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Shear Strength of Concrete Deep Beam Subjected to Uniformly Distributed Load

Abstract- *In this paper, result of tests on 20 simply supported concrete deep beams are presented. All tested beams have dimensions of (150 x 400 x 1100) mm and tested under (1, 2, 4 and 8) point loads. The considered parameters are shear span to effective depth ratio (a/d), concrete compressive strength (f'c) and longitudinal reinforcement ratio (ρw).The influence of these parameters on cracking and ultimate load, load versus deflection response and concrete strain are investigated. The results showed that the decrease in the (a/d) ratio from 1.373 to 0.412 leads to a decrease in cracking and ultimate shear strengths by average ratios of 40 % and 57 % respectively, while increasing (f'c) and (ρw) leads to the increase in the cracking and ultimate shear strengths. The load-deflection response is significantly affected by the (a/d) ratio and becomes appreciably nonlinear as the (a/d) ratio increases, while it is slightly affected by the compressive strength of concrete (f'c) and steel ratio (ρw). Strain distribution through the depth at mid span is nonlinear even in elastic stage. At the same load level, strain distribution increases as (a/d) increases and decreases as (f'c) and (ρw) increase. The analytical work has been made on the 20 deep beams plus 62 from literature using the regression analysis. Proposed equation was compared with four equations available in literature and gave less average and coefficient of variation equal to1.04 and 16.98% respectively.*

Keywords- *Shear Strength, Concrete Beam, Concrete Deep Beam, compressive strength.*

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1. Introduction

Reinforced concrete deep beams are structural members having depth much greater than normal in relation to their span, while the thickness in the perpendicular direction is much smaller than either span or depth [1]. These members are used in many structural applications such as diaphragms, water tanks, foundations, bunkers, offshore structures, shear walls, girders used in multistory buildings to provide column offsets, and floor slabs under horizontal loads [1,2].

According to the ACI code Provisions for shear (ACI 318M-2011) [3], deep beams are members with length of clear span measured face to face of supports (ℓn) not exceeding four times total depth (h) (ℓn ≤ 4h) or region of beams with concentrated loads within a distance (a) two times the total depth measured from the support (a ≤ 2h) that is loaded on one face and supported on the opposite face .

Due to their proportions, the strength of deep beams is usually controlled by shear rather than flexural. On the other hand, its shear strength is significantly greater than that predicted using expressions developed for slender beams [4]. Thus, special design methods to account for these differences are required.

Shear resistance of reinforced concrete beams has been studied extensively over the last few decades. Nevertheless, the study of shear resistance of beams subjected to uniformly distributed loads is limited [5]. One of the reasons is the difficulty to achieve a uniformly distributed load in experiments. Another reason is that the mechanism of shear failure was difficult to be found, as most of the research has concentrated on the simpler case of two-point loading. The shear behavior of beams under a uniformly distributed load has been examined in earlier studies [6,7] to be essentially the same as the behavior under a point loading arrangement of two-point loads at the quarter points.

2. Aim of the Present Research

The main aim of the present investigation is to study the shear behavior and strength of concrete deep beams under uniformly distributed load. This general aim can be divided into two categories:

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1. Experimental program, consisting of testing twenty deep beams which have been designed to fail in shear to investigate the effect of three parameters on the shear behavior of reinforced concrete deep beams. These parameters are; shear span to depth ratio (a/d), main reinforcement ratio (ρw) and compressive strength of concrete (f'_c).
2. Empirical expression based on experimental data from previous studies will be developed to predict the shear resistance capacity of reinforced concrete deep beams.

3. Experimental Program

All the twenty beams have the same dimensions, which have an overall length of 1100 mm with span of 1000 mm, a width of 150 mm and a total depth of 400 mm as shown in Figure 1.

The specimens are divided into five groups (A, B, C, D and E). Each group consists of four beams which have variable shear span to effective depth ratio (a/d) and constant of each longitudinal reinforcement (ρ_w) and compressive strength (f'_c) in order to study the effect of (a/d) on each group. The groups (A, B and C) used constant (f'_c=22 MPa) and variable (ρ_w) equal to (0.00736, 0.00880 and 0.01055 respectively) to study the influence of longitudinal reinforcement (ρ_w), while the groups (A, D and E) used constant (ρ_w=0.00736) and variable (f'_c) equal to (22, 30 and 26 MPa respectively) to study the effect of compressive strength (f'_c). Table 1 shows the details of the twenty beams with their related parameters.

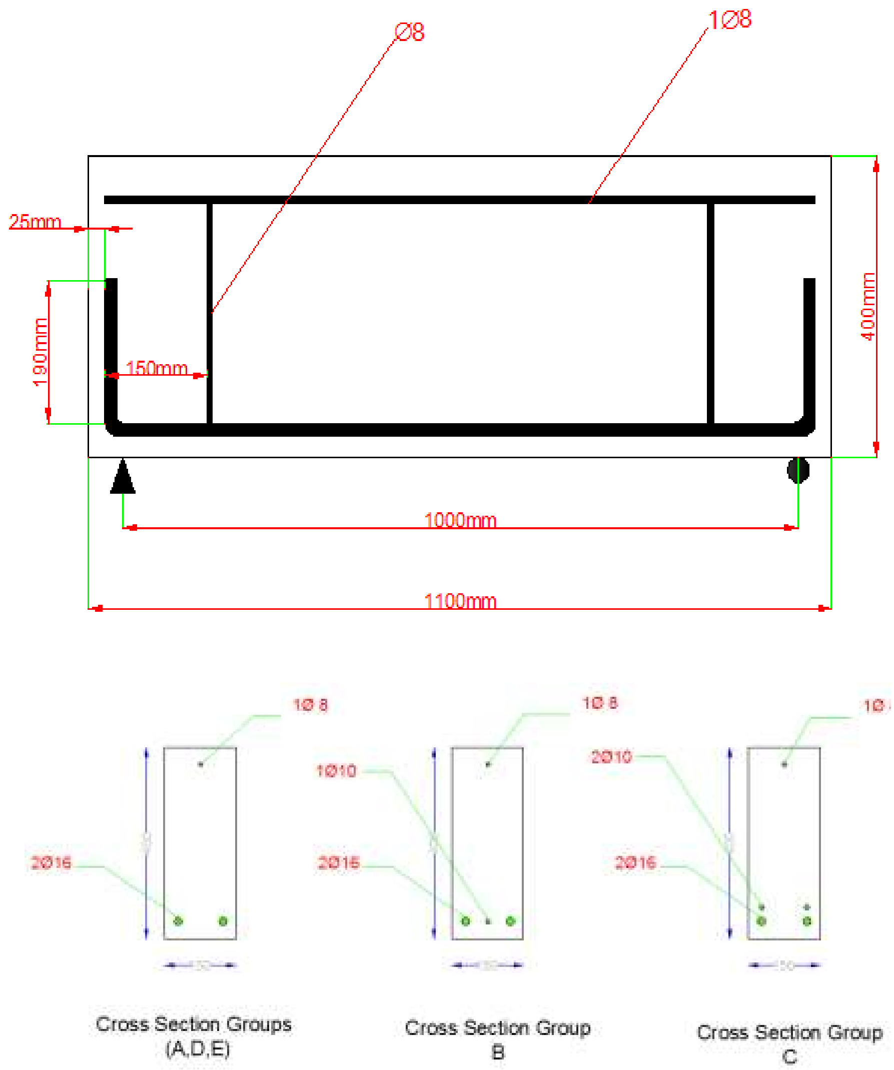


Figure 1: Stress-strain relationships for series CY-B and HEX-B at the age of 28 days

Group no.	Beam	Number of point load (n)	a(mm)	a/d*	ρw	f'_c (MPa) (design strength)	Mix number
A	A1	1	500	1.373	0.00736	22	1
	A2	2	300	0. 824	0.00736	22	
	A3	4	230	0.632	0.00736	22	
	A4	8	150	0.412	0.00736	22	
B	B1	1	500	1.373	0.00880	22	1
	B2	2	300	0. 824	0.00880	22	
	B3	4	230	0.632	0.00880	22	
	B4	8	150	0.412	0.00880	22	
C	C1	1	500	1.416	0.01055	22	1
	C2	2	300	0.849	0.01055	22	
	C3	4	230	0.651	0.01055	22	
	C4	8	150	0.425	0.01055	22	
D	D1	1	500	1.373	0.00736	30	2
	D2	2	300	0. 824	0.00736	30	
	D3	4	230	0.632	0.00736	30	
	D4	8	150	0.412	0.00736	30	
E	E1	1	500	1.373	0.00736	26	3
	E2	2	300	0. 824	0.00736	26	
	E3	4	230	0.632	0.00736	26	
	E4	8	150	0.412	0.00736	26	

Table 1: Weight of short, particle, powder, and polyester resin with different volume fraction

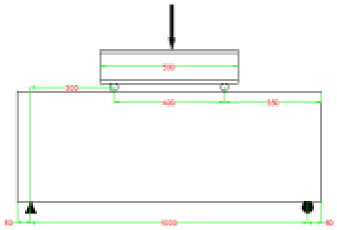
*Note :

1. All beams have shear span to effective depth ratio (a/d) less than 2.5 according to ACI-ASCE Committee 426 that achieves the deep beam condition.
2. All beams have effective depth (d) =364 mm, except group (C) which has (d) =353 mm .
3. The shear span (a) is the distance between center of support and center of the nearest load while the depth (d) is the distance between centers of tension reinforcement to outer fiber of compression side.

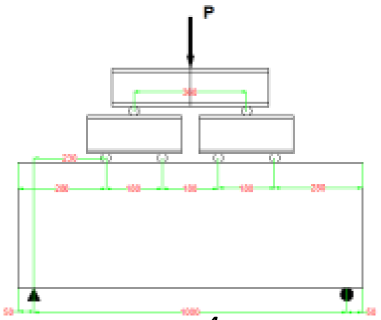
4. Loading Type

In this investigation, twenty shear tests will be reported. They are arranged as follows: Five beams are one point load (the first beam of each group), five beams are two point loads (the second beam of each group), five beams are four point loads (the third beam of each group) and five beams are eight point loads (the fourth beam of each group) on the beams as shown in Figure 2 (a,b,c).

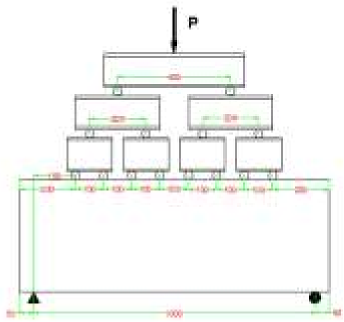
n=1



n=2



n=4



n=8

Figure 2: Type of Loading

5. Materials Properties

All materials used in this investigation are conforming to the Iraqi standard No.5 and No.45 1984[8,9].

6. Mix Design

Three mixes are adopted in this work in accordance ACI 211-05 as shown in Table 2.

Table 2: Mix Concrete Design

Mix No.	Group name	w/c Ratio	Mix proportions (kg / m3)				Compressive strength fcu (MPa)		Compressive strength f'_c (MPa)*	Tensile strength fct(Mpa)
			W	C	S	G	Cube		Cylinder	Test of 28 day
							7 days	Test of 28 day	Test of 28 day	
1	A,B,C	0.5	190	380	473	996	15.75	24.39	20	2.68
3	D	0.45	190	423	451	996	25.33	39.39	32.3	3.3
2	E	0.48	190	396	465	996	21.45	30	24.6	2.95

* $f'_c \approx 0.82 f_{cu}$

7. Load Measurement

All beams were tested using Testing Frame with hydraulic jacks of 1000 kN capacity under monotonic loads up to ultimate load at the Structural Laboratory of Engineering College in Al- Qadesiya University as shown in Plate 1. The division of loading to more than one was based on the principle of dividing a load P into two loads of P/**2** each. With a varied total span according to (a /d) ratio in order to divide the total applied point load into (one, two, four, eight) point loads applied on the beam.

Plate 1: Testing Frame machine

8. Testing Procedure

All beams and control specimens were removed from curing water at the age of 28 days. During the 14 drying days, the beams were cleaned and painted in order to clarify the crack propagation (after loading). The demec point positions were located, and then mounted on the beams. Each beam was labelled and the locations of support points, loading points, and the dial gauge position were marked on the surface to facilitate the precise setup of testing equipment. The beams were placed in the machine on the supports with a clear span of 1000 mm and adjusted so that the centerline, supports, load arms and dial gages were fixed at their correct and proper locations. To avoid local failure at load application and support positions and to insure uniform bearing stress at these regions, steel plates of 200×60×8 mm dimensions are used. The plates are placed so that the centerline of the plates and centerline of load and support positions coincide. All beams were tested under (one, two, four, and eight) points loading. The dial gauges were mounted in their marked positions to touch the bottom of center of the beam, in order to confirm that the dial plungers had touched the concrete surface.

Loading was started by the application of a single point load from the testing machine to the upper midpoint of the loading beam. The single load was then equally divided into (one, two, four, and eight) point loads which were transferred to the concrete beam through the variable steel bars supporting the beam. Initially the zero-load reading for the mechanical deflection gauges as well as the dial gauge was taken and then a load of 5 kN was applied and released in order to recheck the zero-load readings. The load magnitude for each load stage was chosen according to the expected strength of the beam.

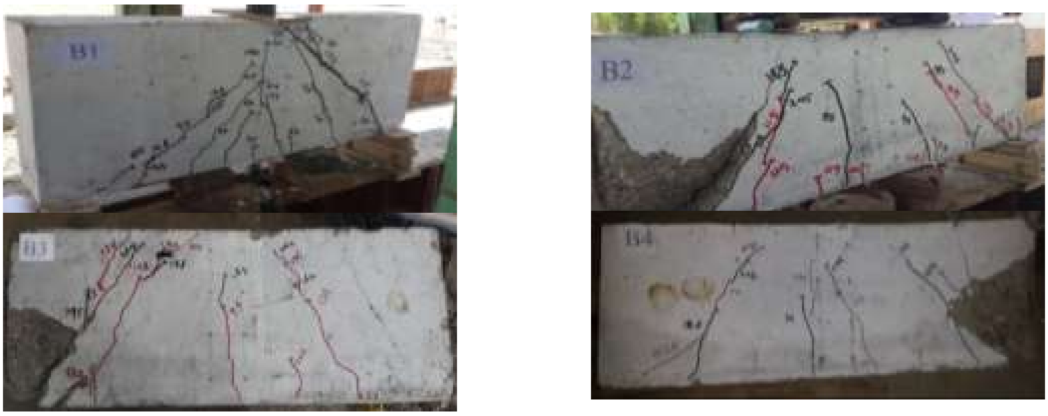
9. Behavior and Test Results of RC Deep Beams

Table 3 reveals the results of diagonal cracking load (first cracking load) (P_{cr}) and ultimate load failure (P_u) for all tested beams together with their modes of failure. Plate 2 shows the beams after failure with their cracks.

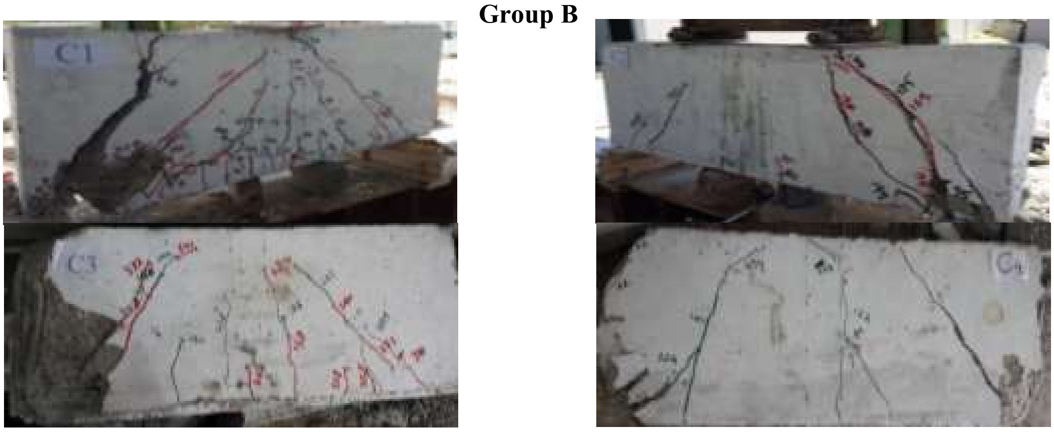
Table 3: Tests results of Deep Beams

Group no.	Beam	Loading state	a/d	ρ_w	f'_c MPa	P_{cr} kN	P_u kN	P_{cr}/P_u	P_{STM} kN	P_u/P_{STM}	Mode failure
A	A1	One point	1.373	0.00736	20	70	180	0.39	238.2	0.76	Shear compression
	A2	Two points	0.824	0.00736	20	100	245	0.41	216.3	1.13	Bearing failure
	A3	Four points	0.632	0.00736	20	140	400	0.35	358.2	1.12	Shear compression
	A4	Eight points	0.412	0.00736	20	140	410	0.34	337	1.22	Shear tension
B	B1	One point	1.373	0.0088	20	75	185	0.41	238.2	0.78	Shear tension
	B2	Two points	0.824	0.0088	20	115	270	028.43	216.3	1.25	Shear compression
	B3	Four points	0.632	0.0088	20	121	435	0.28	358.2	1.21	Shear compression
	B4	Eight points	0.412	0.0088	20	141	465	0.30	337	1.38	Shear compression
C	C1	One point	1.416	0.01055	20	100	225	0.44	291	0.77	Shear compression
	C2	Two points	0.849	0.01055	20	120	275	0.44	244.5	1.12	Shear compression
	C3	Four point	0.651	0.01055	20	140	445	0.31	407	1.09	Shear compression
	C4	Eight points	0.425	0.01055	20	145	510	0.28	383.6	1.33	Shear compression
D	D1	One point	1.373	0.00736	32.3	100	275	0.36	384.76	0.71	Shear tension
	D2	Two points	0.824	0.00736	32.3	125	345	0.36	345.26	1.00	Shear tension
	D3	Four points	0.632	0.00736	32.3	150	610	0.25	578.46	1.05	Shear tension
	D4	Eight points	0.412	0.00736	32.3	162	648	0.25	527.82	1.23	Shear tension
E	E1	One point	1.373	0.00736	24.6	90	210	0.43	293	0.72	Shear tension
	E2	Two points	0.824	0.00736	24.6	120	280	0.43	266	1.05	Shear compression
	E3	Four points	0.632	0.00736	24.6	140	435	0.32	440.6	0.99	Shear tension
	E4	Eight points	0.412	0.00736	24.6	145	510	0.28	414.6	1.23	Shear compression

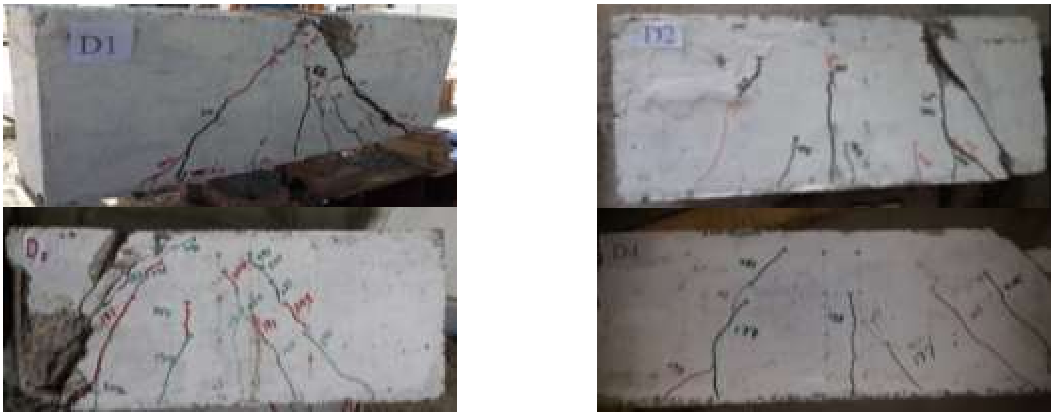
Group A



Group B



Group C



Group D

Group E
Plate 2: Cracking Pattern at Loading Stages

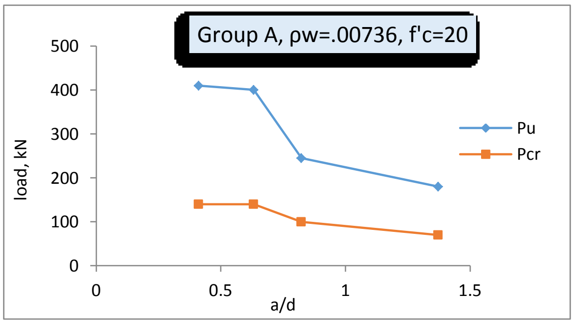
10. Submission Procedure

The influence of considered parameters on cracking and ultimate load, load–deflection response and concrete strain were investigated and illustrated in figures.

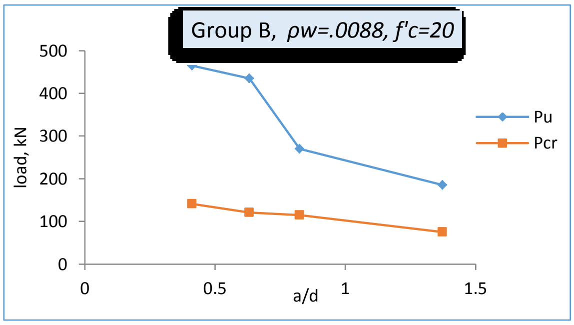
I. Cracking (Pcr) and ultimate load (Pu)

1. Effect of Shear Span to Effective Depth Ratio (a/d)

Increasing (a/d) leads to decrease cracking and ultimate load as shown in Figure 3.



(a)

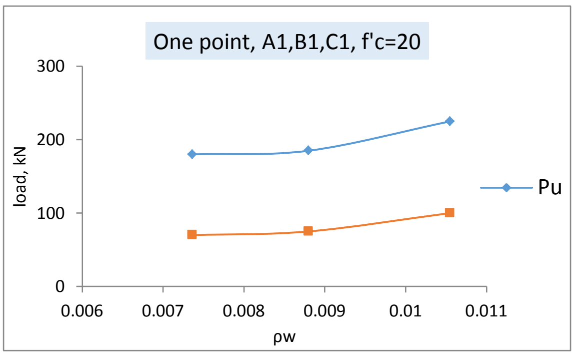


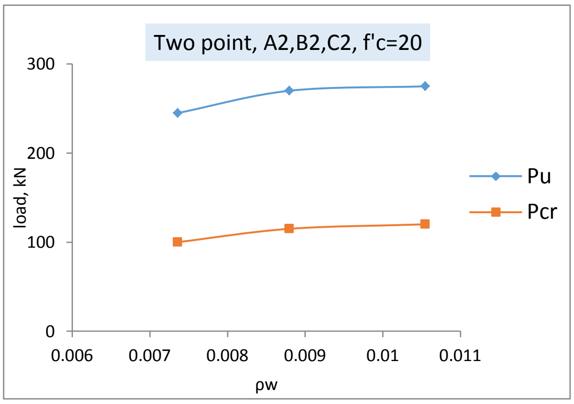
(b)

Figure 3: Effect (a/d) Ratio on Cracking and Ultimate load of Deep Beams

2. Effect of Longitudinal Reinforcement Ratio (ρ_w)

Figure 4 shows the effect of tensile reinforcement (ρw) on the shear strength, it can be seen that increasing the amount of reinforcement results in an increase in the diagonal cracking and ultimate loads for tested deep beams.



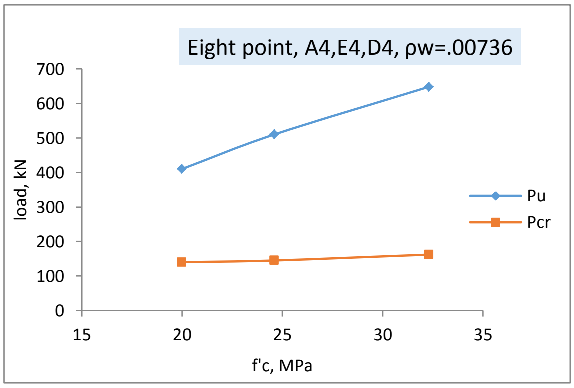


(b)

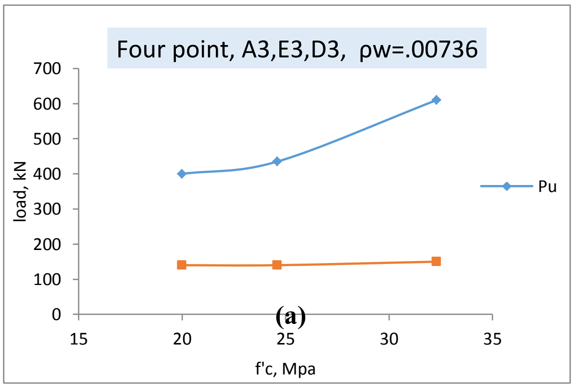
Figure 4: Effect (ρw) Ratio on Cracking and Ultimate load of Deep Beams

3. Effect of Shear Span to Effective Depth Ratio (a/d)

Effects of the parameter (f'c) on cracking and ultimate loads for deep beams tested in this study are shown in Figure 5. It can be observed that increasing the compressive strength of concrete results in an increase in the diagonal cracking load and the ultimate load for the beams which having the same amount of tensile reinforcement and varied (a/d).



(a)



(a)

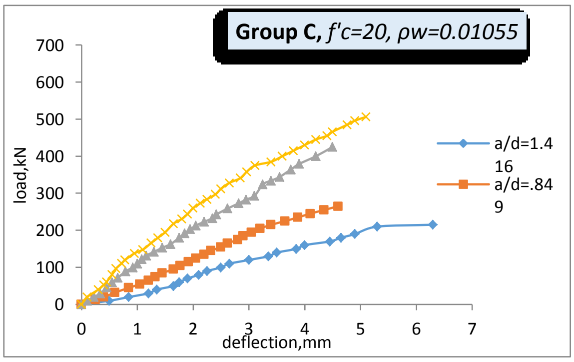
(b)

Figure 5: Effect (f’c) Ratio on Cracking and Ultimate load of Deep Beams

II. Effect of Compressive Strength (f’c)

1. Effect of Shear Span to Effective Depth Ratio (a/d)

Figure 6 exhibits the load-deflection plot for deep beams of group C and D, It is clear that the relation is approximately linear throughout the entire path, as the shear span to effective depth ratio (a/d) decrease but the line slightly bends and the nonlinearity increases as the applied load is increased especially at load levels close to failure.



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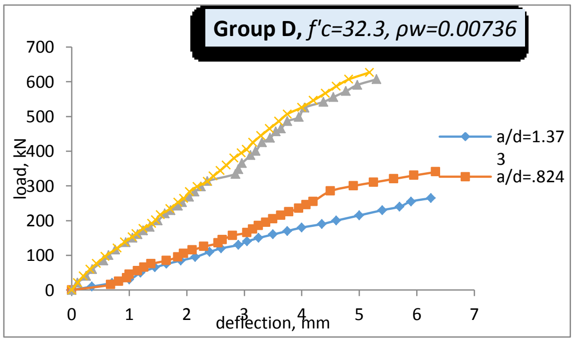
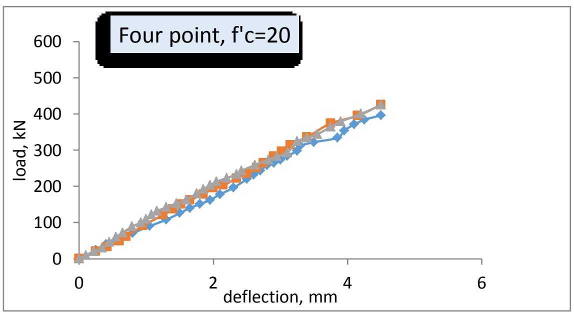


(b)

Figure 6: Effect of a/d Ratio on the Load-Midspan Deflection Curves of Deep Beams

2. Effect of Longitudinal Reinforcement Ratio (ρ_w)

At the same load level, the deflection decreases with the increase of ρ_w, as shown in Figure 7 This is due to the fact that any increase in ρ_w enhances the crack control and prevents the flexural cracks from further widening and hence decreases the deflection of the deep beam.



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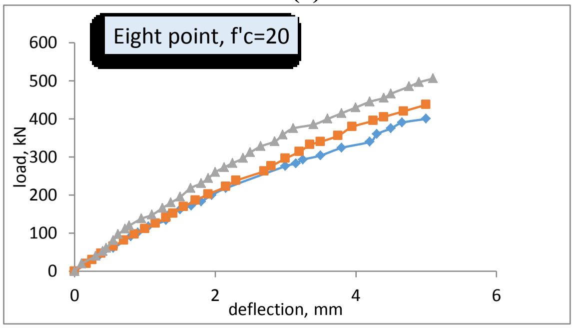


(b)

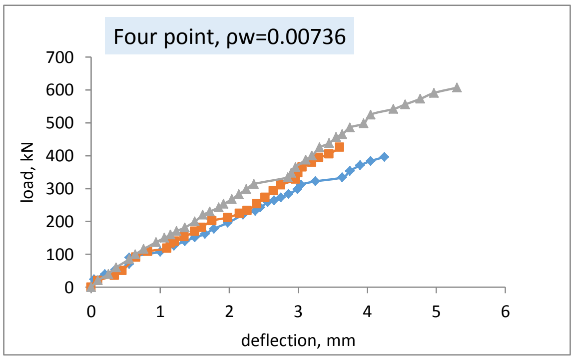
Figure 7: Effect of ρw Ratio on the Load-Midspan Deflection Curves of Deep Beams

3. Effect of Compressive Strength (f’c)

From figure 8, it is clear that the increase in (f’c) value reduces the deflection for all load stages.

III. Strain of Concrete Surface

Strain distribution through the depth at mid span for all deep beams is nonlinear even in elastic stage. At the same load level, strain distribution increases as (a/d) increases and decreases as (ρ_w) and (f'_c) increase as shown in Figure 9,a,b and c respectively



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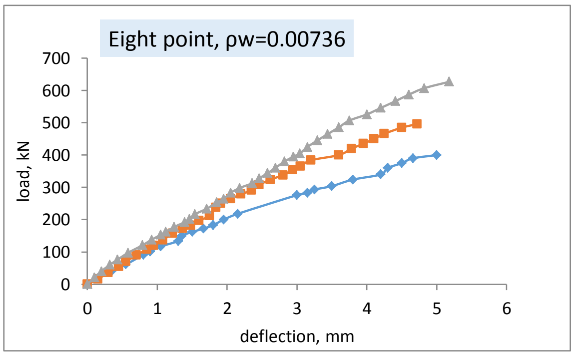
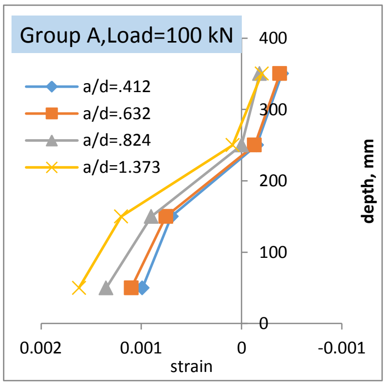


(b)

Figure 8: Effect of f'c Ratio on the Load-Midspan Deflection Curves of Deep Beams



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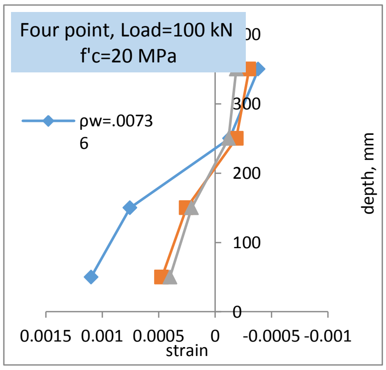

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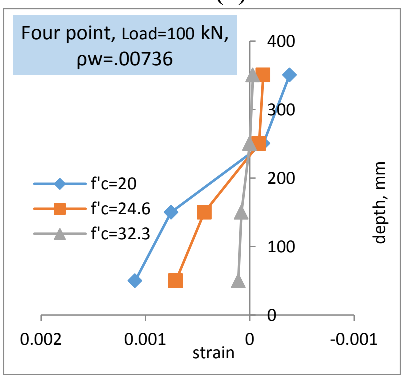


(c)

Figure 9: a. influence of (a/d), b. influence of (ρw), c. influence of (f'c)

10. Statistical Study and Proposed Equation

The analytical work of this study involves analyzing the twenty tested beams and other available 62 deep beams without shear reinforcement in literature. An equation is proposed in the current research work to predict the ultimate shear strength of deep beams using the regression analysis to the experimental data. Good agreement with the experimental results is obtained with sufficient safety where average value (Avg.) of ratios of tested to calculated ultimate shear strengths for all beams is 1.04 while coefficient of variation (C.O.V.) value is 16.98%.

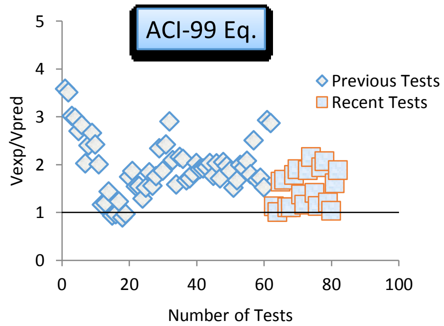
$$V_n = 10\,(f'_c)^{.37}(\rho_w)^{.56}(d/a)^{.66}b_w d \qquad (1)$$

Table 4 gives a comparison for the results of applying the 82 beams to more than one method, based on the ratio of Vexp/Vpredicted (relative shear strength RSS). From the table, it can be seen that the lowest COV percentage is by Eq.(1): 16.98%. These compare favorably with (24.89%-36.58%) by other existing methods (ACI318M-99[10], ACI318M-11[3], British Code [11] and Zararis 2003[5].

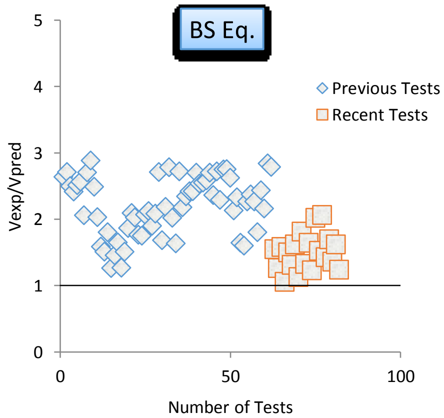
Figure 10 shows the ratio of experimental to predicted ultimate shear strengths (relative shear strength) versus the number of all tests.

Table 4: Comparison of Predicting Vexp/Vprd based on five different Methods for 82 Beams.

No.	Method	Avg	S.D	COV %	Min	Max	R
1	ACI-99	1.85	0.579	31.32	0.89	3.58	2.69
2	ACI-11	1.70	0.536	31.47	0.89	3.58	2.69
3	BS	2.55	0.636	24.89	1.32	3.61	2.28
4	Zararis 2003	0.84	0.309	36.58	0.28	1.62	1.34
5	Eq 1	1.04	0.176	16.98	0.73	1.40	0.67



(a)



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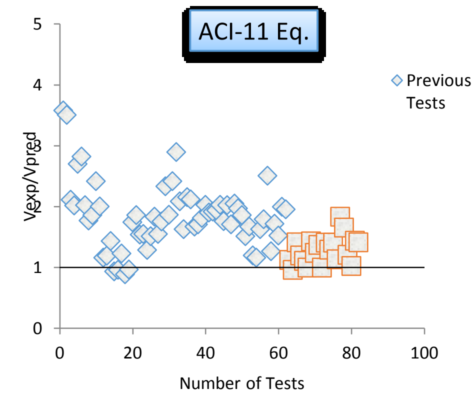

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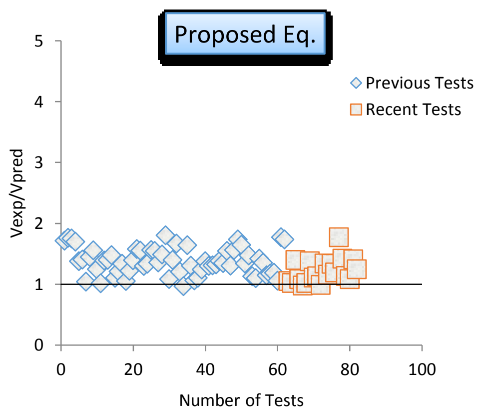
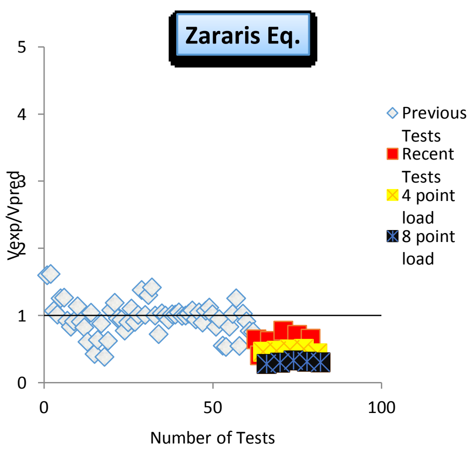


(d)



(e)

Figure 10: Ratio of Experimental to Predicted Ultimate Shear versus 82 Tested Deep Beams

11. Conclusions

I. Conclusions from Experimental Work

1. Beams generally failed in shear. The shear failure took place by diagonal splitting mode or diagonal compression mode for all tested beams except beam (A2) where its shear failure took place by bearing mode.
2. It was found that for all tested beams the increase in the shear span to effective depth ratio (a/d) reduces the cracking and ultimate load. Decreasing (a/d) from 1.373 to 0.412 increases the cracking load by a range of 31 % to 50 % (average of increasing is 40 %), while the ultimate load increases from 55 % to 60 % (average of increasing is 57(%
3. In all beams, increasing concrete strength increased the cracking and ultimate load. Increasing (f'c) from 20 Mpa to 32.3 Mpa improves the cracking load by a range of 6 % to 30% (average increase is 18.5 %), whereas the ultimate load improves with a range of 29 % to 36 % (average increase is 33.(%
4. In general, longitudinal reinforcement increased cracking and ultimate load for all tested beams. The increase in the longitudinal reinforcement ratio (□w) from 0.736 % to 1.055 % leads to an increase in cracking load in the range from 0.0 % to 30 % (the average of increase is 12.25 %), while the ultimate load increases by a range of 10 % to 20 % (the average of increase is 15 .(%
5. For all tests of RC deep beams, the ratio of the observed diagonal cracking load to ultimate load (Pcr/Pu) had a range between (0.25-0.44). This may not be as accurate as other results, since it depends on the observer noticing cracking.
6. The load- deflection response of RC deep beams is significantly affected by the (a/d) ratio. The response becomes appreciably nonlinear as the (a/d) ratio increases. Load- deflection response is slightly affected by the compressive strength of concrete (f'c) and steel ratio (ρw) . It was found that the response is slightly stiffer as (f'c) and (ρw) increase.
7. Strain distribution through the depth at mid span for all deep beams is nonlinear even in elastic stage. At the same load level, strain distribution increases as (a/d) increases and decreases as (f'c) and (ρw) increase.
8. The ratio between ultimate load (experimental load) to the load predicted by strut and tie method (STM) had a range between (0.71-1.38).

II. Conclusions from Analytical Work

1. Four available existing empirical equations (ACI-1999, ACI-2011, BS 8110:1997, Zararis-2003) are used to predict the ultimate shear

strength (Vn). The BS Code equation is too much safe (Avg. = 2.55) and has relatively inadequate accuracy (C.O.V. = 24.89%). Zararis's equation gives unsafe results (Avg. =0.84) while it gives the largest C.O.V. value equals to 36.58%. The ACI- 1999 and ACI-2011 Code equations show similar results with slight changes, they give relatively conservative results where their Avg. = 1.85 and 1.7respectively, while they give C.O.V. of 31.32 % and 31.42 % respectively.

1. Equation (5-5) is proposed to predict the ultimate shear strength (Vn) based on regression analysis of experimental data which include the variables that affect the ultimate strength. It was found that this proposed equation is more accurate than existing equations when compared with the test results. This proposed equation gives Avg. value of 1.04 while it gives C.O.V. value of 16.98 %. It gives consistent results with variation of all considered variables. This conclusion confirms the accuracy and rationality of this equation.

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