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Profiled sandwich composite wall with high performance concrete subjected to monotonic shear

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ABSTRACT

This research investigated the behavior of a composite shear wall system consisting of two skins of profiled steel sheeting and an infill of concrete under in-plane monotonic loading. Three sets of double skin composite wall (DSCW) specimens with overall wall dimensions of 1626 mm high by 720 mm wide were tested. Steel sheet–concrete connections were provided by intermediate fasteners along the height and width of the wall to generate composite action. Two types of concrete namely self-consolidating concrete (SCC) and highly ductile engineered cementitious composite (ECC) as well as cold formed profiled steel sheet having same geometry but with two different yield strengths were incorporated to investigate their influence on the composite wall behavior. Analytical models for the shear resistance of the composite wall were developed based on existing models taking into account the shear capacity of steel sheet, concrete core and steel sheet–concrete interaction. The advantage of using ECC over SCC was exhibited through more ductile wall behavior and energy absorbing capacity. The benefit of using mild over high strength steel was also demonstrated through more ductile failure. The steel–concrete intermediate fasteners along the height and width of the wall provided sufficient steel–concrete composite action to prevent early elastic buckling of the profiled steel sheets. Experimental and analytical shear resistance of composite walls showed very good agreement. The proposed analytical models can be used for the prediction of shear resistance of composite walls with reasonable accuracy.

1. Introduction

Reinforced concrete (RC) shear walls have been traditionally used as lateral load resisting systems in many structures [1–3]. Steel plate shear walls have been also used as lateral load resisting system in mid-rise and tall buildings. Design methods for steel plate shear walls, are available [4,5]. A steel–concrete composite shear wall can have the benefits of both steel and RC shear walls and yield the best traits of concrete and steel [6–9].

The concept of double skin composite wall (DSCW) was originated from the floor structure using profiled steel deck and concrete [10,11]. A typical DSCW system consisting of two skins profiled steel sheets and a concrete infill is shown in Fig. 1. Such composite walling as shear or core walls in steel frame buildings has many advantages. In building construction stage, profiled steel sheeting can act as a bracing system to the steel frame against lateral loads and also can act as a permanent formwork for infill concrete [12]. During the in-service stage, profiled steel sheets and infill concrete work together to resist lateral loads [12]. Research has been conducted on the axial, flexural and shear load resistance of the DSCW system [13–18]. The interaction between the profiled steel sheet and concrete has an important role in the composite action of the DSCW system. The interface shear bond failure is a limiting criterion for designing this kind of system [13–16]. The bond between the steel sheet and concrete can be improved by embossments or using other forms of shear connector. The mechanical interlock at the sheet–concrete interface may govern the brittle or ductile mode of failure of such composite wall [13–16].

Previous research studies [12–16] conducted on the DSCW system under monotonic and cyclic shear loadings have the following shortcomings: steel sheets and concrete were connected only at the boundary (no sheet–concrete interface connections within the panel) causing premature steel sheet buckling, no variability in concrete types (besides ordinary concrete no new generation of high performance concrete was used), used small-scale tests without using commercially available profiled steel sheets. It is important to prevent the buckling of profiled steel sheets in order to increase the shear resistance of the DSCWs.

The current research addresses the abovementioned shortcomings of previous research studies. The buckling of steel sheet is prevented by using adequate intermediate fasteners (acting as sheet–concrete interface connection) along the height and width of the composite wall (as shown in Fig. 1) to ensure failure due to steel yielding under shear loading. The combined effect of intermediate fasteners and profiled

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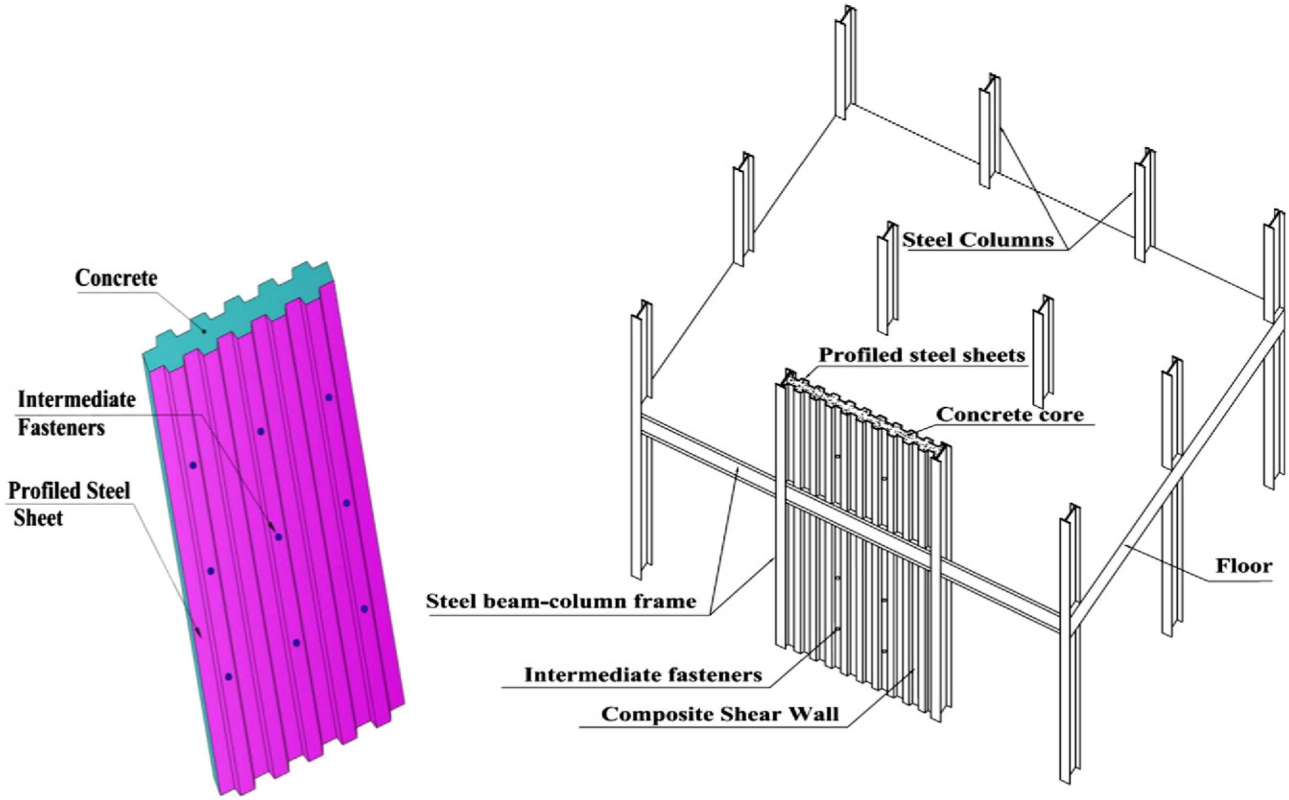

Fig. 1. Application of composite walling system in building.

concrete core (which acts as a stiffener and bracing to the profiled steel sheet) should enhance buckling strength and overall shear strength of the system. The study of the structural response of DSCW system under in-plane monotonic/cyclic shear and impact loadings is the main aspects of the current research.

This paper presents the behavior of DSCW system subjected to in-plane monotonic shear loading based on experimental and theoretical investigations. It highlights the performance of DSCW system based on the use of: profiled steel sheets of different properties, high performance concretes and intermediate steel sheet–concrete connections. Commercial profiled steel sheets of two yield strengths (classified as mild and high strength) and two types of infill concrete namely self-consolidating concrete (SCC) and engineered cementitious composites (ECC) are used to construct DSCWs. SCC is flowable and can flow into place between two profiled steel sheets without vibration [19–21]. On the other hand, ECC is a new generation of high performance concrete with ultra-high ductility. ECC is flowable and exhibits a strain capacity up to several hundred times larger than normal concrete due to its micro-cracking characteristics [22–24]. The use of ECC in-fill can significantly improve the structural performance of DSCWs. This paper compares the shear strength, ductility, stress–strain characteristics, failure modes and energy absorbing capacity of DSCWs made with ECC and SCC. Developed analytical models for the shear resistance of DSCWs are presented with their performance validation through test results.

2. Significance of the research

The concept of a DSCW system using mechanical shear connectors in combination with ECC material is new and design methods are not currently available. No research has been conducted till to date using ECC in DSCW system [12–18] and current research incorporating ECC in DSCW is a timely initiative to develop a structural system with enhanced strength, ductility and energy absorbing capacity. This research will make original contributions to the understanding of the behavior of DSCWs with ECC compared to conventional SCC and the development of design guidelines for such structural systems. The newly developed analytical models for the shear resistance of DSCW system (based on modified compression field theory and steel sheet yielding) are also modifications to the models (based on buckling of steel sheets) suggested in previous research studies. The recommendations of this research will surely benefit engineers, designers and construction companies to understand the potentials of the proposed DSCW technology with ECC.

3. Experimental program

Three series (DSCW-1, DSCW-3 and DSCW-5) of composite wall specimens were tested under in-plane monotonic shear loading. The variable parameters in the tests were: type of concrete (ECC and SCC) and steel sheet strength while geometric dimensions remained the same.

3.1. Test-set-up, DSCW specimen details, instrumentation and material properties

The overall dimension of the DSCW specimens was 720 mm wide and 1626 mm high (Fig. 2 and 3). The composite wall panels were fastened by bolts to a shear rig consisting of a pair of pin-ended beam-column steel frames as shown in Fig. 2 and 3. Shear rig frame beams and columns were made of steel plate and were made of 30 mm thick steel plates. Four corner pins of the shear frame were made of 30 mm high strength steel bolts. 44 intermediate bolts (fasteners) used to connect the pair of profiled steel sheets through concrete core served as steel–concrete interface connections (Fig. 2–3). These intermediate fasteners prevented steel sheet–concrete deboning and mobilized the composite action.