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Simple approach for calculating maximum temperature of insulated steel members in natural-fires

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ABSTRACT

The maximum steel temperature of key elements to natural fires should be considered in evaluating the fire resistance of steel structures by rational approach. Natural fires are complex that advanced analytical simulations are always required to obtain the temperature distribution of steel members in natural fires. Simple calculation approaches which can give acceptable predictions are needed for the daily design work. This paper proposes a simple approach for calculating the maximum steel temperature of insulated steel members subjected to natural fires. The approach adopts time equivalent to relate natural fires with the standard fire, and use a simple quadratic equation for calculating the maximum steel temperatures. By comparing with numerical results and test data, the proposed approach can give satisfactory prediction of maximum steel temperatures in the range from 300 to 600 °C. The approach only need hand calculations which is easy and convenient for practical usage.

1. Introduction

The behavior of a real fire is complex, which depends on many parameters such as active fire detection and suppression systems (smoke detector and sprinkler), fire load (amount and distribution), combustion, ventilation, compartment size and geometry, and thermal properties of compartment boundaries [1]. So far, with increase in complexity, empirical correlations (e.g. nominal fire curves and parameter fire curve [2]), zone models (e.g. one-zone models for post-flashover fires [3,4] and two-zone models for pre-flashover fires [4,5]), and sophisticated CFD models (e.g. Fire Dynamic Simulation [6]) have been developed to model the fire behavior. Also, stochastic models have been developed for compartment fires [7,8].

When evaluating the fire resistance of steel structures, the temperature of the key elements to fire is the most significant and critical parameter, and should be determined by rational approach with agreeable accuracy. In literature, the temperature of steel members exposed to fire is usually determined by first modeling the fire phenomenon by an empirical correlation [2] or advanced compute simulation [4,6] to obtain a temperature–time curve to represent the fire environment, then substituting the fire curve into a 1D condensed heat transfer model to obtain the steel temperatures [9,10]. At present, various formulae are provided by fire codes in different countries for calculating the temperature of insulated steel members in fire [10]. In deriving those formulae by different technologies like separation of variables, laplace transform and green's function approach, the standard fire curve is always adopted to represent the fire environment [9]. The current formulae, which are based on the standard fire, might give unacceptable results for calculation in natural fires [10]. Besides, the current formulae are developed as "simplified" methods that their applications are limited to situations where the properties of the insulation materials are or can be treated as constant or temperature-independent [10]. The temperature of steel members in a fire can also be determined by advanced CFD simulations [11], or by solving the heat balance equation for modified one zone compartment fire model with considering the heating effect of steel members [12].

When considering the structural behavior of a steel member in fire, it is usually assumed that the load capacity of the member is only related to the maximum temperature it reached, or the effect of heating rate is ignorable (for composite structures like composite slab, however, the effect of heating rate should be considered [13]). In other words, if the maximum temperatures of a same steel member in different fires are equal, the load capacities of the member in those fires are consistent. Correspondingly, the approaches for calculating the load capacity of steel members, which are based on standard fire tests conducted in laboratory, are applied for practical design of the fire resistance of steel members exposed to potential real fires. As a result, with considering the complexities in both modeling real fires and simulating the structural behavior in real fires (which usually includes advanced compute simulations), if the severity of a real fire can be represented by an equivalent duration in the standard fire, it will simplify the daily design work greatly. Thus, the concept of time equivalent had been developed (first by Ingberg [14]) to relate real fires with the standard fire. Till now, a

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