Shear strength of normal, medium and high strength reinforced concrete beams

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An experimental test program and theoretical analysis were performed to investigate the shear strength of normal, medium and high strength reinforced concrete simple beams with and without web reinforcement, which included testing of thirty-six simply supported rectangular high-strength concrete beams. The major test variables were: the concrete compressive strength (f_{cu}) = 25, 60 and 90 MPa; the shear span-to-depth ratio (a/d) = 2 and 3; the longitudinal main steel reinforcement ratio (ρ) = 2.26 and 4.02 %; and the web reinforcement ratio (ρ_v) = 0.0, 0.57 and 1.01 % in the form of vertical stirrups. Based on the experimental results and others' test results (of 201 for cracking and 271 for ultimate strengths) two equations were proposed for predicting the cracking and the ultimate shear strengths of reinforced concrete beams. The two proposed equations seem to predict the cracking and ultimate shear strengths fairly well.

يتضمن البحث دراسة معملية و نظرية لسلوك الكمرات الخرسانية المسلحة بسيطة الإرتكاز ذات المقاومة العادية و المتوسطة والعالية المعرضة لقوى قص ناتجة من تأثير حملين متساويين و متماثلين على جانبى محور منتصف الكمرة. البرنامج العملى لهذا البحث يشتمل على إختبار ٣٦ كمرة خرسانية مسلحة مع تغيير بعض العوامل لدراسة تأثيرها على سلوك الكمرات فى القص، و هى: مقاومة الضغط للخرسانة، و كانت قيمها (٢٥، ٦٠، ٩٠) نيوتن / مم^{٢}، و نسبة بحر القص إلى العمق الفعال، وكانت تتراوح ما بين (٢، ٣)، و نسبة التسليح الطولى الرئيسى بالقطاع، و تغيرت ما بين (٢,٢٦٪، ٤,٠٢)٪، و نسبة التسليح الجذعى بالقطاع، و تغيرت ما بين (٠,٠٠٪، ٠,٥٧ ٪، ١,٠١)٪. تم إقتراح معادلتين للتنبؤ بمقاومة القص للكمرات الخرسانية و ذلك عند ظهور أول شرخ فى منطقة القص و كذلك عند حدوث الإنهيار، و هاتان المعادلتان إعتمدتا على تحليل النتائج المعملية للبحث و كذلك نتائج معملية أخري سابقة لعدد من الباحثين (٢٠١ كمرة لإستنتاج معادلة التنبؤ بمقاومة القص عند ظهور أول شرخ فى منطقة القص، و ٢٧١ كمرة لإستنتاج معادلة التنبؤ بمقاومة القص عند حدوث الإنهيار). تم مقارنة النتائج بإستخدام معادلات البحث و المعادلات الأخرى المقترحة بواسطة باحثين أخرين، و قد أعطت المعادلات المقترحة نتائج جيدة.

Keywords: High-strength concrete, Shear strength, Web reinforcement, Shear span-to-depth ratio, Cracking

1. Introduction

In the last 30 years, the compressive strength of concrete that can be produced reliably in the field has more than doubled, from 35 to 85 MPa. Strengths as high as 140 MPa can be achieved in the laboratory and on rare occasions in the field. Very high strengths have been achieved with Reactive Powder Concrete, which made of powders with no aggregate. The admixtures allow the production of workable concrete mixtures with very low water-cement ratios, and the silica fume can produce cement paste with very low porosity. Since the structural behaviour of concrete member may be affected as the compressive strength of concrete is increased and hence additional information is necessary to understand the structural behaviour of concrete members made with HSC. Studying shear in reinforced concrete beams is important because shear failure is brittle, catastrophic and occur suddenly without warning. Failures due to shear in beams with HSC may be even more brittle and explosive than beams with NSC. Shear failure surfaces in HSC members are smoother than in NSC members, with cracks propagation through coarse aggregate particles rather than around them [2 and 8].

2. Experimental program

2.1. Test specimens and loading arrangement

Thirty-six beams with rectangular cross sections of width (b=100 mm) and effective depth (d=200 mm) were tested. The tested beams were arranged into three groups according to the concrete compressive strength. The details of tested beams are shown in table 1. All beams were simply supported and loaded by two concentrated loads applied at the top of the beams. Fig. 1 shows the reinforcement details of tested beams. The cracking and ultimate loads were recorded. In addition, the deflection and the strain at different positions were measured for each beam. Besides, cracking patterns and failure modes were monitored and traced.

2.2. Materials

Locally produced materials were used. Fine and coarse aggregates were composed of harsh desert sand and crushed dolomite with two sizes having nominal maximum sizes 9.5mm (Size1) and 16mm (Size1) respectively combined together to meet ASTM grading. Ordinary Portland cement and tap drinking water were used. Addicrete (BVF) was used as a high-range water-reducing admixture complying with ASTM C494-81 type F to enhance workability and increase early strength. Also silica fume was used to get high-strength concrete mixes.

Table 1
Details of tested beams

Group	Concrete grade	Beam No.	a/d	Clear span (mm)	Main steel	Stirrups
1	Normal	B1	2	1300	4ϕ 12	No stirrups
		B2	2	1300	4ϕ 12	10 ϕ 6/m
	(f_{cu}=25 N/mm^2)	B3	2	1300	4ϕ 12	10 ϕ 8/m
		B4	2	1300	4ϕ 16	No stirrups
		B5	2	1300	4ϕ 16	10 ϕ 6/m
		B6	2	1300	4ϕ 16	10 ϕ 8/m
		B7	3	1700	4ϕ 12	No stirrups
		B8	3	1700	4ϕ 12	10 ϕ 6/m
		B9	3	1700	4ϕ 12	10 ϕ 8/m
		B10	3	1700	4ϕ 16	No stirrups
		B11	3	1700	4ϕ 16	10 ϕ 6/m
		B12	3	1700	4ϕ 16	10 ϕ 8/m
2	Medium	B13	2	1300	4ϕ 12	No stirrups
		B14	2	1300	4ϕ 12	10 ϕ 6/m
	(f_{cu}=60 N/mm^2)	B15	2	1300	4ϕ 12	10 ϕ 8/m
		B16	2	1300	4ϕ 16	No stirrups
		B17	2	1300	4ϕ 16	10 ϕ 6/m
		B18	2	1300	4ϕ 16	10 ϕ 8/m
		B19	3	1700	4ϕ 12	No stirrups
		B20	3	1700	4ϕ 12	10 ϕ 6/m
		B21	3	1700	4ϕ 12	10 ϕ 8/m
		B22	3	1700	4ϕ 16	No stirrups
		B23	3	1700	4ϕ 16	10 ϕ 6/m
		B24	3	1700	4ϕ 16	10 ϕ 8/m
3	High	B25	2	1300	4ϕ 12	No stirrups
		B26	2	1300	4ϕ 12	10 ϕ 6/m
	(f_{cu}=90 N/mm^2)	B27	2	1300	4ϕ 12	10 ϕ 8/m
		B28	2	1300	4ϕ 16	No stirrups
		B29	2	1300	4ϕ 16	10 ϕ 6/m
		B30	2	1300	4ϕ 16	10 ϕ 8/m
		B31	3	1700	4ϕ 12	No stirrups
		B32	3	1700	4ϕ 12	10 ϕ 6/m
		B33	3	1700	4ϕ 12	10 ϕ 8/m
		B34	3	1700	4ϕ 16	No stirrups
		B35	3	1700	4ϕ 16	10 ϕ 6/m
		B36	3	1700	4ϕ 16	10 ϕ 8/m

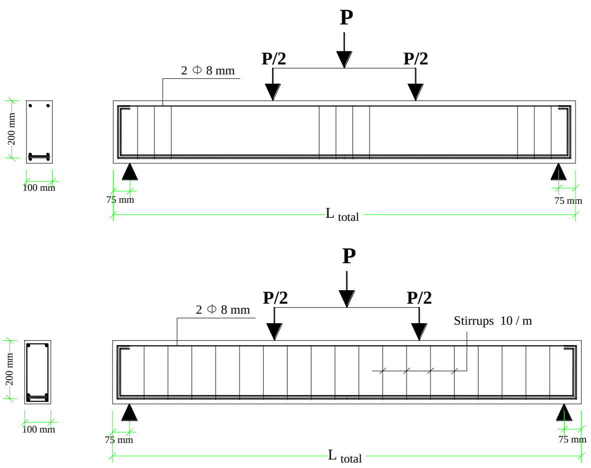


Fig. 1. Reinforcement details of tested beams.

Two types of reinforcing bars were used in this work. The first was locally produced high strength steel with ($fy/fult$=360/520) as high tensile bars used as longitudinal reinforcement. The second one was ordinary plain mild steel with ($fy/fult$=240/350) was used both as secondary reinforcement (top reinforcement) and as stirrups (web reinforcement).

Three concrete mixes were designed for specified compressive concrete strength of 25, 60, and 90 MPa at 28 days. The concrete mix proportions are given in table 2.

3. Test results and discussion

3.1. Failure mode

The trend of cracking was almost the same for all tested beams that failed in shear. The failure was as follows; in early stages of loading, the beams were free of cracks, then flexural cracks were observed in the region of pure bending. With further increase of load, rarely additional flexural cracks formed in the central region and new flexural cracks in the shear span between load and support. Shear cracks initiated as flexural cracks in the shear span and then curved towards the loading points or a diagonal crack formed at the mid height of the beam within the shear span. Table 3 shows the observed test results. Crack patterns of some chosen beams are shown in fig. 2.

3.2. Deflection of the tested beams

Deflection of the tested beams was measured at three positions for each beam, central and under concentrated loads, then readings were recorded. Figs. 3 to 14 were plotted to represent the relation between load and the corresponding central deflection. The main variables considered in these figures are the concrete compressive strength, the web reinforcement, the shear span-to-depth ratio (a/d) and the main steel ratio (ρ). The slopes of the load-midspan deflection curves increase slightly with increase of both the concrete compressive strength and the web reinforcement ratio (ρ_v).

3.3. Strain of the tested beams

Strain values were recorded for all tested beams at each step of loading. Longitudinal strains at the flexure span and at the shear span were measured. Figs. 15 to 20 were plotted to represent the relation between load and the corresponding longitudinal strain (at midheight of the shear span). The main variables considered in these figures are the concrete compressive strength, the web reinforcement and the shear span-to-depth ratio (a/d). From figures, it is noticed that, the values of the measured longitudinal strains at the shear span for all beams increased significantly after the formation of the diagonal crack. It is concluded that, the increase of web reinforcement, decreases the longitudinal strains at the shear span, and the increase of concrete compressive strength, decreases the longitudinal strain values at the shear span zone.

Table 2
Concrete mix proportions

Compressive strength MPa	Cement kg/m^3	Sand kg/m^3	Coarse aggregate kg/m^3		Silica fume kg/m^3	Addicrete (BVF) liter/m^3	Water liter/m^3
			Dolomite size 1	Dolomite size 2			
25	300	658.4	658.4	658.4	---	---	165
60	400	483.3	483.3	966.6	60	12	110.4
90	500	437.3	437.3	874.5	75	15	138

Table 3
Observed results

Group	Beam	a/d	Main steel	Stirrups	P_{cr} (kN)	P_u (kN)	Failure mode
Group (1) Normal, f_{cu}=25 N/mm^2	B 1	2	4 ϕ 12	No stirrups	50	110	Shear compression
	B 2	2	4 ϕ 12	10 ϕ 6/m	65	170	Shear compression
	B 3	2	4 ϕ 12	10 ϕ 8/m	90	198	Diagonal tension
	B 4	2	4 ϕ 16	No stirrups	55	135	Diagonal tension
	B 5	2	4 ϕ 16	10 ϕ 6/m	75	190	Diagonal tension
	B 6	2	4 ϕ 16	10 ϕ 8/m	100	220	Diagonal tension
	B 7	3	4 ϕ 12	No stirrups	40	75	Shear compression
	B 8	3	4 ϕ 12	10 ϕ 6/m	50	120	Shear compression
	B 9	3	4 ϕ 12	10 ϕ 8/m	55	160	Diagonal tension
	B 10	3	4 ϕ 16	No stirrups	45	90	Shear compression
	B 11	3	4 ϕ 16	10 ϕ 6/m	60	135	Diagonal tension
	B 12	3	4 ϕ 16	10 ϕ 8/m	75	180	Diagonal tension
Group (2) Medium, f_{cu}=60 N/mm^2	B 13	2	4 ϕ 12	No stirrups	65	120	Shear compression
	B 14	2	4 ϕ 12	10 ϕ 6/m	90	210	Diagonal tension
	B 15	2	4 ϕ 12	10 ϕ 8/m	110	250	Diagonal tension
	B 16	2	4 ϕ 16	No stirrups	70	146	Shear compression
	B 17	2	4 ϕ 16	10 ϕ 6/m	90	240	Diagonal tension
	B 18	2	4 ϕ 16	10 ϕ 8/m	105	260	Diagonal tension
	B 19	3	4 ϕ 12	No stirrups	50	90	Shear compression
	B 20	3	4 ϕ 12	10 ϕ 6/m	60	150	Diagonal tension
	B 21	3	4 ϕ 12	10 ϕ 8/m	80	193	Diagonal tension
	B 22	3	4 ϕ 16	No stirrups	50	100	Shear compression
	B 23	3	4 ϕ 16	10 ϕ 6/m	60	185	Diagonal tension
	B 24	3	4 ϕ 16	10 ϕ 8/m	90	210	Diagonal tension
Group (3) High, f_{cu}=90 N/mm^2	B 25	2	4 ϕ 12	No stirrups	80	165	Shear compression
	B 26	2	4 ϕ 12	10 ϕ 6/m	105	220	Diagonal tension
	B 27	2	4 ϕ 12	10 ϕ 8/m	130	270	Diagonal tension
	B 28	2	4 ϕ 16	No stirrups	80	192	Diagonal tension
	B 29	2	4 ϕ 16	10 ϕ 6/m	105	240	Diagonal tension
	B 30	2	4 ϕ 16	10 ϕ 8/m	145	300	Shear compression
	B 31	3	4 ϕ 12	No stirrups	55	115	Shear compression
	B 32	3	4 ϕ 12	10 ϕ 6/m	70	150	Shear compression
	B 33	3	4 ϕ 12	10 ϕ 8/m	100	250	Diagonal tension
	B 34	3	4 ϕ 16	No stirrups	70	130	Shear compression
	B 35	3	4 ϕ 16	10 ϕ 6/m	90	210	Diagonal tension
	B 36	3	4 ϕ 16	10 ϕ 8/m	115	265	Diagonal tension

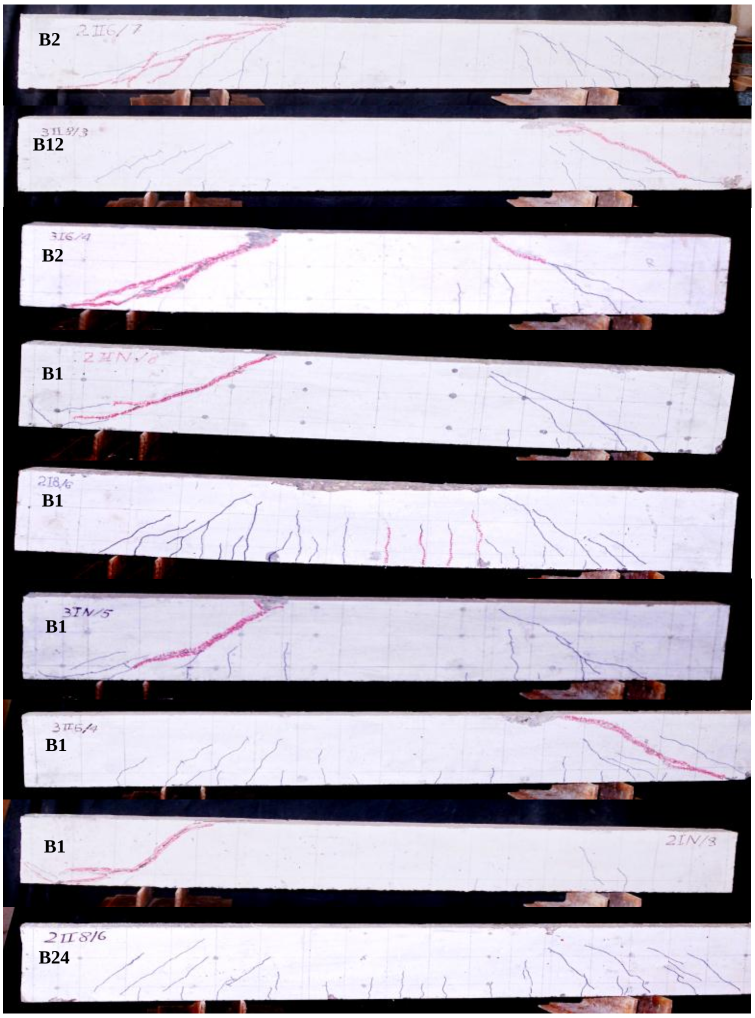


Fig. 2. Crack patterns of some chosen beams.

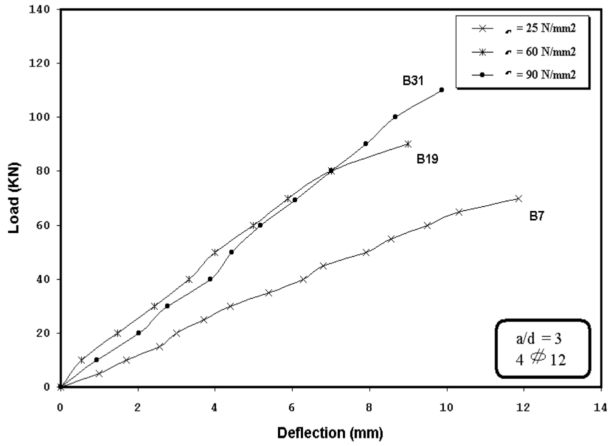


Fig. 3. Effect of main variables on deflection for B31, B19 and B7.

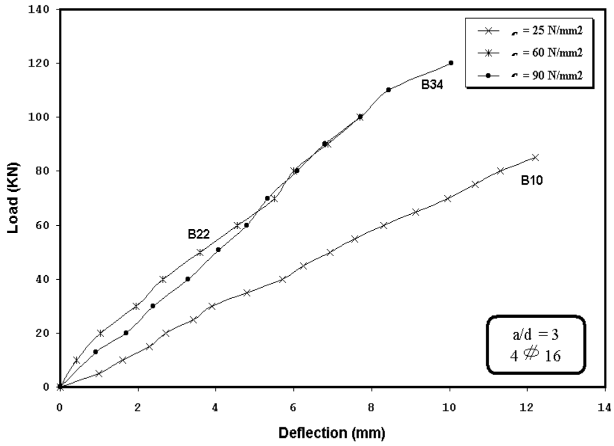


Fig. 4. Effect of main variables on deflection for B31, B19 and B7.

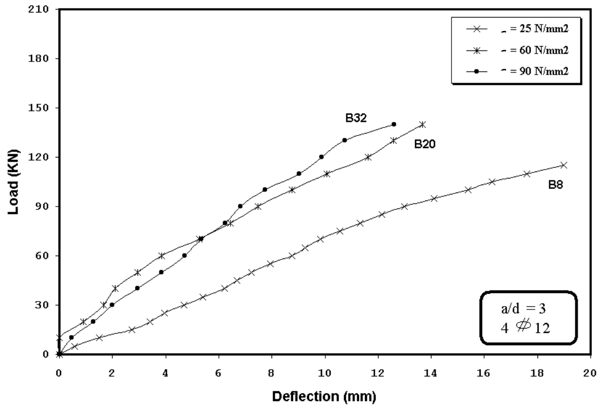


Fig. 5. Effect of main variables on deflection for B32, B20 and B8.

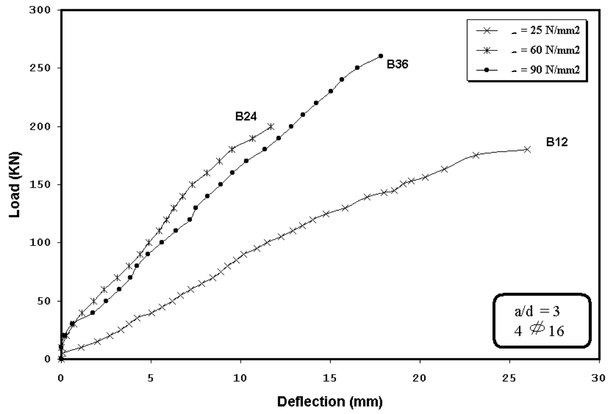


Fig. 8. Effect of main variables on deflection for B42, B36 and B12.

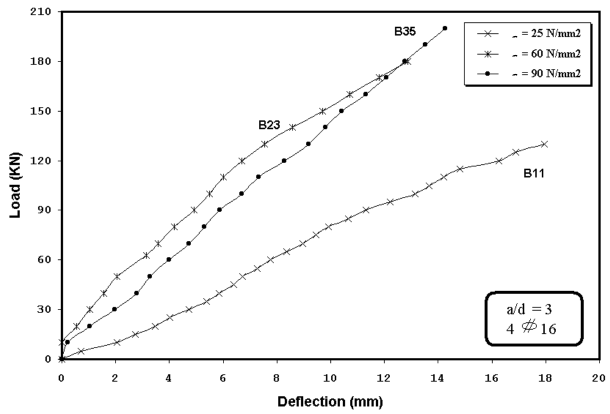


Fig. 6 Effect of main variables on deflection for B35, B23 and B11.

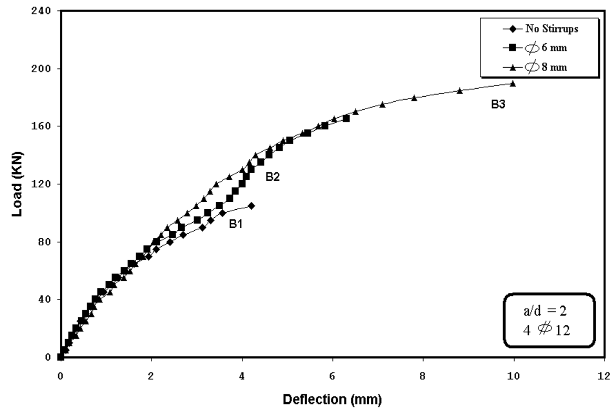


Fig. 9. Effect of main variables on deflection for B1, B2 and B3.

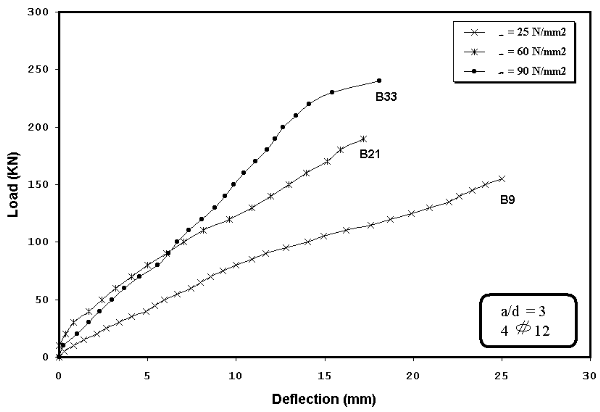


Fig. 7. Effect of main variables on deflection for B35, B23 and B11.

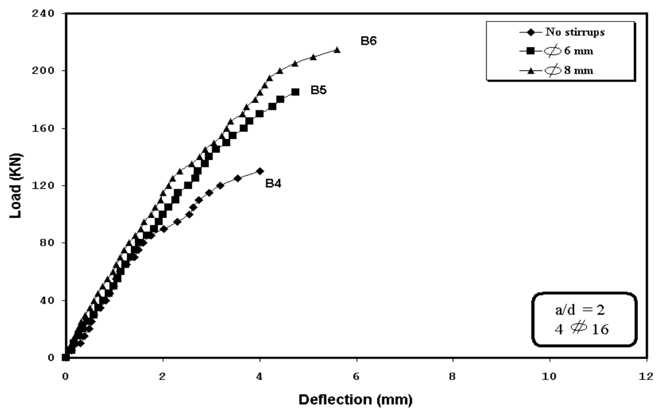


Fig. 10. Effect of main variables on deflection for B4, B5 and B6.

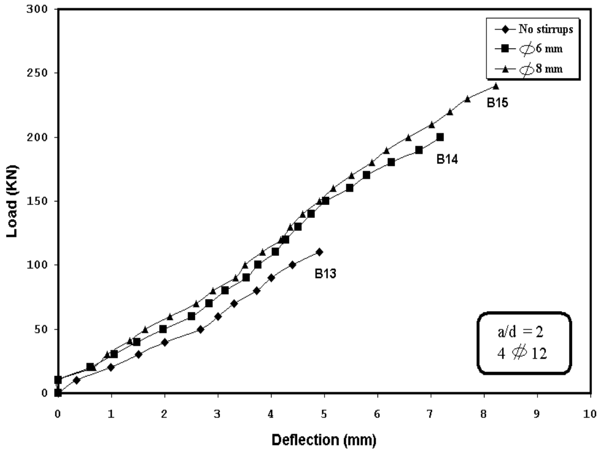


Fig. 11. Effect of main variables on deflection for B13, B14 and B15.

Fig. 14. Effect of main variables on deflection for B28, B29 and B30.

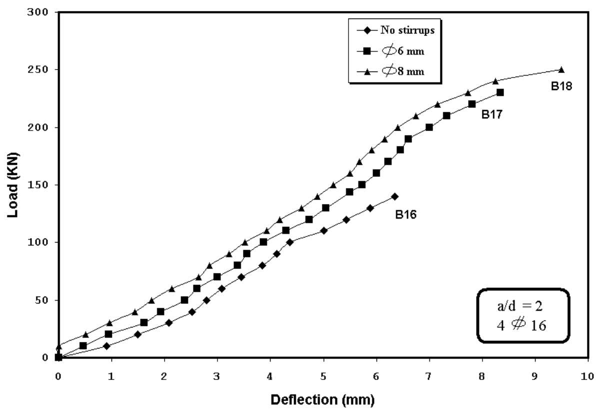


Fig. 12. Effect of main variables on deflection for B16, B17 and B18.

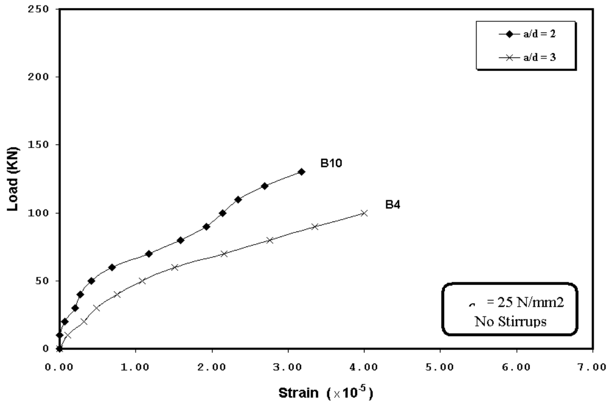


Fig. 15. Effect of (a/d) on beam strain for B4, B10.

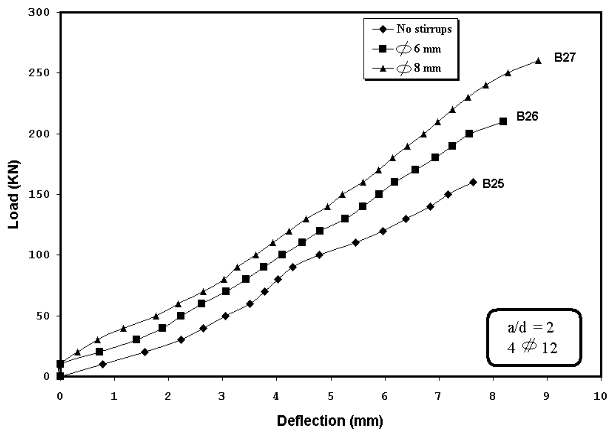
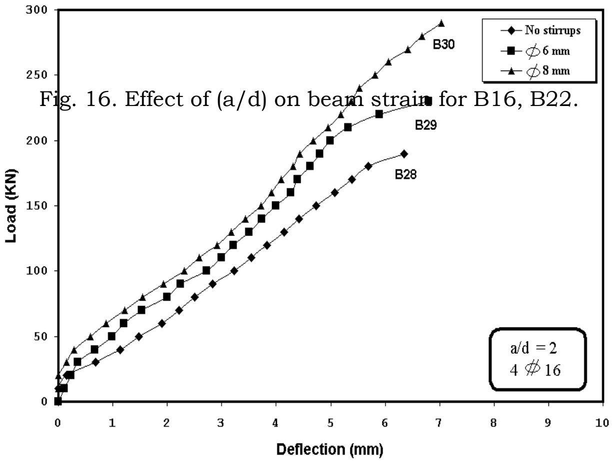


Fig. 13. Effect of main variables on deflection for B25, B26 and B27.

Fig. 16. Effect of (a/d) on beam strain for B16, B22.



Strain ($\times 10^{-5}$)

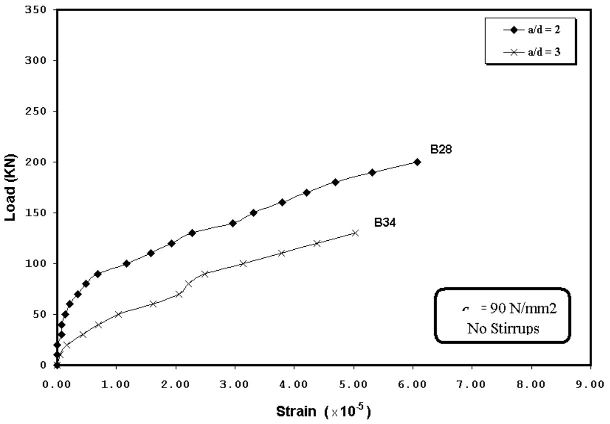


Fig. 17 Effect of (a/d) on beam strain for B28, B34.

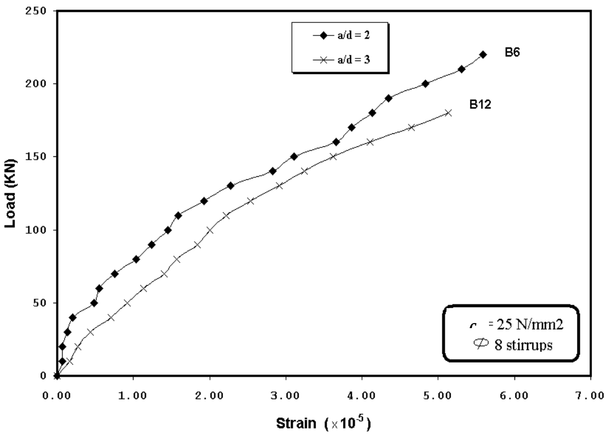


Fig. 18. Effect of (a/d) on beam strain for B6, B12.

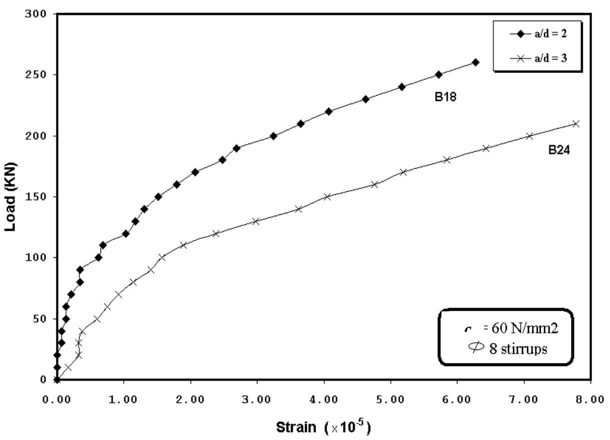


Fig. 19. Effect of (a/d) on beam strain for B18, B24.

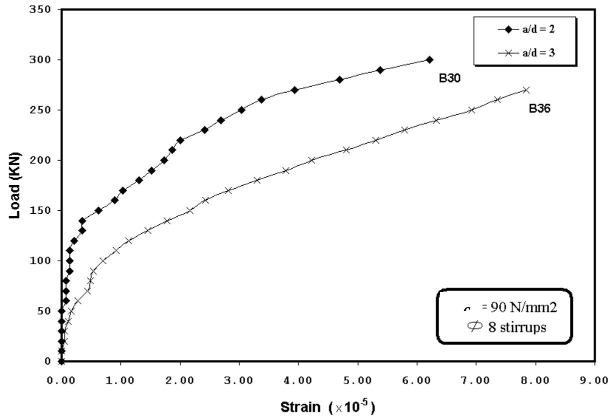


Fig. 20. Effect of (a/d) on beam strain for B30, B36.

3.4. Shear strength of the tested beams

By observing the results of the tested beams listed in table 3 and figs. 21 to 30, it is noticed that, many factors affect the cracking and ultimate shear strengths for the tested beams as follows: The higher the compressive strength, the higher is the initial crack load, and also, it is noticed that, the number of cracks and their widths decreases, this is due to the increase in tensile strength. The cracking and the ultimate loads increase as shear span-to-depth ratio (a/d) decreases, this is because cracks form in the shear regions at places of high moments which are towards the applied concentrated loads. As shear span-to-depth ratio (a/d) decreases this distance also decreases, and the slope of the cracks become more steep. As the longitudinal steel reinforcement ratio (ρ) increases, the penetration of the flexural crack decreases. Also beams with low longitudinal steel reinforcement ratio (ρ) have large deflection since their inertia is relatively low and hence will have wide large cracks in contrast to short narrow cracks in beams with high longitudinal steel reinforcement ratio (ρ). As the web reinforcement ratio increases, the shear resistance of the beams increases, and also, the beams became more ductile and hence, failures were less sudden. Failure and cracking loads increase with increase of the web reinforcement (ρ_v).

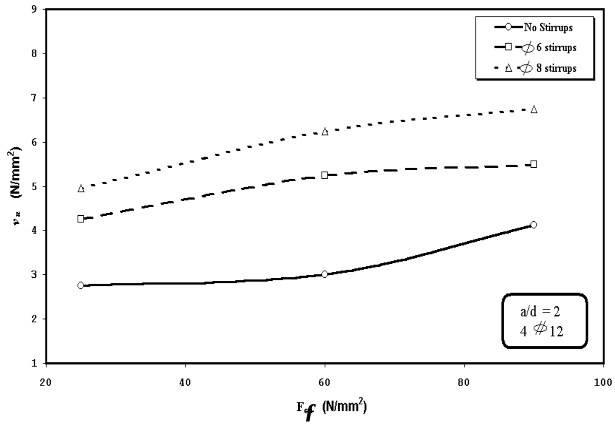


Fig. 21. Effect of (f_{cu}) on (υ_u).

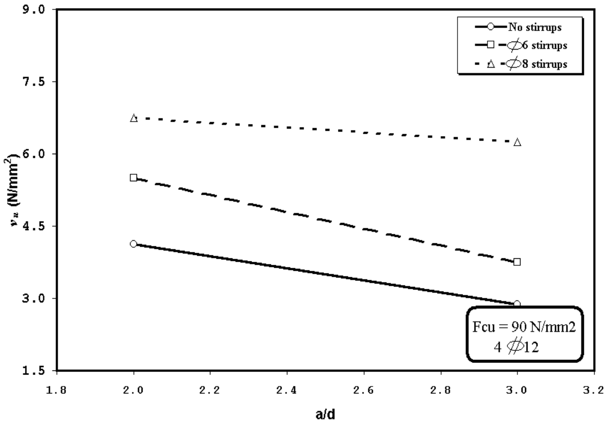


Fig. 24. Effect of (f_{cu}) on (υ_u).

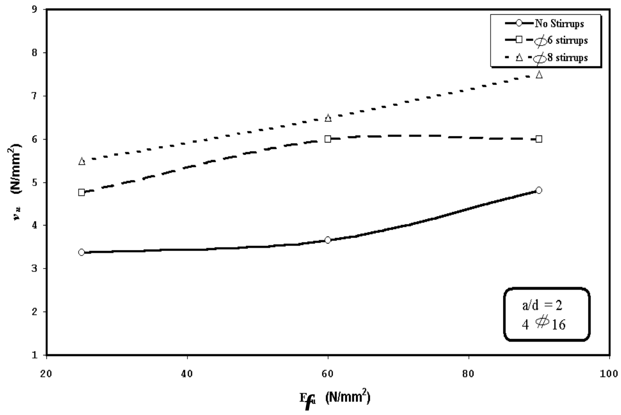


Fig. 22. Effect of (f_{cu}) on (υ_u).

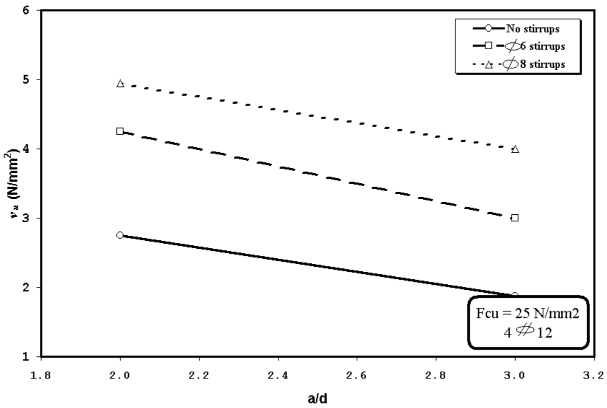


Fig. 25. Effect of (a/d) on (υ_u).

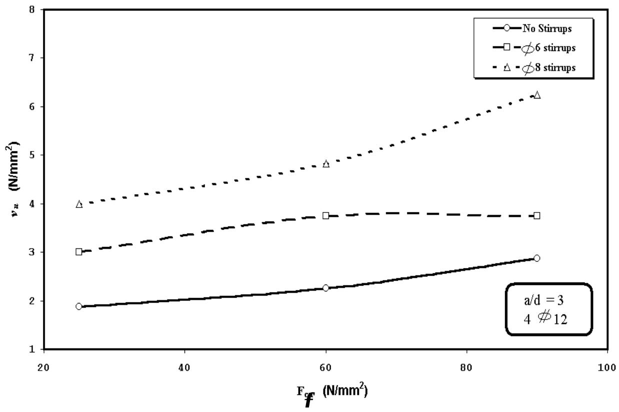


Fig. 23. Effect of (f_{cu}) on (υ_u).

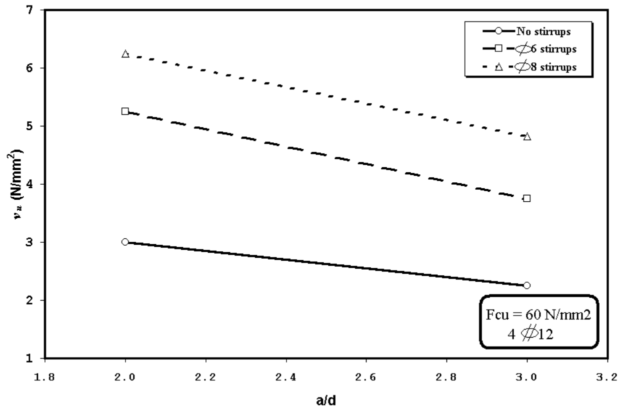


Fig. 26. Effect of (a/d) on (υ_u).

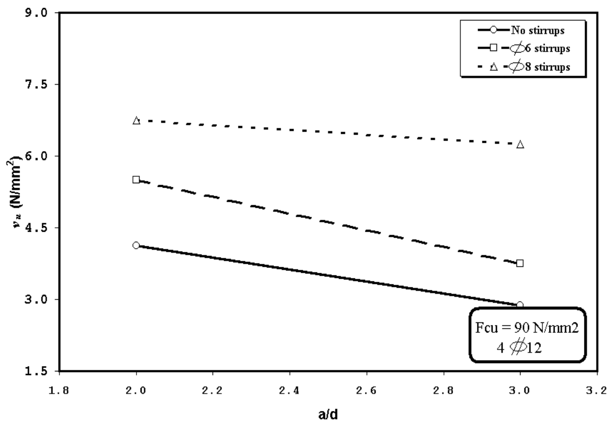


Fig. 27. Effect of (a/d) on (υ_u).

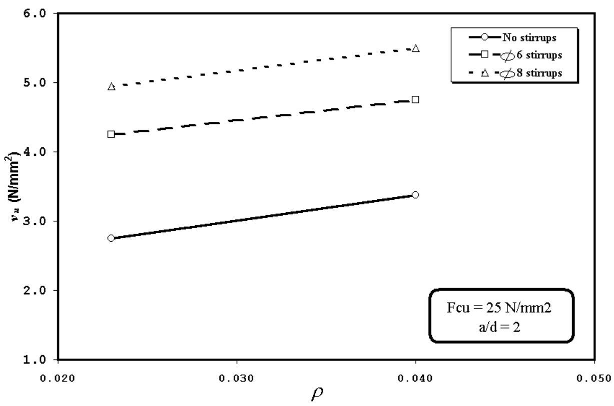


Fig. 28. Effect of (ρ) on (υ_u).

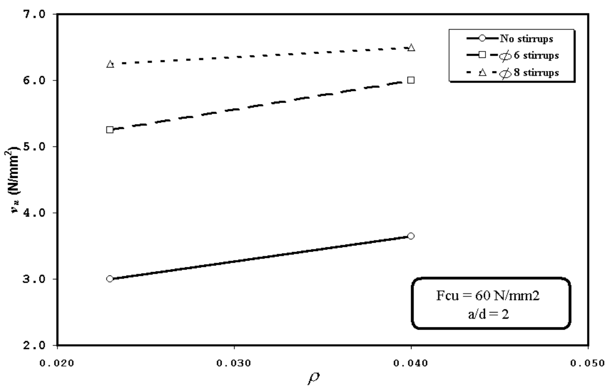


Fig. 29. Effect of (ρ) on (υ_u).

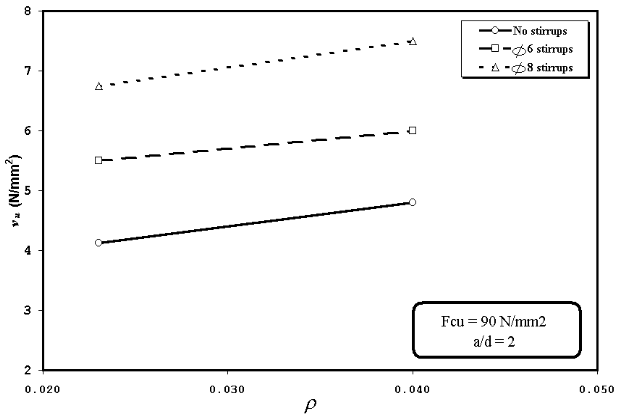


Fig. 30. Effect of (ρ) on (υ_u).

4. Evaluation of cracking and ultimate shear strengths

4.1. Equations predicting cracking shear strength

Many equations have been proposed to estimate the cracking shear strength of beams. Among them, the well known equation deduced by Zsutty [18] for NSC using the multiple regression analysis as follows:

$$\upsilon_{cr} = 2.1\,(f_c'\,\rho\,d/a)^{1/3} \quad \text{(mm-N)}\,. \qquad (1)$$

Hashem [4] suggested an empirical equation for the evaluation of cracking shear strength for NSC as follows:

$$\upsilon_{cr} = 0.59\sqrt{f_{cu}} + 230\,\rho\,d/a \quad \text{(kg-cm)}. \qquad (2)$$

Rebeiz [12] developed an equation obtained from the multiple regression analysis using the technique of dimensional analysis for beams without web reinforcement, incorporated the use of the three important variables: the shear span to depth ratio (a/d), the compressive strength f_c', and the tensile reinforcement ratio ρ as follows:

$$\upsilon_{cr} = 0.4 + \sqrt{f_c'\,\rho\,d/a}\,\left[2.7 - 0.4A_d\right] \quad \text{(mm-N)}. \qquad (3)$$

(Where: A_d is shape factor taken = a/d for 1 < a/d < 2.5 or 2.5 for a/d ≥ 2.5)

Moustafa [8] proposed two equations for predicting the cracking shear strength of

reinforced HSC beams based on the experimental results and others' test results. These equations are refined modifications of other available ACI and Zsutty equations as follows:
Moustafa's eq. (1),

$$\upsilon_{cr} = (1/7)\ \sqrt{f'_c} \quad \text{(mm-N)} . \qquad (4)$$

Moustafa's eq. (2),

$$\upsilon_{cr} = 1.6\ (40\ f^{*}\ \rho\ d/a)^{1/3} + 0.2\ \beta \quad \text{(mm-N)}. \qquad (5)$$

Where:
$f^{*} = f_c'/40 \leq 1$ (mm-N)

$\beta = [(f_c' - 40)\ \rho\ d/a]^{1/3}$ (mm-N).

Shin et al. [14] have expressed the cracking shear strength depending on the test of thirty reinforced HSC beams. The test variables were the compressive strength of concrete, the shear span to depth ratio, and the vertical shear reinforcement ratio as follows:

$$\upsilon_{cr} = 2.6\ (f_c'\ \rho)^{1/3}\ (d/a)^{1/2} \quad \text{(mm-N)}. \qquad (6)$$

4.2. Equations predicting ultimate shear strength

Zsutty [18] segregated the data and performed separate regression analysis for short beams and long beams. However, the main problem of performing separate regression analysis for short beams and long beams is that his approach would lead to two different equations and would cause discontinuity to occur for a certain value of a/d as follows:

$$\upsilon_u = 2.3\ (f_c'\ \rho\ d/a)^{1/3} \quad \text{for } (a/d \geq 2.5) \text{ (mm-N)}, \qquad (7)$$

$$\upsilon_u = 2.3\ (f_c'\ \rho\ d/a)^{1/3}\ (2.5\ d/a) \text{ for } (a/d < 2.5) \text{ (mm-N)}. \qquad (8)$$

Hashem [4] suggested an empirical equation for the evaluation of ultimate shear strength for NSC. The obtained equation can be used for both rectangular and T-beams as follows:

$$\upsilon_u = 0.59\sqrt{f_{cu}} + 230\ \rho\ d/a + 5.17\sqrt{f_{cu}}\ \frac{(B-b)}{b}\ \frac{t_s}{t}\ \frac{d}{a} + \frac{A_v\ f_{yv}}{b \cdot S} \text{ (kg-cm)}. \qquad (9)$$

Mphonde and Frantz [9] tested three series of reinforced concrete beams without shear reinforcement. A new regression equation is proposed to more accurately predict ultimate shear capacity of slender beams over the entire range of concrete strengths tested. The equation is as follows:

$$\upsilon_u = 0.366\ \sqrt[3]{f'_c} + 0.49 \text{ (mm-N)}. \qquad (10)$$

Mphonde and Frantz [10] also tested 12 reinforced concrete beams with shear reinforcement index $\upsilon_s = A_v f_{yv}/bS$ of 0.34, 0.69, or 1.03 MPa and f_c' ranging from 24 to 90 MPa. Only three of these beams had $f_c' < 41$ MPa. The equation is as follows:

$$\upsilon_u = 0.125\sqrt{f'_c} + 0.62 + 1.6\ \frac{A_v\ f_{yv}}{b \cdot S} \text{ (mm-N)}. \qquad (11)$$

Sarsam and Al-Musawi [13] examined 14 beams with stirrups failing in shear, in addition to 107 from the literature. These include reinforced HSC beams with compressive strength of $f_c' > 41$ MPa, and reinforced NSC beams with lower f_c' values. The principal variables were concrete compressive strength, stirrups nominal strength ($\rho_v\ f_{yv}$), longitudinal steel ratio (ρ) and shear span to depth ratio (a/d). The proposed design method is as follows:

$$\upsilon_u = 0.85\ [1.8\ (f_c'\ \rho\ d/a)^{0.38} + \frac{A_v\ f_{yv}}{b \cdot S}] \text{(mm-N)}. \qquad (12)$$

Kim and Park [6] proposed a rational and mechanics-based equation for the prediction of shear strength of reinforced concrete beams without web reinforcement. This prediction is based on basic shear transfer mechanisms, a modified Bazant's size effect law, and numerous published experimental data, including reinforced HSC beams with compressive strengths of concrete up to 100 MPa. The effect of concrete strength on the shear strength of reinforced beams with a/d < 3.0 is estimated well by introducing failure mode index α. The equation is as follows:

$$\upsilon_u = 3.5\, f_c'^{\alpha/3} \rho^{3/8} (0.4 + d/a) \left(1/\sqrt{1 + 0.008\, d} + 0.18\right) \quad \text{(mm-N)}. \qquad (13)$$

(Where: α is a failure mode index, α =1 for ($a/d \geq 3$), or [2-(a/d)/3] for ($1 \leq a/d < 3$))

Rebeiz [12] developed a new equation for the ultimate shear strength prediction obtained from the multiple regression analysis using the technique of dimensional analysis. More than 350 data (more than 300 data for NSC and more than 50 data for HSC) were obtained from existing sources of reinforced beam shear test results covering a wide range of beam properties and test methods. The analysis was done for both reinforced NSC and HSC beams with compressive concrete strength up to 104 MPa as follows:

$$\upsilon_u = 0.4 + \sqrt{f_c' \,\rho\, d/a}\;\left[10 - 3A_d\right] \quad \text{(mm-N)}. \qquad (14)$$

(Where: A_d is shape factor taken = a/d for $1 < a/d < 2.5$ or 2.5 for $a/d \geq 2.5$)

4.3. Proposed equation for cracking shear strength

Based on the observations of first cracks in shear of the performed experimental results in this study and test results carried out by other investigators such as Ahmad et al. [1]; Moustafa [8]; Mphonde and Frantz [9]; Pendyala and Mendis [11]; Yoon et al. [17]; Thornfeldt and Drangholt [15]; Xie et al. [16]; and Shin et al. [14], test data of 201 reinforced concrete beams with and without web reinforcement failed in shear (36 test results obtained from this study and 165 test results from other previous investigators) were used in multiple regression analysis to formulate the most important factors affecting the cracking shear strength in a suitable predictive equation. These data are summarized in table 4. The test data cover a wide range of individual parameters as: cylinder concrete compressive strength ($19.5 \leq f_c' \leq 103.2$ N/mm^2); longitudinal main steel reinforcement ratio ($1.6 \leq \rho \leq 6.64$ %); and shear span-to-depth ratio ($1 \leq a/d \leq 5$). A modified equation is proposed to predict the cracking shear strength based on the statistical analysis of the above-mentioned test data as follows:

$$\upsilon_{cr} = 2.88\,(f_c' \rho)^{0.3}\,(d/a)^{0.6} \quad \text{(mm-N)}. \qquad (15)$$

Acceptable results are obtained from the application of eq. (15) on the 201 tested beams. The mean value of the observed cracking shear strength to the predicted cracking shear strength is 0.99 with a standard deviation of 0.220. Based on the statistical analysis, the mean standard error of estimate is found to be 0.033 and the correlation coefficient between the predicted and observed values is 0.81. Table 5 shows a summary of the mentioned statistical study for all predictive equations.

4.4. Proposed equation for ultimate shear strength

Based on the performed experimental results in this study and test results carried out by other investigators such as Ahmad et al. [1]; Elzanaty et al. [3]; Kim and Park [5]; Kong and Rangan [7]; Moustafa [8]; Mphonde and Frantz [9]; Pendyala and Mendis [11]; Sarsam and Al-Musawi [13]; Shin et al. [14]; Xie et al. [16]; and Yoon et al. [17], test data of 271 reinforced concrete beams with and without web reinforcement failed in shear (36 test results obtained from this study and 235 test results from other previous investigators) were used in multiple regression analysis to formulate the most important factors affecting the ultimate shear strength in a suitable predictive equation. These data are summarized in tables 6 and 7. The test data cover a wide range of individual parameters as: cylinder concrete compressive strength ($19.5 \leq f_c' \leq 103.2$ N/mm^2); longitudinal main steel reinforcement ratio ($1.6 \leq \rho \leq 6.64$ %); shear span to depth ratio ($1 \leq a/d \leq 5$); and web reinforcement ratio ($0.0 \leq \rho_v \leq 1.81$ %). A modified equation is proposed to predict the ultimate shear strength based on the statistical analysis of the above-mentioned test data as follows:

Table 4
Test data for cracking shear strength

Source	Beam mark	Measured values υ_{cr} N/mm²	Estimated values υ_{cr}, N/mm² Eq. (1)	Eq. (2)	Eq. (3)	Eq. (4)	Eq.(5)	Eq. (6)	Eq. (15)
Present Study	B1	1.25	1.283	1.208	1.308	0.755	1.008	1.416	1.502
	B2	1.63	1.271	1.195	1.294	0.744	0.995	1.401	1.488
	B3	2.25	1.277	1.200	1.301	0.750	1.002	1.409	1.495
	B4	1.38	1.550	1.404	1.605	0.752	1.216	1.710	1.780
	B5	1.88	1.550	1.404	1.605	0.752	1.216	1.710	1.780
	B6	2.50	1.545	1.401	1.599	0.748	1.210	1.704	1.774
	B7	1.00	1.108	1.106	1.052	0.742	0.867	1.142	1.165
	B8	1.25	1.123	1.123	1.065	0.757	0.882	1.158	1.179
	B9	1.38	1.121	1.121	1.063	0.755	0.880	1.156	1.177
	B10	1.13	1.356	1.254	1.282	0.754	1.065	1.398	1.397
	B11	1.50	1.349	1.247	1.276	0.748	1.057	1.391	1.391
	B12	1.88	1.356	1.252	1.282	0.754	1.065	1.398	1.397
	B13	1.63	1.752	1.705	1.848	1.205	1.563	1.933	1.987
	B14	2.25	1.760	1.713	1.858	1.213	1.566	1.941	1.996
	B15	2.75	1.758	1.711	1.855	1.211	1.565	1.939	1.993
	B16	1.75	2.123	1.907	2.331	1.205	1.894	2.342	2.362
	B17	2.25	2.134	1.917	2.346	1.214	1.898	2.354	2.373
	B18	2.63	2.127	1.911	2.337	1.208	1.896	2.346	2.366
	B19	1.25	1.531	1.618	1.458	1.205	1.366	1.578	1.558
	B20	1.50	1.540	1.630	1.468	1.217	1.369	1.588	1.567
	B21	2.00	1.538	1.627	1.465	1.213	1.368	1.585	1.565
	B22	1.25	1.862	1.761	1.819	1.212	1.657	1.919	1.859
	B23	1.50	1.858	1.757	1.815	1.208	1.656	1.916	1.855
	B24	2.25	1.857	1.756	1.814	1.207	1.656	1.914	1.854
	B25	2.00	2.038	2.036	2.217	1.512	1.627	2.248	2.277
	B26	2.63	2.041	2.040	2.221	1.515	1.627	2.252	2.281
	B27	3.25	2.040	2.038	2.219	1.514	1.627	2.250	2.279
	B28	2.00	2.465	2.234	2.817	1.508	1.970	2.719	2.703
	B29	2.63	2.468	2.237	2.821	1.511	1.971	2.723	2.706
	B30	3.63	2.468	2.237	2.821	1.511	1.971	2.723	2.706
	B31	1.38	1.779	1.947	1.725	1.510	1.421	1.834	1.784
	B32	1.75	1.780	1.948	1.726	1.511	1.421	1.835	1.785
	B33	2.50	1.780	1.949	1.727	1.512	1.421	1.836	1.785
	B34	1.75	2.157	2.084	2.170	1.512	1.722	2.224	2.122
	B35	2.25	2.158	2.085	2.171	1.513	1.722	2.225	2.123
	B36	2.88	2.154	2.080	2.166	1.508	1.721	2.220	2.119

Table 4 Cont..

Source	Beam mark	Measured values	Estimated values						
		υ_{cr}	υ_{cr} , N/mm^2						
		N/mm^2	Eq.(1)	Eq.(2)	Eq.(3)	Eq.(4)	Eq.(5)	Eq.(6)	Eq.(15)
Ahmad et al. [7]	A1	2.24	1.769	1.785	1.714	1.311	1.517	1.738	1.628
	A2	2.40	1.947	1.860	1.917	1.311	1.670	2.007	1.935
	A3	2.40	2.016	1.894	1.999	1.311	1.730	2.115	2.061
	A4	2.46	2.127	1.952	2.214	1.311	1.825	2.292	2.269
	A5	2.93	2.228	2.011	2.477	1.311	1.912	2.458	2.468
	A6	5.94	2.807	2.463	3.955	1.311	2.409	3.476	3.740
	A7	1.43	1.356	1.661	1.282	1.311	1.163	1.332	1.282
	A8	1.60	1.492	1.694	1.418	1.311	1.280	1.538	1.523
	A9	1.85	1.545	1.710	1.473	1.311	1.326	1.622	1.622
	A10	1.85	1.630	1.736	1.618	1.311	1.399	1.757	1.786
	A11	2.02	1.708	1.762	1.794	1.311	1.465	1.884	1.942
	A12	5.05	2.152	1.966	2.786	1.311	1.846	2.664	2.944
	B1	1.99	1.985	1.919	1.962	1.376	1.662	1.950	1.806
	B2	2.21	2.184	2.016	2.203	1.376	1.830	2.252	2.146
	B3	2.43	2.262	2.059	2.301	1.376	1.895	2.374	2.286
	B4	2.43	2.387	2.134	2.556	1.376	1.999	2.572	2.517
	B5	3.04	2.500	2.209	2.868	1.376	2.094	2.758	2.737
	B6	5.20	3.150	2.789	4.626	1.376	2.639	3.900	4.149
	B7	1.68	1.517	1.759	1.443	1.376	1.270	1.490	1.418
	B8	1.76	1.669	1.802	1.605	1.376	1.398	1.721	1.685
	B9	1.77	1.729	1.821	1.670	1.376	1.448	1.814	1.795
	B10	2.10	1.824	1.855	1.841	1.376	1.528	1.966	1.976
	B11	2.35	1.911	1.888	2.049	1.376	1.601	2.108	2.149
	B12	4.20	2.408	2.147	3.224	1.376	2.017	2.981	3.257
	C1	2.28	2.146	1.981	2.156	1.348	1.816	2.109	1.938
	C2	2.09	2.362	2.109	2.428	1.348	1.999	2.435	2.303
	C3	1.71	2.447	2.165	2.538	1.348	2.070	2.567	2.453
	C4	2.37	2.581	2.264	2.825	1.348	2.184	2.781	2.701
	C5	2.85	2.704	2.363	3.176	1.348	2.288	2.983	2.937
	C6	5.68	3.407	3.127	5.152	1.348	2.883	4.218	4.451
	C7	1.35	1.693	1.787	1.631	1.348	1.433	1.664	1.565
	C8	1.69	1.863	1.849	1.821	1.348	1.577	1.921	1.860
	C9	1.69	1.930	1.877	1.898	1.348	1.633	2.025	1.982
	C10	1.56	2.036	1.926	2.099	1.348	1.723	2.194	2.182
	C11	2.45	2.133	1.974	2.345	1.348	1.805	2.353	2.372
	C12	3.39	2.688	2.349	3.730	1.348	2.274	3.327	3.596

Table 4. Cont.

Source	Beam mark	Measured values υ_{cr} N/mm^2	Estimated values υ_{cr}, N/mm^2 Eq. (1)	Eq. (2)	Eq. (3)	Eq. (4)	Eq. (5)	Eq. (6)	Eq. (15)
Moustafa [53]	S1	2.04	2.042	1.902	2.414	1.302	1.758	2.363	2.487
	S2	1.77	2.256	2.025	2.738	1.302	1.942	2.611	2.720
	S3	1.49	2.042	1.902	2.414	1.302	1.758	2.363	2.487
	M1	1.22	1.683	1.713	1.620	1.258	1.473	1.789	1.793
	M2	1.43	1.860	1.787	1.817	1.258	1.627	1.976	1.961
	M3	1.22	1.683	1.713	1.620	1.258	1.473	1.789	1.793
	N1	1.36	1.540	1.701	1.467	1.302	1.325	1.547	1.496
	N2	1.49	1.701	1.753	1.639	1.302	1.464	1.709	1.636
	N3	1.36	1.502	1.650	1.429	1.254	1.316	1.509	1.463
	C1	1.46	1.763	1.741	2.016	1.252	1.546	2.040	2.179
	C2	1.98	1.990	1.849	2.337	1.252	1.745	2.303	2.430
	C3	1.90	2.198	1.971	2.649	1.252	1.928	2.544	2.657
	A1	1.36	1.871	1.800	1.829	1.269	1.630	1.988	1.972
	A2	1.08	1.693	1.726	1.631	1.269	1.476	1.800	1.803
	A4	1.22	1.741	1.788	1.683	1.329	1.484	1.850	1.848
	A5	1.36	1.694	1.772	1.632	1.329	1.444	1.800	1.803
	A8	1.22	1.496	1.641	1.422	1.246	1.315	1.503	1.457
	A9	1.56	1.652	1.694	1.587	1.246	1.452	1.660	1.594
Mphonde and Frantz [54]	AO-3-3b	1.25	1.216	1.175	1.149	0.767	0.957	1.216	1.199
	AO-3-3c	0.83	1.174	1.230	1.111	0.875	0.950	1.174	1.162
	AO-7-3a	1.47	1.483	1.470	1.408	1.032	1.264	1.483	1.434
	AO-7-3b	1.37	1.532	1.527	1.459	1.084	1.413	1.532	1.477
	AO-11-3a	1.47	1.864	1.929	1.821	1.455	1.517	1.864	1.761
	AO-11-3b	1.47	1.861	1.926	1.819	1.452	1.517	1.861	1.759
	AO-15-3a	1.86	1.915	1.994	1.881	1.515	1.527	1.916	1.805
	AO-15-3c	2.10	1.995	2.096	1.974	1.610	1.540	1.995	1.872
	AO-3-2	1.37	1.369	1.264	1.295	0.763	1.077	1.455	1.488
	AO-7-2	1.76	1.779	1.672	1.725	1.130	1.628	1.890	1.884
	AO-11-2	1.96	2.145	2.069	2.155	1.497	1.721	2.280	2.230
	AO-15-2a	2.34	2.185	2.113	2.204	1.539	1.728	2.322	2.267
	AO-15-2b	1.76	2.052	1.965	2.042	1.400	1.703	2.181	2.143
	AO-3-1	1.57	1.686	1.522	1.911	0.808	1.341	1.951	2.093
	AO-7-1	2.34	2.054	1.830	2.432	1.087	1.895	2.377	2.500
	AO-11-1	2.54	2.389	2.131	2.948	1.362	2.010	2.764	2.864
	AO-15-1a	3.13	2.545	2.277	3.202	1.499	2.041	2.946	3.032
	AO-15-1b	2.94	2.564	2.295	3.234	1.515	2.044	2.968	3.053
Pendyala and Mendis [64]	1	1.90	1.466	1.428	1.508	0.980	1.222	1.617	1.692
	2	1.48	1.080	1.290	1.027	0.980	0.900	1.022	0.977
	3	1.85	1.800	1.814	1.908	1.334	1.531	1.986	2.037
	4	1.48	1.326	1.676	1.253	1.334	1.128	1.256	1.175
	5	1.90	2.005	2.066	2.172	1.568	1.570	2.211	2.244
	6	1.62	1.477	1.928	1.403	1.568	1.157	1.399	1.295
	8	1.90	1.451	1.411	1.491	0.965	1.204	1.601	1.677
	12	1.44	1.856	1.882	1.978	1.396	1.543	2.047	2.093
	14	1.94	1.436	1.395	1.475	0.951	1.186	1.584	1.662
	15	1.71	1.781	1.792	1.884	1.313	1.527	1.964	2.017
	18	1.99	2.035	2.104	2.212	1.603	1.575	2.245	2.274
	20	2.36	1.974	2.026	2.131	1.531	1.565	2.177	2.212
	21	1.94	1.494	1.459	1.540	1.008	1.259	1.648	1.722

Table 4. Cont.

Source	Beam mark	Measured values	Estimated values						
		υ_{cr}	υ_{cr} , N/mm²						
		N/mm²	Eq. (1)	Eq. (2)	Eq. (3)	Eq. (4)	Eq. (5)	Eq. (6)	Eq. (15)
Yoon et al. [90]	N1-S	1.00	1.460	1.444	1.385	1.008	1.230	1.505	1.493
	N1-N	1.06	1.460	1.444	1.385	1.008	1.230	1.505	1.493
	N2-S	0.81	1.460	1.444	1.385	1.008	1.230	1.505	1.493
	N2-N	1.03	1.460	1.444	1.385	1.008	1.230	1.505	1.493
	M1-S	1.18	1.796	1.844	1.744	1.376	1.504	1.851	1.799
	M1-N	1.18	1.796	1.844	1.744	1.376	1.504	1.851	1.799
	M2-S	1.18	1.796	1.844	1.744	1.376	1.504	1.851	1.799
	M2-N	1.18	1.796	1.844	1.744	1.376	1.504	1.851	1.799
	H1-S	1.27	1.959	2.050	1.932	1.568	1.534	2.020	1.946
	H1-N	1.27	1.959	2.050	1.932	1.568	1.534	2.020	1.946
	H2-S	1.27	1.959	2.050	1.932	1.568	1.534	2.020	1.946
	H2-N	1.36	1.959	2.050	1.932	1.568	1.534	2.020	1.946
Thornfeldt and Drangholt [84]	1	1.75	1.448	1.617	1.373	1.235	1.278	1.492	1.482
	2	1.71	1.582	1.659	1.564	1.235	1.396	1.705	1.738
	3	2.22	1.592	1.663	1.523	1.235	1.405	1.565	1.481
	4	2.14	1.753	1.725	1.696	1.235	1.547	1.807	1.760
	5	2.44	1.915	1.800	1.950	1.235	1.690	2.064	2.065
	6	1.75	1.634	1.883	1.567	1.482	1.318	1.685	1.653
	7	1.93	1.786	1.925	1.796	1.482	1.440	1.924	1.939
	8	2.47	1.798	1.929	1.747	1.482	1.450	1.767	1.652
	9	2.50	1.979	1.991	1.955	1.482	1.596	2.040	1.963
	10	2.66	2.162	2.066	2.259	1.482	1.744	2.330	2.303
	11	2.51	1.863	2.016	1.820	1.562	1.461	1.830	1.706
	12	2.50	2.050	2.078	2.040	1.562	1.608	2.113	2.027
	13	2.82	2.240	2.153	2.361	1.562	1.757	2.414	2.377
	14	2.69	1.764	2.075	1.709	1.661	1.340	1.819	1.771
	15	2.05	1.927	2.117	1.965	1.661	1.464	2.077	2.077
	16	2.47	1.940	2.121	1.910	1.661	1.474	1.907	1.770
	17	2.50	2.136	2.183	2.144	1.661	1.622	2.202	2.103
	18	2.82	2.334	2.258	2.485	1.661	1.773	2.515	2.467
	19	1.36	1.634	1.883	1.567	1.482	1.318	1.685	1.653
	20	1.38	1.786	1.925	1.796	1.482	1.440	1.924	1.939
	21	1.79	1.798	1.929	1.747	1.482	1.450	1.767	1.652
	22	1.93	1.979	1.991	1.955	1.482	1.596	2.040	1.963
	23	1.95	2.162	2.066	2.259	1.482	1.744	2.330	2.303
Xie et al. [89]	NNN-1	2.93	2.045	1.831	2.610	1.122	1.875	2.532	2.812
	NNN-2	1.28	1.556	1.517	1.612	1.054	1.357	1.716	1.786
	NNN-3	1.06	1.341	1.414	1.267	1.032	1.143	1.382	1.383
	NNW-1	3.09	2.286	2.030	3.012	1.067	2.094	2.830	3.108
	NNW-2	1.57	1.828	1.675	1.943	1.079	1.685	2.016	2.064
	NNW-3	1.40	1.590	1.545	1.520	1.072	1.463	1.639	1.613
	NHN-1	3.38	2.664	2.419	3.686	1.669	2.019	3.298	3.567
	NHN-2	1.71	2.111	2.178	2.315	1.666	1.602	2.329	2.351
	NHN-3	1.47	1.849	2.105	1.804	1.671	1.400	1.906	1.847
	NHW-1	4.10	3.392	2.935	5.121	1.619	2.612	4.199	4.434
	NHW-2	2.52	2.710	2.430	3.186	1.636	2.076	2.989	2.943
	NHW-3	1.83	2.397	2.289	2.473	1.666	1.818	2.471	2.333
	NHW-3a	2.04	2.328	2.212	2.384	1.594	1.807	2.400	2.273
	NHW-3b	2.58	2.436	2.332	2.524	1.707	1.824	2.512	2.368
	NHW-4	1.65	2.182	2.207	2.201	1.671	1.653	2.145	1.967

Table 4. cont.

Source	Beam mark	Measured values	Estimated values						
		υ_{cr}	υ_{cr} , N/mm^2						
		N/mm^2	Eq. (1)	Eq. (2)	Eq. (3)	Eq. (4)	Eq. (5)	Eq. (6)	Eq. (15)
Shin et al. [77]	MHB1.5-0	2.56	2.296	2.030	2.801	1.212	2.044	2.657	2.763
	MHB1.5-25	2.82	2.296	2.030	2.801	1.212	2.044	2.657	2.763
	MHB1.5-50	2.83	2.296	2.030	2.801	1.212	2.044	2.657	2.763
	MHB1.5-75	2.86	2.296	2.030	2.801	1.212	2.044	2.657	2.763
	MHB1.5-100	2.79	2.296	2.030	2.801	1.212	2.044	2.657	2.763
	MHB2.0-0	2.10	2.086	1.886	2.281	1.212	1.857	2.301	2.325
	MHB2.0-25	2.23	2.086	1.886	2.281	1.212	1.857	2.301	2.325
	MHB2.0-50	2.35	2.086	1.886	2.281	1.212	1.857	2.301	2.325
	MHB2.0-75	2.21	2.086	1.886	2.281	1.212	1.857	2.301	2.325
	MHB2.0-100	2.17	2.086	1.886	2.281	1.212	1.857	2.301	2.325
	MHB2.5-0	1.92	1.937	1.799	1.905	1.212	1.724	2.058	2.034
	MHB2.5-25	2.15	1.937	1.799	1.905	1.212	1.724	2.058	2.034
	MHB2.5-50	1.95	1.937	1.799	1.905	1.212	1.724	2.058	2.034
	MHB2.5-75	2.06	1.937	1.799	1.905	1.212	1.724	2.058	2.034
	MHB2.5-100	2.04	1.937	1.799	1.905	1.212	1.724	2.058	2.034
	HB1.5-0	3.17	2.571	2.273	3.244	1.436	2.107	2.975	3.059
	HB1.5-25	3.10	2.571	2.273	3.244	1.436	2.107	2.975	3.059
	HB1.5-50	2.83	2.571	2.273	3.244	1.436	2.107	2.975	3.059
	HB1.5-75	2.55	2.571	2.273	3.244	1.436	2.107	2.975	3.059
	HB1.5-100	3.21	2.571	2.273	3.244	1.436	2.107	2.975	3.059
	HB2.0-0	2.64	2.336	2.128	2.629	1.436	1.914	2.576	2.574
	HB2.0-25	2.32	2.336	2.128	2.629	1.436	1.914	2.576	2.574
	HB2.0-50	2.79	2.336	2.128	2.629	1.436	1.914	2.576	2.574
	HB2.0-75	2.57	2.336	2.128	2.629	1.436	1.914	2.576	2.574
	HB2.0-100	2.55	2.336	2.128	2.629	1.436	1.914	2.576	2.574
	HB2.5-0	2.34	2.168	2.041	2.184	1.436	1.777	2.304	2.252
	HB2.5-25	2.26	2.168	2.041	2.184	1.436	1.777	2.304	2.252
	HB2.5-50	2.30	2.168	2.041	2.184	1.436	1.777	2.304	2.252
	HB2.5-75	2.14	2.168	2.041	2.184	1.436	1.777	2.304	2.252
	HB2.5-100	2.35	2.168	2.041	2.184	1.436	1.777	2.304	2.252

Table 5
Summary of the statistical study

Eq.	Proposed by	Statistical data				
		Estimated with measured values		Measured / estimated ratios		
		Correlation coefficient (r)	Mean Standard error of Estimate (M.S.E)	No. of tested beams	Mean	Standard deviation
(1)	Zsutty [18]	0.75	0.039		1.06	0.261
(2)	Hashem [4]	0.67	0.044		1.09	0.303
(3)	Rebeiz [12]	0.81	0.033		1.01	0.223
(4)	Moustafa [8]	0.30	0.053	201	1.60	0.591
(5)	Moustafa [8]	0.74	0.041		1.27	0.322
(6)	Shin et al. [14]	0.79	0.034		0.98	0.223
(15)	Auther	0.81	0.033		0.99	0.220

$$\upsilon_u = 2.88\ \sqrt{f'_c}\ \sqrt[3]{\rho}\ \ d/a + 1.1\ \frac{A_v\ f_{yv}}{b \cdot S}\ \text{(mm-N)}. \quad (16)$$

Test data of 271 reinforced concrete beams with and without web reinforcement failed in shear (129 reinforced concrete beams without web reinforcement and 142 reinforced concrete beams with web reinforcement) were compared with the estimated values calculated using eqs. (7-8, 10, 13 and 14) which are applicable for beams without stirrups and also eqs. (9, 11-12 and 16) which are applicable for both beams without stirrups and beams with stirrups. Acceptable results are obtained from the application of eq. (16) on the all tested beams (with and without stirrups). Table 8 shows a summary of the mentioned statistical study for all predictive equations.

5. Conclusions

Based on the test results and the discussions reported in this study, the following conclusions can be drawn:

1. The higher the compressive strength, the higher is the initial crack load, and also, it is noticed that, the number of cracks and their widths decreases, and this is attributed to the increase in tensile strength.
2. The cracking and the ultimate loads increase as shear span-to-depth ratio (a/d) decreases, this is because cracks form in the shear regions at places of high moments which are towards the applied concentrated loads, as shear span-to-depth ratio (a/d) decreases this distance also decreases, and the slope of the cracks become more steep.
3. As the longitudinal steel reinforcement ratio (ρ) increases, the penetration of the flexural crack decreases. Also beams with low longitudinal steel reinforcement ratio (ρ) have large deflection since their inertia is relatively low and hence will have wide large cracks in contrast to short narrow cracks in beams with high longitudinal steel reinforcement ratio (ρ).

Table 6
Test data of beams without stirrups for ultimate shear strength

Source	Beam mark	Measured values	Estimated values							
		υ_u /mm^2	υ_u , N/mm^2							
			Eq. (7- 8)	Eq. (9)	Eq. (10)	Eq. (11)	Eq. (12)	Eq. (13)	Eq. (14)	Eq. (16)
Present study	B1	2.75	1.757	1.208	1.749	1.182	1.027	2.314	2.311	1.830
	B4	3.38	2.122	1.404	1.745	1.179	1.273	2.860	2.936	2.206
	B7	1.88	1.214	1.106	1.735	1.172	0.868	1.335	1.358	1.199
	B10	2.25	1.485	1.254	1.747	1.180	1.093	1.673	1.697	1.474
	B13	3.00	2.399	1.705	2.177	1.516	1.464	3.505	3.448	2.919
	B16	3.65	2.906	1.907	2.177	1.516	1.822	4.350	4.466	3.537
	B19	2.25	1.676	1.618	2.177	1.516	1.255	1.844	1.956	1.946
	B22	2.50	2.039	1.761	2.184	1.521	1.569	2.297	2.487	2.371
	B25	4.13	2.790	2.036	2.439	1.744	1.740	4.288	4.224	3.662
	B28	4.80	3.375	2.234	2.436	1.742	2.161	5.310	5.488	4.426
	B31	2.88	1.948	1.947	2.437	1.743	1.490	2.143	2.349	2.438
	B34	3.25	2.363	2.084	2.439	1.744	1.856	2.661	3.003	2.958
Ahmad et al. [7]	A1	2.24	1.937	1.785	2.270	1.595	1.480	2.119	2.332	1.909
	A2	2.67	2.132	1.860	2.270	1.595	1.651	2.390	2.631	2.545
	A3	2.67	2.208	1.894	2.270	1.595	1.718	2.879	2.752	2.828
	A4	3.62	2.532	1.952	2.270	1.595	1.826	3.745	3.560	3.320
	A5	6.46	3.051	2.011	2.270	1.595	1.926	4.630	4.772	3.817
	A6	15.51	7.687	2.463	2.270	1.595	2.506	11.37	11.22	7.635
	A7	1.77	1.485	1.661	2.270	1.595	1.093	1.562	1.697	1.463
	A8	1.85	1.634	1.694	2.270	1.595	1.219	1.762	1.897	1.951
	A9	3.03	1.693	1.710	2.270	1.595	1.269	2.123	1.978	2.168
	A10	3.12	1.941	1.736	2.270	1.595	1.349	2.761	2.520	2.545
	A11	2.11	2.338	1.762	2.270	1.595	1.422	3.414	3.334	2.926
	A12	8.42	5.892	1.966	2.270	1.595	1.851	8.382	7.662	5.852
	B1	2.00	2.174	1.920	2.325	1.643	1.688	2.406	2.697	2.177
	B2	2.69	2.392	2.016	2.325	1.643	1.883	2.715	3.052	2.902
	B3	3.91	2.478	2.059	2.325	1.643	1.959	3.281	3.195	3.225
	B4	5.59	2.841	2.134	2.325	1.643	2.083	4.286	4.156	3.785
	B5	4.17	3.423	2.209	2.325	1.643	2.196	5.316	5.597	4.353
	B6	8.02	8.626	2.789	2.325	1.643	2.858	13.19	13.26	8.706
	B7	1.69	1.661	1.759	2.325	1.643	1.242	1.765	1.935	1.664
	B8	1.77	1.828	1.802	2.325	1.643	1.386	1.992	2.172	2.218
	B9	3.03	1.894	1.821	2.325	1.643	1.442	2.407	2.268	2.464
	B10	2.42	2.171	1.855	2.325	1.643	1.533	3.144	2.909	2.893
	B11	4.63	2.616	1.888	2.325	1.643	1.616	3.899	3.872	3.327
	B12	8.08	6.592	2.147	2.325	1.643	2.104	9.678	8.993	6.654
	C1	2.32	2.351	1.981	2.302	1.622	1.845	2.689	2.983	2.338
	C2	3.23	2.587	2.109	2.302	1.622	2.058	3.034	3.382	3.117
	C3	2.95	2.680	2.165	2.302	1.622	2.142	3.662	3.544	3.464
	C4	3.80	3.072	2.264	2.302	1.622	2.277	4.774	4.624	4.066
	C5	10.56	3.702	2.363	2.302	1.622	2.401	5.914	6.244	4.676
	C7	1.73	1.854	1.787	2.302	1.622	1.408	2.005	2.210	1.844

Table 6. Cont.

Source	Beam mark	Measured values	Estimated values							
		υ_u /mm²	υ_u , N/mm²							
			Eq. (7- 8)	Eq. (9)	Eq. (10)	Eq. (11)	Eq. (12)	Eq.(13)	Eq. (14)	Eq. (16)
	C8	1.7	2.041	1.849	2.302	1.622	1.571	2.262	2.490	2.459
	C9	1.73	2.114	1.877	2.302	1.622	1.635	2.730	2.603	2.732
	C10	2.17	2.424	1.926	2.302	1.622	1.738	3.559	3.359	3.208
	C11	4.07	2.920	1.974	2.302	1.622	1.832	4.408	4.495	3.689
	C12	9.33	7.359	2.349	2.302	1.622	2.385	10.89	10.54	7.377
Elzanaty et al. [29]	F7	0.70	0.723	0.991	1.759	1.189	0.481	0.675	0.841	0.595
	F11	0.92	0.911	1.026	1.759	1.189	0.626	0.875	1.023	0.750
	F12	1.12	1.163	1.101	1.759	1.189	0.828	1.153	1.299	0.958
	F8	0.95	1.068	1.347	2.049	1.411	0.750	1.018	1.191	0.981
	F13	0.96	1.134	1.359	2.049	1.411	0.804	1.090	1.266	1.043
	F14	1.34	1.449	1.434	2.049	1.411	1.063	1.436	1.650	1.332
	F1	1.20	1.337	1.683	2.312	1.632	0.970	1.285	1.508	1.334
	F2	1.38	1.708	1.757	2.312	1.632	1.282	1.692	2.000	1.704
	F10	1.60	1.873	1.803	2.312	1.632	1.425	1.878	2.238	1.869
	F9	1.30	1.569	1.852	2.426	1.733	1.164	1.526	1.808	1.616
	F15	1.40	1.820	1.904	2.426	1.733	1.379	1.804	2.160	1.875
	F3	1.66	2.142	1.788	2.342	1.658	1.287	2.896	2.972	2.737
	F4	2.40	2.735	1.938	2.342	1.658	1.701	3.814	4.112	3.495
	F5	0.90	1.155	1.635	2.293	1.615	0.821	1.108	1.290	0.875
	F6	1.27	1.476	1.684	2.293	1.615	1.085	1.459	1.685	1.118
Kim and Park [44]	CTL-1	1.54	1.598	1.616	2.201	1.536	1.189	1.618	1.848	1.869
	CTL-2	1.56	1.598	1.616	2.201	1.536	1.189	1.618	1.848	1.869
	P1.0-1	1.26	1.301	1.550	2.201	1.536	0.940	1.282	1.464	1.522
	P1.0-2	1.22	1.301	1.550	2.201	1.536	0.940	1.282	1.464	1.522
	P3.4-1	1.72	1.939	1.729	2.201	1.536	1.482	2.018	2.336	2.268
	P3.4-2	1.73	1.939	1.729	2.201	1.536	1.482	2.018	2.336	2.268
	P4.6-1	2.07	2.168	1.831	2.201	1.536	1.682	2.314	2.687	2.534
	P4.6-2	2.20	2.168	1.831	2.201	1.536	1.682	2.314	2.687	2.534
	A1.5-1	4.63	3.356	1.760	2.201	1.536	1.547	4.572	4.905	3.737
	A1.5-2	4.69	3.356	1.760	2.201	1.536	1.547	4.572	4.905	3.737
	A4.5-1	1.45	1.396	1.568	2.201	1.536	1.019	1.373	1.582	1.246
	A4.5-2	1.39	1.396	1.568	2.201	1.536	1.019	1.373	1.582	1.246
	D142-1	1.70	1.598	1.616	2.201	1.536	1.188	1.883	1.847	1.868
	D142-2	1.63	1.598	1.616	2.201	1.536	1.188	1.883	1.847	1.868
	D550-1	1.37	1.599	1.617	2.201	1.536	1.189	1.331	1.849	1.870
	D550-2	1.30	1.599	1.617	2.201	1.536	1.189	1.331	1.849	1.870
	D915-1	0.99	1.598	1.616	2.201	1.536	1.188	1.147	1.847	1.868
	D915-2	1.21	1.598	1.616	2.201	1.536	1.188	1.147	1.847	1.868
Moustafa [53]	C1	3.26	3.219	1.741	2.219	1.551	1.475	4.562	4.632	3.604
	C2	3.94	3.633	1.849	2.219	1.551	1.693	5.227	5.474	4.068
	C3	2.51	4.013	1.971	2.219	1.551	1.896	5.847	6.290	4.493
	A1	1.44	2.049	1.800	2.234	1.564	1.578	2.836	2.502	2.732
	A2	1.30	1.855	1.726	2.234	1.564	1.408	2.535	2.210	2.473
	A4	1.33	1.907	1.788	2.285	1.608	1.454	2.619	2.287	2.582
	A5	1.36	1.855	1.772	2.285	1.608	1.409	2.540	2.211	2.513
	A8	1.22	1.638	1.641	2.214	1.547	1.223	1.715	1.903	1.735
	A9	1.73	1.810	1.694	2.214	1.547	1.370	1.919	2.145	1.917

Table 6. Cont.

Source	Beam mark	Measured values	Estimated values							
			υ_u , N/mm^2							
		υ_u /mm^2	Eq. (7- 8)	Eq. (9)	Eq. (10)	Eq. (11)	Eq. (12)	Eq.(13)	Eq. (14)	Eq. (16)
Mphonde and Frantz [54]	AO-3-3b	1.42	1.332	1.175	1.761	1.190	0.965	1.322	1.502	1.177
	AO-3-3c	1.47	1.286	1.230	1.870	1.271	0.928	1.258	1.445	1.188
	AO-7-3a	1.81	1.624	1.470	2.020	1.388	1.210	1.612	1.883	1.585
	AO-7-3b	1.82	1.678	1.527	2.068	1.426	1.256	1.666	1.958	1.665
	AO-11-3a	1.97	2.041	1.929	2.392	1.702	1.571	2.027	2.490	2.234
	AO-11-3b	1.97	2.039	1.926	2.389	1.700	1.569	2.024	2.486	2.230
	AO-15-3a	2.10	2.098	1.994	2.442	1.747	1.621	2.083	2.578	2.328
	AO-15-3b	2.20	2.199	2.114	2.532	1.830	1.711	2.184	2.738	2.499
	AO-15-3c	2.15	2.185	2.096	2.519	1.818	1.697	2.169	2.714	2.473
	AO-3-2	1.71	1.499	1.264	1.757	1.187	1.105	1.841	1.715	1.687
	AO-7-2	2.59	1.948	1.673	2.110	1.460	1.489	2.499	2.349	2.499
	AO-11-2	2.45	2.349	2.069	2.426	1.733	1.844	3.109	2.981	3.310
	AO-15-2a	3.91	2.393	2.113	2.461	1.764	1.883	3.177	3.053	3.403
	AO-15-2b	4.52	2.247	1.965	2.346	1.661	1.753	2.952	2.814	3.097
	AO-3-1	2.55	3.077	1.522	1.803	1.221	1.401	3.637	4.356	2.978
	AO-7-1	6.85	3.750	1.831	2.071	1.428	1.756	4.893	5.722	4.006
	AO-11-1	9.51	4.360	2.131	2.314	1.633	2.085	6.134	7.072	5.022
	AO-15-1a	6.06	4.646	2.277	2.428	1.735	2.241	6.748	7.740	5.524
	AO-15-1b	10.88	4.681	2.295	2.442	1.747	2.260	6.824	7.822	5.586
Pendyala and Mendis [64]	1	2.31	2.007	1.428	1.971	1.349	1.195	3.041	2.732	2.279
	2	1.53	1.183	1.290	1.971	1.349	0.843	1.370	1.322	0.912
	3	2.87	2.465	1.814	2.290	1.612	1.510	4.000	3.575	3.102
	4	1.48	1.453	1.676	2.290	1.612	1.066	1.683	1.655	1.241
	5	3.24	2.745	2.066	2.484	1.786	1.707	4.617	4.131	3.646
	6	1.67	1.618	1.928	2.484	1.786	1.205	1.874	1.875	1.458
Shin et al. [77]	MHB1.5-0	4.20	4.191	2.030	2.184	1.521	1.993	6.192	6.688	4.642
	MHB2.0-0	3.27	2.856	1.886	2.184	1.521	1.786	4.195	4.360	3.482
	MHB2.5-0	2.10	2.121	1.799	2.184	1.521	1.641	2.994	2.614	2.785
	HB1.5-0	5.29	4.693	2.273	2.376	1.688	2.267	7.337	7.850	5.501
	HB2.0-0	3.70	3.198	2.128	2.376	1.688	2.032	4.877	5.092	4.125
	HB2.5-0	2.99	2.375	2.041	2.376	1.688	1.867	3.416	3.023	3.300
Yoon et al. [90]	N1-S	1.01	1.599	1.444	1.998	1.370	1.189	1.287	1.849	1.749
	M1-S	1.21	1.967	1.844	2.325	1.643	1.506	1.583	2.377	2.386
	H1-S	1.33	2.146	2.050	2.484	1.786	1.663	1.727	2.653	2.719
Xie et al. [89]	NNN-1	5.68	5.599	1.831	2.103	1.455	1.746	7.416	7.126	1.788
	NNN-2	2.07	2.130	1.517	2.040	1.404	1.279	2.955	2.951	1.734
	NNN-3	1.34	1.468	1.414	2.020	1.388	1.079	1.579	1.675	1.717
	NHN-1	8.81	7.294	2.420	2.566	1.861	2.361	11.52	10.40	2.181
	NHN-2	3.71	2.891	2.178	2.563	1.859	1.811	4.440	4.433	2.179
	NHN-3	1.67	2.025	2.105	2.568	1.863	1.557	2.178	2.465	2.183

Table 7
Test data of beams with stirrups for ultimate shear strength

Source	Beam mark	Measured values	Estimated values			
		υ_u N/mm^2	υ_u , N/mm^2			
			Eq. (9)	Eq. (11)	Eq. (12)	Eq. (16)
Present study	B2	4.25	1.346	3.589	2.525	3.463
	B3	4.95	1.470	5.498	3.721	4.786
	B5	4.75	1.555	3.595	2.783	3.867
	B6	5.50	1.671	5.496	3.968	5.165
	B8	3.00	1.274	3.599	2.392	2.884
	B9	4.00	1.391	5.502	3.580	4.190
	B11	3.38	1.398	3.592	2.597	3.124
	B12	4.50	1.522	5.500	3.793	4.444
	B14	5.25	1.865	3.938	2.982	4.600
	B15	6.25	1.981	5.841	4.170	5.903
	B17	6.00	2.068	3.939	3.343	5.225
	B18	6.50	2.181	5.839	4.526	6.517
	B20	3.75	1.781	3.941	2.774	3.626
	B21	4.83	1.897	5.842	3.962	4.929
	B23	4.63	1.908	3.935	3.076	4.026
	B24	5.25	2.026	5.838	4.265	5.332
	B26	5.50	2.191	4.163	3.253	5.332
	B27	6.75	2.308	6.066	4.441	6.636
	B29	6.00	2.388	4.160	3.674	6.095
	B30	7.50	2.507	6.064	4.864	7.404
	B32	3.75	2.099	4.160	3.001	4.101
	B33	6.25	2.219	6.064	4.191	5.411
	B35	5.25	2.236	4.161	3.367	4.621
	B36	6.63	2.350	6.062	4.553	5.921
Kong and Rangan [47]	S1-1	3.13	1.937	3.041	2.472	3.769
	S1-2	2.85	1.937	3.041	2.472	3.769
	S1-3	2.82	1.937	3.041	2.472	3.769
	S1-4	3.81	1.937	3.041	2.472	3.769
	S1-5	3.47	1.937	3.041	2.472	3.769
	S1-6	3.07	1.937	3.041	2.472	3.769
	S2-1	3.57	2.007	2.644	2.263	3.639
	S2-2	3.18	2.019	2.836	2.383	3.771
	S2-3	3.47	2.036	3.108	2.553	3.958
	S2-4	3.01	2.036	3.108	2.553	3.958
	S2-5	3.86	2.066	3.588	2.853	4.288
	S3-1	2.82	1.852	2.670	1.968	3.126
	S3-2	2.40	1.852	2.670	1.968	3.126
	S3-3	3.12	1.956	2.670	2.258	3.584
	S3-4	2.39	1.956	2.670	2.258	3.584
	S3-5	3.97	2.050	2.670	2.462	3.970
	S3-6	3.78	2.050	2.670	2.462	3.970

Table 7. Cont.

Source	Beam mark	Measured values	Estimated values			
		υ_u N/mm^2	υ_u , N/mm^2			
			Eq. (9)	Eq. (11)	Eq. (12)	Eq. (16)
	S4-1	2.61	2.217	3.212	2.755	4.471
	S4-2	5.16	2.210	3.212	2.738	4.433
	S4-3	2.81	2.201	3.212	2.715	4.404
	S4-4	3.54	2.185	3.212	2.675	4.247
	S4-6	4.10	2.181	3.212	2.664	4.205
	S5-1	3.31	2.161	3.226	2.568	3.726
	S5-2	3.56	2.182	3.226	2.629	3.997
	S5-3	3.34	2.205	3.226	2.691	4.287
	S5-4	6.53	2.271	3.226	2.854	5.134
	S5-5	7.85	2.315	3.226	2.952	5.704
	S6-3	2.44	1.949	2.682	2.215	3.360
	S6-4	2.93	1.949	2.682	2.215	3.360
	S6-5	3.97	2.036	2.682	2.414	3.719
	S6-6	3.84	2.036	2.682	2.414	3.719
	S7-1	2.96	2.085	2.661	2.409	3.339
	S7-2	2.79	2.097	2.853	2.529	3.471
	S7-3	3.35	2.114	3.125	2.699	3.658
	S7-4	3.72	2.137	3.493	2.929	3.911
	S7-5	4.14	2.152	3.733	3.079	4.076
	S7-6	4.23	2.174	4.085	3.299	4.318
	S8-1	3.73	2.029	2.660	2.281	3.681
	S8-2	3.44	2.041	2.852	2.401	3.813
	S8-3	4.24	2.058	3.124	2.571	4.000
	S8-4	3.64	2.058	3.124	2.571	4.000
	S8-5	3.96	2.081	3.492	2.801	4.253
	S8-6	3.89	2.096	3.732	2.951	4.418
Elzanaty et al. [29]	G4	3.01	1.836	2.650	2.051	2.544
	G5	2.25	1.499	2.451	1.713	2.047
	G6	1.57	1.166	2.229	1.478	1.673
Moustafa [53]	S1	4.35	1.944	2.260	2.164	4.691
	S2	3.67	2.067	2.260	2.373	5.134
	S3	3.53	1.959	2.500	2.314	4.856
	M1	1.56	1.755	2.227	1.819	2.914
	M2	1.83	1.829	2.227	1.987	3.170
	M3	2.31	1.770	2.467	1.969	3.079
	N1	1.83	1.743	2.260	1.684	2.275
	N2	1.73	1.796	2.260	1.836	2.464
	N3	1.97	1.707	2.465	1.799	2.373
Pendyala and Mendis [64]	8	3.15	1.596	4.298	3.031	4.280
	12	4.49	2.067	4.618	3.413	5.282
	14	3.98	1.521	3.343	2.427	3.597
	15	4.07	1.918	3.612	2.752	4.439
	18	4.26	2.230	3.828	2.997	5.115
	20	4.07	2.152	3.775	2.937	4.947
	21	4.31	1.644	4.330	3.071	4.380

Table 7. Cont.

Source	Beam mark	Measured values	Estimated values			
		υ_u N/mm^2	υ_u , N/mm^2			
			Eq. (9)	Eq. (11)	Eq. (12)	Eq. (16)
Sarsam and Al-Musawi [72]	AL-2N	2.71	1.500	2.631	1.782	2.124
	AL2-H	2.90	1.922	2.921	2.054	2.595
	AS2-N	4.48	1.558	2.617	1.965	2.861
	AS2-H	4.81	2.004	2.922	2.317	3.666
	AS3-N	4.71	1.612	3.237	2.359	3.310
	AS3-H	4.71	2.000	3.503	2.660	4.002
	BL2-H	3.30	1.960	2.924	2.178	2.743
	BS2-H	5.33	2.039	2.911	2.440	3.850
	BS3-H	5.44	2.072	3.515	2.815	4.258
	BS4-H	4.93	2.180	4.187	3.262	4.821
	CL2-H	3.51	1.941	2.883	2.257	2.810
	CS2-H	5.89	2.064	2.883	2.550	3.996
	CS3-H	5.89	2.144	3.521	2.968	4.503
	CS4-H	5.26	2.198	4.156	3.372	4.965
Shin et al. [77]	MHB1.5-25	5.82	2.216	4.497	3.853	6.688
	MHB1.5-50	7.74	2.407	7.553	5.763	8.789
	MHB1.5-75	8.92	2.593	10.53	7.623	10.84
	MHB1.5-100	9.58	2.779	13.51	9.483	12.88
	MHB2.0-25	4.12	2.018	3.633	3.106	4.934
	MHB2.0-50	6.47	2.155	5.825	4.476	6.441
	MHB2.0-75	6.90	2.288	7.953	5.806	7.904
	MHB2.0-100	7.19	2.420	10.07	7.126	9.356
	MHB2.5-25	3.67	1.903	3.185	2.681	3.929
	MHB2.5-50	5.16	1.994	4.641	3.591	4.930
	MHB2.5-75	5.93	2.093	6.225	4.581	6.019
	MHB2.5-100	6.11	2.188	7.745	5.531	7.064
	HB1.5-25	7.97	2.459	4.664	4.127	7.547
	HB1.5-50	9.16	2.650	7.720	6.037	9.648
	HB1.5-75	9.89	2.836	10.7	7.897	11.69
	HB1.5-100	10.43	3.022	13.67	9.757	13.74
	HB2.0-25	5.31	2.260	3.800	3.352	5.577
	HB2.0-50	7.29	2.397	5.992	4.722	7.084
	HB2.0-75	8.56	2.530	8.120	6.052	8.547
	HB2.0-100	9.01	2.662	10.23	7.372	9.999
	HB2.5-25	4.30	2.140	3.272	2.857	4.389
	HB2.5-50	5.54	2.236	4.808	3.817	5.445
	HB2.5-75	6.21	2.335	6.392	4.807	6.534
	HB2.5-100	6.84	2.430	7.912	5.757	7.579
Yoon et al. [90]	N1-N	1.86	1.479	1.930	1.539	2.134
	N2-S	1.48	1.479	1.930	1.539	2.134
	N2-N	1.97	1.494	2.170	1.689	2.299
	M1-N	1.65	1.879	2.203	1.856	2.771
	M2-S	2.25	1.894	2.443	2.006	2.936
	M2-N	2.81	1.914	2.763	2.206	3.156
	H1-N	1.97	2.085	2.346	2.013	3.104
	H2-S	2.43	2.110	2.746	2.263	3.379
	H2-N	2.94	2.150	3.386	2.663	3.819

Table 7. Cont.

Source	Beam mark	Measured values	Estimated values			
		υ_u N/mm^2	υ_u , N/mm^2			
			Eq. (9)	Eq. (11)	Eq. (12)	Eq. (16)
Xie et al. [89]	NNW-1	9.26	2.189	3.958	3.573	1.745
	NNW-2	4.77	1.834	3.966	3.126	1.754
	NNW-3	3.37	1.704	3.961	2.901	1.749
	NHW-1	12.85	3.100	4.464	4.759	2.147
	NHW-2	7.08	2.595	4.476	4.058	2.158
	NHW-3	4.07	2.454	4.499	3.743	2.179
	NHW-3a	4.30	2.423	5.182	4.134	2.130
	NHW-3b	4.87	2.585	5.938	4.662	2.207
	NHW-4	3.73	2.372	4.503	3.531	2.183

Table 8
Summary of the statistical study

Eq.	Proposed by	Statistical data				
		Estimated with measured values		Measured / Estimated ratios		
		Correlation coefficient (r)	Mean Standard Error of estimate (M.S.E)	No. of tested beams	Mean	Standard deviation
(7)&(8) *	Zsutty [18]	0.86	0.11	129	1.14	0.37
(9) *	Hashem [4]	0.64	0.19	129	1.56	0.98
(10) *	Mphonde and Frantz [9]	0.24	0.20	129	1.31	1.00
(11) *	Mphonde and Frantz [10]	0.24	0.20	129	1.87	1.42
(12) *	Sarsam and Al-Musawi [13]	0.74	0.18	129	1.81	0.91
(13) *	Kim and Park [6]	0.87	0.10	129	0.94	0.24
(14) *	Rebeiz [12]	0.88	0.10	129	0.88	0.24
(16) *	Auther	0.87	0.11	129	1.01	0.31
(9) **	Hashem [4]	0.71	0.15	142	2.16	0.73
(11) **	Mphonde and Frantz [10]	0.77	0.11	142	1.14	0.34
(12) **	Sarsam and Al-Musawi [13]	0.83	0.09	142	1.42	0.34
(16) **	Auther	0.91	0.07	142	0.96	0.18
(9) ***	Hashem [4]	0.71	0.12	271	1.87	0.91
(11) ***	Mphonde and Frantz [10]	0.60	0.11	271	1.48	1.07
(12) ***	Sarsam and Al-Musawi [13]	0.72	0.10	271	1.60	0.70
(16) ***	Auther	0.88	0.06	271	0.98	0.25

Note;
* Equation applied for test beams without stirrups.
** Equation applied for test beams with stirrups only.
*** Equation applied for all of test beams (with stirrups and without stirrups).

4. As the web reinforcement ratio increases, the shear resistance of the beams increases, and also, the beams become more ductile.
5. The slopes of the load-midspan deflection curves increase slightly with increase of the web reinforcement ratio (ρ_v). Also, it is noticed that, failure and cracking loads increase with increase of the web reinforcement (ρ_v).
6. The values of the measured longitudinal strains at the shear span for all beams increased significantly after the formation of the diagonal crack. However, strain values were more or less small at the first stages of loading before the first diagonal crack was formed. Also, it is concluded that, the increase of web reinforcement, decreases the longitudinal strains at the shear span, and the increase of concrete compressive strength, decreases the longitudinal strain values at the shear span.
7. An equation has been proposed for predicting the cracking shear strength of reinforced concrete beams eq. (15) based on the multiple regression analysis for the test data of 201 reinforced concrete beams with and without stirrups failed in shear obtained from this study and from other previous investigators including the major factors affecting the cracking shear strength.
8. A second equation has been proposed for predicting the ultimate shear strength of reinforced concrete beams eq. (16) based on the multiple regression analysis for the test data of 271 reinforced concrete beams with and without stirrups failed in shear obtained from this study and from other previous investigators including the major factors affecting the ultimate shear strength.

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Received October 15, 2005
Accepted May 30, 2006