

Reliability of Ancient RC Structures by Means of Numerical Modeling



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SSCS 2012 Aix en Provence May 29 - June 1, 2012

Objective of the work:

- In sustainability theme it is very important to know if the historical existing buildings may be used nowadays or they must be refurbished or, even, demolished and reconstructed. Among them may be included even reinforced concrete structures.
- The research work was carried out within the framework of the Italian National Project “Architecture and Structures in Italy after the 2nd World War”
- The paper deals with the steps that plan out the understanding of the behaviour of such structures:
 - critical approach,
 - original documents research and interpretation,
 - paraphrase of former calculations,
 - safety assessment by means of current calculation methods and codes.

Work Plan:

- 1) Reconstruct the original concept design by means of documental research.
Then describe the computation models (usually very simplified) developed by the original designer.
- 2) Compare the original computation models with the current constructions codes.
- 3) Analyse the whole structures by means of modern computational numerical methods (FEM).
- 4) The results obtained by these last methods have been compared to the original ones. It allows a better understanding of the behaviour, and in such cases to discover unsuspected resources of the structures.

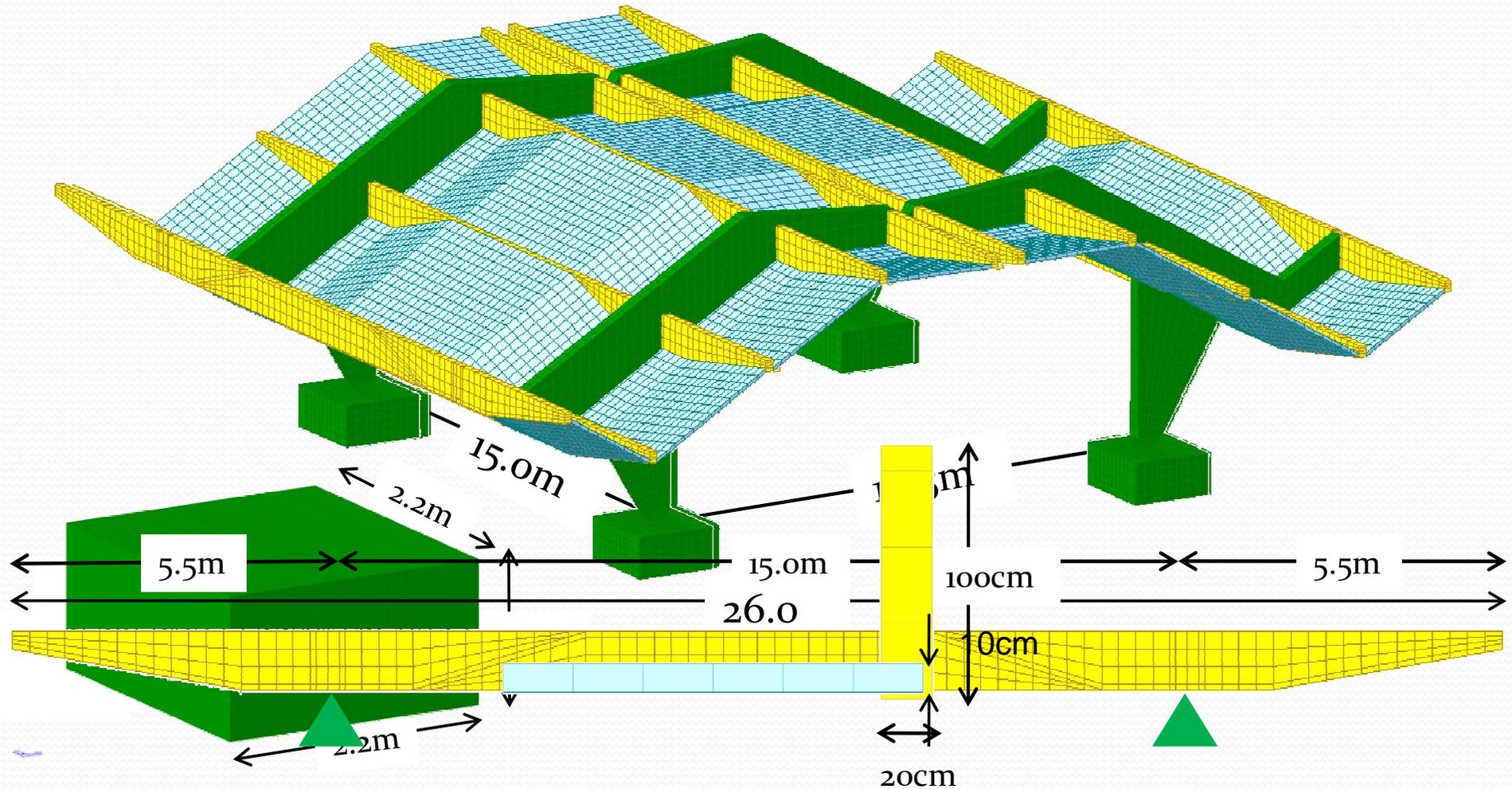
CasMez Pavillion: Description

- Trade Fair Center of Cagliari (Italy)
- Year of construction: 1953
- Designer: Arch. Adalberto Libera
- 1973 Lateral cladding of the building

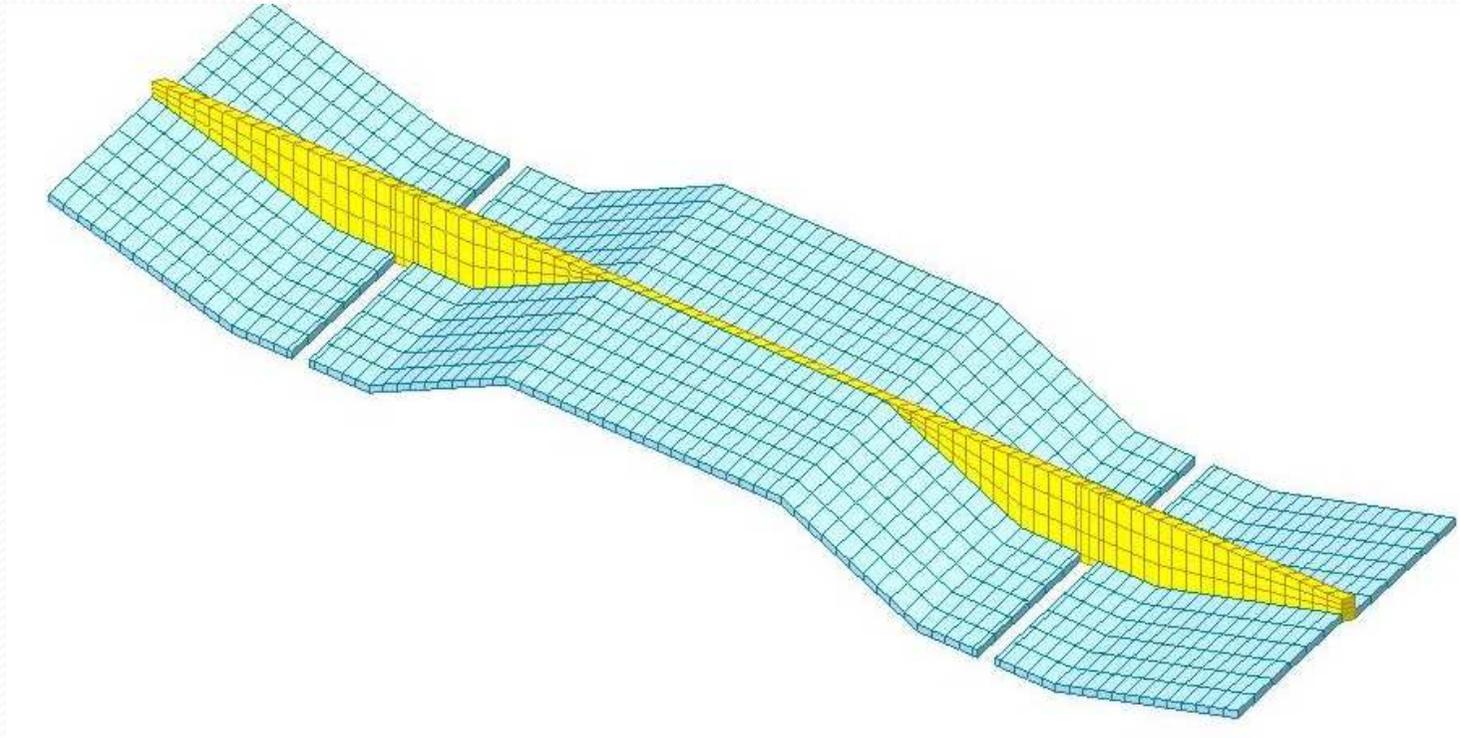


Structure Description

- Portals
- Footings
- Beams
- Slab



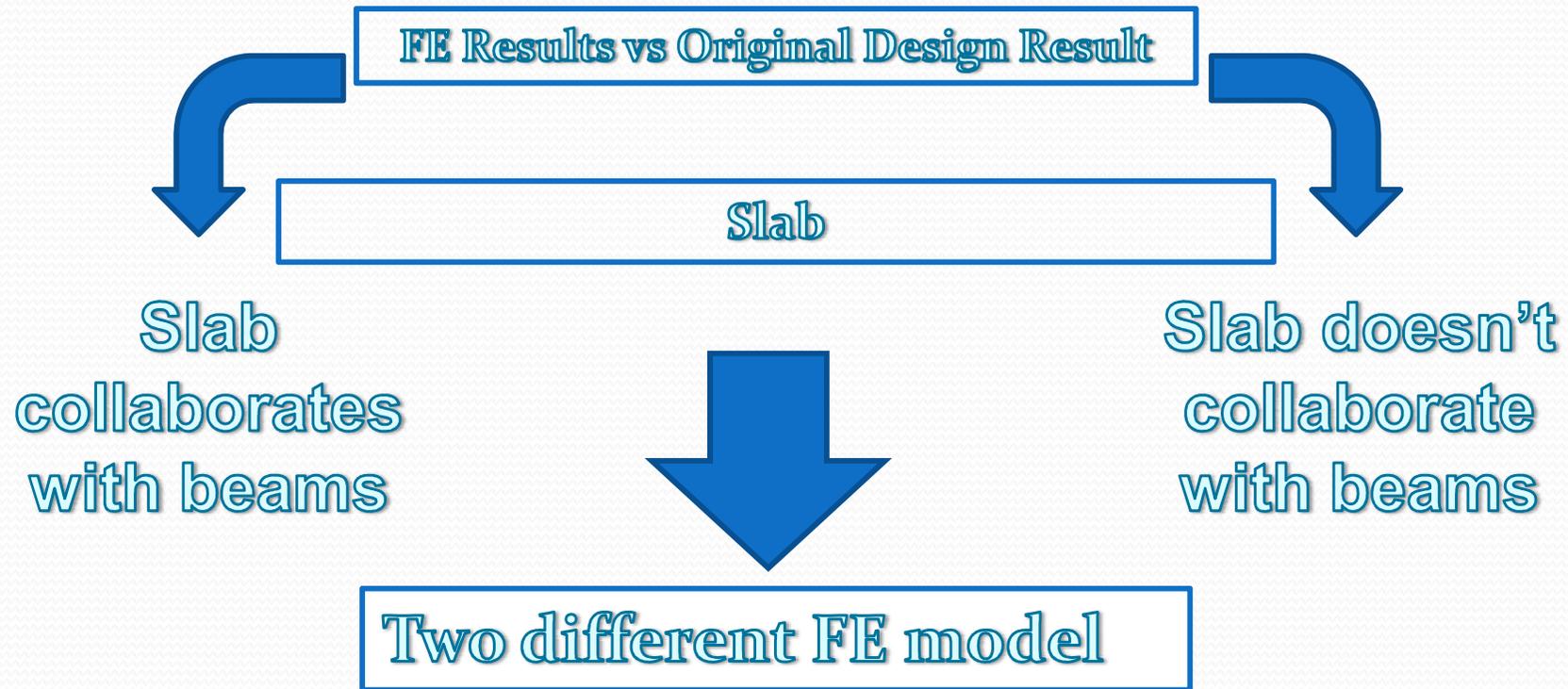
Beams-Slab connection



Materials

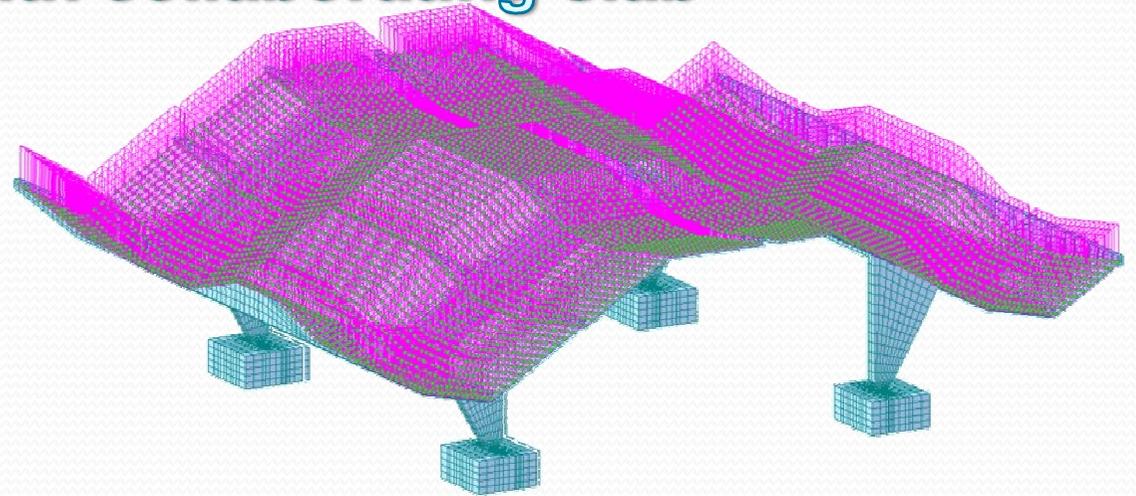


Structural Model

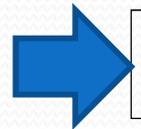


FE model with collaborating slab

- FE model
- Load analysis
- Load model
- Load combination

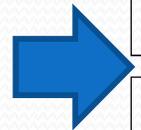


SLU



$$\gamma_{G1} \cdot G_1 + \gamma_{G2} \cdot G_2 + \gamma_P \cdot P + \gamma_{Q1} \cdot Q_{k1} + \gamma_{Q2} \cdot \Psi_{02} \cdot Q_{k2} + \gamma_{Q3} \cdot \Psi_{03} \cdot Q_{k3} \dots$$

SLE



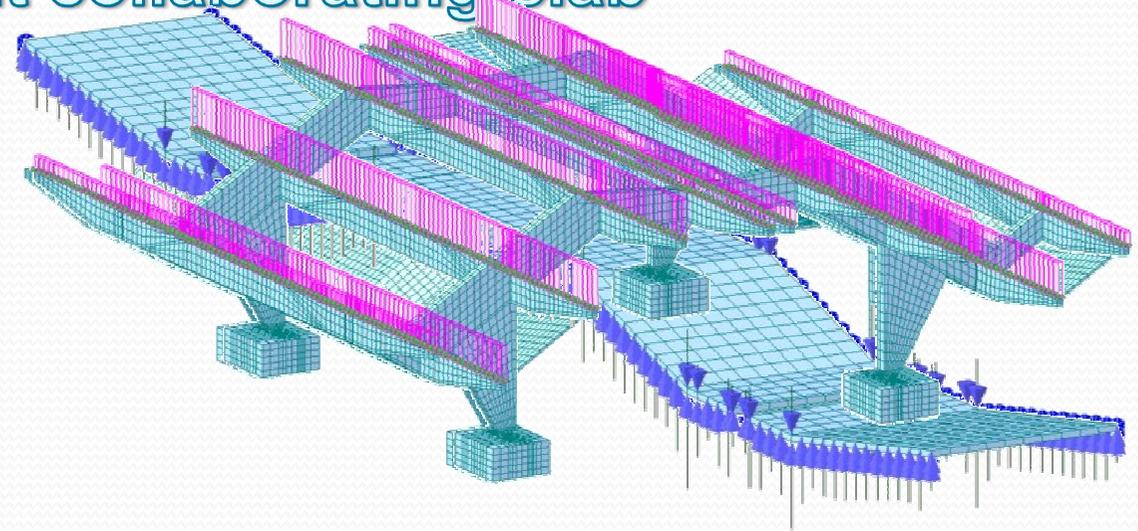
$$G_1 + G_2 + P + \Psi_{11} \cdot Q_{k1} + \Psi_{22} \cdot Q_{k2} + \Psi_{23} \cdot Q_{k3} + \dots$$

$$G_1 + G_2 + P + \Psi_{21} \cdot Q_{k1} + \Psi_{22} \cdot Q_{k2} + \Psi_{23} \cdot Q_{k3} + \dots$$

- D.M. 14/01/2008 - Norme Tecniche per le Costruzioni
- CNR-DT 207/2008
- Eurocodice 2

FE model without collaborating slab

From the first model



- Separate the slab
- Full constraint condition
- Reaction calculation

- Transfer the forces on the beams

Ultimate Limit State Checks

Slab ✓ Beams ✓ Portal ✗

Checks	Beam 1	Beam 2	Beam 3	Beam 4	Beam 5
Bending A	YES	YES	YES	YES	YES
Bending B	YES	YES	YES	YES	YES
Bending + Axial C	YES	YES	YES	YES	YES
Shear A	YES	YES	YES	YES	YES
Shear B	YES	YES	YES	YES	YES
Shear C	YES	YES	YES	YES	YES



A = Original Result

B = FE result coll. Slab

C = FE result not coll. Slab

Serviceability Limit States

Slab

Checks	Field 1	Field 2	Field 3	Field 4
Crack	YES	YES	YES	YES
Displacement	YES	YES	YES	YES



Beams

Checks	Beam 1	Beam 2	Beam 3	Beam 4	Beam 5
Crack	YES	YES	YES	YES	YES
Displacement	YES	YES	YES	YES	YES



Portal

Checks	Node 2	Node 3	Node A	Node 4
Crack	NO	NO	NO	NO



A = Original Result

B = FE result coll. Slab

C = FE result not coll. Slab

Serviceability Limit States

Portal **X**

Node 2 { $W_{d\ 2C,per} = 0.707\text{ mm}$
 $W_{d\ 2C,freq} = 0.724\text{ mm}$

Node 3 { $W_{d\ 3C,per} = 0.419\text{ mm}$
 $W_{d\ 3C,freq} = 0.429\text{ mm}$

Node A { $W_{d\ AB,per} = 0.451\text{ mm}$
 $W_{d\ AC,per} = 0.697\text{ mm}$
 $W_{d\ AB,freq} = 0.722\text{ mm}$
 $W_{d\ AC,freq} = 0.706\text{ mm}$

Node 4 { $W_{d\ 4C,per} = 0.331\text{ mm}$
 $W_{d\ 2C,freq} = 0.333\text{ mm}$

$w_d \leq 0.4\text{mm freq.}$
 $w_d \leq 0.3\text{mm quasi perm.}$

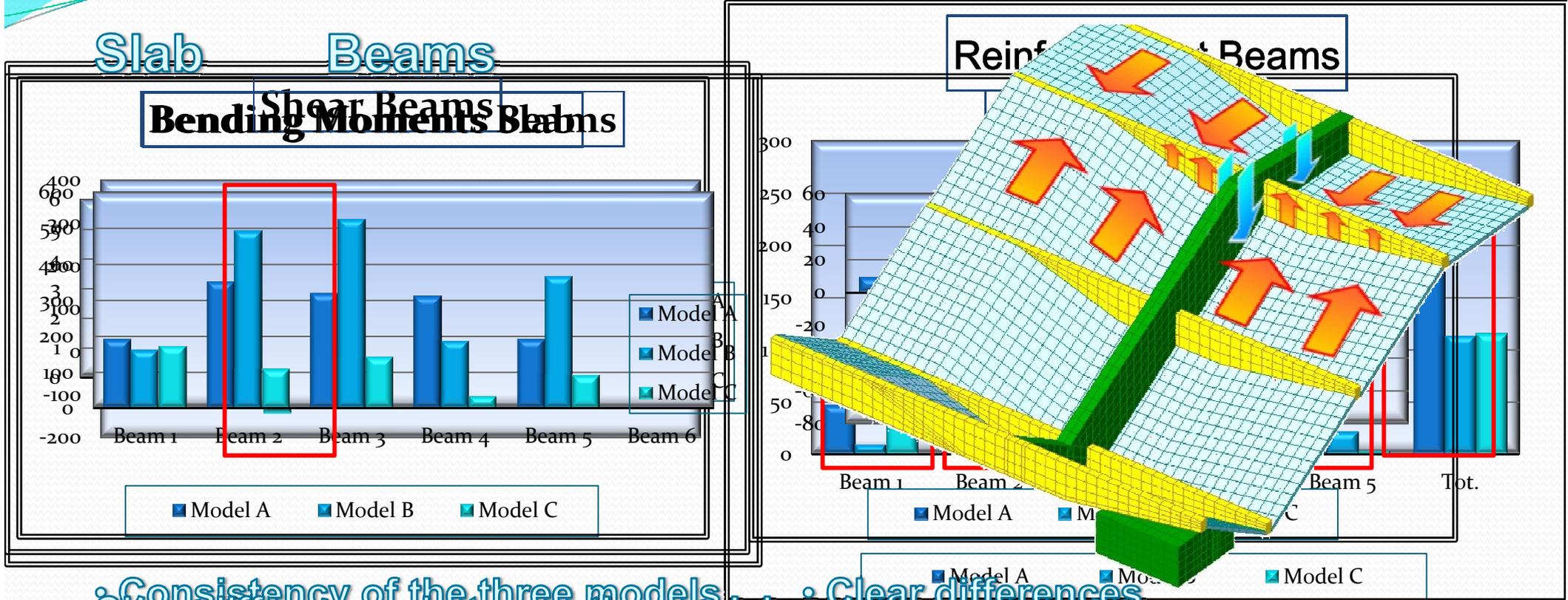
B model is not suitable to evaluate the crack magnitude

A = Original Result

B = FE result coll. Slab

C = FE result not coll. Slab

Results comparison and analysis 1

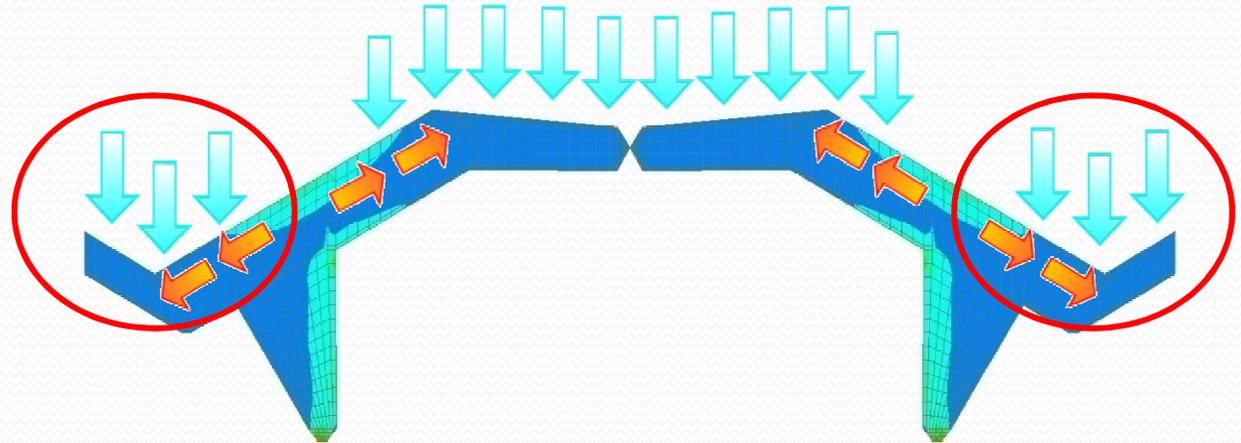


- Consistency of the three models
- Clear differences between the models
- Beam 2: matching slab field 2 and 3
- Clear differences
- Total reinforcement
- Field 2 and 3
- Le Model B would prevent us from a right design
- More reinforcement

Beam-Slab are a single structural element

Results comparison and analysis 2

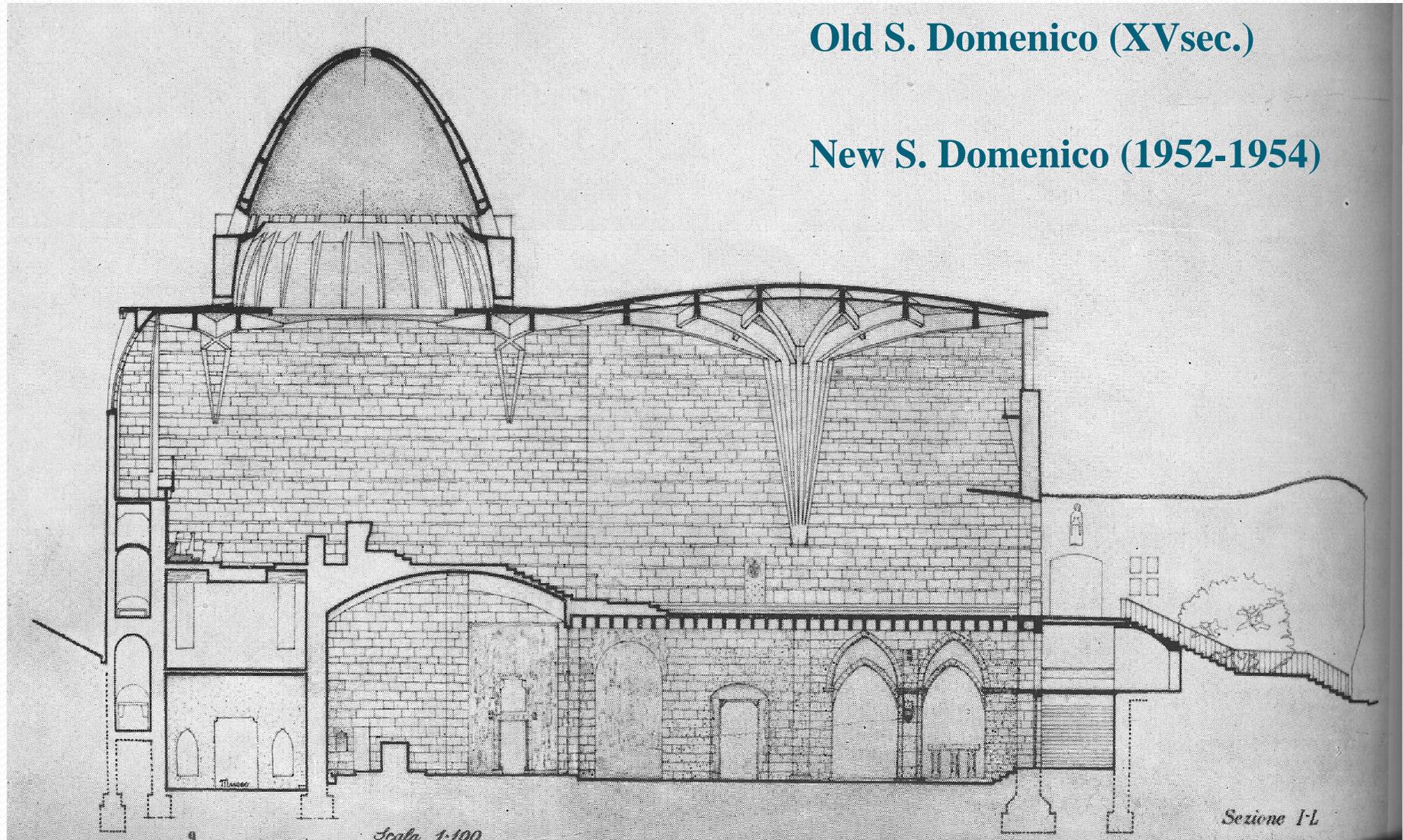
Portals



- Tensile bending
 - Cantilever load
 - Slope of the beam

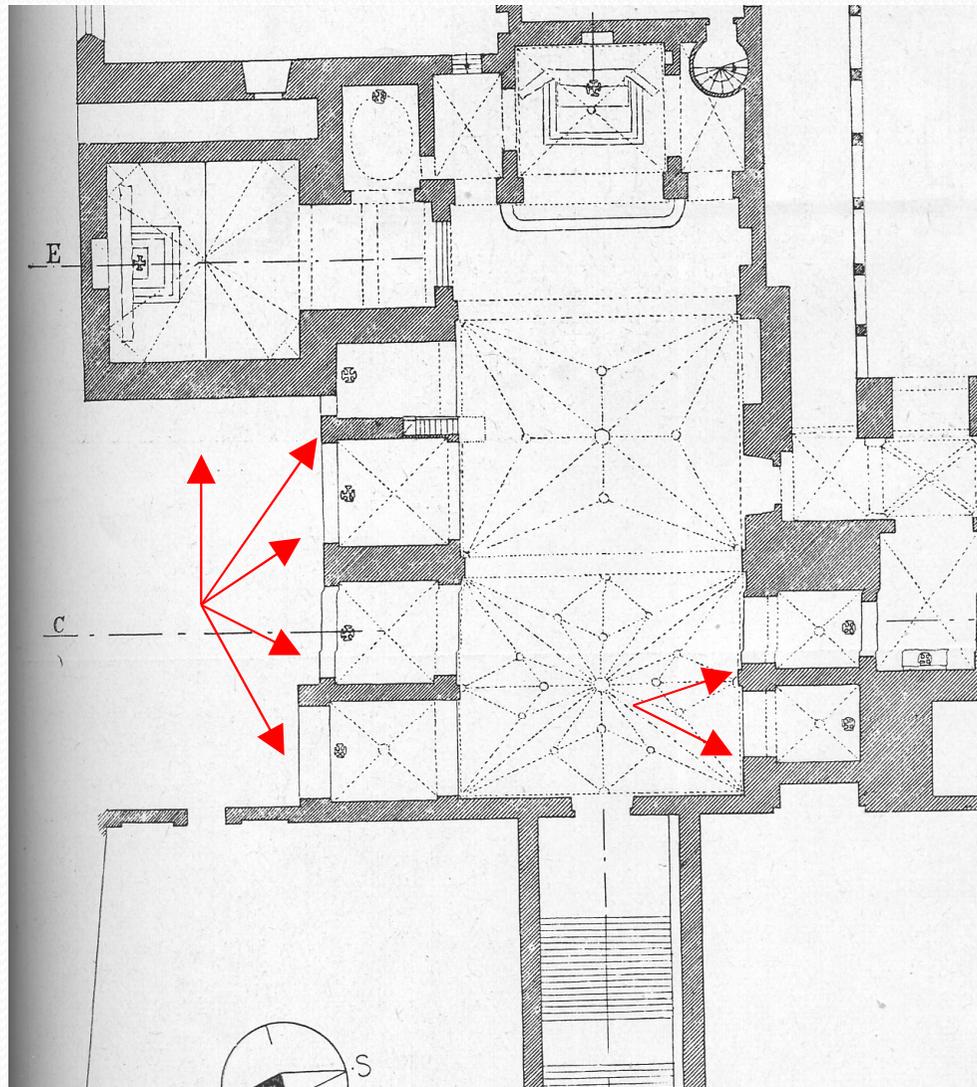
It hasn't a three hinged arch behaviour

Saint Domenico's church: Description 1

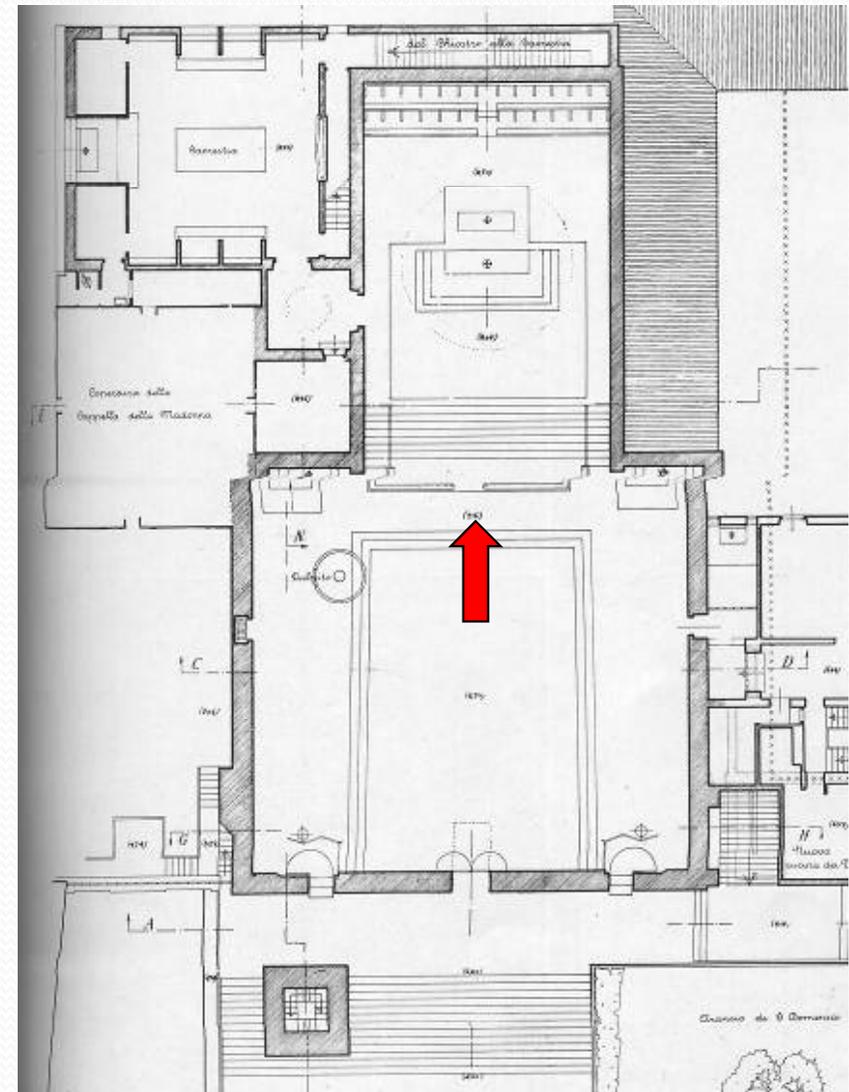


Saint Domenico's church: Description 2

Old church plan view

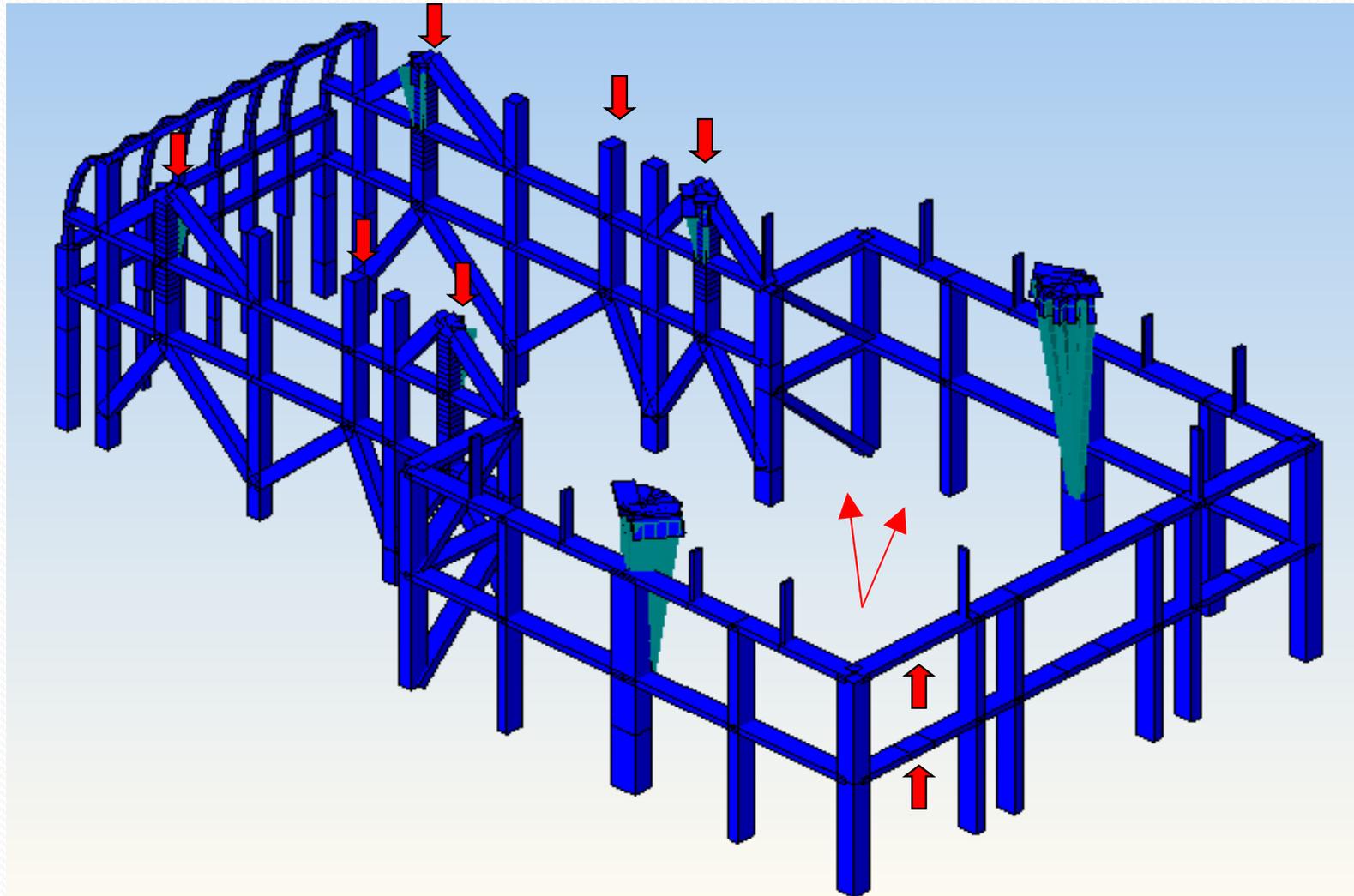


New church plan view



Structure

Frame : 30 Columns - 2 Kerbs – 6 secondary pillars



Materials

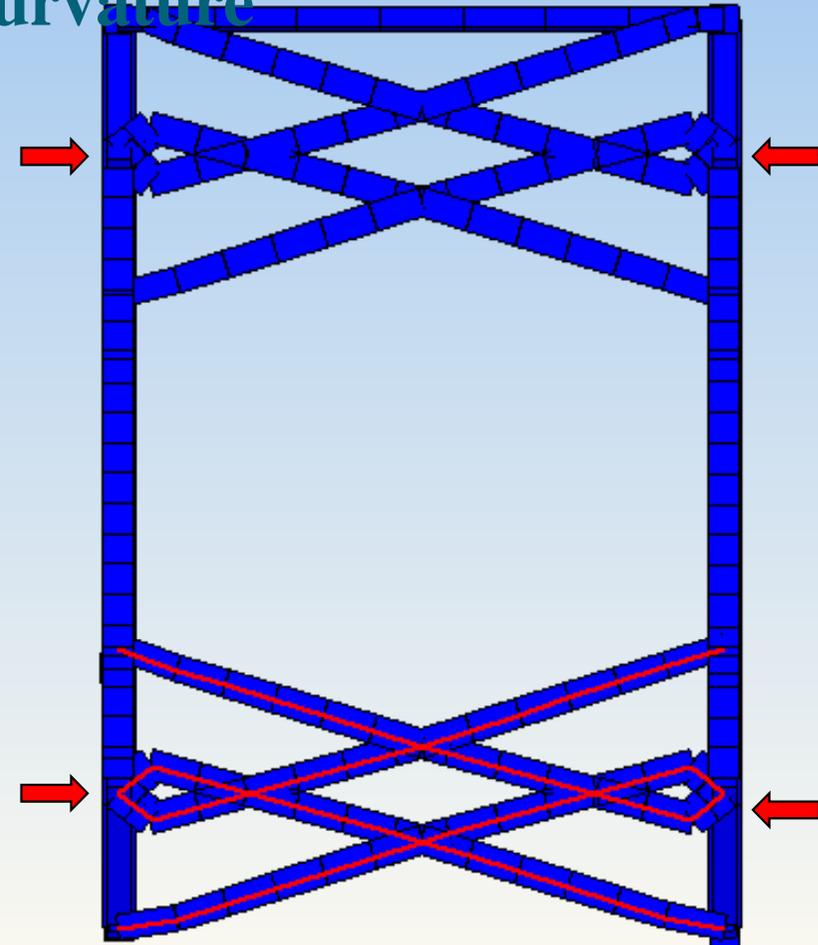
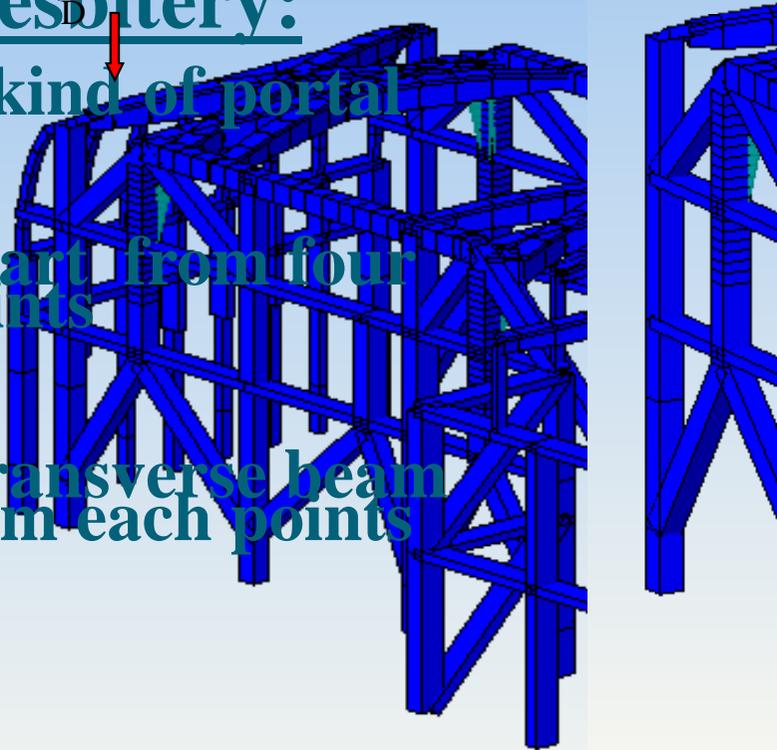


Cover of the new nave 1

- R.C. structure
- Triple Curvature roof
- 4 kind of half portal
- Different in length and curvature

Presbitery:

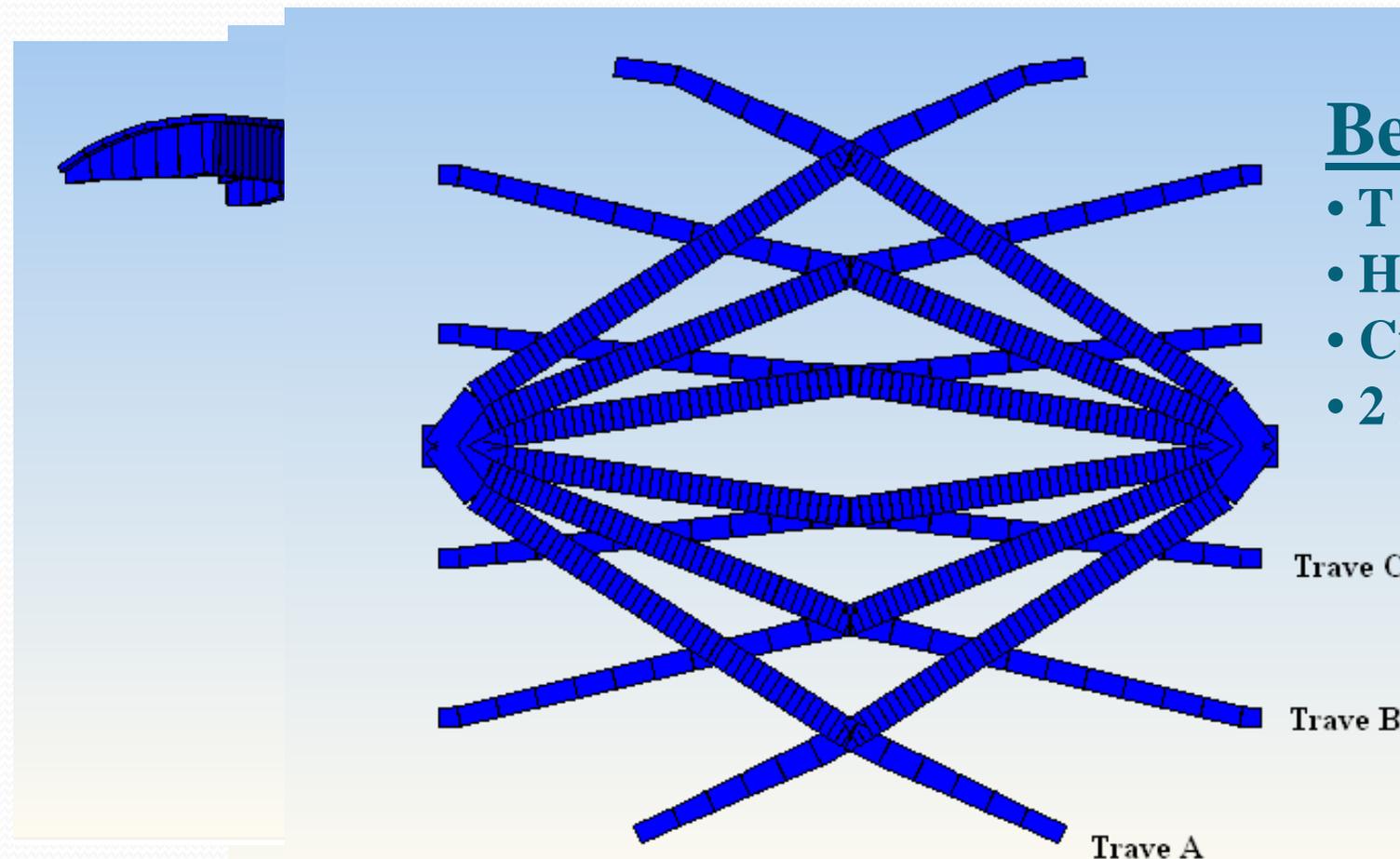
- 1 kind of portal
- Start from four points
- Transverse beam from each points



Cover of the new nave 2

Portals :

- 2 fans of beams
- 1 fundamental column
- 6 beams for each fans
- 18 intersection points
- 20 m length
- 3 half portals

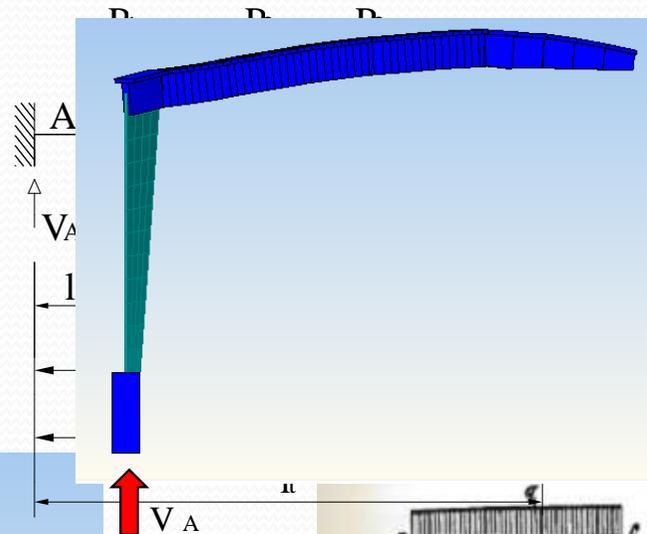
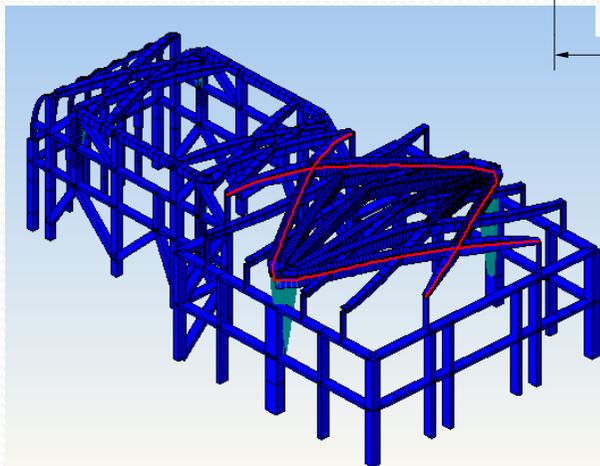


Beams :

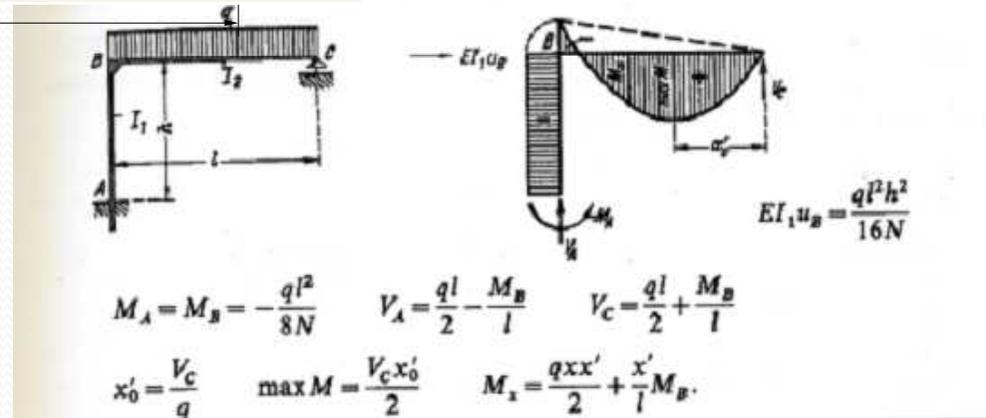
- T section
- H variable
- Curved long. axe
- 2 inflection points

Original Design vs FE model

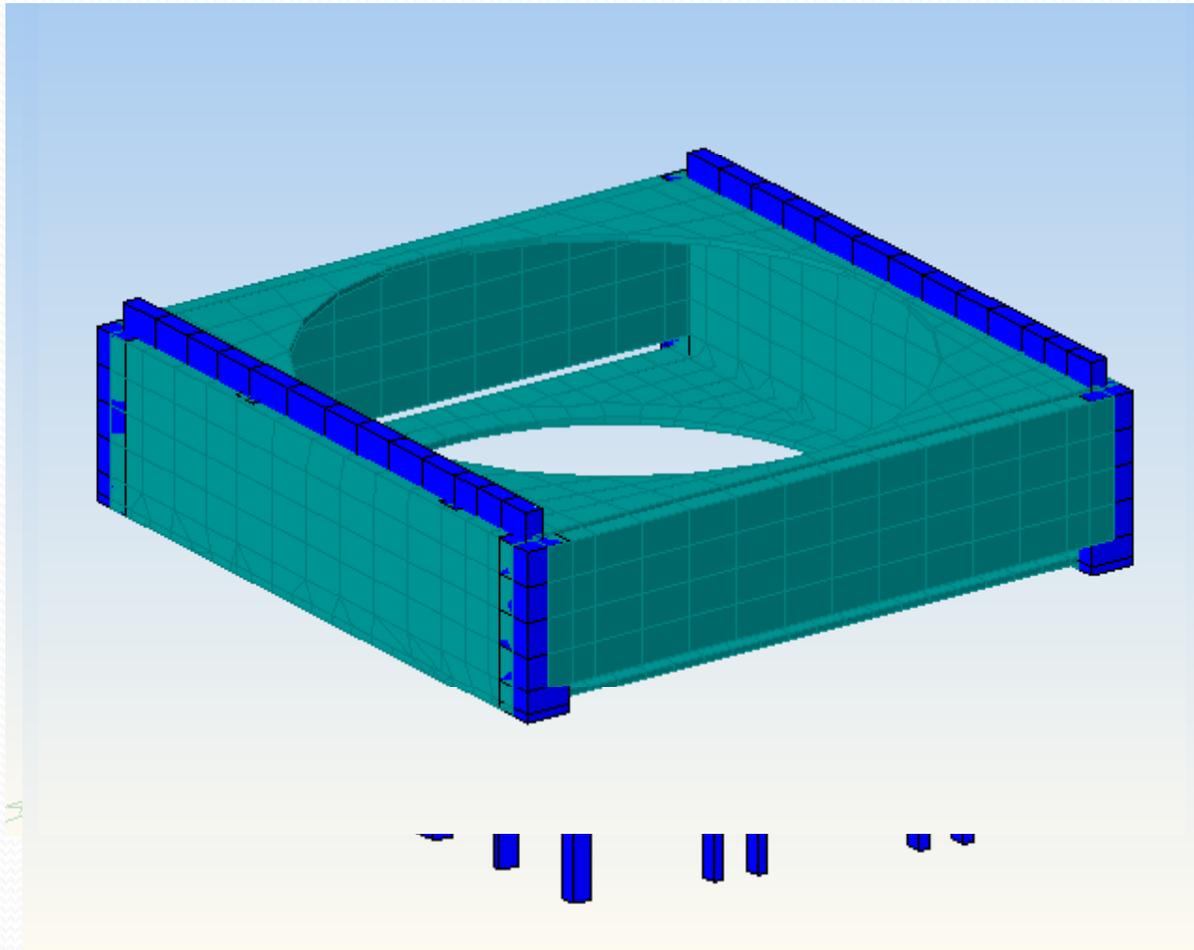
FE model
 $V_{AM} = 1807,4 \text{ KN}$



Original Design
 $V_{AR} = 495,9 \text{ KN}$



Dome and Tambour



Dome:

- Defined between Portals

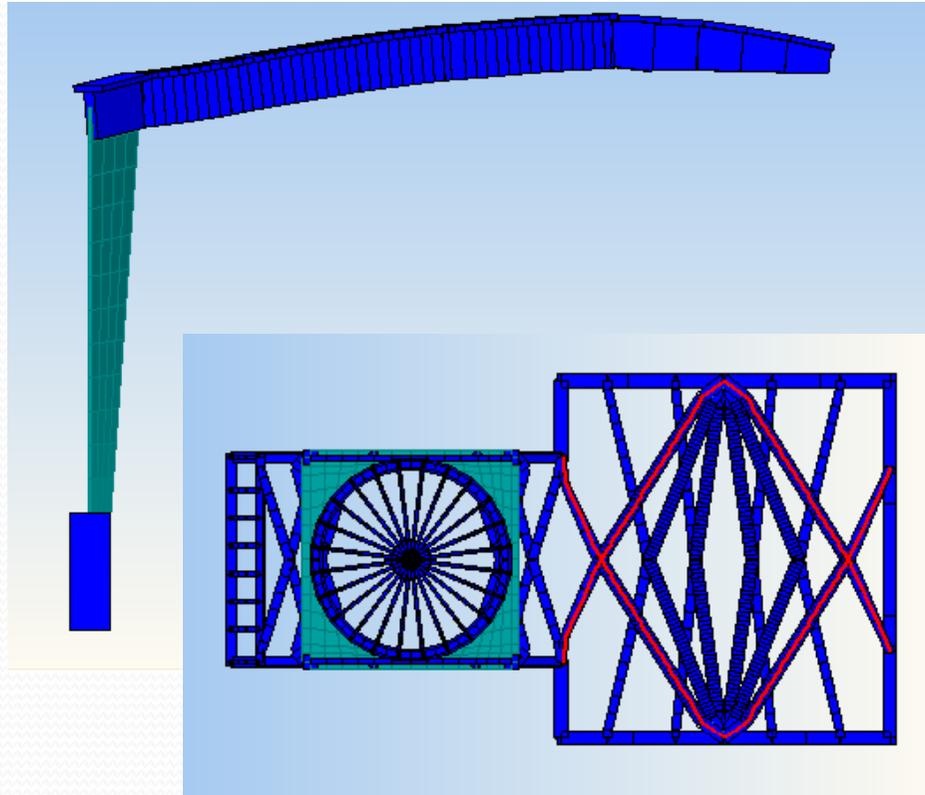
Ring:

- “Sottile, equilibrata e di Rotazione”
- Link between tambour and meridian

Meridians:

- Parabolic shape

Portal (type A)



ULS :

Bending

NO

Shear

NO

SLS :

Material Stress

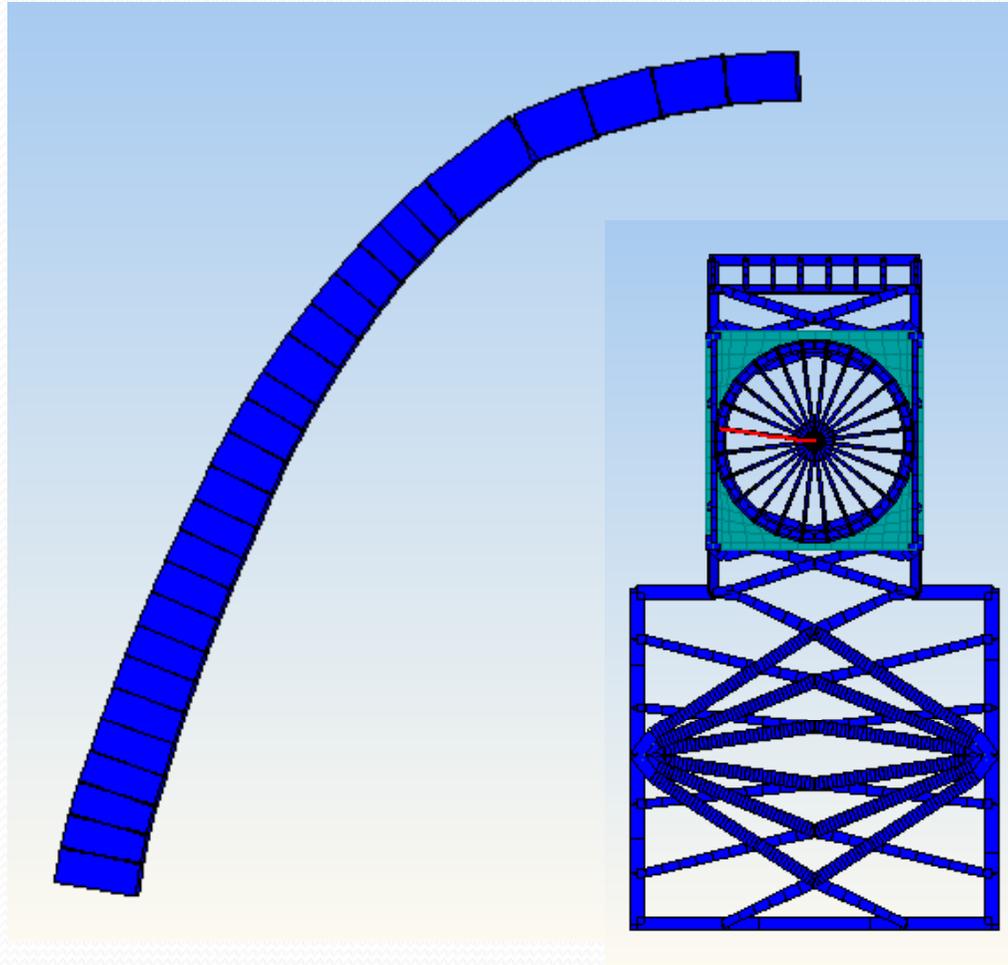
YES

Crack

NO

Bending → lack of informations from the original design,
unknown amount of negative bending reinforcement
Shear → no information about stirrups

Meridian



ULS :

Bending

YES

Shear

YES

SLS :

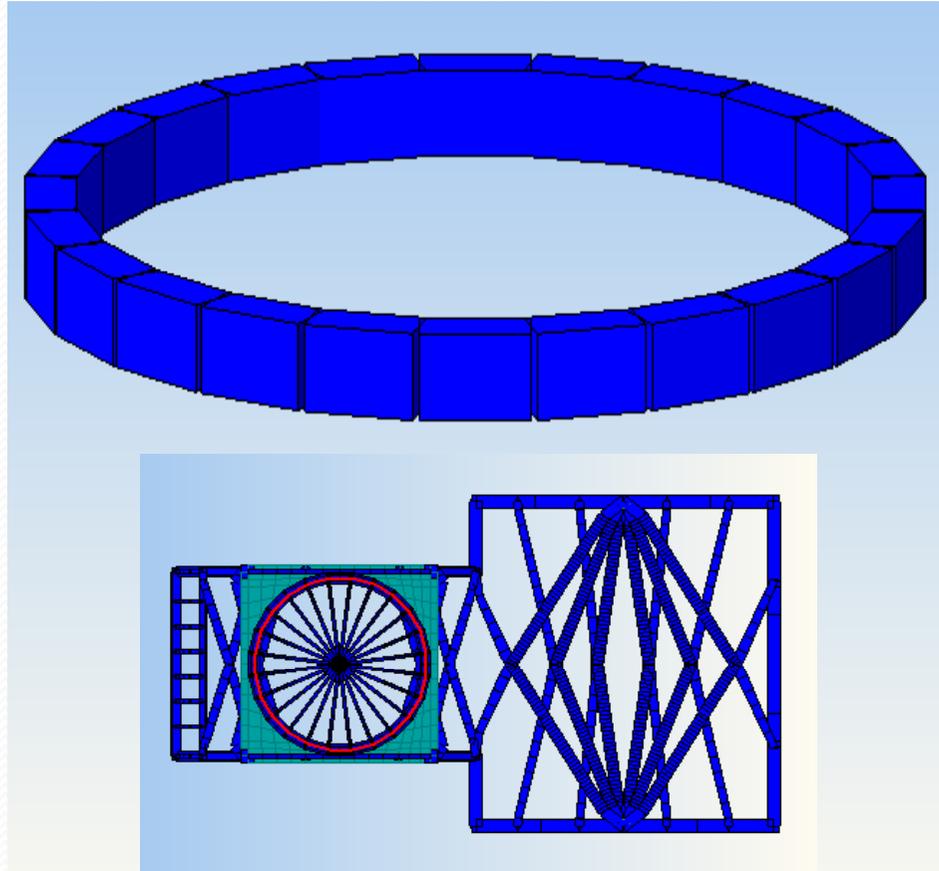
Material Stress

YES

Crack

YES

Dome Ring



ULS :

Bending

YES

Shear

YES

SLS :

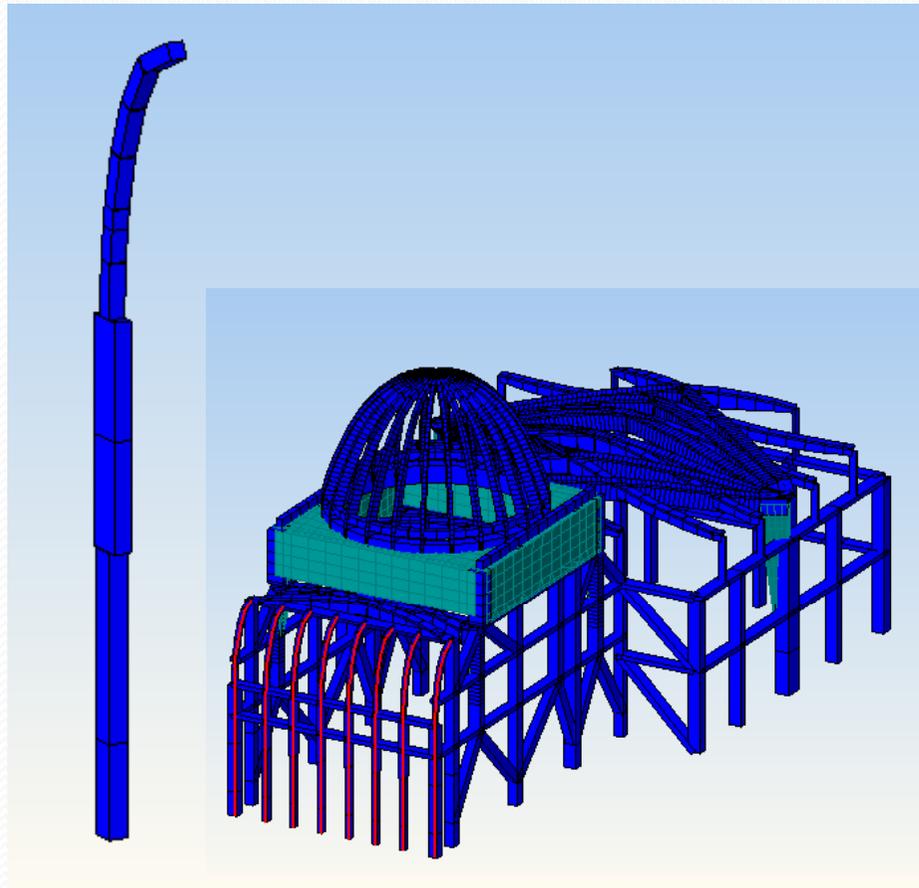
Material Stress

YES

Crack

YES

Column of the choir



ULS :

Bending

YES

Shear

YES

SLS :

Material Stress

YES

Crack

YES

Conclusions 1:

- Thanks to F.E. method it was possible to model the structural behavior of ancient existing R.C. buildings with good accuracy under the service loads. For both structures the results of the numerical calculation led to the conclusion that the original models are not totally accurate in describing the real structural behavior; it is, however, sufficient for most of the elements, thanks to a very conservative approach.
- For both the structures it can be said that the standards of that time were mostly sufficient to guarantee an adequate safety level. Actually, the FE model set-up for this analysis and new performance-based standards make it possible to have a more accurate loading definition, a better knowledge of the structural behavior and, consequently, a refined judgment in evaluating the actual safety levels.

Conclusions 2:

- The last consideration regards the importance of the link between shape and structure. In cases like the ones here investigated, namely buildings with a strong architectural value, the structural engineer should try to rationalize the architect's point of view by means of a synergic action. The structural concept must be appropriated to the characteristics of the building and, with a constant research of smartness, too simplistic approaches have to be refused. Perhaps they could be used for ordinary manufactures, but in the case of structures like the San Domenico church or CasMez pavilion, they can lead to lots of errors.

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Thank you for your kind attention!

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