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Fire scenario influence on fire resistance of reinforced concrete frame structure

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Abstract

Understanding the performance and the response of the frame structures in fire is of a particular importance for structural fire design. The specialized computer program SAFIR enables analysis of different types of structures, constructed with different structural materials. The options of program SAFIR are presented on eight different fire scenarios of standard fire exposure of a three bay two story reinforced concrete frame. The results for the: temperature distribution within the structural elements, fire resistance of the whole structure, bending moments and deformations of elements are presented and discussed. The worst fire scenario of the frame is defined. The higher the fire compartment is, the lower fire resistance of the structure is reached.

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Keywords: reinforced concrete frame, fire resistance, fire scenario, internal forces, deformation

1. Introduction

Fires are rare but possible catastrophic events in building`s lifetime with serious consequences on building`s operation, stability, bearing capacity, etc. Different fire scenarios mean different locations of the fire in the building. In general, fire location is hard to be predicted and therefore defining the worst fire scenario that has to be considered in the structural fire design is very challenging. In order to create the worst but still realistic fire scenario, several variations of the fire position were done in this research.

The aim of this research is to determine the behaviour of a 2D reinforced concrete frame exposed to fire, with accent on the influence of the different fire scenarios on the frame's fire resistance. For this purpose, eight different fire scenarios were considered. The fire scenario assume fire in different locations of the frame structure i.e. different fire compartments, considering that the fire is limited within the compartment and fire spread is prevented.

According to the EN1991-1-2 [1], for compartment fire in ordinary buildings with ordinary thermal properties of the compartment boundaries, load density and ventilation conditions, the design fire is given as standard fire curve or parametric fire curve [1]. In this research the heating regime was defined with the standard temperature-time curve ISO-834.

In developing countries, where lack of technical standards and codes in the field of fire safety of buildings exists, raising awareness for necessity of assessing the fire resistance of reinforced concrete frame structures is especially important. In practice, in these countries, only some single member elements are analysed with simplified calculation methods.

Nowadays, the global structural response of buildings in fire conditions is accurately determined with the use of advanced calculation methods. The nonlinear numerical analyses presented in this paper are conducted with the computer

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program specialized for structural fire analysis – SAFIR [2]. The nonlinearity of the problem comes from the changes in material properties by high temperatures, the nonlinear temperature distribution in the element cross-sections (no heath transfer is considered along the axis of the beams and columns) and the continuous change of the internal forces [3].

Using the SAFIR program, the numerical analysis of the structure exposed to fire consists of two steps. The first step involves determining the temperature distribution inside the structural members, referred to as ‘thermal analysis’. The second step of the analysis, termed as ‘structural analysis’, is carried out for the main purpose of determining the response of the structure due to static and thermal loading [2]. For modelling the structure beam elements are used.

2. Numerical analysis

2.1. Description of the program SAFIR

SAFIR is a special purpose computer program for the analysis of structures under ambient and elevated temperature conditions, developed at the University of Liège, Belgium. The program, which is based on the Finite Element Method (FEM), can be used to study the behavior of one, two and three-dimensional structures made of: concrete, steel, reinforced concrete, wood, composite etc.

As a finite element program, SAFIR accommodates various elements for different idealization, calculation procedures and various material models for incorporating stress-strain behavior. The elements include the 2-D SOLID elements, 3-D SOLID elements, BEAM elements, SHELL elements and TRUSS elements. The stress-strain material laws are generally linear-elliptic for steel and non-linear for concrete.

SAFIR can be used for performing three different types of calculations, namely, thermal, torsional and structural analysis. The analysis of a structure exposed to fire may consist of several steps. The first step involves predicting the temperature distribution inside the structural members, referred to as ‘thermal analysis’. The torsional analysis may be necessary for 3-D BEAM elements, a section subject to warping and where the warping function table and torsional stiffness of the cross section are not available. The last part of the analysis, termed the ‘structural analysis’, is carried out for the main purpose of determining the response of the structure due to static and thermal loading.

In each time step SAFIR uses an iterative procedure to converge to the correct solution. A precision value of 0.0001 and the modified Newton-Raphson convergence procedure are used in the analyses presented in this paper.

2.2. Description of the structure

The three-bay two-story reinforced concrete frame analyzed in this paper is shown in Fig 1. The structure is made of concrete with siliceous aggregate, with a compressive strength fc=30 MPa and reinforcing bars with a yield strength fy=400 MPa. The reinforced concrete structure was designed for load combinations that include seismic action, according to the national standards. The cross-sections of all beams are 0.35×0.45 m^2 and the column sections are 0.40×0.40 m^2. The concrete cover of all cross-sections is a=2 cm. Uniformly distributed load of 50 kN/m was applied on the beams and forces of 12 kN were applied in the beam to column joints of the first floor. Geometry, support conditions, reinforcement details and numeration of: bays, beams, columns and joints are shown in Fig 1. Top compartment beams are assumed to be fire exposed on three sides (bottom, left and right side) and bottom compartment beams are assumed to be fire exposed only on the top side. Outer compartment columns are heated only on one side and middle compartment columns are heated on two sides.

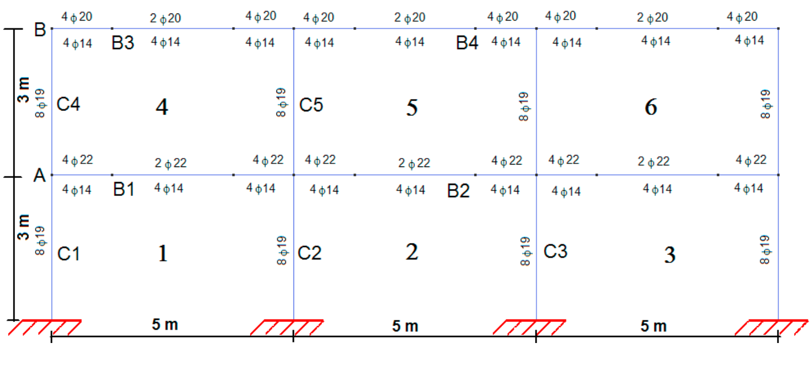

Fig.1. Frame geometry, support conditions, reinforcement, numeration of: beams, columns, joints and bays