Thermo-mechanical analysis of composite slabs under fire conditions

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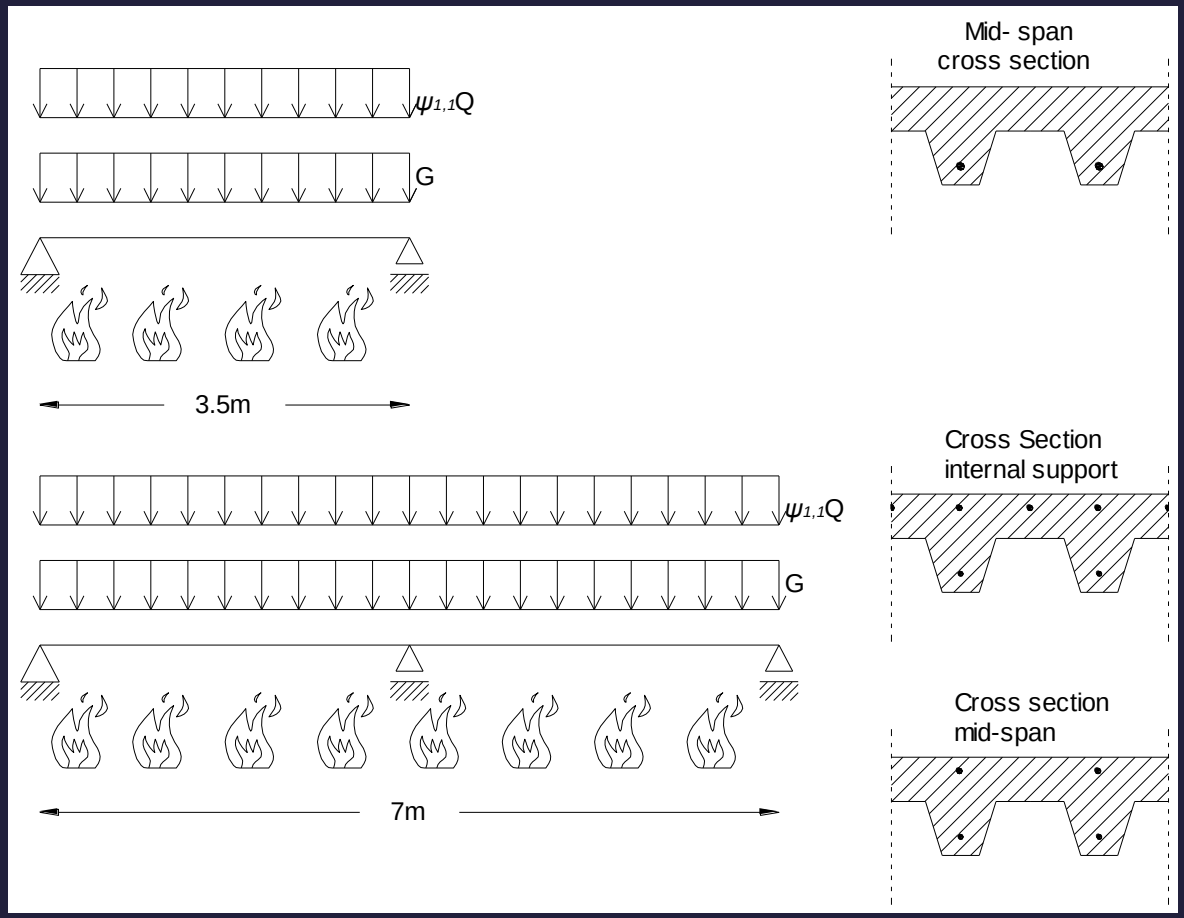
Description of the problem

In this study two structural systems are considered:
(a) a simply supported slab
(b) a continuous slab consisting of two equal spans



Description of the problem

In both cases the slabs are designed according to EC4 to have almost the same load-bearing capacity.

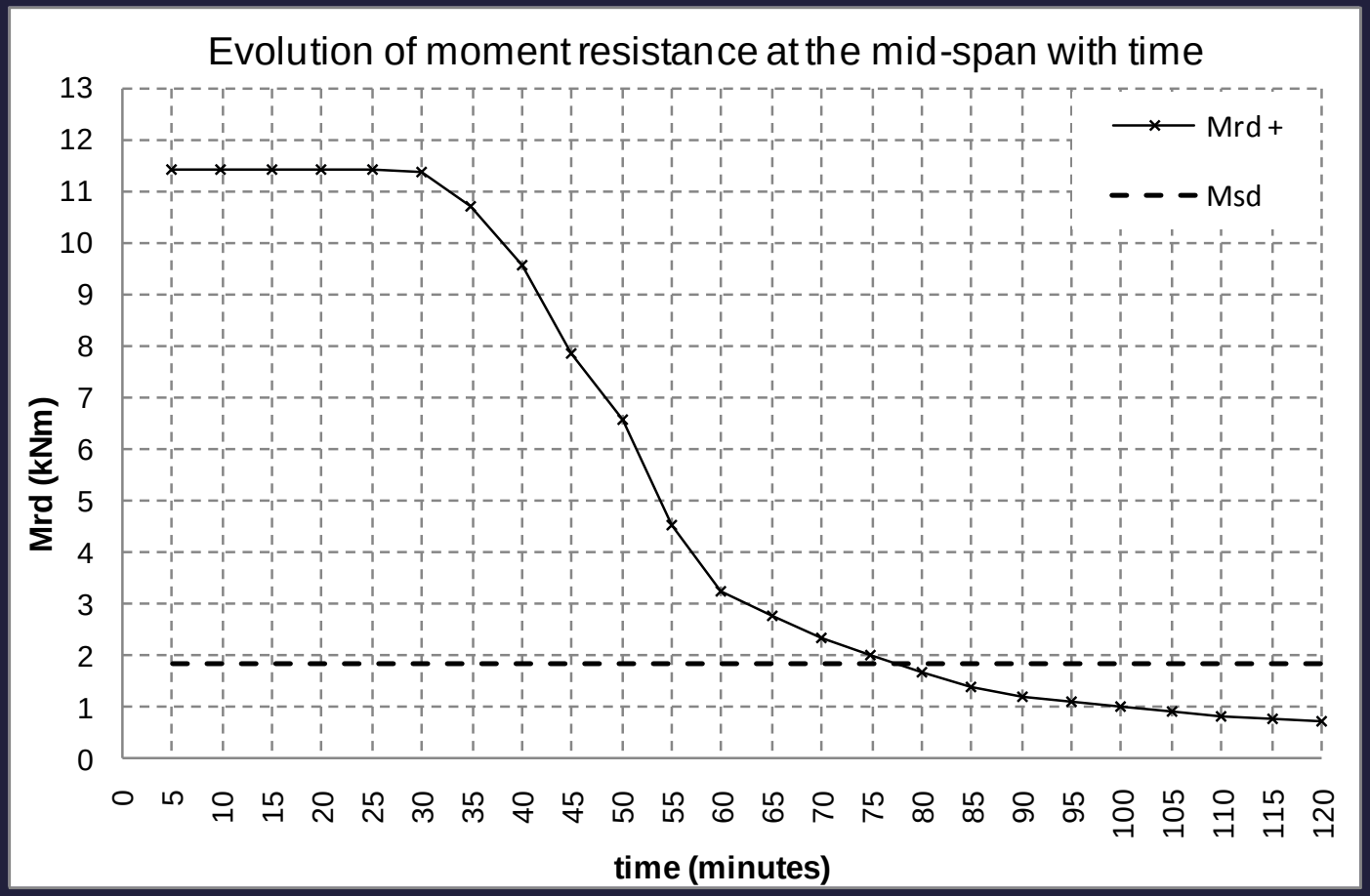
At room temperature

$M_{Rd}^{(+)}$ simply supported slab $\approx$ $M_{Rd}^{(-)}$ continuous slab

	$M_{Rd}^{(+)}$ kN·m/m	$M_{Rd}^{(-)}$ kN·m/m	Lower reinf.	Upper reinf.	*Over strength factor* λ
Simply supported slab	54.19	-	Φ8/187.5	-	0.363
Continuous slab	55.09	54.61	Φ8/187.5	Φ12/120	0.357

Description of the problem

✓**The fire resistance time for the simply supported system results to be 75 mins (R75).**

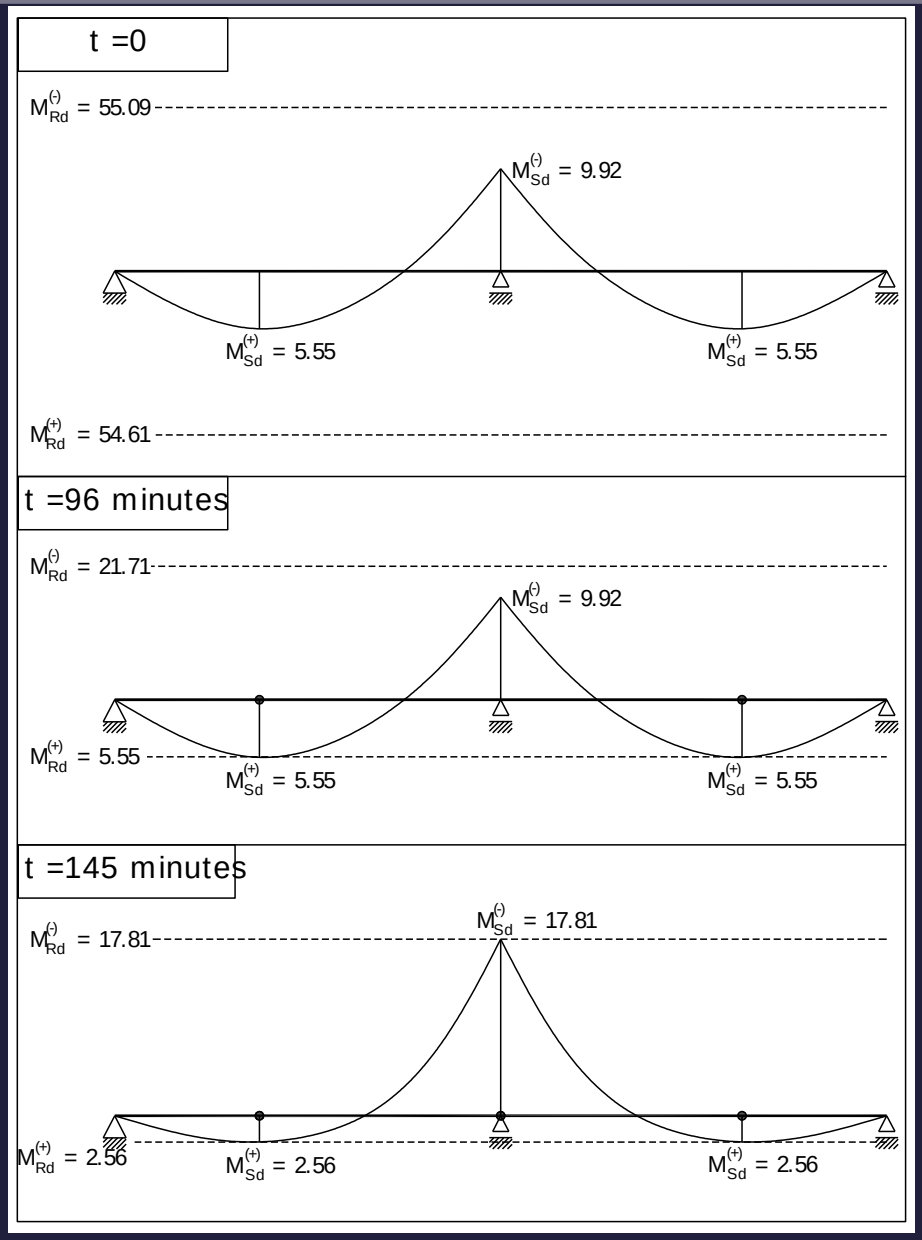


Description of the problem

✓**The case of the continuous slab is a little bit more complex, due to the fact that the system is statically indeterminate**

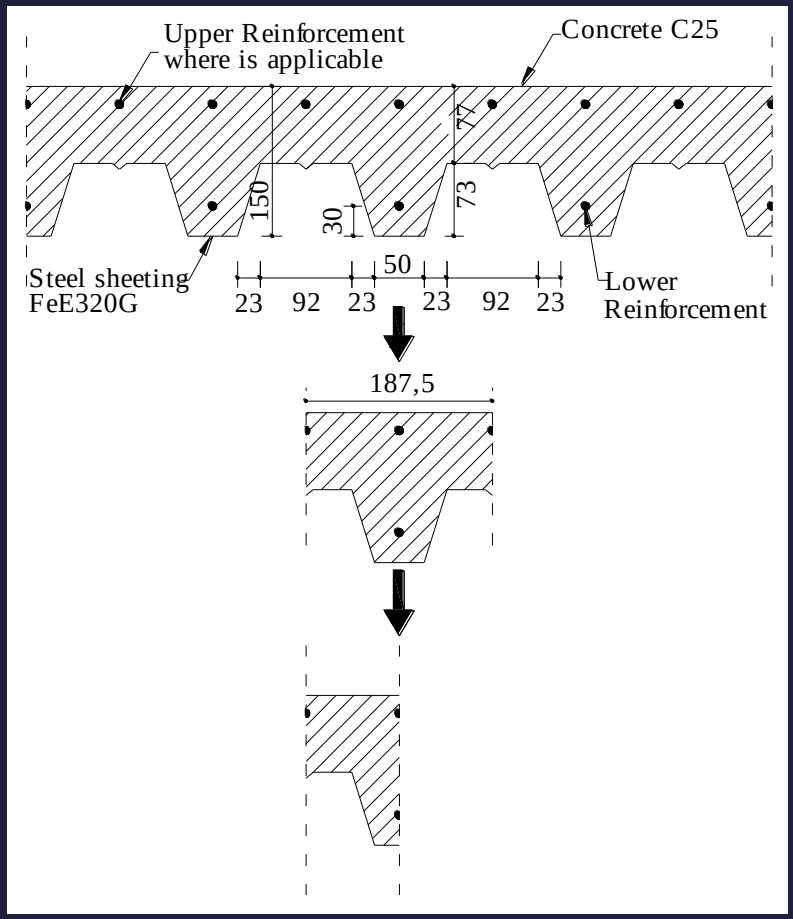
1. First the moment at the span will reach the resistance moment. This happens at the 96th minute of the ISO fire.
2. After this point, moment redistribution takes place and the moment increases at the internal support.
3. As the fire continues, both the hogging and sagging resistance moments decrease.
4. At a critical time, both the sagging moment and the hogging moment reach to the corresponding resistance values and the slab becomes kinematically unstable. This happens at the 145th minute of the fire exposure

Description of the problem



The numerical model

- Taking into account that the composite slabs are formed using continuous profiled sheeting, it is adequate to simulate a section which is 187.5mm wide.
- Due to the symmetry of this section with respect to the vertical axis, it is adequate to finally model only half of this.

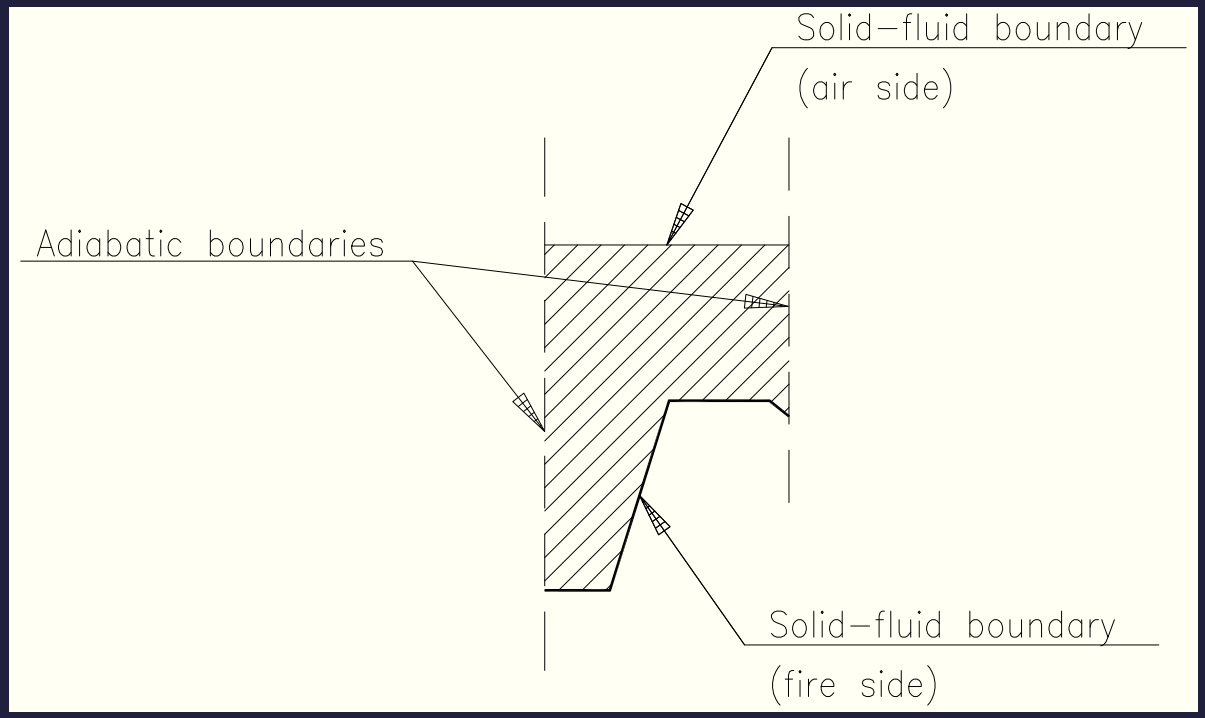


- The steel profile is modeled through four-node shell elements.
- Concrete is simulated with three-dimensional solid elements.
- Two-node truss elements are used for modeling the reinforcing bars.

Thermal boundary conditions

Solid-fluid boundary conditions

$$-k_n \frac{\partial T}{\partial n} = a(T_f - T_s)^{\beta} + \Phi \varepsilon_r \sigma (T_f^4 - T_s^4)$$



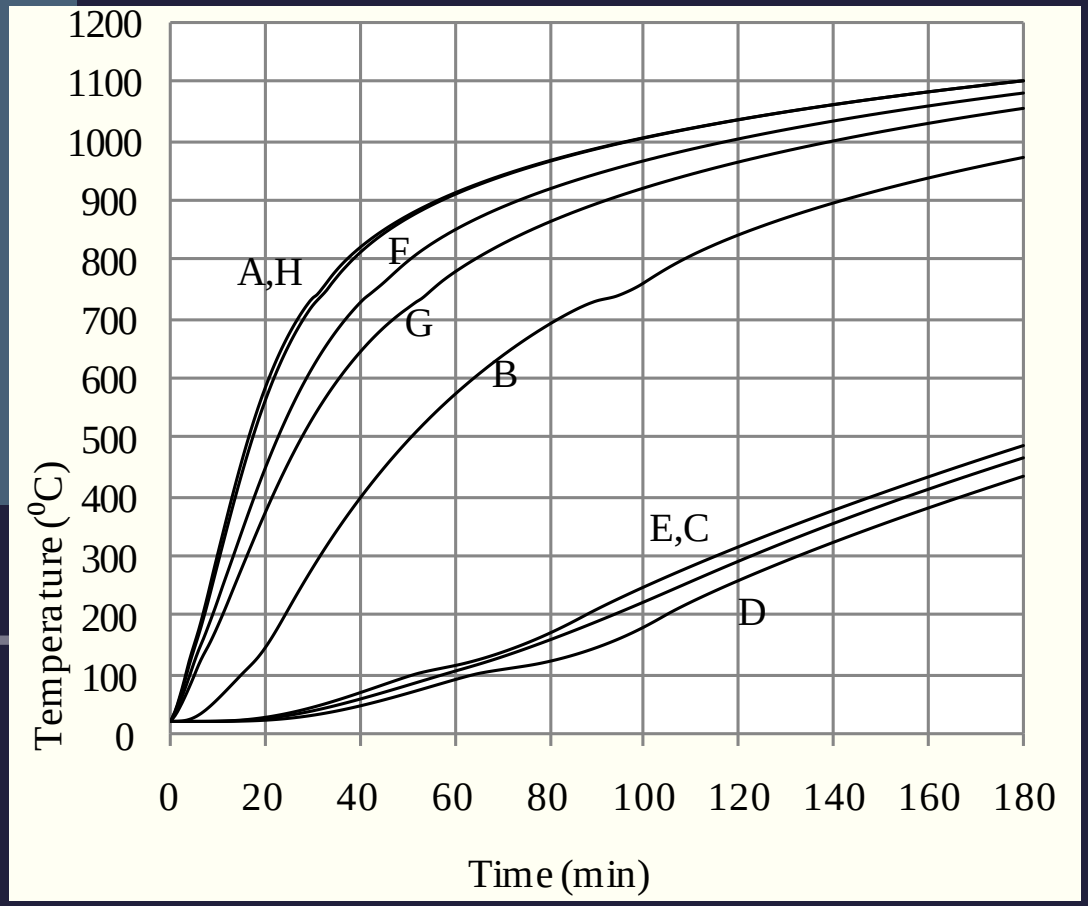
Upper side of the composite slab (air-side): the radiative term was ignored

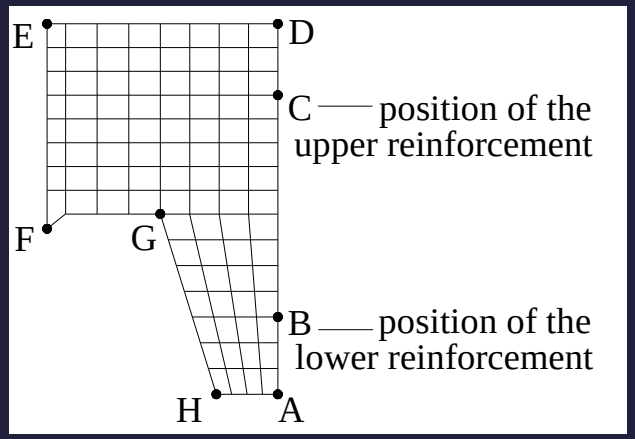
Numerical analysis

- The problem at hand is solved through non-linear coupled mechanical - thermal analysis.
- Transient heat transfer under constant imposed load is assumed.
- The composite slab is exposed to the standard fire curve (ISO fire) for 180 minutes.
- The initial temperature is taken equal to 20° C for the composite slab.

Results of heat transfer analysis

Variation of the temperature in characteristic cross-section points with time





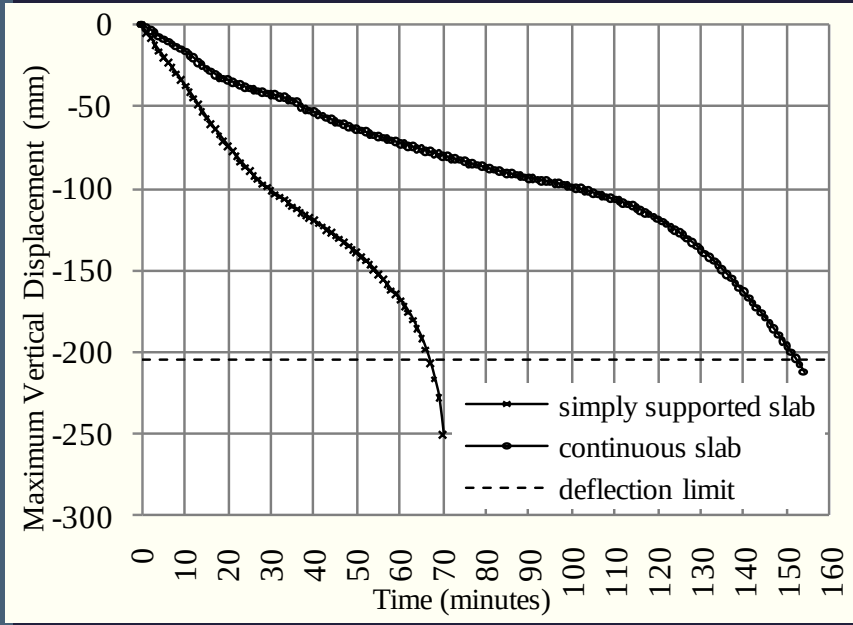
According to EC4 the fire resistance time with respect to the maximum temperature rise is <u>70 minutes.</u>

Comparison between the numerically obtained results and those obtained by the recommendations of EC4

		Mean temperature in the numerical model (º C)	Eurocode 4 procedure (º C)
60 minutes	Lower Flange	914.0	870.1
	Web	846.4	775.1
	Upper Flange	818.5	694.4
	Lower Reinf.	573.3	571.4
90 minutes	Lower Flange	989.9	965.2
	Web	947.8	906.1
	Upper Flange	922.4	840.1
	Lower Reinf.	732.0	743.5
120 minutes	Lower Flange	1038.7	1021.6
	Web	1008.2	977.8
	Upper Flange	986.5	924.3.
	Lower Reinf.	843.9	844.7

- Differences are noticed for the temperatures of the steel sheeting, indicating that EC4 is rather conservative in this respect.

Results of the coupled thermo-mechanical analysis



- ✓In the case of the simply supported slab the failure displacement is equal to 250mm when the temperature is 968^0C.
- ✓In the case of the continuous slab, the maximum vertical deflection reaches the value of 210mm when the corresponding temperature is equal to 1086^0C.

The deflection limit that is used in practice in order to avoid the excessive deformation, for flexural members is $\delta_{max} = L^2/400d = 204$mm

- In the case of the simply supported slab the limit deflection occurs around the 67^{th} minute
- The continuous slab reaches the limit deflection approximately at the 152^{nd} minute.

Conclusions - Results of the coupled thermo-mechanical analysis

✓The simply supported slab is designed to have a load bearing capacity during fire exposure for 75mins. according to the numerical analysis, the fire resistance time as it is indicated is 70 minutes.

The difference can be attributed to the fact that the temperature values that are proposed by the Eurocode 4 for the steel sheeting are lower compared with the relevant values that result from the thermal analysis. Finally, the slab fails due to excessive deformation at the mid-span.

✓The continuous slab was found to have fire resistance for 145 mins according to Eurocode 4. The results of the numerical analysis indicate that the failure occurs at the 154nd minute which is very close to the time obtained by means of advanced numerical analysis (145 mins).

The difference is reasonable and can be attributed to the assumptions that are adopted by the simplified calculation method.

Thank you for your attention