UNSW SYDNEY | Australia's Global University

On the FE Modelling of Steel Fibre-Reinforced Concrete: Key Challenges and Insights

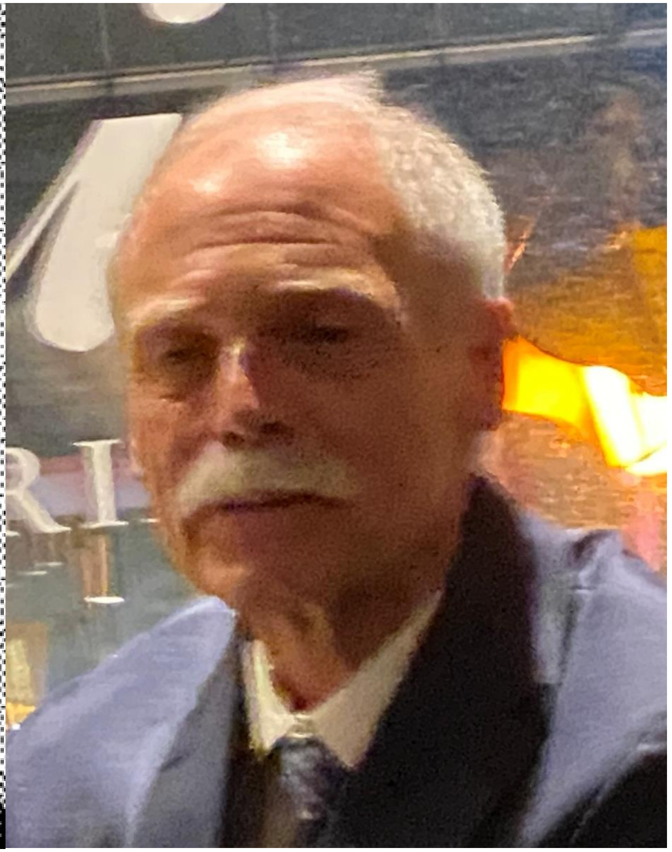
Professor Stephen Foster

School of Civil and Environmental Engineering

UNSW Sydney

Modeling and Performance Assessment of Concrete Structures: Honoring Prof Frank J. Vecchio

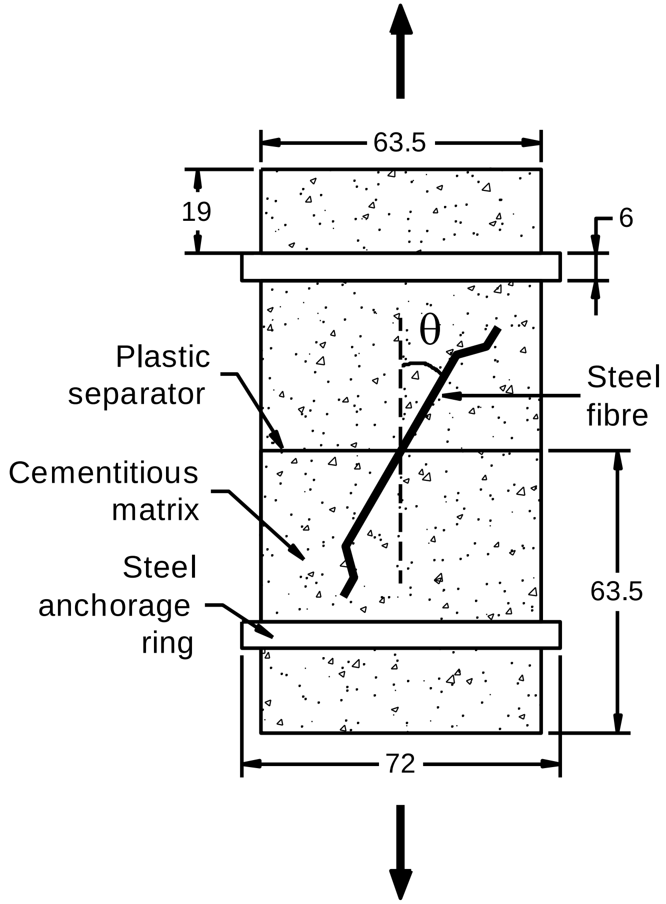
Honoring Prof. Frank J. Vecchio:
Modelling and Performance Assessment of Concrete Structures

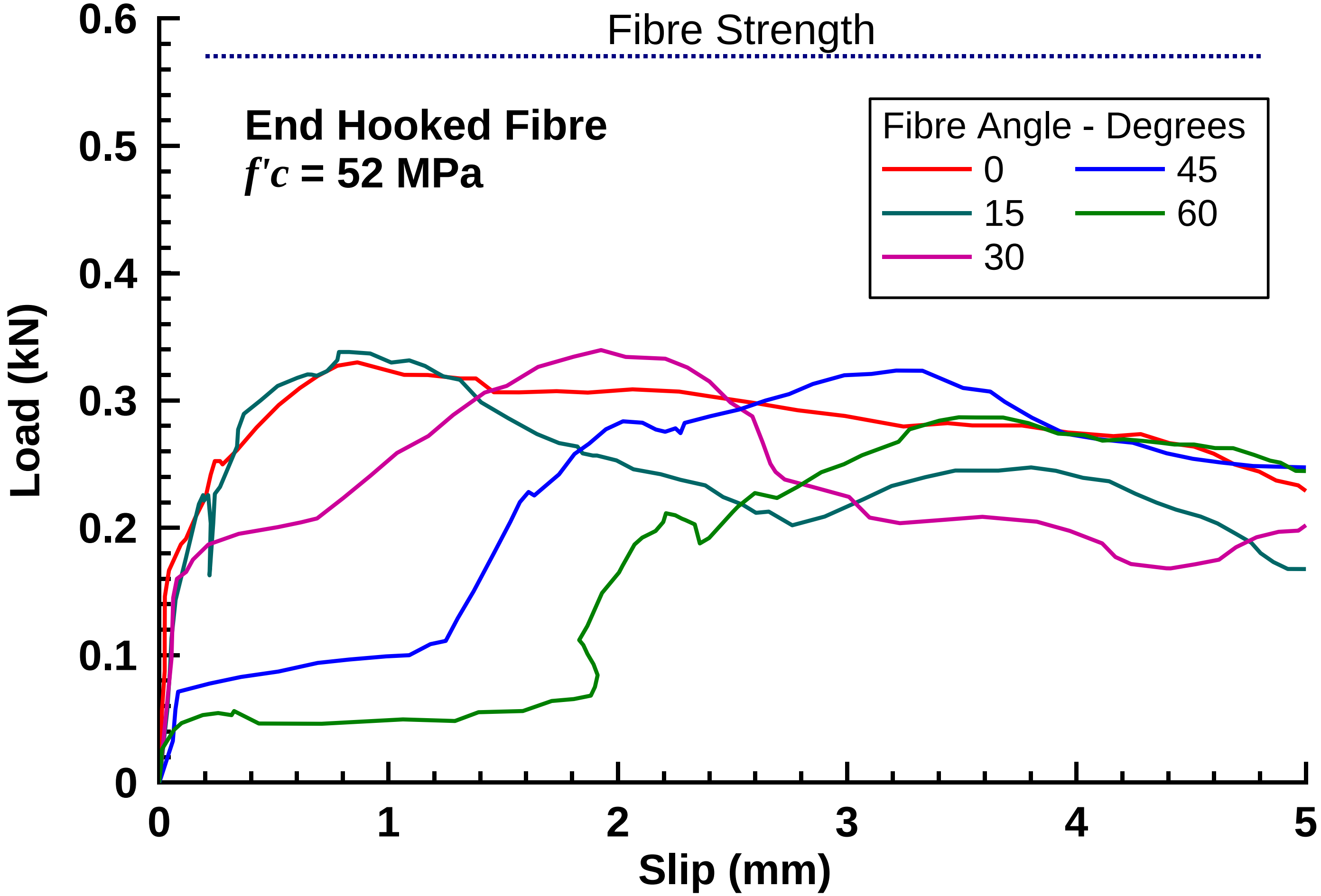


Introduction

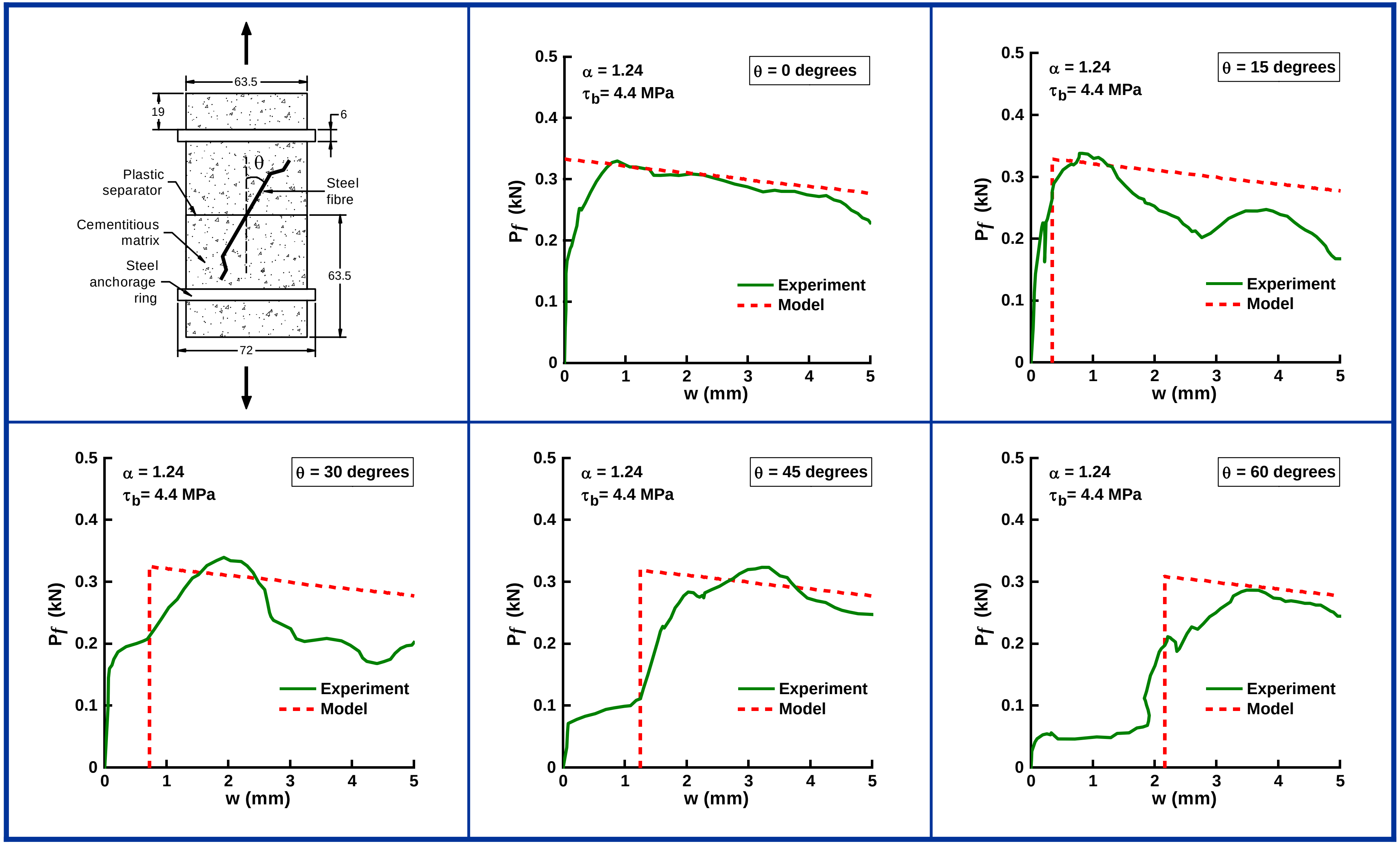
- Brief introduction to the variable engagement model
- The importance of non-local modelling for FRC
- Example 1: UHPC beams failing in shear
- Example 2: Modelling of continuous R-SFRC beams and slabs failing in flexure and designed for moment redistribution
- Concluding remarks

Banthia and Trottier (1994) Single Fibre Pullout Tests



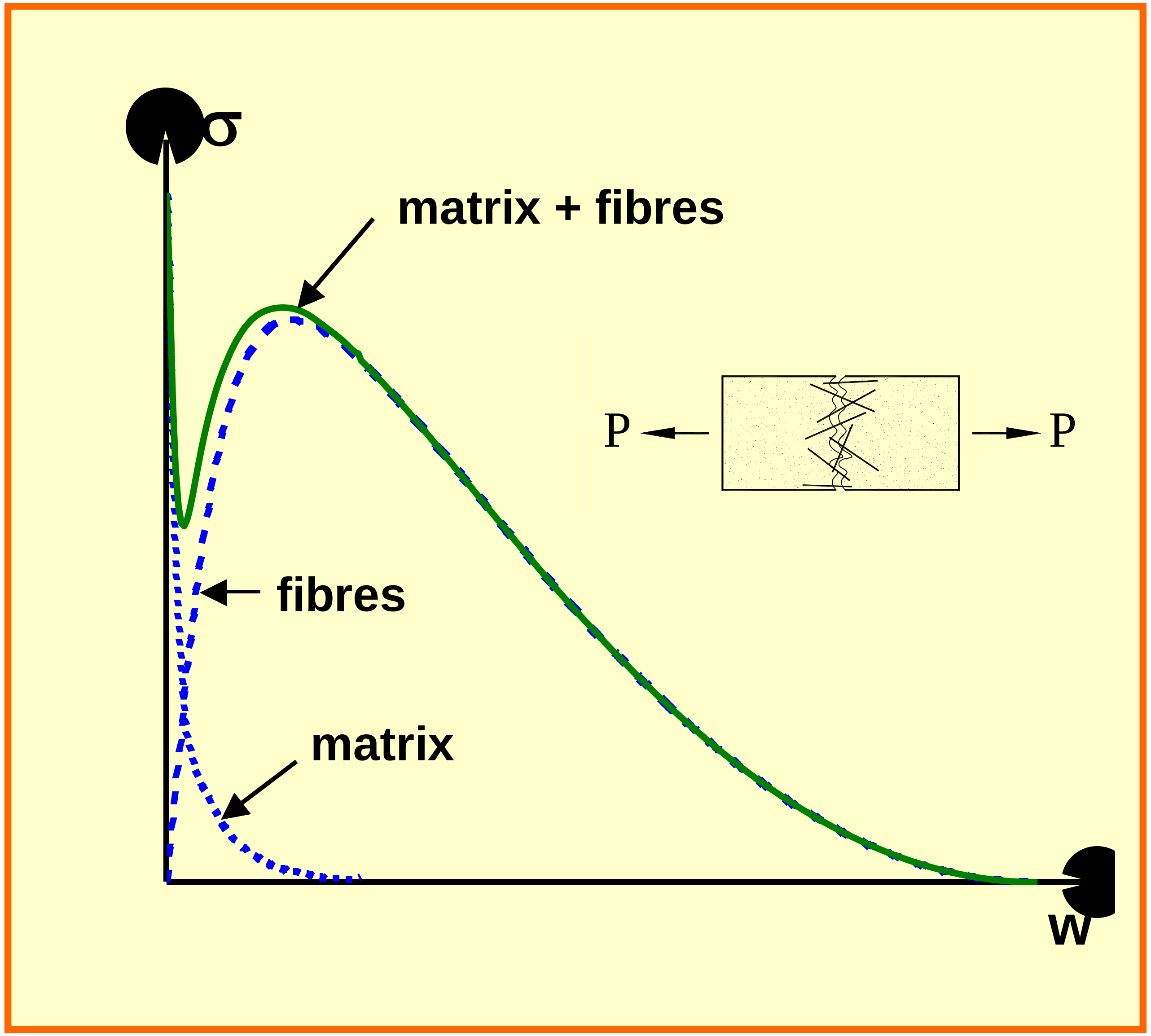


Variable Engagement Model



Variable Engagement Model

Behaviour of FRC in tension is equal to the summation of all components.



VEM I (2003)

PhD Student: Jackie Voo

$$\sigma = K_f \ \alpha_f \ \rho_f \ \tau_b$$

K_f = global orientation factor

α_f = aspect ratio (fibre length/diameter)

ρ_f = volumetric ratio of fibres

τ_f = fibre-matrix bond strength

VEM II (2007)

PhD Student: Greg Lee

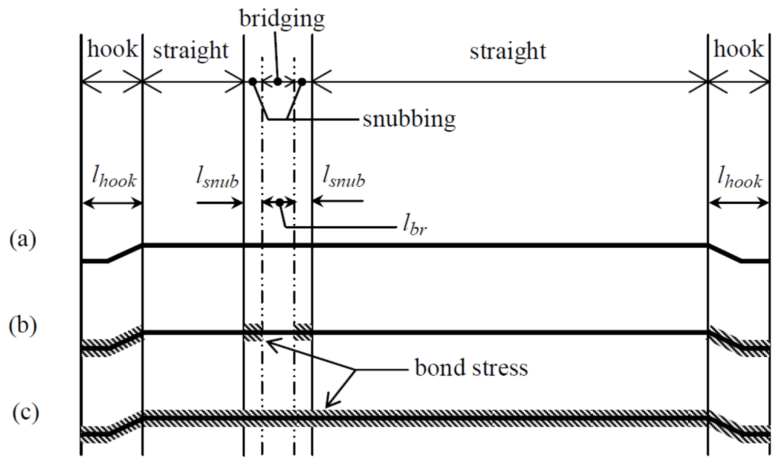


Figure 2.14 Hooked-ended fibre shear contribution: (a) general arrangement; (b) lumped bond stress approach; and (c) uniform bond stress approach.

UVEM (2012)

PhD Students: Tian Sing Ng and Trevor Htut

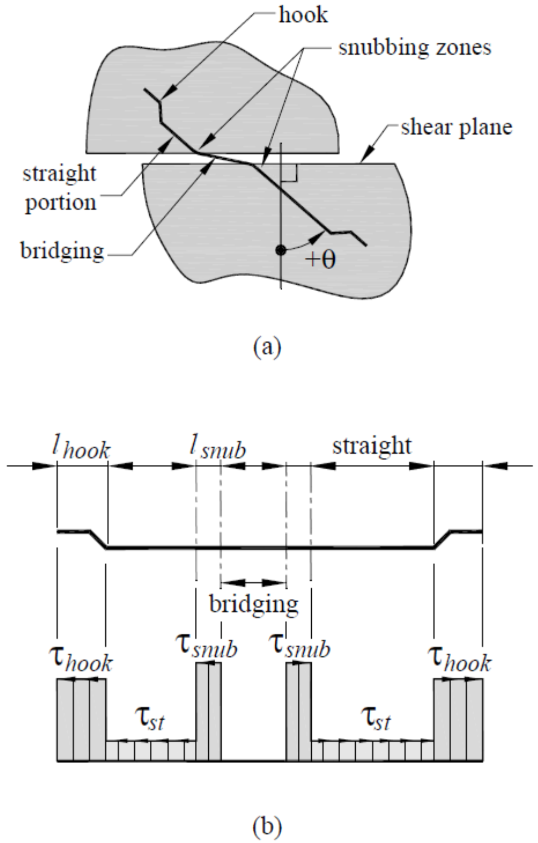
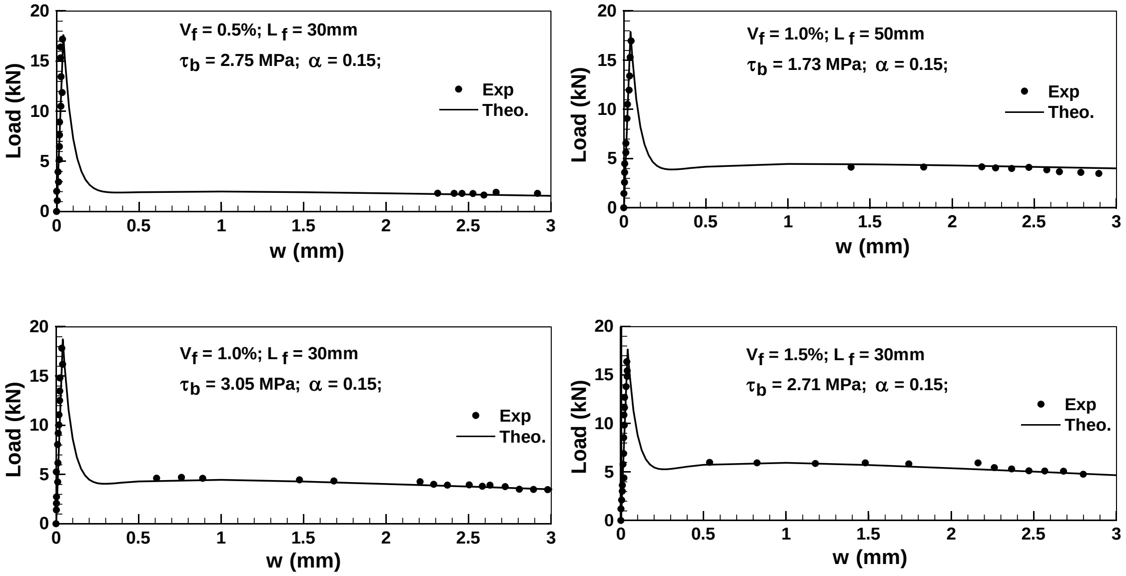
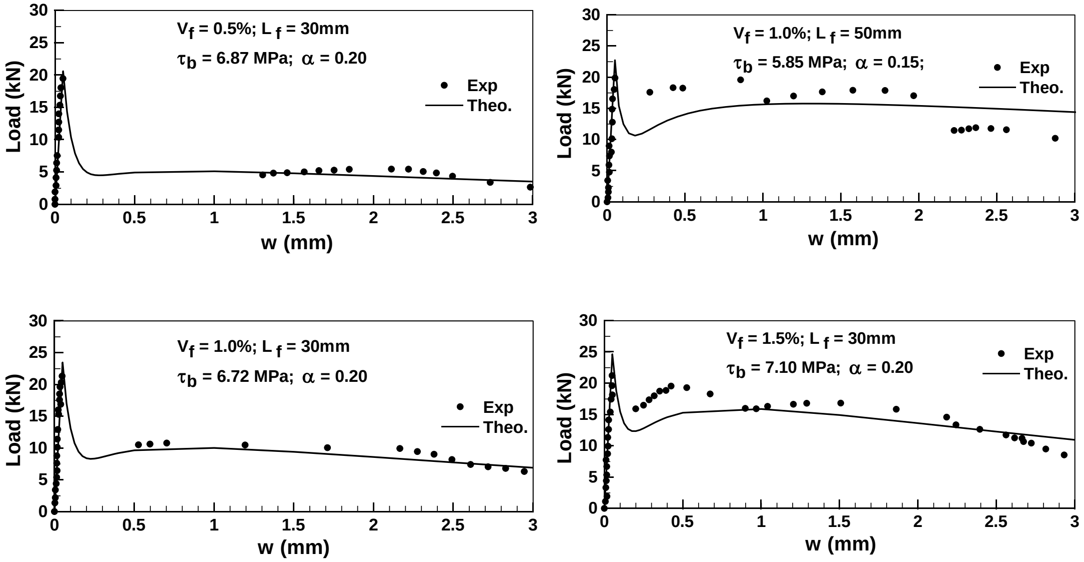


Figure 3.14: (a) Fibre performance zones and (b) shear contributions.

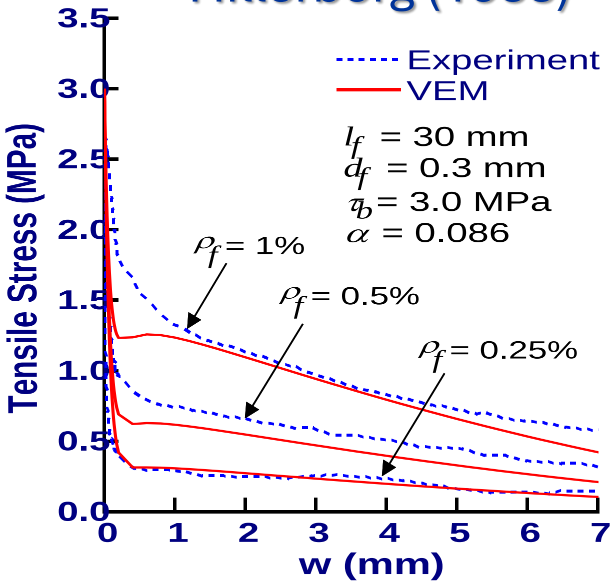
Lim et al. (1987): Straight Fibres



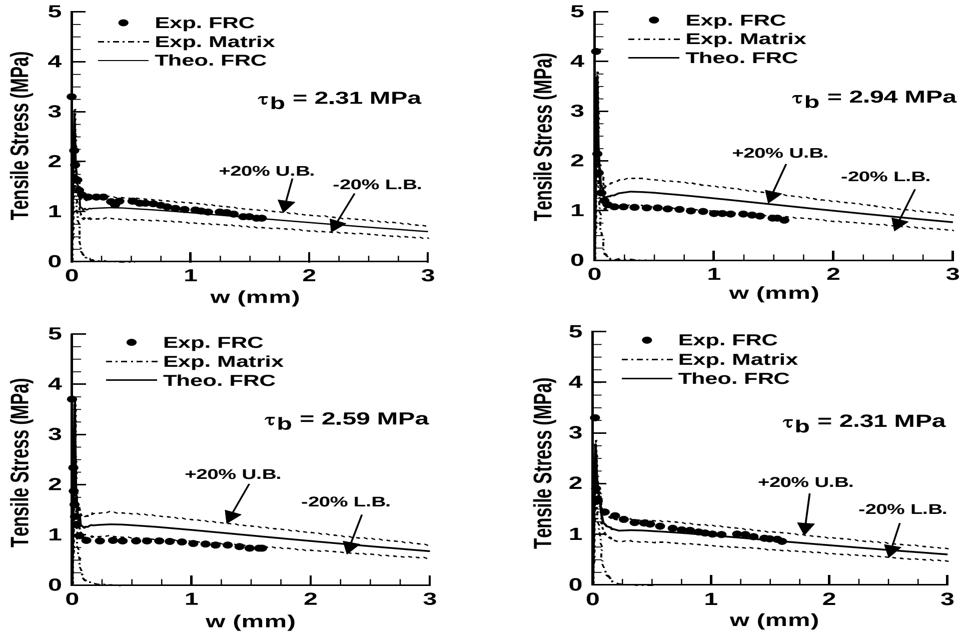
Lim et al. (1987): End Hooked Fibres



Hillerborg (1983)



Groth (2000)



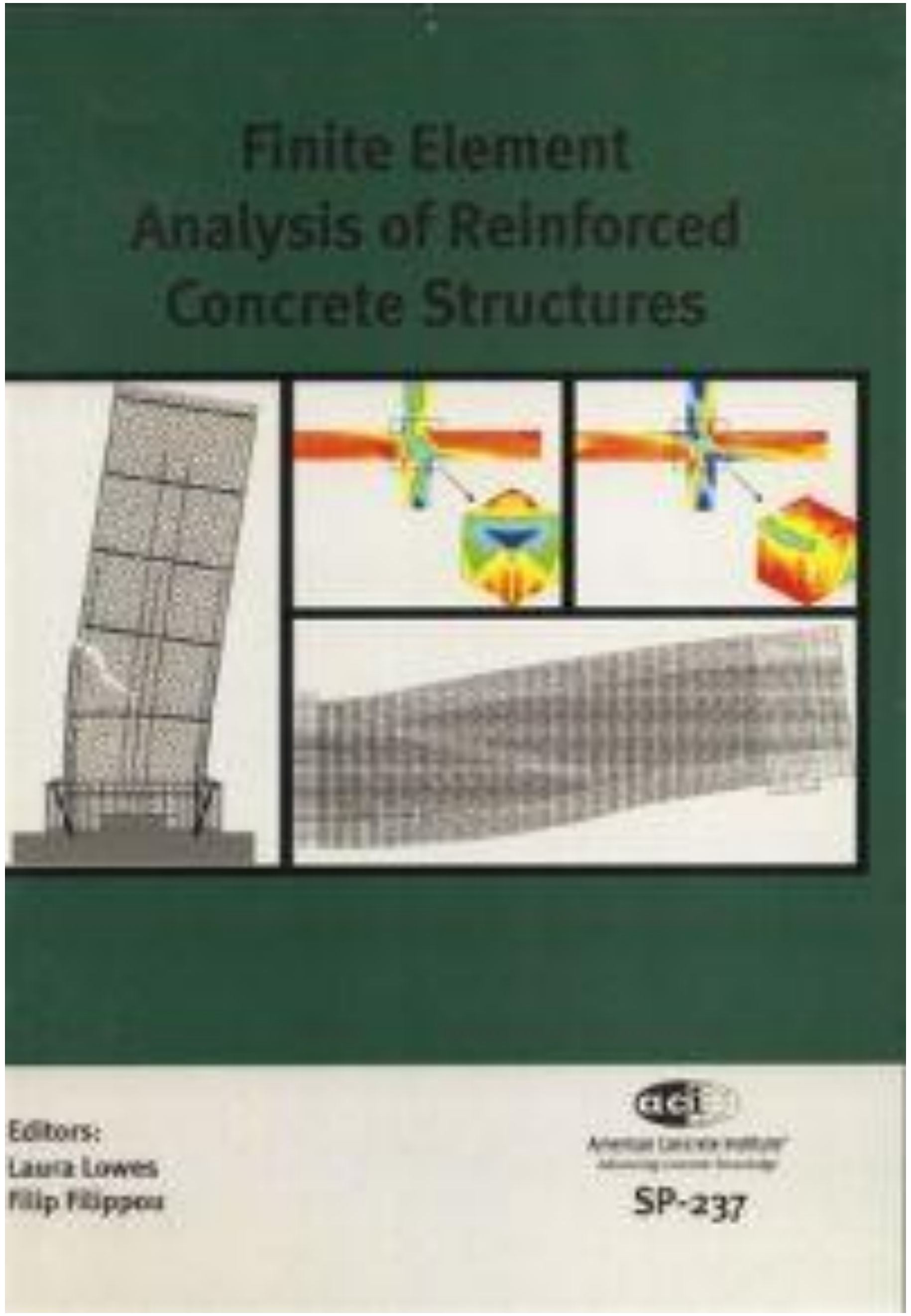
Example 1

SP-237—5

FE Analysis of Steel Fiber Reinforced Concrete Beams Failing in Shear: Variable Engagement Model

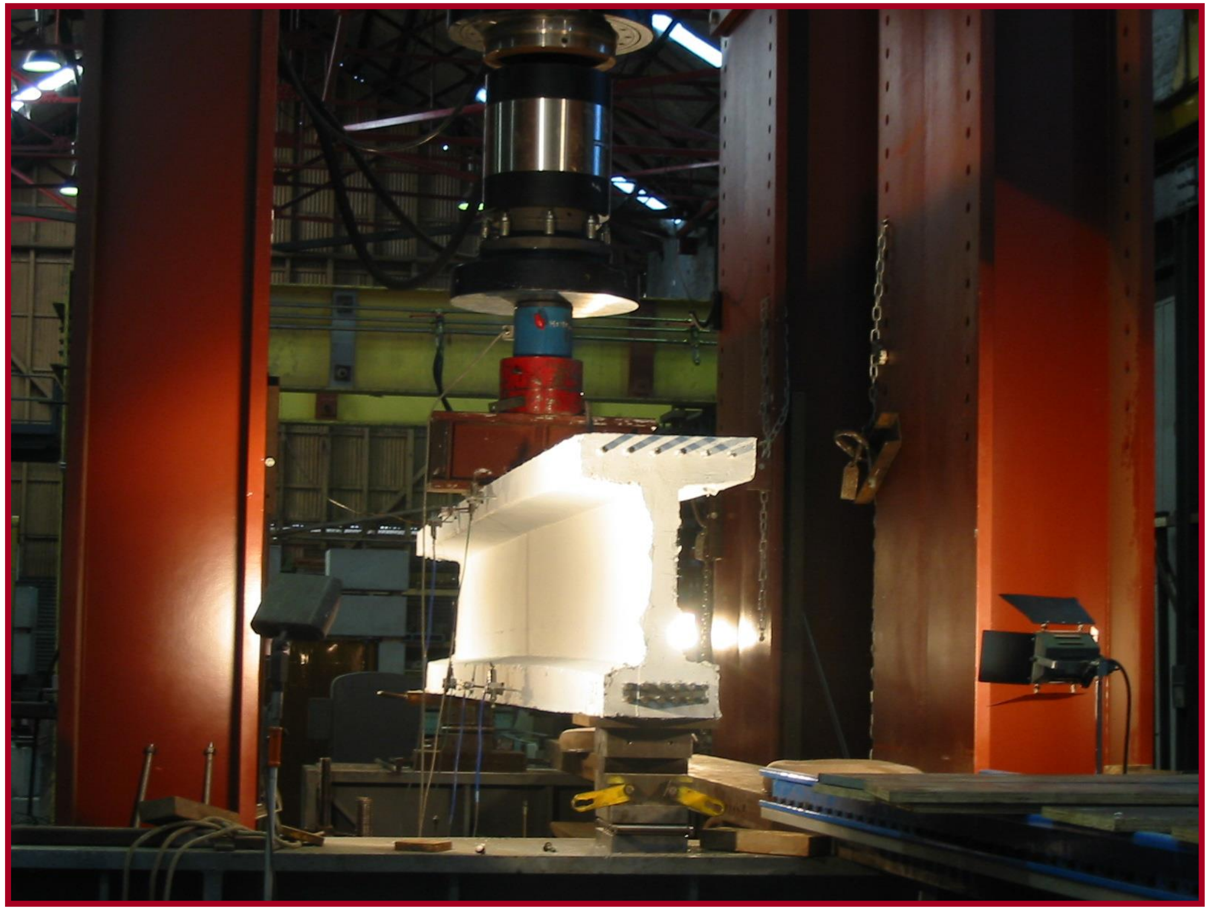
by S.J. Foster, Y.L. Voo, and K.T. Chong

Workshop sponsored by Joint ACI-ASCE Committee 447, Finite Element Analysis of Reinforced Concrete Structures, and JCI Committee 016SP, in Maui, Hawaii, USA, in November 2003.

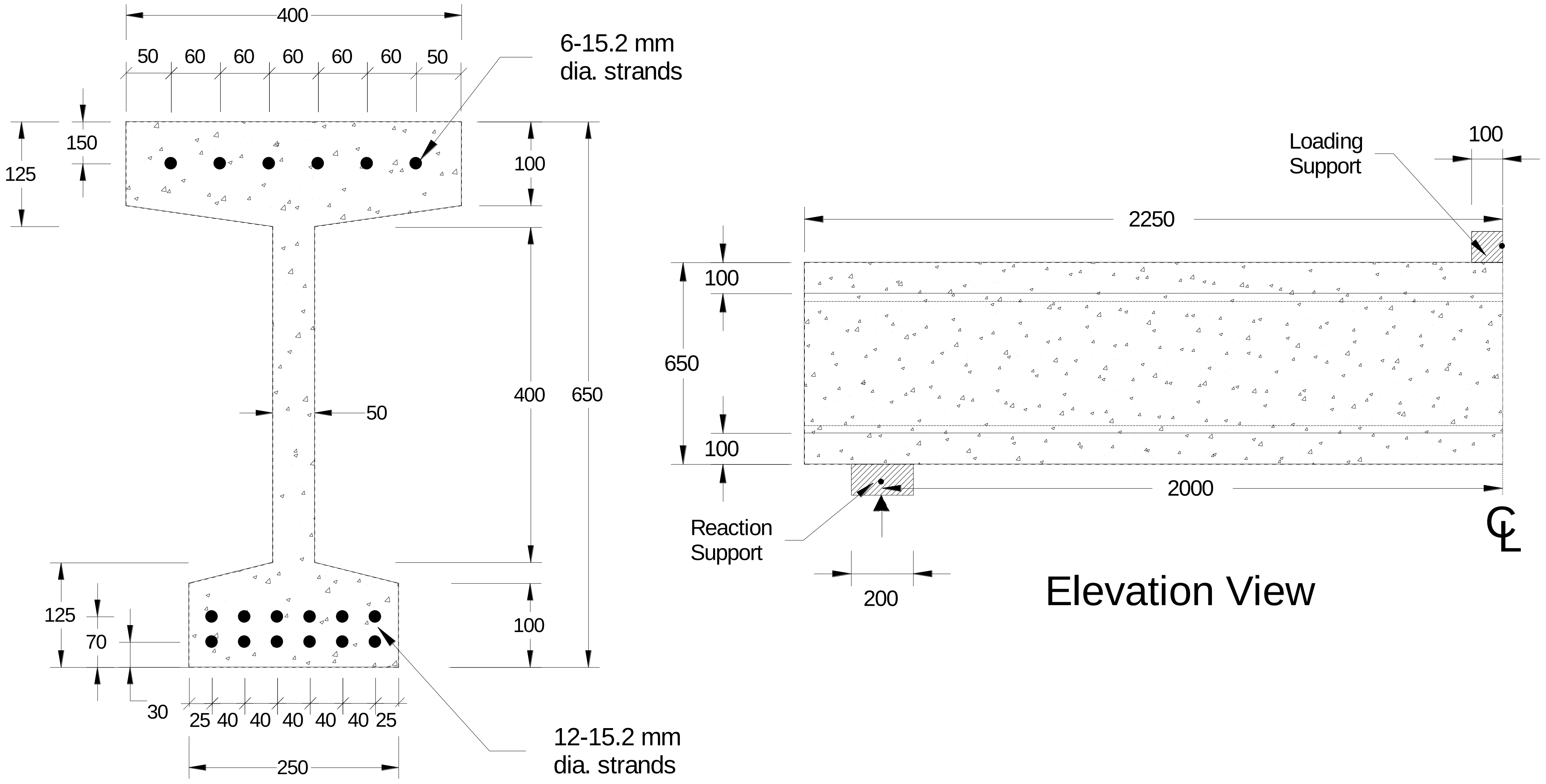


UNSW SYDNEY

FEM of Prestressed UHPC Girders Failing in Shear



Dimensions of RPC Beams

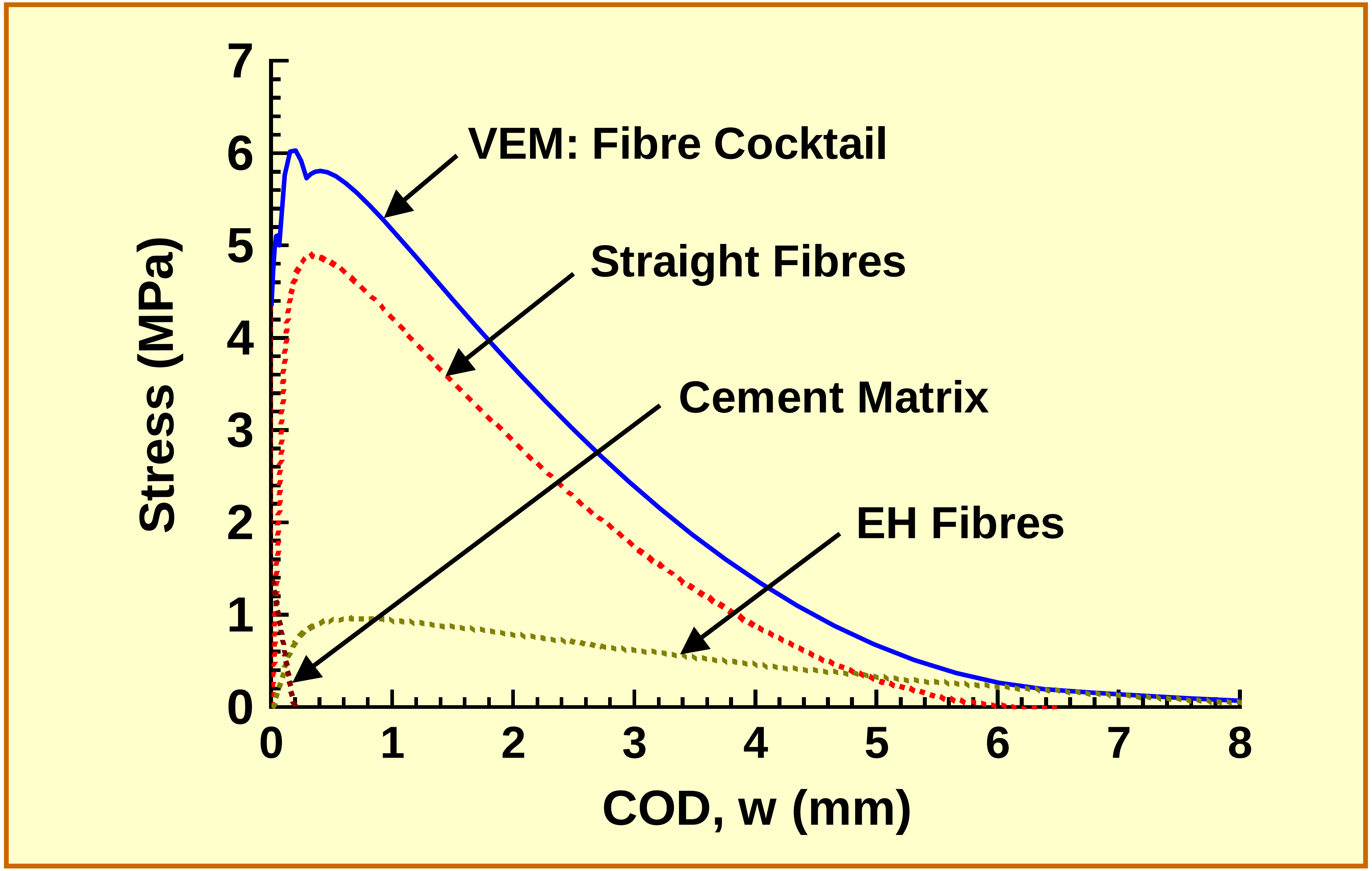


Material Properties

Property	SB7
Straight Fibres	
- volume	1.88 %
- length	13 mm
- diameter	0.2 mm
- σ_{fu}	1000 MPa
- τ_b	10 MPa
- α	0.057 mm
EH Fibres	
- volume	0.62%
- length	30 mm
- diameter	0.5 mm
- σ_{fu}	1800 MPa
- τ_b	15 MPa
- α	0.143 mm

Property	SB7
Concrete	
- f_{cm}	170 MPa
- E_c	46 GPa
- f_{ct} (0.33√fcm)	4.35 MPa
- ν	0.15
Prestressing Steel	
- Area (top)	860 mm^2
- Area (bot)	1720 mm^2
- Prestress	15% GUTS
- Ave Prestress	7.2 MPa

Tensile stress versus COD for SB7 (VEM I)

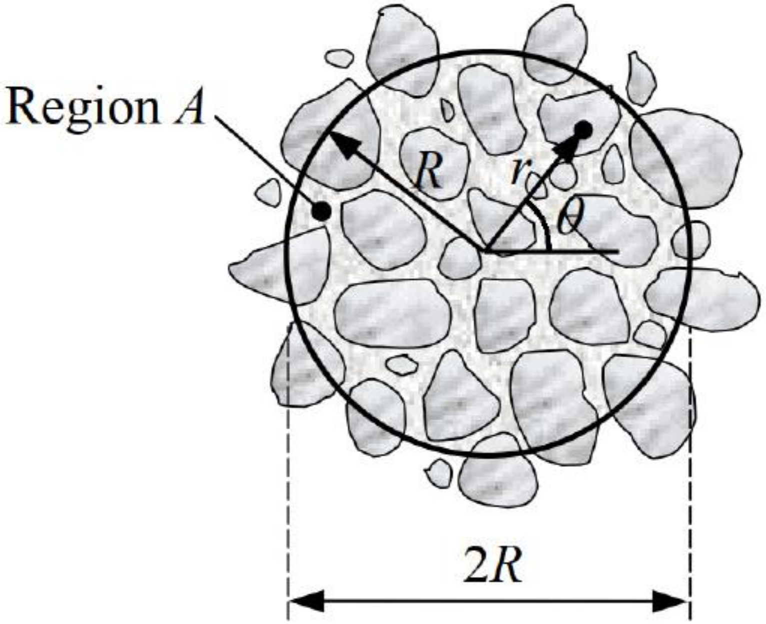


Non-local Model for the Inclusion on Mesh Size Influence

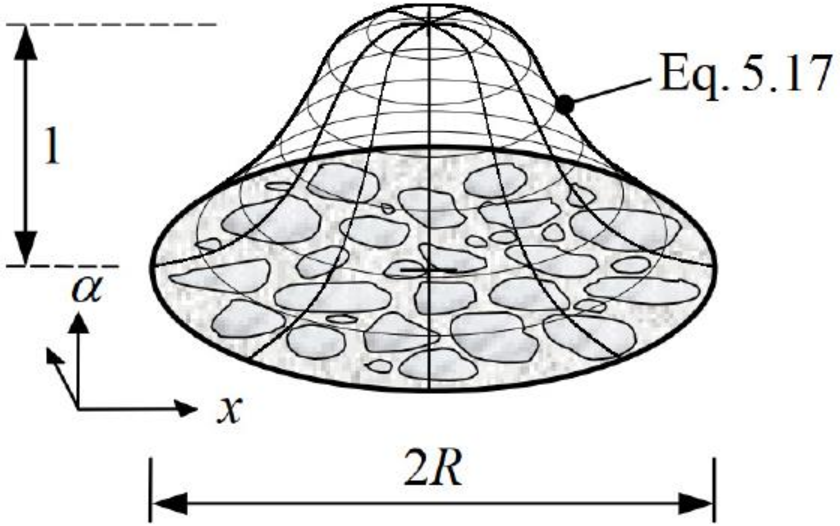
Bažant, Z. P. and Ožbolt, J., Nonlocal microplane model for fracture, damage, and size effect in structures. Journal of Engineering Mechanics, 1990. 116(11): 2485-2505.

$$\gamma(r) = \langle 1 - (r/R)^2 \rangle^2$$

$$R = 0.9086 l_{ch}$$



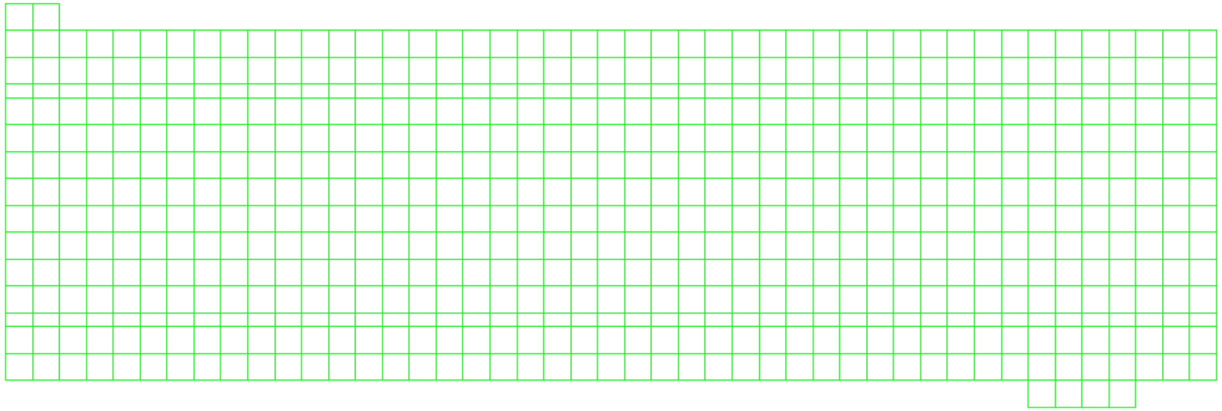
Non-local neighbourhood



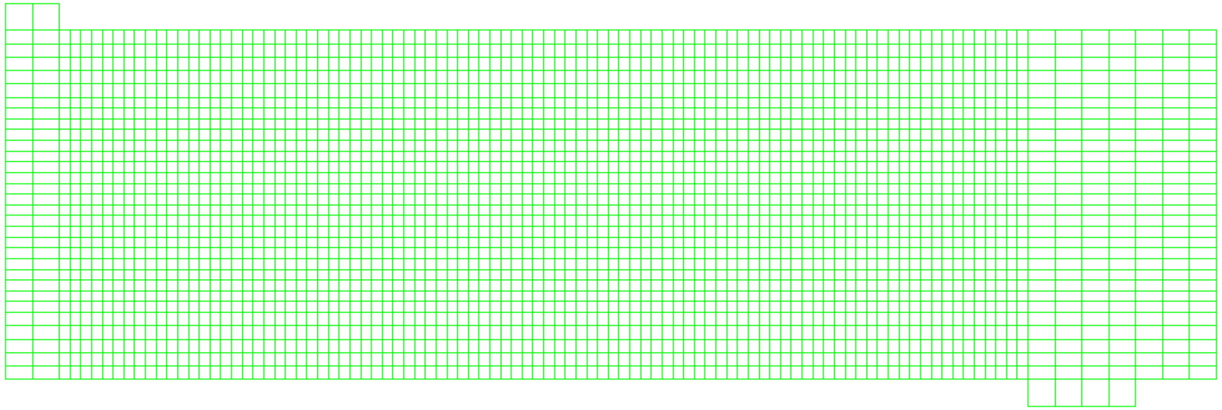
Bell-shaped weight function

Finite Element Meshes

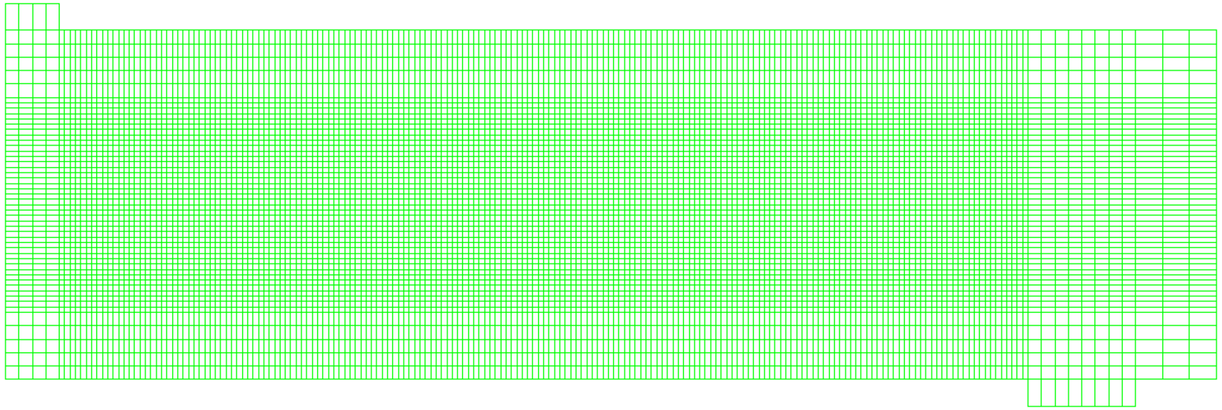
l_{ch} = 50 mm (all meshes)



50 mm x 50 mm Mesh
Nodes: 698
Elements: 726

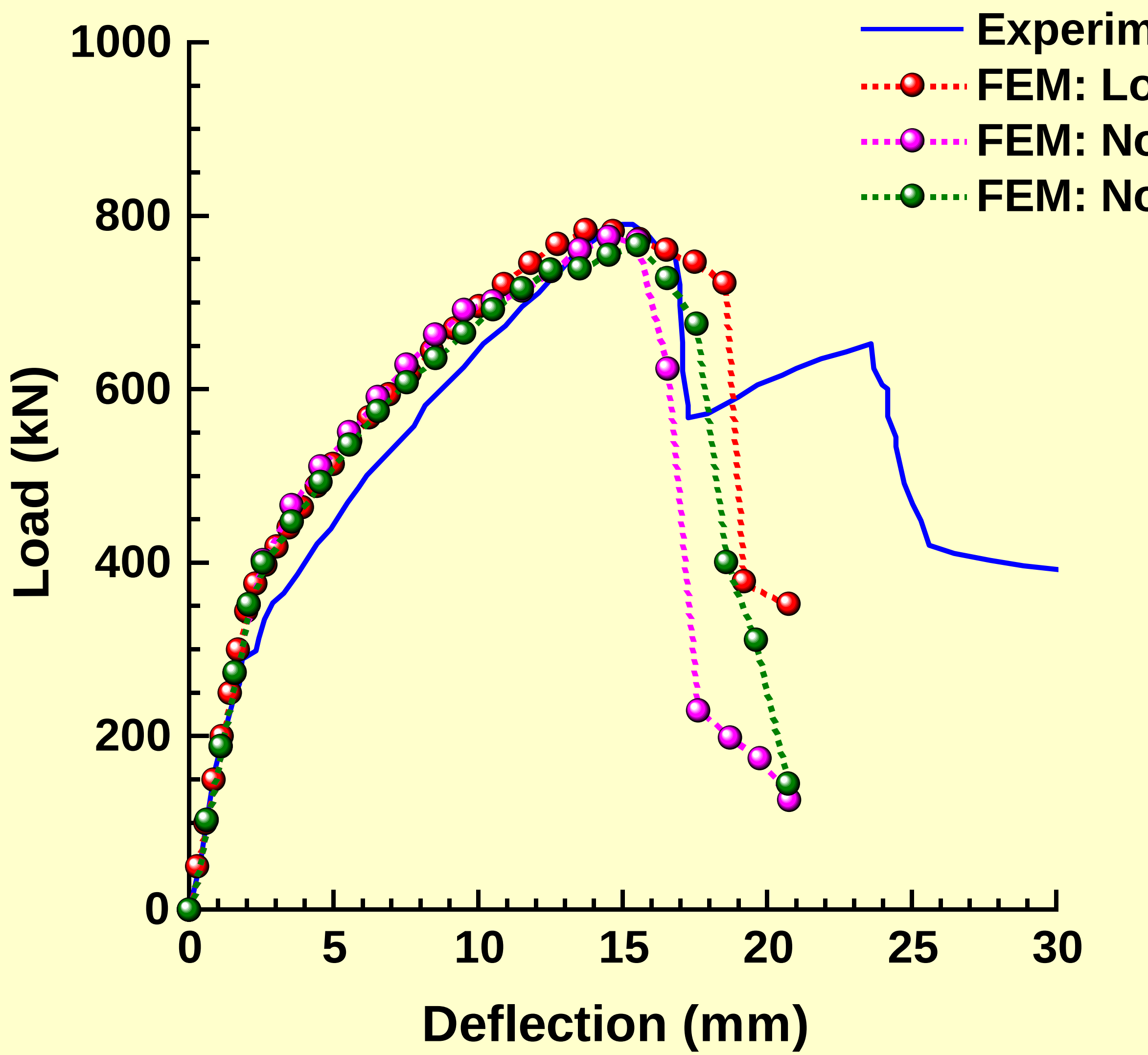


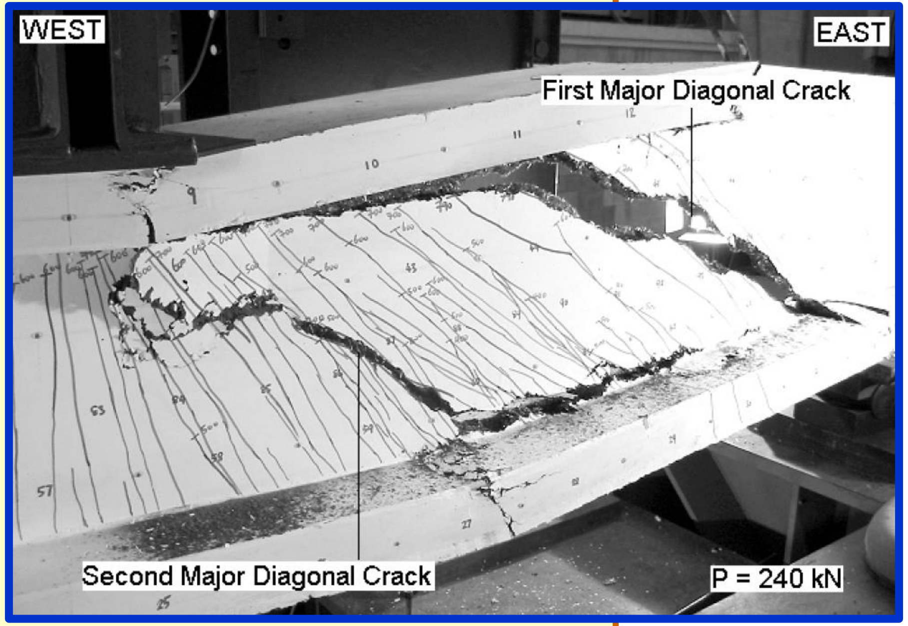
20 mm x 20 mm Mesh
Nodes: 3108
Elements: 3174



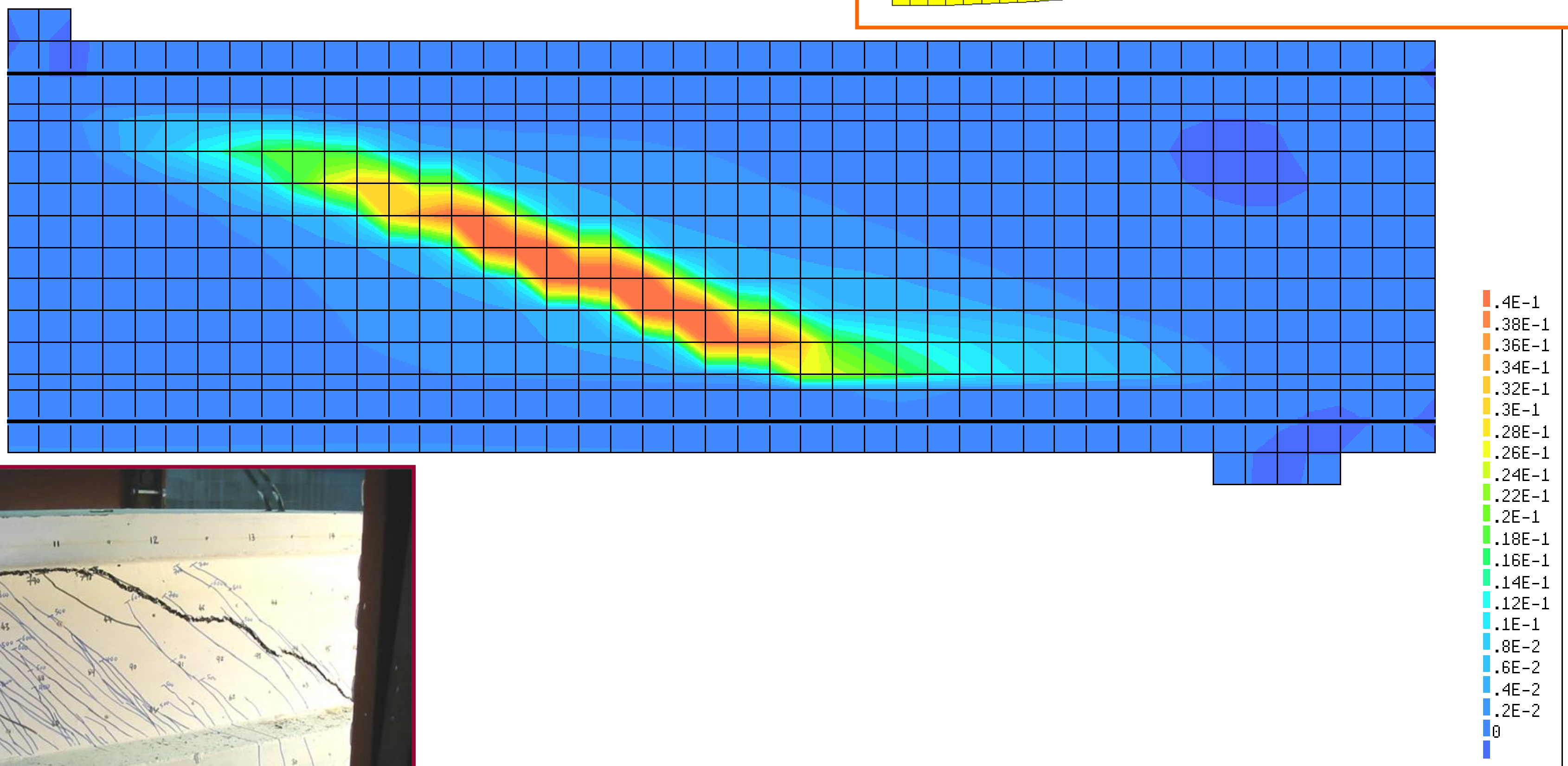
10 mm x 10 mm Mesh
Nodes: 10010
Elements: 10152

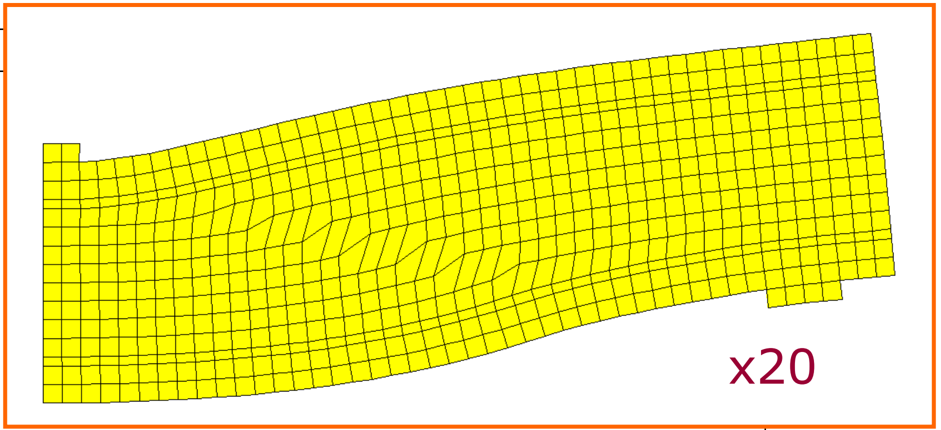
Load versus Deflection SB7

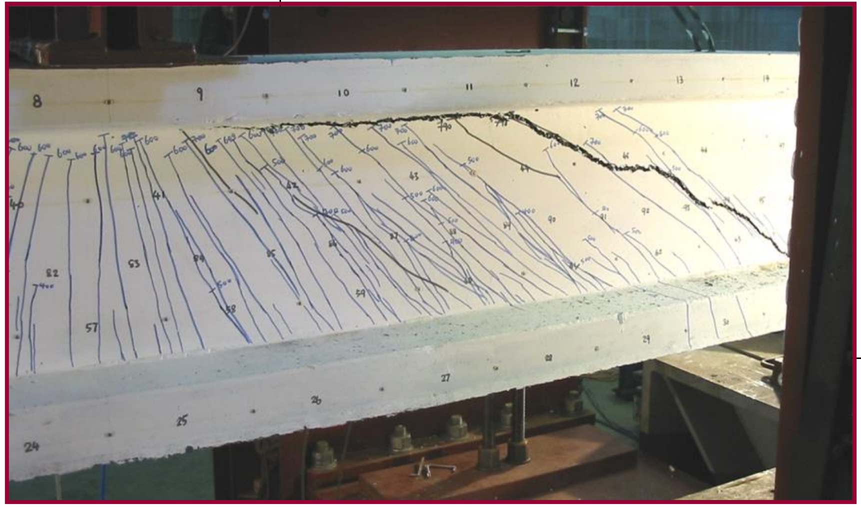




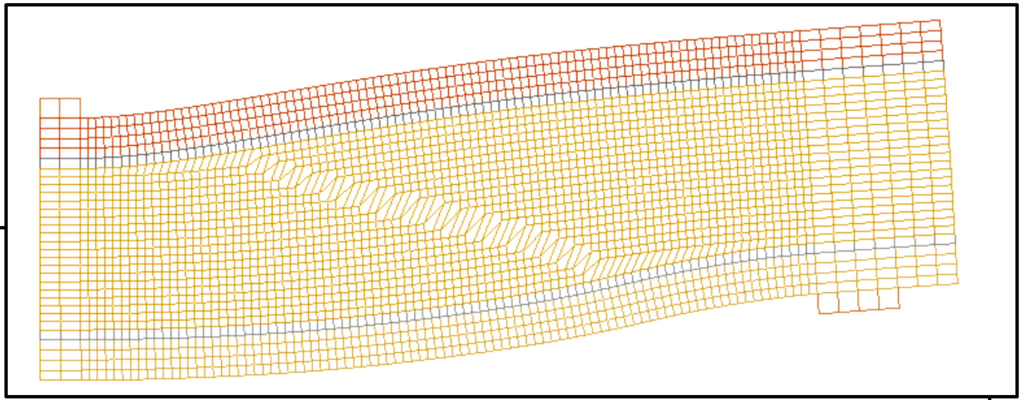
50 mm mesh

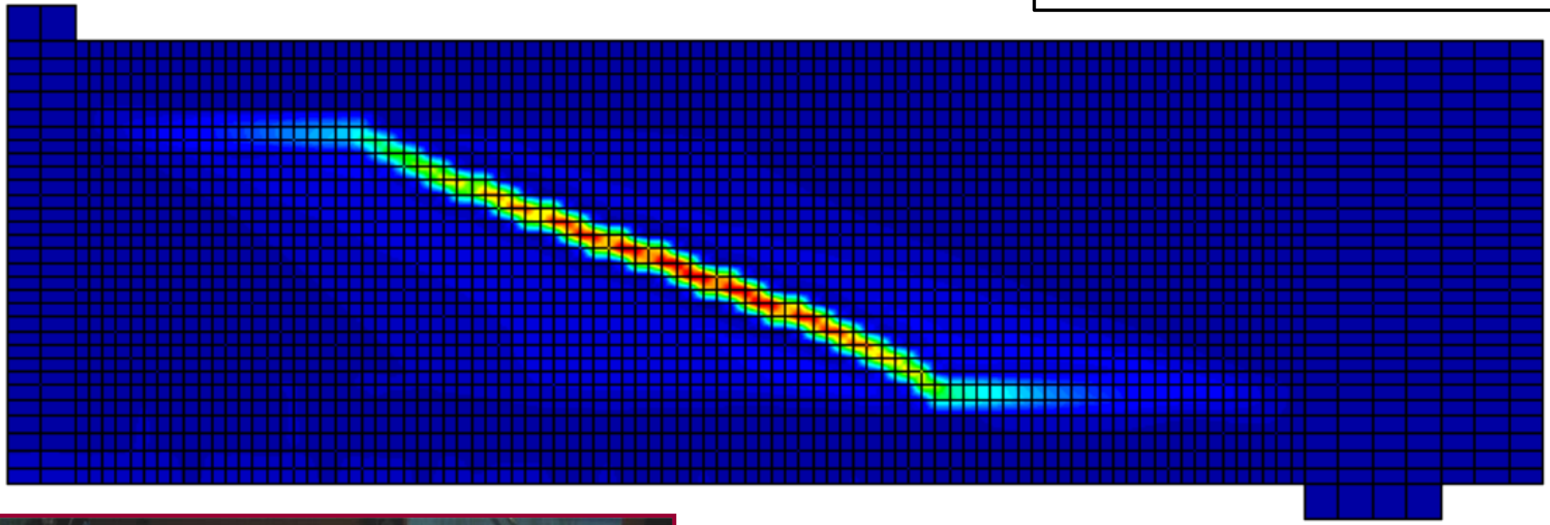

iDIANA 8.1.2-01 : Uni New South Wales
MODEL: SB7
NSTRAI: - RPC SHEAR BEAM
STEP: 29 761
NODAL PRINC ESTRN PMAX
CALCULATED FROM: NSTRAINS
NOT EXPLICITLY E.STRAIN
MAX = .503E-1
MIN = -.418E-3
.4E-1
.38E-1
.36E-1
.34E-1
.32E-1
.3E-1
.28E-1
.26E-1
.24E-1
.22E-1
.2E-1
.18E-1
.16E-1
.14E-1
.12E-1
.1E-1
.8E-2
.6E-2
.4E-2
.2E-2
0

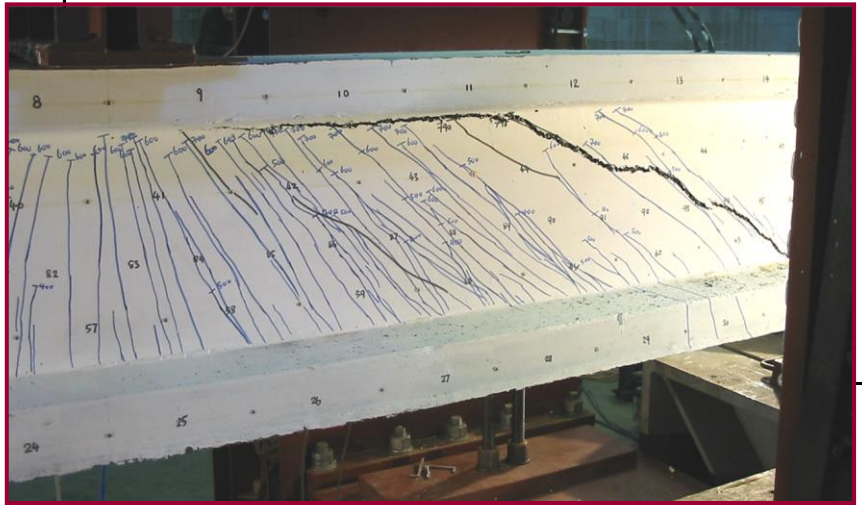

x20



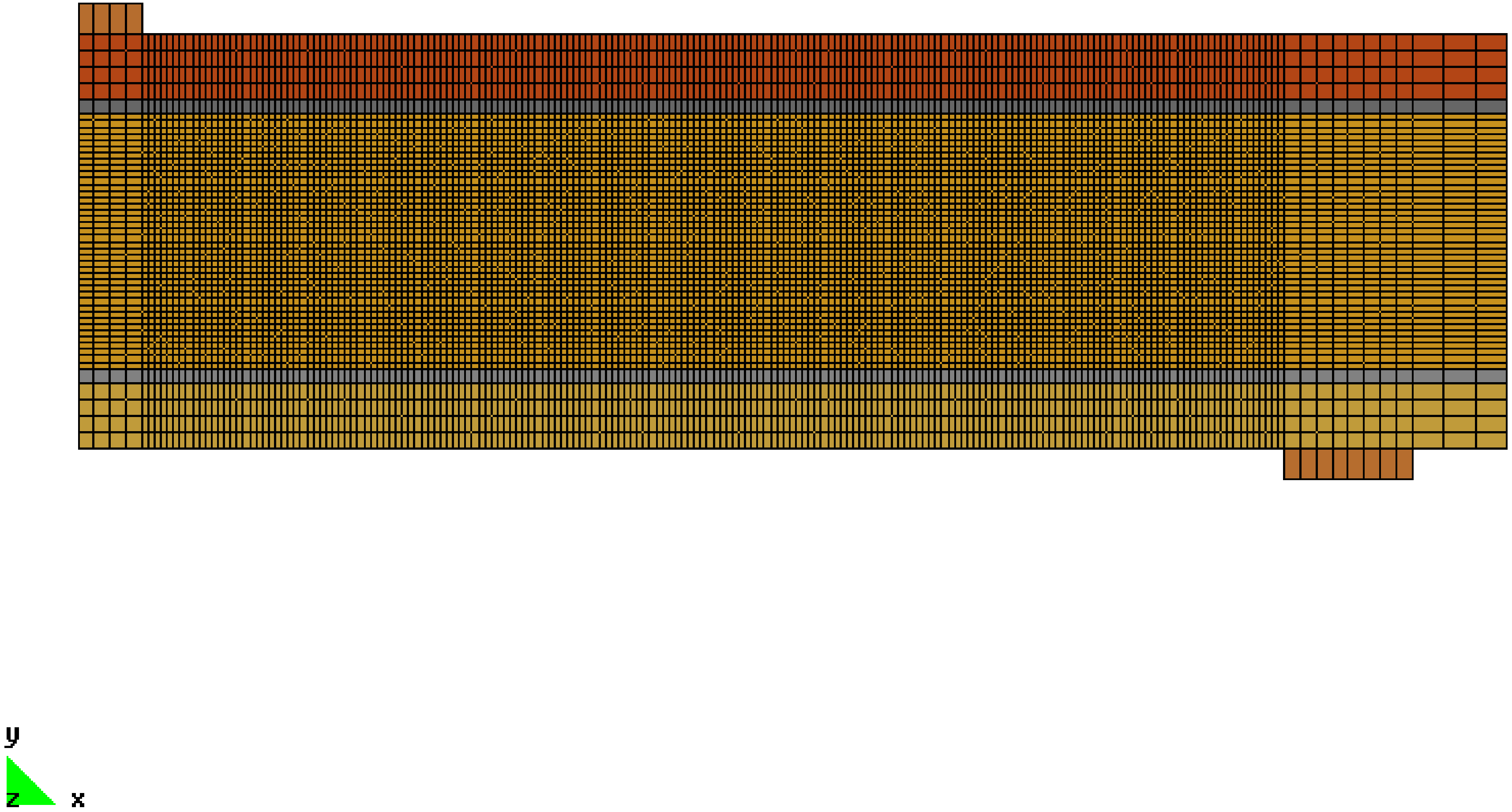
20 mm mesh



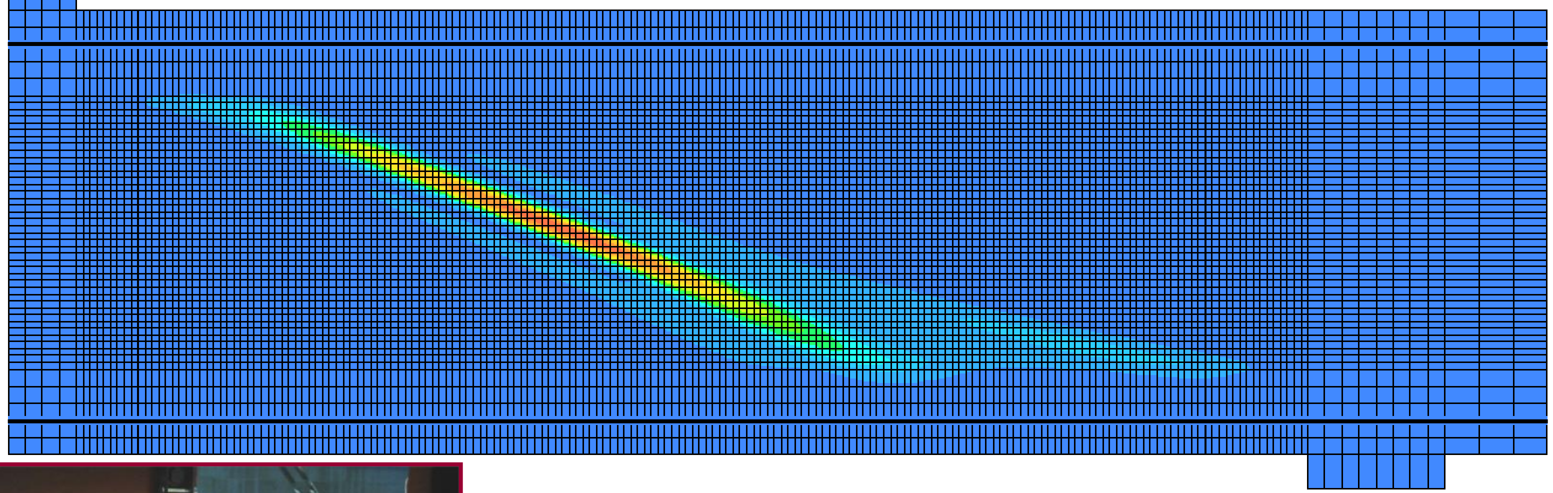

Princ_Strain-1
0.095069
0.084486
0.073903
0.063321
0.052738
0.042155
0.031573
0.02099
0.010407
-0.00017458

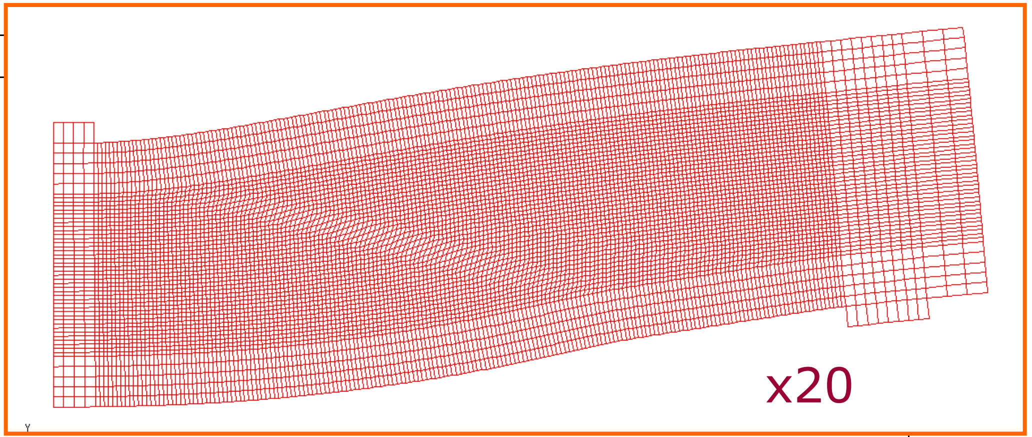


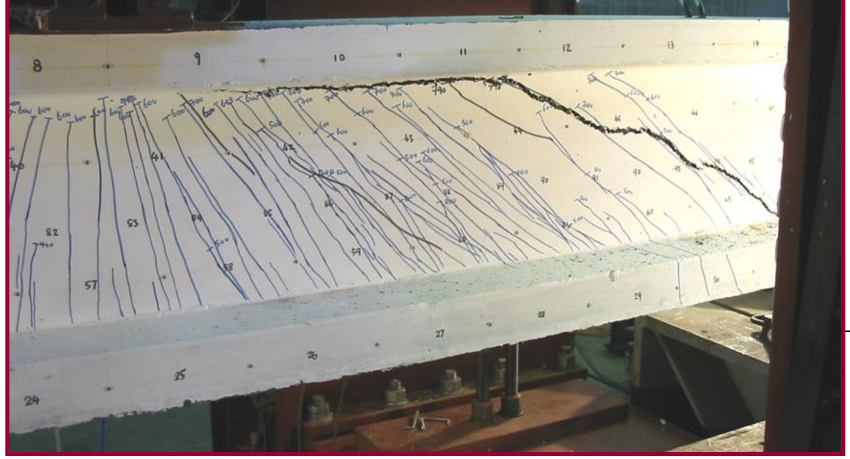
Local Strains: Non-Local Model 10 mm Mesh



10 mm mesh



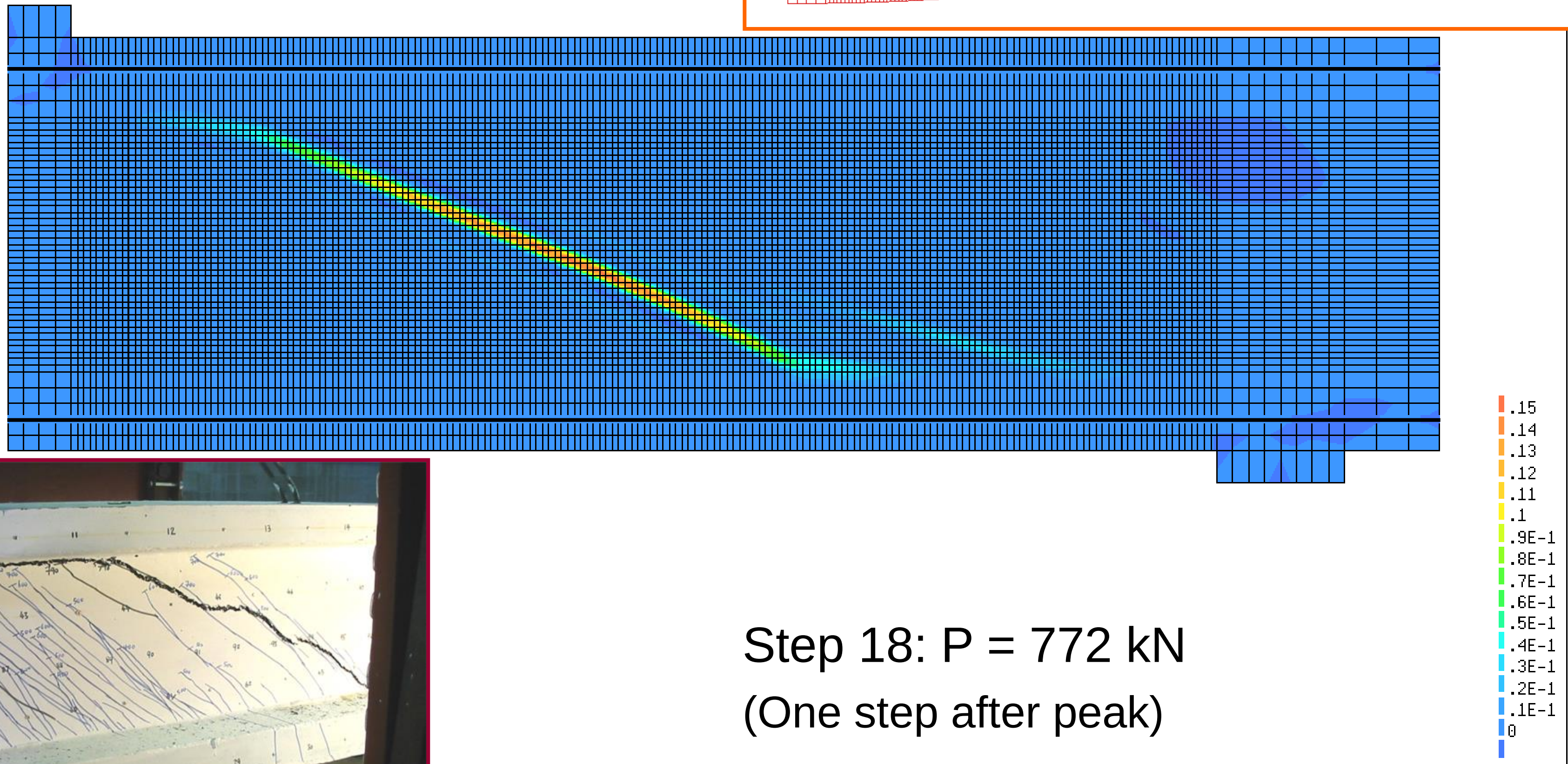


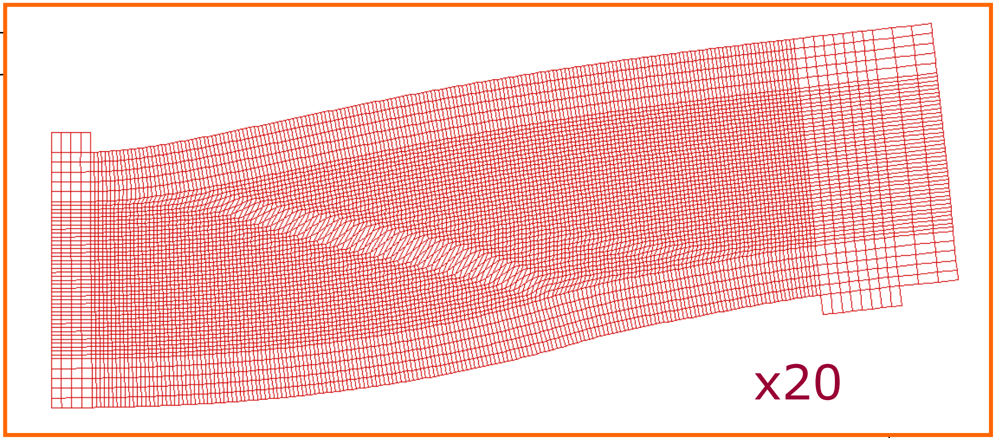


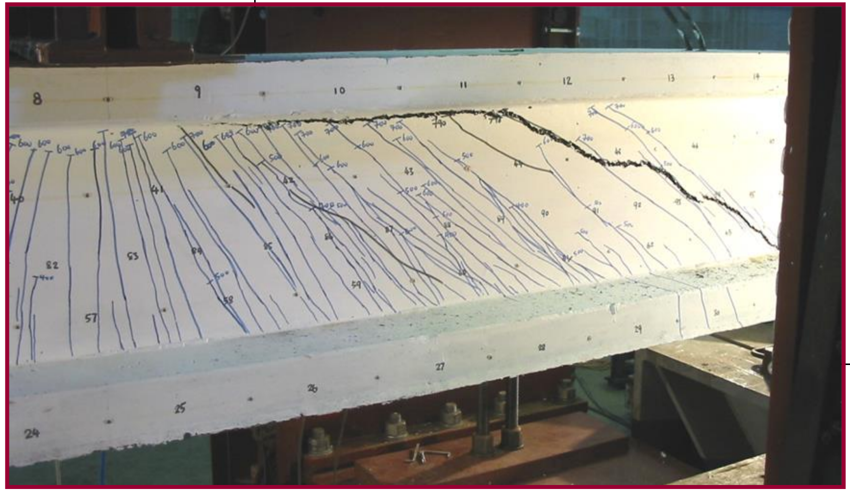
Step 16: P = 761 kN

(One step before peak)

10 mm mesh







Step 18: P = 772 kN

(One step after peak)

Example 2

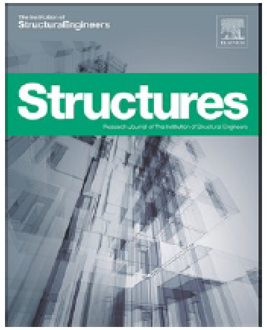
Structures 63 (2024) 106320

Contents lists available at ScienceDirect

Structures

journal homepage: www.elsevier.com/locate/structures

ELSEVIER



Check for updates

Minimum tensile reinforcement ratio for conventionally reinforced-SFRC beams and slabs

S M Faisal Mahmood [a,1,*], Tamanna Akter [a,2], Stephen J. Foster [b,3], Hamid Valipour [b,4]

[a] *Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka 1000, Bangladesh*
[b] *Centre for Infrastructure Engineering and Safety, School of Civil and Environmental Engineering, UNSW Sydney, NSW 2052, Australia*

Contents lists available at ScienceDirect

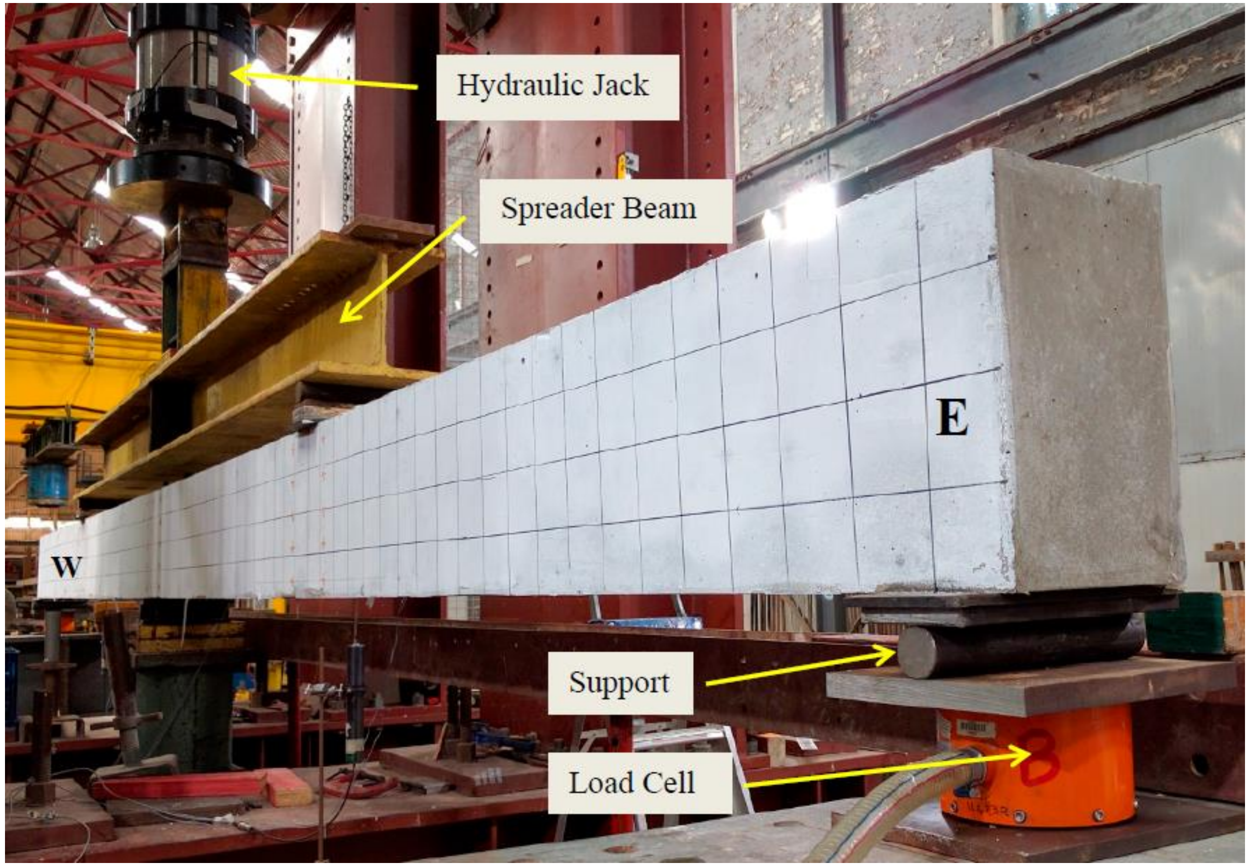
Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Flexural performance of steel fibre reinforced concrete beams designed for moment redistribution

S M Faisal Mahmood*, Ankit Agarwal, Stephen J. Foster, Hamid Valipour

Centre for Infrastructure Engineering and Safety, School of Civil and Environmental Engineering, UNSW Sydney, NSW 2052, Australia



Contents lists available at ScienceDirect

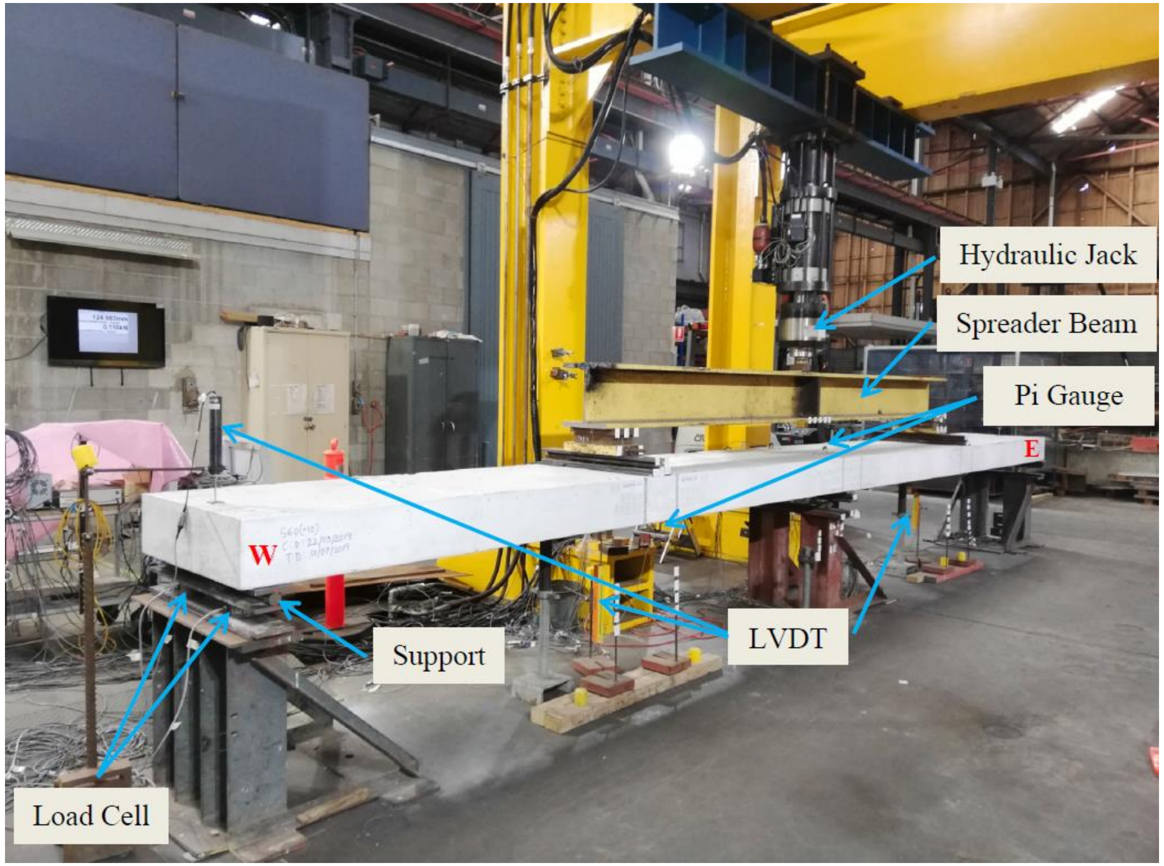
Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Moment redistribution and post-peak behaviour of lightly reinforced-SFRC continuous slabs

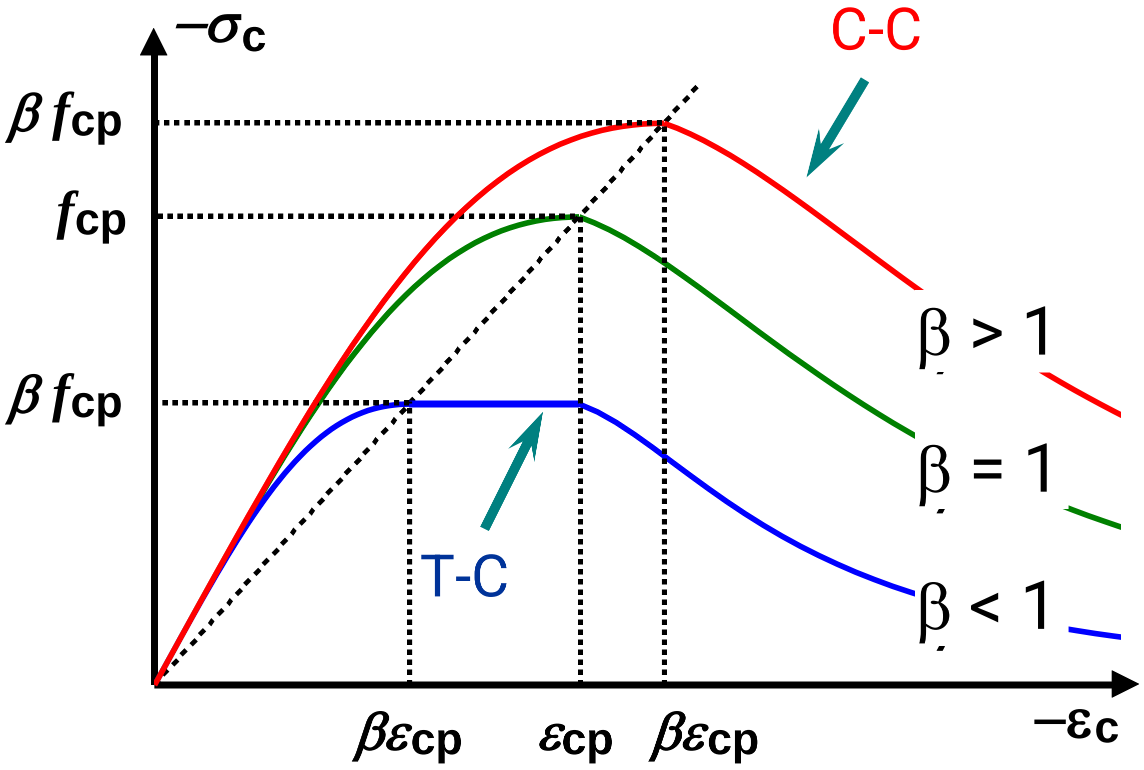
S M Faisal Mahmood, Stephen J. Foster, Hamid Valipour*

Centre for Infrastructure Engineering and Safety, School of Civil and Environmental Engineering, UNSW Sydney, NSW 2052, Australia

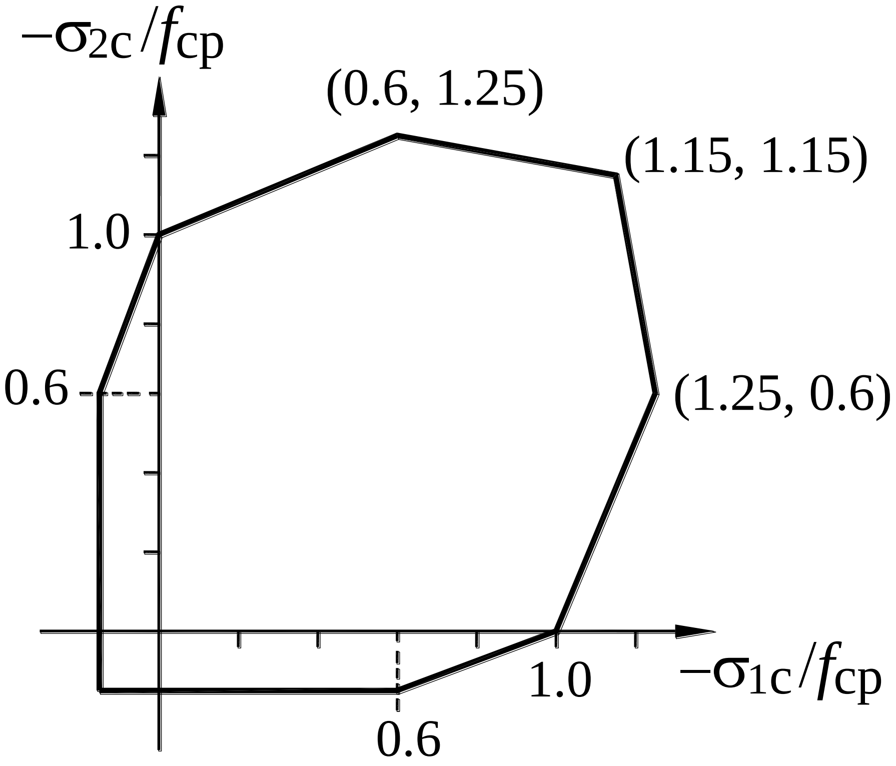


UNSW SYDNEY

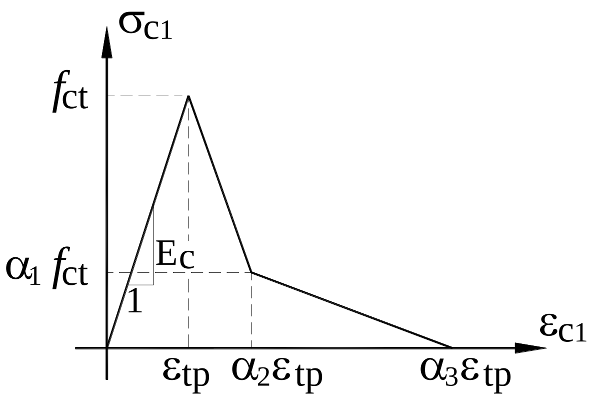
Concrete Material Model

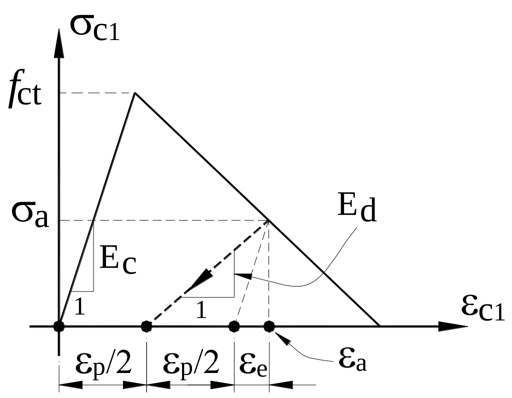


Compression base curve



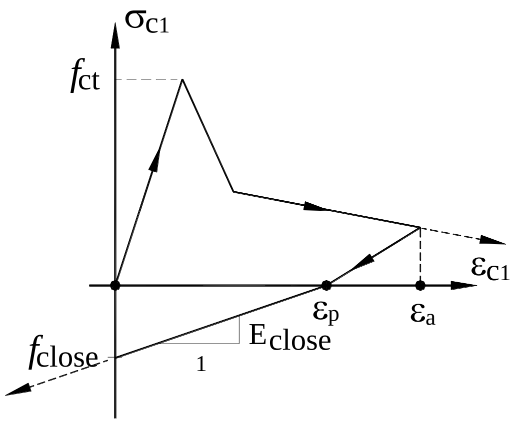
Biaxial strength envelope

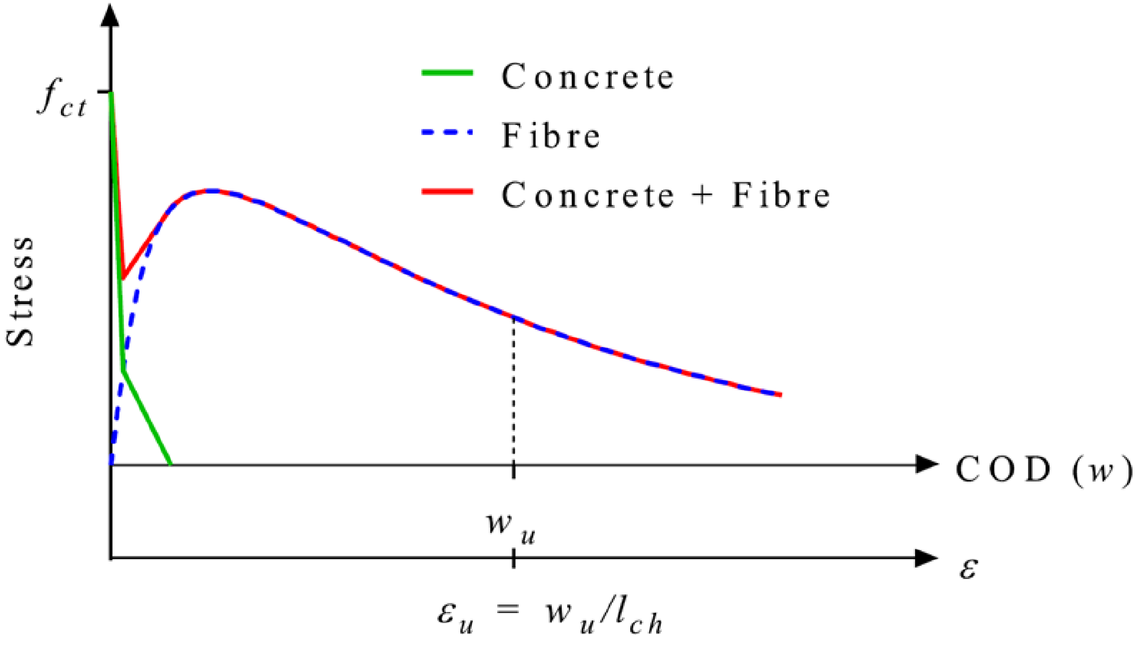




$$f_{close} = -E_c(0.0016\varepsilon_a + 50\times10^{-6})$$

$$E_{close} = \frac{f_{close}}{\varepsilon_p}$$



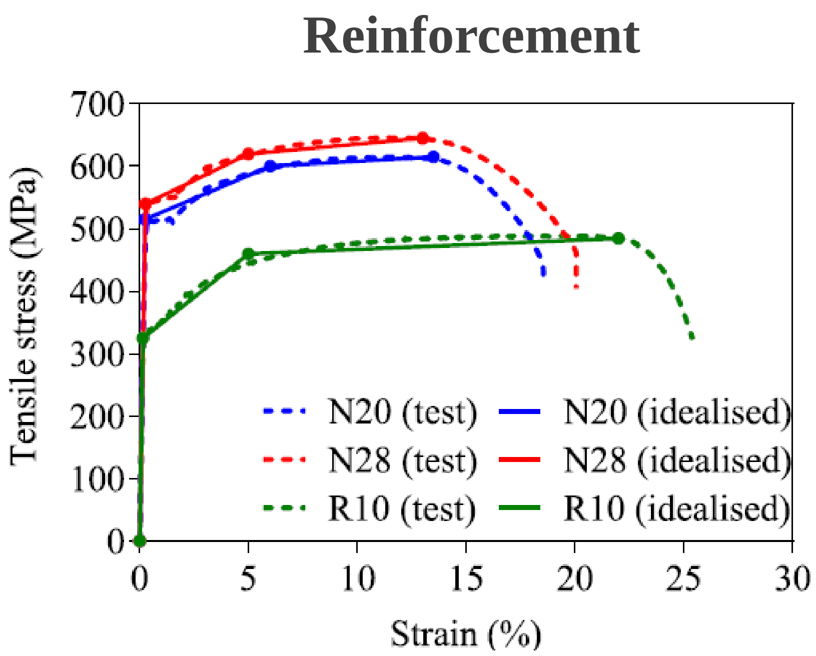


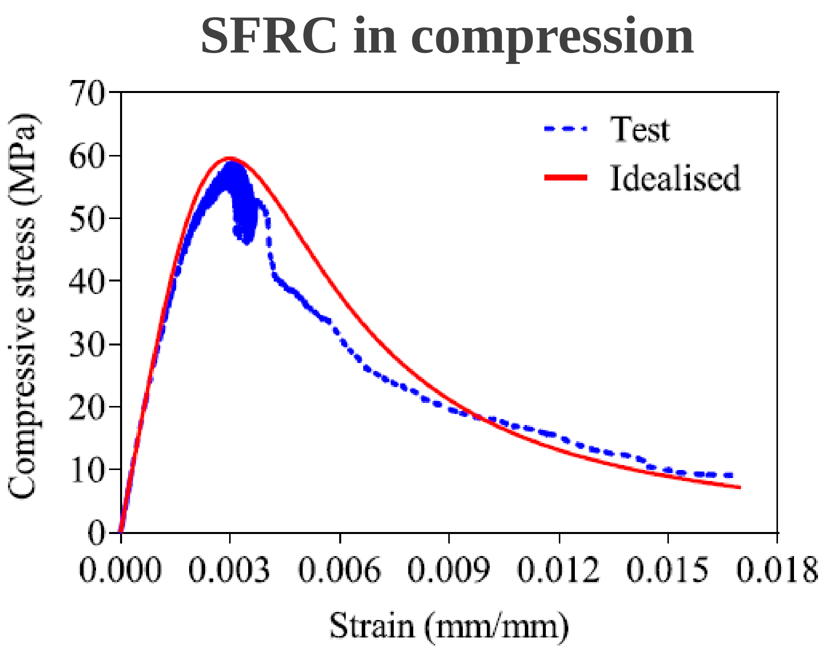
Concrete in tension: without fibres

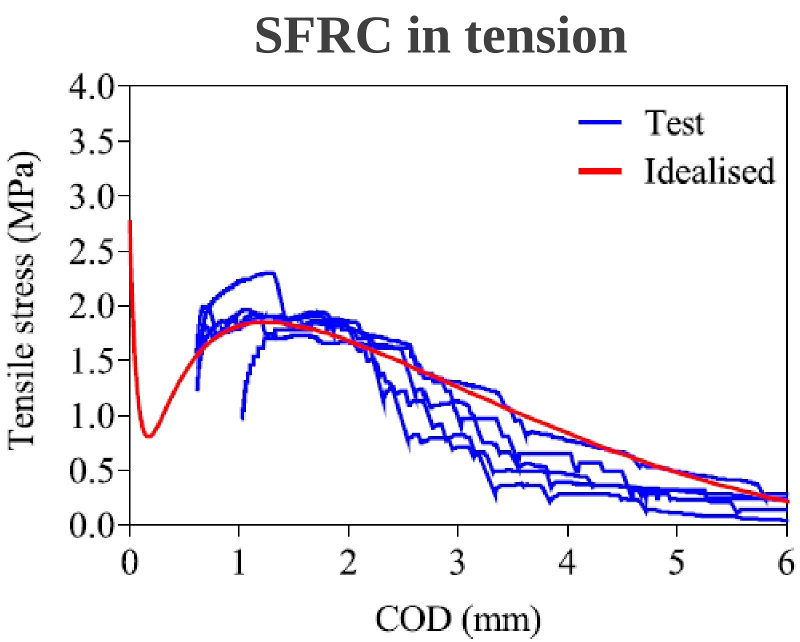
Concrete in tension: with fibres

Materials: test data and model

Beam tests with 30 kg/m^3 of Dramix 5D steel fibres



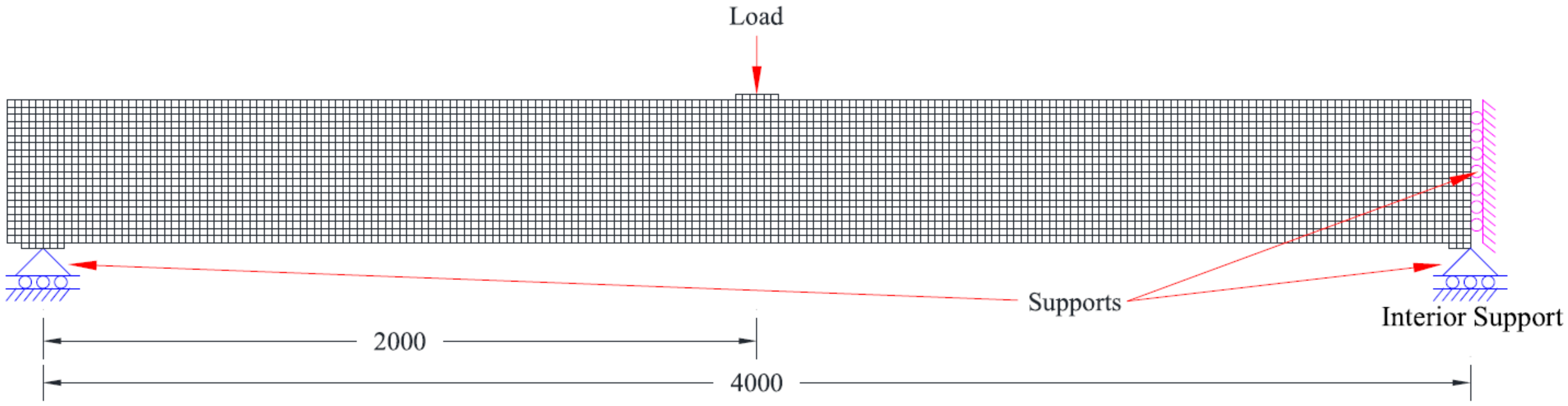




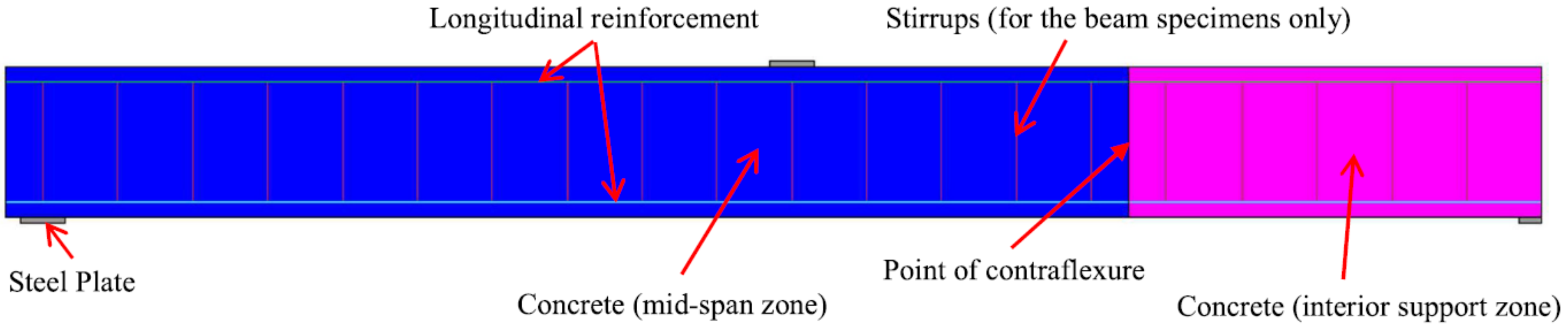
f_{cm} (beams): 52~60 MPa
f_{cm} (slabs): 28~42 MPa

VEM parameters adjusted to provide best fit to direct tension obtained from dogbone tests

Model Validation: FE Mesh



(a) Meshing, loading and supporting conditions

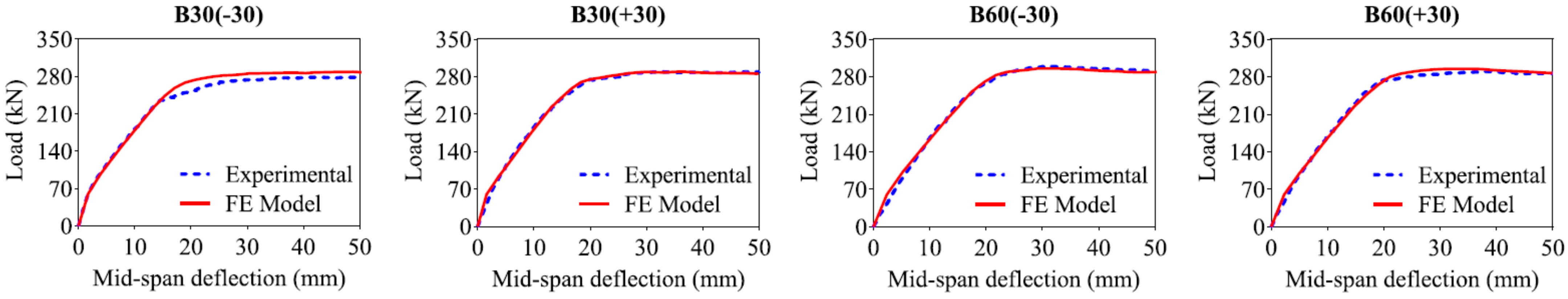


(b) Elements of the FE model

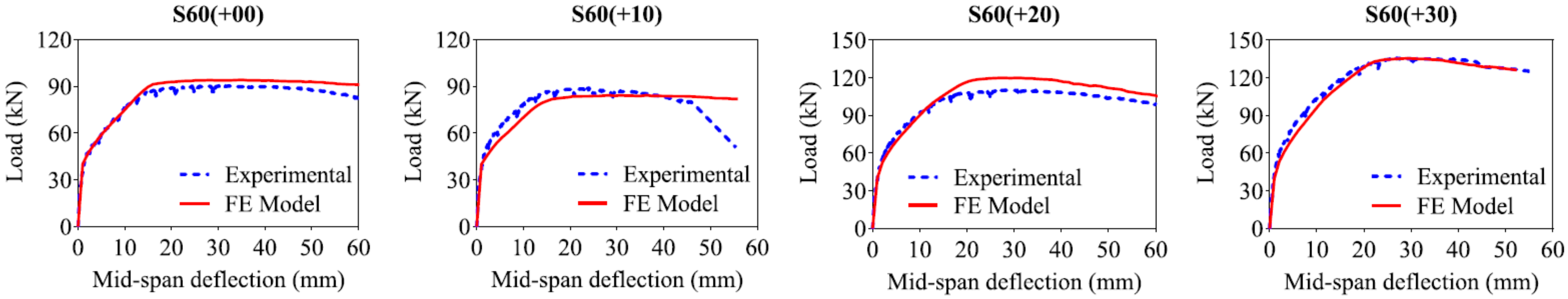
For the non-local model, the characteristic length is taken as 30 mm (being three times the size of the aggregate size).

UNSW SYDNEY

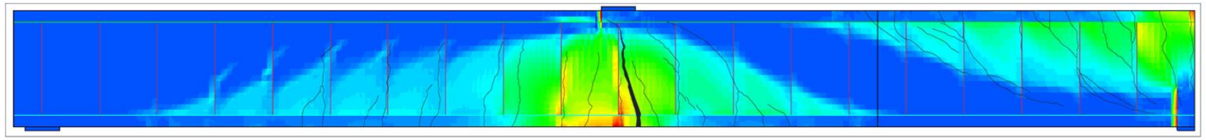
Comparison of load-deflection responses



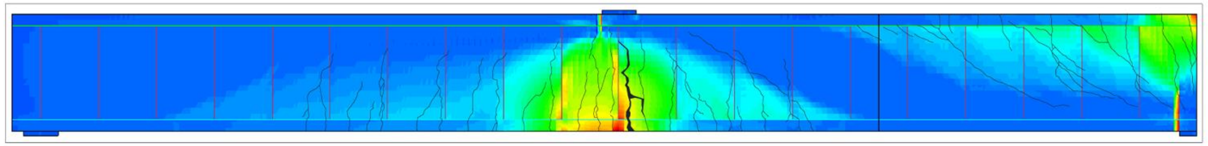
(a) Beam specimens



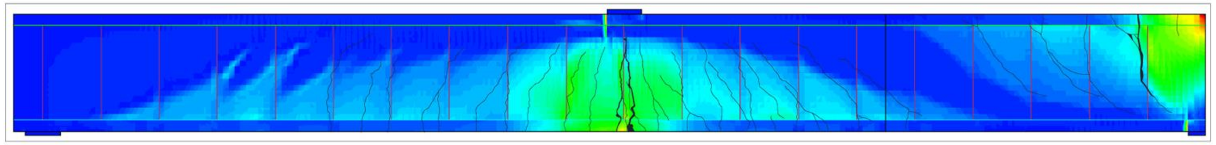
(b) Slab specimens



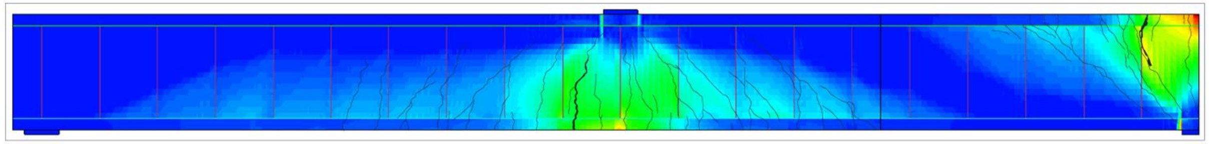
B30(-30)



B60(-30)



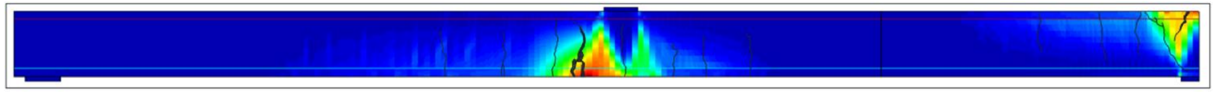
B30(+30)



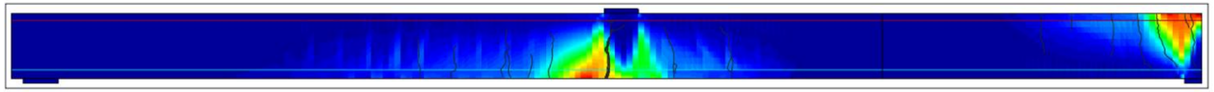
B60(+30)

Comparison of crack patterns (lines) from the experiments and major principal (tensile) strain from FE modelling – beam specimens.

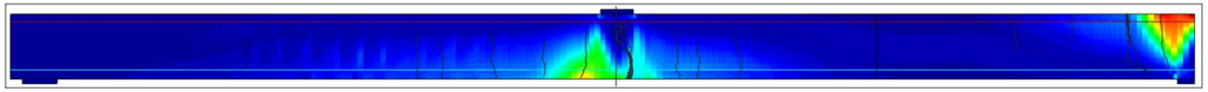
Specimen	Intermediate support		Mid-span		Intermediate support	Mid-span	Average
	w_{exp} (mm)	w_{FEM} (mm)	w_{exp} (mm)	w_{FEM} (mm)	$\frac{w_{FEM}}{w_{exp}}$	$\frac{w_{FEM}}{w_{exp}}$	$\frac{w_{FEM}}{w_{exp}}$
B30(–30)	0.20	0.25	0.30	0.31	1.23	1.02	1.13
B60(–30)	0.30	0.34	0.20	0.21	1.13	1.07	1.10
B30(+30)	0.72	0.81	0.24	0.26	1.12	1.07	1.09
B60(+30)	0.56	0.76	0.20	0.21	1.36	1.07	1.22
Average (COV)							**1.13 (0.043)**



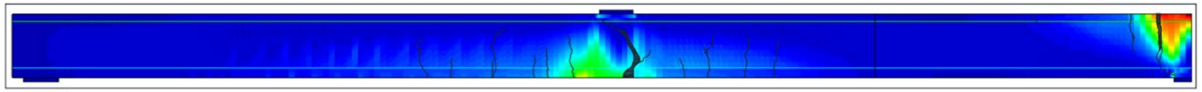
S60(+00)



S60(+10)



S60(+20)



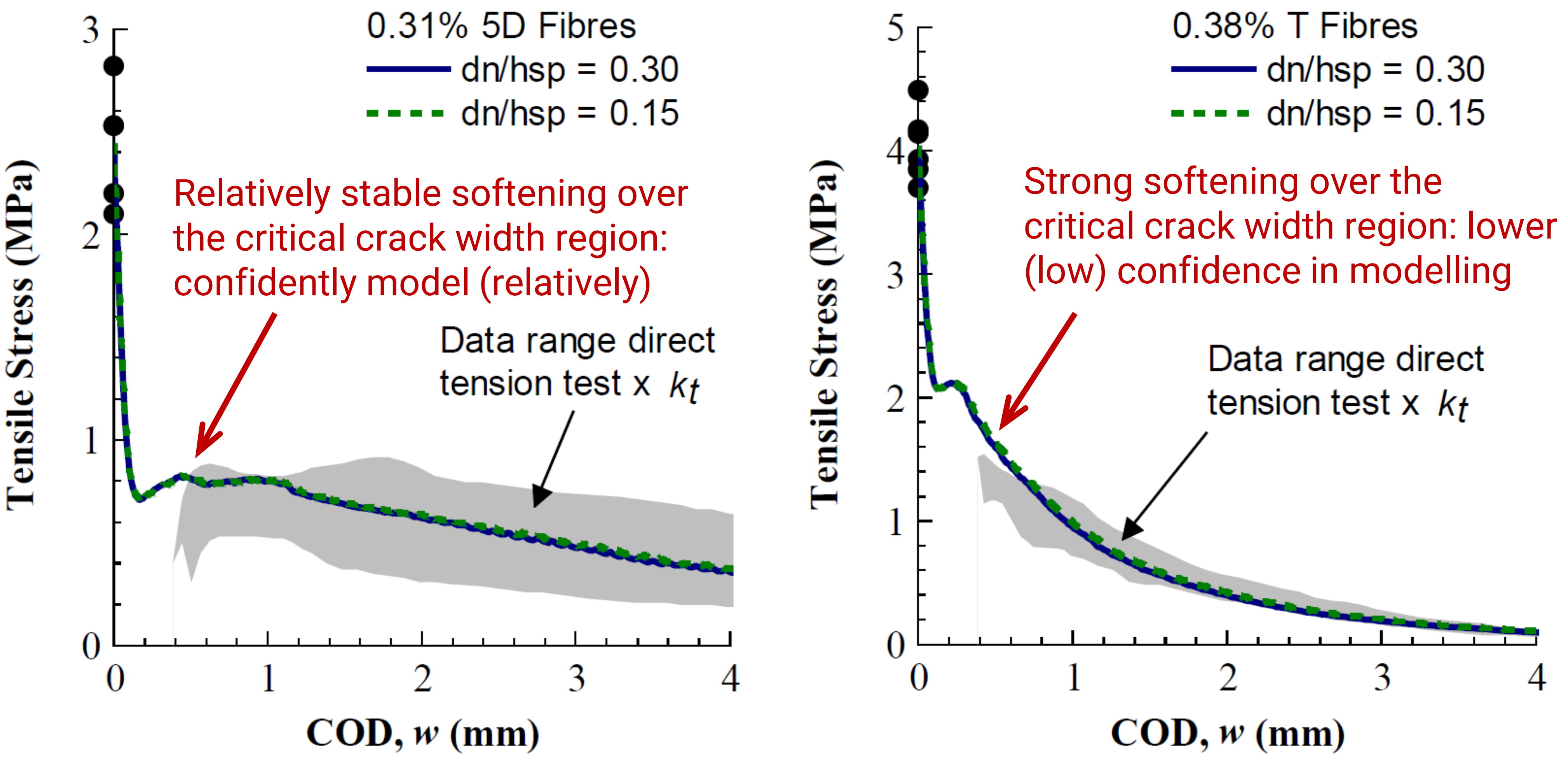
S60(+30)

Comparison of crack patterns (lines) from the experiments and major principal (tensile) strain from FE modelling – slab specimens.

Specimen	Intermediate support		Mid-span		Intermediate support	Mid-span	Average
	w_{exp} (mm)	w_{FEM} (mm)	w_{exp} (mm)	w_{FEM} (mm)	$\frac{w_{FEM}}{w_{exp}}$	$\frac{w_{FEM}}{w_{exp}}$	$\frac{w_{FEM}}{w_{exp}}$
S60(+00)	0.28	0.25	0.26	0.20	0.88	0.78	0.83
S60(+10)	0.32	0.29	0.30	0.24	0.92	0.79	0.86
S60(+20)	0.36	0.32	0.20	0.19	0.88	0.97	0.92
S60(+30)	0.42	0.30	0.18	0.21	0.71	1.17	0.94
Average (COV)							**0.89 (0.051)**

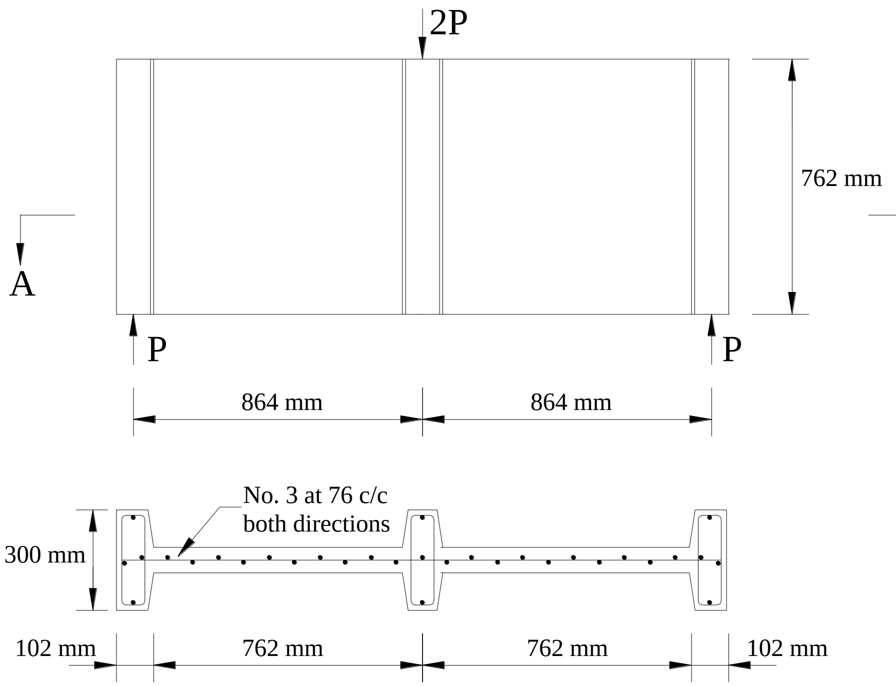
UNSW SYDNEY

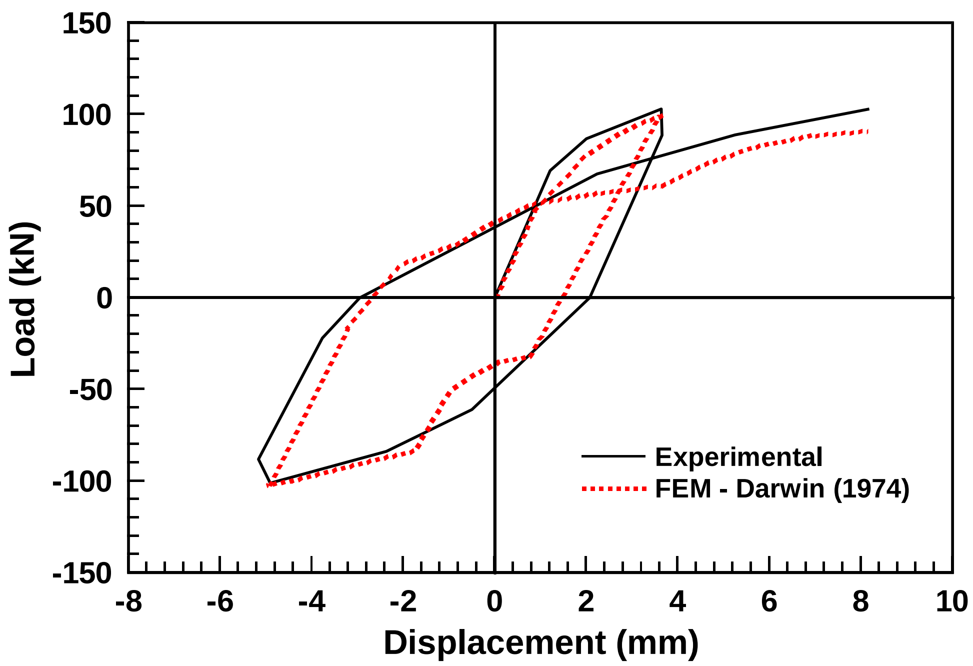
Comment: weak verse strong tensile softening

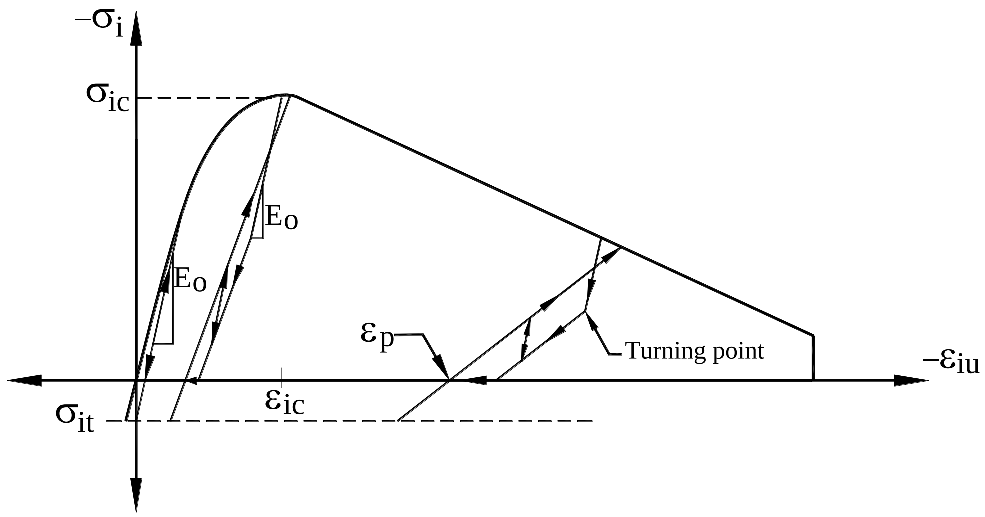


Ali Amin, Post Cracking Behaviour of Steel Fibre Reinforced Concrete: From Material to Structure, PhD Thesis, UNSW Sydney, 2015

Darwin and Pecknold (1974, 1976)







"... the present model is intended primarily as a research tool. It is too costly to be used in analysis of large scale structures ..." (Darwin and Pecknold. 1976)

Concluding Remarks

- Accurately modelling FRC behaviour at the structural level can be challenging, particularly when the FRC exhibits tensile softening.
- If crack widths are to be accurately determined – which FRC material models rely on – crack spacing must be well predicted.
- The two examples presented (one tensile hardening UHPC and one tensile softening SFRC) demonstrate that non-local models can provide accurate model predictions, provided that crack spacing models are reliable – this requires further investigation.