

# Thermo Structural Optimisation Study on Slim Floor Beam with Hollow Core Slabs



Athul Deepak Krishna and Neeraja Nair

**Abstract** Slim-floor beams are a novel typology of steel beams where the steel profile is fully embedded within the concrete floor depth. Slim-floor beams are a well-known and cost-effective solution that permits a significant reduction of floor thickness, and are increasingly used in industrial and commercial buildings. While the use of this system is increasing in the construction practice, the available investigations on its thermal performance are still scarce. Therefore, this paper focuses on analyzing the fire behaviour of slim-floor beams with hollow-core slabs as a flooring system and improving its fire-resistance. A finite element model was developed through ANSYS 16.1 and the thermal performance of different type of composite beam configuration and steel plate thickness was studied by conducting transient thermal analysis. Also, structural analysis of the following models using these material sections for SFB were conducted and its structural behaviour was studied. The conclusions suggest that the thermal performance of SFB configuration can be improved by using innovative solutions, advanced materials or external protection.

**Keywords** Slim floor beam · Hollow core slab · Thermal performance · ANSYS

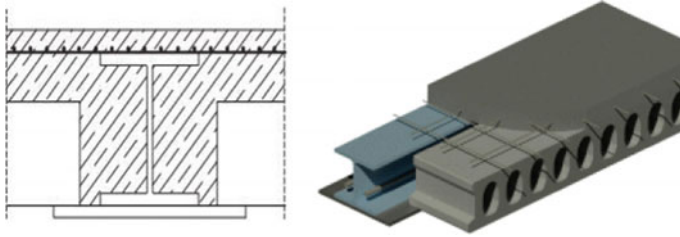
## 1 Introduction

One of the most common typologies of steel–concrete composite beam used in practice is the so-called slim-floor beam [1]. The main characteristic of this typology is that the whole height of the beam remains embedded within the floor depth. Taking advantage of this reduced height, slim-floor beams offer several improved performances such as the total floor thickness reduction and the provision of clear under-floor space for the easy installation of technical equipment.

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**Fig. 1** Slim floor beam with hollow core slab

Slim-floor beams can be used combined with different floor elements, such as profiled steel deck or precast concrete slabs. One of the most interesting typology is obtained from combining the slim-floor beam with precast hollow core slabs, which provides additional benefits as the fast erection and the structural efficiency for longer spans shown in Fig. 1.

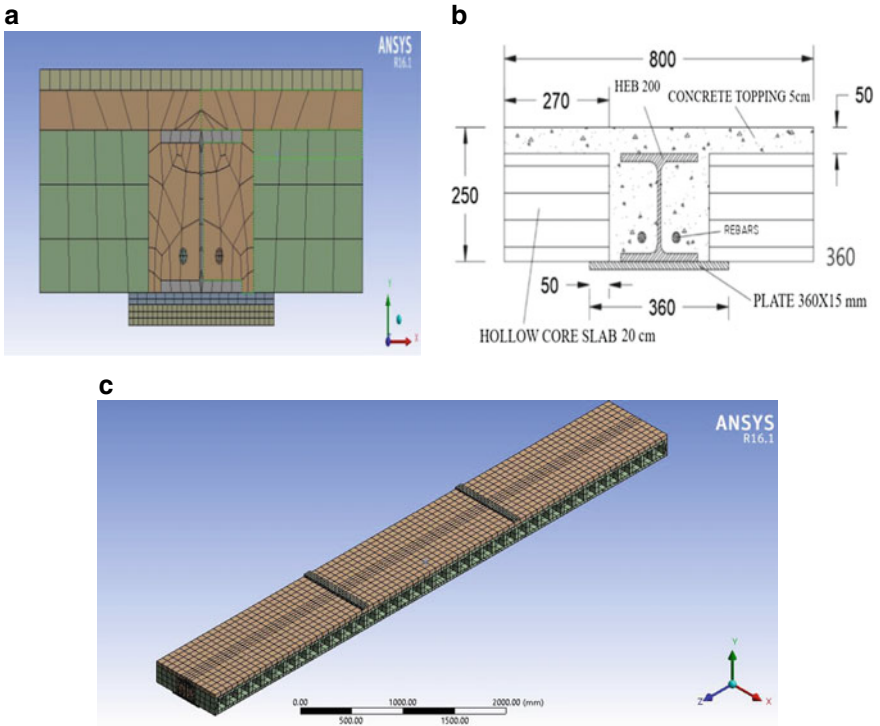
Due to the fact that the steel beam is totally embedded within the concrete floor, the fire behaviour of slim floor beams is remarkable [2]. Being exposed to fire only from their lower flange, in contrast with other types of composite beams not fully embedded within the concrete floor, slim-floor beams can achieve higher fire resistance times.

## 2 FEM of Slim Floor Beam with Hollow Core Slab

### 2.1 Geometry

This research is focused on the development of an advanced Finite Element Model for the evaluation of slim-floor composite beams, mainly of SFB typology, combined with precast hollow core slab floors supported by the bottom steel plate and welded to the lower flange of the beam. A finite element thermal model for simulating nonlinear heat transfer analysis was developed through ANSYS 16.1 and the thermal performance of different type of composite beam configuration, types of thermal resistant concrete, and steel plate thickness was studied by conducting transient thermal analysis. Also, structural analysis of the following models using these material sections for SFB were conducted and its structural behaviour was studied.

Particularly, for the analysis of the slim-floor in fire, two finite element models were needed: a thermal model and a mechanical model. Thermal model was for conducting the transient thermal analysis to find their thermal performance and mechanical model was for conducting the static structural analysis for finding their structural performance. All model parts were meshed using three dimensional eight-noded heat transfer solid elements. A maximum finite element size of 20 mm was employed for meshing all concrete parts and size of 5 mm was used for steel elements (Fig. 2; Table 1).



**Fig. 2** a Mesh view of numerical model, b CAD drawing, c 3D View of SFB with HCS model

**Table 1** The sizes of validated slim floor beam with hollow core slab [1]

Parameters	Size
Length	3200 mm
I Section	HEB 200
Base plate	360 × 15 mm
Rebars	2Ø20 mm bar
Concrete topping	50 mm
Hollow core slab	200 mm
Width of web	42 mm
Width of hole	115 mm
Height of hole	130 mm

## 2.2 Material Specification and Engineering Properties

The objective of the parametric study is to assess the influence of the below mentioned parameters over the fire behaviour of slim-floor beams. The list of parameters

**Table 2** Parametric study

Parameter	Different material cases
I Beam material type	GFRP [3]
Base plate	Stainless Steel [4]
Bottom plate thickness	5 mm, 10 mm, 15 mm

**Table 3** Thermal properties of various materials used

Material	Density (kg/m <sup>3</sup> )	Thermal conductivity (W/mK)	Specific heat (J/kgK)
Structural steel [1]	7850	60.5	434
GFRP [3]	1870	0.35	640
Stainless steel [4]	7750	15.1	480

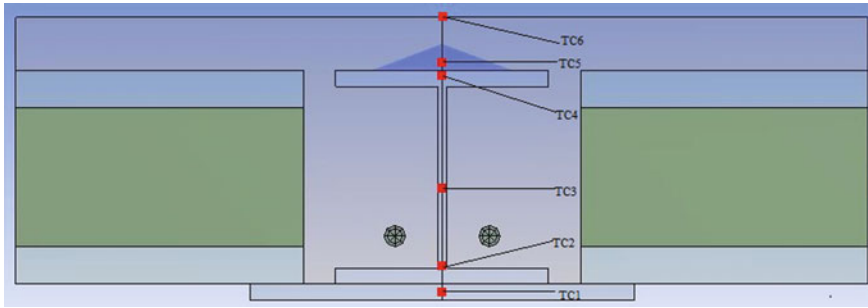
studied is shown in Table 2 and the thermal properties of various materials used is shown in Table 3.

### 2.3 Analysis

A sequentially coupled thermal-stress analysis was used to conduct the numerical simulation, thus two different models were needed: a heat transfer model and a mechanical model. The analysis was performed by first conducting a pure heat transfer analysis for computing the temperature field and afterwards a stress/deformation analysis for calculating the structural response. The slim-floor cross-section was only exposed to fire from its lower surface, matching with the electrical furnace setup and real fire exposure conditions of slim-floor beams in practical situations. The values recommended in EN 1991-1-2 were adopted for the governing parameters of the heat transfer problem. The thermal analysis is done by using transient thermal analysis.

## 3 Comparison of the Thermal Performance

During transient thermal analysis, the SFB configuration was exposed to standard fire ISO-834 model [1]. In order to evaluate the thermal behaviour of each specimen, based on journals [5], six thermocouples positions are located in the cross section of finite element model. They are TC1, TC2, TC3, TC4, TC5 and TC6. But out of these six locations; three locations are taken for thermal performance comparison. They



**Fig. 3** Six Thermocouple location in SFB with HCS

are TC1 placed at the middle part of the base plate, TC3 was placed at the middle of the I beam and TC6 was placed at the top of the slim floor beam shown in Fig. 3.

After conducting the thermal analysis then the static structural analysis was carried out. The SFB model was roller supported at the both ends. Loading plates were provided at  $L/3$  distance of the total span length shown in Fig. 2c. The structural analysis was carried out by displacement control method. And maximum load carrying capacity was found by plotting load displacement graph.

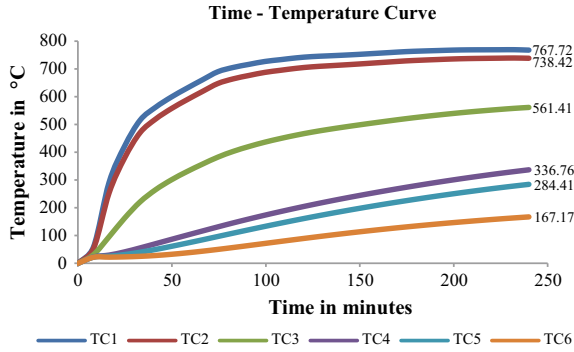
### ***3.1 Effect of Structural Steel***

After transient thermal analysis the maximum temperature recorded in various thermocouple locations were recorded. The maximum temperature recorded in SFB using structural steel in embedded I beam and base plate was  $769\text{ }^{\circ}\text{C}$  at TC1,  $560\text{ }^{\circ}\text{C}$  at TC4 and  $167.7\text{ }^{\circ}\text{C}$  at top surface. This shows the temperature distribution of structural steel material. The temperature curve for slim floor beam with hollow core slab using structural steel material section in the embedded I beam section and base plate is shown in Fig. 4.

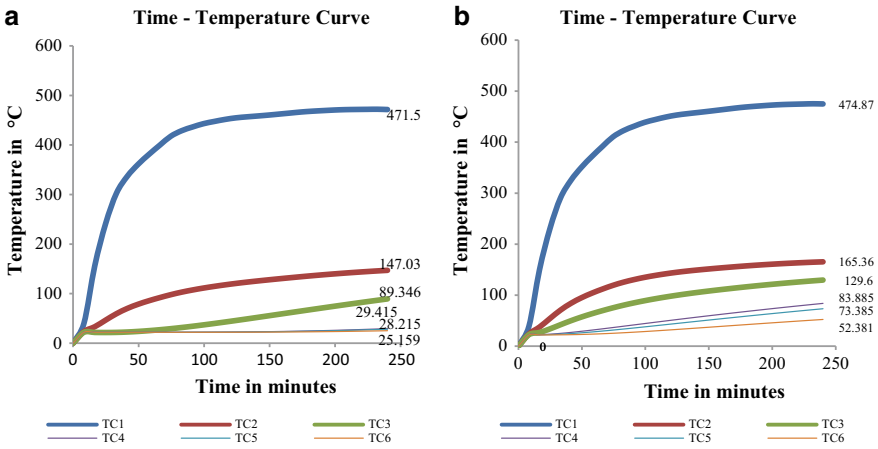
The structural response for slim floor is presented in terms of the total load carrying capacity obtained from the FE modeling. For comparison purposes the load values are taken, after the static analysis the maximum load it can carry is  $341.432\text{ kN}$  for structural steel.

### ***3.2 Effect of GFRP***

In this thermal analysis the SFB with HCS is analysed by changing the structural steel section by GFRP section was carried out. After the thermal analysis the temperature curve for slim floor beam with hollow core slab using GFRP material section is shown in Fig. 5.



**Fig. 4** The temperature curve of SFB with HCS using structural steel material section



**Fig. 5** The temperature curve of SFB with HCS using GFRP material section **a** in the embedded I beam section and base plate **b** in base plate only

The maximum temperature recorded in SFB using GFRP in embedded I beam and base plate was 471.5 °C at TC1, 89.35 °C at TC3 and 25.16 °C at top surface TC6. And in case of GFRP in base plate only, the maximum temperature recorded was 474.87 °C at TC1, 129.6 °C at TC3 and 52.38 °C at TC6. This decrease in temperature in SFB with HCS is due to the change in the thermal properties of GFRP. This shows that GFRP material section has good thermal performance compared to structural steel material. After the static analysis the maximum load the GFRP that can carry in two cases are 272.4 kN and 320.84 kN. Thus the maximum load the GFRP material section that can carry in both cases are low when compared to structural steel material section. But it has good thermal properties than structural steel material section.

### 3.3 Effect of Stainless Steel

In this thermal analysis, the SFB with HCS is analysed by changing the structural steel section by stainless steel section was carried out. After the thermal analysis the temperature curve for slim floor beam with hollow core slab using stainless steel section is shown in Fig. 6.

The maximum temperature was recorded in various thermocouple locations. The maximum temperature recorded in SFB using stainless steel in embedded I beam and base plate was 741.28 °C at TC1, 425.32 °C at TC3 and 77.635 °C at top surface TC6. And in case of stainless steel in base plate only, the maximum temperature recorded was 739.23 °C at TC1, 517.8 °C at TC3 and 156.24 °C at TC6. This decrease in temperature in SFB with HCS is due to the change in the thermal properties of stainless steel. This shows that stainless steel material section has good thermal performance compared to structural steel material. After the static analysis the maximum load the stainless steel that can carry in two cases are 242.724 kN and 341.1 kN. Thus the maximum load the stainless steel material sections that can carry in both cases are low when compared to steel material section. But it has good thermal properties than steel material section.

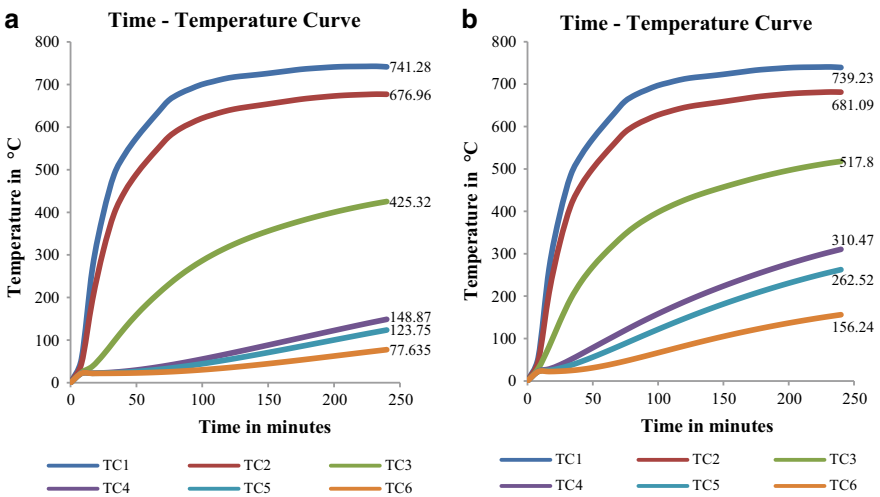


Fig. 6 The temperature curve of SFB with HCS using stainless steel material section **a** in the embedded I beam section and base plate, **b** in base plate only

**Table 4** Maximum temperature at thermocouple location

S. No.	Material	Thickness (mm)	TC1 (°C)	TC3 (°C)	TC6 (°C)
1	Structural steel	15	769	560	167.7
2	Stainless steel	15	739	517.8	156.75
3	Structural steel	5	775.2	569.35	170.53
4	Stainless steel	5	764.5	552.35	166.28

### 3.4 Effect of Bottom Plate Thickness

In this thermal analysis, the SFB with HCS is analysed by changing the depth of bottom plate. And also the property of the structural steel and stainless steel was applied to the varying bottom plate thickness simultaneously.

Table 4 shows the maximum temperature recorded in various thermocouple locations. From the result it can be observed that reducing the bottom plate thickness of SFB using stainless steel leads to a decrease in temperature between 1.4 and 3.9%. As far as stainless steel material is concerned its material cost is high compared to structural steel. By comparing the above tabulated result and cost of each material it can be concluded that the base plate of thickness 15 mm can be replaced by base plate of 5 mm thickness having material property of stainless steel. Here we can reduce material required for base plate and also use of stainless steel material will have better strength retention at elevated temperatures.

## 4 Conclusion

Based on parametric studies conducted, the influence of the different parameters over slim-floor configuration, the following conclusion can be drawn:

- Hence by use of thermal resistant material like GFRP the temperature can be reduced by a percentage of 38–77% in different locations of SFB model when compared to structural steel model. This shows good thermal performance than structural steel.
- By use of stainless steel, the temperature can be reduced by a percentage of 3–8% in different locations of SFB model when compared to structural steel model. Hence a better fire performance.
- But in case of their structural performance, the maximum load carrying capacities obtained are 320.84 and 341.1 for GFRP and stainless steel respectively. Hence they have considerably low loading carrying capacity than structural steel.



- The effect of the bottom steel plate thickness was studied. It may also be regarded as good alternatives to applying external protection by means of using stainless steel base plate of small thickness, with the related cost and material savings. Apart from a better fire performance, it also provides improved durability and an aesthetic finishing to the ceiling.

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