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ENHANCING THE ROLE OF BENT-UP BARS IN SHEAR BEYOND THE CODE REQUIREMENTS BY USING PLANE-CRACK INTERCEPTOR-CROSS DIAGONAL FORM

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ABSTRACT: Swimmer bars are a new type of shears reinforcement; these are small inclined bars, with their both ends bent horizontally for a short distance; welded to both top and bottom longitudinal steel reinforcement, or welded to hanger bars when compression reinforcement is absent. Regardless of the number of swimmer bars used in each inclined plane, the system forms with the added horizontal bars plane-crack interceptor instead of bars-crack interceptors. The results obtained from the testing of beams provided with this system, and the effectiveness of this new system is discussed. The width of the shear cracks was much smaller than the width of the shear cracks in beams reinforced by the traditional stirrup's system. The equivalent steel amount used to replace the conventional steel for the same purposes showed the superior performance of this system over the conventional system; especially when a smaller amount of reinforcement was used by the new system preventing shear failure that took place for the beams which are reinforced with the conventional shear reinforcement. The system used to replace the congestion of stirrups when high shears forces exist.

Keywords: Swimmer bars, Shear, Crack, Stirrup

1. INTRODUCTION

Beams carry loads primarily by internal moments and shears. In the design of a reinforced concrete member, flexure is usually considered first, leading to the size of the section and the arrangement of reinforcement to provide the necessary resistance for moments.

Limits are placed on the amounts of flexural reinforcement to ensure a ductile type of failure; beams are then designed for shear. Since shear failure is frequently sudden with little or no advanced warning, the design for shear must ensure that the shear strength for every member in the structure exceeds the flexural strength.

The shear failure mechanism varies depending upon the cross-sectional dimensions, the geometry, the types of loading, and the properties of the member. Reinforced concrete (RC) beams are important structural elements that transmit the loads from slabs to columns.

Beams must have an adequate safety margin against bending and shear forces so that it will perform effectively during its service life. At the ultimate limit state, the combined effects of bending and shear may exceed the resistance capacity of the beam causing tensile cracks. The shear failure is difficult to predict accurately despite extensive experimental research.

The failure of reinforced concrete beams by shear is distinctly different from their failure by bending, which may be unsafe. The shear failure of beams is usually sudden and without sufficient warning. The diagonal cracks that develop are considerably wider than the flexural cracks.

2. RESEARCH SIGNIFICANCE

In general, the purpose of this research is to investigate the behavior of rectangular beams in the shear, using special forms of "Swimmer bars" as cross diagonal form

2.1 Scope of the Study

The scope of the study is limited by the:

a) The study based on an experimental investigation of two rectangular reinforced concrete beams.

b) All specimens were of the same size and reinforced with the same amount of longitudinal steel.

c) The beams were tested to fail due to two point loads by the shear given the ratio of a shear span to an effective depth of 2.5.

d) The concrete compressive strength of the specimens on the testing day was in the range of 25 N/mm^2 to 37 N/mm^2.

e) The variables in these specimens are the shear reinforcement systems

2.2 Experimental Investigation

Experimental works were carried out at the

Structure Laboratory in the University of Jordan. Different types of shear reinforcement were used.

In general, the objective of this study is to explore the shear structural behaviors in beams. In this investigation, all of the tested beams were designed to fail by the shear, thus adequate amount of tension and compression reinforcements were provided to give sufficient bending moment strength in these beams

3. MODEL OF SHEAR REINFORCEMENT SYSTEM

To achieve the objectives of this study, one stage of experimental work was done; this stage has different types of shear reinforcement. These beams were designed and prepared for laboratory testing to serve the main purpose of this study. The dimensions of these tested beams are 200 mm in width x 250 mm in height x 2000 mm in length. All of these beams were the same grade of concrete.

3.1 Beams Detail

Figures 1 –2 shows design detailing of 'B1-5, ' B6-5

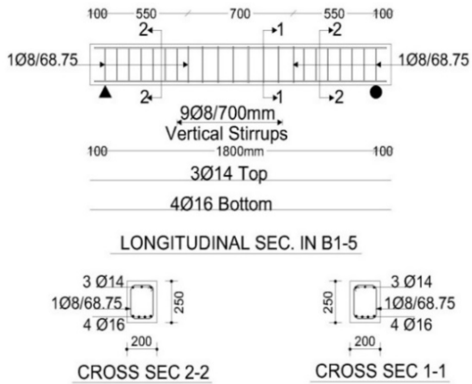

Fig.1 Details of Beam 'B1-5

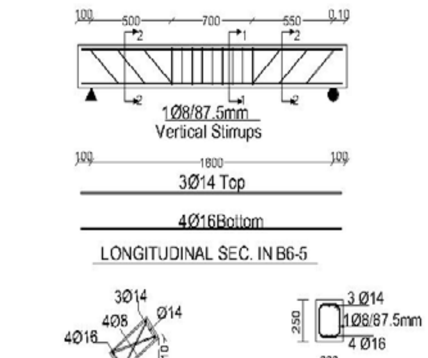

Fig.2 Details of Beam 'B6-5

3.2 Casting of Specimens

Each specimen was marked carefully to ensure that each of the specimens would satisfy the strength specification. Several steps were carried out such as reinforcement installation, mixing, concreting and curing. Installation of steel reinforcement was carried out in the early stage before concreting works.

Shear and nominal links were fastened together with the top and bottom reinforcement.

To ease the fastening works, wire and welding were used. The molds were first cleaned of any dirt and then a thin layer of oil was applied on its surface before placed a steel cage.

Stable temporary's woods supports were provided to hold the loaded end of the bars in place, while the other end was placed in the base of the mold. These are referred to as hanging concepts. The spacers were withdrawn slowly during the compaction process.

A forklift truck was used to carry the fresh concrete from the Rotating mixer to formwork. The concrete was placed in the formwork steel mold manually in two layers.

The concrete was compacted by an internal vibrator of (25) mm diameter. After leveling and smoothing the surface, the specimens were covered with polythene sheeting for at least three days.

After the concrete hardens or after 3 days, the molds were stripped.

Control specimens comprising six 150 mm cubs, were also prepared from the same batch of concrete. They were all air-cured in the same manner as the test specimens.

3.3 Compression Tests: Cube Test

The compressive strength is the most important property of the concrete. To determine the compressive strength of the concrete, the compressive test was carried out for each concrete mix proportion.

The fresh concrete was cast in cast-iron cubic molds with a standard size 150 mm x 150 mm x 150 mm.

The standard practice prescribed by A.S.T.M C 192-57 was filling the molds in three layers of fresh concrete and each layer was compacted by not less than 35 times of 25 mm square steel bar.

After the top surface of the cubes had been finished by means of a trowel, all of the cubes were cured by water. The curing process for cubes took only 7 days.

After the concrete hardens, the cubes were tested at 7 days and at 28 days.

The results of the testing are shown in Table 1 and Figure3.

Table 1 Compressive Strength Cubes Results.

Days	Sample	Cubes result N/mm^2	Average cubes result N/mm^2	$f'_c = 0.80$ cubes result N/mm^2
7	1	34.9		28.50
days	2	36.2	35.60	
	3	35.8		
28	4	37.1	37.0	29.60
days	5	36.7		
	6	37.2		

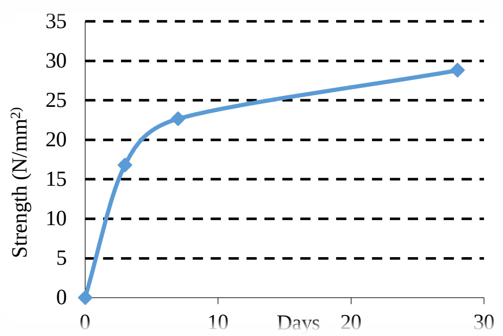

Fig.3 Compressive Strength of Concrete vs. Days

3.4 Test Procedure

Prior to testing, the surface of the specimens was painted with white emulsion so that the detection of the cracks during the test was easier and their marking become clearer.

At age 28 days reinforced concrete beams were prepared for testing. The line's position of point load, support and the middle of the beam span were marked to ease the installation of the beam in the testing frame.

In this experimental investigation, a hydraulic jack was used and the arrangement of the test setup. The test was carried out with the specimen placed horizontally in a simple loading arrangement. The beam was supported by solid round steel on their two edges as a simply supported beam.

The effective length of each beam is 1800 mm from support to support, but the total length of the beam is 2000 mm. Beams were designed to ensure that they will only fail in the shear rather than in the flexure. To ensure that shear cracks will occur near the support, two concentrated loads were applied symmetrically to the beam with **av** less than 2.5d. In this testing, **av** ≈ 550 mm, where **av** is shear span (the distance from the point of the applied load to the support), and **d** is the effective depth of the beam.

The loading jack was placed at the mid-span position above the beam. The load was applied by jacking the beam against the rig base member at a constant rate until the ultimate load capacity of the beam was reached.

A universal column section was used to transfer the load to the beam at two-point loads via transfer girder. A reasonable time interval was allowed in between 20.0 kN load increments for measuring deflections, marking cracks, measuring the shear reinforcement strains and recording the ultimate loads. Each beam took about two hours to test.

4. TEST RESULTS

The program presents the test result of each specimen, covering the specimen behavior, cracks formation, deflections, and strains of mid-section and ultimate loads. The compressive strength of the specimens was obtained by testing the concrete samples that carried out on the same day of casting. The concrete compressive strength of the tested samples ranged from 25 to 37 N/mm2.

4.1 The Behavior of Beam 'B1-5

This beam is a reference beam, which is reinforced with stirrups as shear reinforcement. Before starting the test, strain and deflection gauge was installed.

Initially, the readings of strain and deflection were taken, then the beam was loaded by 20kN, and the readings of the strains and deflection were taken again. By raising the load up to 40kN, fine cracks appeared at the bottom face between two concentrated loads. At the loading of 60kN, more cracks appeared, and the deflection was 3.7 mm. When loading reached up to 100kN and there were cracks at the shear region as shown in Figure 6.

When loading reached 140kN, cracks appeared in the shear zone on the right side, and at 200kN load, more shear cracks appeared. As the loading increased up to 240kN, more and more shear cracks appeared at both sides of this beam. At each loading, all strain and deflection readings were taken and listed in Table 2. Finally, at the load of 260kN, the beam was failed by shear force at the right side as shown in Figure 7.

4.2 Test Results of the Beam 'B1-5

The ultimate loads, deflections and strains measurements for beam 'B1-5 was listed in Table 2 Figure 4 shows the load-deflection curve and the maximum deflection of 14.54 mm at the load 260kN. Figure 5 shows load - strain data.

Table 2: Test Results for Beam 'B1-5

Load kN	Def mm	Strain x 10^{-5} mm/mm				
		9	7	5	3	1
0	0	0	0	0	0	0
20	1.92	12	9.6	4.8	2.4	-3.2
40	2.78	26.4	18.4	12.8	1.6	9.6
60	3.7	42.4	28	9.6	0	2.4
80	4.65	56	36	23.2	-1.6	-0.8
100	5.48	71.2	45.6	26.4	-3.2	-11.2
120	6.47	87.2	53.6	34.4	-2.4	-22.4
140	7.4	100.8	68	38.4	-3.2	-54.4
160	8.28	125	78.4	44.8	-31.2	-64.8
180	9.21	143.2	89.6	46.4	1.6	-68
200	10.11	164	103.2	48.8	2.4	-84
220	11.2	186.4	121.6	52	5.6	-92
240	12.51	204	133.6	67.2	8.8	-100
260	14.54	229.6	152	70.4	14.4	-104

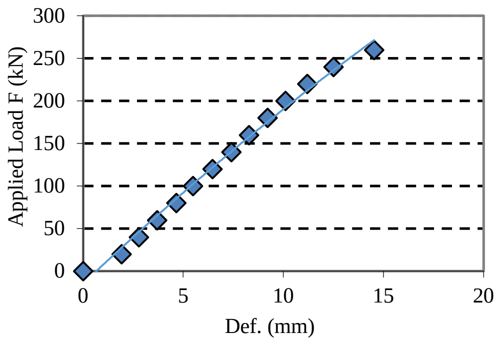

Fig.4 Load vs. Deflection for 'B1-5

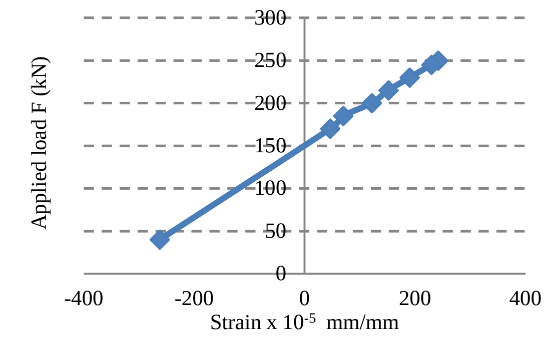

Fig.5 Strain Diagram for 'B1-5

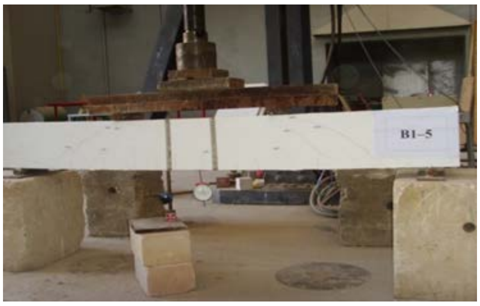

Fig.6 'B1-5 Cracks at the Load of 100kN

Fig.7 'B1-5 Shear Failure at the Load of 260kN

4.3 Behavior of Beam 'B6-5

This beam was reinforced with two swimmer bars of ø 8 mm forming a rectangle shape with 2 ø8 as a cross. Initially, 20kN load was applied, but no cracks were observed. Flexural hair cracks appeared at the load of 60kN. When the load reached up to 120kN no shear cracks appeared.

While when the applied load reached 140kN, shear cracks appeared with a small length and width at the right side of the beam as shown in Figure 10. Then the load was increased up to 200kN, more shear cracks appeared at both sides of the beam.

The deflection at this point was about 6.73 mm. At a loading of 240kN, the width and the length of the shear cracks were increased, and the deflection at this point was about 8.18 mm.

Finally, at the load of 280kN, the beam was failed by shear with shear cracks making an angle of 30º as shown in Figure 11.

4.4 Test Results of the Beam 'B6-5

Table 3 shows the loads, deflections and strain of this beam. The maximum deflection was measured to be 6.73mm at the load of 200kN and the maximum strain was measured to be 0.00158. Figure 8 shows shear loads - deflection data and Fig. 9 shows the strain cross-section data at a specific load.

Table 3 Test Results for the Beam 'B6-5'

Load F (kN)	Def. (mm)	Strain x 10-5 mm/mm				
		9	7	5	3	1
0	0	0	0	0	0	0
20	0.67	14.4	10.4	4.8	-3.2	-0.8
40	1.3	31.2	19.2	11.2	3.2	-4
60	2.05	44	28.8	20.8	8	-11.2
80	2.71	57.6	38.4	15.2	-13.6	-25.6
100	3.37	70.4	46.4	16	2.4	-24
120	4	90.4	59.2	22.4	-9.6	-25.6
140	4.66	100	67.2	28	-11.2	-30.4
160	5.27	119	77.6	32.8	-13.6	-32
180	5.95	130	87.2	38.4	-5.6	-36
200	6.73	158	103.2	46.4	10.4	-41.6
220	7.38	166	112.8	51.2	-13.6	-44.8
240	8.18	186	124	56.8	-11.2	-49.6
260	9.1	204	136.8	62.4	2.4	-53.6
280	10.75	220	152.8	71.2	24	-53.6

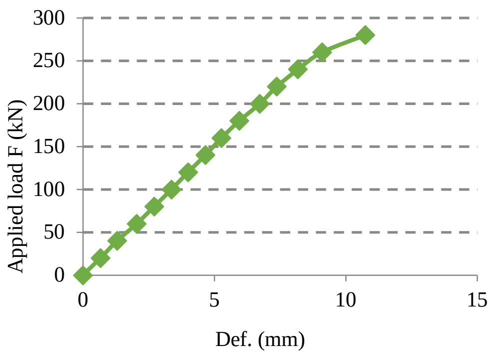

Fig.8 Load vs. Deflection for 'B6-5'

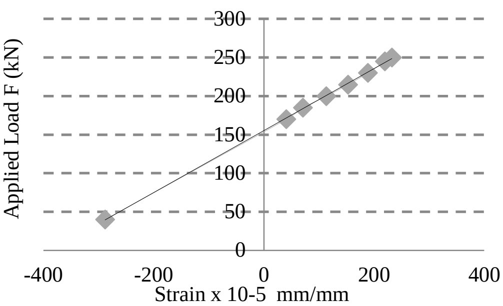

Fig.9 Load vs. Strain for 'B6-5'

Fig.10 'B6-5 Shear Cracks at the Load of 140 kN

Fig.11 'B6-5 Shear Failure at the Load of 280 kN

5. ANALYSIS

The results from two beams of reinforced concrete beams were analyzed and presented. The performance of each specimen in terms of it is behavior, crack formation; shear resistance, deflection, strain, and cost of the shear reinforcement were discussed.

It was found that the use of swimmer bars as a shear reinforcement performed better than the use of conventional shear reinforcements such as stirrups. Although variation among different casts in the same testing was unavoidable, they were relatively small.

5.1 Cracks

It was observed that beams showed several cracks once the stresses exceeded the cracking moment, and by increasing the applied load, the length and width of these cracks were increased.

5.1.1 Cracks Pattern of Beams

It was observed that initial flexural cracks appeared in the bottom face of these beams between the two applied loads. By increasing the loads, diagonal cracks were developed in the shear region at approximately 29° angle with respect to the longitudinal axis of these beams.

The length and width of these shear cracks increased gradually until shear failure took place.

The width of shear cracks of the beam 'B6-5', were relatively smaller than the width of the shear cracks of the beam 'B1-5 as shown in Figure 12 and Figure 13 In beams 'B6-5', the width of the shear cracks were relatively smaller than the width of the shear cracks of the beam 'B1-5, which means that by using swimmer bars as shear reinforcement reduce the control cracks.

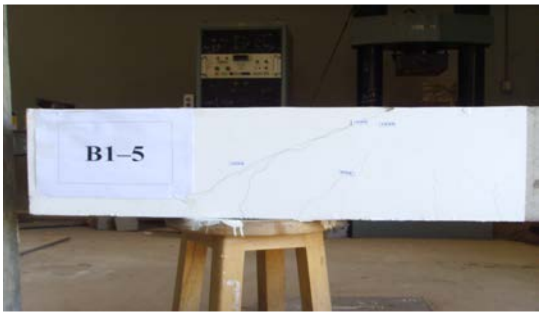

Fig.12 Cracks Pattern of Beam 'B1-5

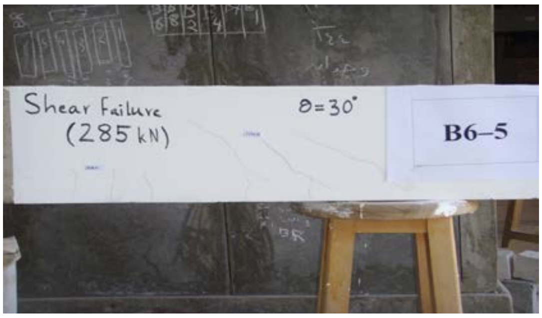

Fig.13 Cracks Pattern of Beam 'B6-5

5.2 Shear Resistance

All beams were tested by one - third concentrated load as shown in previous. Loads used in this study are listed in tables in 2 and 3. Each of these beams failed at its ultimate load.

5.2.1 Shear Resistance of Beams B1-5 and B6-5

The differences in shear resistance of these beams between experimental results and the theoretical values were listed in Table 4.

The beam 'B1-5' which is used as a reference beam failed at 280kN total applied load, which is 15% higher in value than the theoretical shear value. Beam 'B6-5 failed at 280kN which is 3% higher than the theoretical value.

Table 4 The Differences in Shear Resistance between Theory and Test Results

Beam	Shear Resistance Theory (kN)	Shear Resistance Results (kN)	% Test / Theory	Note
B1-5	91.44	104	115%	-
B6-5	135	140	103%	-

5.3 Deflection

Different values of deflections were showed in this study

5.3.1 Deflection in Beams B1-5 and B6-5

Table 5 shows the deflection of the Beam 'B1-5 and the Beam B6-5 at given loads. The deflection of the Beam B1-5 at the load of 100kN is 5.48 mm and the deflection at the load of 160kN is 8.28 mm and the maximum deflection at the load of 240kN is 12.51 mm. Beam 'B6-5 deflected at the load of 100 kN by 3.37 mm and at the load of 160kN by 5.27 mm, and the maximum deflection at the load of 240kN is 8.18 (mm) which. The summary of the deflections of the beams were listed in Table 5.

Table 5 Deflection of the Beams B1-5&B6-5

Load	B1-5	B6-5
kN	Deflection (mm)	
100	5.48	3.37
160	8.28	5.27
240	12.51	8.18

5.4 Strain

A strain is the change in length of the cross-section of the beam in the middle. The beams divided into nine spacing from the centerline of the beam to the top face.

5.4.1 Strains for Beams B1-5 and B6-5

The maximum strain of the beam 'B1-5' is 0.00204 at load of 240kN but the maximum strain of the beam 'B6-5 at the load of 240kN is 0.00186 which is smaller than the strain in the beam 'B1-5. These data are shown in Table 6. In summary, the beam which used a swimmer bar system B6-5 exhibits higher values of stiffness in comparison with the beam 'B1-5 which used stirrups.

Table 6 Strains in Beams.

Load kN	B1-5	B6-5
	strains	
100	0.000712	0.00704
160	0.00125	0.00119
240	0.00204	0.00186

6. CONCLUSIONS

This study presented a new type of shear reinforcement called the swimmer bars. This type of shear reinforcement can be formed in many shapes such as a single swimmer and rectangle with a cross similar to the types of shear reinforcement. The following are the major highlights of this study:

1. The use of a swimmer bars system improved the shear capacity.
2. The use of swimmer bars system reduced the beam deflection.
3. The width and length of the cracks in beams with a swimmer bar system under loads are relatively smaller than the width and length of the cracks in beams with traditional stirrups.
4. The cost of reinforced concrete beams reinforced with a swimmer bar system is less than the cost of reinforced concrete beams reinforced with traditional stirrups.

7. ACKNOWLEDGMENTS

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