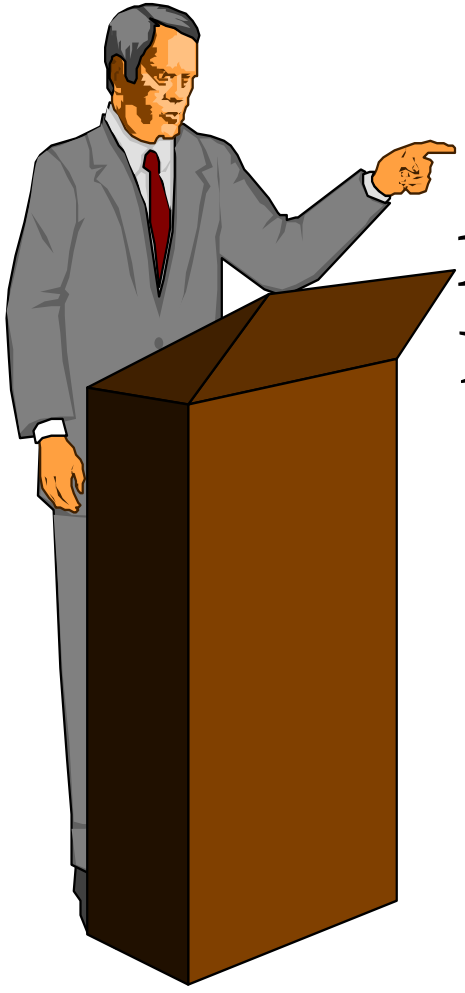
Punching Shear Behaviour and Design of FRP RC Flat Slabs



Dr Kypros Pilakoutas, Reader

Dr Abdel Wahab El-Ghandour, Researcher

Professor Peter Waldron, Pro-Vice Chancellor

Centre for Cement and Concrete
Dept. of Civil and Structural Engineering
The University of Sheffield, UK

http://www.shef.ac.uk/~tmrnet

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Outline

- Why FRP?
- Context of Work
- Experiments on Flat Slabs
- Bond Slip and Punching Shear
- Concrete Shear Resistance (FRP RC)
- FRP Shear Reinforcement (Predictive Model)
- Conclusions

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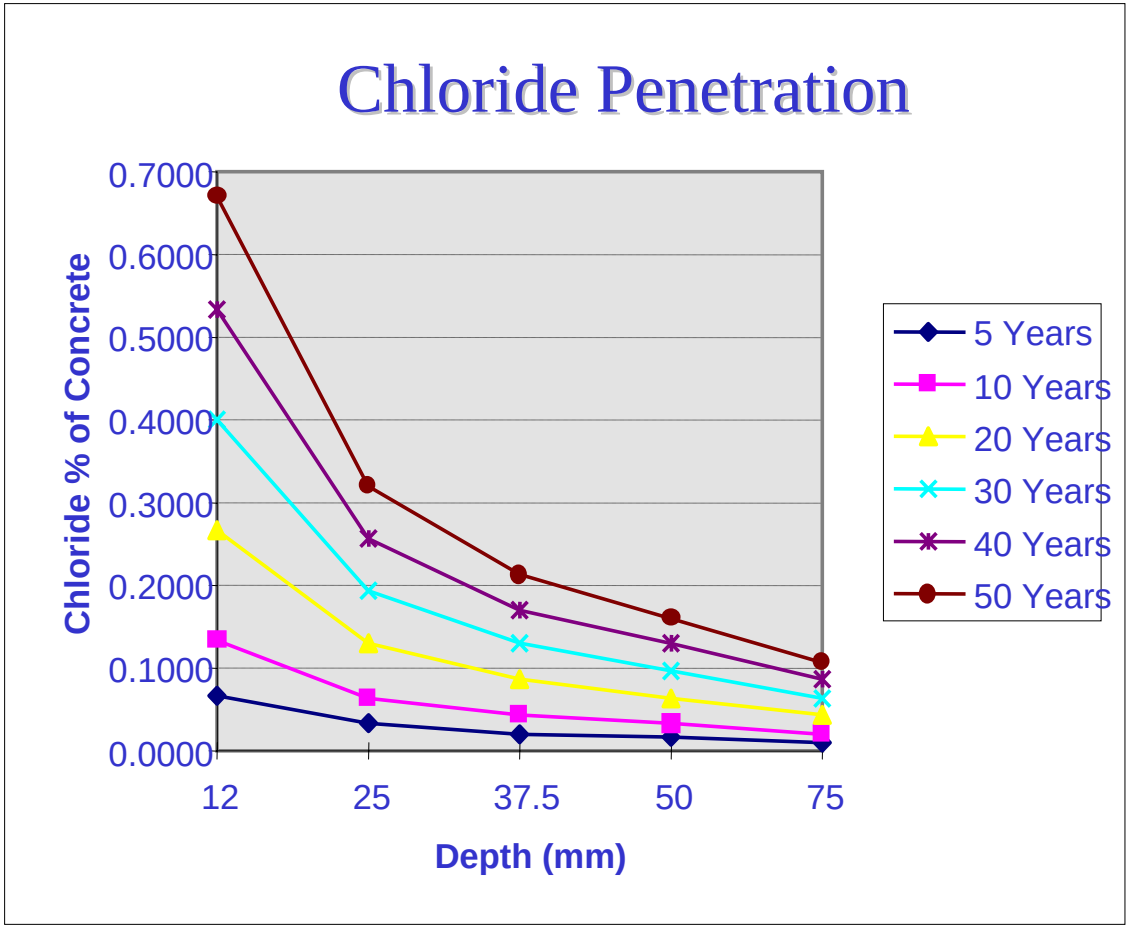
Why FRP Reinforcement?



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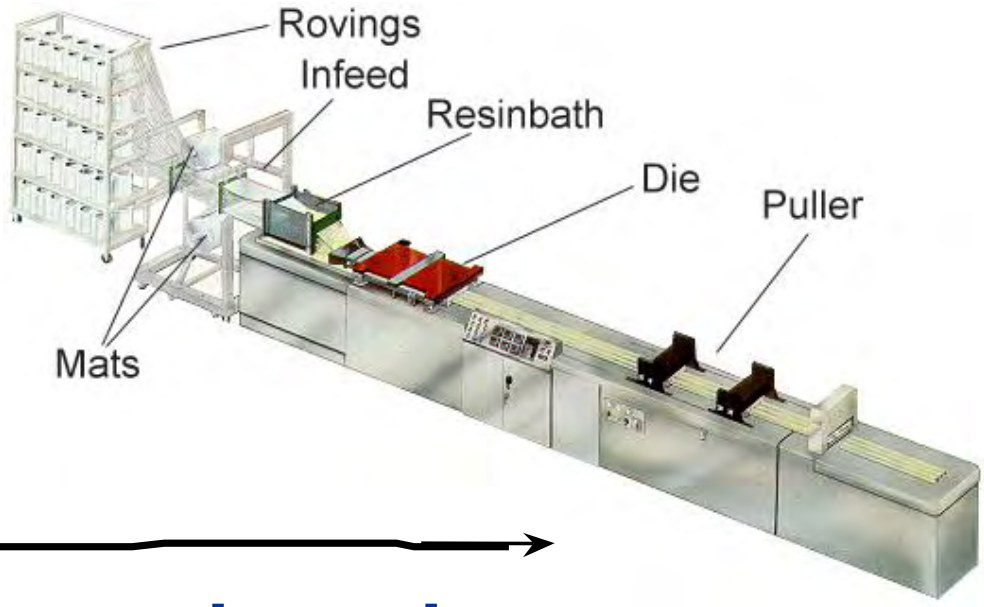
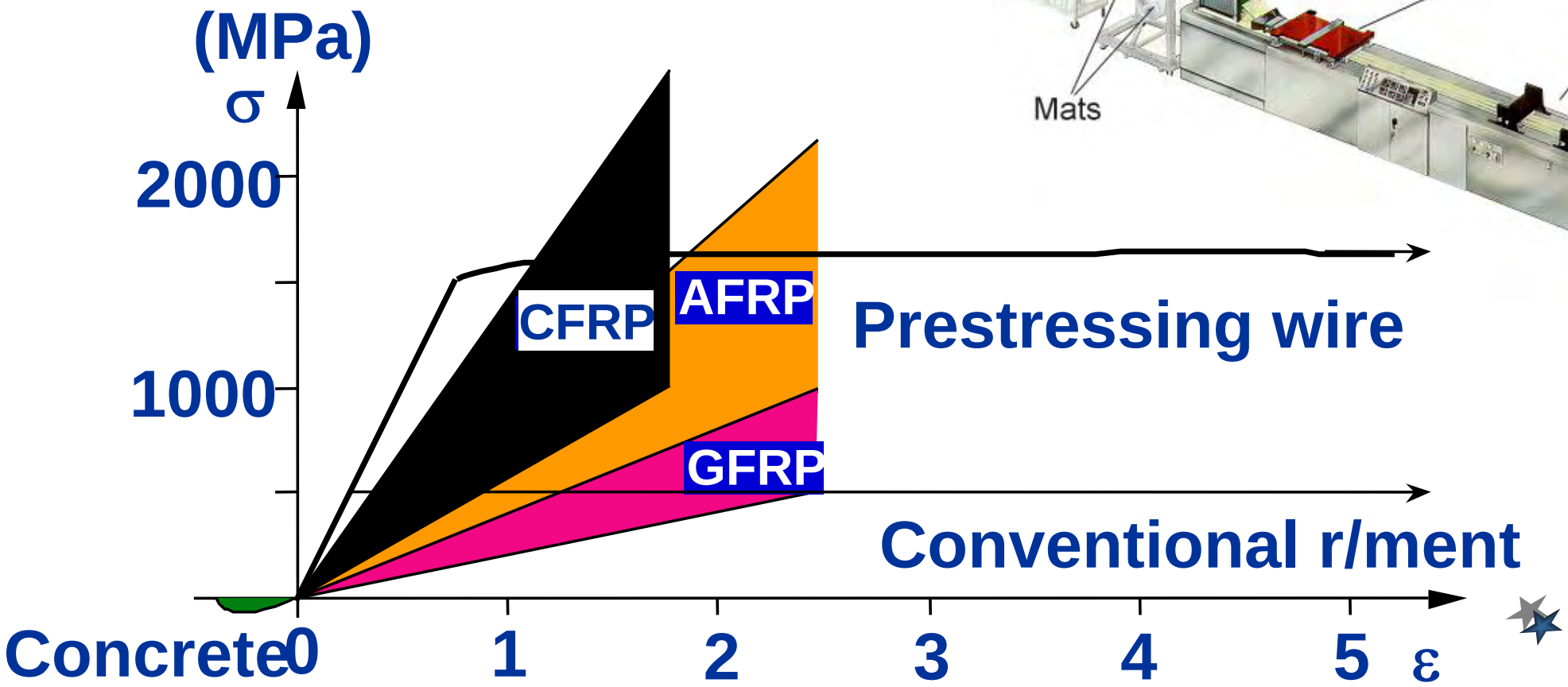
What is FRP Reinforcement?





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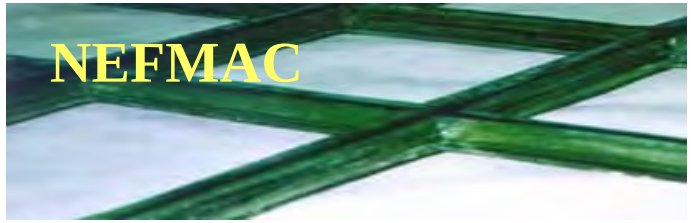
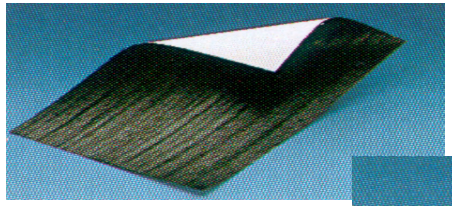
Types of FRP Reinforcement

Hughes Brothers

EUROCRETE

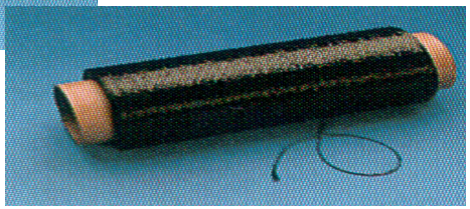
C-Bar





UD Tape

Mitsubishi



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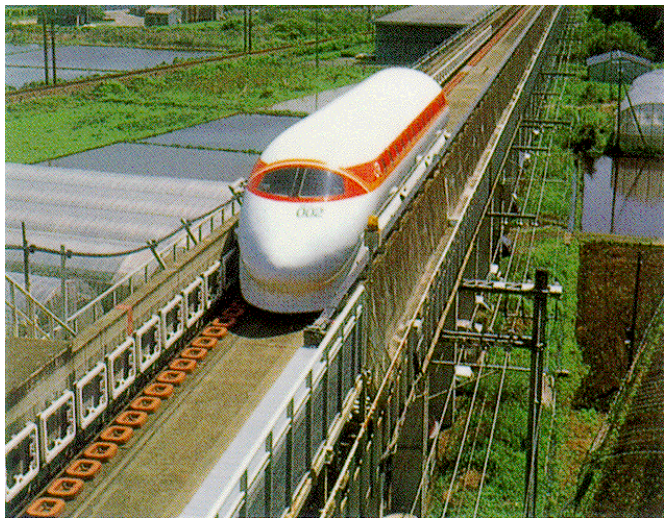
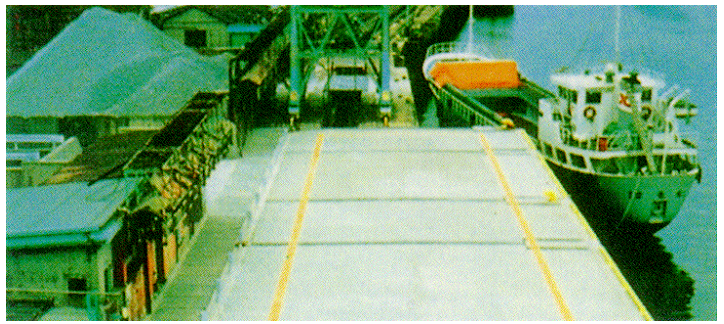
Applications





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ConFibreCrete TMR Network

Context Of Work

- **Eurocrete Project**
  - *Aim:* **Durable FRP Reinforcement**
  - *Partners:* **9 Companies + University of Sheffield**
  - *Funds:* **5.6 million ECU**
- ***fib* TG 9.3 + ConFibreCrete Research Network**
  - *Aim:* **Design Guidelines**
  - *Members:* **Over 40 International Experts**
  - *TMR:* **11 Institutions from 9 EC Countries**
  - *Funds:* **1.3 million Euro**

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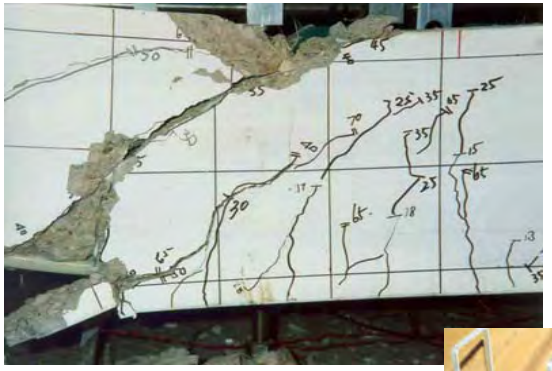
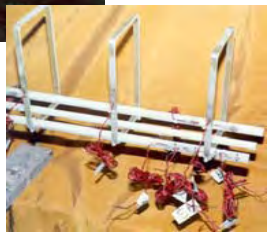
Research on FRP Reinforcement

Flexure and Cracking

Bond

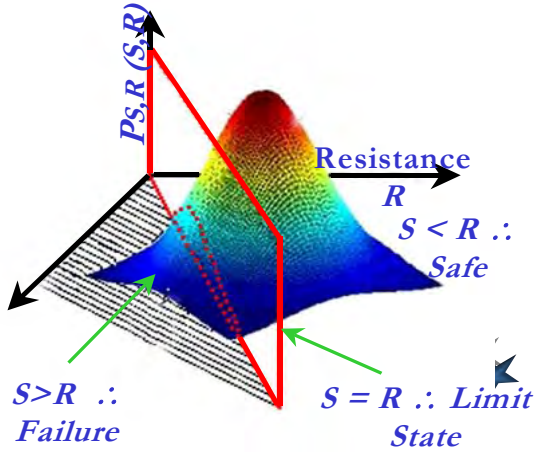




Shear

Punching Shear

Pre-cast Concrete



Design Philosophy

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Slab Details

First Series

Second Series

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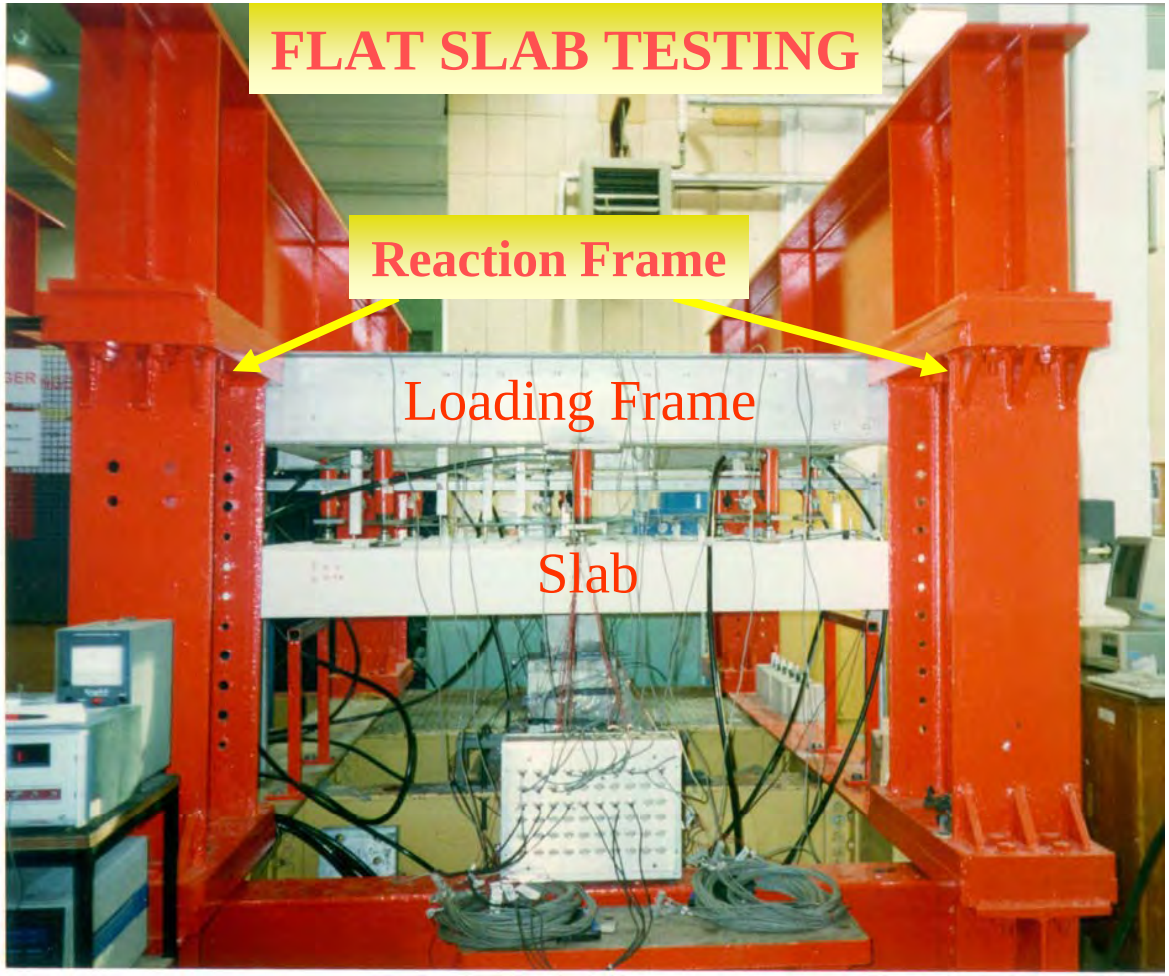
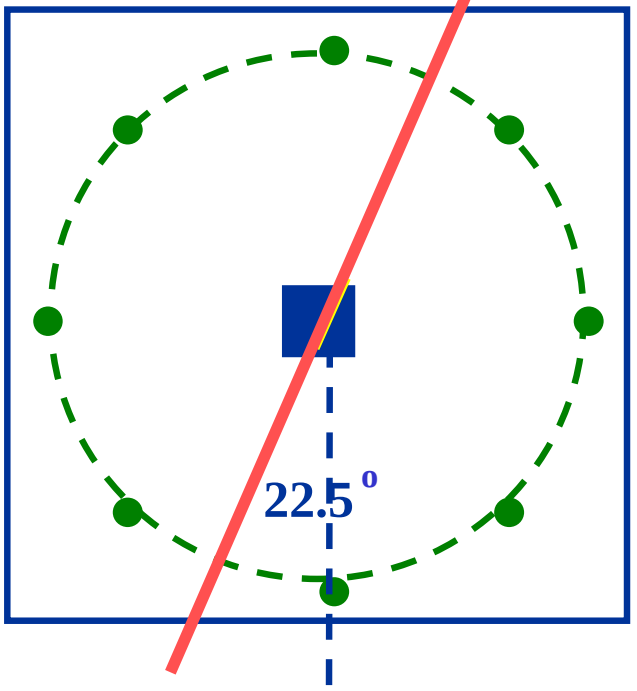
RC Slab Design and Testing

FLAT SLAB TESTING



DESIGN OF SLABS

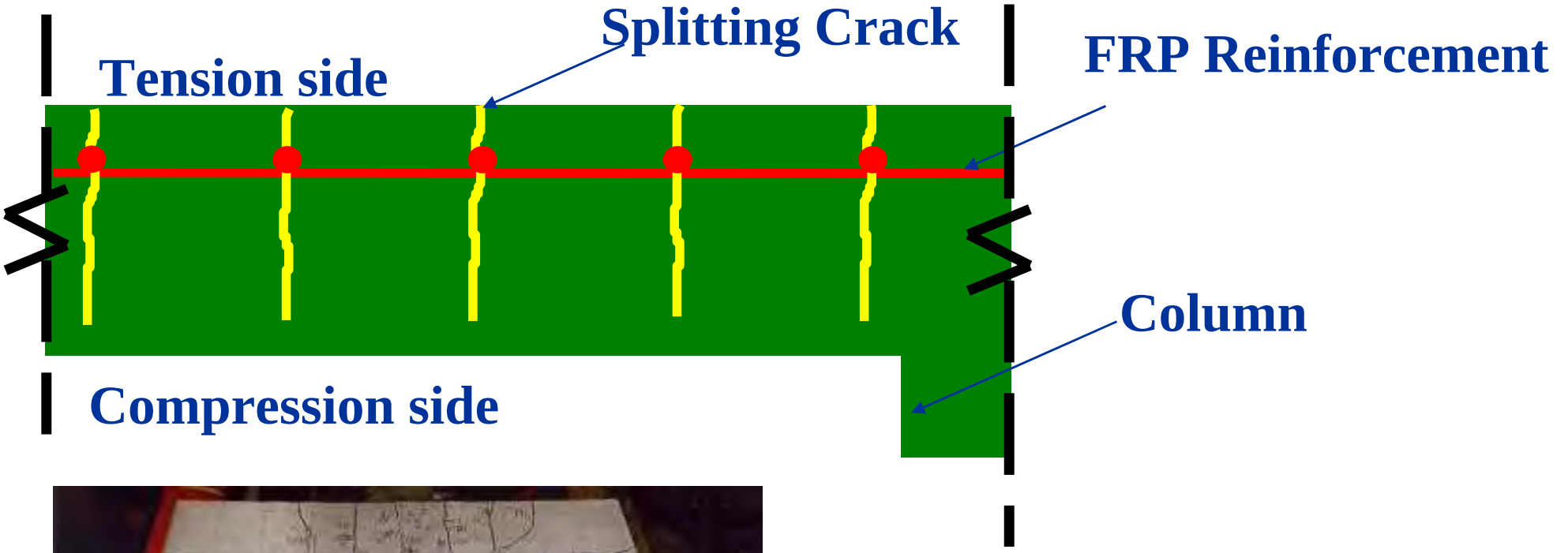


Critical Pattern

Slab SCS1

Bond Slip and Crack Localisation

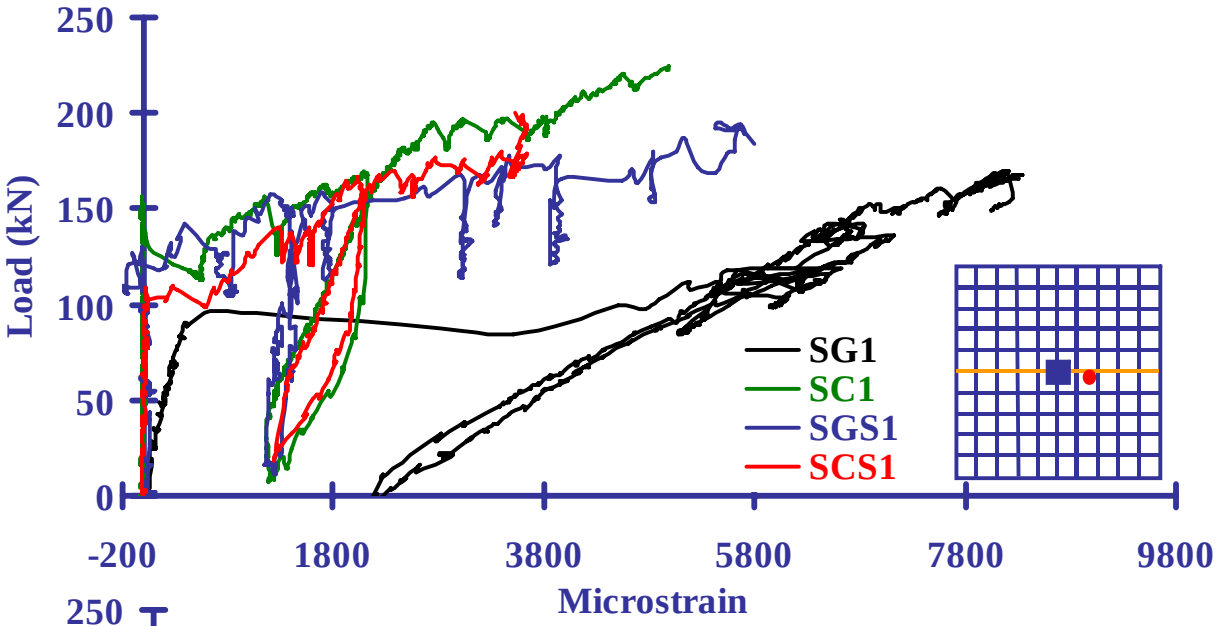
Slabs of the First Series



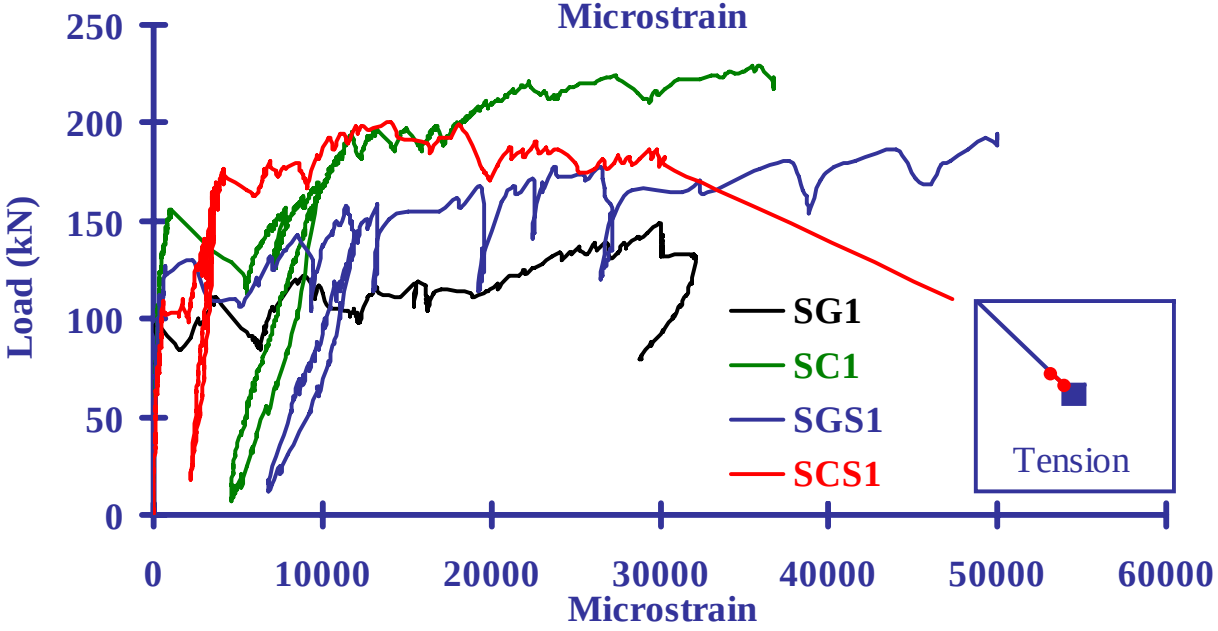
Slab SGS1 at Failure

Bond Slip and Crack Localisation

Slabs of the First Series



Strains in Flexural Bars



Concrete Strains

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Punching Shear Failure

Slabs of the Second Series

Section through Slab SG3
at Failure

Section through Slab SC2
at Failure

Section through Slab SGS2
at Failure

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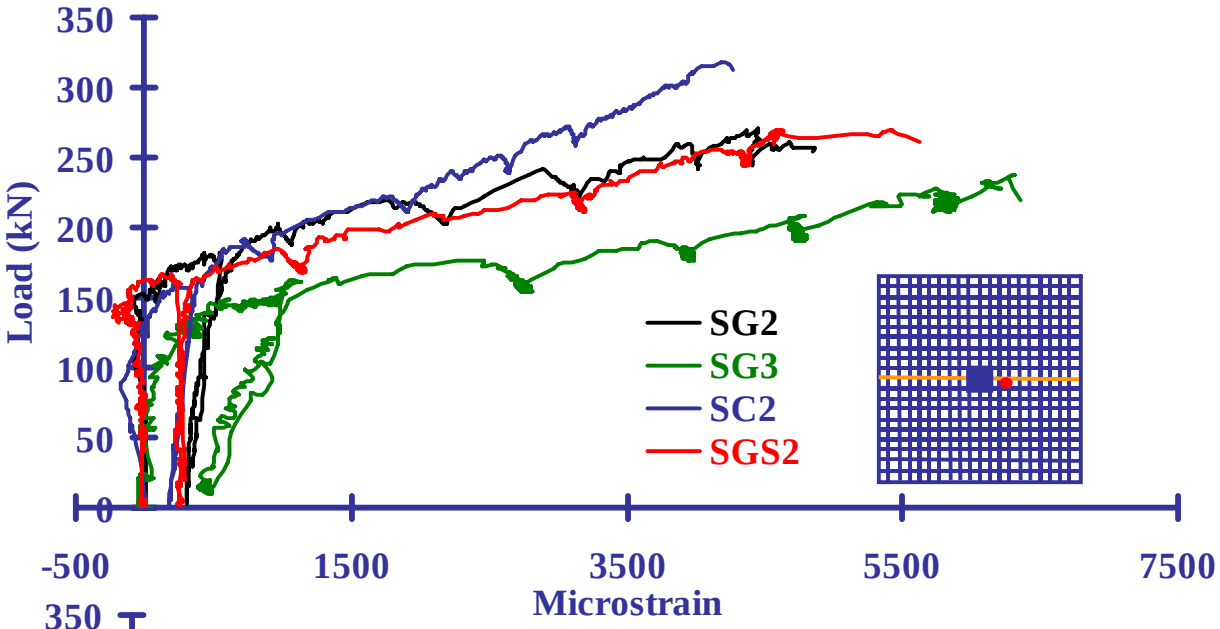
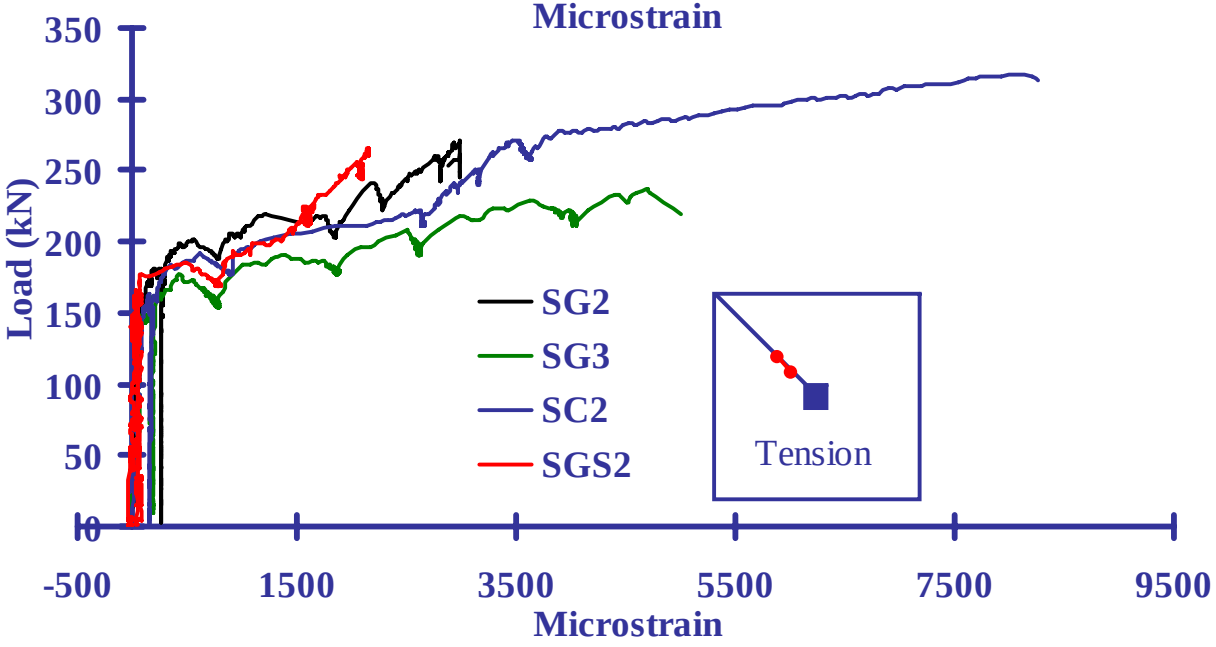
Punching Shear Failure

Slabs of the Second Series



Strains in Flexural Bars



Concrete Strains

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Concrete Shear Resistance

Predictive Approaches

The concrete section does not recognize what it is reinforced with, but only experiences forces and strains.

BS 8110

$$v_c = (100\ A_e / b_v\ d)^{1/3}\ (400 / d)^{1/4}\ (0.27)\ (f_{cu})^{1/3}\ ,$$

Strain Approach $A_e = A_{FRP}\ (E_{FRP} / E_{steel})$

Stress Approach $A_e = A_{FRP}\ (\sigma_{FRP} / \sigma_{yield\ steel})$

Modified Approach $A_e = A_{FRP}\ (E_{FRP} / E_{steel})\ (\Phi)$

$$\Phi = \varepsilon_{FRP} / \varepsilon_{yield\ steel}$$

when $\varepsilon_{FRP} = 0.0045$, $\Phi = 1.8$

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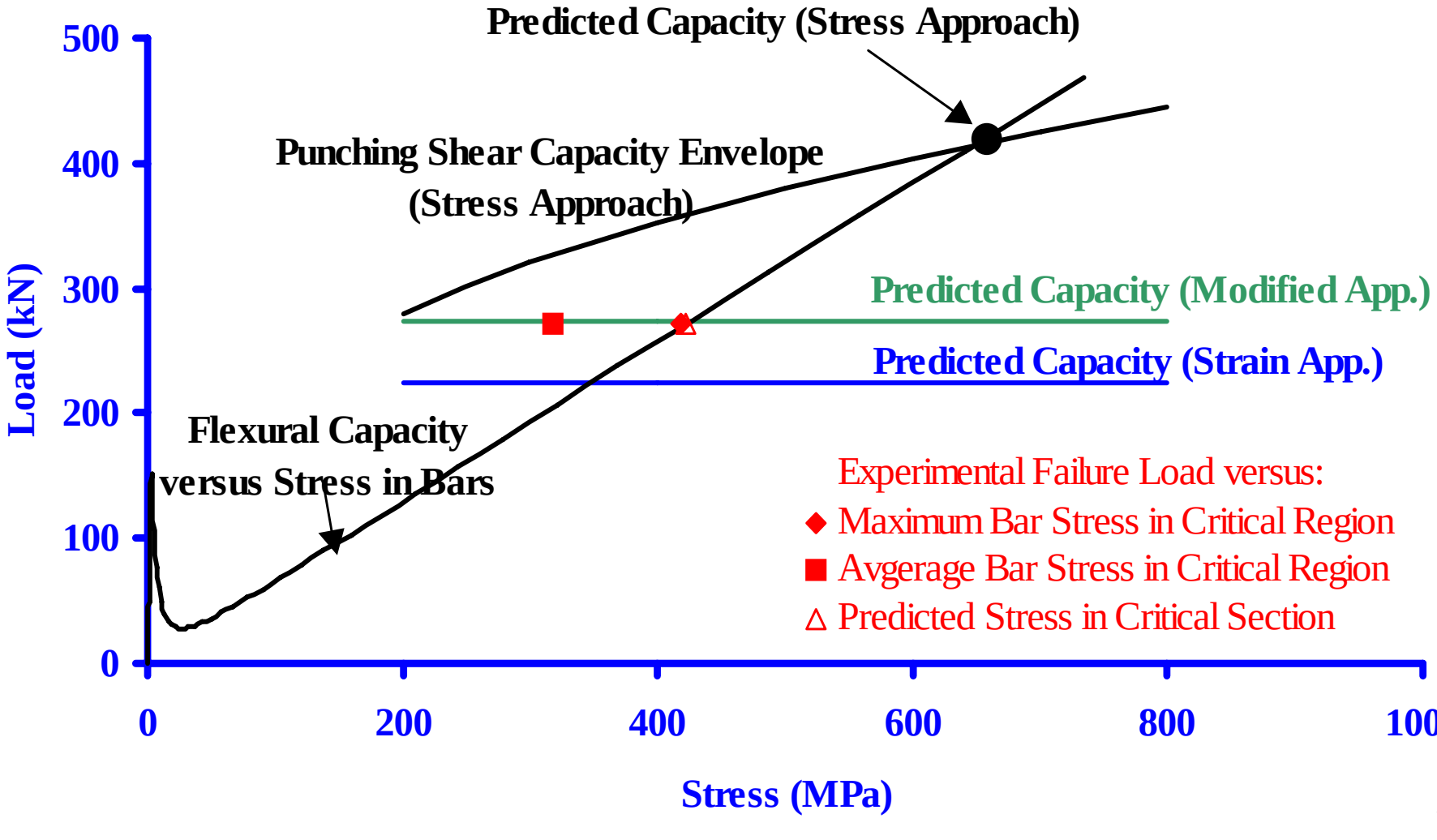
Concrete Shear Resistance

Predictive Approaches

Experimental & BS Predicted Capacities of SG2



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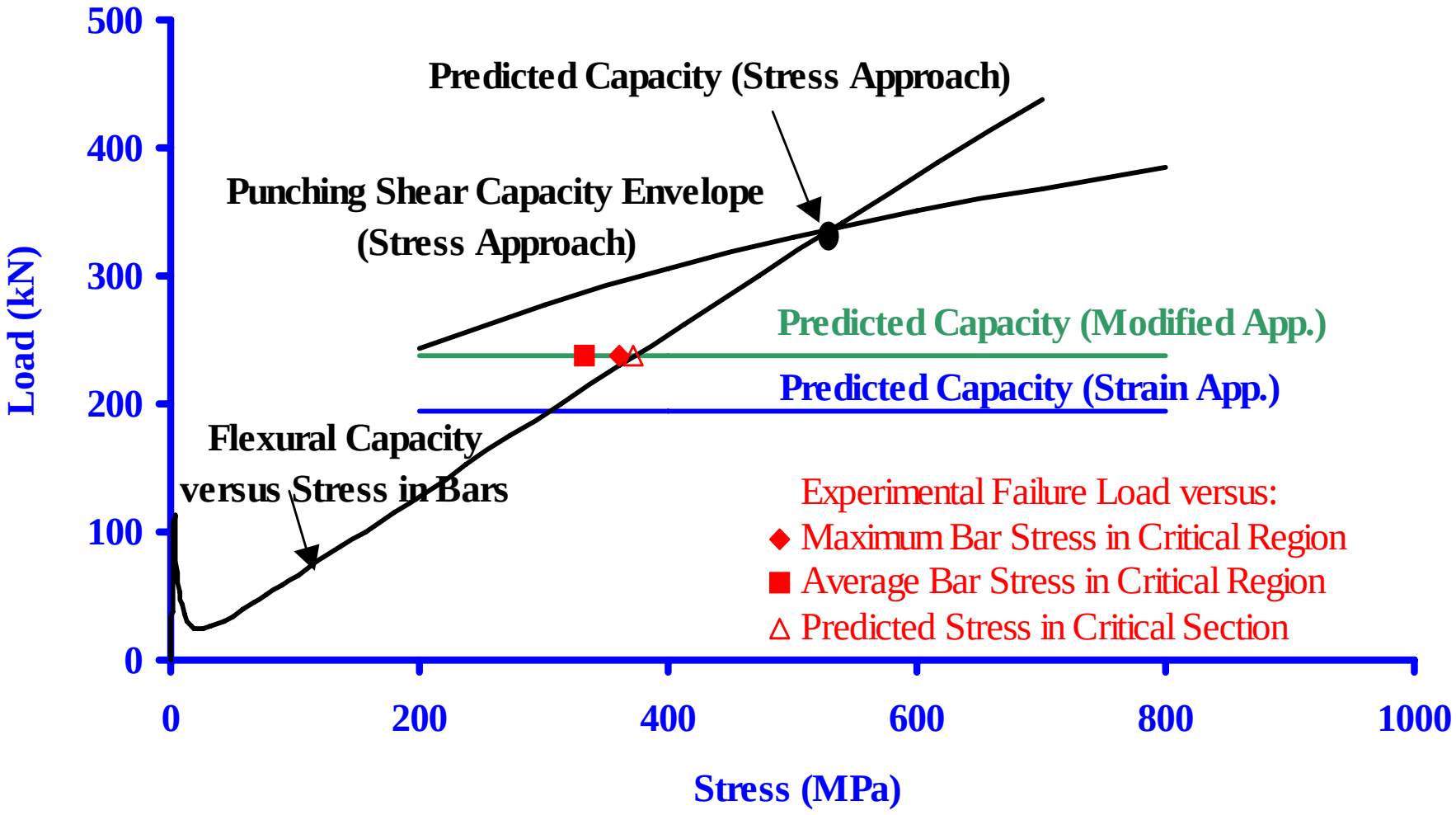
Concrete Shear Resistance

Predictive Approaches

Experimental & BS Predicted Capacities of SG3



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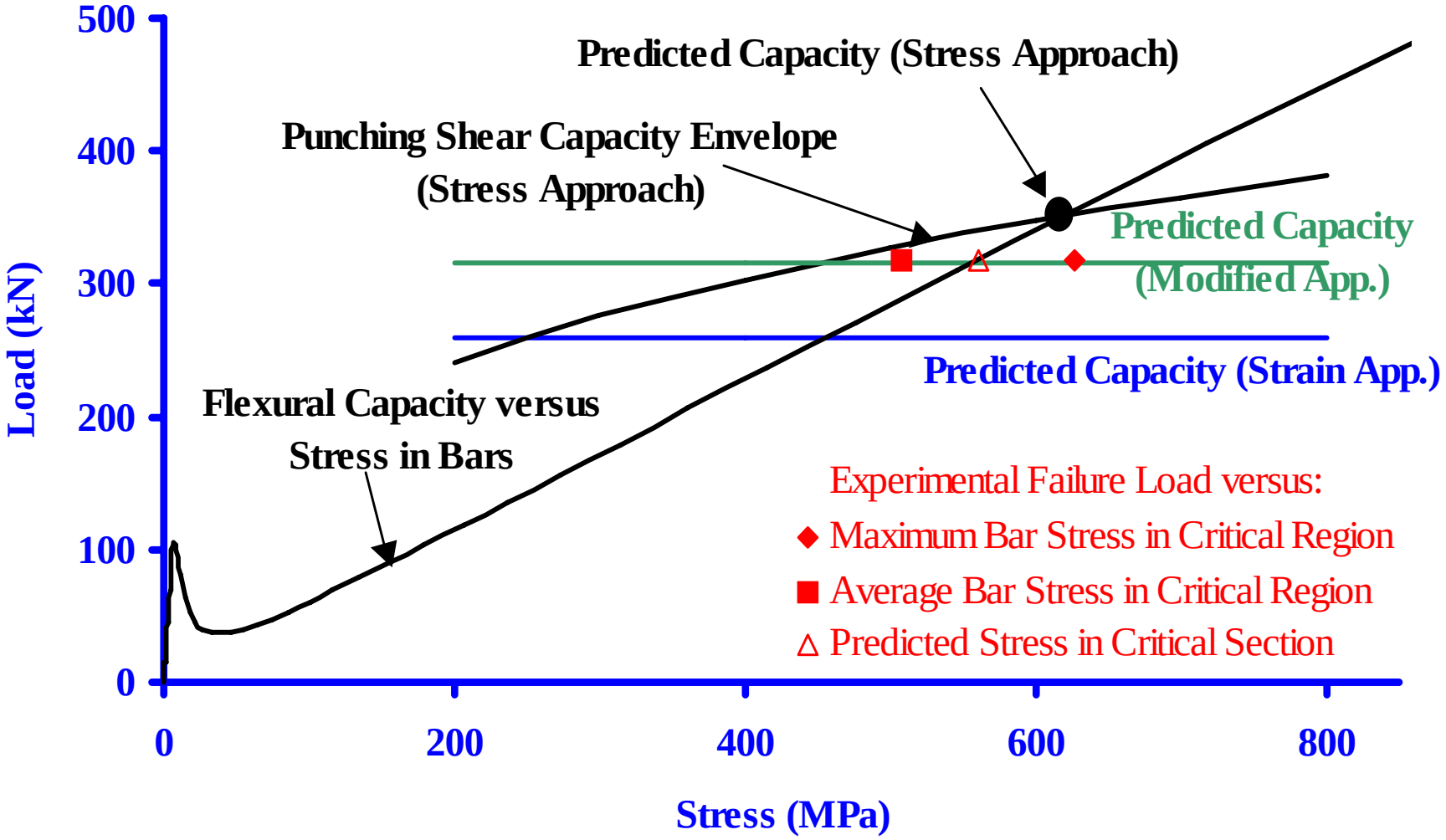
Concrete Shear Resistance

Predictive Approaches

Experimental & BS Predicted Capacities of SC2



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FRP Shear Reinforcement

Predictive Model

P. S. Capacity	Experimental	Conventional	Proposed
Concrete Contribution (v_c) (u) (d) , v_c = concrete shear resistance u = critical perimeter d = effective depth		$v_{c\ (Strain\ App.)}$ (Conservative)	(0.5) $v_{c\ (Modified)}$ (Good)
Reinforcement Contribution (n) $(\varepsilon_{FRP}\ E_{FRP})$ (A) , n = number of vertical legs ε_{FRP} = strain at P.S. failure E = modulus of elasticity A= cross sectional area	ε_{FRP} = 0.0041	ε_{FRP} = 0.0025 (Conservative)	$\varepsilon_{FRP} = (\Phi)\ (0.0025)$ Φ = 1.8 ε_{FRP} = (0.0045) (Good)
SGS2 Capacity (kN)	270	286 (Unconservative)	272 (Good)
Spacing of Reinforcement	Only One Layer of Shear Reinforcement was Fully Activated	0.75 d (Unconservative)	0. 5 d

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CONCLUSIONS

- Bond Slip and Crack Localisation (first series)
- Punching Shear Failure (second series)
- Concrete Shear Resistance
  - Strain Approach is Conservative
  - Stress Approach offers Upper Limit
  - Sheffield Method offers Good Predictions

(Strain Correction Factor $\Phi = 1.8$)

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CONCLUSIONS

- **FRP Shear Reinforcement**
  - **Concrete Contribution = $v_{c(\text{mod. app})}$ / 2**
  - **$\varepsilon_{(\text{shear reinforcement})}$ = (0.0025) (Φ = 1.8)**
  - **Max. Spacing of Shear Reinforcement = 0.5 d**