Numerical modelling of the dynamic behaviour of masonry constructions

Laboratorio di Meccanica

dei Materiali e delle Strutture

Cristina Padovani

Giuseppe Pasquinelli

Maria Girardi

Istituto di Scienza e Tecnologie
dell'Informazione "A. Faedo"
ISTI-CNR Pisa

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• The NOSA code is a finite element solver for nonlinear analyses.

• Masonry is modelled by a nonlinear isotropic elastic material with zero tensile strength and limited compressive strength (masonry-like or no-tension material).   [G. Del Piero, *Meccanica* 1989; S. Di Pasquale, *Meccanica* 1992; M. Lucchesi, C. Padovani et al., *Masonry Constructions and Numerical Applications,* Springer 2008].

• Static analyses

• Dynamic analyses

• Thermo-mechanical analyses

• Stress fields

• Collapse loads

• Elastic, fracture and crushing strain fields

• Displacement fields

• Temperature fields

• Time- histories

• NOSA library: beam, shell, 2D, 3D elements   (17 elements)

The NOSA version for static analyses is freely downloadable by
www.isti.cnr.it/research/unit.php?unit=MMS&section=software

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The masonry-like constitutive equation

E the infinitesimal strain tensor,

$\mathbf{T}$ the Cauchy stress tensor,

E^e the elastic part of the strain,

E^f the fracture strain,

E^c the crushing strain,

$\mathbf{E}, \nu$ the modulus of elasticity and the Poisson's ratio,

$\sigma_0 < 0$ the masonry maximum compressive stress.

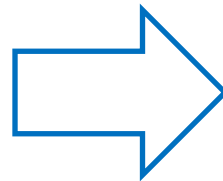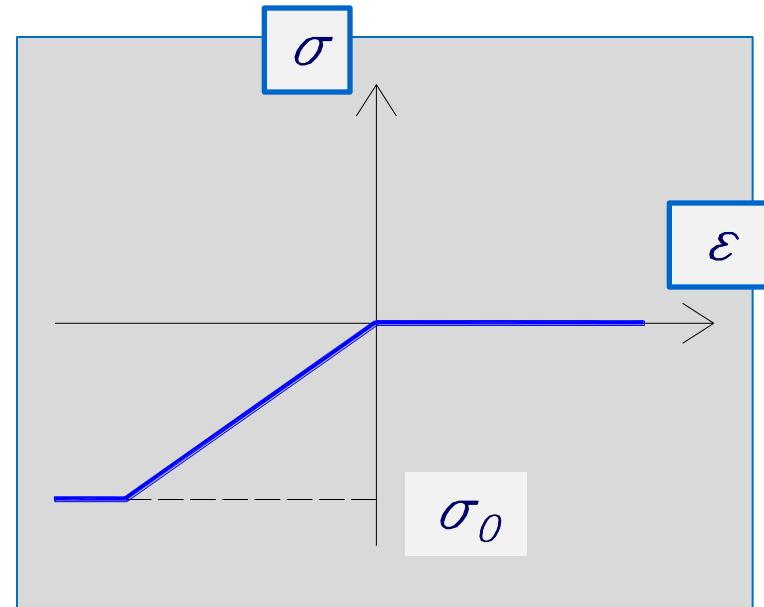**Given $\mathbf{E}$, find $\mathbf{E^f}$, $\mathbf{E^c}$, $\mathbf{T}$ such that**

$$E = E^e + E^f + E^c,$$

$$E^f \cdot E^c = 0,$$

$$T = \frac{E}{1+\nu}\left[E^e + \frac{\nu}{1-2\nu}\, tr(E^e)I \right],$$

$$T \cdot E^f = \left(T - \sigma_0 I\right) \cdot E^c = 0,$$

$$T, E^c \leq 0, \quad T - \sigma_0 I \geq 0, \quad E^f \geq 0$$

$$\Longrightarrow \quad T = \hat{T}(E), \quad D_E \hat{T}(E)$$
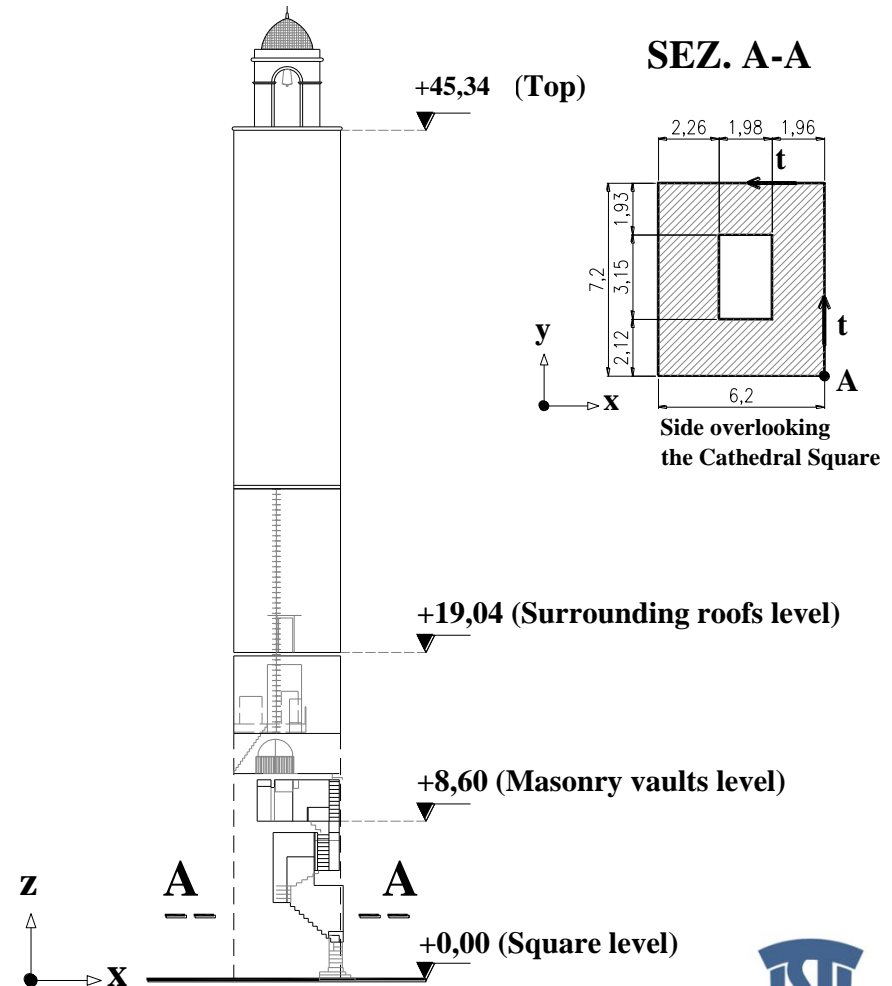
Some example applications

Static Analyses

- 1995   Battistero del Duomo, Volterra

- 1996   Arsenale Mediceo, Pisa

- 1998   Teatro Goldoni, Livorno

- 1998   Chiesa Madre di S. Nicolò, Noto

- 2004   Chiesa di Santa Maria Maddalena, Morano Calabro

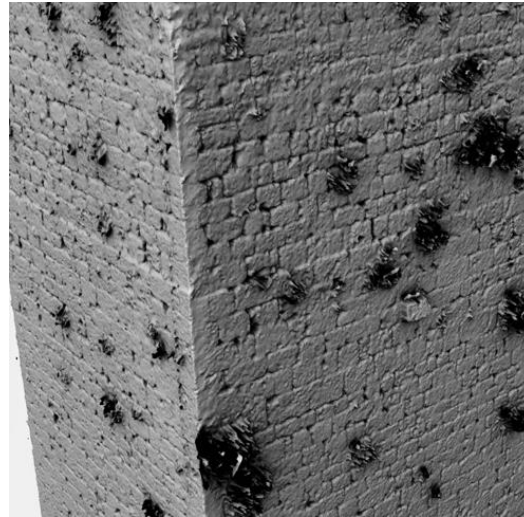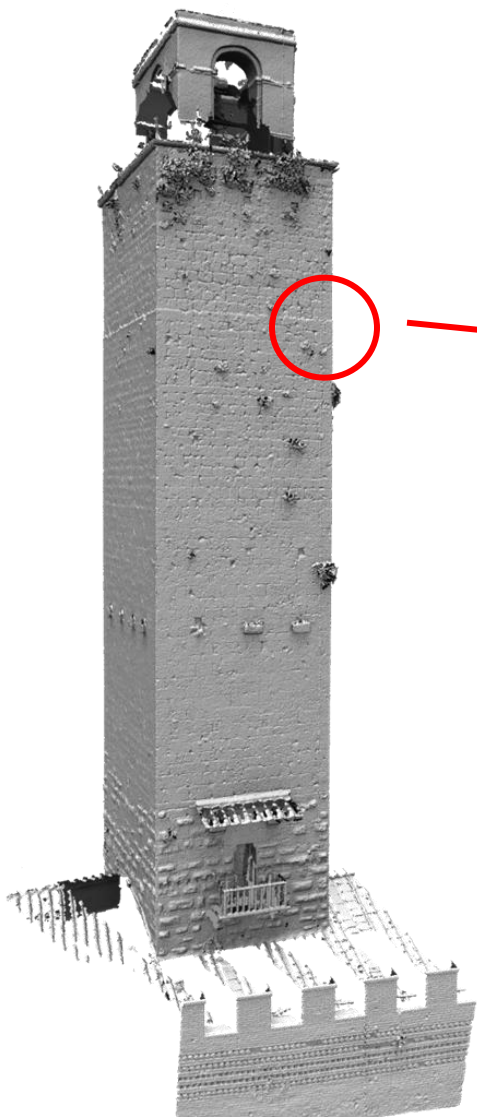- 2005   Chiesa di San Ponziano, Lucca

Dynamic Analyses

- 2008   Chiesa Abbaziale di Santa Maria della Roccella, Roccella Ionica

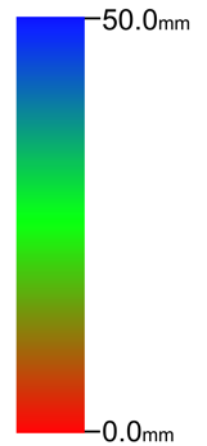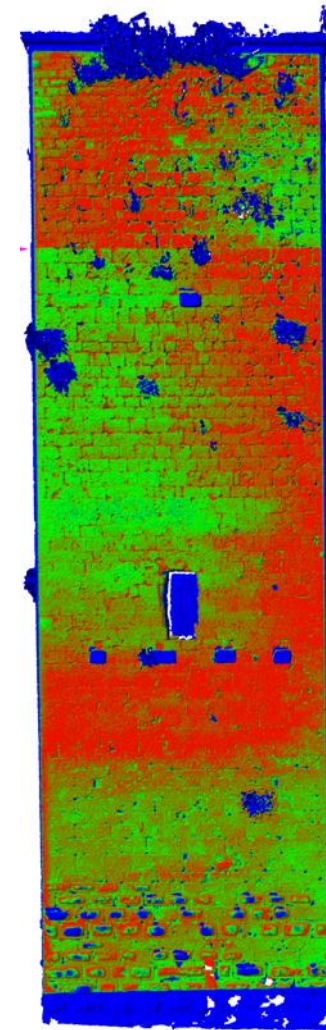- 2008   Torre "Rognosa" , San Gimignano

- 2010   Torre "delle Ore", Lucca

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The "Rognosa" tower in San Gimignano (St@rt project)

SEZ. A-A

Side overlooking the Cathedral Square

+45,34 (Top)

+19,04 (Surrounding roofs level)

+8,60 (Masonry vaults level)

+0,00 (Square level)

Numerical modelling of the dynamic behaviour of masonry constructions

The "Rognosa" tower in San Gimignano: digital acquisition of the geometry (VC Lab – ISTI CNR)
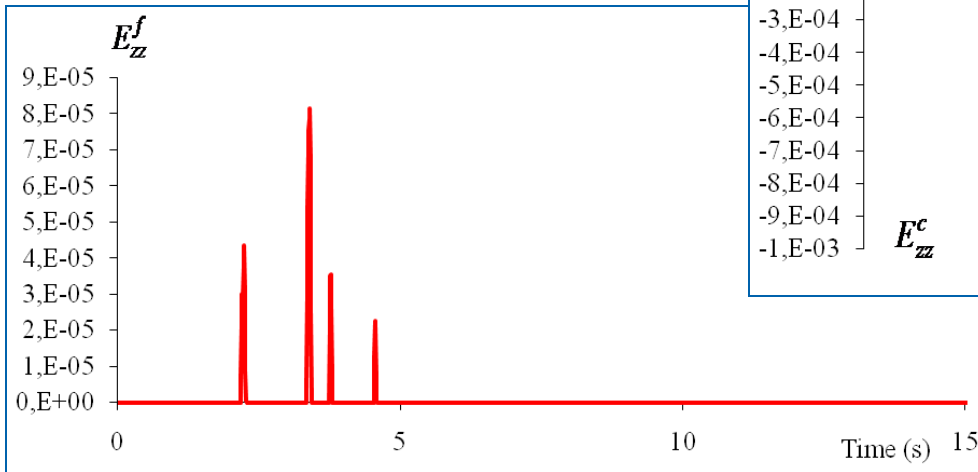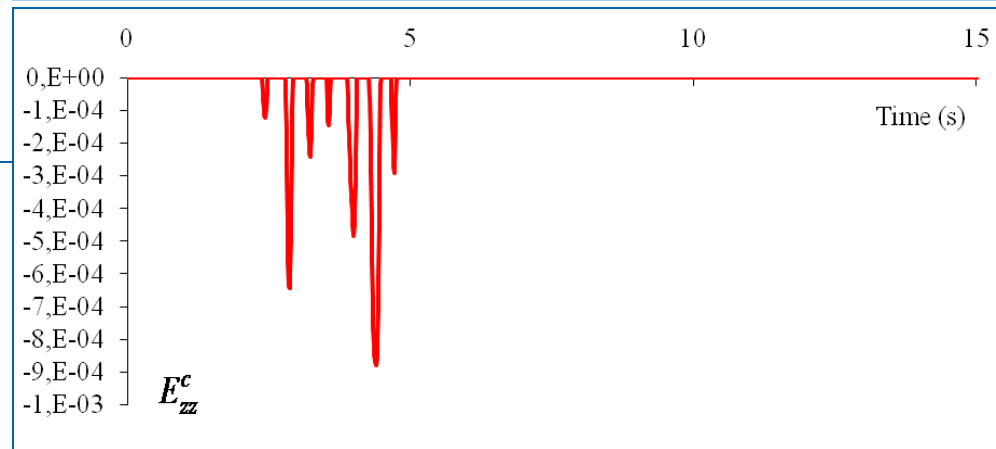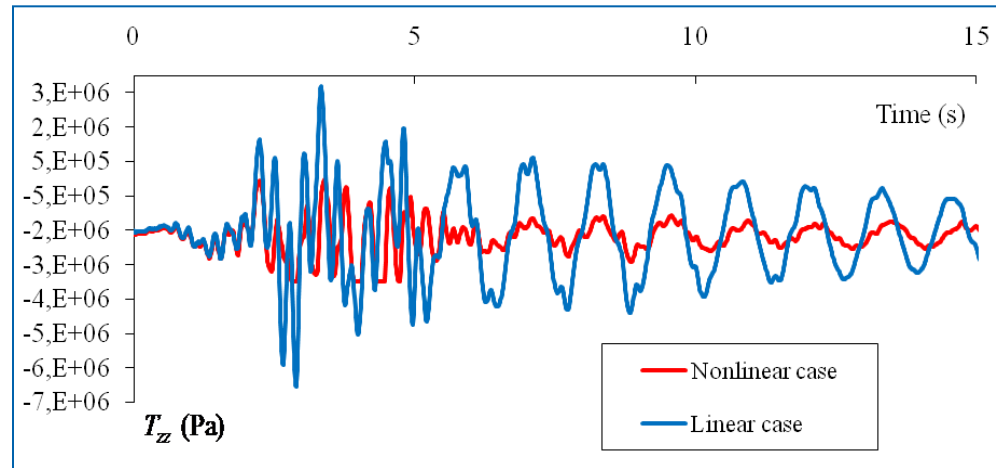

Merging resolution=1 cm

-50.0mm

-0.0mm

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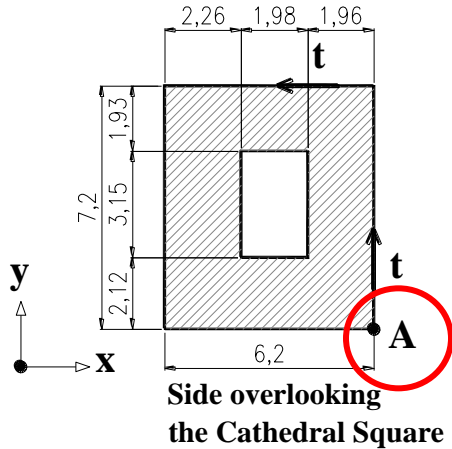dell'Informazione
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The "Rognosa" tower in San Gimignano:

- Static analysis The Tower is subjected to its own weight and to the weight of the surrounding buildings

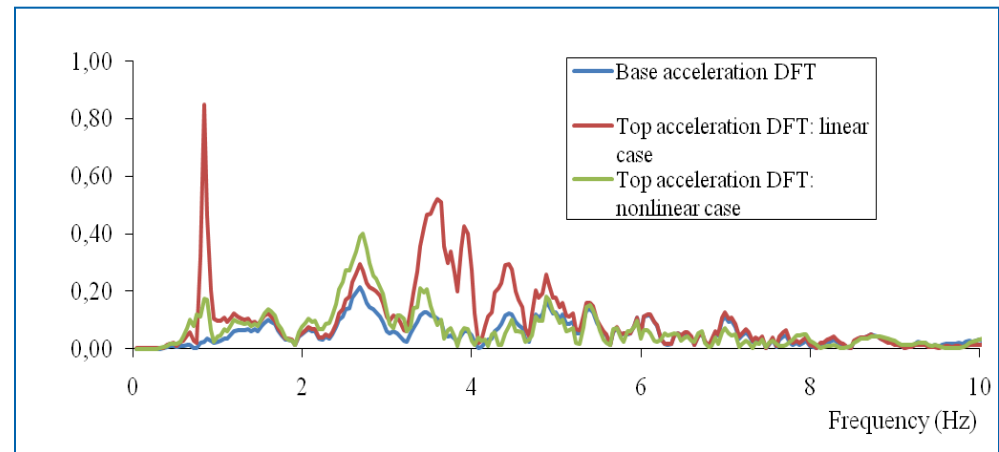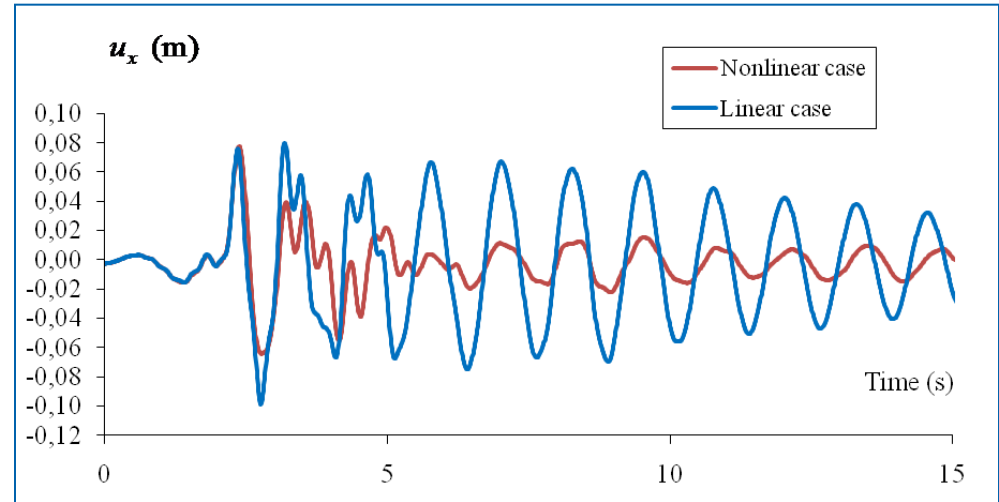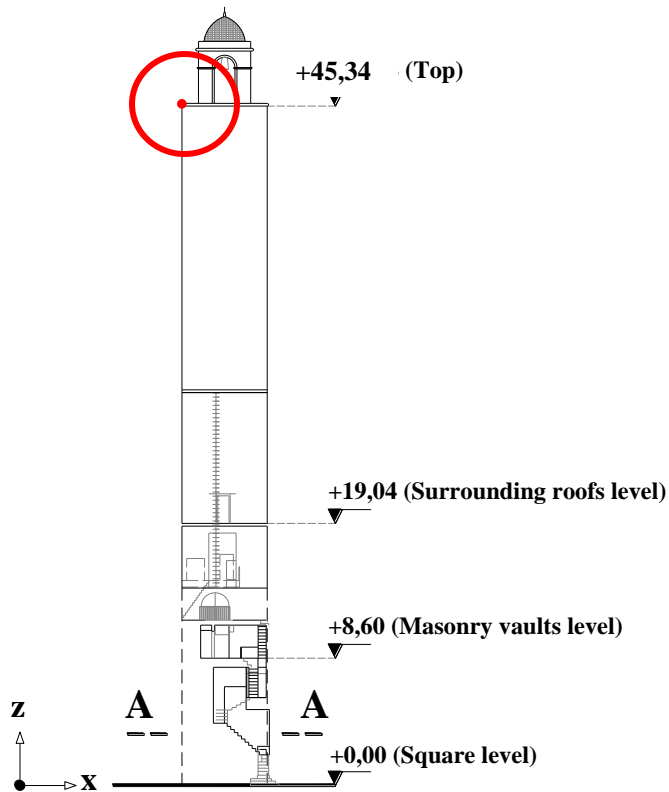- Dynamic analysis The Tower subjected to the Nocera Umbra earthquake in x - direction
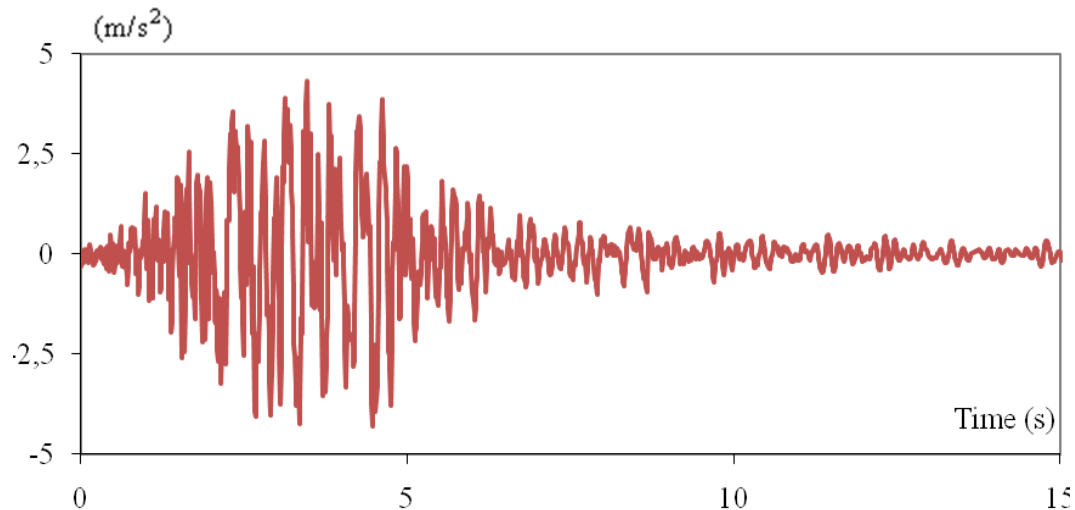
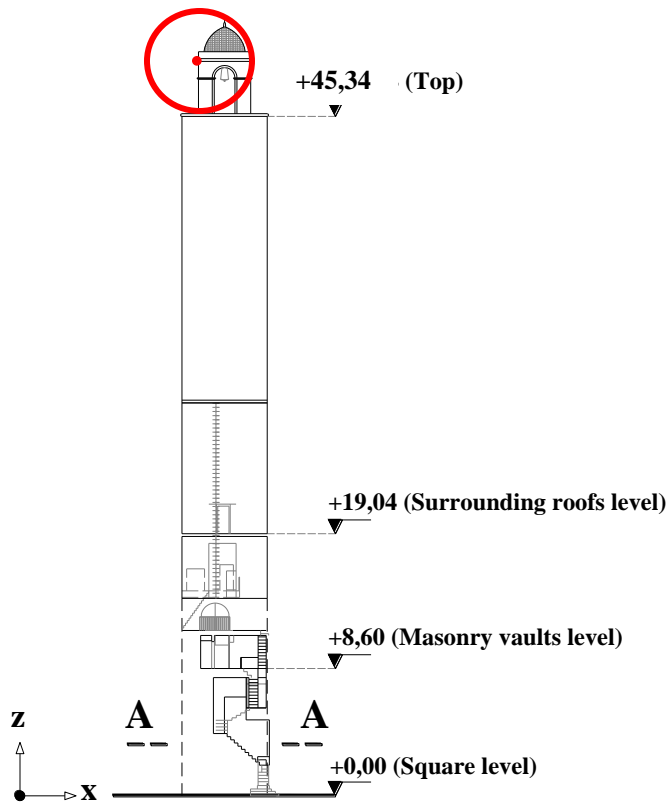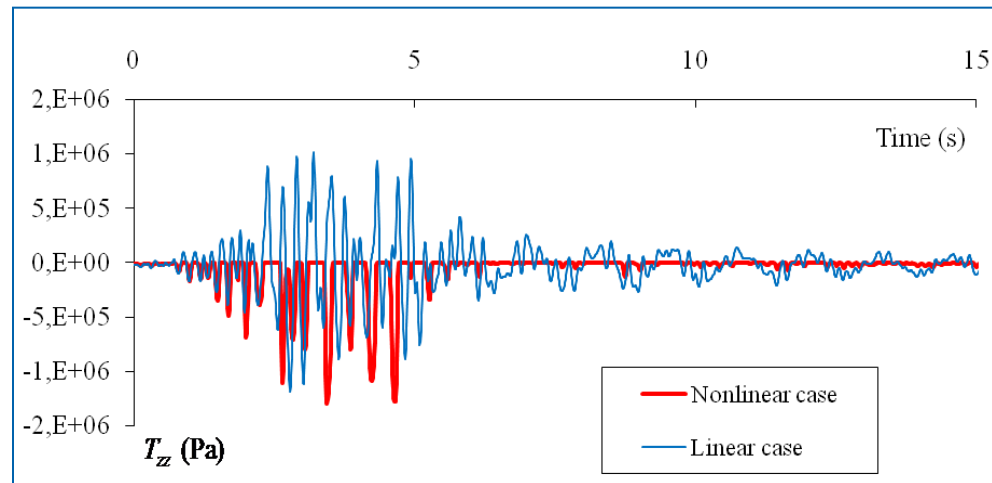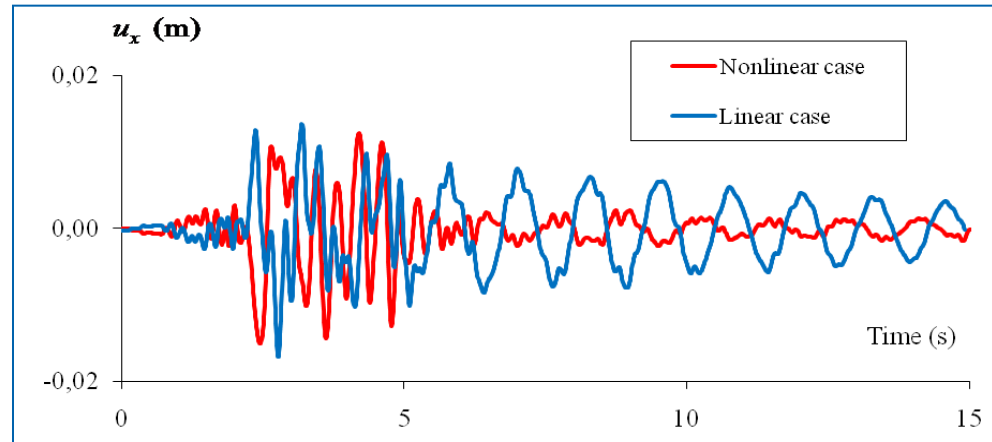## The "Rognosa" tower in San Gimignano: dynamic analysis

Tower base section

Side overlooking the Cathedral Square

T_{zz} (Pa)

— Nonlinear case
— Linear case

E_{zz}^f

E_{zz}^c

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The "Rognosa" tower in San Gimignano: dynamic analysis

Tower vertical section

+45,34 (Top)

+19,04 (Surrounding roofs level)

+8,60 (Masonry vaults level)

A   A

+0,00 (Square level)

The bell chamber

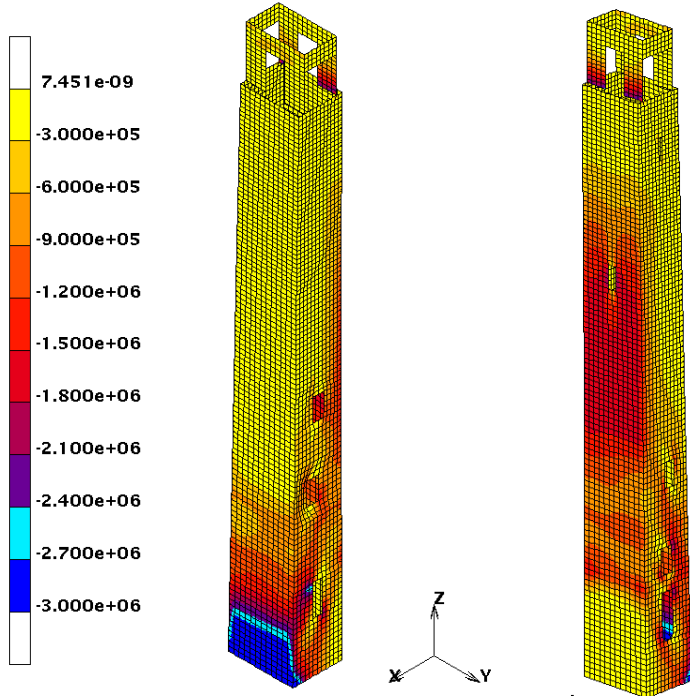*The "Rognosa" Tower in San Gimignano: digital acquisition and structural analysis*
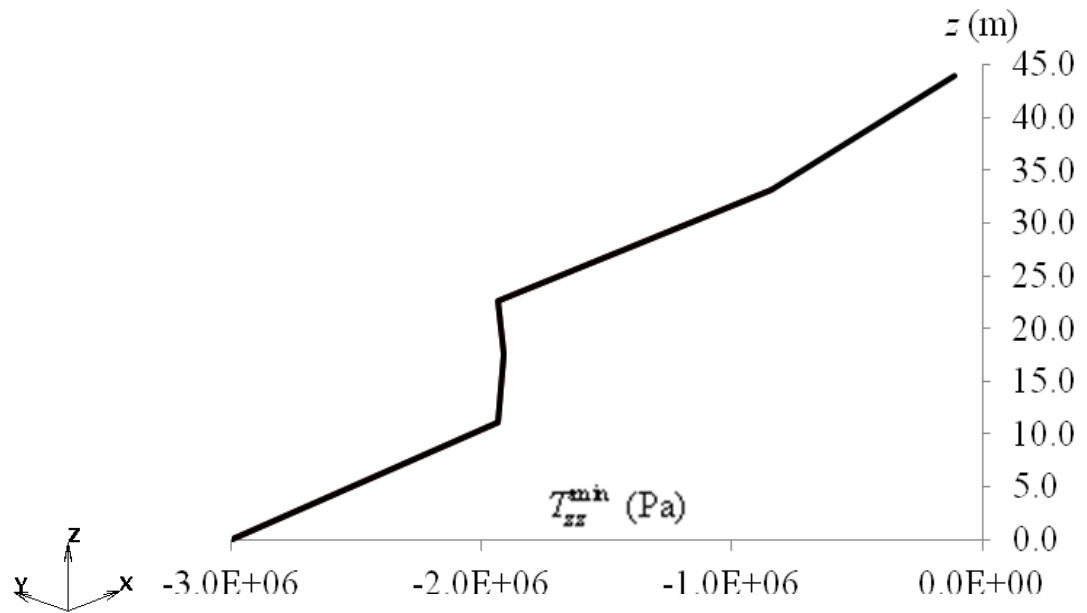
The "Rognosa" tower in San Gimignano: dynamic analysis

Compressive stresses T_{zz}

At time t=3,41 s:

Minimum values reached during the analysis :

Inc: 343
Time: 3.410e+00
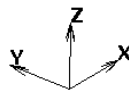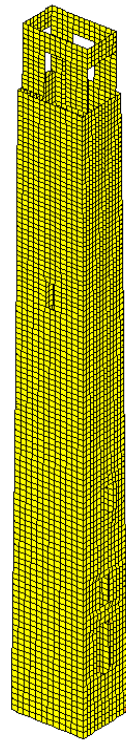
7.451e-09
-3.000e+05
-6.000e+05
-9.000e+05
-1.200e+06
-1.500e+06
-1.800e+06
-2.100e+06
-2.400e+06
-2.700e+06
-3.000e+06

z (m)

45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0

T_{zz}^{min} (Pa)

-3.0E+06   -2.0E+06   -1.0E+06   0.0E+00

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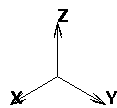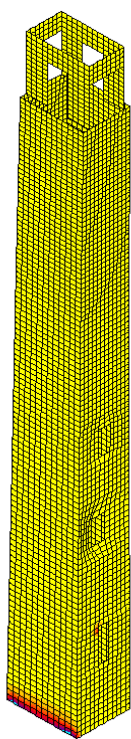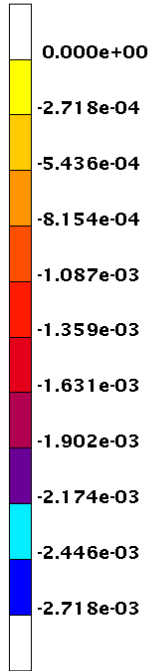Consiglio Nazionale delle Ricerche

The "Rognosa" tower in San Gimignano: dynamic analysis

Crushing strain E^c_{zz}

At time t=3,41 s:

Minimum values reached during the analysis :
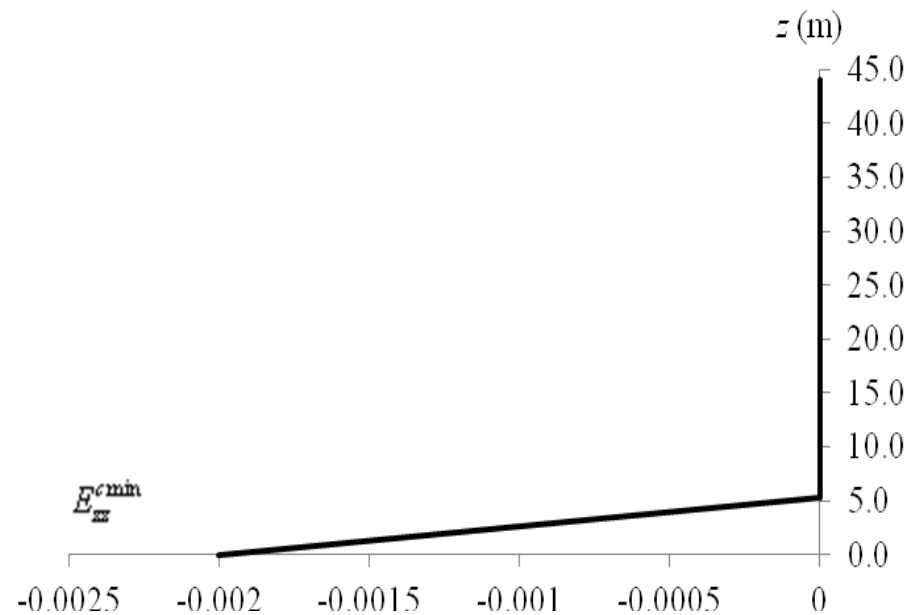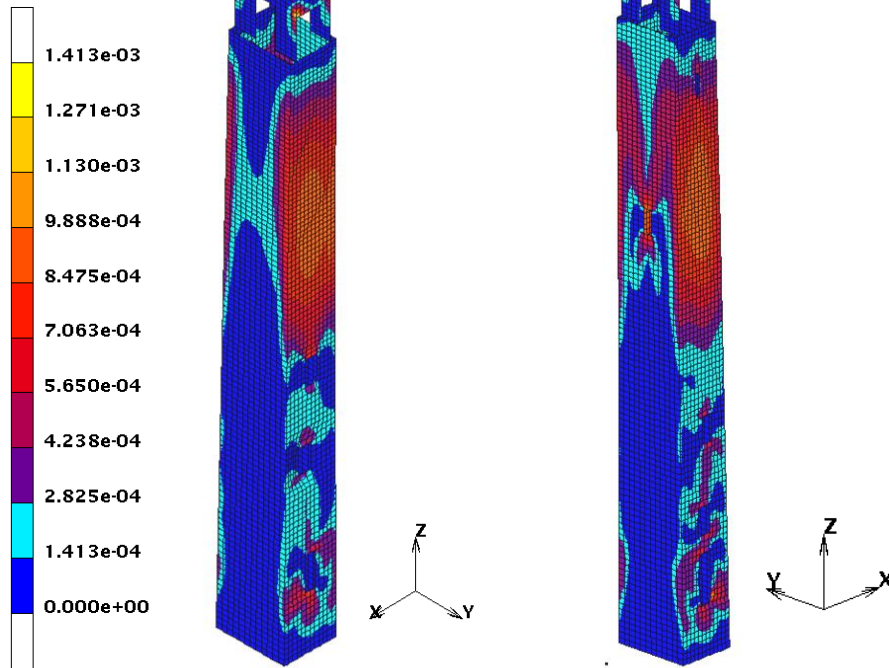
The "Rognosa" tower in San Gimignano: dynamic analysis

Tangential fracture strain E^f_{tt}

At time t=3,41 s:

Maximum values reached during the analysis :

The "Rognosa" tower in San Gimignano: dynamic analysis

Fracture strain E^f_{zz}

At time t=3,41 s:

Maximum values reached during the analysis :
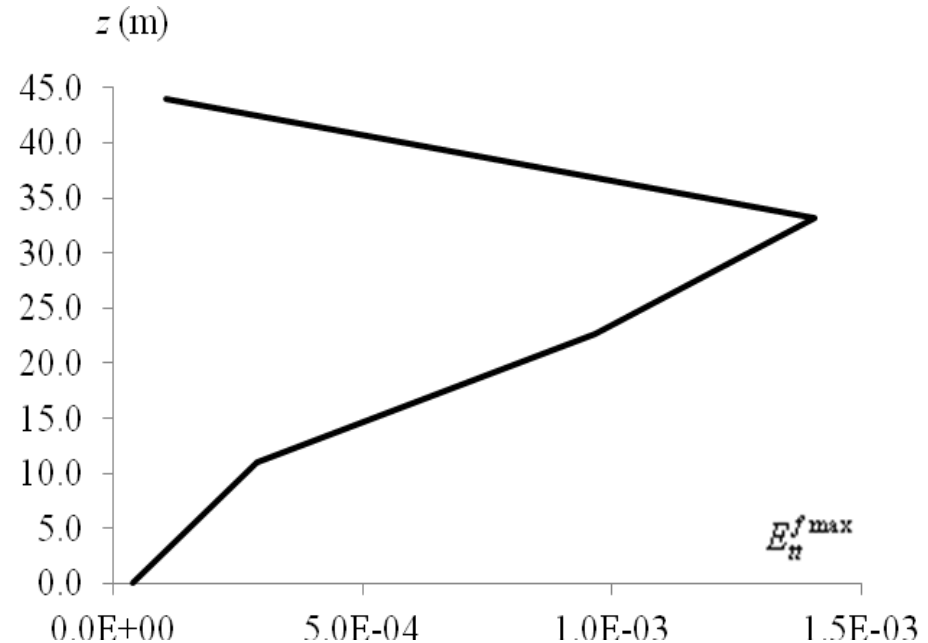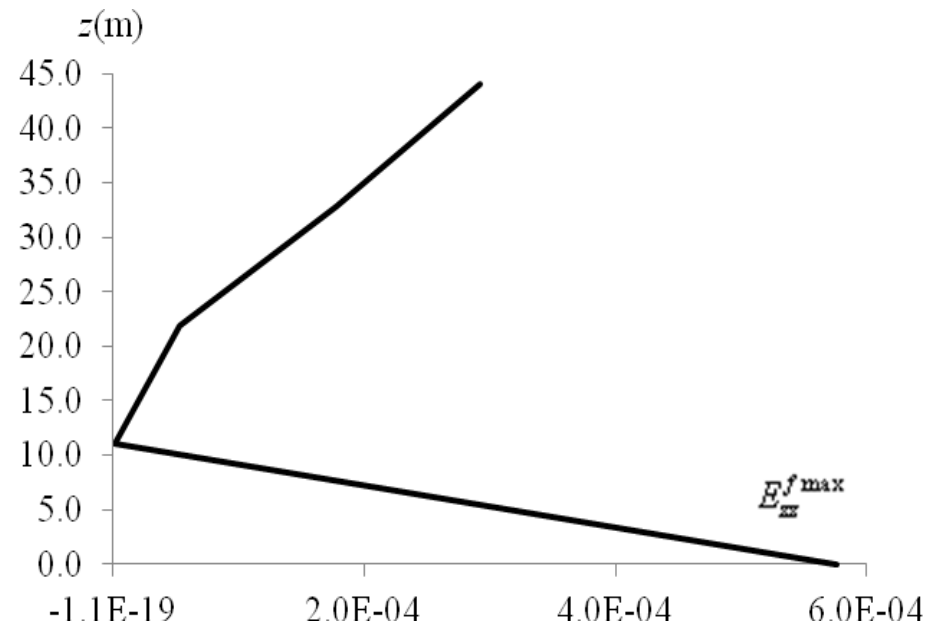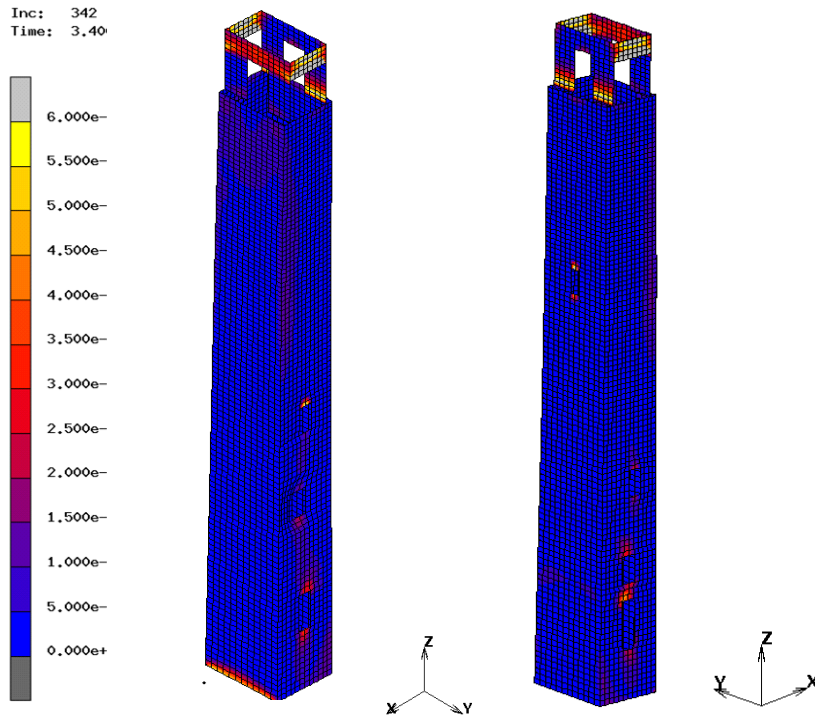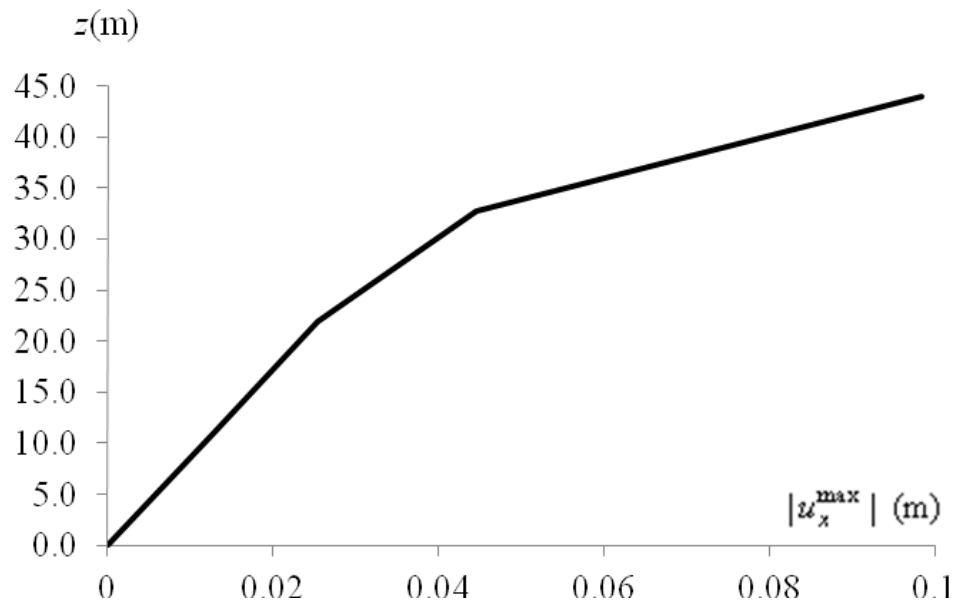
The "Rognosa" tower in San Gimignano: dynamic analysis

Displacements u_x

Maximum values reached during the analysis:

WONDERmasonry 2011, Facoltà di Ingegneria, Firenze

The NOSA-ITACA project
2011-2013

funded by the Region of Tuscany (PAR-FAS 2007-2013)

ISTI-CNR Pisa

DCR Firenze

Basic Research — NOSA –ITACA CODE — Case study — Consulting Service

Numerical modelling of the dynamic behaviour of masonry constructions
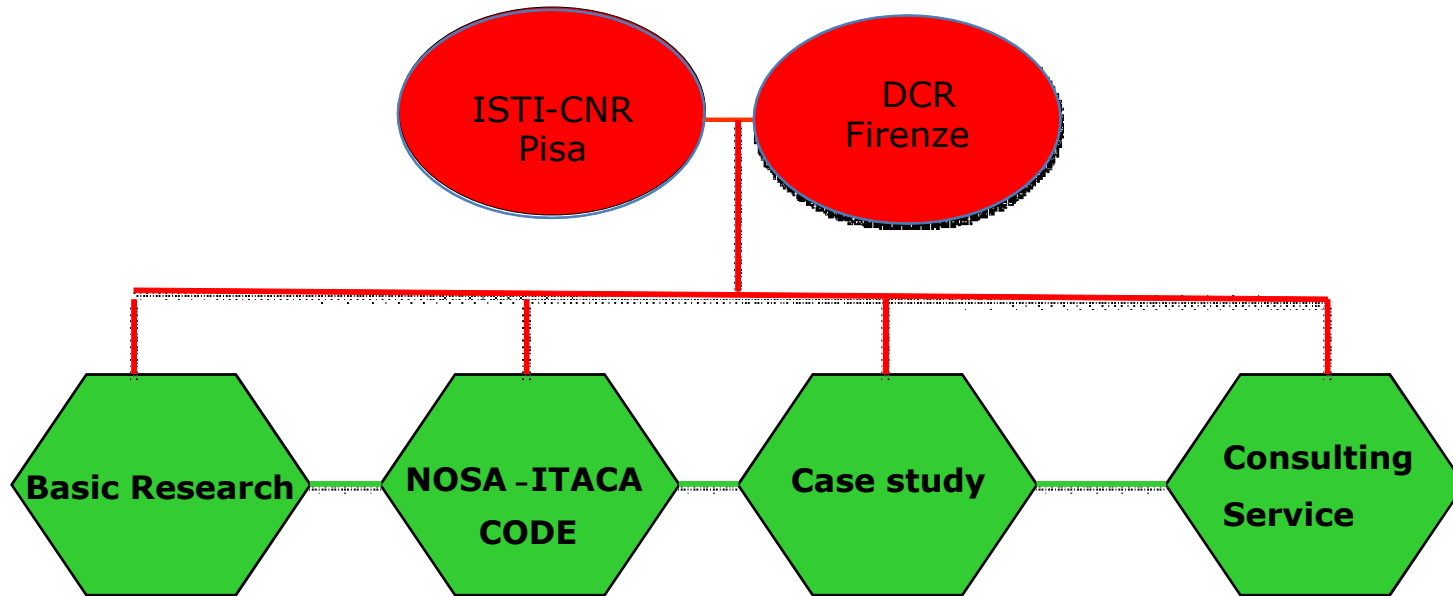
The NOSA-ITACA project

NOSA CODE: f.e.m. nonlinear solver
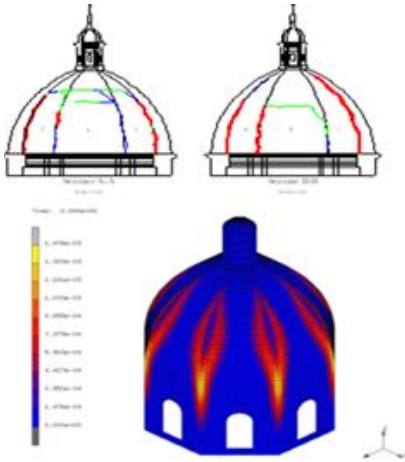
SALOME: pre-post processor
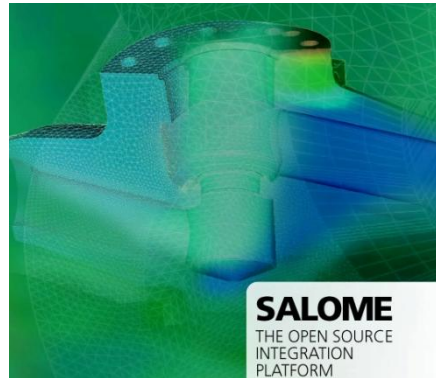
NOSA-ITACA code

Case study: "Voltone", Livorno

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Conclusions

•The NOSA code is a finite element code for static and dynamic nonlinear analyses of masonry structures. The version for static analyses is freely downloadable.

•Masonry is modelled by means of a masonry-like constitutive equation with zero tensile strength and finite or infinite compressive strength.

•A case study has been presented in which the seismic vulnerability of the Rognosa Tower in San Gimignano is assessed by means of a dynamic numerical analysis conducted via NOSA code.

• The NOSA-ITACA project aims to upgrade the NOSA code and disseminate the use of numerical tools in the field of maintenance and restoration of the architectural heritage.