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Initial probabilistic studies into a deflection-based design format for concrete floors exposed to fire

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Abstract

Performance Based Design is increasingly applied in structural fire engineering, sometimes entailing the use of deflection-based criteria to demonstrate adequate performance. Since no deflection-based design format currently exists which takes into account the many uncertainties associated with structural performance during fire, the attainment of an 'adequate safety level' is not necessarily ensured. Building on earlier studies, the feasibility of a deflection-based design format with a single global safety factor is explored for concrete floors exposed to fire. Considering the common assumption of lognormality for slab deflections, safety factors can be defined. The subsequent feasibility study however indicates that the assumption of a lognormal distribution is problematic in case of fire. A conceptual alternative to the global safety factor is explored, where the load on the slab is step-wise increased up to the point where a predefined deflection criterion is reached. This alternative approach seems promising, as it results in a known distribution type for the calculated maximum distributed load. Next steps for the development of this concept are identified.

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Keywords: structural fire engineering; performance based design; reliability; deflection; design format

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1. Introduction

Prescriptive structural fire safety requirements are increasingly avoided in favor of so-called performance based design (PBD) options [1]. Sometimes, this means that deflection-based criteria are used to 'demonstrate' adequate performance in fire (i.e. fire resistance). Whether these deflection-based designs result in adequate, quantifiable levels of safety, let alone optimum levels of investment in structural fire resistance, remains unclear.

On the other hand, it must be recognized that current calculation tools are, in general, not capable of modelling all possible modes of fire-induced structural failures for the full range of available structural materials and systems. More specifically, with current methods – notably including both implicit and explicit finite element methods (FEM) – the true load bearing capacity of many complex structural systems exposed to fire cannot generally be determined, leaving the structural fire safety profession with deflection limit criteria as one commonly chosen, calculable alternative.

This paper explores the feasibility of using a deflection-based design format for concrete floors exposed to fire. The paper builds on earlier studies in [2], where the possibility of demonstrating safety through deflection limits was demonstrated, and [3], where target reliabilities for structural fire design of concrete slabs were established. Those studies are summarily introduced below.

1.1. The possibility of demonstrating safety through deflection criteria [2]

The use of deflection criteria to demonstrate 'adequate safety' hinges on two important assumptions/ requirements. First, the applied deflection criterion must be an unequivocally conservative approximation of the true strength-based ('collapse') failure criterion. For complex structural systems, this requirement cannot be verified with current calculation methods, and thus fundamentally hinges on expert-judgement. Second, the deflection criterion (or any other 'unequivocally' conservative approximation of the strength limit state) should only result in a minor additional investment when optimizing the design over the lifetime of the structure.

Both requirements have been explicitly demonstrated, considering deflection limits for the specific (calculable) example case of a simply supported fire-exposed concrete slab, in [2]. Parameters of the slab were as given in Table 3, and the acceptable deflection limits were assumed as 0.24/0.28/0.32 m. More restrictive deflection limits were found to be overly conservative for the cases considered. Taken together, the evaluations suggested the possibility of obtaining adequate structural fire safety (with respect to the collapse limit state) using deflection-based design.

1.2. Target reliabilities for design [3]

The work in [2] necessitated an evaluation of the uncertain future costs and benefits of the design, which is rather demanding for most practical applications. As in ambient structural design, a reliability-based design would be preferable as it allows design to be based on structural-engineering considerations only (i.e. it avoids the detailed valuation of future costs and benefits). However, a reliability-based design requires definition of target reliabilities. These target reliability indices, β_t, correspond with maximum accepted failure probabilities, $P_{f,t}$, through Eq. (1), with Φ being the standard cumulative normal distribution function [4].

$$P_f = \Phi(-\beta) \tag{1}$$

In [3], tentative target reliabilities for structural fire design were determined through Lifetime Cost Optimization (LCO) calculations for the same concrete slab as in [2]. The calculations were made as a function of the dimensionless 'fire-damage parameter' η_{fi}, defined by Eq. (2), with parameters as given in Table 1, making the results generally applicable to a wide range of applications. The proposed (tentative) target reliabilities specified in [3] are given in Table 2. For the specified concrete slab (span 4.8m, lever arm d = 180mm), these target reliabilities were found to be applicable for both the strength criterion (i.e. bending ultimate limit state) and when applying deflection limits of 0.24/0.28/0.32 m.