Journal of Building Engineering 18 (2018) 245–251

Contents lists available at ScienceDirect

Journal of Building Engineering

journal homepage: www.elsevier.com/locate/jobe

Collapse investigation of the Arquata del Tronto medieval fortress after the 2016 Central Italy seismic sequence

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ARTICLE INFO

Keywords:
Historic masonry buildings
Seismic damage
2016 Central Italy earthquake
Fortified structures
FE seismic analysis

ABSTRACT

In this paper, an investigation is presented of the Arquata del Tronto medieval fortress local collapses that occurred due to the 2016 Central Italy seismic sequence. Both historical evolution and damage inspection of the fortress are discussed. Interestingly, the damage reported to the fortress after the 2016 earthquakes appears similar to what occurred more than 300 years before (due to the 1703 Apennine earthquakes), despite the restoration work of the 1920s. Linear kinematic analysis and 3D modal and seismic FE analyses are carried out to evaluate the safety of the local collapse mechanisms that occurred on the towers' crownings. Numerical findings point out that no failure mode passes the safety check. This suggests that the reconstruction of the collapsed parts should be complemented by specific strengthening devices.

1. Introduction

The 2016 Central Italy seismic sequence caused the death of 299 people. In addition to the loss of human life, widespread destruction of cultural heritage has been also reported. This is a common peculiarity of the last Italian earthquakes (e.g. 2012 Emilia earthquake, 2009 L'Aquila earthquake), due to the high density of monuments in the national territory and the high seismic vulnerability of historic buildings. This latter feature indicates that to guarantee the conservation of these buildings it is necessary to deeply study their seismic behavior aiming at investigating their structural weaknesses and designing potential safeguard interventions.

Due to the huge complexity of these buildings (in terms of geometry, historical evolution, mechanical characterization, etc.), numerical tools, such as the finite element method, have been widely used as support for seismic investigations. Several studies of FE seismic analysis of historic masonry buildings [1–5], domes [6,7], bridges [8] and towers [9–11] were investigated by researchers. In addition, other interesting analysis approaches have been proposed for masonry towers in [12]. Moreover, in the last years more attention has been focused on the seismic behavior of fortified structures, especially after the 2012 Emilia earthquake [13–17]. In particular, in [18,19] an abacus of recurring seismic damage mechanisms in medieval fortresses has been proposed and discussed.

The cited papers highlight the reliability of advanced numerical tools in estimating the seismic behavior of monumental buildings, so encouraging their use as support for restoring interventions.

In this paper, an investigation is presented of the Arquata del Tronto medieval fortress local collapses that occurred due to the 2016 Central Italy seismic sequence. Such a fortress is the symbol of the town, unfortunately almost-totally destroyed, and it characterizes the panorama of the Tronto's valley. Both historical evolution and damage inspection of the fortress are discussed. Interestingly, the damage reported to the fortress after the 2016 earthquakes, and in particular by the crowning of the main tower, appears similar to what occurred more than 300 years before (due to the 1703 Apennine earthquakes), despite the restoration work of the 1920s. Linear kinematic analysis and 3D modal and seismic FE analyses are carried out to evaluate the safety of the local collapse mechanisms that occurred on the towers' crownings.

2. Arquata del Tronto medieval fortress

The fortress under study (Fig. 1) is located on a cliff near the Arquata del Tronto town center, in the Marche region, Italy. It is constituted by the curtain walls equipped with chemin de ronde, a main tower 24 m tall in the North side (N tower) with a squared plan (8 m side), a hexagonal tower 12 m tall in the South-East side (SE tower) and the few rests of a third tower in the South-West side. The fortress, which is a typical example of Umbrian-Marchean Apennines fortified architecture of the XIII century, is mainly made by calcareous stone masonry

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https://doi.org/10.1016/j.jobe.2018.03.021
Received 22 January 2018; Received in revised form 26 March 2018; Accepted 26 March 2018
Available online 27 March 2018

Fig. 1. Historical pictures of the fortress: at the end of XIX Century (a); during the Sacconi restoration work in 1921 (b). Schematic plan of the fortress (c). Recent pictures before the 2016 seismic sequence: global view (d); North tower top (e); North tower inner stairs (f); South-East tower(g)-(h).

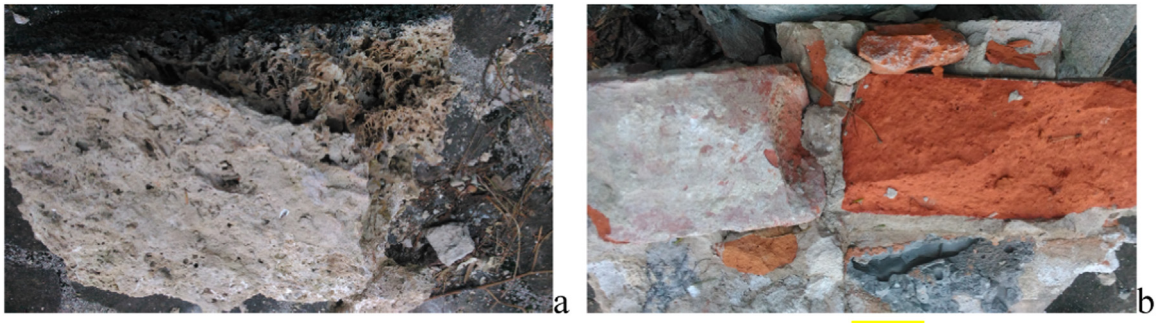

Fig. 2. In situ materials: calcareous stone masonry (a) and clay-brick masonry (b).

(Fig. 2a). The fortress was in a strategical position, located on the border between the Ascoli and Norcia's administrations, place of many battles.

The historical evolution of the structure is deeply complex. The first documented restoration date back to 1564 by the Norcia's municipality. The 1703 Apennine earthquakes caused serious damages and cracks to the structure [20]. The condition of the fortress at the end of the XIX century is depicted in Fig. 1(a). During the 1920s it was restored by Giuseppe Sacconi [20], see Fig. 1(b), with the reconstruction of the towers' crownings with clay-brick masonry (Fig. 2b). The last restoring