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Experimental study on the response of seismically isolated masonry infilled steel frames during the initial stages of a seismic movement

Francisco J. Pallarés *, Luis Pallarés

ICITECH – Instituto de Ciencia y Tecnología del Hormigón, Universitat Politécnica de Valéncia, c/ Camino de Vera s/n, 46022 Valencia, Spain

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ABSTRACT

A novel seismic isolator is presented to detach the structural behavior from the infill effect during earth movements, with the aim of avoiding strong interactions. An experimental campaign was carried out to determine the influence of this isolator during the early stages of the seismic response of masonry-infilled steel frames, testing different configuration schemes to assess their effectiveness in terms of overall isolation, reduction of peak loads, strain levels and energy dissipation. The device was found to hinder the formation of the damaging diagonal compression struts by absorbing the relative displacements between frame and infill. The results achieved show that seismic interaction between infill panels and the structural skeleton can be faced from an isolation point of view.

1. Introduction

Clay brick or concrete block masonry is used to build walls that provide good thermal and sound insulation, and resistant capacities. As it is easy to install and light enough to be carried around the building site, it is one of the most frequently used materials for curtain walls in the openings between reinforced concrete or steel frames in building construction.

In this form and without any reinforcement, it is considered as a non-structural element by many international Standards [1–5] and so is ignored in the calculations. This is quite realistic when only gravity loads are taken into account, but could be a grave shortcoming when dynamic loads are considered, as many research groups have been pointing out for some time [6–8]. Masonry panels stiffen the structure against seismic loads and modify building's strength, damping, hysteretic behavior and deformation capacity. For example, El-Dakhakhni et al. [8] proposed a strut model for masonry-infilled steel frames in an attempt to take into account the important effect of masonry panels in a structure's seismic response. These authors point out the complexity of the problem, since total or partial panel failure may cause the sudden transfer of seismic forces to other parts of the structure, while admitting that no realistic analytical models are available.

Recent earthquakes in Spain (Lorca, 2011) [9] and other parts of the world [10] have made it clear that non-structural masonry plays an important role in the seismic behavior of framed buildings [11–13] and can help to reduce economic losses and human casualties (Fig. 1). Refs. [14–17] point out this role when study the response of buildings in Lorca earthquake. These non-structural elements can induce damage to structural elements under seismic loads (ends of beams and columns) leading to failure mechanisms, as has occurred in Lorca and many earthquakes.

There are two main approaches to the problem of masonry infills in building design: [18–20] (a) consideration, (b) isolation.

The former approach takes masonry walls into account in the seismic design, which are usually strengthened to consider the interacting structural infill influencing the seismic response. Different methods have been used to model the phenomenon, including: elastic theory, plastic theory, limit state and equilibrium, finite elements using macro- and micro-modeling for masonry, experimental formulae, etc., and many references from many years ago to present can be found in the scientific literature related to this approach: e.g. tying walls [21,22], concrete jacketing of walls [23], epoxy and cementitious fiber composites [24–29], prestressing techniques [30], or design of new units [31,32]. However, these methods and techniques are sometimes rather complex and difficult to replicate without the help of precise numerical models able to reproduce a building's actual behavior. Furthermore, the interaction also varies during the course of the seismic action, thus complicating the design even further. Nevertheless, the interaction between the building structure and non-structural masonry is usually studied from the resistance point of view by including the non-structural panels in the resistant elements. Together with the fact that masonry panels are considered

* Corresponding author.
E-mail addresses: frapalru@fis.upv.es (F.J. Pallarés), luipalru@cst.upv.es (L. Pallarés).

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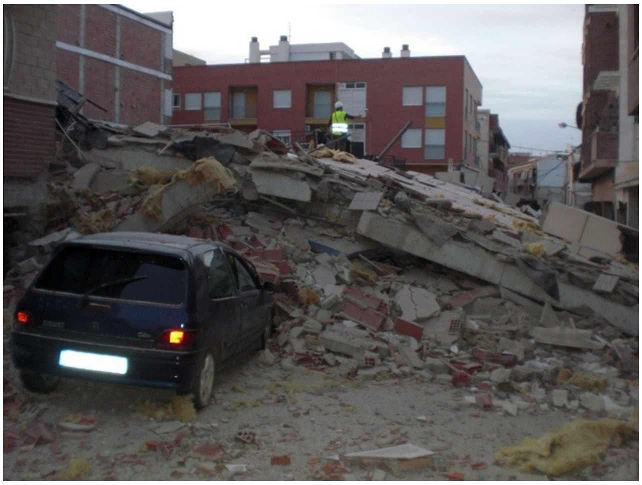

Fig. 1. Building failure in Lorca earthquake (Spain, 2011).

as non-structural elements and can be freely moved around in the architectural design, this would invalidate any analytical consideration. For these reasons the authors focused on the second approach to the problem of interaction: isolation.

Regarding this second approach, of the different techniques that can be used to isolate a masonry panel from the building's structural skeleton, one of the most obvious is to fill the joint between frame and panel with a flexible strip. However, the main drawback to this technique is that it is not advisable to have a soft joint at the base of the panel, besides the fact that a flexible joint around the frame would reduce the panel's out-of-plane performance.

A big step towards a practical solution to isolating masonry panels and frames would be obtained if it were possible to design a connection able to provide flexibility through the in-plane behavior and stiffness through the out-of-plane behavior. Although this has already been pointed out many times in the scientific literature, as far as the authors are aware, no practical commercial systems have as yet been developed to isolate the resisting skeleton from the non-structural masonry walls.

A number of different solutions have been suggested by several research groups in this field; e.g. [33,34] developed a steel subframe attached to the steel building frame. Basically, this subframe is made of vertical and horizontal steel members and a special piece acting as a 'fuse' separates the infill from the structure in case of large lateral forces. Markulak et al. [35] studied the behavior of steel frames infilled with masonry, introducing special perforated blocks and lightweight autoclaved aerated concrete blocks that allowed partial separation of the masonry from the frame to limit combined frame-infill action. Others have proposed the use of different materials, e.g. polymers [36], to avoid structural interaction between frame and infill or enhancement properties.

Other references about base isolation of masonry buildings can be found [37–39], but they are not specifically related to panels' seismic isolation. In the same sense, the works [40,41] can be referenced here. The former introduced a visco-elastic material (lead) between beam and the top layer of the masonry wall in an attempt to isolate the restraint introduced by the wall on to the columns when these creep in the long term. Beside, these authors performed in-plane tests to confirm that the lead layer did not have adverse effects on the specimens. The latter work shows tests performed using a 'frictional sliding fuse', which is a device composed of steel plates that divides the infill into two parts by a horizontal layer, allowing sliding in longitudinal direction before infill crushing but restraining transversal movements. The device can be regulated to adjust strength and ductility.

Since few references can be found related to seismic isolation of masonry panels, the authors decided to carry out some research themselves in this important field. In the following sections it is described the result in the form of a new product intended to solve the problems that arise when retrofitting masonry panels that have not been seismically isolated.

This paper thus proposes an experimental procedure designed to test a novel seismic isolation device conceived to separate the dynamic response of the building from the influence of its masonry walls, in an attempt to shed some light on the field of seismic isolation. Experiments were carried out to evaluate the energy dissipation, peak load, hysteretic curves and strain levels of isolated infilled frames under small displacements before the onset of visual damage to panels and frames. In this way the authors thought it would be possible to determine the behavior of the structure during the initial phases, close to the elastic range and compare the actual response with the predicted response in the design phase of the bare structure, in which the infills are not usually considered.

2. Seismic isolator for masonry panels

It is clear that one of the main phenomena affecting the seismic response of frame buildings infilled with masonry panels is the formation of diagonal compression struts (e.g. FEMA 273 [42]).

As a consequence of horizontal displacements, when there is drift between different floors, a resisting mechanism known as a 'diagonal compression strut' appears to resist the seismic loads. This mechanism often causes damage to the ends of beams and columns and to masonry panels, as can be observed in the simplified sketch in Fig. 2. This phenomenon also occurs in partially infilled frames, in which the panel reduces the effective length of the columns, leading to unexpected failures.

These diagonal compression struts are used to account for the contribution of the masonry panel when modeling infilled frames; however the way in which the infill and frame interact is not clear, so that it is difficult to explain the complex behavior exhibited by panels under seismic movements.

Since no practical models have yet been developed to properly consider the panels in the computations, and since infills are considered as non-structural and can be added or removed from the structure by the tenants, the present authors opted to aim their efforts towards the isolation philosophy.

In tests carried out at the Universitat Politècnica de Valéncia, the authors initiated research on a novel device and achieved a high degree of structural independence between the seismic response of the building structure and the influence of the masonry infill. The purpose of this device is to act as a seismic isolator in a way that allows the structural frames to deform without being affected by the high stiffness introduced by the masonry panels.

The SISBRICK seismic isolator (Fig. 3a) is similar to a normal brick in shape and size and is made of a deformable matrix with an elastic modulus a few orders of magnitude smaller than commercial bricks, able to allow movements in one direction, and contain a steel frame able to withstand forces in the two perpendicular directions. Installed at the corners of the frame, it can absorb the relative movements induced by the structure, increasing out of plane resistance and hindering the formation of diagonal compression struts. Fig. 3b shows the compression test performed on the deformable matrix material, with an elastic modulus of 15 MPa and elastic behavior in a wide range of strain. The material used in the tests is polyurethane, but any material accomplishing this mechanical characteristic would be valid from a seismic point of view. The steel frame is made of reinforcement bars B500S with 6 mm diameter, not all of them fully crossing the matrix to allow for deformability.

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