COST C26 – WG1

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STRUCTURAL MEMBER BEHAVIOUR AND ANALYSIS IN CASE OF FIRE

Description

- The purpose of this datasheet is to summarize the existing knowledge on the topic of the behavior and analysis of structural members in case of fire.
- It summarizes the research contributions from the COST-WG1 members in the study of structural elements in case of fire.

Field of Application

- The analysis of isolated structural elements has been the more used type of analysis in the fire design of buildings, due to the fact that it is much more easy and fast to be made, when compared with a global analysis of the structure.

Research activity

The main research activities in the domain of structural elements, of the COST C26 members have been the study of: class 4 stainless steel box columns in fire (Uppfeldt and Veljkovic, 2007); steel and stainless steel structural elements in case of fire (Lopes et al, 2008, 2007, 2004), (Vila Real et al, 2007a, 2007b); a numerical and analytical model for cellular steel beams (Vassart et al., 2007); Simplified grid model for analysis of reinforced concrete members subjected to fire (Gribniak et al, 2007); and some remarks on the simplified design methods for steel and concrete composite beams (Nigro and Cefarelli, 2007). In this section it is made a brief summary of these research works.

- **1.** Class 4 stainless steel box columns in fire (Uppfeldt and Veljkovic, 2007)
  A study of stainless steel cold-rolled box columns at elevated temperatures is presented, which was a part of a RFCS project "Stainless Steel in Fire". Experimental results of six, class 4, stub columns at elevated temperature, were used to evaluate the FE model. The FE analysis obtained using the commercially available software,

ABAQUS, shows that the critical temperature was closely predicted. Further, a parametric study was performed using the same numerical model. This was a basis to check the quality of prediction of a newly proposed improvement for design rules of class 4 cross-sections in fire according to Part 1.4 and Part 1.2 of EC3 (CEN, 2005d and 2005a), stainless steel and fire design part respectively.

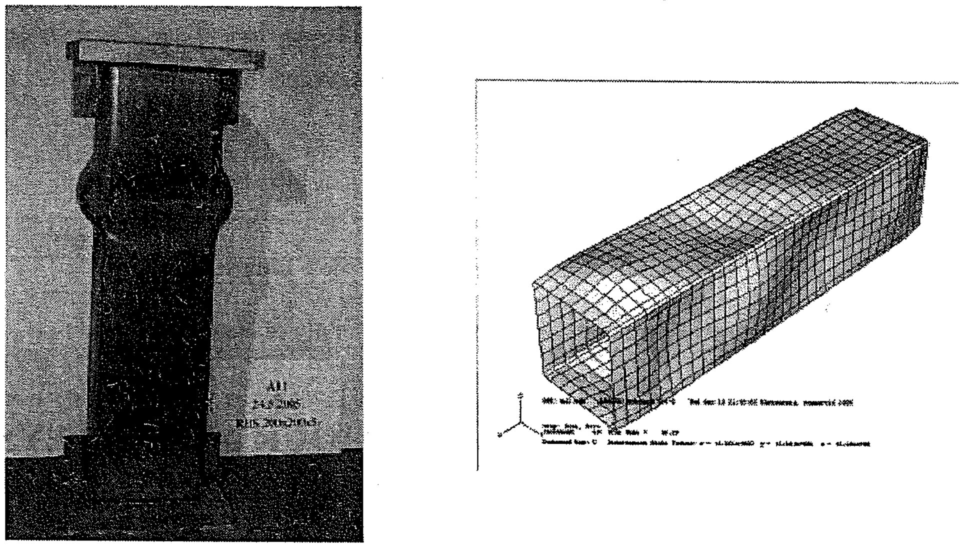

Figure 1. Experimental and finite element tests

The comparison between experiments at the elevated temperature and results obtained from FEA indicated that: assumptions made for the influence of the material properties in the corners are realistic; assumptions for the shape and level of the local buckling, b/200, and global imperfections, L/1000, are consistent with assumptions established at ambient temperature.

The design recommendations for class 4 cross sections made of austenitic stainless steel presented are coherent with part1-2 and part1-4 of EC3. The proposed design model is an improvement compared to the design model on EN 1993-1-2.

- **2.** Steel and stainless steel structural elements in case of fire (Lopes et al, 2008, 2007, 2004), (Vila Real et al, 2007a, 2007b)

Numerical modelling of the lateral–torsional buckling of steel beams at elevated temperature (Vila Real et al, 2007a) has shown that the beam design curve from EN 1993-1-2 is over-conservative in the case of non- uniform bending. An improved proposal was presented that addresses the issue of the influence of the loading type, the steel grade, the pattern of the residual stresses (hot-rolled or welded sections) and the ratio h/b, between the depth h and the width b of the cross-section on the resistance of the beam, achieving better agreement with the numerical behaviour while maintaining safety. A statistical study of the results was performed, showing the accuracy of the improved proposal. (see figure 3a)

Two new formulae for the design of beam-columns at room temperature have been proposed in EN 1993-1-1 as the result of extensive work by two working groups that followed different approaches, namely, a French-Belgian team and an Austrian-German one. Under fire conditions, in EN 1993-1-2, the proposed formulae for the design of beam-columns in case of fire have not changed and are still based on ENV 1993-1-1. In order to study the possibility of having, in parts 1-1 and 1-2 of the EN version Eurocode 3, the same approach for beam-columns, a numerical investigation was carried out (Lopes et al, 2004), with the conclusion that it is possible to use the formulae from the part 1-1 provided that some factors are modified to consider high temperatures (see figure 3b).

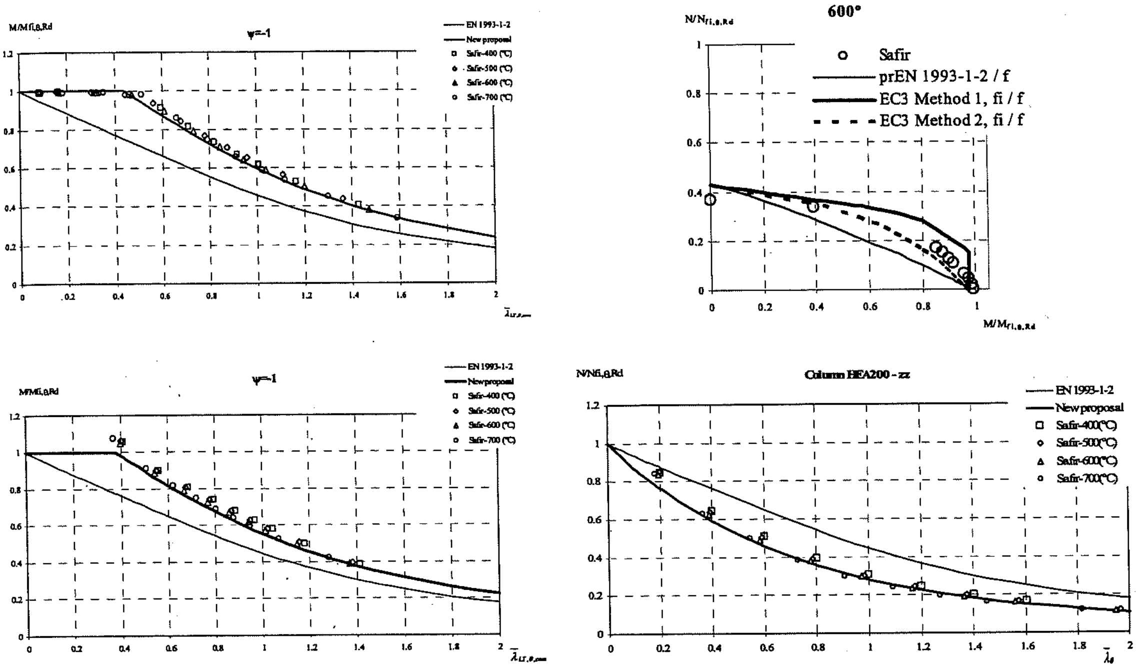

Figure 2. a) Lateral-torsional buckling of steel beams; b) Interaction curves of steel beam columns c)Lateral-torsional buckling of stainless steel beams; d) Buckling of stainless steel columns

New formulae for lateral-torsional buckling (Vila Real et al, 2007b), that approximate better the real behaviour of stainless steel structural elements in case of fire were proposed (see figure 3c), These new formulae were based on numerical simulations using the program SAFIR, which was modified to take into account the material properties of the stainless steel.

It were evaluated the accuracy and safety of the currently prescribed design rules in part 1.2 of Eurocode 3 for the evaluation of the resistance of stainless steel columns (see figure 3d) and beam-columns (Lopes et al, 2008, 2007). This evaluation was carried out by performing numerical simulations on Class1 and Class 2 stainless steel H-columns. It was considered buckling in the two main cross-section axis and, in the case of the beam-columns, different bending moment diagrams. The results presented shown that Eurocode 3 formulae for the evaluation of the fire resistance of columns and beam-columns need to be improved.

- **3.** Numerical and analytical models for the cellular beams (Vassart et al. 2007)

An analytical model representing the web post buckling for cellular beams in case of fire is developed on the basis of that for cold conditions. The analytical model is checked using a finite element model (SAFIR) considering both material and geometrical non-linearity. This model is calibrated on the basis of experimental results (failure modes, stiffness, strength). During fire tests, the main failure mode is web-post buckling. The numerical model is able to simulate the behaviour of composite cellular beams in both cold and elevated temperature conditions with a relatively high accuracy. The analytical model used to evaluate the critical temperature of the web-post gives accurate and safe sided results compared to the experimental tests and FEM model for cellular steel beams. Further improvement must be done in order to take into account the composite cellular beams in the analytical model and define its limits of validity. An example of the numerical model results showing the instability of the web-post and the lateral displacement of the beam and the load-deflection curves are given on Figure 3.

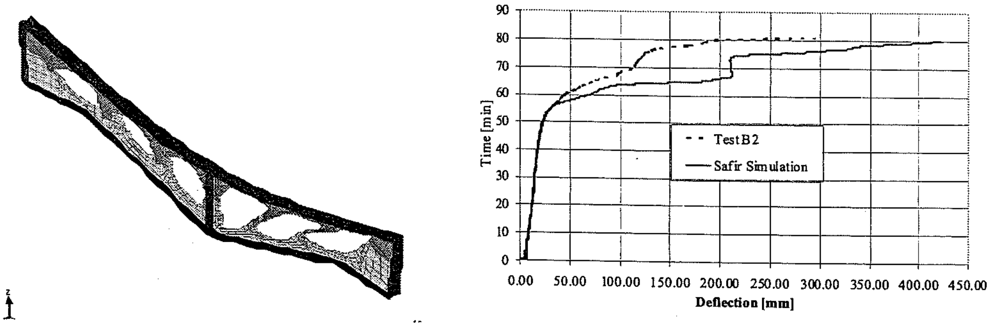

Figure 3. FEM model (cellular beam deformed shape in fire)

- **4.** Simplified grid model for analysis of reinforced concrete members subjected to fire (Gribniak, 2007)

Analytical and computational methods have been extensively developed in the field of RC building exposed to high temperature or accidental fire. Generally an engineer employs various formulae for the fire resistance of structures offered by building codes, without really understanding the thermo-mechanical behaviour of a structure during fire. On the other hand, advanced non-linear mechanical models based on the 2D or 3D finite element (FE) method which were rapidly progressing within last decades are based on universal principles and can include all possible effects. However, such models are computationally too demanding.

This research is aimed at developing a simple computationally effective technique based on formulas of strength of materials and *grid* approach employing temperature dependant material diagrams.

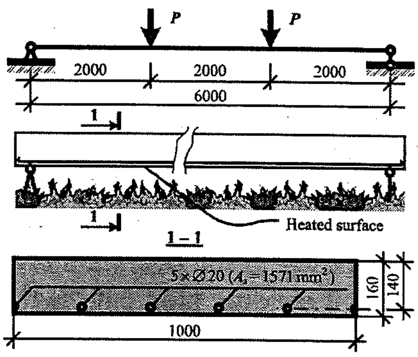

Figure 4. Structural system and cross-section of slab.

The proposed calculation technique is based on the following approaches and assumptions: 1) smeared crack approach; 2) linear distribution of strain within the depth of the section; 3) perfect bond between concrete and reinforcement.

The iterative technique is based on simple formulas of strength of materials. The calculation uses temperature dependent stress-strain constitutive laws of concrete and steel. Thermal strain in a simple and universal way is modelled by the fictitious actions (axial force and bending moment). Thermal creep effect is to be also included in the analysis.

The beam's cross-section is divided into a number of horizontal and vertical layers comprising a grid section. Each grid element may have different material properties.

A step-by-step nonlinear sectional analysis is performed under the external mechanical loads for a given temperature distribution obtained from thermal analysis. Starting with the cross-sectional strains and stresses due to the initial mechanical load a new strain and stress distribution is calculated at any time of the transient thermal analysis.

- **5.** Parametric study of fire resistance of centrically and eccentrically loaded columns (Cvetkovska and Lazarov, 2005, 2004)

  A computational procedure for the nonlinear analysis of a reinforced concrete elements and plane frame structures subjected to fire loading is developed. The program FIRE carries out the nonlinear transient heat flow analysis (modulus FIRE-T) and nonlinear stress-strain response associated with fire (modulus FIRE-S). The solution technique used in FIRE is a finite element method coupled with time step integration.

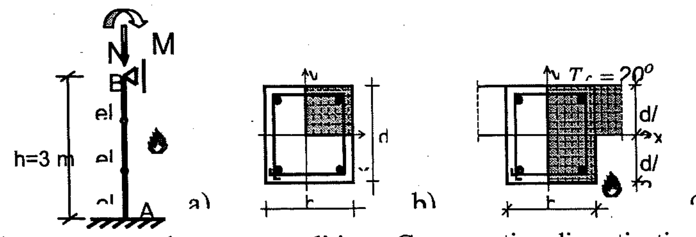

Figure 5. a) Geometry and support conditions. Cross-section discretization when column is: b) exposed to fire from all sides; c) part of a wall for separation the fire compartment

  The influence of: element geometry; support conditions; concrete cover thickness; type of aggregate; compression strength of concrete; steel ratio; intensity of the axial force and different fire scenarios are analyzed and the results are presented. ISO 834 standard fire model is used (recommended in EC2, part 1.2).

- **6.** Some remarks on the simplified design methods for steel and concrete composite beams (Nigro and Cefarelli, 2007)

  This work recalls the main characteristics of a general numerical approach to assess the ultimate bearing capacity of steel and concrete composite beams in fire conditions. It is shown the comparison of the fire resistance between steel beam, composite beam and composite beam with partial concrete encasement.

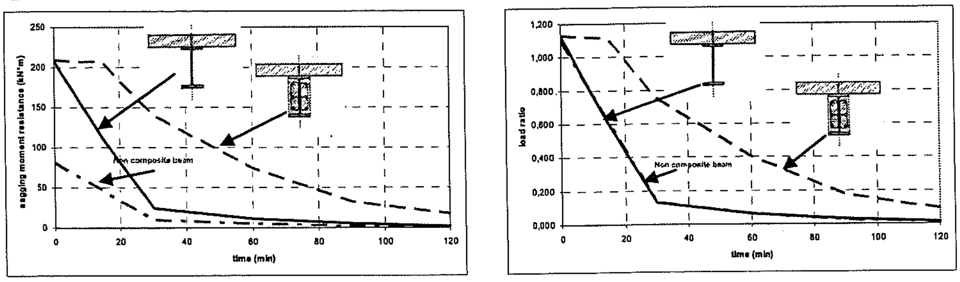

Figure 6. Comparison between various types of beams.

  The following features affecting the resistance of the composite beam with partial concrete encasement are firstly investigated: influence of the beam dimensions and effectiveness of the reinforcing bars in concrete encasement. Moreover, it is shown a comparison between the general numerical approach and the simplified method proposed in EN 1994-1-2 for evaluating the sagging moment resistance of the composite beam with partial concrete encasement. Finally, it is proposed a simplified plastic method for evaluating the sagging moment resistance of the composite beam with partial concrete encasement in fire conditions.

Further developments

The needs for further developments of the WG1 research contributions are:

- Steel and stainless steel structural elements in case of fire

  Developing simple design procedure for columns and beam columns in case of fire, that provides safety and economy, for all stainless steel grades for material properties at high temperatures given in EN 1993-1-2. Study the behaviour of thin-walled (Class4 cross-sections) stainless steel members in case of fire.

- Aluminium structural elements in case of fire

  Validate the simplified calculations methods for the evaluation of instability phenomena on aluminium members in case of fire (lateral-torsional buckling, flexural buckling and beam-columns).

- Numerical and analytical models for the cellular beams

  Simple analytical models for the composite steel-concrete cellular beam based on FEM and tests with the same level of reliability as for steel beams.

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