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EXTENDED ABSTRACT

Investigating the seismic performance of masonry infills with opening and non-opening by considering the interaction of behavior in plane and out of the plane and providing the reduction factor of effective stiffness and ultimate strength

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1. Introduction

Masonry infills are an unavoidable member of any building. The presence of openings in a masonry infill alters its behaviour and reduces the load strength and stiffness of the infilled frame. Considering the reality of the masonry infill, the capacity of masonry infill is defined in two separate modes of in-plane (IP) force and out-plane (OOP) force (Asteris et al., 2017). In this paper, the main goal is to investigate masonry infills with different window and door openings with different dimensions and locations under three types of loading, which are: 1- Out-of-plane Loading of masonry infill under different accelerations. 2- Out-of-plane loading after in-plane loading at relative displacements (drift) of 0.5%, 1%, 2%, and 3% and check for Out-of-plane damage. 3- In-plane loading up to 6% relative displacement (drift) after out-of-plane loading and checking for in-plane damage. The numerical models are generated in finite element ABAQUS soft. Nonlinear pushover analyses have been conducted for each of the three loading. At the end, reduction factors of effective stiffness and ultimate strength are suggested. By using these suggested reduction factors, the design engineer can model the interaction effects in-plane and out-of-plane using the compression diagonal struts method. The average reduction of the infill stiffness was calculated by considering the interaction in-plane and out-of-plane 30%.

2. Methodology

2.1. Numerical study

In this article, the laboratory models of Mansouri et al. (2014) (Mansouri et al., 2014) have been used for analytical models. Analytical specimens, as shown in Figure 1, consist of a one-story single-story of reinforced concrete frame, a reinforced concrete frame with solid masonry infill, a reinforced concrete frames with masonry infill with a non-central door opening, and three reinforced concrete frame with a window opening with different dimensions and location with a scale of 1:2. The geometric characteristics of the non-seismic reinforced concrete frame are shown in Figure 2. The dimensions of the brick are 31 * 49 * 106 respectively (thickness * height * length) in millimeters. The material properties of masonry infill, are shown in Table 1. These results of tests have been used in numerical modeling.

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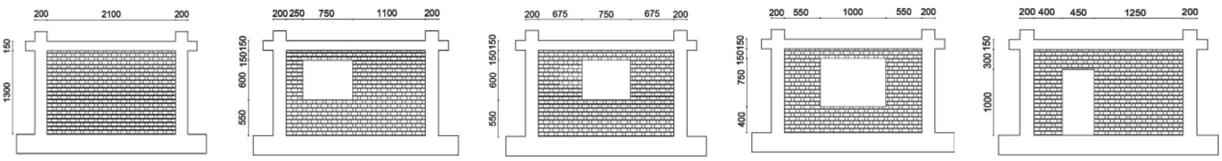

(a) SOLID (b) EWO (c) RWO (d) LWO (e) DO

Fig. 1. Dimensions (mm) of experimental specimens (Mansouri et al., 2014)

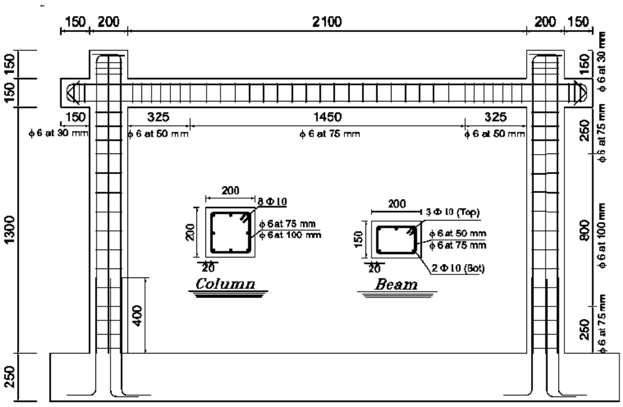

Fig. 2. Geometry and reinforcing details of reinforced concrete frame (millimeter) (Mansouri et al., 2014)

Table 1. Test results of materials (MPa) (Mansouri et al., 2014)

Material	Property	Value
concrete	Compressive strength	21.9
Brick units	Compressive strength	9.16
mortar	Compressive strength	8.33
longitudinal steel reinforcements	Yield strength	438.3
	Ultimate strength	645
Transverse steel reinforcements	Yield strength	396.3
	Ultimate strength	509.3

2.2. FE modeling

In this paper, configurations have been evaluated by using the general finite element software ABAQUS, which offers comprehensive material constitutive laws and capable interaction features for the simulation of masonry infills. The Eight-node three-dimensional reduced integration elements with a Gaussian integration point in the elements (C3D8R) are used for simulation of reinforced concrete frames, and solid bricks and element (TRUSS T3D2) are used for simulation of longitudinal and transverse rebars, and steel bars are "embedded" to the concrete element.

Numerical modeling of brittle materials such as concrete and masonry in the past few decades are mainly categorized into three groups namely: micro, macro, and meso scale. Due to the numerical methods, meso scale analysis can be categorized mainly into the implicit and explicit analysis. In this paper, Meso-scale modeling and the explicit solution procedure has been used. Analysis is performed to evaluate the masonry infilled frames, and quasi-static analysis for in-plane and out-of-plane directions.

3. Results and discussion

3.1. out of plane behavior

First, for each specimen, the model with 0% drift (undamaged) is also included for comparison. In the step, the out-of-plane pressure is applied on the entire surface of masonry infills equal to the ground acceleration from (g1) to (g10). No axial load was considered in the loading step. The bottom beam of the frame was fully restrained to simulate a rigid foundation beam.

3.2. Out-of-plane behaviour with in-plane damage

Specimens were analyzed under in-plane loading and then under out-of-plane loading. During the in-plane step, the frame was applied and analyzed with the level of drift of (0.5%, 1%, 2%, and 3%. respectively). During the out of- plane step, the damaged model was analyzed under monotonic out-of-plane pressure to 10g. During the out-of-plane step, the RC frame was restrained for out-of-plane displacement. No axial load was considered during either loading step. In both steps, the bottom beam of the frame was fully restrained to simulate a rigid foundation beam. Afterward, the influence of IP damages on OP behavior is investigated by comparing the force-displacement curves.

3.3. Out-of-plane behaviour with in-plane damage

Specimens were analyzed under out-of-plane loading and then under in-plane loading. During the out of- plane step, the damaged model was analyzed under monotonic out-of-plane pressure to 1g. During the in-plane step, the frame was applied and analyzed with a level of drift of 6%. No axial load was considered during either loading step. Analytical specimens then were loaded at different levels of ground accelerations in the out-of-plane direction and the amount of a reduction of strength and effectiveness was measured with in-plane loading capacity. Afterward, the influence of out-of-plane damages on in-plane behavior is investigated by comparing the force-displacement curves.

3.4. Reduction factor

In this paper, it has been tried to modify the stiffness and strength reduction factor equations by Mansouri et al. (2014) (Mansouri et al., 2014) with factor the interaction out-of-plane on the in-plane masonry infill with different opening. The factors of the presented equations have been estimated using the partial least square (PLS) method in the statistical programming language R (Hastie et al., 2014). Considering the interaction out-of-plane on the in plane, stiffness reduction was observed in all specimens. The opening type (window, door) also has little effect on the trend in variation in the stiffness-reduction factor concering opening ratio.

4. Conclusions

The masonry infill-frame with in-plane loading with previous out-of-plane damage has the lowest loss of strength and effective stiffness compared to the opening specimens. In out-of-plane loading of masonry infills with an opening (windows and door), openings with larger dimensions or farther from the center of the infill lead to a further reduction in the strength and effective stiffness of the masonry infills. In out-of-plane loading with previous in-plane damage, the effective stiffness degradation of the opening specimens was about 90%, and the specimen with the door opening had the highest effective stiffness, whose effective stiffness is equal to the effective stiffness of the reinforced concrete (RC) frame. Effective stiffness variations are very significant compared to strength variations, interactions in-plane (IP) and out-of-plane (OOP) have a greater effect on effective stiffness. The effective stiffness reduction factor of opening specimens under in-plane loading with previous out-of-plane damage has decreased by an average of 30% compared to specimens with only in-plane loading. The strength reduction factor of opening specimens under in-plane loading with previous out-of-plane damage, in some specimens, instead of reducing the strength in the interaction in-plane and out of plane, has increased the strength compared to specimens with only in-plane loading. It is believed that this may be due to the nature of the arching action in the interaction of between the masonry infill and the surrounding frame in the opening specimens. This is an open issue, on which further analytical studies are certainly necessary.

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