NCCI: Column base stiffness for global analysis

This document presents detailed classification of column base plates, determination of its rotational stiffness and recommendations for the structural analysis.

Contents

1. Introduction

The moment rotation behaviour of a column base is influenced by:

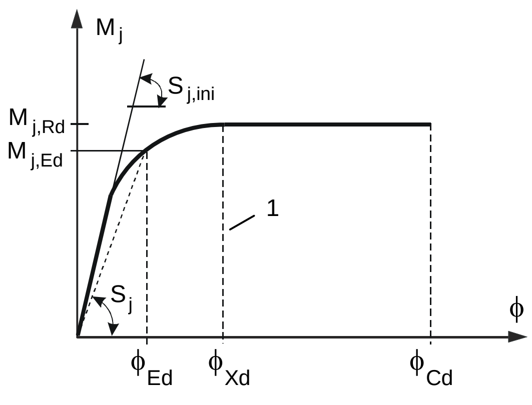
- The base plate
- Foundation stiffness
- Foundation – soil interaction
- Behaviour of the soil

Some of these influences are difficult to quantify and some will be beyond the influence and knowledge of the steelwork designer, e.g. soil behaviour.

After a general discussion on connection classification, this document presents three approaches for determining values of column base stiffness for practical global analysis. The first, empirical, approach provides simple conservative ways of recognising that all practical column base arrangements have some rotational stiffness in practice. The second presents a more detailed analysis of the response of the column base steelwork. The third introduces a method for taking account of the interaction between the foundation and the surrounding soil

2. Classification by stiffness

For the global analysis, account must be taken into the effects of the behaviour of the joints on the distribution of internal forces and moments within a structure and on the overall deformations of the structure. The information about the behaviour of the joint is provided by its design moment – rotation characteristic, see Figure 2.1.



Key: 1 = Limit for *S*j [1]

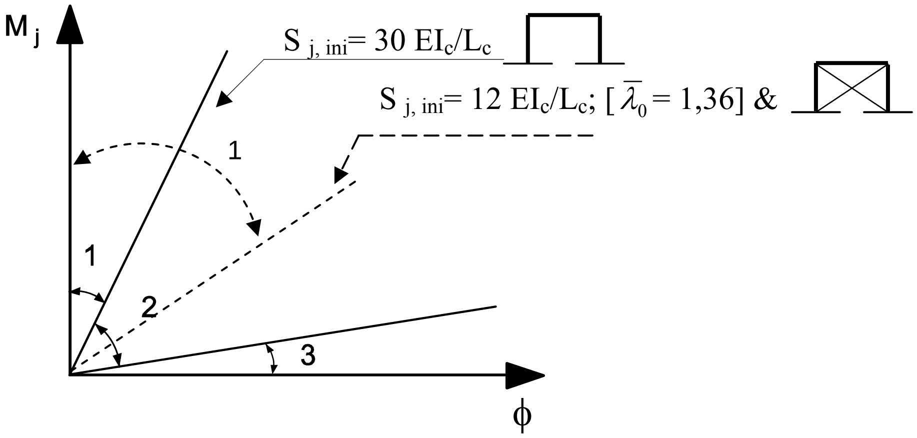
Figure 2.1 Design moment- rotation characteristic

The definition of the symbols and magnitudes related to column bases stiffness presented in the design moment – rotation characteristic (Figure 2.1) are described below:

- S_j : rotational stiffness, is the secant stiffness as indicated in Figure 2.1. For a design moment-rotation characteristic this definition of S_j applies up to the rotation ϕ_{Xd} at which $M_{j,Ed}$ first reaches $M_{j,Rd}$, but not for larger rotations.

- $S_{j,ini}$: initial rotational stiffness, is the slope of the elastic range of the design moment-rotation characteristic, see Figure 2.1

Column bases may be classified as rigid, nominally pinned or semi-rigid according to its rotational stiffness, by comparing its initial rotational stiffness $S_{j,ini}$ with the classification boundaries, see Figure 2.2.



Key: 1 = Rigid; 2 = Semi-rigid; 3 = Nominally pinned

Figure 2.2 Classification by stiffness [3]

EN 1993-1-8§5.2.2.5(2) provides the conditions that column bases must satisfy to be classified as rigid:

- in frames where the bracing system reduces the horizontal displacement by at least 80 % and where the effects of deformation may be neglected:
  - if $\bar{\lambda}_0 \leq 0{,}5$;
  - if $0{,}5 < \bar{\lambda}_0 < 3{,}93$ and $S_{j,ini} \geq 7\,(2\,\bar{\lambda}_0 - 1)\,EI_c / L_c$;
  - if $\bar{\lambda}_0 \geq 3{,}93$ and $S_{j,ini} \geq 48\,EI_c / L_c$ (*)
- otherwise if $S_{j,ini} \geq 30\,EI_c / L_c$

where:

$\bar{\lambda}_0$ is the slenderness of the column in which both ends are assumed to be pinned;

I_c is the second moment of area of the column;

L_c is the storey height of the column.

The limit (*) is a conservative approximation and can be used for all columns. The limiting stiffness $12\,E\,I_c / L_c$ may be used for braced frames for columns with a slenderness lower than $\bar{\lambda}_0 = 1{,}36$ [3], see Figure 2.2.

Similarly, conditions to classify a column base as a pinned joint could be defined. However few column bases are likely to have such a low initial stiffness. A nominally pinned column base should be capable of transmitting the internal forces without developing significant moments which might adversely affect the members or the structure as a whole. It should also have sufficient rotation capacity under the design loads. In practice a column base with a higher initial stiffness may be considered as a pinned joint, as long as the previously mentioned conditions are satisfied.

Semi-rigid column bases are those that do not meet the criteria to be classified as rigid or as nominally pinned. However, taking into account the previous considerations on pinned joints, most of the column bases which are not rigid will be treated as semi-rigid.

(a) (b)

Figure 2.3 (a) Nominally pinned column base and (b) rigid column base with stiffeners

NOTE: The use of stiffners for rigid column base plates is economical for small columns but the use of thicker unstiffened base plate lead to cost effective solutions by minimising fabrication costs.

3. Empirical Approach

In absence of detailed knowledge of the stiffness of the base, design may be based on the following assumptions [2]:

3.1 Nominally pinned column bases

The stiffness of a base with a pin or a rocker should be taken as zero.

If a column is nominally pin – connected to a foundation that is designed assuming that the base moment is zero, the base should be assumed to be pinned when using elastic global analysis to calculate the other moments and forces in the frame under ultimate limit state loading.

The stiffness of the base may be assumed to be equal to the following proportion of the column stiffness:

- 10% when checking frame stability or determining in – plane effective lengths.
- 20% when calculating deflections under serviceability loads.

NOTE: Column base plates with a thin base plate and four bolts are considered in some countries, e.g. Sweden, as pinned if they have sufficient deformation capacity, although in fact they have a semi – rigid behaviour.

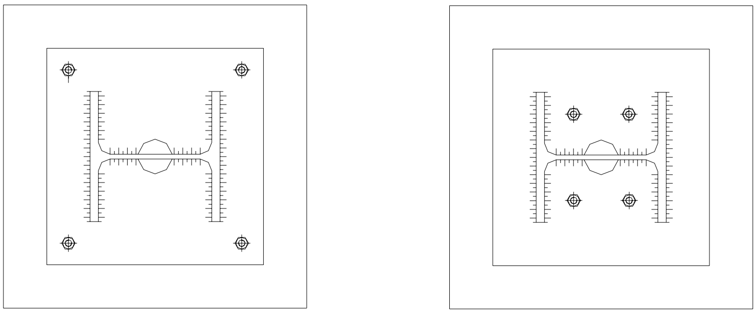


Figure 3.1 Examples of nominally pinned column bases.

3.2 Nominally rigid column bases

If a column is rigidly connected to a suitable foundation, the following recommendations should be adopted:

- Elastic – global analysis:

Ultimate Limit State calculations: stiffness of the base as equal to the stiffness of the column.

Service Limit State calculations: base can be treated as rigid to determine deflections under serviceability loads.

- Plastic – global analysis:

Any base moment capacity between zero and the plastic moment capacity of the column may be assumed, provided that the foundation is designed to resist a moment equal to this assumed moment capacity, together with the forces obtained from the analysis.

- Elastic - plastic – global analysis:

The assumed base stiffness must be consistent with the assumed base moment capacity, but should not exceed the stiffness of the column.

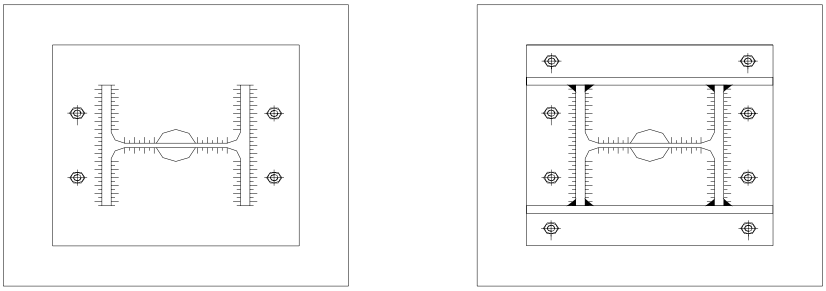


Figure 3.2 Examples of nominally rigid column bases

3.3 Nominally semi-rigid column bases

A nominal base stiffness of up to 20 % of the column may be assumed in elastic global analysis, provided that the foundation is designed for the moments and forces obtained from this analysis.

4. Column base stiffness determination

4.1 Determination procedure according to Eurocode

The influence of the support of the soil and the foundation is not covered in the EN 1993-1-8. Guidance for calculation of soil-structure interaction is given in the EN 1997.

The column bases stiffness determination can be calculated using the method given in EN 1993-1-8 §6.3.4:

$$S_{\mathrm{j}} = \frac{E z^2}{\mu (1/k_{\mathrm{T},1} + 1/k_{\mathrm{C,r}})} \frac{e}{e + e_{\mathrm{k}}}$$

where:

$$e = \frac{M_{Ed}}{N_{Ed}} = \frac{M_{Rd}}{N_{Rd}}$$

e_{k} to determine according the type of loading (see Table 6 11 and Table 6.12 of EN 1993-1-8)

k_{T} and k_{C} stiffness coefficient for basic joint component (see Table 6 11 and Table 6.12 of EN 1993-1-8);

z the lever arm, see Figure 4.1;

μ the stiffness ratio $S_{\mathrm{j,ini}}/S_{\mathrm{j}}$:

- if $M_{\mathrm{j,Ed}} \leq 2/3 \; M_{\mathrm{j,Rd}}$:
  $\mu = 1$
- if $2/3 \; M_{\mathrm{j,Rd}} < M_{\mathrm{j,Ed}} \leq M_{\mathrm{j,Rd}}$:
  $\mu = (1{,}5 M_{j,Ed} / M_{j,Rd})^{\Psi}$; for base plate connections $\psi = 2{,}7$

a) Column base connection in case of a dominant compressive normal force

b) Column base connection in case of a dominant tensile normal force

c) Column base connection in case of a dominant bending moment

d) Column base connection in case of a dominant bending moment

Figure 4.1 Determination of the lever arm z for column base connections [1]

4.2 Formulae for preliminary design

For preliminary design, the following formulas developed in [Steenhuis, 1999] & [3] may be adopted.

The estimation of the stiffness of the joint is based on the weakest component.

- ❑ Base plate rotational stiffness

$$S_{\mathrm{j,ini}} = \frac{E z^2 t_{\mathrm{fc}}}{20}$$

t_{fc} thickness of the base plate.

r lever arm, i.e. the distance between the anchor bolt and the flange subject to compression see Figure 4.2.

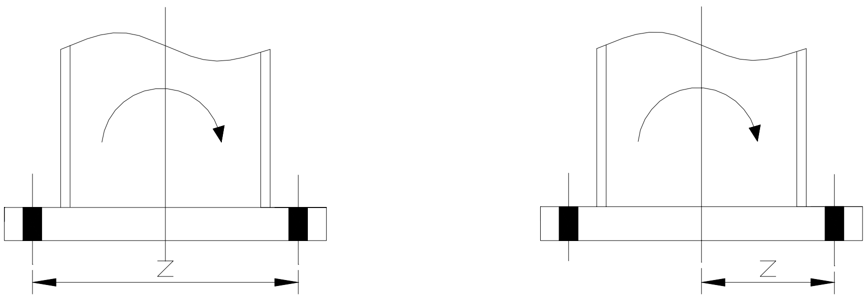


Figure 4.2 Definition of lever arm

5. Advanced design for soil-foundation interaction

In the introduction of this document, it has been settled that the moment rotation behaviour of a column base is influenced by the base plate, the foundation stiffness and the foundation – soil interaction and the behaviour of the soil

Although two latest issues might be far from the influence and knowledge of the steelwork designer, sometimes it could be necessary to estimate the rotation of a base. For that following it is presented a formula for the rotation estimation of a footing on an elastic base [4]:

$$\tan\theta = \frac{1-\mu^2}{E_s} \cdot \frac{M}{B^2 L} \cdot I_\theta$$

θ rotation of the base

μ soil parameter: Poisson's ratio

E_s soil parameter: modulus of elasticity

I_θ footing parameter: moment of inertia

B, L footing parameters: least lateral dimension and length

6. References

1 EN 1993 1-8: 2005
Eurocode 3: Design of steel structures. Part 1.8: Design of joints. CEN

2 BS 5950 - 1: 2000, *Structural use of steelwork in building. Code of practice for design. Rolled and welded sections,* BSI 2000.

3 CESTRUCO
Continuing Education in Structural Connections (www.fsv.cvut.cz/cestruco). Project funded by European Commision Leonardo da Vinci programme.

4 *Foundation analysis and design 5th edition*
J E Bowles. McGraw-Hill International Editions. Civil Engineering Series

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