*Journal of Engineering Sciences, Assiut University, Vol. 37, No. 6, pp.1369-1387, November 2009.*

# EXPERIMENTAL STUDY ON STATIC SHEAR BEHAVIOR OF HIGH STRENGTH CONCRETE BEAMS AS COMPARED WITH NORMAL STRENGTH CONCRETE BEAMS.

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*(Received September 8, 2009 Accepted October 11, 2009)*

*In the current study, nineteen reinforced concrete beams were tested to investigate the static shear behavior of high strength concrete beams as compared with normal strength concrete beams. The concrete compressive strength of the beams at the age of the tests ranged from 300 to 800 kg/cm$^2$. The parameters of the study included the concrete strength, shear span to depth ratio a/d, the amount of shear reinforcement (stirrup spacing S) and the inclination of the stirrups with the horizontal axis of the beam. The details of the beam specimens, material properties, instrumentation and the testing procedure are described in this paper. The test results are presented and discussed, and the influence of each design parameter is investigated. Furthermore, parametric analysis was carried out to deduce equations for predicting the cracking and ultimate shear strength and the ratio between them for both normal and high strength concrete beams. Test results are also compared with different existing approaches.*

**KEYWORDS:** *Normal and High-strength concrete; Beams; Shear reinforcement; Spacing of stirrup; Shear span to depth ratio; Cracking and Ultimate shear strength.*

## 1. INTRODUCTION

The use of High-Strength Concrete (HSC) has increased considerably during the last decades, since it can be produced reliably in the field using low water–cement ratios in addition to high-quality water-reducing admixtures. Furthermore, HSC is more frequently used in columns, in precast elements and in structures where durability is an important design parameter. To give a simplified explanation, HSC is obtained by improving the compactness of the concrete mix, which increases the strength of both the paste and the interface between the paste and the coarse aggregate. However, an increase in the strength of the concrete produces an increase in its brittleness and smoother shear failure surfaces leading to some concerns about the application of high-strength concrete.

Since most of the current shear procedures are based on tests carried out on beams with a concrete compressive strength lower than 40 MPa, and one of the shear transfer mechanisms is shear-friction across the cracks, the failure shear strength needs to be re-evaluated. Moreover, shear failure in a beam without web reinforcement is sudden and brittle. Therefore, it is necessary to provide an amount of shear reinforcement, which must prevent sudden shear failure on the formation of first diagonal tension cracking and, in addition, must adequately control the diagonal tension cracks at service load levels.

Due to the higher tensile strength of high-strength concrete, a higher cracking shear is expected and hence, would require a larger amount of shear reinforcement. In some codes of practice, the shear strength of a reinforced concrete beam is taken as the sum of the shear force that is carried by the concrete (Vc) and the web reinforcement (Vs). The term (Vc) in a diagonally cracked beam with web reinforcement represents the sum of three separate components. These components are: (a) dowel action resistance of the longitudinal reinforcement, (b) aggregate interlock resistance along the diagonal crack, and (c) the shear resistance carried by the uncracked concrete compressive zone. The term (Vs) represents the vertical component of the shear force carried by the vertical (shear) reinforcement (strut mechanism).

## 2. RESEARCH SIGNIFICANCE:

This research was carried out for the following purposes:

**1.** To study the effect of compressive strength, a/d ratio, shear reinforcement and the inclination of the stirrups with the horizontal axis of the beam on the cracking and ultimate shear strength of reinforced high strength concrete beams of rectangular cross section, and

**2.** To compare the obtained test results and proposed equations results with the ACI Code.

## 3. PREVIOUS WORKS

Extensive experimental tests were carried out to get a better understanding of the fundamental behavior of shear strength of high strength concrete beams and to estimate the amount of the shear reinforcement required to high strength concrete beams in order to prevent sudden failure of the beam and to improve its ductility. In ref.(3), the author carried out a theoretical study on shear behavior of R.C beams with high strength concrete using finite element program. The main parameters of his study were: shear span to depth ratio, compressive strength of concrete, main reinforcement ratio, and spacing of stirrups. He noticed that the existence of stirrups increases the shear strength and ductility of beams. The ductility of beams with small shear reinforcement is less than that of beams of higher shear reinforcement. He stated that beams with higher main reinforcement ratio and concrete compressive have greater shear strength than that of low main reinforcement and concrete strength.

In ref. (4), the authors carried out an experimental study on high strength beams failing in shear. They tested eighteen reinforced concrete beams. The main objectives of the experimental campaign carried out were to study the influence of the concrete compressive strength on the shear strength in beams with and without shear reinforcement and to propose and verify a minimum amount of web reinforcement for high-strength concrete beams in accordance with the increase in concrete tensile strength for high-strength concretes. They concluded that:

- High-strength concrete beams with stirrups presented a less fragile response than similar beams without web reinforcement,
- For beams with the same geometric amount of transverse reinforcement, the higher their concrete compressive strength, the more effective stirrups are, and
- For high-strength concrete beams with stirrups, the limitation of the amount of longitudinal reinforcement to 2% is not experimentally justified.

In ref. (5), an experimental investigation was conducted to study the ductility of shear critical reinforced concrete beams of normal as well as high-strength concrete. The experimental variables were concrete compressive strength, shear span-to-depth ratio, and the amount of shear reinforcement. The authors stated that for the range of variables tested, the results indicate that shear reinforcement improves the shear ductility index of reinforced normal and high strength concrete beams. High-strength reinforced concrete beams with a/d =3 exhibit a plastic post-peak response, when shear reinforcement provided is about twice the minimum recommended by the ACI Building Code. For beams with shear reinforcement, the shear ductility index for beams with a/d of 1 decreases with an increase in concrete strength, whereas for beams with a/d of 2 and 3 there is an significant change in the shear ductility index due to an increase in the concrete strength.

In ref. (6), the authors carried out a study to predict the effect of stirrups on shear strength of reinforced normal strength concrete (NSC) and high strength concrete (HSC) slender beam. They stated that the effect that each of the basic shear design parameters exerts on the shear capacity of reinforced concrete (RC) beams without shear reinforcement ($V_C$) is still unclear. A parametric study revealed that the effect of shear reinforcement on the shear strength of RC beams decreases at higher reinforcement ratio. It was also observed that the concrete contribution to shear resistance ($V_C$) in RC beams with shear reinforcement is noticeably larger than that in beams without shear reinforcement.

# 4. EXPERIMENTAL PROGRAM:

## 4.1. Tested Beams

Nineteen reinforced concrete beams were tested. All tested beams have over all depth 30cm and 12 cm width. All beams were tested under two points static loading up to failure. Steel reinforcement of all beams was two bars 10 mm diameter as compression reinforcement, three bars 12 mm diameter as main reinforcement and the stirrups was 8 mm diameter having variable spacing. The yield strengths of the 8mm, 10mm and 12mm bars are 3060 kg/cm$^2$, 4249 kg/cm$^2$ and 4330 kg/cm$^2$ respectively. The test beams have concrete strength 300, 500 and 800 kg/cm$^2$ and a/d ratio from 1 to 4 and have shear reinforcement ($\rho_w . f_{yw}$)12.74, 19.61 and 25.48 kg/cm$^2$ and variable angle of inclination ($\alpha$).

Details of the tested beams are given in Figs.(1.a), (1-b) and (1.c). The test program is given in table (1). The test program consists of three series I, II, and III. Within each series, a number of cubes were cast to determine the compressive strength of the concrete at 28 days. After 24 hours of casting, concrete cubes were put into a rectangular tank for curing. The concrete compressive strengths at 28 days of age were 300 kg/cm$^2$, 500 kg/cm$^2$ and 800 kg/cm$^2$.

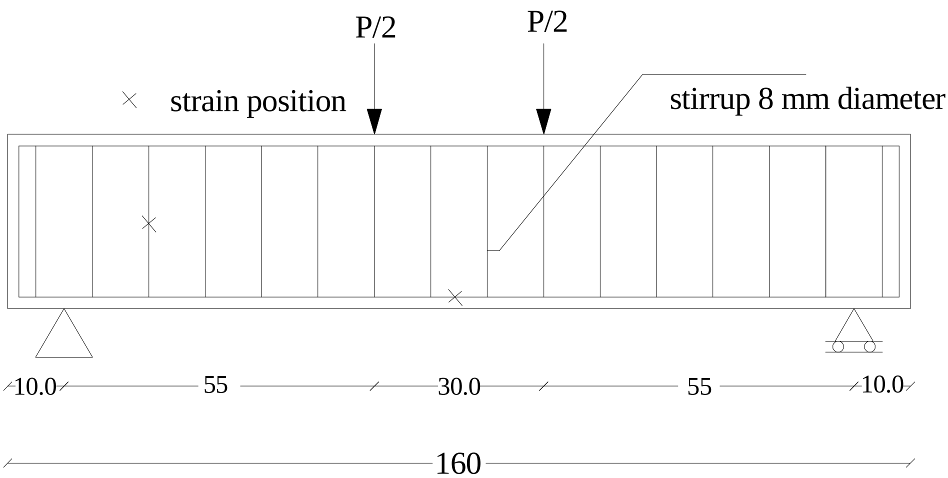


Fig. (1.a): Details of beams having vertical stirrups.

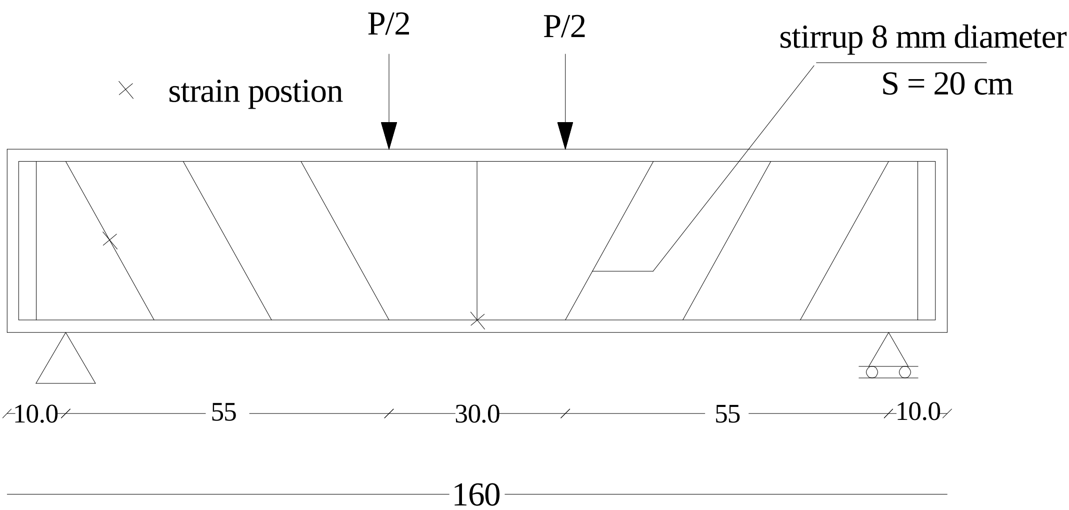


Fig. (1.b): Details of beams having inclined stirrups.

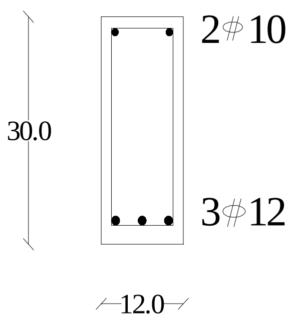


Fig. (1-c): Cross section of test specimens

Table (1): Test specimens

| Series | Group | Beam | $f_c$ (kg/cm) | S (cm) | a/d ratio | Length of beam | $\rho_w . f_{yw}$ (kg/cm$^2$) | Config-iguration ($\alpha$) | Variables |
|---|---|---|---|---|---|---|---|---|---|
| I | A1-4 | A1 | 300 | 20 | 1 | 105 | 12.74 | 90 deg. | a/d |
| | | A2 | 300 | 20 | 2 | 160 | 12.74 | 90 deg. | |
| | | A3 | 300 | 20 | 3 | 215 | 12.74 | 90 deg. | |
| | | A4 | 300 | 20 | 4 | 270 | 12.74 | 90 deg. | |
| | A5-6 | A5 | 300 | 10 | 2 | 160 | 25.48 | 90 deg. | Shear reinf. |
| | | A6 | 300 | 13 | 2 | 160 | 19.61 | 90 deg. | |
| | A7-8 | A7 | 300 | 20 | 2 | 160 | 12.74 | 45 deg. | Inclination ($\alpha$) |
| | | A8 | 300 | 20 | 2 | 160 | 12.74 | 60 deg. | |
| II | B1-3 | B1 | 500 | 10 | 2 | 160 | 25.48 | 90 deg. | Shear reinf. |
| | | B2 | 500 | 13 | 2 | 160 | 19.61 | 90 deg. | |
| | | B3 | 500 | 20 | 2 | 160 | 12.74 | 90 deg. | |
| III | C1-4 | C1 | 800 | 20 | 1 | 105 | 12.74 | 90 deg. | a/d |
| | | C2 | 800 | 20 | 2 | 160 | 12.74 | 90 deg. | |
| | | C3 | 800 | 20 | 3 | 215 | 12.74 | 90 deg. | |
| | | C4 | 800 | 20 | 4 | 270 | 12.74 | 90 deg. | |
| | C5-6 | C5 | 800 | 10 | 2 | 160 | 25.48 | 90 deg. | Shear reinf. |
| | | C6 | 800 | 13 | 2 | 160 | 19.61 | 90 deg. | |
| | C7-8 | C7 | 800 | 20 | 2 | 160 | 12.74 | 45 deg. | Inclination ($\alpha$) |
| | | C8 | 800 | 20 | 2 | 160 | 12.74 | 60 deg. | |

Where $f_c$ is the concrete compressive strength (kg/cm$^2$), $S$ is stirrup spacing (cm), $\rho_w . f_{yw}$ is the shear reinforcement index, and $\alpha$ is the angle of inclination of stirrups

## 4.2 Materials

The cement used in the beam specimens is the ordinary Portland cement which is usually used in normal practice. The properties of the used materials were as shown in table (2).

Table (2): properties of used aggregate

| Property | Basalt | Gravel | Sand |
|---|---|---|---|
| Volume weight(t/m$^3$) | 1.58 | 1.66 | 1.75 |
| Specific gravity | 2.6 | 2.65 | 2.53 |

Three concrete mixes were made to produce normal and high strength concrete having a 28 days cubic strength of about 300, 500, and 800 kg/cm$^2$. Normal strength concrete mix proportion is given in table (3), and high strength concrete mix proportion is given in table (4).In order to obtain high strength concrete, low water cement-ratio was used which led to concrete with low workability. To improve the workability of the concrete mix, a superplasticizer has been used known as ADECRETE BVF. Also the Silica fume was used in high strength concrete mix.

Table (3): Normal strength concrete mix proportion by weight

| Mix no. | Cement ($kg/m^3$) | Sand ($kg/m^3$) | Gravel. ($kg/m^3$) | Water ($Liter/m^3$) |
|---|---|---|---|---|
| 1 | 350 | 670 | 1200 | 165 |

Table (4): High strength concrete mix proportion by weight

| Mix no. | Cement. ($Kg/m^3$) | Sand ($Kg/m^3$) | Crushed Basalt ($Kg/m^3$) | Silica fume ($Kg/m^3$) | Additives ($Liter/m^3$) | Water ($Liter/m^3$) |
|---|---|---|---|---|---|---|
| 1 | 450 | 600 | 1200 | 70 | 14 | 165 |
| 2 | 550 | 450 | 1200 | 110 | 20 | 140 |

## 4.3. Instrumentation and test setup

Beam specimens were simply supported and tested using two concentrated point loads. One end of the beam was hinged and the other end was roller.

A testing machine of 60 tons capacity was used to apply the load. Dial gauges were fixed at mid span of the beam. The strains were fixed in the positions shown in Figs. (1.a) and (1.b).

Details of the beam instrumentation, the testing machine are shown in Fig. 2.

Fig. (2): The beam instrumentation and testing machine.

### 4.3. Test Procedure

All the beams were loaded symmetrically with two equal point loads. The load was applied in increments of about 0.5 ton till the occurrence of the first crack. Thereafter the increments were increased to 1.0 ton. At each load increment, all displacement readings were measured, the beam was carefully inspected, and all cracks were observed. With each beam test, cubes taken from the same concrete mix were tested to determine the compressive strength of the concrete. The average compressive strength of cubes were 300, 500 and 800 kg/cm$^2$

## 5. TEST RESULTS AND DISCUSSIONS

### 5.1. Crack pattern and general behavior

Tested beams of a/d =3, 4 failed in flexure but those of a/d = 1, 2 failed in shear or shear compression. The cracking pattern of these beams was almost similar. Initially, cracks started either vertically at the mid span. Extension of existing cracks and appearance of new flexural cracks in the shear spans spread from the load application points towards the supports. The flexural cracks in the shear spans tend to become inclined as the load was increased. With further increase in the applied load, the diagonal shear crack between the loading point and the support and in some cases a new shear crack was initiated as an extension of an existing flexural crack. The crack angle varied between 30 º and 60º with the axis of the beam. The failure cracks in beams with the highest concrete strength tended to be steeper than those of normal strength concrete. Generally, the cracks were developed in the shear spans and then propagated upward towards the load bearing plate and downward towards the supports. Typical failure crack patterns for some beams are shown in Fig. (3). The number of inclined cracks in beams with high amount of shear reinforcement was more than that of lower amount of shear reinforcement, indicating an enhanced redistribution of internal forces in the beam with high shear reinforcement.

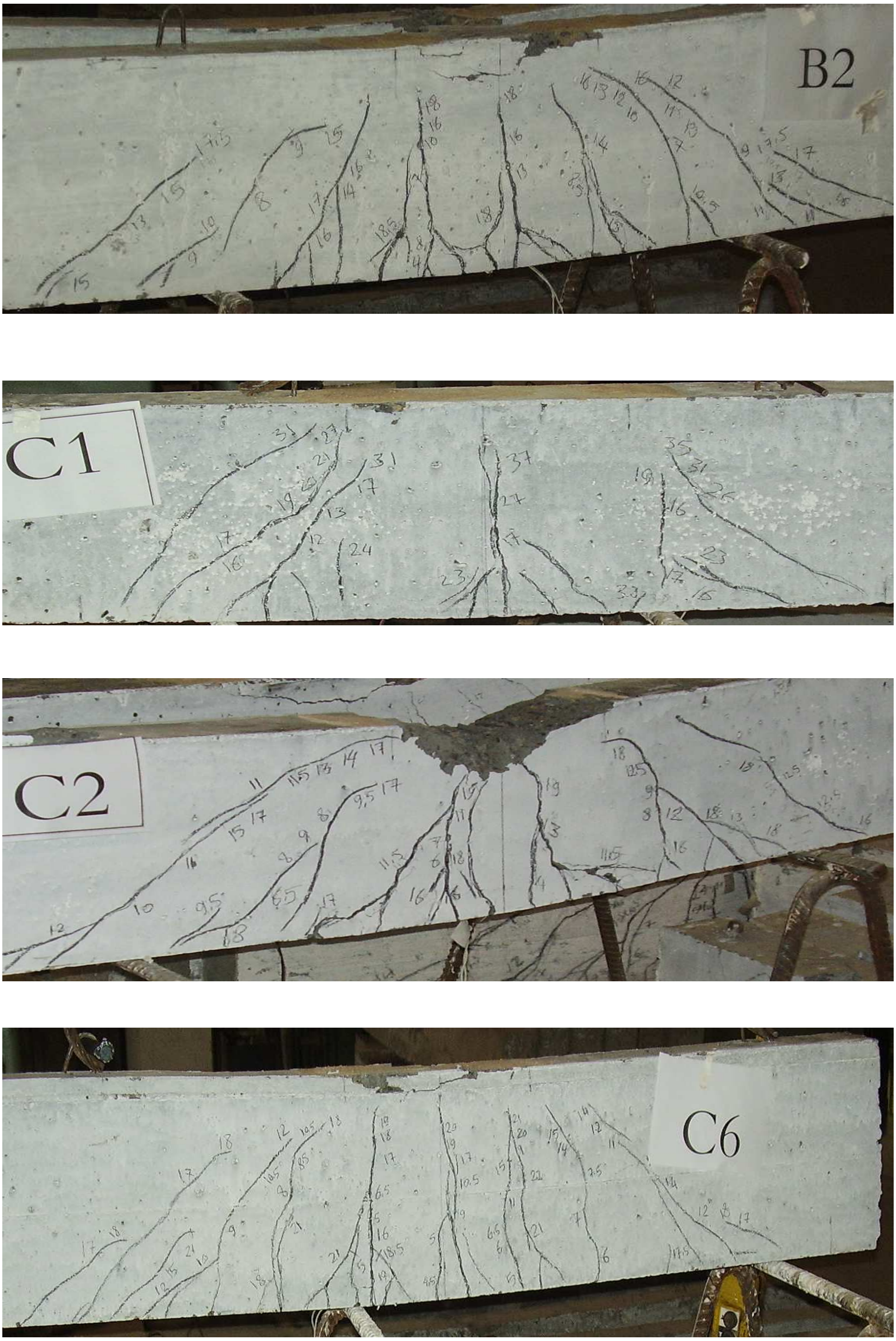


Fig. (3): Photos of some tested beams

## 5.2. Test results

Table (5) shows the test results of all tested beams. This table also shows the measured diagonal cracking shear strength and the failure shear strength and the ratio between them for each beam specimen. It can be seen that as the shear reinforcement was increased, the failure load also increased. Also, another important conclusion can be drawn from the test results, which is as the compressive strength increases, the failure shear stress increased.

## 5.3. Load – Deflection and Load Strain Diagrams

At the position of mid-span, the deflection measured values have been plotted against the corresponding applied loads from starting of loading up to failure as shown in Figs (4) to (6). Also the main steel and stirrup strain measured values were plotted against the corresponding applied loads from starting of loading up to failure as shown in Figs (7) to (10).

Table (5): Results of tested beams

| Beam | $f_c$ $(kg/cm^2)$ | S (cm) | inclination of stirrups | a/d ratio | $v_{cr}$ $(kg/cm^2)$ | $v_u$ $(kg/cm^2)$ | $\frac{v_{cr}}{v_u}$ | Failure mode |
|---|---|---|---|---|---|---|---|---|
| A1 | 300 | 20 | 90 deg. | 1 | 12.2 | 39.97 | 0.31 | Shear |
| A2 | 300 | 20 | 90 deg. | 2 | 8.6 | 24.38 | 0.35 | S.F |
| A3 | 300 | 20 | 90 deg. | 3 | 7.1 | 20.37 | 0.35 | S.C |
| A4 | 300 | 20 | 90 deg. | 4 | 3.9 | 11.27 | 0.34 | Flexure |
| A5 | 300 | 10 | 90 deg. | 2 | 11.6 | 27.01 | 0.43 | S.F |
| A6 | 300 | 13 | 90 deg. | 2 | 9.8 | 26.54 | 0.37 | S.C |
| A7 | 300 | 20 | 45 deg. | 2 | 10.8 | 26.22 | 0.41 | S.F |
| A8 | 300 | 20 | 60 deg. | 2 | 9.3 | 25.00 | 0.37 | S.C |
| B1 | 500 | 10 | 90 deg. | 2 | 14.1 | 33.70 | 0.42 | S.F |
| B2 | 500 | 13 | 90 deg. | 2 | 12.00 | 31.94 | 0.38 | S.C |
| B3 | 500 | 20 | 90 deg. | 2 | 10.00 | 29.78 | 0.34 | S.F |
| C1 | 800 | 20 | 90 deg. | 1 | 18.50 | 83.95 | 0.22 | Shear |
| C2 | 800 | 20 | 90 deg. | 2 | 10.80 | 34.57 | 0.31 | S.C |
| C3 | 800 | 20 | 90 deg. | 3 | 7.7 | 23.74 | 0.32 | S.C |
| C4 | 800 | 20 | 90 deg. | 4 | 4.2 | 14.66 | 0.42 | Flexure |
| C5 | 800 | 10 | 90 deg. | 2 | 15.4 | 37.34 | 0.41 | S.F |
| C6 | 800 | 13 | 90 deg. | 2 | 13.9 | 36.26 | 0.38 | S.F |
| C7 | 800 | 20 | 45 deg. | 2 | 12.7 | 36.57 | 0.35 | S.F |
| C8 | 800 | 20 | 60 deg. | 2 | 11.7 | 36.11 | 0.32 | S.F |

S.F = shear flexure

S.C = shear compression

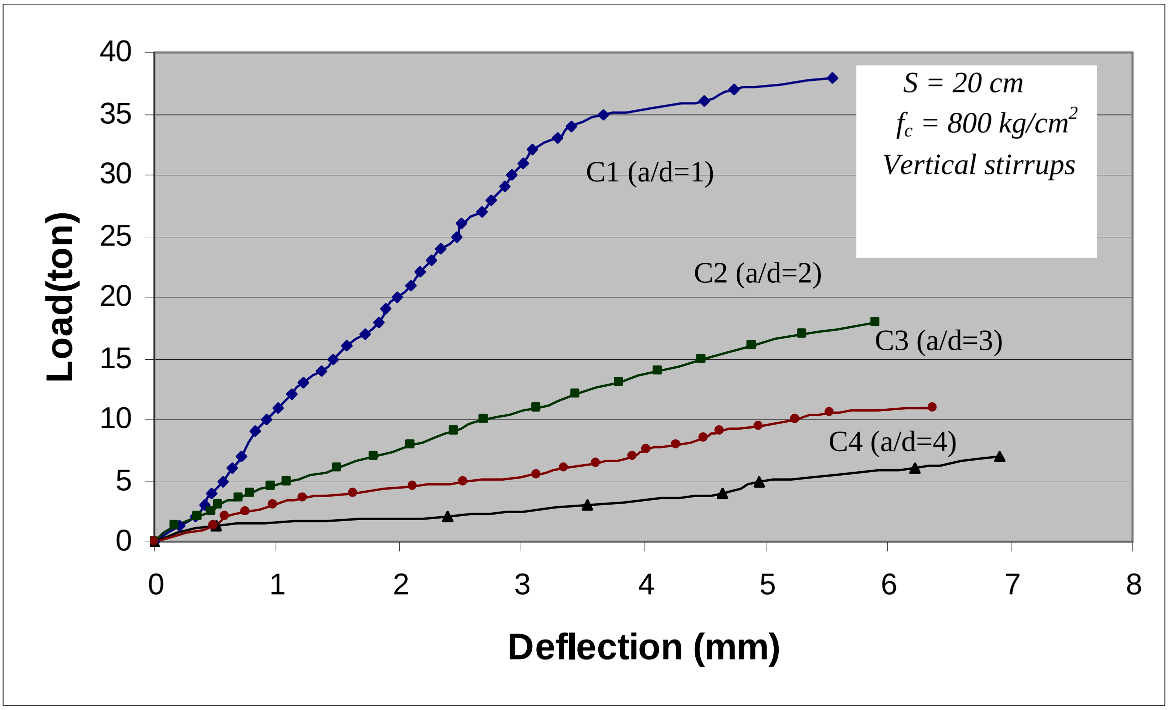


Fig. (4). Load-Deflection relationship for beams with different a/d ratios

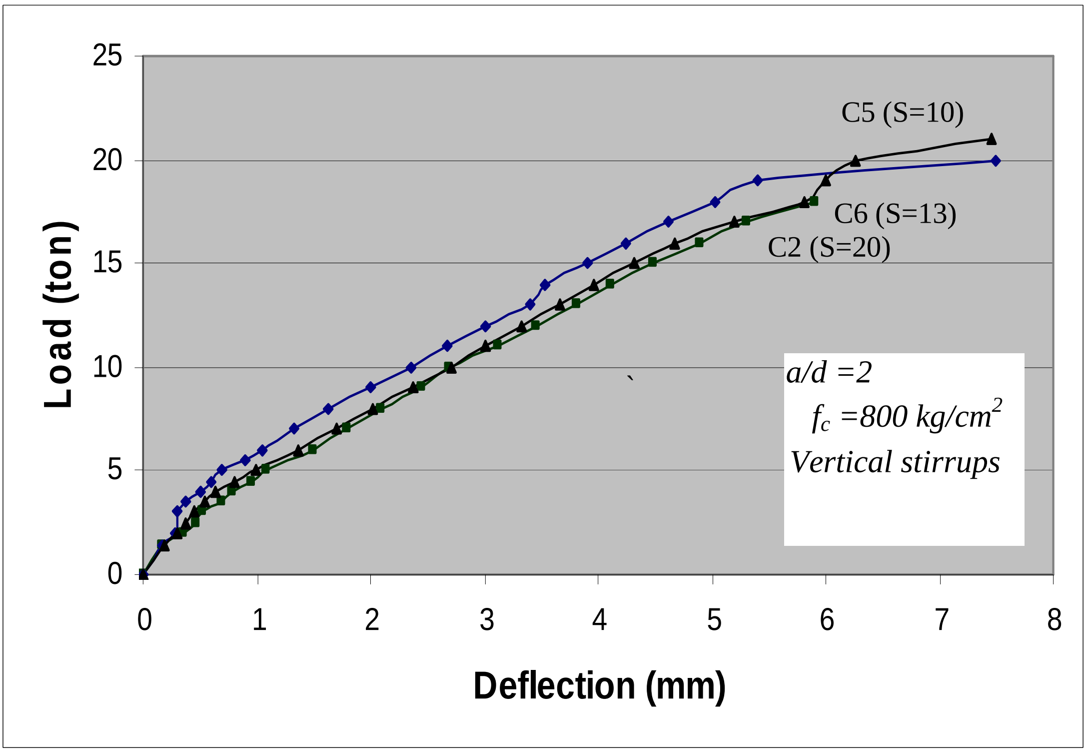


Fig. (5). Load-Deflection relationship for beams with different spacing of stirrups

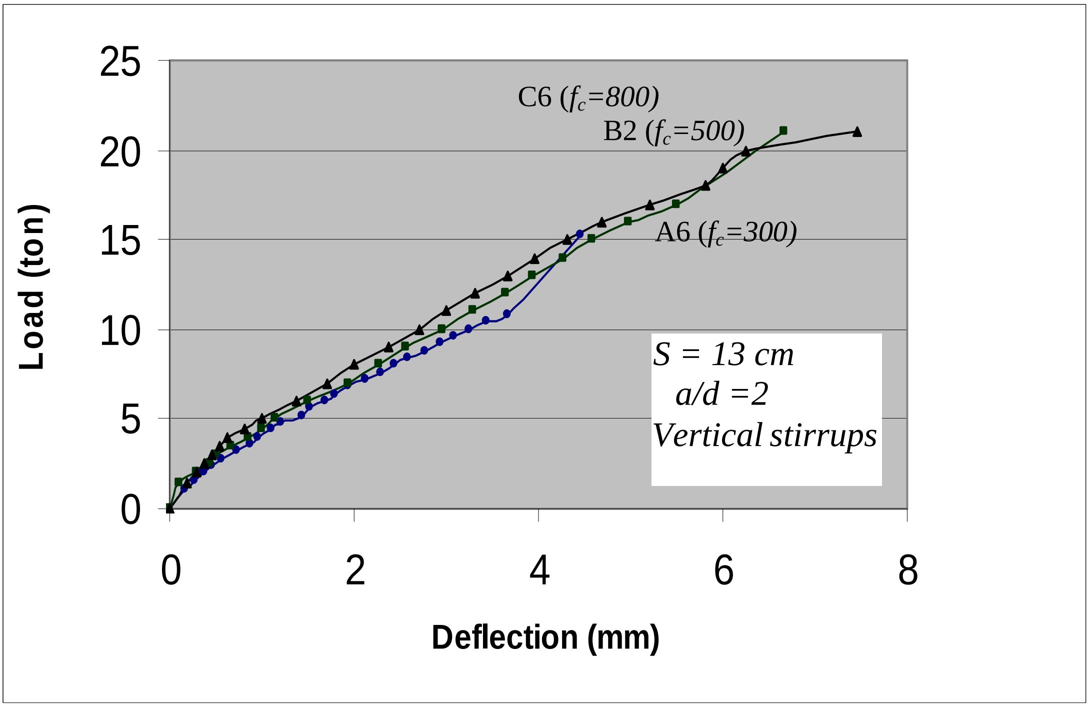


Fig. (6). Load-Deflection relationship for beams with different concrete strength.

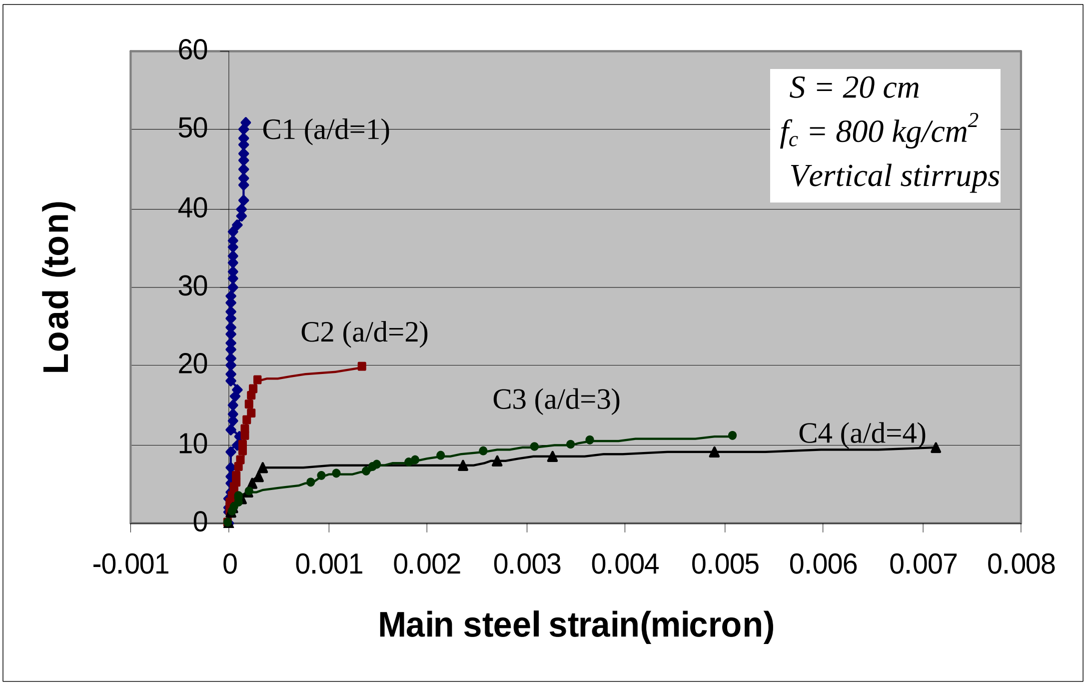


Fig. (7). Relationship of Load- Main steel strain for beams with different a/d ratio.
C2 ($f_c$=800)

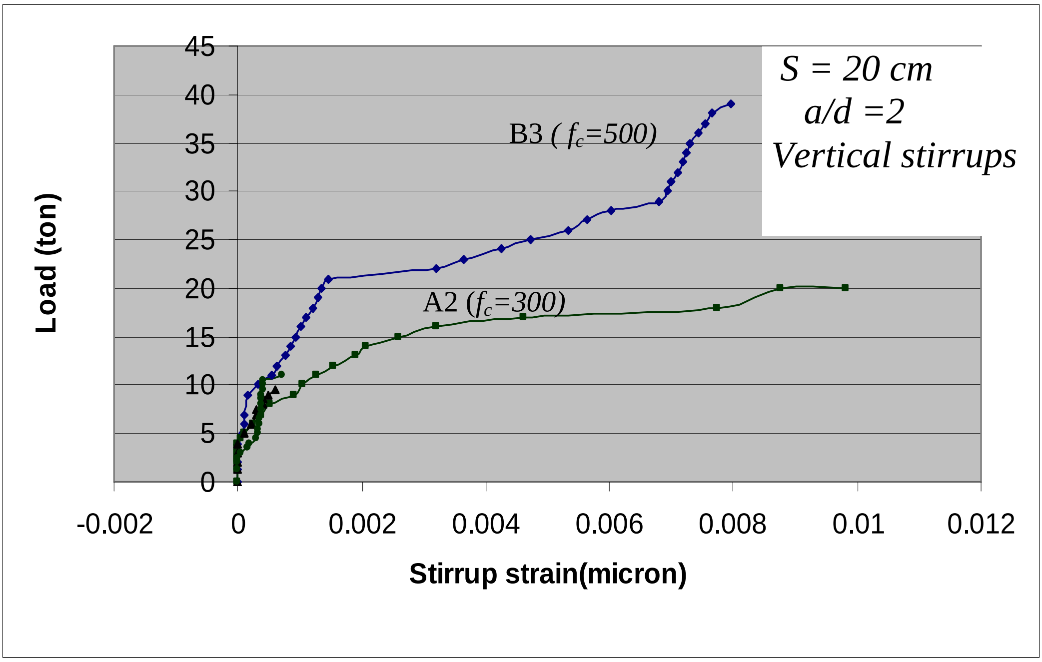


Fig. (8). Relationship of Load- Main steel strain for beams with different concrete strength.

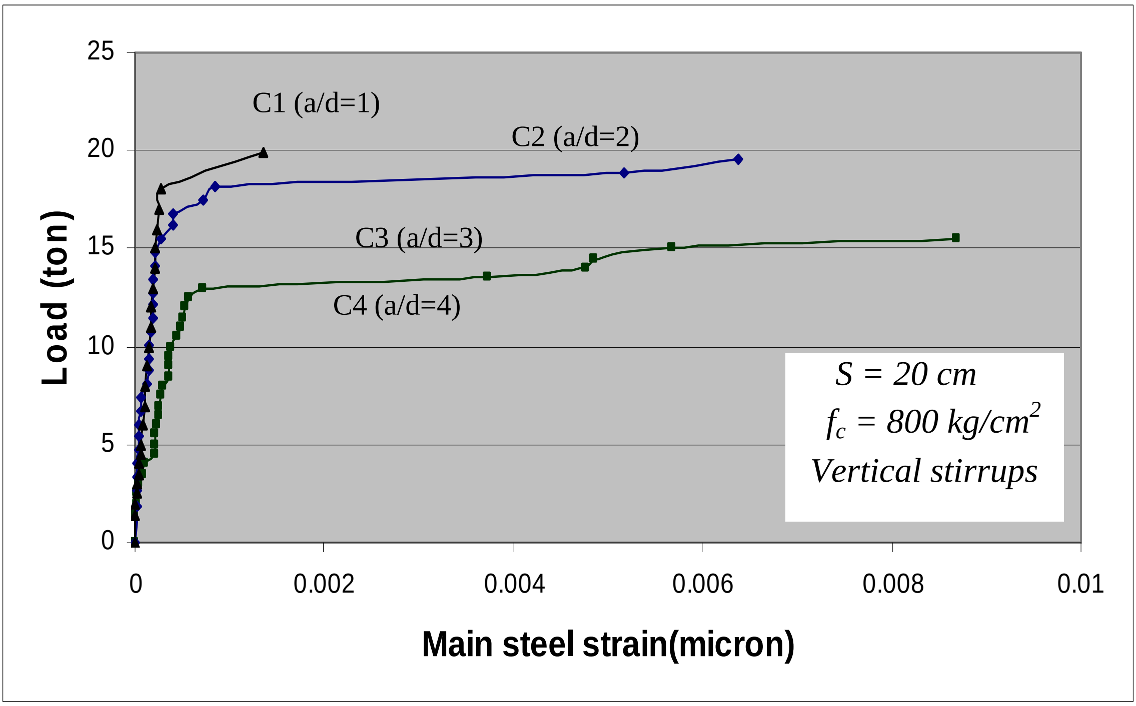


Fig. (9). Relationship of Load-Stirrup strain for beams with different a/d ratio

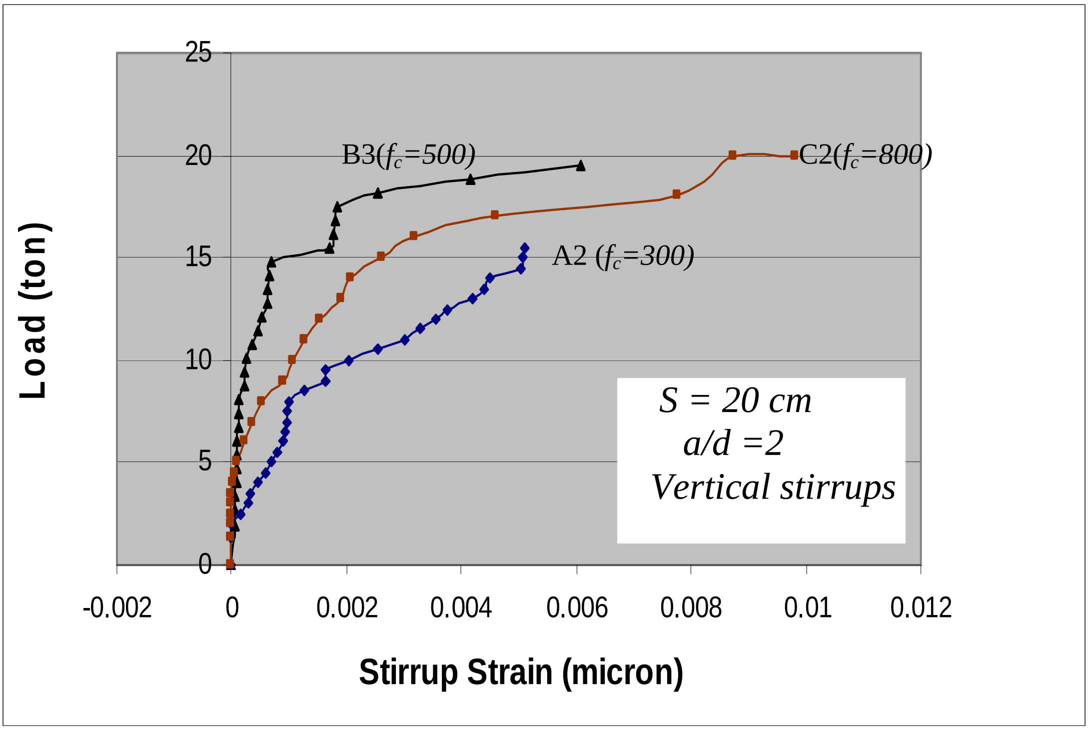


Fig. (10). Relationship of Load-Stirrup strain for beams with different concrete strength.

## 5.4. Effect of Compressive Strength

Increasing concrete compressive strength increases the cracking load and ultimate load for concrete grades C300, C500 and C800 (table 5). The concrete strength affects the deflection as it can be noticed that the measured deflection at a certain load decreases as the compressive strength increase see fig.(6). The maximum measured stirrup strain increased as the concrete strength increased see fig.(10). All stirrups crossed by the main diagonal crack showed high strain readings at the maximum measured load, this high stirrup strain resulted from the small contribution of aggregate interlock in resisting load which resulted in an increase on the share of the load of the remaining components of the shear failure mechanism.

## 5.5. Effect of Shear Reinforcement

It is obvious that the cracking and ultimate load values decreases with the increase of spacing of stirrups (table 5). Increasing of the spacing of stirrups leads to a decrease of the maximum measured deflection for beams of either normal or high strength concrete. This means that as the stirrups increased in the beam, the ductility of that beam increases. Also, a decrease of the spacing of stirrups (increasing shear reinforcement) leads to a decrease of the maximum measured stirrup strain for the beams of grade C300, C500, and C800. As the stirrups number in the beam increases, the share of load for one stirrup decreases and this small share of load cause the stirrup not to be highly stressed.

### 5.6. Effect of Stirrups Inclination

The angle of inclination of the stirrups has a remarkable effect on both the cracking and the ultimate shear strengths for either normal or high strength concrete (table 5) for example the cracking and ultimate shear strengths for angle $\alpha = 45^o$ is bigger than that of $\alpha = 60^o$ and also bigger than that of $\alpha = 90^o$. Increasing of the angle of inclination from $45^o$ to $60^o$ to $90^o$ leads to an increase of the maximum measured deflection for beams of either normal or high strength concrete (C300 and C800), this means that beams with vertical stirrups $\alpha = 90^o$ is more ductile than that of beams having inclined stirrups $\alpha = 60^o$ and also more than that of beams having inclined stirrups $\alpha = 45^o$.

## 6. PROPOSED EQUATIONS FOR CRACKING AND ULTIMATE SHEAR STRENGTH

From test results and the parametric analysis it appears that the cracking shear strength for R.C beams depends mainly on the concrete strength ($f_c$), the a/d ratio and the amount of web reinforcement (spacing and $A_S$). Based on best fit method and using a statistical program, the equation (1) is proposed to calculate the cracking shear strength for R.C beams

$$v_{cr} = 0.559 \left( \sqrt{f_c} \times \frac{d}{a} \right) + 0.359 \left( \frac{\rho_w . f_{yw}}{\sin\alpha} \right) - 1.58 \quad \text{kg/cm}^2 \qquad (1)$$

Also from test results and the parametric analysis it appears that the ultimate shear strength for R.C beams depends mainly on the concrete strength ($f_c$), the a/d ratio, the amount of web reinforcement and the stirrups inclination. Based on best fit method and using a statistical program the equation (2) is proposed to calculate the ultimate shear strength for R.C beams.

$$v_u = 2.754 \left( \sqrt{f_c} \times \frac{d}{a} \right) + 0.205 \left( \frac{\rho_w . f_{yw}}{\sin\alpha} \right) - 3.71 \quad \text{kg/cm}^2 \qquad (2)$$

Where

| | |
|---|---|
| $f_c$ | the concrete compressive strength in kg/cm$^2$ , |
| d/a | the depth to shear span ratio, |
| $\rho_w . f_{yw}$ | the shear reinforcement index ( kg/cm$^2$), |
| $\alpha$ | the inclination angle of stirrups . |

Comparison between the predicted cracking and ultimate shear strength from proposed equations (1) and (2) with the experimental cracking and ultimate shear strengths is given in Figs.(11 ) and (12 ).

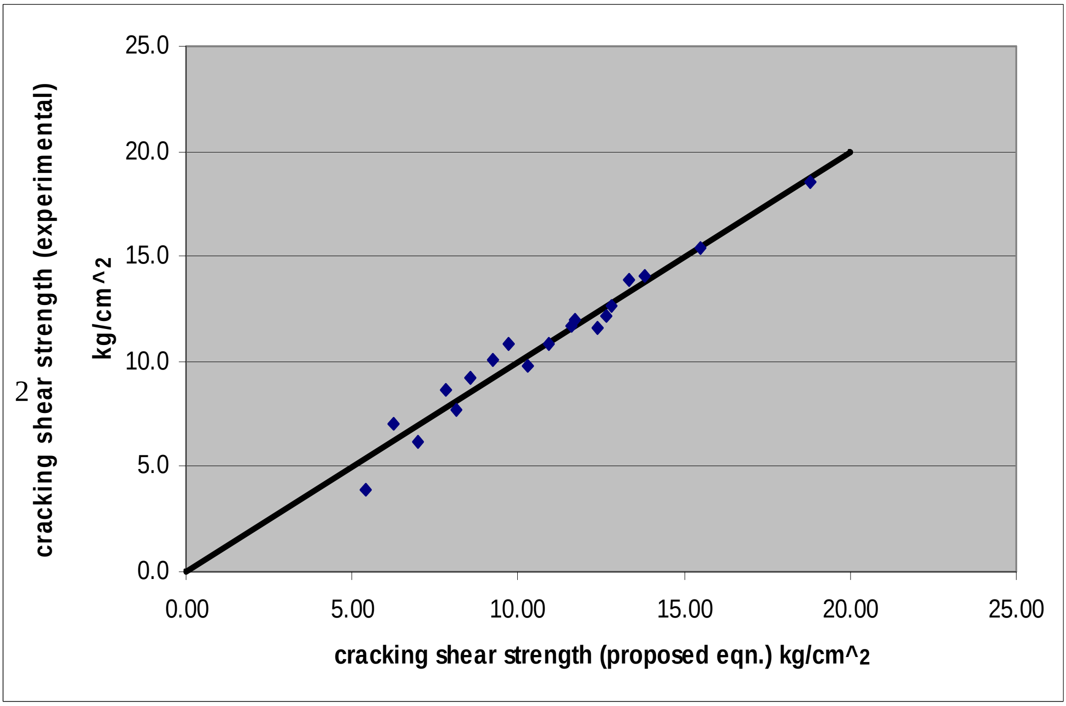


Fig. (11): Experimental cracking shear strength versus calculated cracking shear strength.

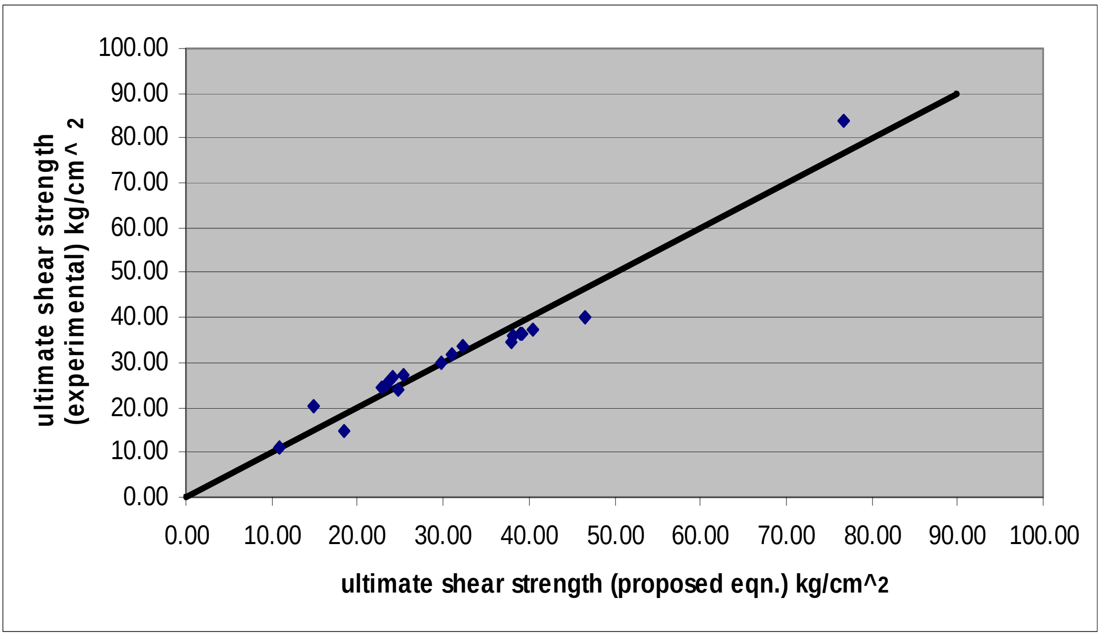


Fig. (12): Experimental ultimate shear strength versus calculated ultimate shear strength

## 7. ULTIMATE SHEAR CAPACITY ADOPTED BY THE ACI CODE OF PRACTICE

The present ACI code of practice (3) assumes that in beams with web reinforcement, the amount of shear stress resisted by the concrete at ultimate is equal to the amount of shear stress that would cause diagonal tension cracking. The amount of shear strength of the concrete was based and determined from test results on beams without web reinforcement and with concrete compressive strengths up to 41.1 MPa (6000 psi). The shear strength of concrete without shear reinforcement is given by

$$v_{cr} = 1.9\sqrt{f_c^{/}} + 2500 \; .\rho_w . \frac{V_u . d}{M_u} \qquad (3)$$

And not greater than $3.5\sqrt{f_c^{/}}$

$$v_u = v_{cr} + \frac{A_{st} . f_y}{b.s} \qquad (4)$$

where $f_c$ cylinder compressive strength (Psi) , $\rho_w$ main reinforcement ratio, $A_{st}$ area of stirrups in spacing S, $v_{cr}$ *and* $v_u$ are in Psi units

## 8. COMPARISON BETWEEN THE ACI CODE AND EXPERIMENTAL CRACKING AND ULTIMATE SHEAR STRENGTH

From Figs. (13 ) and (14), it can be noticed that the ACI code equations for predicting cracking shear strength of R.C beams gives values smaller than the experimental values for beams of a/d = 1.0 and greater than that of beams of a/d equal to 2, 3 and 4 for normal and high strength concrete beams. Also the ACI code equation underestimate the effect of the concrete strength in high strength concrete.

## 9. CONCLUSIONS AND REMARKS

On the basis of the test results obtained in this study, the following conclusions have been reached:

1- Increasing the compressive strength and the amount of shear reinforcement leads to an increase of the cracking and ultimate shear strengths.
2- Angle of inclination of the stirrups has a remarkable effect on both the cracking and the ultimate shear strengths for either normal or high strength concrete for example the cracking and ultimate shear strengths for angle $\alpha = 45^o$ is bigger than that of $\alpha = 60^o$ and also bigger than that of $\alpha = 90^o$ .
3- Increasing the amount of shear reinforcement leads to an increase in the beam ductility, so the minimum amount of shear reinforcement must be increased for high strength concrete.

4- The maximum measured stirrup strain in high strength concrete beams has a greater value than that in normal strength concrete beams because of the small contribution of aggregate interlock in resisting load which resulted in an increase on the share of the load of the remaining components of the shear failure mechanism.

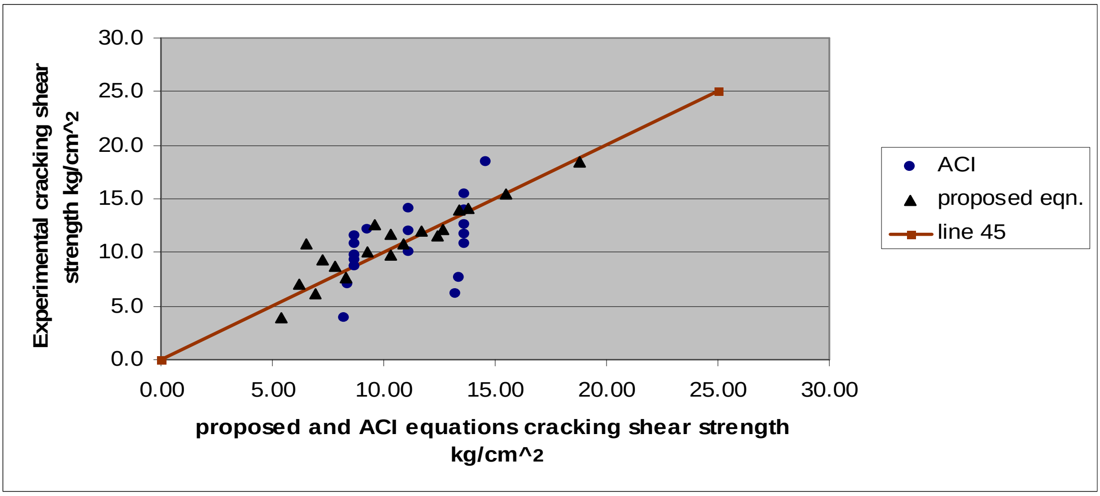


Fig. (14): Comparisons between experimental and predicted cracking shear strengths based on proposed equation (1) and ACI codes

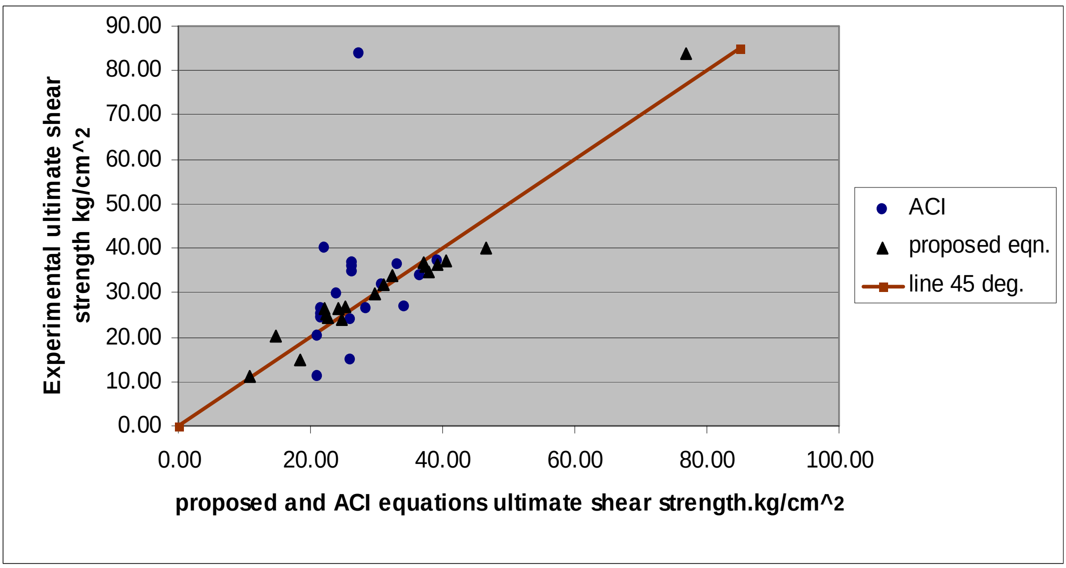


Fig.(15): Comparisons between experimental and predicted ultimate shear strengths based on proposed equation (2) and ACI code.

## REFERENCES

1- “Shear Design of High-Strength Concrete” A State-of-Art Report (August1996) from the Internet
2- ACI committee 318, Building Code Requirements for Reinforced Concrete (ACI 318-99).
3- Khairy Hassan A., “Finite Element Study on Shear Behavior of RC Beams with HSC” 1st Int. conference of civil Eng. Science” ICCES1, Vol.1, 835-845, Oct.2003
4- A.Cladera, A.R. Mari “Experimental Study on High-Strength Concrete Beams Failing in Shear” Journal of Engineering Structures 27(2005) 1519-1527.
5- Yuliang Xie, Shuaib.H.Ahmed, Tiejun Yu, S.Hino, and W.Chung “Shear Ductility of Reinforced Concrete Beams of Normal and High-Strength Concrete” ACI Structural Journal, March-April 1994, pp. 140-149.
6- H.El Chabib, M. Nehdi, and A.Said “Predicting the Effect of Stirrups on Shear Strength of Reinforced Normal-Strength Concrete (NSC) and High-Strength Concrete (HSC) Slender Beams Using Artificial Intelligence” Can.J.Civ.Eng.33: 933-944 (2006)
7- Guray Arslan “Shear Strength of Reinforced Concrete Beams with Stirrups” Materials and Structures (2008) 41:113-122
8- Yehia Anis Daou, Hassan Ghanem “ Study of the Minimum Shear Reinforcement in High Strength Concrete Beams” Alexandria Engineering Journal, Vol.42, No.4, July 2003
9- Karim S.Rebeiz et al. “Effect of Variables on Shear Strength of Concrete Beams” Journal of Materials in Civil Engineering. November-December 2001
10- Prodromos D. Zarais “Shear Compression Failure in Reinforced Concrete Deep Beams” Journal of Structural Engineering ASCE, April 2002

## دراسة معملية عن سلوك القص الاستاتيكي في الكمرات عالية المقاومة و مقارنته بالكمرات ذات المقاومة العادية

فى هذه الدراسة تم صب عدد 19 كمرة من خرسانات ذات رتب مختلفة . المتغيرات التي تمت دراستها هي مقاومة الخرسانة،النسبة بين بحر القص والعمق الفعال، نسبة حديد تسليح القص(الكانات) و زاوية ميل الكانات مع محور الكمرة. تم تقسيم الكمرات الي ثلاث مجموعات المجموعة I ذات مقاومة 300 كجم/سم$^2$ وبها 8 كمرات مختلفة في نسبة بحر القص و العمق الفعال و نسبة حديد القص وميله المجموعةII ذات مقاومة 500 كجم/سم$^2$ وبها 3 كمرات مختلفة في نسبة حديد القص و ا لمجموعة III ذات مقاومة 800 كجم/سم$^2$ وبها 8 كمرات مختلفة في نسبة بحر القص و العمق الفعال و نسبة حديد القص وميله. في هذا البحث تم تحليل النتائج المعملية و استنتاج تاثير هذه المتغيرات علي سلوك الكمرات و نموذج الانهيار للكمرات والعلاقة بين الحمل والتشكل وبين الحمل والإجهاد ومنها تم استنتاج معادلات لحساب قيم اجهادات التشريخ والانهيار للقص في الكمرات ذات المقاومة العادية والعالية

باستخدام برنامج تحليل احصائي وكذلك تمت مقارنة هذه النتائج مع القيم المتوقعة من الكود الامريكي (ACI ). من الدراسه امكن استخلاص النتائج التالية :

1- تزداد قيمة كل من اجهاد القص عند التشريخ وعند الانهيار بزيادة كل من مقاومة الخرسانة وكمية حديد تسليح القص في الكمرات ذات خرسانه عاديه وعالية المقاومة .

2-وجود كانات مائلة علي محور الكمرة ادي الي زيادة اجهاد القص عند التشريخ وكذلك عند الانهيار في الكمرات ذات خرسانه المقاومة العاديه والعالية.

3-زيادة نسبة حديد القص يؤدي ايضا الي زيادة ممطولية الكمرات ذات خرسانه عاديه وعاليه المقاومة .

4-الانفعال الأقصي المتولد في الكانات في الكمرات ذاتالخرسانه عاليه المقاومة اكبر منه في الكمرات ذات خرسانه عاديه المقاومة ولذا يجب زيادة حديد تسليح القص (الكانات) بزيادة رتبة الخرسانة.