COLUMN BASE PLATE CONNECTIONS: THE DUTCH APPROACH

Dick A. Hordijk* and Jan W.B. Stark**

*Eindhoven University of Technology and Adviesbureau Hageman, The Netherlands
**Delft University of Technology and Stark Partners, The Netherlands

Abstract

This paper outlines the approach for the design of column base plate connections based on the Eurocodes as it is recommended in the Netherlands. The setup of a Dutch report [1] containing the design method for a number of the most common column base plate connections, as well as worked out examples, is presented and the reason to make this report, is discussed. Attention is paid to a number of inconsistencies and omissions in the relevant Eurocodes ('Steel' and 'Concrete') and Technical Specifications ('Fastenings'), and the method chosen in the Dutch report for these aspects is explained.

1. Introduction

It is the authors a great privilege to contribute to this publication to commemorate the 70th birthday of Prof. Rolf Eligehausen. The current extensive knowledge on the behaviour of fastenings in concrete and the availability of design methods for fastenings in concrete is undoubtedly mainly due to Prof. Rolf Eligehausen and his coworkers.

Fastenings in concrete are generally applied to connect a steel structure to a concrete structure. The connection is the place '*where structural steel and concrete meet*'. During the RILEM Symposium in 2001 in Stuttgart, organized by Prof. Eligehausen, the authors paid attention to the fact that '*steel structures*' and '*concrete structures*' are traditionally two worlds in structural engineering [2]. This holds true for as well education and Codes, as also in practice. Though in practice the situation is rapidly changing to some extent it is still the case. For the Codes, it is in fact logical to have separate parts for concrete (Eurocode 2; EN 1992 series) and steel (Eurocode 3; EN 1993 series) structures. Besides that, there are composite elements for e.g. beams, slabs and columns, for which there is Eurocode 4 (EN 1994; series). For the joints between steel and concrete structures the question arises in which part of the Eurocodes it should be treated. Traditionally in the

Dutch Code the anchorage of a column base plate connection in the concrete was treated in the Code for steel structures, while for, e.g. the effect of concentrated loads on the concrete foundation, reference was made to the Code for concrete structures. In the Eurocodes now there is a similar situation.

Besides the steel and concrete world, in the last decennia another world developed as far as the connection between steel and concrete structures is concerned. This is the world of the *fastening technique*. It mainly concerns fastenings with short anchors, where concrete failure may be governing. This is different from the approach in the steel Code where steel failure is generally the starting point for design (*reinforced concrete technique*). Design methods for fastenings were first developed within CEB (now *fib*). With the introduction of the European Technical Approvals for fastenings, in which it is prescribed how to determine the properties of fastenings, it was required to have a design method. Since in the CEN-context there was not such a design method, it was then (nineties of the last century) decided to add it as a Annex C to the ETAG's (European Technical Approval Guidelines). By now there are the CEN Technical Specifications for the design of fastenings for use in concrete [5].

Figure 1 Cover of the Dutch report [1] for column base plate connections.

In order to support the structural engineer with the design of column base plate connections, it was decided in the Netherlands to make a report [1] (*Figure 1*). The reason for this and the chosen set-up is explained in the next chapters.

2. Why recommendations for the design of column base plate connections?

The most frequently used type of connection between steel and concrete is undoubtedly the column base plate connection (*Figure 2*). For the design of this connection the structural engineer may see himself placed for the question which European document to apply: EN 1993-1-8 [4] or CEN/TS 1992-4 [5]. A first reaction may be: "It depends on the type of fastening that is applied". In case of a relatively short anchor, like headed fasteners or post-installed fasteners, CEN/TS 1992-4 applies (*fastening technique*), whereas in case of anchors with yielding as governing mechanism EN 1993-1-8 applies. But is it that simple and will all the rules be clear to the structural engineer? In that respect it can be mentioned that:

- EN 1993-1-8 gives the opening to use other fixings unless adequately tested and approved;
- For the same mechanisms different approaches are used and rules are given in [4] and [5] with a significant difference in outcome;
- CEN/TS 1992-4 mainly concentrates on the tensile behavior of the connection with an elastic design approach assuming a sufficient stiff base plate, while transfer of large compressive forces is not treated;
- For several issues related to concrete EN 1993-1-8 refers to Eurocode 2 (EN 1992-1-1 [3]) while the required information cannot be found there;
- Column base plate connections are often situated at edges of floor slabs (*Figure 3*) or on foundation beams with almost the same width as the base plate, where application of CEN/TS 1992-4 will be difficult or not possible, because of small edge distances.

Figure 2 Typical detail of a column base plate connection.

Figure 3 Examples of column base plate connections at edges of floor slabs.

Furthermore in EN 1993-1-8 [4] the design rules are given for all types of joints. As a result, the column base plate connection is not treated separately, but it is integrated in the so-called “component approach”. The advantage is that the rules are fully consistent with the design approach for steel-steel connections. It, however, makes the rules not easy accessible for users.

To conclude, the authors were of the opinion that for design of column base plate connections:

- the rules to apply are not easy to find;
- some aspects are not treated consistently in the different Codes;
- a number of aspects is treated only vaguely or left out completely.

So, it was felt that there are enough arguments to make a report with recommendations for the design of column base plate connections in order to give guidance to the structural engineer.

3. Set-up of the report

There are many appearances for base plate connections and also the loading conditions may vary significantly. As a result, the rules that apply to all different situations, are complex for simple base plate configurations. For the report [1] it was decided to treat a number of basic cases, using the common situation as shown in *Figure 4* and starting very simple. The various cases treated, are:

A. Centric compression (only N_{Ed})
B. Normal force and bending (combination of N_{Ed} and M_{Ed})
C. Shear (only V_{Ed})
D. Combination of shear, normal force and bending (combination of N_{Ed}, M_{Ed} and V_{Ed})
E. Other types of base plate connections and special aspects

Furthermore, for each of the cases A to D, first the situation of no edge influences was treated, followed by the situation that edges of the concrete foundation influence the design.

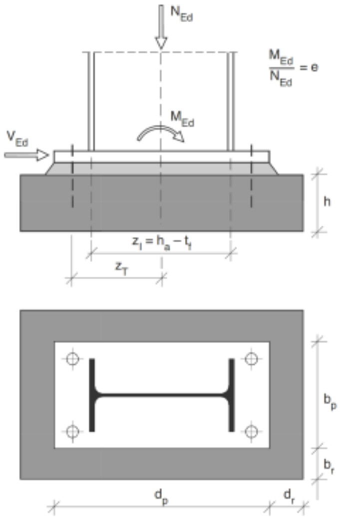


Figure 4 Used common column base plate situation.

Starting point for the design was Eurocode 3: EN 1993-1-8 [3]. It is assumed that a leveling layer of grout is applied and for the anchoring in the concrete foundation use can be made of:

- a hook of a smooth steel bar;
- threaded rods with anchor plate;
- headed fasteners
- fasteners with an European Technical Approval

Though not mentioned explicitly in EN 1993-1-8 [4], in [1] hooks are supposed to be of smooth steel with a threaded end, since these appear to be applied in practice. In order to give general rules for the criterion of the edge distance (when it playes a role in the design or not), distinction is made in two groups of anchors:

- anchors on bond, like the anchorage of longitudinal reinforcement (EN 1992-1-1 [3])
- anchors with mechanical anchoring, where the resistance is determined by an effective depth h_{ef}.

Though most attention in the report [1] is on the design of the column base plate connection in the ultimate limit state, also a method for determining the stiffness is given and attention is paid to execution. Furthermore, it contains a commentary, where inconsistencies and omissions in the Codes are discussed and the proposed solutions are explained. Furthermore, the calculation method has been illustrated with a number of worked examples.

4. Discussion on several items

4.1 General

In the report [1], for several items inconsistencies in the Codes are discussed and choices had to be made for the design. As mentioned before, EN 1993-1-8 [4] was taken as starting point. Nevertheless, differences with rules in other Codes are discussed. Furthermore, for several aspects that were not dealt with in the Codes the background for the proposed design rules is presented. With respect to the latter, in general it can be mentioned that for the transfer of com-pressive, tensile and shear forces into the concrete foundation rules are given in EN 1993-1-8. For the consequences of these load introductions into the foundation, reference is made to EN 1992-1-1 [3], where no specific rules are given that can be applied. So the structural engineer has to solve it by engineering judgment. As an example the situation of a column base plate connection, directly adjacent to an edge of the foundation and loaded with a normal force, bending moment and shear force, the latter transferred by friction, is shown in *Figure 5*.

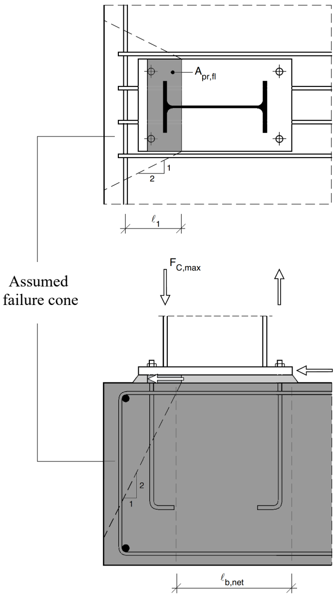


Figure 5 Situation of column base plate connection at edge of foundation.

4.2 Plastic design approach

It is obvious that for (short) fasteners with concrete failure as possible governing mechanism an elastic approach is applied. Though also CEN/TS 1992-4 [5] is based on an elastic approach, in Annex B of [5] also rules for a plastic design approach are given.

Besides a number of conditions that should be met in order to ensure ductile steel failure, for the concrete failure mechanisms it is required that the value is 1,25 times higher than the design value for steel failure of the fastener based on the steel tensile strength.

Like in EN 1993-1-8 [4], the plastic design approach is applied in the report [1]. It is regarded to be important to do so, because in practice the schematization of the structure of which the connection is part of, is often not exactly according to its real behavior. In a frame the load distribution depends on the stiffness of the components, including the column base plate connection. In practice, in general a hinge or a fully stiff connection (*Figure 6*) is assumed. A schematization with a hinge is conservative for the structure, but not necessarily for the base plate connection. The base plate connection is than calculated for a centric loading, while in general it is not free to rotate (*Figure 4*), so that also bending moment will occur. With a ductile behavior of the connection with sufficient rotational capacity this is not a problem. Furthermore, temperature effects or support settlements are often not taken into account, which is also not a problem in a plastic design approach.

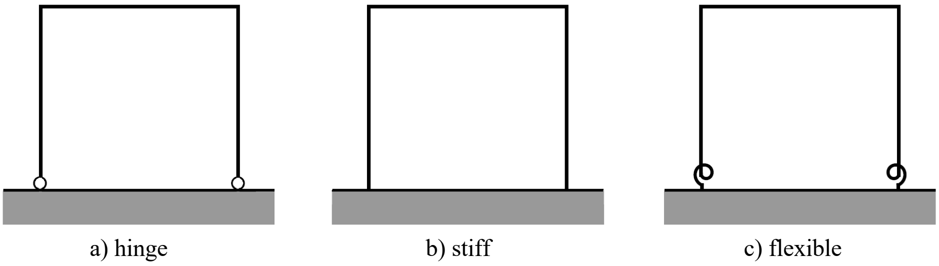


Figure 6 Possibilities for the schematization of the connection.

In order to secure that ductile behaviour occurs, similarly to CEN/TS 1992-4 [5] it is required that the capacity for brittle concrete failure is 1,25 times higher that de governing capacity for steel failure (either tensile failure of the fasting or yielding of the base plate directly adjacent the column). In case of small tensile forces, because of practical dimensions for the fasteners and the base plate this may still result in a significant required capacity for concrete failure. Therefor, it is allowed not to fulfill the plasticity requirement when the capacity of brittle concrete failure is at least 1,7 times higher than the existing tensile load (design values). De factor 1,7 is chosen in analogy with requirements for minimum dimensions of welds and the calculation of corner connections in steel structures.

4.3 Base plate and concrete foundation in compression

The resistance is determined by an equivalent rigid plate concept. In *Figure 7* is shown how an equivalent rigid plate is defined to replace a flexible plate in case the base plate connection is loaded by axial force only.

This rigid plate follows the footprint of the column. The resistance is now determined by two parameters: the bearing strength of the concrete and the dimensions of the equivalent rigid plate. The flexible base plate is replaced by an equivalent rigid plate with an area equal to the sum of the area under the T-stub under the column web (2) and the area under the two T- stubs under the column flanges (1 and 3).

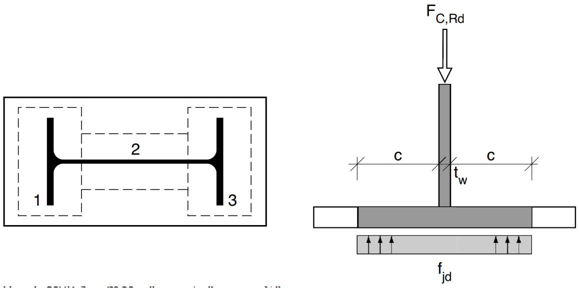


Figure 7 T-stubs in compression.

The additional bearing width c of the T-stub is determined on the basis of the following assumptions:

- No plastic deformations occur in the flange of the T-stub, so that the flange remains relatively flat. Therefore, the resistance per unit length of the T-stub flange is taken as the elastic resistance:

  $$m_{bp} = t^2 f_y/6 \tag{1}$$

- It is assumed that the T-stub is loaded by a uniform stress distribution. The bending moment per unit length on the base plate acting as a cantilever of span c is:

  $$m_{bp} = f_{jd}\, c^2/2 \tag{2}$$

- The equivalent width c can be resolved by combining equations (1) and (2):

  $$c = t\,[f_y/(3f_{jd})\,]^{0,5} \tag{3}$$

The bearing strength of the concrete under the plate is dependent on the size of the concrete block. According to EN1992-1-8 [4] with reference to EN1992-1-1 [3] for partially loaded concrete, the design bearing strength of the joint f_{jd} is determined by:

$$f_{jd} = \beta_j\, k_d\, f_{cd} \tag{4}$$

with

$$k_d = (A_{c1}/A_{c0})^{0,5} \leq 3,0 \text{ (see } \textit{Figure 8}\text{)} \tag{5}$$

β_j is the foundation joint material coefficient, which may be taken as 2/3 provided that the characteristic strength of the grout is not less than 0,2 times the characteristic strength of the concrete foundation and the thickness of the grout is not greater than 0,2 times the smallest width of the steel base plate. In cases 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.

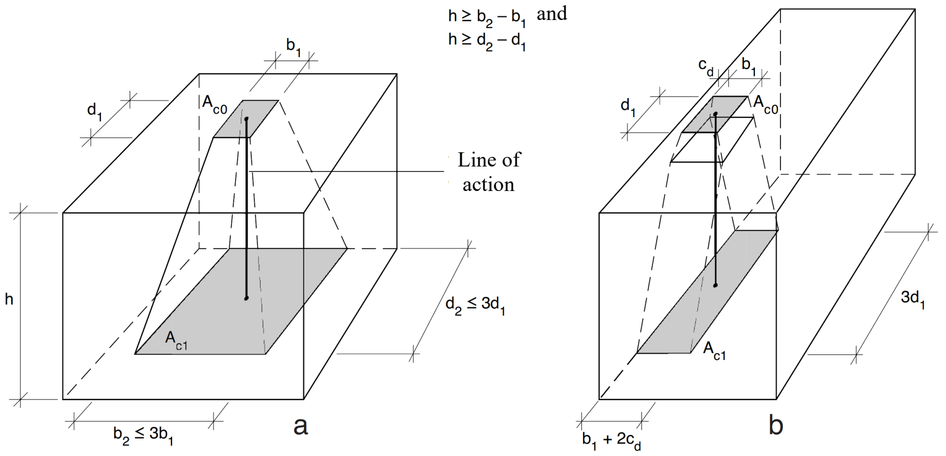


Figure 8 Design distribution for partially loaded areas according to EN 1992-1-1 [3] (a) and the distribution in case of an area loaded at an edge (b).

The following remarks can be made:

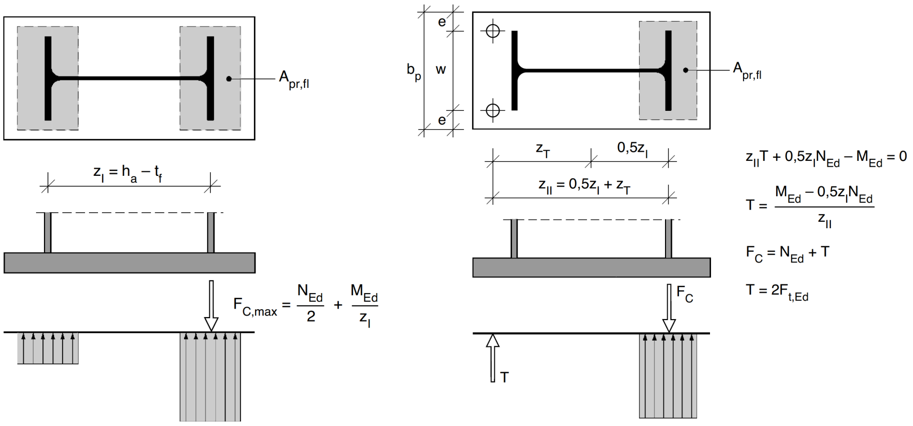
- The limit for the characteristic strength of the grout according to EN 1993-1-8 [4] is very low. In EN 1992-1-1 [3] grout layers are not dealt with, but in CEN/TS 1992-4 [5] for the leveling layer a compressive strength ≥ 30 N/mm^2 is required. In the report [1] it was decided to apply the rule in EN 1993-1-8 because it fits the best to the application and has not led to problems in several decennia.
- In EN 1992-1-1 [3] it is stated that the shape of the maximum design area A_{c1} should be similar to the loaded area A_{c0}, which might suggest that d_2/b_2 has to be equal to d_1/b_1 and the situation as sketched in *Figure 8b* is not allowed. Based on the literature that was used many years ago for this rule, it was determined that the situation in *Figure 8b* is okay. This was communicated with and confirmed by the Dutch commission for the structural concrete Code.
- Due to spreading of the concentrated load in the foundation, tensile splitting stresses occur. EN 1992-1-1 [3] states in this respect: "*Reinforcement should be provided for the tensile force due to the effect of the action*.". In [1] it is explained that in many cases it will not be necessary to apply special reinforcement for the splitting stresses under the concentrated load of a column base plate. In [1] it is proposed that reinforcement for the tensile force is not required if $N_{Ed}/A_{c0} \leq f_{cd}$ or $N_{Ed}/A_{c1} \leq 5$ N/mm^2, with N_{Ed} being the design value for the compressive force, f_{cd} the design value for the uniaxial compressive strength of the concrete and A_{c0} and A_{c1} according to *Figure 8*. If this requirement is not fulfilled, then, adopting the rule in 9.8.4 of EN 1992-1-1 for a '*column footing on rock*', in the direction parallel to b_1 and b_2 a splitting force equal to $F_{sb}=0{,}25[1-(b_1/b_2)]$ should be taken into account and similarly for the perpendicular direction.

4.4 Base plate in bending and anchors in tension

For the basic situation B (normal force and bending moment) three different situations with respect to the stress distribution in the joint are distinguished:

I. Only compression if $N_{Ed} \leq 0$ (compression) and $e < 0{,}5\ z_I$
II. A compression zone and tensile zone
III. Only tension if $N_{Ed} > 0$ (tension) and $e < 0{,}5\ z_T$

In *Figure 9* the determination of the compressive force F_C and tensile force is shown for situation I and II. For reasons of simplicity, the contribution of a part of the T-stub under the web of the column to the compression force is not taken into account. As a result there is a discontinuity in the transition from only a centric compression force to a combination of a compression force and bending moment.



a) b)

Figure 9 Compressive forces for situation I (a) and compression and tension force for situation II (b).

In case of hooks of smooth steel, the required anchorage length is determined according to EN 1992-1-1 [3]. Because of smooth steel, which is not incorporated in EN 1992-1-1, the required anchoring length is multiplied by a factor 2 according to the last Dutch concrete Code. For anchors with a mechanical anchoring at a depth equal to h_{ef}, as much as possible the rules in CEN/TS 1992-4 are applied (*Figure 10*). Also recommendations are given for the application of splitting reinforcement is case of a column base plate connection near an edge or a corner of the concrete foundation.

4.5 Shear resistance

Similar as discussed before for the required strength of a leveling layer, in the report [1] for the shear resistance rules according EN 1993-1-8 are applied, that differ significantly from those in design guides for fasteners (e.g. CEN/TS 1992-4). These rules originate from National Codes for steel structures (e.g. those in The Netherlands), where they have been applied for many years.

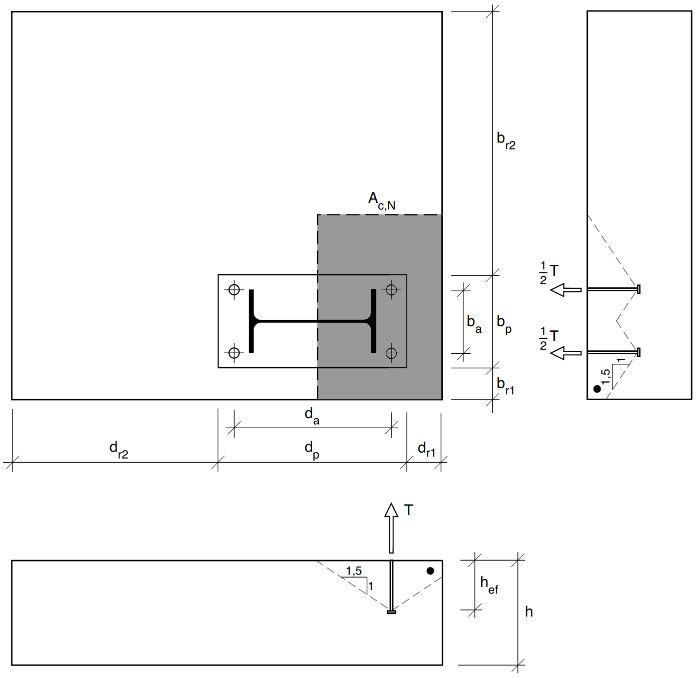


Figure 10 Column base plate connection with two headed anchors at an edge loaded in tension.

Similarly to 6.2.2. of EN 1993-1-8 [4], the design shear resistance $F_{v,Rd}$ of a column base plate connection should be derived as follows:

$$F_{v,Rd} = F_{f,Rd} + nF_{vb,Rd} \tag{6}$$

The design friction resistance $F_{f,Rd}$ is to be derived as follows:

$$F_{f,Rd} = C_{f,d}\, F_C \tag{7}$$

where:

$C_{f,d}$	is the coefficient of friction. The following values may be used: • for sand-cement mortar $C_{f,d} = 0,20$; • for other types of grout $C_{f,d}$ should be determined by testing.	
F_C	is the design value of the normal compressive force in the column.	
n	is the number of anchors in the base plate that contribute to the shear resistance.	
$F_{vb,Rd}$	$\min[F_{1,vb,Rd}; F_{2,vb,Rd}]$	
$F_{1,vb,Rd}$	is the bearing resistance of the anchor bolt calculated as for a normal bolt.	
$F_{2,vb,Rd}$	$= \alpha_b\, f_{ub} A_s / \gamma_{Mb}$	(8)
α_b	$= 0,44 - 0,0003\, f_{yb}$	
f_{yb}	is the yield strength of the anchor bolt, where $235\ \text{N/mm}^2 \leq f_{yb} \leq 640\ \text{N/mm}^2$	
γ_{Mb}	$= 1,25$	

The following remarks can be made:

- The design method in EN1993-1-8 is based on the results of a research project (*Figure 11*), carried out at the Delft University of Technology [6]. These tests were aimed to investigate the behaviour of a base plate under shear, while so called cast-in-place long anchors were applied and failure of the concrete block was prevented by appropriate reinforcement.

Figure 11 Test specimen loaded by shear force [6].

- In EN 1993-1-8 it is stated: "*If anchor bolts are used to resist the shear forces between the base plate and its support, rupture of the concrete in bearing should also be checked, according to EN 1992.*" In EN 1992-1-1, however, no rules are given for this specific situation, so the structural engineer has to apply engineering judgment or apply rules in CEN/TS 1992-4 [5] for hanger reinforcement.
- In the report [1] the reinforcement to apply in such a situation is discussed.
- The shear resistance according to the rules described, is very much higher than the value according to the rules in CEN/TS 1992-4. The applicability for shorter anchors should be investigated.
- Similar to EN 1993-1-8 the design shear resistance may be based on the summation of friction and shear capacity of the anchors. This summation, however, seems to be in contradiction with the clauses 6.2.2(5) and 6.2.8.1(5) of EN 1993-1-8 [4].
- According to EN 1993-1-8 for the shear resistance also special elements such as block or bar shear connectors may be used, while for its design reference is made to EN 1992. But this is not explicitly covered in that document.

4. Concluding remarks

Column base plate connections are very often applied in practice. In the past (*several decennia ago*), the design of these connections was treated in the national Code for steel structures, with some reference to the national Code for concrete structures; at least that was the case in the Netherlands. A plastic design approach was applied. Steel failure had to be the governing failure mechanism, like in the *reinforced concrete technique*. With the enormous development of the *fastening technique* in the last decennia, connections between steel and concrete are more and more executed with short anchors, pre- or post-installed. Since concrete failure may also be governing in this technique, most attention is paid to an elastic approach. Looking at the European standards (Eurocodes 2 and 3 and CEN/TS 1992-4) that are developed in recent years, the authors are of the opinion that harmonization between these different documents could be better and still should be addressed. In that respect it is regarded to be advantageous for the structural engineer when there is a document addressing the full range of column base plate connections ranging from those loaded with high compressive loads till those were the compressive stresses are of secondary importance and the design is mainly governed by transfer of tensile stresses in the concrete foundation. Furthermore, the consequences of the introduction of forces from the connection into the concrete foundation should be better addressed. With the Dutch report for column base plate connections [1] the authors has attempted to make a first step in the described direction. Another example of a document where for base plate connections old knowledge originating from steel Codes is combined with more recent knowledge of fastenings, is [7], by the American Institute of Steel Construction.

References

1. Hordijk, D.A. and Stark, J.W.B., 'Column base plate connections; Recommendations for the design according to the Eurocodes', CUR/BmS-report 10, CURNET/Bouwen met Staal, 2009 (in Dutch).
2. Stark, J.W.B. and Hordijk, D.A., 'Where steel and concrete meet', in 'Connections between Steel and Concrete', Proceedings International Symposium, Stuttgart, 2001 (RILEM Publications S.A.R.L.) 1-10.
3. EN 1992-1-1: Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings, CEN, 2004.
4. EN 1993-1-8: Eurocode 3: Design of steel structures - Part 1-8: Design of joints, CEN, 2005.
5. CEN/TS 1992-4-..:2009, Design of fastenings for use in concrete, CEN TC 250.
   Part 4-1: General
   Part 4-2: Headed fasteners
   Part 4-3: Anchor channels
   Part 4-4: Post-installed fasteners - mechanical systems
   Part 4-5: Post-installed fasteners - chemical systems
6. Bouwman, L.P., Gresnigt, A.M. and Romeijn, A., Research into the connection of steel base plates to concrete foundations (in Dutch), Stevin Laboratory report 25.6.89.05/c6, Delft university of Technology, 1989.
7. Base plate and anchor rod design, American Institute of Steel Construction inc., Second Edition, 2006.