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TECHNICAL REPORT

Design of structural connections with Column Shoes

TR 068

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EUROPEAN ORGANISATION FOR TECHNICAL ASSESSMENT
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Contents

1 GENERAL

1.1 Scope

This Technical Report (TR) provides calculation methods for verification of load-bearing resistance of column shoe connections with column shoes in two stages:

- column shoe connection before grouting (Stage I) and
- column shoe connection in use after grouting (Stage II).

This TR covers column shoes with an ETA issued on the basis of EAD 200102-00-0302.

This TR covers the following specifications of the intended use:

- columns made of reinforced normal weight concrete of strength class C30/37 to C70/85 according to EN 1992-1-1
- design of the columns for static and quasi-static loads is based on EN 1992-1-1

This TR does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this technical report to establish appropriate safety practices and determine the applicability of regulatory limitations prior to use.

2 SPECIFIC TERMS AND ABBREVIATIONS

2.1 Specific terms

See Figure 1 for the illustration of the specific terms.

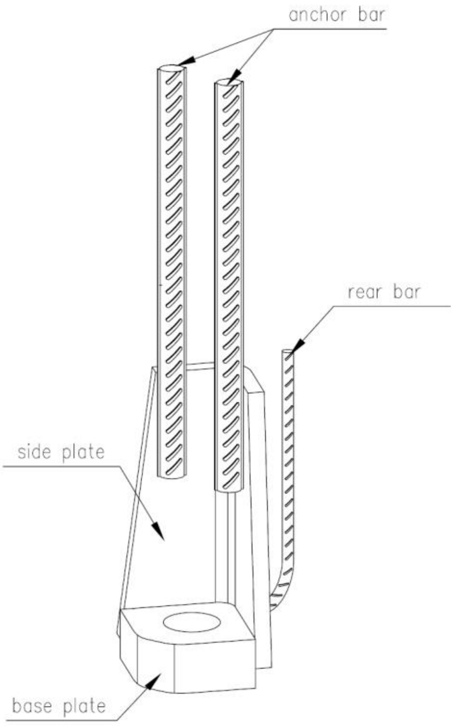

Figure 1 Illustration of specific terms

Base plate	Thick, horizontal steel plate provided with a vertical hole; fixed to a threaded anchor bolt by two nuts and two washers
Side plate	Vertical, bent or straight steel plate(s) welded to the bottom plate
Anchor bar	Vertical reinforcing bar welded to side plate
Rear bar	Partly vertical reinforcing bar, lower end bent, welded to side plate
Top plate	A thin, non-structural steel plate parallel to the base plate but above it, serves as a mould when the column is concreted

2.2 Abbreviations

$A_{anc,i}$	nominal cross-sectional area of anchor bar i
A_{bolt}	tensile stress area of anchor bolt
$A_{plate,i}$	nominal cross-sectional area of side plate i
$F_{w,I}$	the nominal resistance of the weld joint i
L_{eff}	effective length to be used instead of l_0 when designing the column with column shoes in accordance with EN 1992-1-1
L_{lap}	lap length
M_{Ed}	design value of bending moment (action effect)
M_t	theoretical yielding moment of column shoe connection
N_{anc}	sum of nominal axial resistances of straight anchor bars
$N_{anc,weld}$	sum of calculated nominal resistances of welds between straight anchor bars and side plate(s) in the direction of anchor bolt
$N_{bolt,nom}$	nominal axial resistance of anchor bolt
$N_{side,weld}$	sum of calculated nominal resistances of welds between the side plate(s) and base plate in the direction of the anchor bolt
N_{Ed}	design value of axial load on connection
N_{Ed}^1	design value of axial load on a single bolt or column shoe
N_{plate}	sum of nominal axial resistances of side plates
N_{Rd}	design value of axial resistance of column shoe and corresponding anchor bolt
P	point load
V	shear force
V_{Ed}	design value of shear load on a connection
V_{Ed}^1	design value of shear load on a single bolt or column shoe
V_{Rd}	design value of shear resistance of a column shoe
a_b	coefficient calculated as in EN 1993-1-8, table 3.4
d_b	diameter of nominal stress area in thread of anchor bolt
$f_{anc,y,i}$	yield strength of anchor bar i
$f_{base,u}$	ultimate strength of base plate
$f_{bolt,u}$	ultimate strength of anchor bolt
$f_{bolt,y}$	yield strength of anchor bolt
$f_{plate,y,i}$	nominal yield strength of side plate i
$f_{bolt,yd}$	design yield strength of anchor bolt, used for design of column shoe connection
h_{nut}	thickness of nut below base plate
k_1	coefficient calculated as in EN 1993-1-8, table 3.4
k_L	bending stiffness factor acc. to the ETA: - if $k_L \leq 1{,}10$, $k_L l_0$ gives the effective length to be used instead of l_0 when designing the columns in accordance with EN 1992-1-1 - if $k_L > 1{,}10$, the connection is assumed to be hinged in design and effective length l_0 specified in EN 1992-1-1 is used as such l_0 Euler's buckling length (effective length in EN 1992-1-1)
m	number of straight anchor bars or number of measured subzones outside column shoe zone
n	number of active column shoes, number of tests, number of subzones Z_i in column shoe zone
t_r	equivalent span of anchor bolt
t_{grout}	thickness of grout

t_{base}	thickness of base plate
α_b	coefficient calculated from $f_{bolt,y}$
γ_{M2}	safety factor for ultimate strength of anchor bolt, used for design of anchor bolt
γ_{bolt}	safety factor for yield strength of anchor bolt, used for design of column shoe
η_d	bending resistance factor acc. to the ETA
μ	friction coefficient between base plate and grout

3 DESIGN OF COLUMN HSOE CONNECTIONS

3.1 General

There is no one-to-one correspondence between the mechanical resistance of a column shoe as delivered and the mechanical resistance of a column shoe connection. A connection is subjected to various action effects like axial force, shear force and bending moment in different combinations, and the stiffness of the connection also has an impact on the design of the column. It is impossible to determine the mechanical resistance or stiffness of a column shoe connection as a set of values determined according to some standards. Therefore, these properties are declared as a set of design rules for the connection or column or works in which the column shoes are intended to be used.

A difference is made between

- the design of the column shoe connection before grouting (Stage I)
- the design of the column shoe connection after the grout has hardened (Stage II)

3.2 Position of column shoes and design of connected structures

In ordinary cases the column shoes are placed in the corners of a column as shown in Fig. 2.a. Intermediate columns shoes, see Fig. 2.d, are used if the resistance of those in the corners is not high enough or when the tensile forces cannot be properly transferred through the corners of the concrete element only (Fig. 2.b). In some cases two columns shoes per column may be enough (Fig. 2.c).

Column shoes for which kL = 1,1 have no requirement for the rigidity and the columns with such column shoes or connections with less than four column shoes can only be designed assuming that the connection with the column shoes is hinged in Stage II.

The distance between the column shoes is determined by the transfer of the forces from the anchor bars to the concrete element and from the anchor bolt to the foundation. In all cases shall the concrete structures be designed to carry the concentrated loads due to the column shoes and anchor bolts.

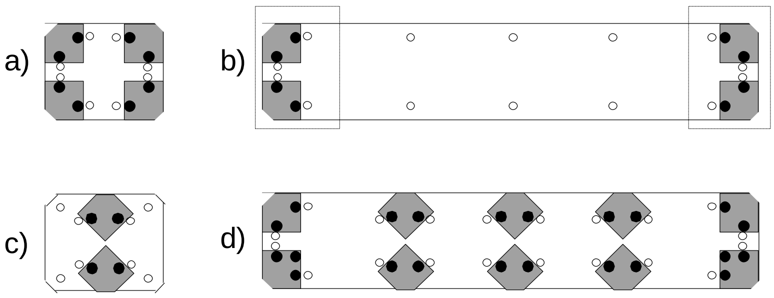

Figure 2 Examples of column shoe configurations.

3.3 Verification of column shoe connection at Stage I

3.3.1 Action effects

Before grouting the connection, the normal force N_{Ed}^{1} for a single column shoe is calculated from the total normal force N_{Ed} and bending moment M_{Ed} acting at the connection, assuming that the column shoes act as an infinitely stiff plate fixed rigidly to the end of the column. This is also assumed when calculating the normal force and bending moment which the anchor bolts are subjected to.

The design shear force for a column shoe is calculated by dividing the total shear force to those column shoes only which are compressed horizontally and transversely against the end of the column when the column is subjected to a shear force, see Fig. 3.

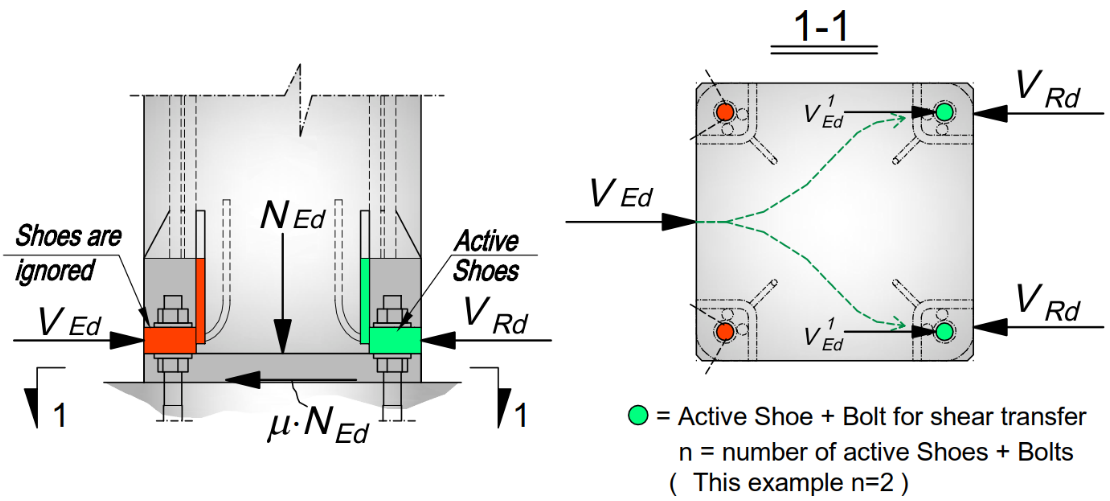

Figure 3 Only the column shoes on the right hand side are considered active against shear.

3.3.2 Resistance

The resistance of a column shoe subjected to axial force and shear shall satisfy

$$\frac{16|V_{Ed}^{1}|t_R}{\pi d_b^3} + \frac{4|N_{Ed}^{1}|}{\pi d_b^2} \leq f_{bolt,yd} \tag{1}$$

where, see Fig. 4,

V^1_{Ed}	=	design value of shear load on a single bolt (action effect)
N^1_{Ed}	=	design value of axial load on a single bolt (action effect), calculated from the total axial force N_{Ed} and bending moment M_{Ed}
d_b	=	diameter of nominal stress area in thread of anchor bolt
t_R	=	$t_{grout} – h_{nut}+d_b/2$
$f_{bolt,yd}$	=	yield strength of bolt steel, see Eq. (3)

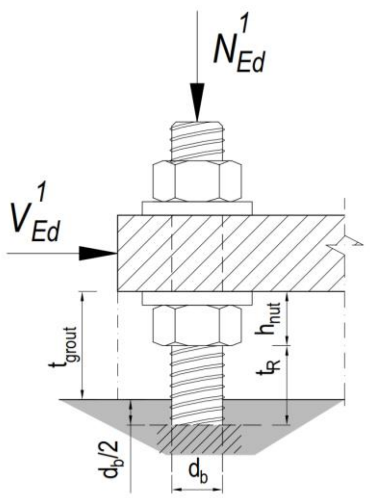

Figure 4 Loads and parameters characterising the column shoe connection in Stage I.

3.4 Verification of column shoe connection at Stage II

3.4.1 General

When calculating the action effects of a column, the rigidity of the end connections has to be estimated. A connection of a precast column comprising anchor bolts and column shoes may be less rigid than a continuously reinforced connection between a cast-in-place column and foundation. On the other hand, the additional reinforcing bars anchoring the column shoes to the column make the anchoring zone stiffer than the rest of the column. The net effect of these two factors is taken into account by the bending stiffness factor k_L assessed acc. to EAD 200102—00-0302. The columns with column shoes at the lower end with boundary conditions illustrated in EN 1992-1-1, Fig. 5.7 cases b), c), d), and e) are designed replacing the effective length l_0 by

$$L_{eff} = k_L l_0 \tag{2}$$

when k_L is ≤ 1,10.When k_L is > 1,10 the column shoe connection is considered hinged. The factor k_L shall be taken from the ETA.

For cases f) and g) in Fig. 5.7 of EN 1992-1-1, the flexibilities k_i in equations 5.15 and 5.16 of EN 1992-1-1 are replaced by $k_i k_L^2$ at each connection i provided with column shoes.

When calculating the resistance of the connection, four different cases are considered:

1. Resistance of the grouted connection subjected to axial load and bending
2. Shear resistance of individual column shoes subjected to compression
3. Shear resistance of individual column shoes subjected to tension
4. Resistance of the column end

3.4.2 Design criterion for grouted section subjected to axial force and bending

The resistance of the grouted section above the foundation and below the column shoes is calculated according to EN 1992-1-1 assuming that the section behaves as a reinforced concrete section which is reinforced with the anchor bolts. For the bolts, the bilinear stress-strain assumption with a horizontal top branch (EN 1992-1-1, 3.2.7 b) is applied. Design criterion for column end

The resistance of the column end subjected to axial load, shear and bending is calculated according to EN 1992-1-1 and EN 1993-1-8. Particularly, the main reinforcement shall be extended down to the column shoe level and the lap length L_1, see Fig. 5, shall meet the requirements given in EN 1992-1-1, Chapter 8.7.

For the calculation of the lap length, the length of the filled weld of the reinforcement bars may be used but with a reduced bond at 50%.

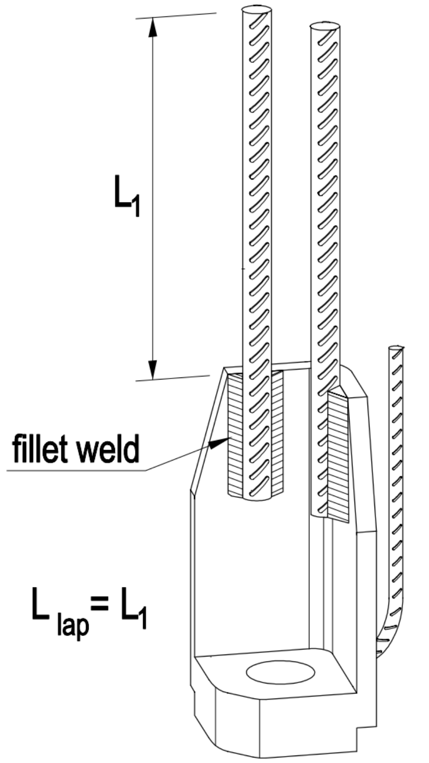

Figure 5 Determining lap length L_{lap}. The fillet welds and the side plate next to the anchor bar reduce the bond effectively.

3.4.3 Design criterion for interaction of axial force, bending moment and shear force

Interaction of axial force, bending moment and shear force is taken into account by considering each individual column shoe separately. Since the bending and axial loading result in tensile or compressive forces in the individual column shoe - anchor bolt combinations, the interaction problem is simplified to interaction of normal force and shear force.

The action effects at the connection are first divided to the individual column shoes.

The axial force N_{Ed}^1 for a single anchor bolt or column shoe is calculated from the total axial force N_{Ed} and bending moment M_{Ed} acting at the connection, assuming that the column shoes act as an infinitely stiff plate, fixed rigidly to the end of the column, and the grouted connection behaves as a concrete section reinforced with the anchor bolts.

The design value of the shear force for a single column shoe on the active side is calculated from

$$V_{Ed}^1 = \frac{V_{Ed} - \mu N_{Ed}}{n} \qquad (3)$$

where

V_{Ed}	=	the design value of the total shear force
μ	=	friction coefficient between base plate and grout (= 0,20 for sand-cement mortar according to EN 1993-1-8, 6.2.2 (6))
N_{Ed}	=	the design value of the total axial compressive force
n	=	the number of the individual column shoes which are horizontally and transversely compressed against the end of the column due to the shear force. The column shoes at the opposite side of the connection are ignored when calculating the shear resistance, see Fig. 3.

3.4.4 Design criterion for column shoe connection subjected to shear and axial load

The shear resistance of a column shoe subjected to shear and compression shall meet the requirement

$$V_{Ed}^{1} \leq V_{Rd} \tag{4}$$

where V_{Ed}^{1} and V_{Rd} are calculated from Equations (4) and (6), respectively.

The simultaneous tensile force N_{Ed}^{1} and shear force V_{Ed}^{1} in each column shoe shall satisfy the conditions

$$\frac{|N_{Ed}^{1}|}{1{,}4N_{Rd}} + \frac{|V_{Ed}^{1}|}{V_{Rd}} \leq 1 \tag{5}$$

$$\frac{N_{Ed}^{1}}{N_{Rd}} \leq 1 \tag{6}$$

where N_{Rd} and V_{Rd} are calculated from Equations (5) and (6), respectively.

If it can be shown that the total shear force is transmitted by friction, verification according to Eq. (1) may be omitted.

This predicts that shear force, moment and normal force occur in the same load case.

In this case the verifications according to Eq. (10) and (12) must be fulfilled only and V_{Rd} should be calculated according to Eq. (13).

$$V_{Rd} = \mu \cdot F_{cd} \tag{7}$$

For the compressive force F_{cd} to be applied, the pressure resultant from the bending design may be used. This includes the normal force.

In general, μ = 0.2 should be used for the coefficient of friction.

3.4.5 Resistance of column shoe connection in axial loading

The resistance of a column shoe connection in tension and compression is calculated as follows:

(1) For bolt connections or foundation anchors according to EC3 Eq. (8) applies
(2) For bolt connections or foundation anchors according to EC2 Eq. (9) applies
(3) For foundation anchors according with an ETA acc. to EAD … Eq. (10) applies

$$N_{Rd} = \eta_d \cdot \min (0{,}9\ A_{bolt} \cdot f_{bolt,u} / 1{,}25;\ A_{bolt} \cdot f_{bolt,y} / 1{,}15;\ N_{Rd,s}) \tag{8}$$

$$N_{Rd} = \eta_d \cdot \min (A_{bolt} \cdot f_{bolt,y} / 1{,}15;\ N_{Rd,s}) \tag{9}$$

$$N_{Rd} = \eta_d \cdot \min (N_{Rd,ETA};\ N_{Rd,s}) \tag{10}$$

3.4.6 Resistance of column shoe connection in shear loading

The shear resistance of a column shoe connection is calculated according to EN 1993-1-8, Chapter 6.2.2, from

$$V_{Rd} = k_s \cdot \min\{F_{1,vb,Rd}\,;F_{2,vb,Rd}\} \tag{11}$$

where $F_{1,vb,Rd}$ and $F_{2,vb,Rd}$ are obtained from

$$F_{1,vb,Rd} = 0{,}8\,\frac{k_1 a_b f_{base,u} d_b t_{base}}{\gamma_{M2}} \tag{12}$$

$$F_{2,vb,Rd} = \frac{\alpha_b f_{bolt,u} A_{bolt}}{\gamma_{M2}} \tag{13}$$

$$\alpha_b = 0{,}44 - (0{,}0003 MPa^{-1}) f_{bolt,y} \tag{14}$$

In these expressions

k_s	=	acc. to the ETA
k_1 and a_b	=	coefficients calculated as in EN 1993-1-8, Table 3.4
$f_{base,u}$	=	the ultimate strength of the base plate
d_b	=	diameter of nominal stress area in thread of anchor bolt
t_{base}	=	thickness of the base plate
γ_{M2}	=	material safety factor according to EN 1993-1-8, Table 2.1
$f_{bolt,u}$	=	ultimate strength of steel of the anchor bolt
A_{bolt}	=	tensile stress area of the anchor bolt

3.4.7 Resistance to fire based on steel temperature curve under fire exposure $T_{cr}(t_i)$ [°C]

The fire rating for the unprotected column shoes is done based on the following principles.

1. For all column shoes the temperature in the critical point of the column shoe is given in the European Technical Assessment at relevant time intervals (15 min, 20 min, 30 min, 45 min, 60 min, 90 min, 120min, …).
2. When the column shoes are in compression, the fire rating for the shoe is the same as that for the column.
3. When the column shoe is in tension, the fire rating is determined by the temperature and the utilisation level of the tensile resistance. The relevant design rules given in EN 1992-1-2 and EN 1993-1-2 are applied.

4 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 1993-1-8:2005 + AC:2009	Eurocode 3: Design of steel structures - Part 1-8: Design of joints
EAD 200102-00-0302	European Assessment Document for column shoes