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Experimental Investigation on Shear Resistance of Reinforced Concrete Beam without Stirrups

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Abstract: *Shear failure in concrete structures are very hazardous. These failures can be rarely predicted and happen suddenly. This paper presents the result of experimental investigation that was carried out to examine the shear resistance on longitudinally reinforced concrete beam without shear reinforcements. This experiment involves three series of beam, three of each totally nine numbers of simply supported beams, tested with a two point loading system. The variables of the investigation involve percentage of reinforcing steel and ratio of shear span to effective depth and all other parameters are left constant. The experimental test in this paper indicates the result of mode of failure and ultimate shear strength of a longitudinally reinforced concrete beam. The comparison with conventionally reinforced concrete beams was closest to the experimental results.*
Keywords: *Shear span to effective depth, shear transfer mechanism, flexure, dowel action, Shear strength.*

I. INTRODUCTION

Several theoretical and experimental studies have been carried out to analyze the phenomenon of the shear failure of reinforced concrete beams. This failure is due to the combined action of shear and flexure, and may happen in a brittle way and without warning signs. Due to shear, beam flexural strength may be greatly reduced compared with the case of pure flexure. Failure under flexure and shear interaction may happen in very different modes, and the parameters affecting the failure type and the beam capacity are several, including the web reinforcement. For this reason a lot of researchers have concentrated their attention on the behavior of only longitudinally reinforced beams.

According to the report of the ASCE-ACI Joint Committee (1973), the shear failure mechanism of RC beams is characterized by the occurrence of an inclined shear crack. The inclined shear crack in the web of a beam may develop either before or after a flexural crack occurs nearby. The first type of inclined shear crack is usually referred to as a web-shear crack, which is well defined as a principal diagonal-tension crack. The second type is generally identified as a flexural-shear crack. This crack develops after the onset of nearby flexural cracking, which means that the initial flexural cracks greatly influence the stress redistribution that follows the development of the flexural cracks. Therefore, any analysis that neglects the factors influencing this redistribution cannot predict subsequent behavior adequately, which is the main reason for unsuccessful attempts to predict flexural - shear cracking analytically. Furthermore, because shear failures of beams without web reinforcement are brittle in nature, experimental observations have provided relatively little information on the shear failure process.

Despite numerous studies carried out on this subject over the last 50 years by researchers from every part of the world, shear failure of longitudinally reinforced concrete beams still remains unresolved, and so of great interest, as it is demonstrated by the great number of recent studies in this field. By means of an analytical approach and a mechanical study of shear strength and previous experimental results, the research work described in this project attempts to identify the mechanism of shear failure in terms of the initiation and propagation of a critical shear crack in slender reinforced concrete beam without stirrups.

II. SHEAR TRANSFER MECHANISM

The factors assumed to be carrying shear force in cracked concrete to the supports when no shear reinforcement is provided for the member, are illustrated in the following free body diagram.

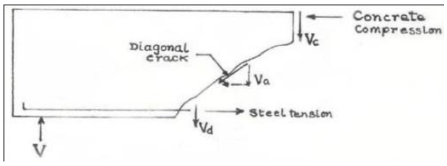


Fig. 1: Shear transfer mechanism

These three factors are the sum of beam action. In addition to beam action, arch action also contributes to the shear resistance.

Many investigators have tried to determine the contribution from each of the elements of beam action to shear resistance. It was concluded by some that, after inclined cracks developed in the concrete, the contribution from each of the following V_d, V_a and V_c altered between 15-25%, 33-50% and 20-40%.

2.1. Concrete Compression Zone (V_c)

Gradually inclined cracks widen in the concrete, the shear resistance from V_a decreases while $V_c$and V_d increase. Finally when the aggregate interlock reaches failure, large shear force transfers rapidly to the compression zone causing sudden and often explosive failure o the beam when arch action contribution is low.

2.2. Dowel Action (V_d)

Shear resistance caused by dowel action increases as the shear reinforcement decreases. Consequently it has a significant effect in members where no shear reinforcement is provided. When inclined cracks cross the longitudinal reinforcing bar, forces act on the dowel due to deflection of the bar at the face of the crack Aggregates around the bar try to resist the deflection by interlocking with each other and those entire forces sum up as the total shear resistant of dowel action.

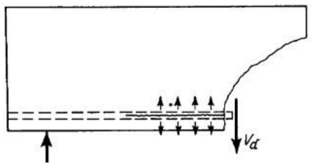


Fig. 2: Crack passing through the concrete

2.3. Aggregate Interlock (V_a)

It is generally believed that aggregate interlock transfers a large part of the total shear force to the supports. Width of the cracks, aggregate size and concrete strength are the most important variables. When the longitudinal reinforcement ratio is increased with added bars to the beam, the width of the flexural cracks gets smaller due to increased shear resistance and consequently the contribution of V_d decreases.

2.4. Arch Action

When beams develop a flexure-shear interaction, the shear resistance consists of two different mechanisms, beam and arch mechanisms. The former governs when the a/d ratio is above the critical (transition) point and the latter when it is below. When the arch action begins to contribute more than beam action, the member can achieve considerably more load than at diagonal cracking.

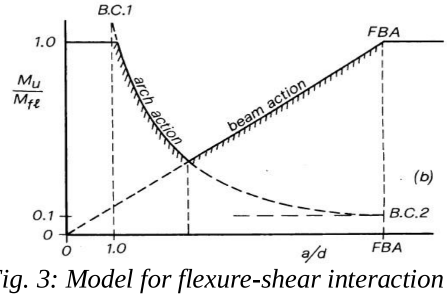


Fig. 3: Model for flexure-shear interaction

Distance of critical shear crack

In a simply supported reinforced concrete beam applying two point loads atmid-span of the beam. The first hair line cracks (flexural crack) by bending moment occurred near the mid-span of the beam. Subsequently additional flexural cracks appeared in the mid-span as the applied load increased. As the applied load continually increased, the major cracks extended laterally into inclined shear cracks near support ends to form detrimental diagonal cracks formed within the shear span. Since the previous studies after the flexural cracks, the first branch of critical shear crack will appear at x distance from the supports. It can be obtained by the following geometric relation.

$$\frac{x}{d} = \left(1 - \frac{\mathrm{c}}{\mathrm{d}}\right)\left(1 - \frac{\mathrm{a/d}}{1 - 0.36\mathrm{c/d}} - \tan\Phi\right)$$

III. THE EXPERIMENT

This experiment involves three series of beam, three of each totally nine numbers of simply supported beam testing under the two point loading conditions. All the beams were rectangular cross section, 120 mm width 150mm depth and 1200 mm length. The beams were provided with only longitudinal reinforcement. To maintain the spacing of longitudinal bar and the concrete cover, the longitudinal bar were welded with 10 mm piece rods for avoiding the sliding and moving of bar while placing of concrete. The primary variables of the investigation includes percent of reinforcing steel 1.33, 1.51, 1.77 and ratio of shear span to effective depth 1.5 to 2.5.

3.1. Material properties

Standard M25 grade of concrete were used.

Material	Quantity	Proportion
Cement	380 kg/m^3	1
Fine Aggregate	380 kg/m^3	1
Coarse Aggregate	760 kg/m^3	2
20mm	456 kg/m^3	60% of C.A
10mm	304 kg/m^3	40% of C.A
Water	152 lit	0.45

Compressive strength of M_{25} grades of concrete cube at 7th, 14th and 28th day.
Size of the cube = 150 mm x150 mm x 150 mm
Stress = Load /Area

Table.1: Compressive Strength of Concrete cube (N/mm^2)

	Trail -1	Trail -2	Trail -3	Avg
7th day	17.51	19.56	18.75	18.60
14th day	23.78	24.49	22.35	23.54
28th day	28.44	30.31	27.86	28.87

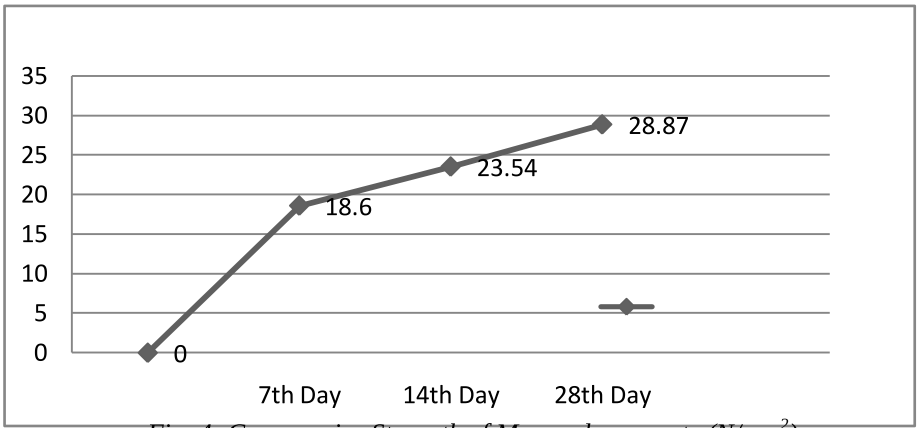


Fig. 4: Compressive Strength of M_{25} grade concrete (N/mm^2)

Split tensile strength of M_{25} grades of concrete cylinder at 7^{th} and 28^{th}day.

Size of the cylinder =150 mm x300 mm

f_{ct}= 2p/πld

Table.2: Split tensile Strength of cylinder (N/mm^2)

	Trail -1	Trail -2	Avg
7^{th} day	1.67	1.51	1.59
28^{th} day	4.84	4.20	4.52

3.2. Reinforcing steel

Fe500 grade steel with three different diameters was used in this experiment.

For experimental beams three numbers of longitudinal bars were placed with cranked ends as shown in the figure. 5. For conventional beams two numbers of 10 mm bars at bottom and two numbers of 8 mm bars at top with 6 mm dia bars provided for stirrups.

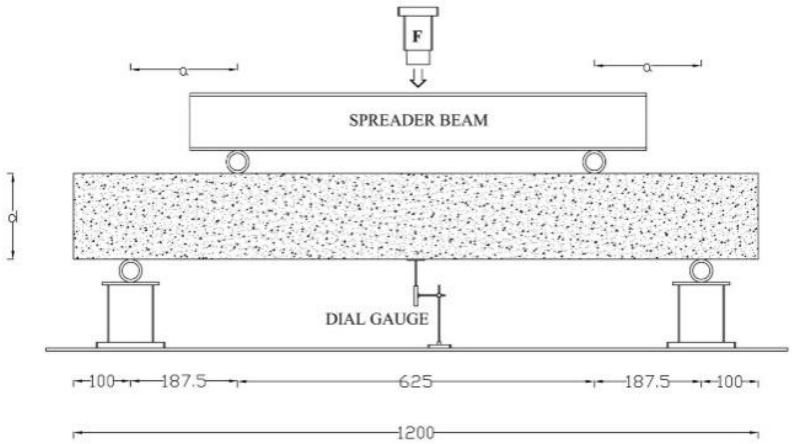


Fig. 5: Reinforcement details

3.3. Test setup

The beams were all loaded in the loading frame in the structural laboratory. The hydraulic jack that ran the machine had a compressive strength of 30 tons (300kN). The beams were all carefully positioned in the machine. The hydraulic jack was manually controlled and maintains an even constant slow speed while applying the load. The vertical deflections were monitored in dial gauge.

The following test setup was used for specimen EB-A1, EB-B1, EB-C1, OB-1

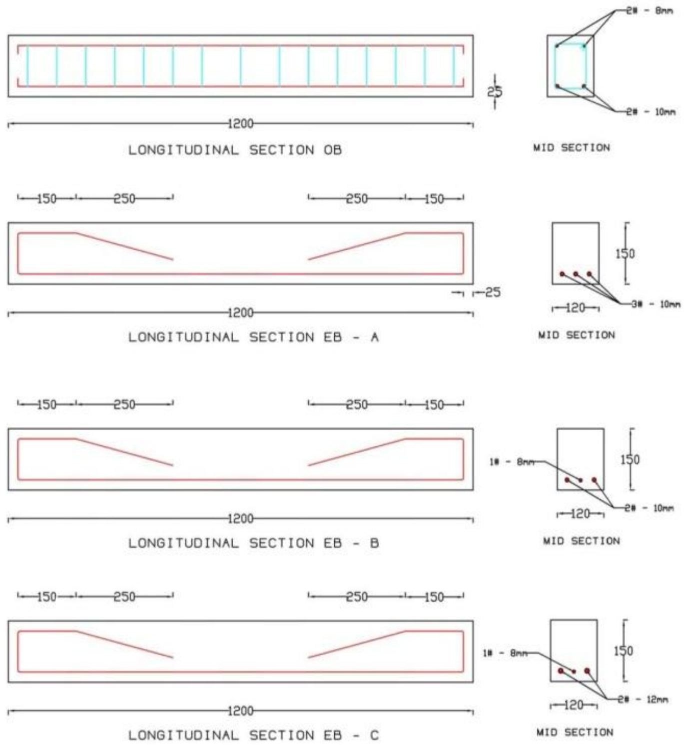
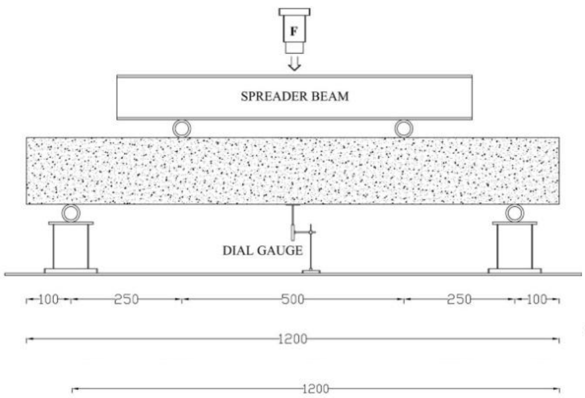


Fig. 6: Test Setup 1 (a/d = 1.5)

The following test setup was used for specimen EB-A2, EB-B2, EB-C2, OB-2

Fig. 7: Test Setup 2 (a/d = 2.0)



The following test setup was used for specimen EB-A3, EB-B3, EB-C3, OB -3

Fig. 8: Test Setup 3 (a/d = 2.5)

3.4. Experimental results

Due to the application of external load first hair line crack by bending moment occurred near the mid-span of the beam, at the load reached 20-40% of the ultimate load. Subsequently additional flexural cracks appeared in the mid-span as the applied loads increased. As the applied load continually increased, the major cracks extended laterally into inclined shear cracks near support ends to form diagonal cracks formed within the shear span, approximately 1.5d to 2d away from the end supports.

Table. 3: Experimental test results

Beam	ρ (%)	a/d	F_{cr} (kN)	V_{cr}(kN)	V_u (kN)	δ_{cr} (mm)	δ_u (mm)
EB-A1	1.77	1.5	14.2	19.4	26.5	5.4	9.6
			14.5	18.8	26.8	6.2	9.2
			14.4	**19.1**	**26.7**	**5.8**	**9.4**
EB-A2	1.77	2.0	13.5	18.5	23.6	4.6	8.8
			13.2	18.2	24.5	3.9	8.5
			13.4	**18.4**	**24.0**	**4.3**	**5.8**
EB-A3	1.77	2.5	12.6	16.8	22.3	4.8	7.4
			12.8	15.6	23.5	4.5	7.6
			12.7	**16.2**	**22.9**	**4.7**	**7.5**
EB-B1	1.51	1.5	14.8	20.8	25.8	6.2	9.2
			15.2	19.6	25.6	5.8	10.5
			15.0	**20.2**	**25.7**	**6.0**	**9.9**
EB-B2	1.51	2.0	14.5	19.3	23.5	5.5	8.6
			15.2	20.4	22.6	5.8	9.5
			14.9	**19.9**	**24.0**	**5.7**	**9.1**
EB-B3	1.51	2.5	12.3	18.5	22.6	4.8	7.8
			11.9	18.6	23.5	5.2	7.5
			12.1	**18.55**	**23.05**	**5.0**	**7.65**
EB-C1	1.33	1.5	12.6	19.8	22.8	5.2	8.8
			13.2	20.5	21.6	6.8	10.9
			12.9	**20.15**	**22.2**	**6.0**	**9.85**
EB-C2	1.33	2.0	12.8	19.5	20.6	4.4	8.5
			13.5	18.5	21.6	5.9	9.4
			13.2	**19.0**	**21.1**	**5.2**	**8.8**
EB-C3	1.33	2.5	12.6	18.8	19.2	4.2	7.9
			13.5	19.5	20.6	4.6	8.9
			13.05	**19.15**	**19.9**	**4.4**	**8.4**
CB	1.51	1.5	13.8	19.5	24.8	5.2	8.2
			14.5	17.6	26.6	6.8	9.5
			14.2	**18.55**	**25.7**	**6.0**	**8.9**
CB	1.51	2.0	13.8	18.5	22.3	5.5	9.4
			15.5	19.4	23.8	4.8	7.5
			14.7	**18.9**	**23.1**	**5.2**	**8.5**
CB	1.51	2.5	11.5	17.8	23.4	5.8	7.8
			12.3	18.5	21.2	4.2	7.4
			11.9	**18.2**	**22.3**	**5.0**	**7.6**

Note: ρ = Percentage of reinforcement; a/d = Shear span to effective depth; F_{cr}= First crack load; V_{cr} = First shear crack load; V_u = Ultimate shear strength; δ_{cr} = Deflection at first crack; δ_u = Deflection at ultimate load. EB = Experimental Beam; CB = Conventional Beam.
Load - Shear span to Effective depth

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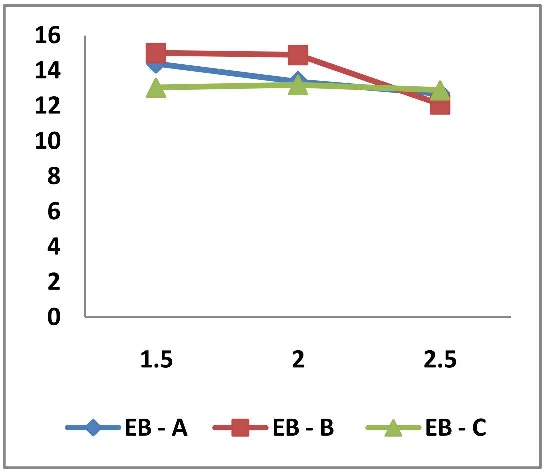

Fig. 9: First Crack Load (kN)

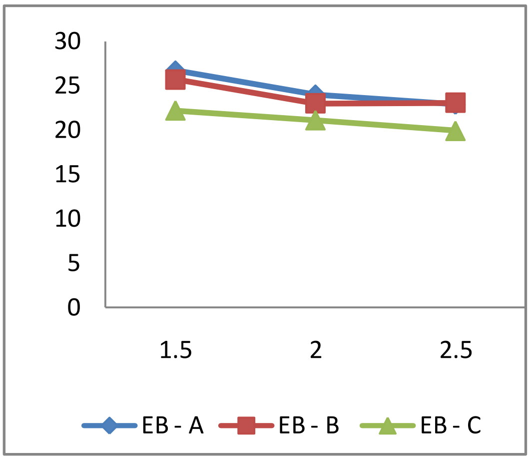

Fig. 10: : First Shear Crack load (kN)

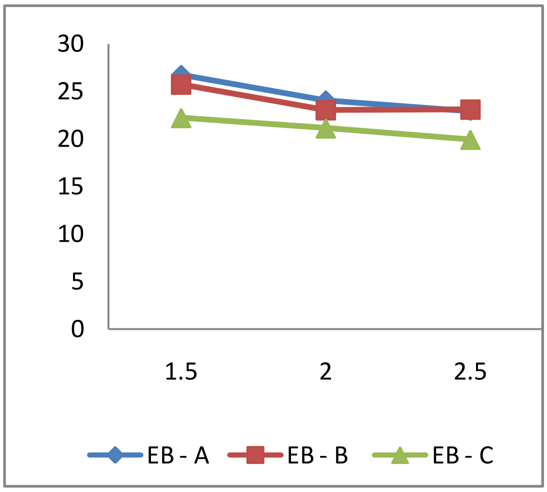

Fig. 11: First Ultimate load (kN)

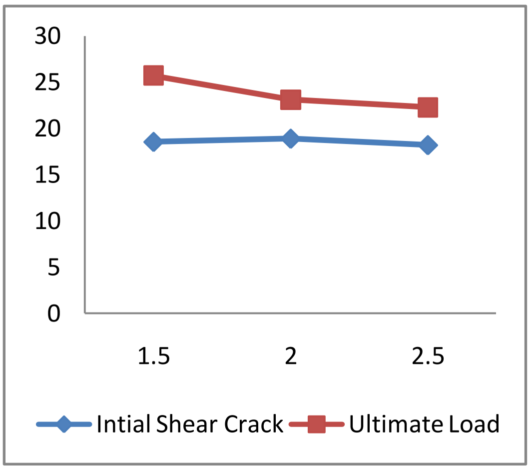

Fig. 12: Conventional RC beam (kN)

Deflection - Shear span to Effective depth

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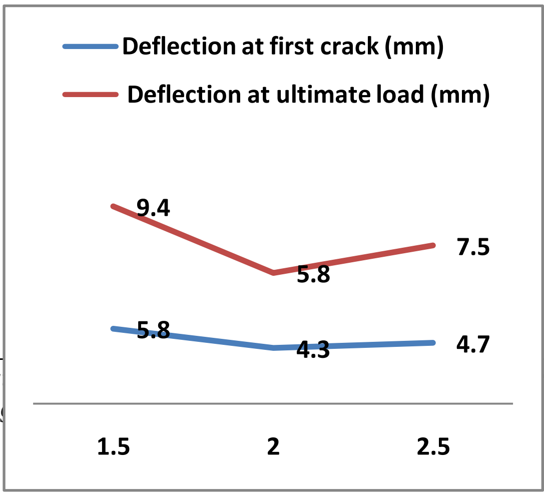


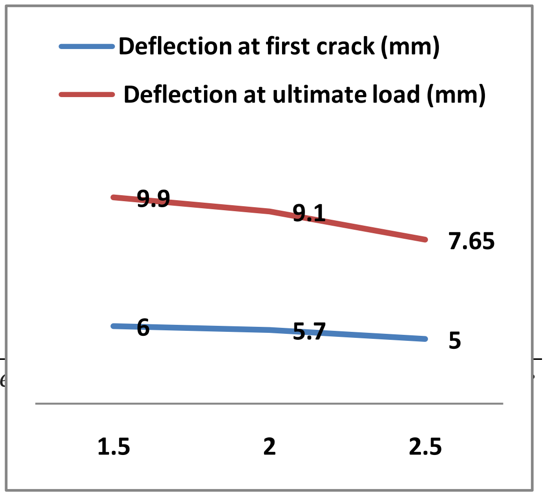
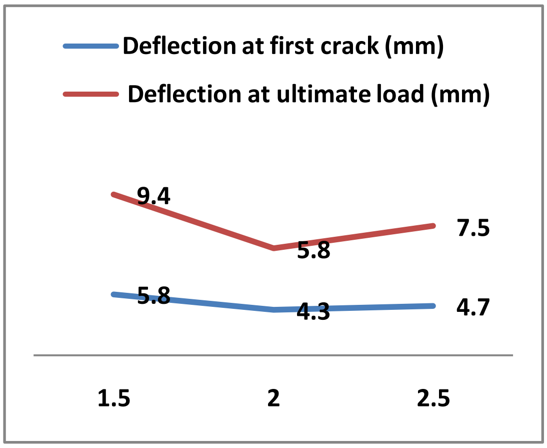


Fig. 13: Experimental Beam – A

Fig. 14: Experimental Beam – B



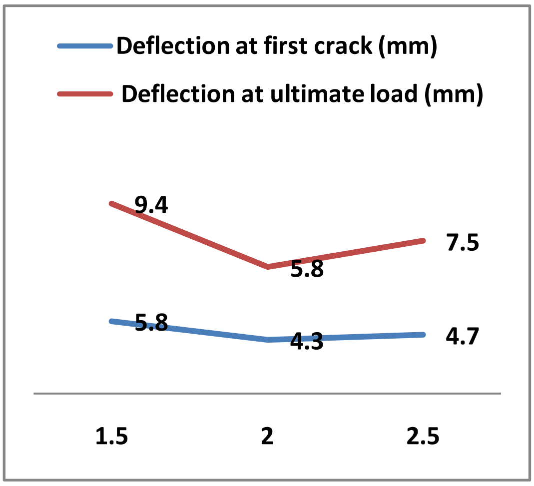


Fig. 15: Experimental Beam – C

Fig. 16: Conventionally RC beam (kN)

3.5. Result Comparisons

Experimental values at failure, first shear crack and deflections are displayed in the charts. Figures. 10, 11, 12 and 13 showed, the load carrying capacity of the beams was increased while decreasing a/d ratio. The load versus deflection behavior of the beam is shown in the figures. 14, 15 and 16. Due to the absence of shear reinforcement, the beam failed shortly after the formation of the diagonal cracks. From the above results the experimental beam B series were having nearly equal properties of conventionally reinforced concrete beams. The prediction of shear crack distances are nearly coincides with all experimental beams expect in the case of 1.33 percentage reinforcement series. In this case of beams the shear cracks were appeared very nearer to the supports. From the experimental test the change in longitudinal reinforcement profiles were satisfied the conventional beam properties, at the percentage of reinforcement 1.5 and a/ d ratio from 2.0 to 2.5.

IV. CONCLUSIONS

The following conclusions are reported in this paper:

- An increase in amount of longitudinal reinforcement across the shear span will increases the shear resistance
- Due to the absence of shear reinforcement, the beam failed shortly after the formation of the diagonal cracks.
- The initial shear cracks will appears at the distance of 1.5d to 2d from the supports.

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NOTATION

The following symbols are used in this paper:

a shear span
a/d shear span to effective depth
b beam width
d effective beam depth
f_c concrete compressive strength
f_{ct} cylindrical concrete compressive strength
l beam length
F concentrated load
V shear force
V_a shear resistance due to aggregate interlock action
V_c shear resistance of the concrete
V_{cy} shear resistance of concrete compression zone
V_d shear resistance due to dowel action
x initiation of the critical diagonal crack from the support
Φ angle from tangential crack line to zero shear at crack tip
Z internal lever arm distance