Fire Engineering Research: Key Issues for the Future

Post-tensioned Concrete Structures in Fire

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Co supervision: Martin Gillie- modelling, Phase 1 and 3

Tim Stratford- experimentation, Phase 2 and 3

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 <u>optimization trends</u>**

*“ **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:**

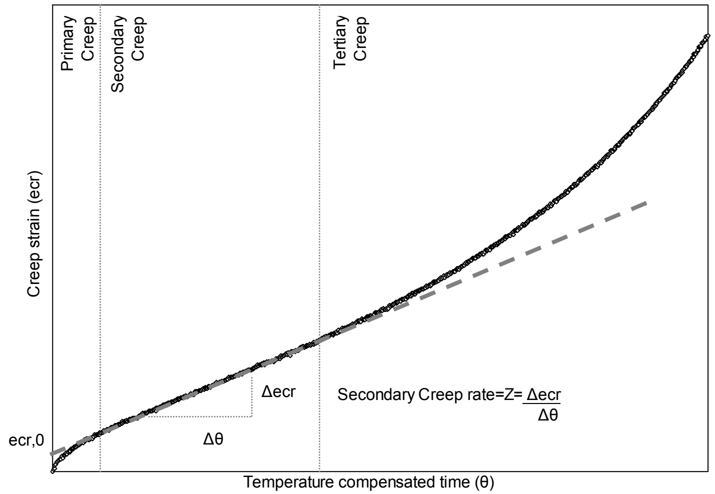
- modern construction?, building materials?, real fires?

PT Standard fire test (Kelly and Purkiss, 2008)

The PhD

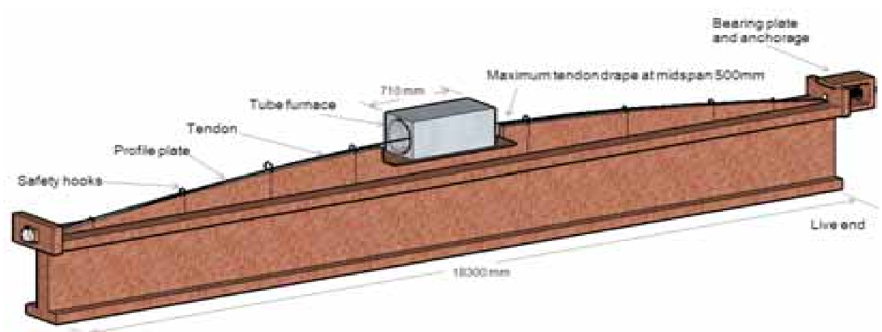
- **Phase 1 Fire code assessment** for unbonded PS steel rupture (spalling, and variable heating length)
- **Phase 2 High temperature mechanical behaviour** of modern PS steel (softening, strength and creep)
- **Phase 3 three large-scale continuous PT slab tests** under localised heating

- *Side projects while I wait for Phase 3 to begin (curing time delayed)*

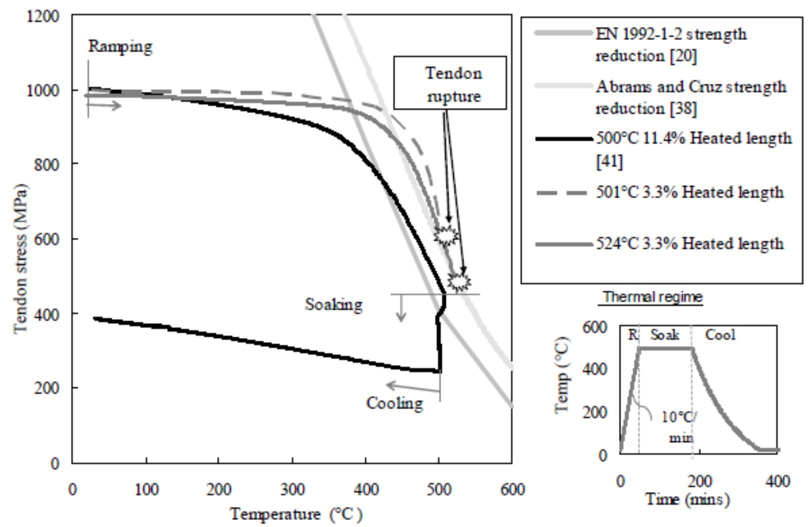


Phase 1: Localized fire damage to unbonded PS steel

- **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…***



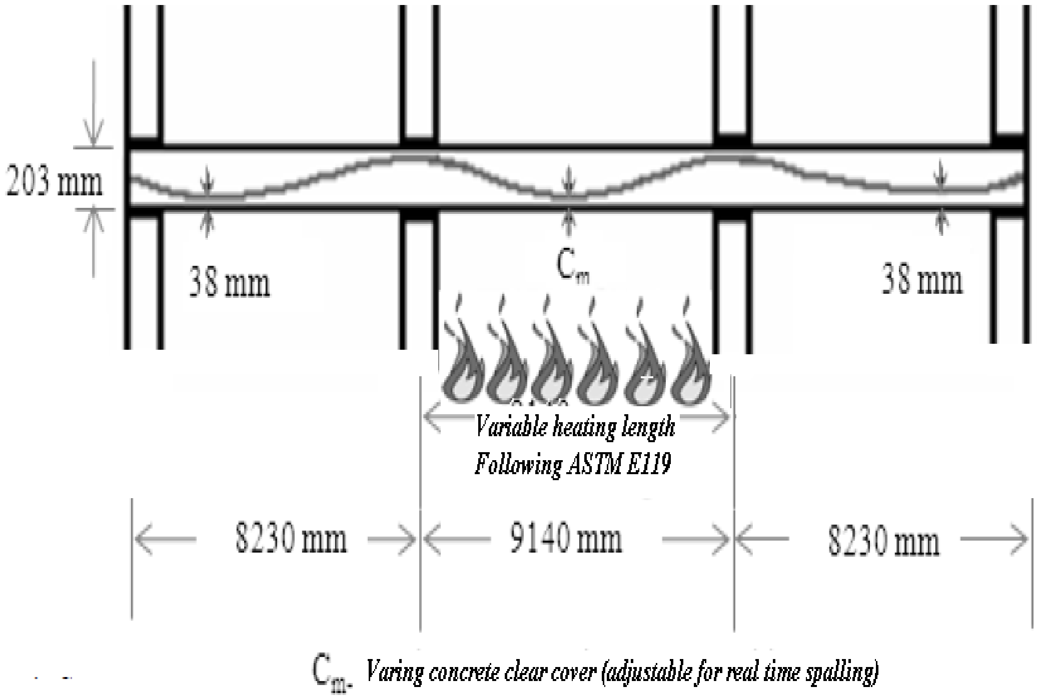
*Localized heated UPT tendon tests (**strong back tests**) conducted in my masters*

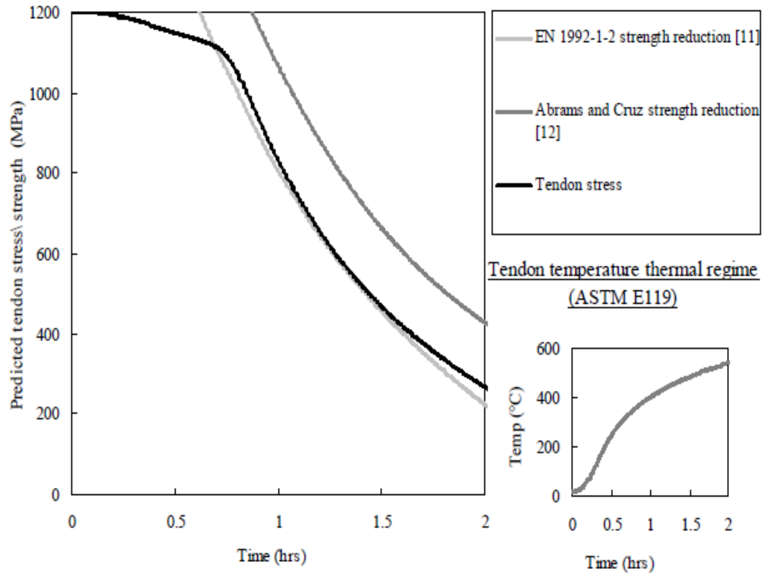


Lower ratio of heating, failed tendons at equivalent temperatures

Phase 1: Localized fire damage to unbonded PS steel

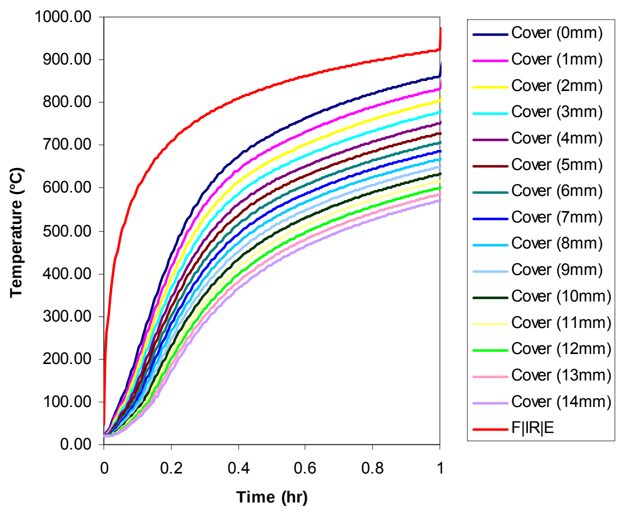
- **IBC, and EC2 analyzed with <u>simple</u> tendon rupture modelling with creep (time, temp, load dependent) relation and heat transfer (ASTM E119 curve)**

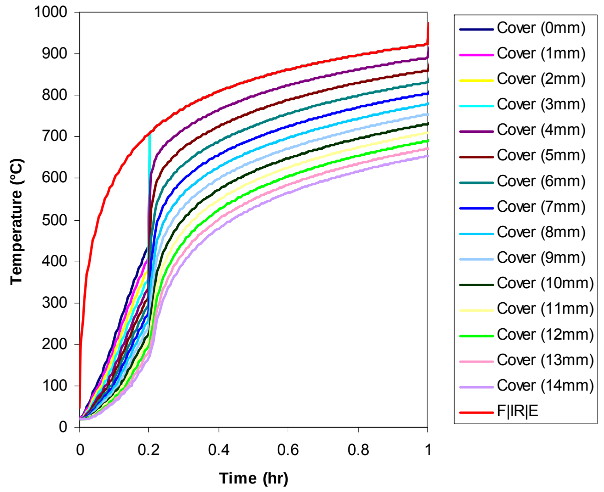




***Parametric analysis**: Heated length ratio, spalling, specified concrete cover*

Phase 1 results

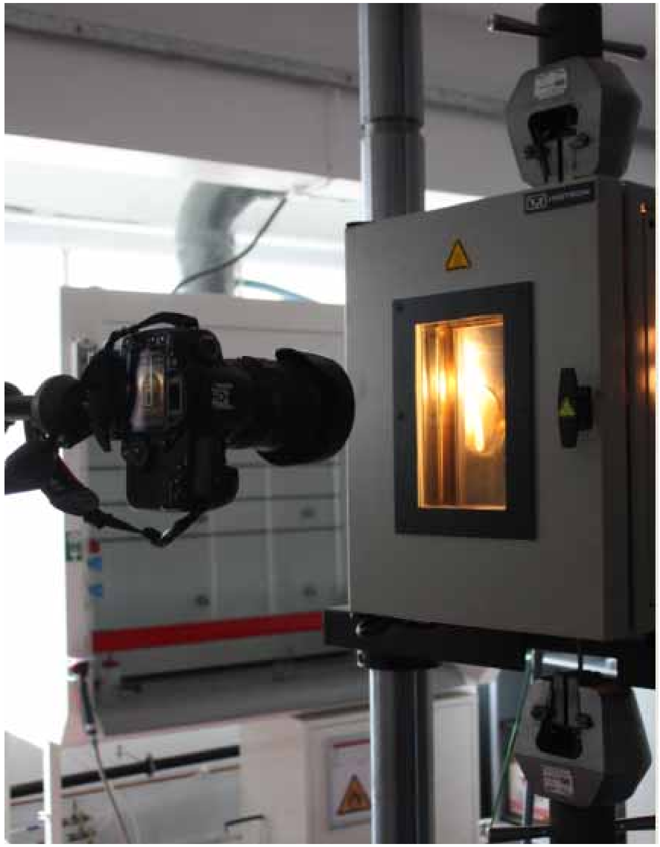




- **Performance based guidance not clearly specified in codes** with respect to losing unbonded PS steel in a fire
- **Considerations to made**; ***restraint, bonded reinforcing, spalling mitigation***
- **American IBC code was unconservative**
- Real unbonded PS steel behaviour more severe than Phase 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)

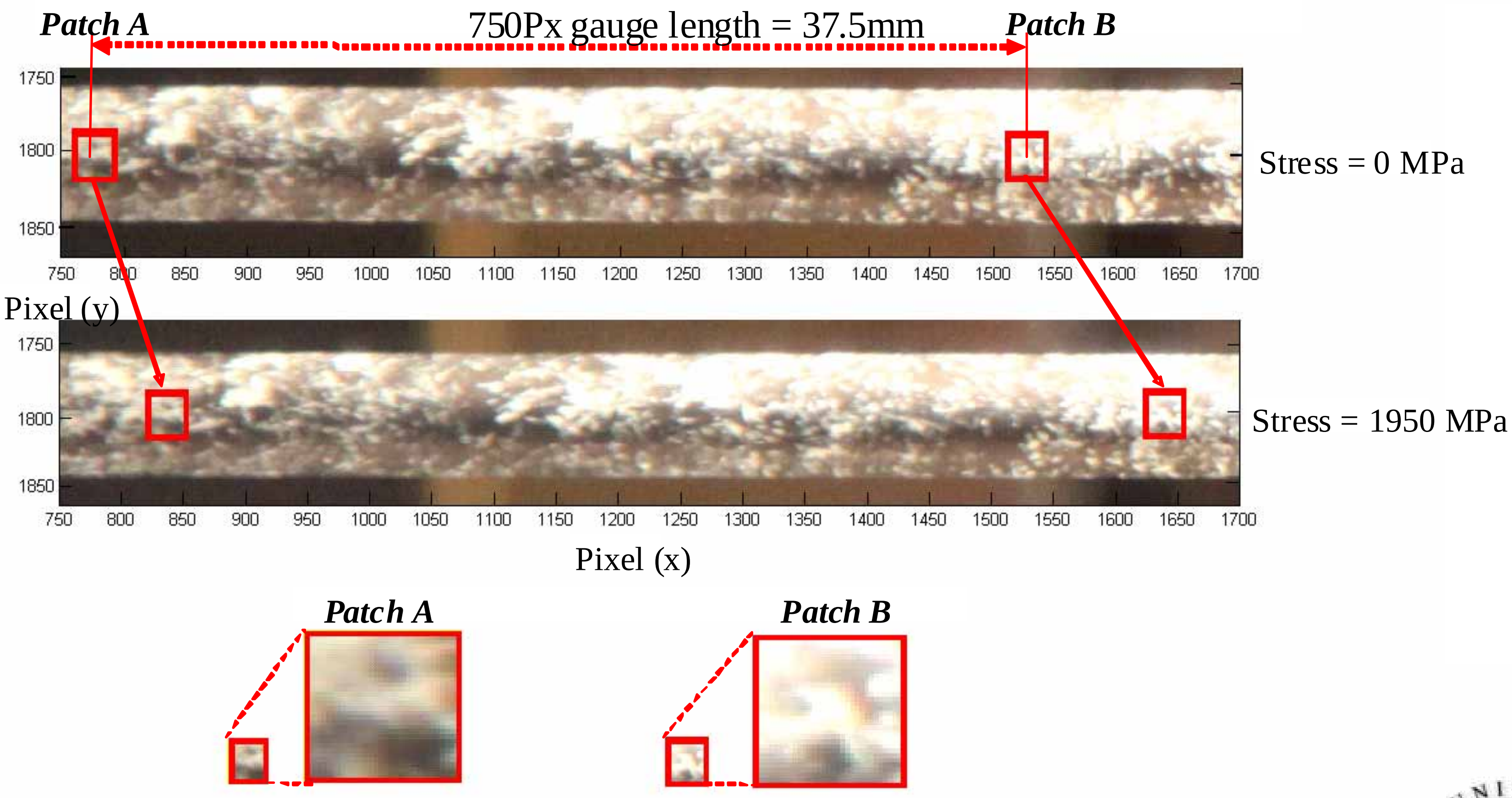
Phase 2: Modern PS steel behaviour in high temperature



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

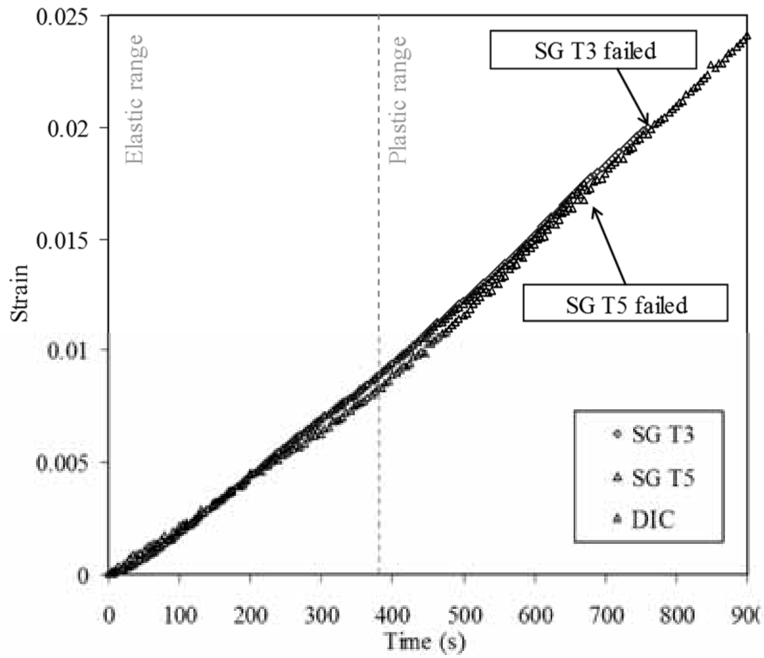
- **DIC patch correlations based on HT paint speckle pattern**

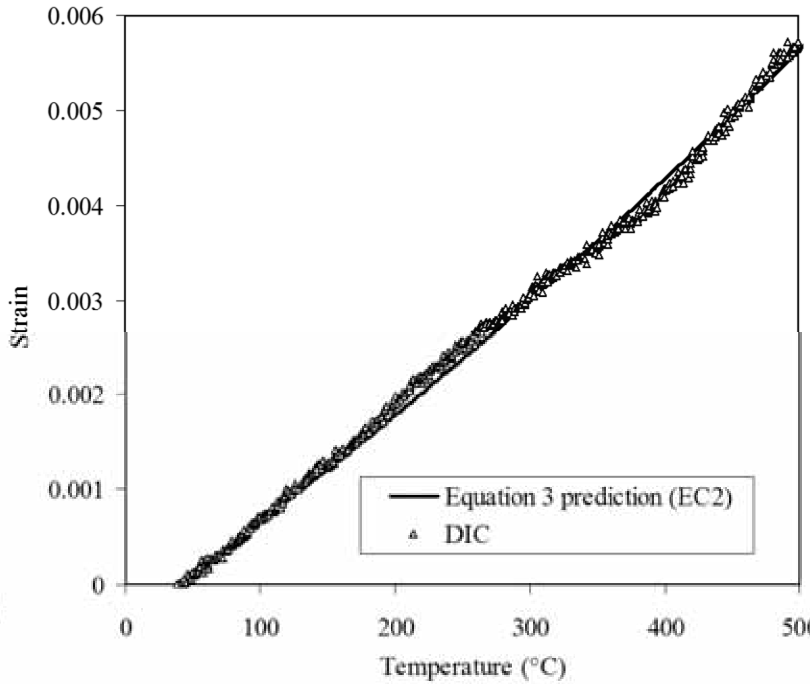


Method needed validation for current use………………

Phase 2: Modern PS steel behaviour in high temperature

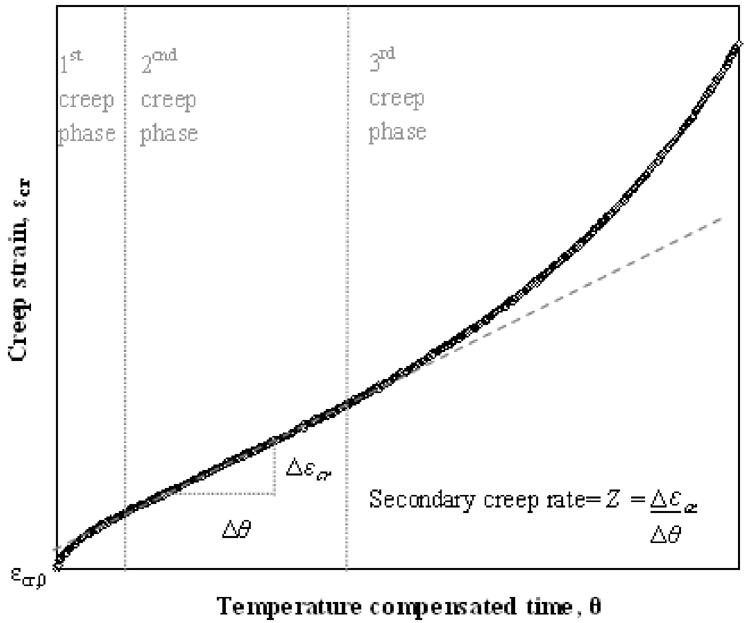
- **DIC to bonded foil strain gauges and extensometer**
- **DIC cross section to *Poisson constant volume theory***
- **DIC to theoretical thermal expansion calculation (EC2)**

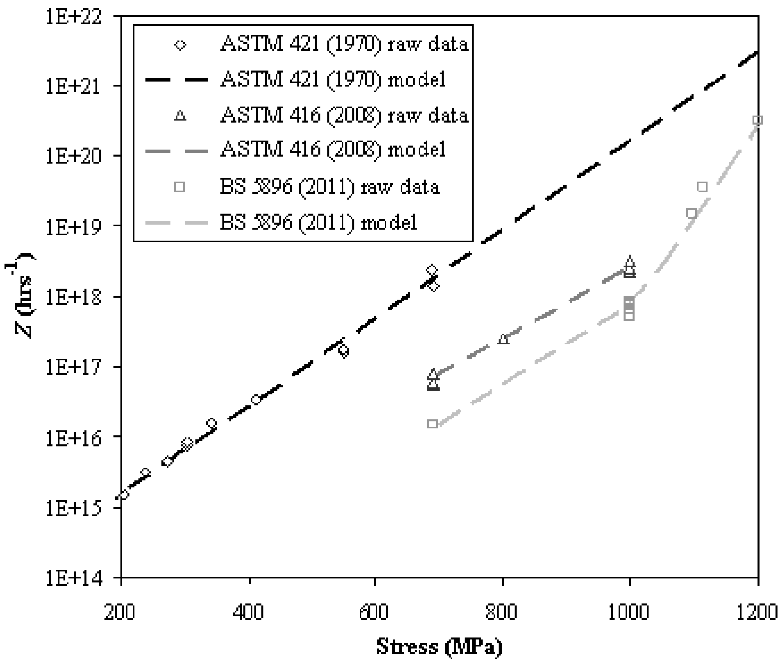




Phase 2: Modern PS steel behaviour in high temperature

- **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)*





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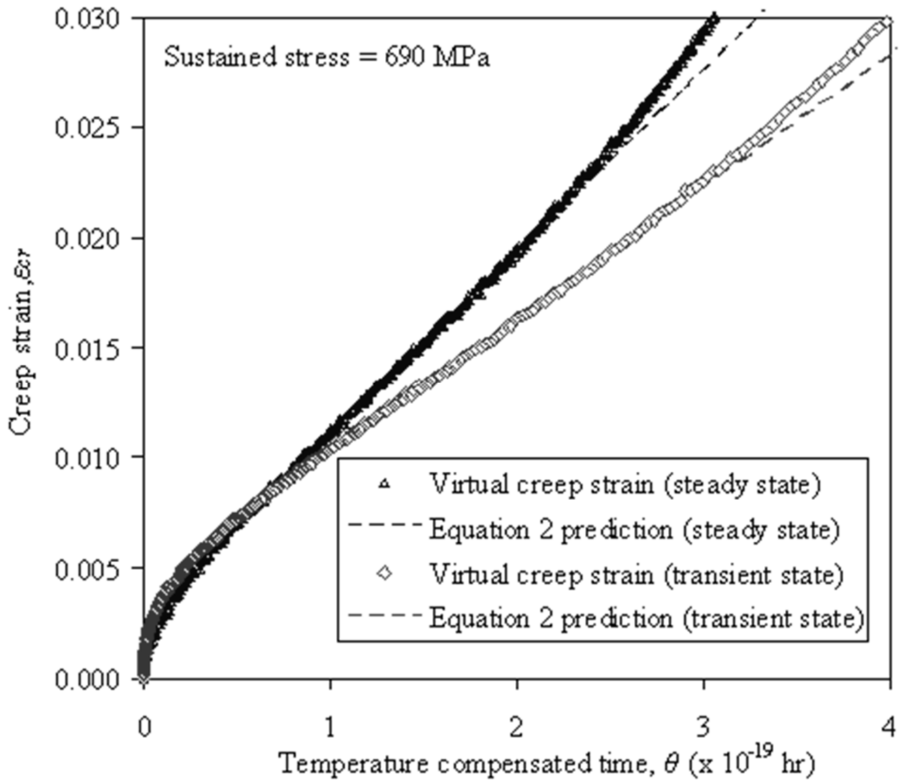
Phase 2 results

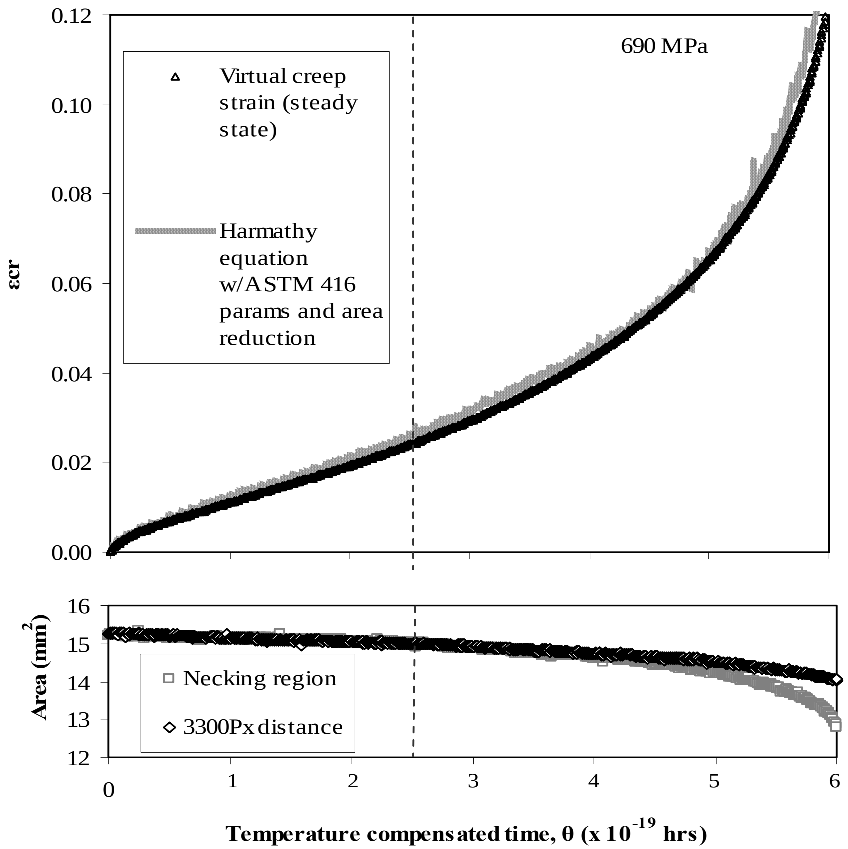
- **Uniaxial creep tests at *Steady state* and *Transient* investigating equivalency**



- ➢ *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

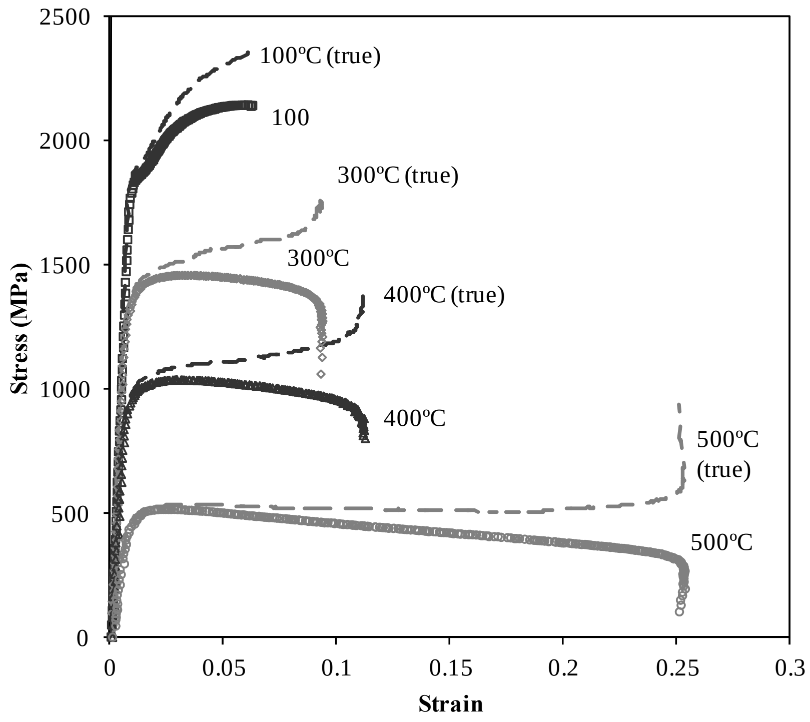
- **Tertiary creep as manifestation of localized yielding**



- ➢ *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

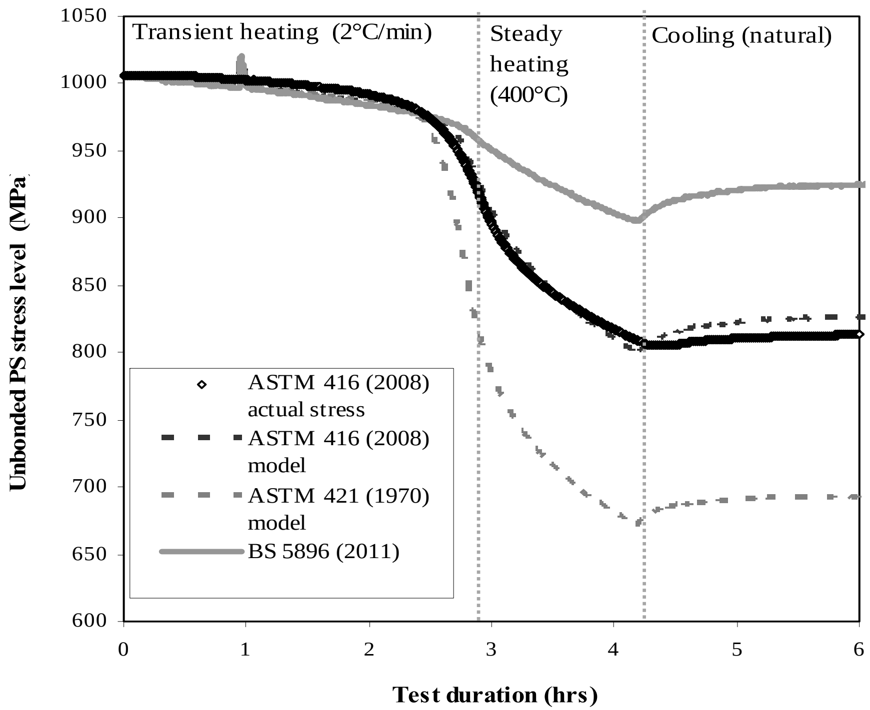
- **Strength tests with true stress in steady state; Implicit creep strength tests comparison underway (post peak softening).**



- *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

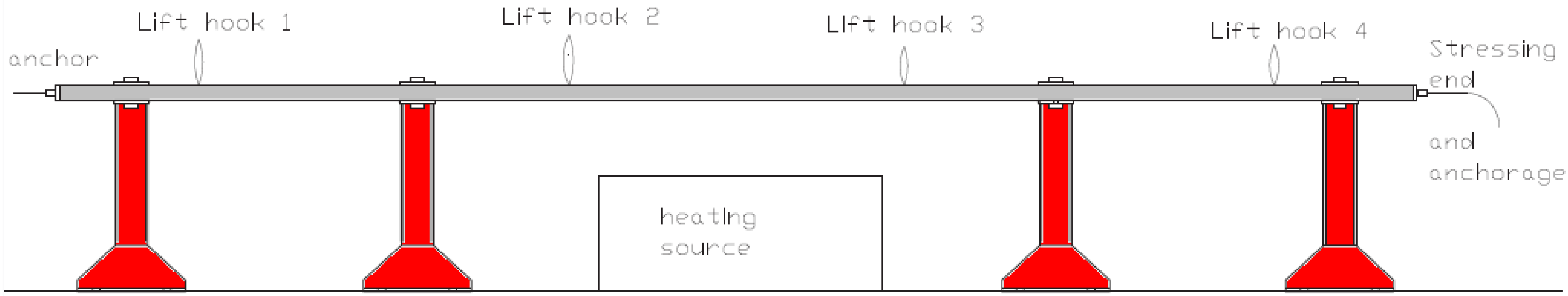
- **Creep models were compared with the results of the locally heated strong back tests** *(varied transient and steady state heating with cooling)*



- *Creep model accuracy function of heating rate and metallurgy*
- *Error at 2% for2^{o}C/min growing to 7% error at 30^{o}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?**

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**

MANIERE
DE RENDRE
TOUTES SORTES D'ÉDIFICES
INCOMBUSTIBLES;
OU
TRAITÉ sur la Construction des Voutes, faites avec des briques & du plâtre, dites Voutes plates ; & d'un Toit de brique, sans Charpente, appellé Comble Briqueté.
De l'invention de M. le Comte D'ESPIE; Chevalier de l'Ordre Royal & Militaire de Saint Louis.
Avec les Plans gravés en taille-douce.
PARIS,
NE, Libraire, Rue St. Jacques, la Fontaine Saint Benoît, Temple du Goût.
DCC. LIV.
ation & Privilége du Roi.

Thank you

For additional information

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Further reading:

- *http://www.eng.ed.ac.uk/fire/2009-phd-john.html*
- *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.*