Shear Capacity Assessment of Reinforced Concrete Beams using Swimmer Bars as Shear Reinforcement

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ABSTRACT
This study is based upon the experimental investigation of shear reinforcement used in the reinforced concrete beams by using swimmer bars. In practice, vertical stirrup system is used in order to enhance the shear carrying capacity of beams. However in this research, a new type of shear reinforcement known as swimmer bars (inclined at an angle of 45°) are used in beams. Swimmer bars have more shear carrying capacity than vertical stirrups and can be placed with larger spacing. The effectiveness in terms of cost and shear carrying capacity is studied by casting beams in laboratory.
The beam consisting of swimmer bars showed much more stiffness than beam with vertical bars. Also the ultimate load carrying capacity of swimmer bars is more than the vertical stirrups. Less number of cracks is formed in beams having swimmer bars.

Keyword: *Concrete, Shear, Swimmer bars, Stiffness*

1 INTRODUCTION

Beams are structural members used to carry loads primarily by internal moments and shear. 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. Beams are then designed for shear. Since shear failure is frequently sudden with little or no advanced warning, the design must ensure adequate safety margin for every member. Since the shear cracks are in inclined direction, therefore reinforcement at certain angle must be provided in order to utilize its full capacity. Development of the construction industry demands factors that suit the current requirements of society which includes performance, safety, cost effectiveness and rapid construction.

In reinforced concrete structures, reinforcement plays a vital role as it theoretically provides all the tensile capacity to an element. 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. Beams are then designed for shear. Since shear failure is frequently sudden with little or no advanced warning, the design must ensure adequate safety margin for every member.

Shear carrying capacity of a beam element is generally enhanced by providing vertical stirrups at region of high shear. The nominal shear capacity depends upon the amount, location and spacing of shear reinforcement, provided. It is common that a designer usually meet with such a situation that to counter ultimate shear, stirrups at very less distances apart are to be provided. Such conditions aggravate further problems, including uneconomical design, steel congestion and concrete pouring during construction. Aziz & Yaseen (2013) in his research carried out the investigation of deep beams by using different stirrup system. He provided the experimental beams with horizontal, inclined and vertical stirrups and studied the effect of orientation on the orientation of shear reinforcement. According to his studies, beams with inclined stirrups showed more ultimate strength than the vertical bars system. Also the deflection was relatively less. Beams with horizontal shear reinforcement also failed at relatively less ultimate value than the vertical bar system. Thus the use of inclined shear reinforcement can increase the ultimate shear strength with less deflection.

Another important factor regarding shear failure in beams is the span to depth ratio (a/d). Shear span to depth ratio (a/d) greatly influences the behavior of shear failure in beams. Bukhari & Ahmad (2007) investigated the shear span ratio effect on the failure mechanism and observed that a decrease in a/d ratio actually increases the shear strength. He carried out the investigation by altering the values of a/d from 1 to 4 and found that an increase in a/d ratio from 2 to 3, relative flexure strength decreases however this decrease is also dependent on the tensile steel ratio. Shear span from 1.5 to 2.5 causes the failure of beam after the formation of inclined cracks. Ahmad &Gasham (2011) worked on the shear capacity equations for a/d greater than and equal to 2. He proposed an equation which reflects more realistic behavior of beam at cracking shear. Similarly Ghaffar, Javed, Rehman, Ahmad &Ilyas (2010) also worked on the shear capacity equations for beams without stirrups. He studied the equations developed by Zustty, Frant and Bazant for predicting the ultimate shear capacity of beams and it was compared with the ACI equations. According to his studies ACI equations only predict the cracking strength. Based on experiments, new equations were developed which helped in estimating both the cracking and ultimate strengths. For ensuring the shear compression failure within the stress region, a/d must be between 2 and 2.5. Zakaria, Ueda, Wu and Meng (2009) carried out an extensive research on the cracking behavior of RC beams by altering the parameters such as concrete cover, longitudinal reinforcement ratio, orientation of stirrups and the effective depth. He observed that shear crack width proportionally increase with the spacing between the shear cracks. He also concluded that at same stirrup strain, increasing the stirrup spacing causes an increase in the shear crack width.

In this research swimmer bars are used instead of traditional vertical stirrups. Swimmer bar is a type of shear reinforcement in the form of I shaped which is welded at top and bottom with main reinforcement. Swimmer bars can be single swimmer, two legged swimmer and three legged swimmer. Sayyad, patankar (2013) studied the effect of stirrup orientation in deep beams. He tested the concrete beams consisting of vertical, lateral & inclined stirrups. During the experiment he concluded that with shear to span ratio of 0.5, the beam consisting of inclined stirrups showed much more flexure strength but less ductility than beam with vertical stirrups. Also the beam with inclined stirrups resisted the shear cracks more effectively than vertical stirrups. Nasra (2013) carried out research on the use of inclined swimmer bars in order to enhance the shear capacity of beams. He replaced the vertical stirrup system with the swimmer bars by keeping all other parameters constant. According to his research, the swimmer bars showed 25 % increase in the ultimate load carrying capacity at same amount of steel. Also the deflection was reduced by 14%.

2 MATERIALS & METHODS

For the determination of shear capacity of reinforced beams, laboratory testing of 4 beams were carried out. Materials required for 4 x beams consist of cement, sand, aggregate, reinforcing bars & welding electrode. All the material was tested thus ensuring its specifications as per the ASTM.

2.1 CEMENT

Ordinary Portland cement conforming to ASTM type –I was used in the preparation of four (4) beam specimens.

2.2 FINE AGGREGATE

Sand locally available was used in the preparation of concrete. The sand was selected ensuring that it is free from any organic or deleterious substances.

2.3 COARSEAGGREGATE

Normal weight aggregate locally available was used in the preparation of concrete. Rough and irregular shape rather than round shape of aggregate was selected in order to ensure good bond between the concrete mixes. It was ensured that the aggregate does not contain any clay lumps or any undesirable substances in it.

2.4 REINFORCING STEEL

15.8 mm deformed bars, grade 60 having a total length of 2438.4 mm each was used as flexure reinforcement. 9.5 mm deformed bars, Grade 60 as shear reinforcement were also used in beam specimens.

2.5 WELDING ELECTRODE

The welding electrode for the welding purpose was obtained from a local market. The electrode class E6013 having a nominal dimension of 2.5 mm x 300 mm (each) was used for the welding purpose. The electrode had a minimum tensile strength of 427.4MPa and could be used either in horizontal or vertical direction.

2.6 DESIGN CALCULATIONS

In reinforced concrete, shear resistance is mainly provided by two main components, i.e. concrete and the shear reinforcement. For the assessment of shear capacity all four beams were provided with different amount and type of shear reinforcement. ACI 318-08 equations were used to determine the capacity of each beam.

In Beam B-1 no shear reinforcement was provided, therefore the shear resistance is provided by concrete only. The shear resisted by the concrete is determined by the ACI equation (1).

$$\boldsymbol{V_c = \left[1.9\lambda\sqrt{f'c} + 25000\,\rho_w \frac{V_u d}{M_u}\right] b.d} \qquad [1]$$

where,
λ = concrete factor
f'c = compressive strength of main reinforcement
ρw = ratio of longitudinal steel
b = width of member (in)
d = effective depth of member (in)

In beam B-2, #3 stirrups @ 76 mm c/c was provided. The shear resistance is provided by both concrete and stirrups and is given by ACI Equation (2) and (3).

$$\boldsymbol{V_c = \left[1.9\lambda\sqrt{f'c} + 25000\,\rho_w \frac{V_u d}{M_u}\right] b.d} \qquad [2]$$

$$\boldsymbol{V_s = \frac{A_v f_y d}{s}} \qquad [3]$$

where,
Av = Area of stirrup (in2)
fy = Tensile strength of stirrup (psi)
d = Effective depth of the member (in)
s = Spacing of stirrup (in)
In beam B-3 and B-4, single legged swimmer bars #3 at 76mm c/c and 3 legged swimmer bars #3 at 165mm c/c were provided respectively as shown inPhoto 1&Photo 2 . The swimmer bars were welded at an angle of 45 degrees with main steel. The nominal capacity is given by ACI Equation (4) and (5).

$$V_c = \left[1.9\lambda\sqrt{f'c} + 25000\,\rho_w \frac{V_u d}{M_u}\right] b.d \qquad [4]$$

$$V_s = \frac{A_v f_y (sin\alpha + cos\,\alpha) d}{s} \qquad [5]$$

where,
α = angle of inclination of swimmer bar (degrees)

Photo 1– Single swimmer bar B-3

Photo 2 – 3 legged swimmer bar B-4

3 EXPERIMENTAL PROCEDURES

In order to obtain the concrete compressive strength of 20.6 MPa and to satisfy the performance requirements for specific use, concrete mix design of ratio 1:2:4 and water cement ratio of 0.6 was selected. Nominal maximum size of aggregate selected was 25 mm. All the RCC beams were casted in laboratory. Each beam had a total length of 2438.4 mm and effective length of 2133.6 mm. The cross sectional dimensions of each beam were 203 mm x 254 mm. Beam B-1 contains only flexure reinforcement as shown inFigure 1 .
Beam B-2 consists of closed loop vertical stirrups at 76 mm c/c as shown inFigure 2. Beam B-3 contains single swimmer bars at 76 mm c/c as shown inFigure 3. Beam B-4 consists of 3 legged swimmer bars at 165mm c/c as shown inFigure 4.

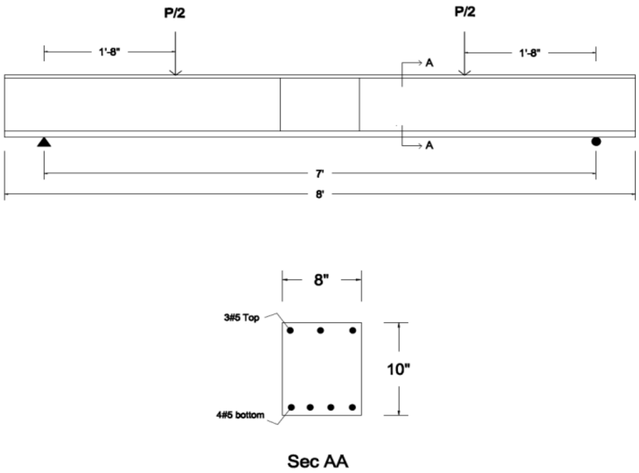

Figure 1 - Beam B-1

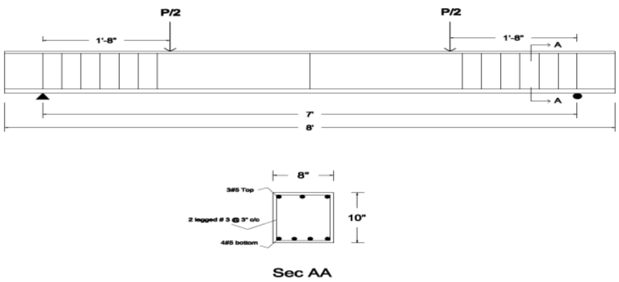

Figure 2 - Beam B-2

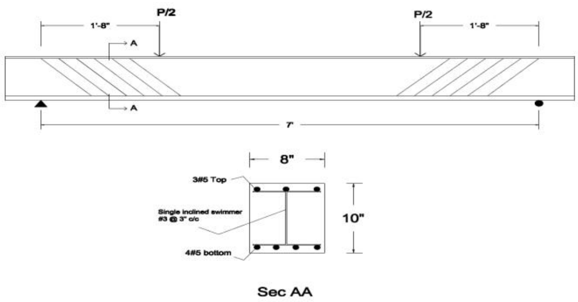

Figure 3 – Beam B-3

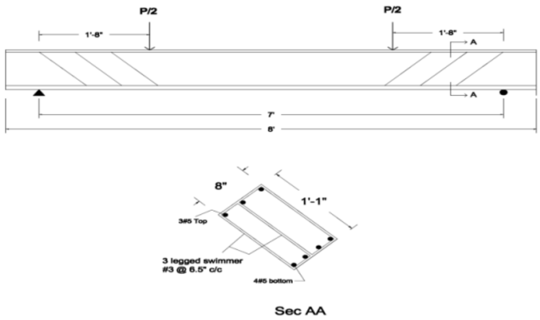

Figure 4 - Beam B-4

The reinforcement detail of all beams is shown in Table **1**.

Table 1 - Beam Details

Beam specimen	Flexure Reinforcement	Shear reinforcement (mm)	Shear details	Weight of Shear Reinforcement - kg
B-1	4 #5 (B) + 3 #5 (T)	-	-	-
B-2	4 #5 (B) + 3 #5 (T)	#3 @ 76 mm c/c	Closed loop stirrups up to 457 mm from each support	7.2
B-3	4 #5 (B) + 3 #5 (T)	# 3 @ 76 mm c/c	I shaped Single swimmer bars up to 457 mm from each support	5.4
B-4	4 #5 (B) + 3 #5 (T)	#3 @ 165 mm c/c	Three legged swimmer bars up to 457 mm from each support	5.0

For ensuring the shear failure of each beam, application of two point loads was selected near the supports. The shear span to depth ratio (a/d) of 2.2 was therefore selected for each beam.

For determining the deflections, three linear displacement sensors (LDS) were installed at the bottom of each beam. Two LDS were installed under each load point while one was installed at mid span. The load was applied constantly and without any shock. A stiff girder was used to transfer the load to load points as shown inFigure 5.

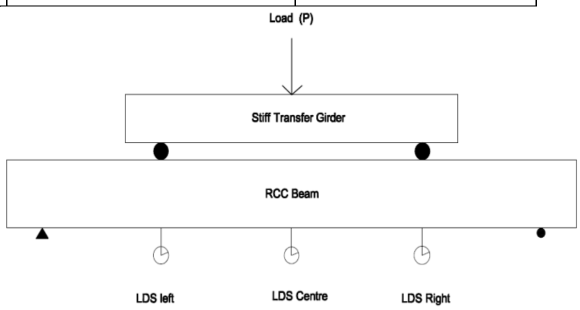

Figure 5 - Testing Assembly

The load cell, hydraulic jack system and LDS were attached to a data logger for the acquisition of data during testing. Lab view software was used for the controlling of load and for measuring the deflections at a regular interval of time. All necessary calibrations of load cell and LDS were carried out before testing. The hydraulic jack assembly had a total capacity of 490 kN and each LDS had a total capacity of 50 mm.

4 RESULTS & DISCUSSIONS

4.1 FAILURE OF BEAM SPECIMENS

All beams under the load were failed after the formation of shear cracks within the shear span. During loading, flexure cracks initially appeared near the mid span however they were followed by diagonal cracks and then the inclined shear cracks near the supports. The specimens were considered as a failed specimen when high deflections were recorded without any appreciable increase in load. The propagation of shear and flexure cracks at the same stage was also observed. The peak value of load was considered as an ultimate load.

4.2 FAILURE PATTERN OF BEAM B-1

During loading of Beam B-1, first flexure crack on the surface appeared at 82.72 kN and second at 89.5 kN. The width of cracks was very less (about 0.1 mm). First inclined hairline crack was observed at 97.39 kN load. The crack appeared at a distance of 254 mm from the left support. As the loading was increased, these cracks further propagated towards the top of the beam. At 131.33 kN load, the beam ultimately failed in shear with a wide shear crack which propagated from the left support point to point of loading.

The failure of Beam B-1 was sudden and without any ample warning. The explosive sound with splitting of concrete along the shear crack (at left side of beam) was observed. The splitting width of concrete at the bottom of beam was 15 mm which further reduced to 10 mm near the top of beam. The average width of shear crack was calculated to be 13 mm. Similar crack pattern was also observed on the other face of beam, however the failure mechanism on the other face was quite dominant. The splitting of concrete along the main reinforcement was observed up to a length of 305 mm horizontally. The final failure of beam was a "diagonal tension failure" and caused due to splitting of the concrete along the inclined crack. The failure pattern of beam B-1 is shown inPhoto 3.

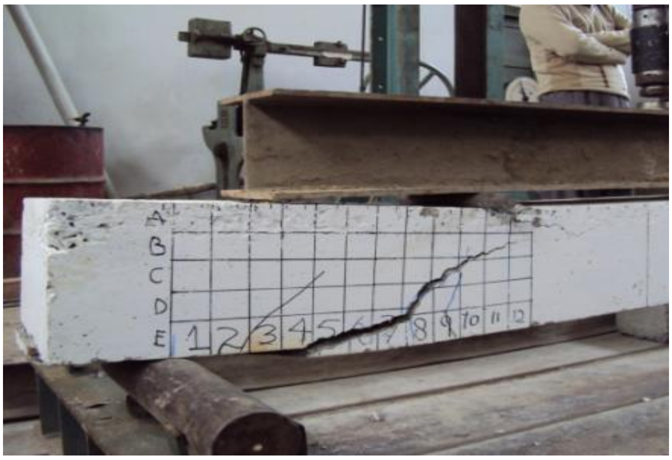

Photo 3 - Failure of B-1

4.3 FAILURE PATTERN OF BEAM B-2

Loading of Beam B-2 was carried out in the same way as B-1. The load from hydraulic jack was applied at a constant rate. During the load, beam specimen was checked for cracks. First hairline crack appeared at 67.83 kN load. The first crack was a flexure crack and was observed near mid span. Similar cracks also appeared near the mid span at 78.5 kN load. First shear crack was observed at 104.58 kN. At first shear crack the beam deflection at center was measured to be 3.72 mm. The shear cracks near the left support started to widen at 284.5 kN load. Similarly the crushing of beam specimen at supports was also observed at 294.25 kN load. At 389.71 kN shear slip of beam specimen was observed and the loading was stopped at this point. The ultimate loading was measured to be 389.71 kN. The failure pattern of beam B-2 is shown inPhoto 4.

Photo 4 - Failure of B-2

4.4 FAILURE PATTERN OF BEAM B-3

During loading of beam B-3, first surface crack that appeared was a flexure crack at 114.73 kN load. The crack appeared near the bottom of beam at the mid span. First shear crack was observed near right support at 129.19 kN load. The center deflection at this point was measured to be 2.71 mm. The widening of shear crack at left support point was noted at 277.25 kN load. Similarly, shear crack on the right support started widening at 294.2 kN load and the spalling of concrete under the load point was observed at 317.66 kN. The ultimate load of 379.01 kN was noted and the failure of the beam specimen was abrupt and was by slippage of the beam along the shear crack at left support.

During testing it was observed that less of shear cracks were formed within the left and right shear spans. The inclined cracks were formed near the point of load application. The failure of beam was sudden and due to the slippage of concrete along the shear crack. The final failure of beam B-3 is shown inPhoto 5.

Photo 5 - Failure of B-3

4.5 FAILURE PATTERN OF BEAM B-4

Beam B-4 was also loaded at a constant rate. First vertical crack appeared near the mid span at 54.4 kN load. First crack in shear was observed near right support of beam at 183.06 kN load. The center deflection at this point was measured to be 5.67 mm. With further increase in loads the flexure and shear cracks started to originate at different areas along the beam length. A shear crack near the left support originated at 209.4 kN load. The crushing of concrete at load points were observed when the loading reached 262.99 kN load. At 366.58 kN load, a horizontal crack originating from the left support was observed which further propagated horizontally towards the right support. The loading was stopped at 422.89 kN load, having a center deflection of 28.69 mm. The failure of beam B-4 is shown inPhoto 6.

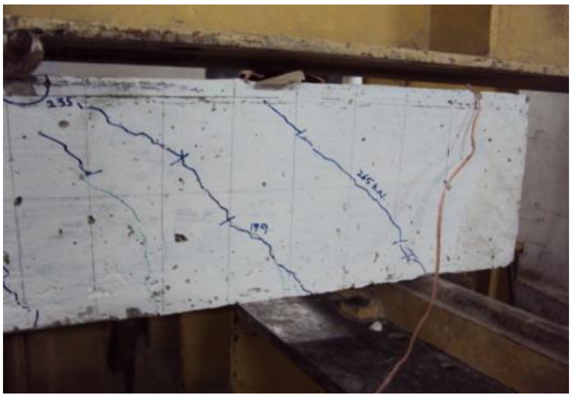

Photo 6 - Failure of B-4

5 COMPARISON OF RESULTS

The mode of failure of each beam is showed in **Error! Reference source not found.**. Beam B-3 showed more stiffness than B-2. The load at which first shear crack appeared was more in B-3. Also the deflection at first shear crack was less as compared to beam B-2. While analyzing the cracking behavior it was observed that near ultimate loads, the amount of inclined cracks within shear spans of B-2 were more than B-3. The failure mechanism of beam B-2 initially consisted of formation and propagation of diagonal cracks which was then followed by the crack widening, concrete crushing and splitting of concrete along the diagonal crack. The failure mechanism of beam B-3 was somehow different from B-2. The number of cracks formed within the shear span was less. Also few major diagonal cracks were formed prior to the failure of specimen. At ultimate, the failure of beam B-3 was sudden as compared to B-2 and by splitting of concrete along the diagonal crack. The ultimate load carrying capacity of B-3 was almost same as that of B-2.

Beam B-4 also showed high stiffness than B-2 under loads. Centre deflection at first shear crack in B-4 was much less than B-2. The amount of steel used in B-4 was 30 % less than beam B-2. In beam B-4 two types of cracks were seen on the beam surface. One was inclined cracks within the shear span and the other was a horizontal crack that extended from one load point to the other within the compression concrete. Further increasing the load caused the propagation and extension of flexure cracks towards the compression zone. During loading of B-4 it was observed that only few inclined cracks were formed on the beam surface as compared to B-2. The comparison of failure of each beam is shown in.

Ductility is defined as the ability of structure to go large deformations without any strength reduction. The ratio of deflection at ultimate to the deflection at first crack (yielding) is known as ductility ratio. The comparisons of ductility ratio for all beams are given in**Error! Reference source not found.**.

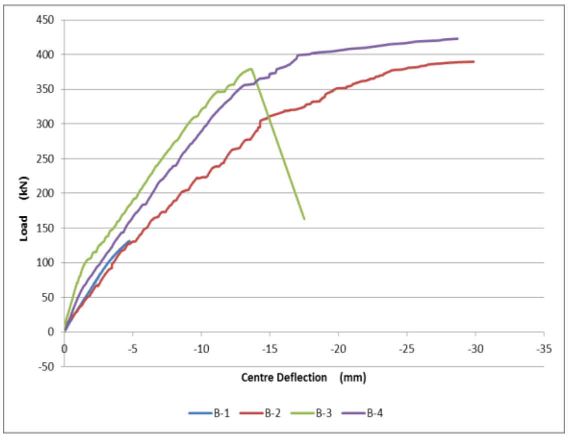

Figure 6 - Load & deflection graph

Table 2 - Ductility ratio

Beam specimen	Deflection at first crack (mm)	Deflection at ultimate (mm)	Ductility ratio
B-1	2.57	4.47	1.74
B-2	2.40	29.87	12.44
B-3	2.09	13.52	6.48
B-4	1.21	28.69	23.70

6 CONCLUSIONS

1. The failure of B-1 was sudden with wide diagonal crack near left support as no shear reinforcement was provided to enhance its shear capacity.
2. The failure of B-3 was also sudden with only few inclined cracks however, the ultimate load carrying capacity of B-3 was much more than B-1.
3. The ultimate load carrying capacity of beam B-4 was 9.3 % more than beam B-2.
4. By comparing the amount of shear steel used in each beam, beams having swimmer bars showed high shear carrying capacity under the applied loads
5. Beam B-2 showed much more deflection during loading stage as compared to beams B-3 & B-4.
6. The amount of shear reinforcement provided in beam B-4 was 30 % less than B-2. Also the swimmer bars in Beam B-4 were provided at much more spacing than B-2.
7. Due to large spacing between shear reinforcement, less number of cracks was formed. Also the inclined crack width was much less than crack width in B-2.
8. Swimmer bars as shear reinforcement thus fulfills the two important perimeters of construction industry i.e. ease in construction and economy without compromising the strength factor.

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