Basic principles of steel structures

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Compression members

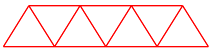
Outlines

Compression members

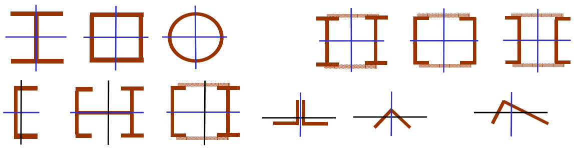
introduction

☑ Compression members in structures

- truss members
- bracing
- pinned columns



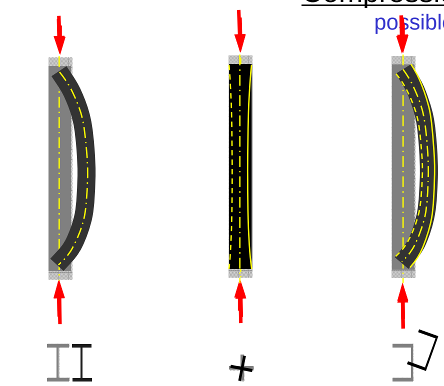
☑ Structural shapes used in compression members



- doubly symmetric cross-section
- singly symmetric cross-section
- unsymmetric cross-section

Compression members

possible buckling mode



flexural buckling | torsional buckling | flexural torsional buckling

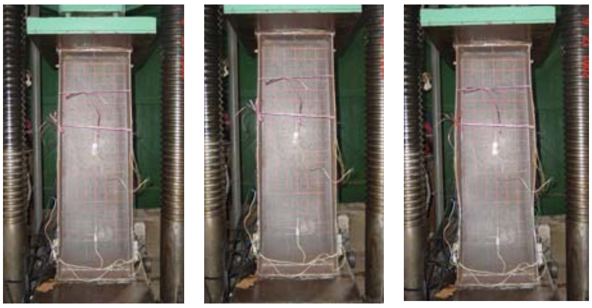
Compression members

global buckling of members

Compression members

local buckling of plates

Compression members
local buckling of plates



Compression members
resistance of cross section

☑ Resistance of cross section for compression members

- same as tension members, but no fracture
- no need to check if no large hole existence

$$N_u = A_n f_y$$

☑ Design equation in design code

$$N \le A_n f_d,\quad f_d = f_y/\gamma_R,\ \text{or}\ \ f_d = f_y/K$$

$$\Rightarrow\quad \sigma = \frac{N}{A_n} \le f_d$$

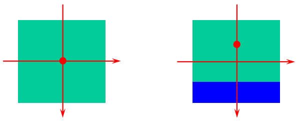
Overall stability of solid-web compression members
concept of ideal compression member

☑ Ideal compression member

perfectly centrally loaded straight member

☑ Definition (or assumption) of ideal compression member

- center of figure (centroid) always coincides with its barycenter



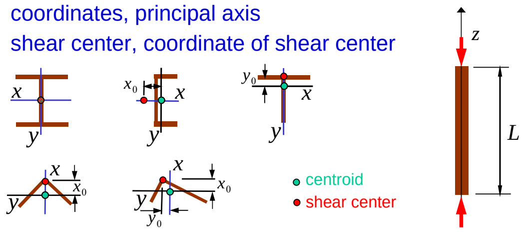
- the member axis is perfectly straight
- perfectly centrally loaded member
  (axis of force always coincides with member axis)

Overall stability of solid-web compression members
differential equation of elastic buckling for ideal member (1)

$$EI_x v^{IV} + Nv'' - Nx_0\theta'' = 0$$
$$EI_y u^{IV} + Nu'' - Ny_0\theta'' = 0$$
$$EI_\omega \theta^{IV} - GI_t\theta'' - Nx_0 v'' + Ny_0 u'' + (Nr_0^2 - \overline{R})\theta'' = 0$$

☑ coordinates, principal axis

☑ shear center, coordinate of shear center



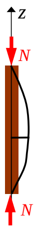
Overall stability of solid-web compression members
differential equation of elastic buckling for ideal member (2)

☑ simultaneous differential equation

$$EI_x v^{IV} + Nv'' - Nx_0\theta'' = 0$$
$$EI_y u^{IV} + Nu'' - Ny_0\theta'' = 0$$
$$EI_\omega \theta^{IV} - GI_t\theta'' - Nx_0 v'' + Ny_0 u'' + (Nr_0^2 - \overline{R})\theta'' = 0$$

effect of actions

reaction or resistance

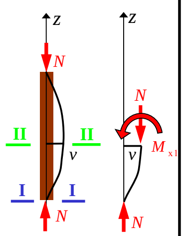


☑ global buckling mode (deformation)

- involves flexural and torsional buckling mode
- small deformation, but must be considered
- fixed peripheral shape
- second-order nonlinear analysis: equilibrium in a deflected position

Overall stability of solid-web compression members
differential equation of elastic buckling for ideal member (3)

$$EI_x v^{IV} + Nv'' - Nx_0\theta'' = 0$$
$$EI_y u^{IV} + Nu'' - Ny_0\theta'' = 0$$
$$EI_\omega \theta^{IV} - GI_t\theta'' - Nx_0 v'' + Ny_0 u'' + (Nr_0^2 - \overline{R})\theta'' = 0$$



☑ Equilibrium in flexural mode

- effect of action (1): deflection in y-direction

  equilibrium while bending: $M_{x1} = Nv$

- effect of action (2): rotation of centroid

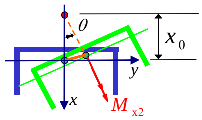
  moment generated due to offset of axial force after the centroid rotating about shear center:

  $$M_{x2} \approx -Nx_0\theta$$

- equilibrium in flexural mode

  $$EI_x v'' = -(M_{x1} + M_{x2})$$

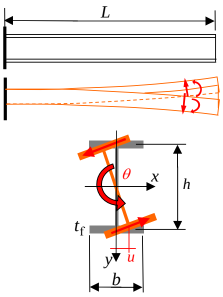
x_0 is negative in this system



Overall stability of solid-web compression members
differential equation of elastic buckling for ideal member (4)

$$EI_x v^{IV} + Nv'' - Nx_0\theta'' = 0$$
$$EI_y u^{IV} + Nu'' - Ny_0\theta'' = 0$$
$$EI_\omega\theta^{IV} - GI_t\theta'' - Nx_0 v'' + Ny_0 u'' + (Nr_0^2 - \overline{R})\theta'' = 0$$

Example:
cantilevered I-shape beam
under end torsional moment

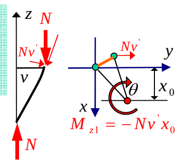


☑ restrained torsion and warping

$$u = 0.5h\theta$$
$$\phi_y = u'' = 0.5h\theta''$$
$$M_y = -EI_y u'' = -0.5EI_y h\theta''$$
$$V_y = dM/dz = -0.5EI_y h\theta'''$$
$$M_\omega = V_y h = -0.5EI_y h^2\theta'''$$
$$I_\omega = 0.5I_y h^2 \approx b^3 t_f h^2/24$$
$$M_\omega = -EI_\omega\theta''' \qquad M_k = GI_t\theta'$$
$$M_\omega + M_k = M_T$$

Overall stability of solid-web compression members
differential equation of elastic buckling for ideal member (5)

$$EI_x v^{IV} + Nv'' - Nx_0\theta'' = 0$$
$$EI_y u^{IV} + Nu'' - Ny_0\theta'' = 0$$
$$EI_\omega\theta^{IV} - GI_t\theta'' - Nx_0 v'' + Ny_0 u'' + (Nr_0^2 - \overline{R})\theta'' = 0$$



☑ Equilibrium in torsional mode

- effect of action (1): bending of axis

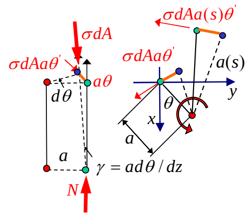
  moment generated: $-Nv'x_0, \ Nu'y_0$

- effect of action (2): longitudinal stress and residual stress

$$\sigma dAa(s)\theta' \cdot a(s) \Rightarrow \theta'\int a(s)^2\sigma dA \Rightarrow Nr_0^2\theta'$$
$$r_0^2 = \frac{I_x + I_y}{A} + x_0^2 + y_0^2$$
$$\theta'\int a(s)^2\sigma_r dA \Rightarrow \theta'\overline{R}$$

- equilibrium in torsional mode

$$M_\omega + M_k = M_T$$



Overall stability of solid-web compression members
critical load of ideal member with doubly symmetric section

☑ critical buckling load

$$EI_x v^{IV} + Nv'' - Nx_0\theta'' = 0 \;\Rightarrow\; EI_x v'' + Nv = 0$$
$$\Rightarrow\; N_{Ex} = \pi^2 EI_x / L_{ox}^2 = \pi^2 EA(I_x/A)/L_{ox}^2 = \pi^2 EA/\lambda_x^2$$

similarly $\Rightarrow$ $N_{Ey} = \pi^2 EI_y/L_{oy}^2 = \pi^2 EA/\lambda_y^2$

$$N_{E\theta} = (\pi^2 EI_\omega/L_{o\theta}^2 + GI_t + \overline{R})/r_0^2 = \pi^2 EA/\lambda_\theta^2$$

Each equation only has one unknown variable and can be solved separately, indicating that those three buckling modes are independent from each other.

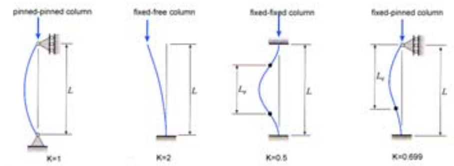
$$\lambda_x = \frac{l_{ox}}{i_x} = \frac{l_{ox}}{\sqrt{I_x/A}} \qquad \lambda_y = \frac{l_{oy}}{i_y} = \frac{l_{oy}}{\sqrt{I_y/A}} \qquad \lambda_\theta = \frac{l_{o\theta}}{\sqrt{\frac{I_w}{Ar_o^2} + \frac{l_{o\theta}^2}{\pi^2}\cdot\frac{GI_t + \overline{R}}{EAr_o^2}}}$$

Which critical load among these three will be the dominant one?

Overall stability of solid-web compression members
critical load of ideal member with doubly symmetric section

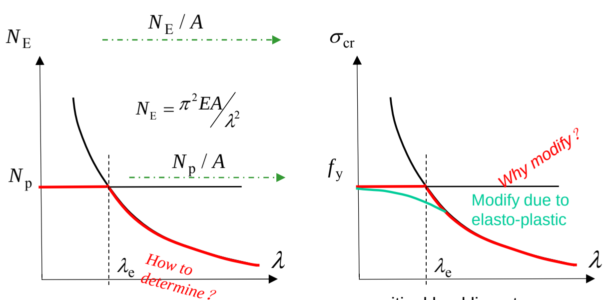
☑ Effective length factor for different end constraint

- End constraint: bending and torsional deformation
- Constraint types: free end, pinned, fixed end
- Effective length factor: Table 5-4 in page 101



☑ How about the critical stress? $\sigma_E = N_E/A = \pi^2 E/\lambda^2$

Overall stability of solid-web compression members
relationships: critical load, critical stress and slenderness



critical buckling load vs. slenderness

critical buckling stress vs. slenderness

Overall stability of solid-web compression members
critical load of ideal member with singly symmetric section

☑ decouple one of the simultaneous differential equation
(x-axis is axis of symmetry)

$$EI_x v^{IV} + Nv'' - Nx_0\theta'' = 0 \;\Rightarrow\; EI_x v^{IV} + Nv'' - Nx_0\theta'' = 0$$
$$EI_y u^{IV} + Nu'' - Ny_0\theta'' = 0 \;\Rightarrow\; EI_y u'' + Nu = 0$$
$$EI_\omega\theta^{IV} - GI_t\theta'' - Nx_0 v'' + Ny_0 u'' + (Nr_0^2 - \overline{R})\theta'' = 0$$
$$\Rightarrow\; EI_\omega\theta'' - (GI_t + \overline{R} - Nr_0^2)\theta - Nx_0 v = 0$$

- two buckling mode: flexural buckling and flexural-torsional buckling (FTB)
- flexural buckling about the unsymmetric axis and FTB about symmetric axis

☑ Critical buckling load

$$N_{Ey} = \pi^2 EI_y/L_{ox}^2$$
$$\lambda_\omega^2 = \frac{1}{2}(\lambda_x^2 + \lambda_\theta^2) + \frac{1}{2}\sqrt{(\lambda_x^2 + \lambda_\theta^2)^2 - 4(1 - \frac{x_o^2}{r_o^2})\lambda_x^2\lambda_\theta^2}$$
$$(\frac{1}{N_{Ex}} + \frac{1}{N_{E\theta}})N_{E\omega} - (1 - \frac{x_0^2}{r_0^2})\frac{N_{E\omega}^2}{N_{Ex}N_{E\theta}} = 1 \;\Rightarrow\; N_{E\omega} = \pi^2 EA/\lambda_\omega^2$$

Overall stability of solid-web compression members

buckling capacity for compression member with imperfection

☑ Imperfection in compression members

- Mechanical imperfection

  residual stress, variable yield strength at each point of a plane

- Geometrical imperfection

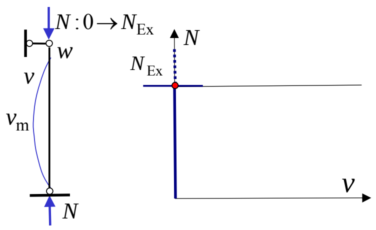
  initial out-of-straightness (crookedness), initial non-concentric loading

☑ Deformation of perfect column

without any initial geometrical imperfection

$$EI_x v'' + Nv = 0$$

$$N_{Ex} = \pi^2 EI_x / L_{ox}^2$$



Overall stability of solid-web compression members

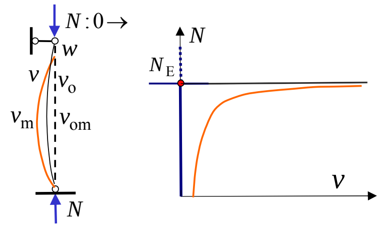
buckling capacity for compression member with imperfection

☑ Effect of initial crookedness on buckling capacity

If initial crookedness about major axis exists for doubly symmetric cross-section

Flexural equilibrium equation $EI_x v'' + Nv = 0$

$$EI_x (v - v_o)'' + Nv = 0$$



if $v_o = v_{om} \sin(\pi \cdot z / L)$

$$v_m = v_{om} / (1 - N / N_E)$$

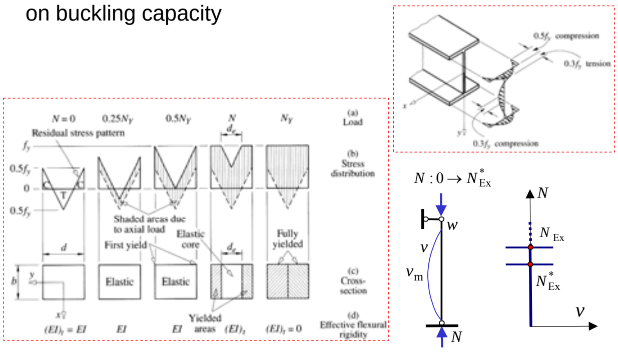
or $N = (1 - v_o / v_m) N_E$

$$N_{ult} < N_E$$

Overall stability of solid-web compression members

buckling capacity for compression member with imperfection

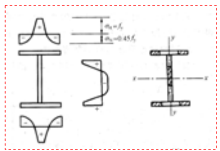
☑ Effect of distribution and amplitude of residual stress on buckling capacity



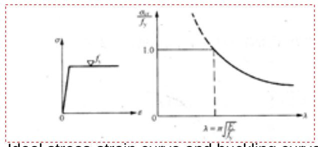
Overall stability of solid-web compression members

buckling capacity for compression member with imperfection

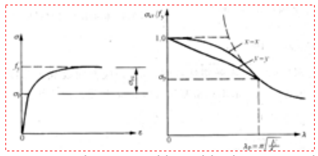
☑ Effect of distribution and amplitude of residual stress on buckling capacity



residual stress and plastic area after compression



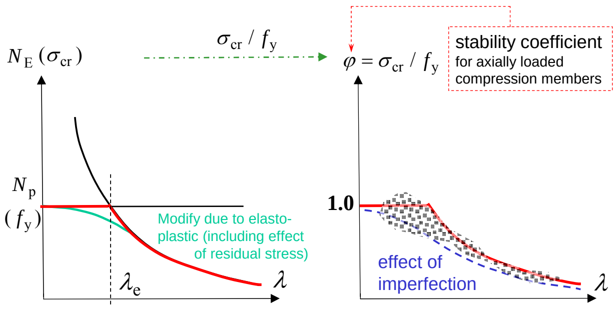
Ideal stress-strain curve and buckling curve



stress-strain curve with residual stress and corresponding buckling curve

Overall stability of solid-web compression members

buckling curve (柱子曲线)



Critical buckling load (stress) vs. slenderness

Buckling curve (stability coefficient) for axially load compression member

Overall stability of solid-web compression members

buckling curve – how to get the stability coefficient (1)

☑ flexural buckling capacity (1) criteria of yield at extra fibre

$$\frac{N}{A} + \frac{N\Delta_m}{W_x} = f_y \quad \Leftarrow \quad \Delta_m = \frac{\Delta_o}{1 - N/N_{Ex}}$$

$$\sigma_{cr} = \frac{N}{A} = \frac{f_y + (1+\varepsilon_o)\sigma_{Ex}}{2} - \sqrt{\left[\frac{f_y + (1+\varepsilon_o)\sigma_{Ex}}{2}\right]^2 - f_y \sigma_{Ex}} \quad \Leftarrow \quad \varepsilon_o = \frac{A\Delta_o}{W_x}$$

(eccentric ratio)

$$\varphi = \frac{\sigma_{cr}}{f_y} = \frac{1}{2}\left\{1 + \frac{1}{\bar{\lambda}^2}(1+\varepsilon_o) - \sqrt{\left[1 + \frac{1}{\bar{\lambda}^2}(1+\varepsilon_o)\right]^2 - \frac{4}{\bar{\lambda}^2}}\right\} \quad \Leftarrow \quad \bar{\lambda} = \frac{\lambda}{\pi}\sqrt{\frac{f_y}{E}}$$

(non-dimensional slenderness)

- applied in ***Technical code of cold-formed thin-wall steel structures*** (GB50018-2002)
- Feasibility used in thin-wall structures:

  (a) should not consider plastic development for thin-wall element
  (b) less effect of residual stress
  (c) just consider initial crookedness and non-concentric loading

Overall stability of solid-web compression members

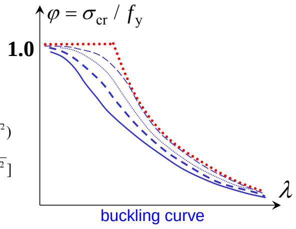
buckling curve – how to get the stability coefficient (2)

☑ flexural buckling capacity (2) criteria of ultimate buckling capacity

- numerical simulation method, considering:
  shape and dimension of section, mechanical properties of steel, distribution and amplitude of residual stress, initial crookedness and torsion of member, non-concentric loading and buckling direction *etc*.
- applied in *code for design of steel structures* (GB50017-2003)
- four buckling curves:
  curve a, b, c, d

if $\bar{\lambda} \le 0.215$, $\varphi = \frac{\sigma_{cr}}{f_y} = 1 - \alpha_1 \bar{\lambda}^2$

if $\bar{\lambda} \succ 0.215$, $\varphi = \frac{\sigma_{cr}}{f_y} = \frac{1}{2\bar{\lambda}^2}[(\alpha_2 + \alpha_3\bar{\lambda} + \bar{\lambda}^2) - \sqrt{(\alpha_2 + \alpha_3\bar{\lambda} + \bar{\lambda}^2)^2 - 4\bar{\lambda}^2}\,]$



buckling curve

Overall stability of solid-web compression members

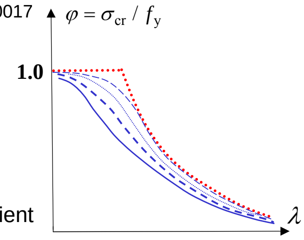
buckling curve (柱子曲线)

☑ buckling curves used in GB50017

- 4 buckling curves:
  curve a, b, c, d
- select relevant curve by:
  section types, buckling direction, plate thickness and manufacture method
- refer to Table5-4 in page 105

☑ calculation of stability coefficient

- Equation method
  calculate from former equations
- Chart method
  slenderness → section type → Annex Table 4-3 to 4-6 in page 371-374



buckling curve
(reduction factor for relevant buckling mode)

Overall stability of solid-web compression members

buckling resistance (design) of a member

☑ practical equation

$$N \le N_{ult} = \sigma_{cr} A = (\sigma_{cr} / f_y) A f_y = \varphi A f_y$$

$$\Rightarrow N \le \varphi A f_d$$

☑ Note:

- adopt gross section for buckling resistance
- adopt stability coefficient specified in GB50017-2003

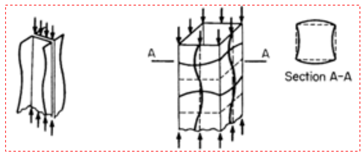
☑ procedure of buckling resistance design

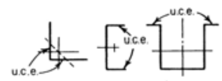
- ascertain the design value of axial load
- calculate the slenderness about two principal axis separately, or the equivalent slenderness if needed
- ascertain the stability coefficient
- check the buckling resistance of the member

Local buckling of plate elements

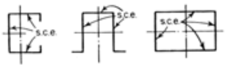
introduction

local buckling of plate element





u.c.e: unstiffened compression element

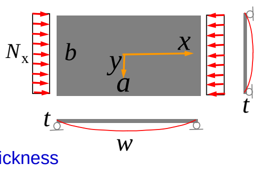


s.c.e: stiffened or partially stiffened compression element

Local buckling of plate elements

differential equation of local buckling of plates

☑ a square plate subjected to a uniform compression stress in one direction



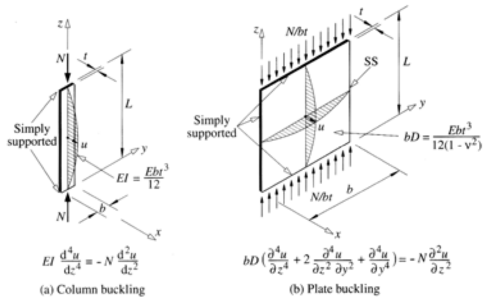
- flat and straight plate with equal thickness
- ratio of width to thickness greater than 10
- uniform compression stress in mid-surface

☑ perform as compression members?

Local buckling of plate elements

differential equation of local buckling of plates

☑ comparison with compression members



perform as compression members! but, flexural buckling …

Local buckling of plate elements

differential equation of local buckling of plates

☑ differential equations of local buckling for plate

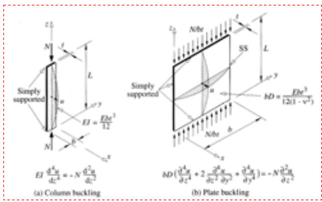
$$D(\frac{\partial^4 w}{\partial x^4}+2\frac{\partial^4 w}{\partial x^2 \partial y^4}+\frac{\partial^4 w}{\partial y^4})+N_x\frac{\partial^2 w}{\partial x^2}=0 \Rightarrow EI_x v^{IV}+Nv''=0$$

$$D=\frac{Et^3}{12(1-\mu^2)} \Rightarrow EI_x=\frac{Ebh^3}{12}$$

plate rigidity per width

N_x

uniform compression stress per width

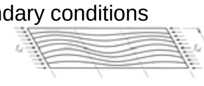


Local buckling of plate elements

critical local buckling of a simply supported square plate

☑ a simply supported square plate: boundary conditions

- deflection at four edges equals zero
- bending moment at four edges equals zero



$$w=\sum_{m=1}^{\infty}\sum_{n=1}^{\infty}A_{mn}\sin\frac{m\pi x}{a}\sin\frac{n\pi y}{b} \Rightarrow D(\frac{\partial^4 w}{\partial x^4}+2\frac{\partial^4 w}{\partial x^2 \partial y^4}+\frac{\partial^4 w}{\partial y^4})+N_x\frac{\partial^2 w}{\partial x^2}=0$$

☑ critical local buckling of a simply supported square plate

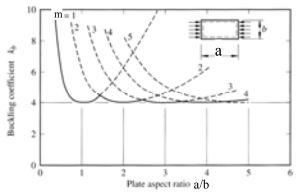
$$N_{xcr}=\frac{\pi^2 D}{b^2}(\frac{mb}{a}+\frac{n^2 a}{mb})^2$$

numbers of half sine waves

$$N_{xcr|n=1}=\frac{\pi^2 D}{b^2}(\frac{mb}{a}+\frac{a}{mb})^2=k\frac{\pi^2 D}{b^2}$$

critical buckling while n=1

$$N_{xcr}=4\frac{\pi^2 D}{b^2}=4\frac{\pi^2 E}{12(1-\mu^2)}\cdot\frac{t^3}{b^2}$$



Local buckling of plate elements

critical local buckling stress & its boundary conditions

☑ critical local buckling stress for a simply supported square plate

$$\sigma_{xcr}=\frac{N_{xcr}}{t}=4\frac{\pi^2 E}{12(1-\mu^2)}/\frac{b^2}{t^2}$$

b/t: ratio of width to thickness (宽厚比)

☑ critical local buckling stress for a square plate

$$\sigma_{xcr}=4\frac{\pi^2 E}{12(1-\mu^2)}/\frac{b^2}{t^2}\Rightarrow k\frac{\pi^2 E}{12(1-\mu^2)}\cdot\frac{t^2}{b^2}$$

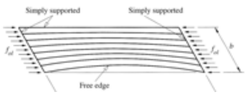
?

$$\sigma_E=\pi^2 E/\lambda^2$$

buckling coefficient for a plate, pertain to load distribution and boundary conditions

☑ boundary conditions of a plate

- simply-supported, fixed, free end
- combination of different constraint at edges
- constraint in a real plate



Local buckling of plate elements

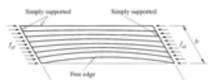
critical local buckling stress & its boundary conditions

☑ buckling coefficient for different boundary conditions

Case	Boundary condition	Type of stress	Value of k for long plate
(a)	s.s. / s.s. / s.s. / s.s.	Compression	4.0
(b)	Fixed / s.s. / s.s. / Fixed	Compression	6.97
(c)	s.s. / s.s. / s.s. / Free	Compression	0.425
(d)	Fixed / s.s. / s.s. / Free	Compression	1.277
(e)	Fixed / s.s. / s.s. / s.s.	Compression	5.42

$$\sigma_{xcr}=4\frac{\pi^2 E}{12(1-\mu^2)}/\frac{b^2}{t^2}\Rightarrow k\frac{\pi^2 E}{12(1-\mu^2)}\cdot\frac{t^2}{b^2}$$

1.35 if free end changing to stiffeners

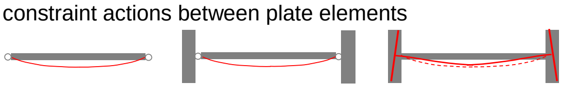


The stronger the constraint, the larger the local buckling coefficient, and the bigger the critical local buckling resistance

Local buckling of plate elements

constraint actions between plate elements & effects of elasto-plastic property

☑ constraint actions between plate elements



☑ effects of constraint of adjacent plate elements

$$\sigma_{xcr}=k\frac{\pi^2 E}{12(1-\mu^2)}\cdot\frac{t^2}{b^2} \Rightarrow \sigma_{xcr}=\chi\cdot k\cdot\frac{\pi^2 E}{12(1-\mu^2)}\cdot\frac{t^2}{b^2}$$

constraint coefficient between plate elements for a designated plate

☑ modification due to the elasto-plastic property

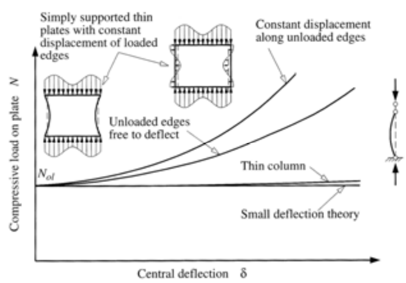
$$\sigma_{xcr}=k\frac{\pi^2 E}{12(1-\mu^2)}\cdot\frac{t^2}{b^2} \Rightarrow \sigma_{xcr}=\sqrt{\psi_t}\cdot k\cdot\frac{\pi^2 E}{12(1-\mu^2)}\cdot\frac{t^2}{b^2}$$

$$\psi_t=E_t/E$$

Local buckling of plate elements

post-buckling strength of thin plate elements

☑ structural performance of thin plate after local buckling

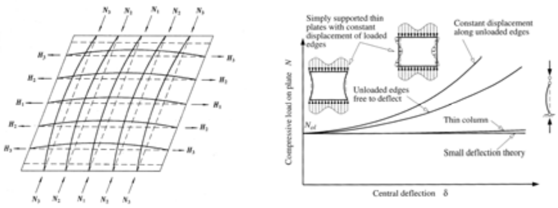


Local buckling of plate elements

post-buckling strength of thin plate elements

☑ structural performance of thin plate after local buckling

Mechanism (physics): stress redistribution



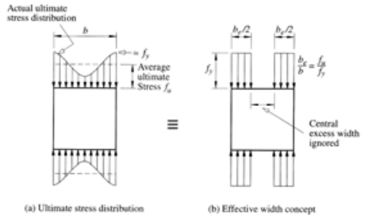
Mechanism (mathematics): large deflection theory, pp123-125

Post-buckling strength will be larger than yield strength?

Local buckling of plate elements

effective width concept and post-buckling strength

☆ Effective width concept for simply supported plates



$$\frac{b_e}{b} = \frac{1}{\lambda_e}(1 - 0.22\frac{1}{\lambda_e})$$

$$\lambda_e = 1.05\left(\frac{b}{t}\right)\sqrt{\frac{\sigma_e}{kE}}$$

☑ increase the bending rigidity of member
☑ increase the buckling resistance of member
☒ decrease the cross-section resistance
☒ become less development of plasticity
☒ deteriorate the hysteretic performance

Local buckling of plate elements

design criteria of preventing local buckling of plates

☑ Criteria 1: No local buckling allowed in any plate

$$\begin{cases}\sigma_{cr} \ge f \\ \sigma_{cr} \ge \varphi \cdot f\end{cases} \Rightarrow \sigma_{cr} = \sqrt{\psi_t}\chi k \frac{\pi^2 E}{12(1-\upsilon^2)}(\frac{t}{b})^2 \ge \varphi f_y \Rightarrow \frac{b}{t} \le \left[\frac{\sqrt{\psi_t}\chi k \pi^2 E}{12(1-\upsilon^2)\varphi f_y}\right]^{\frac{1}{2}}$$

Use ratio of width to thickness of a plate to guarantee the local buckling, pp127

☑ Criteria 2: local buckling allowed, use post-buckling strength

1. effective width and effective cross-section

$$\frac{b_e}{b} = \frac{1}{\lambda_e}(1 - 0.22\frac{1}{\lambda_e}) \qquad \lambda_e = 1.05\left(\frac{b}{t}\right)\sqrt{\frac{\sigma_e}{kE}}$$

2. cross-section resistance and buckling resistance using effective width

$$\frac{N}{\varphi \cdot A_e} \le f_d$$

Overall stability of built-up compression member

concept of built-up compression members

☑ Why use built-up compression members?

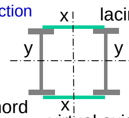
pursuing identical buckling resistance in x, y direction

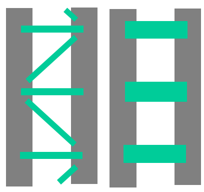
☑ Types of built-up members

Chord: built-up section / shaped section
two-, three-, four-chord

Bracing: lacing → form triangular shape
battening → form rectangular shape

Axis: actual axis / virtual axis





☑ Overall stability about actual axis

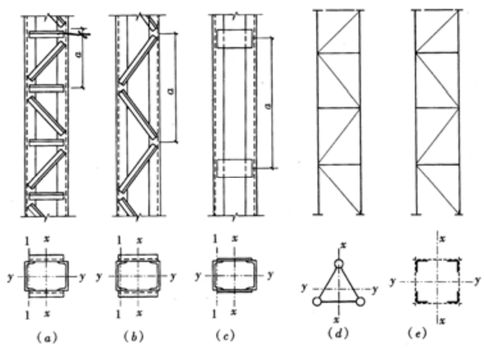
The same as solid-web compression members

⇧

even for channel shape?

Overall stability of built-up compression member

concept of built-up compression members



Overall stability of built-up compression member

differential equation considering shear deformation

☑ differential equation for buckling resistance considering the effect of shear deformation

$$v = v_1 + v_2$$

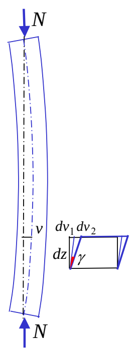
$$v_1'' = -M_x / EI_x = -Nv / EI_x$$

$$\frac{dv_2}{dz} = \gamma = \gamma_1 V = \gamma_1 \frac{dM_x}{dz} = \gamma_1 Nv' \quad \rightarrow v_2'' = \gamma_1 Nv''$$

γ_1—shear stain under unit shear force

$$v'' = v_1'' + v_2'' = -Nv / EI_x + \gamma_1 Nv''$$

$$\rightarrow v'' + \frac{N}{EI_x(1-\gamma_1 N)} v = 0$$



☑ solution of the differential equation

$$N_{cr} = \frac{\pi^2 EI_x(1-\gamma_1 N_{cr})}{L^2} \rightarrow N_{cr} = \frac{\pi^2 EA}{\lambda_x + \pi^2 EA\gamma_1}$$

Overall stability of built-up compression member

buckling resistance of built-up members considering shear deformation

☑ buckling resistance of built-up members

$$N_{cr} = \frac{\pi^2 EA}{\lambda_x^2 + \pi^2 EA\gamma_1} = \frac{\pi^2 EA}{\lambda_{0x}^2}$$

Equivalent slenderness

$$\lambda_{0x} = \sqrt{\lambda_x^2 + \pi^2 EA\gamma_1} \quad \rightarrow \lambda_{0x} \geq \lambda_x$$

Shear stain decrease the bending rigidity of member, thus decrease the flexural buckling resistance

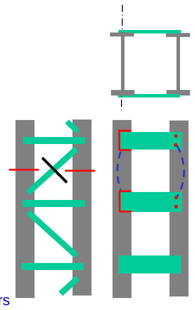
☑ How to get the shear strain γ_1 ?

☑ calculation of equivalent slenderness

Table 5-5, pp111

$$\lambda_{0x} = \sqrt{\lambda_x^2 + 27A/A_{1x}}$$ ←laced compression members

$$\lambda_{0x} = \sqrt{\lambda_x^2 + \lambda_1^2}$$ ←battened compression members



Local buckling of laced compression members

local buckling of plate, chord and lacing

☑ Local buckling of compressive plate in chords

Design as that of solid-web compression members.

☑ buckling of each chord

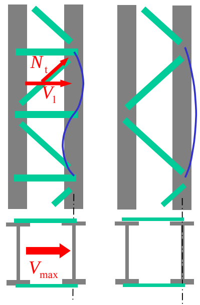
$$\lambda_1 \leq 0.7\lambda_{max} = 0.7\max\{\lambda_y,\ \lambda_{ox}\}$$

☑ buckling of lacing

$$V_{max} = \frac{Af_d}{85}\sqrt{\frac{235}{f_y}}$$

$$N_t = \frac{V_1}{n\cdot\cos\alpha} = \frac{V_{max}}{2n\cdot\cos\alpha}$$

$$\frac{N_t}{\varphi\cdot A_t} \leq \gamma_0\cdot f_d$$



Local buckling of battened compression member

local buckling of plate, chord and battening

☑ Local buckling of compressive plate in chords

Design as that of solid-web compression members.

☑ buckling of each chord

$$\lambda_1 \leq \min\{40,\ 0.5\lambda_{max}\}$$

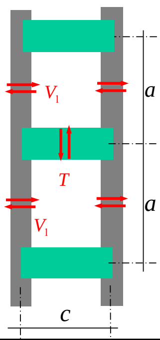
☑ buckling of battening

Structural behavior of battened compression members is similar to that of multi-storey rigid frame.

Internal force of battening: $T = V_1 \frac{a}{c}$

$$M = V_1 \frac{a}{2}$$

Local buckling and strength like deep beam



Overall and local buckling of built-up compression member

design procedures

☑ distinguish the actual axis and virtual axis

☑ overall stability design about actual axis

design as that of solid-web compression members.

how about channel section?

☑ overall stability design about virtual axis

compute the slenderness about virtual axis (*note: just consider the chord*)

compute the equivalent slenderness (*note: types of built-up members*)

Table 5-5 or $\lambda_{ox} = \sqrt{\lambda_x^2 + \frac{\pi^2}{12}(1 + 2\frac{k_1}{k_b})\lambda_1^2}$

compute the buckling coefficient of member about virtual axis

compute the buckling resistance about virtual axis

☑ local buckling resistance

local buckling of plates, buckling of chord and bracing

Rigidity of compression members

allowable slenderness

☑ concept of rigidity of compression members is the same as that of tension members

☑ allowable slenderness

more rigorous than allowable slenderness of tension members

$$\lambda_{max} \leq [\lambda]$$

$[\lambda]$ is about 150~200

Overall and local buckling of compression member

design procedures

☑ Selection of member section

Section: requirement of overall stability, local buckling and ease to connect

☑ Strength: cross-section resistance

☑ Overall buckling resistance

Solid-web compression members

Laced or battened compression members: actual and virtual axis/ chord and bracing

☑ local buckling resistance

Allowable ratio of width to thickness

Effective width and effective area

☑ rigidity of compression members