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Numerical study of high strength LSF floor systems in fire

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ABSTRACT

Light gauge steel frames (LSF) are commonly used in floor systems. The LSF floor systems must be designed to serve as fire compartment boundaries and provide adequate fire resistance. However, limited research has been undertaken on LSF floor systems, particularly on those made of high strength steel joists, and hence a thorough understanding of their fire resistance behaviour is not available. Recently a new composite floor system was also developed to provide higher fire resistance rating. But its increased fire rating could not be determined using the currently available design methods. This paper presents the details of finite element models of high strength LSF floor systems developed to simulate their structural performance under standard fire conditions. The numerical analyses of LSF floor joists were undertaken using the finite element program ABAQUS based on the measured time–temperature profiles obtained from full scale fire tests under both steady state and transient state conditions. Finite element models were calibrated using full scale fire test results and used to further investigate the structural fire behaviour of LSF floor systems. Numerical analyses provided a good understanding of the structural fire behaviour of LSF floor systems and confirmed the superior performance of the new composite floor system. This paper has shown that fire resistance ratings of a range of LSF floor systems can be predicted from the critical average joist temperature obtained from finite element analyses.

1. Introduction

Cold-formed and thin-walled steel members can be assembled in various combinations to provide cost-efficient and safe light gauge floor systems for buildings. Such light gauge steel framing (LSF) systems are widely accepted in industrial and commercial building construction. Light gauge cold-formed steel joist sections are commonly used in planer structural floor systems with gypsum plasterboards providing fire protection. Under fire conditions, thin steel joist sections heat up quickly resulting in a rapid reduction to their strength and stiffness, and hence a good understanding of the fire behaviour of LSF floor systems is important. In comparison to the many research studies on the fire behaviour of LSF wall panels [1–7], such work on LSF floor panels has been limited. To date limited research has been undertaken in this research area of LSF floor systems under fire conditions. This research was also conducted only outside Australia [8–12], representing specific materials and methods of construction used in those countries. There has not been any fire research on the LSF floor systems used in Australia. Hence a detailed research study was conducted on the fire performance of Australian LSF floor systems made of high strength steel joists under standard fire conditions.

The use of plasterboards provides protection to steel joists during fires, delaying the temperature rise in the cavity. Fire resistance rating (FRR) of LSF floor systems can be increased simply by adding more plasterboard sheets to the steel joists. Improved fire protection systems are essential. Kolarkar and Mahendran [13] developed a new composite panel system, where the insulation was sandwiched between two plasterboards and placed outside the steel frame, and suggested that the fire resistance of LSF floors and walls can be improved considerably. Such improvements in the plasterboard and insulation systems, steel joist configurations and construction methods have the potential of increasing the FRR of LSF floor systems. Therefore this research investigated the structural fire performance of LSF floor systems with the new composite panel system [13] using full scale fire tests and numerical studies. Both the conventional (with and without rock fibre cavity insulation) and the new composite panel systems [13] were considered. The new composite floor system using rock fibre insulation was used on the ceiling side of the steel frame. Four 2.4 m long 180 mm × 40 mm × 15 mm × 1.15 mm lipped channel section joists made of Grade 500 steel (measured yield strength of 612 MPa) were screw fastened to channel tracks at 600 mm spacing to form 2.1 m × 2.4 m frames. The LSF floor specimens were first loaded to pre-determined values (load ratio of 0.40), and then exposed to standard fire [14] conditions on the ceiling side

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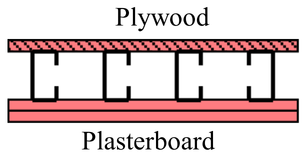
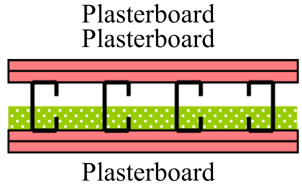
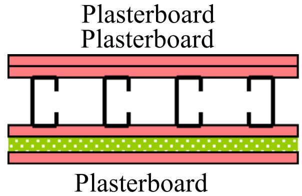
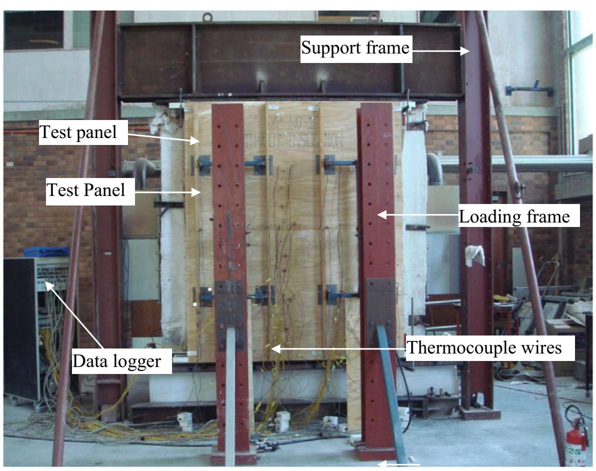
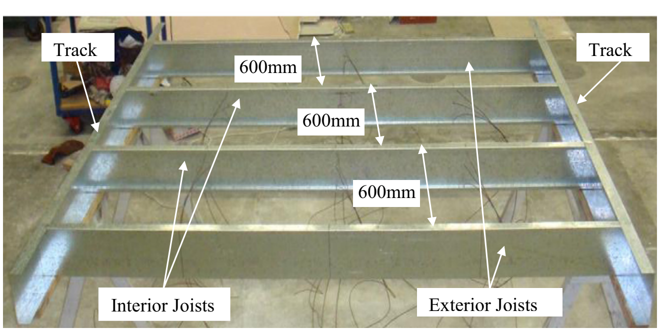
0263-8231/

Table 1
Details of test panel configurations and failure times.

Test no.	Configuration	Insulation	Failure mode	Failure time (min)
01		None	Structural	107
02		Rock fibre Cavity insulation	Structural	99
03		Rock fibre External insulation	Structural	139



(a) Test Setup



(b) LSF Floor Specimen

Fig. 1. Fire tests of LSF floor panels [15]. (a) Test Setup. (b) LSF Floor Specimen.

(plasterboards). The floor panel loading was simulated as a series of concentrated loads distributed over the panel. Table 1 gives the details of the three full scale floor specimens while Fig. 1(a) and (b) show the fire test set-up and LSF floor frame used in this study. In Test 1 plywood sub-floor was used on the ambient side but in the remaining tests two plasterboard layers were used to avoid any burning of plywood in the laboratory. Full scale fire tests showed that the fire performance of externally insulated LSF floor system was superior than traditional LSF floors with or without cavity insulation. Further details of the full scale fire tests are given in Baleshan [15].

Compared with full-scale fire tests, finite element analyses (FEA) provide a relatively inexpensive and time efficient alternative. They can be used to expand the investigation into the behaviour of LSF floor joists under fire conditions without using excessive resources. Therefore FEA of the tested LSF floor systems were undertaken using ABAQUS [16] based on the measured time–temperature profiles obtained from the fire tests. The developed finite element models were calibrated using the fire test results and were used to further investigate the structural fire behaviour of LSF floor systems. This paper presents the development of suitable finite element models of LSF floor joists to simulate their significant buckling and ultimate strength behavioural characteristics under ambient and fire conditions. It also includes the comparisons of FEA and fire test results, and some useful results gained by using the validated finite element models.

2. Finite element models

2.1. Model details

Lipped channel section (180 mm depth × 40 mm flange width × 15 mm lip height × 1.15 mm thickness) joists were modelled as an individual simply supported member under a uniformly distributed load applied on their upper flanges. A half model was considered adequate with simply supported boundary conditions to simulate the tested joist as described next:

1. The pin support end was modelled by restraining the degrees of freedom "234" for all the nodes at the support as shown in Fig. 2.
2. Due to the presence of symmetry conditions, half span modelling was permitted by restraining the degrees of freedom "156" for all the nodes at mid-span (Fig. 2).

It is important to simulate the available plasterboard restraints to the joists. In Zhao et al.'s [12] model, the steel joist to plasterboard connections were represented by restraining lateral displacement (DOF 3) at the centre of both exposed and unexposed flanges at screw points. However, in Kaitila's [10] model the lateral displacement (DOF 3) was restrained at all the points along the