ANCHOR BOLTS

TECHNICAL MANUAL

EXMET
PRECAST ACCESSORIES

Version 1.0

Replaces EXM- BAS -DC-1002 RT
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1. PRODUCT PROPERTIES

GENERAL

Exmet produces anchor bolts in two capacity categories: Normal Capacity Bolts (NKP) and High Strength Bolts (SKP). NKP and SKP anchor bolts are designed for connecting structural elements to cast in-situ concrete structures or prefabricated concrete elements. Bolts are used in new concrete structures and are casted during concreting of the structures. NKP and SKP anchor bolts are designed for quasi-static loading. Anchor bolts consist of reinforcement bar(s) and threaded part, which is equipped with nuts and washers for connecting other structural elements from steel, concrete or timber.

Both NKP and SKP bolts are produced in two different types:

- Type L with reduced anchorage length and anchor plates at end of reinforcement bar for casting in concrete structures with low structural depth

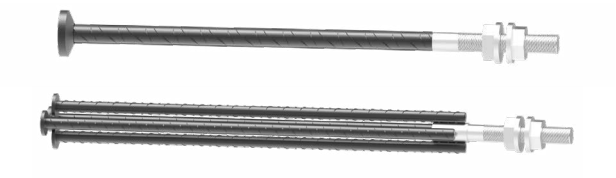


Figure 1
Anchor bolts NKP-L (upper picture) and SKP-L (lower picture)

- Type P with full anchorage length of reinforcement bar part(s) for structures with sufficient structural depth for providing anchorage of bolt in concrete via bond or overlapping with structural reinforcement in concrete.

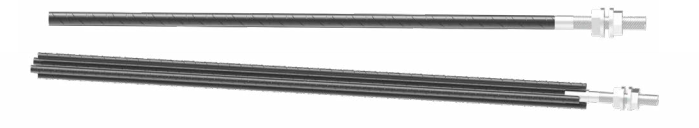


Figure 2
Anchor bolts NKP-P (upper picture) and SKP-P (lower picture)

NKP and SKP anchor bolts are designed to transfer loads, as specified in the capacity tables, from the attached structure to the base concrete structure. To ensure a safe structural solution, both the attached and base structures must be designed and constructed to handle the loads specified in the anchor bolt capacity tables. The additional reinforcement provided in the tables below ensures safe load transfer from the bolts to the base structure, but the structural design of the base concrete structure, the added structure, or geotechnical design for the foundation is the responsibility of the structural designer. This should be executed according to all relevant Eurocode rules by the designer responsible for this task.

NKP and SKP anchor bolts are primarily designed to be compatible with Exmet column shoes and wall shoes for concrete elements. Installation rules for anchor bolts, including the height of the bolt head from the base level and the need for additional reinforcement in the base structure to ensure safe force transfer, are determined based on the use of Exmet products at their declared capacities in the overall structural connection.

NKP and SKP anchor bolts are suitable for connecting steel structures, machinery, prefab concrete elements, or timber structures with other types of connecting devices, including Exmet products. However, in such cases, the designer of the added structure must ensure that the bolt location, height of the bolt head in the base structure, and the size of the bolt holes in the added structure correspond to the size and type of Exmet NKP or SKP bolts used. Additionally, the structural design of the attached structure and/or connection should adhere to structural design rules, including provisions for additional transfer reinforcement and the design of the added structure itself.

MATERIALS

NKP and SKP anchor bolts are manufactured from following materials:

Part	Material quality	Standard
Ribbed reinforcement bars	B500B	EN10080:2006
Washers	S355J2+N	EN10025-2:2019
Nuts (NKP bolts)	Class 8	ISO 4032:2023
Nuts (SKP bolts)	Class 10	ISO 4032:2023
Anchor plates	S355J2+N	EN10025-2:2019
Threaded bars (SKP bolts)	Imacro M $f_{yk} \geq 640$ MPa; $f_{uk} \geq 800$ MPa	EN 10027-1:2016, ISO 898-1:2013

Table 1

Anchor plates are welded to reinforcement bars, threads of rebar anchor bolts are produced by rolling. Threaded parts of high strength bolts are produced by thread machining.

MARKINGS

Manufactured anchor bolts are marked with identification tags that contain the following information: Bolt type (NKP/SKP), thread size, year of the manufacturing and a batch number.

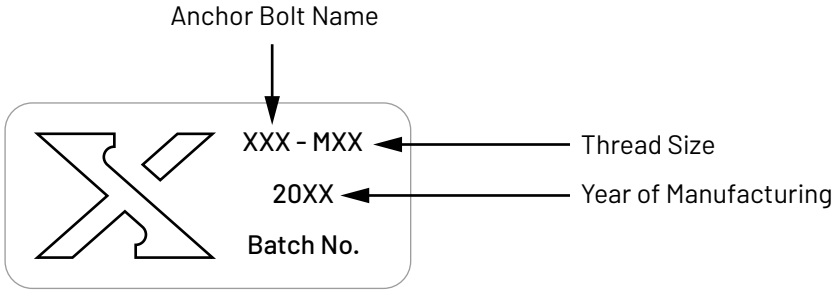


Figure 3 Identification tag for anchor bolts

In addition to the identification tags, all anchor bolts are marked with a color code to facilitate the identification of the shoe type after it has been cast into concrete.

Bolt type	Type of product	Color code
Normal capacity anchor bolts **NKP**	NKP-L and NKP-P M16	Yellow
	NKP-L and NKP-P M20	Blue
	NKP-L and NKP-P M24	Grey
	NKP-L and NKP-P M30	Green
	NKP-L and NKP-P M39	Orange
High capacity anchor bolts **SKP**	SKP-L and SKP-P M30	Black
	SKP-L and SKP-P M36	Red
	SKP-L and SKP-P M39	Brown
	SKP-L and SKP-P M45	Purple
	SKP-L and SKP-P M52	White
	SKP-L and SKP-P M60	Pink

Table 2

PRODUCTION TOLERANCES FOR ANCHOR BOLTS

Allowed deviation for bolt lengths for all types of bolts in manufacturing: ±10mm.
Threaded part length deviation in production: +5, - 0mm

ENVIRONMENTAL CONDITIONS

Anchor bolts are typically cast into concrete before the installation of structures. The connection's geometry then provides resistance to corrosion, provided that sufficient concrete cover is achieved according to the environmental exposure class and intended operating class. In addition to standard anchor bolts, Exmet offers hot-dip galvanized bolts (EN ISO 1461:2022) for more demanding conditions. For hot-dip galvanized bolts, galvanized nuts and washers are used instead of the standard set. Additional protective painting by the installer after installation can further enhance corrosion resistance.

To ensure fire safety, bolts must be covered with cast-in situ concrete if the connection is exposed to fire. Standard bolt placement in the shoe ensures R60 fire resistance after casting. For higher fire resistance ratings, bolts and shoes must be adjusted during the design phase based on structural calculations and the utilization rate of the connection. The allowable deviation for concrete cover c_{dev} is ±10 mm, and the required concrete covers for bolt sides c_{nom} are detailed in the following table.

Exposure class	c_{nom} [mm] for shoe plates Structural class S4, Lifetime 50 years	c_{nom} [mm] Lifetime 100 years
X0	20	30
XC1	25	35
XC2/XC3	35	45
XC4	40	50
XD1/XS1	45	55
XD2/XS2	50	60
XD3/XS3	55	65

Table 3

STRUCTURAL BEHAVIOR

Anchor bolts are designed as connection elements between parts of a structure. They primarily transfer axial forces (tension and compression) and shear forces, as well as their combinations. Groups of anchors can create pairs of tension and compression forces, which enable the transfer of bending moments. Direct bending of individual anchor bolts is not recommended, as it can significantly reduce their declared capacities.

The placement and size of anchor bolts within the structure must be determined by the structural designer based on design loads and the structure's geometry. It is highly recommended to use symmetric bolt placement within sections and uniform bolt sizes to simplify the connection.

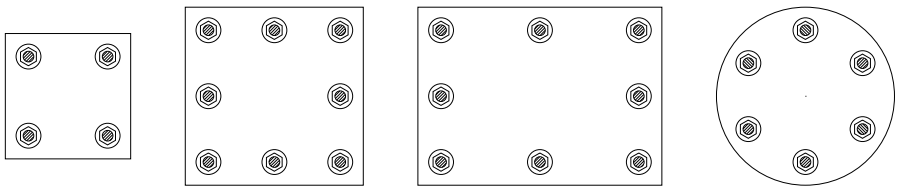


Figure 3
Typical layouts for bolt locations. Bolts transfer N, M_y, V_z forces

The placement of anchor bolts must align with the main reinforcement of the concrete structure, both in the foundation pad and in the column or wall, to ensure that the column or wall shoe can be installed in the intended position.

Typically, short anchor bolts (Type L) are used for foundation pads. When the foundation is cast against soil, the concrete cover c_{nom} at the bottom of the pad is increased to 85 mm in typical foundations (environmental class XC2) to accommodate surface deviations. Minimum edge distances and pad dimensions are specified in Table 1. These dimensions are the minimum required for bolt placement; the final structural and geotechnical design of the pad will determine the necessary size of the structure. Additionally, the minimum thickness beneath the bolt must be checked for punching shear if the installation method leaves the column supported only by bolts before the jointing process.

Figure 5

Minimum padding sizes for NKP-L and SKP-L bolts for enough concrete cover and place for force transfer reinforcement.

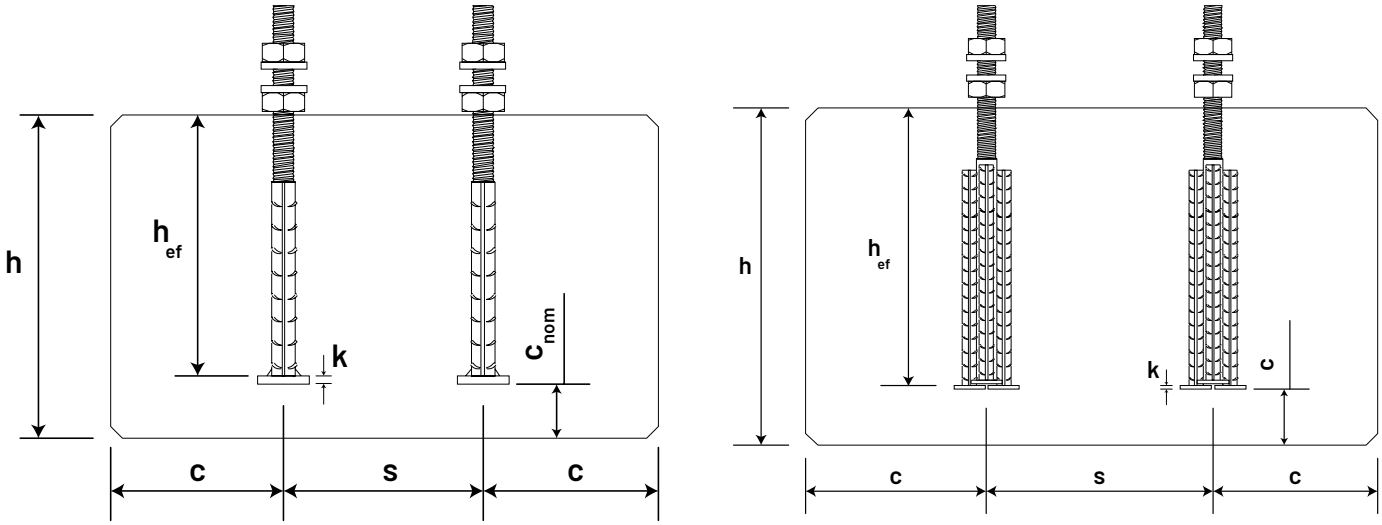


Table 4

	Type of bolt	h mm	h_{ef} mm	k mm	c_{nom} mm	c mm	s mm
NKP	NKP-L M16	270	165	10	85	50	80
	NKP-L M20	330	225	10	85	70	100
	NKP-L M24	395	290	10	85	70	100
	NKP-L M30	445	340	10	85	100	130
	NKP-L M39	610	505	12	85	130	150
SKP	SKP-L M30	600	505	15	85	120	130
	SKP-L M36	665	562	12	85	140	160
	SKP-L M39	780	680	15	85	150	180
	SKP-L M45	865	764	15	85	160	200
	SKP-L M52	990	890	15	85	180	280
	SKP-L M60	1155	1057	15	85	180	280

For NKP-P and SKP-P anchor bolts, minimum edge distances must meet the minimum concrete cover thicknesses specified in Chapter 4 of EN1992-1-1. When overlapping with the main reinforcement, the rules for stirrups and lap lengths outlined in Chapter 8.7 apply. Additionally, to ensure adequate bonding, the requirements set forth in Section 8.2 must be met.

2. PRODUCT DIMENSIONS

Table 5
NKP-L and SKP-L anchor bolts basic dimensions:

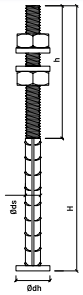
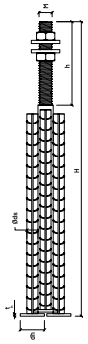
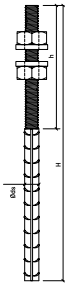
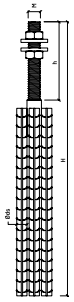
	Type of bolt	H [mm]	h [mm]	Bar Øds [mm]	Anchor Ødh [mm]	Color code
	NKP-L M16	280	140	Ø16	36	Yellow
	NKP-L M20	350	140	Ø20	46	Blue
	NKP-L M24	430	170	Ø25	55	Grey
	NKP-L M30	500	190	Ø32	70	Green
	NKP-L M39	700	200	Ø40	90	Orange
	SKP-L M30	670	190	2Ø25	55	Black
	SKP-L M36	740	190	4Ø20	46	Red
	SKP-L M39	880	200	3Ø25	55	Brown
	SKP-L M45	990	220	4Ø25	55	Purple
	SKP-L M52	1140	250	4Ø32	70	White
	SKP-L M60	1330	310	4Ø32	70	Pink

Table 6
Anchor bolts type NKP-P and SKP-P basic dimensions:

	Type of bolt	H [mm]	h [mm]	Bar Øds [mm]	Color code
	NKP-P M16	810	140	Ø16	Yellow
	NKP-P M20	960	140	Ø20	Blue
	NKP-P M24	1160	170	Ø25	Grey
	NKP-P M30	1460	190	Ø32	Green
	NKP-P M39	2000	200	Ø40	Orange
	SKP-P M30	1705	190	2Ø25	Black
	SKP-P M36	1370	190	4Ø20	Red
	SKP-P M39	1710	200	3Ø25	Brown
	SKP-P M45	1720	220	4Ø25	Purple
	SKP-P M52	1860	250	4Ø32	White
	SKP-P M60	2390	310	4Ø32	Pink

3. RESISTANCES

Resistances of NKP and SKP anchor bolts are calculated according following standards:

EN 1992-1-1: 2004
EN 1992 -4: 2018
EN 1993-1-1: 2005
EN 1993-1-8: 2005

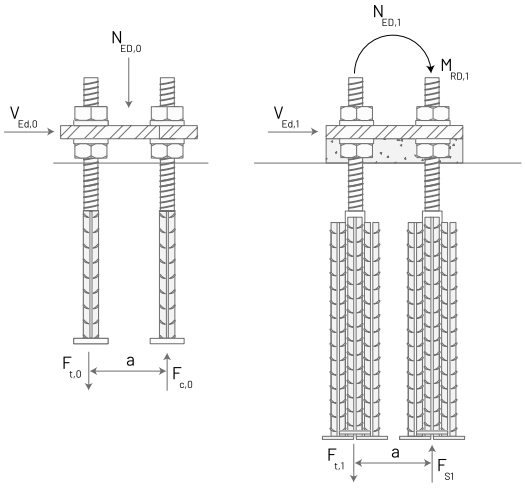
The resistance of an anchor bolt connection is influenced by the steel strength of the anchor bolts, the concrete strength, and the anchorage of the bolts in the concrete. When the concrete cone capacity is critical for the connection's capacity, supplementary reinforcement is required to transfer forces from the bolt to the concrete. The supplementary reinforcement quantities provided in the tables below are based on the steel component's capacity. Additional checks for the main reinforcement of the column, foundation, and EQV must be performed by the structural designer.

The resistances for anchor bolt steel capacity presented in Table 8 are calculated for separate load cases—either shear load or axial load alone. The combined application of shear and axial loads must be managed according to the rules in EN1992-4 for steel and concrete verifications.

All capacities listed in Table 8 apply to quasi-static loads only. For dynamic loads, the designer must account for fatigue and dynamic impact, which may necessitate a reduction in the capacities.

Anchor bolts must be checked in two stages:

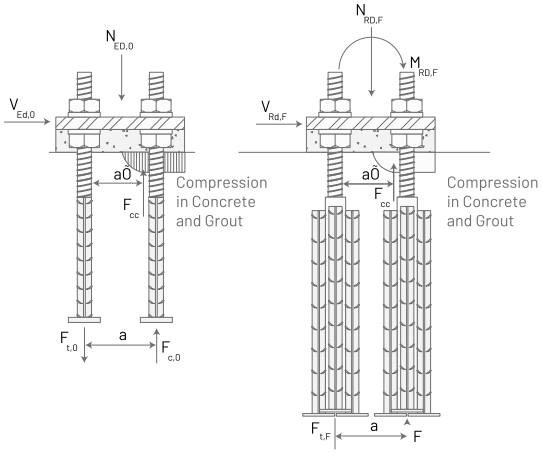
Table 7



Temporary stage (installation of frame)

In this stage, only the bolts and shoes are functioning. Even if the joint is filled with concrete, the joint concrete has not yet achieved the required strength. Therefore, in cases of combined axial and shear loads, the capacity relies solely on the shear and tension/ compression capacities of the bolts. If the combined capacity of the bolts during the installation phase is insufficient, then:

- The size of the bolts and shoes needs to be increased to achieve the required capacity.
  Or
- The frame must be braced during installation to ensure that forces in the critical connection are reduced to the required level.



Final stage

Concrete in joint has reached the design strength, assembly works as reinforced concrete structure. Tension is taken by bolts and shoes, compression with concrete and grout. For shear transfer three different options are available:

- Shear is transferred via friction on the compressed side of connection.
- Shear is transferred via bolt hole edge compression and dowel effect of bolt (significant drop of capacity).
- Shear is transferred with additional shear key at bottom level of connected structure.

The shear forces for the connection, as presented in Table 10, are based on the presence of sufficient friction in the connection.

TENSILE RESISTANCES

The estimation of the tensile resistance of anchor bolts is based on EN 1993-1-8. The structure fixed with anchor bolts must have adequate local stiffness at the joint, which includes sufficient thickness of the fixing plate, additional stiffeners, etc. This ensures that the bolt capacity can be assessed without accounting for additional prying forces in the connection. Exmet column shoes and wall shoes are designed to provide the necessary stiffness in the connection. If Exmet bolts are used with other types of matching components, such as Exmet shoes, the structural designer must ensure that the connection maintains the required stiffness.

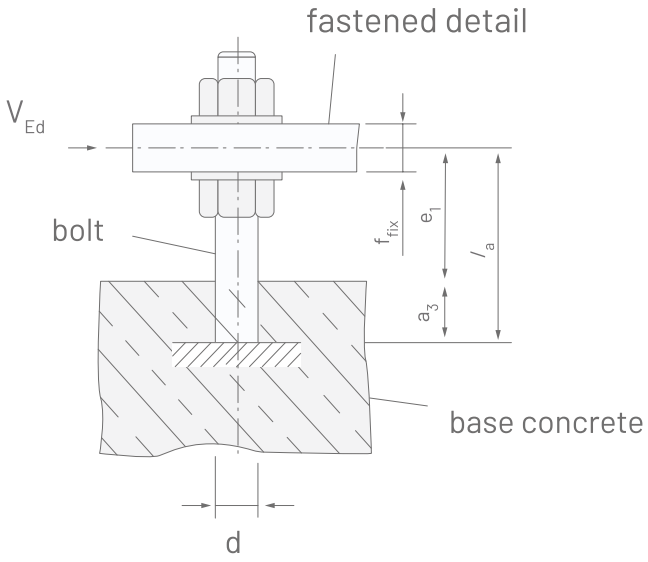
Tensile capacity of threaded bar:

$$N_{Rd0} = N_{Rd} = 0{,}9\frac{f_{ub}A_s}{\gamma_{Mb}}$$

Where A_s - minimum area of threaded bar, f_{ub} - threaded bar material tensile strength and γ_{Mb} – safety factor for bolt material (γ_{Mb} = 1,25).

SHEAR RESISTANCES

At installation the stage shear load acts with a lever arm.



Lever arm $l_a = a_3 + e_1$, where $a_3 = 0{,}5\ d_{nom}$

Distance e_1 is a distance between shear load and concrete surface, e- thickness of grouting.

Bending moment in bolt is calculated as:

$M_{Ed} = V_{Ed}\frac{l_a}{\alpha_M}$, in case of restrain α_M =2.0

In case of pure shear load bolt bending capacity is

$M_{Rd,s} = \frac{1{,}2\ W_{el} f_{uk}}{\gamma_{Ms}} = \frac{1{,}2\ \pi d_{min}^3\ \ f_{uk}}{32\ \gamma_{Ms}}$ where

γ_{Ms} = 1,25

d_{min} is minimum diameter of thread and

$f_{uk} \geq 550\ MPa$ for B500B (For NKK bolts)

$$V_{Rd,s} = \frac{1{,}2\alpha_M\ \pi d_{min}^3\ \ f_{uk}}{32\ \gamma_{Ms} l_a}$$

COMBINED SHEAR AND TENSION RESISTANCES

Without supplementary reinforcement combined tension and shear loads verification in connection must be done according to the following conditions from EN1992-4: 2018

1. **Steel failure of bolt (shoe)**: $\left(\frac{N_{Ed}}{N_{Rd,s}}\right)^2 + \left(\frac{V_{Ed}}{V_{Rd,s}}\right)^2 \leq 1$, verification shall be done for each bolt in the group
2. **Failure modes other than steel failure of bolt**, verification shall be done for largest value of $\frac{N_{Ed}}{N_{Rd,i}}$ and $\frac{V_{Ed}}{V_{Rd,i}}$ for each different failure mode (failure modes are listed in Table 9):

$$\left(\frac{N_{Ed}}{N_{Rd,i}}\right)^{1,5} + \left(\frac{V_{Ed}}{V_{Rd,i}}\right)^{1,5} \leq 1 \qquad \text{EQ.1}$$

Or

$$\left(\frac{N_{Ed}}{N_{Rd,i}}\right) + \left(\frac{V_{Ed}}{V_{Rd,i}}\right) \leq 1{,}2 \;, if \;\; \frac{N_{Ed}}{N_{Rd,i}} \leq 1 \; and \; \frac{V_{Ed}}{V_{Rd,i}} \leq 1 \qquad \text{EQ. 2}$$

If bolt has supplementary reinforcement for both tension and shear loads, same formulas EQ.1 and EQ.2 are valid for verifications, only instead of $\frac{N_{Ed}}{N_{Rd,i}}$ in concrete cone failure mode (in case of tension) and $\frac{V_{Ed}}{V_{Rd,i}}$ for concrete edge failure mode (in case of shear) corresponding ratios for failure of supplementary reinforcement must be used.

If supplementary reinforcement for bolt is provided for tension loads or for shear loads only, conditions for combined shear and tension verification will be done according to the following equation:

$$\left(\frac{N_{Ed}}{N_{Rd,i}}\right)^{2/3} + \left(\frac{V_{Ed}}{V_{Rd,i}}\right)^{2/3} \leq 1 \qquad \text{EQ.3}$$

With additional limitations $\frac{N_{Ed}}{N_{Rd,i}} \leq 1 \; and \; \frac{V_{Ed}}{V_{Rd,i}} \leq 1$

If supplementary reinforcement is provided only for tension loads, $N_{Rd,i}$ and $V_{Rd,i}$ in EQ.3 represent following design resistances:

$N_{Rd,p}$ - design resistance in case of pull-out failure under tension load

$N_{Rd,sp}$ - design resistance of concrete under splitting failure under tension load

$N_{Rd,cb}$ - design resistance in case of concrete blow out failure under tension load

$N_{Rd,re}$ - design resistance of steel failure of supplementary reinforcement

$N_{Rd,a}$ - design resistance associated with supplementary reinforcement anchorage failure

$V_{Rd,c}$ - design resistance in case of concrete edge failure under shear load

$V_{Rd,cp}$ - design resistance in case of concrete pry -out failure under shear load

If supplementary reinforcement is provided only for taking shear loads, $N_{Rd,i}$ and $V_{Rd,i}$ in EQ.3 represent following design resistances:

$N_{Rd,p}$ - design resistance in case of pull-out failure under tension load

$N_{Rd,sp}$ - design resistance of concrete under splitting failure under tension load

$N_{Rd,c}$ - design resistance in case of concrete cone failure under tension

$N_{Rd,cb}$ - design resistance in case of concrete blow out failure under tension load

$N_{Rd,re}$ - design resistance of steel failure of supplementary reinforcement

$N_{Rd,a}$ - design resistance associated with supplementary reinforcement anchorage

$V_{Rd,cp}$ - design resistance in case of concrete pry -out failure under shear load

For both cases N_{Ed} and V_{Ed} are actions corresponding to the specific failure modes. Calculation formulas for $N_{Rd,i}$ and $V_{Rd,i}$ are presented in EN1992-4:2018. All verification for concrete part according to EQ1, EQ2 or EQ3 shall be executed by designer. In table 8 steel capacities for bolts are presented for installation and for final stages.

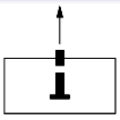
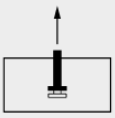
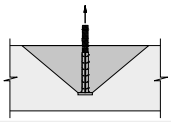
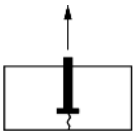
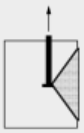
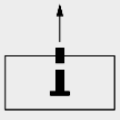
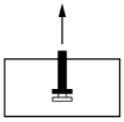
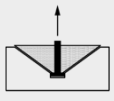
STEEL RESISTANCES FOR ANCHOR BOLTS

Table 8

Anchor bolt	Grout thickness	Lever arm	Installation stage (only one force acting)		Final stage (only one force acting)	
	e	l_a	$N_{Rd0,s}$	$V_{Rd0,s}$	$N_{Rd,s}$	$V_{Rd,s}$
	[mm]	[mm]	[kN]	[kN]	[kN]	[kN]
NKP L/P – M16	50	66	62	4	62	20
NKP L/P – M20	50	70	97	8	97	31
NKP L/P – M24	50	74	140	12,5	140	45
NKP L/P – M30	50	80	220	24	220	71
NKP L/P – M39	60	100	385	39	385	125
SKP L/P – M30	50	80	299	32	299	71
SKP L/P – M36	55	91	435	50	435	103
SKP L/P – M39	60	99	520	59	520	124
SKP L/P – M45	65	110	695	82	695	165
SKP L/P – M52	70	122	938	119	938	219
SKP L/P – M60	80	140	1260	162	1260	225

Complete list of checks for single bolts and for groups of bolts

Table 9

Type of failure	Scheme	Type of bolt	Single bolt	Group of bolts	
				Most loaded bolt	Whole group of bolts
Required verifications for Tension					
Bolt steel failure in tension $N_{Rd,s}$		NKP L/P SKP L/P	Required Required	Required Required	Not Not
Bolt pull out failure in tension $N_{Rd,p}$		NKP L SKP L NKP P SKP P	Required Required Not Not	Required Required Not Not	Not Not Not Not
Concrete cone failure $N_{Rd,c}$		NKP L SKP L NKP P SKP P	Required Required Not Not	Not Not Not Not	Required Required Not Not
Combined pull out and concrete failure $N_{Rd,p}$		NKP L SKP L NKP P SKP P	Not Not Required Required	Not Not Not Not	Not Not Required Required
Concrete splitting failure $N_{Rd,sp}$		NKP L SKP L NKP P SKP P	Required Required Not Not	Not Not Not Not	Required Required Not Not
Concrete blow out failure NRd,cb		NKP L SKP L NKP P SKP P	Required Required Not Not	Not Not Not Not	Required Required Not Not
Steel failure of reinforcement NRd,re		NKP L SKP L NKP P SKP P	Required Required Not Not	Required Required Not Not	Not Not Not Not
Anchorage failure of reinforcement NRd,re		NKP L SKP L NKP P SKP P	Required Required Not Not	Required Required Not Not	Not Not Not Not
Lapping with main reinforcement		NKP L /P SKP L /P	Required Required	Not Not	Required Required
Bolt steel failure in compression NRd,s		NKP L /P SKP L /P	Required Required (at installation)	Required Required (at installation)	Not Not
Punching under anchor		NKP L SKP L NKP P SKP P	Required Required Not Not	Required Required Not Not	Not Not Not Not
Buckling		NKP L /P SKP L /P	Required Required	Required Required	Not Not
Partially loaded area in base structure		NKP L /P SKP L /P	Required Required	Not Not	Required Required
Lapping with main reinforcement		NKP L /P SKP L /P	Required Required	Not Not	Required Required

Verification for other cases e.g steel, shall be done by structural engineer responsible for design of the structure.

FIRE RESISTANCE

Fire resistance of bolted connection should be checked according to EN1992-1-2. If connection fire resistance is not sufficient, concrete cover must be increased or other measures for improving fire resistance should be implemented.

4. INSTALLATION OF BOLTS

Installation of bolts, whether on-site or in the factory, must follow the specified location of the fixing part, structural depth, and concrete casting joint thickness beneath the prefabricated element. The casting joint thickness beneath the fixing must accommodate the size of the nut and the installation tolerances. For Exmet products, installation data can be found in Tables 10 and 11.

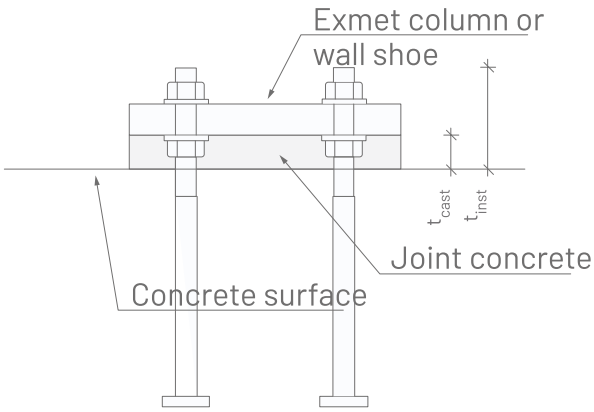


Figure 6 Installation heights for Exmet bolts if shoe is located at the bottom of the column

Installation tolerance for Exmet bolts is ±3mm in horizontal plane and ±20mm in vertical direction if shoes are in use.

Bolts installation heights and standard joint thicknesses for column and wall joints with Exmet bolts and shoes are specified under Tables 10 and 11.

	Column shoe NKK (mm)		Wall shoe NSK (mm)	
Bolt type	Height from casting t_{inst}	Thickness of joint t_{cast}	Height from casting t_{inst}	Thickness of joint t_{cast}
NKP L/P – M16	105	50	100	20
NKP L/P – M20	115	50	110	20
NKP L/P – M24	130	50	115	20
NKP L/P – M30	150	50	135	20
NKP L/P – M39	180	60	160	20

Table 10

Table 11

Bolt type	Column shoe (mm)		Wall shoe SKK (mm)	
	Height from casting t_{inst}	Thickness of joint t_{cast}	Height from casting t_{inst}	Thickness of joint t_{cast}
SKP L/P – M30	Product from Exmet not available at the moment		145	20
SKP L/P – M36			165	20
SKP L/P – M39			185	20
SKP L/P – M45			195	20
SKP L/P – M52			220	20

For types of fixings other than Exmet bolts and shoes, bolt height from casting surface should be adjusted according to design drawing of connection.

After the installation of the column or wall, bolts should be tightened once the vertical alignment of the element is confirmed. A torque wrench must be used to ensure that the torque applied meets or exceeds the minimum values specified in the table below.

Table 12

Bolt	T_{min} [Nm]	T_{max} [Nm]
NKP L/P – M16	120	200
NKP L/P – M20	150	250
NKP L/P – M24	200	350
NKP L/P – M30	250	450
NKP L/P – M39	350	1000
SKP L/P – M30	250	700
SKP L/P – M36	300	1200
SKP L/P – M39	350	1400
SKP L/P – M45	400	2000
SKP L/P – M52	450	3300
SKP L/P – M60	500	3800

WELDING

As a general rule, welding of bolts on-site is not recommended. The materials used in anchor bolts are weldable (excluding nuts), and welding has been carried out in the production of NKP-L type bolts and SKP L and P type bolts under controlled conditions. If on-site welding of bolts is necessary, the requirements and instructions outlined in standard EN 17660-1, "Welding of Reinforcing Steel," must be followed during work planning, execution, and supervision.

BENDING

Rebars in NKP and SKP bolts are made from B500B reinforcement steel. If installation requires bending of anchor bolts, it must be done in accordance with EN1992-1-1 requirements. Bending is permitted only in the rebar section, and as a general rule, there should be at least 300 mm of straight length before the bend begins. The mandrel diameter should conform to the specifications in Table 8.1N of EN1992-1-1.
For bolts with more than two rebars, it is advisable to order custom bolts as per the drawing with the required bent shape.

APPENDIX 1, SPECIAL REINFORCEMENT DESIGN

The reinforcement design for concrete structures with anchor bolts adheres to the concrete design rules outlined in EN1992-1-1. Additionally, due to load transfer through connectors, specific provisions from EN 1992-4:2018 must be applied to the areas around bolts and shoes. If the conditions for the full development of the concrete cone—either pull-out or breakout—are not met as per EN1992-4:2018, supplementary reinforcement around the anchor bolts must be designed according to the supplementary reinforcement rules specified in EN1992-4:2018. These rules address axial and shear forces separately; therefore, for combined actions, supplementary reinforcement must be designed to accommodate all acting forces.

1. Additional reinforcement for pull out cone

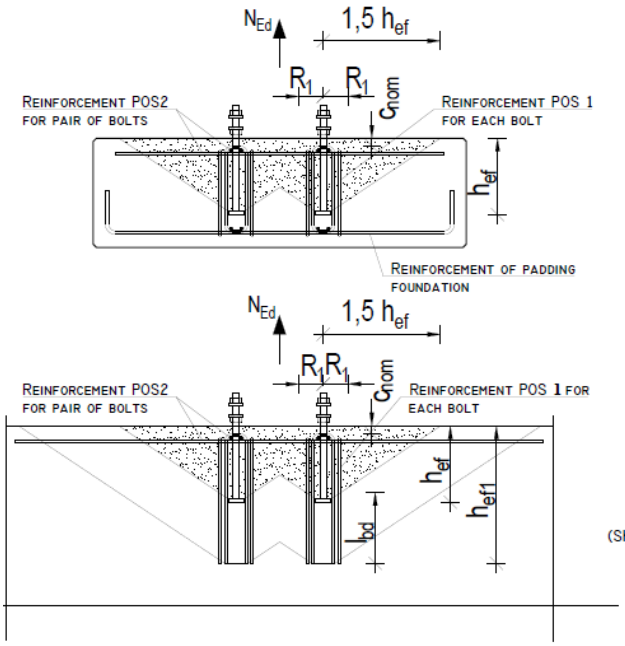
The concrete used in foundations should have a minimum grade of C25/30 and include gravel with a maximum size of 16mm. The clear spacing between stirrups should be 25mm. If additional reinforcement is required to ensure the pull-out capacity of the concrete cone, two methods can be used, depending on the foundation depth:

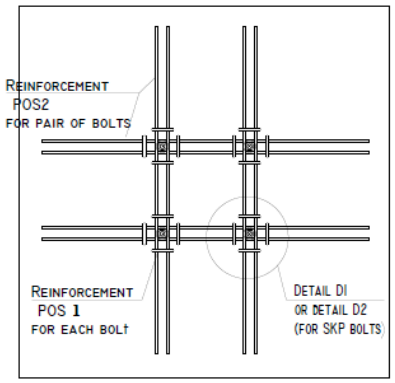
- Shallow Foundations: Tie the additional reinforcement to the bottom reinforcement of the concrete member.
- Deep Foundations: Provide stirrups with full anchorage length extending behind the concrete cone.

Both reinforcement methods use the same diameters, and the results are summarized in Table 13.
For further details, refer to Figure 7.

Table 13

Anchor bolt	Stirrups POS 1 (pcs /bolt)	Surface bars POS 2	C_{nom} [mm]	R_1 [mm]	R_2 [mm]	h_{ef} [mm]	Width of Stirrup [mm]
NKP L/P – M16	4 pcs Ø8	Ø 8	35	75		165	90
NKP L/P – M20	4 pcs Ø8	Ø 8	35	85		225	90
NKP L/P – M24	4 pcs Ø8	Ø 8	35	100		290	110
NKP L/P – M30	4 pcs Ø10	Ø 10	35	100		340	130
NKP L/P – M39	4 pcs Ø12	Ø 10	35	200		505	150
SKP L/P – M30	4 pcs Ø12	Ø 10	35	170		505	170
SKP L/P – M36	4 pcs Ø14	Ø 12	35	200		562	180
SKP L/P – M39	4 pcs Ø14	Ø 12	35	220		680	190
SKP L/P – M45	4 pcs Ø16	Ø 12	35	250		764	210
SKP L/P – M52	4 +2 pcs Ø16	Ø 12	35	280	315	890	250
SKP L/P – M60	4 +4 pcs Ø16	Ø 12	35	300	335	1057	250





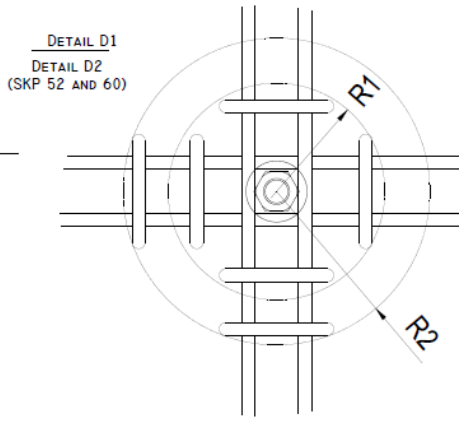


Figure 7
Additional reinforcement for pull out cone

2. Additional reinforcement for avoiding splitting due to tensile force in case of bolt short edge distance

The required splitting reinforcement to prevent splitting during the tightening of headed bolts and long anchor bolts is calculated using Formula 7.22 from EN 1992-4:2018.

$$\sum A_{s,re} = 0.5 \frac{\sum N_{Ed}}{f_{yk,re} / \gamma_{M_{s,re}}}$$

Where $\sum N_{Ed}$ is the sum of the design tensile force of the fasteners in tension under design value of actions

$f_{yk,re}$ is nominal yield strength of reinforcement (=500MPa)

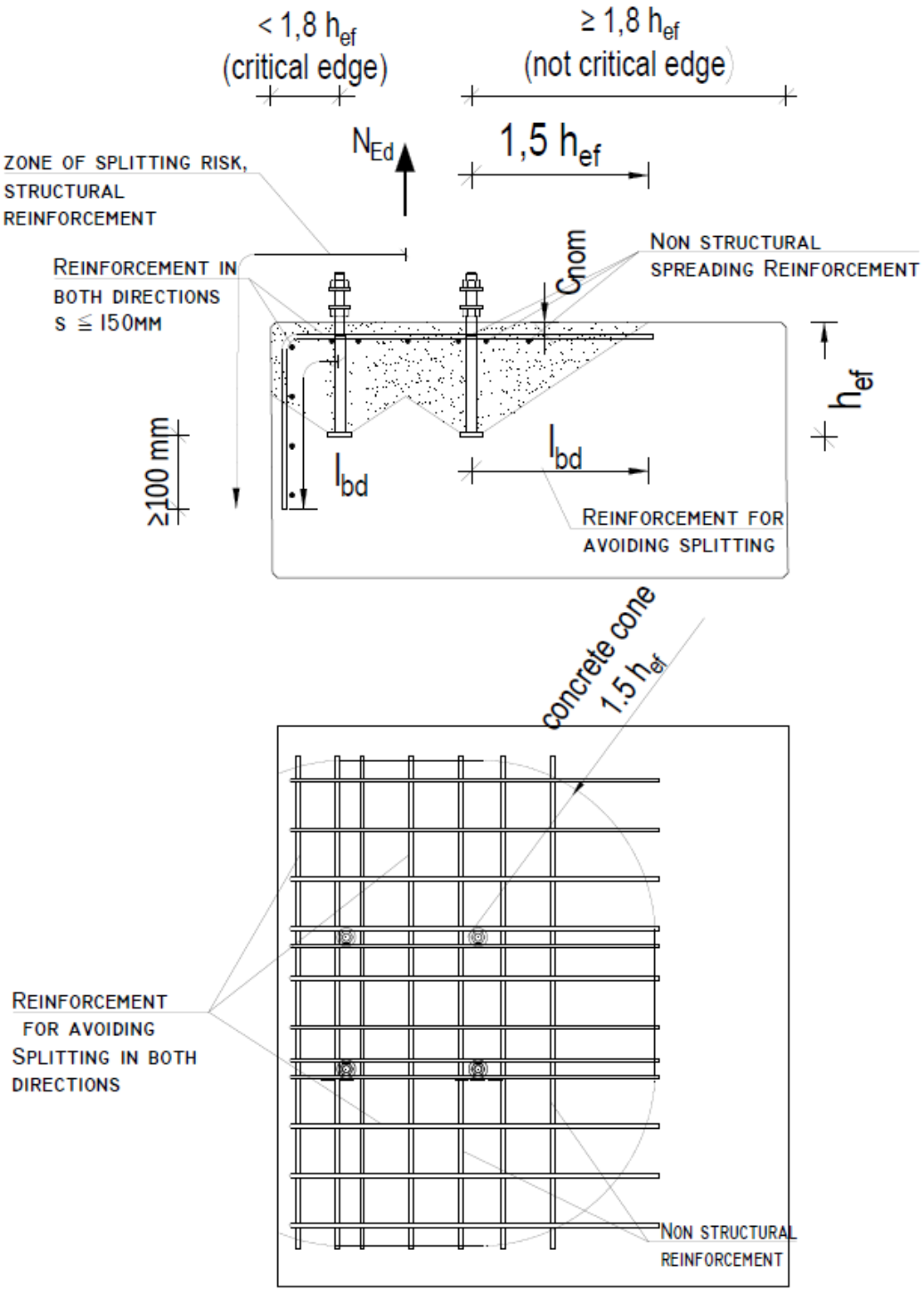
$\gamma_{M_{s,re}}$ is partial safety factor for steel failure of supplementary reinforcement (=1.15)

Splitting reinforcement should be placed with a maximum spacing of 150mm and evenly distributed along the critical edges. This reinforcement must cover the entire splitting risk zone and be provided in both directions. Definitions for the splitting risk zone, critical edge, and anchorage length for bars are illustrated in Figure 8. The required reinforcement for one bolt under maximum tension force is detailed in Table 14.

Table 14

Anchor bolt	Splitting reinforcement [mm²]	Surface bars	Anchor bolt	Splitting reinforcement [mm²]	Surface bars
NKP L/P – M16	70	3 Ø 8	SKP L/P – M30	343	4 Ø 12
NKP L/P – M20	110	3 Ø 8	SKP L/P – M36	500	5 Ø 12
NKP L/P – M24	160	4 Ø 8	SKP L/P – M39	608	6 Ø 12
NKP L/P – M30	253	4 Ø 10	SKP L/P – M45	800	4 Ø 16
NKP L/P – M39	442	4 Ø 10	SKP L/P – M52	1080	6 Ø 16
			SKP L/P – M60	1440	8 Ø 16

Figure 8 Additional reinforcement for avoiding splitting in case of critical edge distance



3. Additional reinforcement for avoiding break out in shear load

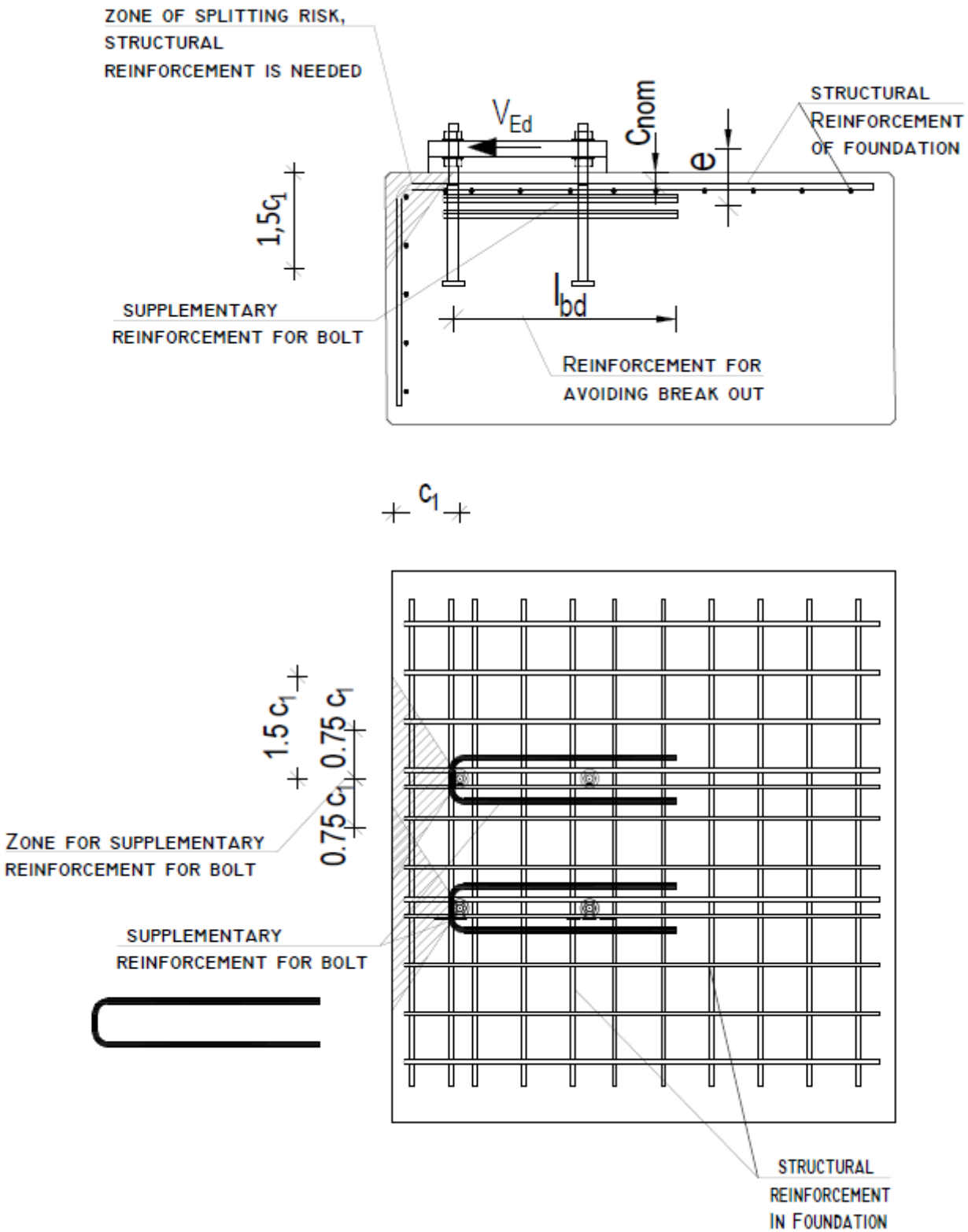
If the placement of bolts in the foundation or substructure does not provide a sufficient edge distance to develop a full-sized breakout concrete cone, supplementary reinforcement must be added to handle the total shear load (as per EN 1992-4:2018, Section 7.2.2.2). This reinforcement must fully overlap with the structural reinforcement and be anchored outside the failure zone with an anchorage length l_{bd} according to EN 1992-1-1.

- Supplementary reinforcement designed for the most heavily loaded bolt must be applied to all bolts.
- The maximum allowed diameter for supplementary reinforcement is 16mm (B500B), and the mandrel diameter should comply with EN 1992-1-1.
- Supplementary reinforcement should be positioned within a distance of 0.75 c1 from the bolt, where c1 is the edge distance of the bolt.
- Supplementary reinforcement should be placed as close as possible to the structural reinforcement of the foundation.
- The structural reinforcement must have the same capacity as the supplementary reinforcement. To facilitate effective force transfer from the supplementary to the structural reinforcement, the transfer zone should be reinforced in both directions to develop a proper strut-and-tie system. The transfer angle can be assumed to be 45 degrees.
- The structural reinforcement should be anchored at the end of the transfer zone.
- If supplementary reinforcement is provided in two layers, the distance between the layers must follow the rules specified in EN 1992-1-1.

Table 15

Anchor bolt	Edge distance C_1 [mm]	Lever arm *e* [mm]	U bars	Anchor bolt	Edge distance C_1 [mm]	Lever arm *e* [mm]	U bars
NKP L/P – M16	50	3 Ø 8	1 Ø 12	SKP L/P – M30	120	170	2 Ø 16
NKP L/P – M20	70	3 Ø 8	1 Ø 14	SKP L/P – M36	140	170	3 Ø 16
NKP L/P – M24	70	4 Ø 8	1 Ø 16	SKP L/P – M39	150	180	2+2 Ø 16
NKP L/P – M30	100	4 Ø 10	2 Ø 16	SKP L/P – M45	160	190	2+2 Ø 16
NKP L/P – M39	130	4 Ø 10	3 Ø 16	SKP L/P – M52	180	230	3+3 Ø 16
				SKP L/P – M60	180	270	3+3 Ø 16

Figure 9 Additional reinforcement for avoiding break out in shear load in case of critical edge distance



SUPPLEMENTARY REINFORCEMENT

If the punching resistance of the concrete under a headed anchor bolt is exceeded, supplementary reinforcement must be provided. The type of additional reinforcement depends on the foundation depth and may consist of either links or closed stirrups. Closed stirrups are preferred and can also be used to secure the pull-out cone, provided that the reinforcement is designed to handle both load cases separately.

If the concrete depth below the bolt exceeds the required depth hreq specified in Table 16, the supplementary reinforcement for punching may be omitted.

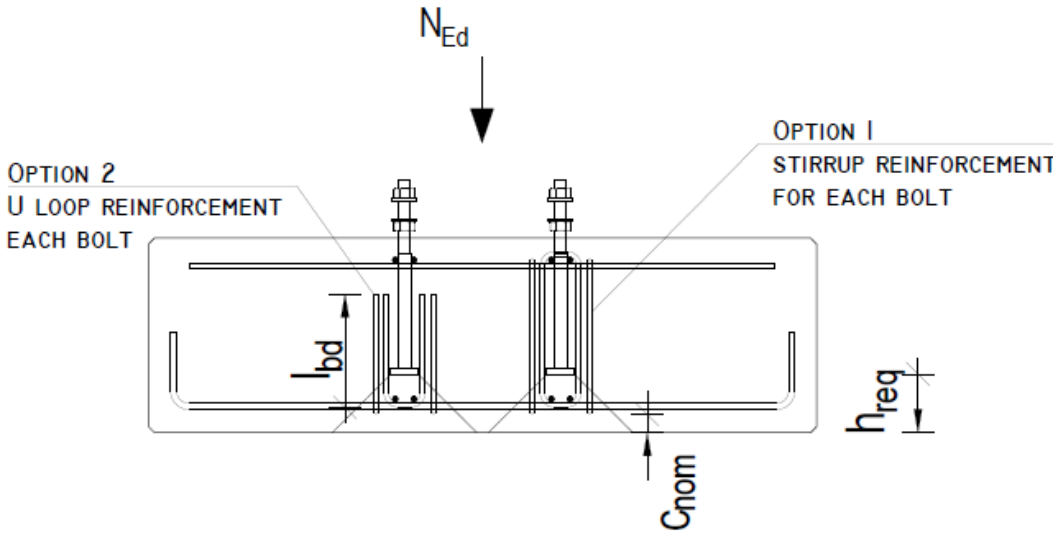
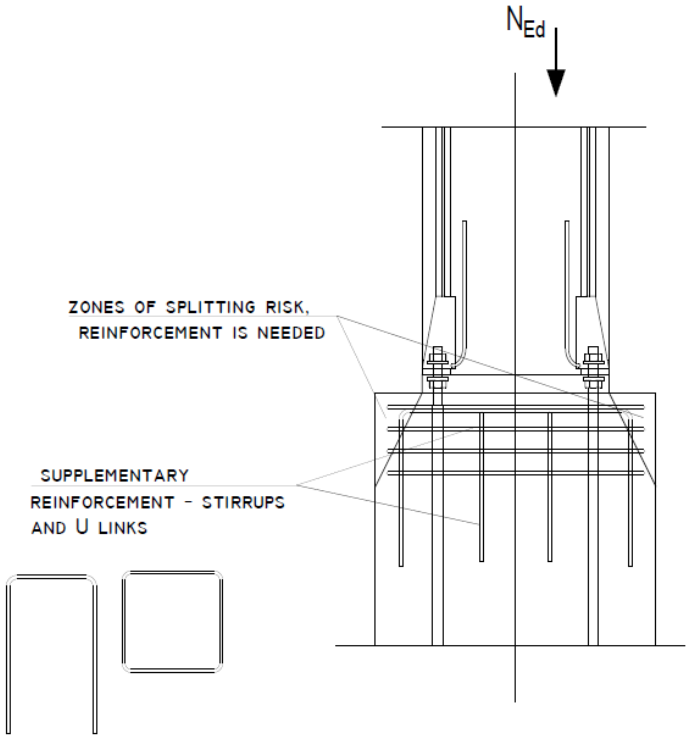


Table 16

Anchor bolt	h_{req} [mm]	U bars	Anchor bolt	h_{req} [mm]	U bars
NKP L/P – M16	80	2 Ø 8	SKP L/P – M30	90	2 Ø 8
NKP L/P – M20	100	2 Ø 8	SKP L/P – M36	100	2 Ø 10
NKP L/P – M24	120	2 Ø 10	SKP L/P – M39	110	2 Ø 10
NKP L/P – M30	140	2 Ø 10	SKP L/P – M45	110	2+2 Ø 10
NKP L/P – M39	160	2 Ø 12	SKP L/P – M52	110	2+2 Ø 10
			SKP L/P – M60	110	2+2 Ø 10

Other cases where special supplementary reinforcement is needed

In column foundation connections, where structural elements often have varying cross-sections and concrete strengths, changes in cross-section necessitate additional reinforcement to address splitting and spalling due to partially loaded areas. The design of this reinforcement and the assessment of stresses in the connection should be carried out according to the basic rules outlined in EN 1992-1-1, specifically Sections 6.7, 9.8, and 10.9, regardless of the type of bolts used in the connection.



A bolted connection essentially functions as a lapping joint, concluding with a reinforcement coupler. All reinforcement lapping rules from EC2 apply to the overlap between bolts and main reinforcement. To achieve the full capacity of the lapping joint, the stirrups in the lapping zone must comply with the requirements specified in EN 1992-1-1, Section 8.7.

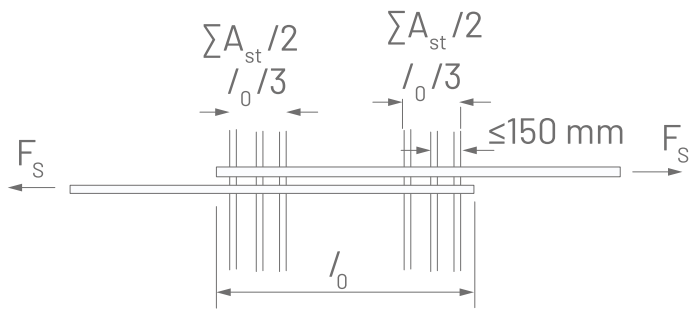


Figure 8-1 General reinforcement demand in shoe / reinforcement cage overlap according to EC2.

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