APPLICATION OF STRUCTURAL FIRE DESIGN TO STEEL BUILDINGS
New Zealand Experience 1986 to 2008

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INTRODUCTION

Structural fire engineering design has been applied to more than 100 steel framed buildings in New Zealand, most since the introduction of a performance based Building Control System in 1992. New Zealand's long-standing requirements for seismic design and detailing, which require structures to withstand inelastic demand without failure, have been exploited in the development of structural fire engineering solutions. This has been supplemented more recently by design procedures developed from research focussed specifically on experimental testing of structures exposed to fire.

1. HISTORY OF BUILDING REGULATORY CONTROLS AFFECTING FIRE

Prior to the introduction of the performance-based building control system in 1992, building fire safety in New Zealand was controlled by a prescriptive Model Building Bylaw NZS1900 Chapter 5. In 1992, the Model Building Bylaws were all replaced with a fully performance based Building Control System.

The NZ Building Code specifies mandatory functional requirements and performance criteria, but these may be achieved by any means. A prescriptive fire safety Compliance Document is available, providing designers with one option for a solution which is deemed to comply with the Building Code, but is non-mandatory. Routine fire safety design for most buildings is undertaken in accordance with the Compliance Document.

2. DEVELOPMENT OF ANALYSIS AND DESIGN METHODS IN NEW ZEALAND FOR STRUCTURAL FIRE ENGINEERING

The traditional prescriptive approach to structural fire design was a two stage design process: structure design and then subsequently ensuring adequate fire resistance were carried out as two separate activities. For structural fire safety the only solutions available were construction in concrete, or applied insulative fire protection of the structure.

The 1992 performance based Building Control System offered the option of quantifying the expected fire severity (fire threat) on an individual building basis, subject to knowing the building use (hence fire load energy density) and characteristics such as firecell geometry and features of the external walls. The most common simplified design approach is still semi-prescriptive and assessment of structure performance is also most commonly done with reference to individual structural element/member fire resistance as measured by the standard fire test eg. ISO 834. Structure fire safety solutions derived in this way almost always use externally applied fire protection to achieve the calculated fire resistance rating.

Since 1996, more advanced analyses have based fire exposure on natural fires eg. the parametric fire curve described in Eurocode ENV 1991-2-2. While the fire time-temperature equations are a function of many of the same variables as simpler methods. The fire curve includes a cooling phase.

For some steel structures, in which the fire load is low and ventilation conditions good, or the building is sprinkler protected, adequate performance is achieved without externally applied fire protection as the fire temperature does not increase indefinitely (as it does in the standard fire test). Assessment of limiting temperature hence period of structural adequacy takes account of reduced likelihood of maximum effect from other loads occurring during a fire. Although performance is assessed on an individual structural element basis, in some cases a nominal level of inelastic structure behaviour has been included in the assessment of member capacity eg. partial moment capacity from simple (pinned) end connections.

The HERA Slab Panel Method (based on the tensile membrane model of Bailey) was released in 2006. This HERA method is the result of New Zealand experimental and theoretical research programme as well as overseas research and testing. Consideration of three dimensional structure behaviour goes beyond an assessment which considers only individual structural elements basis and strength contribution from one material (steel) and provides a much better understanding of overall behaviour of steel structures in fire. In special circumstances, 3D finite element modelling of structure sub-assemblages with partial fire protection has been carried out.

3. CASE STUDIES

APARTMENT AND HOTEL BUILDINGS

- These typically contain low fire load, have small firecell area and have large amounts of external glazing
- Accordingly the structural fire severity usually very low
- Apartment buildings have a high amount of compartmentation on each floor
- Fully developed fire in one firecell is usually limited to only part of floor
- Beams: assessed for period of structural adequacy using limiting temperature concepts for exposure to a parametric time temperature relationship (individual member performance in standard ISO fire test)
- Sometimes the ceiling construction is used as a radiation shield for partial protection of beams above (where the ceiling construction is required anyway for compliance with other parts of the Building Code

CROWD OCCUPANCY BUILDINGS

- This includes shopping centres, conference facilities, stadia, public assembly buildings
- Firecells in these buildings are typically of large floor area
- Concept of uniform burning as "fully developed" fire not applicable
- Natural fire concept used to compare 'real time' time line effects on structure with the actual (calculated) time required for safe egress
- Safety margin is included to account for uncertainty in predicting fire effects and occupant response

OFFICE BUILDINGS

- Firecell floor area for offices ranges from small to large, ventilation of fire ranges from minimal to highly ventilated
- Occupant egress times can often be in the range 30 to 60 minutes
- Assessment of structure performance assuming performance from a standard fire test is not sufficiently accurate to predict unprotected structure performance
- 3D structure performance with partial structure protection in New Zealand has been carried out using the (HERA) Slab Panel Method – membrane action
- Some finite element analysis has been carried out in design office applications
- Equivalent time is usually used as the basis for acceptance criteria but natural fire time-temperatures are also used (to assess steel temperatures in fire)

EXISTING BUILDINGS

- Full compliance with the Building Code is permitted to be to an extent "as nearly as reasonably practicable"
- A 'first principles' approach has provided flexibility to account for particular circumstances for each building
- Design verification includes reference to outcomes from relevant experimental testing
- Features which have been accepted to support structural fire assessment include improving the reliability of sprinkler system
- Judgments for compliance (made by regulatory authorities are frequently qualitative

4. STRUCTURE REQUIRING SPECIAL CONSIDERATION

Load transfer beams, transfer trusses, slender columns or any other part of structure whose deformation or collapse during a fire would result in a disproportionate extent of damage or collapse are designed with greater caution (usually they receive insulative fire protection, even if the strength of the member is sufficient without it). This applies particularly to structural elements which could endanger fire fighters located in other firecells during fire fighting operations.

5. EXPERIENCE WITH REGULATORY REVIEW AND APPROVAL

The necessary level of expertise is not available within the authorities with jurisdiction for building approvals. The assessment of adequacy of structural fire designs requires greater reliance on independent peer review. This has been the experience in New Zealand.

Confusion arises between the meaning of 'equivalent time' (eg. period of structural adequacy measured with reference to performance in the standard fire test) and 'real' time relating to fire development or occupant evacuation time or Fire Service response time. The difference between fire protection (usually applied insulative coatings or concealment) and fire resistance – a measure of a structure or member's ability to resist fire effects – is still a common misunderstanding. Misconceptions about performance of various structural materials in fire (steel, concrete and timber) are still widespread. Structures provided with traditional solutions for insulative fire protection are usually assumed by regulators to be immune from the effects of fire, and structures without such protection are therefore regarded as highly vulnerable.

Recent 3D finite element analyses for natural fire exposure which compared the performance of partially protected structure with fully protected structure showed better performance with partial fire protection. The structure with full fire protection exhibited a much less desirable potential failure mode for the same fire exposure. Experience from 3D modelling of structure behaviour in fire has highlighted that structure robustness, rather than strength at elevated temperature, is likely to be the dominant feature characterising adequate performance.