Engineering Applications

P.B. Lourenço

www.civil.uminho.pt/masonry

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Applications

Mosteiro dos Jerónimos

Mosteiro de Salzedas

Sé do Porto

Convento Tomar

Applications

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Chimney in Arouca

See: Lourenço, P.B., Recommendations for restoration of ancient buildings and the survival of a masonry chimney, Construction and Building Materials, 20(4), p. 239-251 (2006)

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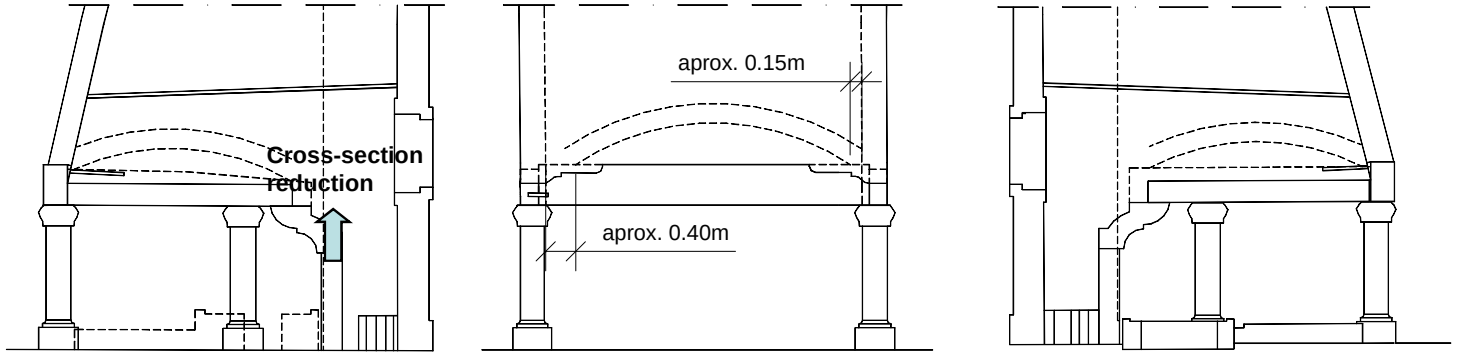
Geometry

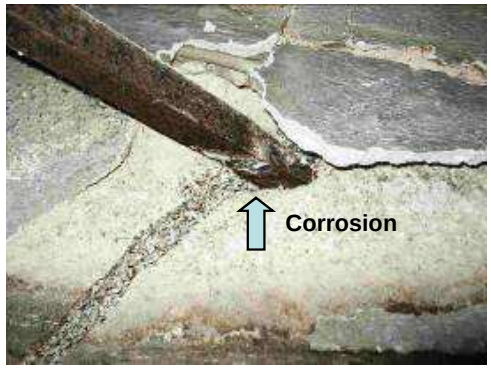


Aspects chimney: In plan size of 4.3 x 4.1 m2 and 16.2 m height

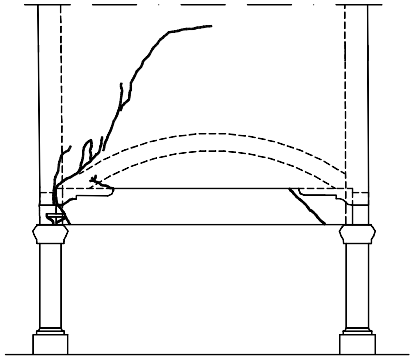


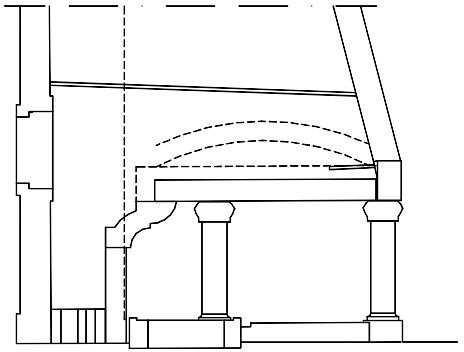
Geometry and internal arching system

Existing Damage



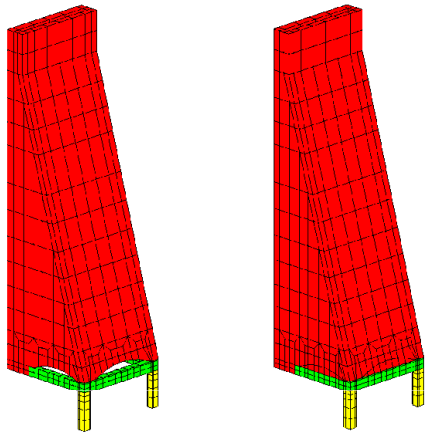
Details of cracking in the supports



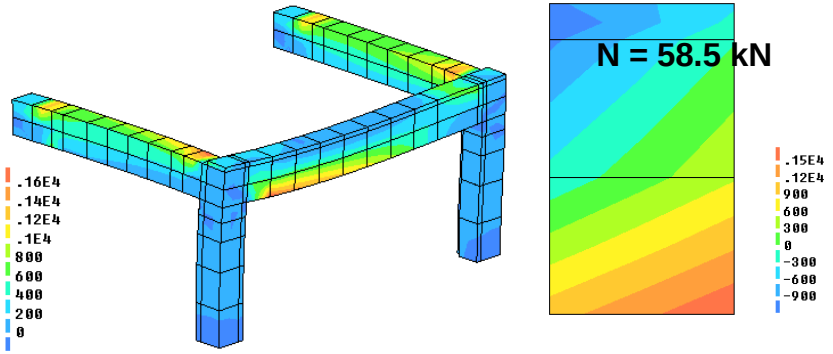


Cracking in the front wall and left wall

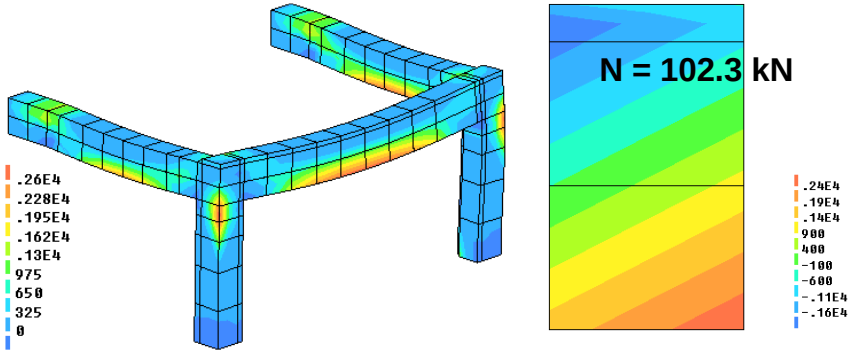
Numerical Analysis (I)



Two models
(with and without arching action)

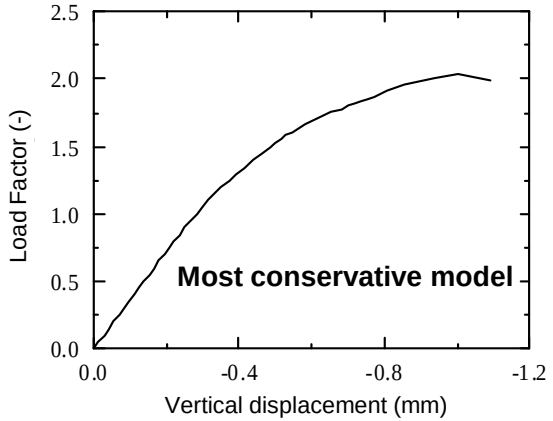


Elastic results with arching action:
$\sigma_{t,max}$ = 3.5 N/mm^2

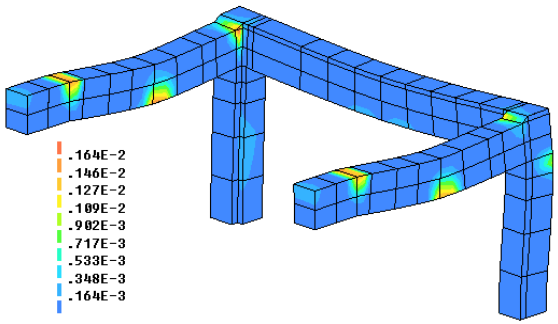


Elastic results without arching action:
$\sigma_{t,max}$ = 6.2 N/mm^2

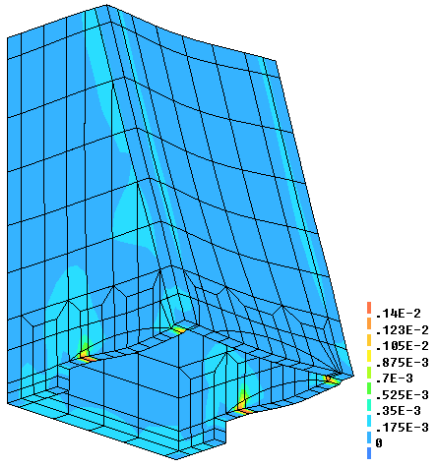
Numerical Analysis (II)



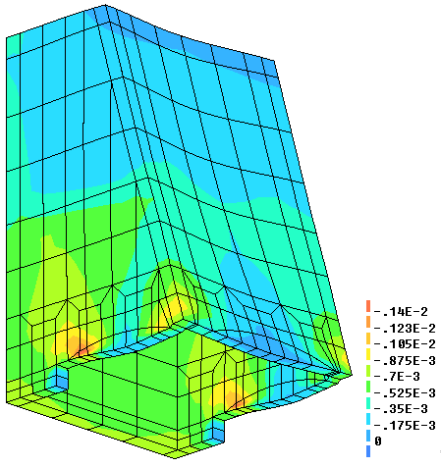
Load-displacement diagram



Cracking in transverse beams



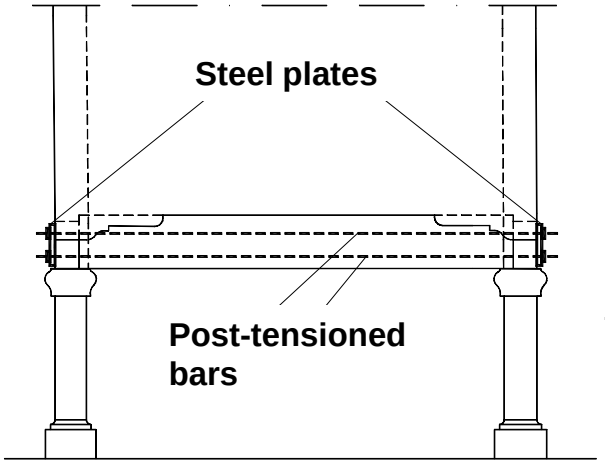
Cracking

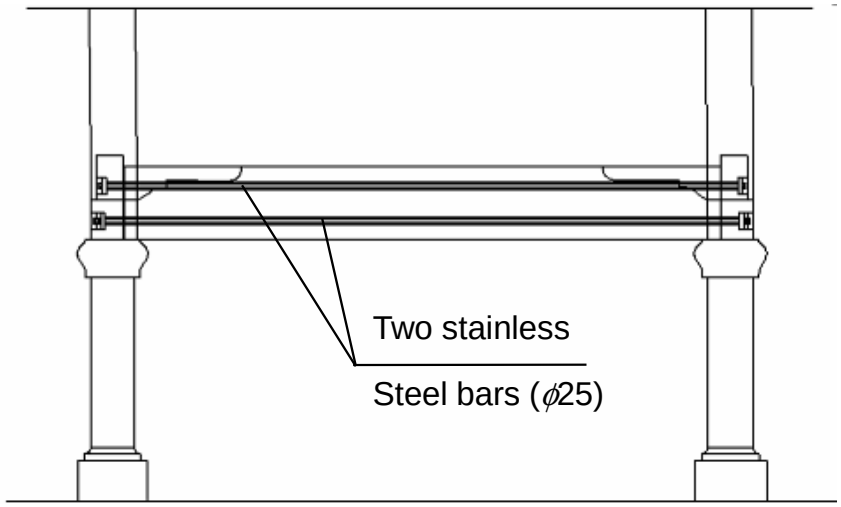


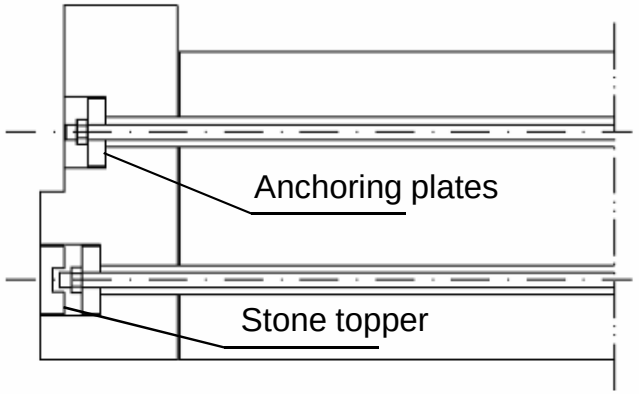
Crushing

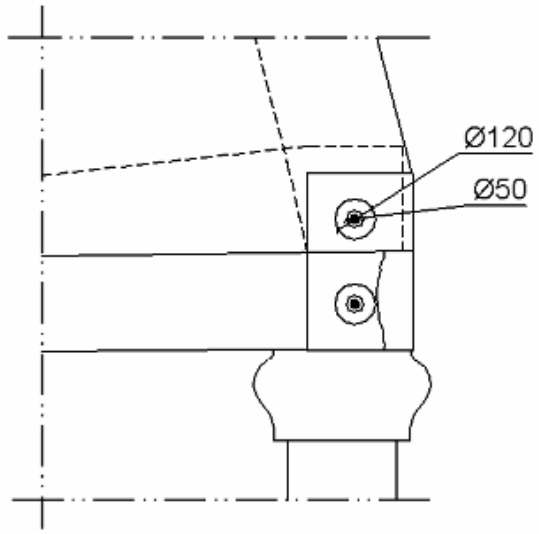
Conclusions and remedial actions

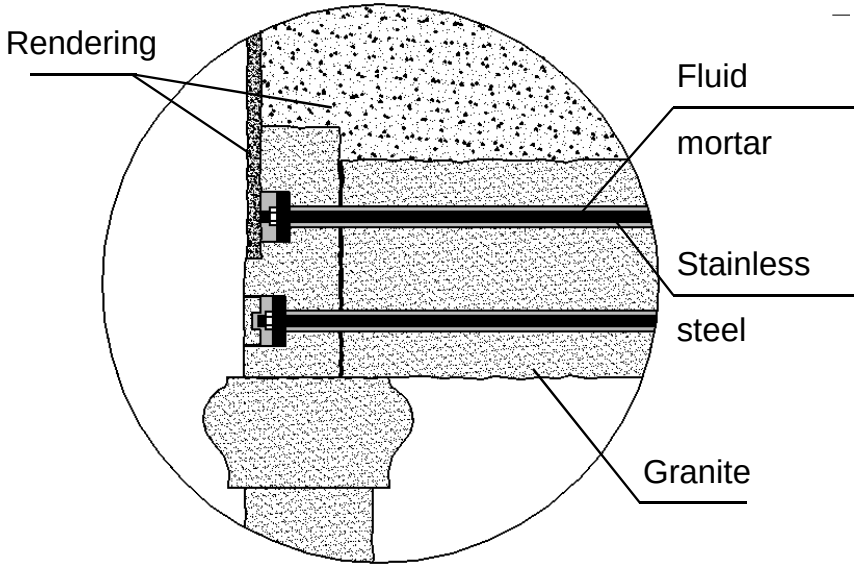
- Cracks in main lintel and one side lintel. Corrosion in the ties.
- Original building defects: asymmetric positioning of the main arch; possible lack of separation between arch and masonry infill; progressive cross-section reduction of the cracked side lintel.
- Numerical analysis indicates that the collapse of the main lintel is not due only to structural reasons. Corrosion might be the precursor of failure. For a loading factor of 2.0, collapse of the side lintel could be expected in the most unfavorable conditions, but not the main lintel.
- A crack did occur in the side lintel with the cross-section reduction and new columns have been added to the structure. The cross-section reduction has not been considered in the computer simulation.
- Chimney can be used for firing exceptionally.
- Corroded ties must be replaced by stainless steel. Other ties to be depassivated and fire protected.
- Two possible remedial measures: (a) glue stone with epoxy resin and inner strengthening, drill a long hole and insert post-tensioned bars; (b) lift chimney and replace stone by a new one




Two stainless
Steel bars (ϕ25)


Anchoring plates
Stone topper


Ø120
Ø50


Rendering
Fluid
mortar
Stainless
steel
Granite

Monastery of Salzedas (Portugal): Intervention in the cloister

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See: Lourenço, P.B., Ramos, L.F., Vasconcelos, G., Peña, F., Monastery of Salzedas (Portugal): Intervention in the cloister and information management, in: 6th International Conference on Structural Analysis of Historic Constructions, Eds. D. D'Ayala e E. Fodde, Taylor & Francis Group, p. 95-108 (2008)

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Contents

- Brief historical review
- Damage survey
- Highlights of structural survey, NDT and numerical analysis
- Execution details
- Information management system
- Conclusions


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Brief historical review
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Typical Cistercian Abbey. Considerable size in plan, 75.0×101.0 m^2. Origin from the XII century. Cloister from the 17th century. Classical model with columns and closed upper gallery. Ribbed crossed vaults in the first floor and cannon vaults in the second floor.

Context

- Portugal 1834: the new political system, of liberal and constitutional origin, decides the extinction of religious Orders, confiscates their properties and sells them in auction. Monastery of Salzedas was left abandoned with demolitions, stealing, ruined or in the verge of collapse parts.
- Nature slowly taking care of the site. No “restoration”. Unfinished works.
- A harmonious disorder where everything evokes “time”. A time of multiple pasts felt in each single part of the building: the scars, the clear vestiges from other eras, the unexpected shapes of the incomplete and the empty.
- General actions: (a) **Cleaning** – removal of biological infestation, and removal and selection of debris with the archaeological assistance, from which a set of stabilized and stored elements and fragments resulted; (b) **Consolidation** – of the parts considered at risk; (c) **Protection** – stopping, even if with temporary system, infiltration of rainwater; (d) **Access creation** – reinstate, using permanent, or temporary structures, the horizontal and vertical communications lost; install scaffolding for inspection; (e) **Geometrical Survey** – of the entire compound; (f) – **Inventory and Conservation** – for movable heritage.

Actions in the main cloister

- Stop tourist visits
- Protect against rainwater infiltration

Step 1

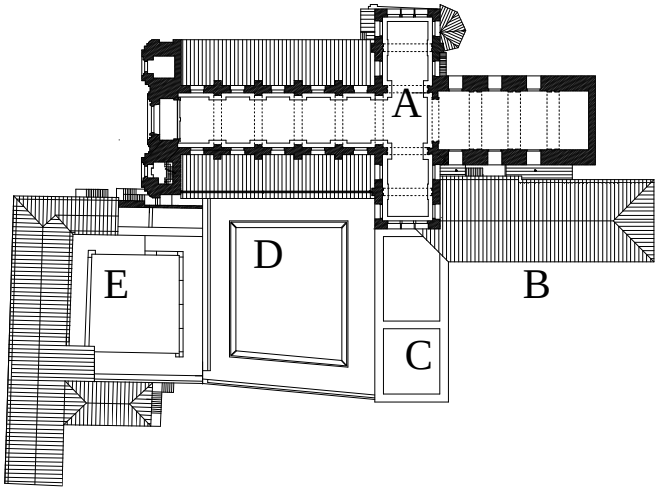
- Urgent measures in the cloister
- Moderate funding
- Decision: To preserve the ruin (or keep the aesthetics of time). *Present intervention would be as much effective, as it would remain invisible*

Step 2

- Further action once a global compound strategy is decided

Step 3

Situation found



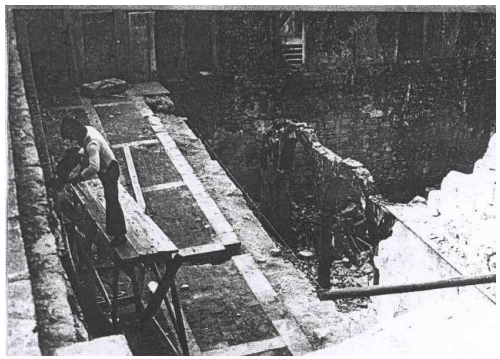
A – Church

B – Sacristy

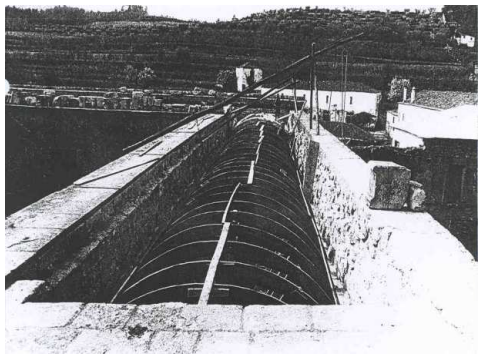
C – Chapter room

D – Main cloister

E – Small cloister



Dismantling and reassembly of the wall between the small and the large cloisters



Replacement of the barrel vault of the West wing

Damage survey

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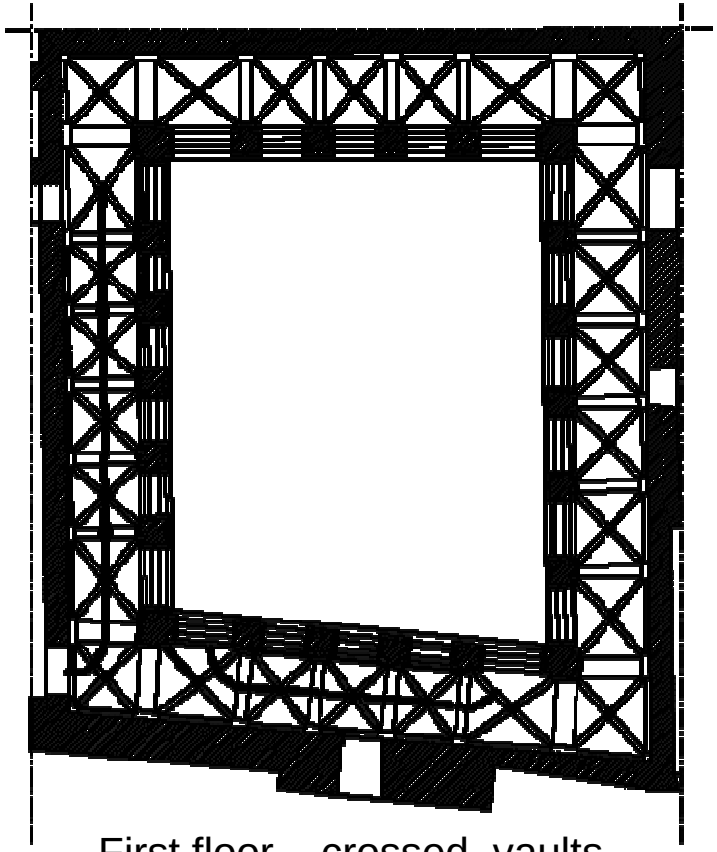
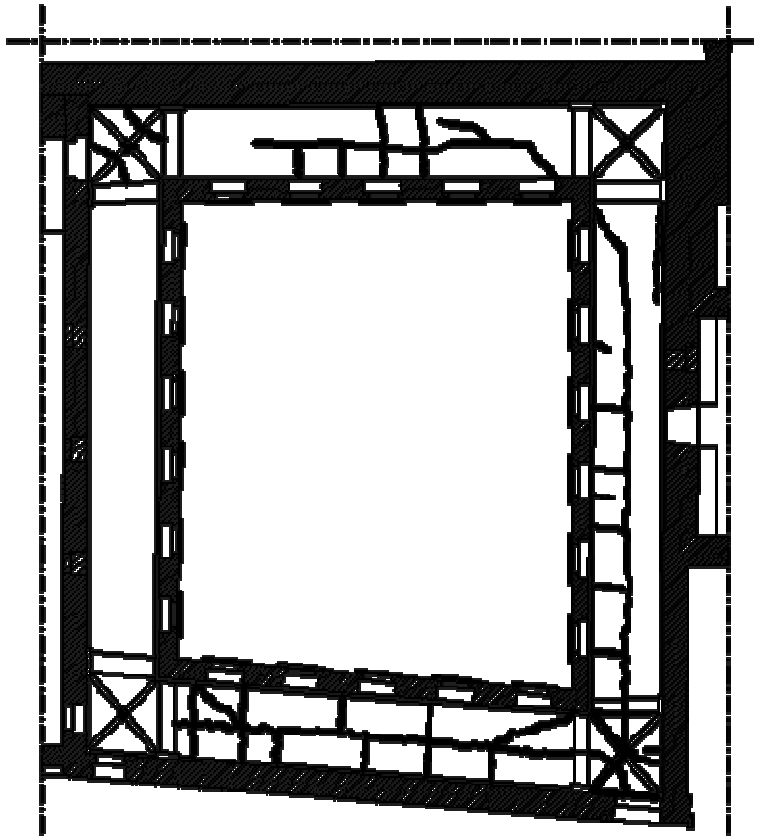
Main cracks (I)



First floor – crossed vaults



Second floor – barrel vaults

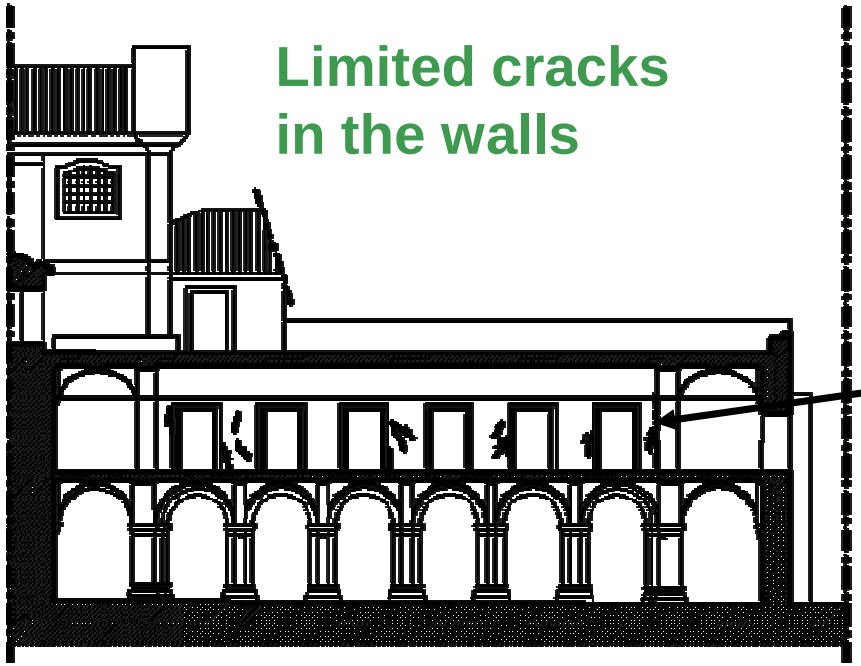
Main cracks (II)

South wing at the 2nd level

South-West corner at the 2nd level

West wing at the 1st level

South-West corner at the 1st level



Limited cracks in the walls

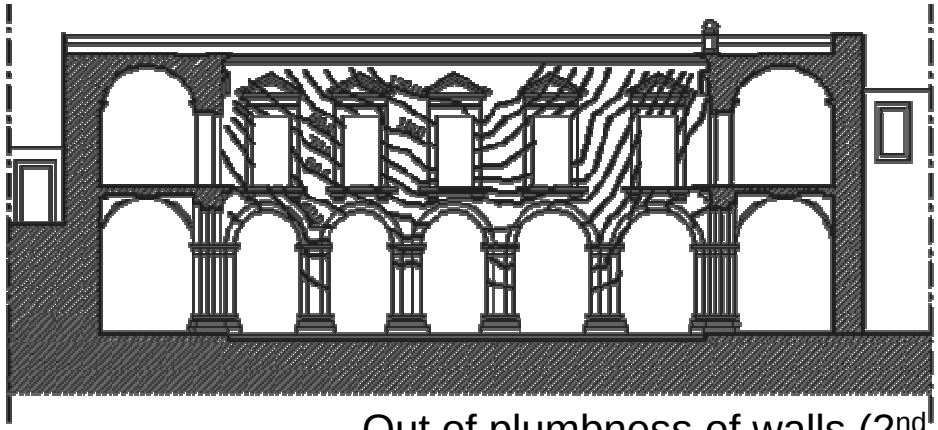
Internal wall of the West wing

External wall of East wing

External wall of South wing

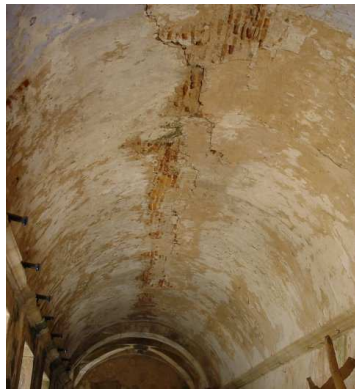
Large movements in the cloister's internal walls

Separation between vaults and walls



Out of plumbness of walls (2nd level). Resulted in vertical displacements in vaults' extrados up to 0.10 m

Other damage



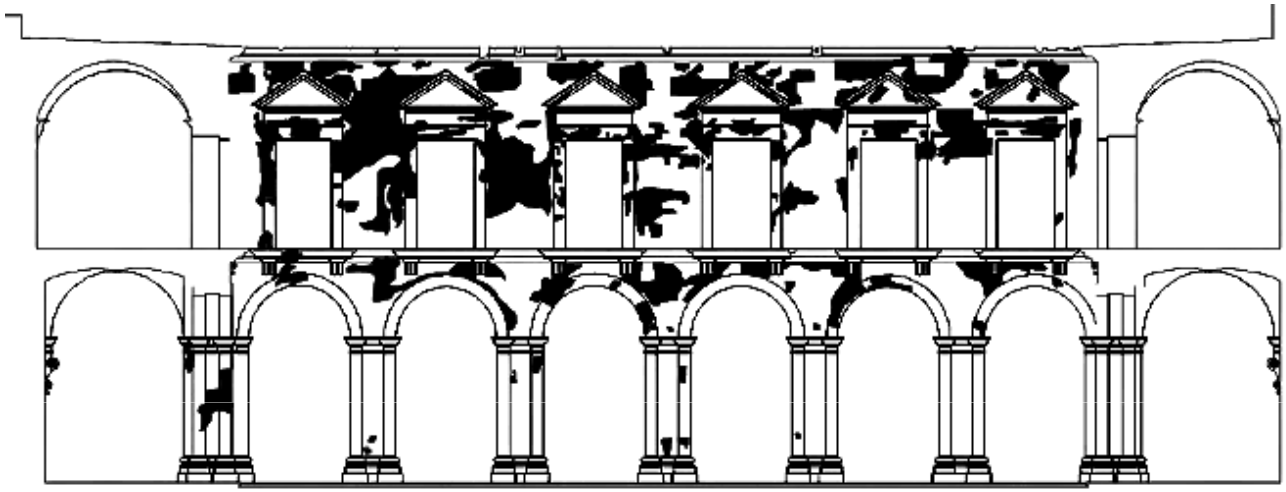
Crushing / shearing of brackets

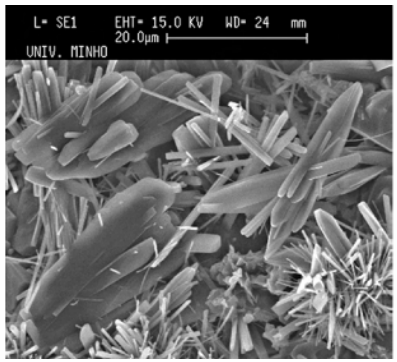
Deterioration of bricks

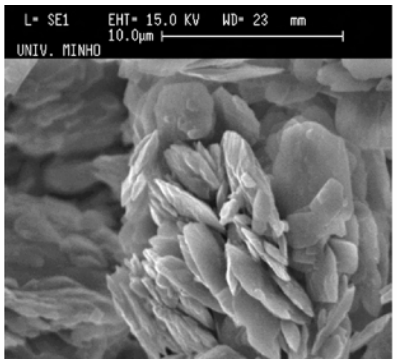
Stone deterioration

Biological colonization and moisture stains

Stone deterioration mapping and study on salts







Highlights of structural survey, NDT and numerical analysis

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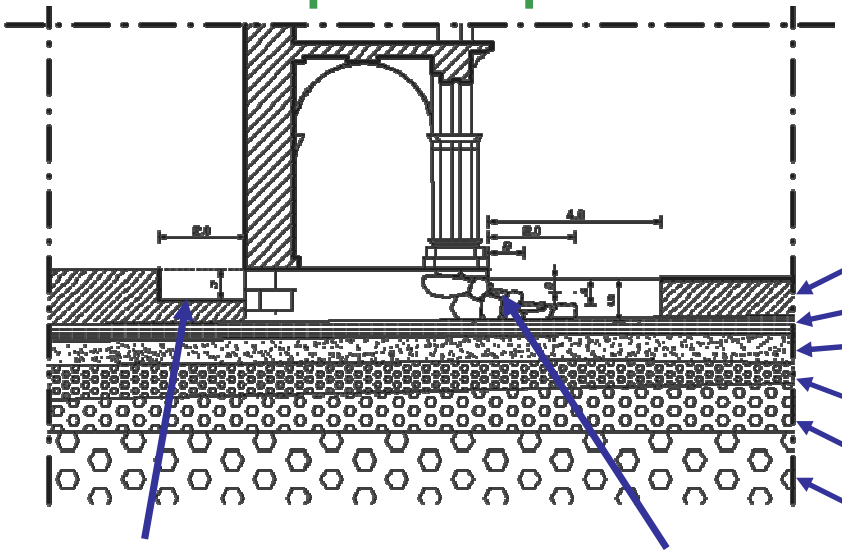
Foundation inspection pits

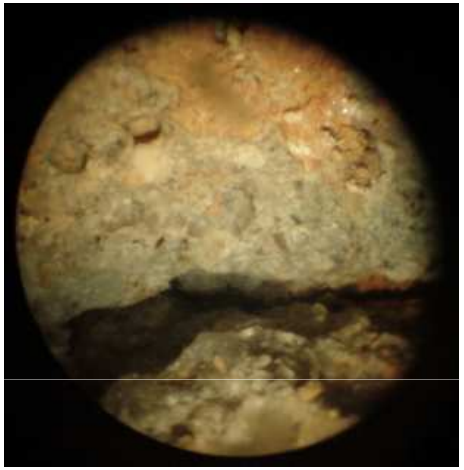


Aspect of wall foundations

Aspect of column foundations

Soil foundation exhibits moderate resistance and very large heterogeneity for depths between 1.0 and 1.8 m

Tests on walls and vaults (I)



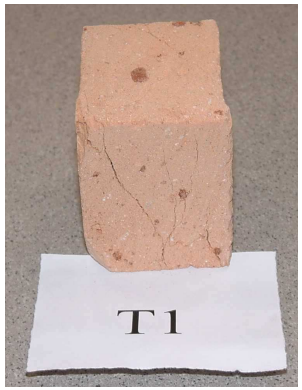
The vaults are built with clay brick masonry with 0.22m thickness and infill (soil in 1st level and lime “concrete” in the 2nd level)

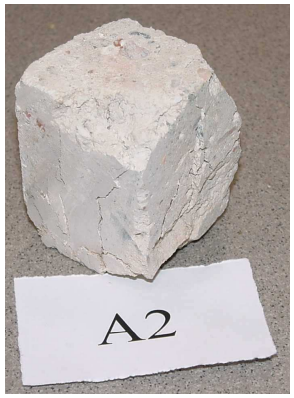
The walls are built with large granite stones, mostly with clay mortared joints

Internal longitudinal cracks or voids were not found

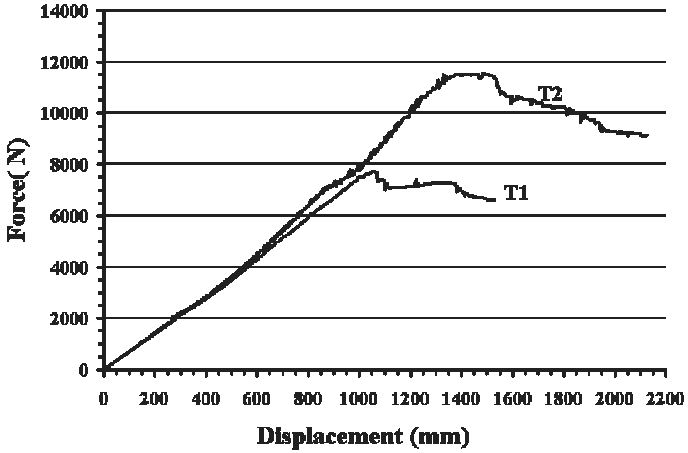
Low strength and high porosity bricks (compressive strength 5 N/mm^2)

Tests on walls and vaults (II)





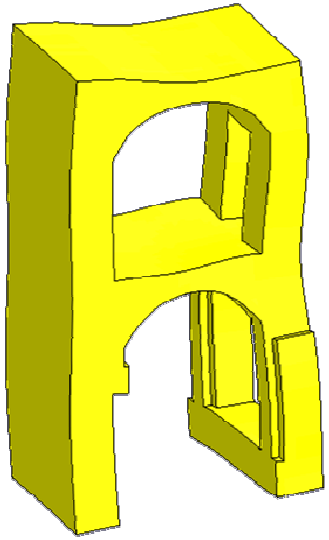
Samples for the uniaxial compression tests



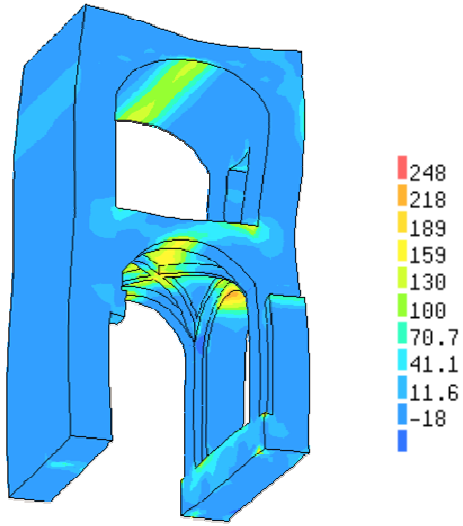
E_b = 7.3 GPa f_b = 5.2 MPa

E_m = 8.6 GPa f_m = 3.8 MPa

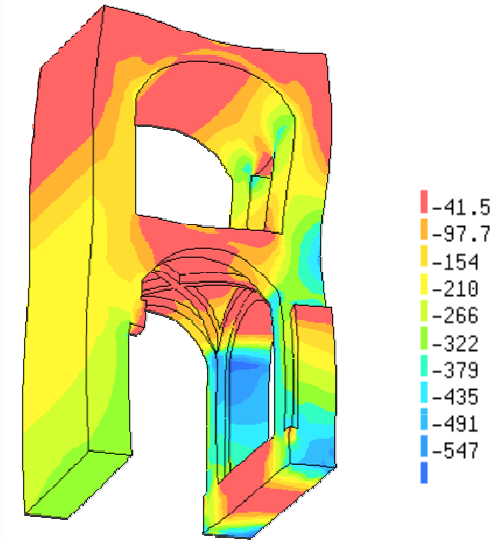
Structural analysis (Linear Elastic)



Deformation of the structure



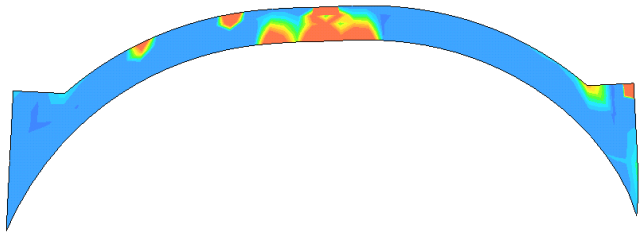
Maximum principal stresses



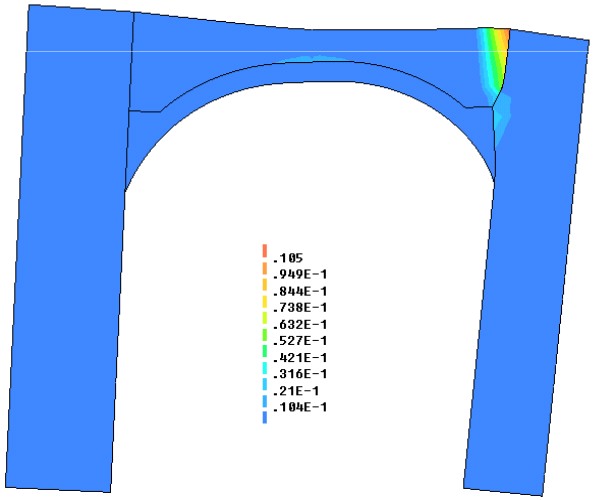
Minimal principal stresses

- The large horizontal displacements observed in the structure can only be explained by a geometrical and physical non-linear analysis
- The 3D model served also for validation of a simplified 2D model (only of the 2nd floor)
- The structure presents original conceptual deficiencies (insufficient buttressing in internal walls)

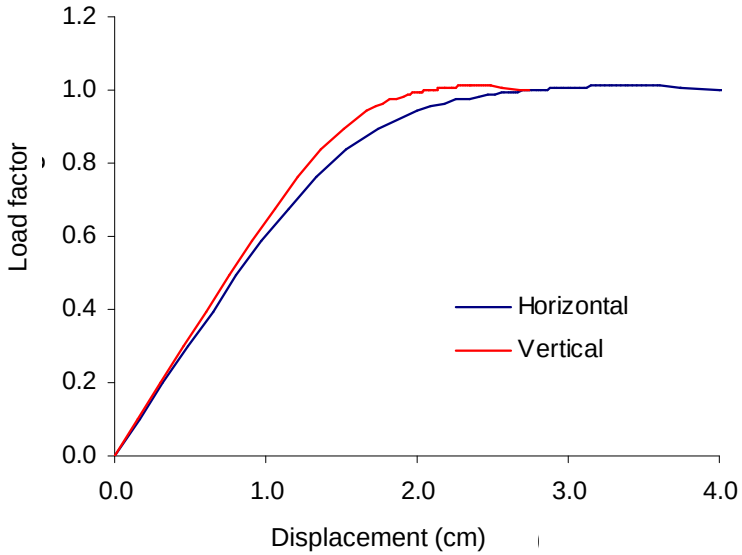
Non-linear analysis



Damage in the barrel vault



Damage in all the entire structure



Relation between the load factor and the displacements exhibited by the structure ("zero safety level")

- Foundations and long term behaviour of the structure are mostly responsible for observed damage
- Strengthening is needed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Execution details
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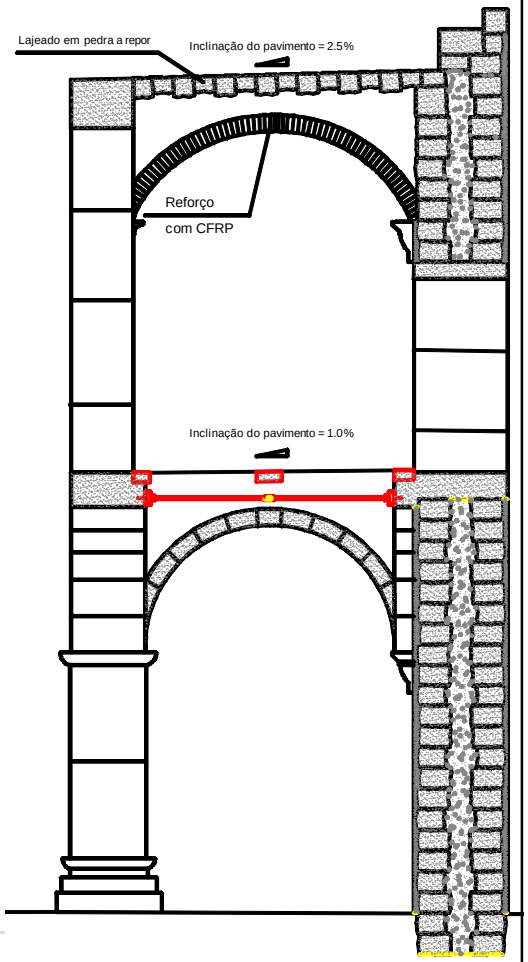
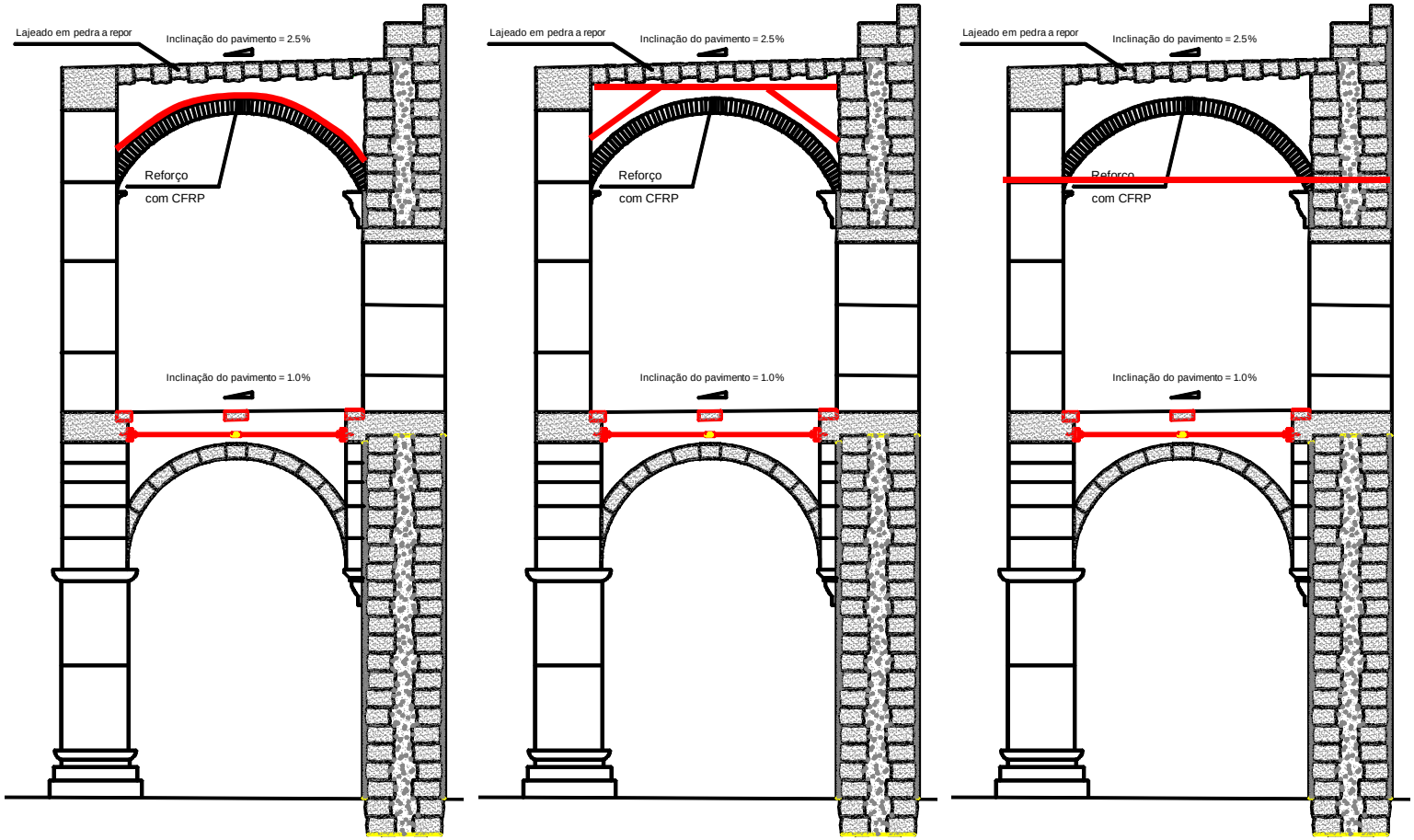
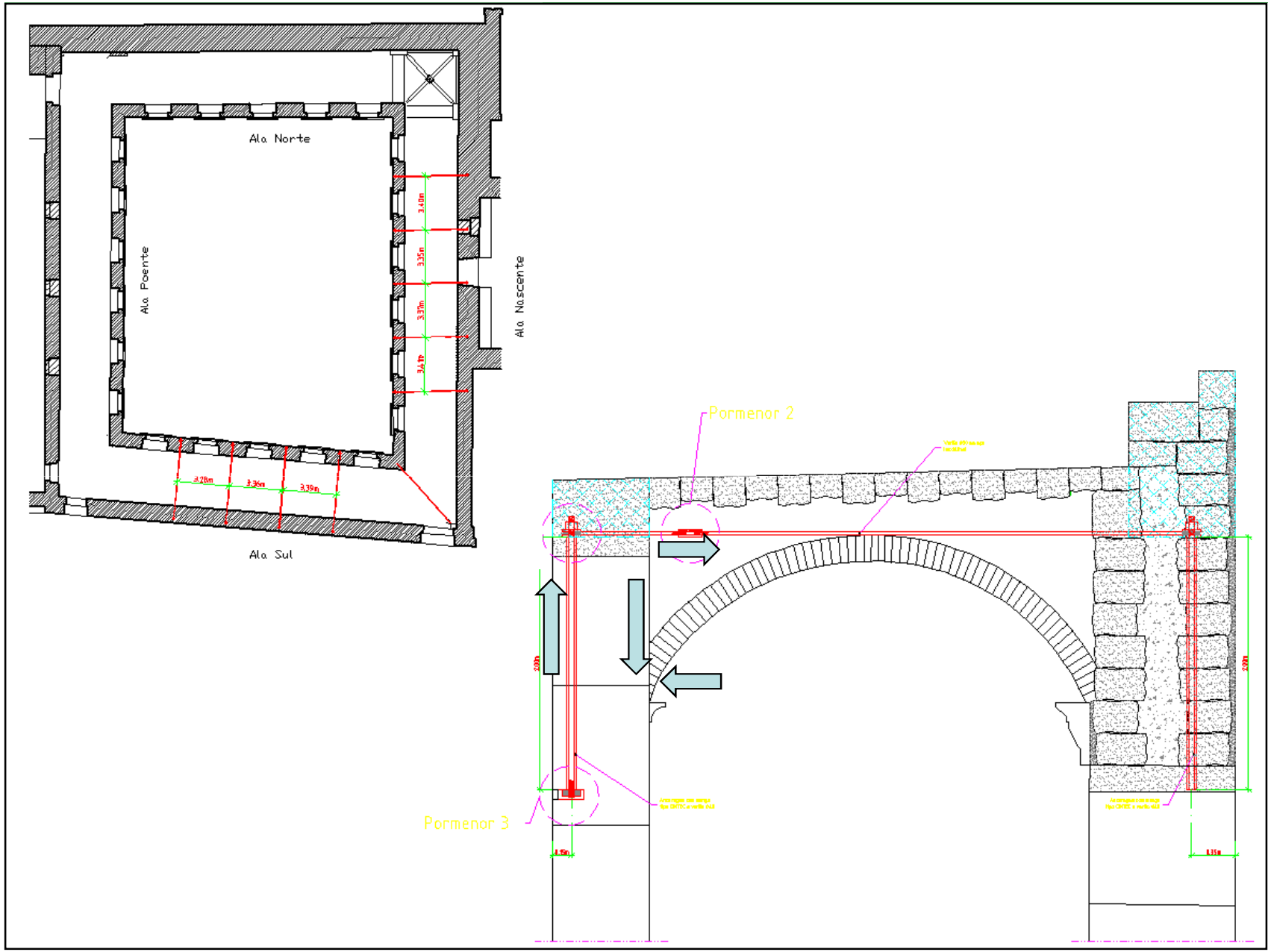
Remedial measures

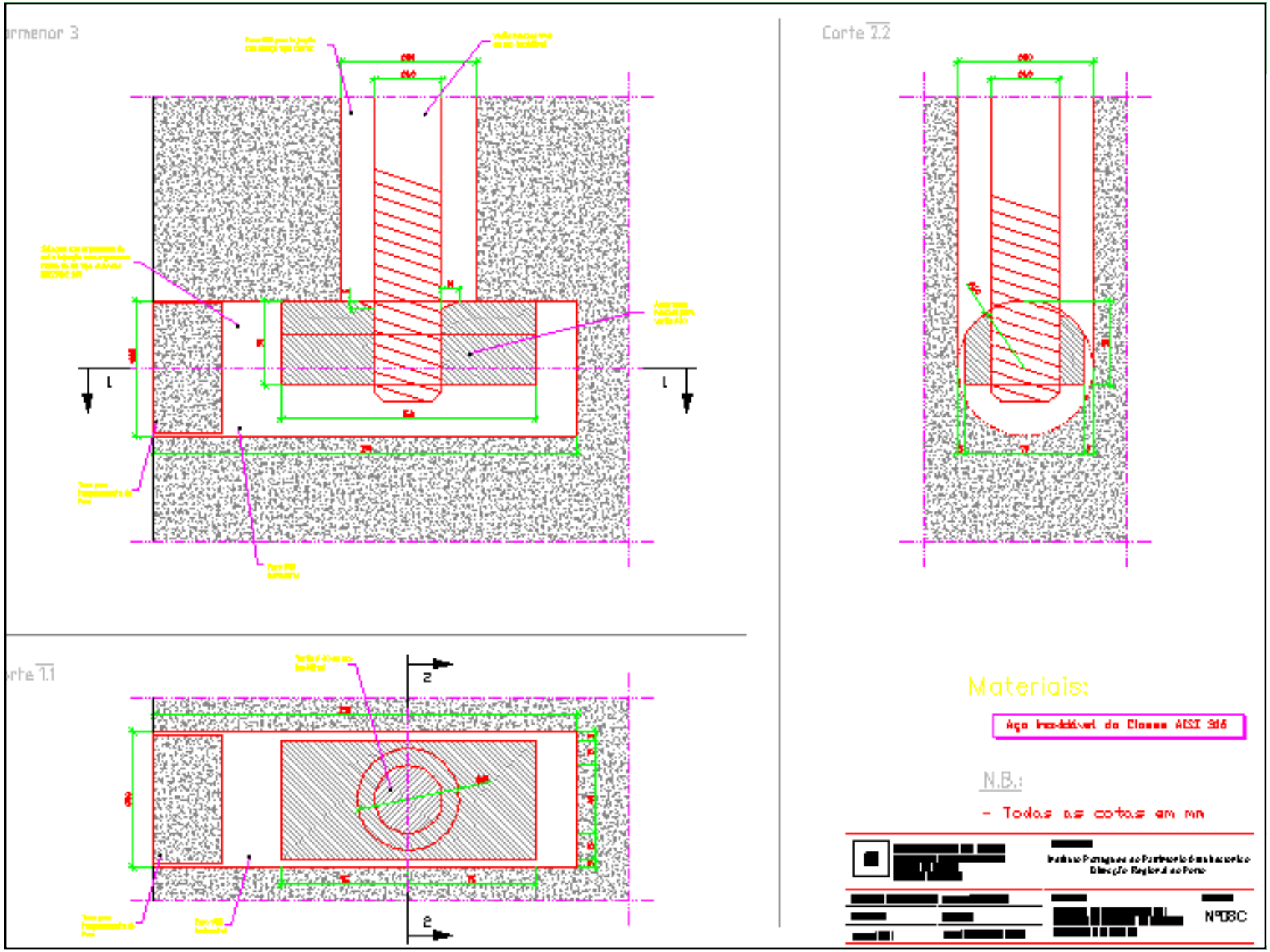
- Adjustable propping
- Partial removal of infill (2 wings in 2nd level)
- Partial removal of infill (2 wings in 1st level)
- Elevation of 2 wings (1 in each level). 10 cm
- Pulling of one corner. 12.5 cm
- Local protheses in stone brackets / ribs
- Repointing and injection of cracks and joints in vaults
- Stainless steel ties

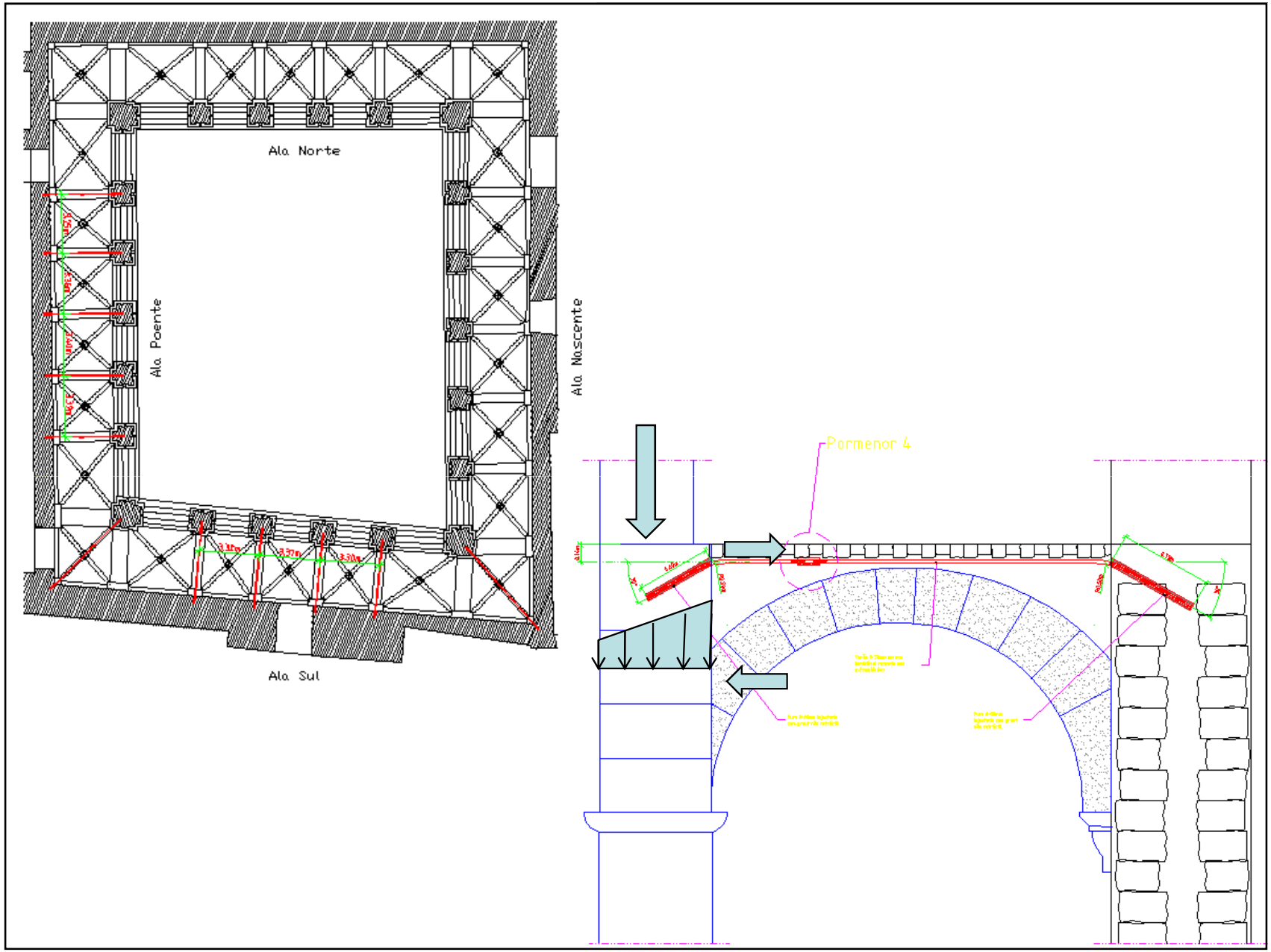
- Water tightening of 2nd level
- Repointing joints in the external walls
- Closing of openings




Lajeado em pedra a repor
Inclinação do pavimento = 2.5%
Reforço
com CFRP
Inclinação do pavimento = 1.0%
Lajeado em pedra a repor
Inclinação do pavimento = 2.5%
Reforço
com CFRP
Inclinação do pavimento = 1.0%
Lajeado em pedra a repor
Inclinação do pavimento = 2.5%
Reforço
com CFRP
Inclinação do pavimento = 1.0%


Ala Norte
Ala Poente
Ala Nascente
Ala Sul
Pormenor 2
Pormenor 3


Corte 2.2
Materiais:
Aço Inoxidável da Classe AISI 316
N.B.:
- Todas as cotas em mm


Ala Norte
Ala Poente
Ala Nascente
Ala Sul
Pormenor 4

Protection

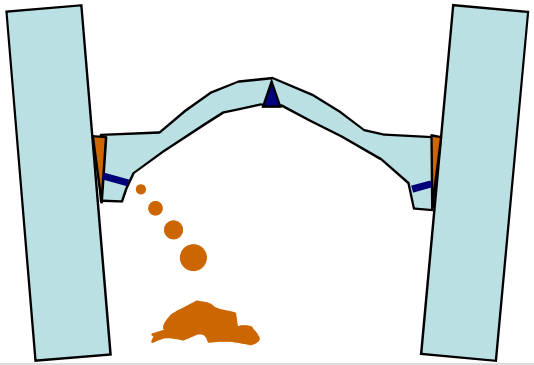
Protection

Propping

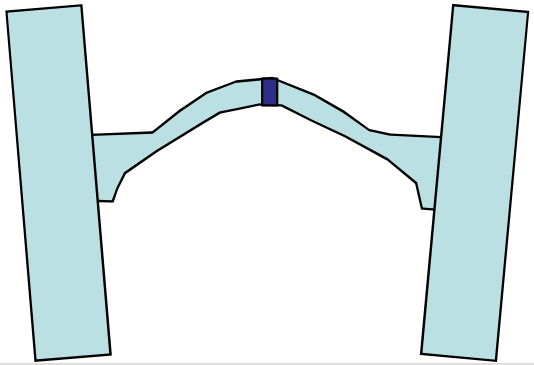
First inspection pits

Dismantling (I)….

Dismantling (II)….



Dismantling (II)….



Dismantling (III)….

Protection

Adjusting colors

Protection

Completed South wall

Before

After

Stainless steel AISI 316L

Drilling





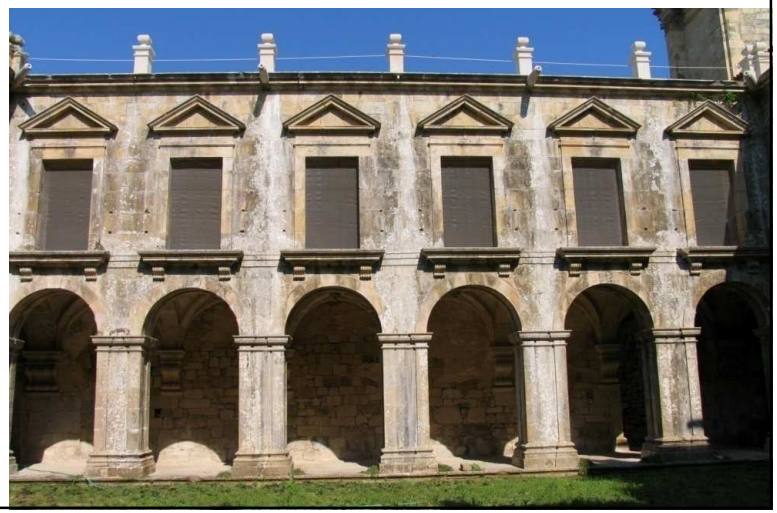

2nd Level

1st Level


2nd Level


Floor Level


1st Level



Information management system

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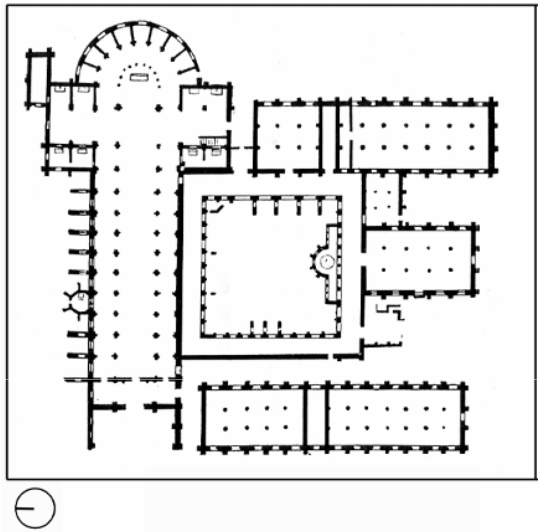
Why?

- Large amount of information generated by the different specialists, which is generally not handled adequately by owners and/or authorities.
- Valuable information is lost in a complex process of reaching a decision and information tends to get forgotten or misplaced in the course of time.

- Objective 1: Develop an application for the efficient management and visualization of the information for interventions of cultural heritage buildings.
- Objective 2: Promote “technical and scientific” culture and dissemination

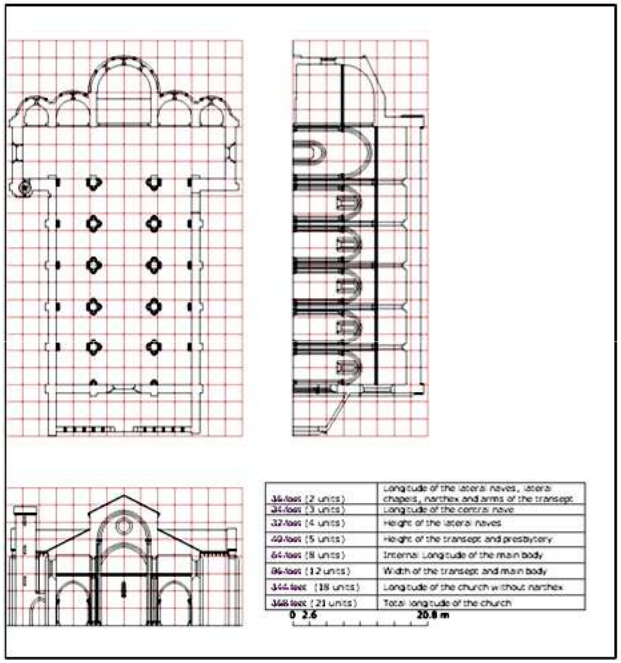
Virtual reconstruction



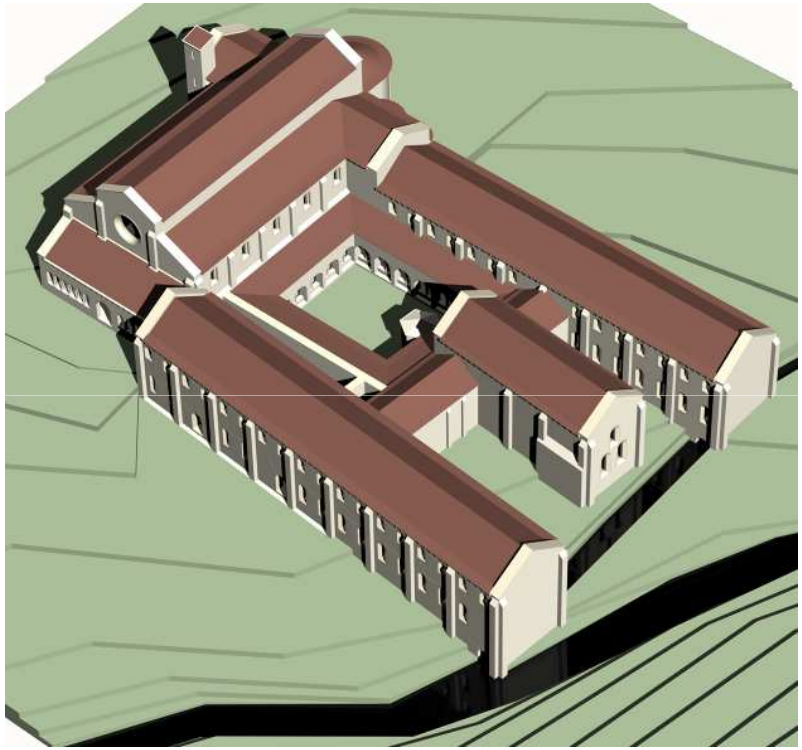
“Ideal plan” of Clairvaux, France

Medieval parts of the monastery

Virtual reconstruction (II)



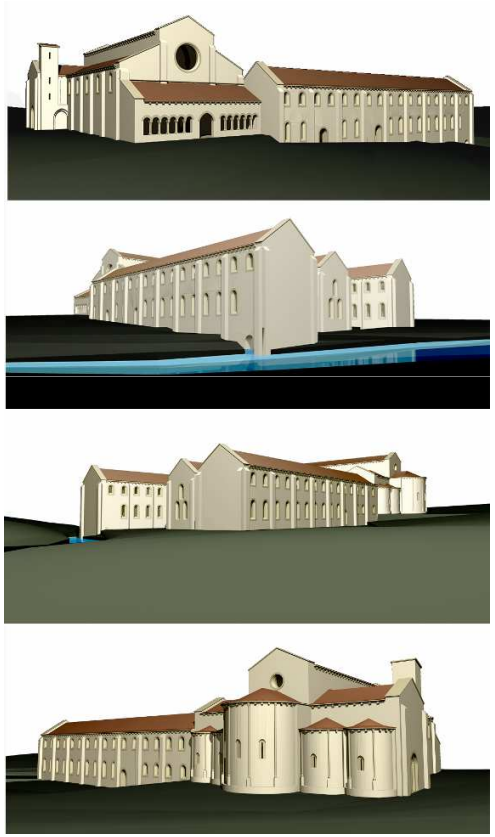
Reference model for church



General view

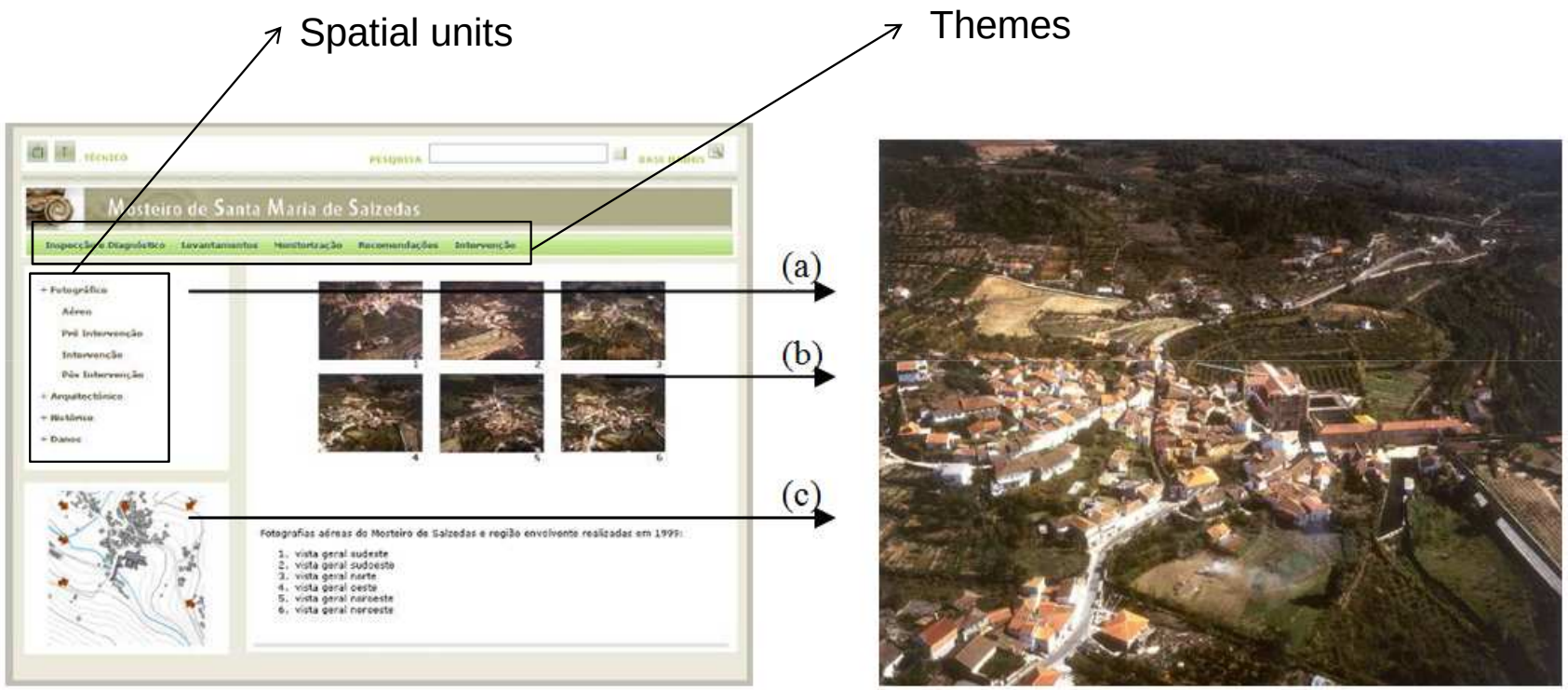
Virtual reconstruction (III)

External views



Internal views

Web-based application (I)



Database is browsed through: (a) menus; (b) photographs, 3D models, panoramic views; (c) hotspots.

Web-based application (II)

Panoramic views

Web-based application (III)

TITULO	LEGENDA	TIPO	FORMATO	LOCALIZAÇÃO	TEMA		
pagInt2_vista aerea	conteudo da pagina d	Fotografia	jpg	Global	Estado Actual	n/p	download
lev_fot_aer_vista ae	vista aerea do monte	Fotografia	jpg	Global	Levantamentos	n/p	download
lev_fot_aer_vista ae	Vista aerea do monte	Fotografia	jpg	Global	Levantamentos	n/p	download
lev_fot_aer_vista ae	Vista aerea do monte	Fotografia	jpg	Global	Levantamentos	n/p	download
lev_fot_aer_vista ae	Vista aerea do monte	Fotografia	jpg	Global	Levantamentos	n/p	download
lev_fot_aer_vista ae	Vista aerea do monte	Fotografia	jpg	Global	Levantamentos	n/p	download
lev_fot_aer_vista ae	Vista aerea do monte	Fotografia	jpg	Global	Levantamentos	n/p	download
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lev_fot_aer_Vista ae	Vista aerea oeste do	Fotografia	jpg	Global	Levantamentos	preview	download
Lev_Fot_PreInt_vista	Vista Parcial do Cir	Fotografia	jpg	Claustro Grande	Levantamentos	preview	download
Lev_Fot_PreInt_Vista	Vista Parcial da Fac	Fotografia	jpg	Claustro Grande	Levantamentos	n/p	download
lev_fot_posInt_vista	Vista oeste da nave	Fotografia	jpg	Igreja	Levantamentos	n/p	download
ClaustroQ_Vista2	n/I	Fotografia	jpg	Claustro Pequeno	Inspecção e Diagnóstico	n/p	download

Database is searched with pdf, doc, dwg and other files

Conclusions

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Conclusions

- A program involving inspection, diagnosis, safety assessment and remedial measures of a Cistercian cloister was presented.
- The cloister was in very bad structural conditions and the consolidation works aimed at stopping further degradation and at preventing collapse. With the objective of keeping the abandoned / ruined condition of the cloister, all works have been hidden, while ample information is available to document the intervention.
- These tasks are complemented by a virtual reconstruction of the medieval monastery and an information management tool, with the objective of providing simple technical information to the visitor and of managing the significant amount of expert documentation gathered in the process.

Monastery of Salzedas (Portugal): Intervention in the cloister

P.B. Lourenço

www.civil.uminho.pt/masonry

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