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Versatility of steel in correcting construction deficiencies and in seismic retrofitting of RC buildings

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ABSTRACT

This paper presents the structural upgrade of a public school building, which did not guarantee safety against collapse under gravity loads and which had been designed ignoring seismic actions.

The design of the upgrade took full advantage of the properties, capabilities and opportunities afforded by steel, which was used in a variety of forms and functions — namely, cold-formed members, thin-walled sections, welded elements, steel-concrete horizontal and vertical structures. The activity presented here did not use numerical calculation as a means of structural design. The multifarious roles that steel can play make steelwork particularly suited to conservation and upgrade of twentieth century architecture, especially seminal reinforced concrete buildings.

1. Introduction

Starting in the late 1990s, the Reinforced Concrete (RC) buildings of the postwar rebuilding and the following construction boom began to reach fifty years of age, the point at which in Italy they typically become eligible for heritage protection (while the first generation RC buildings had already reached that age). Along with the growing appreciation of those structures, and not only in the case of seminal buildings, is the search for a new approach to conservation for the buildings constructed in the twentieth century, as the traditional conservation theories and techniques are devoted to masonry constructions and, as such, are not suited to RC structures (let alone to steel structures) [1–6]. The materials and construction methods of the latter have challenged traditional conservation theories and techniques, and raised new conservation issues [7–15]. The problem is particularly acute for buildings in seismic areas [13–17], since the common seismic retrofit techniques for RC constructions that were not designed to withstand seismic actions do not retain authenticity. There have been some research attempts to blend structural and conservation issues for twentieth century architecture [1,5,7,15,17–19], but the topic remains ongoing. A viable and suitable solution is offered by steel structures [20–28].

This paper deals with a public school building (Fig. 1), located in Montelabbate, a town close to Pesaro, in Italy (Marche Region), which had been destined for demolition. The building represented a typical RC framed structure of the 1960s. Although not being a ‘Listed Building’, the edifice was of interest and importance, since it was of good quality design and appearance. Moreover, not only was the building attractive in its own right, but also it contributed to the character and appearance of the area where it was (and is) located. In fact, the building, which was the only elementary school of the town, illustrated, and was reminder of, the historical development of that area. For those reasons, the building was worthy of recognition and retention as much as possible.

The paper presents the key features of the structural work — design and construction — that provided that building with the capacity of resisting the loads prescribed by the current Italian code. That work saved the school from demolition, maintaining the building's architectural integrity. Now the building continues to serve as the public school of the town and conserves the original character and appearance, since the new structures neither gave the building a new look nor hid the original building nor even obscured it. Part of the addition was concealed behind the suspended ceiling or was placed in the attic, while the design made the other part identifiable.

The design was the result of mental conceptual models and simple manual analytical calculations, by which the author comprehended and explained how the design would have worked in reality, governed the relationships between existing and new structures, and obtained realistic assessments. Neither numerical modeling nor code compliance checking was performed during the design process. When the entire structure had been completely defined at the end of the design process, the author assessed the design of the structural work he had planned to do and provided a certificate, in the form of a signed report, stating that the entire structure had been designed to comply with the Italian structural code. Assessment was accomplished according to the provisions of the Italian code and certified that the designed structure

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Fig. 1. Public school building located in Montelabbate, close to Pesaro (Italy). Long wing of the building: front of the school, which faces onto the garden, and lateral side that faces onto the street. The school complex was built in 1964.

guaranteed the prescribed safety levels.

The study's statement of purpose is to provide useable and reproducible recipes for structural work on existing RC buildings. The emphasis is placed on developing both theory and practice relevant to the field of structural steel, with appropriate links established to design and construction. One leading idea that the paper is going to propose about the topic is that structural designers should borrow the solutions directly from the scientific domain, which is the source of creativity and innovation, as opposite to the prevailing tendency among present practitioners towards replacing structural design with finite element modeling.

2. Original building structurally considered

The construction of the school complex was completed in 1964; it was used as elementary public school of the town of Montelabbate until 2006, when it was closed. After the structural work described in this paper, the complex was reopened and it is again being used as the public elementary school of the town.

The complex was, and is, composed of the classroom building, the gym, and a porch that connects the former to the latter (Fig. 2). This paper focuses on the classroom building, which is the main part of the complex (Fig. 3). The classroom building, which has L-shaped plan, is composed of a long wing and a short wing, joined to one another by the atrium (Figs. 2 and 4). Both of the wings are made up of the first story (ground story), the second story (first level), the attic (third story and second level), and the roof (gable roof; top level). The long wing also presents a small basement.

The structures of each wing (as well as of the atrium) before the structural upgrade consisted of three longitudinal RC frames (i.e., two edge frames and one spine frame), plus the floors in the transverse direction (Fig. 5). The frames were connected to each other by some secondary beams in the transverse direction. The spine frame was

Fig. 2. The school complex is composed of the classroom building, the gym and a porch. Long wing (on the left) and short wing (on the right) of the classroom building: school's backside, which faces onto the courtyard.

Fig. 3. One of the classrooms on the ground story. The photo also shows the drop ceiling, which allowed the new transverse beams to be covered.

inserted into the walls that separated the classroom from the corridor (Fig. 6); the edge frames were inserted into the external walls (Fig. 7). Hence, the structure was not visible, except for some of the vertical structures of one edge frame, which were walls instead of columns, but for esthetic purpose only (Fig. 1).

The RC frames were composed of columns (apart from the aforesaid walls) and T-beams with height substantially greater than the thickness of the floor (Figs. 5–7). The T-beams were inserted into the partitions, which were thick since they included the plumbing and heating system. The floors were composed of RC joists (rafters), infill hollow flooring brick blocks, and extrados RC slab.

2.1. Wrong structural engineering assessments of the existing building

Due to inadequate seismic hazard evaluations, the contemporary code (1964) did not prescribe seismic actions for the buildings of that zone. Conversely, the new generation Italian codes that have been issued starting from 2003 include that zone in the seismic areas. In 2006, some practitioners were entrusted with the task of assessing the seismic risk of the building according to the new code. Those practitioners came to the conclusion that, independently of the static capacity and seismic capacity of the structure, the building had to be demolished, since the compressive strength of the concrete was less than the lower value accepted by the Italian code.

After the report of the practitioners, the municipality declared the building dangerous; so, the complex was shut and the surrounding area closed. Nevertheless, since the school complex was, and is, considered a seminal building, the municipality consulted the writer, hoping that the academic milieu could offer a solution different from that offered by the practitioners.

First of all, the writer observed that the minimum compressive strength of concrete prescribed by the Italian code applies only to new structures (it is related to durability and not to load-carrying capacity or safety), whereas existing buildings have to fulfill rules different from new buildings. Thus, the strength of the concrete was in itself not enough to establish that the building was unsafe, let alone that had to be demolished (Fig. 7).

Then, the writer entrusted a specialized company with the structural survey work. That work took the form of a site survey with sampling, followed by the associated laboratory work carried out in an accredited laboratory. On site and laboratory activities were planned by the writer so as to obtain the highest possible level of knowledge. The structural survey work undertaken by the company encompassed foundation details (with information on the bearing strata), structural form (including load path information), reinforcement layout (including the connections), structural detailing; moreover, it assessed aging, corrosion and degradation of steel and concrete structures.

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