Engineering Structures 173 (2018) 546–558

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Out-of-plane structural identification of a masonry infill wall inside beam-column RC frames

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ARTICLE INFO

Keywords:
Out-of-plane
Infill masonry wall
Structural identification, in situ test
Updating

ABSTRACT

Field observations after seismic events have shown that out-of-plane collapses are one of the predominant modes of infill masonry wall failure leading to life-safety hazards. This type of mechanism depends on the geometrical and mechanical features of the structure, but it is substantially affected by the constraints along the structural frame. However, the actual boundary conditions are very difficult to define, especially in the case of an existing building, for which information is lacking, a visual screening can be inefficient, and deterioration may have occurred due to the design conditions.

In this paper, a procedure for the structural identification of the out-of-plane behaviour of infill masonry walls using a simple and cost effective innovative procedure based on an in situ experimental dynamic test and a consequent process of updating is proposed. The procedure, composed of the in situ test and the updating of the numerical model, was implemented for a case study to confirm that it is effective in defining the mechanical characteristics of the masonry, the absence of collaboration between the two brick leaves of the infill wall, and the out-of-plane constraints along the perimeter.

1. Introduction

Infill walls are commonly used as the enclosure elements of RC framed buildings in Italy, as well as throughout the world, mainly to ensure adequate thermal and sound insulation. However, because of their low bearing capacity, they are usually considered non-structural components. Even though no structural function is attributed to the infill walls and they are not usually considered in the seismic resisting system models, they are able to interact with the frame structure, influencing the seismic response of the buildings [1,2]. Furthermore, among the non-structural components, the infill walls can cause serious economic damages and pose a risk to human life. In fact, field observations after seismic events proved that an out-of-plane (OOP) collapse is one of the predominant modes of infill failure, depending on the type of wall and the efficiency of its connection to the RC frame, as in the case of the L'Aquila earthquake in Italy in 2009 [3].

This failure mode in the OOP direction leads to life-safety hazards from falling debris and needs to be considered during the design process and erection.

In addition, the out-of-plane damage can limit the immediate occupancy after the earthquake event. In fact, during L'Aquila earthquake in 2009 [4] and recent Italian earthquakes (Emilia 2012; Central Italy 2016–2017), in many cases no immediate occupancy was possible due to the generalized damage in the infill masonry walls, due to OOP mechanism, compared to the minor cracks observed in the structure (Fig. 1).

The OOP failure mechanisms and associated cracking patterns of infill masonry walls are influenced by several aspects. A detailed study of the parameters that influence the out-of-plane seismic response was developed in [5], in which linear analysis of infill masonry walls standing alone or inserted in frames was performed, and the role of the connection efficiency along the perimeter was proven.

Furthermore, also the vertical load in the masonry wall could influence its degree of constraint and strength. Experimental investigations on the in-plane behaviour of the infill masonry walls conducted by [6] showed that high vertical loads in the frames increase the masonry-frame contact length and constraint. In fact the lateral strength and stiffness of the infilled frames are increased, by applying vertical load if it is lower than approximately half of compressive strength of the infill panels; nevertheless, higher levels of vertical load have adverse effect on the resistance of the system [7,8]. The effect of vertical pre-stressing load on the out-of-plane behaviour of infill masonry walls was studied by [9] showing that it delays the development of cracking stresses and higher first cracking and failure pressures were obtained. However there are few researches on this topic and it is very difficult to check the vertical load value in site, but in general the presence of the vertical

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https://doi.org/10.1016/j.engstruct.2018.06.072
Received 18 December 2017; Received in revised form 15 May 2018; Accepted 19 June 2018

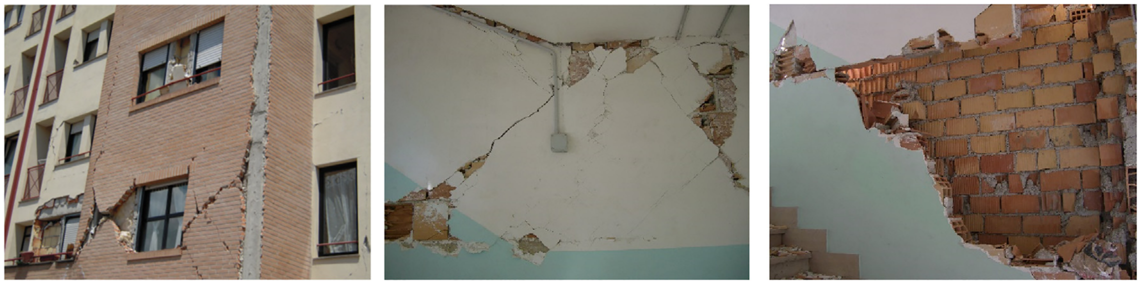

Fig. 1. Damage in the infill masonry walls.

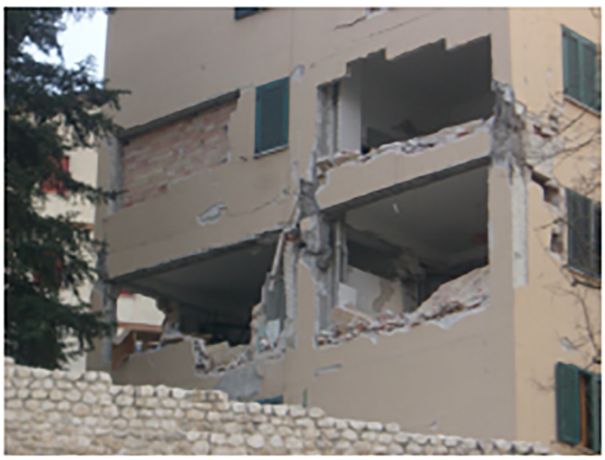

Fig. 2. Out of plane infill wall failure.

load can increase the friction effect and therefore the degree of constraint in the out-of-plane direction.

Anyway the boundary conditions of the masonry infill walls depend on various effects as the orthogonal infill walls and inner leaf panels, the upper and lower RC beams, the lateral columns, the vertical load, therefore they are very difficult to define, especially in the case of an existing building, for which information is lacking and a visual screening is inefficient.

Therefore, the main topic of the research presented in this paper is to examine a possible procedure to identify the actual degree of constraint of the infill masonry walls in existing buildings.

The problem can be assimilated to a general problem of structural identification of a complex system influenced by the real conditions of restraints and the uncertain mechanical characteristics of the material, which is currently often approached by dynamic tests in situ [10–13] and modelling calibration through experimental results [14–17].

Generally, the dynamic in situ tests are carried out to identify the global behaviour of the structures, whereas, in this case, the proposed procedure aims to identify a single component in terms of a local behaviour. This type of procedure has been applied for masonry facades in few cases [18], and recently to infill masonry walls [19] but only to analyse the experimental response without the calibration of a model.

In this paper the structural identification of a single infill masonry wall of an existing RC framed building is presented; the procedure was developed carrying out an in situ experimental dynamic test and updating a numerical model with the main topic of assessing the effectiveness of the boundary condition due to the RC frame.

Thus a Hammer Impact Modal Testing (HIMT), applying an impact force to the infill masonry wall, was adopted as dynamic test, because this employment of the local excitation facilitates the identification of the response of the panel respect to the surrounding RC frame.

The results of the proposed research confirm the effectiveness of the method, complete of the in situ test and the updating of the numerical model, to define the mechanical characteristics of the masonry and the out-of-plane constraints along the perimeter.

The study presented in this paper has been carried out on a solid masonry infill wall, however the dynamic test can be carried out also for a holed wall (window or door can be present) changing the location of the instruments; furthermore the numerical model can be implemented considering the hole or other types of materials and different dimensions of the wall.

2. The out-of-plane seismic response of the infill walls

Observation of the damage after earthquakes reveals that infill walls and partitions are often prone to OOP failures among the elements of a framed building.

The OOP mechanisms are of particular interest because they influence two aspects of the building's safety. First, they may affect the overall structural response by excluding the infill walls from the cooperation in the plane of the frames, modifying the initial configuration of the structure and sometimes introducing irregularities in stiffness and strength. Furthermore, they can pose a threat to human health since the OOP is a brittle failure, which includes the falling of rubble.

This type of mechanisms may often occur even in the case of low or moderate earthquakes. In fact, in most earthquakes, the ground motion is not strong enough to cause structural damage, but the external infill walls are expelled from the structural frame (Fig. 2) due to improper anchorage and interaction between the infill walls and the surrounding frame.

The OOP mechanism depends on the geometrical (slenderness) and mechanical (elastic modulus and strength) features, but it is substantially conditioned to the peripheral connection that establishes the degree of constraint.

For infill masonry walls made of double leaves, the connection efficiency between the two leaves also plays a key role [20,21].

Traditionally, the external masonry of single or double leaf walls were constructed to fill concrete or steel frame cells having structural members with the same thicknesses. However, in most cases the infill masonry walls have an external overhanging of 50–80 mm outwards from the structure surface, which assures external protection of the concrete members with one or two clay brick voids to minimize thermal bridge effects over internal surfaces, such as mould growth and internal and external condensation [20] or to hide the concrete frame. In these cases, the width of the support of the walls on the floor slabs or beams is reduced, which causes the infill wall to be more prone to OOP failure. However, earthquake damage also reveals that the OOP mechanism can occur for lower levels of acceleration if previous in-plane damage is inflicted over the wall or if secondary elements (as cabinets) are connected to the external walls [3].

Recently, the interest in the OOP response of infill masonry walls has been growing in regards to both the aspect of building safety and the economic loss caused by the seismic damage of non-structural components; in fact, various experimental tests [22–28] were carried out on this subject. The results highlighted that the OOP carrying capacity of the infill masonry walls is noticeably affected by the slenderness and the boundary conditions of the panel, the mechanical