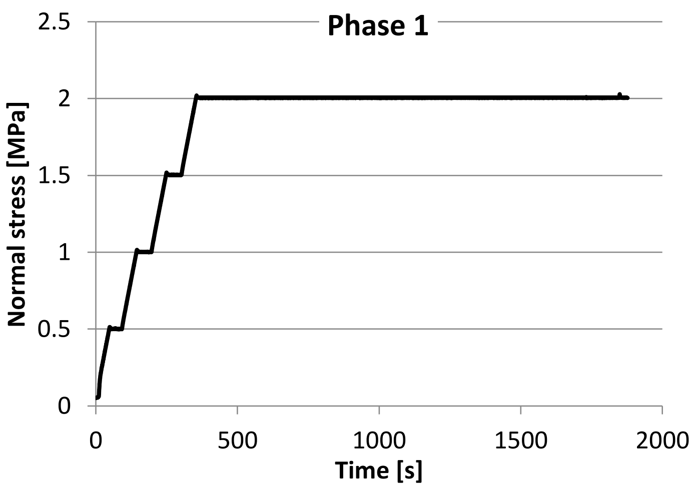
ID	Set	Tilt angle (α)	JRC	JCS [MPa]
SC1	K2	44.81°	2.5	72.42
SC4_A	K3	49°	9	57.65
SC4_B	K3	52.6°	10	59.64

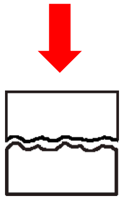
⇨ Smooth surfaces

⇨ Rough surfaces

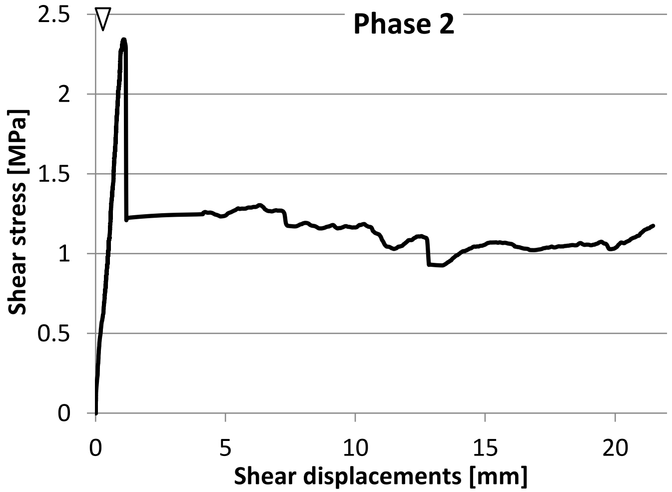
3. Shear tests

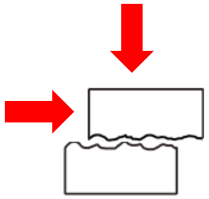
PHASE 1: normal load (1-6 MPa) ⟶ Δh - σ_N





PHASE 2: shear load ⟶ Δs - τ





PHASE 3: multiple cycles

Not conventional phase

- Five cycles for K3 joints coming from SC4 site
- Three cycles for K2 joints coming from SC1 site

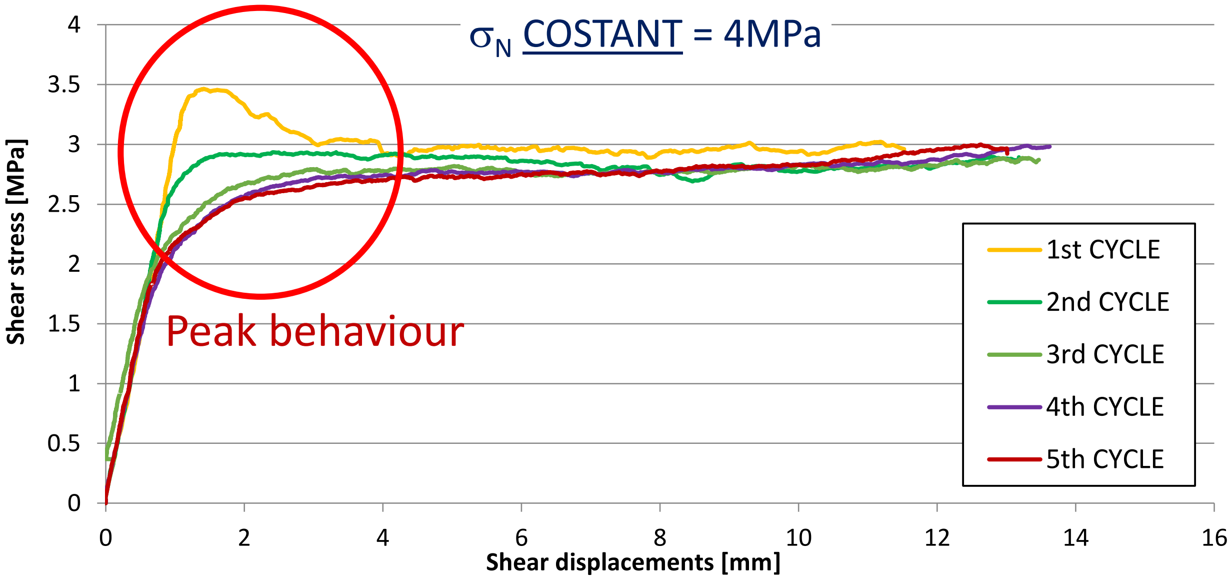
τ_p τ_r

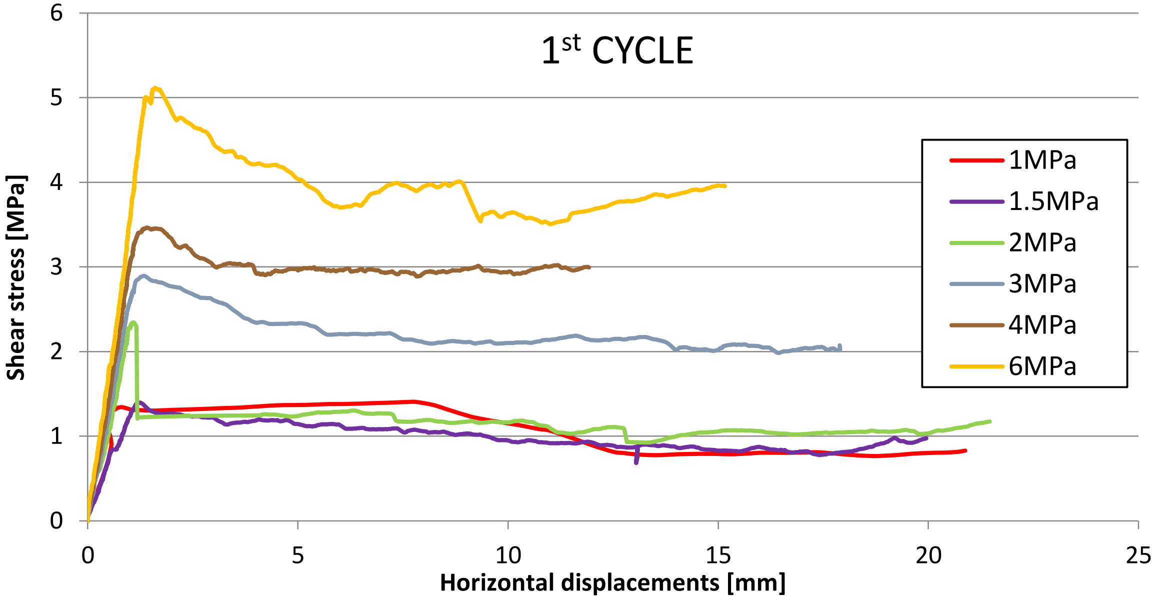
2012 landslide site (SC4): K3 set

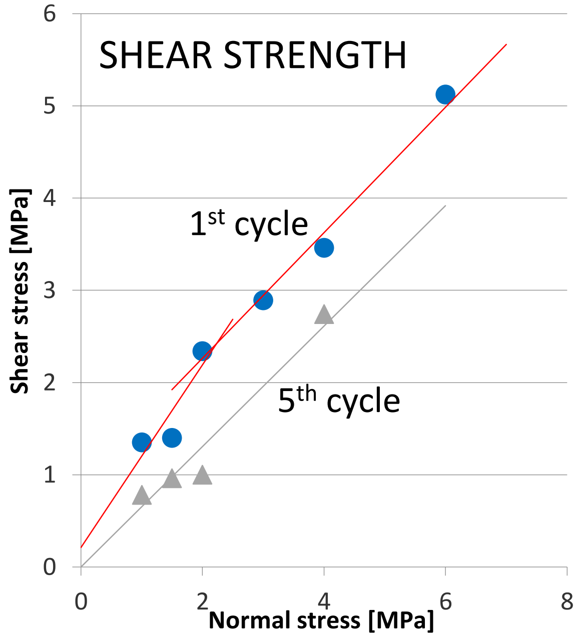
- *Rough and fresh surfaces*


Before testing


5th cycle







Bilinear Patton strength criteria

Mohr-Coulomb parameters

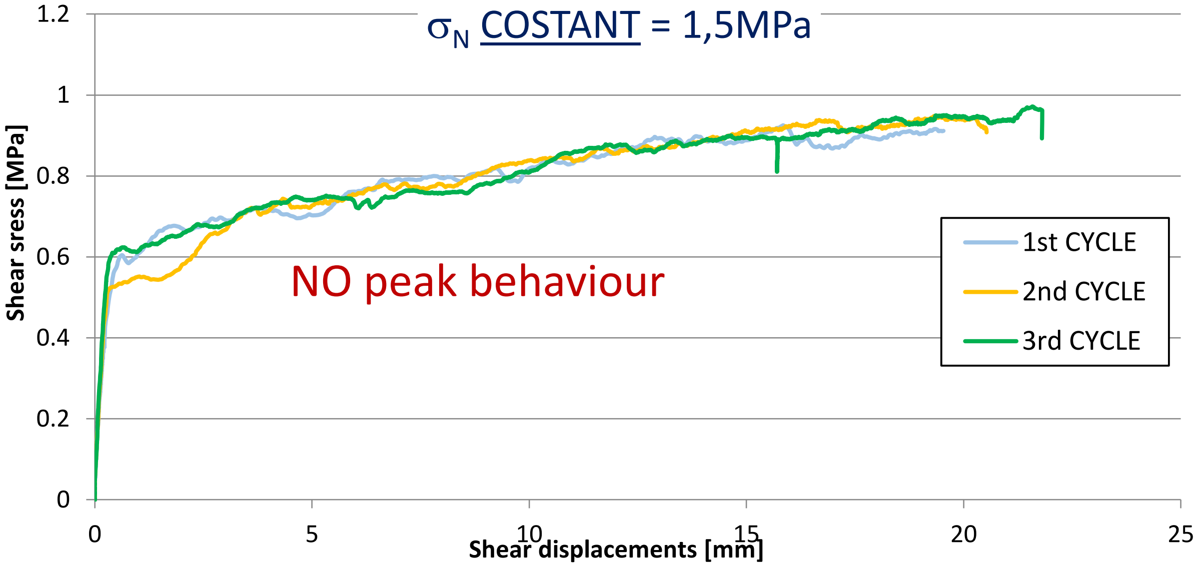
Parameter	Value
Φ_P	48°
Φr	27°
C_p	0,2 MPa
C_r	0 MPa

Ancient landslide site (SC1): K2 set

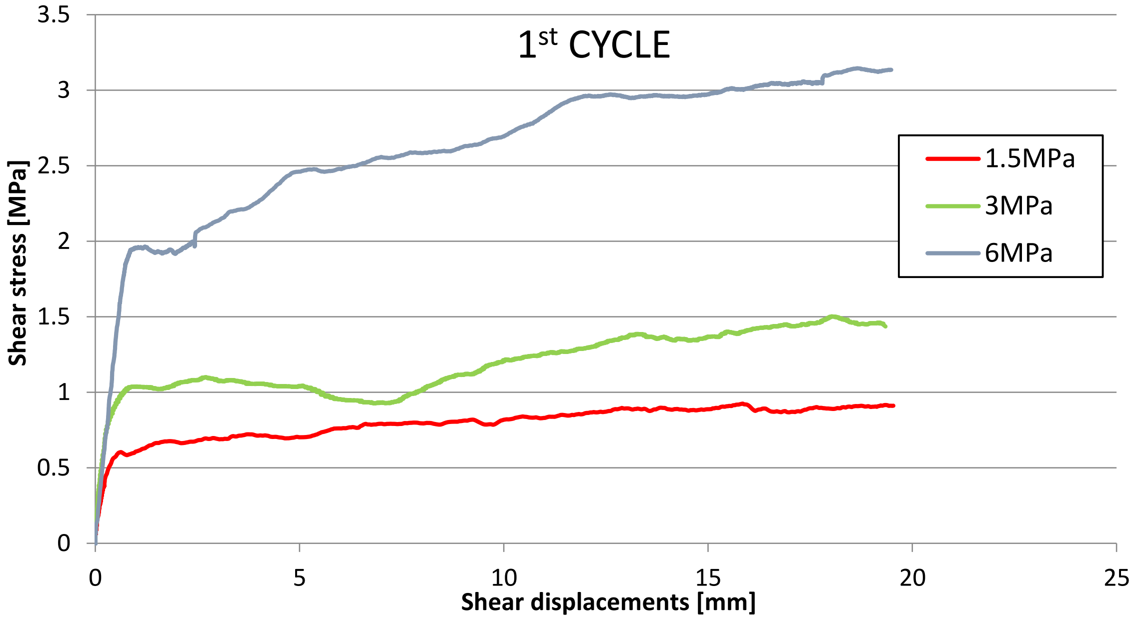
- *Weathered and soft surfaces*

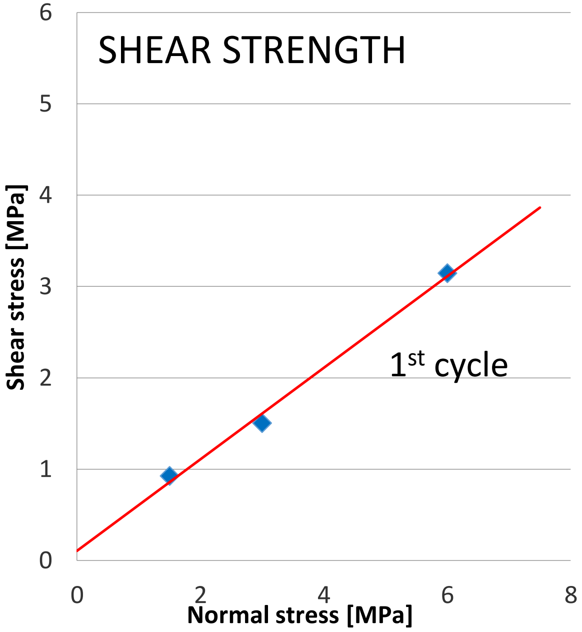
Before testing

3rd cycle



NO peak behaviour





Linear strength criteria

Mohr-Coulomb parameters

Parameter	Value
Φ_P	27°
C_p	0,1 MPa

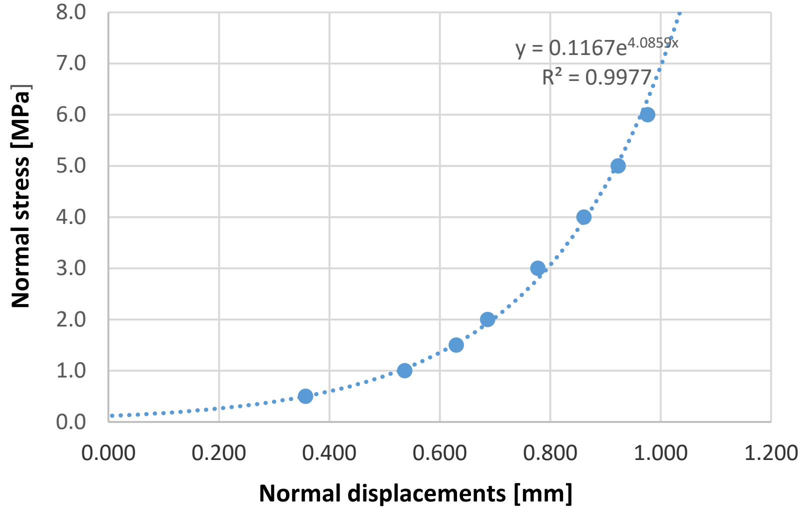
Residuals are coencident with peak values

T_{max} at 1st cycle of K2 set= T_{res} at 5th cycle of K3 set

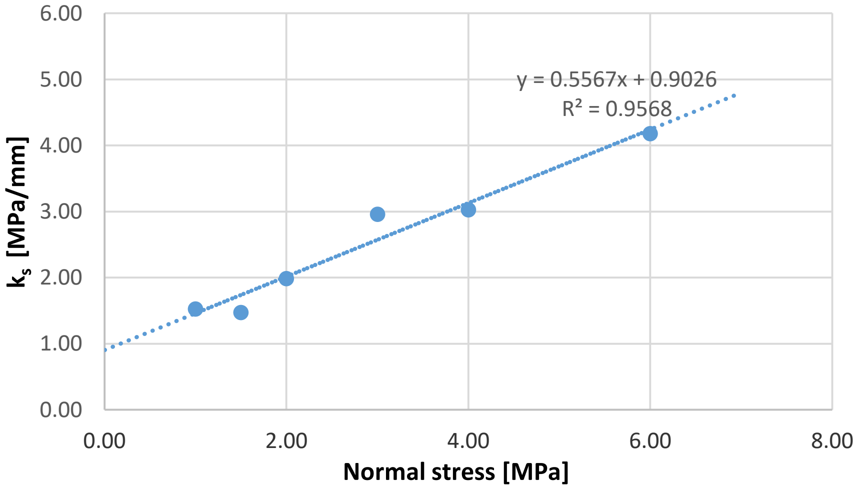
Normal and shear stiffness

SC4 site (K3 set)

Normal stiffness (k_n)

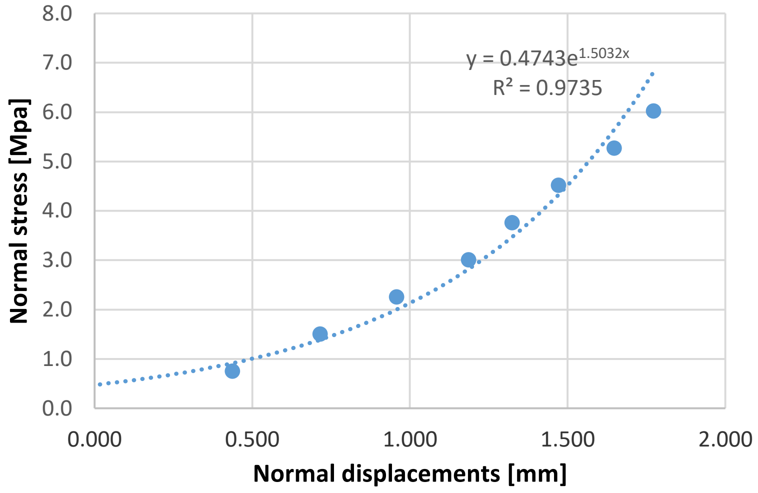


Shear stiffness (K_s)

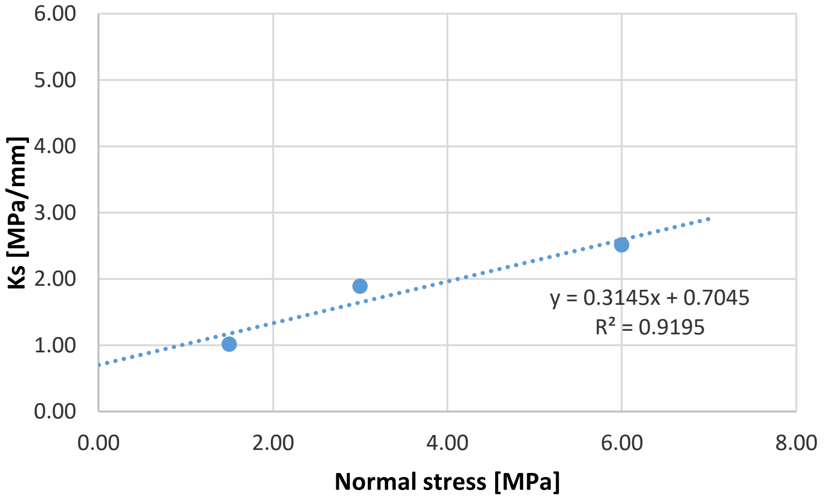


SC1 site (K2 set)

Normal stiffness (K_n)



Shear stiffness (K_s)



Stiffness= [Loading/displacement]

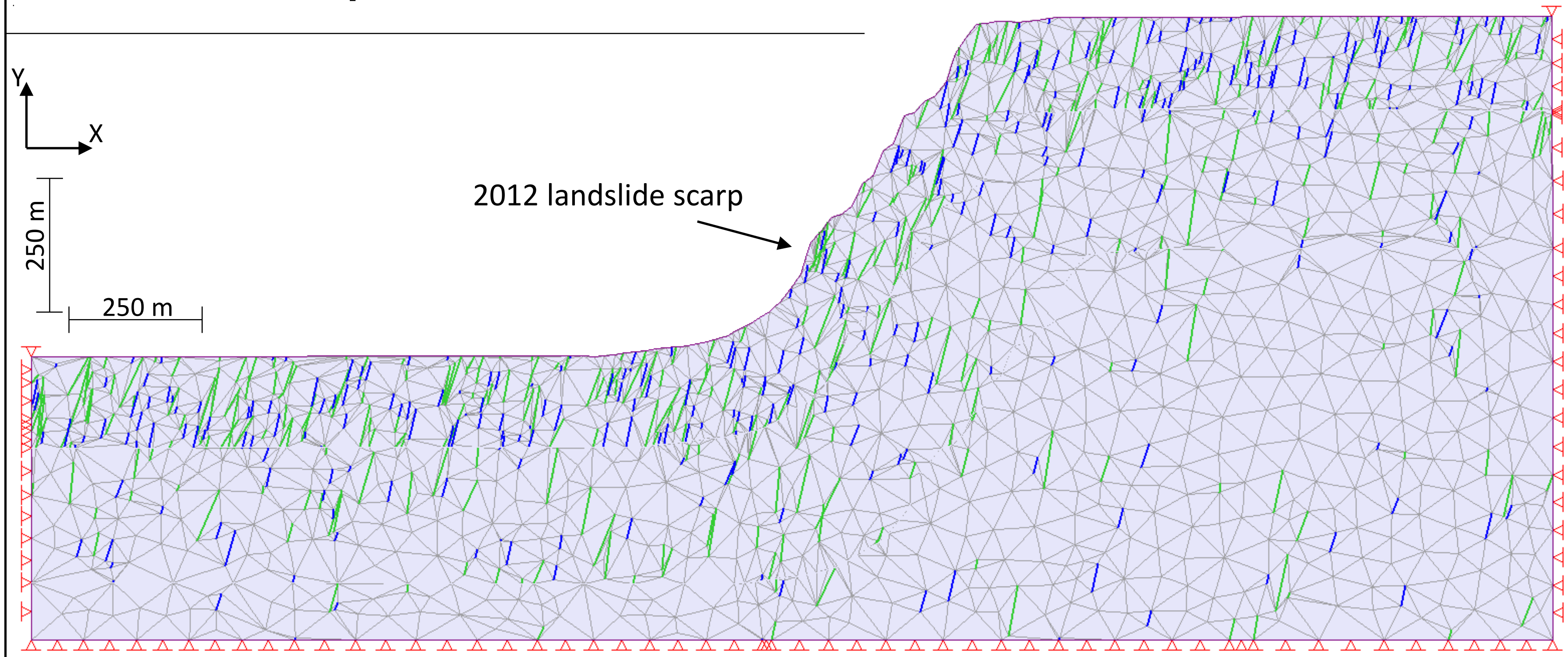
$$K_n = 4.08 * \sigma_n \qquad \text{(K3)}$$

$$K_n = 1.5 * \sigma_n \qquad \text{(K2)}$$

$$K_s = 0.9 + (0.55 * \sigma_n) \qquad \text{(K3)}$$

$$K_s = 0.7 + (0.31 * \sigma_n) \qquad \text{(K2)}$$

Conceptual model



Numerical code: Finite element (RS2, Rocscience)

Morphology:
DTM Regione Lombardia (20x20), 2002

Material properties:
HB parameters, E_0 as function of depth;
Anisotropy behaviour.

Joint network:
Intensity of fracturing as function of depth;
MC parameters/equivalent MC parameters

IMPUT DATA

Boundary conditions:
Auto restrain surface (pins)

Mesh:
Uniform 6 noded triangles
Number of elements: 4301
Numer of nodes: 8299

MODELLING SETTINGS

Joint network: ''Beacher'' model

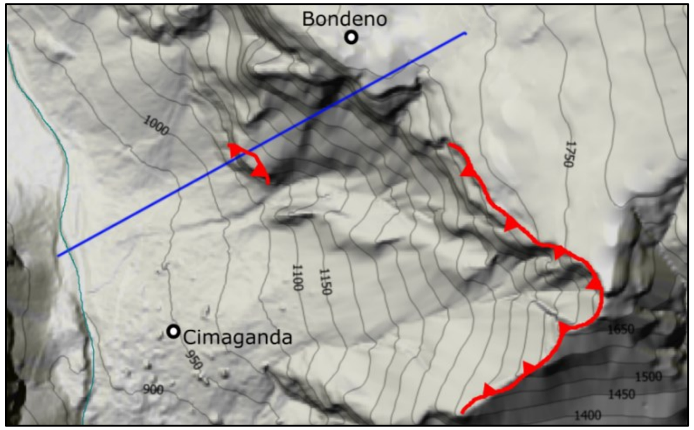
Geometrical parameters describing joint network					
SET	TIPO	Imm. [°]	dip [°]	Mean length [m]	Intensity of fracturing
K1	Shistosity	34	27	/	/
K2	Joint	287	78	58.2	0.00013
K3	Joint	222	79	34.3	0.00013

→ IMPLICIT (K1)

EXPLICIT (K2, K3)

Statistical distribution from surveys data (Imm., dip)

Image analysis (Mean length, Intensity of fracturing)



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Back analysis

Progressive failure

Model 1 – Starting point: Best mechanical properties detected

↓

Model 2: Introduction of a piezometric surface, corresponding to the hypothesized ordinary hydrogeological conditions

↓

Model 3: reduction of the rock mass quality index

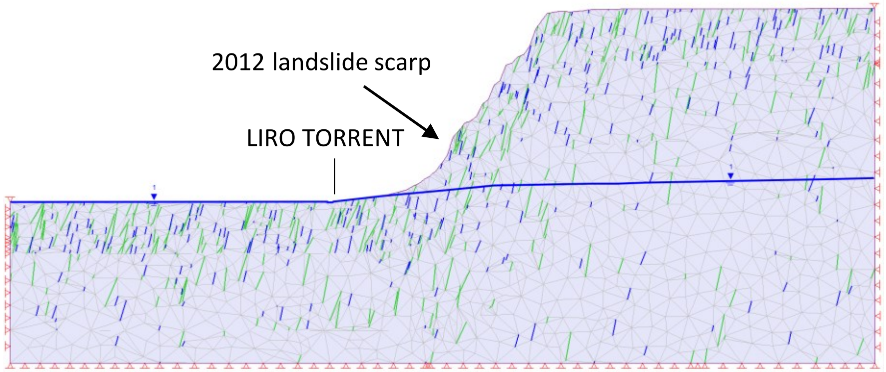
GSI: 60 ⇨ 55

↓

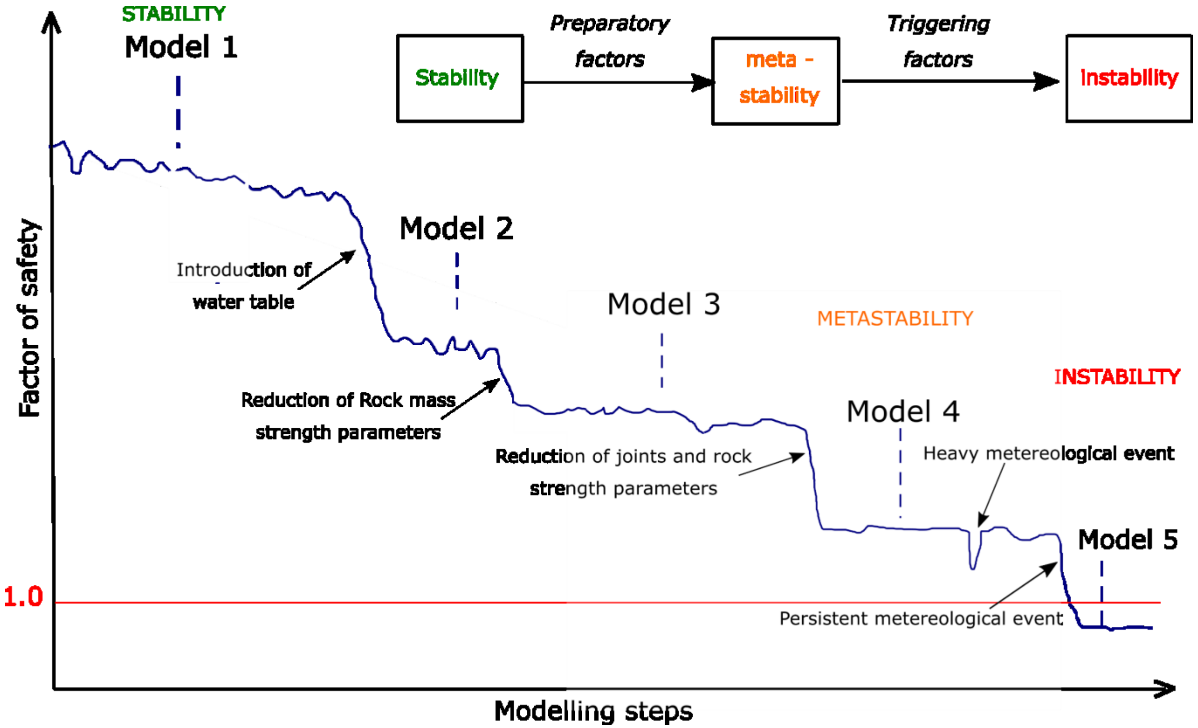
Model 4: reduction of the material and joints mechanical strength

σ_c: 175 ⇨ 61 [MPa]

E: 35 ⇨ 20 [GPa]

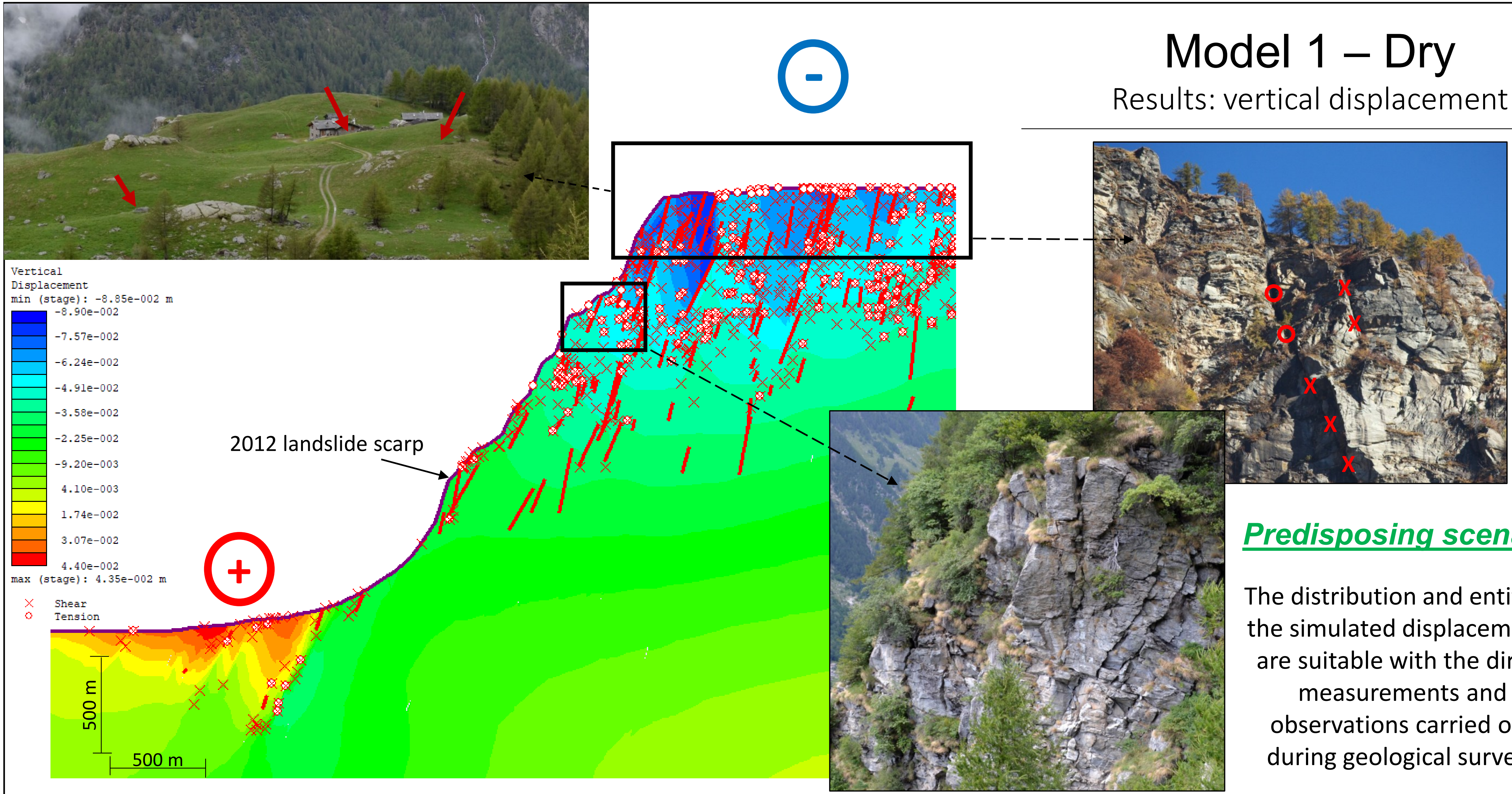


Progressive failure mechanism



Model 1 – Dry

Results: vertical displacement



Predisposing scenario

The distribution and entity of the simulated displacements are suitable with the direct measurements and observations carried out during geological surveys

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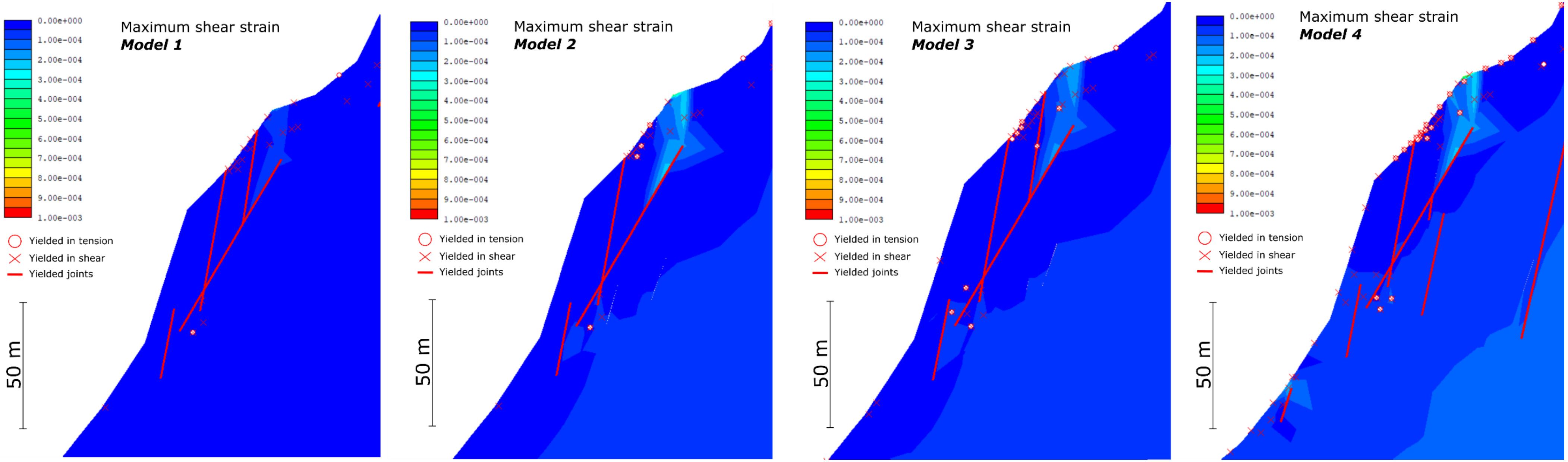
Models 2 to 4

results

Maximum shear strain distribution at the 2012 landslide scarp

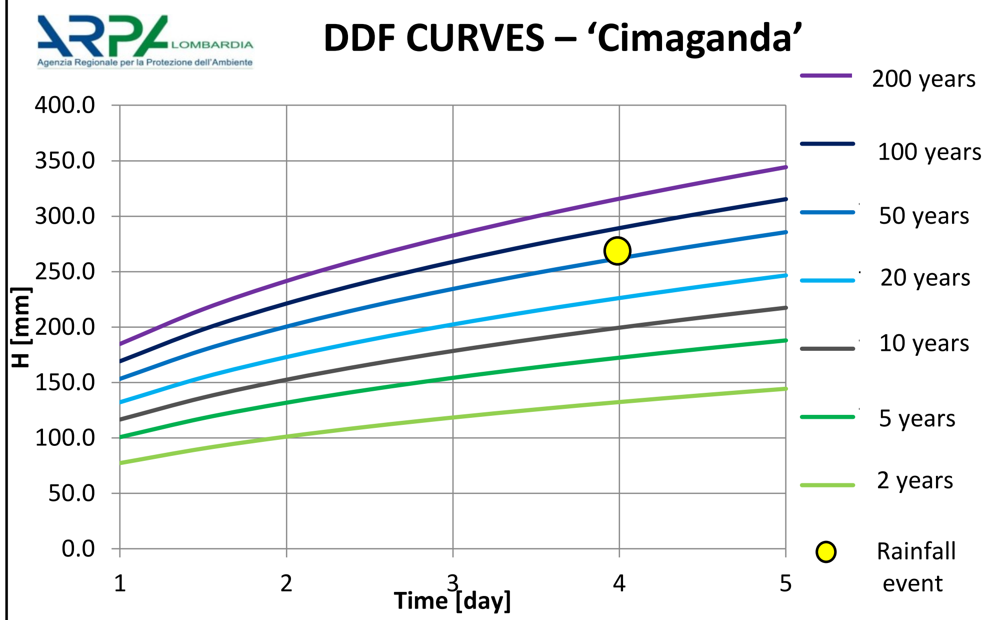


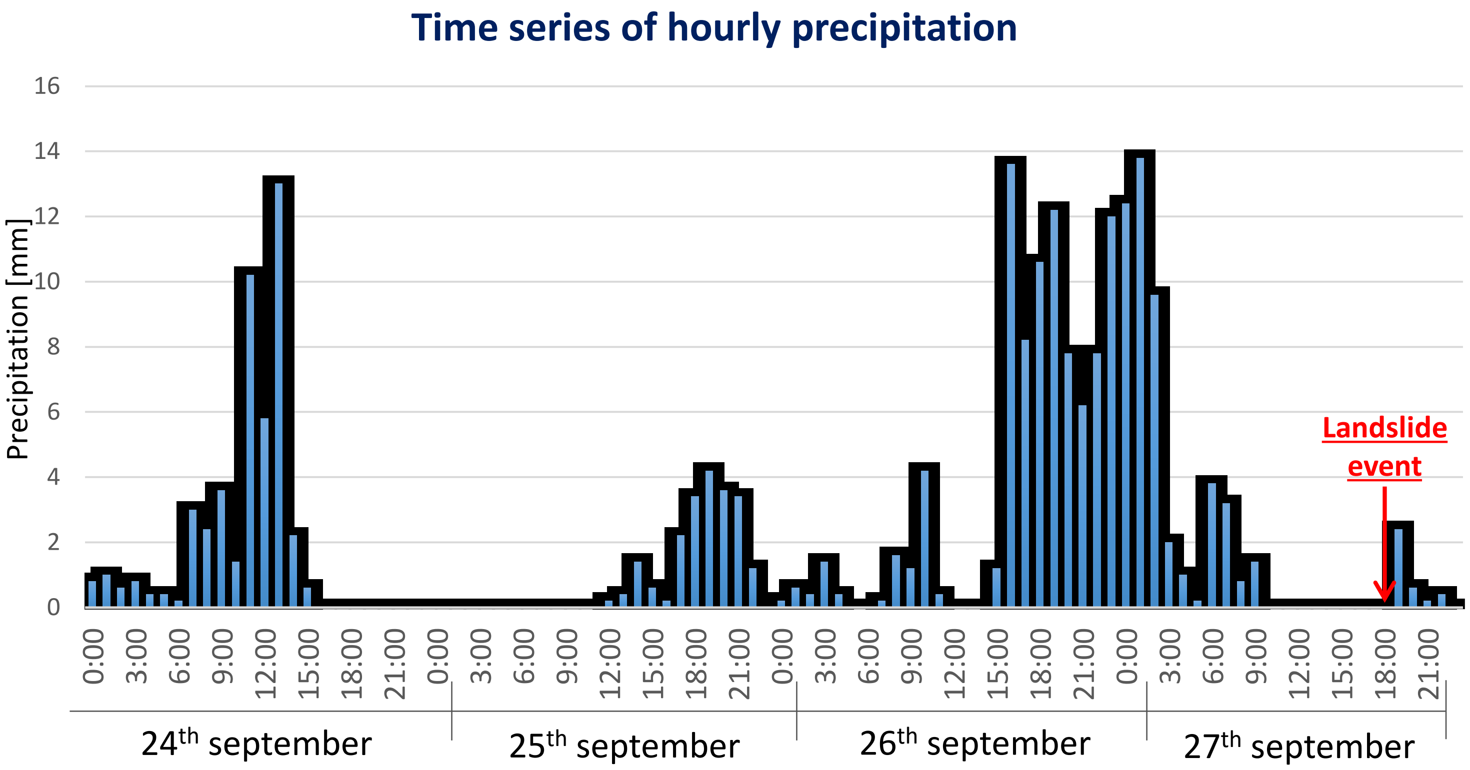
- The hypothesized piezometric surface does not alter the displacements distribution (mod 1→mod 2)

- The decrement of mechanical properties to the lowest detected, led to a significant increase in the yielded elements and slightly in displacements modulus. Focusing on the part of the slope where the event occurred, a shear strain surface begins to develop (mod 2→mod 3→mod 4)

Preparatory factors

Triggering factor





	Stazione ARPA di "San Giacomo Filippo – Lago del Truzzo"
Data	mm di pioggia accumulati in 24h
21/09/2012	0
22/09/2012	0
23/09/2012	1
24/09/2012	84.2
25/09/2012	32
26/09/2012	113.4
27/09/2012	37.2
28/09/2012	0
Totale accumulato	267.8 mm

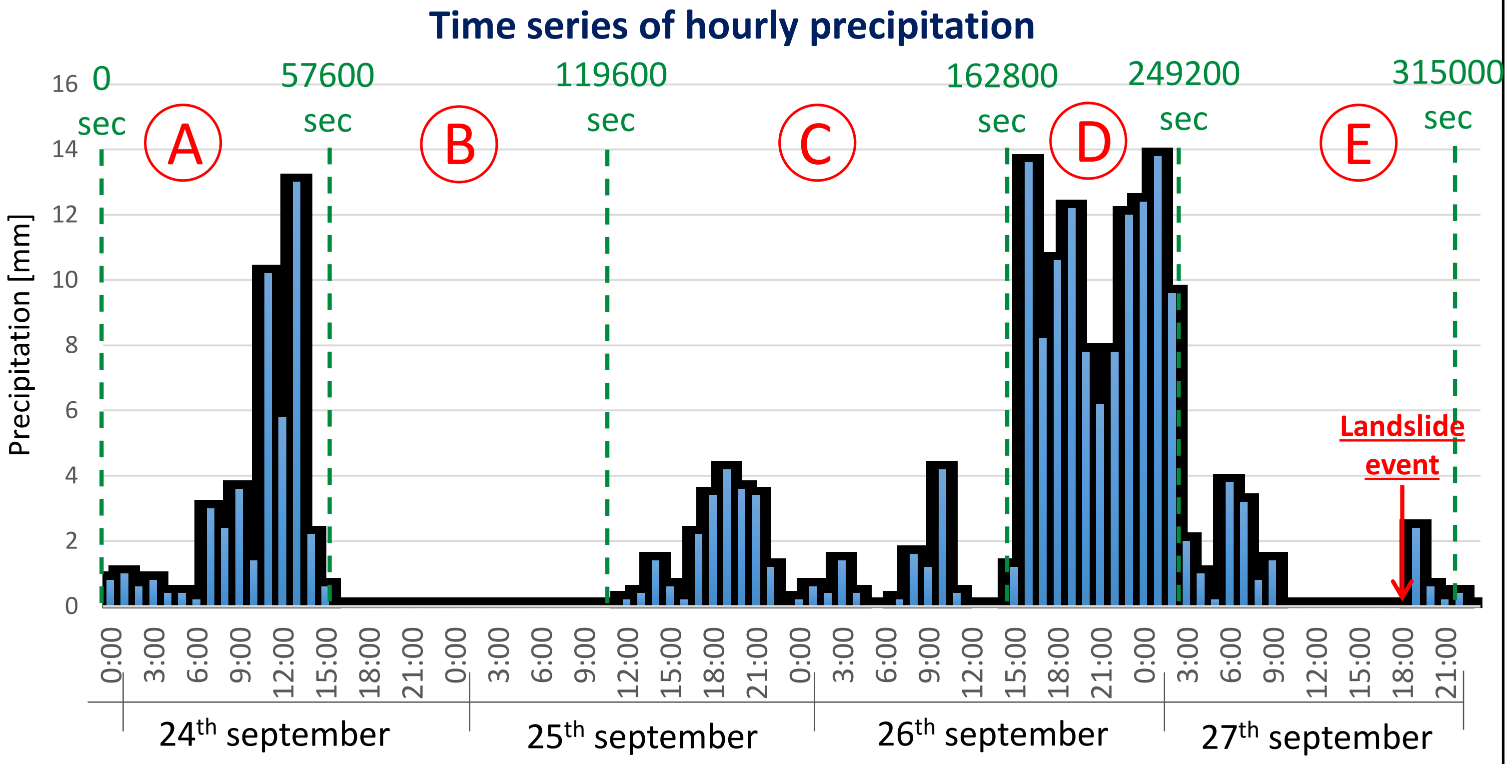
Triggering factor: Rainfall infiltration, accompanied by a restricted and temporary rising of piezometric level

To consider this is necessary to improve a **transient analysis**

Imput data: **vertical infiltration** varying with time according to the rainfall data

Transient finite element analysis

- On the base of the precipiation data pattern five different steps (A to E) were identified
- Different vertical infiltration input values were calculated considering the total amount of water at each step
- The effects of the pore pressure increment, was analyzed using a semi-coupled hydro-mechanical analysis



Vertical infiltration data

1.5x10^{-6} m/s

0 m/s

7.5x10^{-7} m/s

2.6x10^{-6} m/s

1x10^{-6} m/s

!! **Assumption**: the total amount of water will infiltrate in the slope!!

Transient finite element analysis

Hydraulic parameters

Rock masses principal hydraulic conductivities were calculated considering joint orientation, JRC, aperture and fracture frequency of each discontinuity set (i); (Coli S. et al; 2008).

$$\underline{\boldsymbol{K}} = \frac{g}{12v} \cdot \sum_{i=1}^{N} f_i \cdot e_i^3 \cdot \left[\mathbf{I} - \overrightarrow{\boldsymbol{n}_i} \otimes \overrightarrow{\boldsymbol{n}_i} \right]$$

Where ''e'' is the effective hydraulic opening defined as:

$$e = \frac{E^2}{JRC_0^{2.5}}$$

Mechanical aperture

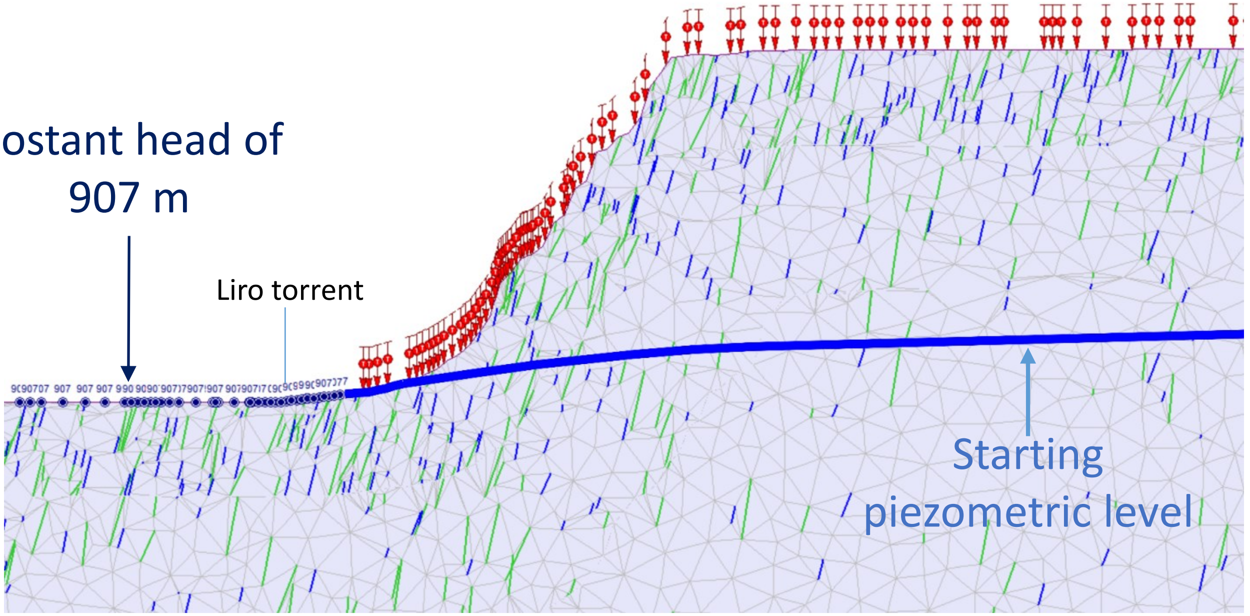
Roughness

From collecting data was calculated a value of

$K_1 = 1.26x10{-}5$ m/s

$K_2 = 2.21x10{-}9$ m/s

Boundary conditions

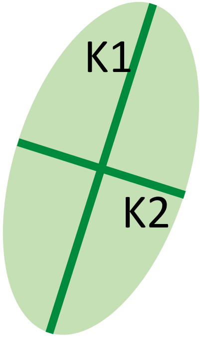


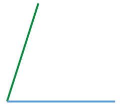
Vertical infiltration

Costant head of 907 m

Liro torrent

Starting piezometric level





K1 ϑ angle of 80°
ANISOTROPY

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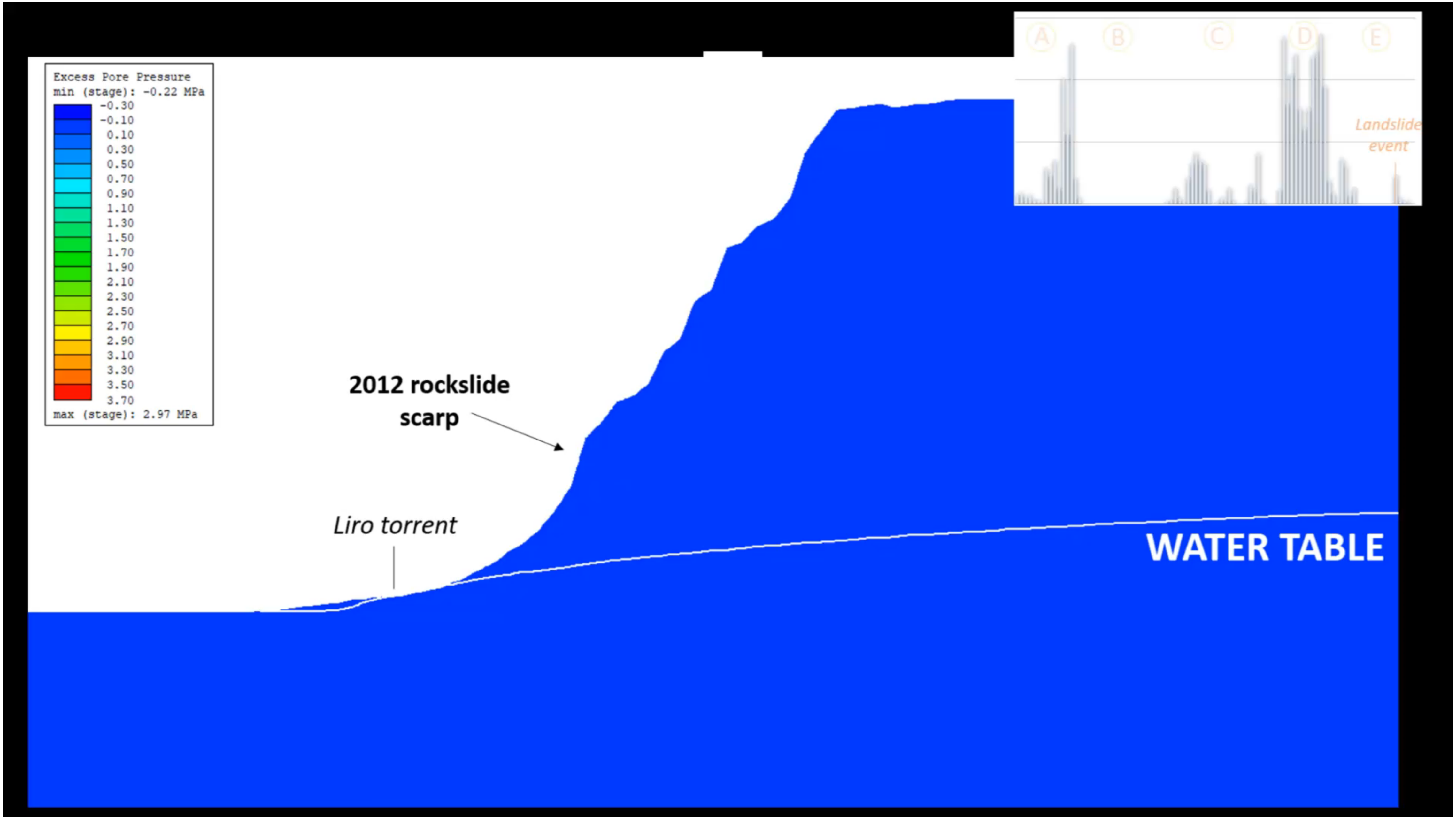
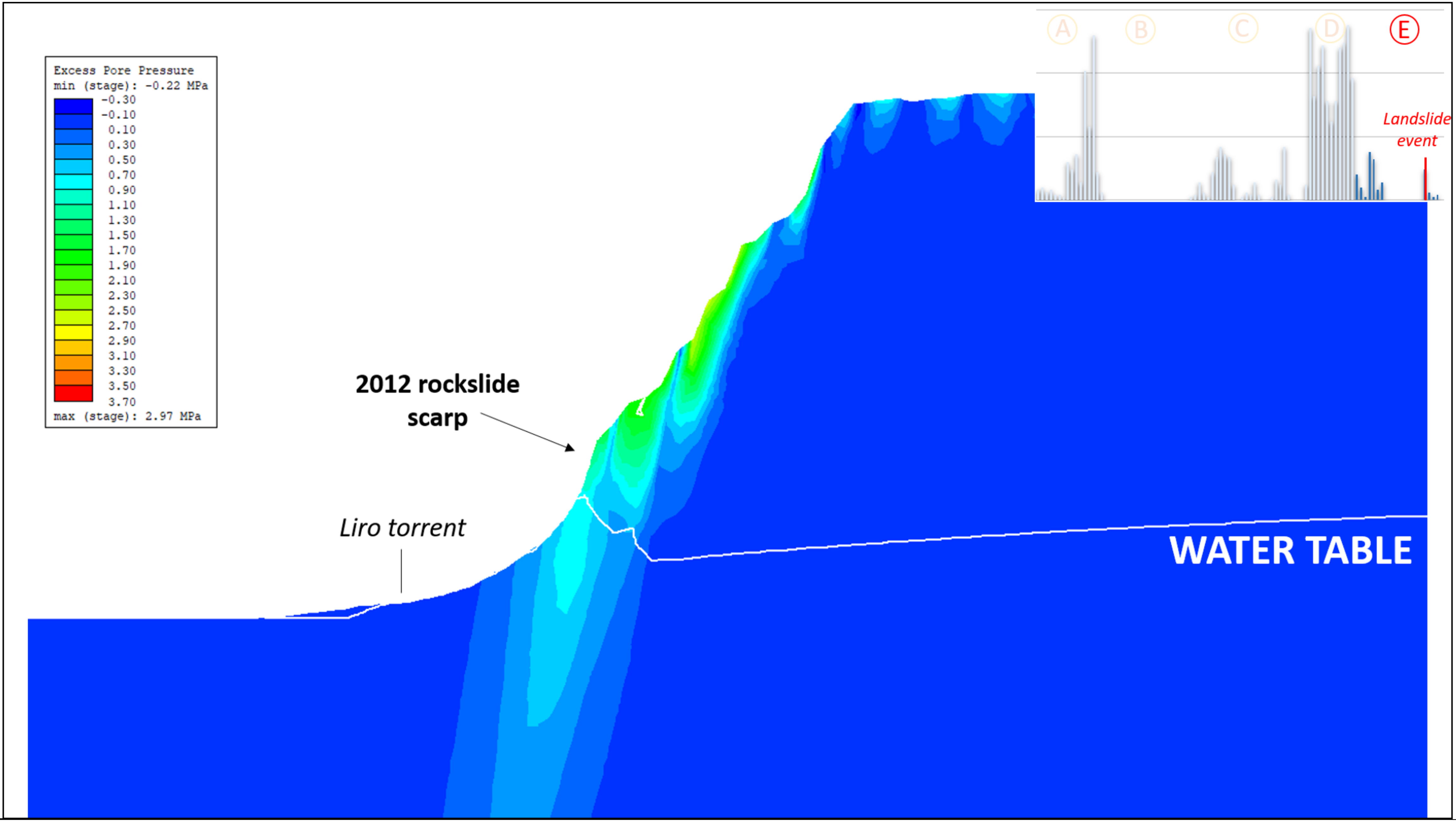
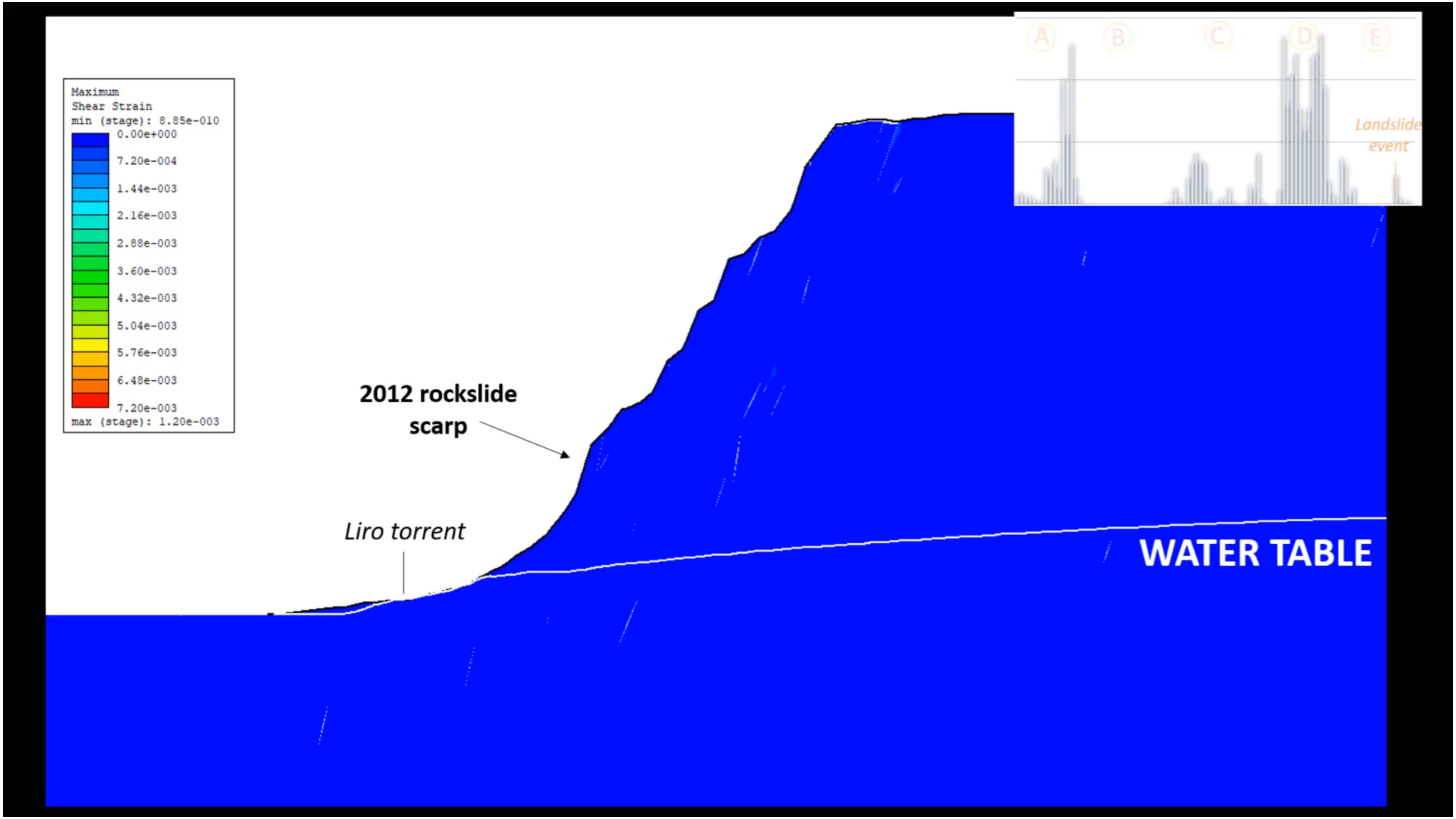
Transient analysis results: excess of pore pressure



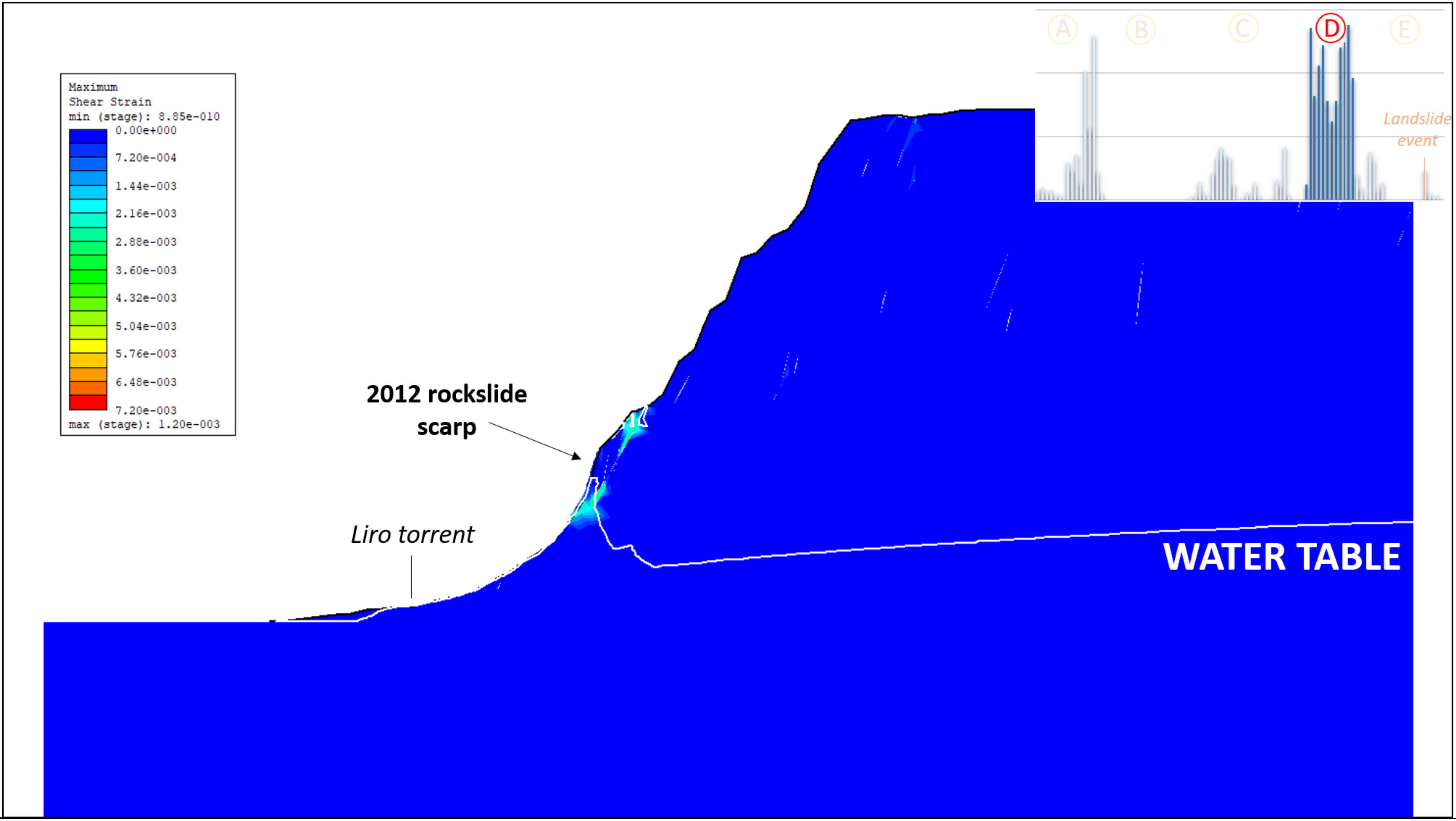
Transient analysis results: excess of pore pressure



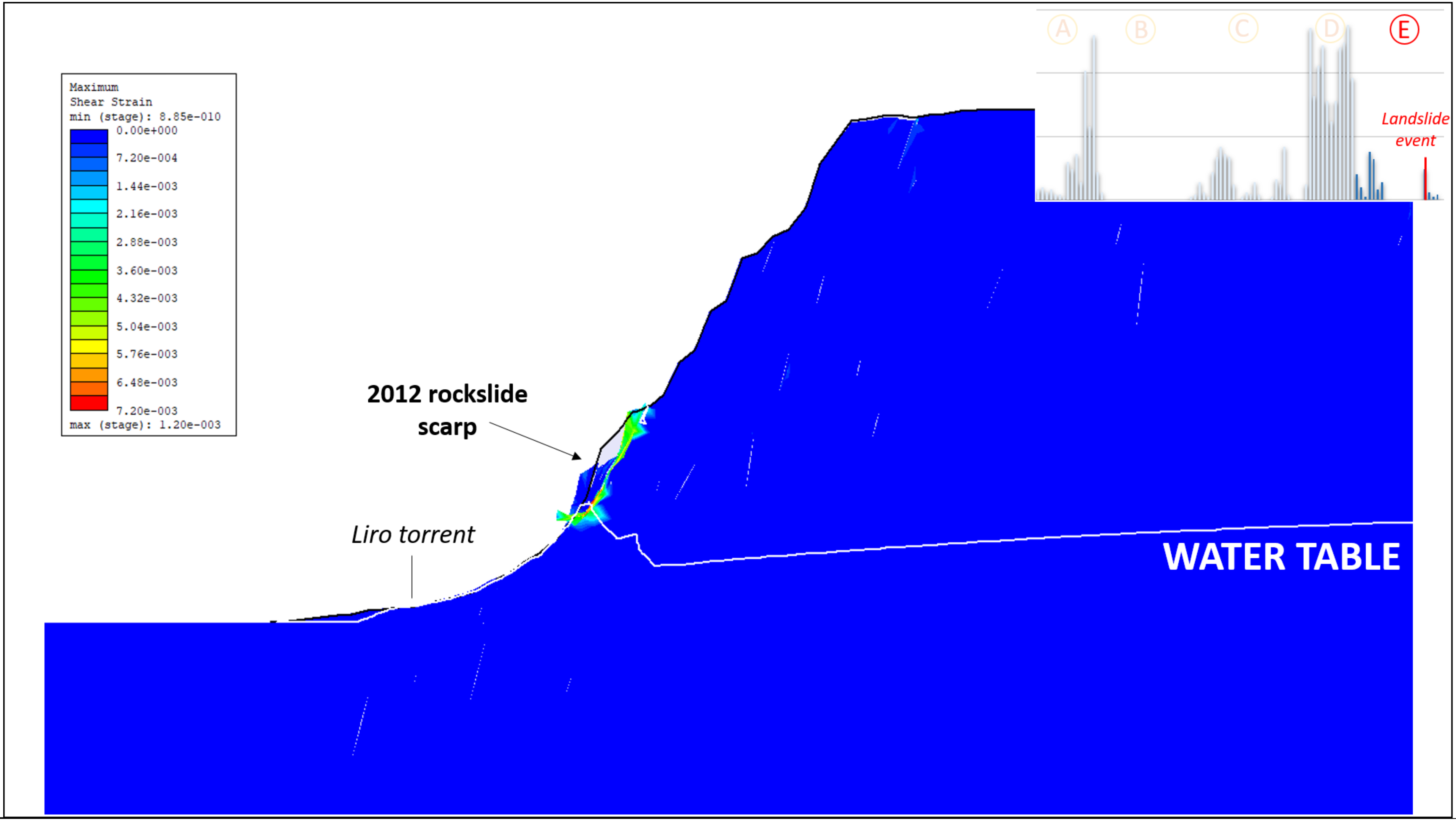
Transient analysis results: maximum shear solid strain



Transient analysis results: maximum shear solid strain



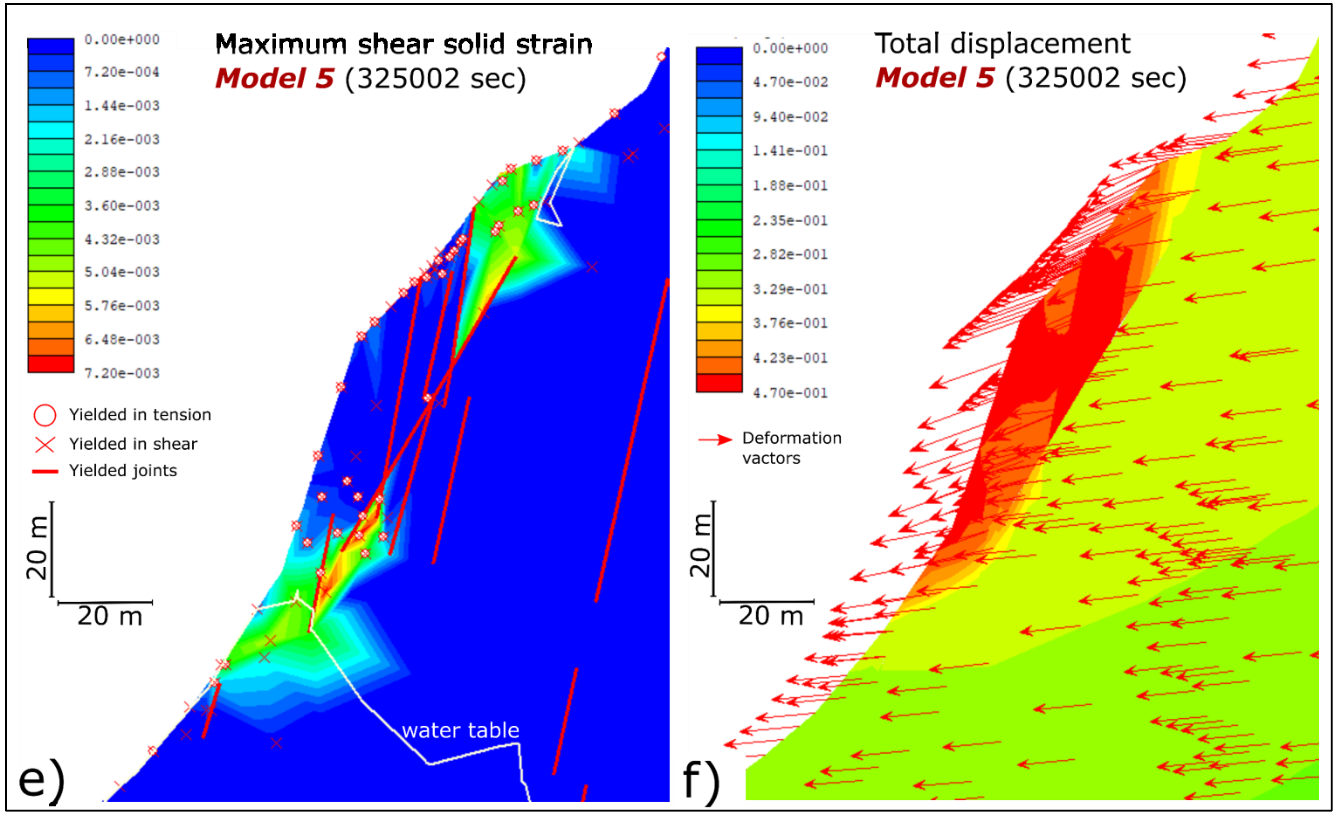
Transient analysis results: maximum shear solid strain



Model 5

Results

- The introduction of rainfall infiltration, accompanied by a restricted and temporary rising of piezometric level, develops a localized excess of pore pressure sufficient to lead the slope to a critical state.
- The maximum shear solid strain and total displacement distribution (in the order of 5x10^{-1} m) clearly show the presence of a critical composite shear sliding surface roughly coincident with the observed one.



<u>Shear solid strain and total displacements distribution in corrispondence of the 2012 landslide scarp</u>

Critical state

Conclusions

- An accurate geomechanical characterization of the 2012 landslide slope was carried out. This led to implement a numerical model through which was possible to simulate the general evolution of the slope considering the predisposing and preparatory factors;
- Only considering a semi-coupled hydro-mechanical analysis, a critical state was reached an thus the recent instability event was reproduced;

FUTURE PLAN

- This model clearly represent a great strating point to improve the simulation of the ancient rockslide and to study future evolutions of the slope;
- The FEM analysis and the use of a semi-coupled hydro-mechanical modelling, does not reproduce the natural groundwater flow along the fracture network and consequently imply an overestimation of the landslide triggering factors. The use of a distinct element model approach could be thus explored in order to overcome the hydrogeological simplifications of FEM approach.

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Thanks for your attention!!

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Dott.ssa Greta Bajni
Prof.ssa Tiziana Apuani

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