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Fire design rules for load bearing cold-formed steel frame walls exposed to realistic design fire curves

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ABSTRACT

Light gauge Steel Frame (LSF) walls are extensively used in the building industry due to the many advantages they provide over other wall systems. Although LSF walls have been used widely, fire design of LSF walls is based on approximate prescriptive methods based on limited fire tests. Also these fire tests were conducted using the standard fire curve (ISO 834-1, 1999 [1]) and the applicability of available design rules to realistic design fire curves has not been verified. This paper investigates the accuracy of existing fire design rules in the current cold-formed steel standards and the modifications proposed by previous researchers. Of these the recently developed design rules by Gunalan and Mahendran (2013) [2] based on Eurocode 3 Part 1.3 (EN 1993-1-3, 2006 [3]) and AS/NZS 4600 (Standards Australia (SA), 2005 [4]) for standard fire exposure (ISO 834-1, 1999 [1]) were investigated in detail to determine their applicability to predict the axial compression strengths and fire resistance ratings of LSF walls exposed to realistic design fire curves. This paper also presents the fire performance results of LSF walls exposed to a range of realistic fire curves obtained using a finite element analysis based parametric study. The results from the parametric study were used to develop a simplified design method based on the critical hot flange temperature to predict the fire resistance ratings of LSF walls exposed to realistic fire curves. Finally, the stud failure times (fire resistance rating) obtained from the fire design rules and the simplified design method were compared with parametric study results for LSF walls lined with single and double plasterboards, and externally insulated with rock fibres under realistic fire curves.

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1. Introduction

In recent times, Light gauge Steel Frame (LSF) wall systems are widely used in buildings as primary load bearing components. LSF wall panels are made of thin-walled cold-formed steel stud and track sections and lined with single and double gypsum plasterboards with and without insulations (Fig. 1). The insulated wall panels can be either cavity insulated or externally insulated, i.e. insulation layer sandwiched between two plasterboards. The structural and thermal behaviour of load bearing LSF wall panels exposed to fires is complicated due to the use of thin-walled cold-formed steel sections, for which local buckling may become a major concern. Fire events usually occur on one side of LSF walls during which a non-uniform temperature distribution is developed across the steel stud cross-sections. This results in thermal bowing deformations and non-uniform distribution of strength and stiffness of studs, making the structural behaviour of LSF wall panels even more complicated. Hence complex calculations are needed to determine the reduced axial compressive capacities of wall studs under non-uniform elevated temperature distributions in a fire, and the important fire resistance rating (FRR) of LSF wall panels.

Many experimental and numerical studies have been undertaken in the past to investigate the fire performance of load bearing LSF walls. Alfawakhiri [5], Klippstein [6], Gerlich [7], Feng and Wang [8], Ranby [9], Kaitila [10], and Zhao et al. [11] conducted detailed studies on the LSF wall systems used in Canada, USA, New Zealand and Europe. Recently Gunalan et al. [12] and Gunalan and Mahendran [13,14] conducted similar studies on LSF wall systems used in Australia, in particular, LSF wall panels made of high strength steel studs and various wall configurations including cavity and external insulations made of rock wool, glass fibre and cellulose fibre. However, all these studies were for LSF wall panels exposed to the standard fire time–temperature curve given in [1].

Although the standard fire curve has been used for more than 100 years to determine the FRR of building components, it does not represent most of the potential fires in modern buildings This was demonstrated by many researchers [15–17] using compartment fire tests. The shape of the fire curve also strongly relates to

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the behaviour of a structural element in a fire. The real building fire has a decay phase whereas the standard fire curve rises continuously as seen in Fig. 2. Also there are increasing concerns nowadays about the behaviour of structural members in the decay (cooling) phase of a fire. Fire testing using the standard fire time–temperature curve will give good comparative results for building systems tested under identical conditions. However, it does not provide accurate FRR for modern residential and commercial buildings where the fuel load has increased due to the increased usage of thermoplastic materials, synthetic foams and fabrics [18,19]. Hence Ariyanayagam and Mahendran [20] investigated the characteristics of real building fires, and developed suitable realistic design fire time–temperature curves based on Eurocode parametric [21] and Barnett's 'BFD' [20] curves to simulate possible fire scenarios in modern buildings. Fig. 2 shows these time–temperature curves developed for LSF walls lined with double plasterboards. As seen in this figure, the rate of temperature rise and peak temperatures in the Eurocode parametric curves [21] are well above those in the standard fire curve [1] in most situations for the same time period. But the decay rates are linear and very fast, leading to shorter fire durations. Barnett's 'BFD' [22] curve uses a single log-normal equation to represent both the growth and decay phases of a fire and has been developed using curve fitting to fire test results.

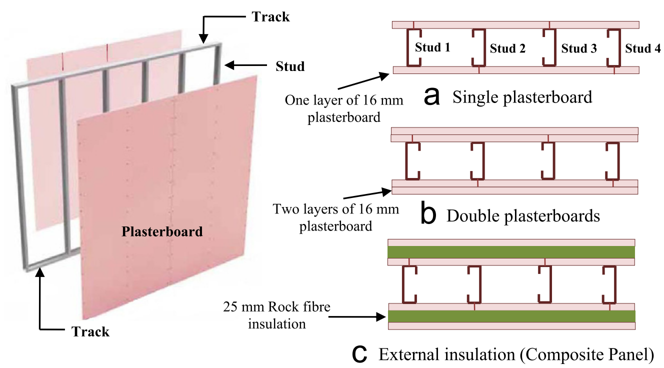

Fig. 1. LSF wall panel. *Note*: Si—single plasterboard; Db—double plasterboards and Cp—externally insulated with rock fibre.

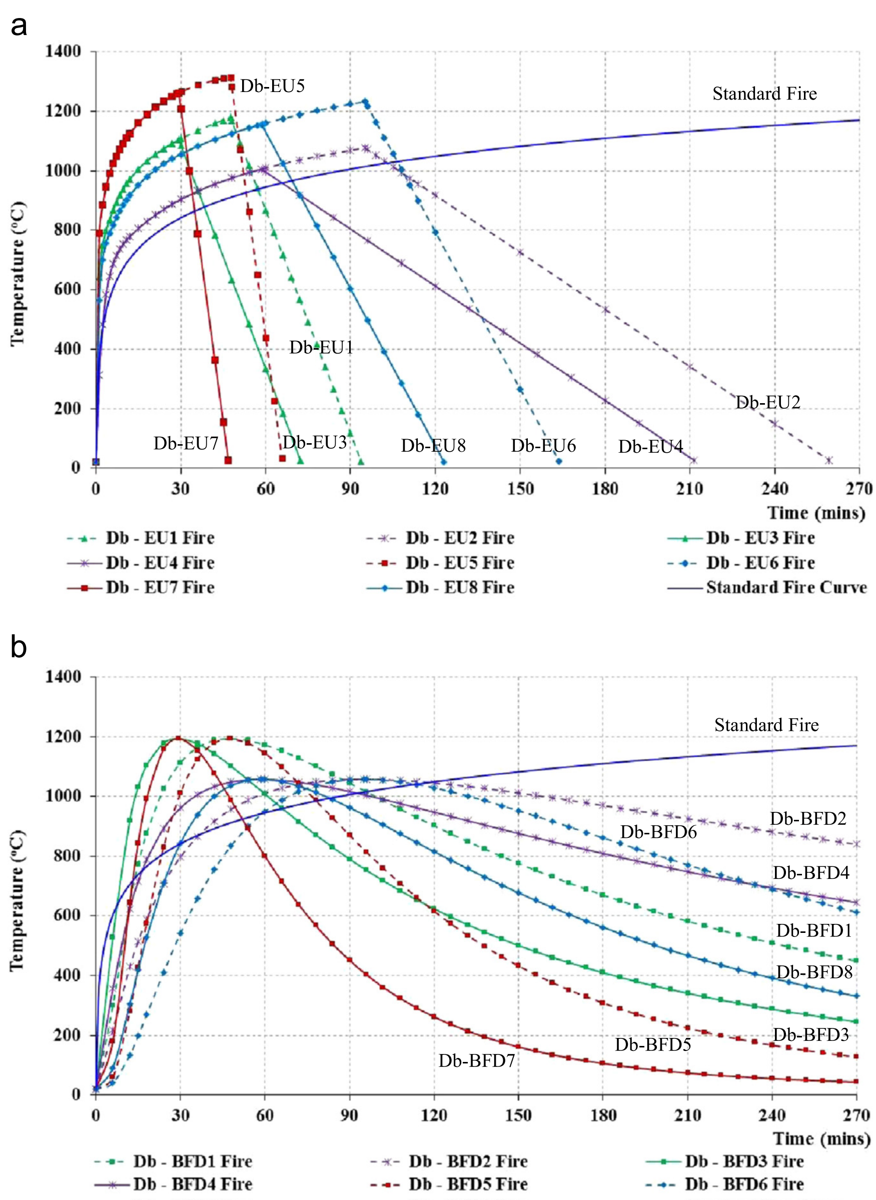

Fig. 2. Realistic design fire time–temperature curves for LSF walls lined with double plasterboards [20]. (a) Eurocode parametric fire curves. (b) 'BFD' fire curves.

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