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Influence of the annex on seismic behavior of historic churches

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ABSTRACT

In May 2012, two major earthquakes occurred in Emilia Romagna region in Northern Italy, causing widespread damage. The hypocentre of the second one, strokes Mirandola where is located the Gesù Church investigated in this research. The church has a long and important annex to the south built during the same period of the church. This paper addresses how the important annex influenced the seismic response of this historical church and how, more generally, this kind of asymmetric mass can influence the behavior of historic churches. The final considerations are based on the comparison between the structural damage pattern survey and modal and seismic FE analysis. A FE model was constructed considering four different configurations: (i) isolated church, (ii) the church with the presence of the real annex with a perfect connection, (iii) the church with the presence of the same annex but with an interface between the church and the annex and (iv) this last configuration with the stiffness degradation of the interface. Firstly the dynamic modal analysis and subsequently the seismic spectral analysis were performed. The results indicate that the annex's presences play a significant role in the dynamic response of the church and affect the distribution of damages for the whole building. The results of the seismic simulation are in agreement with the observed damage.

1. Introduction

The recent earthquakes that hit Italy in the last century proved the high vulnerability of cultural heritage, with particular reference to churches. These particular monumental buildings cannot be reduced to any standard structural scheme and this makes it difficult to evaluate their seismic reliability. To overcome this problem, the macro-element approach has been proposed a few years ago and since then repeatedly used to recognizing the collapse mechanisms in the different macro-elements of the church [1,2]. The common collapsing configurations are shown in PCM-DPC-MiBAC M.-A.-D. [3].

The historical centers often occur as the result of an uncontrolled constructive evolution, whose complex configurations lead the structures to strongly interact with each other when are subjected to seismic action [4]. As a matter of fact, several historic churches are not isolated from the urban context but are often characterized by the presence of adjacent buildings, usually named annex (convents, sacristy, tower, minor constructions, etc.) at the same time of the church or subsequently constructed as we have seen in other case studies (Fig. 1).

Besides the monitoring of historical constructions in seismic areas is a predominant issue also in Europe and especially in Italy because of the richness of its inestimable architectural heritage [5,6]. In the last century the seismic events stroked severely the cultural historic heritage and in particular the 49% of the damaged structures are churches highlighting their

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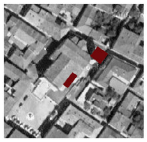
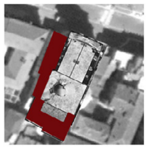
CHURCH	CITY and EARTHQUAKE (Mw=moment magnitude)	EVIDENCE OF DAMAGE	HIGHLIGHTING ANNEXES
Church of San Francesco (Emilia Romagna)	Mirandola, 2012 Mw= 5.8		
Church of Sant Eusanio Martire (Abruzzo)	L'Aquila, 2009 Mw= 6.3		
Church of San Pietro di Coppito (Abruzzo)	L'Aquila, 2009 Mw= 6.3		
Church of Santa Maria del Suffragio (Abruzzo)	L'Aquila, 2009 Mw= 6.3		
Church of Santa Maria Assunta (Molise)	Ripabottoni, 2002 Mw= 5.4		
Church of Santa Maria Assunta (Friuli Venezia Giulia)	Gemona, 1976 Mw= 6.5		

Fig. 1. Some examples of churches characterized by the presence of the annex and damaged by earthquakes.

intrinsic vulnerability [7–17] due first to the absence of any kind of diaphragm except the covering. Tuned with this issue it becomes necessary to take a census of the weakness of these monuments through the structural identification procedures and the evaluation of the related ground motion characteristics [18,19].

By the way the paper presents the case study of Gesù church in Mirandola, which was severely damaged by the strong earthquake that occurred in Emilia Romagna region in Northern Italy, in May 2012. The question of how the important annex had engraved on the dynamic behavior during the earthquake arise from the observation of an unsymmetrical damage survey. The construction of the undamaged FE model, firstly, of the isolated church (*WA*) and then with the presence of its annex (*A*) was fundamental to simulate the dynamic and seismic behavior. As previously said, the annex could have been built later than the church; this hypothesis is considered in an additional FE model (A_i) with the inclusion of an interface between the church and the annex. One of the main problems of the historic masonry buildings is certainly the materials deterioration, particularly of the mortars. The reason of the deterioration of this part is often due to the low quality of conservation and other exceptional events or new additional loads [20]. It is chosen therefore to simulate also this problem in the FE model with a deteriorated interface A_{i_d}.

The dynamic modal analysis and the response spectrum analysis have been performed to determine the possible collapse mechanisms and to study the stresses distribution on each macro-element of the whole church analyzed. This case study highlights the importance of a deeper study on the incidence of the presence of an important annex on the dynamic response of the churches. The analysis of this case study achieves some results, which may be useful also for correctly driving future strengthening interventions on similar context.