Effect of Type and Position of Shear Reinforcement of High-Strength Reinforced Concrete Deep Beams

Dr.Omar Qarani Aziz(Assist Prof.), Dr.Sinan Abdulkhaliq Yaseen
Civil Engineering Dept. / College of Engineering / University of Salahaddin-Hawler

Abstract

This paper reports experimental data on the behavior and strength of high-strength concrete deep beams reinforced with shear reinforcement. Tests were conducted on eight reinforced concrete deep beams with stirrups in different type and positions using high-strength concrete (compressive strength of about 85.0 MPa). The beams measured 1400 mm long, 100 mm wide and 300 mm deep, and were tested under two point loads. The test variables were type and position of web reinforcements [Shear stress of vertical stirrups ($\rho_v fy$), Shear stress of horizontal stirrups ($\rho_h fy$) and Shear stress of inclined stirrups ($\rho_\alpha fy$)] within shear span, within middle span(between two point loads) and along the beam. Conventional steel bars were used as longitudinal reinforcement in this investigation. The test results indicated that beams with vertical and inclined shear reinforcement within the shear span (B4) resisting the ultimate load of about 417.90kN. While beams with horizontal shear reinforcement (B3), shear reinforcement between two point loads (B7), and the beam without shear reinforcement (B8) resisting, 255.77, 260.18 and 250.55kN respectively. All the beams failed in shear and the optimum position of stirrups is the shear span for high strength concrete deep beams and with combination of vertical and inclined stirrups.

Keywords: Concrete; Deep beams; High strength; Position; Shear; Stirrups.

تأثيرالنوع و الموقع لتسليح القص على سلوك و مقاومة القص للعتبات الخرسانية العميقة و ذات المقاومة العالية

أ.م.د. عمر قره نى عزيز د سنان عبدالخالق ياسين
قسم الهندسة المدنية / كلية الهندسة / جامعة صلاح الدين / أربيل

الخلاصة

فى هذا البحث تم صب و فحص 8 عتبات خرسانية عميقة و ذات المقاومة العالية (بحدود 85 ميكا باسكال) لدراسة النوع و الموقع المثالي لتسليح القص ,جميع العتبات لها نفس نسبة التسليح الطولى تقريبا "و هذه النسبة كانت 2,34 % " و ذلك لتفادى فشل الانحناء، نسبة فضاء القص الى العمق للنماذج كانت بحدود 1.5، طول العتبة 1400ملم، عمق 300ملم و عرض 100ملم. تم فحص النماذج لثلاثة مواقع من تسليح القص (منطقة القص، وسط العتبة و على طول العتبة) و لثلاثة انواع من تسليح القص(العمودى و ألافقى والمائل) بالاضافة الى نموذج بدون حديد تسليح القص .أظهرت النتائج بان نمذج ذات حديد تسليح القص العمودى و المائل في منطقة القص(B4) لها مقاومة الحمل 417.9 كيلو نيوتن. بينما عتبات ذات حديد تسليح القص الأفقي(B3). و حديد تسليح القص بين نقطتي التحميل (B7) و نموذج بدون حديد تسليح القص (B8) تحملت.255.77، 260.18 و 250.55 كيلو نيوتن على التوالى.نوع افشل لجميع النماذج كانت فشل القص. الموقع المثالي لحديد القص هي منطقة القص لعتبات خرسانية عميقة وذات المقاومة العالية.

Received: 31 – 10 - 2012 Accepted: 25 – 3 - 2013

Introduction:

Deep beams are defined as members loaded on one face and supported on the opposite face, so that compression struts can develop between the loads and the supports. Moreover, deep beams have either ($\frac{l_n}{h}$) ≤ 4.0 , for distributed load case or ($\frac{a}{d}$) ≤ 2.0 for points load case [1]. A typical sketch of a deep beam is shown in Fig. (1)

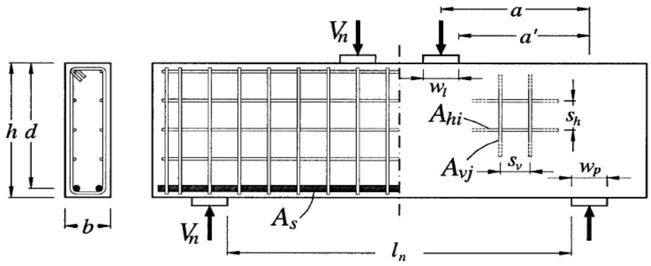


Fig.(1), Typical sketch of a deep beam

Stephen J. Foster and R. Lan Gilbert (1998)[2]. In his study, 16 high-strength concrete deep beams were tested. Variables considered in the investigation are shear-span to depth ratio, concrete strength (50 to 120 MPa), and the provision of shear reinforcement. The investigation examines deep beam behavior and compares the experimental results with the ACI 318 method and other methods. The results of the investigation show that the design methods given ACI 318 generally conservative for deep beams fabricated with high-strength concrete.

A. F. Ashour (2000)[3]. A numerical method of estimating the shear capacity of RC deep beams is proposed. Deep beams are considered to be in a state of plane stress. The concrete and steel reinforcement are assumed to be rigid perfectly plastic. Shear failure mechanisms are idealized as assemblage of moving rigid blocks separated by yield lines. Good agreement is observed between the predicted shear capacity and experimental results. The proposed model shows that the shear capacity is influenced by the shear span but not the beam span, contrary to the difinition of deep beams in most codes of practice. The model predicts that the shear capacity increased with increasing shear span to depth ratio from 2 to 0.5. in the case of deep beams without web reinforcement, a linear increse of the shear capacity is observed with increase in the main longitudinal bottom steel up to a sertain value byond which no shear capacity improvement could be achieved.

Omar Q. Aziz(2005)[4]. Twelve high strength fibrous reinforced concrete beams (HSFRCDB) were tested under two point loading. All the specimens were reinforced with main steel reinforcement ratio of about (2.4%) to avoid flexural failure of beams, (a/d) ratio was about (2) and the volume fraction of steel fibers was (0.5 %). The variables were; the vertical stirrups nominal strength ($\rho_v f_y$), ranging from 0.15 to 4.44 MPa, horizontal stirrups nominal strength ($\rho_h f_y$), ranging from 0.4 to 3.63 MPa and vertical and horizontal (combination) stirrups nominal strength ($\rho_{vh} f_y$), ranging from 2.57 to 8.07MPa. In his study, the results showed that the horizontal stirrups has little influence on the magnitude of failure load and the researcher proposed imperical equations for estimatingthe shear strength of deep beams and compared with several codes and works of investigators, the result of comparison of 244 high and normal strength concret deep beams with stirrups showed lowest standar deviation, COV and conservatives predictions for the proposed equations. The proposed equations were;

$$V_u = 0.85(V_c + V_s) \quad \text{------------- (1)}$$

$$V_c = 1.51[\frac{(f'_c \rho_w (1+F) bd)}{l\, a}]^{0.46} \quad \text{-------------- (2)}$$

$$V_s = \rho_v f_y + \rho_h f_y \quad \text{-------------- (3)}$$

F (Fiber factor) = $(l_f / d_f V_f \beta)$, *β=0.75for deformed steel fibers.*

Xiangguo Wu and Sang-Mook Han (2009)[5]. Eleven girders were cast and tested to predict the first diagonal crack and ultimate shear load of reinforced girder made of ultra-high performance fiber reinforced concrete (UHPFRC) in which eight girders failed in shear. A simplified formulation for the first diagonal cracking load was proposed. An analytical model to predict the ultimate shear load was formulated based on the two bounds theory (upper and lower). The predicted values were compared with the conventional predictions and the test results. The proposed equation can be used for the first cracking status analysis.

$$V_c = \frac{\xi}{\sqrt{\lambda(1+\lambda)}} (\frac{b_w}{d})^{0.5} f_{ck} b_w d \quad \text{----------- (4)}$$

Where;

ξ is the fiber volume fraction effective coefficient and $\xi = 5.08 V_f^{\,0.2}$

λ is the shear span ratio and $\lambda = a / d$ in which a is the half shear span and d is the girder depth. $f_{ck}$is the normal compressive strength of UHPFRC. $b_w$is the girder web width. $V_f$is the fiber volume fraction.

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 [6,7].

The use of HSC 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 [8, 9].

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 [1, 10].

Research Significance

The present experimental investigation examines the effect of type and position of stirrups of HSC deep beams (a/d = 1.5) 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

Eight reinforced concrete beams were tested under two symmetrically placed concentrated loads. Each beam was 1400 mm long with an overall cross-section of 100x300 mm. All the tested specimens were simply supported over a span of 1200mm. Fig.2 and Table 1 give the properties and the details of the tested specimens. All the specimens were designed to show the effect of type and position of shear reinforcement, a/d of about 1.50 and main steel reinforcement ratio ($\rho_{w})$ of about 0.0234.

The beam B1 was provided with vertical shear reinforcement ($\rho_v fy$ = 2.223MPa), beam B2 with vertical and horizontal shear reinforcement ($\rho_v fy$ = 2.223MPa and $\rho_h fy$ = 2.96MPa), beam B3 with horizontal shear reinforcement ($\rho_h fy$ = 2.96MPa), beam B4 with vertical and inclined shear reinforcement ($\rho_v fy$ = 2.223MPa and ($\rho_\alpha fy$ = 2.223MPa), beam B5 with inclined shear reinforcement ($\rho_\alpha fy$ = 2.223MPa). The beams (B1 to B5) stirrups were provided within the shear span. Beam B6 with vertical shear reinforcement ($\rho_v fy$ = 2.223MPa) and stirrups provided along the beam length. Beam B7 with vertical shear reinforcement ($\rho_v fy$ = 2.223MPa) and the stirrups provided in the middle span (between point loads). One beam (B8) tested without shear reinforcement.

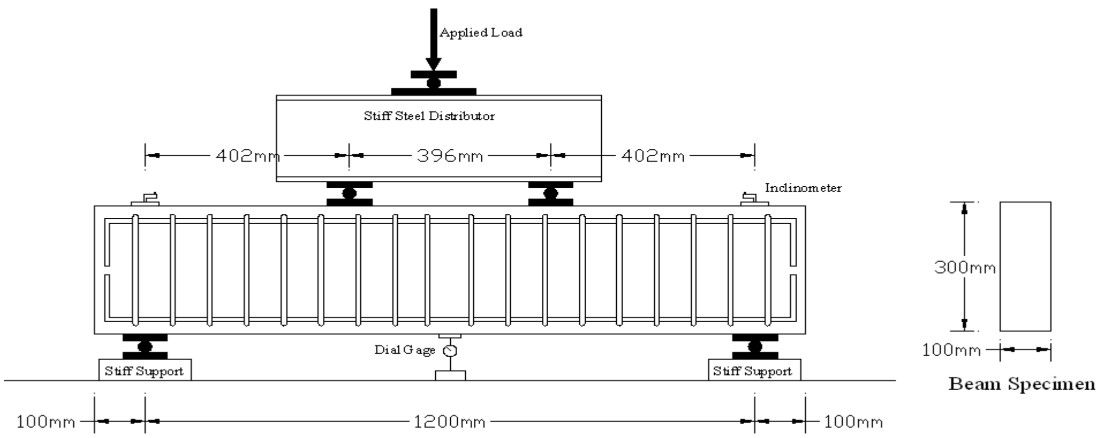
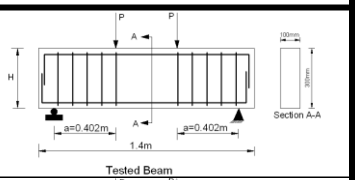
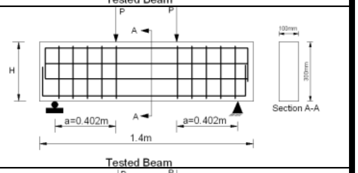
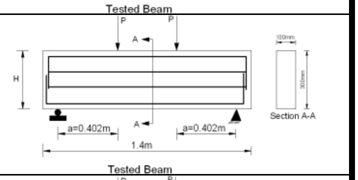
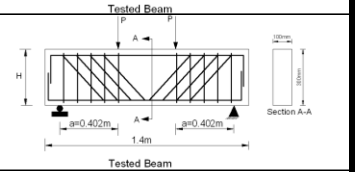
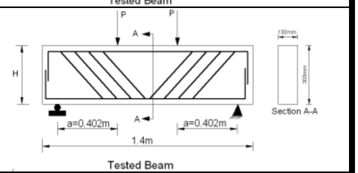
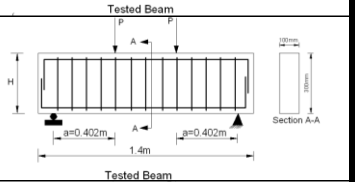
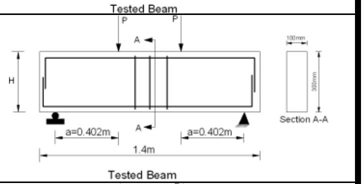
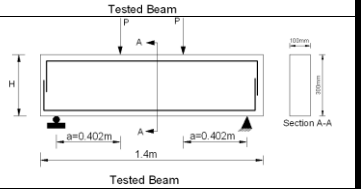


Fig. (2) Details of Tested Specimens

Table 1, Detail of Tested Beams

Beams	b mm	d mm	a/d	ρ_w %	Vert $\rho_v f_y$ MPa	Horiz $\rho_h$fy MPa	Incl. $\rho_\alpha f_y$ MPa	Remark DRAWINGS
B1	100	268	1.5	2.34	2.223	---	---	
B2	100	268	1.5	2.34	2.223	2.96	---	
B3	100	268	1.5	2.34	---	2.96	---	
B4	100	268	1.5	2.34	2.223	---	2.223	
B5	100	268	1.5	2.34	---	---	2.223	
B6	100	268	1.5	2.34	2.223	---	---	
B7	100	268	1.5	2.34	2.223	---	---	
B8	100	268	1.5	2.34	---	---	---	

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 0.30 were used throughout tests to obtain concrete with compressive strength more than 80 MPa. 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 Fig.2. The amount of reinforcement in each beam corresponded a value of ρ_w =0.0234. Plain steel bars with diameters of 5mm and yield strength (fy) of about 562MPa was used as stirrups.

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 under two symmetrical point loads (using universal testing machine, type Marue Mie, maximum capacity of 50tons, 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.

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

Results of the Tested Specimens and Discussion

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 Fig. 3.

All the 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

At the early stages of loading, the beams 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 Figs.4 and 5, then followed by increasing deformation until the ultimate load was reached. The curves indicate that, vertical and horizontal stirrups, vertical and inclined stirrups improve ductility. Beams with shear reinforcement within the shear span had resisted the ultimate shear capacity more than the others.

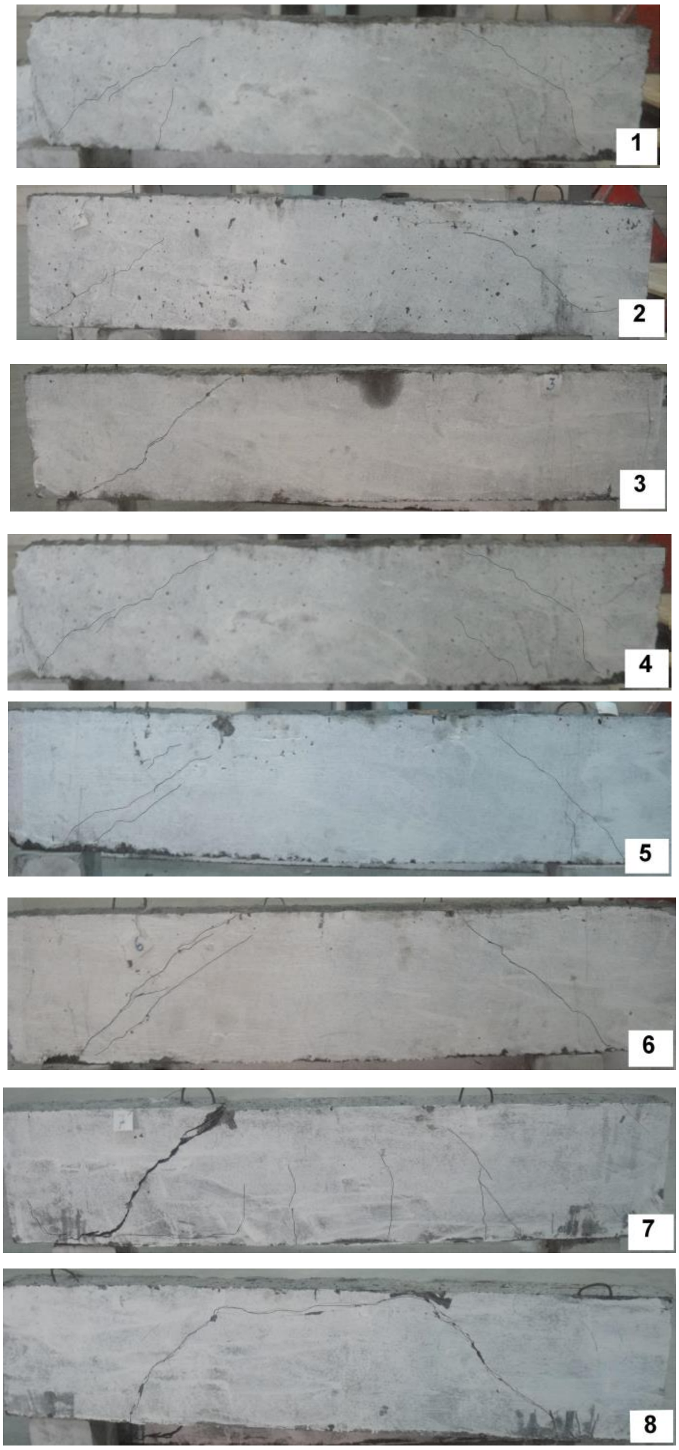


Fig. 3, Crack pattern of reinforced concrete beams

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 and behaved essentially as tied arches until collapse. Effect of type and position of shear reinforcement on the shear strength shown in Figs.6, 7, 8 and 9. As shown by increasing $\rho_v fy$, $\rho_h fy$, $\rho_\alpha fy$, $\rho_v fy+\rho_\alpha fy$ and $\rho_v fy+\rho_h fy$ (bemas B1 to B5), the shear strength improved, by increasing 2.23MPa vertical shear stress($\rho_v fy$), and2.23MPa vertical shear stress(ρ_α fy), the ultimate shear strength increased by 26.8 and 27.2% respectively, while horizontal shear stress increased by only2%. It is also clear that the vertical and inclined stirrups are more effective than the horizontal stirrups. Beam B6 (stirrups along the beam length) behaved same as B1 (with vertical stirrup only), while beam B7 behavior same as beam B8 (without shear reinforcement).

Cracking and Ultimate Shear Stresses

Cracking shear strength (V_{cr}) or diagonal cracking strength is defined here as the shear strength at which an inclined crack was formed within the shear span traversing the centroidal axis of the beam. As shown in Table 2 and Figs. 6, 7, 8 and 9, the shear strength was observed to increase almost linearly with increase in the amount of shear reinforcement. The increase in the ultimate shear strength is attributed to the types of shear transfer mechanisms. One of the characteristics of high strength concrete members loaded to failure is that it fractures suddenly and forms a smooth failure surface. In order to prevent the brittle failure, the minimum shear reinforcement suggested by codes of practice should be increased with the concrete compressive strength. Shear reinforcement resists very little shear prior to inclined cracking. When diagonal cracks forms, shear reinforcement starts to carry a portion of the shear stress. As the amount of shear reinforcement increases, the shear failure becomes more ductile and less sudden. The required minimum shear reinforcement should be increased as the concrete compressive strength increases [10].

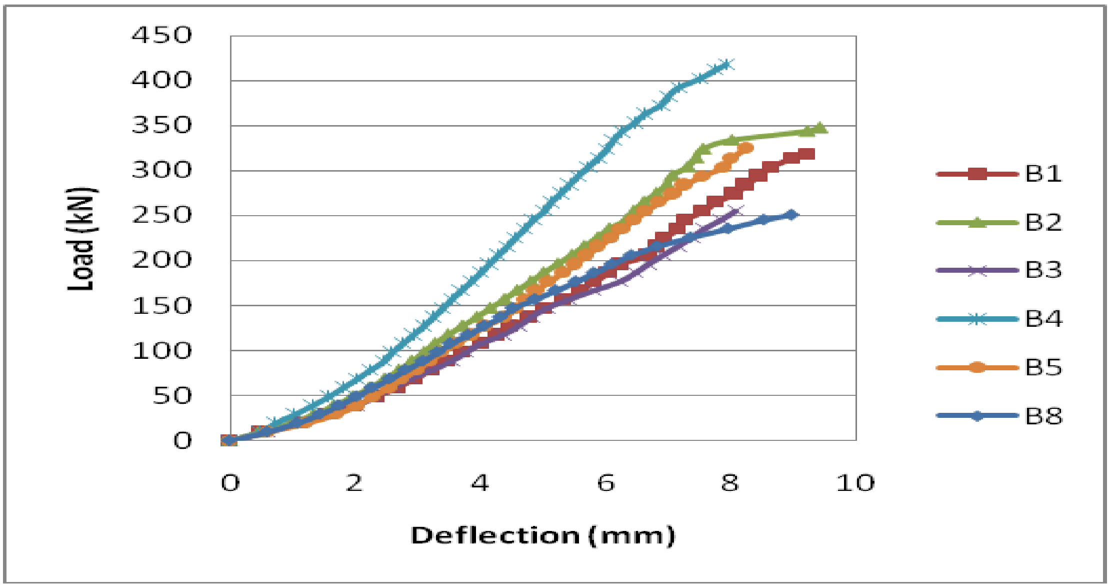


Figure 4, Load Deflection Curve for Beams B1 to B5,B8

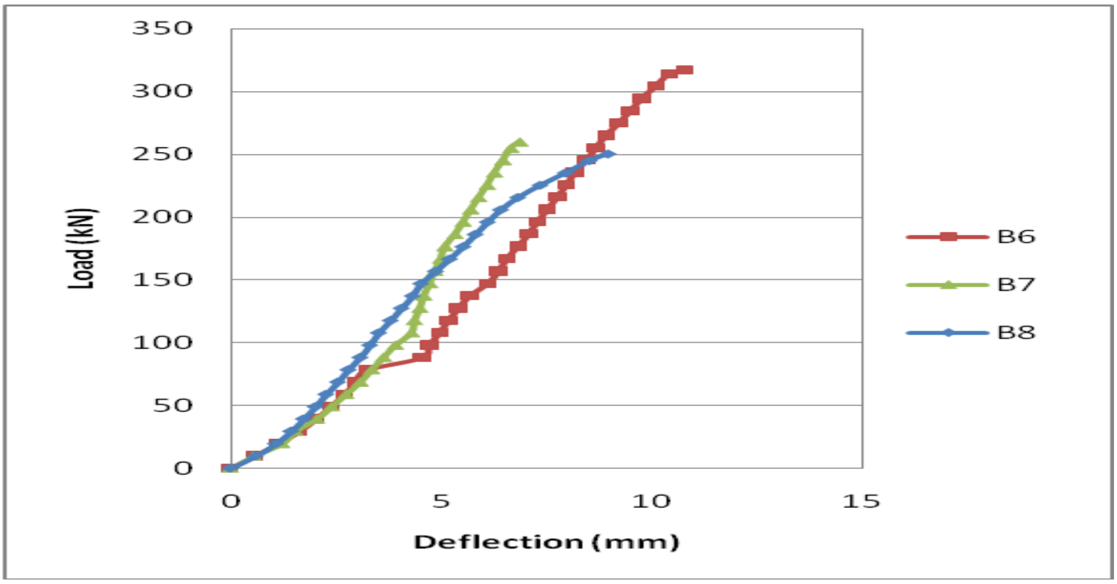


Figure 5, Load Deflection Curve for Beams B6,B7, B8

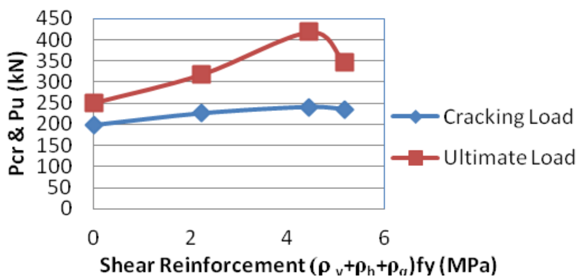


Figure 6, Cracking and Ultiamte Load Versus Shear reinforcement for (B1,B2,B4, B8)

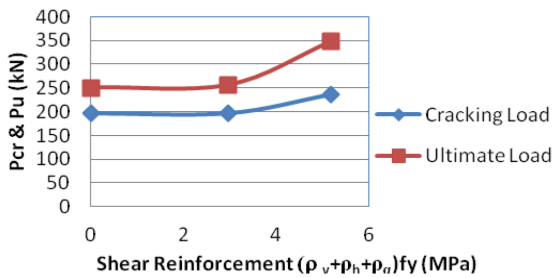


Figure 7, Cracking and Ultiamte Load Versus Shear reinforcement for (B2,B3, B8)

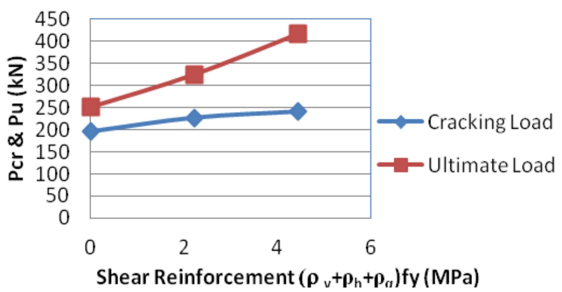


Figure 8, Cracking and Ultiamte Load Versus Shear reinforcement for (B4,B5, B8)

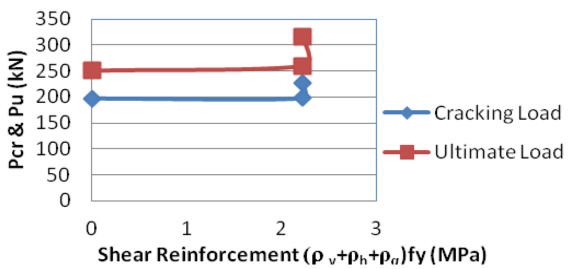


Figure 9, Cracking and Ultiamte Load Versus Shear reinforcement for (B6,B7, B8)

Table 2 Results of Tested Beams

Beams	ρ_w%	Vert. $\rho_v f_y$ MPa	Horiz. $\rho_v f_y$ MPa	Incl. $\rho_\alpha f_y$ MPa	f'_c MPa	Cracking Load kN Flexural	Cracking Load kN Shear	Ultimate Load kN	Mode of Failure
B1	2.34	2.223	---	---	84.32	169.20	225.63	317.84	Shear
B2	2.34	2.223	2.96	---	84.32	176.10	235.32	347.27	Shear
B3	2.34	---	2.96	---	84.32	147.91	197.66	255.77	Shear
B4	2.34	2.223	---	2.223	85.60	156.96	240.82	417.90	Shear
B5	2.34	---	---	2.223	85.60	167.72	227.47	325.09	Shear
B6	2.34	2.223	---	---	85.60	156.96	226.69	316.86	Shear
B7	2.34	2.223	---	---	84.60	148.29	197.86	260.18	Shear
B8	2.34	---	---	---	84.60	147.91	197.47	250.55	Shear

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 improved by increasing the stirrups, amount of improvement depend on the type and amount of shear reinforcement.
2. When adequate longitudinal reinforcement provided, all the beams fail in shear.
3. The beam with shear reinforcement within the shear span(B1), it is behavior under the load like the beam with shear reinforcement along the length(B6).
4. The beam with shear reinforcement between two point loads (B7) has the same properties with the beam without shear reinforcement (B8.
5. It was observed that the concrete contribution to shear resistance reinforced concrete deep beams with shear reinforcement is noticeably larger than that in beams without shear reinforcement, and therefore most current shear design procedures provide conservative predictions for the shear strength of reinforced concrete deep beams with shear reinforcement.
6. The improvement in the effect of longitudinal steel reinforcement on the shear capacity of beams with stirrups is believed to be due to the fact that stirrups help confine the longitudinal steel bars in place, thus preventing shear cracks from widening, and therefore allowing an increase in dowel action.
7. High strength concrete deep beams loaded to failure, its fracture suddenly and forms a smooth failure surface. In order to prevent the brittle failure, the minimum shear reinforcement suggested by codes of practice should be increased with high concrete compressive strength.

Acknowledgement

The experimental work reported in this study was carried out at the Department of Civil Engineering, University of Salahaddin, Erbil, Iraq. The assistance of Mr. Mohammad in conducting the testing program is gratefully acknowledged.

Notation

a : Shear span, distance between concentrated load and face of support, mm.
a/d : Shear span to depth ratio.
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.
l/d : Clear span to effective depth ratio.
M_u : Ultimate moment of the section, kN. m.
V_u : Ultimate shear strength of reinforced concrete beams, MPa.
ρ_w : Reinforcement ratio of the main steel.
ρ_v fy : Shear stress of vertical stirrups.
ρ_h fy : Shear stress of horizontal stirrups.
ρ_α fy : Shear stress of inclined stirrups.

References:

[1] ACI 318M-11, "**Building Code Requirements for Structural Concrete and Commentary**", Reported by ACI Committee 318, 2011.

[2] Stephen J. Foster and R. Ian Gilbert, "**Experimental Studies on High-Strength Concrete Deep Beams",** ACI Structural Journal, V. 95, No. 4, July-August 1998, pp. (382-390).

[3] A. F. Ashour, "**Shear Capacity of Reinforced Concrete Deep Beams**", Journal of Structural Engineering, V. 126, No. 9 September 2000, pp. (1045-1052).

[4] Omer Qarani Aziz, "**Shear Strength Behavior of High Strength Fibrous R.C. Deep Beams With Stirrups",**Journal of Engineering Technology, Baghdad, V. 24, No.5, 2005.

[5] Xiangguo Wu and Sang-Mook Han, "**First Diagonal Cracking and Ultimate Shear of I-Shaped Reinforced Girders of Ultra High Performance Fiber Reinfored Concrete without Stirrup**", International Journal of Concrete Structures and Materials, Vol/3, No.1, June 2009, pp.(47-56).

[6] Antoni C.Bohigas and Antoio R. Mari Bernat "**Shear Design of Reinforced High Strength Concrete Beams**" Doctorial thesis, Barcelona, December 2002.

[7] Yoon, Y. S.; Cook, W. D.; and Mitchell, D., "**Minimum Shear Reinforcement in Normal, Medium, and High-Strength Concrete Beams**," ACI Structural Journal, V. 93, No. 5, Sept.-Oct. 1996, pp. 576-584.

[8] Johnson, M. K., and Ramirez, J. A., "**Minimum Shear Reinforcement in Beams with Higher Strength Concrete**," ACI Structural Journal, V. 86, No. 4, July-Aug. 1989, pp. 376-382.

[9] Guney Ozcebe, Ugur Ersoy, and Tugrul Tankut, "**Evaluation of Minimum Shear Reinforcement Requirements for Higher Strength Concrete**," ACI Structural Journal, V. 96, No. 3, May-June 1999, pp. 361-369.

[10] Yehia Anis Daou and Hassan Ghanem," **Study of the minimum shear reinforcement in high strength concrete Beams**" Alexandria Engineering Journal, Vol. 42, No. 4, July 2003, pp. 601-615.

The work was carried out at the college of Engineering. University of Salahaddin, Erbil, Iraq