JES, Vol. 50, No. 1, January 2022 DOI: 10.21608/JESAUN.2021.87650.1065 Part A: Civil Engineering

Journal of
Engineering Sciences
Faculty of Engineering
Assiut University

مجلة
العلوم الهندسية
كلية الهندسة
جامعة أسيوط

journal homepage: http://jesaun.journals.ekb.eg

Shear Behaviour of R.C. Beams Reinforced with Swimmer Bars

Received 26 July 2021; Revised 13 November 2021; Accepted 15 November 2021

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Keywords
High strength concrete, Stirrup, Single Swimmer bar, Shear, Deflection

Abstract

Designers have to be very careful with respected to shear requirements in reinforced concrete (R.C.) elements due to their riskiness. Shear failure in R.C. beams is considered an undesirable failure mode because shear cracks develop without any warning. Swimmer bars are web reinforcement system alternatives for traditional shear reinforcement. Swimmer bars are small diagonal bars, with both ends bend over horizontally and tied with top and bottom reinforcement. The system of swimmer bars can be spliced, welded, or bolted and arranged in one or two rows. In this paper, an experimental study is carried out to investigate the shear behaviour of R.C beams which reinforced with swimmer bars as web reinforcement. Fifteen R.C beams are experimentally tested under monotonic load to study the effect of the number of swimming bars, type of splice, splice length and concrete strength on shear behaviour. The test results showed that using swimming bars as shear reinforcement increases the shear strength, stiffness, toughness as well as decreasing crack width, deflection values and the deformability of the tested beams.

1. Introduction

The failure mechanism in concrete elements due to shear stresses varies according to element properties like such cross-sectional dimensions, geometry, and material properties. Also, types and rates of loading can affect the shear failure mechanism. Reinforcements of shear zones are essential to enhance the shear strength of concrete elements especially if the allowable shear is less than the acting shear. Inclined cracks refer to shear failure, shear cracks are wider than the flexural cracks and occurred in the shear zones near the supports. disadvantages of shear cracks were they're rapidly progressing without any cautions, and the member fails down suddenly. Whenever the value of actual shear stress exceeds the permissible shear stress of the concrete used, the shear reinforcement must be provided to withstand shear or diagonal tension stresses. Shear reinforcement is important to prevent shear failure, increase the ductility of concrete element and subsequently the likelihood of sudden failure will be reduced. Bent-up bars are commonly used to reinforce shear zones. These bent-up bars engendered from the bottom reinforcement bars, which shaped and bent bent right next to the pillar to join the upper reinforcement. In many cases, all the flexure rebar is moreover than the need to resist bending moment. Anyway, this technique is not

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preferred because of its cost and other technical considerations [1]. Stirrups widely used to resist shear stresses, due to simplicity in fabrication and installation. Stirrups are used mightily at the high shear zones. The cost and time required for stirrups installation depended on the congestion near the supports of the reinforced concrete beams[1–3]. The swimmer bar system is considered a new technique of shear reinforcement. It distinguishes with more flexibility, simplicity, efficiency, speed of construction and low cost than bent up bars or stirrups systems. One of the most important advantages that the swimmer bars from the plane – crack interceptor system instead of the bar–crack interceptor system when stirrups are used. There are many forms and shapes of the swimmer bar systems like as single swimmers, rectangular shape, rectangular shape with cross bracings and swimmer bar planes with vertical and horizontal stiffeners. Also, many addendum shapes can be explored [1]. The single swimmer bar is tied to both top by the horizontal stiffener bar with to flexural steel reinforcement. The swimmer bar system can be welded, spliced or bolted as shown in Fig.1, [4].

Fig. 1. a.: Spliced tying type.

Fig. 1.b: Bolted tying type.

Fig. 1.c: Welded tying type.

Fig.1.d: spiral spliced type of tying- 2 rows

Fig.1 .e: spliced tying type-2 rows

Azlina et al , [5], studied the shear behaviour of six RC beams, and focused on the shear behaviour of these beams reinforced with a swimmer bars looks as a Z shape. to investigate the effect of horizontal reinforcement on shear strength in beams with rectangular cross section. Also, Noor determined the optimum manner of shear reinforcement to obtain the best shear capacity. They conclude that, using of horizontal reinforcement with bent bars as a shear reinforcement were preferred than traditional shear reinforcement system. This study

According to the ACI Code [6], design of reinforced concrete beams due to shear based on the following relation:

$$V_u \leq \O V_n \qquad (1)$$

Where:

V_u equals to the total applied shear force at the required section of the beam

V_n equals to the nominal shear strength. It equals to the sum of the contribution of the concrete

Ø is the strength reduction factor for shear, and equals to 0.75

(V_c), and the web reinforcement if present (V_s). and can calculated by the following equations:

- If it was vertical stirrups:

$$V_u = \phi\,\mathrm{V_c} + \phi \times \frac{\mathrm{A_v\ F_{yt}\ d}}{\mathrm{s}} \tag{2}$$

If it was inclined bars:

$$V_u = \phi\,\mathrm{V_c} + \phi \times \frac{\mathrm{A_v\ F_{yt}\ d}}{\mathrm{s}} \times (\sin\alpha + \cos\alpha) \tag{3}$$

Where: A_v is the area of one stirrup, α is the angle of the stirrup with the horizontal, F_{yt} = yield strength of transverse reinforcement and s is the stirrup spacing. The nominal shear strength contribution of the concrete (including the contributions from aggregate interlock, the dowel action of the main reinforcing bars, and that of the un-cracked concrete) can be simplified as present in Eq. 4.

$$V_c = 0.17\lambda\sqrt{f_c'}\;b_w d \tag{4}$$

Where b_w and $d$are the section dimensions, f_c' is the concrete compressive strength and for normal weight concrete, $\lambda = 1.0$. This simplified formula is permitted by the ACI code expressed in metric units. Using truss analogy concept, swimmer bar system as a shear reinforcement was designed. If s_1 is the swimmer bar interval in a single truss analogy, n is the number of bars, and A_s is the area of steel of a single swimmer bar [1], then:

$$s_1 = nA_s \tag{5}$$

$$\frac{T_s}{s_1} = \frac{T_s}{\mathrm{ns}_c} = \frac{V}{\mathrm{s} \times \sin\alpha\,(\mathrm{d} - \mathrm{d}') \times \cot(\beta + \cot\alpha)} \tag{6}$$

Where:

T_s equals to the tension force on the bend bars.

s equals to the spacing of the swimmer bars.

d' equals to the effective depth of the concrete section.

α equals to the angle between both tension force and the horizontal in the triangular truss.

β equals to is the angle between the simulated concrete strut and the horizontal in the triangular truss.

If the enumeration of swimmer's bars = n, within the s_1 = the length of the truss chord, and Av is the area of steel of one swimmer bar, then:

$$T_s = n\,Av\,fyt \tag{7}$$

$$n\mathrm{A_v} = \frac{T_s}{\mathrm{ns}} = \frac{V_s\ \mathrm{n\ s}}{(\mathrm{d} - \mathrm{d}') \times (\sin\alpha \times \cot\beta + \cot\alpha) \times \mathrm{f_{yt}}} \tag{8}$$

In the case of diagonal tension failure, the compression diagonal makes an angle $\beta = 45^o$ with the horizontal, thus Eq. 6 becomes:

$$V_s = \frac{A_v\ f_{yt} \times (d - d')}{s} \times (\sin\alpha \times (1 + \cot\alpha)) \tag{9}$$

Which can be simplified as:

$$V_s = \frac{A_v \, f_{yt} \times (d - d')}{s} \times (\sin \alpha + \cos \alpha) \tag{10}$$

Which is similar to those used by ACI code.

$$V_n = V_s + V_c \tag{11}$$

2. Experimental Program

To investigate the research objectives, an experimental study was done on fifteen simply supported RC beams. Three beams were made from high-strength concrete and the remaining beams were made from normal strength concrete. Details of the experimental program were presented in the following section.

2.1 Test beams

Tested beams details are shown in Fig.2 to Fig.4 and listed in Table- 1. beams cross section were 300 mm ×150 mm with length equals to 1400 mm. The beams had three bars 16 mm diameter as main longitudinal reinforcement and two bars diameter 10 mm as compression steel. The shear span to depth ratio, a/d was kept constants for all beams and equal to 1.5. The studied variables were concrete compressive strength, type of tying, area of web shear reinforcement and lap splice length of swimmer bars. In the control beam, vertical stirrups 8 mm at 100 mm spacing were used, along the overall length of the control beam. The other beams were designed for shear with single or double swimmer bars in the cross-section at 150 mm spacing and tested under third point load.

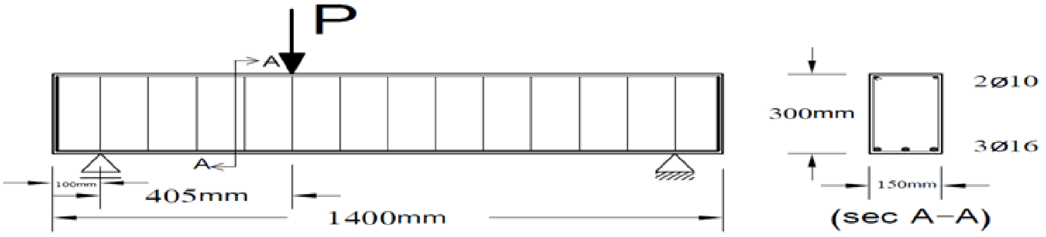

Fig. 2. Longitudinal Sec in control beam.

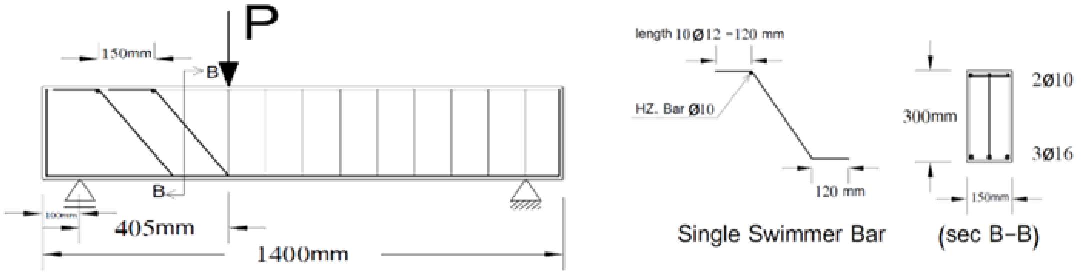

Fig. 3. Longitudinal and cross Sec in beam with two single swimmer bars in the cross- section.

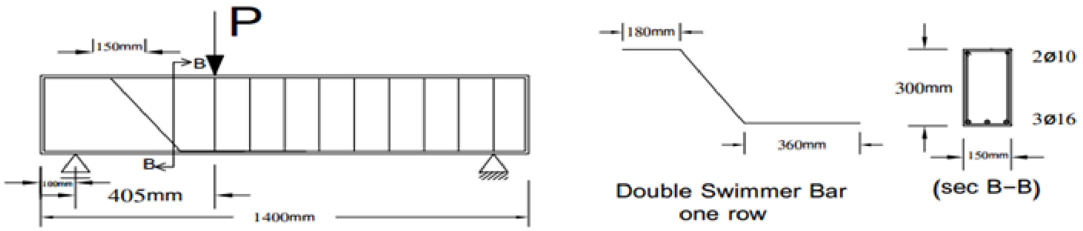

Fig. 4: Cross Sec in beam with double swimmer bars in the cross-section

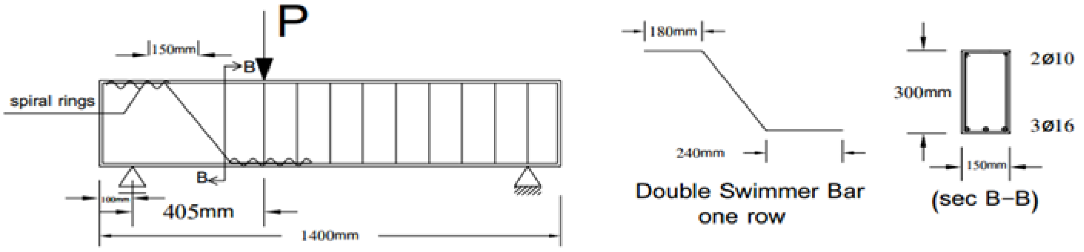

Fig. 5: Cross Sec in beam with double swimmer bars –spiral type of tying.

Table 1: Test specimen's details

Group	Beam No	F_{cu} N/mm^2	Shear Reinforcement				Type of splice
			Stirrups	swimmer bars			
				Number of bars	Position	Lap splice length	
Control beams	BC1	25	1Ø 8@100mm	-	-	-	-
	BC2	25	1Ø 8@100mm	-	-	-	-
A	A1	25	-	1Ø10 @150mm	At mid of cross section	100 mm	Spliced
	A2	25	-	1Ø16 @150mm		160 mm	Spliced
	A3	25	-	1Ø12 @150mm		120 mm	Spliced
B	B1	25	-	1Ø12@150mm		120 mm	Welded
	B2	25	-	1Ø12 @150mm		120 mm	Bolted
C	C1	40	-	1Ø12@150mm		120 mm	Spliced
	C2	60	-	1Ø12@150mm		120 mm	Spliced
	C3	80	-	1Ø12@150mm		120 mm	Spliced
D	D1	25	-	2Ø12		120 mm	S.S.
	D2	25	-	2Ø12@mid shear span.	At cross section sides	240 mm	S.S.
	D3	25	-	2Ø12@mid shear span.		360 mm	Spliced
	D4	25	-	2Ø12@mid shear span.		480 mm	Spliced
	D5	25	-	2Ø12@mid shear span.		600 mm	Spliced

2.2 Materials and Mixes

Concrete mixes were designed to produce cubic compressive strength of 25, 40, 60 and 80 MPa after 28 days. Ordinary Portland cement with a grade of 42.5 N was used for all specimens. Crushed gravel has 20 mm maximum nominal size and specific gravity 2.53 was used as coarse aggregate in normal strength concrete. Crushed basalt with M.N.S = 20 mm and specific gravity = 2.78 for high strength concrete. Local natural sand has specific gravity 2.5 and fineness Modulus 2.4 was used. Silica fume with specific gravity = 2.1 was used with a maximum dose equals 20 % of cement as a replacement was used to enhance the high strength concrete properties. An admixture type G was used to improve the workability of the mix. Deformed bars having 400 N/mm^2 proof strength with diameters 10, 12, and 16 mm were used as main reinforcement and swimmer bars. The stirrups used were made of 8 mm diameter smooth bars of 330 N/mm^2 yield strength. The properties of all used materials are agreed with ECP [203] requirements, [6]. The quantities of materials and the cube compressive strengths for these mixes are illustrated in Table 2.

Table 2: Mixing proportions for the designed mix mixes.

Target strength N/mm^2	Cement Kg/m^3	Sand Kg/m^3	Coarse Aggregate Kg/m^3	Water $Liter/m^3$	Silica fume kg/m^3	Super plasticizer kg/m^3	F_{cu} N/mm^2	Slump value (mm)
25	350	570.0	1140	210.0	0	0	28.6	80
40	500	535.0	1070	200.0	0	0	45.3	80
60	475	576.5	1153	164.0	71.25	8.20	67.2	75
80	475	596.5	1193	125.5	95.00	14.25	83.4	75

2.3 Test procedure

Two - third point loads were applied to the tested beams, with shear span to depth ratio equal to 1.5 as shown in Fig. 6. Vertical deflections at third span were measured by LVDTs. At each load stage, the deflection readings are recorded, the cracks are marked on the surface of, and cracks width was monitored at each load increment. All shear and flexure reinforcement strains and the ultimate load were also measured.

Fig. 6. Test setup.

2.4 Test results and discussion

2.4.1 Crack pattern and mode of failure

In control beam BC, diagonal shear cracks observed at a load of 100 KN. These cracks were extended and widened as the load increased. The cracks emigrated towards the point of loading and increased to the support. More flexure cracks appeared at a load of 160 KN along the loaded span. Fig. 7 shows the crack pattern and mode of failure of control beam and other tested beams. The behavior of other normal strength beams with single swimmer bar system was similar to the mode of failure of control beam, but there multi diagonal cracks through the shear span. In high strength concrete beams flexure cracks and diagonal shear cracks were appeared and the mode of failure was converted to shear –flexure failure. Using of the swimmer bar system decreases the crack width and length compared with using of stirrups system. Bolted tying beam improves the property of crack width more than other types of tying but, it is considered much cost. The higher concrete strength beams reduce the values of crack width to lower limits. In beams with double swimmer bars, shear cracks appeared, and these cracks were inclined with approximately angle 45°, then flexure cracks appeared along the beam length. After that it was noticed horizontal cracks in the splice region before failure.

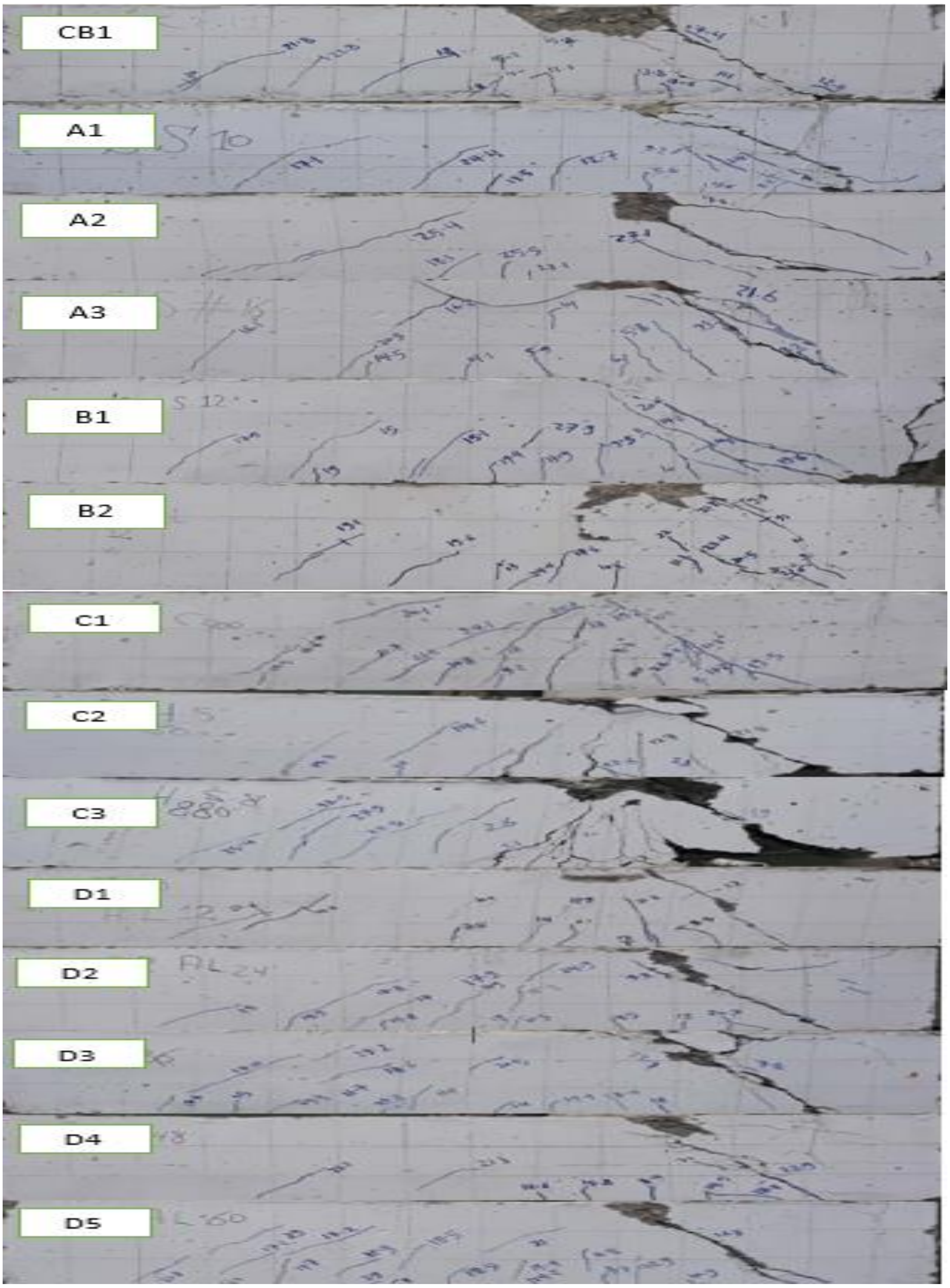

Fig. 7: Cracking pattern and mode of failure of tested beams.

2.4.2 Load – deflection

To assure the objectives of this paper, beams reinforced with swimmer bars must be compared to beams with traditional stirrups. [Figure- 8. a and b] show the curves of load deflection for normal and high strength concrete beams, respectively. It is noticed that spliced tying beam reduces the maximum deflection value to 15% compared to control beam. Also, welded tying beam improves the maximum deflection value at failure by about 40.13% with respect to control beam. The maximum deflection value of the bolted tying beam decreased at failure stage by about 30.5% compared with maximum deflection of control beam. It is clear that using swimmer bars system gives values of less deflection at a higher rate in the case of normal concrete than that of high strength concrete and that is agreed with [3]. From curves, we notice the behaviour of spliced tying beam is similar to the behaviour of beam with traditional stirrups.

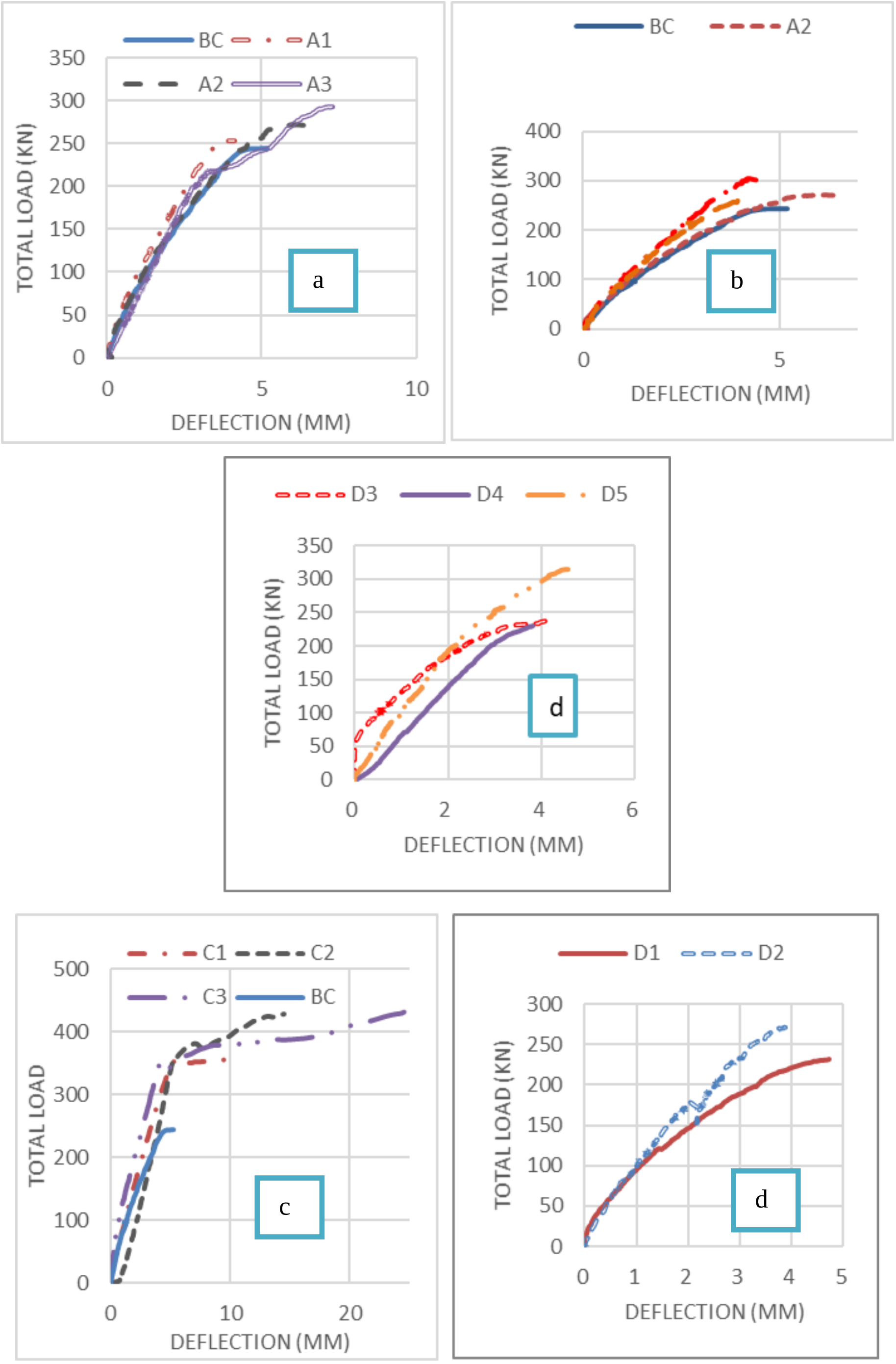

Fig. 8: Load-deflection relationships for tested beams.

2.4.3. Cracking and Ultimate loads

Table No. (3) shows the ultimate loads values for all tested beams, and it is observed the efficiency of using swimmer bars over than stirrups in RC beams. Spliced tying beam increases the ultimate load about 11.88% in comparison with control beam. It is obviously observed improvement in ultimate load capacity by 23.36% in the case of using welded tying beam. Innately, using high strength beams leads to a massive improvement in ultimate load capacity for example, beam with compressive strength 80 N/mm^2 increases the ultimate load up to 80.33% with respect to control beam.

2.4.4. Ultimate shear load and Ultimate Shear stress

The importance of ultimate shear stress appears clearly in the shear behaviour, especially in high strength concrete [3]. The ultimate shear load and stress of the tested beams are calculated and presented in Table 3. It was noticed that the ultimate shear load of welded typing beam is increased by about 23.36 % compared to beam with stirrups. Shear stress, increased by about 61.33% of the normal strength spliced tying beam compared to beam with strength 80N/mm^2, and so on for other beams.

Table:3. Values of cracking, ultimate loads, and ultimate shear stress of the tested beams.

Beam No	P_{cr} kN	P_u kN	Δ	Q_u kN	q_u N/mm^2	$Δ_s$
BC	83.0	244.0	0.00	163.48	3.63	0.00
A1	88.0	238.0	-2.46	159.46	3.54	-2.46
A2	97.0	273.0	11.88	182.91	4.06	11.88
A3	103.0	293.0	20.08	196.31	4.36	20.08
B1	91.0	301.0	11.88	201.67	4.48	11.88
B2	95.0	271.5	23.36	181.91	4.04	23.36
C1	80.1	350.0	43.44	234.5	5.21	43.44
C2	147.0	429.0	75.82	287.43	6.39	75.82
C3	152.0	440.0	80.33	294.8	6.55	80.33
D1	61.0	232.0	-4.92	155.44	3.45	-4.92
D2	85.0	272.0	11.48	182.24	4.05	11.48
D3	84.0	244.0	0.00	163.48	3.63	0.00
D4	83.5	276.0	13.11	184.92	4.11	13.11
D5	91.0	314.0	28.7	210.38	4.68	28.7

Where:
P_{cr}: Cracking load
$P_{u:}$ Ultimate load
P_{cr}: Shear load
Δ: Percentage of increasing of ultimate loads of tested beam compared with control beam.
$Δ_s$: Percentage of increasing of shear stress of tested beam compared with control beam.

2.4.5. Maximum Measured Strains

Values of steel strains were recorded as presented in Table 4. It is clear from this table that using swimmer bars with Z shape as shear reinforcement decreases flexure strain values, that in turn leads to improvements in flexure strength at same load. The values of main steel strain indicated No. 1 in beams with swimmer bars are less than its value for control beam BC. Strains No.1 and No.2 are installed at the mid of inclined length of swimmer bars, however the values maximum strain values differ along the length of swimmer bars. So, the values of shear steel stain vary from position to other according to the type of tying. The values of shear steel strains show that swimmer bars yielded but that did not occur in beam reinforced with traditional stirrups and that in turn indicate that using of swimmer bars with z shape increase the shear capacity for beams. It can be noticed that the recorded maximum concrete compressive strain for control beam was less than the crushing strain of 0.003 specified by both ECP 203, [7],and ACI 318, [6]. But, for beams with swimmer bars was more crushing strain value. Beam with bolted type of tying did not reach to crushing value of concrete.

Table 4: Values of strains, ductility, and toughness for tested beams.

Beam No.	Steel strain1	Steel strain2	Steel strain3	Concrete strain4	Δ_{cr} mm	Δ_{max} mm	Ductility μD	Toughness KN.mm
BC	2774	534	980	-1754	1.035	3.675	3.55	817.093
A1	2451	1233	956	-3130.63	0.86	2.81	3.27	720
A2	2904	2521	1382	-3390	1.47	4.48	3.05	1174.83
A3	2999	2896	1498	-3427	1.62	5.34	3.30	1423.88
B1	2563	2150	1342	-3895	0.891	3.61	4.05	790.19
B2	2267	1748	2164	-2288	0.936	3.517	3.76	792
C1	80.1	350	43.44	234.5	0.99	4.516	4.57	2608.26
C2	147	429	75.82	287.43	1.16	8.3	7.16	4435.1
C3	152	440	80.33	294.8	1.375	14.61	10.62	8900.18
D1	2400	2467	-	-2163	0.341	3.51	10.29	718
D2	1926	1997	-	-4267	0.84	3.16	3.76	667
D3	1745	1880	-	-3556	.77	3.29	4.27	755
D4	2130	2340	-	-4700	.83	3.44	4.14	784
D5	2413	2467	-	-2163	0.9	3.72	4.13	805

2.4.6. Ductility and toughness

Ductility of reinforced concrete beams can be measured based on structural characteristics such as: third-span deflection, curvature. The displacement ductility (μD) considered here was measured as the ratio between maximum deflection (Δ_{max}) (corresponding to 90% of the maximum recorded load) and the deflection corresponding to cracking load (Δ_{cr}). Moreover, toughness up to failure is represented by the area underneath the load-deflection curve and the values shown in Table 4. Single swimmer bars improve stiffness and modulus of elasticity by decreasing crack width and deflection values for tested. This could be attributed to the increase in strength of beams.

3. Conclusions

Based on the experimental program results, the following conclusions can be drawn:

- Using of single swimmer bars system with z shape increases the shear resistance and reduces the deflection values with respect to using of traditional stirrups system in normal and high strength concrete beams.
- Shear performance of single swimmer bar system improves in higher strength concrete beams over normal strength beams, diagonal shear failure occurred in normal strength beam, however using of higher strength concrete beams converted the failure to shear-flexure failure.
- Using of high strength concrete increases modulus of elasticity of concrete and toughness that, in turn led to increase in shear resistance capacity and improves deflection values.
- In high strength beams, the cracks propagate in a slower rate than in normal strength beams, the failure in HSB is more explosive and sudden than NSC and the surface of failure in HSC is sleek but the surface of failure in NSC is rough that in turn, ensures the fact that high strength concrete is a more brittle more material than normal strength concrete.

- Using of clips in bolted type of tying is very effective to decrease the crack width property by about 95% in comparison with spliced type of tying but was cost.
- Using single swimmer bars is better than double swimmer bars in beams crowded with shear reinforcement, where single swimmer bars increase the ultimate load capacity by about 12% compared with double swimmer bars.

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