PROVINCIA DI VICENZA

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UNIVERSITÀ DEGLI STUDI DI PADOVA

ICEA

DIPARTIMENTO DI INGEGNERIA CIVILE, EDILE E AMBIENTALE
DEPARTMENT OF CIVIL, ARCHITECTURAL AND ENVIRONMENTAL ENGINEERING

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AGI Associazione Geotecnica Italiana

FONDAZIONE INGEGNERI PADOVA

ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI PADOVA

PROGETTO UNIMPRESA 2019 – TITANO

SISTEMI INNOVATIVI DI MONITORAGGIO GEOTECNICO MEDIANTE SENSORI IN FIBRA OTTICA

SALA AUDITORIUM DELL'ORTO BOTANICO
28 GIUGNO 2022, ORE 9.00/17.30

SVILUPPO DELLE FORZE DI STABILIZZAZIONE NEGLI ANCORAGGI PASSIVI

Development of stabilization actions in passive anchors

Simonetta Cola[(1)], **Lorenzo Brezzi**[(1)], Luca Schenato[(2)], Francine Tchamaleo Pangop[(1)], Luca Palmieri[(3)], Massimo Lovison[(4)], Alberto Bisson[(5)]

[(1)] DICEA, Università di Padova
[(2)] CNR-IRPI Padova
[(3)] DEI, Università di Padova
[(4)] Provincia di Vicenza
[(5)] SIRIVE srl, Cornedo Vicentino

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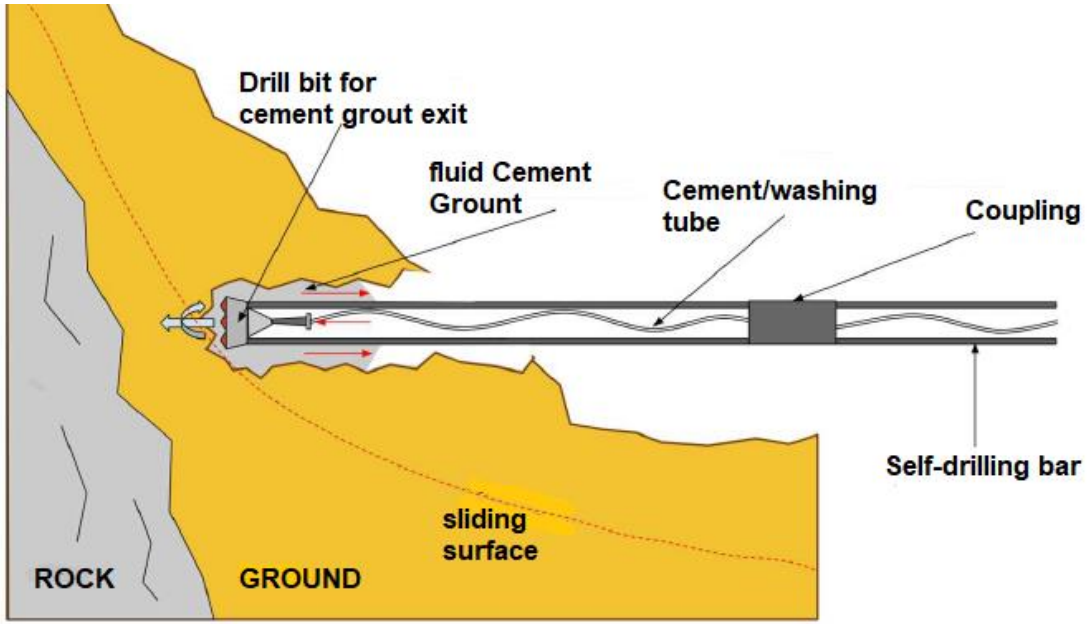
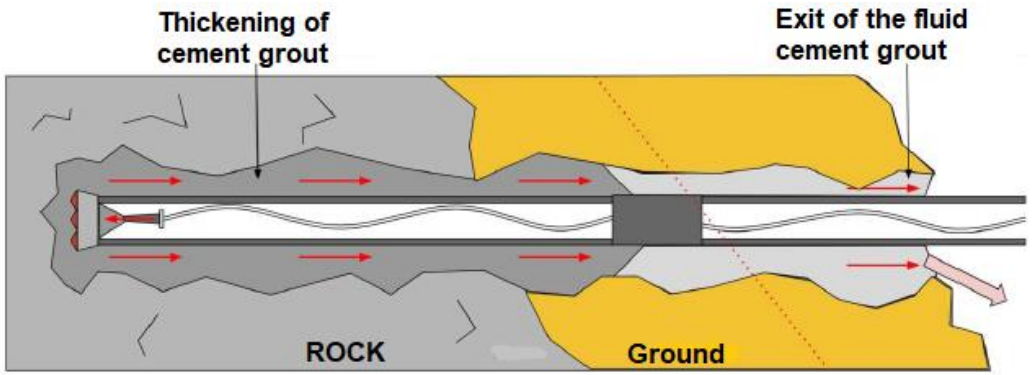
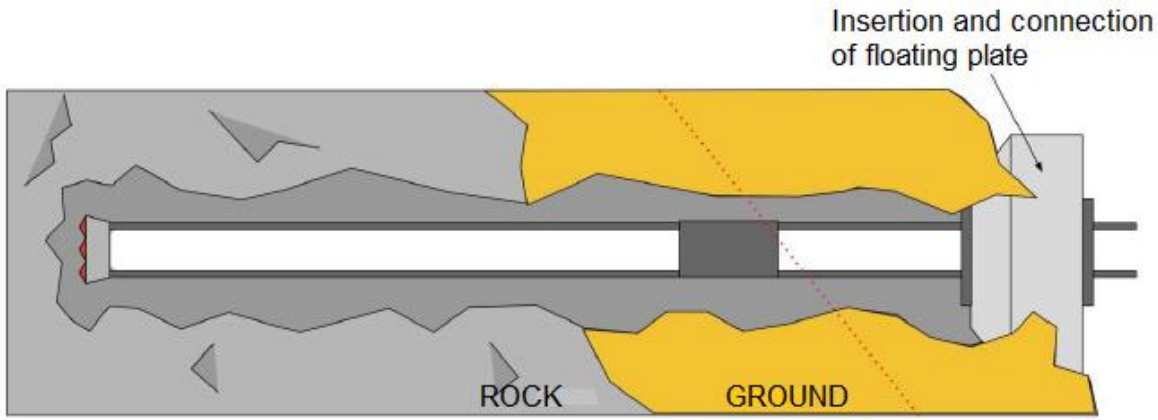
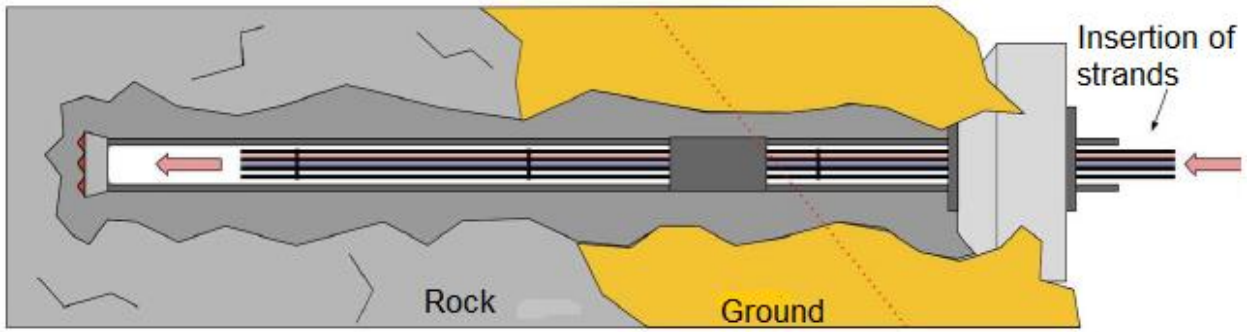
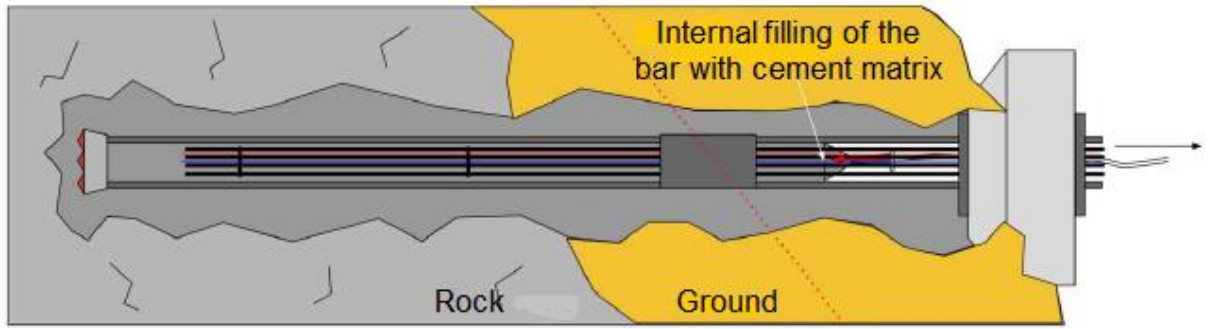
Passive Composite Anchor





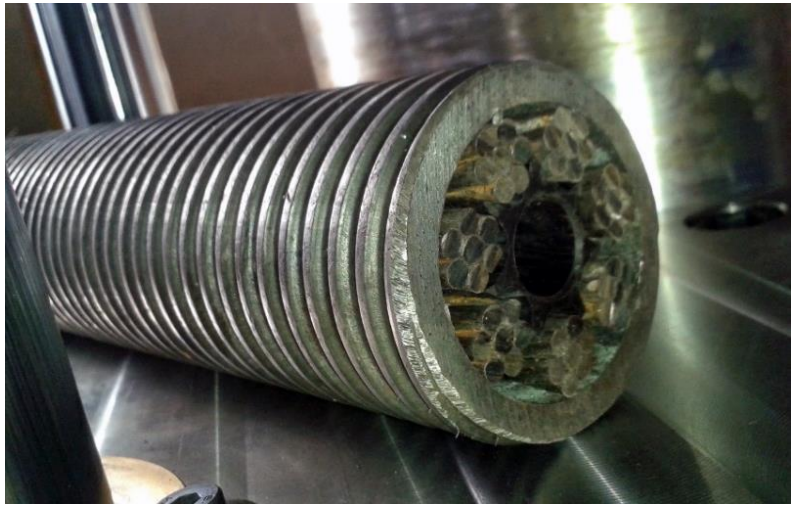






Passive Composite Anchor

Hollow Bar (eventually galvanized) T_{max} = 1680 kN



Bar eith strands T_{max} = 3150 kN

Drilling bits

Accessories (drilling bits, sleevers, clamping nuts)

Some installations

Val di Maso landslide
(Valli del Pasubio, VI)

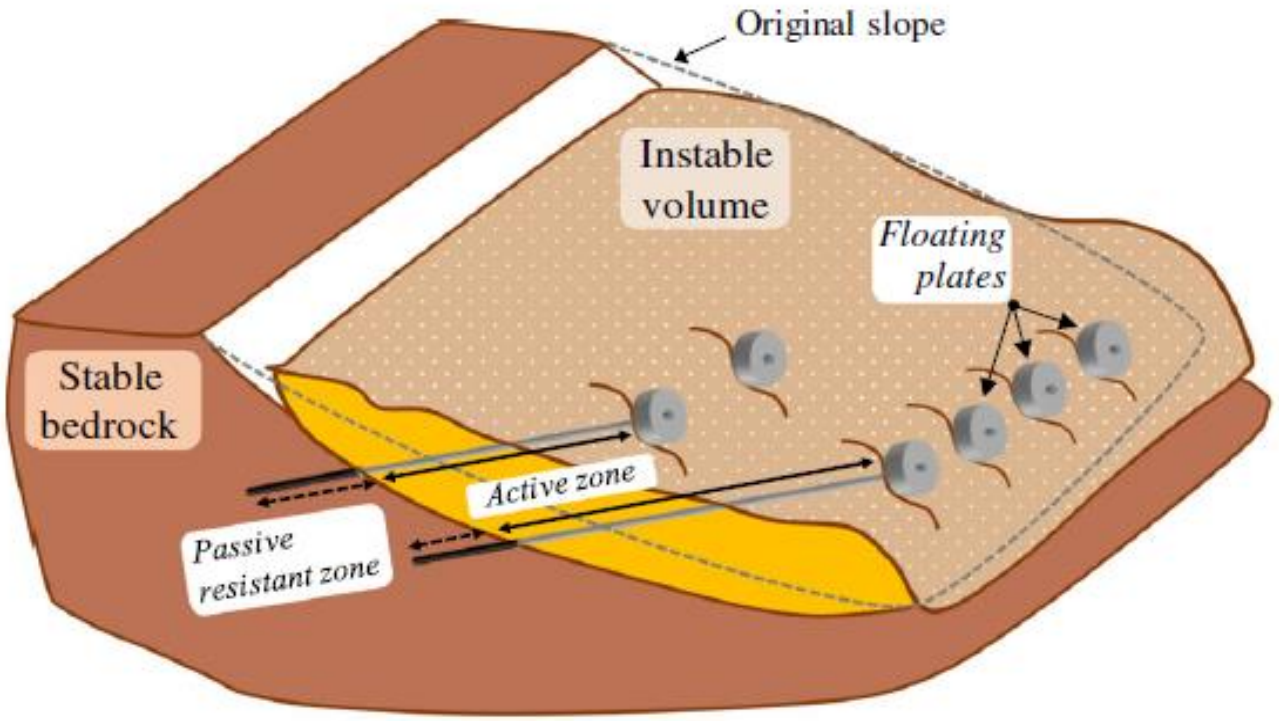
Cischele landslide
(Recoaro Terme, VI)

Gisbenti landslide
(Valli del Pasubio, VI)

… and many more…..

Advantages

- **Passive anchors: not pre-tensioned** (no maintenance). Traction develops due to the friction along the soil-bar interface, as the landslide move
- **Self-drilling installation, higher resistance with minor cost, more adaptability to the stratigraphy during installation, minor external impact**

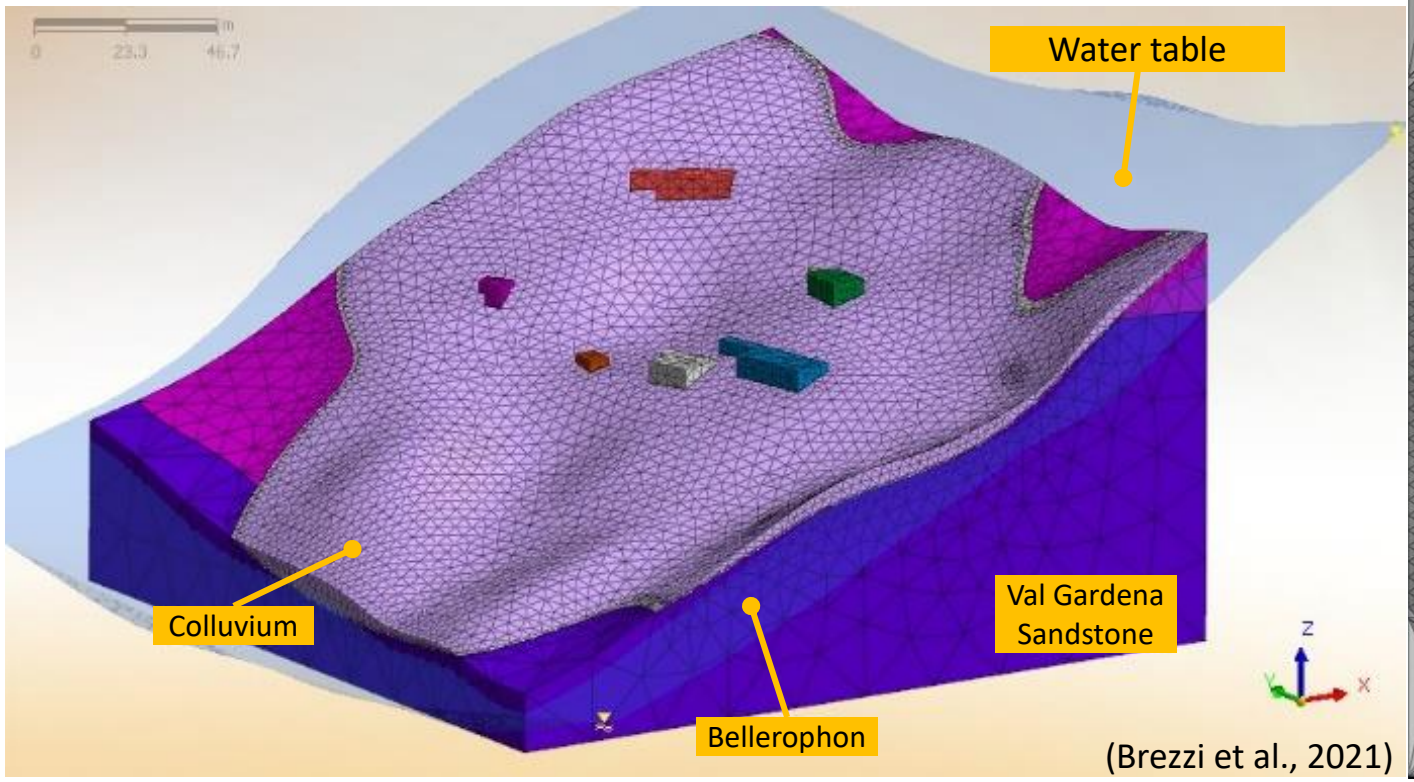


Open questions

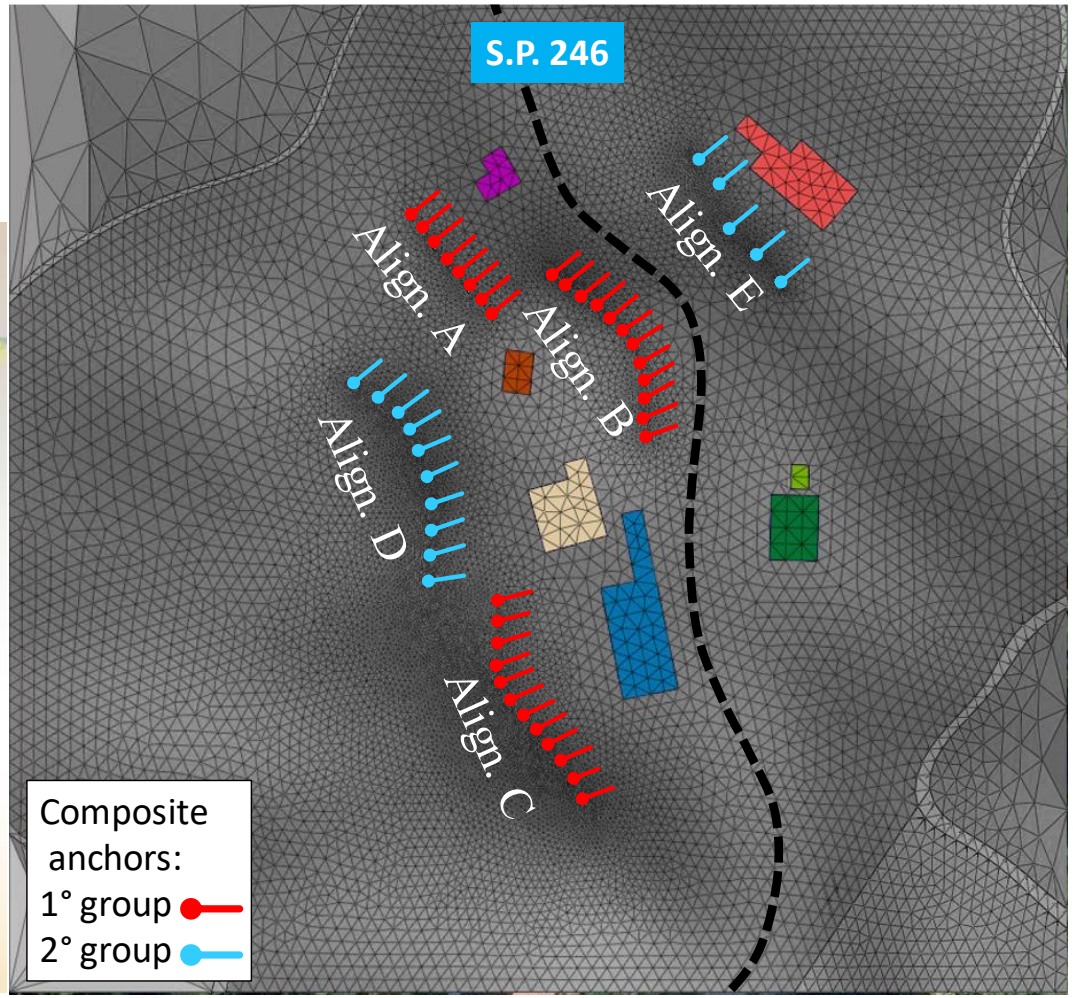
- What about the **correct coupling bar-strands?**
- Which is the **load distribution along the bar**?
- **Is the external plate large enough**?

Numerical evaluation of traction with FEM

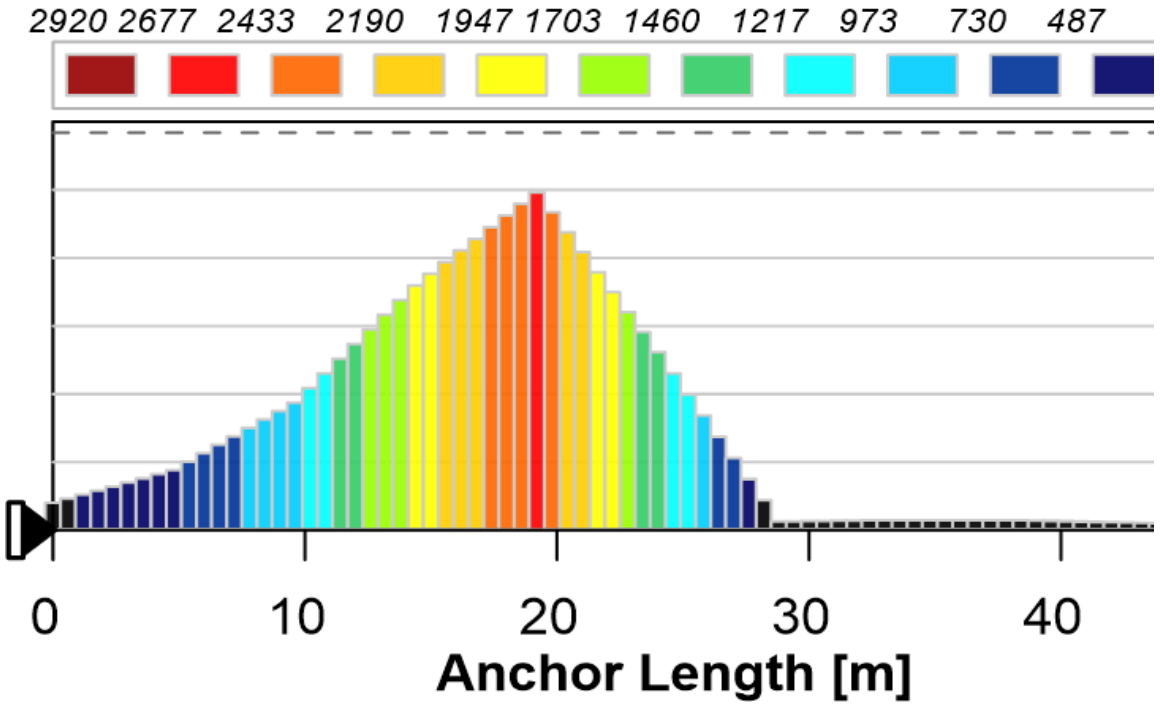
- Cischele landslide analized with FEM-3D and Strength Reduction Method (SRM)
- Without and with different lines of anchors
- Various water levels

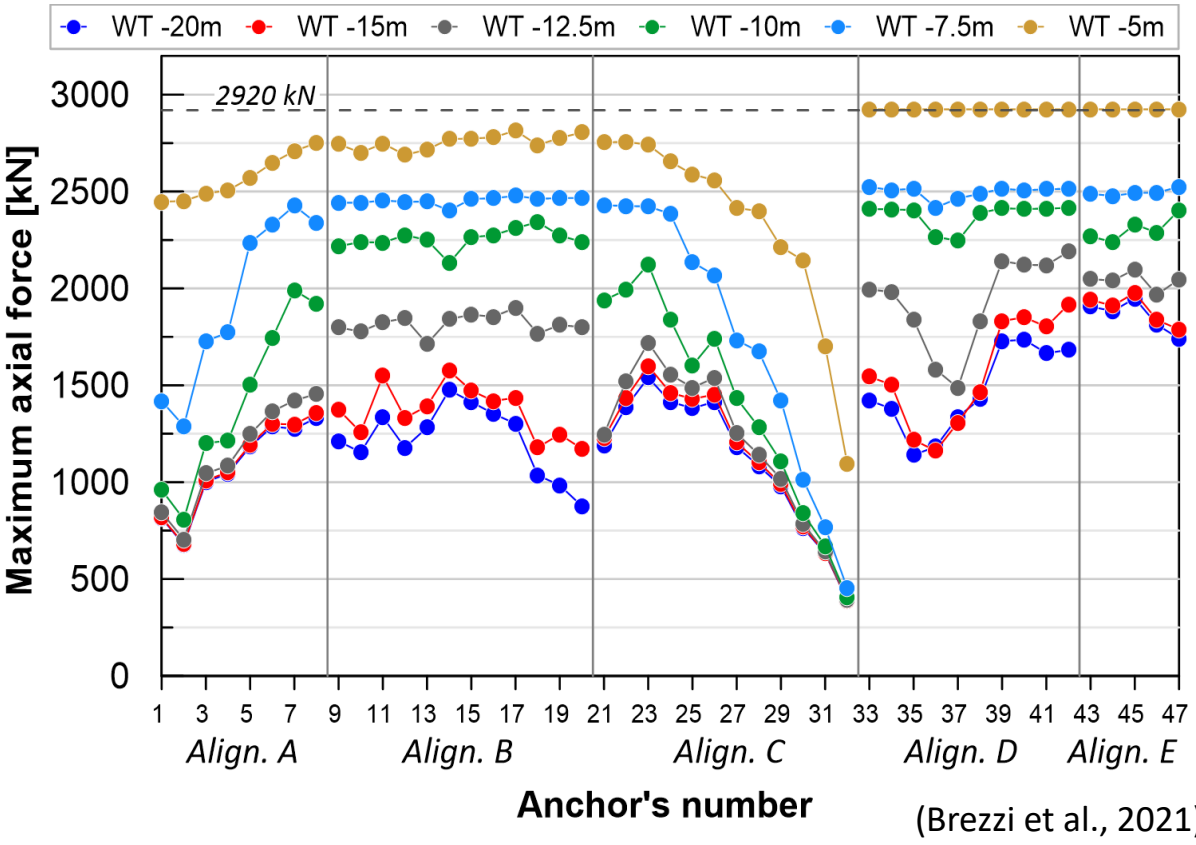


(Brezzi et al., 2021)



Numerical evaluation of traction with FEM





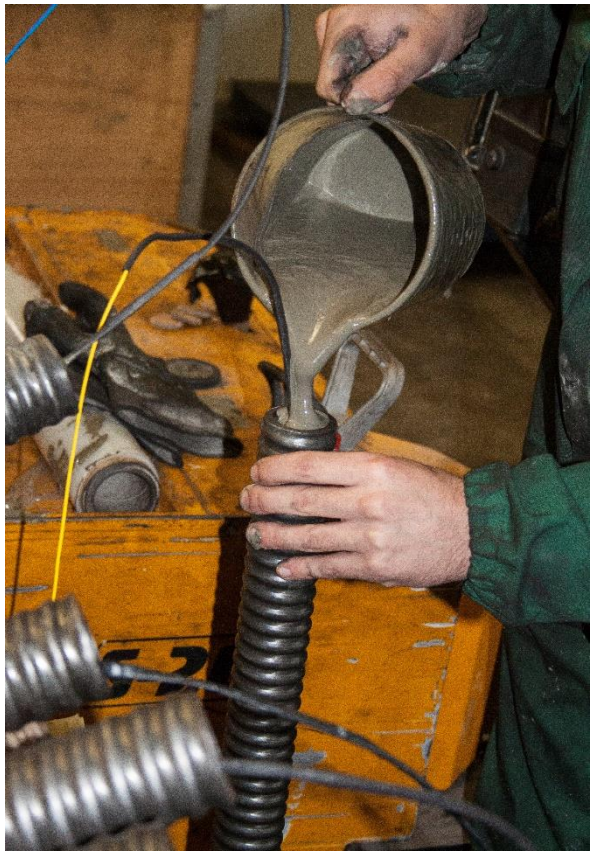
(Brezzi et al., 2021)

Research goal → **Set up of a monitoring system to measure and verify the development of load over time in the anchors**

Laboratory tests

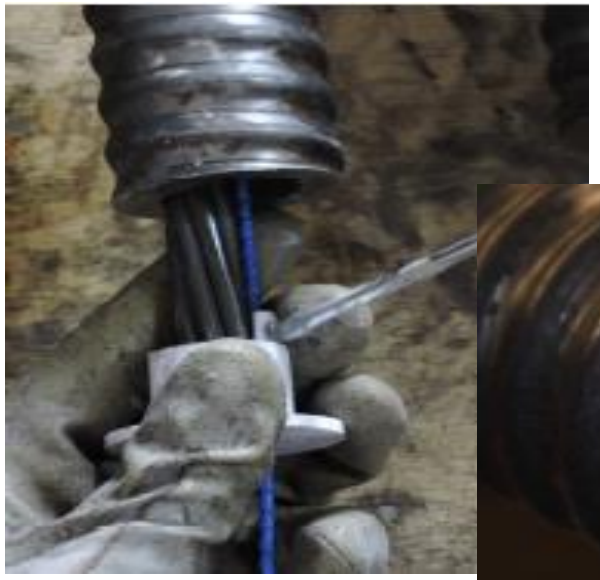
Simple bar

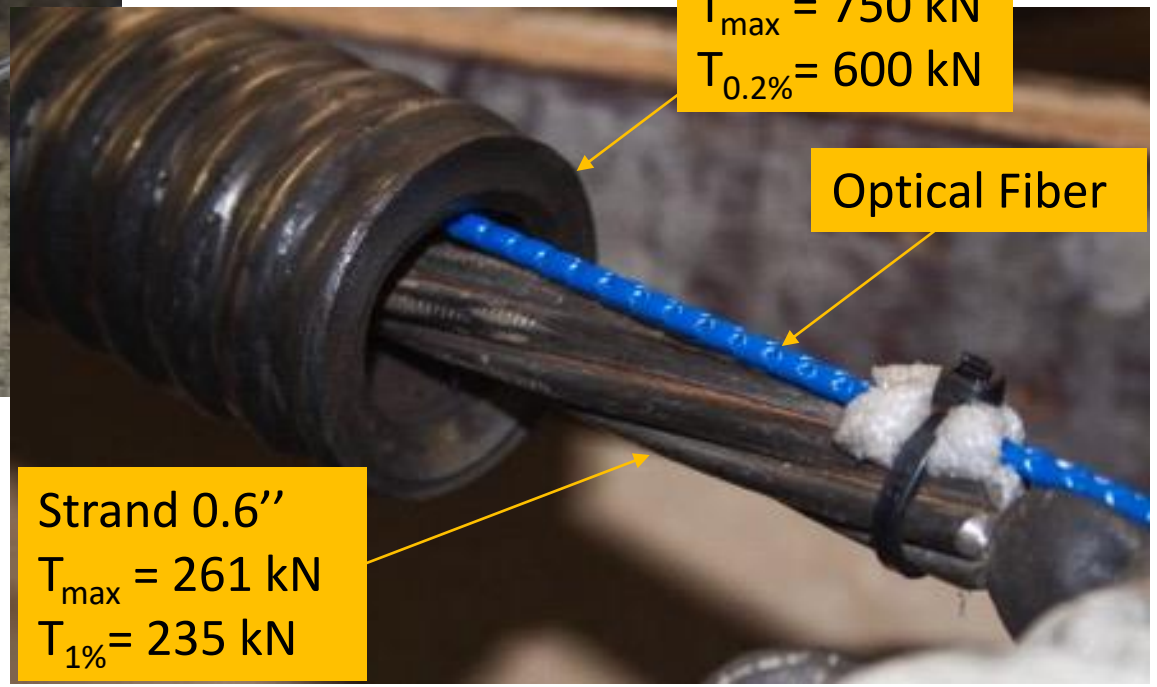
Bar + mortar + DFOS



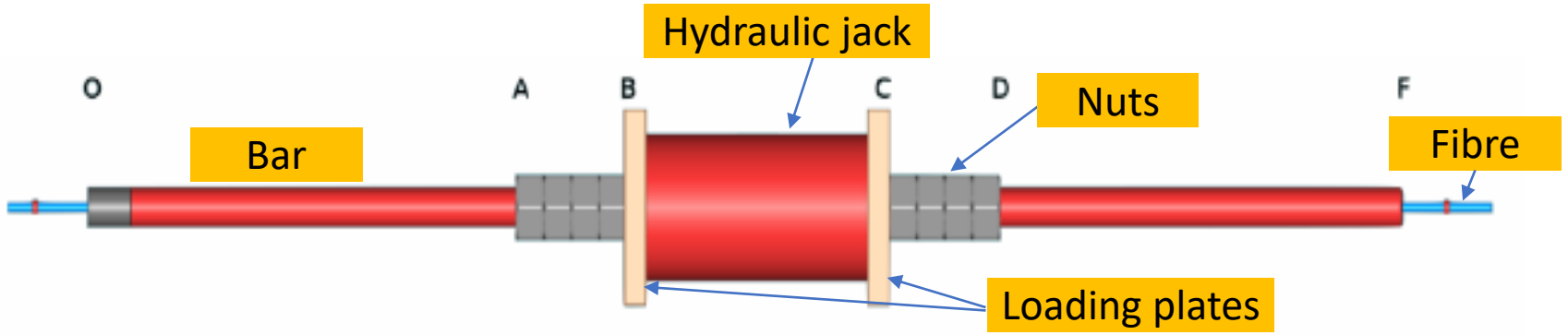
Composite bar

Bar + strand + mortar + DFOS

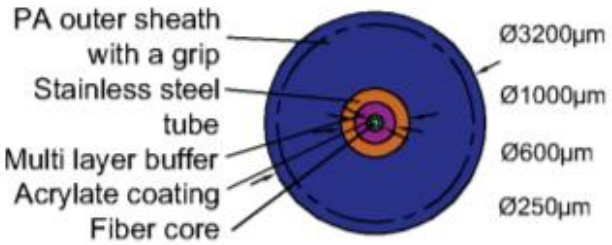




Laboratory tests

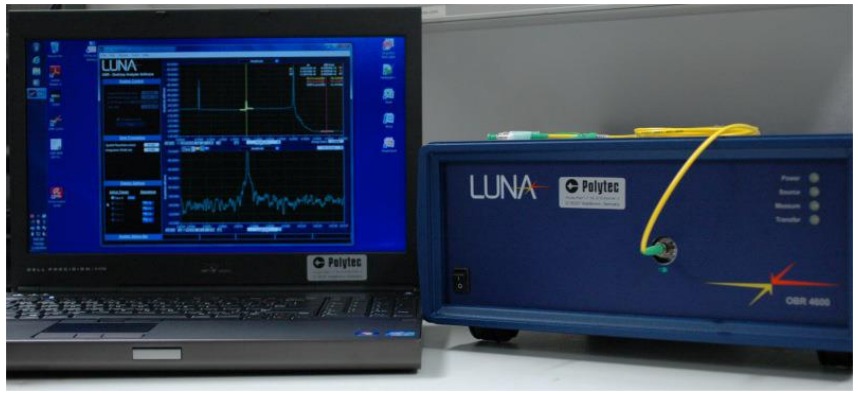


BRUSens V9 strain cable (ø 32mm)



- Strain range up to 1% (10000 με)
- Attenuation < 0.5 dB/km for a wavelength of 1550 nm
- Max tensile strength at installation: 260 N

Luna OBR4600 (Rayleigh-OFDR)



- One ended configuration
- Sensing range: 70m – 2km
- Accuracy: 1με / 0.1°C
- Spatial resolution: 10µm – 1mm

Laboratory tests

- **Tensile traction:**

$$Q(s) = (EA)_{eq}\varepsilon$$

with $(EA)_{eq}$ = equivalent stiffness of composite bar

$$(EA)_{eq} \approx E_b A_b + n \cdot E_s A_s$$

where:

$E_b = E_s$ = 201 GPa

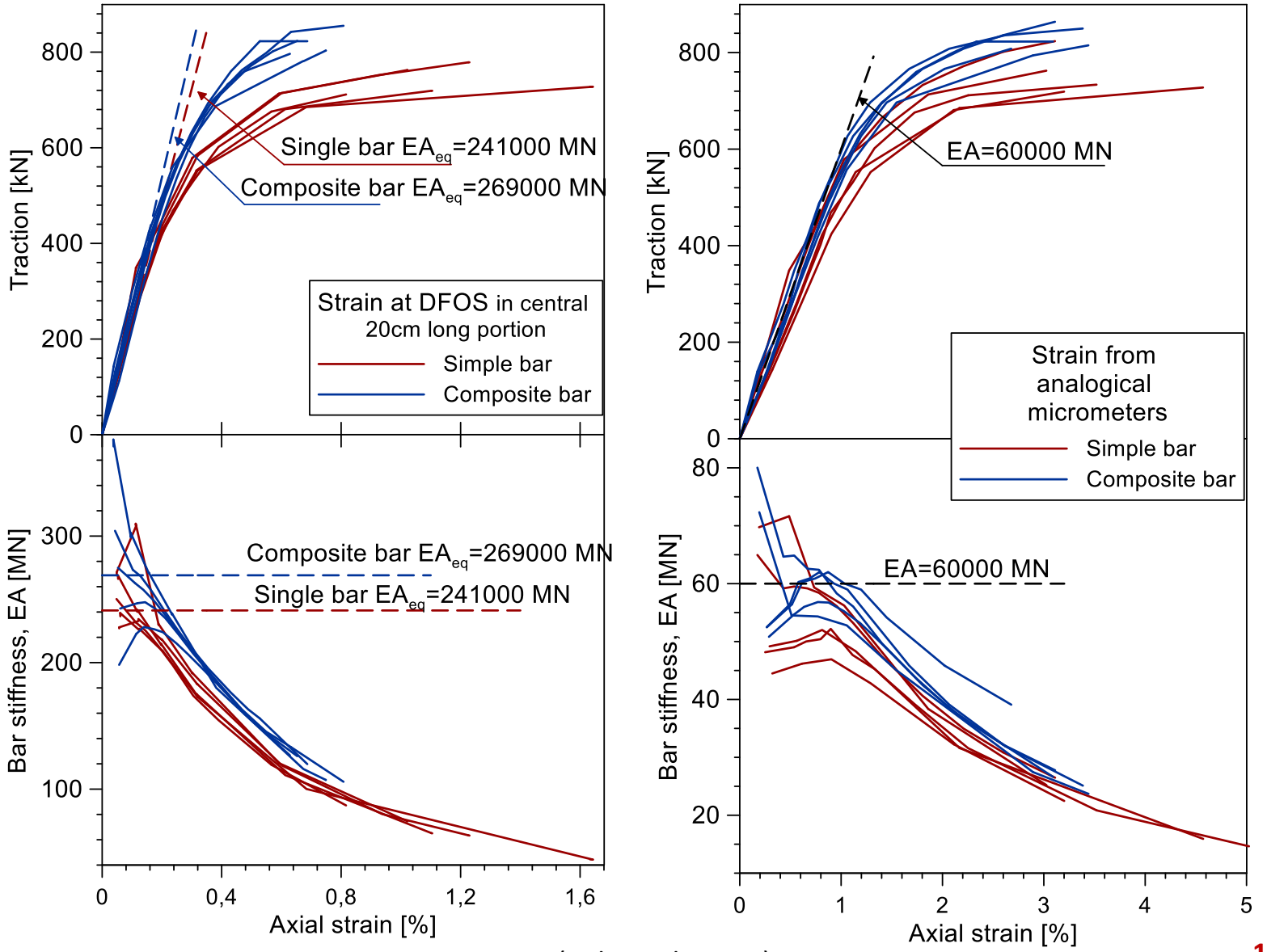
A_b=1200 mm²

A_s=140 mm²

$n = 1$

$(EA)_{eq}$ = 241000 MN Single bar

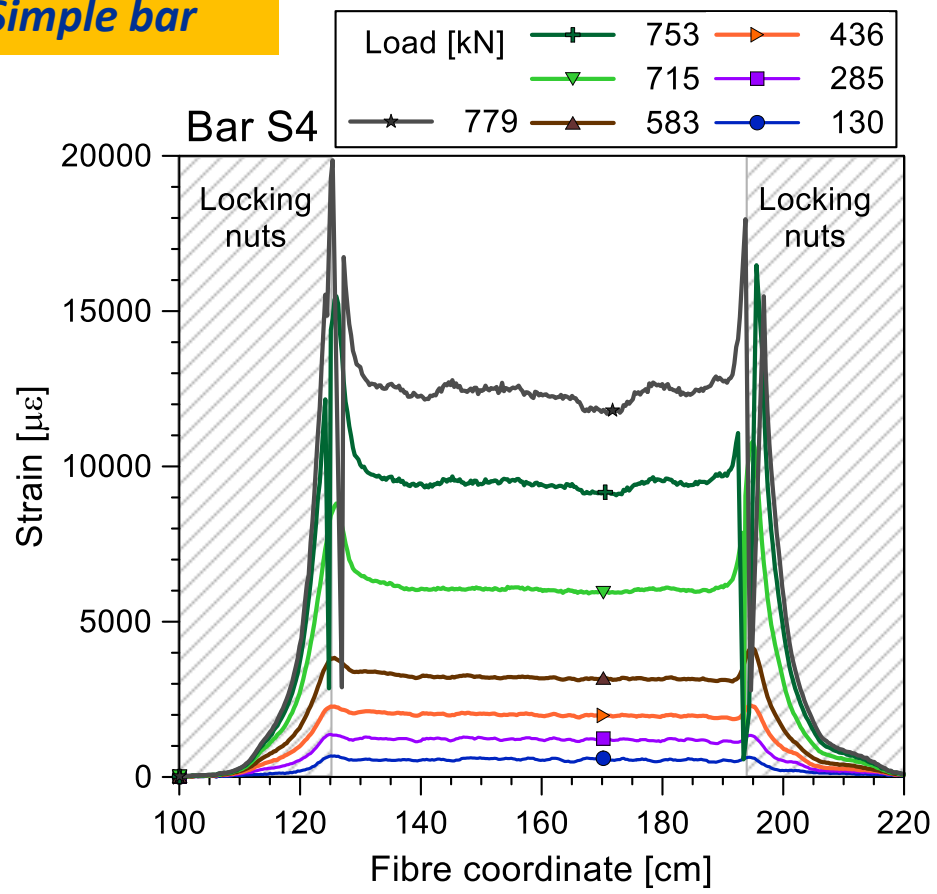
$(EA)_{eq}$ = 269000 MN Composite bar



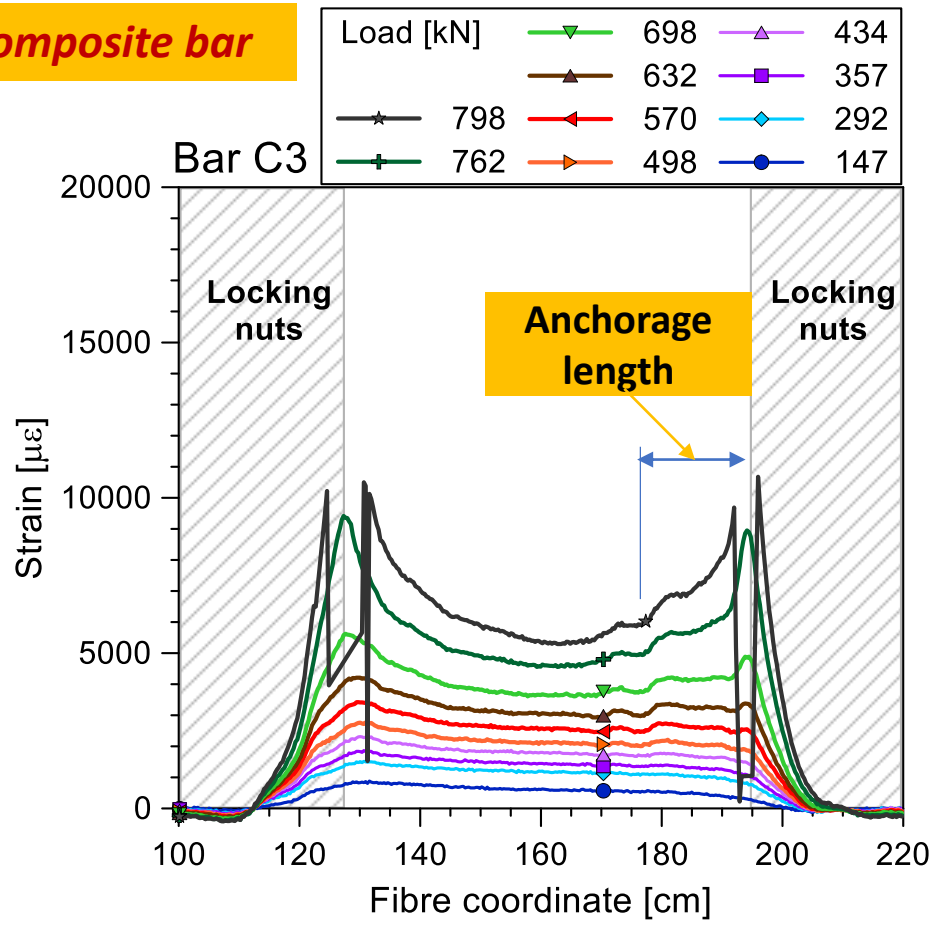
(Cola et al., 2019)

Misure in laboratorio

Simple bar



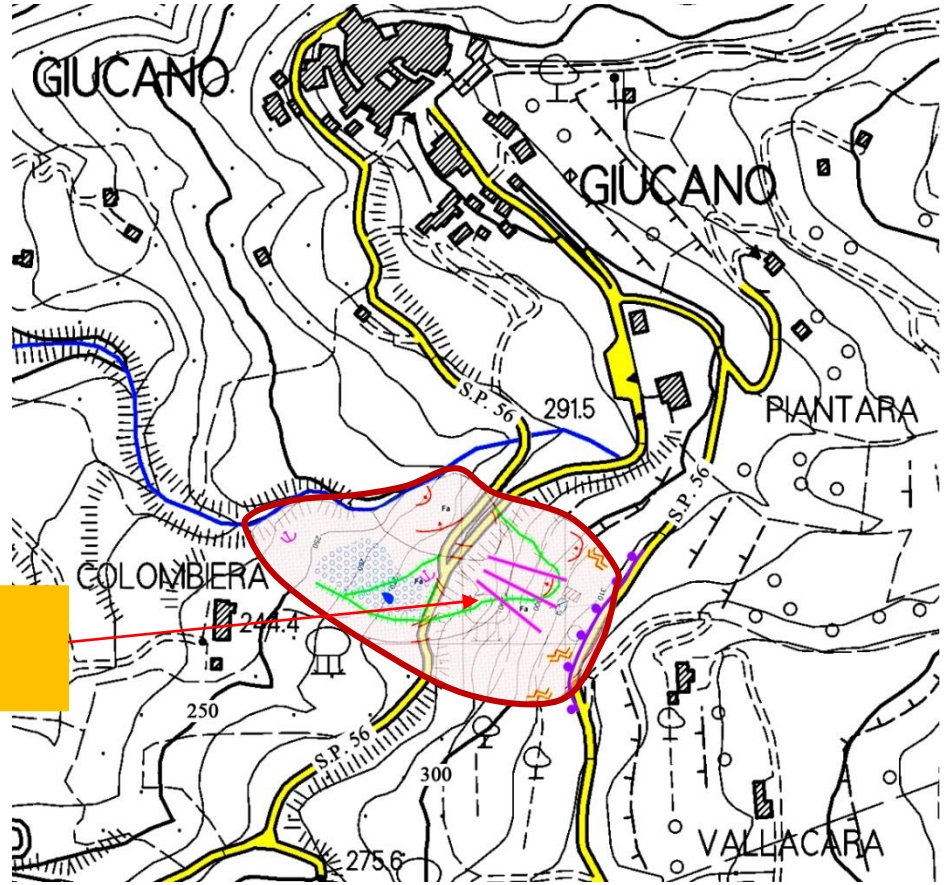
Composite bar

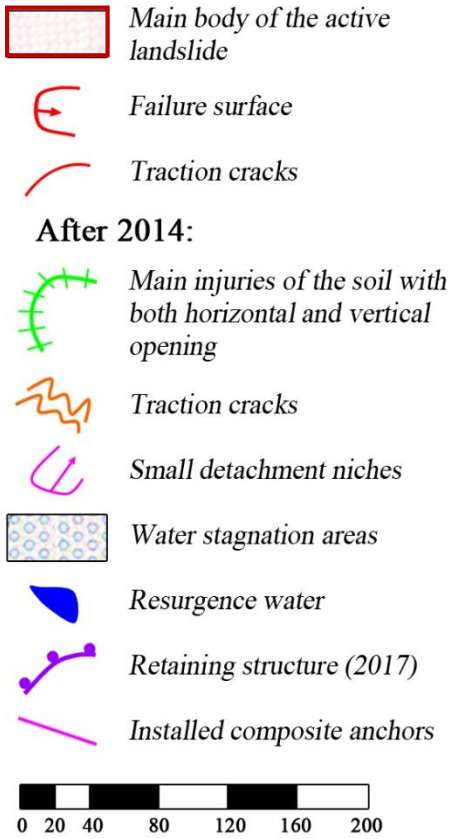


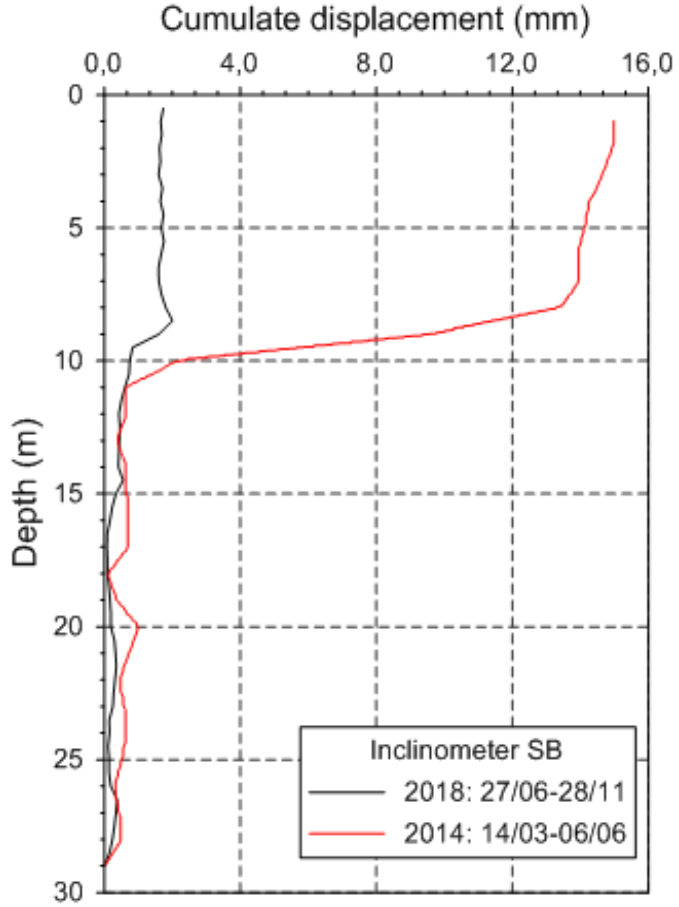
(Cola et al., 2019)

2° in-situ test at Giucano landslide

- Giucano (Fosdinovo, Toscana)
- Activated in 2013, not stabilized even if some interventions were performed in the upper border

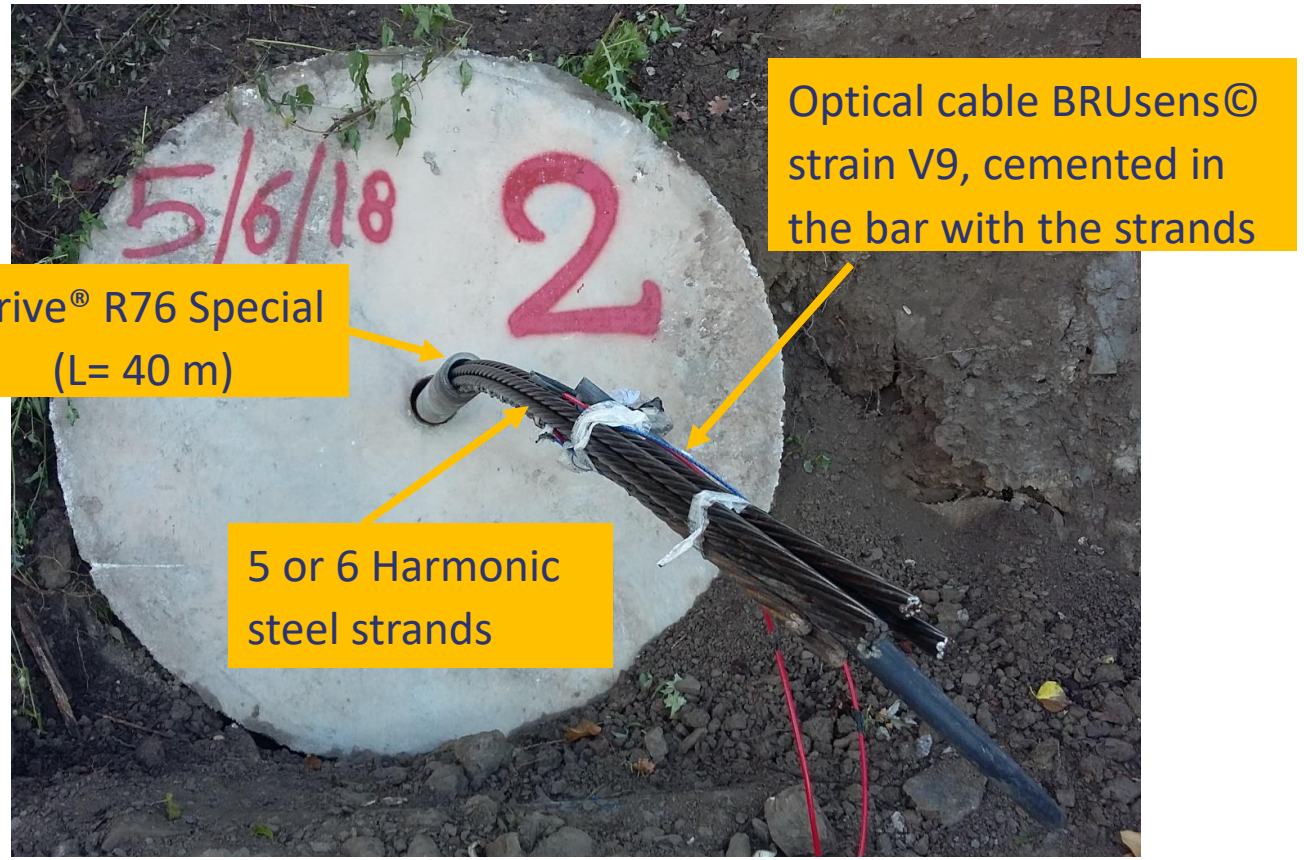






2° in-situ test at Giucano landslide

- 3 Bar Sirive® R76 Special (T_{max}=1159 kN, 40 m-long)
- 5 (bar n.1) or 6 (bars n.2 and 3) 0.6” strands (T_{max} =240 kN)



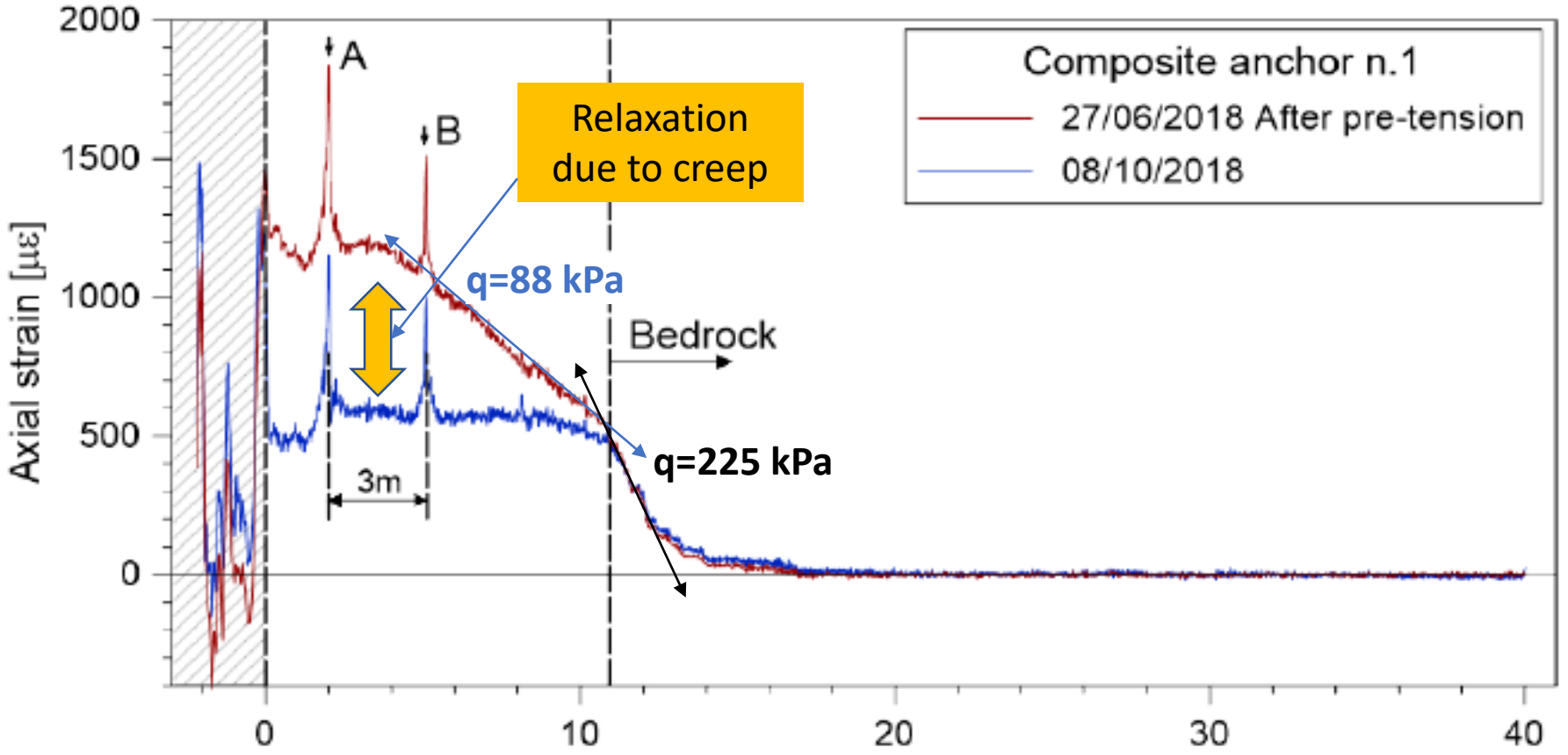
2° in-situ test at Giucano landslide

- **Mobilized lateral resistance:**

$$q = \pi D_c \frac{dQ}{ds} \approx \pi D_c \frac{\Delta Q}{\Delta s}$$

This can be calculated in the portions with constant slope.

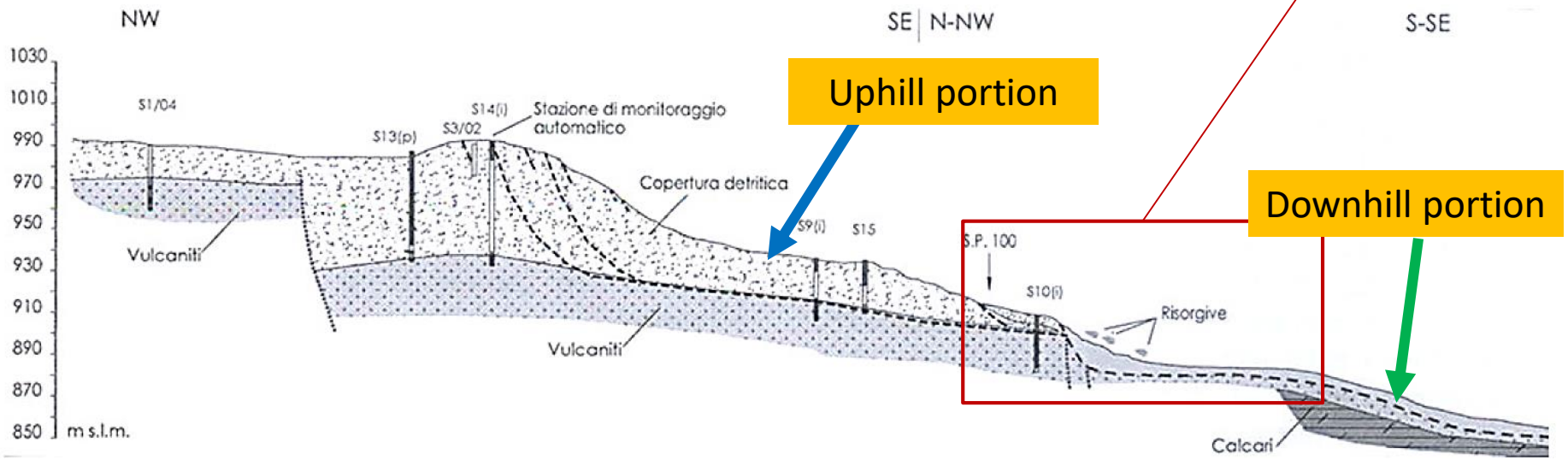
Each anchor is tensioned after the mortar has hardened. Strain is measured after the hardening and 3 months later



(Cola et al., 2019)

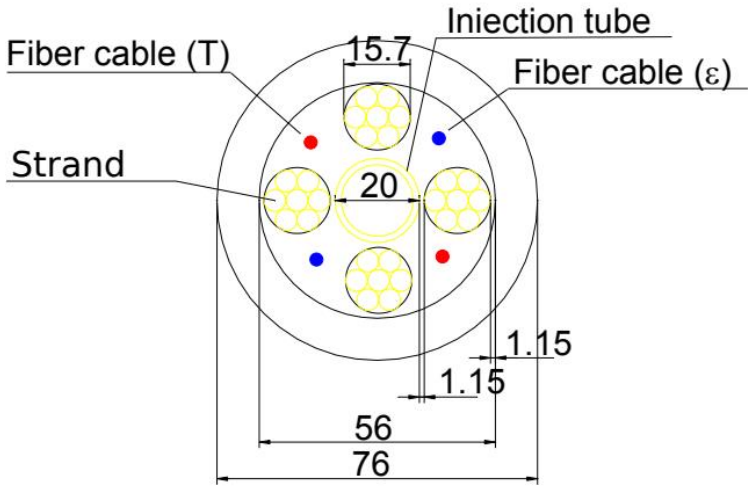
2° in-situ test at Fantoni landslide

- **Site:** Contrada Fantoni, Recoaro Mille (VI)
- **Landslide estension:** 57.000 m^2
- **2 portions:** uphill a roto-translational movement, downhill a slow creeping slope
- **Material:** coarse colluvioum above Vulcanic rock or Limestone



2° in-situ test at Fantoni landslide

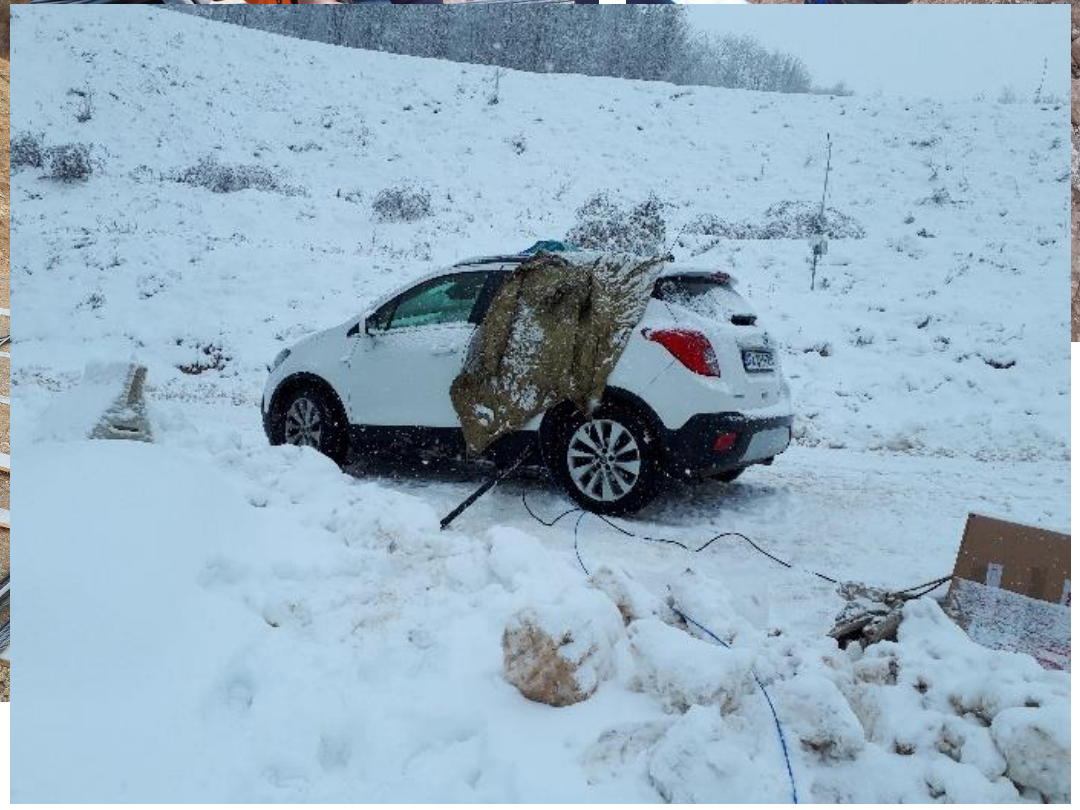
- **Optical cable BRUsens© strain V9,** installed in double mode
- **Optical cable BRUsens© temperature** only in anchor 5



7 composite anchors installed in November-December ‘20

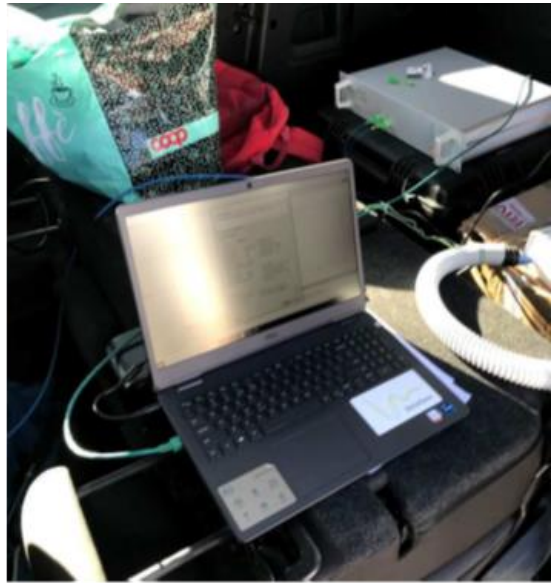
- Bar **SIRIVE® S76 driven up to** 5-6 m in the stable bedrock
- **4 strands**
- **Different lengths and inclinations**

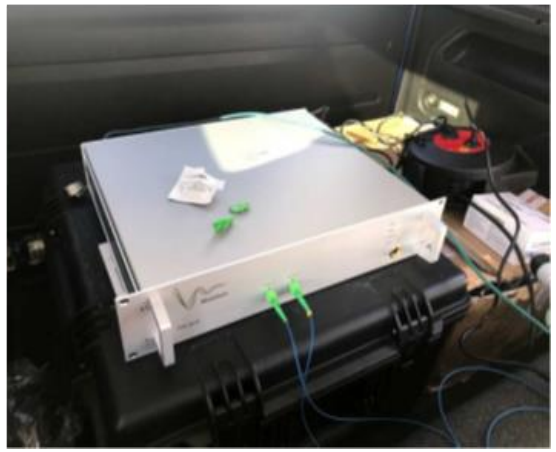
2° in-situ test at Fantoni landslide



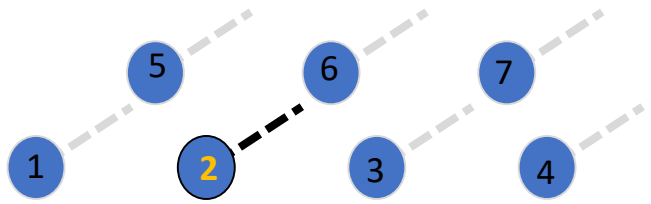
2° in-situ test at Fantoni landslide

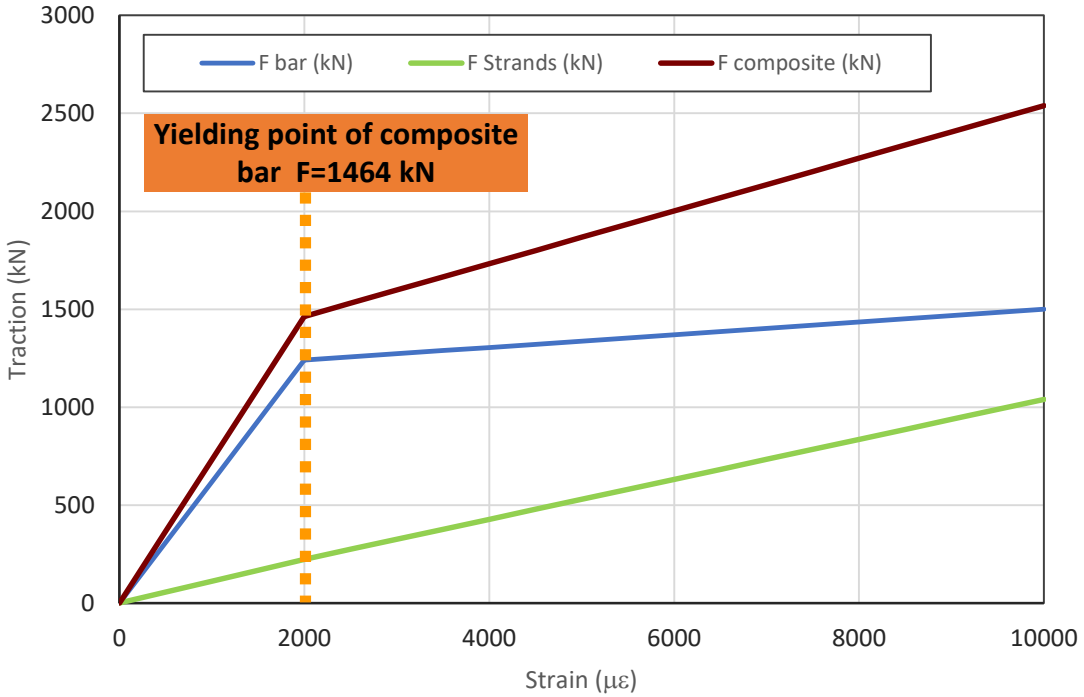
- **DFOS installed on 01/12/2020**
- **Brillouin Optical Frequency Domain Analyzer** (BOFDA) from fibrisTerre (Germany) with:
  - maximum sampling: 5
  - spatial resolution: 20 cm
  - strain measurement accuracy: 2 με
  - temperature measurement accuracy: 0.1°C
- Reference reading at **02/12/2020**
- **10 readings with time from December 2020 to June 2022**

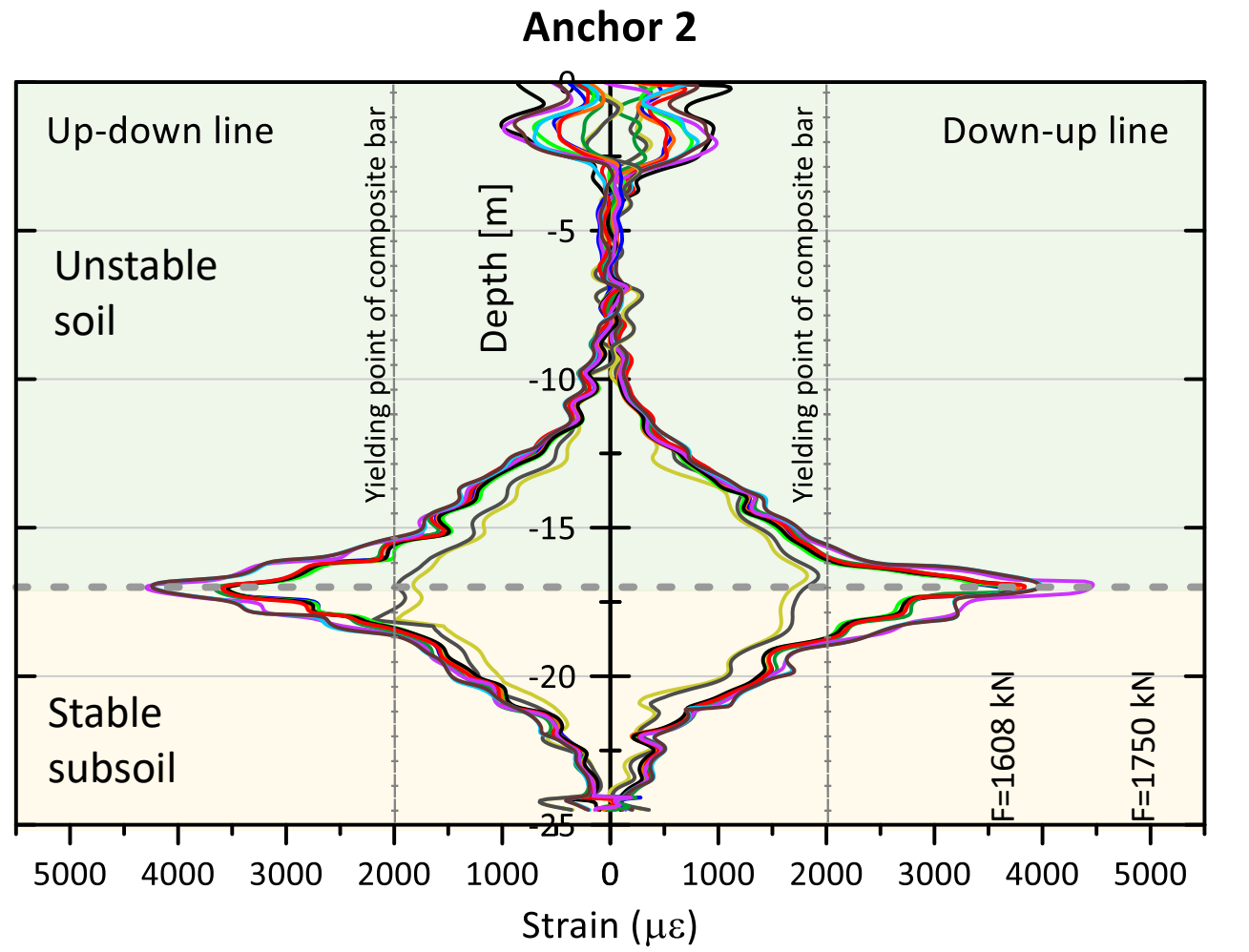




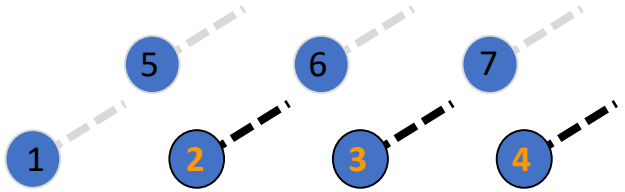
2° in-situ test at Fantoni landslide

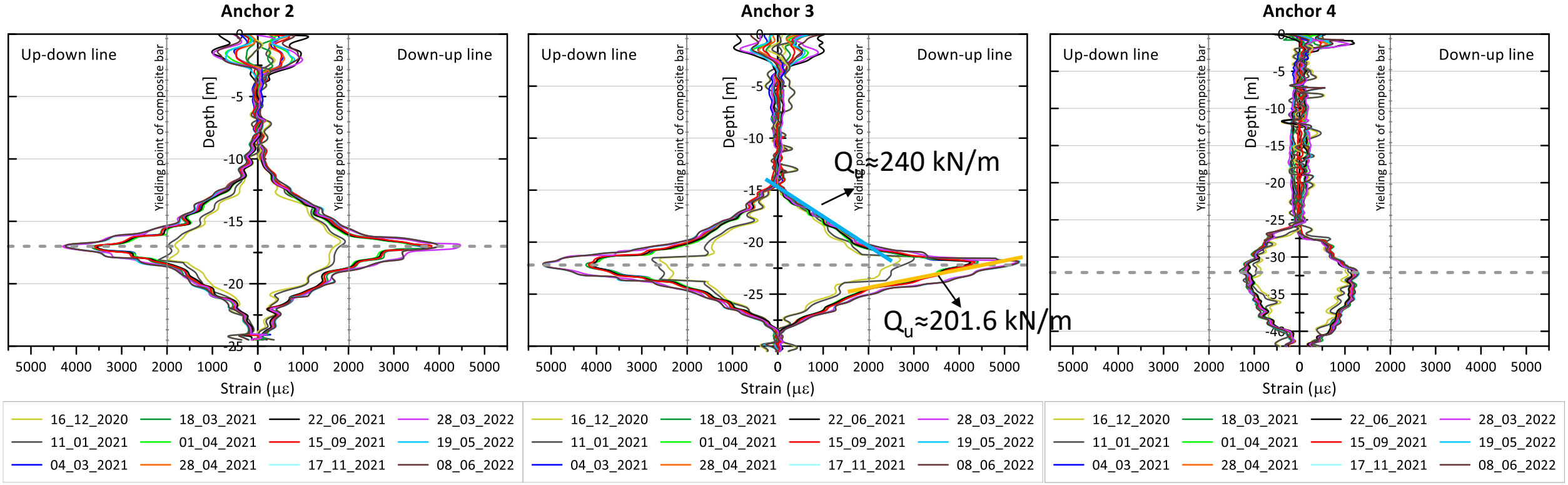




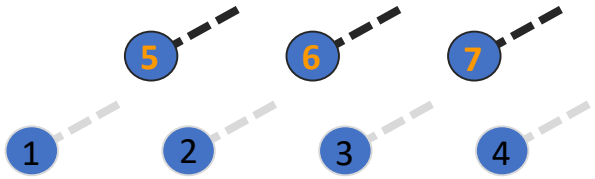


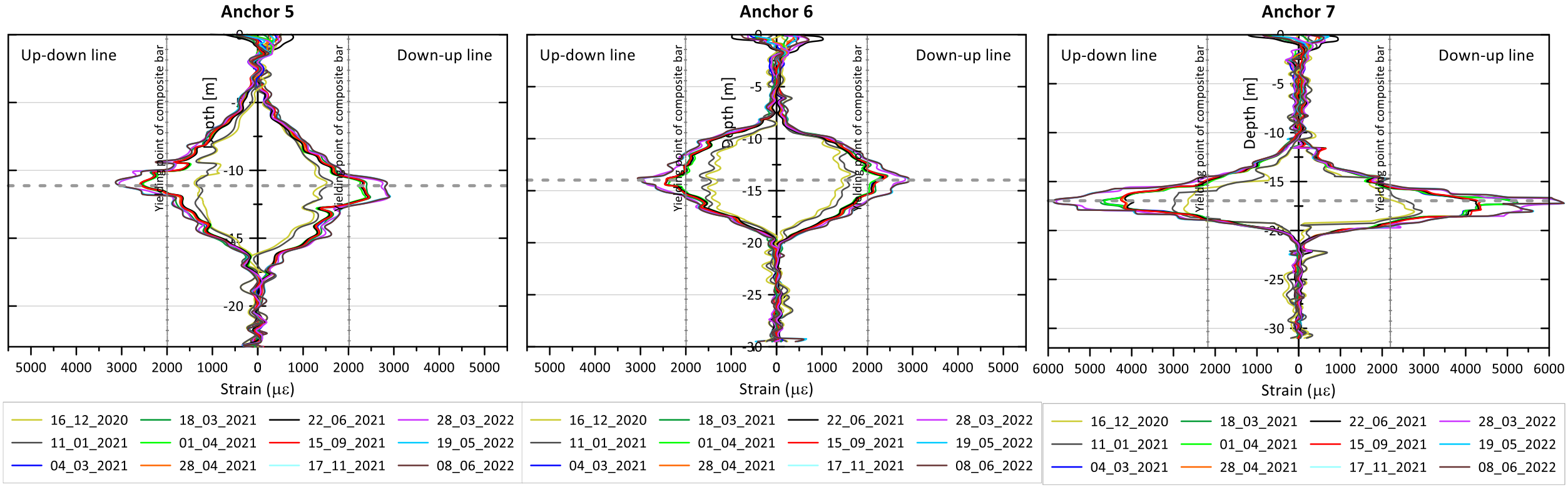
Strain distribution over time



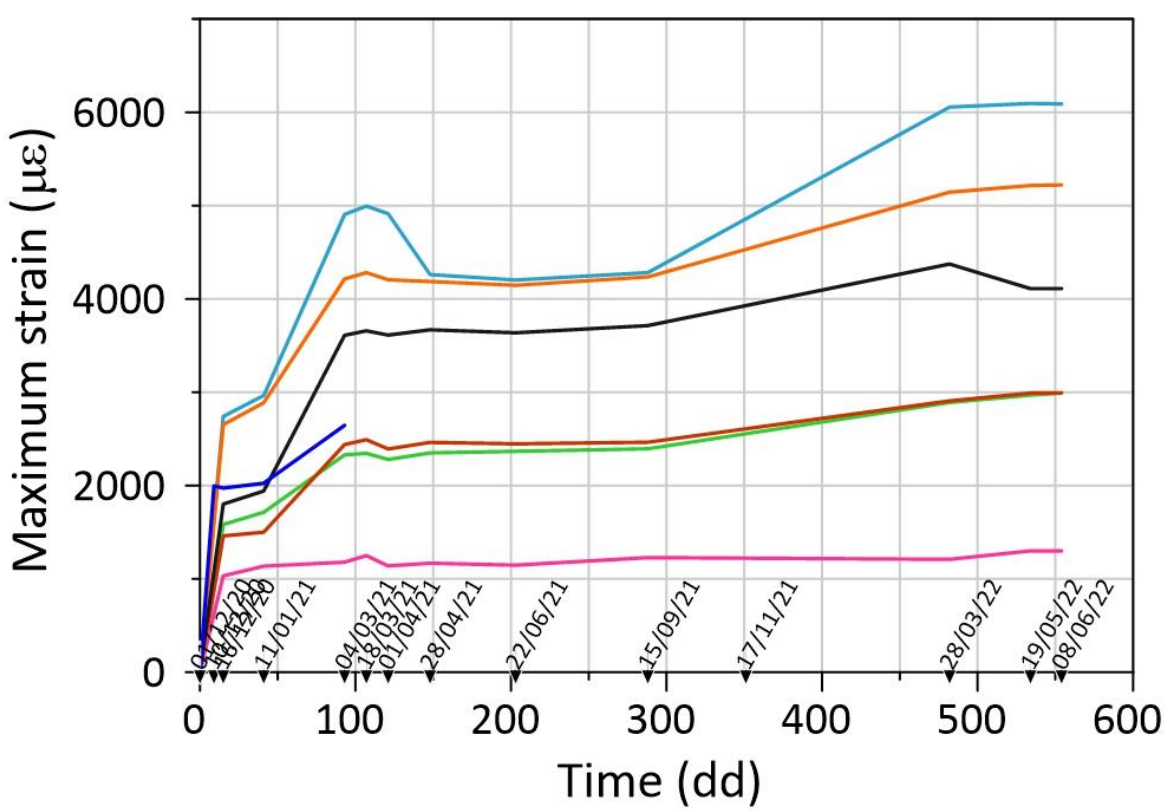


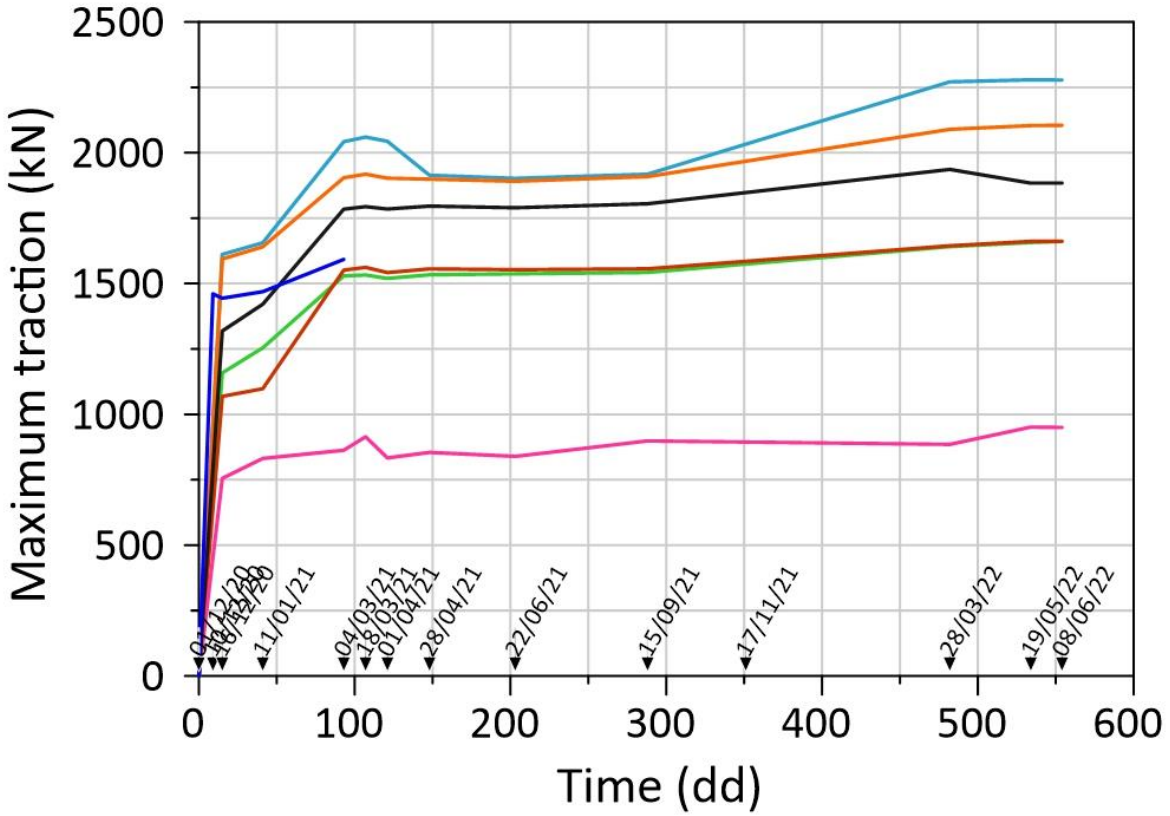
Strain distribution over time





Strain and traction over time



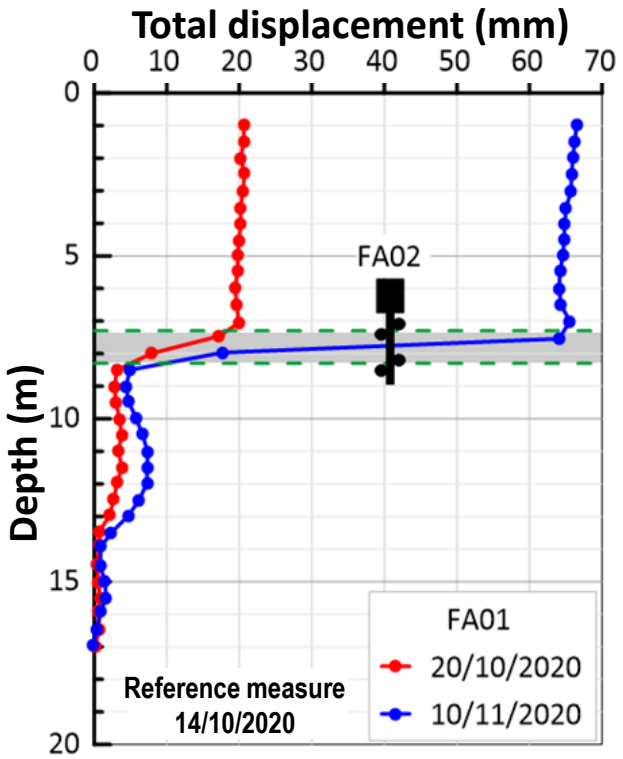


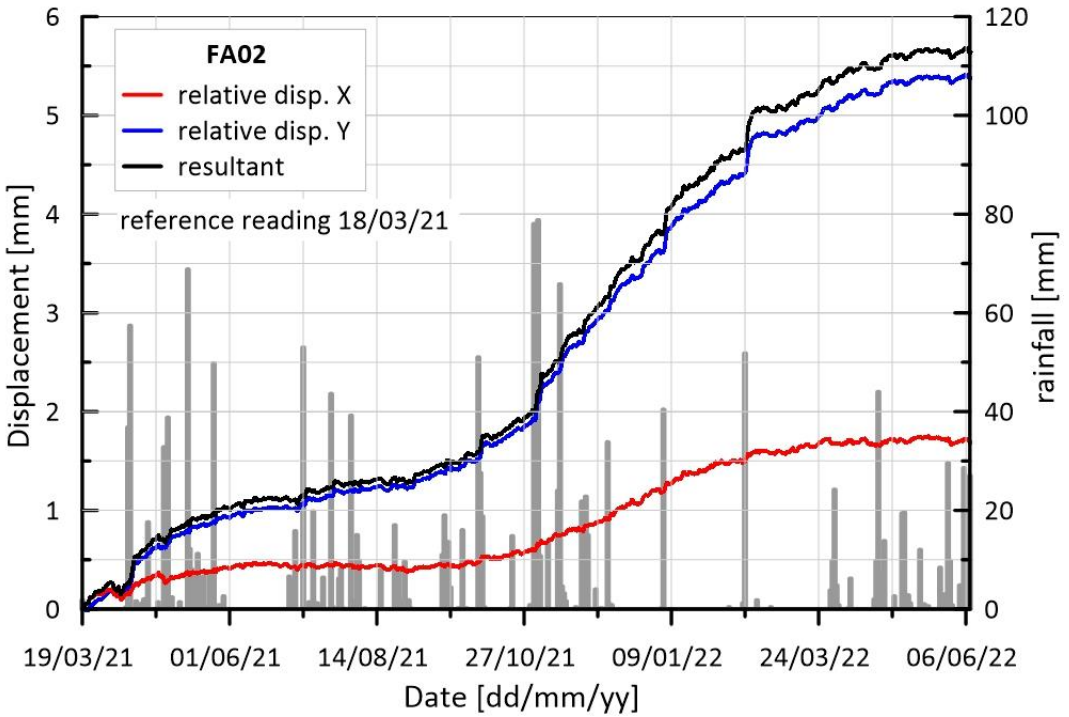
2° in-situ test at Fantoni landslide

- Manual inclinometer **FA01 installed pre-anchors**
  - 14/10/2020 - 10/11/2020 **con 6.7 cm in 27 gg (v=2.5 mm/g)**

→ Interrupted

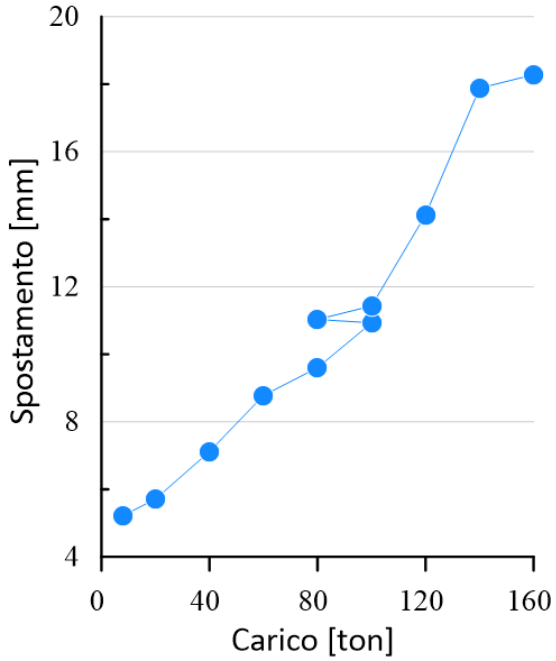
- Fixed inclinometer **FA02 installed post-anchors**
  - March – June 2021: **1,1 mm in 3 months (v=0,012mm/g)**
  - October 2021 – March 2022: **3,8 mm in 6 months (v=0,021mm/g)**

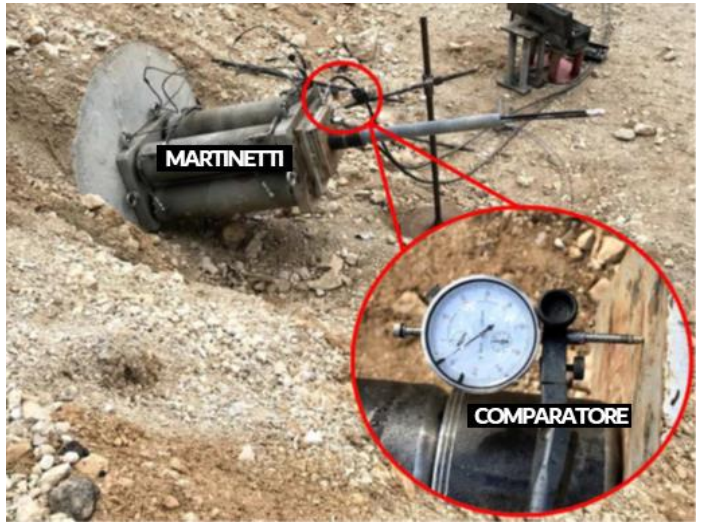


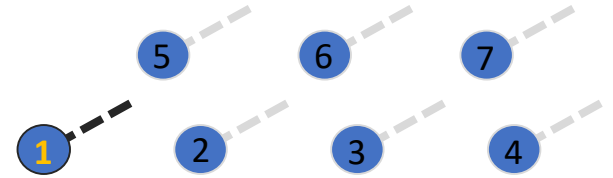


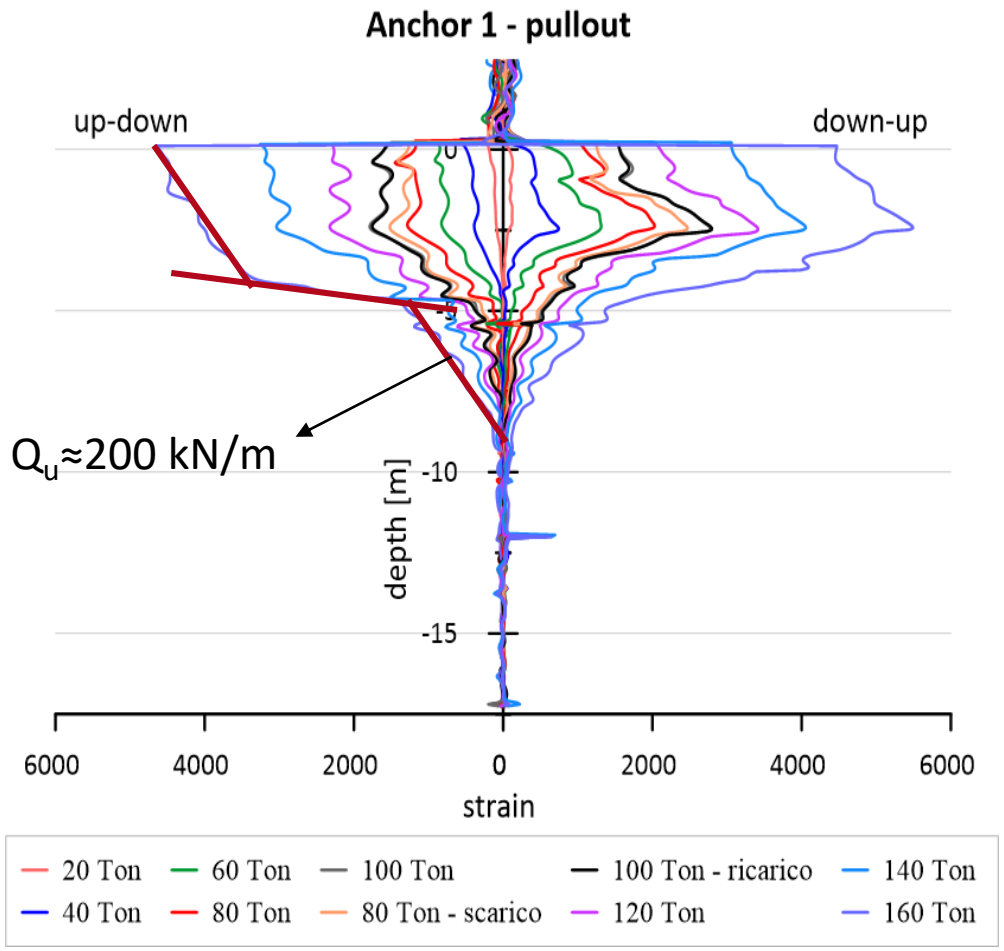
Pull-out test

- Failure at 160 ton ≈ 1600 kN due to lost of contact between mortar and bar in the external portion
- Not all the bar was involved in load
- Some bending moment in the external portion
- Information about the unitary pull-out resistance









Final remarks of DFOS application

- In this application DFOS demonstrate to be the most proper technique for studying the behavior of composite anchors in laboratory but also in site
- They permit to study the interaction of the bar with the inner strands and the presence of bending moments or local discontinuities
- In the in-situ measurements, they give the possibility to:
  - measure the distribution of axial force along the bar
  - individuate the position of the sliding surface
  - understand the interaction between composite anchor and soil
  - evaluate its behavior over time
  - evaluate the effective contribution given for the landslide stabilization
- In the pull-out test, they demonstrate that the test procedure needs to be modified if the aim is to characterize the resistance of the deep stable soil

Thanks you for the attention!

Acknowledgements:

- **Dalla Gassa srl**: Gaetano Dalla Gassa, Alberto Bisson and all the staff
- **UNIPD**: Lorenzo Brezzi, Simonetta Cola, Paolo Simonini, Fabio Gabrieli, Nicola Fabbian, Antonio Pol, Francine Tchamaleu Pangop, Fabio Schiavon, Zeno Lucchese
- **CNR-IRPI Padova**: Luca Schenato, Giacomo Tedesco, Gianluca Marcato
- **EPC**: Giordano Munaretto, Federico Carollo
- **M3E**: Nicolò Spiezia
- **PROV. VICENZA**: Massimo Lovison
- **GEOASSET srl:** Massimo Moracchiolo