

TR 065



Design of structural joints with shear dowels

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1 GENERAL

1.1 Scope

This Technical Report (TR) provides calculation methods for verification of load-bearing capacity of dowels that transmit shear loads across an expansion joint between structural concrete elements made of reinforced normal weight concrete of strength class C20/25 to C50/60 according to EN 206.

This TR covers dowels with an ETA issued on basis of EAD 050019-00-0301.

This TR covers concrete elements the following specifications:

- Concrete elements with a minimum slab thickness of $h = 6 d_{\text{bar}}$
- Concrete elements that are subjected to static and quasi-static actions
- Concrete elements that are subjected to fire exposure
- Concrete elements that are designed according to EN 1992-1-1 or EN 1992-1-2

This document was written to represent current best practice. However, users should verify that applying its provisions allows local regulatory requirements to be satisfied.

1.2 Assumptions

It is assumed that

- The maximum spacing between adjacent dowel connectors resisting the same relative movement is set at 8 times the thickness of the concrete elements ($\geq 15\text{cm}$) connected by the dowel connectors to provide a linear support. For the purposes of this requirement, the thickness shall be measured according to the direction of action of the shear force transmitted by the dowel connector.
- The concrete reinforcing bars (rebars) intended to transmit the localised shear force from the dowel to the surrounding concrete are arranged and formed in such a way that the incidental shear force is resisted by the whole concrete element. In the case of slabs, this requirement is met by placing hangers - shear links or U-bars positioned vertically on either side of the dowel, in such a way that the horizontal sides of the link (or the legs of the U-bar) are situated close to the upper and lower faces of the slab. The legs of the shear links or U-bars should be formed in such a way that the concrete cover to the primary reinforcement is maintained.
- No minimum spacing between adjacent dowels resisting a same relative movement is specified in theory. However, in order to take into account the eventuality for the networks of cracks originating from two adjacent dowels to intersect, a penalty shall be applied in the case of slabs, where the spacing of the dowels is less than 1,5 times the thickness of the concrete element connected by them. This penalty shall consist of one of the following:
 - The allowable shear forces are reduced by a coefficient equal to $0,67 \cdot a_r/h$ or
 - the cross section of the reinforcing steel is increased by a coefficient equal to $(2 - 0,67 \cdot a_r/h)^3$ with "a_r" the spacing of two adjacent dowels and "h" the thickness of the concrete element
- The minimum embedment depth to ensure that the dowel functions properly is at least $5 d_{\text{bar}}$. This minimum anchorage length shall be checked in the least favourable case of the joint opening.
- The dowels are not incorporated in thin slabs on account of their mode of operation. A table in the ETA shall indicate the conditions to be met for the allowable shear forces to apply. In any cases, the thickness h of the slabs shall not be less than $h = \max(6 d_{\text{bar}}, 150 \text{ mm})$
- In the case of a floor slab with concrete permanent formwork (pre-slab), the designer's attention is drawn to the need, in the detailing, to allow for both the specific reinforcement required for the dowel bars and the connecting reinforcement between the shuttering and the cast in-situ concrete, since the permanent formwork is hanging from the cast in-situ concrete slab.
- The design joint width "t" in millimetres to be used in the calculations is defined as follows:
$$t = a_0 + \Delta a_s + \Delta a_d + \Delta a_f$$
where
 - a₀ is the construction width of the joint.

- Δa_s is the increase in the width of the joint under the effect of the combination of actions considered in the verification.
- Δa_d is the increase in the width of the joint under the effect of delayed deformations due to shrinkage and temperature. Where the effects of these actions are accounted for by a fixed (default) value, Δa_d is taken equal to 5 mm. In other cases, Δa_d shall be taken as zero and the corresponding deformations included in Δa_s .
- Δa_r is intended to account for the uncertainties related to the sharing of forces between the dowels in the case of stiff elements. It is taken as zero where at least one of the two elements connected by the dowels is a floor slab. It is taken as half the diameter (or the height) of the dowel section in other cases.
- Edge beams are formed (within the bulk of the slab or otherwise) along the length of the joint in which the dowels are placed. If the dowel distance is larger than 8 times the slab thickness, these beams shall be designed assuming as follows:
 - the beam forms a linear support for the adjacent slab,
 - the dowels form individual supports for the beam.
- In beam ends containing vertically stacked dowels, the loads are assumed to be transmitted to the dowels by a strut acting at 45° to each dowel (see figure 1). Vertical hangers and horizontal reinforcing bars should thus be provided to resist the corresponding loads.

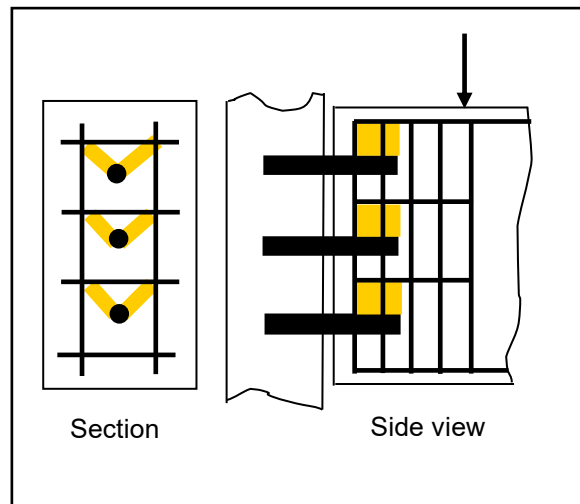


Figure 1: Schematic positions of reinforcements near and around superimposed dowels

2 CALCULATION OF SHEAR RESISTANCE

2.1 General

Next to the dowel a structural reinforcement is provided either side of each dowel, and shear resistance is verified as follows:

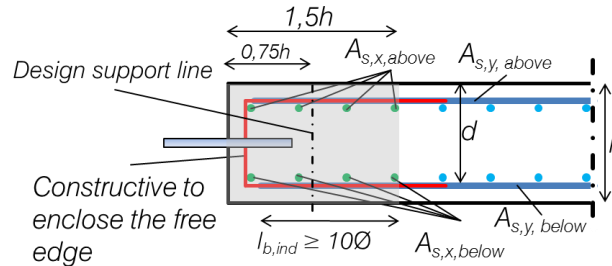


Figure 2: Specification on structural reinforcement next to the dowel

where

$$A_{s,y,below} = A_{s,y,above} \geq \max \left\{ \begin{array}{l} \max\{0,5 \cdot A_{s, support}; 0,5 \cdot A_{s, span}\} \\ \frac{1,11 \cdot V_{Ed}}{f_{yd}} \end{array} \right. \quad \text{from shear design with } V_{Ed} \text{ and effective width } \min\{a; b\}$$

$$A_{s,x,below} = A_{s,x,above} \geq \max \left\{ \begin{array}{l} \text{calculation as continuous beam} \\ \frac{A_{s,y} \cdot 1,5 h}{\min\{a, b\}} \end{array} \right. \quad \text{with effective width } 1,5 h \text{ for } A_{s,y}$$

where

a is the distance of the dowel and $b = 5d$ (2,5d each side)

The minimum distance of the dowels to the edge is defined as 0,75h (h = slab thickness) and the spacing between dowels is limited to $\geq 1,5h$.

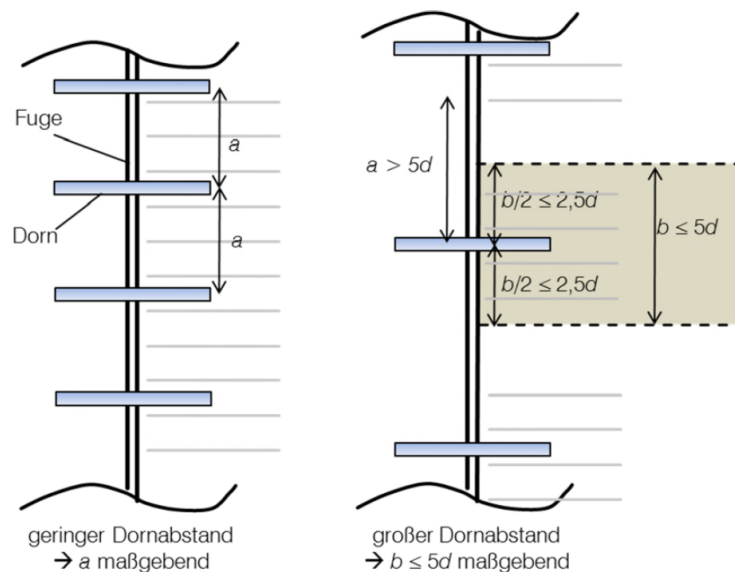


Figure 3: Specification on dowel distances

2.2 Verifications

The following verification shall be performed.

At ULS:

$$V_{Ed} \leq \min \left(V_{Rk,s,ULS} / \gamma_{m,s,ULS} ; V_{Rk,ce,ULS} / \gamma_{m,ce,ULS} \right) \quad (1)$$

At SLS:

$$V_{Ed} \leq V_{Rk,ce,SLS} / \gamma_{m,ce,SLS} \quad (\text{for dowel without regular lateral movements}) \quad (2)$$

$$V_{Ed} \leq \min \left(V_{Rk,s,SLS} / \gamma_{m,s,SLS} ; V_{Rk,ce,SLS} / \gamma_{m,ce,SLS} \right) \quad (\text{for dowel with regular lateral movements}) \quad (3)$$

with

- V_{Ed} = design value of the actions taking into account the provisions according to EN 1990
- $V_{Rk,s,ULS}$ = characteristic resistance to steel failure of the dowel according to section 2.3
- $V_{Rk,s,SLS}$ = characteristic resistance to steel failure of the dowel according to section 2.6
- $V_{Rk,ce,ULS}$ = characteristic resistance to concrete edge failure of the slab according to section 2.4
- $V_{Rk,ce,SLS}$ = characteristic resistance to concrete edge failure of the slab according to section 2.5
- $\gamma_{m,s,ULS}$ = partial safety factor according to section 2.3
- $\gamma_{m,s,SLS}$ = partial safety factor according to section 2.6
- $\gamma_{m,ce,ULS}$ = partial safety factor according to section 2.4
- $\gamma_{m,ce,SLS}$ = partial safety factor according to section 2.5

2.3 Characteristic resistance to steel failure of the dowel at ULS

The characteristic resistance $V_{Rk,s,ULS}$ results from the following equation:

$$V_{Rk,s,ULS} = \frac{f_{yk,bar}}{\sqrt{\frac{(t+2e)^2}{(4 \cdot W_{pl,bar}^2) + A_{s,bar}^2}}} \quad (4)$$

with:

- $f_{yk,bar}$ = yield strength of the bar [N/mm²]
- t = joint width [mm]
- e = point of restraint according to the relevant ETA of the dowel [mm]
- $W_{pl,bar}$ = plastic section modulus [mm³]
- $A_{s,bar}$ = cross-sectional area of the bar [mm²]

In order to consider additional tension forces caused by the axial movement of the dowel bar, the characteristic resistance has to be reduced by a factor 0,9 (for dowels with axial movement only) or by a factor 0,81 (for dowels with axial and lateral transverse movement).

The partial safety factor is $\gamma_{m,s,ULS} = 1,10$.

The verification of steel failure according to Equation (4) is based on EN 1993-1-1, 6.2.1, Equation 6.1 and assuming a fully plasticised cross-section by using the plastic resistances of the cross-section. The static system behind Equation (4) simplifies the shear dowel to a beam with a fixed support on each end at which the shear dowel is fully restraint. Due to this static system the maximum value of moment and shear appears at the same cross-section at the point of restraint "e". Verification of steel failure according to EN 1993-1-1 as well as an alternative static system is possible too. In this case the provisions of EN 1993-1-1, 6.2.5 and 6.2.8 shall be considered. Additionally, to the verification of steel failure, local concrete compressive stresses along the shear dowel axis shall be considered.

2.4 Characteristic resistance to concrete edge failure of the slab at ULS

The characteristic resistance $V_{Rk,ce,ULS}$ results from the following equation:

$$V_{Rk,ce,ULS} = V_{Rk,ce,1} + V_{Rk,ce,2} \quad (5)$$

where

$$V_{Rk,ce,1} = X_1 \cdot \sum \psi_i \cdot A_s \cdot f_{yk} \cdot (f_{ck}/f_{ck,nom})^{k_1} \quad (5a)$$

$$V_{Rk,ce,2} = \pi \cdot d_s \cdot \sum l'_{1,i} \cdot 2,25 \cdot 0,7 \cdot 0,3 \cdot f_{ck}^{2/3} \quad (5b)$$

where

$$\psi_i = 1 - 0,2 \cdot (l_{c,i} / c_1)$$

$l_{c,i}$ and c_1 according to Fig. 4

Note: Factor ψ_i is taking into account the lateral distance of the stirrups from the dowel

A_s = cross section area of the stirrup

f_{yk} = characteristic yield strength of the stirrup

$$l'_{1,i} = l_{1,i} - l_{1,min}$$

$l_{1,i}$ acc. to Fig. 4

$$l_{1,min} = d_s + 0,5 d_b \geq 4d_s$$

X_1 = $X_{1,1}$ or $X_{1,2}$ according to the ETA for the specific dowel

$f_{ck,nom}$ = according to the ETA for the specific dowel

k_1 = $k_{1,1}$ or $k_{1,2}$ according to the ETA for the specific dowel.

The partial safety factor is $\gamma_{m,ce,ULS} = \gamma_c$ according to EN 1992-1-1

2.5 Characteristic resistance to concrete edge failure of the slab at SLS

The characteristic resistance $V_{Rk,ce,SLS}$ results from the following equation:

$$V_{Rk,ce,SLS} = X_2 \cdot V_{Rk,ce,ULS} \quad (6)$$

where

$V_{Rk,ce,ULS}$ = according to section 2.4

X_2 = according to the ETA for the specific dowel

The partial safety factor is $\gamma_{m,ce,SLS} = 1,0$

2.6 Characteristic resistance to steel failure of the dowel at SLS

If regular lateral movements occur during the working life the characteristic resistance $V_{Rk,s,SLS}$ results from the following equation:

$$V_{Rk,s,SLS} = X_3 \cdot V_{Rk,s,20,ULS} \quad (7)$$

where

$V_{Rk,s,20,ULS}$ = characteristic resistance to steel failure of the dowel at 20mm joint width ($t = 20\text{mm}$) according to section 2.3

X_3 = according to the ETA for the specific dowel

The partial safety factor is $\gamma_{m,s,SLS} = 1,0$

2.7 Characteristic resistance under fire exposure

If the steel grade is S360¹ or lower, the performance under fire conditions is calculated from the characteristic value of the load by applying the method of verification and calculation that can be taken from EN 1992-1-2 and EN 1993-1-2, using the national safety parameters.

¹ According to EN 10025 Hot rolled products of structural steels - Part 1: General technical delivery conditions

2.8 Abbreviations

In this TR the following abbreviations are used. For further definitions see also Figure 3.

$V_{Rk,ce,1}$	=	force transmitted into the concrete by the stirrups arranged to the left and right of the dowel, only taking into account the part which can be allocated to the hook (bent pin at the top and bottom faces of the slab)
$V_{Rk,ce,2}$	=	bonding action along the straight part of the stirrup between top and bottom faces of the slab
$A_{s,bar}$	=	cross section area of the bar
A_s	=	cross section area of the stirrup
$f_{yk,bar}$	=	characteristic yield strength of the bar
f_{yk}	=	characteristic yield strength of the stirrup
f_{ck}	=	characteristic concrete compressive cylinder strength
ψ_i	=	factor taking into account the distance $l_{c,i}$ of the considered stirrup to the dowel
$l_{c,i}$	=	distance of the considered stirrup to the dowel
c_1	=	distance between the bar and the face of the concrete in the direction of the load: see figure 3 (for dowels with multiple bars this corresponds to the shortest distance between an individual bar and the face of the concrete in the direction of the load)
k_1	=	factor taking into account the influence of start the concrete strength
$l'_{1,i}$	=	effective anchorage length of the considered stirrup
$l_{1,i}$	=	anchorage length of the considered stirrup
$l_{1,min}$	=	$(0,5 \cdot d_b + d_s)$
d_b	=	mandrel diameter of the stirrup
d_s	=	diameter of the stirrup
b_{cone}	=	$B_{spec,1(2)} + 2 \times (H_{spec,1(2)} / \tan \alpha)$ with $1/\tan \alpha = 1,5$
$B_{spec,1(2)}$	=	distance between the starting points of the cracks according to the ETA for the specific dowel
$H_{spec,1(2)}$	=	height of the starting point of the crack taken (height of the concrete failure cone) according to the ETA for the specific dowel

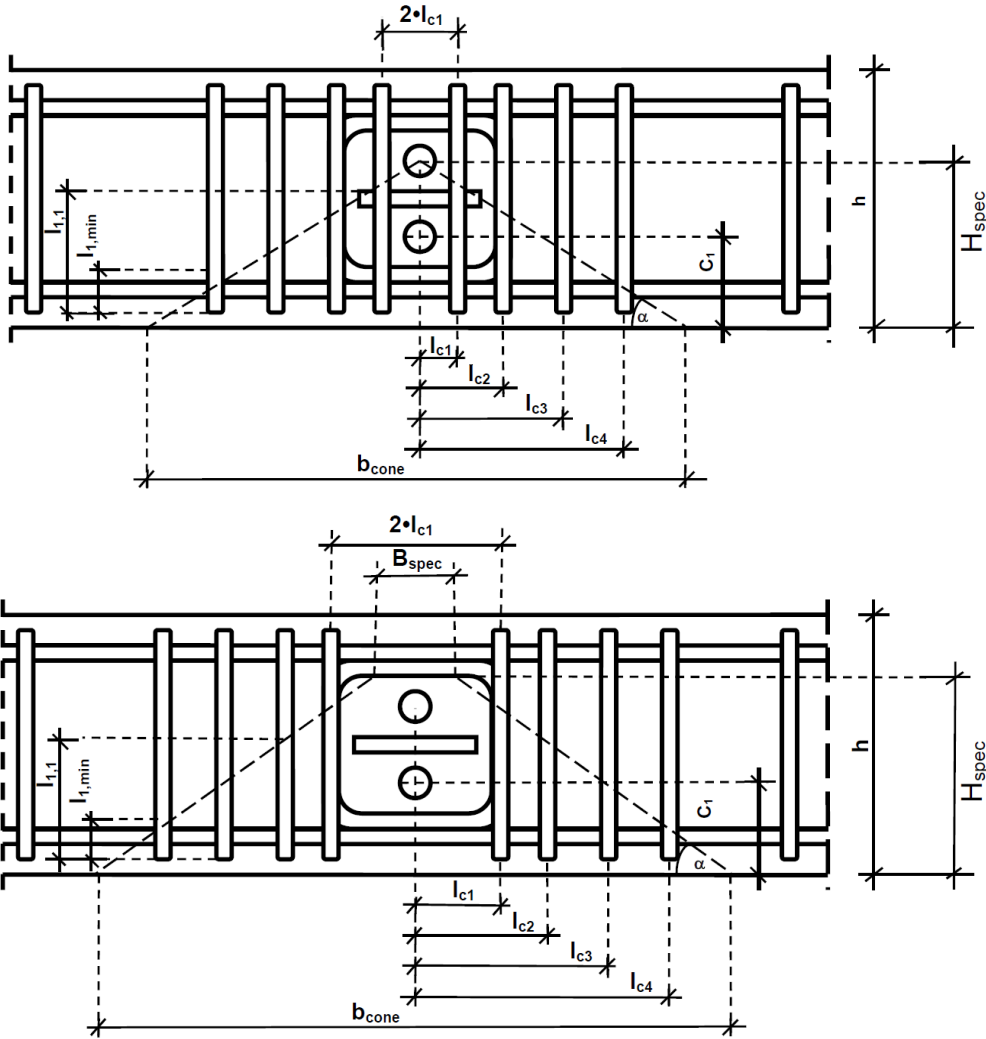


Figure 4: Definition of the relevant parameters

3 REFERENCE DOCUMENTS

EN 1990:2002 + A1:2005 + A1:2005/AC:2010	Eurocode: Basis of structural design
EN 1992-1-1:2004 + AC:2010	Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings
EN 1992-1-2:2004 + AC:2008	Eurocode 2: Design of concrete structures - Part 1-2: General rules – Structural fire design
EN 1993-1-1:2005 + AC:2009	Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings
EN 1993-1-2:2005 + AC:2009	Eurocode 3: Design of steel structures - Part 1-1: General rules – Structural fire design
EN 1993-1-4:2006 + A1:2015	Eurocode 3: Design of steel structures - Part 1-4: General rules - Supplementary rules for stainless steels
EN 206:2013+A1:2016	Concrete - Specification, performance, production and conformity
EAD 050019-00-0601	Dowels for structural joints under static and quasi-static loading