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ESTIMATION OF CRACK WIDTH IN REINFORCED CONCRETE MEMBERS

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Abstract— ***In this paper, the crack width in reinforced concrete beams is investigated. In practice, the propagation of concrete crack width is seen as one of the most significant benchmarks for the designing and investigation of the long term amenity of the reinforced concrete structures. It is therefore beneficiary and necessary to gain full understanding of the process of growth of crack width over time. This paper attempts to assess the phenomenon of concrete cracking and estimate the concrete surface crack width under the action of applied loads. This assessment is carried out by analytical methods. In the analytical method, the experimental RC beams were taken as examples for the computation of the crack width by using the simplified methods as given in the standard design codes of reinforced concrete structures (IS: 456-2000).The codes used for comparison are Eurocode, national code of Finland, German Institute for standardization and IS code. The crack width is compared for different cases like clear cover, diameter of reinforcements etc.***

Keywords— ***Crack width, Concrete Beam, IS code, Eurocode, Finland code, German Code***

I. INTRODUCTION

The cracking of concrete cannot be avoided as concrete bears a low tensile strength. The increasing use of limit state method of design and high strength steel leads to wide cracks in concrete structures, thus necessitating control for cracking. Wider cracks in concrete may not only degrade the aesthetics of the structure, but also expose steel reinforcement to the environment leading to its corrosion. A number of significant efforts have been put all over the world for the clarification of the concept of cracking in reinforced concrete. For controlling the concrete crack width at the surface of members, designers may use various guidelines in building codes. The provisions given in codes are based on the crack width estimation formulas recommended by researchers all over the world. The IS Code has recommended that the surface crack width should not exceed 0.3 mm for structures not subjected to aggressive environment. However, if the structure is exposed to aggressive environments, the crack width near the main reinforcement should not exceed 0.004 times the nominal cover to the reinforcement bars.

Cracking causes significant increments in deflections in reinforced concrete members. This is caused due to the reduction of bending stiffness at cracked sections when there is a reduction in the effect of tensile concrete below the neutral axis. However at some sections between successive cracks, some tensile stress is retained in the concrete around steel bars due to the action of concrete-steel bond, thereby contributing to the bending stiffness of the member. This is known as the tension stiffening effect. Taking into consideration this tension stiffening effect, the calculated deflection may be estimated in an accurate proportion. In simplified methods of calculation of deflection, the tension stiffening effect is incorporated in a semi-empirical manner by using the effective moment of inertia method. In analytical methods, the deflection is calculated using the curvature values which is evaluated by adopting a non-linear stress-strain relationship for tensile concrete. This relationship permits the concrete to retain considerable amount of tensile stress beyond the cracking strain.

1.1. Types of Cracking

1.1.1 Flexural Cracking

In plain concrete, the members, such as beams and slabs, which are subjected to loads and bending moments, will develop flexural cracks when the stresses in the tension zone exceed the bending. It can be assumed practically that the cracks usually extend from the tension face to the location of the neutral axis of the cross section. One of the most important factors controlling flexural crack width under different loading conditions is the magnitude of the tensile strain in the steel reinforcement. Controlling steel strain serves as a great means for limiting crack widths in structures where limited widths are necessary for performing the intended function. Predicting the number and width of flexural cracks is a difficult task because various complex processes are involved in the mechanism. No approach has been adopted universally and different codes use different methods to determine these quantities. Crack widths increase over time.

1.1.2 Shrinkage cracking

Due to drying and thermal contraction the shrinkage of concrete can lead to cracking if a member is constructed such that there is a restraint to shrinkage. This restrain induces tensile stresses that can cause cracking if the applied stresses exceed the tensile strength of the concrete. Due to the complexities involved in predicting drying shrinkage cracking, the ACI Code has provisions for a minimum quantity of temperature and shrinkage steel to provide for control of crack widths.

1.2. Causes of Cracking

Two types of cracks are formed in reinforced concrete members, namely cracks caused by externally applied loads, and those which occur independently of the loads (Leonhardt (1977), Base (1978)). Those which are caused by external loads are flexural cracks and inclined shear cracks (Fig. 2.1). Those cracks which are formed in the tensile zone and are wedged shaped with its crack width maximum at the tension face and negligible near the neutral axis are Flexural cracks. On the other hand, those which generally occur in thin-web beams on application of high shear forces are Inclined shear cracks (Warner *et. al* (1998), Loo (1990)). The scope of this paper is only limited to the flexural cracking. In Fig. 1.1, and 1.2 indicates the location of crack initiation.

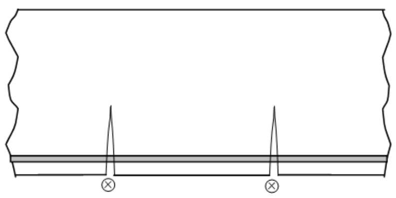


Fig.1.1 Flexural cracks

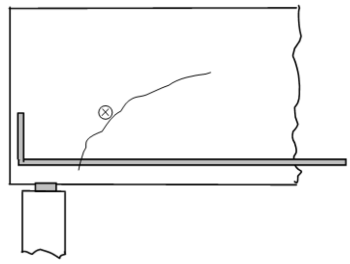


Fig.1.2. Inclined Shear cracks

The cracks of second category, the ones which are independent of applied loads, are developed in restrained members due to concrete shrinkage, or due to changes in temperature. These cracks, having a uniform width, may extend through the entire cross section in thin restrained members such as the floor slabs (Warner *et. al* (1998)). The width of these types of cracks needs to be controlled or they may result in the disruption of the structural integrity and reduction of the bending stiffness and therefore, resulting in greater deflections.

The main aim of this paper is to investigate the process of cracking in concrete under various combinations of reinforcements and applied loads. The basic codes are used to examine the effects of various variables on the strains and width of cracks. For this investigation, crack width is calculated for various members having different material and sectional properties.

II. ANALYTICAL METHODS FOR CRACK WIDTH CALCULATION

2.1. IS Code Method of crack width calculation

IS: 456 - 2000, Annex F, gives a procedure to determine the flexural crack width. The design crack width (Wcr) can be determined by the following formula which gives quite accurate results under normal design circumstances

$$Wcr = \frac{3a_{cr}e_m}{1 + 2\frac{a_{cr} - c_{min}}{D - x}}$$

The notations in the equation are as follows.

a_{cr} = Shortest distance from the selected level to the surface of the nearest longitudinal bar

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

D = Overall depth of the member

x = depth of the neutral axis of the member

$\mathcal{E}m$ or e_m = average strain at the level at which cracking is being considered

$$= e1 - \frac{b(D-x)(a-x)}{3E_sA_{st}(d-x)}$$

$\mathcal{E}1$ or $e1$ = Strain at the level being considered

$$= \frac{fs(D-x)}{E_s(d-x)}$$

bt = Width of the section at the centroid of the tension steel

a' = distance from the point at which the crack width is being considered to the compression face.

Ast = area of tension reinforcement

fs = Service stress in tension reinforcement in N/mm2

Es = Modulus of elasticity of steel

d = Effective depth of beam or slab

2.2. Eurocode Method

The formula for crack width as per Eurocode is:

$w_k = s_{r,max}$ $(\mathcal{E}_{sm} - \mathcal{E}_{cm})$ *where*

$s_{r,max} = k_3c + k1k2k4 \frac{\phi}{\rho_{\rho,eff}}$, when bar spacing ≤ $5(c+\phi/2)$

$s_{r,max} = 1.3(h-x)$, when bar spacing $>5(c+\phi/2)$

$$\mathcal{E}sm - \mathcal{E}cm = \frac{\sigma s - kt\frac{f_{ct,eff}}{\rho_{\rho,eff}}(1+\alpha_e \rho_{\rho,eff})}{Es} \geq 0.6\ \sigma s/Es$$

Where *sr,max* is the maximum crack spacing and the its calculation is dependent on the main reinforcing bars spacing. In the crack width equation, the average strain of the main bars $\mathcal{E}sm$ and the concrete $\mathcal{E}cm$ are taken into consideration as well.

2.3. National Code of Finland (RakMK B4) Method

As per the provisions of the National code of Finland the formula for the computation of crack width is:
$w_k = \mathcal{E}_s(3.5c + k_w\frac{\phi}{\rho r})$

2.4. German Institute for Standardization (DIN 1045-1)

The formula for crack width as per the German Institute for Standardization (DIN) is:
$w_k = s_{r,max}(\mathcal{E}_{sm} - \mathcal{E}_{cm})$

2.5. Limits of Crack Width

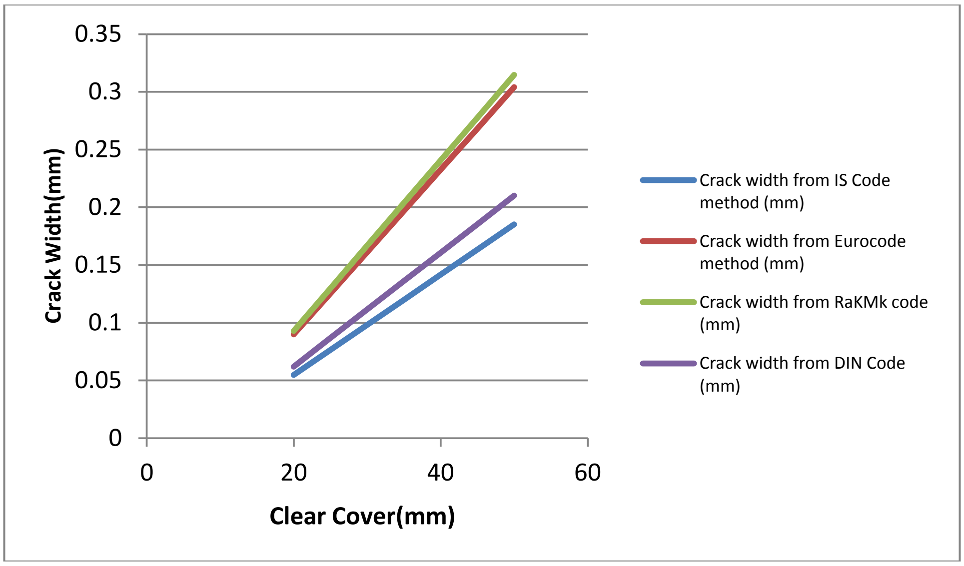
Clause 19.3.2 of IS: 1343 - 1980 recommends the limits of crack width such that the appearance and durability of the elements of structure are not affected.
The limits of crack width are provided as.
Crack width ≤ 0.2 mm for the moderate and mild environments
≤ 0.1 mm for severe environments.
IS-456:2000 specifies that the surface crack width should not exceed 0.3 mm for structures which are not subjected to aggressive environments. However, if the surface is exposed to aggressive environments, the crack width near the main reinforcement should not exceed 0.004 times the nominal cover to the reinforcement bars. A number of beams were analyzed using the above method with variations in reinforcements, clear covers, and applied loads; and the crack width in each case was calculated. It was noticed that all these factors have considerable effects on crack width.

III.COMPARISION OF RESULTS

Results from three cases are compared here. They are:
Case 1: Effect of clear cover.
Case 2: Effect of reinforcement diameter.
Case 3: Effect of applied loads.

Case 1: Effect of clear cover:
Data taken: A simply supported beam having 5m span was taken. It was 400x650mm in cross section. Bending moment at the midspan was 300 KN-m out of which 40% was due to permanent loads. The characteristic strength for concrete used was *fck* =30 MPa and for steel was *fy* =415 MPa. The beam was reinforced with 5- 25mm diameter bars in the tension zone. Keeping all these values as constant the values of clear cover were varied and the effect was checked.

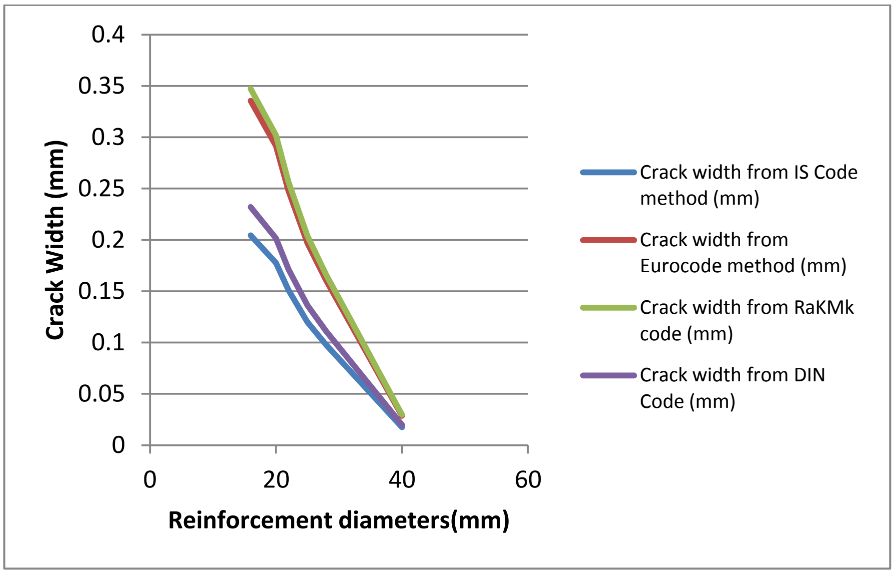
Clear cover(mm)	Crack width from IS Code method (mm)	Crack width from Eurocode method (mm)	Crack width from RaKMk code (mm)	Crack width from DIN Code (mm)
20	0.05479434	0.0899	0.0930	0.0621
25	0.07653456	0.1255	0.1299	0.0868
30	0.09827478	0.1613	0.16695	0.11151
35	0.120015	0.197	0.2039	0.136187
40	0.14175522	0.23267	0.240826	0.16085
45	0.16349544	0.26836	0.2777	0.18552
50	0.18523566	0.30405	0.314705	0.210195



Case 2: Effect of reinforcement diameter:

Data taken: A simply supported beam having 5m span was taken. It was 400x650mm in cross section. Bending moment at the midspan was 300 KN-m out of which 40% was due to permanent loads. The characteristic strength for concrete used was *fck* =30 MPa and for steel was *fy* =415 MPa. The clear cover was kept constant as equal to 35mm in this case. Keeping all these factors constant the effect of varying the diameter of reinforcement bars was observed.

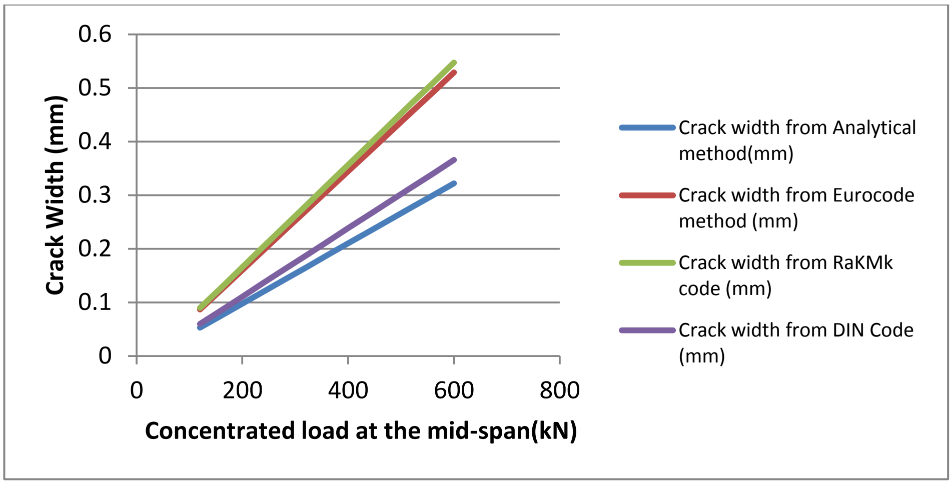
Diameter of rebar (mm)	Crack width from IS Code method (mm)	Crack width from Eurocode method (mm)	Crack width from RaKMk code (mm)	Crack width from DIN Code (mm)
5 bars of 16 ϕ	0.2043995	0.33549	0.34724	0.2319
5 bars of 20 ϕ	0.1776964	0.29168	0.30189	0.20164
5 bars of 22 ϕ	0.1509933	0.24784	0.25653	0.171339
5 bars of 25 ϕ	0.1200150	0.19699	0.20389	0.136187
5 bars of 28 ϕ	0.0975868	0.160184	0.16579	0.1107
5 bars of 32 ϕ	0.0708837	0.11635	0.120428	0.08043
5 bars of 36 ϕ	0.0441806	0.07252	0.07506	0.05013
5 bars of 40 ϕ	0.0174775	0.02868	0.02968	0.01982



Case 3: Effect of applied loads:

Data taken: A simply supported beam having 5m span was taken. It was 400x650mm in cross section. The objective was to find out the Surface crack width under the bar on the tension face. The characteristic strength for concrete used was *fck* =30 MPa and for steel was *fy* =415 MPa. The beam was reinforced with 5- 25mm diameter bars in the tension zone. The clear cover of 35 mm was assumed. Keeping these values constant the effect of varying the concentrated load values was observed.

Concentrated load at the mid-span (kN)	Crack width from IS method(mm)	Crack width from Eurocode method (mm)	Crack width from RaKMk code (mm)	Crack width from DIN Code (mm)
120	0.052653	0.0864	0.08945	0.05974
160	0.075107	0.12328	0.12760	0.085227
200	0.097561	0.16014	0.16575	0.110707
240	0.120015	0.197	0.2039	0.136187
280	0.142469	0.23385	0.242048	0.161665
320	0.16491	0.27069	0.28017	0.187129
360	0.187372	0.30756	0.318336	0.212618
400	0.209826	0.3444	0.356484	0.23809
440	0.23228	0.38125	0.39463	0.263577
480	0.25473	0.41810	0.43277	0.28905
520	0.277184	0.45495	0.47092	0.314529
560	0.299638	0.49180	0.50906	0.340010
600	0.322092	0.52865	0.54720	0.365493



IV. CONCLUSIONS

The following conclusions can be drawn from the above work:

1. The crack width increases as the clear cover increases and all the codes estimate nearly the same results.
2. As the diameter of reinforcement bars increase the crack width decreased and this trend is followed from all the codes
3. As the load gets increased the crack width increases in all the cases.

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