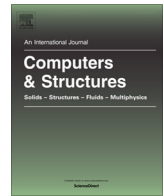




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# Simplified and refined methods for seismic vulnerability assessment and retrofitting of an Italian cultural heritage masonry building

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## ARTICLE INFO

### Article history:

Accepted 18 July 2016

Available online xxxx

### Keywords:

Emilia-Romagna earthquake

Cultural heritage building

Usability check

Seismic vulnerability

Italian Guidelines on Cultural Heritage

Repairing interventions

## ABSTRACT

In the paper the usability check and the seismic vulnerability appraisal and repairing of a masonry building with cultural and artistic value located in the Municipality of Cento (Ferrara, Italy) after the last Italian seismic events (Emilia-Romagna, 2012 May 20th and 29th), are reported and discussed.

After some indications on the mentioned earthquakes are given, the case study has been presented and useful information on both historical news and geometrical properties have been given. So, the usability check of examined building has been done through the identification of damages occurred under earthquake.

Later on, seismic vulnerability assessment of the building on the basis of both the simplified LV1 and the refined LV3 analysis levels given by Italian Guidelines on Cultural Heritage has been performed. The analysis results, compared each other in terms of seismic safety factors, have shown that building has an average vulnerability degree, so to require local repairing and strengthening interventions, which have been herein presented. Finally, the effectiveness of the proposed local interventions has been proved by numerical analysis in the non-linear field.

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## 1. The 2012 Emilia-Romagna earthquake

In May 2012, two major earthquakes occurred in the Emilia-Romagna Italian region.

The first earthquake, having magnitude 5.9, happened on 2012 May 20th at 04:03 local time with epicentre between Finale Emilia and San Felice sul Panaro. Two aftershocks of magnitude 5.2 followed and seven people were killed. The second earthquake occurred on 2012 May 29th at 9:00 with a magnitude of 5.8 and produced twenty deaths and wide damages, particularly to buildings already weakened by the first seismic event. The epicentre was in Medolla at a depth of about 10 km from the ground, where the fault rupture was observed.

However, a very huge seismic sequence happened, especially within the districts of Ferrara and Modena, before and after the aforementioned earthquakes [1].

Immediately after these earthquakes, usability checks on public and private buildings, made of masonry, steel and r.c. (casted and prefabricated) structures, were quickly performed by members of the Italian DPC-ReLUI research project, analogously to the activity

carried out in L'Aquila and its neighbourhoods [2–4]. The aim of this activity was to know both the conditions of constructions and damages they suffered in order to evaluate if they were able to withstand or not a further earthquake with the same features of the occurred one. Results of this activity are reported in detail into specific papers and reports [5–18] investigating the behaviour of masonry buildings, that can be either isolated or clustered, the latter representing the largest part of Italian and some European historical centres, which the attention of different researchers is focused on [19–24].

In the current paper, which is an updated version of [25], the usability check and the related seismic vulnerability assessment and repairing, according to the Italian Guidelines on Cultural Heritage's analysis levels, of a cultural heritage building located in Cento, a city in the district of Ferrara, is illustrated in detail.

## 2. The case study

### 2.1. Historical news and geometrical features

The case study is an isolated masonry palace with an internal oratory located in Cento, a city in the district of Ferrara, one km far from its historical centre.

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According to the sure first news about the building, it was erected around 1578, year when the pastoral visit of the Cardinal Paleotti was performed. The confraternity of St. Bartolomeo kept there the relics of St. Zenone up to 1587. During XVIII century the building was subjected to different property transfers, whereas in XIX century it became a subsidiary building of the church of St. Maria of Penzale.

Nowadays the building, which had in the past the role of public oratory, has a configuration similar to the 1760 dated one, when it was radically transformed from its original layout.

The oratory is included into a larger construction, having irregular L-shaped plan scheme with area of about 450 m<sup>2</sup>, and developing on two levels with average height of 3 m, which delimitate the same oratory on three sides (Fig. 1). Initially, the building, composed of two heads brick walls and covered by a timber pitched roof, hosted a religious school, which underwent some internal modification in 1960, while, at the moment, it is used for residential purpose. Some external views of the building are reported in Fig. 2.

The main facade is divided into three parts by columns: in the central zone there are a door and a window, both of them framed by a stucco configuration, whereas the lateral zones, with lower height, are connected to the central part by means of two spirals (Fig. 3a). The facade is completed in the upper part by a cornice surmounted by a tympanum with segmental arches; on the roof a small bell tower is located.

The oratory has a rectangular plan covered by a barrel vault in the entrance, a vault in the central zone and a hemispherical dome with square layout in the presbytery. The central zone is characterised by four Corinthian columns which sustain a wide frame bracket.

Lateral walls are decorated with 18th century paintings attributed to Stefano Ficatelli (Fig. 3b), whereas the altar is adorned with the representations of Santa Liberata and San Rocco (Fig. 3c), made by an unknown author of the same century previously mentioned.

Actually the building complex, thanks to its significant historical-artistic features, is covered by the bond of the Superintendence of Cultural Heritage of the province of Ferrara, which consider it as a particularly interesting construction according to the Italian Law n. 1089 promulgated on 1939 June 1st [26].

## 2.2. Earthquake damages and usability check

The Emilia-Romagna seismic events were characterised by both horizontal waves, which produced rotation and translation of the building due to its irregular plan shape, and vertical waves, which affected flexible timber floors and masonry piers and spandrels.

The seismic wave movements led to:

- (1) Detachment of plaster between walls and floors due to the poor connection degree between timber beams and masonry walls (Fig. 4a);
- (2) Detachment of plaster among orthogonal walls, caused by the reduced degree of junction between the walls themselves (Fig. 4b);
- (3) Cracks in the floor ceilings (Fig. 4c);
- (4) Cracks in vaults and arches (Fig. 5a);
- (5) Lesions in the church walls caused by their overturning mechanism (Fig. 5a);
- (6) Diagonal cracks into masonry walls (Fig. 5b);
- (7) Lesions in masonry piers above openings due to lack of effective lintels (Fig. 6a);
- (8) Vertical cracks on walls due to the load transferred by timber beams to the same walls (Fig. 6b);
- (9) Collapse of ceilings caused by excessive deformation of timber beams which, consequently, lost their support (Fig. 6c).

The usability check performed by the first Author on the inspected building after the earthquake has indicated that the major damages occurred in the oratory, where the initial

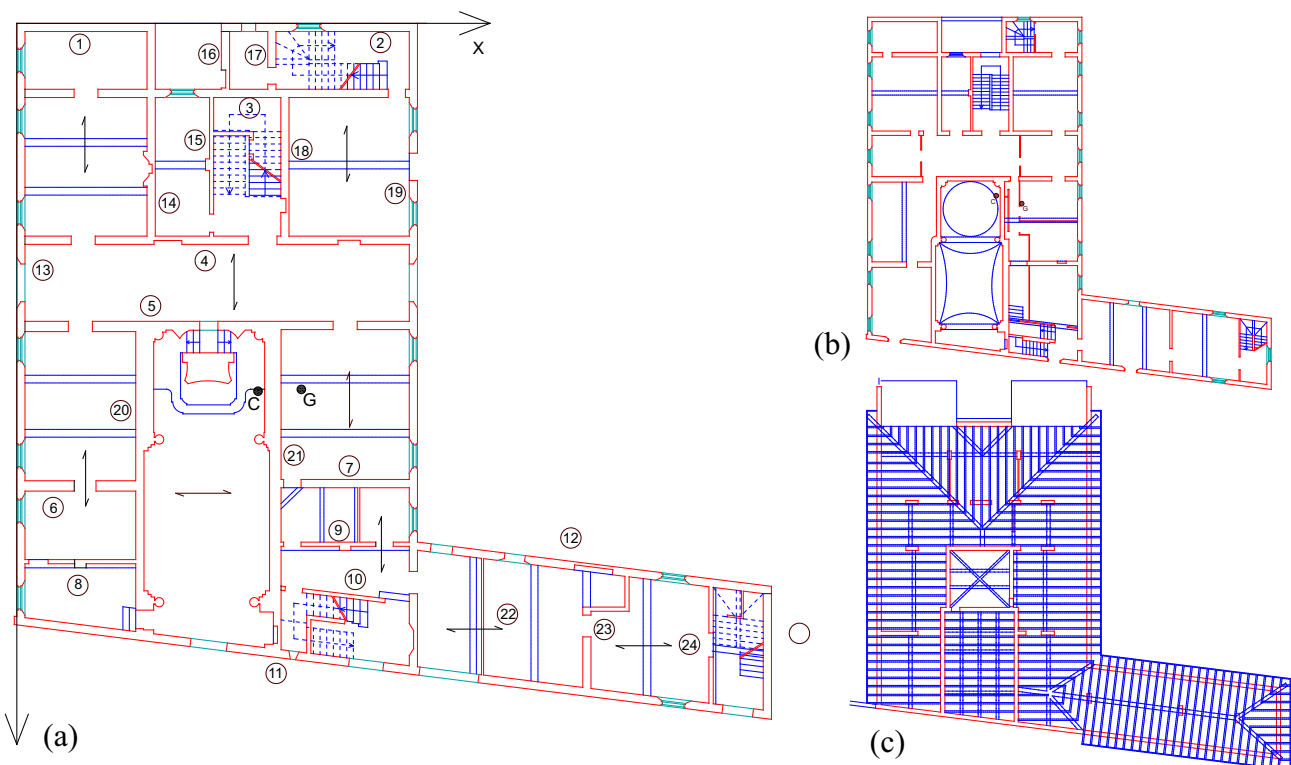


Fig. 1. Ground (a), first (b) and roof (c) floors of the investigated masonry building.

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