Section 8 Members subject to combined actions

8.1 General

A member subject to combined axial and bending actions shall be proportioned so that its design actions specified in Clause 8.2, in combination with the nominal section and member capacities (see Sections 5, 6 and 7), satisfy Clauses 8.3 and 8.4. For plastic design (see Clause 4.5), only the requirements of Clause 8.4.3 need to be satisfied.

Eccentrically loaded double-bolted or welded angles in trusses shall be proportioned to satisfy Clause 8.3, and either Clause 8.4.5 or Clause 8.4.6.

8.2 Design actions

For checking the section capacity at a section, the design axial force (N^*), which may be tension or compression, shall be the force at the section, and the design bending moments (M_x^*, M_y^*) shall be the bending moments at the section about the major *x*- and minor *y*-principal axes, respectively.

For checking the member capacity, the design axial force (N^*) shall be the maximum axial force in the member, and the design bending moments (M_x^*, M_y^*) shall be the maximum bending moments in the member.

M_x^*, M_y^* are the design bending moments resulting from frame action and transverse loading on the member, and include the second order design bending moments resulting from the design loads acting on the structure and its members in their displaced and deformed configuration.

The design bending moments (M_x^*, M_y^*) shall be determined from one of the following methods of analysis:

(a) *First-order linear elastic analysis* — By modifying the first-order design bending moments, by using the appropriate moment amplification factors determined in accordance with Clause 4.4.2.

(b) *Second-order elastic analysis* — In which the design bending moments (M^*) are obtained either directly, or by modifying the second-order end moments by using the moment amplification factors determined in accordance with Appendix E.

(c) *First-order plastic analysis* — In which the design bending moments (M^*) are obtained directly for frames where the elastic buckling load factor (λ_c) satisfies $\lambda_c \geq 5$ and the requirements of Clause 4.5.4 are satisfied.

(d) *Second-order plastic analysis* — In which the design bending moments (M^*) are obtained directly for frames where the elastic buckling load factor (λ_c) satisfies $\lambda_c < 5$.

(e) *Advanced structural analysis* — In which the design bending moments (M_x^* or M_y^*) are obtained directly in accordance with Appendix D, in which case only the section capacity requirements of Clause 8.3 and the connection requirements of Section 9 need to be satisfied.

8.3 Section capacity

8.3.1 General

The member shall satisfy Clauses 8.3.2, 8.3.3 and 8.3.4, as appropriate:

(a) For bending about the major principal *x*-axis only, sections at all points along the member shall have sufficient capacity to satisfy Clause 8.3.2.

(b) For bending about the minor principal y-axis only, sections at all points along the member shall have sufficient capacity to satisfy Clause 8.3.3.

(c) For bending about a non-principal axis, or bending about both principal axes, sections at all points along the member shall have sufficient capacity to satisfy Clause 8.3.4.

In this Section —

M_{sx}, M_{sy} = nominal section moment capacities about the x- and y-axes respectively, determined in accordance with Clause 5.2

N_s = nominal section axial load capacity determined in accordance with Clause 6.2 for axial compression, or Clause 7.2 for axial tension (for which N_s equals N_t).

8.3.2 Uniaxial bending about the major principal *x*-axis

Where uniaxial bending occurs about the major principal x-axis, the following shall be satisfied:

$$M_x^* \leq \phi M_{rx}$$

where

ϕ = capacity factor (see Table 3.4)

M_{rx} = nominal section moment capacity, reduced by axial force (tension or compression)

$$= M_{sx}\left(1 - \frac{N^*}{\phi N_s}\right)$$

Alternatively, for doubly symmetric I-sections and rectangular and square hollow sections to AS/NZS 1163, which are compact as defined in Clause 5.2.3, M_{rx} may be calculated by one of the following:

(a) For compression members where k_f is equal to 1.0 and for tension members —

$$M_{rx} = 1.18 M_{sx}\left(1 - \frac{N^*}{\phi N_s}\right) \leq M_{sx}$$

(b) For compression members where k_f is less than 1.0 —

$$M_{rx} = M_{sx}\left(1 - \frac{N^*}{\phi N_s}\right)\left[1 + 0.18\left(\frac{82 - \lambda_w}{82 - \lambda_{wy}}\right)\right] \leq M_{sx}$$

λ_w and λ_{wy} are the values of λ_e and λ_{ey} for the web (see Clause 6.2.3 and Table 6.2.4).

8.3.3 Uniaxial bending about the minor principal *y*-axis

Where uniaxial bending occurs about the minor principal y-axis, the design bending moment (M_y^*) about the minor principal y-axis shall satisfy —

$$M_y^* \leq \phi M_{ry}$$

where

ϕ = capacity factor (see Table 3.4)

M_{ry} = nominal section moment capacity, reduced by the axial tensile or compressive force

$$= M_{sy}\left[1 - \frac{N^*}{\phi N_s}\right]$$

Alternatively, M_{ry} may be calculated by one of the following:

(a) For doubly symmetric I-sections which are compact, as defined in Clause 5.2.3 —

$$M_{ry} = 1.19 M_{sy}\left[1 - \left(\frac{N^*}{\phi N_s}\right)^2\right] \le M_{sy}$$

(b) For rectangular or square hollow sections to AS/NZS 1163 which are compact, as defined in Clause 5.2.3 —

$$M_{ry} = 1.18 M_{sy}\left[1 - \left(\frac{N^*}{\phi N_s}\right)\right] \le M_{sy}$$

8.3.4 Biaxial bending

Where biaxial bending occurs, the design tensile or compressive force (N^*) and the design bending moments (M_x^*) and (M_y^*) about the major principal x-axis and minor principal y-axis shall satisfy —

$$\frac{N^*}{\phi N_s} + \frac{M_x^*}{\phi M_{sx}} + \frac{M_y^*}{\phi M_{sy}} \le 1$$

Alternatively, for doubly symmetric I-sections and rectangular and square hollow sections to AS/NZS 1163, which are compact as defined in Clause 5.2.3, sections at all points along the member shall satisfy —

$$\left(\frac{M_x^*}{\phi M_{rx}}\right)^{\gamma} + \left(\frac{M_y^*}{\phi M_{ry}}\right)^{\gamma} \le 1$$

where M_{rx} and M_{ry} shall be calculated in accordance with Clauses 8.3.2 and 8.3.3 respectively, and

$$\gamma = 1.4 + \left(\frac{N^*}{\phi N_s}\right) \le 2.0$$

8.4 Member capacity

8.4.1 General

The member shall satisfy Clauses 8.4.2, 8.4.3 and 8.4.4, as appropriate:

(a) For a member bent about the major principal x-axis only and where there is sufficient restraint to prevent lateral buckling, or for a member bent about the minor principal y-axis only, the member shall satisfy the in-plane requirements of Clause 8.4.2 for a frame analysed elastically, or Clause 8.4.3 for a frame analysed plastically.

(b) For a member bent about the major principal x-axis only and with insufficient restraint to prevent lateral buckling, the member shall satisfy both the in-plane requirements of Clause 8.4.2 and out-of-plane requirements of Clause 8.4.4.

(c) For a member bent about a non-principal axis, or bent about both principal axes, the member shall satisfy the biaxial bending requirements of Clause 8.4.5.

8.4.2 In-plane capacity — Elastic analysis

8.4.2.1 Application

This Clause applies to a member analysed using an elastic method in accordance with Clause 4.4, or to a member in a statically determinate structure.

8.4.2.2 Compression members

A member bent about a principal axis shall have sufficient in-plane capacity to satisfy the following:

$$M^* \leq \phi M_i$$

where

M^* = design bending moment about the principal axis

ϕ = capacity factor (see Table 3.4)

M_i = nominal in-plane member moment capacity

$$= M_s\left(1 - \frac{N^*}{\phi N_c}\right)$$

M_s = nominal section moment capacity determined in accordance with Clause 5.2 for bending about the same principal axis as the design bending moment

N^* = design axial compressive force

N_c = nominal member capacity in axial compression determined in accordance with Clause 6.3 for buckling about the same principal axis, with the effective length factor (k_e) taken as 1.0 for both braced and sway members, unless a lower value is calculated for braced members from Clause 4.6.3.2, 4.6.3.3 or Clause 4.6.3.5, provided Clause 6.1 is satisfied for N_c calculated using l_e determined in accordance with Clause 4.6.3

Alternatively, for doubly symmetric I-sections and rectangular and square hollow sections to AS/NZS 1163, which are compact as defined in Clause 5.2.3, and where the form factor (k_f) determined in accordance with Clause 6.2.2 is unity, M_i may be calculated as follows:

$$M_i = M_s\left\{\left[1 - \left(\frac{1+\beta_m}{2}\right)^3\right]\left(1 - \frac{N^*}{\phi N_c}\right) + 1.18\left(\frac{1+\beta_m}{2}\right)^3\sqrt{\left(1 - \frac{N^*}{\phi N_c}\right)}\right\}$$

$$\leq M_{rx} \text{ or } M_{ry} \text{ as appropriate}$$

where

β_m = ratio of the smaller to the larger end bending moment, taken as positive when the member is bent in reverse curvature for members without transverse load, or

= value determined in accordance with Clause 4.4.2.2 for members with transverse load

M_{rx} or M_{ry} = nominal section moment capacity about the appropriate principal axis determined in accordance with Clause 8.3

8.4.2.3 Tension members

A member subject to a design axial tensile force (N^*) and a design bending moment (M^*) shall satisfy Clause 8.3.

8.4.3 In-plane capacity — Plastic analysis

8.4.3.1 Application

This Clause applies only to compact doubly symmetric I-section members. When the distribution of moments in a frame is determined using a plastic method of analysis in accordance with Clause 4.5, then the design axial compressive force (N^*) in any member of the frame which is assumed to contain a plastic hinge shall satisfy the member slenderness requirements of Clause 8.4.3.2, and the web slenderness requirements of Clause 8.4.3.3.

The design plastic moment capacity reduced by axial force (tension or compression) for compact doubly symmetric I-sections shall be as specified in Clause 8.4.3.4.

8.4.3.2 Member slenderness

The design axial compressive force (N^*) in every member assumed to contain a plastic hinge shall satisfy the following:

$$\frac{N^*}{\phi N_s} \le \left[\frac{0.60 + 0.40\beta_m}{\sqrt{(N_s / N_{ol})}}\right]^2 \quad \text{when } \frac{N^*}{\phi N_s} \le 0.15,$$

and

$$\frac{N^*}{\phi N_s} \le \frac{1 + \beta_m - \sqrt{(N_s / N_{ol})}}{1 + \beta_m + \sqrt{(N_s / N_{ol})}} \quad \text{when } \frac{N^*}{\phi N_s} > 0.15,$$

where

β_m = ratio of the smaller to the larger end bending moment, taken as positive when the member is bent in reverse curvature

N_s = nominal section capacity in axial compression determined in accordance with Clause 6.2

N_{ol} = $\dfrac{\pi^2 EI}{l^2}$

I = second moment of area for a the axis about which the design moment acts

l = actual length of the member

A member for which —

$$\frac{N^*}{\phi N_s} > 0.15, \text{ and}$$

$$\frac{N^*}{\phi N_s} > \frac{1 + \beta_m - \sqrt{(N_s / N_{ol})}}{1 + \beta_m + \sqrt{(N_s / N_{ol})}}$$

shall not contain plastic hinges, although it shall be permissible to design the member as an elastic member in a plastically analysed structure to satisfy the requirements of Clause 8.4.2.

8.4.3.3 Web slenderness

The design axial compressive force (N^*) in every member assumed to contain a plastic hinge shall satisfy the following:

(a) For webs where $45 \le \frac{d_1}{t}\sqrt{\left(\frac{f_y}{250}\right)} \le 82$ —

$$\frac{N^*}{\phi N_s} \le 0.60 - \left[\frac{d_1}{t}\frac{\sqrt{(f_y / 250)}}{137}\right]$$

(b) For webs where $25 < \frac{d_1}{t}\sqrt{\left(\frac{f_y}{250}\right)} < 45$ —

$$\frac{N^*}{\phi N_s} \le 1.91 - \left[\frac{d_1}{t}\frac{\sqrt{(f_y / 250)}}{27.4}\right] \le 1.0$$

(c) For webs where $0 \le \frac{d_1}{t}\sqrt{\left(\frac{f_y}{250}\right)} \le 25$ —

$$\frac{N^*}{\phi N_s} \le 1.0$$

Members which have webs for which $(d_1/t)\sqrt{(f_y/250)}$ exceeds 82 shall not contain plastic hinges, although it shall be permissible to design such a member as an elastic member in a plastically analysed structure to satisfy the requirements of Clause 8.4.2.

8.4.3.4 Plastic moment capacity

The design plastic moment capacity (ϕM_{pr}) reduced for axial force (tension or compression) shall be calculated as follows:

(a) For members bent about the major principal x-axis —

$$\phi M_{prx} = 1.18\phi M_{sx}\left(1 - \frac{N^*}{\phi N_s}\right) \le \phi M_{sx}$$

(b) For members bent about the minor principal y-axis —

$$\phi M_{pry} = 1.19\phi M_{sy}\left[1 - \left(\frac{N^*}{\phi N_s}\right)^2\right] \le \phi M_{sy}$$

where M_{sx} and M_{sy} are the nominal section moment capacities determined in accordance with Clauses 5.2.1 and 5.2.3.

8.4.4 Out-of-plane capacity

8.4.4.1 Compression members

A member subject to a design axial compressive force (N^*) and a design bending moment (M_x^*) about its major principal x-axis, and which may buckle laterally, shall satisfy Clause 8.4.2 and also the following:

$$M_x^* \leq \phi M_{ox}$$

where

ϕ = capacity factor (see Table 3.4)

M_{ox} = nominal out-of-plane member moment capacity

$$= M_{bx}\left(1 - \frac{N^*}{\phi N_{cy}}\right)$$

M_{bx} = the nominal member moment capacity of the member without full lateral restraint and bent about the major principal x-axis, determined in accordance with Clause 5.6 using a moment modification factor (α_m) appropriate to the distribution of design bending moment along the member

N_{cy} = the nominal member capacity in axial compression, determined in accordance with Clause 6.3 for buckling about the minor principal y-axis

Alternatively, for members without transverse loads which are of compact doubly symmetric I-section (see Clause 5.2.3), are fully or partially restrained at both ends, and have a form factor (k_f) of unity determined in accordance with Clause 6.2.2, M_{ox} may be calculated as follows:

$$M_{ox} = \alpha_{bc} M_{bxo} \sqrt{\left[\left(1 - \frac{N^*}{\phi N_{cy}}\right)\left(1 - \frac{N^*}{\phi N_{oz}}\right)\right]} \leq M_{rx}$$

where

$$\frac{1}{\alpha_{bc}} = \frac{1-\beta_m}{2} + \left(\frac{1+\beta_m}{2}\right)^3 \left(0.4 - 0.23\frac{N^*}{\phi N_{cy}}\right)$$

M_{bxo} = nominal member moment capacity without full lateral restraint and with a uniform distribution of design bending moment so that α_m is unity, determined in accordance with Clause 5.6

N_{cy} = nominal member capacity in axial compression, determined in accordance with Clause 6.3 for buckling about the minor principal y-axis

β_m = ratio of the smaller to the larger end bending moment, taken as positive when the member is bent in reverse curvature

N_{oz} = nominal elastic torsional buckling capacity of the member, calculated as follows:

$$N_{oz} = \frac{GJ + \left(\pi^2 EI_w / l_z^2\right)}{\left(I_x + I_y\right)/A}$$

E, G = elastic moduli

A, I_w, I_x, I_y and J = section constants

l_z = distance between partial or full torsional restraints

NOTE Values of E and G, and expressions for I_w and J are given in Appendix H.

8.4.4.2 Tension members

A member subject to a design axial tensile force (N^*) and a design bending moment (M_x^*) about its major principal x-axis, and which may buckle laterally, shall satisfy the following:

$$M_x^* \leq \phi M_{ox}$$

where

ϕ = capacity factor (see Table 3.4)

M_{ox} = nominal out-of-plane member moment capacity

= $M_{bx}\left(1 + \dfrac{N^*}{\phi N_t}\right) \leq M_{rx}$

M_{bx} = nominal member moment capacity defined in Clause 8.4.4.1

N_t = nominal section capacity in axial tension determined in accordance with Clause 7.2

M_{rx} = nominal section moment capacity reduced by axial force determined in accordance with Clause 8.3.2

8.4.5 Biaxial bending capacity

8.4.5.1 Compression members

A member subject to a design axial compressive force (N^*) and design bending moments (M_x^*) and (M_y^*) about the major x- and minor y- principal axes respectively shall satisfy the following:

where

ϕ = capacity factor (see Table 3.4)

M_{cx} = lesser of the nominal in-plane member moment capacity (M_{ix}) and the nominal out-of-plane member moment capacity (M_{ox}) for bending about the major principal x-axis, determined in accordance with Clauses 8.4.2 and 8.4.4 respectively

M_{iy} = nominal in-plane member moment capacity, determined in accordance with Clause 8.4.2, for bending about the minor principal y-axis

8.4.5.2 Tension members

A member subject to a design axial tensile force (N^*) and design bending moments (M_x^*) and (M_y^*) about the major x- and minor y- principal axes respectively shall satisfy the following:

$$\left(\frac{M_x^*}{\phi M_{cx}}\right)^{1.4} + \left(\frac{M_y^*}{\phi M_{iy}}\right)^{1.4} \leq 1$$

where

ϕ = capacity factor (see Table 3.4)

M_{tx} = lesser of the nominal section moment capacity (M_{rx}) reduced by axial tension and the nominal out-of-plane member moment capacity (M_{ox}) determined in accordance with Clauses 8.3.2 and 8.4.4.2 respectively

M_{ry} = nominal section moment capacity reduced by axial tension, determined in accordance with Clause 8.3.3

8.4.6 Eccentrically loaded double bolted or welded single angles in trusses

A member subject to a design axial tensile force (N^*) and design bending moments (M_x^*) and (M_y^*) about the major x- and minor y-principal axes respectively shall satisfy the following:

$$\left(\frac{M_x^*}{\phi M_{tx}}\right)^{1.4} + \left(\frac{M_y^*}{\phi M_{ry}}\right)^{1.4} \leq 1$$

where

N^* = design axial compression force in the member

M_h^* = design bending moment acting about the rectangular h-axis parallel to the loaded leg

ϕ = capacity factor (see Table 3.4)

N_{ch} = nominal member capacity in axial compression, determined in accordance with Clause 6.3, of a single angle compression member buckling with l_e equals l about the rectangular h-axis parallel to the loaded leg

M_{bx} = nominal member capacity, determined in accordance with Clause 5.6, for an angle without full lateral support, bent about the major principal x-axis using a factor α_m appropriate to the distribution of design bending moment along the member

α = angle between x- and h-axes

For equal leg angles, where $l/t \leq (210 + 175\beta_m)(250/f_y)$, M_{bx} may be taken as M_{sx},

where

M_{sx} = nominal section moment capacity about the x-principal axis, determined in accordance with Clause 5.2

l = member length

t = thickness of the angle

For other equal leg angles, M_{bx} may be determined by using Clause 5.6.1.1 with —

$$M_o = \left(\frac{525t}{l}\right)\left(\frac{250}{f_y}\right)M_s$$

The design end bending moment (M_h^*) shall be calculated from a rational elastic analysis of the truss, or shall be taken as not less than N^*e, resulting from the out-of-plane eccentricity (e) of the design axial force (N^*) in the member,

where

$e \quad = \quad \left(c_h - \frac{t}{2}\right)$, for angles on the same side of the truss chord

$\quad = \quad \left(e_c + e_t\right)$, for angles on opposite sides of the truss chord

(see Figure 8.4.6).

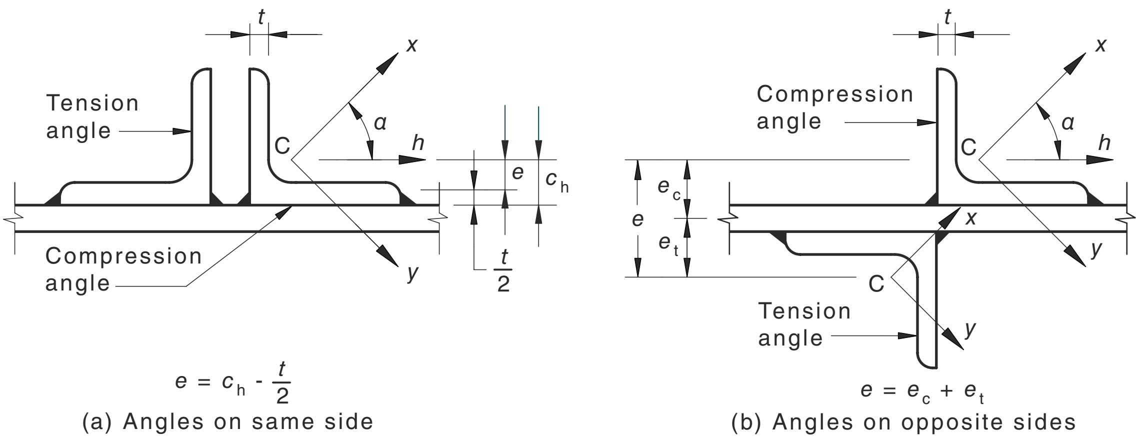

Figure 8.4.6 — Single angles loaded through one leg