

Carrying Capacity Definition of Steel-Concrete Beams with External Reinforcement under the Fire Impact

VATULIA Glib^{1,a*}, OREL Yevhen^{1,b} and KOVALOV Maksym^{1,c}

¹Ukrainian State Academy of Railway Transport, Feuerbach square, 7, 61050 Kharkiv, Ukraine

^avatulya@kart.edu.ua, ^borel@kart.edu.ua, ^cbm@kart.edu.ua

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Abstract. The authors proposed the results of fire resistance evaluation of steel-concrete beams with external sheet reinforcement at standard temperature range of fire in the room and justified specifications for flame-retardant coat due to design standards. In order to analyze fire resistance the three-dimensional computer models have been developed taking into account basic conditions of beams loading and bearing as well as non-linear "stress-strain" dependencies of concrete and external reinforcement.

Introduction

Application of calculation method of fire resistance analysis and assessment of beams with external steel sheet reinforcement helps evaluate fire-resistance rating of the structures due to the impact of possible fire from the sides and bottom of the beam (three-sided heating). Calculations have been performed with the subsequent analysis of beams limit states according to the selected criteria of fire-resistance rating.

ANSYS software package used during the investigations gives the possibility to calculate the heat transfer, describe the stress-strain state of the structures in various sections and provides joint solution of these problems.

The calculation methodology was elaborated according to the existing technical approaches and design standards for fire-resistance rating definition of reinforced concrete and steel-concrete structures [1,2].

The authors considered concrete beams with external steel sheet reinforcement with the thickness values varying from 2 to 4 mm (Fig. 1) as object of research.

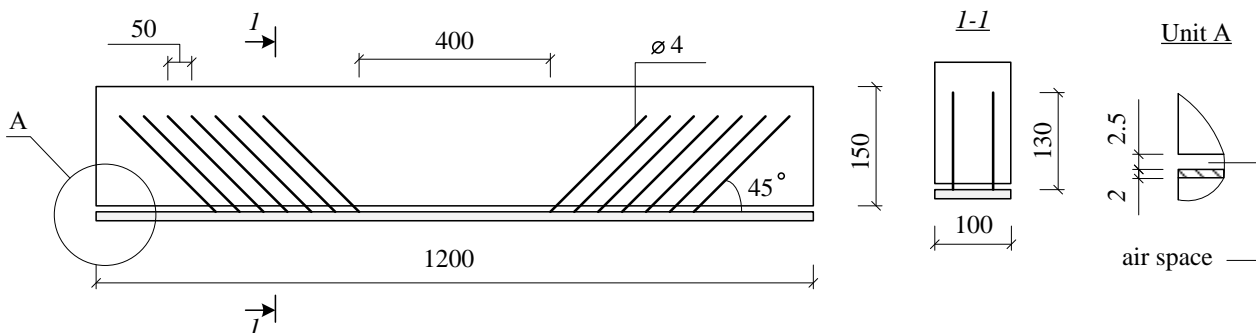


Fig. 1 Design model of steel-concrete beam

Beams were made from C20/25 concrete, with density value of 2300 kg/m^3 and normal humidity of 3%, corresponding to the conditions of concrete hardening during 28 days. Bearing steel sheet was made from St.3 structural steel; fixing anchors were made of A240 reinforcement steel with the diameter of 4 mm.

It's assumed that minimal fire resistance rating for proposed steel-concrete beams will be chosen among several values R15, R30, R45 and R60. Cause and fire scenario are not considered [2-4].

The authors used finite-element method as the resolving equations of stress-strain state definition of steel-concrete beams [5]. Determination of fire resistance was done on the basis of computer simulations using mathematical models of crack formation according to the working strength theory, models of plastic deformation and plastic strain hardening of concrete compression area and steel elements tension, size and location of the finite elements and boundary conditions taking into account the structure symmetry.

The verification of proposed finite element models and calculation has been performed by comparing the obtained results with experimental data of steel-concrete beams destruction under the mechanical load [6]. Convection and radiation boundary conditions have been imposed to created finite element models. Radiation boundary conditions have been laid on the formed finite-element mesh with the surface effect of radiative heat transfer.

Thermal and physical characteristics of the materials used in calculations have been taken according to [1]. The coefficient of heat conductivity was described by the power polynomial, and the specific heat was described by piecewise linear function.

Boundary conditions on heated and unheated side correspond to the boundary conditions of III type and take into account the convective and radiative heat transfer. Only radiative heat transfer occurs in the air space. Heat transfer parameters have been taken in accordance with [7].

As a result of calculation the temperature-time relationship curves were plotted in different points of the cross-section under standard fire impact (Fig. 2). Analyzing them it's possible to make a preliminary determination of the occurrence of fire resistance rating using conditional criterion of "critical temperature". It is assumed that when the steel temperature reaches 500°C stress values in external sheet reinforcement reach the yield point and lose its ability to resist the power loads. On the basis of this hypothesis, we can conclude that the fire resistance rating of proposed beams occurs on the 400th second (7th minute) of standard fire impact.

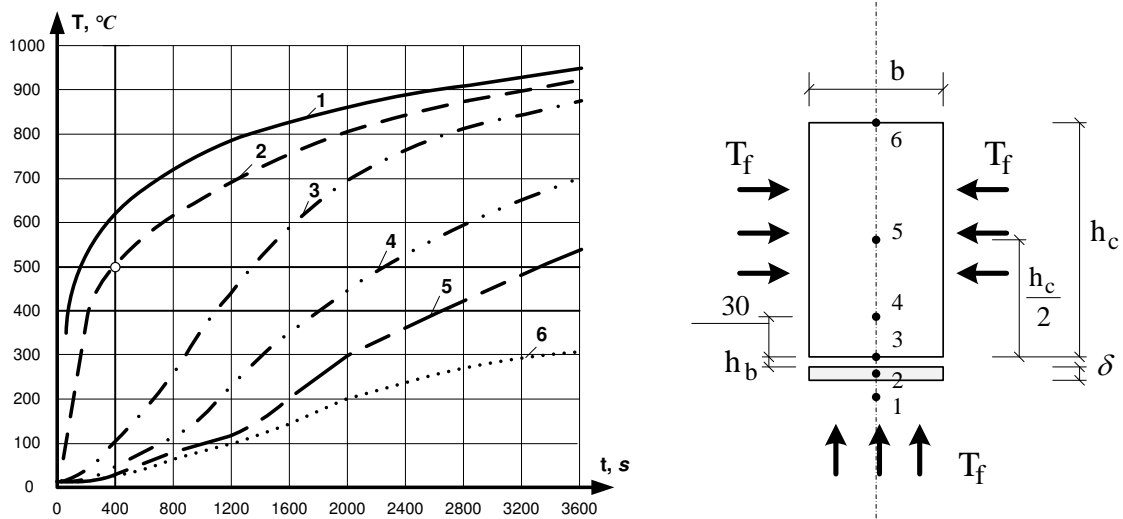


Fig. 2 Temperature-time relationship curves in different points of beam cross-section under standard fire impact: 1 – standard temperature range of fire; 2 – temperature in steel sheet; 3 – temperature in bottom concrete layer; 4 – temperature in concrete layer, located on 30 mm from bottom; 5 – temperature in middle concrete layer; 6 – temperature in upper (unheated) concrete layer

Loss of system invariability occurs on the 20th minute. Let us plot the chart of maximum flexure from standard fire impact due to more accurate determination of limiting state occurrence (Fig. 3).

The obtained chart of flexure has atypical behavior for regular reinforced concrete beams, because of the flexure excursion from the 2nd till the 5th minute of the fire impact. It happens due to rapid heating of external steel sheet reinforcement up to the temperature of 400°C and after that the character of temperature excursion slows down. At this time the sheet reinforcement sharply

expands, which results in the flexure increase and extensive crack formation of the concrete. Using the known procedure of fire resistance rating determination, described in [2], we have drawn tangent to the chart plots before and after inflection of the curve. The point of intersection characterises the fire resistance rating of investigated beams, which is equal to 18 minutes.

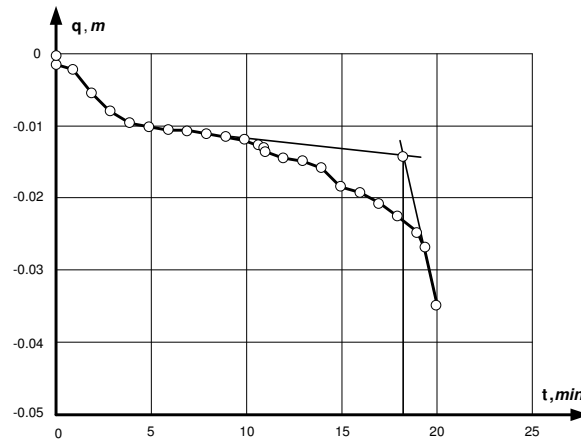


Fig. 3 Chart of maximum flexure from standard fire impact

As a result it is possible to ensure the R15 fire resistance rating, which is equal to fire resistance degree of IVa and IIIa type according to [8].

In order to provide the required fire resistance rating of steel-concrete beams several types of fire protection has been examined: Conlit SL150 Rockwool mineral wool coat, Piro-Safe FlamoPlast SP-A2 fire retardant intumescent coating and Natresk fire-retardant coating. The adhesion and cohesive properties of Natresk gypsum based fire retardant coating remain invariable during the temperature interval of standard fire. Piro-Safe FlamoPlast SP-A2 intumescent coating is sprayed only on external steel sheet reinforcement.

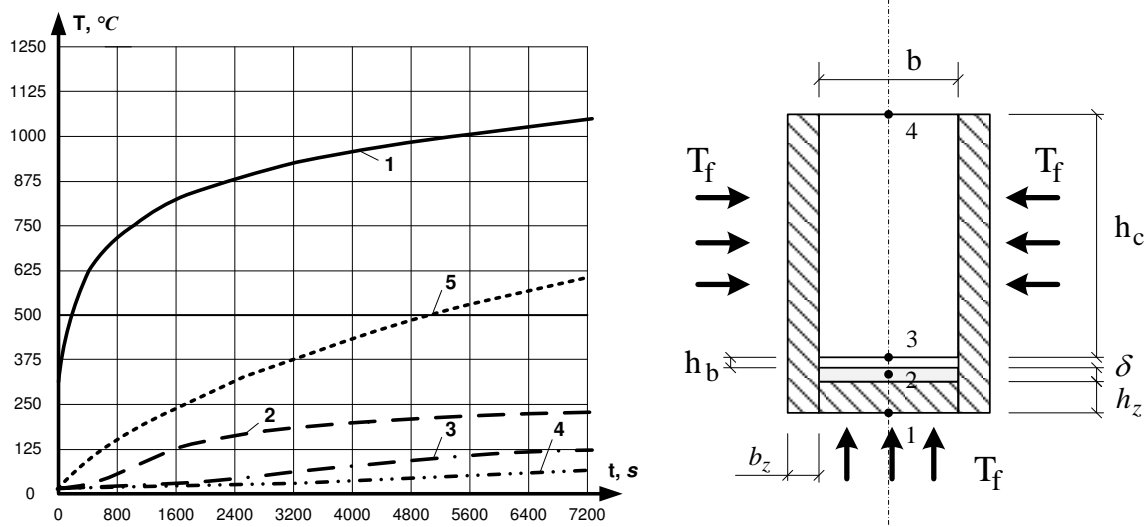


Fig. 4 Temperature-time relationship curves in different points of beam cross-section with Conlit SL150 flame-retardant coat from mineral wool board (thickness 25 mm) under standard fire impact: 1 – temperature in flame-retardant coat; 2 – temperature in steel sheet; 3 – temperature in bottom concrete layer; 4 – temperature in upper (unheated) concrete layer; 5 – maximum temperature in concrete with Natresk fire-retardant coating

The temperature-time relationship curves in different points of beam cross-section with Conlit SL150 flame-retardant board and Natresk gypsum based coating (Fig. 4), Piro-Safe FlamoPlast SP-A2 intumescent coating (Fig. 5), and charts of maximum flexure (Fig. 6) have been built under the standard fire impact on the basis of the obtained results.

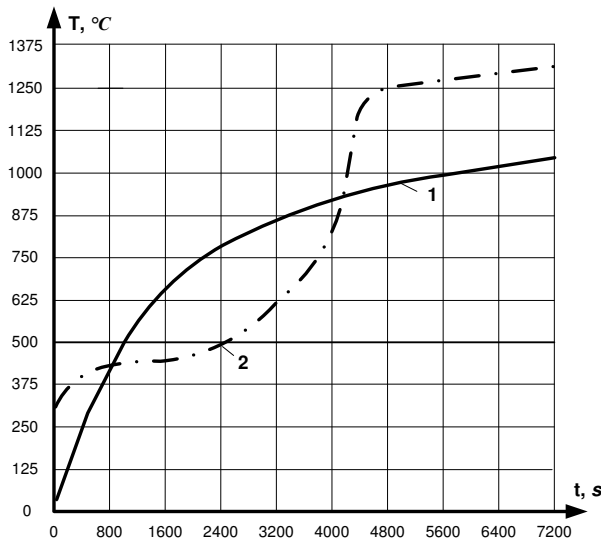


Fig. 5 Temperature-time relationship curves in beam with Piro-Safe FlamoPlast SP-A2 intumescent coating (thickness 1.1 mm) under standard fire impact: 1 – temperature in concrete; 2 – temperature in steel sheet

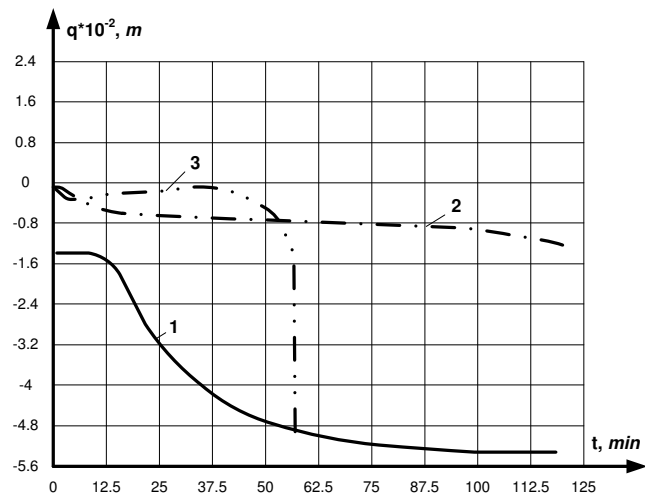


Fig. 6 Charts of maximum flexure of beam with flame-retardant coat under standard fire impact: 1 – Conlit SL150 mineral wool board; 2 – Natresk coating; 3 – Piro-Safe FlamoPlast SP-A2 coating

Summary

As a result of the investigation we proved that examined flame-retardant coatings help to ensure demanding rate of fire resistance of concrete beams with external steel sheet reinforcement under standard fire impact. It's enough to use plates with a minimum thickness of 25 mm and Conlit Glue, to provide fire resistance of proposed beams over 120 min for Conlit SL150 Rockwool fire-retardant mineral wool coat. The utilization of Natresk fire-retardant coating, with minimum 10 mm thickness helps to provide fire resistance rating for more than 100 min. The Piro-Safe FlamoPlast SP-A2 fire retardant intumescent coating with thickness range from 1 to 1.5 mm provides fire resistance within the period of time from 47 to 69 min. Thus, it is necessary to use 1 mm coating to ensure R15, R30, R45 fire resistance ratings. The coating of not less than 1.3 mm should be used to provide R60 rating.

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