Testing and analysis of ultra-high performance fibre-reinforced concrete panels

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45th UKELG One-Day Discussion Meeting

University of Liverpool, 31st March 2010

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Constitution of UHPFRC

very high cement content

very low water-cement ratio

very high superplasticiser dosage

fine silica sand (150-400 microns)

heat treatment after setting

small-size steel fibres

UHPFRC – typical properties

Property	High Strength Concrete	UHPFRC
Compressive Strength, N/mm^2	~ 100	150-200
Flexural Strength, N/mm^2	< 10	20-50
Fracture Energy, J/m^2	~ 100	20,000-40,000

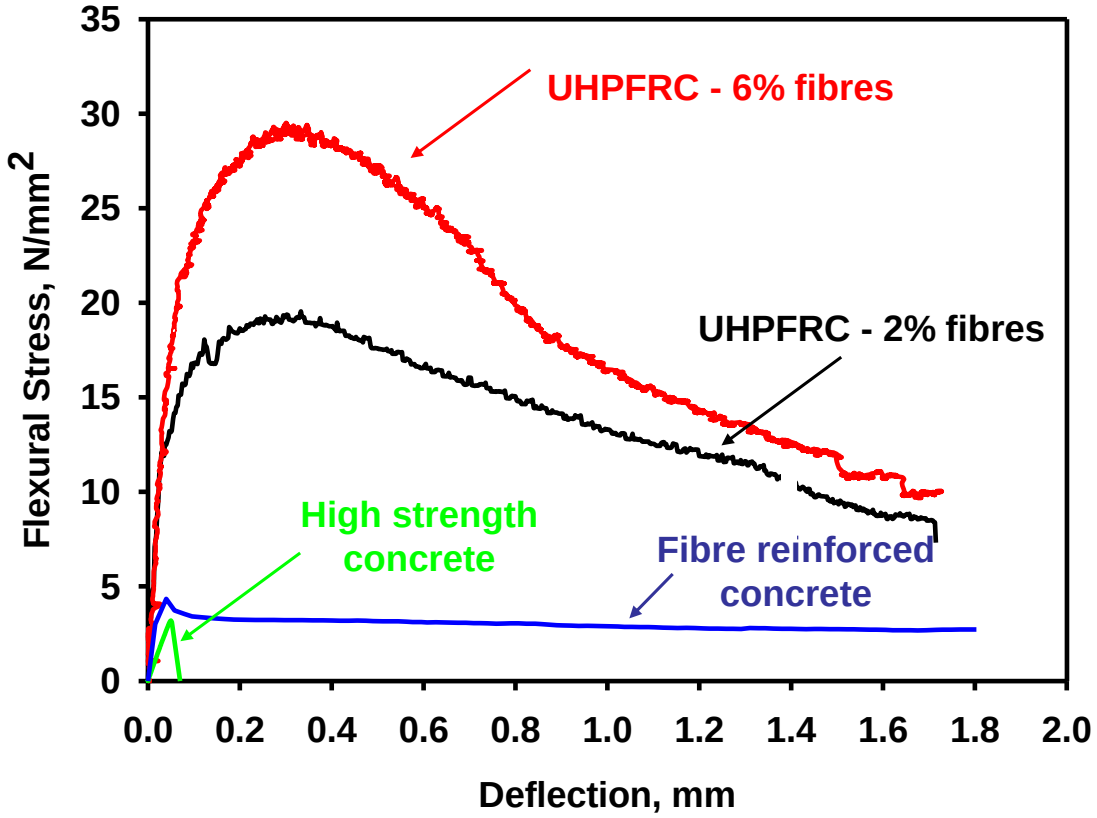
Blast performance

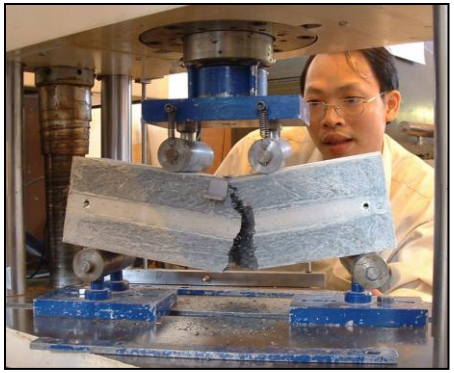
5 T of TNT @ 30 m

“standard” concrete

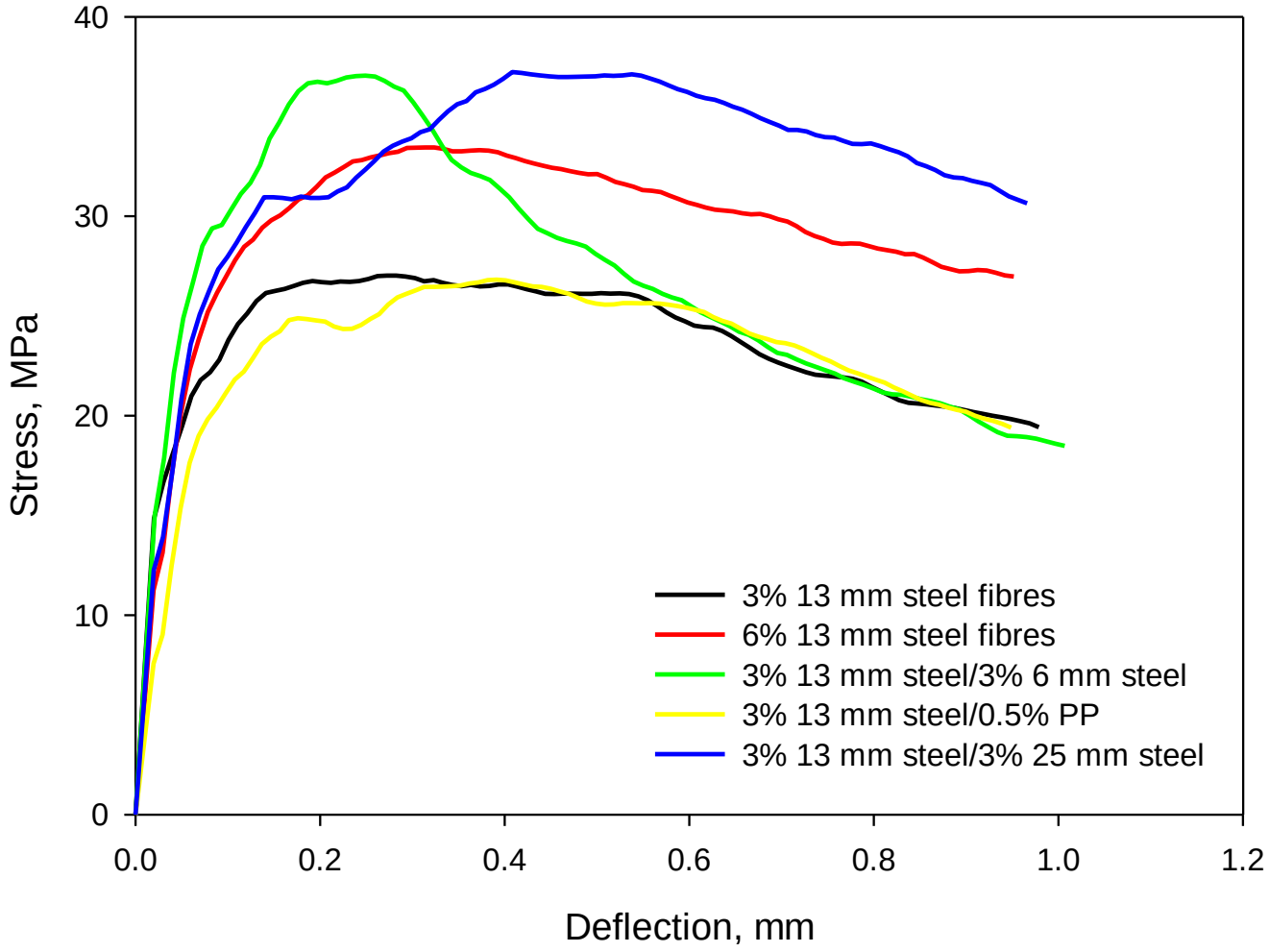
UHPFRC

Flexural performance of 100 x 100 x 350 mm beam specimens





Hybrid fibre beam tests



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Small-scale tests

- 500mm x 500mm x 25mm thick panels manufactured at University of Liverpool
- Explosion testing at University of Sheffield Buxton site

Fibres	Charge sizes (g)
2% mix	200-600
4% hybrid mix	400-800
6% hybrid mix	200-1100

Stand-off: 500mm

6% hybrid mix / 500 mm stand-off

900g charge

1100g charge

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6% hybrid mix / 200g / 200mm stand-off

Full-scale tests

- 3.5 m x 1.3 m x 100 mm thick panels manufactured in Melbourne by VSL, Australia (Ductal®)
- Explosion testing in conjunction with CPNI in July/October 2008
- Predictive modelling using Autodyn prior to the tests

Panel #	Fibres	Reinforced?	Stand-off (metres)
1	2% 13mm long	YES	9
4	2% 13mm long	YES	7
2	2% 13mm long	NO	12
3	2% 13mm + 2% 25mm	NO	12

GL Industrial Services, Spadeadam

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Reinforced panels (2% fibres), 100 kg TNT @ 7 and 9 m

Panel #	Stand-off (m)	Maximum deflection (mm)	Permanent deformation (mm)
1	9	110	20
4	7	210	50

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Unreinforced panels, 100 kg TNT @ 12 m

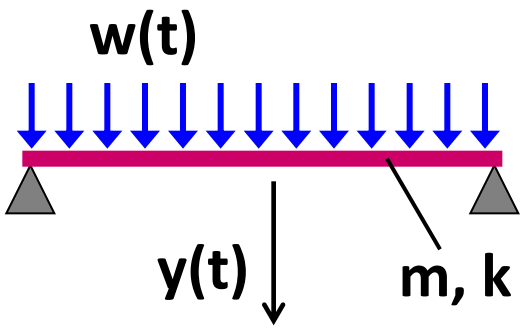
Panel #2
2% fibres
180 mm perm.

NO BACK FACE SPALLING

Panel #3
4% hybrid fibres
90 mm perm.

SDOF representation

Actual structure with distributed mass m, stiffness k and loading w(t)

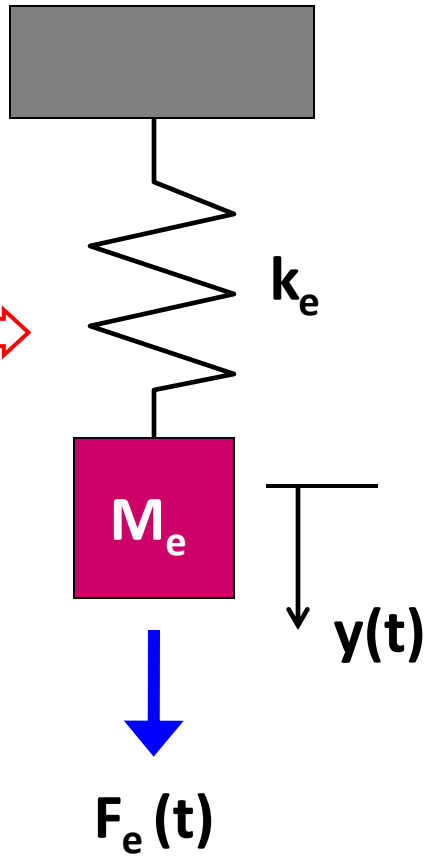


$$K_L = F_e / F$$

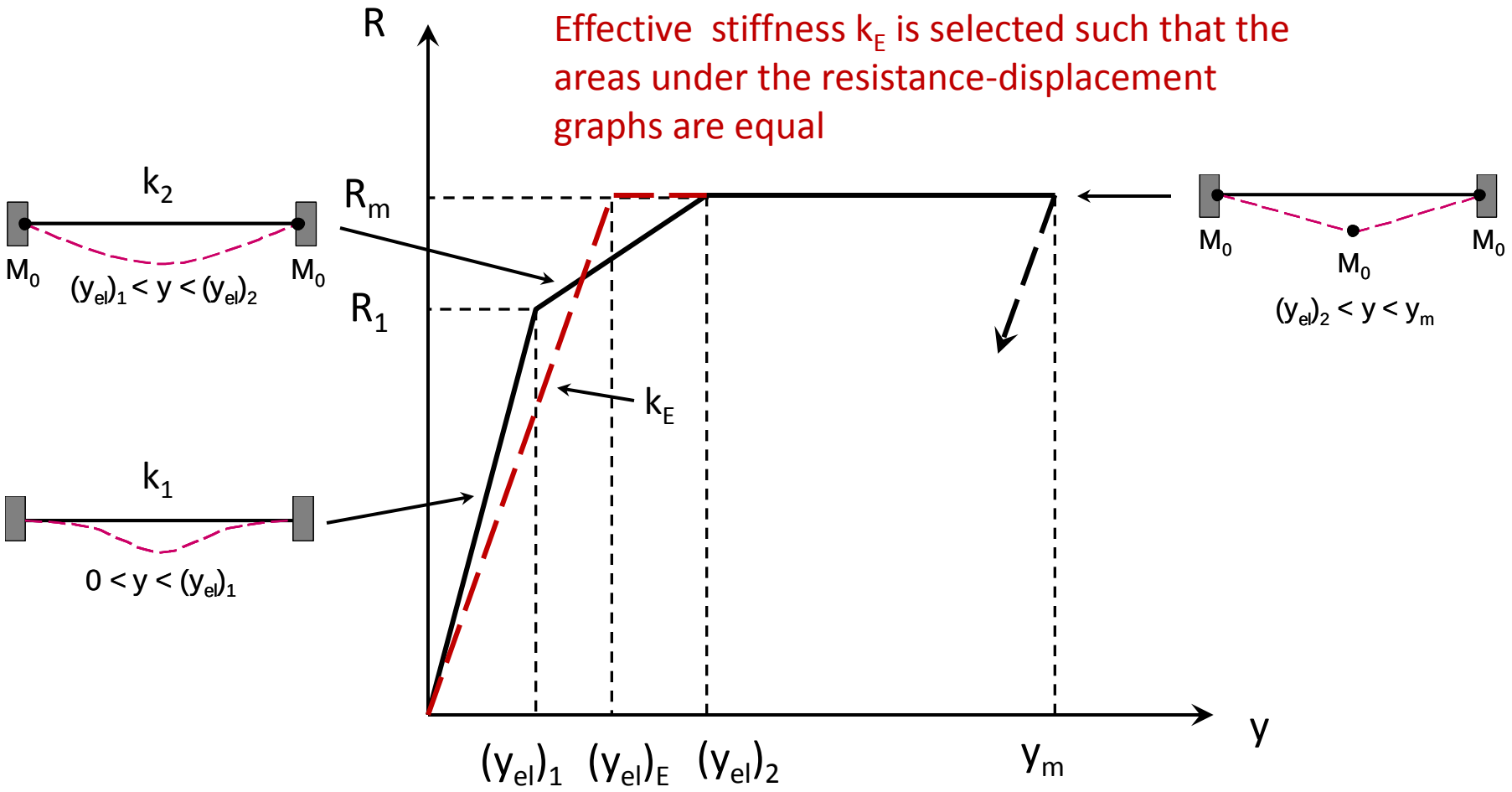
$$K_M = M_e / M$$

Transformation factors based on deformed shape, strain range,...

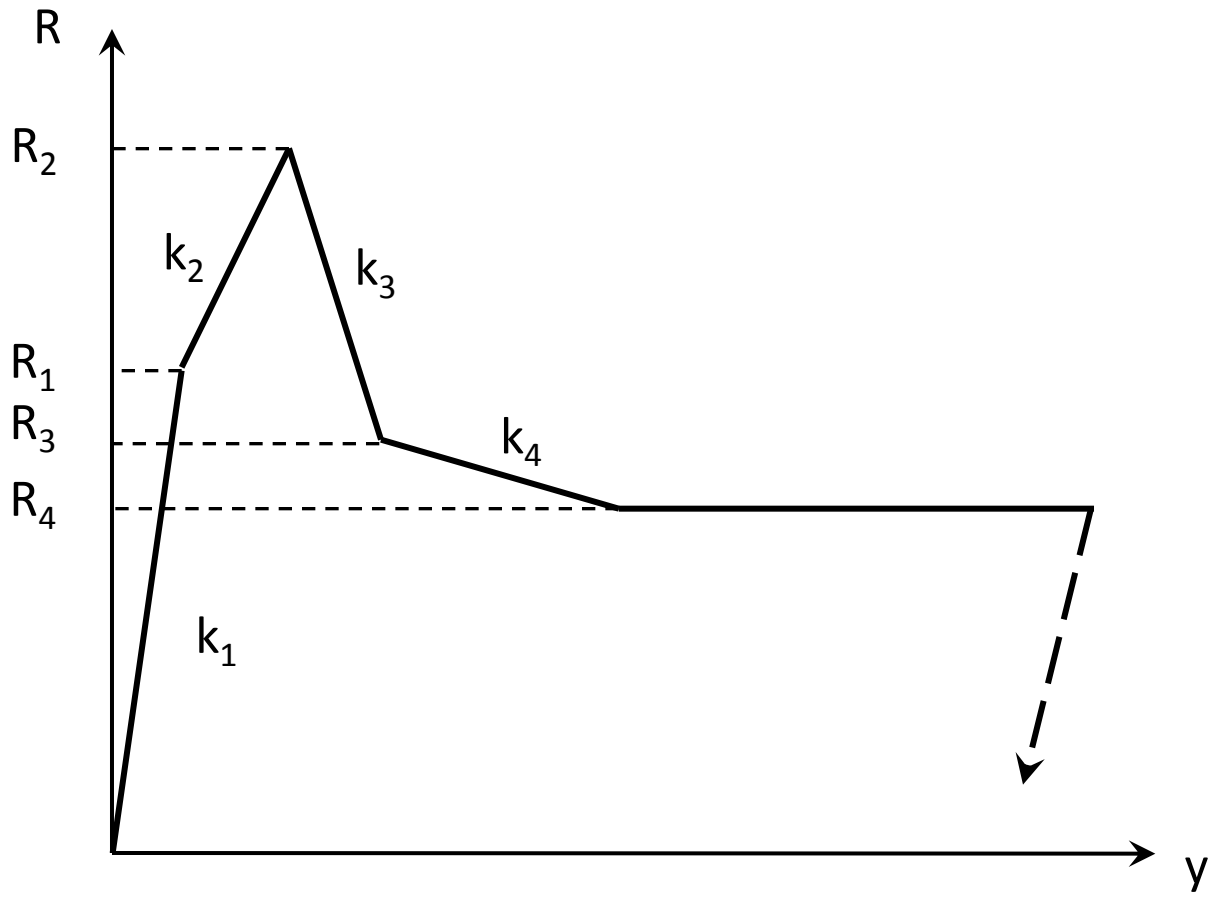
Equivalent spring-mass system



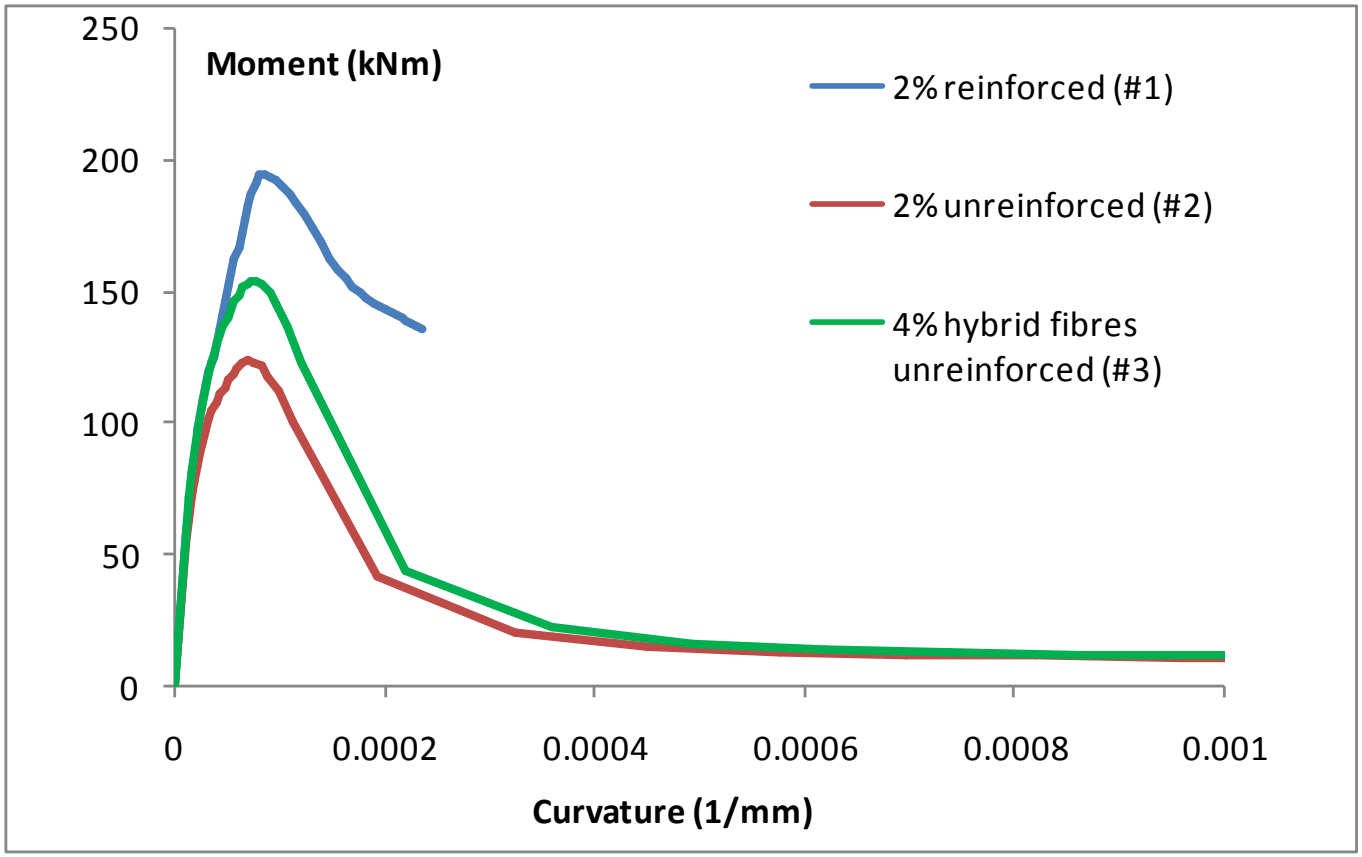
Effective bi-linear resistance function



Resistance function with softening



Moment capacity of panels based on static design



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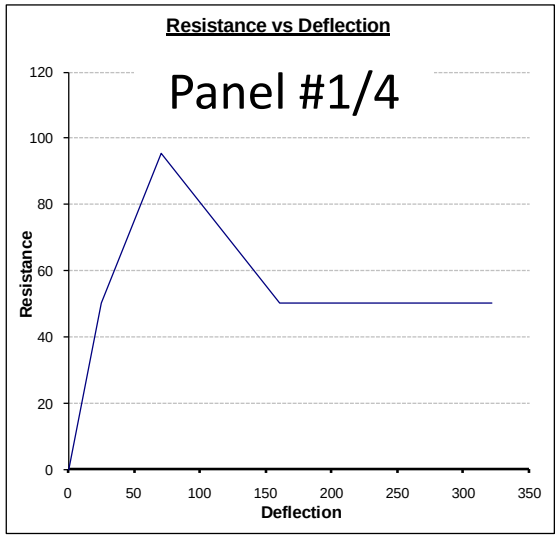
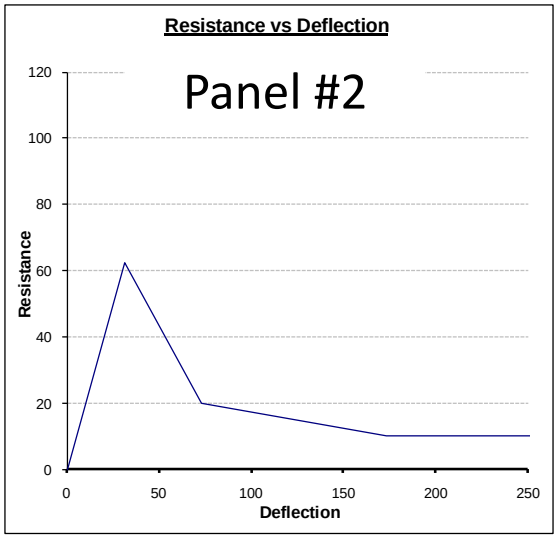
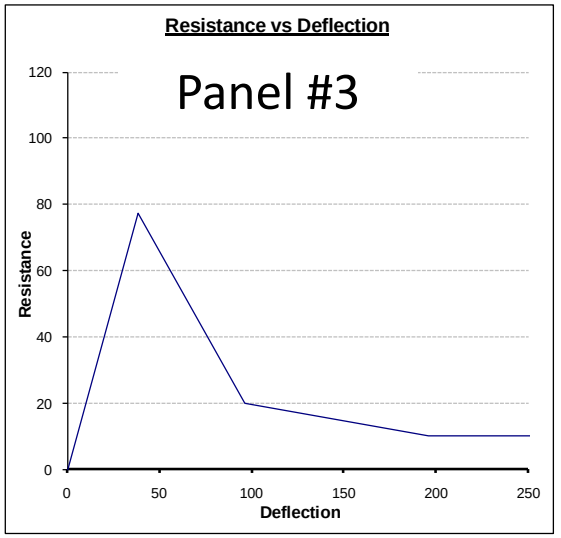
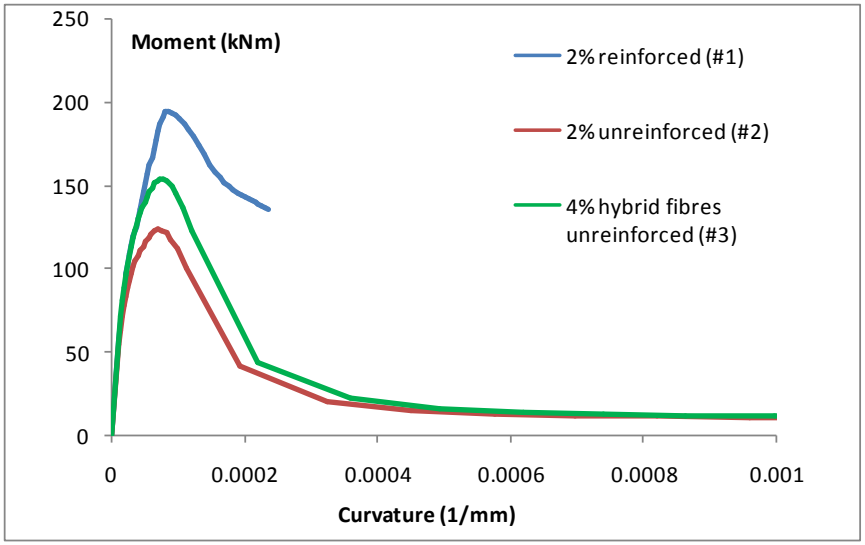
Resistance functions









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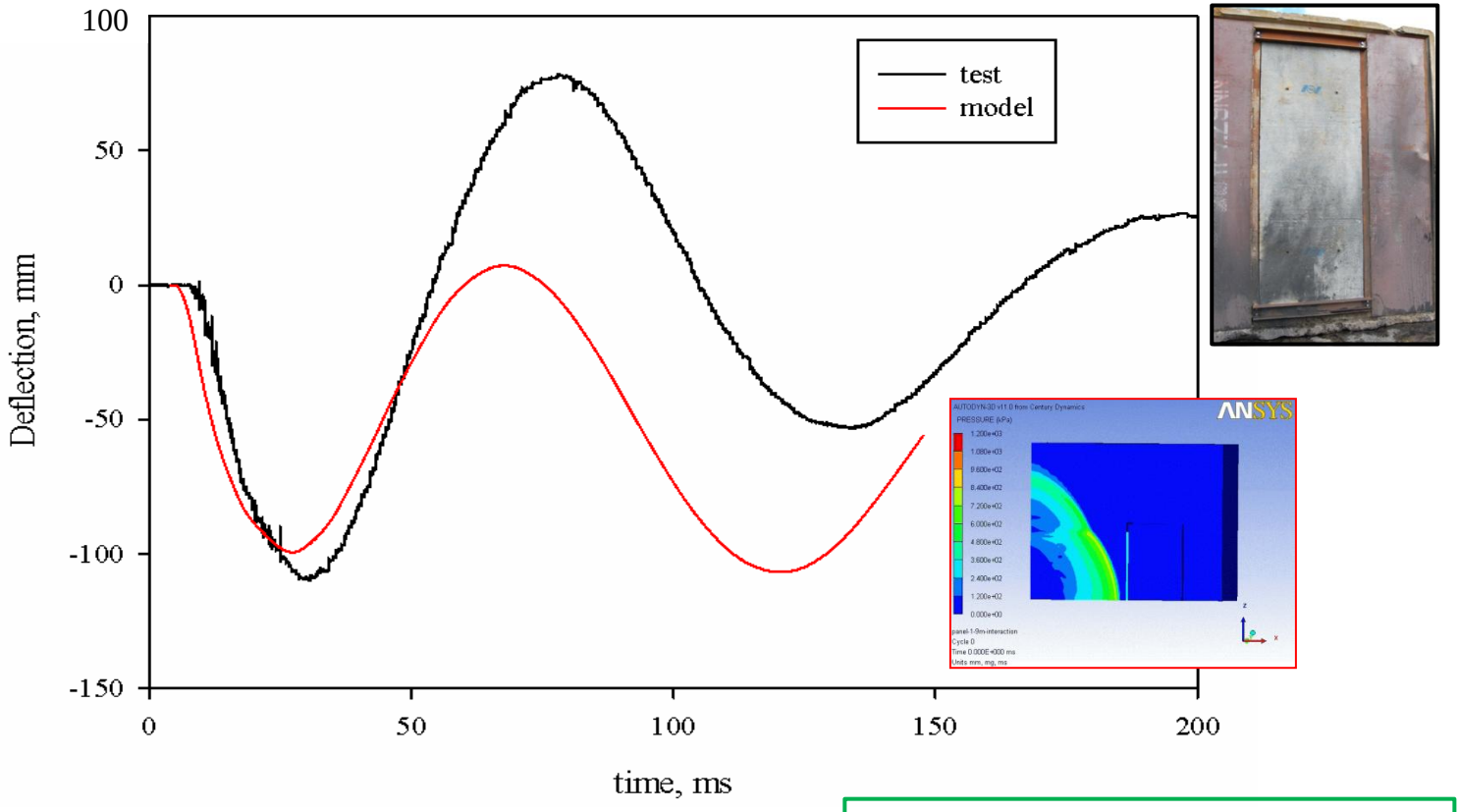
Autodyn prediction of Panel #1
2% fibres / reinforced / 9m stand-off



SDOF: 117 mm @ 25 msec

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Summary

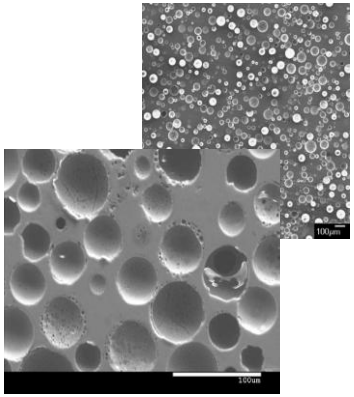
- UHPFRC achieved superior performance over standard concrete
- Increasing fibre content increased both flexural strength and toughness but the increase was disproportionate
- Forced orientation of fibres close to the moulded surfaces of test specimens was found to have no effect on flexural strength
- UHPFRC panels performed well in both small-scale and full-scale explosion tests with no rear-face spalling

Project sponsors

- EPSRC
- Centre for Protection of National Infrastructure (CPNI)
- VSL Australia – manufacturers of Ductal®
- Bekaert – fibres
- Elkem Materials – microsilica
- Fosroc International – chemical admixtures
- Castle Cement
- Hanson

Structural Materials and Mechanics Research – current projects

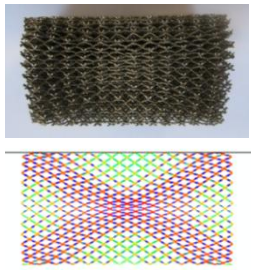
Epoxy syntactic foam

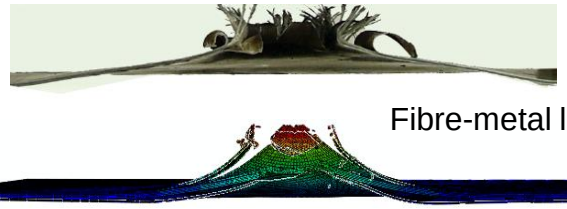


Al foam

- Novel fibre-metal laminates for blast and impact resistance
- Syntactic / metal foams for reducing shock loadings
- Fibre-reinforced concrete for protective engineering applications
- Combined blast and fragment loading behaviour of steel plates
- Pulse pressure testing and analysis of steel plates with openings
- Lightweight cable supported structures subject to blast fragmentation
- Micro-lattice structures for enhanced impact and blast protection

Micro-lattice structure





Fibre-metal laminate

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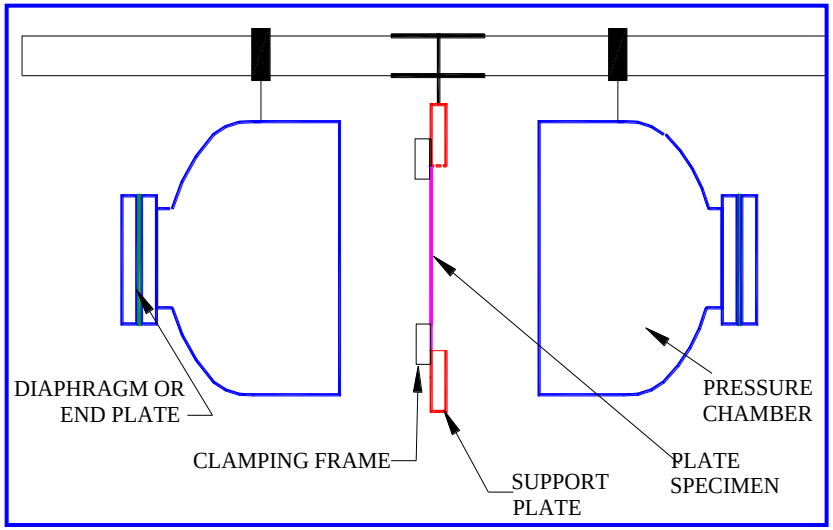
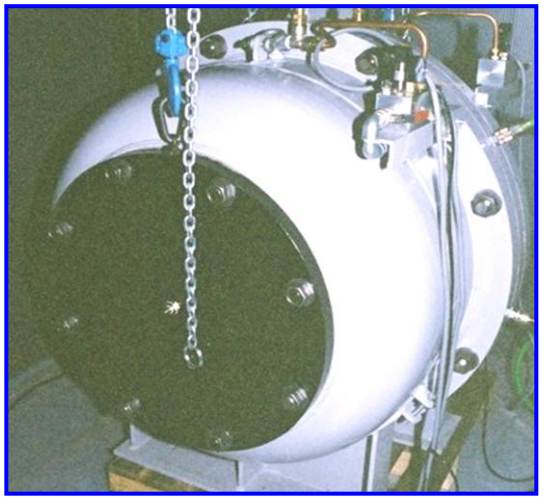
Pulse Pressure Loading Rig (PPLR)

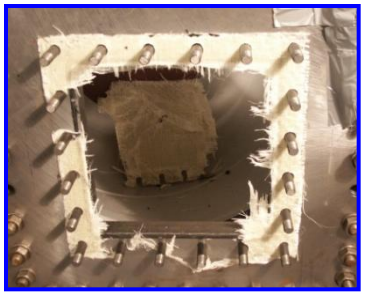


SCHEMATIC OF PPLR



PPLR in Static Mode

- Max. pressure = 800kPa
- Max. specimen size
  = 500mm square
  (pressurised area)
- ~ 9msec rise time at 200kPa



PPLR in Dynamic Mode

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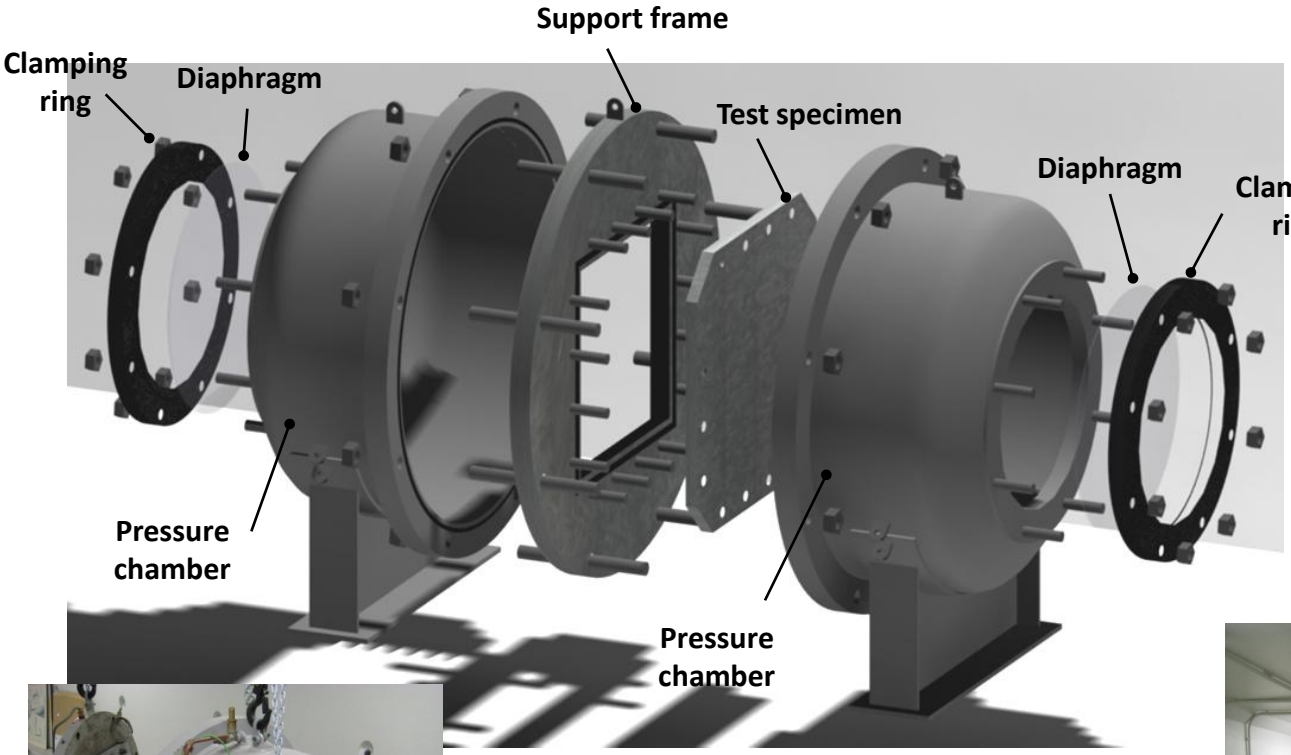
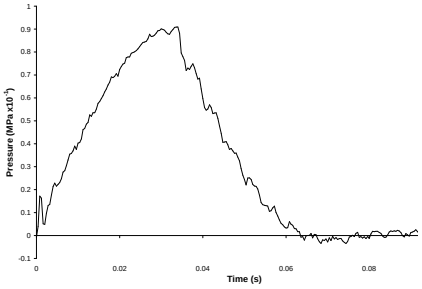
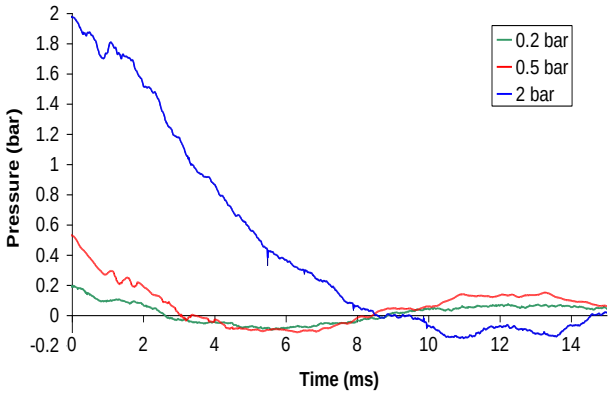
Pulse Pressure Loading Rig (PPLR)







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