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NUMERICAL ANALYSIS OF SLIM FLOOR SLABS IN FIRE

BY

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Abstract. The paper presents the numerical simulation of a composite slab which combines prefabricated concrete slabs with built-in steel beams (Slim Floor type) subjected to standard ISO fire. The numerical model is calibrated through an experimental research for such type of slabs. At normal temperature, the calculation of the floor may consider the composite action or may consider, in a simplified and conservative way, only the steel profile and the rebars above the lower flange of the profile. Both hypotheses are considered in the numerical analysis.

Key words: fire design; slim floor; numerical analysis.

1. Introduction

The floors using steel beams and prefabricated concrete elements are usually built with the prefabricated concrete elements resting on the top flange of the beam. In Slim Floor slabs, the prefabricated units rest on the bottom flange of the steel profile. As shown in Fig. 1, Slim Floor composite slabs are made of asymmetric steel beams with a wide lower flange supporting usually prefabricated concrete elements, the gap between the steel beam and prefabricated elements being filled with concrete.

This particular constructive detailing produces some obvious benefits. First, it offers a flat ceiling and a reduced floor construction depth. Second, this

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solution leads to lower deflections, while the concrete around the steel section improves the load bearing capacity of the beam and additional reinforcement may be provided above the bottom flange, in order to increase the resistance. Last but not least, this solution improves the fire resistance of the composite slab, taking into account that the steel beam, excepting for the lower flange, is insulated by the concrete.

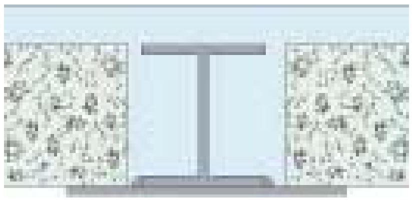

Fig. 1 – Slim Floor system – steel beam supporting prefabricated elements.

For the design of this type of floor, the composite action between the casted concrete and the steel beams is usually neglected in the calculation of the plastic design bending moment. The beams may be then calculated as steel elements and not as composite steel–concrete elements. In the present paper a numerical study is performed, in which both hypothesis (composite action or not) are considered, to determine the behaviour of a Slim Floor slab, in fire situation. The numerical model is calibrated through an experimental research for such type of slabs, performed by ARBED in 1994 (PROFILARBED, 1995). The numerical analysis under elevated temperatures was performed considering two hypotheses: composite action between the steel profile and the concrete and no composite action, by taking into account only the steel profile and the rebars above the lower flange of the profile.

2. Fire Test

A fire test made on a Slim Floor slab, as shown in Fig. 2 (PROFILARBED, 1995), was considered to calibrate the numerical model. This test was made in order to determine the fire resistance of the slab, used to build the building of the Swiss Society Winterthur. The floor was designed and executed under the supervision of Prof. M. Fontana, from ETH Zurich, in 1994. The floor in the test comprises three steel beams of 2.71 m length each, with a distance between beams of 2.4 m. The beam was realized by a half of IPE400 (f_y = 28.5 kN/cm^2) and a welded plate 400 × 12, (f_y = 20.7 kN/cm^2), as bottom flange. This plate sustained a precast concrete unit on each side. The precast units have a thickness of 16 cm, a length of 216 cm and a width of 120 cm, with a self-weight of 2.7 kN/m^2. In order to fix the precast units, concrete was poured in site with f_c = 6.2 kN/cm^2, 4 cm above top flange of profile. At the upper part of the floor a reinforcement mesh of ø8 was considered and two rebars of ø26, S500, were placed above the bottom flange of the steel beam. The beam, charged with distributed and concentrated loads (in order to reproduce the stress state which arises in the floor of the real Winterthur building) was subjected to ISO fire for 120 min.

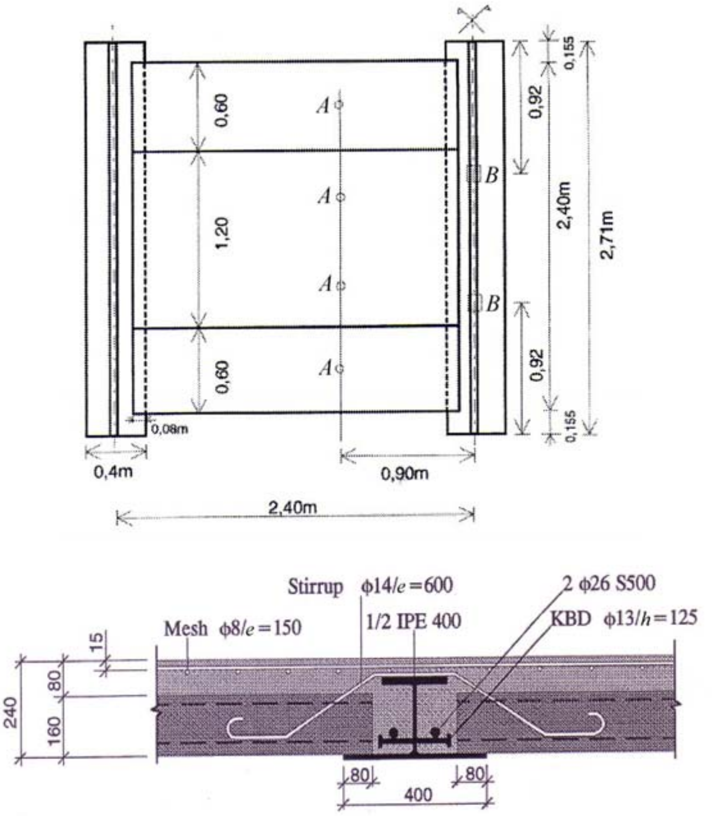

Fig. 2 – Tested slab (PROFILARBED, 1995).

3. Numerical Analysis

The numerical analysis of the Slim Floor tested in fire, presented above, was made with SAFIR (Frassen, 2005), a special purpose computer program, developed for the analysis of structures under ambient and elevated temperature conditions, at the University of Liège. As a finite element program, SAFIR accommodates various elements for different idealization, calculation procedures and various material models for incorporating stress–strain behaviour. The elements include the 2-D SOLID elements, 3-D SOLID elements, BEAM elements, SHELL elements and TRUSS elements. The stress–strain material laws are generally linear-elliptic for steel and non-linear for concrete.

The analysis of a structure exposed to fire consists of two steps. The first step involves predicting the temperature distribution inside the structural members, referred to as *thermal analysis*. The second part of the analysis, termed the *structural analysis* is carried out to determine the structural response due to static and thermal loading.

3.1. Thermal Analysis

For the thermal analysis, the material properties used in the numerical model, are those of the Eurocodes for fire design (EN 1992-1-2, 2005; EN 1993-1-2, 2005) considering the upper limit of the thermal conductivity for concrete. No moisture was considered for the concrete in the thermal analysis. The cross-section of the beam is exposed to ISO fire only from below, the temperature in the top of the floor being considered 20^{o}C.

In the numerical simulation of the test, for the thermal analysis, all elements of the cross-section that influence the bending resistance were considered, *i.e.* the steel beam with the extended bottom flange, the rebars above the bottom flange, the top reinforcement and the casted concrete. The prefabricated concrete elements were considered with the corresponding material properties only for the temperature distribution. Taking into account that these elements work in bending on the transverse direction, being supported by the extended bottom flanges of the beams, they do not participate to the flexural capacity of the cross-section.

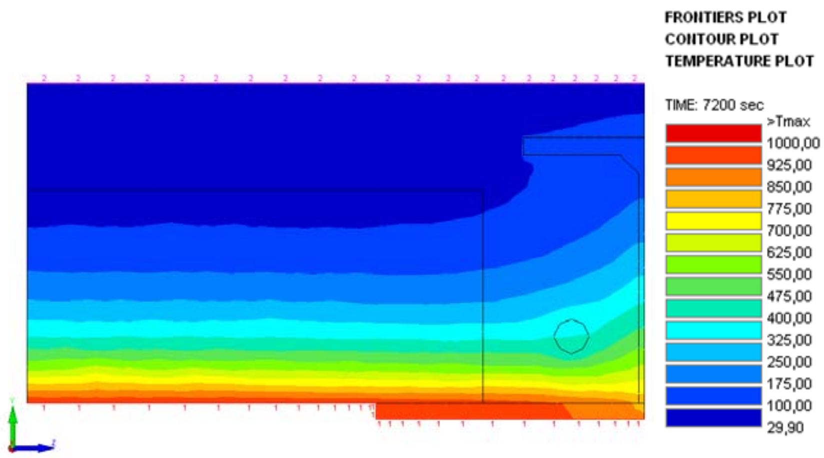

Fig. 3 – Temperature distribution on the cross-section after two hours of ISO fire.

Fig. 3 shows the temperature distribution on the cross-section of the floor, after two hours of standard ISO fire. On the cross-section, the contours of the elements may be distinguished namely: the steel beam with the wider bottom flange, the prefabricated concrete elements and the rebar above the bottom flange (due to symmetry, only half of the cross-section is represented).

As shown in Figs. 4 and 5, the temperatures calculated in the numerical simulation in the extended bottom flange and in the rebars above the bottom flange, are in good agreement with the temperatures determined experimentally. The numerical simulation offers conservative results, all the temperatures being slightly higher than the corresponding temperatures determined in the test. It may be observed that, after two hours of ISO fire, the temperatures in the rebars does not exceed the 400^{o}C limit. This corresponds to the temperature from which it is considered that the yield strength of steel begins to decrease at elevated temperatures (EN 1993-1-2, 2005) and therefore, the rebars maintain the full yield strength on the entire duration of the test and within the numerical simulation, performed for the same duration.

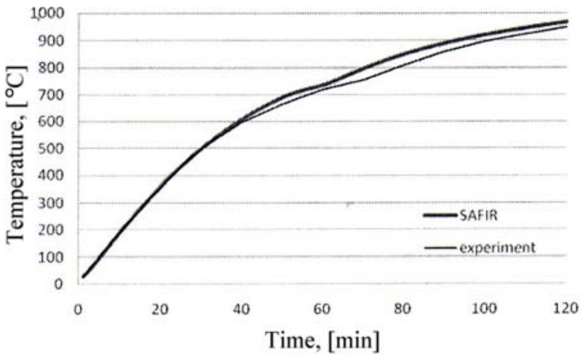

Fig. 4 – Temperature evolution in the bottom flange.

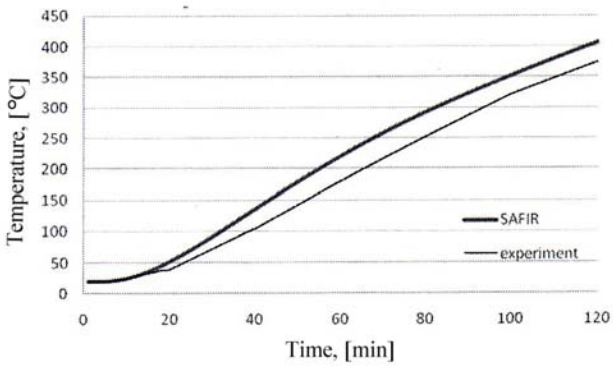

Fig. 5 – Temperature in rebars.

3.2. Mechanical Analysis under Elevated Temperatures

For the mechanical analysis under elevated temperatures, two situations were analysed:

a) the composite action is considered and all the elements of the cross-section mentioned above (the steel beam with the extended bottom flange, the rebars above the bottom flange, the top reinforcement and the casted concrete) participate to the flexural capacity;

b) no composite action is considered and only the steel beam with the extended bottom flange and the rebars above the bottom flange participate to the flexural capacity.

As Fig. 6 shows, if the composite action is considered, there is a very good agreement between the time–displacement characteristics resulted from the test and from the numerical simulation, for the two hours of ISO fire exposure at which the experiment was stopped. If no composite action is considered and only the steel beam and the rebars above the bottom flange of the beam participate to the flexural capacity (the casted and prefabricated concrete are present in the model, for temperature distribution, but are declared with zero resistance), the numerical model follows a similar path, but with higher values for displacements.

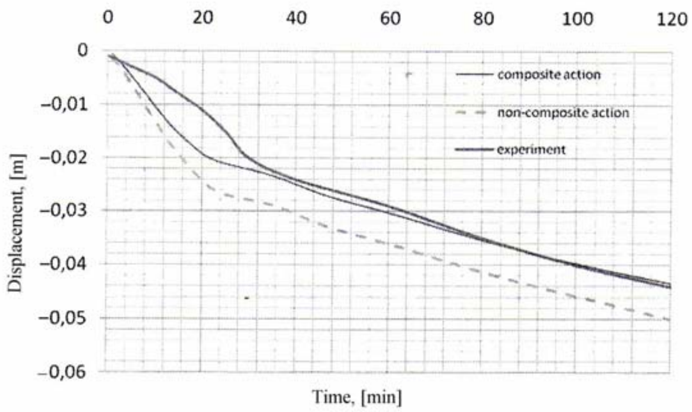

Fig. 6 – Displacement evolution at mid-span of the floor.

Therefore, in order to calculate the fire resistance of a Slim Floor composite slab, only the steel beam with the extended bottom flange may be considered, together with the supplementary reinforcement rebars above the bottom flange, if they exist, in a conservative yet economical manner (no ruin of the slab was emphasised for the two hours of ISO fire).

4. Conclusions

The behaviour of the composite Slim Floor beams in fire situation was investigated using numerical methods, considering two hypotheses: composite action between the steel profile and the concrete and no composite action, taking into account only the steel profile and the rebars above the lower flange of the profile. The comparison of the thermal analysis with the results of the fire test demonstrated that the numerical model offers good prediction at the level of temperatures in the lower flange of the steel profile and in the rebars. The comparison of the mechanical analysis under elevated temperatures with the results of the fire test also demonstrated that the numerical model offers good prediction at the level of time–displacement characteristics. Therefore, the calibrated numerical model is a reliable one to calculate the behaviour of the composite floors of Slim Floor type in fire situation. The numerical analysis emphasized that the composite action may be neglected in fire situation, in a conservative but still economical manner.

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REFERENCES

Duma D., *Simple Design Method for the Fire Resistance of Composite Steel–Concrete Slim Floor Systems*. B. Sc. Diploma, Univ. de Liège, the "Politehnica" Univ. of Timişoara, 2010.

Franssen J.-M., *SAFIR. A Thermal/Structural Program Modelling Structures under Fire.* Engng. J., A.I.S.C., **42**, *3*, 143-158, 2005, http://hdl.handle.net/2268/2928

* * * *Test au feu sur un Plancher type 'Slim Floor'*. PROFILARBED s.a., Groupe Arcelor, Centre de Recherches, EMPA/ETH, Zurich, RPS Report No *24/95*, 1994.

* * * *Design of Concrete Structures*. Part **1**-**2**. *General Rules – Structural Fire Design*. EN 1992-1-2, Eurocode 2, CEN, Brussels, 2005.

* * * *Design of Steel Structures*. Part **1**-**2**. *General Rules – Structural Fire Design*. EN 1993-1-2, Eurocode 3, CEN, Brussels, 2005.

ANALIZA NUMERICĂ A PLANŞEELOR DE TIP SLIM FLOOR IN SITUAȚIA DE INCENDIU

(Rezumat)

Se prezintă analiza numerică a unui planşeu compozit, solicitat la acțiunea focului standard ISO. Planşeul este alcătuit din elemente prefabricate din beton care reazemă pe tălpile grinzilor metalice, întreg ansamblul fiind înglobat în beton (planşeu tip Slim Floor). Modelul numeric este calibrat pe bază de încercări experimentale. Calculul unui astfel de planşeu poate fi efectuat luând în considerare acțiunea compozită sau, într-o maniera simplificată şi conservativă, considerând doar profilul din oțel şi barele de armătură de deasupra tălpii inferioare a profilului metalic, dacă aceasta există. Ambele ipoteze sunt considerate în analiză numerică.