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*AMBIENTE, TERRITORIO E CULTURAL HERITAGE*
*PATRIMONIO DA MANUTENERE PER I NATIVI DIGITALI*

# IL PATRIMONIO DA CONSERVARE E CUSTODIRE

***Luigi Petti***

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*Nepal, 2015*

*Italy, 2012*

*Italy, 2009*

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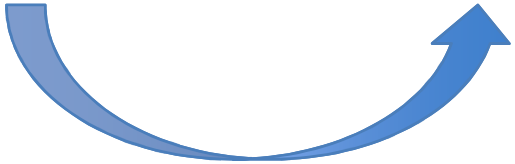
***Scientists***
*Eugene Viollet-le-Duc*
*John Ruskin*
*Camillo Boito*
*Luca Beltrami*
*…*

**Consequence**

**Conservation** **Restauration**



***Charts***
*Athene Chart 1931*
*Venice Chart 1964*
*Nara Chart 1994*
*…*

**Performance**

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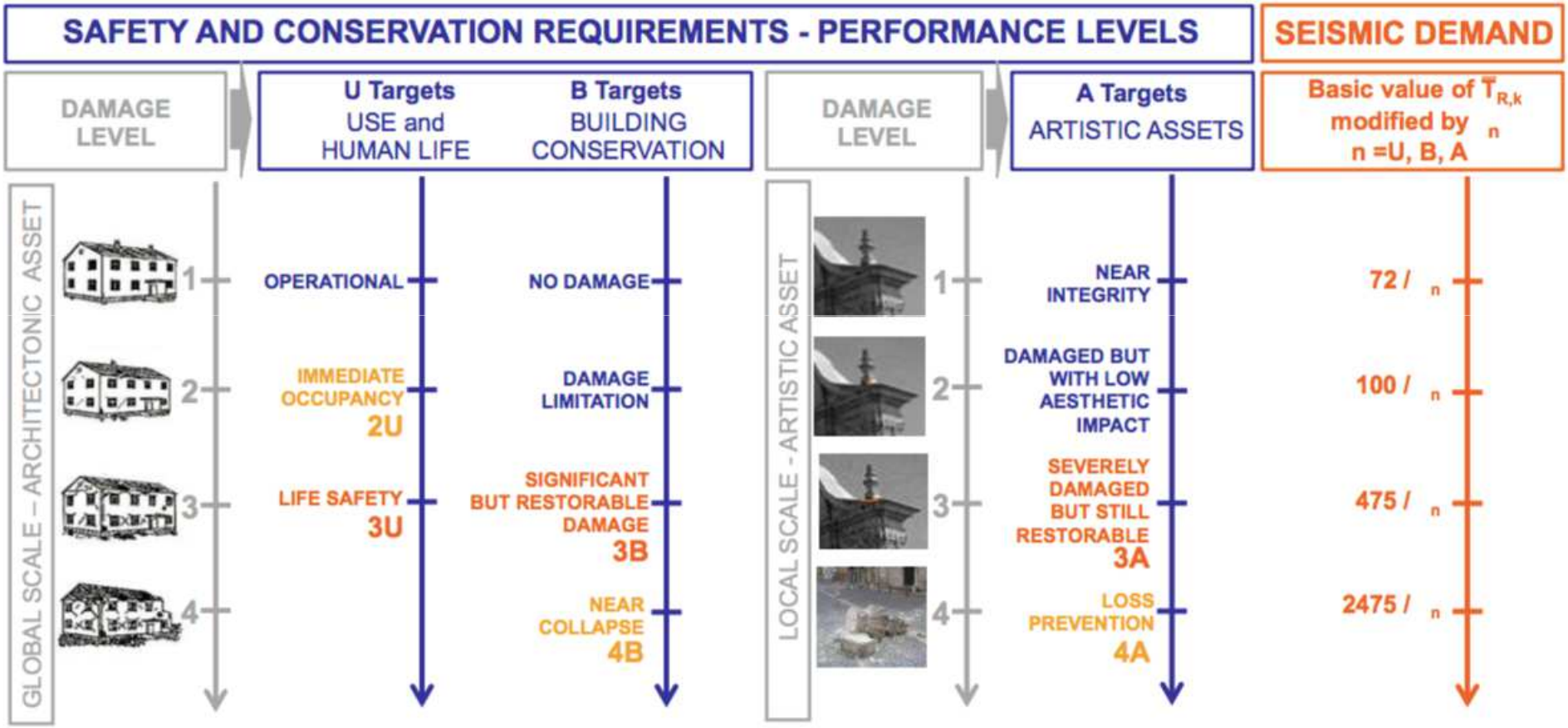
# Performance




Lagomarsino and Cattari, 2013

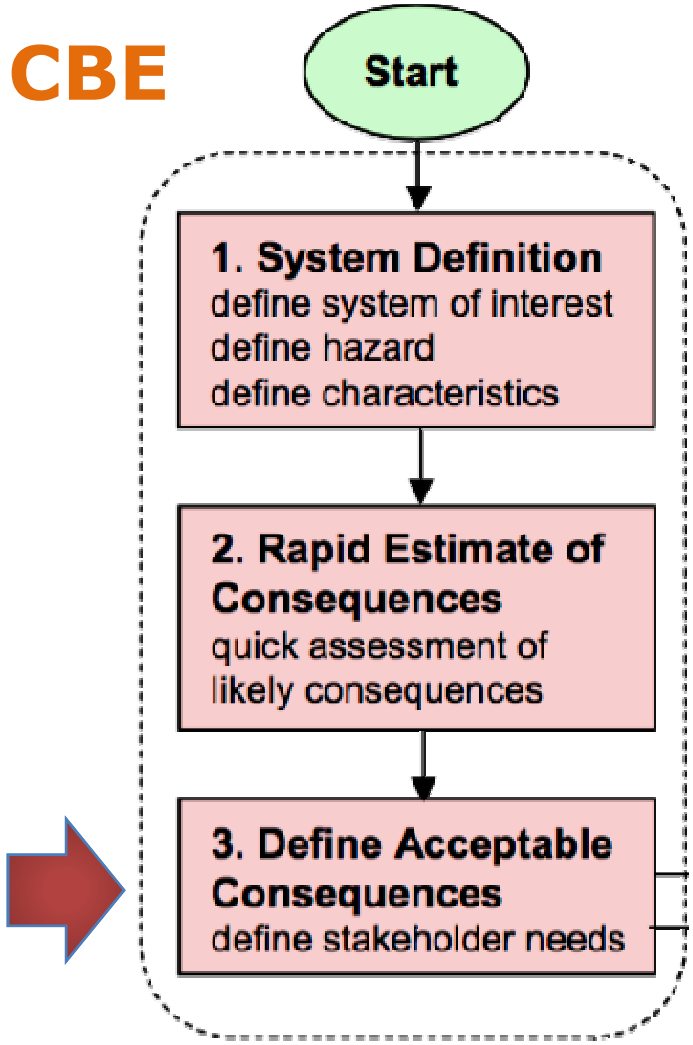
# Consequence

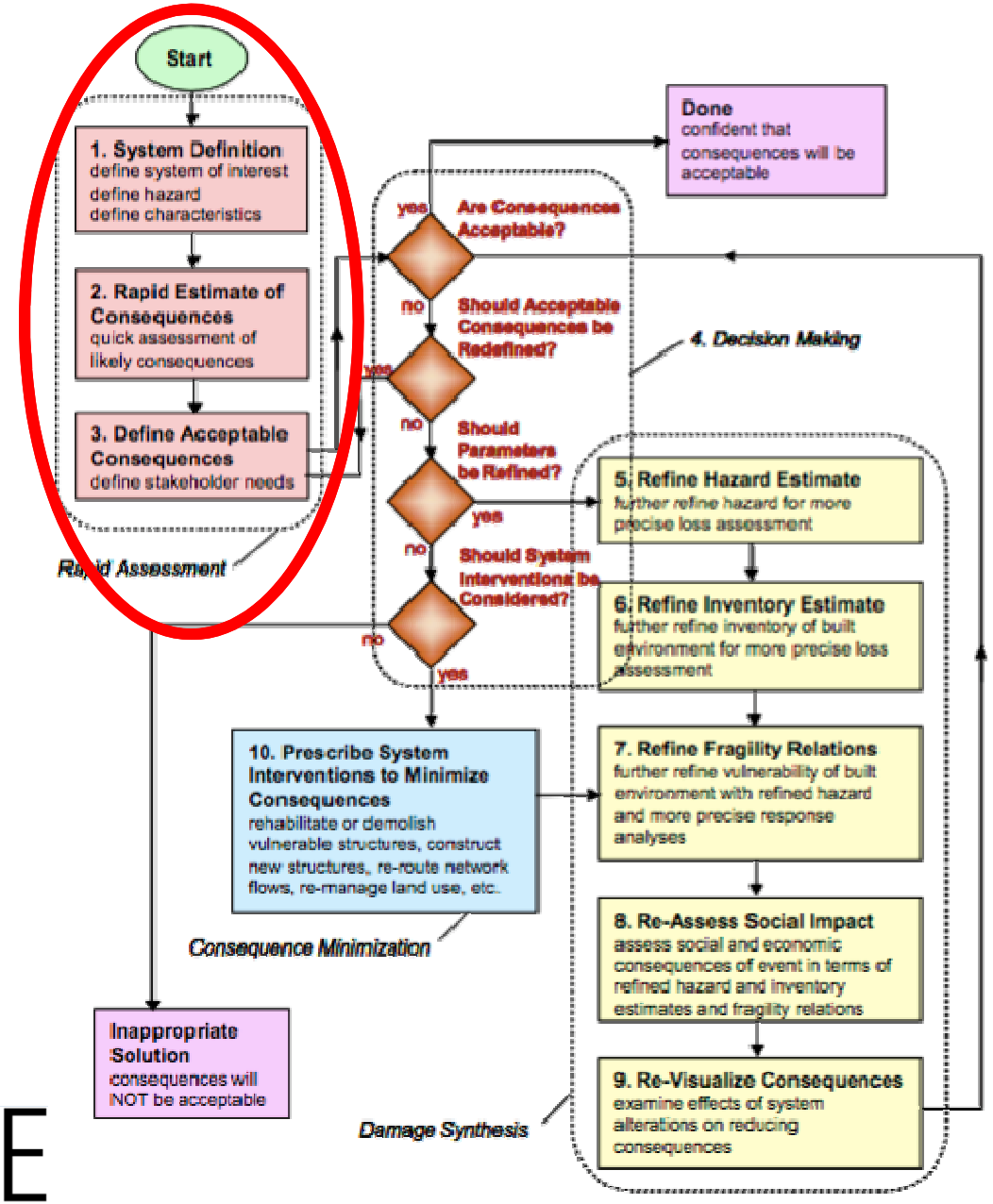
*Nepal, 2015*

**CBE Consequence-Based Engineering is a new paradigm for seismic risk reduction across regions or systems, which quantifies the risk to societal systems and subsystems by working with policy-makers, decision-makers and stakeholders to ultimately develop risk reduction strategies and implement mitigation actions.**

Mid-America Earthquake Center, 2002

# CBE

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# Alcune (in)Experience

*Strutture povere*

*Onna*
*L'Aquila, 2009*

# Alcune (in)Experience

*Uso improprio di materiali e modifica schemi statici*

*City Hall*
*Sant'Agostino, Ferrara*
*Emilia 2012*

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# Some (in)Experiences

*Uso improprio di materiali tradizionali*

*Arch of Costantino*
*Benevento, Italy 2012*

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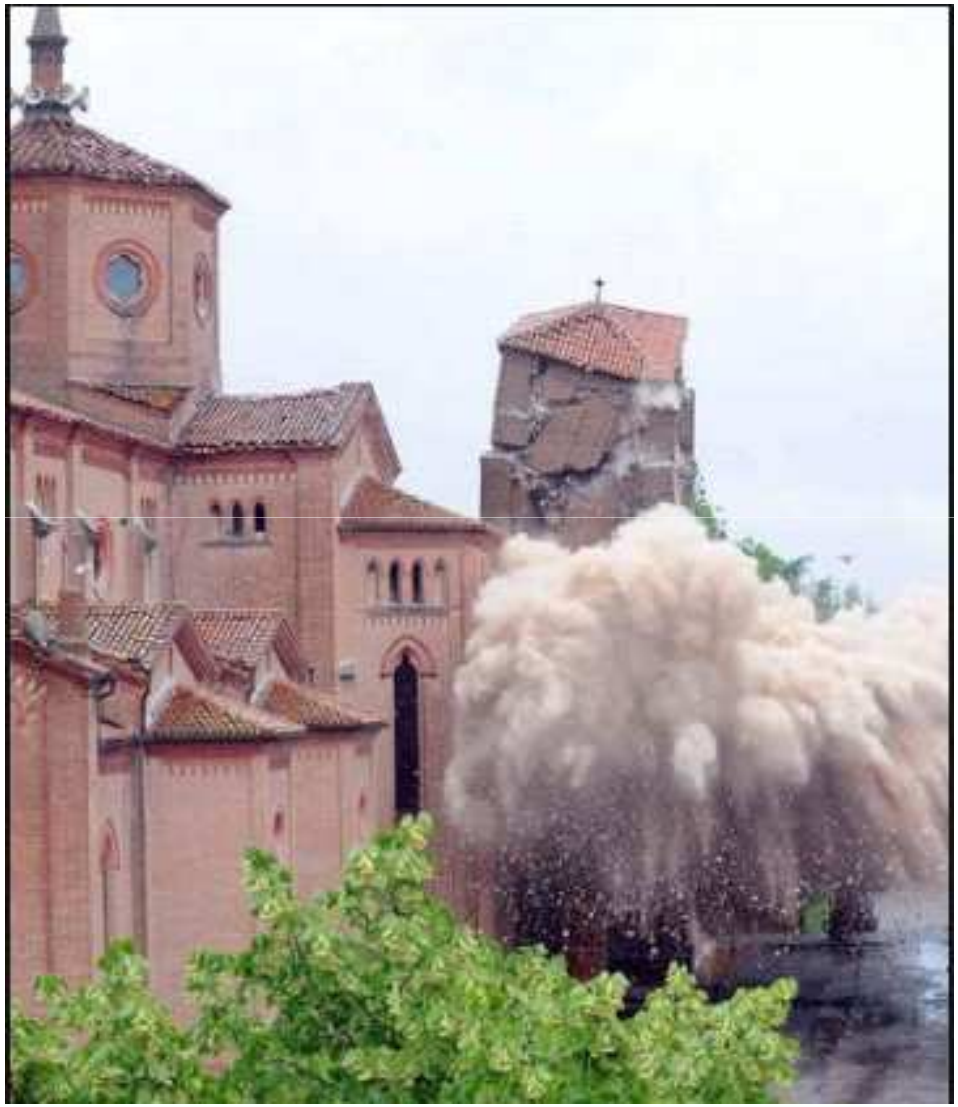
# Some (in)Experiences

*Post-earthquake safety measures (demolitioni)*



*San Michele Arcangelo a Poggio Renatico, Ferrara Emilia 2012*

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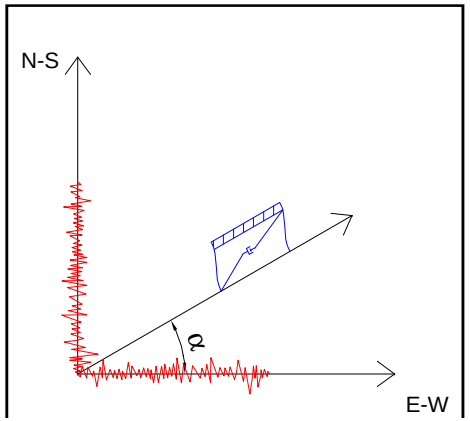
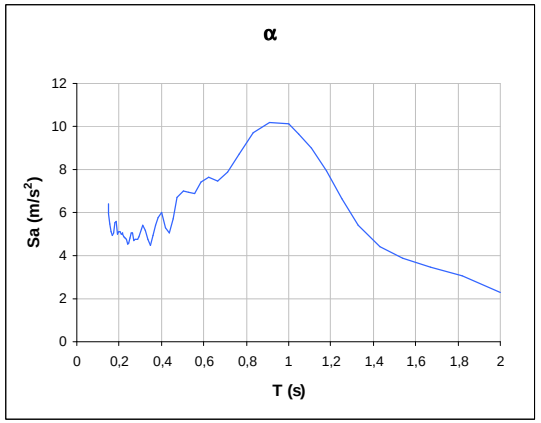
# Innovative Assessment tools

# Innovative Assessment tools

**Seismic demand direction α**



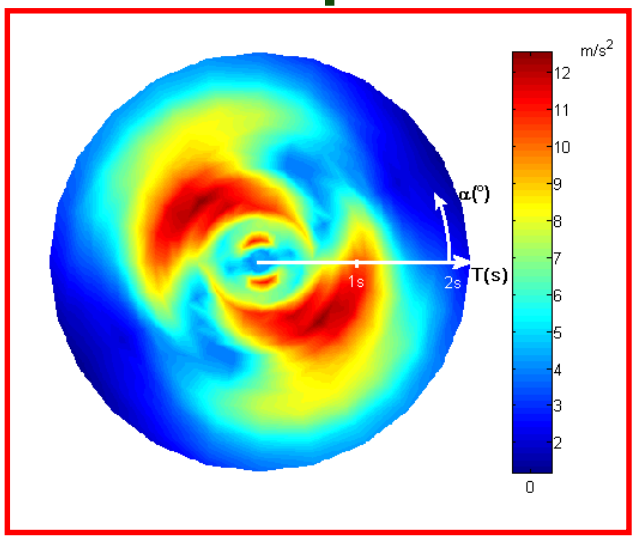

**Responce spectra direction α**




**Spectral responce surface**

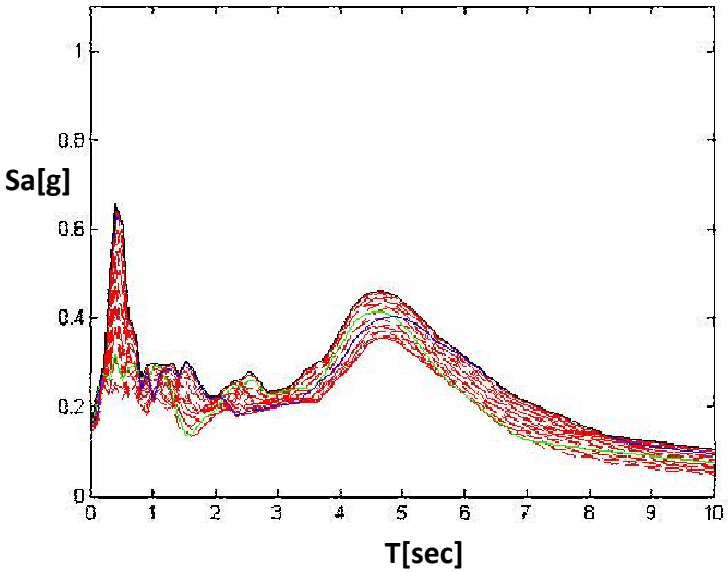
L. Petti et al., 2011 "*Seismic assessment of asymmetric structures behaviour by using static non linear analysis*"

## Polar Spectrum

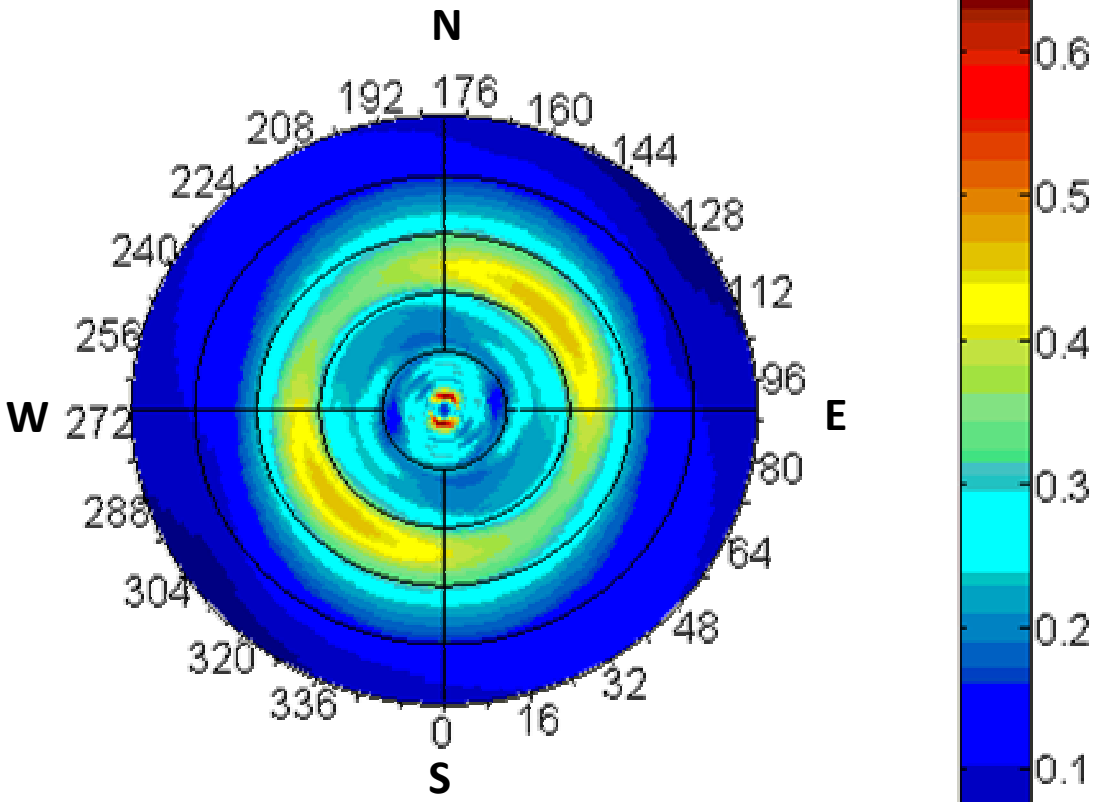


# Innovative Assessment tools

## Spectral Response

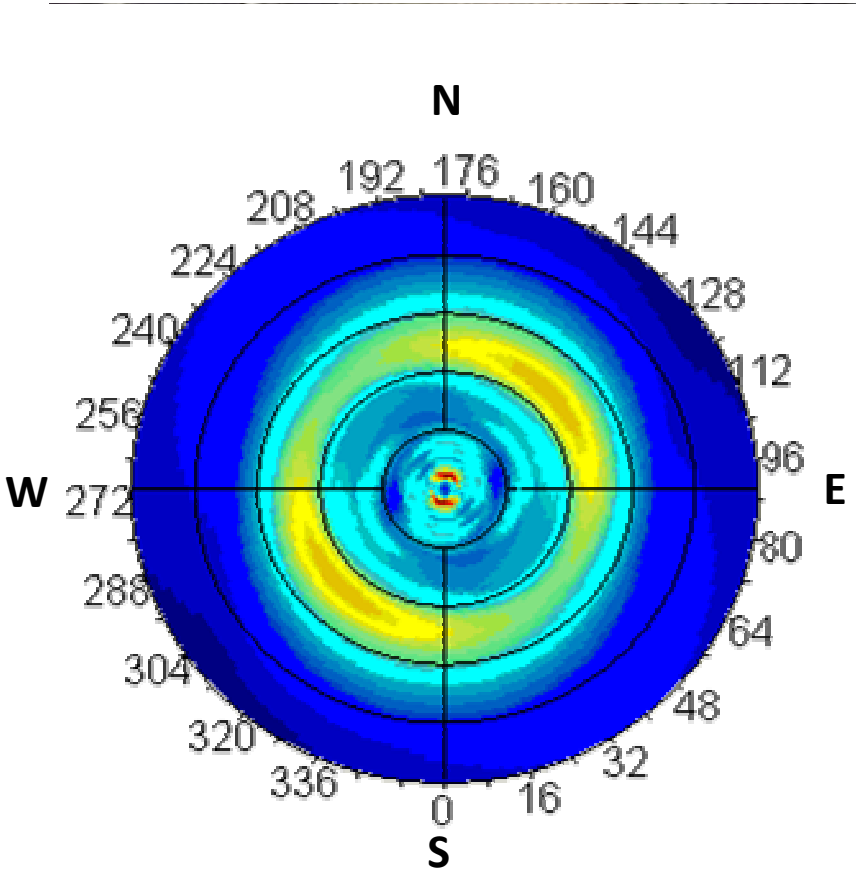



2015 Nepal Event




Polar Spectrum

# Innovative Assessment tools





**Dharahara Tower**
**2015 Nepal Event**

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# Innovative tools for design criteria evaluation

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# Innovative tools for design criteria evaluation

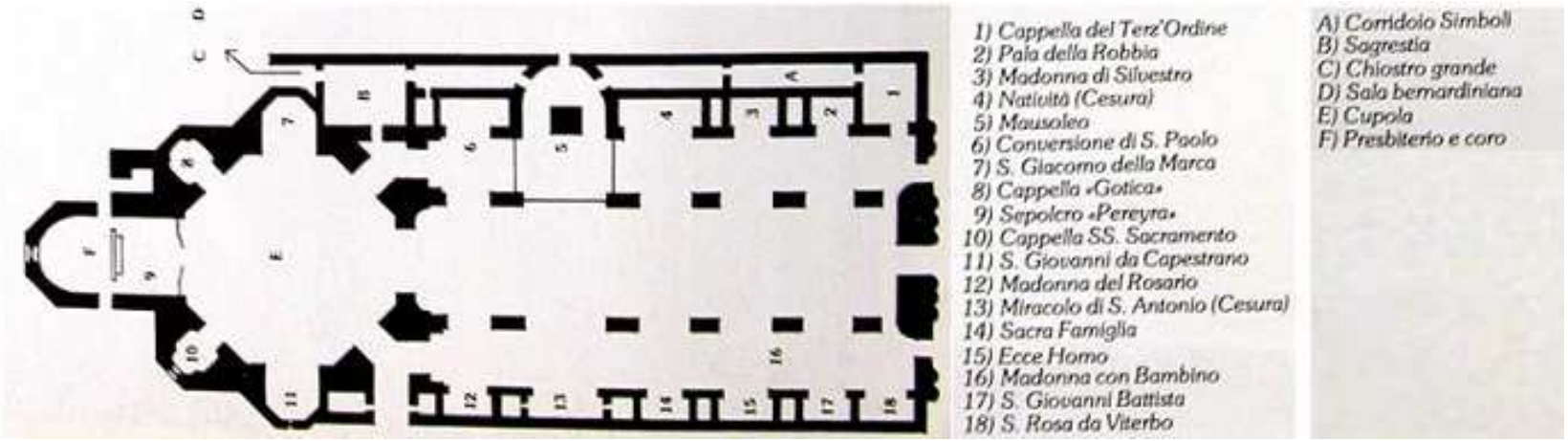
## Compatibility Matrix

Compatibility indexes (Venice Charter)

**EI** *Extensions*
**IN** *Invasiveness*
**CM** *Materials compatibility*
**RE** *Reversibility*
**DU** *Durability*
**IA** *Architectural integrity*
**IM** *Weight increase*
**CS** *Static and dynamic behavior change*
**IR** *Stiffness change*
**RE** *Local strength change*
**DU** *Local ductility change*

L. Petti et al. 2014, www.lacelab.net

# San Bernardino church
# L'Aquila



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# San Bernardino church
# Damage example
*2009 earthquake*
# L'Aquila

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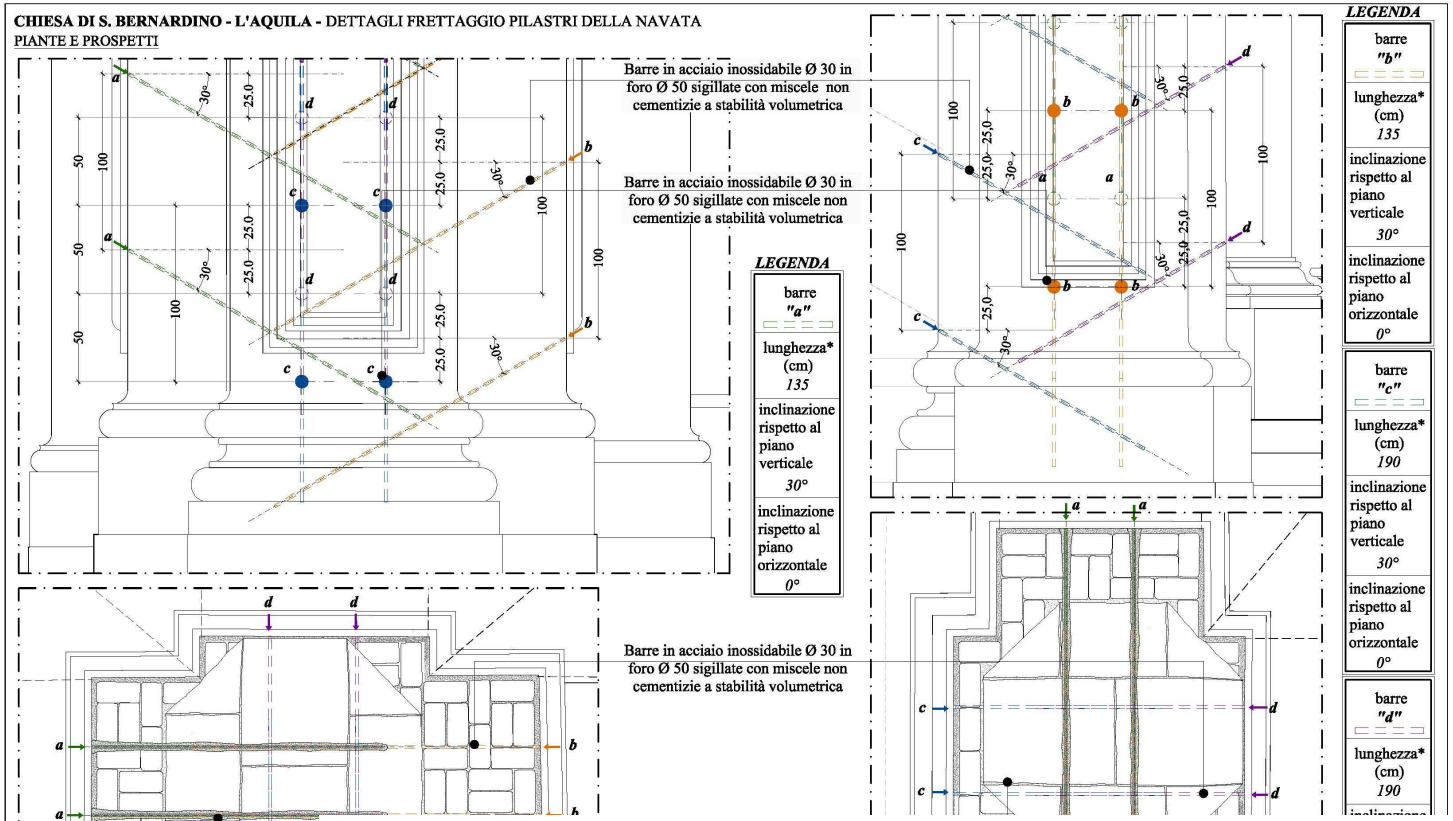
# Reference Restoration Design Arch abutments

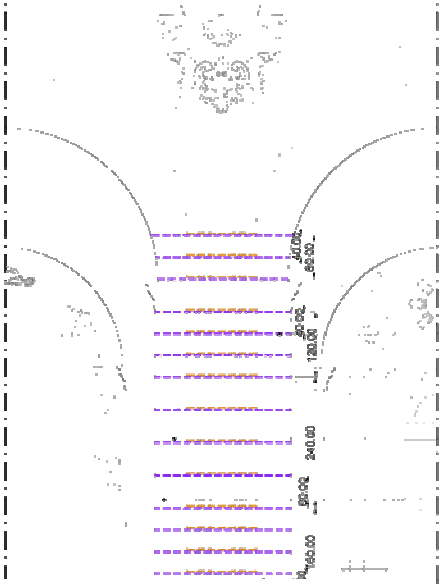


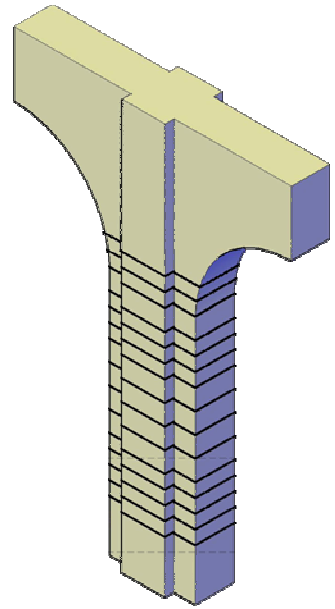

*Tipologia intervento A*

| Interventi sui piedritti in corrispondenza della navata centrale ed in corrispondenza della cupola | | | | | | | | | | | | Compatibilità MIBAC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intervento | ES | IN | CM | RE | DU | IA | IM | CS | IR | IS | DT | |
| Cuciture con iniezioni armate con barre in acciaio e sigillatura con malta a stabilità volumetrica | C | C | M | C | B | B | B | M | C | M | C | C |

## Compatibility matrix

# Proposed Restoration Design Arch abutments



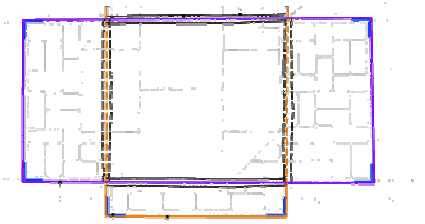


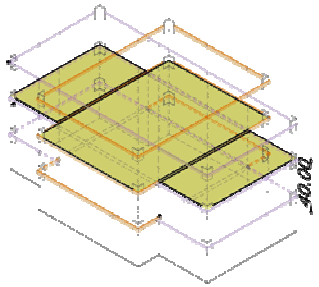
*VISTA ASSONOMETRICA INTERVENTO TIPO*

*Tipologia intervento A.1*

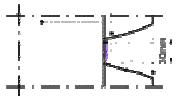
| Interventi su piedritti in corrispondenza della cupola | | | | | | | | | | | | Compatibilità MIBAC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Intervento** | **ES** | **IN** | **CM** | **RE** | **DU** | **IA** | **IM** | **CS** | **IR** | **IS** | **DT** | |
| Risarcitura lesioni con malta consolidante | B | M | B | M | B | B | B | B | B | M | M | B |
| Sigillatura lesioni profonde con tecnica scuci-cuci | B | M | B | B | B | M | B | B | B | B | M | B |
| Disposizione tiranti orizzontali | B | B | B | M | M | B | B | B | B | B | M | B |

## *Compatibility matrix*





*DETTAGLIO DISPOSIZIONE NASTRI E ANGOLARI*



*DETTAGLIO SEZIONE ALLETTAMENTO DEI NASTRI*

*SEZIONE ORIZZONTALE PIEDRITTO TIPO*

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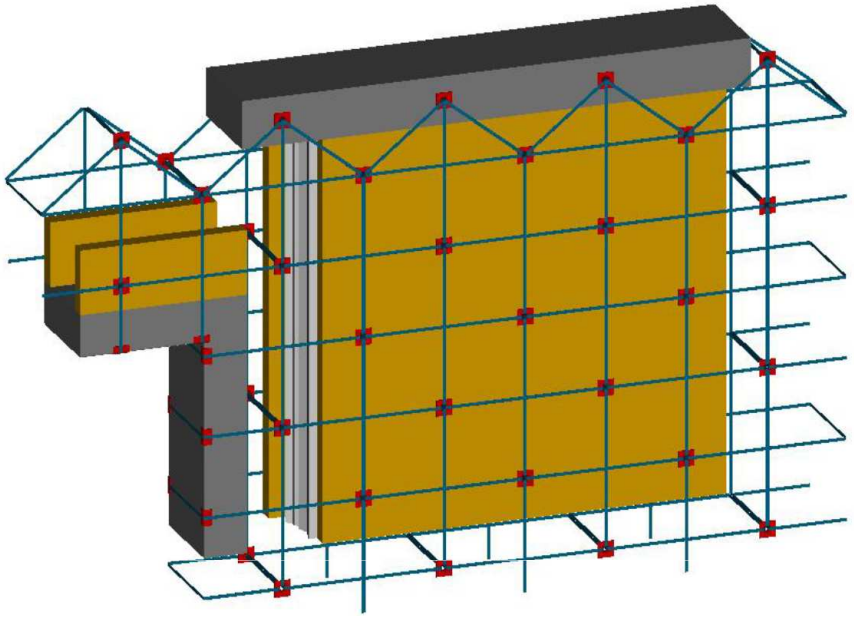
# Proposed Restoration Design CAM Technology



*http://www2.ing.unipi.it/~a005843/Recupero%20e%20conservazione%20edifici/bibliografia/CAM.pdf.*

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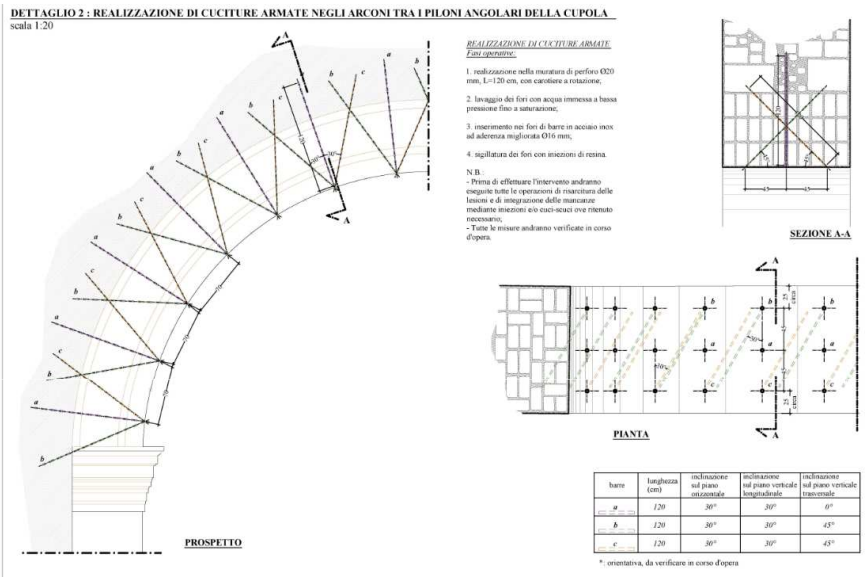


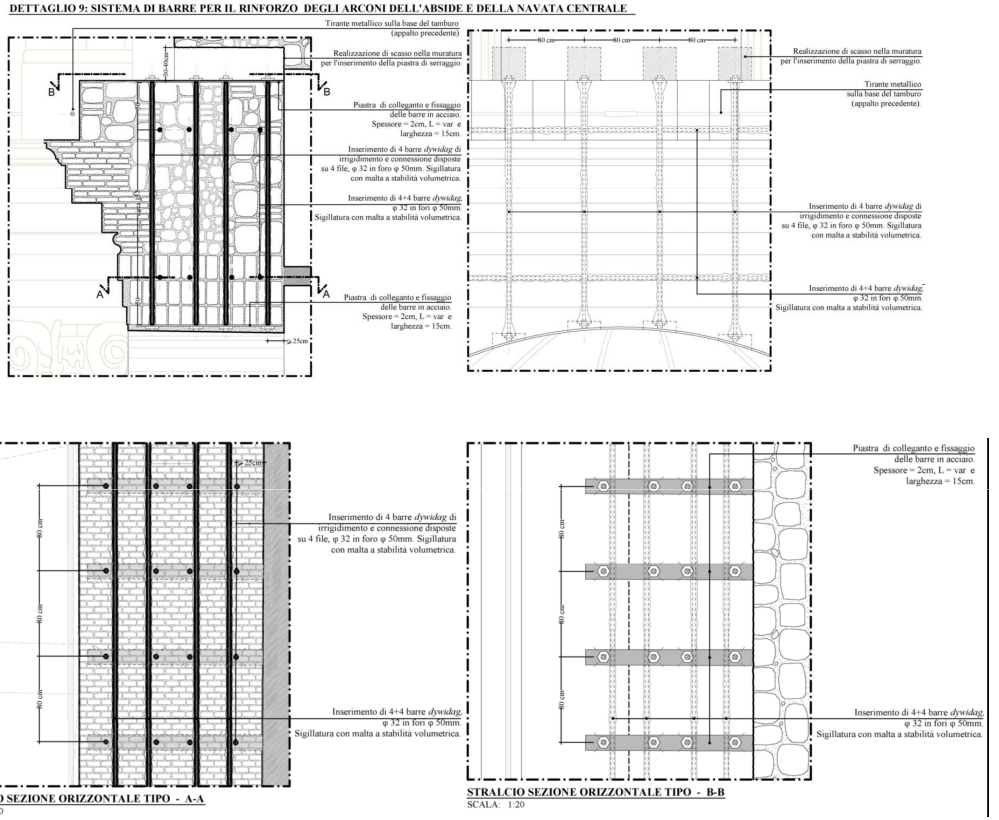


# Reference Restoration Design Triumphal Arch

*Tipologia intervento B*

| Interventi sulle archeggiature e sulle murature soprastanti in corrispondenza della cupola | | | | | | | | | | | | Compatibilità MIBAC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intervento | ES | IN | CM | RE | DU | IA | IM | CS | IR | IS | DT | |
| Sigillatura lesioni profonde con tecnica scuci-cuci | B | M | B | B | B | M | B | B | B | B | M | B |
| Impermiature armate a raggiera | C | C | M | C | B | B | B | M | C | M | C | C |
| Disposizione tiranti orizzontali | B | B | B | M | M | B | B | B | B | B | M | B |
| Disposizione barre verticali | M | M | B | C | M | M | B | M | M | M | M | M |

## *Compatibility matrix*

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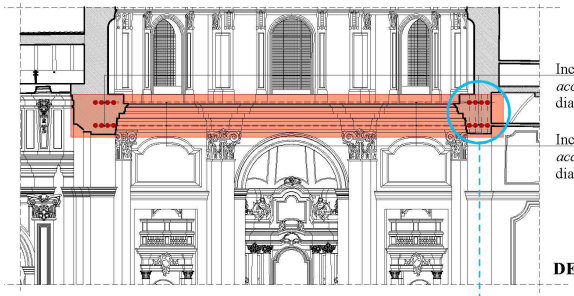
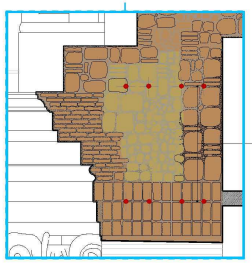


Incatenamento base tamburo con 4+4 barre in *acciaio INOX tipo AISI 329* diametro φ 32 in fori φ 50mm

Incatenamento base tamburo con 2+2 barre in *acciaio INOX tipo AISI 329* diametro φ 32 in fori φ 50mm

**DETTAGLIO SEZIONE LONGITUDINALE**

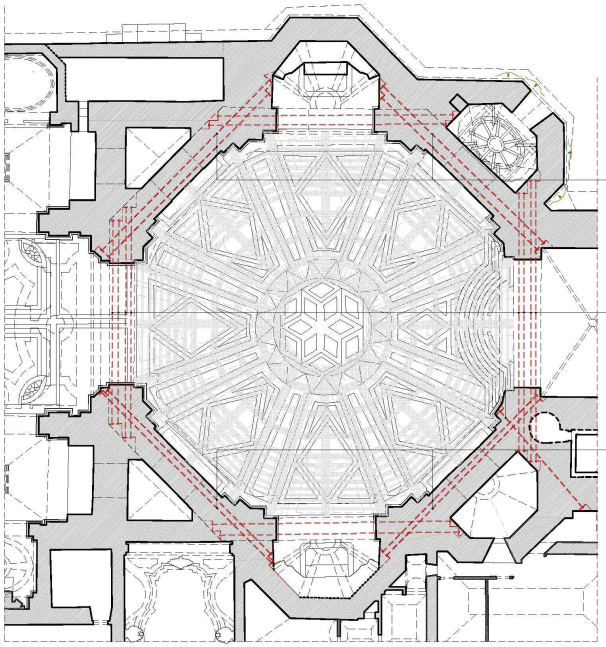


aree interessate da interventi di riparazione mediante scuci e cuci, iniezioni di malta ove occorre (rif. TAV. A6)

aree interessate da interventi di riparazione mediante iniezioni di malta (rif. TAV. A6)

Predisposizione di catene realizzate con barre in *acciaio INOX* tipo *AISI 329*, diametro φ 32 in fori φ 50mm

**STRALCIO SEZIONE TIPO ARCHI**



Incatenamento base tamburo con 2+2 barre in *acciaio INOX tipo AISI 329* diametro φ 32 in fori φ 50mm

Incatenamento base tamburo con 4+4 barre in *acciaio INOX tipo AISI 329* diametro φ 32 in fori φ 50mm

Incatenamento base tamburo con 2+2 barre in *acciaio INOX tipo AISI 329* diametro φ 32 in fori φ 50mm

**PIANTA DELLA CHIESA**
PIANO PRIMO

# Proposed Restoration Design Triumphal Arch

*Tipologia intervento B.1*

| Interventi sulle archeggiature e sulle murature soprastanti in corrispondenza della cupola | | | | | | | | | | | | Compatibilità MIBAC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intervento | ES | IN | CM | RE | DU | IA | IM | CS | IR | IS | DT | |
| Risarcitura lesioni con malta consolidante | B | M | B | M | B | B | B | B | B | M | M | B |
| Sigillatura lesioni profonde con tecnica scuci-cuci | B | M | B | B | B | M | B | B | B | B | M | B |
| Disposizione tiranti orizzontali | B | B | B | M | B | B | B | B | B | B | M | B |

## *Compatibility matrix*

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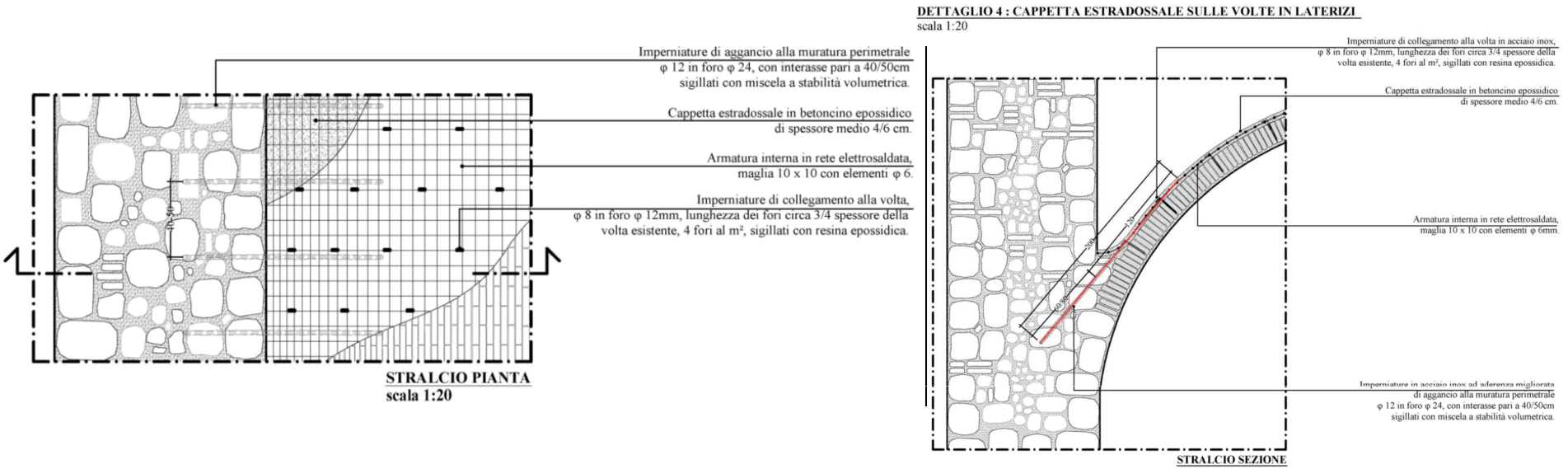



# Reference Restoration Design Vaults

*Tipologia intervento C*

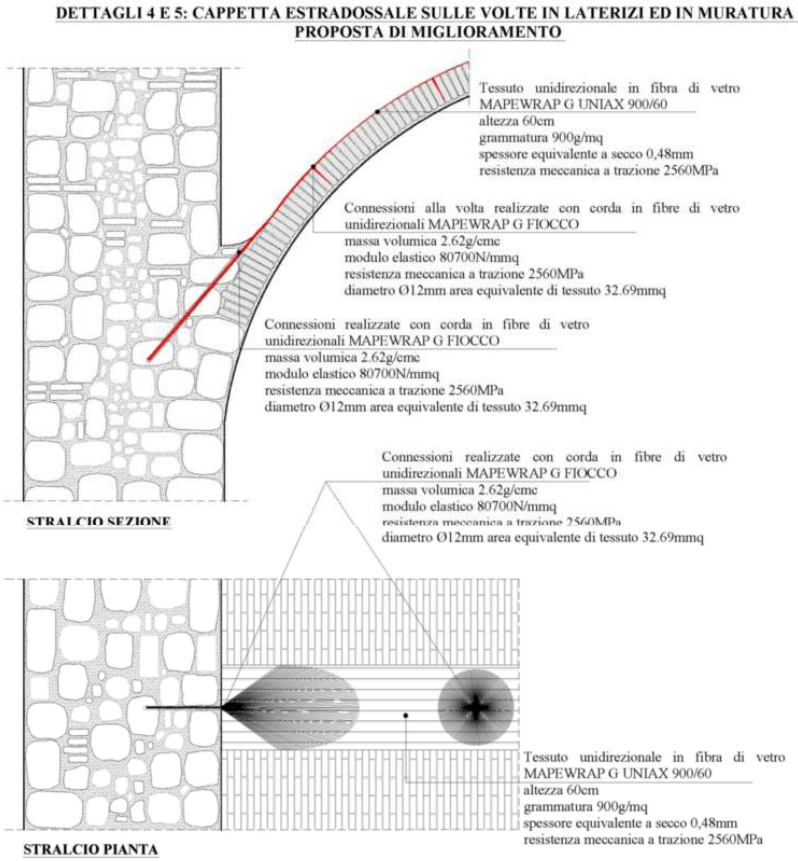
| Interventi sulle volte in muratura ovvero in laterizi | | | | | | | | | | | | Compatibilità MIBAC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intervento | ES | IN | CM | RE | DU | IA | IM | CS | IR | IS | DT | |
| Risarcitura lesioni con malta consolidante | B | M | B | M | B | B | B | B | B | M | M | B |
| Sigillatura con malta priva di alcali | B | M | B | M | B | B | B | B | B | M | C | B |
| Controvolta/Cappetta in betoncino/malta armata | C | C | M | M | B | B | C | C | C | M | C | C |
| Disposizione fasce in CFRC estradosso volte | M | B | M | B | B | B | B | B | B | B | B | B |
| Consolidamento vele in camera canna con fasce canapa o lino | M | B | B | B | B | B | B | B | B | B | B | B |
| Demolizione e ricostruzione volta in muratura | C | C | B | C | B | C | B | B | B | B | B | M |
| Demolizione e ricostruzione volta in camera canna | C | C | B | C | B | C | B | B | B | B | B | M |

## *Compatibility matrix*

# FASCE IN FIBRA DI VETRO

## Reference
## Restoration Design
## Vaults

# Proposed Restoration Design Vaults




*Tipologia intervento C.1*

| Interventi sulle volte in muratura ovvero in laterizi | | | | | | | | | | | | Compatibilità MIBAC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intervento | ES | IN | CM | RE | DU | IA | IM | CS | IR | IS | DT | |
| Risarcitura lesioni con malta consolidante | B | M | B | M | B | B | B | B | B | M | M | B |
| Sigillatura lesioni profonde con tecnica scuci-cuci | B | M | B | B | B | M | B | B | B | B | M | B |
| Consolidamento volte con fasce in fibre di vetro | B | B | M | B | B | B | B | B | B | B | M | B |

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# Innovative post-event tools
# emergency design criteria

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# emergency design criteria

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## Collemaggio Church
## 2009, L'Aquila IT

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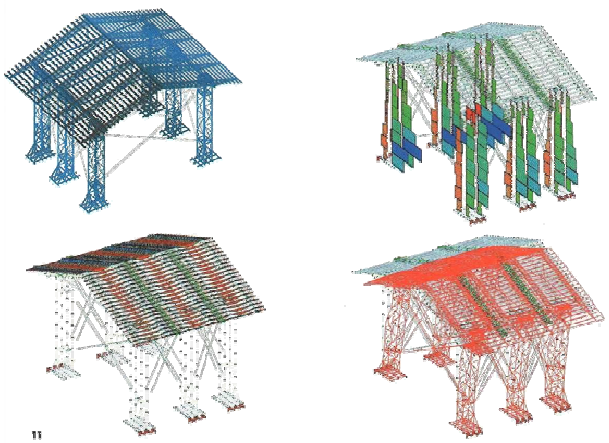

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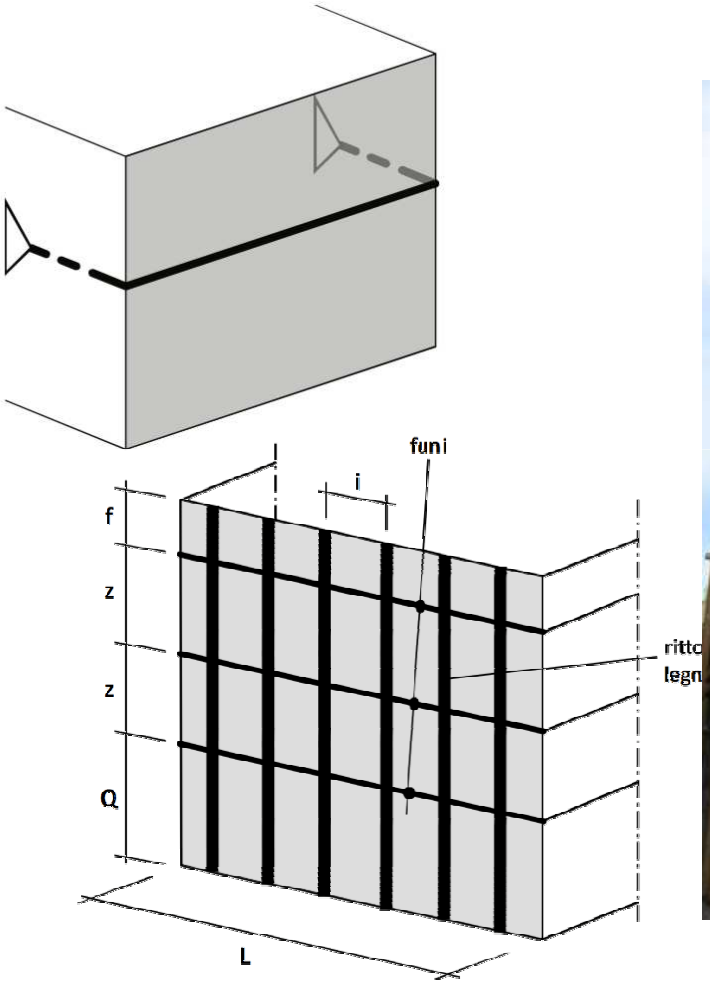
# Christmas 2009, Collemaggio – L'Aquila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# Innovative materials design criteria

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# Innovative materials design criteria




## The Trajan's Arch

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# Damage assessment seepage

*2012*


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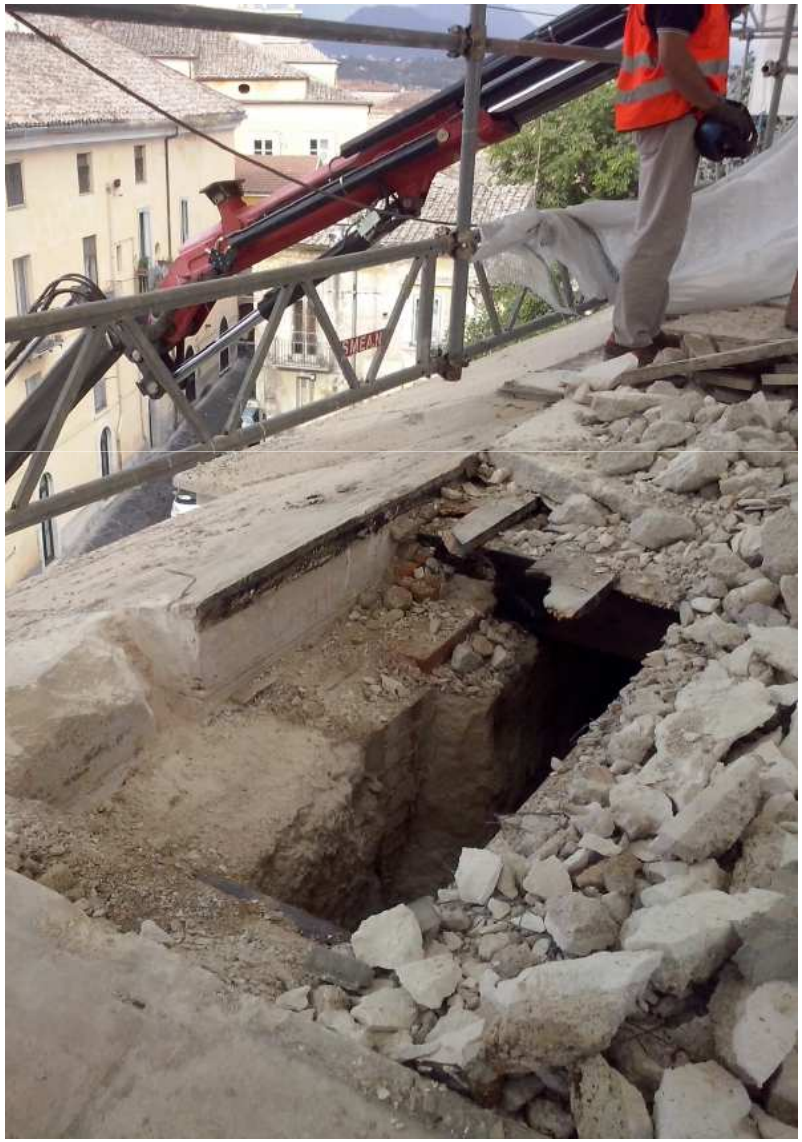
# Damage assessment of wooden beams



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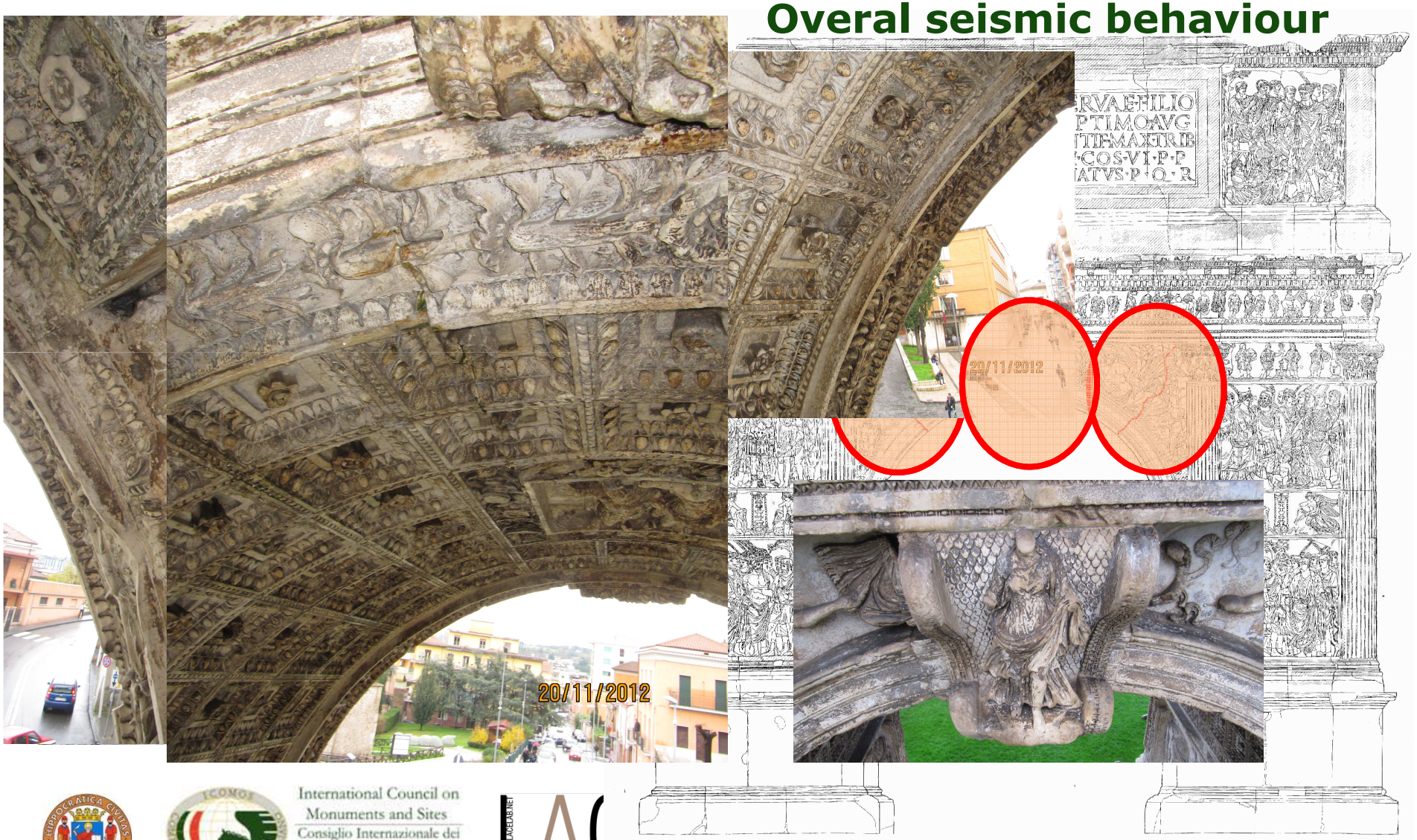
# Overal seismic behaviour

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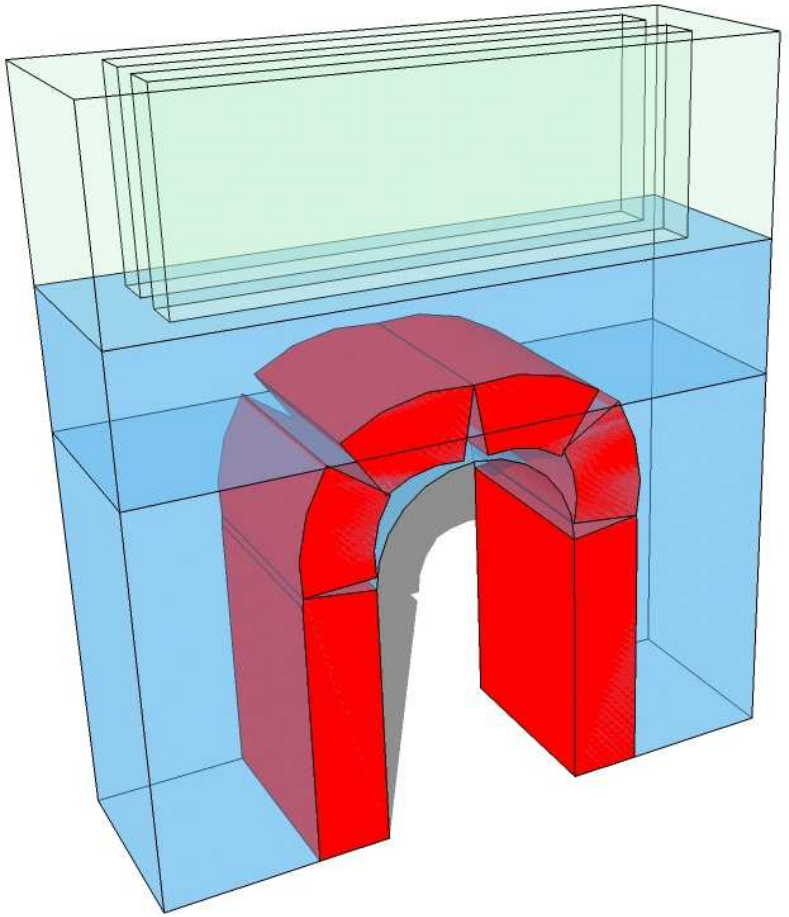
# Arch in Active Thrust



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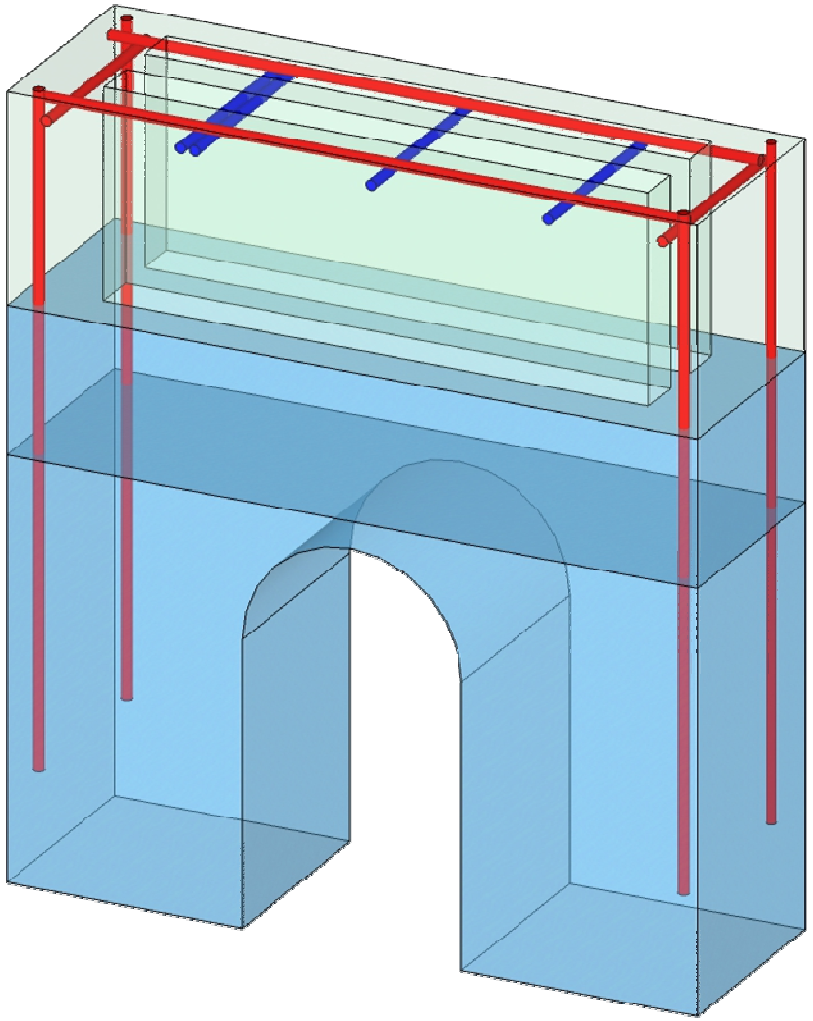
## Gianmarco Jacobitti

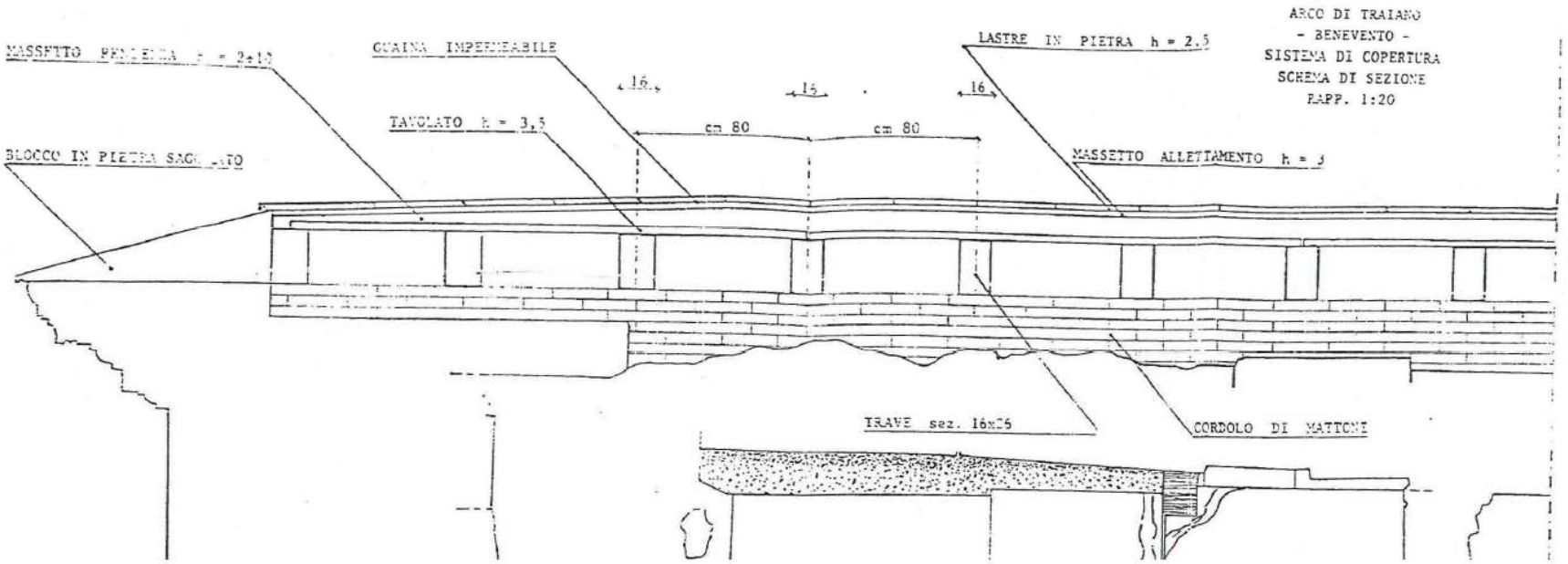
*1972-1973*


Steel chains reinforcement



## Salvatore D'Agostino

*1991*




Roof protection design

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*Degrado materiali tradizionali*

*Arch of Codtantino*
*Benevento, Italy 2012*

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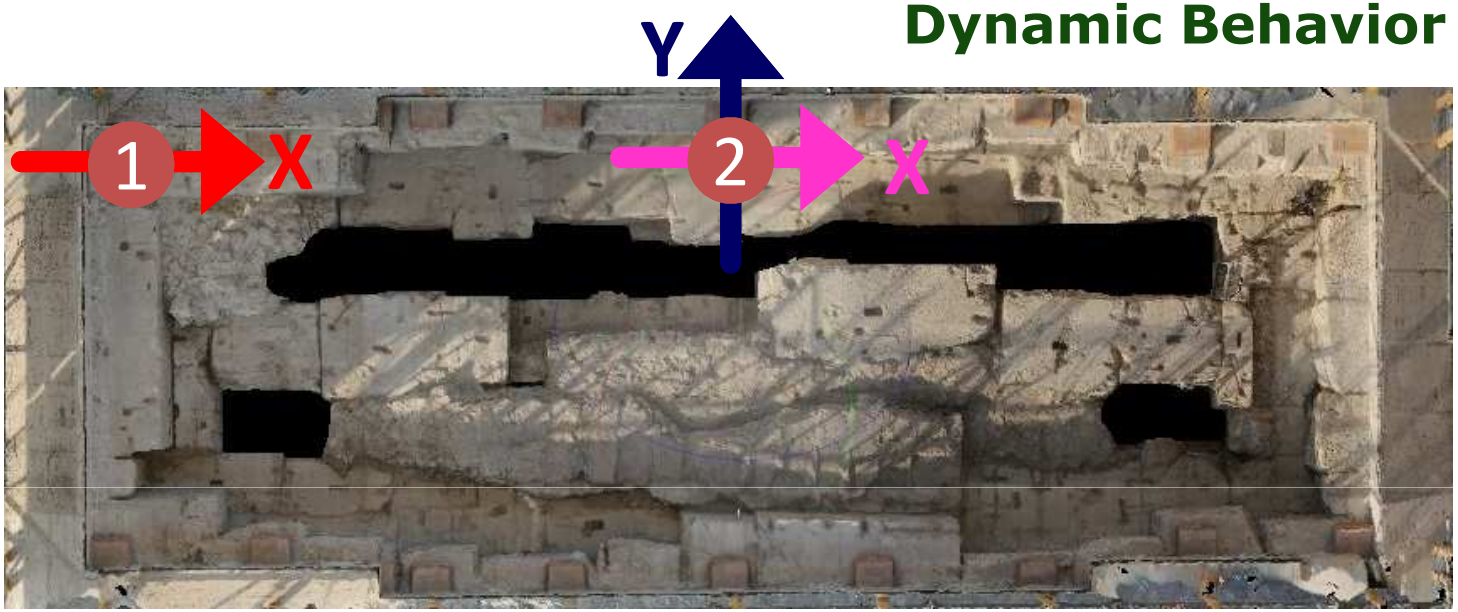
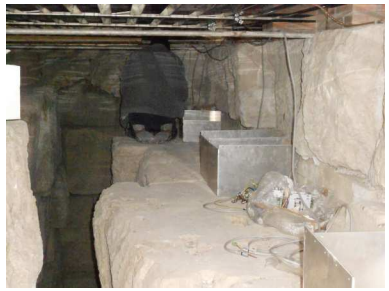
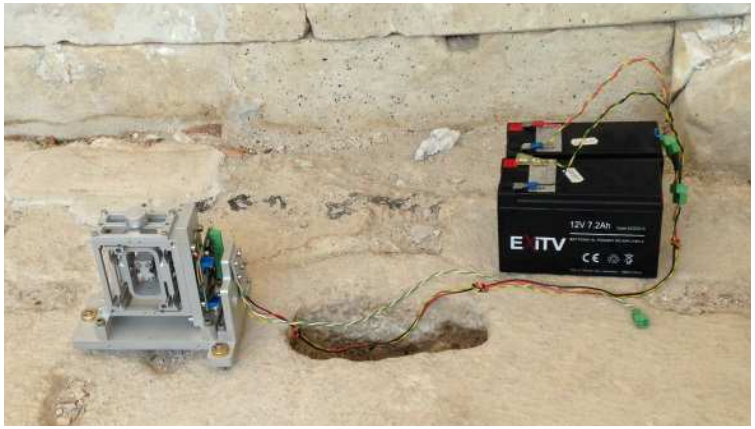
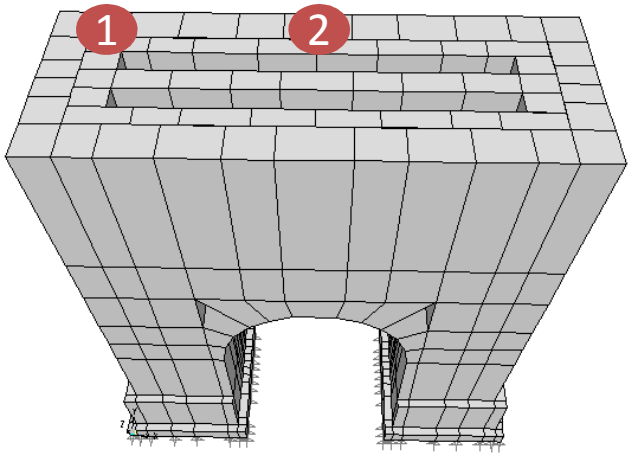
# Dynamic Behavior Monitoring



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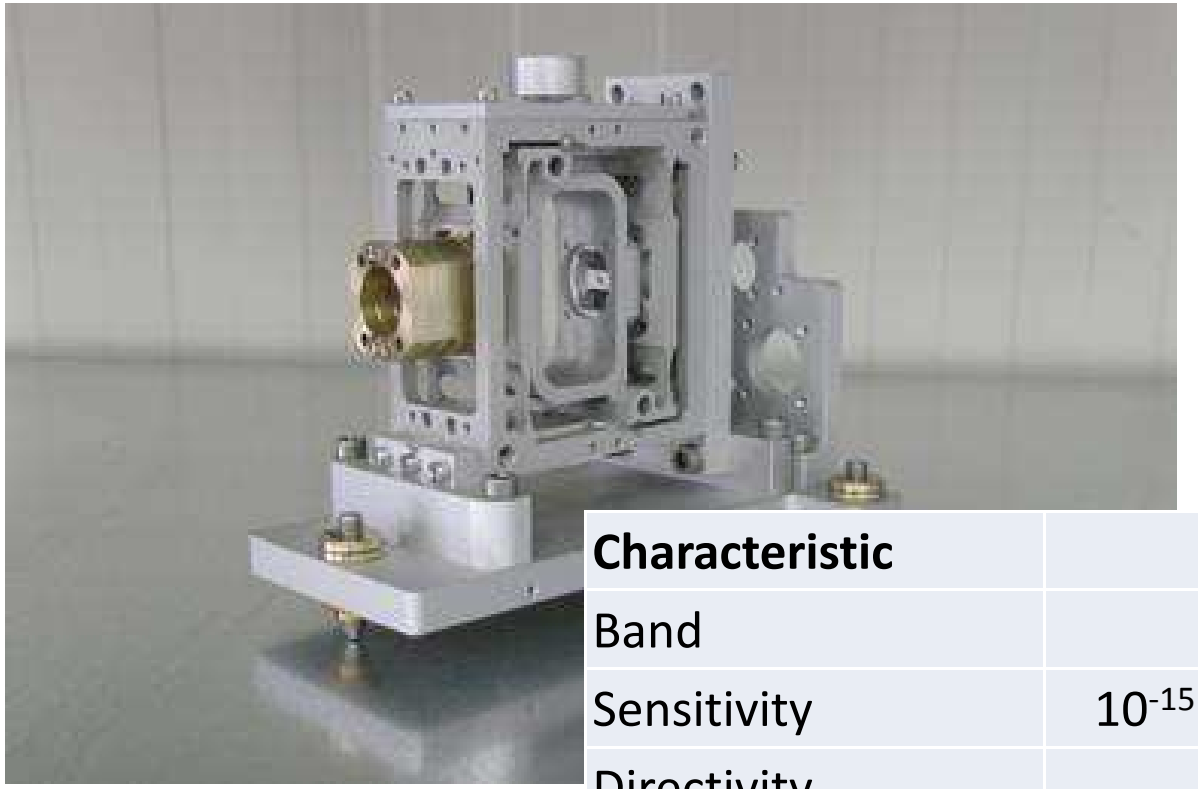

# Uniaxial Horizonthal Monolithic Folded Pendulum

*University of Salerno*
*Prof. F. Barone*

| Characteristic | Properties |
|---|---|
| Band | 10 nHz < B < 1 kHz |
| Sensitivity | $10^{-15}$ m/Hz$^{1/2}$ < S < $10^{-6}$ m/Hz$^{1/2}$ |
| Directivity | > $10^{4}$ |
| Sensitivity (readout) | $10^{-15}$ m/Hz$^{1/2}$ < S < $10^{-6}$ m/Hz$^{1/2}$ |
| Dimensions (typical) | 10 cm x 10 cm x 4 cm |
| Weight | < 0,4 Kg |

UNISA Folded Pendulum
Class Main Characteristics
*Prof. Fabrizio Barone*

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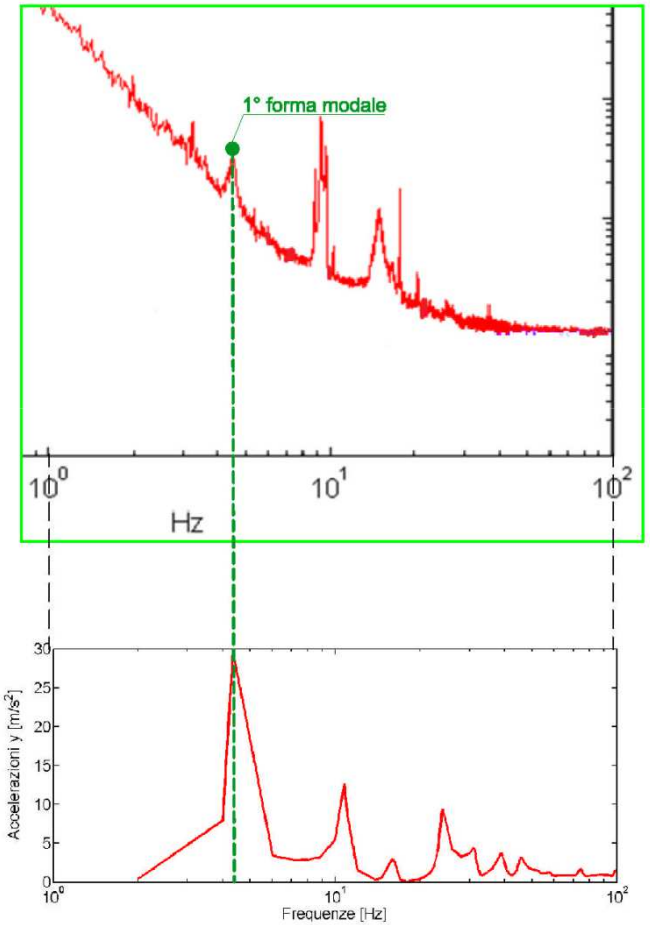
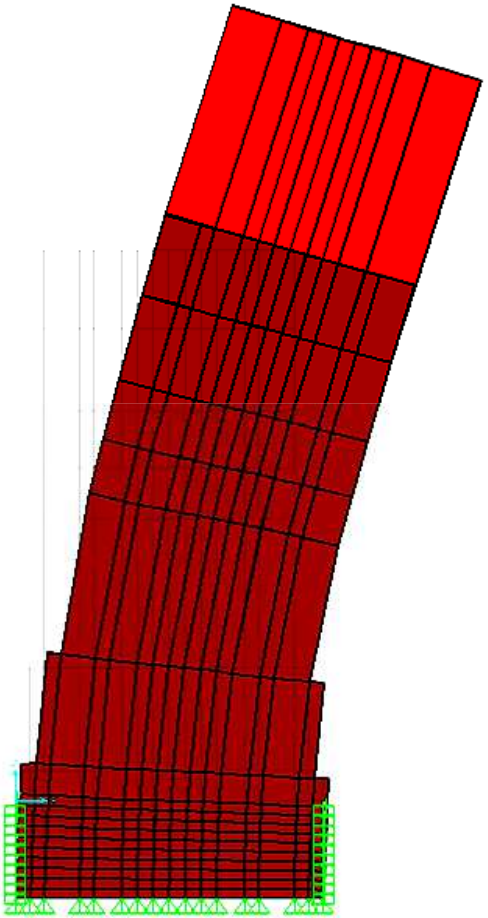
# 1° Modal Shape

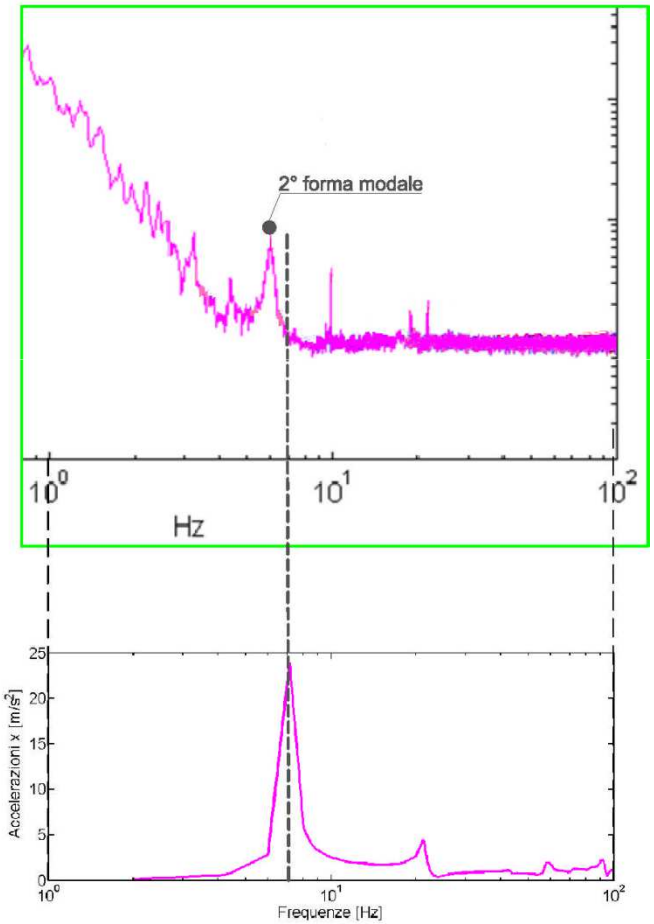
*4,33 Hz*

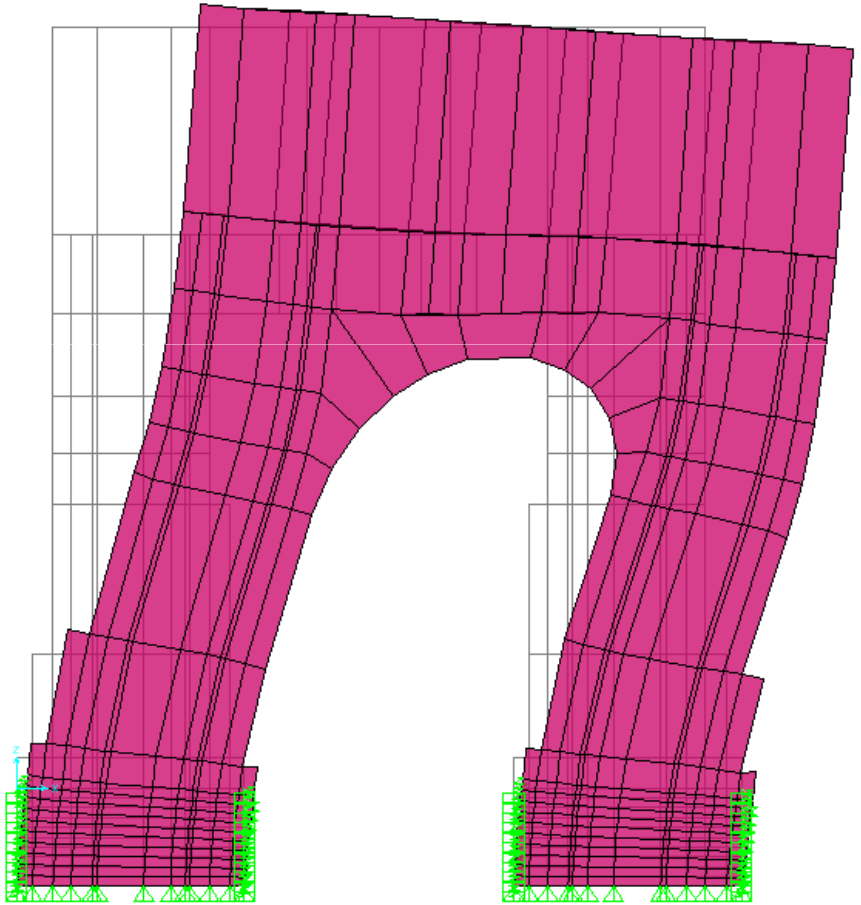


# 2° Modal Shape

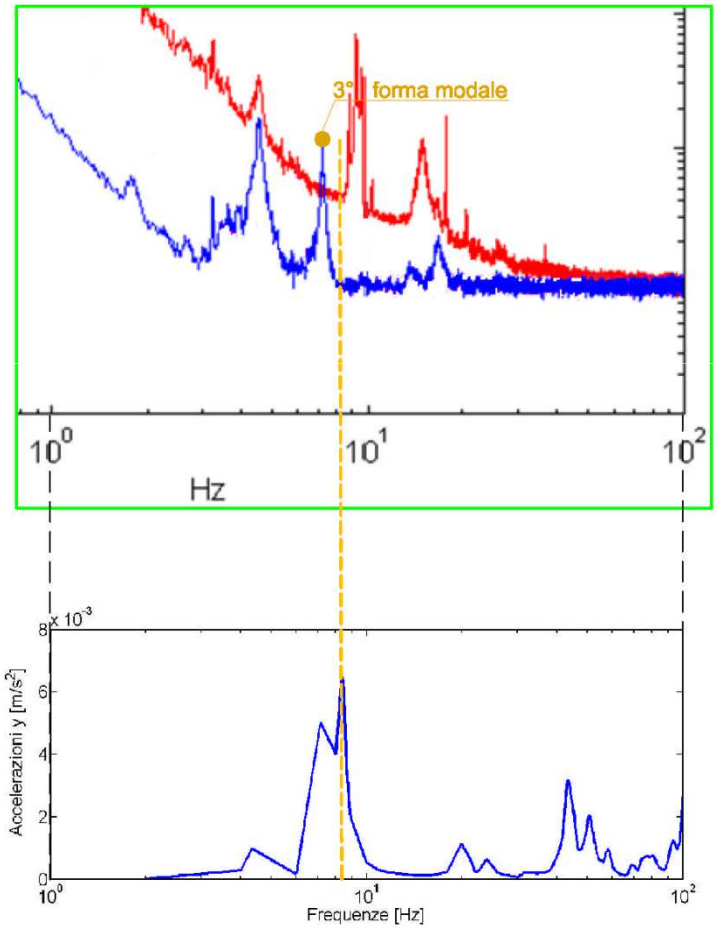
*7,14 Hz*

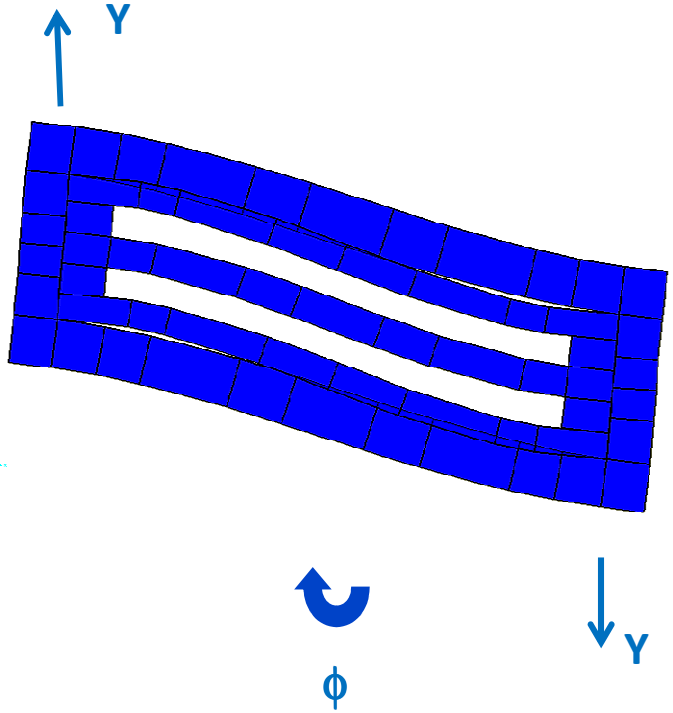


# 3° Modal Shape

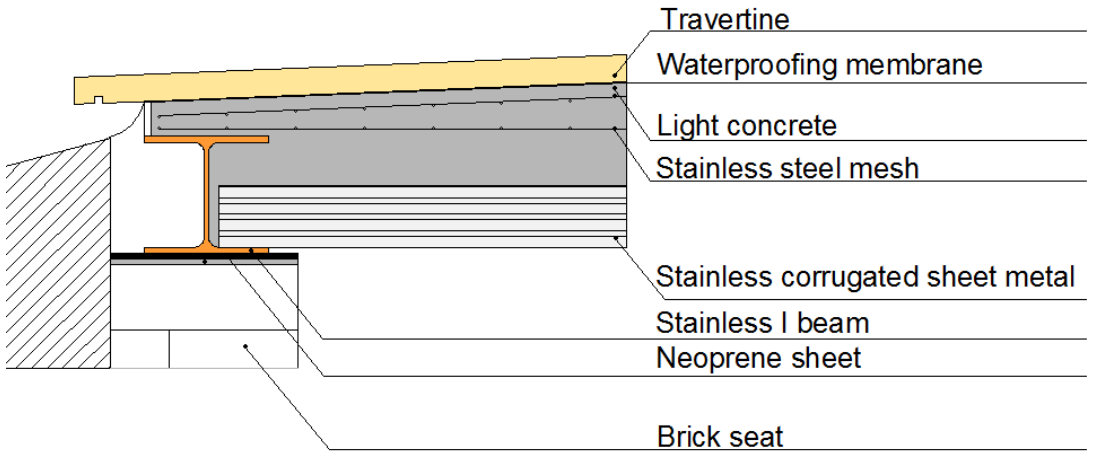
*8,38 Hz*

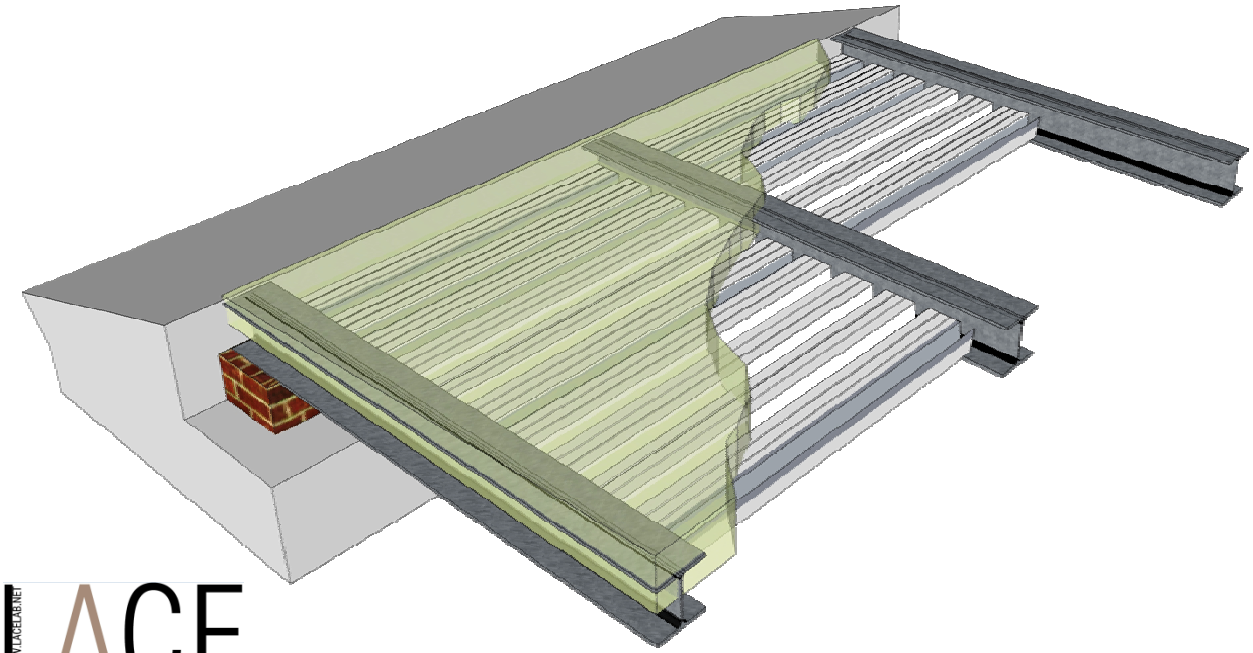


# New Roof Design

*Luigi Petti, 2015*



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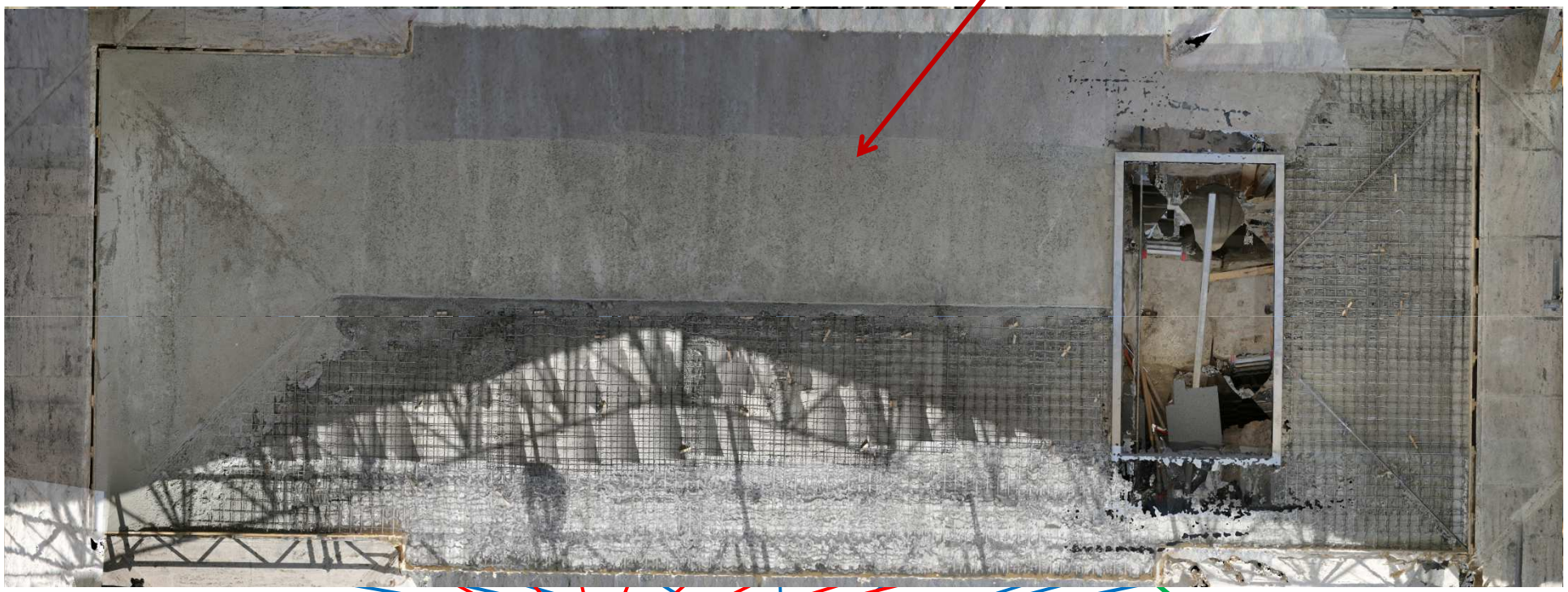
Lightweight concrete



Corrugated sheet AISI 304

HEA180 beams AISI 304

Welded mesh

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**The question:**

**Cosa siamo disposti a perdere oggi ….**

**…. per evitare di perdere tutto domani**

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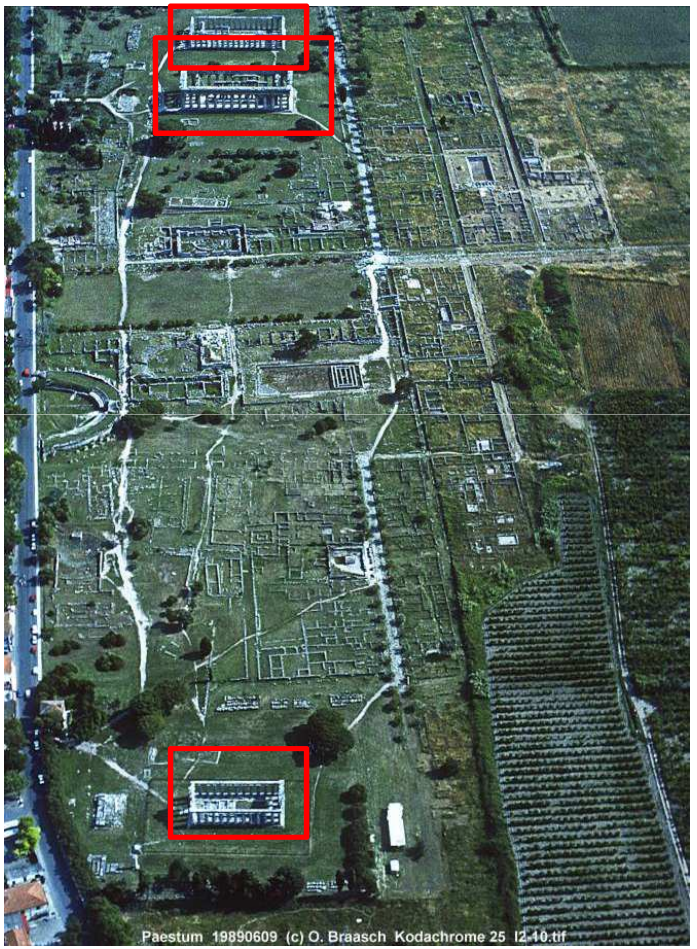
# THE ARCHAEOLOGICAL SITE OF PAESTUM

*Hera Temple*
*(550 B.C.)*

*Athena Temple*
*(510 B.C.)*

*Neptune Temple*
*(450 B.C.)*

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# STUDY OF THE SEISMIC RESPONSE OF MONUMENTAL STRUCTURES MADE OF STONE BLOCKS

*Conservation of Cultural Heritage needs in-deep assessment of many factors by preserving the structural behaviour and, among over, our past history over the time*

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**TeSSPACS Project 2014-2016**

*"Tendon System for Seismic Protection of Ancient Column Structures"*

**TeSSPACS Project 2014-2016**

*"Tendon System for Seismic Protection of Ancient Column Structures"*

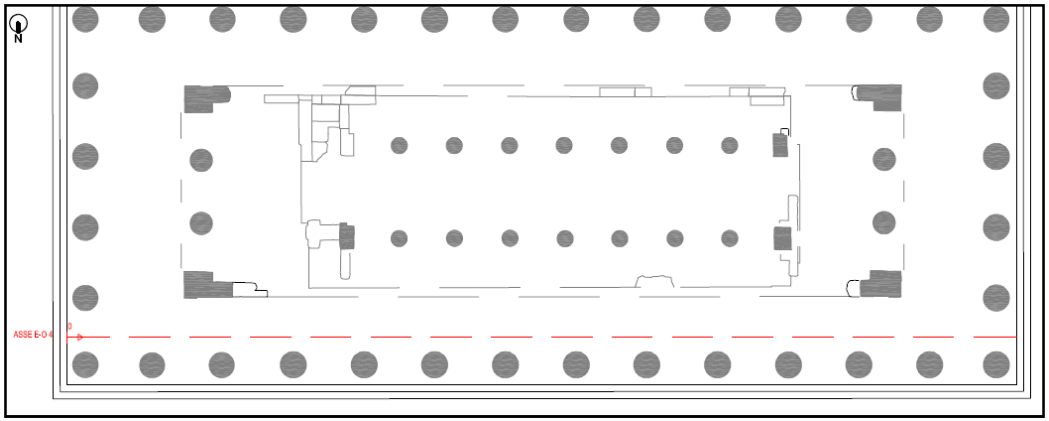
**FARB 2014-2019**

*Fondi di Ateneo per la Ricerca di Base: "Analisi della sicurezza strutturale in condizioni di carico sismico"*

**PRIN 2015**

*"Protecting Cultural Heritage from Water – Soil Interactions"*

# ON-SITE EXPERIMENTAL TEST: ELECTRICAL TOMOGRAPHY



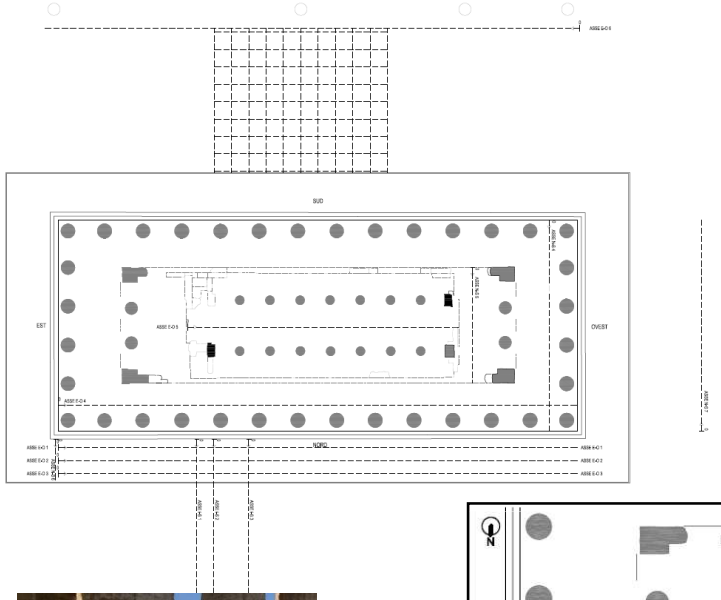

Valori di medio-bassa resistività elettrica (valori compresi tra 35 e 400 *Ohm* x *m*), verosimilmente correlabili con la presenza di terreni sabbioso - limosi a scarsa componente argillosa.

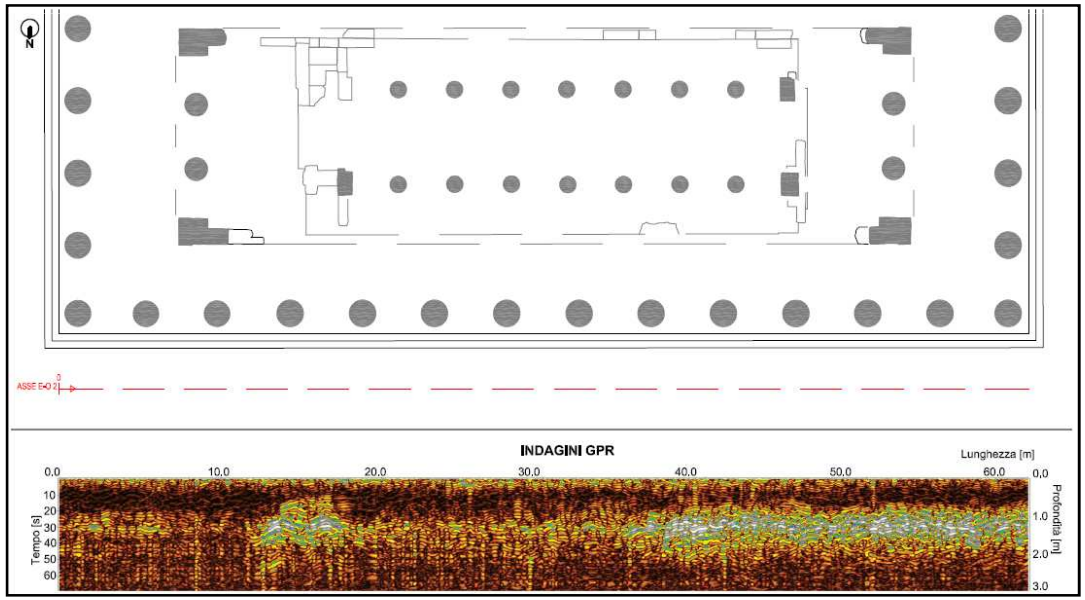



Anomalie di alta resistività elettrica (valori superiori a 800 *Ohm* x *m*), verosimilmente correlabili con la presenza di sottoservizi antropici e/o influenza di reticoli cavearli nel complesso tufaceo.

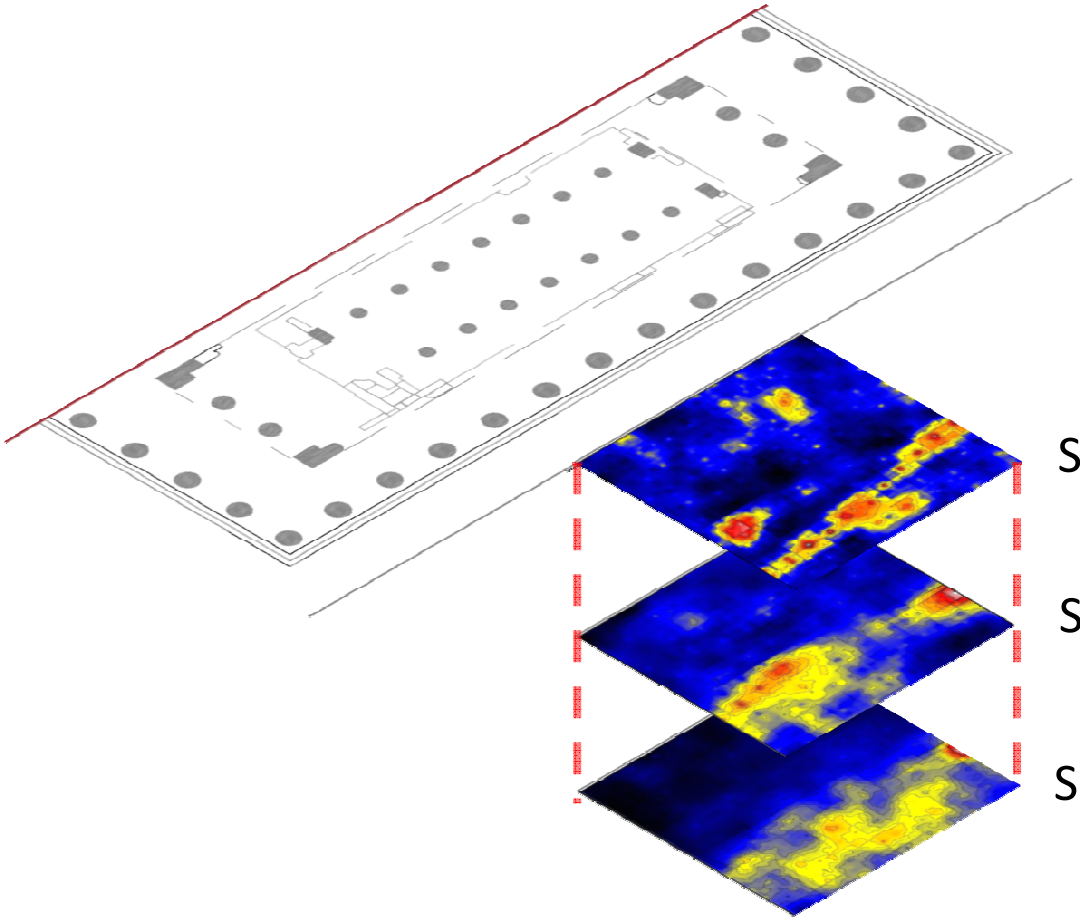
| LITOTIPO | ρ (Ω m) | ϕ (%) |
|---|---|---|
| Acqua | 10÷100 | - |
| Acqua di mare | 2÷3 | - |
| Arenarie | 200÷5000 | 7÷30 |
| Argille | 1÷50 | 40÷70 |
| Calcari | 300÷10000 | 2÷30 |
| Detrito alluvionale | 50÷1000 | 15÷60 |
| Dolomie | 500÷10000 | 2÷20 |
| Sabbie e Ghiaie | 70÷700 | 30÷60 |
| Graniti | 1000÷20000 | 0.2÷0.8 |
| Marne | 100÷500 | 8÷15 |
| Piroclastiti | 50÷600 | 15÷60 |
| Rocce ignee | 100÷10000 | 30÷10 |
| Suolo di copertura | 10÷200 | 60÷90 |
| Tufi | 150÷900 | 10÷40 |

# ON-SITE EXPERIMENTAL TESTS: GPR (Ground Probing Radar)





# ON-SITE EXPERIMENTAL TESTS: 3D GPR SURVEY



Sez. 0-30 cm

Sez. 30-120 cm

Sez. 120-180 cm

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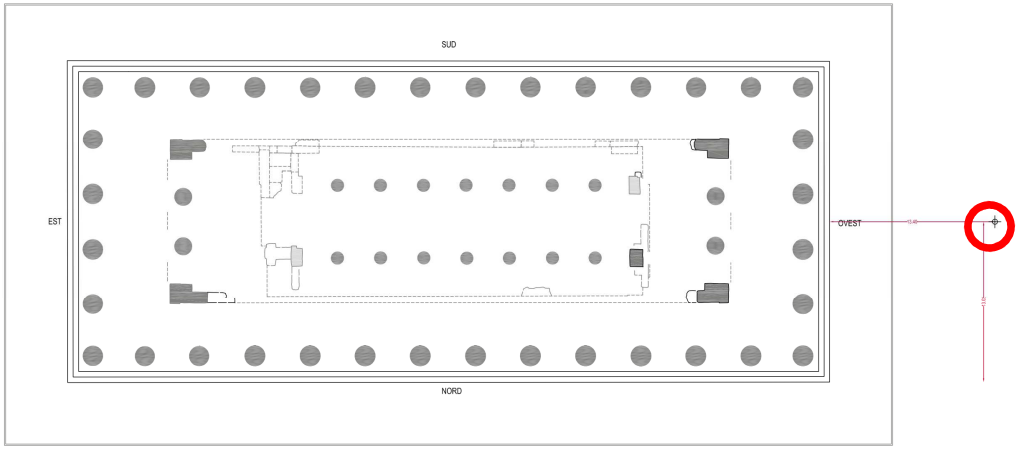
# ON-SITE EXPERIMENTAL TESTS: GEOLOGIC SURVEY

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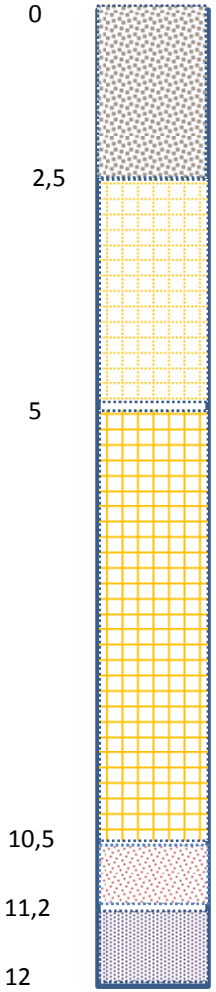
# ON-SITE EXPERIMENTAL TESTS: GEOLOGIC SURVEY



0

Loose anthropogenic sandy material with artifacts and brick fragments and weathered pumix grains

2,5

Travertine lenses from centimeter to decimeter thick, normally very vacuolar; laminated phytoclastic sands and phytohermal layers with grasses, reeds and Quercus/Laurus leaf footprints. Prehistorical age; Coded $SLG_{f1}$ in the Foce Sele Geological Sheet

5

Cemented and friable travertine layers, convolute stromatolitic lenses and laminated, phytohermal layers; locally karst conduit ;
Age: 8K yeras BP.
Coded TPP in the Foce Sele Geological Sheet

10,5

Reddish, loose silty sand horizon, as weathered horizon of:

11,2

Dense and slightly cemented, dunal silty sand , Coded GMLd in the Foce Sele Geological Sheet.

12

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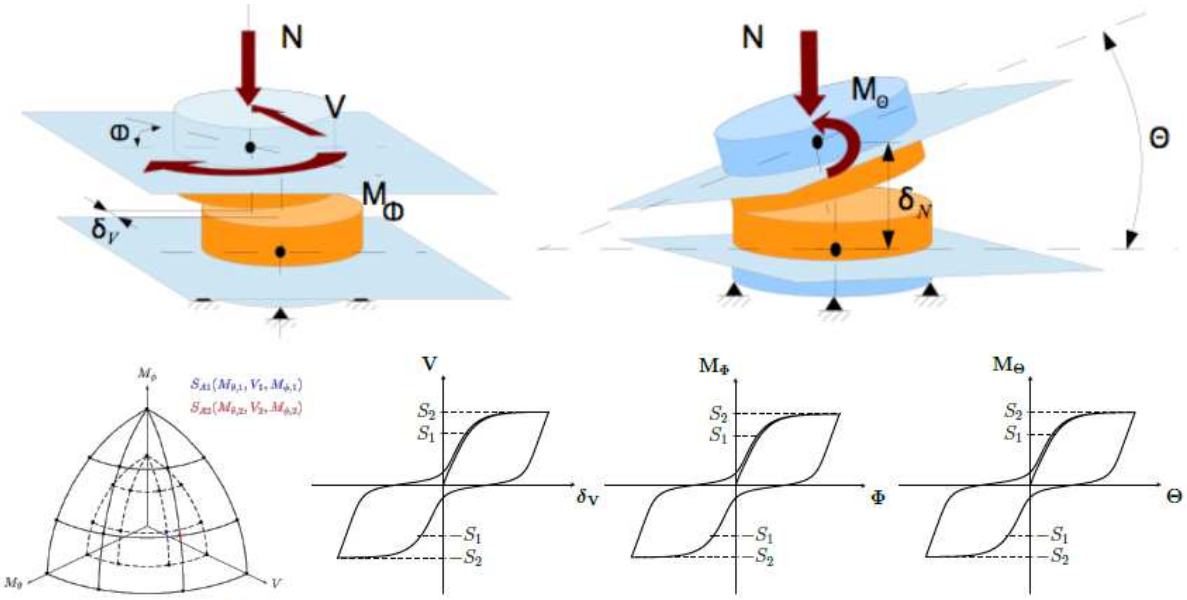
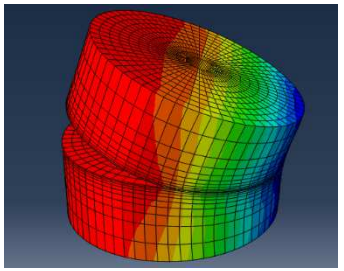
# ONGOING RESEARCH ACTIVITIES: DRUM INTERACTION ANALYSIS



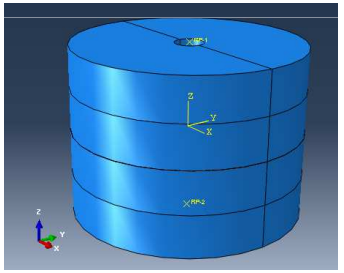
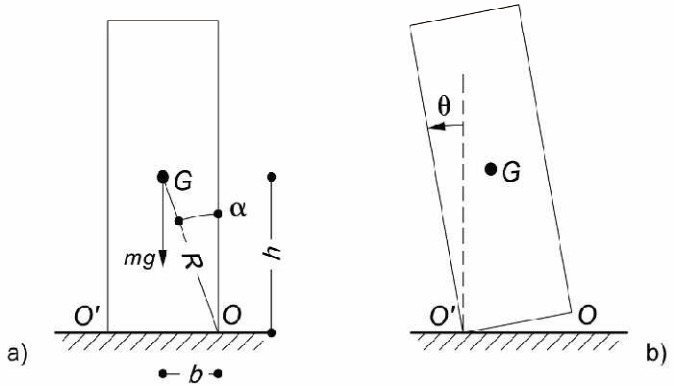


Figure 4: Independent states of two consecutive stone drums (top). By exploiting the symmetries of the experiments, 2-surface laws can be developed, which can be represented in 3-dimensions when the normal force N is used as a surface parameter (bottom).

# Equations of the motion of a rigid block under free oscillations




***Frequency parameter [rad/s]***

$$p = \sqrt{\frac{mgR}{I_0}} = \sqrt{\frac{3mgR}{4mR^2}} = \sqrt{\frac{3g}{4R}}$$

$$\ddot{\theta} = -sgn(\theta) \cdot p^2 \cdot sen(\alpha - |\theta|)$$

$$\theta = -sgn(\theta_0) \cdot \alpha \cdot \left[1 - \left(1 - \frac{|\theta_0|}{\alpha}\right) \cdot \cosh(p \cdot t)\right] + \frac{\dot{\theta}_0^{\,2}}{\alpha} \cdot senh(p \cdot t)$$

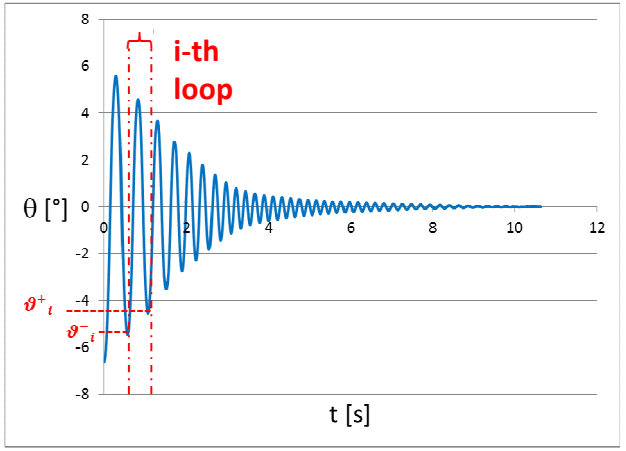
Double non-linearity:

- presence of trigonometric terms;
- presence of the sign function, which describes the alternation of the rotation point at the base from *0* to *0'* in correspondence with the collisions at the base.

# EXPERIMENTAL TESTS: RELEASE TESTS

Characteristics of the specimen:

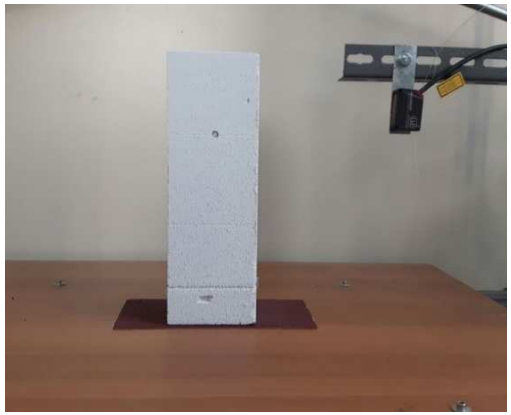
- Material: Autoclaved Aerated Concrete (AAC)
- Geometry: square base (b=5.0 cm), h=15.0 cm, R=15.8 cm, $\alpha$=18°.
- Weight : 1.5 kg

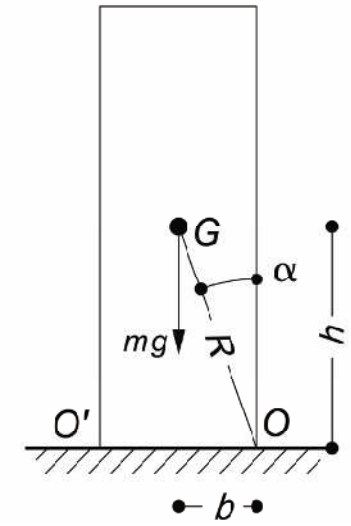



Test layout:

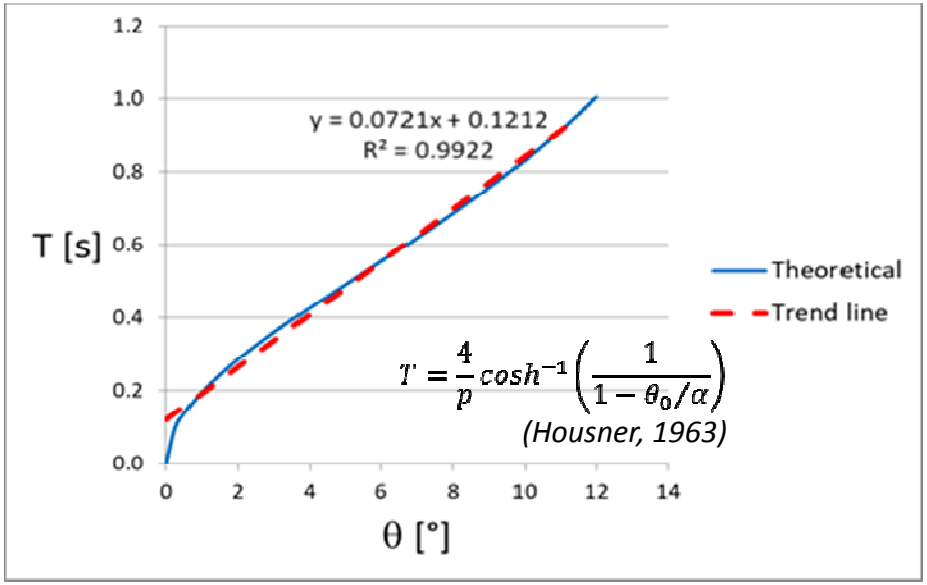
- Type of material on which the block is placed:
  - Sandpaper;
  - Autoclaved Aerated Concrete (AAC);
  - Wood.

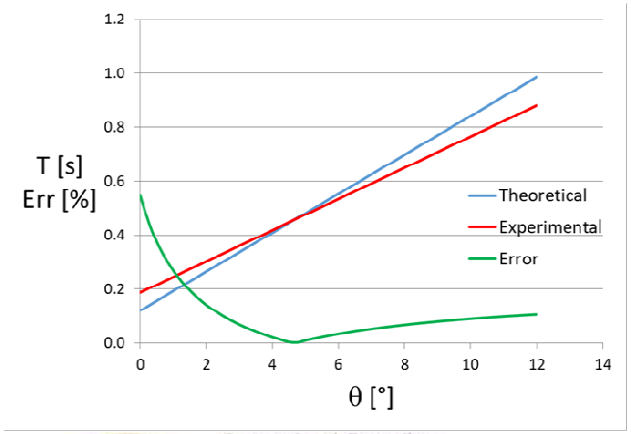
$$\vartheta^* = \frac{|\vartheta^-_i + \vartheta^+_i|}{2}$$

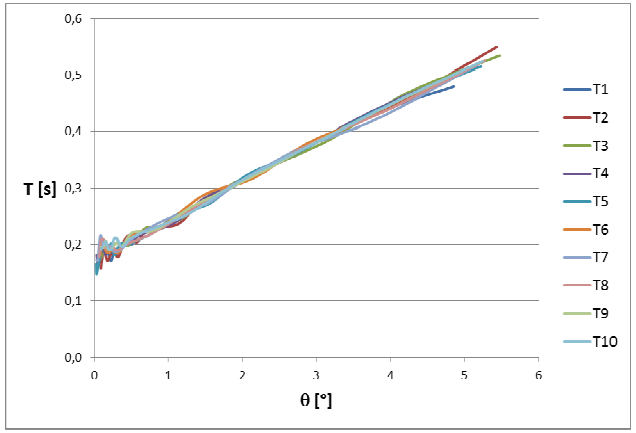




# EXPERIMENTAL TESTS: RELEASE TESTS

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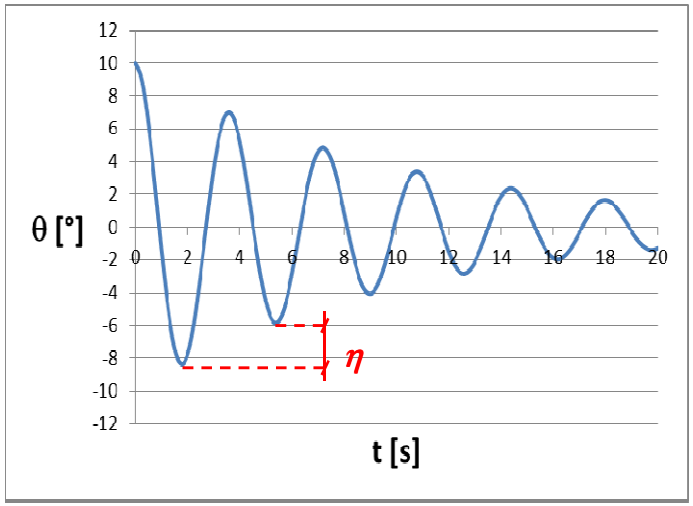
## EXPERIMENTAL TESTS: RELEASE TESTS

# DYNAMIC PARAMETERS

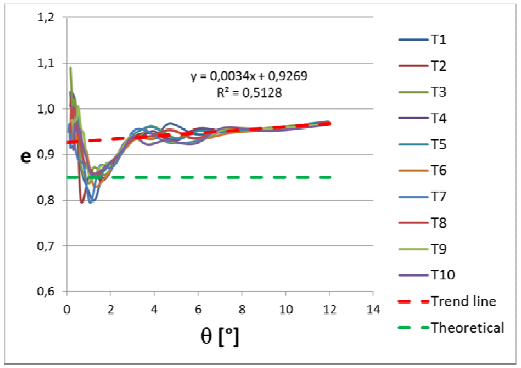
*(Clough and Penzien, 2003)*

$$\xi = \sqrt{\frac{(\ln \eta)^2}{4\pi^2 + (\ln \eta)^2}}$$

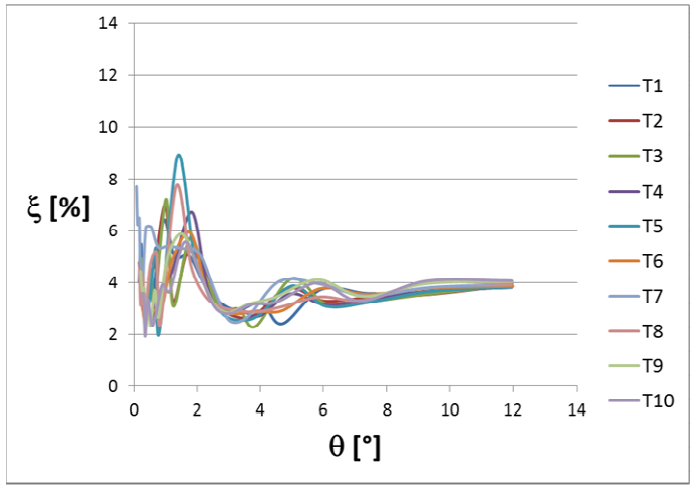
**Equivalent Damping Factor**




**SANDPAPER**




$$e = e(\vartheta_i^-)$$




$$e = \frac{\dot{\theta}_2}{\dot{\theta}_1} = \sqrt{r} = \frac{1}{4} + \frac{3}{4} \cdot \cos(2\alpha) = 0{,}85$$

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L. Petti, F. Sicignano, D. Greco, "*Dynamic behaviour assessment of rigid block systems through experimental campaign*", 16th European Conference on Earthquake Engineering, **Thessaloniki (Grecia) 2018.**

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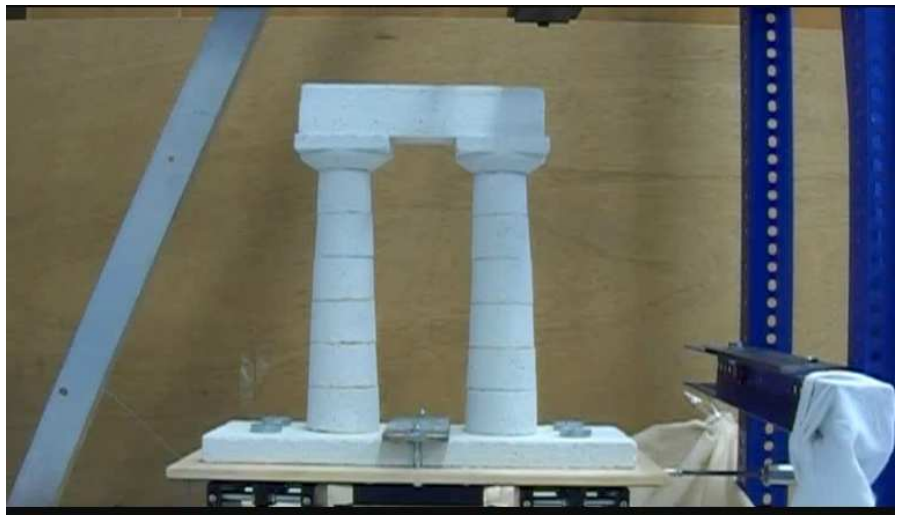
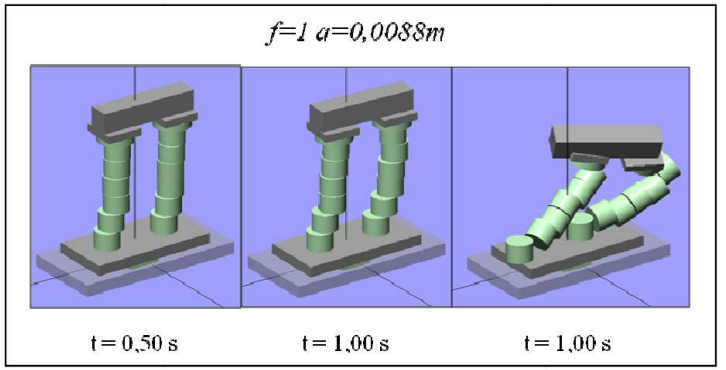
AMBIENTE, TERRITORIO E CULTURAL HERITAGE

## ONGOING RESEARCH ACTIVITIES






Scaled model studies carried out in order to better understand the dynamic behaviour of such ancient structures

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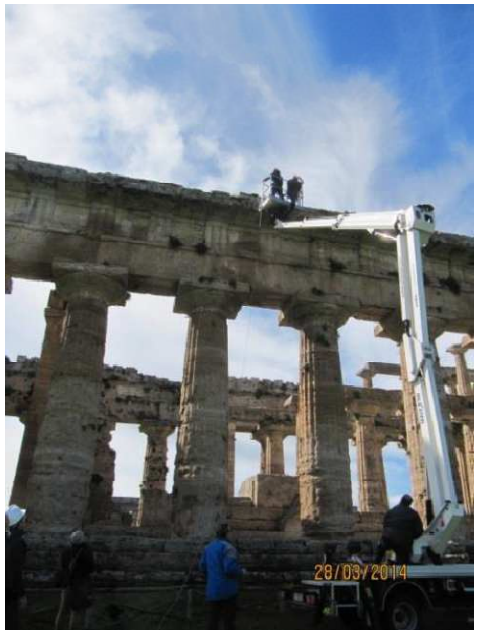
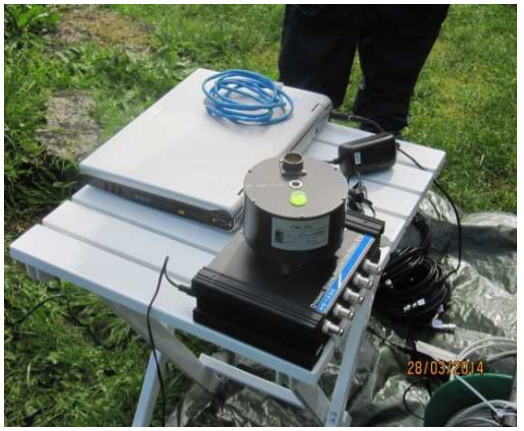
## ON-SITE RESEARCH ACTIVITIES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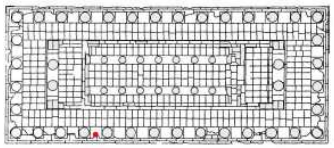
**AMBIENTE, TERRITORIO E CULTURAL HERITAGE**

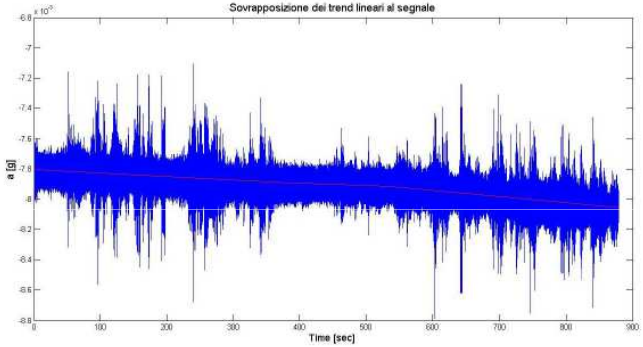
## ONGOING RESEARCH ACTIVITIES
## NUMERICAL MODELS RESULTS

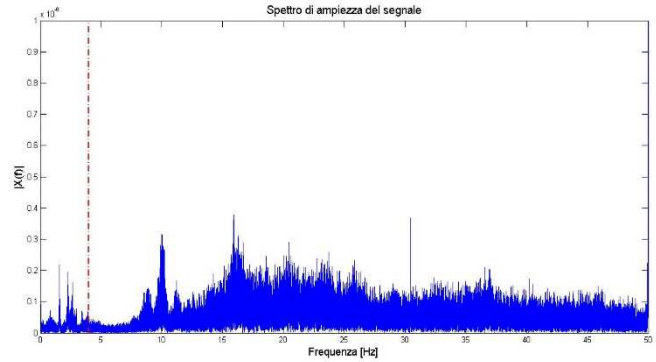
## *Onsite tests*

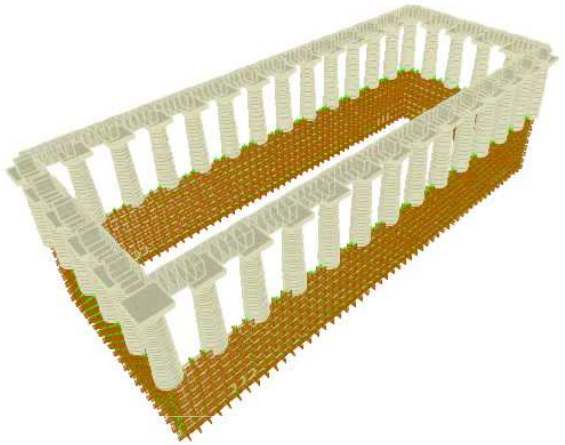
**Misura:** Signal_L1_TX_512_10:54 **Data:** 28/03/2014 **Ora:** 10:54:49

**Frequenza di acquisizione:** 512 Hz

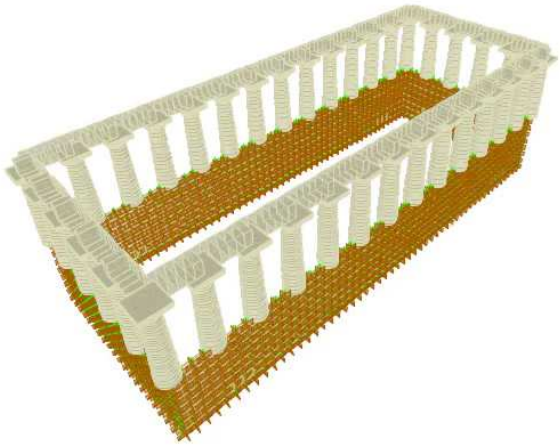




*2° Modal Form*



*3° Modal Form*

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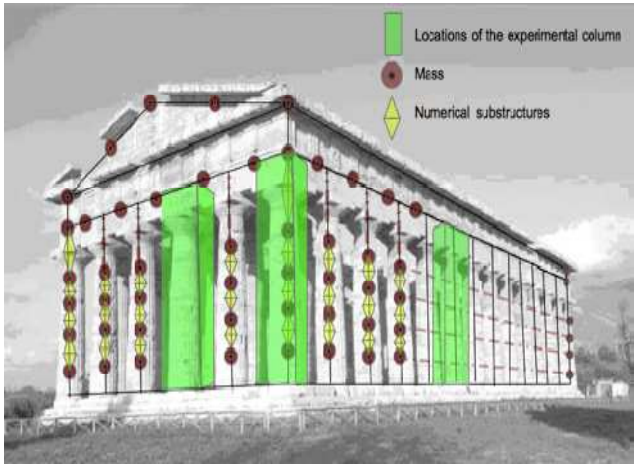
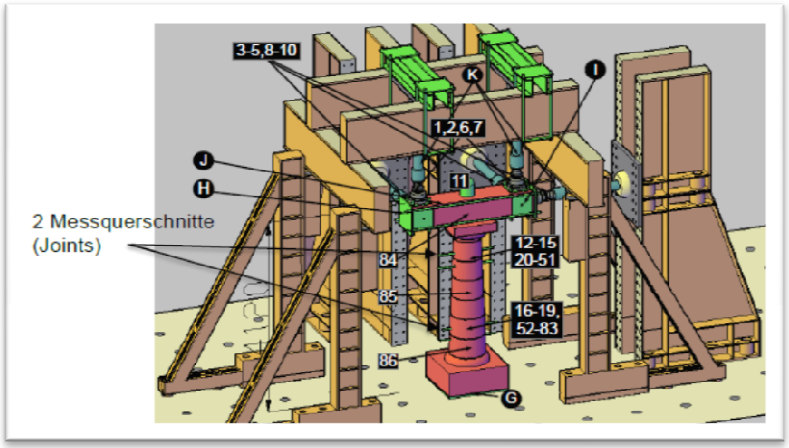
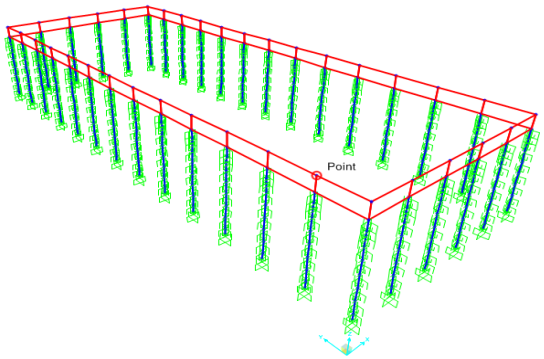
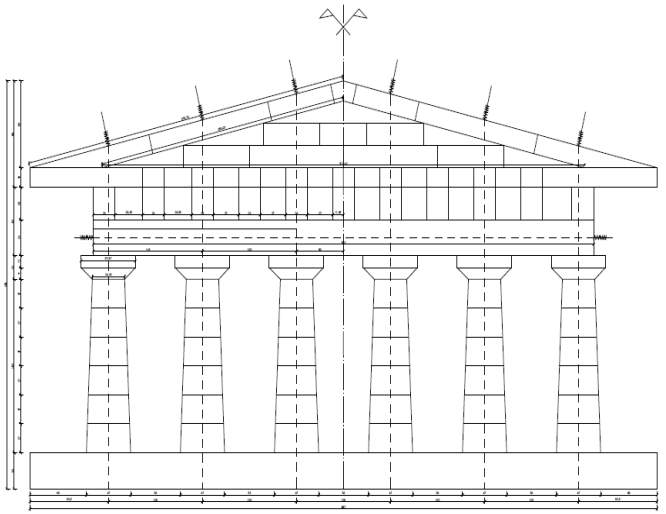
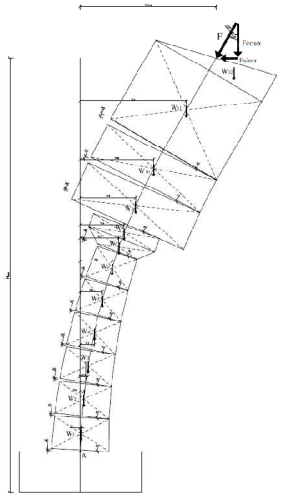
# ONGOING RESEARCH ACTIVITIES





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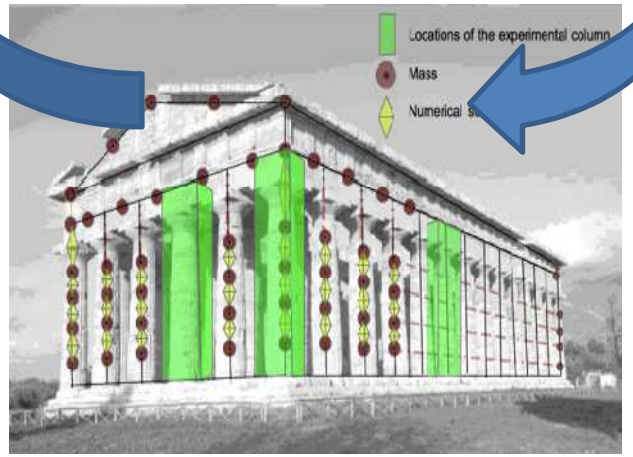


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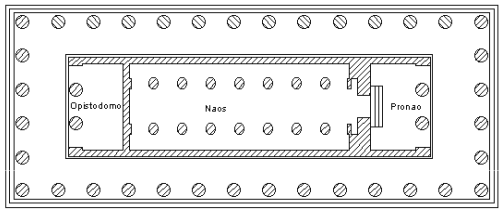
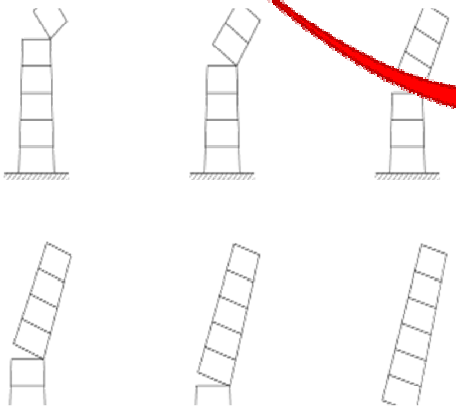
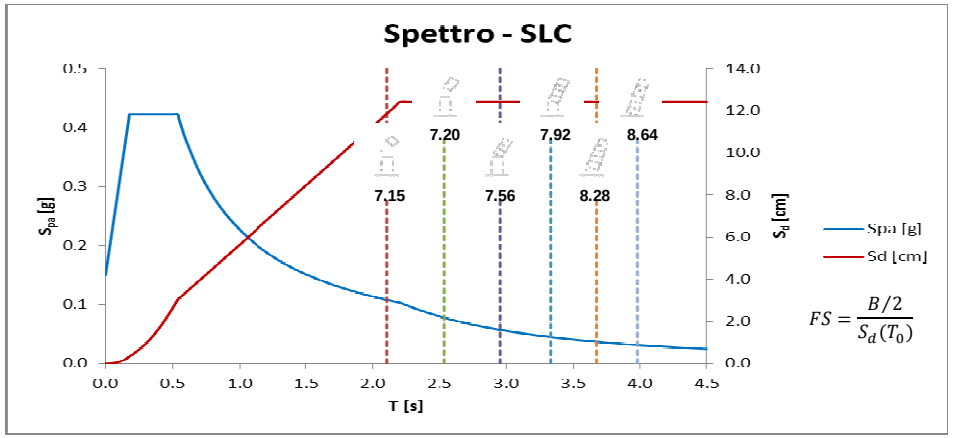
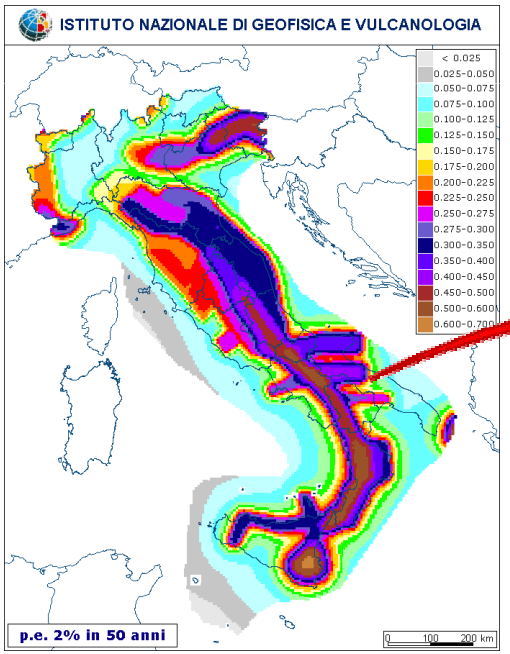
## EXPERIMENTAL TESTS: RELEASE TESTS

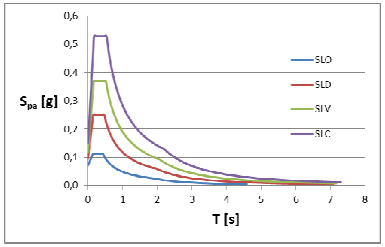
Poseidonia - Tempio di Poseidon






| SLATO LIMITE | $T_R$ [anni] | $a_g$ [g] | $F_o$ [-] | $T_C^*$ [s] |
|---|---|---|---|---|
| SLO | 120 | 0.058 | 2.524 | 0.395 |
| SLD | 201 | 0.071 | 2.539 | 0.436 |
| SLV | 1898 | 0.140 | 2.781 | 0.530 |
| SLC | 2475 | 0.150 | 2.819 | 0.537 |

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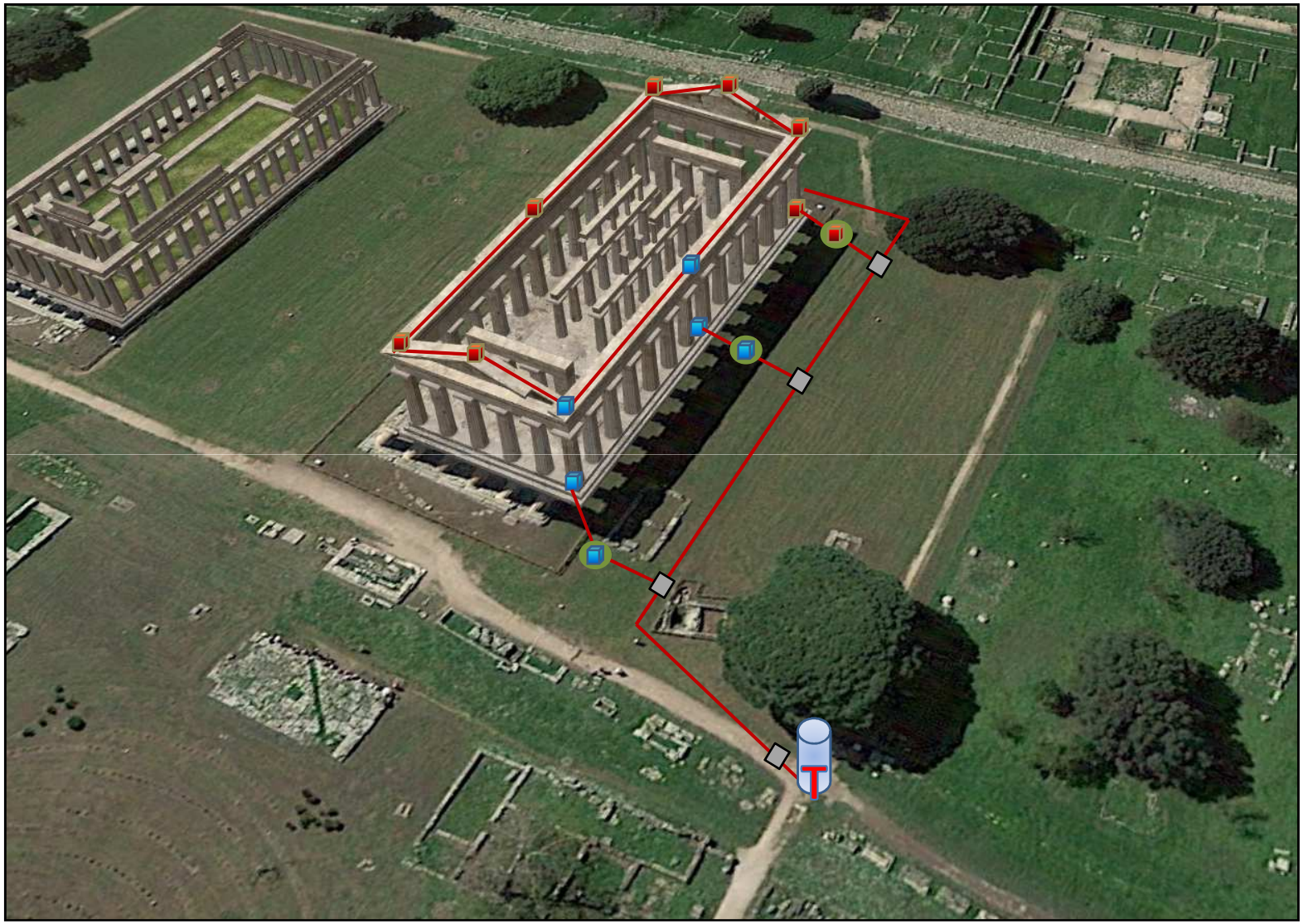
## AMBIENTE, TERRITORIO E CULTURAL HERITAGE

## MONITORING SYSTEM SET-UP



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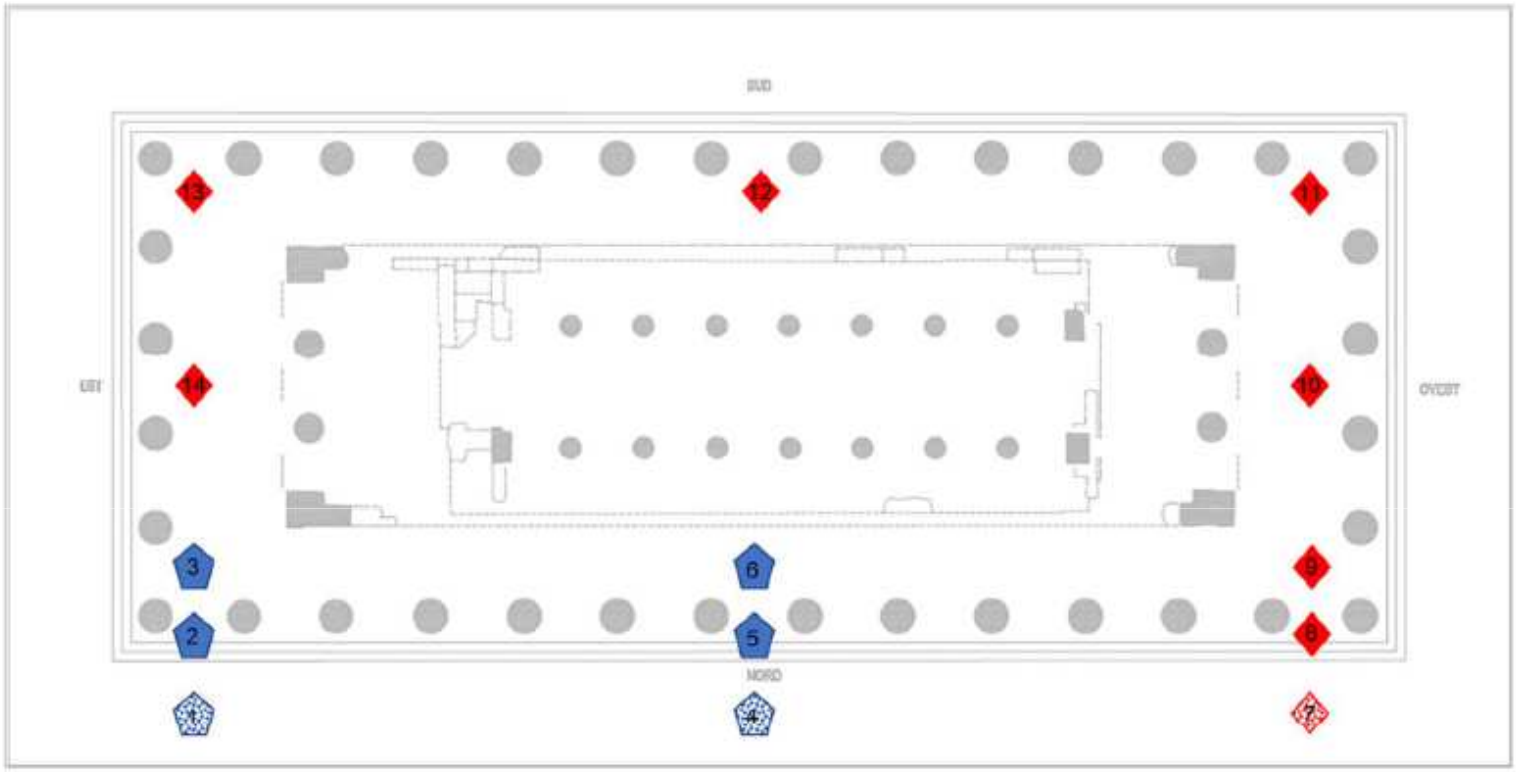
# MONITORING SYSTEM SET-UP




n Sensori triassiali posti sul basamento e in sommità del tempio

n Sensori triassiali posti sul piano di posa della fondazione del tempio

n Sensori biassiali posti sul basamento e in sommità del tempio

n Sensori biassiali posti sul piano di posa della fondazione del tempio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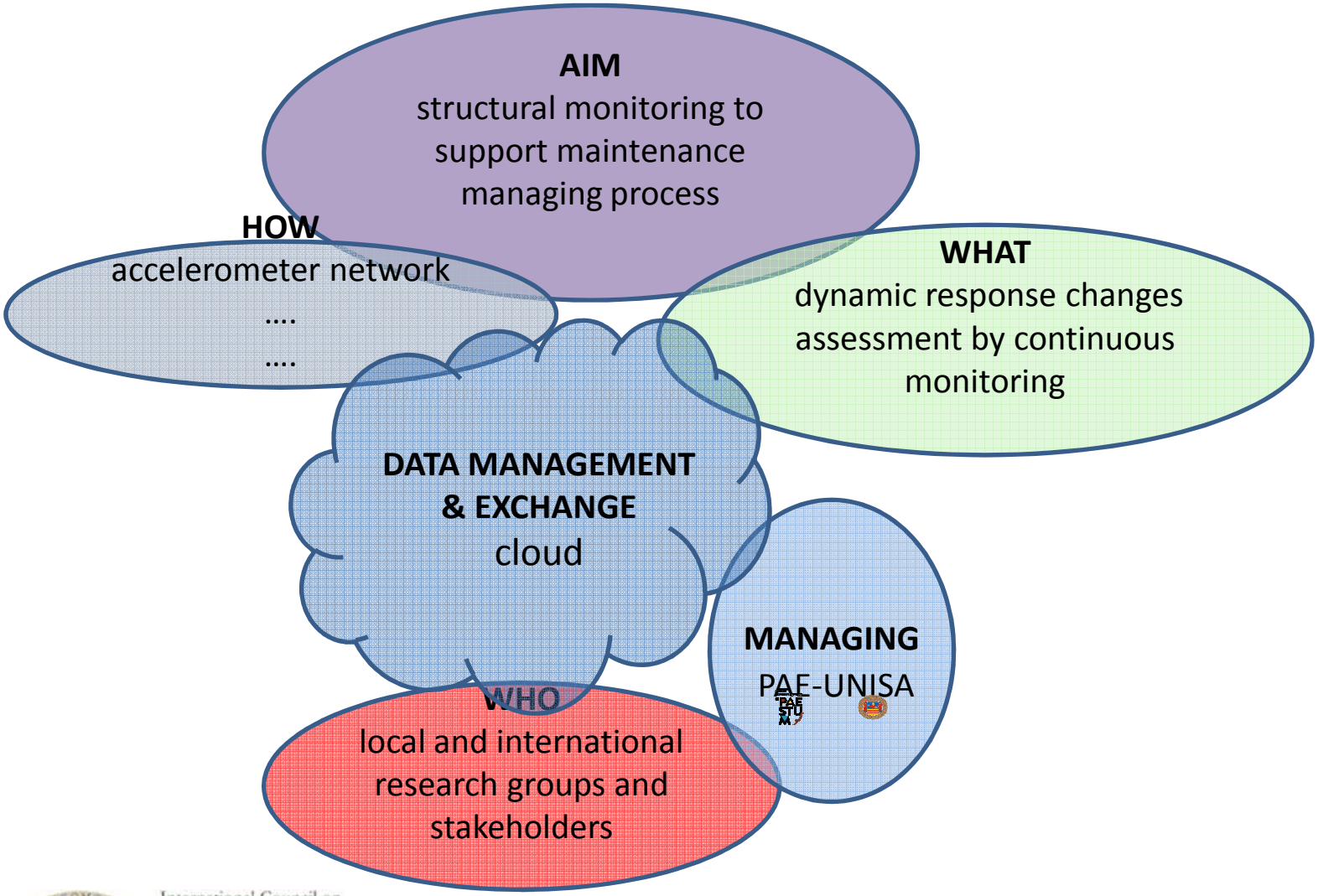
# MONITORING SYSTEM: GOALS and STRUCTURE



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# *Thanks for the attention*

***Luigi Petti***
*petti@unisa.it*

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