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Full Length Research Paper

Shear failure investigation of reinforced concrete beams with swimmer bars

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Shear failure of reinforced concrete beams is usually sudden, occur without sufficient advanced warning. This type of shear failure is considered to be high risk type of failure. The cost and safety of shear reinforcement in reinforced concrete beams led to the study of other alternatives. Designers try to avoid the shear mode of failure when designing reinforced concrete beam due to the sudden nature of shear failure. Swimmer bar system is a new type of shear reinforcement. It is a small inclined bar, with its both ends bent horizontally for a short distance and welded to both top and bottom flexural steel reinforcement. Regardless of the number of swimmer bars used in each inclined plane, the swimmer bars form plane-crack interceptor system instead of bar-crack interceptor system when stirrups are used. Test results of reinforced concrete beams will be presented. The effectiveness of the new swimmer bar system as related to the old stirrup system will be discussed. Beam deformation is also measured in the laboratory.

Key words: Swimmer bar, deflection, shear, crack, stirrup.

INTRODUCTION

Beams are common members in reinforced concrete structures. Several types of beams can be used in the same structure. Reinforced concrete beams can also take unlimited number of different shapes. 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 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.

Shear failures in beams are caused by the diagonal cracks near the support providing no shear reinforcement. Beams fail immediately upon formation of critical cracks in the high-shear region near the beam supports. Whenever the value of actual shear stress exceeds the permissible shear stress of the concrete used, the shear reinforcement must be provided. The purpose of shear reinforcement is to prevent failure in shear, and to increase beam ductility and subsequently the likelihood of sudden failure will be reduced.

Normally, the inclined shear cracks start at the middle height of the beam near support at approximately 45° and extend toward the compression zone. Any form of effectively anchored reinforcement that intersects these diagonal cracks will be able to resist the shear forces to a certain extent. In practice, shear reinforcement is provided in three forms; stirrups, inclined bent-up bars and combination system of stirrups and bent-up bars.

In building construction, stirrups are most commonly used as shear reinforcement, for their simplicity in fabrication and installation. Normally, spacing between stirrups is reduced to resist high shear stress. Congestion near the support of RC beams due to the presence of the closely spaced stirrups increase the cost and time required for installation.

The use of bent-up bars along with stirrups had been used in the past. In case where all the tensile reinforcement is not needed to resist bending moment, some of the tensile bars where bent-up in the region of high shear to form the inclined legs of shear reinforcement. For example, beams provided with 4 bars of main tensile reinforcement, 2 bars may be bent diagonally in shear region and used as shear reinforcement, while the other 2 bars will be left straight up to the support. The use of bent-up bars is not preferred nowadays. Due to difficulties in construction, bent-up bars are rarely used. In beams with small number of bars provided, the bent-up bar system is not suitable due to insufficient amount of straight bars left to be extended to the support as required by the code of practice.

In this study, reinforced concrete beams were tested using new shear reinforcement swimmer bar system. Beams with traditional stirrups as shear reinforcement were also tested in order to study the effectiveness of the new swimmer bar system. The beams with traditional stirrups are used as reference beams. In this investigation, all of the beams are supposed to fail solely in shear, so adequate amount of tension reinforcement were provided to give sufficient bending moment strength. This study aims at investigating a new approach of design of shear reinforcement through the use of swimmer bars provided in the high shear region. The main advantages of this type of shear reinforcement system are: flexibility, simplicity, efficiency, and speed of construction.

Piyamahant (2002) showed that the existing reinforced concrete structures should have stirrup reinforcement equal to the minimum requirement specified the code. The theoretical analysis shows that the amount of stirrup of 0.2% is appropriate. The paper concluded that small amount of web reinforcement is sufficient to improve the shear carrying capacity. The study focused on the applicability of the superposition method that used in predicting shear carrying capacity of reinforced concrete beam with a small amount of web reinforcement at the shear span ratio of 3. Also the failure mechanisms were considered when small amount of stirrup used.

Sneed and Julio (2008) discussed the results of experimental research performed to test the hypothesis that the effective depth does not influence the shear strength of reinforced concrete flexural members that do not contain web reinforcement. The results of eight simply supported reinforced concrete beam tests without shear and skin reinforcement were investigated. The beams were designed such that the effective depth is the variable while the values of other traditionally-considered parameters proven to influence the shear strength (such as the compressive strength of concrete, longitudinal reinforcement ratio, shear span-to-depth ratio, and maximum aggregate size) were held constant. The values selected for the parameters held constant were chosen in an attempt to minimize the concrete shear strength.

Kwak et al. (2002) studied the shear strength of steel fiber-reinforced concrete beams without stirrups in an attempt to improve the shear strength of reinforced concrete beams. Other investigators have developed empirical expressions for calculating shear strength including the studies done by Sharma (1986), Narayanan and Darwish (1987), Ashour et al. (1992), and Imam et al. (1997). Ashour (2006) studied the shear strength of glass fiber reinforced beams by testing experimentally twelve beams. Al-Nasra and Wang (1994) studied the shear strength of concrete on floor slabs. Asha et al. (2012) investigated the use of swimmer bars in reinforced concrete beams. They showed an improvement in shear strength of reinforced concrete beam by using several swimmer bars.

Noor (2005) presented several results of experimental investigation on six reinforced concrete beams in which their structural behavior in shear was studied. The research conducted was about the use of additional horizontal and independent bent- up bars to increase the beam resistance against shear forces. The main objectives of that study were studying the effectiveness of adding horizontal bars on shear strength in rectangular beams, the effectiveness of shear reinforcement, and determining the optimum amount of both types of shear reinforcement to achieve a shear capacity similar to that of a normal links system. From experimental investigation of the system it was found that, the use of independent horizontal and bent-up bars as shear reinforcement were stronger than conventional shear reinforcement system.

SWIMMER BARS

A swimmer bar is a small inclined bar, with its both ends bent horizontally for a short distance, welded at the top and the bottom of the longitudinal bars. There are three major standard shapes; single swimmers, rectangular shape, and rectangular shape with cross bracings as shown in Figures 1, 2 and 3. Several additions to these standard shapes can be explored, such as addition of horizontal stiffener bars in the rectangular shapes, dividing the large rectangle horizontally into smaller rectangles. Additional swimmer bars can also be used. By adding one more swimmer bar to the rectangular

Figure 1. Single swimmer bar system.

Figure 2. Rectangular swimmer bar system.

Figure 3. Rectangular swimmer bar system with cross bracings.

shape, the large rectangular shape will be divided vertically into two rectangles. Addition of two more swimmer bars will divide the large rectangle vertically into four small rectangles. A combination of horizontal bars and additional swimmer bars may also be explored. This swimmer bar system is integrated fully with the longitudinal steel bars. Several options of the swimmer bar systems are used in order to improve the shear performance of the reinforced concrete beams, reduce the amount of cracks, reduce the width and the length of cracks and reduce overall beam deflection. Different bar diameters can be used in order to add stiffness to the steel cage, and increase shear strength of the reinforced concrete beam. Figure 4 shows the steel reinforcement cage of the beam B1-5. Figure 5 shows the steel reinforcement cage used in the beam B4-5. Figures 6 and 7 show the steel reinforcement detailing for beam B1-5, and beam B4-5 respectively.

AMERICA CONCRETE INSTITUTE (ACI) CODE PROVISION FOR SHEAR DESIGN

According to the ACI Code (2011), the design of beams for shear is to be based on the following relation:

$$V_u \leq \varnothing V_n \quad (1)$$

Where: V_u is the total shear force applied at a given section of the beam due to factored loads and $V_n = V_c + V_s$ is the nominal shear strength, equal to the sum of the contribution of the concrete and the web steel if present. Thus for vertical stirrups

$$V_u \leq \varnothing V_c + \frac{\varnothing A_v f_{yt} d}{s} \quad (2)$$

and for inclined bars

$$V_u \leq \varnothing V_c + \frac{\varnothing A_v f_{yt} d(\sin\alpha + \cos\alpha)}{s} \quad (3)$$

Where: $A_v$is the area of one stirrup, α is the angle of the stirrup with the horizontal, and S is the stirrup spacing.

The nominal shear strength contribution of the concrete (including the contributions from aggregate interlock, dowel action of the main reinforcing bars, and that of the un-cracked concrete) can be simplified as shown in Equation 4.

$$V_c = 0.17\lambda\sqrt{f'_c}\, b_w d \quad (4)$$

Where: b_w and d are the section dimensions, and for normal weight concrete, $\lambda = 1.0$. This simplified formula is permitted by the ACI code expressed in metric units.

TESTED BEAMS

This study concentrates on two basic beams; one with swimmer bars that has steel cage weight of 282 N, and the other one with stirrup that has steel cage weight of

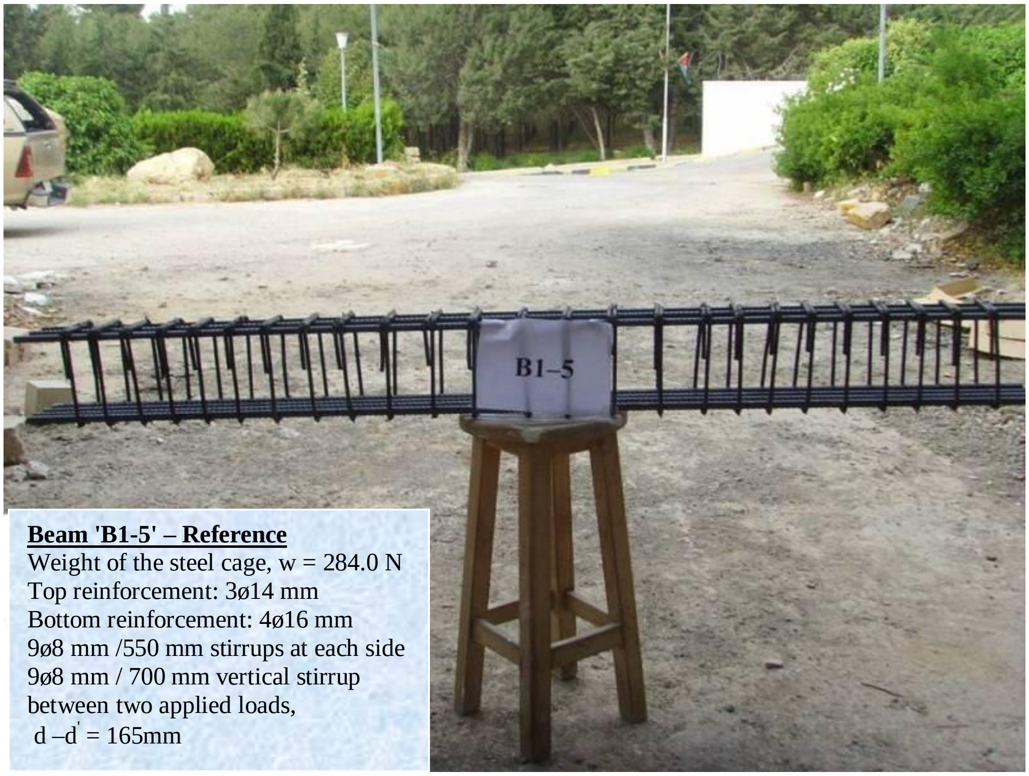

Figure 4. Steel cage for beam B1-5.

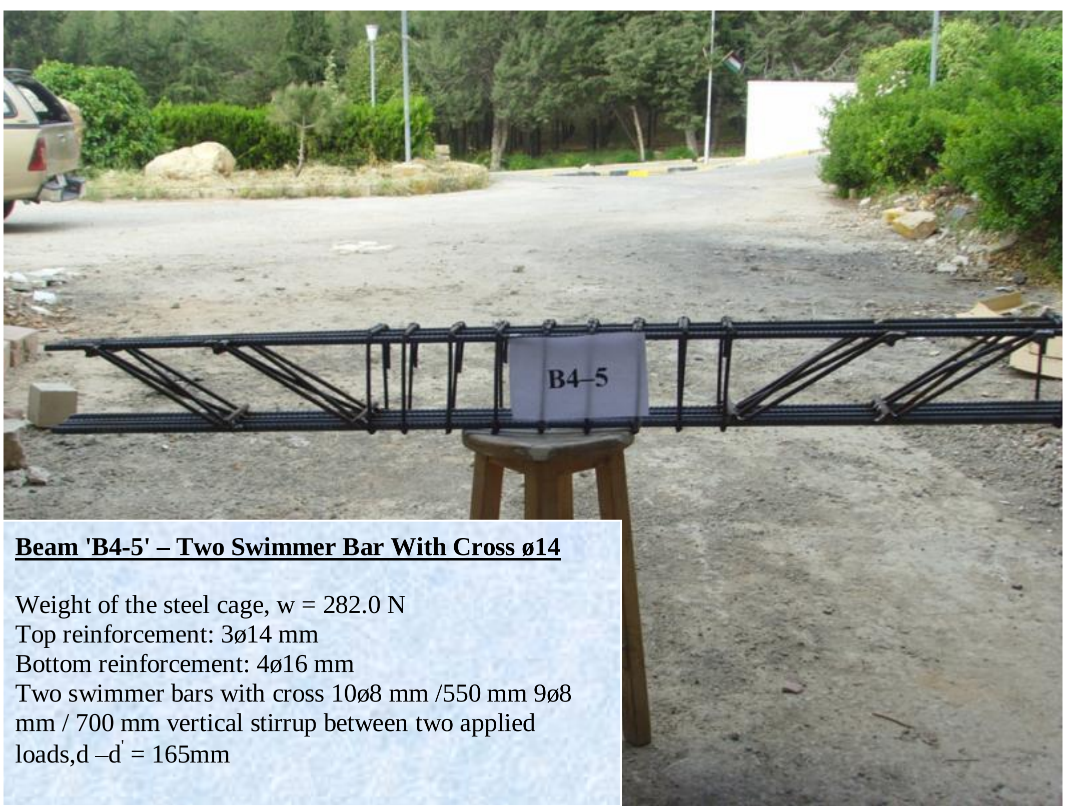

Figure 5. Steel Cage for Beam B4-5.

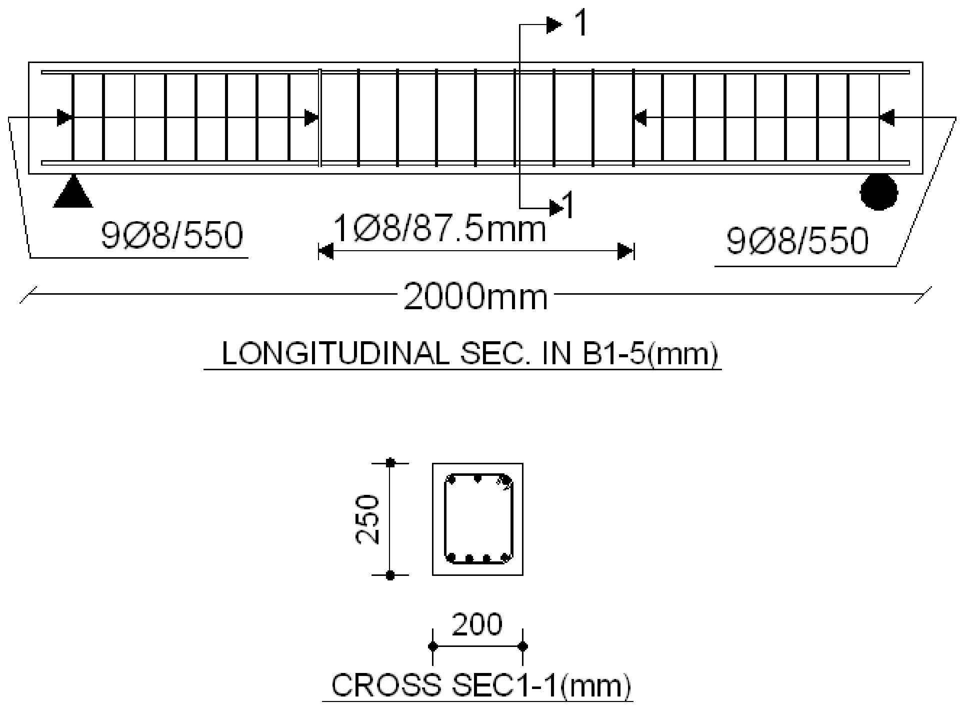

Figure 6. Steel reinforcement detailing of beam, B1-5.

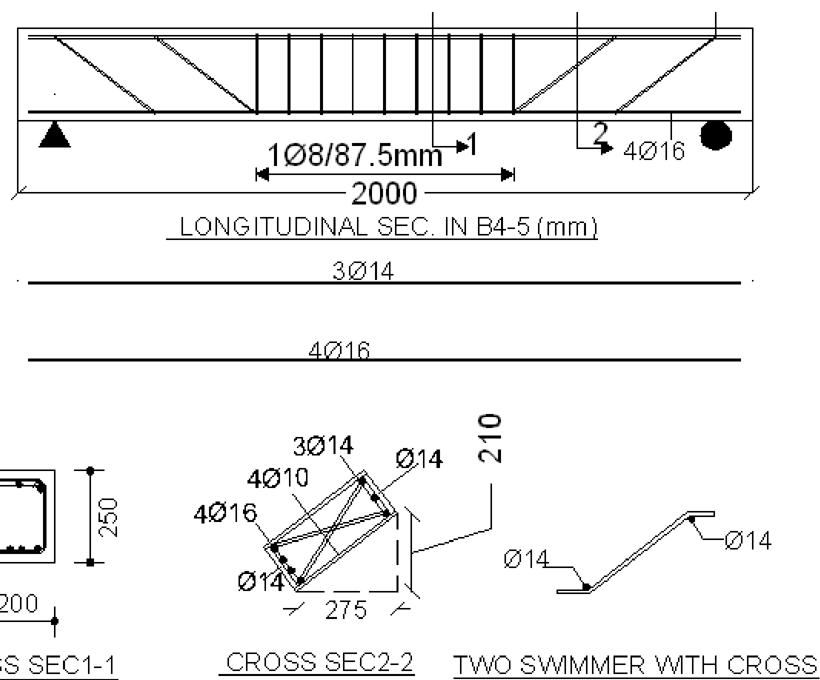

Figure 7. Steel reinforcement detailing of beam B4-5.

284 N. The two beams are of 2000 × 200 × 250 dimension. The effective length was also kept at constant value of 1800 mm. These beams were designed with 3ø14 top steel and 4ø16 bottom steel reinforcement. Table 1 shows details of the steel reinforcement for both beams used in this study. The compressive strength of

Table 1. Details of beam design used in this study.

Beam No.	Main einforcement		Shear Reinforcement	
	Bottom	**Top**	**Stirrups**	**Swimmer bar-system**
B1-5	4ø16	3ø14	8ø8 @ 550 mm	-
B4-5	4ø16	3ø14	-	Two swimmer with cross ø10 @ 275 mm

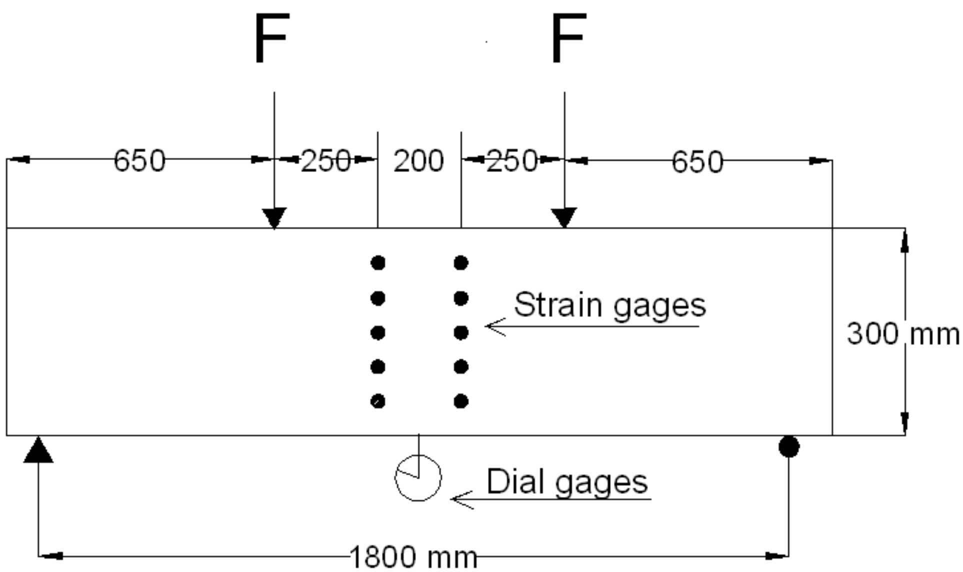

Figure 8. Experimental setup.

concrete is measured according to ASTM C 192-57. Fifteen concrete samples were prepared. The compressive strength of concrete is measured at the 28th day. The concrete compressive strength results range between 34.9 to 37.2 N/mm^2.

TEST PROCEDURE

Prior to testing, the surface of the specimens was painted with white emulsion to make it easy to detect and follow cracks in the concrete beam. At age 28 days, the reinforced concrete beams were prepared for testing. Lines locating the positions of point loads, supports and the middle of each beam were marked. Beams were placed in the testing frame that uses hydraulic jacks. The test was carried out with the specimen placed horizontally in a simple loading arrangement. The beams were supported by solid round steel on their two edges as simply supported member. The effective length of each beam was kept at 1800 mm measured from the center of each support. All the beams were designed to ensure that they will only fail in shear rather than in flexure.

To ensure that shear cracks will occur near the support, two point loads were applied symmetrically to the beam with a_v less than *2.5 d*. In this testing, $a_v \approx 550$ *mm*, where $a_v$is shear span (the distance from the point of the applied load to the support), and *d* is the effective depth of a beam.

A 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 as shown in Figure 8. A reasonable time interval was allowed in between 20.0 kN load increments for measuring deflections, marking cracks, measuring the shear reinforcement strain and recording the ultimate load. Each beam took about two hours to complete the test.

BEHAVIOR OF BEAMS UNDER LOADS

The reference beam ‘B1-5’ which is reinforced by stirrups only as shear reinforcement was loaded incrementally by 20 kN. Readings for the deflection and the strain deformation were taken at the end of each increment. Hair cracks were observed at 40 kN at the bottom face of

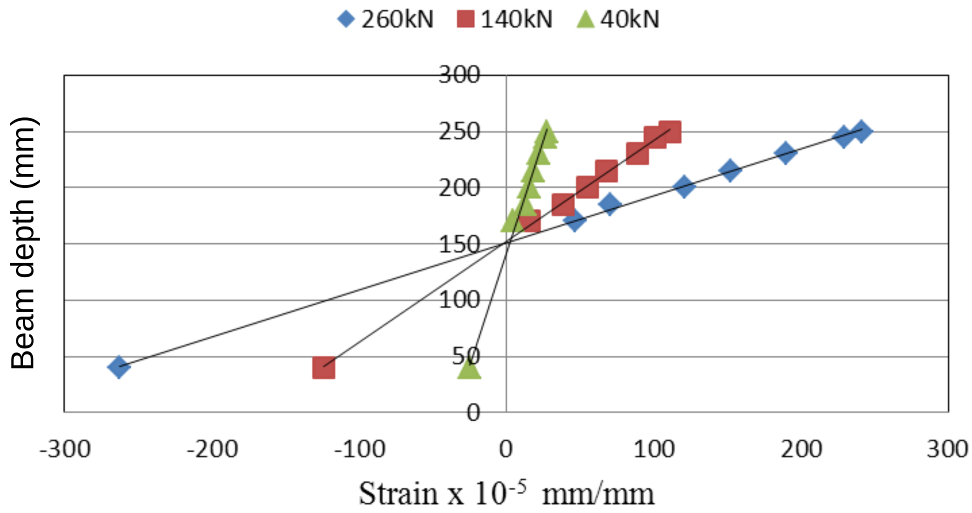

Figure 9. Strain diagram for the reference beam 'B1-5'.

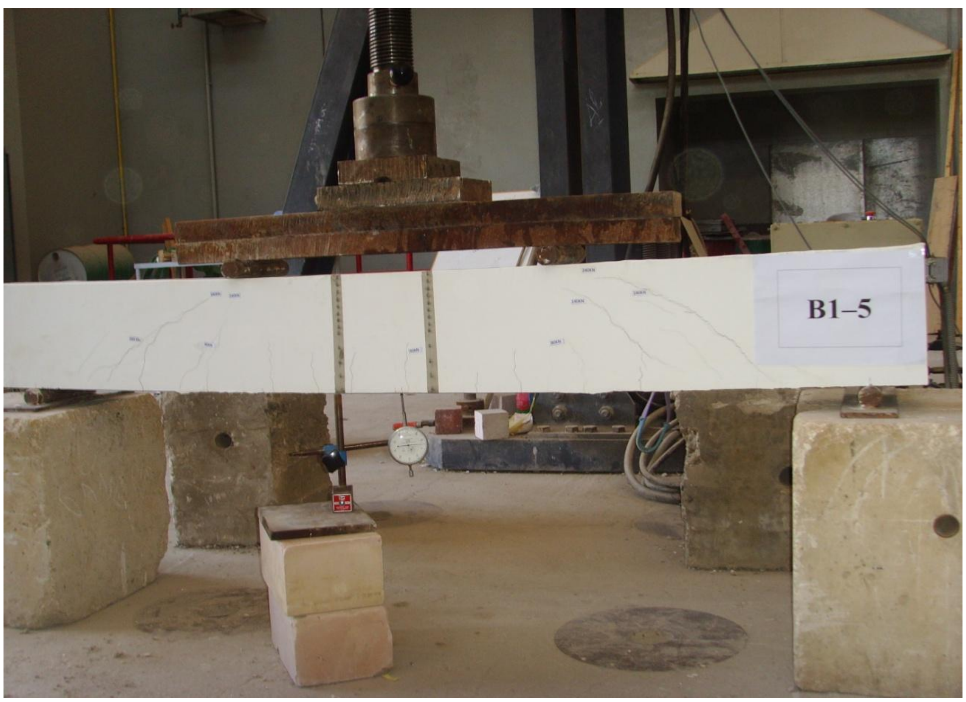

Figure 10. Mode of failure of the reference beam, B1-5.

the beam and between the two concentrated loads. More hair cracks became visible as load reached 100 kN. When load reached 140 kN, hair shear cracks became visible, which widened and increase in numbers as the load approached the ultimate failure load of 280 kN. Finally, at the load of 280 kN, the beam failed by shear at right side and the maximum deflection of the beam was measured to be 14.54 mm. Strain gauge transducers were installed on the side face and the top surface of specimen to measure the concrete strain with an accuracy of 0.002 mm as shows in Figure 8. The distance between two opposite points was measured, then the strain is calculated. Figure 9 shows the results of stain measurements plotted at different applied load of 40, 140, and 260 kN. At each applied load eight readings were taken representing the distance between the strain points. Figure 10 shows the experimental setup and the mode of failure of this beam, which is identical to the

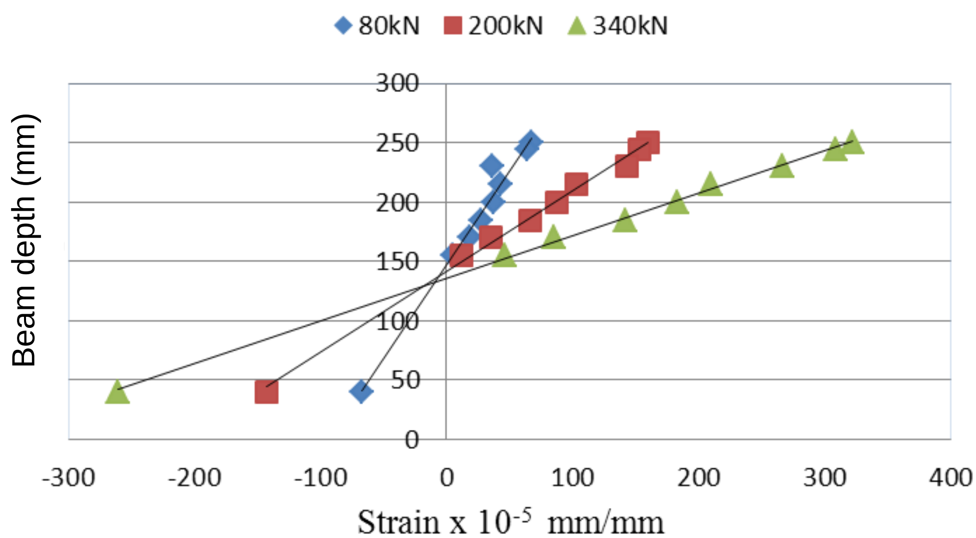

Figure 11. Strain diagram for beam with swimmer bars, B4-5.

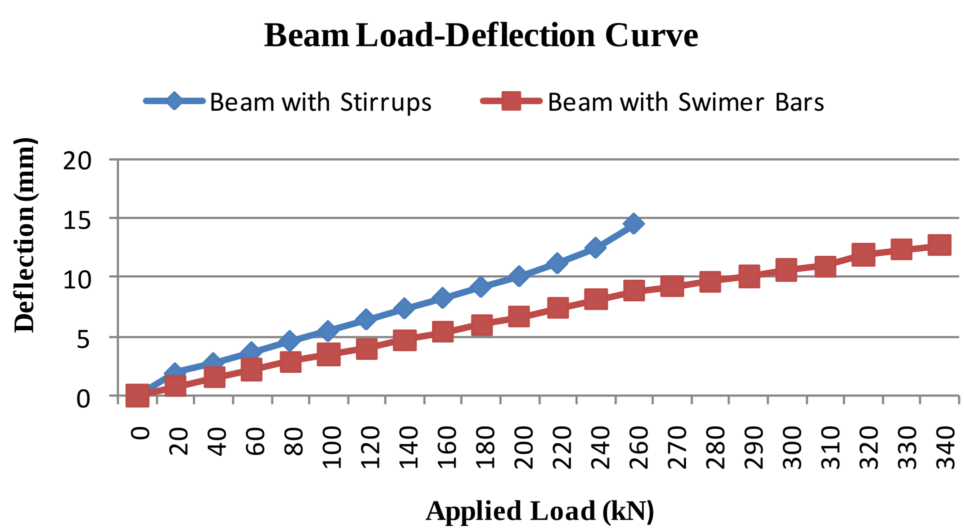

Figure 12. Load-Deflection Curves of Beams with Stirrups and with Simmer Bars.

experimental setup and the mode of failure of the beam B4-5.

The second beam 'B4-5' which was reinforced with two swimmer bars of ø10 mm diameter forming a rectangle shape with 2ø10 as cross shape, showed some hair cracks at the bottom face of the beam at a load of 60 kN. Shear cracks started to be become visible at the load of 160 kN. When the applied load reached 300 kN, the width and the length of the shear cracks were increased at the both sides of shear region of this beam. Finally, this beam failed by shear at 350 kN applied load at which the maximum deflection was measure to be 12.72 mm at the mid-span of the beam. Figure 11 shows the strain deformation readings of this beam taken at the mid-span of the beam. As can be noticed from Figure 12, the beam with swimmer bars showed higher stiffness behavior under load compared to the other beam which was reinforced with traditional stirrups as shear reinforcement. This beam showed 25% increase in strength, which is considered substantial improvement given that the same amount of steel is used for both beams. Also the deflection is reduced by a considerable amount.

CONCLUSIONS

Beams reinforced with swimmer bars systems add stiffness to the reinforced concrete beams and improves it load carrying capacity. The beam which is reinforced by swimmer bars showed 25% increase in strength compared with the traditional stirrups beam, which is considered substantial improvement given that the same amount of steel is used for both beams. Also the deflection is reduced by 14%, at the same time the number of shear cracks were less, and the widths of these cracks were slight less. The new swimmer bar system can be at a great advantage over the traditional stirrup system when used in congested reinforced concrete beams.

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