7 STEEL-CONCRETE CONNECTIONS

7.1 Column Bases

The EN 1993-1-8 [Eurocode 3, 2001] includes rules to determine the strength and stiffness the column bases, which is the system of column, of base plate and of holding down assembly. The end plates are designed preferable unstiffened, but the design procedure for stiffened base plates may be utilize. The Procedure is applicable for columns of open and of closed cross sections [Wald at al., 2000]. Further column base details may be adopted, including embedding the lower portion of column into a pocket in the foundation, or the use of base plates strengthened by additional horizontal steel members. Foundations themselves are supported by the sub-structure. The foundation may be supported directly on the existing ground, or may be supported by piles, or the foundation may be part of a slab. The influence of the support to the foundation, which may be considerable in certain ground conditions, is not covered in the EN 1993-1-8 [Eurocode 3, 2001].

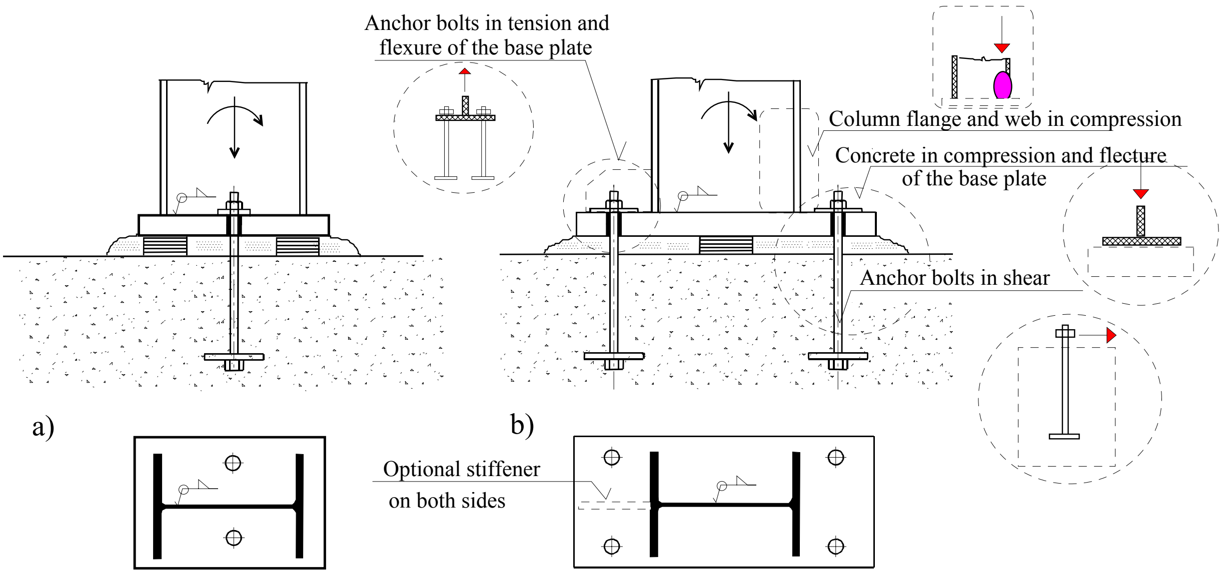

Fig. 7.1 Typical column base assembly of column, base plate and holding down bolts, a) bolts inside the base plate, b) bolts outside the base plate (an optional stiffener), the components for prediction of stiffness and resistance

Traditional approaches to the design of the pinned bases predict the base plate thickness stiff enough to be modelled as all rigid to ensure the uniform stress in compression. The traditional design of moment-resisting bases involves also an elastic analysis, based on the assumption that plane sections remain plane. By solving equilibrium equations, the maximum stress in the concrete (based on a triangular distribution of stress), the extent of the stress block and the tension in the holding down assemblies 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 if they are strengthening by stiffener), the holding down assemblies and the concrete.

The concept adopted in EN 1993-1-8 [Eurocode 3, 2001] is the transfer of the flexible base plate into the effective rigid plate allowing the strength of concrete in concentrated compression, which is crushing of the concrete surface. The plastic distribution of the internal forces is applied. The component method, the same as for the beam-to-column joint prediction, is used to allow also calculation of stiffness. The component approach involves identifying each of the important features in the base connection and determining the strength and stiffness of each of these 'components'. The components are then 'assembled' to produce a model of the complete arrangement.

The resistance of column base is included in EN 1993-1-8 [Eurocode 3, 2001] in Chapter 6.2.6. The stiffness column bases is introduced in Chapter 6.3.4. Details of the components in a column base connection are described as well, namely: the compression side - the concrete in compression and the flexure of the base plate (Chapter 6.3.2), the column flange and web in compression (Chapter 6.2.4.7), the tension side - the holding-down assemblies in tension and the flexure of the base plate (Chapter 6.2.4.12), the transfer of horizontal shear (Chapter 6.2.1.2). The classification boundaries for column base stiffness are included in Chapter 3.2.2.5.

Elastic resistance of a base plate

Why do you calculate the resistance of a base plate based on the elastic 1/6 t^2 and not the plastic 1/4 t^2?

The formula for calculation of the effective bearing area under the flexible base plate around the column cross section is based on estimation of the effective width *c*. It secures that the yield strength of base plate is not exceed in the compression zone but limits also model of concentrated stress under the flexible base plate by restricting the deformations of plate into the elastic range only [Bijlaard, 1982]. Elastic bending moment resistance of the base plate per unit length should be taken as

$$M' = \frac{1}{6} t^2 f_y \tag{7.1}$$

and the bending moment per unit length on the base plate acting as a cantilever of span *c* is, see Fig. 7.1:

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

When these moments are equal, the bending moment resistance is reached and the formula evaluating *c* can be obtained

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

as

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

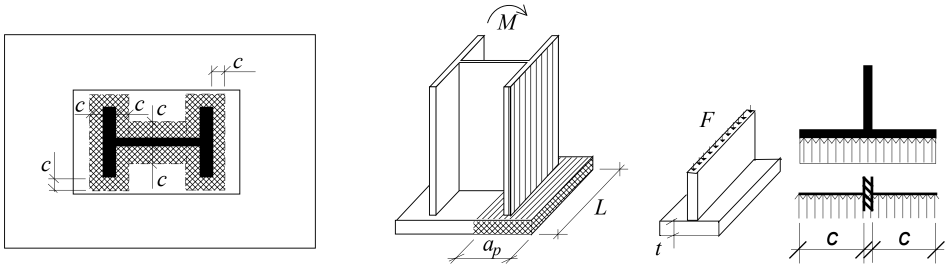

Fig. 7.1 The engineering model of the base plate as a cantilever

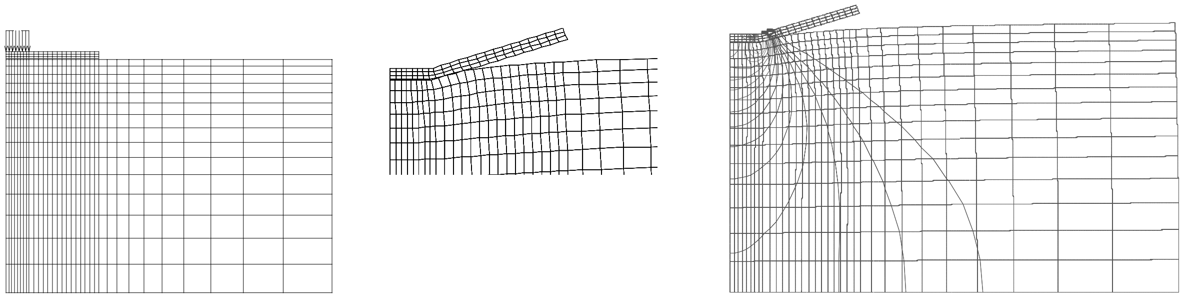

Fig. 7.2 2 D finite element model of base plate T stub ant concrete block in compression, the net, the deformed mesh, the major stresses in concrete [Wald, Banitopoulos, 1998]

Calculation of base plate resistance with low quality grout

In Annex L, 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 problem of low quality grout was studied by experimentally and numerically. It was found, that the grout layer of limited thickness does not affect the resistance of concrete in bearing. It is expected that the layer under three-dimensional boundary conditions, the mortal between the concrete and the base plate, behaves similar to liquid. All test ware carried with real grouts of same resistance. These boundaries of knowledge are introduced in standard. The lower resistance of mortal (just a sand) may cause the changes of the working diagram of the layer material under the repeated loading.

Most of the used mortals have higher resistance compare to the concrete block [Stark, Bijlaard, 1988]. In such case the layer may be neglected or taken into account by checking its bearing resistance as well as concrete block resistance with distribution of normal stresses under the effective rigid plate in angle of *45*°, see Fig. 7.3.

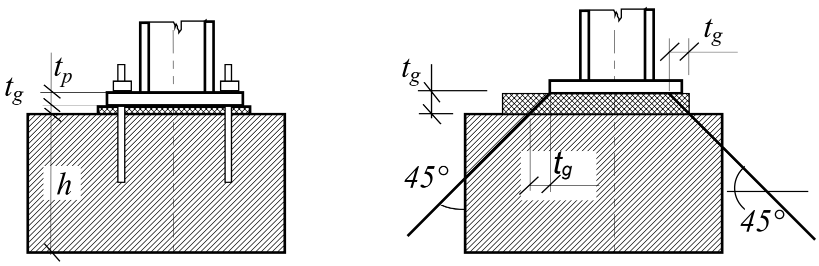

Fig. 7.3 The stress distribution in the grout

Comparison of concrete strength calculation according to EC2 and EC3

It seems the results of calculation of bearing strength of column base f_j are the same as calculation according to EC2.

According to 5.4.8.1 of ENV 1992 is:

$$F_{Rdu} = A_{co} * f_{cd} * \sqrt{A_{c1}/A_{c0}} \quad \leq 3{,}3\, f_{cd} * A_{co}.$$

According to EC3 the maximum value for k_j is *5,0*. For this value we get the value of $f_j = (2/3) * 5 * f_{cd} = 3{,}33\, f_{cd}$.

The result is the same as given in the EC2, however the methods are different in EC3 and EC2. Could you find any background information about this?

The Eurocodes 2 and 3 are solving of the same problem of the bearing resistance of concrete under the steel plate. The bearing resistance is limited by the crashing of the concrete. 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 were concerned the prestressed tendons. Secondly, studies were concentrated on flexible plates loaded by the column cross section due to an only portion of the plate.

The experimental and analytical models are including the ratio of concrete strength to plate area, relative concrete depth, the 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 offer qualitative information on the behaviour of base plate foundations where the plate is only partially loaded by the column. Failure occurs when an inverted pyramid forms under the plate. The application of limit state analysis on concrete can include the three-dimensional behaviour of materials, plastification and cracking. Experimental studies [Shelson, 1957; Hawkins, 1968, DeWolf, 1978] led to the development of an appropriate model for column base bearing stress estimation that was adopted into the current codes. The separate check of the concrete block itself is necessary to provide to check the shear resistance of the concrete block as well as the bending or punching shear resistance according to the concrete block geometry detailing.

The proposed model is validated against the tests. 50 tests in total were examined in this part of study to check the concrete bearing resistance [DeWolf, 1978; Hawkins, 1968]. The test specimens consist of a concrete cube of size from 150 to 330 mm with centric load acting through a steel plate. The size of the concrete block, the size and thickness of the steel plate and the concrete strength are the main variables. 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 design approach given in

Eurocode 3 is in agreement with the test results, but conservative. 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 Eurocode 3 with an average value of 1,75.

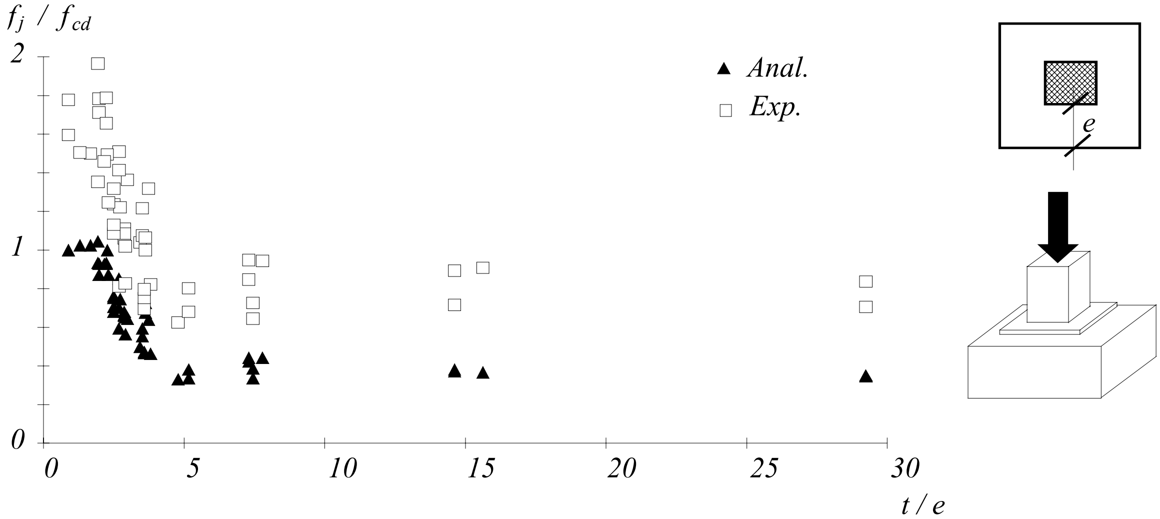

Fig. 7.4 Relative bearing resistance-base plate slenderness relationship, experiments [DeWolf, 1978, and Hawkins, 1968]

The influence of a flexible plate was solved by replacing the equivalent rigid plate [Stockwell, 1975]. This reasoning is based on recognition that uniform bearing pressure is unrealistic and that maximum pressure would logically follow the profile shape. This simple practical method was modified and checked against the experimental results, [Bijlaard, 1982; Murray, 1983]. Eurocode 3, Annex L [Eurocode 3, 1992] adopted this method in conservative form suitable for standardisation using an estimate including the dimensions of the concrete block cross-section and its height. It was also found [DeWolf and Sarisley, 1980; Wald, 1993] that the bearing stress increases with larger eccentricity of normal force. In this case is the base plate in larger contact with the concrete block due to its bending. In case, when the distance between the plate edge and the block edge is fixed and the eccentricity is increased, the contact area is reduced and the value of bearing stress increases. In case of the crushing of the concrete surface under the rigid edge is necessary to apply the theory of damage. These cases are unacceptable from design point of view and are determining the boundaries of above described analysis.

The influence of the concrete strength is shown on Figure 7.6, where is shown the validation of the proposal based on proposal $t_w + 2\,c$. A set of 16 tests with similar geometry and material properties was used in this diagram from the set of tests [Hawkins, 1968]. The only variable was the concrete strength of *19, 31* and *42 MPa*.

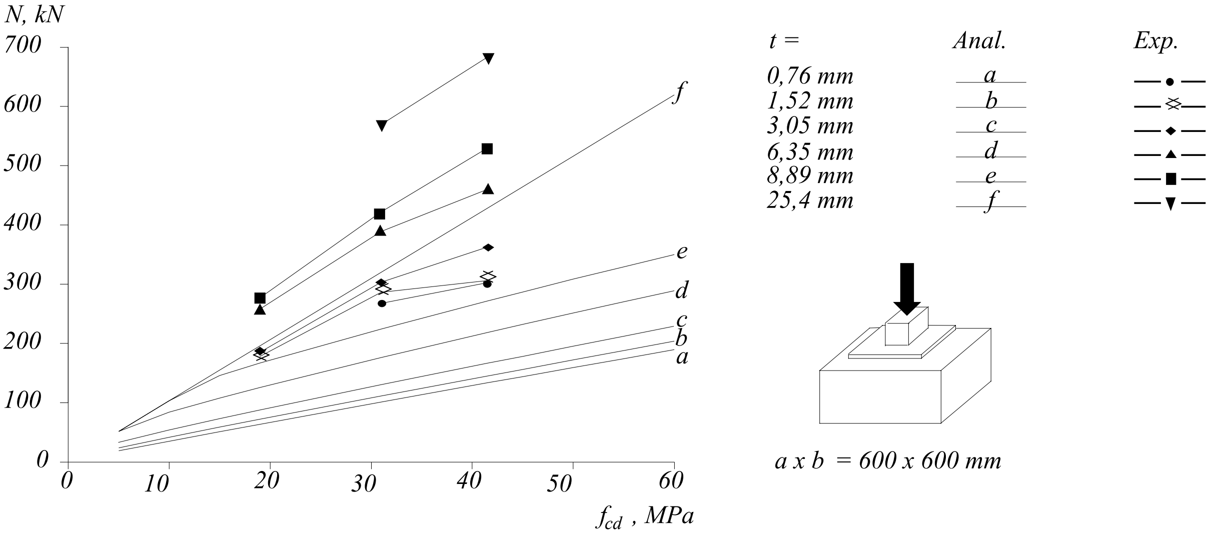

Fig. 7.5 Concrete strength - ultimate load capacity relationship [Hawkins, 196])

Stress concentration factor k_j for column bases

> Please, provide background documentation to justify using 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 Annex L of Eurocode 3, 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 joint coefficient $\beta_j = 2/3$ 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 the crushing of the grout or concrete under the flexible base plate. In engineering models, the flexible base plate is transferred to an equivalent rigid plate round the column cross section, see Fig. 7.7, [Eurocode 3, 2001]. The calculation of the bearing resistance $F_{c.Rd}$ under the base plate is based on the evaluation of the joint concentration factor k_j. The concrete bearing resistance f_j is calculated from

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

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

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

$$f_j = \frac{\beta\ k_j\ f_{ck}}{\gamma_c} \tag{7.7}$$

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

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

In these formulas is f_{ck} the characteristic value of the concrete compressive cylinder strength, γ_c the partial safety factor for concrete and γ_{M0} the partial safety factor for steel. The effective area A_{eff} round the part of the column cross – section, which is in compression is described in Fig. 7.6.

The grout quality and thickness is introduced by the joint coefficient β. For $\beta_j = 2/3$, it is expected that the grout characteristic strength $f_{c.g}$ is not less than $0,2$ times the characteristic strength of the concrete foundation f_c ($f_{c.g} \geq 0,2$) and the thickness of the grout is $t_g \leq 0,2\ min\ (a\ ;\ b)$. In cases of a different grout quality or higher thickness of the grout $t_g \geq 0,2\ min\ (a\ ;\ b)$, it is necessary to check the grout separately. In this case the three-dimensional conditions of grout can be treated similar to concrete block.

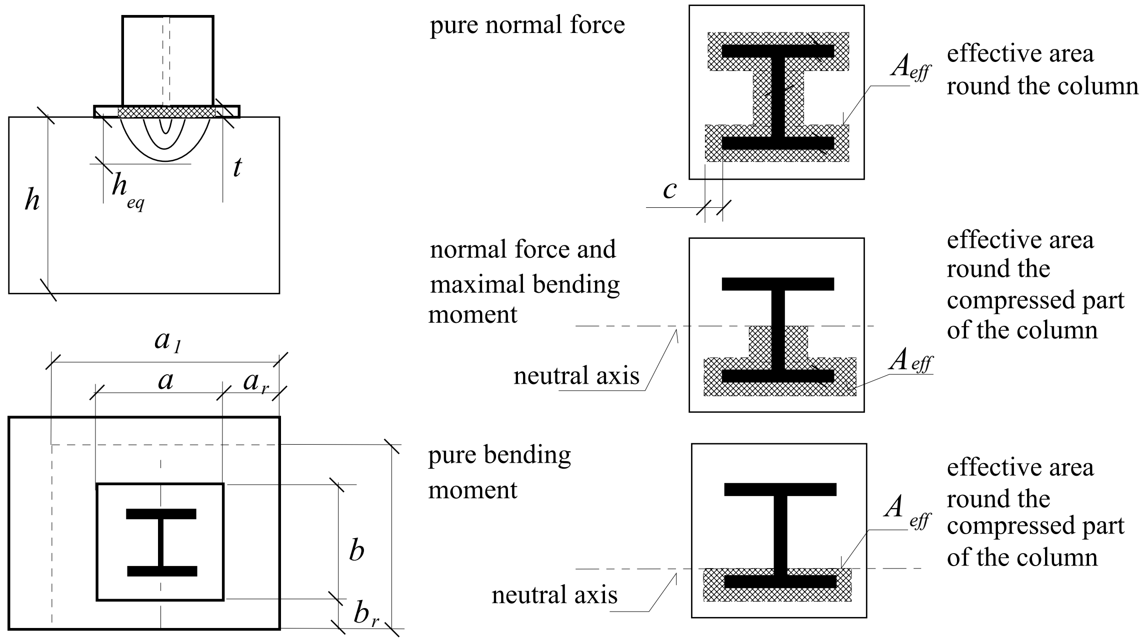

Fig. 7.6 Local deformation of the concrete block, the effective area under the flexible plate

The concrete bearing resistance in joint express the case, where the concrete is loaded in compression under 3D conditions. In this case the reached resistance was experimentally find higher compare to simple compression about 6,25 higher. This is reflected in Eurocode rules by joint factor k_j with the maximum value $5,0$ for a square base plate.

The problem of grout is different, we may take the layer of grout into calculation or we may apply the knowledge in Eurocode. The thin layer of grout is not affecting the column base resistance.

The both effects are separate problem and may not be mixed by increasing the resistance.

Effective length of base plate T-stub

Can the table with effective length of end-plate connections be used also for base plates?

The tables may be used but the modes with prying and without prying needs to be distinguished. The effective length of the T-stub in tension is affected by the failure mode of the T stub. The anchor bolts are rather longer and the base plates mostly thicker compare to typical configuration of end plates in the beam to column connections.

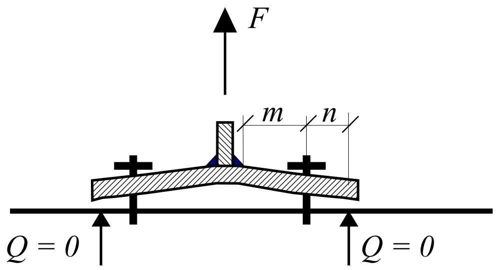

Fig. 7.7 T-stub in case of lost of the contact to the concrete block

The boundaries between the praying and not prying modes may be found form the assumption of $n = 1{,}25\ m$, see Fig. 7.7,

$$L_{b.lim} = \frac{8{,}82\ m^3\ A_s}{\ell_{eff}\ t^3} \quad \begin{matrix} < \\ > \end{matrix} \quad L_b\ , \qquad (7.10)$$

where A_s is the bolts area and L_b is the holding down bolt free length, see Fig. 7.7. For the bolts embedded into concrete this length L_b may be assumed as free length L_{bf} and effective free length of embedded part as $L_{be} \cong 8\ d$, e.g. $L_b = L_{bf} + L_{be}$, see [Wald, 1999]. For the bolt length L_b longer to $L_{b.lim}$ no prying occurs.

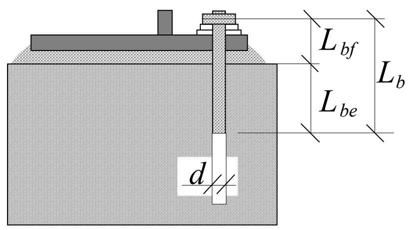

Fig. 7.8 Free length of bolts in case of embedded into concrete block

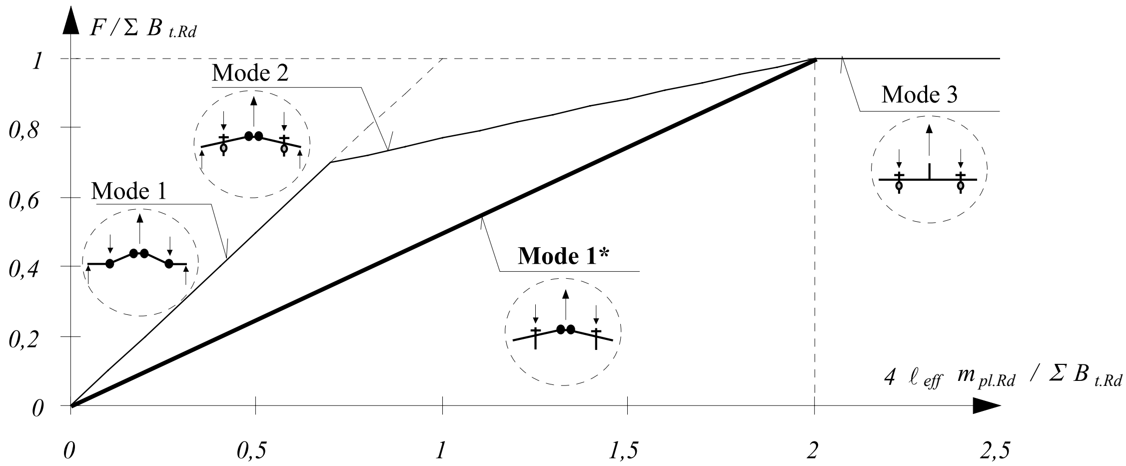

Fig. 7.9 Failure mode 1 for the T-stubs of column base*

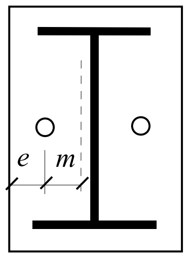

Fig. 7.10 Effective lengths of T-stub of base plate with bolts inside the column flanges

Tab. 7.1 Effective lengths of T-stub of base plate with bolts inside the column flanges

prying occurs	no prying
$\ell_1 = 2\,\alpha\, m - (4\, m + 1{,}25\, e)$	$\ell_1 = 2\,\alpha\, m - (4\, m + 1{,}25\, e)$
$\ell_2 = 2\,\pi\, m$	$\ell_2 = 4\,\pi\, m$
$\ell_{eff,1} = min(\ell_1 ; \ell_2)$	$\ell_{eff,1} = min(\ell_1 ; \ell_2)$
$\ell_{eff,2} = \ell_1$	$\ell_{eff,2} = \ell_1$

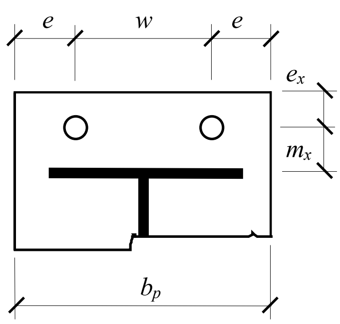

Fig. 7.11 Effective lengths of T-stub of base plate with bolts outside the column flange

text to be completed

Tab. 7.2 Effective lengths of T-stub of base plate with bolts outside the column flange prying occurs

$\ell_1 = 4\, m_x + 1{,}25\, e_x$

$\ell_2 = 2\, \pi\, m_x$

$\ell_3 = 0{,}5\, b_p$

$\ell_4 = 0{,}5\, w + 2\, m_x + 0{,}625\, e_x$

$\ell_5 = e + 2\, m_x + 0{,}625\, e_x$

$\ell_6 = \pi\, m_x + 2\, e$

$\ell_7 = \pi\, m_x + p$

$\ell_{eff.1} = min\left(\ell_1; \ell_2; \ell_3; \ell_4; \ell_5; \ell_6; \ell_7\right)$

$\ell_{eff.2} = \min\left(\ell_1; \ell_3; \ell_4; \ell_5\right)$

no prying

$\ell_1 = 4\, m_x + 1{,}25\, e_x$

$\ell_2 = 4 \pi\, m_x$

$\ell_3 = 0{,}5\, b_p$

$\ell_4 = 0{,}5\, w + 2\, m_x + 0{,}625\, e_x$

$\ell_5 = e + 2\, m_x + 0{,}625\, e_x$

$\ell_6 = 2\, \pi\, m_x + 4\, e$

$\ell_7 = 2\, (\pi\, m_x + p)$

$\ell_{eff.1} = min\left(\ell_1; \ell_2; \ell_3; \ell_4; \ell_5; \ell_6; \ell_7\right)$

$\ell_{eff.2} = \min\left(\ell_1; \ell_3; \ell_4; \ell_5\right)$

Effective length of base plate with bolts outside the column flange

The tables for calculating of effective width of a T-stub include only cases where all bolts are placed within the width of the beam flange. When this table is applied to base plates, the bolts are often outside the column flange. Can these formulas still be used?

The yield pattern of cases where all bolts are placed outside the width of the beam flange where studied by [Wald at al., 2000]. The application of the tables for beam to column joints needs to be modified. One more pattern may occur.

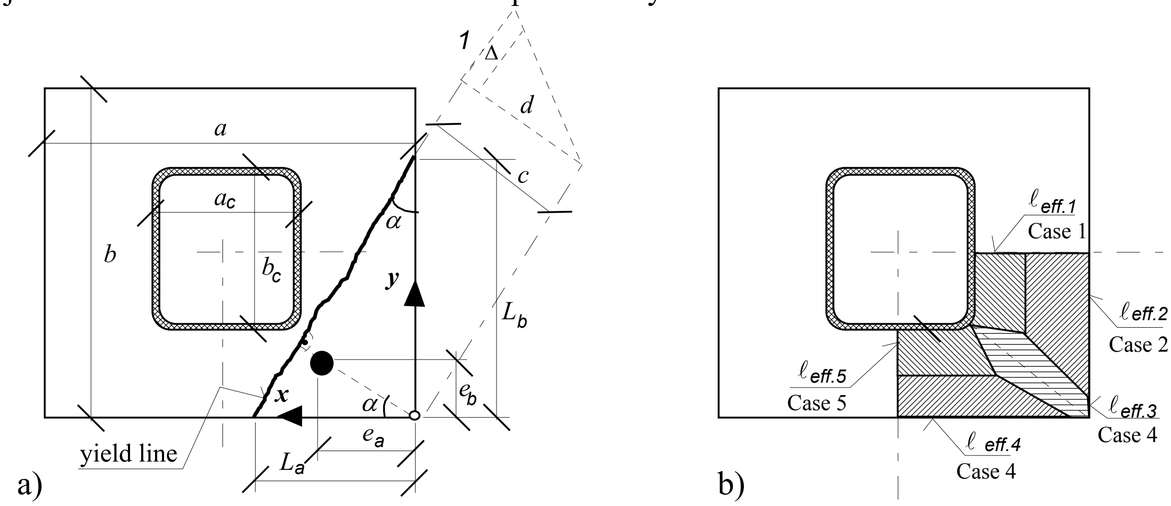

Fig. 7.12 The base plate geometry a), assumption of the range of effective length of T-stub for base plate b)

The effective length of the base plate T-stub can be determined by the yield line method. The yield line is a straight line, and this line is perpendicular to a line, that pass through the bolt and the corner of the plate. α represents the angle of the yield line with the edge and c the minimal distance between the corner of the plate and the yield line. The following relations can be obtained

$$tan\,\alpha = \frac{x}{y}, \qquad (7.11)$$

where x and y are the variable coordinates of the bolt. For the design of the parameter c, we use the work method of the yield line theory. The internal work

$$W_i = \sum_n \left[\bar{\theta}_j ; \bar{m}_{uj} ; \ell_j\right] = m_{pl} \left(\frac{1}{y} x + \frac{1}{x} y \right). \tag{7.12}$$

The external work

$$W_e = P_u \, \Delta = F_{pl} \, \Delta . \tag{7.13}$$

Δ represents the deformation of the plate in the bolt position, see Fig. 4.

$$\frac{\Delta}{1} = \frac{d}{c} = \frac{\sqrt{x^2 + y^2}}{c}, \tag{7.14}$$

$$\frac{\sqrt{x^2 + y^2}}{c} F_{pl} = m_{pl} \left(\frac{x}{y} + \frac{y}{x} \right), \tag{7.15}$$

$$\ell_{eff} = \frac{c\, m}{4} \frac{\sqrt{x^2 + y^2}}{x\, y}, \tag{7.16}$$

For the resistance can be derived

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

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

Five cases may be observed for the yield lines round by the corner of the column, see Tab. 7.3 from [Wald at al, 2000], if are taken into account the modes without the contact of the edge of base plate to the concrete surfaces, e.j. in no prying cases.

Tab. 7.3 The calculation of the effective length of a T-stub per bolt, Case 1 to 3

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

The Case 4 and Case 5 are similar to 2 and 1 respectively. The results of prediction of effective lengths per anchor bolt are summarised in Tab. 2. The results of the FE simulation is shown at Fig. 13 in the case no prying.

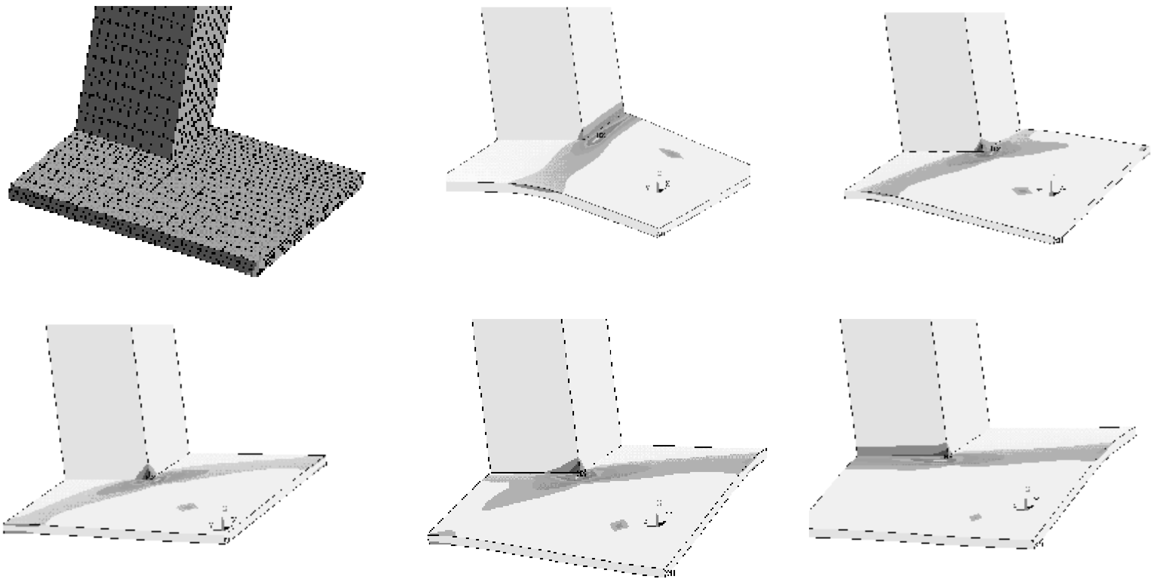

Fig. 13 FE mesh of simulation, the different yield patterns under the moving of the anchorage round the base plate corner

Slip factor between steel and concrete

What is the slip factor between steel and concrete?

In the EN 1993-1-8 Cl. 6.2.1.2 [Eurocode 3, 2001] is included the coefficient of friction between base plate and ground layer $C_{f.d} = 0{,}20$ for the sand-cement mortar and $C_{f.d} = 0{,}30$ for the special grout.

In the CEB Guide [CEB, 1997] is for a thin layer or grout, thickness less than 3 mm, used a friction coefficient is used of *0,4*. In this case is recommended the partial safety factor for the ultimate limit state design as $\gamma_{Mf} = 1{,}5$.

Transfer of shear forces by anchor bolts

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

The use of anchor bolts to transfer the shear resistance forces is approved by practice, in USA for example [DeWolf and Ricker 1990], by many years. The boltholes in base plate need to have a clearance in tolerances as recommended by EN 1990. The most conservative approach is summarized in CEB document. It is expected that the anchor bolt acts as cantilever of length of mortal thickness plus *0,5 d* in the case of post installed or cast-in – place anchors. The cantilever is guided in base plate, its length is reduced to *L/2*, see Fig. 7.14.

The advanced model of resistance to shear forces is described in EN 1993-1-8. The resistance is based on experimental and analytical work [Bouwman at al., 1989]. The model expects the deformation of the anchor bolt and the development of the membrane effect by the tension force bolt and the compressed force in the mortal. The design procedure is simplified for practical application, see EN 1993-1-8 Cl. 6.2.1.2 [Eurocode 3, 2001], see Fig. 7.15.

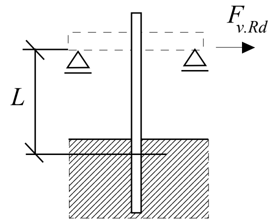

Fig. 7.14 Model of anchor bolt in bending

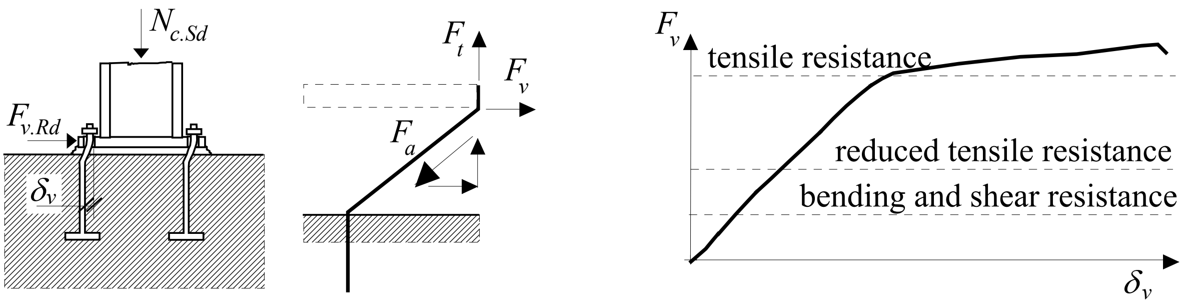

Fig. 7.15 The shear behavior of an anchor bolt, the resistance in tension

Transfer of shear forces by friction and anchor bolts

> Is it safe adding the friction resistance with the bearing resistances of all the anchor bolts, as clearances in anchor boltholes are large and with uncontrolled distribution.

The advanced model of resistance to shear forces used in EN 1993-1-8 Cl. 6.2.1.2 [Eurocode 3, 2001] is based on the evaluation of resistance based on deformed shape. The bolt resistance in bending is smaller compare to the tensile resistance. This allows for deformable ductile bolts to use the post bending resistance on deformed shape, see Fig. 7.16. The shear resistance than consist of the friction resistance and of all bolts reduced tensile resistance.

$$F_{v.Rd} = F_{t.Rd} + n\, F_{vb.Rd} \tag{7.19}$$

The resistance of the bolts in bearing in the concrete block and the bearing resistance of the bolts in base plate need to be checked separately. Only the anchor bolts in the compressed part of the base plate may be used for the transfer of shear forces.

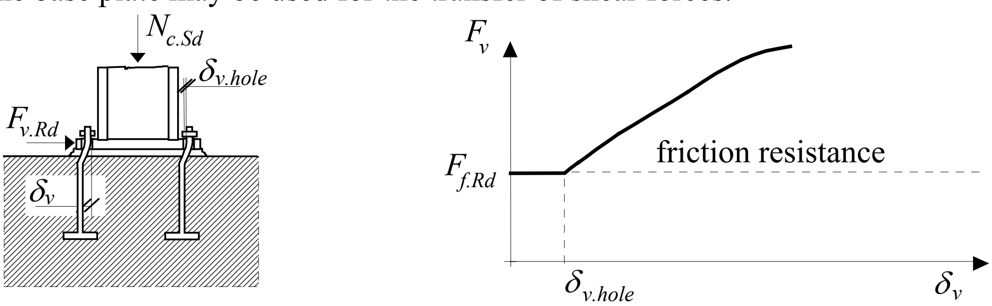

Fig. 7.16 The friction resistance and in tension resistance of anchor bolt

Rules for anchorage of holding down bolts

The proper anchorage is the most important criteria for appropriate design of holding down bolts but it is not dealt within Annex L. Where are given the rules for anchorage?

The models of design resistance of anchoring compatible with Eurocode were published in CEB Guide [CEB, 1997] and in contribution by [Eligehausen 1990]. The required verification for a single anchor bolt is:
steel failure

$$N_{Sd} \le N_{a.Rd} \le N_{Rd.S} = \frac{f_{yb}\ A_s}{\gamma_{Mb}} \tag{7.20}$$

pullout failure

$$N_{Sd} \le N_{a.Rd} \le N_{Rd.p} = N_{Rk.p} / \gamma_{Mp}, \tag{7.21}$$

concrete cone failure

$$N_{Sd} \le N_{a.Rd} \le N_{Rd.c} = N_{Rk.c} / \gamma_{Mc} \tag{7.22}$$

and splitting failure of the concrete

$$N_{Sd} \le N_{Rd.sp} = N_{Rk.sp} / \gamma_{Msp}. \tag{7.23}$$

Similar verification is required for anchor group $N_{sd}{}^{h}$.

The rules of EUROCODE 3, Tab. 6.5.3, [Eurocode 3, 1992] on bolts tension resistance are satisfied for all steel grades used for anchor bolts

$$F_{v.Rd} \le \beta_b \frac{0{,}9\ f_{ub}\ A_s}{\gamma_{Mb}}, \tag{7.24}$$

where f_{yb} is the yield tensile strength of bolt, γ_{Mb} the partial safety factor for the bolts, f_{ub} the ultimate tensile strength of the bolt, β_b the cut tread reduction factor, if applicable $\beta_b = 0{,}85$.

Different types of anchoring are used, hooked bars for light anchoring, the cast-in-place headed anchors and bounded anchors to drilled holes. The expensive anchoring to grillage beams embedded in concrete are designed for large frames, see Fig. 7.17.

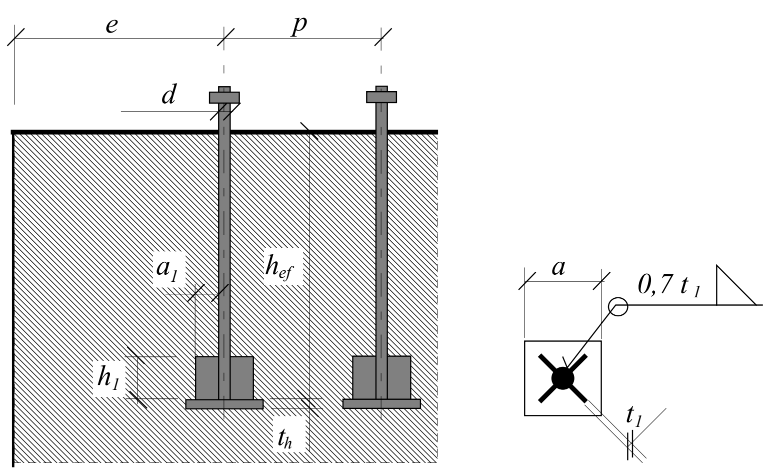

Fig. 7.17 The geometry of the In-situ-cast headed anchor bolt

The calculation of design resistance of fastenings with cast-in-situ headed anchor bolts loaded by tension force is included in the following part.
The pullout failure design resistance can be obtained as

$$N_{Rd.p} = p_k\ A_h / \gamma_{Mp}, \tag{7.25}$$

where p_k is taken in non-cracked concrete as

$$p_k = 11{,}0\, f_{ck} \tag{7.26}$$

and A_h is the bearing area of the head, for circular head can be written

$$A_h = \pi\,(d_h^2 - d^2) / 4 \tag{7.27}$$

The concrete cone failure design resistance is given as

$$N_{Rd.c} = N^0_{Rd.c}\,\frac{A_{c.N}}{A^0_{c.N}}\,\Psi_{s.N}\;\Psi_{ec.N}\;\Psi_{re.N}\;\Psi_{ucr.N}, \tag{7.28}$$

where

$$N^0_{Rk.c} = k_1\, f_{ck}^{0,5}\, h_{ef}^{1,5}\, /\, \gamma_{Mc} \tag{7.29}$$

is the characteristic resistance of a single fastener. The coefficient k_1 could be taken for non cracked concrete as

$$k_1 = 11{,}0 \quad \left[\sqrt{N / mm}\right]. \tag{7.30}$$

The geometric effect of spacing p and edge distance e is included in calculation of the area of the cone, see Fig. , as

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

$$A_{c.N} = \left(p_{cr.N} + p_1\right)\left(p_{cr.N} + p_2\right), \tag{7.32}$$

for example for Fig. a,b, or

$$A_{c.N} = \left(e + 0{,}5\; p_{cr.N}\right)\; p_{cr.N} \tag{7.33}$$

for Fig. c. It is possible to take approximately

$$p_{cr.N} \cong 2{,}0\, e_{cr.N} \cong 3{,}0\; h_{ef} \tag{7.34}$$

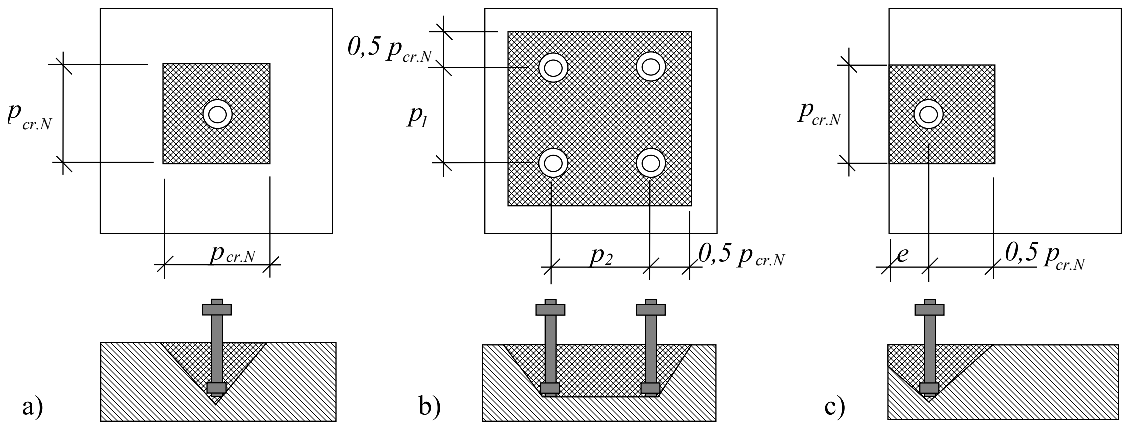

Fig. 7.18 An idealised concrete cone, individual anchor a), anchor group b), single anchor at edge c)

The disturbance of the stress distribution in concrete could be introduced by parameter

$$\Psi_{s.N} = 0{,}7 + 0{,}3\,\frac{e}{e_{cr.N}} \le 1. \tag{7.35}$$

The parameter $\Psi_{ec.N}$ takes into account the group effect. Parameter $\Psi_{re.N}$ is used for small embedded depths ($h_{ef} \le 100\ mm$). The resistance is increased in non-cracked concrete by parameter $\Psi_{ure.N} = 1{,}4$.

The splitting failure for the in-situ-cast anchors is prevented if the concrete is reinforced or by limiting:
spacing

$$p_{min} = 5\, d_h \geq 50\ mm, \tag{7.36}$$

edge distances

$$e_{min} = 3\, d_h \geq 50\ mm, \tag{7.37}$$

and height of the concrete block

$$h_{min} = h_{ef} + t_h + c_{\varnothing}, \tag{7.38}$$

where

t_h is thickness of anchor head and

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

For fastenings with an edge distance $e > 0{,}5\ h_{ef}$ in all directions, a check of the characteristic blow-out resistance may be omitted.

The detailed complex description of the design resistance of different types of fastenings loaded by tensile force, by shear force and by combined tension and shear forces is included in CEB Guide [CEB, 1994].

Base plate of circular hollow section

Are there any guidelines how to handle the T-stub of a circular hollow column section on a rectangular base plate?

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to be completed

Yield strength of hooked anchor bolts

Why is yield strength of anchor bolt limited to 300 MPa in case of anchorage with hook (paragraph 5.2.6.12 in EC3 part 1.8)?

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to be completed

7.2 Beam-to-Column Steel-Concrete Connections

to be completed

Symbols

a	length of the base plate
a_1	effective length of the foundation
b	width of the base plate
b_c	width of the column
b_w	width of the washer
b_1	effective width of the foundation
c, c_i	effective width
$c_\varnothing$	required concrete cover for reinforcement
d	diameter of the bolt
d_h	diameter of anchor head
d_w	diameter of washer
d_0	diameter of the bolt hole
e, e_a, e_b	deviation, distances
f_{cd}	design value of concrete compressive cylinder strength $f_{cd} = f_{ck} / \gamma_c$
f_{ck}	characteristic value of concrete compressive cylinder strength
f_t	effective stress of the tension part
f_j	concrete bearing strength
f_{jh}	concrete bearing strength in horizontal direction
f_y	yield stress of steel
f_{yb}	yield stress of the bolt
f_u	ultimate tensile strength
f_{ub}	ultimate strength of the bolt
g	distance
h	height of the foundation
h_c	height of column cross section
k_j	concentration factor
k_i	component stiffness
m	distance from the bolt axes to the weld edge
p	pitch
q	load
r_b	lever arm of bolt force
r_c	lever arm of concrete force
s	elongation
t	thickness of the base plate
t_f	thickness of the flange
t_h	thickness of anchor head
t_p	limiting thickness of base plate for prying
t_w	thickness of the column web
t_{wa}	thickness of the washer
x, y, z	axes, distance
A	area
A_b	total area of the bolt, untreated part
A_c	area of the column
A_{eff}	effective area
A_h	bearing area of the bolt head

A_s	net area of the bolt, in tread
E	Young's modulus, Young's modulus of steel
E_c	Young's modulus of concrete
F	force
I	second moment of inertia
L	length
L_b	length of the untreated part of the anchor bolt
L_{be}	effective length of the anchor bolt
L_{eq}	equivalent length of the anchor bolt
L_s	length of the treated part of the anchor bolt
L_{eff}	effective length
M	bending moment
M'	bending moment of unique width
Q	prying force
S_j	joint stiffness
$S_{j.ini}$	initial stiffness
$\overline{S}$	relative stiffness
V	shear force
W	section modulus
α	coefficient
β	relative thickness of the base plate
β_j	joint coefficient
β_w	correlation factor
ϕ	rotation
γ_i	partial safety factor
η	ratio of the base plate dimensions, a / b
σ	stress
σ_T	stress in the tension part
$\sigma_\perp$	normal stress perpendicular to the throat
τ_{II}	shear stress, in the plane of the throat, parallel to the axis of the weld
$\tau_\perp$	shear stress, in the plane of the throat, perpendicular to the axis of the weld

Subscripts

b	bolt
c	concrete, column
k	characteristic
cr	critical
eff	effective
eq	equivalent
f	flange
ge	free length
h	horizontally, bolt head
n	non-sway
p	plate, effective
pl	plastic
s	sway, treated part
w	web
wa	washer

we weld

Rd resistance, design
Sd internal, design

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