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Influence of connection and constructional details on masonry-infilled RC frames under cyclic loading

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ABSTRACT

Infill walls significantly affect the dynamic characteristics and the seismic performance of reinforced concrete (RC) frames. To evaluate the influence of connection type and constructional details of infill on the cyclic response of RC frames, a quasi-static test was performed on four infilled frame specimens and a bare frame specimen. The infilled frames were constructed with rigid connection or flexible connection between frames and infills, and the infill walls were constructed with or without core columns. The test results show that the presence of the masonry infill wall increased the lateral strength, stiffness, ductility and energy dissipation capacity of the RC frame. The contribution of connection type and core column were analyzed and compared. Additionally, finite element (FE) modeling was conducted and validated with the experimental observations.

1. Introduction

Masonry-infilled reinforced concrete (RC) frames are commonly used in many parts of the world, even in areas of high seismic risk including China and Mediterranean countries. Although infill walls, serving as interior and exterior partitions, are usually considered non-structural in design, they can significantly affect the dynamic characteristics and the seismic performance of RC frames [1–5]. The presence of infill walls may increase the strength, stiffness and ductility of RC frames. However, infill may also increase the base shear, the undesired soft-story mechanisms of structures, brittle damage imposed on the surrounding frame components, and serious damage to the infill walls themselves. These advantages and disadvantages result from the complex interaction between the surrounding frames and the infill walls when they are subjected to earthquake loads.

Extensive experimental and analytical studies on the seismic performance of infilled RC frames have been conducted to understand the interaction between frame and infill and to assess the effects of infill under different conditions. Studies have mainly focused on strength, stiffness, ductility, energy dissipation and failure mode of the structural system. The variables investigated have included a variety of infill materials from concrete [6–8] to different kinds of masonry [6,9,10], strength of the frame or of the infill [9,11], frame aspect ratio [8,9,12], geometry of infill panel opening [11,13–15], connection between the frame and the infill [8,12,16], and constructional details of infill such as the presence of a concrete lintel beam [12] and constructional columns [16]. Mehrabi et al. [9] reported that strong frames (weak columns and a strong beam) infilled with strong panels (solid concrete masonry) exhibited better performance than weak frames (strong columns and a weak beam) infilled with weak panels (hollow concrete masonry) in terms of load resistance and energy-dissipation capability. The data from Kakaletsis and Karayannis [11] indicated that RC frames with strong infills (vitrified ceramic brick) showed higher initial stiffness and higher ductility than those with weak infills (clay brick), but infill strength did not substantially influence strength or energy dissipation. Cavaleri and Trapani [10] reported that frames infilled with light-weight concrete masonry and calcarenite masonry show improved dissipative properties compared to the frames infilled with clay masonry. Regarding the influence of masonry openings on the seismic performance of infilled RC frames, Kakaletsis and Karayannis [11,15] investigated single-story, single-bay scaled specimens under cyclic horizontal loading. The results showed that for low lateral displacement, the energy dissipation of specimens with openings was higher than that of the bare frame; for high lateral displacement, the energy dissipation of specimens with openings was reduced and that of the bare frame remained constant. The window openings with a width from 25% to 50% of the infill length led to an average reduction of 18.7% in lateral resistance, 26.3% in initial stiffness, and 4.3% in cumulative energy dissipation capacity. The door openings with a width from 25% to 50% of the infill length led to an average reduction of 28.7% in lateral resistance, 30.3% in initial stiffness, and 27% in cumulative energy dissipation capacity. Quasi-static experiments conducted by Asteris and Kakaletsis et al. [17] revealed that the failure modes of masonry-infilled RC frames with openings were more complex than

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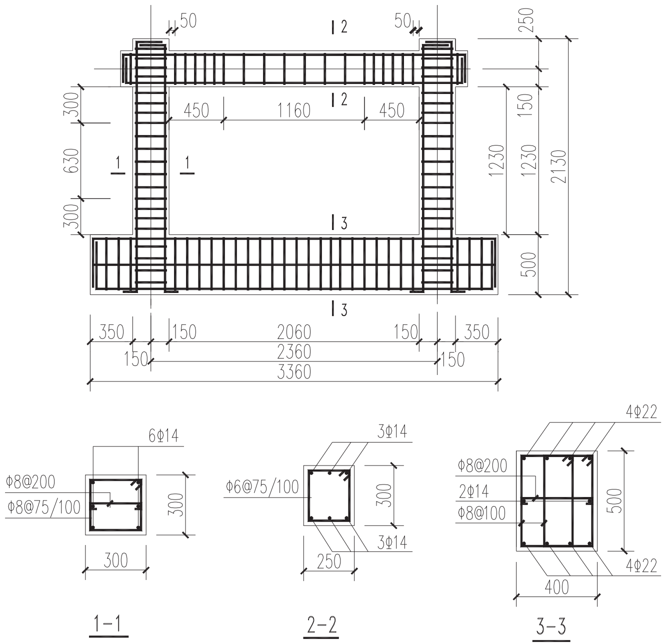

Fig. 1. Geometry and reinforcement details of frame specimens.

those with solid infill panels. The presence of an opening upon the diagonal of an infill panel led to the abolishment of the failure modes of Diagonal Compression (DC) and Diagonal Cracking (DK). The experimental findings also showed that frames with infill walls connected to both the column and beams of the frame were superior to less connected frames [8,12]. Jiang et al. [16] compared the effect of connection between infill walls and frames on the seismic performance of aerated concrete blocks infilled RC frames. They found that the addition of a masonry infill wall with rigid connection contributed more than one with flexible connection to the observed increase in the lateral strength, stiffness and energy-dissipation capacity of the bare RC frame, and to the observed decrease in the displacement ductility.

Both micro-models and macro-models have been developed to simulate the performance. Micro-models usually mean finite element (FE) models, in which the structure is discretized into numerous elements. For example, beam or continuum elements are used for the surrounding frame, continuum elements for the infill or masonry blocks, and interface or contact elements for the interaction between the frame and infill or between masonry blocks [2,13,18–24]. Chiou et al. [18] modeled infilled RC frames by discretizing the brick units and concrete members into blocks that were interconnected with contact springs to simulate tensile and shear failure. Asteris developed a new FE technology, estimating the infill/frame contact lengths and stresses as an integral part of the solution, to investigate the stiffness reduction of the infill wall with opening under monotonic loading [13], and to simulate the response of a masonry infilled RC frame under a lateral static load [23]. Asteris and Cotsovos [24] conducted a nonlinear FE analysis of the effect of infill walls on the response of RC frames under static and seismic loading. The concrete and masonry were modeled by 27-node Lagrangian brick elements, and the reinforcement bars were modeled by 3-node truss elements. Stavridis and Shing [19] combined the smeared-crack continuum elements with interface elements to capture the different failure modes of masonry-infilled RC frames. Koutromanos et al. [20] extended this work by means of with a developed cohesive interface model and an improved smeared-crack model to capture the cyclic behavior of such structures. Mohyeddin et al. [21] constructed a 3D discrete-finite-element model using ANSYS, and RC and masonry materials were modeled using the Solid65 element. The mortar joint thickness was halved into two parts that attached to adjacent masonry units and could interact with each other through interface (contact) elements.

Macro-models are typically simplified models that use a single (or multiple) diagonal strut (or struts) connected to the frame through beam-column joints to represent the entire infill panel. Many equivalent diagonal strut models have been developed, differing in amount, position, cross-section width and cyclic nonlinear behavior of the equivalent diagonal strut [1,2,10,25–28]. Aiming to simply reproduce the effects of infills in the global and local response, Fiore et al. [2] proposed a two-non-parallel-strut model, and the positions of the two struts were determined according to the geometry of the infill and the story level. Asteris et al. proposed an analytical equation for the reduction factor of the equivalent strut width that considered the opening [1], and then proposed an equation for dimensionless width to consider both the opening and the vertical load [28]. Attempts have also been made to

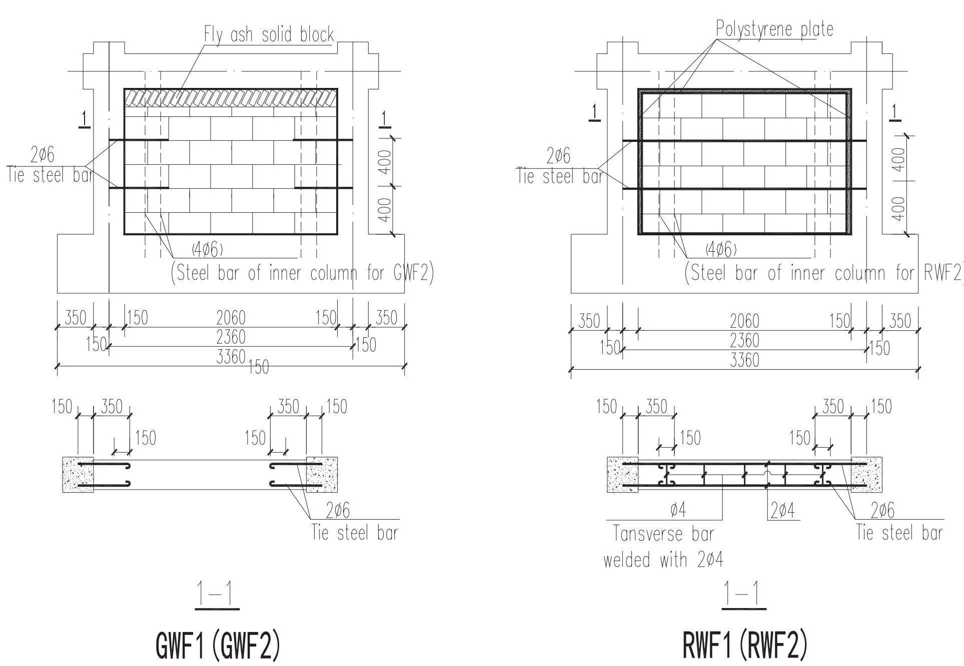

Fig. 2. Configuration of infilled frame specimens.