BENDING PROPERTIES OF HIGH PERFORMANCE CARBON FIBER REINFORCED CONCRETE BEAMS

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Abstract

The flexural behaviour of high performance reinforced concrete beams containing chopped carbon fibers with different volume fractions (0%, 0.2%, 0.3%, 0.4% and 0.5%) in full and partial depths of beams cross sections is studied in this investigation. The load deflection relationship, resilience, toughness indices, first crack and ultimate loads, concrete and steel strains were investigated. Generally, the experimental results show that the fiber volume fraction has no significant effect on load-deflection and ultimate load of beam specimens, while, it has a considerable effect on the first crack load, resilience and toughness indices. The ultimate strength of fibre reinforced concrete (FRC) has been re-derived and contributed in order to calculate the moment capacity of high performance carbon fiber concrete beams. The calculated ultimate moment capacity was in good agreement with the measured ultimate moment capacity. The results also show that applying the conventional flexural theory ACI 318 and ACI 544 model cause significant error in estimating the moment capacity of carbon fiber reinforced concrete beams.

Keywords: high performance, carbon fiber, volume fraction, ultimate strength

1. Experimental Work

High performance concrete mix with different carbon fiber (CF) content (0%, 0.2%, 0.3%, 0.4% and 0.5%) prepared in previous research[1] was used to manufacture the conventional steel reinforced beam with dimensions of 150 x 300 x 2000 mm in full-depth, half-depth, and one-third depth fiber inclusion. The mix proportions was 1.0:1.19:1.8 by weight, water/cementations

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ratio 0.33, high range water reducing admixture with 3 % dosage by weight of cement and silica fumes dosage 15 % by weight of cement as addition of cement content was used. The compressive strength was 78.8 MPa at 28 days. The beams were tested under a four-point loading system. A dial gauge, demec point and electrical strain gauges were used to measure the deflection, concrete and steel strains respectively.

Fiber volume fraction has no significant effect on the load-deflection pattern of beam specimens. The addition of CF causes considerable increase in the first crack load; the percentage increase for full depth fiber inclusion is between 80-105%, while there is a slight increase in ultimate load between 7-14% relative to the plain concrete beam as shown in figures (4.14 to 4.21). The resilience of CF beam specimens significantly increases in comparison with the reference beam specimen, also the resilience increases as fiber volume fraction increases. The increase in resilience for beams with partial depth fiber inclusion is less than that with full depth fiber inclusion.

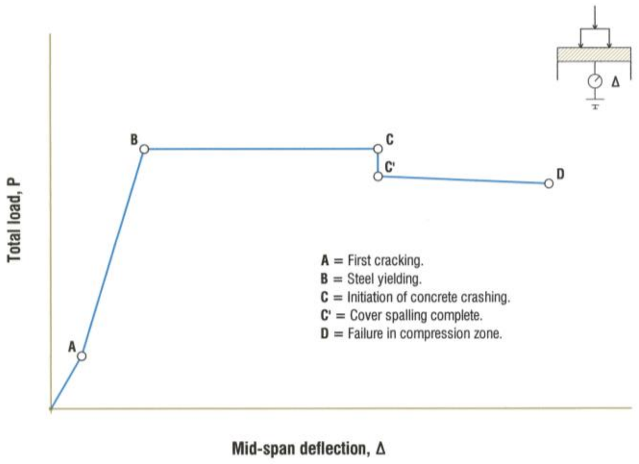


Figure (4.14) Idealized load-deflection curve [91]

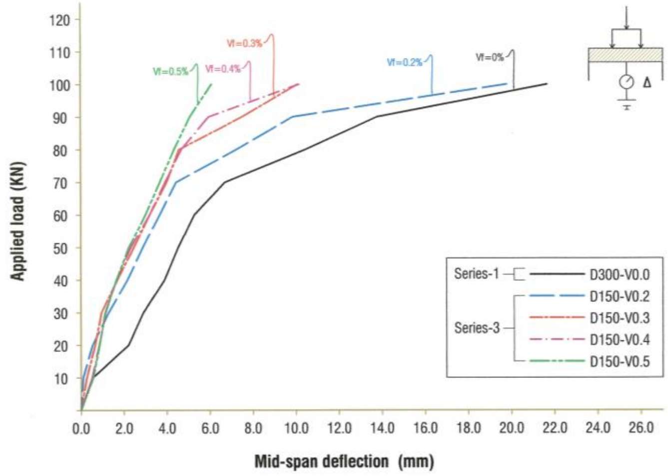


Figure (4.16) Load-deflection relationship at mid-span of half depth fiber reinforced concrete beam specimens (series-1 and series-3)

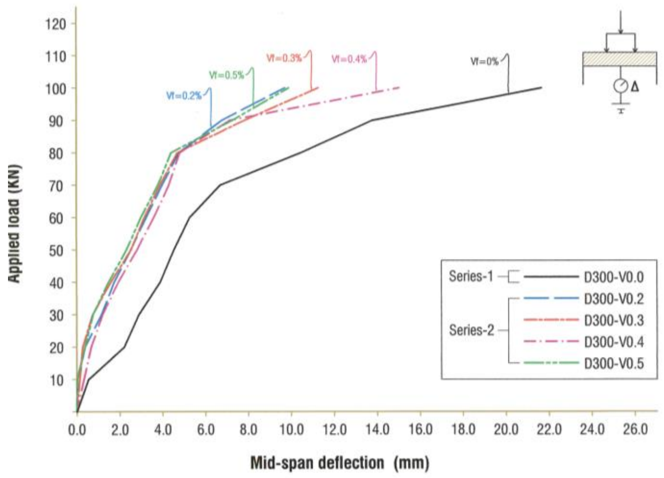


Figure (4.15) Load-deflection relationship at mid-span of full depth fiber reinforced concrete beam specimens (series-1 and series-2)

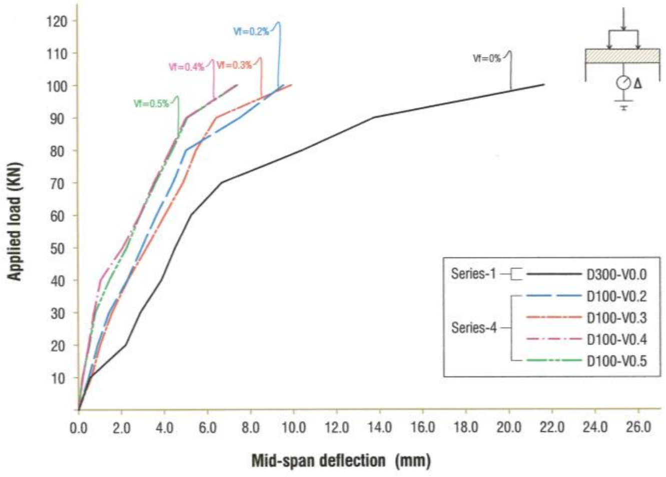


Figure (4.17) Load-deflection relationship at mid-span of one-third depth fiber reinforced concrete beam specimens (series-1 and series-4)

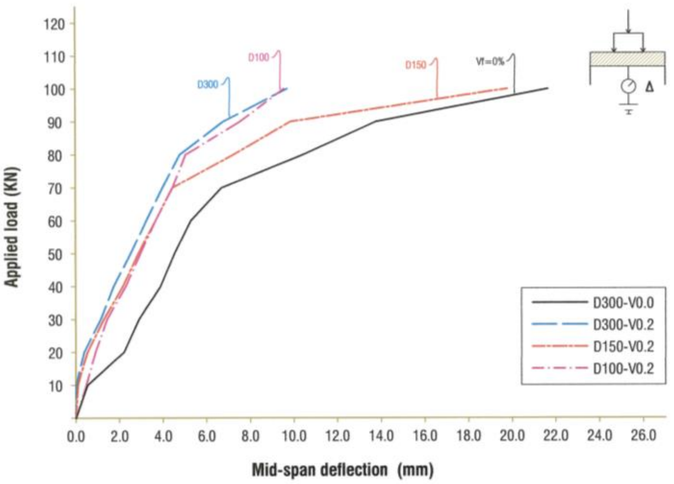


Figure (4.18) Load-deflection relationship at mid-span of various fiber depth inclusion beam specimens with fiber volume fraction of 0.2%

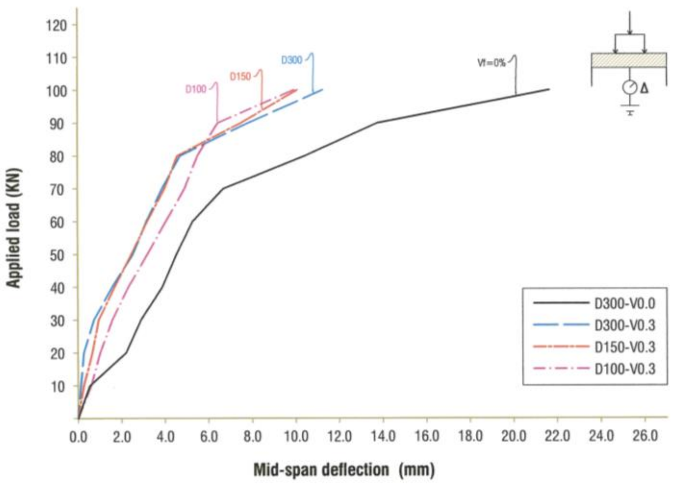


Figure (4.19) Load-deflection relationship at mid-span of various fiber depth inclusion beam specimens with fiber volume fraction of 0.3%

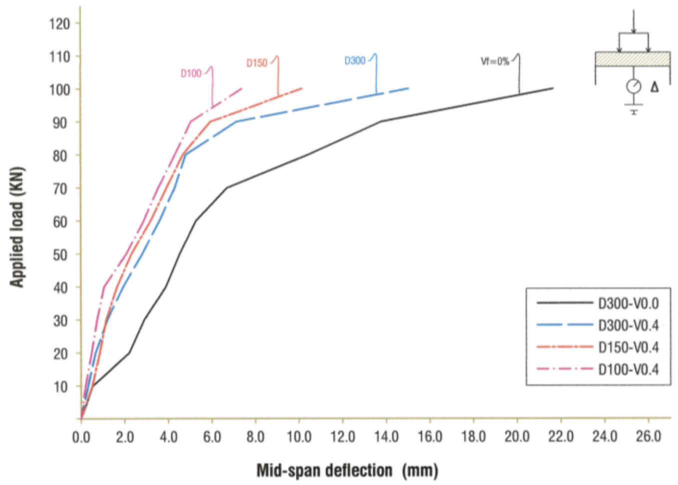


Figure (4.20) Load-deflection relationship at mid-span of various fiber depth inclusion beam specimens with fiber volume fraction of 0.4%

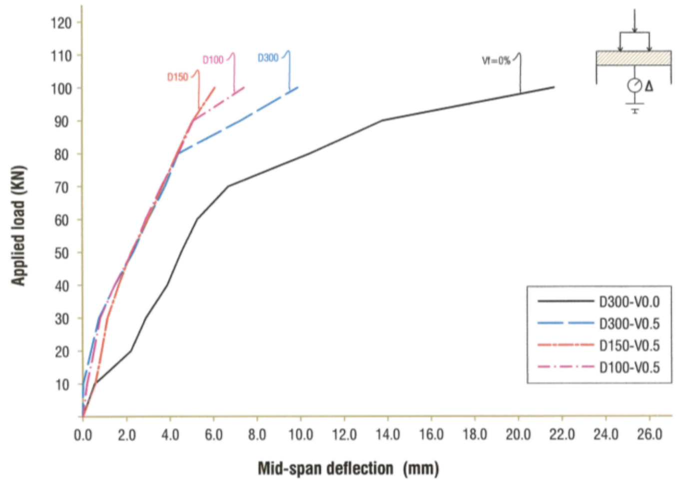


Figure (4.21) Load-deflection relationship at mid-span of various fiber depth inclusion beam specimens with fiber volume fraction of 0.5%

The toughness of all FRC beam specimens is considerably enhanced over that of plain concrete beam specimen. The values of toughness indices I_5 and I_{10} for partial depth FRC beam specimens are higher than that for full depth FRC beam specimens as shown in the figures (4.31) and (4.32). This enhanced performance of FRC beam specimens results from their improved capacity to absorb energy during fracture, since fibers continue to carry stresses beyond matrix cracking, and this helps to maintain structural integrity and cohesiveness in the material [2,3].

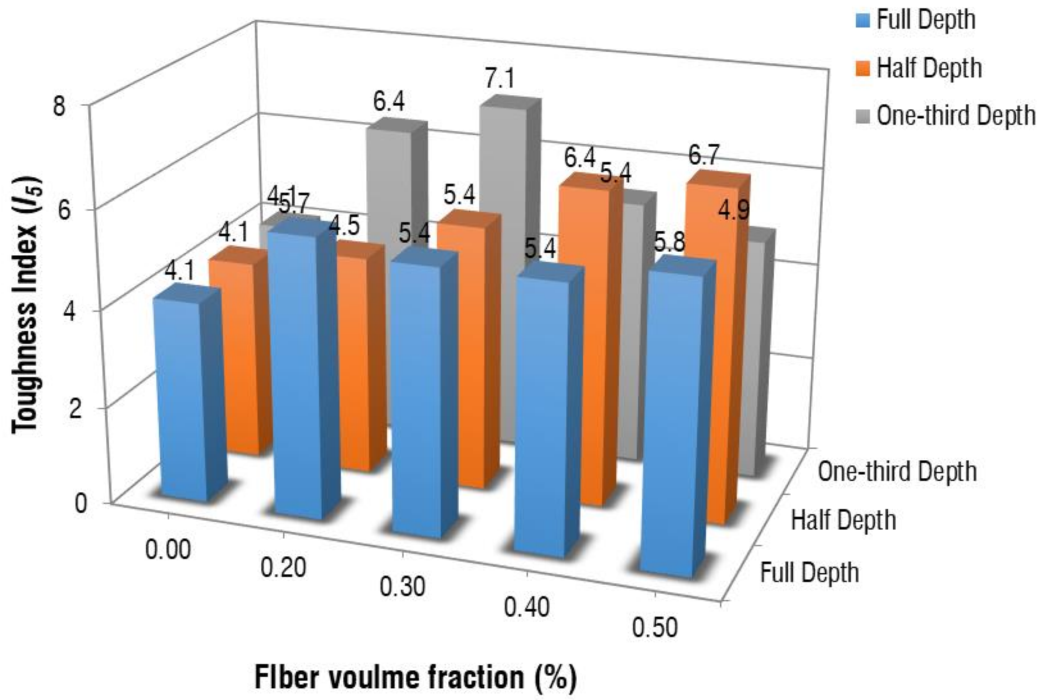


Figure (4.31)

Comparison of toughness index (I_5) of beam specimens

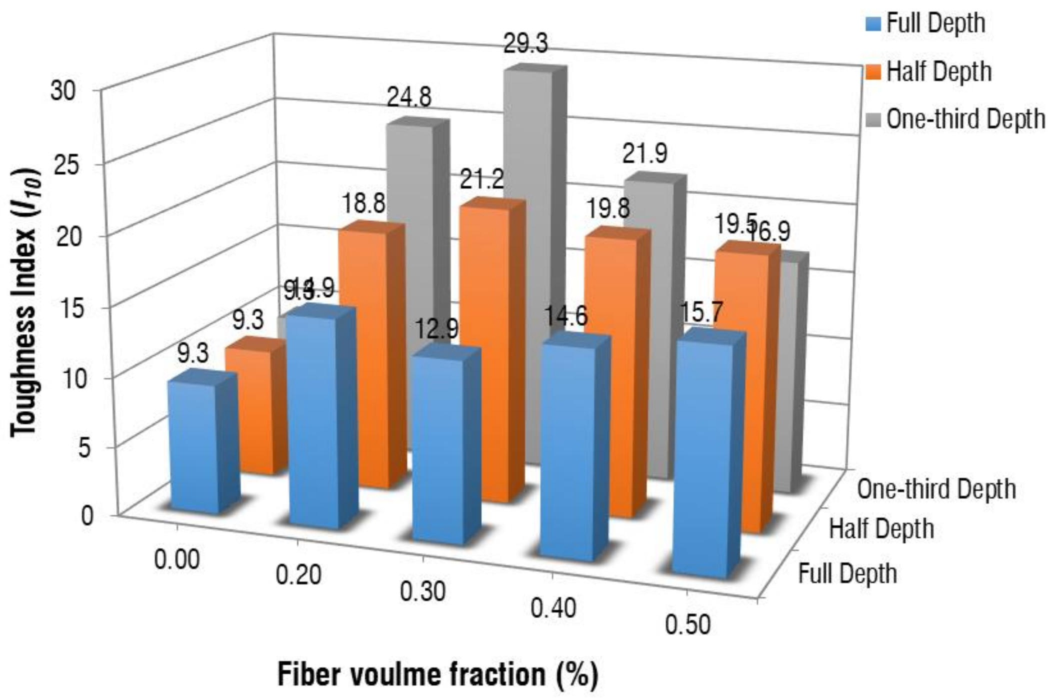


Figure (4.32)

Comparison of toughness index (I_{10}) of beam specimens

2. Theoretical Analysis

The ultimate strength of fiber reinforced concrete has been rederived and contributed in order to calculate the moment capacity of fiber reinforced high performance concrete beams. The calculated ultimate moment capacity was in good agreement with the measured ultimate moment capacity as shown in Table (5-1). The results also show that applying the conventional flexural theory (ACI 318M-08) and the ACI 544 model(4) yields errors in estimating the flexural capacity and it is not applicable for prediction either for flexural moment of carbon fiber reinforced concrete beams or for partial depth fiber inclusion. The asumption of strain and stress are shown in the figure (5.2)

Table (5-1) measured and calculated ultimate moment capacity for beam specimens

Test series	Test beam label	Experimental failure moment (Measured) KN.m)	Ultimate tensile strength FRC (MPa)	Ultimate tensile strength FRC (MPa) (ACI 544.4R-88)	Calculated moment (KN.m)			Ratio Cal./Exp. Moments		
					Without considering fibers (ACI 318M-08)	With considering fibers	With considering fibers (ACI 544.4R-88)	Without considering fibers (ACI 318M-08)	With considering fibers	With considering fibers (ACI 544.4R-88)
1	$D_{300}V_{0.0}$	38.35	----	----	33.13	33.13	33.13	0.864	0.864	0.864
2	$D_{300}V_{0.2}$	42.90	0.89	0.12	36.27	41.65	37.03	0.845	0.971	0.863
	$D_{300}V_{0.3}$	41.28	1.33	0.18	32.56	40.66	33.73	0.789	0.985	0.817
	$D_{300}V_{0.4}$	40.95	1.78	0.24	29.42	40.25	30.99	0.719	0.983	0.757
	$D_{300}V_{0.5}$	43.55	2.22	0.30	29.14	42.60	31.10	0.669	0.978	0.714
3	$D_{150}V_{0.2}$	38.68	0.89	----	32.80	37.02	----	0.848	0.957	----
	$D_{150}V_{0.3}$	41.60	1.33	----	33.10	39.41	----	0.796	0.947	----
	$D_{150}V_{0.4}$	42.58	1.78	----	32.55	40.98	----	0.764	0.962	----
	$D_{150}V_{0.5}$	43.88	2.22	----	31.41	41.94	----	0.716	0.956	----
4	$D_{100}V_{0.2}$	43.55	0.89	----	34.82	37.97	----	0.800	0.872	----
	$D_{100}V_{0.3}$	40.63	1.33	----	31.40	36.13	----	0.773	0.889	----
	$D_{100}V_{0.4}$	42.25	1.78	----	32.29	38.61	----	0.764	0.914	----
	$D_{100}V_{0.5}$	43.23	2.22	----	31.42	39.32	----	0.727	0.910	----

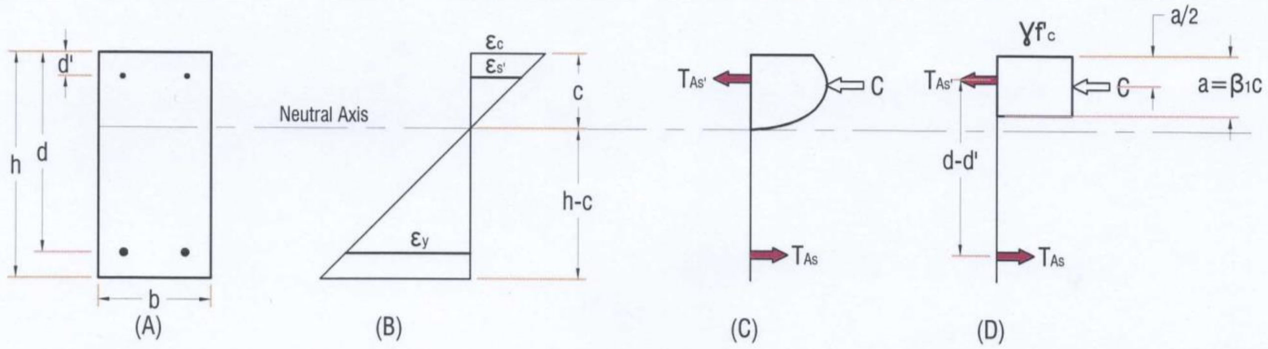
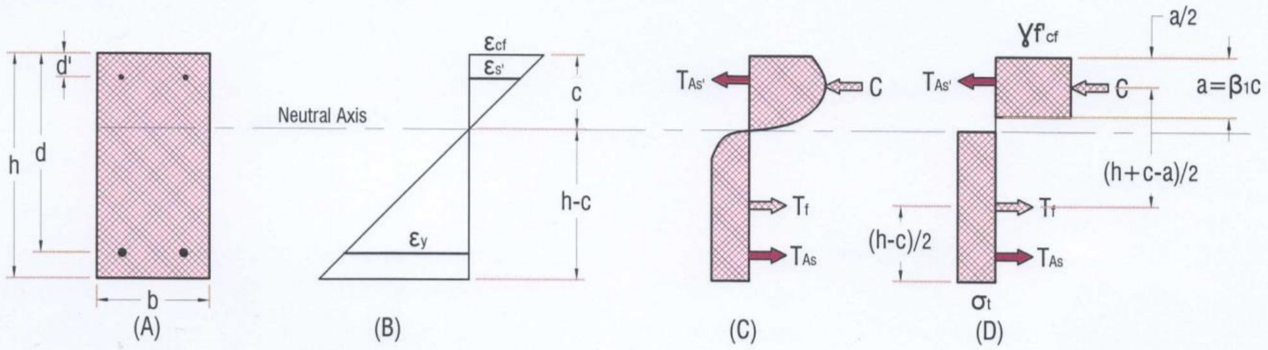
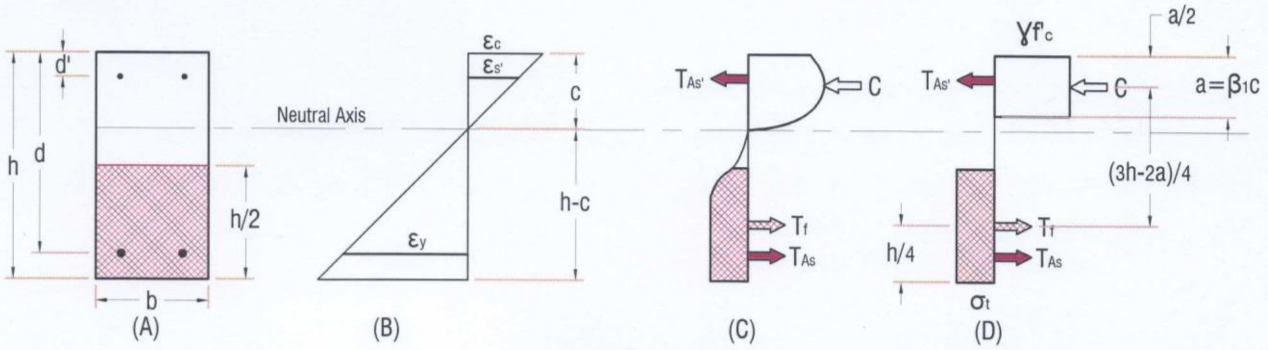


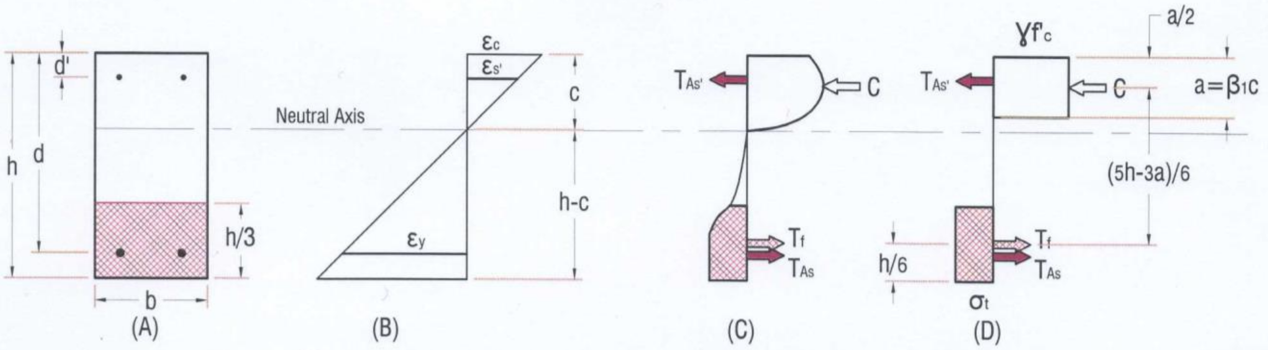
Figure (5.1) Strain and stress distribution for cross section of the doubly reinforced plain concrete beam (ACI 318M-08)



(a) Full depth fiber inclusion



(b) Half depth fiber inclusion



(c) One-third depth fiber inclusion

Figure (5.2) Strain and stress distribution for the cross section of conventional reinforced fiber concrete beams

3. Conclusions

1. Partial depth inclusion of fiber can be used in more efficient and economical manner.

2. The addition of CF causes a considerable increase in the first crack load, while there is a slight increase in ultimate load relative to the plain concrete beam.

3. The resilience of beam specimens containing CF significantly increases in comparison with the reference beam specimenand it is increases as the fiber volume fraction increases. Beam specimens with full depth fiber inclusion shows superior resilience in comparision with partial depth fiber inclusion.

4. Both models (ACI 318M-08 and ACI 544.4R-88) considerably underestimate ultimate flexural capacity of fiber reinforced beams, while the contribution of ultimate tensile strength of fiber reinforced concrete matrix with ultimate moment capacity of conventional steel reinforced beams makes the analysis more realistic and close with measured moment capacity.

4. References

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