Introduction

Following subjects are covered:

- Introduction
- Stability
- Laterally supported beams
- Serviceability
- Shear strength
- Concentrated loads
- Biaxial bending

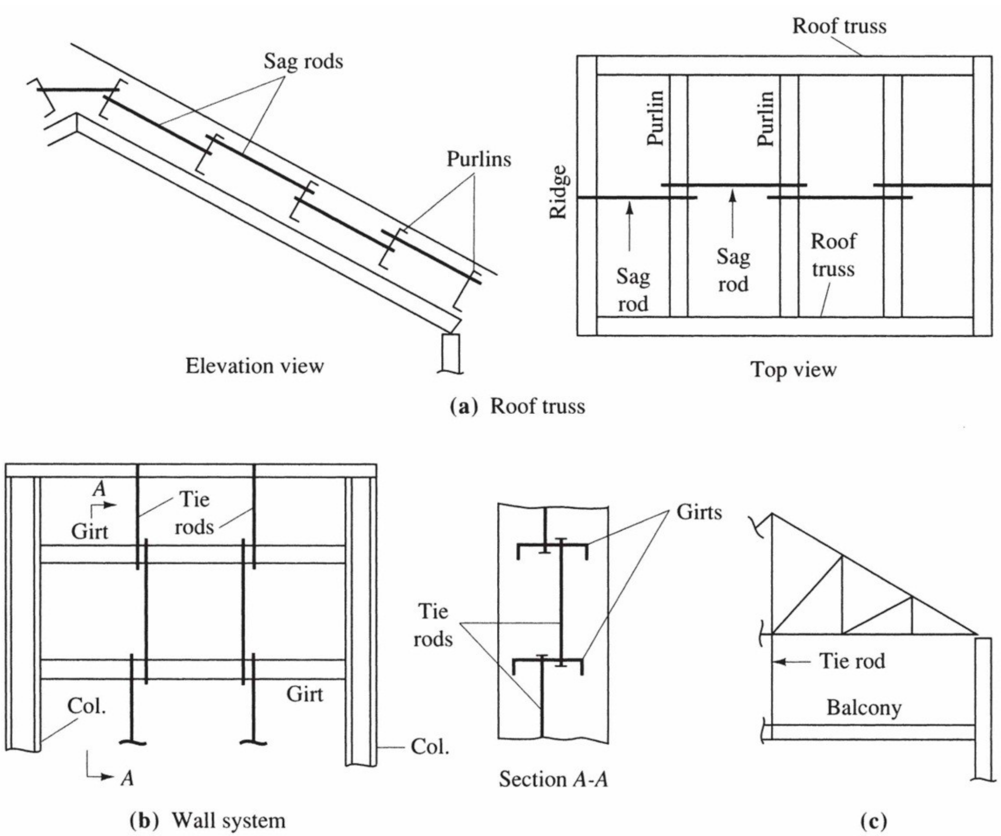
Reading:

- Chapters 7 and 9 of Salmon & Johnson
- AISC Steel Manual Specifications Chapters B (Design Requirements), F (Beams and Other Flexural Members), L (Serviceability Design), and Appendix 2 (Design for Ponding)

Introduction (cont.)

- Flexural members/beams are defined as members acted upon primarily by transverse loading, often gravity dead and live load effects. Thus, flexural members in a structure may also be referred to as:
  - Girders – usually the most important beams, which are frequently at wide spacing.
  - Joists – usually less important beams which are closely spaced, frequently with truss-type webs.
  - Purlins – roof beams spanning between trusses.
  - Stringers – longitudinal bridge beams spanning between floor beams.
  - Girts – horizontal wall beams serving principally to resist bending due to wind on the side of an industrial building, frequently supporting corrugated siding.
  - Lintels – members supporting a wall over window or door openings

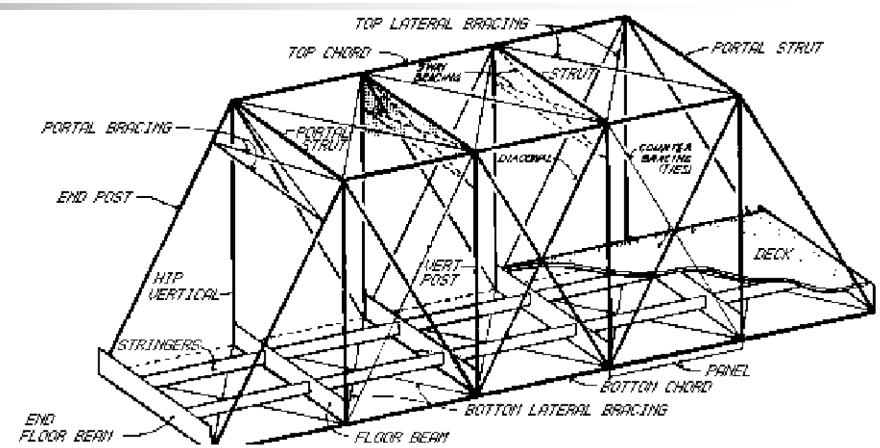
Introduction (cont.)

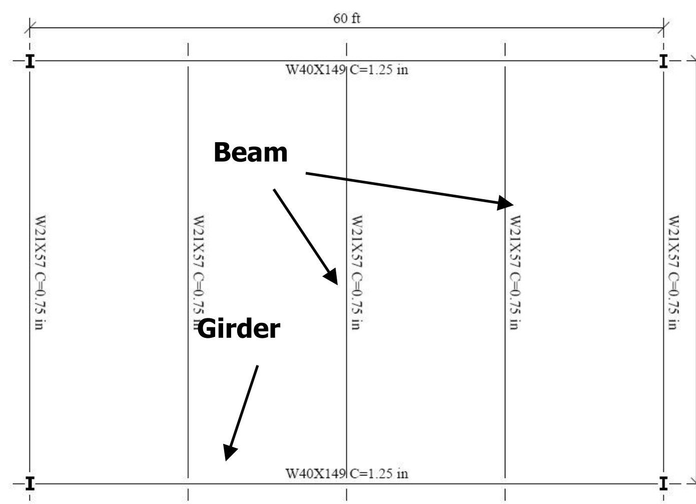


(a) Roof truss

(b) Wall system

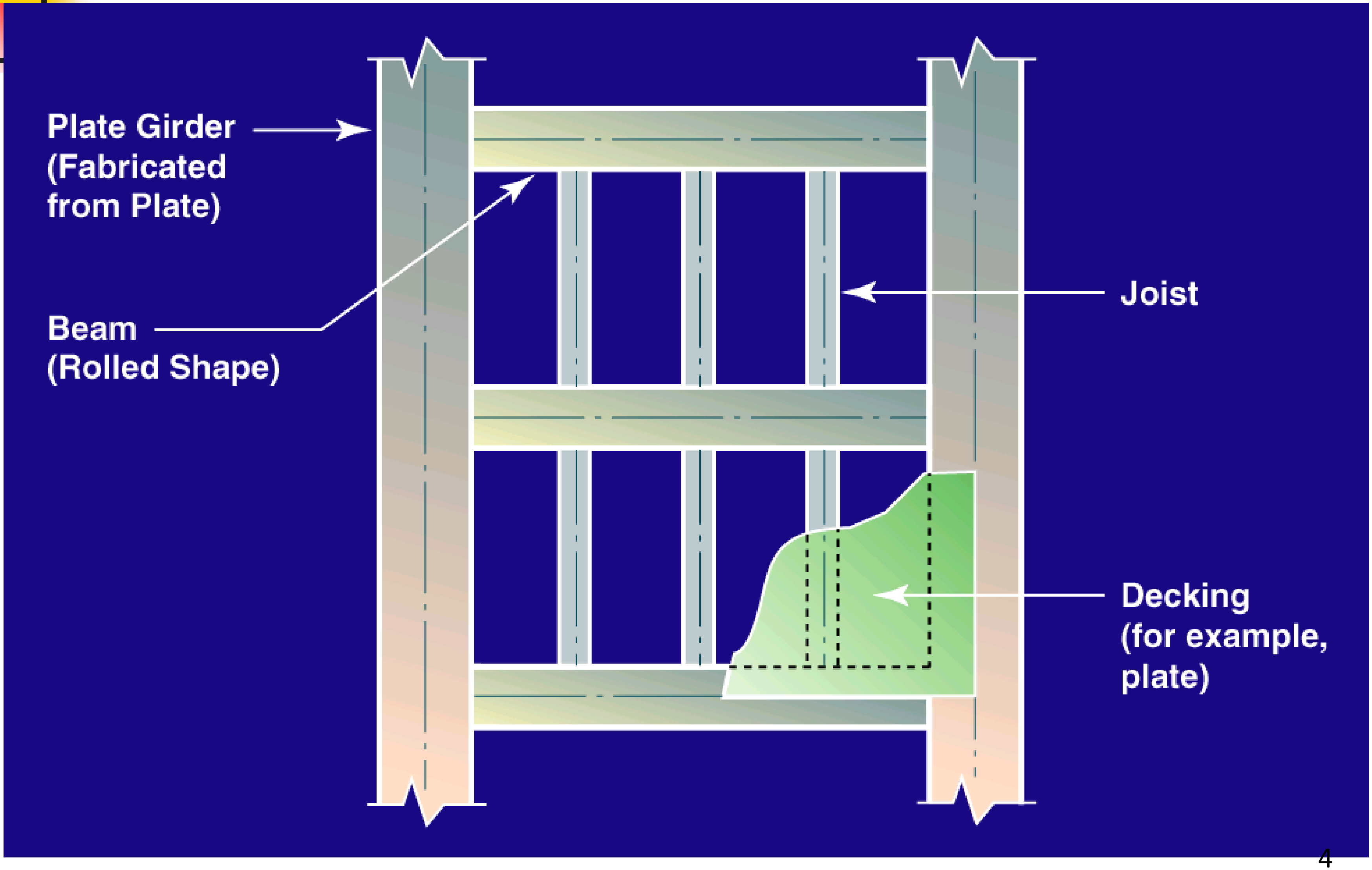
(c)



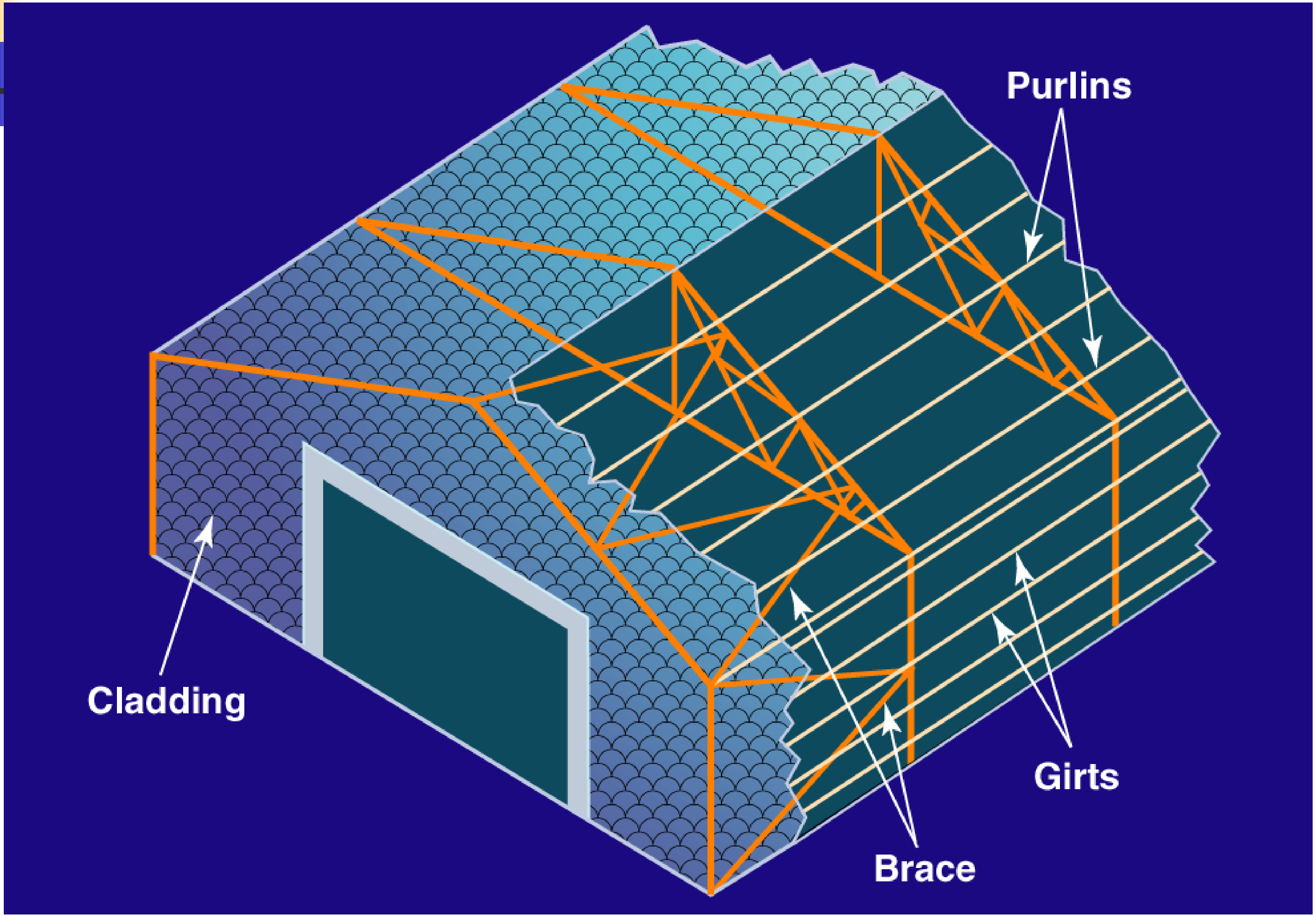


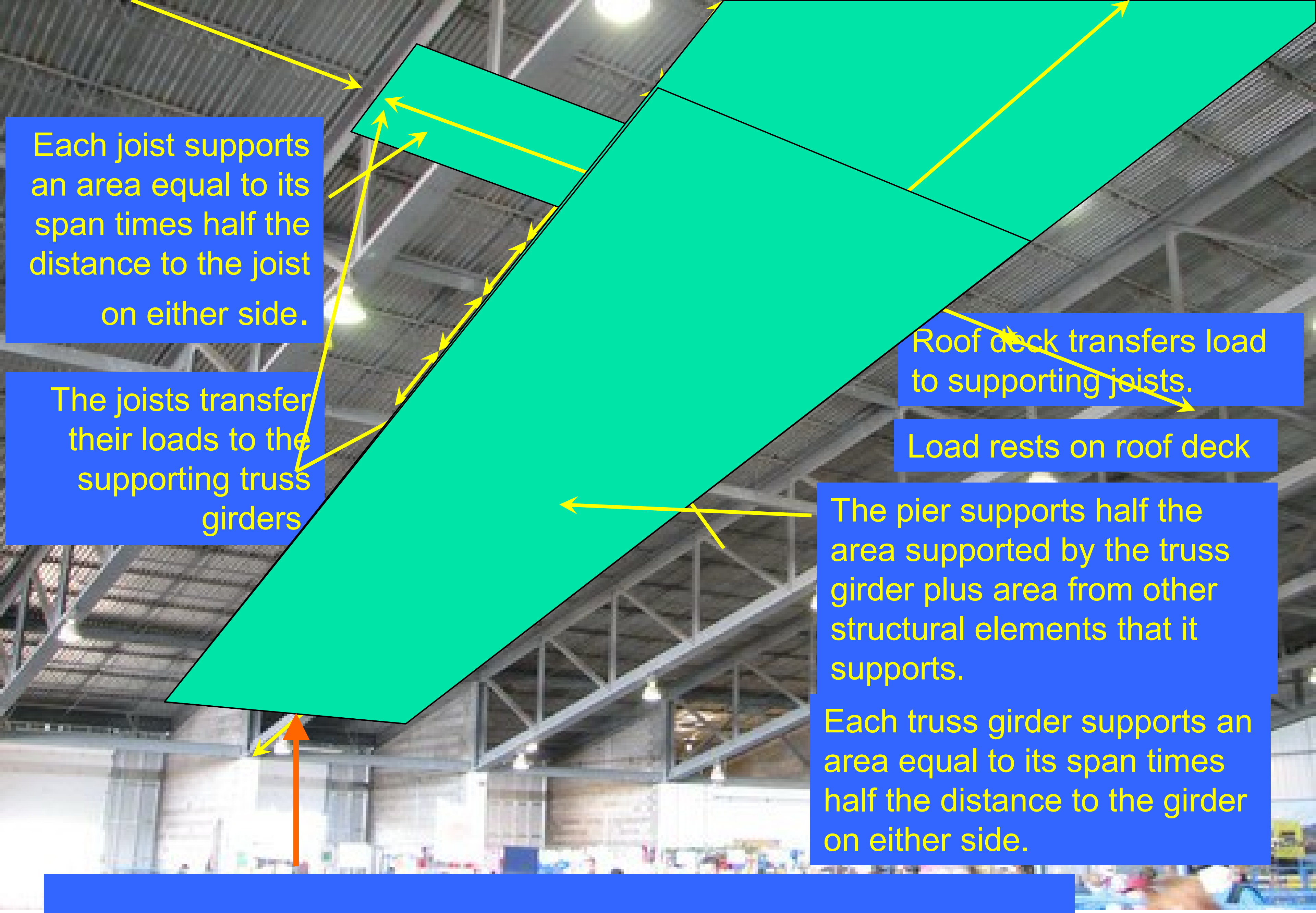
based on FloorFraming Program

Example of a Typical Floor Plan



Example of a Typical Steel Structure





Joist Roof Load Path by Tributary Area

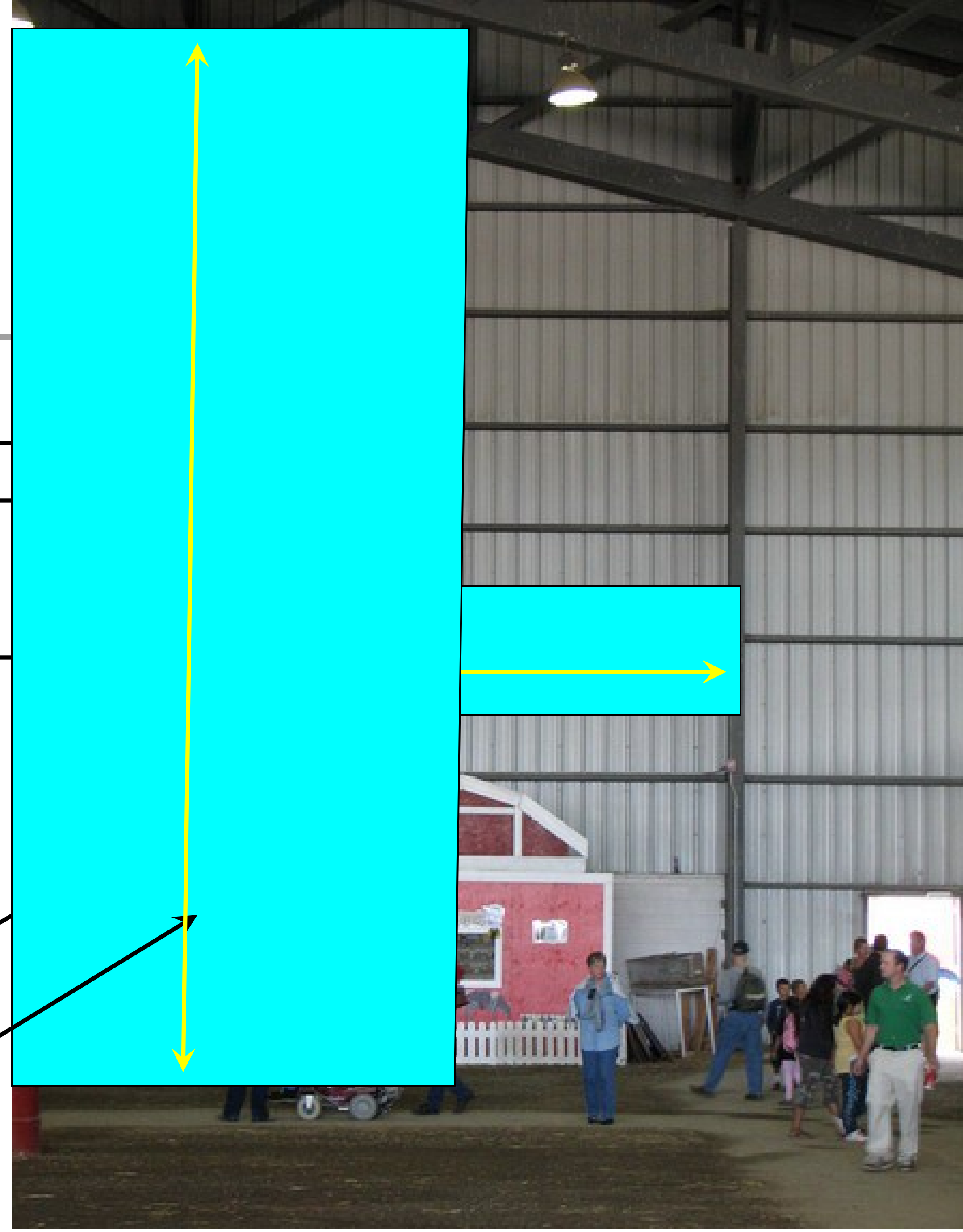
End Wall Framing

For lateral pressures, the siding spans between the horizontal girts (yet another fancy word for a beam!)

The girts support half the siding to the adjacent girts. This is the tributary area for one girt.

The girts transfer their lateral load to the supporting beam-columns.

The beam-columns transfer their lateral loads equally to the roof and foundation.



Stability

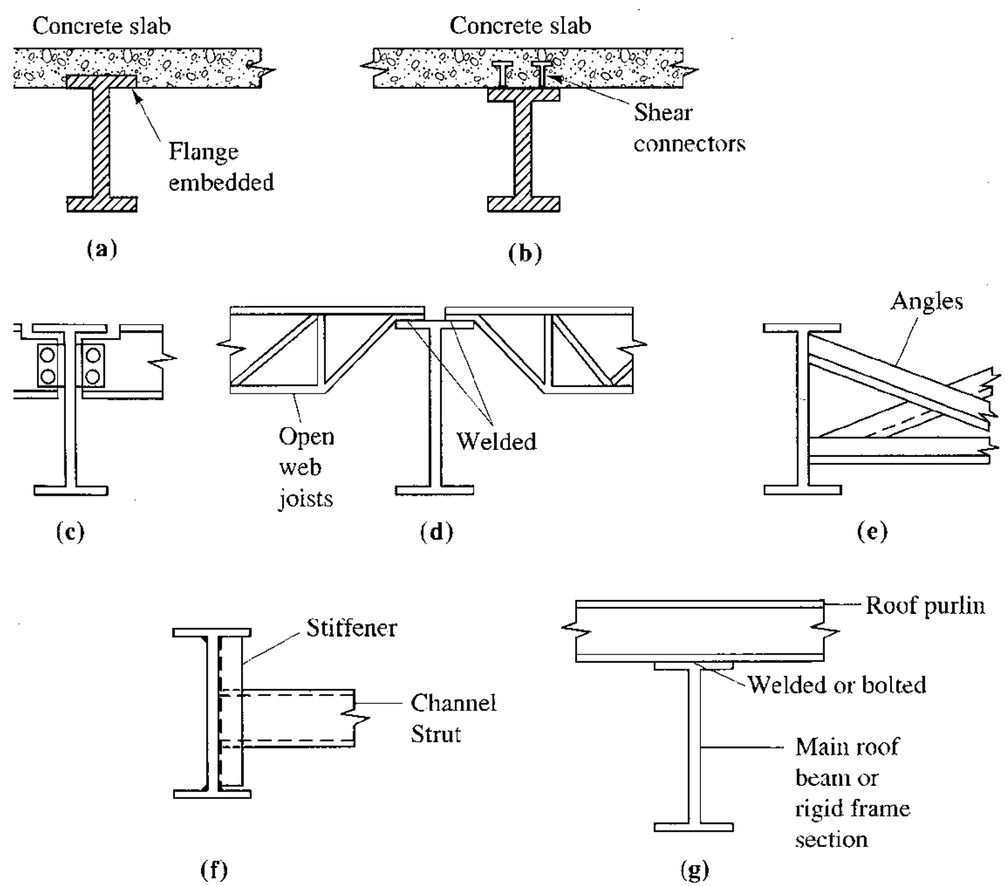
- The laterally supported beams assume that the beam is stable up to the fully plastic condition, that is, the nominal strength is equal to the plastic strength, or $M_n = M_p$
- If stability is not guaranteed, the nominal strength will be less than the plastic strength due to
  - Lateral-torsional buckling (LTB)
  - Flange and web local buckling (FLB & WLB)
- When a beam bends, one half (of a doubly symmetric beam) is in compression and, analogous to a column, will buckle.

Stability (cont.)

- Unlike a column, the compression region is restrained by a tension region (the other half of the beam) and the outward deflection of the compression region (flexural buckling) is accompanied by twisting (torsion). This form of instability is known as lateral- torsional buckling (LTB)
- LTB can be prevented by lateral bracing of the compression flange. The moment strength of the beam is thus controlled by the spacing of these lateral supports, which is termed the unbraced length.

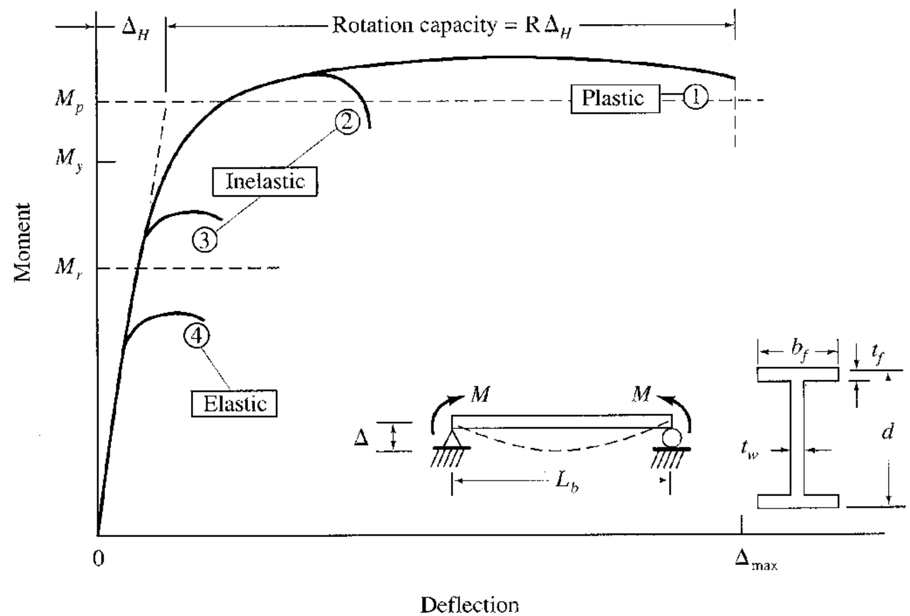
Stability (cont.)

- Flange and web local buckling (FLB and WLB, respectively) must be avoided if a beam is to develop its calculated plastic moment.



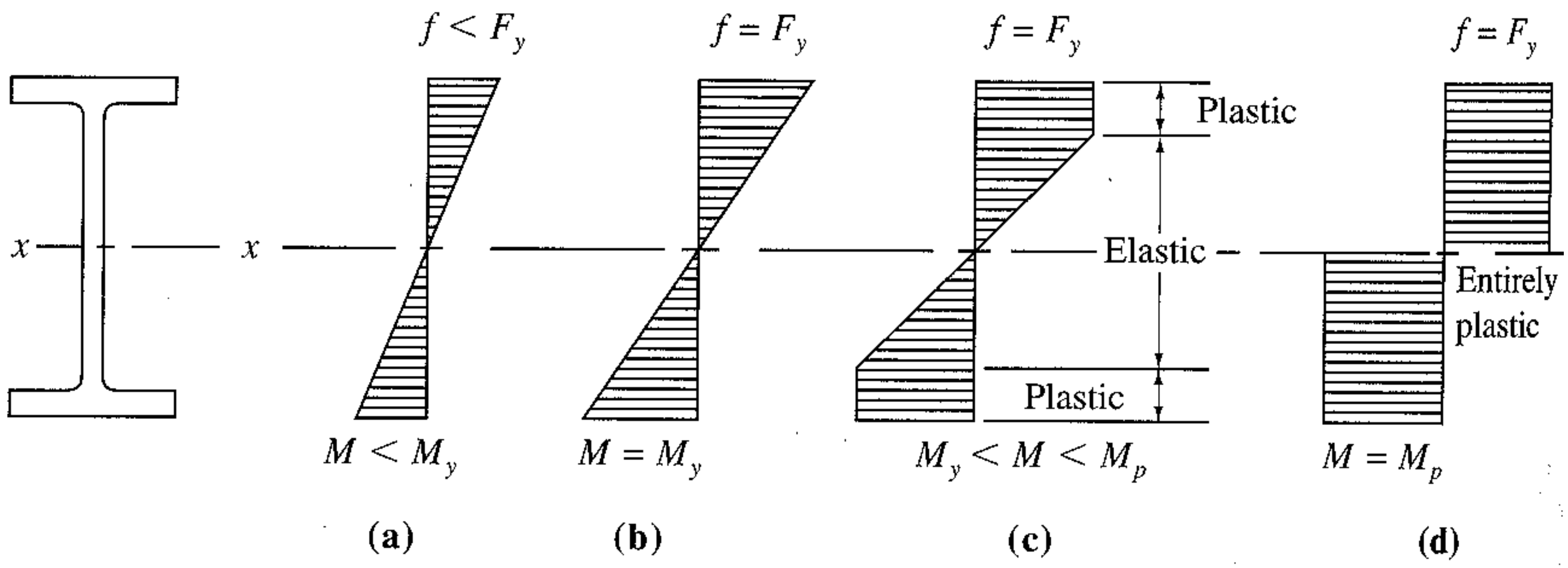
Stability (cont.)

- Four categories of behavior are shown in the figure:
  - Plastic moment strength M_p along with large deformation.
  - Inelastic behavior where plastic moment strength M_p is achieved but little rotation capacity is exhibited.
  - Inelastic behavior where the moment strength M_r, the moment above which residual stresses cause inelastic behavior to begin, is reached or exceeded.
  - Elastic behavior where moment strength M_{cr} is controlled by elastic buckling.



Laterally Supported Beams

- The stress distribution on a typical wide-flange shape subjected to increasing bending moment is shown below



Laterally Supported Beams (cont.)

- In the service load range the section is elastic as in (a)
- When the yield stress is reached at the extreme fiber (b), the yield moment M_y is

$$M_n = M_y = S_x F_y \qquad (7.3.1)$$

- When the condition (d) is reached, every fiber has a strain equal to or greater than $\varepsilon_y = F_y/E_s$, the plastic moment M_p is

$$M_P = F_y \int_A y\,dA = F_y Z \qquad (7.3.2)$$

Where Z is called the plastic modulus

Laterally Supported Beams (cont.)

- Note that ratio, shape factor ξ, M_p/M_y is a property of the cross-sectional shape and is independent of the material properties.

  $\xi = M_p/M_y = Z/S$ (7.3.3)

- Values of S and Z (about both x and y axes) are presented in the Steel Manual Specification for all rolled shapes.
- For W-shapes, the ratio of Z to S is in the range of 1.10 to 1.15

  (Salmon & Johnson Example 7.3.1)

Laterally Supported Beams (cont.)

- The AISC strength requirement for beams:

  $\phi_b M_n \geq M_u$ (7.4.1)

  - Compact sections: $M_n = M_p = Z F_y$ (7.4.2)
  - Noncompact sections: $M_n = M_r = (F_y - F_r) S_x = 0.7 F_y S_x$ (7.4.3)
  - Partially compact sections

$$M_n = M_P - (M_p - M_r)\left(\frac{\lambda - \lambda_p}{\lambda_r - \lambda_p}\right) \leq M_P \qquad (7.4.4)$$

  where $\lambda = b_f/2t_f$ for I-shaped member flanges

  $= h/t_w$ for beam web

  λ_r, λ_p from Salmon & Johnson Tables 7.4.1 & 2 or AISC Table B4.1 (Salmon & Johnson Example 7.4.1)

  - Slender sections: When the width/thickness ratio λ exceed the limits λ_r of AISC-B4.1

Serviceability of Beam

- Deflection
  - AISC – Section L3: Deformations in structural members and structural system due to service loads shall not impair the serviceability of the structure
  - ASD - $\Delta_{max} = 5wL^4/(384EI)$

    As a guide in ASD –Commentary L3.1

    - L/240 (roof); L/300 (architectural); L/200 (movable components)

    Past guides (still useful) listed in Salmon & Johnson

    - Floor beams and girders $L/d \leq 800/F_y$, ksi

      to shock or vibratory loads, large open area $L/d \leq 20$

    - Roof purlins, except flat roofs, $L/d \leq 1000/F_y$

(Salmon & Johnson Example 7.6.1)

Serviceability of Beam

- Ponding (AISC Appendix 2, Sec. 2.1)

  $C_p + 0.9C_s \leq 0.25$

  $I_d \geq 25(s^4)10^{-6}$

  where

  $C_p = 32L_sL_p^4/(10^7I_p)$

  $C_s = 32SL_s^4/(10^7I_s)$

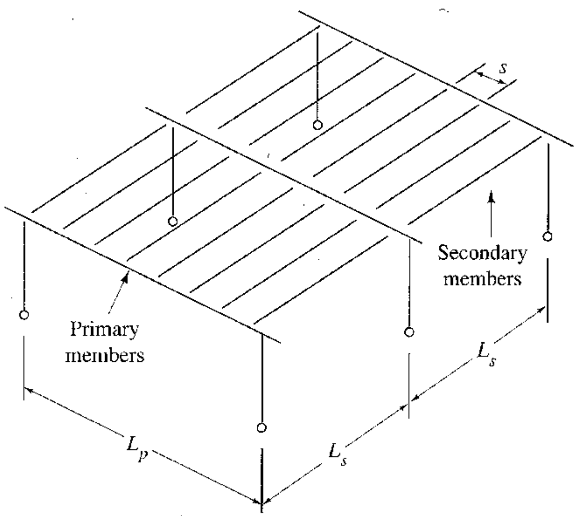
  L_p = Column spacing in direction of girder

  L_s = Column spacing perpendicular to direction of girder

  I_p = moment of inertia of primary members

  I_s = moment of inertia of secondary members

  I_d = moment of inertia of the steel deck



Shear on Rolled Beams

- General Form $v = VQ/(It)$ and average form is

  $f_v = V/A_w = V/(dt_w)$ (7.7.7)

- AISC-F2

  $\phi_v V_n \geq V_u$ (7.7.11)

  where

  $\phi_v = 1.0$

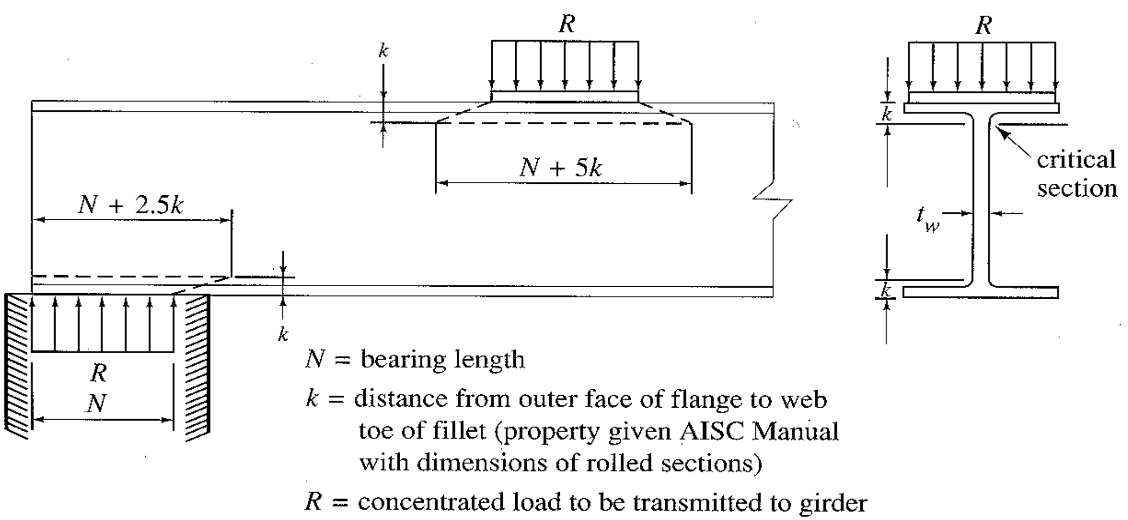
  $V_n = 0.6F_{yw}A_w$ for beams without transverse stiffeners and $h/t_w \leq 2.24/\sqrt{E/F_y}$

Concentrated Loads

- AISC-J10.2 $\phi R_n \geq R_u$ (7.8.1)
  - Local web yielding (use R_1 & R_2 in AISC Table 9-4)
    1. Interior loads

       $R_n = (5k + N)F_{yw}t_w$ (7.8.2)
    2. End reactions

       $R_n = (2.5k + N)F_{yw}t_w$ (7.8.3)



Concentrated Loads (cont.)

- AISC-J10.3 (cont.)
  - Web Crippling (use R_3, R_4, R_5 & R_6 in AISC Table 9-4)
    1. Interior loads

$$R_n = 0.80t_w^2\left[1+3\left(\frac{N}{d}\right)\left(\frac{t_w}{t_f}\right)^{1.5}\right]\sqrt{\frac{EF_{yw}t_f}{t_w}} \qquad (7.8.8)$$

    2. End reactions

$$R_n = 0.4t_w^2\left[1+3\left(\frac{N}{d}\right)\left(\frac{t_w}{t_f}\right)^{1.5}\right]\sqrt{\frac{EF_{yw}t_f}{t_w}} \qquad (7.8.9)\ \text{for } N/d \le 0.2$$

$$R_n = 0.4t_w^2\left[1+\left(\frac{4N}{d}-0.2\right)\left(\frac{t_w}{t_f}\right)^{1.5}\right]\sqrt{\frac{EF_{yw}t_f}{t_w}} \qquad (7.8.10)\ \text{for } N/d > 0.2$$

Concentrated Loads (cont.)

- AISC-J10.4 (cont.)
  - Sidesway Web Buckling

1. When the compression flange is restrained against rotation for $(h/t_w)/(L_b/b_f) \leq 2.3$

$$R_n = \frac{C_r t_w^3 t_f}{h^2}\left[1 + 0.4\left(\frac{h/t_w}{L_b/b_f}\right)^3\right] \qquad (7.8.7)$$

if > 2.3 R_n = no limit

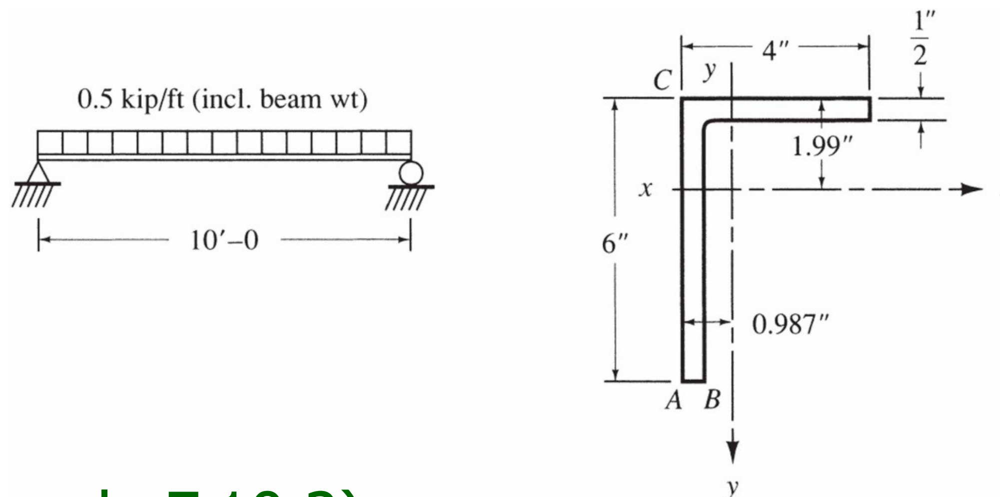
2. When the compression flange is not restrained against rotation: for $(h/t_w)/(L_b/b_f) \leq 1.7$

$$R_n = \frac{C_r t_w^3 t_f}{h^2}\left[0.4\left(\frac{h/t_w}{L_b/b_f}\right)^3\right] \qquad (7.8.8)$$

if > 1.7 R_n = no limit

General Flexural Theory

$$\sigma \le \frac{M_x I_y - M_y I_{xy}}{I_x I_y - I_{xy}^2} y + \frac{M_y I_x - M_x I_{xy}}{I_x I_y - I_{xy}^2} x$$



(Salmon & Johnson Example 7.10.2)

(a) Angle free to bend in any direction

(c) Angle restrained to bend in the vertical plane

Biaxial Bending of Symmetric Sections

- AISC-H2

$$\frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \leq 1 \qquad (7.11.3)$$

$$S_x \leq \frac{M_{ux}}{\phi_b F_y} + \frac{M_{uy}}{\phi_b F_y}\left(\frac{S_x}{S_y}\right) \qquad (7.11.6)$$

(Salmon & Johnson Example 7.8.1)

(for concentrated loads applied to tolled beams)

(Salmon & Johnson Example 7.11.1)

(for biaxial bending)