Sufficient cover is required for the reinforcement in concrete structures for protection against corrosion. Though several codes of practices have specified minimum cover for various climatic conditions, it is often not maintained in practice. In this paper, the authors contend that the Indian Codal provisions relating to concrete cover have to be revised as they do not account for many factors related to minimum concrete cover. Also, some devices and methods to increase the quality of cover are discussed. The authors also stress that just an increase in concrete cover does not ensure durable structures.

For durable concrete structures, it is imperative that the steel embedded in concrete is protected adequately against corrosion. It is also necessary that concrete should be dense, uniform and free from deleterious components. For this, adequate cover to the steel should be provided on all faces of the concrete element.

Concrete protects steel in two ways: one, by providing a barrier against the ingress of moisture and air and two, by forming a passive protective film on the steel surface. The protective film remains effective so long as concrete is strongly alkaline (pH value > 12). However, the external atmospheric gases like carbondioxide when combined with atmospheric moisture starts carbonation of concrete at the surface. This carbonation makes the concrete less alkaline and may render the embedded steel susceptible to corrosion, when the depth of carbonation is large. Table 1 relates carbonation time (years) to the water-cement ratio for various depths of cover (mm). This table applies to Ordinary Portland Cement (no additive) with sand and gravel aggregate.

Thus with a water-cement ratio of 0.55 and 10mm cover, the carbonated zone will penetrate the cover in 12 years. This table should be considered as indicative only as the environmental conditions are not defined. However, it does emphasise the significance of cover to the reinforcement and the water-cement ratio.

The depth of carbonation in concrete subjected to 15 years of normal indoor exposure in Tokyo is approximately equal to 5mm. Further, the corrosion may occur due to chloride attack, once the threshold chloride levels are exceeded. The corrosion due to chloride attack is more severe, and difficult to control.

Though a minimum cover is specified by the codes of practice, this is often not maintained in practice. Moreover, the devices used to ensure specified concrete cover are themselves not of adequate quality. These aspects and the methods to be adopted to ensure quality cover are discussed in this paper.

Sometimes increasing the concrete cover may lead to higher transverse tension in the concrete of the compression zone, for example in frame corners subjected to positive moments and in beams subjected to shear and bending. These effects are also discussed.

Codal specifications for minimum cover

Minimum cover should be related to the exposure conditions, concrete strength, water-cement ratio, nominal maximum size of aggregate depending upon the method of compaction of concrete, degree of grading of coarse aggregate, congestion of steel and likely exposure to fire.

Concrete cover and tolerances specified by various codes of practice vary over a fairly wide range. For example, the Indian code specifications are summarised in Table 1 and those

<table>
<thead>
<tr>
<th>Water-cement ratio</th>
<th>Cover, mm</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.45</td>
<td></td>
<td>19</td>
<td>75</td>
<td>100+</td>
<td>100+</td>
<td>100+</td>
<td>100+</td>
</tr>
<tr>
<td>0.50</td>
<td></td>
<td>6</td>
<td>25</td>
<td>50</td>
<td>99</td>
<td>100+</td>
<td>100+</td>
</tr>
<tr>
<td>0.55</td>
<td></td>
<td>3</td>
<td>12</td>
<td>27</td>
<td>49</td>
<td>76</td>
<td>100+</td>
</tr>
<tr>
<td>0.60</td>
<td></td>
<td>1.8</td>
<td>7</td>
<td>16</td>
<td>.29</td>
<td>45</td>
<td>65</td>
</tr>
<tr>
<td>0.65</td>
<td></td>
<td>1.5</td>
<td>6</td>
<td>13</td>
<td>23</td>
<td>36</td>
<td>52</td>
</tr>
<tr>
<td>0.70</td>
<td></td>
<td>1.2</td>
<td>5</td>
<td>11</td>
<td>19</td>
<td>30</td>
<td>43</td>
</tr>
</tbody>
</table>

April 1997 * The Indian Concrete Journal
of the British code in Table 3\textsuperscript{a}. It can be seen that the Indian code does not take into account factors such as concrete quality, water-cement ratio and fire rating of the structure. Compared to IS : 456 the recommendations of IRC 21 are more conservative, probably because those recommendations are applicable to bridge structures\textsuperscript{2}. It has become imperative to revise the relevant provisions pertaining to concrete cover in both the IS and IRC specifications.

The requirements of cover as per ACI 318-95 are given in Table 4\textsuperscript{4}. There are other categories and special conditions relating to concrete cover in ACI 318-95 that are not discussed here. However it is emphasised that ACI 318-95 requires that the amount of concrete protection shall be suitably increased for concrete in corrosive environments or other severe exposure conditions and the denseness and low permeability of protecting concrete shall be considered, or other protection devices to ensure specified concrete cover shall be provided. However, ACI 318 does not consider water-cement ratio which is equally, if not more, important.

The minimum concrete cover required to be specified as per Australian Standard Specifications for purposes of corrosion protection is as per Table 5\textsuperscript{5}.

![Fig 1](image)

**Fig 1** shows the largest minimum covers specified for reinforced concrete in the design codes of 14 countries\textsuperscript{6}. These apply to members exposed to severe climatic conditions. The very wide range of permissible covers as seen from this figure suggest an arbitrary element in their selection.

### Devices to ensure specified concrete cover

Site surveys reported from several countries indicate that the cover specified is not maintained within the tolerance limits\textsuperscript{7}. The situation in India is more serious, considering the high percentage of semi-skilled or unskilled labour\textsuperscript{8}. It should be noted that the surveys reported refer only to pre-pour situations, which do not consider the possibility of bars getting displaced during the concreting operation\textsuperscript{9,10,12}. It is also to be noted that too large covers will result in the reduction of effective depths and too little cover may lead to deterioration of concrete due to corrosion.
It is essential that proper guidelines are made available to site engineers and supervisors. BS 8110 : Part 1 : 1985, section seven has given a thought to this problem and has recommended certain specifications, chief amongst which are the "wing":

(i) spacers, chairs and other supports should be used to maintain the specified nominal cover to reinforcement

(ii) spacers or chairs should be placed at a maximum spacing of 1m

(iii) material for spacers should be durable, and it should neither lead to corrosion of reinforcement nor cause spalling of concrete cover

(iv) mix used for spacer blocks should be comparable in strength, durability, porosity and appearance to the surrounding concrete

(v) nominal cover should be checked before and during concrete placement

(vi) the position of reinforcement in hardened concrete should also be checked with the help of a cover meter.

The British Cement Association has brought out a publication which gives recommendations to the number and position of spacers and ties required to provide active cover to reinforcement in the most common RC members, which could serve as a reference to site supervisors to readily check compliance. Fig 2 shows an illustration from the above mentioned reference for slab reinforcement.

At several construction sites, stone chips are used as bar supports which may get dislodged during concreting operations and the bars may rest directly on the shuttering leaving little or no cover to the bars. Many times small cover blocks made of cement mortar are cast before concreting and are placed below the reinforcing bars. They are usually of poor quality compared to that of the concrete placed in the member. Hence, instead of protecting the reinforcement, they act as the starting points of corrosion. Blue metal jelly or broken mosaic tiles are also used as cover blocks. Most often, they are not placed in regular intervals and are of non-uniform size and shape. In countries like USA, Germany and Japan, cover blocks made of cement mortar, asbestos cement, metal or plastic manufactured in factory and available ready-made are used. Hence, these cover blocks are uniform and their quality is also of the required standard. As shown in Figs 3 and 4, they are either tied to the reinforcement bars or placed just between the bars and the shuttering. According to the required

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**Table 4 : Minimum cover for reinforcement in concrete not exposed to weather or not in contact with ground (as per ACI 318-95)**

<table>
<thead>
<tr>
<th>Location</th>
<th>Slab, wall &amp; post</th>
<th>Beam, column</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 mm diameter</td>
<td>40 (50)*</td>
<td>40 (50)*</td>
</tr>
<tr>
<td>55 mm diameter</td>
<td>20 (40)*</td>
<td>40 (50)*</td>
</tr>
<tr>
<td>up to 35 mm</td>
<td>20 (40)*</td>
<td>40 (50)*</td>
</tr>
<tr>
<td>diameter bars</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>reinforcement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ties, stirrups</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spirals</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* exposed to weather or in contact with ground

---

**Table 5 : Minimum reinforcement cover for the protection of reinforcement, tendons or ducts from corrosion (as per AS 3600-1988)**

<table>
<thead>
<tr>
<th>Exposure classification</th>
<th>Minimum cover to relevant steel, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully enclosed within a building except for a brief period of exposure during construction*</td>
<td>first class 15(\times)20, second class 20(\times)25, third class 25(\times)30</td>
</tr>
<tr>
<td>Exposed to average humidity &lt; 50 percent and annual rainfall &lt; 500 mm*</td>
<td>first class 20, second class 25, third class 30</td>
</tr>
<tr>
<td>Exposed to average humidity 50 percent to 80 percent and rainfall &lt; 1000 mm**</td>
<td>first class 20, second class 25, third class 30</td>
</tr>
<tr>
<td>Exposed to average humidity 65 percent to 100 percent annual average maximum daily temperature &gt; 25°C and annual average rainfall &gt; 1200 mm</td>
<td>third class 25, fourth class 30, fifth class 40</td>
</tr>
<tr>
<td>Very severe conditions***</td>
<td>fourth class 30, fifth class 40, sixth class 50</td>
</tr>
</tbody>
</table>

* For slabs subjected to this type of exposure, the cover may be reduced by 5mm for M32 grade concrete or higher.
** For slabs subjected to this type of exposure, the cover may be reduced by 5mm for M40 grade concrete or higher.
*** Minimum values in some circumstances may be even higher.

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[Fig 1 Minimum covers for worst exposure conditions in various national codes](#)
thickness of cover, the size of the cover blocks may be chosen. In RC slabs, when reinforcement is provided at top and bottom, chairs should be provided, so that they are kept at the required distance. If these chairs are not provided, the reinforcement bars may be bent or distorted due to the movement of men during concreting. These chairs also maintain the top cover for the top reinforcement. They should be placed at sufficient intervals. In India, such chairs are very rarely provided, leading to reduced strength of reinforced concrete elements (especially when the rods are cranked).

**Enhancing quality of cover**

Attempts have been made in the past to reduce the water-cement ratio of the surface layers of low/medium strength concrete in order to improve the protective properties. This is similar to case hardening of steel. The process of vacuum dewatering of concrete was thus developed. In this process, some of the excess water not required for hydration of the cement is withdrawn by means of a vacuum, subsequent to placement of the concrete, thus reducing the water-cement ratio in the region. The system requires a filtering mat to draw off the excess water without the fine aggregates from the concrete and a vacuum pump. However, the vacuum process has been found to be more practicable and effective for large horizontal surfaces such as floor slabs, deck slabs, etc.

Another method has been developed and used in Japan since 1985 to improve the quality of concrete in the cover region. The idea is based on reducing the water-cement ratio of concrete in the cover region. This is realised by development and use of permeable formwork in which the normal formwork sheeting is lined with double-woven synthetic fabric on the inner face in contact with concrete. When concrete is placed and vibrated, the excess water is drained off through the fabric. This results in a higher impermeability in the cover region, thus providing effective, long-term protection to the reinforcement.

The quality of cover also needs to be enhanced by increasing the cement content, reduced water-cement ratio and using higher grade of concrete for the entire volume of concrete in the structure. It has to be noted that the draft Indian code has increased the minimum grade of concrete to M20 for reinforced concrete, whereas other developed countries do not use less than M30 concrete in reinforced concrete structures, Table 2.

**Super cover concrete**

Researchers at the South Bank University, U.K., have proposed a radical new and patented technique called "Super cover..."
A high concentration of chloride ions reside in thin covers up to the subsequent decrease of the failure moment, compared to increase of the transverse tensile stresses in concrete and moments and showed that a thick cover leads to substantial transverse tensile stress in the case of a cover (with and without a bond) upon the resistance of reinforced concrete members. Recent work has shown the critical role a 50 to 70 mm concrete cover plays in protecting the reinforcement against corrosion. This aims to combine the advantages of steel and Fibre Composite Reinforcements (FCR).

This technique involves using traditional steel reinforcement together with concrete covers in excess of 100 mm thus providing a lifetime barrier to carbon dioxide and chloride attack - with a limited amount of FCR at a nominal depth of, say 40 mm, to control cracking in the cover as shown in Fig 5. This additional reinforcement is attached to the main steel and offset with spacers.

Preliminary results from tests on super cover concrete suggests that the structural behaviour is not impaired and that the surface crack widths are within the BS 8110 limit of 0.3 mm. Though the cost may increase due to the extra cover and FCR, it was found to be cheaper than cathodic protection.

**Effect of increased cover thickness**

Recent work has shown the critical role a 50 to 70 mm concrete cover plays in protecting the reinforcement against corrosion in an aggressive environment. It was also shown that high concentration of chloride ions reside in thin covers up to 40 mm.

However, it is seen that using a thick cover of 50 to70 mm will lead to increased crack widths that exceed the maximum limits permitted by the codes. If the spacing of the wide cracks is less than twice the cover thickness (S < 2C), which may be the case for a thick cover, then there will be a reduction in the effectiveness of the thick cover in protecting the steel bars against corrosion. Hence both the requirements (crack width and cover) are to be coupled for meeting durability requirements.

Streit and others have shown the negative influence of an increased concrete cover (specified for durability consideration) upon the resistance of reinforced concrete. They examined the influence of an increased concrete cover on the transverse tensile stress in the case of a cover (with and without reinforced reinforcement) subjected to positive bending moments and showed that a thick cover leads to substantial increase of the transverse tensile stresses in concrete and subsequent decrease of the failure moment, compared to members with smaller concrete cover.

Hence, instead of simply increasing the thickness of concrete cover, sufficient experimental research should be done to study the influence of these increased covers on the behaviour of reinforced concrete elements.

**Conclusions**

Adequate concrete cover is very important for durable RC structures. This aspect has been re-emphasised in this paper. Certain methods and devices which could improve the quality of the cover have been included. It is also found that just an increase in the concrete cover does not ensure durable structures; on the contrary, it can have a negative result on some of the desirable properties.

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