Validation of Models for Structural Steel Cables in Fire

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Cable-bridge fires

2005
Rio-Antirio Bridge
Greece

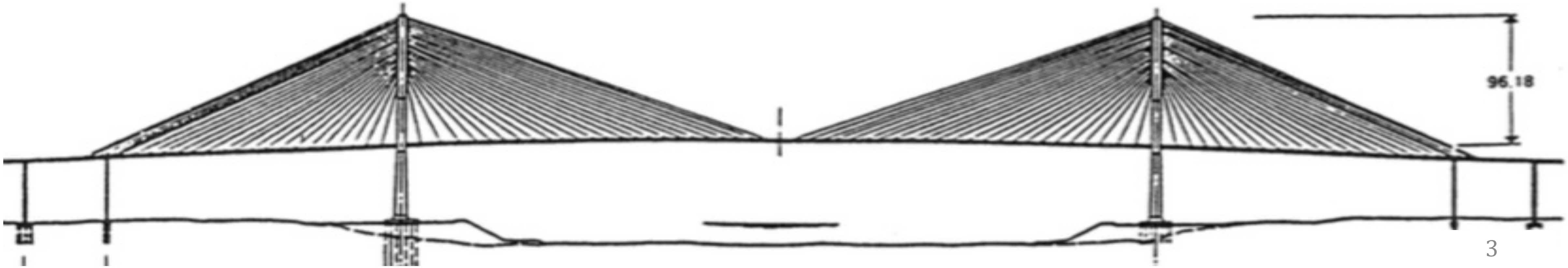
2007
Mezcala Bridge
Mexico

2009
Manhattan Bridge
USA

2011
Russky Bridge
Russia

2012
Brooklyn Bridge
USA

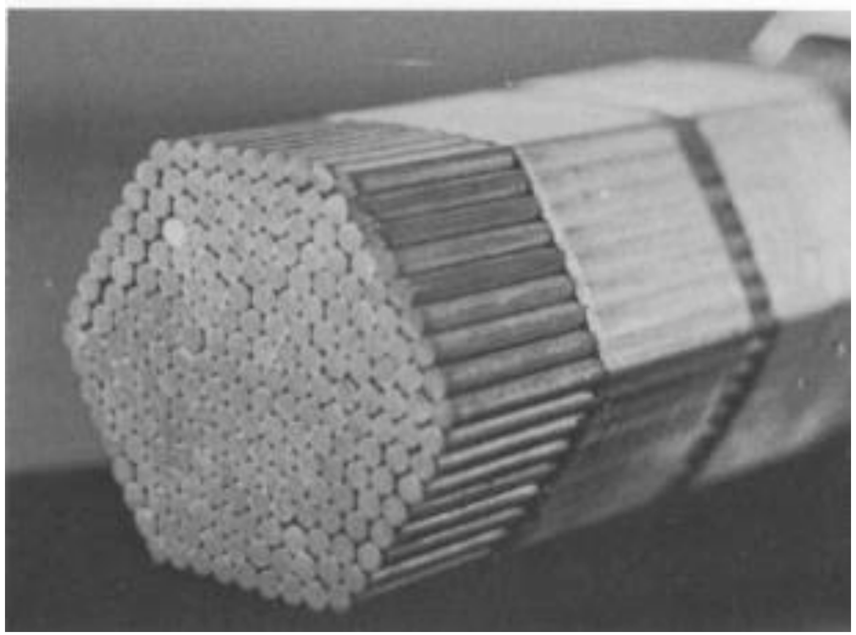
2014
Zakim Bridge
USA



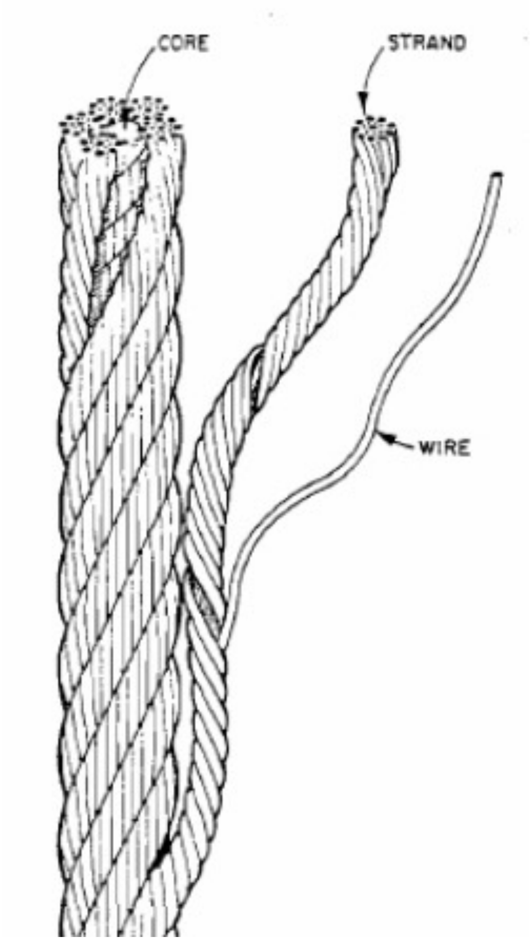
LPG Tanker accident on highway bypass
6th August 2018
Bologna, Italy

Cable Geometries

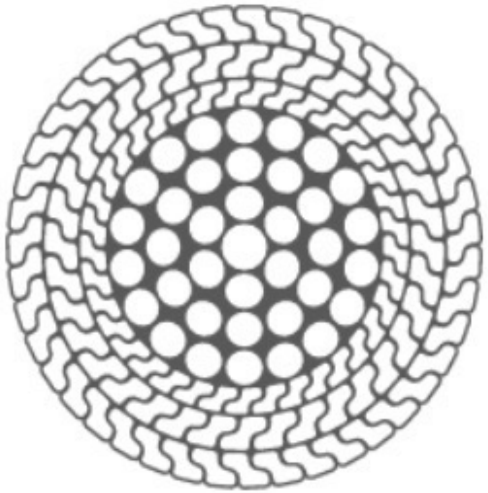
Assembled with High-strength wires cold drawn from carbon steel



Bundle of wires



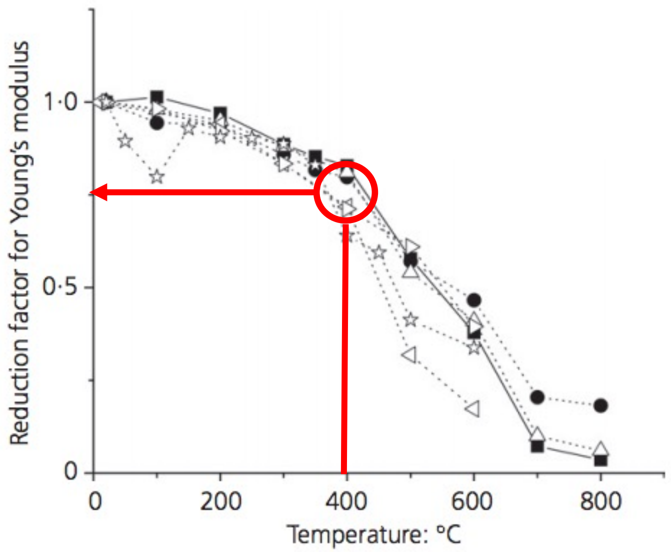
Spiral Strand rope



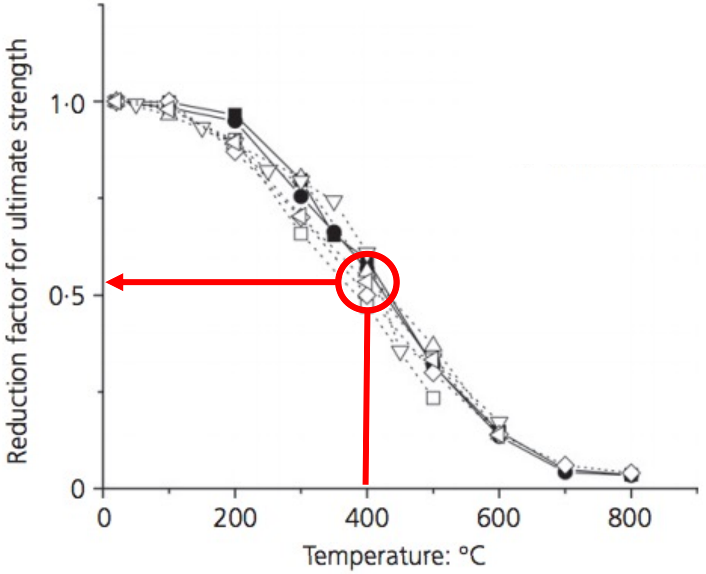
Locked Coil rope

Degradation of Mechanical Properties

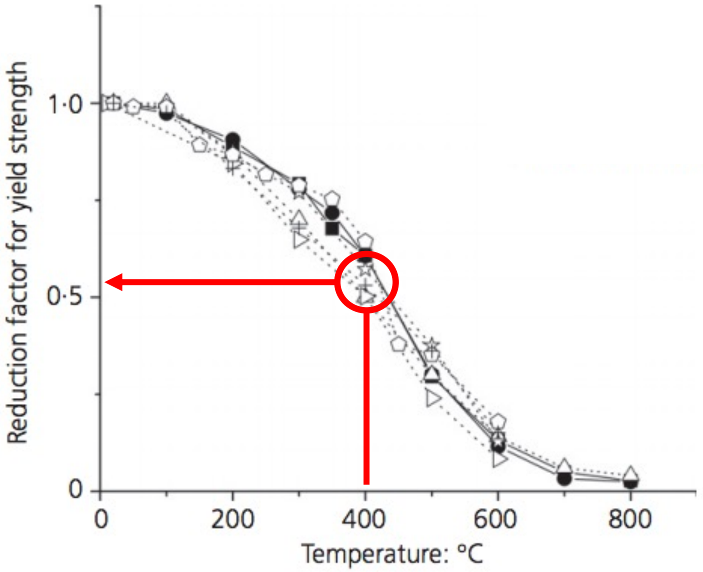
Prestressing steel wires – same manufacturing process



Young's modulus



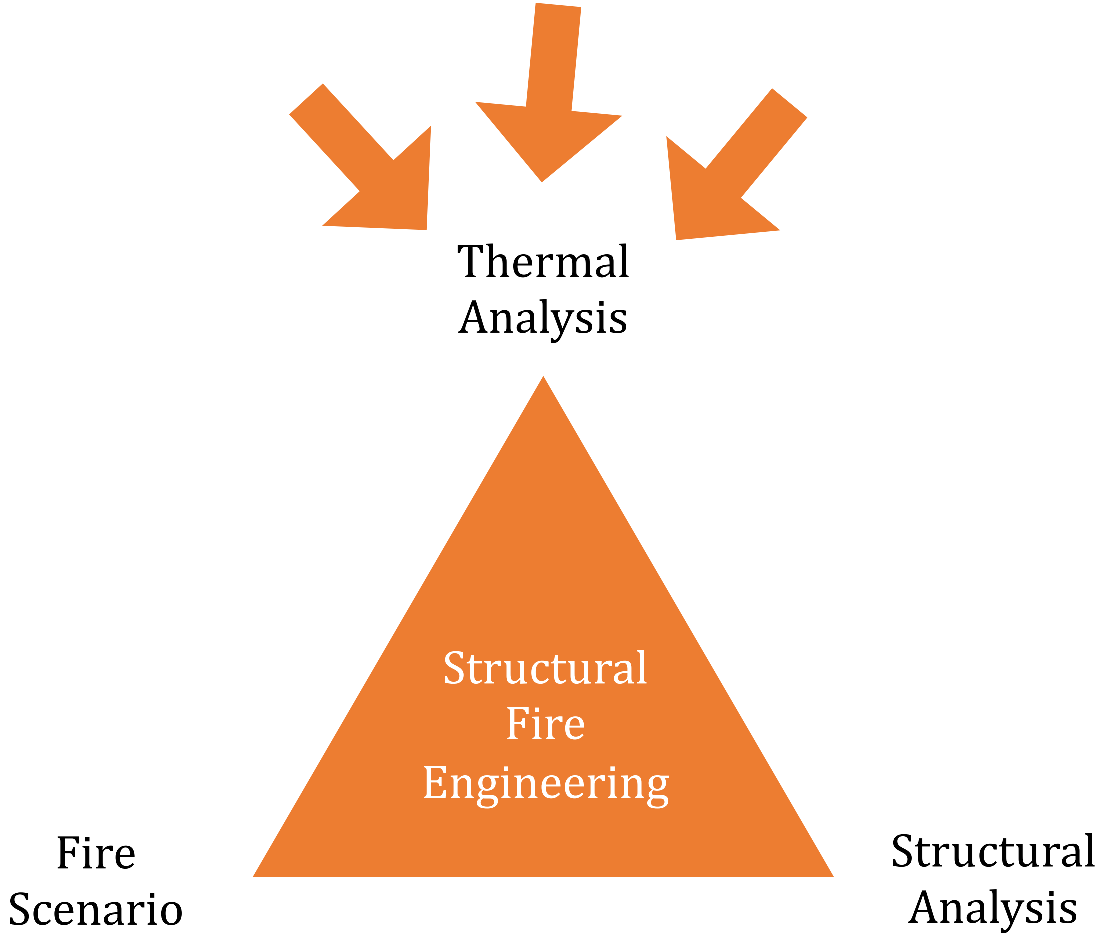
Ultimate strength



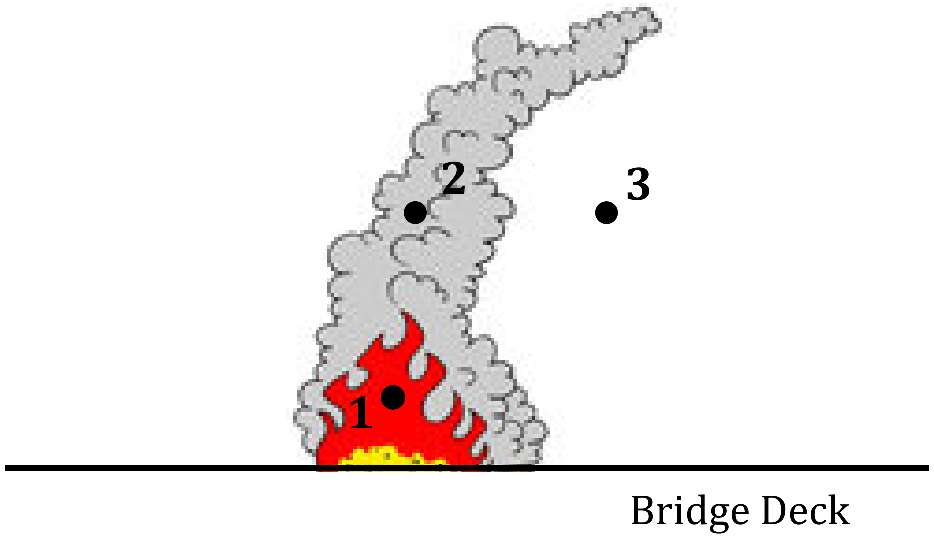
Yield strength

Zhang et al. (2017)

Structures in Fire

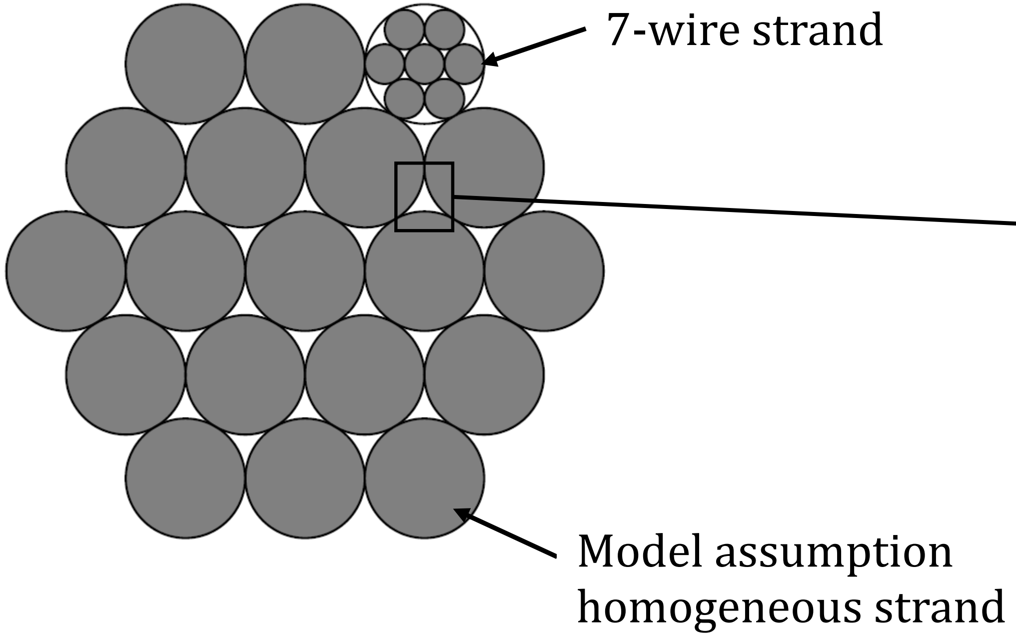


Cable-Fire Scenarios

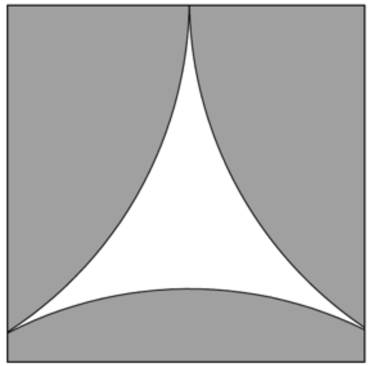


Contact and Air Gap model - Assumptions

Bundle of wires or strands – Lumped NO

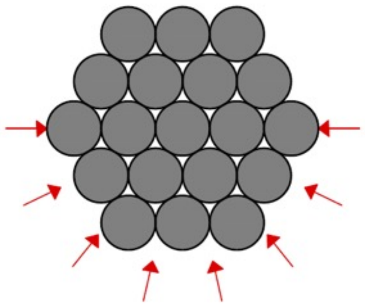


Convection across air cavity neglected
Cavities are small and movement of air is restricted by viscous force.



Contact and air gap model - Boundary

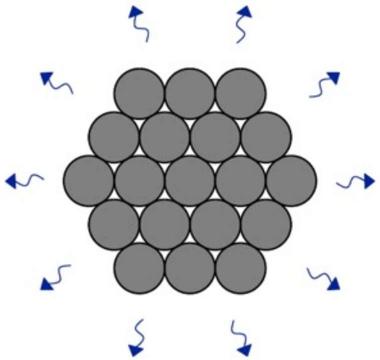
Irradiation



d
Distance from flames

q''

Convection at external surface

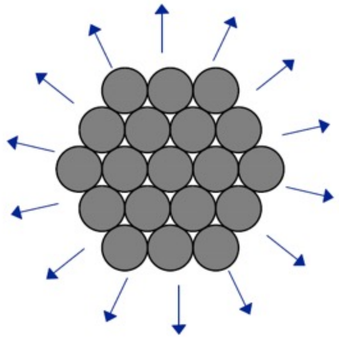


h
Convection coefficient

T_∞
Temperature surrounding smoke

$q'' = h(T_\infty - T_s)$

Re-radiation to environment



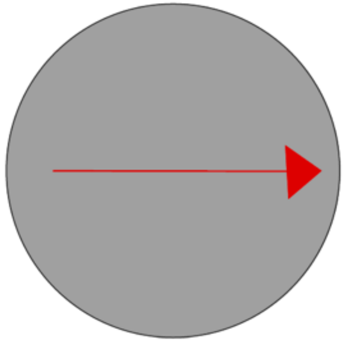
T_s
Temperature of steel surface

ε
Steel emissivity

$q'' = \varepsilon\sigma\, T_s^4$

Contact and air gap model – Internal

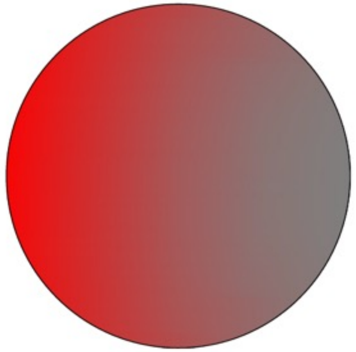
Conduction across strand



k
Conductivity steel

$$q'' = k \frac{dT}{dx}$$

Transient Heating

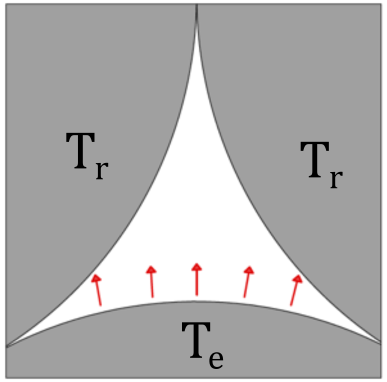


c_p
Specific Heat steel

ρ
Density steel

$$q = c_p \, \rho V \frac{dT}{dt}$$

Radiation between strands



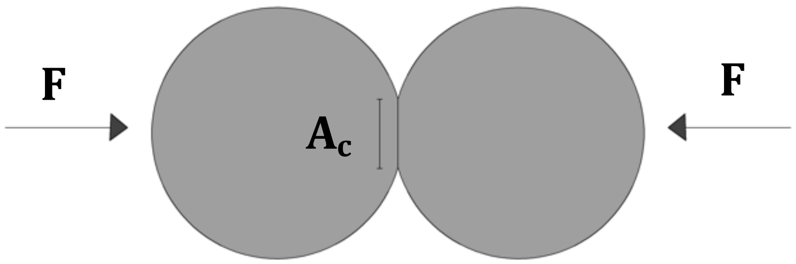
φ
View factor

ε
Steel emissivity

$$q'' = \varepsilon \sigma \varphi (T_e^4 - T_r^4)$$

Contact and air gap model – Internal

Conduction by contact

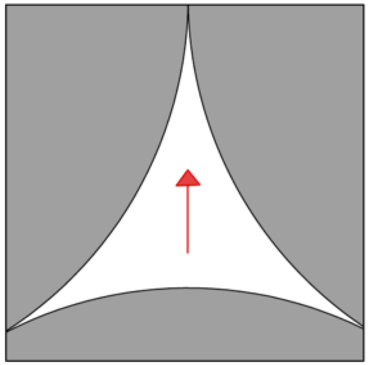


k_s
Conductivity steel

A_c
Contact area

$$q = k_s A_c \frac{dT}{dx}$$

Conduction across air gap

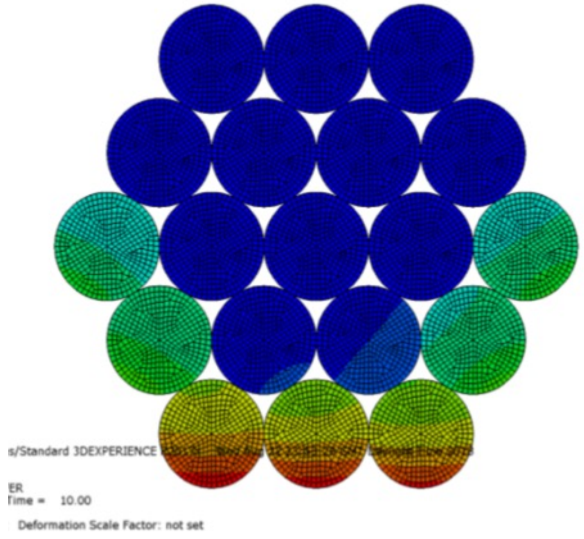


k_a
Conductivity air

$$q'' = k_a \frac{dT}{dx}$$

Contact and Air Gap model - Assumptions

Mechanism	Assumption	Bennetts et al. (2009)	Main & Luecke (2010)	Quiel et al. (2015b)	CAG model
Conduction	Lumped	✓	✗	✓	✗
	Gradient	✗	✓	✗	✓
	Contact	✗	✗	✗	✓
Convection	Air gap	✗	✗	✗	✗
	Boundary	✓	✗	✓	✓
Radiation	Air gap	✓	✗	✓	✓
	Boundary	✓	✗	✓	✓
Heating	Uniform	✓	✓	✗	✓
	Asymmetric /local	✗	✓	✓	✓



One-at-a-time Sensitivity Analysis

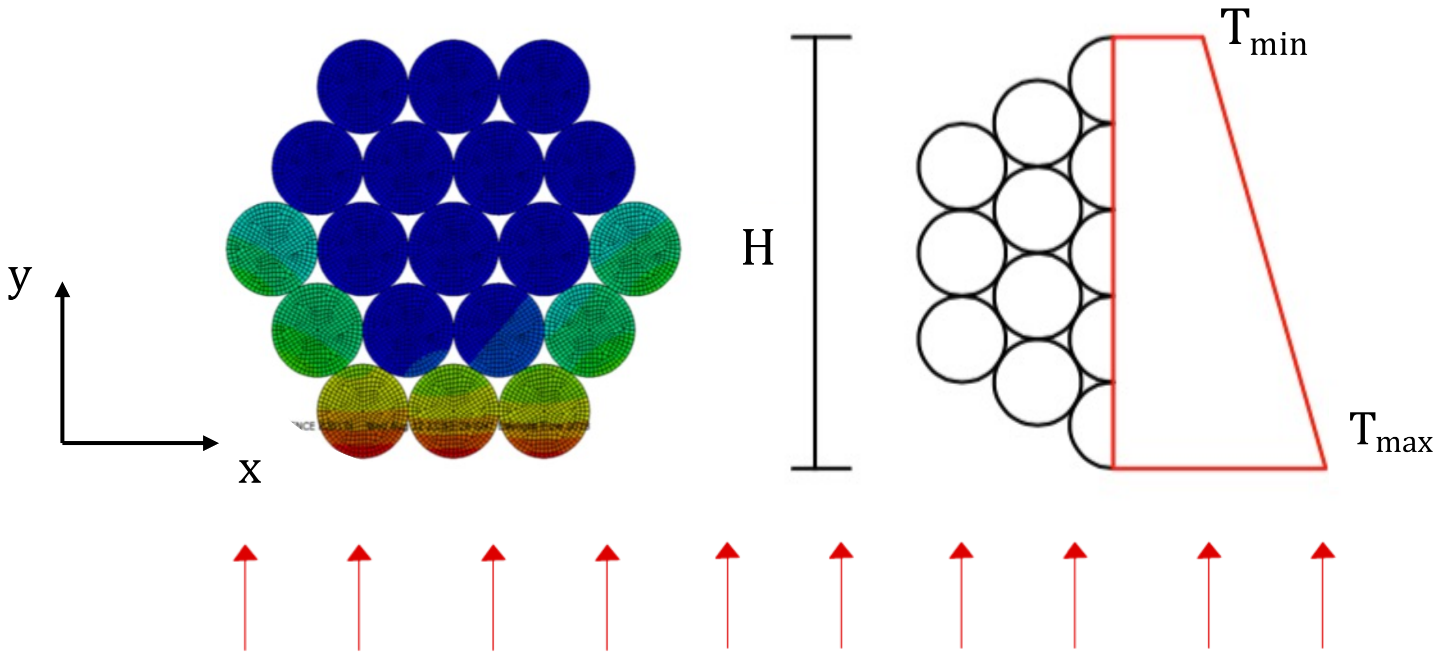
Input parameters

Output function

$Ƒ = \max \Delta\overline{T_y}\,(t)$

Linear temperature gradient

$$\Delta\overline{T_y} = \frac{T_{max} - T_{min}}{H}$$



Input Parameters

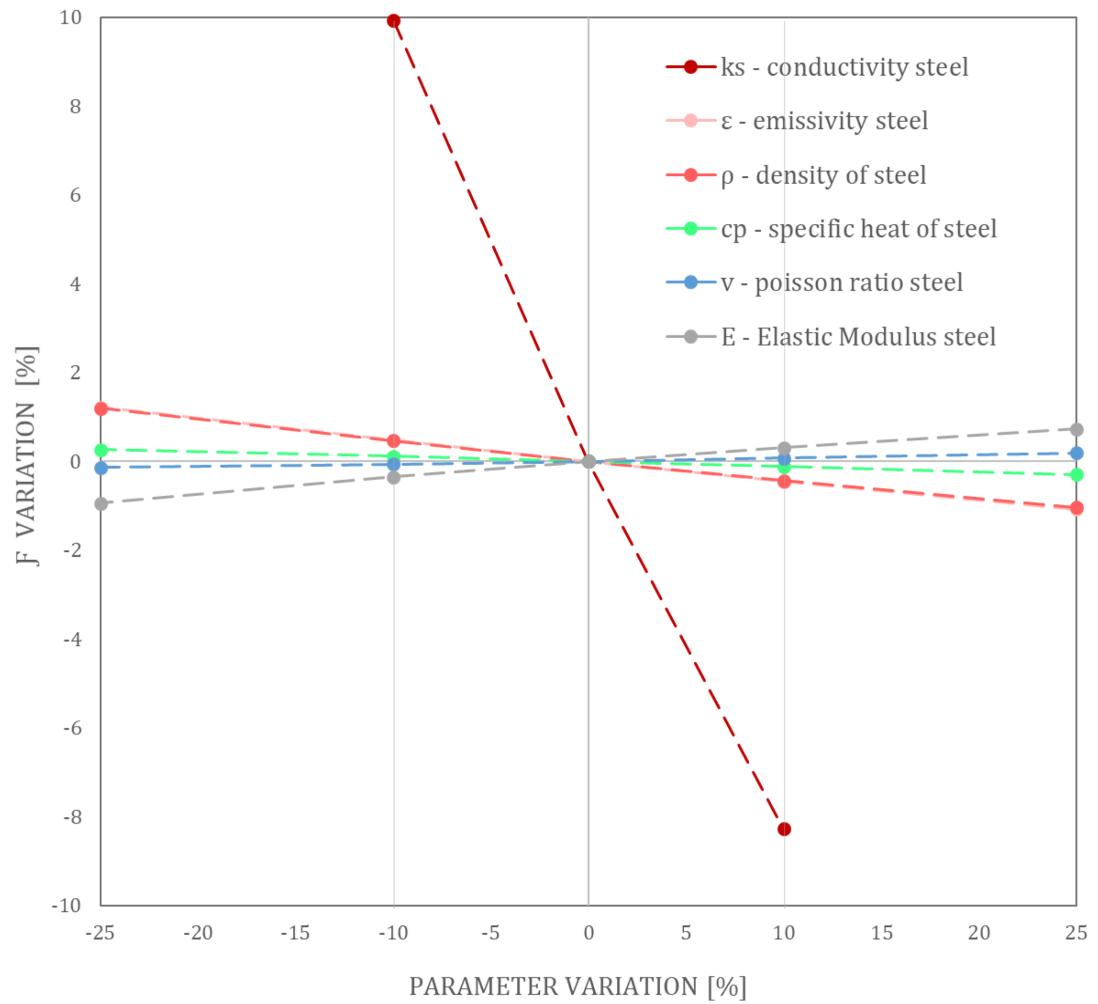
Material Parameters (7)	
Poisson ratio steel	v [-]
Elastic modulus steel	E [GPa]
Conductivity steel	k(t) [W/m.K]
Heat capacity steel	c_p(t) [j/kg.K}
Density steel	ρ [kg/m^3]
Emissivity steel	ε [-]
Conductivity air	k_a [W/m.K]

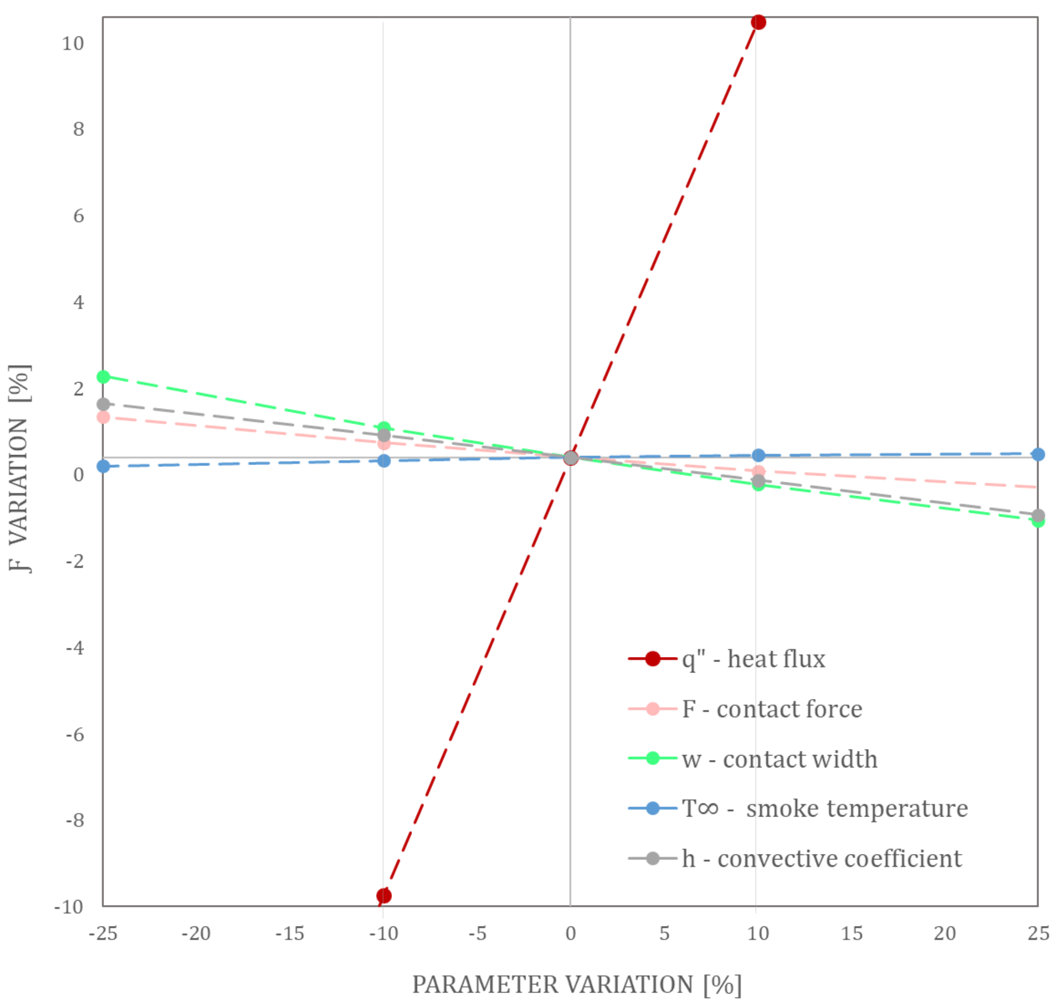
Heat Transfer Parameters (5)	
Convective coefficient	h [W/m^2.K]
Incident Heat Flux	q" [W/m^2]
Temperature smoke	T_∞ [K]
Contact width	w [m]
Contact force (self-weight)	F [N]

Total of 12 Input parameters!

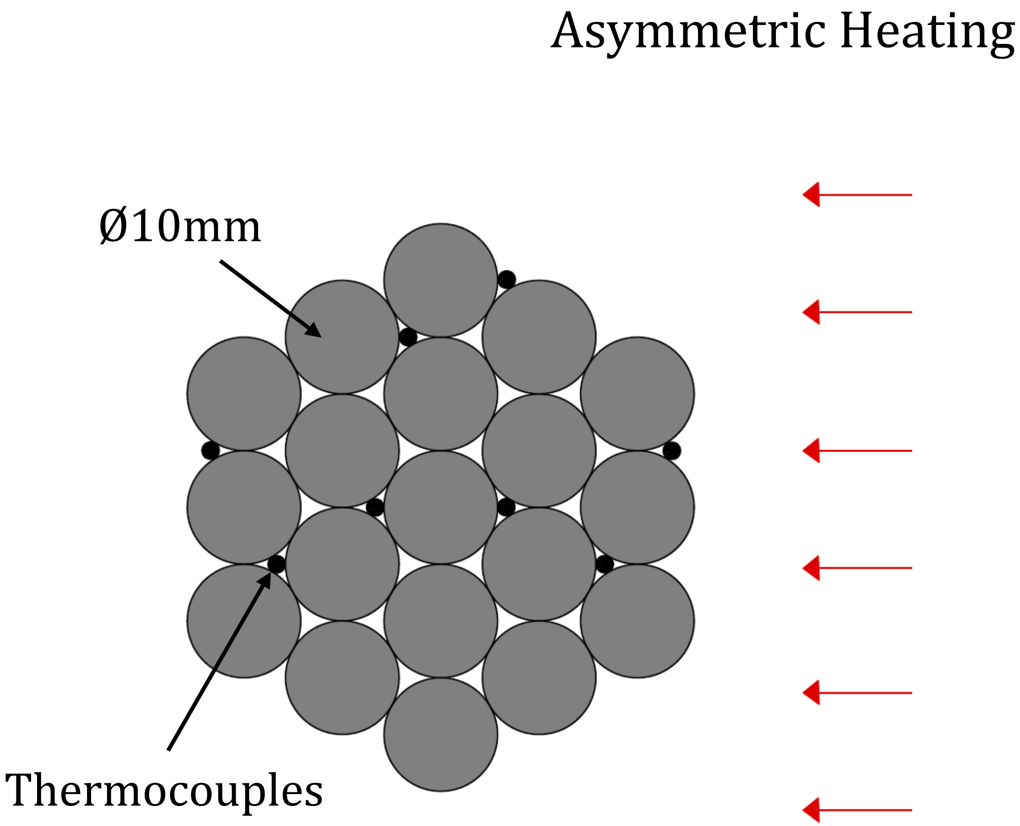
Sensitivity Analysis Results

Output function $Ƒ = \max \Delta\overline{T_y}\,(t)$





Experimental Data



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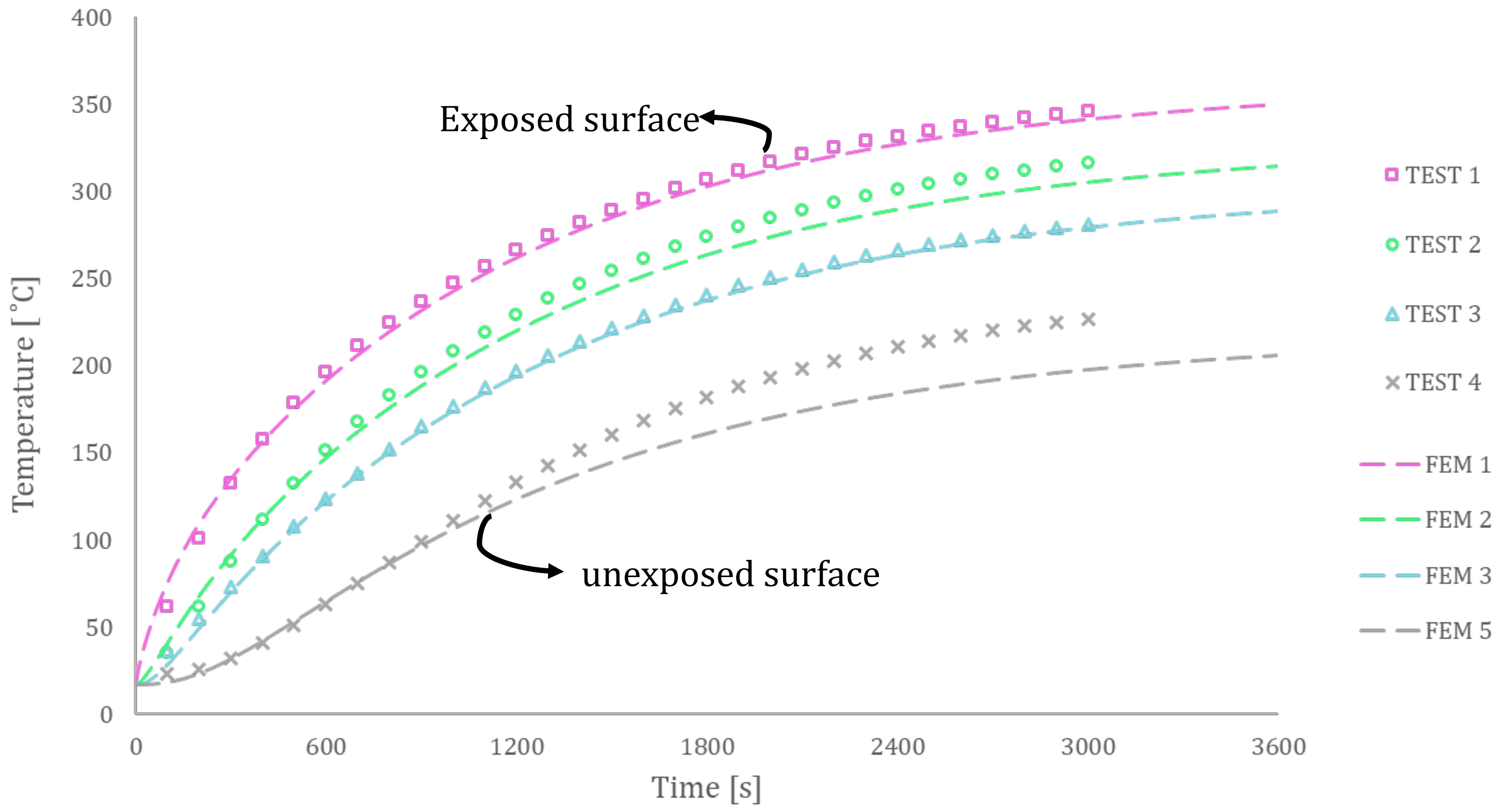
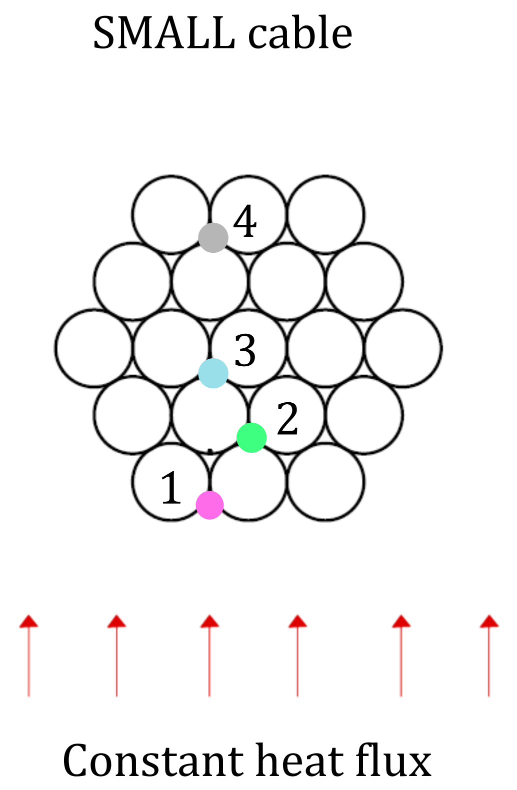
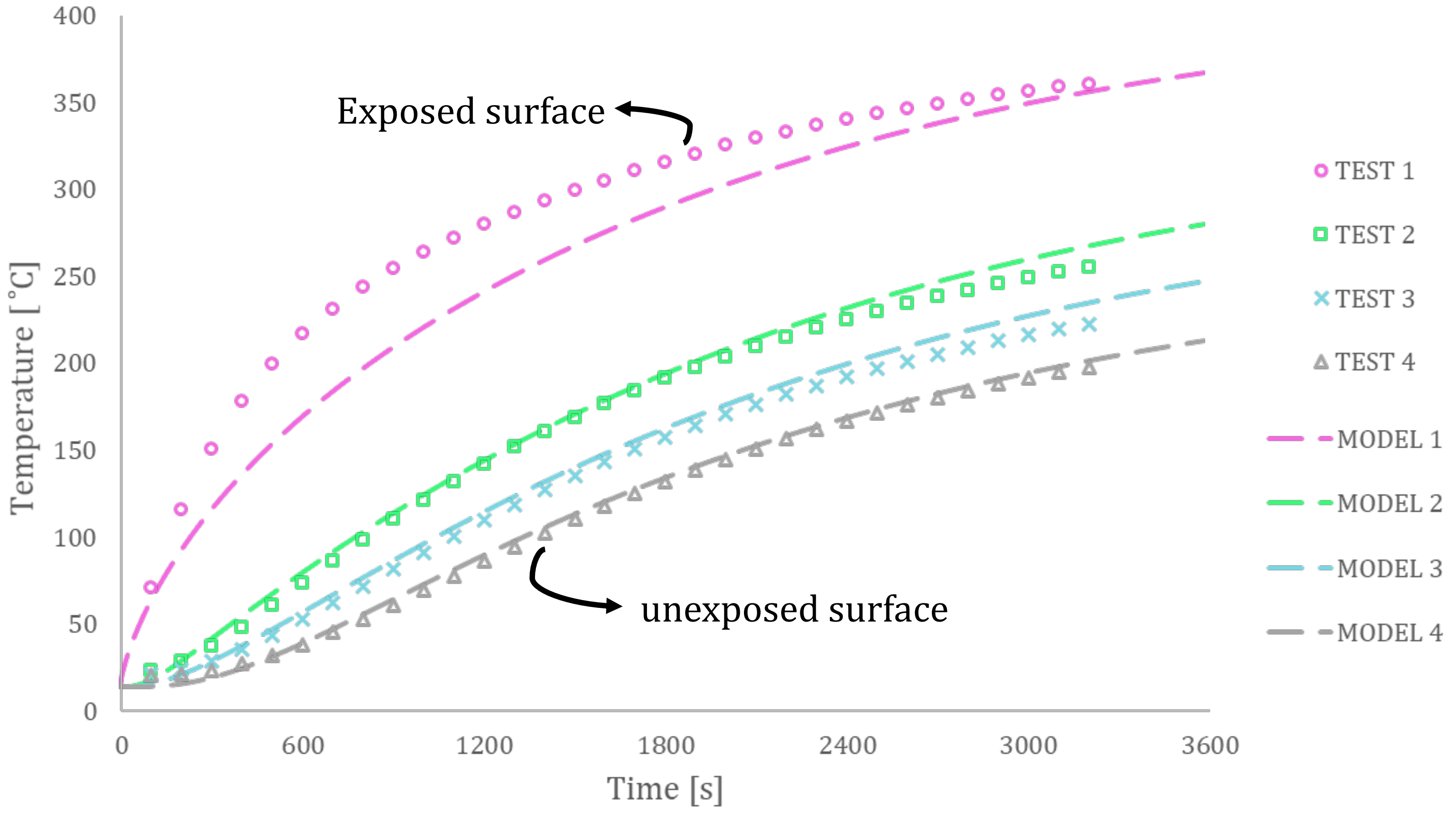
Validating the Model

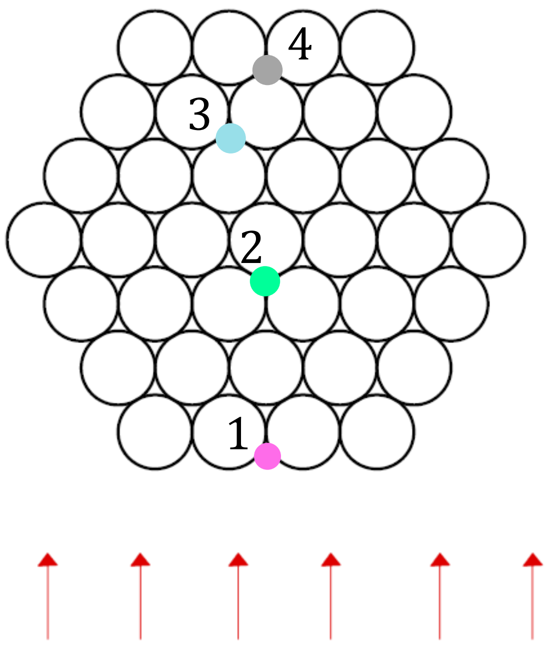




Validating the Model

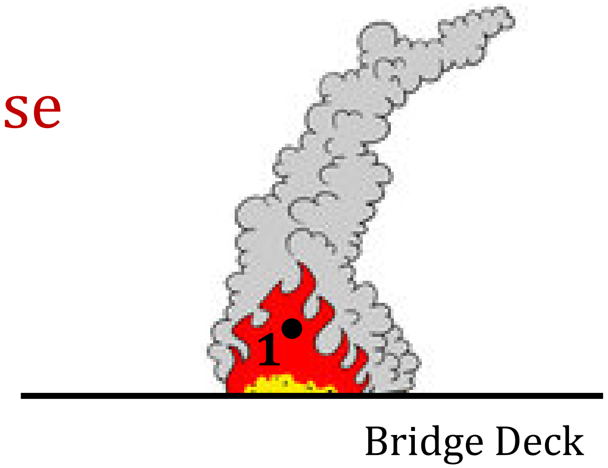


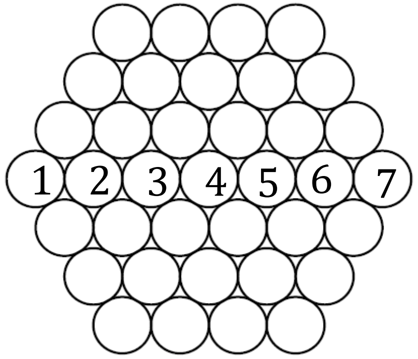
BIG Cable

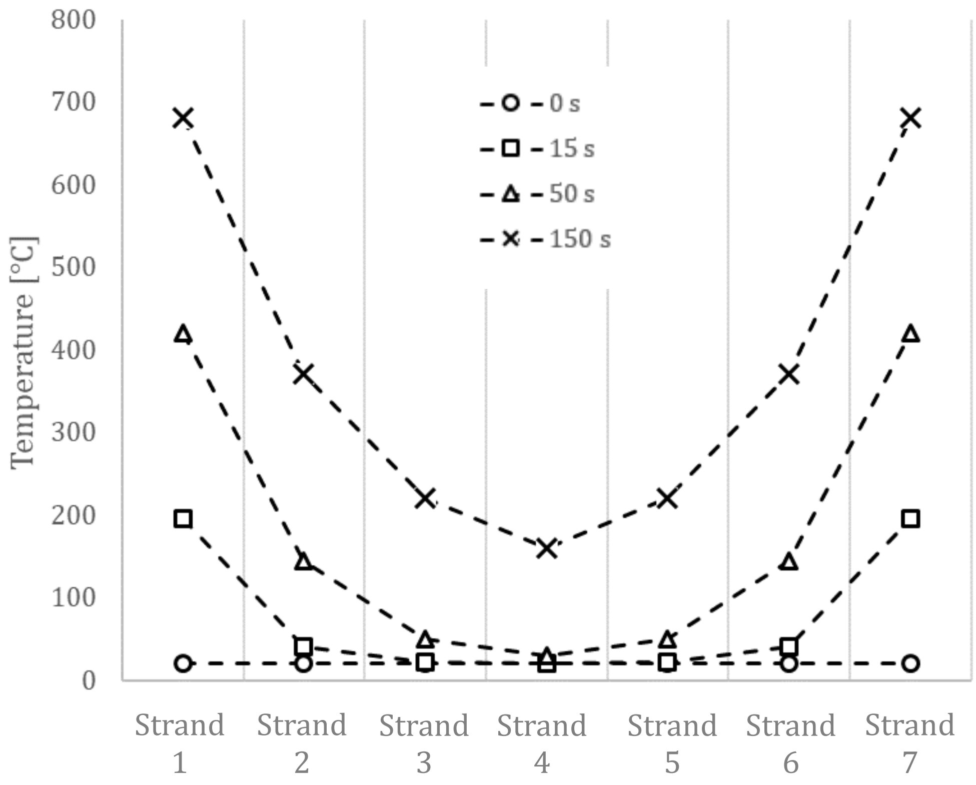


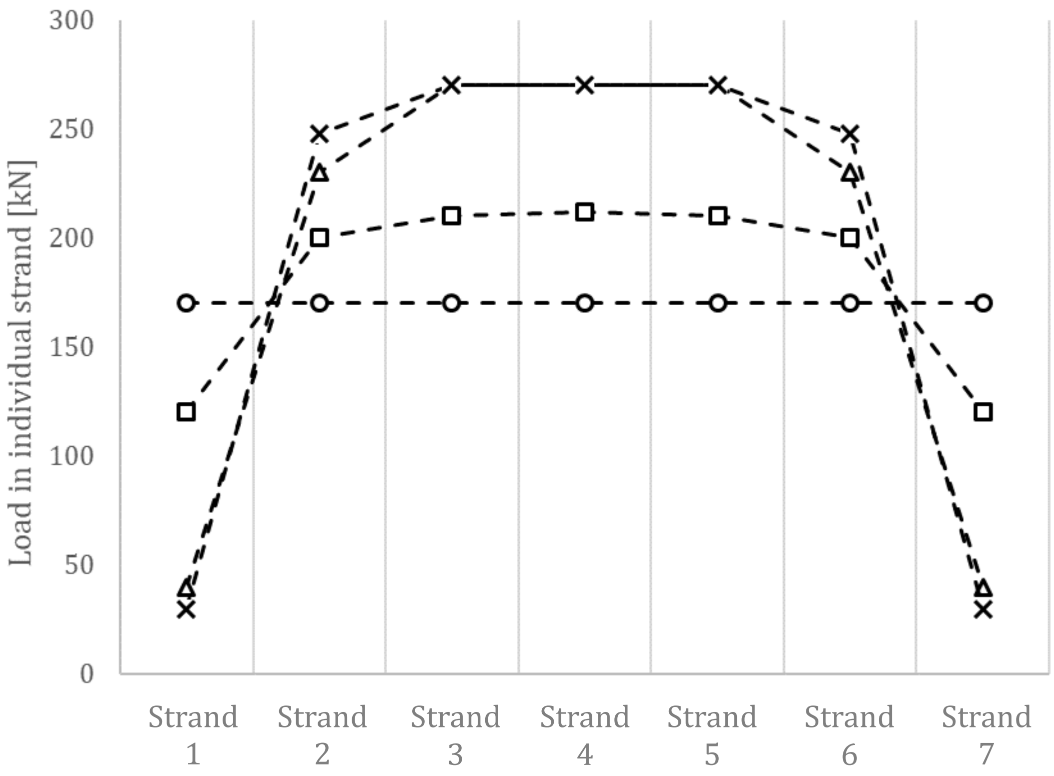
Constant heat flux

Coupled thermal and mechanical response
Scenario 1 – Uniform Heating

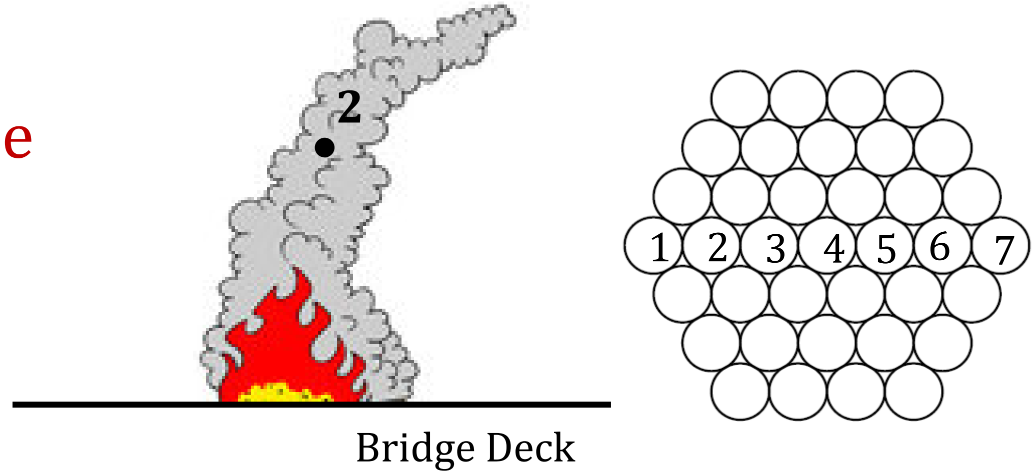


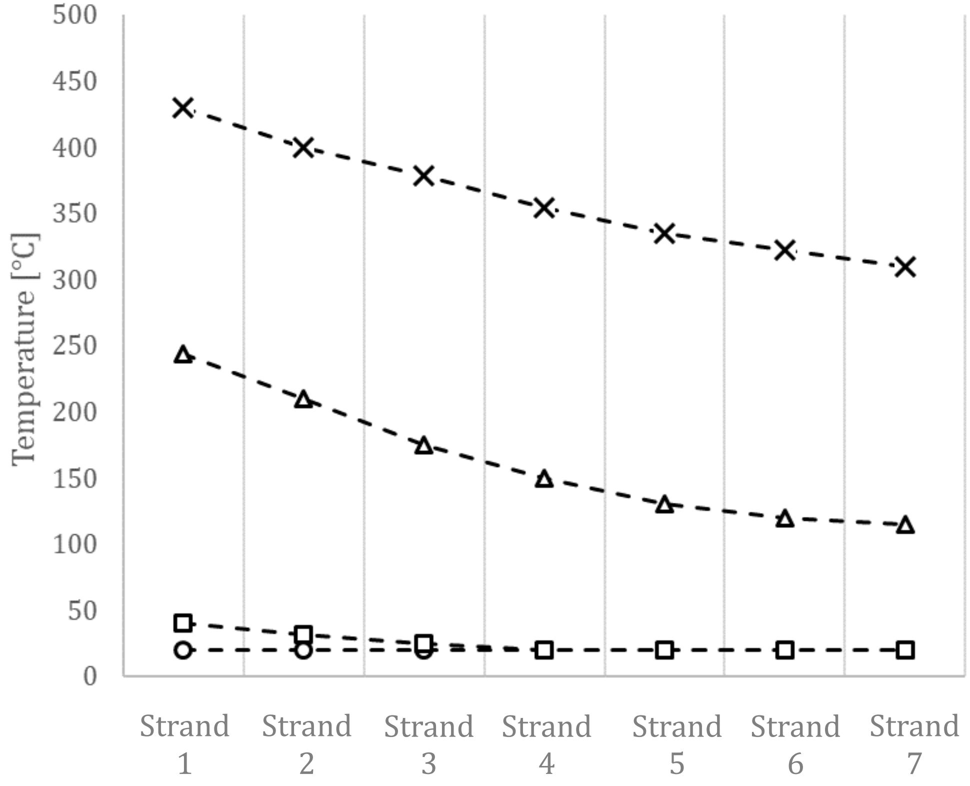


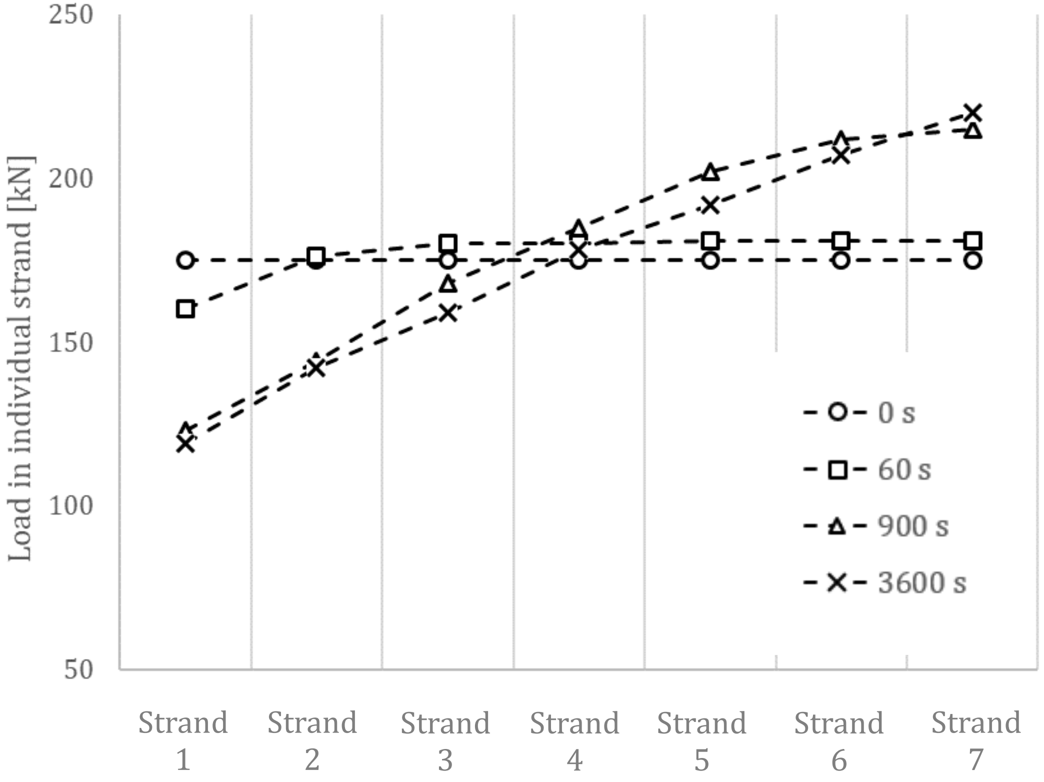




Coupled thermal and mechanical response
Scenario 2 – Asymmetric Heating

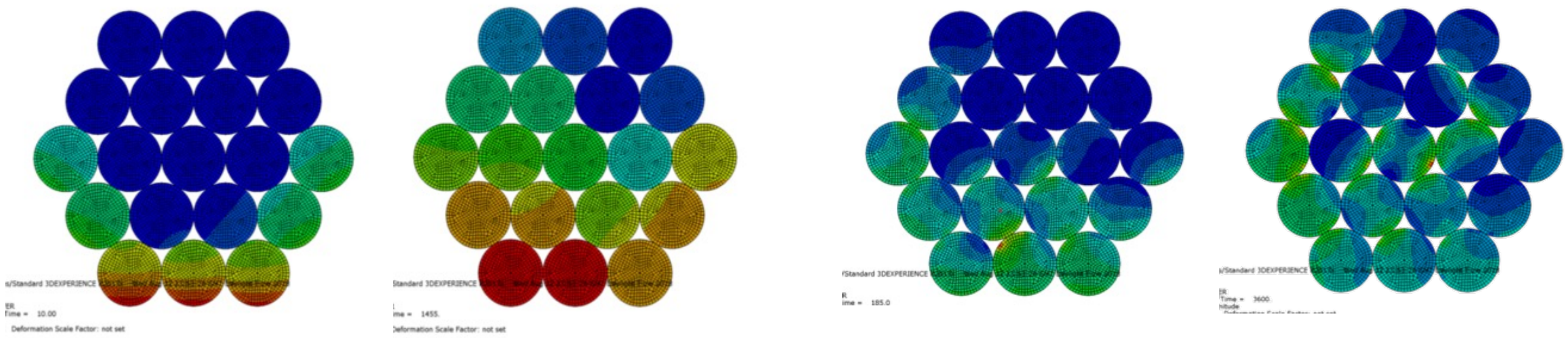






Summary of Key Points

- Created a code that automates model (software ABAQUS)
- Performed a sensitivity analysis and identified governing parameters
- Validate model with available experimental data
- Model can be used to analyze different fire scenarios and obtain a realistic prediction of temperature and mechanical response



Thank you !

Conduction Across Contact

Contact width

$$\Delta = \left(\frac{1-v^2}{E}\right)$$ - effective modulus

$$A_c = 2b = \sqrt{\frac{8F\Delta D}{L\pi}}$$

Contact resistance

$$R_S = \frac{1}{\pi L k_S} \ln\left(\frac{2D}{b}\right) - \frac{1}{2Lk_S}$$

(McGee et al. 1986)