Fire Engineering Research: Key Issues for the Future

**Post-tensioned Concrete Structures in Fire**

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What are post-tensioned buildings?

Conventional steel rebar

Prestressing (PS) steel

- Advantages of post-tensioning concrete with PS steel for load balancing
  - Thin floors (high ceilings)
  - Increased span lengths
  - Reduces building materials
  - Rapid construction

Highly optimized
Typical post-tensioned buildings

Modern BPT building, UK

Modern UPT building, USA

Antiquated (1960s) UPT building, USA
Novel building optimization

- **Current guidance is dated** and has not kept up with modern optimization trends

“Today’s flat-slab post-tensioned buildings, for example, with columns spaced (12 m) on center and span-depth ratios of 40 are more complex and require more engineering attention than typical flat-slab buildings of 40 years ago, with columns spaced at (6 m) on center and span-depth ratios of 20.” - Randall Poston (chair ACI 318)
Real PT slab behaviour in fire is debatable

- **PT optimization** increases susceptibility to fire:
  - *PS steel* more sensitive to strength loss in high temperature
  - **Spalling** of concrete cover (HS concrete, precompression of slab)
  - Unbonded tendons run continuous, local damage **will** effect the entire floor *(Key Biscayne demolition)*

- **Code guidance** is based on (often dated) standard furnace tests of simple span slabs:
  - modern construction?, building materials?, real fires?
The PhD

- **Phase 1** Fire code assessment for unbonded PS steel rupture (spalling, and variable heating length)
- **Phase 2** High temperature mechanical behaviour of modern PS steel (softening, strength and creep)
- **Phase 3** three large-scale continuous PT slab tests under localised heating

- *Side projects while I wait for Phase 3 to begin (curing time delayed)*
Phase 1: Localized fire damage to unbonded PS steel

- 2009 Tests demonstrated unbonded PS steel rupture is more probable under localized heating - influenced by creep
- Localized fires may be due to *spalling, travelling, ceiling jets...*

Localized heated UPT tendon tests *(strong back tests)* conducted in my masters

Lower ratio of heating, failed tendons at equivalent temperatures
Phase 1: Localized fire damage to unbonded PS steel

- IBC, and EC2 analyzed with **simple** tendon rupture modelling with creep (time, temp, load dependent) relation and heat transfer (ASTM E119 curve)

**Parametric analysis:** Heated length ratio, spalling, specified concrete cover
Phase 1 results

- Performance based guidance not clearly specified in codes with respect to losing unbonded PS steel in a fire
- Considerations to make; 
  
  restraint, bonded reinforcing, spalling mitigation
- American IBC code was unconservative
- Real unbonded PS steel behaviour more severe than Phase 1 modelling, new modelling parameters needed (Phase 2)
- Results have tied in directly or inspired related PhD projects at Edinburgh (spalling, concrete cover influence using FEM)

Example heat transfer compensated for spalling input (200mm slab)
Phase 2: Modern PS steel behaviour in high temperature

Used Digital Image Correlation (DIC) in uniaxial tensile tests to measure deformation and cross section reduction
Phase 2: Modern PS steel behaviour in high temperature

- DIC patch correlations based on HT paint speckle pattern

Method needed validation for current use.....................
Phase 2: Modern PS steel behaviour in high temperature

- DIC to bonded foil strain gauges and extensometer
- DIC cross section to Poisson constant volume theory
- DIC to theoretical thermal expansion calculation (EC2)
Phase 2: Modern PS steel behaviour in high temperature

- Creep behaviour using temperature compensated time.
- PS steel types considered: ASTM 421-1970, ASTM 416-2008, and BS 5896-2011 (all of different composition, but considered structurally equivalent)
Phase 2 results

- Uniaxial creep tests at *Steady state* and *Transient* investigating equivalency

- Results appeared similar (creep parameters were identical magnitudes; at 690MPa and 1000MPa stress levels)

- Change in transient test heating rate had same magnitudes
Phase 2 results

- Tertiary creep as manifestation of localized yielding

- Creep curve initiates runaway (tertiary) failure when a local necking region develops
- Result appears in transient test
- Possible to model, but relations produce error
Phase 2 results

- **Strength tests with true stress** in steady state; Implicit creep strength tests comparison underway (post peak softening).

  - Reduction ratios matched well to Eurocode
  - Loading rate decrease, decreased yield point
  - True strength retention at elevated temperature better than EC2 until post peak softening occurs
Phase 2 results

- Creep models were compared with the results of the locally heated strong back tests (varied transient and steady state heating with cooling)

- Creep model accuracy function of heating rate and metallurgy

- Error at 2% for 2°C/min growing to 7% error at 30°C/min

- Third creep phase not considered yet
Phase 3: Continuous post-tensioned concrete slabs under localized fire

- Two UPT and One BPT, 1-hour rated EC2 slabs

- Tests planned for this summer (6+ months, low MC%)
- Restraining forces measured from steel columns (stiffness based on representative concrete columns)
- Applied loading
- Realistic span to depth ratio (>40)
- Bonded steel provided
- Thermocouples (x24), Linear Potentiometers (x8), Load cells (x2)
- Radiant panel heating (locally heated)
Phase 3: Continuous post-tensioned concrete slabs under localized fire

Issues and problems with Phase 3:

• **What do we want to do with the results.....**
  - Apriori and Aposteriori round robin modelling?
  - In house modelling (FEM packages)?

• **Instrumentation**
  - What should we be measuring and what does it mean?
  - Motion imaging? (2D DIC, 3D tracking?)

• **Pretesting**
  - Ambient tests before heating?

• **Intangibles; prestressing the slabs?**

BRE Centre for Fire Safety Engineering
Current collaborative side projects

• **Project 1:** The History of Fire Safety Engineering *(The full story is not recorded)*
  - Traditional and non traditional construction
  - Large scale testing *(Modern and antiquated)*
  - ICEM15 conference this July in Porto
  - Fire behaviour, dynamics and design philosophy

• **Project 2:** Axis distance vs. clear cover of miniature PS slabs exposed to ISO 834. Should this design rule change?

• **Project 3:** Open access repositories for historical fire engineering photographs and articles
Thank you

For additional information

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Further reading:


• Results of Phase 1 can be consulted in the Journal of Structural Fire Engineering and Fire Safety Journal (see web link for references)

• Some preliminary results of Phase 2 will be presented at SIF 2012 conference in Zurich

• Phase 3 is currently in progress targeting 2013 for completion.