Comparative seismic evaluation of numerical analysis and Italian Guidelines on Cultural Heritage forecast applied to the case study of a masonry building compound

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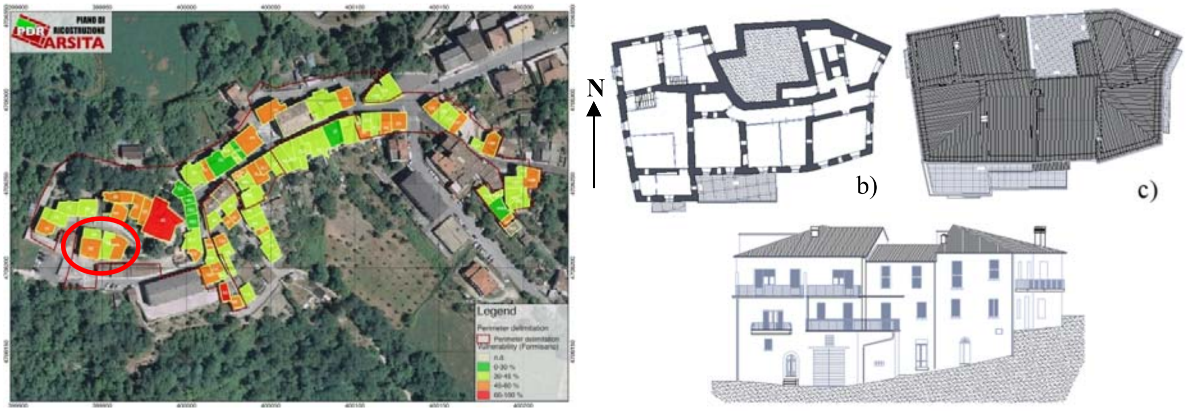
Abstract. The general objective of the work is to draw attention to the issue of seismic vulnerability analysis of masonry building compounds, which characterise most of the Italian historic towns. The study is, in particular, based on the analysis of an aggregated construction falling in the town of Arsita (Teramo, Italy) damaged after the 2009 L'Aquila earthquake. A comparison between the seismic verifications carried out by using the 3Muri commercial software and those deriving from the application of the Italian Guidelines on Cultural Heritage has been performed. The comparison has shown that Guidelines provide results on the safe side in predicting the seismic behaviour of the building compound under study. Further analyses should be performed aiming at suggesting some modifications of the simplified calculation method to better interpret the behaviour of building compounds under earthquake.

THE HISTORICAL CENTRE OF ARSITA

Arsita is an Italian town in the province of Teramo (Abruzzo region of Italy) composed of 829 inhabitants. It is located about 470 m above sea level in the valley of the Fino river, near the Gran Sasso mountain. The town was damaged by the 2009 L'Aquila earthquake (1, 2) and the consequent reconstruction plan was entrusted to the University of Naples "Federico II", the ENEA research centre of Bologna, the University of Chieti-Pescara "Gabriele D'Annunzio" and the University of Ferrara. All information used for implementing the reconstruction plan were obtained from in-situ survey of the historical centre, which were stored on a dedicated website (3). The 17 aggregates and the 91 structural units forming the historic centre of Arsita are shown in Figure 1a. The urban-scale seismic assessment of the buildings health has been carried out by means of an *ad hoc* speedy methodology for building aggregates (4, 5) which has shown the results depicted in Figure 1a, where building vulnerability indices are framed within four vulnerability classes (0-30%; 30-45%; 45-60%; 60-100%). In particular, just over 9% of the buildings falls under the vulnerability range [0 -30%], whereas 2 % represents the percentage of structural units belonging to the highest vulnerability range [60-100%]. Therefore, an average-high vulnerability level of the inspected centre has been noticed, since about 52% of the buildings falls within the range [30-45%], while about 37% of the buildings belongs to the vulnerability range [45-60%].



(a) (d)

FIGURE 1. Vulnerability map of the Arsita historical centre (a) and first floor (b), roof floor (c) and south view (d) of the examined building aggregate (circled in Fig. 1a).

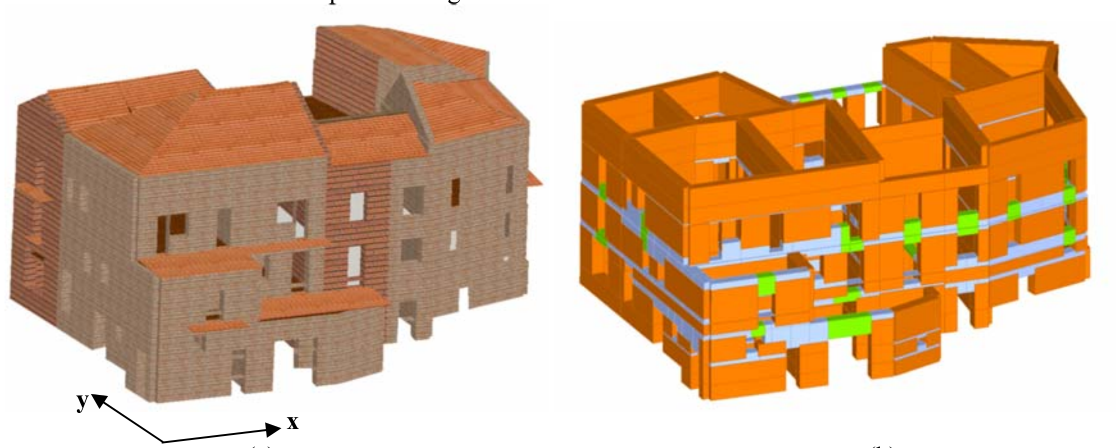
THE BUILDING COMPOUND UNDER STUDY

The examined aggregate, called "The Tower" and identified with the label n. 8, is located southwest of the historical center of Arsita along Mazzini 7 street. It was erected earlier than 1919 and it is characterised by a discrete architectural value. The building has both residential and productive uses. It has been divided into 4 structural units (see Fig. 1a). The identification of the geometrical characteristics of the aggregate is fundamental for understanding its seismic behaviour. For this reason, the in-situ survey of the study building compound has been done, as it is visible in Figures 1,where some plan layouts (Figures 1b and 1c) and the main view (Figure 1d) of the aggregate are depicted. From these pictures it is apparent that, about the morphology, the aggregate is rather regular in plan, while the major discontinuities are detected in elevation, with the presence of staggered floors and floors at different heights due to the placement of the building compound on a steep slope.

SEISMIC ASSESSMENT ANALYSES

Numerical and theoretical analyses have been carried out on the basis of the geometrical survey of the aggregate and by taking into account the mechanical properties of the rubble masonry derived from the current Italian code, considering a limit knowledge (LC1 level) of the building.

Firstly, seismic pushover analyses on the building aggregates have been performed with the 3MURI software, whose macro-elements model is depicted in Figure 2.



(a) (b)

FIGURE 2. 3D Modelling (a) and macro-elements structural model (b) of the inspected building aggregate.

The performed analyses have shown that the most vulnerable direction of the aggregate is the longest one (x). In fact, the collapse of the last storey occurred due to both shear failure and bending plastic engagement and failure of masonry piers (Fig. 3). Moreover, in Figure 4 the seismic responses of the building aggregate deriving from the 24 analyses (12 green curves with loads proportional to masses and other 12 pink and violet curves with loads proportional to the first vibration mode of the construction) performed with 3MURI are reported through two separate pictures related to the building seismic behaviour in directions *x* and *y*. From these pictures it is apparent that the building aggregate, due to the higher masonry wall areas, offers greater strength and stiffness in direction *y*.

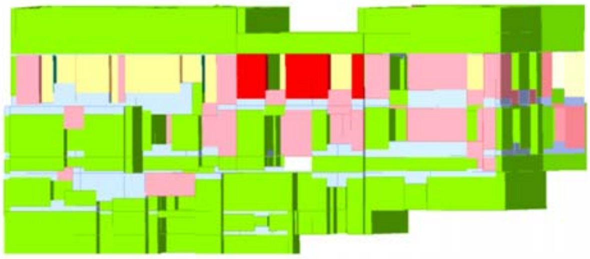
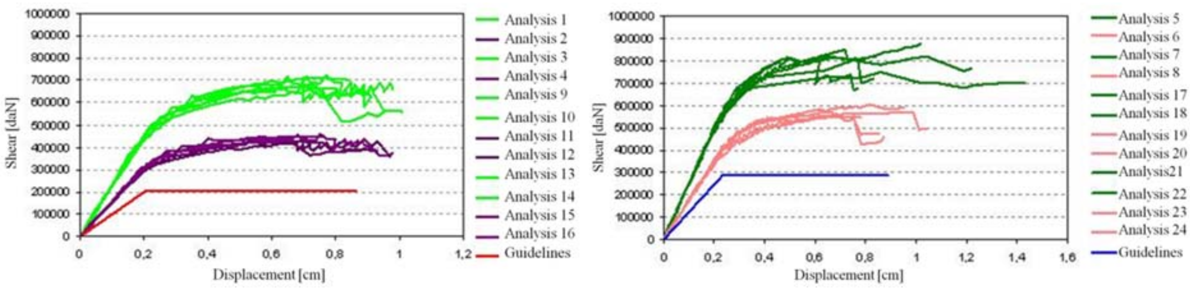


FIGURE 3. Damaging state of the south view main wall on the after earthquake (red: bending failure – pink: bending plastic behaviour - yellow: shear failure – green: no damage).



(a) (b)

FIGURE 4. Comparison among pushover curves in directions *x* (a) and *y* (b).

Secondly, the Italian Guidelines on Cultural Heritage (6) have been applied to the case study. Based on the principle of "minimal intervention", rightly directed to the preservation of heritage, the application of these guidelines requires a numerical evaluation of the building seismic capacity with precise models which, in the case of complex historic buildings and modelling difficulties, are rather problematic to be applied. For these reasons, the attention has been herein focused on the "simplified mechanical models" (LV1 approach) proposed for palaces and villas, without any particular construction type, which exhibit in-plane failure of their walls. With this analysis level it is possible to estimate the building seismic safety through an acceleration factor $f_{a,SLV} = a_{SLV}/a_{g,SLV}$, defined by the ratio between the ground acceleration which leads to the achievement of the Life Safety Limit State (SLV) and that corresponding to the reference return period (PGA). In practical terms, a_{SLV} represents the minimum acceleration value attained, for each direction, at the weakest storey. Therefore, this acceleration factor considers only one of the parameters that define the building seismic capacity, but has the advantage of providing a quantitative indication of its deficit in terms of resistance. Nevertheless, also by using the Italian ReLUIS guidelines (7) for evaluating the yielding and ultimate displacements of the examined construction, simplified pushover cures have been plotted for each analysis direction (Fig. 4). As a consequence, these simplified curves based on Cultural heritage and ReLUIS guidelines can be put in comparison with those provided by the 3MURI analysis program in order to provide a critical judgment of the building responses detected with the former analysis method and, consequently, to highlight the problems and limitations of this simplified approach, as already done in previous researches (8, 9, 10).

For comparison purpose, first of all it is assumed that the reference curves are those deriving from loads proportional to the first vibration modes (pink curves and violet ones in Figures 4a and 4b, respectively, for directions *x* and *y*), since Guidelines use this analysis approach.

From a qualitative review of curves it appears that, in both analysis directions, the Guidelines curves are on the safe side in predicting the building seismic response.

More in detail, if a quantitative examination of the curves offered by the two analysis approaches is made, it is detected that the shear strengths attained by Guidelines are about one-half of those achieved with the 3MURI software. Moreover, in terms of stiffness, the Guidelines underestimate of about 2/3 the curve elastic part inclination provided by the 3MURI software. On the other hand, ultimate displacements achieved with Guidelines seem to be very close to that obtained with the calculation software.

Finally, the Guidelines provide conservative values of the building strength and stiffness useful for an approximate understanding of its structural behaviour under earthquakes and they can be used for rough seismic checks only. However, if further comparisons on other structural types will be made, appropriate correction coefficients could be defined in order to improve the simplified estimate proposed by the Guidelines LV1 analysis approach to better foresee the building seismic response with simple calculations.

CONCLUSIONS

In the paper the comparison between the 3MURI macro-seismic analysis and the LV1 calculation method proposed by the Italian Guidelines on Cultural Heritage in foreseeing the seismic behaviour of masonry building compounds has been proposed and illustrated. The comparison, applied to the case study of a building aggregate within the historical centre of Arsita (district of Teramo), has shown that Guidelines provide results on the safe side in predicting its seismic behaviour. In particular, the ultimate shear strength and the elastic stiffness attained by Guidelines are about 1/2 and 2/3 of those achieved with the 3MURI software.

In conclusion the described study sought to provide the tool for assessing the global structural behaviour of building aggregates in simplified way, indicating the criticism of the Guidelines calculation method. Further studies will be devoted to perform additional analysis on different aggregate types with the aim to provide appropriate correction factors for both elastic stiffness and ultimate base shear to better envisage in simple way the seismic behaviour of masonry building aggregates.

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