FIRE DESIGN OF CONCRETE STRUCTURES BASED ON A LEVELS-OF-APPROXIMATION APPROACH

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Abstract

Concrete structures, contrary to steel or timber structures, have not been traditionally considered as significantly sensitive to fire conditions. As a consequence, their performance under fire scenarios has generally been assessed on the basis of quite simplified rules provided in codes of practice, mostly dealing with minimum geometric requirements in terms of thickness and concrete cover. Accidents under fire conditions have nevertheless revealed a certain level of vulnerability of concrete structures in fire and have thus shown that code regulations are potentially insufficient to cover this aspect of design.

As a reaction to this level of simplicity, some codes are currently available with specific and very detailed provisions with reference to fire design in concrete structures, such as EN 1992-1-2, covering a wide number of simplified and advanced design procedures. Unfortunately, the hierarchy of these procedures and which one is most suitable for a given situation is sometimes unclear for designers. In addition, it is probably not necessary to perform rather complex and detailed analyses for all types of structures, but the level of refinement can be adapted to the sensitivity of the structure to fire conditions and to its significance for the society.

In this paper, a possible approach for consistent design of concrete structures under fire conditions is proposed based on the Levels-of-Approximation philosophy. The Levels-of-Approximation approach has been successfully introduced into new Model Code 2010 for a number of problems (such as shear, punching and 2nd order effects) and allows refining the accuracy of the analysis when necessary. This allows keeping simple rules for most cases but provides a general frame for assessing complex or sensitive structures. In addition, it does not only incorporate calculation methods, but specifies which ductility requirements are to be fulfilled in order to ensure a correct applicability of each method.

Keywords: concrete structures, fire design, Levels-of-Approximation approach, robustness, codes of design

1 Introduction

When designing concrete structures under fire conditions, various potential failure modes may develop: failures associated to degradation of material properties or cover spalling, shearing of columns due to imposed displacements, punching of slabs at column regions and others. Consistent design rules to avoid occurrence of such failure modes can be simplified (by means for instance of tabulated data dealing with minimum thickness or concrete cover) or be implemented into numerical models allowing refined analyses (most accurate approaches but demanding quite large calculation efforts). It is clear that simplified rules may be appropriate for design of a large number of structures (particularly conventional ones) and that advanced methods have to available for unusual or particularly sensitive structures.

Due to the fact that the different levels of analysis should be based on the same set of physical models, fire design provisions can be written in a consistent manner by using the Levels-of-

Approximation (LoA) approach (Fig. 1). This approach allows incorporating the necessary requirements for satisfactory fire behaviour at sectional, element and structural levels. Simple design and ductility (robustness) criteria are provided for conventional structures (LoAI). The design criteria can however be refined (if necessary) for more complex structures or for assessment of existing critical members not complying with the simple design rules (using higher-order LoA's). In this paper, a proposal of the authors for so doing is presented (a similar reasoning can also be applied to determining the fire action, from simpler analyses to more refined ones).

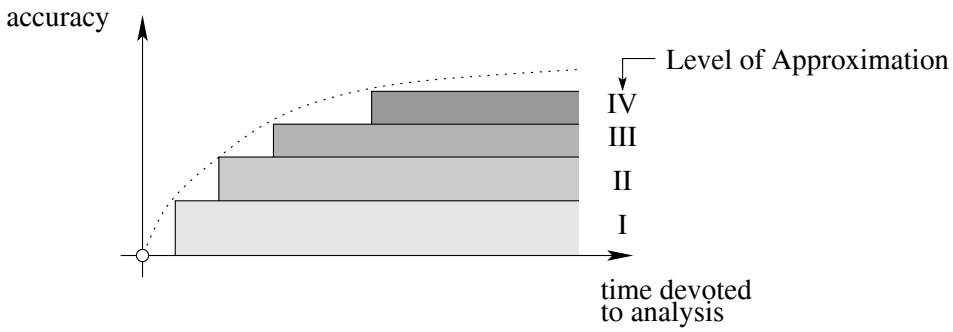

Fig. 1 Levels-of-approximation approach: accuracy of the estimate as a function of the time devoted to analyses

2 Conclusions

Codes of practice currently show low uniformity on their requirements for fire design. In this paper, the governing aspects for fire design are reviewed and, on that basis, a consistent method for design based on a Levels-of-Approximation (LoA) approach is proposed. The main conclusions of the paper are:

1. Failures in fire are usually related to lack of deformation capacity of a member in a given structural system. Ductility requirements, not explicit in most codes for fire design, are thus instrumental for satisfactory behaviour and strength
2. The LoA approach is a suitable manner to write consistent and efficient fire design provisions. Low level LoA are based on geometric conditions but also include considerations on the ductility of the system. Higher-order LoA's have to account for heat transmission in concrete and lead to tailored results for special cases (structures of significant importance or particularly sensitive to fire).
3. Spalling is treated in a simple manner for low-order LoA by means of prescribing exposure conditions (related to moisture content) or detailing measurements (such as polypropylene fibres). Its analysis can be progressively refined (numerical methods, testing) allowing to analyse this phenomenon from a general perspective
4. Simple rules suitable for most cases can be identified for low-order LoA, that can be progressively refined (in higher-order LoA) for assessment of existing (non-conforming with low-level LoA) structures or for detailed analysis of peculiar or fire-sensitive structures

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