

## 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. As 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 (Part 1) of BS 5951-1:1990, Part 5: 1990, and the Swedish Code (Prestorm, 1974) are discussed and critical comparisons made.

### Introduction

One reason of limiting the effects of fire is to ensure 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.

Elevated temperatures affect 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 arise around sharp corners 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 may be assessed using BS 5951-1:1990, European Recommendations for the Fire Safety of Steel Structures, 1990, BS 5950: Part 4: 1989, and the Swedish Code (Prestorm, 1974).

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 stability 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 based on full virtual structural elements subjected to the standard fire as defined in BS 5951-1:1990. 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. Fire resistance is therefore defined here as the time necessary

for the steel element to reach its critical temperature, temperature at collapse of the entire section.

BS 5951-1:1990 Part 4 introduced the concept of 'limiting temperature', the temperature that the bottom part of a section must reach at any given time to cause failure of the member. The 'limiting temperature' concept replaced the 'critical temperature' failure criterion as given by a more realistic way the failure 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 nature 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 guidelines 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 criterion. This criterion may be either a limit of deformation or the capacity to support a given load.

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

The loadbearing capacity of structural members can be calculated using elementary plastic theory, in those cases the lower 500°C fire test used at normal 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 evaluated explicitly. For the analysis of columns in a fire environment, buckling curves at elevated temperatures are recommended and could be derived from the EC3 building code at room temperature.

BS 5951-1: Part 4: Code of practice for fire resistant design

BS 5951-1: Part 4 gives recommendations for the following methods:

- (1) Fire resistance determined from tests in accordance with BS 4794: Part 20.2.1: 1987. Different test procedures are used for different types of construction.
- (2) BS 4794: 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 4794: Part 20. This ensures the thermal exposure encountered in a fire involving 'realistic' materials. Another temperature-time curve should be applied for the situation of lightweight steel roofs in the BS4:1987 method curve.
- (4) Failure is defined in the Code by a variety of criteria. The design criterion is chosen considering the function of the element in question. The fire resistance of steel columns is taken according to the time to the limit of yielding or the limiting steel temperature of 500°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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