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Development of a seismic risk mitigation methodology for public buildings applied to the hospitals of Basilicata region (Southern Italy)

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ABSTRACT

This paper deals with the development of a procedure aimed at defining a seismic risk mitigation strategy for public buildings in terms of prioritization, time required and funds. The procedure is based on a global risk index involving the entire building stock under study thus facilitating an examination of risk variation over time up to its final value. Relationships between the current seismic capacity–demand ratios and the required strengthening costs (cost models) have been developed. Each of the assumed cost models has a different target in terms of capacity–demand ratio to be obtained after strengthening, basically ranging between full retrofit and upgrading. The procedure has been applied to 69 hospital buildings located in Basilicata region for which the vulnerability data was available as a result of a large assessment program set up by the regional government. Priorities have been defined on the basis of seismic capacity, local hazard and number of human beings possibly involved (exposure). The results of different strengthening strategies have been outlined with a special focus on the pros and cons of the upgrading strategy with respect to various retrofit strategies. The procedure may be applied to different categories of public buildings by properly modifying some input parameters and partially redefining criteria for prioritization.

1. Introduction

There is a large number of public buildings throughout the world, originally designed without seismic criteria, which are located in places which have been subsequently classified as seismic zones. In Italy, the National Department of Civil Protection (DPC) estimates that there are about 75,000 public buildings designed without seismic criteria, nearly 35,000 of them situated in areas with medium to high seismic hazard [1]. Most of these buildings are hospitals and schools and so their collapse could have dramatic consequences on the affected community. Hospitals, especially, play a unique role in the survival capability of the community during an emergency phase: following a catastrophic event, if these critical buildings are damaged, there are direct consequences on the occupants but, crucially, they are not available for use, which increases community vulnerability.

In Italy, public buildings, including hospitals, have shown poor performance during past earthquakes. For example, during the M_w 6.4 1976 Friuli and the M_w 6.9 1980 Campania–Basilicata earthquakes, the healthcare system suffered severe and extensive damage. Specifically, the 1980 earthquake caused the complete collapse of the Sant'Angelo dei Lombardi Hospital (RC structure, 7-storeys) and serious damage to the Curteri Hospital at Mercato San Severino. Despite these tragic events, little attention was paid by the Italian Government to evaluate and mitigate the seismic risk of hospitals, schools and, generally, public buildings until the 2002 M_w 5.8 Molise earthquake. During this earthquake a primary school building collapsed causing the loss of the lives of 27 children and their teacher [2], and dramatically emphasizing once again the high vulnerability of the existing public structures.

After the Molise earthquake the Italian Government initiated an exhaustive mitigation policy issuing the Ordinance of the President of the Ministers' Council (OPCM) no. 3274 [3]. Among other actions, a prominent national plan was set up to define actions to assess and mitigate the seismic risk of all the public buildings and infrastructures designed without earthquake resistant criteria. Specifically, among the buildings whose integrity during earthquakes is of primary importance for civil protection or is significant in view of the consequences associated with their collapse, particular attention was devoted to hospitals and schools. Moreover, the new seismic codes enforced in the following years provided more adequate methods and techniques to achieve the seismic risk mitigation of both new and existing strategic buildings, although considerations of the structural performances against collapse risk prevailed. Also, the current seismic code aims at limiting damage to non structural components through limitation of interstorey drift values, while no specific provisions about content restraining (e.g., medical

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equipment) are provided. Indeed, equipment is essential to ensure the operation of a hospital during and after an earthquake, as recently confirmed by the loss of care capacity of the hospitals stricken by the 2012 Emilia Earthquake [4] and, before that, during the 2009 L'Aquila earthquake whose effects necessitated the complete evacuation of the large local hospital complex [5]. Italy also has frequent difficulties regarding the lengthy periods often required for the strengthening interventions especially in the case of hospital buildings hosting acute care units [6].

Along with due attention to the capacity of structural and non structural elements, the preparedness of the operators and management of public structures to a disaster emergency is also fundamental for an effective post-event response. In the case of hospitals, particularly, emergency plans should be set up beforehand in order to make swift and effective use of the available resources in the aftermath of a seismic event.

Lessons learnt from past earthquakes clearly indicate that preventive efforts have largely paid off in subsequent emergencies and that these efforts need to be planned and implemented through a continuous process [7]. The good performance of the Californian health-care system during the 1994 Northridge earthquake is a prominent example which clearly illustrates the effectiveness of the investment plan implemented by the State of California in 1973 (Hospital Facilities Seismic Safety Act, HFSSA) to improve the seismic safety of hospitals. This plan was strongly influenced by the severe damage suffered during the 1971 San Fernando earthquake when about 85% of fatalities (50 people) were caused by the collapse of hospital buildings [8].

Since the application of OPCM 3274 [3] provisions in 2003, many of the Italian regional governments have started activities to assess and mitigate the seismic risk of their public building stock. The government of Basilicata region (Southern Italy) set up the "*1st Program for the assessment of strategic and important public buildings in Basilicata Region*" to be performed in the period 2004–2007, involving all the hospitals and larger schools designed without seismic criteria. Of the more than 200 buildings evaluated, 69 of them were hospital buildings. The assessment of these buildings enables the definition of a list of intervention priorities on the basis of their seismic risk level. However, the huge amount of funds required to strengthen all the unsafe buildings clearly indicates that prioritization needs to be supported by an appropriate strategy to optimize the use of the available resources [9].

It is necessary to define the minimal amount of annual resources to be used in reducing the seismic protection deficit while effectively balancing the factors of required times and regional budget. This requires a different approach from the models and methodologies available in literature including those dealing with other types of natural hazards [10,11], related to a large number of buildings [12] for which a classical loss estimation procedure is useful in setting-up intervention programs [13]. Other studies proposed in literature (e.g., [14]) are oriented to evaluate the response of a group of hospitals to a post-earthquake emergency based on a seismic scenario which takes into account the treatment capacity of the system and its overtime degradation in the first hours after the seismic event. Furthermore, some papers (e.g., [15]) outline different intervention choices to mitigate the risk showing that simple as well as not very expensive interventions on non-structural elements can effectively improve the performance of the whole system. Generally, this kind of studies aim at evaluating expected economic annual losses once the seismic hazard and the current vulnerability of the buildings under consideration have been assessed mainly from a probabilistic point of view [16].

The focus of the present paper is not a discussion of the economic viability of strengthening – or not – existing public buildings without seismic protection. The need for strengthening of the public buildings that are judged to have inadequate resistance according to the specifications of the current seismic code is assumed to be, in some respects, mandatory in Italy (after the tragic 2002 Molise earthquake). Therefore no reference is made to benefit-cost analysis deriving from expected economic losses and accounting for the design working life to be adopted when assessing and, if needed, retrofitting existing structures, with relation to either their residual life or the working life adopted for newly designed structures. The main purpose of the paper is to propose a procedure to define intervention strategies and priorities for the seismic risk mitigation of strategic buildings. The procedure makes strict reference to the framework of rules of the most prominent seismic codes for existing structures (e.g., EuroCode 8 part 3 [17] in Europe, FEMA 356 [18] in US). Various seismic risk levels have been accounted for with respect to either individual or sets of buildings, by defining appropriate risk indexes. An automated procedure, capable of estimating the variation over time of the global risk index during and at the end of a selected risk reduction strategy, has been implemented. Some criteria to define priorities for seismic intervention have been developed, and the problem has been addressed on the basis of different approaches. The obtained results can be used to develop intervention strategies and to define priorities and timescales of the strengthening program on hospital buildings, as already proposed for school buildings in Italy [19,20]. Thanks to the availability of data regarding the seismic capacity of the individual hospital buildings obtained as a result of the 1st assessment program, the proposed procedure has been applied to the hospital network of the Basilicata region, thus offering ideas regarding the seismic risk mitigation strategy to be adopted. Although the procedure has been applied to hospitals, it can also be used for other classes of public buildings, e.g., schools, basically by modifying some parameters.

2. Methodology

The procedure to define a seismic risk mitigation strategy of a given set of public buildings is made up of the following steps:

1. Inventory of the main typological data of the building set to be examined;
2. analysis of the current seismic risk levels of the buildings of the dataset basically combining local hazard and structural vulnerability;
3. cost estimation of the seismic strengthening actions considering different tolerable values of the capacity–demand ratio before and post intervention;
4. definition of criteria for assigning intervention priorities;
5. construction of time–risk curves on the basis of different strengthening strategies; and
6. selection of the optimal intervention strategy in terms of progressive and final risk reduction.

The main steps of the proposed procedure are outlined in the flow-chart in Fig. 1.

With respect to steps 1 and 2, the procedure makes strict reference to the framework of rules of the seismic codes for existing structures (e.g., the Italian code, substantially consistent to EuroCode 8 part 3). Therefore, an ad hoc vulnerability model is not provided in the paper on the assumption that seismic capacity is known from detailed assessment, following code provisions in terms of knowledge process, methods of analysis, and safety verifications. For the same reason, the hazard model is not discussed in the paper on the assumption that it is given in the