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Parametric Investigation on Structural Behavior of Steel Fiber Reinforced Concrete Corbels

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Abstract. The paper presents the effect of reinforcement parameters on the structural behavior of steel fiber reinforced concrete (SFRC) corbels using the general-purpose ANSYS computer program. The parameters studied herein include the effect of fiber index (I_f),ratio of the main longitudinal steel reinforcement (ρ_s), yield strength of the longitudinal steel reinforcement (f_y), ratio of the horizontal stirrups (ρ_h), yield strength of the horizontal stirrups (f_{yh}) and ratio of the vertical stirrups (ρ_v). It is predicted that increase of I_f improves shear capacity and strain ductility. Steel fiber delays the premature failure for corbels. Increasing ρ_s improves the shear capacity but reduces the strain ductility. A slight increase in shear capacity is observed by increasing f_y. An enhancement on shear capacity and strain ductility is noticed by increasing ρ_h. On the other hand, a slight increase in shear capacity and reduction in ductility for corbels is observed by increasing f_{yh}. It is found that minimum ρ_v is required only to improve the shear capacity and strain ductility

KEYWORDS: Reinforced concrete corbels; Steel fibers; Load-deflection curves; Load-steel strain curves; Crack patterns; Finite element; ANSYS.

1. INTRODUCTION

Corbels are short cantilever members that project from a column or a wall to support another beam or heavy concentrated load. The importance of these members is clear in precast buildings where corbels support beams and girders. Corbels are characterized by a shear span-to-depth ratio (*a/d*) lower than unity. Over the years, the contribution of steel fibers parameters has been studied on the structural behavior of concrete corbels [3-6].It was found that steel fibers could replace partially or fully the stirrups. In addition, using steel fiber improves the ductility and toughness of the reinforced concrete corbels.

The aim of this paper is to present the results of reinforcement parametric studies on the performance of (SFRC) corbels using ANSYS computer program [1]. Numerical model was developed [2] and used successfully to predict the structural response of the tested SFRC corbels [3-6]. The main parameters include the effect of fiber index (I_f), ratio of the main longitudinal steel reinforcement (ρ_s), yield strength of the longitudinal steel reinforcement (f_y), ratio of the horizontal stirrups (ρ_h), yield strength of the horizontal stirrups (f_{yh}) and ratio of the vertical stirrups (ρ_v).

2. Modeling of SFRC Corbels

2.1Model Description of the Tested Corbels

For the parametric study, finite element modeling is made for SFRC corbel that experimentally tested in[3]. Figure (1) shows the geometrical and reinforcement details for the SFRC corbel. In order to investigate the effect of different parameters; series of SFRC corbels, which labeled with (S1, S2...S18) are analyzed.

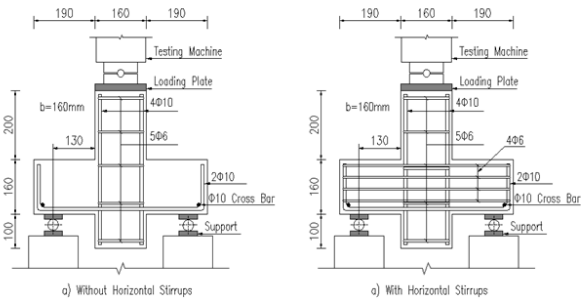

Figure (1) Corbels Geometrical and Steel Reinforcement Details[3]

2.2 Finite Element Geometric and Material Idealization

The finite element modeling and nonlinear analysis is performed by using ANSYS software[1]. The structural element types used to discrete the different materials are given in Table 1. The 3-D finite element model made by ANSYS software is shown in Figure (2). The formulation of related elements is given in [2]. For concrete in compression, Hognestad-Popvics stress-strain curve [7] is used. For concrete in tension, a linear-tension softening curve is used [8]. Bilinear stress-strain curve is adopted for steel reinforcement in compression and tension. The concrete models were modified to take the effect of steel fiber inclusion[2]. Nonlinear incremental-iterative solution technique is used to follow material nonlinearities in compression and tension.

Table 1: Structural Element Types Used to Discrete the Numerical Models

Material	Structural Element
Fibrous Concrete	SOLID 65
Non-fibrous Concrete	SOLID 65
Steel bars	LINK 8
Bearing and Loading Plates	SOLID 45

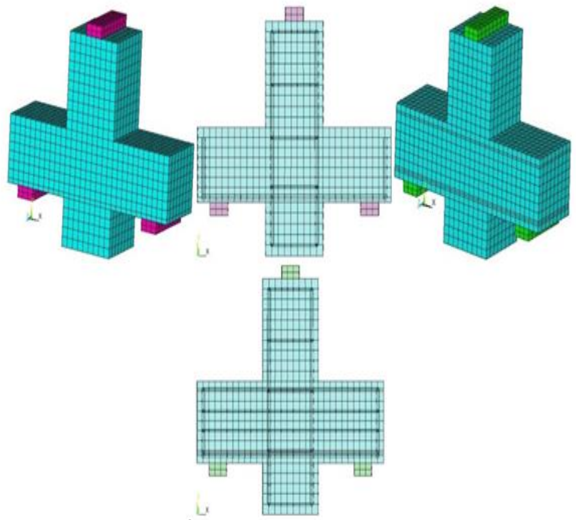

Figure (2) 3-D Finite Element Idealization models for the Corbels[2]

3. Parametric Studies

Table 2 presents the parameters used in this study. Fiber index (I_f) is defined as a function of steel fiber volume (V_f), fiber aspect ratio (l_f/ϕ_f) and shape factor of steel fiber (λ) as follows [8]:

$$I_f = V_f \frac{l_f}{\phi_f} \lambda (1)$$

Table 2: The Input Parameters for the Analyzed Specimens [2]

Corbel	I_f	$\rho_s = \frac{A_s}{b.d}$ %	f_y (MPa)	$\rho_h = \frac{A_h}{b.S}$ %	f_{yh} (MPa)	$\rho_v = \frac{A_v}{b.S}$ %
S1	---	0.613	488	---	---	---
S2	0.50	0.613	488	---	---	---
S3	1.00	0.613	488	---	---	---
S4	0.60	0.613	488	---	---	---
S5	0.60	0.883	488	---	---	---
S6	0.60	1.325	488	---	---	---
S7	0.60	0.613	360	---	---	---
S8	0.60	0.613	420	---	---	---
S9	0.60	0.613	488	---	---	---
S10	0.60	0.613	488	---	---	---
S11	0.60	0.613	488	1.77	445	---
S12	0.60	0.613	488	4.90	445	---
S13	0.60	0.613	488	1.77	240	---
S14	0.60	0.613	488	1.77	360	---
S15	0.60	0.613	488	1.77	445	---
S16	0.60	0.613	488	---	---	---
S17	0.60	0.613	488	---	---	1.77
S18	0.60	0.613	488	---	---	4.90

3.1. Effect of Fibber Index

Three SFRC corbels were analyzed with different I_f values. The values used are (0.0, 0.50 and 1.0) respectively for (S1, S2 and S3).The load-deflection curves and the load-steel strain curves for the analyzed specimens are plotted in Figure(3). The crack patterns are shown in Figure (4) for S1, S2 and S3.

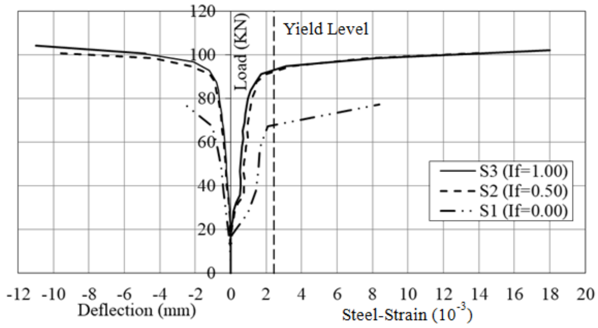

Figure (3) Predicted Response Curves for Corbels S1, S2 and S3

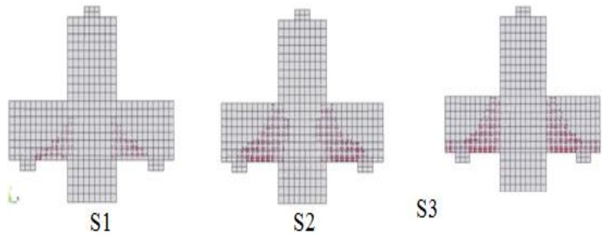

Figure (4) Crack Patterns for Corbels S1, S2 and S3

The comparison between the given results indicates that increasing I_f leads to an enhancement in shear capacity (V_u) by 31% and 35% for specimens S2 and

S3 when compared to S1.Also, it increases the longitudinal steel strain (ε_s) for corbels S2 and S3 respectively by 67% and 114%. In addition, strain ductility has been increased. The calculated strain ductility (= ultimate strain/yield strain) is 3.4, 5.8 and 7.4 for S1, S2 and S3 respectively. Compared to specimen S1, the increase of I_f delays the possibility of premature shear failure and also leads to more spreading in cracks through corbel length and depth. Accordingly, steel fibber can replace partially or fully the horizontal stirrups. Significant enhancement in the toughness (I) which calculated from the area under the load-deflection curve is observed due to the increase in I_f. Toughness is enhanced by 522% for specimen S2 and by605% for specimen S3 compared to specimen S1.

3.2. Ratio of Longitudinal Steel

Three SFRC corbels were analyzed with different ρ_s values (0.613%, 0.883% and 1.325%) respectively for corbels (S4, S5 and S6).Figure (5) presents the predicted response curves for the analyzed specimens (S4, S5 and S6).

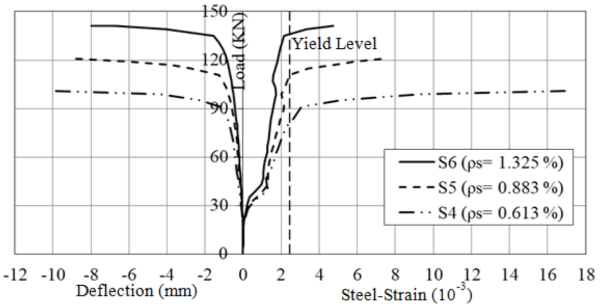

Figure (5) Predicted Response Curves for Corbels S4, S5 and S6

It is clear that increasing ρ_s improves shear capacity V_u of the specimens by 18.82% and 39.10% for S5 and S6 with respect to S4. Slight enhancement in the toughness (I) has been observed by 7.10% and 11.0% for specimens S5 and S6 respectively when compared to S4. On the other hand, increasing ρ_s decreases the steel strain(ε_s) and strain ductility. The predicted decrease of (ε_s) is37.5% and 73.0% for S5 and S6 respectively. The predicted values of strain ductility are 6.96, 3.0, and 1.95 for S4, S5 and S6 respectively.

3.3. Yield Strength of the Longitudinal Steel

Three SFRC corbels were analyzed with different (f_y).The values used are (360, 420 and 488 MPa) respectively for corbels (S7, S8 and S9).Figure (6) represents the predicted response curves for specimens (S7, S8 and S9).The increase of f_y leads to a slight increase in shear capacity (V_u) by 4.50% and 13.22% respectively for specimens S8 and S9 with respect to S7. On the other hand, a significant decrease in strain ductility is observed due to increase f_y.

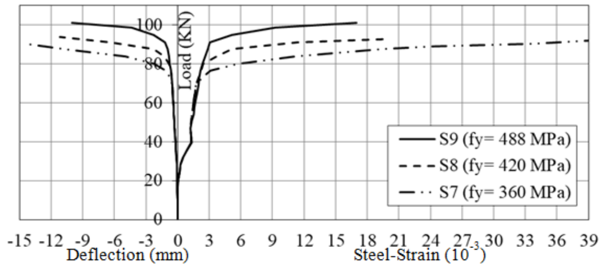

Figure (6) Predicted Response Curves for Corbels S7, S8 and S9

3.4. Effect of the Horizontal Stirrups Ratio

Three corbels with different horizontal stirrups ratio ρ_h have been investigated. The corbels are denoted by S10, S11 and S12 and reinforced with ρ_h of values 0.0%, 1.77% and 4.90% respectively. Figures (7) and (8) present the predicted response curves and the crack patterns respectively for the analyzed specimens.

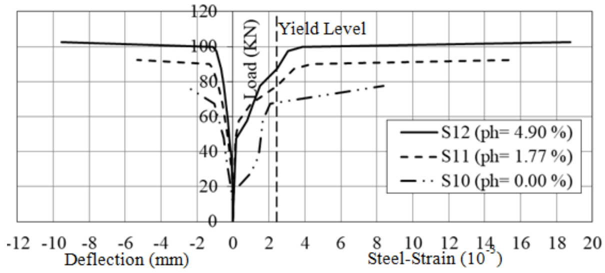

Figure (7) Predicted Response Curves for Corbels S10, S11 and S12

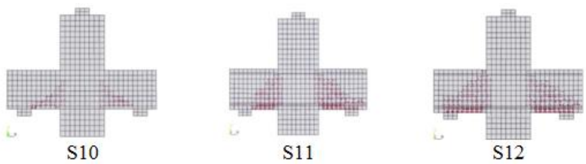

Figure (8) Crack Patterns for Corbels S10, S11 and S12

An enhancement in shear capacity (V_u) by 20.20% and 32.46% has been observed for S11 and S12respectively when compared with S10.With respect to S10, significant enhancement in the toughness (I) and strain ductility is noticed. The predicted increase in toughness (I) is 194% for specimen S11 and 512% for specimen S12. The predicted values of strain ductility are 3.34, 6.43, and 7.69 for S10, S11 and S12 respectively. Compared with specimen S10 the increase of ρ_h delays the possibility of premature shear failure and leads to more spreading in cracks through corbel length and depth.

3.5. Yield Strength of the Horizontal Stirrups

Three corbels were analyzed with different f_{yh}. The used values are (240, 360 and 445MPa) respectively for corbels (S13, S14 and S15).Figure (9) presents the predicted response curves for the analyzed specimens.Increasing f_{yh} leads to slight increases in shear capacity(V_u).In addition, it decreases the ductility by 10% and 36% respectively for specimens S14 and S16 with respect to S13.

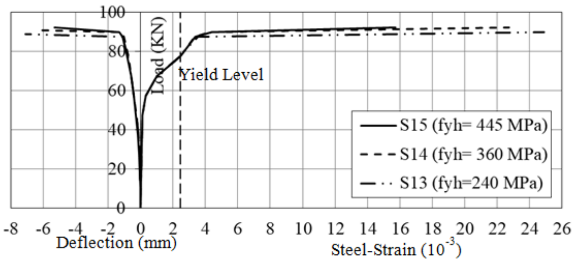

Figure (9) Predicted Response Curves for Corbels S13, S14 and S15

3.6. Ratio of Vertical Stirrups of Corbels

Three SFRC corbels S16, S17 and S18having ρ_v0.0%, 1.77%and 4.90% respectively are chosen to investigate effect of ρ_v. The stirrups ratio ρ_v =1.77% is the minimum requirement for vertical stirrups content. The predicted response curves for the specimens are shown in Figure (10).

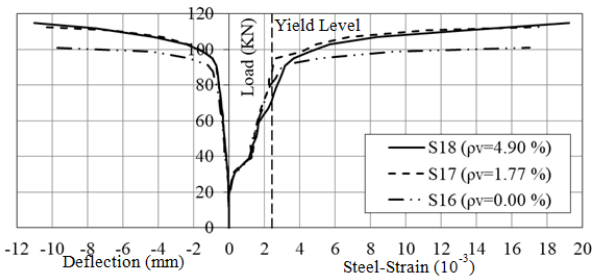

Figure (10) Predicted Response Curves for Corbels S16, S17 and S18

As shown in the figure, providing minimum vertical stirrups ($\rho_{v,\ min}$) in corbels leads to increase shear capacity (V_u) and strain ductility respectively by 13% and 20% for specimen S17 with respect to specimen S16. On the other hand, using ρ_v more than $\rho_{v,\ min}$ has a negligible effect on shear capacity and the strain ductility of SFRC corbels.

Conclusions

From the results obtained from the numerical results for reinforcement parameters, the following conclusions can be drawn:

1. The inclusion of steel fiber in corbels improves the shear capacity and the strain ductility. Compared with non-fibrous corbel, the use of corbel with I_f =0.50 and 1.0 increases respectively the shear capacity (V_u) by 31% and 35% and the strain ductility by 70% and 117%.
2. Increasing the longitudinal steel ratio (ρ_s)improves shear capacity (V_u) but reduces the strain ductility of SFRC corbels. Compared with corbel with ρ_s=0.613%, the use of corbels withρ_s =0.883% and 1.325% enhances respectively (V_u) by 18.82% and 39.10% and decreases the strain ductility by 56% and 71%.On the other hand, using corbels with f_y= 420 MPa and 488 MPa leads to a slight increase in (V_u) by 4.50% and 13.22%when compared to corbel with f_y= 360 MPa.
3. Compared with corbel without ρ_h, significant improvement in toughness (I) is observed respectively by 194% and 512% for corbels with ρ_h = 1.77% and 4.90%. Also, $V_u$is improved by 20.20% and 32.46% with respect to corbel without ρ_h. On the other hand, a slight increase in (V_u) is observed respectively by 1% and 3% when using corbel with f_{yh}=360MPa and 445MPs with respect to corbel with f_{yh}=240MPa.
4. It is important to provide $\rho_{v,\ min}$ for corbels to improve the shear capacity and strain ductility but using $\rho_v$more than $\rho_{v,\ min}$ has a negligible effect on the structural response of SFRC corbels.

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