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Original Research Article

Cyclic testing of steel frames infilled with concrete sandwich panels

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ABSTRACT

In-plane seismic behaviour of concrete sandwich panel-infilled steel frame (CSP-ISF) was experimentally and numerically investigated. Four large-scale, single bay and single story steel frame specimens were tested under reversed cyclic lateral loading. Three infilled frames with different aspect ratios along with one bare frame were considered. It was found that addition of sandwich panels leads to considerable increase in the lateral stiffness and strength, ductility, energy dissipation capacity as well as equivalent viscous damping ratio of the steel frames. Furthermore, the maximum shear capacity of CSP-ISF specimens was validated by analytical approaches which showed good agreement with experimental results. Based on the present experiments, structural performance levels required for *Performance-based Analysis* are also proposed for concrete sandwich panel used as infill walls. Finally, a numerical model is presented to analyze the nonlinear behaviour of CSP-ISFs.

1. Introduction

Infilled frames are widely used as structural systems all around the world. Experiences from past earthquakes reveal that infill walls dramatically affect the seismic response of structures. Thus, ignoring the effect of interaction between infill wall and surrounding frame is not recommended especially in seismic regions. Therefore, in the last several decades the infilled frame system has been a scope of research, both experimentally and analytically. Masonry is the most common type of construction material used as infill walls in many countries. Hence, researchers have paid special attention to this material in their studies [1–5].

The use of composite sandwich panel as infill wall in framed structures is gradually growing in some countries, e.g. Iran. The main advantages of these panels are: (i) fast and easy erection with lower labour costs, (ii) structurally stable construction and good out-of-plane performance, (iii) good thermal and sound insulation, and (iv) use of prefabricated

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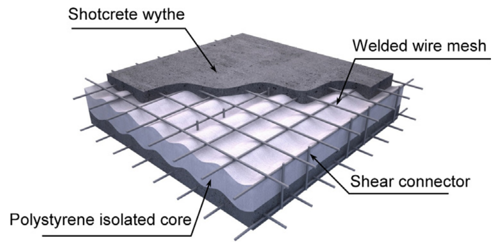

Fig. 1 – Detail of concrete sandwich panel.

elements produced on an industrial scale which is economically favourable. Concrete sandwich panel (CSP) includes a polystyrene sheet with welded wire mesh mounted on the both sides of the polystyrene core and covered by a wythe of shotcrete which is applied on both sides, as shown in Fig. 1.

Literature shows that much effort has been made in this area to investigate the performance of CSP structures with load-bearing wall system. Experimental investigation of sandwich panels can be classified into four main categories: (i) thermal efficiency, (ii) mechanical behaviour, i.e. flexural and/or shear behaviour [6,7], (iii) material components of a sandwich panel [8,9], and (iv) structural performance [10–16].

Einea studied the structural efficiency of CSP systems for the first time [10]. Salmon et al. further developed the work of Einea and introduced a new type of sandwich panels equipped with a system of *Fiber Reinforced Plastic* (*FRP*) connectors [11]. Kabir et al. presented details of their experiments conducted on four small-scale test specimens to investigate the nonlinear behaviour of the combined system, CSP and bending steel frame subjected to quasi-static cyclic loading [12]. A comprehensive study on dynamic behaviour of single-story and 4-story buildings constructed with the CSP system was carried out by Rezaifar et al. using shaking table testing [13,14]. Teeuwen investigated the lateral behaviour of steel frames with discretely connected concrete infill panels using experimental and analytical approaches [15]. Pavese and Bournas carried out several tests on the seismic performance of a prefabricated CSP system [16]. Test specimens included 10 walls with and without openings and a double-story full-scale H-shaped structure.

Not enough experimental data is available regarding the behaviour of *Concrete Sandwich Panel-Infilled Steel Frame* (*CSP-ISF*) structures and many studies have largely focused on only load bearing sandwich panels. Therefore, in order to identify the in-plane lateral behaviour of CSP-ISFs, conducting a comprehensive experimental research is necessary.

This research mainly deals with the cyclic behaviour of CSP-ISFs under in-plane lateral loading. The effect of the aspect ratio, i.e. length to height of the infill wall, was examined. Three large-scale, single-bay and single-story CSP-ISF specimens along with one bare frame were tested under reversed cyclic lateral loading. Experimental results including lateral stiffness and strength, general behaviour and failure pattern, ductility, energy dissipation capacity as well as viscous damping ratio of different specimens are reported. In addition, based on the present experiments, structural performance levels of CSP infill walls, which are required for *Performance-based Analysis*, are proposed. Finally, a numerical model is presented to analyze the nonlinear behaviour of CSP-ISFs.

2. Experimental programme

2.1. *Test specimens*

Based on the field observation a great deal of CSP-ISF systems are being installed in mid-rise buildings. Hence, a typical single-story, single-bay frame chosen from middle stories of an eight-story building was used in the current investigation. The main steel structure was designed according to American National Standards [17,18]. An intermediate moment-resistant frame was designed as surrounding steel frame of specimens. A prequalified connection, welded unreinforced flange-welded web (WUF-W), was used as a beam to column connection (see Fig. 2). Due to the construction restrictions and limitation of the structural engineering laboratory, the CSP-ISF specimens were scaled down by the scale factor of 2:3.2. Similitude requirements for test specimens are given in Table 1. With the help of Table 1, it is possible to convert the results of scaled specimens to full-size structural systems. More details can be found in Ref. [19].

Based on the results of Šipoš et al., which were obtained from experimental database of 113 infilled frames, the most important factor that affects the performance of such structures is the aspect ratio [20]. As such, CSP-ISF specimens were constructed with various aspect ratios (as listed in Table 2). The steel frames were built using HEA 140 section for beams and HEA 160 section as columns. The quality of all welds was evaluated by ultrasonic testing (UT) method to make sure that a fully restrained moment connection is provided (Fig. 3). Fig. 4(a) shows the geometry and dimensions of the test specimens.

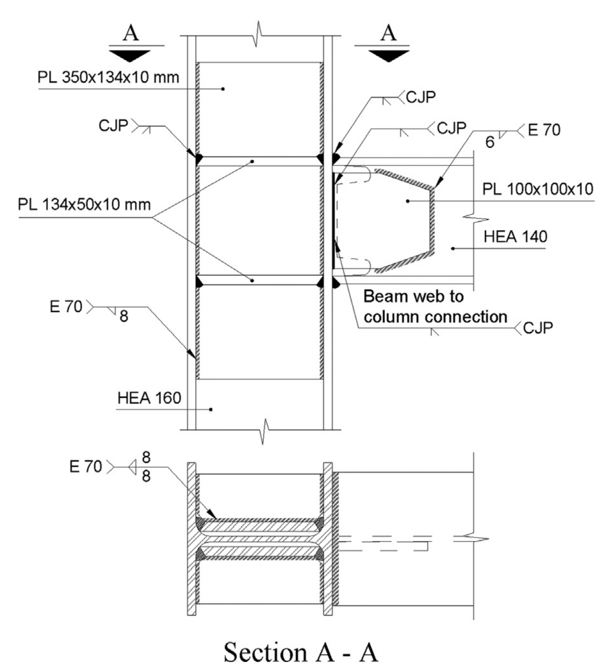

Fig. 2 – Detail of beam-to-column connection.