Tension Stiffening in GFRP RC Beams

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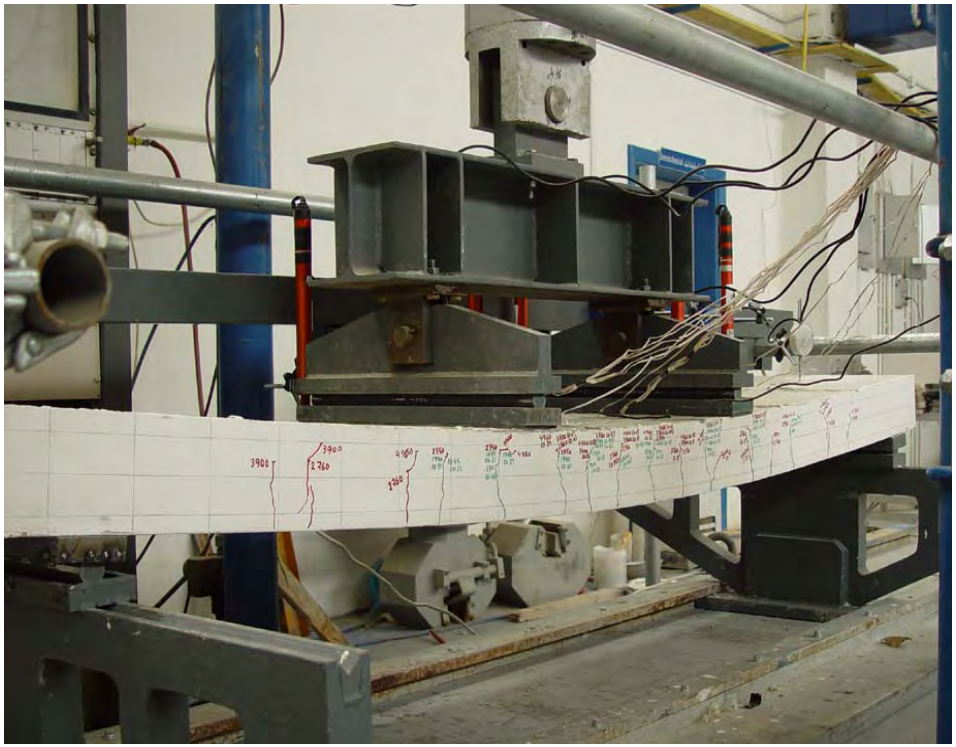
Tension Stiffening in GFRP RC Beams

OUTLINE

- Background
- Methodology
- Experimental Programme
- Experimental Results
- Conclusions



BACKGROUND

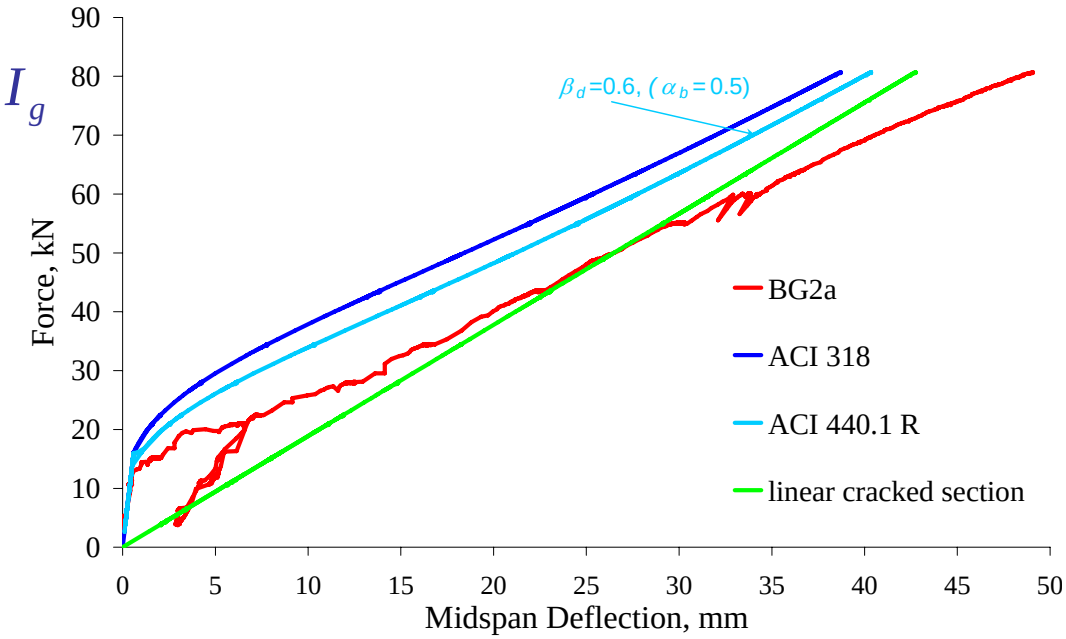
- **Serviceability-controlled design**

  - **ACI 440.1R-03**

$$I_e = I_{cr} + \left(\beta_d I_g - I_{cr}\right)\left[\frac{M_{cr}}{M_a}\right]^3 \leq I_g$$

$$\beta_d = \alpha_b\left[\frac{E_f}{E_s} + 1\right]$$

α_b = *bond coefficient = 0.5*



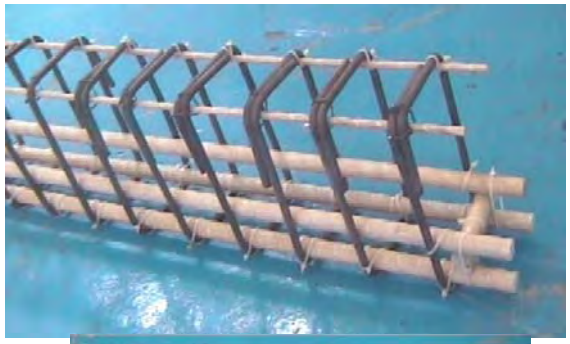
  - **IStructE (1999)**

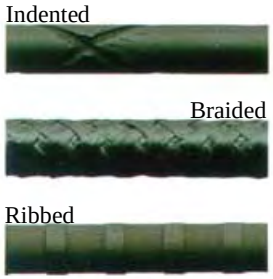
- Steel RC equations applicable

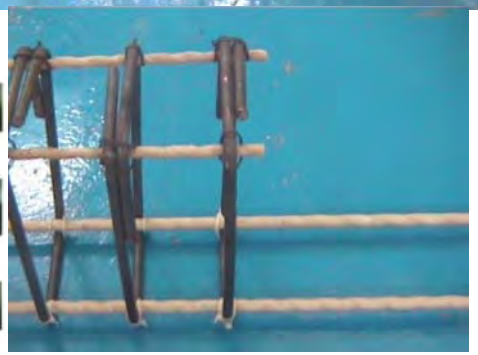
BACKGROUND

➢Key Variables

- *Reinforcement Ratio*
- *Modulus of Elasticity*
- *Bond Characteristics*



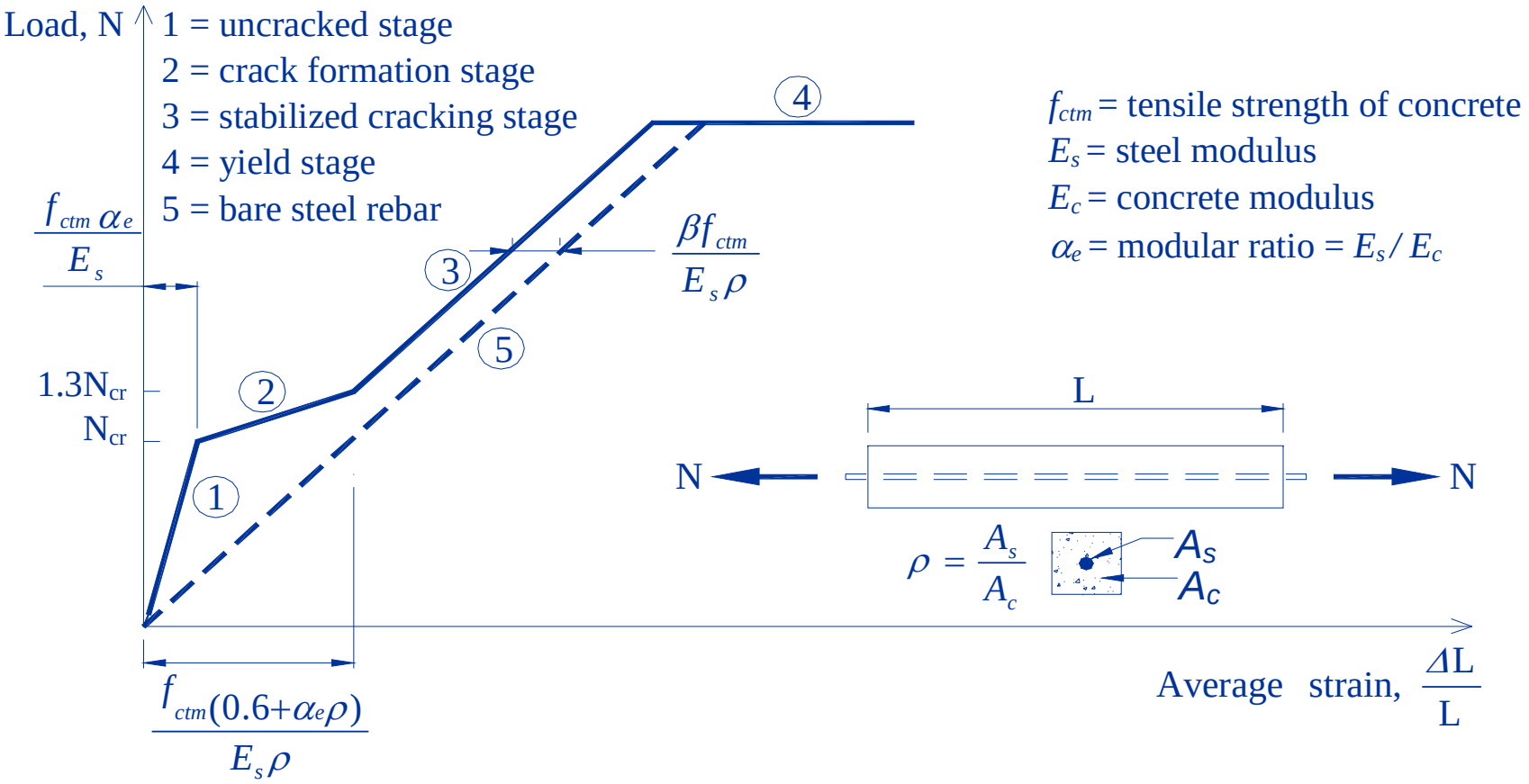




➢Other Variables

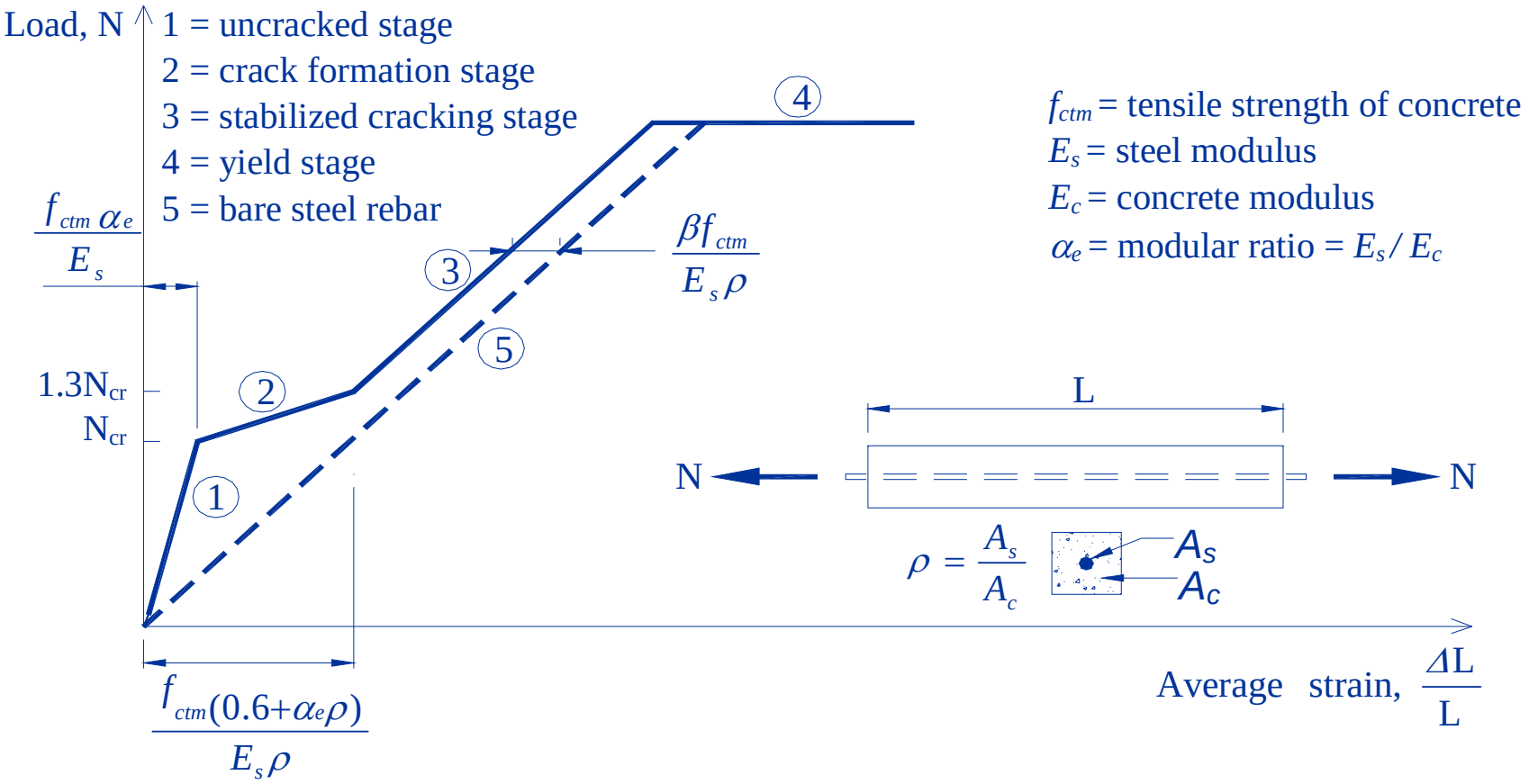
- *Concrete cover*
- *Concrete Strength*
- *Rebar diameter*

BACKGROUND



Load-strain relationship of a steel RC tie (*fib 1999*)

BACKGROUND



Load-strain relationship of a steel RC tie (*fib 1999*)

METHODOLOGY

➢Experimental:

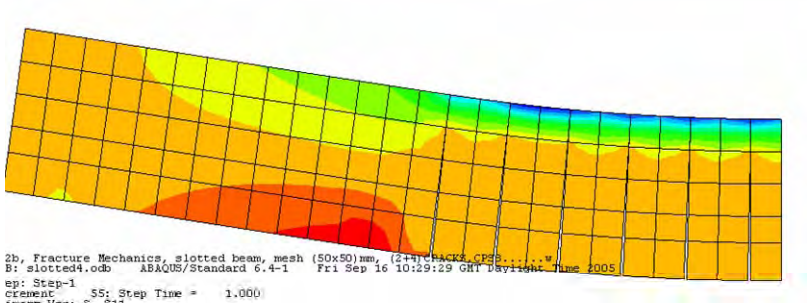
- Structural tests: (Beams and Slabs, CFRP and GFRP)

- Material tests (Concrete and rebars)

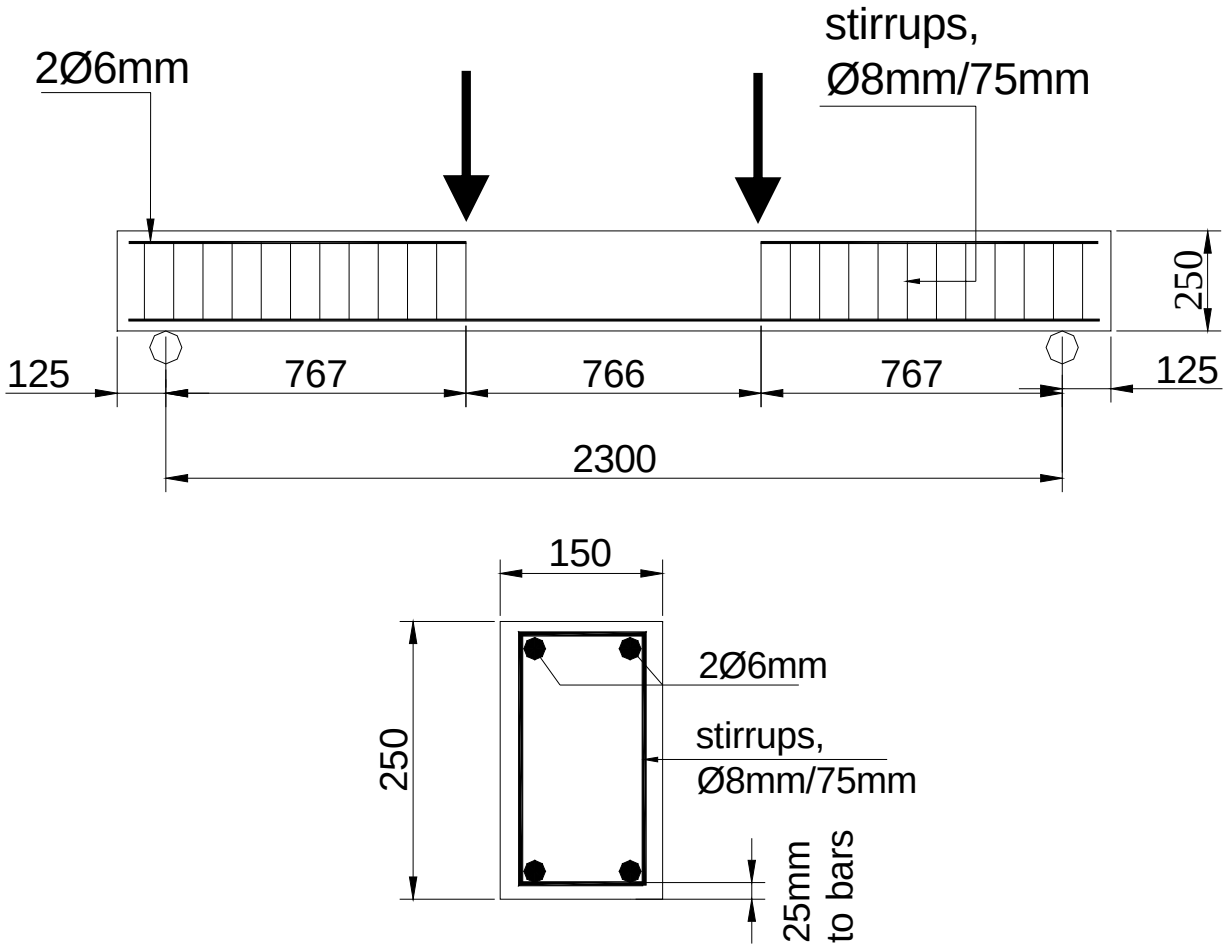
➢Analytical:

- Sectional analysis

- Finite element analysis



EXPERIMENTAL PROGRAMME *(GFRP RC Beams)*

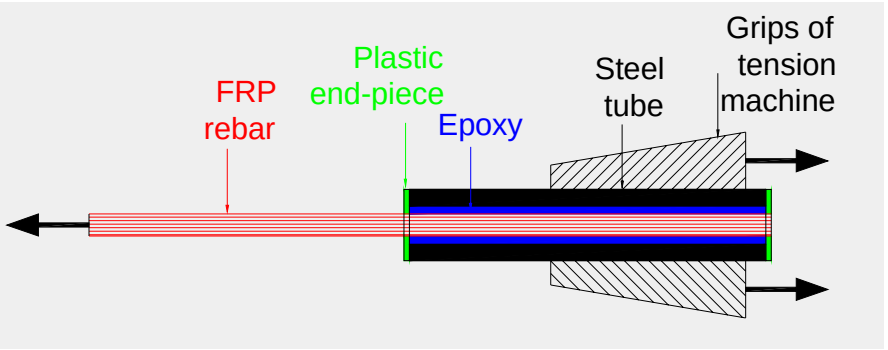


EXPERIMENTAL PROGRAMME *(GFRP RC Beams)*

Rebar type	Series designation	Beam designation	Rebar details	Reinforcement ratio	Relation to control steel beam
GFRP	BG1	BG1a	2∅9.53	0.00432	Equal flexural capacity
		BG1b			
	BG2	BG2a	2∅12.7	0.00772	Equal area of rebars
		BG2b			
	BG3	BG3a	4∅19.05	0.0391	Equal stiffness of rebars
		BG3b			
Steel	BS	BSa	2∅12	0.00688	-
		BSb			

EXPERIMENTAL PROGRAMME *(GFRP RC Beams)*

Rebar type	Nominal diameter, (mm)	Modulus of elasticity, (MPa)	Tensile strength, (MPa)
GFRP	9.53	42500	650
	12.70	41500	600
	19.05	42000	650



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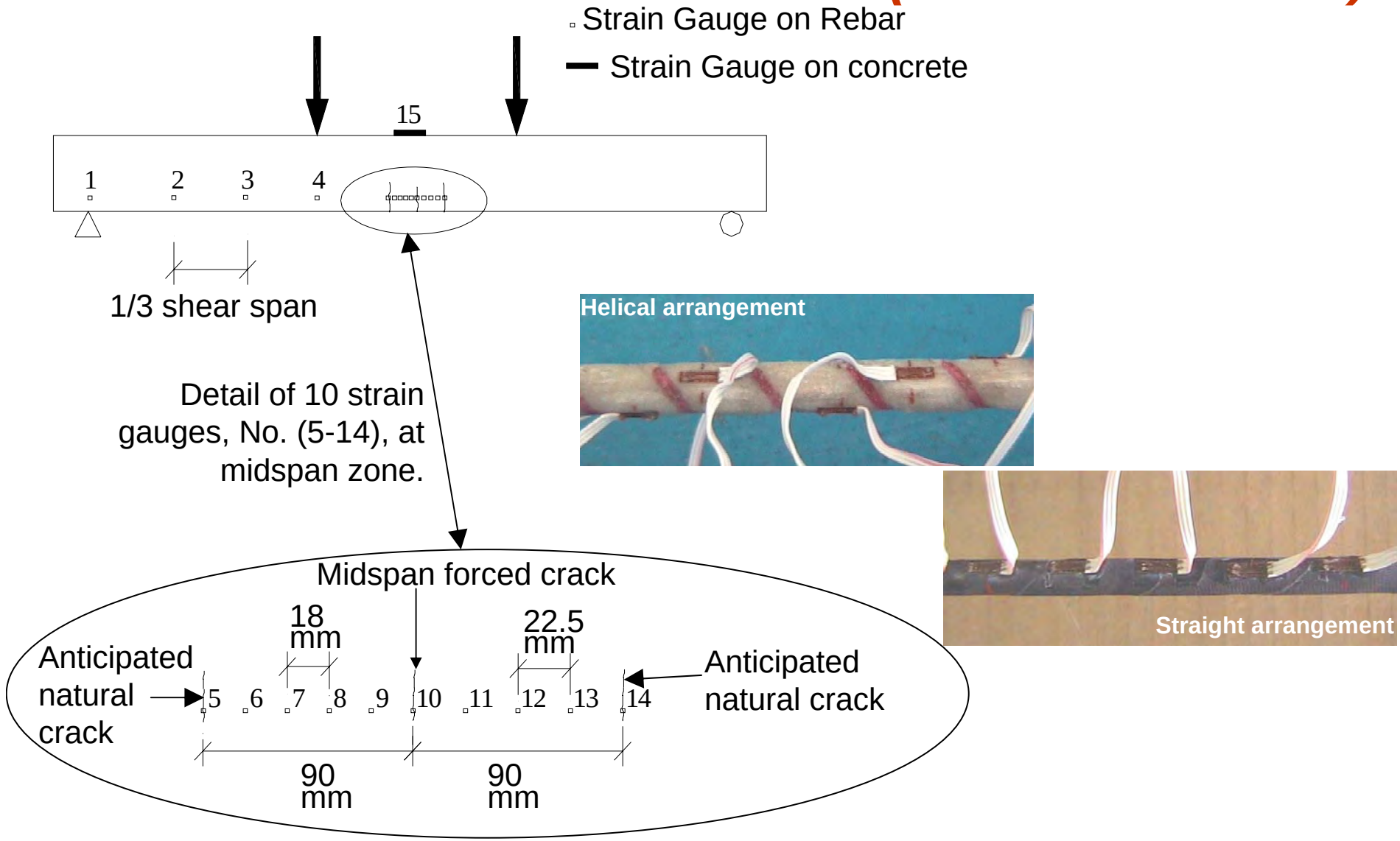

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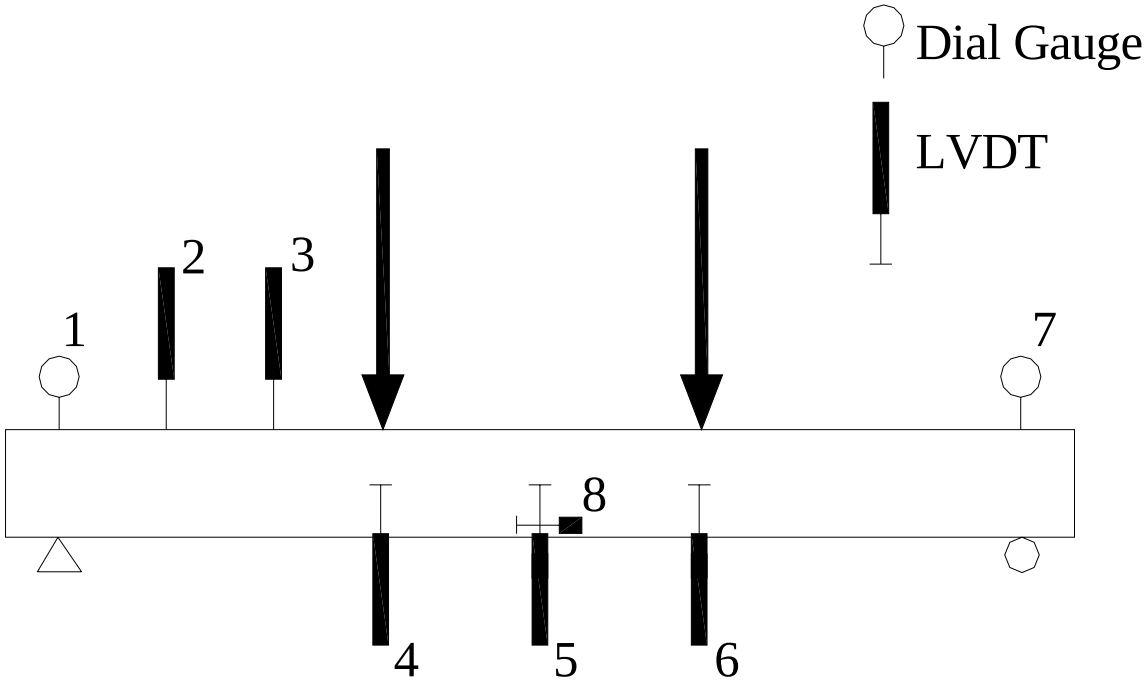

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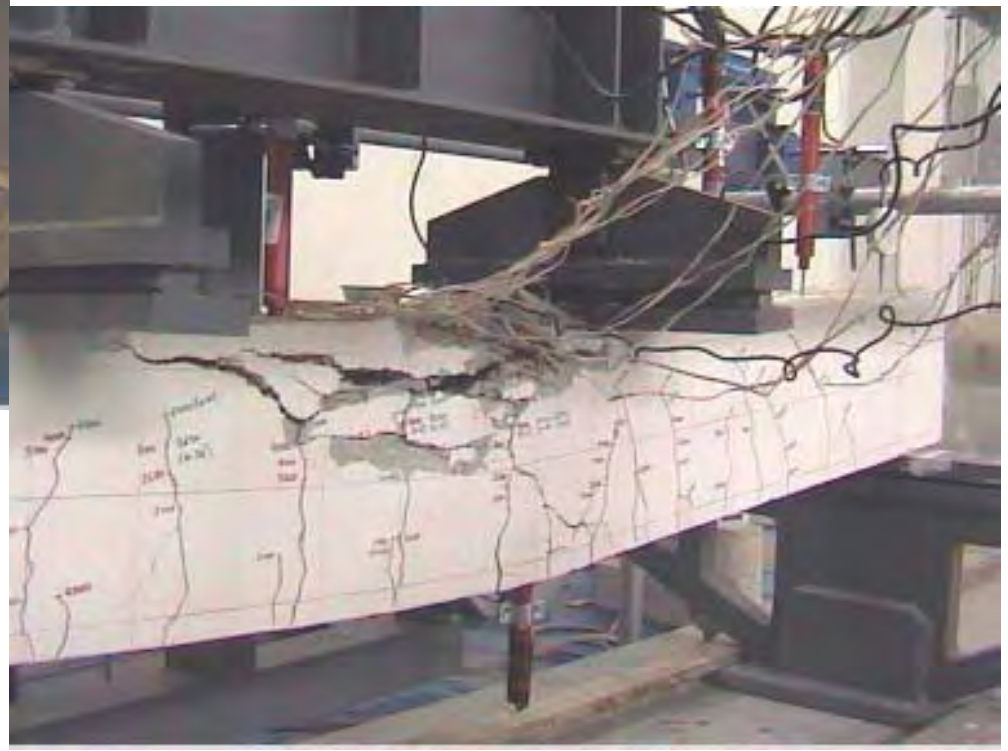

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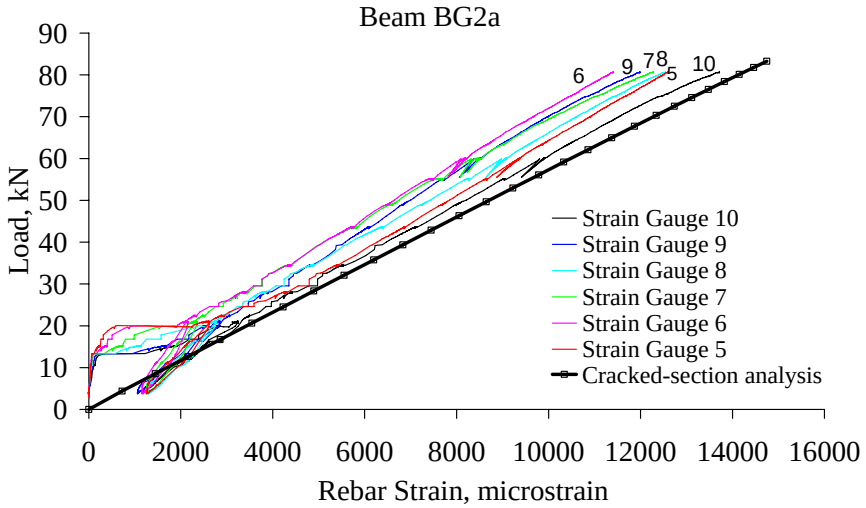
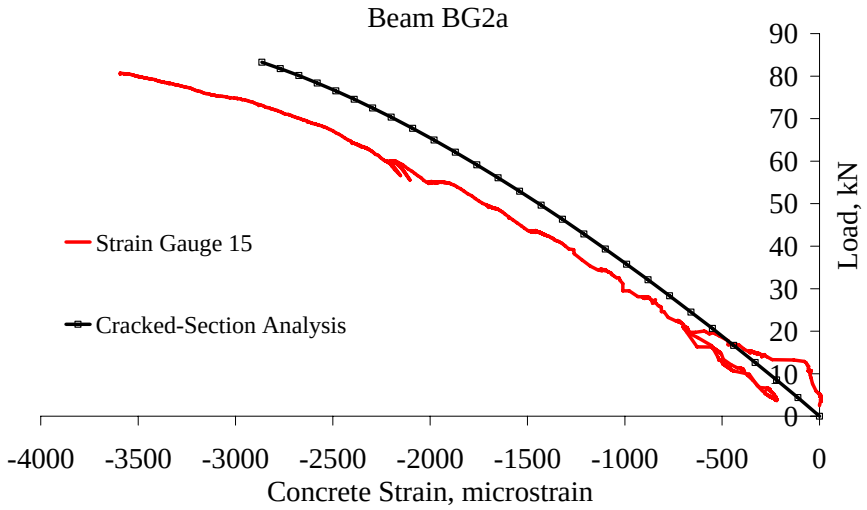
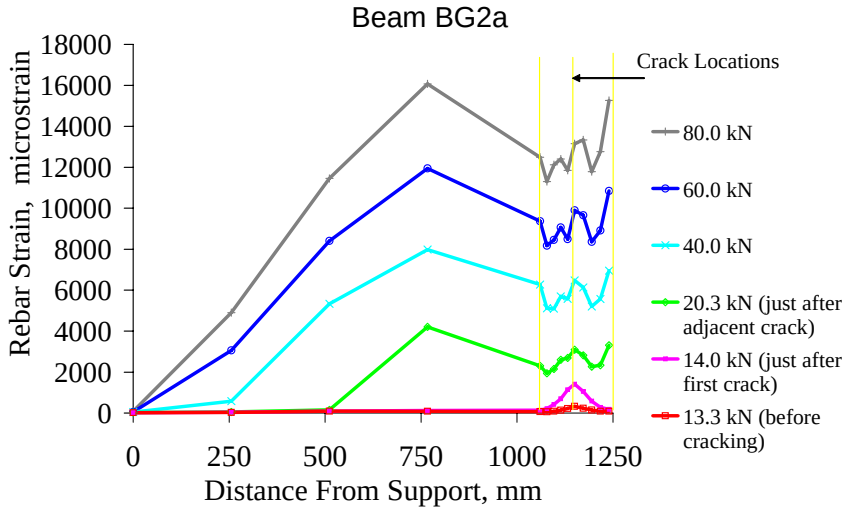
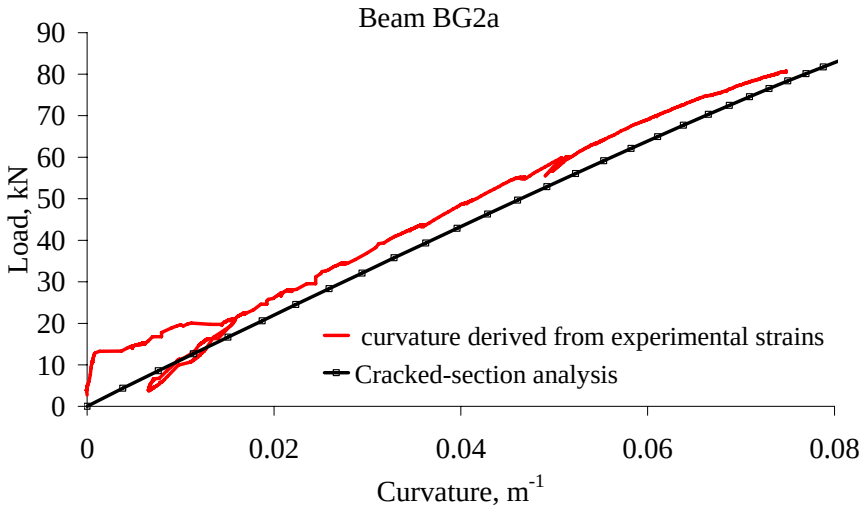
Tension Stiffening in GFRP RC Beams

EXPERIMENTAL RESULTS









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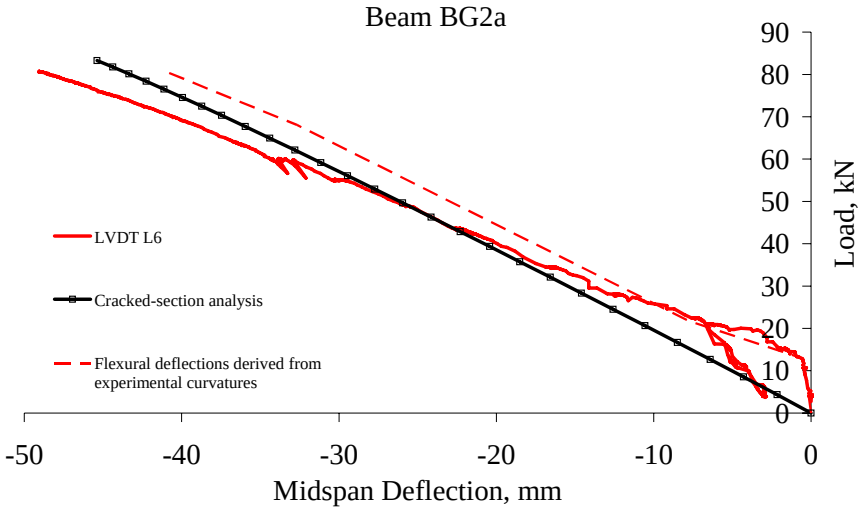

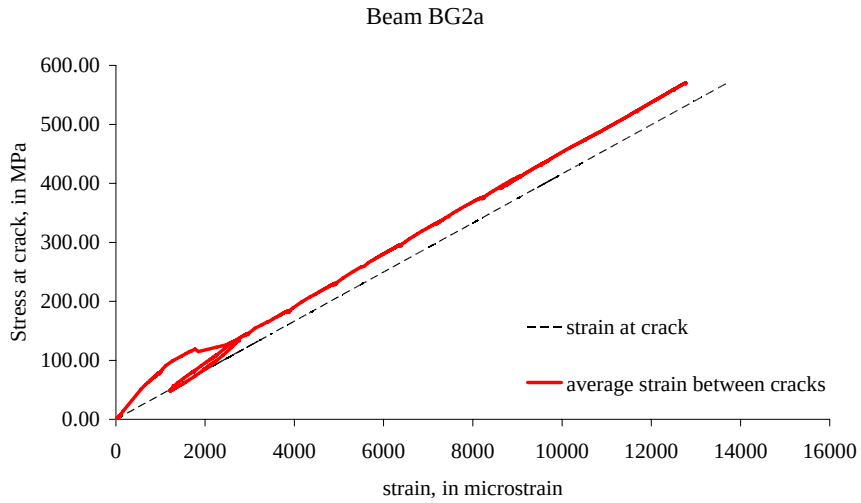

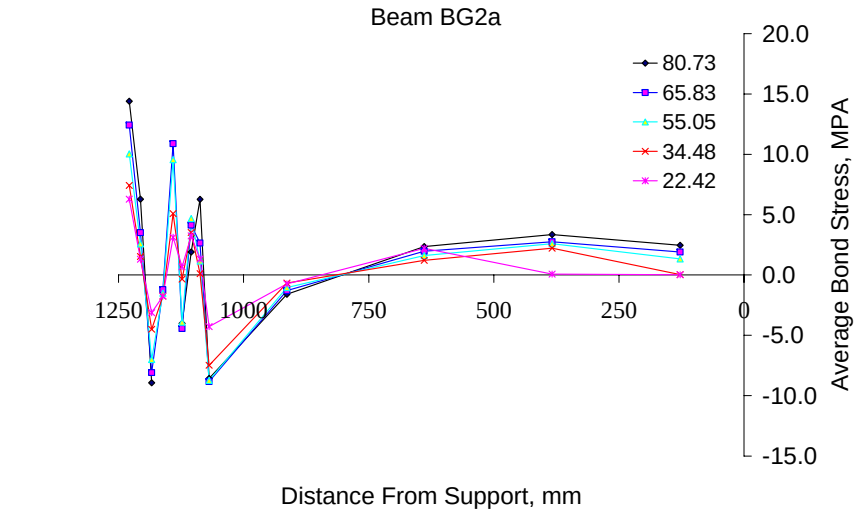

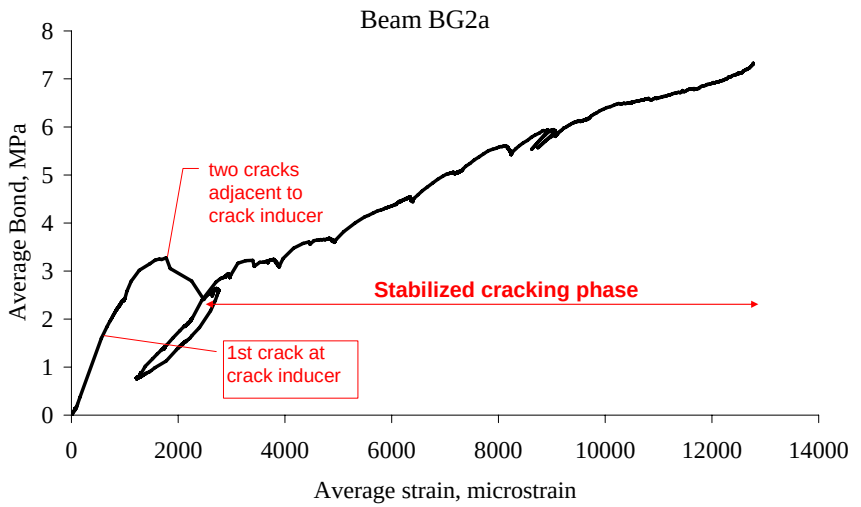

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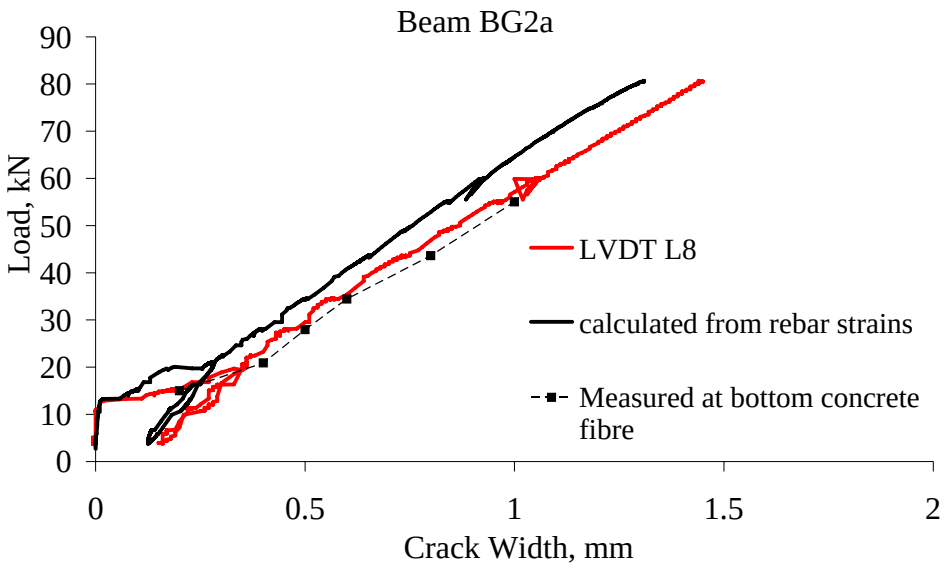

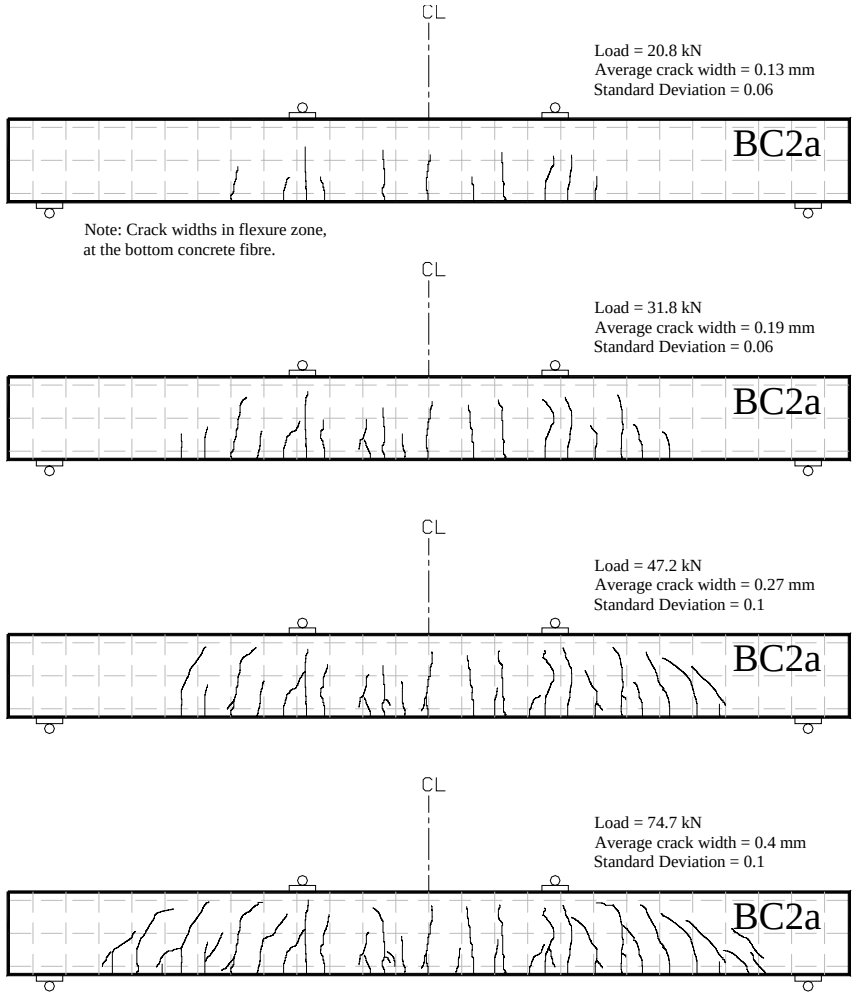

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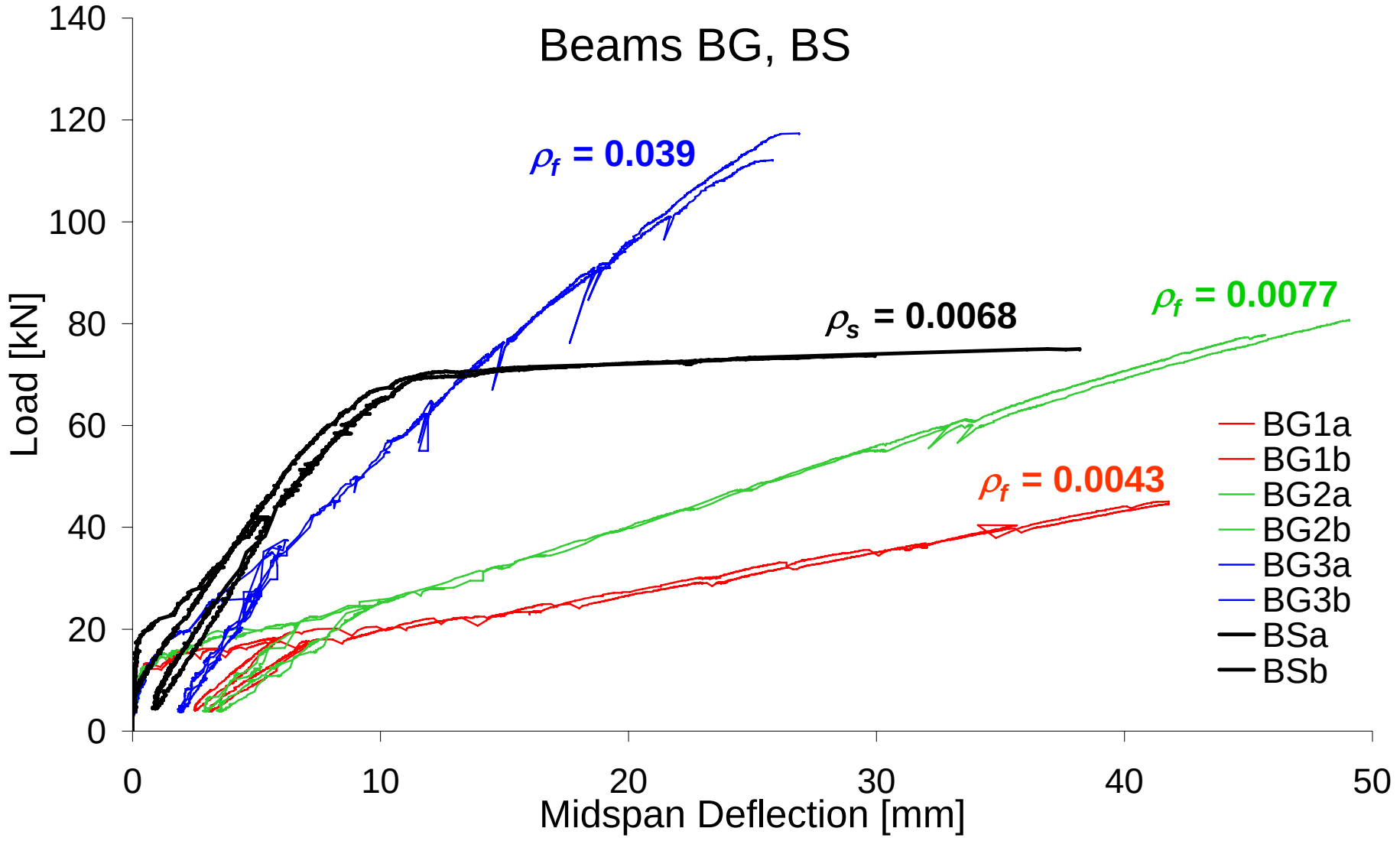
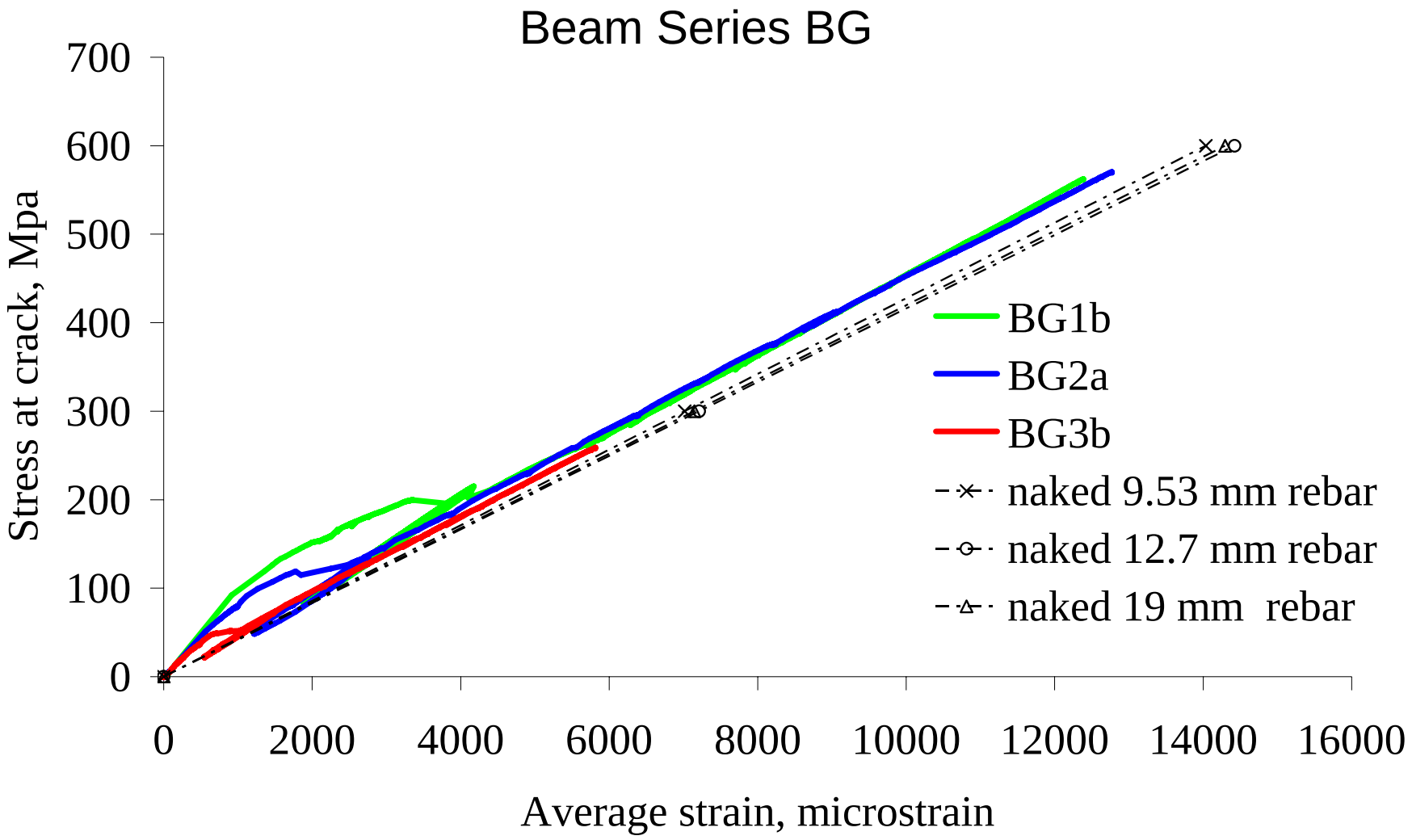


TENSION STIFFENING ANALYSIS

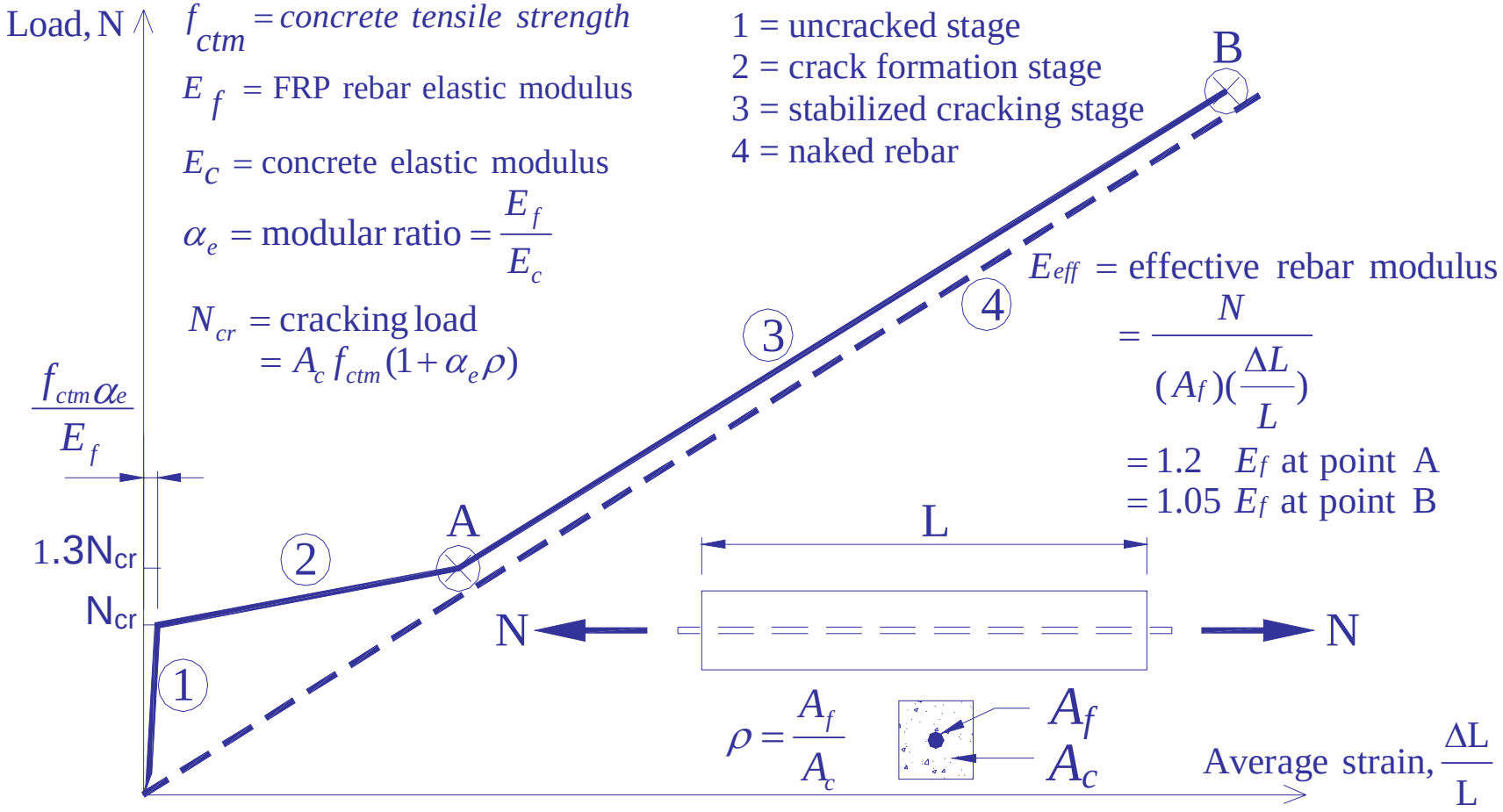


TENSION STIFFENING ANALYSIS

Tension Stiffening in the Stabilised Cracking Phase

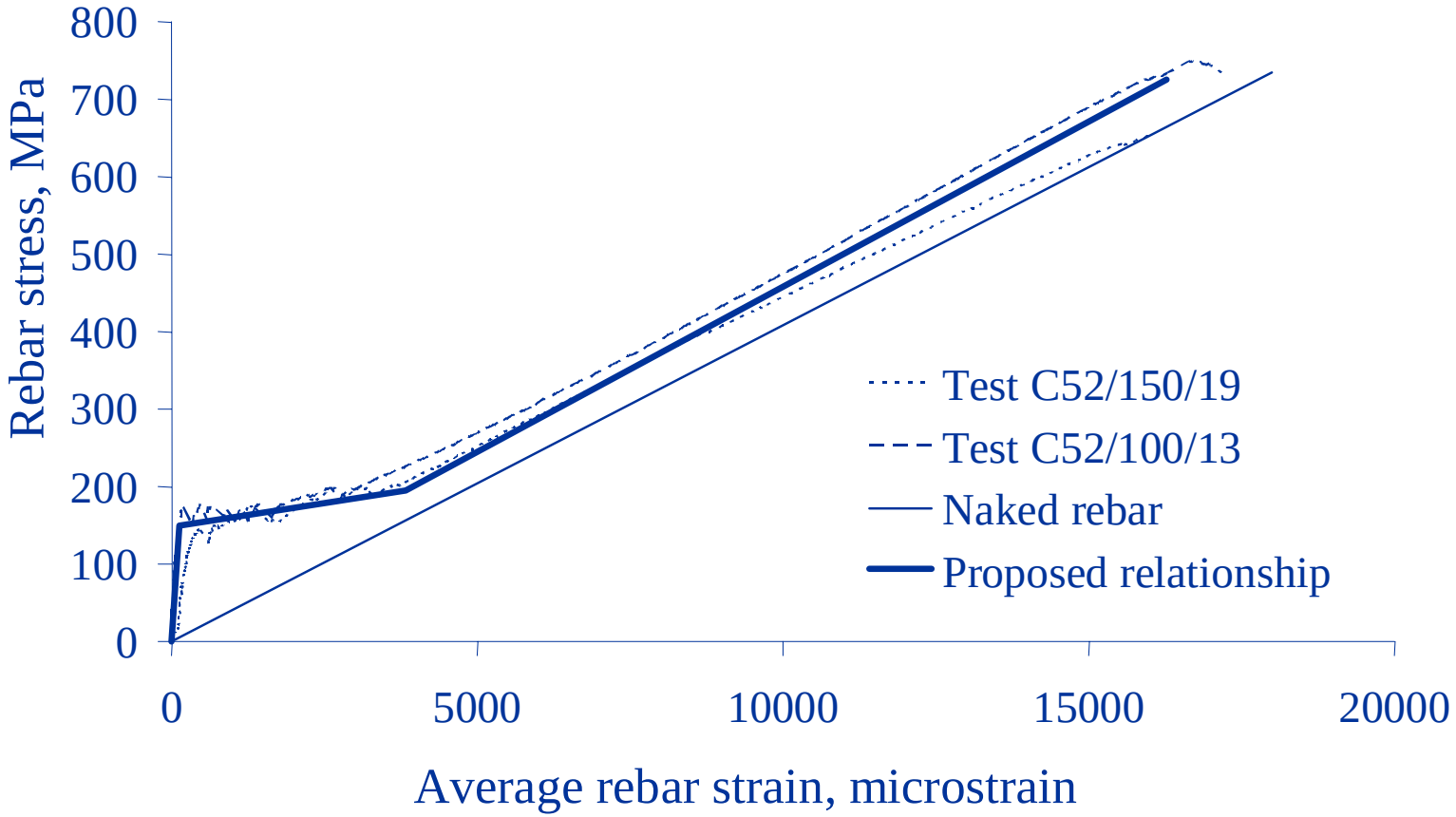
Beam ID	Naked rebar modulus, E_f, "MPa"	Beginning of stabilized cracking phase		End of stabilized cracking phase		Stabilized cracking phase
		Effective Modulus, E_{eff}, "MPa"	E_{eff}/E_f	Effective Modulus, E_{eff}, "MPa"	E_{eff}/E_f	Average E_{eff}/E_f
BG3b	41970	47715	1.14	44548	1.06	1.1
BG2a	41600	49889	1.20	44636	1.07	1.14
BG1b	42750	492280	1.15	45370	1.06	1.11
		For steel RC, ρ=1%	**1.6**		**1.39**	
		For steel RC, ρ=10%	**1.31**		**1.03**	

TENSION STIFFENING ANALYSIS



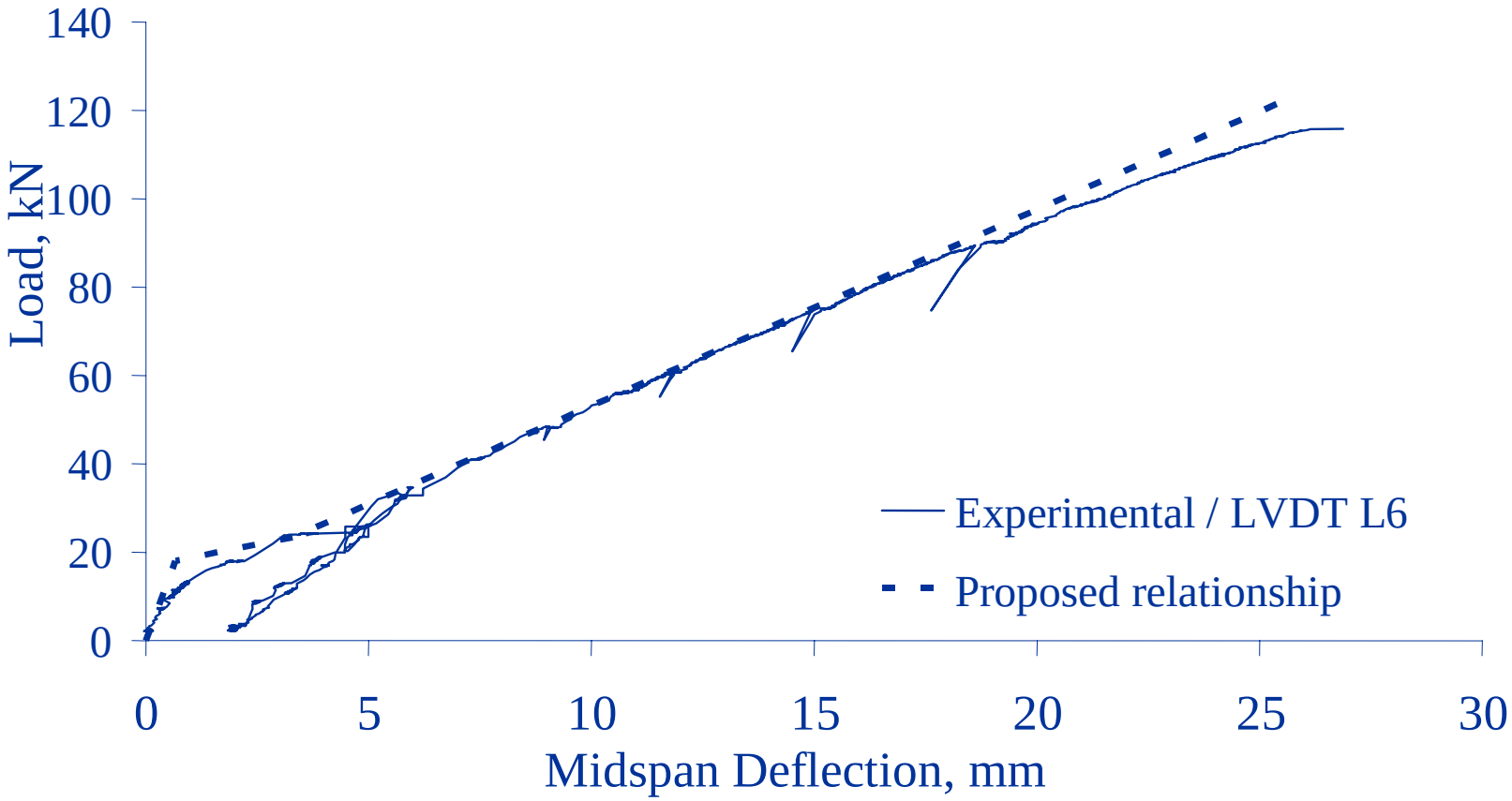
Proposed load-strain relationship of a GFRP RC tension tie

TENSION STIFFENING ANALYSIS



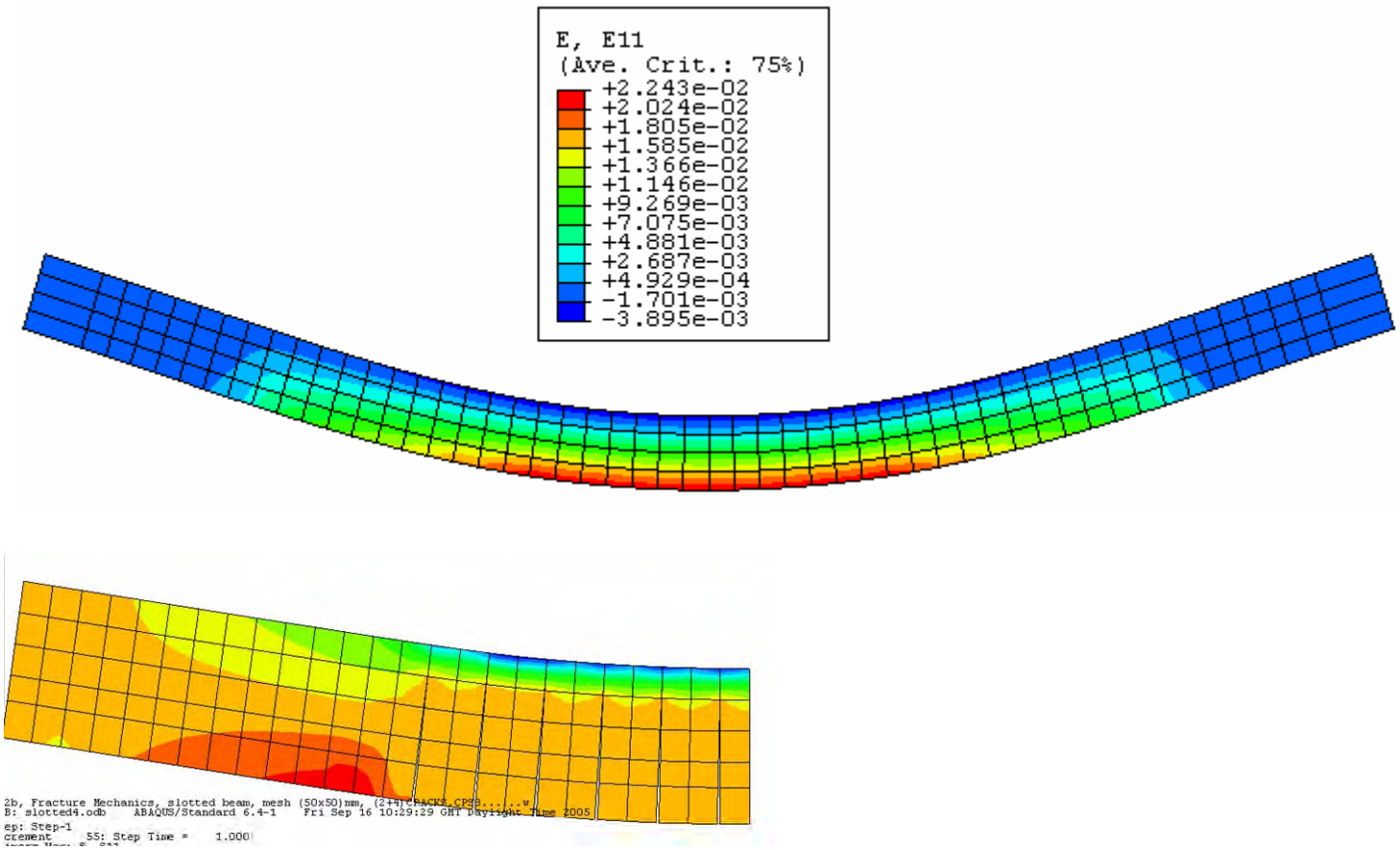
Tests of GFRP RC tension ties by Sooriyaararachchi

TENSION STIFFENING ANALYSIS



Midspan Deflection of Beam BG3

FINITE ELEMENT ANALYSIS



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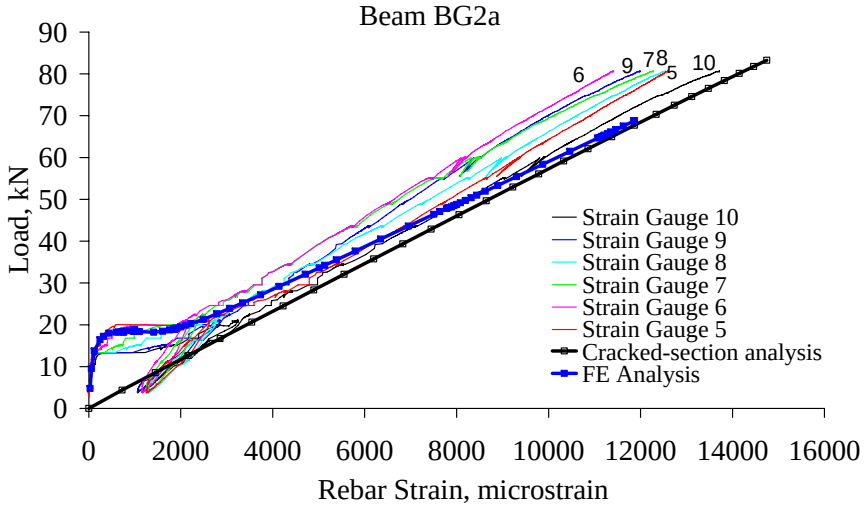

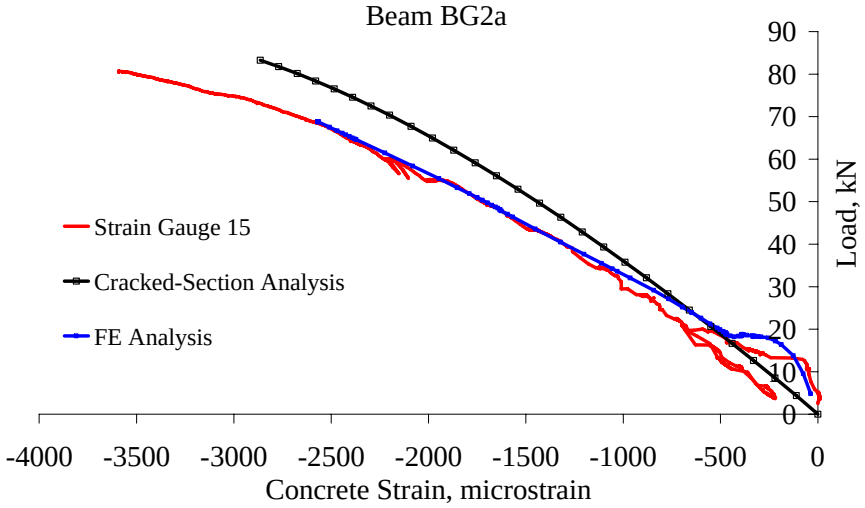

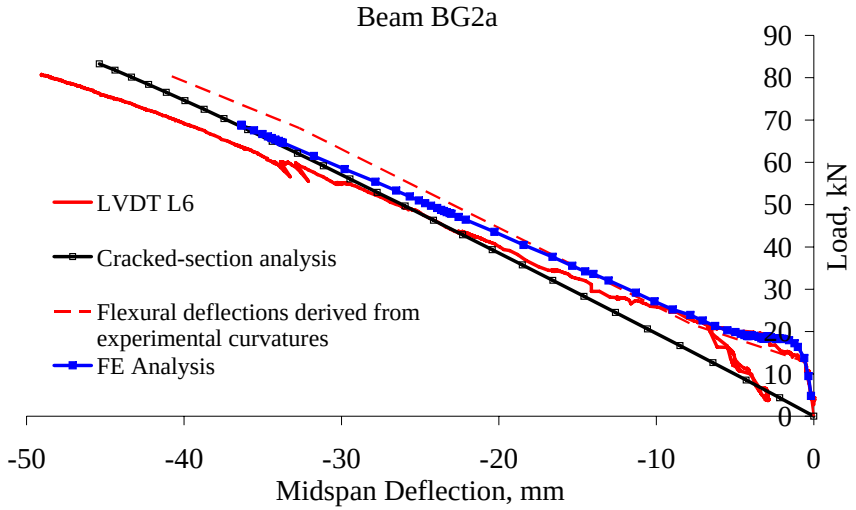

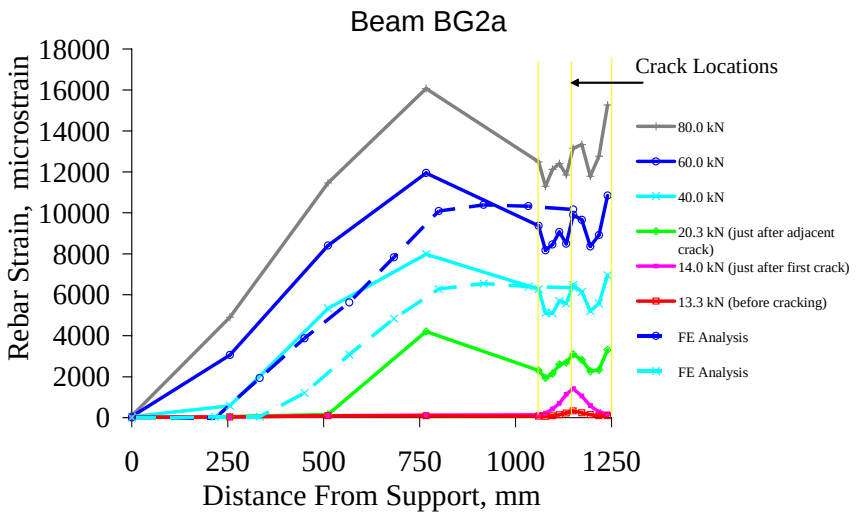

CONCLUSIONS

Behaviour of GFRP RC beams:

- *Deflection of GFRP RC is mainly caused by flexural curvatures.*
- *Shear-induced deflections may not be negligible for low reinforcement ratios and deep-penetrating wide cracks.*
- *The response of the compressive concrete zone requires further consideration due to the increased localised effect of cracks.*
- *GFRP RC show good bond.*
- *CSA predicts the maximum rebar strain at a crack, underestimates the extreme-fibre concrete strain, and when shear induced deformations are sizeable may not provide an upper-bound deflection.*

CONCLUSIONS

Tension Stiffening of GFRP RC beams:

- *Contrary to steel RC, the amount of GFRP reinforcement may have negligible effect on tension stiffening in the stabilised cracking phase*

  (ρ>0.4%, or ρ_{eff}>1.25%)
- *An average Eeff (1.10 E) offers a reasonable approximation for the whole stabilised cracking phase.*
- *Tension stiffening in GFRP is lower than steel RC, which is due to the high levels of rebar strain involved.*
- *An initial tension stiffening relationship is proposed but needs to be expressed more fundamentally.*

ACKNOWLEDGEMENTS

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