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STUDY OF REINFORCED CONCRETE SLAB FIRERESISTANCE

STUDIE POŽÁRNÍ ODOLNOSTI ŽELEZOBETONOVÉ DESKY

Abstract

Eurocode 1992-1-2 includes the following alternative design methods: detailing according to tabulated data, simplified calculating method for specific types of members and advanced calculating method for simulating the behavior of structural members, parts of a structure or an entire structure. For determining the fire resistance of a reinforced concrete slab structure the tabulated data and the simplified calculating method of isotherm 500 are used. Temperature distribution in the concrete cross-section is determined using FEM analysis (ANsys) and numerical solution (Nonstac) of differential equation of heat transfer. Calculated temperatures are compared with temperature profiles given in annex A of ČSN EN 1992-1-2.

Keywords

Fire resistance, heat exposure, reinforced concrete slab.

Abstrakt

ČSN EN 1992-1-2 obsahuje následující návrhové metody: návrh podle tabulek, jednoduchá výpočetní metoda pro určité typy prvků a zpřesněné výpočetní metody pro simulaci chování konstrukčních prvků, částí konstrukce nebo celé konstrukce. Pro výpočet požární odolnosti železobetonové desky byly použity tabulkové hodnoty požární odolnosti a jednoduchá výpočetní metoda, konkrétně metoda izotermy 500. Teplotní pole je stanoveno metodou konečných prvků (Ansys) a numerickým řešením diferenciální rovnice vedení tepla (Nonstac). Vypočtené teploty jsou porovnány s teplotními profily v Příloze A ČSN EN 1992-1-2.

Klíčová slova

Požární odolnost, teplotní odezva, železobetonová deska.

1 HEAT EXPOSURE

1.1 Study example and input data

In the paper study an example of a slab cross-section with a 200 mm thickness is analysed. The slab is reinforced with profile 10/100 mm, concrete cover is 25 mm, distance between the

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reinforcement centre of gravity and exposed side of the slab is 30 mm. The slab is made of concrete C20/25 and steel B420B.

Thermal properties of the concrete are assumed as temperature dependant according to Eurocode 2 [3]. Heat conductivity is given with upper (1) and lower (2) limit value in $W.m^{-1}.K^{-1}$.

$$\lambda_c = 2.0 - 0.2451(\theta/100) + 0.0107(\theta/100)^2 \qquad (1)$$

$$\lambda_c = 1.36 - 0.136(\theta/100) + 0.0057(\theta/100)^2 \qquad (2)$$

The basic value of concrete specific heat is 900 (J/kgK). With increasing temperature, the concrete specific heat is gradually raised to the value 1100 (J/kgK). According to Eurocode 2 [3] it is possible to take into account the initial concrete humidity with significant increasing of heat conductivity in the temperature interim 100°C-115°C. In this paper zero initial humidity is supposed on the safe side, only for verification of temperature profiles the initial humidity 1.5% is supposed.

According to the PENV version of Eurocode 2 [4], it is recommended to use the density 2300 kg/m^3, without dependence on temperature. According to Eurocode 2[3], the density is given as a function of the temperature, as the density is influenced by water evaporation, but without the recommended value for the initial density. The common concrete density is given also in Eurocode 1, part 1-1 [1] with the value 2400 kg/m^3 for plain concrete and 2500 kg/m^3 for reinforced concrete. Reinforcement in the concrete cross-section influences the final density but as the reinforcement is placed locally it cannot significantly influence the resulting temperature distribution. Therefore, in this study example the density is supposed with the values 2300 kg/m^3 and 2400 kg/m^3.

The temperature in the burning area is supposed according to the standard time temperature curve, see Fig. 1, heat transfer takes place partly by convection and partly by radiation. The temperature on the unexposed side is supposed as a constant 20°C. Appropriate parameters of heat transfer are given explicitly in Eurocode 1, part 1-2 [2].

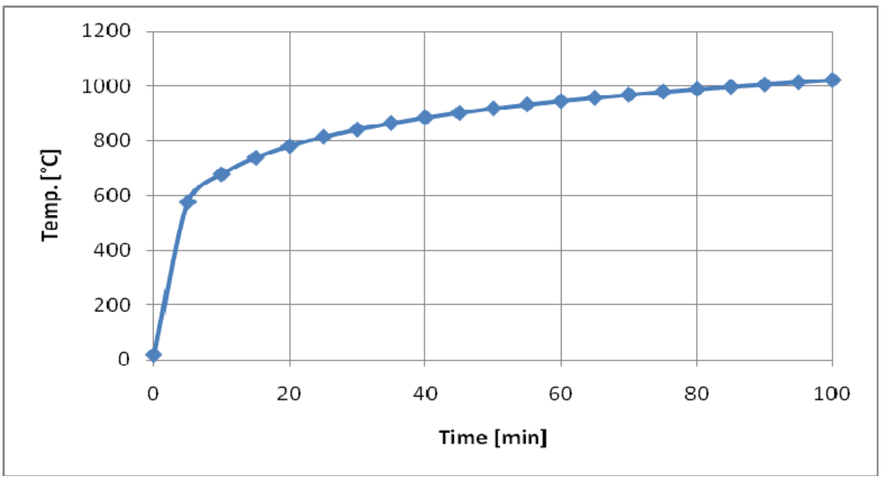

Fig. 1: Standard time/temperature curve according to ČSN EN 1991-1-2

1.2 Temperature profiles

The easiest way to appoint the temperatures in the cross-section exposed to standard fire is to use the temperature profiles in Annex A of Eurocode 2 [3], see Fig. 2. The temperature profiles were appointed for the lower value of heat conductivity, initial density 2300 $kg.m^{-3}$ and initial humidity 1.5%. As for the slab structures, the temperature profile is given only for the thickness of 200 mm. Particular temperatures in the reinforcement are compared with calculated temperatures in Fig. 3.

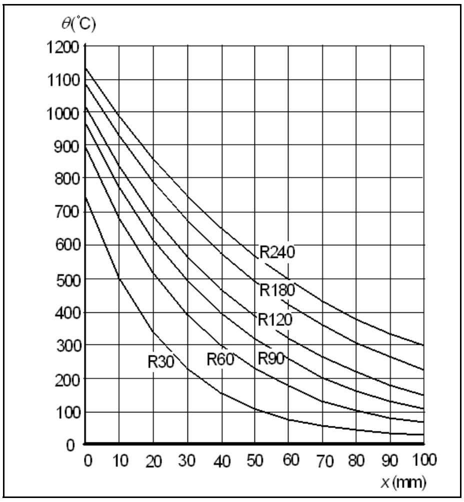

Fig. 2: Temperature profiles for slabs (thickness h=200) according to ČSN EN 1992-1-2, where x is the distance from exposed side

1.3 FEM analysis

The FEM analysis is provided using the ANsys computer program. In Table 1 there are sequenced temperatures in the reinforcement for different input data. Also noted is the calculation for the same input parameters as for the temperature profiles. Temperatures in the reinforcement are compared in the Fig.3.

Tab.1: Temperatures in reinforcement – Ansys

		temperature dependant			constant		
λ	2.0	1.36	2.0	1.36	2.0	1.36	2.0
density	2400	2400	2300	2300	2400	2400	2300
humidity	0%	0%	0%	1.5%	0%	0%	0%
Time	**Temp.**	**Temp.**	**Temp.**	**Temp.**	**Temp.**	**Temp.**	**Temp.**
min	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**
0	20	20	20	20	20	20	20
30	271	245	277	237	370	332	367
60	423	402	430	398	574	533	574
90	517	502	524	500	687	647	689
120	585	575	592	573	765	726	767
150	640	632	647	631	824	785	826
180	686	679	693	678	871	833	874
210	725	720	733	720	912	872	914
240	761	756	768	756	946	907	948

1.4 Numerické řešení - Nonstac

Numerical analysis is provided using the Nonstac computer program [5]. Though the temperature distribution in the cross-section in case of fire is generally three dimensional, in many cases one dimensional temperature distribution satisfies with sufficient accuracy. The Nonstac computer program numerically solves the Fourier differential equation of one dimensional heat transfer using the Runge-Kutta method. It is possible to input the time dependant thermal properties of material and heat transfer due to convection and radiation. Thermal material properties are entered as polynomial cubic function. According to EN 1992-1-2 [3] the thermal properties are given as a linear function for different temperature intervals and therefore the thermal properties are entered into Nonstac as regression polynomial. In Table 2 are the calculated temperatures in the reinforcement for different values of input data.

If we consider the constant values of thermal material properties, then the temperature values in the reinforcement calculated using ANsys and Nonstac software correspond. Considering the temperature dependant values of the thermal material properties, the temperatures calculated using Nonstac software are higher than temperatures calculated using ANsys software. One of the reasons could be the fact that thermal properties are input as regression polynomial. The temperatures are compared in the Figure 3.

Tab.2: Temperatures in reinforcement – Nonstac

	temp. dependant		constant		
λ	2.0	1.36	2.0	1.36	2.0
density	2400	2400	2400	2400	2300
Time	**Temp.**	**Temp.**	**Temp.**	**Temp.**	**Temp.**
min	**°C**	**°C**	**°C**	**°C**	**°C**
0	20	20	20	20	20
30	331	291	370	332	340
60	504	465	574	533	540
90	604	569	687	647	654
120	670	643	765	726	732
150	718	699	824	785	791
180	751	744	871	833	838
210	772	782	912	872	877
240	782	814	946	907	911

2 STRUCTURAL RESPONSE AND FIRERESISTANCE

2.1 Action effect

In this study example the bending moment from action effect for permanent and temporary design situations is $m_{Ed} \cong m_{Rd} = 46$ kNm/m.

Reducing the coefficient for an accidental situation in case of fire is in the interim approximately 0.4 to 0.7. In the simplified analysis it is possible to use 0.7 on the safe side, then $m_{Ed,fi} = \eta_{fi} . m_{Ed} = 0.7 \times 46 = 32$ kNm/m.

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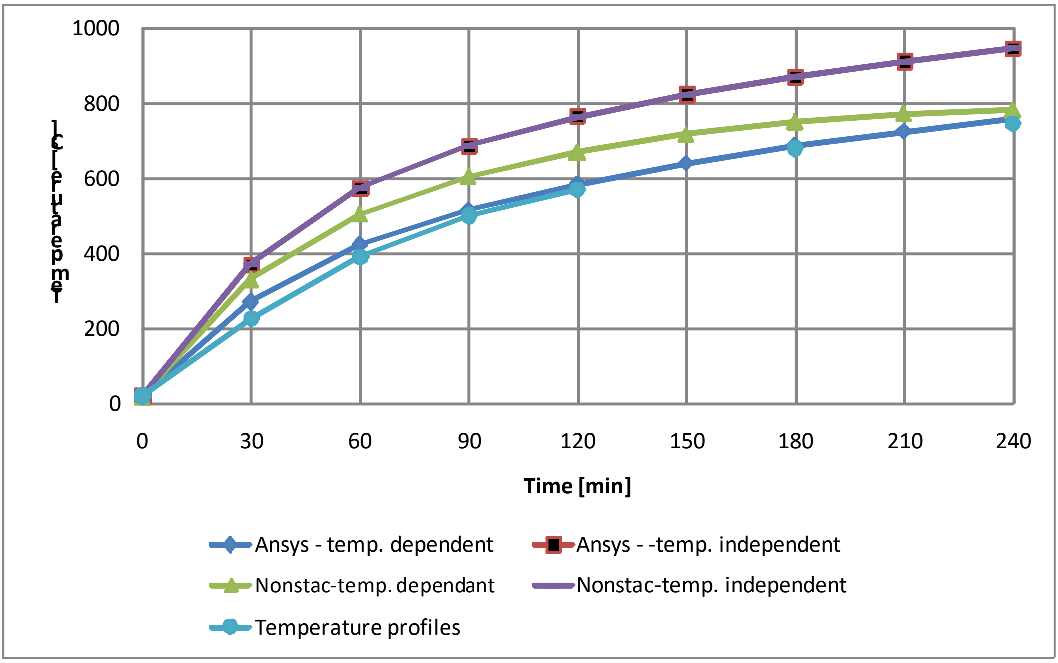

Fig. 3: Comparing the temperature in reinforcement

2.1 Fire resistance

A simple way to appoint the fire resistance is to use the tables in Chapter 5 of Eurocode 2 [3]. In Table 5.8. in Eurocode 2 it is possible to deduct the fire resistance in 90 minutes.

In Table 3 the load bearing capacities in case of fire for a time of 90 minutes are shown, the temperature in the reinforcement is supposed according to temperature profiles and calculated using Nonstac and Ansys software; the thermal material properties are considered as temperature dependant.

Tab. 3 Bending moment load bearing capacity – time 90 minutes

			Profiles	**Ansys**	**Ansys**	**Nonstac**
Heat conductivity - temp. dep.	λ	kJ/kg.K	1.36	2.0	2.0	2.0
Density - temperature dep.	ρ	kg/m^3	2300	2400	2300	2400
Temperature in reinforcement	θ_R	°C	500	517	524	604
Steel strength	$f_{yd,fi}$	Mpa	328	305	232	193
Bending moment - capacity	$m_{Rd,fi}$	kNm/m	42	39	30	25
Bending moment - action effect	$m_{Ed,fi}$	kNm/m	32	32	32	32
Assessment			OK	OK	X	X

It is obvious that appointing the temperature in the reinforcement according to the temperature profiles and consequent fire resistance corresponds with the fire resistance tables. The temperature in the reinforcement according to temperature profiles respond well with the temperatures calculated using ANsys for particular input parameters given in Annex A of Eurocode 2.

Considering the initial density 2300 kg/m^3 and the heat conductivity with a higher limit value, the temperatures in the reinforcement are higher and criterion R for bending moment bearing capacity for the time of 90 minutes is not fulfilled.

Temperatures in the reinforcement calculated using Nonstac software are higher than using Ansys software and the fire resistance for the time of 90 minutes for criterion R-bearing capacity is not fulfilled.

3 CONCLUSION

In the paper study an example of reinforced concrete slab exposed to standard fire is analyzed. Temperature in the reinforcement is determined using temperature profiles and Ansys and Nonstac software. Input data for the thermal analysis according to code [3] are not clearly specified. In the paper, temperatures in the reinforcement for different input data using different computational methods are compared. The numerical solution of the Fourier differential equation of heat transfer is provided using FEM analysis and Ansys software and the Runge-Kutta method and Nonstac software. If the temperature independent thermal properties are considered, the temperature results correspond. But if the temperature dependant thermal properties are considered, then the temperature results calculated using Nonstac software are higher than temperatures calculated with the ANsys software.

The tabulated fire resistance of the analyzed slab is 90 minutes. In this time the bending moment load bearing capacity is determined for the different calculated temperatures in the reinforcement. In view of the fact that the simplified method is more advanced than detailing according to the tabulated data, it is expected that the resulting fire resistance of the slab structure using simplified calculating methods gives more favourable values than detailing according to the tabulated data. This study would like to point out that in some cases design according to tabulated data is more favourable than the simplified method.

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