

Lecture 7: ELEMENTS

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ELEMENTS

[Lecture 7.1 : Methods of Analysis of Steel Structures](#)

[Lecture 7.2 : Cross-Section Classification](#)

[Lecture 7.3 : Local Buckling](#)

[Lecture 7.4.1 : Tension Members I](#)

[Lecture 7.4.2 : Tension Members II](#)

[Lecture 7.5.1 : Columns I](#)

[Lecture 7.5.2 : Columns II](#)

[Lecture 7.6 : Built-up Columns](#)

[Lecture 7.7 : Buckling Lengths](#)

[Lecture 7.8.1 : Restrained Beams I](#)

[Lecture 7.8.2 : Restrained Beams II](#)

[Lecture 7.9.1 : Unrestrained Beams I](#)

[Lecture 7.9.2 : Unrestrained Beams II](#)

[Lecture 7.10.1 : Beam Columns I](#)

[Lecture 7.10.2 : Beam Columns II](#)

[Lecture 7.10.3 : Beam Columns III](#)

[Lecture 7.11 : Frames](#)

[Lecture 7.12 : Trusses and Lattice Girders](#)

Lecture 7.3: Local Buckling

SUMMARY: For members with Class 4 sections [1] the effect of local plate buckling on the overall member behaviour has to be taken into account. The buckling is allowed for by using effective cross-sections which assume parts of the gross cross-section are inactive. The rules for the determination of the effective cross-section and the design checks required are given.

1. INTRODUCTION

For members with Class 4 sections the effect of local buckling on global behaviour at the ultimate limit state is such that the elastic resistance, calculated on the assumption of yielding of the extreme fibres of the gross section (criteria for Class 3 sections), cannot be achieved.

Figure 1 gives the moment deflection curve for a point loaded beam (Class 4). The reason for the reduction in strength is that local buckling occurs at an early stage in parts of the compression elements of the member; the stiffness of these parts in compression is thereby reduced and the stresses are distributed to the stiffer edges, see Figure 2.

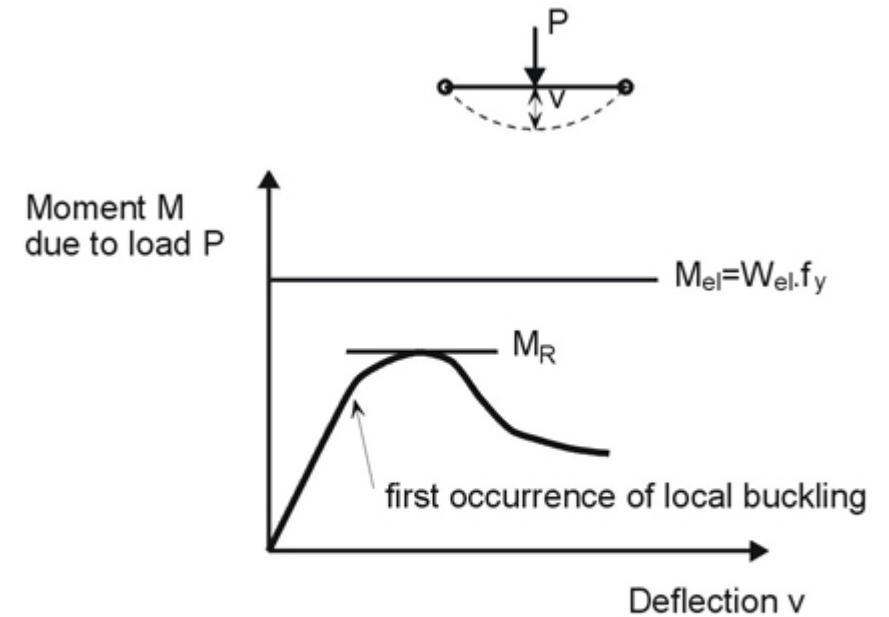


Figure 1 Moment - deflection curve of a point loaded beam

1. INTRODUCTION

To allow for the reduction in strength the actual non linear distribution of stress is taken into account by a linear distribution of stress acting on a reduced "effective plate width" leaving an "effective hole" where the buckle occurs, Figure 2.

By applying this model an "effective cross-section" is defined for which the resistance is then calculated as for Class 3 sections (by limiting the stresses in the extreme fibres to the yield strength).

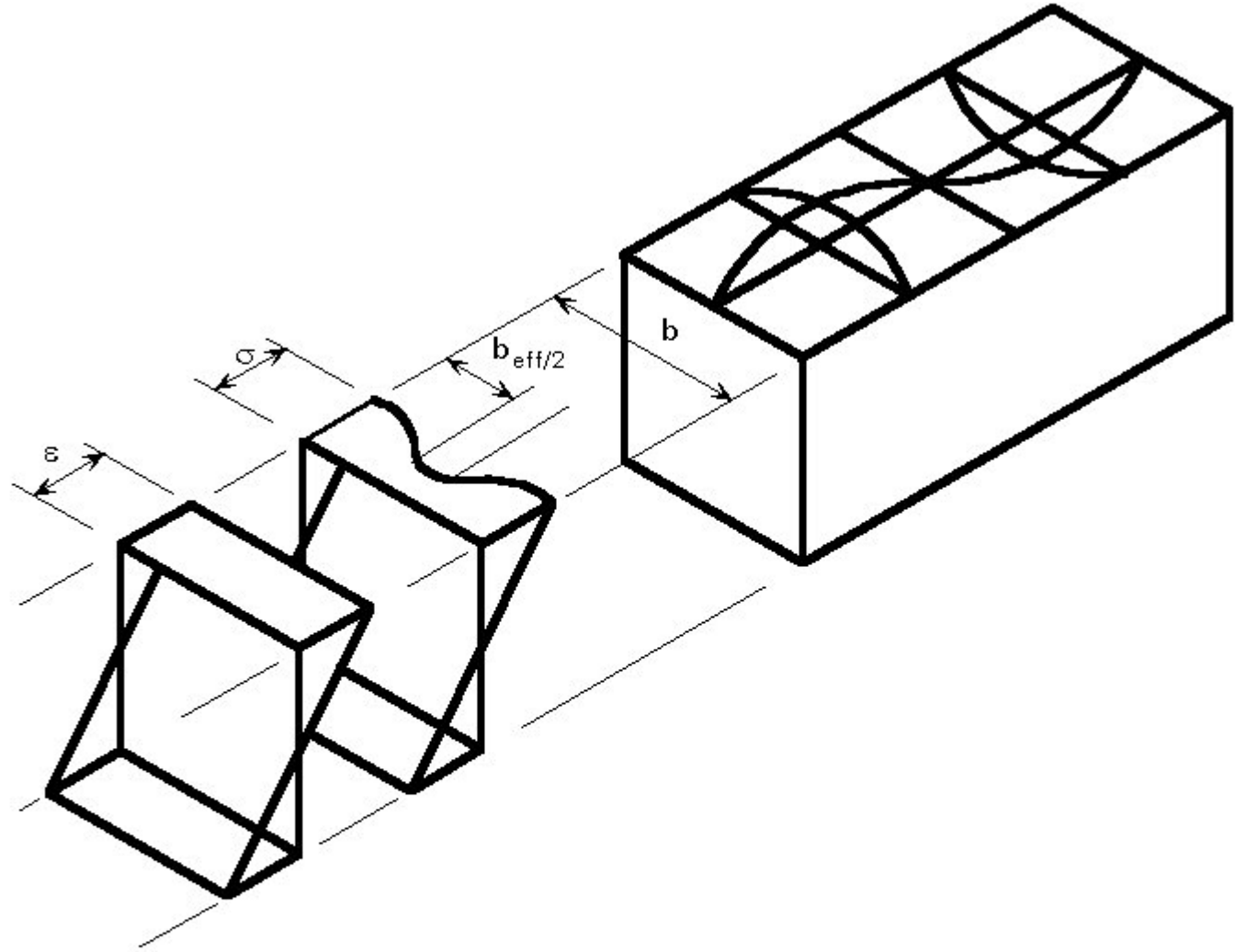


Figure 2 Strain and stress distribution in a member with local buckling of the deckplate in compression

2. DEFINITION OF THE "EFFECTIVE WIDTHS"

The effective widths b_{eff} are calculated on the basis of the Winter formula:

$$b_{\text{eff}} = \rho \cdot b$$

where the reduction coefficient ρ is dependent on the plate slenderness λ_p defined by linear plate buckling theory, as shown in Figure 3.

Figure 4 gives some examples of effective cross-sections for members in compression.

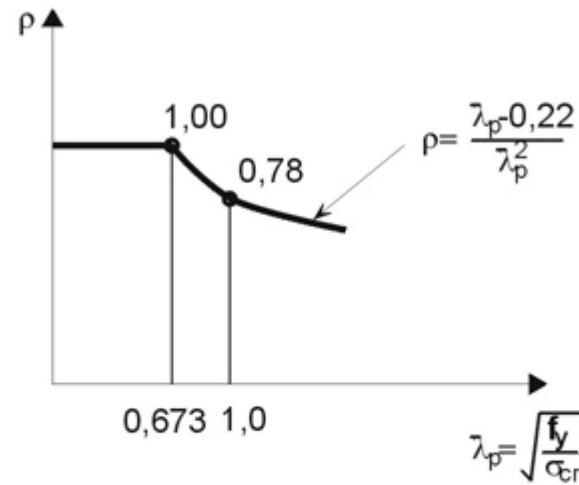


Figure 3 Reduction coefficient ρ for the effective width

No	Cross-section	Effective cross-section	$\bar{\lambda}_p$
1			$\frac{b}{t} \cdot \frac{1}{56,8}$ $\frac{h}{t} \cdot \frac{1}{56,8}$
2			$\frac{b}{t} \cdot \frac{1}{18,6}$ $\frac{h}{t} \cdot \frac{1}{56,8}$
3			$\frac{b_2}{t} \cdot \frac{1}{18,6}$ $\frac{h}{t} \cdot \frac{1}{56,8}$ $\frac{b_2}{t} \cdot \frac{1}{18,6}$

Figure 4 Effective cross - sections for members in compression

2. DEFINITION OF THE "EFFECTIVE WIDTHS"

For members in bending test results have shown that the effective widths may be determined on the basis of stress distributions calculated using the gross section modulus, W_{el} , even though the formation of "effective holes" in the compression parts will shift the neutral axis of the effective cross-section; an interactive process is not, therefore, necessary.

Figure 5 gives some examples of effective cross-sections for members in bending.

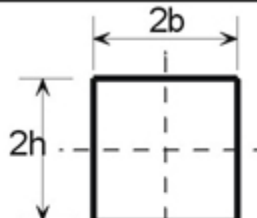
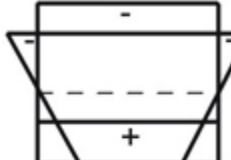
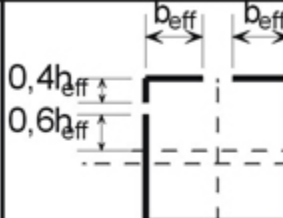
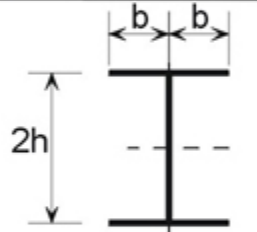
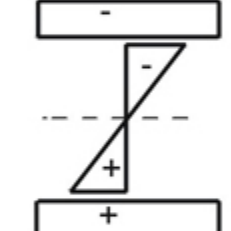
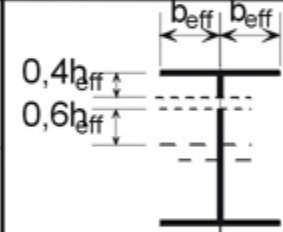

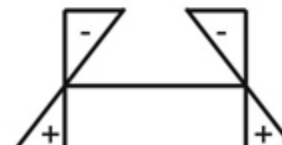

No	Cross-section	Gross-section stress distribution	Effective cross-section	γ_p
1				$\frac{b}{t} \cdot \frac{1}{56,8}$ $\frac{h}{t} \cdot \frac{1}{138,8}$
2				$\frac{b}{t} \cdot \frac{1}{18,6}$ $\frac{h}{t} \cdot \frac{1}{138,8}$
3				$\frac{h}{t} \cdot \frac{1}{21,4}$

Figure 5 Effective cross - sections for members in bending

3. DESIGN OF MEMBERS

3.1 Columns in Compression

As shown by the effective cross-sections 1 and 2, in Figure 4, the neutral axes of doubly-symmetrical cross-sections will not change with the formation of effective holes. Hence the compression load N_{sd} that is central to the gross cross-sections will also be central to the effective cross-section.

The column buckling design check, therefore, is based on the non-dimensional slenderness $\bar{\lambda} = \sqrt{\frac{N_{pe}}{N_{cr}}}$ where N_{cr} is calculated on the basis of the gross cross-section and N_{pl} is calculated using the effective cross-sectional area A_{eff} ($N_{pl} = A_{eff} \cdot f_y$).

The design buckling resistance is given by:

$$N_{bRd} = \chi \cdot N_{pl} / \gamma_M$$

where χ is the reduction factor for the relevant buckling curve.

For singly symmetrical cross-sections - type 3 in Figure 4 - or unsymmetrical cross-sections, the formation of effective holes may lead to a shift, e_N , in the neutral axes position. The compression load, N_{sd} , that is central to the gross cross-section will, therefore, be eccentric to the effective cross-section and hence will cause an additional bending moment $M = N_{sd} \cdot e_N$. The member is now a beam-column and must be checked in accordance with Section 3.3.

3. DESIGN OF MEMBERS

3.2 Beams in Bending

Beams must be checked using the section modulus determined for the effective cross-sections, as given in Figure 5. In general the attainment of the yield strength at the compression face will limit the design bending resistance of effective cross-sections:

$$M_{o,Rd} = W_{eff} \cdot f_y / \gamma_{M1}$$

For cross-sections similar to type 3 of Figure 5, W_{eff} will be determined for the actual edge (e):

$$W_{eff} = \frac{I_{eff}}{e}$$

and not the edge of the effective hole.

The lateral-torsional buckling check for beams is analogous to that for columns. The nondimensional Slenderness $\bar{\lambda}_{LT} = \sqrt{\frac{M_u}{M_{cr}}}$, is calculated with $M_u = W_{eff} \cdot f_y$ for the effective cross-section, and with M_{cr} calculated for the gross cross-sectional values. The design lateral-torsional buckling resistance is then given by:

$$M_{b,Rd} = \chi_{LT} \cdot M_u / \gamma_{M1}$$

where χ_{LT} is the reduction factor for the relevant buckling curve.

3. DESIGN OF MEMBERS

3.3 Beam-Columns

In the case of members that are subject to compression and monoaxial or biaxial bending (e.g. in the case of columns with monosymmetrical or unsymmetrical cross-sections) the design check is carried out using an interaction formula in which the checks for a centrally compressed column, for a beam with bending about the y-axis only, and for a beam with bending about the z-axis only, are combined.

If lateral-torsional buckling is prevented the interaction formula is as follows:

$$\frac{N_{sd}}{N_{bRd}} + \frac{k_y (M_{y,sd} + N_{sd} e_{Ny})}{M_{oy,Rd}} + \frac{k_z (M_{z,sd} + N_{sd} e_{Nz})}{M_{oz,Rd}} \leq 1$$

If lateral-torsional buckling can occur:

$$\frac{N_{sd}}{N_{bzRd}} + \frac{k_{LT} (M_{y,sd} + N_{sd} e_{Ny})}{M_{by,Rd}} + \frac{k_z (M_{y,sd} + N_{sd} e_{Nz})}{M_{oz,Rd}} \leq 1$$

where e_{Ny} or e_{Nz} are the eccentricities due to the shift of the neutral axis for compression only. The resistances N_{bRd} and $N_{bz,Rd}$ are related to the case of central compression; $M_{oy,Rd}$ and $M_{by,Rd}$ are related to bending about the y-axis only; and $M_{oz,Rd}$ is related to bending about the z-axis (weak axis) only.

4. CONCLUDING SUMMARY

- The design of members with Class 4 sections is carried out as for members with Class 3 sections (elastic analysis, elastic cross-sectional resistance limited by yielding in the extreme fibres) except that an effective cross-section (derived from gross sections with "effective holes", where buckles may occur) is used.
- The buckling checks for columns and the lateral-torsional buckling check for beams, requires the critical values, N_{cr} and M_{cr} , to be calculated using the gross cross-sectional data without considering "effective holes".
- In the case of columns with non-doubly symmetric cross-sections, the formation of "effective holes" may cause a shift in the neutral axis position resulting in eccentric compression and hence a beam-column problem.
- Beam-columns (compression and biaxial bending) are verified by using an interaction formula where the checks for the column in compression only, for the beam with bending about the y-axis only, and for the beam with bending about the z-axis only, are combined.

5. REFERENCES

[1] "Eurocode 3: "Design of steel structures" ENV 1993-1-1: Part 1.1, General rules and rules for buildings, CEN, 1992.

6. ADDITIONAL READING

1. "Eurocode 3: Part 1.3: "Cold formed thin gauge members and sheeting", CEN.
2. Eurocode 3: Background Document 5.5. (Justification of the design resistances, for buckling verifications)