Chapter 45
On the Assessment of the Seismic Vulnerability of Ancient Churches: The Case of "San Francesco ad Alto" in Ancona (Italy)

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ABSTRACT

The chapter deals with the assessment of the seismic vulnerability of the "San Francesco ad Alto" historical masonry building, a former church located in Ancona (Italy), which is currently used as a Regional Headquarter of the Marche Region by the Italian Army. The interest toward this building comes from a double motivation. From the one side, it underwent a series of structural changes, including the addition of a new floor splitting in two levels the original nave, which makes the structure very peculiar and closer to a classical building than to a church. From the other side, it is no longer used as a church, a fact that changes the hazard aspects. The construction schematically consists of two masonry boxes overlapping, the lower being wider than the upper. It has various characteristic structural elements, such as some semicircular arches, segmental arches, timber floors, a barrel vault, some wooden trusses on the roof and steel ties in retention of the facade and of the external walls. The equivalent frame method is used, and several pushover analyses are performed. The seismic action has been defined considering the building both with strategic (current situation) and with ordinary (possible future situation) importance during earthquakes. The role of the masonry spandrels on the response of the structure has been investigated in depth and the main effects highlighted. The result of the pushover analyses is a seismic risk index (IR), that defines the safety level of the construction with respect to one ultimate limit state (SLU), in particular the so-called limit state of "saving life" (SLV).

DOI: 10.4018/978-1-4666-9619-8.ch045

INTRODUCTION AND BACKGROUND

The issue of structural safety of the historical buildings (Asteris, 2014) during calamitous events is of fundamental importance to preserve human lives, and to protect the whole cultural heritage, not only the architectural one (Lagomarsino, 2006).

This is particularly true in Italy, for at least two reasons. One is the elevated presence of the historical and artistic heritage, which needed to be preserved for next generations. The second reason is the strategic function that sometimes these constructions have during calamitous events, having to guarantee safety to host headquarters of rescue teams and safe place for short term hosting of people that lose their house. This has been implemented by the Italian Codes that require performing the assessment of the seismic vulnerability of existing building with a strategic relevance. The Italian Codes (Code 1), (Code 2) and (Code 3) – that in the following will be referred to as Italian Codes for brevity – also provides a new classification of the seismic hazard of the Italian territory, which is more demanding with respect to the previous one and thus makes the check more difficult.

Generally, the Italian Codes follow the Eurocodes and there are not remarkable differences with them. For existing masonry building subject to seismic action, the Europe reference is the Eurocode 8, particularly its Parts 1 and 3, which recommend the same methods of the Italian Codes to evaluate the seismic action, to model and to analyze the structure and to verify the structural elements.

The assessment of the seismic vulnerability can be performed in different modes (Calvi, 2006), depending on the objectives to reach. In particular, if a classification of the building with higher seismic vulnerability is needed in order to draw up a priority scale, or if one is interested in the urban system and not in a given building, simplified procedures can be used. In the last years, many methods of macro-scale assessment have been developed by several authors (Benedetti and Petrini, 1984; Lourenço and Roque, 2004; Lagomarsino, 2006; Dolce and Martinelli, 2006; Mazzotti, 2008; Kappos et al., 2008; Neves et al., 2010).

On the contrary, if the seismic vulnerability of a specific building, which can be an ordinary building, a monumental construction, a building with a strategic function, etc., is requested, then a structural analysis through various mechanical models and methods is needed (Lourenço, 1999; Lagomarsino et al., 2006; Mistler et al., 2006; Valluzzi, 2007; Alemi et al., 2010; Lagomarsino et al., 2010; Pagnini et al., 2011).

The seismic analysis of monumental or historical buildings has been the subject of various investigations in the recent past. Mele et al. (2000) studied the S. Ippolisto Martire Church, located in Atripalda (Avellino, Italy). Lourenço and Mourão (2001) investigated the safety assessment of the Monastery of Jerónimos in Lisbon (Portugal). Irizarry et al. (2002) determined the capacity curves of the Santa Maria del Mar Church in Barcelona (Spain). Rinaldis et al. (2004) investigated a former monastery in Cerreto di Spoleto (Italy) by also measuring vibrations due to ambient excitation. Mallardo et al. (2008) have studied the seismic vulnerability of the "Palazzo Renata di Francia", a Renaissance Palace in Ferrara (Italy). De Matteis and Mazzolani (2010) assessed the seismic vulnerability of the Fossanova Abbey (Priverno, Italy). Ceroni et al. (2012) performed a structural analysis of the "Palazzo Bosco Lucarelli', an old noble palace located in Benevento (Italy). Betti and Vignoli (2013) studied the seismic behaviour of the Basilica of Santa Maria all'Impruneta, close to Florence (Italy). Barbieri et al. (2013) investigate the structural response of Palazzo del Capitano in Mantua (Italy), in both static and seismic conditions.

The previous list is of course far from exhaustive, and this work wishes to add a further case, namely the S. Francesco ad Alto former church located in Ancona (Italy). The interest toward this building comes from some of its specific charac-