

The Behavior of Reinforced Concrete Corbels with Steel Fibers and Shear Strength Prediction

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ABSTRACT: The main goal of this experimental and analytical study is to investigate the behavior and shear strength of steel fiber reinforced concrete corbels. . An experimental results and predicted values by truss analogy method, ACI Building Code (ACI 381-83) provisions for corbels, and shear friction equation is investigated. Test were carried out on twenty-seven samples of size 150 x 150 x 200- mm were shear span was varied as shown in table (E) and concrete corbels reinforced with steel fiber. M-60 grade of concrete is used in corbels. The different properties of corbels varied and fiber content and span to depth ratio also varied. The different percentage of fiber content of 0.5 percent intervals was used ranging from 0.5 to 4 percent .For all the reinforced concrete corbels vertical loading was used. It was observed that the ultimate strength of reinforced concrete corbels along with fibers can be predicted by adding the fibers contribution to strength using the shear friction equation to the ACI Building Code provisions. It is found that considerable improvement in ultimate shear strength, toughness and first crack in the corbels.

KEYWORDS: Steel fibers, Corbels, Compressive strength, Shear strength, Truss analogy, ACI-318.

I. INTRODUCTION

The corbel is generally built monolithically with the column or wall. The shear span-to-depth is often less than unity. Corbels projecting from the faces of reinforced concrete columns are extensively used in precast concrete construction to support the primary beam and girders. Corbels are structural members characterized by a shear span-to-depth ratio (a/d), generally lower than unity. Recently, high strength concrete has been increasing used in practice. However high-strength concrete is considered to be a relatively brittle material and has low ductility. The ACI Building Code (ACI 318-83) specify that stirrups that have to be included in the corbel should not be less than 50 percent of the main tension reinforcement. Simple design and construction procedures to produce safe and economic corbels are therefore required. Many parameters influence the strength of reinforced concrete corbels including type of loading, shear span-to-depth ratio, strength of concrete, type and quantity of reinforcement, and possibly corbel geometry. In this investigation, the main goal was using steel fibers to convert the brittle characteristic to a ductile one, increases the shear strength of corbels and improves the ductility and by using different analytical method the ultimate shear strength of SFRC corbels is investigated. The different types of brackets and corbels may be described as short cantilevers that project from the inner face of concrete columns or walls to support heavy concentrated loads of cranes and beams. By many experimental evidence it is clear that use of steel fibers improves the shear strength of reinforced concrete structures. It is also observed that steel fibers used in reinforced concrete corbels improves the energy absorption of

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fiber reinforced concrete structures and also act as a arrestors of cracks in the concrete and addition of steel fibers is also known to improve the bond between steel and concrete, and the compressive, impact, flexural, tensile, and toughness properties of the concrete. Also, during the testing of conventionally reinforced or prestressed concrete beams, it was found that the replacement of stirrups with steel fibers, or the addition of steel fibers, provided effective reinforcement against shear failure.

II. RELATED WORK

It is observed that in reinforced concrete corbels the ultimate strength and toughness of reinforced concrete corbels are considerably enhance by addition of steel fibers. The main goal of the study is to notice the variations in reinforced concrete corbels by different percentage of steel fibers and use of ACI building code, truss analogy method and modified shear friction equation given by Hashim M.S. Abdul-Wahab [5]. The investigation of steel fiber reinforced concrete corbels with steel fibers was studied by many researchers and there is not much data in the field of reinforced concrete corbels. In the early work of Nijad I. Fattuhi and Barry P. Hughes [7] they observed the strength of reinforced concrete corbels in presence of steel fibers or stirrups. However, many techniques were used by the researchers in the field of concrete corbels as Wael Kassem [10], Jules Assih1 [11], Giuseppe Campione [4]. Moreover, some researcher like Gaetano Russo et al. [3] studied on shear strength of corbels and derived some formulae for designing reinforced corbel. And in similar manner Nijad I. Fattuhi and Barry P. Hughes [6] worked on concrete corbels by varying the span to depth ratios and changing the steel fiber volume in the concrete mix. Some more researchers worked on concrete corbels like Zhi-Qi He, Zhao Liu et al [2] worked in the load transfer mechanism of different deep beams and corbels. The ACI 318-08, Building Code Requirements for Structural Concrete and Commentary [1] also gives some provision for the steel fiber reinforced concrete corbels. Further Hashim M.S. Abdul-Wahab [5] work on the reinforced concrete corbels and the shear strength of the corbels were predicted by comparing the ACI building code provision and truss analogy method and used modified shear friction equation which was given by Nijad I. Fattuhi [8].

III. EXPERIMENTAL RESULTS

For corbels ranging from 0 to 3 percent of steel fibers the primary steel reinforcement and secondary reinforcement were provided similar. In the project twenty-seven number of corbels were casted and to failure under vertical loading is observed. In all the corbels the steel fiber volumes were varied from 0.5 to 4 percent. In all the corbels shear span-depth ratio a/d was varied from 0.4 to 0.5 as shown in table (E).

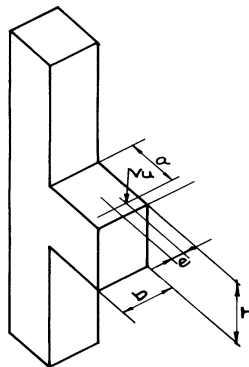


Fig (a) 3D corbel

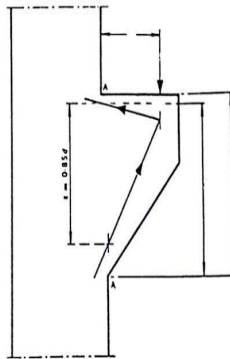
As suggested by ACI building code that $a/d < 1$. The shear span was taken from 175 mm to 200 mm and depth of corbels 300 mm to 370 mm is considered. And for throughout the corbels the width=150 mm is constant. Corbels were

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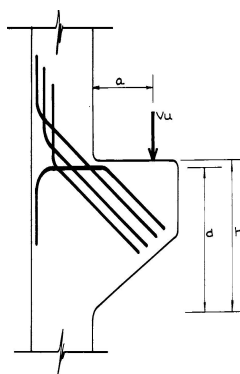
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cast horizontally in wooden mold and concrete was vibrated for 1 minute by a handle needle vibrator. A rotary mixer of 0.1 m³ capacity was used in the preparation of the concrete mixes.



Fig(b) corbel strut action

The concrete mix used was 1: 0.74: 1.46 of ordinary Portland cement: natural sand: coarse aggregate with maximum size of 20 mm. The nominal yield strength of 1177 MPa and the fiber used were plain, high tensile steel, straight, 25 mm and 0.40 mm in diameter with an aspect ratio of 62.5 and water-cement ratio (w/c) of 0.29 was used in the concrete mix. During the casting, no segregation of balls of fibers were observed. The average yield strength of the primary steel was $f_y = 386$ MPa and was $F_{vf} = 348$ MPa for the stirrups. All corbels were reinforced with two 12 mm diameter deformed steel bars ($A_s = 226 \text{ mm}^2$) and 8 mm diameter shaping bars were to hold horizontal stirrups ($A_h = 202 \text{ mm}^2$). And for corbels having steel fibers from 3 to 4 percent the horizontal stirrups are taken 6 mm in diameter (113.09 mm^2). The ingredients cement, sand, and gravels were mixed thoroughly first and then after adding the water, the fibers were spread gradually over the fresh concrete with mixing continuing to make sure that a proper mix was obtained. The size of each mix was designed in such a way to make one corbel at a time.



Fig(c) corbel section

After casting, the specimens were cured for 28 days in the water tank in laboratory. The reinforced concrete corbels and the control specimens were demolded after 24 hr and all the corbels were covered with polythene sheets, and properly cured under laboratory conditions. All the steel fiber reinforced concrete corbels were tested when attained 28 days of age. The Concrete strain readings on selected points on the faces of the corbel were taken using a mechanical extensometer having a gauge length of 200 mm and the mode of failure of concrete corbels was observed. The corbels were tested in a vertical loading in the testing machine and from the faces of the column to the support position was changed. The load on the corbels was applied monotonically in increments until failure in the steel fiber reinforced concrete corbel takes place and no horizontal load was applied.

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IV. RESULT AND DISCUSSION

Table A – Experimental results of shear strength of corbels tested

SPECIMEN	FIBER VOLUME PERCENT (%)	Vu test KN
S-0	0	200.8
S-0.5	0.5	225.2
S-1	1.0	330.6
S-1.5	1.5	320.5
S-2	2.0	363.2
S-2.5	2.5	399.0
S-3	3.0	275.6
S-3.5	3.5	272.4
S-4	4.0	311.9

Table B – Analytical results of shear strength of corbels by ACI method

SPECIMEN	FIBER VOLUME PERCENT (%)	Vu ACI method KN
S-0	0	157.00
S-0.5	0.5	156.38
S-1	1.0	161.15
S-1.5	1.5	166.95
S-2	2.0	170.00
S-2.5	2.5	173.94
S-3	3.0	142.92
S-3.5	3.5	154.30
S-4	4.0	162.03

Table C – Analytical results of shear strength of corbels by truss analogy method

SPECIMEN	FIBER VOLUME PERCENT (%)	Vu TRUSS analogy KN
S-0	0	236.04
S-0.5	0.5	237.50
S-1	1.0	245.30
S-1.5	1.5	254.26
S-2	2.0	258.09
S-2.5	2.5	262.59
S-3	3.0	193.28
S-3.5	3.5	205.80
S-4	4.0	214.30

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Table D – Analytical results of shear strength of corbels by ref (8)

SPECIMEN	FIBER VOLUME PERCENT (%)	Vu ref. (5) KN
S-0	0	196.03
S-0.5	0.5	223.1
S-1	1.0	327.48
S-1.5	1.5	316.62
S-2	2.0	361.7
S-2.5	2.5	397.51
S-3	3.0	272.54
S-3.5	3.5	270.8
S-4	4.0	308.98

Table E – Details of corbel properties

SPECIMEN	FIBER VOLUME PERCENT (%)	a (mm)	a/d ratio span/depth ratio	Vu ultimate KN
S-0	0	200	0.547	200.8
S-0.5	0.5	195	0.534	225.2
S-1	1.0	192	0.526	330.6
S-1.5	1.5	188	0.515	320.5
S-2	2.0	185	0.506	363.2
S-2.5	2.5	183	0.501	399
S-3	3.0	180	0.493	275.6
S-3.5	3.5	178	0.487	272.4
S-4	4.0	175	0.479	311.9

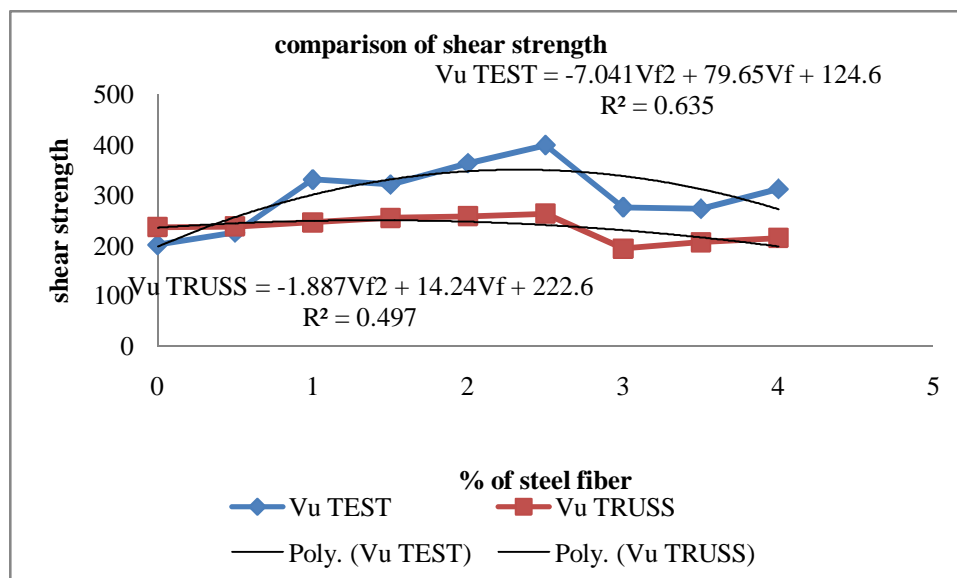
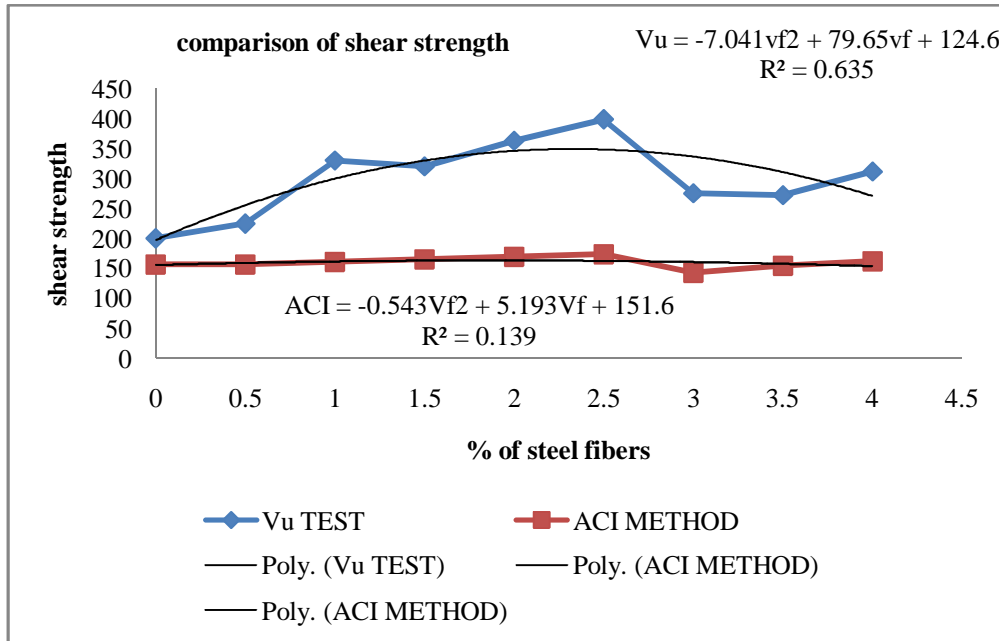
Table-F Comparison of ratio of shear strength of tested corbels with the analyzed corbels

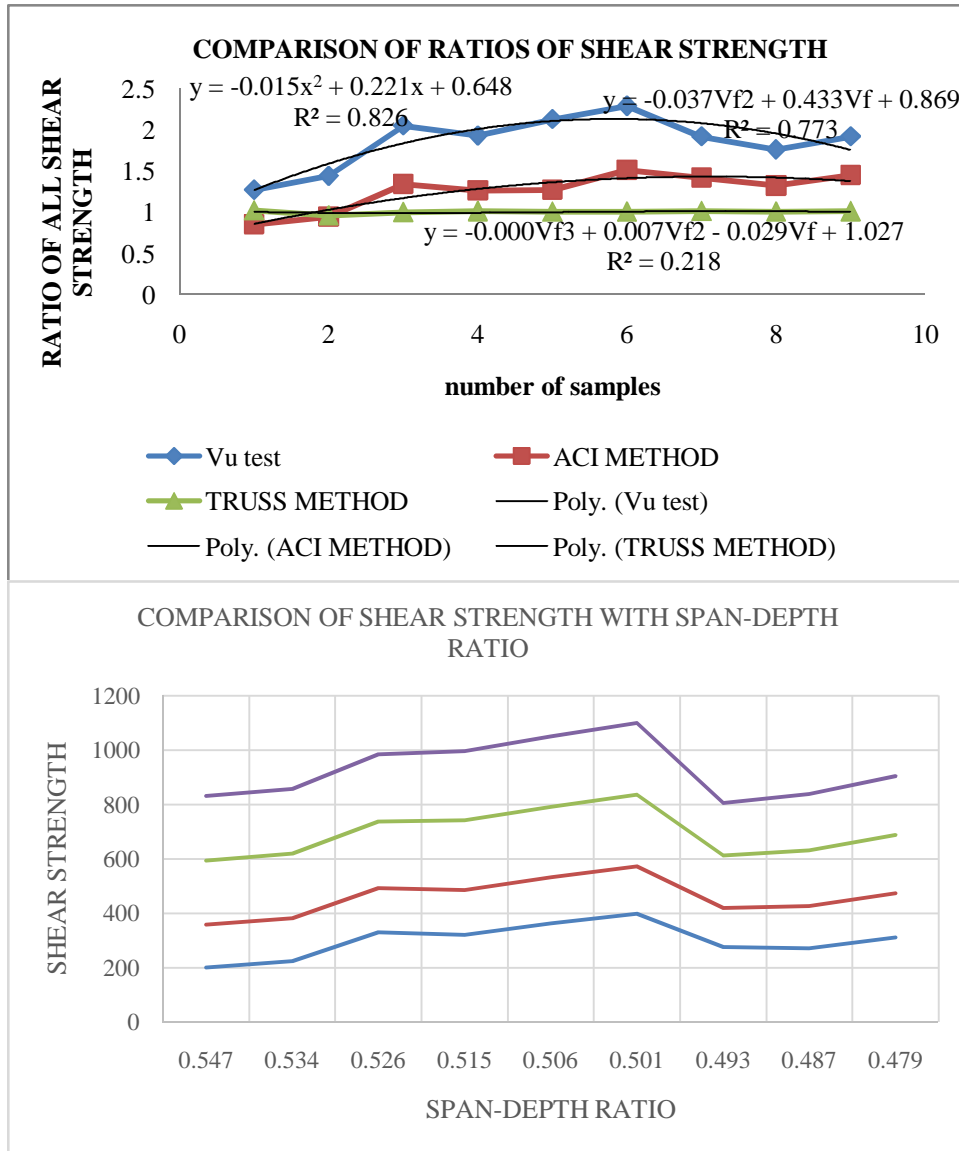
SPECIMEN	FIBER VOLUME PERCENT (%)	Vu test/V u ACI	Vu test/Vu truss	Vu test/Vu ref. (5)
S-0	0	1.27	0.85	1.020
S-0.5	0.5	1.44	0.94	0.960
S-1	1.0	2.05	1.34	1.000
S-1.5	1.5	1.93	1.26	1.010
S-2	2.0	2.13	1.27	1.004
S-2.5	2.5	2.29	1.51	1.003
S-3	3.0	1.92	1.42	1.011
S-3.5	3.5	1.76	1.32	1.005
S-4	4.0	1.92	1.45	1.009

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Discussion

The results obtained from the twenty-seven steel fiber reinforced corbels tested in this study were analyzed and compared with predicted values using three different methods, as shown in Table (F). Predicted values using the ACI Building Code method. The strength reduction factor (Φ) is taken as 1.0. And the different values obtained by the truss analogy method proposed by Hagberg⁶. And the predicted values are obtained by using the following modified shear-friction equation suggested by Hashim M.S⁵

$$V_u = \phi (\eta A_{vf} f_{fu} \mu) + \phi (A_v f_y \mu) \quad (S1)$$

Where

A_{vf} = total area of fibers at the critical section

f_{fu} = ultimate tensile strength of the fiber

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A_v = area of reinforcement extending across the critical section

f_y = yield strength of the reinforcement

η = overall fiber efficiency factor (with average value of 0.1 from test results)

ϕ = strength reduction factor (assumed to be 0.85 for shear)

μ = coefficient of friction (assumed to be 1.4 for monolithic concrete)

It is also noticed that the effective area of fibers at the critical section (ηA_{vf}), working in shear friction and resisting diagonal tension as well as direct shear, is not real and the empirical coefficient for the overall fiber efficiency $\eta = 0.1$, as suggested by Hashim M.S⁵ takes into fiber orientation and bond strength but it varies with the amount of fiber content, fiber length, and a/d ratio. The different predicted values obtained from the three methods just mentioned are compared with the actual values from tests obtained and the predicted values by the ACI Building Code method or the truss analogy method remains constant. Some other different equations given by Hashim M.S⁵

$$V_u = \phi (V_{u1} + V_{uf}) \quad (S2)$$

Where

η = fiber efficiency factor (assumed to be 0.1)

V_{u1} = minimum value of the ultimate load for reinforced concrete corbels using the ACI Building code method [$V_{uf} = \eta A_{vf} f_{ru} \mu$]

V. CONCLUSION

The shear-friction equation [Eq. (S1)] is used for the prediction of the ultimate strength of all the corbels, as given by Hashim M.S. Abdul-Wahab⁵, and it does not include the effect of the variation in the shear span-depth ratio a/d and can be used only to a very limited range of a/d (about 0.45 to 0.55) in the steel fiber reinforced concrete corbels. The study shows that there is a considerable increase in the ultimate shear strength of steel fiber reinforced concrete corbels is obtained by the addition of steel fibers for a specific range and with a fiber content of 0.5, 1, 1.5.. to 4 percent, an increase in the shear strength was obtained. At 2.5 percent of steel fiber maximum shear strength was achieved. The comparison of test values with those predicted using the ACI Building Code provisions, modified shear friction equation and truss analogy method shows that the contribution of steel fibers to shear strength not much changed. The proposed method [Eq. (S2)] of predicting the contribution of the steel fibers to the shear resistance, then after adding it to the predicted values obtained by the ACI code provisions, is supported by the available experimental data. Hence safe and Economical corbel design can be made by adding steel fiber contribution to shear resistance in less congested and conventionally reinforced corbels.

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