Efficiency of Un-Reinforced Bottle Shapped Struts in Glass Fiber Reinforced Concrete

Rajeswara Rao Moida[1] Murali Sagar Varma[2]
[1,2]Department of Civil Engineering
[1,2]M.V.G.R College of Engineering, India

Abstract— An experimental investigation was carried out to determine the performance of concrete under compression and tension for different amounts of glass fibers in concrete. Fibers are added in the amounts of 0%, 0.5%, 1.0%, 1.5%, 2% and 2.5% of weight of cement. It is observed that characteristic compressive strength of concrete is increased by 10% and 14 % and split tensile strength was increased by 18% and 10 % for M25 and M40 grade concrete respectively for 1 % of fibers. As the transverse tension is the main problem in bottle-shaped struts, addition of fibers in concrete will increase the performance of bottle-shaped struts. Performance of the strut is assessed from the efficiency factor#. Test specimen consisted of 400mm X 400 mm X 100 mm panels, tested for in plane loading under compression for two different grades of concrete and different amounts fiber contents. From the test results, it was observed that efficiency of bottle shaped struts increased up to 34% and 28% for M25 and M40 grade concrete respectively for 1% fibers in cement weight. Also addition of fibers to the concrete delayed the occurrence of main crack in the bottle-shaped strut. Therefore it can be concluded that addition of glass fibers to the concrete is an economical solution to increase the performance of the concrete in terms of capacity and serviceability.

Key words: GRC, STM

I. INTRODUCTION

Glass fiber reinforced concrete (GRC) is a composite material consisting of normal concrete reinforced with alkali resistant glass fibers. Glass fibers are available in continuous or chopped lengths. Glass fibers have high tensile strength and elastic modulus but have brittle stress-strain characteristics and low creep at room temperature. Glass fibers are usually with diameters from 0.005 mm to 0.015 mm. In the view of global sustainable scenario, it is imperative that fibers like glass, carbon and poly-propylene provide very wide improvements in tensile strength, fatigue characteristics, durability, shrinkage characteristics, impact, cavitation's, erosion resistance and serviceability of concrete. Due to high tensile strength and sufficient bonding properties and low cost compared to other fibers, addition of glass fibers in concrete may increase the performance of concrete, especially the tensile strength. Improvement of tensile strength of concrete greatly affects the strength of non-flexural members (shear critical regions) designed using strut-and-tie method.

Shear critical regions of structural concrete can be conveniently analyzed and detailed using strut-and-tie modeling. A strut-and-tie model (STM) represents a statically admissible stress field in the lower-bound (static) solution. Like a real truss, a strut-and-tie model consists of struts (compression members) and ties (tension members) interconnected at hypothetical pin-jointed connections called nodes. Depending on the geometric profile of the compressive stress field, struts in structural concrete members are classified as either prismatic or bottle-shaped as shown in Fig. 1. A prismatic strut has straight out-lines with uniform cross-section throughout its length, and a bottle-shaped strut has a convex profile with non-uniform and non-linear variation in its cross-section.

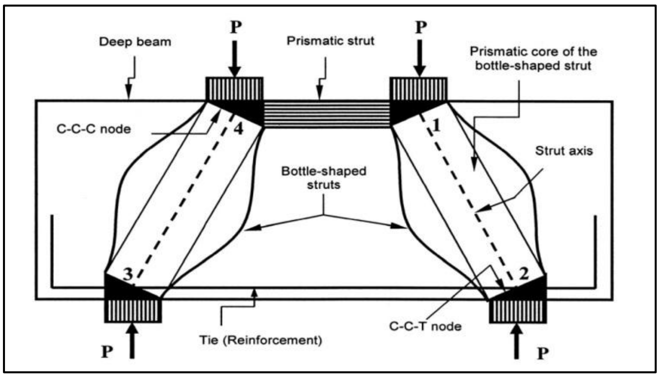


Fig. 1: Prismatic and Bottle-Shaped Struts in a Deep Beam.

Among those two struts, the behavior of a bottle-shaped strut is relatively complex due to the presence of transverse tension, T', which is induced by the outwardly dispersing compressive stress trajectories as shown in Fig. 2. The transverse tension is primarily resisted by concrete until the formation of a splitting crack. Even after cracking, a bottle-shaped strut can continue to remain serviceable and carry significantly higher load provided sufficient and properly detailed transverse reinforcement is available to ensure equilibrium of forces in the strut.

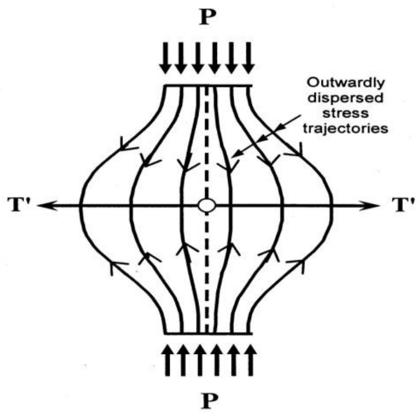


Fig. 2: Transverse Tension in a Bottle-Shaped Strut.

As per the STM provisions in ACI 318-08 Appendix-A (American Concrete Institute 2008), the nominal strength of a bottle shaped strut without axial reinforcement, F_{ns}, is calculated from the expression

$$F_{ns} = f_{ce} A_{cs}$$

Where A_{cs} is the lesser of the cross-sectional areas of the node-strut interfaces at the two ends of a bottle-shaped strut and f_{ce} is the smaller of the effective compressive strength values of concrete in the strut obtained from Eqs. (2) and (3) below.

$$f_{ce}=0.85\beta_s f_c'$$

$$f_{ce} = 0.85\beta_n f_c'$$

where f_{ce} is the specified cylinder crushing strength of concrete, β_s and β_n are the strut efficiency and nodal efficiency factors as per Secs. A.3.2 and A.5.2 of ACI 318 - 08 respectively.

Type of strut	Efficiency factor (β_s)
Prismatic strut	1
Bottle-shaped strut with reinforcement satisfying equation (A-4) of ACI 3186	0.75
Bottle-shaped strut without reinforcement satisfying equation (A-4) of ACI 318[6]	0.6`0 λ
Struts in tension members	0.4
Other type of struts	0.6
Type of Node	Efficiency Factor (β_n)
CCC node	1
CTT node	0.8
CTT node	0.6

Table 1: Strut and Nodal Efficiency Factors in ACI 318-08 (American Concrete Institute 2008)

Note: λ =1.00 for normal weight concrete, 0.85 for sand-lightweight concrete and 0.75 for all-lightweight concrete. In the nodal nomenclature, the number of T's indicates the number of ties joining the node.

II. RESEARCH SIGNIFICANCE

As the bottle shaped strut is subjected to transverse tension due to outward flow of compressive force, resistance to this tensile force plays major role in deciding strength of the strut. Due to very low tensile strength of normal concrete, efficiency factor of 0.6 only considered for unreinforced strut as pet ACI 318-08. It is known that addition of fibers will increase the tensile strength of concrete; thereby efficiency of bottle shaped strut. Therefore it is attempted to study the increase in the compressive and tensile strength of glass fiber reinforced concrete and corresponding changes in efficiency factors of bottle shaped strut for different amounts of fibers in concrete.

III. EXPERIMENTAL PROGRAM

The experimental program carried out for two different grades of concrete in two phases. In phase 1, effect of adding glass fiber to the concrete on compressive strength and split tensile strength was studied as per respectively, for different amounts of fiber contents. In phase II, concrete panels of size 400mm X 400mm X 100 mm are tested to determine the efficiency of bottle shaped struts for different amounts of fiber contents as shown in table below.

S.No	Grade of Concrete	% of Fiber
1	M25	0
2		0.5
3		1.0
4		1.5
5		2.0
6		2.5
7	M40	0
8		0.5
9		1.0
10		1.5
11		2.0
12		2.5

Table 2: Specimen Details

IV. INSTRUMENTATION AND TEST PROCEDURE

Cubes and Cylinders are tested for ultimate load under axial compression in CTM. Panels are tested under compression in plane loading using 200kN capacity UTM as shown in Fig.____. Peak load are measured for every panel.

Phase – I Results:

A. *Compressive Strength:*

Grade	% fiber	Comp. Strength (fck)	% increase
M25	0	26.25	0
	0.5	27.58	5
	1.0	28.79	10
	1.5	26.95	3
	2.0	22.49	-14
	2.5	20.28	-23
M40	0	41.2	0
	0.5	42.4	3
	1.0	47.12	14
	1.5	42.72	4
	2.0	34.67	-16
	2.5	31.18	-24

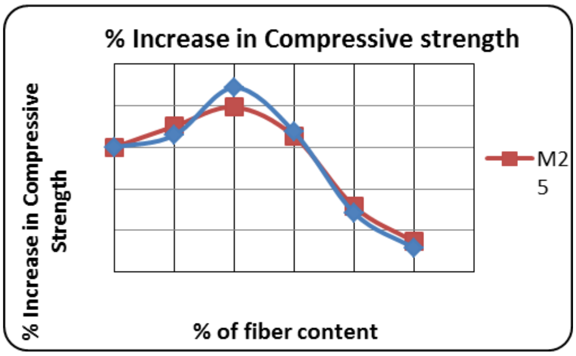
Table 3: Compressive Strength Results

B. *Split Tensile Strength:*

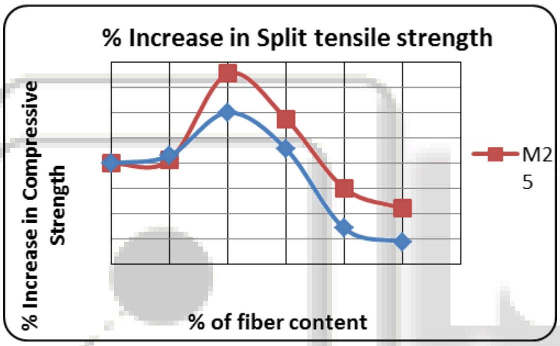
Grade	% fiber	Split Tensile Load (kN)	% Increase
M25	0	199.45	0
	0.5	200.73	1
	1	234.96	18
	1.5	217.1	9
	2	189.53	-5
	2.5	181.53	-9
M40	0	437.84	0
	0.5	444.47	2
	1	482.06	10
	1.5	450.46	3
	2	381.3	-13
	2.5	369.5	-16

Table 4: Split Tensile Strength Results

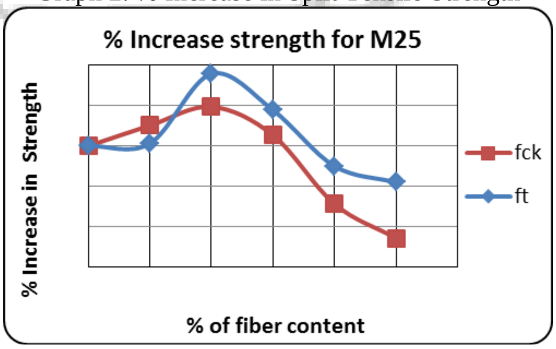
Fig. 3: Test Setup



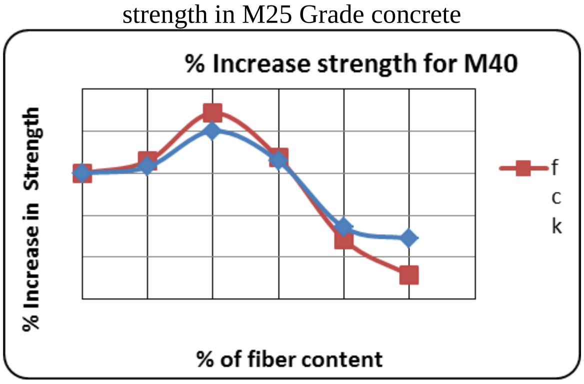
Graph 1: % Increase in Compressive strength



Graph 2: % Increase in Split Tensile Strength



Graph 3: % Increase in Compressive and Split tensile strength in M25 Grade concrete



Graph 4: % Increase in Compressive and Split tensile strength in M40 Grade concrete

V. Discussion on Phase –I Results

From Table 3,4 and Graphs 1 to 4, it is observed that, addition of glass fibers to the concrete improve the performance of concrete for fiber content up to 1% of, cement weight, beyond which the performance is degraded. For a given volume of concrete, as the % fiber increases, amount of cement content is reduced. This could be the reason for reduction in the strength for higher amounts of fibers. For lower grade concrete, % increase in split tensile strength is more than compressive strength. As the grade of concrete increases, % increase in split tensile strength is reduced.

A. Strut Efficiency:

Let P_u be the actual load carrying capacity of the bottle shaped strut. As per ACI 318 -08, theoretical load carrying capacity is 0.85 β_s A_s f_{ce} . where β_s is the strut efficiency factor which depends on the amount of transverse tension developed in the strut. Table 1 shows the strut efficiency factors for different conditions in normal concrete. In this study strut efficiency factors are evaluated for different amounts of fibers in glass fiber reinforced concrete by equating the theoretical strut capacity to the actual value by testing fiber reinforced concrete panels as shown in Fig___.

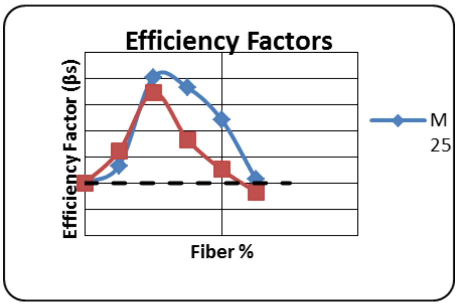
B. Phase II Results:

Efficiency factors are calculated by the following formula for different amounts of fiber contents.

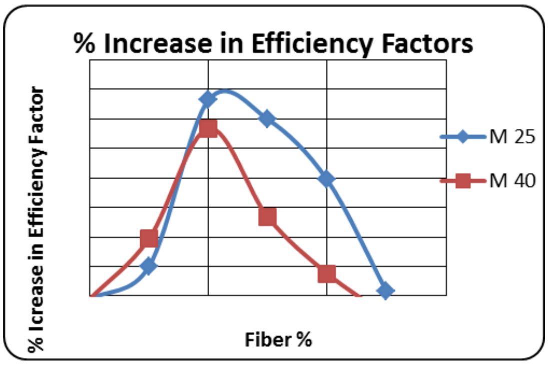
$\beta_s = P_u / (0.85 \text{ x } A_s \, f_{ce})$

Concrete Grade	fck	% fiber	Peak Load(kN)	Actual Efficiency factor (β)	βs as per ACI 318
M25	26.3	0.0	150.2	0.85	0.60
	27.6	0.5	158.5	0.90	0.63
	28.8	1.0	200.8	1.14	0.80
	27.0	1.5	195.9	1.11	0.78
	22.5	2.0	180.5	1.02	0.72
	20.3	2.5	152.1	0.86	0.61
M40	41.2	0.0	210.9	0.76	0.60
	42.4	0.5	232.5	0.84	0.66
	47.1	1.0	271.8	0.98	0.77
	42.7	1.5	240.1	0.87	0.68
	34.7	2.0	220	0.79	0.63
	31.2	2.5	205	0.74	0.58

Table 1: Efficiency Factors of Fiber Reinforced Concrete



Graph 5: Graphical representation of Efficiency factor compared to normal concrete



Graph 6: % Increase In Efficiency Factors

VI. DISCUSSION ON PHASE II RESULTS

Due to increase in the tensile strength of concrete with the addition of glass fibers, efficiency factors also increased significantly for 1% of glass fibers in the cement weight. Column 6 in Table ___ is the efficiency factor calculated as per factor of safety adopted by ACI 318. Percentage increase in the efficiency factor reduced as the concrete grade increases. This may be because of less improvement in the tensile strength compared to the compressive strength.

VII. CONCLUSION

1) Addition of glass fibers to the concrete improve the performance of concrete for fiber content up to 1% of, cement weight, beyond which the performance is degraded. Compressive strength of concrete increases by around 10% for M25 grade concrete and around 14% for M40 grade concrete.
2) Split tensile strength increase by 18% for M25 grade concrete and 10% for M40 grade concrete. Improvement in the tensile strength reduced as the grade of concrete increases.
3) Bottle shaped strut efficiency factors increased by around 34 % for M25 Grade concrete and 28 % for M40 Grade concrete at 1% fiber content in cement weight.
4) Addition of glass fibers in the concrete at 1% in cement weight is an economical solution to improve the performance of bottle shaped Strut in strut and Tie method.

VIII. ACKNOWLEDGEMENT

I would like to thank Department of Civil Engineering staff and management of MVGR College of Engineering for their support in doing this work.

REFERENCES

[1] Crist, R. A. (1966). “Shear behavior of deep reinforced concrete beams.” Proceedings, Symposium on the Effects of Repeated Loading of Materials and Structural Elements, Mexico City, 4, RILEM, Paris, 31 pp.
[2] De Silva, S., Mutsuyoshi, H. and Witchukreangkrai, E. (2008). “Evaluation of shear crack width in I-shaped prestressed reinforced concrete beams.” Journal of Advanced Concrete Technology, 6(3), 443-458.
[3] Hwang, S. J., Yu, H. W. and Lee, H. J. (2000). “Shear strength predictions for deep beams.” ACI Structural Journal, 97(3), 367-376.
[4] Kim, K.-H., Kim, W. -B., Kim, J. -M. and Kim, S.-W. (2009). “Composite strut and tie model for reinforced concrete deep beams.” Journal of Advanced Concrete Technology, 7(1), 97-109.
[5] Kong, F. K., (1990). “Reinforced concrete deep beams.” 2nd ed. London: Blackie and Son Ltd., 288 pp. Kong, F.
[6] K., Robins, P. J. and Cole, D. F. (1970). “Web reinforcement effects on deep beams.” ACI Journal, 67(12), 1010-1017.
[7] Marti, P. (1985). “Basic tools of reinforced concrete design.” ACI Journal, 82(1), 46-56.
[8] Rogowsky, D. M. and MacGregor, J. G. (1986). “Design of reinforced concrete deep beams.” Concrete International, 8(8), 49-58.
[9] Sagi, M. S. V. (2008). “An investigation of minimum reinforcement requirements in bottle-shaped struts.” Thesis (M.Tech.). Indian Institute of Technology Roorkee, Roorkee.
[10] Sahoo, D. K. (2009). “An investigation of the strength of bottle-shaped struts.” Thesis (Ph.D.). Indian Institute of Technology Roorkee, Roorkee.
[11] Sahoo, D. K., Singh, B. and Bhargava, P. (2009). “An appraisal of the ACI strut efficiency factors.”
[12] Magazine of Concrete Research, 61(6), 445-456. Smith, [12] K. N. and Vantsiotis, A. S. (1982). “Shear strength of deep beams.” ACI Journal, 79(22), 201-213. Sumpter,
[13] M. S., Rizkalla, S. H. and Zia, P. (2009). “Behaviour of high performance steel as shear reinforcement for concrete beams.” ACI Structural Journal, 106(2), 171-177.
[14] Tan, K.-H, Kong, F.-K., Teng, S. and Weng, L.W. (1997). “Effect of web reinforcement on high-strength concrete deep beams.” ACI Structural Journal, 94(5), 572-582.

