The NOSA-ITACA code for the modelling of the structural behaviour of historic masonry constructions

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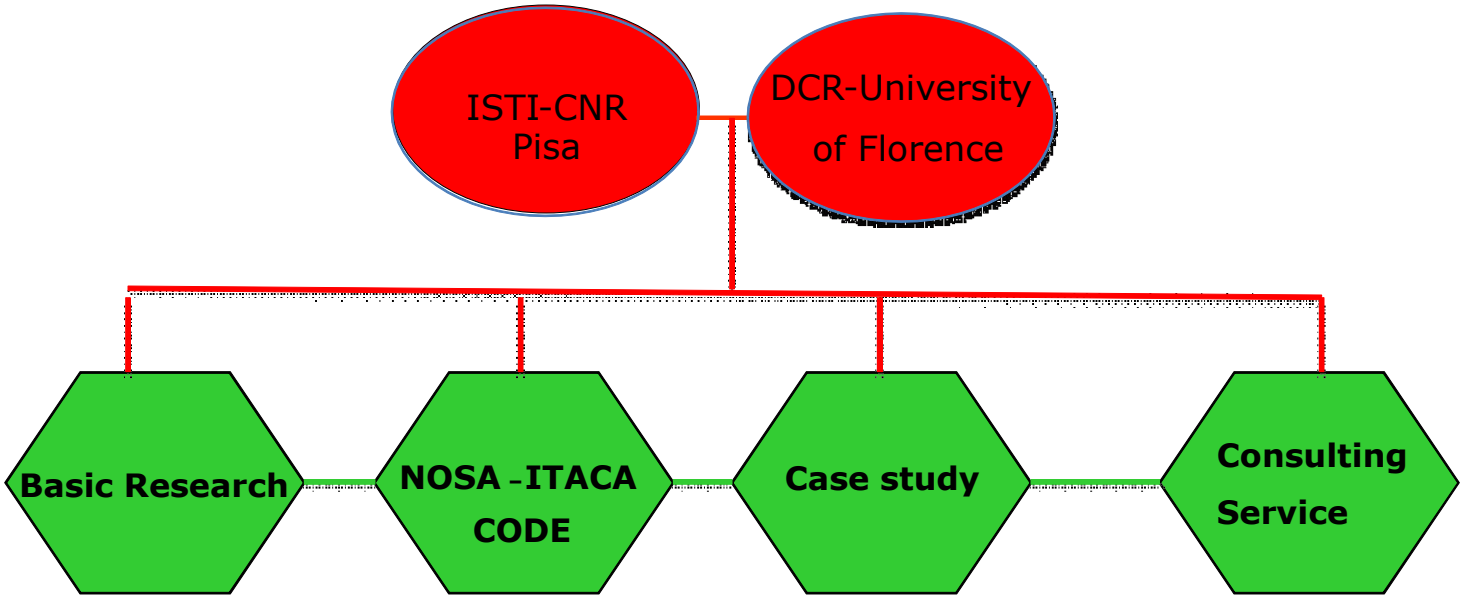
The NOSA-ITACA project
2011-2013

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



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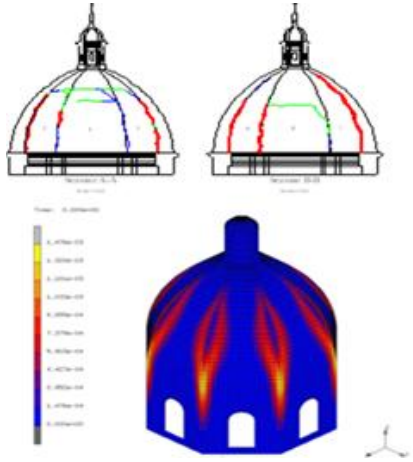
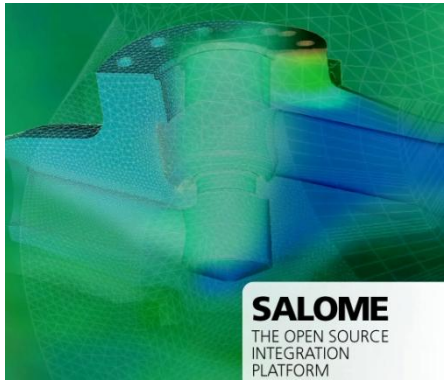
The NOSA-ITACA project

NOSA CODE: f.e.m. nonlinear solver



SALOME: pre-post processor



NOSA-ITACA code

Case study: "Voltone", Livorno

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The NOSA Code (http://www.isti.cnr.it/research/unit.php?unit=MMS)

- The NOSA code is a freeware finite element solver for nonlinear analyses.
- Masonry is modelled as a nonlinear isotropic elastic material with zero tensile strength and bounded 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: Mechanical Models 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, plane stress, plane strain, solid and heat transfer elements (17 elements)

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The masonry-like constitutive equation

$\boldsymbol{E}$ the infinitesimal strain tensor,

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

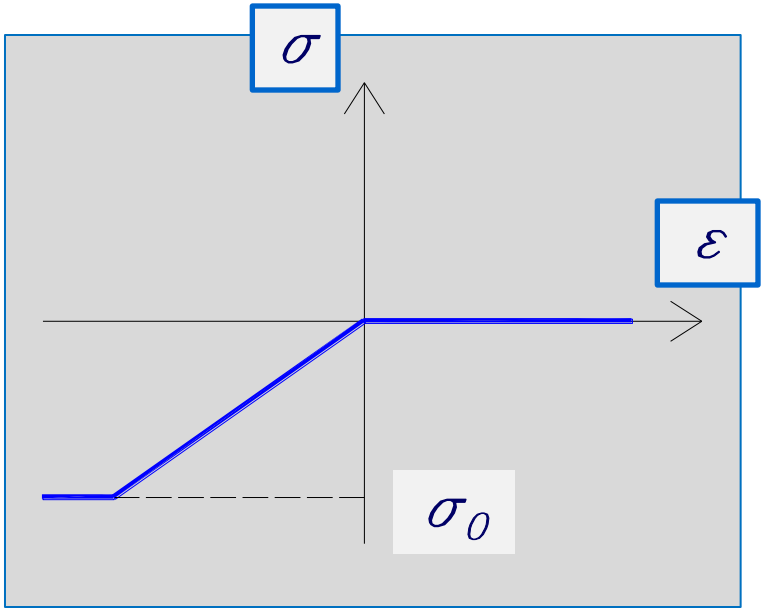
$\boldsymbol{E}^e$ the elastic part of the strain,

$\boldsymbol{E}^f$ the fracture strain,

$\boldsymbol{E}^c$ the crushing strain,

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

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



Given E, find E^f, E^c, T such that

$$\boldsymbol{E} = \boldsymbol{E}^e + \boldsymbol{E}^f + \boldsymbol{E}^c,$$

$$\boldsymbol{E}^f \cdot \boldsymbol{E}^c = \boldsymbol{0},$$

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

$$\boldsymbol{T} \cdot \boldsymbol{E}^f = (\boldsymbol{T} - \sigma_0 \boldsymbol{I}) \cdot \boldsymbol{E}^c = \boldsymbol{0},$$

$$\boldsymbol{T}, \boldsymbol{E}^c \le \boldsymbol{0}, \ \boldsymbol{T} - \sigma_0 \boldsymbol{I} \ge \boldsymbol{0}, \boldsymbol{E}^f \ge \boldsymbol{0}$$

$$\Rightarrow \quad \boldsymbol{T} = \hat{\boldsymbol{T}}(\boldsymbol{E}), \quad \mathbf{D}_{\boldsymbol{E}} \hat{\boldsymbol{T}}(\boldsymbol{E})$$

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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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NOSA-ITACA SOFTWARE

Until now, the NOSA solver was not supported by an efficient pre and post-processor; for this reason, the use of NOSA is limited to its developers.

One of the main aims of the NOSA-ITACA project is to develop an integrated platform, CAD/CAE software + NOSA fem code, in order to obtain a powerful tool for the safeguard of architectural heritage, available for all and flexible to upgrading.

As pre and post-processor, the **SALOME platform** is employed (***http://www.salome-platform.org/***), which is an **open-source software** developed by CEA (Commissariat à l'énergie atomique et aux énergies alternatives) and EDF industry with the support of EURIWARE/Open Cascade.

NOSA-ITACA SOFTWARE: the Salome software as pre and post-processors

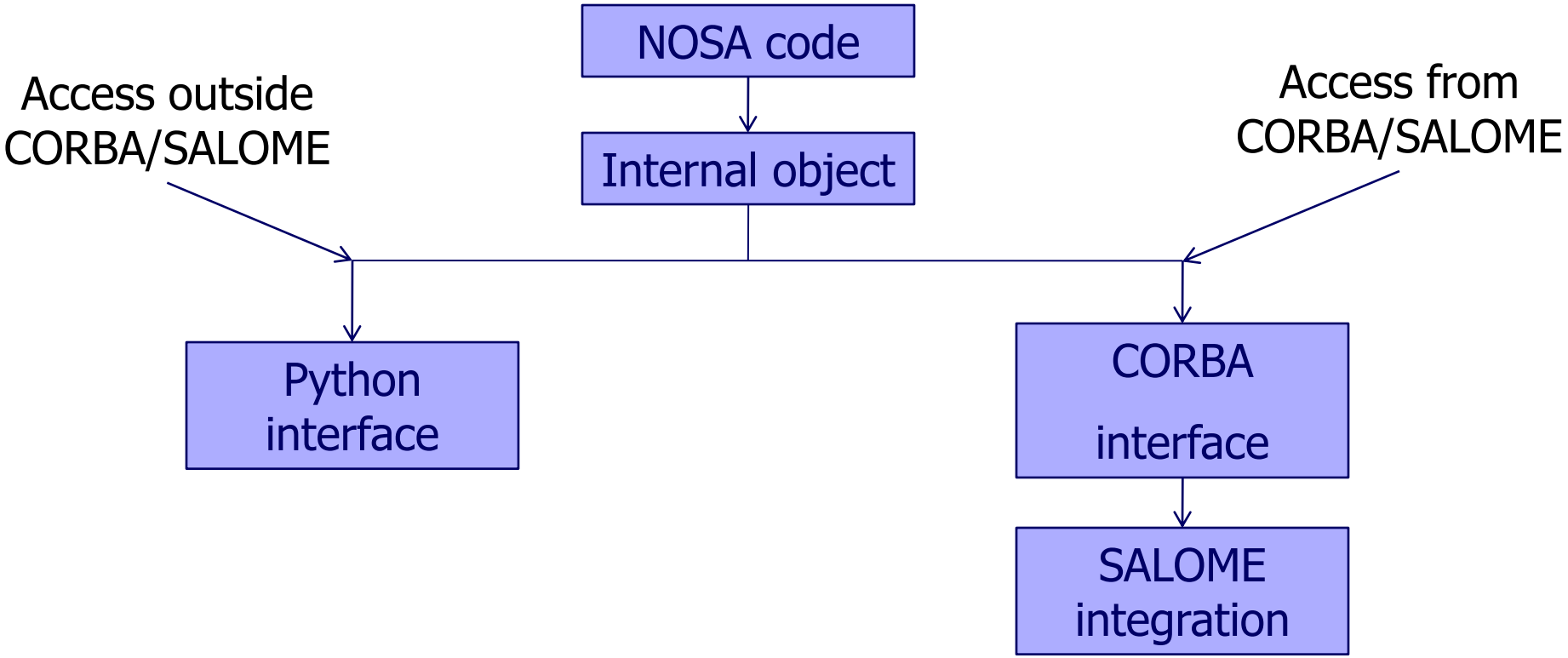
The Salome platform is based on an open and flexible architecture made of reusable components; it can be used as:

- **standalone application** for generation of CAD models, their preparation for numerical calculations and post-processing of the calculation results;
- alternatively, as in the NOSA-ITACA project, it can be used as a **platform for integration** of the external third-party fem code.

The Salome architecture was, mainly, developed in C/C++ and Python languages, which are object-oriented programming languages.

NOSA-ITACA SOFTWARE: the integration of the NOSA code

Flow-chart of integration stages NOSA-SALOME



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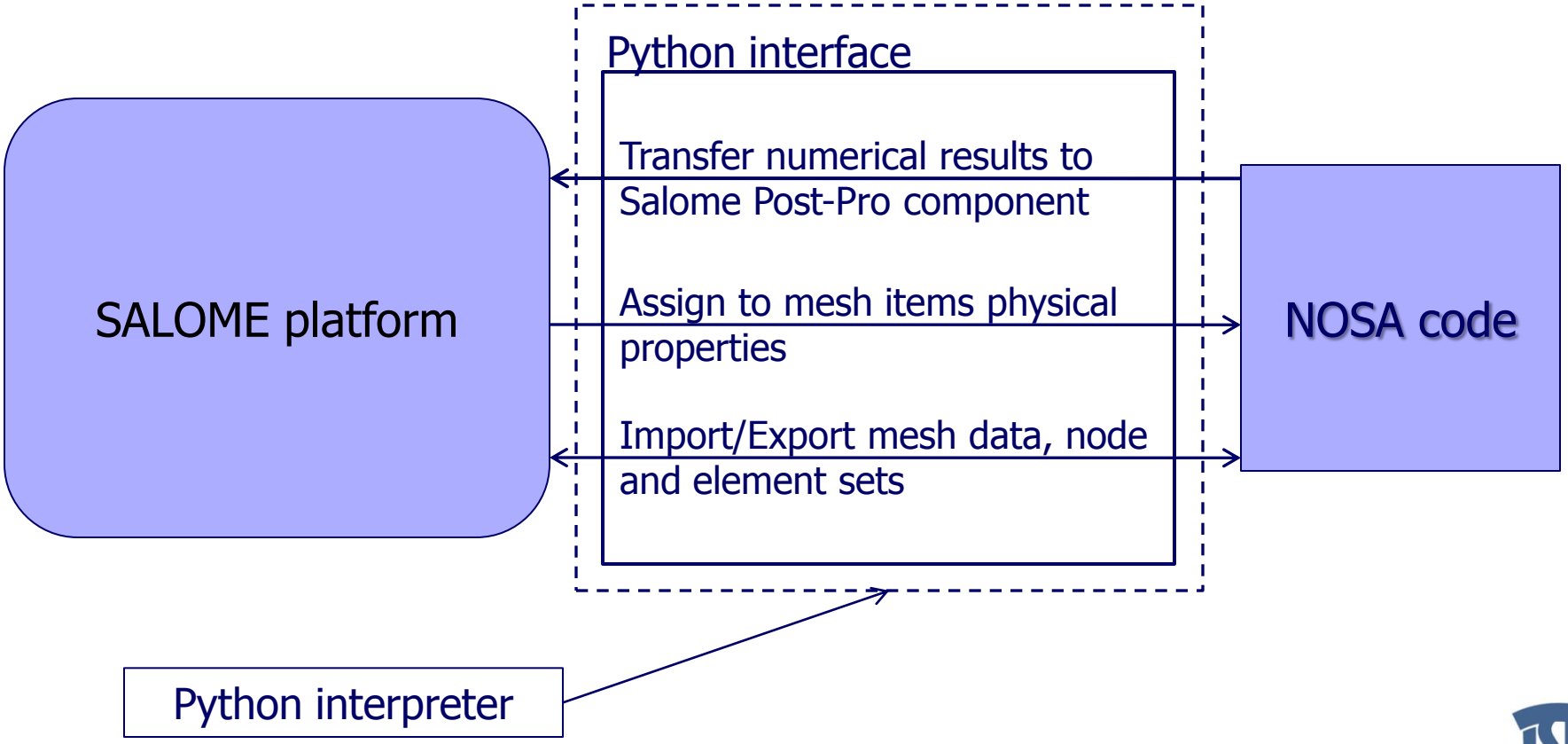
NOSA-ITACA SOFTWARE: the integration of the NOSA code

What can be done with the first stage of integration



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NOSA-ITACA SOFTWARE: the integration of the NOSA code

The Salome architecture is modular, made of several components; among them, there are:

- **Geometry module**;
- **Mesh module**;
- **Post-Pro module**.

Each Salome module is characterized by a set of methods and attributes and specific operations can be done.

Data exchange from a Salome component to another one are done through CORBA interfaces, which each module is supplied with. The set of a Salome component and its CORBA interfaces represents a CORBA component. Each communication between a Salome module and others occurs in a CORBA server-CORBA clients way, where the CORBA server sends/receives from CORBA clients the necessary information.

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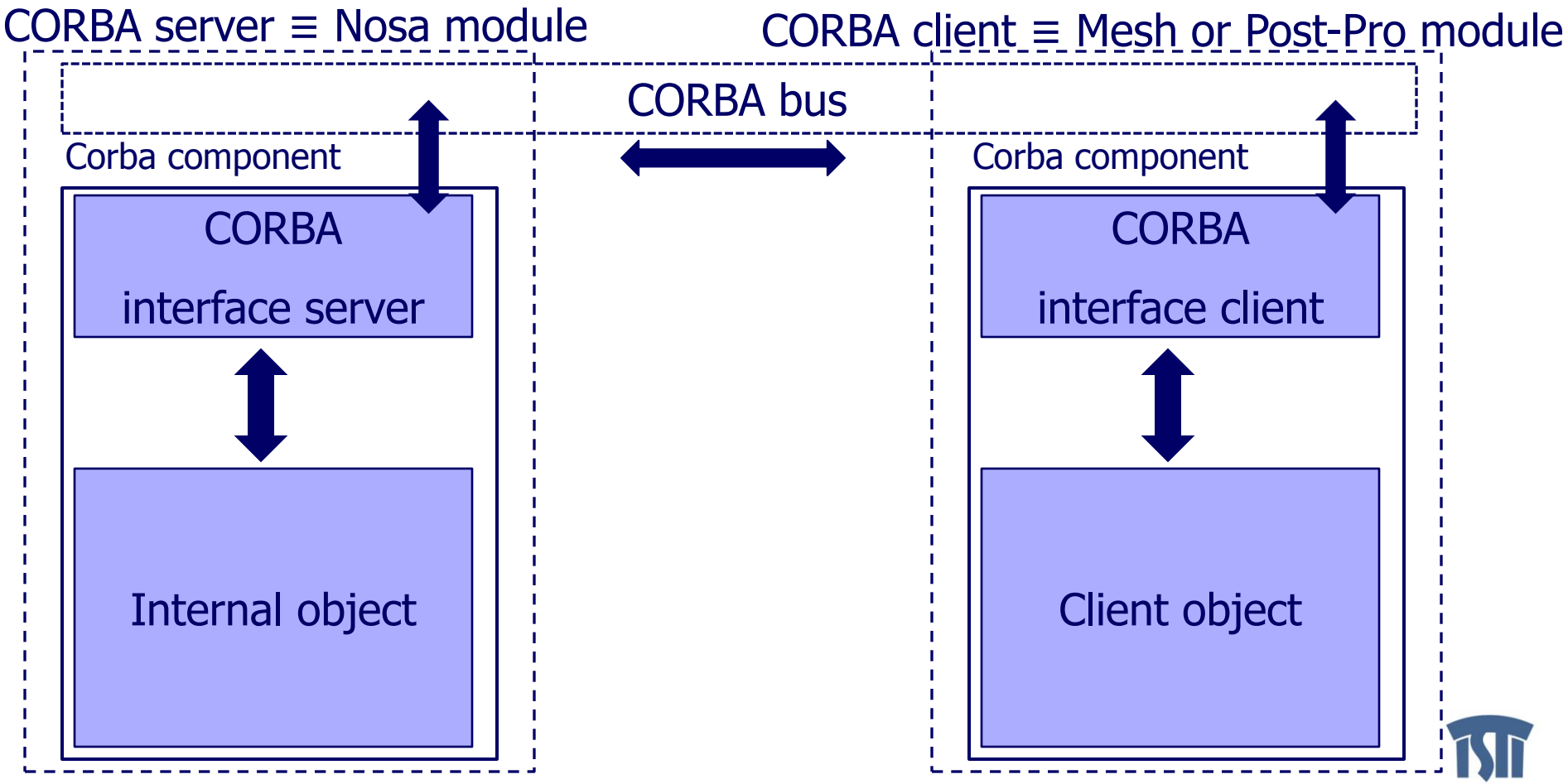
NOSA-ITACA SOFTWARE: the integration of the NOSA code

According to this approach, the integration of the Nosa code in the Salome architecture must be done in the following way:



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NOSA-ITACA SOFTWARE: the integration of the NOSA code

At the end of the integration process, the NOSA-ITACA software will be made of an additional module:

- **Geometry module**;
- **Mesh module**;
- **Nosa module**;
- **Post-Pro module**.

According to this integration scheme, it is possible to control locally or remotely the numerical code, from monitoring of solution progress to visualization of numerical results.

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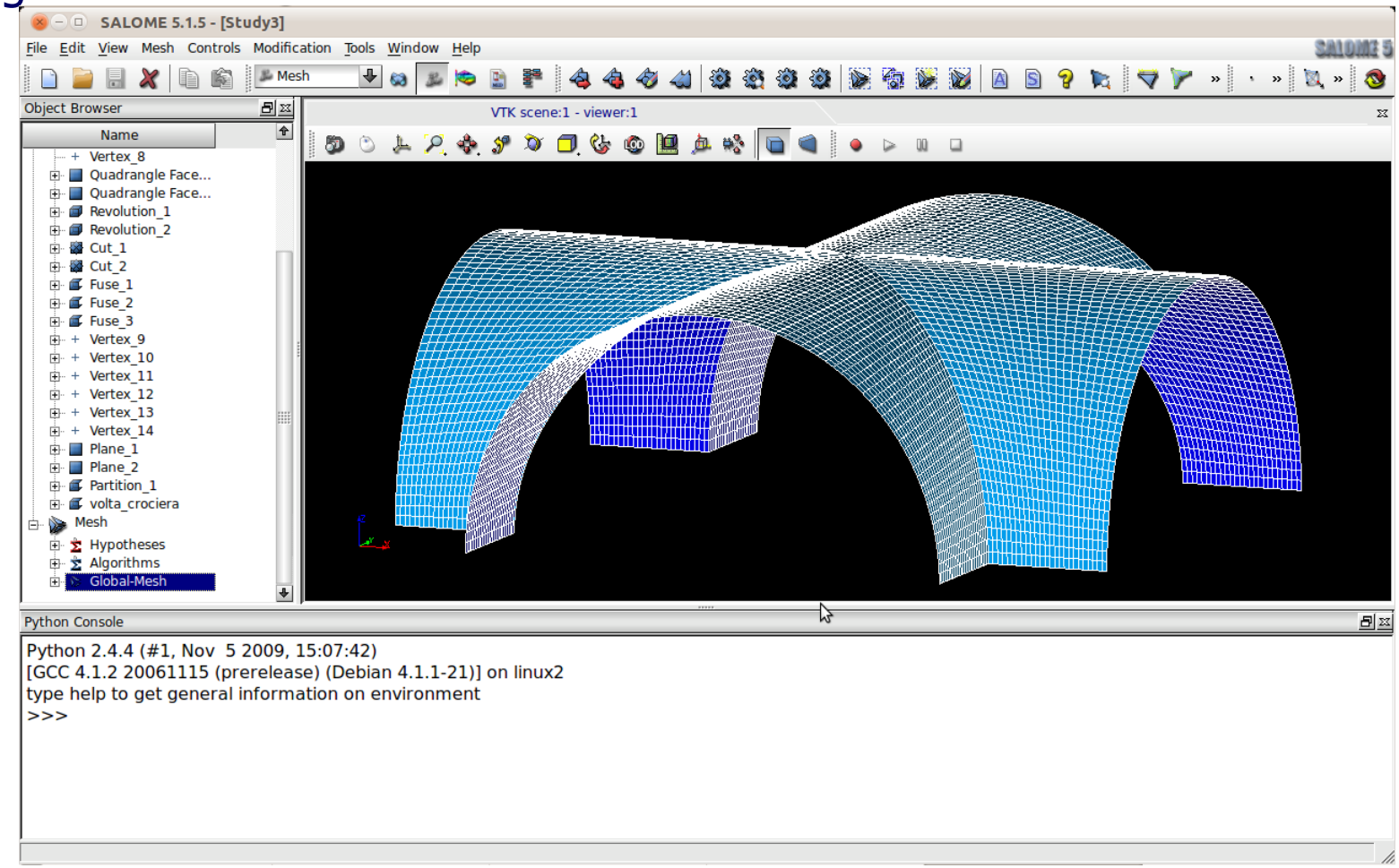
NOSA-ITACA SOFTWARE: some examples

Analysis of a vault made of masonry-like material subjected to its own weight



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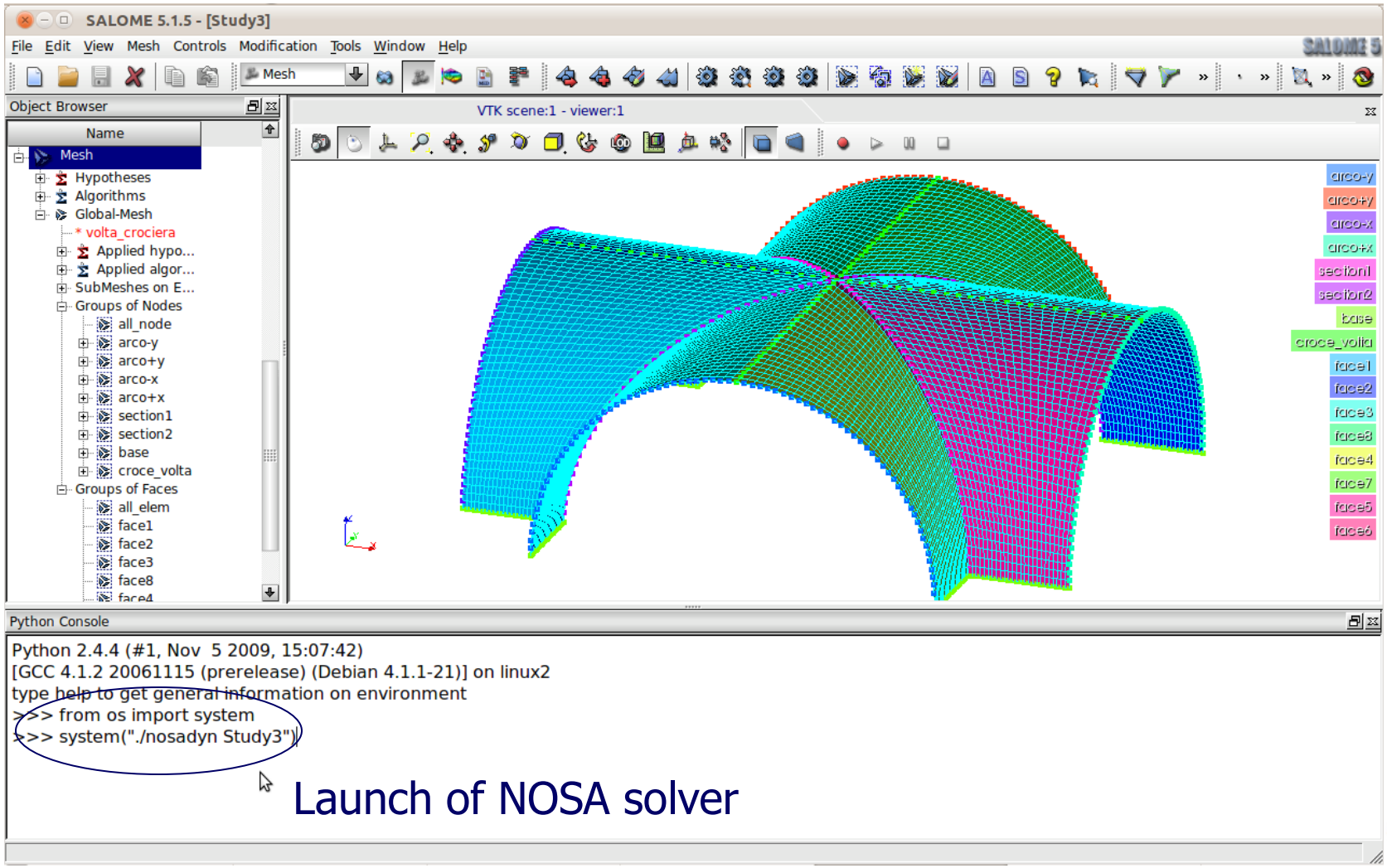
NOSA-ITACA SOFTWARE: some examples



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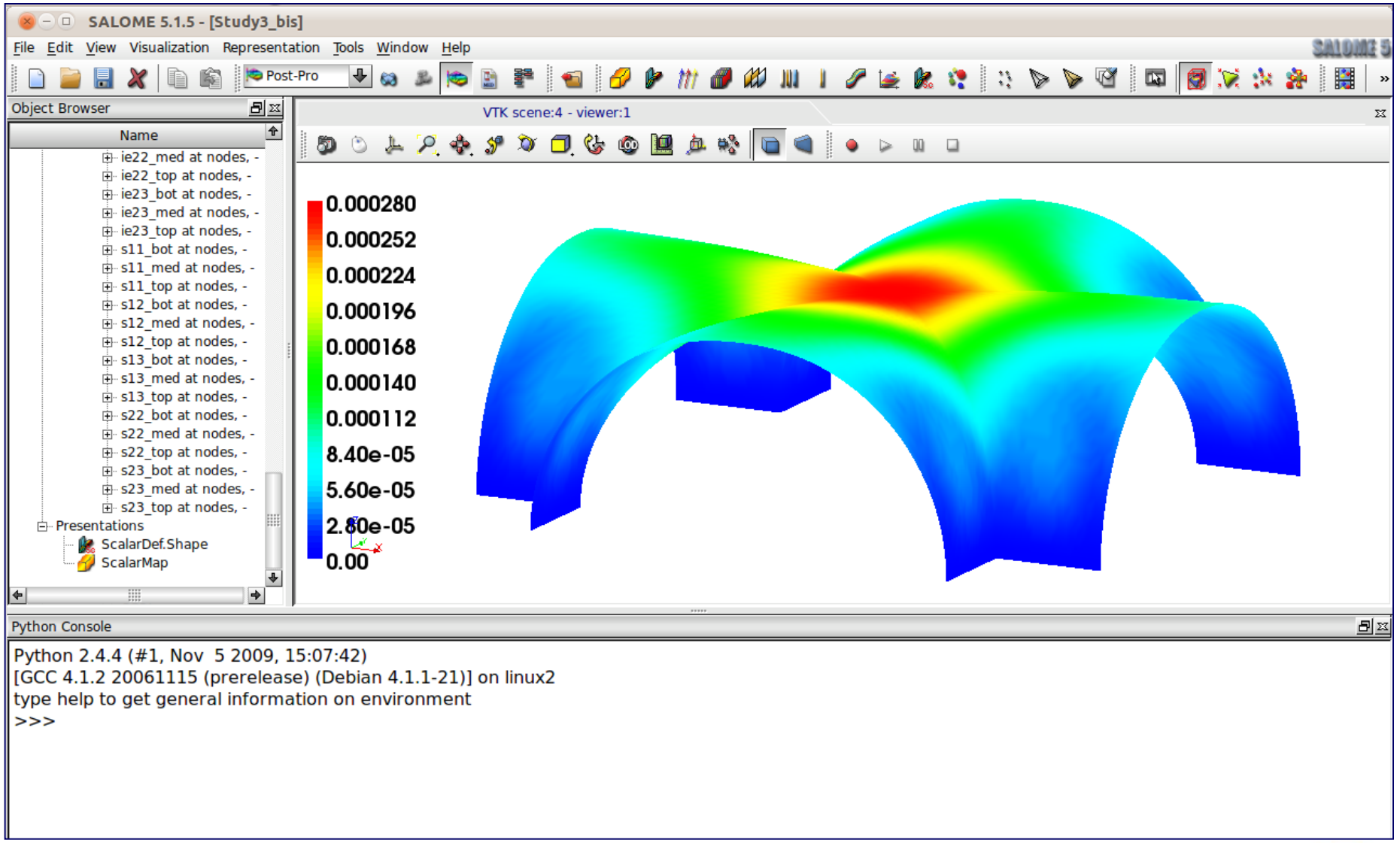

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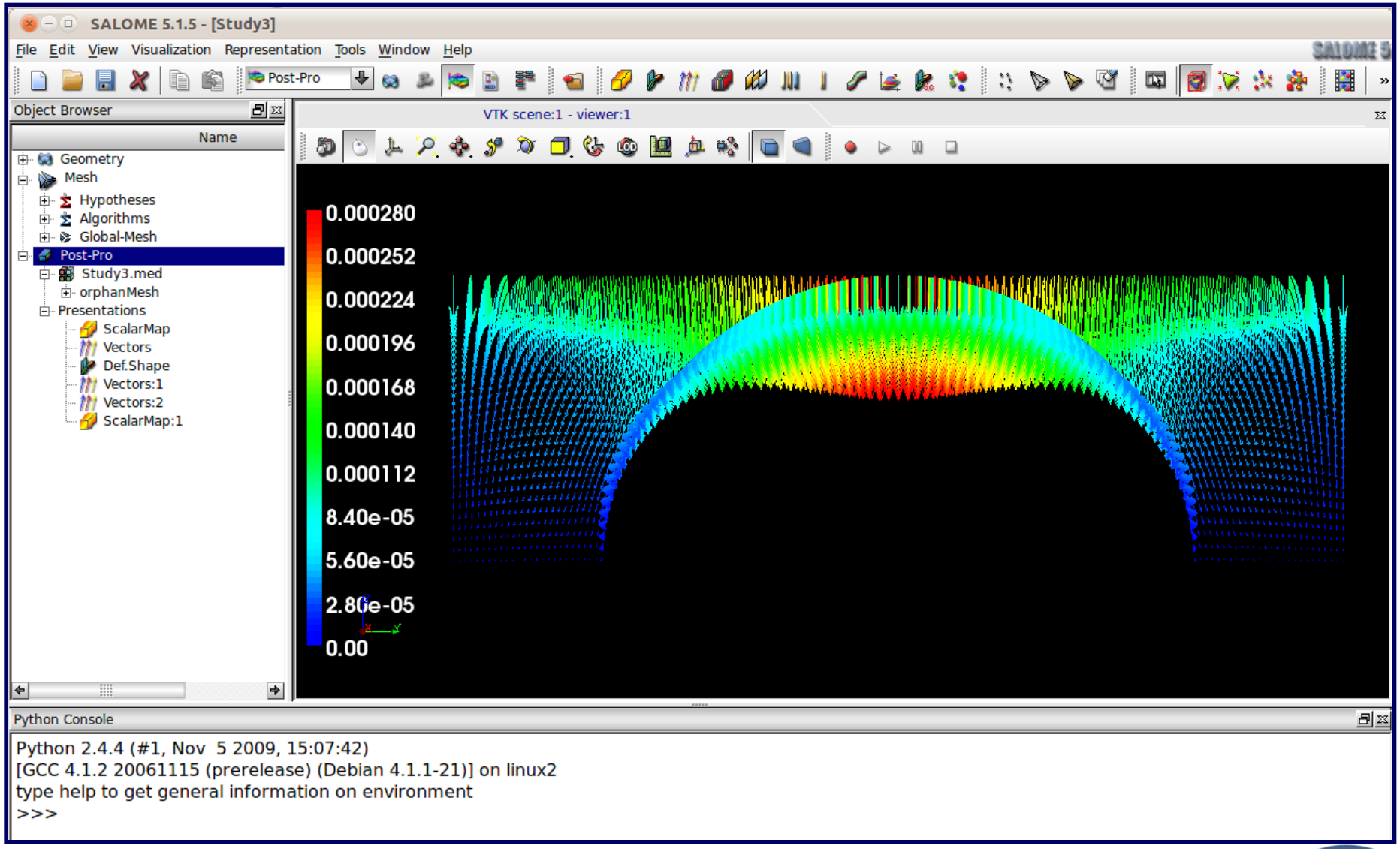

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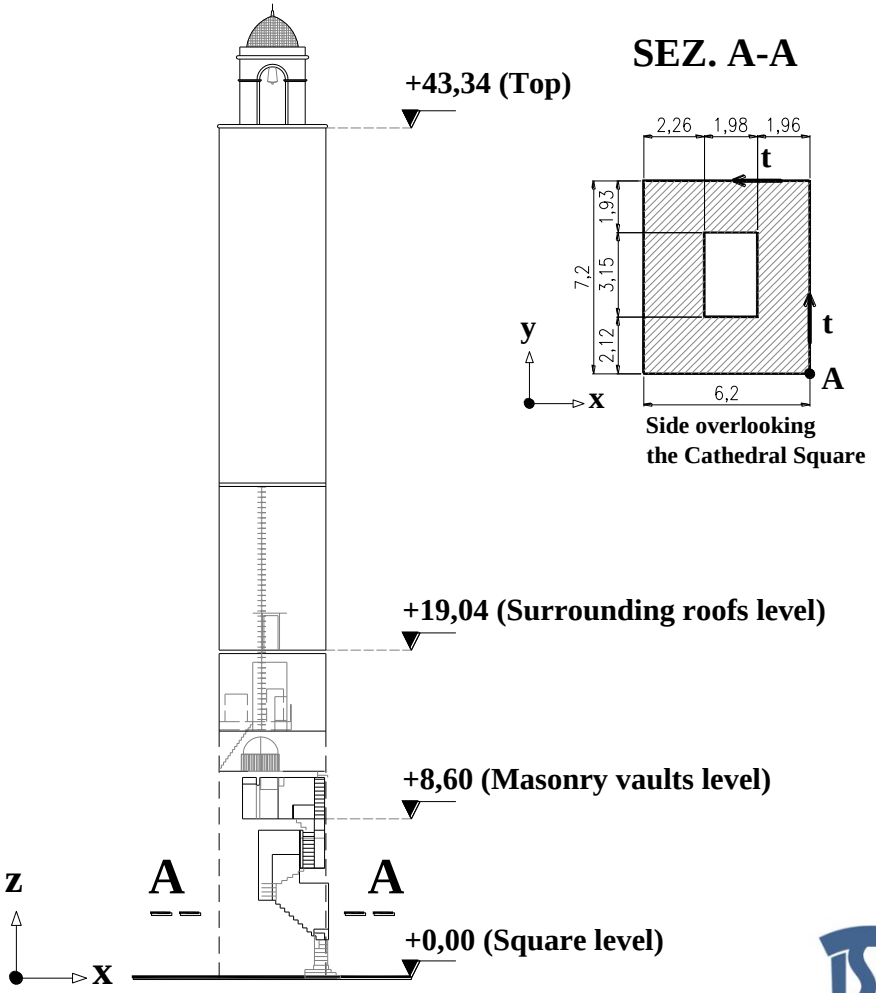
The "Rognosa" tower in San Gimignano



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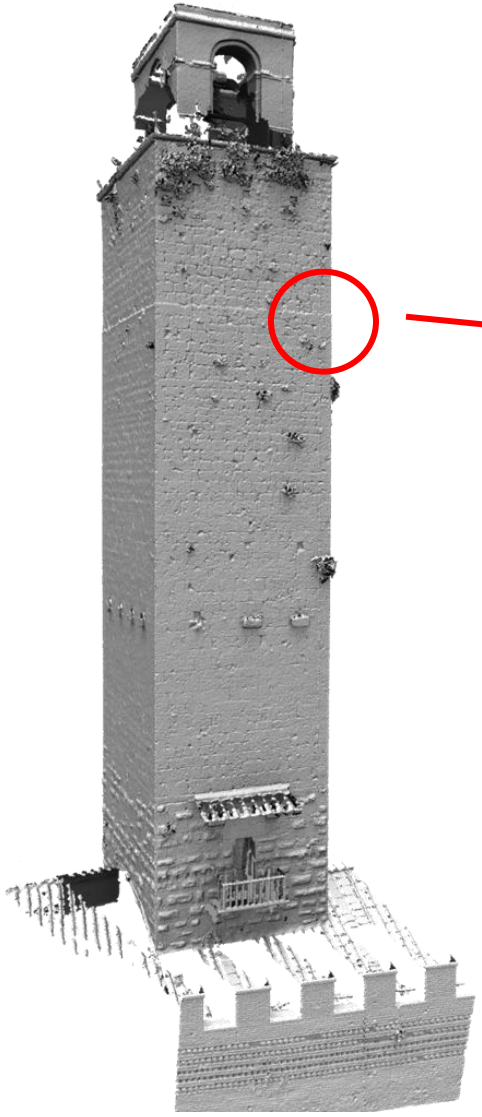
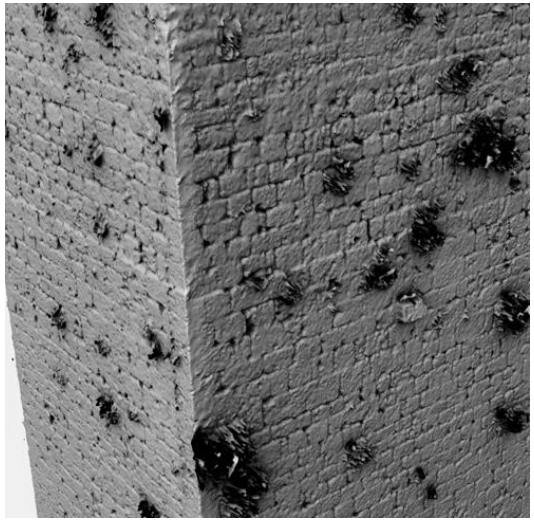
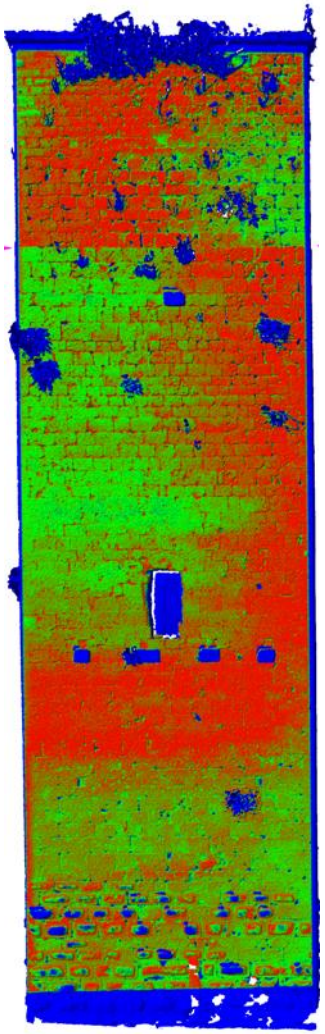
The "Rognosa" tower in San Gimignano: digital acquisition of the geometry

(VC Lab – ISTI CNR)





Merging resolution=1 cm



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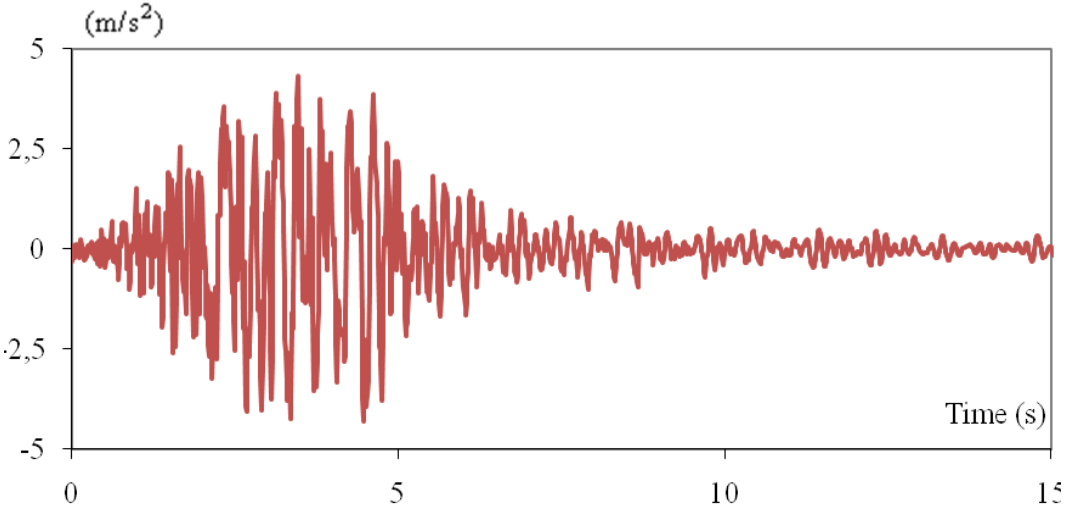
The "Rognosa" tower in San Gimignano:

- 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



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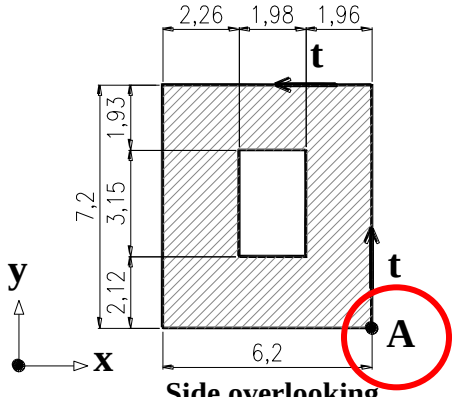
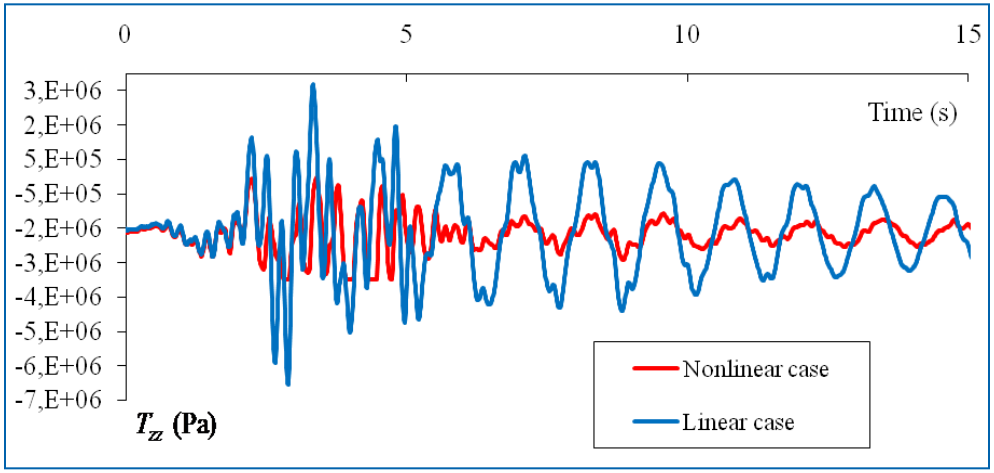
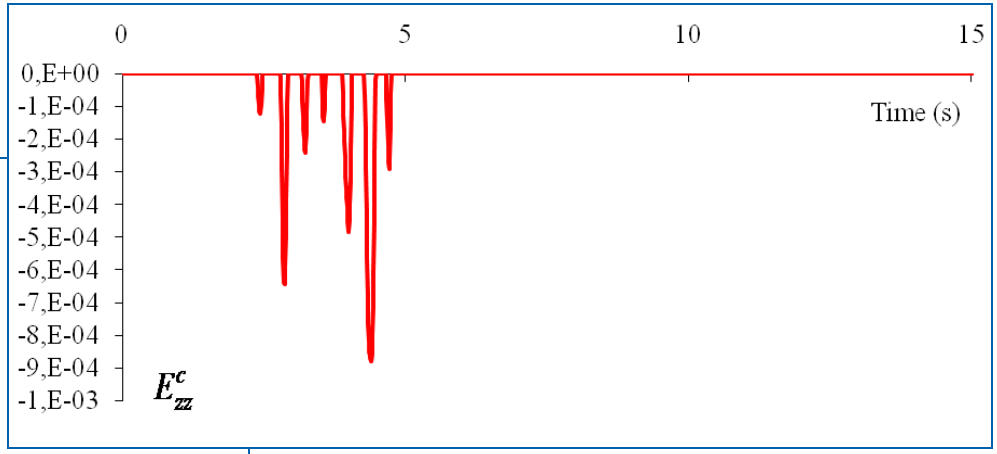
The "Rognosa" tower in San Gimignano: dynamic analysis

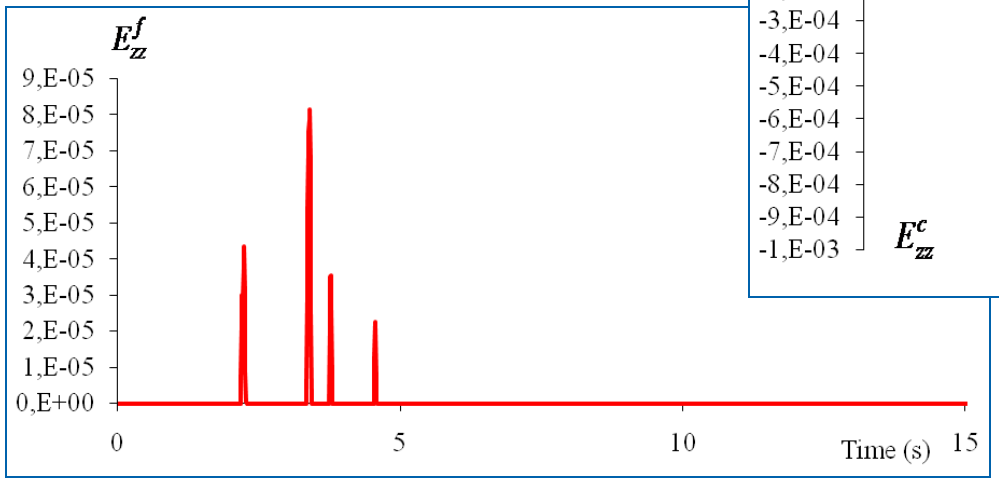
Tower base section



Side overlooking the Cathedral Square







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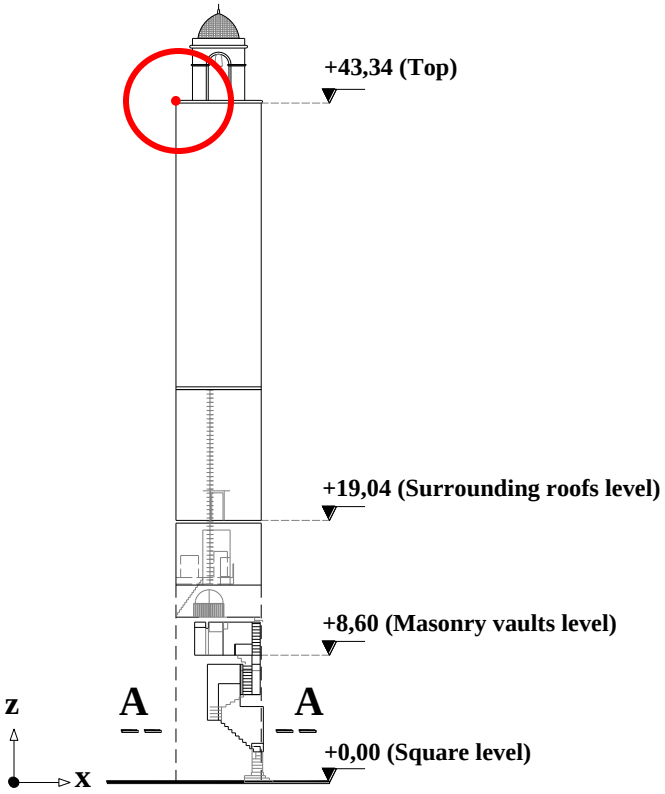
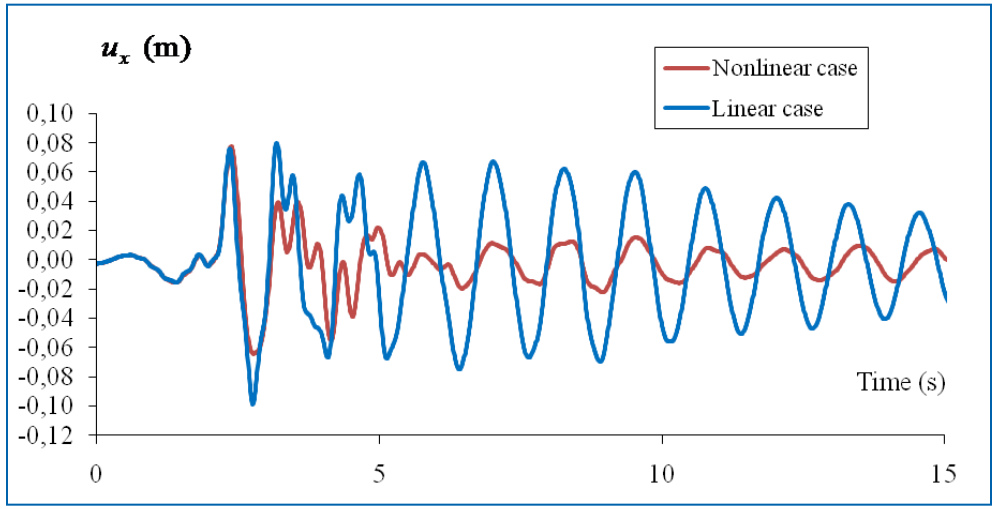
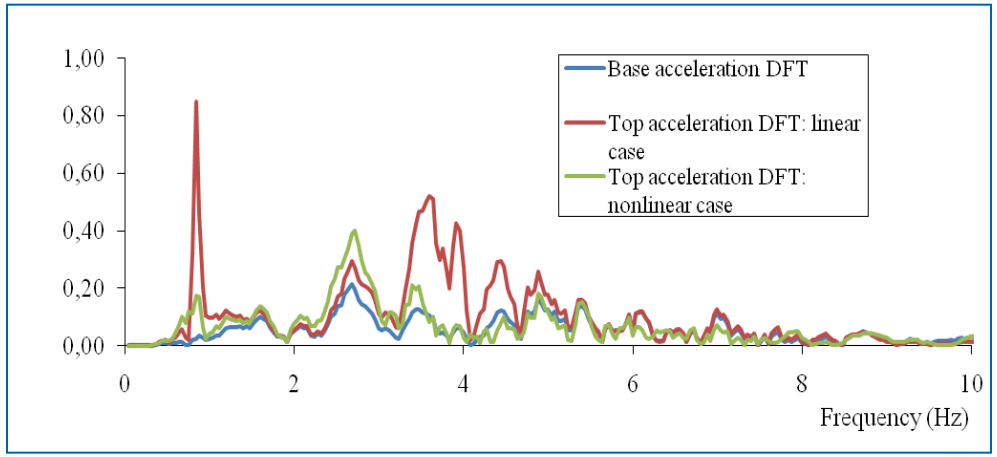
The "Rognosa" tower in San Gimignano: dynamic analysis







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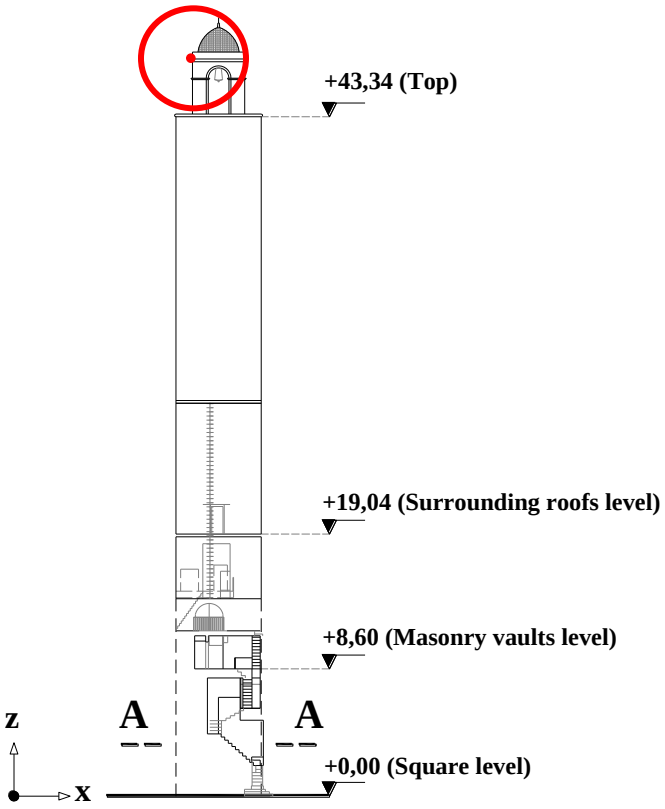
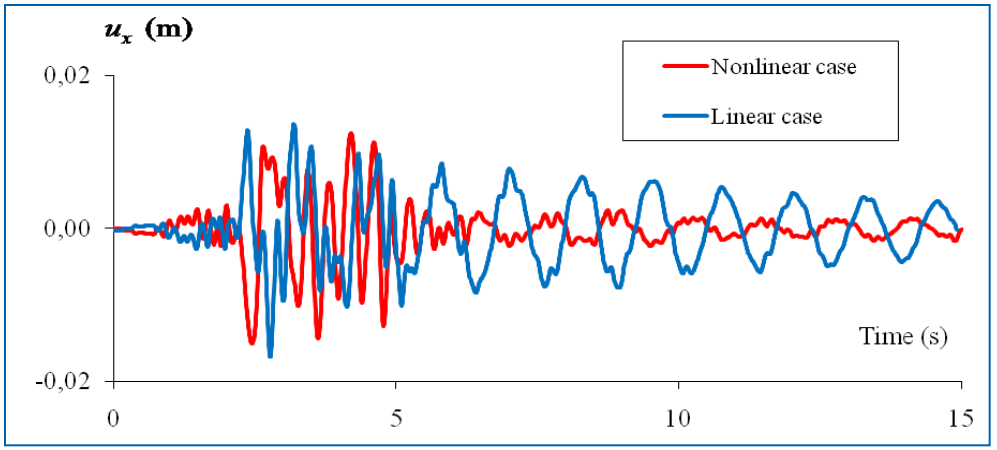
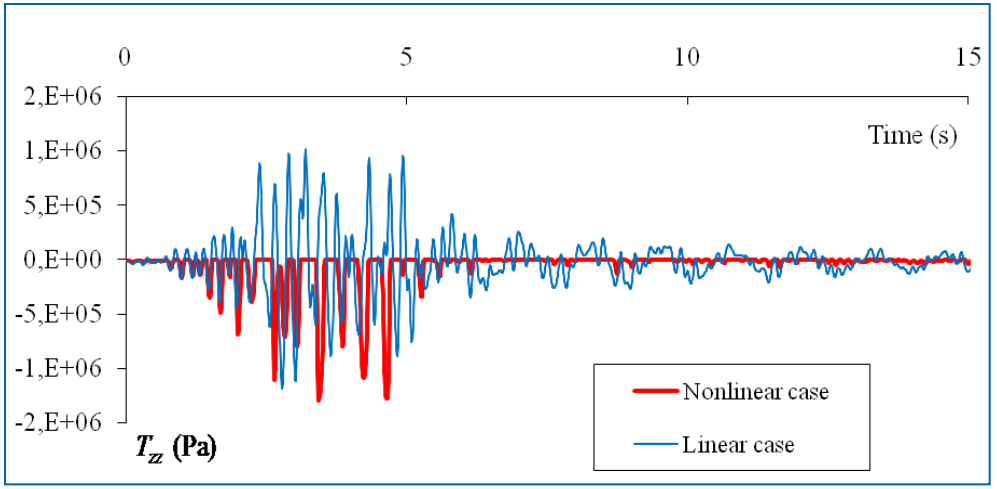
The "Rognosa" tower in San Gimignano: dynamic analysis

Tower vertical section



The bell chamber





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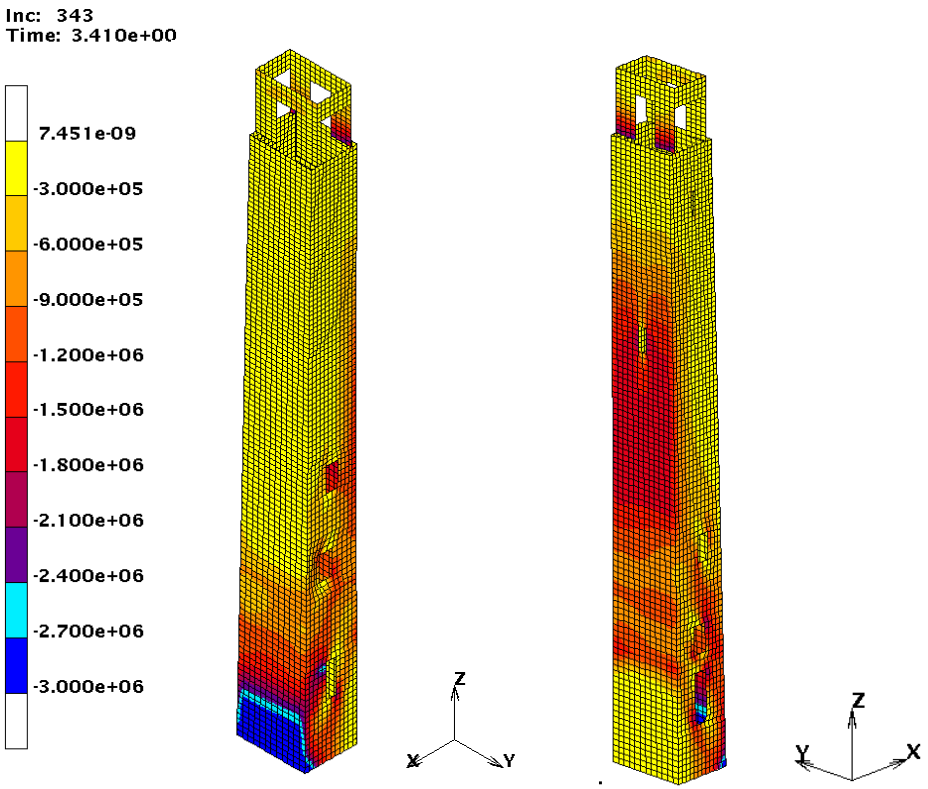
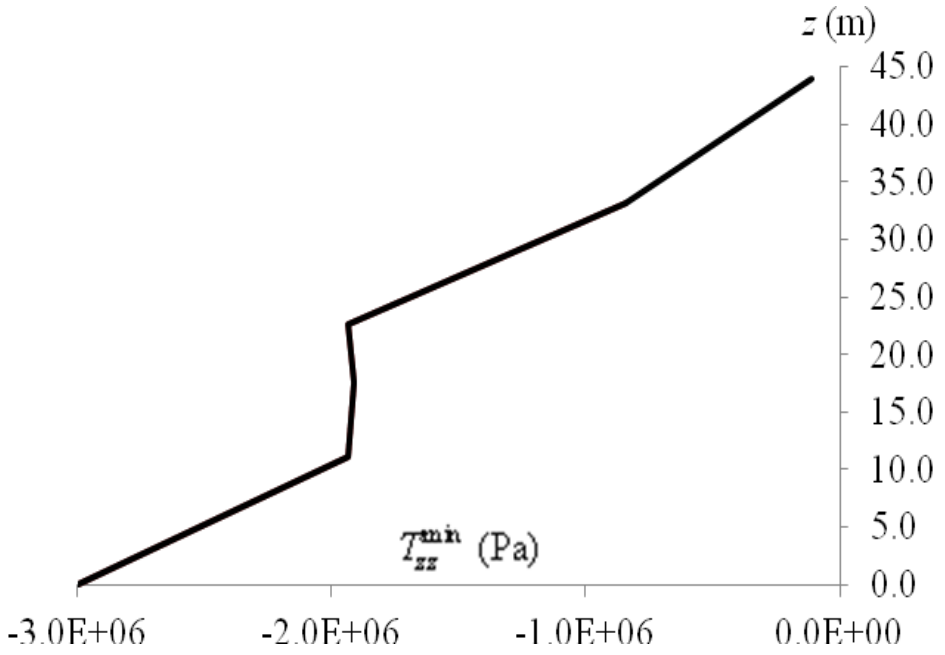
The "Rognosa" tower in San Gimignano: dynamic analysis

Compressive stress T_{zz}

At time t=3,41 s:



Minimum values reached during the analysis :



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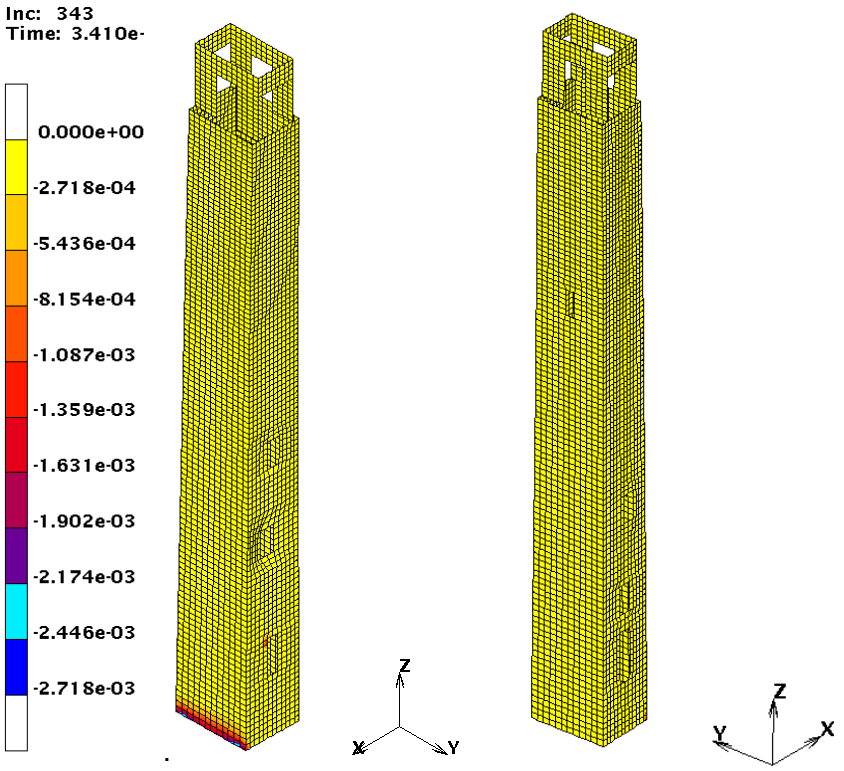
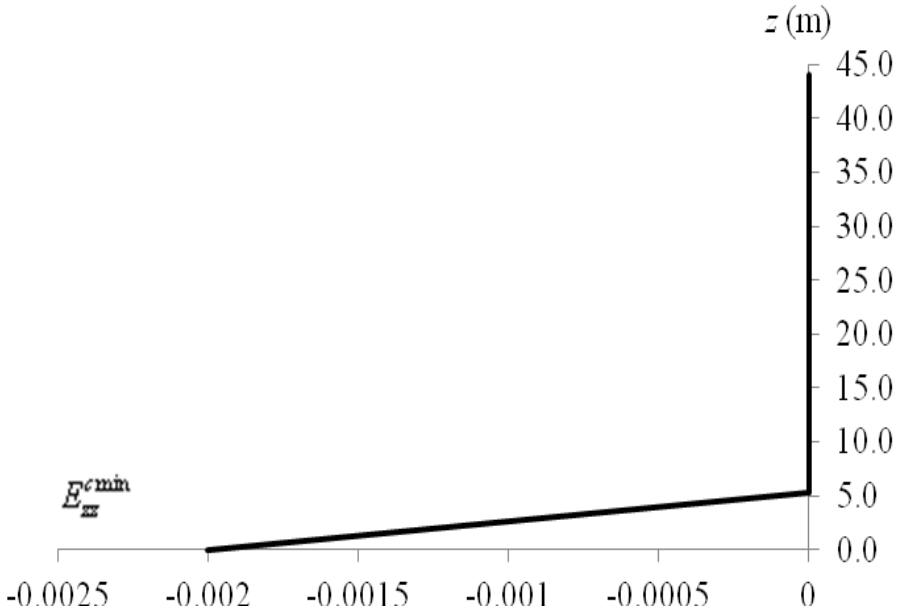
The "Rognosa" tower in San Gimignano: dynamic analysis

Crushing strain E^c_{zz}

At time t=3,41 s:



Minimum values reached during the analysis :



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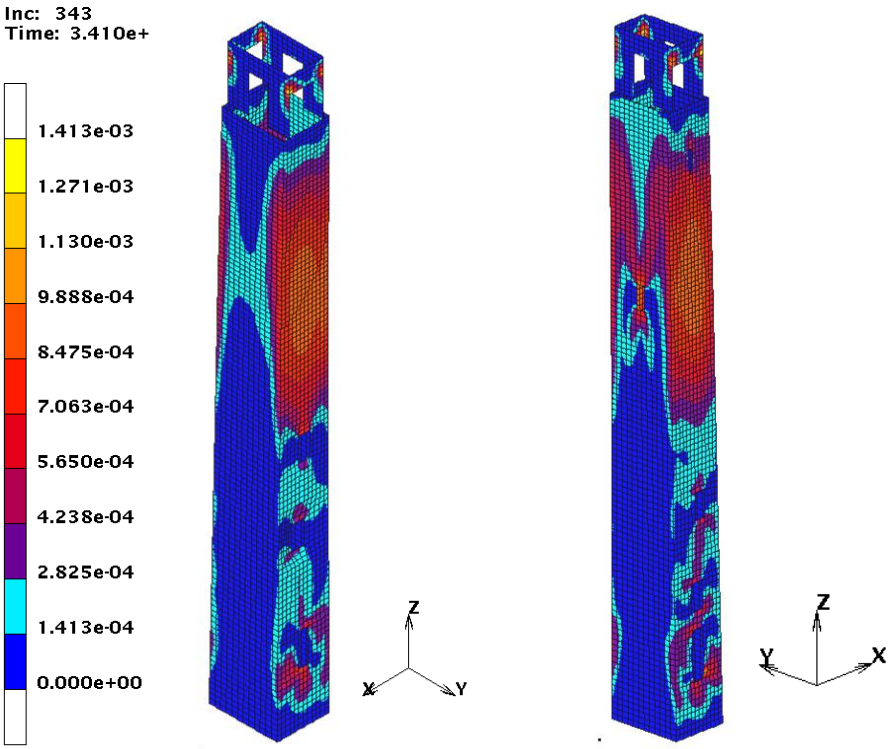
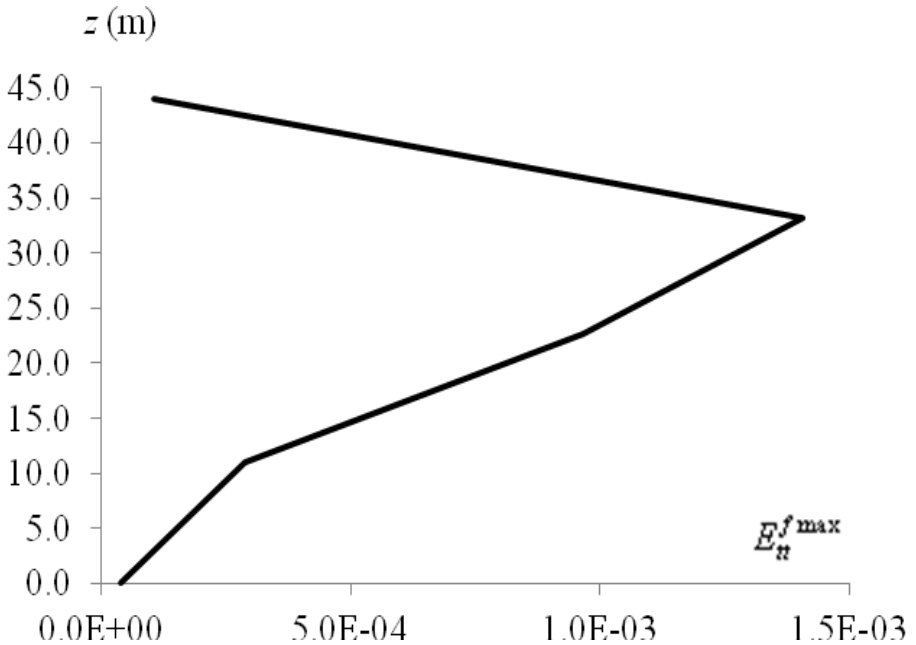
The "Rognosa" tower in San Gimignano: dynamic analysis

Tangential fracture strain E^f_{tt}

At time t=3,41 s:



Maximum values reached during the analysis :



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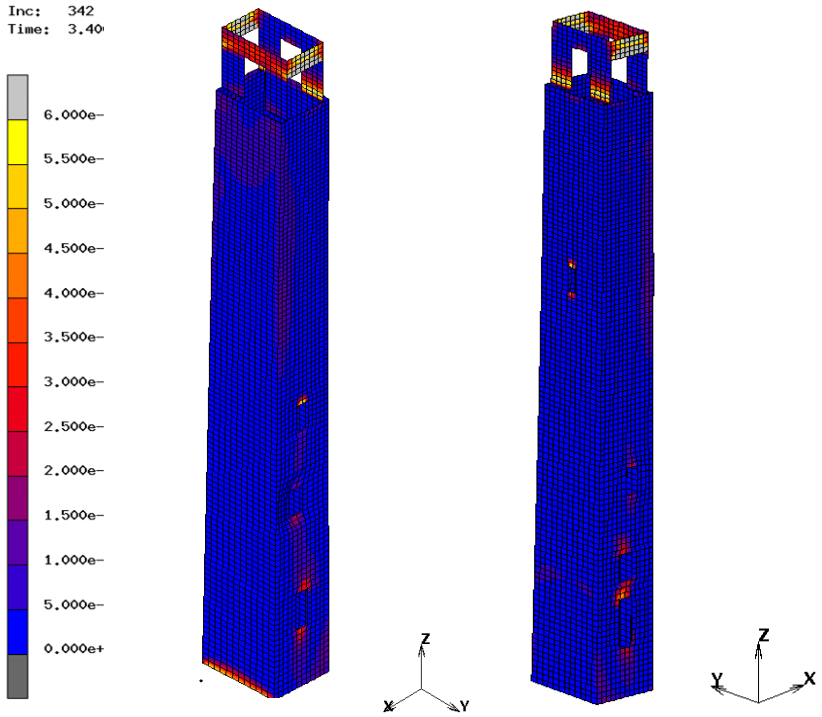
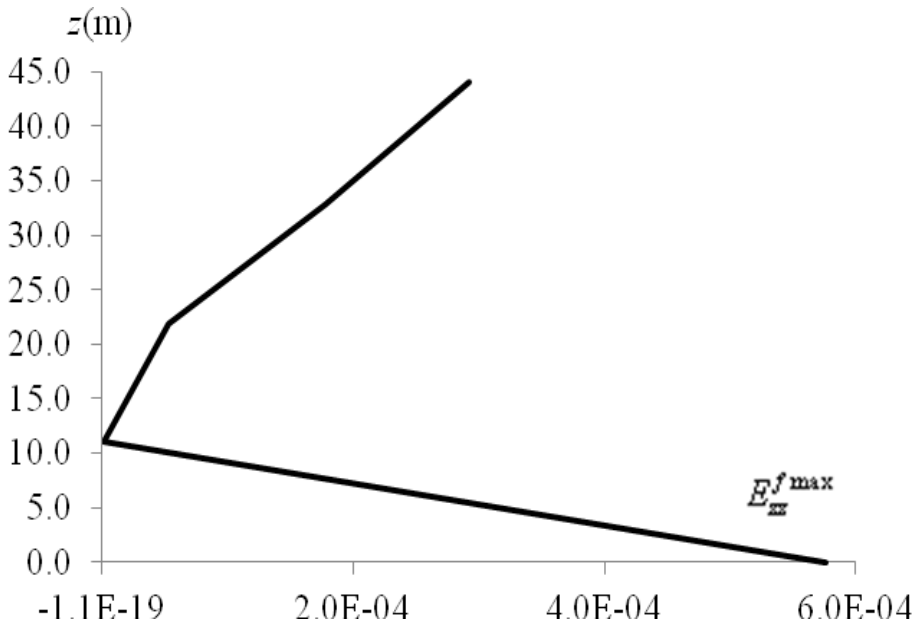
The "Rognosa" tower in San Gimignano: dynamic analysis

Fracture strain E^f_{zz}

At time t=3,41 s:



Maximum values reached during the analysis :



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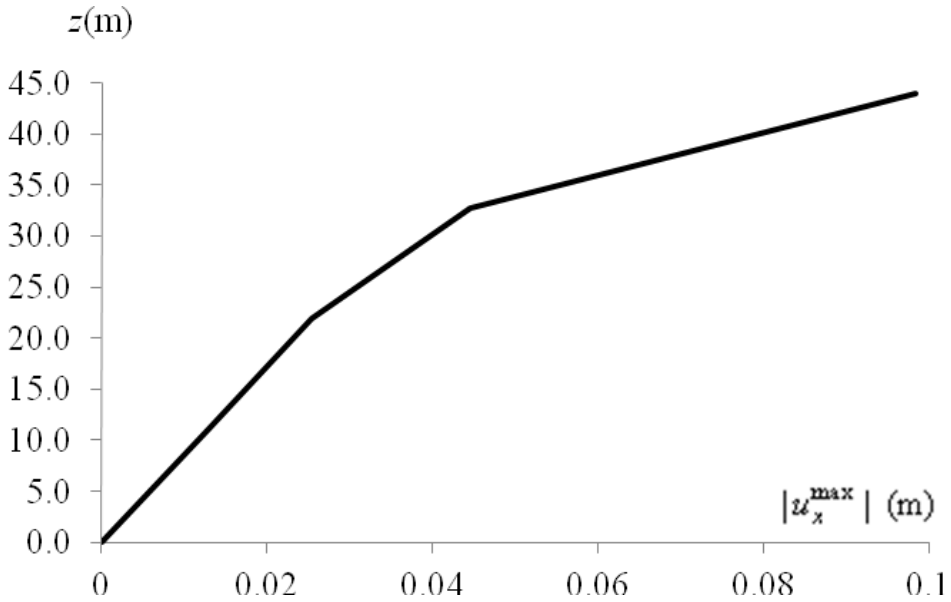
Displacements u_x

Maximum values reached during the analysis:



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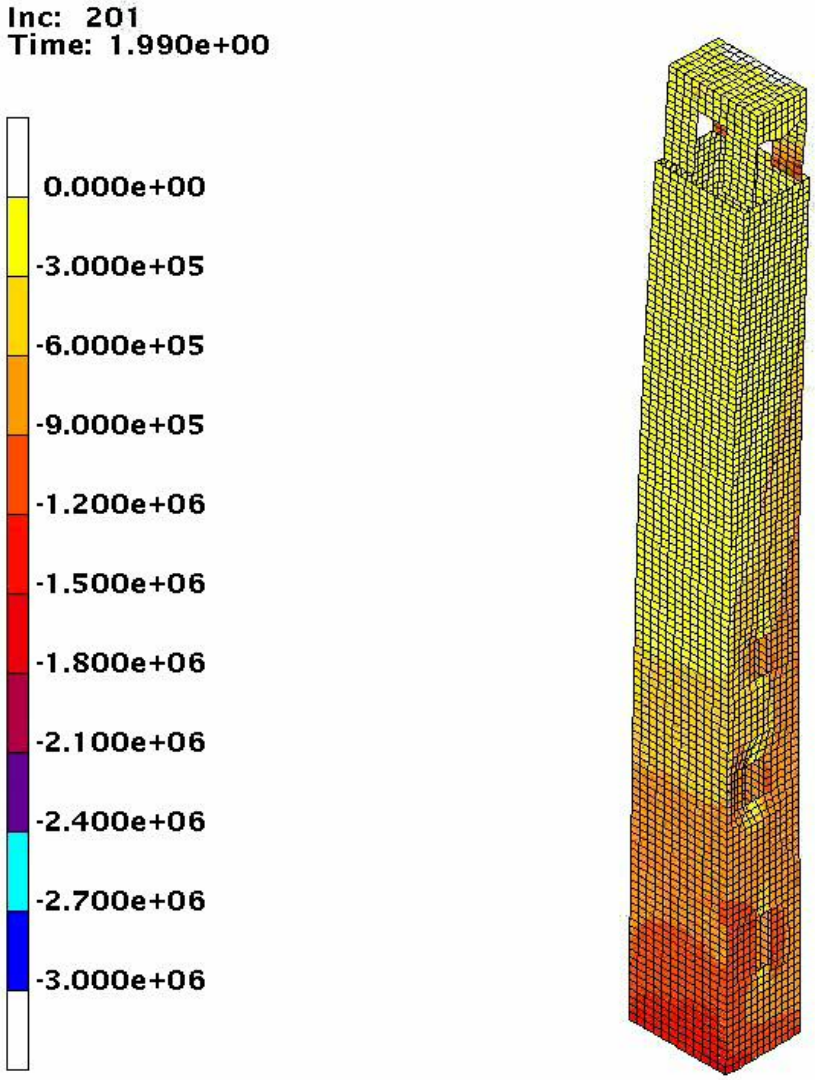
The "Rognosa" tower in San Gimignano: dynamic analysis



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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 (COMES-NOSA) is freely downloadable at http://www.isti.cnr.it/research/unit.php?unit=MMS.

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

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

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

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