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Shear Capacity of Reinforced Concrete Beam with Different Cross Section Types of Lateral Reinforcement on Minimum Ratio

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Abstract

This research has an objective to determine shear capacity of a reinforced concrete beam with different cross section types of lateral reinforcement. The specimens used in this research are made from a reinforced concrete beam with its dimension is 100 mm width times 150 mm height and f'_c = 18 MPa. The beam has 2#2 tension reinforcement lie at the bottom of the beam, and 2#2 reinforcement lie at the upper side of the beam to maintain the position of shear reinforcement. Shear reinforcement provide by ϕ4 mm steel reinforcement spaced every 150 mm – 200 mm at the middle of the beam. This shear reinforcement area fulfill minimum limit ratio specified in ACI 318-08. The test results indicated that no significant differences for shear capacity from each types of shear reinforcement cross section. But open stirrups can be considered as a practical use in the construction field.

Keywords : beam; reinforced concrete; shear reinforcement; deflection, tension reinforcement

1. Introduction

Concrete is weak in tension, and the concrete beam will collapse if there are no proper reinforcement. The tensile stresses develop in beams due to axial tension, bending, shear, torsion, or a combination of these forces. The location of cracks in the concrete beam depends on the direction of principal stresses. For the combined action of normal stresses and shear stresses, maximum diagonal tension may occur at about a distance d from the face of the support [1]. The distance d is measure from the extreme compression fiber to the centre of the longitudinal tension reinforcement. Flexural – shear cracks are the

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most common type found in reinforced concrete beams. A flexural crack extends vertically into the beam; then the inclined crack forms, starting from the top of the beam when shear stresses develop in that region. In regions of high shear stresses, beams must be reinforced by stirrups or by bent bars to produce ductile beams that do not rupture at a failure. If shear reinforcement is not provided, brittle failure will occur without warning. To avoid brittle failure, ACI 318-08 Code requires that the minimum shear reinforcement area, $A_v = 0.35 b_w s / f_y$ for the compressive strength of concrete up to 31 MPa. For concrete with compressive strength more than 31 MPa, the ACI 318-08 Code specify minimum shear reinforcement area, $A_v = 0.0062\sqrt{f'_c}\ (b_w s / f_y)$. Maximum amount of shear reinforcement is limited by the Code to $\rho_{\text{maks}} = 0.67\sqrt{f'_c} / f_y$. The Code limits the maximum spacing of the stirrups, s_{max} less than $d/2$ or 600 mm, which shall be reduced to $d/4$ or 300 mm if the nominal strength provided by shear reinforcement, V_s is greater than $0.33\sqrt{f'_c}(b_w d)$. Test result on minimum shear reinforcement in beams by Lee and Kim [2] indicated that the shear strength of the beam with minimum amount of shear reinforcement increased as the longitudinal tensile reinforcement ratio increased, but decreased as the a/d increased.

Experimental studies focused on minimum shear reinforcement ratio were conducted by Johnson and Ramirez [3], Krauthammer [4], Yoon et al. [5] and Ozcebe et al. [6]. The test result shown that the higher the compressive strength of concrete, the higher the shear reinforcement needed. Kang et al. [7] investigate the effect of steel fibers on the shear strength of lightweight concrete beams without web reinforcement. The test results also indicate that a/d adversely affects the shear capacity. Another research on shear strength were conducted by Montesinos [8], 147 FRC beams with deformed steel fibers and 45 companion beams without fibers used in this research. Montesinos indicated that steel fibers can be used as minimum shear reinforcement with fiber volume fraction, V_f equal to 0.75%.

Varney et al. [9] investigate the effect of stirrup anchorage on shear strength of concrete beam, the experimental results of four 13 × 24 in reinforced concrete beam section, suggest that reinforcement anchorage has no significant effect on the shear capacity of a reinforced concrete section. Lubell et al. [10] showed that the capacity of members with well-distributed shear reinforcement could be safely predicted by the ACI 318 shear model, but stirrup efficiency decreased significantly as the stirrup leg spacing across the width increased.

Different cross section of stirrups can be used as shear reinforcement. Some stirrups types are U-stirrups, multi-leg stirrups and spliced stirrups [20]. U-stirrups is one of the most usual stirrups used in the construction field, this type of stirrups can be open or closed stirrups.

2. Research Significance

To avoid brittle failure, ACI Codes specify the minimum amount of shear and longitudinal reinforcement area of a reinforced concrete beam. This paper presents the test results of 9RC beams having minimum shear reinforcement ratio, and minimum flexural reinforcement ratio. Three different types of shear reinforcement cross section used in this research. Shear capacity and deflections of the RC beams are studied.

3. Test Program and Measurements

Minimum shear reinforcement are needed to prevent a sudden failure of a reinforced concrete beams. After inclined cracking was developed in a beam, it will fail unless the cracked concrete section can resist the applied forces. If shear reinforcing is not present, the items that are available to transfer the shear are as follows [21]: (1) the shear resistance of the un-cracked section above the crack, (2) the aggregate interlock, (3) the resistance of the longitudinal reinforcing to a frictional force, often called *dowel action*, and (4) a tied-arch type of behavior that exists in rather deep beams produced by the longitudinal bars acting as the tie and by the un-cracked concrete above and to the sides of the crack acting as the arch above. Although there are some test results on shear reinforcement [2-19], there is very few test result concern on effect of different cross section of shear reinforcement. Thus 9 RC beams with different types of shear reinforcement cross section to investigate the shear capacity of the beams.

The specimens used in the research were made from a concrete beam with 100 mm width and 150 mm height. Concrete beam was reinforced with 2#2 tension bars lie at the bottom of the beam, and 2#2 bars lie at the top of the beam to maintain the position of the lateral reinforcement. Lateral reinforcement provide by ϕ4 mm steel reinforcement spaced every 150 mm near the support until ¼ length of the beam, and spaced every 200 mm at the middle of the beam. The concrete compressive strength used in this research is f'_c = 18 MPa. Beams are classified into 3 groups, Group A beams used closed stirrups, Group B beams used open stirrups, while Group C beams used open stirrups with additional horizontal bar placed in the top of the beam. Figure 1 shows beams dimension and its cross section.

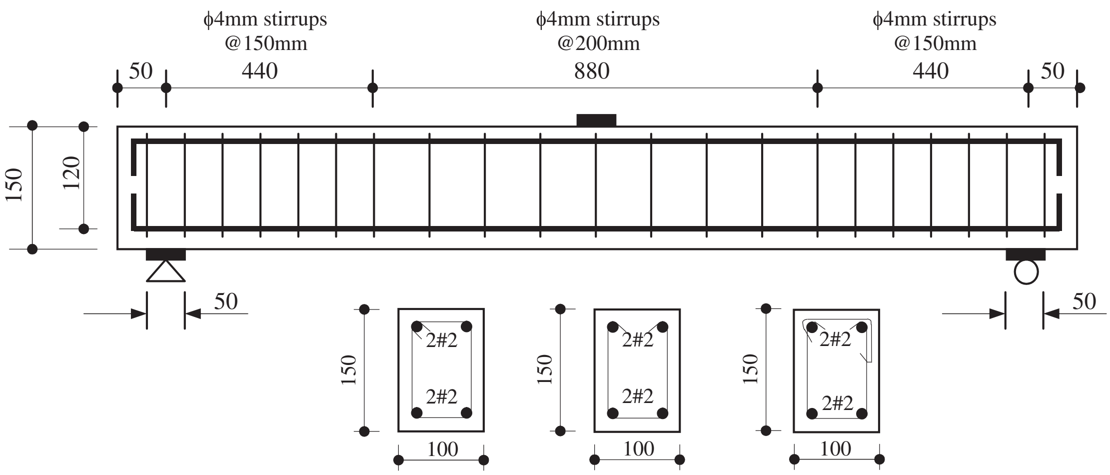
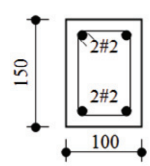
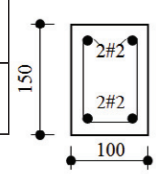


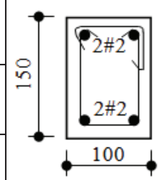
Fig. 1. Beams dimension and cross section (a) closed stirrups; (b) open stirrups; (c) open stirrups with additional hook

Table 1. Specification of specimen and material properties

Beams		f'_c, MPa	b, mm	h, mm	L, mm	Longitudinal Bar				Shear Reinforcement Bar			Cross Section
						n_{bar}	d_b, mm	ρl	f_y, MPa	s support, mm	s middle, mm	f_y, MPa	
Group A	A1	18	100	150	1860	2	6	0,00471	400	150	200	240	
	A2	18	100	150	1860	2	6	0,00471	400	150	200	240	
	A3	18	100	150	1860	2	6	0,00471	400	150	200	240	
Group B	B1	18	100	150	1860	2	6	0,00471	400	150	200	240	
	B2	18	100	150	1860	2	6	0,00471	400	150	200	240	

	B3	18	100	150	1860	2	6	0,00471	400	150	200	240	

Table 1. (Cont.) Specification of specimen and material properties

Beams		f'_c, MPa	b, mm	h, mm	L, mm	Longitudinal Bar				Shear Reinforcement Bar			Cross Section
						n_{bar}	d_b, mm	ρl	f_y, MPa	$s_{support}$, mm	s_{middle}, mm	f_y, MPa	
Group C	C1	18	100	150	1860	2	6	0,00471	400	150	200	240	
	C2	18	100	150	1860	2	6	0,00471	400	150	200	240	
	C3	18	100	150	1860	2	6	0,00471	400	150	200	240	

The schematic diagram of experimental setup is shown in Fig.2. The specimens are simply supported beam in the two side of the beam, and a concentrated load is applied at the mid span of the beam. The load was applied monotonically, and the related deflection occur at the mid span were recorded at specified load interval. After the peak load is achieved, the test was continued until the load dropped to 80% of peak load. At this phase, beam's deflections were recorded too.

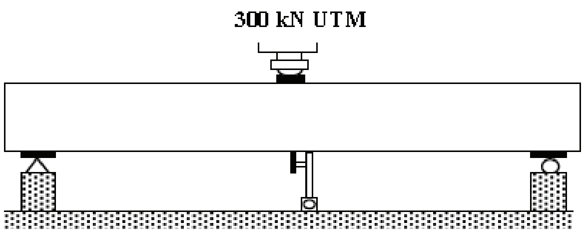


Fig. 2. Schematic Diagram of Experimental Set Up

4. Test Results

All of the beams, which have minimum shear reinforcement required by ACI 318-08, showed flexural-diagonal cracks. Diagonal crack exhibits at the location between concentrated load and support. The higher the concentrated load applied, the more cracking happens in the beam. Fig.3 shows the load-deflection curves for beam Group A, consists of specimens A_1, A_2 and A_3 respectively. Each beam in Group A has closed stirrups shows relatively the same pattern. The highest peak load 3,250 N is achieved by beam number A1. Critical load, P_{cr}, for beam Group A is ranging between 3,050 – 3,150 N, with Δ_{cr} is ranging between 8.00 – 8.50 mm. Maximum deflection measured from the deflection of the beam subjected to 80% of peak load, after the peak load achieved in the experimental. For beam Group A, Δ_{max} is ranging from 17 – 17.50 mm.

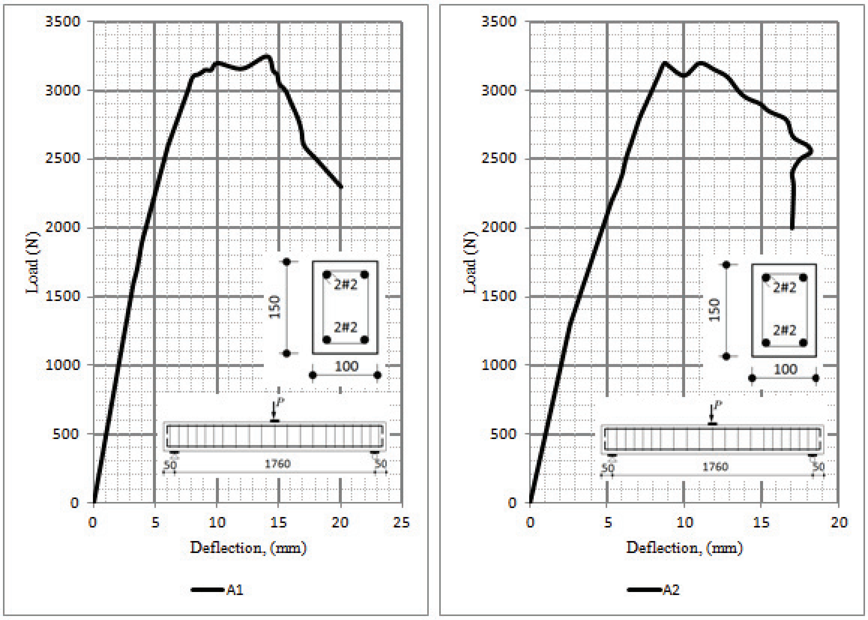


Fig. 3.a. Load-deflection curves of beam Group A

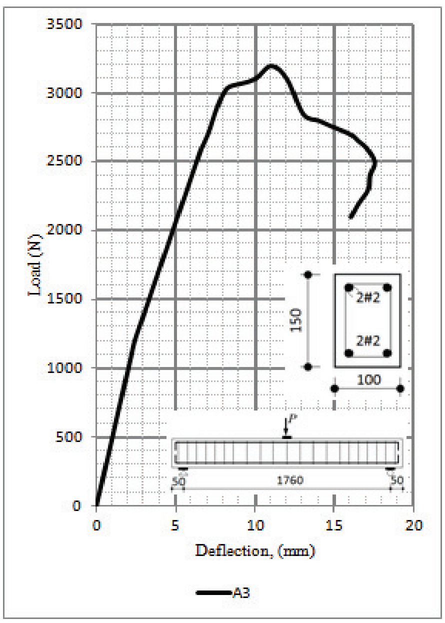


Fig. 3.b. Load-deflection curves of beam Group A

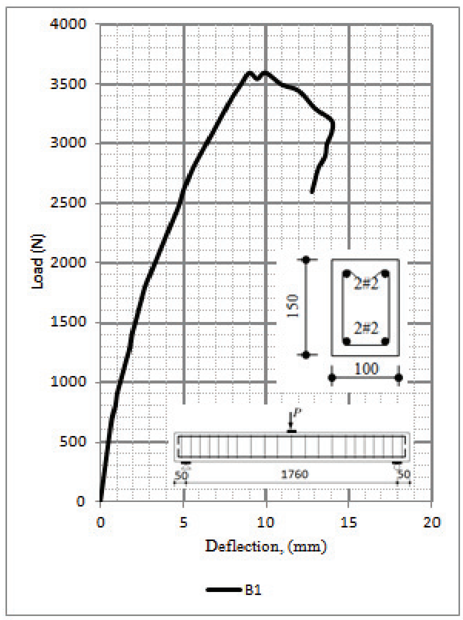


Fig. 4.a. Load-deflection curves of beam Group B

Fig.4 shows the load-deflection curves for beam Group B, consists of specimens B_1, B_2 and B_3 respectively. Each beam in Group B has open stirrups. The highest peak load 3,650 N is achieved by beam number B2. Critical load, P_{cr}, for beam Group B is ranging from the lowest 2,800 N to 3,450 N, with Δ_{cr} is ranging between 5.00 to 8.50 mm. Maximum deflections, Δ_{max} are ranging from 13 – 15 mm.

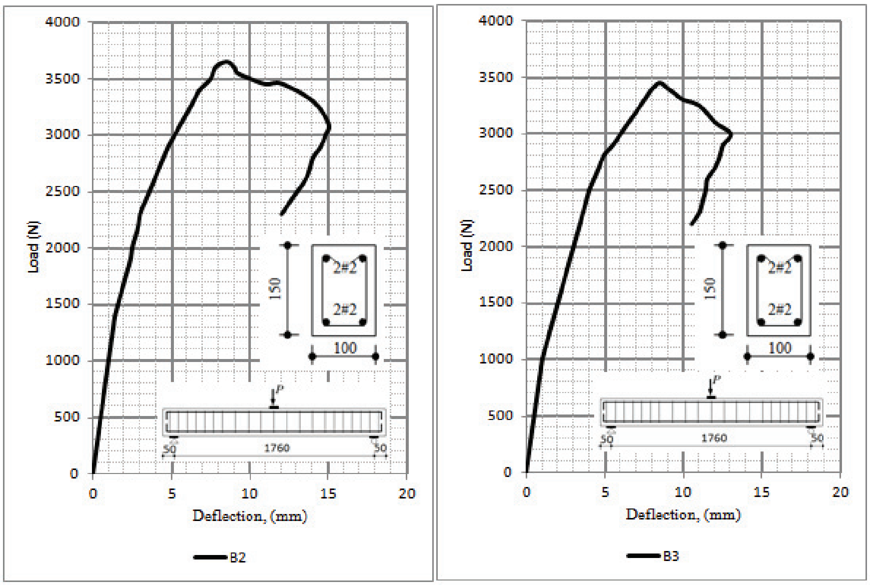


Fig. 4.b. Load-deflection curves of beam Group B

Fig.5 shows the load-deflection curves for beam Group C. Each beam in Group C has open stirrups with horizontal additional bar lies at the top side of the beam. The highest peak load 3,350 N is achieved by beam number C3. Critical load, P_{cr}, for beam Group C is ranging from the lowest 2,850 N to 2,950 N, with Δ_{cr} is ranging between 8.00 to 9.00 mm. Maximum deflection, Δ_{max} is ranging from 15.20 – 17 mm.

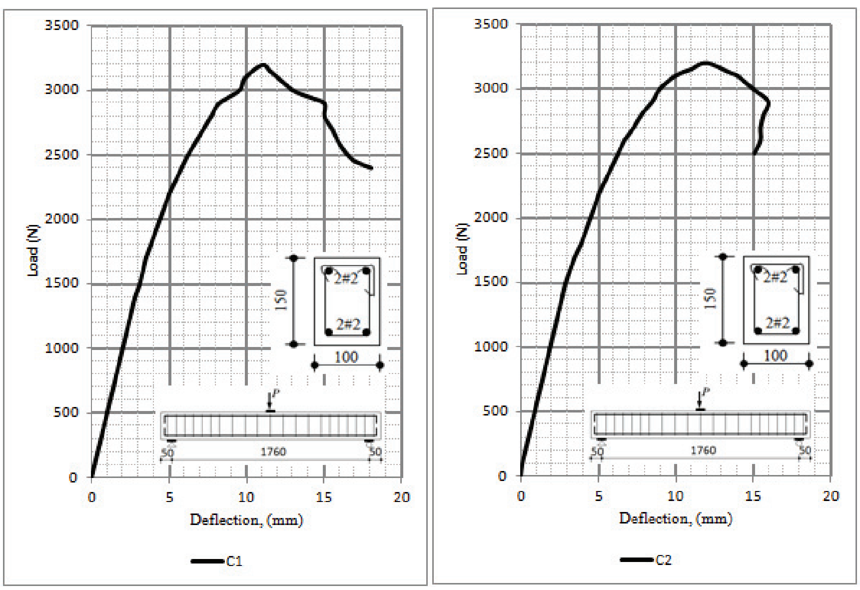


Fig. 5.a. Load-deflection curves of beam Group C

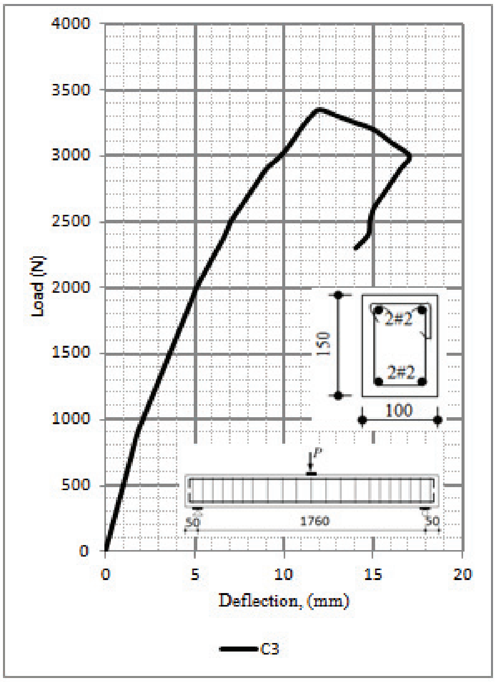


Fig. 5.b. Load-deflection curves of beam Group C

Tabulated result from experimental program for each beam, are listed in Table 2. According to Table 2, there are no significant differences in the critical load that can be support by all of the specimens. The critical load are varying between 2,800 N until 3,400 N, with the average critical load for beam Group A, B and C respectively are 3,100 N, 3,215 N and 2,900 N. Based on these values and considering self weight of the beam, the factored shear force for each group can be calculated using the following expression:

$$V_u = 1.2\left(\frac{q_{sw} \times L}{2}\right) + 1.6\left(\frac{1}{2} \times P_{cr\,avg}\right) \tag{1}$$

Nominal shear strength of the specimens calculated based on ACI 318-08 Code Section 11.2.1.1. It is stated that for member subjected to shear and flexure only, shear strength provided by concrete is:

$$V_c = \frac{1}{6}\sqrt{f'_c}\,b_w \cdot d \tag{2}$$

From P_{cr}, it can be calculated the factored moment applied to the beam using the expression bellow:

$$M_u = 1.2\left(\frac{q_{sw} \times L^2}{8}\right) + 1.6\left(\frac{1}{4} \times P_{cr\,avg} \times L\right) \tag{3}$$

Nominal moment strength of the specimens, calculated using the formula below

$$M_u = A_s \cdot f_y\left(d - \frac{A_s \cdot f_y}{1.70 \cdot f'c \cdot b}\right) \tag{4}$$

Table 2. Test results of reinforced concrete beam

Beams	P_{cr}, (N)	Δ_{cr}, (mm)	P_{peak}, (N)	Δ_{max}, (mm)
A_1	3,100	8.00	3,250	17.50
A_2	3,150	8.50	3,200	17.00
A_3	3,050	8.00	3,200	17.50
B_1	3,450	8.50	3,600	14.00
B_2	3,400	7.50	3,650	15.00
B_3	2,800	5.00	3,450	13.00
C_1	2,850	8.00	3,200	15.20
C_2	2,950	9.00	3,200	16.00
C_3	2,900	9.00	3,350	17.00

Comparison between factored shear force, V_u, and design shear strength, ϕV_c, are tabulated in Table 3. From the table, can be obtain percentage ratio between $V_u/\phi V_c$. According to ACI 318-08 Section 9.3.2.3, the reduction factor, ϕ, for shear strength is 0.75. The table also presented the factored moment, M_u, and the design moment strength, ϕM_n. For tension controlled section, the reduction factor for moment strength is 0.90.

Table 3. Test results of reinforced concrete beam

Beam	V_u, N	ϕV_c, N	$V_u/\phi V_c$	M_u, $N{\cdot}m$	ϕM_n, $N{\cdot}m$	$M_u/\phi M_n$
Group A	2,849.60	6,363.96	0.447	2,345.02	2,292.42	1.023
Group B	2,941.60	6,363.96	0.462	2,425.98	2,292.42	1.058
Group C	2,689.60	6,363.96	0.422	2,204.22	2,292.42	0.961

Table 3 shows that factored shear force, V_u, is less than $0.50\phi V_c$, but the factored moment, M_u, is more than design moment strength of the beam, ϕM_n. It can be concluded that the beam is fail in flexural before the shear failure reached. Or it can be said that the failure behavior is ductile, no brittle failure occurred. According to the deflection requirement stated in ACI 318-08 Section 9.5.3.1, maximum deflection is limited to $l/240$, or for this experimental program is equal to 7.33 mm (length span of the beam from support to support is 1,760 mm). All of the beams were tested beyond this deflection limit. From average peak load that can be achieved by each group of the beam, beam Group A, B and C have their average peak load 3126 N, 3566 N and 3250 N respectively. It can be concluded that there are no more significant differences for shear capacity from each types of shear reinforcement cross section. But open stirrups can be considered as a practical use in the construction field. In the seismic region, however, closed stirrup is a must. The third type of shear reinforcement consists of open stirrups with additional horizontal bar applicable when the beam element must resist some torsion force.

5. Conclusions

In this experimental program, 9 reinforced concrete beams were tested to investigate the effect of different types of shear reinforcement cross sections. Each of the beams has minimum ratio of shear reinforcement and flexural reinforcement. Based on the test results, the following conclusions are drawn:

1. Group A beam with 100 mm width and 150 mm height, reinforced with 2#2 tension bars and closed stirrups from ϕ4 mm @ 150 – 200 mm, and f'_c = 18 MPa, has critical load 3,100 N, resist factored shear force equal to 2,849.60 N ($0.447\phi V_c$) and factored moment equal to 2,345.02 N·mm ($1.023\phi \cdot M_n$). The beam failed in flexural before its shear failure reached. The average value of maximum deflection is 17.33 mm.
2. Group B beam with 100 mm width and 150 mm height, reinforced with 2#2 tension bars and open stirrups from ϕ4 mm @ 150 – 200 mm, and f'_c = 18 MPa, has the highest critical load 3,215 N, resist factored shear force equal to 2,941.60 N ($0.462\phi V_c$) and factored moment equal to 2,425.98 N·mm (1.058 $\phi \cdot M_n$). The beam failed in flexural before its shear failure reached. The average value of maximum deflection is 14 mm.
3. Group C beam with 100 mm width and 150 mm height, reinforced with 2#2 tension bars and open stirrups with additional horizontal bars from ϕ4 mm @ 150 – 200 mm, and f'_c = 18 MPa, has the lowest critical load 2,900 N, resist factored shear force equal to 2,689.60 N ($0.422\phi V_c$) and factored moment equal to 2,204.22 N·mm ($0.961\phi \cdot M_n$).. The beam failed in flexural before its shear failure reached. The average value of maximum deflection is 16.07 mm.
4. No more significant differences for shear capacity from each types of shear reinforcement cross section. But open stirrups can be considered as a practical use in the construction field. In the seismic region, however, closed stirrup is a must. The third type of shear reinforcement consists of open stirrups with additional horizontal bar applicable when the beam element must resist some torsion force

Further experimental program is needed to investigate the influence of higher concrete compressive strength, the influence of longitudinal reinforcement and the *a/d* factor.

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