Msikaba Bridge

Concrete mix design development for ladder deck

Background

- 580m span cable stay bridge
- Initial focus was thermal effects on large foundations during curing.
  - 4 gravity Anchors 50x10x17 each
  - 4 Pylon bases 12x12x8 each
- The ladder deck, at 3m x 2m cross section was comparatively insignificant…

Ladder deck – The Challenge

- 24m long deck with two edge beams
- Large axial compression & bending due to cables
- Very congested – 3 layers Y40@150
- Restricted – end is encased in steel box with dense rebar to transfer steel deck box axial load to deck
- Previous history with mix design constituents where in under certain conditions fresh concrete appears to undergo a type of flash set

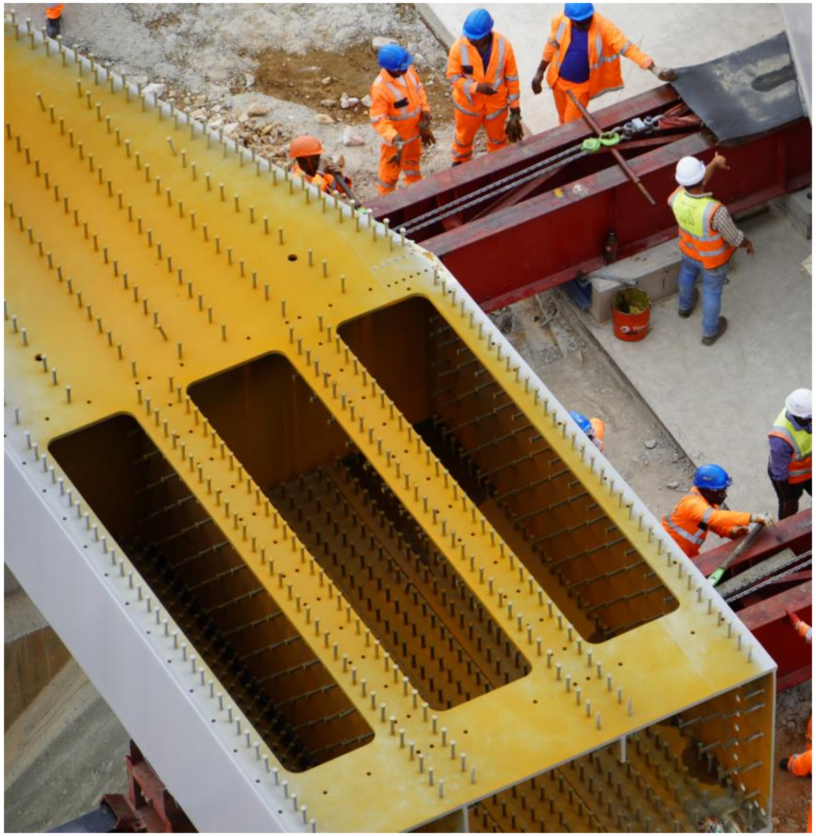
Ladder deck – Thermal

- Specification:
  - 65 MPa
  - 85/15 OPC/GGBS: ☑ strength, ✕ thermal
  - Maximum T 70°C during curing
  - Maximum ΔT 22°C between inside and outside

Rebar Congestion

Add rebar photos in box

Rebar congestion in ladder deck into steel box girders



Ladder deck - Solutions

- 7 different mix designs trialed, focusing on:
  - Workability (SCC type properties)
  - Strength
  - Mitigating thermal effects

Ladder deck - Solutions

- Changed 19mm coarse aggregate to a 14mm due to congestion.
- Concerns during trials of early set properties
- Designed for slump of 210mm, but early mix designs set after 15 minutes
- Final 65MPa required 535kg/m^3 binder and changed testing to 56d to address slower strength gain

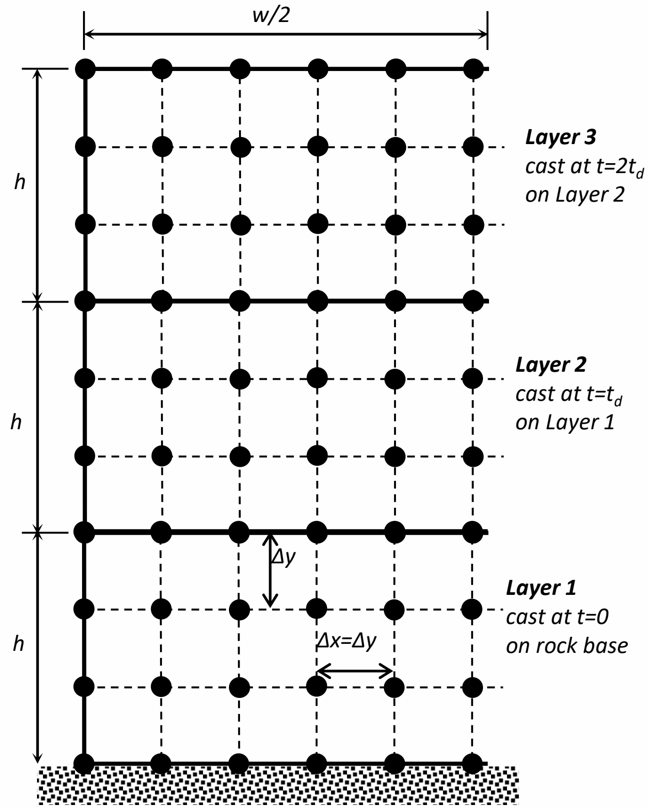
Ladder deck – Thermal Solutions

- To reduce thermal effects the following were evaluated:
  - Reduced input temperature (aggregate and water)
  - Plumbing to cool curing concrete
  - Insulation
  - Splitting pour
  - Modifying mix design to reduce temperatures
- Increasing GGBS lowered temperatures, but slowed rate of strength gain.

Ladder deck – Thermal Solutions

- Wits temperature model developed by Professor Ballim (2004).
- Finite Difference Method to solve for heat flow.
- Predicts time-temperature profile for 2D elements.

Finite difference model approach



Solve 2-D Fourier Equation:

$$\rho \cdot C_p \cdot \frac{\partial T}{\partial t} = k\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) + \frac{\partial q}{\partial t}$$

Boundary Conditions:

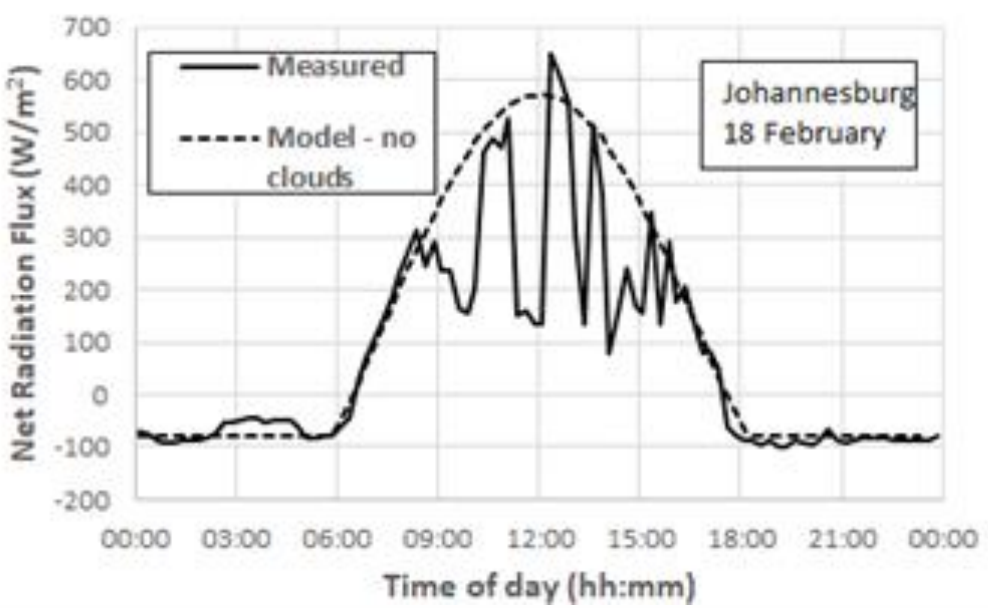
- 1st layer cast on rock
- Side surfaces with steel or timber formwork
- Varying diurnal ambient temperature
- Top surface exposed to air and solar radiation
- Long-wave exit radiation at night

Note use of maturity heat rate $\frac{\partial q}{\partial M}$

System taken as symmetrical about vertical axis – analyse left half of concrete layers

Net solar radiation as a boundary condition

Radiation on a horizontal surface Johannesburg, February



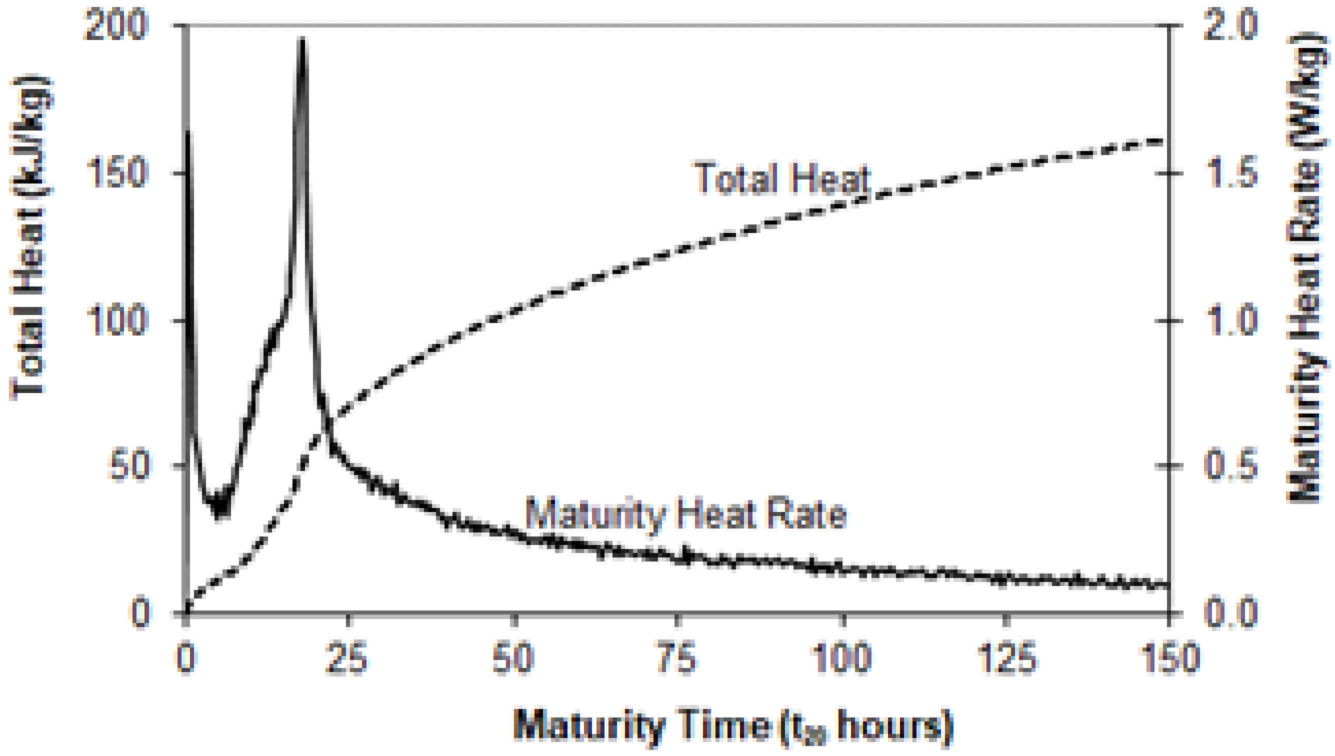
For $t_{d,am}<t_d<t_{d,pm}$:
$$R_n = A + B\cos(C.t_d + D)$$

For $t_d<t_{d,am}$ and $t_d>t_{d,pm}$:
$$R_n = -80\ W/m^2$$

Note: Sinusoidal variation in ambient temperature between likely maximum and minimum Daytime temperatures

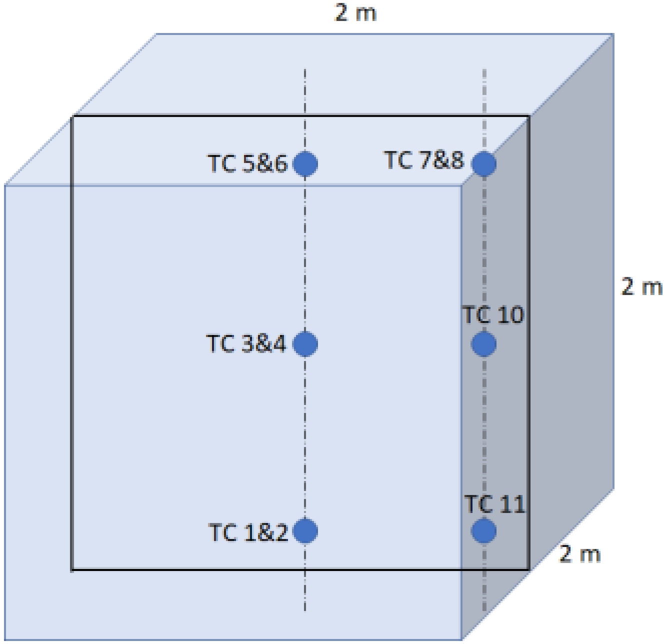
Maturity heat rate for Fourier Equation

(measured in WITS University adiabatic calorimeter for the proposed concrete materials and mixture design)



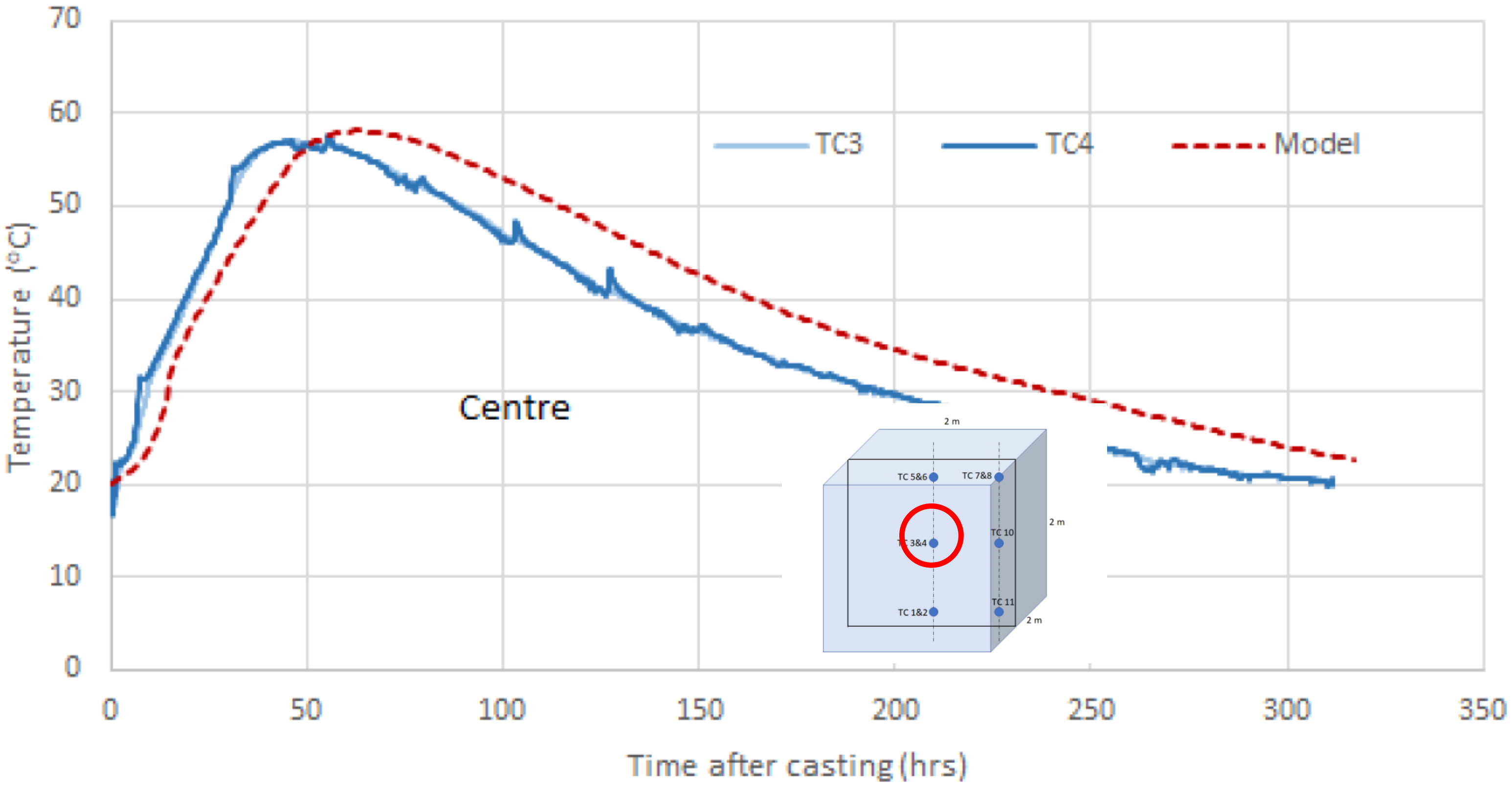
Ladder deck – Thermal Solutions

- How do you know your results are correct?



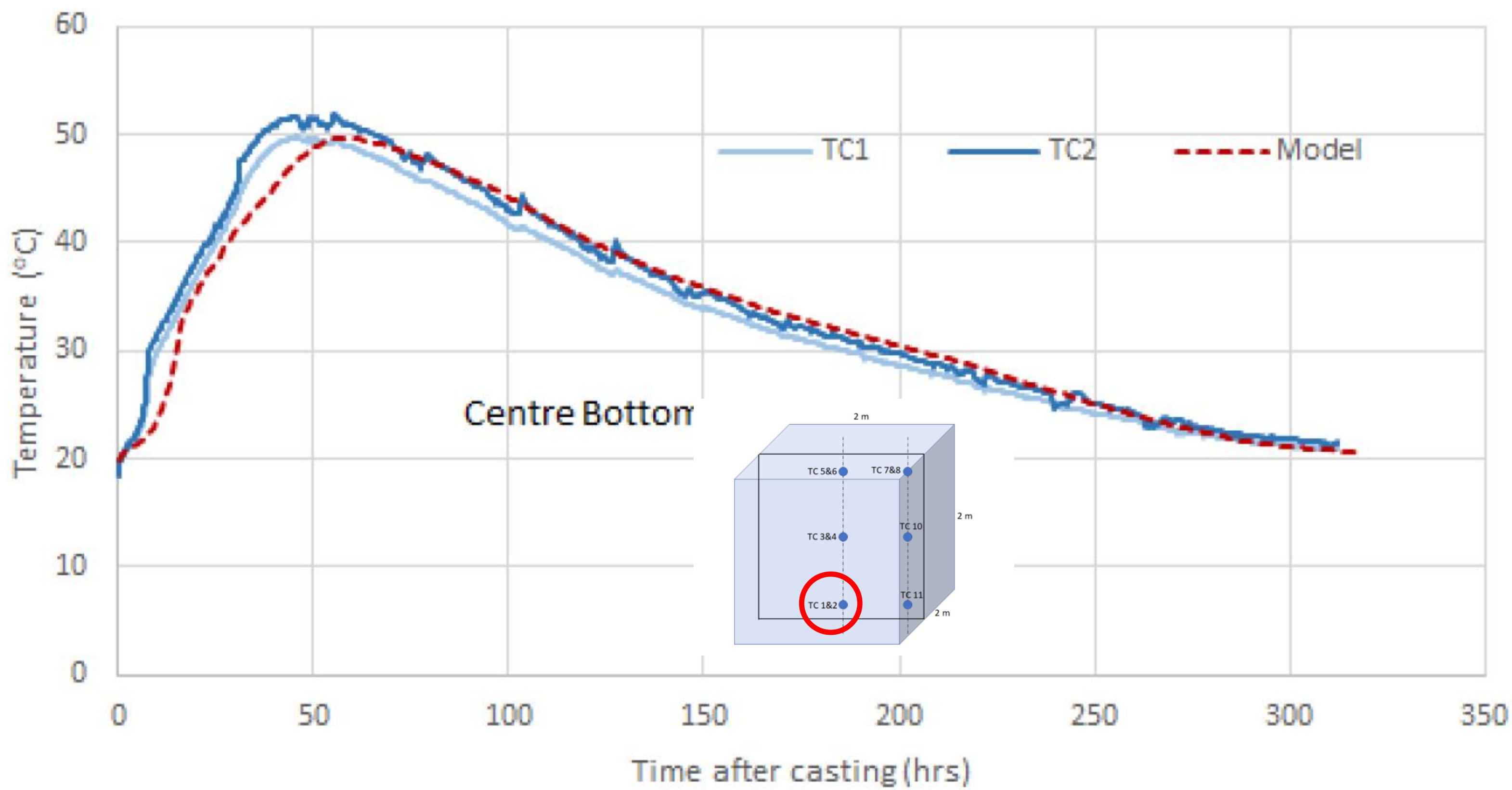
Ladder deck – Thermal Solutions

- In-situ testing: Centre



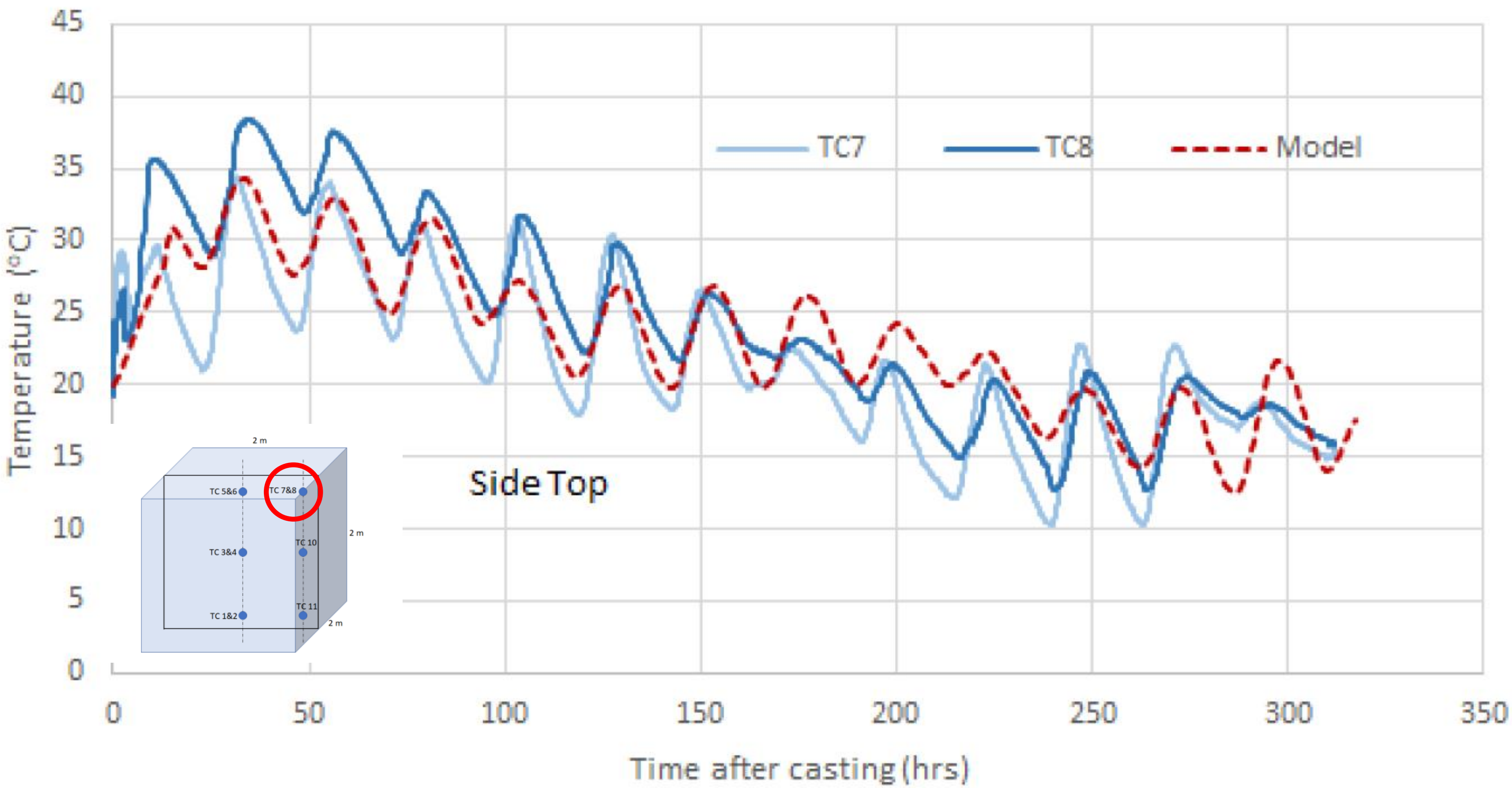
Ladder deck – Thermal Solutions

- In-situ testing: Centre Bottom



Ladder deck – Thermal Solutions

- In-situ testing: Side Top



Ladder deck – Thermal Solutions

- In-situ testing

Position	Model	Trial Block	Difference
Centre-Bottom	50 °C	52 °C	-2 °C
Centre-Centre	58 °C	57 °C	+1°C
Centre-Top	42 °C	43 °C	-1 °C
Side-Top	35 °C	38 °C	-3 °C
Side Middle	40 °C	44 °C	-4 °C
Side Bottom	35 °C	42 °C	-7 °C

Ladder deck – Thermal Solutions

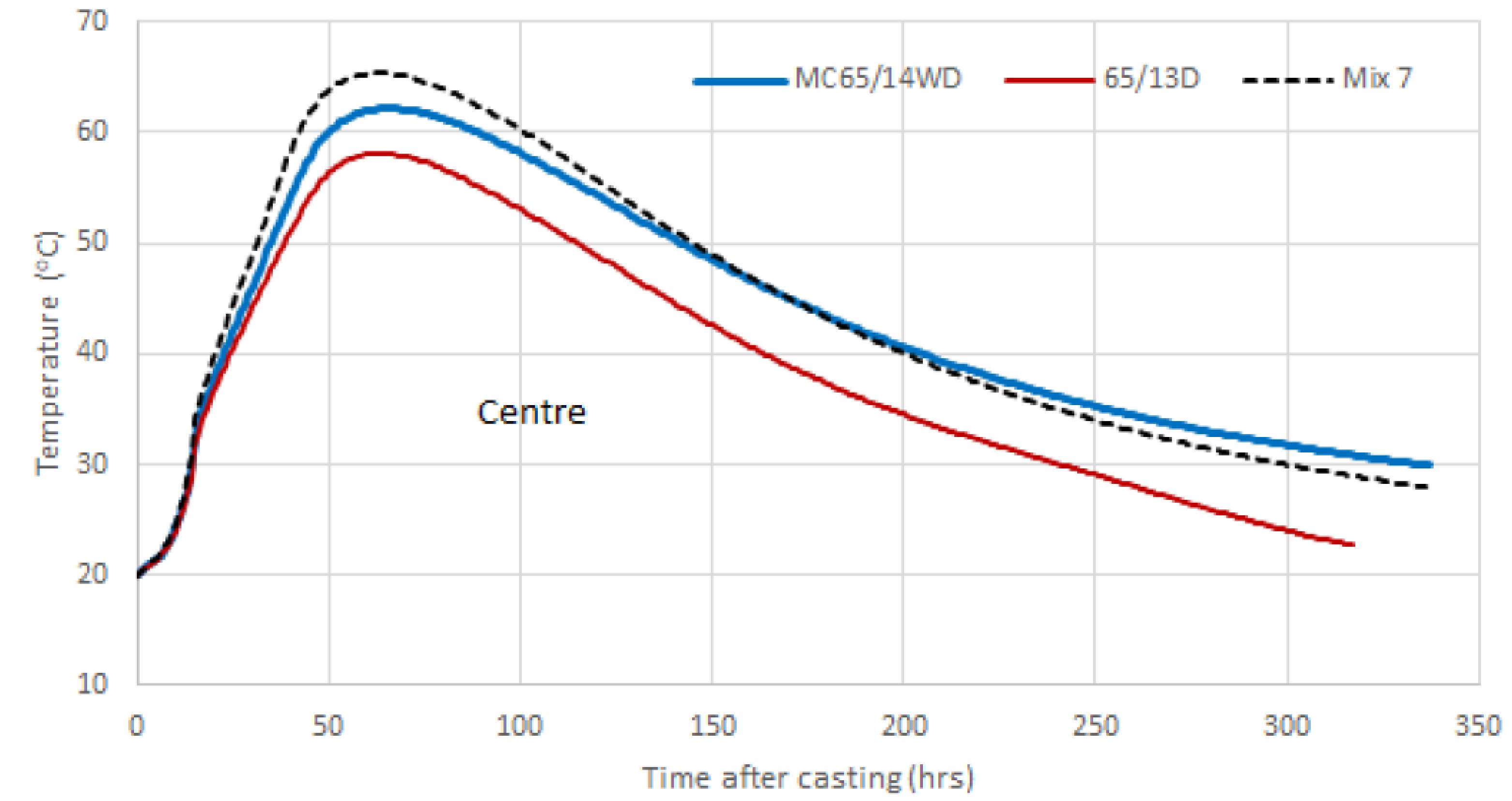
- Mix design met project spec but required adjustments.
- New mix required re-evaluation.

Ladder deck – Thermal Solutions

- Initial mix design met project spec but required adjustments.
- New mix required re-evaluation.
- ~10% increase in binder.

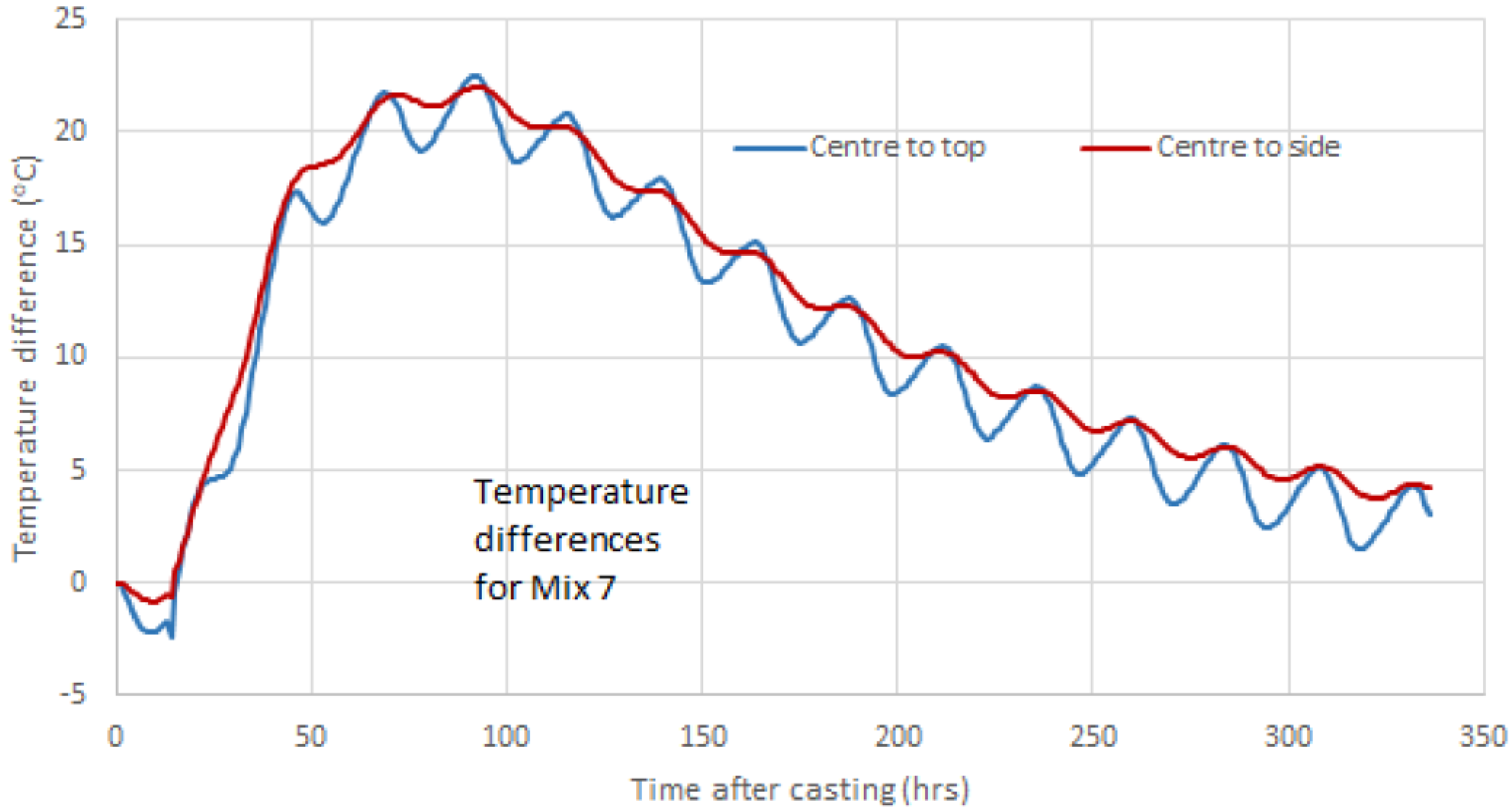
Ladder deck – Thermal Solutions

- Mix comparison results



Ladder deck – Thermal Solutions

- Differential



Ladder deck – Thermal Solutions

- Peak below 67 °C (< 70°C)
- Differential 22° C (≮ 20°C)
- Early-age thermal strains acceptable.