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Symposium
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5. Emerging tools for Conservation practice

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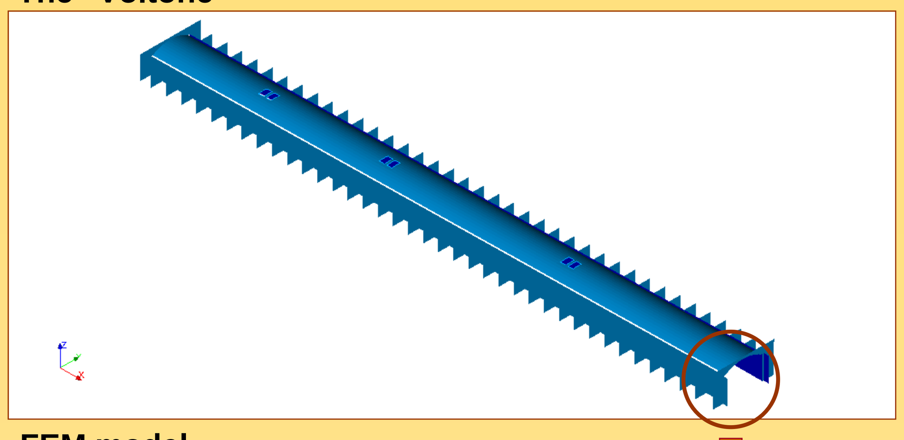
Consiglio Nazionale delle Ricerche – ISTITUTO DI SCIENZA E TECNOLOGIE DELL'INFORMAZIONE "A. FAEDO"
UNIVERSITÀ DEGLI STUDI FIRENZE – DICEA DIPARTIMENTO DI INGEGNERIA CIVILE E AMBIENTALE
REGIONE TOSCANA
FAS Fondo Aree Sottoutilizzate 2007-2013
COMUNE LIVORNO

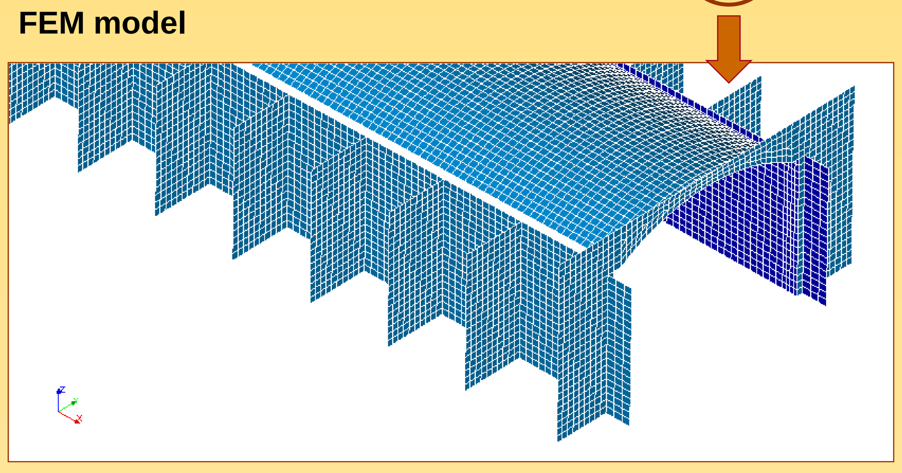
SAFETY ASSESSMENT OF MASONRY CONSTRUCTIONS VIA NUMERICAL TOOLS: THE NOSA-ITACA CODE

The "Voltone" (i.e., the great vault), built in 1845 after the design of Bettarini, is a 220-meter long, tunnel-like masonry structure located beneath Piazza della Repubblica in Livorno. It is constituted by a segmental vault, that is set on two lateral walls and strengthened by buttresses placed at intervals of about 5.8 meters one from the other. The vault, made of lime mortar and bricks, is about 0.41÷0.43 m thick, with constant thickness along the section and length of the vault, except for the tunnel's ends. The lateral walls, made up of external layers of a local chalky stone and an inner cohesive mortar core layer, are variable in height above the surface of the canal.

The "Voltone"

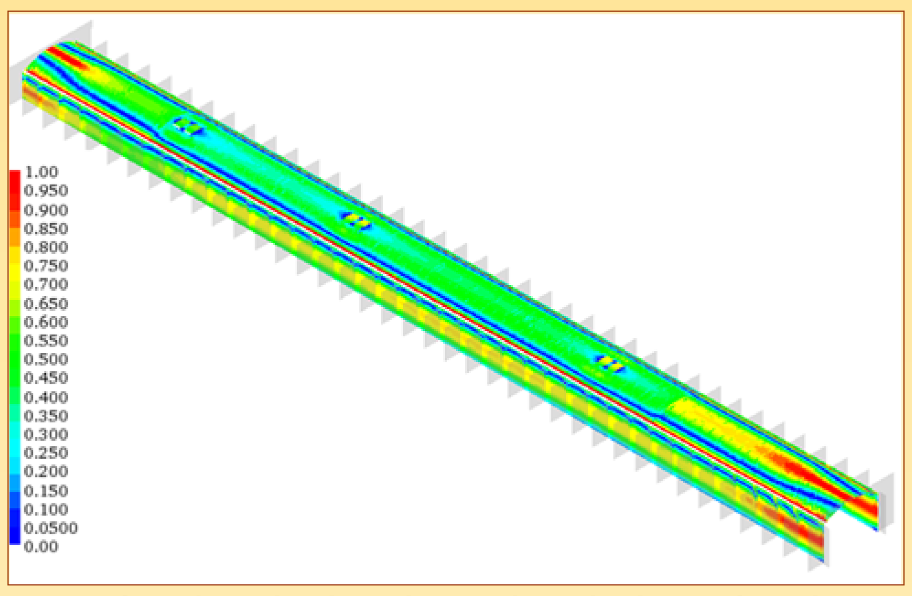


FEM model

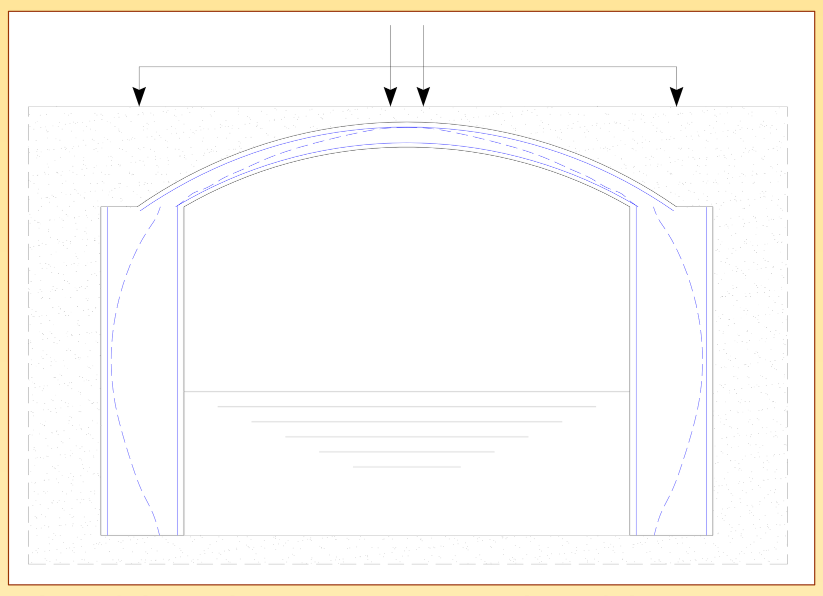


FEM model detail

In order to realistically model the structural behaviour of this monument via the NOSA-ITACA code, the geometry, the mechanical properties of the constituent materials and the characteristics of the soil and surrounding structures must be known. To this end, some non-destructive tests were conducted, and four vertical core samples extracted, two from the wall and surrounding soil, and two from the vault. The information collected allowed us to build a three-dimensional finite element model of the structure. The model was built by using 43228 thick shell and beam elements and 45379 nodes. The analyses have been conducted adopting the constitutive equation of masonry-like material with bounded compressive strength, under the assumption that the structure is subjected to permanent and accidental loads, calculated on the basis of the structure's usage class. The analyses have enabled calculating the stress field and then assessing the structure's safety. The results are also reported in terms of the line of thrust.



Example safety check: ratio M_{1Ed}/M_{1Rd} in the vault and lateral walls.



Line of thrust in a transverse section of the "Voltone"

SALOME PLATFORM

- Open source graphics software package that provides a generic platform for Pre- and Post-Processing for numerical simulation
- Based on an open and flexible architecture made of reusable components.
- Allows performing computation using one or more external solvers

NOSA-CODE: FEM nonlinear solver

THE CONSTITUTIVE EQUATION OF *MASONRY-LIKE* MATERIALS

$\mathbf{E}$	infinitesimal strain tensor,
$\mathbf{T}$	Cauchy stress tensor,
$\mathbf{E}^e$	elastic part of the strain,
$\mathbf{E}^f$	fracture strain,
$\mathbf{E}^c$	crushing strain,
$E,\ \nu$	Young 's modulus and Poisson's ratio,
$\sigma^c > 0$	maximum resistance to compression.

Given $\mathbf{E}$, it is possible to calculate $\mathbf{E}^f, \mathbf{E}^c, \mathbf{T}$ such that :

$$\mathbf{E} = \mathbf{E}^e + \mathbf{E}^c + \mathbf{E}^f$$

$$\mathbf{E}^f \geq \mathbf{0}, \quad \mathbf{E}^c \leq \mathbf{0}$$

$$\mathbf{E}^c \cdot \mathbf{E}^f = 0$$

$$\mathbf{T} = \frac{E}{1+\nu}\mathbf{E}^e + \frac{\nu E}{(1+\nu)(1-2\nu)} tr(\mathbf{E}^e)\mathbf{I}$$

$$\mathbf{T} \leq \mathbf{0}, \qquad \mathbf{T}\cdot\mathbf{E}^f = 0$$

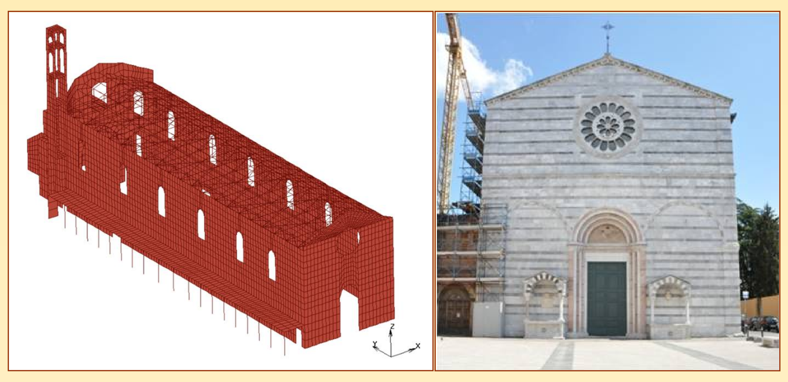
$$\mathbf{T} + \sigma^c\mathbf{I} \geq \mathbf{0}, \quad (\mathbf{T} + \sigma^c\mathbf{I})\cdot\mathbf{E}^c = 0$$

THE NUMERICAL METHOD

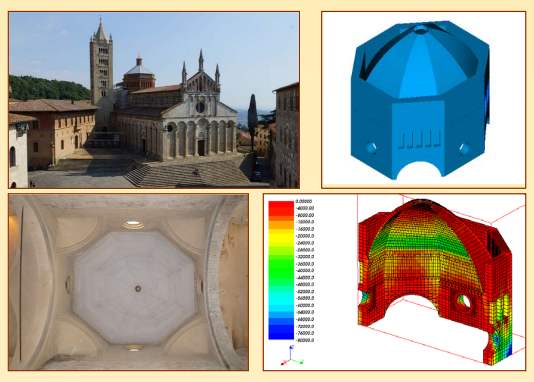
- The Newton-Raphson method is adopted for solving the nonlinear algebraic system resulting from application of the finite element method. The derivative of the stress with respect to the total strain (necessary to build the tangent stiffness matrix) is explicitly calculated.
- The dynamic problem is solved via the Newmark method which has been implemented within NOSA in order to perform the integration with respect to time of the system of ordinary differential equations obtained by discretizing the structure into finite elements.
- A procedure for the modal analysis of linear elastic structures has been implemented. This procedure, aimed at solving the generalised eigenvalue problem obtained by discretizing the structure into finite elements and assembling the stiffness and mass matrices, takes into account both the sparsity of the matrices and the features of master-slave constraints (multipoint constraints).

SOME APPLICATIONS OF THE CODE

Devil's bridge – Borgo a Mozzano Lucca



Church of San Francesco - Lucca



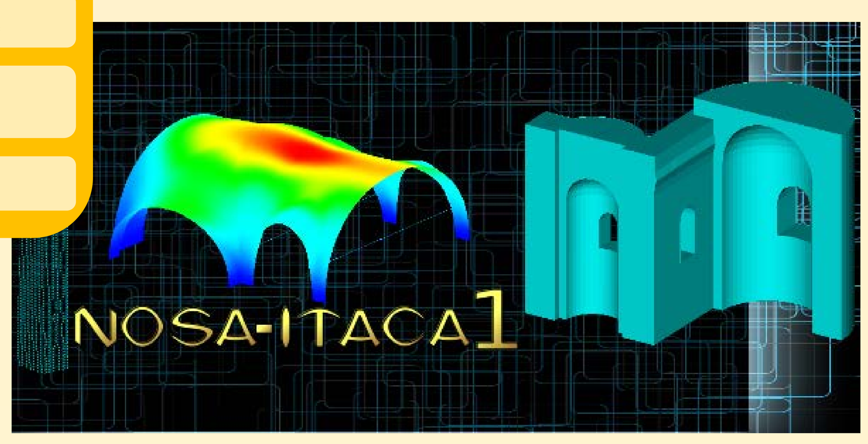
The dome of San Cerbone – Massa Marittima Grosseto

NOSA-ITACA ARCHITECTURE

*.t19 → SALOME module Nosa → SALOME software open source → SALOME module Nosa → *.crd

Finite element code NOSA (nosan):
- Static analysis
- Dynamic analysis
- Thermal loads
- Modal analysis

*.crd → Finite element code NOSA (nosan) → *.t19



FINITE ELEMENT CODE NOSA-ITACA
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