

Paper

Behaviour of steel structures in fire conditions

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Synopsis

Traditionally, structural fire engineering design has been considered an area outside the scope of engineering design. In the United Kingdom, the Building Regulations specify minimum periods of fire resistance for loadbearing elements depending on the function and size of the building. Fire statistics, particularly those related to fatalities, show that the Regulations have been effective in terms of fire safety against structural collapse but are perhaps less conservative.

The introduction of structural fire engineering Codes for structural steelwork allows the assessment of the fire resistance of steel members and, where appropriate, specification of the protection required. In this paper EC3, Part 1: 1993, BS 5950, Part 8, 1990, and the Swedish Code (Pernstom, 1978), are discussed and critical comparisons made.

Introduction

One means of limiting the effects of fire is to strengthen the structural elements to have appropriate structural resistance. Traditional design methods for structural fire resistance involve three concepts:

- a standard fire temperature-time curve;
- rating of the fire resistance for the building elements — time elapsed between the start of the fire test and the point at which the load-carrying performance in terms of critical temperature or loadbearing capacity is reached;
- classification of the various building elements specified in the local building Code in terms of required standard fire exposure.

Analytical methods of predicting structural response to fire provide a more consistent assessment of structural fire safety than that provided by tests of isolated specimens, often limited by the size of the furnace.

However, temperature affects the bearing capacity of the structure in several ways, including the following:

- (1) Yield strength and modulus of elasticity decrease with increase in temperature.
- (2) Thermal stresses are induced in some elements against thermal expansion.
- (3) In cases where the member is axially loaded, differential thermal expansion causes bending affecting the local bearing capacity of the member in tension.

Codes related to the performance of structures in fire
Codes applicable

The structural response of steel to fire must be assessed using EC3, Part 1: 1993, European Recommendations for the Fire Safety of Steel Structures, 1993, BS 5950, Part 8, 1990, and the Swedish Code (Pernstom, 1978).

The European Recommendations for the calculation of the resistance of structural steel members have as a primary objective to provide the designer with a simple method of calculation that will enable him to justify the duration of making of the structure in a fire. The Recommendations are limited to the presentation of a mathematical model which has the objective of predicting results identical with those that would be obtained by testing structural elements in a furnace. In other words, the analysis is limited to full virtual structural elements subjected to the standard fire as defined in BS 476, 478. Uniform temperature is assumed over the entire section and length of each element. Creep is included as an implicit way to the relationships which describe the variation of the mechanical behaviour with temperature. This resistance is therefore defined here as the time necessary

for the steel element to reach its critical temperature; temperature is collapse of the entire section.

BS 5950, Part 8 introduced the concept of 'limiting temperature', the temperature that the bottom part of a section must reach at any given time in order to cause failure of the member. The 'limiting temperature' concept replaced the 'critical temperature' failure criterion as applied to a more realistic way: the bottom temperature of an axially loaded structural member. In such a member, one flange is heated faster than the other and the hot flange reaches its elastic limit while the cooler flange will not plastically. The hot flange yields plastically and transfers load to the cool flange. The member retains stability until the load transferred from the cool flange is sufficiently high to cause the whole cross-section to yield plastically. The hot flange temperature, at which an axially loaded member fails, depends on the severity of its temperature gradient and the level of applied stress. The limiting temperature method is applied only to supported structural elements and it is valid when the members are not subjected to second order effects resulting from their deflection in the fire environment.

The Swedish Code gives particular design for natural fires. Natural fires are considered as fires which build up and decay in accordance with the mass and energy balance within the compartment.

The Codes cited in this paper apply only to welded structures.

Codes description

European Recommendations for the fire safety of steel structures

The required performance of a structural element is defined in terms of a particular failure condition. This condition may be either a limit of deformation or the capacity to support a given load.

The time when deformation is considered to be obtained if it is assumed that actual failure occurs at extreme deformations. This results in the function of support members not being fulfilled and the spread of fire to other zones not being prevented.

The loadbearing capacity at elevated temperatures can be calculated using elementary plastic theory, as these analyses use the same theory has been used at ambient temperatures. This implies that secondary stress and influence the loadbearing capacity significantly. If elementary plastic theory is not considered applicable, the reliability of the calculation method must be calculated explicitly. For the analysis of columns in a fire environment, loading curves at elevated temperatures are recommended and could be derived from the EC3 Building rules at room temperature.

BS 5950, Part 8, Code of practice for fire resistant design

BS 5950, Part 8 gives recommendations for the following methods:

- (1) Fire resistance determined from tests in accordance with BS 476, Parts 20.2.1, 1997. Different test procedures are used for different types of construction.
- (2) BS 476, Part 20.2.2 presents general guidelines which are appropriate for the specific construction under test.
- (3) The common feature of these procedures is that the tested construction is heated using the heating curve recommended by BS 476, Part 20. This assumes the thermal exposure encountered in a fire involving 'cellulosic' materials. Another temperature-time curve should be applied for the situation of hydrocarbon fires such as the BS 476 hydrocarbon curve.
- (4) Failure is defined in this Code by a variety of criteria. The design criterion is chosen considering the function of the element in question. The fire resistance of the column is taken as either the time to the limit of stability or the limiting steel temperature of 550°C for members loaded to their maximum permissible design stress.
- (5) Fire resistance derived from calculations. In this Code of Practice, the

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