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OVERVIEW OF FIRE DESIGN

Description

- Performance-based fire safety design is an accepted methodology in many countries of Europe for the verification of structural resistance in fire conditions. This calculation procedure takes into account the individual characteristics of the building and the passive and active fire protection methods.
- A realistic understanding of the behaviour of structures in fire can be achieved and the overall safety of the building can be verified by using performance-based fire safety design. Through the more profound understanding of phenomena and a more precise analysis of structures in fire, an equal to or higher safety level than with prescriptive fire design can be obtained.
- Generally more economical designs, compared to the simple prescriptive approaches, whilst still maintaining acceptable levels of life safety. The construction of more innovative and complex buildings which were not possible due to the restrictive nature of the simple prescriptive rules.
- A better understanding of the actual structural behaviour of the building during a possible fire.
- The construction of more robust buildings due to the advanced design approach allowing identification, and strengthening, of any 'weak' links within the structure.
- An increase in the levels of safety offered by the simple prescriptive design approaches, by incorporating advanced structural fire design within a global fire strategy.

Field of application

- Present day structural fire resistance regulations are largely based on the so-called standard fire curve, which has led to very different practices in different European countries. For example, the fire resistance time for a similar building can vary between 60 min in the Netherlands and 120 min in Finland.
- Due to the different uses and other individual characteristics of buildings, fire resistance requirements and design should be based on factors that actually have an influence on the growth and the development of fires, the safety of persons in the specific building as well as the loading conditions of the specific building. Fire safety engineering has been developed into a separate engineering discipline, of which structural fire resistance, which is covered in this technical sheet, forms part of the fire protection system.

Technical information

- Fire resistance is concerned with ensuring that a fire is contained within the compartment of fire origin so that it does not spread. A fire may spread through the compartment of fire origin in three ways: collapse of the compartment structure, excessive temperature rise on the unexposed side to cause further ignition, burning through the compartment. In fire resistance terminology, the ability to prevent fire spread through the above three ways is termed loarbearing capacity, insulation, and integrity. This technical sheet is concerned with structural loadbearing capacity, which is to ensure that the structure has sufficient resistance so that it does not collapse when exposed to fire. Assessment of structural loadbearing capacity maybe considered in either the strength domain or time domain. In the strength domain, the residual strength of the structure under fire attack should not be lower than the applied load in fire. In the time domain, the structure should not collapse before the required fire resistance time is reached.
- The Institution of Structural Engineers in the UK has recently published a guide on structural fire resistance design. A dedicated website (www.structuralfiresafety.com) with free access may be consulted to obtain more detailed guidance, tutorial and reference materials.

Structural aspects

- In general, structural fire resistance calculations may be divided into three steps: evaluation of fire behaviour, calculation of temperatures in structural components and assessment of residual loadbearing capacity.
- Depending on the project requirement, different types of fire exposure may be considered, including the usual standard fire resistance rating, parametric fire curves simulating realistic post-flashover compartment fires or localised fires.
- Having obtained the fire behaviour, the temperatures in different structural members exposed to fire can be obtained by a number of methods, including fire test, tabulated values based on fire tests of validated numerical analysis or through a heat transfer analysis. Technical sheet No. 4 provides detailed method of heat transfer analysis. When carrying out heat transfer analysis, it is important to use appropriate thermal properties of the structural materials and any fire protection materials. The most important thermal properties of materials are thermal conductivity, specific heat and density. It is also important that the appropriate thermal boundary conditions are used. In structural fire engineering calculations, the thermal boundary condition is usually conveniently represented by a heat transfer coefficient, which is divided into a convective heat transfer coefficient and radiant heat transfer coefficient. Under post-flashover fire condition, the radiant heat transfer coefficient is of primary importance. This value directly depends on the fire and structural surface emissivity values.
- Once the structural temperatures are obtained, the residual loadbearing capacity of the structure at elevated temperatures can be calculated. Elevated temperatures have two general effects on a structure: (1) the mechanical properties of structural materials are reduced at high temperatures; (2) thermal elongation (at increasing temperature) and contraction (at reducing temperature) impose additional loading to structural members.
- Mechanical properties of structural materials at elevated temperatures are provided in technical sheet No. 5.
- When checking the loadbearing capacity of a structure at elevated temperatures, the calculations may be carried out at different levels: analysis of members with statically determinate loading condition; part of structure analysis; whole structural analysis. Structural member analysis does not consider interactions between different structural members in fire and methods of checking member capacity at elevated temperatures are

given in technical sheet No. 8. When conducting member analysis and design, it may be necessary to include the contribution of joints. Guidance on joint analysis and design if fire is provided in technical sheet No. 12. Both part of structural analysis and whole structural analysis should consider structural interactions. In particular, when checking structural resistance in fire, the structure is often allowed to develop very large deflections. Such large deflections will necessitate the consideration of structural phenomena that are often ignored in normal structural analysis and design at ambient temperature. For example, beams and slabs are only analysed for their bending moment resistance at ambient temperature so that the in-plane behaviour (catenary action in beams, membrane action in slabs) is not considered. However, such modes of behaviour can have significant impact on structural fire resistance. Technical sheet No. 6 provides further guidance.

- In addition to assessment of structural loadbearing capacity under the expected fire condition, it is also important to make provision for the "unexpected" consequence of fire attack (exceptional fire loading). This is the same as checking for structural robustness. The difference between normal structural robustness (control of progressive collapse) and design for exceptional fire loading is that the additional requirement of fire spread through compartments should be considered. Technical sheet No. 15 provides some provisional guidance on design for structural robustness and fire integrity.
- Structural fire safety design interacts with both the structural engineering profession and the fire engineering profession. Therefore, when carrying out structural fire safety design and analysis, it is important that the designer interacts with the two closely related professions as well as the client, the architect and the fire and building authorities as early as possible so that important decisions such as the safety level to be achieved, the choice of design fire and the objectives of structural fire engineering design are clearly agreed.
- The choice of the critical design fires for the designed building is an important phase in performance-based fire design. The number of possible fire scenarios is of course very large, but only a part of them can be considered critical and require further analysis. The characteristics and number of design fires depends on e.g. the geometry of the compartment, the use of the building, the fire load etc. The degree of criticality and probability of occurrence of different fire scenarios should be determined. It is also important to remember to carry out sensitivity analyses on different factors. Fundamentally the choice of design fires is the job of the building administration authorities and they should be discussed in the Fire Engineering Briefing at the start of the project.

Guidelines

- The Institution of Structural Engineers in the UK has published a design guide to fire safety engineering of structures. A list of contents of this guide is provided on Fig. 1 for reference. Similar guidelines may be found in most European countries see Technical sheet No. 3.

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References
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Figure 1. List of contents ISE (2007).

Definitions

- *Design fire*: a specified fire temperature development assumed for structural design purposes.
- *Fire resistance*: the ability of a structure, a part of a structure or a member to fulfil its required functions (load bearing function and/or separating function), for a specified load level, for a specified fire exposure and for a specified period of time.
- *Fire scenario*: a qualitative description of the course of a fire with time identifying key events that characterise the fire and differentiate it from other possible fires. It typically defines the ignition and fire growth process, the fully developed stage, decay stage together with the building environment and systems that will impact on the course of the fire.
- *Indirect fire actions*: internal forces and moments caused by thermal expansion.
- *Load bearing function*: the ability of a structure or a member to sustain specified actions during the relevant fire, according to defined criteria.
- *Nominal fire*: conventional design fire, adopted for classification or verification of fire resistance, e.g. the standard temperature-time curve.
- *Separating function*: the ability of a separating element to prevent fire spread (e.g. by passage of flames or hot gases) or ignition beyond the exposed surface during the relevant fire.
- *Standard temperature-time curve*: a nominal curve for representing a model of a fully developed fire in a compartment.

References

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