Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 172 (2017) 692 – 700

Procedia Engineering

www.elsevier.com/locate/procedia

11th International Conference on Modern Building Materials, Structures and Techniques, MBMST 2016

Development and Implementation of Coupling Method for CFD-FEM Analyses of Steel Structures in Natural Fire

Michał Malendowski*, Adam Glema,

Institute of Structural Engineering, Faculty of Civil and Enivironmental Engineering, Poznan University of Technology, pl. Marii Skłodowskiej-Curie 5, 60-965 Poznań, Poland

Abstract

The work aims in the problem of numerical analysis of steel structures under natural fire. The emphasis is put on the proper calculation of temperature field inside the structural members and, in particular, the non-uniform temperature distribution inside the section. Thus, the main contribution is the coupling method between computational fluid dynamics (CFD) and finite element analysis (FEA). Coupling is done by dedicated scripts, which utilize developed methods and compute the heat transfer between gas and solid phase. The example of simple steel structure under different fire scenarios is presented. Conclusions presenting advantages of proposed procedure are given.

Peer-review under responsibility of the organizing committee of MBMST 2016

Keywords: fire engineering; natural fire; multi-physics; coupled problems; cross-scale consideration; performance based design.

1. Introduction

Nowadays more and more structures are designed with respect to performance based design methods, what in fire safety engineering field leads to natural fire approach. There is mainly one reasons for that: investors, fire officers and engineers tends to make design more "real", but safe and reliable at the same time. In such case, proper definition of boundary conditions both in CFD and FEA models become crucial. A lot of difficulties cause especially the translation of heat condition from CFD fire analysis into solid mechanics boundary conditions. It is because of significant differences between those two approaches [1]. Therefore, to study the influence of elevated temperature onto the structural response of structures under natural fire, the coupling method is developed. The dedicated scripts, able to translate results from CFD computation into the transient boundary conditions for FEA, are used on the example of simple steel structure.

2. Standard approaches and performance based methods

In practical design, calculations of structures in fire are made usually using simple, empirical, so called prescriptive approaches or more advanced simple calculation models. Both types of design approaches are regulated

* Corresponding author. Tel.: +48 61 665 2829;
E-mail address: michal.malendowski@put.poznan.pl

Peer-review under responsibility of the organizing committee of MBMST 2016
doi:10.1016/j.proeng.2017.02.082

by design codes as Eurocodes [2,3] and specific law regulations characteristic for particular country or region.

Most of the prescriptive methods base on the fire tests of single elements or small assemblies under standard ISO 834 fire curve. The same is for simple calculation model described in Eurocode 1993-1-2 [3], where the standardized fire curves are used to simulate thermal conditions acting on structural members.

On the other hand, several performance based methods are already formulated. In those cases, history of thermal analyses are done using partly empirical, partly theoretical equations, or the fire is simulated using zone or field (CFD) modelling [4,5]. The last two approaches are the most flexible and allow to introduce different fire scenarios into fire model, what gives more detailed description of a fire incident. But, the more general description of thermal conditions is, it needs consideration of several fire scenarios and results in more complex model of heat transfer between gas and solids. It is worth to mention that fire scenarios dedicated for structural analyses may differ for those dedicated for other fire engineering problems [6]. In this paper, the coupling procedure between CFD fire analyses and FE structural analyses is introduced as an contribution for performance based fire engineering structural design methods.

3. Heat flux and section temperatures calculation method

3.1. View angles on section faces

In proposed approach, the section temperature is calculated by taking into account both convective and radiative heat fluxes facing the particular section surfaces. As long as we consider convective heat flux is dependent only on the constant coefficient of the heat transfer by convection α and difference between fluid and surface temperature, calculation of section temperature does not generate many problems. The special concern must be paid for the proper definition of radiation problem by recognition of radiation's directions. Authors introduce the definition of face view angles as the lower and the upper limit of radiation direction angle that can reach particular point on the section surface (Fig.1). It is assumed that only the radiation along the direction β within α_1 and α_2 limits can reach particular point of interest on the section edge. That can be simply described by the condition:

$$\alpha_1 < \beta < \alpha_2 \tag{1}$$

The mean value of all view angles along the section edge divided by 180^0 converges to Eurocode [3] shape factor k_{sh}, what can be written as:

$$\frac{1}{\ell}\oint_0^{\ell} \frac{\alpha_2(\ell) - \alpha_1(\ell)}{180^\circ} d\ell \cong k_{sh} \tag{2}$$

where ℓ is the section's perimeter and k_{sh} is the section factor as in Eurocode [3]. That regularity is valid at least for the I-sections. This approach is similar to the one proposed in FIRESTRUC research program report [14], where coupling between CFD code called JASMINE and FE code SAFIR has been done. Nevertheless, contrary to [14], hereafter different method is used to assign the incoming incident radiation to the particular face point.

3.2. Heat transfer into the section

Above approach is useful for the derivation of boundary conditions at the section's surface. Let consider the small, one dimensional element cut out from the section's wall as shown in Fig.2.