LITS – Recent Work and Applications

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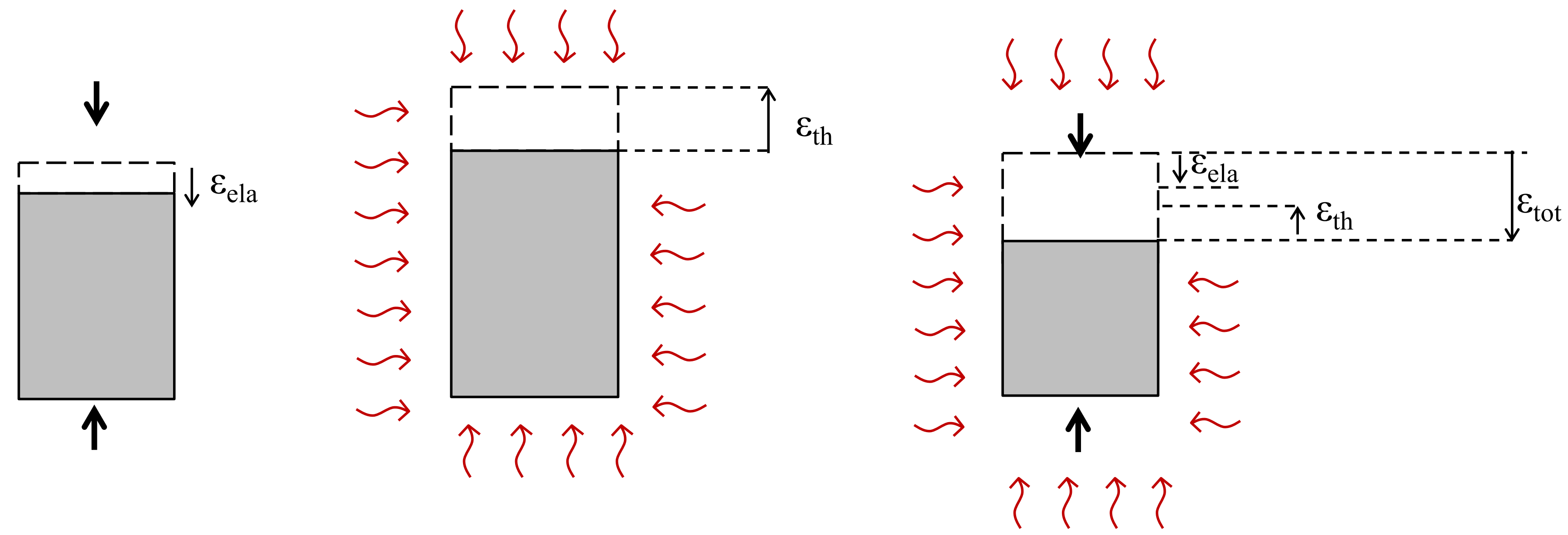
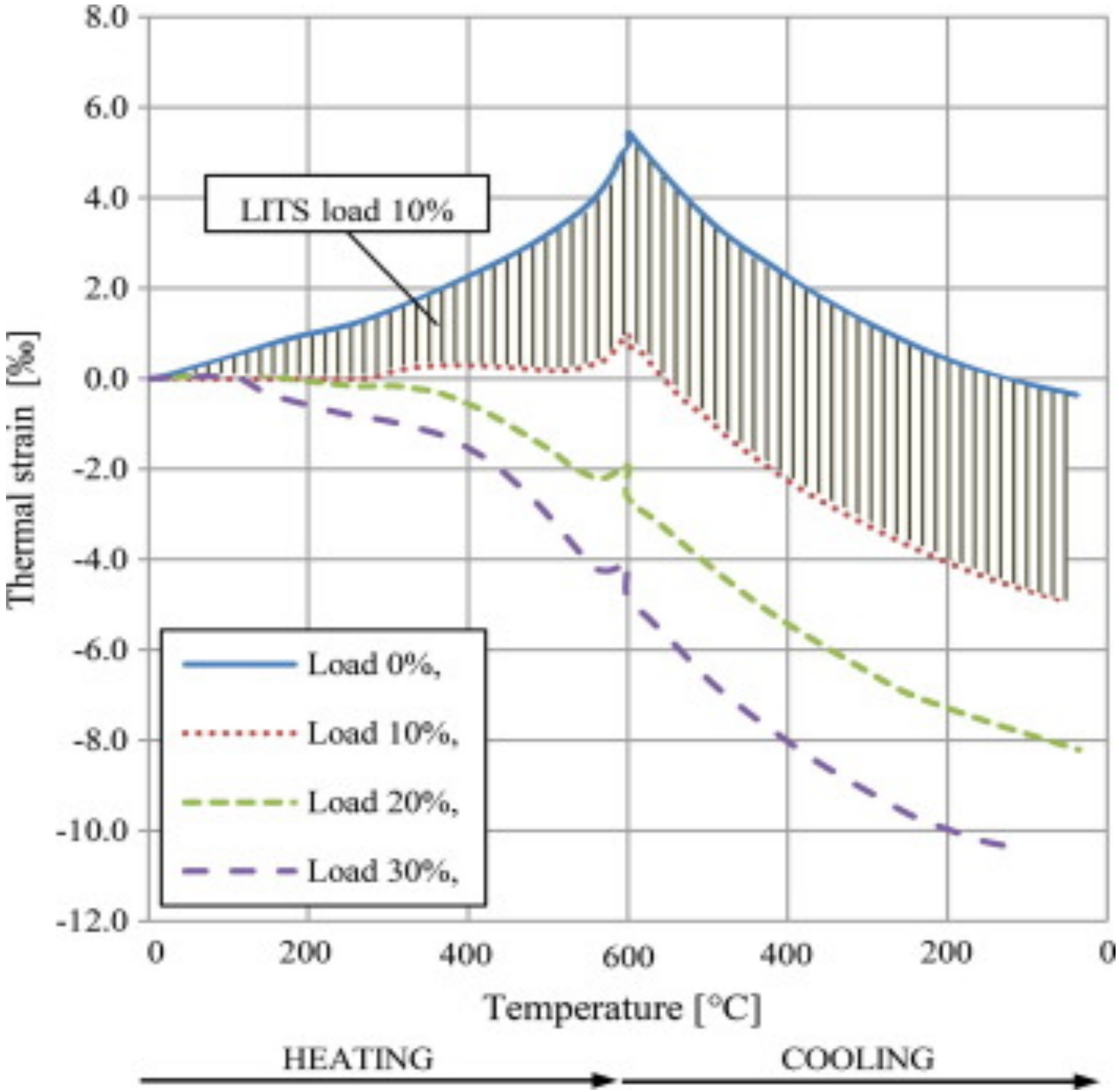
What is LITS?

Compression Heat Compression + Heat



$$\varepsilon_{tot}=\varepsilon_{ela}+\varepsilon_{th}+\varepsilon_{lits}$$

Additional comp. strain



Adapted from G.A. Khoury, B.N. Grainger, P.J.E. Sullivan **Strain of concrete during first cooling from 600 °C under load** Mag Concr Res, 38 1986

LITS: Some details

- Does not recover on cooling or unloading
- Develops during the first heating only
- Extensive 1-d experiments
- Limited 2 and 3-d work
- Numerical models also limited
- Is a bit of a rabbit hole!

G Torelli, P Mandal, M Gillie, V Tran, Concrete strains under transient thermal conditions: A state-of-the-art review, *Engineering Structures*, 125(15) 2016
http://dx.doi.org/10.1016/j.engstruct.2016.08.021

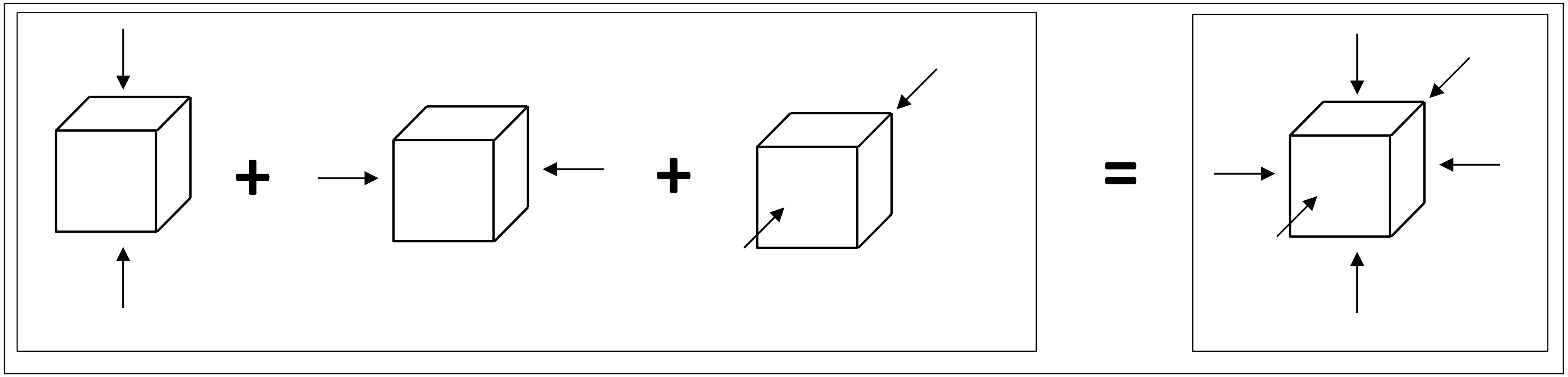
LITS: New Stuff

- Developed a 3-d numerical models
- Applied to bulk heated concrete
- Serendipitously discovered to matter for punching shear

Previous 3d LITS models

$$\dot{\varepsilon}_{ij}^{lits} = \frac{\beta(T)}{\sigma_{u0}}\left(-\upsilon_{lits}\sigma_{\bar{kk}}\delta_{ij} + (1+\upsilon_{lits})\sigma_{\bar{ij}}\right)\dot{T}$$

SUPERPOSITION PRINCIPLE



[1] Pearce CJ, Nielsen C V., Bićanić N. 1987 *Gradient enhanced thermo-mechanical damage model for concrete at high temperatures including transient thermal creep. Int J Numer Anal Methods Geomech*

[2] Thelandersson S. 1987 *Modeling of combined thermal and mechanical action in concrete. J Eng Mech*

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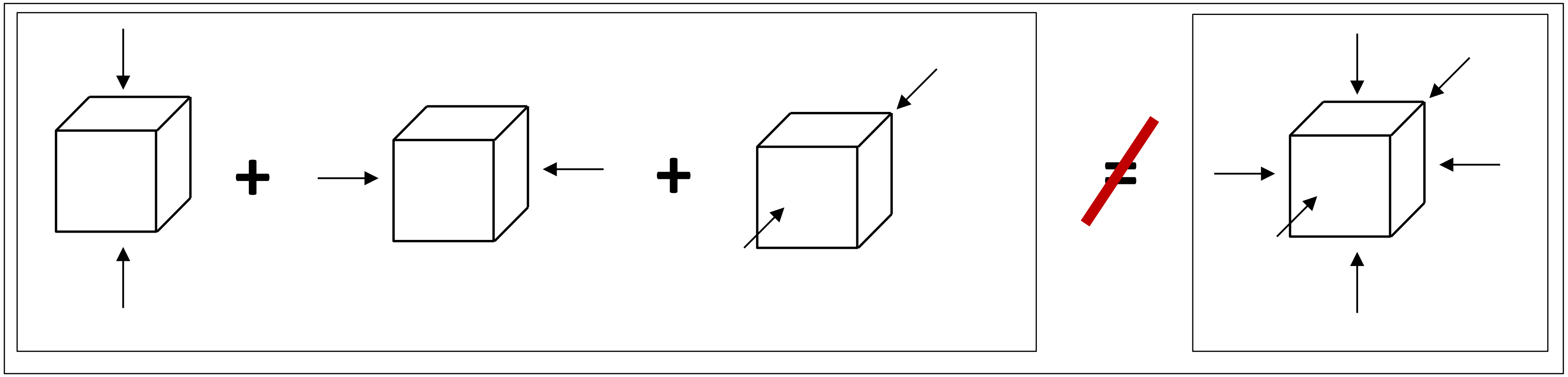

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New 3D LITS Model

CLASSIC APPROACH

$$\dot{\varepsilon}_{ij}^{lits} = \frac{\beta(T)}{\sigma_{u0}}\left(-\upsilon_{lits}\sigma_{kk}^{-}\delta_{ij} + (1+\upsilon_{lits})\sigma_{ij}^{-}\right)\dot{T}$$

⇩

NEW APPROACH

$$\dot{\varepsilon}_{ij}^{lits} = \eta\frac{\beta(T)}{\sigma_{u0}}\left(-\upsilon_{lits}\sigma_{kk}^{-}\delta_{ij} + (1+\upsilon_{lits})\sigma_{ij}^{-}\right)\dot{T}$$

1. Captures effect of confinement ($\boldsymbol{\eta}$)
2. Develops only in compression ($\boldsymbol{\sigma_{kk}^{-}}$)
3. Develops just during the first heating under compressive load – does not recover on cooling or unloading ($\boldsymbol{T_{MAX}}$)

Torelli G, Gillie M, Mandal P, Tran V-X. *A multiaxial load-induced thermal strain constitutive model for concrete*. Int J Solids Struct 2017. http://dx.doi.org/10.1016/j.ijsolstr.2016.11.017

Torelli G, Mandal P, Gillie M, Tran V-X. *A confinement-dependent load-induced thermal strain constitutive model for concrete subjected to temperatures up to 500°C*. Int J Mech Sci - ***UNDER Rev 2017.

New 3D LITS Model

CLASSIC APPROACH

$$\dot{\varepsilon}_{ij}^{lits} = \frac{\beta(T)}{\sigma_{u0}}\left(-\upsilon_{lits}\sigma_{kk}^{-}\delta_{ij} + (1+\upsilon_{lits})\sigma_{ij}^{-}\right)\dot{T}$$

⇩

NEW APPROACH

$$\dot{\varepsilon}_{ij}^{lits} = \eta\frac{\beta(T)}{\sigma_{u0}}\left(-\upsilon_{lits}\sigma_{kk}^{-}\delta_{ij} + (1+\upsilon_{lits})\sigma_{ij}^{-}\right)\dot{T}$$

Where:

- η confinement coefficient – captures the LITS dependency on triaxiality of the stress state

$$\eta = 1 + (C_m - 1)\gamma$$

C_m=-$\frac{\sigma_1^- + \sigma_2^- + \sigma_3^-}{\sqrt{(\sigma_1^-)^2 + (\sigma_2^-)^2 + (\sigma_3^-)^2}}$ Triaxiality index

γ Triaxiality scaling factor (recommended γ= 1.5)

Note:
$\uparrow C_m \uparrow \eta$
$\uparrow \gamma \quad \uparrow \eta$

9

General strain decomposition

$$\dot{\varepsilon}_{ij}^{tot} = \frac{1+\upsilon}{E}\dot{\sigma}_{ij} - \frac{\upsilon}{E}\dot{\sigma}_{kk}\delta_{ij} + \eta\frac{\beta(T)}{\sigma_{u0}}\left(-\upsilon_{lits}\sigma_{kk}^{-}\delta_{ij} + (1+\upsilon_{lits})\sigma_{ij}^{-}\right)\dot{T} + \alpha(T)\delta_{ij}\dot{T}$$

$\dot{\varepsilon}_{ij}^{el}$ — ELASTIC STRAIN

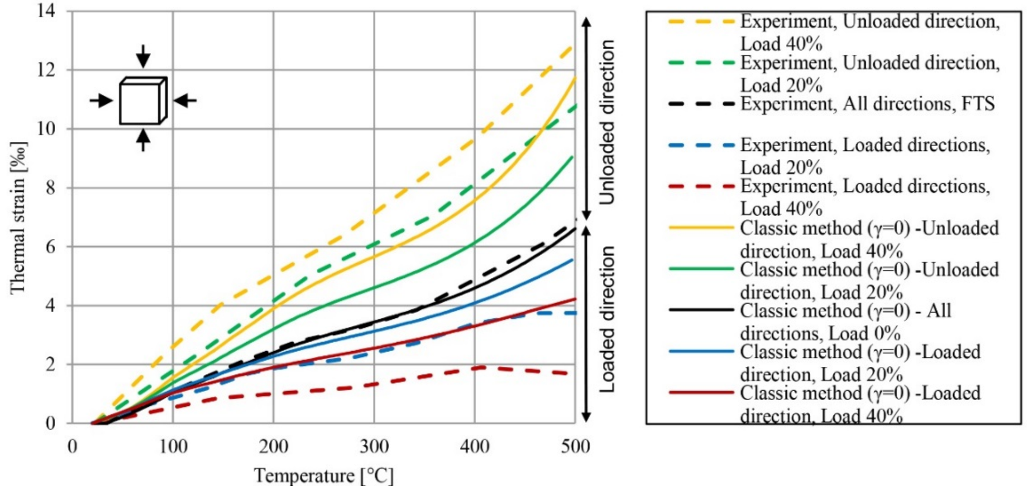
$\dot{\varepsilon}_{ij}^{lits}$ — 3D LITS

$\dot{\varepsilon}_{ij}^{th}$ — NON-LINEAR FREE THERMAL STRAIN

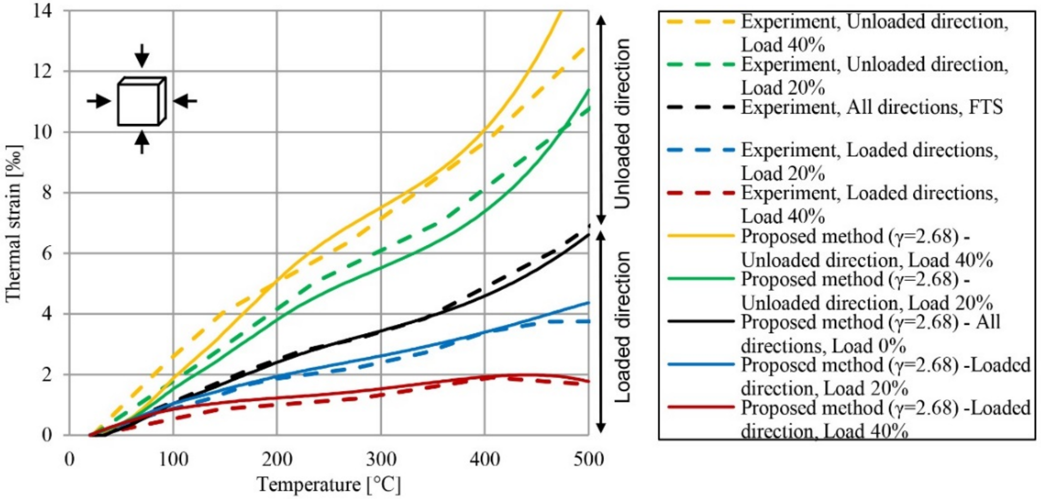
Validation Study

Transient tests by Kordina et al. (also Petovski et al)

- Biaxial compression



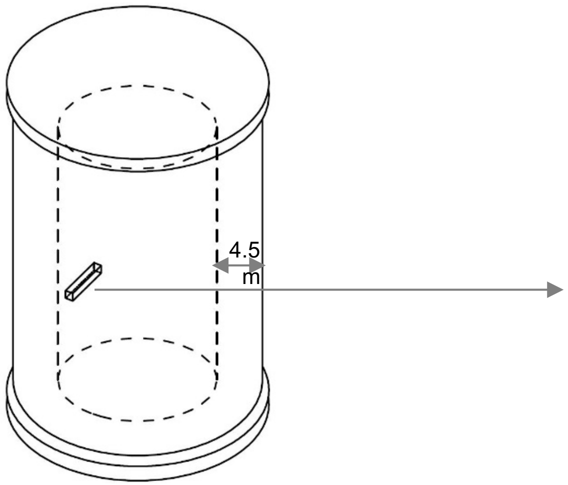
Results obtained by the "Classic Method" (γ=0)



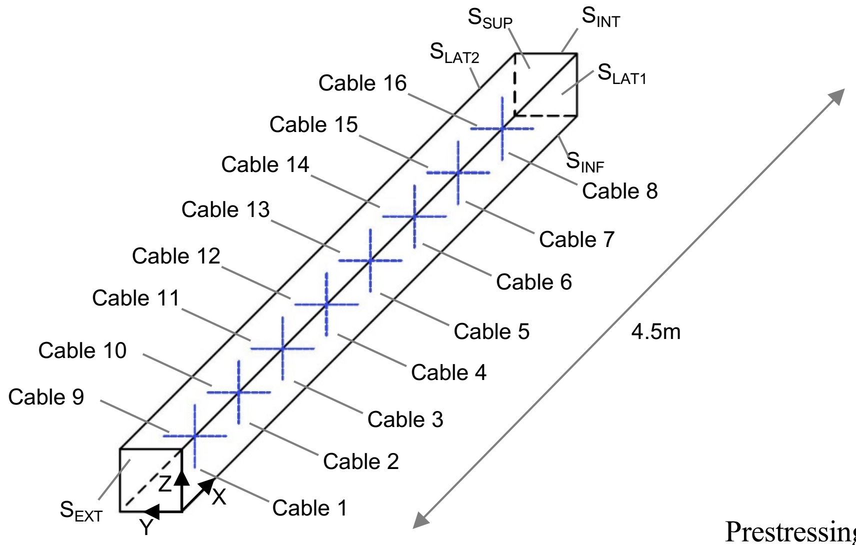
Results obtained by the "Confinement-dependent Method" (γ=2.63)

Application: AGR Concrete Containment Vessel

Typical PCPV geometry



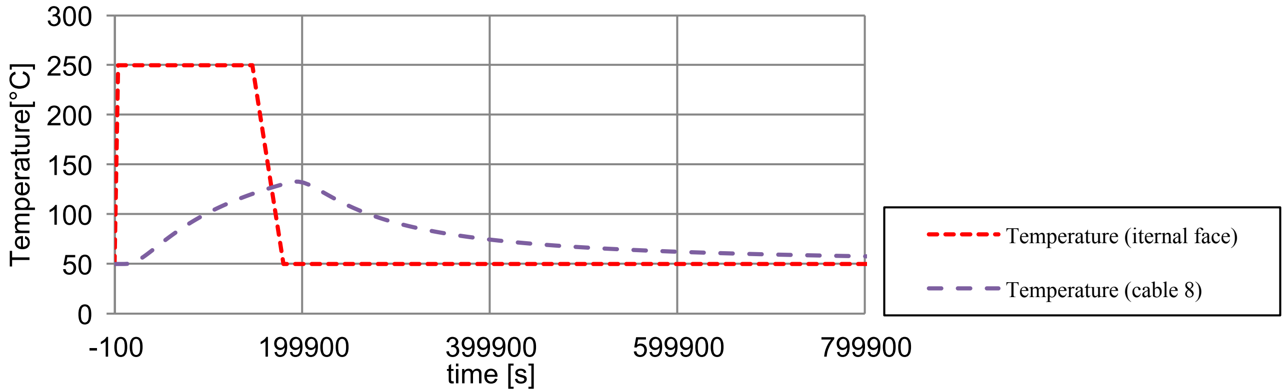
Studied representative portion



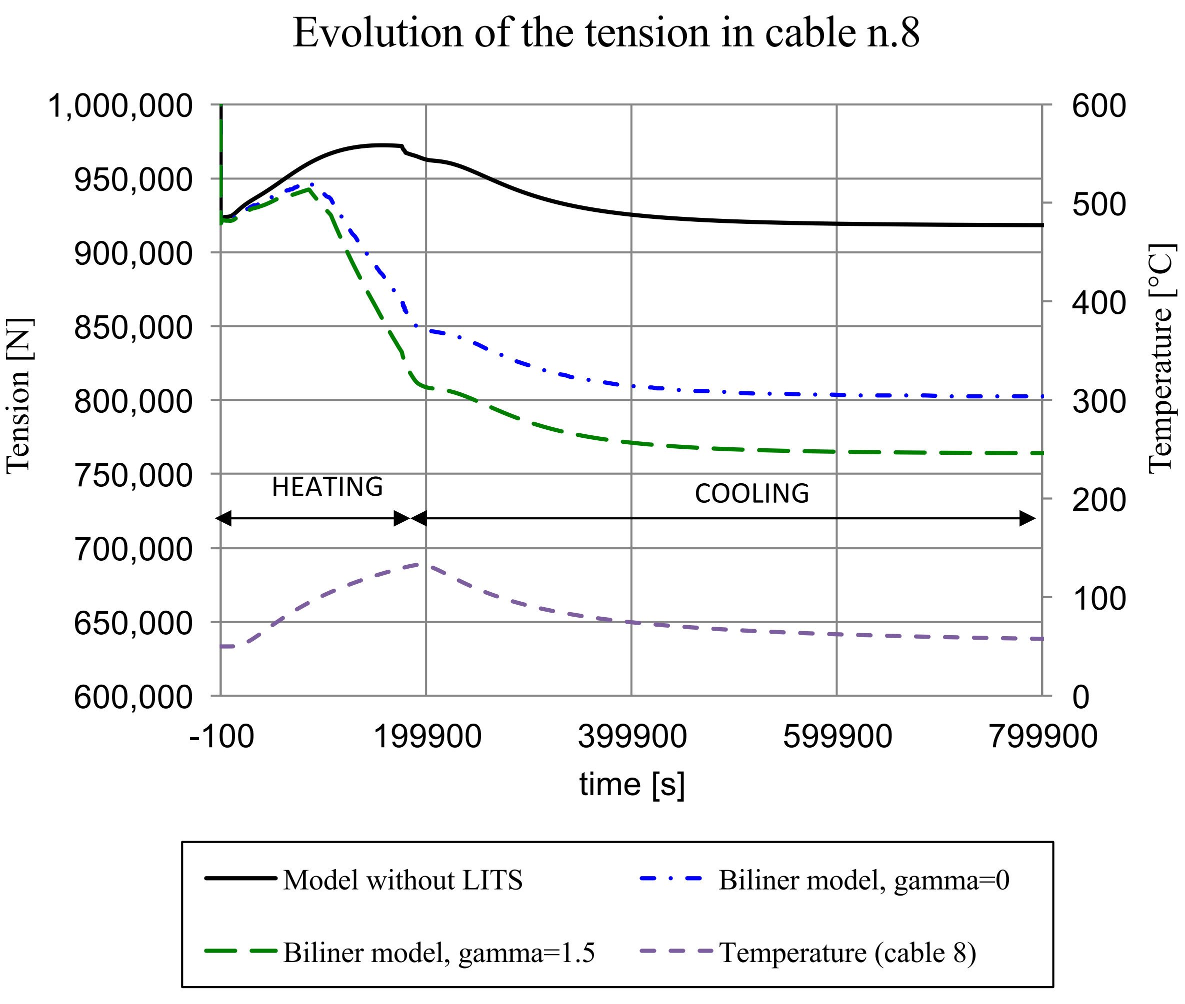
Prestressing system:

- 8 vertical tendons
- 8 horizontal tendons

Considered design scenario: fault of the cooling system



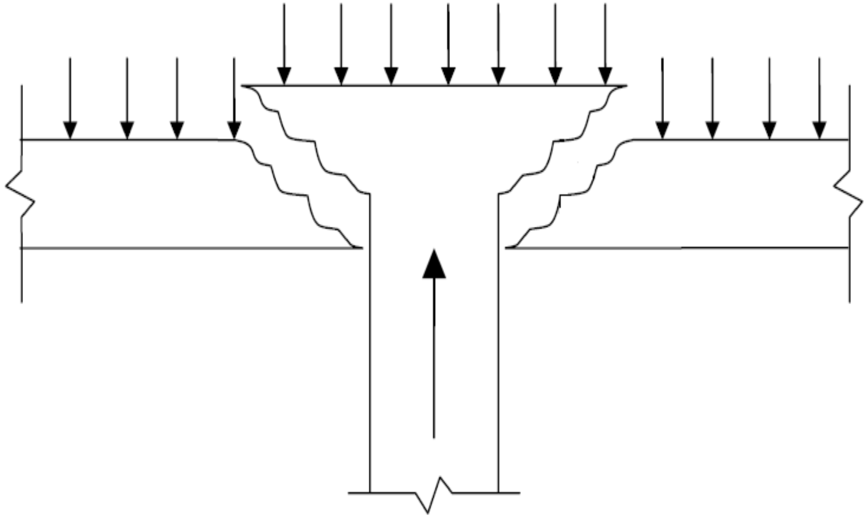
Loss of prestress in Pressure Vessel



LOSS IN PRETENSION
16.80%

MANCHESTER 1824
The University of Manchester

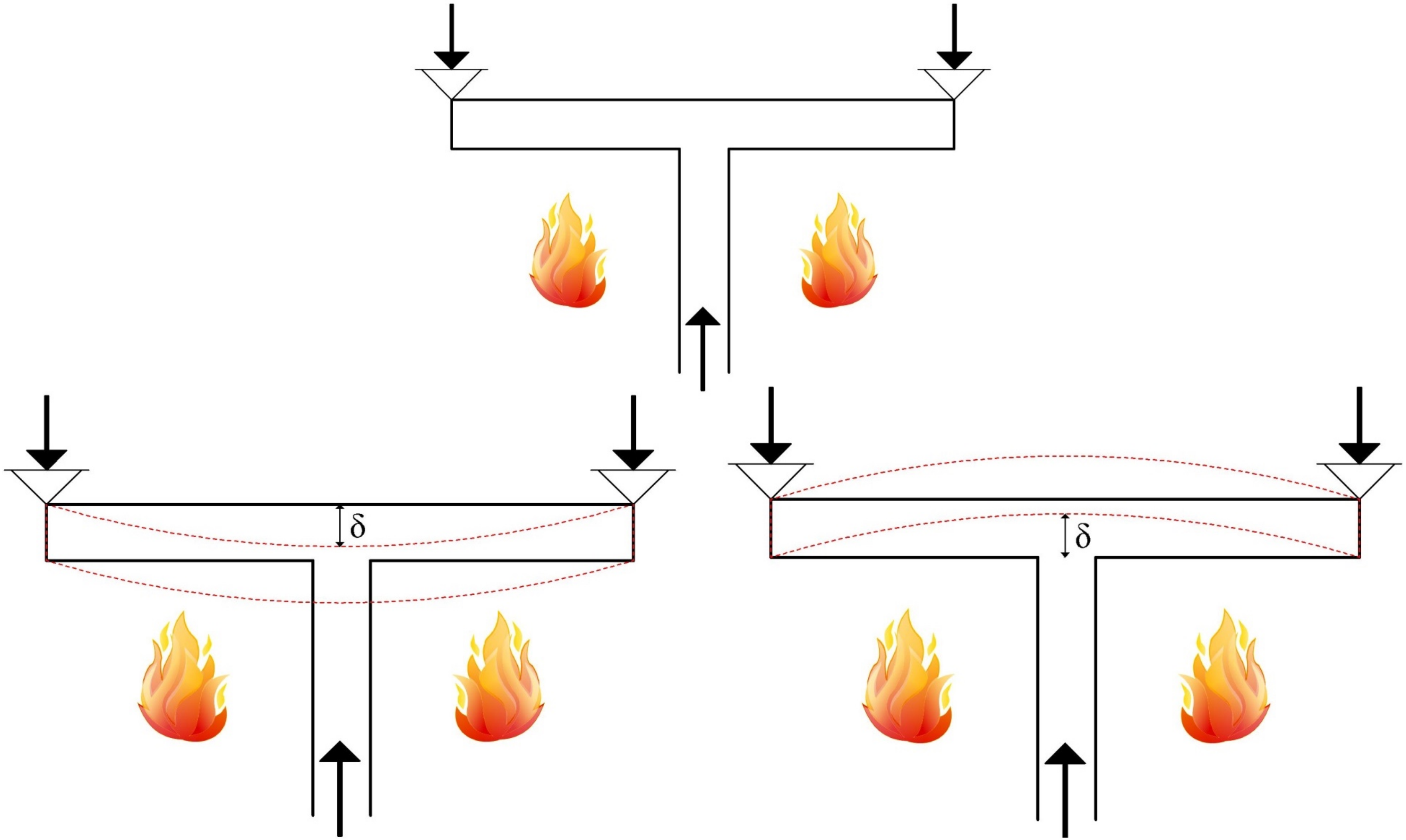
Introduction



Piper's Row Car Park, Wolverhampton, UK, 1997 (built in 1965).

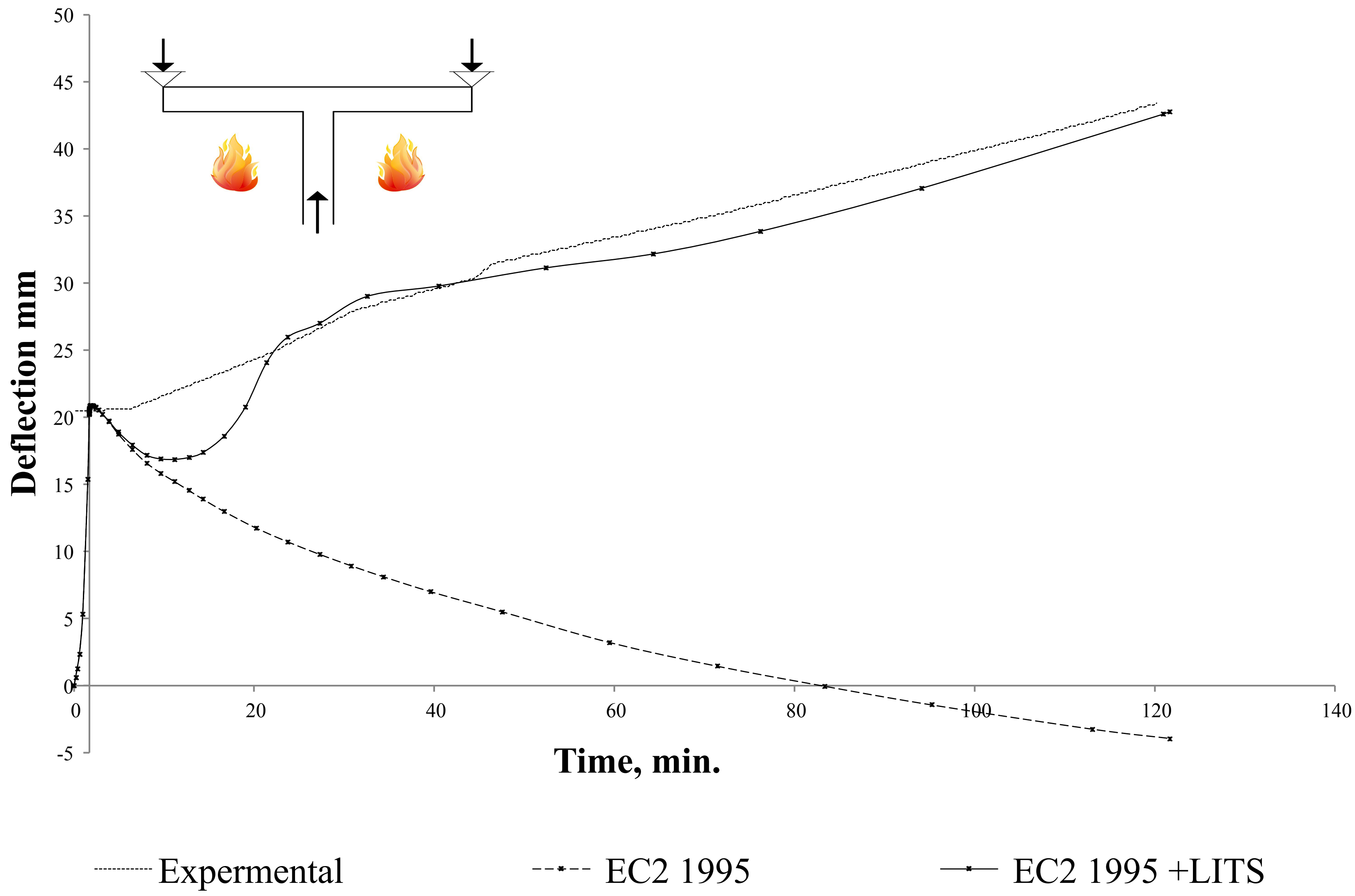
Experimental tests

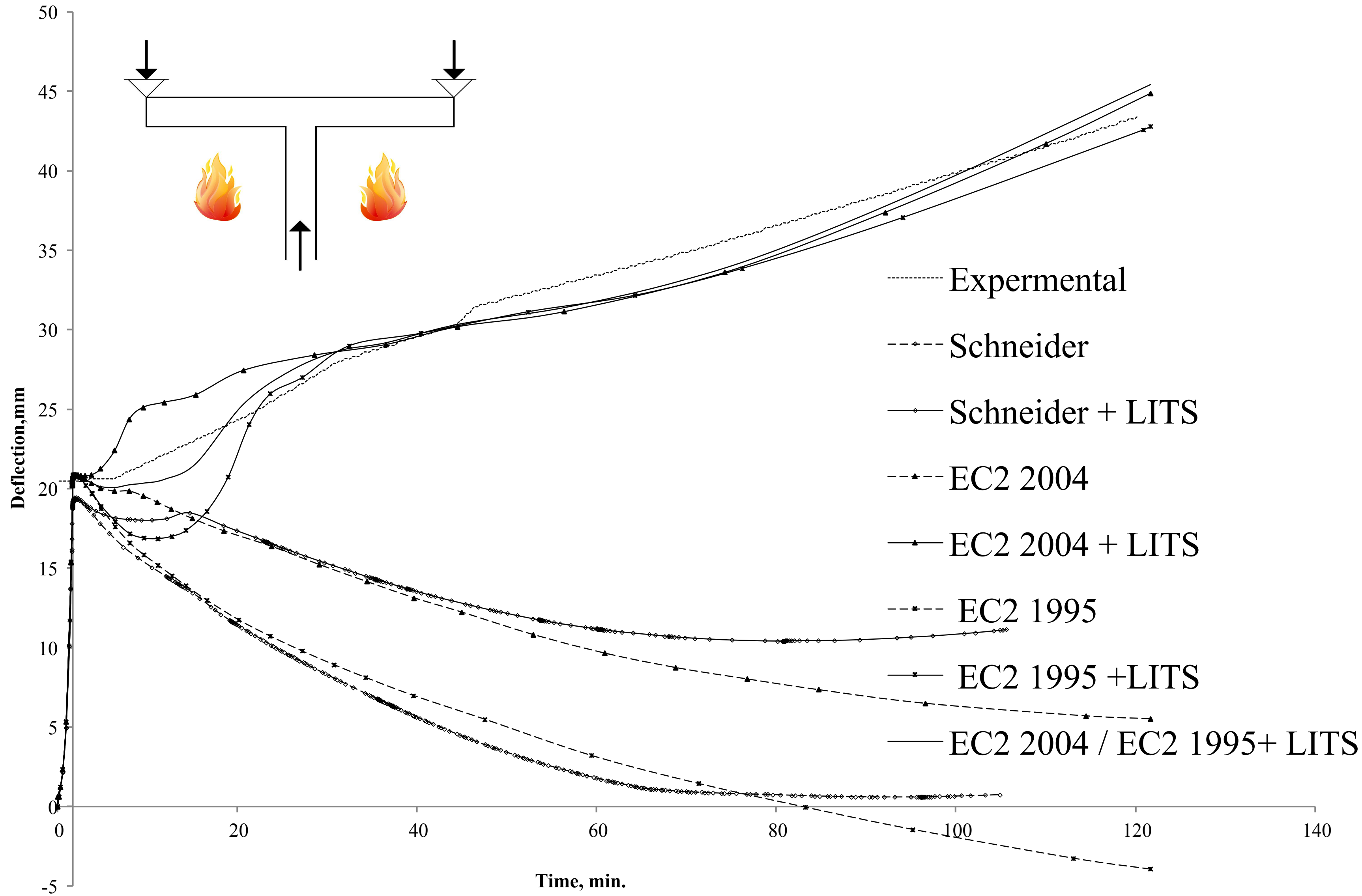
Smith et al. and Liao et al.



What was expected

What actually happened


Deflection mm
50
45
40
35
30
25
20
15
10
5
0
-5
0
20
40
60
80
100
120
140
Time, min.
Expermental
EC2 1995
EC2 1995 +LITS


50
45
40
35
30
25
20
15
10
5
0
-5
Deflection,mm
0
20
40
60
80
100
120
140
Time, min.
Expermental
Schneider
Schneider + LITS
EC2 2004
EC2 2004 + LITS
EC2 1995
EC2 1995 +LITS
EC2 2004 / EC2 1995+ LITS