Optimum Position of Shear Reinforcement of High-Strength Reinforced Concrete Beams

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ABSTRACT

This paper reports experimental data on the behavior and strength of high-strength concrete slender beams reinforced with vertical shear reinforcement. Tests were conducted on ten reinforced concrete beams with stirrups in different positions using high-strength concrete (compressive strength about 85.0 MPa). The beams measured 2000 mm long, 100 mm wide and 200 mm deep, and were tested under two point loads. The test variables were position and amount of web reinforcement; conventional steel bars were used as longitudinal reinforcement in this investigation. The test results indicated that beams with shear reinforcement ($\rho_v fy$ = 1.65 to 4.24MPa) within the shear span (G1) and along the beam length (G2), were failed in flexure, while beams with shear reinforcement ($\rho_v fy$ = 1.65 to 4.24MPa) between two point loads (G3) and the beam without shear reinforcement (G4) were failed in shear. The optimum position of stirrups is the shear span for high strength concrete beams and for different amounts.

Keywords: beams; Concrete; Flexural; High strength; Position; stirrups.

الموقع الامثل لحديد تسليح القص لعتبات خرسانية ذات المقاومة العالية

الخُلاصة

في هذا البحث تم دراسة سلوك ومقاومة عتبات خرسانية ذات المقاومة العالية مع حديد تسليح قص عمودي. تم صب وفحص عشرة نماذج من الخرسانة المسلحة لمواقع مختلفة لحديد القص ومقاومة الانظغاط بحدود ٨٥ ميكاباسكال. ابعاد النماذج كانت ١٥٠ ملم (عرض) و ٢٠٠ملم (عمق) و ٢٠٠٠ملم (طول)، تم فحص النماذج تحت تأثير نقطتين حميل،(Two-Point Loads)، اهم المتغيرات الرئيسية في هذا البحث هي كمية و موقع حديد التسليح القص، واستخدام تسليح اعتيادي للانحناء ولجميع النماذج. اظهرت النتائج بأن نماذج مجموعة (G2,G1) ذات حديد تسبيح قص في منطقة فضاء القص و على طول النموذج فشلت في الانحناء (مقاومة القص كانت عالية)، بينما نماذج مجموعة (G4,G3) فشلت في القص. امثل وافضل موقع لحديد التسليح للعتبات ذات مقاومة خرسانية عالية هي فضاء القص.

INTRODUCTION

The use of high strength concrete(HSC) has increased considerably during the last decade, since it can be produced reliability in the field using low water cement ratios by adding high quality water reducing admixtures. An increase in the strength of the concrete produces an increase in brittleness and smoother shear failure surfaces [(1).]

The use of HSC, with strengths exceeding 50 MPa, is rapidly increasing in bridges, buildings, and other structures due to its superior strength and stiffness. In some instances, however, HSC members exhibit different behavior and direct extrapolation of models and design equations for normal-strength concrete (NSC) members to be applied on HSC members may lead to un conservative design. One feature of HSC that affects the structural response is the tendency of cracks to pass through instead of around the aggregates due to the smaller difference between the strength of aggregate and concrete matrix. This creates smoother crack surfaces, reducing the contribution of aggregate interlock and, hence, reducing shear force carried by the concrete. As a result, higher dowel forces occur in the longitudinal reinforcing bars. These higher dowel forces, together with the highly concentrated bond stresses in HSC beams, result in higher bond-splitting stresses where the shear cracks cross the longitudinal tension bars. These combined effects can ultimately lead to brittle shear failures for beams without shear reinforcement within shear span [(2, 3)].

In General reinforced concrete beams should have adequate shear reinforcement to prevent sudden and brittle failure after formation of the diagonal cracks, and also to keep crack width at an acceptable level. However, there are no established quantitative criteria for reserve strength required beyond cracking strength and limits for the crack width. The minimum shear reinforcement is also required to provide somewhat ductile behavior prior to failure (4, 5).

RESEARCH SIGNIFICANCE

The present experimental investigation examines the optimum position of stirrups of HSC slender beams (a/d = 4.0) on the ultimate shear capacity. The study provides experimental data considering the effect of the shear reinforcement ratio and the location of stirrups for the same concrete strength.

EXPERIMENTAL PROGRAM

Specimen details and materials

Ten reinforced concrete beams were tested under two symmetrically placed concentrated loads. Each beam was 2000 mm long with an overall cross-section of 100x200 mm. All test specimens were simply supported over a span of 1800mm. The tested beams were divided into four series. Table (1) and Fig.[1] give the properties and the details of the tested specimens. All the specimens were designed to show the effect of position and amount of shear reinforcement, a/d of about 4 and main steel reinforcement ratio ($\rho_{w)}$ of about 0.0204.

The three beams in series one (namely, G11 to G13) were provided with varying amount of shear reinforcement ($\rho_v fy$ = 1.65 to 4.24MPa) and stirrups provided within the shear span. The three beams tested in series two (namely G21 to G23) had same shear reinforcement as provided in group one, the stirrups provided in the overall length of the beam. The three beams tested in series three (namely, G31 to G33) had same shear reinforcement as provided in group one, the stirrups provided in the middle span (between point loads). One beam tested in series four (namely, G41) without shear reinforcement.

Ordinary Portland cement, 12.5 mm maximum size of coarse aggregate, sand of 2.64 fineness modulus and mix proportion of about (1 : 1.20 : 1.80), (cement: sand : gravel), with w/c ratio of 0.3 were used throughout tests to obtain concrete with compressive strength greater than 41.4 MPa(HSC). Locally available melamine Plasticizer (Type F) was used conforming ASTM C_{494-86} specifications. Deformed steel bars with 16 mm diameter and yield strength of about 416 MPa were used to provide the main tensile reinforcement. Each beam was reinforced with two bars and hooked at ends as shown in Figure[1]. The amount of reinforcement in each beam corresponded a value of ρ_w =0.0204. Plain steel bars with diameters of 5mm and yield strength (fy) of about 562MPa was used as stirrups.

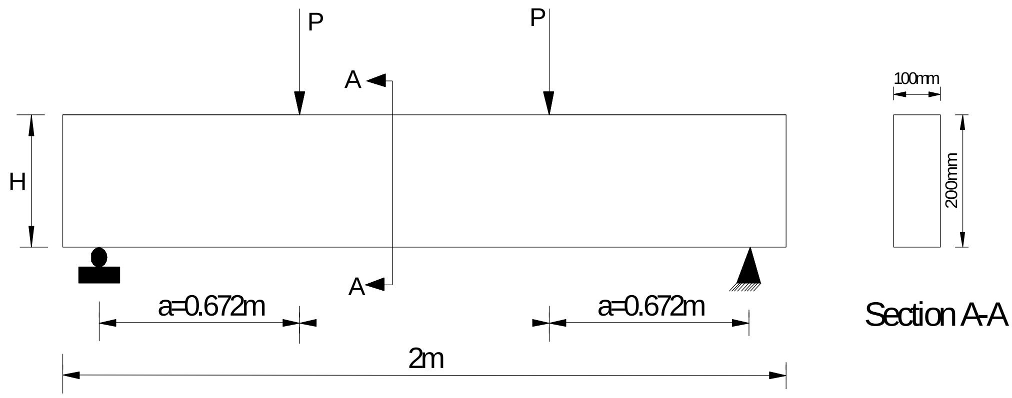
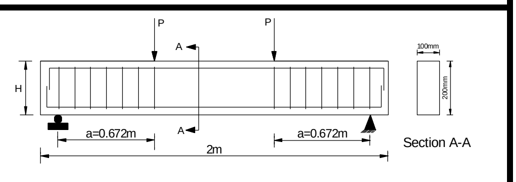
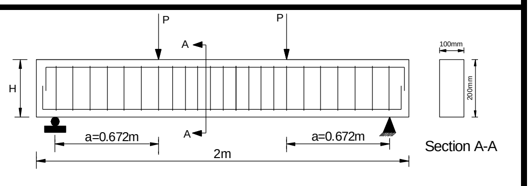
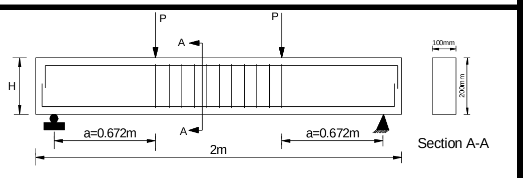
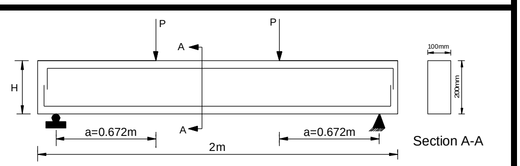


Figure (1)Detail of Tested beams.

Table (1), Detail of Tested Beams and test results.

Group No.	Beams	B mm	d mm	a/d	$\rho_w\%$	$\rho_v f_y$ MPa	f'_c MPa	Cracking Load kN	Ultimate Load kN	Mode of Failure	Position of stirrups
Group 1	G11	100	168	4.0	2.04	1.65	84.32	39.10	117.72	Flexural	
	G12					2.94		39.20	120.66	Flexural	
	G13					4.24		39.14	125.56	Flexural	
Group 2	G21	100	168	4.0	2.04	1.65	85.60	39.20	116.49	Flexural	
	G22					2.94		29.18	117.72	Flexural	
	G23					4.24		39.24	117.72	Flexural	
Group 3	G31	100	168	4.0	2.04	1.65	84.60	39.10	79.65	Shear	
	G32					2.94		39.05	79.95	Shear	
	G33					4.24		39.00	79.95	Shear	
Group 4	G4	100	168	4.0	2.04	---	84.60	39.20	78.48	Shear	

FABRICATION

A rotary mixer of 0.80m^3 capacity was used. Initially the fine and coarse aggregate were poured in the mixer, followed by 25% of the mixing water(water and admixture) to wet them; after words the cement was added and the material were mixed until a uniform color was obtained. Finally the remaining water was added gradually to the mix; the mixing operation was continued until homogenous concrete was obtained.

TESTING

The specimens were simply supported and tested fewer than two symmetrical point loads (using universal testing machine, type Marue Mie, maximum capacity of 50ton, No. 19258-Japan). Loads and reactions were applied through rollers and bearing blocks to allow free rotation and horizontal movement of the end supports. Deflections were measured at centre of the span using dial gauge of 0.01mm accuracy with a maximum travel of 30mm.

An incremental stage loading was applied in order to obtain a continuous view of the performance of each beam. The deflection was recorded at each load stage and a search was made for cracks and their extensions. Cracking load was recorded and the loading was continued until failure. The failure load was recorded and finally some photographs were taken to show the crack patterns.

RESULTS OF THE TESTED SPECIMENS AND DISCUSSION

Test results of ten high strength concrete beams and their crack patterns are included to study the effect of position and amount of shear reinforcement on the ultimate shear /flexural stress and behavior of such beams.

Crack Patterns and Modes of Failure

Cracks in the concrete beams are formed generally in regions where tensile stresses exist and exceed the specified tensile strength of concrete. Two types of cracks were observed in the tested beams; the flexural cracks which resulted due to flexural tensile stresses in the region of the beam cross-section below the neutral axis for positive bending and shear cracks which are formed as a result of the inclined or "principal" tensile stresses acting on the web of the beam in the region of combined bending and shear, typical crack patterns of the tested beams are shown in Figure(2).

Figure (2), Crack pattern of reinforced concrete beams

Beams in group 1 and 2 (stirrups within the shear span and along the beam length), when the load on such beams increased from zero to the magnitude that will cause the beam to fail, several stages of behavior can be clearly distinguished. At low loads, as long as maximum tensile stress in the concrete smaller than the modulus of rupture, the entire concrete is effective in resisting stress in compression in one side and in tension on the other side of the natural axis. In addition, the reinforcement, deforming the same amount at the adjacent concrete, is also subjected to tensile stresses. At this stage, all stresses in the concrete are of small magnitude and are proportional to strains. The distribution of strains and stresses in concrete and steel over the depth of the section is in elastic range.

When the load is further increased, the tensile strength of concrete is soon reached, and at this stage tension cracks develop, these propagate quickly upward to or close to the level of neutral plan, which in turn shifts up ward with progressive cracking. The width of these cracks is so small (hair line cracks), in a cross section located at crack, the concrete does not transmit any tensile stresses. At moderate loads (concrete stresses exceed about 0.5 f`c), stresses and strains rise correspondingly and are no longer proportional. At final stage, when the carrying capacity of the beam is reached(flexural steel reach its yield point and shear reinforcement resisting more), at that stress, the reinforcement yields suddenly and stretches a large amount, and the tension cracks in the concrete widen visibly and propagate upward, with simultaneous significant deflection of the beam.

Beams in group 3 and 4, they had the same behavior up to cracking load, since the stirrups within middle span(G3) not contributing the resistance and the shear stress carried only by the concrete, all beams were failed in shear – compression or shear tension according to the following sequence:

1- Vertical shear-flexural cracks formed at the shear span.

2- The crack propagation continued towards the point load, approaching the compression zone.
3- As the load increased, the cracks extended in two directions; the first towards the compression zone and the second followed a horizontal path at the reinforcement level towards the supports.
4- Crack propagation continued until it reached the point load region, after which the beam carried further loads without much cracking. Finally the crack extended in the compression zone towards the pure moment region and beyond the point load or extended in the tension zone towards the supports causing failure.

Load Deflection Relationship

Beams in group 1 and 2, the resisting tensile strength within the shear span greater than the flexural cracking stress (for all amounts of shear reinforcement), then the flexural failure occurred at ultimate loading. The load deflection of beams in group 1 and 2 are shown in Figure (3) and Figure(4).

At the early stages of loading, the beams in group 3 and 4 behaved in an elastic manner up to about (60 – 80) percent of the ultimate load depending on the amount of shear reinforcement as shown in the Figure(5), then followed by increasing deformation until the ultimate load was reached. The curves indicate no improvement in beam ductility with an increase in the amount of shear reinforcement, i.e. stirrups not located in the shear span did not carry loads.

In all specimens diagonal shear cracks were observed first at or near the support. They were initiated along a line joining the loading and reaction points. All the beams developed such cracks.

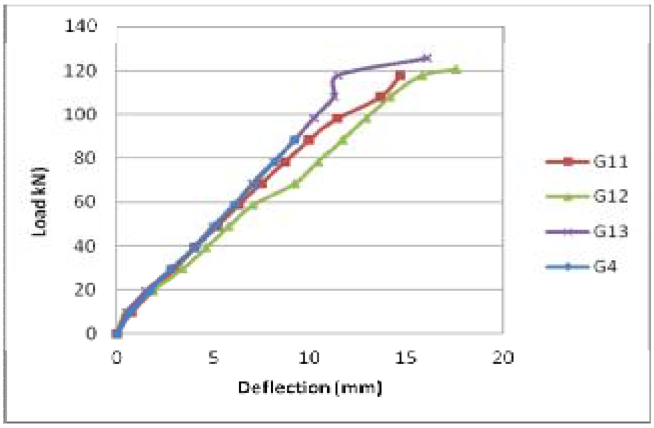


Figure (3), Load Deflection Curve for Group 1.

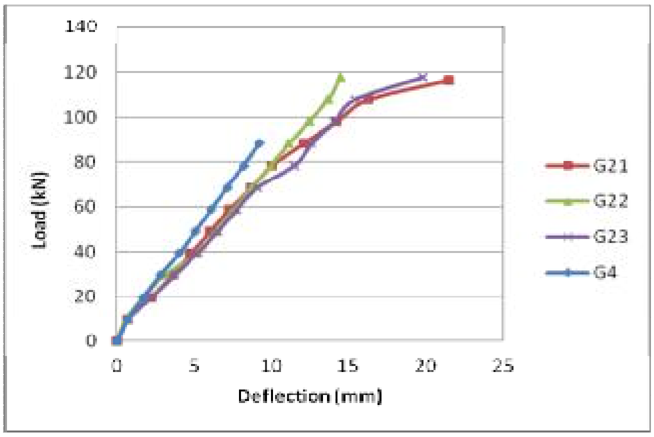


Figure (4), Load Deflection Curve for Group 2.

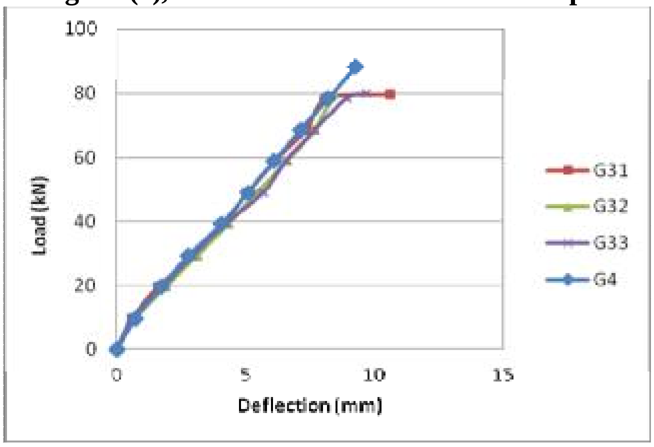


Figure (5), Load Deflection Curve for Group 3.

Effect of shear reinforcement on the cracking and ultimate load capacity shown in Figures(6, 7 and 8). As shown by increasing $\rho_v$fy from 1.65 to 4.24MPa, the cracking load does not affect, the ultimate load also does not affected significantly, since beams in group 1 and 2 failed in flexure and beams in group3 and 4 are without shear reinforcement. The strength of flexural members without web reinforcement is identified by the formation of the critical inclined crack and the subsequent sudden drop in load carrying capacity. In general, for members with shear span to- depth ratio greater than 2.5, the difference between the critical inclined cracking and the ultimate capacity is small. Therefore, for such members, the inclined cracking shear capacity can be assumed to be the same as the ultimate shear capacity for all practical purposes, In addition, shear strength at ultimate failure is a more defined and reliable measure than cracking shear strength.

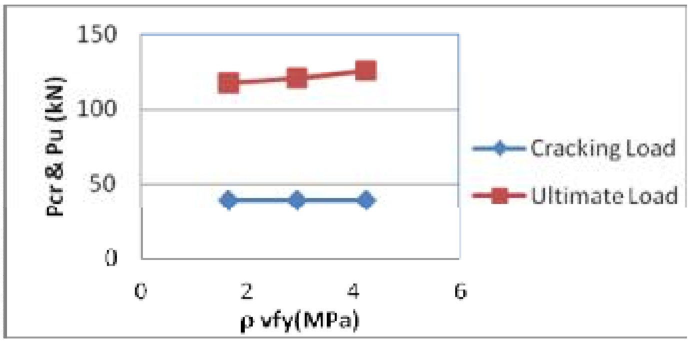


Figure (6), Cracking and Ultiamte Load Versus $\rho_v f_y$ (Group 1).

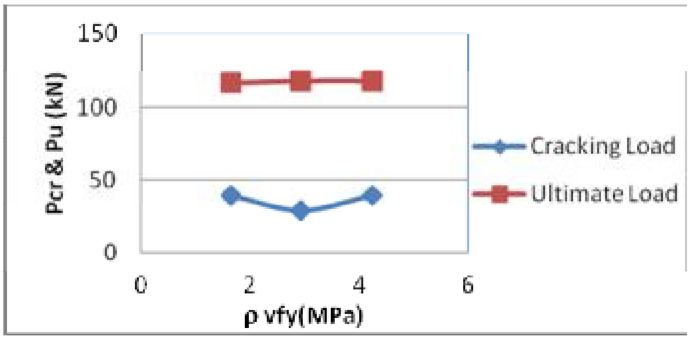


Figure (7), Cracking and Ultiamte Load Versus $\rho_v f_y$ (Group 2).

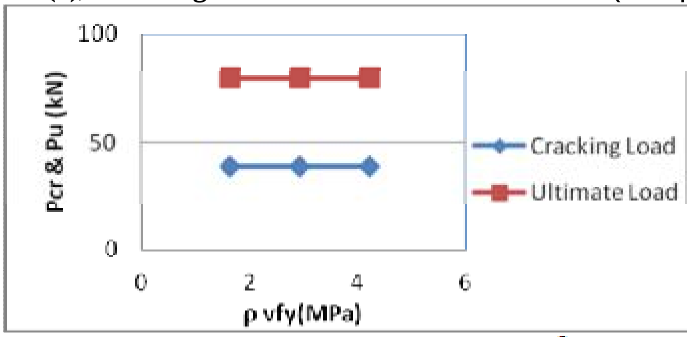


Figure (8), Cracking and Ultiamte Load Versus $\rho_v f_y$ (Group 3 & 4).

CONCLUSIONS

Based on tests of high strength concrete beams with web reinforcement, the following conclusions are made:

1. For the same cross-section, l/d ratio, a/d ratio and main reinforcement, the ultimate load capacity does not affect by increasing the vertical stirrup nominal shear strength from 1.65 to 4.24MPa.

2. When shear reinforcement provided within the shear span, beams fail in flexure (beams in group 1).
3. For beams with shear reinforcement within the shear span and along the length of the beam, all the beams fail in flexure (beams in group 2).
4. Beams with shear reinforcement between two point loads (beams in group3) and without shear reinforcement (beam in group 4), all the beams fail in shear and they had the same properties.

ACKNOWLEDGEMENT

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NOTATION

a : Shear span, distance between concentrated load and face of support, mm.
a/d : Shear span to depth ratio.
A_s : Area of tension reinforcement, mm^2.
b : Width of the beam, mm.
d : Effective depth of the beam, mm.
f_c\` : Compressive strength of concrete based on ASTM specifications, MPa.
f_y : Yield strength of steel reinforcement, MPa.
h : Overall depth of the beam, mm
l : Clear span of the beam, mm
l/d : Clear span to effective depth ratio.
M_u : Ultimate moment of the section, kN. m.
v_u : Ultimate shear stress of reinforced concrete beams, MPa.
ρ_w : Reinforcement ratio of the main steel.
$\rho_v fy$: Shear stress of vertical and horizontal stirrups.

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