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Post-World War II Italian school buildings: typical and specific seismic vulnerabilities

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ABSTRACT

Structures belonging to the same type and built in the same period may share similar geometrical and spatial characteristics. When these features also affect the seismic response of the buildings, they are referred to as typical seismic vulnerabilities. When a building presents one or more of these typical vulnerabilities, some general and qualitative considerations on its seismic behaviour can be made a priori, considering their actual influence on the seismic behaviour of other similar cases. In this work, we propose and apply a specific procedure based on a priori considerations to a specific building type: the post-World War II Italian Schools. To this purpose, we first improved our knowledge about this type of building, pointing out typical and specific seismic vulnerabilities by studying the standard architectural principles suggested by the main manuals and laws of that time. Then, in order to find how these typological features affect the global seismic behaviour of the examined structures, we analysed a real case study representative of the entire building type. Pushover and Nonlinear Dynamic analyses have been carried out, considering four different models, representing three different configurations that may result from different combinations of the most significant typical vulnerabilities.

The result of this work confirms that in the case of post-World War II Italian school buildings, typological vulnerabilities such as wide atriums, eccentric stairs and tall windows, along with irregularity in plan configuration, can strongly affect the global seismic behaviour of the school buildings.

1. Introduction

Most recent seismic events (e.g. Molise 2002 [1,2], L'Aquila 2009 [3–13], Emilia 2012 [14]) have clearly shown the high seismic vulnerability of the Italian existing RC buildings, which often provide an inadequate safety level against seismic actions. This high vulnerability is due to many aspects, mostly related to the age of the buildings, the low standards of construction and maintenance [15], and the legislation in force at the time that did not effectively address the seismic problem, even allowing the design for gravity loads in some earthquake prone areas, erroneously considered as non-seismic zones. For this reason, old existing RC framed buildings are today characterized by poor quality concrete [16], inefficient construction details-especially in the joints – a lack of the fundamental principle of the capacity design and low column ductility mainly due to the inadequate use of stirrups. Moreover, high shear forces, usually determined by global torsional effects, often result in brittle collapse susceptibility.

All these matters play an important role when considering the Italian building stock, of which RC buildings currently represent the greatest portion, mostly built after World War II when building stock increased exponentially [17] (Table 1).

The evaluation of the seismic vulnerability of these RC building structures has a key role in the determination and reduction of earthquake impact. For this reason, after the tragic collapse of a school building during the 2002 Molise earthquake [1], the Italian Government started a mitigation policy issuing the Ordinance of the President of the Ministers' Council n. 3274 [18]. More specifically, an important national plan was set up with the aim of assessing and mitigating the risk of those buildings and infrastructures designed without earthquake resistant criteria, and whose integrity during earthquakes is of vital importance for communities (e.g. hospitals) or which is significant in view of the consequences associated with their collapse (e.g. schools) [19–21].

Concerning the latter, more than 60% of the Italian school buildings were built between 1945 and 1980 [22,23], showing all of the problems related to old RC framed buildings mentioned above. Unfortunately, the difficult economic situation that Italy is currently facing reduces the capability of local authorities in allocating funds for their maintenance, and many school buildings do not have a proper structural validation yet [23]. For this reason, ad-hoc methods, reliable and not too costly are required for the

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Table 1
Year of construction of the Italian RC building stock (% values) [17] on the national territory.

Year of construction	1919–1945	1946–1961	1962–1971	1972–1981	1981–1991	From 1991
Percentage of the RC building stock	3%	10%	21%	30%	22%	14%

assessment of these buildings.

The purpose of this paper is then to improve the knowledge of the school buildings built in Italy between 1950 and 1975 – i.e. the post-World War II Italian School Buildings – by pointing out typical and specific seismic vulnerabilities related to their architectural layout and construction characteristics.

To this aim, through the study of the requirements of the coeval legislation and the suggestions of the manuals of that period, some typological aspects that often characterize these buildings have been defined. Then, within comprehensive vulnerability seismic analyses of different structures built between 1950 and 1975, we chose a case study by following the rules and the principles of the period taken into account, as it represents a classic Italian school building designed in the same period. Its specific vulnerabilities were also defined by an on-site investigation programme, providing the reference database for the characteristics of the materials and geometry of the structural elements. With regard to the properties of the materials, a large investigation with destructive (coring and sampling of the bars) and non-destructive (SonReb) testing was carried out.

Analyses on spatial models by the computer programme Midas Gen 2015™ [24] have been carried out on four different three-dimensional models of the building in order to assess how different typological vulnerabilities may affect the seismic behaviour of structures. In particular nonlinear static procedure (pushover analysis) and Incremental Dynamical Analysis (I.D.A.) have been used to provide useful quantitative and qualitative information on the influence of the models adopted, while secondary structural elements are evaluated only as masses or as stiffness.

2. Methodologies

Assessing the seismic vulnerability of existing RC buildings is a very difficult task. In fact, it requires an accurate knowledge of the mechanical and geometric proprieties of its structural elements that, contrarily to the construction of new buildings, are obtainable only by means of long and costly experimental campaigns. These campaigns are inclusive of (1) direct inspections aimed at identifying the geometrical characteristics of all the structural elements, and not only of the hidden ones, (2) on site non-destructive testing (i.e. SonReb) and (3) laboratory tests on the specimens pulled out from the structural elements. In some cases, carbonation tests (4) can be added with the aim of assessing the state of degradation of the structural elements.

Nevertheless, for existing buildings that present similar spatial configurations and follow the same construction and architectural principles, some general and qualitative considerations on their seismic behaviour might be made a priori, due to the possibility of observing the seismic performance of other similar buildings. This is the case of homogeneous building typologies, in which common structural characteristics are present and whose seismic response can be related to the common typological aspects shared by the whole class of buildings [15,25].

The basic idea behind this study is therefore that some kind of buildings can have seismic vulnerabilities that could be the same for the entire typological class. These vulnerabilities are referred to as *typical vulnerabilities* and they are the main topic of this study. They substantially differ from another type of vulnerability, the *specific vulnerabilities*, which instead are related to methods of construction, materials quality and peculiarities of each single building that may vary from case to case. The presence of specific vulnerabilities usually worsens the seismic damage related to the typical ones.

This study focuses on school building typologies, and in particular on primary schools and kindergartens built between 1950 and 1975. The aim of the paper is therefore to define typical and specific seismic vulnerabilities for such buildings and a specific procedure has been implemented for this purpose. It consists of three steps described as follows:

1. *Selection of the building typology* (Section 3.1). Through the study of laws in force during the period of study [26], prominent manuals [27–29] and the related literature [1,15,25,30,31] we outlined a typological recurrent model with *typical seismic vulnerabilities* (typological analysis). Such model should be representative of the entire building typology in order to estimate the vulnerabilities of the entire class of buildings. The *specific vulnerabilities* of the typology have been also analysed through the study of the materials properties and the methods of construction, making references to the most prominent manuals [32–37] and codes [38,39] in the field used in the period of study;
2. *Selection of the case of study* (Section 3.2). A school building representative of the entire building typology has been selected as a case study, after verifying that it meets the rules of construction outlined in the first step and after having carried out broad vulnerability seismic analyses of different structures. Typical and specific vulnerabilities for the selected building was identified by also using the results of the on-site investigations.
3. *Performance analysis* (Section 3.3). The performance analysis has been carried out by means of nonlinear static and nonlinear dynamic analyses as made in [40–42] and [43], respectively. To study the seismic behaviour of the entire typological class, the modelling of the case of study should be carried out taking into account as much as possible the different configurations that may result by the combination of the most significant vulnerabilities. This can be easily obtained by using different models. From the comparison of those, we might assess the influence of the typical and specific vulnerabilities on the seismic response.

3. Results

In this Section, we report and discus the main results of the procedure described in Section 2.

3.1. Typical Italian school building typology

Most part of the school buildings are spatially organised in the same way: the classrooms are placed next to each other in front of a corridor or a hallway [25]. This layout supports the school's functions but increases inevitably seismic vulnerability. With the aim of defining the vulnerabilities of these buildings, a typological analysis has been carried out on the Italian building stock built between 1950 and 1975, by studying the regulatory framework and the prominent manuals (Section 3.1.1). In this way, the relative typical and specific vulnerabilities have been outlined.

3.1.1. Regulatory framework and prominent manuals for the design of school buildings between 1950 and 1975

During the first ‘50s, a significant typological innovation for