Advances in Engineering Software 80 (2015) 116–138

Contents lists available at ScienceDirect

Advances in Engineering Software

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

Numerical calibration of an easy method for seismic behaviour assessment on large scale of masonry building aggregates

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ARTICLE INFO

Article history:
Available online 14 November 2014

Keywords:
Masonry aggregates
Seismic vulnerability
Frame by Macro-Elements analysis
Survey form
Quick methods
Damage analysis

ABSTRACT

The paper deals with the numerical calibration of a speedy procedure for large scale seismic vulnerability assessment of masonry building aggregates, which are typical building compounds diffused within historical centres of many Italian towns. First of all, based on several numerical analyses developed with the 3MURI calculation program, this simplified assessment procedure has been implemented, it being derived from the well known vulnerability form for masonry buildings integrated by five parameters accounting for the aggregate conditions among adjacent units. Later on, the set-up procedure has been validated through an application to a single building aggregate in the Vesuvius area. Since the results previously achieved have been again confirmed, subsequently the procedure has been used to investigate a wide area of the historical centre of Torre del Greco, allowing for the knowledge of the buildings most at risk under earthquake.

Finally, the methodology has been applied to the historical centre of Poggio Picenze (AQ), damaged by the recent Italian earthquake (2009), in order to prove its effectiveness to foresee the damage level experienced by other types of masonry aggregates under seismic actions.

1. Introductory remarks

Masonry is the most diffused construction material in the Italian historical centres, which are often the result of an uncontrolled urban development based on buildings erected in continuity to each other, so resulting into aggregates of constructions. These were generated by the progressive transformation of the urban tissue, in which elevation floors were added to existing constructions and plan extensions were made by adding structural units to the existing ones, so that often adjacent units shared the same boundary walls. Therefore, it is very difficult, if not impossible in some cases, to distinguish the structurally independent units and also to identify the global response of the building compound. So, seismic vulnerability assessment of masonry aggregates in the Italian historical centres represents a specific and very actual problem to be solved in order to foresee their behaviour under earthquake and, where deficiencies occur, to implement seismic protection measures.

The main difficulties of this task are related to the low knowledge level of these structures, which were in many cases built without anti-seismic design regulations, particularly due to the absence of drawings and/or reports. In addition, the careful analysis of these building complexes should take into account all structural units. This can be performed from the research point of view only by using either very complex numerical approaches [1,2] or experimental dynamic tests [3,4]. On the contrary, this is an activity complicated to be developed at the design level by engineers and architects for seismic vulnerability analysis of these building groups.

Furthermore, the recent and innovative technical Italian code (NTC 2008) [5] does not provide reliable methodologies to solve problematic issues connected to this topic.

On the other hand, in literature, starting from "codes of practice" for different historical city centres proposed by Giuffrè [6], some interesting papers have analysed the current topic in order to evaluate the behaviour of masonry buildings grouped into aggregates.

In 2005 Binda and Saisi [7] gave a general methodology to be followed for seismic vulnerability assessment and protection of historical masonry buildings. In particular, they prepared a report on the state of the art of research carried out in Italy in the field of cultural heritage restoration and conservation, also by focusing

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http://dx.doi.org/10.1016/j.advengsoft.2014.09.013
0965-9978/

their attention on building compounds. After the classification of typologies of historic buildings was presented and the materials and masonry construction technologies were discussed, several mathematic models for structural analysis were provided. Finally, appropriate repair and improvement techniques for different type masonry buildings were given.

In 2004 Ramos and Lourenço [8] addressed the seismic analysis and vulnerability of historical city centres by treating the case study of the 18th century downtown part of Lisbon. Different finite element method analyses considering the non-linear behaviour of materials were performed on a selected building compound aiming at evaluating its stability with respect to overturning mechanisms.

Analysis results showed that the "aggregate effect" is felt in two ways: globally, since the force distribution obtained from analysis of each building is different from the one calculated on the whole compound, and locally, considering pounding damages due to change of building stiffness resulting from the insertion of new reinforced concrete and steel members in the structure. It was found that individual buildings are more flexible than the compound and have lower safety factors. So, "compound effect" is beneficial for buildings which can be studied as isolated in order to reduce the computational efforts. However, the mentioned approaches can be usefully applied when local analysis on single masonry building compounds are of concern only.

Instead, about large scale analysis of building aggregates, the work of Pagnini et al. [9] is noteworthy. The paper discusses in particular a mechanical model for vulnerability assessment of masonry building compounds in the historical city centre of Coimbra considering uncertainties related to different factors, such as building parameters, seismic demand and model error. Capacity curves were assessed according to a probabilistic approach taking into account the variability of both structural response and seismic demand. In addition, by representing seismic demand as response spectra, vulnerability analysis was carried out with reference to several random limit states. Finally, fragility curves were derived taking into account the influence of uncertainties of different parameters examined.

Nevertheless, the need to have simpler approaches for large scale seismic vulnerability assessment of masonry building aggregates is particularly felt aiming at providing effective management tools to be used by Municipalities, especially in the prevention phase from earthquakes, for directing retrofitting interventions. In addition, the individuation of most vulnerable aggregates allows also to address aids in a rational way during the post-earthquake emergency phase.

To this purpose, a quick procedure for seismic vulnerability assessment of masonry compounds opportunely calibrated on the basis of numerical analyses performed at different urban scale levels, namely small scale (single aggregates) and large scale (parts of historical centres), has been implemented and proposed in the current paper. This should be the first step towards the implementation of a rigorous methodology to evaluate the seismic vulnerability of single buildings grouped into aggregates.

2. A simplified seismic vulnerability assessment methodology

2.1. The proposed form

Aiming at implementing a speedy seismic evaluation procedure for masonry aggregates, the starting point has been represented by the Benedetti and Petrini's methodology, widely used in the past as a quick technique, based on collecting into an appropriate form some information on single buildings, for investigating their vulnerability under earthquake [10,11].

This form is based on ten parameters used to recognise the main structural system and its fundamental seismic deficiencies.

The first parameter "Organization of vertical structures" identifies features of the building structural apparatus, defined as the system withstanding more than 70% of the seismic forces.

The second parameter "Nature of vertical structures" appraises the structural system quality with respect to different criteria, such as construction materials, workmanship features and execution efficacy.

The third parameter "Location of the building type and foundation" evaluates the influence of both consistency and slope of soil category and height difference between foundations on the building seismic performances.

The fourth parameter "Distribution of plan resisting elements" is based on the ratio between the acting base-shear, gotten by the elastic response spectrum, and the structure resistant base-shear, representative of the system shear resistant capacity.

The fifth parameter "In-plane regularity" takes into account both the building plane configuration and the seismic-resistant elements mass and stiffness distribution.

The sixth parameter "Vertical regularity" considers the mass change among levels and possible discontinuities in the positioning of vertical seismic-resistant systems.

The seventh parameter "Type of floor" accounts for the in-plane stiffness of floors and their connections with the vertical seismic-resistant systems.

The eightieth parameter "Roofing" judges the roof typology and the possible pushing actions applied to masonry walls.

The ninth parameter "Details" classifies non-structural elements as internal (partition walls, furniture, flush ceilings, etc.) and external (antennas, cornices, parapets, chimneys, balconies, etc.) elements that may or may not collapse partial or totally depending on the connection quality to the resisting elements in the structure.

The tenth parameter "Physical conditions" evaluates structural imperfections and damages into both in-elevation load-bearing systems and foundations.

Based on this approach, which requires external inspection of buildings only, the vulnerability index of an isolated masonry building was calculated according to the following expression [12]:

$$I_{\mathrm{V,I}} = \sum_{i=1}^{10} s_{\mathrm{i}} \cdot w_{\mathrm{i}} \tag{1}$$

where s_{i} and w_{i} are the score and weight, respectively, of the form generic parameter. Four scores (from A, minor, to D, major) are used to describe the vulnerability classes of each parameter, whereas weight (ranging from 0.25 to 1.50) represents the less or more importance of the parameter in quantifying the building vulnerability.

This vulnerability assessment form, whose basic parameters are reported in Table 1 with white background, has been adopted with some small adjustments by the Italian National Group Against Earthquakes as first screening tool for vulnerability assessment of masonry and r.c. buildings belonging to historical centres [12].

In order to consider the structural interaction among adjacent buildings, not considered in the cited method, a new form has been ideated [13]. This is resulted from adding to the basic ten parameters of the original form new five parameters taking into account interaction effects among aggregate structural units under earthquakes. These factors, in part derived from previous studies found in literature [14], are:

1. In elevation interaction.
2. Plan interaction.
3. Number of staggered floors.