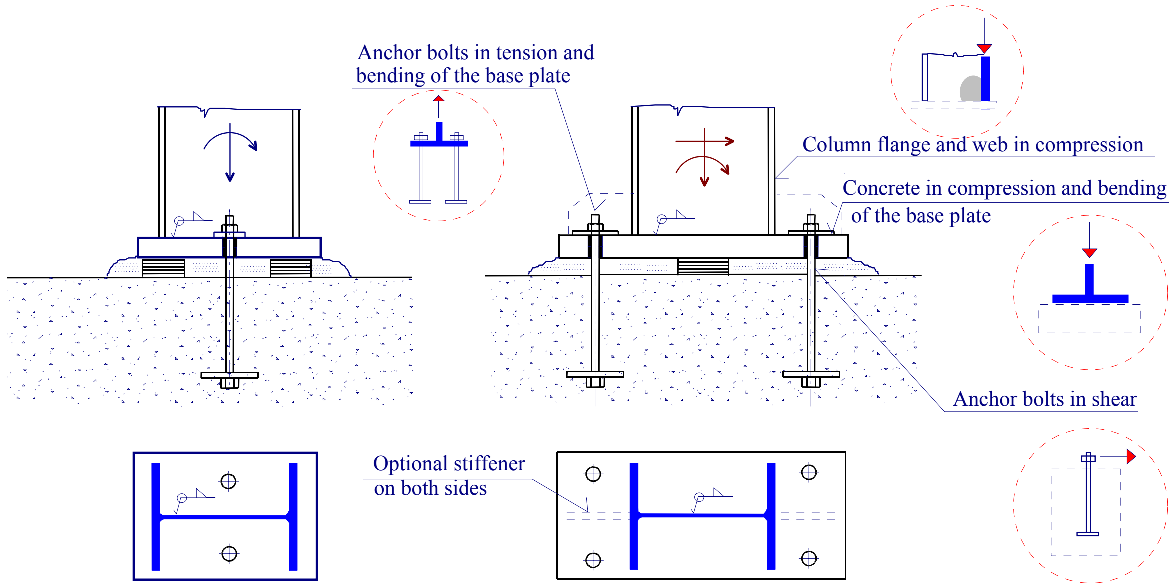
7 COLUMN BASES

A column base consists of a column, a base plate and an anchoring assembly. In general they are designed with unstiffened base plates, but stiffened base plates may be used where the connection is required to transfer high bending moments. The column base is usually supported by either a concrete slab or a sub-structure (e.g. a piled foundation).

prEN 1993-1-8: 2003 includes rules for calculating the strength and stiffness of column bases. The procedure is applicable to columns of both open and closed cross sections [Wald et al, 2000]. Further column base details may also be adopted, including base plates strengthened by adding steel elements and embedding the lower portion of the column into a pocket in the concrete foundation. The influence of the support of the concrete foundation, which may be considerable in certain ground conditions, is not covered in prEN 1993-1-8: 2003.



a) bolts inside the base plate *b) bolts outside the base plate (with optional stiffener)*

Figure 7.1 Typical column base assembly and the selection of components

The traditional approach for the design of pinned bases results in a base plate thickness of sufficient stiffness to ensure a uniform stress under the base plate and therefore the base plate can be modelled as a rigid plate [DeWolf, 1978]. The traditional design of moment-resisting column bases involves an elastic analysis based on the assumption that the sections remain plane. By solving equilibrium equations, the maximum stress in the concrete foundation (based on linear stress distribution) and the tension in the holding down assembly may be determined. Whilst this procedure has proved satisfactory in service over many years, the approach ignores the flexibility of the base plate in bending (even when it is strengthened by stiffeners), the holding down assemblies and the concrete [DeWolf, Ricker, 1990]. The concept, which was adopted in prEN 1993-1-8: transfers the flexible base plate into an effective rigid plate and allows stress in the concrete foundation equal to the resistance in concentrated compression [Murray, 1983]. A plastic distribution of the internal forces is used for calculations at the ultimate limit state.

The component method similar to method for beam-to-column joints is used for the calculation of stiffness [Wald, 1995]. The component approach involves identifying the important parts of the connection, see Figure 7.1 [Wald et al, 1998], called components, and determining the strength and stiffness of each component. The components are assembled to produce a model of the complete arrangement.

The rules for resistance calculation of column bases are included in prEN 1993-1-8: 2003 Chapter 6.2.6 and rules for stiffness calculation are given in Chapter 6.3.4. Methods for transferring the horizontal shear forces are given in Chapter 6.2.1.2. Classification boundaries, see [Wald, Jaspart, 1999], for column base stiffness are included in Chapter 3.2.2.5.

Q&A 7.1 Elastic Resistance of a Base Plate

Why is the resistance of a base plate based on its elastic properties?

By limiting the deformations of the base plate to the elastic range a uniform stress under the base plate may be assumed, see Figure 7.2. It also ensures that the yield strength of the base plate is not exceeded. The effective bearing area of a flexible base plate is based on an effective width c.

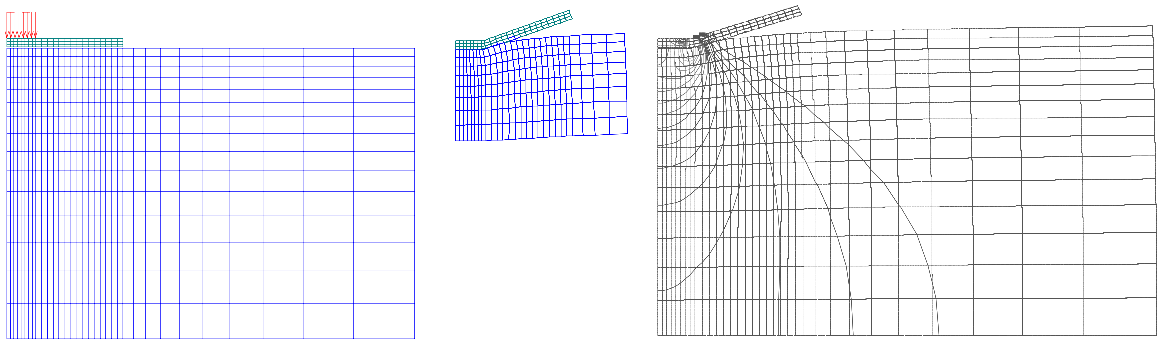


Figure 7.2 Finite element model of base plate T stub and concrete block in compression, undeformed and deformed mesh and the principal stress in concrete [Wald, Baniotopoulos, 1998]

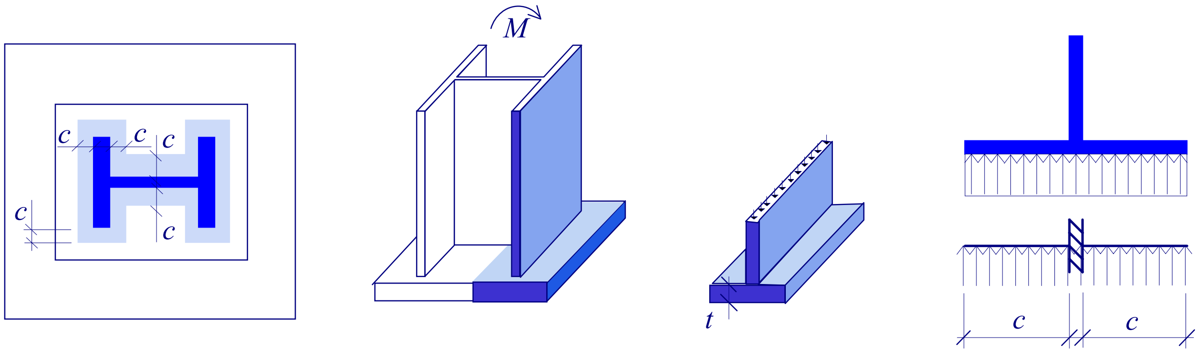


Figure 7.3 Engineering model of the base plate

The elastic bending moment resistance per unit length of the base plate should be taken as

$$M' = \frac{1}{6}\, t^2 f_{yd}\,, \tag{7.1}$$

and the bending moment per unit length [DeWolf, Sarisley, 1980], acting on the base plate represented by a cantilever of span c, see Figure 7.3, is

$$M' = \frac{1}{2}\, f_j\, c^2\,, \tag{7.2}$$

where f_j is concrete bearing strength. When these moments are equal, the bending moment resistance of the base plate is reached and the formula for evaluating c can be obtained from

$$\frac{1}{2}\, f_j\, c^2 = \frac{1}{6}\, t^2 f_y \tag{7.3}$$

as

$$c = t\sqrt{\frac{f_y}{3\, f_j\, \gamma_{M0}}}\,. \tag{7.4}$$

Q&A 7.2 Base Plate Resistance with Low Quality Grout

In prEN 1993-1-8, the joint coefficient β_j is taken as *2/3* when the grout has at least 20% of the characteristic strength of the concrete foundation. What value should be taken when the strength of the grout is smaller?

The influence of low quality grout has been studied experimentally and numerically. It was found that the thin layer of grout does not affect the resistance of the concrete in bearing. It is expected that the grout layer is in three-dimensional compression, i.e. the grout between the concrete and the base plate, is similar to a liquid.

Most of the mortars have a higher resistance compared to the material of the concrete block [Stark, Bijlaard, 1988]. In such cases, the grout layer may be neglected. In other cases, the bearing resistance can be checked, assuming a distribution of normal stress under the effective plate at an angle of *45°*, see Figure 7.4. Where the thickness of the grout is more than *50 mm*, the characteristic strength of the grout should be at least the same as that of the concrete foundation [prEN 1993-1-8: 2003]. Further information is given in Q&A 0.3.

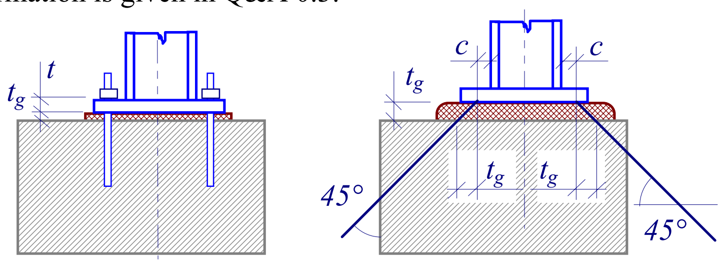


Figure 7.4 The stress distribution in the grout

Q&A 7.3 Comparison of Concrete Strength Calculation according to EC2 and EC3

It seems the results from calculating the bearing strength of a column base f_j are the same as those given in prEN 1992-1-1.

According to prEN 1992-1-1 the strength is

$$F_{Rdu} = A_{c0}\, f_{cd} \sqrt{\frac{A_{c1}}{A_{c0}}} \leq 3{,}3\, A_{c0}\, f_{cd}\,.$$

According to prEN 1993-1-8 the maximum value for k_j is *5,0*. For this value we get a value of

$$f_j = \frac{2}{3} \cdot 5 \cdot f_{cd} = 3{,}33\, f_{cd}$$

The result is the same as given in prEN 1992-1-1, however the methods are different. Is there any background information on this?

PrEN 1993-1 – Design of concrete structures and prEN 1993-1 - Design of steel structures, solve the same problem of the bearing resistance of concrete loaded by a steel plate. The bearing resistance is limited by crushing of the concrete [Hawkins, 1968a,b]. The technical literature concerned with the bearing strength of the concrete block loaded through a plate may be treated in two broad categories. Firstly, investigations focused on the bearing stress of rigid plates, most of the research concerned pre-stressed tendons. Secondly, studies were focused on flexible plates loaded by the column cross section, resulting in transfer of the load only by a portion of the plate.

The experimental and analytical models include ratios of concrete strength to plate area, relative concrete depth, and location of the plate on the concrete foundation and the effects of reinforcement. The result of these studies on foundations with punch loading and fully loaded plates offers qualitative information on the behaviour of base plate foundations. Failure occurs when an inverted pyramid forms under the plate. The application of limit state analysis on concrete includes three-dimensional behaviour of materials, plasticization, and cracking. Experimental studies [Shelson, 1957; Hawkins, 1968, DeWolf, 1978] led to the development of an appropriate model for column base bearing stress, which has been adopted by current codes. A separate check on the concrete block is necessary to calculate shear resistance, bending and punching shear resistance of the concrete block according to the block geometry and detailing.

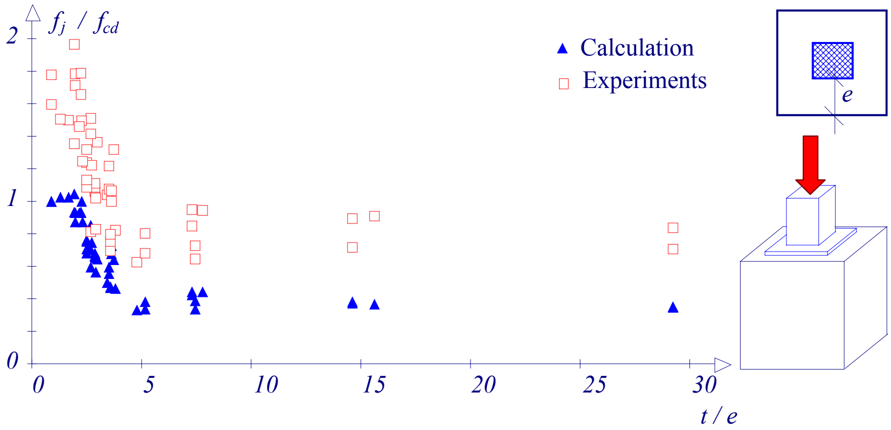


Figure 7.5 Relative bearing resistance - base plate slenderness relationship, calculation and experiments [DeWolf, 1978], [Hawkins, 1968a]

The influence of a flexible plate was solved by the introduction of the equivalent rigid plate [Stockwell, 1975]. This assumption reflects realistic non-uniform stress distribution with maximum pressure following the profile shape. The model is validated by tests. In total, 50 tests were examined to check the concrete bearing resistance [DeWolf, 1978; Hawkins, 1968a]. The size of the concrete block, the size and thickness of the steel plate and the concrete strength were the variables. The test specimens consist of a concrete cube of size from *150* to *330 mm* with a centric load acting through a steel plate. Figure 7.5 shows the relationship between the slenderness of the base plate, expressed as a ratio of the base plate thickness to the edge distance, and the relative bearing resistance. The bearing capacity of test specimens at concrete failure is in the range from *1,4* to *2,5* times the capacity calculated according to prEN1993-1-8 with an average value of *1,75*.

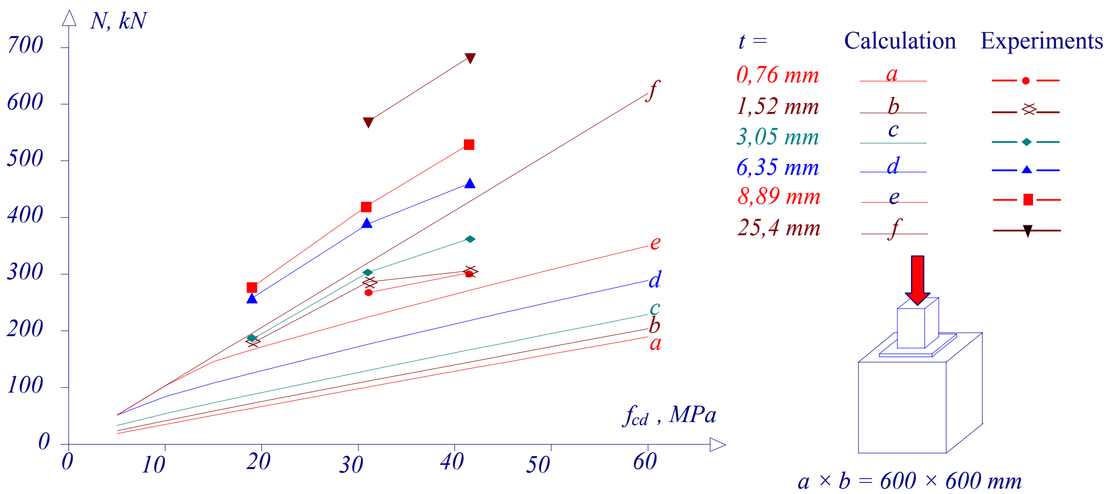


Figure 7.6 Concrete strength - ultimate load capacity relationship [Hawkins, 1968a]

This simple and practical method was modified and checked against the experimental results, [Bijlaard, 1982], [Murray, 1983]. It was also found [DeWolf and Sarisley, 1980] that the bearing stress increases with the eccentricity of the normal force. Where the distance from the plate edge to the block edge is fixed and the load eccentricity is increased, the contact area is reduced resulting in an increase of the bearing stress. In the case of crushing of the concrete surface under the rigid edge, it is necessary to apply the theory of damage. This is not acceptable for practical design and determines the boundaries of the analysis described above.

The influence of the concrete strength is shown in Figure 7.6. 16 tests with similar geometry and material properties were selected from the experimental programme carried out by Hawkins [Hawkins, 1968a]. The only variable was the concrete strength and strengths of *19*, *31* and *42 MPa* were used.

Q&A 7.4 Stress Concentration under the Base Plate

Please, provide background documentation to justify using a value of f_j, which can lead to values of f_j more than *10* times higher than the characteristic strength of the grout. According to prEN 1993-1-8, the maximum value for k_j is *5,0* for a square base plate. For this maximum value we get the maximum value of $f_j = 2/3 * 5 * f_{cd} = 3,33\, f_{cd}$. It is recommended to use a joint coefficient of $\beta_j = 2/3$, when the characteristic strength of the grout is not less than *0,2* times the characteristic strength of the concrete, therefore the lowest strength of the grout is $f_{cd.g} = 3,33 * f_{cd} / 0,2 = 16,66\, f_{cd}$.

The resistance of the grout and the concrete block in compression is limited by crushing of the grout or concrete under a flexible base plate. In the engineering models used, the flexible base plate is replaced by an equivalent rigid plate. The equivalent plate is formed from the column cross-section increased by a strip of effective width c, see Figure 7.7 [prEN 1993-1-8: 2003]. The bearing resistance of the concrete foundation represents a 3D loading condition for the concrete. In this case, the experimental resistance was about *6,25* higher than compression resistance of the concrete. The calculation of the concrete bearing strength f_j is reflected in the standard prEN 1993-1-8 by use of a stress concentration factor k_j with a maximum value of *5,0* for a square base plate. The bearing resistance of the base plate $F_{c,Rd}$ is calculated from

$$a_1 = min\begin{Bmatrix} a + 2a_r \\ 5a \\ a + h \\ 5b_1 \end{Bmatrix},\ a_1 \geq a\ , \tag{7.5a}$$

$$b_1 = min\begin{Bmatrix} b + 2b_r \\ 5b \\ b + h \\ 5a_1 \end{Bmatrix},\ b_1 \geq b\ , \tag{7.5b}$$

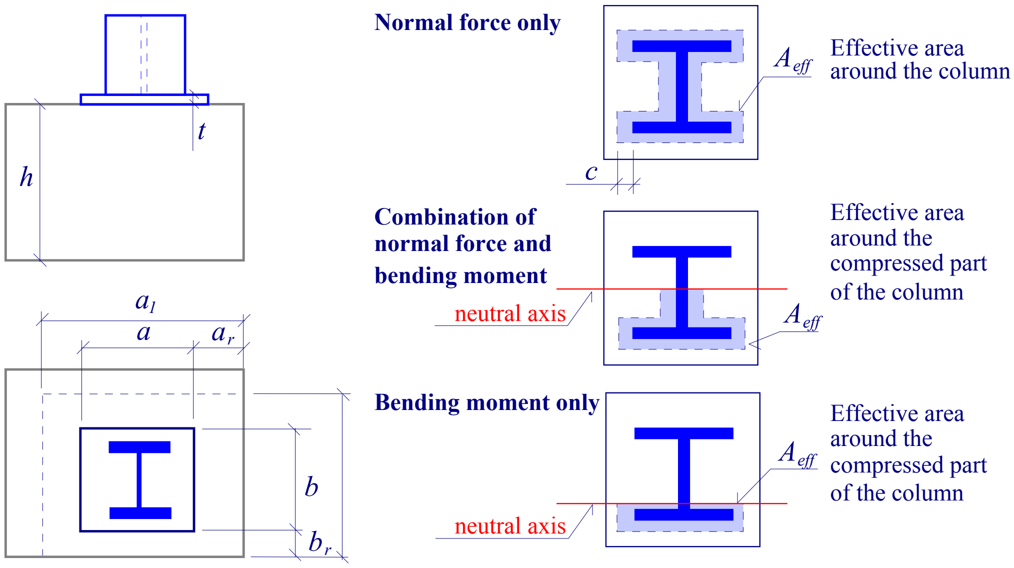
$$k_j = \sqrt{\frac{a_1\ b_1}{a\ b}}\ , \tag{7.6}$$

$$f_j = \frac{2}{3}\frac{k_j\ f_{ck}}{\gamma_C}\ , \tag{7.7}$$

$$c = t\sqrt{\frac{f_y}{3\ f_j \gamma_{M0}}}\ , \tag{7.8}$$

$$F_{c.Rd} = A_{eff}\ f_j\ . \tag{7.9}$$

The effective area A_{eff} is described in Figure 7.7. The grout quality and thickness is introduced by the joint coefficient β_j. For $\beta_j = 2/3$, it is expected that the characteristic strength $f_{ck,g}$ of the grout is not less than *0,2* times the characteristic strength of the concrete foundation f_{ck} ($f_{ck,g} \leq 0{,}2\, f_{ck}$) and the thickness of the grout is $t_g \leq 0{,}2\ min(a;\ b)$. In the case of a lower quality or thicker layer of the grout, it is necessary to check the grout separately. This check should be carried out in the same way as for the resistance calculation for the concrete block.



a) symbols *b) effective area under the flexible base plate*

Figure 7.7 Concrete foundation

Q&A 7.5 Effective Length of a Base Plate T-stub

Can the table with effective lengths for end-plate connections be used for base plates?

The effective length of a T-stub in tension is affected by the failure mode of the T-stub. The T-stubs in a base plate are similar to T-stubs in an end plate beam to column joint, but the failure modes may be different. This is because of the long anchor bolts and thick base plate compared to an end plate. This usually results in uplift of the T-stub from the concrete foundation and therefore prying of anchor bolts is not observed, see Figure 7.8. This results in a new collapse mode called 1*. The resistance of the T-stub without contact with the concrete is

$$F_t = \frac{2\, L_{eff}\ m_{pl,Rd}}{m}, \tag{7.10}$$

where $m_{pl,Rd}$ is plastic bending moment resistance of the base plate of unit length. The relationship of failure mode 1* and failure modes of T-stub with contact is shown on Figure 7.9, $B_{t,Rd}$ where design resistance of bolt in tension.

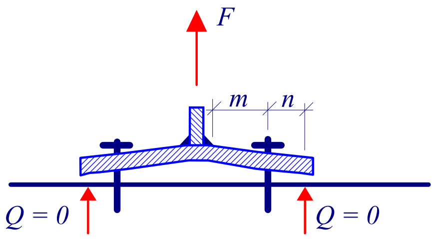


Figure 7.8 T-stub without contact with the concrete block

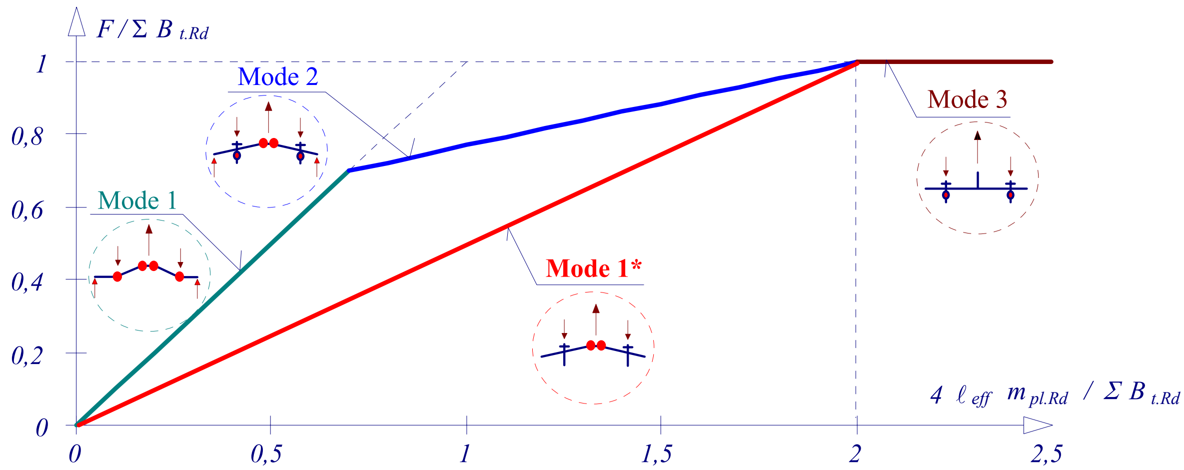


Figure 7.9 Failure mode 1 for the T-stubs of column base*

The boundary between the modes with and without contact may be found from an analysis of elastic deformations of the T-stub. It can be expressed in several ways, for example as the limiting bolt length $L_{b,lim}$. No contact and prying of the anchor bolts occurs for bolts longer than $L_{b.lim}$. The limit is

$$L_{b,lim} = \frac{8{,}82\; m^3 A_s}{L_{eff}\; t^3} \begin{matrix} < \\ > \end{matrix} L_b \,, \tag{7.11}$$

where A_s is the bolt area and L_b is the free length of the anchor bolt, see Figure 7.10, where t_n is the nut height. For bolts embedded in the concrete foundation, the length L_b may be assumed to be the length above the concrete surface L_{bf} and the effective length of the embedded part estimated as $L_{be} = 8\ d$, e.g. $L_b = L_{bf} + L_{be}$ [Wald, 1999].

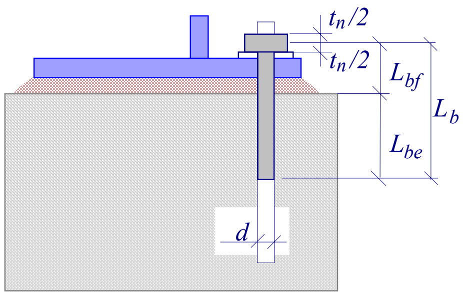
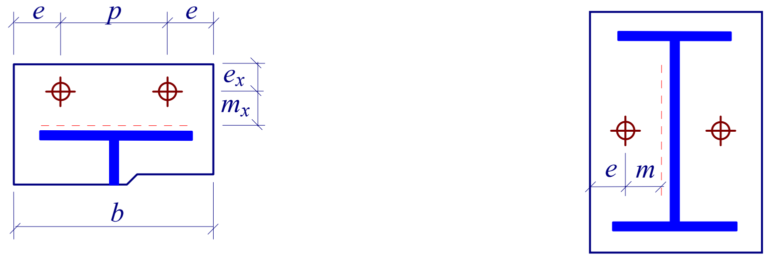


Figure 7.10 Free length of bolts embedded in concrete foundation

The effective lengths of the T-stub L_{eff} of a base plate, see Figure 7.11, are summarized in Table 7.1 and Table 7.2.



a) bolts outside the column flanges *b) bolts inside the column flanges*

Figure 7.11 Dimensions of base plate with bolts inside and outside the column flanges

Table 7.1 Effective lengths for a T-stub of base plate with bolts outside the column flange

Prying occurs	No prying
$L_1 = 4\,m_x + 1{,}25\,e_x$ $L_2 = 2\,\pi\,m_x$ $L_3 = 0{,}5\,b$ $L_4 = 2\,m_x + 0{,}625 e_x + 0{,}5\,p$ $L_5 = 2\,m_x + 0{,}625 e_x + e$ $L_6 = \pi\,m_x + 2\,e$ $L_7 = \pi\,m_x + p$	$L_1 = 4\,m_x + 1{,}25\,e_x$ $L_2 = 4\,\pi\,m_x$ $L_3 = 0{,}5\,b$ $L_4 = 2\,m_x + 0{,}625 e_x + 0{,}5\,p$ $L_5 = 2\,m_x + 0{,}625 e_x + e$ $L_6 = 2\,\pi\,m_x + 4\,e$ $L_7 = 2\,\pi\,m_x + 2\,p$
$L_{eff,1} = min\,(L_1;L_2;L_3;L_4;L_5;L_6;L_7)$ $L_{eff,2} = min\,(L_1;L_3;L_4;L_5)$	$L_{eff,1} = min\,(L_1;L_2;L_3;L_4;L_5;L_6;L_7)$ $L_{eff,2} = min\,(L_1;L_3;L_4;L_5)$

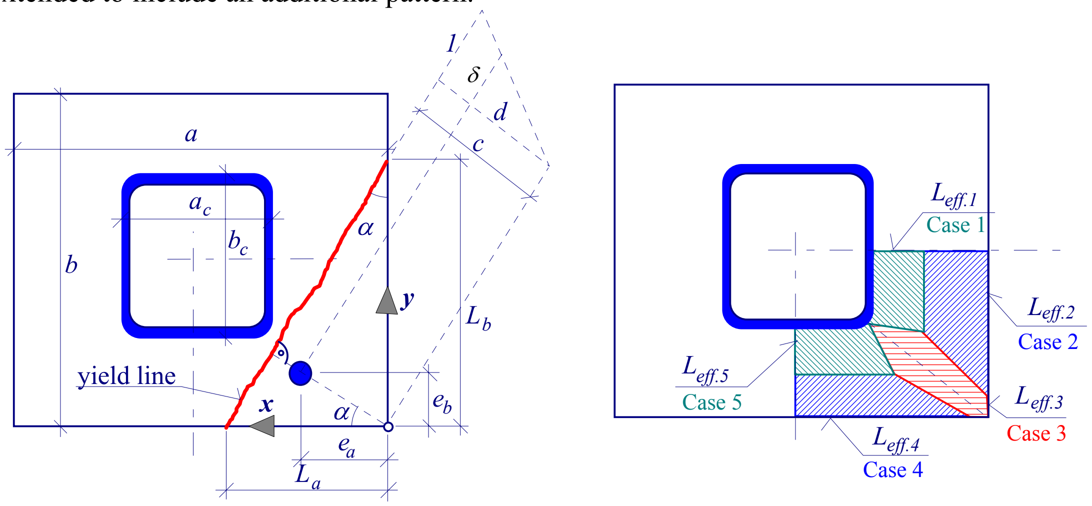
Table 7.2 Effective lengths for a T-stub of base plate with bolts inside the column flanges

Prying occurs	No prying
$L_1 = 2\,\alpha\,m - (4\,m + 1{,}25\,e)$ $L_2 = 2\,\pi\,m$	$L_1 = 2\,\alpha\,m - (4\,m + 1{,}25\,e)$ $L_2 = 4\,\pi\,m$
$L_{eff,1} = min\,(L_1;L_2)$ $L_{eff,2} = L_1$	$L_{eff,1} = min\,(L_1;L_2)$ $L_{eff,2} = L_1$

Q&A 7.6 Base Plates with Bolts outside the Column Flange

The tables for calculating the effective width of a T-stub include cases where all the bolts are placed within the width of the column flange. Can these formulas be used when the bolts are placed the column flanges?

The yield line patterns for plates with bolts placed outside the width of the column flanges were studied by Wald [Wald et al, 2000]. The formulas in the tables for beam to column joints need to be extended to include an additional pattern.



a) yield line pattern *b) position of bolt by different failure modes*

Figure 7.12 Base plate with bolts outside the column flange width

The position of the bolt is described by its coordinates x and y. The yield line is a straight line perpendicular to a line passing through the bolt and the corner of the plate. The angle α represents deviation of the yield line and c is the minimal distance from the corner of the plate to the yield line. Yield line theory together with the principle of virtual energy can be used to determine the parameter c. The internal energy of the yield line is

$$W_i = m_{pl} \left(\frac{1}{y} x + \frac{1}{x} y \right). \tag{7.12}$$

The external energy is

$$W_e = F_{pl} \, \delta , \tag{7.13}$$

The internal and external energy should be equal, therefore

$$m_{pl} \left(\frac{1}{y} x + \frac{1}{x} y \right) = F_{pl} \, \delta . \tag{7.14}$$

The virtual displacement δ represents deformation of the plate at the bolt position, see Figure 7.12, and is equal to

$$\delta = \frac{\sqrt{x^2 + y^2}}{c} . \tag{7.15}$$

Substituting the displacement Δ into the previous equation

$$F_{pl} \frac{\sqrt{x^2 + y^2}}{c} = m_{pl} \left(\frac{x^2 + y^2}{x \, y} \right), \tag{7.16}$$

and

$$F_{pl} = m_{pl} \, c \, \frac{\sqrt{x^2 + y^2}}{x \, y} , \tag{7.17}$$

$$\frac{\partial F_{pl}}{\partial c} = m_{pl} \frac{\sqrt{x^2 + y^2}}{xy} = const . \tag{7.18}$$

Therefore, the effective length L_{eff} is equal to

$$L_{eff} = c \, \frac{\sqrt{x^2 + y^2}}{x \, y} . \tag{7.19}$$

Five yield line patterns may be observed at the corner of the column, see Table 7.3, [Wald et al, 2000]. Assuming there is no contact between the edge of base plate and the concrete surface, than prying of the bolts does not exist.

Table 7.3 Calculation of the effective length of a T-stub, Cases 1 to 3

Case 1	*Case 2*	*Case 3*
$W_{ext} = F_{pl}\ \delta$	$W_{ext} = F_{pl}\ \delta$ $\delta = \dfrac{a - a_c - 2\ e_a}{a - a_c}$	$W_{ext} = F_{pl}\ \delta$ $\delta = \dfrac{\sqrt{(b - b_c)^2 + (a - a_c)^2} - 2\sqrt{e_a^{\ 2} + e_b^{\ 2}}}{\sqrt{(b - b_c)^2 + (a - a_c)^2}}$
$W_{int} = 4\ \pi\ m_{pl}\ \delta$	$W_{int} = m_{pl}\ \dfrac{b}{a - a_c}$	$W_{int} = m_{pl}\left(\dfrac{e_a}{e_b} + \dfrac{e_b}{e_a}\right)$
$F_{pl} = 4\ \pi\ m_{pl}$	$F_{pl} = m_{pl}\ \dfrac{b}{a - a_c - 2\ e_a}$	$F_{pl} = \dfrac{m_{pl}}{\delta}\left(\dfrac{e_a}{e_b} + \dfrac{e_b}{e_a}\right)$
$m = \dfrac{a - a_c}{2} - e_a$		
$L_{eff.1} = \pi\ m$	$L_{eff.2} = \dfrac{b}{4}$	$L_{eff.3} = \dfrac{\sqrt{(a - a_c)^2 + (b - b_c)^2}}{8}\left(\dfrac{e_a}{e_b} + \dfrac{e_b}{e_a}\right)$

The Cases 4 and 5 are similar to Cases 2 and 1, respectively. The results of the FE simulation are shown at Figure 7.13.

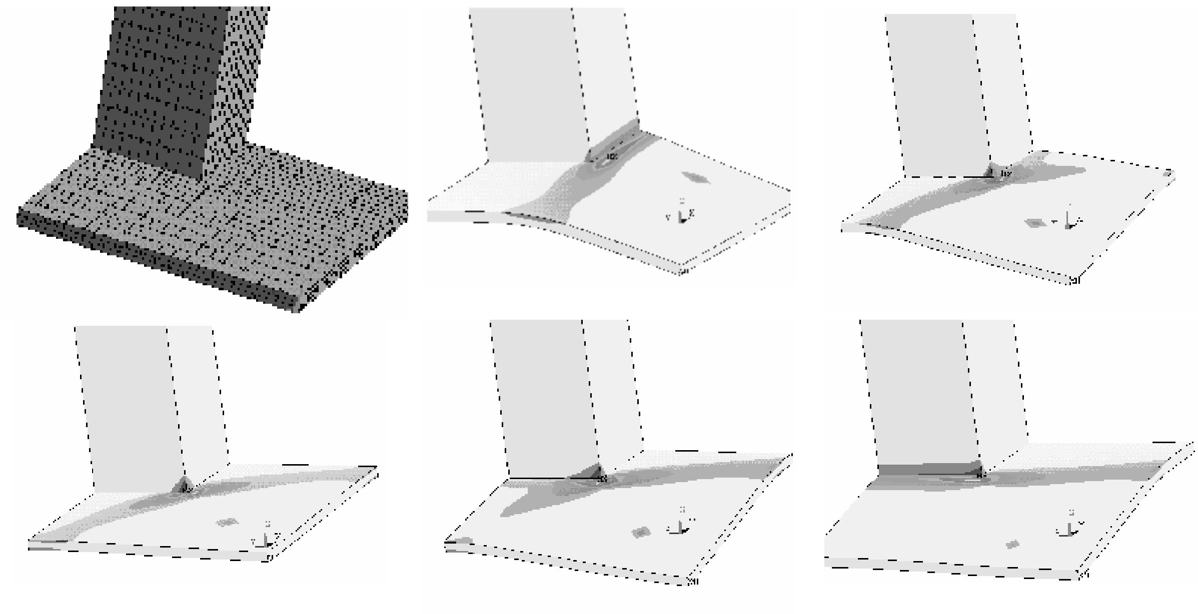


Figure 7.13 Finite element simulation of yield line patterns, the mesh, different yield patterns for variable position of the anchor bolt on the base plate

Q&A 7.7 Slip Factor between Steel and Concrete

What is the slip factor between steel and concrete?

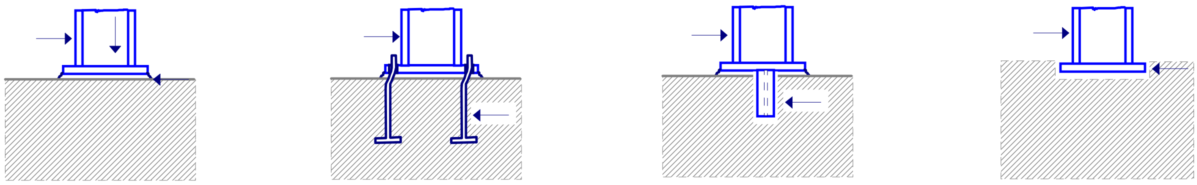
In prEN 1993-1-8: Clause 6.2.1.2 [prEN 1993-1-8: 2003], the coefficient of friction between the base plate and ground layer is given. A value of $C_{f.d} = 0{,}20$ is used for sand-cement mortar and a value of $C_{f.d} = 0{,}30$ for special grout.

CEB Guide [CEB, 1997] and [Eligehausen, 1990] suggests that a friction coefficient of *0,4* may be used when a thin layer of grout less than *3 mm* is used. In this case, a partial safety factor for the ultimate limit state $\gamma_{Mf} = 1{,}5$ should be used.

Q&A 7.8 Transfer of Shear Forces by Anchor Bolts

Can anchor bolts be used to transfer horizontal forces into the concrete foundation?

Horizontal shear force in column bases may be resisted by: friction between the base plate, grout and concrete footing; shear and bending of the anchor bolts; a special shear key, for example a block of I-stub or T-section or steel pad welded onto the bottom of the base plate; direct contact, e.g. achieved by recessing the base plate into the concrete footing, see Fig. 7.14 [Nakashima, 1998]. In most cases, the shear force can be resisted through friction between the base plate and the grout. The friction depends on the minimum compressive load and on the coefficient of friction. Pre-stressing the anchor bolts will increase the resistance of the shear force transfer by friction. In cases, where the horizontal shear force cannot be transmitted through friction between the base plate and the grout due to absence of normal force, the anchor bolts will transmit shear forces or other provisions need to be installed (e.g. shear studs).



a) friction between the base plate, grout and concrete footing

b) shear and bending of the anchor bolts

c) a special shear key

d) direct contact, e.g. achieved by recessing the base plate into the concrete footing

Fig. 7.14 Transfer of horizontal shear force in base plate

The transfer of shear forces by anchor bolts has been good practice in the USA for many years [DeWolf, Ricker 1990]. The bolt holes in the base plate are designed to have clearance as recommended to accommodate tolerance of the bolt position. The design is summarized in CEB document [CEB, 1997]. It is assumed that the anchor bolts will act as a cantilever of span equal to the thickness of the grout increased by $0,5\ d$. When rotation of the nut is prevented by the base plate, the span is reduced to $L/2$, see Figure 7.15.

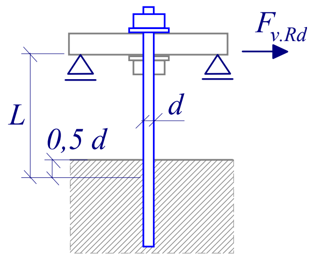
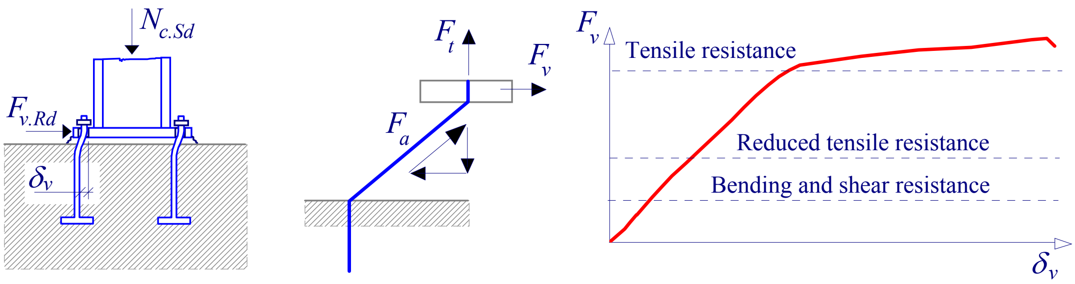


Figure 7.15 Model of anchor bolt in bending, see [CEB, 1997]

In the model of the resistance, described in EN 1993-1-8: 2003, it is assumed the anchor bolts will deflect, which allows the development of a tensile force in the bolt and compression in the grout, see Figure 7.16. This prediction is based on experimental and analytical work by Bouwman [Bouwman et al, 1989]. The design procedure is simplified for practical application and is limited to a shear check.



a) notation *b) forces,* *c) force deformation diagram*

Figure 7.16 Behaviour of an anchor bolt loaded by shear

Q 7.9 Transfer of Shear Forces by Friction and Anchor Bolts

Is it safe to add the friction resistance to the bearing resistances of all the anchor bolts, as clearances in anchor bolt holes are large?

The shear force model used in prEN 1993-1-8: Clause 6.2.1.2 [prEN 1993-1-8: 2003] is based on the assumption that the bolts loaded by a shear force bend, which results in the development of tension in anchor bolts, see Figure 7.16. The resistance of bolts in bending is small, therefore plastic hinges may form in the bolts. This activates hardening effects of the ductile bolt material, see Figure 7.17. Only the anchor bolts in the compressed part of the base plate may be used to transfer shear force. The shear resistance then consist of the friction resistance at the concrete-base plate interface and the reduced tensile resistance of the bolts

$$F_{v.Rd} = F_{t.Rd} + n\, F_{vb.Rd} \,. \qquad (7.20)$$

The resistance of the bolts in bearing in the concrete block and in the base plate should be checked separately.

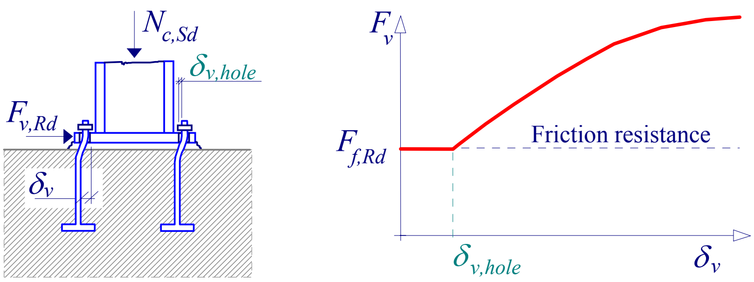


Figure 7.17 The friction resistance and in tension resistance of anchor bolt

Q 7.10 Anchorage rules for Holding Down Bolts

Proper anchorage is the most important criteria for the design of holding down bolts but it is not dealt with in prEN 1993-1-8. What rules should be used?

The rules in prEN 1993-1-8: Table 3.2 for tension resistance of bolts can be used for all steel grades including anchor bolts [Wald, 1999]. The bolt force N_{Sd} should satisfy

$$N_{Sd} \le F_{t,Rd} = \beta_b \, \frac{0{,}9\; A_s\; f_{ub}}{\gamma_{Mb}} \,, \qquad (7.21)$$

where A_s is net area of the bolt, f_{ub} is the ultimate strength of the bolt, γ_{Mb} is partial safety factor for bolted connections and β_b is the reduction factor for cut treads. The factor $\beta_b = 0{,}85$, if applicable.

Different anchoring types can be used, for example cast-in-situ headed anchors, hooked bars, anchors bonded to drilled holes, undercut anchors, see Figure 7.18 [CEB, 1994]. Anchoring to grillage beams embedded in the concrete foundation is designed only for column bases loaded by large bending moment, because it is very expensive. Models of design resistance of anchoring compatible with Eurocode were published in CEB Guide [CEB, 1997] based on Eligehausen [Eligehausen 1990]. It is required to verify the following failure modes of single anchor bolt:

- steel failure

$$N_{Sd} \leq N_{a,Rd} \leq N_{Rd,s} = \frac{A_s\, f_{yb}}{\gamma_{Mb}}, \tag{7.22}$$

- pull-out failure

$$N_{Sd} \leq N_{a,Rd} \leq N_{Rd,p} = \frac{N_{Rk,p}}{\gamma_{Mp}}, \tag{7.23}$$

- concrete cone failure

$$N_{Sd} \leq N_{a,Rd} \leq N_{Rd,c} = \frac{N_{Rk,c}}{\gamma_{Mc}}, \tag{7.24}$$

- and splitting failure of the concrete

$$N_{Sd} \leq N_{Rd,sp} = \frac{N_{Rk,sp}}{\gamma_{Msp}}. \tag{7.25}$$

Similar verification is required for group of anchor bolts.

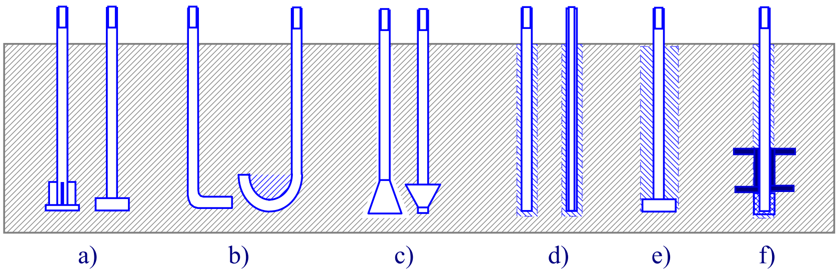


Figure 7.18 Types of anchor bolts, a) cast-in-situ headed anchor bolts, b) hooked bars, c) undercut anchor bolts, d) bonded anchor bolts, e) grouted anchor bolts, f) anchoring to grillage beams

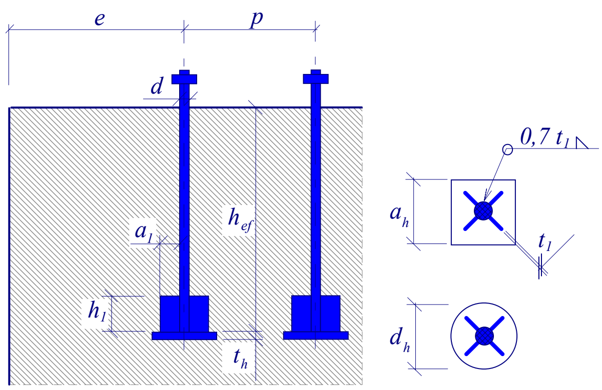


Figure 7.19 Geometry of cast-in-situ headed anchor bolt

Calculation of the design resistance of anchoring by cast-in-situ headed anchor bolts, see Figure 7.19, loaded by tension force is included in the following parts: The pullout design resistance can be obtained as

$$N_{Rd,p} = \frac{p_k\, A_h}{\gamma_{Mp}}, \tag{7.26}$$

where p_k for non-cracked concrete is taken as

$$p_k = 11{,}0\, f_{ck} \tag{7.27}$$

and A_h is the bearing area of the anchor head for circular and square anchor head

$$A_h = \pi\, \frac{\left(d_h^{\,2} - d^2\right)}{4} \tag{7.28a}$$

$$A_h = a_h^2 - \pi \frac{d^2}{4}. \tag{7.28b}$$

The concrete cone design resistance, see Figure 7.20, is given by

$$N_{Rd,c} = N^0_{Rd,c} \frac{A_{c,N}}{A^0_{c,N}} \Psi_{s,N}\ \Psi_{ec,N}\ \Psi_{re,N}\ \Psi_{ucr,N}\ , \tag{7.29}$$

where

$$N^0_{Rk,c} = \frac{k_1\ f_{ck}^{0,5}\ h_{ef}^{1,5}}{\gamma_{Mc}} \tag{7.30}$$

is the characteristic resistance of a single fastener. The coefficient $k_1 = 11\ (N/mm)^{0,5}$ could be taken for non-cracked concrete. The geometric effect of spacing of anchors p and edge distance e is included in the area of the cone, see Figure 7.20, as

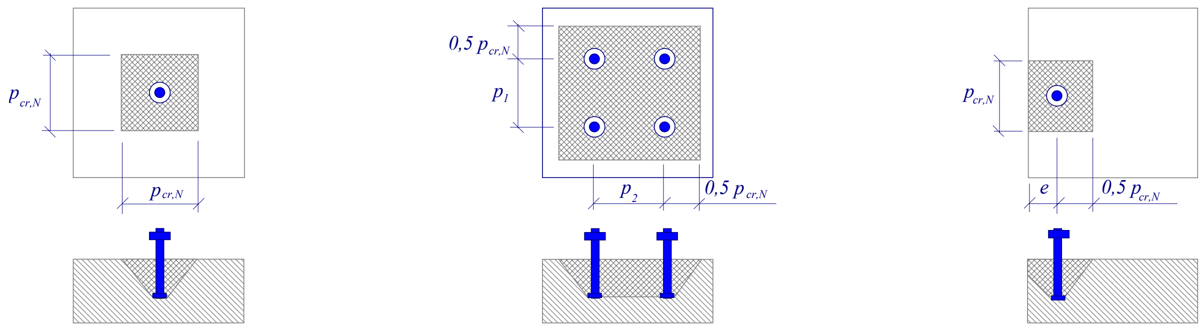
$$A_{c,N}^{\ 0} = p_{cr,N}^{\ \ 2}\ , \tag{7.31a}$$

$$A_{c,N} = (p_{cr,N} + p_1)(p_{cr,N} + p_2), \tag{7.31b}$$

$$A_{c,N} = (e + 0,5\, p_{cr,N})\, p_{cr,N}\ . \tag{7.31c}$$

Width of the concrete cone can be taken approximately

$$p_{cr.N} = 3,0\ h_{ef}\ . \tag{7.32}$$



a) individual anchor *b) anchor group* *c) single anchor at edge*

Figure 7.20 Idealised concrete cone

The disturbance of the stress distribution in the concrete can be introduced by using the parameter $\Psi_{s,N}$

$$\Psi_{s,N} = 0,7 + 0,3 \frac{e}{e_{cr,N}} \le 1\ . \tag{7.33}$$

This parameter $\Psi_{ec,N}$ is introduced to take into account the effect of a group of anchors. It is used for small embedded depths ($h_{ef} \le 100\ mm$). The resistance is increased for anchoring to non-cracked concrete by the parameter $\Psi_{ure,N} = 1,4$. The splitting failure for the in-situ-cast anchors is prevented if the concrete is reinforced and the position of the anchors is limited. Spacing of the anchors should not exceed

$$p_{min} = (5\ d_h;\ \ 50\ mm), \tag{7.34}$$

the edge distance should be larger than

$$e_{min} = (3\ d_h;\ \ 50\ mm) \tag{7.35}$$

and height of the concrete block, should not be smaller than

$$h_{min} = h_{ef} + t_h + c_{\varnothing}\ , \tag{7.36}$$

where $c_{\varnothing}$ is the required concrete cover for reinforcement.

For fastenings with edge distance $e > 0,5\ h_{ef}$ in all directions, the check of the splitting failure may be omitted. The detailed description of the design resistance of different types of fastenings loaded in tension, shear and a combination of tension and shear forces is included in CEB Guide [CEB, 1994].