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Axial load behaviour of pierced profiled composite walls with strength enhancement devices

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ABSTRACT

This paper presents the results of experimental and theoretical investigations on a novel form of pierced double skin composite wall (DSCW) system consisting of two skins of profiled steel sheeting with an in-fill of concrete. Nineteen composite walls are tested to failure under axial loading. The test variables include: types of profiled steel sheeting, types of load transfer device, size/orientation of opening/holes, wall height and types of strength enhancement devices around holes. The effects of each of these variables on axial load–deformation response, axial strength, steel–sheet concrete interaction, failure modes (including concrete core cracking and steel sheet buckling) and stress–strain development are critically evaluated. Strengthening of hole boundaries is found to be essential in enhancing the axial strength of the walls. The performance of strength enhancement devices installed in the walls is found satisfactory based on axial strength–deformation characteristics and failure modes of walls. Theoretical model for the prediction of axial strength of both pierced and non-pierced composite walls is developed taking into consideration the reduction of concrete capacity due to profiling and buckling of steel sheeting. The performance of the model is validated through comparisons with experimental results.

1. Introduction

The novel form of composite walling refers to a building system consisting of two outer skins of profiled steel sheeting with an infill of concrete. Its development has come about as an extension of the now well-known composite flooring system used worldwide. Fig. 1 shows a schematic diagram of the composite wall, allowing openings for doors and windows in building applications. As with composite flooring, the advantages of the double skin composite wall (DSCW) lie in the speed and convenience of construction [1–4]. The composite walling described herein was originally conceived for use as a shear or core wall to stabilise steel frame building structures, although it has potential in concrete buildings, basements and blast resistant structures. It can be noted that the steel sheeting will act to stabilise the building frame as soon as it is fixed, and provides permanent formwork for the infill concrete [5]. Once the concrete has hardened, axial, lateral and in-plane loads will be carried through both the steel and concrete. The interaction between the profiled steel sheet and concrete has an important role in the composite action of the system. The bond between the steel sheet and concrete can be improved by embossments or using other forms of connectors. The mechanical interlock at the sheet–concrete interface may govern the brittle or ductile mode of failure of such composite walls [6].

Similar walling systems with flat steel plates built on loose sand or stone rather than concrete infill have been researched for missile and blast-resistant systems [7–10]. Flat steel plated composite walls with concrete in-fill have also shown better strength and ductility characteristics compared to conventional reinforced concrete walls [11–14].

Previous studies on non-pierced DSCWs under axial and in-plane shear loading have shown that adequate load transfer devices in the form embossments or other mechanical connections between sheeting and concrete are necessary to fully mobilise the composite action and to improve wall performance [2–4,15–18]. Such studies also confirmed their potential use as viable alternative to reinforced concrete and masonry walls [15–21]. Until to date very limited research has been conducted on pierced DSCWs with profiled steel sheets and problems of load transfer in such walls are found to be critical [22]. No research has been conducted to study the behaviour of pierced walls with strength enhancement devices to ensure better composite action and efficient load transfer.

This paper describes the axial load behaviour of pierced and non-pierced DSCWs based on comprehensive experimental investigation. The dimension and orientation of holes, use of strengthening devices around the openings/holes, installation of load transfer devices, and varying geometry of profiled steel sheeting and slenderness of walls are innovative and interesting aspects of the current study. The

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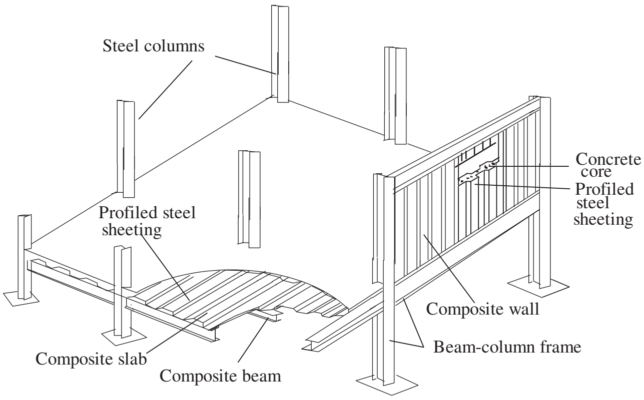

Fig. 1. Schematic of double skin composite wall (DSCW) in a building.

effects of all these parameters on strength, stress–strain characteristics and failure modes of the walls are described. The axial strengths of the tested pierced and non-pierced composite walls are compared with those obtained from proposed analytical model derived based on Codes. The recommendations of this research will surely benefit engineers, designers and construction companies to understand the potentials of the proposed DSCW system.

2. Experimental investigation

A comprehensive experimental investigation had been performed to study the axial load behaviour of the pierced composite walls. The tests were conducted to study comparative performance of pierced and non-pierced walls based on various parameters such as: types of profiled steel sheeting, size and orientation of holes, strengthening of holes with various modes of connections, load transfer or strength enhancement devices and slenderness of walls.

2.1. Description and features of DSCWs

Nineteen walls were tested with (pierced) and without (non-pierced) holes under axial loading. Walls were made with two types of profiled steel sheets commercially known as Spandek (SD) and Trimdek (TD). Table 1 summarises the details of the tested walls. Six walls were non-pierced (np) while the rest thirteen were pierced (p). The pierced walls had openings/holes of varying dimensions located at the centre of the walls. The overall dimension of Trimdek walls was 840 mm (width) × 900 mm (height). The Spandek walls had a width of 680 mm. The height of all Spandek walls was maintained at 900 mm except for Wall13np and Wall14p where the height was 1200 mm (and increase of 33.3%). Fig. 2a–b shows details of typical Trimdek and Spandek walls. The details of the walls are described based on different aspects of the study in the following sub-sections:

2.1.1. Study of the effect of perforation and type of sheeting

Wall1np and Wall2p made of Spandek as well as Wall5np and Wall6p were tested in this study. The geometric dimensions of both pierced and non-pierced walls were the same. Pierced walls were provided with a 260 mm (height) × 210 mm (width) hole/opening at the centre as shown in Fig. 2. The interface connection between profiled steel sheeting and concrete in the non-pierced walls was solely provided with three rows (top, bottom and middle of the wall) of threaded rod and nut arrangement

Table 1
Geometric dimensions, material properties and strengthening of walls.

Wall	Geometric and material variation considered			Concrete properties		
Specimen	Sheet type	Hole size $b_h \times h_h$ (mm × mm)	Parameter ($b_w \times h_w$: mm × mm)	f′c MPa	f_{cu} MPa	
Wall1np	TD	No hole	None[a] (840 × 900)	28.80	32.42	
Wall2p	TD	210 × 260	None[a] (840 × 900)	25.50	28.40	
Wall3np	SD	No hole	Welded hooks (680 × 900	30.95	36.60	
Wall4p	SD	210 × 260	Welded hooks (680 × 900)	31.31	37.57	
Wall5np	SD	No hole	None[a] (680 × 900)	31.31	32.28	
Wall6p	SD	210 × 260	None[a] (680 × 900)	29.15	28.34	
Wall7p	SD	210 × 260	Wire mesh (680 × 900)	31.29	33.46	
Wall8p	SD	210 × 260	Lintel beam (680 × 900)	25.92	26.51	
Wall9p	SD	210 × 130	50% RHH (680 × 900)	26.93	27.29	
Wall10p	SD	210 × 390	50% IHH (680 × 900)	22.91	29.90	
Wall11p	SD	105 × 260	50% RHW (680 × 900)	27.59	25.55	
Wall12p	SD	315 × 260	50% IHW (680 × 900)	23.50	24.46	
Wall13np	SD	No hole	IWH –Slender (680 × 1200)	31.93	34.44	
Wall14p	SD	210 × 260	IWH-Slender (680 × 1200)	22.29	27.61	
Wall15np	SD	No hole	Concrete core (680 × 900)	23.16	35.27	
Wall16p	SD	210 × 260	Concrete core (680 × 900)	22.52	35.51	
Wall18np	SD	210 × 260	Unfilled steel wall (680 × 900)	–	–	–
Wall19p	SD	210 × 260	Unfilled steel wall (680 × 900)	–	–	–

SD: Spandek; TD: Trimdek; IHH: increased hole height; RHH: reduced hole height; IHW: increased hole width; IWH-Slender: increased wall height from 900 to1200 mm; Yield strength of Spandek and Trimdek profiled steel sheet (f_{sy}) = 430MPa; f′c, f_{cu}: concrete cylinder and cube strength, respectively.
b_w and h_w: width and height of wall; b_h and h_h: width and height of hole/opening.
Different types of sheeting (Spandek and Trimdek): Wall1np, Wall2p, Wall5np, and Wall6p.
Effect of modes of connection around the hole (Spandek): Wall5np, Wall6np, Wall7p, and Wall8p.
Effect of hole size (Spandek): Wall5np, Wall6np, Wall9p, Wall10p, Wall11p, and Wall12p.
Effect of load transfer devices (Spandek):Wall5np, Wall6p, Wall3np, and Wall4p.
Effect of increased wall height/slenderness (Spandek): Wall5np, Wall6p, Wall13np, and Wall14p.
Steel–concrete interaction (Spandek): Wall5np, Wall15np, Wall18np, Wall6p, Wall16p, and Wall19p.
[a] No load transfer or strengthening devices.