May 2nd, 11:00 AM - 1:00 PM

Concrete Beams with Fully Corroded Steel Repaired with CFRP Laminates

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Abstract

This research focused on concrete beams with voids simulating beams with fully corroded steel that were repaired with CFRP laminates. The experimental program included testing five, approximately one- third-scaled simply supported rectangular concrete beams. The aim was to investigate the extent of improvement by CFRP to flexural and shear capacity of beams that contain fully corroded steel bars, simulated by voids. Load carrying capacity, deflection, and ductility were measured and compared. Test results showed that one layer of CFRP increased the load capacity to slightly higher than the typical code-designed RC beam, and two layers of CFRP increased it by a factor of two. Finally, a computer model was created to estimate the performance of the tested beams and to carry out a parametric study to investigate the effects of CFRP longitudinal reinforcement ratio and CFRP transverse confinement ratio on the flexural performance of CFRP-repaired concrete beams. The predicted contribution of CFRP to flexure and shear capacities was in good agreement with test results.

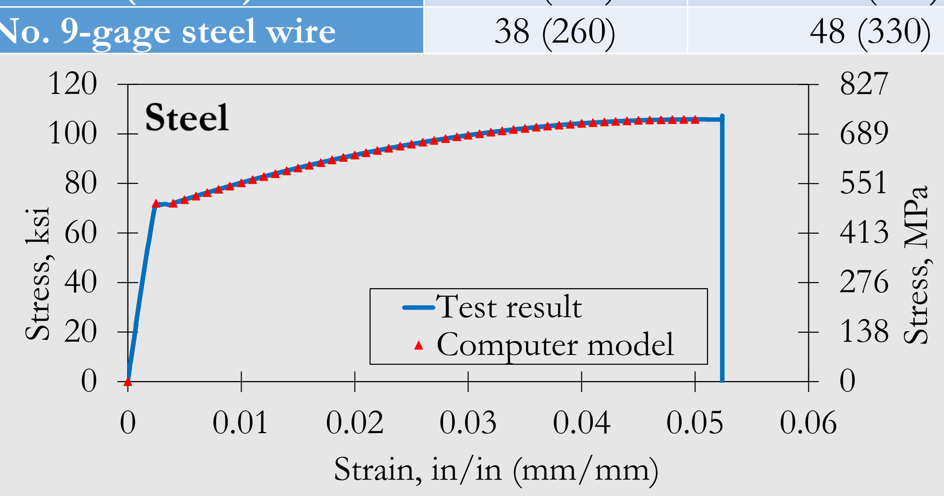
Objectives

Extreme corrosion is defined in this study as fully corroded or fully ineffective steel reinforcement resulting in complete loss in the rebar cross sectional area and the bond between the concrete and reinforcement. This hypothetical assumption was made to (1) understand the flexural and shear behavior of concrete beams strengthened with CFRP sheets, conservatively assuming complete loss of steel rebars due to corrosion, and (2) add new data to the literature about how plain concrete beams with completely deteriorated steel behave when strengthened with CFRP laminates.

Material Properties

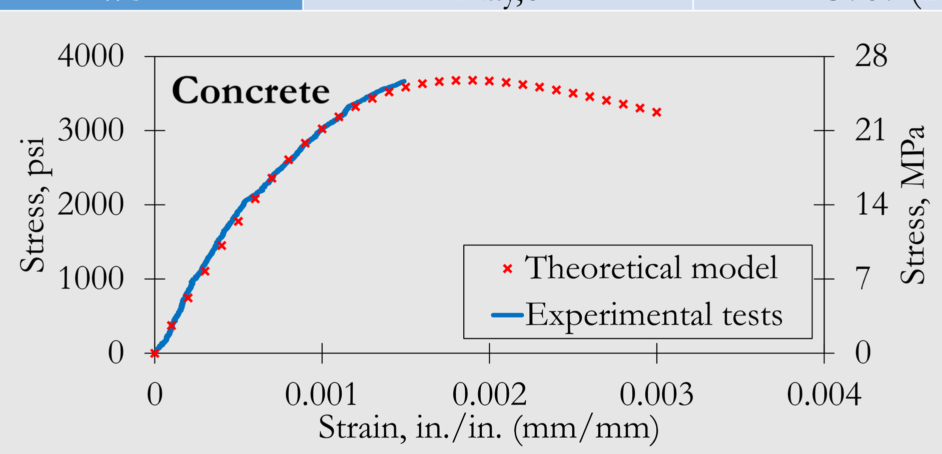
Steel tensile properties

Size	Yield, f_y, ksi (MPa)	Maximum, F_u, ksi (MPa)
#3 (No. 10)	72 (500)	107 (740)
No. 9-gage steel wire	38 (260)	48 (330)



Concrete compressive strength

Beam No.	Test Date	f_c', psi (MPa)
#1	March, 11	2476 (15)
#2	March, 16	3042 (21)
#3	April, 15	3679 (25)
#4	April, 20	3136 (22)
#5	May,6	3767 (26)



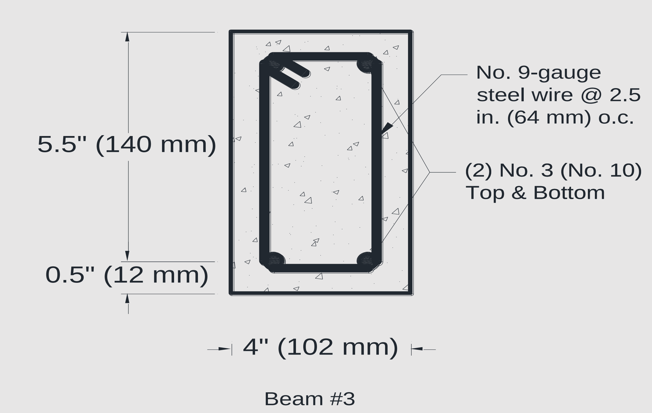
Carbon Fiber Reinforced Polymer (CFRP)

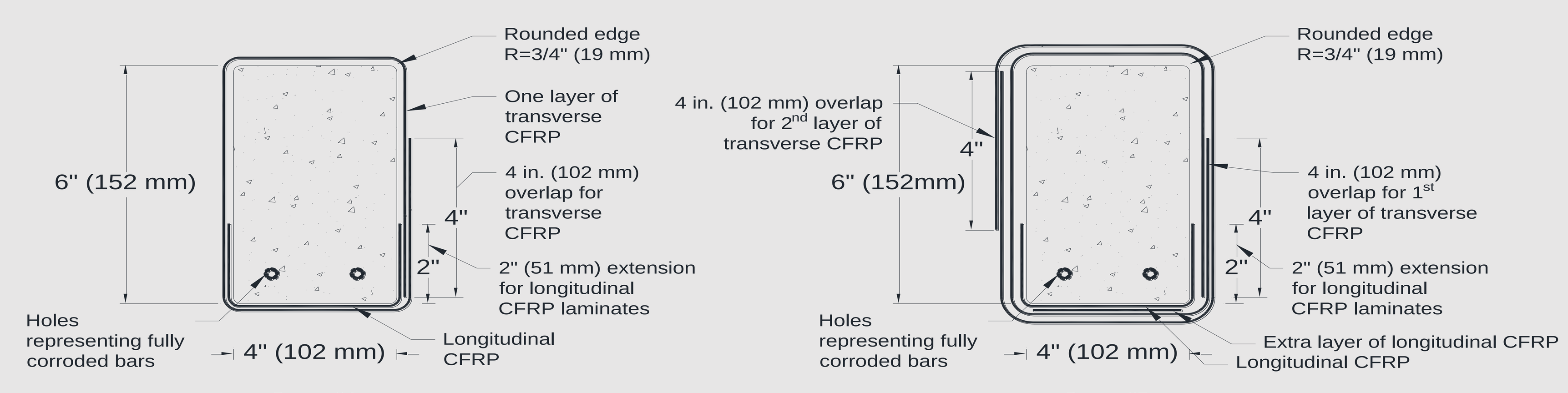
Tensile strength, f_{fu}	550 ksi (3800 MPa)
Tensile modulus, E_f	33000 ksi (227 GPa)
Ultimate Strain, ε_{fu}	1.67%
Nominal Thickness, t_f	0.0065 in (0.165 mm)/ply

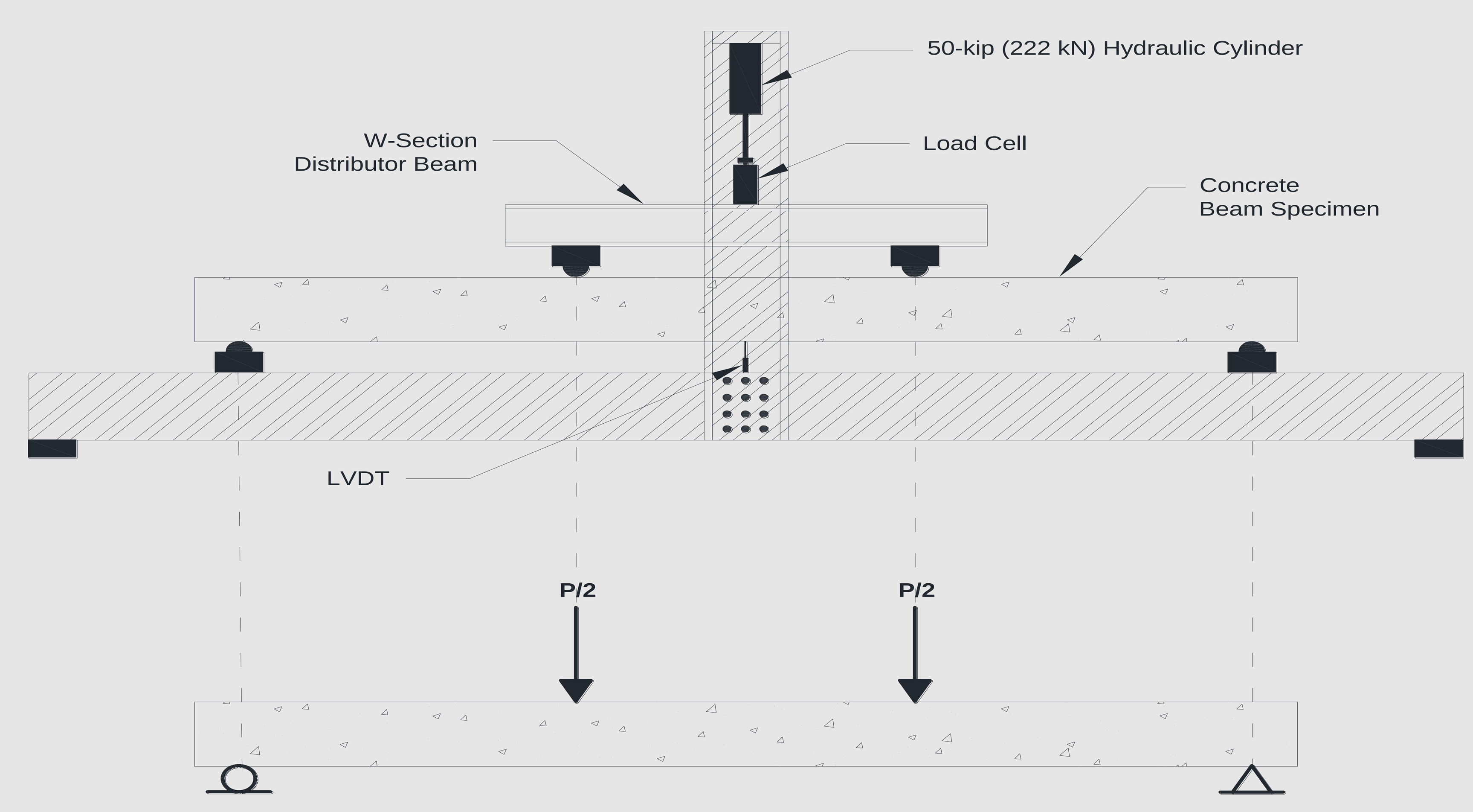
Specimens Preparations & Fabrications

Specimens Design and Testing Procedure

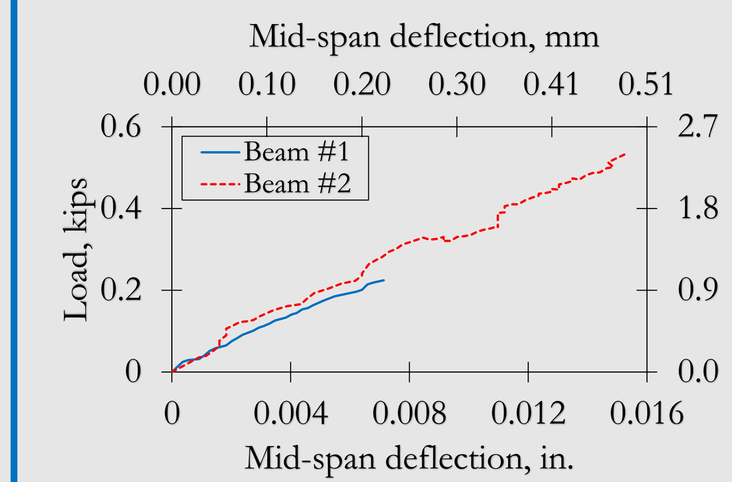
Beam No.	Description
#1	Deteriorated
#2	Plain concrete beam
#3	Control RC beam, un-corroded
#4	Deteriorated beam + one layer of CFRP
#5	Deteriorated beam + two layers of CFRP

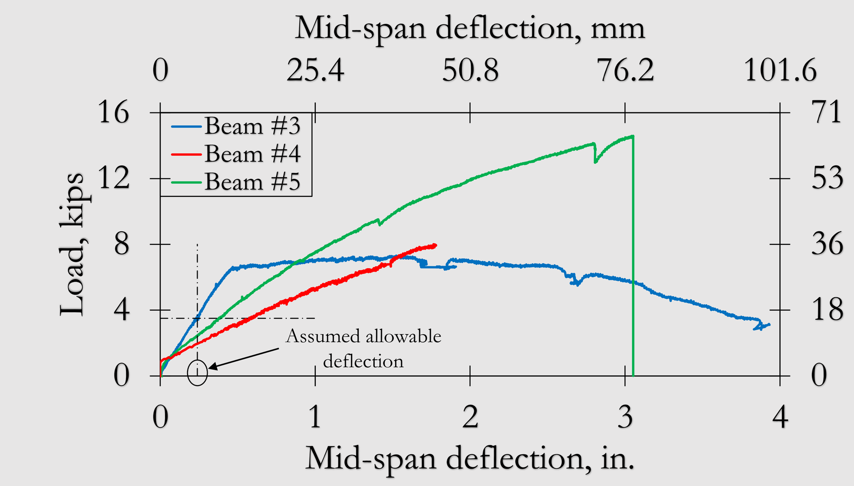






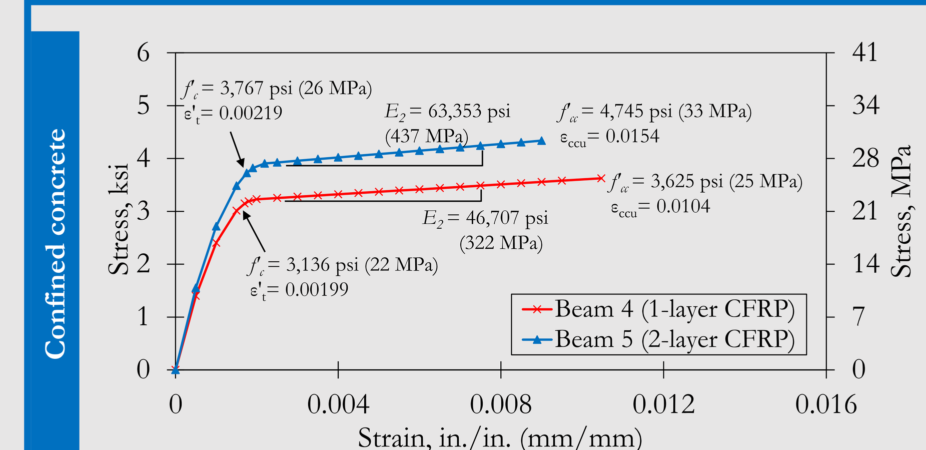
Experimental Results

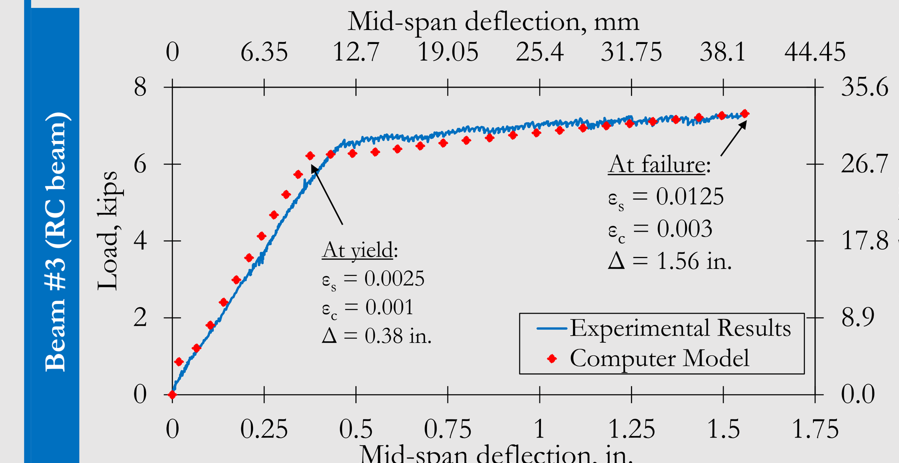


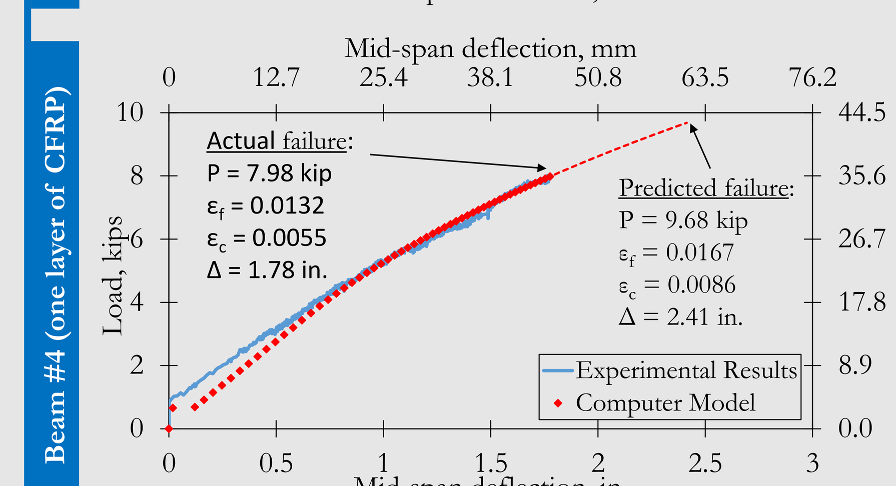


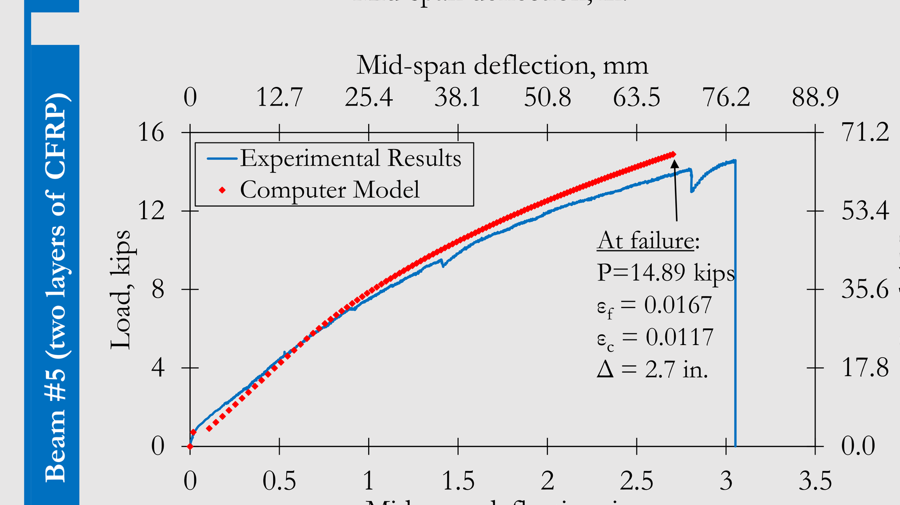
Beam label	Beam description	Experimental max. load, kip (kN)	Max. load normalized to RC	Deflection at max. load, in (mm)	Deflection normalized to RC
#1	Deteriorated	0.22 (1.0)	3 %	0.007 (0.2)	0.5 %
#2	Plain	0.54 (2.4)	7 %	0.015 (0.4)	1 %
#3	RC (Control)	7.33 (32.6)	100 %	1.55 (39.4)	100 %
#4	CFRP (one layer)	7.96 (35.4)	109 %	1.78 (45.2)	115 %
#5	CFRP (two layers)	14.59 (64.9)	200 %	3.05 (77.5)	197%

Theoretical Correlation

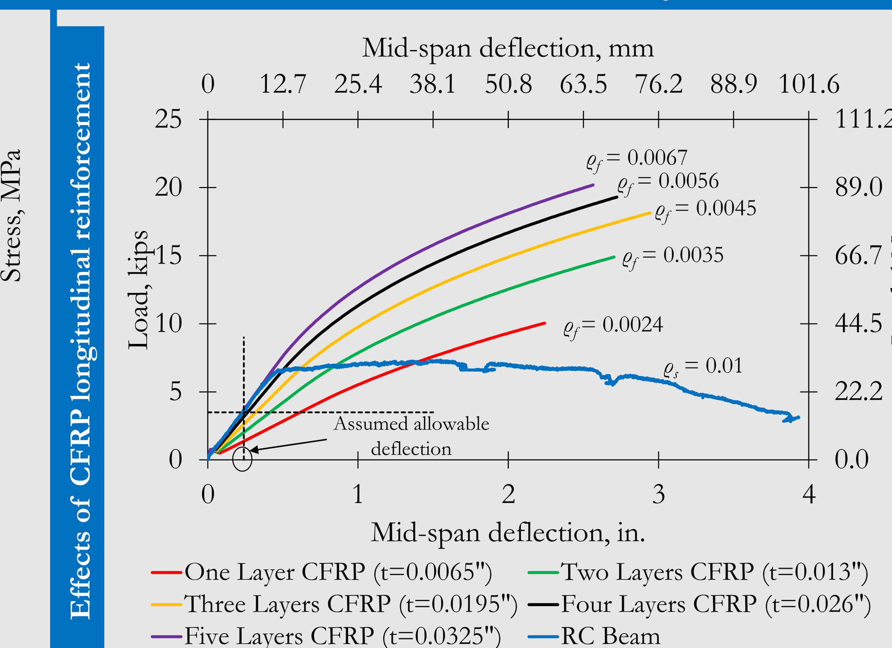


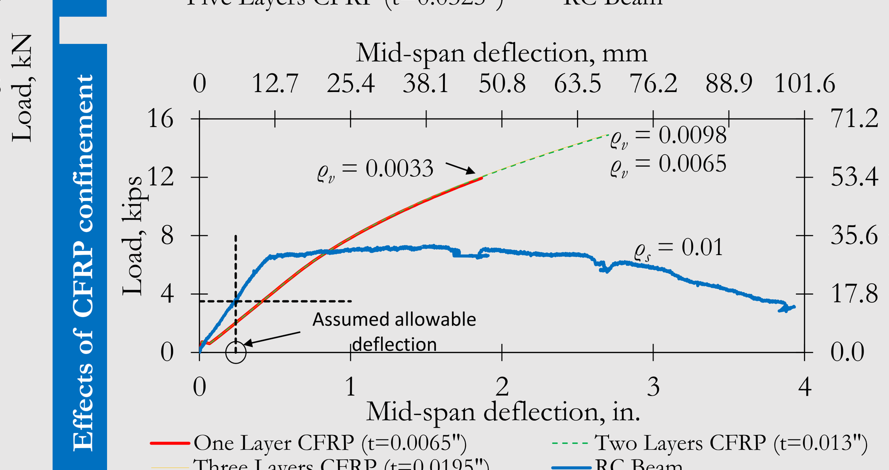






Parametric Study





Conclusions

- Using a proper combination of circumferential and longitudinal CFRP laminates improved the ultimate load carrying capacity of the deteriorated beam to be even higher than twice the capacity of a comparable ACI-designed RC beam.
- All the CFRP strengthened beams exhibited brittle behavior requiring a higher factor of safety in practice.
- The proposed ACI 440.2R design guidelines to estimate the flexural and shear capacity of beams strengthened with externally bonded CFRP laminates produced results in good agreement with experimental results.
- A higher CFRP longitudinal reinforcement ratio should be considered if serviceability is an issue.