COMSOL CONFERENCE 2018 LAUSANNE

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Solar radiation effects on the epoxy adhesive temperature used to bond CFRP to concrete road bridges

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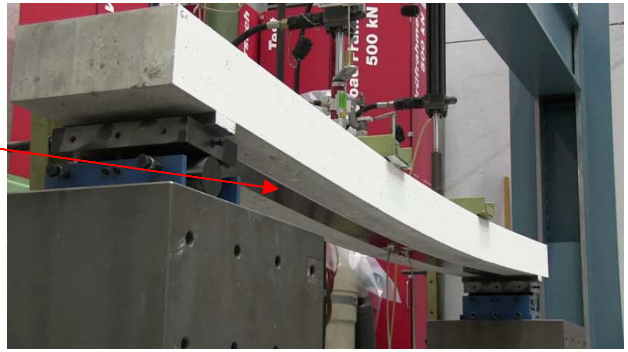
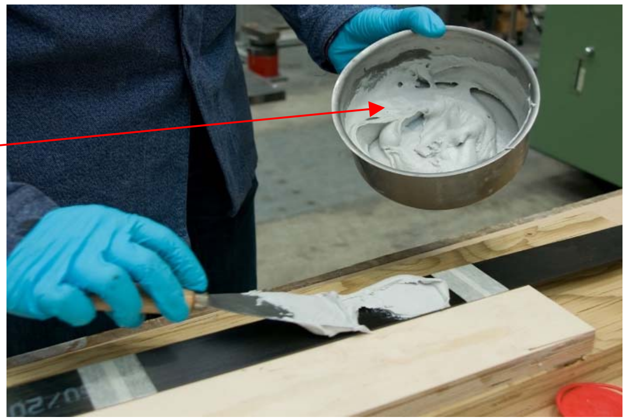
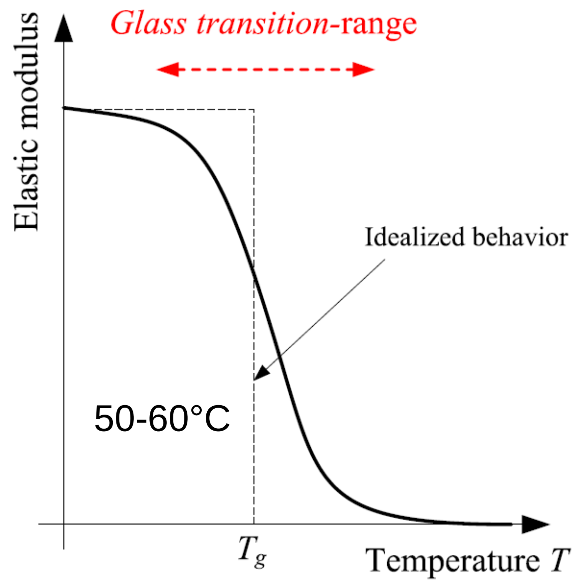
Carbon fiber polymers (CFRP) strengthening of concrete structures

CFRP strip



Epoxy-based adhesive





Michels et al. Comp.PartB 77 (2015)

Research significance:

Understanding and improving the long-term behavior of CFRP strengthened structures

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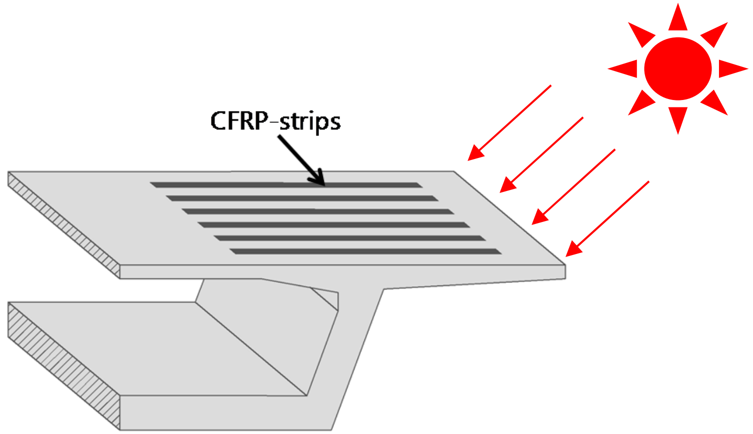
https://erkrishneelram.files.wordpress.com/2015/03/box-girder-bridge.png



CFRP strengthening of hollow box girder bridge decks: a critical scenario

Two different modeling approaches to calculate the temperature in the adhesive layer, and thermal stress in the CFRP:

Full domain approach and *Lumped boundary approach.*

Experimental tests: Dübendorf (CH)

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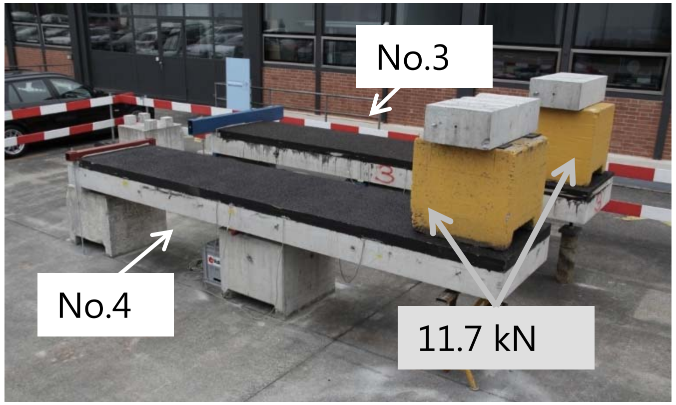

Non-prestressed strips / Asphalt layer

Test No.3 Loaded since September 2015
Test No.4 Loaded since March 2016

Prestressed strips + Gradient Anchorage
Epoxy protective layer

Test No.6 (Prestressing strain 0.5%)
Loaded since June 2016

Monitored data: Air temperature, Humidity, Epoxy-adhesive temperature, Asphalt temperature, CFRP strain, Solar radiation

Strip debonding in August 2018

Problem definition and governing equations

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The numerical model was implemented in COMSOL Multiphysics® software by using the Heat Transfer with Surface-to-Surface Radiation and the Structural Mechanics modules.

$$\rho C_P \frac{\partial T}{\partial t} + \nabla \mathrm{q} = 0, \qquad with\ q = -k\nabla T$$

$$T = T_0$$

$$-k\frac{\partial T}{\partial n} + q_c + q_r = 0$$

$$\nabla \sigma = F_v$$

$$\sigma = \sigma = \boldsymbol{C}\,(E,\nu): \varepsilon_{el} = \boldsymbol{C}\,(E,\nu): (\varepsilon - \varepsilon_{th})$$

$$\varepsilon_{th} = \alpha(T - T_{ref})$$

Temperature in the cross section

↓

One way copuled problem

↓

Thermally induced stress

Heat transfer at the boundary:
Surface radiation and convective heat flux

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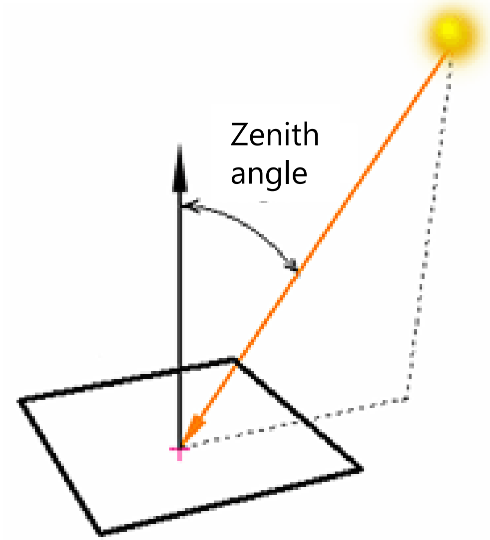
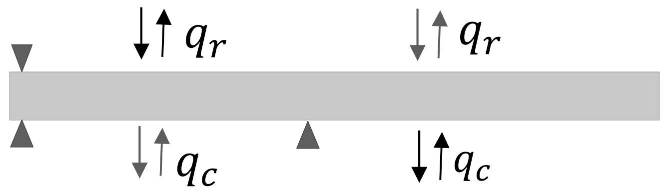
$$-k\frac{\partial T}{\partial n} + q_c + q_r = 0$$



https://www.cibsejournal.com/cpd/modules/2013-07/

ASHRAE climatic design condition



Surface radiation

$$q_r = \sum_{i=1}^{2} \varepsilon_{\lambda i}\left(G_{\lambda i} - e_{b,\lambda i}(T)\cdot FEP_{\lambda i}(T)\right)$$

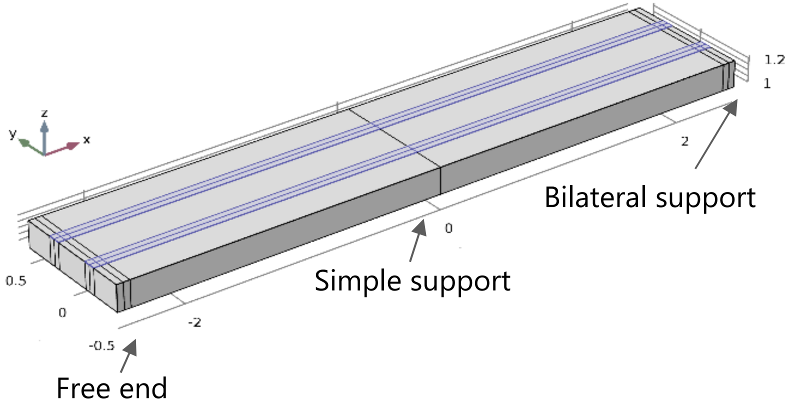
$$G_{\lambda i} = G_{\lambda i,amb} + G_{\lambda i.ext}$$

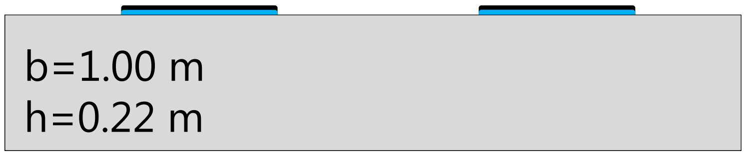
Ambient radiation — Solar radiation

Convective heat flux

$$q_c = h(T_{ext} - T)$$

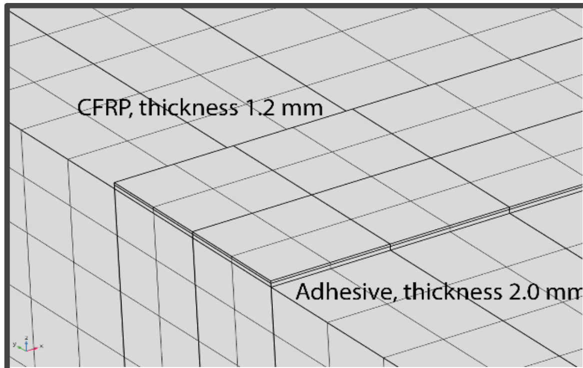
COMSOL Multiphysics® model





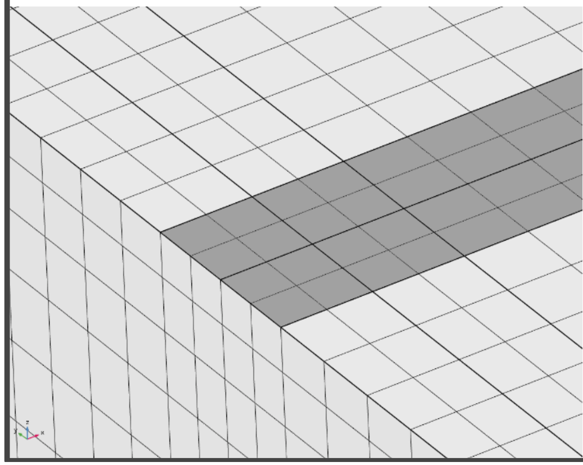
CFRP: 1.2mm x 100 mm
Adhesive Thickness: ~2mm

CFRP and adhesive have a high geometrical aspect-ratio



Full domain approach:

Accurately reproduces the geometry, however, require a fine mesh in order to avoid highly distorted elements.



Lumped boundary approach:

"Thin Layer" approximation in the heat transfer problem, facilitate the meshing procedure.

Lumped boundary approach

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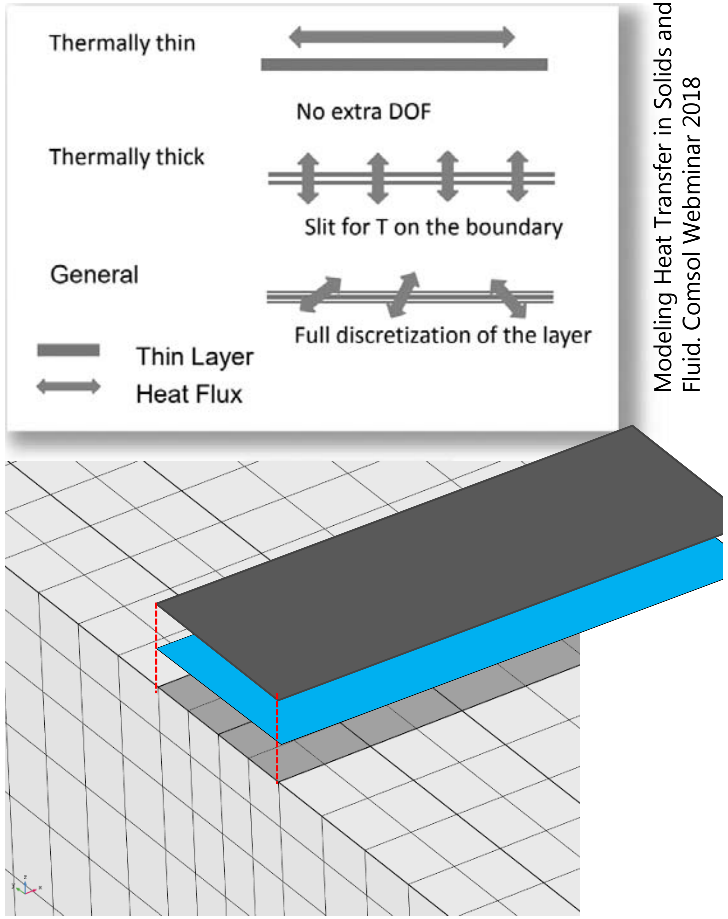
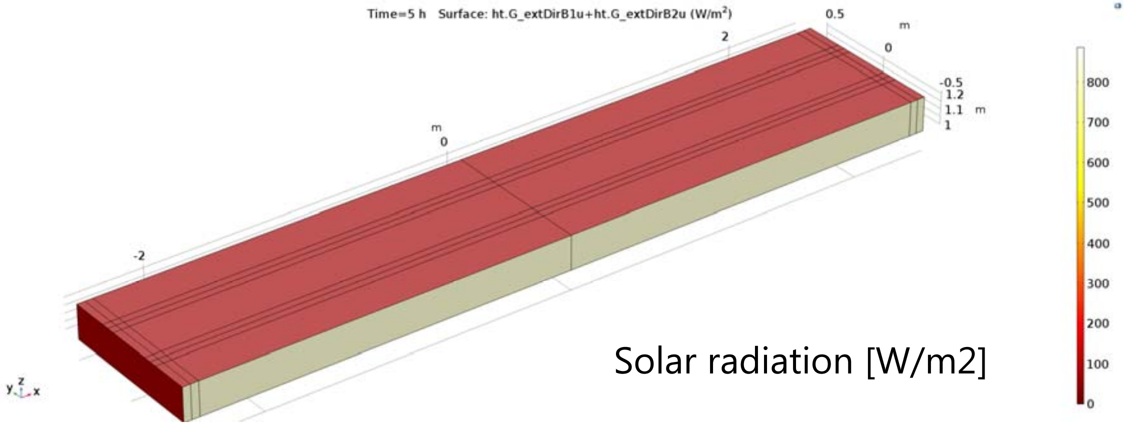
- In the Heat Transfer, the calculation of the conductive heat transfer is performed in an extra dimension, representing the thickness of the element.
- General formulation: allows the solution of the conductive heat transfer problem into the boundaries (tangential direction) and through the thickness (normal direction) of the structure
- In Structural mechanics, CFRP and adhesive are modeled as shell elements.

→ Approximation in the temperature of the shell

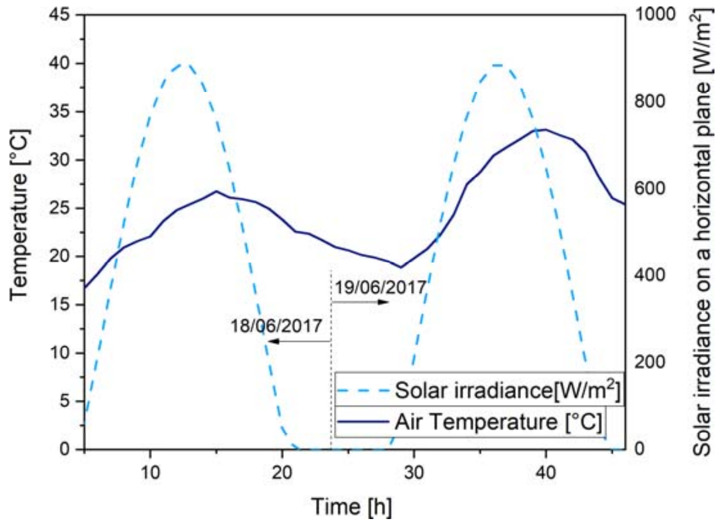


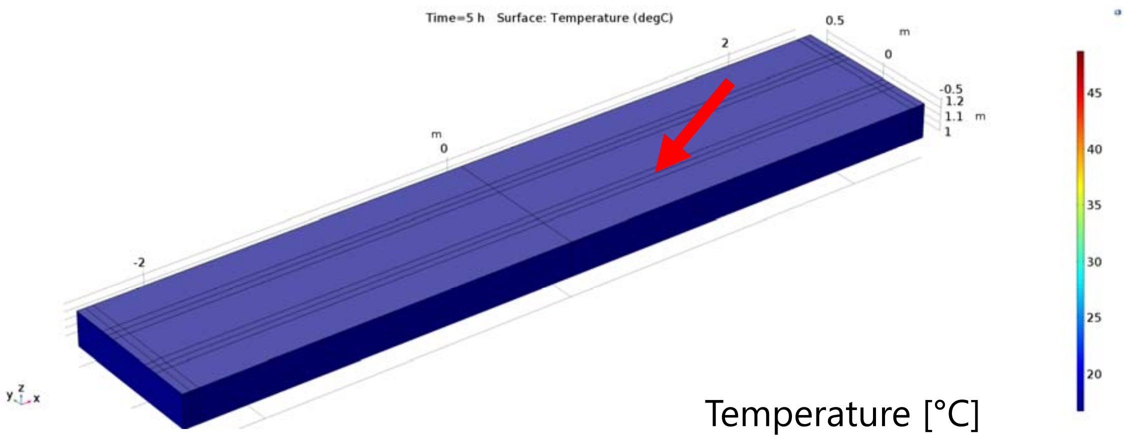
Modeling Heat Transfer in Solids and Fluid. Comsol Webminar 2018

Models results and comparison

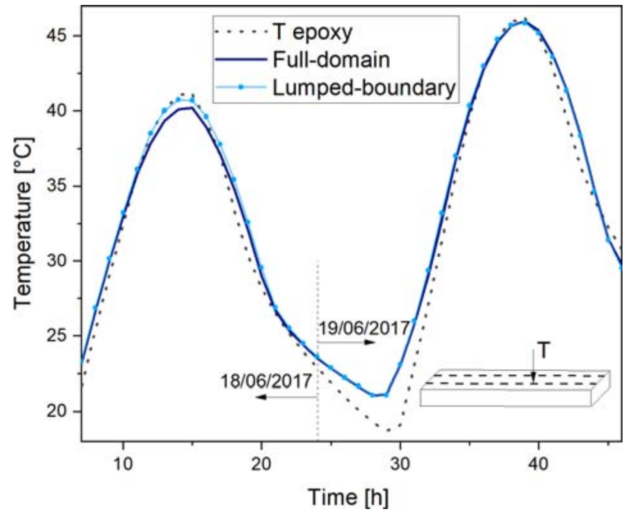


Solar radiation [W/m2]





Temperature [°C]



Temperature profile along the cross-section height

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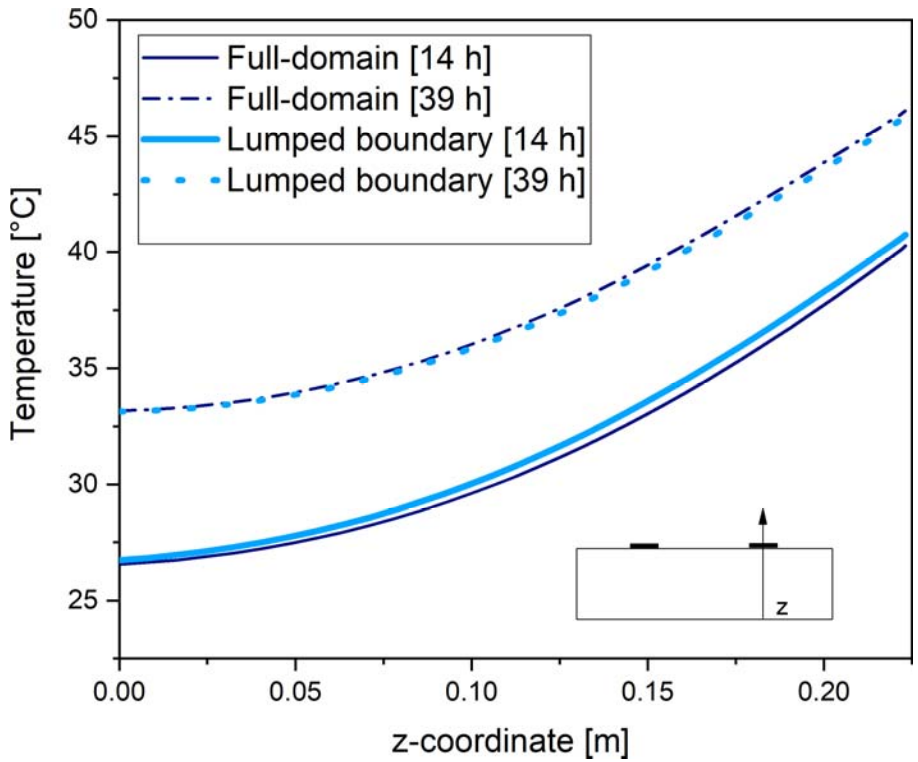
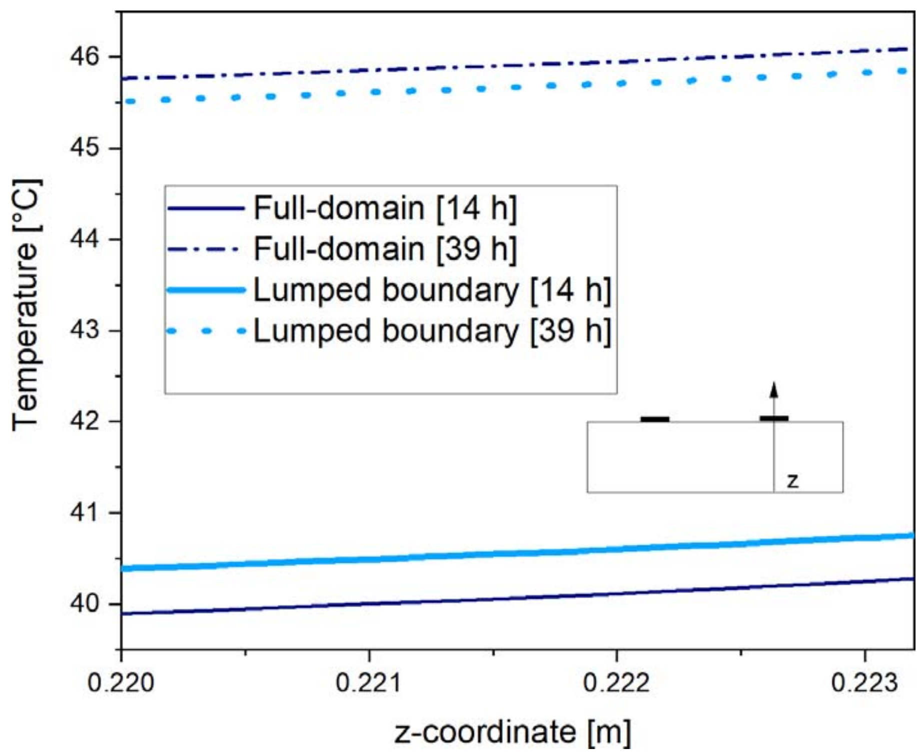
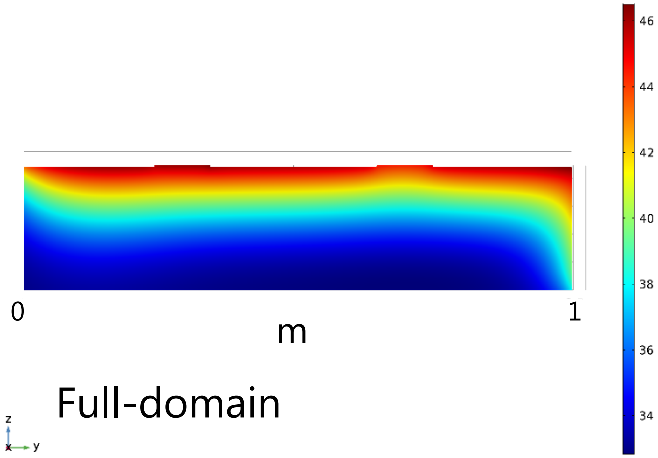
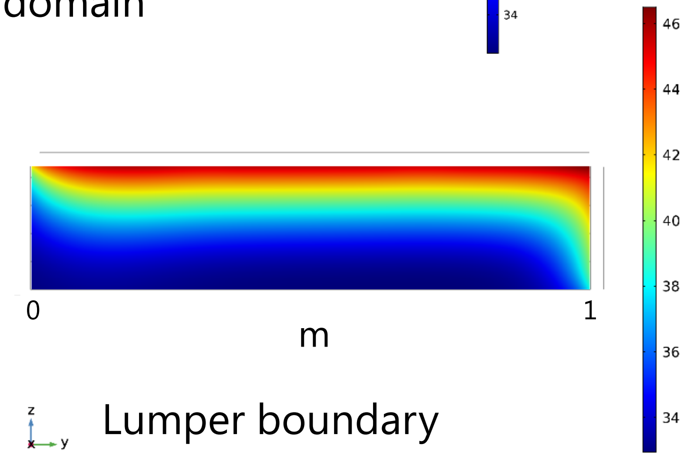
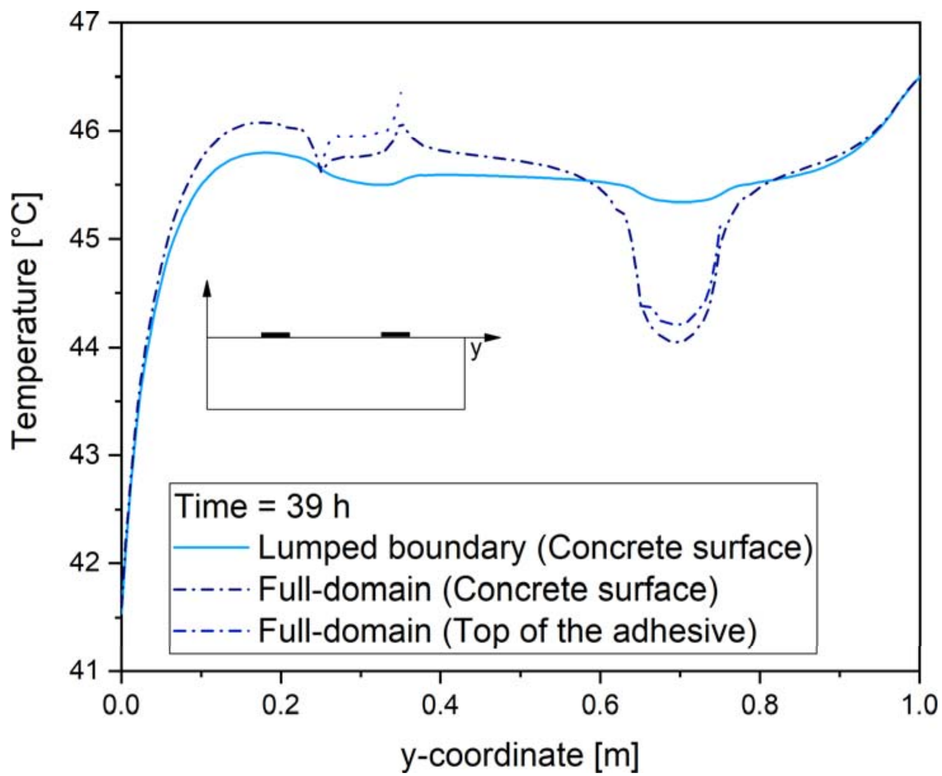




Temperature on the top concrete surface

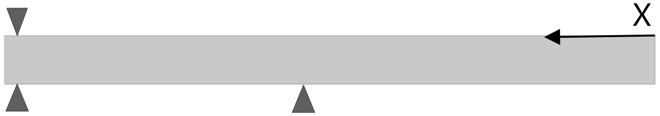




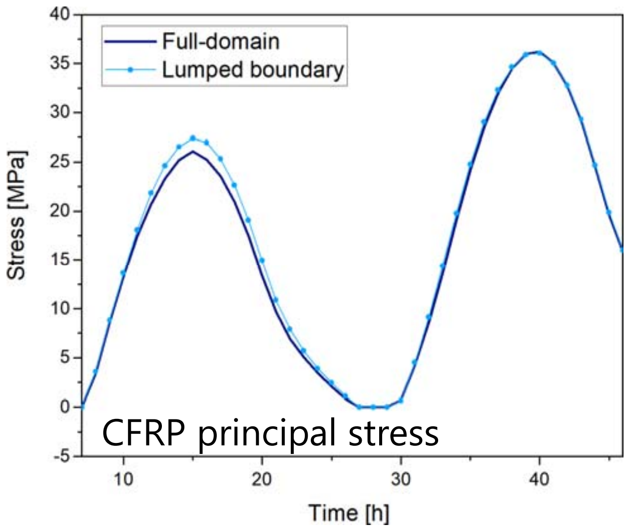


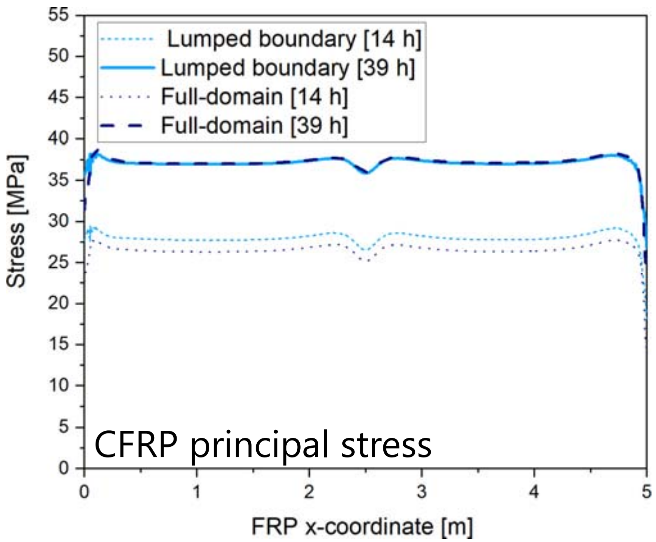
Thermally induced stress

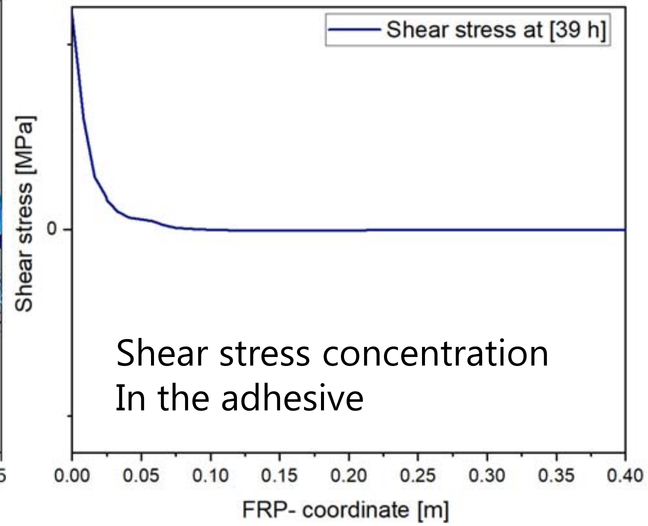
$$\varepsilon_{th} = \alpha(T - T_{ref})$$



$$\alpha_{CFRP}(\sim 0) \neq \alpha_{conc}\ (1x10^{-5}\ °C^{-1})$$







Conclusions and future works

Both models can fit the experimental measurements:

- Accurate results can be obtained with the boundary layer approach.
- The full-domain approach can, however, provide more accurate and detailed results

The thermal stress in the FRP is negligible in comparison to the one typically generated from external loads.

CFRP strengthening faces directly the solar radiation, an additional protective layer or high safety factors might be necessary.

Further studies are needed to evaluate if the thermally generated stresses combined with sustained loads can affect the long-term behavior.

This project is financially supported by the

Bundesamt für Strassen ASTRA, Project AGB 2016/003

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

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