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Structural fire resistance: Rating system manifests crude, inconsistent design

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ABSTRACT

This paper highlights a shortcoming in the current system of structural fire resistance design, proposes how it can be addressed and shows how the perceived barriers to change can be overcome. It is an opinion piece intended to stimulate discussion.

Whilst structural fire engineering knowledge may be relatively underdeveloped compared to other engineering disciplines, the industry has made great progress in recent decades in understanding and analysing fire behaviour and the response of structures, as well as developing fire protection products that can be accurately specified to meet performance criteria. In addition, through modern fire and risk engineering there are also methods to establish the appropriate fire resistance rating for a building (or element) based on risk profile, fire loading, building fabric and potential ventilation amongst other things. It is the objective of many within the industry for structural fire engineering to become an integrated part of the design process, ultimately leading to safer and more efficient structures. However, this paper questions whether current structural fire resistance design methods achieve the consistent level of crudeness required for this, or whether the means by which structural performance in fire is quantified, standard fire resistance, represents a weak link that undermines the entire process.Although the concept of standard fire resistance, benchmarked against performance under normalised furnace test heating regimes, is useful in that it allows for the comparison necessary to safeguard consistency across products, design methods and geographies, the historic 15-min fire resistance increments (for example 60, 75, 90 min) result in inconsistent levels of safety. Refined grades, as in fact already allowed under fire resistance testing standards, would yield significant benefits for reliability and design efficiency. The paper uses hypothetical case studies to exhibit the merits of refined fire resistance grades and explains how implementing the enhanced classification system may be readily achievable.

Introduction

In general, since the turn of the 19th century there has been steady improvement in the means by which adequately safe structural response in fire is designed for and implemented. The aspirations for acceptable building performance have become better defined and documented in regulatory literature and design codes. Understanding of fire dynamics and the

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thermo-mechanical behaviour of construction elements and buildings as a whole has advanced greatly. Fire protection products (intumescent paint to steel for example) have evolved to be highly effective systems for which thickness can be specified to the micron to meet given performance criteria. However, the fire resistance ratings against which satisfactory behaviour of structural elements is benchmarked (determined by the duration of standardised furnace-test heating regimes experienced by an element before defined performance criteria are breached) are specified in 15-min intervals (for example 60, 75, 90 min) that relate to figures in prescriptive guidance which have remained largely unchanged since the post-war era [1]. This despite the fact that fire resistance test standards [2] state that any furnace test duration may be applied. Does the 15-min grading system therefore represent a crudeness that limits the reliability and consistency of the overall design process? This paper presents the authors' views on this issue, and is posed as an opinion piece intending to stimulate discussion amongst the fire safety community.

Structural fire engineering: innovative design, arbitrary solutions

The aspirations of architecture and structural design are advancing ever further and the limits of the industry's understanding of material and structural response in fire are being stretched. Innovative structural systems are being employed, traditional materials are being used in novel ways and built spaces are being created in shapes and sizes previously not envisaged. As such, the applicability of prescriptive codes in fire resistance design is rightly coming under increasing scrutiny and performance-based fire resistance design, broadly referred to as structural fire engineering, is becoming increasingly important in delivering structures that meet life safety and property protection objectives. Ensuring considered application of engineering methods and avoiding blind application of prescriptive codes will be crucial to delivering safety in the next generation of buildings, particularly in the developing world where international best practice is often seen as a panacea for all buildings. When structural fire engineering is integrated and considered as part of a holistic fire resistance design approach, considering all project goals and the full life cycle of an asset, it can also help meet the growing expectations of investors and society generally for sustainable, robust, cost-effective buildings [3].

In an effort to maintain pace with evolving goals and design challenges, recent decades have seen increased sophistication in the input parameters and analysis methods used in structural fire engineering. In her provocative 1995 paper "Magic Numbers and Golden Rules" [4], Margaret Law challenged the fire safety community, particularly those involved in regulation, to allow designers to implement judgement and engineering-based rules in the development of fire safety solutions, as opposed to the unthinking application of prescriptive rules for which the underpinning assumptions and limitations may no longer be relevant. Only through a holistic approach, incorporating performance-based methods as appropriate, can fire engineers deliver consistent, acceptable levels of safety in buildings that are also fit for purpose, meet client aspirations and are delivered within the often competing constraints. The industry has made progress on this front but, as fire engineers around the world including the authors will attest to [5], code-based design (for example, in accordance with BS 9999 [6] or Approved Document B [7] in the UK) is still typically viewed as the "target" for safety, and there is a long way to go before prescriptive "golden rules" and performance-based engineering are given the respective appropriate consideration they warrant.

The engineering analysis that supports performance-led design must be founded on sound principles, and applied with a rigour and accuracy appropriate to the particular technical challenges presented and solutions proposed. As Elms professed on engineering generally in 1985 [10], the design process is only as strong as its weakest link and "the choice of level of detail in any part of an engineering procedure must to some extent be governed by the crudest part of that procedure". In short, if one part of an answer is overly crude, it will render the refinement and complexity of any other methods largely irrelevant. As design methods, codes and understanding evolve, certain areas evolve at faster rates than others and, as such, inconsistent levels of crudeness or accuracy are almost unavoidable. Good engineering should recognise the crudest inputs or procedures in a process, and seek to reduce their uncertainty or the impact that their uncertainty will have on the validity of the process.

This principle of achieving a "consistent level of crudeness" has since been applied to the specific field of structural fire engineering by Buchanan in 2009 [11] as part of his challenge to structural engineers and fire engineers to talk to one another, and again by Angus Law in 2014 [9] in highlighting the challenges of delivering designs that balance the goals, constraints and products required on a particular project. The latter paper highlights that not only are the fields of fire engineering and structural fire engineering evolving disciplines that are still research-led in many facets and therefore far from exact, there are also numerous other factors which can affect the crudeness of structural fire resistance design. These include defining the fire safety goals and consequently the performance acceptability criteria, regulatory / legislative restrictions, limitation imposed by coordination with other elements of the design and construction, and the available and viable fire protection methods.

Designers must interrogate their design methods to establish whether certain aspects are compromising the remainder of the process. There are well-documented limitations associated with structural fire engineering [9], but it is the authors' opinion that the outputs for specification of fire protection solutions (i.e. fire resistance ratings) remaining benchmarked in 15-min increments is the crudest part of the fire resistance design process and it should be refined.

Without a refined rating system, progress in the field of structural design for fire safety will continue to be constrained by the crude means in which fire protection solutions are categorised. This paper explains the numerous negative implications arising from this, primary amongst them being the delivery of inconsistent and unreliable levels of safety. Firstly however, in order to discuss the consequences of the crude rating system, the context of the fire resistance ratings themselves must be clarified.