Bauforschung

Proposal for a mutual adjustment of different concepts of crack control in (pr)EN 1992-1-1

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Vorschlag zum Abgleich verschiedener Konzepte zur Rissbreitenbegrenzung in (pr)EN 1992-1-1

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Postfach 80 04 69
70504 Stuttgart

Nobelstraße 12
70569 Stuttgart

Telefon (07 11) 9 70 - 25 00
Telefax (07 11) 9 70 - 25 08

E-Mail irb@irb.fraunhofer.de

www.IRBbuch.de

TECHNISCHE
UNIVERSITÄT
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Institut für Baustoffe und Konstruktion

MPA Bau

Lehrstuhl für Massivbau
Univ.-Prof.
Dr.-Ing. K. Zilch

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„Vorschlag zum Abgleich verschiedener Konzepte zur Rissbreitenbegrenzung in (pr)EN 1992-1-1"

"Proposal for a mutual adjustment of different concepts of crack control in (pr)EN 1992-1-1"

Univ.-Prof. Dr.-Ing. Konrad Zilch

Dipl.-Ing. Michael Cyllok

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Deutsches Institut für Bautechnik
Kolonnenstraße 30L
10829 Berlin

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BRIEFANSCHRIFT: 80290 MÜNCHEN – TELEFON 089 / 289 – 23039 – TELEFAX 089 / 289 – 23046
HAUSANSCHRIFT: GEBÄUDE N6 THERESIENSTRASSE 90 80333 MÜNCHEN
IHR ANSPRECHPARTNER: DIPL.-ING. M. CYLLOK – TELEFON: +49 / 89 / 289 – 23036
E-MAIL: cyllok@massivbau.bauwesen.tu-muenchen.de

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1 Introduction

This paper develops a proposal for an adjustable, consistent crack control for EN 1992-1-1.

Crack control is crucial for the serviceability and durability of structures. In the history of the development of the structural Eurocode for concrete structures various formulae came and went, see 1.1.

Even now a debate is under way if the current set of formulae satisfies the needs of the member states of the Eurocode program. From this situation, the paper sets the goal to find a satisfying solution for all parties by producing an adjustable set of formulae, see 1.2.

To achieve this goal actions (e.g. comparing and analysing the different sets of formulae) are set, see 1.3. This chapter also gives an overview over the paper.

1.1 Situation – Historical development of formulae to control crack widths

Crack control is the control of crack widths for serviceability and durability reasons.

All formulae for crack control ever introduced into the code (EN 1992-1-1) are well deduced from mechanical correlations and tests. Nevertheless different parameters may be emphasised in calculating the correlations.

The paper focuses on a total of four versions. Starting from the current version of the code to the oldest dealt with in this paper the versions are:

I) EN 1992-1-1 (Feb 2004 – post voting) – current version, [3]

II) EN 1992-1-1 (Apr 2003) – version forwarded to CEN, [4]

III) prEN 1992-1-1 (Sep 2001 – final draft), [5]

IV) prEN 1992-1-1 (Jan 2001 – 2nd draft)[1], [6]

The basic correlation for the calculation of crack widths is that the strain difference between the reinforcement steel and the surrounding concrete times the crack spacing is the crack

[1] In this version of the Eurocode 2-1-1 the formulae for crack control including the modification formulae for the maximum bar diameter are identical with those provided in Modelcode 90. The table for the maximum bar diameter to control cracking is almost identical with that given in Modelcode 90.

width. Hence, the appearance of the formulae for crack control is similar for all examined cases. However the formula for the crack spacing differs.

1.2 Goals – Development of satisfying formulae

The goals of this paper are:

- Development of a proposal for a consistent crack control.
- The tools and formulae should allow for national safety requirements (e.g. quantile for characteristic crack width) and national economic needs.
- The system of crack control should be easily adaptable on the special requirements of part 2 and part 3 of EN 1992.
- The analysis of the basis of test data used for deducing the formula of the respective version of the code should not be part of this paper.

1.3 Actions – Comparison, Analysis and Development

To reach the goals of this paper the following actions are taken:

The first action is the comparison of the different formulae and tools for crack control in the various stages of the Eurocode's history. For this purpose firstly the formulae and tools for crack control in different stages of the Eurocode are compiled, see 2. Secondly the formulae are evaluated in particular with respect to the concrete cover, see 3.

From this comparison a proposal for an improved crack control will be developed, see 4. Finally a conclusion is given, see 5.

2 Compilation of formulae for crack control associated with different stages of the code

In all versions of the code the provisions for crack control give the user two methods.

One method is to directly calculate the crack width to verify the target values (e.g. for durability), see 2.1.

The other method works without a direct calculation. Tables provide approximated target values for detailing (maximum bar diameters or maximum bar spacing). The target values must be adapted for certain cases, see 2.2.

2.1 Calculation of crack widths

2.1.1 Overview of the current version (Feb 2004)

The following equations are taken from EN 1992-1-1 (Feb 2004 - post voting). The numbers in squared brackets are in accordance with this version of the code.

$$w_k = s_{r,\max}(\varepsilon_{sm} - \varepsilon_{cm}) \qquad [7.8]$$

$$\varepsilon_{sm} - \varepsilon_{cm} = \frac{\sigma_s - k_t \dfrac{f_{ct,eff}}{\rho_{p,eff}}(1 + \alpha_e \rho_{p,eff})}{E_s} \geq 0{,}6\frac{\sigma_s}{E_s} \qquad [7.9]$$

$$\alpha_e = \frac{E_s}{E_{cm}}$$

$$\rho_{p,eff} = \frac{A_s + \xi_1^2 A'_p}{A_{c,eff}} \qquad [7.10]$$

$$s_{r,\max} = \frac{3{,}4c + 0{,}425 k_1 k_2 \phi}{\rho_{p,eff}} \qquad [7.11]$$

$k_1 = 0{,}8$ for high bond bars

$k_2 = 0{,}5$ for pure bending

$k_2 = 1{,}0$ for pure tension

$$\phi_{eq} = \frac{n_1\phi_1^2 + n_2\phi_2^2}{n_1\phi_1 + n_2\phi_2} \quad [7.12]$$

$$k_2 = \frac{\varepsilon_1 + \varepsilon_2}{2\varepsilon_1} \quad [7.13]$$

$$s_{r,\max} = 1{,}3(h - x) \text{ for } s_l > 5\left(c + \frac{\phi}{2}\right) \text{ or no bonded reinforcement in the tension area} \quad [7.14]$$

where:

k_t = 0,4 for longterm loading

$f_{ct,eff}$ is the mean value of the tensile strength of the concrete effective at the time when the cracks may first be expected to occur

ϕ is the bar diameter. Where a mixture of bar diameters is used in a section, an equivalent diameter, ϕ_{eq}, should be used. For a section with n_1 bars of diameter ϕ_1 and n_2 bars of diameter ϕ_2, expression [7.12] should be used

c concrete cover

A_s is the area of reinforcing steel within $A_{c,eff}$

A'_p is the area of pre or post-tensioned tendons within $A_{c,eff}$

s_l transverse spacing of the bonded reinforcement

ε_1 is the greater and ε_2 is the lesser tensile strain at the boundaries of the section considered, assessed on the basis of a cracked section

$A_{c,eff}$ is the effective area of concrete in tension surrounding the reinforcement or prestressing tendons of depth, $h_{c,ef}$, where $h_{c,ef}$ is the lesser of 2,5(h-d), (h-x)/3 or h/2, see figure

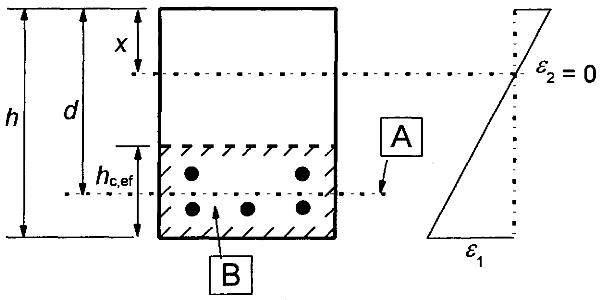

Fig. 1 Beam (A – level of steel centroid, B – effective tension area, $A_{c,eff}$)

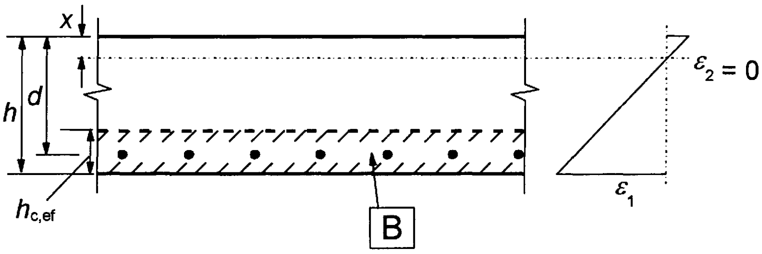

Fig. 2 Slab (B – effective tension area, $A_{c,eff}$)

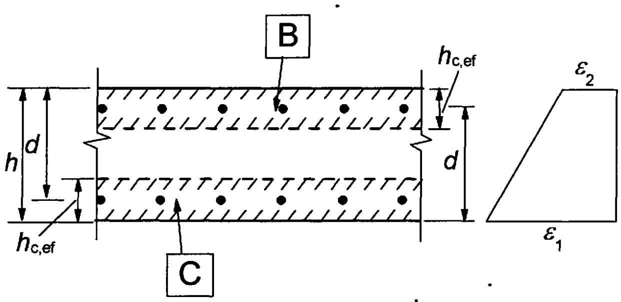

Fig. 3 Member under tension (B – effective tension area for upper surface $A_{ct,eff}$, C – effective tension area for lower surface $A_{cb,eff}$)

2.1.2 Comparison with older versions

In the three newer versions (Feb 2004, Apr 2003, Sep 2001) the set of formulae to directly calculate the crack widths is the same.

The 2nd draft (Jan 2001) provides a different formula to calculate the crack spacing. This equation is taken from Model Code 90 (as is the equation for the strain difference used in all four versions).

EN 1992-1-1 (Feb 2004)	prEN 1992-1-1 (Jan 2001)
$s_{r,\max} = \frac{3{,}4c + 0{,}425 k_1 k_2 \phi}{\rho_{p,eff}}$ [7.11] $\phi_{eq} = \frac{n_1\phi_1^2 + n_2\phi_2^2}{n_1\phi_1 + n_2\phi_2}$ [7.12]	$s_{r,\max} = \frac{\phi_s}{3{,}6\rho_{p,eff}} \leq \frac{\sigma_s\phi_s}{3{,}6 f_{ct,eff}}$ where ϕ_s equals ϕ approximately, see 2.1.1. The difference is that in the Jan 2001 version no rule is given for a section with n_1 bars of diameter ϕ_1 and n_2 bars of diameter ϕ_2 for bar diameter. The Feb 2004 version provides that, see [7.12].

In the old equation for crack spacing two cases are modelled: the left part of the inequality represents the stable cracking phase whereas the right part represents the cracking formation phase. In the new version only the stable cracking phase is modelled.

2.2 Control of cracking without direct calculation

For all considered versions the method of a maximum bar spacing to control cracks may only be used for control of cracks caused mainly by loading.

The method of a maximum bar diameter for control of cracking may be used for cracks both caused dominantly by restraint and caused mainly by loading.

2.2.1 Overview of the current version (Feb 2004)

The following equations and tables are taken from EN 1992-1-1 (Feb 2004 - post voting). The numbers in squared brackets are in accordance with this version of the code.

Recommended adoption for bending (at least part of section in compression):

$$\phi_s = \phi_s^* \frac{f_{ct,eff}}{2{,}9} \cdot \frac{k_c \cdot h_{cr}}{2(h-d)} \qquad [7.6]$$

Recommended adoption for tension (all of section under tensile stress):

$$\phi_s = \phi_s^* \frac{f_{ct,eff}}{2{,}9} \cdot \frac{h_{cr}}{8(h-d)} \qquad [7.7]$$

where:

ϕ_s is the adjusted maximum bar diameter

ϕ_s^* is the maximum bar size given in the Table [7.2]

h is the overall depth of the section

h_{cr} is the depth of the tensile zone immediately prior to cracking, considering the characteristic values of prestress and axial forces under the quasi-permanent combination of actions

d is the effective depth to the centroid of the outer layer of reinforcement

Table 1 Maximum bar diameter (Table [7.2] of EN 1992-1-1 Feb 2004)

Steelstress [N/mm²]	Maximum bar diameter [mm]		
	w_k=0,4 mm	w_k=0,3 mm	w_k=0,2 mm
160	40	32	25
200	32	25	16
240	20	16	12
280	16	12	8
320	12	10	6
360	10	8	5
400	8	6	4
450	6	5	-

Table 2 Maximum bar spacing (Table [7.3] of EN 1992-1-1 Feb 2004)

Steelstress [N/mm²]	Maximum bar spacing [mm]		
	w_k=0,4 mm	w_k=0,3 mm	w_k=0,2 mm
160	300	300	200
200	300	250	150
240	250	200	100
280	200	150	50
320	150	100	-
360	100	50	-

2.2.2 Comparison with older versions

Comparing the four versions of the Eurocode 2-1-1 the steady change of the adoption formulae for the maximum bar diameter or even the crack spacing (see 2.1.2) attracts attention. Even more as this change is not accompanied by a change of the table for maximum bar diameters. This table remains the one more or less taken from Modelcode 90 [1].

EN 1992-1-1 (Apr 2003)

In EN 1992-1-1 (Apr 2003) Table [7.2] and Table [7.3] equal the respective tables in the current (Feb 2004) version. Equation [7.6] of the Apr 2003 version equals the current version. Equation [7.7] differs from the current version. The difference in the numerator was indicated as an editorial error.

EN 1992-1-1 (Feb 2004)	EN 1992-1-1 (Apr 2003)
$\phi_s = \phi_s^* \frac{f_{ct,eff}}{2,9} \cdot \frac{h_{cr}}{8(h-d)}$ [7.7]	$\phi_s = \phi_s^* \frac{f_{ct,eff}}{2,9} \cdot \frac{h_{cr}}{4(h-d)}$ [7.7 Apr 2003]

prEN 1992-1-1 (Sep 2001)

In prEN 1992-1-1 (Sep 2001) Table [7.2] and Table [7.3] equal the respective tables in the current (Feb 2004) version.

The modifications for the bar diameter vary from the current version. The two cases considered are not tension and bending as in the current version, but are a case for restraint cracking and a case for load induced cracking.

The equations for the modifications have no official numbering.

EN 1992-1-1 (Feb 2004)	prEN 1992-1-1 (Sep 2001)
for bending (at least part of section in compression): $\phi_s = \phi_s^* \frac{f_{ct,eff}}{2,9} \cdot \frac{k_c \cdot h_{cr}}{2(h-d)}$	for restraint cracking: $\phi_s = \phi_s^* \frac{f_{ct,eff}}{2,9} \cdot \frac{h_{cr}}{10(h-d)} \geq \phi_s^* \frac{f_{ct,eff}}{2,9}$
for tension (all of section under tensile stress): $\phi_s = \phi_s^* \frac{f_{ct,eff}}{2,9} \cdot \frac{h_{cr}}{8(h-d)}$	for load induced cracking: $\phi_s = \phi_s^* \frac{h_{cr}}{10(h-d)} \geq \phi_s^*$

prEN 1992-1-1 (Jan 2001)

In prEN 1992-1-1 (Jan 2001) Table [7.2] and Table [7.3] equal the respective tables in the current (Feb 2004) version.

The modifications for the bar diameter equal the Sep 2001 version. Those equations can also be found in Modelcode 90.

3 Evaluation of the crack control

The formulae to control crack widths in the different versions of the code are introduced, see 2. Not considering the modifications for the simplified method, only two major calculation methods remain. Method one is according to EN 1992-1-1 (Feb 2004 – post vote) and the second one is according to prEN 1992-1-1 (Jan 2001 – 2nd draft).

The difference between the two ways is the calculation of the crack spacing, see 2.1.2. The "post vote"-formula allows directly for the influence of the concrete cover on the crack spacing. In the correspondent "2nd draft"-formula this influence is allowed for indirectly. It is done via the effective reinforcement ration $\rho_{p,eff}$ which contains $A_{c,eff}$ and therefore $c \approx d_1 = (h - d)$. It should be stated that by the shown relationship the "post vote"-formula allows for the concrete cover via two different ways.

The goal of the chapter is to compare and visualise the consistency of the crack control considering the set of formulae and the appendant tools.

For better comprehension this will be visualised by graphs. The basis of the graphs and the comparison itself is explained in 3.1. With the evaluation of the two sets of formulae it will be shown, how the direct calculations of crack widths relate to each other, see 3.2. Furthermore the relation between the formulae and the table for maximum bar diameters will be investigated, see 3.3.

3.1 Notes on the display of the comparison

The usage of graphs and figures helps understanding the comparison of the different formulae for crack control. Frequently used are graphs with the abscissa showing the steel stress σ_s and the ordinate giving the maximum bar diameter ϕ_s. They're valid for a certain crack width respectively. To be more specific, they're valid for a certain quantile (e.g. 95%) of a crack distribution. The reason for the popularity of this way of display is that tables for maximum bar diameters can easily be extracted from the graphs.

As there are more than the above mentioned three parameters, approximations and assumptions are to be made, see 3.1.1 and 3.1.2.

These simplifications can be introduced into the code's equations and solved for the maximum bar diameter, see 3.1.3.

3.1.1 Assumptions (constants)

Assumptions need to be taken for the module of elasticity of the reinforcement, the area of the prestressing steel and the effective tensile strength.

Module of elasticity of the reinforcement

For the formulae considered, see 2, the area of prestressing steel is converted to an equivalent area of reinforcing steel, see [7.10]. As an approximation the module of elasticity for reinforcing steel may be used, see (1).

$$E_s = 200000 \text{ MPa} \tag{1}$$

Area of the prestressing steel

The user of the code is free to compose the reinforcement for crack control from prestressing steel and reinforcement steel via [7.10]. This equation gives an equivalent area of reinforcing steel. Hence, no special evaluation needs to be performed for the use of prestressing steel. As a simplification, the area of prestressing steel is set to zero, see (2).

$$A_p' = 0 \tag{2}$$

Effective tensile strength

The effective tensile strength $f_{ct,eff}$ may vary from case to case. In a first step the tensile strength is set to a constant value, see (3). For cases where the actual tensile strength varies from this constant, a modification to allow for the provision in (3) is needed.

$$f_{ct,eff} = 2{,}9 \text{ MPa} \tag{3}$$

3.1.2 Simplifications and approximations

Simplifications and approximations are needed for the influence of the concrete's module of elasticity and the effective steel ratio.

Influence of the concrete's module of elasticity

An often used approximation is given by (4):

$$(1 + \alpha_e \rho_{p,eff}) = 1 \tag{4}$$

Effective steel ratio

The effective steel ratio $\rho_{\mathrm{p,eff}}$ should be assessed to decrease the number of unidentified parameters.

The post vote formula [7.11] to assess the crack spacing bases on the assumption of stable cracking. According to Modelcode 90 [1] stable cracking is given if the steel force F_{s} is greater than the cracking force F_{cr}, see (5).

$$F_{\mathrm{s}} > F_{\mathrm{cr}} \tag{5}$$

The force F_{cr} indicates the force, which has to be introduced into the concrete by bond in order to provoke cracking within $A_{\mathrm{c,eff}}$ at the end of the transmission length. Again according to Modelcode 90 the cracking force is given by (6).

$$F_{\mathrm{cr}} = A_{\mathrm{c,eff}} \cdot f_{\mathrm{ct,eff}} \tag{6}$$

A minimum reinforcement $A_{\mathrm{s,sc}}$ to allow for stable cracking at stress σ_{s} needs to bear at least F_{cr}. Hence, this reinforcement area can be calculated from equilibrium, see (7). The value of $A_{\mathrm{s,sc}}$ equals approximately $A_{\mathrm{s,min}}$ calculated from [7.1] of EN 1992-1-1 (Feb 2004).

$$A_{\mathrm{s,sc}} = \frac{A_{\mathrm{c,eff}} \cdot f_{\mathrm{ct,eff}}}{\sigma_{\mathrm{s}}} \tag{7}$$

The provided reinforcement area controls the crack width calculated with the code's formulae. A greater area of reinforcement leads to smaller crack width. Due to the criteria of the ultimate limit states the reinforcement area provided is normally greater than the minimum reinforcement (7). To allow for greater reinforcement areas the ratio n is introduced, see (8).

$$n = \frac{A_s}{A_{\mathrm{s,sc}}} = \frac{\sigma_{\mathrm{s}} \cdot A_s}{A_{\mathrm{c,eff}} \cdot f_{\mathrm{ct,eff}}} \tag{8}$$

3.1.3 Solving for the bar diameter

Introducing (1), (2), (3), (4), and (8) into the code's equations [7.8], [7.9] and [7.11] the equation (9) is obtained. This can be done manually or with a computer system for mathematics like Maple™. Stresses are in MPa, the crack widths, the cover and the bar diameter are in m.

$$\phi_{\mathrm{s}} = -\frac{3{,}411764705n\left(-\dfrac{0{,}145E8w_k n}{\sigma_s} + 246{,}5cn - 98{,}6c\right)}{\sigma_s(14{,}5n - 5{,}8)} \tag{9}$$

To actually plot a graph showing the relation between bar diameter ϕ_s and steel stress σ_s, the ratio n, the crack width w_k and the concrete cover c must be set to a constant value. Using $n = 1$, $w_k = 0{,}3\text{mm}$ and $c = 2{,}5\text{cm}$, equation (10) is obtained.

$$\phi_s = -\frac{3{,}411764705(-500 + 17\sigma_s c)}{\sigma_s^2} \approx \frac{1706}{\sigma_s^2} - \frac{58c}{\sigma_s} \tag{10}$$

The same can be done for the above mentioned set of equations and constants where the crack spacing is according to prEN 1992-1-1 (Jan 2001 - 2nd draft). This results in equation (11). Stresses are in MPa, the crack widths and the bar diameter are in m.

$$\phi_s = -\frac{0{,}30276E8 w_k n^2}{\sigma_s^2(14{,}5n - 5{,}8)} \tag{11}$$

Unlike in equation (9) in (11) the concrete cover has no influence on the bar diameter. Using $n = 1$ and $w_k = 0{,}3$ mm equation (12) is obtained. The reason that in (11) and (12) no influence of the cover remains is that the effective reinforcement ratio in the equation for crack spacing and the effective reinforcement ratio in the equation for the strain difference [7.9] are cancelling out each other. As mentioned above this ratio contains the influence of c.

$$\phi_s = \frac{1044}{\sigma_s^2} \tag{12}$$

3.2 Graphs for maximum bar diameters

The following figures show the graphs for different concrete covers. The minimum reinforcement according to (7) is assumed. The graph for the formulation according to prEN 1992-1-1 (Jan 2001- 2nd draft) is not related to the concrete cover. Hence, it's the same for all figures. The graphs are discusses for a crack width of 0,2 mm, 3.2.1, for 0,3 mm, 3.2.2, and for 0,4 mm, 3.2.3.

3.2.1 Crack width 0,2 mm

In the figures Fig. 4 to Fig. 7 the relation between the bar diameter and the steel stress is displayed for concrete covers c from 1 cm to 5,5 cm for a crack width of 0,2 mm.

It can be observed that for $c = 1{,}0$ cm the curve calculated according to EN 1992-1-1 (Feb 2004 – post vote) is more favourable than the curve calculated according to prEN 1992-1-1 (Jan 2001 – 2nd draft), see Fig. 4. For the often encountered cover of $c = 2{,}5$ cm both curves give similar values, see Fig. 5.

For greater covers like c = 4,0 cm the "2nd draft"-graph is more favourable than the "post vote"-graph. Latter results in bar diameters less than 6 mm (the smallest diameter available) for steel stresses above 300 MPa, see Fig. 6. Negative bar diameters for the "post vote"-graph are obtained for c = 5,5 cm at stresses above 350 MPa. The 6 mm border is reached at ca. 250 MPa, see Fig. 7.

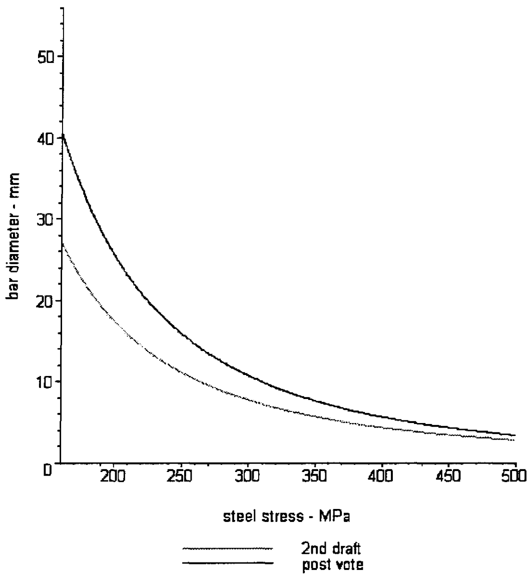

Fig. 4 Bar diameter for w_k = 0,2 mm, c = 1,0 cm

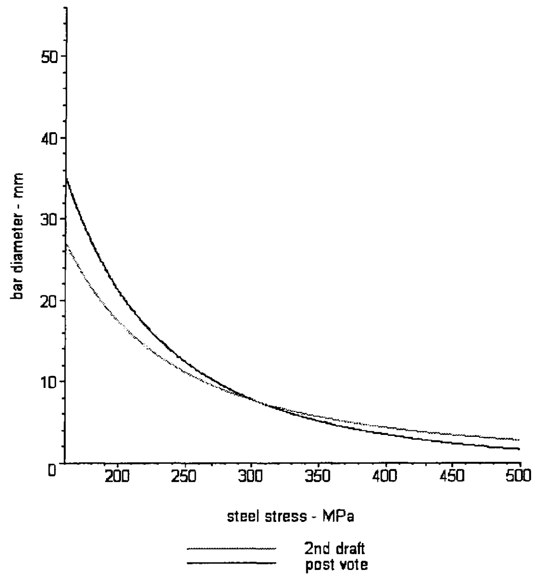

Fig. 5 Bar diameter for w_k = 0,2 mm, c = 2,5 cm

The conditional equations for graphs according to EN 1992-1-1 (Feb 2004 – post vote) are:

$$\phi_s = \frac{0{,}3921568626\left(\frac{2900}{\sigma_s} - 1{,}479\right)}{\sigma_s} \quad \text{for } c = 1{,}0 \text{ cm, see Fig. 4} \tag{13}$$

$$\phi_s = \frac{0{,}3921568626\left(\frac{2900}{\sigma_s} - 3{,}6975\right)}{\sigma_s} \quad \text{for } c = 2{,}5 \text{ cm, see Fig. 5} \tag{14}$$

$$\phi_s = \frac{0{,}3921568626\left(\frac{2900}{\sigma_s} - 5{,}916\right)}{\sigma_s} \quad \text{for } c = 4{,}0 \text{ cm, see Fig. 6} \tag{15}$$

$$\phi_s = \frac{0{,}3921568626\left(\frac{2900}{\sigma_s} - 8{,}1345\right)}{\sigma_s} \qquad \text{for } c = 5{,}5 \text{ cm, see Fig. 7} \qquad (16)$$

The conditional equation for the graphs according to prEN 1992-1-1 (Jan 2001 – 2nd draft) in Fig. 4 to Fig. 7 are:

$$\phi_s = \frac{696}{\sigma_s^2} \qquad (17)$$

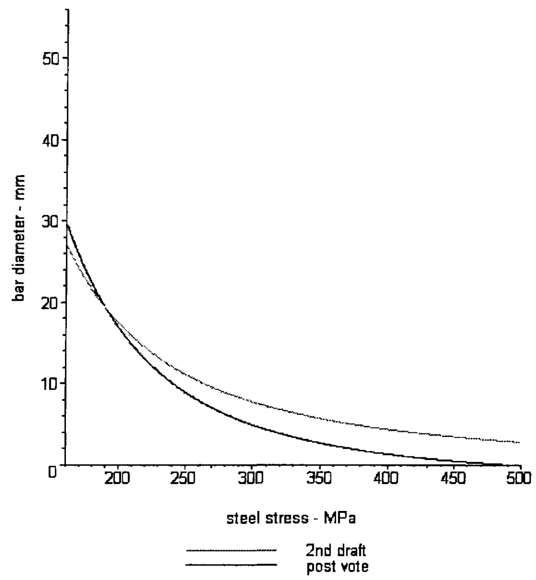

Fig. 6 Bar diameter for w_k = 0,2 mm, c = 4,0 cm

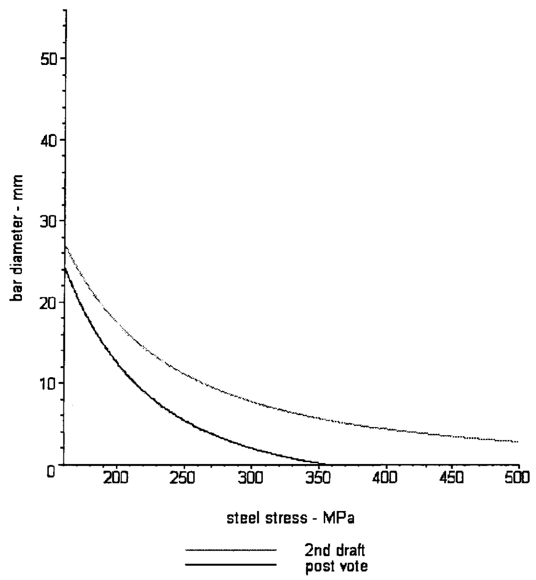

Fig. 7 Bar diameter for w_k = 0,2 mm, c = 5,5 cm

3.2.2 Crack width 0,3 mm

In the figures Fig. 8 to Fig. 11 the relation between the bar diameter and the steel stress is displayed for concrete covers c from 1 cm to 5,5 cm for a crack width of 0,3 mm.

It can be observed that for c = 1,0 cm the curve calculated according to EN 1992-1-1 (Feb 2004 – post vote) is more favourable than the curve calculated according to prEN 1992-1-1 (Jan 2001 – 2nd draft), see Fig. 8. Same is true for c = 2,5 cm. see Fig. 9.

For greater covers like c = 4,0 cm the "2nd draft"-graph is more favourable than the "post vote"-graph for stresses above ca. 290 MPa. Bar diameters less than 6 mm are obtained for the "post vote"-graph for stresses above ca. 360 MPa. This border is reached for the "2^{nd} draft"-graph not until ca. 400 MPa, see Fig. 10. From a qualitative point of view, the same is true for c = 5,5 cm. Here, the 6 mm-Border is set to ca. 320 MPa, see Fig. 11.

The conditional equations for graphs according to EN 1992-1-1 (Feb 2004 – post vote) are:

$$\phi_s = \frac{0{,}3921568626\left(\frac{4350}{\sigma_s} - 1{,}479\right)}{\sigma_s} \quad \text{for } c = 1{,}0 \text{ cm, see Fig. 8} \qquad (18)$$

$$\phi_s = \frac{0{,}3921568626\left(\frac{4350}{\sigma_s} - 3{,}6975\right)}{\sigma_s} \quad \text{for } c = 2{,}5 \text{ cm, see Fig. 9} \qquad (19)$$

$$\phi_s = \frac{0{,}3921568626\left(\frac{4350}{\sigma_s} - 5{,}916\right)}{\sigma_s} \quad \text{for } c = 4{,}0 \text{ cm, see Fig. 10} \qquad (20)$$

$$\phi_s = \frac{0{,}3921568626\left(\frac{4350}{\sigma_s} - 8{,}1345\right)}{\sigma_s} \quad \text{for } c = 5{,}5 \text{ cm, see Fig. 11} \qquad (21)$$

The conditional equation for the graphs according to prEN 1992-1-1 (Jan 2001 – 2^{nd} draft) in Fig. 8 to Fig. 11 are:

$$\phi_s = \frac{1044}{\sigma_s^2} \qquad (22)$$

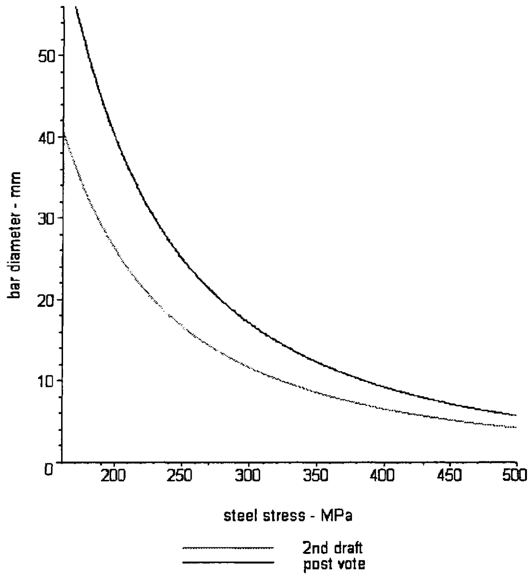

Fig. 8 Bar diameter for w_k = 0,3 mm, c = 1,0 cm

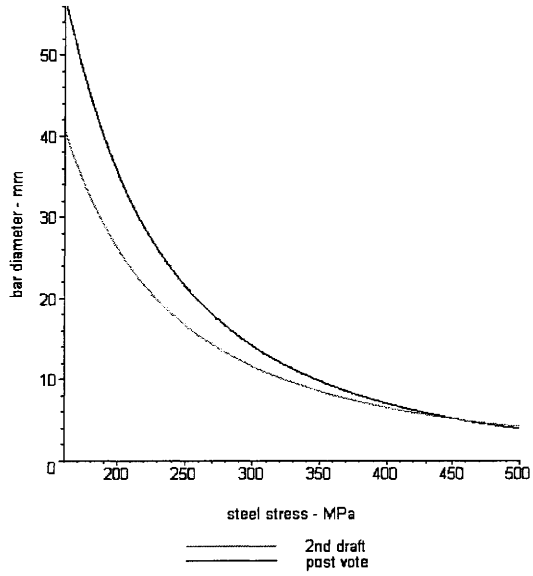

Fig. 9 Bar diameter for w_k = 0,3 mm, c = 2,5 cm

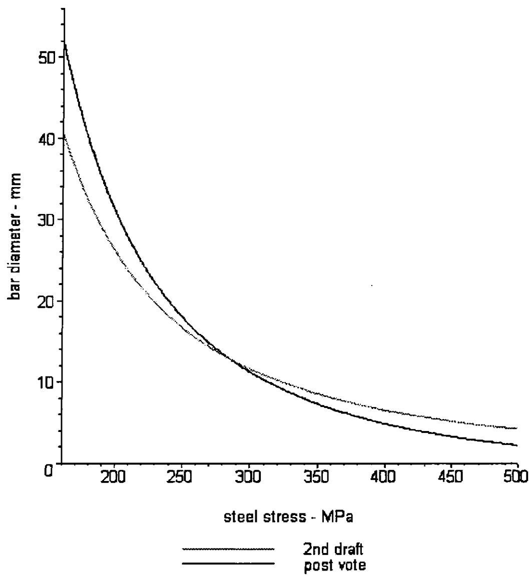

Fig. 10 Bar diameter for w_k = 0,3 mm, c = 4,0 cm

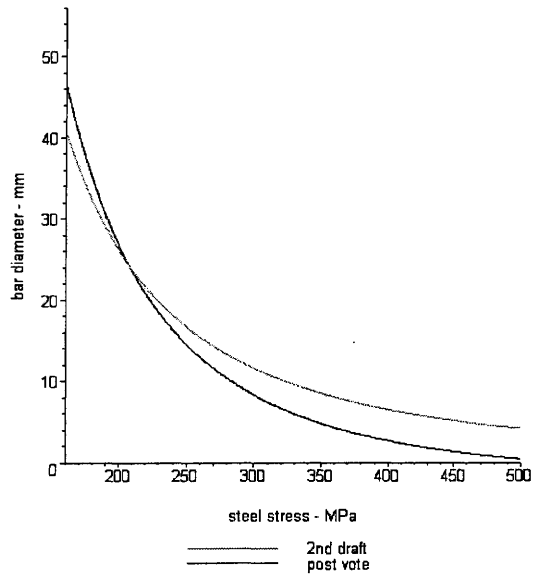

Fig. 11 Bar diameter for w_k = 0,3 mm, c = 5,5 cm

3.2.3 Crack width 0,4 mm

In the figures Fig. 12 to Fig. 15 the relation between the bar diameter and the steel stress is displayed for concrete covers c from 1 cm to 5,5 cm for a crack width of 0,4 mm.

It can be observed that for c = 1,0 cm the curve calculated according to EN 1992-1-1 (Feb 2004 – post vote) is more favourable than the curve calculated according to prEN 1992-1-1 (Jan 2001 – 2^{nd} draft), see Fig. 12. Same is true for c = 2,5 cm. see Fig. 13.

For greater covers like c = 4,0 cm the "2^{nd} draft"-graph is more favourable than the "post vote"-graph for stresses above ca. 380 MPa. This means in ca. 75% of the relevant stress range the "post vote"-graph is more favourable than the "2^{nd} draft"-graph, see Fig. 14.

This border lies for c = 5,5 cm at ca. 280 MPa, see Fig. 15.

The conditional equations for graphs according to EN 1992-1-1 (Feb 2004 – post vote) are:

$$\phi_s = \frac{0{,}3921568626\left(\frac{5800}{\sigma_s} - 1{,}479\right)}{\sigma_s} \quad \text{for } c = 1{,}0 \text{ cm, see Fig. 12} \qquad (23)$$

$$\phi_s = \frac{0{,}3921568626\left(\frac{5800}{\sigma_s} - 3{,}6975\right)}{\sigma_s} \quad \text{for } c = 2{,}5 \text{ cm, see Fig. 13} \qquad (24)$$

$$\phi_s = \frac{0{,}3921568626\left(\frac{5800}{\sigma_s} - 5{,}916\right)}{\sigma_s} \quad \text{for } c = 4{,}0 \text{ cm, see Fig. 14} \qquad (25)$$

$$\phi_s = \frac{0{,}3921568626\left(\frac{5800}{\sigma_s} - 8{,}1345\right)}{\sigma_s} \quad \text{for } c = 5{,}5 \text{ cm, see Fig. 15} \qquad (26)$$

The conditional equation for the graphs according to prEN 1992-1-1 (Jan 2001 – 2^{nd} draft) in Fig. 12 to Fig. 15 are:

$$\phi_s = \frac{1392}{\sigma_s^2} \qquad (27)$$

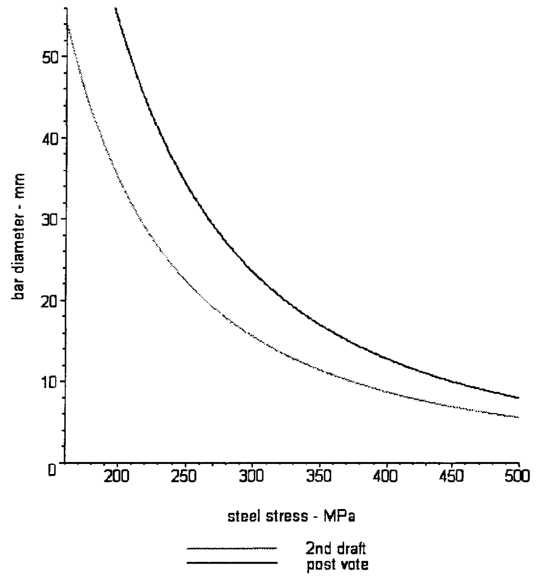

Fig. 12 Bar diameter for $w_k = 0{,}4$ mm, $c = 1{,}0$ cm

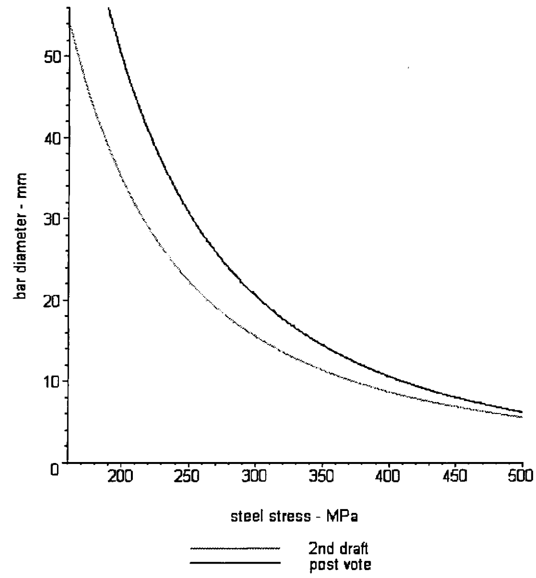

Fig. 13 Bar diameter for $w_k = 0{,}4$ mm, $c = 2{,}5$ cm

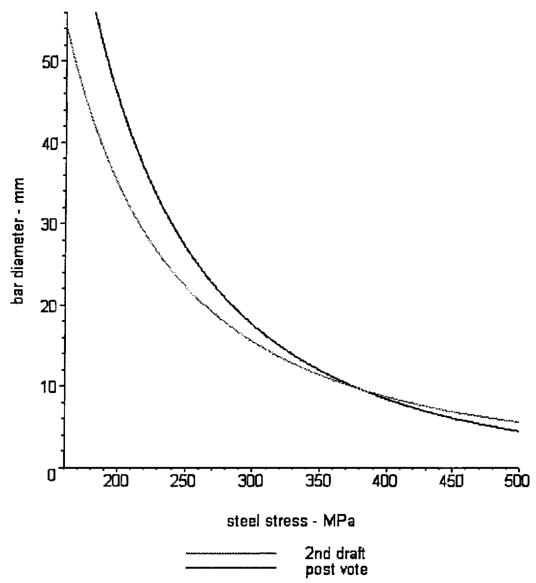

Fig. 14 Bar diameter for $w_k = 0{,}4$ mm, $c = 4{,}0$ cm

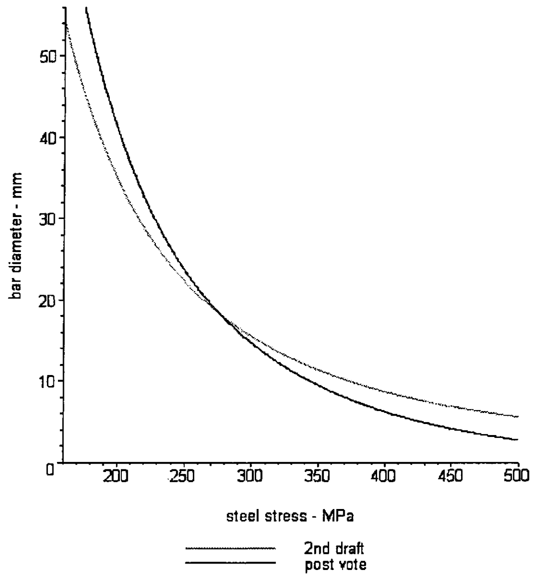

Fig. 15 Bar diameter for $w_k = 0{,}4$ mm, $c = 5{,}5$ cm

3.3 Tables for maximum bar diameters

The following Table 3 contains maximum bar diameters for the crack widths 0,2 mm to 0,4 mm. To determine the values the set of formulae of EN 1992-1-1 (Feb 2004 – post vote) is taken. The reference concrete cover is 2,5 cm. For the reinforcement area A_s the minimum area $A_{s,sc}$ according to (7) is used. This means the ratio n equals one. The equations (14), (19) and (24) were used to calculate the values in the table. The values are calculated and do not consider the availability of diameters for bars. To assess the maximum bar diameter for other cover depths and other provided steel areas, a modification is needed, see 4.

It can be seen, that Table 3 is less restrictive than Table 1 which is part of the code. From the examinations performed, it can't be comprehended, why the simplification should be much more restrictive than the direct calculation.

Table 3 Maximum bar diameter for c = 2,5 cm and $A_s = A_{s,sc}$

Steel stress σ_s in MPa	Maximum bar diameter ϕ_s in mm for w_k		
	w_k = 0,4 mm	w_k = 0,3 mm	w_k = 0,2 mm
160	80	58	35
200	50	35	21
240	33	24	14
280	24	17	9
320	18	12	7
360	14	9	5
400	11	7	3
450	8	5	2

4 Proposal for an improved crack control

The Evaluation of the crack control, see 3, for the two major concepts in the recent history of EN 1992-1-1 showed that the crack control which considered different concrete covers directly (EN 1992-1-1 Feb 2004 – post vote) gives more unfavourable crack spacings and therefore more unfavourable crack widths for deep covers than the old crack control from prEN 1992-1-1 (Jan 2001). Latter was taken from Modelcode 90 and considers the influence of the concrete cover only via the effective reinforcement ratio, see 3.1.3.

The more unfavourable crack widths have a great impact on the economic efficiency as the allowable steel stress for a certain crack width is decreased and thus more reinforcement is needed. In both versions of the crack control no reliability element is provided with which the quantile of the crack widths could be controlled.

Especially in the demanded quantile and the influence of the concrete cover opinions and experiences vary widely. This manifests in the different means provided by the different parts of Eurocode 2. An equalisation between the parts maybe with different reliability levels would be desirable. A national opening for the crack spacing is proposed, see 4.1.
Furthermore in chapter 3 it was shown that the existing Table 1 for maximum bar diameters is more restrictive than the direct calculation of crack widths. A less restrictive table with appendant modifications (see [7.6], [7.7]) which allows for the national opening of the crack spacing is presented in 4.2.

4.1 Proposal for improved formulae for direct calculation of crack widths

The differences in the set of formulae for crack control lie in the formula for crack spacing, see [7.11]. Other formulae for the direct calculation of the crack widths are equal in both versions.
The following equation (28) for [7.11] as well as appendant explanations is proposed.

$$s_{r,\max} = k_2 c + k_3 k_4 k_5 \frac{\phi}{\rho_{p,eff}} \qquad (28)$$

where

k_2 *is a coefficient which takes account of the influence of cover and reliability*

k_3 *is a coefficient which takes account of the influence of reinforcement ratio and reliability*

k_4 *is a coefficient which takes account of the bond properties of the bonded reinforcement*

k_5 *is a coefficient which takes account of the distribution of strain*

Note: The values for k_2 and k_3 for use in a country may be found in its National Annex. The recommended value for k_2 is 3,4. The recommended value for k_3 is 0,425. For high bond bars the recommended value for k_4 is 0,8, for bars with an effectively plain surface (e.g. prestressing tendons) bars the recommended value for k_4 is 1,6. For bending the recommended value for k_5 is 0,5, for pure tension the recommended value for k_5 is 1,0.

4.2 Proposal for improved tools for crack control without direct calculation

The crack control without direct calculation bases on a table from which the maximum bar size for a given crack width and steel stress can be obtained, see 2.2. As the table can't contain values for all cases, a modification is used to adjust the table value to further parameters, see also 2.2.

If the direct calculation of the crack width is altered as proposed in 4.1, the table is as well affected. Hence, for the improved tools for crack control without direct calculation a new table to replace Table [7.2] of EN 1992-1-1 Feb 2004 is proposed, see 4.2.1.

The same is true for the modifying equations [7.6] and [7.7] as they're deduced from the direct calculation, too. The modification of the table values should comply with various criteria, see 4.2.2. The implementation of the criteria into formulae is presented in 4.2.3. These formulae are to replace [7.6] and [7.7] of EN 1992-1-1 (Apr 2003).

4.2.1 Table for maximum bar diameters

It is proposed to open Table [7.2] from EN 1992-1-1 Feb 2004 nationally and replace it for the needed recommendation with Table 3 as the existing table is very conservative, see 3.3. Table 3 is deduced from (9). This equation satisfies the code's equations [7.8], [7.9] and [7.11].

Apart from the general simplifications, see 3.1.1 and 3.1.2, the table uses a constant concrete cover $c = 2{,}5$ cm and the minimum reinforcement area $A_{s,sc}$ according to (7).

4.2.2 Criteria for a practical modification of maximum bar diameters

The modifications of the table values of the maximum bar diameter are to allow for actual circumstances that are not adequately represented by the used simplifications and approximations of the table.

The modifications should be as accurate as possible. Nevertheless it should be borne in mind that they're part of a simplification and should therefore be simple. Approximations for the sake of simplicity may be accepted as long as they're not insecure.

The considered approximations are the concrete cover, the effective concrete tensile strength and the reinforcement area provided.

Provided concrete cover

The graphs in 3.2 show well the great influence of the concrete cover on the maximum bar diameter.

For the tabled value a constant concrete cover $c = 2{,}5$ cm is used. If deep concrete covers have the negative effect reflected in [7.11] it would be insecure to use the table values of Table 3 for maximum bar diameters without modification for deeper concrete covers than 2,5 cm.

Alternatively a more conservative table could be used, but this would have great impact on the economic efficiency. Hence, a modification to account for the provided concrete cover is to be included.

Provided concrete tensile strength

The provided concrete tensile strength $f_{ct,eff}$ controls the bar diameter ϕ_s directly. Equation (9) can be written as (29).

$$\phi_s = -\frac{1{,}17647058793 \cdot f_{ct,eff} \cdot n\left(-\frac{0{,}145E8w_k n}{\sigma_s} + 246{,}5cn - 98{,}6c\right)}{\sigma_s(14{,}5n - 5{,}8)} \qquad (29)$$

Due to the linear effect of $f_{ct,eff}$ on the bar diameter ϕ_s a modification of the table value is necessary.

Provided reinforcement area

As stated in 4.2.1 the table uses a minimum reinforcement area instead of the actual provided reinforcement area. The modifications should compensate for using this provision.

The effect of a greater actual reinforcement area A_s than assumed for deducing the table values is displayed in Fig. 16. Here for $w_k = 0{,}3$ mm one curve is showing the maximum bar diameter for $A_s = A_{s,sc}$ and the other one for $A_s = 3\,A_{s,sc}$. With three times[2] more reinforcement provided than assumed for $\phi_s = 10$ mm ca. 70 MPa more stress could be accepted to control the crack width to 0,3 mm than assumed with the table value.

This difference has a great effect on the economic efficiency. The actual provided reinforcement area should be accounted for in the modification.

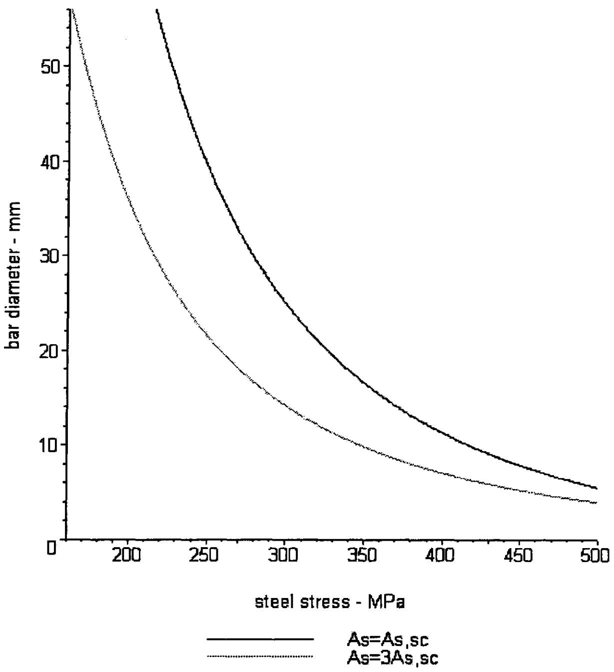

Fig. 16 Influence of a reinforcement area A_s higher than assumed for deducing table values

[2] Examples [2] show, that the provided reinforcement area can easily be three times the minimum reinforcement area.

4.2.3 Implementation of modifications

The modification of the table values of the maximum bar diameter should allow for the effect of the actual provided concrete cover c and the actual provided reinforcement area A_s. Those modifications should be compiled to one formula.

Approximations fit the curve to favoured values. Normally they're not exact for all cases. Therefore priorities must be set and a case or an interval of cases to be considered must be chosen.

For approximations the steel stress σ_s considered should be between 150 MPa and 450 MPa. Below this interval normally cracks are not likely to be excessive and above this interval they're too likely to be excessive. For the latter case a direct calculation should be preferred.

Provided concrete cover

The influence of the provided concrete cover c can be exactly isolated. The element for the effect of the concrete cover (30) can be deduced from (9).

$$\frac{c \cdot 58\,\text{MPa}}{\sigma_s} \tag{30}$$

The idea is to subtract from the table value ϕ_s^* the term (30) containing the effect of $c = 2{,}5$ cm and add the term (30) controlled by the provided cover c. The table value ϕ_s^* for the maximum bar diameter can be modified to allow for the actual provided concrete cover c by equation (31).

$$\phi_s = \phi_s^* + \frac{(2{,}5\,\text{cm} - c) \cdot 58\,\text{MPa}}{\sigma_s} \tag{31}$$

To allow for a national opening a nationally determined parameter k_6 needs to be introduced into (31), see (32).

$$\phi_s = \phi_s^* + \frac{k_6 \cdot (2{,}5\,\text{cm} - c) \cdot 58\,\text{MPa}}{\sigma_s} \tag{32}$$

Provided concrete tensile strength

As the concrete tensile strength $f_{ct,eff}$ effects the maximum bar diameter ϕ_s linearly, see (29), a modification of the table value is simply done by multiplication, see (33).

$$\phi_s = \phi_s^* \frac{f_{ct,eff}}{2{,}9\text{MPa}} \tag{33}$$

Provided reinforcement area

With a growing reinforcement area even if the steel stress is set to a constant value the crack width decreases.

In 3.1.2 the ratio n of the provided reinforcement area A_s to the assumed $A_{s,sc}$ is introduced. This is done for easier handling of the provided A_s.

An approximation to allow for $n \neq 1$ often used is to multiply the table value ϕ_s^* with the ratio n, see (34).

$$\phi_s = \phi_s^* \cdot n \tag{34}$$

This is not mathematically exact, see (9), and can furthermore be insecure, see Fig. 17. To avoid the approximation (34) being insecure a nationally determined factor $k_7 < 1$ needs to be multiplied to decrease the product, see (35).

$$\phi_s = \phi_s^* \cdot n \cdot k_7 \tag{35}$$

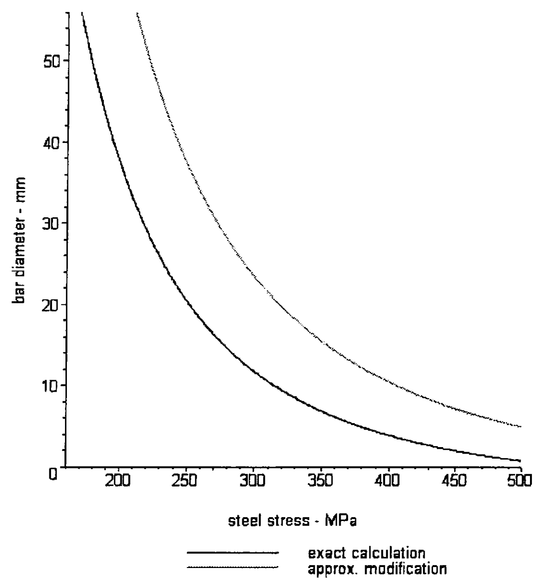

Fig. 17 Insecurity for simple approximation $\phi_s = \phi_s^* \cdot n$

This approximation (35) may be optional. This means it will only be used if its result is more favourable than the original table value. This could be written as in (36).

$$\phi_s = \phi_s^* \cdot n \cdot k_7 > \phi_s^* \tag{36}$$

If the ration n should be avoided in the code, equation (36) can be written as (37).

$$\phi_s = \phi_s^* \cdot \frac{A_s \cdot \sigma_s \cdot k_7}{2{,}5 \cdot (h-d) \cdot b \cdot 2{,}9\,\text{MPa}} > \phi_s^* \tag{37}$$

For a recommendation for k_7 the relevant cases should be determined. The ratio n will normally not be greater than three. Hence, the considered interval lies between one and three. In this interval k_7 should not produce insecure results for the bar diameter ϕ_s, but should also not be to conservative. If k_7 would be less than $\frac{1}{3}$ the modification would be more unfavourable than the original table value in the complete interval between one and three.

A value for k_7 that produced negligible insecurities would be 0,5, see Fig. 18.

$$k_7 = 0{,}5 \tag{38}$$

In prEN 1992-1-1 (Jan 2001 – 2nd draft) the minimum reinforcement area $A_{s,min}$ according to [7.1] was additionally considered. Nevertheless normally the difference between $A_{s,sc}$ and $A_{s,min}$ is too small to have any effect on the relatively rough modification for the provided reinforcement area. Hence, no extra modification or equation is needed.

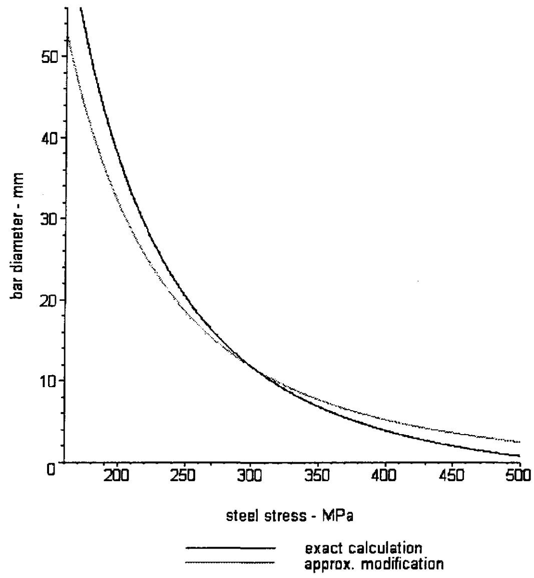

Fig. 18 Graph for w_k = 0,2 mm, c =2,5 cm, k_7 = 0,5

Compiled formula for modification

The modification for concrete cover, see (32), effective concrete tensile strength, see (33), and reinforcement area, see (37), are compiled into one formula, see (39).

$$\phi_s = \left(\phi_s^* + \frac{k_6 \cdot (2{,}5\,\mathrm{cm} - c) \cdot 58\,\mathrm{MPa}}{\sigma_s} \right) \cdot \frac{A_s \cdot \sigma_s \cdot k_7}{2{,}5 \cdot (h-d) \cdot b \cdot 2{,}9\,\mathrm{MPa}} >$$

$$\left(\phi_s^* + \frac{k_6 \cdot (2{,}5\,\mathrm{cm} - c) \cdot 58\,\mathrm{MPa}}{\sigma_s} \right) \cdot \frac{f_{ct,eff}}{2{,}9\mathrm{MPa}} \qquad (39)$$

If the effect of the concrete cover should be neglected, equation (40) follows.

$$\phi_s = \phi_s^* \cdot \frac{A_s \cdot \sigma_s \cdot k_7}{2{,}5 \cdot (h-d) \cdot b \cdot 2{,}9\,\mathrm{MPa}} > \phi_s^* \cdot \frac{f_{ct,eff}}{2{,}9\mathrm{MPa}} \qquad (40)$$

5 Conclusion

Experiences and opinions on crack control vary widely among the different member states of the Eurocode program. A solution to end the debate is to provide a nationally adjustable set of formulae for crack control.

This paper analysed the competing regulations and formulae among the different stages of (pr)EN 1992-1-1 to show where and how big the differences are.

From this analysis a consistent, adjustable concept for crack control was developed. The new elements are:

- An altered equation for the crack spacing with the nationally determined parameters k_2 and k_3:

$$s_{r,\max} = k_2 c + k_3 k_4 k_5 \frac{\phi}{\rho_{p,eff}} \qquad [7.11]$$

- A new calculated table [7.2N] for maximum bar diameters:

Steel stress σ_s in MPa	Maximum bar diameter ϕ_s in mm for w_k		
	w_k = 0,4 mm	w_k = 0,3 mm	w_k = 0,2 mm
160	80	58	35
200	50	35	21
240	33	24	14
280	24	17	9
320	18	12	7
360	14	9	5
400	11	7	3
450	8	5	2

- And a new single modification function to replace [7.6] and [7.7] of EN 1992-1-1 with the nationally determined parameters k_6 and k_7:

$$\phi_s = \left(\phi_s^* + \frac{k_6 \cdot (2{,}5\,\mathrm{cm} - c) \cdot 58\,\mathrm{MPa}}{\sigma_s}\right) \cdot \frac{A_s \cdot \sigma_s \cdot k_7}{2{,}5 \cdot (h-d) \cdot b \cdot 2{,}9\,\mathrm{MPa}} >$$

$$\left(\phi_s^* + \frac{k_6 \cdot (2{,}5\,\mathrm{cm} - c) \cdot 58\,\mathrm{MPa}}{\sigma_s}\right) \cdot \frac{f_{ct,eff}}{2{,}9\,\mathrm{MPa}} \qquad [7.6]$$

6 Unterschriften / Signatures

Univ.-Prof. Dr.-Ing, Konrad Zilch	Dipl.-Ing. Michael Cyllok
Antragsteller / Applicant	Sachbearbeiter / Person in charge

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Annex A Abstracts for the research project

Vorschlag zum Abgleich verschiedener Konzepte zur Rissbreitenbegrenzung in (pr)EN 1992-1-1 (Langform – deutsch) / Proposal for a mutual adjustment of different concepts of crack control in (pr)EN 1992-1-1 (Long form – German language)

Die europäische Norm EN 1992-1-1 beschränkt wie z.B. auch ihr deutsches Pendant DIN 1045-1 die Rissbreite zur Sicherung der Dauerhaftigkeit und der Gebrauchstauglichkeit von Bauteilen aus Beton, Stahlbeton und Spannbeton. Im Verlauf der Erstellung von EN 1992-1-1 wurden die Formeln, Hilfsmittel und Bestimmungen zur Rissbreitenbegrenzung immer wieder verändert. Die letzten, sehr rigiden Veränderungen bzw. Verschärfungen in Bezug auf die Rissbreitenbegrenzung (ab September 2001) haben besonders in der Bundesrepublik Deutschland für große Diskussionen geführt. Durch einzelne Beispielrechnungen belegt, zeigte sich, dass sich für große Betondeckungen eine Bewehrungsführung (Vorgabe der maximal zu verwendenden Stabdurchmesser) ergab, die nicht mehr baupraktisch umsetzbar erschien. Zusätzlich wurde die rigide Begrenzung als nicht sinnvoll erachtet. Mit weniger strengen Grenzwerten, wie sie in früheren Versionen vorlagen und Eingang in die nationale Normung gefunden haben, wurden gebrauchstaugliche und dauerhafte Bauteile aus Beton, Stahlbeton und Spannbeton hergestellt. Eine Verschärfung der Grenzwerte wäre deshalb nicht notwendig.

Aufgrund der großen technischen Auswirkungen nicht nur auf den Massivbau, sondern auch auf den ihm verwandten Verbundbau, sollte die aktuelle Formulierung samt der dazugehörigen Hilfsmittel (Tabelle der maximal zu verwendenden Stabdurchmesser) überprüft und ggf. verbessert werden. Das Ziel der Arbeit war somit, eine konsistente und national anpassbare Normenformulierung der Rissbreitenbegrenzung einschließlich Formelapparat und Hilfsmitteln (z.B. Tabellen) bereitzustellen.

Zur Umsetzung des Ziels der Arbeit wurde eine Literaturrecherche durchgeführt, die den Modelcode 90, verschiedene Versionen des Eurocodes (pr)EN 1992-1-1, DIN 1045-1 und weiterführende Literatur berücksichtigte. Aus dieser Recherche wurden die verschiedenen Konzepte der Rissbreitenbegrenzung in der Entwicklung der Norm EN 1992-1-1 zusammengestellt. Die in dieser Zusammenstellung identifizierten Konzepte wurden daraufhin ausgewertet und die relevanten Einflussfaktoren (Betondeckung, Betonzugfestigkeit, Bewehrungsmenge) mittels einer Parameterstudie untersucht. Die Tendenz aus den oben erwähnten Beispielrechungen eines baupraktisch nicht umsetzbaren Grenzdurchmessers für große Betondeckungen und eines sehr großzügigen Grenzdurchmessers für kleine Betondeckungen konnte für die neuere Formulierung (ab September 2001) bestätigt werden. Aus den Ergebnissen wurde eine konsistente und national anpassbare Bemessung mit dazupassenden Hilfsmitteln entwickelt, die einige Elemente der neueren Formulierung verändert. Dies betrifft insbesondere die Hilfsmittel, da diese mit dem neueren Ansatz zur Berechnung der Rissbreite nicht harmonierten. Für die alte Formulierung (Januar 2001) musste dies nicht getan werden, da z.B. in DIN 1045-1 mit der Berechnung der Rissbreite konsistente Hilfsmittel bereits vorliegen. Die die neuere Formulierung verändernden Elemente werden im Folgenden aufgelistet:

- Eine modifizierte Gleichung zur Bestimmung des Rissabstands mit den national bestimmbaren Parametern k_2 und k_3: $s_{r,\max} = k_2 c + k_3 k_4 k_5 \dfrac{\phi}{\rho_{p,eff}}$ [7.11]

- Eine neu berechnete Tabelle [7.2N] für den Grenzdurchmesser:

Stahlspannung σ_s in MPa	Grenzdurchmesser ϕ_s in mm für w_k		
	w_k = 0,4 mm	w_k = 0,3 mm	w_k = 0,2 mm
160	80	58	35
200	50	35	21
240	33	24	14
280	24	17	9
320	18	12	7
360	14	9	5
400	11	7	3
450	8	5	2

- Eine neue Anpassungsfunktion als Ersatz für [7.6] und [7.7] aus EN 1992-1-1 mit den national bestimmbaren Parametern k_6 und k_7:

$$\phi_s = \left(\phi_s^* + \frac{k_6 \cdot (2{,}5\,\text{cm} - c) \cdot 58\,\text{MPa}}{\sigma_s}\right) \cdot \frac{A_s \cdot \sigma_s \cdot k_7}{2{,}5 \cdot (h-d) \cdot b \cdot 2{,}9\,\text{MPa}} >$$

$$\left(\phi_s^* + \frac{k_6 \cdot (2{,}5\,\text{cm} - c) \cdot 58\,\text{MPa}}{\sigma_s}\right) \cdot \frac{f_{ct,eff}}{2{,}9\,\text{MPa}} \qquad [7.6]$$

Vorschlag zum Abgleich verschiedener Konzepte zur Rissbreitenbegrenzung in (pr)EN 1992-1-1

(Kurzzusammenfassung)

Die europäische Norm EN 1992-1-1 beschränkt die Rissbreite zur Sicherung der Dauerhaftigkeit und der Gebrauchstauglichkeit von Bauteilen aus Beton, Stahlbeton und Spannbeton. Im Verlauf der Erstellung der Norm wurden die Formeln, Hilfsmittel und Bestimmungen zur Rissbreitenbegrenzung immer wieder verändert. Die letzten Veränderungen bzw. Verschärfungen in Bezug auf die Rissbreitenbegrenzung (ab September 2001) haben besonders in der Bundesrepublik Deutschland für große Diskussionen geführt, da mit weniger strengen Grenzwerten, wie sie in früheren Versionen vorlagen und Eingang in die nationale Normung gefunden haben, bereits gebrauchstaugliche und dauerhafte Bauteile aus Beton, Stahlbeton und Spannbeton hergestellt wurden.

Aufgrund der großen technischen Auswirkungen sollte die aktuelle Formulierung samt der dazugehörigen Hilfsmittel (Tabelle der maximal zu verwendenden Stabdurchmesser) überprüft und ggf. verbessert werden. Das Ziel der Arbeit war somit, eine konsistente und national anpassbare Normenformulierung der Rissbreitenbegrenzung einschließlich Formelapparat und Hilfsmitteln (z.B. Tabellen) bereitzustellen.

Zur Umsetzung des Ziels der Arbeit wurde eine Literaturrecherche einschließlich der Untersuchung verschiedener Fassungen der Norm (pr)EN 1992-1-1 durchgeführt. Aus dieser wurden die verschiedenen Konzepte der Rissbreitenbegrenzung in der Entwicklung der Norm zusammengestellt. Die in dieser Zusammenstellung identifizierten Konzepte wurden daraufhin ausgewertet und die relevanten Einflussfaktoren mittels einer Parameterstudie untersucht. Es zeigte sich die Tendenz eines baupraktisch nicht umsetzbaren Grenzdurchmessers für große Betondeckungen und eines sehr großzügigen Grenzdurchmessers für kleine Betondeckungen für die neuere Formulierung (ab September 2001). Aus den Ergebnissen wurde eine konsistente und national anpassbare Bemessung mit dazupassenden Hilfsmitteln entwickelt, die einige Elemente der neueren Formulierung verändert. Dies betrifft insbesondere die Hilfsmittel, da diese mit dem neueren Ansatz zur Berechnung der Rissbreite nicht harmonierten.

Proposal for a mutual adjustment of different concepts of crack control in (pr)EN 1992-1-1

(Short abstract)

In the European standard EN 1992-1-1 cracking must be controlled to provide durability and serviceability of concrete members. In the process of developing the standard, the equations, utilities and regulations for crack control were changed over and over again. The most recent changes for crack control (beginning with September 2001) lead to a big controversy. The less rigid rules from earlier versions have been already used nationally and with them serviceable and durable members have already been produced.

Due to the great technical effects, the recent rules including utilities (table with maximum bar diameters) should be checked and be improved where necessary. Hence, the goal of this paper was to provide a consistent and nationally adjustable formulation to control cracks including equations and utilities (e.g. tables).

To implement the goal a literature research including the investigation of the different versions of the standard (pr)EN 1992-1-1 was undertaken. From this the diverse concepts for crack control in the different stages of the standard were compiled. The here identified concepts were evaluated and the relevant parameters were analysed. The results showed for the recent version (beginning with September 2001) a tendency of not feasible maximum bar diameters in day-to-day construction practice for a large concrete cover. They also showed very liberal maximum bar diameters for a small concrete cover.

From this outcome a consistent and nationally adjustable design including utilities was developed, changing some elements of the recent formulation. This affected especially the utilities, as they didn't match with the recent equation to calculate the crack width.

Proposition d'un ajustage mutuel des concepts de la maîtrise de la fissuration en EN 1992-1-1
(Petit résumé)

Selon la norme européenne EN 1992-1-1 il faut maîtriser la fissuration afin d'assurer la durabilité et l'utilité des éléments en béton. En élaborant la norme, les équations, les aides et les règles de la maîtrise de la fissuration étaient changés continuellement. Les derniers changements ou durcissements de la maîtrise de la fissuration (au début de septembre 2001) ont provoqué une grande débatte en Allemagne parce qu'avec les valeurs limites moins strictes des versions précédentes on déjà produisait des éléments en béton durables et aptes au service.
En vertu des grands effets techniques il faut examiner (le cas échéant, augmenter) les formulations et leurs aides (tableau de diamètre maximal des barres). Ainsi l'objectif de la recherche était de proposer une formulation de la maîtrise de la fissuration consistante et ajustable, y compris équations et aides (par exemple tableaux).
En réaliser l'objectif on performait une recherche en littérature qui comprit des versions différentes de la norme (pr)EN 1992-1-1. Cela formait la base pour assembler des concepts différents de la maîtrise de la fissuration en les versions différentes de la norme. Les paramètres identifiés dans l'assemblage furent investigués. Pour des grands enrobages, on recoît tendanciellement des diamètres maximaux ne pas réalisables en pratique, si l'on suit les dernières formulations(au début de septembre 2001), tandis que pour des petits enrobages, les diamètres maximaux deviennent très libéraux. Ces résultats conduisaient au développement d'un calcul consistant et ajustable au moyen des aides appropriées, ce qui change quelques éléments de la dernière formulation.