Experimental Investigation of Pre-Cracking Behavior of Reinforced Concrete Beams with and without Steel Fiber

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Abstract **—** This paper presents an experimental study of cracking behavior of reinforced concrete beams made with and without steel fibers. The goal of this paper was to investigate the effect of using steel fibers on the first cracking behavior of concrete. Two groups of reinforced concrete beams with and without steel fiber were used. The first class (group A) consisted of six ordinary RC beams made with three different reinforcement ratios, the second (group B) consisted of additional six RC beams made with steel fiber. The two classes were categorized into three groups according to reinforcement ratios of 0.92%, 1.33% and 2.39%. All beams were designed to crack under pure moment applied to the middle third of the beam span (four-point bending). The main parameters investigated were mainly reinforcement ratios (0.92%, 1.33% and 2.39%) and the type of concrete (with and without steel fibers). The mid-span deflection, reinforcement strains and cracking load of the tested beams were recorded and compared with calculated theoretical values recommended by the Egyptian reinforced concrete and the ACI codes. The test results revealed that steel reinforcement participates in delaying first crack occurrence according to reinforcement ratios, and the effect of steel fibers in additional to reinforcement to improve the cracking behavior. Steel participation ratio was around 15% of cracking capacity of cross section and this participation ratio decreases by using steel fiber.

Keywords— *Concrete Cracking, Steel Reinforcement, Flexural Strength*

I. INTRODUCTION

Liquid retaining structures are usually used to store water, chemicals and other harsh fluids. Water storage structural elements are sized such that their critical sections are uncracked, which helps minimizing liquid leakage. Water and liquid leakages usually produce corrosion and structure deterioration. The main goal of water structures design is to force the tensile stresses in concrete to be less than its flexural rupture strength [1,2]. As per the literature [3,4,5,6,7,8], various reasons could be attributed to concrete cracking such as free shrinkage, thermal stresses, and swelling due to ASR or carbonation. The main goal of the experimental work is to investigate effect of steel fibers on the cracking moment of RC beams and to compare the results with the theoretical values to quantify the steel-concrete contribution that is usually neglected by design codes. This investigation was done by using different schemes of RC beams made with various steel ratios at the tension side.

II. EXPERIMENTAL PROGRAM

A. Test Setup

Six RC beams with three various reinforcement ratios for each group. All specimens had cross section of 100 mm width, 200 mm thickness and a total span of 1650 mm (1500 mm clear span between supports). the tested beams layout is detailed in **Figure 1**. All reinforcement details are summarized in **Table (1).** Four-point bending protocol was used to test all the specimens as shown in **Figure 2.** The displacement at the mid span was measured by LVDTs at the constant moment region. Strain gauges were attached to the steel bars to measure the strain-time history through a data logger. All beams were loaded up to failure with a loading rate of 0.5 kN per minute. The mode of failure as along as cracks history were observed as discussed in the following sections.

Table 1. Specimens details

Class Name	Group Name	Model Name	Cross section	Main RFT	Stirrups hangers	stirrups
(A)	Group 1A	B (1-1)	100 x 200 x 1650	2 Φ 10	2 Φ 10	ϕ 8 @ 166 mm
		B (1-2)	100 x 200 x 1650	2 Φ 10	2 Φ 10	ϕ 8 @ 166 mm
	Group 2A	B (2-1)	100 x 200 x 1650	2 Φ 12	2 Φ 10	ϕ 8 @ 166 mm
		B (2-2)	100 x 200 x 1650	2 Φ 12	2 Φ 10	ϕ 8 @ 166 mm
	Group 3A	B (3-1)	100 x 200 x 1650	2 Φ 12 + 2 Φ 10	2 Φ 10	ϕ 8 @ 166 mm
		B (3-2)	100 x 200 x 1650	2 Φ 12 + 2 Φ 10	2 Φ 10	ϕ 8 @ 166 mm
(B)	Group 1B	B (1-1)	100 x 200 x 1650	2 Φ 10	2 Φ 10	ϕ 8 @ 166 mm
		B (1-2)	100 x 200 x 1650	2 Φ 10	2 Φ 10	ϕ 8 @ 166 mm
	Group 2B	B (2-1)	100 x 200 x 1650	2 Φ 12	2 Φ 10	ϕ 8 @ 166 mm
		B (2-2)	100 x 200 x 1650	2 Φ 12	2 Φ 10	ϕ 8 @ 166 mm
	Group 3B	B (3-1)	100 x 200 x 1650	2 Φ 12 + 2 Φ 10	2 Φ 10	ϕ 8 @ 166 mm
		B (3-2)	100 x 200 x 1650	2 Φ 12 + 2 Φ 10	2 Φ 10	ϕ 8 @ 166 mm

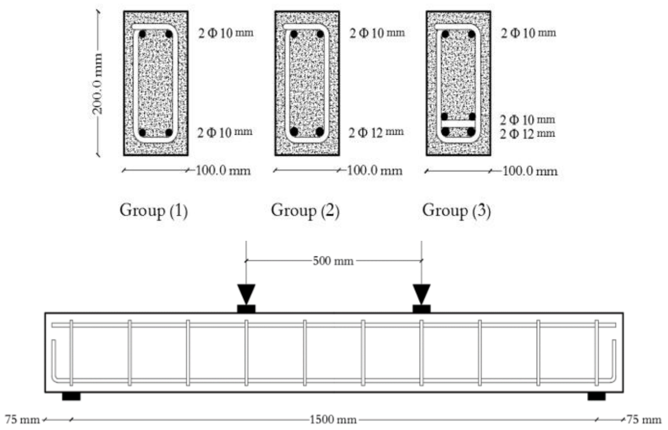


Figure 1. Specimens Details

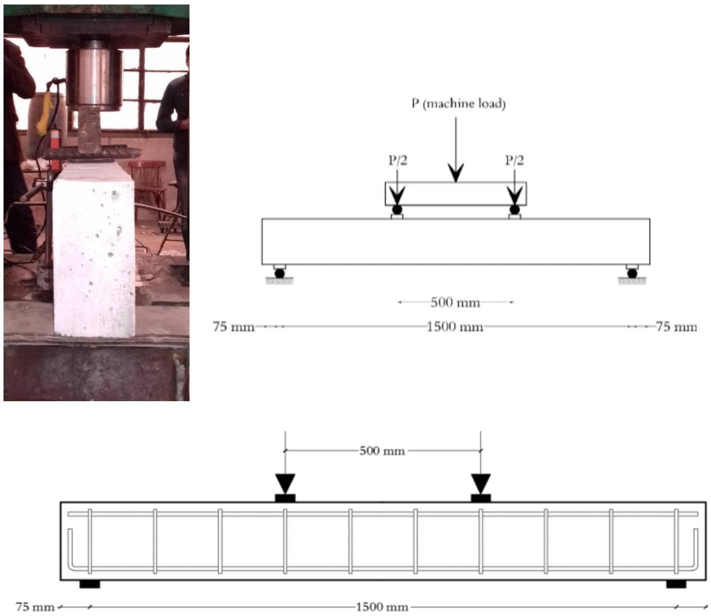


Figure 2. Test Setup

III. CRACKING MOMENT

Cracking moment (M_{cr}) is the moment which causes the first crack in RC sections. Modulus of rupture (f_{ct}) was considered as reference value for the predicted cracking moment from the experiments, which is based on [2] or guideline as the following formulas [9]:

$$M_{cr} = \frac{f_{ct}\, I_g}{y_t} \qquad \text{where } F_{ct} = 0.6\sqrt{F_{cu}} \qquad (1)$$

IV. TEST RESULTS

Control cubes, reference prisms and beams of the two groups were tested at 28 days of curing as shown in **Figure 3.** The first crack in each beam was observed visually and the corresponding load was recorded. The first cracking load was also verified from the load-deflection and load-strain time histories as shown in **Figure 4. Table 2** provides a summary of the experimental results for all tested specimens.

Figure 3. Control cubes and reference prisms

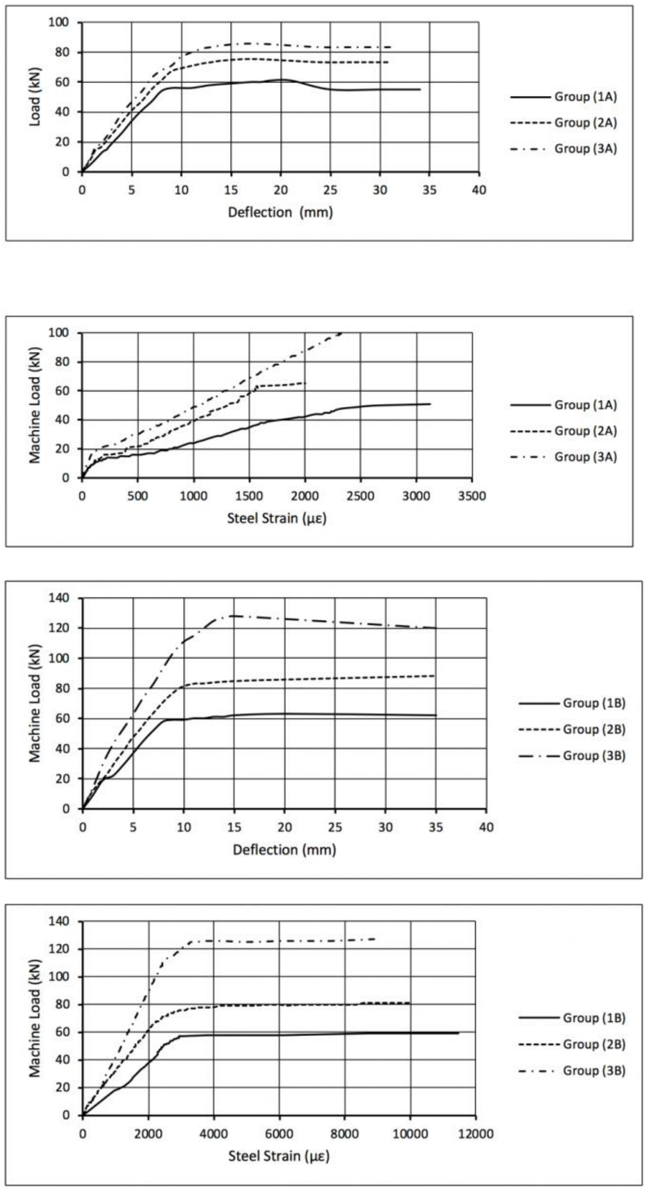


Figure 4. Deflection and strain relationships of class (A & B)

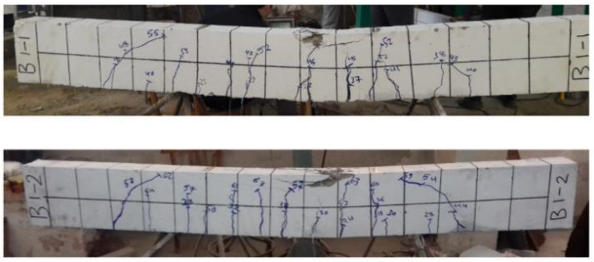
Table 2. Experimental test results

Group Name	Model Label	Comp. Strength (MPa)	Modulus of Rupture (MPa)	Cracking Load (KN)	Failure Load (KN)	Mode of Failure
1A	Beam (1-1)	33	4.30	14	56	Flexural failure
	Beam (1-2)			14	55	Flexural failure

2A	Beam (2-1)			17	75	Flexural failure
	Beam (2-2)			17	70	Shear failure
3A	Beam (3-1)			18	80	Shear failure
	Beam (3-2)			18	85	Shear failure
1B	Beam (1-1)			17	62	Flexural failure
	Beam (1-2)			17	65	Flexural failure
2B	Beam (2-1)	40	4.90	21	91	Flexural failure
	Beam (2-2)			21	88	Flexural failure
3B	Beam (3-1)			22	127	Flexural failure
	Beam (3-2)			22	122	Flexural failure

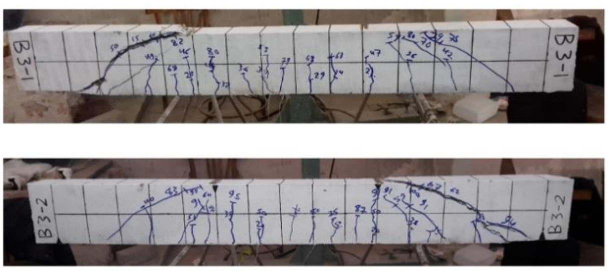
A. Cracking pattern

The cracking pattern for each group is shown in **Figure 5**. As expected, the first crack has been observed as a vertical flexural crack located at the middle third of each beam (constant moment region). As the load increase, new cracks continued to extend from the tension surface vertically towards the neutral axis and to the compression zone. At higher loading stages, the rate of crack formation considerably decreased. Furthermore, the old formed cracks started to get wider, and splitted to small short cracks adjacent to the main steel bars.

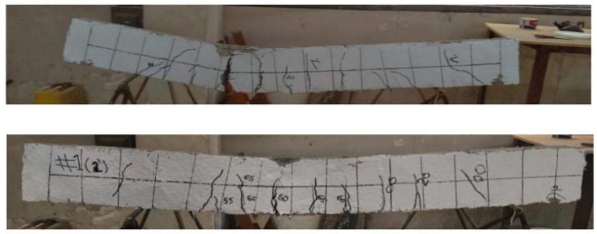


Crack pattern of group (1A)

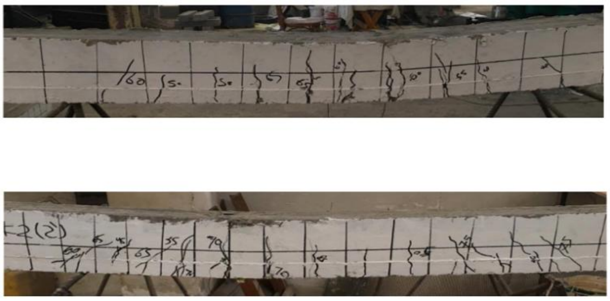
Crack pattern of group (2A)



Crack pattern of group (3A)



Crack pattern of group (1B)



Crack pattern of group (2B)

Crack pattern of group (3B)

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B. Modes of failure

The failure mechanism for each specimen is given in Table 2 and shown in Figure 5. The steel reinforcement was failed in flexure by yielding. Concrete crushing was the most common failure mode for all beams. Specimens with shear failure reached the maximum shear capacity before moment capacity but the first crack was happened due to moment.

V. DISCUSSION OF EXPERIMENTAL RESULTS

For reference prisms, observed cracking moment - for class (A) - is increased by 25.6 % of the calculated one however, it increased by 32.0 % for class (B).

group (1): It was observed that cracking moment for class (A) was increased by 32.6 % of the calculated one. Actually, increasing reinforcement ratio from 0.00 % to 0.92 % participated in delaying crack occurrence by 7 %. This ratio could represent the contribution between steel and concrete. For class (B), the observed cracking moment was increased by 40.6 % of the calculated value so participation ratio was 5 % with respect to reference prisms

group (2): observed cracking moment for class (A) was increased by 45.9 % of the calculated one. Increasing reinforcement ratio from 0.00 % to 1.33 % participated in delaying crack occurrence by 20.3 %. For class (B), the observed cracking moment was increased by 50.0 % of the calculated value so participation ratio was 18 % with respect to reference prisms.

group (3): the observed cracking moment for class (A) was is increased by 43.6 % of the calculated one. Increasing reinforcement ratio from 0.00 % to 2.96 % participates in delaying crack occurrence by 18 %. While for class (B), the observed cracking moment increased by 34.6 % of the theoretical value so participation ratio was 2.6 % with respect to reference prisms.

Table 3. Comparative study of cracking moments for classes "A" and "B"

	Group	Ref	Group (1)	Group (2)	Group (3)
	RFT ratio (%)	**0.0**	**0.92**	**1.33**	**2.39**
Group (A)	Calculated M_{cr} (kN.m)	2.30	2.64	2.74	2.96
	Observed M_{cr} (kN.m)	2.89	3.50	4.00	4.25
	Variance ratio (%)	25.6	32.6	45.9	43.6
	Participation ratio (%)	0	7	20.3	18
Group (B)	Calculated M_{cr} (kN.m)	2.50	3.10	3.50	3.90
	Observed M_{cr} (kN.m)	3.30	4.25	5.25	5.25
	Variance ratio (%)	32.00	37.00	50.00	34.60
	Participation ratio (%)	0	5	18	2.6

The relationship between RFT ratio and participation ratio could be represented as shown in Table 3 and hence, Participation ratio of steel reinforcement increases by increasing the reinforcement ratio up to max. RFT ratio (μ_{max}) then, participation ratio decreases.

CONCLUSION

As a result of this investigation, the following conclusions could be summarized.

1) The relationships between the applied load, midspan and strains for concrete and steel showing linear increase behavior before cracking followed by a nonlinear behavior until failure
2) Always, - For ordinary RC beams - observed cracking moment for tested beams is more than the calculated values. So, reinforcement participates in delaying of cracks occurrence as follow:
   - For reference prisms, observed cracking moment is increased by 25.6 % of the calculated one.
   - Increasing reinforcement ratio from 0.00 % to 0.92 % participates in delaying crack occurrence by 7 %. This ratio could represent the contribution between steel and concrete.
   - Increasing reinforcement ratio from 0.00 % to 1.33% participates in delaying crack occurrence by 20.3 %. This ratio could represent the contribution between steel and concrete.
   - Increasing reinforcement ratio from 0.00 % to 2.39% participates in delaying crack occurrence by 18 %. This ratio could represent the contribution between steel and concrete.
3) Always, - For RC beams with steel fiber - observed cracking moment for tested beams is more than the calculated values. So, reinforcement participates in delaying of cracks occurrence as follow:
   - For reference prisms, observed cracking moment is increased by 32.0 % of the calculated one.
   - Increasing reinforcement ratio from 0.00 % to 0.92 % participates in delaying crack occurrence by 5 %. This ratio could represent the contribution between steel and concrete.
   - Increasing reinforcement ratio from 0.00 % to 1.33% participates in delaying crack occurrence by 18 %. This ratio could represent the contribution between steel and concrete.
   - Increasing reinforcement ratio from 0.00 % to 2.39% participates in delaying crack occurrence by 2.6 %. This ratio could represent the contribution between steel and concrete.
4) Participation ratio of steel reinforcement increases by increasing the reinforcement ratio up to max. RFT ratio (µmax) then, participation ratio decreases.
5) Using steel fiber increases cracking capacity but decreases the participation ratio of reinforcement.

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