



Effect of concrete cover on crack width of RC beams

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ABSTRACT

This paper describes an experimental investigation to clarify flexural cracking behavior of reinforced concrete beams. The effects of thickness of concrete cover of tension reinforcement on the crack width were carefully investigated. It was found that flexural crack width proportionally increases with increase in thickness of concrete cover. To control these crack widths and to enhance durability, different codes prescribe limiting crack width based on environment in which the structure exists. The latest revision of the Indian code stresses the importance of durability and has introduced formulae to calculate the crack widths. A simple formula involving the clear cover and calculated stress in reinforcement at service load has been included in latest revision of ACI code. A total six under reinforced beams with varying concrete cover (25 mm and 30mm) were fabricated and tested. Data presented include the deflection characteristics and cracking behavior. The experiment results compare reasonably well with the current codes of practice. It was observed that a beam with less concrete cover (25mm) reduces the flexural crack width.

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Introduction

Cracking in reinforced concrete structures is unavoidable due to low tensile strength of concrete. Wider cracks may not only destroy the aesthetics of the structures, but also expose steel reinforcement to the environment leading to corrosion. Significant efforts have been put all over the world to clarify the problem of cracking and control in reinforced concrete members. Although the existing guidelines which are related to crack control in concrete structures provide some design formulae for flexural crack width prediction.

Cracking can be caused by any of variety of actions which include loads applied during construction or in service condition, foundation movements, temperature changes & gradients, shrinkage and creep of concrete etc. Before loading, volume changes in cement paste because interfacial cracks to form at the mortar-coarse aggregate boundary. The concrete has low tensile strength relative to its compressive strength. In zones of tension, the steel reinforcement is engaged primarily when a crack occurs, and design of reinforced concrete structures is carried out based on the fact that significant portions of the structure are cracked. However, the widths of these cracks must be limited for appearance, durability and structural integrity. In situation when bending is the main action effect, flexural cracks will form.

These cracks appear in the tension face & grow more or less vertically in a small region over interior supports & in mid span regions of continuous beams. Flexure shear cracks form from short vertical flexural cracks, but become inclined in the beam web. Cracking usually near the level of elastic neutral axis, due to diagonal tension caused when shear force is the dominant action effect.

Members which are subjected to bending moments will develop flexural cracks when the stresses in the tension zone exceed the bending strength of plain concrete. For practical purposes it can be assumed that the cracks will extend from the tension face to the location of the neutral axis of the cross

section. Inadequate durability is due to several parameters such as improper mixing, placing, compaction and curing of concrete, results in corrosion, inadequate sizes of structural member which results in excessive deflection and crack widths. Hence appendix 'F' of IS 456-2000 was added to calculate the crack width of flexural members but equation given in appendix 'F' of IS 456-2000 involves complex and tedious calculation of crack width. This paper discussed the effect of thickness of concrete cover on flexural crack width.

Objective:

The objective of present experimental investigation was to provide an overview of the behavior of reinforced concrete members subjected to bending with variation of concrete cover (25mm & 30mm) also to obtain the clear information of factors affecting the formation of cracks due to externally applied loads are discussed.

Analytical approach for crack width calculation

IS 456-2000 approach:

$$W_{cr} = \frac{3a_{cr} \varepsilon_m}{1 + \frac{2(a_{cr} - C_{min})}{h - x}}$$

The notations in the above equation are as follows.

a_{cr} = shortest distance from the selected level on the surface to a longitudinal bar

C_{min} = minimum clear cover to the longitudinal bar

h = total depth of the member

x = depth of the neutral axis

ε_m = average strain at the selected level.

The values of C_{min} and h are obtained from the section of the member.

ACI Approach:

The American code formula was based on formula suggested by Gergely & Lutz, which gives the maximum crack width as

$$w_{cr} = \left[(11 \times 10^{-6}) \sqrt[3]{d_c \left(\frac{A_e}{n} \right) \beta} \right] f_{st}$$

Where,

w_{cr} = most probable crack width,
 β = ratio of distance between neutral axis and tension face to distance between neutral axis and centroid of reinforcing steel,
 A_e = effective area of concrete in tension surrounding the main tension reinforcement, having the same centroid as the tension steel

($A_e = 2(D-d) b_w$) – Refer fig.1

d_c = thickness of concrete cover measured from extreme tension fibre to center of nearest bar.

n = number of bars in tension

f_{st} = stress at the centroid of the tension steel and may be taken as 0.6 f_y

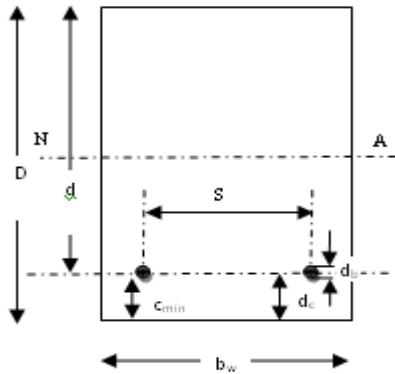


Figure 1 Parameters for Crack Width

Experimental program

Materials and mix proportions

For the purpose of current investigation, the materials used in the mix were ordinary Portland cement, river sand, locally available coarse aggregate and potable water. The river sand properties namely the specific gravity, water absorption and fineness modulus were 2.652, 3.40% & 3.175 respectively. All mixes had 432.55 kg/m³ cement, 550.32 kg/m³ sand, 1196.59 kg/m³ coarse aggregate & 186 kg/m³ of water with water cement ratio of 0.43.

Reinforced Concrete beams details

A total of 6 beams fabricated and tested. The beams were designed as under reinforced beams. Three beams having 25 mm concrete cover and remaining three having 30 mm concrete cover. All beams are simply supported on effective span of 2200mm were tested under two point loading. Length of beam and web were kept constant (2400mm and 300mm resp.) The beams were divided in to two series with varying concrete cover. Each series comprised of three beams. A beam series having 25mm cover denoted as BC1025 & beam series having 30mm cover denoted as BC1030.

Before testing commenced reference pins are attached to the beam specimen with adhesives. The reference pins were attached to the concrete surface in central region of the beam to measure the strain in concrete. Reference pins are attached to specimen by adhesive with spacing of 10 mm.

Testing:

All the beams were tested under two point concentrated loadings positioned at one third spans. All the beams were simply supported with an effective span of 2200 mm. Beams were centered on platform and leveled horizontally and vertically by adjusting the bearing plates. Load was applied gradually.

Three dial gauges were used to measure the deflection at the center and under the points of loadings as shown in fig:2. Here, Demec gauge is used for measuring crack width at predefined zone.

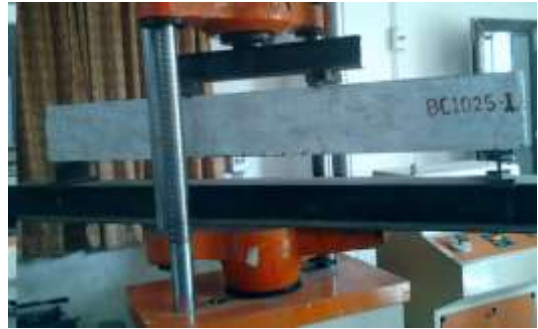
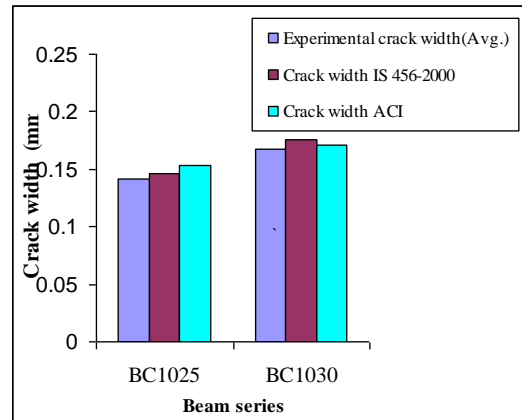


Fig:2 Test Setup

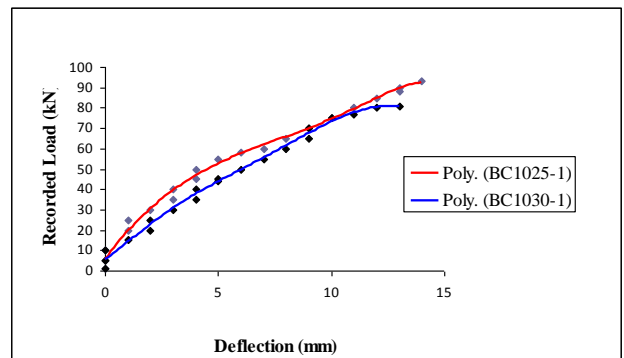
Results and discussion:

For beam of BC1025 series, experimentally bending moments at first crack are 22.15kN.m, 19.93kN.m and 21.78kN.m where as the failure occurs at the moments 35.10kN.m, 34.73kN.m and 35.47kN.m respectively as against the ultimate moment of resistance by the analysis is 25.63kN.m. For beam of BC1030 series, experimentally bending moments at first crack are 16.97kN.m, 17.34kN.m and 16.60kN.m where as the failure occurs at the moments 30.66kN.m, 31.77kN.m and 31.03kN.m respectively as against the ultimate moment of resistance by the analysis is 25.13kN.m.

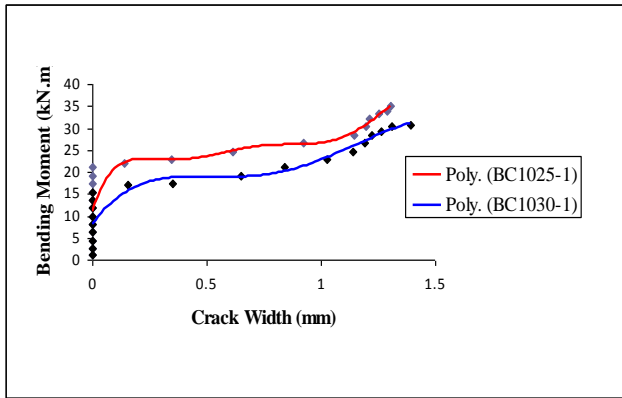
From the table 3, it is clear that, the experimental crack width at service loads ranged between 0.130 mm to 0.190mm and this was within the maximum allowable value as stipulated by IS 1343-1980 and ACI 214.



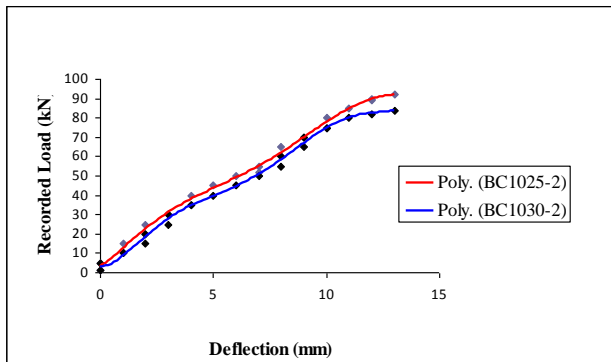
Graph 1 Comparison between Predicted and Experimental Crack Widths at Service Loads



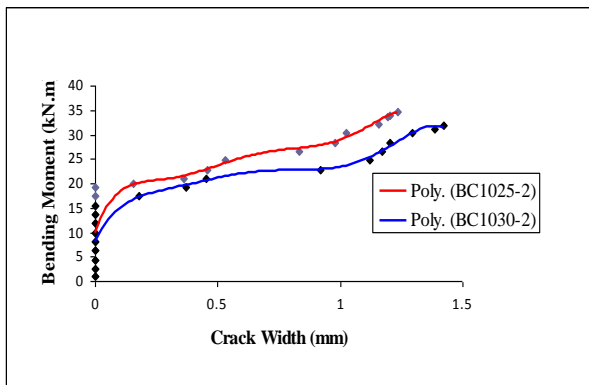
Graph 2 Recorded Load - Deflection Curve for Beam BC1025-1 & BC1030-1



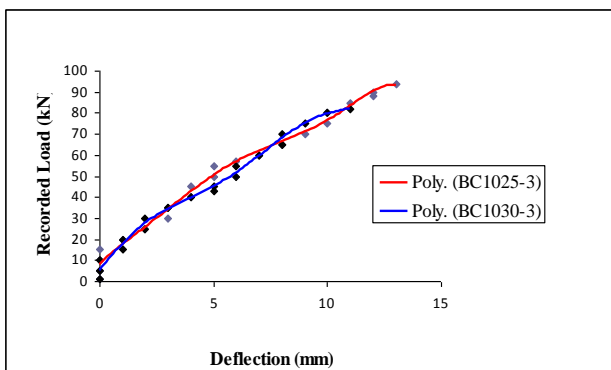
Graph 3 Moment - Crack Width Curve for Beam BC1025-1 & BC1030-1



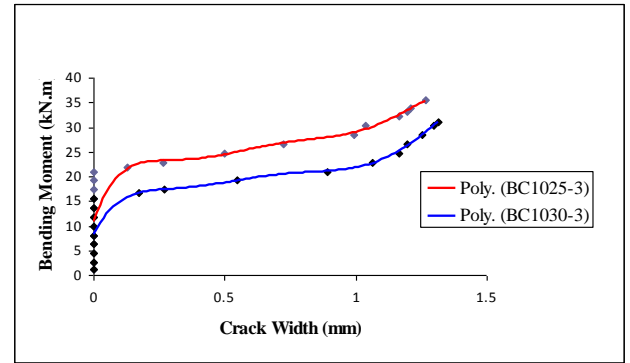
Graph 4 Recorded Load - Deflection Curve for Beam BC1025-2 & BC1030-2



Graph 5 Moment - Crack Width Curve for Beam BC1025-2 & BC1030-2



Graph 6 Recorded Load - Deflection Curve for Beam BC1025-3 & BC1030-3



Graph 7 Moment - Crack Width Curve for Beam BC1025-3 & BC1030-3

Conclusions:

Total six beams are cast and tested under flexural loading conditions. Three beams are cast by maintaining concrete cover 25 mm and remaining three beams are cast with 30mm concrete cover with same tensile reinforcement. After testing of beams the following concluding points are drawn,

According to prediction formulas, an increase in concrete cover, results in larger calculated crack width. In spite of this fact, provision of larger concrete cover considered as the most practical means of protecting reinforcement against corrosion. Test results are revealed that the measured crack width is increased by 8 % to 8.5% when the cover changes from 25mm to 30mm.

All type of beams have shown flexural failure, no shear cracks were seen, may be because of large span of the test specimen. While testing the beam under flexural loading conditions, it is found that the ultimate bending moment remains same where bending moment at first crack decreases as concrete cover changes from 25mm to 30mm.

As the thickness of concrete cover reduces from 30mm to 25mm, resistance to first crack development also increases.

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Table No.1: Main steel reinforcement and concrete cover details

Sr No	1	2
Name Of Beam	BC1025 (1,2,3)	BC1030 (1,2,3)
Concrete Cover (mm)	25	30
Top Steel	2 Ø 8mm	2 Ø 8mm
Bottom Steel	3 Ø 10mm	3 Ø 10mm
Beam C/S (mm)	150x300	150x300

Table No. 2 Comparison between Predicted and Experimental Crack Widths at Service Loads

Sr. No	Beam	Experimental Crack Width (mm)	Theoretical Crack Width (mm)	
			IS 456-2000	ACI
1	BC1025-1	0.140	0.146	0.153
2	BC1025-2	0.155	0.146	0.153
3	BC1025-3	0.130	0.146	0.153
4	BC1030-1	0.155	0.176	0.171
5	BC1030-2	0.180	0.176	0.171
6	BC1030-3	0.170	0.176	0.171

Table No.3: Crack propagation, failure load , design and experimental moment for beam series BC1025 and BC1030

Sr. No.	Beam	At crack propagation		At bending failure		Theoretical Design Moment Md (kN.m)	Moment at 1 st Crack (kN.m)	Experimental Ultimate Moment Mu (kN.m)
		Load (kN)	Crack width (mm)	Load (kN)	Crack width (mm)			
1	BC1025	1	58	0.140	93	25.63	22.15	35.10
2		2	52	0.155	92		19.93	34.73
3		3	57	0.130	94		21.78	35.47
4	BC1030	1	44	0.155	81	25.13	16.97	30.66
5		2	45	0.180	84		17.34	31.77
6		3	43	0.170	82		16.60	31.03