# Novel Design of Concrete FRP Reinforcement for Fire Resistant Performance

Mohamed Kiari  Tim Stratford  Luke Bisby

# What is FRP?

- FRP = Fibres + Polymer
- Fibres: Strength
- Polymer: Load transfer

# FRP vs. Steel

Light weight

High strength

Corrosion resistance

Chlorides resistance

Cost £££

Stiffness

Fire performance

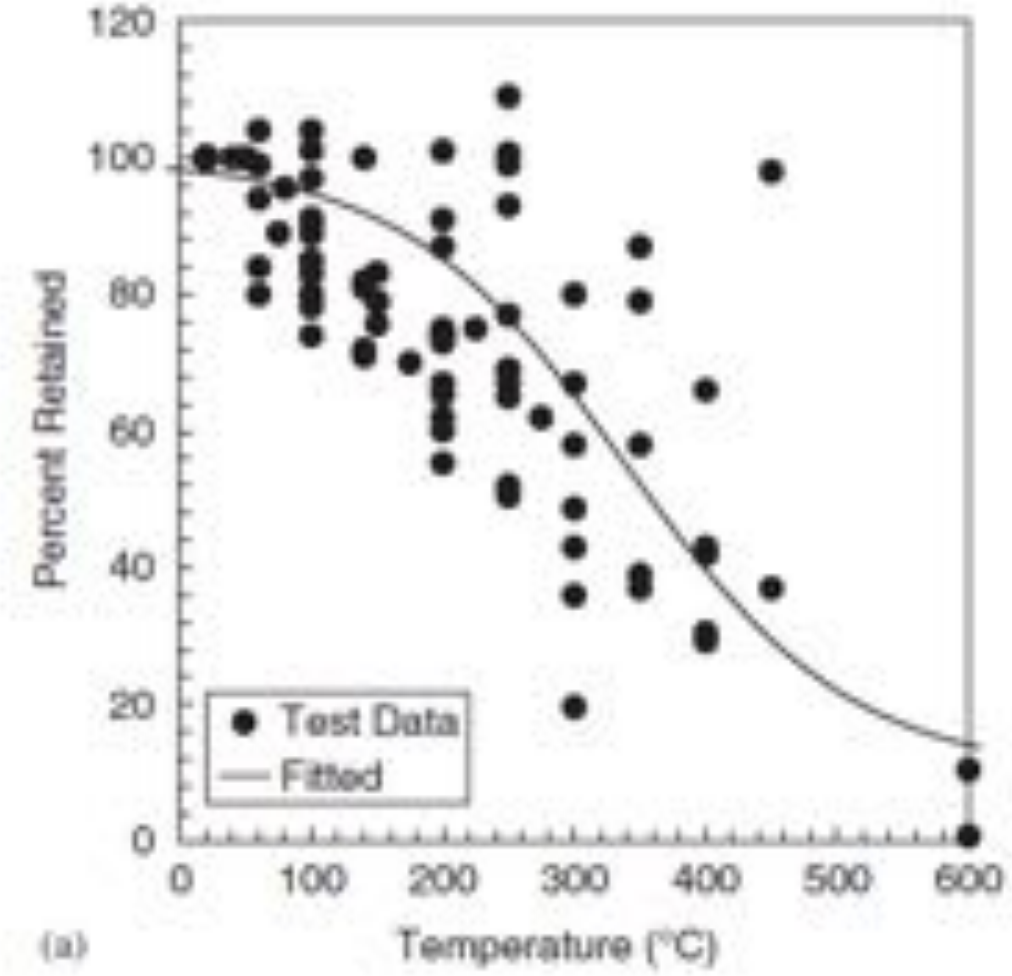
# Main motivation:

*in Europe the annual cost of repair and maintenance of the infrastructure, as a result of problems associated with corrosion, is around* ***£20 billion*** *(Rafi et al, 2011).*

# Major drawback:

*''The use of FRP reinforcement is not recommended for structures in which fire resistance is essential to maintain structural integrity'' ACI 440.1R-04*

# Fire Performance!



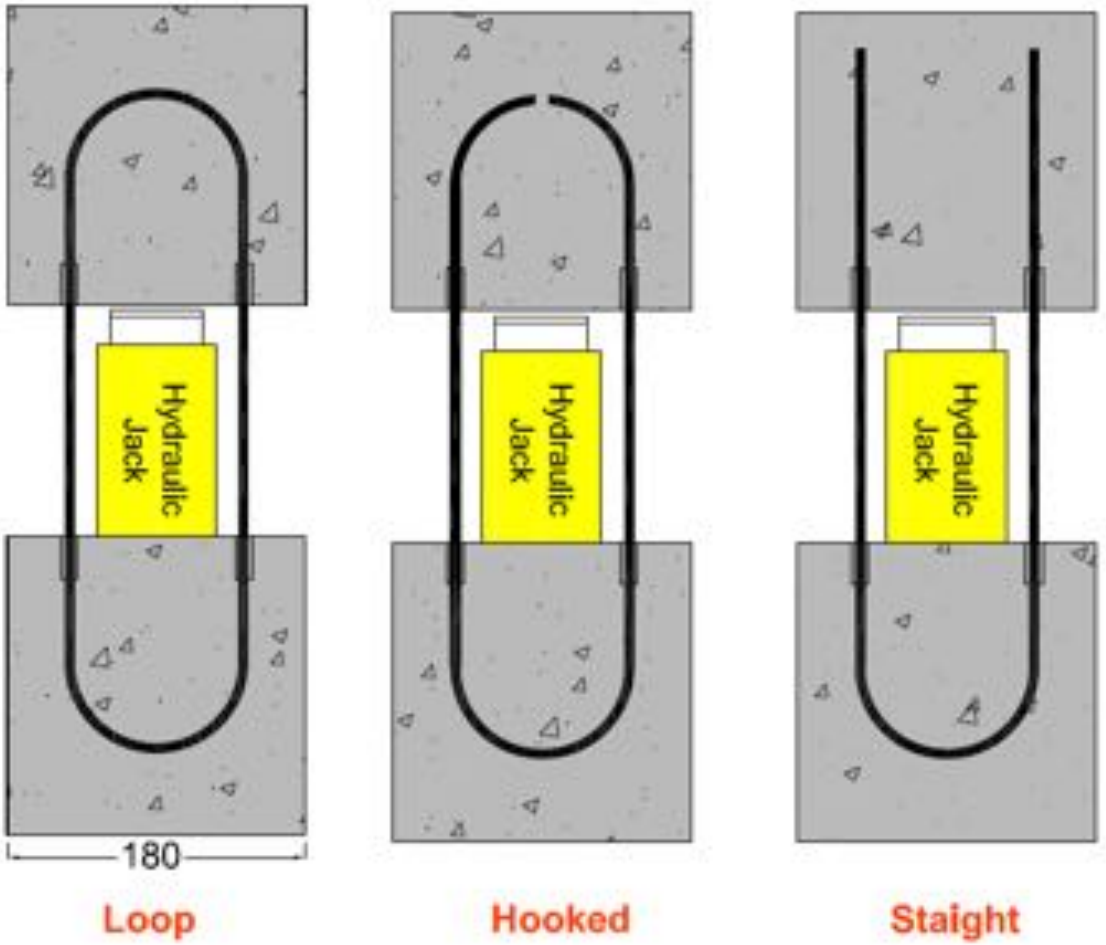

*Bisby L. et al (2005)*

Critical temperature

- Polymer up to 150 C
- Carbon fibres up to ***1000 C***

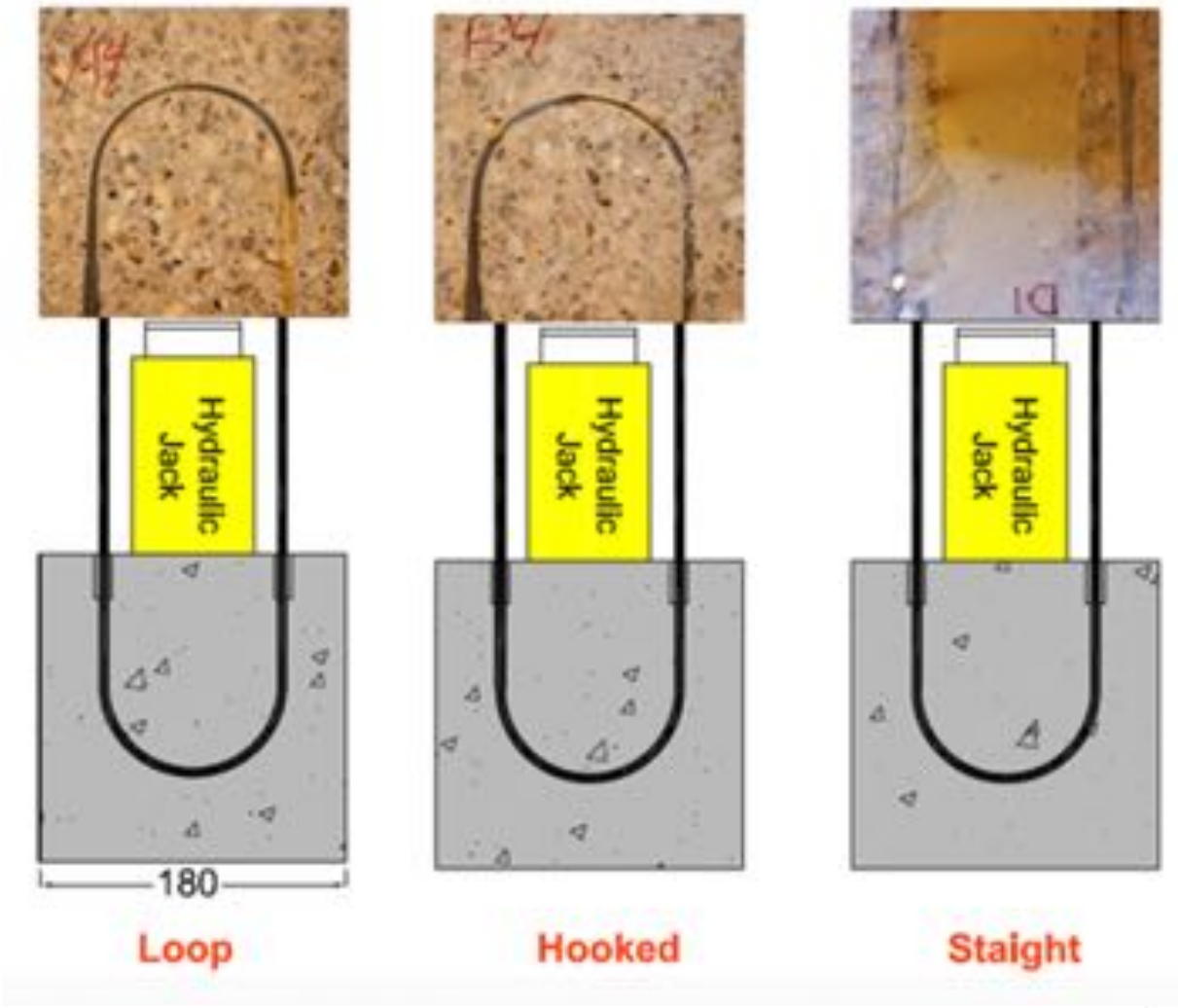
# FRP Loops!

# Testing programme

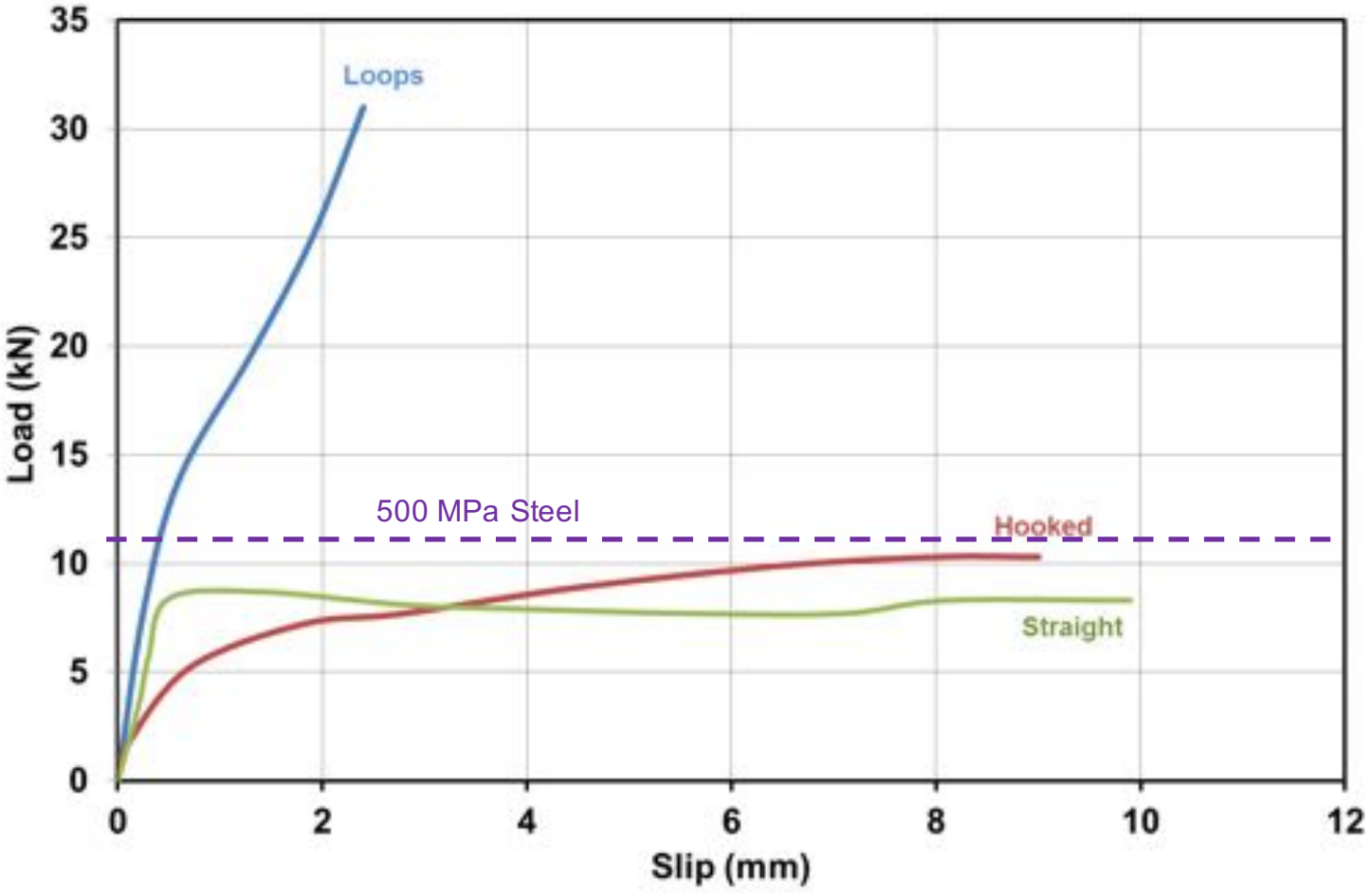



Dimensions in mm

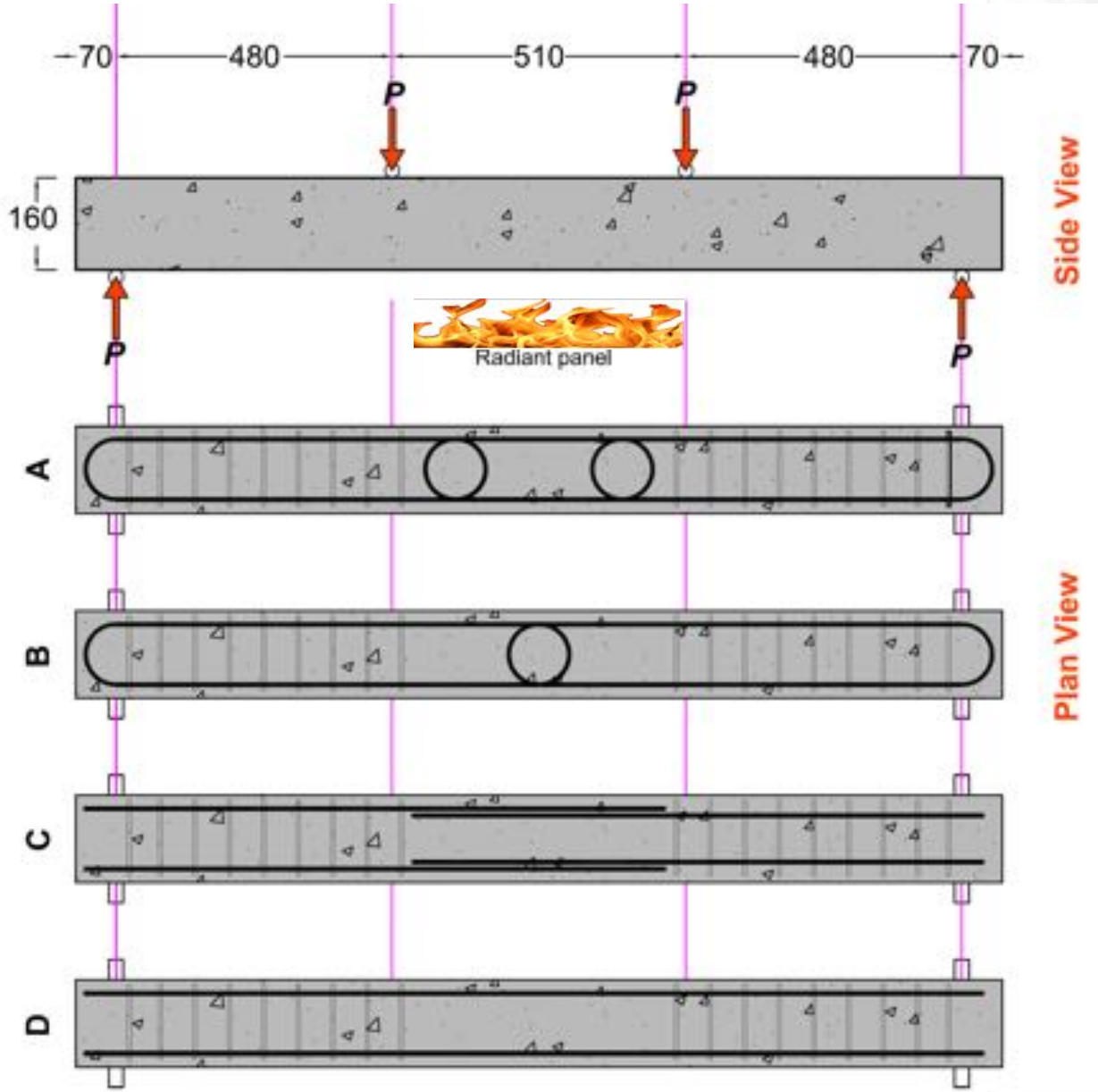
# Failure mode



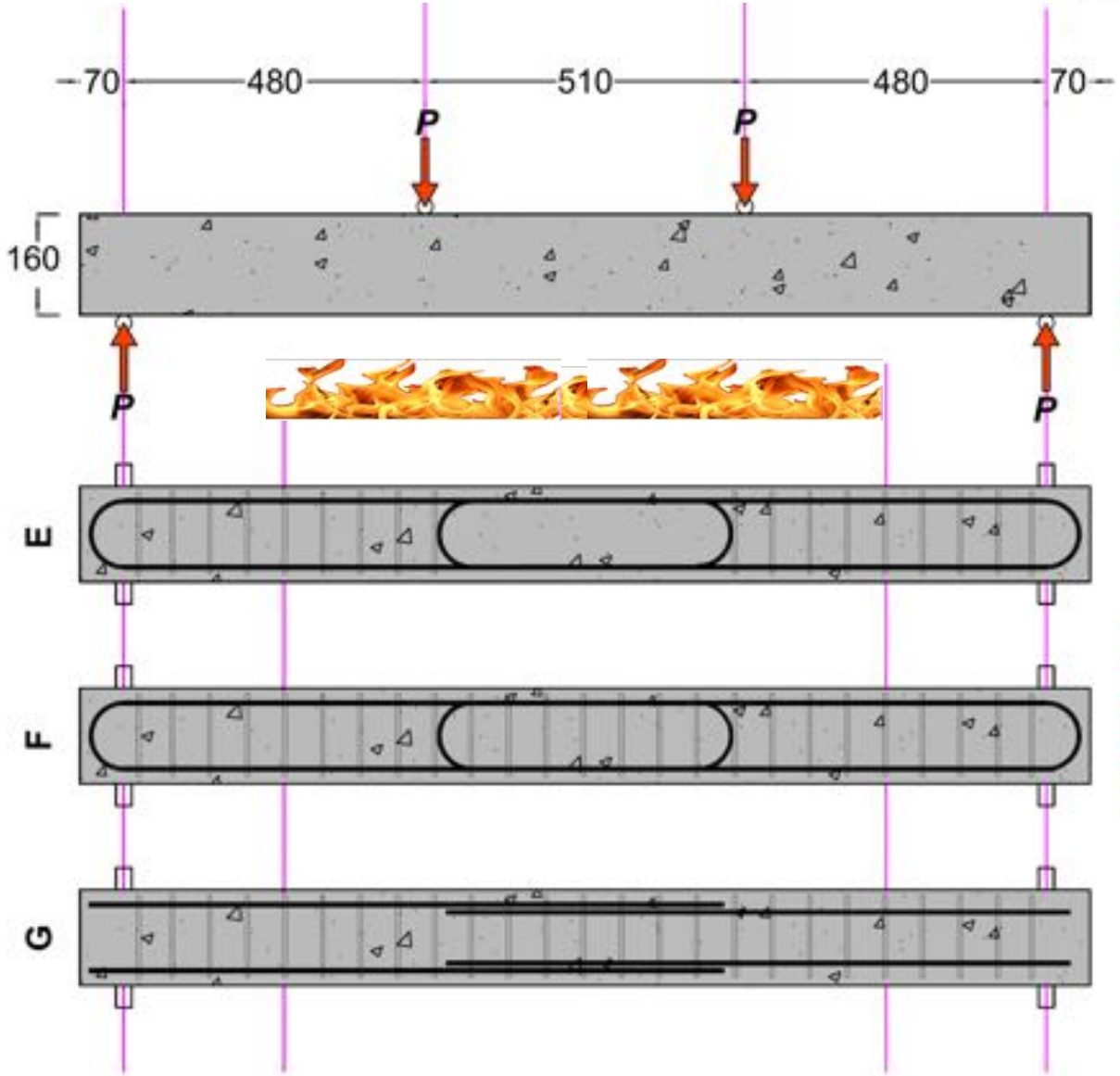
# Results


35
30
25
20
15
10
5
0
Load (kN)
0
2
4
6
8
10
12
Slip (mm)
Loops
500 MPa Steel
Hooked
Straight

# Beam Tests


70
480
510
480
70
P
P
160
P
P
Radiant panel
A
B
C
D
Side View
Plan View

# Beam Tests



# Testing Frame:

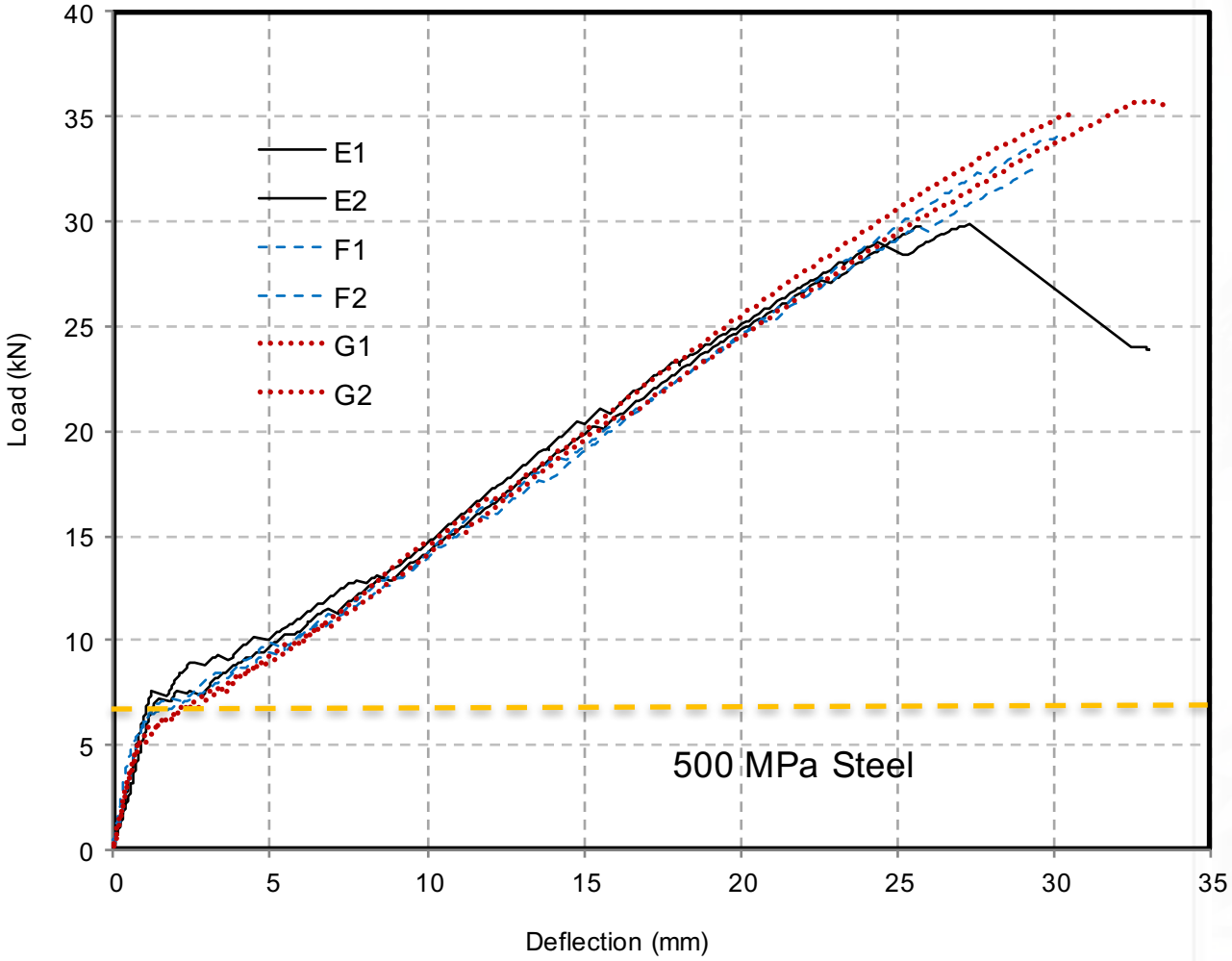
# Failure Modes:

Short splice FRP Loops

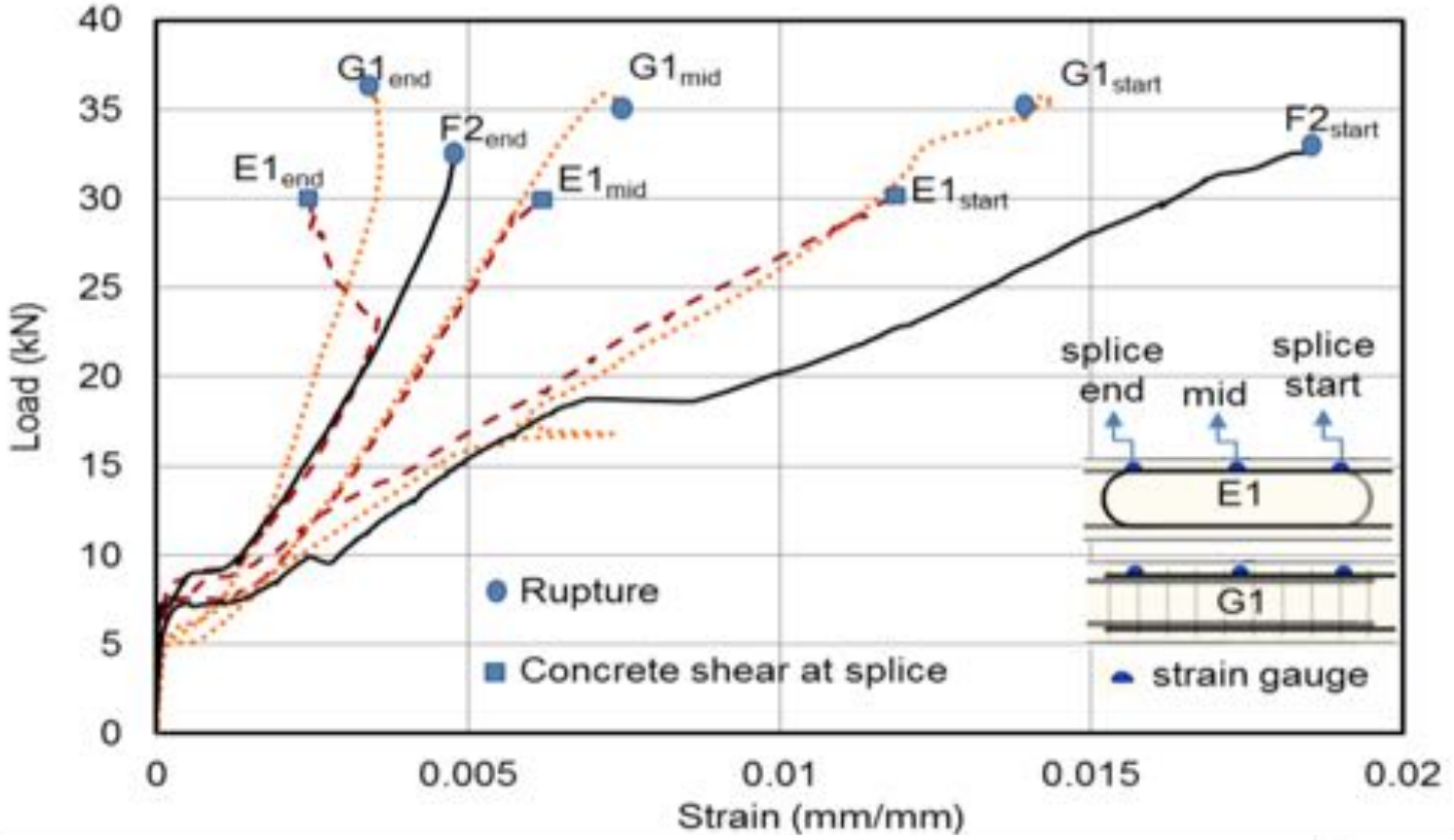
Straight rebars

CFRP loops (longer splice)

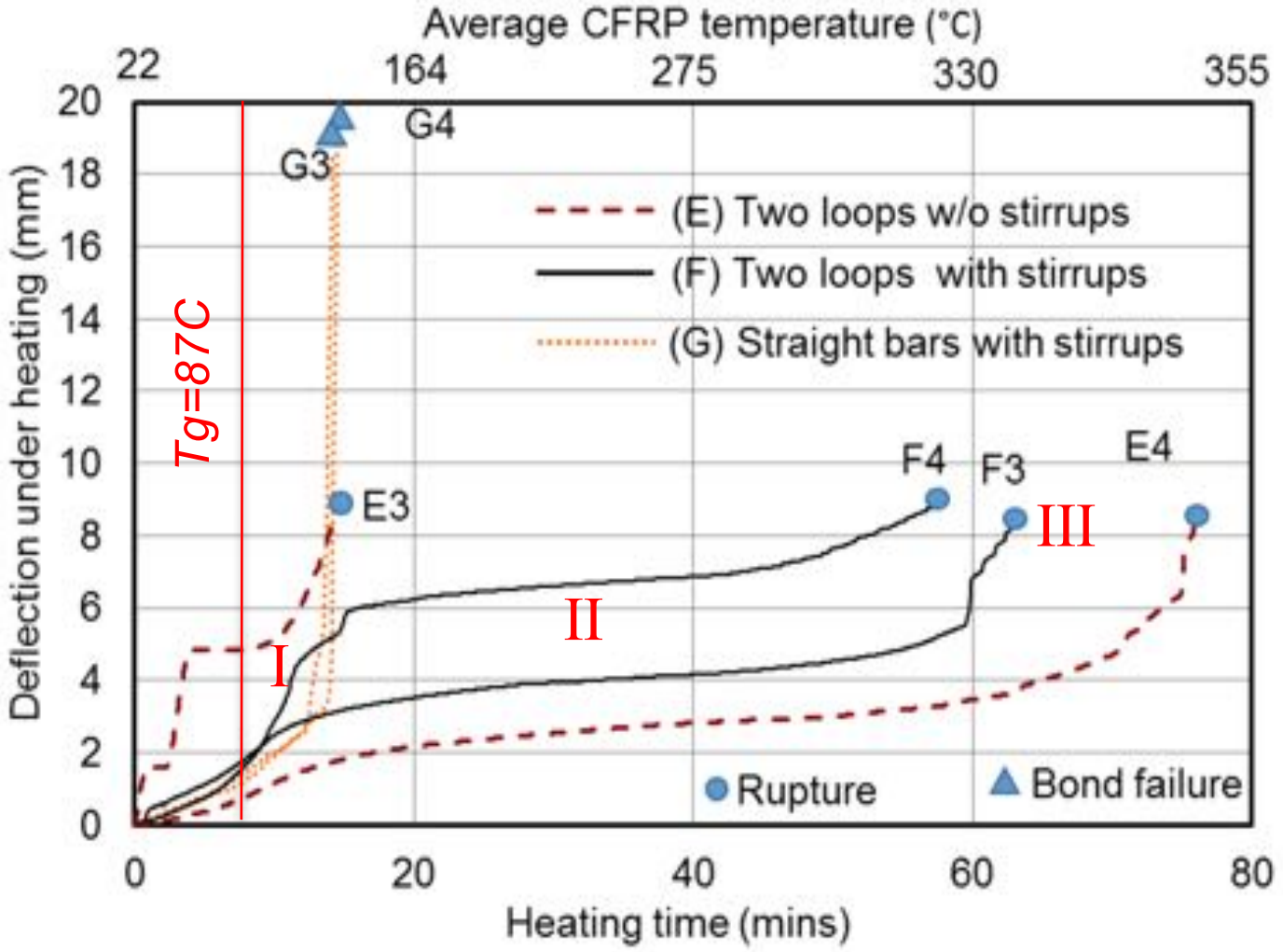
# Results: ambient



# FRP Strain


Load (kN)
Strain (mm/mm)
0
5
10
15
20
25
30
35
40
0
0.005
0.01
0.015
0.02
G1end
G1mid
G1start
F2end
F2start
E1end
E1mid
E1start
Rupture
Concrete shear at splice
splice end
mid
splice start
E1
G1
strain gauge

# Results (High Temp.):



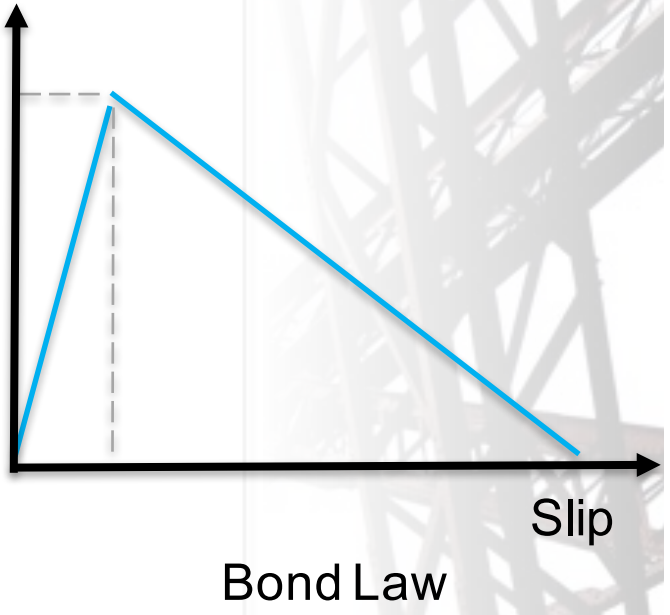
# Predicting Fire Performance

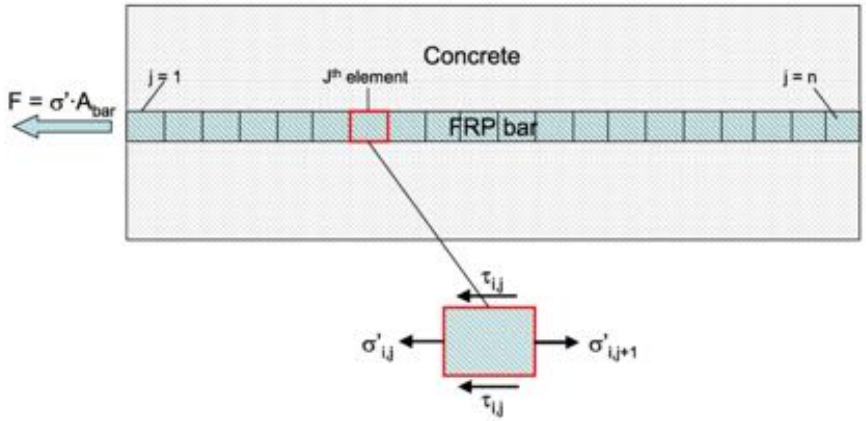
Develop length: *Nigro et al* 2012

$$\sigma_{i,j+1} = \sigma_{i,j} - \Delta\sigma_{i,j}$$

$$\Delta\sigma_{i,j} = \tau_{i,j} \cdot (\pi \cdot \phi \cdot \Delta z)$$

$$s_{i,j+1} = s_{i,j} - \left(\frac{\sigma_{i,j} + \sigma_{i,j+1}}{2 \cdot E}\right) \cdot \Delta z$$



# Predicting Fire Performance

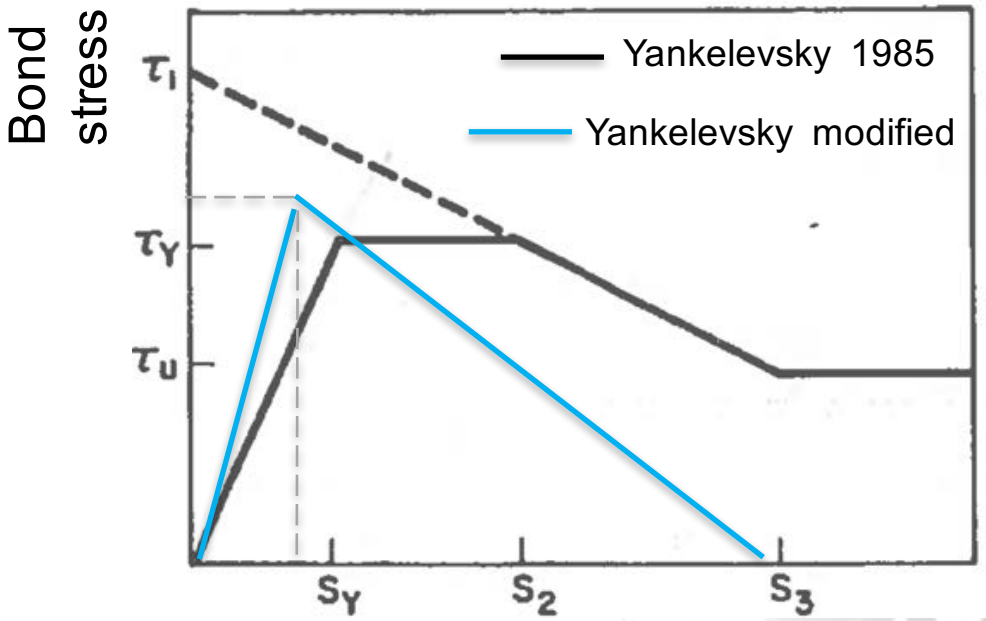
## Steel Bond-Slip: Yankelevsky. 1985

$$\tau(x) = \frac{1}{\pi D} \cdot \frac{dT(x)}{dx}$$

$$\tau(x) = \frac{ED}{4} \cdot \frac{d^2 S(x)}{dx^2}$$

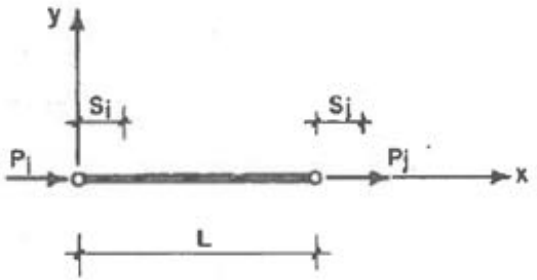
$$P_i = \frac{\alpha_1 EA}{\sinh(\alpha_1 L)} [-S_j + S_i \cosh(\alpha_1 L)]$$

$$P_j = \frac{\alpha_1 EA}{\sinh(\alpha_1 L)} [S_j \cosh(\alpha_1 L) - S_i].$$

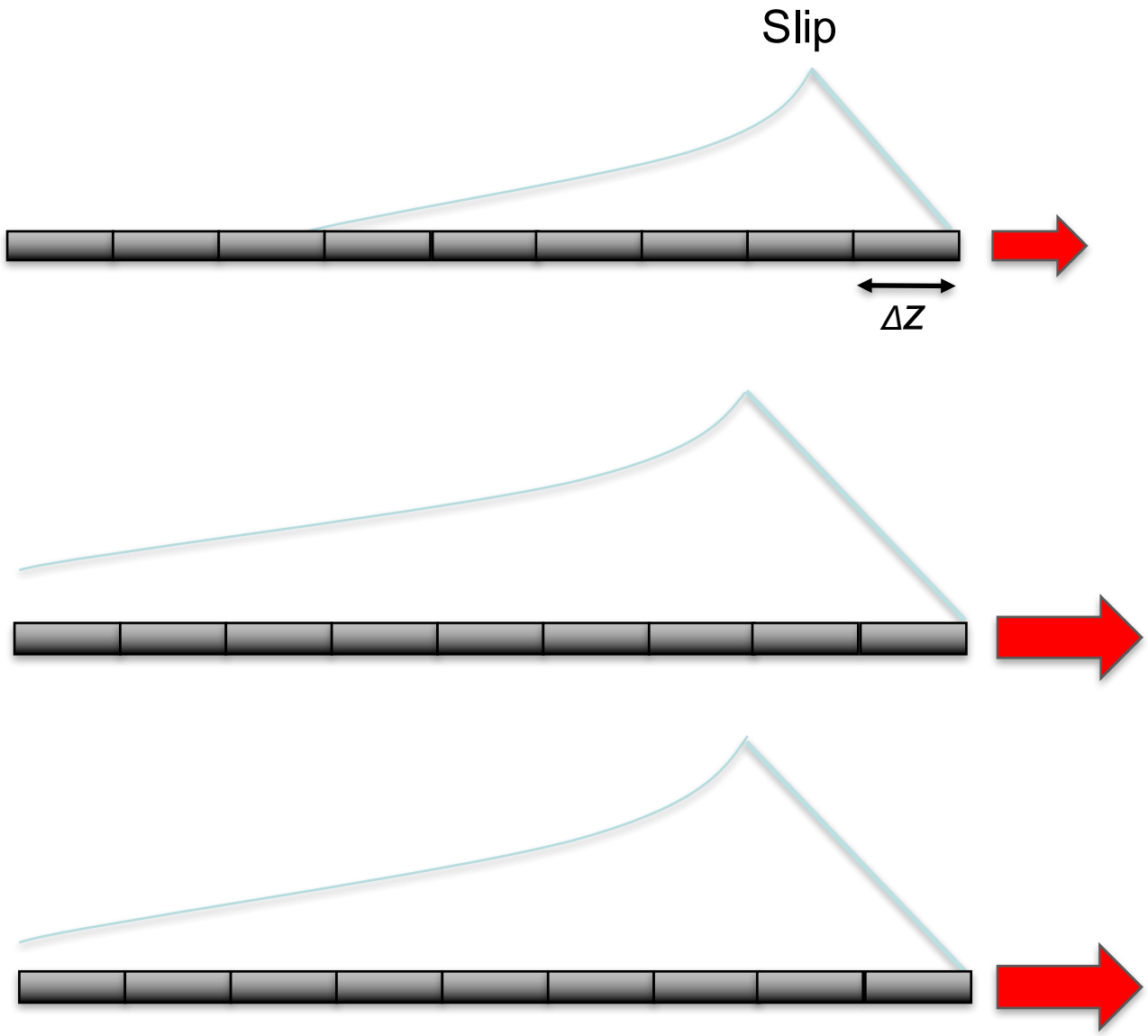


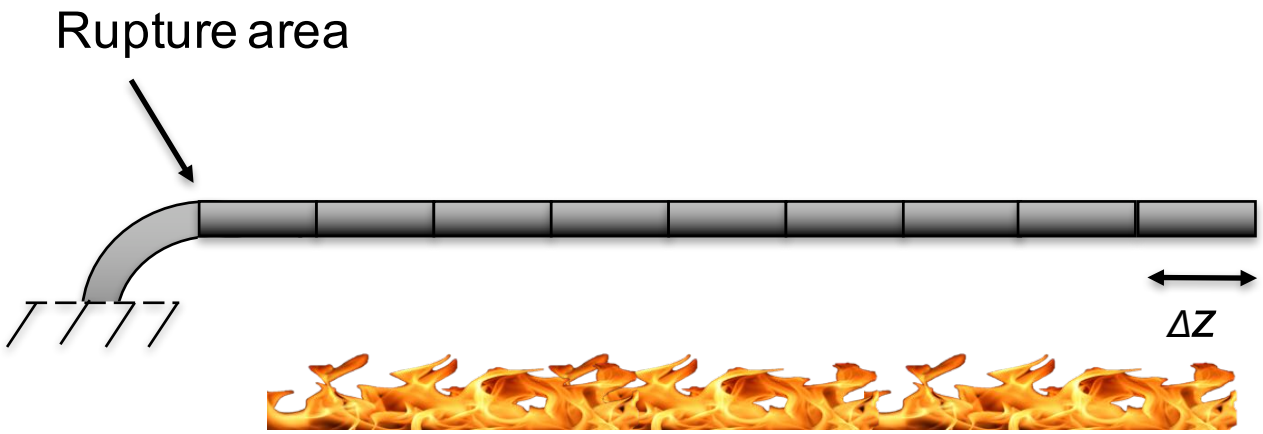

Bond Law

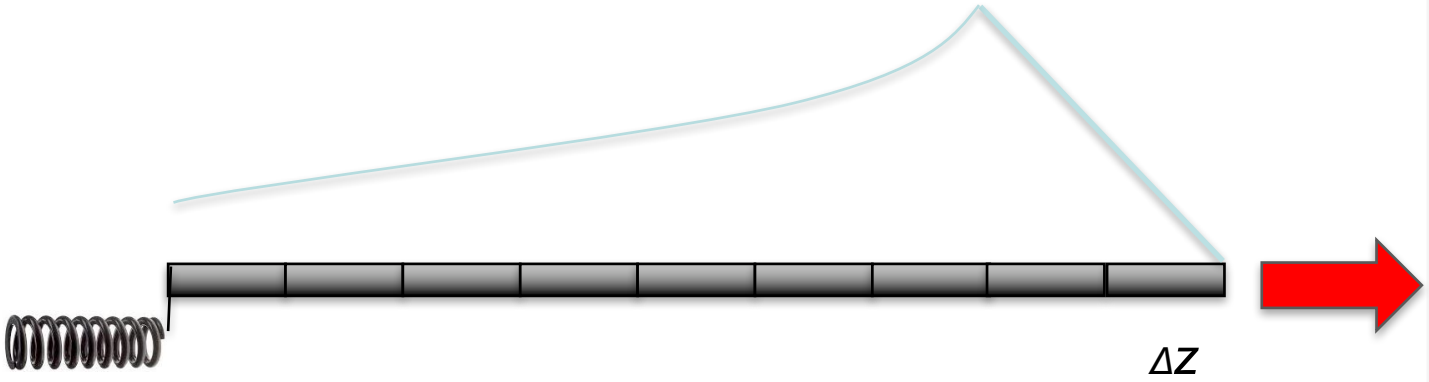
$$\begin{Bmatrix} P_i \\ P_j \end{Bmatrix} = \begin{pmatrix} k_{11}^1 & k_{12}^1 \\ k_{21}^1 & k_{22}^1 \end{pmatrix} \cdot \begin{Bmatrix} S_i \\ S_j \end{Bmatrix}$$



# Predicting Fire Performance

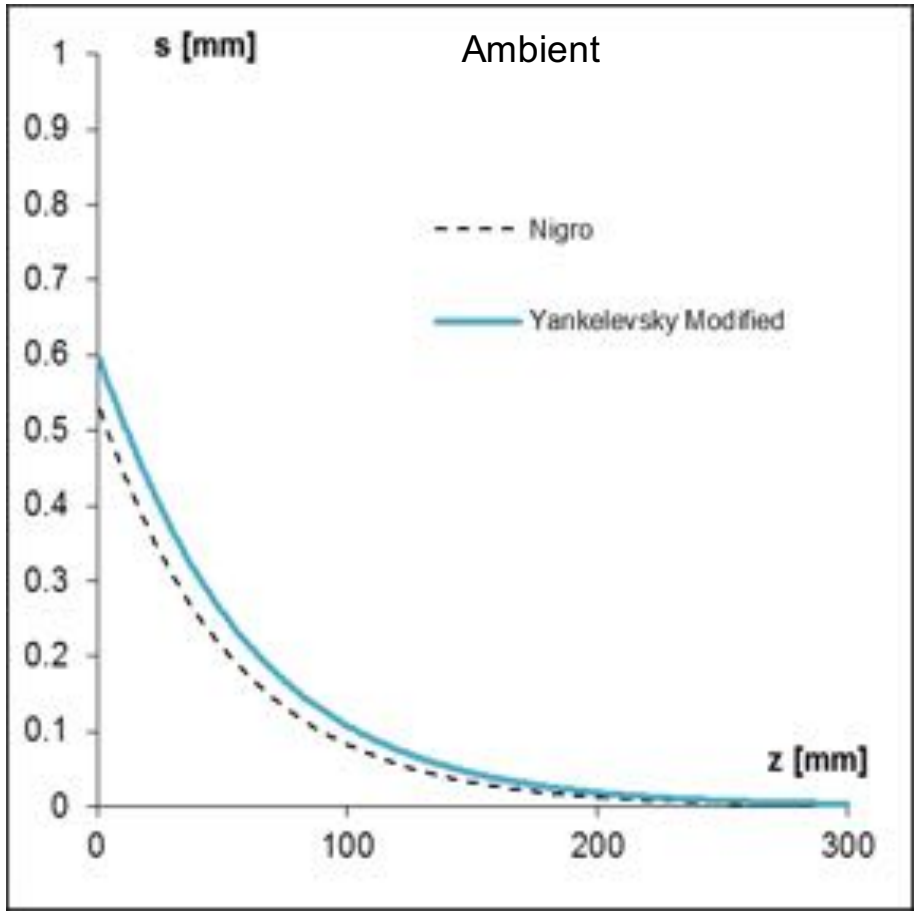


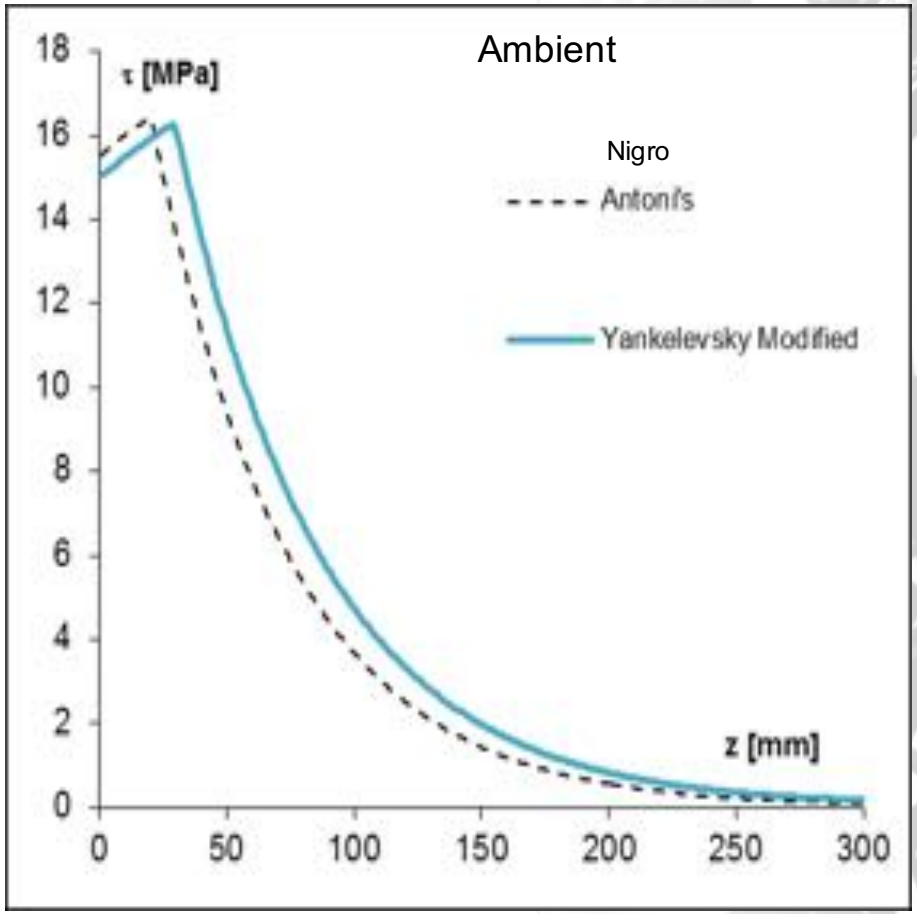


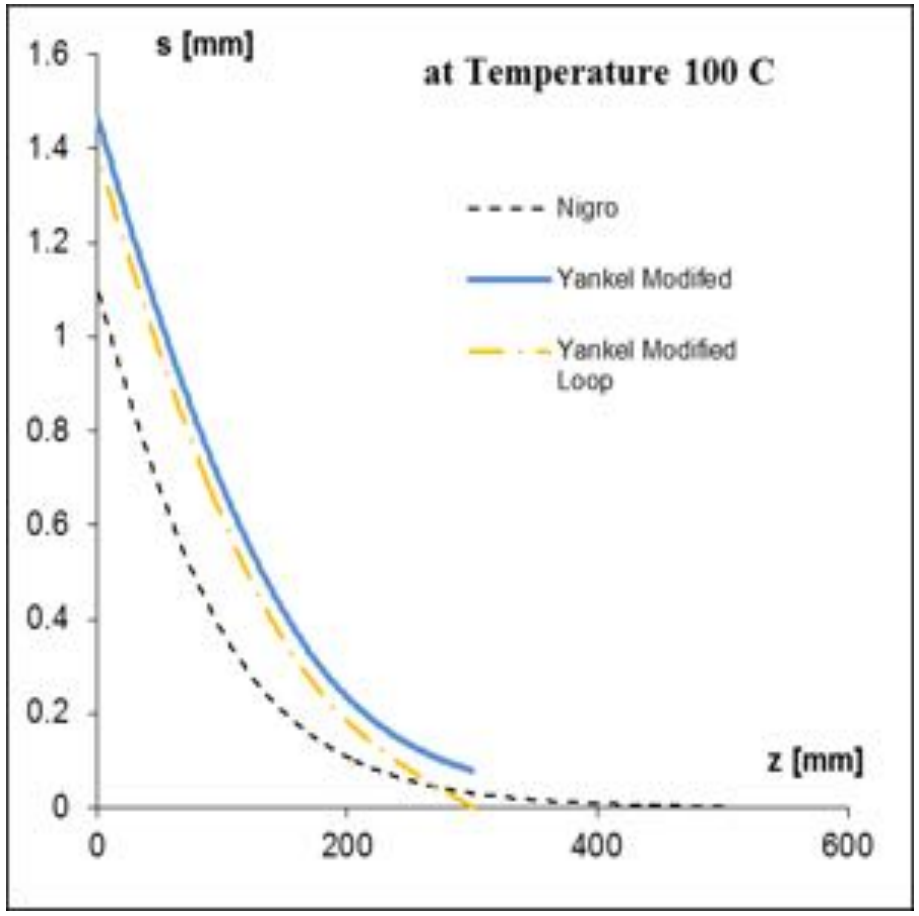

$$\begin{Bmatrix} P_i \\ P_j \end{Bmatrix} = \begin{pmatrix} k_{11}^1 & k_{12}^1 \\ k_{21}^1 & k_{22}^1 \end{pmatrix} \cdot \begin{Bmatrix} S_i \\ S_j \end{Bmatrix}$$

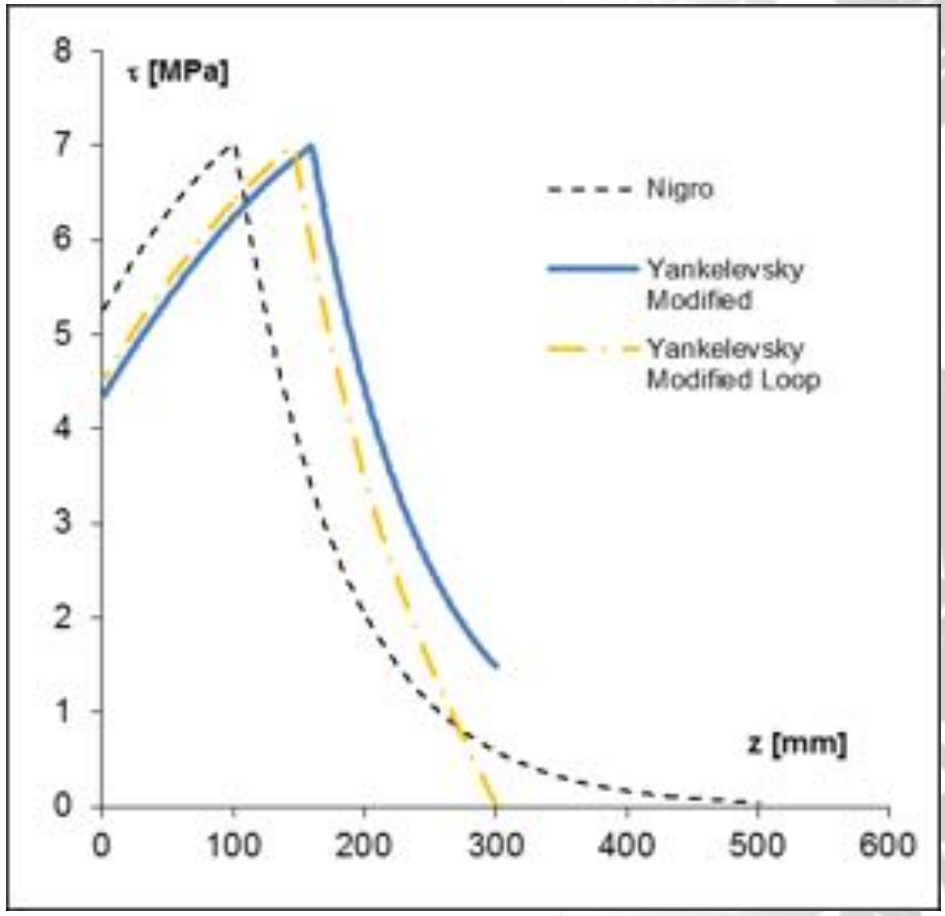
# *Analytical models (ambient)*



# At elevated temperature



# Conclusion:

- Significant improvement of fire resistance time
- Failure mode changed from pull-out to rupture
- Potential restrain of cracks opening and formation
- Analytical prediction of bond stress at ambient and elevated temperatures

# THANK YOU!