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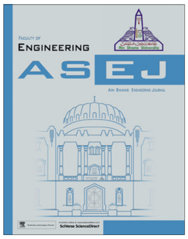

CIVIL ENGINEERING

Effect of using swimmer bars on the behavior of normal and high strength reinforced concrete beams

Heba A. Mohamed *

Department of Structural Engineering, Faculty of Engineering, Zagazig University, Egypt

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KEYWORDS

High strength concrete;
Shear;
Traditional stirrups;
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Abstract Shear failure of RC beams is often sudden and catastrophic. The shear cracks progress rapidly without warning, and the diagonal cracks are considerably wider than the flexural cracks. In this study, two types of shear reinforcement are used, traditional stirrups and swimmer bars. Swimmer bar system is a new type of shear reinforcement defined as inclined bars welded to longitudinal top and bottom bars. High strength concrete is a more brittle material than normal strength concrete, and the cracks that form in high strength concrete will propagate more extensively than in normal strength concrete. Ten beams are tested, and the main variables investigated were two different shapes of swimmer bars in addition to traditional stirrups, number of swimmer bar planes, and compressive strength of concrete. The test results will be presented and discussed in order as deflection, ultimate loads, ultimate shear stress, cracking stress and failure modes. Moreover, shear strain is calculated.

1. Introduction

Reinforced concrete 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. Retrofitting of reinforced concrete beams with multiple shear cracks is not considered an option [1]. 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 [2].

In reinforced concrete building construction, stirrups are most commonly used as shear reinforcement, for their simplicity in fabrication and installation. Stirrups are spaced closely

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* Tel.: +20 01060054760.
E-mail address: hebawahbe@yahoo.com.

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at the high shear region. Congestion near the support of the reinforced concrete beams due to the presence of the closely spaced stirrups increases the cost and time required for installation. Bent up bars are also used along with stirrups in the past to carry some of the applied shear forces. In case where all the tensile reinforcement is not needed to resist bending moment, some of the tensile bars were bent-up in the region of high shear to form the inclined legs of shear reinforcement. The use of bent-up bars is not preferred nowadays [3]. Piyamahant [4] 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 stirrups of 0.2% is appropriate. The paper concluded that small amount of web reinforcement is sufficient to improve the shear carrying capacity.

High-strength concrete is a more brittle material than normal-strength concrete. This means that cracks that form in high-strength concrete will propagate more extensively than in normal-strength concrete. This is due to the fact that cracks tend to propagate through the aggregates in the higher strength concretes rather than around the aggregates as in normal-strength concrete. The result is a much smoother shear failure surface meaning that the shear carried by aggregate interlock tends to decrease with increasing concrete strength. The total shear force V_u is distributed between the concrete V_c and the stirrups V_s. Initially upon loading, the shear reinforcement carries only a small portion of the shear force which is carried by the concrete .On the formation of the first inclined crack, redistribution of shear stresses occurs, with some part of the shear being carried by concrete, and the rest being carried by stirrups. It is assumed that the total shear is resisted by concrete until the formation of diagonal cracks [5–7].

Swimmer bar system is used as shear reinforcement, and the main advantages of this type are flexibility, simplicity, efficiency, and speed of construction. The swimmer bars form plane – crack interceptor system instead of bar – crack interceptor system when stirrups are used. Asha et al. [8], tested four reinforced concrete beams using new shear reinforcement swimmer bar system and the traditional stirrups. Several shapes of swimmer bars are used to study the effect of swimmer bar configuration on the shear load carrying capacity of the beams. It was found that the use of swimmer bar system improved the shear load carrying capacity in the reinforced concrete beams. The width and length of the cracks were observed to be less using swimmer bars compared to the traditional stirrups system.

2. Normal and high strength concrete

Use of high strength concrete in construction sector has increased due to its improved mechanical properties compared to ordinary concrete. One such mechanical property, shear resistance of concrete beams is an intensive area of research [9]. The difference between high strength concrete (HSC) and normal strength concrete (NSC) is:

- The fracture surface in NSC is rough. The fracture develops along the transition zone between the matrix and aggregates. Fewer aggregate particles are broken.
- The fracture surface in HSC is smooth. The cracks move without discontinuities between the matrix and aggregates.

An increase in the strength of concrete produces an increase in its brittleness and smoother shear failure surfaces, leading to some concerns about the application of HSC [10]. In this study HSC is used as a result of the above and compared with NSC due to NSC is still used in many applications.

3. Research significance

The present study demonstrates the effect of using swimmer bars instead of traditional stirrups on improvement of shear performance in reinforced concrete beams, as well as studying the effect of concrete strength in normal and high strength concrete and to identify the most efficient shape and number of swimmer bar planes to carry shear forces.

4. ACI code provision for shear design

According to ACI Code [11], the design of beams for shear is to be based on the following relation:

$$V_u \leqslant \phi\ V_n$$

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 contributions of the concrete and the web steel if present. Thus for vertical stirrups

$$V_u \leqslant \phi\ V_c + \frac{\phi A_v f_{yt} d}{s}$$

and for inclined bars

$$V_u \leqslant \phi\ V_c + \frac{\phi A_v f_{yt} d(\sin\alpha + \cos\alpha)}{s}$$

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 the following equation:

$$V_c = 0.17\ \lambda\ \sqrt{f'_c}\ b_w\ d$$

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.

5. Experimental program

In order to investigate the above mentioned objectives, an experimental program was carried out to test ten simply supported reinforced concrete beams. Five beams were made of normal concrete compressive strength and the remaining five were made of high concrete compressive strength. Detailed description of the specimens, the material properties, mix proportions, test set-up, test procedure, and measurements were presented in this section.

5.1. Test specimens

The details of the tested beams are shown in Fig. 1 and are listed in Table 1. All beams were 250 mm height, 150 mm width, and overall length 1600 mm. Five beams had three

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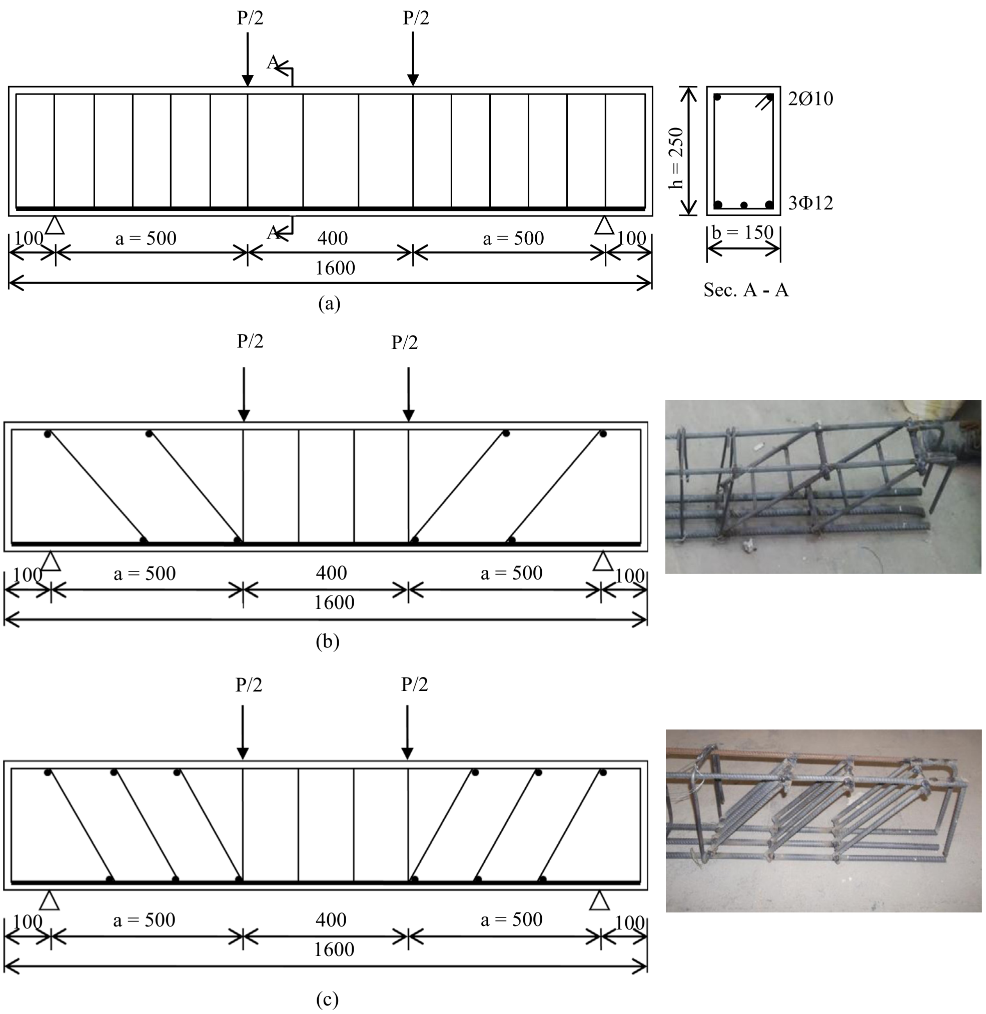

Figure 1 Specimen details for beams: (a) R1; (b) R3; (c) R4 (unit:mm).

Table 1 Test specimens details.

Specimen	Type of concrete	Main reinforcement (bottom)	Shear reinforcement	
			Stirrups	Swimmer bar
R_1	Normal	3Φ12	6 ∅ 8 mm@500 mm at shear sides	–
R_2	Normal	3Φ12	–	Four swimmer ∅ 10 mm (shape 1) @ 250 mm (two planes)
R_3	Normal	3Φ12	–	Two swimmer ∅ 10 mm with HL. Stiffener bars (shape 2) @ 250 mm (two planes)
R_4	Normal	3Φ12	–	Four swimmer ∅ 10 mm (shape 1) @ 166.67 mm (three planes)
R_5	Normal	3Φ12	–	Two swimmer ∅ 10 mm with HL. Stiffener bars (shape 2) @ 166.67 mm (three planes)
R_6	High strength	3Φ16	6 ∅ 8 mm@500 mm at shear sides	–
R_7	High strength	3Φ16	–	Four swimmer ∅ 10 mm (shape 1) @ 250 mm (two planes)
R_8	High strength	3Φ16	–	Two swimmer ∅ 10 mm with HL. Stiffener bars (shape 2) @ 250 mm (two planes)
R_9	High strength	3Φ16	–	Four swimmer ∅ 10 mm (shape 1) @ 166.67 mm (three planes)
R_{10}	High strength	3Φ16	–	Two swimmer ∅ 10 mm with HL. Stiffener bars (shape 2) @ 166.67 mm (three planes)

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Table 2 Properties of cement.

Tests	Results	ECP 203-2007 specification limits
Initial setting time	1 h and 15 min	Not less than 45 min
Final setting time	4 h and 45 min	Not more than 10 h
3 days compressive strength	20 N/mm^2	Not less than 18 N/mm^2
7 days compressive strength	29.5 N/mm^2	Not less than 27 N/mm^2

12 mm diameter as main longitudinal reinforcement for normal strength concrete, on the other hand for high strength concrete, beams were reinforced with three 16 mm diameter as main reinforcement. The shear span to depth ratio (a/h) was constant for all beams and equal to 2.0. The variables in these beams are the shear reinforcement systems, and concrete compressive strength. In two beams, 1∅8 mm at 100 mm spacing vertical stirrups was used in each shear span and at 133.3 mm spacing between two point loads. Four beams were designed with two swimmer bar planes at 250 mm spacing from each other, and four beams with three swimmer bar planes at 166.67 mm spacing from each other of two shapes in each shear span.

Cubes of size 150 mm which had been cast along with the beams were tested on the same day on which the respective beams were tested (i.e. 28 days) to ascertain concrete compressive strength used in both normal strength R.C. beams and high strength R.C. beams. The cubes test was carried out in a compression testing machine of 2500 kN capacity.

5.2. Materials properties

The cement used throughout this work was Ordinary Portland Cement (OPC) for all test specimens. Cement is tested and the test results satisfied Egyptian Code of Practice requirements, the test results of used cement are given in Table 2. 20 mm nominal maximum size dolomite is used as coarse aggregate and the fine aggregate was natural sand free from impurities. A swimmer bar is a small inclined bar welded at the top and the bottom longitudinal bars. Two shapes of swimmer bars are used as shown in Fig. 2, the first one was rectangular shape by addition of two more swimmer bars dividing the large rectangle vertically into three rectangles (shape (1)). The second shape was rectangle shape by addition of horizontal stiffener bars dividing the large rectangle horizontally into three rectangles (shape (2)), as proposed in Ref. [2] to explore new shape of swimmer bars in addition to standard shapes. A mineral admixture silica fume is used for high strength concrete. Silica fume is a light gray powder has a specific gravity of 2.1 and a fixed dose to be 15% of cement as a replacement of cement. In this study, high range water reducing admixture was used to improve the workability of high strength concrete and to reduce the water content for increasing the strength of concrete.

Figure 2 Shape of swimmer bar planes.

Table 3 Mix proportions for normal strength concrete.

Cement content (kg/m^3)	300
Water content (kg/m^3)	150
Coarse aggregate (kg /m^3)	1400
Fine aggregate (kg/m^3)	600
W/C ratio	0.5
Slump value (cm)	7

Table 4 Mix proportions for high strength concrete.

Cement content (kg/m^3)	425
Water content (kg/m^3)	135
Coarse aggregate (kg/m^3)	1272.6
Fine aggregate (kg/m^3)	545.5
Silica fume (kg/m^3)	75
Super plasticizer (kg/m^3)	12.5
W/(C + S.F.) ratio	0.27
Slump value (cm)	5

5.3. Mix proportions

For this study, two mixes are produced according to concrete strength. The quantities of materials used for two mixes are illustrated in Tables 3 and 4 for normal and high strength concrete respectively. Concrete compressive strength of normal and high strength concrete after 28 days was 25.6 N/mm^2 and 65.2 N/mm^2. The slump test was carried out on fresh concrete for both normal and high strength concrete and the values are listed in Tables 3 and 4.

5.4. Test procedure

Test setup is shown in Fig. 3. All beams are tested to failure under two-point symmetric top loading using 2500 kN capacity testing machine. Vertical deflections at mid-span are monitored by LVDTs. Surfaces of the beam are painted in a white color with the objective of the observation of crack development during testing. At each load stage, the deflection readings are recorded and the cracks are marked on the surface of the beam.

6. Test results and discussion

6.1. Load–deflection at mid span

To obtain the effect of swimmer bar shapes compared to stirrups on the behavior of reinforced concrete beams, the vertical

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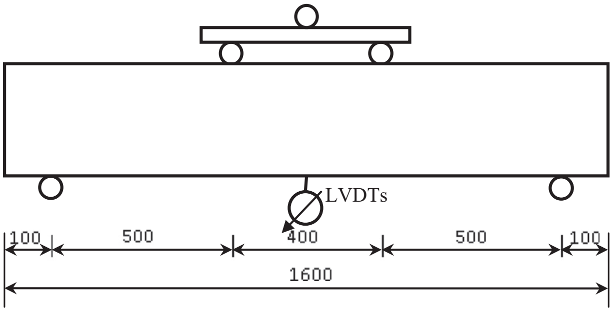

Figure 3 Test setup (unit: mm).

deflections obtained from experimental program at mid span for beams reinforced with stirrups and two planes of swimmer bars at 250 mm spacing in the shear span, are plotted against the loads as shown in Fig. 4(a) and (b) for normal and high strength concrete, respectively. Through the study of these curves, find that in normal strength concrete using two swimmer bar planes of shape (1) as in beam R_2 gives lower values of deflection at the same load than that when stirrups and swimmer bars of shape (2) are used. The decrease in deflection value at failure load is estimated by about 21.42% from beam R_2 to beam R_3. Fig. 4(b) illustrated that there was a convergence to some extent in the values of deflection for high strength concrete. But in beam R_7, the deflection value at failure load decreased by about 12.26% than that in beam R_8. Fig. 5 (a) and (b) shows the same relation but with three swimmer bar planes at 166.67 mm spacing. Deflection value decreased by about 38.4% when using swimmer bar of shape (1) compared to that with swimmer bar of shape (2) for normal strength concrete. To show the effect of spacing between swimmer bar planes, the values of deflection are plotted versus load in Fig. 6(a) for normal strength and Fig. 6(b) for high strength concrete beams with swimmer bar of shape (1), while these relations are plotted in Fig. 7(a) and (b) for beams reinforced with swimmer bars of shape (2). From these figures, one can see that for all cases the use of swimmer bar planes at 250 mm spacing in each shear span gives values of less deflections at a higher rate in the case of normal concrete than that of high strength concrete. The effect of concrete strength on the load deflection behavior is also evident as shown in Fig. 8 for stirrups, and Fig. 9(a) and (b) for swimmer bars of shapes (1) and (2), respectively. The concrete strength shows clearly in the case of using stirrups and swimmer bars of shape (1), as the deflection value increased by about 28.3% from beam R_2 to beam R_7 and by about 64.8% from beam R_4 to R_9 at failure load, while there was a clear convergence in the values of deflection in the case of using three swimmer bar planes of shape (2) at 166.67 mm spacing as shown in Fig. 9

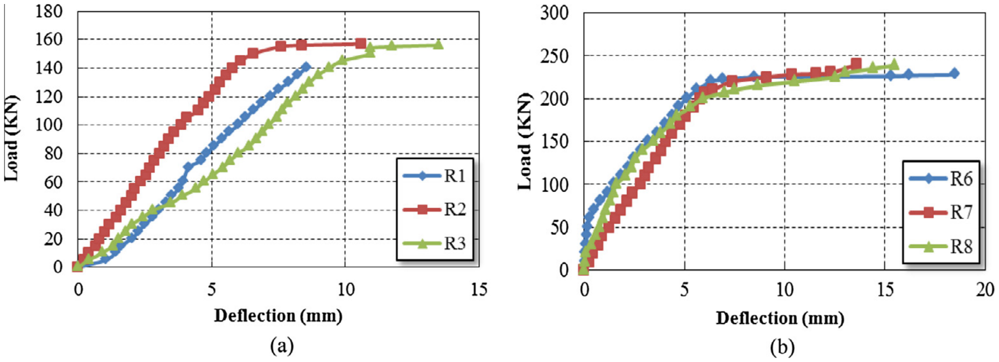

Figure 4 Shape effect of two swimmer bar planes using at 250 mm spacing on the values of deflection: (a) normal strength and (b) high strength.

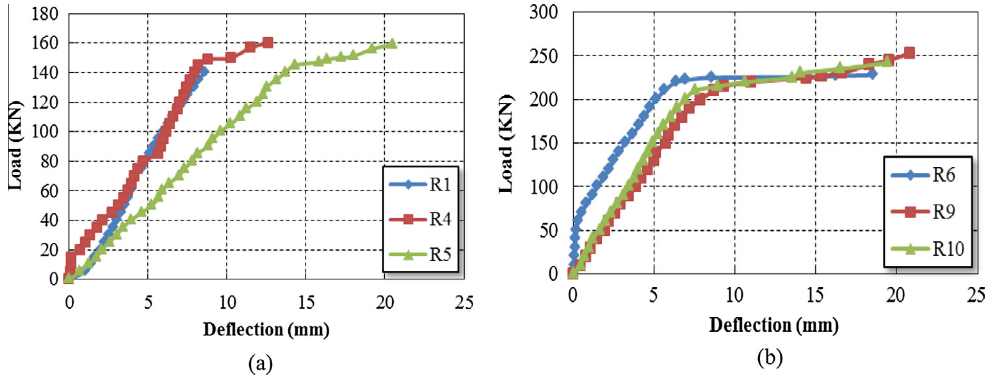

Figure 5 Shape effect of three swimmer bar planes using at 166.67 mm spacing on the values of deflection: (a) normal strength and (b) high strength.

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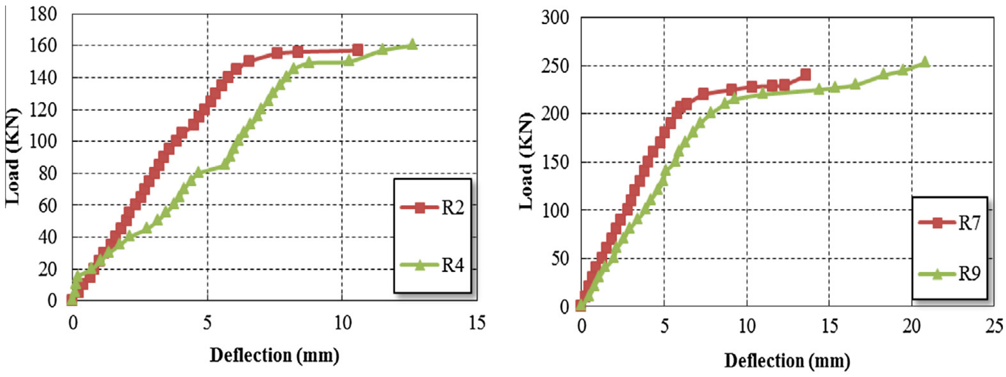
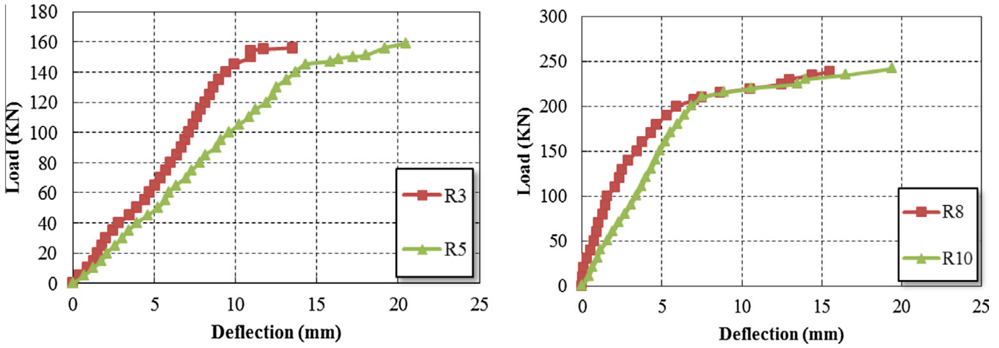


(a) (b)

Figure 6 Effect of spacing between swimmer bar planes of shape (1) on the values of deflection: (a) normal strength and (b) high strength.



(a) (b)

Figure 7 Effect of spacing between swimmer bar planes of shape (2) on the values of deflection: (a) normal strength and (b) high strength.

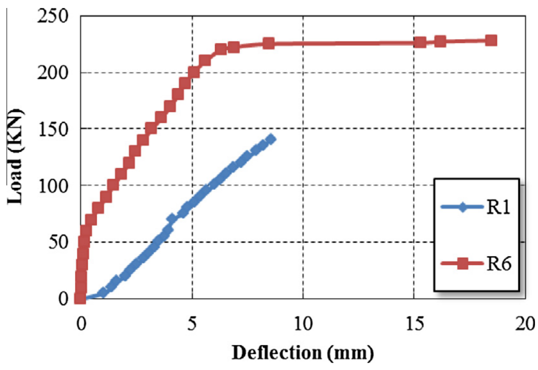


Figure 8 Effect of concrete strength for beams with stirrups.

(b). Based on above, the use of two swimmer bar planes of shape (1) generally reduces the values of deflection for normal strength concrete.

6.2. Ultimate load

The values of ultimate loads for all test specimens are listed in Table 5 and are shown in Fig. 10. From table and figure, one can notice that the use of three swimmer bar planes of shape (1) in each shear span, is more effective in carrying the ultimate loads in both normal and high strength reinforced concrete beams. The ultimate load in beam R_4 increased by about 14.3% compared to beam R_1 reinforced with stirrups at shear span. While this increase is estimated by about 11% for high strength reinforced concrete beams. The use of three swimmer bar planes of shape (1) at 166.67 mm spacing is one of the best forms proposed in this research to increase the value of the ultimate load.

6.3. Ultimate shear stress and cracking stress

The ultimate shear stress is very important in the shear behavior specially for high strength concrete. The ultimate shear stress and cracking stress of the tested beams are calculated by the following equations and shown in Table 6.

$$v_u = \frac{P_u}{2bd}, \quad v_{cr} = \frac{P_{cr}}{2bd}$$

It was observed that, the ultimate shear stress increased by about 58.1% from NSC beam R_4 to HSC beam R_9 in case of using three swimmer bar planes of shape (1). However, the cracking stress at such beams increased by about 40.26%.

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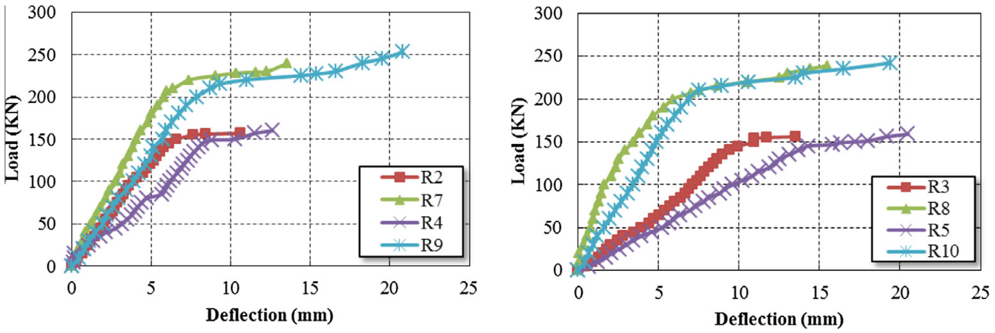

(a) (b)

Figure 9 Effect of concrete strength for beams with swimmer bars: (a) shape (1) and (b) shape (2).

Table 5 The values of ultimate load.

Specimen	Ultimate load (kN)	% of increase
R_1	140	–
R_2	157	12.14
R_1	140	–
R_3	156	11.43
R_1	140	–
R_4	160	14.3
R_1	140	–
R_5	159	13.57
R_6	228	–
R_7	240	5.26
R_6	228	–
R_8	239	4.82
R_6	228	–
R_9	253	11
R_6	228	–
R_{10}	242	6.14

Table 6 Ultimate shear stress and cracking stress.

Specimen	Ultimate shear load P_u (kN)	Ultimate shear stress v_u (N/mm^2)	Cracking load P_{cr} (kN)	Cracking stress v_{rc} (N/mm^2)
R_1	140	1.986	35	0.993
R_2	157	2.23	28	0.794
R_3	156	2.213	33	0.936
R_4	160	2.27	20	0.567
R_5	159	2.255	25	0.71
R_6	228	3.234	75	2.128
R_7	240	3.404	60	1.702
R_8	239	3.39	65	1.844
R_9	253	3.589	45	1.277
R_{10}	242	3.433	55	1.56

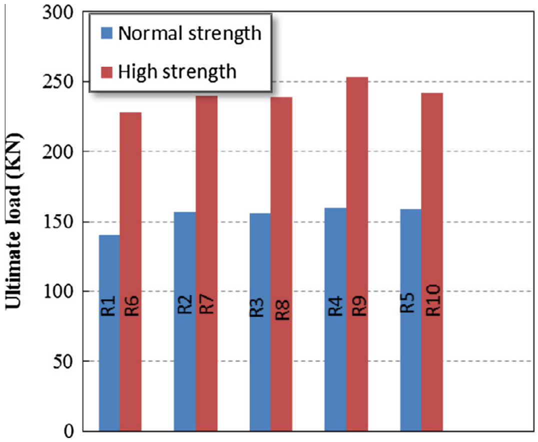

Figure 10 The values of ultimate load.

6.4. Crack pattern and failure mode

Fig. 11 displays the failure mode of high strength reinforced concrete beam with stirrups (R_6). The beam R_6 showed typical shear failure at 228 kN ultimate load. The failure mode of high strength reinforced concrete beams with two swimmer bar planes at 250 mm spacing is presented in Fig. 12. For beam R_7 in the early stage of loading, hair cracks appeared between the two applied loads. With the load increase, the width and length of cracks increased and became visible. More flexure cracks appeared and shear cracks appeared at sides of beam in the shear region as the load increases, finally flexural failure occurred. The behavior of beam R_8 under load was almost identical to beam R_7 except that the propagation of diagonal shear crack was at a faster rate, and the number and the width of shear cracks were higher than these in beam R_7. According to above, the use of two swimmer bar planes of shape (1) at 250 mm spacing reduces the number and the propagation of shear cracks than that of using swimmer bars of shape (2). Fig. 13 shows the failure mode of high strength reinforced concrete beams with three swimmer bar planes at 166.67 mm spacing. From these figures, one can see that the use of three swimmer bar planes prevented the appearance of shear cracks and converted the failure to flexure failure. The behavior of normal strength reinforced concrete beams was almost identical to that of high strength reinforced concrete beams but with slower rate of crack width, number, and propagation. This is due to the fact that high strength concrete is a more brittle material than normal strength concrete.

7. Shear strain

Shear strain is usually represented by γ and defined as $\gamma = \tau/G$, where τ is shear stress and G is modulus of elasticity in shear or

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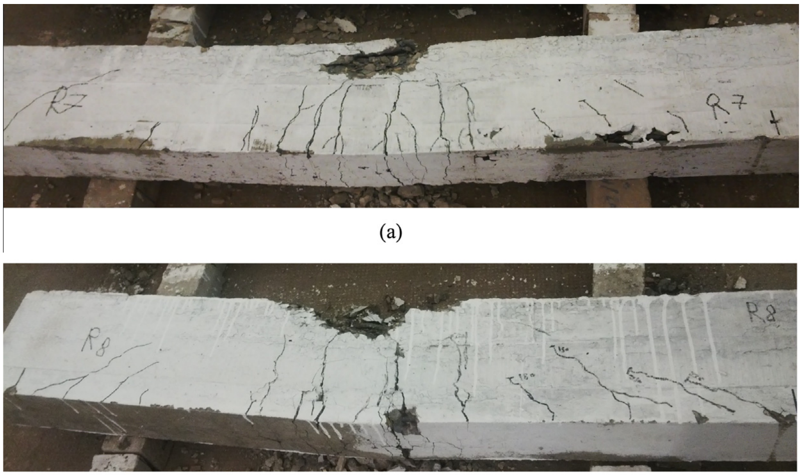
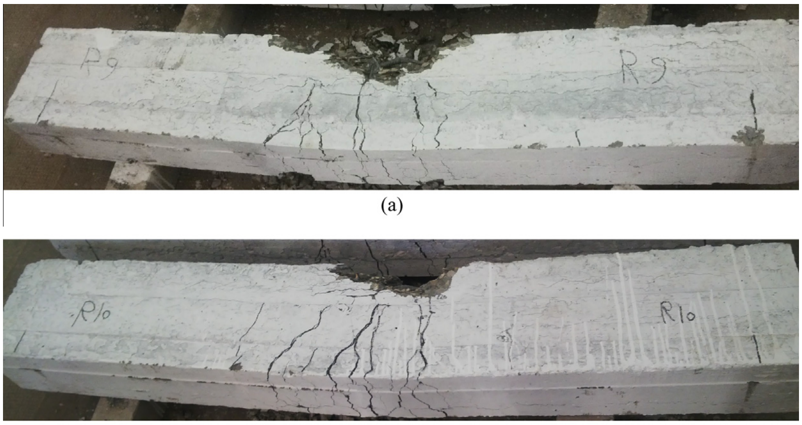
Figure 11 Crack pattern at failure of high strength RC beams with stirrups.



(a)

(b)

Figure 12 Crack pattern at failure of high strength RC beams with two swimmer bar planes at 250 mm spacing: (a) shape (1) and (b) shape (2).



(a)

(b)

Figure 13 Crack pattern at failure of high strength RC beams with three swimmer bar planes at 166.67 mm spacing: (a) shape (1) and (b) shape (2).

modulus of rigidity and is given by $G = \frac{E}{2(1+\upsilon)}$ where E is modulus of elasticity and υ is Poisson's ratio. Shear strain is calculated for all test beams and listed in Table 7. This table shows that shear strain is directly proportional to number of swimmer bar planes of the same shape for both normal and high strength concrete. Also it was found that, the values of shear strain by using swimmer bars whether in shape (1) or shape (2) were higher than those by using traditional stirrups.

Table 7 Shear strain.

Specimen	Ultimate shear stress v_u (N/mm^2)	Shear strain $\times 10^{-4}$
R_1	1.986	2.14
R_2	2.23	2.4
R_3	2.213	2.386
R_4	2.27	2.447
R_5	2.255	2.431
R_6	3.234	2.185
R_7	3.404	2.3
R_8	3.39	2.29
R_9	3.589	2.42
R_{10}	3.433	2.32

8. Conclusions

This paper presents an experimental program to describe the effect of using swimmer bar system as shear reinforcement on the behavior of reinforced concrete beams. Based on the obtained results, the following main conclusions can be drawn:

- The use of swimmer bars in each shear span gives values of less deflections at a higher rate in the case of normal concrete than that of high strength concrete.
- Deflection value decreased by about 38.4% when using three swimmer bar planes of shape (1) compared to that of shape (2) for normal strength concrete.
- The use of three swimmer bar planes at 166.67 mm spacing of shape (1) is one of the best forms proposed in this research to increase the value of the ultimate load.
- The ultimate shear stress increased by about 58.1% from NSC beam to HSC beam in case of using three swimmer bar planes of shape (1). However, the cracking stress at such beams increased by about 40.26%.
- The use of two swimmer bar planes of shape (1) at 250 mm spacing reduces the number and the propagation of shear cracks than that of use of swimmer bars of shape (2).
- The use of three swimmer bar planes at 166.67 mm spacing prevented the appearance of shear cracks and converted the failure to flexure failure.
- Shear strain is directly proportional to number of swimmer bar planes of the same shape for both normal and high strength concrete. Also it was found that, the values of shear strain by using swimmer bars whether in shape (1) or shape (2) were higher than those by using traditional stirrups.
- The cracks progress with slower rate of crack width, number, and propagation for normal strength concrete than high strength concrete. This is due to the fact that high strength concrete is a more brittle material than normal strength concrete.

References

[1] Al-Nasra MM, Wang LRL. Parametric study of slab-on-grade problems: due to initial warping and point loads. ACI Struct J 1994;91(2), < http://www.concrete.org/PUBS/JOUR >.

[2] Al-Nasra Moayyad M. Shear failure investigation of reinforced concrete beams with swimmer bars. J Civ Eng Constr Technol 2013;4(2):56–74.

[3] Najmi Abdul Qader S, Al-Nasra Moayyad M, Asha Naiem M. Improved shear performance of bent-up bars in reinforced concrete beams. Int J Eng Sci Res Technol (IJESRT) 2013;2():1264–8.

[4] Piyamahant. Shear behavior of reinforced concrete beams with small amount of web reinforcement. M. Eng. Dissertation, Kochi University of Technology, Japan; 2002.

[5] Krauthammer Theodor. Minimum shear reinforcement based on interface shear transfer. ACI Struct J 1992(January–):99–105.

[6] Collins Michael P, Kuchma Daniel. How safe are our large, lightly reinforced concrete beams, slabs, and footings. ACI Struct J 1999(July–August):482–90.

[7] Yoon Young-soo, Cook William D, Nitchell Denis. Minimum shear reinforcement in normal, medium, and high-strength concrete beams. ACI Struct J 1996(September–October):576–84.

[8] Asha Naiem M, Al-Nasra Moayyad M, Najmi Abdelqader S. Optimizing the use of swimmer bars as shear reinforcement in the reinforced concrete beams. Int J Civ Struct Eng 2012;3(2):313–20.

[9] Sudheer Reddy L, Ramana Rao NV, Gunneswara Rao TD. Shear resistance of high strength concrete beams without shear reinforcement. In: 1st International interactive symposium on ultra-high performance-concrete; 2015. p. 19–22.

[10] DesaI Satish B. Influence of constituents of concrete on its tensile strength and shear strength. ACI Struct J 2004:29–38.

[11] ACI 318-11. Building code requirements for structural concrete commentary; 2011.

Heba Allah Mohamed Ali is an Egyptian. She is working at Structural Engineering Department, Faculty of Engineering, Zagazig University, Egypt. Her current position is Associate Professor in Structural Engineering Dep., Faculty of Engineering, Zagazig University. Her major is Civil Engineering and with a specialization in Structural Engineering. Her areas of interest are Seismic behavior of flat slabs and shear strength. She may be contacted at hebawahbe@yahoo.com, and through the mobile number 01060054760.

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