Third Edition

RISK MANAGEMENT

Knowledge, Forecasting, Prevention, Protection, Planning, Preparedness

20 - 27 July 2025

Post-earthquake reconstruction: problems and solutions

Ing. Gianluca Loffredo

Deputy Commissioner Reconstruction Italian Earthquake 2016

LOCATION

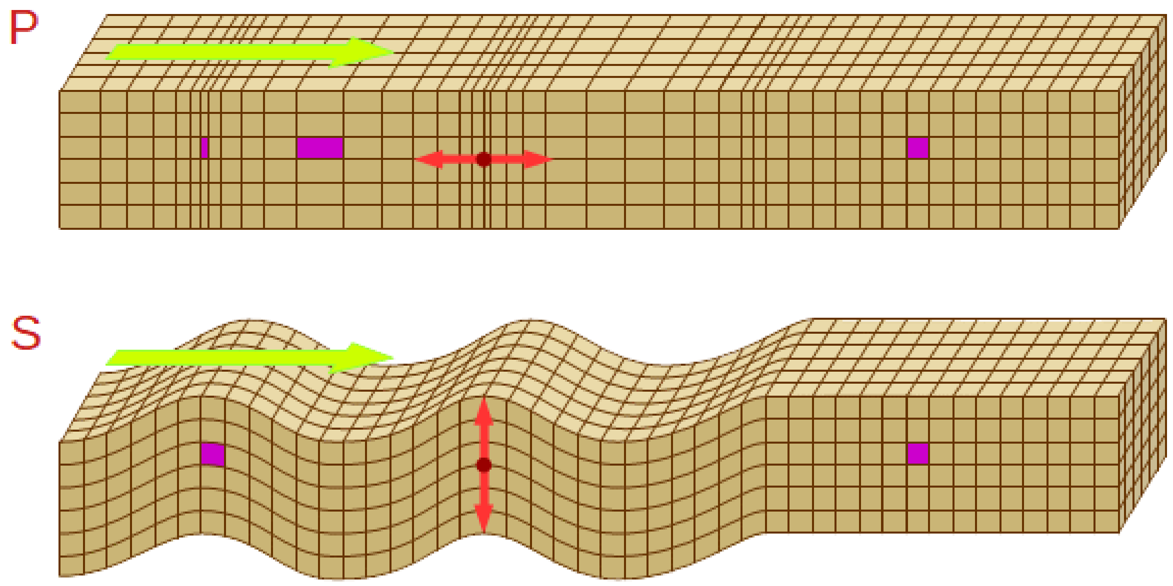
date 22 July 2025

SEISMIC WAVES

Seismic waves originate from the **hypocenter**. These ground vibrations radiate in all directions, which is why they're called **body waves**. These waves, in turn, are divided into **P-waves** and **S-waves**.

P-waves (primary longitudinal waves) are very fast (7-13 km/s). They are produced by the oscillation of rock in the same direction as the wave's propagation, causing changes in both volume and shape. They can travel through both solids and fluids and are responsible for the low rumble felt at the beginning of an earthquake.

S-waves (secondary transverse waves) are slower than P-waves (4-7 km/s). Their oscillation direction is perpendicular to the direction of propagation, and they only change the shape of the rock. They cannot propagate through fluids.



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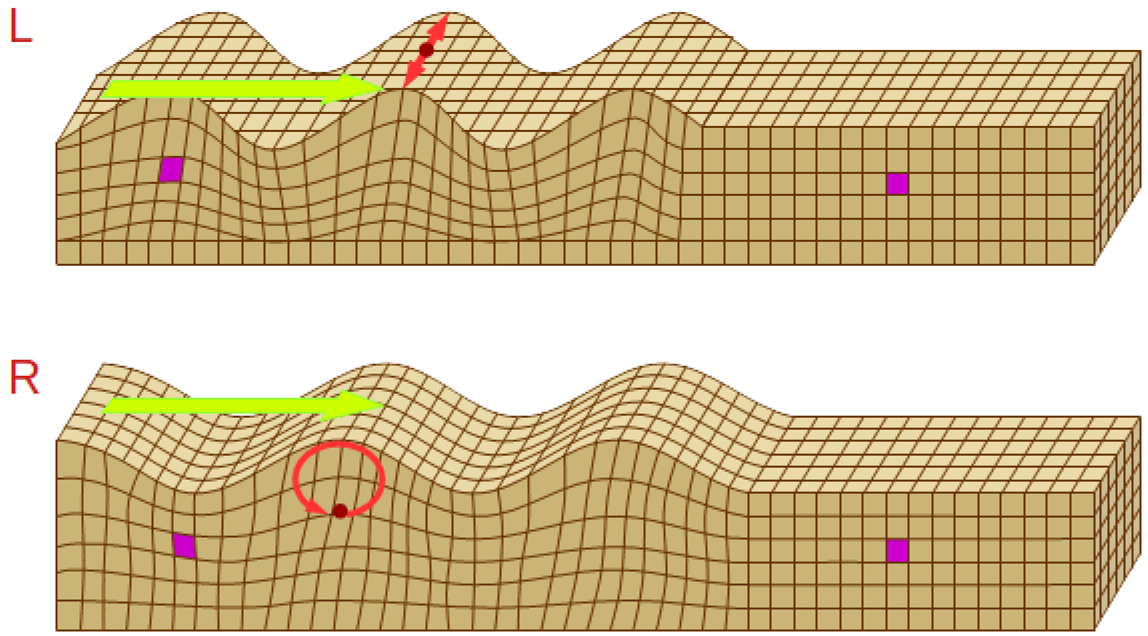
SEISMIC WAVES

When **body waves** reach the surface at the **epicenter**, they give rise to other slower waves (3 km/s) known as **surface waves**, which are also divided into two categories.

R-waves (Rayleigh waves) oscillate perpendicularly to the ground, much like ocean waves, producing elliptical ground movements in planes oriented in the same direction as the wave's propagation.

L-waves (Love waves) oscillate perpendicularly to the direction of propagation (some authors use "L waves," meaning long waves, to refer to surface waves as a whole).

Surface waves are much slower than body waves, but they are responsible for the damage caused by earthquakes.



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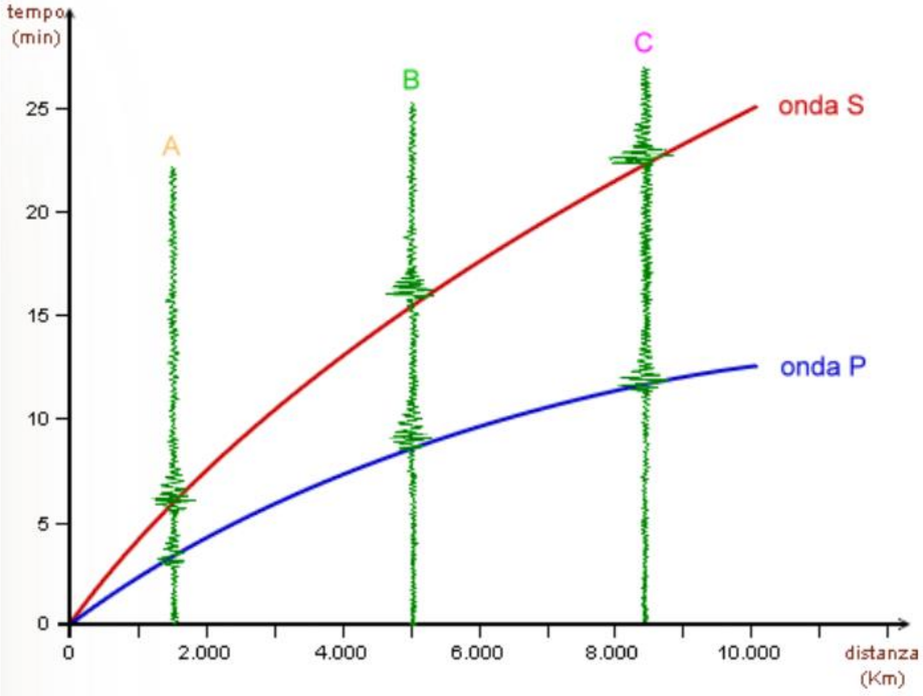
EPICENTER

To determine the **epicenter**, the difference in velocity between P-waves and S-waves is utilized. Indeed, the greater the time interval between the arrival of the two types of waves, the farther away the earthquake's epicenter is.

The **distance** is established using a graph where time is plotted on the y-axis (ordinate) and distance on the x-axis (abscissa); on this graph, two curves, called **travel-time curves (dromochrones)**, are plotted, indicating propagation times as a function of distance. By superimposing the seismogram onto this graph, the time interval between the arrival of the two waves is determined, which corresponds on the x-axis to the distance of the earthquake from the epicenter.

The position needs to be established. To do this, one must first know the distance from at least three seismic monitoring stations. Then, from these three stations, three circles are drawn with radii corresponding to the determined distances: the point of intersection indicates the epicenter.



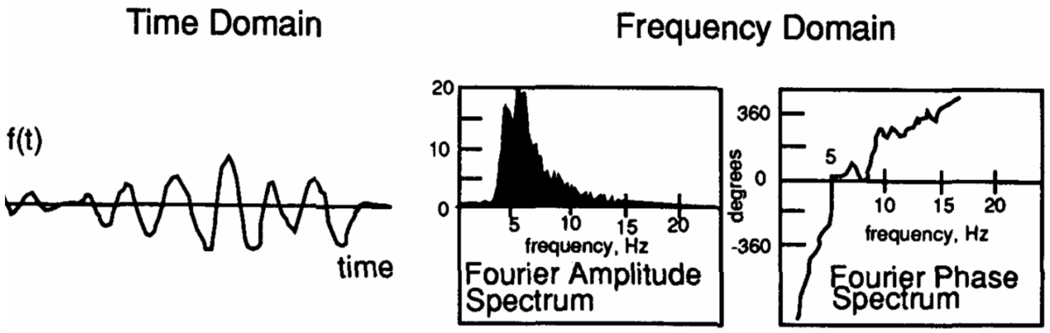
SEISMOGRAM TO RESPONSE SPECTRUM CONVERSION

The signal radiated by a seismic source is a finite-duration step function in displacement, lasting from milliseconds to a few minutes at most.

According to **Fourier's theorem**, any arbitrary transient function f(t) in the time domain can be represented by an equivalent function F(ω) in the frequency domain, the Fourier transform of f(t). The following relationships hold:

$$f(t) = (2\pi)^{-1} \int_{-\infty}^{\infty} \mathrm{F}(\omega)\exp(i\omega t)d\omega$$

$$F(\omega) = \int_{-\infty}^{\infty} f(t)exp(-i\omega t)dt = |F(\omega)|exp\big(i\phi(\omega)\big)$$



$|F(\omega)| = A(\omega)$ is the **amplitude spectral density** with units of m/Hz, $\omega = 2\pi f$ is the **angular frequency** (where f is the frequency with units of Hz), and $\phi(\omega)$ is the **phase spectrum** with units of deg, rad, or 2π rad. The integral is equivalent to a summation. Thus, Fourier's theorem states that an arbitrary finite time series, even an impulsive one, can be expressed as a sum of monochromatic periodic functions, i.e., $f(t) = (2\pi)^{-1}\Sigma F(\omega)\exp[i(\omega t + \phi(\omega))]\Delta\omega$.

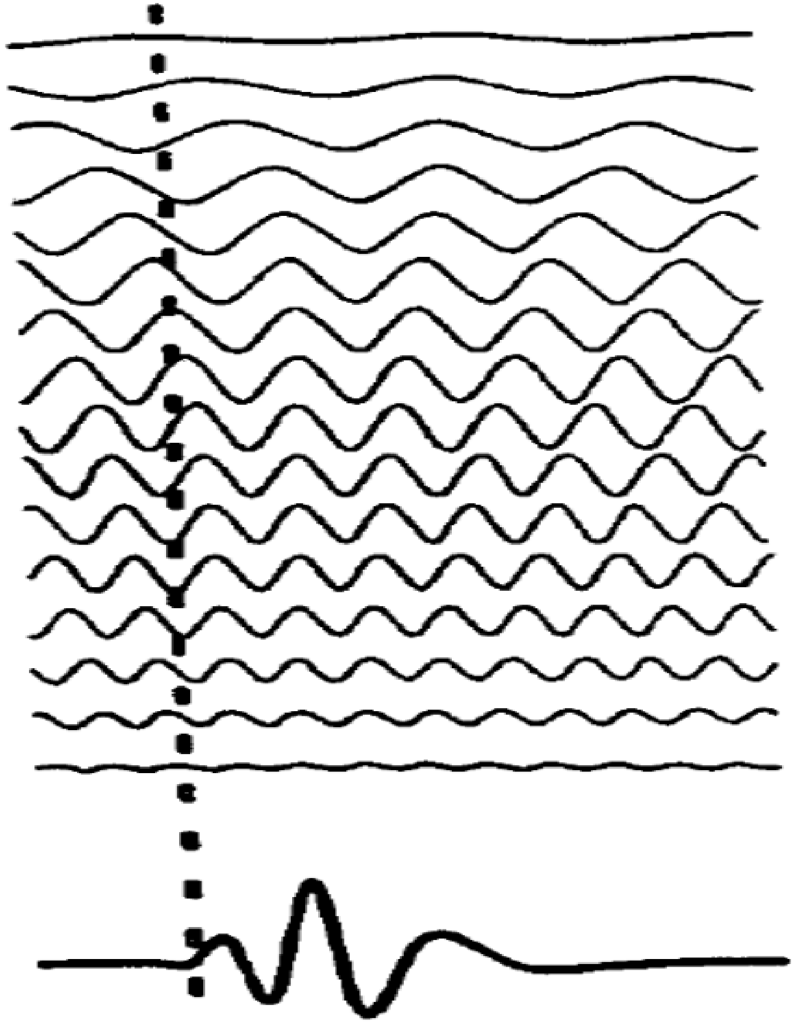
SEISMOGRAM TO RESPONSE SPECTRUM CONVERSION

A transient function f(t) refers to a signal that has a limited duration in time and is, by definition, non-periodic.

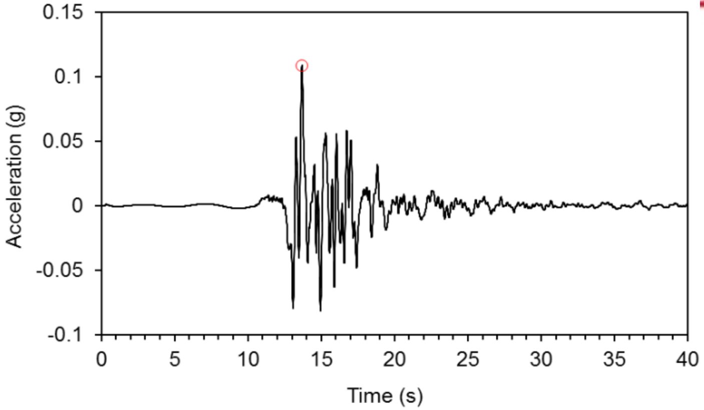
Fourier's theorem is fundamental because it allows us to analyze these complex and non-periodic functions. Since we can't describe them with a simple frequency (as we would with a periodic wave), the Fourier Transform decomposes them into a **continuum of frequencies**.

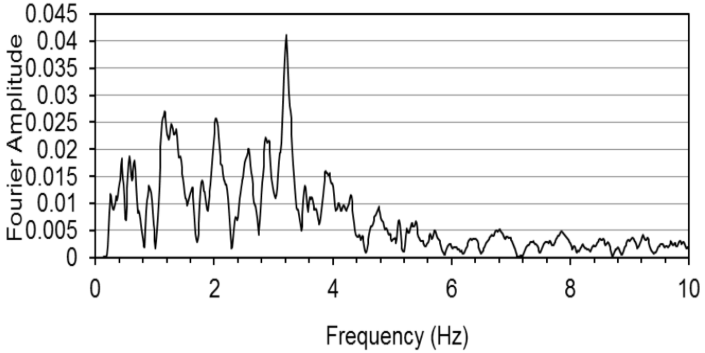
Each frequency in this spectrum (F(ω)) has its own amplitude and phase, indicating "how much" of that specific frequency is present in the original transient signal.

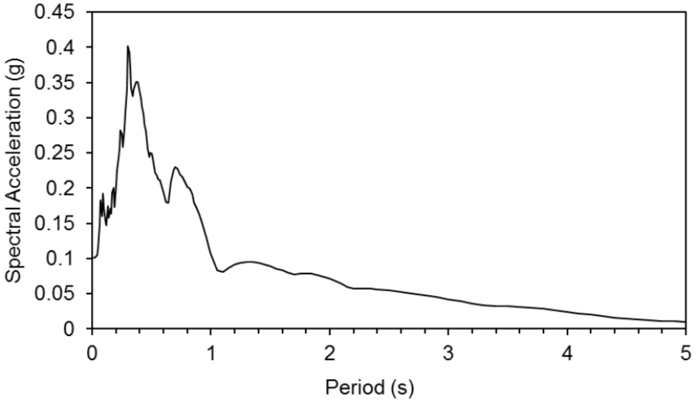
This allows us to shift from viewing the signal in the **time domain** (where we see how the signal's amplitude changes over time) to viewing it in the **frequency domain** (where we see which frequencies compose the signal and with what intensity), providing crucial information about its nature.



$$f(t) = \frac{1}{2\pi} \sum |F(\omega)| \exp(i[\omega t + \phi(\omega)]) \Delta\omega$$







HARMONIC OSCILLATOR

One can make some considerations that are useful both for understanding how an oscillator can be calibrated and for better understanding a structure's behavior during an earthquake. If we excite an oscillator, it will take a certain amount of time (defined as the period and called T1) to complete one full oscillation (returning to its starting point).

If we analyze what was said previously, we might notice that when we decrease the stiffness (k) of the oscillator (by increasing L or decreasing the cross-section S), we lengthen its oscillation period. Similarly, by increasing the oscillator's mass (M), we lengthen its period. Therefore, it can be empirically deduced that the mass (M) and the stiffness (k) of the oscillator identify and influence its period (T1).

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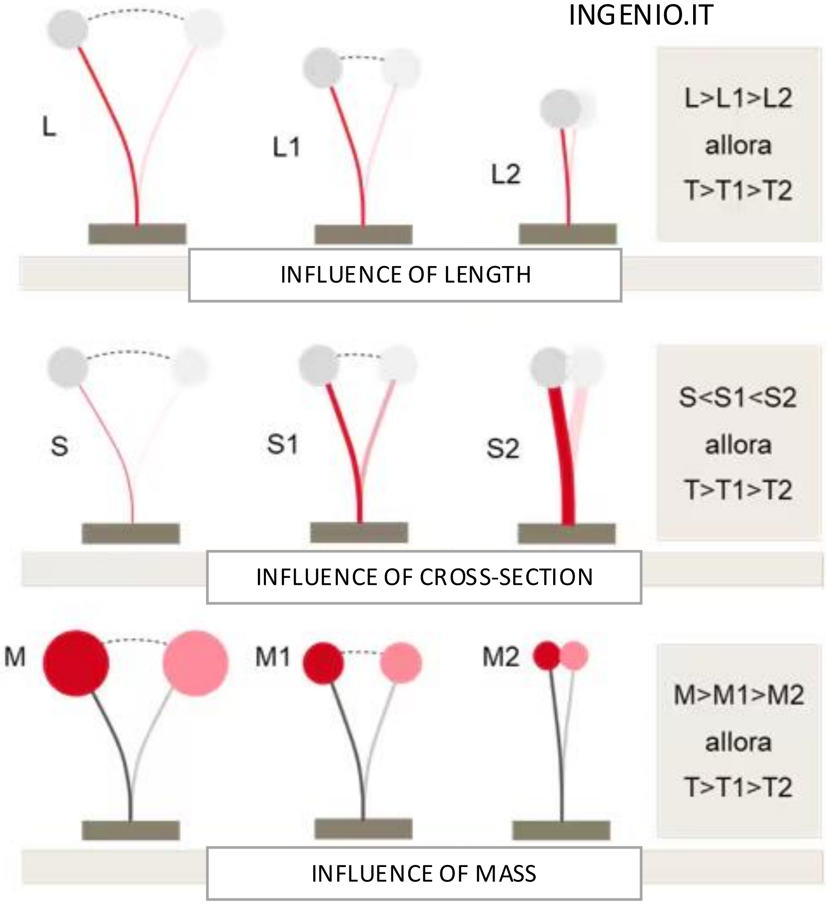
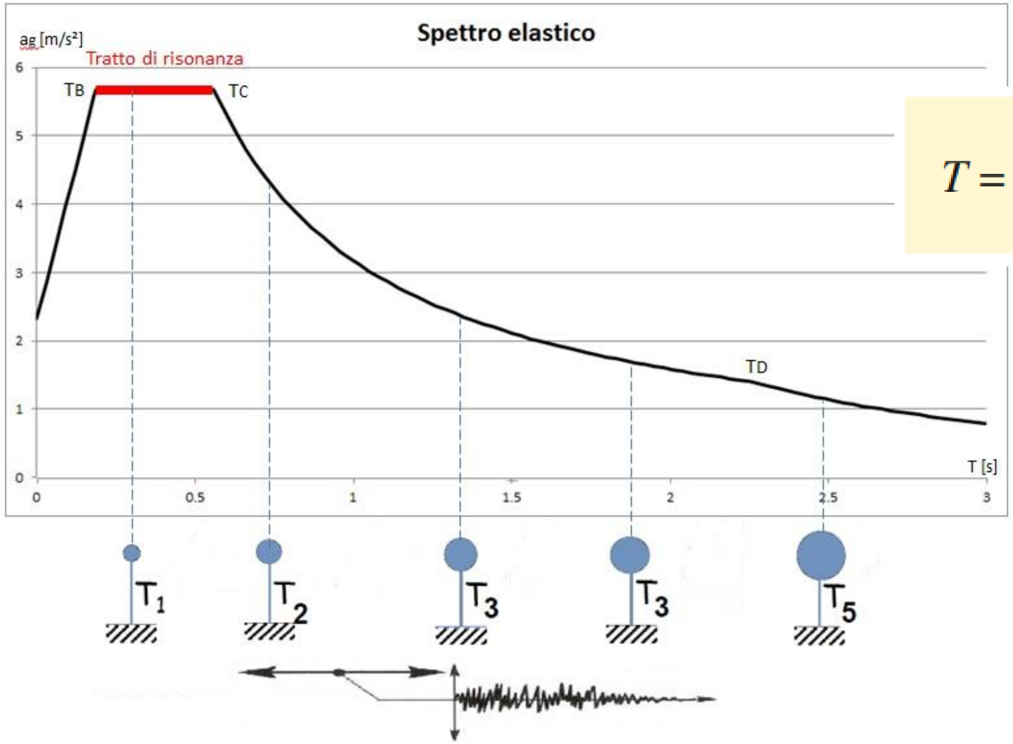




$$T = 2\pi \sqrt{\frac{m}{k}}$$

$$f = \frac{1}{2\pi} \sqrt{\frac{k}{m}}$$

The response spectrum is the primary tool for earthquake-resistant design. It's constructed by graphing the acceleration response of various simple oscillators as a function of their vibration period. This shows that, for typical seismic events, certain types of structures are more likely to enter into resonance with both the ground and the seismic waves

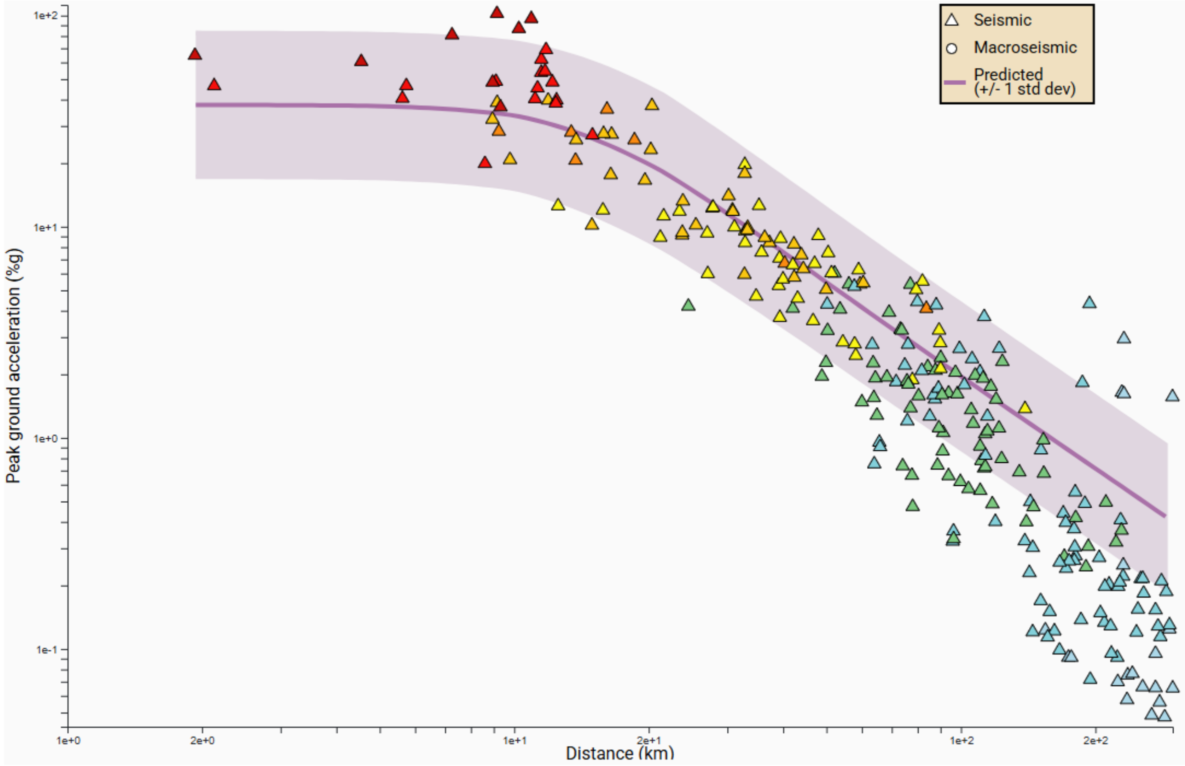
ATTENUATION LAW

Seismic attenuation is an intrinsic and complex process that describes the loss of energy of seismic waves as they propagate through the Earth's medium. This loss is attributed to two main mechanisms: **geometric attenuation**, caused by the dispersion of energy over an increasing volume, and **anelastic attenuation**, which includes intrinsic dissipation (conversion into heat) and scattering (redistribution of energy due to medium heterogeneities).

The phenomenon is influenced by a variety of geological and physical factors, including the elastic and dissipative properties of rocks, the presence and distribution of subsurface fluids, temperature, pressure, and the frequency of the seismic waves.
It's crucial to distinguish the attenuative behavior of different types of waves: **surface waves** attenuate significantly less than **body waves** (P and S), making them the primary cause of structural damage at considerable distances from the epicenter.

Attenuation laws are fundamental for:
•**Assessing seismic hazard** and creating hazard maps.
•**Developing ShakeMaps**, by estimating shaking in areas without seismic stations.

EVENT 30/10/2016



ITA10 - D. Bindi, F. Pacor, L. Luzi, R. Puglia, M. Massa, G. Ameri
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SHAKE MAP

A ShakeMap (or shaking map) is a key tool in seismology and emergency management. It provides a near real-time visualization of ground shaking levels caused by an earthquake over a specific area.

A ShakeMap doesn't just show the epicenter and magnitude; it represents the geographical distribution of **shaking intensities**. These maps combine instrumental data from seismic stations (accelerometers and seismometers) with geological and seismic wave attenuation models. This allows for the estimation of shaking even in areas without monitoring stations.

- The more seismic stations we have, the more data we collect, making our models more precise.
- Attenuation laws aren't universal. They depend on local factors like geology, soil type (e.g., VS30), and the fault's mechanism. This is why the laws for volcanic earthquakes are different from those for tectonic earthquakes.
- A dense seismic network in a specific area allows us to calibrate GMPEs with regional data, reducing uncertainty and improving our ability to predict the impact of future earthquakes.

The values, 0,3 sec – 1 sec – 3 sec, represent the **vibrational periods** of structures and are related to **spectral acceleration**, a parameter that ShakeMaps can display.

- **Spectral Acceleration (Sa) ShakeMap at 0.3 seconds:** This map is useful for assessing potential damage to **short, stiff buildings**, like one or two-story houses.

- **Spectral Acceleration (Sa) ShakeMap at 1.0 seconds:** This is relevant for estimating the effects on **mid-rise buildings**, such as 5-10 story apartment or office blocks.

- **Spectral Acceleration (Sa) ShakeMap at 3.0 seconds:** This is important for understanding the shaking that could damage **tall, flexible structures**, like skyscrapers.

SHAKE MAP

Shake Maps combine data recorded by seismic stations with ground motion attenuation models and local geological information to create an estimate of the extent and distribution of shaking over a wider geographic area. The curves serve to immediately visualize these areas of homogeneous shaking.

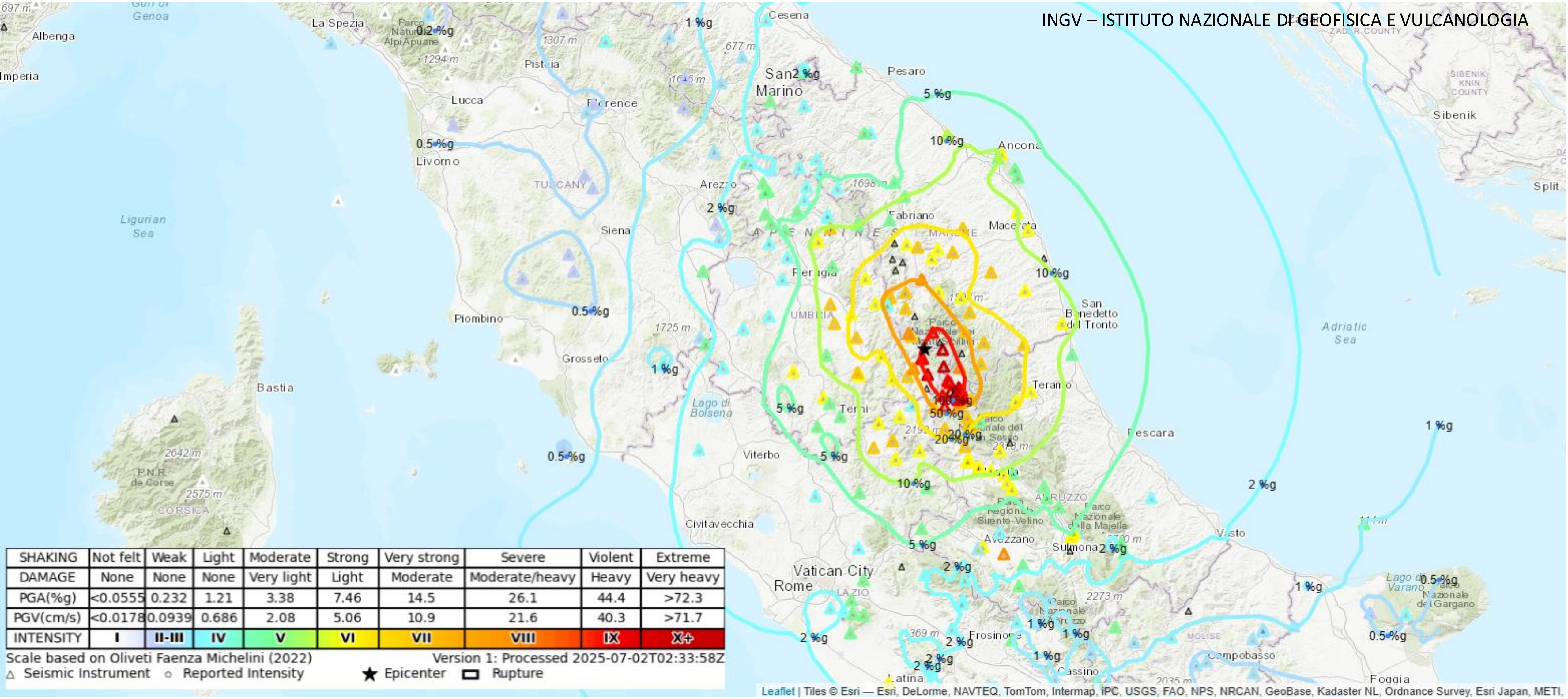
Macroseismic Intensity (e.g., Modified Mercalli Intensity Scale - MMI): These curves delineate areas where the perceived intensity of the earthquake (based on observed effects on people and buildings) is the same.

Peak Ground Acceleration (PGA): They connect points with the same maximum value of ground acceleration. It is measured in %g (percentage of the acceleration due to gravity).

Peak Ground Velocity (PGV): They connect points with the same maximum value of ground velocity. It is measured in cm/s.

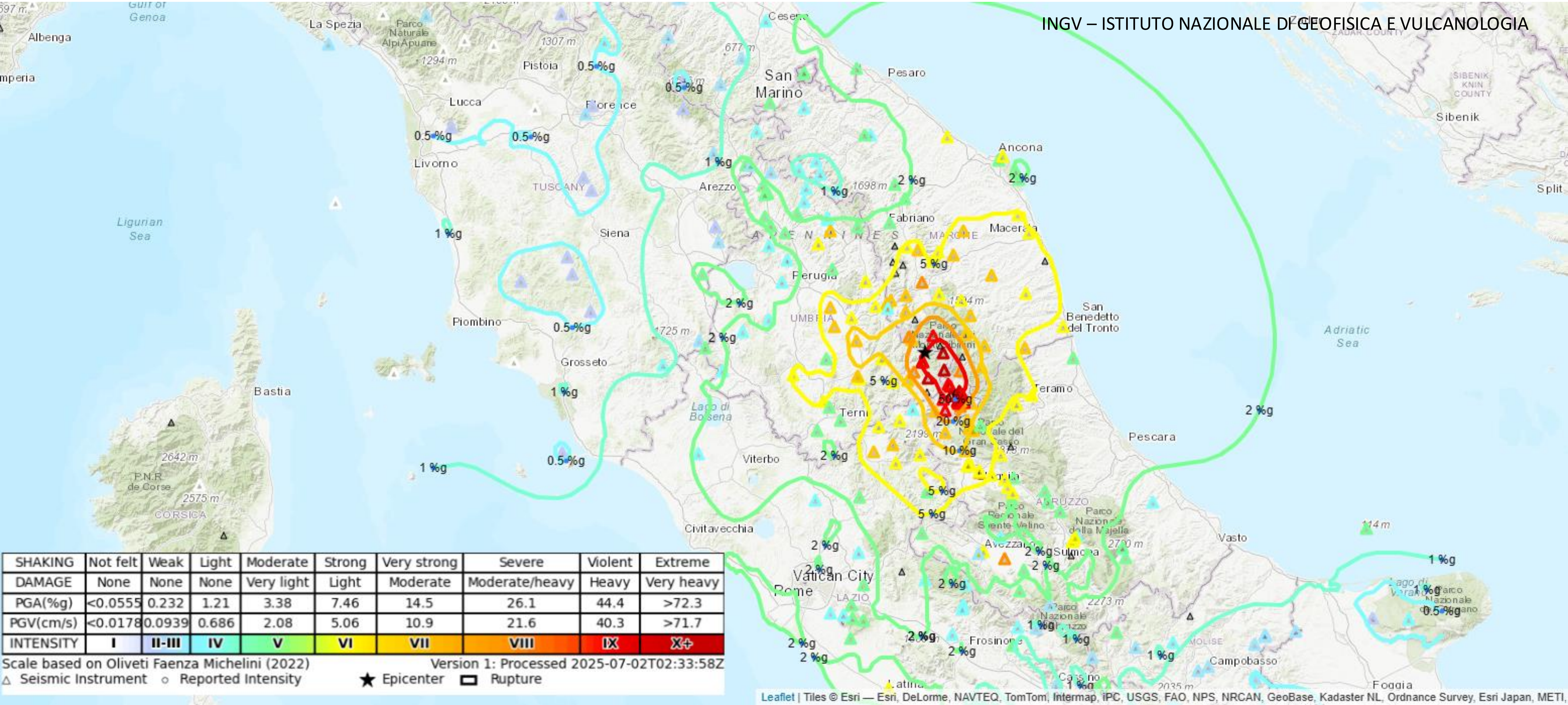
Pseudo Spectral Acceleration (PSA): These curves are more complex and represent the maximum response of a single oscillator (a simplified model of a building) to different frequencies of ground vibration (periods). They are particularly useful for structural engineers as they indicate how different types of structures (with different "natural periods" of oscillation) might be affected by the shaking.

PSA 0,3 SEC – 30/10/2016 06:40 am



SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.0555	0.232	1.21	3.38	7.46	14.5	26.1	44.4	>72.3
PGV(cm/s)	<0.0178	0.0939	0.686	2.08	5.06	10.9	21.6	40.3	>71.7
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

PSA 1 SEC – 30/10/2016 06:40 am



SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
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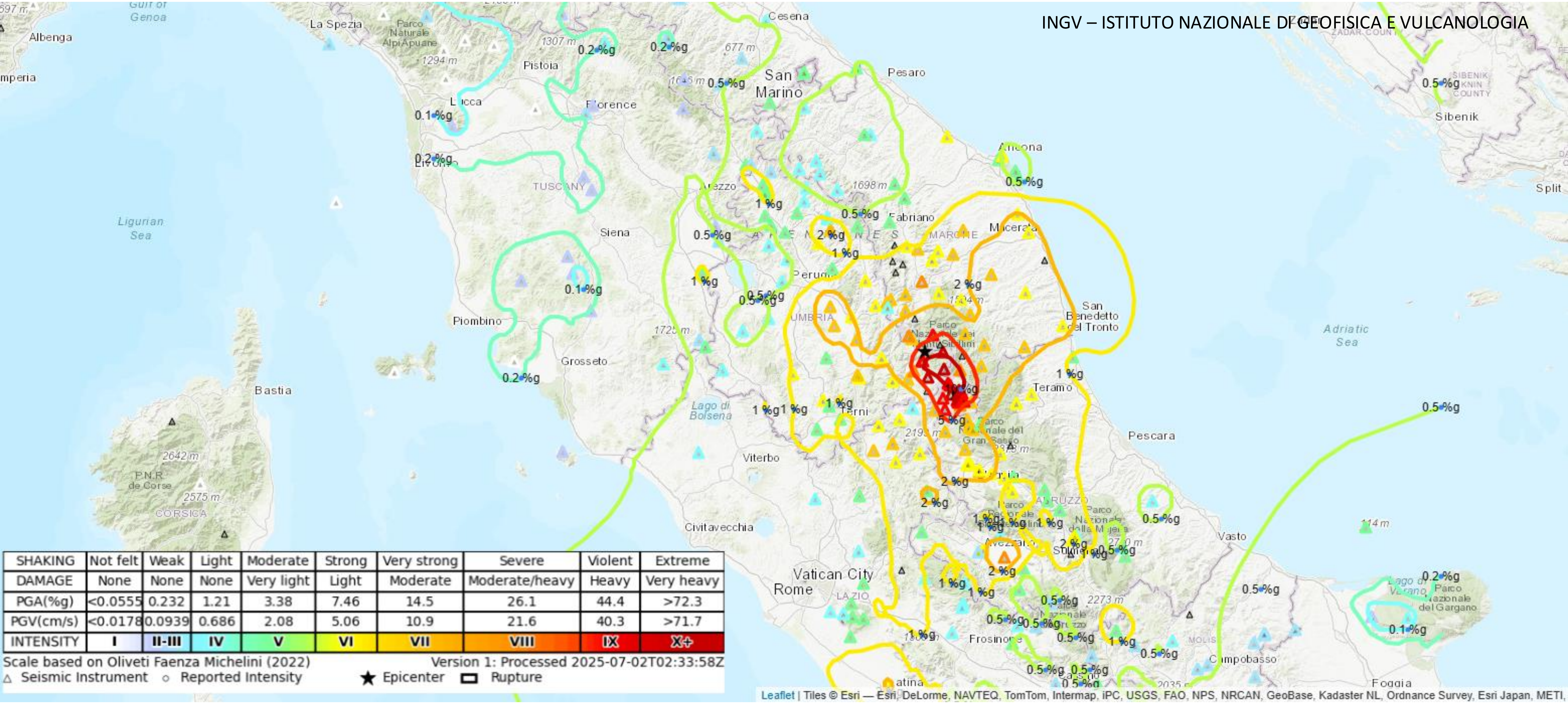
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based on Oliveti Faenza Michelini (2022) Version 1: Processed 2025-07-02T02:33:58Z
△ Seismic Instrument ○ Reported Intensity ★ Epicenter ▭ Rupture

PSA 3 SEC – 30/10/2016 06:40 am



SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.0555	0.232	1.21	3.38	7.46	14.5	26.1	44.4	>72.3
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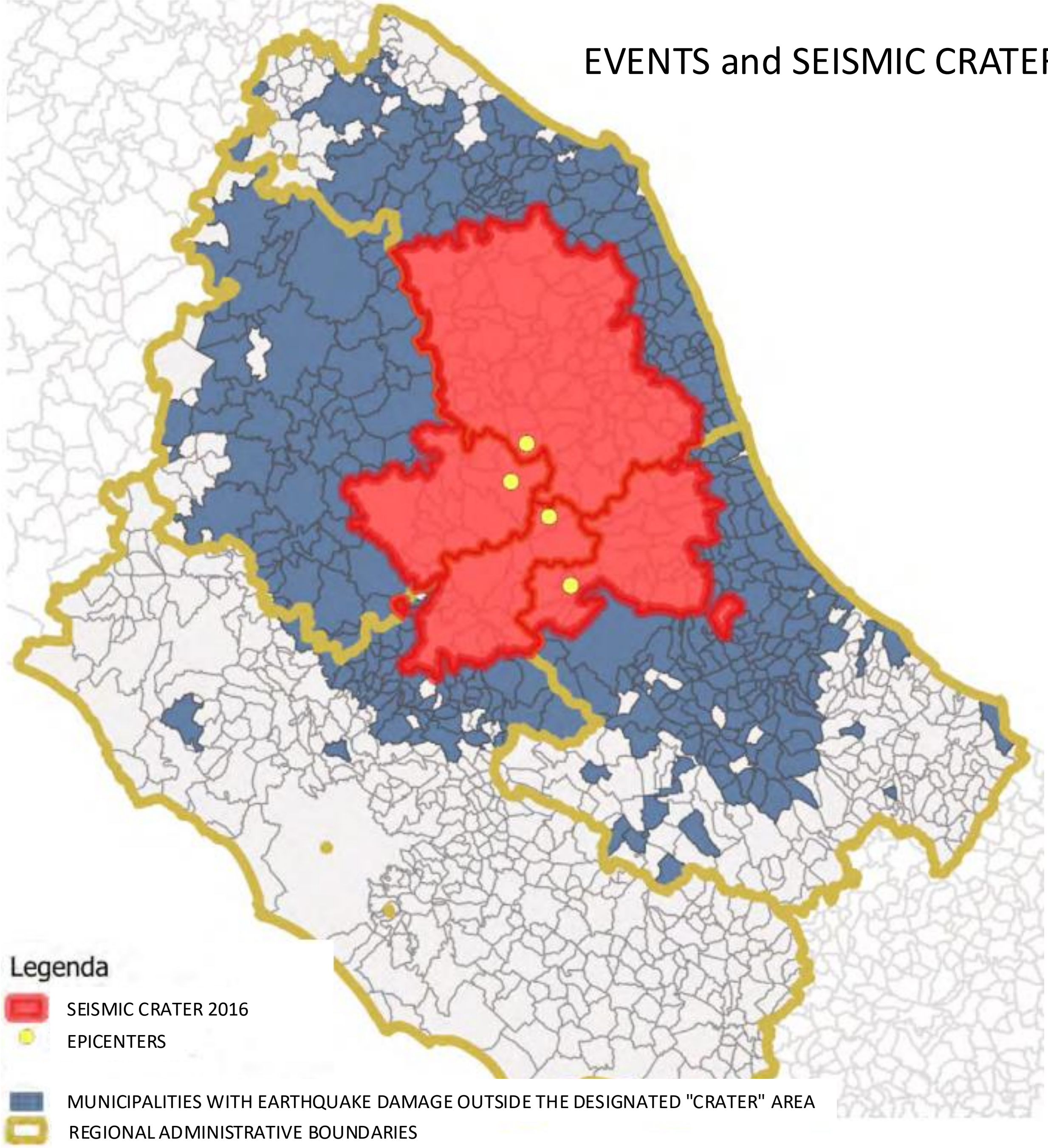
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

EVENTS and SEISMIC CRATER 2016



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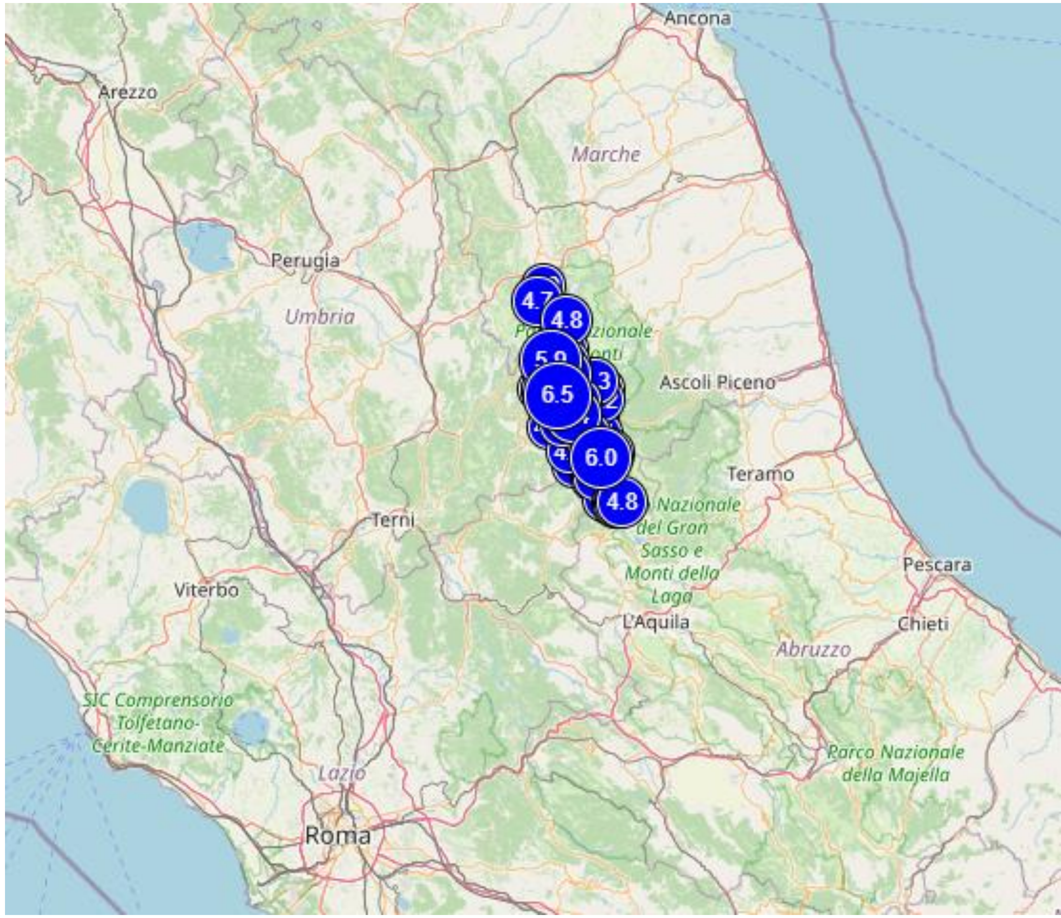
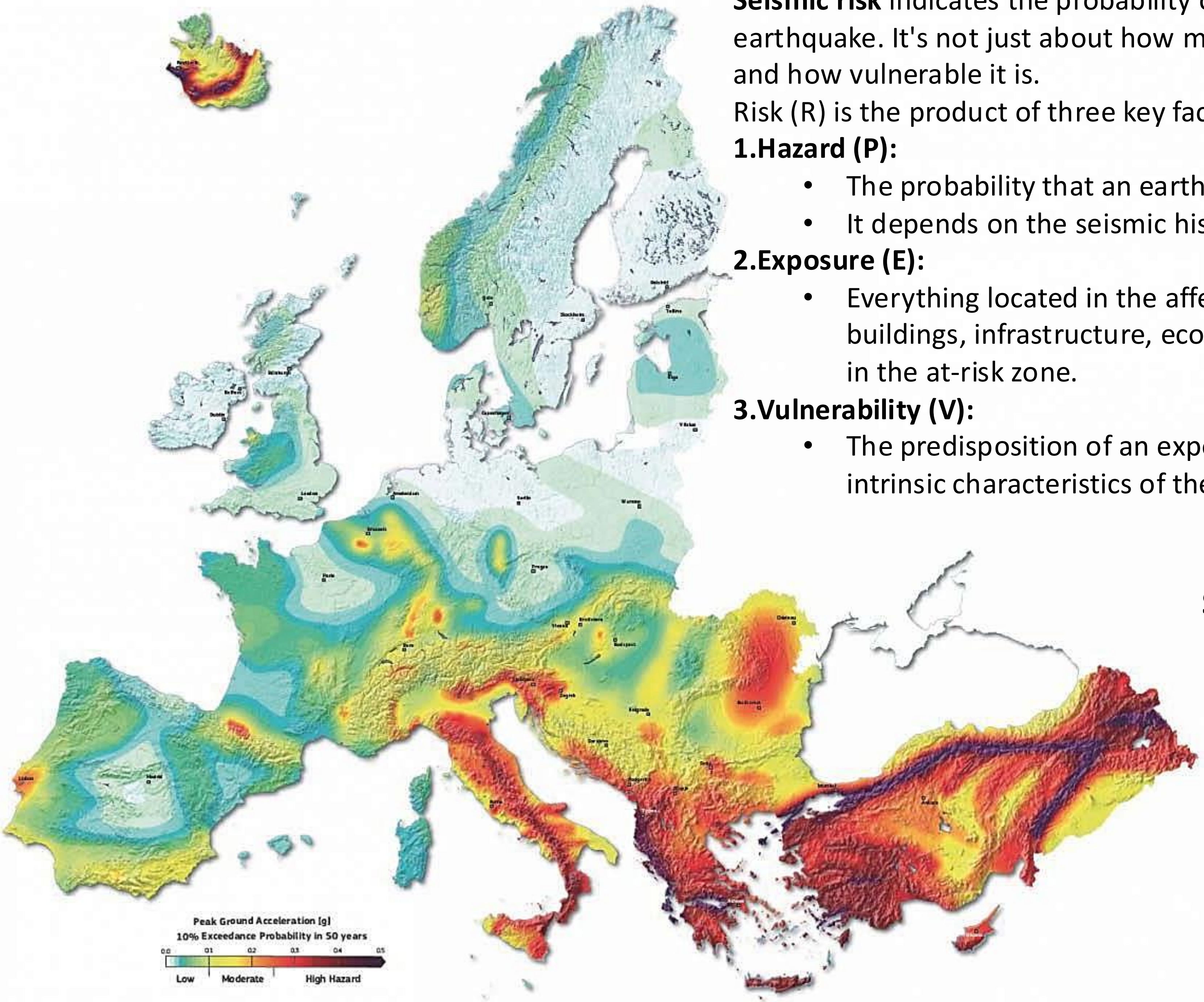


49 EARTHQUAKES WITH MAGNITUDES BETWEEN 4 AND 6.5 THAT OCCURRED BETWEEN AUGUST AND OCTOBER 2016.



Seismic risk indicates the probability of experiencing damage or losses due to an earthquake. It's not just about how much the ground shakes, but also what's at stake and how vulnerable it is.

Risk (R) is the product of three key factors:

1.Hazard (P):

- The probability that an earthquake of a certain intensity will strike an area.
- It depends on the seismic history and geology of the location.

2.Exposure (E):

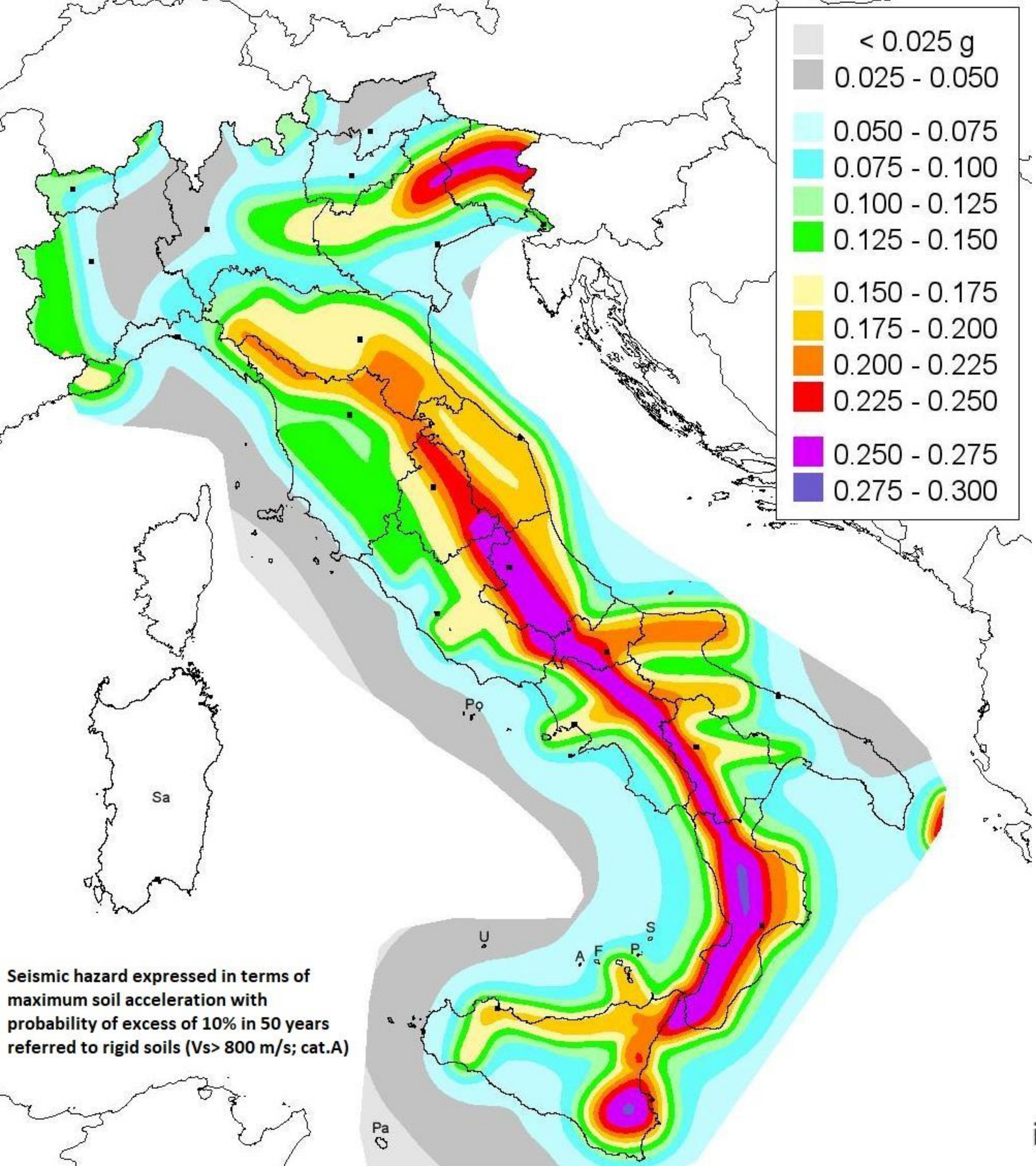
- Everything located in the affected area that could sustain damage: people, buildings, infrastructure, economic activities. **How many elements are present** in the at-risk zone.

3.Vulnerability (V):

- The predisposition of an exposed element to suffer damage. It depends on the intrinsic characteristics of the element (e.g., building type, age of structures).

Seismic Risk

R=V×P×E



Seismic hazard expressed in terms of maximum soil acceleration with probability of excess of 10% in 50 years referred to rigid soils (Vs> 800 m/s; cat.A)

The **return period** for an earthquake is a **statistical average of the time between seismic events of a given intensity or greater** in a specific area. It's a key measure of **seismic hazard**, derived from historical data and statistical models (like the Gutenberg-Richter Law).

This concept is fundamental for **seismic engineering and building codes**, dictating the design standards required for structures to withstand earthquakes of varying probabilities, thereby mitigating seismic risk. It's a probabilistic tool for risk assessment, not a precise prediction of when the next earthquake will strike.

The **NTC 2018** (Italian Technical Standards for Construction) adopt a **semi-probabilistic design approach** based on the concept of "**limit states**." This method allows for uncertainties inherent in loads and material resistances to be accounted for by introducing distinct **partial safety factors** (γf for loads and γm for resistances). This ensures an adequate safety margin ($Sd=Sk \cdot \gamma f$, $Rd=Rk/\gamma m$).

A **limit state** is defined as a critical condition beyond which a structure or one of its elements no longer meets the performance requirements for which it was designed.

Life Safety Limit State (SLV): Following a design-level earthquake, the building experiences failures and collapses of non-structural and plant components, along with significant damage to structural components, associated with a substantial loss of stiffness against horizontal actions.

Damage Limit State (SLD): Following a moderate intensity earthquake, the building as a whole (including structural elements, non-structural elements, and relevant equipment) sustains damage that does not endanger users and does not significantly compromise its resistance and stiffness capacity for vertical and horizontal actions. The structure remains immediately usable, albeit with temporary interruptions in the use of some non-critical equipment or systems.

VULNERABILITIES IN EXISTING MASONRY BUILDINGS

The primary vulnerabilities in existing masonry buildings stem from a lack of effective **box-like behavior**, which can be attributed to deficiencies in three key areas:

Slab Stiffness in Their Own Plane

Floor and roof slabs must act as **rigid diaphragms** to effectively distribute seismic forces among the vertical resisting elements (walls). Vulnerabilities arise from slabs with insufficient in-plane stiffness (for example, flexible timber slabs without a collaborating concrete topping) or those not adequately connected to all perimeter walls. This can lead to non-uniform force distribution or localized failures.

Structural Connection Between Slabs and Walls

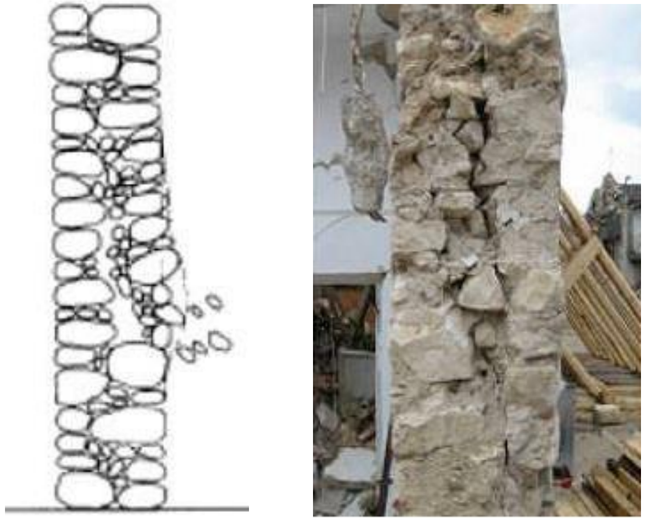
If slabs are poorly connected to perimeter walls, especially those orthogonal to the seismic action, the walls can experience **out-of-plane overturning mechanisms** (classified as Mode I damage). This type of brittle failure prevents the development of more ductile in-plane wall behavior (Mode II damage).

Interconnection Between Walls

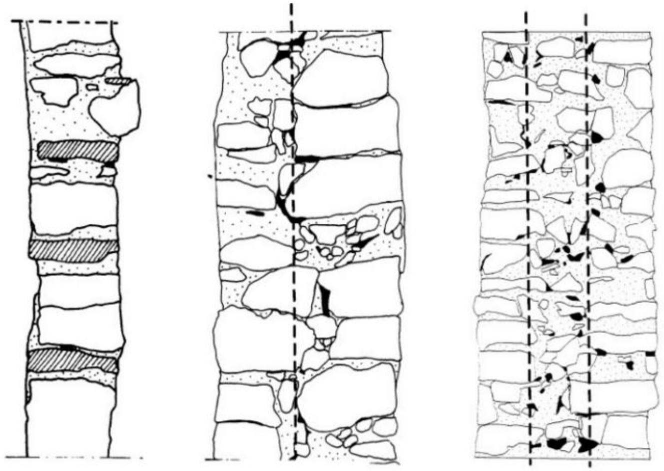
The structural connection between orthogonal masonry walls at corners and intersections is crucial. If walls are simply abutted without adequate interconnection (for example, without staggered brick joints), they can separate during an earthquake, leading to out-of-plane instability and local collapses.

Disintegrating behavior of mansory:

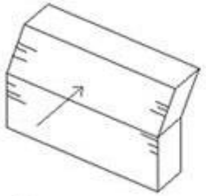
- The poor quality of the materials (decay of bricks, presence of gaps, old age of materials, rubble masonry, etc.);
- The poor quality of the mortar (poor or too lean mortar). Mortars characterized by a small amount of binder, sometimes even composed of raw earth, are widespread mainly in poorer constructions, but their presence cannot be excluded even in more valuable buildings, hidden within more carefully crafted external facings. These mortars essentially only play a role in distributing vertical loads, contributing very little to the connection between the blocks, especially in the presence of cyclic or vibrational stresses. Disintegrated masonry in which the bricks or stones retain no trace of mortar adhering to their surfaces is certainly a sign of poor mortar quality;
- The poor quality of the masonry bond and the absence of through stones (diatoni). Rubble-fill masonry (or "sac-masonry") is certainly among the most critical types, also due to the thrust that the infill itself can generate on the external facings if it is not cohesive enough. Also very common are stone masonries made with two essentially juxtaposed facings, with a scarce presence of through stones for transversal connection and with slabs often resting only on the internal facing.



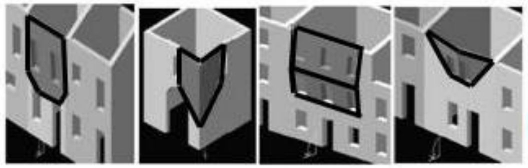
THE DISINTEGRATION MECHANISM OF MASONRY



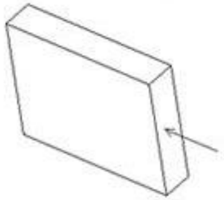
TYPE OF ANCIENT MASONRY



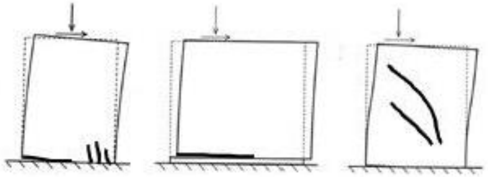
OUT-OF-PLANE COLLAPSE →



I MODE COLLAPSE MECHANISMS



IN-PLANE COLLAPSE →



II MODE COLLAPSE MECHANISMS

$$\alpha_o\left(\sum_{i=1}^{n}P_i\delta_{x,i}+\sum_{j=n+1}^{n+m}P_j\delta_{x,j}\right)-\sum_{i=1}^{n}P_i\delta_{y,i}-\sum_{k=1}^{o}F_k\delta_k=L_{fi}$$

Horizontal load multiplier

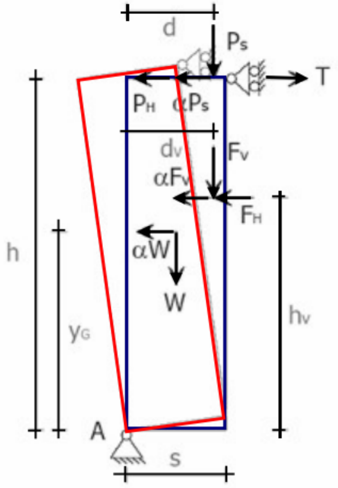
Spectral acceleration activating the mechanism

$$a_0=\frac{\alpha_o\sum_{i=1}^{n+m}P_i}{M^*FC}$$

$$M^*=\frac{\left(\sum_{i=1}^{n+m}P_i\,\delta_{x,i}\right)^2}{g\sum_{i=1}^{n+m}P_i\,\delta_{x,i}^2}$$

$$a_o=\alpha_o\cdot g$$

$$q=2$$



$$a_0\geq\begin{cases}\dfrac{a_g\cdot S}{q} & \text{Ground element}\\[2ex] \dfrac{S_e(T_1)\cdot\dfrac{z}{H}\cdot\gamma}{q} & \text{Elevated element}\end{cases}$$

$$\gamma=\frac{3N}{2N+1}$$

Modal participation factor

Ing. Gianluca Loffredo

VULNERABILITIES IN EXISTING REINFORCED CONCRETE BUILDINGS

Existing reinforced concrete (RC) buildings, especially those constructed before the implementation of modern seismic codes, often exhibit several common vulnerabilities:

Insufficient Transverse Reinforcement (Stirrups)

This is a critical deficiency. Older designs often included inadequate stirrups (transverse reinforcement) in columns and beams. Stirrups are essential for providing **shear strength**, **confining the concrete core** (improving its strength and ductility), and preventing the **buckling of longitudinal reinforcement bars**. Stirrups were frequently too sparse, poorly detailed (e.g., 90-degree open hooks prone to opening under cyclic loads), and too widely spaced (e.g., 300-450 mm in the central zones of columns).

"Strong Beam-Weak Column" Mechanism

Many older RC frames were primarily designed for vertical (gravity) loads, often resulting in beams that are proportionally much stronger than the columns. Under seismic action, this can lead to the undesirable formation of **plastic hinges predominantly in the columns** (especially within a single story), causing a **"story collapse mechanism"** or **"soft story" effect**, rather than the more ductile "weak beam-strong column" system where plastic hinges form in the beams.

Soft Story Effect

The presence of **"soft stories,"** typically ground floors with fewer or less stiff infill walls (which contribute to energy dissipation despite not being considered in calculations), can exacerbate the "strong beam-weak column" mechanism. This concentrates damage and plastic hinges at the base and top of the columns within that specific story, making the structure extremely vulnerable to collapse.

AMATRICE

During the initial shocks, the infamous 'red building' and the bell tower of Amatrice (Figure 4) held strong. The frequency content of those tremors particularly 'excited' structures with a period between 0.1 and 0.2, which is a typical range for one- or two-story masonry buildings.

- Ing. Gianluca Loffredo

AMATRICE
VIA ROMA

- Ing. Gianluca Loffredo

FRANE SISMOINDOTTE

- Ing. Gianluca Loffredo

ARQUATA DEL TRONTO

- Ing. Gianluca Loffredo

PESCARA
DEL
TRONTO

- Ing. Gianluca Loffredo

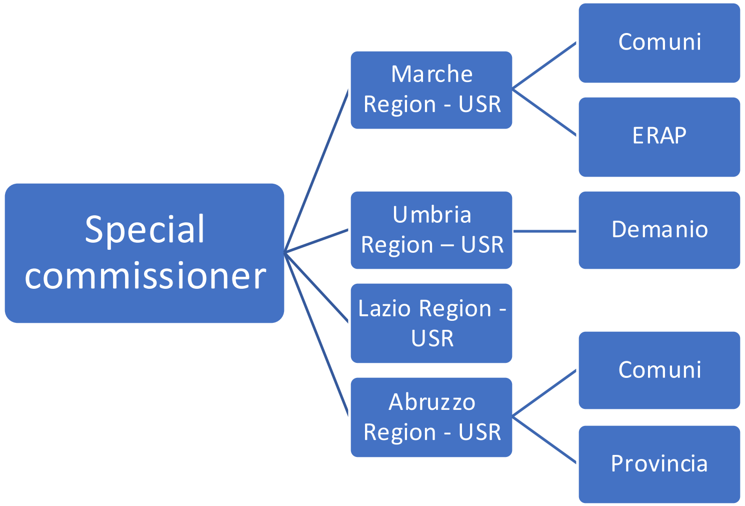
CAMERINO

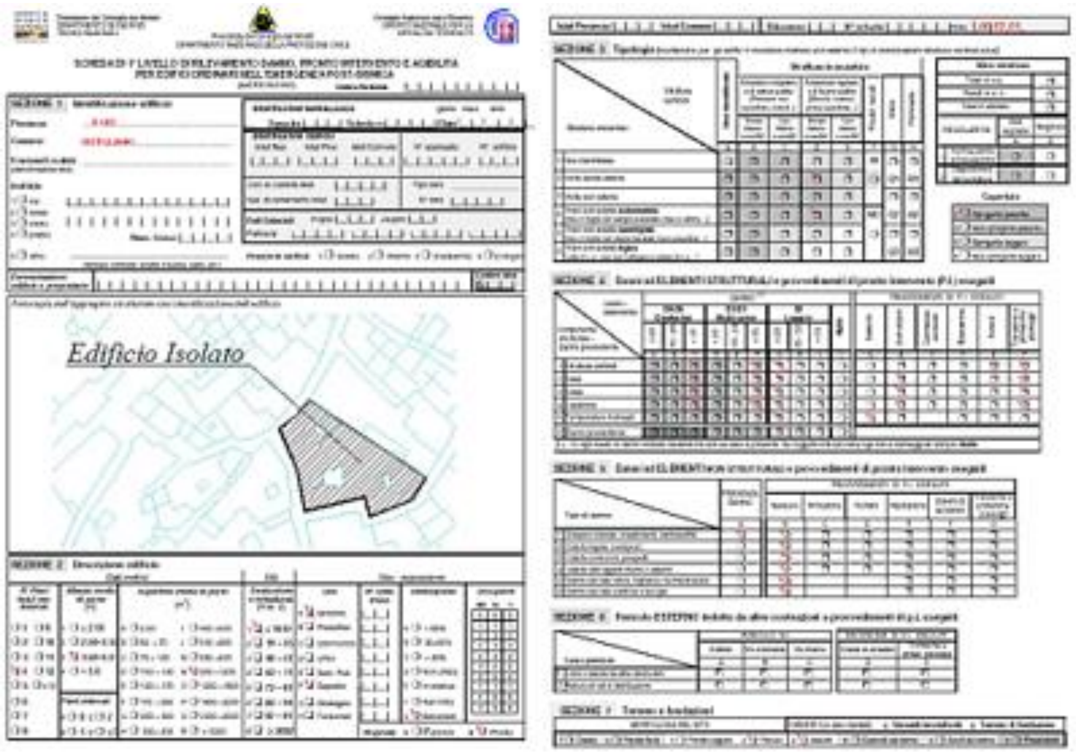
Governance Structure

A Special Commissioner is appointed with special powers to coordinate reconstruction and assistance efforts, supported by the Presidents of the affected Regions acting as deputy commissioners. Each Region establishes Special Reconstruction Offices that serve as a single point of contact for urban planning management, contribution application processing, and intervention implementation.

Reconstruction Interventions

A Reconstruction Fund is established and managed by the Commissioner, with a special accounting system to ensure transparency and traceability of resources. Criteria are defined for the repair, restoration, or reconstruction of damaged residential and productive properties, with contributions that can cover up to 100% of expenses. Access to these contributions is subject to damage assessment through the completion of **AEDES forms** (Seismic Emergency Usability and Damage), which are essential for certifying the usability and extent of damage sustained by buildings.





Contributions for primary and secondary homes

Contributions for private reconstruction can cover up to 100% of expenses for primary homes, regardless of their location inside or outside the seismic "crater." For secondary homes, the 100% contribution is granted if they are located within the crater or in historic centers/characteristic villages outside the crater.

Secondary homes situated outside these specific areas receive a contribution of 50% of the expenses. Access to these contributions is contingent upon damage assessment carried out through AEDES forms (Seismic Emergency Usability and Damage).

Urban planning

Post-earthquake urban planning for destroyed villages is a complex process aimed at safe reconstruction while preserving the identity of the places. This process includes:

- **Strategic Planning**: Detailed Reconstruction Plans are developed that modify existing urban planning instruments, with the goal of rebuilding resilient villages and safeguarding their distinctive characteristics, also encouraging public participation.
- **Risk Assessment**: A fundamental aspect is the thorough analysis of the hydro-geological and orogenetic conditions of the site. Interventions to mitigate hydro-geological instability are planned and funded to ensure safety.
- **Delocalization**: Abandoning the original site and constructing in a new area is considered only in cases of clear and continuous risk (e.g., active faults, severe hydro-geological issues) that make on-site reconstruction impractical. If implemented, the original areas can be redeveloped for public use.

Based on the survey, there are a total of **61,000 private buildings** damaged by the earthquake that are eligible for public contributions for repairs. Of these, **5,078 are public works** and **3,509 are churches and religious buildings**.

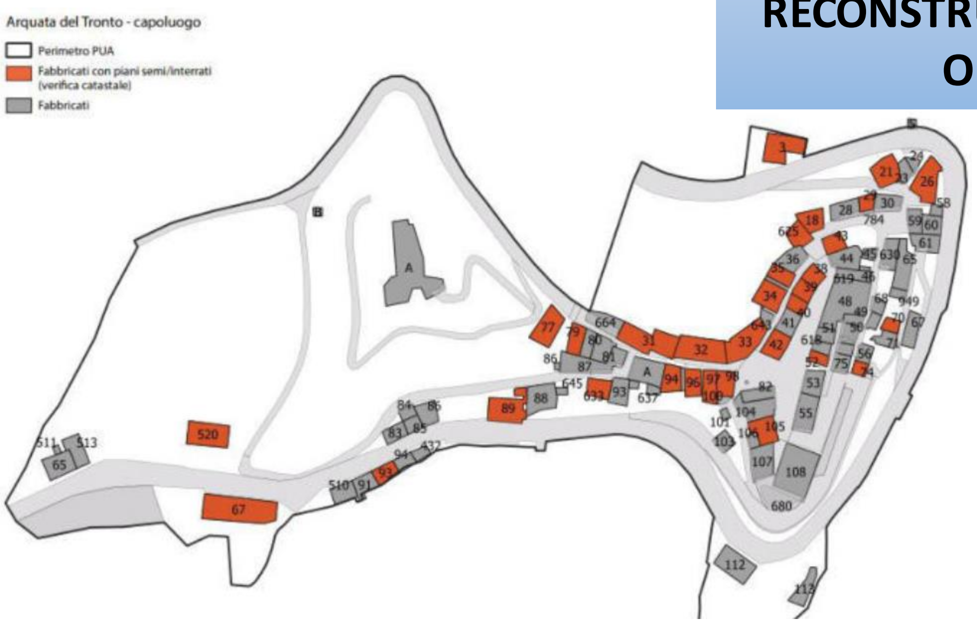
The estimated cost for repairing the damages is **27.2 billion euros**: **19.4 billion euros for private reconstruction**, **6.6 billion for public reconstruction**, and **1.2 billion for churches**.

Overall, the public post-earthquake reconstruction plan for 2016 includes 3,542 projects with an investment value exceeding 4.6 billion euros. These projects are divided into two main categories:

Ordinary planning: This includes 2,553 projects valued at 1.9 billion euros, regulated by commissarial ordinances.

Special planning: This covers 989 projects worth 2.6 billion euros, implemented through special derogation ordinances.

RECONSTRUCTION OF THE HISTORIC CENTER OF ARQUATA DEL TRONTO



CARTOGRAFIA AREA SEDIME EDIFICI

Current aerial photogrammetry

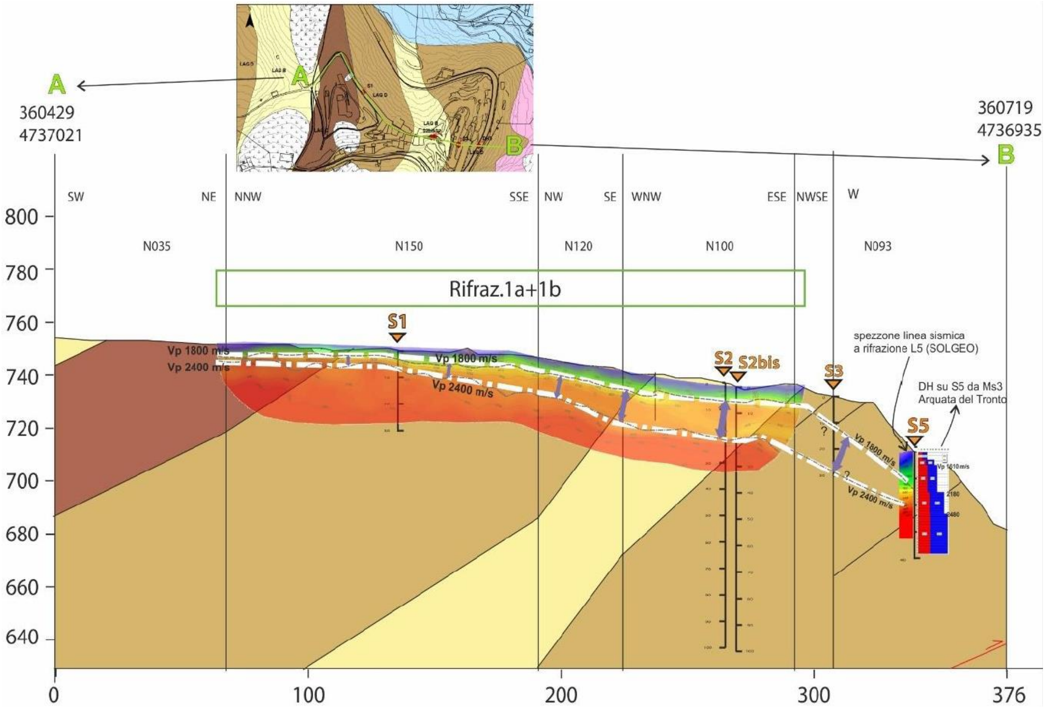
The main criticalities to be considered in the reconstruction of Arquata del Tronto's historic center are geological, hydrogeological, and seismic.

- **Seismic Criticality**: The area is located in a zone of high seismic hazard. The territory of Arquata del Tronto is subject to high-magnitude seismic events and is situated east of the active fault system of Mount Vettore-Mount Bove. The expected acceleration values at the bedrock for the area are between 0.225 and 0.275 g.

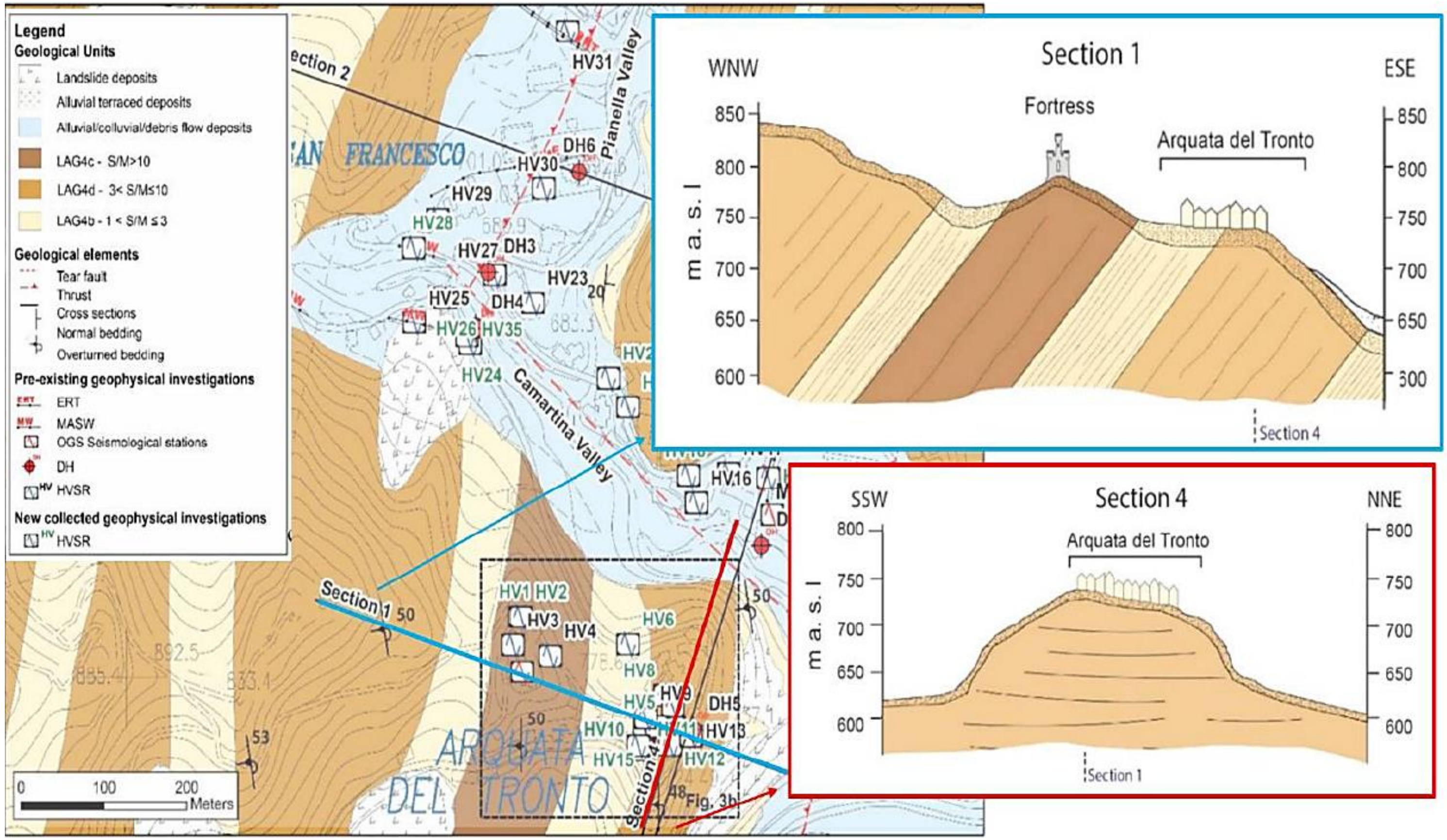
- **Geological and Instability Criticalities**:
  - **Collapses and Landslides**: The geological survey highlighted the presence of unstable rock walls, with highly fractured sandstone layers. The areas with more pelitic (clayey) lithologies are subject to greater erosion and show altered bedrock thicknesses (eluvial and colluvial blankets) that can reach 20-25 meters. These blankets can be remobilized by water flow or gravity, leading to landslide phenomena, including slides and flows. In particular, an active landslide body with a "very high risk" rating (R4) was identified in one of the small valleys.
  - **Ground Behavior**: The geological-structural setting is responsible for a peculiar alternation of ridges and small valleys, which correspond respectively to more sandy layers and more pelitic lithologies.

- **Differential Soil Behavior**: The different lithologies (more sandy vs. more pelitic) show significant differences in terms of stiffness and the thickness of the superficial alteration layer. This variability can cause a local seismic response and differential soil behavior that must be carefully considered during the reconstruction.

RECONSTRUCTION OF THE HISTORIC CENTER OF ARQUATA DEL TRONTO



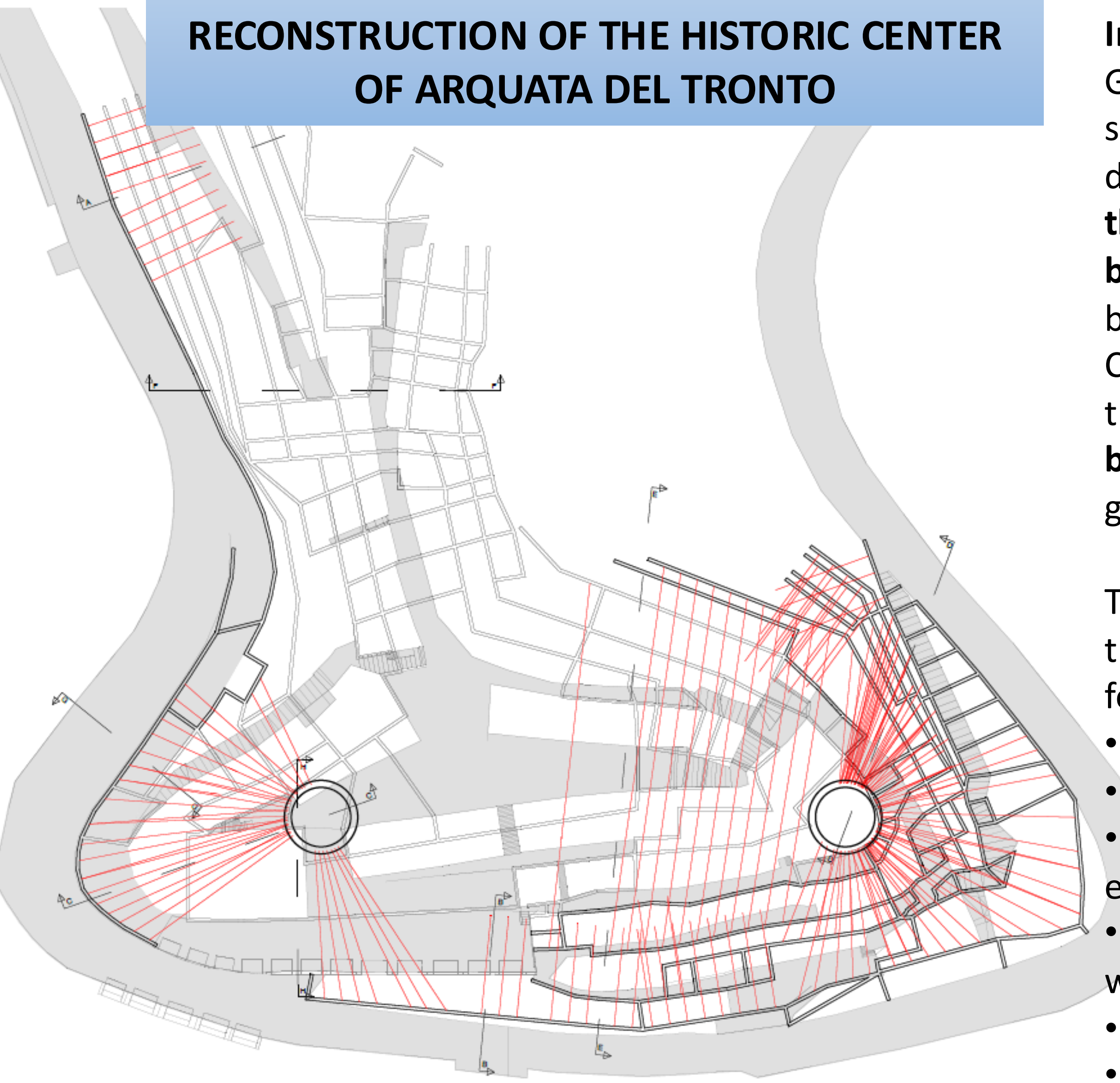
Comparison between the geophysical results of Vs velocities obtained from seismic refraction profiles and DH (MS3), with the geological results obtained from the geological survey and from the comparison with the stratigraphy of the boreholes.



Geological boundary scheme of the Laga Formation, delineated on the survey of the western sector of Arquata del Tronto hill.

- **MASW (Multichannel Analysis of Surface Waves):** Measures the shear wave velocity (Vs) of the ground by analyzing the dispersion of surface waves, to understand soil stiffness.
- **DH (Down-Hole):** Determines the velocity of seismic waves (Vs and Vp) at depth, by measuring the travel time of waves generated on the surface and recorded by sensors in a borehole.
- **HVSR (Horizontal-to-Vertical Spectral Ratio):** Estimates the resonance frequency of a site by analyzing ambient seismic noise. This helps to understand at which frequencies the ground tends to amplify seismic waves.

RECONSTRUCTION OF THE HISTORIC CENTER OF ARQUATA DEL TRONTO



Tie-rod plan

Innovative Anchoring Solution for Complex Terrain

Given the complex topography and steep slopes of the Arquata del Tronto site, coupled with highly fractured rock, the project employs an innovative design prioritizing **active permanent tie-rods**. The primary solution involves **through-tie-rods** connecting opposing walls, minimizing the use of traditional **blind active tie-rods** (which have a free length and an anchorage section). In both cases, the tie-rod reinforcement consists of **Dywidag steel bars**.

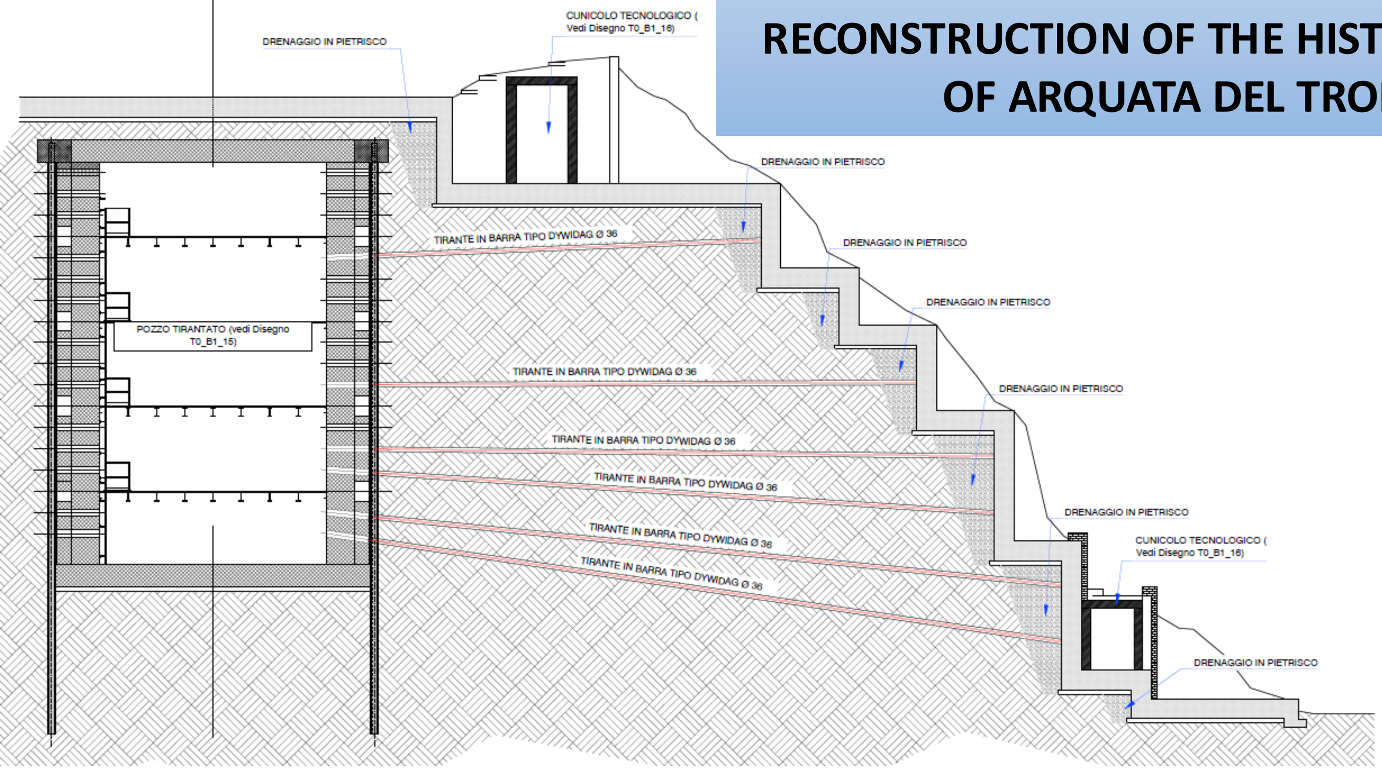
Considering the **100-year design life** for these permanent tie-rods, both through and blind types will be protected with an **HDPE casing**. Additionally, **blind tie-rods** will feature a **double anti-corrosion protection** using a pre-grouted, controlled-fissure casing.

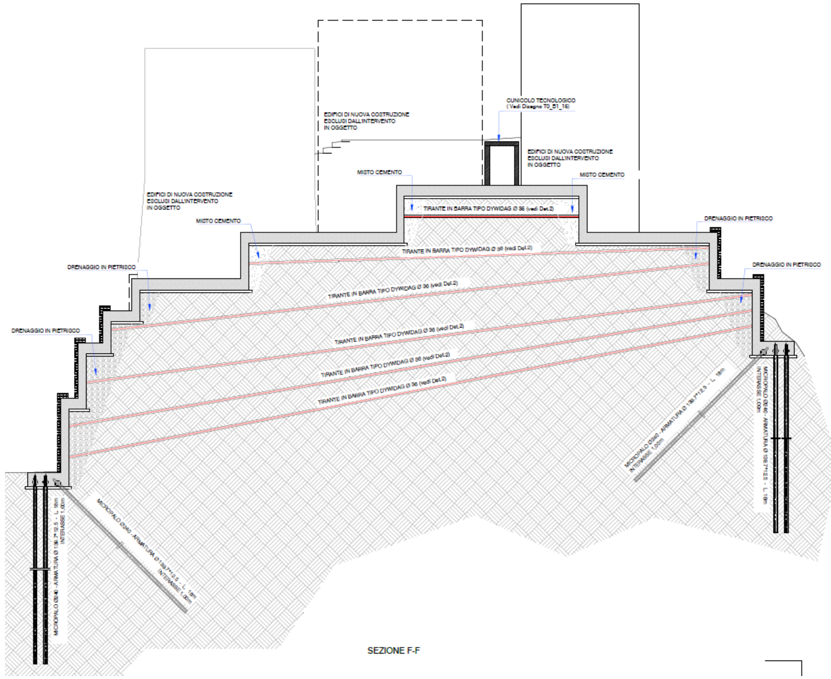
The challenging orographic and slope configuration at Arquata necessitated the use of both through and blind permanent tie-rods. The selection criteria for the most suitable type included:

- Maximum drilling length of 60m.
- Maximum inclination of 15° from horizontal.
- Maximum horizontal deviation of 15° between the perpendicular to the entry wall and the drilling axis.
- Maximum horizontal deviation of 30° between the perpendicular to the exit wall and the drilling axis.
- Presence of opposing walls meeting the above criteria.
- Minimizing intersection between tie-rod paths.

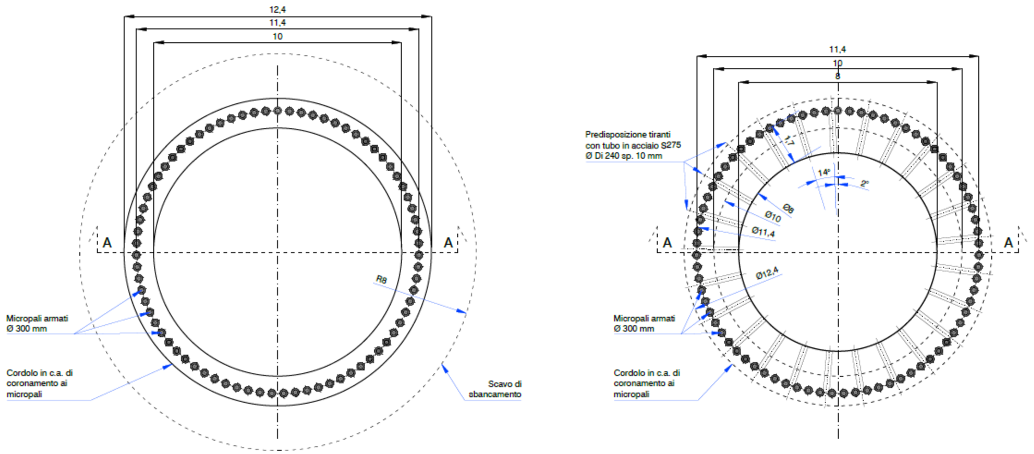
To ensure uniform tie-rod distribution, the design also includes **two vertical shafts** located near the ends of the hill along the predominant southwest-northeast direction.

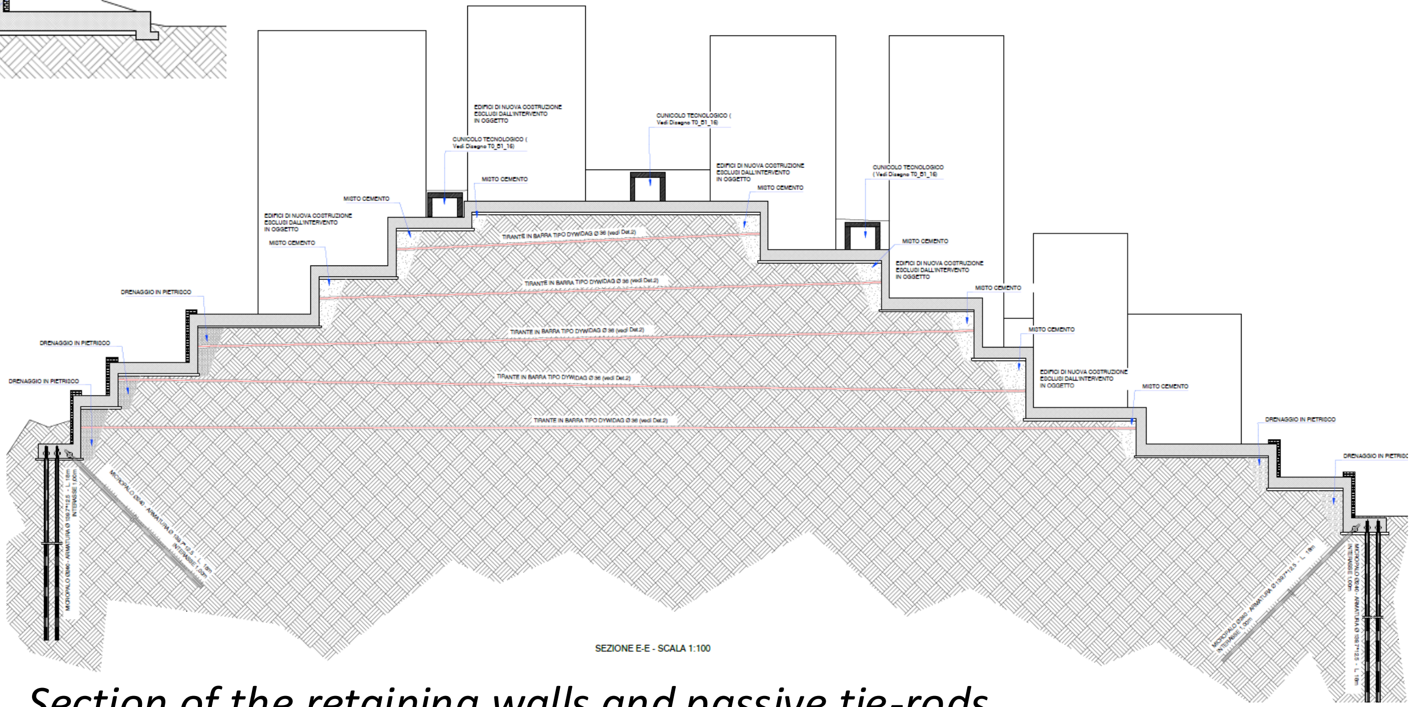
RECONSTRUCTION OF THE HISTORIC CENTER OF ARQUATA DEL TRONTO





Section of the tie-rod-supported shaft



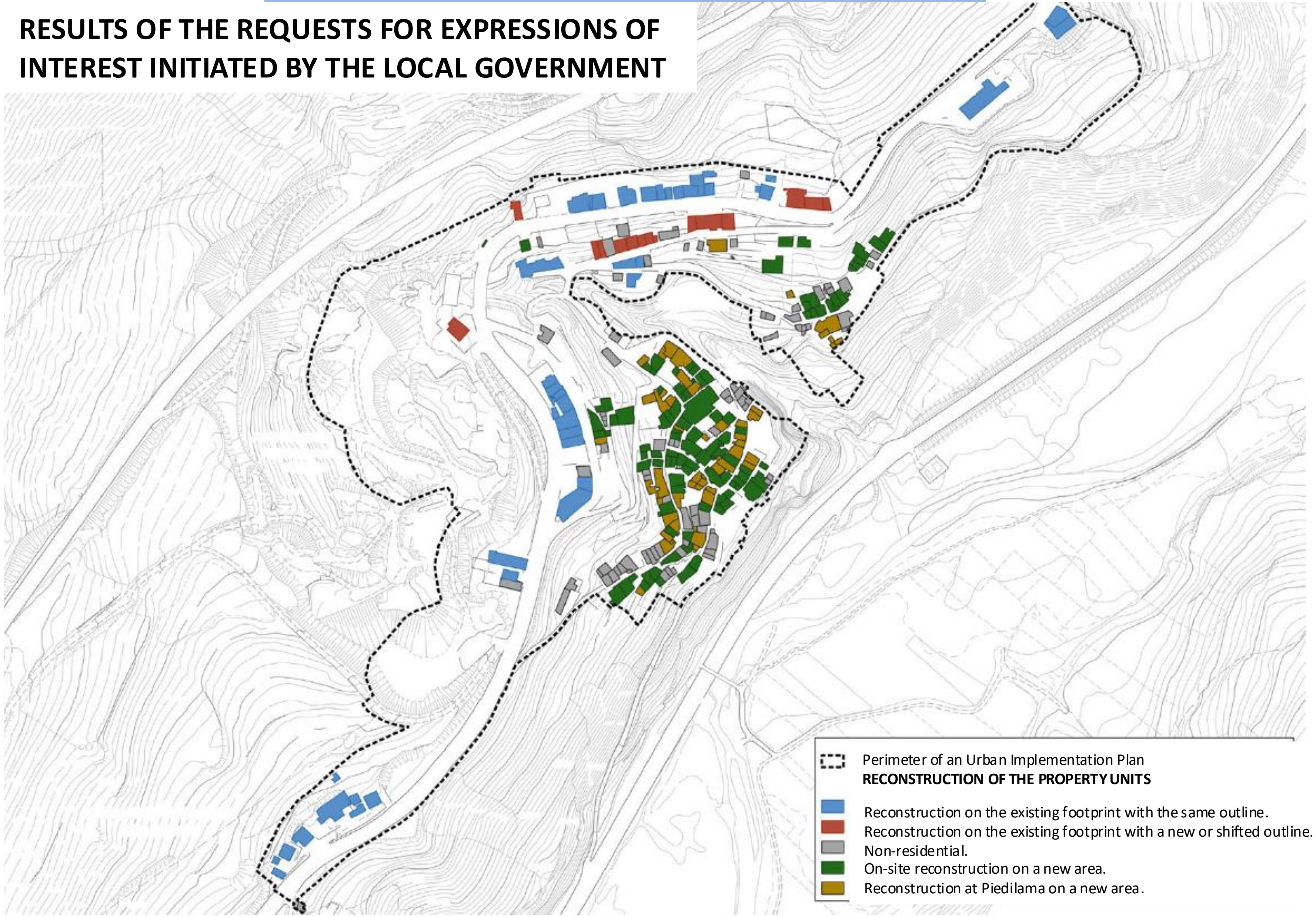


Sections of the anchored shaft and excavation phases

Section of the retaining walls and passive tie-rods

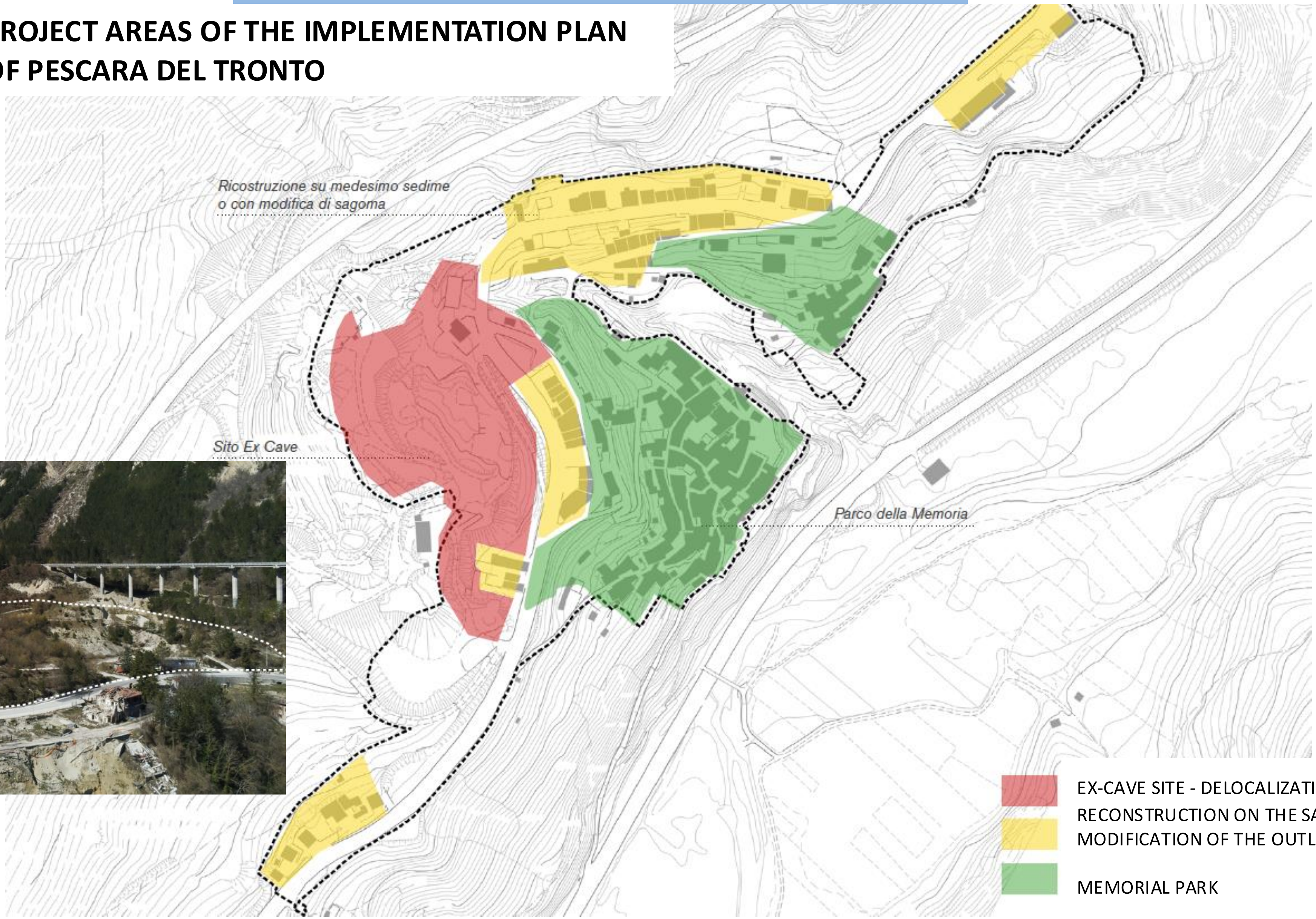
RECONSTRUCTION AND RELOCATION OF THE VILLAGE OF PESCARA DEL TRONTO.

RESULTS OF THE REQUESTS FOR EXPRESSIONS OF INTEREST INITIATED BY THE LOCAL GOVERNMENT



RECONSTRUCTION AND RELOCATION OF THE VILLAGE OF PESCARA DEL TRONTO.

PROJECT AREAS OF THE IMPLEMENTATION PLAN OF PESCARA DEL TRONTO



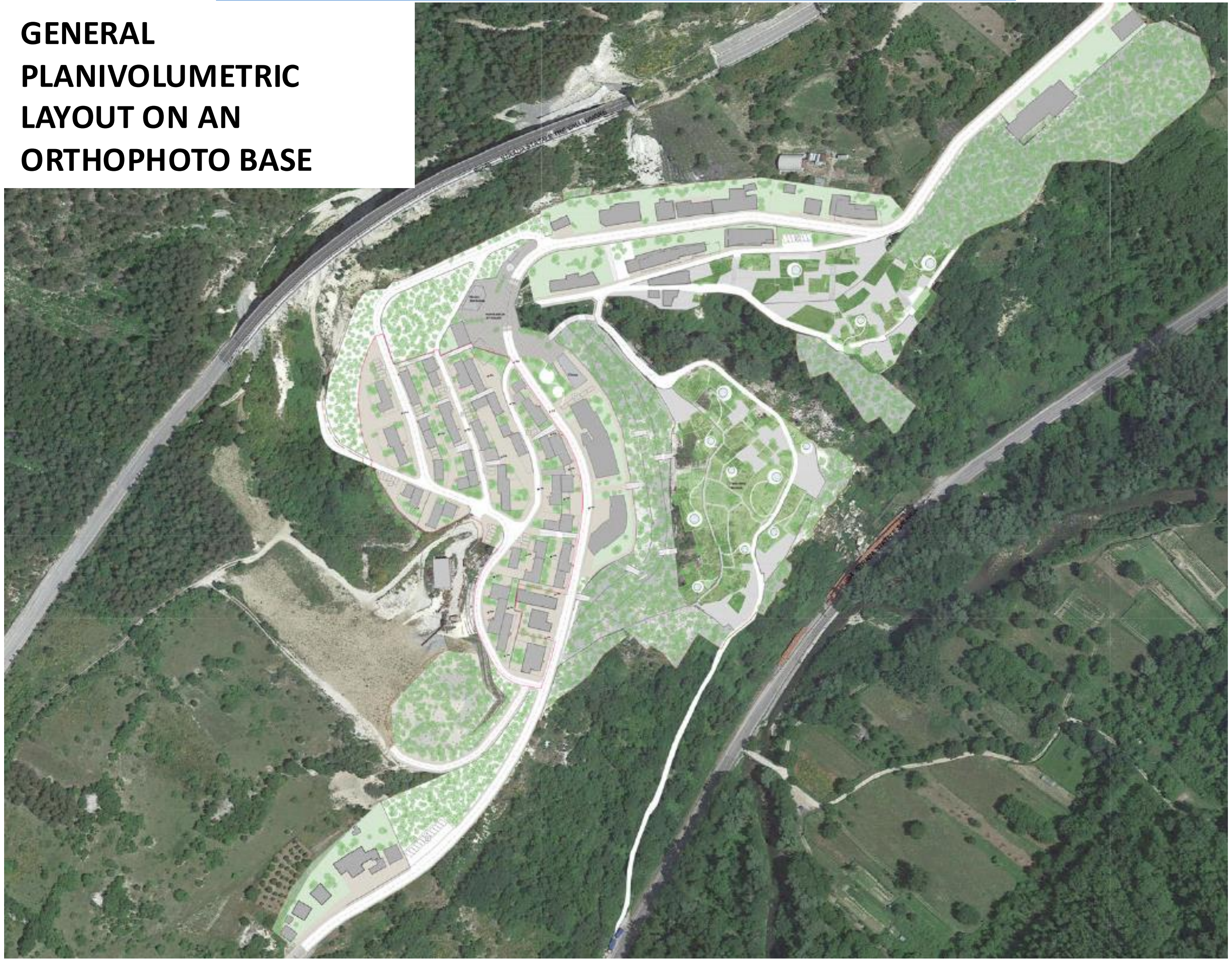
EX-CAVE SITE - DELOCALIZATION AREA

RECONSTRUCTION ON THE SAME FOOTPRINT OR MODIFICATION OF THE OUTLINE

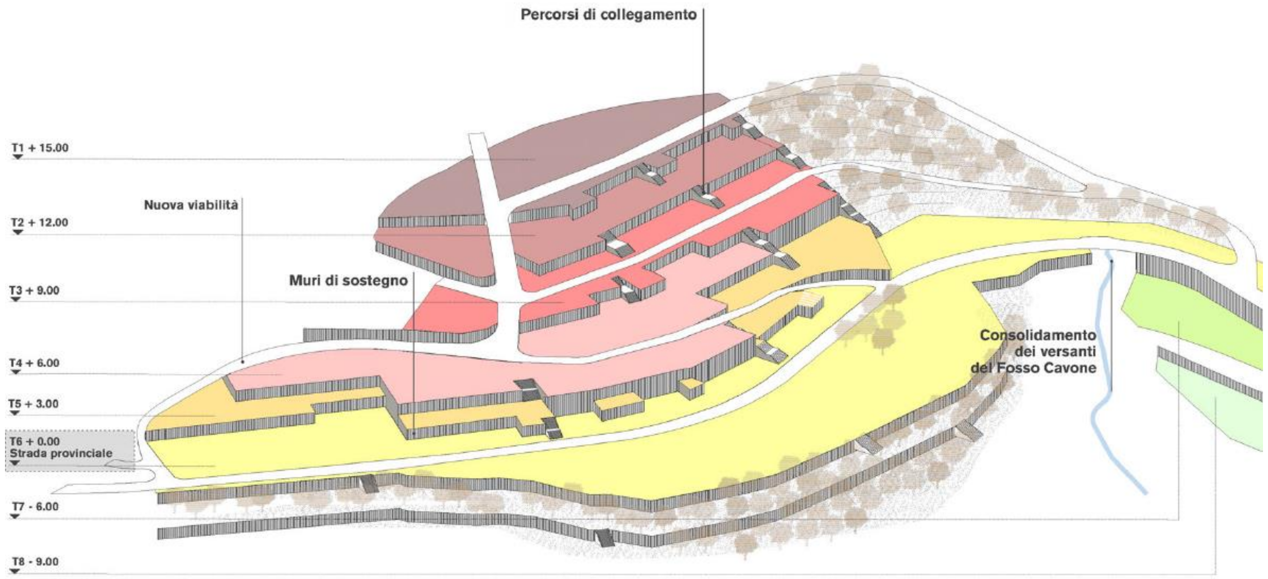
MEMORIAL PARK

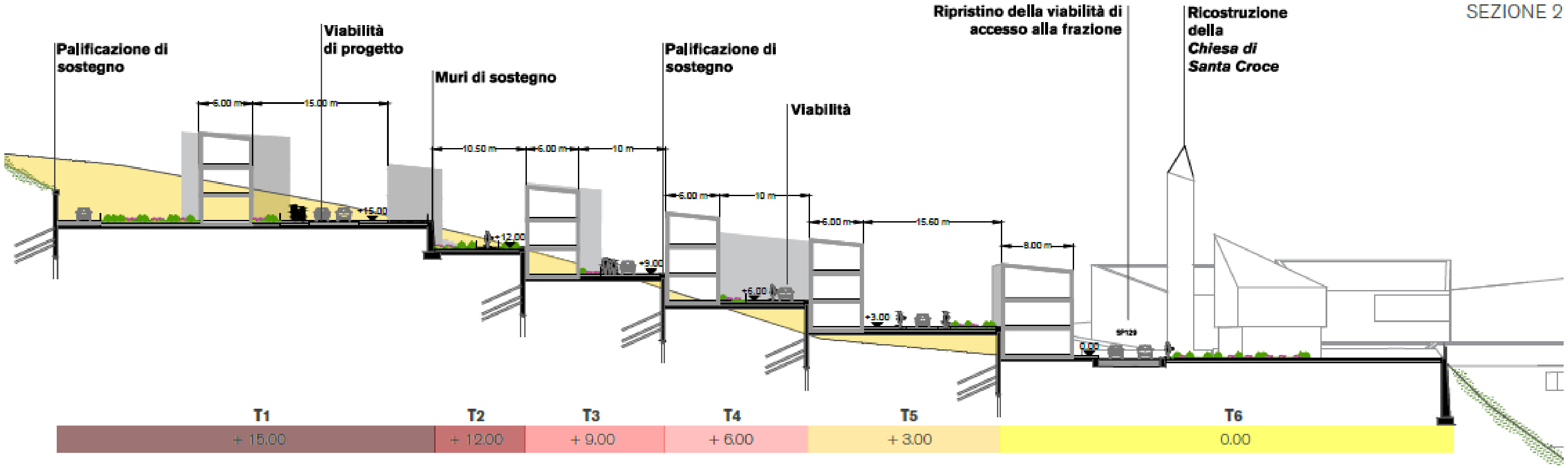
RECONSTRUCTION AND RELOCATION OF THE VILLAGE OF PESCARA DEL TRONTO.

GENERAL PLANIVOLUMETRIC LAYOUT ON AN ORTHOPHOTO BASE



RECONSTRUCTION AND RELOCATION OF THE VILLAGE OF PESCARA DEL TRONTO.



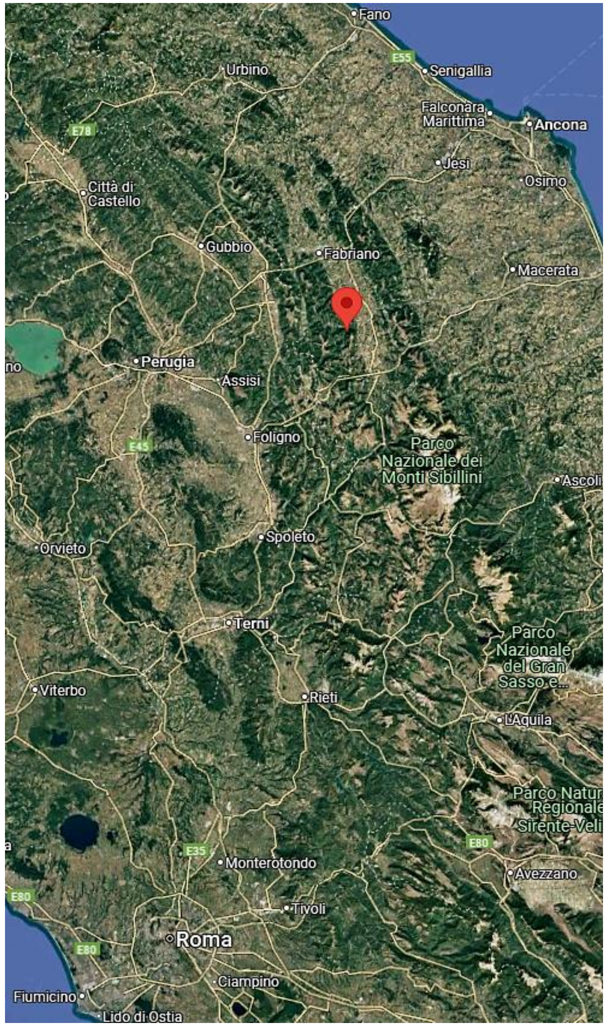


The planned structural works include:

- **Support piling**
- **Retaining walls**

Furthermore, the restoration of the **road network** and associated access points is planned, in addition to the reconstruction of the **Church of Santa Croce**.

CASE PIORACO

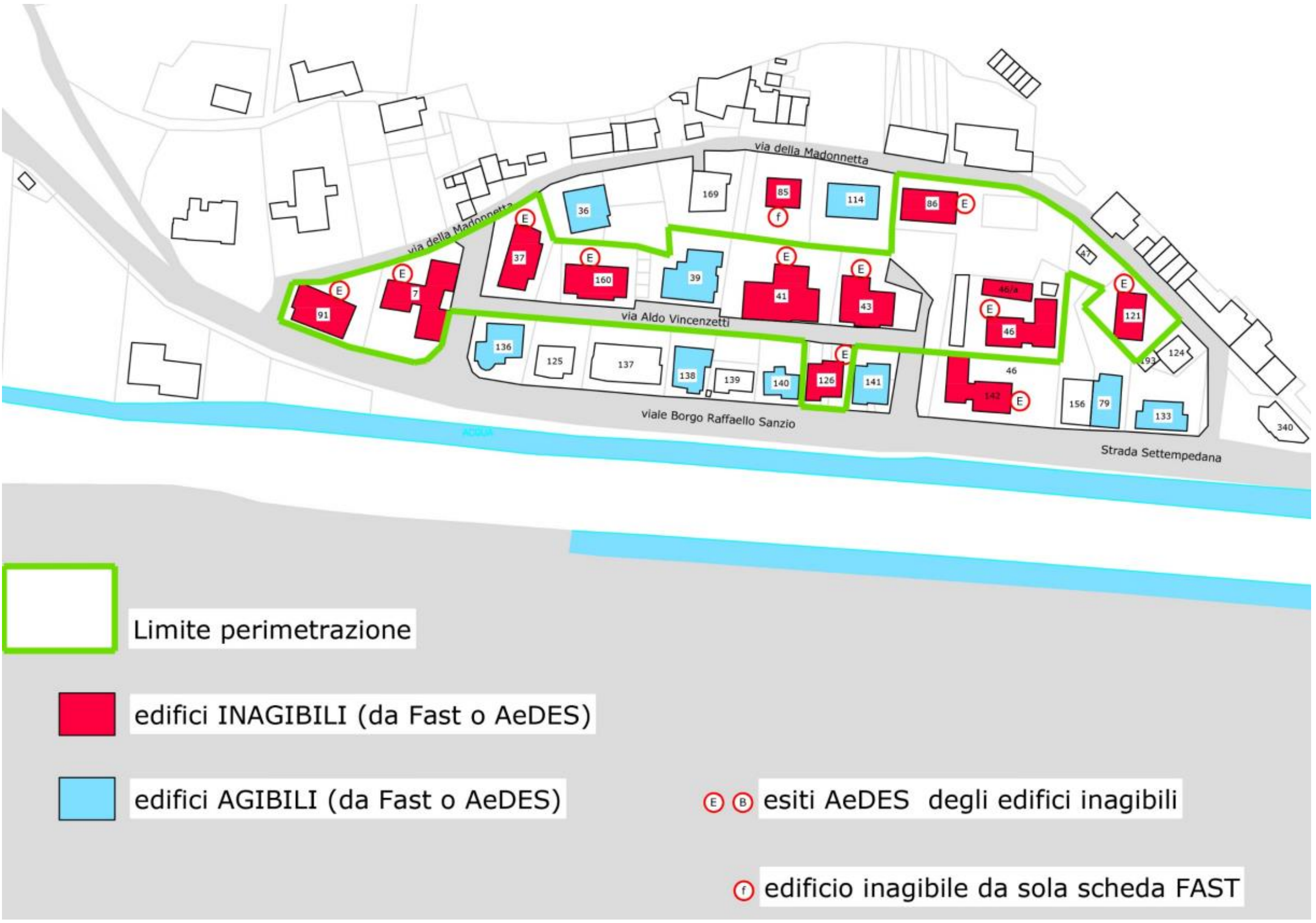


The study has ascertained two main types of hazards for the Quartiere Madonnetta:

Hydraulic Risk from Flooding: The neighborhood, located in proximity to the Potenza River, is vulnerable to flooding. The hydraulic modeling shows that the area is at risk of inundation starting from events with a return period of 50 years.

Geomorphological Risk from Debris Flows: The rocky slope overlooking the neighborhood presents conditions that can trigger rapid flows of detrital material (debris flows) in case of intense meteorological events."

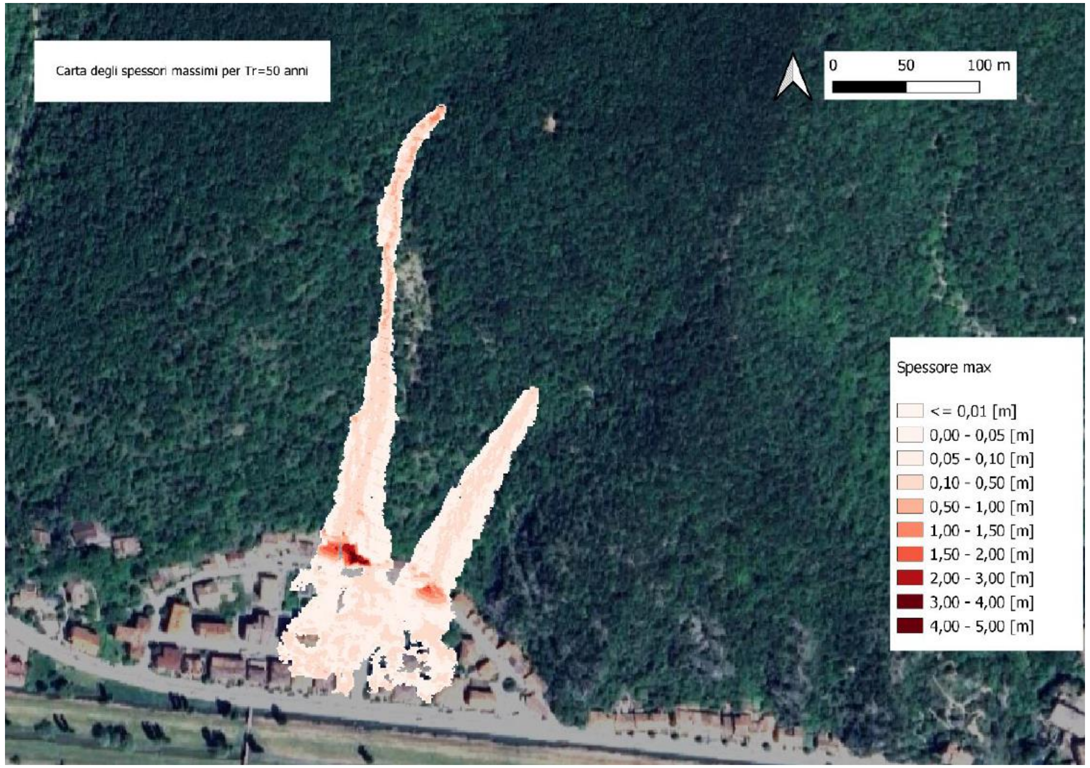
CASE PIORACO



The study conducted by the Università Politecnica delle Marche highlighted expected ground settlements (approximately 30-35 cm over the next 50 years) and significant seismic amplification.
Consequently, for reconstruction, a limit of three above-ground floors is imposed for buildings, which implies the relocation of part of the original volumes.

The intervention foresees on-site reconstruction and the relocation of residential units. Of the 63 residential units in the area, 35 private owners chose to remain on-site, while ERAP (14 units) and 14 private owners opted for relocation. Overall, 28 housing units will be relocated.

CASE PIORACO

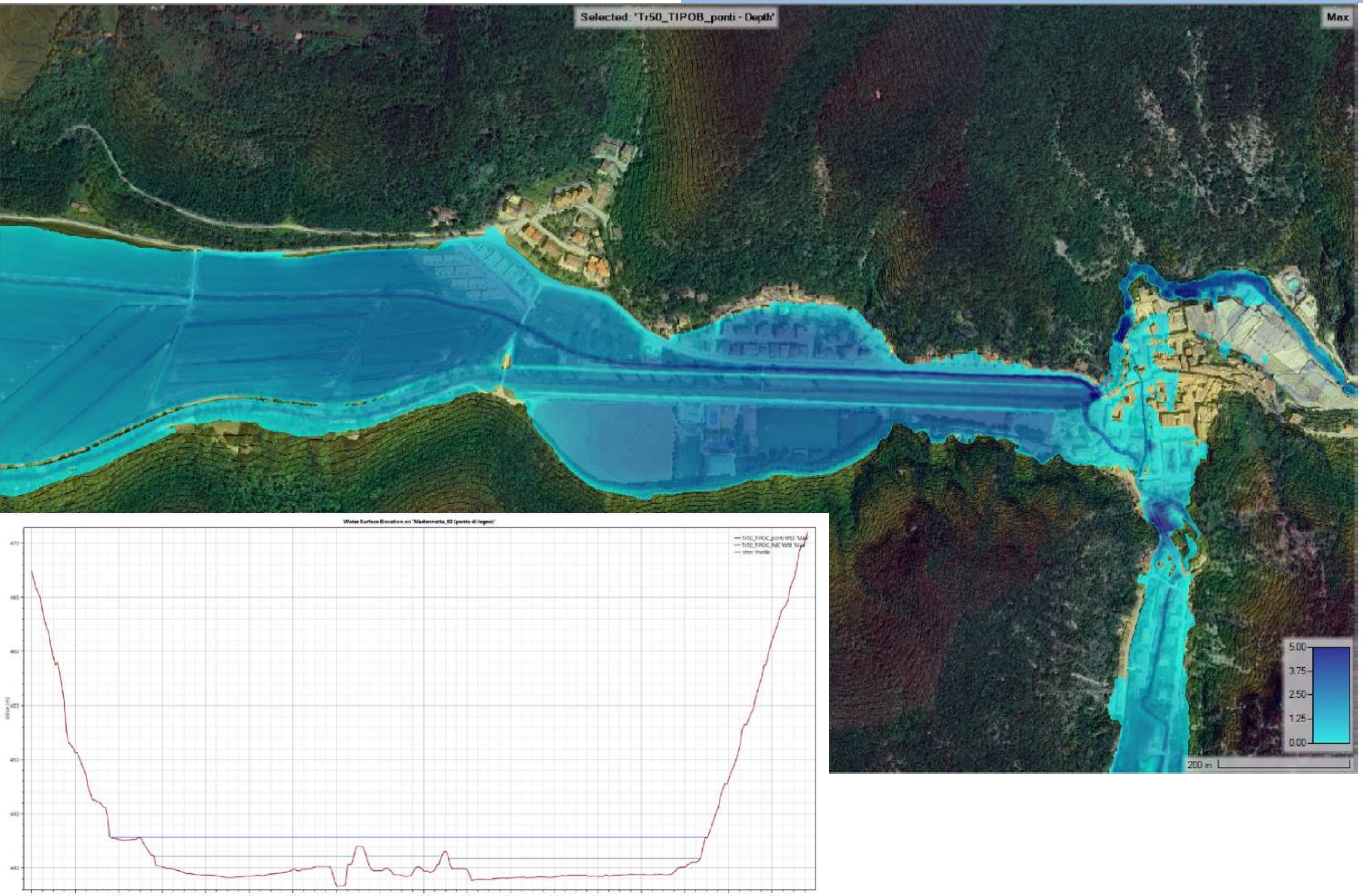


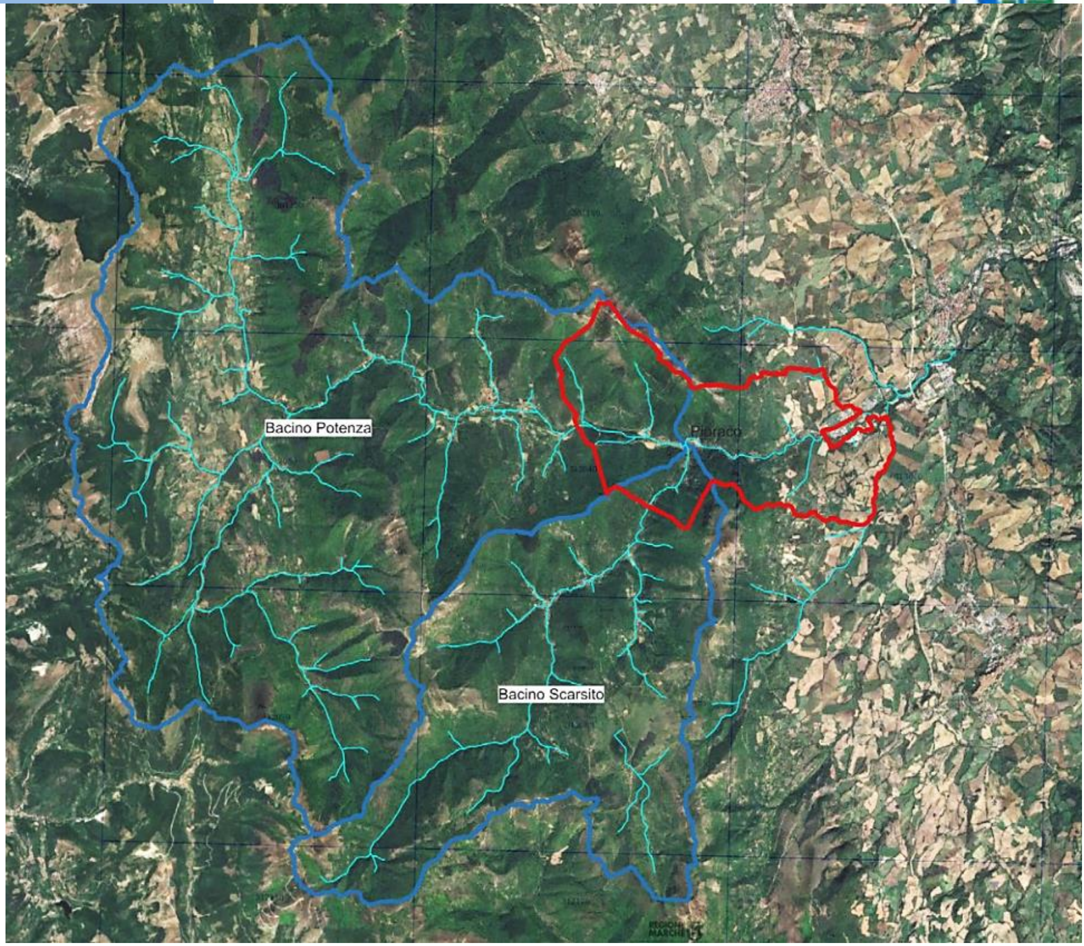
Analysis of the current state with a return period of 50 years.

Analysis of the project state with a return period of 200 years.

The Hydrogeological Asset Plan (PAI) of the Marche Region highlights active instability on the upstream slope of the Madonnetta Quarter due to collapse phenomena and rapid debris flows, with high and medium risks respectively. To mitigate these risks, the project proposes structural interventions, such as flexible anti-debris-flow steel net barriers in two sections with different resistances, and non-structural measures, including monitoring, maintenance, early warning systems, and public awareness campaigns.

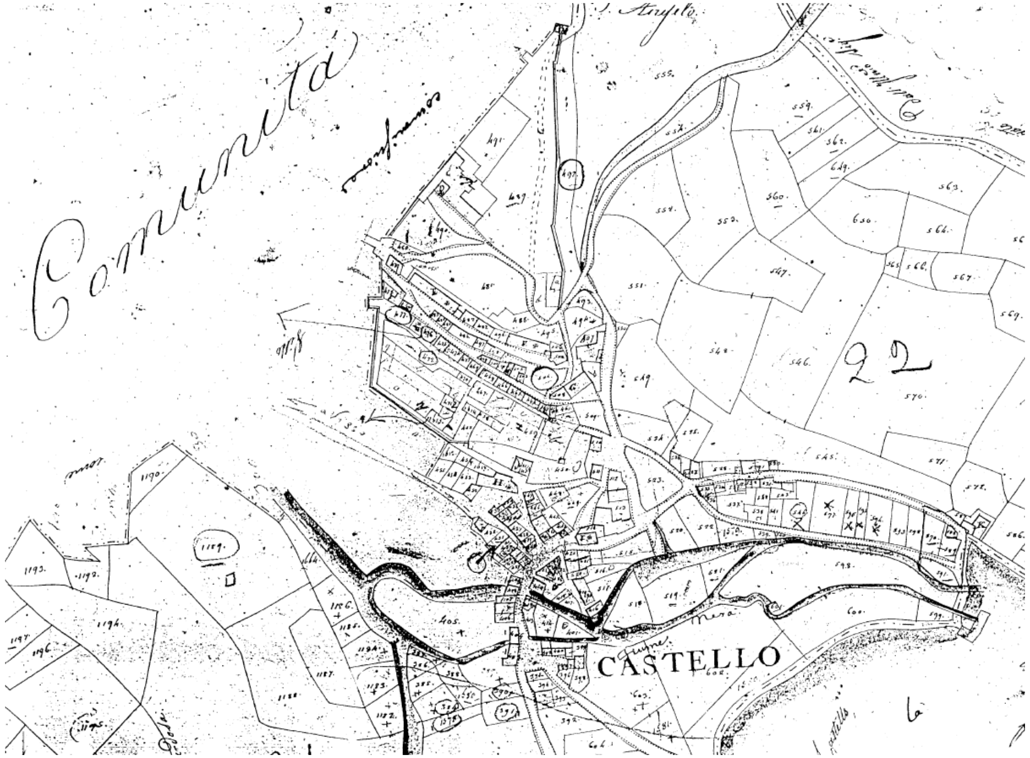
CASE PIORACO

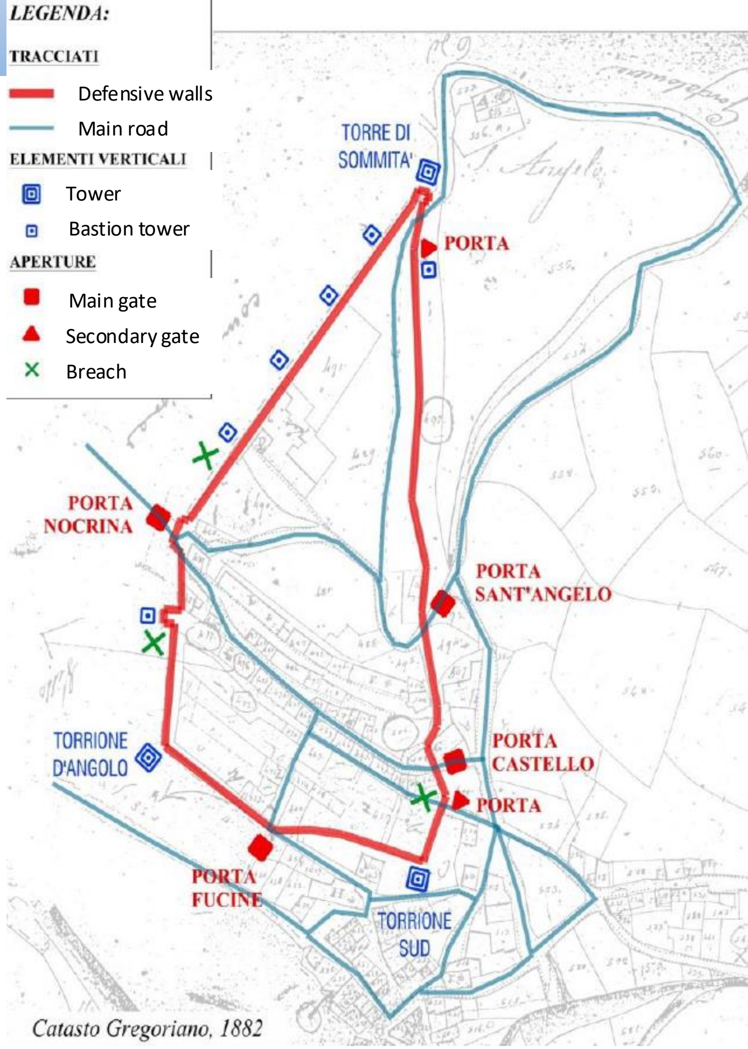




The hydraulic simulations indicate that the risk of flooding begins with meteorological events that have a return period of 50 years. To mitigate this risk, the construction of an in-line lamination basin upstream of the river is proposed, with the aim of temporarily storing excess water and controlling the flow downstream. The slope overlooking the neighborhood has the potential to trigger rapid flows of debris flow in the event of intense rainfall. The simulations show that these flows could reach the first homes in the neighborhood, which would act as a barrier, with contained energy. Structural interventions such as the construction of check dams or selective barriers are suggested to capture the coarsest material and protect the neighborhood.

CASE CASTELSANTANGELO SUL NERA - CAPOLUOGO

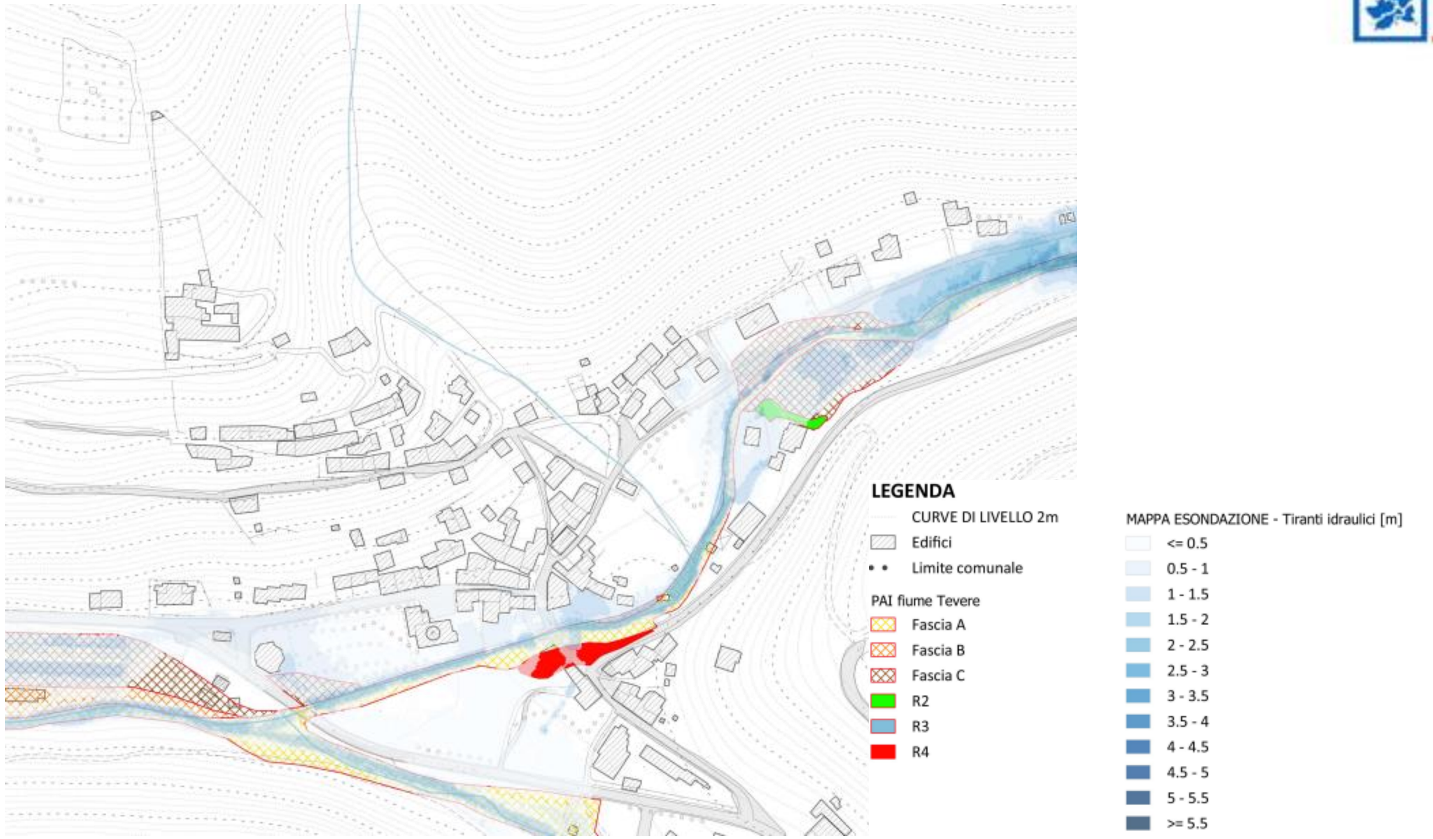




Catasto Gregoriano, 1882

The project aims to mitigate the high hydrogeological and hydraulic risk to facilitate post-earthquake reconstruction.
During the construction phase, sub-construction sites, continuous weather monitoring, and environmental protection measures, including safeguarding fish fauna, are planned.

CASE CASTELSANTANGELO SUL NERA - CAPOLUOGO

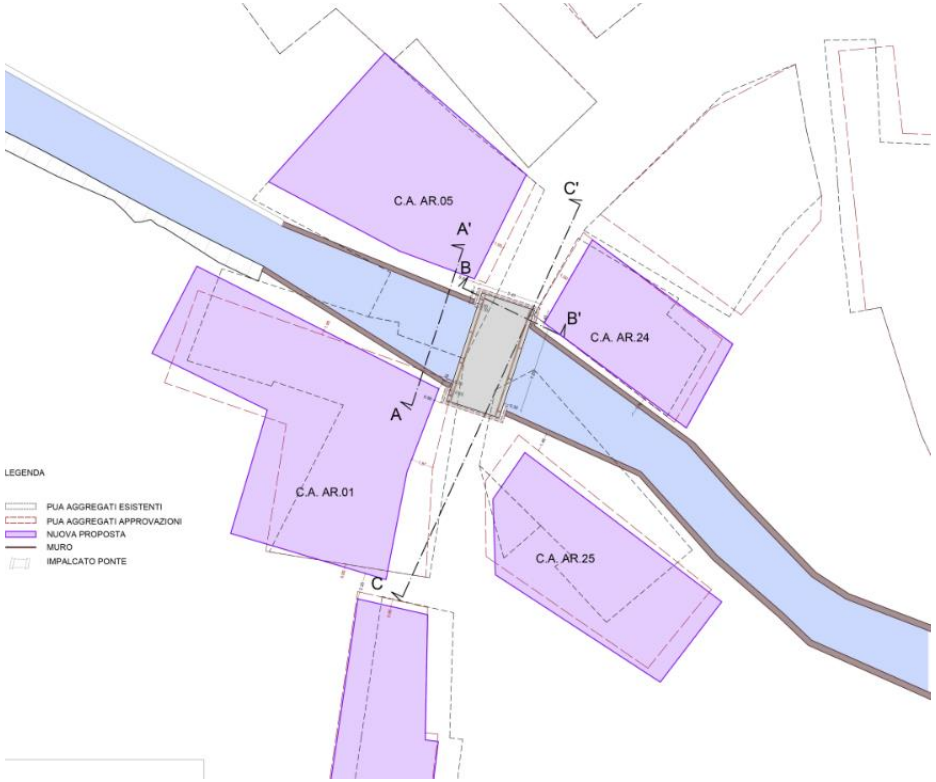


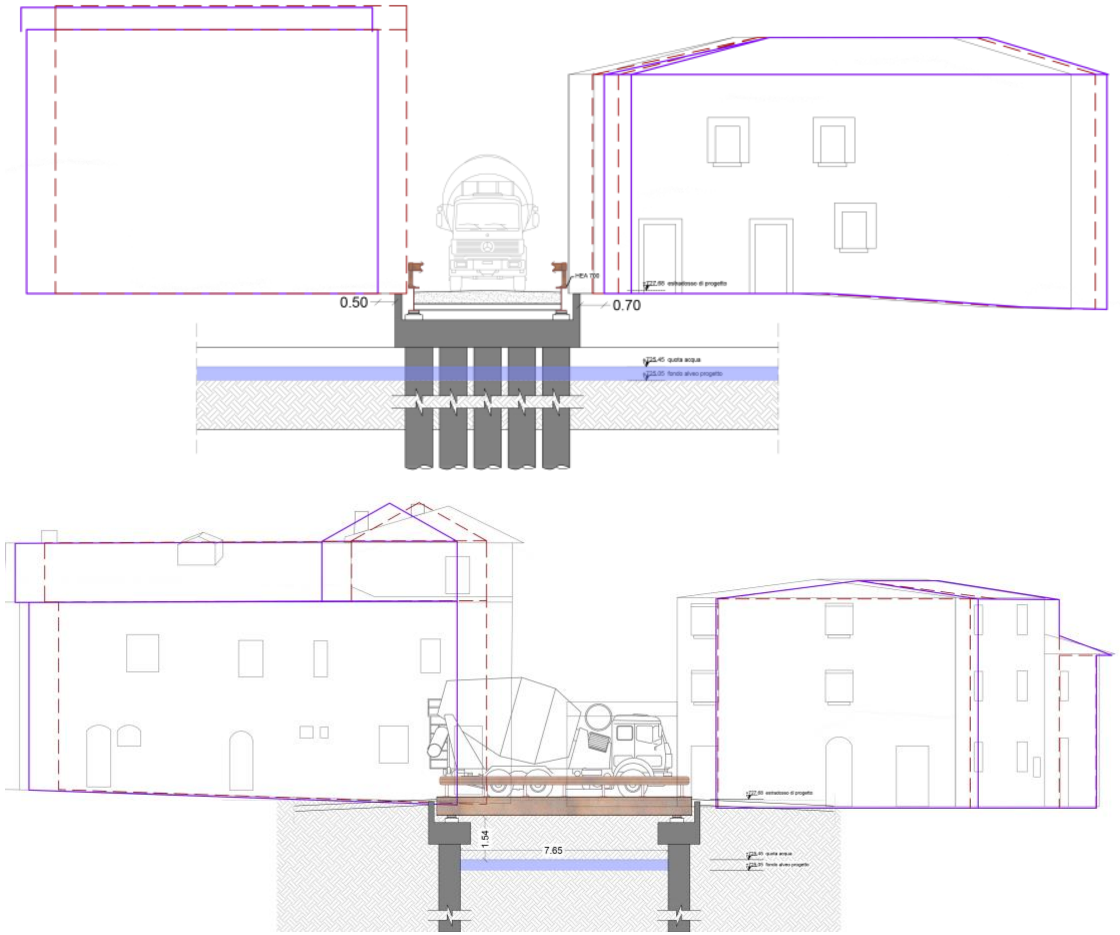
The project focuses on restoring the public infrastructure and urban areas of the town, which were damaged by the seismic events. The planned interventions are complementary to private reconstruction and are designed to guide and accelerate the reconstruction process. The plan was drafted in accordance with the Reconstruction Implementation Plan for the town, approved in 2021.

The Municipality of Castelsantangelo sul Nera, which had 241 inhabitants as of 31/12/2020, is located within the Sibilline Mountains National Park. The territory and project area are subject to various constraints and limitations:

Landscape Constraint | Hydrogeological Risk | Seismic Risk | Protected Areas

CASE CASTELSANTANGELO SUL NERA - CAPOLUOGO





The text describes an intervention involving the widening of the hydraulic section of the Nera river, alternating between the right and left sides depending on the presence of a road. Due to these modifications, existing bridges that are insufficient for water flow will be upgraded, which will also require a change to the overlying road surface.

CASE CASTELSANTANGELO SUL NERA - CAPOLUOGO

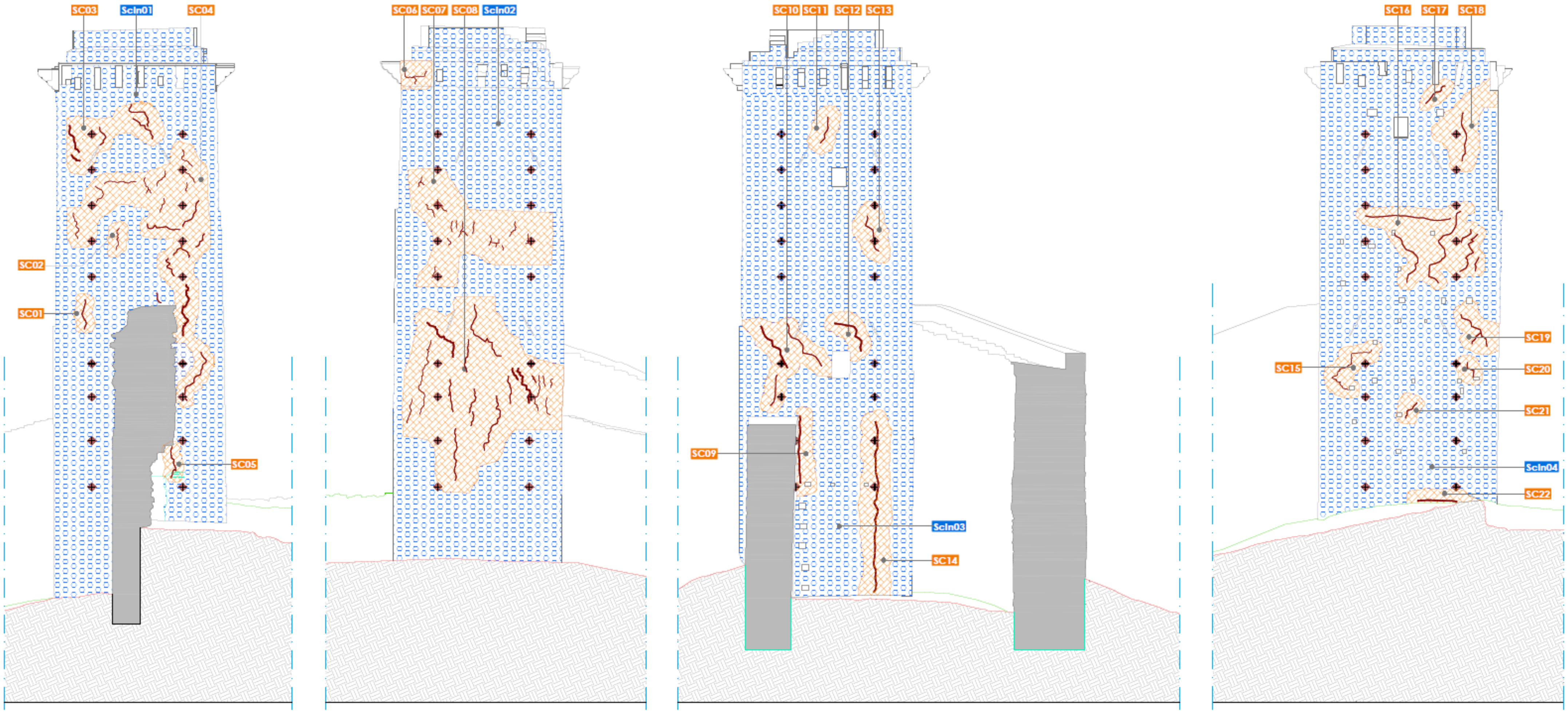
CASE CASTELSANTANGELO SUL NERA – DEFENSIVE WALLS

Historical Evolution of Castelsantangelo sul Nera

- **Pre-Roman Era:** Limited evidence suggests the presence of fortified settlements ("castellieri") and a forest-pastoral economy. The area was a crucial transit point for transhumance.
- **Roman Age:** Despite scarce direct evidence, the strategic position of the territory, part of the *ager Nursinus* and *Sabina*, led to the consolidation of pre-existing transhumance routes.
- **Middle Ages:** Significant development under the Duchy of Spoleto, with the emergence of fortified villages ("incastellamento"). Castelsantangelo sul Nera is documented from 1249 and joined the Municipality of Visso. In the 13th century, it became a fortified center with triangular walls.
- **The Urban Walls:** Built in the 13th century with local stone, they featured a double curtain, considerable thickness, at least nine towers/turrets, and six main and secondary gates (e.g., Porta S. Croce, Porta Fucine, Porta Nocrina, Porta S. Angelo/S. Martino, Porta Castello/S. Angelo), some with complex defensive structures.
- **Post-Medieval Age:** Characterized by expansions of religious and civil buildings. The Battle of Pian Perduto (1522) was a key event against Norcia. Conflicts between communes for commercial control influenced architecture and defense works.
- **Modern Era:** Administrative independence was achieved in 1913 with the French introduction of the "municipio" (municipality). Subsequently, the area was enhanced with its integration into the Monti Sibillini National Park and the development of a ski resort.

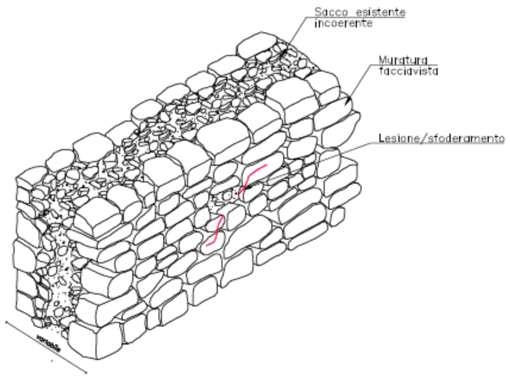
Map of 1808

CASE CASTELSANTANGELO SUL NERA - MURA

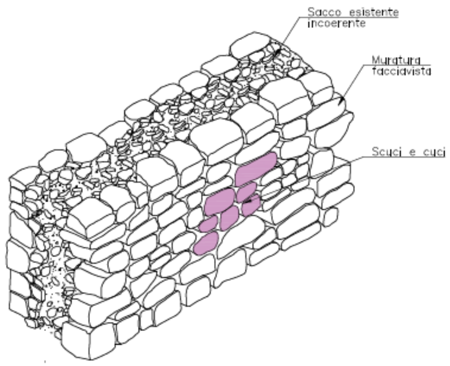


The walls and towers of Castelsantangelo sul Nera's historic center have suffered widespread collapses, damage, and detachments due to the 1997 and 2016 earthquakes, rendering the area a "red zone." The definitive project aims at the consolidation, restoration, repair, and reconstruction of these fundamental historical structures, with the goal of improving their seismic resistance to prevent future damage and preserve the monumental heritage, which is crucial for the village's identity.

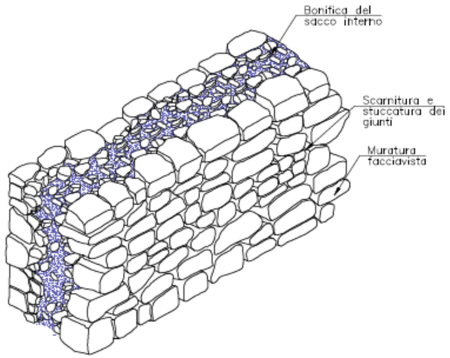
CASE CASTELSANTANGELO SUL NERA - MURA



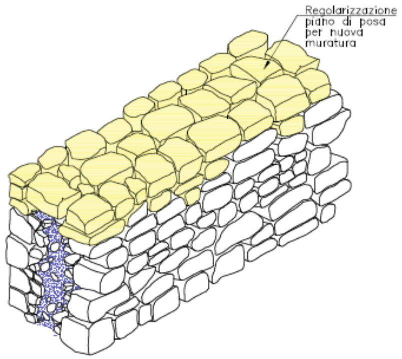
Current state



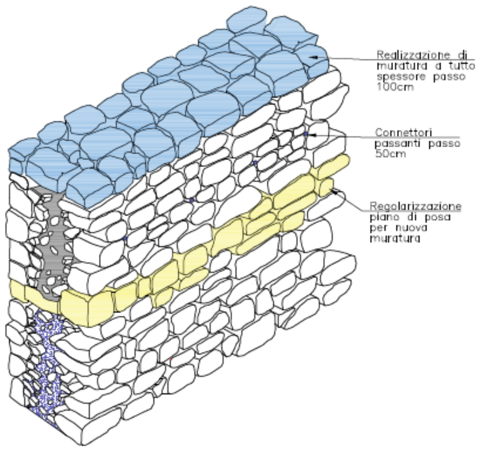
Phase 1, restoration of the wall facing's integrity and repair of lesions using the "sew-unstitch" technique.



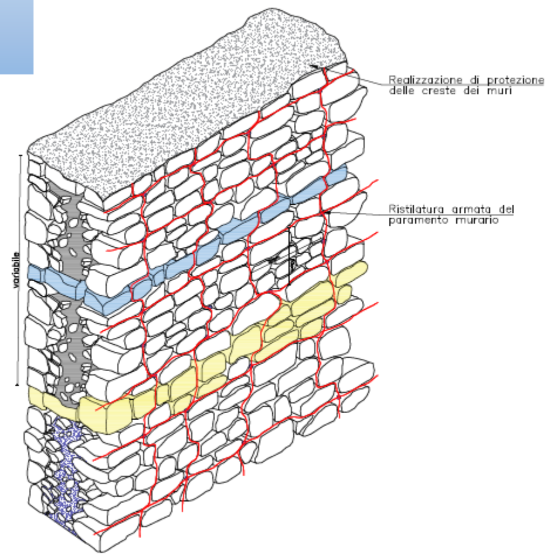
Phase 2 - consolidation of existing masonry by grouting mortar joints and injecting lime-based mortar



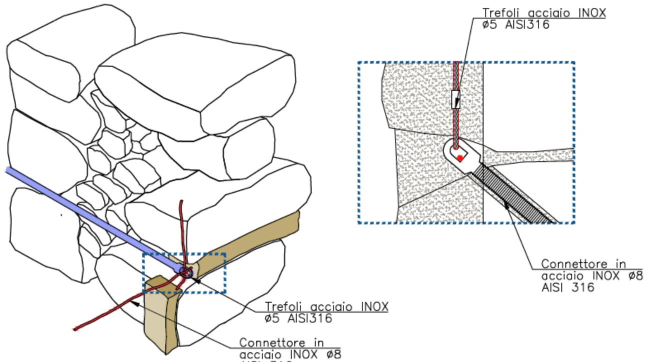
Phase 3 - Connection of the wall facings through "sew-unstitch" for subsequent reconstruction of the collapsed portion of the wall facing



Phase 4 - Construction of new masonry with elements to be sourced on site through the creation of diatones and the formation of rubble masonry with a lime-based binding mixture.



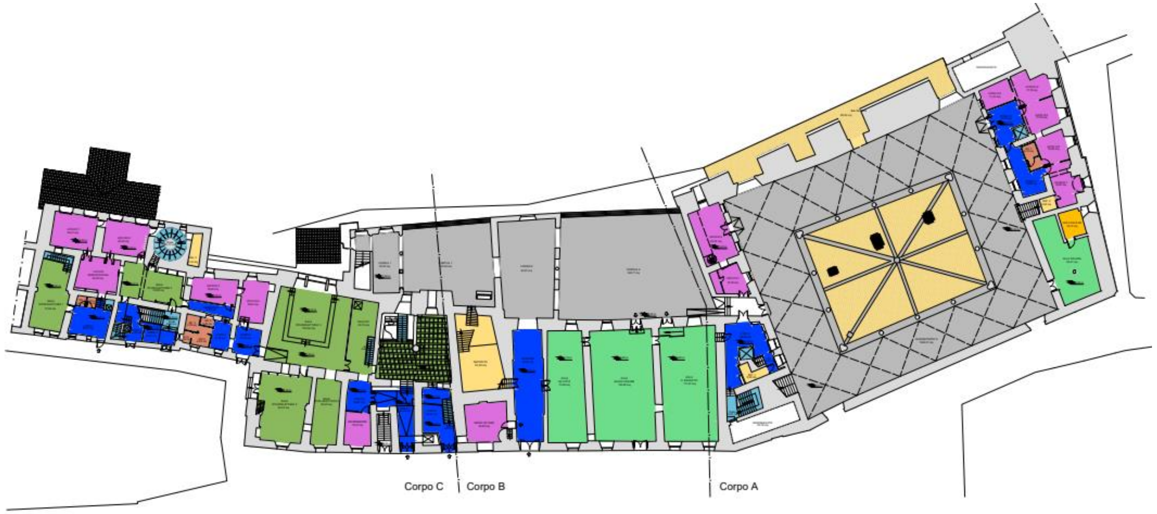
Phase 5 - Reinforcement of the wall facing by armed repointing in the masonry joints and through connectors (5 per square meter), grouting of the joints, and creation of protection for the tops of the masonry walls using a lime-based mortar coping.

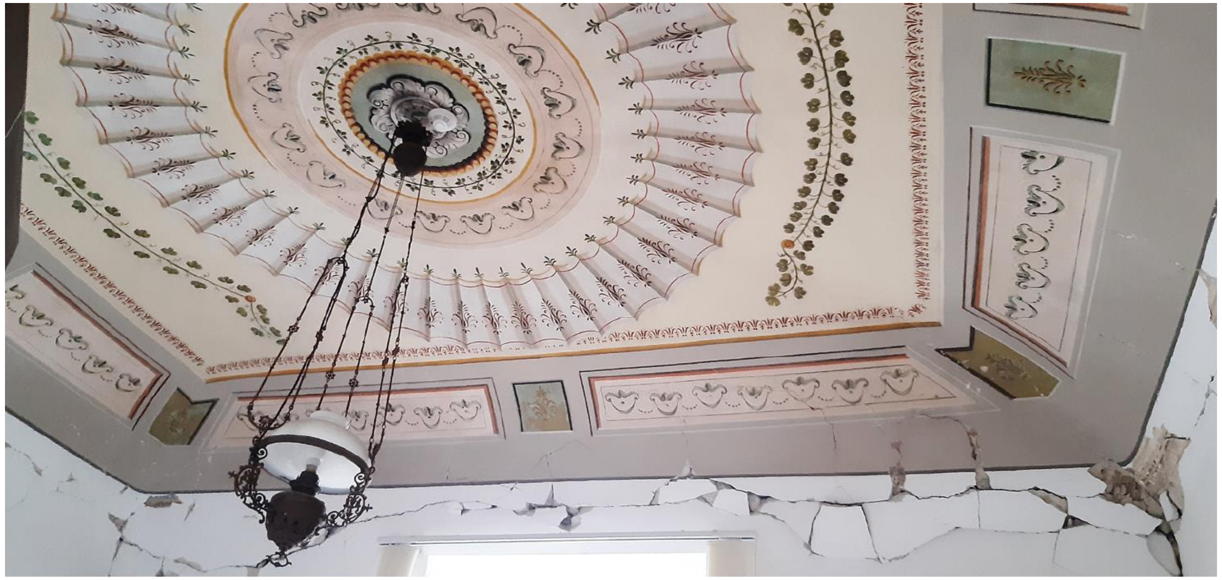


CASE PALAZZO DUCALE (DA VARANO)- CAMERINO

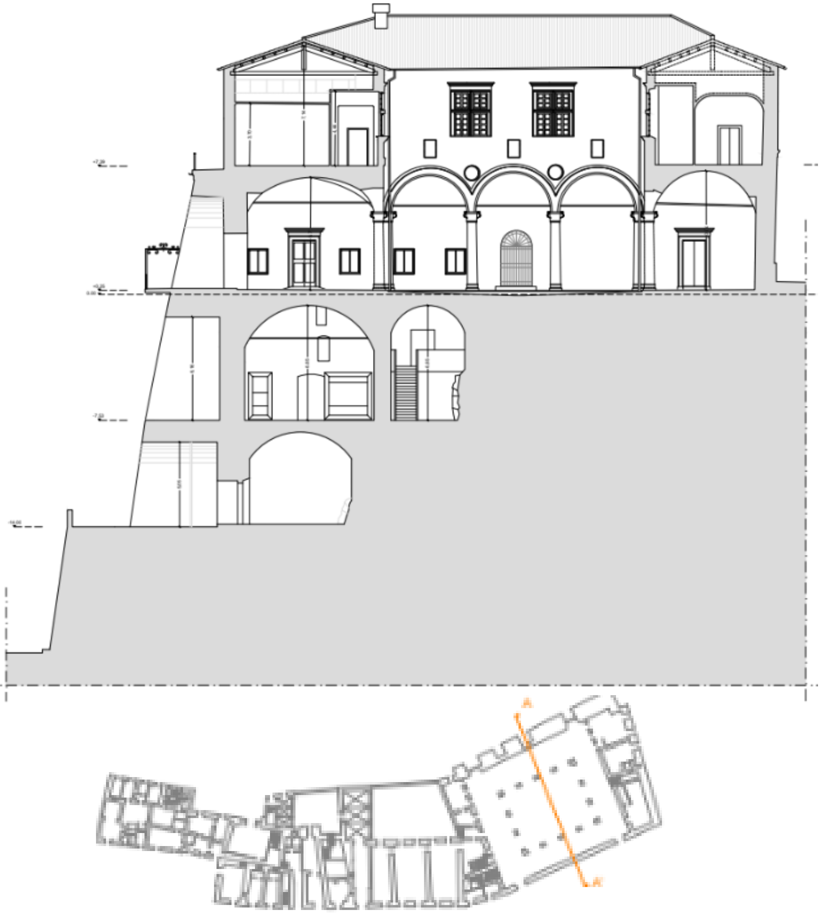
The Palazzo Ducale is a complex structure composed of multiple interconnected aggregates, with historical sections dating back to 1250 ("Case vecchie"), a tower and part of the original city walls, the Palazzo di Venanzio (early 1300s), the "Palazzo novo" (Quadriportico, late 1400s), and the "Logge" (1527).

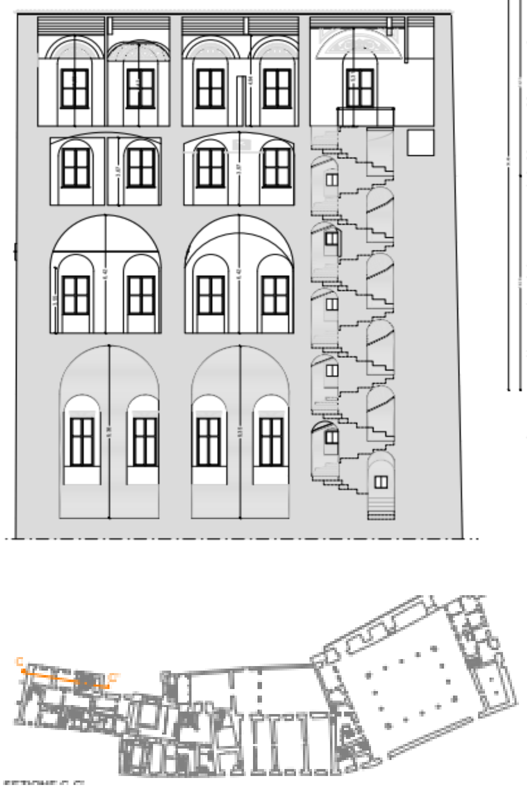
The building has a long history of seismic damage and subsequent restoration and consolidation works, with notable interventions after the 1799, 1850, 1950, 1957, 1968, 1973-76, and 1997 earthquakes.



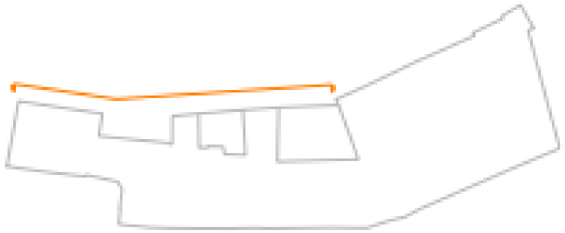


CASE PALAZZO DUCALE (DA VARANO)- CAMERINO





PROSPETTO VERSO VALLE - Lato Case Vecchie - Orto Botanico



CASE PALAZZO DUCALE (DA VARANO)- CAMERINO

CASE PALAZZO DUCALE (DA VARANO)- CAMERINO

Geometric survey: Use of laser scanner to obtain 3D point clouds, measurement of sections, plumb deviations, and stone disintegration state. Plumb deviation for each column (Column 10: -11.6 cm; Column 11: 13.1 cm; Column 12: -14.5 cm; Column 13: -10.1 cm; Column 14: 9.8 cm).

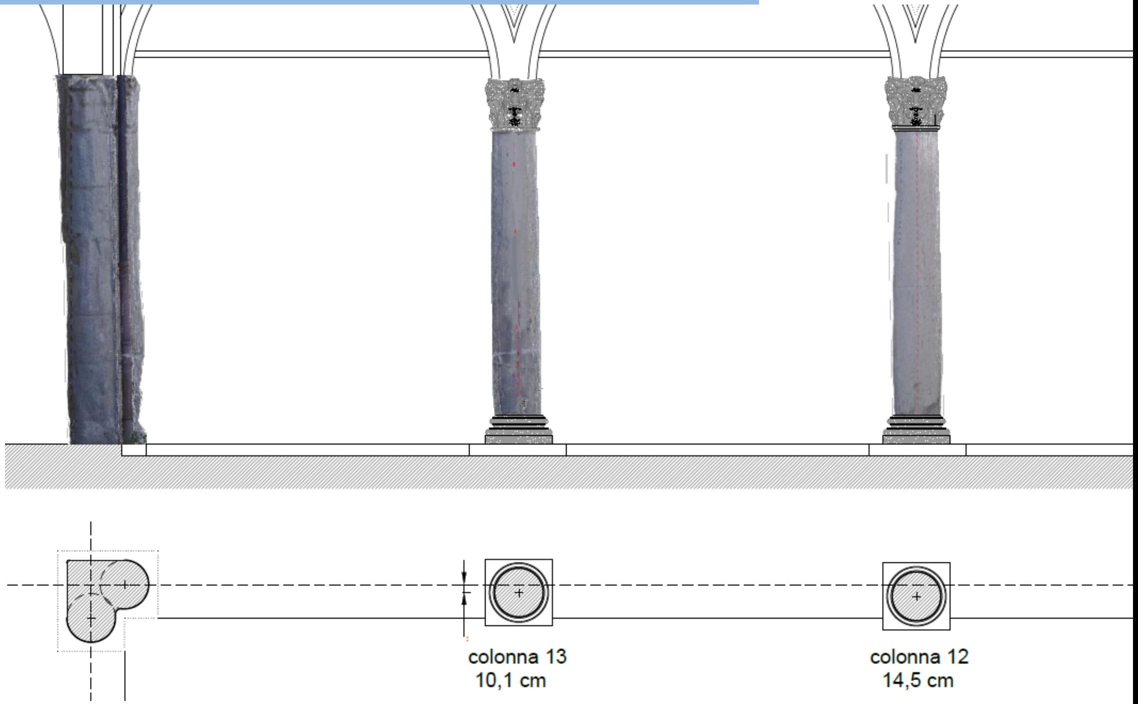
Historical research: Analysis of documentation related to structural reinforcement interventions on the columns between 1975 and 1979 with the insertion of steel bars.

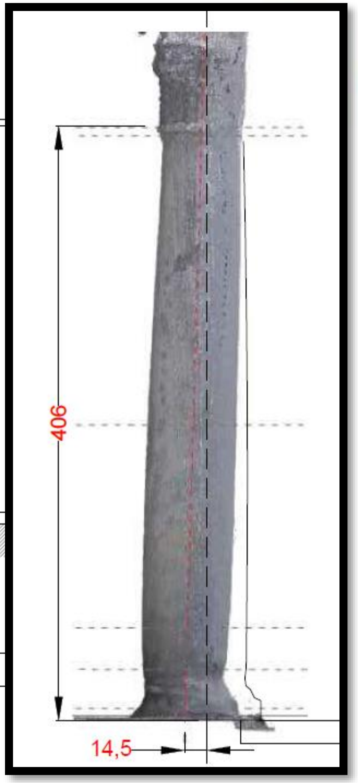
Ultrasonic tests: Performed at the bases, mid-span, and tops of the columns.

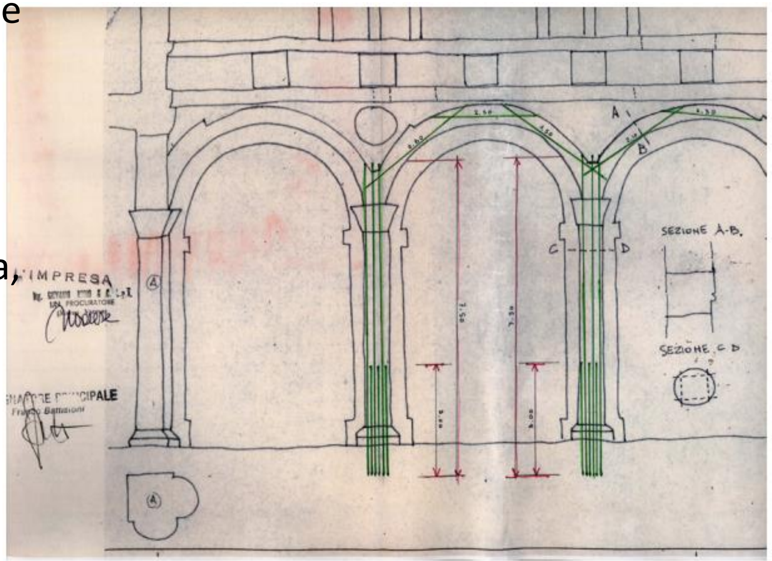
Radiographs: Performed on 4 columns by a specialized company.

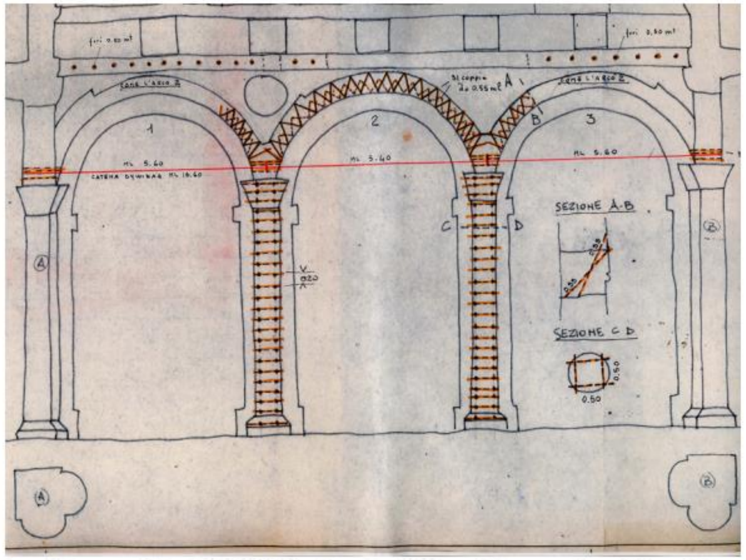
Brief historical notes: Describes the late fifteenth-century construction of the palace and the interventions undergone by the columns in the eighteenth century (incorporation into brick masonry) and from 1975 (removal of masonry and reinforcement with steel bars).

Degradation: Describes the forms of degradation (exfoliation, washout, stains, erosion, loss, biological patina, capillary rise) for plaster and stone, with their respective causes and proposed interventions.







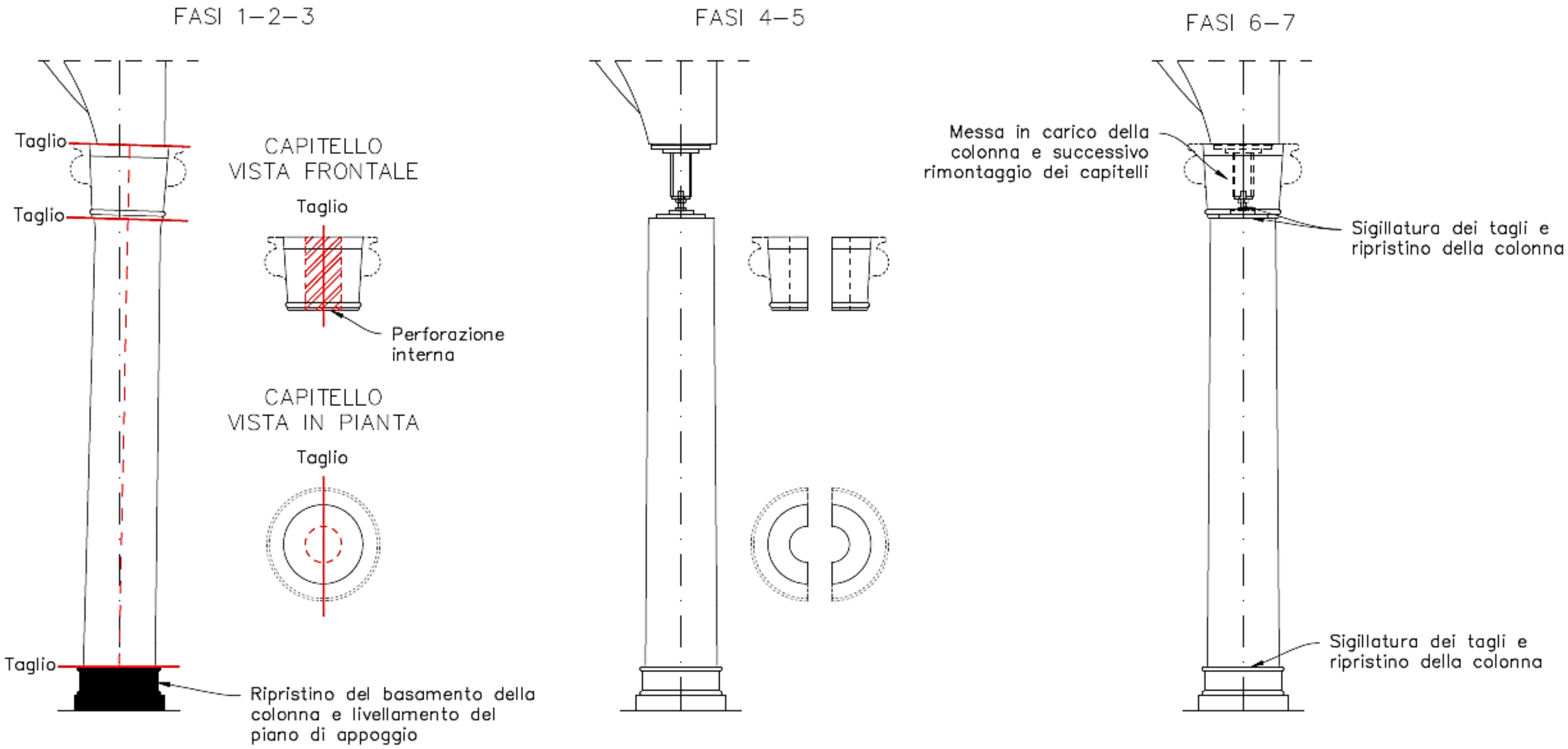


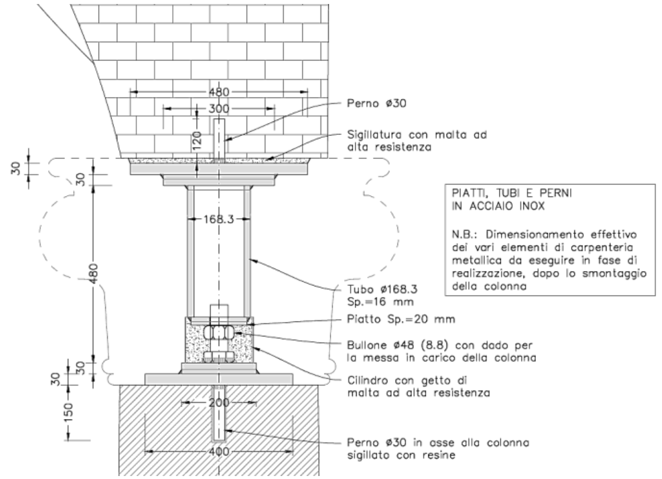
CASE PALAZZO DUCALE (DA VARANO)- CAMERINO

WORK PHASES FOR COLUMNS WITH ECCENTRICITY GREATER THAN THE LIMIT (7 cm)

1. **Disassembly of the column and the upper capital:** This involves making three cuts: two along the column shaft (one at the base and one at the top), and one at the top of the capital.
2. **Cutting the capital in half and creating an internal perforation:** This perforation will subsequently house the metal framework for loading the column after reassembly.
3. **Restoration of the column base and leveling of the bearing surface:** This step is crucial to eliminate the eccentricity.
4. **Reassembly of the column shaft.**
5. **Installation of the metal framework** for loading at the top of the column.
6. **Loading of the column and reassembly of the two halves of the capital.**
7. **Closing the cuts and restoring the column surfaces.**

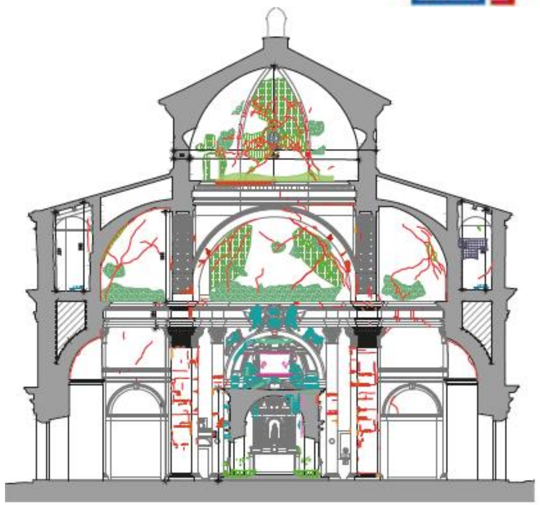
N.B.: The disassembly of the affected columns must occur after prior shoring (propping).



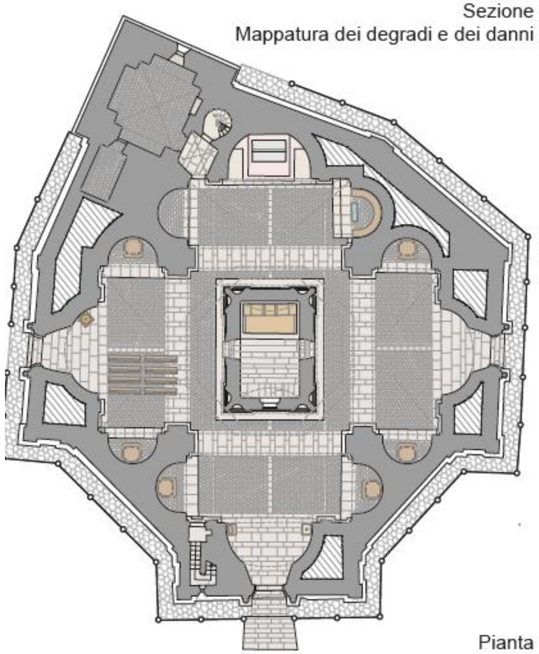


SANTUARIO DI MACERETO - VISSO

The Santuario originated from a miraculous event in 1359. Over centuries, structures like the fountain (1521-1524), the Church (1527-1569), Palazzo delle Guaite, Casa del Pellegrino, and Casa dell'Armata were added. The complex has undergone previous restorations, notably after the 1979 earthquake.

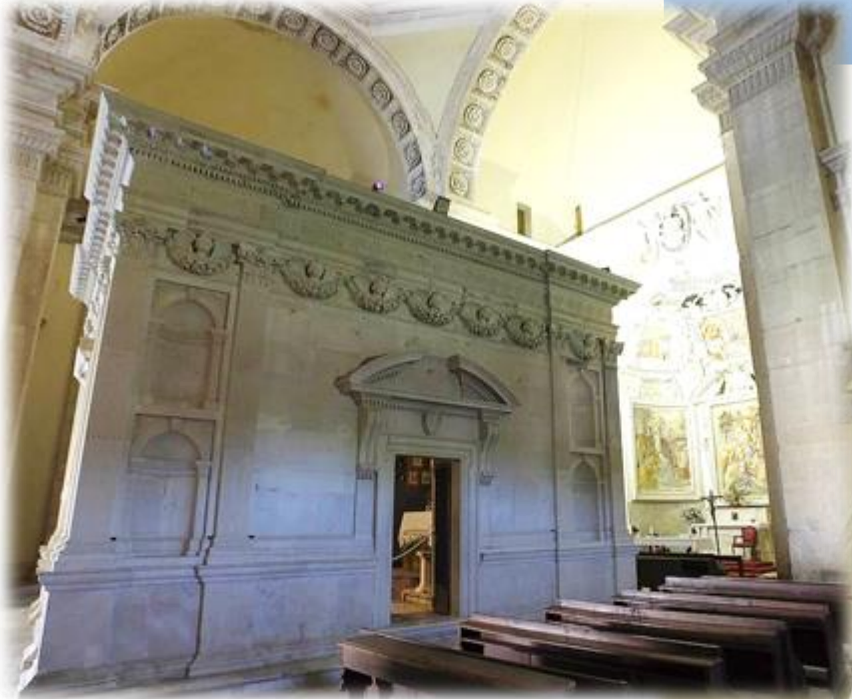


Sezione
Mappatura dei degradi e dei danni



Pianta
Individuazione aree liturgiche

SANTUARIO DI MACERETO - VISSO



ANCIENT CHAPEL INCORPORATED INTO THE NEW BUILDING CLAD IN LOCAL STONE

DECORATED DOME ABOVE THE ALTAR OF MATERNITY

FRESCOED APSE

SANTUARIO DI MACERETO - VISSO

The church exhibits widespread cracking, deterioration from humidity and atmospheric agents, and damage to portals, columns, cornices, and the drum. The lantern and bell gable were dismounted due to earthquake damage.
The roof tiles are damaged, risking infiltrations. Internally, the central vault, ribs, and decorative elements show significant cracking, detachments, and material loss. The sacristy and bell room also suffer from seismic damage, humidity, and water infiltration.

- ✓ **Exterior**: Verification and securing of decorative elements, surface cleaning, dismantling and reassembly of stone elements for structural intervention (tie rods), and restoration of decorative stone elements.

- ✓ **Roof**: Dismantling, repair, structural consolidation, and installation of a waterproofing sheath. The lantern and bell gable will be reinstalled with new metallic reinforcements and restored.

- ✓ **Interior**: Repainting and re-plastering of surfaces where necessary, cleaning and chromatic matching of original plaster. Original terracotta and stone floors will be cataloged, dismantled, and reinstalled after structural consolidation of the vaults. Stucco angelic figures on the main altar will be secured and restored.

SANTUARIO DI MACERETO - VISSO

Reinforcement of masonry through the application of unidirectional basalt fabric strips

Consolidation of the incoherent internal core through the installation of pipes for lime grout injection

Consolidation of the incoherent internal core through the installation of pipes for lime grout injection