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Research on Cracks in Reinforced Concrete Elements by Taking Into Account the Experimentally Determined Concrete and Reinforcing Steel Mechanical Properties

KEYWORDS: crack width, crack spacing, reinforced concrete beams, bending, regulations

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ABSTRACT *In this paper are presented the results obtained from calculations for cracks width and spacing for reinforced concrete beams subjected to bending. For the experimental investigations 12 reinforced concrete beams were produced – 4 specimens with 3 beams in each one. The specimens differ in provided reinforcement, concrete cover and reinforcement ratio. The clear spans for all the beams are the same. In calculations are used the experimentally determined concrete and reinforcing steel mechanical properties used for the beams. Crack widths and spacing are calculated according to EC2, MC2010 and DIN 1045-1.*

1. INTRODUCTION

Cracks are forming in reinforced concrete elements due to bending, shear, torsion, tension or imposed deformations. Cracks worsen the durability and adequate perform of the structures and are a natural result of concrete low tensile strength. Main reasons for limiting the widths of the cracks are:

- durability of the structures(protection of reinforcement);
- appearance of the elements;
- stiffness of the elements.

Determining crack widths is enshrined in various theories and regulations in order to avoid unacceptably large cracks and to ensure normal exploitation of the structures. Research of crack widths is topical issue and various formulas for their determination are proposed.

2.Determining crack widths and spacing according to EC2, Model code 2010 and din 1045-1

2.1. Crack widths and spacing according to EC2

Maximum crack width is calculated by the formula [1,3,4,5,7]:

$$(1)\quad w_k = s_{r,\max}(\varepsilon_{sm} - \varepsilon_{cm}) =$$

$$= s_{r,\max}\left[\frac{\sigma_s - k_t \dfrac{f_{ct,eff}}{\rho_{eff}}(1+\alpha_e\rho_{eff})}{E_s}\right] \geq 0,6\frac{\sigma_s}{E_s}s_{r,\max},$$

where: $s_{r,\max}$ - maximum crack spacing; ε_{sm} - mean deformation in the reinforcement; ε_{cm} - mean deformation in the concrete between the cracks; σ_s - stress in the tensile reinforcement in cracked section; k_t - factor depending on the duration of the load, it is assumed $k_t = 0,6$ for short-term loads; α_e - modular ratio.

Effective reinforcement ratio for tensile bars is:

$$(2)\quad \rho_{eff} = \frac{A_s}{bh_{c,eff}},$$

where: b - width of the effective tension zone; $h_{c,eff}$ - height of effective tensile zone, depends on height of the section, effective depth and height of compression zone.

Maximum crack spacing after stabilized cracking stage might be calculated with:

$$(3)\quad s_{r,\max} = k_3 c + k_1 k_2 k_4 \phi / \rho_{eff}$$

where: ϕ - bar diameter; c - concrete cover of the longitudinal reinforcement; k_1 - factor depending on the bond properties of reinforcement, k_1 =0,8 for deformed bars; k_2 - factor accounting for the nature of strain distribution in the section, for bending k_2 =0,5; it is assumed k_3 =3,4 and k_4 = 0,425.

2.2. Crack widths and spacing according to Model Code 2010[6]

Maximum crack width is calculated by the formula:

$$(4)\quad w_d = 2l_{s,\max}(\varepsilon_{sm} - \varepsilon_{cm} - \varepsilon_{cs}) =$$

$$= s_{r,\max}\left[\frac{\sigma_s - \beta \dfrac{f_{ct,eff}}{\rho_{eff}}(1+\alpha_e\rho_{eff})}{E_s}\right],$$

where: $2l_{s,\max}$ - maximum crack spacing; ε_{sm} - mean deformation in the reinforcement; ε_{cm} - mean deformation in the concrete between the cracks; ε_{cs} - mean deformation in the concrete caused by the shrinkage; β - factor depending on the duration of the load, it is assumed $\beta = 0,6$ for short-term loads; α_e - modular ratio. Effective reinforcement ratio for tensile bars ρ_{eff} is determined with (2).

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Maximum crack spacing after stabilized cracking stage might be calculated with:

$$(5)\quad 2l_{s,\max} = 2.k.c + 2.\frac{1}{4}.\frac{f_{ct,eff}}{\tau_{cm}}.\frac{\phi_s}{\rho_{s,eff}}$$

,

where: τ_{cm} - mean value of the bond stress; ϕ_s - bar diameter; c - concrete cover of the longitudinal reinforcement; k - factor which is assumed to be 1.

2.3. Crack widths and spacing according to DIN 1045-1[2]

Crack width is determined with (1), but here $k_t = 0,4$. Effective reinforcement ratio for tensile bars ρ_{eff} is in function of height of the beam, effective depth and height of compression zone.

Maximum crack spacing is determined with:

$$(6)\quad s_{r,\max} = \frac{\phi_s}{3,6\rho_{eff}} \le \frac{\sigma_s \phi_s}{3,6 f_{ct,eff}},$$

where: σ_s - stress in the tensile reinforcement in cracked section; ρ_{eff} - effective reinforcement ratio for tensile bars; $f_{ct,eff}$ - mean value of tensile strength of the concrete in the moment when is expecting the first crack formation; ϕ_s - bar diameter.

3.EXPERIMENTAL PROCEDURE

For the experimental investigation for crack widths and spacing in reinforced concrete elements, subjected to bending were produced 12 beams – 4 specimens with 3 beams in each one. Specimens differ in provided reinforcement, concrete cover and reinforcement ratio. The clear spans of the beams are the same. The specimens are: 3 beams (A1, A2, A3) with section 27/15cm, clear span 3m, provided longitudinal bottom reinforcement 2N12, concrete cover 28mm, stirrups ϕ8/10(15)cm (figure 1); 3 beams (B1, B2, B3) with section 27/15cm, clear span 3m, provided longitudinal bottom reinforcement 2N18, concrete cover 28mm, stirrups N8/10(15)cm; 3 beams (C1, C2, C3) with section 30/15cm, clear span 3m, provided longitudinal bottom reinforcement 2N12, concrete cover 58mm, stirrups ϕ8/10(15)cm; 3 beams (D1, D2, D3) with section 30/15cm, clear span 3m, provided longitudinal bottom reinforcement 2N18, concrete cover 58mm, stirrups N8/10(15)cm. The load is two concentrated forces in the thirds of beams.

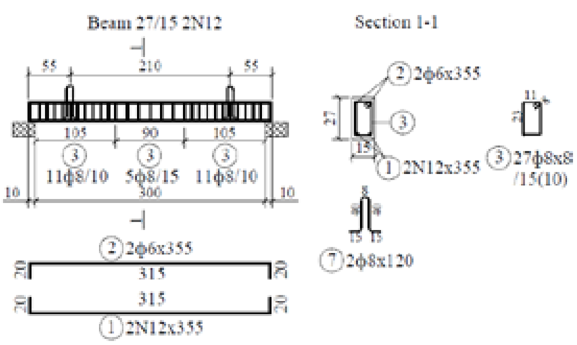

Figure 1. Beams A1, A2, A3-section 27/15cm, bottom longitudinal reinforcement 2N12, top reinforcement 2 ϕ 6, stirrups ϕ 8/10(15).

Beams are produced of concrete grade C25/30, fine fraction of coarse aggregate (dmax=12mm), consistence S3. For investigating cube compressive strength, cylindrical compressive strength, tensile strength at splitting, modulus of elasticity were made 138 test specimens according to BDS EN 12390-2.

Reinforcing steel for longitudinal bottom reinforcement is grade B500. Test pieces of reinforcing steel with diameter N12 and N18 were produced (3 for each diameter) for experimental investigation of stress-strain diagrams, strength and ductility properties.

4.Results and discussion

Concrete cylindrical compressive strength 30,1MPa, cube compressive strength 34,3MPa, tensile strength at splitting 3,1MPa, modulus of elasticity 28033 MPa were experimentally determined.

Steel yielding strength 535MPa and modulus of elasticity 214 000MPa were experimentally determined.

With the experimentally obtained results for concrete and reinforcing steel, used for the beams are calculated the expected crack widths and spacing according to EC2, MC2010 and DIN 1045-1 (figure 2 and 3).

For determining crack widths and spacing are developed tables in Microsoft Excel. In these tables are set formulas for determining the stress in the tensile reinforcement in cracked section σ_s, cracking bending moment M_{crc}, deformation in the compression zone of the section ε_{c2}, effective reinforcement ratio for tensile bars ρ_{eff}.

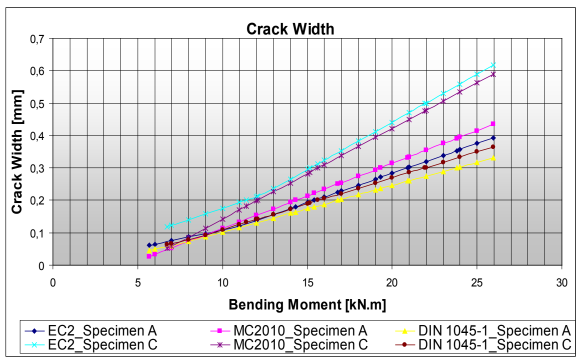

Figure 2. Crack width [mm] in function of the Bending Moment [kN.m] due to EC2, MC2010 and DIN 1045-1 for Specimens A and C.

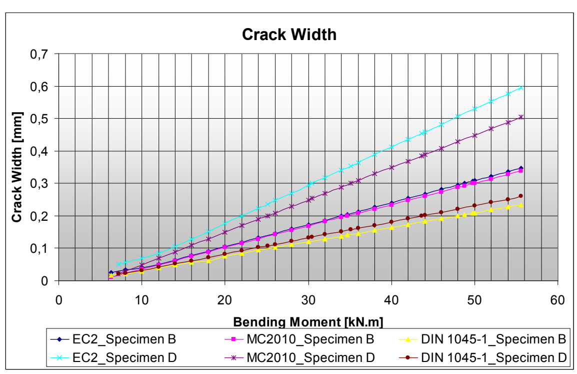

Figure 3. Crack width [mm] in function of the Bending Moment [kN.m] due to EC2, MC2010 and DIN 1045-1 for Specimens B and D.

Different dependences of crack width in function of bending moment are due to various factors preceding concrete cover in formulas of EC2 and MC2010 and its neglecting in formula of DIN 1045-1, and also differences in the factors preceding ϕ / ρ_{eff} .

CONCLUSIONS

The paper is dedicated to determination crack widths and spacing. The results obtained by formulas of EC2, MC2010 and DIN 1045-1 for four specimens of beams are presented. Experimentally obtained mechanical properties for reinforcing steel and concrete were used in calculations. Future aim is comparing above results with the results of upcoming experiments of beams subjected to bending.

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