STRUCTURAL ROBUSTNESS AND FIRE

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Robustness – What is it?

A robust solution is one that is more likely to work given an unexpected event or an event that is of unexpected extent or magnitude.

EN1991-1-7-2006 defines robustness as the ability of a structure to withstand effects like fire, explosions, impact or the consequences of human error, without being damaged to an extent disproportionate to the original cause
BCA (2016) – BP1.1

(a) A building or structure, during construction and use, with appropriate degrees of reliability, must —

(i) perform adequately under all reasonably expected design actions; and

(ii) withstand extreme or frequently repeated design actions; and

(iii) be designed to sustain local damage, with the structural system as a whole remaining stable and not being damaged to an extent disproportionate to the original local damage; and

(iv) avoid causing damage to other properties, by resisting the actions to which it may reasonably expect to be subjected.

(b) Actions to be considered to satisfy (a)...

fire not specifically mentioned although not explicitly excluded
BCA Verification Method for BP1.1

(a) assessment of the structure such that upon the notional removal in isolation of —
   (i) any supporting column; or
   (ii) any beam supporting one or more columns; or
   (iii) any segment of a load bearing wall of length equal to the height of the wall

   the building remains stable and the resulting collapse does not extend further than the immediately adjacent storeys; and

(b) demonstrating that if a supporting structural component is relied upon to carry more than 25% of the total structure a systematic risk assessment of the building is undertaken and critical high risk components are identified and designed to cope with the identified hazard or protective measures chosen to minimise the risk.
Key Questions

Will structural robustness \textit{in the case of fire events} be adequate if:

- the provisions of Section C (fire resistance) of the BCA are met, and
- the requirements of BP1.1 (and BV2) are met for other loading events?

Do fire events pose \textit{unique} challenges with respect to structural robustness – i.e. above approach will not be adequate?
Approach

- Consider the origins of building fires
- Consider aspects of fire dynamics
- Review major fire incidents
- Consider potential preventative and mitigation measures
- Review research findings on structural robustness in fire
- Note the relationship between risk and robustness and the need to minimise the occurrence of “loss-of-control” events
Origins of Building Fires

- Fire is not a natural phenomenon, but results from:
  - arson (as opposed to terrorist attack)
  - equipment malfunction
  - inappropriate use of equipment
  - poor work practices
  - accidents associated with use of heating
  - smoking (becoming less of a contributor)
Fire Dynamics

- Fire localised and then spreads laterally
- Fire temperature and duration – depends on fuel and ventilation
- If high rate of pyrolysis – external flaming
  - possible vertical spread to level above
  - more significant heating of edge columns
Incidents

- Madrid High Rise
- Caracus Twin Towers
- WTC 7
Incidents – WTC 7

Comments:

• steel columns and beams, external moment frame, no braced or concrete core
• no spread between levels – spandrels effective
• fire severity high in part of floor > 60 mins - fire protection only 13mm – inadequate
• mechanism of failure of girders and connections:

![Diagram](image-url)
Summary of Other Incidents

- Sprinkler systems not functional
- Fire spread over many levels due to poor compartmentation
- Substantial concrete framing/cores with high fire-resistance
- Not occupied and no overall collapse
Preventative and Mitigation Measures

- Preventative measures:
  - surveillance and security (including presence of other people)
  - adequate work practices
  - adequate equipment maintenance
  - automatic detection and alarms
  - fire extinguishers
  - automatic fire sprinklers

- Mitigation Measures:
  - exits and signage
  - Hydrants – brigades
  - structural fire protection
Research Summary (structural steel)

- Development of connection models
  - strength and ductility under ambient and elevated temperature
  - effect of axial forces
  - FEM and empirical models

- Effect of localised heating
  - loss of column in carpark
  - load redistribution to cooler structure
  - loss of edge or corner column presents greatest challenge
  - tensile (catenary) forces must be resisted
Risk and Robustness - Fire

- Link is recognised in BV2 (b) in BCA
- An adequate risk assessment will seek to:
  - identify rare events (unexpected or extreme)
  - identify robust preventative measures with respect to fire to avoid a “loss-of-control” event
  - identify robust mitigation measures in relation to prevention of fire spread between floors, structural adequacy and maintaining exit paths
- Structural robustness may be difficult to achieve with some “loss-of-control” fire events.
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Conclusions

- Meeting BP1.1 and BV2 under ambient conditions will achieve level of robustness in fire in case of:
  - defective fire protection to a member
  - fire is locally more severe than expected

- Structural robustness in fire:
  - depends on extent of fire
  - depends on fire resistance of structure
  - depends on the structural system
Conclusions

Better to reduce risk by:

- limit fire to one level
  - avoid combustible facades
  - utilise edge spandrels with improved details
  - more robust sprinkler system
  - adequate penetration sealing

- Increase fire resistance of some members
  - based on relative member importance
  - realistic fire severity calculations