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General approach for the assessment of the fire vulnerability of existing steel and composite steel-concrete structures

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ABSTRACT

The fire safety of existing structures is very important from the socio-economic point of view and has high social impact for civil, industrial and commercial buildings. The minimum fire resistance of structures is verified through some regulations, drafted to ensure safety for occupants and rescue teams as well as limited structural damage. Fire design rules are not always directly applicable to existing buildings, which need specific provisions to take account of uncertainties on the structural geometry, and the mechanical and thermal properties of the materials. This paper aims to provide guidance about the assessment of structural fire safety of existing buildings during a fire. A possible approach is obtained by integrating the general approach suggested by the Eurocodes for the structural assessment of existing buildings with more specific details concerning the structural fire safety check. The approach focuses on the criteria and the tests required to assess thermal properties and effectiveness of protective materials. The methodology is applied to assess an existing steel building protected with intumescent coating (IC), designed and built about 30 years ago. Applied to assess the existing IC, the procedure also provides data required to design a new protection system with advanced calculation methods according to a performance-based approach.

1. Introduction

In order to mitigate risks from fires, buildings must be designed and built to ensure strength and stability and to limit the spread of fire and smoke, as required by fire regulations [1]. In the Eurocode [2], the fire resistance requirements for structures are modulated in different performance levels in order to avoid structural damage having unacceptable consequences for the safety of occupants and rescue teams and for the preservation of assets.

The Eurocodes do not provide specific guidance for the assessment of structural vulnerability of existing buildings in fire situations, although this is an issue of considerable importance in socio-economic terms, with high social impact for civil, industrial, and commercial buildings. Indeed, the Eurocodes refer only to the seismic assessment and retrofitting of existing buildings with some specific regulations. In this regard, Eurocode 8 [3,4] provides information necessary for the assessment of the seismic vulnerability, with reference to:

- design documents or any documentation acquired after construction;
- data from structural surveys;
- results of tests on structural members (in situ);
- results of tests conducted in a laboratory on samples taken from the existing structure.

Moreover, Eurocode 8 [4] defines the “level of knowledge” of the structural geometry and the mechanical properties of materials. In particular, it suggests both type and minimum number of tests and surveys required to achieve a knowledge level, on the basis of which it identifies analysis methods and partial safety factors for the material's properties to be used in the structural analysis. This approach, suggested for the assessment of seismic vulnerability, can be a useful reference to define a procedure for evaluating structural safety in fire conditions of existing buildings.

With reference to steel and composite steel-concrete structures, a key role in fire safety is often played by insulating materials, which reduce the temperature of structural members during fire. Such materials can be divided into two categories [5]: passive fire protection, such as incombustible boards, and reactive fire protection, such as intumescent coatings (IC).

While the thermal behaviour of the passive protection systems is fairly stable and known, reactive fire protection, such as intumescent coatings, requires more studies especially to model and analyse structures protected with IC.

The advantages of this kind of protection include low weight compared to other materials, easy application and a good surface

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finishing. The fire resistance of a commercial IC is usually tested in a furnace in order to "certify" its efficacy in fire situations [6]. EN 1363-2 [7] also defines a slow heating curve (smouldering curve) to check the correct initiation of the reaction phenomenon when thermal gradients are low. Despite this, tests usually entail standard fire tests in a furnace. Therefore, the thermophysical properties required to model fire-resistant structures protected by IC with advanced calculation methods could be unknown. Even if these properties could be easily obtained for new IC, knowledge of the behaviour of IC applied to existing buildings is more complex. Hence, experimental tests should be performed according to general criteria suited for existing buildings.

2. Criteria for the assessment of existing buildings

Both prescriptive and performance-based approaches are provided for the check of new structures in fire situation, whereas no approaches and procedures are suggested for the vulnerability assessment of existing buildings in fire. However, the methodology for new structures could be appropriately adapted to existing structures, considering also criteria which take their cue from the provisions suggested in EN1998-3 for the seismic assessment of existing structures [3].

The prescriptive approach establishes a series of rules and requirements to guarantee a predetermined resistance with immediacy and simplicity of calculation (tabular data, simple analytical models, certified products or systems); moreover, thermo-mechanical analyses refer to the standard fire curves [7]. The performance-based approach consists of more detailed analysis of the fire (e.g. natural fires) combined with more sophisticated calculation (advanced methods) for structural models.

Therefore, the choice of the verification method for existing buildings affects the target of the knowledge level of the structure: there is a strong correlation between the verification methods and information about the structure, which can be obtained from paper or digital documents of design and maintenance certifications, or from results of tests performed in situ and / or in the laboratory. On the one hand, the level of detail required for the prescriptive-based approach is lower than that required for the performance-based one. On the other, application of the prescriptive method could be less cost effective and safe [8].

For fire resistance assessment, knowledge of thermo-mechanical properties of structural materials, namely steel profiles and reinforcing bars as well as concrete, should be added to the knowledge of mechanical properties, which are necessary for static and seismic assessment. Moreover, the presence and the effectiveness of any fire protection systems, whether reactive or passive, should be checked. Therefore, an approach for the evaluation of existing buildings during a fire can be obtained by integrating the suggestions provided by the Eurocode for the safety assessment of existing buildings, with more details on the verification of structures in fire conditions.

The assessment and retrofit process could be divided into three phases:

– Phase 1: (a) definition of structure geometry and material thermo-mechanical properties by means of available data and surveys; (b) definition of type, geometry and thermal properties of fire protection systems through available data, surveys and in laboratory/in situ test programmes; (c) choice of the type of structural fire analysis, also based on the level of knowledge.
– Phase 2: assessment of structural fire safety according to the outcomes of phase 1.
– Phase 3 (potential): design of the retrofitting for satisfying the required fire resistance, based also on the results of phases 2 and 3.

Suggestions on how to obtain the properties of structural and protective materials through certifications and in situ or laboratory tests are summarised in Tables 1 and 2. Simplified analysis (e.g. through a prescriptive-based approach with simplified and tabular methods) can be performed with a basic knowledge of structural details. If constructional details are incomplete, information should be integrated with limited testing in situ [4] (limited means at least about 15% of the elements). If details are available, only a random visual survey is necessary to check their compliance with the real structure.

Advanced analysis (i.e. a performance-based approach) can be performed with a more complete knowledge of the structure. If structural details are fully available, only limited checks in situ are necessary (limited means that the geometry and characteristics of the members and connections are verified for at least 15% of the elements). Otherwise, extensive checks in situ are necessary (extensive means at least 35% of the elements). For the mechanical properties of the structural materials, the original design specifications and the original test certificates can be integrated with limited tests in situ (e.g. one steel specimen for each floor of the building, one sample of bolt or nail for each floor of the building, one destructive test or more non-destructive tests for concrete). In the absence of certification, extensive tests should be carried out in situ (e.g. two steel specimens for each floor of the building, two samples of bolts or nails for each floor of the building, two destructive tests or more non-destructive tests for concrete).

As regards the protective systems, specific tests for each type should be performed, taking into account the regulations [10–12] for the certification of products after their installation.

For protective boards the following tests are suggested [10]:

– thickness tests, in situ;
– tests on density, thermal conductivity and specific heat (in the laboratory);
– tests of fire resistance on samples taken from the existing structure, in the laboratory.
– Fire protection systems (e.g. fireproof ceilings or screens) are sometimes built with steel grids, brackets and suspenders. Therefore specific tests on each part or on the whole protective system should be performed, if necessary.

For insulating sprayed systems the following tests are suggested [11]:

– thickness tests, in situ;
– measures of adhesion/cohesion, in the laboratory and in situ;
– tests on density, conductivity, specific heat, in the laboratory;
– tests of fire resistance, on samples taken from the existing structure, in the laboratory;

Again, tests on any accessories and finishes should be performed in accordance with UNI 10898-3 [11].

In the case of intumescent coatings the following tests are suggested:

– thickness tests, in situ [12];
– measures of adhesion/cohesion, in the laboratory and in situ, at ambient temperature;
– furnace tests (unloaded) (with standard and smouldering curves) of samples taken from the existing structure, in order to check that the existing IC has retained its reactivity under different fire conditions, in the laboratory [13];
– fire resistance tests (loaded and/or unloaded) on samples taken from the existing structure, in order to verify the fire resistance of the structural member protected with the existing IC, in the laboratory;
– evaluation of stickability (in fire situation), in the laboratory.

If all certifications of the protection are available, both simplified