Structural analysis and evaluation of interventions for the protection of the Resurrection of Christ by Piero della Francesca mural painting at Sansepolcro[1]

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Keywords: *Resurrection of Christ—Piero della Francesca—Sansepolcro—Seismic hazard—FEM*

CHNT Reference: Ciuffreda, Anna Livia; Coli, Massimo, and Micheloni, Michelangelo. 2021. Structural analysis and evaluation of interventions for the protection of the Resurrection of Christ by Piero della Francesca mural painting at Sansepolcro. Börner, Wolfgang; Kral-Börner, Christina, and Rohland, Hendrik (eds.), Monumental Computations: Digital Archaeology of Large Urban and Underground Infrastructures. Proceedings of the 24th International Conference on Cultural Heritage and New Technologies, held in Vienna, Austria, November 2019. Heidelberg: Propylaeum.
doi: 10.11588/propylaeum.747.

Introduction

The Resurrection of Christ mural painting (Fig. 1) was realized by Piero della Francesca about 1460 on a brick wall (15 cm thick) placed in a different place as it is today. Shortly later, the painting was moved by means of a transport to solid-wall and placed against a pre-existing wall (60 cm thick), where it is today, erecting against this wall a counter wall (15 cm thick) where the mural painting wall-panel (225 × 200 cm) had been inserted. The existing wall is not jointed to the two main lateral walls. The most complete reconstruction of the historical events of the palace is written by C. Blasi (2004), reported here with the additions deriving from A. Cecchi (2012) and A. Borri (2015).

The building that was originally the Conservatori Palace and holds the mural painting, today is incorporated in the aggregate building of the Museo Civico di Sansepolcro. The building was built in the XIVth century as a large hall for public assemblies. In the XVth century the hall was divided into the two current smaller halls with the construction of wall in false. This wall had a fireplace and a chimney in the hall opposite the mural painting one. Below this wall the basement had been reinforced with an arch. In 1474 the original wooden ceiling was replaced with barrel vaults and lunettes and the fireplace was closed with a wall.

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Fig. 1. The Resurrection of Christ by Piero della Francesca in the Sansepolcro museum (courtesy by the Sansepolcro Municipality) and a view of the BIM model (© authors).

A little bit later, on the side opposite the fireplace, the Resurrection of Christ mural painting was placed by means of transport to solid-wall. For this purpose, against the pre-existing wall (60 cm thick) was erected a counter wall (15 cm thick) where the mural painting wall-panel (225 × 200 cm) had been inserted.

The building currently consists of three levels with a rectangular plan (44 × 9 m) and height of about 14 m. A central wall divides the volume into two almost symmetrical parts of about 22 × 9 m. The basement floor overlooks Fiorenzuola street at the south and is buried on the north side. The two halls are located on the first floor. In the attic floor the extrados of the vaults of the two lower halls are visible and the floor built in 1939 on the vault of the hall with the mural painting. The ground floor is covered by cross vaults in bricks (two heads); brick barrel vaults (a head) cover the second floor. The rebuilt vaults in the hall of the mural painting are hung on a floor with tables on metal beams, except for the part near the building's façade. The current roof was built in 1967 with trusses formed by "Varese" joists in prefabricated reinforced concrete and steel chains; replacement of the filling of the vaults with lightened clay and insertion of chains after the earthquake in Umbria in 1997. In 2017, a consolidation of the structures was carried out by positioning structural reinforcements above the vaults or on the floor of the attic.

The Sansepolcro area presents a strong historical seismicity (six earthquakes > VII MCS in the last 1000 years), which caused several damages to buildings. Moreover, in WWII the Nazi retiring blasted some edifices causing local vertical rebound up to 1g. In the last years, the Sansepolcro Municipality supported a series of studies regarding the structural behaviour of the hall where the Resurrection of Christ is, in order to safeguard it from seismic hazard. These studies are also preparatory for the intervention of restoration of the mural painting executed in the years 2016–2018 by the Opificio delle Pietre Dure.

Cognitive framework

To achieve the objectives of the research the Department of Earth Sciences has carried out the surveys, in line with the MIBACT 2011 Guidelines (point 4.1.6) and in full cooperation with the Museum Opificio delle Pietre Dure and local Superintendence. The surveys conducted concerned the type and characteristics of the walls that make up the museum hall and the wall where the wall painting is placed. The history of the building and its current assembly was studied, the fissure crack network mapped, and a series of non-destructive tests (NDT) were performed: GPR, sonic and ultrasonic, DAC-Tests, microendoscopy and thermal. The dynamic behaviour of the hall has been defined through a FEM analysis and has been correlated with the results of the 5-year work monitoring system.

The cognitive studies allowed defining the masonries structures: that of the hall, 110 cm thick, was erected in mortared sandstone slabs, that of the intermediate wall (60 cm thick) supporting the mural painting wall panel in mortared stone cobbles and bricks; these two masonries are not well linked one to the other. The counter wall (15 cm thick) within which the mural panel is inserted, is in mortared bricks and small sandstone cobbles.

The use of the Abacus provided by the Tuscan Region (SSRT 2003) and the Circular 617/2009 ex NTC2008/2018 Ministry Infrastructure and Transport allowed us to attribute the reference values of the physical-mechanical properties of these historical masonries (Table 1).

Masonry type	f_m	τ_m	**E**	**G**	**w**
	N/cm^2	N/cm^2	N/mm^2	N/mm^2	kN/m^3
Masonry in stone cobble and slabs irregularly placed	150	2.5	800	300	19

Table 1. Physical-mechanical properties of the studied masonries.

Structural analysis and an intervention proposal

The target of our structural analysis was to identify the first proper movements that can affect the Resurrection of Christ wall panel in the event of an earthquake. For achieving this goal, a linear elastic analysis was carried out.

The target of our analysis were the first small movements that can damage the mural painting and we are not interested in the further development of the crack pattern. Therefore, it is correct to develop a linear elastic dynamic analysis.

The analysis had been developed onto a 3D FEM of the building in an elastic and isotropic continuum using the software SAP2000 (®Computers and Structures, Inc.). For correctly simulating the package of the wall supporting the mural painting wall-panel, the intermediate wall had been modelled by using “shell” and “layered” elements.

The first movement has oscillatory main modal forms of the whole building along the short sides; for the intermediate wall supporting the mural painting wall-panel the movement results oscillatory in the plane of the wall (Fig. 2).

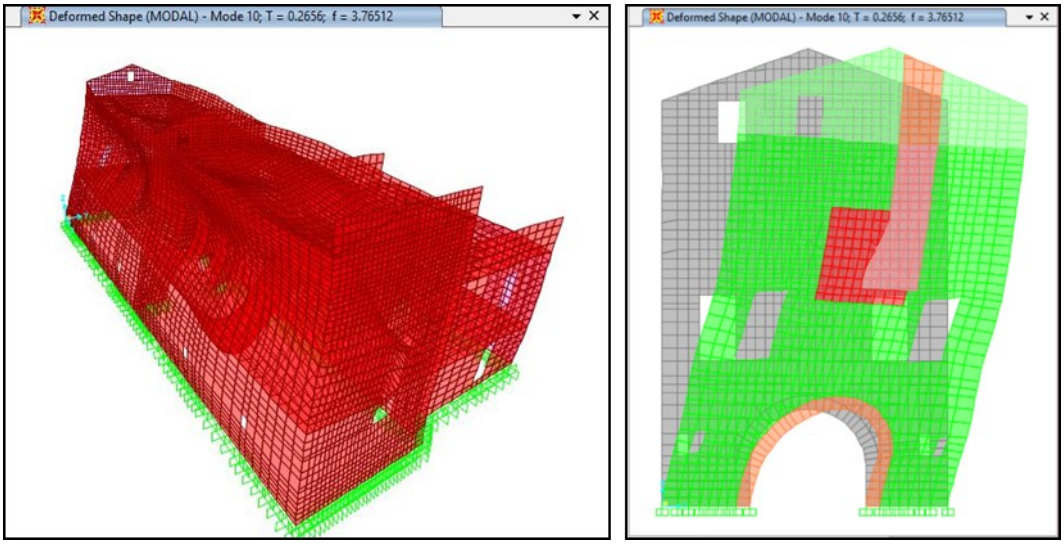

Fig. 2. First modal form for the whole structure and for the intermediate wall with the wall panel (© authors).

The FEM simulation fully describes the first movements in the event of a remote earthquake, which will be in the order of 0.01 mm, 0.2 mm and oscillatory in the plane of the intermediate wall containing the wall-panel. These movements and their entity is fully compatible with the fissure pattern and the five-year monitoring results.

This dynamic behaviour, the soft connections and cracking patterns can explain why the Piero della Francesca's Resurrection of Christ mural painting remained unharmed, despite the numerous seismic events that occurred in the area in the past centuries.

The position of the Resurrection appears optimal, placed in the portion of structure less stressed in the event of an earthquake. However, we can consider a minimal intervention that involves the arrangement of supports aimed at retaining the painting without hindering the current structural behavior. In this way the possibility of a tilting of the painting panel out of the plane of the masonry is avoided that contains.

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