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Modified prediction approach of strength of high strength polyolefin fiber reinforced concrete corbels

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ABSTRACT

This paper aims to investigate the effect of polyolefin fibers on high strength reinforced concrete corbels using twelve specimens with different quantities of fibers and shear span-to-span ratios, all corbels were only tested vertically. Due to the addition of polyolefin fibers, the ultimate load-carrying capacity of corbels was significantly improved, according to the findings of this study and other relevant data. The limitations and insufficiency of the three techniques were proven by a comparison of current test results and anticipated values by the ACI 318 Code -19 rules for the tested specimens, the Strut and Tie Model, and the proposed method. The ultimate shear load of polyolefin fiber reinforced high strength concrete corbels with was determined to be best predicted by applying the Strut and Tie Model technique to account for the fibers' contribution to strength.

Keywords: High strength concrete, Polyolefin fibers, Strut and tie model, Corbels

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1. Introduction

Due to concrete's weak tensile strength, the use of steel bars it was necessary to combine its properties. As a result, reinforced concrete was introduced, and in the preceding century, it became the major structural option. Steel bars might be partially or entirely replaced with fibers, which would not only reduce construction costs but also improve the quality of the finished product. Modern fiber reinforced concrete (FRC) now allows for the removal or replacement of steel reinforcement bars, resulting in structural FRC. Because of their chemical stability and lower weights with equal residual strengths, advances in the plastic industry over the last three decades have enabled the development of macropolymer fibers as an alternative to steel fibers. Polyolefin-based macrofibres have been developed after 30 years of research and practice [1–4].

Polyolefins have become more important in everyday applications as a result of recent developments in polymer research, chemical composition, and engineering. Because of the reduced cost of manufacture relative to the polymers and materials they replace, polyethylene and polypropylene are the most widely used polyolefins and the fastest expanding polymer family [5,6].

Experimental evidence supports the use of polyolefin fibers in the matrix to increase the flexure and shear strength of reinforced concrete parts, depending on the amount of fibers used; polyolefin fibers in the matrix can greatly increase the tensile strength of concrete [6-9]. Fiber reinforced concrete (FRC) members' ductility and energy absorption are considerably improved by the concrete fibers, which act as fracture stoppers [10-13]. It is noted that there is a lack of research that investigated improving the behavior of concrete by bending and shearing using polyolefin fibers, as well as the absence of any research that studies the behavior of high strength concrete corbels that contain these fibers.

Many international codes have taken into account the relationship between the main steel and the quantity of shear reinforcement, and determinants of the ratio between them were set, with the ACI 318-19 [14]

specifying it at 50%, but recent research has focused on manipulating this ratio by adding steel fibers to concrete, where it was noted that stirrups could be dispensed with or reduced in quantity [15-19].
Since 1982, researchers have been attempting to identify the extent to which steel fiber is engaged in the shear strength of concrete corbels, as well as developing empirical formulae to estimate the corbels' maximum resistance based on various bases and points of view [20-25].
There is no recent research on the results of tests on polyolefin fiber reinforced high strength concrete (PFRHSC) corbels under vertical loads, which could indicate that adding polyolefin fibers significantly improved the shear strength of high strength concrete corbels.
The goal of this study was to gather more experimental data on polyolefin fiber reinforced high strength concrete (PFRHSC) corbels with and without secondary reinforcement, as well as to test the applicability of the ACI 318- 2019 [14] and the Strut and Tie Model [26] to PFRHSC corbels, as well as the modified proposed equation which is suggested to predict ultimate shear load. The experimental results collected as part of this study are analyzed and compared to the predictions made by the three theoretical methodologies. The use of fibers in the design of reinforced concrete corbels is suggested as an option.

1.1. Aim of the research

The influence of polyolefin fibers on reinforced concrete corbels is investigated, as well as the application of the ACI Building Code 2019[14] design formulas and the Strut and Tie Model [26] in determining the carrying capacity of polyolefin fiber reinforced concrete corbels. By adding the effect of polyolefin fibers to the values obtained using the Strut and Tie Model, a realistic and safe suggested equation can be obtained

2. Method

Under vertical loading, twelve corbels in three different groups were tested until they failed. The polyolefin fiber percentage per concrete volume was adjusted from 0 to 1.0 percent in the first section (three specimens) of group A, while the shear span/depth ratio (a/d) remained with value of 0.5. Fiber content was held constant at 1.0 percent in the second part of group A (three specimens), but a/d was changed between 0.30 and 0.6. This is within the ACI Code [14] stated acceptable range of a/d of 1. As indicated in Figure 1, the corbels dimensions as well as the flexure and shear reinforcements, were maintained. All corbels have a width of 200 mm, a height of 300 mm, and an effective depth of 270 mm. The square reinforced column(200*200mm) supporting the double corbels on inverse sides measured 200 x 300 x 600 mm and was reinforced with 6 Φ12 mm diameter bars and 10 mm diameter ties placed 75 mm center to center longitudinally. Three Φ12 mm steel bars (A, = 339 mm2) provided the primary steel, and 2Φ8 mm diameter shaping bars as horizontal stirrups (A = 202 mm2), as illustrated in Figure 1. The basic steel's average yield strength was f = 480 MPa, while the stirrups' yield strength was f = 465 MPa. The details of corbel specimens are shown in Table 1. The three specimens in group B are identical to group A's first portion but lack stirrups, whereas the three specimens in group C are similar to group B but have a primary reinforcement of 2Φ12 mm rather than 3Φ12 mm.

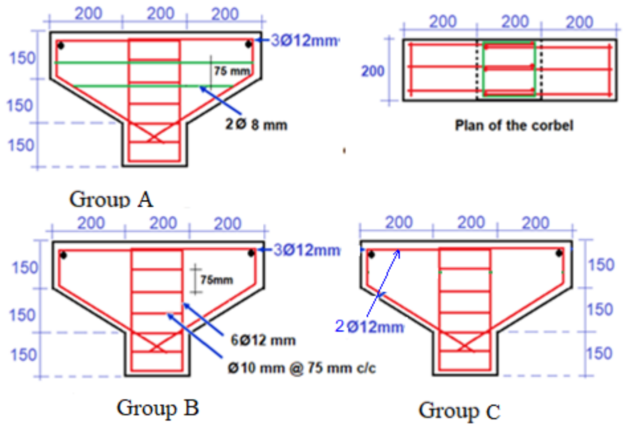

Figure 1. Dimensions and details reinforcement of corbels

The used straight with a rough surface and surface treatment polyolefin fibers as shown in figure 2 have long of 60 mm, diameter of 0.84 mm, 71 aspect ratio and 465 MPa nominal yield strength. Ordinary Portland cement, natural sand, and coarse aggregate (crushed gravel) with a maximum size of 12.5 mm were used in the concrete mix, which was 1:1.1:2.3 (by weight). For both plain and fiber reinforced concrete, a water-cement ratio (w/c) of 0.27 was determined to provide appropriate workability. To ensure constant workability for all mixtures, an appropriate superplasticizer (Viscocrete PC 1000) base polycarpoxy was utilized; consequently, the amount of superplasticizer was changed with varying fiber content.

Figure 3. Polyolefin fiber used

The mixtures have been made with a rotary mixer with a capacity of 0.3 m^3. First, the dry materials completely mixed. After that water was added gradually with superplasticizer with mixing continuing to ensure a homogenous mix, then polyolefin fibers were dispersed over homogenous mix of fresh concrete. Each mix contained enough material to construct one three cubes, nine cylinders, three prisms and one corbel.
The specimens were meticulously poured in three layers with a vibrator table after each layer was inserted in a steel mold. Fiber balling was avoided to the greatest extent possible, and adequate compaction was achieved. Control specimens of 150 mm cubes, 100 x 100 x 500 mm prisms and150 x 300 mm cylinders were also cast with each corbel to determine the compressive, splitting, flexure strengths and static modulus. After 24 hours, the corbels and control specimens were demolded, covered with polythene sheets carfally , and keep in lab. All specimens were tested at the age of 28 days.
As shown in Figure 3, the corbels were put through their paces inverted. At the top of column, the vertical load was subjected using hydraulic testing equipment capacity of 2000 kN capacity. The corbel's horizontal surface contact directly with bearing plates (500 x 70 x 10 mm) which is supported on steel roller. The distance (a) between the column faces and the position of supports.
Small increments of load were continued until failure load was reached. There was no horizontal force applied. Corbel deflection in the mid-span was measured using a laser displacement sensor. All of the cracking loads, crack propagation, and failure mechanisms were recorded.

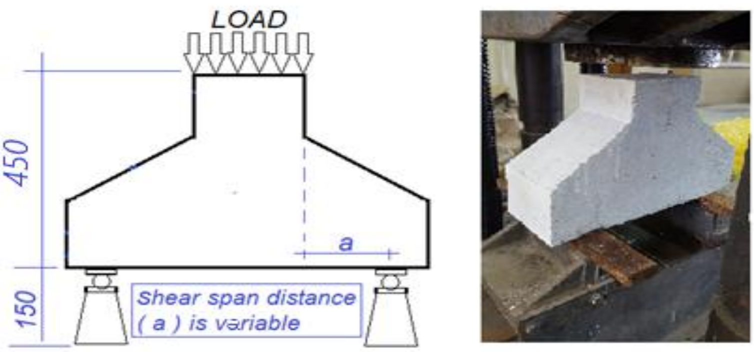

Figure 3. Test setup and load arrangement

4. Discussion of experimental results

4.1. Behavior of specimens

The corbels all failed in the same manner, with a diagonal shear failure. Flexural cracks appeared first, starting at the interior corner and progressing to about half the depth of the corbel at about 30% of the ultimate load. At about 40 % of the ultimate load, another crack appeared at the bearing plate's inner edge, spreading to the corbel's bottom re-entrant corner connection with the column face. As shown in Table 1, cracks were observed at lower loads for Specimens C1, C7, and C10, which did not contain fibers. Figure 4 depicts a typical failure pattern.

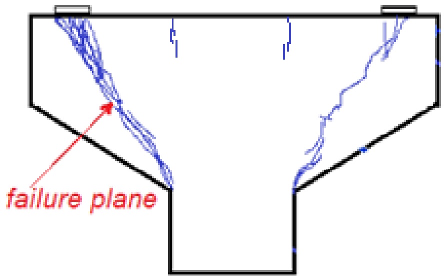

Figure 4- Typical failure plane (specimen C3)

Table1. Details of corbel and properties

Group	**Corbel No.**	fc' MPa	Primary reif.	stirrup	Vf %	a mm	a/d ratio	Vcr kN	Vu ultimate, kN	Vu/Vcr %
A	C1	82.3	3Φ12 mm	2Φ8 mm	0	135	0.5	145	425	0.34
	C2	85.6			0.5	135	0.5	175	474	0.37
	C3	88.2			1.0	135	0.5	205	510	0.40
	C3	81.9			1.0	81	0.3	255	670	0.38
	C5	88.4			1.0	108	0.4	218	580	0.38
	C6	81.5			1.0	162	0.6	175	445	0.39
B	C7	82.9	3Φ12 mm	No stirrup	0	135	0.5	132	335	0.39
	C8	86.6			0.5	135	0.5	158	385	0.41
	C9	87.0			1.0	135	0.5	186	430	0.43
C	C10	83.9	2Φ12 mm	No stirrup	0	135	0.5	125	295	0.42
	C11	84.4			0.5	135	0.5	143	360	0.40
	C12	87.3			1.0	135	0.5	174	400	0.44

Table 2 shows the mechanical properties of the concrete obtained from the control specimens, which show that the polyolefin fiber content had no influence on the cube and cylinder compressive strength. Indirect tensile strength increased by up to 33% and 37%, respectively, with a 1% fiber content, according to cylinder splitting and flexure strength tests. This improvement in tensile strength of high strength concrete is inverter that in the structural behavior and ultimate capability of the tested corbels, significantly which was affected by the volume of fiber percentage. As the fiber content increases, the capacity increase with a 20-36 percent improvement in ultimate strength from 1% fiber content, depending on the percentage of the stirrup and the amount of main reinforcement, as indicated in Table 3. Also, from this table it can be observed that, the corbels with higher number of stirrups (C1, C2, C3) exhibited (19-27) % greater strength as compared with corbels without stirrups (C7, C8, C9) and this effect decreases with increase of fibers content from 0 to 1 percent.

The effect of main reinforcement can be noted from observation of corbels of groups B and C, it can be shown that increasing the amount of the main reinforcement led to an increase in the ultimate strength, but the percentage of the increase of the ultimate strength larger when used less amount of Polyolefin fibers content.

Table 2. Test results summary of all corbels tested

Group	**Corbel No.**	Fiber content by vl., %	Compressive strength Mpa		splitting strength *Fct'*, Mpa	Flexural strength *Fcr*, Mpa	Static Modulus of elasticity *Ec*, MPa
			Cylinder *fc'*	Cube *fcu*			
A	C1	0	82.3	91.4	4.86	6.04	42,125
	C2	0.5	85.6	95.0	5.74	7.25	42,825
	C3	1.0	88.2	97.2	6.43	8.35	43,679
	C3	1.0	87.9	95.3	6.38	8.28	43,369
	C5	1.0	88.4	98.0	6.50	8.36	43,700
	C6	1.0	87.5	95.0	6.23	7.96	42,999
B	C7	0	82.9	94.6	4.96	6.45	42,325
	C8	0.5	86.6	95.4	5.88	7.63	42,845
	C9	1.0	87.0	97.9	6.65	8.54	43,981
C	C10	0	83.9	93.8	4.91	6.33	42,223
	C11	0.5	84.4	95.4	5.90	7.62	42,658
	C12	1.0	87.3	96.5	6.47	8.45	43,912

Table 3. Comparison strength increase of corbels with different Polyolefin fiber contents

Group	**Corbel No.**	fc' MPa	Primary reif.	stirrup	Vf %	Vu ultimate, kN	**strength increase** %
A	C1	82.3	3Φ12 mm	2Φ8 mm	0	425	----
	C2	85.6			0.5	474	12
	C3	88.2			1.0	510	20
B	C7	82.9	3Φ12 mm	No stirrup	0	335	----
	C8	86.6			0.5	385	18
	C9	87.0			1.0	430	39
C	C10	83.9	2Φ12 mm	No stirrup	0	295	----
	C11	84.4			0.5	360	22
	C12	87.3			1.0	400	42

4.2 Analysis of test results

4.2.1 Proposed equation

In 1986 Fattuhi suggested modified shear-friction equation to predict the ultimate strength of corbels containing steel fiber as follows

$$V_u = Ø(\eta\, A_{vf}\, f_{fu}\, \mu) + Ø\,(A_v f_y\, \mu) \qquad (1)$$

where,

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

η = factor of fiber efficiency (with value of 0.1)

A_{vf} = fibers total area at the critical section= $V_f\ h\ b_w$

V_f = percentage of fibers of volume of concrete
h = overall depth of corbel, mm
b= width of corbel, mm
f_{fu} = the fiber ultimate tensile strength, MPa
μ = monolithic concrete friction coefficient (assumed to be 1.4)
fy = the reinforcement yield strength.

In 1989, Abdel-Wahab [22] published an equation to estimate the maximal resistance of the shoulders containing iron fibers, based on the above-mentioned Fattuhi equation, with little difference from the Fattuhi equation in terms of the first portion of the equation. The first is that it chooses the bending and shear strength code with the lowest value.

$$Vu = V_{u\,l} + V_{uf} \qquad (2)$$

Where

Vu= ultimate shear force,
$V_{u\,l}$ = minimum ultimate load for reinforced concrete corbels caculated using the ACI building Code method
Vuf = the ultimate shear force resistance by fibers= $\eta\, A_{vf}\, f_{fu}\, \mu$
η = factor of fiber efficiency (with value of 0.1)
The proposed equation used in this study, gives the predicted ultimate strength which are obtained by adding the fibers' contribution (depending on the modified equation suggested by Fattuhi [21]) to strength obtained using the Strut and Tie Model[26] and regression analysis for the test results as follows

$$Vu = V_{u\,STM} + V_{uf} \qquad (3)$$

Where

Vu= ultimate shear force,
$V_{u\,STM}$ = the ultimate shear force for reinforced concrete corbels using the Strut and Tie Model
Vuf = the ultimate shear force resistance by fibers= $\eta\, A_{vf}\, f_{fu}\, \mu$
η = factor of overall fiber efficiency (with value of 0.189 from regression analysis of current test results)
A_{vf} = fibers total area at the critical section= $V_f\ h\ b_w$
V_f = percentage of fibers of volume of concrete
h = overall depth of corbel, mm
b= width of corbel, mm
f_{fu} = the fiber ultimate tensile strength, MPa
μ = monolithic concrete friction coefficient (assumed to be 1.4)

The suggested equation differs from the two approaches above in that it relies on the Strut and Tie Model, which considers a/d and does so in a way that is closer to the reality of the analysis than the alternative, which ignores the a/d difference. In addition, the efficiency coefficient of the fiber effect for steel fibers is proposed. Instead of 0.1, the coefficient is 0.189 for corbels containing Polyolefin fibers

4.2.2. Comparison between the methods used to estimate the ultimate strength and proposed equation

As indicated in Table 4, the experimental data from the twelve corbels evaluated in this investigation were assessed and compared to projected values using three distinct approaches. Column 4 displays predicted values based on the ACI Code approach [3]. The reduction factor for strength is set to 1.0. The values derived by the Strut and Tie Model are listed in Column 5. In Column 6, The proposed equation as shown below, gives the predicted ultimate strength which are obtained by adding the fibers' participation (depending on the modified shear-friction equation suggested by Fattuhi [21]) to strength obtained using the Strut and Tie Model[26] and regression analysis for the test results.

Table 4. Test results obtained and estimated shear load of corbels tested

Column No.	1	2	3	4	5	6	7	8	9
Group	**Corbel No.**	Concrete strength fc',MPa	Vu test kN	Vu ACI, kN	Vu STM, kN	Vu proposed kN	Vu test / Vu ACI	Vu test / Vu STM	Vu test / Vu proposed
A	C1	82.3	425	318.4	389.4	428.3	1.33	1.09	0.99
	C2	85.6	474	318.7	391	467.0	1.49	1.21	1.01
	C3	88.2	510	318.9	392.2	505.3	1.60	1.30	1.01
	C4	81.9	670	358.7	579.3	711.1	1.87	1.16	0.94
	C5	88.4	580	358.7	472.3	593.4	1.62	1.23	0.98
	C6	81.5	445	265.3	331.9	439.0	1.68	1.34	1.01
B	C7	85.2	310	227.8	299.3	299.3	1.36	1.04	1.04
	C8	84.6	365	227.8	300.2	337.2	1.60	1.22	1.08
	C9	87.0	430	227.8	300.9	374.8	1.89	1.43	1.15
C	C10	83.9	235	151.9	204.8	204.8	1.55	1.15	1.15
	C11	84.4	286	151.9	205.6	242.6	1.88	1.39	1.18
	C12	85.3	333	151.9	204.8	278.7	2.19	1.63	1.19

It's worth noting that, at the critical section, the effective area of fibers (ηAvf) works in shear friction and resists both diagonal and pure shear, is fictional. The coefficient for fiber efficiency that obtained from regression analysis of current test results is η = 0.189, which varies with fiber content and a/d ratio and considers fibers orientation and bond strength, but, rather than being equal to 0.1 for steel fibers as stated by Fattuhi [21].

The influence of polyolefin fiber content on the maximum shear load of the tested corbels is shown in figures 5 to 7. Because the ACI Building Code approach and the Strut and Tie Model do not consider the influence of fiber content, predicted values are nearly constant. When fiber is utilized instead of stirrups, however, a greater increase in strength is achieved. With a fiber content of 1%, corbels without stirrup increased their strength by 42 percent, compared to the 20 percent shown in corbels with stirrup detailed in Table 3.

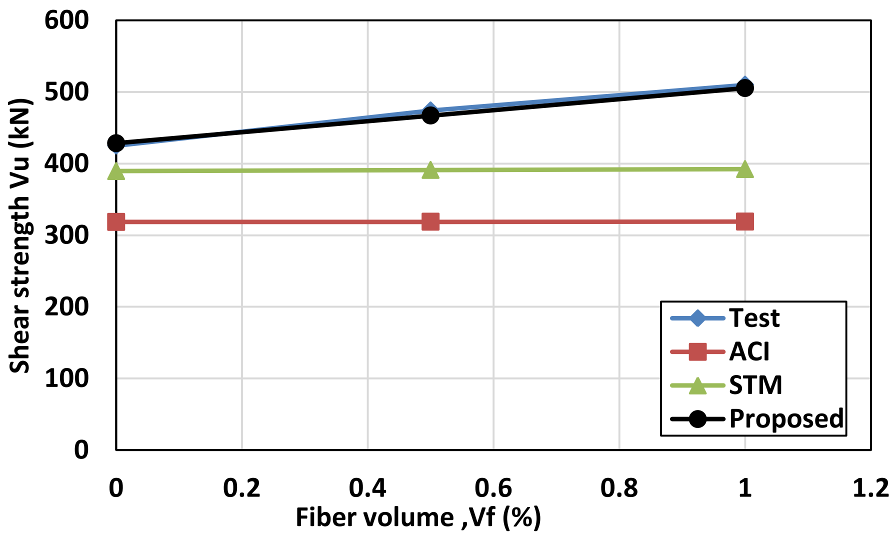

Figure 5. Fiber content effect on group A corbels strength

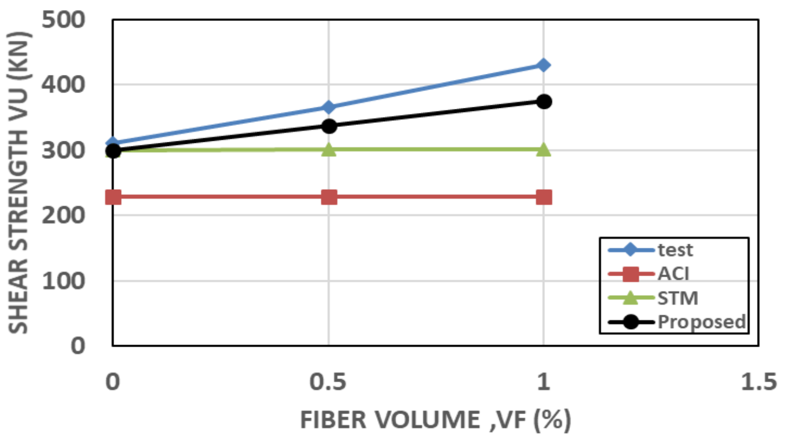

Figure6. Fiber content effect on Group B corbels strength

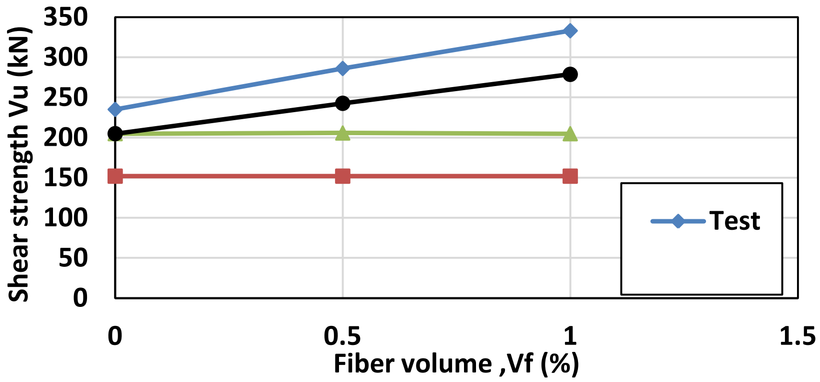

Figure 7. Fiber content effect on Group C corbels strength

Figure 8 depicts the impact of adjusting a/d ratio on corbel ultimate shear load. The ACI 318-2019[14] code equation is the most discreet of the three approaches used in this study. On the other hand, the bending behavior of corbels tested with large a/d ratios is taken into account because either the strength of shear friction, flexural strength, or maximum permitted shear strength reaches its lowest value. The STM is more accurate, and it follows the same pattern as the experimental data. The findings reveal that polyolefin fibers provide a large amount to shear resistance corbels, with the quantity varying according on fiber concentration. The Strut and Tie Model can accurately predict the strength of reinforced concrete corbels. The proposed equation included taking fc’ and the ratio of a / d through the adoption of STM in the first part, as well as introducing the effect of the percentage of fiber content and the tensile strength of the fiber in the second part. The components of the predicted value of ultimate shear load for tested specimens are shown in Table 5.

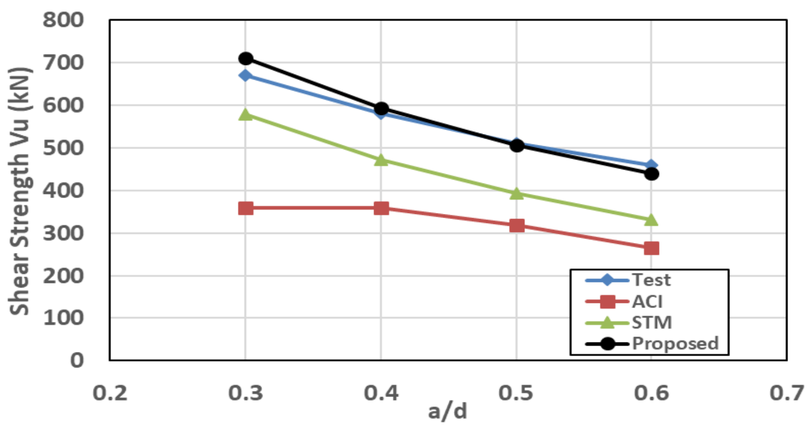

Figure 8. Shear span-depth ratio effect of on polyolefin fibers reinforced corbels strength

Table 5. The components of predicted shear strengths of corbels using the proposed equation

Group	**Corbel No.**	Vu test kN	Vu STM kN	Vu Fiber only kN	Vu STM + fiber kN	Vu test / Vu total
A	C1	425	389.4	428.3	428.3	0.99
	C2	474	391	467.0	467.0	1.01
	C3	510	392.2	505.3	505.3	1.01
	C4	670	579.3	711.1	711.1	0.94
	C5	580	472.3	593.4	593.4	0.98
	C6	445	331.9	439.0	439.0	1.01
B	C7	310	299.3	299.3	299.3	1.04
	C8	365	300.2	337.2	337.2	1.08
	C9	430	300.9	374.8	374.8	1.15
C	C10	235	204.8	204.8	204.8	1.15
	C11	286	205.6	242.6	242.6	1.18
	C12	333	204.8	278.7	278.7	1.19

Figure 8 reals the good relation between the actual ultimate load as compared with the calculated ultimate loads by the proposed equation. The proposed approach of forecasting the participation of fibers to shear adding obstruction, and comparing it to the expected then values code equations, acquired by the ACI, is reasonable and backed by experimental data. By design, shear polyolefin resistant fiber can be combined with less congested and conventionally reinforced corbels to provide a cost-effective contribution. The average ratios between the actual and calculated ultimate loads asre shown in Table 6.

Table 6. Average ratios between the actual and calculated ultimate loads

	Average ($V_{u,test}/V_{u,calc.}$)	Standard deviation
ACI Code equations	1.65	0.176
Strut and Tie Model	I.27	0.223
Proposed	1.09	0.098

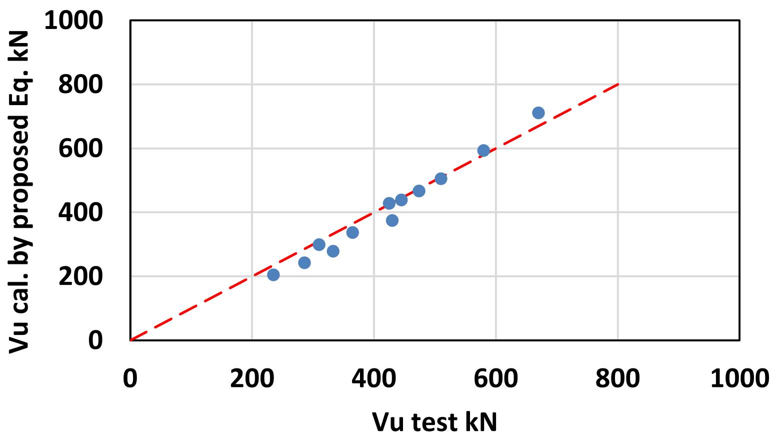

Figure 9. Tested - calculated ultimate load compression using proposed equation

5. Conclusion

- The findings of this study show that adding moderate amounts of polyolefin fibers to high strength reinforced concrete corbels leads in a significant increase in ultimate shear strength. A 1 percent increase in fiber content resulted in a 36 percent increase in strength.

- When test results are compared to those estimated using ACI Building Code and STM, it becomes clear that the code and STM method is overly cautious since it ignores the participation of fibers to corbel shear strength.
- 3. The equation 1 and 2 proposed by Fattuhi and Abdel Wahab respectively , as well as the ACI code equation does not contain the influence of a/d ratio, so you see it effective at a narrow range of a / d values, while it was noted that the proposed equation in this study includes the effect of a / d because it depends on STM.
- The proposed method of forecasting fiber participation to shear adding resistance and comparing it to the expected then values code provisions obtained by the STM is logical and backed up by excellent experimental evidence. By design, shear polyolefin resistance fiber can be a cost-effective addition to less congested and traditionally reinforced corbels.

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