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STRENGTH OF REINFORCED CONCRETE BEAMS PROVIDED WITH SIDE FACE REINFORCEMENT

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Abstract- Side-face reinforcement (SFR) is well recognized in standard codes to control cracking in large reinforced concrete beams (RC-beams). Meanwhile, its contribution to the overall strength is, so far, not accounted in design provisions. Yet, comprehensive experimental and numerical studies are required to find out how important this contribution is. In this research, the relevant experimental studies available in literature is extended numerically to involve more parameters that affect the strength of RC-beam. The present parametric study involves, the amount and arrangement of SFR, the amount of main reinforcement, the amount of transverse shear reinforcement, the shear span-to-depth ratio, and the beam depth and width. Results of the study demonstrate that the contribution of SFR to the beam response is not only affected by SFR amount and arrangement, but also by the other parameters involved in the study. However, this contribution is generally significant; ignoring this contribution by design provisions results in conservative design. Hence, SFR contribution to strength of RC-beams is recommended to be taken into account in design provisions codes.
Keywords – Side-Face Reinforcement, Strength of Reinforced Concrete Beams, Parametric Study, Shear Span-to-Depth Ratio.

1. INTRODUCTION

Yet, it is still difficult to predict accurate behavior of reinforced concrete beams (RC-beams) due to the variety of parameters that affect the strength of such beams. Investigations on the effect of main longitudinal reinforcement on the overall strength and cracking control in beams demonstrated that main longitudinal reinforcement in beams should be utilized to resist forces, not only from bending and axial loads, but also from shear and torsion [1,2]. Indeed, some design provision codes acknowledge the contribution of main longitudinal steel in shear resistance of beams. The general method adopted by AASHTO-LRFD specifications [3] as well as Canadian CSA-A23.3 building code [4], recognizes the contribution of main longitudinal reinforcement in shear and torsion strength, and requires checking on its adequacy to resist the forces from shear and torsion, besides the bending and axial loads.

Installing longitudinal reinforcement along the side-faces of large concrete beams is required by national codes to control cracks that are predictable under service loads due to low tensile strength of concrete. Although cracks in structural members are caused mainly by flexural or shear stresses, shrinkage often causes considerable deformations and substantial stress change in concrete members. Such undesirable phenomenon in concrete introduces a typical problem in RC-structural members, as it leads to corrosion of embedded reinforcement and severely affects durability of structures. Therefore, codes of design provisions consider cracking as one of the important serviceability limit states, which is considered in design of RC-structures. According to the arrangement of side bars, some may be placed in compression or in tension zones. British Code-CP114 [5] recommends that secondary reinforcement should be provided at a distance 2/3 of the beam depth from tension face for beams that exceed 750 mm in depth, bars should be distributed at spacing that does not exceeds 250 mm. ACI 318 code [6] provides Side-face reinforcement (SFR) when beam depth is greater than 915 mm, it should be uniformly distributed on both side-faces of the beam over a distance of half the beam depth from the tension face. Egyptian code-ECCS 203-2007 [7] requires that, for beams with total depth exceeds 700 mm, SFR must be provided with minimum of 8% of the main longitudinal reinforcement. German Code-Din 1045 requires the same amount of side bars that is recommended by ECCS 203-2007 (sited from [8]). Canadian code-CSA A23.3 [4] requires that for beams with overall depth greater than 750 mm, SFR of 1.0 % of concrete cross-sectional area should be provided on each side of the beam web, in case of exterior exposures.

Few experimental studies were conducted to investigate the structural behavior of RC-beams provided with SFR. Ten large RC-beams were tested under static and repeated loads [8], the studied parameters were the amount and distribution of SFR, results showed that, providing side-face bars to large beams has considerable effect on shear response of such beams. Two groups of RC-beams provided with SFR were tested [9], two values of beam depth were considered, it was concluded that SFR has significant contribution to strength of RC-beams. In the experimental analysis carried by [10], it was found that, the average shear capacity of RC-beams reinforced with SFR is 41.1% greater, compared to similar beams without SFR. An experimental study was conducted by [11] on RC-beams provided with different amounts and distributions of SFR, two

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values of shear span-to-depth ratio were considered in the study, it was concluded that, side bars play an important role not only in limiting crack width but also in improving ultimate load capacity of RC-beams.
Although SFR is recommended by standard codes to control cracking in RC-beams, some experimental researches state that SFR not only controls cracking, but also contributes in overall resistance of such beams. Yet, additional studies are needed to find out how important is the contribution of SFR to overall strength of RC-beams. This paper aims at a comprehensive investigation on resistance of RC-beams provided with SFR. For this purpose, results are collected from available experimental researches involving studying structural behavior of RC-beams provided with SFR. Then, wide parametric study is conducted numerically to include more parameters that affect such behavior of RC-beams, numerical analysis is carried out using ANSYS program as a finite-element software. The available experimental results are used to verify the numerical results.
The parametric study encloses the following parameters:

- arrangement of SFR along the beam depth
- amount of SFR
- ratio of transverse shear reinforcement
- dimensions of beam cross-section
- shear span-to-depth ratio
- mount of tension and compression reinforcement

2. EXPERIMENTAL STUDIES USED FOR COMPARISON

Results from the relevant experimental studies [8-11] are collected to verify the results from the present numerical analysis. Table (1) records the parameters which were considered in the relevant experimental studies from literature.

Table 1: Ranges of parameters used in the experimental studies.

	Ref.			
	[8]	[9]	[10]	[11]
Parameter	Value range			
(p)	0-3	2	3	0-3
ρ^h %	0-0.81	0.17	0.41	0-0.4
ρ^v %	0.19	0.12	0.18	0.31
$(d\ mm)$	700	600	400	700
$(b\ mm)$	200	120	120	200
(a/d)	1.5	1.0	1.0	1.5, 3.0
ρ_s %	0.81	0.34	0.51	1.09

Where:
(p), is the number of SFR rows along the beam depth,
$(\rho^h = A_s^h/ba^h)$ %, is the volumetric ratio of SFR,
$(\rho^v = (A_s^v/ba^v)$ %, is the volumetric ratio of transverse shear reinforcement (stirrups),
$(d\ mm)$, is the beam depth,
$(b\ mm)$, is the beam width,
(a/d), is the shear span-to-depth ratio,
$(\rho_s = (A_{st}/bd)$ %, is the volumetric ratio of main longitudinal reinforcement,
(a^h), is the equal distance between SFR rows along the beam depth,
(a^v), is the equal distance between transverse shear reinforcement,
$(A_s^h = A^h/p)$, is the total cross-sectional area of one row of SFR bars,
(A^h), is the total cross-sectional area of SFR,
(A_s^v), is the total cross-sectional area of one stirrup branches,
(A_{st}), is the area of main longitudinal reinforcement.
The above-mentioned variables are clarified on Fig. (1), which represents typical RC-beam with rectangular cross-section.

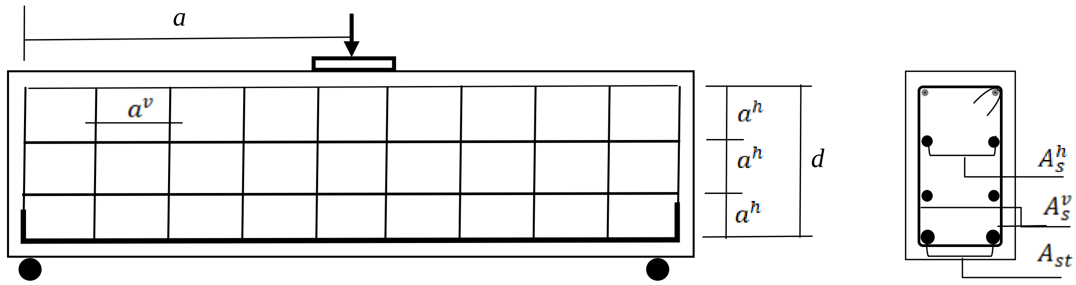

Fig. (1): Detailed dimension and reinforcement of RC-beam.

3. NUMERICAL ANALYSIS

Numerical analysis is intended in the present work to conduct a parametric study on the contribution of SFR to strength of RC-beams. This study involves more parameters and wider range of parameters that affect RC-beams resistance compared to available experimental researches.

3.1 Verification of numerical results

Results available from experimental studies that account for the contribution of SFR to strength of beams are used to verify results obtained from the numerical analysis. Comparison between strengths from the experimental data, denoted as v_{exp}, and strengths from the present numerical analysis results, denoted as v_{nu}, is shown on Fig. (2).

Comparison shows that, ratios between strengths from the experimental data and these from the present numerical analysis results, (v_{exp}/v_{nu}), have an average value (AVG) of 1.024, and the values of the standard deviation (SD), and the correlation coefficient (r) for these ratios are 0.052 and 0.994, respectively. Such good correlation between the experimental data and the results of the present numerical analysis indicates that numerical analysis can be utilized in a comprehensive study on the contribution of SFR to strength of RC-beams

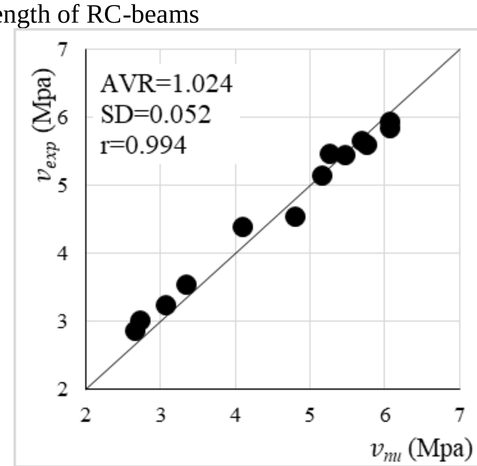

Fig. (2): beams strengths from experimental results, (v_{exp}) versus strengths from numerical analysis results, (v_{nu}).

3.2 Ranges of parameters applied in the numerical analysis

In the present numerical study, more parameters and wider ranges of parameters that affect RC-beams resistance, compared to available experimental researches, are included to conduct a parametric study on the contribution of SFR to strength of RC-beams. The investigated parameters and their ranges are listed in table (2).

Table 2: Ranges of parameters applied in the numerical analysis.

Parameter	Value range
(P)	0 – 6
ρ^h %	0 – 1
ρ^v %	0.16 – 0.31
(d mm)	400 – 1130
(b mm)	100 – 400
(a/d)	1.5 – 3.0
ρ_s %	0.6 – 2.4

4. RESULTS AND DISCUSSION

Contribution of SFR to strength of RC-beams is investigated by considering ranges of parameters that is recorded in table (2). The importance of this contribution is discussed through the following:

4.1 Effect of presence of SFR

In this work, amount of SFR is expressed as volumetric ratio of concrete, ρ^h, the considered ratio in the present study ranges from 0 to 1%. The contribution of SFR to the overall strength of a beam is expressed in this context by the increase in beam strength due to presence of SFR, v_s, to the total strength of the beam provided with SFR, v.

Figs (3-a) to (3-d) display portion of the numerical analysis results for beams with $\rho^v = 0.31\,\%$, $\rho_s = 1.2\,\%$, and $b/d = 0.3$. It is obvious from Figs (3-a) to (3-d) that, presence of SFR increases beam strength in general; regardless the effect of other parameters. For instance, providing SFR equivalent to 8 % of main reinforcement area ($A^h/A_{st} = 8\,\%$), as recommended by ECCS 203-2007 and DIN 1045, results in strength improvement ranges from 2% to 22%, depending on beam shear span-to-depth ratio and SFR arrangement along the beam depth, see Figs (3-a) to (3-d).

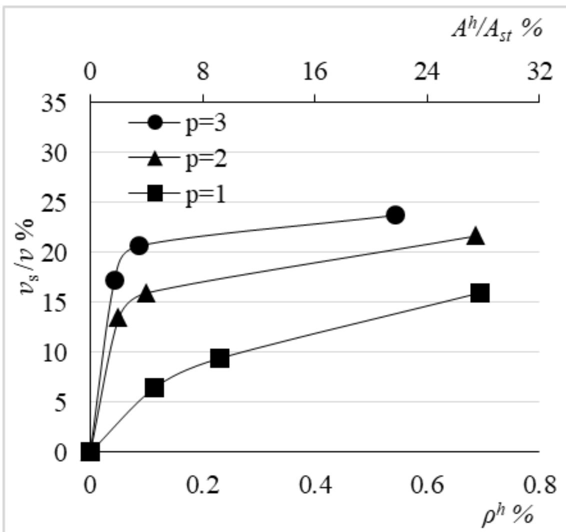

Fig. (3-a): Beams with a/d=1.5

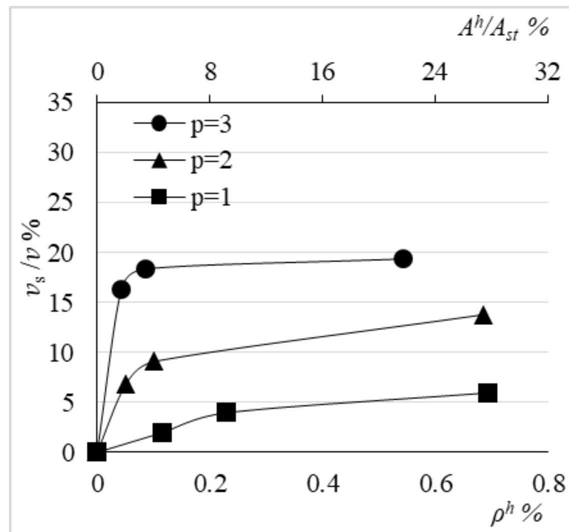

Fig. (3-b): Beams with a/d=2.0

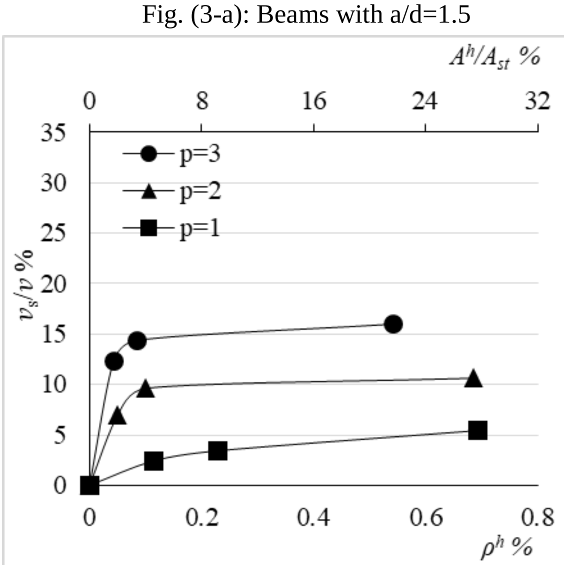

Fig. (3-c): Beams with a/d=2.5

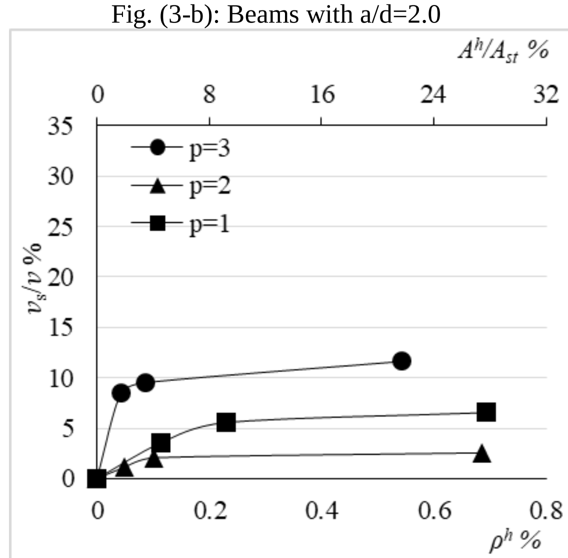

Fig. (3-d): Beams with a/d=3.0

Fig. (3): Relationships between SFR amount, (ρ^h %) and its contribution to beam strength, (v_s/v%), ($\rho_s = 1.2\,\%$, $\rho^v = 0.31\,\%$, and $b/d = 0.3$).

4.2 Effect of distribution of SFR.

Fig. (4) shows that, distributing SFR bars in three rows along the beam depth significantly increases its contribution to the beam strength, this is observed for various values of shear span-to-depth ratio. The contribution is about 300% of the contribution of same amount of SFR when provided in one row at middle depth of the beam. This enhancement is due to that, distribution of SFR bars in several rows along the cross-section depth reduces the width of the formed cracks, increases cracks number, and decreases spaces between cracks, which increases cross-section stiffness and improves the resistance of both tension and compression zones of the cross-section [12].

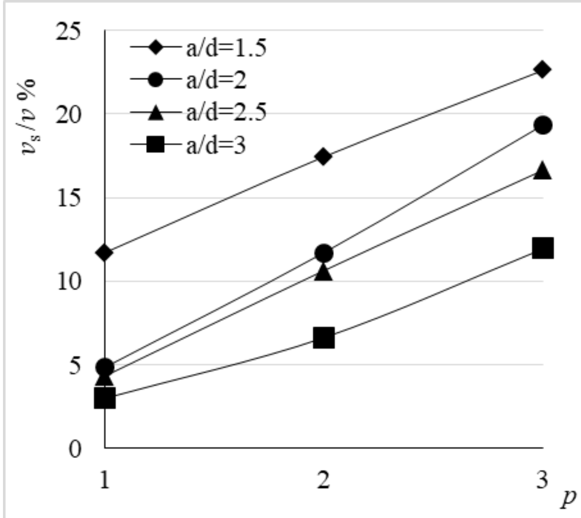

Fig. (4): Relationship between number of SFR rows, (p) and its contribution to beam strength, $(v_s/v\%)$ for different values of beam shear span-to-depth ratio,
($\rho^h = 0.4\,\%$, $\rho_s = 1.2\,\%$, and $b/d = 0.3$).

4.3 Effect of shear span-to-depth ratio

Although it is obvious that SFR contributes to the overall strength of RC-beams, the significance of this contribution depends on shear span-to-depth ratio. The effect of SFR on beams with different values of shear span-to-depth ratio, ($a/d = 1.5 - a/d = 3.0$), is studied for various values of the other parameters recorded in table (2). Fig. (5) represents the relationship between shear span-to-depth ratio and SFR contribution to beam strength, in case of SFR bars is distributed in three rows.

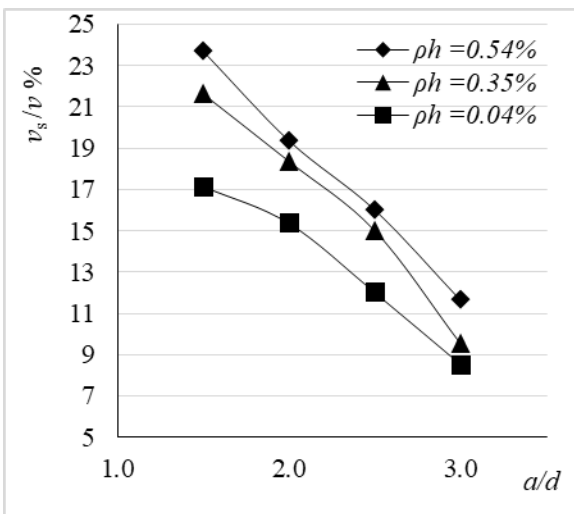

Fig. (5): Relationship between shear span-to-depth ratio, (a/d) and SFR contribution to beam strength, $(v_s/v\%)$.
($p = 3$ and $\rho_s = 1.2\,\%$).

Fig. (5) illustrates that, the increase in strength ranges from 17.1% to 23.7% for beams with $a/d = 1.5$, while the increase in strength ranges from 8.5% to 11.6% when $a/d = 3.0$; this result is for a ranging amount of SFR from 0.04% to 0.54%. Which means that, SFR contribution to strength is more important for beams with smaller shear span-to-depth ratios, this result agrees with [11]. This is owing to that SFR delays the appearance of inclined shear cracks and controls their width and propagation prior to failure, providing significant contribution to strength of beams failing in shear.

Effect of beam width-to-depth ratio

Strength of beams with same depth and different values of width is expected to be affected by the presence of SFR differently. Fig. (6) demonstrates that distributing SFR in several rows generally enhances its contribution to strength of beams with different values of width-to-depth ratio. On the other hand, Fig. (7) shows that, this enhancement increases by increasing width-to-depth ratio to certain value, then the contribution significance decays for higher width-to-depth ratios.

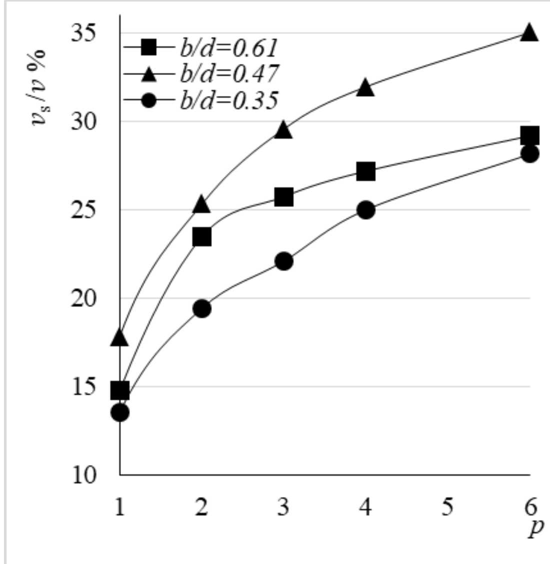

Fig. (6): Relationships between number of SFR rows, (p) and its contribution to beam strength, ($v_s/v\%$) for different values of beam width-to-depth ratio, ($a/d = 1.5$, $\rho^h = 0.4\,\%$, and $\rho_s = 1.2\,\%$).

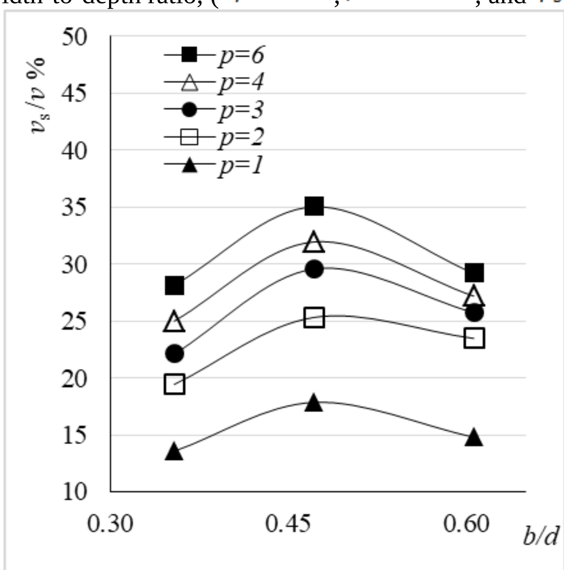

Fig. (7): Relationship between beam width-to-depth ratio, (b/d) and SFR contribution to beam strength, $(v_s/v\%)$, ($a/d = 1.5$, $\rho^h = 0.4\,\%$, and $\rho_s = 1.2\,\%$).

5. CONCLUSION

In this paper, parametric study on resistance of RC-beams provided with side-face reinforcement is conducted numerically. Wide range of parameters are involved in the study to expand the available limited experimental researches in this topic. The numerical results are verified using the available relevant experimental studies. Comparison between experimental and numerical analysis results shows good agreement with standard deviation (SD) and correlation coefficient (r) of 0.052 and 0.994, respectively. The following conclusions can be drawn:

There are considerable differences in standard codes regarding how much SFR is appropriate, ECCS 203-2007 and DIN 1045 recommended the lowest amount.

SFR not only controls cracking, but also contributes to the overall strength of RC-beams.

Capacity of beams provided with SFR arranged in several rows is tremendously improved compared to capacity of beams provided with same amount of SFR installed in one row at the middle of beam depth.

The contribution of SFR when arranged in three rows is three times its contribution when provided in one row at middle depth of the beam.

Contribution of SFR to beam strength depends on shear span-to-depth ratio.

The increase in strength due to the presence of SFR for beams with $a/d = 1.5$ is about twice the increase in strength when $a/d = 3.0$.

The significance of side bars contribution to strength of RC-beams affected not only by beam depth, but also by width-to-depth ratio.

Results of the present work emphasizes on the important contribution of side-face reinforcement to response of RC-beams, and hence, it is recommended to be taken into account in designing of such beams.

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