Numerical investigations on a wide reinforced concrete beam subjected to fire

ATTILA PUSKAS[1], ALEXANDRU CHIRA[2]
[1]Department of Structures, [2]Department of Structural Mechanics
Technical University of Cluj-Napoca
25 G. Baritiu street, 400027, Cluj-Napoca
ROMANIA
attila.puskas@dst.utcluj.ro http:// users.utcluj.ro/~puskas/

Abstract: - Use of wide pre-stressed reinforced concrete beams is moderate due to their mechanical disadvantages with respect to the regular ones but also due to the uncertainty in their behavior. Wide beams are still the right solution when complex optimization parameters are imposed. Fire provisions are foreseeing specific concrete cover of reinforcement but excessive deformation of bended concrete elements can lead to crack appearance and excessive exposure of reinforcement to fire. Limited deformation of a concrete beam by pre-stressing could postpone appearance of cracks and as consequence it could increase the fire resistance of the element, but how the large width of the beam is influencing its behavior when subjected to fire? The paper is presenting numerical modeling for three different fire scenarios for the wide pre-stressed reinforced concrete beam.

Key-Words: - wide pre-stressed concrete beam, non-linear analysis, transient coupled temperature-displacement

1 Introduction

In design activity of a structural engineer several situations might appear when code provisions are not covering all the possible load situations or the structural system used has no or limited references in codes and realized works; such a problem to front is the situation of the wide pre-stressed concrete beams, for which the only specific provision is for establishing the maximum neutral axis depth of the section with respect to the effective depth of the beam (x/d) [1].

Due to limited resources on behavior of such a wide reinforced concrete beams subjected to fire, for the element presented in Fig. 1, already cast in place [2], a numerical investigation have been performed in order to establish the beam sensibility to fire.

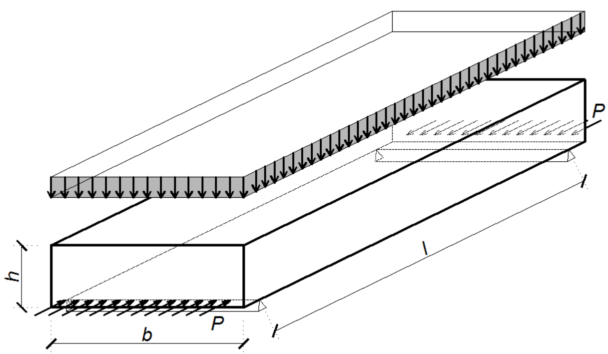

Fig.1: Load scheme of wide beam in service

The beam being pre-stressed, having reduced height, all the tension reinforcements are disposed on the bottom of the beam, increasing the exposure of the beam when fire is acting beneath.

2 Problem Formulation

The wide beam presented in figure 1 has a cross-section of 25x120 cm, and total length of 7.86 m. The concrete quality used for the prefabricated pre-stressed beam is C30/37, while the embedded passive reinforcements, both longitudinal and transversal, are of PC52 type. The active reinforcements are St1660 type having 12.9 mm diameter. The layout of the reinforcements in the cross section of the beam is presented in figure 2. Reinforcements are as follows: no. 1 represents the active reinforcements, disposed on the bottom of the beam, no. 2, 5 and 11 are ø20 diameter bars, no. 4 represents ø14 bars, while no. 7 is ø12 diameter longitudinal reinforcements. Transversal reinforcement of ø8 diameter has been also modeled.

In order to establish the behavior of the beam, three different fire scenarios have been taken into account, as for the fire the code recommended [3] ISO-834 curve have been used. The commercial finite element software ABAQUS [4] have been used in order to simulate the fire action.

Concrete elements were modeled using C3D8T: an 8-node thermally coupled brick, tri-linear displacement and temperature and for the reinforcements T3D2T: a 2-node 3-D thermally coupled truss. Concrete damaged plasticity law has been assigned for concrete and an elasto-plastic bi-linear curve for the reinforcements. In order to establish the thermal properties of the used materials EC2 parameters have been assigned for the model. For the concrete and steel materials change of the properties with temperature increase have been considered [5][6][7].

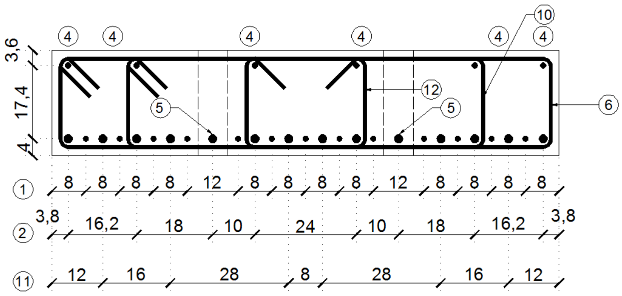

Fig.2: Cross section of the wide beam

For the analysis three different fire scenarios have been used, considering two hours from the curve presented in figure 3.

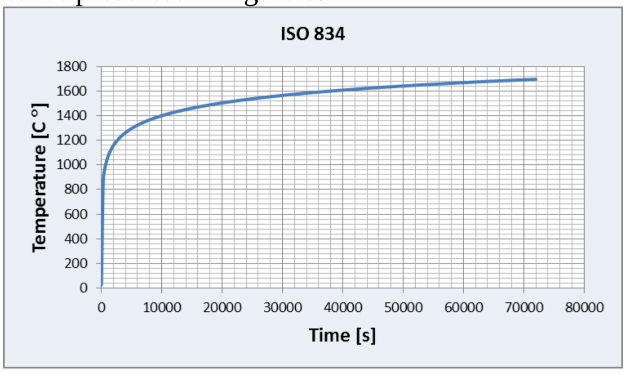

Fig. 3: ISO 834 standard fire curve [3]

2.1 Scenario I

The first scenario considers the fire acting on the whole length of the wide beam and on the three faces besides the top one (figure 4).

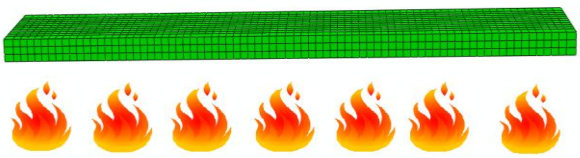

Fig. 4: Scenario I of fire action

2.2 Scenario II

The second scenario considers the fire acting on the middle of the beam opening, on a 0.5 m length, on three faces of the beam, as in scenario one (figure 5).

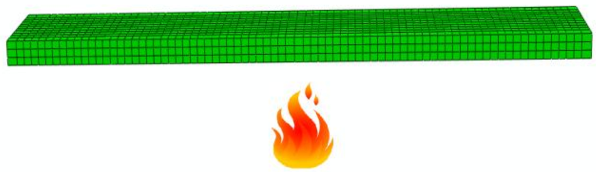

Fig. 5: Scenario II of fire action

2.3 Scenario III

The third scenario considers the fire acting close to the support of the beam, on a 0.5 m length, on three faces of the beam, as in previous scenarios (figure 6).

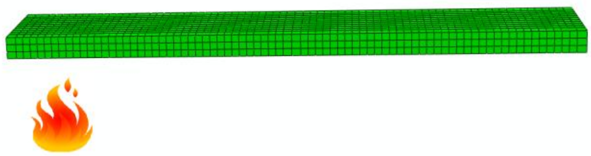

Fig. 6: Scenario III of fire action

2.4 Analysis

The analysis has been realized in 3 steps:

- The pre-tensioning step: in the initial step a predefined field has been created for the pre-tensioning reinforcement, assigning an initial stress with the $0.7f_y$ value. The pre-tensioning phase produces the counter-deflection of the beam (figure 7). A static general step has been used.

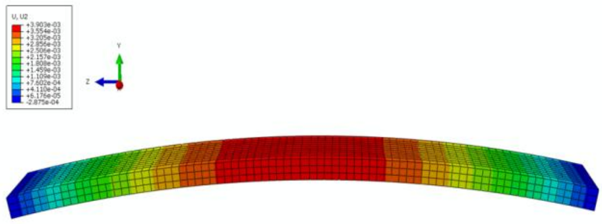

Fig. 7: Counter-deflection of the pre-stressed beam

- The service loads step: the equivalent service loads have been assigned to the beam, producing a long term deflection (figure 8). A static general step has been used.

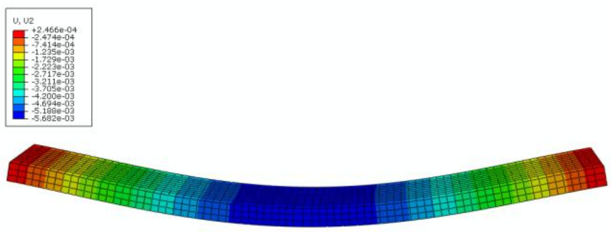

Fig. 8: Service load deflection

ISBN: 978-1-61804-194-4

- The fire load step: two hours of fire action have been considered using a transient coupled temperature-displacement step.

3 Results

3.1 Scenario I

In the following figures results obtained for scenario I are presented, emphasizing displacements, temperatures and strain for the beam and component materials.

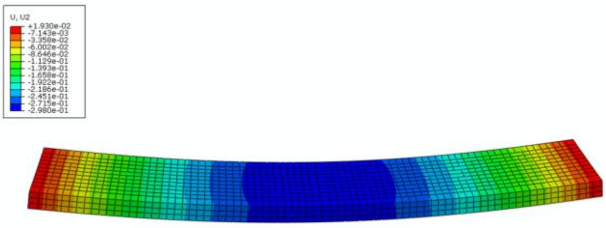

Fig. 9: Displacement after two hours of fire, d=29.8 cm

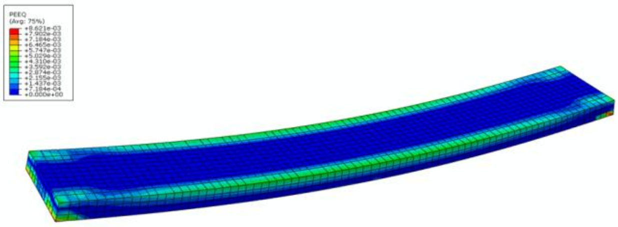

Fig. 10: Concrete plastic equivalent strain from compression, PEEQ=8.62E-3

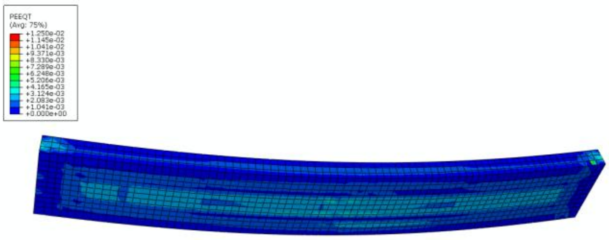

Fig. 11: Concrete plastic equivalent strain from tension, PEEQT=1.25E-2

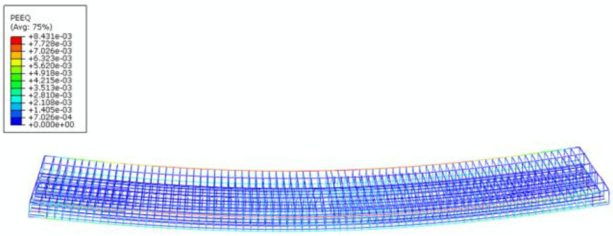

Fig. 12: Steel plastic equivalent strain, PEEQ=1.25E-2

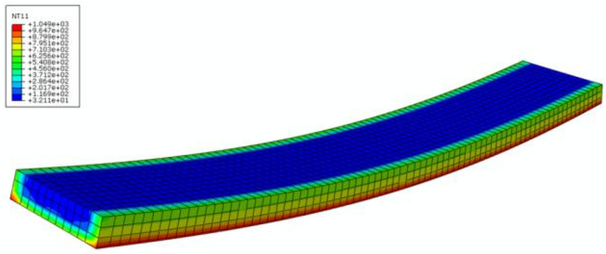

Fig. 13: Temperature distribution on concrete after two hours of fire, T_{max}=1049ºC

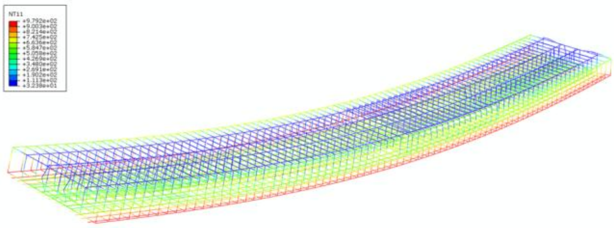

Fig. 14: Temperature distribution on steel after two hours of fire, T_{max}=979 ºC

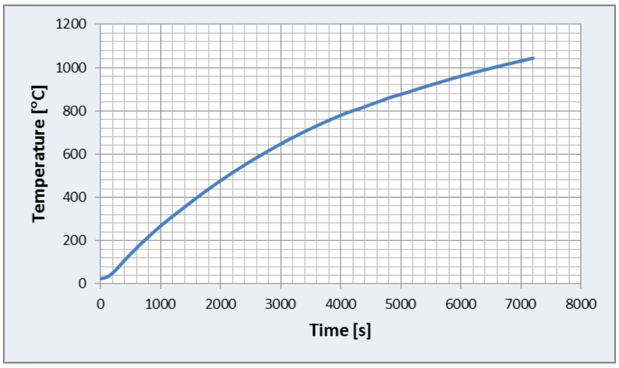

Fig. 15: Time-temperature(max) curve on concrete

Fig. 16: Displacement - temperature(max)

3.2 Scenario II

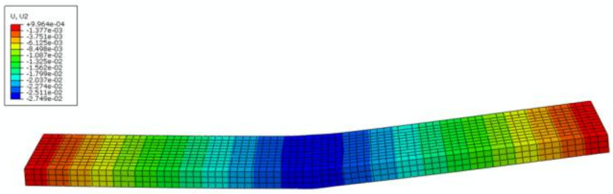

Fig. 17: Displacement after two hours of fire, d=2.74 cm

ISBN: 978-1-61804-194-4

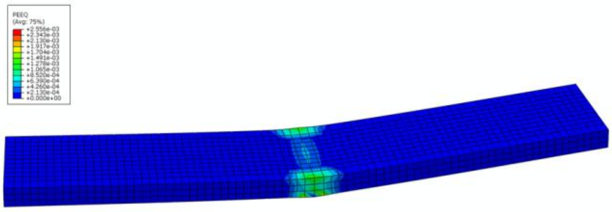

Fig. 18: Concrete plastic equivalent strain from compression, PEEQ=2.55E-3

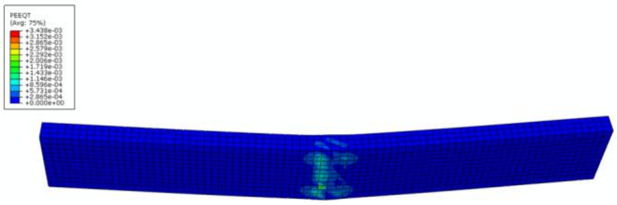

Fig. 19: Concrete plastic equivalent strain from tension, PEEQT=3.44E-3

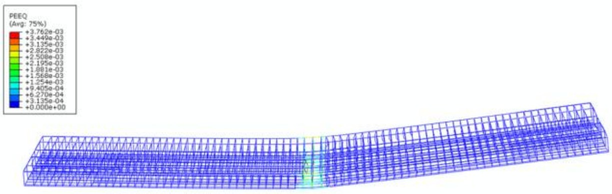

Fig. 20: Steel plastic equivalent strain, PEEQ=3.76E-3

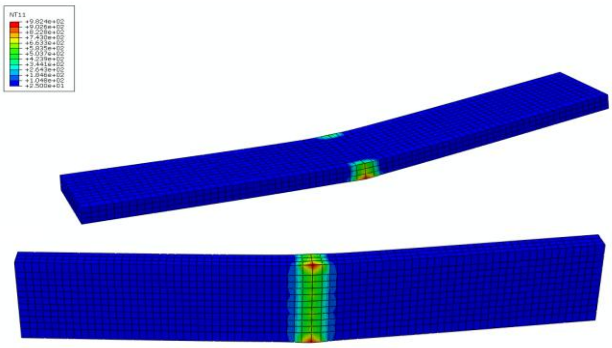

Fig. 21: Temperature distribution on concrete after two hours of fire, T_{max}=982°C

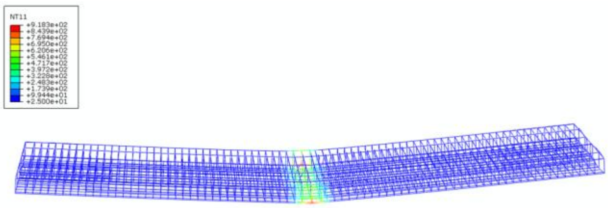

Fig. 22: Temperature distribution on steel after two hours of fire, T_{max}=918 °C

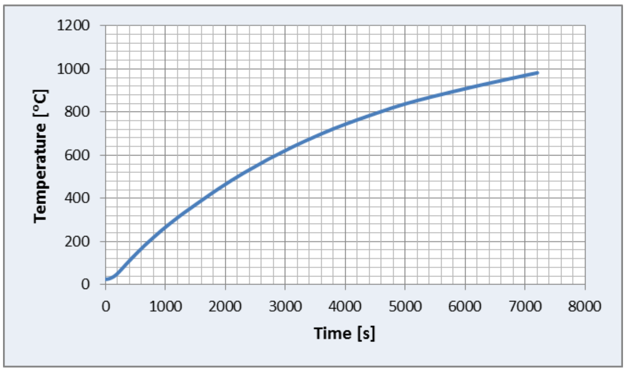

Fig. 23: Time-temperature(max) curve on concrete

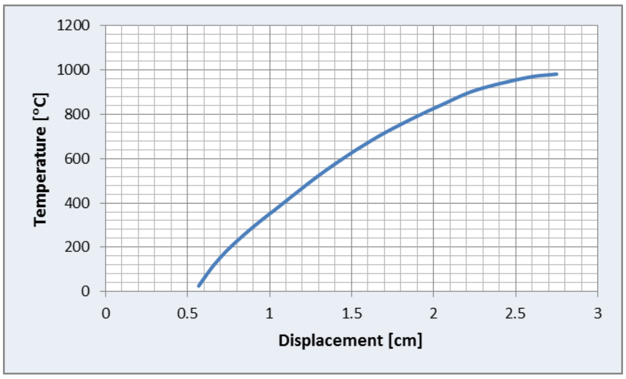

Fig. 24: Displacement - temperature(max)

3.3 Scenario III

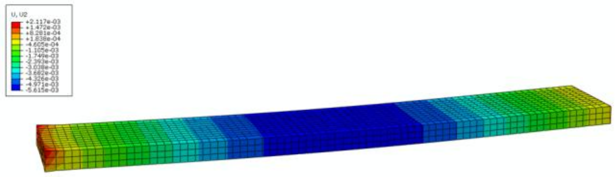

Fig. 25: Displacement after two hours of fire, d=0.56 cm

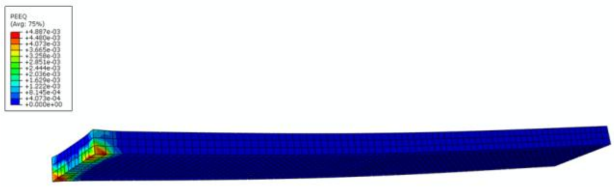

Fig. 26: Concrete plastic equivalent strain from compression, PEEQ=4.88E-3

Fig. 27: Concrete plastic equivalent strain from tension, PEEQT=4.58E-3

ISBN: 978-1-61804-194-4

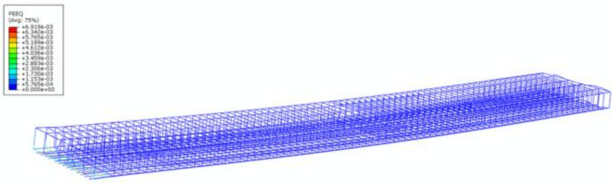

Fig. 28: Steel plastic equivalent strain, PEEQ=6.91E-3

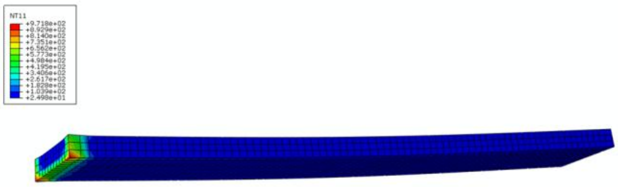

Fig. 29: Temperature distribution on concrete after two hours of fire, T_{max}=971°C

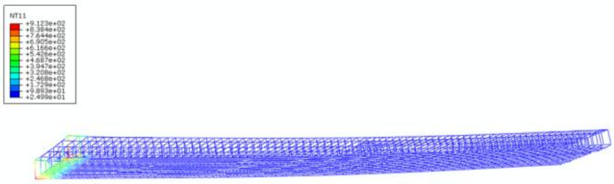

Fig. 30: Temperature distribution on steel after two hours of fire, T_{max}=912 °C

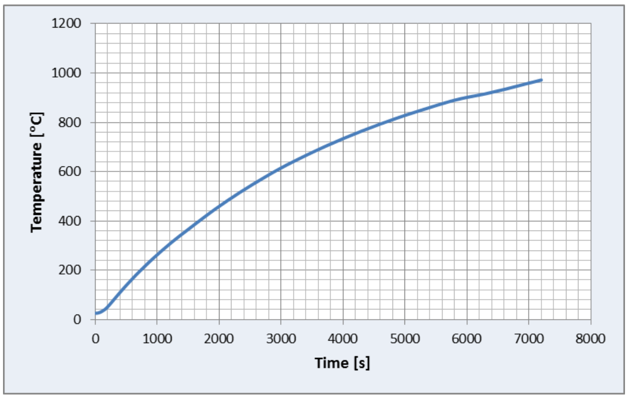

Fig. 31: Time-temperature(max) curve on concrete

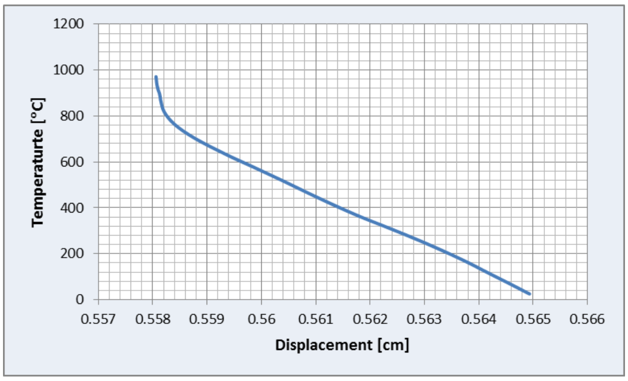

Fig. 32: Displacement - temperature(max)

4 Conclusion

The numerical model of the pre-stressed wide beam experienced some difficulties at the beginning involving the element types and interactions. At first a model with only solid elements (C3D8T) have been considered, but a large computational cost have been encountered so another type of elements needed to be used. The second choice has been the beam elements, but still problems appeared, requiring a next – and last - choice with truss elements, which experienced no bending. The computational cost with these types of finite elements is much lower but the temperature is not transmitted at all from the concrete elements to the reinforcement because of the constraints problems with the degrees of freedom. In general, like in this paper, a perfect bond between the two used materials can be taken into consideration using an embedded interaction law in which the concrete is the host and the reinforcement is the slave. It appears that the degree of freedom 11 representing the temperature is not valid for this type of interaction, as consequence another possibilities had to be found. Using the “tie” interaction constraints all the degrees of freedom including temperature between the solid elements and truss the problem can be solved.

Another issue when modeling the pre-tensioning of pre-stressed beams is with the Young modulus of elasticity: in order to model the real process of pre-stressing a special subroutine needs to be written in order to simulate the increase of the elasticity modulus until it reaches its maximum strength.

In literature there are two ways of modeling a thermal-stress analysis:

- An analysis which first establishes the temperature field and after it elaborates the stress results;
- A fully coupled temperature-displacement that treats simultaneously both temperature field and displacement as used in this paper.

After analyzing the results of the three fire scenario cases it is obvious that the first one produces more damage than the other two scenarios. The damage starts to increase dangerously after reaching approximately 400°C. After half an hour the structures goes beyond its capacity and as it shown in the figures from scenario I it exceeds it limits.

In the second case of scenario when fire is applied only at the middle of the pre-stressed wide beam the deflection limit isn’t exceeded but concrete strains are approaching ultimate values, as consequence there is not too much time remaining until the reinforcement strains will approach the strain capacity as well, so little strength reserve are left in this case.

The third scenario, when fire acts on the beam support vicinity, produces higher damage on concrete and steel although the displacement remains approximately as from the service loads step.

Overall the pre-stressed wide beam presents a good behavior at fire action losing all the strength reserves at approximately one hour in the worst case scenario, confirming the appropriate concrete cover for 1h fire resistance of the element. Further numerical and experimental investigations are in need for this type of structure so that code provisions could give more information regarding the design of wide reinforced concrete beams when subjected to fire.

References:

[1] *** *SR EN 1992-1-1-2004*, Eurocode 2, Design of concrete structures. Part 1-1: General rules and rules for buildings, 2004.

[2] Z. Kiss, K. Bálint, A. Puskás: Steel or concrete structure – prefabricated or cast in situ? The design of a multistory building in Bucharest for Kika, *III, Medunarodna Savetovanke, Subotica*, 8-9. Octobar 2009, p. 79-93.

[3] *** *SR EN 1992-1-2-2004*, Eurocode 2, Design of concrete structures. Part 1-2: General rules – structural fire design, 2004.

[4] Abaqus. *Abaqus Analysis User's Manual.*

[5] Faris Ali , Ali Nadjai, S. Choi, *Numerical and experimental investigations of the behavior of high strength concrete columns in fire,* Engineering structures , 2010.

[6] Venkatesh Kodur , Nikhil Raut, *A simplified approach for predicting fire resistance of reinforced concrete columns under biaxial bending,*Engineering structures, 2012.

[7] Qing-Hua Tan,Lin-HaiHan n, Hong-XiaYu, *Fire performance of concrete filled steel tubular (CFST) column to RC beam joint,* Fire Safety Journal, 2012