Effect of web reinforcement on shear strength of shallow wide beams

Ehab M. Lotfy, Hassan A. Mohamadien, Hussein Mokhtar Hassan

Abstract— **In modern building, many architectural constraints are pushing the designers to provide longer clear spans at a reasonable cost and preferred to use shallow wide beam in slabs. Structural designer during the design stage takes into consideration the Egyptian Code of practice (ECP 203-2007) require that the applied shear stress in the shallow wide beams be less than the concrete shear strength without any shear reinforcement contribution, and the shear strength provided by concrete equals two thirds of concrete shear strength of shallow slender beams. An experimental program was carried out to investigate the contribution of shear reinforcement to shear strength, shear cracks, ductility and mode of failure of shallow concrete wide beams. The main parameters considered in this investigation were: shear reinforcement ratio, shear span to depth ratio (a/d), spacing between stirrups and number of vertical branches, spacing between stirrups to depth ratio (s/d). The experimental program consisted of ten simply-supported reinforced concrete wide beams. The specimens were divided into 2 groups each consists of 5 beams, one control beam without shear reinforcement and 4 beams with different shear reinforcement. The shallow wide beams subjected to two concentrated loads with (a/d) = 3&4 for the first group and the (a/d) =2&5 for the second group. Test results show that shear reinforcement has a great effect on shear strength, mode of failure and ductility of the shallow wide beams.**

Index Terms— **Shear strength, shallow wide beams, stirrups, modified compression field theory.**

I. Introduction

In modern building construction design, floor spans are becoming longer. Hence, there is a need to minimize the overall structural slab depth to achieve more floor clear height, which can be achieved through the use of either shallow wide beams (Hidden Beams) or flat plate slab according to the majority of Egyptian building code of practice (ECP 203) [1], while the code neglects the shear reinforcement contribution in shear strength, it persists on providing specified minimum shear reinforcement, and reduces the concrete shear strength. These lead to a very conservative, yet uneconomic, shear design of shallow wide beams. In the same stream, the code requires the stirrups to be arranged so that the distance between stirrups branches across the beam section not to exceed 250 mm, allowing longer spans and more usable area of building. However an increase in the concrete strength produces an increase in its brittleness and smoothness of shear failure surfaces, leading to some concerns about the application of high strength concrete (Dino Angelakos, et. al.) [2].

(Khalil, A.H.H) [3], carried out an experimental study to investigate the shear behaviour of hidden beams (wide shallow beams) in hollow block slabs. His experimental investigation included nine medium scales simply supported hidden beams and five full scales hollow block one way slabs with normal concrete strength. The results showed that the capacity of specimens with shear reinforcement reached as high as 300% of those without shear reinforcement.

(Adam S. Lubell, et. al) [4], carried out an experimental study to investigate the shear behaviour of the wide beams and thick slabs as well as the influence of member width. In their study they tested five specimens of normal strength concrete with a nominal thickness of 470 mm and varied in width from 250 to 3005 mm. The study demonstrated that the failure shear stresses of narrow beams, wide beams, and slabs are all very similar.

(Adam S. Lubell, et. al) [5], investigated the influence of the shear reinforcement spacing on the one-way shear capacity of wide reinforced concrete members. A series of 13 normal strength concrete specimens were designed and tested. Shear reinforcement spacing was a primary test variable. The specimens contained shear reinforcement ratios close to (ACI 318-11) minimum requirements [6]. The study concluded that the effectiveness of the shear reinforcement decreases as the spacing of web reinforcement legs across the width of a member increases, the use of few shear reinforcement legs, even when widely spaced up to a distance of approximately 2d, has been shown to decrease the brittleness of the failure mode compared with a geometrically similar member without web reinforcement. To ensure that the shear capacity of all members with shear reinforcement are adequate when designed according to ACI 318-11, the study recommended that the transverse spacing of web reinforcement should be limited to the lesser of both the effective member depth and 600 mm. (Mohamed M. Hanafy, et al.) [7], investigated the contribution of web shear reinforcement to shear strength of shallow wide beams and the test results clearly demonstrate the significance of the web reinforcement in improving the shear capacity the ductility of the shallow wide beams which is consistent with the recognized international codes and standards provisions.

The objective of this research program is to investigate the contribution of web shear reinforcement to shear strength, volumetric ratio of vertical stirrups, spacing between vertical stirrups, number of vertical stirrups branches in section shear, and ductility and mode of failure of shallow concrete wide beams. Code Requirements for shear of shallow wide beams Egyptian Code of practice (ECP 203-2007)

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The current Egyptian Code of practice (ECP 203-2007) determines the shear resistance of shallow wide beams as following:

$$q_u \leq q_{cu} \quad (1)$$

$$q_{cu} = 0.16\sqrt{\frac{f_{cu}}{\gamma_c}} \quad (2)$$

Where q_{cu} is the concrete shear capacity (N/mm^2), f_{cu} is the concrete characteristic cube strength (N/mm^2), γ_c is concrete partial safety factor equals 1.50. The code neglects the web reinforcement contribution in shear strength of shallow wide beams, while stressing the need to provide specified minimum web reinforcement, and at the same time reduces the concrete shear strength for shallow wide beams.

II. Experimental Work

In order to investigate effect of the above mentioned parameters on the behaviour in shear of the shallow wide beams, an experimental program was carried out to test ten simply-supported reinforced concrete wide beams with compressive strength of f_{cu} =25 MPa.

The specimens were divided into 2 groups each group consists of 5 beams, one control beam without web reinforcement and 4 beams with different web reinforcement. The shallow wide beams subjected to two concentrated loads with (a/d); 3&4 for the first group and the (a/d); 2&5 for the second group.

Test results show that web reinforcement has a great effect on shear strength, mode of failure and ductility of the shallow wide beams.

A. Test Specimens

In the experimental program, tests were carried out on ten concrete beams divided into 2 groups each consists of 5 beams, one control beam without web reinforcement and 4 beams with different web reinforcement.

The first group under title (A) where A_0 was a control beam without web reinforcement and A_1 to A_4 beams with different web reinforcement subjected to two concentrated loads with (a/d); 3&4. The second group under title (B), B_0 was a control beam without web reinforcement and B_1 to B_4 beams with different web reinforcement subjected to two concentrated loads with (a/d); 2&5. Shear capacity, mode of failure and ductility of the shallow wide beams were studied.

All tested beams are 300mm x 200mm in cross section that have 1280 mm clear span and the same flexural longitudinal top and bottom reinforcement (4T16 Bottom and 3T12 Top). The width/depth ratio is limited to 1.5 in all specimens.

The beams were simply supported and subjected to two concentrated static loads (four-point bending). The details of the tested beams are shown in table (1).

Group (A): This group consists of five specimens (A_0 to A_4) (Beams), A_0 represent the control beam specimen without web reinforcement and the each other four specimen (A_1 to A_4) represents the reference specimen with different web reinforcement, where shear span to depth ratio (a/d); 3 &4.

Groups (B): This group consists of five specimens (B_0 to B_4) (Beams), B_0 represent the control beam specimen without web reinforcement and the each other four specimen (B_1 to B_4) represents the reference specimen with different web reinforcement, where shear span to depth ratio (a/d); 2 & 5.

B. Materials

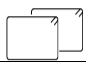
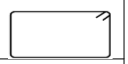
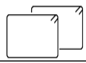
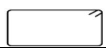
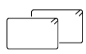
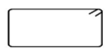
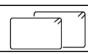
Trial mixes were conducted to reach the target cubic compressive strength of 25 MPa after 28 days. Table (2) shows mix proportions by weight of the quantities needed for one cubic meter of concrete to achieve the target cube compressive strength. Steel used in reinforcement beam with grade 360/520 MPa and with grade 240/370 MPa in stirrups, and the concrete cover with 2 cm.

C. Test Procedure

The specimens were placed in the testing machine between the jack head and the steel frame and supported on two hinged supports. All beams were subjected to two concentrated loads; each load was applied as shown in figures.

The deflection was measured under loading point. The load was applied gradually up to failure; the cracks and deflection were recorded at each load increment.

Table 1: Tested beams details

Group	Specimen	f_{cu}	Longitudinal RFT*		Web Shear RFT.* (Vertical Stirrups)	
		(MPa)	Bottom	Top		
A	A_0	25	4T16	3T12	Without shear reinforcement	
	A_1				Y8@100 Y8@70	
	A_2				2Y8@200 2Y8@140	
	A_3				Y8@150 Y8@105	
	A_4				2Y8@300 2Y8@210	
B	B_0	25	4T16	3T12	Without shear reinforcement	
	B_1				Y8@140 Y8@50	
	B_2				2Y8@280 2Y8@100	
	B_3				Y8@180 Y8@80	
	B_4				2Y8@360 2Y8@150	

*T: High Strength steel reinforcement; f_y =360MPa, Y: Mild steel reinforcement; f_y =240MPa

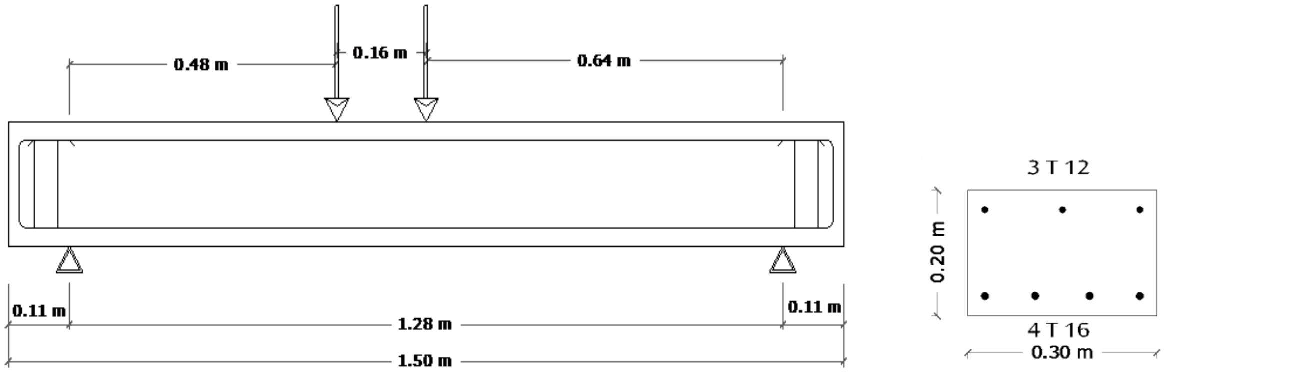


Figure 1a; Details of Specimen A_0

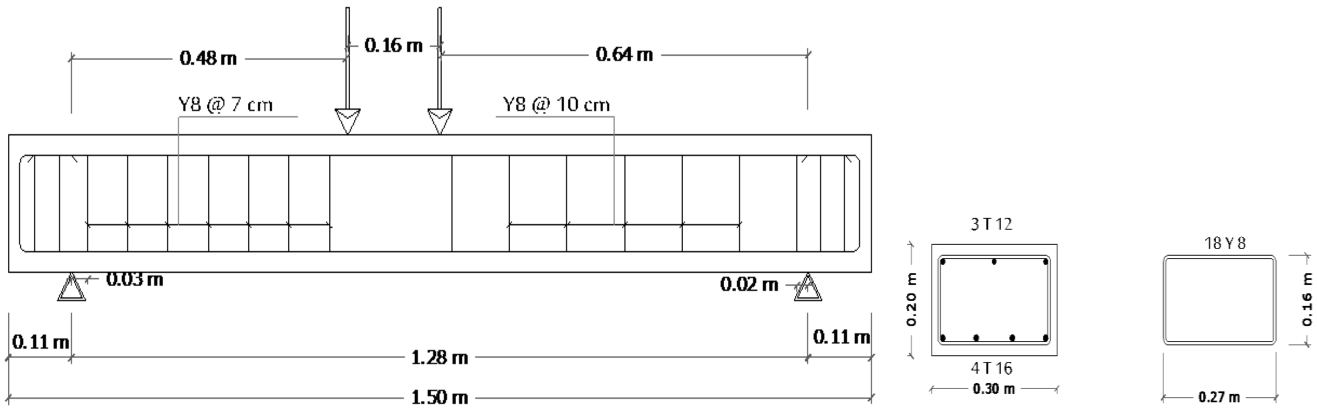


Figure 1b; Details of Specimen A_1

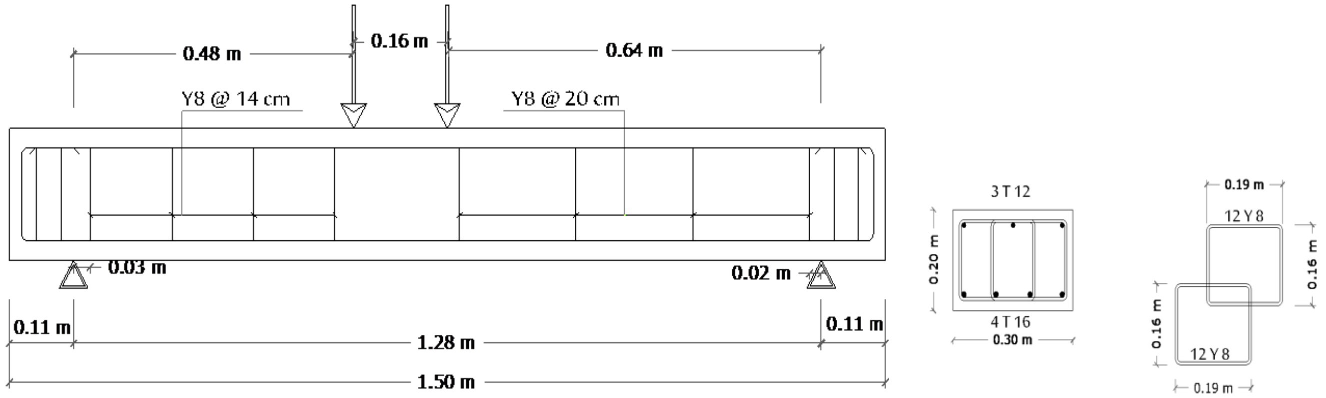


Figure 1c; Details of Specimen A_2

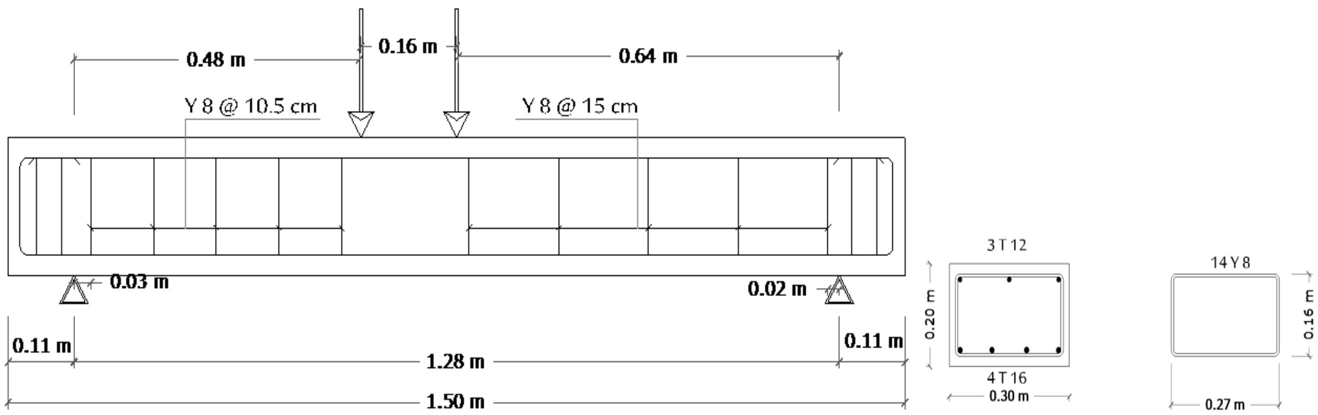


Figure 1d; Details of Specimen A_3

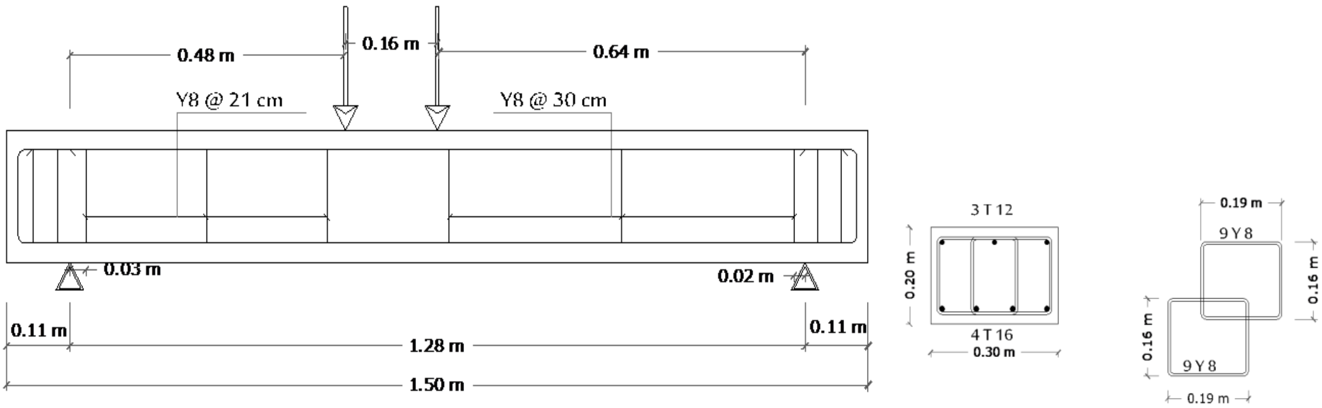


Figure 1e; Details of Specimen A_4

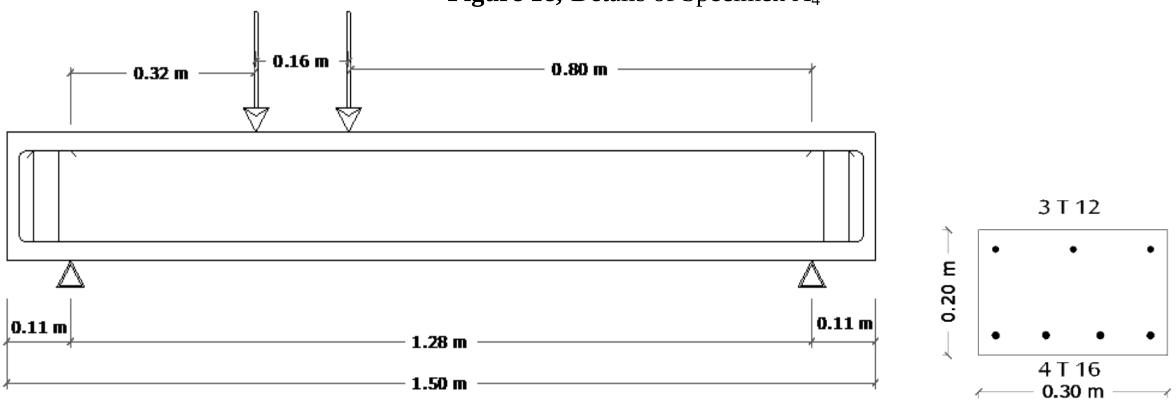


Figure 1f; Details of Specimen B_0

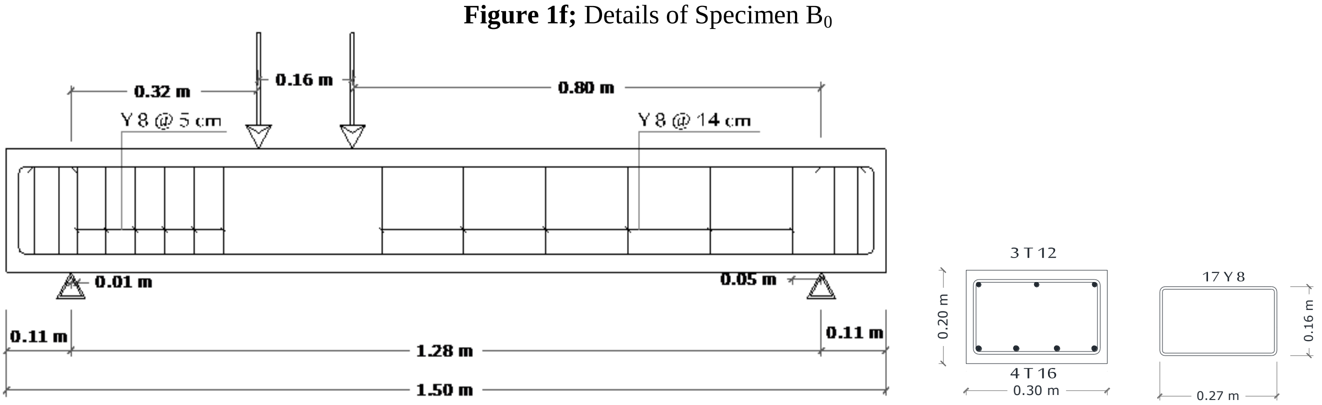


Figure 1g; Details of Specimen B_1

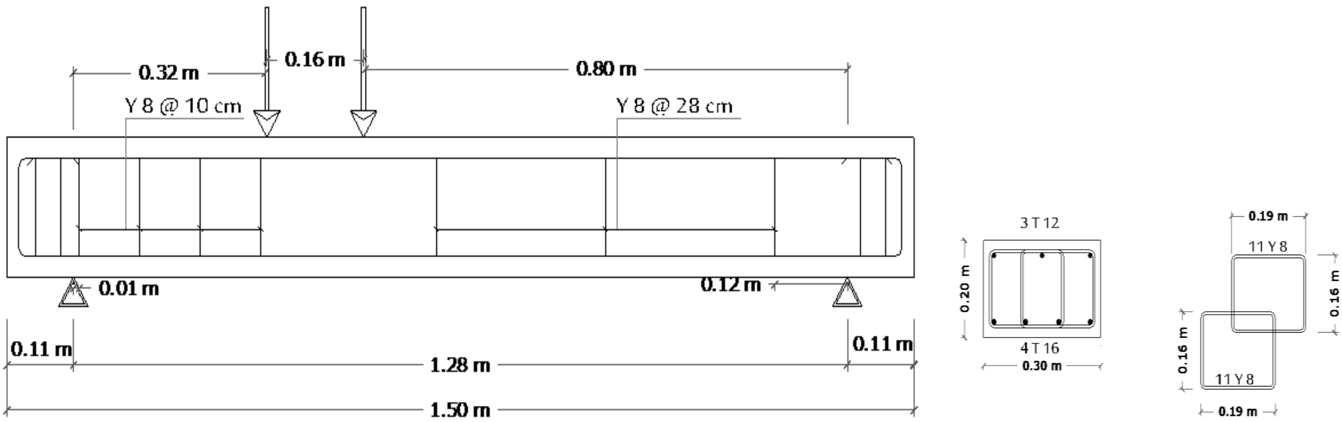


Figure 1h; Details of Specimen B_2

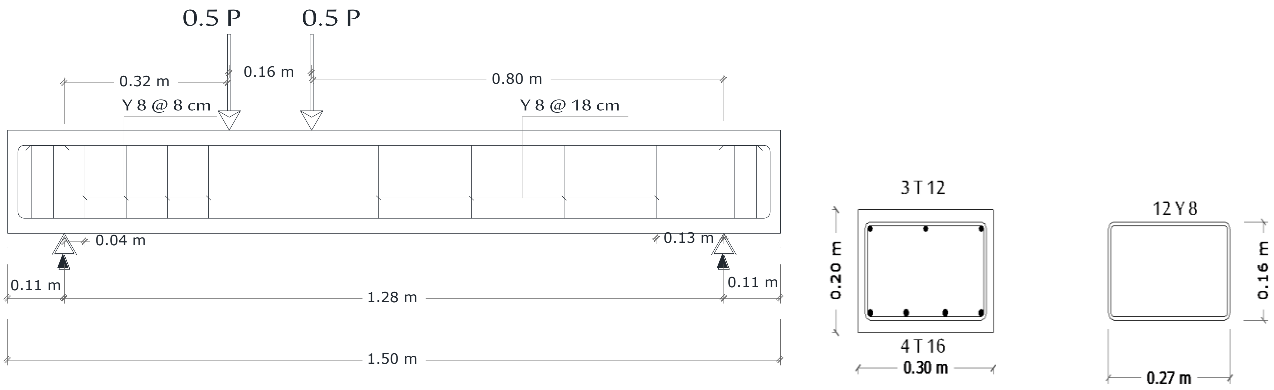


Figure 1i; Details of Specimen B_3

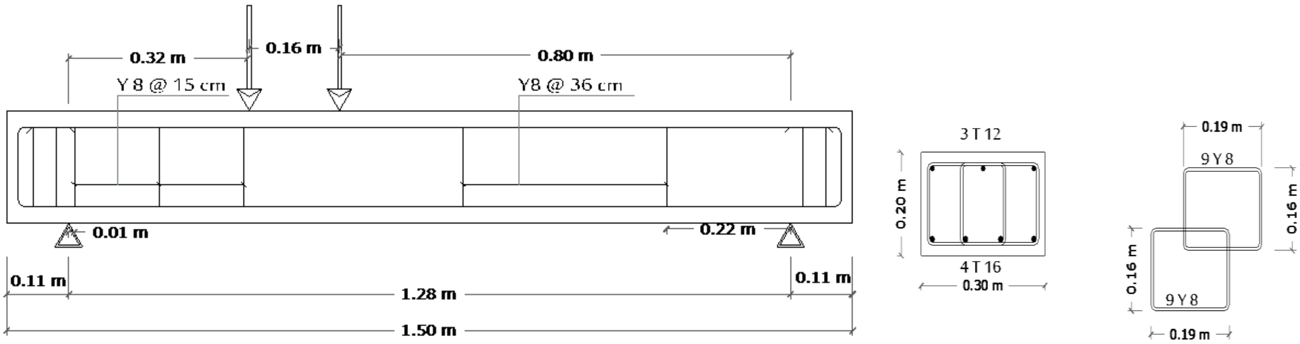


Figure 1j; Details of Specimen B_4

Figure 1; Details of tested specimens

III. Results and Discussion

The main parameters included in this research were shear reinforcement ratio, shear span to depth ratio (a/d), spacing between stirrups and number of vertical branches, spacing between stirrups to depth ratio (s/d). Table (2-1) & (2-2) shows the results of the tested Specimens in this study.

Table (2-1): Tested beams details

No	Ultimate loads P_u (Ton)	(a/d) =3				(a/d) =4			
		V_U (Ton)	V_U-V_C (Ton)	ρ_W (%)	S/d	V_U (Ton)	V_U-V_C (Ton)	ρ_W (%)	S/d
A0	12	6.75	0	0	0	5.25	0	0	0
A1	17.2	9.675	5.28	0.48	0.4375	7.53	3.1	0.33	0.625
A2	18.8	10.86	6.43	0.48	0.875	8.44	4.01	0.33	1.25
A3	17.5	9.84	5.54	0.32	0.65625	7.66	3.36	0.22	0.9375
A4	17.8	10.01	5.71	0.32	1.3125	7.79	3.49	0.22	1.875

Table (2-2): Tested beams details

No	Ultimate loads P_u (Ton)	(a/d) =2				(a/d) =5			
		V_U (Ton)	V_U-V_C (Ton)	ρ_W (%)	S/d	V_U (Ton)	V_U-V_C (Ton)	ρ_W (%)	S/d
B_0	15	10.31	0	0	0	4.69	0	0	0
B_1	21.5	14.78	10.35	0.67	0.3125	6.72	2.29	0.24	0.875
B_2	21.5	14.78	10.35	0.67	0.625	6.72	2.29	0.24	1.75
B_3	23	15.81	11.51	0.44	0.5	7.19	2.89	0.19	1.125
B_4	19.5	13.41	9.11	0.44	0.9375	6.1	1.8	0.19	2.25

V_U : Ultimate Shear
V_C : Shear carried by concrete
ρ_W : Shear reinforcement percentage
S/d: Spacing between stirrups to depth ratio

A. Cracking Pattern and Mode of Failure

For all specimens, the first crack development, crack propagation, and plane of failure were observed during the test. As stated before.

Figures.2 and 3 show the experimental cracking patterns for all specimens. It should be noted that in experimental results; the load is recorded along cracks to show crack propagation history.

Figure 2 a: Shear Cracks on beam (A_0); Sudden Shear Failure

Figure 2 b: Shear Cracks on beam (A_1); Flexure Failure

Figure 2 c: Shear Cracks on beam (A_2); Flexure Failure

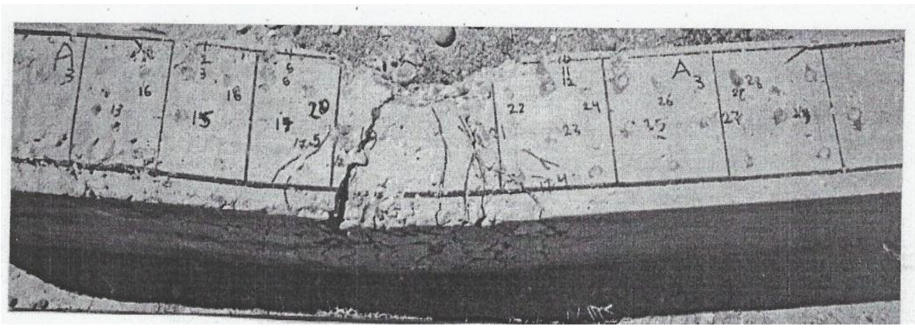


Figure 2 d: Shear Cracks on beam (A_3); Flexure Failure

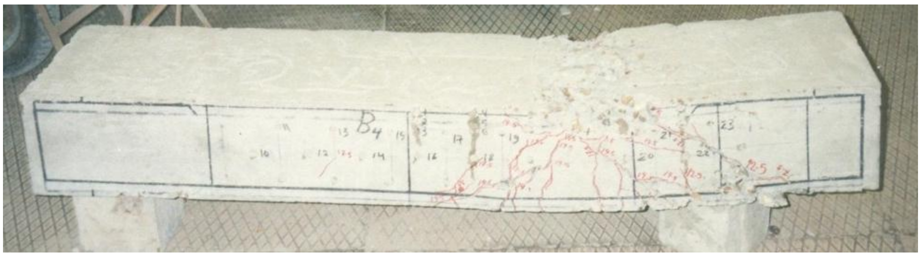


Figure 2 e: Shear Cracks on beam (A_4); Shear Failure
Figure 2: Crack pattern of tested specimens in group (A)

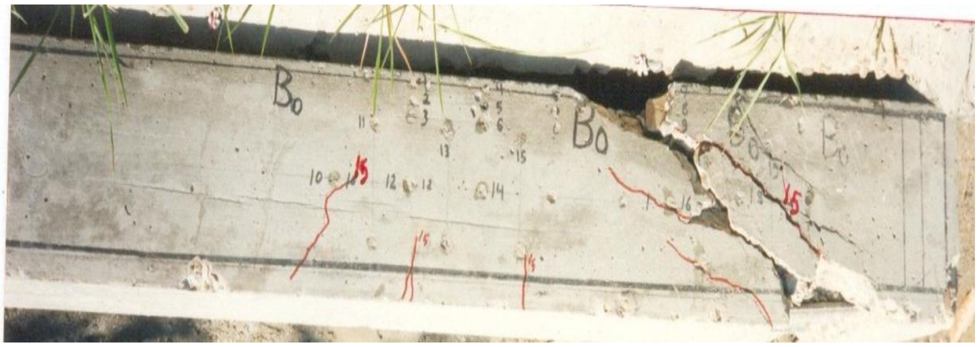


Figure 3 a: Shear Cracks on beam (B_0); Sudden Shear Failure

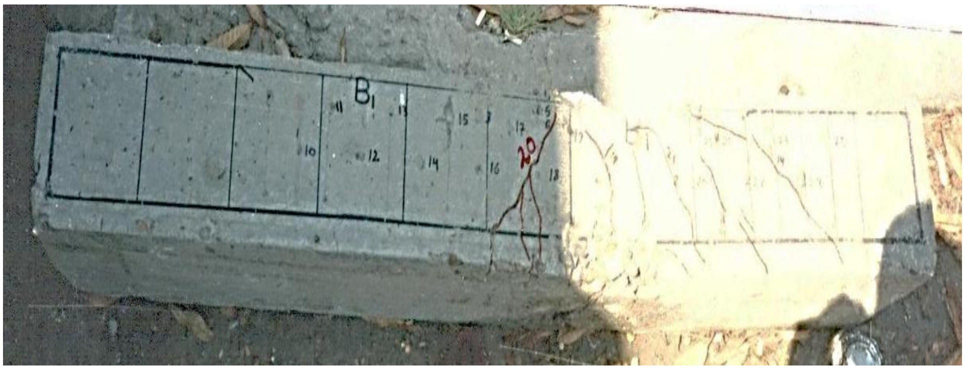


Figure 3 b: Shear Cracks on beam (B_1); Flexure Failure

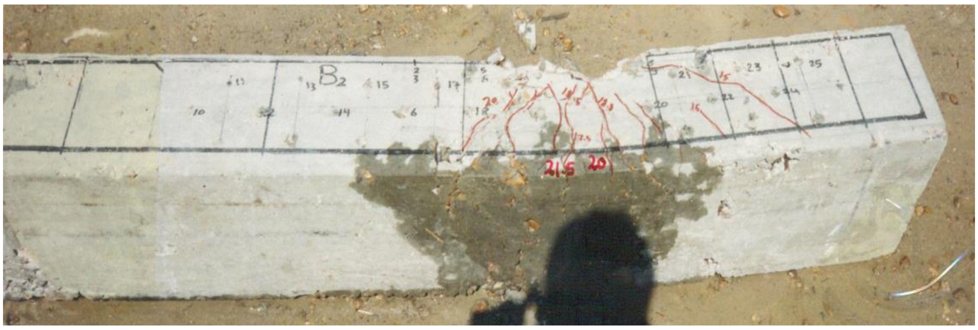


Figure 3 c: Shear Cracks on beam (B_2); Flexure Failure

Figure 3 d: Shear Cracks on beam (B_3); Flexure Failure

Figure 3 e: Shear Cracks on beam (B_4); combined flexure and shear failure
Figure 3: Crack pattern of tested specimens in group (B)

B. Load- Deflection Relationship

Figure (4) shows the load – deflection curves of tested specimens with Shear span to depth ratio (a/d); 2, 3, 4 & 5 where increasing the web reinforcement (**ρ_W**) increase the maximum applied load and ductility of tested specimens. Reduction of spacing between stirrups to depth ratio (s/d) increase the stain of specimens

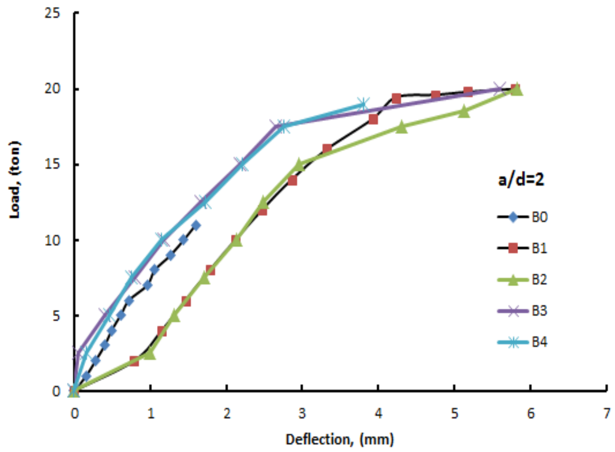


Figure 4 a: Load – deformation of B0,B1,B2,B3 & B4 with a/d=2

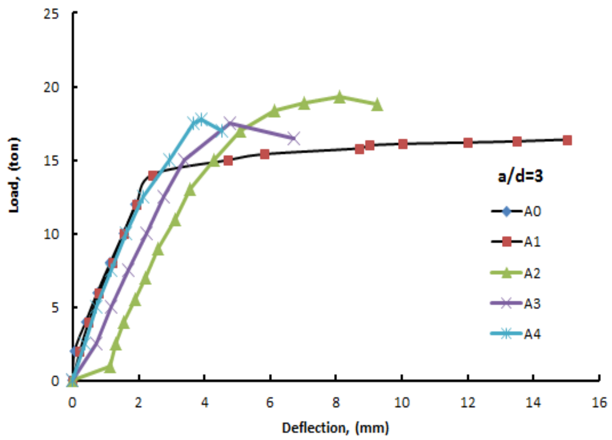


Figure 4 b: Load – deformation of A0,A1,A2,A3 & A4 with a/d=3

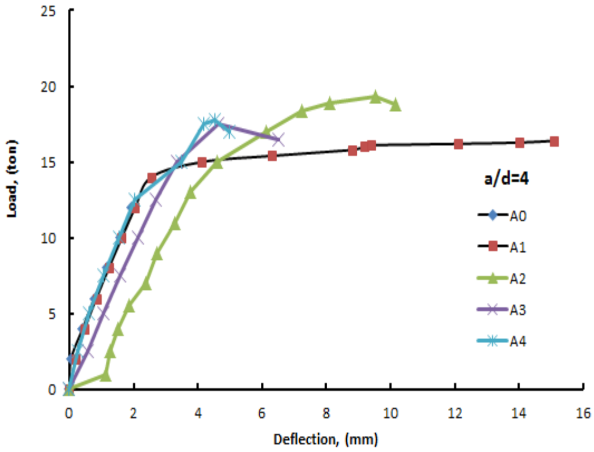


Figure 4 c: Load – deformation of A0,A1,A2,A3 & A4 with a/d=4

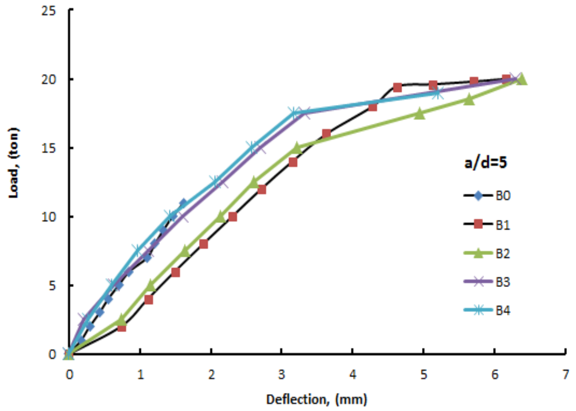


Figure 4 d: Load – deformation of B0,B1,B2,B3 & B4 with a/d=5

Figure 4 : Load – deformation of tested specimens

C. Shear & Moment - Deflection Relationship

Figure (5) shows the Shear-Moment versus deflection for the ten tested specimens. The curves show that the specimens exhibit three stages of behaviour which are marked by a significant change in the slope of the shear- moment deflection curve.

Stage (1) which is the pre-cracking stage, starts from zero loading till the first cracking load. The behaviour in this stage is characterized by the uncracked behaviour where the maximum tensile stress is less than concrete flexural tensile strength (concrete modulus of rupture f_r). This is presented through the steep slope of the shear, moment-deflection line where the deflection almost increased linearly with loading. The pre-cracking stage ends at the initiation of the first crack.

Stage (2) which is the post-cracking stage, begins with the first cracking in the mid span, the specimens behaves with a reduced stiffness compared to the slope of the load deflection line in the first stage where there were slight change in slope of the load deflection curve due to cracking. In this stage, the specimens developed a stable cracking in distribution and width. After cracking, deflections increased linearly with the load again.

Stage (3) which is the post-serviceability stage (steel yields), specimens in this stage behaved with significantly reduced flexural stiffness compared with the previous stages. This is presented through the near horizontal to horizontal load deflection curve in this stage due to substantial loss in stiffness of the specimens section, deeper and wider extensive cracks take placed till failure.

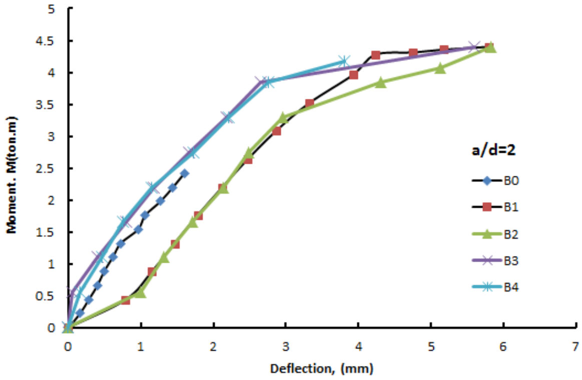


Figure 5a; Moment-Deflection Curves For Beams of B_0,B_1,B_2,B_3 & B_4, (a/d)=2

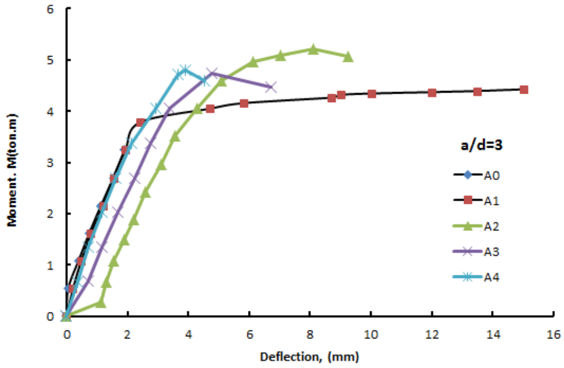


Figure 5b; Moment-Deflection Curves For Beams of A_0,A_1,A_2,A_3 & A_4, (a/d)=3

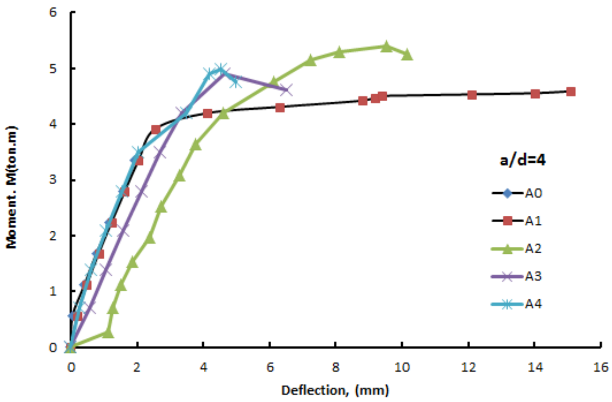


Figure 5c; Moment-Deflection Curves For Beams of A_0,A_1,A_2,A_3 & A_4, (a/d)=4

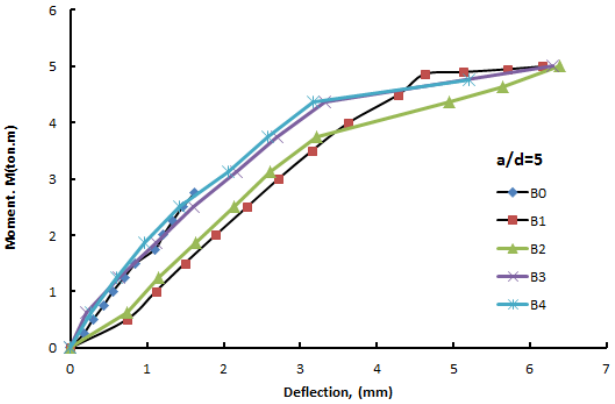


Figure 5d; Moment-Deflection Curves For Beams of B_0,B_1,B_2,B_3 & B_4, (a/d)=5

Figure 5; Moment-Deflection Curves For tested specimens

D. Effect of web reinforcement

Figure (6) shows the Relationship between web reinforcement (ρ_W) and V_U-V_C with a/d=3, 4, 2 &5, where the increasing of the web reinforcement lead to increase V_U-V_C, hence increasing the total applied load.

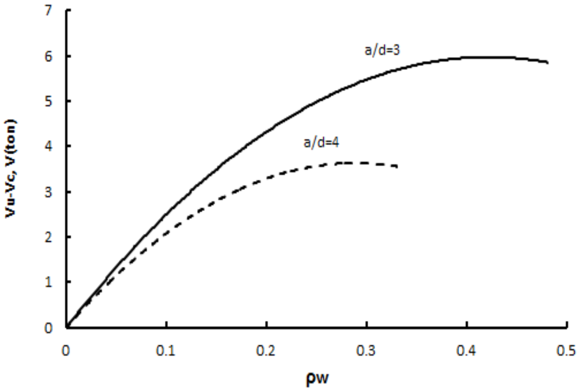


Figure 6a; Relationship between web reinforcement and V_U-V_C with a/d=3 & 4 (Group A)

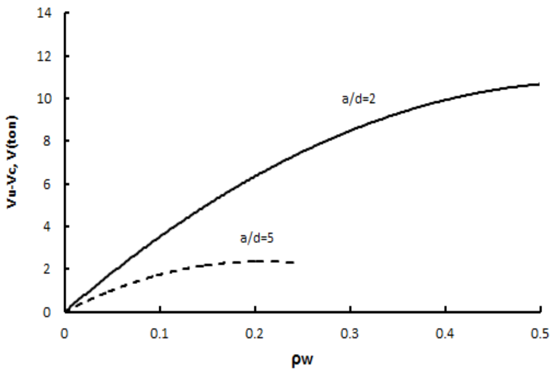


Figure 6a; Relationship between web reinforcement and V_U-V_C with a/d=2 & 5 (Group B)

Figure 6; Relationship between web reinforcement and V_U-V_C

E. Effect of s/d ratio on Shear strength

Figure (7) shows the Relationship between spacing of stirrups to depth ratio (s/d) ratio versus shear strength V_U-V_C with a/d=3, 4, 2 &5, for the tested specimens, where the increasing of s/d ratio leads to decrease V_U-V_C, and indicates the optimum spacing between stirrups to depth (s/d) ratio of shallow wide beams; 1 to 1.5 with shear span to depth ratio (a/d); 3, 4 & 5

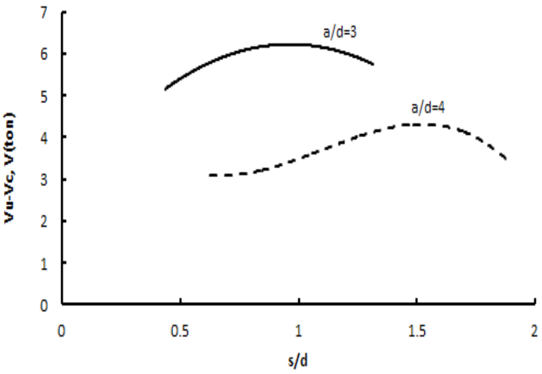


Figure 7a; Relationship between s/d ratio on Shear strength V_U-V_C with a/d=3 & 4 (Group A)

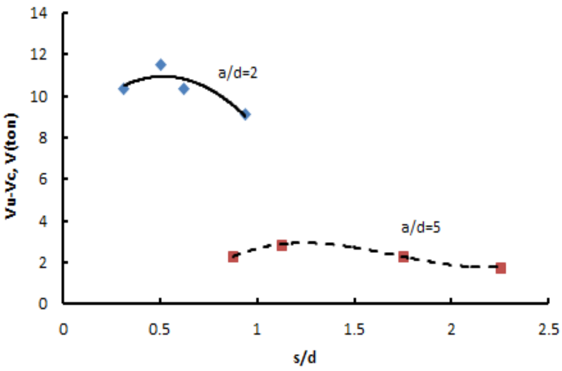


Figure 7b; Relationship between s/d ratio on Shear strength V_U-V_C with a/d=2 & 5 (Group B)

Figure 7; Relationship between s/d ratio on Shear strength V_U-V_C

IV. CONCLUSION

Based on the experimental results and the observed behaviour, the following conclusions may be made:

1) Using vertical stirrups as web reinforcement of shallow wide beams has a significant effect on shear strength of tested specimens
2) The ductility increases by the increase of web reinforcement ratio
3) The Shear strength increases by the increase of web reinforcement ratio
4) The width of shear cracks increases in the small span than that of the large span for the same beam.
5) The shear strength increases as the result of increasing the number of branches of web reinforcement for the same web reinforcement ratio.
6) The shear strength is inversely proportional with shear span to depth ratio (a/d).
7) The shape of the crack depends on the distance between web reinforcement, so by decreasing the distance between stirrups the formed crack angle are close to 45^0 and by increasing the distance between stirrups the crack angle decreases.
8) By increasing the spacing between stirrups, width of shear cracks increase and number of shear cracks decrease.
9) Beams having stirrups enhancing the mode failure from sudden failure to flexure and shear failure.
10) For the same shear reinforcement but using two branches of stirrups with closer spacing compared with four branches with wider spacing affect the mode of failure from flexure failure to combined flexure and shear failure.

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