International Summer School

PRESERVING HERITAGE: STRATEGIES FOR STABILIZING UNSTABLE SLOPES IN HISTORIC CULTURAL CENTERS

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INTRODUCTION – THE TEAM

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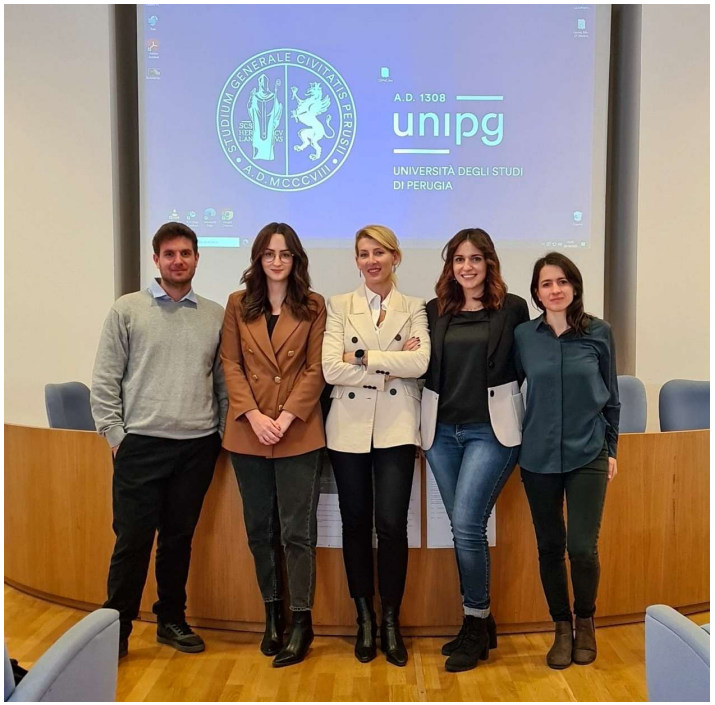

Arianna Lupattelli – PostDoc Researcher

Davide Pauselli – External Co-Worker

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Giulia Capati – Granted Researchers

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INTRODUCTION

- The worsening over time of territorial degradation related to hydrogeological instability highlights the need to address the issue of protecting the cultural heritage threatened by it.

- In Italy, 8 out of 10 municipalities are at hydrogeological risk. In five regions, including Umbria, 100% of the territory is at risk.

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INTRODUCTION

Elements contributing to **environmental degradation**

Measures aimed at **risk mitigation**

The protection of cultural heritage must be addressed through **two synergistic approaches**:

TECHNICAL and **CULTURAL**

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CULTURAL HERITAGE

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CULTURAL LANDSCAPE

The **European Landscape Convention** (Strasbourg, July 19, 2000), in art.1, defines **Landscape** as:

“an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors”

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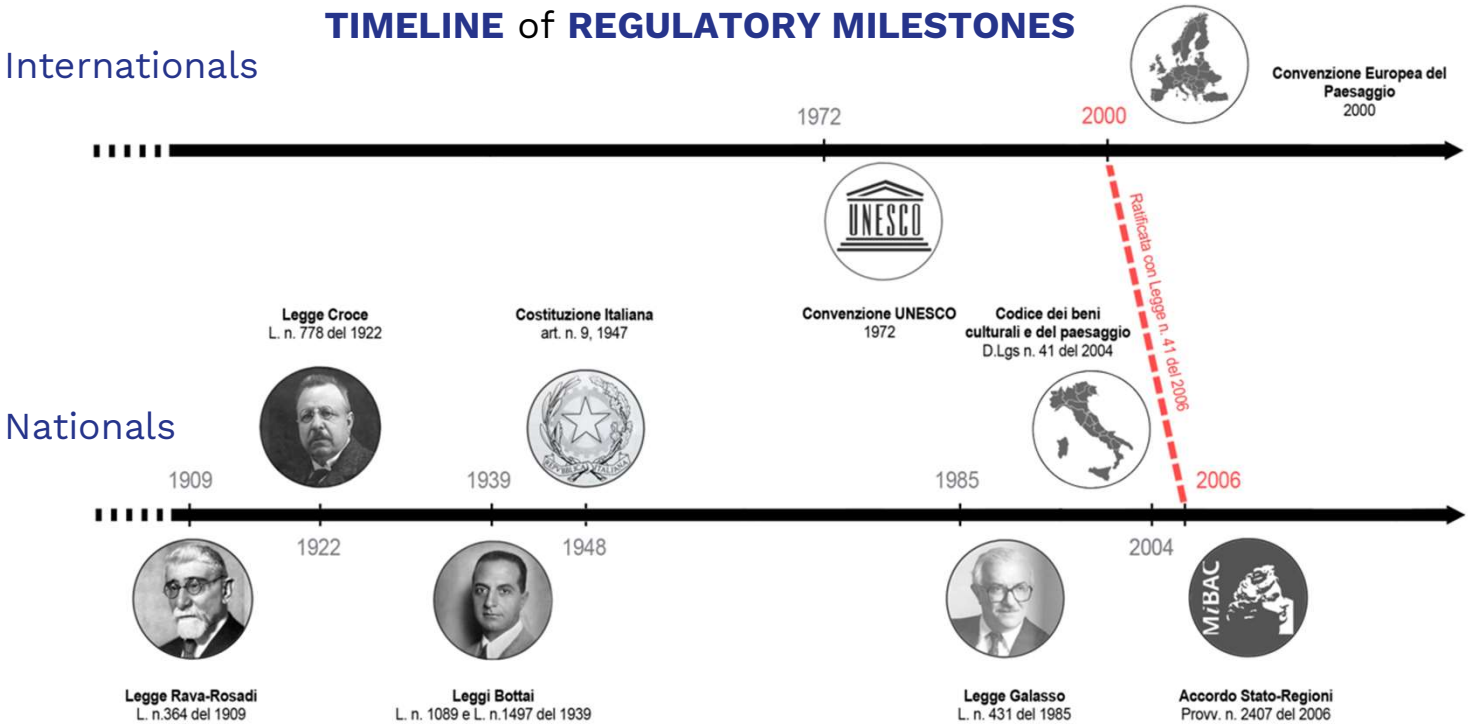
CULTURAL LANDSCAPE

The understanding of the complexity and importance of cultural elements (generally summarized by the term **landscape**), and its necessary protection, are the result of a **long process of definition and refinement.**

TIMELINE of **REGULATORY MILESTONES**



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Case study: The Orvieto cliff

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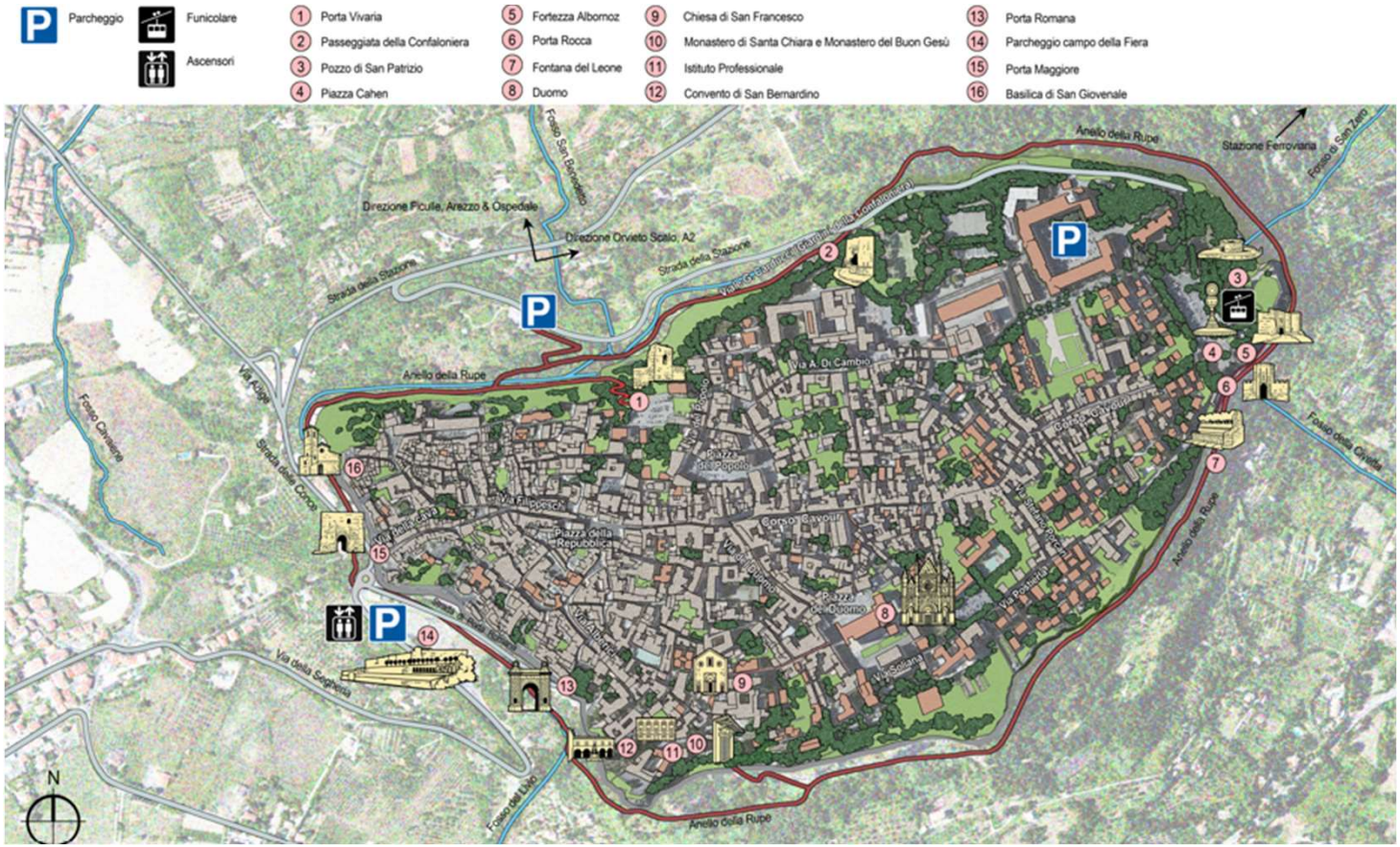
CASE STUDY

The stabilization interventions of the “**Rupe Tufacea of Orvieto**” are among the most well-known on the national and international stage, serving as reference models for a correct approach to land protection in unstable inhabited areas.

They represent a positive experience in terms of:

- Involved **expertise**
- Applied **studies**
- Types and prototypes of **projects**
- **Monitoring** techniques



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CASE STUDY

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GENERAL FRAMEWORK

The **Rupe Tufacea of Orvieto**, whose current configuration has been shaped by erosive processes and natural modeling over the centuries, has the following characteristics:

- It dominates the valley of the Paglia River (50-60 m above it)
- It rises between 280 m a.s.l. (Piazza Chaen) and 325 m a.s.l. (San Francesco)
- It features a complex stratigraphic sequence

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INTERVENTIONS CARRIED OUT WITH ATTENTION TO THE LANDSCAPE HERITAGE

- Covering with grass, re-profiling, reforestation
- Hydraulic management
- Regulation of surface runoff
- Stabilization of the Rupe (cliff)
- Static conservation-restoration of masonry works
- Consolidation of the edge of the Rupe
- Implementation of deep drainage works
- Interventions on cavities
- Initiatives for the valorization of interventions

Cleaning and planting

Consolidation

Reforestation

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Hydrualic dikes

Channel networks

Anti-erosive materials

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Drilling

Anchors

Injections

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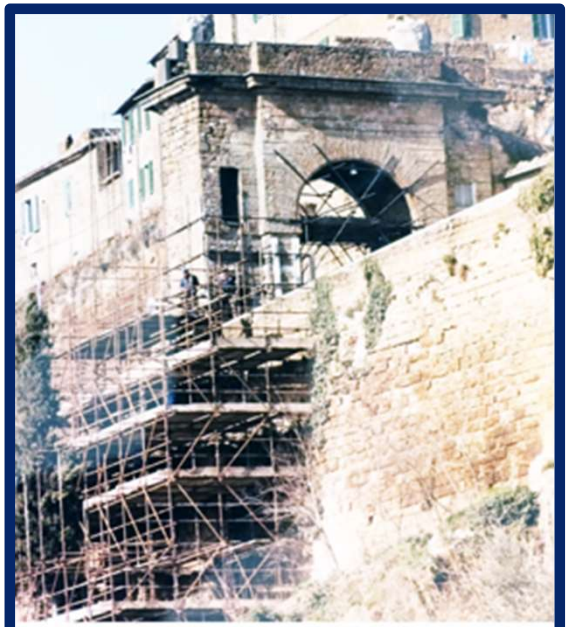
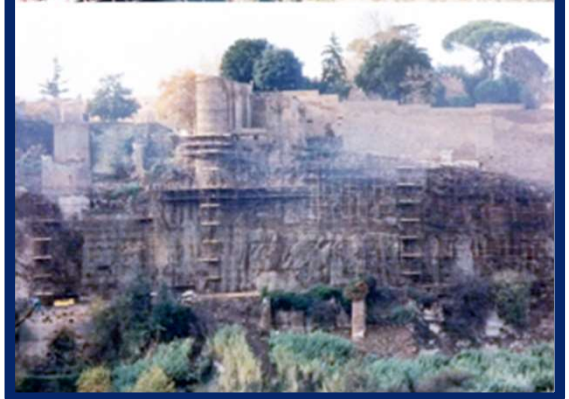
Porta Maggiore



Rocca Albornoz



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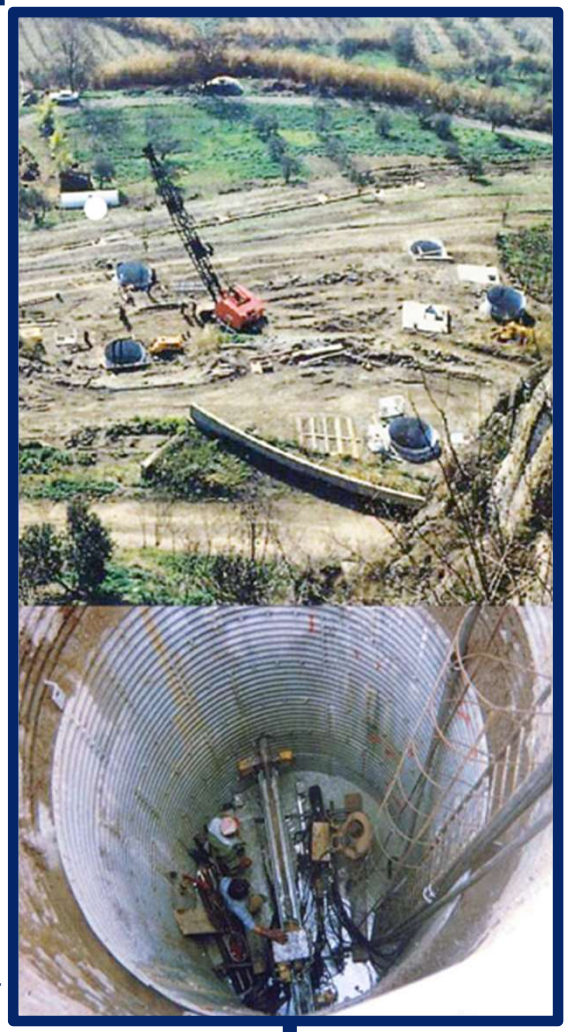
Drainage well system



Inside the well

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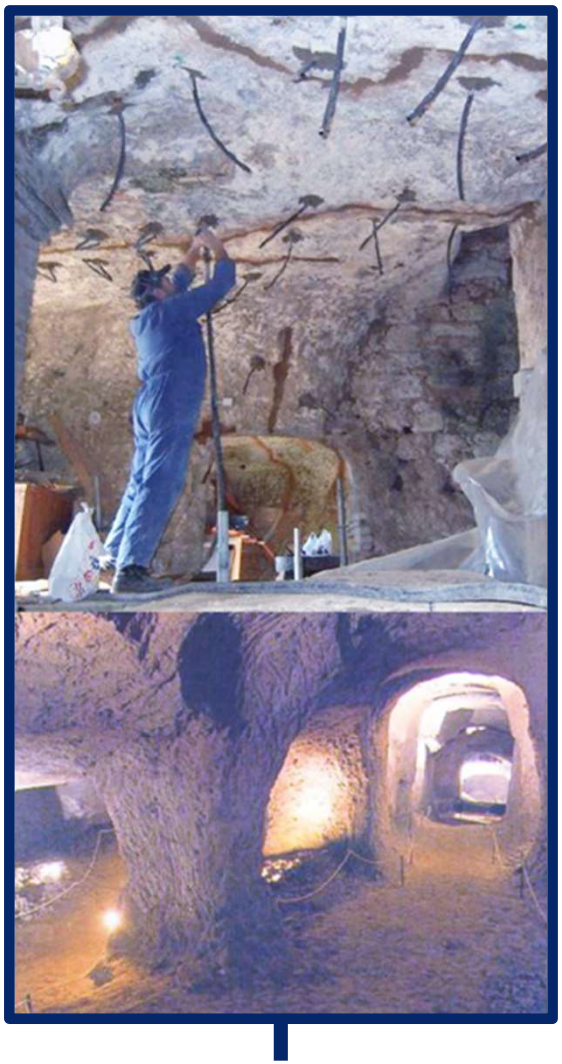

Inside the well

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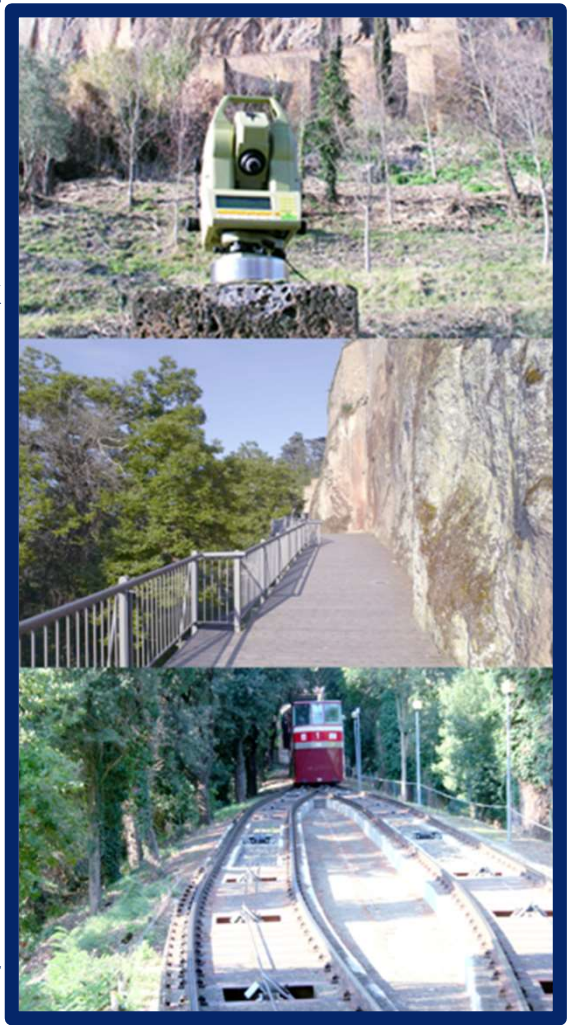
Monitoring network

Panoramic path (ring)

Funicular



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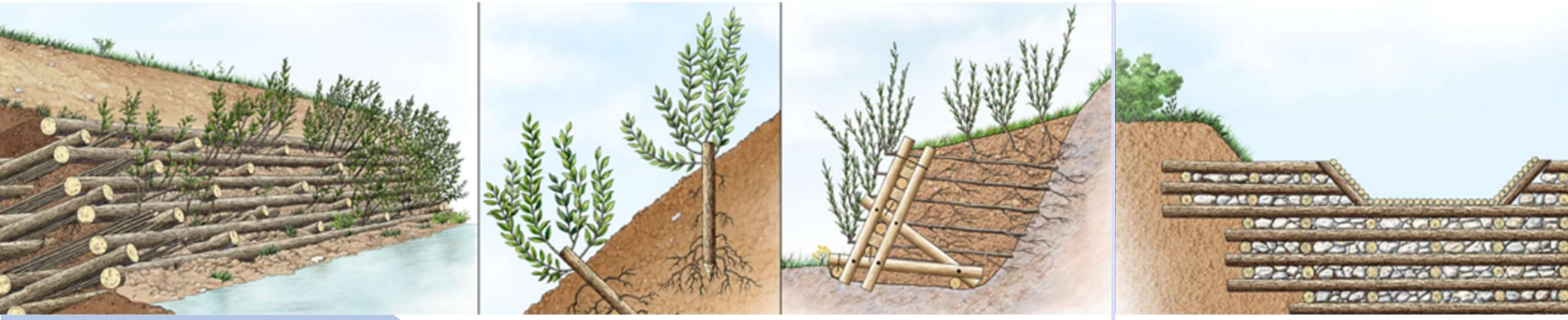
GROUND BIO-ENGINEERING TECHNIQUES

The increasing importance given to the landscape and its protection has led to greater attention towards the interaction between the works to be carried out and the environment in which they are implemented.

Ground Bio-engineering Techniques (*Naturalistic Engineering*): A technical science that includes a range of interventions for re-naturalization, erosion control, and land stabilization using plants or various types of support materials.

Objectives:

- Technical-functional
- Environmental
- Aesthetic-landscape
- Economical



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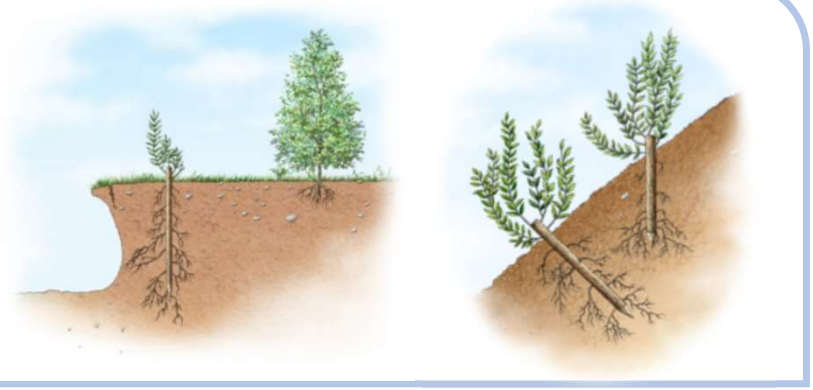
GROUND BIO-ENGINEERING TECHNIQUES

Materials of ground bio-engineering techniques:

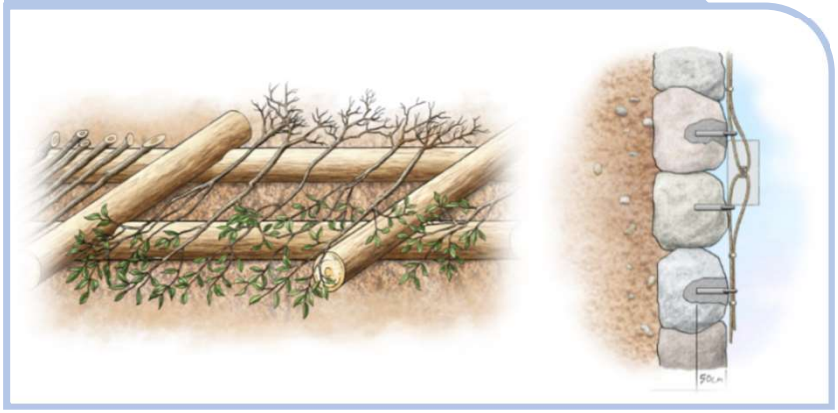
- Live vegetative material: This characterizes most of the works and must be carefully selected according to the environment where it will be implemented. Therefore, native species, meaning those with the same characteristics as the local vegetation, are preferred.

- Inert materials: These are all materials lacking generative capabilities and can be classified as organic or inorganic, natural or artificial.

LIVE VEGETATIVE MATERIAL



INERT MATERIAL



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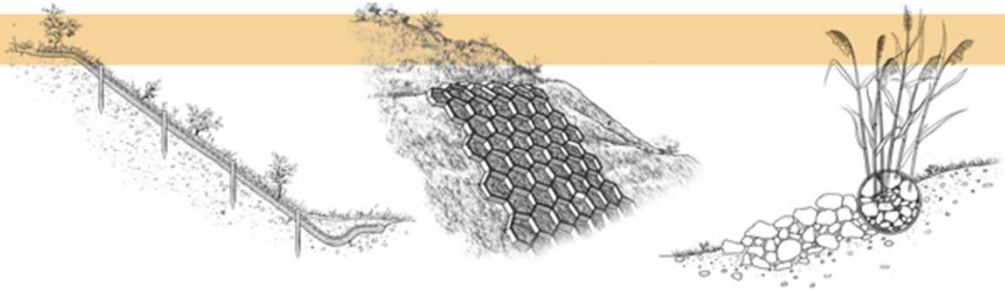
TECHNICAL SOLUTIONS

Support and stabilization

- Drainage of subsurface waters
- Stabilization and support of minor landslides

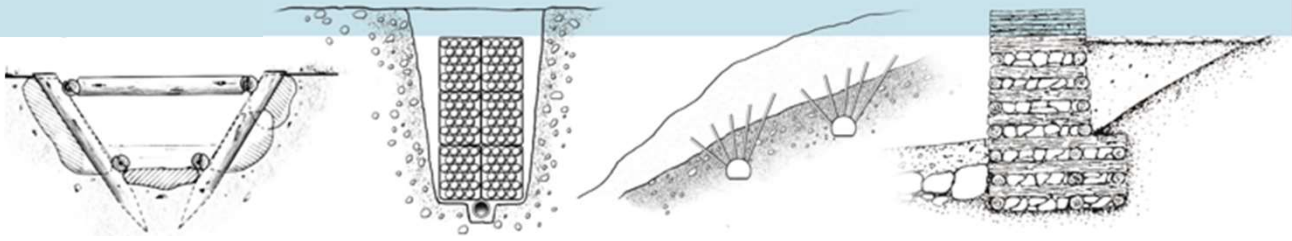
Control of surface erosion

- Re-vegetation of the ground surface and possible re-profiling
- Mechanical protection of surficial soil layers



Control of surficial and deep waters

- Management of torrential and surficial waters
- Reduction of hydraulic load within the landslide mass



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NUMERICAL ANALYSIS

Empirical approach to surface erosion control

- Stabilization using traditional, structural works has been extensively studied in the literature, in terms of design and verification. On the contrary, those involving ground bio-engineering techniques are based on an approach that is mostly empirical.
- There is a lack of calculation methods to quantify the stabilizing action exerted by the root system.

Design guidelines obtained through numerical analysis on ideal slopes considering various variables:

- Slope angle (α)
- Mechanical properties of the soil (c', φ')
- Absence of vegetation
- Different distribution and depth of the root system

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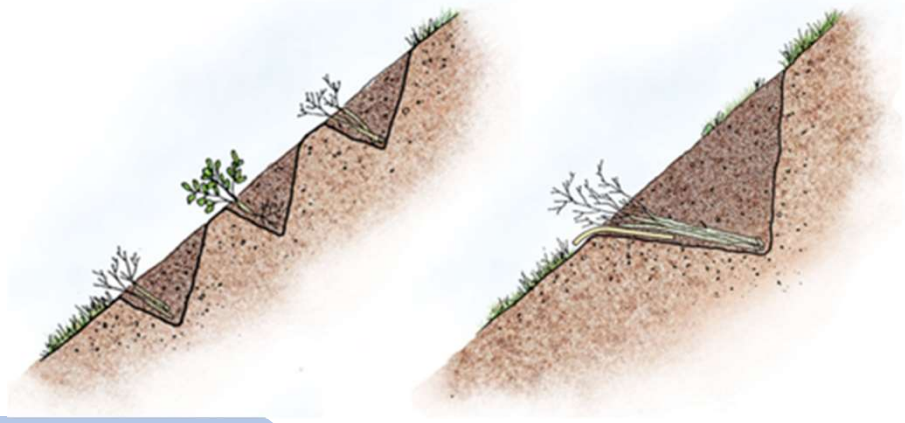
NUMERICAL ANALYSIS

The stabilizing effect on two types of interventions has been studied:

- Grass cover with a **continuous** and **uniform root system**

- Shrub cover with a **clump root system**



In both cases, the root system introduces **additional shear resistance** in the upper layers of the soil

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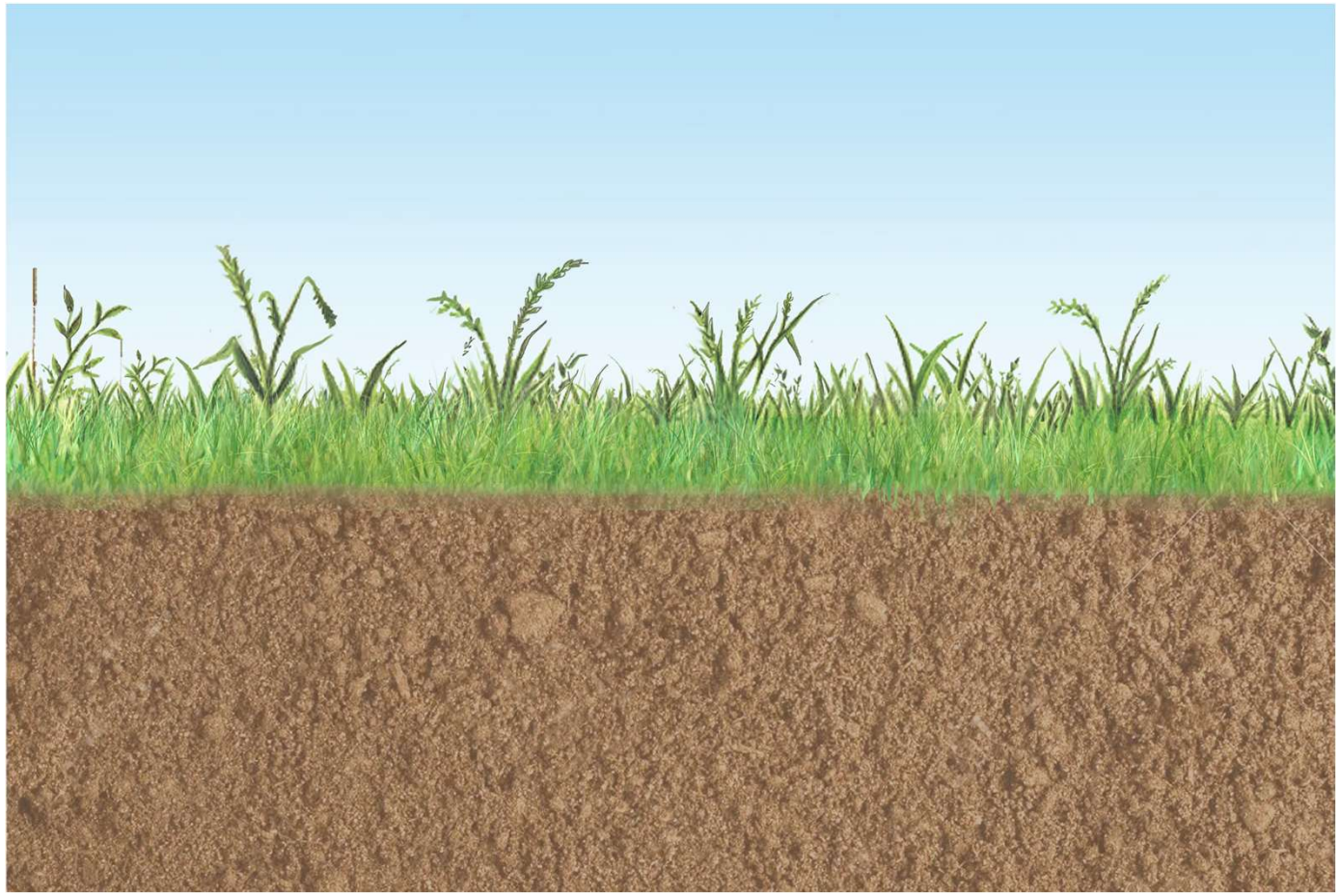
NUMERICAL ANALYSIS



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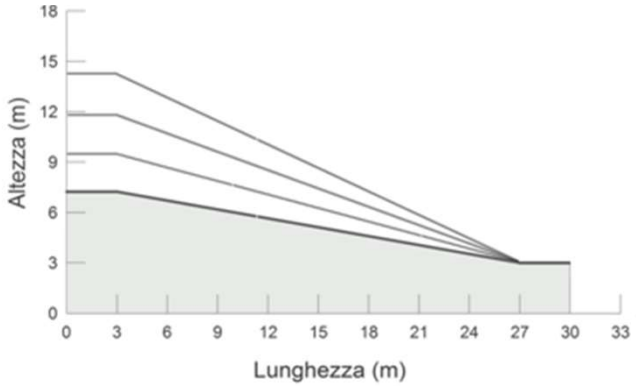
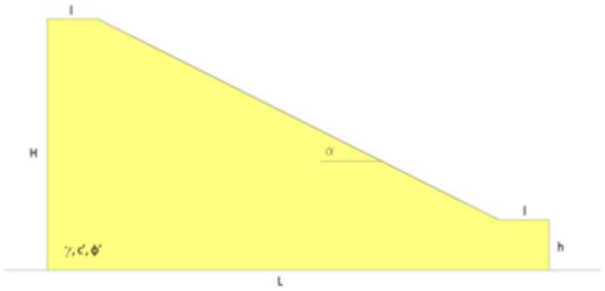
NUMERICAL ANALYSIS

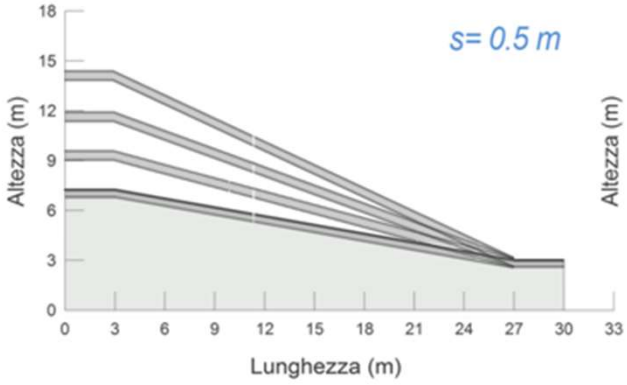
Model without interventions

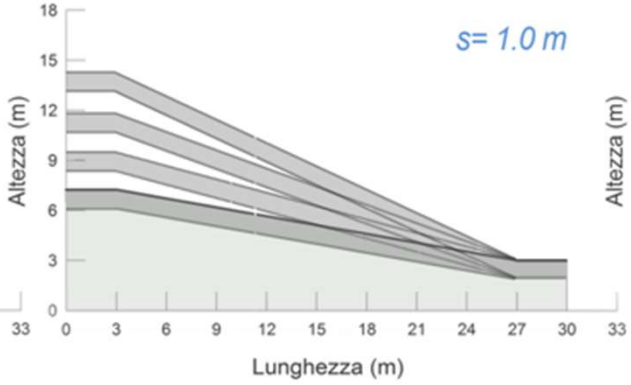


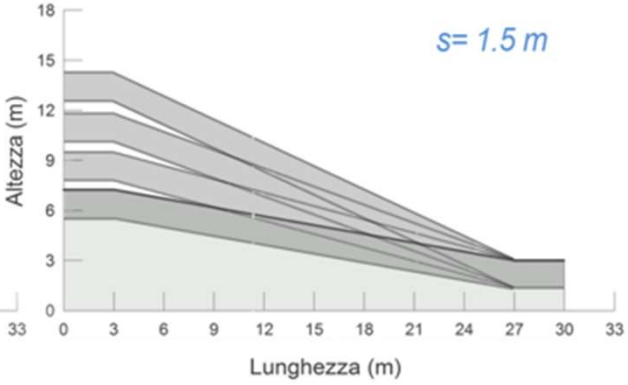


Pendenza (α)				
	10°	15°	20°	25°
H:	7.23 m	9.43 m	11.73 m	14.19 m
L:	30 m	30 m	30 m	30 m
h:	3 m	3 m	3 m	3 m
l:	3 m	3 m	3 m	3 m

Model with uniform vegetation cover







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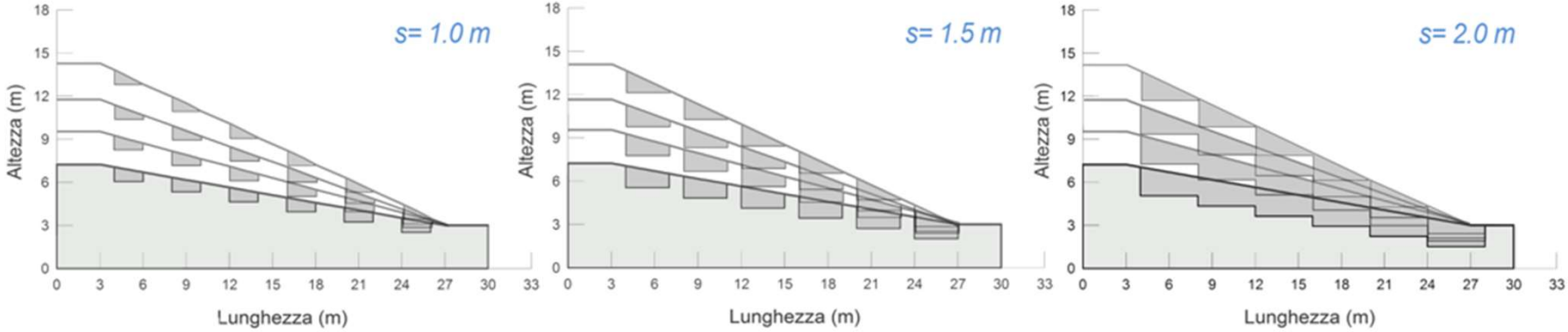
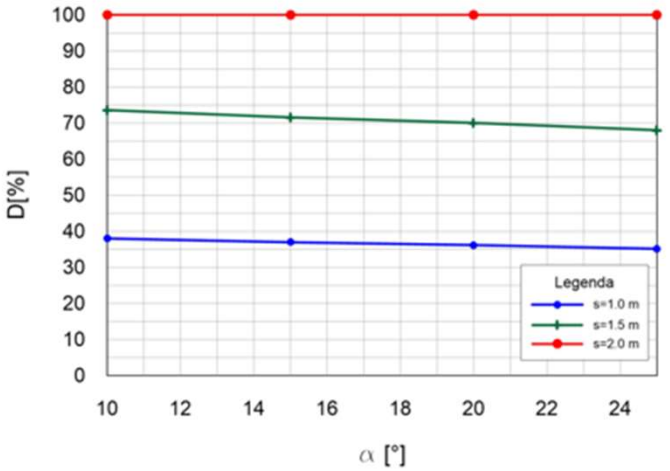
NUMERICAL ANALYSIS

Model with clump root system





α [°]	D[%]
10	38.02
15	36.97
20	36.19
25	35.15

α [°]	D[%]
10	73.62
15	71.60
20	70.08
25	68.06

α [°]	D[%]
10	100
15	100
20	100
25	100

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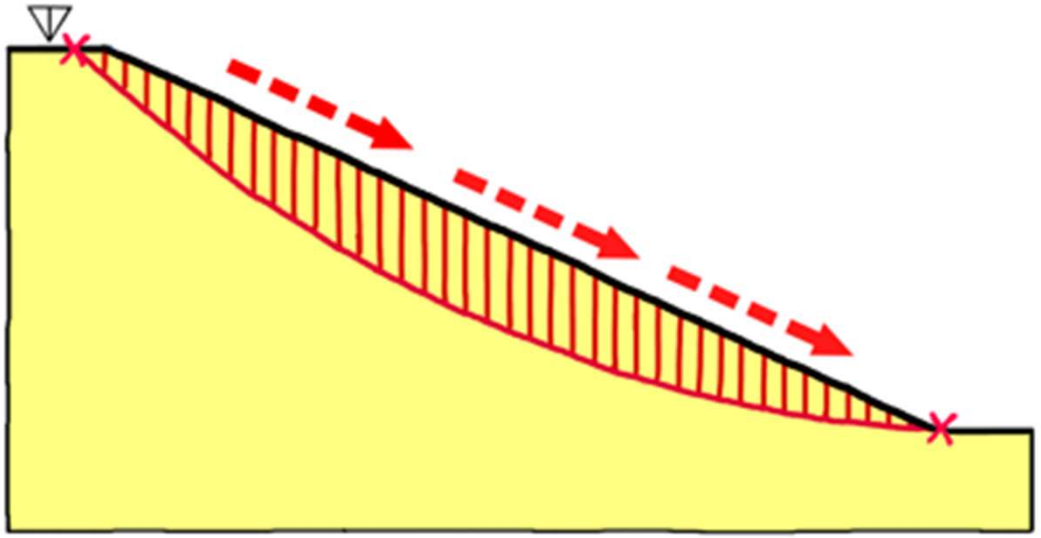
NUMERICAL ANALYSIS

Material Properties

$\gamma =$ 20 KN/m^3
$c' =$ 5 KN/m^2
$\phi' =$ 28°; 32°
c'_{veg} 15 KN/m^2
$\gamma_w =$ 9.8 KN/m^3



Boundary Conditions

- **Entry and Exit** method used for identifying the slip surface
- **Morgenstern & Price** method used in stability analysis
- Landslide movement evolving from top to bottom and from left to right
- Piezometric surface at the field level

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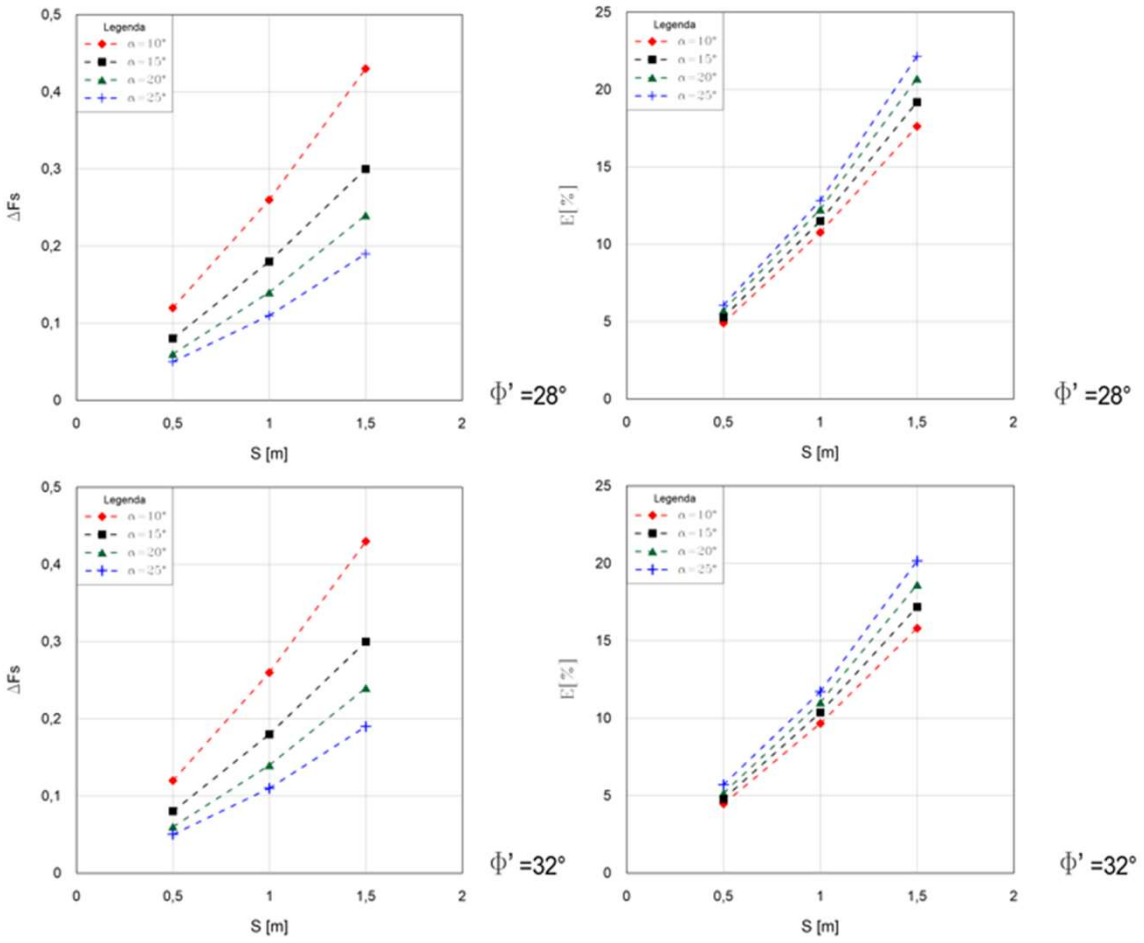
UNIFORM VEGETATION COVER

- ΔFs is not affected by φ’
- ΔFs increases as α decreases
- The variation of ΔFs as a function of α is approximately linear
- E increases with the depth of the root system
- E increases as α decreases

$$E(\%) = \frac{F_{s,post} - F_{s,pre}}{F_{s,pre}} = \frac{\Delta F_s}{F_{s,pre}}$$



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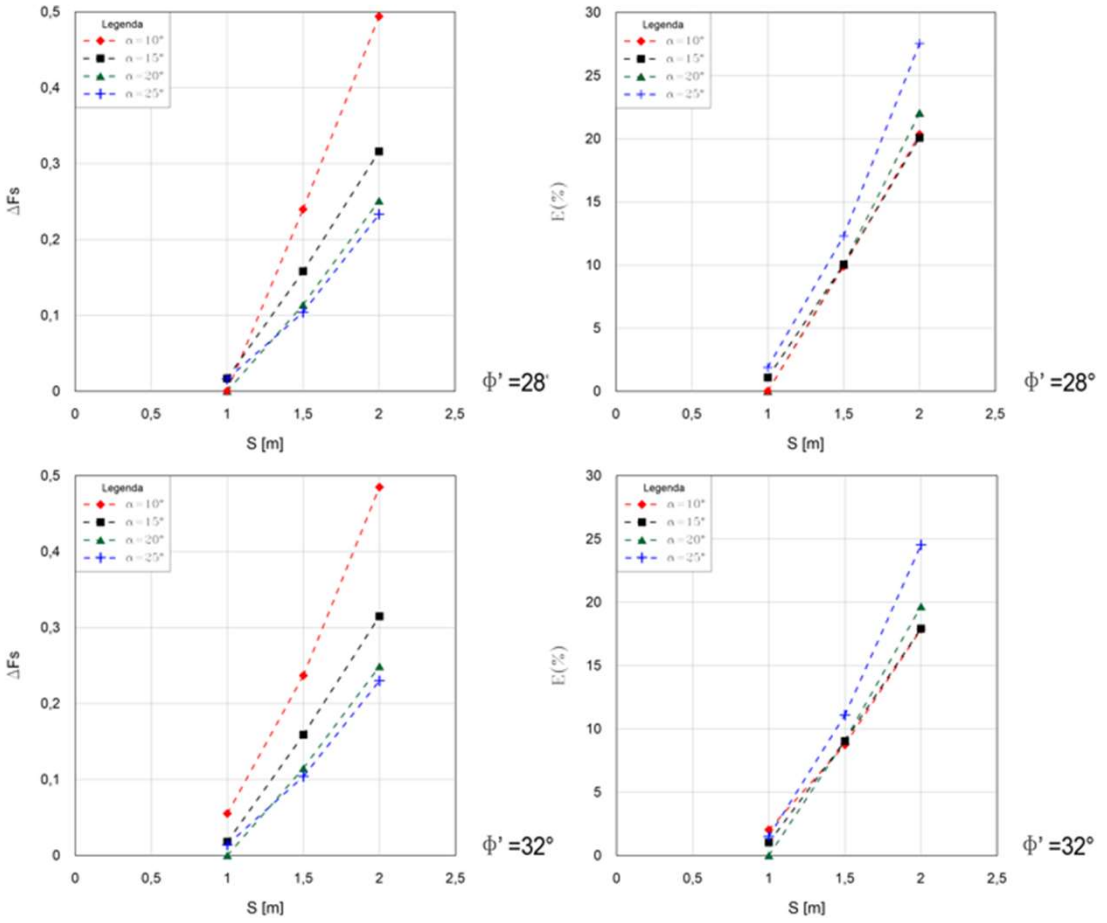
CLUMP ROOT SYSTEM

- ΔFs is not affected by φ’
- ΔFs increases as α decreases
- The variation of ΔFs as a function of α is approximately linear
- E increases with the depth of the root system
- E increases as α decreases

$$E(\%) = \frac{F_{s,post} - F_{s,pre}}{F_{s,pre}} = \frac{\Delta F_s}{F_{s,pre}}$$



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FINAL REMARKS

Operational design guidelines

- Slope with known geometric and mechanical characteristics
- Thickness and morphology of the root system necessary to ensure a certain level of efficiency

Iterative procedure based on the use of tables obtained:

- Determination of ΔFs required to restore safety conditions (**Fs > 1.3**)
- Determination of E(%) required to achieve this $$E(\%) = \frac{F_{s,post} - F_{s,pre}}{F_{s,pre}} = \frac{\Delta F_s}{F_{s,pre}}$$
- Identification of the root morphology and thickness that ensure stability

Future Perspectives

- Expand the range of interventions
- Consider different root morphologies

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Case study: Applied research on hydrogeological risk prevention in the municipality of Deruta

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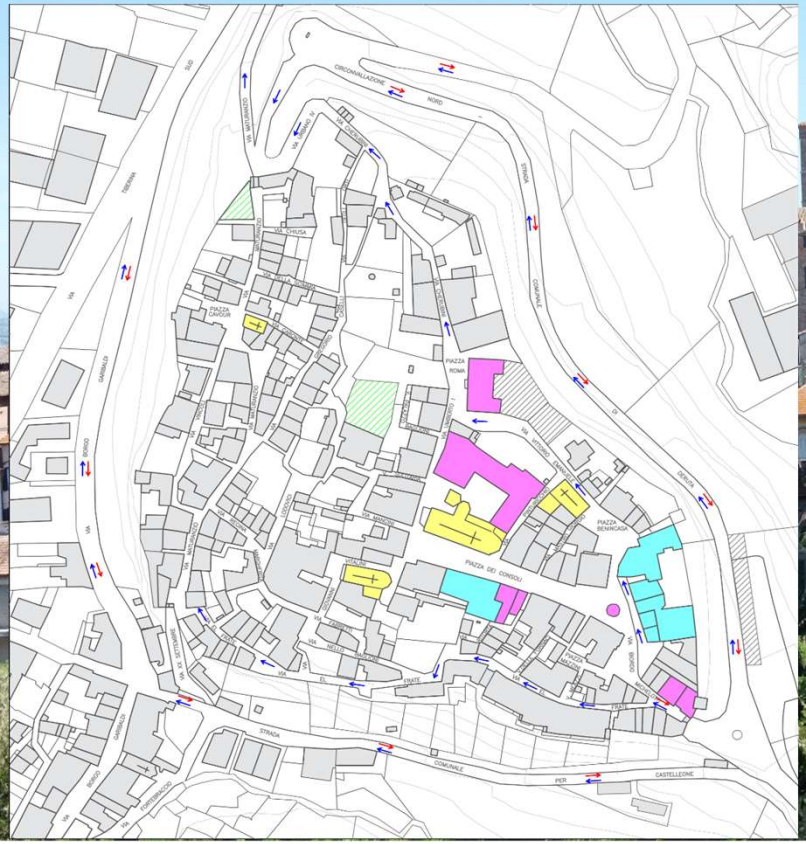
TERRITORIAL FRAMEWORK



Green places

14_ Giardino Panoramico
15_ Panchine Deruta

Parkings

12_ Parcheggio Centro Storico
13_ Parcheggio Panoramico

Road Network:

One way

Two way

Religious Places:

1_Chiesa della Madonna del Divino Amore
2_Chiesa di San Francesco
3_Chiesa di Sant'Antonio Abate
4_ Ufficio Parrocchiale di Deruta

Places of interest

5_Casa della Cultura
6_Fontana di Piazza dei Consoli
7_Municipal Picture Gallery of Deruta
8_Museo regionale della ceramica di Deruta
9_Ufficio informazioni turistiche

Institutional Locations

10_ Liceo Artistico Alpinolo Magnin
11_ Comune di Deruta

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GEOLOGICAL MAP

Coltre eluvio-colluviale
Depositi alluvionali
Depositi alluvionali terrazzati
Depositi di frana in evoluzione
SubSintema di S. Maria di Ciciliano
PIFF-punto identificativo frana
Frane IFFI

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LANDSLIDE CARTOGRAPHY (P.A.I)

IdroGEO ISPRA

Hazard and Risk Indicators

Pericolosità Idrogeo

Pericolosità frane

- Molto elevata P4
- Elevata P3
- Media P2
- Moderata P1
- Aree di Attenzione AA

Pericolosità idraulica

- Elevata
- Media
- Bassa

ISPRA - Istituto Superiore Protezione e Ricerca Ambientale https://idrogeo.isprambiente.it

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LANDSLIDE CARTOGRAPHY (I.F.F.I.)

Inventory Map of Landslide Phenomena

Frane IFFI

Punto Identificativo del Fenomeno Franoso (PIFF)*
- Scheda frane di 1° Livello
- Scheda frane di 2° Livello
- Scheda frane di 3° Livello

Evento franoso
- Evento franoso

Tipologia di frana
- Frane lineari
- Crollo/Ribaltamento
- Scivolamento rotazionale/traslativo
- Espansione
- Colamento lento
- Colamento rapido
- Sprofondamento
- Complesso
- Aree con crolli/ribaltamenti diffusi
- Aree con sprofondamenti diffusi
- Aree con frane superficiali diffuse
- DGPV
- n.d.

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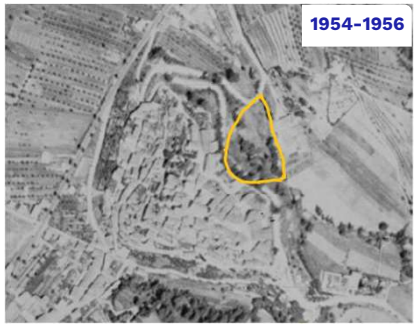
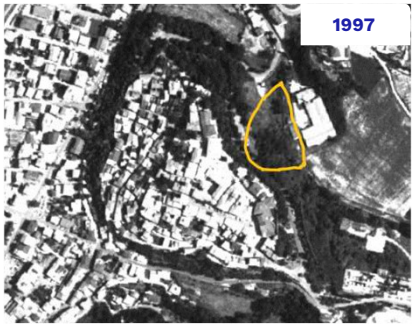
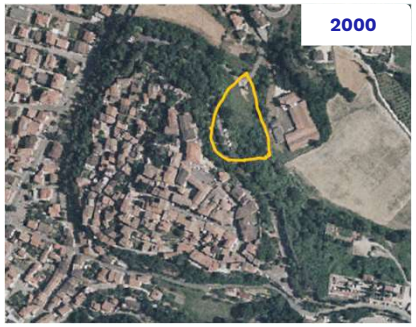
MULTITEMPORAL ANALYSIS OF LANDSLIDE EVOLUTION FROM AERIAL PHOTOS







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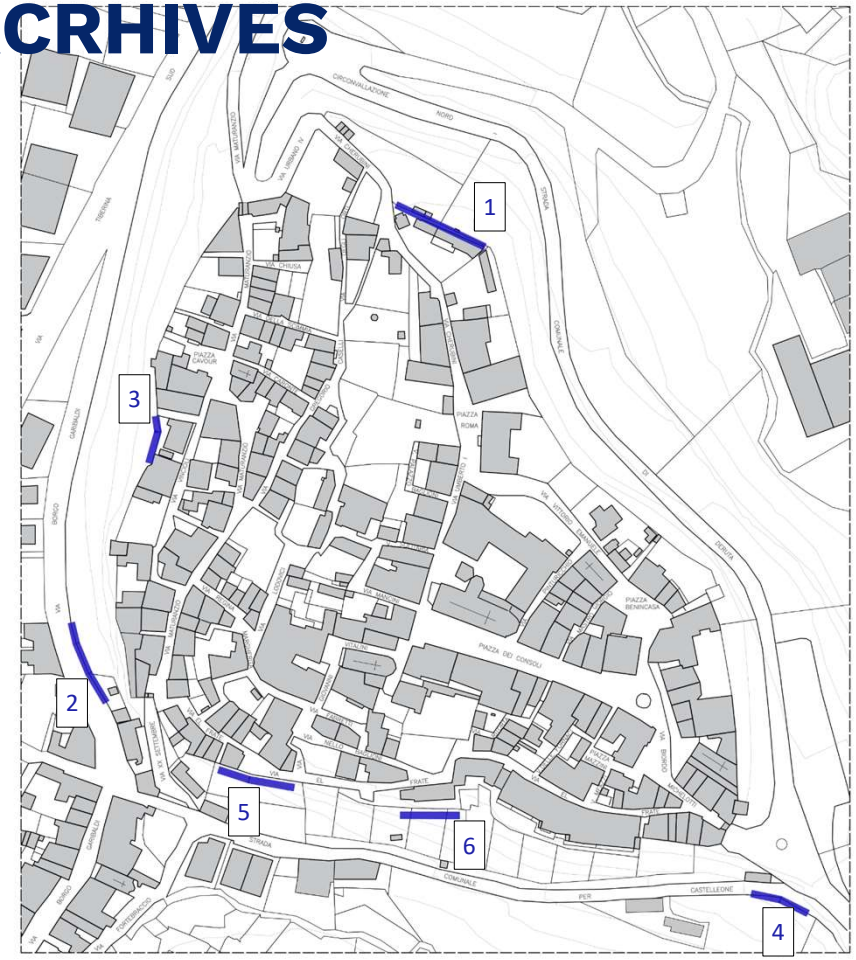
INSTABILITIES ANALYSIS BY ACRHIVES



Landslide 1: In 1990, a landslide occurred due to sliding near a private residence along the wall at the end of Via Cherubini.

Landslide 2: In 2010, surface erosive movements and collapses were observed within the tunnels dug along the wall.

Landslide 3: In 2010, surface slumping was noted on the western slope above the municipal road of Via Borgo Garibaldi.

Landslide 4: In 2010, a landslide occurred due to partial overturning of the retaining wall, leading to the collapse of the roadway along the municipal road to Castelleone.

Landslide 5: In 2010, a sliding landslide took place along the embankment between Via El Frate and the lower municipal road to Castelleone.

Landslide 6: In 2018, a landslide affected the hillside area between Via El Frate and Via di Castelleone, resulting in the closure of Via di Castelleone. This event impacted the peripheral area of the settlement, where private buildings are located on the upper part of the landslide and downstream of the internal road known as Via El Frate. According to the "Geological Report - Structural Analysis for Static Verification of Affected Buildings" prepared by Eng. Paolo Zucconi and Eng. Cristina Zuccaccia, the landslide was caused by gravitational phenomena resulting from the local geological conditions and unusual underground water circulation on the slope.

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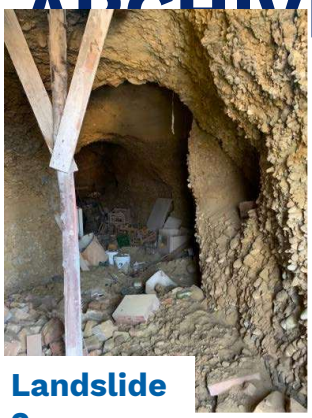
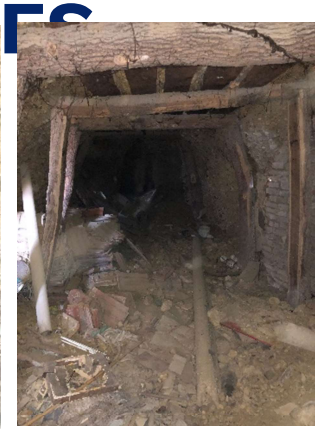
INSTABILITIES ANALYSIS BY ARCHIVES





Landslide 2

Landslide 3

Landslide 4

Landslide 5

Landslide 6

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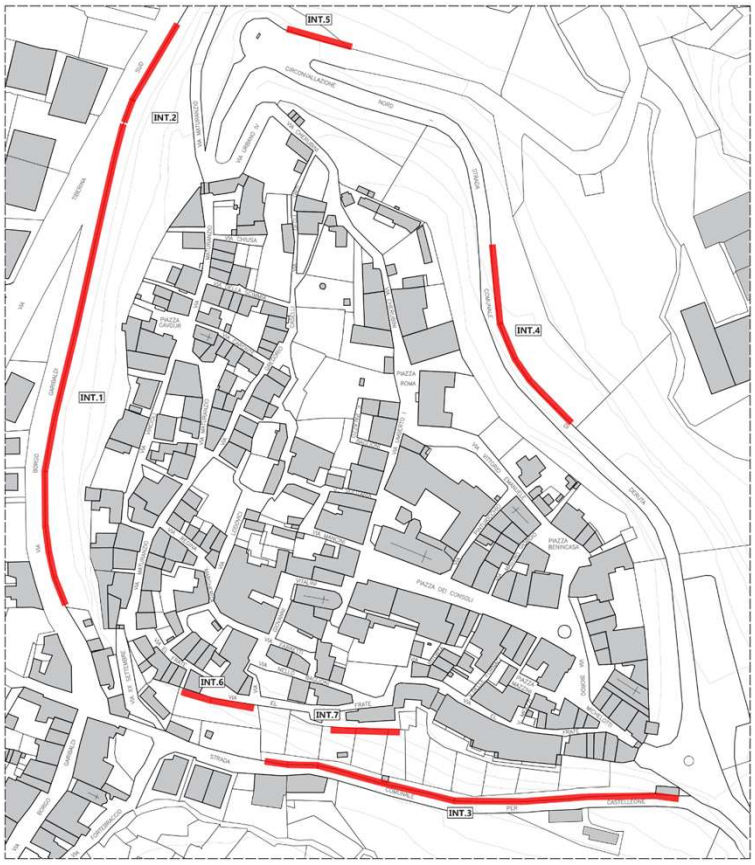
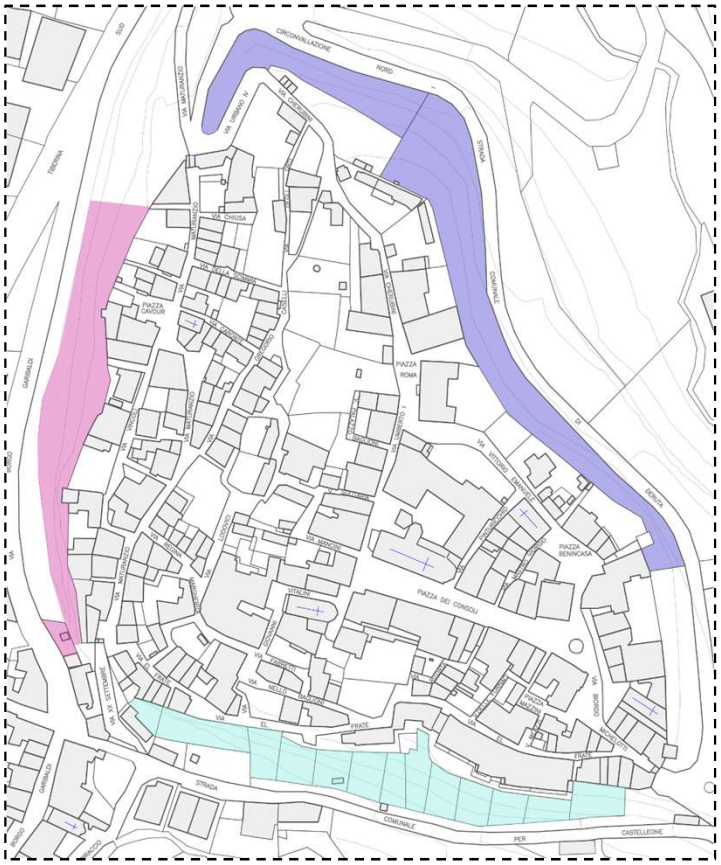
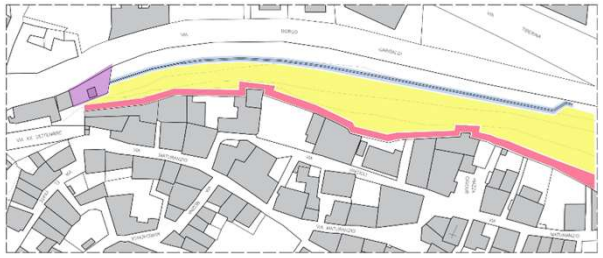
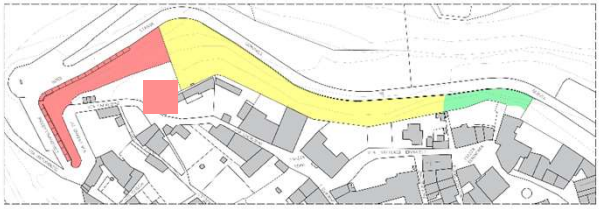
INTERVENTIONS ANALYSIS AND STUDY AREAS



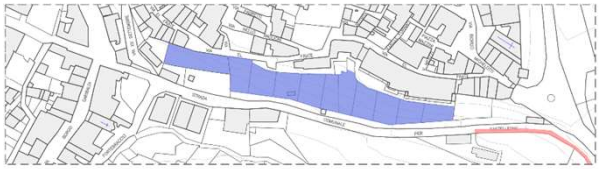




Zone 1 Zone 2 Zone 3 Zone 4



Zone 5 Zone 6 Zone 7



Zone 8 Zone 9

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STUDY AREA - PHOTO

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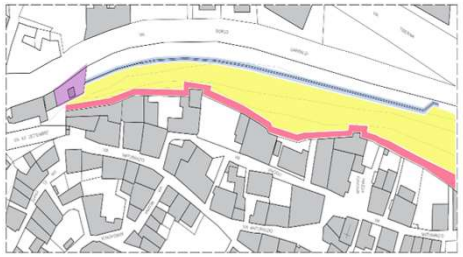
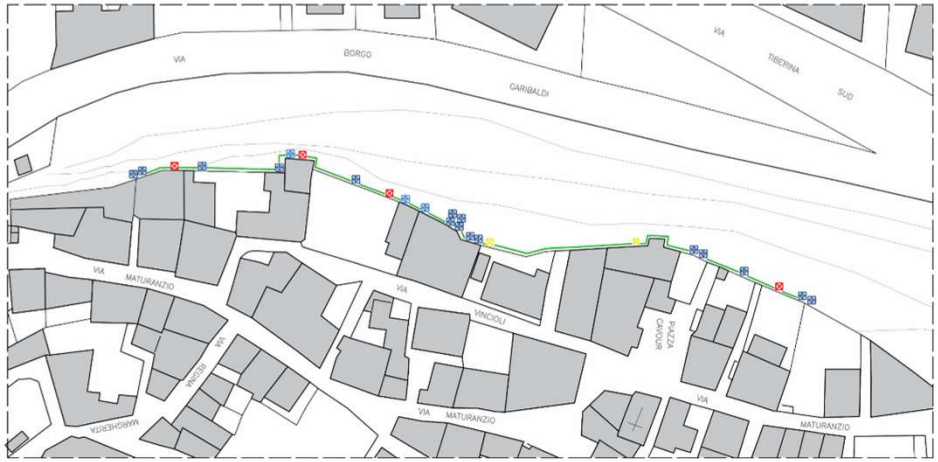
PROPOSED INTERVENTIONS
ZONE 1

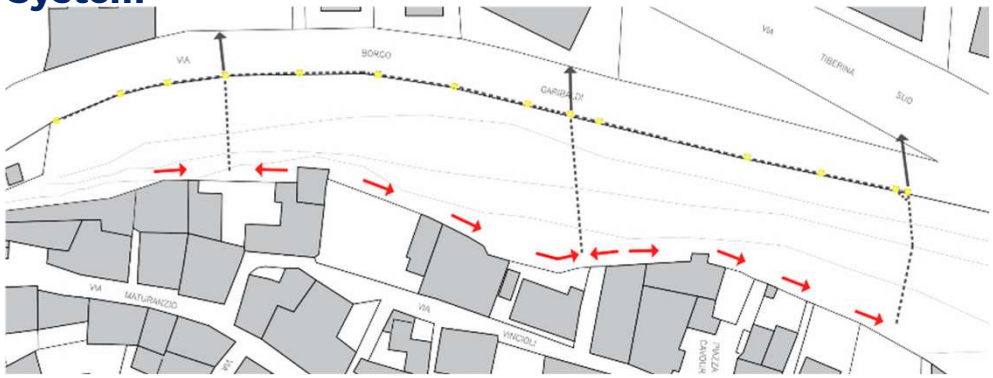




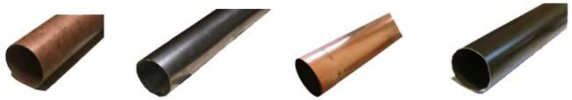
Planned Inspection Chamber
Existing Inspection Chamber
Buried Pipe or Drainage Channel

Planned Inspection Chamber
Existing Inspection Chamber

Diagram of the Connection to the Existing Drainage System



Examples of suitable coloring:



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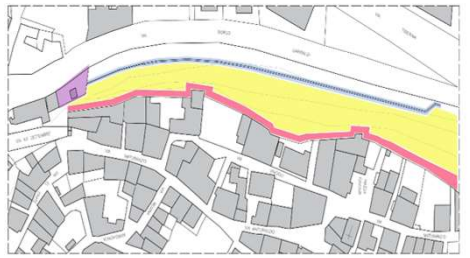
PROPOSED INTERVENTIONS
ZONE 2

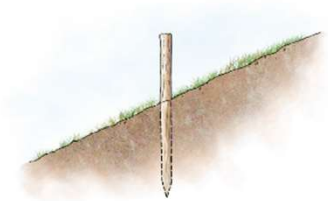


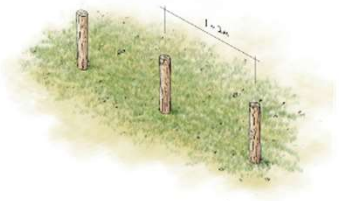
Erosion-Resistant Covering

Live grating

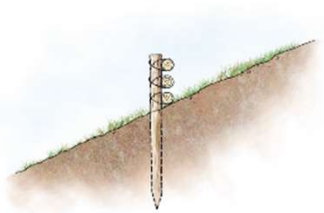
Live palisade

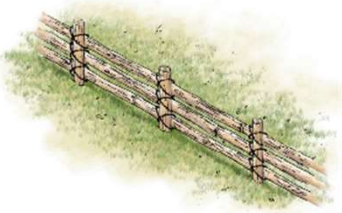
Example of Creating a Live Palisade:



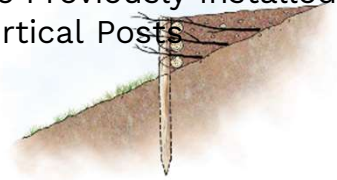


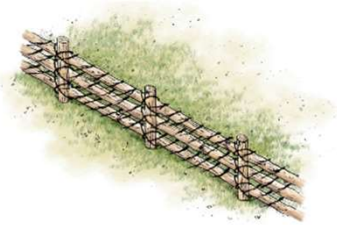
1. Vertical Installation of Posts Spaced 1-2 Meters Apart





2. Placement and Fixing of Horizontal Overlapping Logs, Positioned Upstream of the Previously Installed Vertical Posts





3. Filling with Inert Fill Material and Live Vegetation

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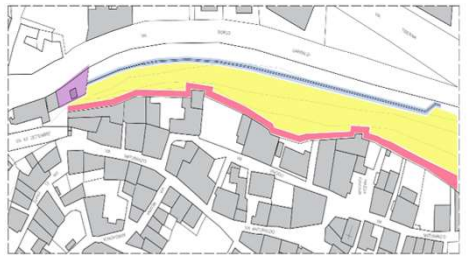
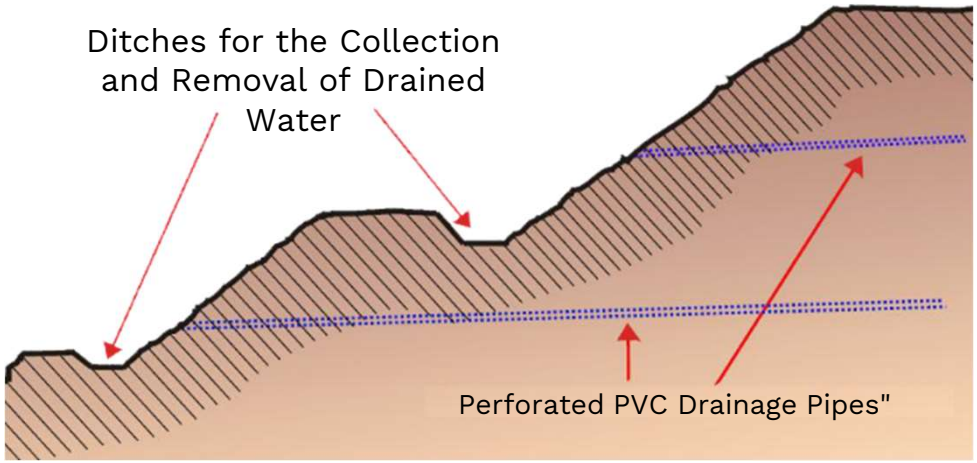
PROPOSED INTERVENTIONS
ZONE 3



Drainage Operation Using Sub-horizontal Drains



Examples of Perforated Drainage Pipes

Implementation Phases:

Drilling: A hole is drilled using rotation or rotary-percussive methods, with a diameter ranging between 50-100 mm and an upward inclination between 5° and 10°.

Installation: Once drilling reaches the design depth, the drilling machinery is removed, and the perforated pipes are installed. PVC pipes with holes ranging from 40-80 mm and thicknesses of 3-6 mm are used. The pipes are covered with geotextiles to prevent clogging of the holes.

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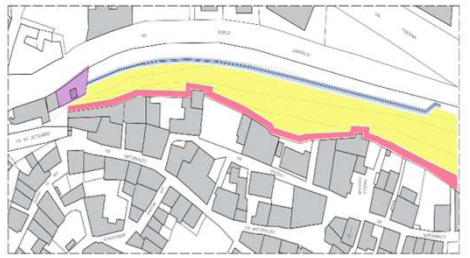
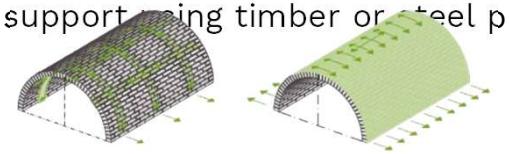
PROPOSED INTERVENTIONS
ZONE 4



Proposals for Intervention:
In the case of cavities being recovered and reused, it is advisable to implement a new structural system that integrates closely with the existing rock surface. The cause of collapse phenomena within the cavity is the lack of a system that effectively supports the overlying loads. For these reasons, a geomechanical analysis of the rock mass should be carried out to correctly design a structural support using timber or steel props.



For areas with existing masonry surfaces, reinforcement and consolidation can be achieved by applying an intradosal cladding with a mesh made of natural fibers and stainless steel, followed by the application of finishing mortars. As an alternative to the distributed system, which allows for even load redistribution, transverse and longitudinal band systems can be used.

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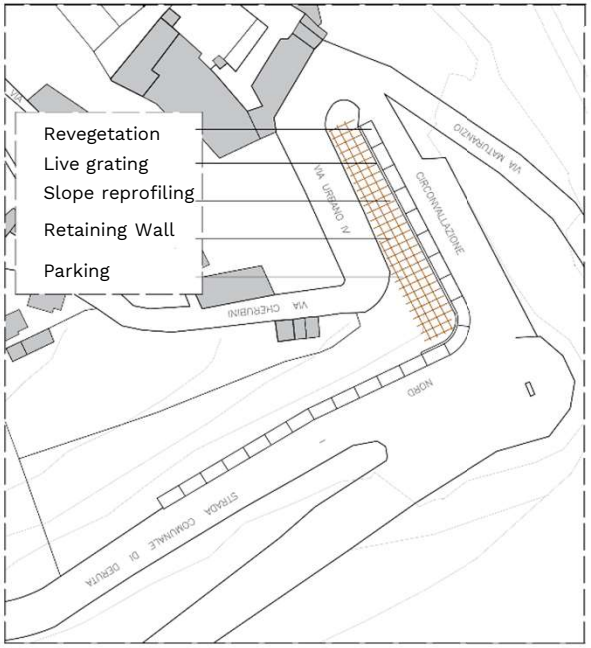
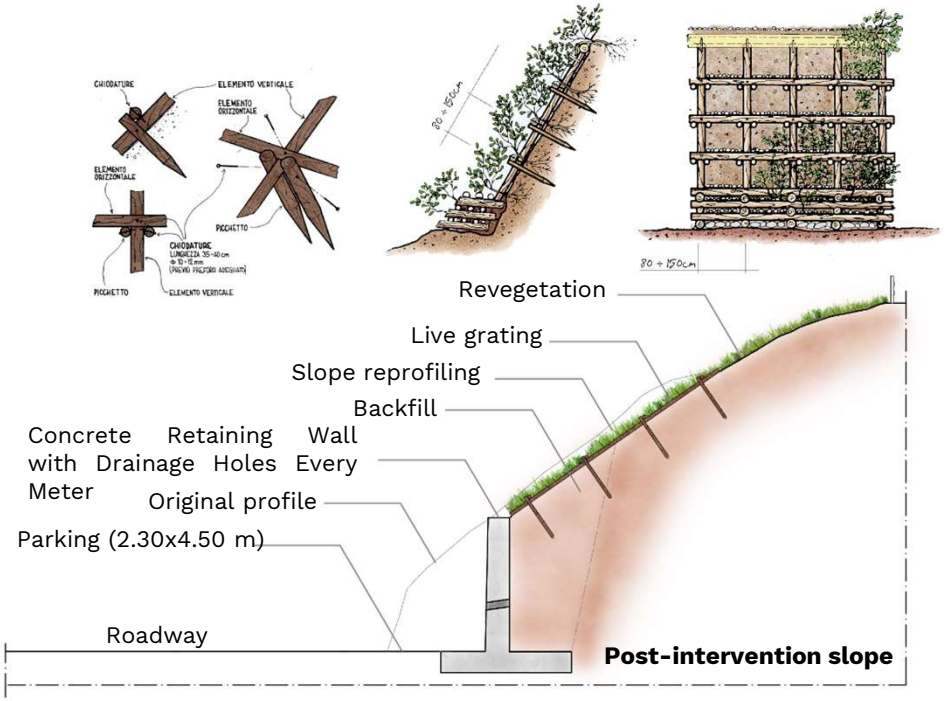
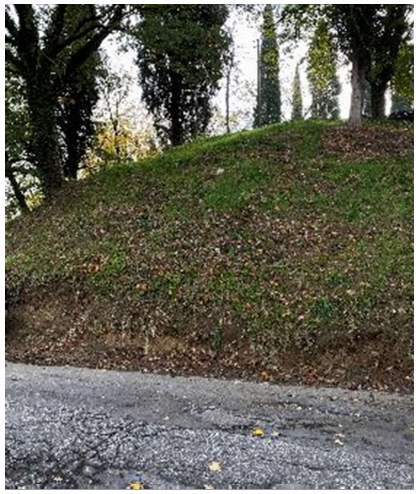
PROPOSED INTERVENTIONS

ZONE 5







Actual

Photo Integration

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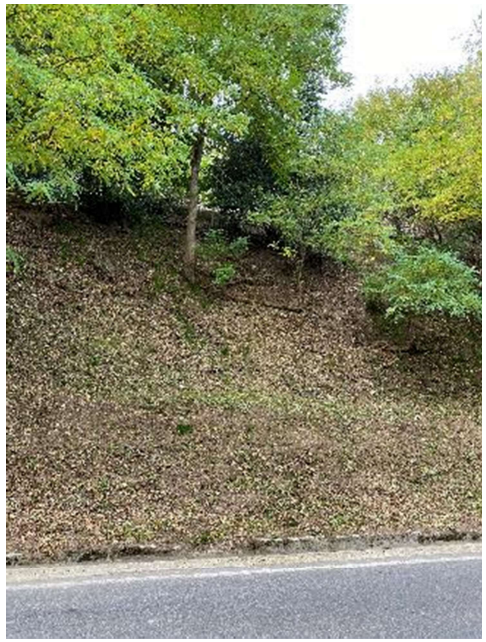
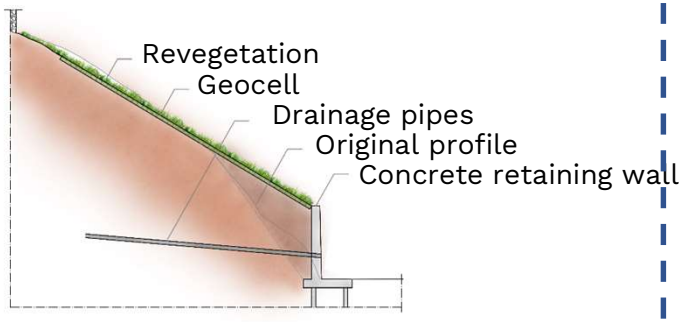
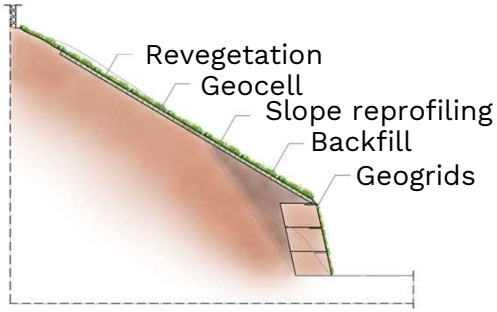
PROPOSED INTERVENTIONS

ZONE 6



Current Condition





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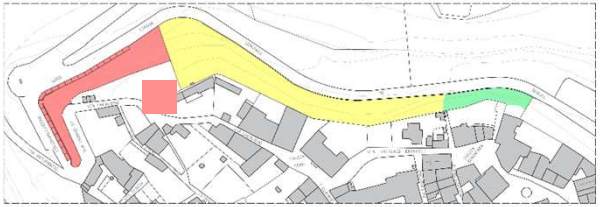
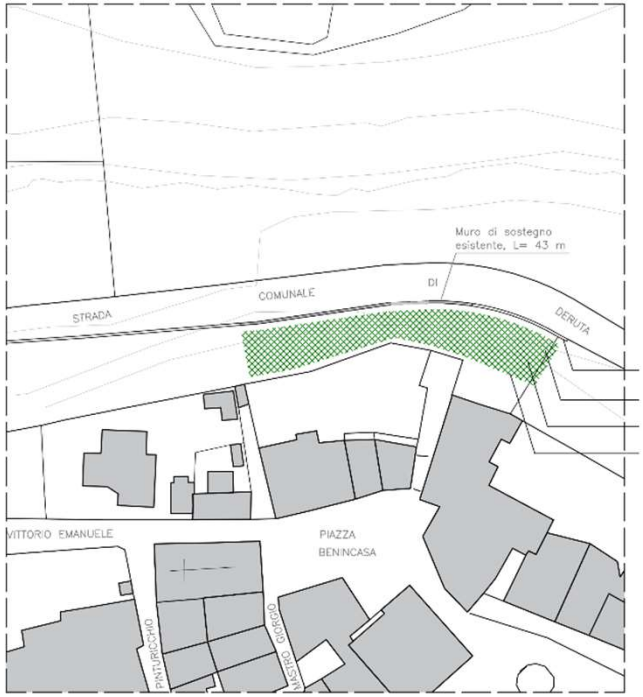
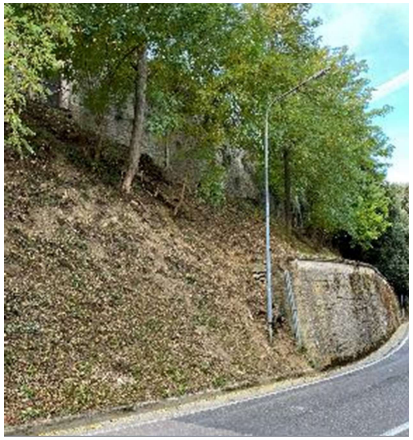
PROPOSED INTERVENTIONS
ZONE 7



Zone 5 Zone 6 Zone 7

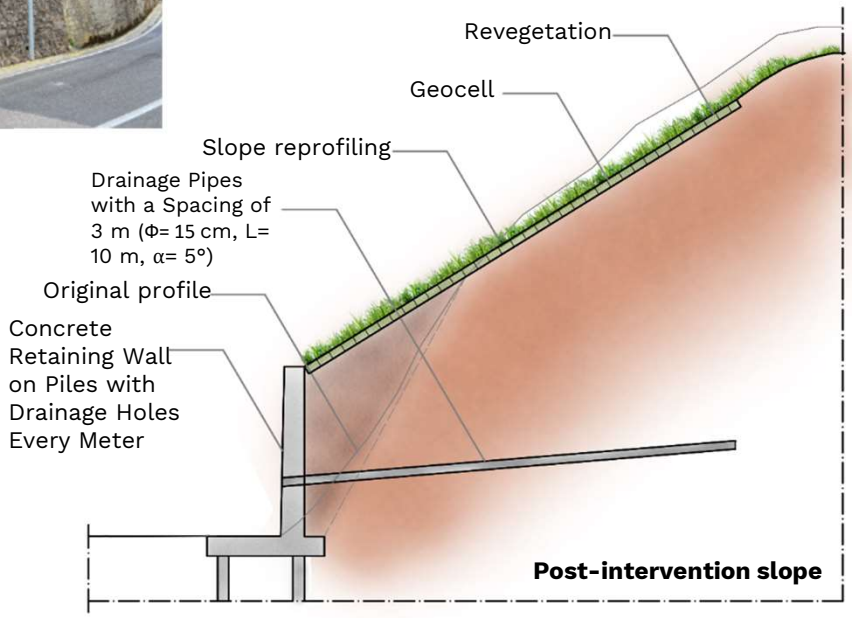




Current conditions

Photo Integration

Three-dimensional honeycomb geocell made of polyethylene through continuous extrusion, without subsequent



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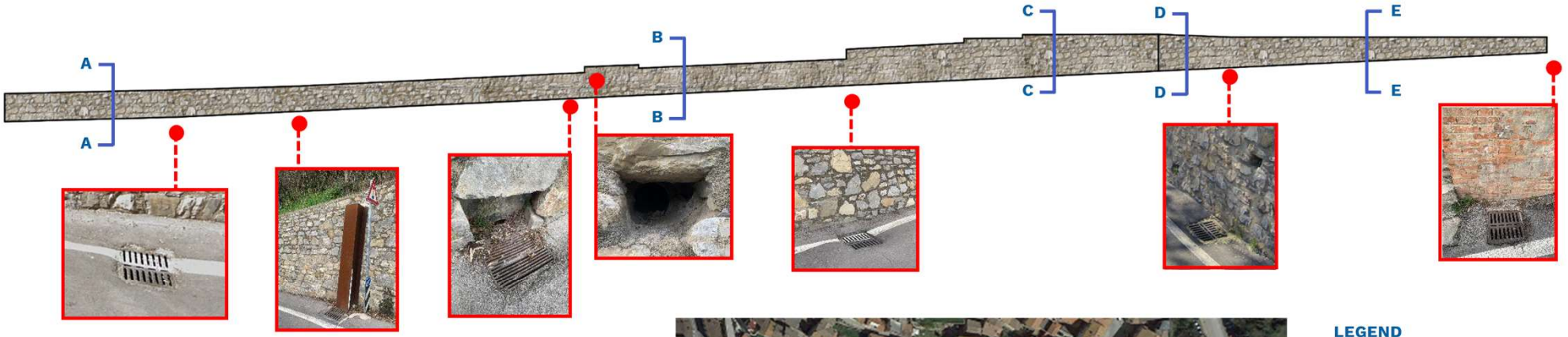
CURRENT CONDITION - SOUTH SLOPE



LEGEND

- Water Element
- Collection Pits
- Downspouts

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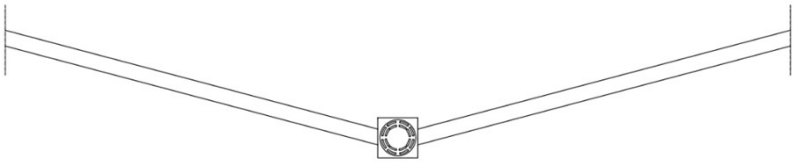
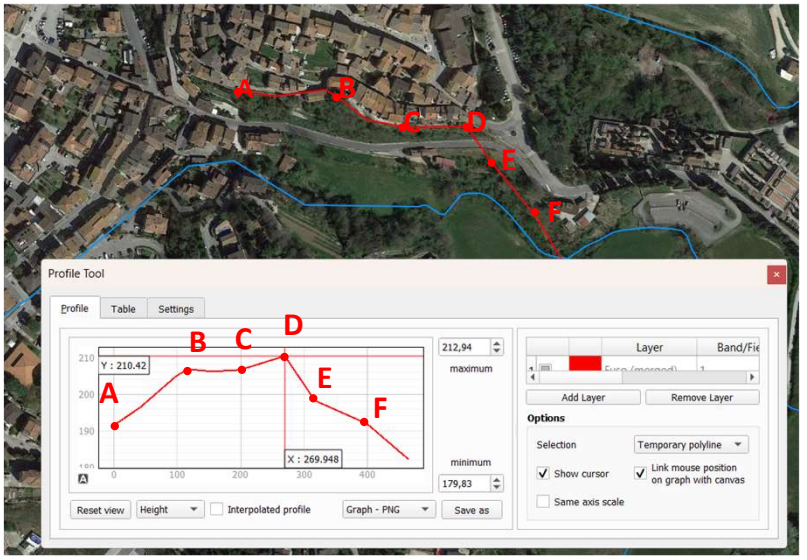
PROPOSED INTERVENTIONS

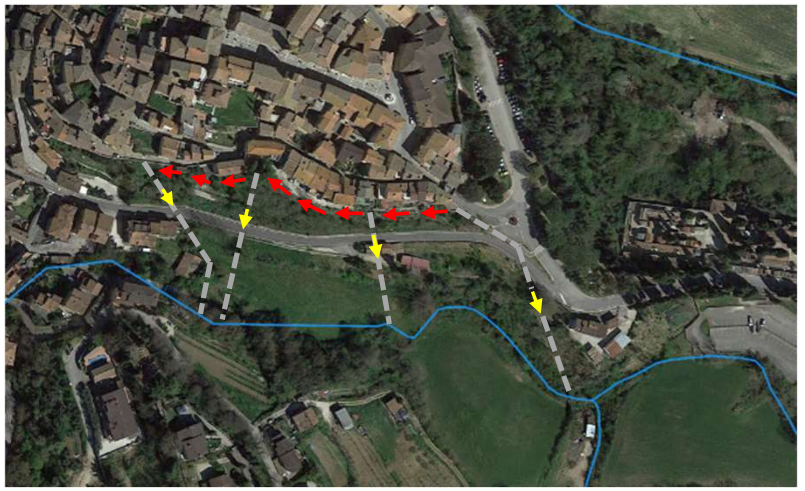
ZONE 9

Management of Surface and Subsurface Waters. The proposed interventions include regulating the waters of the slope through the rationalization, restoration, or correction of the existing sewerage network and drainage systems. The proposal outlines the potential path of the drainage system through underground channels, identified based on local morphological and slope characteristics. These waters will be directed towards four main collectors located along natural convergences on the southern slope of the historic center of Deruta. Through inspection and collection chambers, the waters will then be channeled into manholes beneath the road, leading to the final recipient, namely the watercourse known as "Fosso del Piscinello."

Diagram:







LEGEND

- Slopes
- Water
- Collectors

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International Summer School

PRESERVING HERITAGE: STRATEGIES FOR STABILIZING UNSTABLE SLOPES IN HISTORIC CULTURAL CENTERS

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