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BUILDING BACK BETTER: THE CASE STUDY OF THE FAZZINI COLLEGE

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Abstract

Passive protection systems have proven to be efficient solutions for the seismic protection of both new and existing buildings. Recently an increasing attention is paid towards their use in external configurations, especially for existing structures since their lower interferences with both the structures to protect and the activities carried on within the buildings. Retrofit and seismic upgrading based on external dissipative elements, indeed, are very promising in post-earthquake phases, making it possible a notable reduction of building downtime and impacts on users.

This paper concerns the seismic retrofit of the Fazzini college, an existing r.c. frame building of the University of Camerino severely damaged during the 2016 Central Italy seismic sequence. The retrofit has been designed with an external passive system equipped with fluid viscous dampers aiming to prevent damage to both structural and non-structural components up to severe earthquakes.

Keywords: damage control, external passive system, structure-non-structure interaction, fluid viscous dampers.

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1 INTRODUCTION

Passive damping systems are very efficient solutions for the seismic protection of new constructions and the retrofit of existing structures [1]-[4]. Their use in the last three decades has becoming more and more diffuse due to their ability to dissipate the seismic input energy, even for small displacements. Additionally, if Fluid Viscous Dampers (FVDs) are used, such systems are efficient in reducing both the Interstorey-DRift (IDR) and Peak Floor absolute Accelerations (PFA) demands without notably modifying the stiffness of the building to protect .

Several approaches are to date available for designing both size and location of viscous dampers within a building frame based on direct procedures [5] or optimization methods [6], [7]. A thorough review of design strategies for viscous dampers can be found in [8].

Moreover, there is an increasing interest towards the use of passive systems in external configurations for the retrofit of existing buildings due to some drawbacks which have been already highlighted when using FVDs for the retrofit of existing structures in traditional configurations [9]-[11] (i.e. devices installed within the building frame, in diagonal configurations or V-shaped braces connecting adjacent floors). Such disadvantages concern the increasing of tensile and compressive forces in the columns that can leads to fragile ruptures [12], [13], and the eventual need of localized strengthening of beam-column joints or foundations. Furthermore, the demolition and reconstruction of internal partition walls, the installation of bracings, and the possible structural reinforcement works, may cause downtime of buildings and related indirect costs for the temporary relocation of the activities. All these aspects, as previously mentioned, improve the interest towards the use of FVDs in external configurations [14], [15], where localized interactions may occur only in the zones of connection, notably reducing the interferences with usual activities carried out in the buildings. Moreover, the activities of inspection, maintenance and replacement of the devices can be notably simplified, and the use of passive systems in external arrangements gives the opportunity to use different configurations providing larger flexibility of structural behaviours.

In some recent studies, [16] and [17], the dynamic behaviour of frame structures coupled with external systems has been studied, accounting for the non-classically damped nature of the coupled system. In [17] a performance comparison between two external system configurations is done, first in terms of dynamic properties and then in terms of seismic response of different engineering parameters.

This study concerns the application of theoretical results reported in the mentioned studies to a real case, concerning the retrofit of an existing building (the Fazzini college), which has been seismically upgraded through a fixed base external dissipative system, equipped with FVDs. The building is an existing r.c. frame built in the early '70s in Italy, without adequate seismic detailing, which was severely damaged during the 2016 Central Italy seismic sequence.

2 EXTERNAL PASSIVE CONFIGURATIONS

Among the possible external arrangements three main configurations, depicted in Figure 1, can be identified. All of them exploit the stiffness of external steel trusses, while the FVDs are arranged differently based on their mechanism of activation. The first case (Figure 1 a) refers to a Fixed Base (FB) system where the dampers are located at floor levels between the building to protect and the stiff external steel structure. In such configuration the FVDs work for the relative floor displacements and their efficiency is strictly related to the stiffness of the external bracing. A similar configuration can be achieved when connecting through FVDs two adjacent buildings characterized by notably different dynamical properties.

The solution depicted in Figure 1 b) can be identified as a Diagonal Bracing (DB) system, where the dampers are installed within the external diagonal braces and that work for the inter-storey drifts of adjacent floors.

The last configuration (Figure 1 c) refers to a quite recent patented solution known as "Dissipative Tower" [19]. It consists of an external stiff bracing system pinned at its base and rigidly linked to the existing frame at the floor levels to exploit the Rocking motion of the Base (RB). In this arrangement FVDs are located at the base of the stiff brace pinned on a spherical hinge, and their activation is due to the rocking motion of the base of the bracing.

The three configurations have mainly the same ability in reducing the IDR demands, even though the RB system is the only able to linearize the deformation profile (i.e., constant IDRs distribution). Such linearization, however, have a cost in terms of exchange actions between the building and the external bracing [20]. The FB system, instead, is the one able to provide the higher reduction of PFA, that are a response parameter particularly significant for non-structural components, contents, and plants.

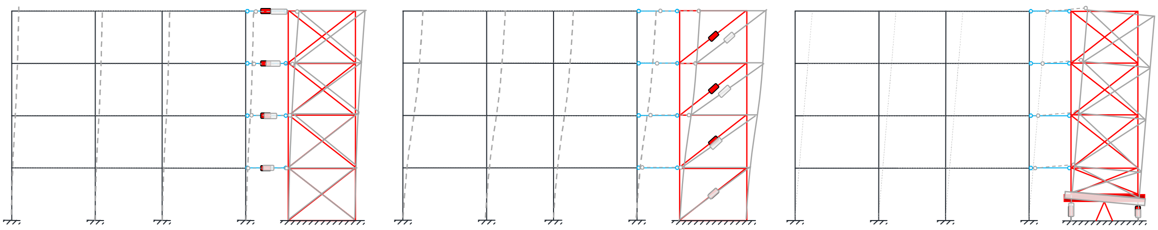

Figure 1: a) Fixed Base system; b) Diagonal Bracing system; c) Rocking Base system.

3 THE FAZZINI COLLEGE

The Fazzini college is a r.c. frame building owned by the University of Camerino and used as student residence. It was built in the early '70s, without seismic standard since the town of Camerino was declared seismic area only in 1981. The building has a partially underground elevation, plus five more levels over the ground and a roof, for a total height of nearly 19.20 m roof excluded. The plan is almost squared with dimensions nearly equal to 31 m x 25 m. The structural configuration is characterized by frames in one direction only (the N-S one), the columns are cast-in-place with nearly squared cross-sections, while the beams are realized with a partially precast system known as "REP" beam, consisting of a steel lattice girder self-supporting during the concrete casting. Such beams are realized in the thickness of the floors (h=21 cm). Figure 2 reports a picture of the building before the occurrence of the 2016 seismic sequence and structural and architectural layouts.

3.1 Seismic damage

The damages suffered by the Fazzini College occurred mainly during the mainshocks of 26th and 30th of October 2016, whose epicentres were, respectively Castelsantangelo sul Nera ($M_w = 5.9$), which is not far from Camerino, and Norcia ($M_w = 6.5$). The damages were mainly concentrated at the lower elevations of the building and related to external and internal infills partitions walls. Some damages also occurred to the stairs, whose structural conception is quite unusual.

Figure 2: a) picture of the Fazzini college before 2016; b) architectural layout of the building; c) structural layout of a floor type; d) structural section of the building.

The stairs, indeed, are realized with thin (15 cm) r.c. cantilever slabs resting only in the perimeter infills of the stairwell without any connections with the concrete core of the lift, nor with the perimeter columns of the stairwell.

Regarding the infills, whose types and distributions are depicted in Figure 3, there are three main typologies, two for the external partitions and one for the internal ones. For what concerns the external perimeter infill walls, it is possible to distinguish between the plastered infills and the "face view" ones. The first typology is realized with an internal leaf of hollow brick (s=8 cm), a cavity of variable thickness, and an external unconnected leaf realized with thicker hollow bricks (s=12.5 cm). The "face view" infill, is composed of an internal leaf of hollow brick (s=8 cm), a cavity of variable thickness, and an external unconnected leaf realized with semi-solid bricks (s=12.5 cm). Finally, the internal infills are realized with a double lining in hollow brick type tile (s=6cm), separated by a cavity of variable thickness among the different elevations.

Two different structural dynamic identifications of the Fazzini college have been performed, before and after the main events of October 2016, revealing a very significant contribution of non-structural components in terms of stiffness on the modal properties of the building (i.e. fundamental frequencies and modal shapes). The first fundamental frequency, indeed, moved from nearly 3.72 Hz to nearly 2.60 Hz. Figure 4 reports some pictures of the damages suffered by the Fazzini college.

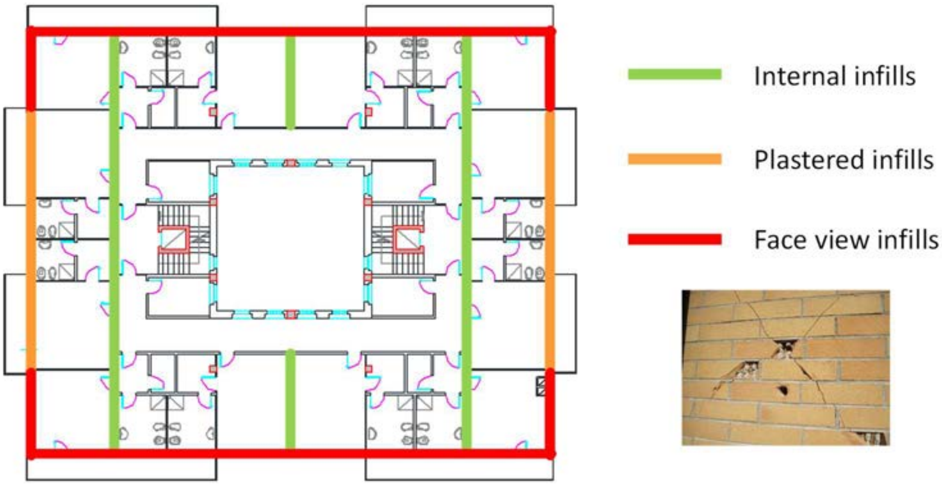

Figure 3: Layout and typologies of the Fazzini college infill walls.

a) b)

Figure 4: Pictures of the seismic damage suffered by the Fazzini college in 2016 a) damages to external infills; b) damages to the stairs of the lower elevations.

3.2 Design of the retrofit system

The retrofit of the Fazzini college has been designed by assuming the FB external passive system introduced in Figure 1. The dimensioning has been conducted by means of a linear three-element model [21] whose behaviour is governed by the following parameters (Figure 5): (i) the mass and the stiffness of the building to protect(evaluated accounting also for non-structural elements due to their relevant contribution), (ii) the stiffness of the external structure, and (iii) the damping contribution provided by the fluid viscous dampers. The efficiency of the system is strongly influenced by the ratio of the stiffness between the external structure and the building to protect, which also defines the maximum amount of added damping exploitable.

To enhance the efficiency of the retrofit and to maximize the FVDs effectiveness up to an added damping nearly equal to $\xi_{add} = 0.28$, it has been chosen to replace all the infill walls and the internal partitions (whose contribution in terms of stiffness provided is very relevant) by drywall elements.

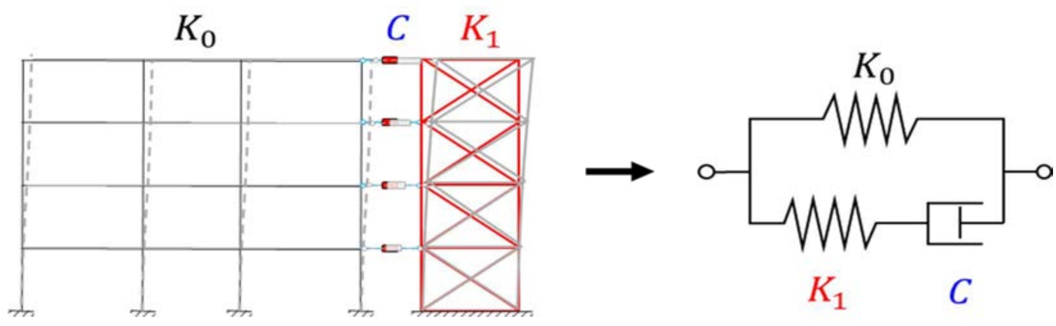

Figure 5: the three-element model, a simplified tool for the preliminary design of the retrofit with a FB system.

3.3 Details of the retrofit intervention

The retrofit of the Fazzini college, which is schematically depicted in Figure 6, involves:

- The insertion of 4 external bracing structures connected to the building through non-linear FVDs and independent foundations.
- The demolition and replacement of perimeter infill panels and internal partitions by drywall elements. This way two main objectives can be reached that are (*i*) the reduction of both mass and seismic inertia; (*ii*) no significant stiffness contribution provided by the new drywall elements, leading to a more efficient external damping system.
- The realization of a 5 cm reinforcing slab connected to the existing floor at each elevation to realize an infinitely stiff floor in its plane.

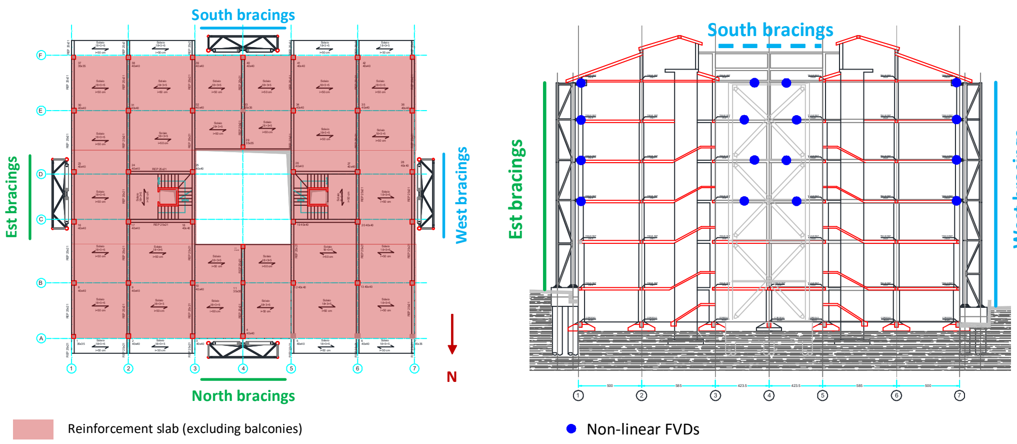

Figure 6: schematic views of the Fazzini college retrofit.

4 CONCLUSIONS

With reference to the retrofit of the Fazzini college, the following conclusions can be drawn:

- The FB system chosen is a retrofit solution characterized by localized interactions in the connection zones, and able to notably reduce the interferences with activities carried out in the buildings.
- The design procedure followed guarantees the protection of structural and non-structural elements against seismic actions (also beyond the design condition), notably increasing the building resilience.

- The replacement of infill walls and partitions by drywall elements reduces the seismic mass, the loads on perimetral beams and leads to a more efficient external damping system.

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