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 prescribes 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 30 mm) 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 (25 mm) reduces the 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 (25 mm & 30 mm) 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
- \(\varepsilon_m\): 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...
\[ w_{cr} = \left(11 \times 10^{-6}\right) \sqrt{d_c \left(\frac{A_s}{n}\right) \beta} f_{ct} \]

Where,
\( w_{cr} \) = most probable crack width,
\( \beta \) = ratio of distance between neutral axis and tension face to distance between neutral axis and centroid of reinforcing steel,
\( A_s \) = effective area of concrete in tension surrounding the main tension reinforcement, having the same centroid as the tension steel
\( (A_s = 2(D-d)b_w) \) – 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
\( f_{ct} \) = stress at the centroid of the tension steel and may be taken as 0.6 fy

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.
Conclusions:

Total six beams are cast and tested under flexural loading conditions. Three beams are cast by maintaining concrete cover 25 mm and remaining thee 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 form 30mm to 25mm, resistance to first crack development also increases.

References:

1) Nicholas J. Carino and James R. Clifton, “Prediction of Cracking in Reinforced Concrete Structures”, ‘ACI Manual of Concrete Practice’


4) Dr. N Subramanian, “Controlling The Crack Width of Flexural RC Member”, ‘The Indian Concrete Journal’, Page No.1-6

5) Ratnamudigedara Piyana, “Crack Spacing, Crack Width and Tension Stiffening Effect in Reinforced Concrete Beams and One Way Slab”, Page No. 1-114.

6) Gargely P. and Lutz L.A., “Maximum Crack Width in Reinforced Concrete Flexural Members, Causes, Mechanism and Control of Cracking in Concrete” American Concrete Institute, Page No.87-117.


8) Ganesan N and Shivnanda K.P, ’Comparison of International Codes For the Prediction of Maximum Width of Cracks in

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

<table>
<thead>
<tr>
<th>Sr No</th>
<th>Name of Beam</th>
<th>Concrete Cover (mm)</th>
<th>Top Steel</th>
<th>Bottom Steel</th>
<th>Beam C/S (mm)</th>
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<tbody>
<tr>
<td>1</td>
<td>BC1025(1,2,3)</td>
<td>25</td>
<td>2 Ø 8mm</td>
<td>3 Ø 10mm</td>
<td>150x300</td>
</tr>
<tr>
<td>2</td>
<td>BC1030(1,2,3)</td>
<td>30</td>
<td>2 Ø 8mm</td>
<td>3 Ø 10mm</td>
<td>150x300</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Beam</th>
<th>Experimental Crack Width (mm)</th>
<th>Theoretical Crack Width (mm)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>IS 456-2000</td>
<td>ACI</td>
</tr>
<tr>
<td>1</td>
<td>BC1025-1</td>
<td>0.140</td>
<td>0.146</td>
</tr>
<tr>
<td>2</td>
<td>BC1025-2</td>
<td>0.155</td>
<td>0.146</td>
</tr>
<tr>
<td>3</td>
<td>BC1025-3</td>
<td>0.130</td>
<td>0.146</td>
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<tr>
<td>4</td>
<td>BC1030-1</td>
<td>0.155</td>
<td>0.176</td>
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<tr>
<td>5</td>
<td>BC1030-2</td>
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<td>0.176</td>
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<tr>
<td>6</td>
<td>BC1030-3</td>
<td>0.170</td>
<td>0.176</td>
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### Table No.3: Crack propagation, failure load, design and experimental moment for beam series BC1025 and BC1030

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Beam</th>
<th>At crack propagation</th>
<th>At bending failure</th>
<th>Theoretical Moment Md (kN.m)</th>
<th>Design Moment</th>
<th>Ultimate Moment (kN.m)</th>
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<tbody>
<tr>
<td>1</td>
<td>BC1025</td>
<td>58 0.140 93 1.305</td>
<td>25.63</td>
<td>22.15</td>
<td>35.10</td>
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<td>2</td>
<td>BC1030</td>
<td>57 0.130 94 1.268</td>
<td>25.13</td>
<td>16.97</td>
<td>31.03</td>
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