Crack Width Verification - B11

Contents

Standards and acronyms / National Annexes

Descriptions and formulas referring to National Annexes are marked with the following abbreviations:

Country Codes for National Annexes (extensive assignment table: see B2 Documentation)

Example: NA-D refers to the National Annex for Germany,
NA-A refers to the National Annex for Austria etc.

Application options

The software application verifies the crack width in accordance with the following standards:

Eurocode EN 1992-1-1:

Implemented National Appendixes (NA):

NA-D:	Germany DIN 1992-1-1/ NA:2015-09 and DIN EN 1992-1-2/NA:2015-09
NA-A:	Austria ÖNORM B 1992-1-1:2018 and ÖNORM B 1992-1-2:2011 These NA replace the previously valid from 2007 and 2011
NA-GB:	Great Britain NA to BS EN 1992-1-1 A2:2015-07, BS8500-1:2015 and NA to BS EN 1992-1-2:2004
NA-NL	Netherland NEN EN 1992-1-1 + C2:2011/NB:2011 and NEN-EN 1992-1-2+C1:2011/NB:2011 These NA replace the previously valid from 2007
NA-B	Belgium NBN EN 1992-1-1 ANB:2010 and NBN EN 1992-1-2 ANB:2010
NA-CZ	Czech Republic CSN EN 1992-1-1/NA:2011 and CSN EN 1992-1-2/NA:2007 The former NA replaces the previously valid 2007 one
NA-PL	Poland PN EN 1992-1-1:2008/NA:2010 and PN-EN 1992-1-2:2008/NA:2010

Comments referring to the calculation in accordance with DIN EN 1992-1-1 / NA:2015-12

Because of the occurrence of damages, the general assumption of 50 % tensile strength under early restraint was removed from the National Annex (NCI to 7.3.2).
Moreover, the NA distinguishes between early and late restraint and points out the consequences of this distinction for the design and the execution.
For special verification variants in connection with early restraint, the default was set to fct,eff = 0.65 fctm, based on a recommendation in reference /22/.

A more stringent classification with respect to the exposure classes XC3, XD1 and XD3 now applies to traffic areas loaded by de-icing salt, also justified by the occurrence of damages. The possible reduction of the concrete cover by 10 mm when applying a crack-bridging coating was cancelled for the XD exposure classes. A maintenance and repair schedule is required for all execution variants of traffic areas loaded by de-icing salt. This schedule is to be based on the directive “Schutz und Instandsetzung von Bauteilen” (Protection and Repair of Structural components) /23/ published by the German Committee for Reinforced Concrete DAfStb.

Former standards:

DIN 1045-1 (2008), DIN 1045-1 (2001) incl. amend. 1 + 2 and Booklet 525 of the German Committee for Reinforced Concrete (DAfStb).

The verification of the crack width limitation under loading (axial force and moment) can be performed for rectangular and T-beam cross sections. You can optionally select whether to calculate the limit diameter or the crack width for a given reinforcement or the required reinforcement for a given diameter. The permissible crack width is determined by the durability requirements of the selected standard in the first place. If special requirements apply (e.g. waterproof concrete), you can specify a user-defined permissible crack width, however.

Moreover, you can calculate the minimum reinforcement for imposed bending on top, imposed bending on bottom or centric restraint based on the internal crack forces for the specified cross sections. You can determine the tensile strength of the concrete either by selecting a time-dependent value from the drop-down list, such as 28 days, or enter a user-defined value for the strength. This allows you to perform verifications for early restraint as well as for late restraint.

You can perform a more accurate verification for floor slabs under early restraint caused by the discharge of hydration heat in accordance with the method described in reference /3/.

You can perform a more accurate verification for walls on previously cast foundations under early restraint caused by the discharge of hydration heat in accordance with the method described in reference /16/.

In may happen that both methods produce much more favourable results than the verification of the minimum reinforcement when the more accurately calculated reactive force remains below the internal crack force. Therefore, you should define all values with utmost care when using the more accurate calculation method.

To obtain results in the software that are comparable to the charts by Meyer /9/ showing the crack width verification under centrical restraints due to hydration, you should calculate the minimum reinforcement of a rectangular cross section with appropriate settings of the options for the effective tensile concrete strength and the internal restraint. As expected, the resulting reinforcement values are higher than those obtained in the methods mentioned above, because the entire internal crack force is considered as a reactive force in this case. In the methods mentioned above, the reactive force is calculated more accurately, however.

Generally, you should keep in mind that hydration and the early restraint are not the only reactive forces that act on a structural component during its service life. Reference /21/ points out that late restraint is rather the rule than the exception. Among other reasons, this is due to newly developed construction methods such as naturally vented underground parkings.

Notes concerning the versions 02/11 and higher

Verification of the crack width under action of reactive forces caused by discharge of hydration heat at walls:

The verification was completely revised in the software. The method in accordance with Booklet 466 by the German Committee for Reinforced Concrete (DAfStb) did not comply with the state of the art any more and was replaced by the method in accordance with Lohmeyer, Ebeling "Weiße Wannen einfach und sicher".

The medium component temperature is essentially determined by the temperature due to the hydration heat Q_h, which depends on the component thickness, the cement portion and cement type. This method allows a more precise and subtle determination of the reactive force.

If the required parameters are not known when preparing the structural calculation, you can specify a medium component temperature on the safe side as before.

The modulus of elasticity is no longer reduced by creep of the early-age concrete. Instead of designing the different areas of the wall h1, h2 and sometimes even h3, design is now done uniformly for the whole wall assuming a reactive force that is calculated using the stress at h/4 and limited by fcteff (t). Therefore, the time for fcteff is of greater importance than before and should be determined with utmost care.

Crack width verification in accordance with Eurocode:

Another innovation of this software version is the option allowing a verification of the crack width in accordance with the Eurocode and its implemented National Annexes. There are some differences to the usual approach based on DIN 1045-1.

The higher values for the concrete's modulus of elasticity produce also higher reactive forces.

If you use the functionality for the time-dependent development of the modulus of elasticity and the tensile strength in accordance with the Eurocode, slightly lower strengths (lower upper limits for the reactive forces) and slightly higher moduli of elasticity (higher reactive force) result in comparison to the method in accordance with MC 90 used until recently.

Since the formulae system for the crack width verification in accordance with the different National Annexes was generalised, the simplification $F_{se} = 0$ was dispensed with also in the German Annex. Therefore, slightly lower values for the required reinforcement are obtained than with DIN 1045-1 under identical conditions.

You can find a comparative analysis of the results produced by the different NAs in /19/.

In connection with the publishing of newer versions of some National Annexes, some changes have been applied to the crack width verification. You can find more details in /20/.

General:

In former versions of this software, hydration was taken into account as a short-term action by default in the verification of cracking due to hydration. This setting is now user-defined, because the assumption of a short-term action is controversial among experts.

Higher requirements on components impermeable to water as defined by the corresponding guideline of the German Committee for Reinforced Concrete DAfStb or in accordance with EN 1992-3 can be realised via user-defined settings.

Basis of calculation

Crack width verification as per Eurocode

With the help of the crack formula Eq. 7.8 you can calculate either the limiting diameter for a selected reinforcement or the crack width for a given diameter.

The result allows you to calculate the reinforcement, which is required to comply with the permissible crack width on the side of the tension zone.

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

$\varepsilon_{sm} - \varepsilon_{cm}$: average expansion difference between steel and concrete (equation .7.9)

$$\varepsilon_{sm} - \varepsilon_{cm} = \frac{\sigma_s - k_t \frac{f_{ct,eff}}{\rho_{p,eff}}\left(1 + \alpha_e \rho_{p,eff}\right)}{E_s} \geq 0.6 \frac{\sigma_s}{E_s}$$

k_t: 0.6 short-term action
0.4 long-term action

σs: steel stress in state II
calculation with $E_{ceff} = E_{cm} / (1 + \varphi\ (t{=}\infty))$

α_e = E_s / E_{ceff}

ρ_{eff}: reinforcement ratio in the effective tension zone
$\rho_{eff} = (A_s + A_p \cdot \xi 1^2)$ / A_{ceff}
A_s: reinforcing steel area included in A_{ceff}
A_p: tensioning steel area included in A_{ceff}
ξ: factor for the bond characteristics of tensioning steel

A_{ceff}: area of the effective tension zone

$A_{ceff} = h_{eff} \cdot b_{eff}$
h_{eff} 2.5 · D1 < (h-X0II)/3
X0II: compression zone height in state II:
if no reinforcement with a distance < heff
was defined, heff = (h-X0I)/2 applies
b_{eff} effective tension zone width for T-beams

NA-D:
as per /5/ p. 191 in accordance with the permissible distribution width of the tensile reinforcement
$b_{eff} <= \sum(0.5 \cdot b_{eff,i}(Z.I)) + bw <= bf$ (NCI to 9.2.1.2 (2))
Definition: -> control dialog for the crack width verification

$s_{r,max}$: maximum crack spacing (Eq. 7.11)

$$s_{r,max} = k_3 \cdot c + \frac{k_1 \cdot k_2 \cdot k_4 \cdot \phi}{\rho_{p,eff}}$$

k_1: coefficient for reinforcement bond quality
0.8 good bond quality
1.6 poor bond quality

k_2: coefficient of expansion distribution
Bending: 0.5
Tension: 1.0
Bending + tension: $(\varepsilon 1 + \varepsilon 2) / (2 \cdot \varepsilon 1)$

c: concrete cover on longitudinal reinforcement

ϕ: average diameter of the tensile reinforcement

NDP	k_3	k_4
EN	3.4	0.425
NA-D	0	$1/(3.6 \cdot k_1 \cdot k_2) < \phi \cdot \sigma s/(3.6 \cdot f_{ct,eff})$
NA-GB	= EN	= EN
NA-A	0	$1/(3.6 \cdot k_1 \cdot k_2) < \phi \cdot \sigma s/(3.6 \cdot f_{ct,eff})$
NA-I	= EN	= EN
NA-B	= EN	= EN
NA-NL	= EN	= EN
NA-CZ	= EN	= EN
NA-PL	= EN	

The limit diameter ϕ is obtained by rearranging the crack equation.

More favourable (larger) limit diameters than specified in table 7.2 may result because the simplifications the table is based on are dispensed with.

Two load states are distinguished for the crack formation. First, individual cracks occur at weak points. They multiply with increasing loads and finally produce a crag propagation pattern. In the final crack pattern, the concrete stress between two cracks does not exceed the tensile concrete strength in any point. Additional cracks cannot occur.

To derive the system of formulae for the required reinforcement, the following intermediate values are used:

Based on the terms $\sigma_s = \frac{F_s}{A_s}$ and $\rho_{eff} = \frac{A_s}{A_{ceff}}$, Eq. 7.9 is transposed depending on

As to $\Delta\varepsilon = \frac{C}{A_s} - D >= \frac{E}{A_s}$ with

$$C = \frac{F_s - ß_t \cdot f_{cteff} \cdot A_{ceff}}{E_s} \qquad D = \frac{ß_t \cdot f_{cteff}}{E_{ceff}}$$

$$E = \frac{F_s \cdot (1 - ß_t)}{E_s}$$

Depending on As, equation 7.9 is transposed to $s_{rmax} = A + \frac{B}{A_s}$ with

$$A = k_3 \cdot c_v$$

$$B = \frac{k_1 \cdot k_2 \cdot k_4 \cdot D_s \cdot F_{cre}}{f_{cteff}}$$

Special case NA-D, NA-A:

$$s_{rmax} = \frac{D_s \cdot A_{ceff}}{3.6 \cdot A_s} <= \frac{F_s \cdot D_s}{3.6 \cdot f_{cteff} \cdot A_s}$$

$$B1 = \frac{D_s \cdot A_{ceff}}{3.6_s} \qquad B2 = \frac{F_s \cdot D_s}{3.6 \cdot f_{cteff}} \qquad \text{B= min(B1,B2)}$$

$$A = 0$$

Required reinforcement for crack control of individual cracks

The following design equation results from the right-hand side of Eq. 7.9 and Eq. 7.11:

$$A_s = \frac{E \cdot A}{2 \cdot w_{max}} + \sqrt{\left(\frac{E \cdot A}{2 \cdot w_{max}}\right)^2 + \frac{E \cdot B}{w_{max}}}$$

Final crack pattern

The following design equation results from the left-hand side of Eq. 7.9 and Eq. 7.11:

$$A_s = \frac{1}{2} \cdot \left(\frac{A \cdot C - B \cdot D}{w_{max} + A \cdot D}\right) + \sqrt{\frac{1}{4}\left(\frac{A \cdot C - B \cdot D}{w_{max} + A \cdot D}\right)^2 + \frac{B \cdot C}{w_{max} + A \cdot D}}$$

Decisive combinations of actions and permissible crack width as per table 7.1 (NDP)

Almost all considered NAs require the verification of a permissible crack width of 0.3 mm for reinforced concrete components of exposure class XC2 and higher.

The verification for XC1 is based on a crack width of 0.4 mm for aesthetical reasons (exception GB: 0.3 mm)

The decisive load combination is the quasi-permanent one (Qk).

Considerably different requirements apply in Italy.

Requirements referring to reinforced concrete components as per table 7.1.

	X0, XC1	XC2/XC3/XC4	XS1-3, XD1-3	Comment
EN	0.4 + Qk	0.3 + Qk	0.3 + Qk	
NA-D	= EN	= EN	= EN	
NA-GB	0.3 + Qk	= EN	= EN	
NA-A	= EN	= EN	= EN	
NA-I	AO 0.3 + Qk 0.4 + Hk	AA 0.2 + Qk 0.3 + Hk	AM 0.2 + Qk 0.2 + Hk	Typical=AO X0,XC1-3,XF1 Aggressive==AA XC4, XD1, XS1, XF2-3, XA1-2 Very aggressive=AM XD2-3,XS2-3, XA3, XF4
NA-B	EI 0.4 + Qk	EE1, EE2, EE3 0.3 + Qk	EE4, ES1, 2, 3, 4 0.3 + Qk	Assignment via milieu classes as per NBN B 15-001
NA-NL	= EN	= EN	0.2 + Hk *1)	*1): Edition 2007: = EN
NA-CZ	= EN	= EN	= EN	
NA-PL	= EN	= EN	= EN	

NA-NL: When the selected reinforcement distance c is greater than cnom, the permissible crack width may be reduced with the help of the factor kx= c/cnom (1<= kx <= 2). This reduction is not automatically taken into account in the current software version. A more favourable permissible crack width can be considered with the help of a user-defined specification of perm. wk., however.

Crack width verification under load

The crack width is verified in accordance with para. 7.3.4 if tensile edge stresses act on the concrete in state I.

To take permanent load action into account, $\beta_t = 0.4$ should be included in the calculation in accordance with /1/.

The following calculation options are available:

- For a given reinforcement area and reinforcement diameter, the crack width is calculated with the help of the crack formula.
- For a given reinforcement area and permissible crack width, the limiting diameter is calculated with the help of the crack formula transposed appropriately.
- For a given diameter and permissible crack width, the required reinforcement is calculated with the help of the above-mentioned equations for the first crack and/or the final crack pattern.
  F_s results from the strain state under load in state II. The strain state is influenced by the selected reinforcement. Therefore, the reinforcement is calculated by iteration.

If tensile strain occurs over the total cross section, the verification of the limiting diameter or the crack width is performed for both sides whereby the side under lower loading with lower reinforcement can become decisive, however.

If the required reinforcement should be calculated, make sure that it is determined for the side with the highest tensile strain. Compliance with the crack width on the other side is to be verified in a separate calculation.

Minimum reinforcement

The present software allows you to calculate minimum reinforcement under imposed bending on top (upper concrete stress corresponds to f_{cteff}), imposed bending on bottom (lower concrete stress corresponds to f_{cteff}) or centrical restraint (upper and lower concrete stress corresponds to f_{cteff}). In combination with imposed bending, you can take the longitudinal axial force N_{cr} into account when calculating the crack moment. In this case, the concrete stress in the cross section's centre of gravity is unequal to zero.

The verification can be performed either for the full tensile strength after 28 days (late restraint) or for lower tensile strengths (early restraint). The verification under early restraint is only permissible if it can be excluded that cracks occur at a later time (see ref. /21/ and others).

$A_{s,min} \cdot \sigma s = kc \cdot k \cdot f_{ct,eff} \cdot A_{ct}$ (equation 7.1)

k	coefficient for non-linearly distributed internal stresses	
	1.0 (h <= 300 mm)... 0.65 (h >= 800 mm)	
	h:	web height or flange width
	NA-D, NA-A:	with inner restraint k · 0.8 applies
	NA-D:	h is the lower value of the partial cross section
Note:	*In accordance with the recommendation of reference /21/, the coefficient k should not be reduced in the following cases:*	
	- If waterproof foundation slabs are designed in accordance with the directive on waterproof concrete published by the German Committee for Reinforced Concrete DAfStb	
	- In combination with thin floor slabs with a thickness < 300 mm or with rigid supports (E_s > 20 MN/m²)	
$f_{ct,eff}$	tensile strength, f_{ctm} (t <= 28d)	
	NA-D: >= 2.9 N/mm² if t >= 28 d	

k_c coefficient for the stress distribution

$kc = 0.4 \cdot (1 - \sigma c / (k_1 \cdot f_{ct,eff} \cdot h/h'))$

σc: concrete stress (state I) under internal crack forces in the centre of gravity of the partial cross section

Flanges hollow box, T-cross sections, for internal crack forces completely under tension

$kc = 0.9 \cdot F_{cr} / (A_{ct} \cdot f_{ct,eff}) >= 0.5$

Fcr: tensile force in the flange under internal crack forces (state I)

σs: Tab. 7.2N with Ds1, derivation see /17/ p. 7-6

Imposed bending as per Eq. 7.6N: $D_{s1} = D_s \cdot f_{ct0} / f_{ct,eff} \cdot 2 \cdot (h-d) / (k_c \cdot h_{cr})$

Centrical restraint as per Eq. 7.7N: $D_{s1} = D_s \cdot f_{ct0} / f_{ct,eff} \cdot 8 \cdot (h-d) / h_{cr}$

NA-D: You can calculate the required minimum reinforcement with the help of the term $F_s = F_{cr} = k \cdot k_c \cdot f_{cteff} \cdot A_{ct}$ and the formulae specified in the chapter "Basis of calculation".

If you have not specified a user-defined value for the tensile concrete strength, $f_{ct,eff} >= 2.9$ N/mm² is assumed in the calculation in accordance with NCI to 7.3.2.(2) (5).

NA-D, NA-A: You may use an alternative equation to calculate the minimum reinforcement for centrical restraint (NA-D: Eq.. 7.5.1DE, NA-A: Eq. 17). It needs not to be greater than the minimum reinforcement calculated as per Eq. 7.1..

Note: In accordance with reference /21/, the possible reduction for slowly hardening concretes mentioned in the NA does not apply to equation 7.1 and the left side of equation 7.5.1DE

If the verification conditions are different at the top and the bottom side, the most unfavourable assumption is used if centrical restraint applies.

Restraint

Preliminary remarks

Restraint is created by a deformation impediment applying to the uncracked component and is reduced by cracking. Restraint can be caused by hydration heat discharge for instance. Also temperature changes or shrinkage can be possible causes of restraint. The reactive forces are limited in regard to their magnitude by the crack forces. The crack forces depend on the tensile strength of the concrete; they are higher under late restraint (t > 28d) than under early restraint.

If reactive loading is calculated more accurately and if it is smaller than the internal crack force, you may determine the minimum reinforcement for this internal reactive force. (EN2: 7.3.2 (2)). You should note in this connection that reactive forces can occur over the entire service life of the component and the verification under early restraint caused by hydration, for instance, does not necessarily constitute the decisive load case.

The modulus of elasticity at the time t is important for the calculation of the reactive forces and should be determined with care.

$$E_{c,t} = \alpha_E \cdot k_{Ec}(t) \cdot E_{cm}:$$

E_{cm}: mean modulus of elasticity

α_E: Coefficient for aggregates as per /8/:

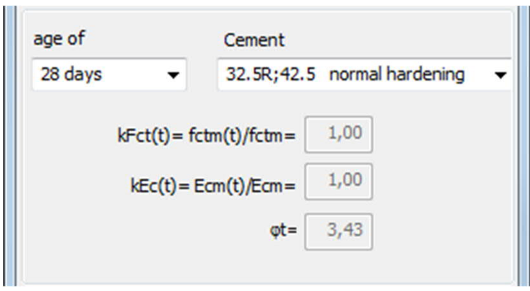
basalt	1.05 ... 1.45
quartz, quartzite	0.80 ... 1.20
limestone	0.70 ... 1.10
sandstone	0.55 ... 0.85

The software allows you to either specify a user-defined value or calculate the time factor of the modulus of elasticity in order to take the concrete age at a given time into account in accordance with Eurocode (Material definition):

$k_{Ec}(t)$: Time factor

as per Eq.3.1, Eq.3.2 and Eq.3.5 (EN 1992-1-1)

$$k_{Ec}(t) = \left\{ e^{s*\left[1-\left(\frac{28}{t}\right)^{0.5}\right]} \right\}^{0,3}$$



t: concrete age

s: cement coefficient

0.2	rapid hardening
0.25	normal hardening
0.38	slow hardening

Alternative: Time factor as per /16/, table 3.24 (enter as user-defined value)

1 day:	0.65
2 days:	0.85
3 days:	0,90

Moreover, the tensile concrete strength at the time of cracking must be taken into account.

The software allows you to either specify a user-defined value or calculate the tensile strength at a given time in accordance with Eurocode:

$k_{Ec}(t)$: time coefficient

as per Eq. 3.1, 3.2 and 3.5 (EN 1992-1-1)

$$k_{Fct}(t) = \left\{ e^{s^*\left[1-\left(\frac{28}{t}\right)^{0.5}\right]} \right\}^{\alpha}$$

t: concrete age α=1 for t < 28d

α=2/3 for t >=28d

s: cement coefficient

0.2 rapid hardening

0.25 normal hardening

0.38 slow hardening

Alternative: Time factor as per /21/, ill. 6 (enter as user-defined value)

1 day: 0.42

2 days: 0.58

3 days: 0.67

Note: *The general assumption of an early tensile strength of 50 % was removed from the current version of the German National Annex (see /22/).*
In accordance with the recommendations of reference /22/, the factor kFct was set by default to 0.65 for early restraint because faster hardening cements are customary in the meantime.

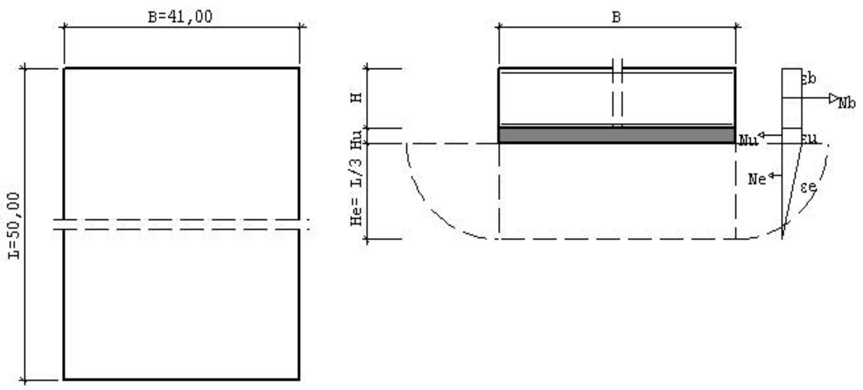
The decisive point in time for the verification depends on the thickness of the component among other factors. In accordance with reference /22/, you are on the safe side when assuming t = 3d for a height h < 0.3 m and t = 7d for a height h > 0.8 m. Other influences such as the ambient temperatures and the concrete temperatures also take effect. Reference /23/, for instance, describes how to take these influences into account.

Two frequent cases of reactive loading due to discharge of hydration heat are implemented in the software.

Restraint due to discharge of hydration heat in floor slabs.

Attention: This method is only suitable if the slab can deform freely. This is not the case when the cross section has different thicknesses or when elevator shafts with deeper foundations are installed.

Due to the subsoil's contribution to the force transfer, the reactive force generated by hydration heat discharge is considerably reduced in accordance with the methods described in reference /5/ (see reference /3/, figure 7.4), particularly where thicker foundations are concerned. This method also allows you to consider an increase in stiffness caused by a concrete subbase, which produces higher reactive forces. The contraction of the sub-concrete due to shrinkage counteracts the increase of the reactive force.



The reactive force is calculated in accordance with /5/ Eq. 6 assuming identical strain in the soil (joint), subconcrete and floor slab:

$$N_{ZW,H} = \frac{-C_u \cdot B \cdot (\varepsilon_{b0} - \varepsilon_{uo}) - C_e \cdot \varepsilon_{b0}}{1 + \frac{C_u}{C_b} + \frac{C_e}{C_b \cdot B}} \qquad (5.1.1)$$

$C_u = H_u \cdot E_u$

- H_u: thickness of concrete subbase
- E_u: modulus of elasticity of subbase

$C_b = H \cdot E_{cm}(t)$

- H: thickness of floor slab
- $E_{cm}(t)$: modulus of elasticity of the concrete at the time of cooling, see 5.1.

$C_e = E_e \cdot (0.5 \cdot H_e \cdot B + \frac{\pi}{6} \cdot H_e^2)$

- H_e: affected subsoil depth, L/3 approx. as per /5/
- E_e: constrained modulus of the subsoil

ε_{u0}: contraction of the subconcrete due to shrinkage

$\varepsilon_{b0} = \alpha_T \cdot \Delta T$: shrinkage of the floor slab without impediment due to the discharge of hydration heat.

α_T: thermal expansion coefficient of the concrete, as per /4/ Table 3.23, which depends on the aggregates and the cement paste portion:
from $5 \cdot 10^{-6}$ /K (compact limestone)
to $12 \cdot 10^{-6}$ /K (quartz rock)

Δ_T: temperature drop due to the discharge of hydration heat

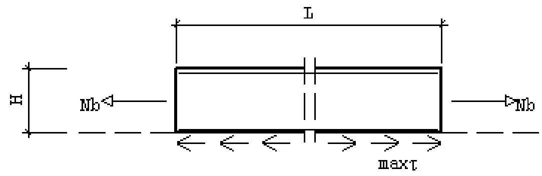
assumption of the safe side according to /3/

H < 0.3 m:	-10 ... -15 K
0.3 m < H < 0.6 m:	-15 ... -25 K
H > 0.6 m:	-20 ... -40 K

The reactive loading for load case of hydration heat discharge calculated this way is limited by the estimated friction force between the soil and the foundation.

In accordance with /6/, the friction force can be calculated via the resisting shear stresses borne by the soil.

$$N_{ZW,B} = 7/8 \cdot \max\tau \cdot B \cdot L/2$$



The following term can be calculated with the inner soil friction angle cal ϕ and max τ = C

$$N_{ZW,B} = 7/8 \cdot \tan(\mathrm{cal}\,\phi) \cdot \gamma_B \cdot H \cdot B \cdot L/2 \qquad (5.1.2\ a)$$

γ_B specific weight of the concrete

H,B,L dimensions of the slab (B = width)

The reactive force is specified in /3/ Eq. 92 a follows:

$$N_{ZW,B} = \mu_d \cdot \gamma_b \cdot H \cdot B \cdot L/2 \qquad (5.1.2\ b)$$

$\mu_d = \mu * \gamma_R$ μ: Basic value of the friction coefficient

γ_R = 1.35 and μ for different slip membrane configurations as per reference /16/, table 4.10

The benefit of this method is that you can optionally take the friction coefficients of various slip membrane configurations into account.

The software calculates the reactive force in accordance with the equations 5.1.1. and 5.1.2. The smaller value is decisive. Optionally, you can use exclusively equation 5.1.2 (soil friction) for the calculation. The specified reactive force N_{zw} always refers the side defined as width (B).

The crack width verification for this reactive force is based on the calculation of the required reinforcement in accordance with the design equations described in chap. 1 and 2.

The verification can be performed under centrical restraint or imposed bending.

In the analysis of imposed bending (e.g. if temperature differences between the top and the bottom face are to be considered) a crack moment is assumed in addition to the longitudinal force caused by the restraint. The tensile strength $f_{ct,eff}$ on the designated side is just great enough to withstand this moment.

$$M_y = W_b \cdot (f_{ct,eff} - \frac{N_{zw}}{A_b})$$

The calculated reinforcement runs in parallel to the side defined as length L and should be distributed over the width B.

Note: *You should note in this connection that reactive forces can occur over the entire service life of the component and that the verification under early restraint, e.g. because of hydration, does not necessarily constitute the decisive load case.*

Restraint due to discharge of hydration heat in subsequently cast concrete walls

The reactive loading due to discharge of hydration heat on walls that have not been built together with the foundation is calculated in accordance with /16/.

$\sigma_{ct} = k \cdot \Delta T_{b,W-F} \cdot \alpha_T \cdot E_{cm}(t)$ Gl.4.24

σ_{ct}: reactive stress due to the discharge of hydration heat

k: coefficient for the bond between wall and floor slab as per /16/ k=1.0

α_T: thermal expansion coefficient of the concrete, as per /4/ Table 3.23, which depends on the aggregates and the cement paste portion:

from $5 \cdot 10^{-6}\,/\,K$ (compact limestone)

to $12 \cdot 10^{-6}\,/\,K$ (quartz rock)

$E_{cm}(t)$: modulus of elasticity of the concrete at the time of cooling, see 5.1.

$\Delta T_{b,W-F}$: temperature difference between the mean component temperature at the wall $T_{b,m}$ and the temperature of the foundation slab T_F

$\Delta T_{b,W-F} = T_{b,m} - T_F$ Eq. 4.25

$T_{b,m} = k_{Tv} \cdot T_{c0} + \Delta T_{b,H}$ Eq. 4.26

T_{c0}: temperature of fresh concrete

k_{Tv}: distribution coefficient (B refers to the wall thickness):

B < 0.5 m:	k_{TV} = 0.5
0.5 m < B < 3.0 m:	k_{TV} = 2/3
B < 3.0 m:	k_{TV} = 1.0

$\Delta T_{b,h}$: temperature due to hydration heat Q_h

$\Delta T_{b,h} = \alpha_b \cdot z \cdot Q_h / C_{c0}$ Eq. 4.4

C_{c0}: thermal capacity of the concrete, C_{C0} ~ 2500 kJ/m³*K

α_b: coefficient for component thickness as per Table 4.4

z: cement portion of the concrete in kg/m³

Q_h: hydration heat as per figure 3.11, depending on the cement and the time of the maximum temperature t_{maxT}

$t_{maxT} = 0.8 \cdot B + 1$ in days with B in m, Eq. 4.2

As detailed information about the cement types is missing, the upper chart of each cement type was implemented in the software. Cement types with low generation of hydration heat can currently not be taken into account. For the rapid-hardening cement types not considered in figure 3.11, the continuous graph of CEM I 32.5 was used. The values are on the safe side compared to those determined in accordance with /18/3.2.2 for CEM 53.5N_42.5R.

$T_{b,m}$ can also be defined by the user (option "user-defined"):

According to /16/, reactive force must not be verified at the wall base, where it reaches its arithmetical maximum, but at ¼ of the wall height.

The cracks forming in the lower quarter of the wall are short and very fine. There is no risk of penetration of moisture.

The design value of the reactive stress results from equation 4.27 to

$\sigma_{ct,d} = k_{ct,d} \cdot \sigma_{ct}$

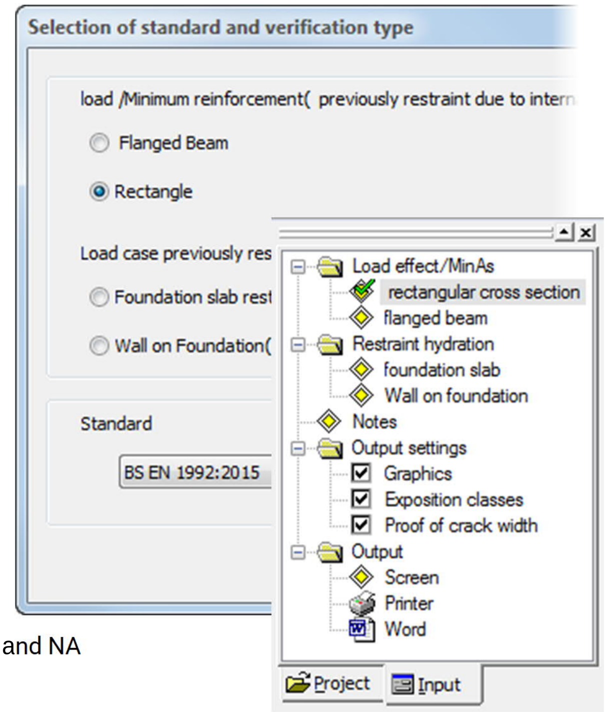
$k_{ct,d}$ is set in accordance with 4.11 appropriate to the relation of the length and height of the wall.

If the resulting $\sigma_{ct,d}$ is greater than $f_{cteff}(t)$, the verification for the limitation of the crack width takes a reactive force into account that is determined with the help of $f_{cteff}(t)$ on the basis of the internal crack force.
Otherwise, the decisive reactive force results from $\sigma_{ct,d}$

Note: *You should note in this connection that reactive forces can occur over the entire service life of the component and the verification for early restraint, e.g. because of hydration, does not necessarily constitute the decisive load case.*

Definition of the system

When defining a new item, select the type of verification and standard in the initial dialog. You can change these settings later vial the main menu or the standard selection list (toolbar).



Loading/MinAs

- Rectangular cross section
- T-beam

Restraint due to

- Floor slab
- Wall on foundation

Definition of the material

Concrete selection dialog as per EN 1992 1-1

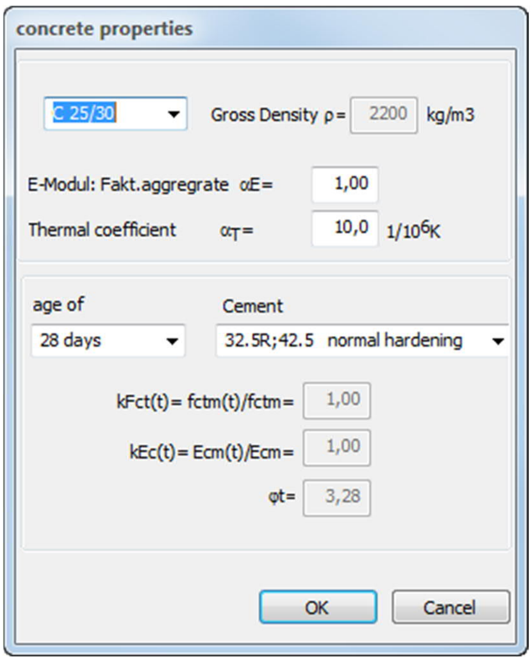
C12/15 ... C100/115	standard concrete as per 3.1.3 and NA
LC12/13 ... LC60/66	lightweight concrete as per 11.3.1 and NA

Steel selection as per EN 1992-1-1

NA-D:	BSt 500 SA ... Bst 500 MB
NA-GB:	B 500 A, B 500 B, B 500 C
NA-A:	Bst 500 (A), Bst 550 (A), Bst 600 (A), Bst 550 (B)

Enhanced concrete dialog

The enhanced concrete dialog is accessible via the >> button.



α_E : coefficient to consider aggregates for the modulus of elasticity as per /8/:

basalt	1.05 ... 1.45
quartz, quartzite	0.80 ... 1.20
limestone	0.70 ... 1.10
sandstone	0.55 ... 0.85

α_T : thermal expansion coefficient of the concrete, as per /4/ Table 3.23. It depends on the aggregates and the cement paste portion: from $5 \cdot 10^{-6}$ /K (compact limestone) up to $12 \cdot 10^{-6}$ /K (quartz rock)

In addition, you can select the age of the concrete and the cement.

kFct coefficient for the development of the tensile concrete strength over time.
Note: For verifications for the hydration load case, the factor 0.65 (recommendation for t = 3 days in reference /22/) is the default setting.

kEc coefficient for the development of the modulus of elasticity over time.
Note: For verifications for the hydration load case, the factor 0.9 (recommendation for t = 3 days) is the default setting.

φt creep factor for early-age concrete 0.12 - 1.0

The corresponding input fields are only enabled if you have selected the item "user-defined" in the Concrete age selection list. Otherwise, these values are set automatically → see Basis of calculation, chapter "Restraint".

Loading on the cross section

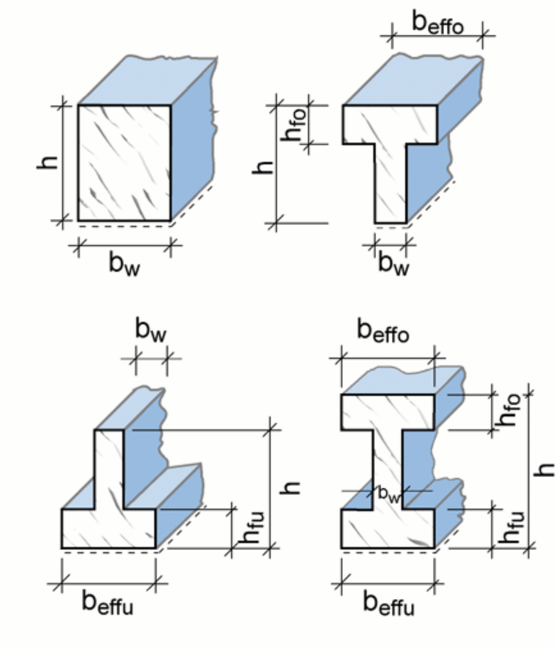
Select/edit the shape of the cross section via the options

- Rectangular cross section
- T-beam

Designation of dimensions

b_{effo}	flange width on top		$b_{effo} > b_w$ or 0
h_{fo}	flange thickness on top	if	$b_{effo} > 0$, then $h_{fo} < h - h_{fu}$, otherwise equal to 0
b_w:	web width		> 0
h	total height		> 0
b_{effu}	flange width on bottom		$b_{effu} > b_w$ or equal to 0
h_{fu}	flange thickness on bottom	if	$b_{effu} > 0$, then $h_{fu} < h - h_{fo}$, otherwise equal to 0

By setting the corresponding dimensions to zero, you can define rectangular cross sections and single T beams with flanges on top or on bottom in addition to double T-beams.

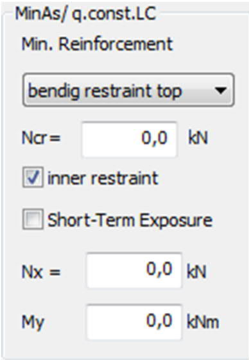


Effective area of tensile reinforcement AsZug

In this section, you can define the effective area of the tensile reinforcement (top/bottom).

Minimum reinforcement for the loading

External loading



The internal forces must correspond to the combinations of actions decisive for the crack width verification (see Basis of calculation).

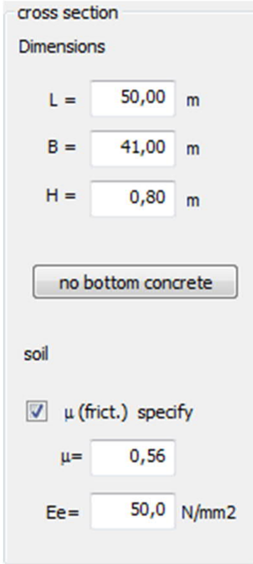
Minimum reinforcement

- Imposed bending on top
- Imposed bending on bottom
- Imposed bending on top and bottom
- Centrical restraint

Ncr	permanently applying longitudinal force [kN], which is taken into account in the calculation of the crack moment (kc coefficient).
Internal restraint	switch for internal restraint (see Basis of calculation)
Short-term action	switch for short-term load (see Basis of calculation)
Nx:	longitudinal force referenced to the centre of gravity
My:	moment

Cross-section of floor slab - hydration restraint

Floor slab



L slab length (length of an increment)

B slab width

H slab thickness

Subconcrete dialog

Hu subconcrete thickness

If Hu = 0, subconcrete is not taken into account

Eu modulus of elasticity of the subconcrete

ε_s shrinkage contraction of subconcrete

Activate the "Concrete>>" button to access the concrete properties dialog

Subsoil

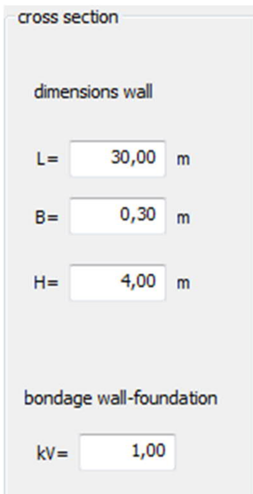
Ee constraint modulus

cal φ inner friction angle of the subsoil

or alternatively

μ user-defined friction coefficient e. g. as per /4/ Table 4.6

Cross-section of wall - hydration restraint



L wall length

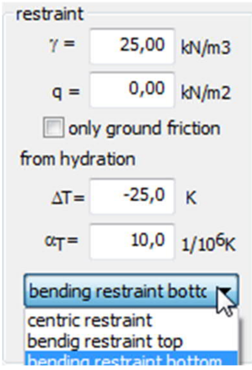
B wall thickness

H wall height

kV bond coefficient wall foundation,

as per /16/ p. 149 0.8 for the connection to reinforced concrete foundation

Restraint due to hydration - soil friction of a floor slab



Soil friction

γ specific weight of the concrete

q load on base plate

If the option "Soil friction only" is checked, the reactive force is calculated exclusively from the soil friction or the soil friction is used as upper limit.

Hydration

ΔT Temperature drop due to the discharge of hydration heat.

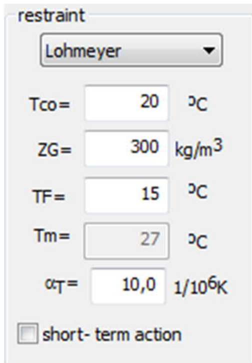
Assumption of the safe side according to /3/:

H < 0.3 m:	-10 ... -15 K
0.3 m < H < 0.6 m:	-15 ... -25 K
H > 0.6 m:	-20 ... -40 K

α_T thermal expansion coefficient of the concrete, as per /4/ Table 3.23. It depends on the aggregates and the cement paste portion: from 5 · 10^{-6}/K (compact limestone) up to 12 · 10^{-6}/K (quartz rock).

In addition to the longitudinal force due to restraint, a crack moment (moment at which the tensile strength $f_{ct,eff}$s is just attained) is taken into account in the verification under imposed bending.

Restraint due to hydration at a wall



Temperature calculation method:

in accordance with Lohmeyer /16/ p. 149 or user-defined.

Tco temperature of fresh concrete
ZG cement portion (as per /16/ p. 119; 270 ... 350 kg/m³)
TF foundation temperature
Tm mean component temperature
α_T Thermal expansion coefficient of the concrete. In accordance with /4/ Table 3.23 the value ranges from 5 · 10^{-6}/K (compact limestone) up to 12 · 10^{-6}/K (quartz rock) depending on the aggregates and the cement paste portion.

Short-term action:

enables the use of the more favourable coefficient ßt = 0.6 in the crack width verification.

User-defined value of Tm

$Tm = k_{Tv} \cdot Tco + \Delta T_{b,H}$ (parameters: see Basis of calculation)

$\Delta T_{b,H}$ Temperature increase due to heat of hydration

assumptions of the safe side as per /3/:

H < 0.3 m:	10 ... 15 K
0.3 m < H < 0.6 m:	15 ... 25 K
H > 0.6 m:	20 ... 40 K

Reinforcement

Cross-section under loading, floor slab

dob distance of upper layer (from top edge)

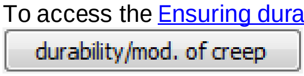
dun distance of lower layer (from bottom edge)

Wall

dli distance of left layer (from left edge)

dre distance of right layer (from right edge)

Durability

To access the [Ensuring durability]() dialog and calculate the creep factor, click on the button


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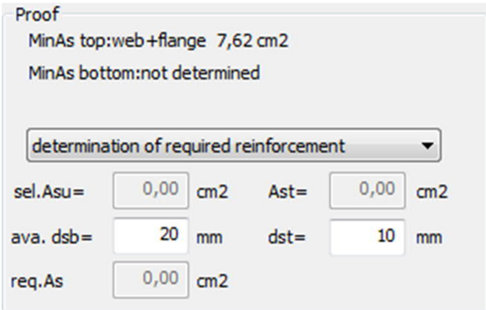
You can define different values for the reinforcement diameter and the permissible crack width for each component side. These specifications are taken into account in the crack width verification.

Only in the calculation of the required reinforcement under centrical tension load (e.g. at walls and, in some cases, at floor slabs) and of the minimum reinforcement under centrical restraint, the most unfavourable values are assumed for the diameter and the permissible crack width.

Control of the verification process

Select the verification format from the corresponding selection list:

- Calculation of the limit diameter
- Calculation of the crack width
- Calculation of the required reinforcement



The input fields are enabled in accordance with the selected verification format:

The required reinforcement under bending with longitudinal force is determined for the side under highest tension and with consideration to a selected reinforcement on the opposite side. If the calculation reveals tensile strain also on this side, a message is displayed recommending the user to verify compliance with the permitted crack width also on this side with the selected reinforcement (switch over in the "Calculation of the crack width" section).

For centrical tension Asu = Aso, if the parameters (diameter, perm. Wk, distance of the reinforcement) are the same for the top and the bottom. If different parameters were set, the most unfavourable values (largest diameter, smallest crack width, greatest reinforcement distance) are assumed for each side. You can optimise these values via the calculation of the crack width.

Output

Output profile — You can adjust the scope of the output be checking and unchecking the corresponding options. Checked options (graphs, exposure classed, crack width verification) are included in the output scope.

Output — Output of the system data, results and graphical representations on the screen or the printer.

Screen	displays the values in a text window on the screen
Printer	starts the output on the printer

You can enter comments to items via the "Notes" option in the main menu. These comments are included in the output.

Print Preview as PDF: ▸ File ▸ Print Preview

Reference literature

/ 1 / Tue, Pierson: "Ermittlung der Rißbreite und Nachweiskonzept nach DIN 1045-1", Beton- und Stahlbeton 5/2001, p.365 ff.

/ 2 / Curbach/Zilch, "Einführung in DIN 1045-1" Ernst und Sohn 2001

/ 3 / König/Tue: "Grundlagen und Bemessungshilfen für die Rissbreitenbeschränkung im Stahlbeton und Spannbeton", German Committee for Reinforced Concrete, Booklet 466, Beuth 1996

/ 4 / Lohmeyer: "Weiße Wannen einfach und sicher", 5th Edition, Verlag Bau und Technik 2000

/ 5 / Simons: "Einige Hinweise zum Entwurf weißer Wannen", Beton- und Stahlbetonbau 8/1993, p.205 et seq.

/ 6 / Beispiele zur Bemessung nach DIN 1045-1, Band 1 Hochbau Deutscher Betonverein, Ernst & Sohn

/ 7 / Paas: "Mindestbewehrung für verformungsbehinderte Betonbauteile im jungen Alter" German Committee for Reinforced Concrete (DAfStb), Booklet 489, Beuth 1998

/ 8 / German Committee for Reinforced Concrete (DAfStb), Booklet 525, Beuth 2003

/ 9 / Meyer: "Rissbreitenbeschränkung nach DIN 1045, Diagramme zur direkten Bemessung", Verlag Bau und Technik 1994

/ 10 / Commented abbreviated version of DIN 1045, 2nd revised edition, Beuth 2005

/11/ Second Amendment of DIN 1045-1 (2005-06)

/12/ Revised Version of DIN 1045-1 (2008)

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/14/ EN 1992-1-1:2004/AC2010

/15/ DIN EN 1992-1-1 / NA:2010-08

/ 16 / Lohmeyer: "Weiße Wannen einfach und sicher", 9th Edition, Verlag Bau und Technik 2009

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/18/ Röhling: "Zwangsspannungen infolge Hydratationswärme", 2nd Edition, Verlag Bau + Technik 2009

/19/ Ziems: "Experiences with the implementation of EUROCODE 2", International Workshop "Design of concrete structures using EN 1992-1-1" at CTU Prague 2010

/20/ Ziems, Müller: "Wesentliche Änderungen in der Stahlbetonbemessung nach EN 1992, Stand 06-2012", www.frilo.de ▸ Eurocode

/21/ A. Meier: „Der späte Zwang als unterschätzter aber maßgebender Lastfall für die Bemessung"; part 2, Beton- und Stahlbetonbau 3/2015

/22/ Fingerloos, Hegger: „Erläuterungen zur Änderung des deutschen nationalen Anhanges zu Eurocode 2"; Beton- und Stahlbetonbau 1/2016

/23/ DAfStb Richtlinie „Schutz und Instandsetzung von Betonbauteilen"; Beuth Verlag 2010