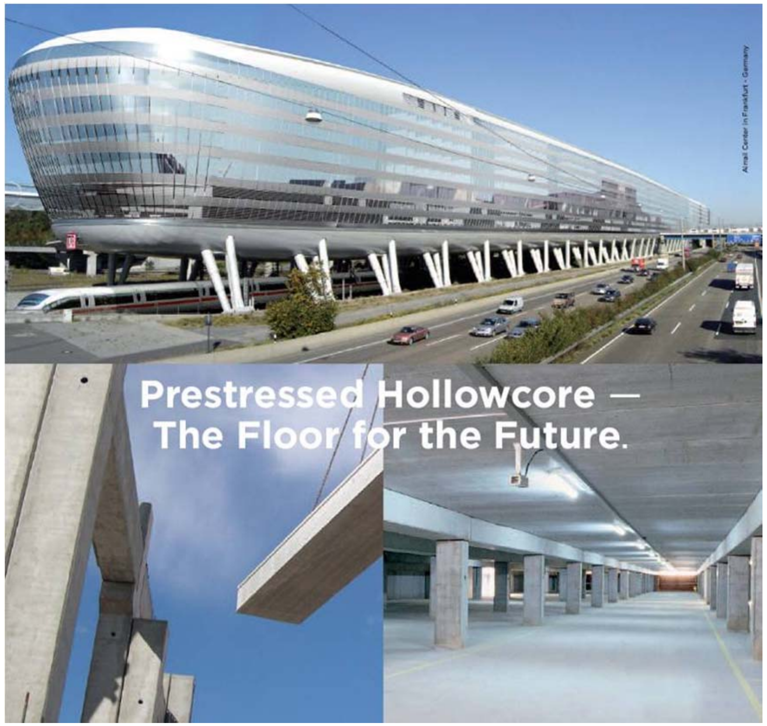
Eurocode 2 and EN 1168

(Dutch) Calculation experiences



Technical Seminar
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RWTH-IMB Aachen (GE)

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Use of Eurocodes in The Netherlands

- Application of the Eurocodes (with Dutch NA) is still not obligatory! ➔ no experiences
- Latest information: Changes of the Building Law (Bouwbesluit 2012) in The Netherlands will take effect at July 1st 2012 (or April 1st)
- Dutch Building Law only assigns the ULS !
- This means that SLS is subject of private law. E.g: a product approval

Use of Eurocode 2 and EN 1168

- **Eurocode 2** : Design of the structure and hollow cores
- **EN 1168** : Product code (product, production requirements and CE marking) and some specific design matters in informative annexes

  "special status": Shear capacity

Calculation aspects

- Relevant topics:

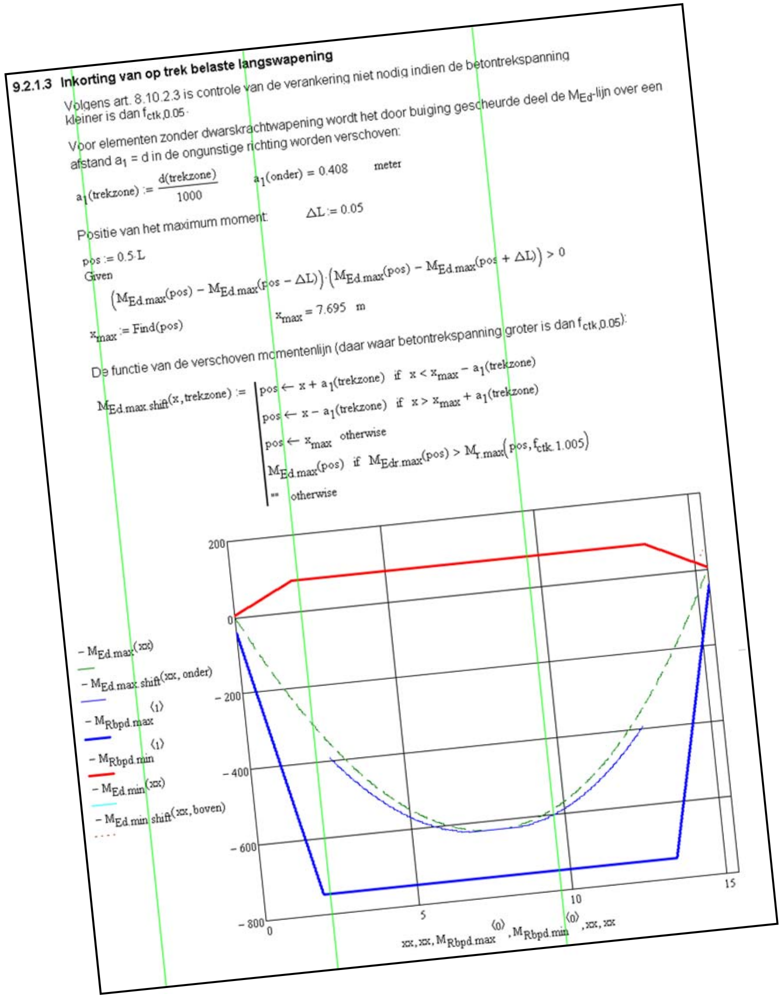
  Deflection control

  Composite action

  Shearcapacity

  Transverse load distribution

  Crack control



9.2.1.3 Inkorting van op trek belaste langswapening

Volgens art. 8.10.2.3 is controle van de verankering niet nodig indien de betontrekspanning kleiner is dan $f_{ctk,0.05}$.

Voor elementen zonder dwarskrachtwapening wordt het door buiging gescheurde deel de M_{Ed}-lijn over een afstand $a_1 = d$ in de ongunstige richting worden verschoven:

$a_1(trekzone) := \frac{d(trekzone)}{1000}$ $\quad a_1(onder) = 0.408$ meter

Positie van het maximum moment: $\quad \Delta L := 0.05$

$pos := 0.5 \cdot L$

Given

$(M_{Ed.max}(pos) - M_{Ed.max}(pos - \Delta L)) \cdot (M_{Ed.max}(pos) - M_{Ed.max}(pos + \Delta L)) > 0$

$x_{max} := Find(pos)$ $\quad x_{max} = 7.695$ m

De functie van de verschoven momentenlijn (daar waar betontrekspanning groter is dan $f_{ctk,0.05}$):

$M_{Ed.max.shift}(x, trekzone) :=$
- $pos \leftarrow x + a_1(trekzone)$ if $x < x_{max} - a_1(trekzone)$
- $pos \leftarrow x - a_1(trekzone)$ if $x > x_{max} + a_1(trekzone)$
- $pos \leftarrow x_{max}$ otherwise
- $M_{Ed.max}(pos)$ if $M_{Edr.max}(pos) > M_{r.max}(pos, f_{ctk} \cdot 1.005)$
- "" otherwise

Deflection control

- Requirements are in Eurocode 2 (not NDP):
  "total deflection" $\leq$ 0.004 x L
  "additional deflection" < 0.002 x L

- Important parameters:
  - Creep coefficient
  - Effective modulus of elasticity

- Uncracked members:
  tensile stresses < f_{ctm} (or $f_{ctm.fl}$)

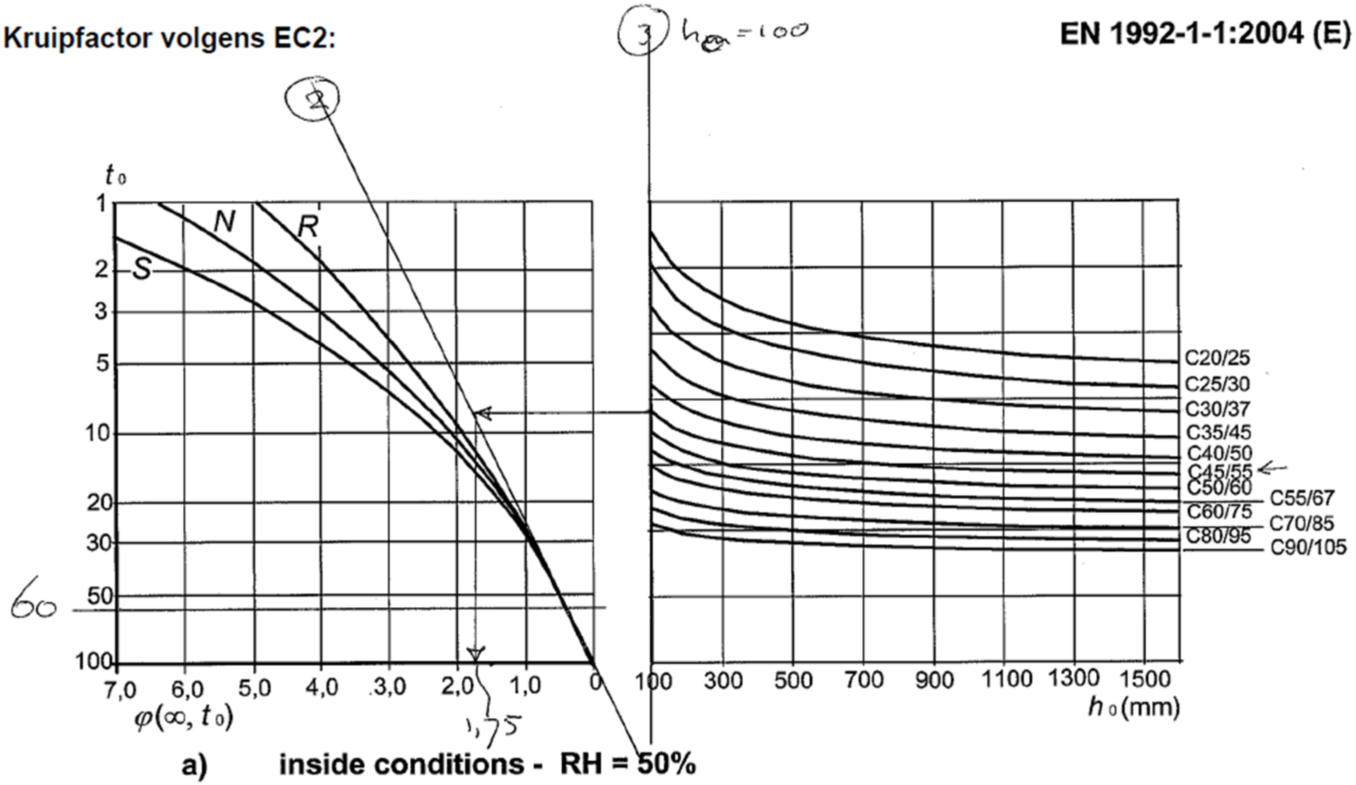
Deflection control

Kruipfactor volgens VBC:

$k_c := 2.6$ $k_d := 0.6$ $k_b := 0.8$ $k_h := 1.0$ $k_t := 1.0$ (t=oo)

$\varphi_{vbc} := k_c \cdot k_d \cdot k_b \cdot k_h \cdot k_t = 1.25$

Kruipfactor volgens EC2:

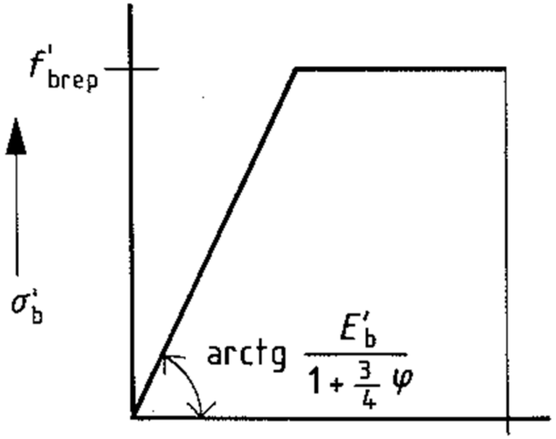


Uit figuur 3.1 van NEN-EN 1992-1-1: $\varphi_{ec2} := 1.75$

Increase creepcoefficient 40% !

Deflection control

- Dutch code:



- Eurocode 2:

(5) For loads with a duration causing creep, the total deformation including creep may be calculated by using an effective modulus of elasticity for concrete according to Expression (7.20):

$$E_{c,eff} = \frac{E_{cm}}{1+\varphi(\infty,t_0)} \tag{7.20}$$

where:

$\varphi(\infty,t_0)$ is the creep coefficient relevant for the load and time interval (see 3.1.3)

Conclusion: Increase deflection due to creep 54%

Composite action

- EC2 6.2.5 Shear at the interface between HC and structural topping

Very smooth: a surface cast against steel, plastic or specially prepared wooden moulds: c = 0.025 to 0.10 and μ = 0.5

Smooth: a slipformed or extruded surface, or a free surface left without further treatment after vibration: **c = 0.20 and μ = 0.6**

Rough: a surface with at least 3 mm roughness at about 40 mm spacing, achieved by raking exposing of aggregate or other methods giving an equivalent behaviour: c = 0.40 and μ = 0.7

- For example: max. design shearforce due to additional load:

(f_{ctd} = 1.0 MPa; z = 260 mm; width of interface b_i = 1000 mm)

V_{Rdi} = 0.20 x 1.0 x 260 x 1000 / 1000 = **52 kN /m**

Shear capacity

- EN 1168: extended formula

$$V_{Rd,c} = \frac{I \cdot b_w}{S} \sqrt{(f_{ctd})^2 + \alpha_l \sigma_{cp} f_{ctd}}$$

Eurocode 2 formula 6.4:
For cross-sections **where the width varies over the height**, the maximum principal stress may occur on an axis other than the centroidal axis. In such a case the minimum value of the shear resistance should be found **by calculating VRd,c at various axes** in the cross-section.

BUT HOW?

Extended formula in EN 1168:

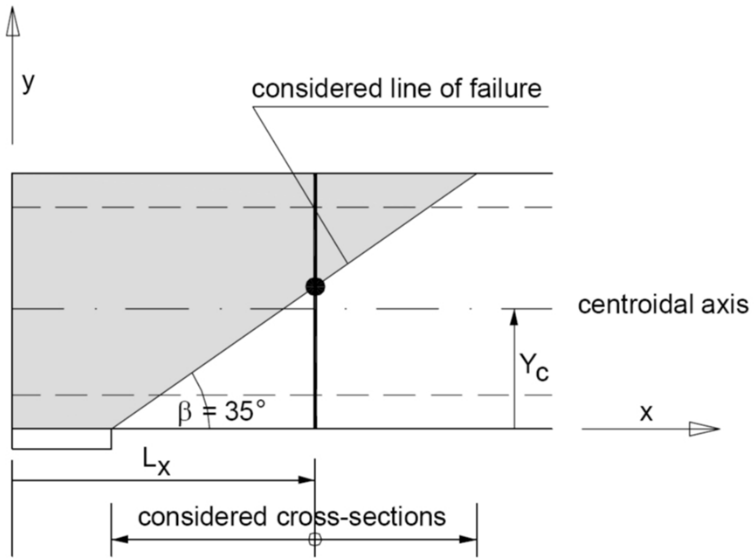
$$V_{Rdc} = \frac{I b_w(y)}{S_c(y)} \left(\sqrt{(f_{ctd})^2 + \sigma_{cp}(y) f_{ctd}} - \tau_{cp}(y) \right)$$

where

$$\sigma_{cp}(y) = \sum_{t=1}^{n} \left\{ \left[\frac{1}{A_i} + \frac{(Y_c - y)(Y_c - Yp_t)}{I} \right] \cdot P_t(l_x) \right\} - \frac{M_{Ed}}{I} \cdot (Y_c - y) \quad \text{(positive if compressive)}$$

$$\tau_{cp}(y) = \frac{1}{b_w(y)} \cdot \sum_{t=1}^{n} \left\{ \left[\frac{A_c(y)}{A_i} - \frac{S_c(y) \cdot (Y_c - Yp_t)}{I} + Cp_t(y) \right] \cdot \frac{dP_t(l_x)}{dx} \right\}$$

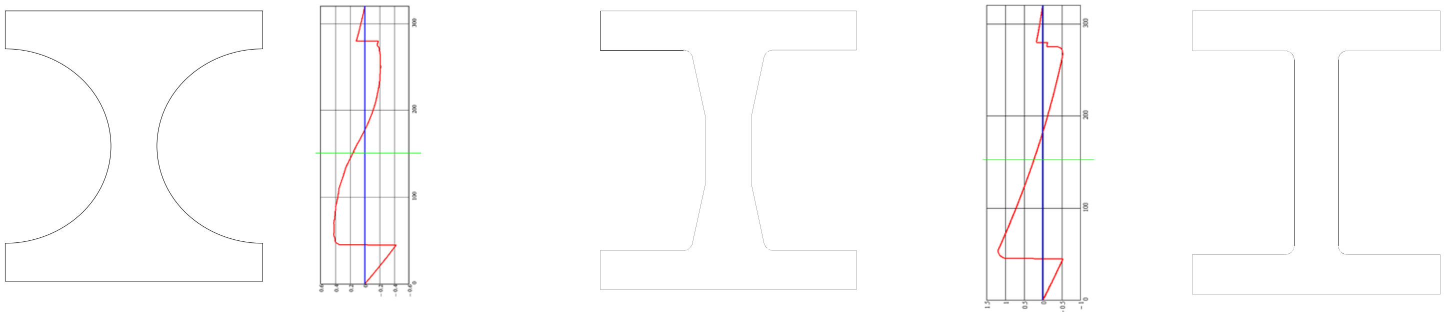
Shear capacity



- Check principle stress at points along the 35° line
- Hand calculation impossible
- Use automated calculation: e.g. a program or MathCad.

Shear capacity

Examples EN 1168 with same webthickness en prestressingforce



V_{Rdc} = 30.3 kN | V_{Rdc} = 27.1 kN | V_{Rdc} = 18.2 kN

EC 2 formula 6.4:

$$V_{Rd,c} = \frac{I \cdot b_w}{S} \sqrt{(f_{ctd})^2 + \alpha_l \sigma_{cp} f_{ctd}}$$

$V_{Rd,c}$ = 30.2 kN | V_{Rdc} = 33.0 kN | V_{Rdc} = 34.0 kN

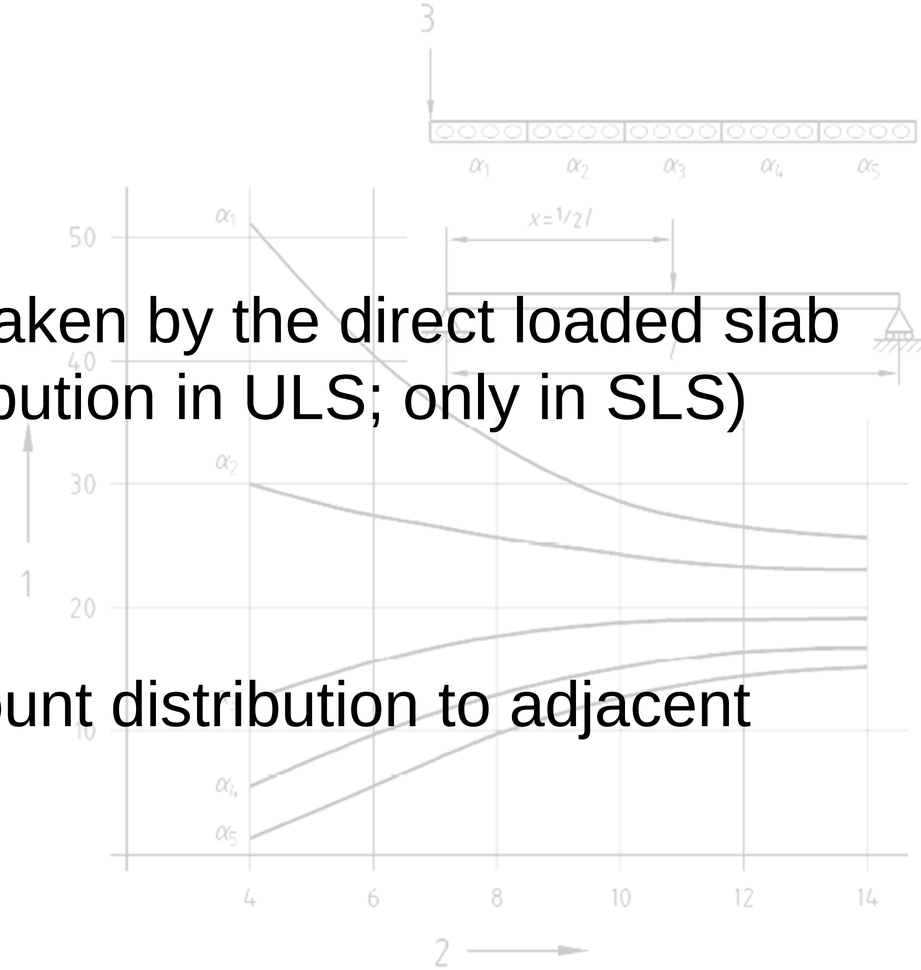
Transverse load distribution

- 2 Possibilities:

  A: in ULS all loads are taken by the direct loaded slab
  (in fact: no load distribution in ULS; only in SLS)

  or

  B: in ULS take into account distribution to adjacent elements



Transverse load distribution

- Restriction for the concentrated loads with regard to the transverse tensile stresses

$$F_k = 3\, W_\ell\, f_{ctk\,0,05}$$

- For example: max. concentrated load for slab without a topping:

(HC 260; W_l = 5300 mm^3/mm; $f_{ctk0.05}$ = 2.7 MPa)

method A: $F_k = 3 \,.\, 5300 \,.\, 2.7 \,.\, 10^{-3} = 42.9$ kN

method B: $F_d = 3 \,.\, 5300 \,.\, 1.8 \,.\, 10^{-3} = 28.6$ kN

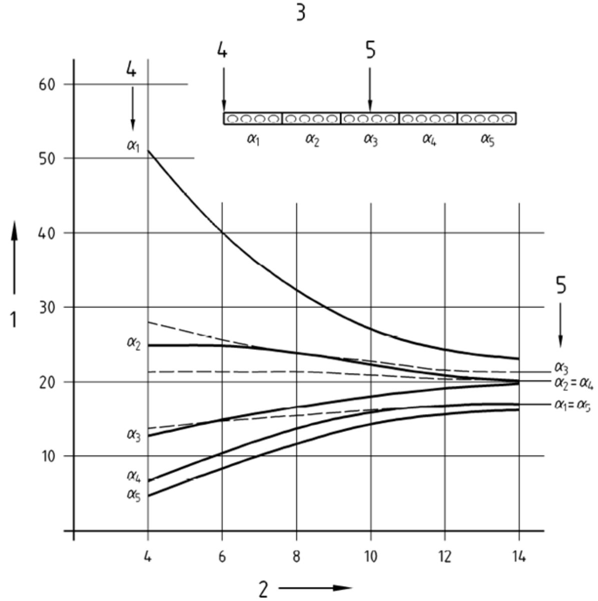
with $\gamma_{load} \approx 1.4$ => $F_k \approx 20.4$ kN

Transverse load distribution

- Our experience:

  In general: only use transverse load distribution over the joints in **SLS**

  Only for special cases use (e.g. the graphs in Annex C) load distribution over several slab elements in ULS.



Crack control - EN 1992-1-1 7.3

(5) A limiting calculated crack width, w_{max}, taking into account the proposed function and nature of the structure and the costs of limiting cracking, should be established.

Note: The value of w_{max} for use in a Country may be found in its National Annex. The recommended values for relevant exposure classes are given in Table 7.1N.

Table 7.1N Recommended values of w_{max} (mm)

Exposure Class	Reinforced members and prestressed members with unbonded tendons	Prestressed members with bonded tendons
	Quasi-permanent load combination	Frequent load combination
X0, XC1	0,4[1]	0,2
XC2, XC3, XC4	0,3	0,2[2]
XD1, XD2, XS1, XS2, XS3		Decompression

Note 1: For X0, XC1 exposure classes, crack width has no influence on durability and this limit is set to guarantee acceptable appearance. In the absence of appearance conditions this limit may be relaxed.

Note 2: For these exposure classes, in addition, decompression should be checked under the quasi-permanent combination of loads.

Crack control - questions on interpretation

7.3.2 Minimum reinforcement areas

(1)P If crack control is required, a minimum amount of bonded reinforcement is required to control cracking in areas where tension is expected. The amount may be estimated from equilibrium between the tensile force in concrete just before cracking and the tensile force in reinforcement at yielding or at a lower stress if necessary to limit the crack width.

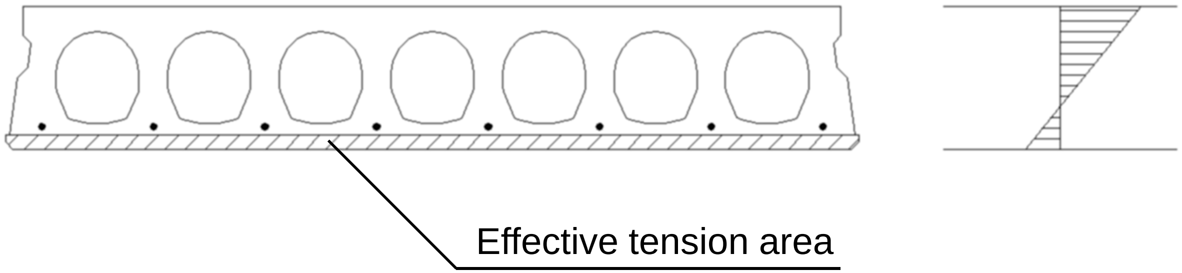
→ Crack control is required → determine the min. reinforcement ✓

(4) In prestressed members no minimum reinforcement is required in sections where, under the characteristic combination of loads and the characteristic value of prestress, the concrete is compressed or the absolute value of the tensile stress in the concrete is below $\sigma_{ct,p}$.

Note: The value of $\sigma_{ct,p}$ for use in a Country may be found in its National Annex. The recommended value is $f_{ct,eff}$ in accordance with 7.3.2 (2).

? No minimum reinforcement needed and no crack control needed?

Crack control - questions on interpretation



Depth of the effective tension area = the lesser of:

2,5 . (h – d)
(h – x) / 3
or
h/2 = 19 mm

No strands in the effective tension area!

Requirements not satisfied!

Crack control - questions on interpretation

Strain variation:

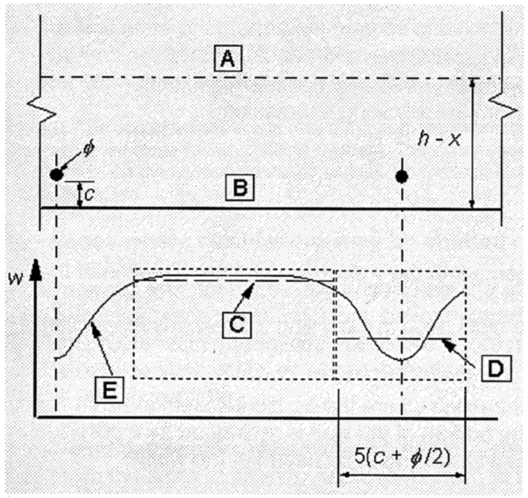
$\varepsilon_{sm} - \varepsilon_{cm}$ = 0,00037

Calculated crack spacing($S_{r,max}$):

Expression 7.11: 484 mm

Expression 7.14: 190 mm

?



A - Neutral axis

B - Concrete tension surface

C - Crack spacing predicted by Expression (7.14)

D - Crack spacing predicted by Expression (7.11)

E - Actual crack width

Crack control - National Annex (Netherlands)

to be published

Tabel 7.1N — Aanbevolen waarden van w_{max} en daarvan afgeleide grootheden

Milieuklasse	Elementen met betonstaal en/of voorspanstaal zonder aanhechting	Elementen met een combinatie van betonstaal en voorspanstaal met aanhechting	Elementen met uitsluitend voorspanstaal met aanhechting
	Frequente belastingscombinatie	Frequente belastingscombinatie	Frequente belastingscombinatie
X0, XC1	$w_{max} \leq 0{,}4$ mm [a]	$w_{max} \leq 0{,}3$ mm	$\Delta\sigma_p \leq \xi\, 275$ N/mm^2
XC2, XC3, XC4	$w_{max} \leq 0{,}3$ mm	$w_{max} \leq 0{,}2$ mm	$\Delta\sigma_p \leq \xi\, 175$ N/mm^2
XD1, XD2, XD3, XS1, XS2, XS3	$w_{max} \leq 0{,}2$ mm	$w_{max} \leq 0{,}1$ mm	$\Delta\sigma_p \leq \xi\, 75$ N/mm^2

[a] Voor milieuklasse X0 en XC1 heeft de scheurwijdte geen invloed op de duurzaamheid; deze grens is gesteld om een in het algemeen aanvaardbaar uiterlijk te verkrijgen. Bij afwezigheid van voorwaarden ten aanzien van het uiterlijk mag deze beperking zijn afgezwakt.

Ingeval scheurwijdtes zijn berekend in overeenstemming met 7.3.3 of 7.3.4 voor de bepaling van de duurzaamheid, mogen de waarden in tabel 7.1N zijn vermenigvuldigd met een factor k_x:

$$k_x = \frac{c_{toegepast}}{c_{nom}} \leq 2$$

Crack control - National Annex (Netherlands)

- Minimum reinforcement:

  7.3.2 (1)P is not necessary if:

  deformation by shrinkage or temperature is not hindered

  OR

  structure is in XC1 and temperature gradient will not exceed 20K.

Crack control - National Annex (Netherlands)

Practical result for the design of hollow cores in The Netherlands with regard to crack control:

- General calculationmodel for XC1 and XC3.
- XC1: Crack width has no influence on the durability. In fact: calculation for non-estetic members is not necessary.
- XC3: Still practical solutions possible such as carparking.

Thank you for your attention