Case Study
Monastery of Jerónimos, Lisbon, Portugal

Paulo B. Lourenço
Universidade do Minho
Department of Civil Engineering
Guimarães, Portugal
Description

The crown asset of Portuguese heritage buildings
Construction from 1499
Built with limestone
Considerable dimensions in plan, more than $300 \times 50 \, \text{m}^2$, and an average height of 20 m (50 m in the towers)

Evolves around two courts. The larger court is bordered by a long arcade of two levels that hosts the Ethnographic Museum of Archaeology and the Maritime Museum. The smaller court or the Cloister is bordered by the Church, the Sacristy, the Chapter Room, the Refectory.
Local Seismicity

Gathered data
Church

Views

Cross-section
In situ investigation

Tiles removal for visual inspection

Radar inspection

Wallets for supporting tiles (20th century)

Ribs visual inspection
In situ geometrical survey

Longitudinal cross-section

Transept cross-section

Nave cross-sections

Plan of the nave
Tilting of the columns and GPR of the columns
Modal Identification of the Church
Mode I

Modal Values
- \( f = 3.685 \text{ Hz} \)
- \( z = 2.337 \% \)

Graphical Objects:
- Lines (Undeformed)
- Surfaces (Undeformed)
- Lines (Deformed)
- Surfaces (Deformed)

3D Display Settings:
- Rotation - Horizontal = 30°
- Rotation - Vertical = 30°
- Translation - Horizontal = 0
- Translation - Vertical = 0
- Zoom Level = 69%
- Amplitude = 87%
- Animation Speed = 100%
- Animation Angle = 165°
Mode II

Modal Values
- $f = 5.124$ Hz
- $z = 1.105\%$

Graphical Objects:
- Lines (Undeformed)
- Surfaces (Undeformed)
- Lines (Deformed)
- Surfaces (Deformed)

3D - Display Settings:
- Rotation - Horizontal = 30°
- Rotation - Vertical = 30°
- Translation - Horizontal = 0
- Translation - Vertical = 0
- Zoom Level = 69%
- Amplitude = 87%
- Animation Speed = 100%
- Animation Angle = 210°

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Static Monitoring System (I)

Measure deformations and temperature variations of two columns in the main nave

The system is focused on the columns structural observation, because they are the best measure of the nave structural behavior.
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Static Monitoring System (II)

North Tiltmeter
(Daily Moving Average)

North Tiltmeter vs Temperature

Date

Rotation [mm/m]

Temperature [ºC]

Rotation [mm/m]

Temperature [ºC]
Dynamic Monitoring System (I)

Accelerations measurements in two points: in the base and in the main nave

Due to the different technical characteristics and sampling rates data acquisitions, the dynamic monitoring system is physically separated from the static one.
Dynamic Monitoring System (II)

1st Frequency versus Temperature

[Graph showing frequency versus temperature with estimated model and 98% CI]

Confidence Intervals

[Graph showing frequency versus date with estimated model and 98% CI]

Date

Frequency [Hz]

Temperature [°C]

Feb-05  Apr-05  Jun-05  Aug-05  Oct-05  Dec-05  Feb-06  Apr-06  Jun-06  Aug-06  Oct-06  Dec-06  Feb-07  Apr-07

+ Estimated  Model  98% CI

Confidence Intervals
Full model with 135,000 dof

Modal superposition

Non-linear with equivalent static loading

Full Building Analysis

Deformed mesh

Load-displacement diagram
Nave Analysis

Non-linear Analysis:
Loading = Self-weight
\( f_t = 0 \)
\( f_{c, \text{masonry}} = 6 \, \text{N/mm}^2 \)
\( f_{c, \text{infill}} = 1 \, \text{N/mm}^2 \)
Transept Analysis

Load-displacement diagram

Incremental deformed mesh

Max. principal strains

Min. principal stresses
Laboratory Testing

Stone and masonry testing
Model for Dynamic Analysis

3D beam element model

Calibration of the model – Dynamic identification
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Results

Seismic action vs. horizontal displacement envelop for different nodes

Example of column response in dynamic analysis

Example of collapse mechanism
Vertical reaction in the columns

General view of the failure mechanism

Failure mode for the church

5000 yrp earthquake

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Virtual Collapse Mechanisms

Vertical loading

North façade

South façade
Possible Strengthening Measures

1: Pre-stress the columns
2: Load transfer
3: Increase column strength
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Paulo B. Lourenço
pbl@civil.uminho.pt
www.civil.uminho.pt/masonry