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Finite element modelling of load bearing cold-formed steel wall systems under fire conditions

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ABSTRACT

Light Gauge Steel Framing (LSF) walls are made of cold-formed, thin-walled steel lipped channel studs with plasterboard linings on both sides. However, these thin-walled steel sections heat up quickly and lose their strength under fire conditions despite the protection provided by plasterboards. A new composite wall panel was recently proposed to improve the fire resistance rating of LSF walls, where an insulation layer was used externally between the plasterboards on both sides of the wall frame instead of using it in the cavity. A research study using both fire tests and numerical studies was undertaken to investigate the structural and thermal behaviour of load bearing LSF walls made of both conventional and the new composite panels under standard fire conditions and to determine their fire resistance rating. This paper presents the details of finite element models of LSF wall studs developed to simulate the structural performance of LSF wall panels under standard fire conditions. Finite element analyses were conducted under both steady and transient state conditions using the time–temperature profiles measured during the fire tests. The developed models were validated using the fire test results of 11 LSF wall panels with various plasterboard/insulation configurations and load ratios. They were able to predict the fire resistance rating within 5 min. The use of accurate numerical models allowed the inclusion of various complex structural and thermal effects such as local buckling, thermal bowing and neutral axis shift that occurred in thin-walled steel studs under non-uniform elevated temperature conditions. Finite element analyses also demonstrated the improvements offered by the new composite panel system over the conventional cavity insulated system.

1. Introduction

Cold-formed lipped channel sections are commonly used as load bearing wall studs in light gauge steel frames (LSFs) lined with plasterboards (Fig. 1(a)). Under fire conditions, these thin-walled steel sections (high section factor) heat up quickly resulting in a rapid reduction to their strength and stiffness despite the protection offered by fire rated plasterboards. Fire resistance rating of LSF wall systems depends on many parameters such as LSF wall configurations (details of plasterboard linings, insulations and their layouts), geometry of LSF wall studs and load ratio. It is important that fire engineers have a good understanding of the fire behaviour and fire resistance rating (FRR) of LSF wall systems and access to simpler design methods capable of predicting their FRR.

The fire behaviour of LSF wall panels has been investigated by many researchers in the past [1–9]. The fire-resistance rating of these wall panels were assigned based on standard full-scale fire tests [1–4,8,9] although a few numerical studies were also performed to simulate the structural performance of LSF wall panels subjected to standard fire conditions [2,4,5,7,9]. Feng et al.'s [6] tests showed that the interior (cavity) insulation improved the fire resistance of LSF wall panels while other studies [3,4] revealed that wall assemblies without cavity insulation provided higher fire resistance than cavity insulated assemblies. There is limited data available on the thermal performance of non-load bearing and load bearing LSF wall systems and past research has often provided contradicting results about the benefits of cavity insulation to the fire rating of LSF wall systems. Further, past research on LSF wall systems has mostly been limited to LSF wall systems used in the UK, USA and Canada. The LSF wall systems used in Australia are made of thinner and high strength steels and protected by Australian plasterboards, and their fire behaviour has not been investigated in detail. The Australian building industry is also interested in developing new LSF wall systems with higher fire resistance rating. Therefore a detailed research program was undertaken to investigate the fire performance of Australian LSF wall systems and to develop LSF wall systems with higher FRR. A series of full scale fire tests of LSF walls (Fig. 1(b)) was conducted first to evaluate the FRR of load bearing LSF wall assemblies [10,11]. One wall specimen was tested to failure under an axial compression load at

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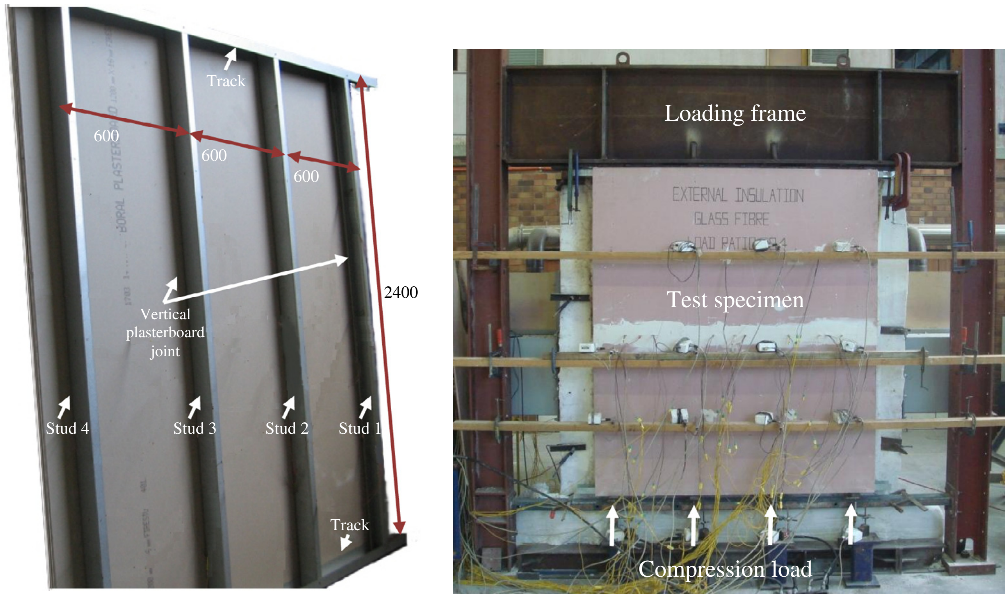
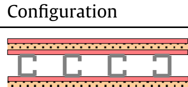
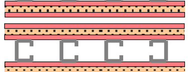
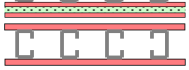
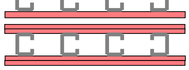
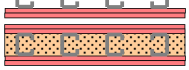
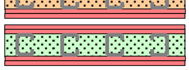
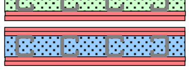
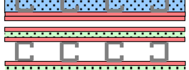
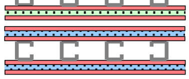


(a) Details of LSF Wall Specimen (b) Test Specimen before Fire Test

Fig. 1. LSF wall.

room temperature while ten wall specimens subjected to a constant axial compression load were exposed to standard fire conditions on one side to evaluate their fire performance (Table 1). Conventional LSF wall assemblies lined with single or double layers of plasterboard with or without cavity insulation were considered. The insulations used were 90 mm thick glass, rockwool and cellulose fibres with densities of 15.42 kg/m^3, 100 kg/m^3 and 100–110 kg/m^3, respectively. A new LSF wall system based on a composite panel was also proposed in which the insulation was sandwiched between two plasterboards and this composite panel was used on both sides of the wall frame instead of cavity insulation (Tests 1–3, 6* and 7* in Table 1). This externally insulated LSF wall system was also tested using 25 mm thick glass, rockwool and cellulose fibres on each side. Since the LSF walls were subjected to fire on one side, non-uniform time–temperature distributions developed across the thickness of LSF wall system as shown in Fig. 2(a). The hot and cold flange temperatures in Fig. 2(a) show that the thin-walled studs are subjected to varying levels of non-uniform temperature distributions with time. The ambient side temperature of the fire side plasterboards develop in three phases as seen in Fig. 2(b). In the first phase the temperature rises quickly to about 100 °C while in the second phase, it is maintained at about 100 °C due to the energy consumed in converting the free and chemically bound water present in the plasterboard into steam.

Table 1
Details of tested LSF wall specimens.

Test	Configuration	Insulation	Load ratio	Test failure time (FRR) (min.)	Vertical plasterboard joints
1		Glass Fibre	0.2	118	Studs 1 and 3
2		Glass Fibre	0.4	108	Studs 1 and 3
3		Rock Fibre	0.4	134	Studs 2 and 4
1*		None	0.2	53	Studs 2 and 4
2*		None	0.2	111	Studs 2 and 4
3*		Glass Fibre	0.2	101	Studs 2 and 4
4*		Rock Fibre	0.2	107	Studs 2 and 4
5*		Cellulose Fibre	0.2	110	Studs 1 and 3
6*		Rock Fibre	0.2	136[a]	Studs 2 and 4
7*		Cellulose Fibre	0.2	124	Studs 2 and 4

(1–3) – Fire Tests conducted by Gunalan [11].
(1*–7*) – Fire Tests conducted by Kolarkar [10].
[a] Earlier failure due to lack of space for thermal expansion.