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Numerical study on masonry-infilled steel frames under vertical and cyclic horizontal loads

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ABSTRACT

Although there are many researches on infilled steel frames with welded beam-to-column connections, however, few studies were undertaken to investigate the behaviour of these infilled structures but with other common connection types (extended endplate, flush endplate and header plate connections), particularly under combined vertical and horizontal loading. In this paper, firstly, a simplified numerical model of infilled steel frames under cyclic loading, considering the interactions between frames, infills and beam-to-column connections' components, was constructed. The model results were compared with experimental data for cyclically-loaded infilled frames, showing good agreement. Using the verified model, a parametric study on infilled steel frames with five different beam-to-column connection types, under vertical and cyclic horizontal loads, was performed. Several parameters, including vertical load level, infill thickness and vertical load application method, were investigated. The results showed that increasing the level of vertical load (uniformly distributed on the beam) minimised the difference in performance between the frames with welded connections and those with bolted connections. Under vertical loads of 0, 16% and 24% of the columns' axial capacity, the horizontal ultimate load of frames with header plate connections, was, respectively, 73%, 86% and 91% of that of frames with welded connections. Hence, when the infilled frames are subjected to relatively high levels of vertical load, utilising header plate connections may be a viable alternative to using welded connections. Furthermore, a simple analytical method for predicting the stiffness and load-carrying capacity of masonry-infilled steel frames (with different connection types) under vertical and horizontal loads, was proposed.

1. Introduction

Masonry panels are usually used as interior or exterior walls in the steel and reinforced concrete structures. These composite structures are referred to as infilled frames and have higher lateral stiffness and strength than structures without walls (bare frames). The masonry walls generally have great impact on the performance of the bounding frames under earthquake loading. However, most of the structural design engineers neglect the contribution of the infills, considering them as non-structural elements, which leads to inaccurate results.

In the past 60 years, numerous experimental and finite element (FE) researches have been performed to understand the combined behaviour of infilled frames, but the majority of these researches explored the response of infilled reinforced concrete (RC) frames. Only few scholars investigated the behaviour of steel frames with infill walls [1–29]. For instance, Dawe et al. [5] undertook a series of tests on masonry-infilled steel frames under dynamic loading. Tasnimi and Mohebkhah [6] experimentally studied the in-plane cyclic behaviour of steel frames with clay brick masonry infill. Also, several bidirectional tests were carried out on clay tile infilled steel frames to evaluate the interaction of in-plane and out-of-plane forces and to explore the behaviour of damaged infill [7]. Tong et al. [8] reported an experimental programme investigating the dynamic response of partially-restrained steel frames with reinforced concrete infill walls. In another experimental study, Peng et al. [11] researched the load transfer mechanism of composite structure of steel frame–reinforced concrete infill wall under dynamic loads. Moreover, an experimental programme on partially-restrained steel frames with RC infill wall under reversed cyclic lateral load was conducted by Sun et al. [12]. Liu and Soon [13] investigated experimentally the response of concrete masonry infills bounded by steel frames, then used the resulting data to evaluate the effectiveness of equations, suggested in the current design standards of both Canada and the US, for the design of masonry infills. Jazany et al. [14] reported an experimental and analytical study which aims to understand the influence of masonry infill on the seismic performance of special concentrically braced frames. The study results demonstrated that the presence of masonry infill resulted in enhancements of the lateral stiffness and load-carrying capacity of the frames by 33% and 41%, respectively. In another study, quasi-static tests on steel frames infilled with three different masonry infill types were

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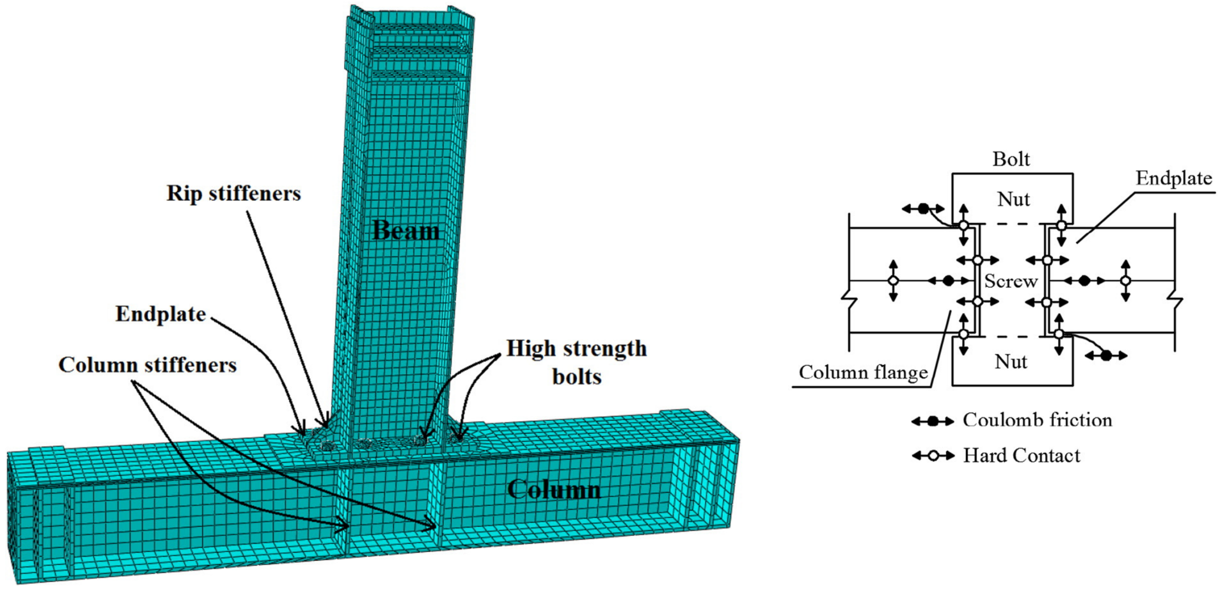

Fig. 1. Interactions between the components of a standard endplate connection.

performed by Markulak et al. [15]. Also, Fang et al. [16] undertook a series of shaking table tests on steel frames with autoclaved lightweight concrete external walls.

All the above experimental studies have done notable researches on infilled steel frames and confirmed that the presence of infill has obvious impact on the stiffness and load-carrying capacity of these combined systems. However, after the development of computer technology in recent years, the finite element simulation of infilled frames is widely utilised as an efficient alternative to laboratory tests (which are very costly, particularly in cases of large-scale parametric studies).

Some researchers numerically studied the behaviour of infilled steel frames [19–29]. For example, Dawe et al. [19,20] constructed a model of masonry infilled frames to investigate the influences of various parameters on concrete masonry-infilled steel frames. Moghadam et al. [22] suggested a new analytical approach for predicting the shear strength and cracking patterns of infill panels. Using a precise linear FE model, Doudoumis [23] investigated the impacts of interface conditions, mesh density, relative beam-to-column stiffness and orthotropy of infill panels on the overall performance of infilled frames. In another numerical study, Radnić et al. [26] developed a model able to statically and dynamically analyse the behaviour of planar masonry-infilled steel frames. Lastly, Radić et al. [27] established an analytical model of infilled steel frame and verified it based on experimental data.

All the aforesaid studies were undertaken on infilled frames subjected to horizontal loading only, although most frames often suffer from a combination of vertical and horizontal loads. In the latter instances, the vertical loads are applied either on beams or directly into columns, according to the structural conditions. Many scholars explored the effect of combined loading on the behaviour of RC frames, concluding that the vertical load can lead to significant enhancements of the lateral stiffness and load-carrying capacity of the infill frames.

In comparison with the infilled RC frames, the studies on infilled steel frames, under combined vertical and horizontal loading, were scarce. Liu and Manesh [10] carried out an experimental programme on concrete masonry-infilled steel frames. Eight specimens were tested under combined in-plane vertical and monotonic lateral loading. The results showed that the presence of vertical load resulted in a remarkable increase in the lateral resistance of the infills. Moreover, Chen and Liu [28] performed a finite element study on the in-plane behaviour of concrete masonry infills bounded by steel frames subjected to vertical and monotonic lateral loading. They found that when applied as a uniformly distributed load (UDL) on the frame beam, the presence of vertical load, up to a certain level, caused an increase in the lateral stiffness and strength of the infilled system. And beyond that level, the benefit of vertical load began to diminish.

Although numerous studies [30–36] underlined the significant difference in response between the various beam-to-column connection types, almost all of the aforementioned researches on infilled steel frames studied the performance of frames with welded connections. Consequently, there is a need to discover the behaviour of infilled steel frames with other common connection types (extended endplate, flush endplate and header plate connections), which all have the advantages of flexibility, easy fabrication and fast installation in comparison with welded connections.

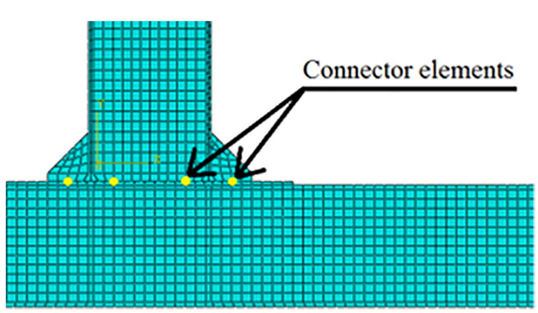

Fig. 2. High-strength bolts represented by connector elements.

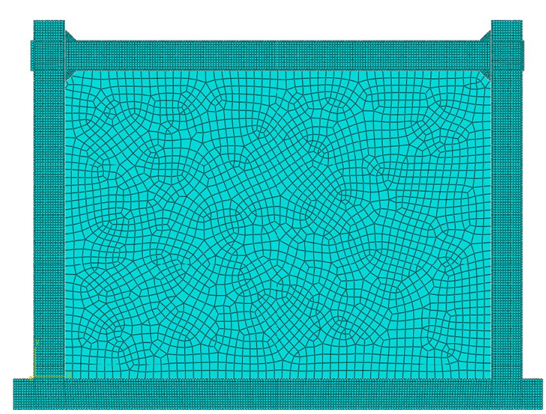

Fig. 3. 2D shell FE model of an infilled steel frame.