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Response of infilled RC frames retrofitted with a cementitious fiber-mesh reinforced coating in moderate seismicity areas

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HIGHLIGHTS

- 3 full-scale reverse cyclic tests on 3 hollow clay brick masonry infills.
- Seismic performance of thin layer of mortar coating connected to both the RC frame and the infilled panel.
- Significant improvement of both lateral stiffness and masonry resistance.
- Need of reducing shear sliding along the masonry panel-RC frame interface.

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ABSTRACT

A significant number of Infilled Reinforce Concrete (RC) frame structures constructed worldwide are not designed to withstand seismic actions. An important contribution to the lateral resistance of the bare frame is usually provided by weak masonry infills, whose interaction with the frame has been frequently neglected by designers.

In case low-rise buildings placed in low seismicity areas are considered, the moderate inelastic demand resulting from the seismic excitation allows implementing retrofitting techniques aiming at improving the structure resistance rather than its ability to dissipate energy by inelastic mechanisms.

This paper studies a retrofitting approach aiming at exploiting the frame-to-infill interaction by using a thin layer of mortar coating connected to the outer surfaces of the perimeter walls of the RC buildings. The coating is applied on the existent plaster and is reinforced with an Alkali-Resistant glass fiber mesh properly anchored to the infill.

A series of reverse cyclic tests on three hollow clay brick masonry infills, including a not strengthened wall as well as a strengthened and a repaired specimen, was carried out. A special RC frame provided with steel hinges at the columns edges was built to simulate flexural mechanisms generally occurring in weakly reinforced frames. Results proved the ability of the adopted technique to significantly improve both lateral stiffness and resistance of infills. However, the observed behavior suggested future improvements that may lead to a further increment of the infill capacity.

1. Introduction

The earthquake events occurred even recently in many seismic prone countries worldwide have focused the attention on the significant vulnerability of existing Reinforced Concrete (RC) buildings designed only for gravity loads. As highlighted by other authors [1,2], most of these constructions were designed before the mid-'70s, when building codes introduced the first seismic provisions.

Several researches [3,4] have proved that the high vulnerability of the RC structures designed only for gravity loads is generally related to the not adequate longitudinal and transverse reinforcement detailing especially in the beam-column joint regions of the structure. The aforementioned RC building typologies usually have quite regular shapes and are made of moment resisting frames placed orthogonally and connected by one-way or two-way slabs. The perimeter frames of the building are traditionally provided with Un-Reinforced Masonry (URM) infills with or without openings, whose behavior is closely related to the considered masonry infill typology [5]. Considering the very poor seismic resistance of the RC frame, the URM infill may represent an important structural resource able to improve the lateral stiffness and resistance of

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the frame because of its bracing effect [6]. On the contrary, compared to the behavior of the bare frame, the frame-to-infill interaction may cause negative effects on the structure response both at the local (e.g., shear failure of columns, column-beam joints damage) [7] and at the global (e.g., soft-story mechanism) level. In spite of its importance, the study of the infill-frame interaction is out of the scope of this work and will not be further investigated in the following.

Two different approaches can be implemented to improve the seismic performance of RC buildings.

The former consists in reducing the frame-infill interaction so that the infills are totally isolated from the structural system or, as an alternative, they are partially isolated by proper joints (partition joints) leading to a more ductile in-plane response of the infill [8–11].

The second approach, much less studied in the literature, considers the URM infill as a structural element whose interaction with the frame has to be properly considered in the design and detailing. As mentioned before, the positive contribution of the masonry infill to the seismic resistance of the frame could be softened by the failure of the masonry panel due to its often low ductility. In order to improve the behavior of existing structures, the URM infills can be reinforced by different techniques able to increase their in-plane stiffness, resistance and, if possible, ductility.

The seismic upgrading of masonry infills can be achieved by using techniques such as the grout injection, pre-stressing or the insertion of reinforcing bars. Alternatively, RC panels or reinforced concrete coating can be applied on both side of the panel and connected to masonry by dowels. From the structural point of view these methods are generally really effective but, on the contrary, they present some drawbacks like the need for skilled labor, the high economical costs and the interruption of the normal function of the building during construction. Moreover, they may cause also an important increment of the structural mass involving more severe actions during the seismic event. When reinforced coating is adopted, these drawbacks could be mitigated by using only a single strengthening layer applied on the external side of the wall and/or by reducing the coating thickness. The latter can be obtained by reinforcing concrete/mortar with GFRP meshes [12] or randomly diffused steel fibers [13,14] that do not require to meet the minimum cover requirements. About techniques adopting GFRP meshes, an interesting work reporting cyclic shear tests on stone masonry walls is reported in [15]. The latter presents and discuss the use of Glass Fiber Reinforced Mortar Jacketing, including a detailed description of the connection devices used to anchor the reinforcing mesh to the masonry wall.

Researches recently suggested the use of textile-reinforcement [16,17] for reinforcing mortar overlays to improve the in-plane resistance of masonry panels. A further development of the technique based on the use of strengthening overlays is represented by the adoption of high performance fiber-reinforced cementitious composites [18] or Engineered Cementitious Composites (ECCs) [19]. Besides the ability of improving the in-plane resistance, the reinforced coating allows increasing the out-of-plane capacity of the infill [20–22]. Note that the latter does not represent the main topic of this work and it will not be further investigated in the following.

Another effective solution able to give additional tensile reinforcement to masonry is the use of fiber reinforced polymer (FRP) laminates [23–25]. Experimental results have proven the ability of these composites to improve the resistance and the energy absorption capacity, especially when FRP laminates are properly anchored to both the masonry surface and to the corners of the RC frame. Anyway, FRPs remain elastic up to failure and they may experience debonding from the infill surface [26]. Considering the high cost of epoxies and skills required for the application of the FRP sheets and the preparation of the masonry surface, this technique is not usually more economical than that adopting reinforced mortar/concrete coating.

A common retrofitting technique consists in connecting RC walls or steel bracing frames to existing structures [27,28]. This type of intervention is quite easy to implement and is really effective from the structural point of view. However, the additional walls are much stiffer than the other vertical structural elements of the frame and, as a consequence, the seismic actions tends to concentrate on their foundations. Therefore, when designing the new walls, the size of the foundations must be carefully chosen because their cost considerably affects the economical effort to undertake the whole retrofitting intervention.

The aim of the present study is to investigate an effective, practical and economically advantageous technique for improving the seismic performance of low-rise (2–3 stories at maximum) gravity load-designed infilled RC buildings, placed in low seismicity areas ($a_g < 0.15$ g). Likewise other studies, which proposed a similar strengthening approach [29,16,30], the proposed technique consists in applying a thin layer (i.e., ~20 mm) of normal strength mortar only on the external façade of the building [31]. The cementitious mortar coating is reinforced by a single sheet of an Alkali-Resistant (AR) glass fiber mesh connected to both the existing plaster and the masonry infill. The latter is made of 120 mm thick hollow clay bricks with horizontal holes typically used in the RC buildings constructed in the North of Italy between the '60s and the '70s of the last century. The technique presents many practical advantages: 1: the Glass Fiber mesh Reinforced Mortar (GFRM) coating can be applied on the existent plaster and it can be used as a new finish coating for the façade of the building; 2: the materials required to build and apply the GFRM coating are relatively inexpensive and are frequently utilized in the retrofitting and restoration interventions; and 3: considering that the retrofitting intervention involves only the exterior walls of the building, the normal functions of the structure are not significantly disturbed and, in case of residential buildings, the inhabitants are not forced to leave their apartments.

The paper summarizes and discusses the results of in-plane reverse cyclic tests performed on three full scale specimens representing a typical masonry infill placed at the ground floor of a RC building. Particular attention was devoted to the design and installation of proper connection devices able to join the coating to the masonry panel as well to the frame. The experimental study included a test on an unstrengthened specimen and two tests performed on a pre-damaged and a new infill repaired and strengthened with GFRM, respectively.

2. Adopted retrofitting technique: description and application to the test frame

RC buildings designed to resist only to gravity loads are made of weak frames horizontally connected by RC floors. The moment resisting frames are not able to withstand important lateral actions by themselves. However, the masonry infills placed within the exterior walls (Fig. 1a) may act as bracing systems that allow increasing the in-plane resistance of the frame. In spite of this the brittle failure of the infills and the low ductility of the frame may lead to the formation of a soft story with consequent large demands of shear and flexural deformations in columns or beams.

Fig. 1 reports a schematic view of a typical RC building constructed before the '70s of the last century. The structure presents moment resisting frames placed only in the longitudinal direction (i.e., the longest side of the building), whereas in the orthogonal direction frames are placed only along the perimeter walls.