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Deflection of FRP RC Beams

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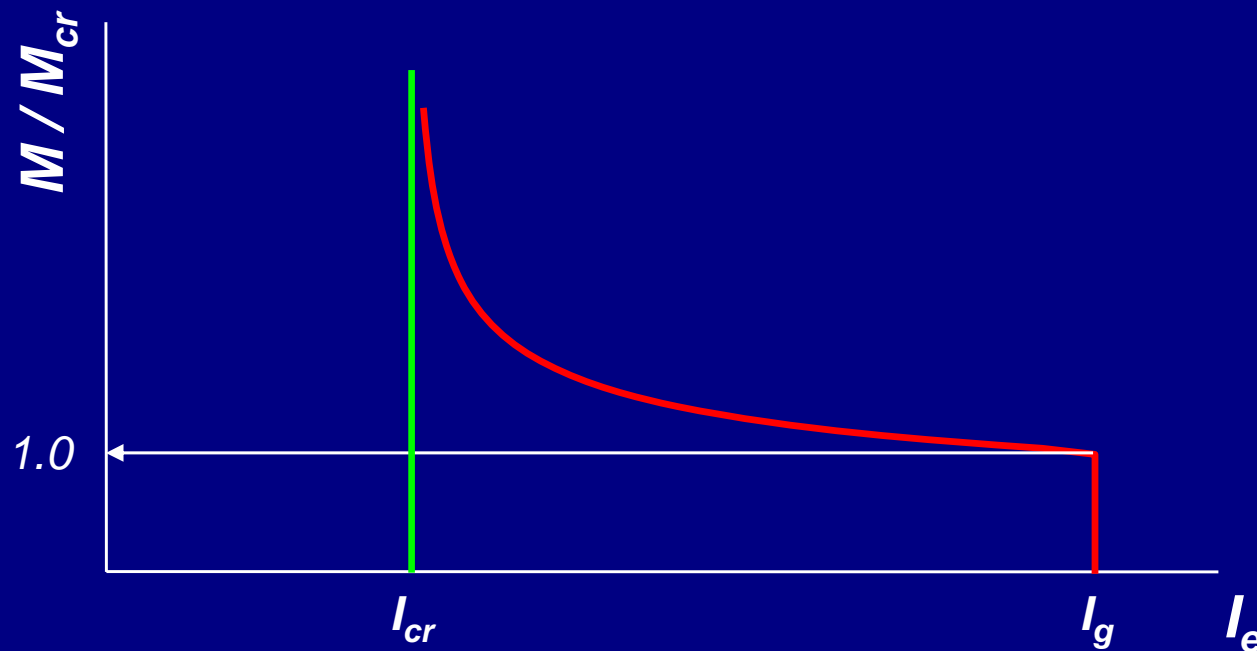
OUTLINE

- Prediction of deflections (ACI).
- Experimental programme.
- Experimental Results.
- Proposed Equation.
- Conclusions.



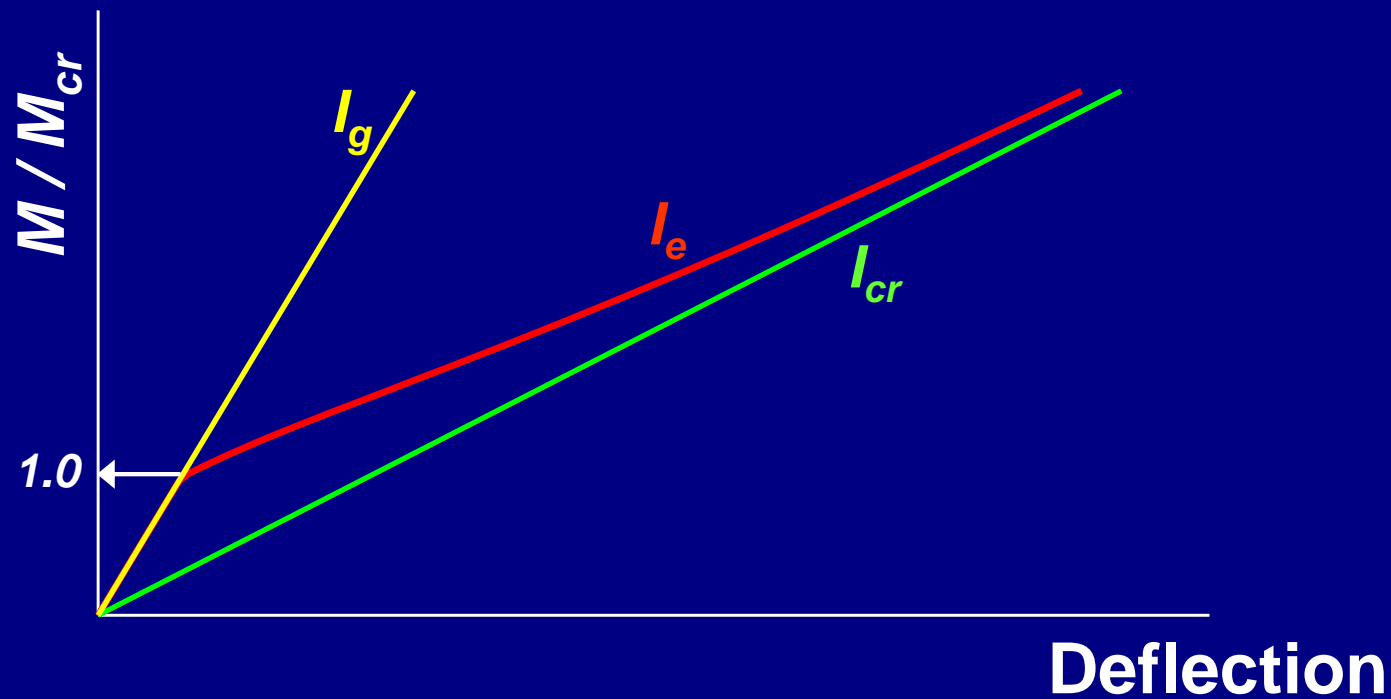
Deflection Prediction (ACI)

- Elastic procedure.
- Effective moment of inertia (I_e).





Deflection Prediction (ACI)





Deflection Prediction (ACI)

– ACI 318-02
for steel RC

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

– ACI 440.1R-03
for FRP RC

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

$$\beta_d = \alpha_b \left[\frac{E_f}{E_s} + 1 \right] \quad \alpha_b = \text{bond coefficient} \\ = 0.5$$

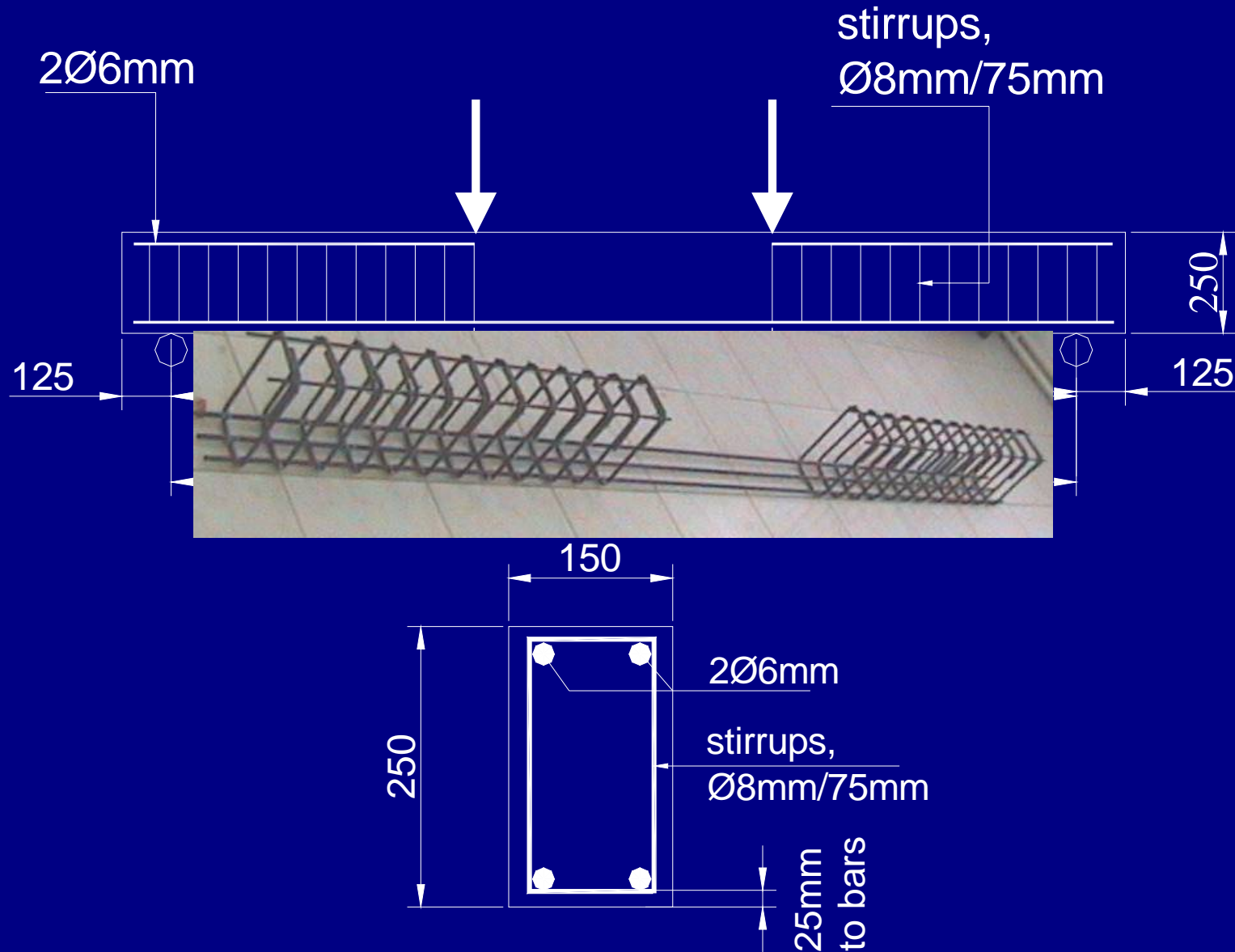


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Experimental Programme





Experimental Programme

Rebar type	Series designation	Beam designation	Rebar details	Reinforcement ratio	Relation to control steel beam
GFRP	BG1	BG1a	2 \emptyset 9.53	0.00432	Equal flexural capacity
		BG1b			
	BG2	BG2a	2 \emptyset 12.7	0.00772	Equal area of rebars
		BG2b			
	BG3	BG3a	4 \emptyset 19.05	0.0391	Equal stiffness of rebars
		BG3b			
CFRP	BC1	BC1a	3 \emptyset 6.35	0.00286	Equal flexural capacity
		BC1b			
	BC2	BC2a	3 \emptyset 9.53	0.00648	Equal area of rebars
		BC2b			
	BC3	BC3a	3 \emptyset 12.7	0.0116	Equal stiffness of rebars
		BC3b			
Steel	BS	BSa	2 \emptyset 12	0.00688	-
		BSb			



Experimental Programme

Rebar type	Nominal diameter, (mm)	Modulus of elasticity, (MPa)	Guaranteed tensile strength, (MPa)
GFRP	9.53	40800	760
	12.70	40800	690
	19.05	40800	620
CFRP	6.35	119750	1250
	9.53	122750	1000
	12.70	111750	900





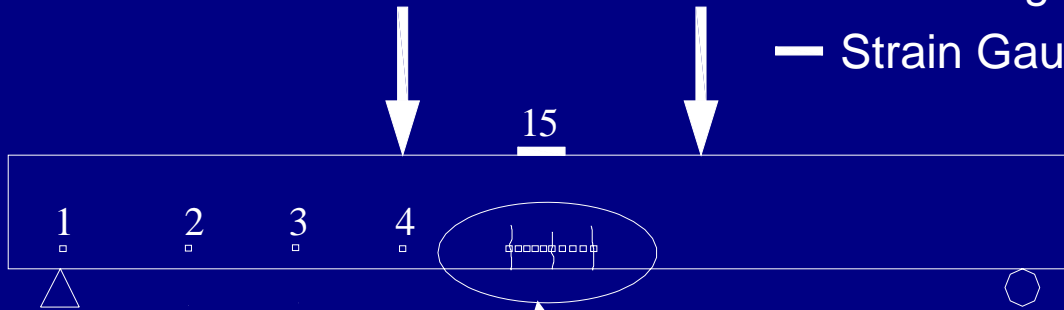
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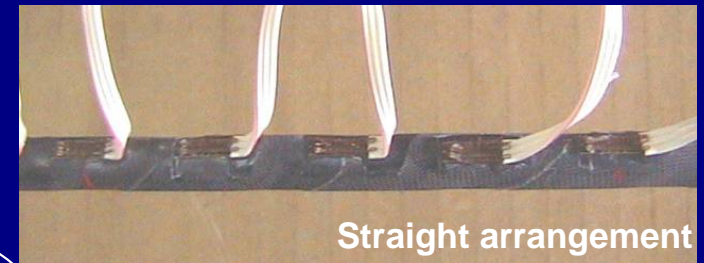
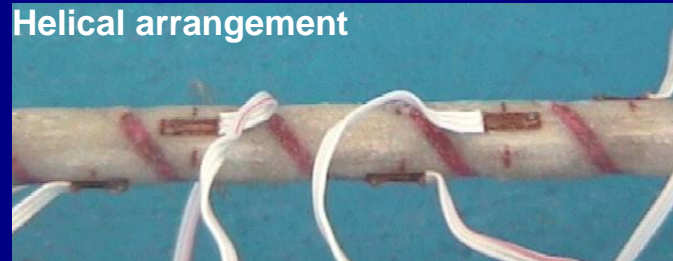
Experimental Programme

- Strain Gauge on Rebar
- Strain Gauge on concrete



1/3 shear span

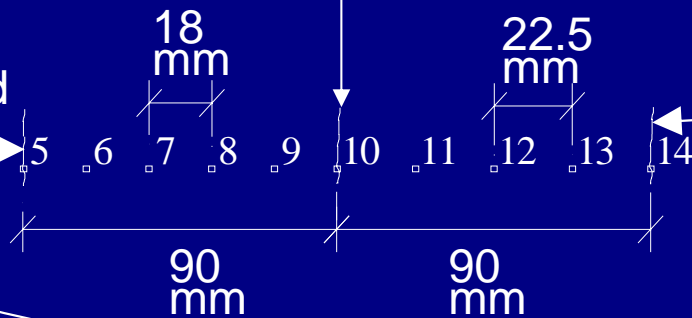
Detail of 10 strain gauges, No. (5-14), at midspan zone.



Midspan forced crack

Anticipated natural crack

Anticipated natural crack





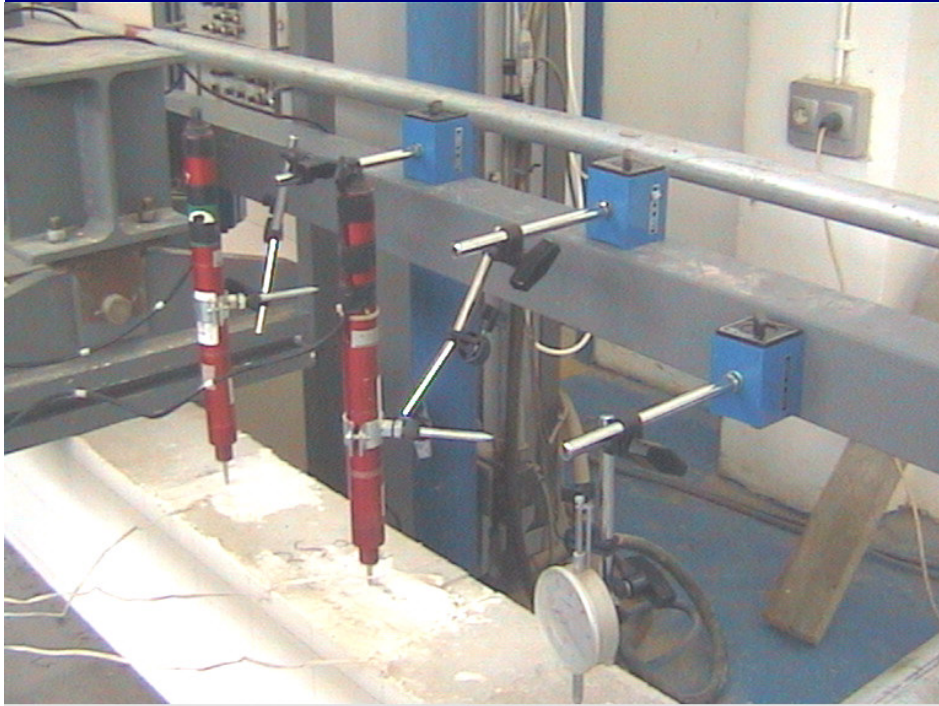
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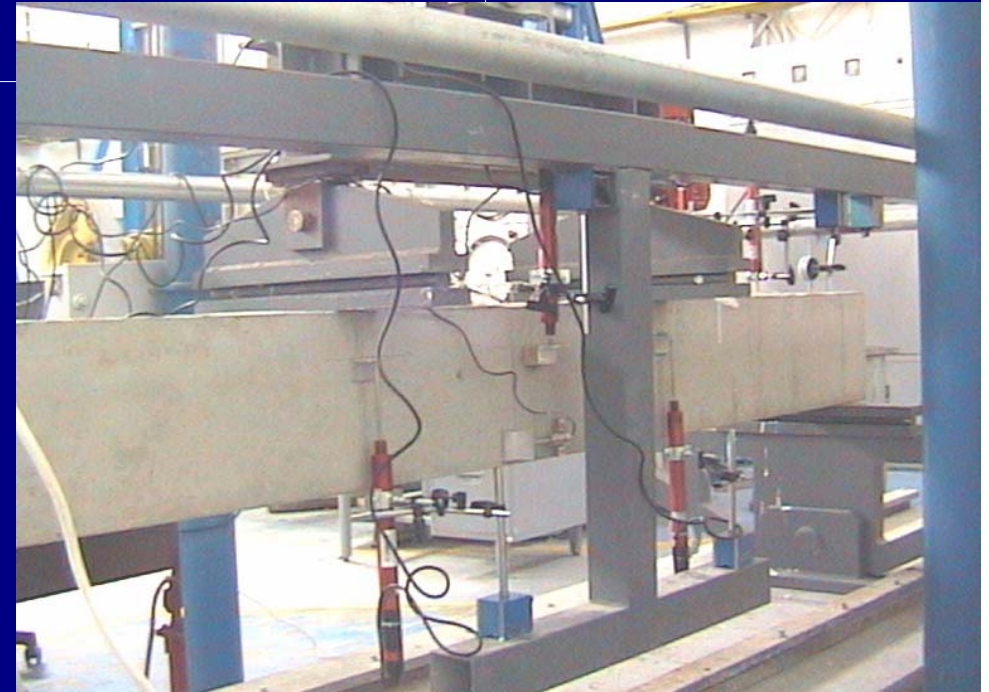
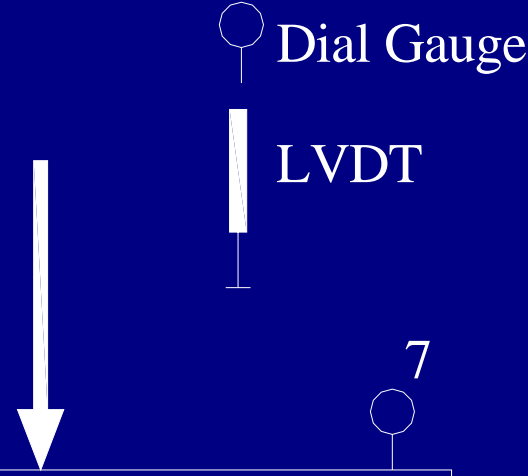
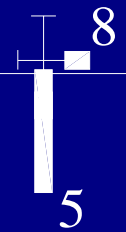
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Experimental Programme



4





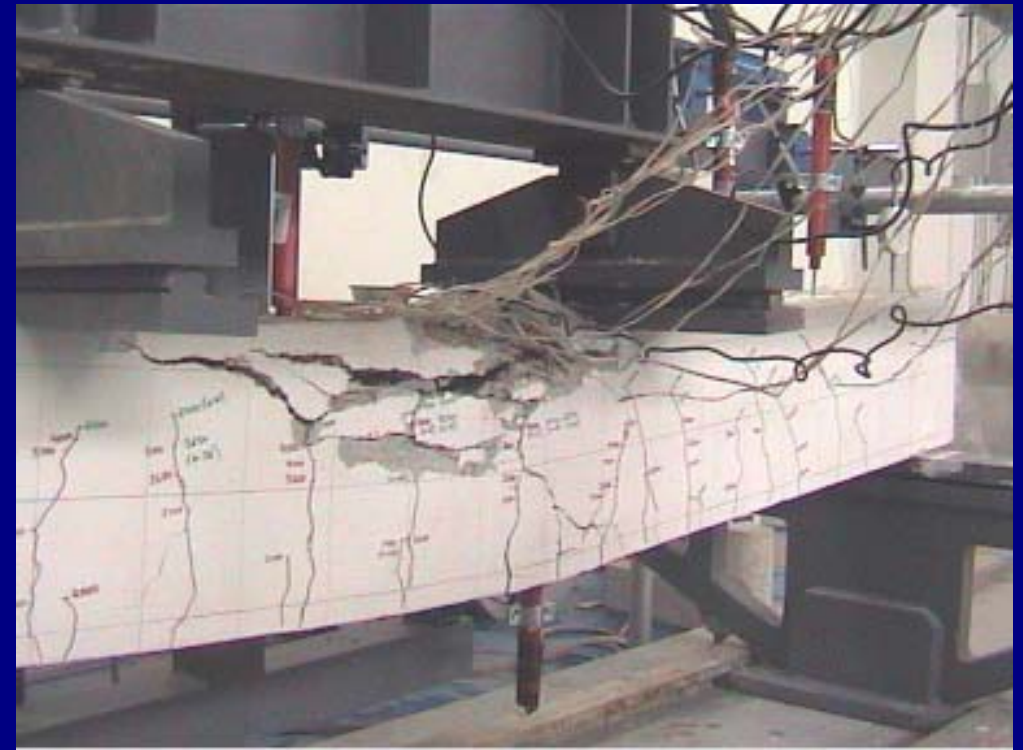
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Experimental Programme



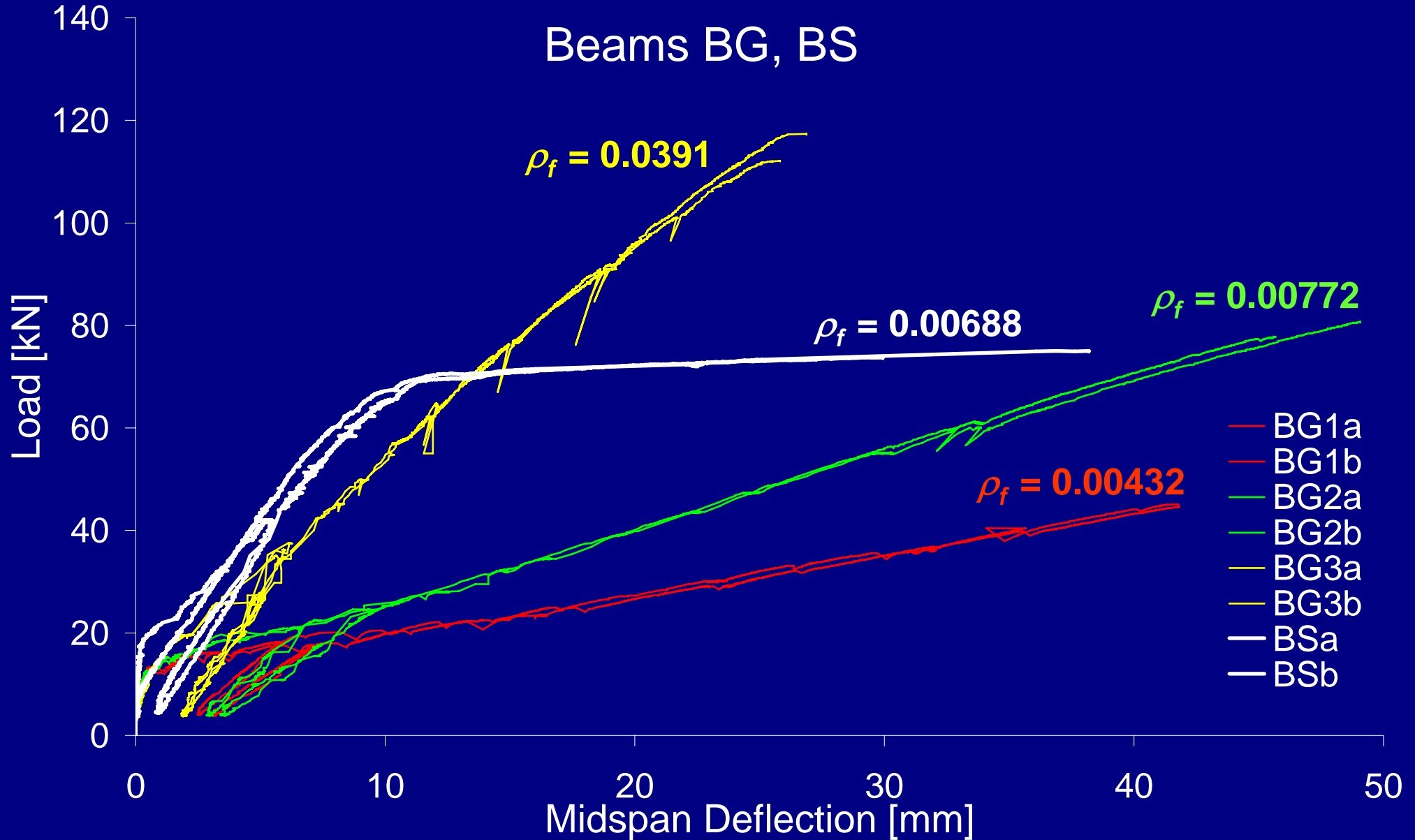


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Experimental Results



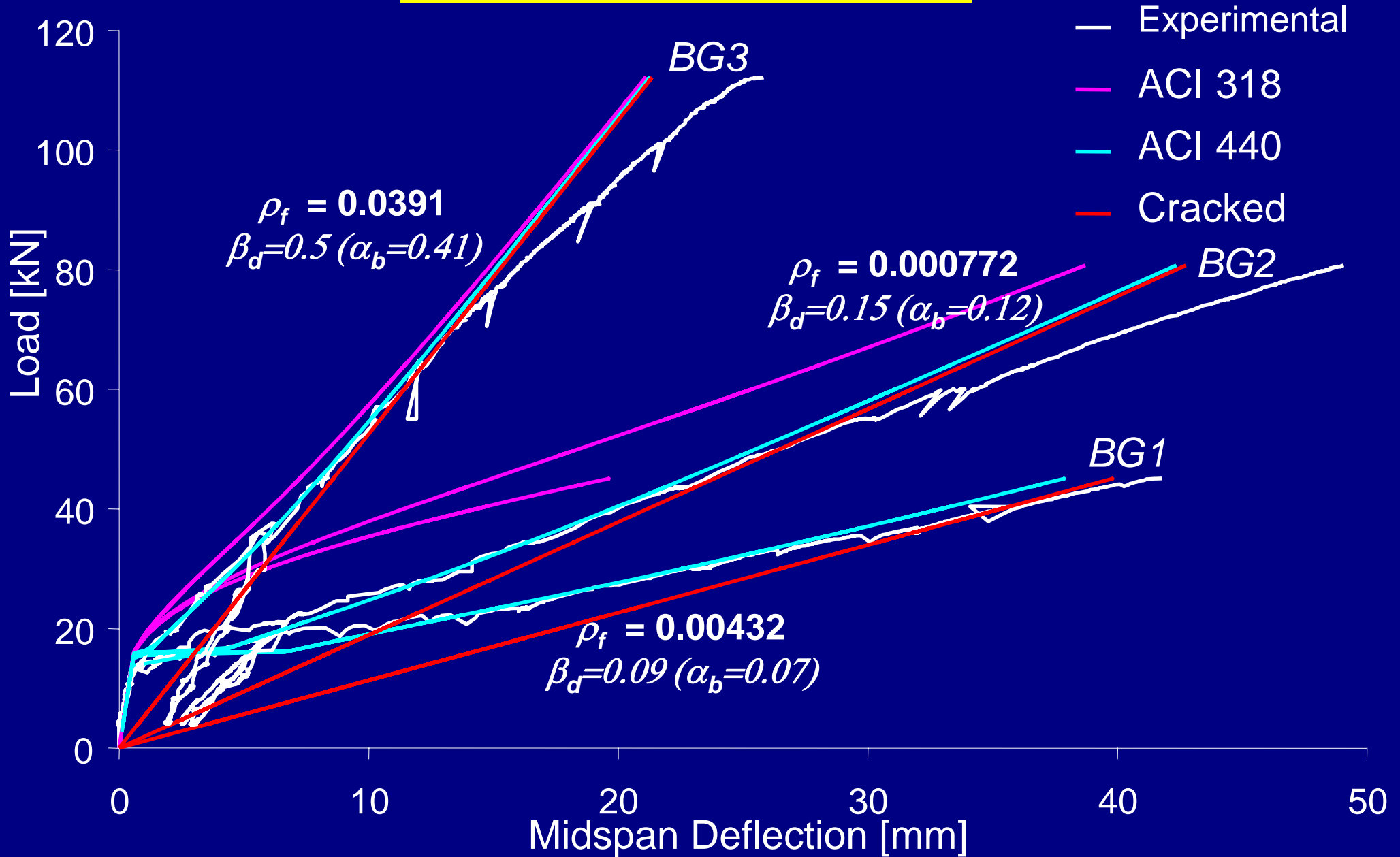


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Experimental Results





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Experimental Results

Rebar Type	GFRP			CFRP		
Beam Series	BG1	BG2	BG3	BC1	BC2	BC3
Reinforcement Ratio, ρ_f	0.00432	0.00772	0.0391	0.00286	0.00648	0.0116
Coefficient β_d	0.09	0.15	0.5	0.19	0.25	0.5
Coefficient α_b	0.07	0.12	0.41	0.12	0.15	0.32



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Proposed Equation

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

$$\beta = 0.1e^{330(\rho E_f / E_s)^{1.2}}$$

	GFRP	CFRP	STEEL
α	0.9	0.85	1.0

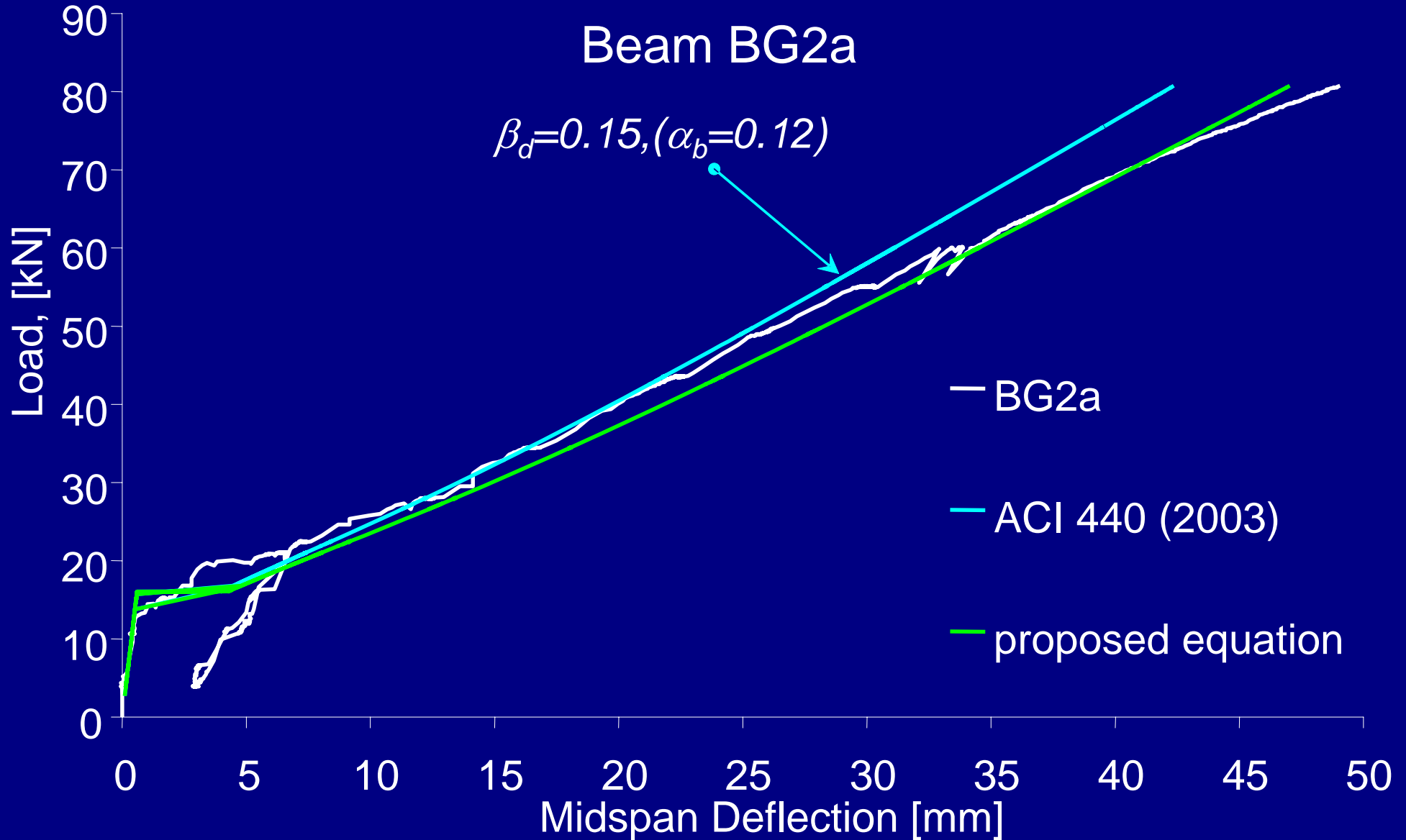


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Proposed Equation





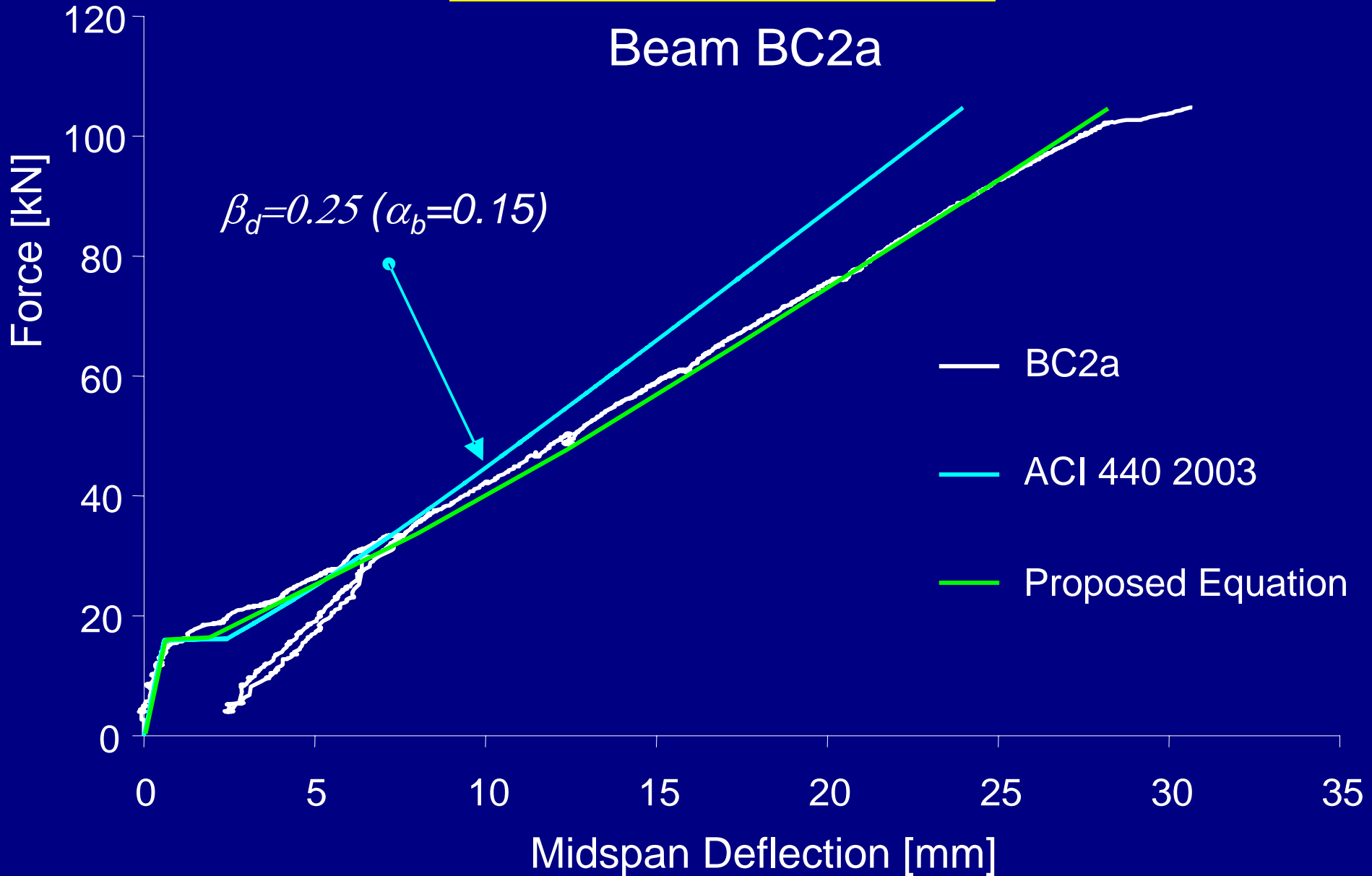
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Proposed Equation

Beam BC2a





CONCLUSIONS

- The original Branson Equation for I_e underestimates deflections of FRP RC.
- The modified form of the equation for I_e , as proposed by ACI 440.1R-03, is not fundamentally sound.
- A more general form is proposed where:
 - * The reinforcement ratio is introduced as a variable.
 - * A reduction factor is introduced to I_{cr}
- More research work is required.



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THANK YOU