Discussion

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The prediction of crack widths in reinforced concrete beams*

F. A. -A. Albandar and G. M. Mills

Contribution by A. W. Beeby

Cement and Concrete Association

It was very interesting to read the paper by Mr Albandar and Dr Mills. It has provided useful confirmation of the view now accepted by most workers that cracking is influenced both by cover and by the arrangement of the steel within the tension zone.

In view of the very thorough comparison of various crack formulae in this paper and the comments made in it about the formula given in CP110, it might be of interest to give rather more detail of the derivation of this equation and the logic behind it. (A full derivation is given in reference 1 and, more briefly, in the Handbook to the Code⁽²⁾.)

When the Code was drafted, the view was taken that the critical design criterion was the maximum width of crack anywhere on the section. This differs from the view taken by some authorities (e.g. the CEB⁽³⁾), who only require the width to be checked at the level of the tension steel. The reason for this is that, though the widths of cracks are controlled largely by the bars which pass through the crack more or less perpendicularly, the risk of corrosion is greatest for bars which lie parallel to these cracks. This is because there is a possibility that some cracks will form along the line of these bars. Figure I sketches the situation envisaged here in an exaggerated form. In general, therefore, CP 110 requires the crack widths to be checked at points on the surface of a member which are not directly over bars perpendicular to the cracks but are,

Figure I: Schematic representation of a crack over a transverse bar.

in fact, as far from the bars as it is possible to get. This will normally be mid-way between bars. As can be seen from the Albandar and Mills formula, the term expressing the influence of the concrete surrounding the bar decreases in importance with increasing distance from a bar (i.e. increasing a_{cr}). The view was therefore taken that, in the critical design condition, a fairly gross approximation to the influence of the concrete surrounding the bar was permissible and so it was simply dealt with by using an increased coefficient for a_{cr} . That this may lead to a low estimate of the crack

*Pages 153 to 160 of MCR 88.

width where large bars are used is explicitly stated in the Handbook⁽²⁾. However, even here the effect is not too serious since the Code, by stating that the cover shall not be less than the bar diameter, ensures that the sections which give the worst results in the paper (S1, S2, S3, S4) should not be constructed.

A difficulty in the drafting of a design formula is that it must not limit present practice where this has been shown, over the years, to be satisfactory. Most research formulae will limit present practice because the framework of Codes, within which they have to be used, is often unrealistic. Crack widths normally have to be checked under the full characteristic loads which, since these theoretically have only a 5% chance of being attained during the life of the structure, are unrealistically high for general service conditions. The logical approach is to use a partial safety factor on the imposed loads of less than 1 (probably about 0.25 for normal occupancy). Effectively, this approach is adopted by the CEB, though here the situation is further complicated by a 'safety factor' of 1.3 built into the equation. However, the concept of partial safety factors of less than unity was considered too advanced for adoption in CP 110, though this is under consideration for the Bridge Code, and an alternative method had to be found to obtain the same objects. What has been done is to adjust the formula to predict a design crack width lower than is commonly adopted (i.e. a value exceeded by 1 crack in 5 instead of the more usual 1 crack in 20).

If it is accepted that the crack width should be checked at points on the surface of a section other than close to the longitudinal steel, a totally different form of equation must be adopted from that used by Albandar and Mills. This is because the crack widths away from the bars are greatly influenced by the height of the tension zone of the section, $(h - x)$. This can be seen from Figure II, which uses data from tests reported in reference 7 of the paper. This Figure shows experimentally obtained crack widths with a 20% chance of being exceeded plotted against a_{cr} for specimens R1, R2, R3 and R4. These specimens all had the same cover (20 mm) and the same reinforcement but different effective depths. The design crack widths calculated from the CP 110 formula are also shown together with the values estimated from equation 3 of the paper. It will be seen that the variation of crack width with a_{cr} is greatly affected by the depth of the section. It can be seen that, mid-way between the bars, where $a_{cr} = 144$ mm, the CP 110 formula is very effective but that it is less good in areas closer to the bars for the deeper sections. The checking of the critical design condition is thus handled very effectively by an equation of the CP 110 type. In these circumstances, the Albandar and Mills' equation may be conservative by a factor of several hundred. This will also be true of the C & C A and Broms formulae. The Albandar and Mills formula is slightly superior to the CP 110 formula for points relatively close to bars on members 400 to 500 mm deep.

Figure II: Experimental results from reference 7 of the paper.

Reply by the authors

We thank Dr Beeby for rightly drawing attention to the fact that our proposed formula is not valid for values of a_{cr} greater than 75 mm. In fact, for none of our reported results (Table 5) was this value of a_{cr} exceeded and we agree that this point should have been emphasized in the original paper. Nevertheless, within this limitation, Dr Beeby's Figure II does confirm that, for beams of depth greater than 300 mm and with a maximum value of a_{cr} less than 100 mm (which would seem to cover a high proportion of practical cases),

CP 110 underestimates the crack width by a significant amount even where allowance is made for a partial safety factor of less than 1 for imposed load.

We suggest that further research work is desirable to determine more accurately the variation in crack widths of deep beams for values of a_{cr} greater than 75 mm. Figure II also suggests the possibility that even our proposed formula may be conservative when the depth of beam exceeds 400 mm and this might also be worthy of investigation.

REFERENCES

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