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The test of a full-scale three-story RC structure with masonry infill walls

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ABSTRACT

Masonry infill walls are used as partitions in many countries. There is no consensus on whether infill walls make a reinforced concrete frame more or less vulnerable to the effects of strong ground motion. To provide hard evidence to address this question, a full-scale three-story reinforced-concrete structure was tested with and without infill walls made out of solid clay bricks. During the test without the walls, the structure experienced a punching shear failure at a slab–column connection. After this first test, infill walls were built with solid bricks. The walls filled completely full bays and ran continuously from the foundation to the roof. It was observed that the walls increased the stiffness and the strength of the structure. The drift capacity of the structure with walls was observed to be 1.5%. Up to this level of deformation, masonry infill walls in structures similar to the one described here can be expected to help control inter-story drift provided that measures are taken to prevent their out-of-plane failure.

1. Introduction

There is no consensus on whether masonry infill walls increase or decrease the seismic vulnerability of a reinforced concrete frame. A review of the literature shows that opinions about the matter are split. Researchers have suggested that infill walls have led to the collapse of buildings [1–3] and that infill walls may affect the response of frames detrimentally [4]. Researchers have also suggested that masonry infill panels may be beneficial [5–12].

The reason for the apparent contradiction may reside in the observations made by researchers [13,14] who have stated that masonry infill panels have both positive and negative effects. Dolsek and Fajfar [15] captured the essence of the problem stating: "The infill walls can have a beneficial effect on the structural response, provided that they are placed regularly throughout the structure, and that they do not cause shear failures of columns".

The strongest evidence supporting this opinion comes from the field [5,8] and from results from pseudo-dynamic tests by Pinto, Negro, et al. [12,16,17]. These tests suggested that masonry infill walls can reduce displacement demands dramatically (Fig. 1(a) and (b)) and remain effective in controlling drift up to inter-story drift ratios exceeding 1%. Negro and Colombo [13] and Dolsek and Fajfar [15] have suggested that at larger drifts, damage tends to concentrate in one story.

The tests by Pinto, Negro, et al. [12,16,17] generate a series of questions. Are the results repeatable? Are they sensitive to the type of materials used? Given that the shear strength of the columns is pivotal [18], are the results sensitive to the details of the reinforcement in the columns? In the two tests reported by Pinto and Negro, the simulated ground motions caused no more than two cycles with amplitudes exceeding 0.6%, which leads to the question: would larger numbers of cycles produce different results?

The literature does not provide solid answers to these questions because few tests of full-scale structures with regularly distributed and continuous infill walls have been made [12,16–19][1] and because computer simulation does not provide reliable results of the drift capacity[2] of reinforced concrete and masonry structures [20].

In the study reported here, experiments on a full-scale building structure were done to address questions about the potentially

[1] Other tests have been made but with irregular full-scale specimens [21–24] and small-scale or one-story specimens [3,9–11,14,25–30]. An exhaustive list of references and a database of test results were presented by Akin [5].

[2] Defined here as the drift associated with a decrease of 20% in the lateral-load carrying capacity.

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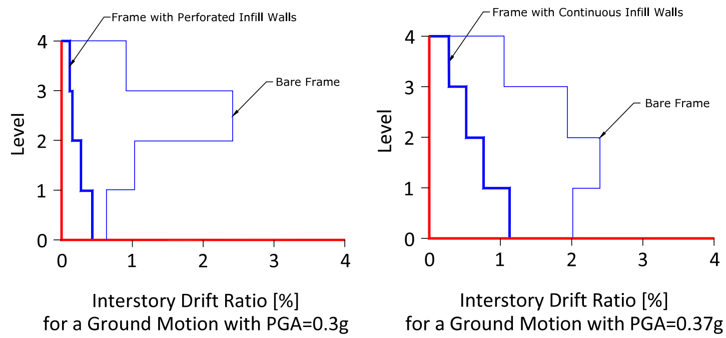

(a) References[16,17]. (b) Reference [12].

Fig. 1. Maximum inter-story drift ratio measured in bare frames and similar frames with masonry infill walls.

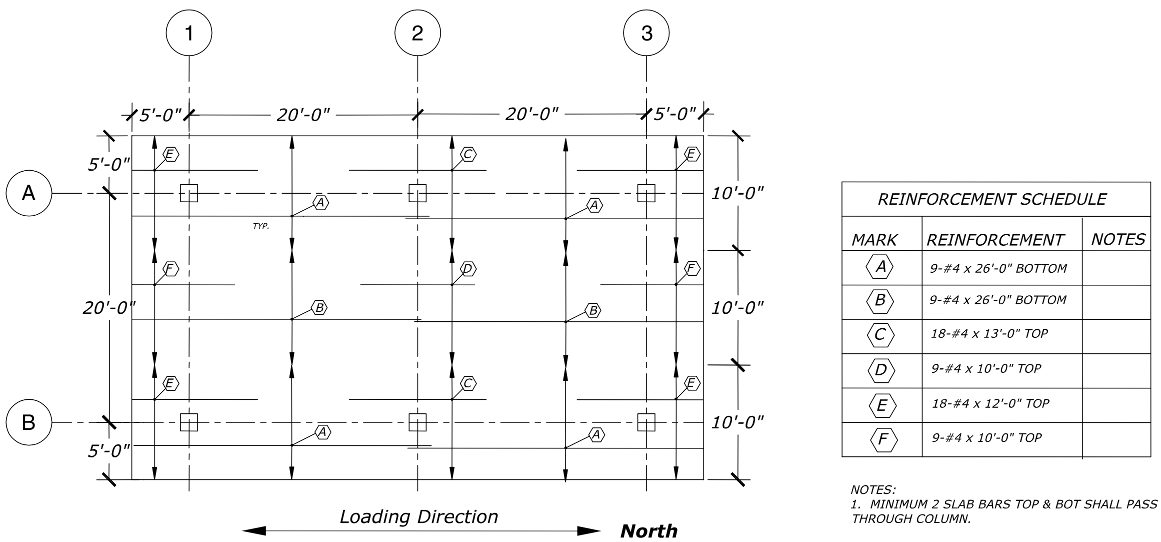

Fig. 2. Original test structure — plan view. (1″ = 25.4 mm, 1′ = 305 mm).

positive or negative effects of masonry infill walls. The study focused on the response of structures with infill walls to in-plane loading. Out-of-plane response of infill panels has been studied extensively by others. An excellent summary on the matter is presented by Calvi and Bolognini [6]. The available information shows that masonry panels bound by a frame develop out-of-plane resistance through arching. Out-of-plane failure of infill panels can be prevented considering:

(1) the dependency of out-of-plane demands on the global response of the structure
(2) the vibrational properties of the wall panel itself, and
(3) the effect of damage caused by in-plane loading.

Calvi and Bolognini [6] also demonstrated that modest amounts of reinforcement embedded in mortar placed on the faces of infill panels can increase dramatically the resistance of the panels to out-of-plane loads.

The study presented here is based on the assumption that measures are taken to prevent out-of-plane failure of masonry panels.

2. Test program

As part of this study, a full-scale three-story reinforced concrete structure that had been previously tested to failure [31] was modified by adding brick infill walls. The original structure and the results of the previous test are described next

3. First test

The original structure consisted of a three-story reinforced concrete flat-plate structure designed and detailed to resist gravity load only [31]. Each floor of the building measured 15, 250 mm × 9150 mm (50 ft × 30 ft.) in plan. The total height of the structure was 9150 mm (30 ft), with each story measuring 3050 mm (10 ft) (from top of slab or footing to top of slab above). Six reinforced concrete columns with 455 mm × 455 mm (18 in. × 18 in.) cross sections and arranged in two column lines supported three (180-mm and 7-in.) thick flat slabs. The floor plan and reinforcement layout of the test structure is shown in Fig. 2. Columns were supported by 1370 mm × 1370 mm × 760 mm (4.5 ft × 4.5 ft × 2.5 ft) monolithic footings fastened to the strong floor of Purdue University's Bowen Laboratory with four 2440 mm (8 ft) long rods (Fig. 3). The measured concrete cylinder strength was 26.9 MPa (3900 psi) for slabs, 25.5 MPa (3700 psi) for columns, and 20.7 MPa (3000 psi) for footings. The slabs were reinforced with 13 mm (#4) bars with a measured yield stress of 469 MPa (68 ksi). Columns had eight 22 mm (#7) longitudinal bars with a yield stress of 455 MPa (66 ksi) (Fig. 4). These bars had 1520 mm (5 ft) splices above footings and slabs. Column ties were cut from 9.5 mm (#3) bars with a yield stress of 517 MPa (75 ksi). The spacing of column ties was 178 mm (7 in.; $d/2$, with d = effective depth). All reinforcement conformed to ASTM Standard A615.