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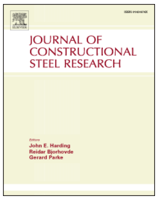

Structural response of unprotected and protected slim floors in fire

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ABSTRACT

Slim floor systems are a latest addition to the existing construction types and are currently being used for various construction purposes. Preference of slim floors over traditional composite floors is due to their ease of construction, when combined with steel decking. Considerable amount experimental work on fire response of slim floors has been conducted since 1980s. Though, these floors offer a better fire resistance, however, fire protection materials including intumescent coatings are often used in situations where a higher fire resistance is desired. Fire tests have also been conducted to analyse the performance of intumescent coating applied on steel elements as a protection material. This study presents a finite element analysis approach to model the behaviour of unprotected and protected slim floors in fire. Initially, FE analysis has been performed to model the thermo-mechanical behaviour of unprotected slim floors and results obtained have been verified against the reported test data. In the middle part, thermal behaviour of an intumescent coating, applied on a steel element as a fire protection, has been modelled and verified. The verified models have finally been combined to perform thermo-mechanical analysis for slim floors protected with intumescent coating. Results show that the protected slim floors offer a higher fire resistance as the temperature of the steel section remains within 400 °C even after 60-minute standard fire exposure. Lower temperatures in steel result in lesser reductions of strength and stiffness, hence, the protected slim floors undergo lesser deflections and offer higher fire resistance.

1. Introduction

Slim floors are amongst the trending methods of construction for high rise residential and commercial buildings and for car parks [1]. Popularity of these floorings is attributed to their shallower depths in comparison to that of traditional steel-concrete composite floors with down-stand steel beams. These floors not only result in a reduction of floor depth itself, but, also reduce the overall height of structure. These floorings offer numerous advantages including, reduction in usage of construction material due to lesser structure height, ease of construction when combined with steel decking, lesser cost requirements, possibility to accommodate services within floor depth through web openings and reduced carbon emissions resulting during manufacturing process due to lesser material consumption [2]. Steel beam section in these floors is encased within the floor depth, hence, these floors are believed to offer a higher fire resistance as steel section is saved from direct exposure to fire [3]. Numerous tests have been conducted on slim floors to study and analyse their response in fire. These include tests conducted on their thermal and thermo-mechanical response against different fire conditions. Many of the tests have been conducted at the Warrington Fire Research Centre (WFRC) in collaboration with British Steel.

This study focuses on the response of protected and unprotected slim floors in fire. In the initial part, Finite Element (FE) modelling has been performed for two slim floor assemblies exposed to ISO-834 standard fire. The modelled test assemblies are same as the ones used during fire tests conducted in the literature [4] [5]. Predictions from the FE analysis are then verified against the reported test data. In the second part of this study, thermal response of an intumescent coating applied on a steel element as a fire protection material has been modelled and verified against the test data (6). Finally, the verified models have been combined to simulate the response of assumed protected slim floor assemblies exposed to standard fire. The assumed protected slim floors are similar to the unprotected floors used during tests with only exception that a layer of intumescent coating has been added on the exposed surfaces of the bottom flange. FE modelling for protected floors has been performed with degree of utilization similar to that adopted during the fire tests on the unprotected assemblies. Response of the protected slim floors under full degree of utilization has also been predicted to check their behaviour in such a scenario. In an earlier study, behaviour of such floors in fire is analysed using two different modelling tools [7]. The earlier study is limited to their thermal response only, while in this study, FE modelling to predict thermal and thermo-mechanical response of unprotected and protected slim floors is performed in detail [4] [5].

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2. Experimental work

Experimental work used during this study is adopted from tests conducted and reported before as no experimental work was conducted during this study by the authors. Details of the tests conducted on slim floor assemblies and on the intumescent coating are given in the following.

2.1. Tests on slim floors

WFRC in collaboration with the British Steel conducted various tests to study thermal and thermo-mechanical response of slim floors in fire. During these tests, rolled asymmetric slim floor beam (ASB) sections were used in combination with composite slab formed using steel decking and normal weight concrete. Two such tests, WFRC 66162 and WFRC 67756, conducted to analyse their thermo-mechanical response are used in this study. Both fire tests were conducted against standard fire exposure, the standard temperature time curve, ISO-834 [8].

Test WFRC 66162, was conducted on the 14th of February 1996 on a 5000 mm long slim floor assembly spanning 4500 mm between supports. This test assembly consisted of an ASB 280 rolled steel beam section and a composite slab. The composite slab was formed using Comflor 210 steel decking and normal weight concrete. Nominal depth of the assembly was 308 mm while the width was 950 mm as shown in Fig. 1. Depth of the steel beam section was 280 mm while the width of top and bottom flange was 180 mm and 280 mm respectively. Thickness of flanges and web were uniform and was 18 mm as shown in Fig. 1. A 28 mm concrete layer reinforced with A-142 steel mesh was laid above the top flange. Dimensions of the steel beam section were found to be slightly different and are given in comparison to nominal ones in Table 1. Aside from the geometric variations, actual yield strength of the structural steel was found to be 402 MPa, much higher than the nominal value of 355 MPa. Further details can be found in a technical note published by the British Steel [4].

Table 1
Geometric properties of steel section, WFRC 66162.

S #	Description	Nominal (mm)	Actual (mm)
1	Beam depth	280	279
2	Beam width, top flange	180	183
3	Beam width, bottom flange	280	280
4	Thickness average, top flange	18	16.6
5	Thickness average, bottom flange	18	18.4
6	Thickness, web	18	19.5

During the test, detailed instrumentation was conducted to record temperatures and vertical deflections. 153 K-type thermocouples were used to record temperatures on steel part at various locations along its length. In addition, temperatures were also recorded at 30 different locations in concrete and at 3 locations on the steel decking. Vertical deflections of the floor were recorded at six distinct locations along its length including that at mid-span. External load was applied at four locations, directly to the steel beam section through hydraulic rams. Each hydraulic ram applied 84.6 kN load which in addition to the self-weight induced a 198.81 kN-m moment in the test assembly. This applied moment represented a 0.423 degree of utilization when compared to the cold capacity of the test assembly. Hydraulic rams were located 1125 mm apart. Under this degree of utilization, the test specimen was expected to achieve a fire resistance of more than 60 min based on the results of analysis ignoring the enhanced action between steel and concrete [4]. The slim floor assembly was tested against ISO-834 standard fire [8].

The second test, WFRC 67756, was conducted on the 4th of September 1996. Details and observations made before, during and after the test are published as a report [5]. These include details on geometry, material properties and thermal and structural data recorded. This test was conducted on a slim floor assembly consisting of an ASB section. Nominal depth of the floor assembly was 334 mm while the width was 1000 mm as shown in Fig. 2. Steel with a 355 MPa yield strength was used to form the steel beam section which was 304 mm deep. Nominal widths of the top and bottom flanges were 190 mm and 300 mm respectively. The nominal thickness of flanges was 20 mm while that of the web was 18 mm. A 30 mm layer of normal weight concrete was laid above the top flange and was reinforced with A-142 steel mesh. Measured dimension of the steel section differed to nominal ones as given in Table 2. Apart from the geometric variations, the actual yield strength of the structural steel was found to be 392 MPa, higher than the nominal 355 MPa strength [5].

Similar to the previous test, instrumentation to record temperatures and displacements was done during the test. K-type thermocouples were used to record temperatures in the steel beam across its section at various locations along its length. In addition, temperatures were recorded in concrete and on steel decking. Vertical deflections of the floor assembly were recorded at mid-span. Load was applied at four locations though hydraulic rams 530 mm apart. Each hydraulic ram applied 85 kN load which in addition to the self-weight induced a moment representing 0.390 of its capacity at ambient temperatures. Calculated moment resistance of the specimen was 796 kNm at normal conditions. Capacity of the assembly is based on the results from analysis ignoring the enhanced action between steel and concrete only considering the resistance offered by the steel section alone. Like in the case of the previous test, slim floor assembly was tested against standard fire exposure, ISO-834.

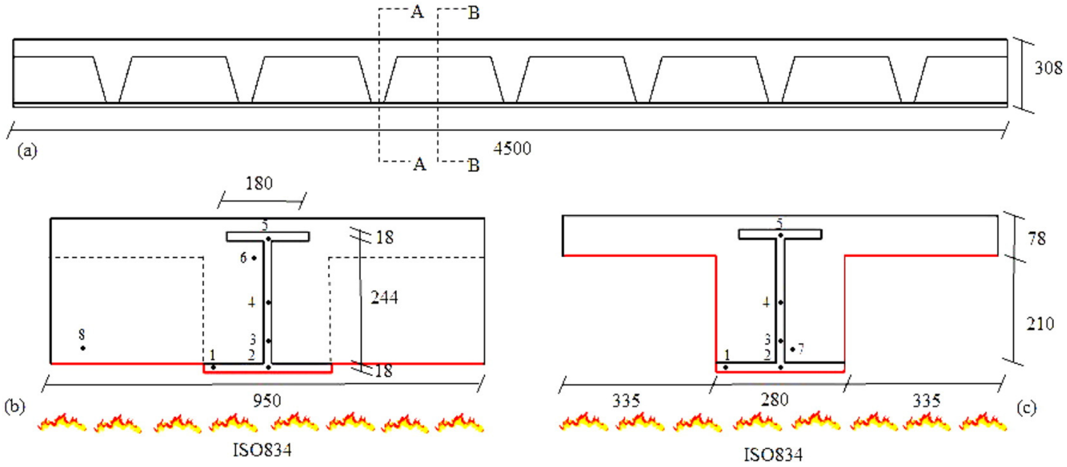

Fig. 1. Test Assembly WFRC 66162, (a) Elevation; (b) Section at A-A; (c) Section at B-B.