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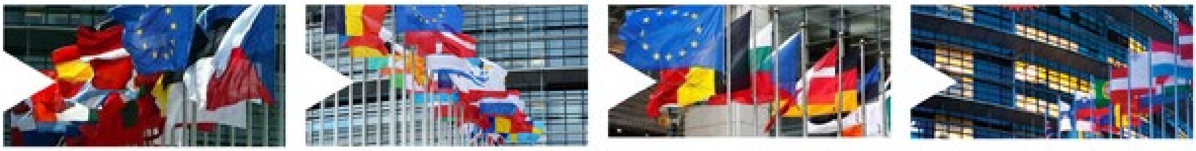

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Fire Safety Engineering — Assessment of Performances of Structures in Fire Following the ISO 24679

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Traditionally, most structural fire designs, also known as fire resistance, follow building regulations, building codes and associated standards. The evaluation of fire resistance of load-bearing elements is mainly determined by fire tests that involve i) a single fire, which is represented by a standard time-temperature curve (such as that given in ISO 834-1) and ii) isolated elements with well-defined boundary conditions and dimensions. Nowadays, many countries are evaluating the fire safety design of structures based on prescriptive requirements whose methods are well consolidated and considered to be good practices. However, in more recent years, there has been a significant increase of advanced calculation methods to estimate the performance of structures in fires, thanks to a greater understanding of the structural behaviour in fire and to an increased knowledge on thermal and mechanical responses of structures at elevated temperatures. It must be said that many of these new calculation methods are still at early stages in replacing conventional fire tests and can only be applied to isolated elements and simple assemblies of structural elements.

Most of the existing calculation methods are simple models applicable to isolated elements and/or simple structural systems. These tools do not provide the necessary means for assessing the performance of a whole structure in different possible real-fire configurations, such as localized or fully developed fires, and do not include any cooling phase that could lead to certain mechanical failures. The simplified calculations usually cover heat transfer analysis through load-bearing elements or non-load bearing separating elements. These methods require the knowledge of the thermal properties of the components and the boundaries conditions. Additionally, these tools can provide calculations for load-bearing fire performance for simplified construction materials such as steel, concrete and timber.

It is well renown that an engineered approach may offer several benefits, including the provisions for better and more reliable structural fire safety and potential cost-effective fire safety measures with more options of choice in regards of these measures. To help navigate structural fire engineers to evaluate structural resistance, a series of international standards have been published. The ISO 24679 follows the principles outlined in the ISO 23932, General Principles of performance-based fire engineering, and provides a performance-based methodology to assess the level of fire safety applicable to new or existing structures.

The steps listed in ISO 24679 provide a methodology for applying an engineered solution to assess of fire performance of structures in real fires. This approach includes:

— defining the built-environment characteristics, including geometry, loads and materials,.;

— identifying the fire safety objectives to impose onto the structures;

— identifying performance criteria for the load bearing elements;

— defining a trial design to verify the fire safety level given to a specific structure;

— identifying the design fire scenarios that could arise within the analysed environment that could pose a challenge to the structure;

— assessing the fire performance of the whole system (including load-bearing and non-load-bearing elements);

— evaluating the structural fire performance against the pre-identified safety objectives.

The picture below shows the logical process introduced by the ISO 23932 and adopted by the ISO 24679 to set the logical steps to undertake when evaluating the performance of a structure exposed to fires.

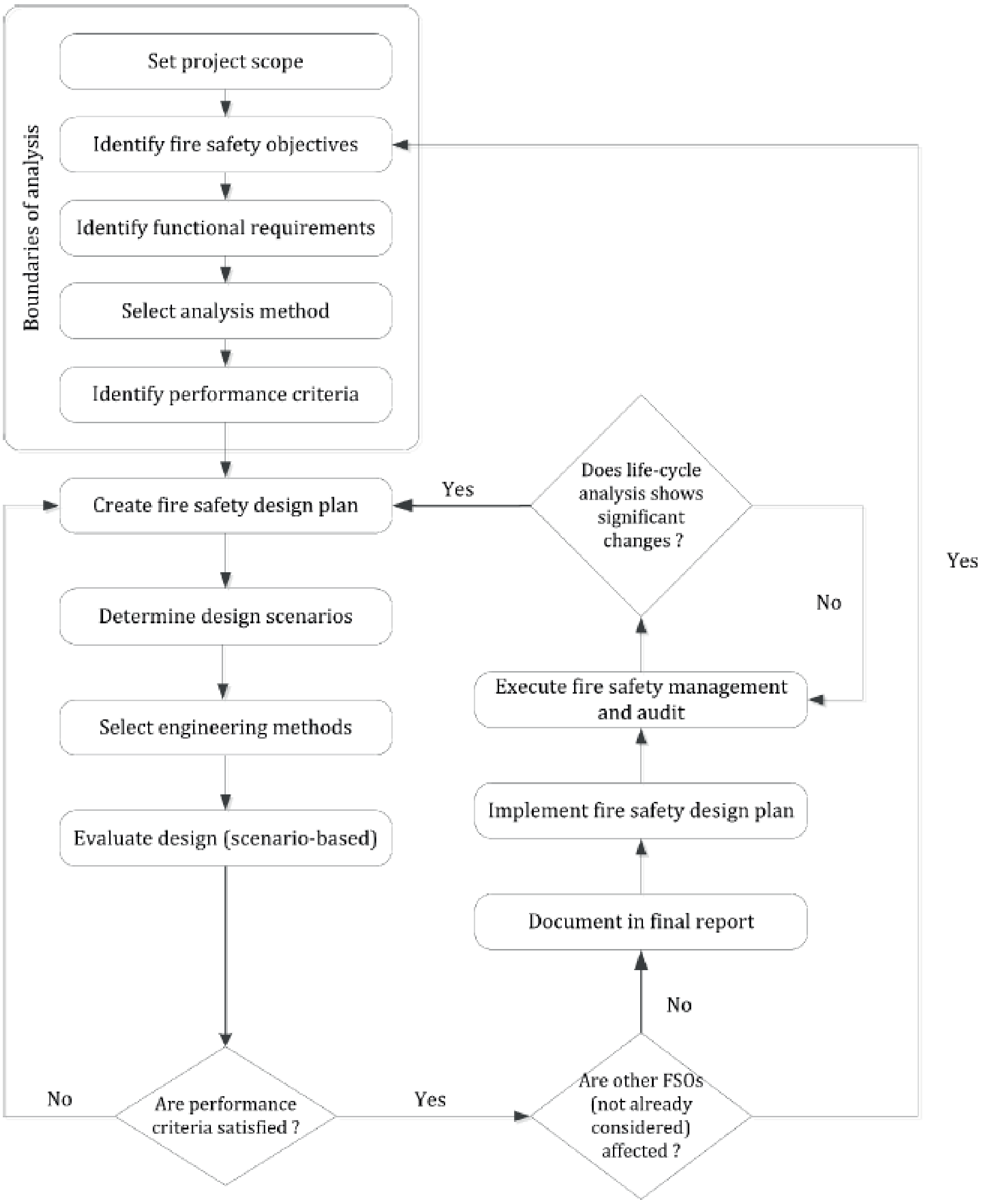

Figure 1 – Design process based on ISO 23932

In order to quantify the structural performance required by a new or existing building, the fire engineer must have knowledge of the **general characteristics** of the built environment. At the same time, to determine the appropriate design fire for the evaluation of the structure, fuel loads must be addressed. These are determined from existing databases or from on-site surveys.

When considering the **mechanical actions** onto the analysed structure, other accidental actions should be considered in conjunction with fire. Fore example, in highly seismic-risk countries, it may be necessary to account for the possibility of structural damage, damage to separating (load-bearing and non-load-bearing) elements, and the unavailability of fire suppression systems.

As well as external factors, fires can induce mechanical actions, directly or indirectly, such as:

a) actions due to the increasing gas pressures developing from a fire;

b) impacts from falling elements onto other structural or separating elements;

c) impact of hose streams by fire-fighters intervention, mainly on the unexposed side of separating elements;

d) forces and moments induced by the restraint of thermal expansion or contraction at the boundaries of elements of a structure;

e) deformations of one or multiple elements leading to deflections that affect the integrity of structural elements.

Once the boundaries conditions are set, **fire safety objectives** are addressed. The objectives are usually expressed in terms of life safety, property protection, business continuity, preservation of heritage and of the environment. The functional requirements and performance criteria ensuring the fire safety of structures are usually stated in terms of compartmentation, integrity and stability of the structure.

The compartmentation is usually achieved by load bearing or non load bearing elements which satisfy functional requirements related to integrity, insulation and fire resistance. The integrity represents the ability to block the passage of hot gases from one compartment to another. The insulation represents the limitation of the temperature increase on the unexposed surface of a partition element. The fire resistance is the ability of a structure to avoid collapsing before a stated period of time.

Following the steps highlighted within the ISO 24679, when using fire safety engineering design and analysis for structural elements, **performance criteria** should be expressed in terms of safeguard of people, property and contents protection, safeguard of the environment etc., and should also take into account the interaction between the different elements within the structure. This international standard divides the performance criteria into two main categories:

a) to limit the damage due to fire spreading, using compartmentation (through separating elements and structural elements);

b) to limit the damage due to the collapse of structural elements (for partial or total collapse).

These are usually associated with criteria to limit heat transfer through separating elements, and/or thermal radiation, in order to avoid any ignition of combustible material on the unexposed side of separating element (e.g. heat flux or temperature of the unexposed side). Alternatively, another criterion is to provide sufficient structural stability of load-bearing elements to allow firefighting, rescue and extinguishment activities, or to allow local failures of non-critical structural elements, while providing sufficient structural stability to avoid any progressive or sudden global collapse of the structure.

Design fire scenarios are a fundamental step in assessing the performance of structures during a fire as these variables have a major influence on all aspects of the design as they represent the input for most of the quantification processes. As there are an quasi-infinite number of possible fire scenarios, it is impossible to analyse all of them. Therefore, there should be a set of fire scenarios which can be taken as representative of the particular combination of events and circumstances that can arise within the analysed building. When choosing the set of fire designs, the type of fire, its distribution, any ventilation conditions and the status of the active systems and passive fire safety measures (as well as their reliability), should be taken into account.

Structural fire safety requires the calculation of the temperature profiles within the elements directly or indirectly affected by thermal actions. When the thermal conditions are known, the temperature profile can be calculated as a function of time, taking into account the heat transfer from flames and smoke onto the structural elements, the heat transfer within the element (induced by conduction) and the heat loss to adjacent elements, adjacent spaces or materials.

Temperatures can vary along a single element, either because of the local action of the fire or because of heat transfer toward non-heated zones of the analysed geometry. To calculate temperature profiles of elements, various assumptions/simplifications can be made:

a) for highly thermal conductive materials, (such as steel or aluminium alloys), uniform temperatures can be taken through the cross-section of the analysed element;

b) for simple flat elements heated just on one side, a one-dimensional heat transfer calculation can be considered;

c) to obtain the temperature gradient within a cross-section of the element, a two-dimensional (2D) heat transfer solution can be used;

d) three-dimensional (3D) heat transfer analysis can be used to obtain the temperature profile for non-uniform temperature distribution within the element's surfaces or axis.

Once the **heat transfer model** is chosen, and all the boundary conditions are set, then the load-bearing capacity can be assessed. The analysis of the fire performance of structures is performed according to two possible representations, i) a global structural analysis, and ii) a partial analysis of the structure.

The former, consider the relevant failure modes in fire exposure, the temperature-dependent material properties and stiffness, and the effects of thermal expansion or contraction that may cause interactions between elements within the structure. The latter considers the magnitude of the loadings and restraints at the boundaries of the analysed element which are kept constant during the fire analysis, bringing into the analysis some uncertainties which the designer should bear in mind.

To assess whether the structure has an adequate level of fire safety against a specific scenario, the relevant performance criterion should be compared against the results obtained during the analysis. For example, this is achieved by comparing the maximum deformation of the components of the structure, or, if applicable, the time in which the structure collapses. Another example could include the assessment of the indication of the limits of structural deflection/contraction/elongation with respect to the integrity of load-bearing elements and/or to evaluate the limit of structural damage at which a structure can be repaired after fire (re-serviceability or re-usability limit state).

In conclusion, with the advancing research in fire safety structural engineering field and the opportunity for designers to take advantage of new engineering tools to evaluate the structural performance during a fire incident, it is necessary to include within the structural fire safety design an holistic view which moves beyond the sole consideration of single elements towards the consideration of the behaviour of the entire structural system. Furthermore, the design and the structural assessment should consider realistic thermal and mechanical load conditions including any possible cooling phase of the fire. In any case, the assessment of the behaviour of a structure, should be supported, and well documented, by calculation, experimentation on structures (although not always possible), and engineering judgement. Generally, only a combination of these three approaches could lead to an accurate assessment of the behaviour of a structure when exposed to real fire, as currently, no single approach alone can provide the full necessary solution.