Thin-Walled Structures 78 (2014) 148–170

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Numerical modelling of load bearing light gauge steel frame wall systems exposed to realistic design fires

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ARTICLE INFO

Article history:
Received 12 November 2013
Received in revised form
8 January 2014
Accepted 8 January 2014
Available online 26 February 2014

Keywords:
Finite element analysis
Realistic design fires
Light gauge steel frame walls
Load bearing walls
Buckling
Fire resistance rating

ABSTRACT

Fire safety has become an important part in structural design due to the ever increasing loss of properties and lives during fires. Conventionally the fire rating of load bearing wall systems made of Light gauge Steel Frames (LSF) is determined using fire tests based on the standard time–temperature curve in ISO834 (ISO 834-1, 1999 [1]). However, modern commercial and residential buildings make use of thermoplastic materials, which mean considerably high fuel loads. Hence a detailed fire research study into the fire performance of LSF walls was undertaken using realistic design fire curves developed based on Eurocode parametric (ENV 1991-1-2, 2002 [2]) and Barnett's BFD (Barnett, 2002 [3]) curves using both full scale fire tests and numerical studies. It included LSF walls without cavity insulation, and the recently developed externally insulated composite panel system. This paper presents the details of finite element models developed to simulate the full scale fire tests of LSF wall panels under realistic design fires. Finite element models of LSF walls exposed to realistic design fires were developed, and analysed under both transient and steady state fire conditions using the measured stud time–temperature curves. Transient state analyses were performed to simulate fire test conditions while steady state analyses were performed to obtain the load ratio versus time and failure temperature curves of LSF walls. Details of the developed finite element models and the results including the axial deformation and lateral deflection versus time curves, and the stud failure modes and times are presented in this paper. Comparison with fire test results demonstrate the ability of developed finite element models to predict the performance and fire resistance ratings of LSF walls under realistic design fires.

1. Introduction

In recent years, building construction industries around the world have shown increased interest in the use of cold-formed Light gauge Steel Frame (LSF) wall panels for residential, industrial and commercial buildings as primary load bearing elements. When LSF wall panels are used in buildings, they need to satisfy certain fire resistance requirements. Fire testing of LSF wall systems is generally based on the standard time–temperature curve given in ISO 834 [1], which originated from the application of wood burning furnaces. In reality, modern residential and commercial buildings include increasing amounts of synthetic foams and thermoplastic materials. These synthetic materials increase both the speed of fire growth and heat release rate, thus increasing the fire severity beyond that is provided by the standard fire curve used to obtain the Fire Resistance Rating (FRR) of construction elements.

The time–temperature curve used in fire tests [2,3] should represent most of the potential fires in buildings. However, the present standard time–temperature curve may not meet this requirement. This was demonstrated by many researchers [4–7] using compartment tests, where the maximum temperature in a natural fire exceeded the standard ISO curve [1] within a short period of time from ignition. Fire testing using the standard fire time–temperature curve will give good comparative results for building systems tested under identical conditions, and also valuable basic data. However, it does not provide accurate FRR for modern residential and commercial buildings. Therefore a detailed research study was undertaken to investigate the fire performance of LSF wall systems under more realistic fire conditions. In a building fire, the fire growth, fully developed and decay phases depend on aspects such as fuel load, ventilation openings and thermal properties of compartment lining materials. Based on the available literature, appropriate values of these parameters were selected to represent the modern building fire scenarios, and suitable realistic design fire time–temperature curves were developed by Ariyanayagam and Mahendran [8]. These realistic design fire curves were then used in full scale fire tests of eight LSF wall specimens of three different wall configurations (single and double plasterboard lined walls and externally insulated walls). Details of these fire tests and the results including the observed

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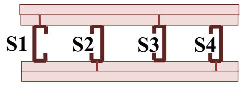
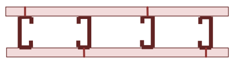
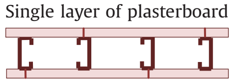
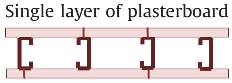
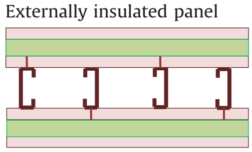
http://dx.doi.org/10.1016/j.tws.2014.01.003

Table 1
Fire tests conducted using realistic design fire curves [9].

Test	LSF wall configuration	Fire curve [8]	Insulation type	Load ratio (load per stud)	Failure time (min)
LSF1	Double layers of plasterboard	EU-2(0.03)—Comp A	–	0.2 (15 kN)	No failure
LSF2		BFD-2(0.03)—Comp A	–	0.2 (15 kN)	139
LSF3	Single layer of plasterboard	EU-1(0.08)—Comp A	–	0.2 (15 kN)	28
LSF4		BFD-1(0.08)—Comp A	–	0.2 (15 kN)	39
LSF3a[a]	Single layer of plasterboard 	EU-1(0.08)—Comp A	–	0.2 (15 kN)	39
LSF3b[a]	Single layer of plasterboard 	EU-1(0.08)—Comp A	–	0.2 (15 kN)	30
LSF5	Externally insulated panel	BFD-2(0.03)—Comp B	Rock fibre	0.4 (30 kN)	118
LSF6		EU-2(0.03)—Comp B	Rock fibre	0.4 (30 kN)	120

[a] Test LSF3a is a repeat of Test LSF3 with 150 mm wide edge plasterboard strip fixed along Stud 4 (right side of the wall) instead of along Stud 1 in Test LSF3 (left side of the wall), and in Test LSF3b vertical plasterboard joints were located along central studs to avoid the 150 mm edge strips of plasterboard [9]. Load per stud was calculated as load ratio × ambient temperature capacity of stud (77 kN).

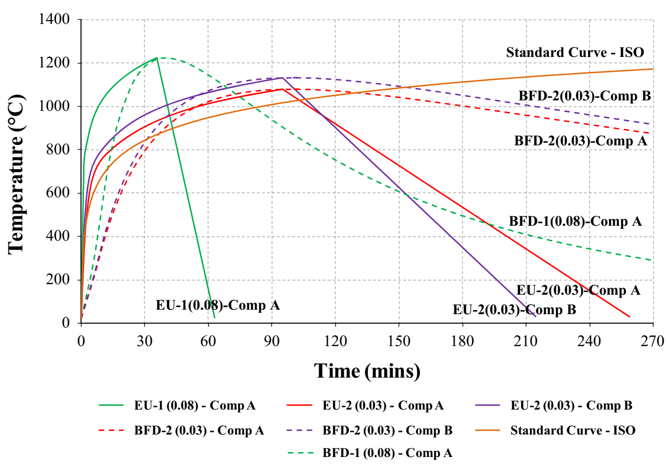


Fig. 1. Realistic design fire time–temperature curves used in fire tests [8].

stud failure modes and times, and the measured time–temperature and deformation curves of LSF wall panels are given in Ariyanayagam and Mahendran [9]. Table 1 presents a summary of test wall configurations used and the results while Figs. 1 and 2 show the realistic design fire curves and the fire test set-up, respectively.

This paper presents the details of finite element models developed to simulate the full scale fire tests of LSF wall panels under realistic design fires. Finite element models of LSF walls under realistic design fire curves were developed using ABAQUS, and analysed under both transient and steady state fire conditions using the measured stud time–temperature curves in the fire tests [9]. Details of the developed finite element models, procedures and the results are presented in this paper. Transient state analyses were performed first to simulate the fire test conditions more closely. They were followed by steady state analyses to obtain the load ratio (ratio of ultimate stud capacities under fire and ambient conditions) versus time and failure temperature curves of LSF wall studs under realistic design fires.

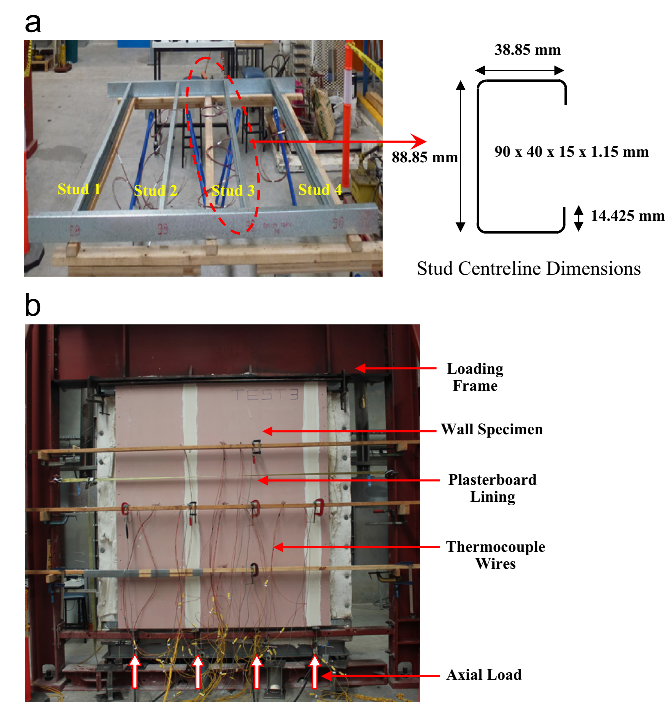


Fig. 2. LSF wall test frame and fire test set-up: (a) LSF wall test frame and stud dimensions and (b) fire test set-up.

2. Model description

Many researchers [10–13] developed suitable finite element models of LSF walls to study their behaviour under standard fire conditions. In this study ABAQUS Version 6.9-1 was used with MSC/Patran 2010.1.2 as pre and post-processors. Experimental LSF wall panel included four cold-formed steel lipped channel section studs ($90 \times 40 \times 15 \times 1.15\ mm^4$) of 2400 mm length spaced at 600 mm centres and connected to top and bottom tracks [9]. Each stud was loaded to a pre-determined axial compression load based on the required load ratios of 0.2 and 0.4 using individual hydraulic ramps