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European Assessment Document for

Column shoes for structural connections of reinforced concrete columns

This European Assessment Document (EAD) has been developed taking into account up-to-date technical and scientific knowledge at the time of issue and is published in accordance with the relevant provisions of Regulation (EU) No 305/2011 as a basis for the preparation and issuing of European Technical Assessments (ETA).

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1 SCOPE OF THE EAD

1.1 Description of the construction product

The column shoes for structural connections of reinforced concrete columns (in the following referred to as column shoes), illustrated in Figures 1.1.1 and 1.1.2, are connectors made of structural steel according to EN 10025-2[1] and -3 and reinforcing steel bars according to EN 1992-1-1. The components of a column shoe are connected to each other by welding.

The column shoe comprises a horizontal part called base plate, vertical side plate or plates which may be bent, vertical main anchorage bars and (a) bent rear bar(s). There may also be thin, non-structural steel plates that serve as moulds when concreting the column.

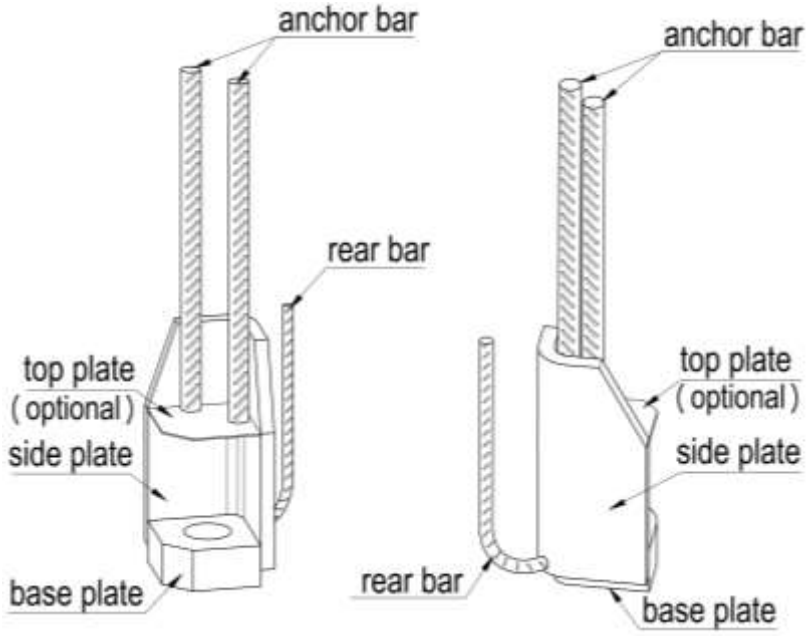

Figure 1.1.1 Principle design of column shoe

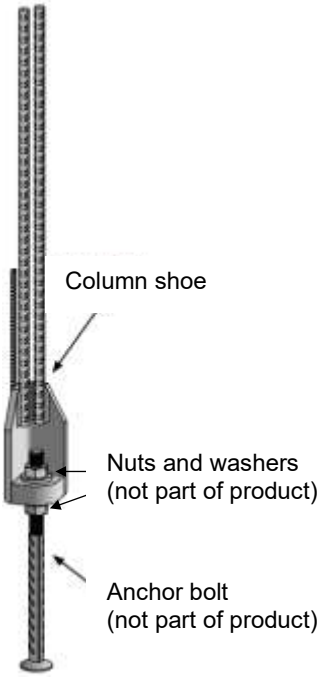

Figure 1.1.2 Example of the connection of a column shoe with an anchor bolt using nuts and washers

The assessment based on this EAD provides for input values for the design of column shoe connections in accordance with TR 068.

The column shoes covered by this EAD do not contain more than 1,0 % by weight or volume (whichever is the more onerous) of homogeneously distributed organic material.

The product is not covered by a harmonised European standard (hEN).

The scope of EN 1090-1 covers products for metallic structures such as metallic beams or columns or substructures for facades. Contrary to those products, the performance of the column shoes related, e.g., to resistance to shear loads or to fire resistance can only be achieved once they have been installed in the concrete base (see Figure 1.2.1.3). Thus, the column shoes are neither covered by the scope of EN 1090-1 nor does the essential characteristics as given in this standard fit to the column shoes.

Concerning product packaging, transport, storage, maintenance, replacement and repair it is the responsibility of the manufacturer to undertake the appropriate measures and to advise his clients on the transport, storage, maintenance, replacement and repair of the product as he considers necessary.

It is assumed that the product will be installed according to the manufacturer's instructions or (in absence of such instructions) according to the usual practice of the building professionals.

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1 All undated references to standards in this EAD are to be understood as references to the dated versions listed in chapter 4.

Relevant manufacturer's stipulations, e.g., with regard to the intended end use conditions, having influence on the performance of the product covered by this European Assessment Document shall be considered for the determination of the performance and detailed in the ETA as long as the details of the assessment methods as laid down in this EAD are respected.

1.2 Information on the intended use of the construction product

1.2.1 Intended use

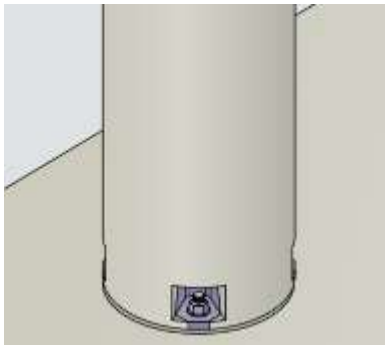
The column shoes serve as connectors between a concrete column and foundation or between two columns (see Figure 1.2.1.1). They are inserted inside the hoop reinforcement at the lower end of a column or beam before concreting (see Figure 1.2.1.2). After hardening of the concrete, the column or beam is installed in its final position. The column shoes are fixed with nuts and washers to carbon steel anchor bolts that have previously been concreted to the supporting lower structure or to other supporting members. The space between the end of the column and the supporting structure as well as the recesses for the nuts are grouted with non-shrink mortar, grout or concrete (see Figure 1.2.1.3).

Each column shoe is intended to be used in connection with a specific carbon steel anchor bolt (see Figures 1.1.2 and 1.2.1.3) which is not part of the product but shall be considered in its assessment.

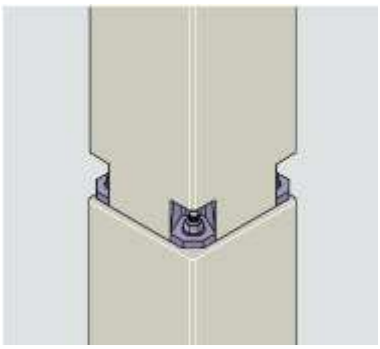
This EAD provides input data needed for the design of column shoe connections according to EOTA TR 068. More specifically, it covers the following intended uses:

- Structural concrete elements (columns or foundation) made of reinforced normal weight concrete of strength class C30/37 to C70/85 according to EN 1992-1-1. This is based on the available experiences and the knowledge about the assessment methods to be technically appropriate;
- Connections subjected to external atmospheric exposure or exposure in internal conditions including permanently damp conditions;
- Connections subjected to static or quasi-static loading;
- Connections where the column is horizontally supported by foundation, columns, floor.

The lowest temperature in use is -20°C.

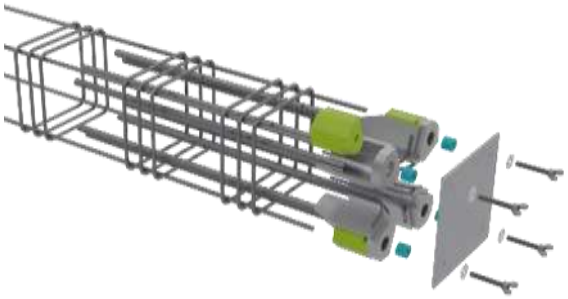


Column / foundation



Column / column

Figure 1.2.1.1 Examples of intended uses



Fixing to formwork base plate, closing the recesses for the nuts and inserting in/fixing with the hoop reinforcement

Casting, concreting and compacting

Removal from formwork

Figure 1.2.1.2 Example of installation of column shoes in a precast concrete element

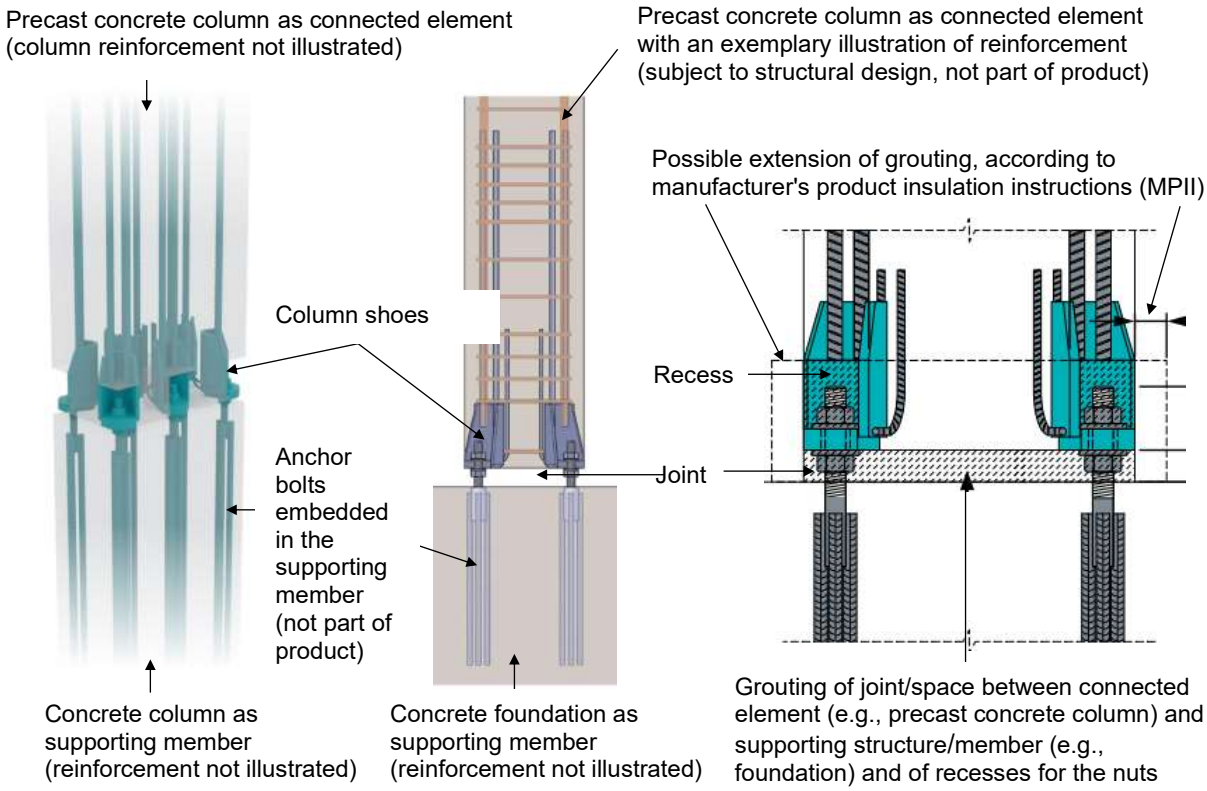


Figure 1.2.1.3 Examples of application of column shoes (MPII means the manufacturer's product installation instructions)

1.2.2 Working life/Durability

The assessment methods included or referred to in this EAD have been written based on the manufacturer's request to take into account a working life of the column shoes for the intended use of 50 years when installed in the works (provided that the column shoes are subject to appropriate installation (see clause 1.1) These provisions are based upon the current state of the art and the available knowledge and experience.

When assessing the product, the intended use as foreseen by the manufacturer shall be taken into account. The real working life may be, in normal use conditions, considerably longer without major degradation affecting the basic requirements for works[2].

The indications given as to the working life of the construction product cannot be interpreted as a guarantee neither given by the product manufacturer or his representative nor by EOTA when drafting this EAD nor by the Technical Assessment Body issuing an ETA based on this EAD, but are regarded only as a means for expressing the expected economically reasonable working life of the product.

1.3 Specific terms used in this EAD

1.3.1 Specific terms

1.3.1.1 Base plate

Thick, horizontal steel plate provided with a vertical hole; fixed to a threaded anchor bolt by two nuts and two washers - see figure 1.1.1

1.3.1.2 Side plate(s)

Vertical, bent or straight steel plate(s) welded to base plate - see figure 1.1.1

1.3.1.3 Anchor bar

Vertical reinforcing bar welded to side plate - see figure 1.1.1

1.3.1.4 Rear bar

Partly vertical reinforcing bar, lower end bent, welded to side plate(s) - see figure 1.1.1

1.3.1.5 Top plate (optional)

A thin, non-structural steel plate parallel to the base plate and above it, serves as a mould when the column is concreted - see figure 1.1.1

[2] The real working life of a product incorporated in a specific works depends on the environmental conditions to which that works is subjected, as well as on the particular conditions of the design, execution, use and maintenance of that works. Therefore, it cannot be excluded that in certain cases the real working life of the product may also be shorter than referred to above.

1.3.2 Abbreviations

In this EAD SI-units are used. Unless stated otherwise in the formulae, the following units are used: dimensions are given in mm, cross sections in mm^2, section modulus in mm^3, moment of inertia in mm^4, forces and loads in N and stresses, strengths and moduli of elasticity in N/mm^2.

$A_{s,nom\ (bolt)}$	[mm^2]	nominal stress area in thread of the anchor bolt
(EI)	[MNm^2]	bending stiffness
$(EI)_i$	[MNm^2]	bending stiffness of subzone *i* in numerical comparison, precast column
$(EI)'_i$	[MNm^2]	bending stiffness of subzone *i* in numerical comparison, cast-in-situ column
$F_{f,i}$	[MN]	failure load in air test *i*
$F_{1,vb,Rd}$	[MN]	shear resistances of two column shoes
$F_{2,vb,Rd}$	[MN]	shear resistances of two anchor bolts
$F_{u,s}$	[MN]	Steel failure
$F_{u,test}$	[MN]	failure load in the test
H	[m]	vertical distance between transducers fixed to the top surface and soffit of test beam
L_c	[m]	height of column in numerical comparison
L_{eff}	[m]	effective length to be used instead of l_0 when designing the column with column shoes in accordance with EN 1992-1-1
$L_{g,j}$	[m]	measuring length of transducers in subzone *j* in bending test
L_{lap}	[m]	lap length
L_{shoe}	[m]	height of column shoe zone
M_i	[MNm]	bending moment in the middle of subzone *i* in numerical comparison
M_t	[MNm]	theoretical yielding moment of column shoe connection
$M_{e,i}$	[MNm]	experimental yielding moment (bending resistances) of column shoe connection
$M_{t,i}$	[MNm]	theoretical yielding moment (bending resistances) of column shoe connection calculated using the actual yield strength of the anchor bolts (mean value of test results) and the nominal strength of the concrete
$N_{Rd,S(bolt)}$	[MN]	tension resistance of anchor bolt
$N_{Rd,S(component)}$	[MN]	tension resistance of a component of column shoe
$N_{Rd,S(component,calculated)}$	[MN]	calculated tension resistance of a component of column shoe before applying Equation D.2.2
$N_{Rd,S(shoe)}$	[MN]	tension resistance of column shoe
$T_{cr}(t_i)$	[°]	steel temperature as a function of the duration of fire exposure
P	[MN]	point load
P_H	[MN]	horizontal force in numerical comparison
V	[MN]	shear force
$V_{e,i}$	[MN]	experimental shear resistance of connection in shear test
$V_{t,i}$	[MN]	theoretical shear resistance of connection in shear test
Z_i	[-]	name of subzone i
a	[mm]	horizontal distance in test arrangements
b	[mm]	horizontal distance in test arrangements
d_b	[mm]	diameter of nominal stress area in thread of anchor bolt
$f_{base,u}$	[N/mm^2]	the ultimate strength of the base plate

$f_{bolt,y}$	[N/mm^2]	yield strength of the anchor bolt
f_u	[N/mm^2]	nominal tensile strength
$f_{uk(bolt)}$	[N/mm^2]	characteristic ultimate strength of the anchor bolt
$f_{u,test}$	[N/mm^2]	actual tensile strength of the steel parts used in the test
h	[mm]	depth of column element in bending and shear tests
k_i	[-]	flexibility factor in accordance with EN 1992-1-1, clause 7.4 and Annex O, i = 1 or 2
k_L	[-]	bending stiffness factor of column shoe
k_n	[-]	deviation factor
k_S	[-]	shear resistance factor of column shoe
k_m *and* α_b	[-]	coefficients calculated as in EN 1993-1-8 Table 5.9
l_0	[mm]	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
m_i	[-]	ratio experimental to theoretical bending resistances
m_k	[-]	characteristic value of m_i-values, i = 1,....,n (n is number of the tests)
m_m	[-]	mean value of m_i-values, i = 1,....,n (n is number of the tests)
N	[-]	number of active column shoes, number of tests, number of subzones Z_i in column shoe zone, number of subzones
s_m	[-]	standard deviation of m_i-values, i = 1,...., n (n is number of the tests)
t_{base}	[mm]	thickness of the base plate
U	[-]	axial contraction of subzone Z_i in bending test
u_i	[-]	measured axial contraction of subzone Z_i in bending test, soffit
V	[-]	axial elongation in bending test
v_i	[-]	measured axial elongation of subzone Z_i in bending test, soffit
v_{ref}	[m]	deflection of cast-in-situ column in numerical comparison
v_{shoe}	[m]	deflection of precast column in numerical comparison
x	[-]	longitudinal coordinate
η_d	[-]	bending resistance factor of column shoe
$\eta_{d,0}$	[-]	bending resistance factor ≤ 1,00 used for the design of the test specimens, see Annex E
κ_i	[1/m]	curvature of column cross-section

2 ESSENTIAL CHARACTERISTICS AND RELEVANT ASSESSMENT METHODS AND CRITERIA

2.1 Essential characteristics of the product

Table 2.1.1 shows how the performance of the column shoes is assessed in relation to the essential characteristics.

Table 2.1.1 Essential characteristic of the product and methods and criteria for assessing the performance of the product in relation to those essential characteristics

No	Essential characteristic	Assessment method	Type of expression of product performance
Basic Works Requirement 1: Mechanical resistance and stability			
1	Resistance to bending and shear loads	2.2.1	Level k_L [-], η_d [-], k_s [-],
Basic Works Requirement 2: Safety in case of fire			
2	Reaction to fire	2.2.2	Class
3	Resistance to fire – steel temperature as a function of the duration of fire exposure	2.2.3	Level $T_{cr}(t_i)$ [°C]

2.2 Methods and criteria for assessing the performance of the product in relation to essential characteristics of the product

This chapter is intended to provide instructions for TABs. Therefore, the use of wordings such as “shall be stated in the ETA” or “it has to be given in the ETA” shall be understood only as such instructions for TABs on how results of assessments shall be presented in the ETA. Such wordings do not impose any obligations for the manufacturer and the TAB shall not carry out the assessment of the performance in relation to a given essential characteristic when the manufacturer does not wish to declare this performance in the Declaration of Performance.

The anchor bolts needed when using the column shoes are not subject to this EAD but shall be taken into account when assessing the column shoes. The anchor bolt used during the assessment shall be in accordance with the MPII. If no relevant information is available, the anchor bolt shall be chosen such that a sufficiently high load-bearing capacity of the anchor bolts can be expected. The specific anchor bolt related to each size of assessed column shoe(s) shall be specified in the ETA with at least designation, type, size, nominal stress area in thread, characteristic yield und ultimate tensile strength.

Details of the concrete members used for the assessment are given in Annex E, clause E.2.

2.2.1 Resistance to bending and shear loads

2.2.1.1 General

This essential characteristic is defined by three parameters. If the performance of this essential characteristic is to be assessed, then all three parameters shall be considered[3] and the performance for the parameters referred to in 2.2.2.2 to 2.2.2.5 shall be given in the ETA.

Note:

The concept consists of assessing the behaviour of a structural connection of a precast column to a foundation or to another column using column shoes and comparing and evaluating it with a monolithic in-situ connection of a column to a foundation or to another column. This is done by tests to determine the

- bending stiffness,
- bending resistance,

3 The design of a connection in accordance with EOTA TR 068 is based on the three parameters.

- shear resistance.

In all cases, the test results shall be compared with the theoretical value according to TR 068 for a similar concrete structure without column shoe. As a result, once get coefficients k_L, η_d, k_s, which can be used for the design of a structural connection of a precast column to a foundation or to another column using column shoes.

The assessment does not result in performances related to the resistance (load-bearing capacity) of the column shoe itself. The assessment results in a performance that shows how a connection of reinforced concrete components using the column shoes performs in comparison to a monolithic connection. (The mentioned standards (e.g., EN 1992-1-1, EN 1993-1-1, EN 1993-1-8) are only necessary for pre-dimensioning of the test specimen.)

2.2.1.2 Bending stiffness factor k_L [-] (BS tests)

The performance of the column shoes related to the bending stiffness factor k_L [-] shall be assessed according to the method and criteria given in Annex A.

2.2.1.3 Bending resistance factor η_d [-] (BR tests)

The performance of the column shoes related to the bending resistance factor η_d [-] shall be assessed according to the method and criteria given in Annex B.

2.2.1.4 Shear resistance factor k_s [-]

The performance of the column shoes related to the shear resistance factor k_s [-] shall be assessed according to the method and criteria given in Annex C.

2.2.2 Reaction to fire

Column shoes are considered to satisfy the requirements of class A1 of the reaction-to-fire performance in accordance with the Commission Decision 96/603/EC, as amended by Commission Decisions 2000/605/EC and 2003/424/EC, without the need for testing on the basis of it fulfilling the conditions set out in that Decision and its intended use being covered by that Decision.

Therefore, when the conditions referred to above are fulfilled, the performance of the column shoes is class A1.

2.2.3 Resistance to fire– steel temperature as a function of the duration of fire exposure

The performance related to the steel temperature as a function of the duration of fire exposure $T_{cr}(t_i)$ [°C] shall be assessed according to the method and criteria given in Annex D.

3 ASSESSMENT AND VERIFICATION OF CONSTANCY OF PERFORMANCE

3.1 System(s) of assessment and verification of constancy of performance to be applied

For the products covered by this EAD the applicable European legal act is Commission Decision 96/582/EC.

The system is 1.

3.2 Tasks of the manufacturer

The cornerstones of the actions to be undertaken by the manufacturer of the product in the procedure of assessment and verification of constancy of performance are laid down in Table 3.2.1.

Table 3.2.1 Control plan for the manufacturer; cornerstones

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Factory production control (FPC) including testing of samples taken at the factory in accordance with a prescribed test plan					
1	Raw material – mechanical characteristics	3.4.1	[1)]	100%	Each delivery
2	Welding	3.4.2	3.4.2	3.4.2	3.4.2
2	Dimensions of the column shoe	3.4.3	[1)]	3	3 column shoes of each manufacturing batch of the same dimension/type

[1)] according to the manufacturer's technical file

3.3 Tasks of the notified body

The cornerstones of the actions to be undertaken by the notified body in the procedure of assessment and verification of constancy of performance for the column shoes are laid down in Table 3.3.1.

Table 3.3.1 Control plan for the notified body; cornerstones

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Initial inspection of the manufacturing plant and of factory production control					
1	The notified body will ascertain that the system of factory production control and the specified manufacturing process are maintained taking into account the staff and equipment as well as the control plan	Verification of the complete factory production control as described in the control plan agreed between the TAB and the manufacturer; check of the measures taken by the manufacturer with regard to personnel, equipment and documentation system in the area of incoming goods and production in accordance with the control plan.	According to control plan; the qualification of personnel, equipment and documentation system shall be appropriate for the controls	According to control plan	When starting the production or a new production line
Continuous surveillance, assessment and evaluation of factory production control					
2	The notified body will ascertain that the system of factory production control and the specified manufacturing process are maintained taking into account the control plan	Verification of the controls carried out by the manufacturer as described in the control plan agreed between the TAB and the manufacturer; check of the qualification of personnel, equipment and documentation system and of the controls carried out by the manufacturer as indicated in Table 3.2.1 as well as of the documented results of the controls in accordance with the control plan	According to control plan; the qualification of personnel, equipment and documentation system shall be maintained and the controls carried out by the manufacturer shall follow the control plan; documented results of the controls shall be in line with the criteria laid down in the manufacturer's technical file	According to control plan	1 per year

3.4 Special methods of control and testing used for the verification of constancy of performance

3.4.1 Control of raw materials by manufacturer

The raw materials shall be subject to control by the manufacturer before acceptance. Check of raw materials shall include control of the inspection documents presented by the suppliers of the initial materials (comparison with nominal values). Details of the factory production control are laid down in a control plan.

The assessment methods as provided for in this EAD have been written based on the assumption that the manufacturer only uses raw materials with the following verifications:

Structural steel:	Material properties to be proven by an inspection certificate 3.1 in accordance with EN 10204 - Yield strength, Tensile strength, Elongation at break A_5
Reinforcing steel:	Material properties to be proven by an inspection certificate 3.1 in accordance with EN 10204 - Yield strength, Tensile strength, Elongation at break A_{gt}

3.4.2 Control of welding by manufacturer

The manufacturing process related to welding shall follow the requirements for execution class EXC3 in accordance with EN 1090-2, Table A.3.

Alternatively, the manufacturing process related to welding shall follow the requirements for execution class EXC2 in accordance with EN 1090-2, Table A.3, with additional control tests according to Annex F. The minimum frequency of this control tests shall be as follows:

- Each size or type 3 per 10000 products or at least 3 per 6 months.

Cornerstones shall be laid down in a control plan.

3.4.3 Control of dimensions of the column shoe by manufacturer

All dimensions (dimensions of the base and side plates, total length of the product, diameter of the anchor bars, distance between base plate and anchor bars, position of the bolt hole, diameter of the bolt hole) including effective throat thickness and length of welds, specified in drawings shall be measured using validated measuring devices (calliper rule, tape measure and throat thickness gauge). Tolerances are detailed in the manufacturer's technical file. Cornerstones are laid down in a control plan.

4 REFERENCE DOCUMENTS

EN 197-1:2011	Cement - Part 1: Composition, specifications and conformity criteria for common cements
EN 206:2013+A2:2021	Concrete - Specification, performance, production and conformity
EN 1090-1:2009+A1:2011	Execution of steel structures and aluminium structures - Part 1: Requirements for conformity assessment of structural components
EN 1090-2:2018+A1:2024	Execution of steel structures and aluminium structures - Part 2: Technical requirements for steel structures
EN 1363-1:2020	Fire resistance tests - Part 1: General Requirements
EN 1365-4:1999	Fire resistance tests for loadbearing elements- Part 4: Columns
EN 1990:2023	Eurocode - Basis of structural and geotechnical design
EN 1992-1-1:2023	Eurocode 2 - Design of concrete structures - Part 1-1: General rules and rules for buildings, bridges and civil engineering structures
EN 1992-1-2:2023	Eurocode 2 - Design of concrete structures – Part 1-2: Structural fire design
EN 1992-4:2018	Eurocode 2 - Design of concrete structures - Part 4: Design of fastenings for use in concrete
EN 1993-1-1:2022	Eurocode 3 - Design of steel structures - Part 1-1: General rules and rules for buildings
EN 1993-1-2:2024	Eurocode 3 - Design of steel structures - Part 1-2: Structural fire design
EN 1993-1-8:2024	Eurocode 3 - Design of steel structures - Part 1-8: Joints
EN 10025-2:2019	Hot rolled products of structural steels - Part 2: Technical delivery conditions for non-alloy structural steels
EN 10204:2004	Metallic products - Types of inspection documents
EN ISO 17660-1:2006	Welding - Welding of reinforcing steel - Part 1: Load-bearing welded joints (ISO 17660-1:2006)
EOTA TR 068:2020-03	Design of structural connections with column shoes

ANNEX A DETERMINATION OF THE BENDING STIFFNESS FACTOR K_L [-] (BS TEST)

A.1 General

Testing vertically restrained cantilever systems is extremely complex and costly in terms of testing technology. Furthermore, when the maximum load capacity is reached, the entire test element must be secured against tipping over or falling.

For this reason, a procedure was developed in which the connection between the foundation and the precast cantilever column is tested on horizontally placed test specimens (column element), as in a beam test.

The test specimen (column element) shall be supported on two bearings and loaded with two loads or two pairs of loads, see Figure A.2.1.

The load shall be increased until the maximum load capacity is reached, and the deformations shall be measured at each load stage.

In the area between the two loads or the two pairs of loads, deformation measurements shall be taken in the area of the column shoe and outside the column shoe area, on both the bottom and top of the test specimen (column element).

The curvatures shall be calculated for each subzone from the measured differential deformations and the distances between the measuring points as well as the support height (see Equation A.6.2.1). The bending moments M_i at certain load steps are defined by Figure A.6.1.1. The bending moment M_i and the curvature shall be used to obtain a bending stiffness $(EI)_1$ to $(EI)_6$ for each load level and each subzone i (see Equation A.6.2.2).

In the area outside the column shoe a total of 6 measurements and thus 3 values for (EI) shall be determined and then averaged to obtain a mean value $(EI)_7$.

The corresponding partial displacements v_1 to v_7 shall be calculated from the measured maximum bending moment, the triangular moment curve for a cantilever column (see Figure A.6.1.1), and the corresponding measured stiffnesses $(EI)_1$ to $(EI)_7$ using the principle of virtual forces. Integration over the height of the precast cantilever column then gives the total displacement v_{shoe} at the end of the precast cantilever column.

The area outside the column shoe is identical for both the precast cantilever column connected via column shoes and the cast-in-situ cantilever column connected monolithic, since in both cases the same dimensions, the same reinforcement, and the same material parameters apply ($(EI)_7 = (EI)'_7$. Therefore, these values can be used for both systems.

For the cast-in-situ cantilever column connected monolithic, the partial displacements shall be determined analogously.

From the values $(EI)'_7$ determined for different load levels, the corresponding values $(EI)'_1$ to $(EI)'_6$ shall be derived from the triangular moment curve and the associated partial displacements v'_1 to v'_7 shall also be calculated using the principle of virtual forces. Integration over the height of the cast-in-situ cantilever column then gives the total displacement v_{ref} at the end of the cast-in-situ cantilever column.

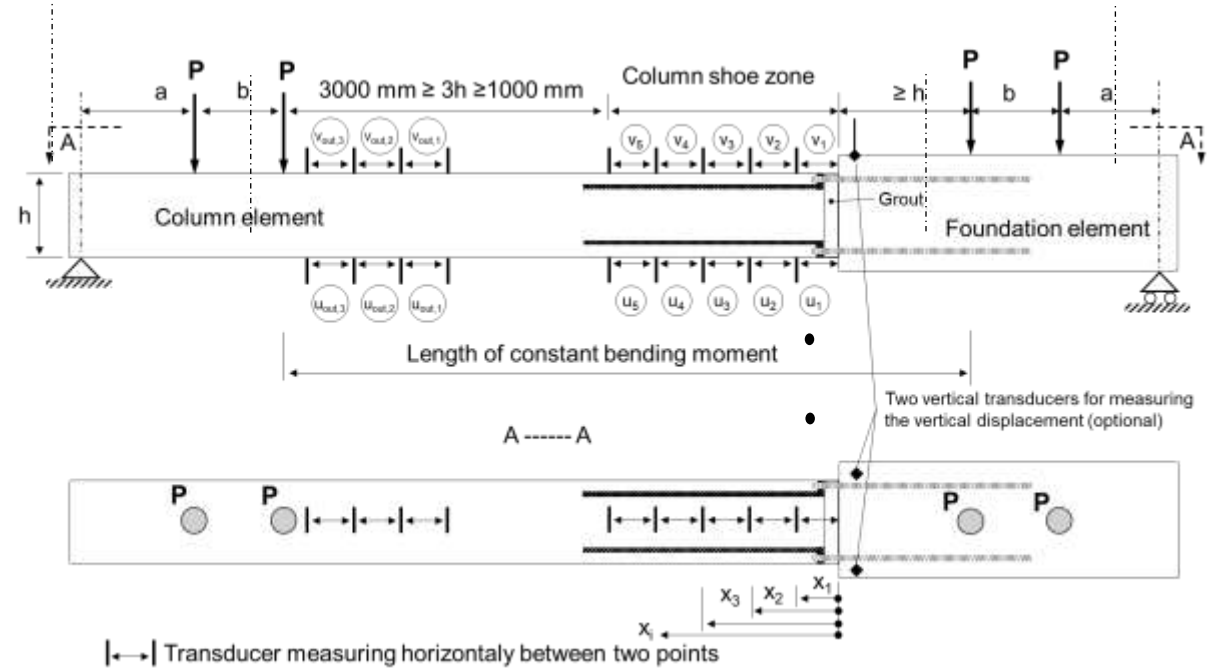
A.2 Test arrangement / test specimen

In the BS test, a reinforced concrete member (hereinafter called "column element") with a square cross-section and provided with four column shoes shall be fixed to another reinforced concrete member (hereinafter called "foundation element"). The cross-section of the column element is the minimum of those which can be used with four column shoes of the considered size and type. The foundation element shall be provided with four anchor bolts. It shall have a cross-section larger than that of the column element (at least 5 cm larger all around). After connecting the column shoes to the bolts and grouting, the concrete elements form a horizontal beam, which shall be supported by two supports as shown in Figures A.2.1 - A.2.3. The horizontal beam shall be loaded by vertical point loads P according to Figures A.2.1 - A.2.3 (see clause A.4). No axial horizontal compression load is allowed. Figures A.2.4 and A.2.5 show position of transducers on top surface and soffit respectively (compare Figure A.2.1). The measurements within the shoe zone shall cover the zone starting from the foundation element and extending over 50% of the length of the shoe zone at least, but preferably more. The chosen length defines the final number and measuring length of the transducers.

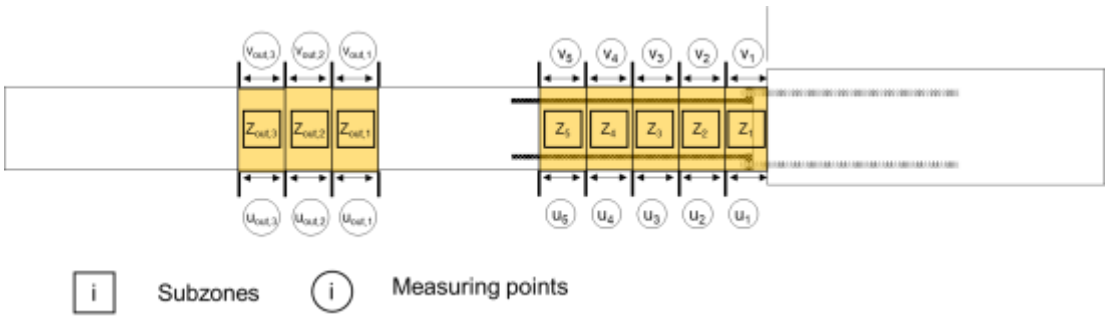
Possible tolerances of material properties and dimensions of the column shoe shall be considered.

In addition to this Annex, the test specimens shall follow the provisions of Annex E and, where applicable, shall be in line with manufacturer's product installation instructions (MPII).

Due to the concept of this assessment method - comparison of the bending stiffness (with/without column shoe) based on the test results obtained from the same test specimen (bending stiffness inside/outside the column shoe zone) - the use of test specimens that follow the above given provisions is considered to be sufficient to produce comparable as well as reproducible results that are then independent of the actually used test arrangement/assembly.



a) elevation and top view (column/foundation reinforcement is not illustrated) with location and numbering of the measuring points (transducers)



b) schematic location and numbering of the subzones and measuring points

Figure A.2.1 Illustration of basic principle of BS test

a) elevation and top view (column element/foundation reinforcement is not illustrated)

b) schematic location and numbering of the subzones and measuring points, further details and provisions are given in this Annex and in Annex E)

Figure A.2.2 Example showing test arrangement, specimen and equipment (details and provisions are given in this Annex and in Annex E)

Figure A.2.3 Example showing steel plates under the acting heads of the hydraulic actuators which shall be thick enough to evenly distribute the concentrated load onto the entire width of the test specimen

Figure A.2.4 Example showing the horizontal transducers fixed on the top surface

Figure A.2.5 Example showing the horizontal transducers fixed along the soffit of the column element

A.3 Number of tests

For each column shoe family, two BS tests shall be performed, one with the smallest and one with the largest column shoe.

A.4 Loads

After the grout has hardened, the jointed horizontal specimen shall be placed on supports and loaded vertically with concentrated loads as shown in Figures A.2.1 – A.2.2. The number of the concentrated loads can be freely chosen based on the capacity of the used hydraulic actuators. The aim is to create a nearly constant bending moment in the mid-part of the test specimen (i.e., part between the inner concentrated loads, see Figure A.2.1) where the horizontal deformation is measured. This is achieved by placing the concentrated loads symmetrically in relation to the supports of the specimen ends.

The test specimen shall be loaded vertically by hydraulic actuators in such a way that the bending moment due to the actuator loads and loading equipment is constant over the length within which the horizontal differential deformations (see clause A.5) are measured. The position of the concentrated load shall be chosen in such a way that the requirements presented in Figure A.2.1 are met.

The loads shall be increased stepwise, until service load level is reached Thereafter, the loads shall be reduced stepwise back to zero or ≤ 3% of the nominal bending resistance. This load cycle shall be carried out 5 times before increasing the loads stepwise until failure. The loads and deformations shall be measured and recorded at each load step.

A.5 Measurements

During the loading, the contraction of the top fibre (v) and elongation of the bottom fibre (u) of the column element shall be measured both within the column shoe zone and outside of it as shown in Figures A.5.1 and A.5.2. From the loads, measured u & v values and the mutual vertical distance of the transducers, the moment-curvature relationship and flexural stiffness of the column element in different subzones Z_i (see Figure A.5.2) shall be calculated (see clause A.6). The measurements within the shoe zone shall cover the zone starting from the foundation element and extending over 50% of the length of the shoe zone at least, but preferably more (up to 100 %). Number of measurement subzones (subzones provided with transducers) shall be ≥ 5 within the column shoe zone and ≥ 3 outside of it. All measurement subzones of a specimen shall have the same initial length (before loading); e.g., if for a column shoe with a total length of 2200 mm 5 measurement subzones with each 400 mm length are set, the length of each subzone outside the column shoe zone shall also be 400 mm).

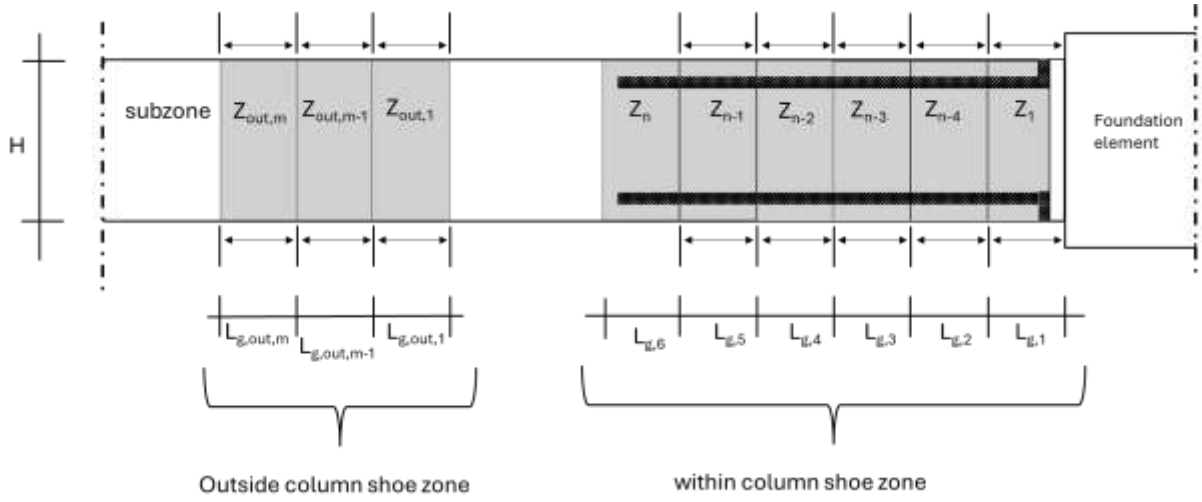


Figure A.5.1 Subzones Z_i in test

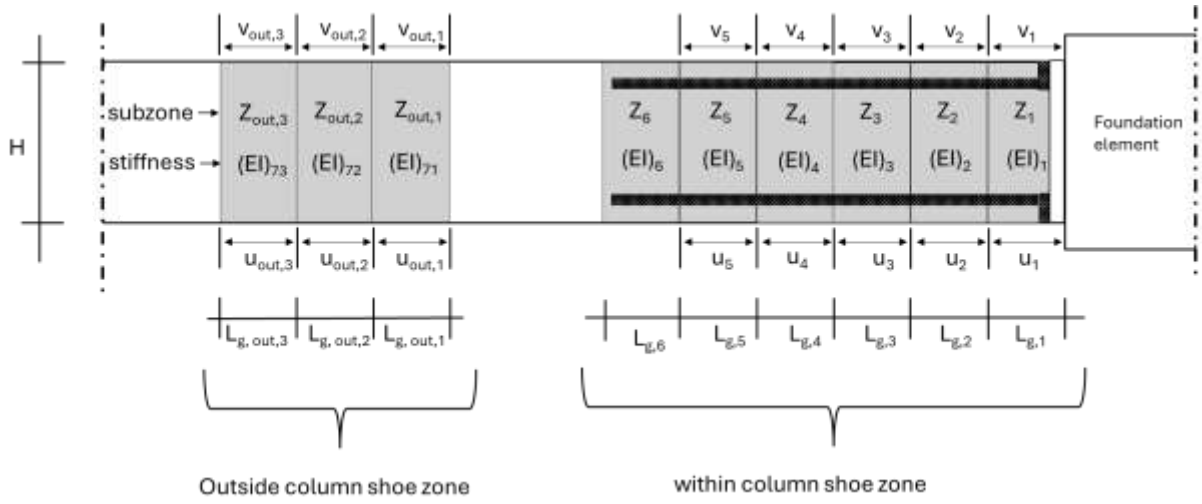


Figure A.5.2 Measured relative deformations u_i and v_i in subzones Z_i and $v_{out,i}$ and $u_{out,i}$ in subzones $Z_{out,i}$. In this example, the number of subzones in accordance with Figure A.5.1 was chosen to n = 6 and m = 3

No measurements of deformation in the subzone Z_n as of the Figure A.5.1 shall be performed (no transducers are placed in these subzones); however, the stiffness of these subzones shall be interpolated in later analysis (see clause A.6.2.1).

$L_{g,i}$ and $L_{g,out,i,}$ respectively, is the measuring length of transducers on the top and at the bottom of subzones Z_i and $Z_{out,i}$ (see Figure 5.2) and equivalent to the length of subzones Z_i and $Z_{out,i}$.

A.6 Determination of the bending stiffness factor k_L [-]

A.6.1 General

The bending stiffness of a column shoe connection shall be obtained by comparing the deflections of two hypothetical cantilever columns shown in Figure A.6.1.1. The comparison is related to the residual deflections determined in the tests with column shoe connections and the theoretical value for monolithic connections in accordance with EN 1992, clause 9.3.4 (7). The subzones in Figure A.6.1.1 are identical to those shown in Figure A.2.1. The difference is given by the fact that Figure A.6.1.1 a) shows Zone 7 after averaging of individual values to determine a mean value.

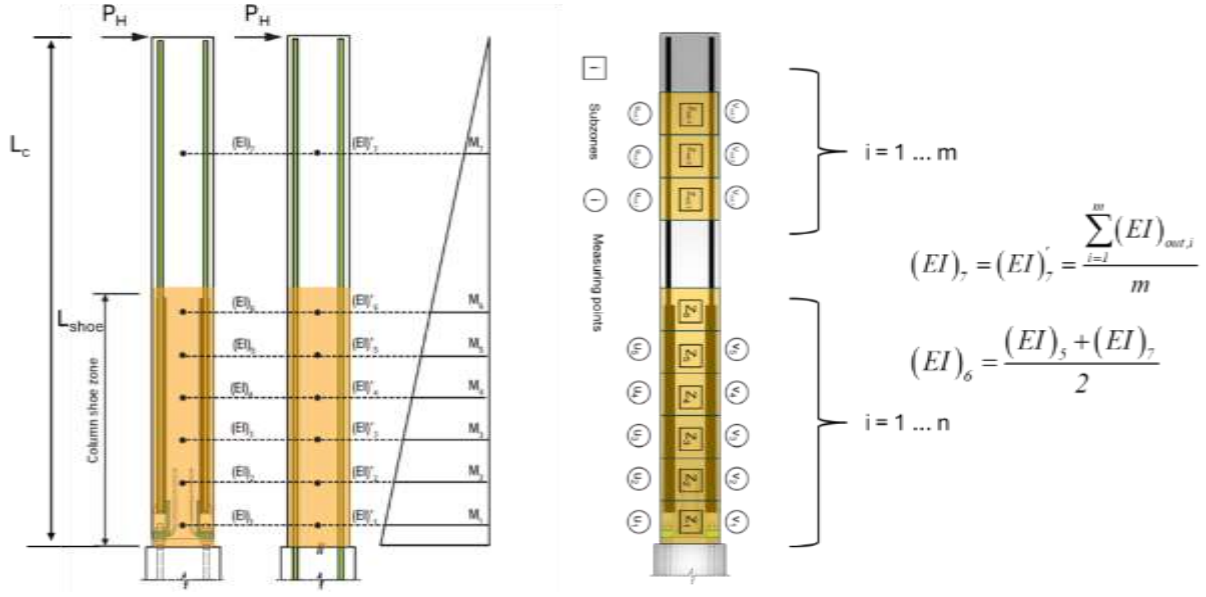


Figure A.6.1.1 Cantilever columns and moment diagram for stiffness comparison.
a) Precast cantilever column A connected via column shoes
b) Cast-in-situ cantilever column B connected monolithic (reference column) with continuous main reinforcement. Subzones in the shoe zone are the same as those in the test, see Figure A.5.2 and A.5.3
c) Moment distribution along the column axis.
d) Position and numbering of the transducers along the tested column element

Precast cantilever **c**olumn A represents a precast column element connected with four column shoes to the base structure.

Cast-in-situ cantilever column B represents a monolithic cast-in-situ column with the same cross-section and a continuous but otherwise similar reinforcement as in precast cantilever column A outside the column shoe zone.

The two cantilever columns shall be subjected to a horizontal load P_H.

Precast cantilever **c**olumn A corresponds to the tested column element with the exception that its length is

$$L_c = min\ \{20h\,;4\,L_{shoe}\} \tag{A.6.1.1}$$

where h and L_{shoe} denote the thickness of the precast cantilever column and the length of the shoe zone, respectively.

P_H shall be obtained from

$$P_H = \frac{\eta_{d,0} M_t}{L_c} \tag{A.6.1.2}$$

where M_t denotes the theoretical yielding moment of the connection calculated[4] in accordance with EN 1992-1-1, clause 6.1, assuming that the section behaves as a concrete section reinforced with the anchor bolts using the nominal yield strength of the anchor bolts, the nominal strength of the concrete and $\eta_{d,0} \leq 1{,}00$ (see Annex E). For the bolts, the bilinear stress-strain assumption with a horizontal top branch (EN 1992-1-1, 3.2.7 b) shall be applied.

4 The EAD does not aim to assess or establish the yielding moment of the connection as performance of the column shoe but only as parameter used in the simulation aimed to assess the stiffness factor k_L of the assessed column shoe.

The upper end deflection of precast cantilever column *A* and cast-in-situ cantilever *B* due to P_H is v_{shoe} and v_{ref}, respectively.

The deflections v_{shoe} and v_{ref} shall be calculated using the stepwise changing stiffnesses $(EI)_i$ and $(EI)'_i$ in accordance with clauses A.6.2 to A.6.4.

The bending stiffness factor k_L shall be obtained by comparing the values of v_{shoe} and v_{ref} as follows:

$$k_L = 1{,}0 \quad \text{if } v_{shoe}/v_{ref} \le 1{,}05$$
$$= (v_{shoe}/v_{ref})^{1/2} \quad \text{if } 1{,}05 < v_{shoe}/v_{ref} \le 1{,}21 \qquad \text{(A.6.1.3)}$$

If $v_{shoe}/v_{ref} > 1{,}21$, the connection is considered hinged. In such a case it is sufficient to state in the test report that $k_L > 1{,}1$.

An example for determination of v_{shoe} and v_{ref} is given in Annex G.

A.6.2 Stiffness of subzones

Consider the subzones Z_i with length $L_{g,i}$ illustrated in Figure A.5.2. For each subzone Z_i, the curvature κ_i shall be calculated from

$$\kappa_i = \frac{u_i - v_i}{HL_{g,i}} \qquad \text{(A.6.2.1)}$$

and secant stiffness $(EI)_i$ from

$$(EI)_i = \frac{M_i}{\kappa_i} \qquad \text{(A.6.2.2)}$$

where

- u_i = elongation of subzone Z_i at the bottom
- v_i = Absolute value elongation of subzone Z_i on the top
- H = vertical distance between depths at which u_i and v_i are measured
- $L_{g,i}$ = mutual horizontal distance of points between which u_i is measured (same for v_i) (= length of subzone Z_i)
- M_i = bending moment due to the imposed load in the middle of subzone Z_i following Figure A.6.1.1

For the given example in Figure A.5.2, this leads to the following:

$\kappa_1 = \frac{u_1 - v_1}{HL_{g,1}}$ ➔ $(EI)_1 = \frac{M_1}{\kappa_1}$

$\kappa_2 = \frac{u_2 - v_2}{HL_{g,2}}$ ➔ $(EI)_2 = \frac{M_2}{\kappa_2}$

$\kappa_3 = \frac{u_3 - v_3}{HL_{g,3}}$ ➔ $(EI)_3 = \frac{M_3}{\kappa_3}$

$\kappa_4 = \frac{u_4 - v_4}{HL_{g,4}}$ ➔ $(EI)_4 = \frac{M_4}{\kappa_4}$

$\kappa_5 = \frac{u_5 - v_5}{HL_{g,5}}$ ➔ $(EI)_5 = \frac{M_5}{\kappa_5}$

For m = 3 subzones outside the column shoe zone, one gets:

$$\kappa_{71} = \frac{u_{out,1} - v_{out,1}}{HL_{g,out,1}} \quad \rightarrow \quad (EI)_{71} = \frac{M_{71}}{\kappa_{71}}$$
$$\kappa_{72} = \frac{u_{out,2} - v_{out,2}}{HL_{g,out,2}} \quad \rightarrow \quad (EI)_{72} = \frac{M_{72}}{\kappa_{72}}$$
$$\kappa_{73} = \frac{u_{out,3} - v_{out,3}}{HL_{g,out,3}} \quad \rightarrow \quad (EI)_{71} = \frac{M_{73}}{\kappa_{73}}$$

$$(EI)_7 = \frac{(EI)_{71} + (EI)_{72} + (EI)_{73}}{3}$$

The stiffness $(EI)_6$ represents the end of the column shoe zone, where the rebars of the column shoe are only present partly. To consider this, it is taken as the mean value of zones with column shoe $(EI)_5$ and without column shoe $(EI)_7$.

$$(EI)_6 = \frac{(EI)_5 + (EI)_7}{2}$$

The symbol *(EI)* represents the real flexural stiffness (secant stiffness) of a cross-section or its conservative approximation in the sense defined by Equation A.6.2.2. It shall not be understood as a product of elasticity modulus *E* and second moment of area *I*.

The *M-(EI)* –relationship for each subzone Z_i and $Z_{out,i}$ shall be calculated from the measured loads and deformations and if done so additionally by FE analysis (see clause A.7).

The corresponding partial displacements v_1 to v_7 shall be calculated from the measured maximum bending moment, the triangular moment curve for a cantilever column, and the corresponding measured stiffnesses $(EI)_1$ to $(EI)_7$ using the principle of virtual forces. Integration over the height of the precast cantilever column A then gives the total displacement v_{shoe} at the end of the precast cantilever column A.

The area outside the column shoe is identical for both the precast cantilever column A connected via column shoes and the cast-in-situ cantilever column B connected monolithic, since in both cases the same dimensions, the same reinforcement, and the same material parameters apply ($(EI)_7 = (EI)'_7$. Therefore, these values can be used for both systems.

For the cast-in-situ cantilever column connected monolithic, the partial displacements shall be determined analogously.

From the values $(EI)'_7$ determined for different load levels, the corresponding values $(EI)'_1$ to $(EI)'_6$ shall be derived from the triangular moment curve and the associated partial displacements v'_1 to v'_7 shall also be calculated using the principle of virtual forces. Integration over the height of the cast-in-situ cantilever column B then gives the total displacement v_{ref} at the end of the cast-in-situ cantilever column B.

A.6.3 Stiffness of precast cantilever column A

M_i is the bending moment due to P_H in the middle of subzone Z_i, see Figure A. 6.1.1.

$(EI)_i$ (i = 1, …, n-1) is the calculated stiffness for subzone Z_i corresponding to the imposed bending moment in the test equal to M_i.

Outside the shoe zone the stiffness $(EI)_{n+1}$ shall be obtained as the mean of the calculated stiffnesses $(EI)_{out,i}$ (see Figure A. 6.1.1) or

$$(EI)_{n+1} = \frac{\sum_{i=1}^{m}(EI)_{out,i}}{m} \qquad (A.6.3.1)$$

where each $(EI)_{out,i}$ corresponds to the imposed bending moment in the bending test equal to M_i.

M_i is the bending moment due to P_H in the middle of subzone Z_{n+1} where $L_{shoe} < x \leq L_c$, see Figure A.6.1.1.

The mean value of the stiffness $(EI)_{n+1}$ shall be obtained by dividing by the number of measuring transducers subzones (m = 3 in the example in Figure A.6.1.1).

For the column shoe zone outside the subzones Z_i (i = 1, ..., *n-1)*

$$(EI)_n = \frac{((EI)_{n-1}+(EI)_{n+1})}{2} \quad \text{(A.6.3.2)}$$

where $(EI)_{n-1}$ and $(EI)_{n+1}$ are the calculated stiffnesses for zone Z_{n-1} and Z_{n+1}, respectively, corresponding to the imposed bending moment equal to M_n. M_n is the bending moment due to P_H in the middle of zone Z_n, see Figure A.6.1.1.

A.6.4 Stiffness of cast-in-situ cantilever column B

$(EI)'_{n+1}$ is obtained from

$$(EI)'_{n+1} = \frac{\sum_{i=1}^{m}(EI)_{out,i}}{m} \quad \text{(A.6.4.1)}$$

where the stiffnesses $(EI)_{out,i}$ (i = *1*, …, *m*) are the calculated stiffnesses for zones $Z_{out,i}$ corresponding to the imposed bending moment equal to M_i. M_i is the bending moment due to P_H in the middle of zone Z_{n+1}, see Figure A. 6.1.1.

A.7 FE analysis

The tests can be supplemented by FE analysis, e.g., for the assessment of an additional size of an already tested column shoe type, provided that the validity of FE modelling and analysis process is demonstrated through at least one comparison with a benchmark laboratory test (a test in accordance with the previous clauses of this Annex which has been already performed on the same test specimen that will be modelled and compared with).

The following conditions shall be considered when Finite Element analyses are used for generation of supplementary response database:

(1) A validated FE-Programme is necessary, that can capture the damage and cracking of concrete. The validation shall be publicly available in terms of benchmark calculations.

(2) The FE-model shall be validated for the aimed failure mode to be investigated. Since BS tests aims at investigation of the flexural behaviour of the connection, any failure mode other than flexure are assumed to be precluded and flexural failure mode governs the overall response. Flexural failure may occur either in the monolithic zone (resulting from yielding of the column reinforcement) or at the grout zone (resulting from yielding of the anchor bolt). It is necessary to design benchmark experiments demonstrating these two failure modes in order to validate the FE modelling procedure.

The following parameters shall be considered when Finite Element analyses are used to exclude a significant influence on the FE results:

(1) Element size,
(2) Element shape, ratio,
(3) Validation with as built specimen,
(4) Bond modelling,
(5) Material modelling of steel, concrete, …,
(6) Boundary conditions,
(7) Load steps, supports.

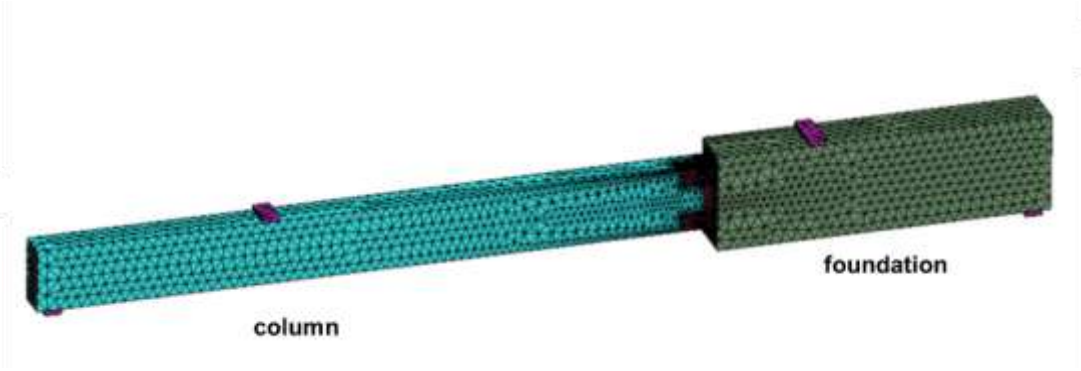
For the Finite Element Model the following modelling shall be considered (compare Figure A.7.1):

(1) Solid elements for simulation of concrete, grout, the shoe plates and the anchor bolt along with the connecting nut are a precondition.
(2) For bearing compression only contacts shall be modelled as applicable.

(3) Reinforcing steel shall be modelled using beam elements or truss elements smeared into the concrete volume for reduction of the model size in order to achieve computational efficiency. Equivalently, solid elements for the reinforcements can also be used.

(4) In cases where splice lengths are as per the provisions of EN 1992-1-1, clause 11.5, or reinforcement is welded, a perfect bond assumption shall be used for achieving computational efficiency. In cases where an insufficiency of splice length or anchorage length is envisaged, appropriate bond slip laws shall be considered.

(5) The boundary conditions in the model shall closely represent the mechanical state of loading in the test set explained in the relevant clauses/annexes of this EAD.



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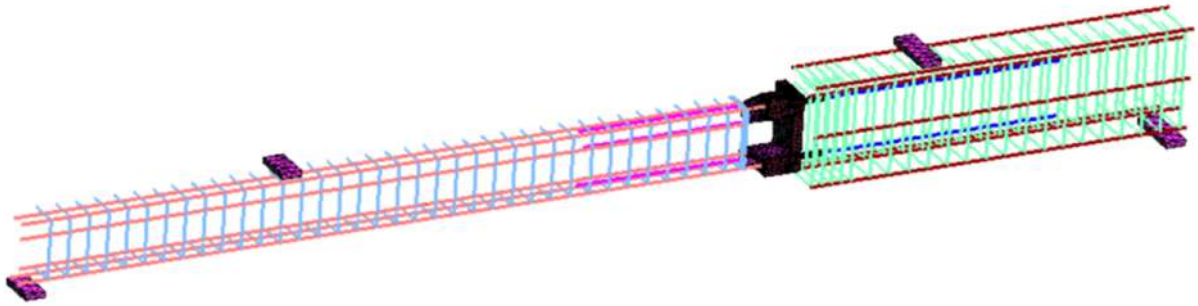

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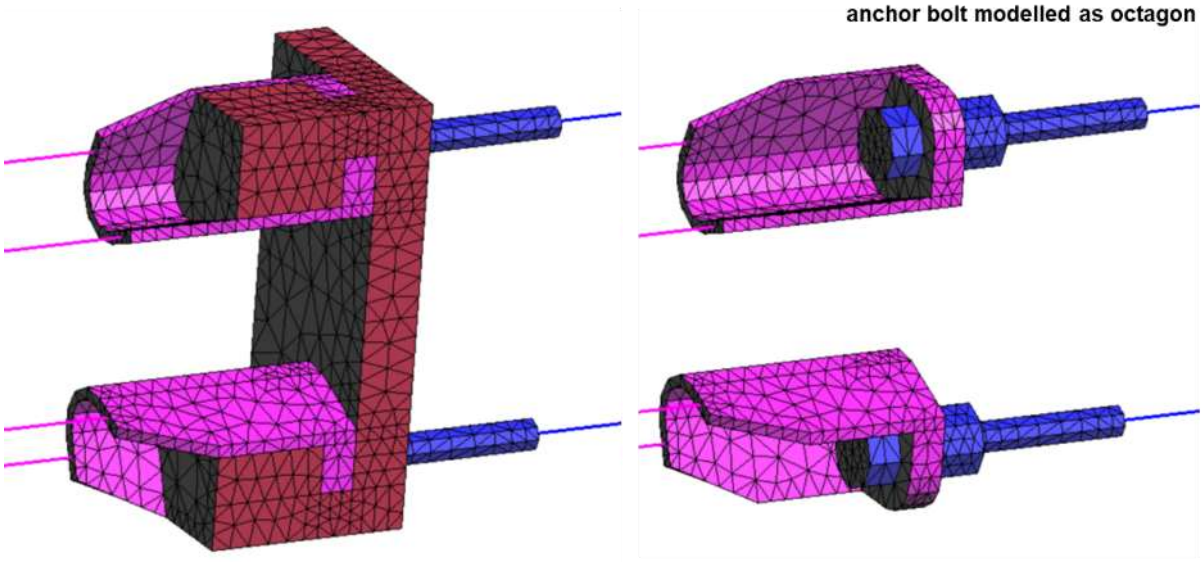


c)

Figure A.7.1 Examples for modelling within the Finite Element analysis
a) Solid elements of column, foundation and loading/support plates
b) 1D-bar elements of the reinforcement
c) Solid elements of column shoe and anchor bolts

For the Finite Element Model the following materials shall be considered:

(1) Material model for concrete shall be representative of the stress-strain relationship of concrete material used in both tension as well as compression.

(2) Both multilinear iso-tropic hardening or non-linear hardening models can equivalently be considered for modelling of the steel, whereby von-Mises based stress-strain relationship shall be used for consideration of non-linearity of steel.

For the Finite Element Model the following loading shall be considered:

(1) To simulate a BS test, the load in the FE model shall be applied in terms of monotonically increasing forces until final failure.

Before using the FE Model for the assessment, it shall be checked in order to ensure that it matches the results of the considered benchmark test with regards to load-bearing capacity, deflections, stiffnesses, stresses and deformations within the usual scattering of reinforced concrete structures.

For the validation of Finite Element Model the following comparisons with the benchmark tests shall be considered:

(1) Comparison of the load defection curve,

(2) Comparison of the failure mode and crack pattern at 50% and 100% peak load,

(3) Comparison of the stress in the reinforcement,

(4) Comparison of the deformations of the LDTV measurements.

ANNEX B DETERMINATION OF BENDING RESISTANCE FACTOR η_D [-] (BR TEST)

B.1 General

The concept of this assessment method is based on:

1. Laboratory tests: The bending resistance (BR) test, see Figure B.2.1, is similar to the BS test except that the aim is to only measure the bending resistance $M_{e,i}$ (without the stiffness properties) of the connection of test specimens which simulate precast cantilever columns connected via column shoes.
2. Calculation of the theoretical bending resistances of the connection $M_{t,i}$ based on the material properties of grout, concrete, reinforcement and yield strength of anchor bolts as well as the nominal geometry used in the test.
3. Comparison of the experimental bending resistances $M_{e,i}$ and theoretical bending resistances $M_{t,i}$. The aim is to assess that the bending resistance of a precast cantilever column connected via column shoes is at least equivalent or better than a cast-in-situ cantilever column connected monolithic.
4. Quantifying the result of the comparison as the bending resistance factor η_d of the assessed column shoe. This is the performance of the column shoe and can serve as well as an input value for the design of connections using this column shoe according to EOTA TR 068 (see clause 1.2.1 "Intended use").

B.2 Test arrangement / test specimen

The test specimen is similar to the one of BS test (see clause A.2), but since the stiffness properties are not measured, there may be vertical point loads on the column shoe zone and the test specimen may be relatively short (see Figure B.2.1). No axial horizontal compression load is allowed. The number of symmetrically applied point loads can be freely chosen provided that the restrictions given in Figure B.2.1 are taken into account.

Possible tolerances of material properties and dimensions of the column shoe shall be considered.

In addition to this Annex, the test specimens shall follow the provisions of Annex E and, where applicable, shall be in line with manufacturer's product installation instructions (MPII).

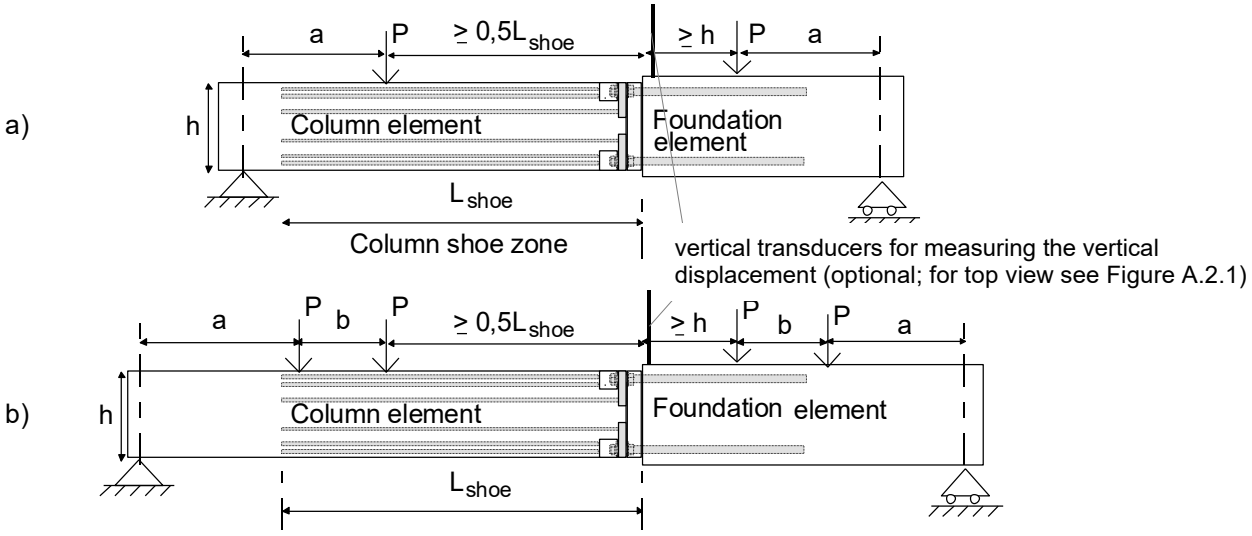


Figure B.2.1 Illustration of basic principle and loading arrangements in test BR, a) with two-point-load and b) with four-point-load (reinforcement not illustrated; further details and provisions are given in this Annex and in Annex E)

Due to the concept of this assessment method - comparison of the experimental and theoretical bending resistances of the same tested connection - the use of test specimens that follow the above given provisions is considered to be sufficient to produce comparable as well as reproducible results that are then independent of the actually used test arrangement/assembly.

Figure B.2.2 Example showing test arrangement, specimen and equipment (details/provision are given in this Annex and in Annex E)

B.3 Number of tests

The tensile resistance of the column shoes is assessed indirectly by bending tests.

In the case of five sizes, in addition to the two (smallest and largest size) BS tests carried out for bending stiffness comparison, at least three BR tests (smallest, intermediate and largest size), see B.1, shall be carried out for each type of column shoe.

B.4 Measured yield resistance or yield strength of anchor bolts

For the determination of bending resistance factor η_d (see B.5) the actual yield resistance or yield strength of the anchor bolts used in the test specimens/ assembly according to clauses B.2 – B.3 shall be determined as the mean yield resistance or mean yield strength, respectively, obtained from three tests /one type of anchor bolt which belong to the same batch and have the same material as the bolts used in the test specimens/ assembly according to clauses B.2 – B.3. The 0,2% yield limit shall be used as yielding criterion if there is no clear yielding point.

B.5 Determination of bending resistance factor η_d [-]

For each type of column shoe, the results of all test specimens as given in clause B.3 (at least 5 tests on five test specimens) shall be evaluated as one family of tests. The test results shall be converted according to Annex E.3.

Assume that the experimental (clauses B.2 – B.3) and theoretical bending resistances for a test specimen are $M_{e,i}$ and $M_{t,i}$, respectively, where i (numbering of test specimens)= 1,...,n ($n \geq 5$).

For each test specimen, the theoretical resistance $M_{t,i}$ (theoretical yielding moment of the connection) shall be calculated in accordance with TR 068, section 3.4.2, assuming that the section behaves as a concrete section reinforced with the anchor bolts using the measured yield strength of the anchor bolts (see clause B.4) and the measured strength of the concrete and using $\eta_{d,0} \leq 1{,}00$ (see Annex E, table E.2.1).

For each specimen the ratio experimental to theoretical bending resistances shall be calculated in accordance with Equation B.5.1.

$$m_i = \frac{M_{e,i}}{M_{t,i}},\ i = 1, \ldots, n \qquad \text{(B.5.1)}$$

Then the characteristic value m_k of above calculated m_i-values (ratios experimental to theoretical bending resistances) shall be calculated in accordance Equation B.5.2.

$$m_k = m_m - k_n s_m \qquad \text{(B.5.2)}$$

where m_m is the mean value of all m_i-values, s_m is the standard deviation of them and the value of k_n (deviation factor) is taken from EN 1990, Table D1 (unknown coefficient of variation).

For the considered type of column shoe, the bending resistance factor η_d shall be obtained from Equation B.5.3.

$$\eta_d = \min\{m_k; \eta_{d,0}\} \qquad \text{(B.5.3)}$$

B.6 FE analysis

The tests can be accompanied by FE analysis, e.g., for the assessment of an additional size of an already tested column shoe type, provided that the validity of FE modelling and analysis process is demonstrated through at least one comparison with a benchmark laboratory test.

For the conditions, parameters, modelling, materials, loading and validation/comparisons with the benchmark tests see clause A.7. Examples for FE modelling see Figure A.7.1. As a rule, within the FE analysis, the geometry, loading, material parameters shall correspond to the situation within the laboratory.

ANNEX C DETERMINATION OF SHEAR RESISTANCE FACTOR K_S [-] (S TEST)

C.1 General

The concept of this assessment method is based on:

1. Laboratory tests: Determination of the shear resistances (S) of reinforced concrete test specimens which simulate precast cantilever columns connected via column shoes.
2. Calculation of the theoretical shear resistances of the same connection based on the ultimate strength of the base plate of the column shoe and the yield strength of the anchor bolts used in the test.
3. Comparison of the experimental and theoretical shear resistances.
4. Quantifying the results of the comparison as the shear resistance factor k_s of the assessed column shoe. This is the performance of the column shoe and can serve as well as an input value for the design of connections using this column shoe according to EOTA TR 068 (see clause 1.2.1 "Intended use").

C.2 Test arrangements / test specimen

In the shear test, a reinforced concrete member called "column element" with a square cross-section and provided with four column shoes, shall be fixed to another reinforced concrete member called "foundation element". The cross-section of the column element is the minimum of those which can be used with four column shoes of the considered size and type. The foundation element is provided with four anchor bolts. It has a cross-section larger than that of the column element (at least 5 cm larger all around). After connecting the column shoes to the bolts and grouting, the concrete elements form a horizontal beam, which will be supported by three supports as shown in Figure C.2.1. The horizontal beam shall be loaded by vertical point load(s) P according to Figures C.2.1 - C.2.2. No axial horizontal compression load is allowed.

Possible tolerances of material properties and dimensions of the column shoe shall be considered.

In addition to this Annex, the test specimens shall follow the provisions of Annex E and, where available, shall be in line with manufacturer’s product installation instructions (MPII).

Due to the concept of this assessment method - comparison of the experimental and theoretical shear resistances of the same tested connection - the use of test specimens that follow the above given provisions is considered to be sufficient to produce comparable as well as reproducible results that are then independent of the actually used test arrangement/assembly.

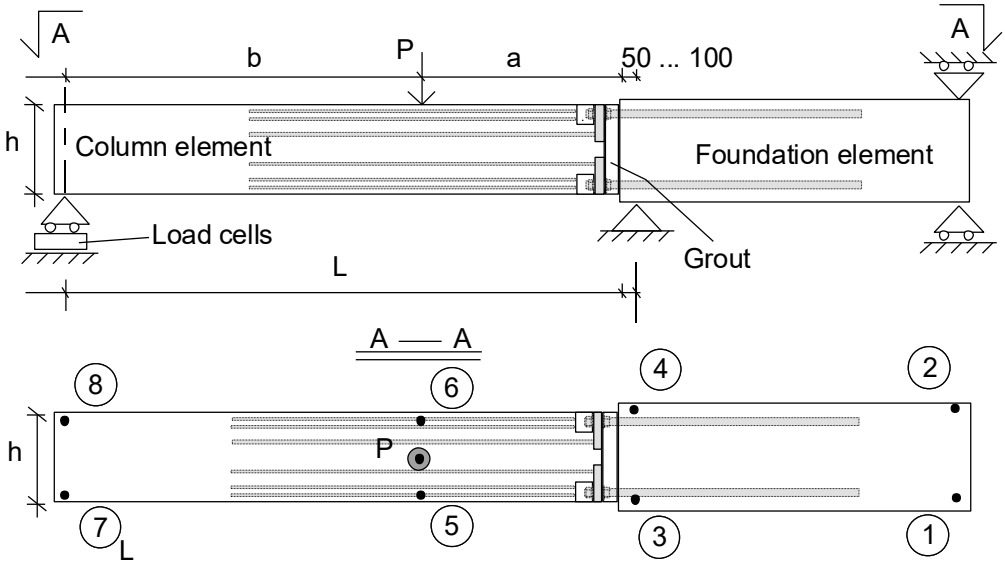


Figure C.2.1 Illustration of basic principle of the load test for assessment of shear resistance. Measuring the displacements with vertical transducers 1 – 8 is optional (reinforcement not illustrated; further details and provisions are given in this Annex and in Annex E). The distance of 50 to 100 mm defines the position of the bottom support.

Figure C.2.2 Example showing test arrangement, specimen and equipment (c.f. the upper part of Figure C.2.1; details/provision are given in this Annex and in Annex E)

Figure C.2.3 Example of positioning of load cells (yellow cells)

The location of vertical point load *P* shall be determined by

$$a = max\ \{1{,}2m\,;\,2\,,\,5h\} \tag{C.2.1}$$

$$b \geq 2a \tag{C.2.2}$$

where *h* is the thickness of the column element. If more than one load is needed, all loads *P* shall meet requirements according to Equations C.2.1 and C.2.2.

The cross-section and reinforcement of the foundation element are chosen to guarantee that the failure takes places outside the foundation element. As a result, it is recommended that the foundation element is produced with a concrete strength one class above the concrete strength of the column element.

Note: The assessment methods as given in this EAD are based on the assumption that the strength of the grout and the concrete in the column element is close to the minimum strength which is allowable for the considered column shoe in accordance with clause 1.2.1 and in addition, where available, with the MPII. The reinforcement in the column element is capable to resist a load corresponding to the expected shear resistance of the column shoes.

Load *P* shall first be increased stepwise until 40 – 60% of the ultimate shear load according to Equation C.4.2 is achieved. Thereafter, the load shall be reduced back to zero or ≤ 3% of the nominal shear resistance. This load cycle shall be repeated 3 – 5 times before *P* is increased stepwise until failure. At each load step, the load, the reaction forces measured by the load cells and the optionally measured displacements shall be recorded.

C.3 Number of shear tests

Two tests shall be carried out for each column shoe family, one for the smallest and one for the largest column shoe in the family. In both cases, the column element cross-section is the minimum applicable to the considered column shoe.

C.4 Determination of shear resistance factor k_S [-]

The factor k_S shall be determined according to Equation C.4.1.

$$k_S = \min (V_{e,i}/V_{t,i}) \leq 1,0 \quad \text{(C.4.1)}$$

where $V_{t,i}$ is the theoretical shear resistance calculated according to Equation C.4.2 and the yield strength of the anchor bolt determined as specified in B.4. This is related to the number of single column shoes acting together against shear (see Figure C.4.1).

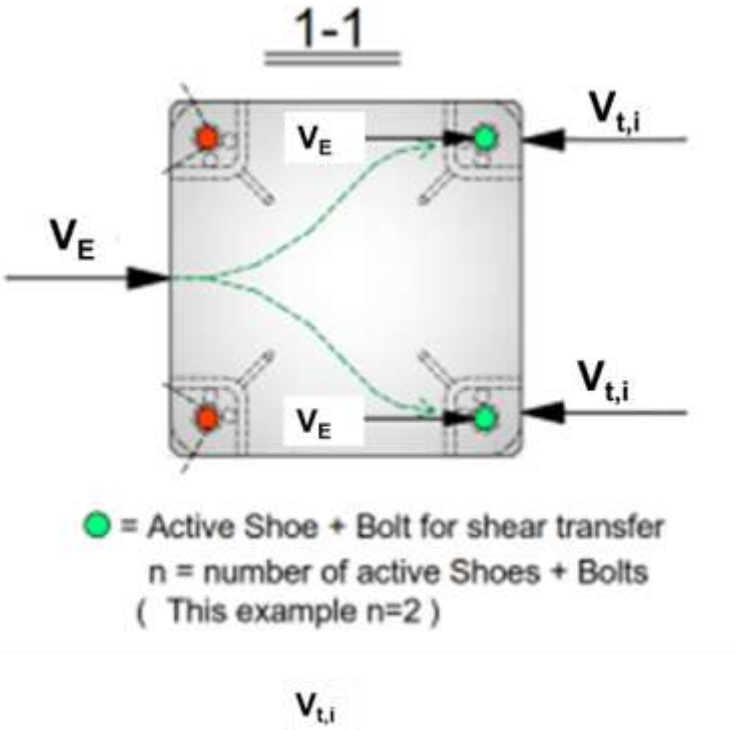


Figure C.4.1 Example for distribution of acting shear loads on column shoes, only the column shoes on the right-hand side are considered active against shear

$V_{e,i}$ is experimental shear resistance of connection obtained by shear test. The test results shall be converted according to Annex E.3.

The strength of the base plate material $f_{base,u}$ shall be taken from the certificates of compliance (inspection certificate 3.1 in accordance with EN 10204).

$$V_{t,i} = \min\{F_{1,vb}\,;\,F_{2,vb}\} \quad \text{(C.4.2)}$$

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

$$F_{1,vb} = 0{,}8\,(k_{m\times\alpha_b} \times f_{base,u} \times d_b \times t_{base}) \quad \text{(C.4.3)}$$

$$F_{2,vb} = \alpha_b \times f_{bolt,u} \times A_{bolt} \quad \text{(C.4.4)}$$

$$\alpha_b = 0{,}44 - (0{,}0003) f_{bolt,y} \quad \text{(C.4.5)}$$

The term 0,0003 in Equation C.4.5 is given with the unit MPa^{-1}.

In these equations

k_m and α_b	=	coefficients calculated as in EN 1993-1-8, clause 5.9.1 and Table 5.9
$f_{base,u}$	=	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
$f_{bolt,y}$	=	yield strength of the anchor bolt
$A_{s,nom\ (bolt)}$	=	nominal stress area in thread of the anchor bolt

C.5 FE analysis

The tests can be accompanied by FE analysis, e.g., for the assessment of an additional size of an already tested column shoe type, provided that the validity of FE modelling and analysis process is demonstrated through at least one comparison with a benchmark laboratory test.

For the conditions, parameters, modelling, materials, loading and validation/comparisons with the benchmark tests see clause A.7. Examples for FE modelling see Figure A.7.1. As a rule, within the FE analysis, the geometry, loading, material parameters shall correspond to the situation within the laboratory.

ANNEX D DETERMINATION OF STEEL TEMPERATURE AS A FUNCTION OF THE DURATION OF FIRE EXPOSURE $T_{CR}(T_I)$ [°C]

D.1 General

The steel temperature as a function of the duration of fire exposure $T_{cr}(t_i)$ [°C] shall be determined by laboratory fire tests and can be accompanied by FE analysis based on laboratory fire tests. FE analysis can be used to get additional results for locations, where no measurement is possible. If doing so, measured and calculated (FE) values at the same measuring points shall be used jointly to evaluate the time-temperature curve of the decisive point of failure. Furthermore, FE analysis can be used to evaluate temperature curves for intermediate sizes not tested. Results of FE analysis shall only be used, when they are conservative compared to test results.

$T_{cr}(t_i)$ is the steel temperature as a function of the duration of fire exposure, which is the decisive (highest) measured temperature T_{cr} of all critical points of the column shoe steel at a specific time point t_i of fire exposure duration; t_i = 15 min, 20 min, 30 min, 45 min, 60 min, 90 min, 120 min, …

The fire tests shall be performed in accordance with EN 1365-4 in connection with EN 1363-1 on unloaded column shoe connections but with the aim of measuring the temperature distribution in the column shoe and, based on this, the assessment of the $T_{cr}(t_i)$ values which shall be stated in the ETA as temperature-time table, see clause D.4 (no assessment of fire resistance of the test specimen shall be performed).

Possible tolerances of material properties and dimensions of the column shoe shall be considered.

D.2 Test specimen

The test specimen shall be designed following the provisions of Annex E.

D.3 Number of tests

- If the steel temperature as a function of the duration of fire exposure $T_{cr}(t_i)$ [°C] is determined by fire tests only, each column shoe size shall be used in the laboratory tests.
- If the steel temperature as a function of the duration of fire exposure $T_{cr}(t_i)$ [°C] is determined by FE analysis based on fire tests, the smallest, middle and largest column shoe size shall be used in the laboratory tests. If a column shoe family covers less than five sizes, the smallest and largest size shall be used in the laboratory tests.

For each column shoe size one column shoe connection shall be prepared and exposed to fire.

D.4 Temperature determined by fire tests

An example of the test layout is shown in Figure D.4.1. The actual arrangements depend on the design and size of the furnace and shall follow EN 1363-1, clause 4.2 b), clause 5.2.2.4 and clause 6.2.2.

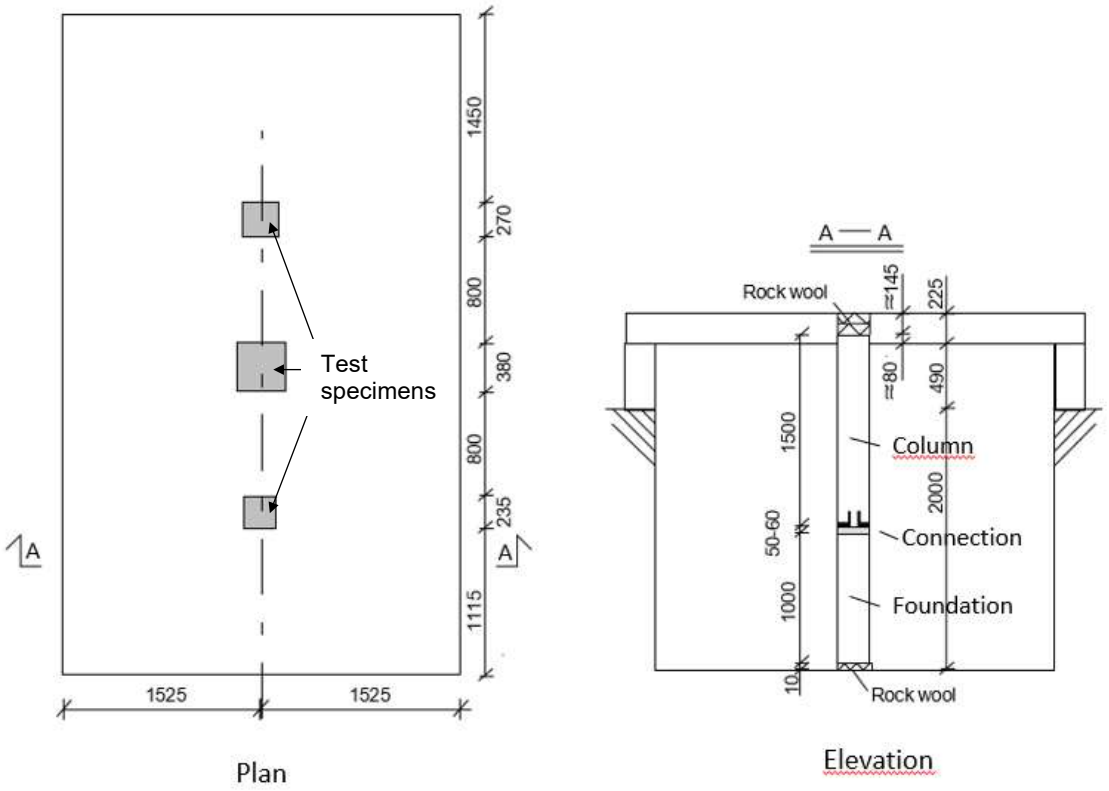


Figure D.4.1 Example of positioning test specimens in furnace (in this example 3 test are illustrated)

In the fire tests the temperature distribution in each column shoe connection shall be measured at critical points of the column shoe. The measuring points (positions of thermocouples) shall be individually determined based on the shape and size of the specific assessed column shoe but shall at least consider the following provisions:

- The number of measuring point shall be at least 10.
- All components of the column shoe shall be covered by the measurements.
- Figure D.4.2 shows an example scheme of distribution of measuring points on critical pints.
- In addition, at least two measuring points in accordance to Figure D.4.3 shall be considered for the interpolation of the temperature in the area of opening/inserted part of anchor bolt.

The wiring of the thermocouples shall be performed in a way that no interference in the temperature distribution can occur (e.g., by leading the wires into the centre of the column element and then vertically inside the column element up to the upper insulation).

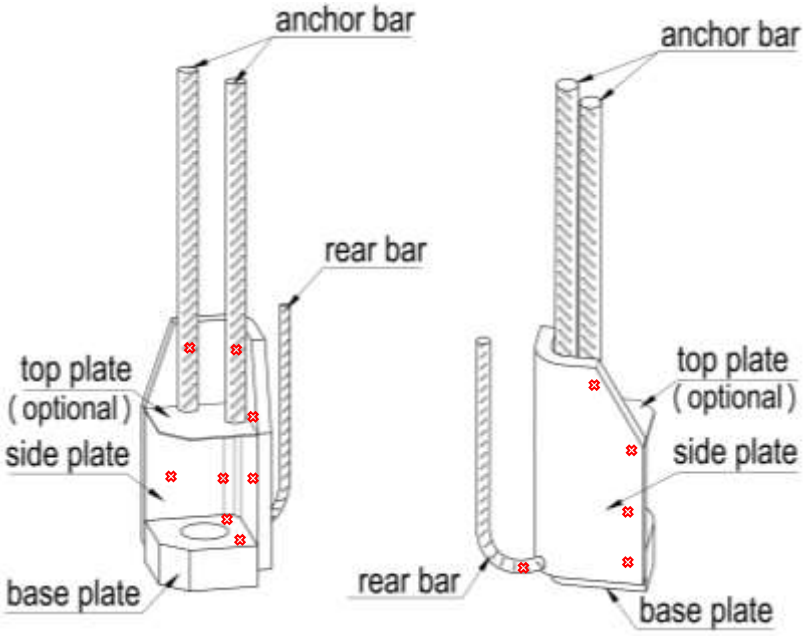


Figure D.4.2 Example scheme of distribution of measuring points

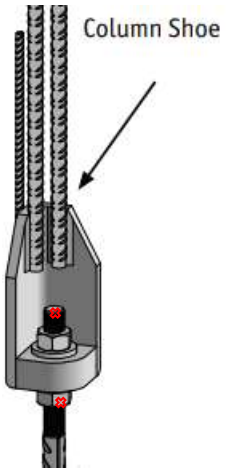


Figure D.4.3 Additional measuring points

The steel temperature as a function of the duration of exposure $T_{cr}(t_i)$ [°C] shall be determined at relevant time intervals (15 min, 20 min, 30 min, 45 min, 60 min, 90 min, 120 min, …). An example of expression of performance in the ETA is given in Table D.4.1

Table D.4.1 Steel temperature/exposure time under fire exposure - $T_{cr}(t_i)$ [°C] (example)

Column shoe type/size	*(Designation of type/Size column shoe 1)*	*(Designation of type and Size column shoe 2)*	*(Designation of type and Size column shoe 3)*	*(Designation of type and Size column shoe 4)*	*(Designation of type and Size column shoe i)*
Minimum Cross-section of column element [mm]	*(Dimensions of related minimum cross-section)*	*(Dimensions of related minimum cross-section)*	*(Dimensions of related minimum cross-section)*	*(Dimensions of related minimum cross-section)*	*(Dimensions of related minimum cross-section)*
Exposure duration (t_i) [min]	**Tcr(ti) [°C]**				
(Time interval 1)	*(Assessed temperature)*	*(Assessed temperature)*	*(Assessed temperature)*	*(Assessed temperature)*	*(Assessed temperature)*
30	*(Assessed temperature)*	*(Assessed temperature)*	*(Assessed temperature)*	*(Assessed temperature)*	*(Assessed temperature)*
45	*(Assessed temperature)*	*(Assessed temperature)*	*(Assessed temperature)*	*(Assessed temperature)*	*(Assessed temperature)*
60	*(Assessed temperature)*	*(Assessed temperature)*	*(Assessed temperature)*	*(Assessed temperature)*	*(Assessed temperature)*
(Time interval i)	*(Assessed temperature)*	*(Assessed temperature)*	*(Assessed temperature)*	*(Assessed temperature)*	*(Assessed temperature)*

D.5 Temperature determined by FE analysis based on fire tests

In the analysis, the column shoe shall be exposed to the standard fire in accordance with EN 1363-1, clause 5.1. Three-dimensional finite element analysis shall be applied. The temperature field of the column shoe shall be calculated and compared with the experimental temperatures determined by fire tests. If necessary, the calculation method shall be modified to give a safe prediction for the temperature distribution.

The geometric model for the analysis of the connection is illustrated in Figure D.5.2. It is assumed that the column shoes considered connect two column elements with the same square cross-section or a column element with a foundation with a larger cross section. The lower column element or the foundation is provided with anchor bolts and the upper one with column shoes placed along the outer faces of the column elements. To simplify the calculations, it is assumed that the connection is positioned in such a way that the foundation, beams and floors can be ignored.

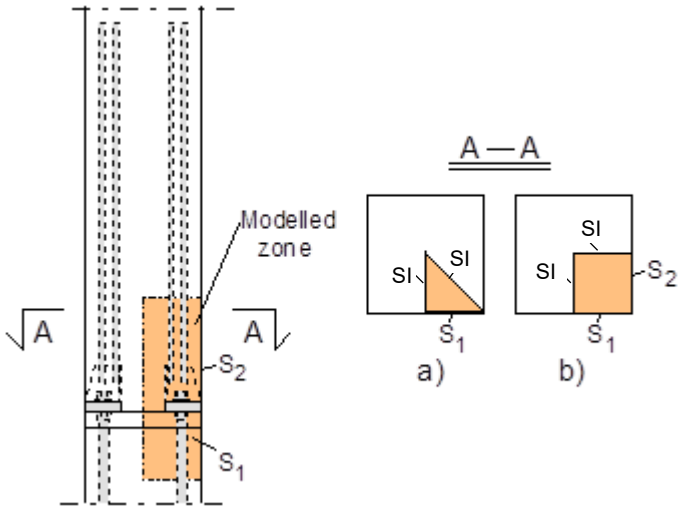


Figure D.5.1 Overview on model. The coloured zone is included in analysis. Either 1/8 (a) or1/4 (b) of the cross-section can be included in the model

Surfaces S_1 and S_2 shown in Figure D.5.1 shall be subjected to heat transfer by convection and radiation from fire. Other surfaces SI (internal surfaces) of the modelled zone are assumed to be perfectly insulated.

In vertical direction, the modelled zone shall cover at least the minimum dimensions shown in Figure D.5.2.

Three-dimensional volume elements shall be used for steel and concrete. The circular bars and anchor bolts may be modelled with coaxial rectangular elements which have the same cross-sectional area. Chamfered steel parts and the column element may be modelled as if they were non-chamfered.

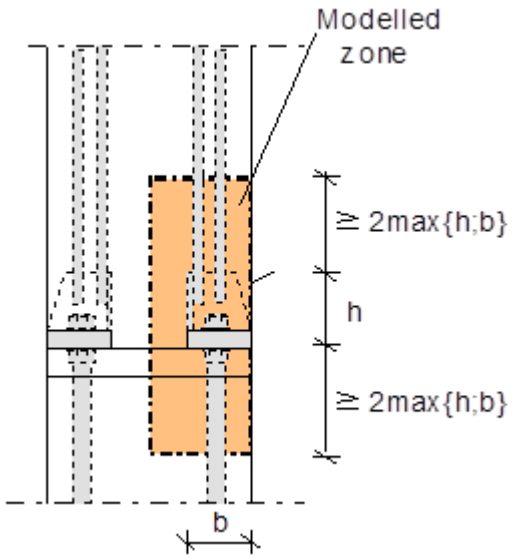


Figure D.5.2 Minimum size of the model

The thermal conductivity, specific heat, coefficient of heat transfer by convection and surface emissivity for the concrete and steel shall be taken from EN 1992-1-2 and EN 1993-1-2, respectively. For the concrete, both the upper and lower limit of the thermal conductivity and the moisture content 0% are applied.

The steel temperature under fire exposure $T_{cr}(t_i)$ [°C] shall be determined at relevant time intervals (15 min, 20 min, 30 min, 45 min, 60 min, 90 min, 120 min, …) as given in clause D.4. Examples for individual finite element models are shown in Figure D.5.3. Figure D.5.4 shows examples for the temperature distribution as result of the FE analysis.

Figure D.5.3 Examples for finite element models

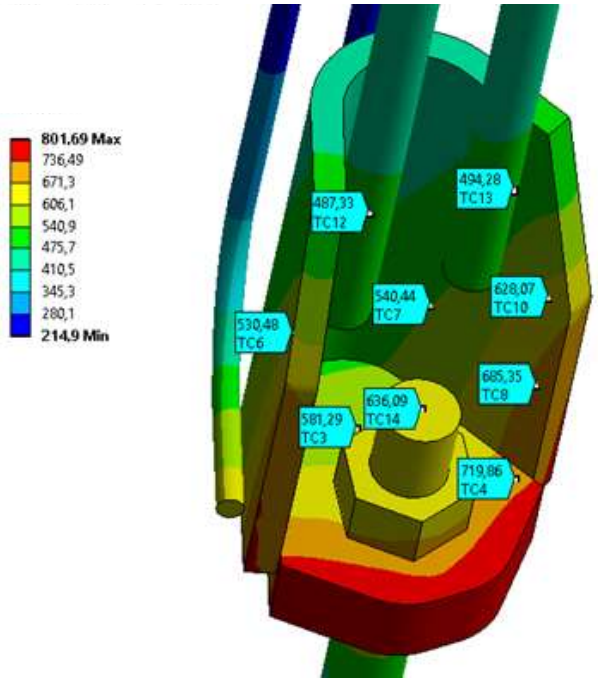


Figure D.5.4 a) Thermal-transient analysis - example of temperature distribution [°C] at a specific time - column shoes

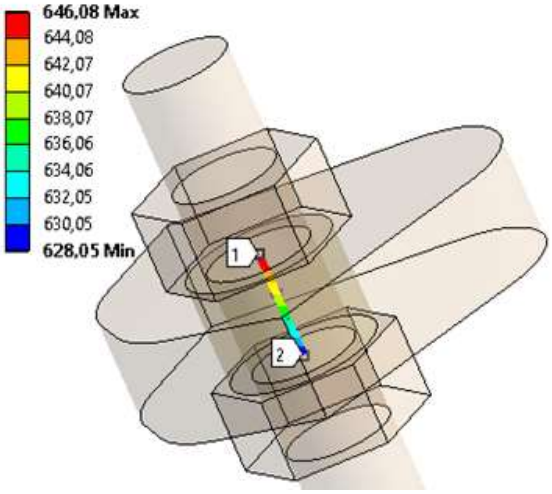


Figure D.5.4 b) Thermal-transient analysis - example of temperature distribution [°C] at a specific time – anchor bolt

ANNEX E DETAILS OF TEST MEMBERS

E.1 General

For the materials used for the preparation of the test specimens the following properties shall be determined based on testing or/and delivery documents:

- Material properties of steel in accordance with EN 1993-1-1, Table 3.1 (i.e., stress-strain curve, materials strain at yielding and failure),
- Material properties of reinforcing steel bars in accordance with EN 1992-1-1,
- Material properties of concrete in accordance with EN 206.

E.2 Concrete members used for the tests

The concrete members shall be made of compacted normal weight concrete with strength classes C30/37 to C70/85 in accordance with EN 206. The concrete members shall meet the following requirements:

- Cement type shall be CEM I, CEM II/A-LL, CEM II/B-LL in accordance with EN 197-1,
- The water-cement ratio shall not exceed 0,75. The cement content shall be at least 270 kg/m^3,
- No fibre content,
- $f_{cm,cube}$ shall not exceed 60 MPa.

The concrete compressive strength shall be measured either on at least 3 cylinders with a diameter of 150 mm and height of 300 mm, or on at least 3 cubes of 150 mm length of the edge.

The joint and the recesses of the column element on the top side are grouted before the test. The recesses on the bottom side may be grouted or not, see Figure E.2.1.

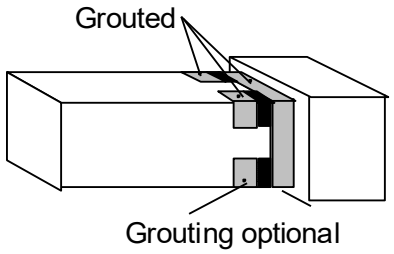


Figure E.2.1 Grouting of the connection

Figure E.2.2 Example of a column element before concreting

The basic properties for the test specimen are summarized in Table E.2.1.

Table E.2.1 Properties of test specimen

Column element	
- Length	Minimum length is determined by the following conditions: 1. For Annex A: The constant moment zone shall be so long that the stiffness within and outside the column shoe zone can reliably be determined 2. For Annexes A, B and C: The loads shall be so far from the supports that the bending moment can be increased until the connection fails. 3. For Annex D: Related to hight of the furnace, see example in Figure D.4.1.
- Cross-section	Minimum allowable when four column shoes of the considered type and size are used in the connection
- Strength of concrete	Of the same order as the minimum allowable for the considered column shoe.
- Main reinforcement	Able to carry bending moment= $\eta_{d,0}$ x M_t; where: - M_t is the bending resistance of the connection calculated using the nominal yield strength of the anchor bolts and the nominal strength of the concrete and - $\eta_{d,0} \leq 1{,}00$ is the initial bending resistance factor used for the design of main reinforcement of the test specimens. The value of $\eta_{d,0} \leq 1{,}00$ shall be chosen in accordance with manufacturer's specifications, if available, otherwise the following values shall be used: For Annex A: 0,90 For Annexes B and C: 1,00
- Shear reinforcement	The column shoe zone reinforced according to the manufacturer's instructions, elsewhere the test result is not sensitive to the shear reinforcement which shall be designed to prevent shear failure in the test and to meet the requirements for minimum reinforcement
- Lifting hooks or inserts	Designed in such a way that they do not affect either the measured bending stiffness or the bending resistance
Foundation element	The cross-section, strength of the concrete and the reinforcement to be so chosen that the anchorage failure of the anchor bolts and the failure of the foundation element itself can be excluded in the test. The foundation element does not influence the behaviour of the column element and the column shoe but is a relevant part of the test lay-out. In case of failure of the foundation element during testing the test shall be repeated with a strengthened foundation element.
Connection	The strength of the jointing mortar at least the lowest specified in the manufacturer's instructions. The recesses on the bottom side may be not grouted, see Figure. F.2.1. The torque applied to the nuts according to the manufacturer's instructions.

E.3 Conversion of failure loads to nominal strength

The conversion of failure loads shall be done according to Equation E.3.1 depending on the failure mode.

Steel failure $$F_{u,s} = F_{u,test} \frac{f_u}{f_{u,test}} \quad \text{(E.3.1)}$$

with

f_u = nominal tensile strength

$f_{u,test}$ = actual tensile strength of the steel parts used in the test

$F_{u,test}$ = failure load in the test

ANNEX F DETAILS FOR AVCP - ADDITIONAL TEST FOR CONTROL OF WELDING BY MANUFACTURER

F.1 Test arrangements

The column shoe shall be tested without concrete, see Figure F.1.1. In the test an anchor bolt shall be fixed to the column shoe only by one upper single nut (and optional washer), and an auxiliary bar shall be welded to the anchor bars.

Thereafter, the test specimen shall be loaded in tension until failure. The column shoe shall be loaded from the bolt hole on the bottom plate and the reinforcement anchors bars. Additional gripping piece (auxiliary bar) may be welded on to the reinforcement anchors bar.

Resistance of the anchor bolt shall be higher than $N_{Rd,s(shoe)}$ x 1,15 of the column shoe to avoid early failure of the anchor bolt in the tests.

Three tests per size or type shall be performed.

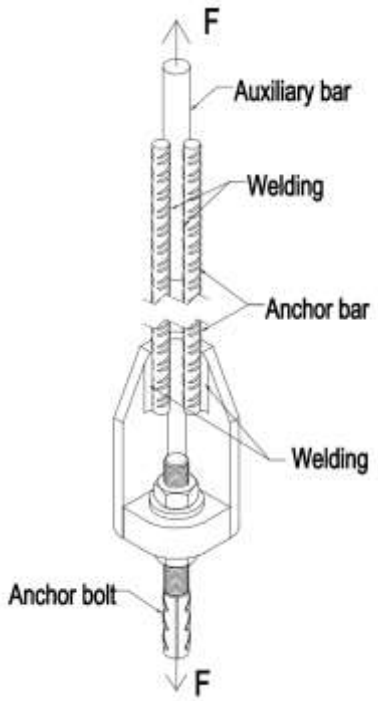


Figure F.1.1 Test setup

F.2 Evaluation of test results

The criteria for assessing the tensile resistance of the column shoe are:

$$F_{f,i} \geq N_{Rk,s(\text{shoe})} \cdot k(shoe)\ for\ i = 1, 2\ and\ 3 \qquad \text{Equation (F.2.1)}$$

where

$F_{f,i}$	is failure load in test *i*,
$N_{Rk,S(shoe)}$	min($N_{Rk,S(component)}$; $N_{Rk,S(bolt)}$)
k(shoe)	≥ 1,00 (agreed between TAB and manufacturer; recommended value is 1,15)

$N_{Rk,S(bolt)}$ shall be calculated as follows (based on concept of EN 1992-4):

$$N_{Rk,S(bolt)} = f_{uk(bolt)} \times A_{s.nom(bolt)} \quad \text{(F.2.2)}$$

where

$f_{uk(bolt)}$ = characteristic ultimate strength of the anchor bolt
$A_{s,nom\ (bolt)}$ = nominal stress area in thread of the anchor bolt

$N_{Rk,S(component)}$ shall be calculated as follows:

$$N_{Rk,S(component)} = \min (N_{Rk,S(bar)}, N_{Rk,S(plates)}, N_{Rk,S(welds)}) \quad \text{(F.2.3)}$$

where:

- $N_{Rk,S(bar)}$ = tension resistance of reinforcing bars (anchor bars) in accordance with EN 1992-1-1:
  - Clause 5.2.3" Welding of reinforcing bars",
  - Clause 5.2.2" Properties",
  - Table 5.1:" Compressive and tensile strength of concrete" (the minimum strength class of concrete intended to be used shall be considered),
  - Equation 5.5 The value of the design tensile strength f_{ctd},
  - Equation (11.3) The design anchorage length l_{bd},
  - Clause 11.5.2 (2) The design lap length l_{sd},
  - ANNEX C, Table C.1: "Strength properties of carbon reinforcing steel" and Table C.2: "Ductility properties of carbon reinforcing steel"
- $N_{Rk,S(plates)}$ = tension resistance of side plates in accordance with EN 1993-1-1:
  - Table 5.1: Nominal values of yield strength f_y and ultimate tensile strength f_u for hot rolled structural steel;
  - Equation (8.3) The linear summation of the utilization ratios,
  - Clause 8.2.3 Tension and Equation (8.13),
  - Clause 8.2.4 Compression and Equation (8.17),
  - Clause 8.2.5 Bending moment and Equation (8.19)
  - Tension resistance of welds connecting the reinforcing bars to the base plate and side plates in accordance with EN ISO 17660-1, clause 6.6.2.1 "Side lap weld joints", Figure 6 b) "Side lap joint, double-sided welded", and Figure 8 "Weld configuration of side lap welds"
- $N_{Rk,S(welds)}$ = tension resistance of welds connecting the side plates to the base plate in accordance with EN 1993-1-8:
  - Table 6.1: Correlation factor β_w for fillet welds,
  - Clause 6.5.3.3 "Simplified method for design resistance of fillet weld": Equations (6.3), (6.4) and (6.5)

When calculating $N_{Rk,S(bar)}$, $N_{Rk,S(plates)}$ and $N_{Rk,S(welds)}$ the following shall be considered;

- primary actions resulting from $N_{Rk,S(bolt)}$
- secondary internal forces resulting from the eccentricity of the reinforcement axis (welded on top of the tensile reinforcement) and bolt axis
- most unfavourable position of the bolt in the hole of the base plate
- diameter of the bolt
- secondary internal forces in sum under the most unfavourable position of the bolt for the respective component of the column shoe (plate, bar or welds)
- nominal material properties and the nominal dimensions of the components of the column shoe (plate, bar or welds)

Instead of calculating $N_{Rk,S(bar)}$, $N_{Rk,S(plates)}$ and $N_{Rk,S(welds)}$ individually, $N_{Rk,S(component)}$ may calculated by using a 3D FE analysis, taking into account the respective material properties.

ANNEX G EXAMPLE FOR DETERMINATION THE VALUES V_{SHOE} AND V_{REF}

The following figures show an evaluation of the stiffnesses and deformations for a specific column shoe size.

Figure G.1 shows a table with the calculation of the deflection for each subzone v_i using the principle of virtual forces and the individual stiffnesses $(EI)_i$ or $(EI)'_i$of the column element in each subzone. It follows the following basic principle:

(1) Calculation of the curvature for each subzone using the Equation A.6.2.1 and the measured elongations corresponding to the individual load steps in the test (see A.6.2)

(2) Calculation of the stiffnesses $(EI)_i$ and $(EI)'_i$ from the curvatures using the Equation A.6.2.2 for each load step. Result is a pair of values $(EI)_i/M_i$ and $(EI)'_i/M_i$.

(3) Calculation of the triangular Moment-distribution along the cantilever column length and for each subzone (see clause A.6.1 and Equation A.6.1.2)

(4) Finding the related stiffnesses $(EI)_i$ and $(EI)'_i$ according to (2) for each moment following the triangular Moment-distribution

(5) Calculation of the deflection for each subzone v_i using the values $(EI)_i$ and $(EI)'_i$ according to (4) following the principle of virtual forces

(6) Summarizing the deflections v_i to calculate v_{shoe} and v_{ref}.

(7) Comparison of v_{shoe} and v_{ref}.

The Figure G.2 shows the distribution of the bending stiffnesses along the cantilever columns' axes related to the bending stiffness of the undisturbed region (subzone 7) in %. In zone 2, the stiffness of precast cantilever column A is significantly higher compared to the cast-in-situ cantilever columns. In Zone 3, the relative stiffness of precast cantilever column A is smaller than the value obtained for cast-in-situ cantilever column B. It can be seen that the significantly higher stiffness of the column shoe connection in the area of the column shoe (Zone 2) compensates for the lower stiffness in the area of the anchor bolts (Zone 3, joint between foundation and cantilever column) and leads to smaller deformations overall.

The calculated deflection at the top of the precast cantilever column based on the measured deformations is v_{shoe} = 167 mm. This value is ca. 13% lower than the reference value of the cast-in-situ cantilever column (v_{ref} = 191 mm). Therefore, a factor k_L = 1,0 can be used in the design of the column shoe connections according to TR 068.

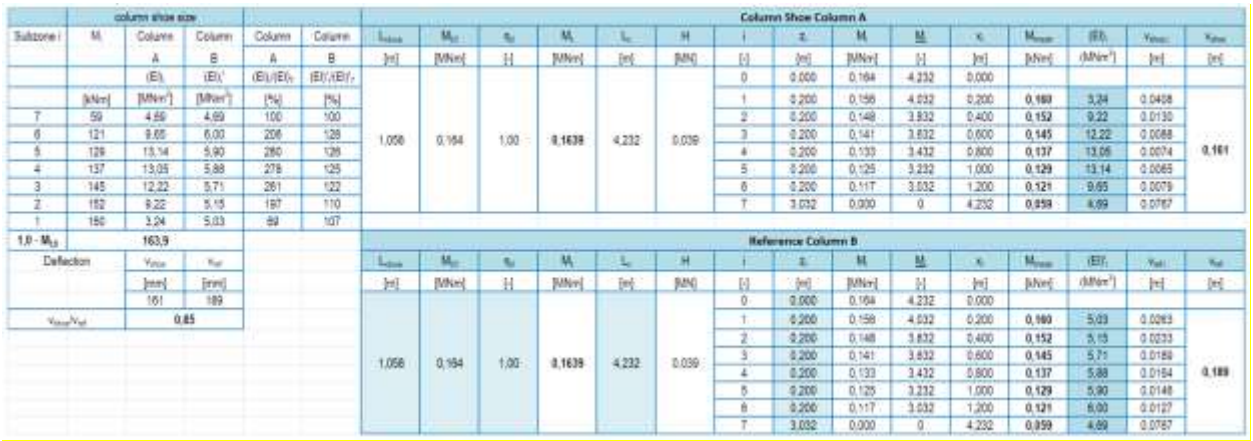
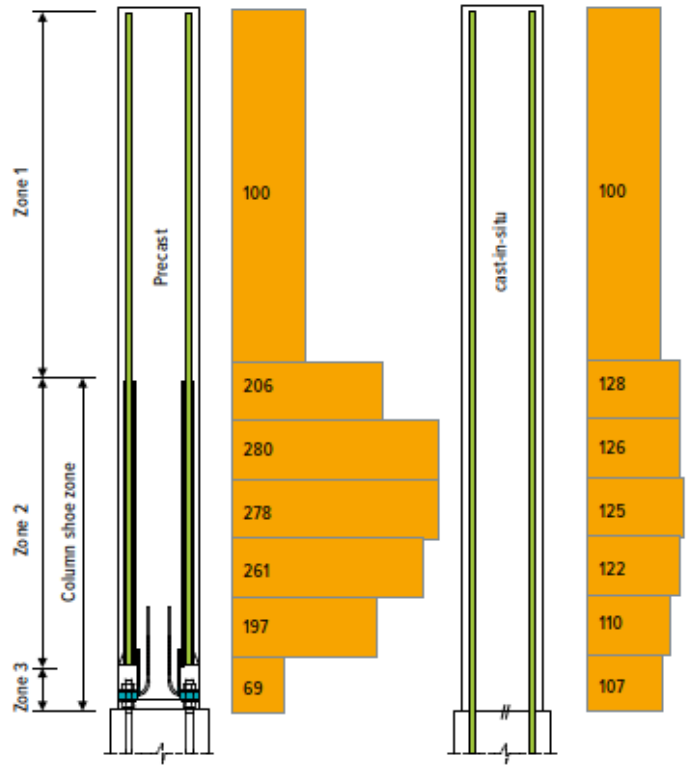


Figure G.1 **T**able showing the calculation of the deflection for each subzone v_i using the principle of virtual forces and the individual stiffnesses $(EI)_i$ or $(EI)'_i$ of the cantilever column in each subzone; $\underline{M}_i$ is the virtual moment as a result of the virtual unit load "1" within the principle of virtual forces

Note:

The principle of virtual forces is a method in which a virtual unit load of magnitude 1 is applied to a static system (e. g. a beam) that is in equilibrium. At the core of the virtual forces method (VFM) is the principle of virtual work. This principle states that the virtual work as a sum of virtual external work done by a virtual

unit load on a virtual displacement and virtual internal work is equal to zero for a system in equilibrium. The virtual unit load is applied in the direction of the desired displacement in order to calculate it. The virtual unit load is dimensionless and serves only as a mathematical tool to specify the direction of the displacement. The virtual unit load (or virtual unit moment) is not a real external force but just an auxiliary tool in the calculation. By definition, it is always set equal to 1 (that is 1 N or 1 kN or …). This ensures that the displacement calculated comes out in the correct physical dimension.



	column shoe size				
Subzone i	M_i	Column A	Column B	Column A	Column B
		$(EI)_i$	$(EI)_i'$	$(EI)_i/(EI)_7$	$(EI)'_i/(EI)'_7$
	[kNm]	[MNm^2]	[MNm^2]	[%]	[%]
7	59	4,69	4,69	100	100
6	121	9,65	6,00	206	128
5	129	13,14	5,90	280	126
4	137	13,05	5,88	278	125
3	145	12,22	5,71	261	122
2	152	9,22	5,15	197	110
1	160	3,24	5,03	69	107
$1{,}0 \cdot M_{t,0}$	**163,9**				
Deflection		v_{shoe}	v_{ref}		
		[mm]	[mm]		
		161	189		
v_{shoe}/v_{ref}		**0,85**			

Figure G.2 Evaluation of test results for a precast cantilever column A (connected via column shoes) and a cast-in-situ cantilever column B connected monolithic) – relative bending stiffness of subzones in %