Reinforced Concrete Infilled Frames

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Masonry-Infilled Reinforced Concrete Frames are a very widespread structural typology all over the world for civil, strategic or productive uses. The damages due to these masonry panels can be life threatening to humans and can severely impact economic losses, as shown during past earthquakes. In fact, during a seismic event, most victims are caused by the collapse of buildings or due to nonstructural elements. The damage caused by an earthquake on nonstructural elements, i.e., those not belonging to the actual structural body of the building, is important for the purposes of a more general description of the effects and, of course, for economic estimates. In fact, after an earthquake, albeit of a low entity, it is very frequent to find even widespread damages of nonstructural elements causing major inconveniences even if the primary structure has reported minor damages. In recent years, many territories have been hit worldwide by strong seismic sequences, which caused widespread damages to the nonstructural elements and in particular to the masonry internal partitions and the masonry infill panels of the buildings in reinforced concrete, with damage to the floor and out-of-plane expulsions/collapses of single layers. Unfortunately, these critical issues have arisen not only in historic, but also in recent buildings with reinforced concrete, in many cases exhibiting inadequate seismic behavior, only partly attributable to the intrinsic vulnerability of the masonry panels against seismic actions. Such problems are due to the following aspects: lack of attention to construction details in the realization of the construction, use of poor-quality materials, and above all lack of design tools for the infill masonry walls. In 2018, regarding the design of nonstructural elements, the formulation of floor spectra has been recently introduced in Italy. This entry article wants to focus on all these aspects, describing the state of the art, the literature studies and the design problems to be solved.

Keywords: infilled RC frames ; nonstructural elements ; earthquake damages ; macro-models ; seismic behavior

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In the complex of a building, are distinguished load-bearing and non-load-bearing elements. The former constitute the structure of the building and they are entrusted with the task of transmitting the vertical and horizontal actions acting on the building. The latter, on the other hand, are entrusted with other tasks:

- delimitation of the building envelope (infill);

- separation between internal environments (partitions);

- environmental comfort (acoustic insulation, thermal insulation, visual comfort, fire resistance).

In particular, the internal partitions fall within the family of vertical closures, i.e., they are those factory elements, of any shape, which constitute the vertical envelope of the built space and also represent the elements of separation between the external and internal microclimate.

Furthermore, in each structure, vertical elements and horizontal elements are also distinguished, and with them the load path is defined, which normally starts from the horizontal ones, continues in the vertical ones and leads them up to the foundation. In the case of structures in masonry, the vertical elements are made up of load-bearing walls, while in the reinforced concrete structures the vertical elements are the pillars. In the first case, therefore, load-bearing and nonbearing walls coexist, while in the second case, the structure is divided into compartments and delimited from the external environment by partitions that theoretically have no static function.

In reality, however, these non-load-bearing walls (infill walls) made within the meshes of the frames—although not considered, in the calculation phase of the structure, to be resistant to any force—influence the behavior of the structure subject to seismic events in terms of increased stiffness and resistance to lateral loads, as well as a significant increase in dissipative capacity.

In fact, the bare frames are designed with reference to bending regimes with the formation of plastic hinges at the nodes under the effect of lateral loads, while in the buffered frames, a mechanism is established in the panel that creates a bracing and traction effect in the pillars. Therefore, a different distribution of acting forces arises which gives rise to stresses not foreseen in the calculation phase, in the absence of partitions and infill panels.

This increase in stiffness, in some cases, allows the structure to adequately resist intense and prolonged seismic actions only thanks to the presence of infill walls, which allow a greater dissipation of the quantity of energy entering the system. Their contribution is demonstrated by the classic X-shaped cracks which indicate a shear failure under cyclic loads (**Figure 1**).

Figure 1. (**a**). Classic X-shaped infill lesion with intact supporting structure; (**b**). Typical expulsion of infill masonry wall [1].

However, the presence of infills does not always create a beneficial effect on the structure subject to an earthquake. In fact, due to the high stiffness, the infill panels can originate irregular plan configurations, jeopardizing a correct upstream structural configuration. These situations can also occur starting from a situation of regularity following a collapse of some wall panels which causes an imbalance in the stresses acting on the structural elements. This occurs because of the high fragility of the materials and because the breakage is a result of the loss of balance outside the plane due to the ineffectiveness of the connection with the structure and due to instability phenomena linked to the reduced thickness of the wall panels compared to the others.

In fact, the seismic behavior of buildings is significantly influenced by presence of masonry infill panels, as is now recognized by numerous studies, as well as reconnaissance for the relief of post-earthquake damage. Although in some cases the presence of rear-end collisions has positive effects on structural behavior, the walls are often susceptible to high levels of damage, even to the expulsion of the panel, particularly dangerous due to falling debris. Despite the critical importance of the infill walls to safeguard life, the presence of the panels is often neglected in the design and numerical modeling phases, as the same they are formally nonstructural elements.

Reinforced Concrete Frames with Masonry

The structures can be assimilated to real organisms consisting of a series of structural elements that collaborate with each other in a synergistic way and allow the loads to discharge to the ground. The structure, however, is not only made up of these structural elements, whose main function is precisely that of allowing the structure to exist and not to collapse under the effect of loads, but it is also made up of many elements which, although not performing a structural function, are however very important, if not fundamental, as they make the structure usable.

These elements, defined precisely as nonstructural elements, can be of an architectural nature (balconies, false ceilings, plasters, partitions, etc.), plant engineering (electrical, ventilation, heating, gas, etc.), may have a function associated with the safety of utilities (escape routes) or can simply be linked to the furniture (shelving, bookcases). However, being classified as nonstructural elements does not make them any less important. In fact, with reference to the seismic events that have struck Italy in recent years, the damage, or in some cases the actual collapse, of these nonstructural elements has caused even irreparable damage to the structural organism to which they belonged (making it unusable and therefore subject to demolition), as well as damage to people. To support the thesis according to which these elements, although not having a purely structural function, play an absolutely not marginal role in terms of safety, reference is made to the Technical Construction Standards 2018 (NTC18 [2]) which in § 7.2.3 define the nonstructural elements as follows: “By nonstructural construction elements we mean those with stiffness, strength and mass such as to significantly influence the structural response and those which, while not affecting the structural response, they are nonetheless significant for the safety and/or safety of people”.

As specified by the legislation, the nonstructural elements do not have a load-bearing function, i.e., their absence does not affect the structural stability; however, they significantly influence the behavior of the structural organism to which they are associated, but above all they can cause damage to people if they are not well designed. Non-structural elements require careful design which is often not carried out in design practice, causing, as already described, serious accidents during earthquakes.

One of the most important nonstructural elements, which has attracted the attention of many researchers in the sector in recent years, is represented by infill masonry walls. The reason for this is straightforward: the most common construction type in many countries of the world, but especially in Europe (including Italy), is represented by reinforced concrete frame structures. The supporting elements of these structures, by their very nature, do not allow one subdivision between internal and external space; therefore, it is necessary to introduce elements of a nonstructural nature that are able to perform this function. In this regard, the best element for economy, ease of installation, versatility and thermal and acoustic performance is represented by the masonry infill. The masonry infill is nothing more than the set of different brick elements (bricks and/or blocks, perforated or not) connected to each other usually with mortar, but it is not uncommon to see other types of binders used (curtain walls represent an example with glue joints). They are superimposed on each other to fill the various perimeter spans of the frame structure to create a separation between the internal and external environments. Obviously, some of these infill walls will have openings which will then be filled with fixtures of various kinds. Often, to improve performance in terms of thermal and acoustic insulation, the masonry infills are made by coupling two layers of brick separated from each other by a filled cavity with insulating material or simply left empty.

In the field of residential constructions, infill panels are usually made of nonreinforced brick. On the contrary, in the field of structures for industrial use, given the larger dimensions and different needs, the type of masonry infill increasingly used is reinforced, characterized simply by the presence of reinforcement pylons placed in correspondence with the sick beds. However, it should be noted that below, with the term plugging, we will always and only refer to plugging in nonreinforced masonry.

On the basis of this description, it is easy to understand how, by its nature, the infill wall is not conceived as an element capable of fulfilling a load-bearing function, which is why it is often neglected from a structural point of view: the less attentive designers, in fact, deal with the design of the load-bearing elements (beams, pillars, curbs, floors, etc.), completely forgetting that these structural elements, during the useful life of the work, will have to collaborate with other nonstructural elements, such as curtain walls, and that the presence of these will necessarily influence it.

This way of designing is justified: the infill walls are made only after the frame structure has been completed, thus releasing them from any load-bearing function against vertical loads. In addition, the utilities and/or the intended use of the structure may change, and with them the arrangement of the openings may also change, which makes the infills susceptible to mutations and makes modifications over time difficult to predict in the design phase.

These might seem to be sufficiently valid reasons to justify the negligence of rear-end collisions in the design phase, but they are not as we will see better below.

First of all, to avoid those tensional states associated with the action of external loads that may arise inside the infills (thus giving these elements a load-bearing structural function when these, as they were conceived, do not have), it is good to realize the infills starting from the top floor of the building and then gradually descend towards the lower floors. This is a good rule of thumb that avoids loading the infill panels by creating first those of the higher floors and then cascading those of the lower floors; the vertical load associated with the elastic deformation suffered by the elements of the frame is not severe on the rear-end collisions themselves. Therefore, operating in this way, it will not be possible to consider the contribution of rear-end collisions to withstand vertical loads representing a valid and justified approximation. Another thing is the negligence of rear-end collisions with respect to horizontal actions, in particular from the stresses deriving from seismic events.

References

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