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New Composite Design Provisions in the 2010 AISC Specification

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Presented by Will Jacobs, V, P.E., S.E.
Stanley D. Lindsey and Associates, Ltd.
Atlanta, GA

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NEW COMPOSITE DESIGN PROVISIONS IN THE 2010 AISC SPECIFICATION

PART I: SPECIFICATION REVISIONS

William P. Jacobs, V, P.E., S.E.
Stanley D. Lindsey & Associates
Atlanta, Georgia

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The Cycle

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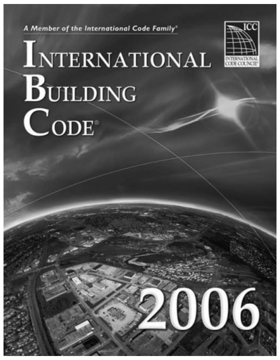
The Cycle



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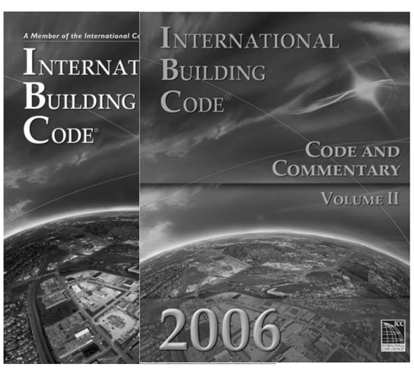
The Cycle



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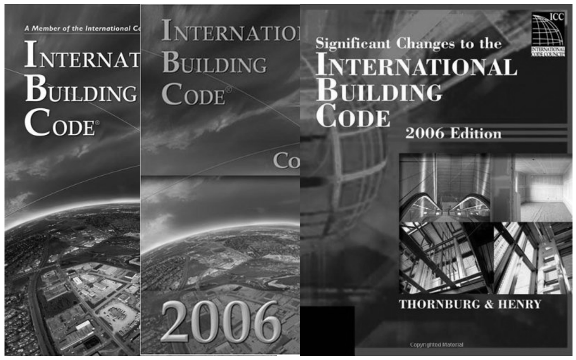

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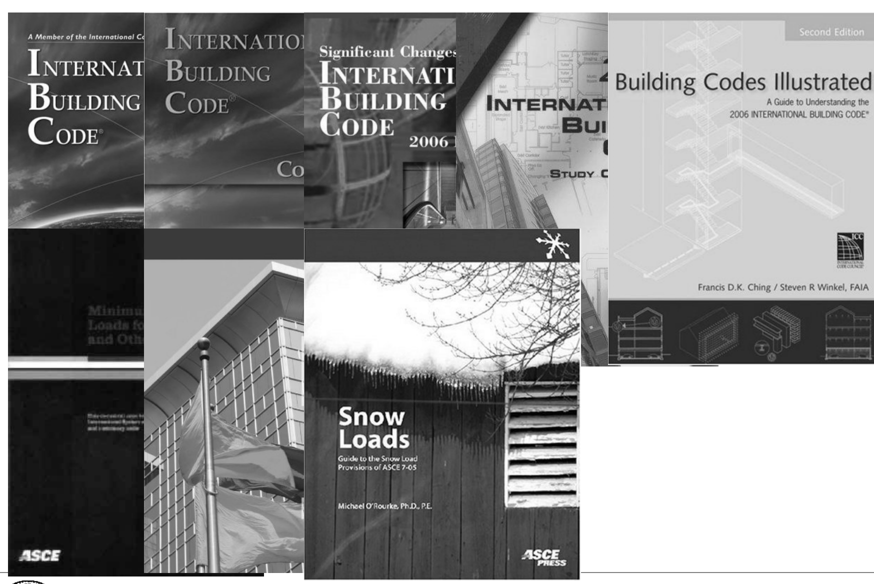
The Cycle



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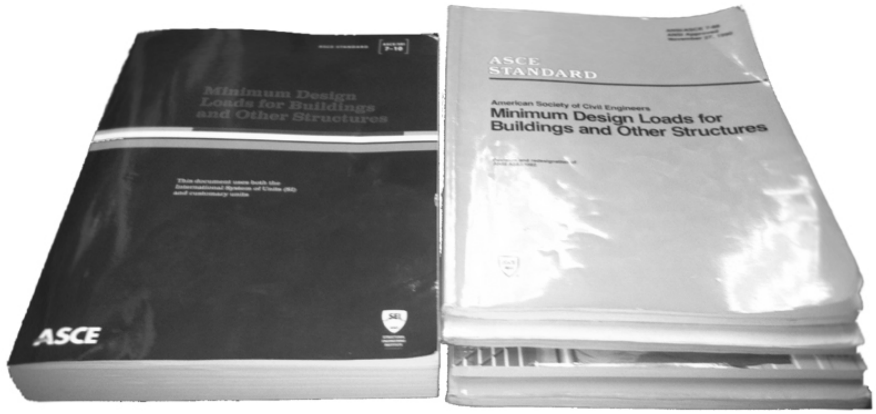
The Cycle



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2010 Chapter I

- **Minimal Change?**

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2010 Chapter I

- **Minimal Change?**

2005 Specification 2010 Specification

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2010 Chapter I

- **Minimal Change?**

2005 Specification 2010 Specification

- 5 Main Sections

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2010 Chapter I

- **Minimal Change?**

2005 Specification
- 5 Main Sections

2010 Specification
- 9 Main Sections

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2010 Chapter I

- **Minimal Change?**

2005 Specification
- 5 Main Sections
- 12 Specification Pages

2010 Specification
- 9 Main Sections

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2010 Chapter I

- **Minimal Change?**

2005 Specification	2010 Specification
• 5 Main Sections	• 9 Main Sections
• 12 Specification Pages	• 24 Specification Pages

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2010 Chapter I

- **Minimal Change?**

2005 Specification	2010 Specification
• 5 Main Sections	• 9 Main Sections
• 12 Specification Pages	• 24 Specification Pages
• 22 Commentary Pages	

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2010 Chapter I

- **Minimal Change?**

2005 Specification
- 5 Main Sections
- 12 Specification Pages
- 22 Commentary Pages

2010 Specification
- 9 Main Sections
- 24 Specification Pages
- 39 Commentary Pages

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2010 Chapter I

- **Minimal Change?**

2005 Specification
- 5 Main Sections
- 12 Specification Pages
- 22 Commentary Pages
- 7 Design Examples
  (28 pages)

2010 Specification
- 9 Main Sections
- 24 Specification Pages
- 39 Commentary Pages

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2010 Chapter I

- **Minimal Change?**

2005 Specification	2010 Specification
• 5 Main Sections	• 9 Main Sections
• 12 Specification Pages	• 24 Specification Pages
• 22 Commentary Pages	• 39 Commentary Pages
• 7 Design Examples (28 pages)	• 12 Design Examples (114 pages)

2010 Chapter I

- **Why the Changes?**
  - Expand Composite Design Beyond Beams
  - Clarify Existing Provisions for Ease of Use
  - Provide Additional Guidance for Designers
  - NOT to Modify the Substance of Existing Provisions

2010 Chapter I

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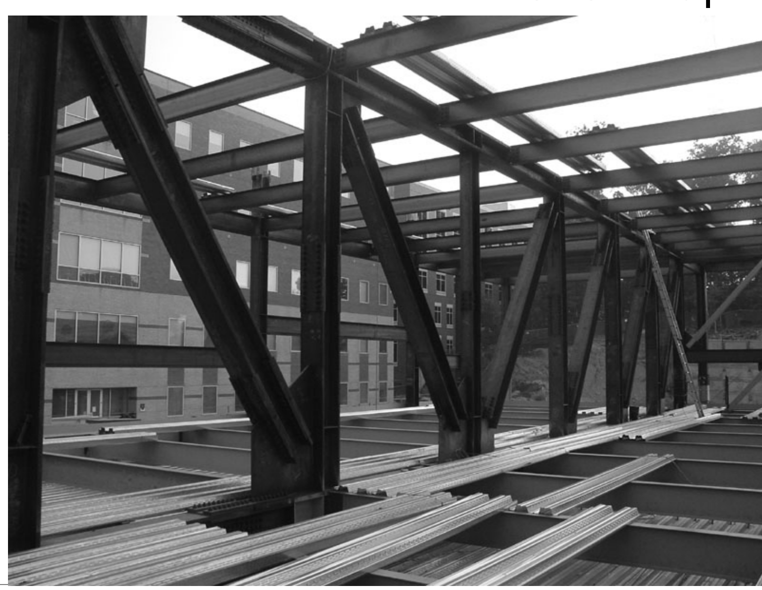
2010 Chapter I



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2010 Chapter I

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2010 Chapter I

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2010 Chapter I

- **Major Revisions and Additions**
  - Reorganization of Chapter
  - Concrete and Steel Reinforcement by Reference to ACI
  - Local Buckling Provisions for Axial and Flexural Members
  - Expanded and Clarified Load Transfer Provisions
  - Consolidated Shear Provisions
  - Added Diaphragm and Collector Beam Section
  - Added New Provisions for Shear Stud Strength

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2010 Chapter I

- **Major Revisions and Additions**
  - Reorganization of Chapter
  - Concrete and Steel Reinforcement by Reference to ACI
  - Local Buckling Provisions for Axial and Flexural Members
  - Expanded and Clarified Load Transfer Provisions
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  - Added New Provisions for ~~Shear Stud~~ Strength

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2010 Chapter I

- **Major Revisions and Additions**
  - Reorganization of Chapter
  - Concrete and Steel Reinforcement by Reference to ACI
  - Local Buckling Provisions for Axial and Flexural Members
  - Expanded and Clarified Load Transfer Provisions
  - Consolidated Shear Provisions
  - Added Diaphragm and Collector Beam Section
  - Added New Provisions for ~~Shear Stud~~ Strength (Steel Anchors)

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Reorganization

- **Outline**

2005 Specification

- I1: General Provisions
- I2: Axial Members
- I3: Flexural Members
- I4: Combined Forces
- I5: Special Cases

2010 Specification

- I1: General Provisions
- I2: Axial Force
- I3: Flexure
- I4: Shear
- I5: Combined Forces
- I6: Load Transfer
- I7: Composite Diaphragms
- I8: Steel Anchors
- I9: Special Cases

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I1: General Provisions

- **2010 Chapter I**
  - **I1: General Provisions**
  - I2: Axial Force
  - I3: Flexure
  - I4: Shear
  - I5: Combined Flexure and Axial Force
  - I6: Load Transfer
  - I7: Composite Diaphragms and Collector Beams
  - I8: Steel Anchors
  - I9: Special Cases

I1: General Provisions

- **References to ACI**

- Reinforced Concrete Detailing by Reference
- Non-Composite Provisions of ACI with Composite-Specific Provisions provided by AISC

I1: General Provisions

- **Local Buckling Classifications**

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I1: General Provisions

TABLE I1.1a
Limiting Width-to-Thickness Ratios for Compression Steel Elements in Composite Members Subject to Axial Compression
For Use with Section I2.2

Description of Element	Width-to-Thickness Ratio	λ_p Compact/ Noncompact	λ_r Noncompact/ Slender	Maximum Permitted
Walls of rectangular HSS and boxes of uniform thickness	b/t	$2.26\sqrt{\frac{E}{F_y}}$	$3.00\sqrt{\frac{E}{F_y}}$	$5.00\sqrt{\frac{E}{F_y}}$
Round HSS	D/t	$0.15\,E/F_y$	$0.19\,E/F_y$	$0.31\,E/F_y$

TABLE I1.1b
Limiting Width-Thickness Ratios for Compression Steel Elements in Composite Members Subject to Flexure
For Use with Section I3.4

Description of Element	Width-Thickness Ratio	λ_p Compact/ Noncompact	λ_r Noncompact/ Slender	Maximum Permitted
Flanges of rectangular HSS and boxes of uniform thickness	b/t	$2.26\sqrt{\frac{E}{F_y}}$	$3.00\sqrt{\frac{E}{F_y}}$	$5.00\sqrt{\frac{E}{F_y}}$
Webs of rectangular HSS and boxes of uniform thickness	h/t	$3.00\sqrt{\frac{E}{F_y}}$	$5.70\sqrt{\frac{E}{F_y}}$	$5.70\sqrt{\frac{E}{F_y}}$
Round HSS	D/t	$0.09\,E/F_y$	$0.31\,E/F_y$	$0.31\,E/F_y$

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I1: General Provisions

TABLE I1.1a
Limiting Width-to-Thickness Ratios for Compression Steel Elements in Composite Members Subject to Axial Compression
For Use with Section I2.2

Description of Element	Width-to-Thickness Ratio	λ_p Compact/ Noncompact	λ_r Noncompact/ Slender	Maximum Permitted
Walls of rectangular HSS and boxes of uniform thickness	b/t	$2.26\sqrt{\frac{E}{F_y}}$	$3.00\sqrt{\frac{E}{F_y}}$	$5.00\sqrt{\frac{E}{F_y}}$
Round HSS	D/t	$0.15\,E/F_y$	$0.19\,E/F_y$	$0.31\,E/F_y$
		104	131	214

TABLE I1.1b
Limiting Width-Thickness Ratios for Compression Steel Elements in Composite Members Subject to Flexure
For Use with Section I3.4

Description of Element	Width-Thickness Ratio	λ_p Compact/ Noncompact	λ_r Noncompact/ Slender	Maximum Permitted
Flanges of rectangular HSS and boxes of uniform thickness	b/t	$2.26\sqrt{\frac{E}{F_y}}$	$3.00\sqrt{\frac{E}{F_y}}$	$5.00\sqrt{\frac{E}{F_y}}$
Webs of rectangular HSS and boxes of uniform thickness	h/t	$3.00\sqrt{\frac{E}{F_y}}$	$5.70\sqrt{\frac{E}{F_y}}$	$5.70\sqrt{\frac{E}{F_y}}$
Round HSS	D/t	$0.09\,E/F_y$	$0.31\,E/F_y$	$0.31\,E/F_y$

I2: Axial Force

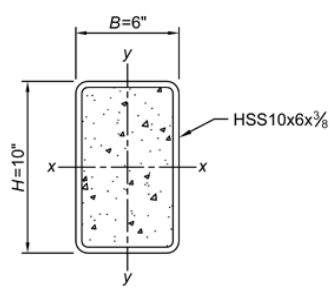
- **2010 Chapter I**
  - I1: General Provisions
  - **I2: Axial Force**
  - I3: Flexure
  - I4: Shear
  - I5: Combined Flexure and Axial Force
  - I6: Load Transfer
  - I7: Composite Diaphragms and Collector Beams
  - I8: Steel Anchors
  - I9: Special Cases

I2: Axial Force

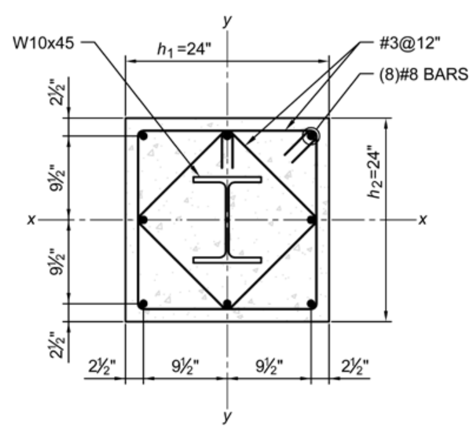
- **Steel-Only Fix**
  - Available Compressive Strength need not be less than bare steel strength

I2: Axial Force

- **Terminology**



FILLED COMPOSITE MEMBER (CFT)



ENCASED COMPOSITE MEMBER (SRC)

I2: Axial Force: Encased

- **Compressive Strength (unchanged)**
  - No Local Buckling Effects
  - Based on a Plastic Strength Model:

$$P_{no} = F_y A_s + F_{ysr} A_{sr} + 0.85 f'_c A_c$$

  - Length (Slenderness) Effects Similar to Noncomposite but Using a Modified EI:

$$EI_{eff} = E_s I_s + 0.5 E_s I_{sr} + C_1 E_c I_c$$

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I2: Axial Force: Encased

- **Material/Detailing Limitations**
  - Minimum Ratio of Encased Shape to Gross Area = 1%
  - Minimum Longitudinal Reinforcement Ratio = 0.4%
  - Transverse Ties…

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I2: Axial Force: Encased

- **Material/Detailing Limitations**

2005 Specification: "The minimum transverse reinforcement shall be at least 0.009 in.^{2} per in. of tie spacing."

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I2: Axial Force: Encased

- **Material/Detailing Limitations**

2005 Specification: "The minimum transverse reinforcement shall be at least 0.009 in.^{2} per in. of tie spacing."

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I2: Axial Force: Encased

- **Material/Detailing Limitations**

2005 Specification: "The minimum transverse reinforcement shall be at least 0.009 in.^{2} per in. of tie spacing."

2010 Specification: No. 3 at 12 in. o.c. or No. 4 at 16 in. o.c.

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I2: Axial Force: Encased

- **Material/Detailing Limitations**

References ACI 318-08 for intermediate tie limitations: "every corner and alternate longitudinal bar shall have lateral support provided by the corner of a tie with an included angle of not more than 135 degrees and no bar shall be farther than 6 in. clear on each side along the tie from such a laterally supported bar."

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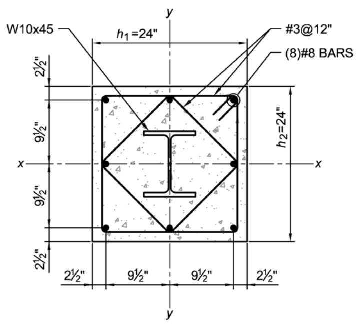
I2: Axial Force: Encased

- **Material/Detailing Limitations**



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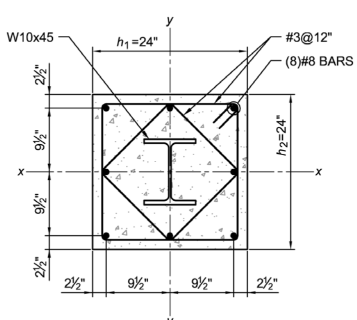
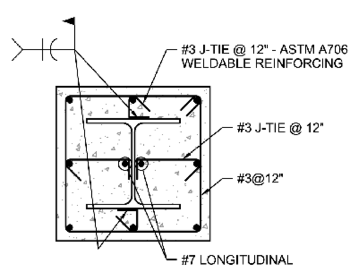
I2: Axial Force: Encased

- **Material/Detailing Limitations**





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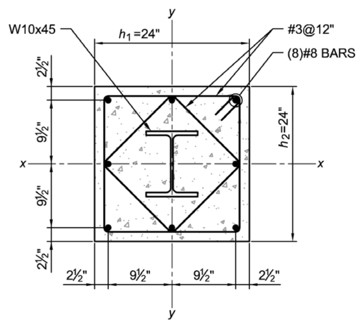
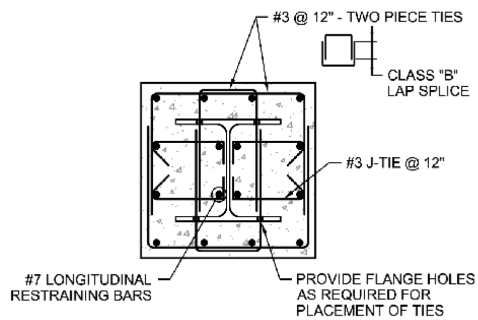
I2: Axial Force: Encased

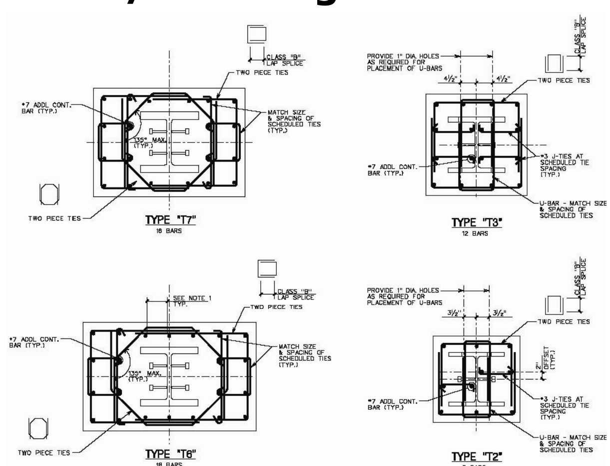
- **Material/Detailing Limitations**





I2: Axial Force: Encased

- **Material/Detailing Limitations**



I2: Axial Force: Filled

- **Local Buckling Effects**
  - Compact Section

I2: Axial Force: Filled

- **Local Buckling Effects**
  - Compact Section

$$P_p = F_y A_s + C_2 f'_c \left(A_c + A_{sr} \frac{E_s}{E_c} \right) \quad where \quad C_2 = 0.85 \, or \, 0.95$$

I2: Axial Force: Filled

•Local Buckling Effects

- Compact Section

$$P_p = F_y A_s + C_2 f'_c \left(A_c + A_{sr} \frac{E_s}{E_c} \right) \quad where \quad C_2 = 0.85\, or\, 0.95$$

- Noncompact Section (Compositely Noncompact)

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I2: Axial Force: Filled

•Local Buckling Effects

- Compact Section

$$P_p = F_y A_s + C_2 f'_c \left(A_c + A_{sr} \frac{E_s}{E_c} \right) \quad where \quad C_2 = 0.85\, or\, 0.95$$

- Noncompact Section (Compositely Noncompact)

$$P_y = F_y A_s + 0.7 f'_c \left(A_c + A_{sr} \frac{E_s}{E_c} \right)$$

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I2: Axial Force: Filled

•Local Buckling Effects

- Compact Section

$$P_p = F_y A_s + C_2 f'_c \left(A_c + A_{sr} \frac{E_s}{E_c} \right) \quad where \quad C_2 = 0.85 \, or \, 0.95$$

- Noncompact Section (Compositely Noncompact)

$$P_y = F_y A_s + 0.7 f'_c \left(A_c + A_{sr} \frac{E_s}{E_c} \right)$$

- Slender Section

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I2: Axial Force: Filled

•Local Buckling Effects

- Compact Section

$$P_p = F_y A_s + C_2 f'_c \left(A_c + A_{sr} \frac{E_s}{E_c} \right) \quad where \quad C_2 = 0.85 \, or \, 0.95$$

- Noncompact Section (Compositely Noncompact)

$$P_y = F_y A_s + 0.7 f'_c \left(A_c + A_{sr} \frac{E_s}{E_c} \right)$$

- Slender Section

$$P_{no} = F_{cr} A_s + 0.7 f'_c \left(A_c + A_{sr} \frac{E_s}{E_c} \right) \quad where \quad F_{cr} = 9E_s / \left(b/t \right)^2$$

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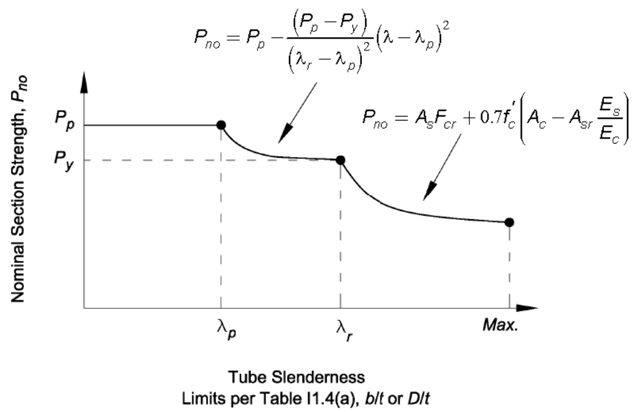
I2: Axial Force: Filled

- **Local Buckling Effects**



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I3: Flexure

- **2010 Chapter I**
  - I1: General Provisions
  - I2: Axial Force
  - **I3: Flexure**
  - I4: Shear
  - I5: Combined Flexure and Axial Force
  - I6: Load Transfer
  - I7: Composite Diaphragms and Collector Beams
  - I8: Steel Anchors
  - I9: Special Cases

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I3: Flexure - Beams

•Flexural Strength

- NO SUBSTANTIAL REVISIONS

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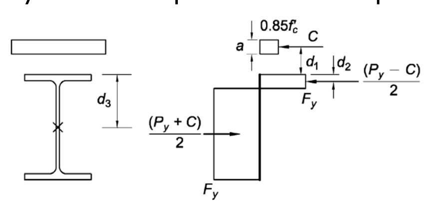
I3: Flexure - Beams

•Flexural Strength

- Commentary with Composite Beam Equations Added Back



$$M_n = C(d_1 + d_2) + P_y(d_3 - d_2) \quad \text{(C-I3-9)}$$

where

P_y = tensile strength of the steel section; for a non-hybrid steel section $P_y = A_s F_y$, kips (N)
d_1 = distance from the centroid of the compression force C in concrete to the top of the steel section, in. (mm)
d_2 = distance from the centroid of the compression force in the steel section to the top of the steel section, in. (mm). For the case of no compression in the steel section $d_2 = 0$.
d_3 = distance from P_y to the top of the steel section, in. (mm)

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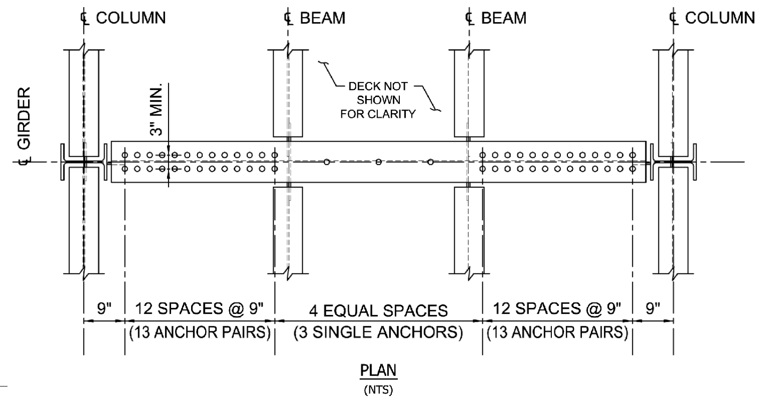
I3: Flexure - Beams

- **Steel Headed Stud Anchors**
  - Added Minimum Free Edge Distances (8 in. and 10 in.)



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I3: Flexure - Filled

- **Local Buckling Effects in Filled Tubes**

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I3: Flexure - Filled

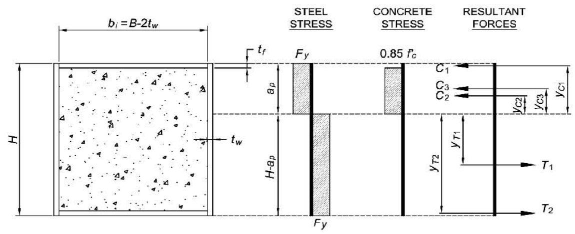

Figure I-7-2. Plastic moment stress blocks and force distribution.

Component	Force	Moment arm
Compression in steel flange	$C_1 = F_y b_i t_f$	$y_{C1} = a_p - \frac{t_f}{2}$
Compression in concrete	$C_2 = 0.85 f'_c (a_p - t_f) b_i$	$y_{C2} = \frac{a_p - t_f}{2}$
Compression in steel web	$C_3 = 2F_y a_p t_w$	$y_{C3} = \frac{a_p}{2}$
Tension in steel web	$T_1 = 2F_y (H - a_p) t_w$	$y_{T1} = \frac{H - a_p}{2}$
Tension in steel flange	$T_2 = F_y b_i t_f$	$y_{T2} = H - a_p - \frac{t_f}{2}$
where: $a_p = \frac{2F_y H t_w + 0.85 f'_c b_i t_f}{4F_y t_w + 0.85 f'_c b_i}$ $M_y = \sum (\text{force})(\text{moment arm})$		

Compact

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I3: Flexure - Filled

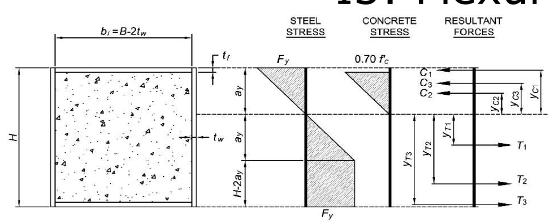

Figure I-7-3. Yield moment stress blocks and force distribution.

Component	Force	Moment arm
Compression in steel flange	$C_1 = F_y b_i t_f$	$y_{C1} = a_y - \frac{t_f}{2}$
Compression in concrete	$C_2 = 0.35 f'_c (a_y - t_f) b_i$	$y_{C2} = \frac{2(a_y - t_f)}{3}$
Compression in steel web	$C_3 = F_y a_y t_w$	$y_{C3} = \frac{2a_y}{3}$
Tension in steel web	$T_1 = F_y a_y t_w$ $T_2 = 2F_y (H - 2a_y) t_w$	$y_{T1} = \frac{2a_y}{3}$ $y_{T2} = \frac{H}{2}$
Tension in steel flange	$T_3 = F_y b_i t_f$	$y_{T3} = H - a_y - \frac{t_f}{2}$
where: $a_y = \frac{2F_y H t_w + 0.35 f'_c b_i t_f}{4F_y t_w + 0.35 f'_c b_i}$ $M_y = \sum (\text{force})(\text{moment arm})$		

Noncompact (at Transition)

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I3: Flexure - Filled

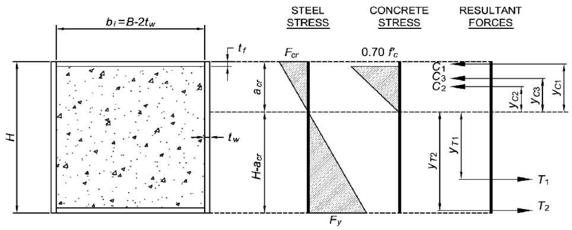


Figure I-7-4. First yield moment stress blocks and force distribution.

Component	Force	Moment arm
Compression in steel flange	$C_1 = F_{cr} b_i t_f$	$y_{C1} = a_{cr} - \frac{t_f}{2}$
Compression in concrete	$C_2 = 0.35 f'_c (a_{cr} - t_f) b_i$	$y_{C2} = \frac{2(a_{cr} - t_f)}{3}$
Compression in steel web	$C_3 = F_{cr} a_{cr} t_w$	$y_{C3} = \frac{2a_{cr}}{3}$
Tension in steel web	$T_1 = F_y (H - a_{cr}) t_w$	$y_{T1} = \frac{2(H - a_{cr})}{3}$
Tension in steel flange	$T_2 = F_y b_i t_f$	$y_{T3} = H - a_{cr} - \frac{t_f}{2}$

where:

$$a_{cr} = \frac{F_y H t_w + b_i t_f (0.35 f'_c + F_y - F_{cr})}{t_w (F_{cr} + F_y) + 0.35 f'_c b_i}$$

$$M_y = \sum (\text{force})(\text{moment arm})$$

Slender

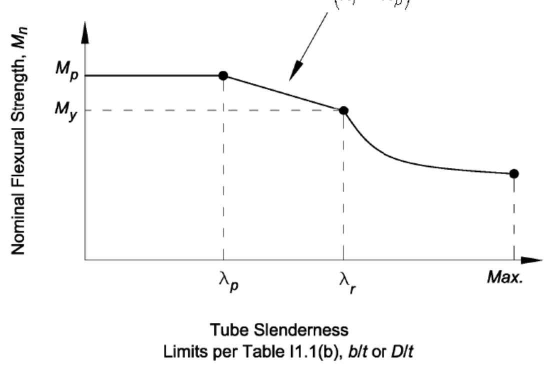
There's always a solution in steel.

69

I3: Flexure - Filled

- **Local Buckling Effects in Filled Tubes**

$$M_n = M_p - \frac{(M_p - M_y)}{(\lambda_r - \lambda_p)}(\lambda - \lambda_p)$$



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70

I4: Shear

- **2010 Chapter I**
  - I1: General Provisions
  - I2: Axial Force
  - I3: Flexure
  - **I4: Shear**
  - I5: Combined Flexure and Axial Force
  - I6: Load Transfer
  - I7: Composite Diaphragms and Collector Beams
  - I8: Steel Anchors
  - I9: Special Cases

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I4: Shear

- **Shear Provisions**
  - For all Member Types Collected into One Place
  - Three Methods Provided for Design

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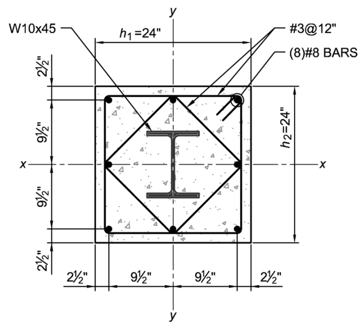
I4: Shear

- **Method 1 – Steel Only (Chapter G)**



$$V_n = 0.6 F_y A_w C_v$$

$\phi = 1.0$ (LRFD)
$\Omega = 1.5$ (ASD)

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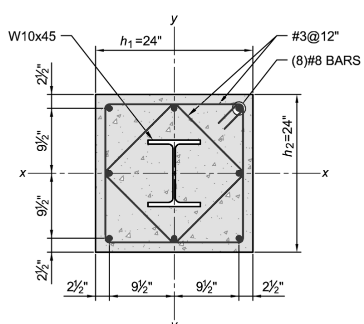
I4: Shear

- **Method 2 – Reinforced Concrete (ACI)**



$$V_n = V_c + V_s$$

$$V_n = 2\sqrt{f'_c} b_w d + \frac{A_v f_{yt} d}{s}$$

$\phi = 0.75$ (LRFD)
$\Omega = 2.0$ (ASD)

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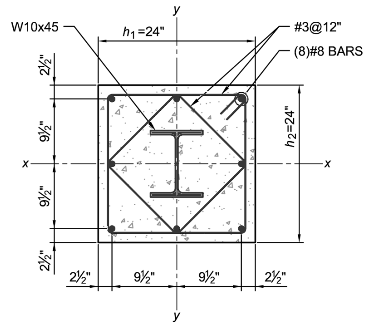
I4: Shear

- **Method 3 – Combination of Steels**



$$V_n = 0.6F_yA_wC_v + \frac{A_vf_{yt}d}{s}$$

$\phi = 0.75$ (LRFD)
$\Omega = 2.0$ (ASD)

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75

I5: Combined Forces

- **2010 Chapter I**
  - I1: General Provisions
  - I2: Axial Force
  - I3: Flexure
  - I4: Shear
  - **I5: Combined Flexure and Axial Force**
  - I6: Load Transfer
  - I7: Composite Diaphragms and Collector Beams
  - I8: Steel Anchors
  - I9: Special Cases

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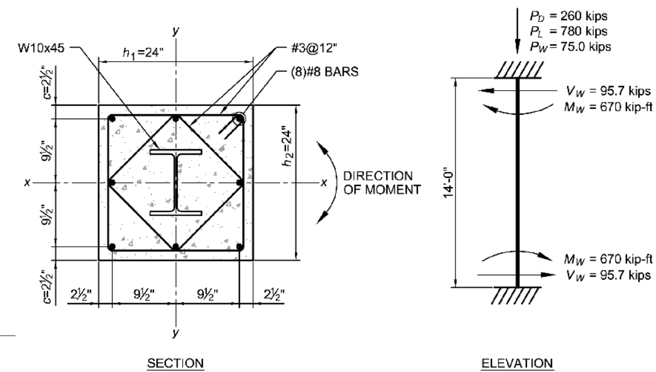
I5: Combined Forces

- **Allowable Methods**
  - Strain Compatibility (Just Like Concrete)
  - Plastic Stress Distribution Methods



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I5: Combined Forces

- **Plastic Stress Distribution Method 1**
  - Chapter H Interaction Equations

When $\frac{P_r}{P_c} \geq 0.2$

$$\frac{P_r}{P_c} + \frac{8}{9}\left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1.0 \qquad \text{(H1-1a)}$$

When $\frac{P_r}{P_c} < 0.2$

$$\frac{P_r}{2P_c} + \left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1.0 \qquad \text{(H1-1b)}$$

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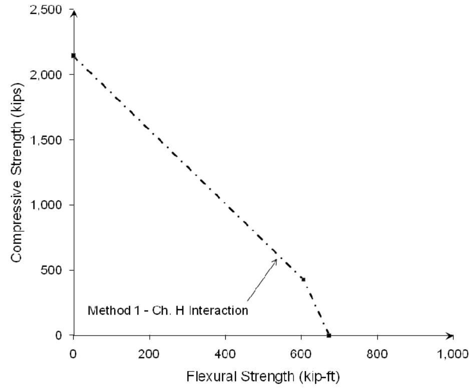
I5: Combined Forces

- **Plastic Stress Distribution Method 1**
  - Chapter H Interaction Equations



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I5: Combined Forces

- **Plastic Stress Distribution Method 2**
  - Piecewise-Linear Interaction Curve

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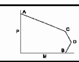
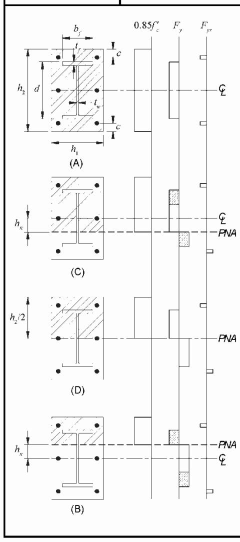
I5: Combined Forces

PLASTIC CAPACITIES FOR RECTANGULAR, ENCASED W-SHAPES BENT ABOUT THE X-X AXIS





Point	Defining Equations
A	$P_A = A_s F_y + A_{sr} F_{yr} + 0.85 f'_c A_c$ $M_A = 0$ A_s = area of steel shape A_{sr} = area of all continuous reinforcing bars $A_c = h_1 h_2 - A_s - A_{sr}$
C	$P_C = 0.85 f'_c A_c$ $M_C = M_B$
D	$P_D = \frac{0.85 f'_c A_c}{2}$ $M_D = Z_s F_y + Z_r F_{yr} + \frac{Z_c}{2}(0.85 f'_c)$ Z_s = full x-axis plastic section modulus of steel shape A_{srs} = area of continuous reinforcing bars at the centerline $Z_r = (A_{sr} - A_{srs})\left(\frac{h_2}{2} - c\right)$ $Z_c = \frac{h_1 h_2^2}{4} - Z_s - Z_r$
B	$P_B = 0$ $M_B = M_D - Z_{sn} F_y - \frac{1}{2} Z_{cn}(0.85 f'_c)$ $Z_{cn} = h_1 h_n^2 - Z_{sn}$ For h_n below the flange $\left(h_n \le \frac{d}{2} - t_f\right)$ $h_n = \frac{0.85 f'_c (A_c + A_{srs}) - 2F_{yr} A_{srs}}{2\left[0.85 f'_c (h_1 - t_w) + 2F_y t_w\right]}$ $Z_{sn} = t_w h_n^2$ For h_n within the flange $\left(\frac{d}{2} - t_f < h_n \le \frac{d}{2}\right)$ $h_n = \frac{0.85 f'_c (A_c + A_s - d b_f + A_{srs}) - 2F_y (A_s - d b_f) - 2F_{yr} A_{srs}}{2\left[0.85 f'_c (h_1 - b_f) + 2F_y b_f\right]}$ $Z_{sn} = Z_s - b_f\left(\frac{d}{2} - h_n\right)\left(\frac{d}{2} + h_n\right)$ For h_n above the flange $\left(h_n > \frac{d}{2}\right)$ $h_n = \frac{0.85 f'_c (A_c - A_s + A_{srs}) - 2F_y A_s - 2F_{yr} A_{srs}}{2(0.85 f'_c h_1)}$ $Z_{sn} = Z_{sx}$ = full x-axis plastic section modulus of steel shape

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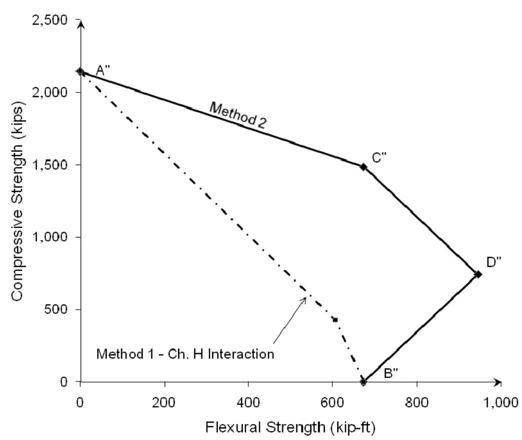
81

I5: Combined Forces

- **Plastic Stress Distribution Method 2**
  - Piecewise-Linear Interaction Curve



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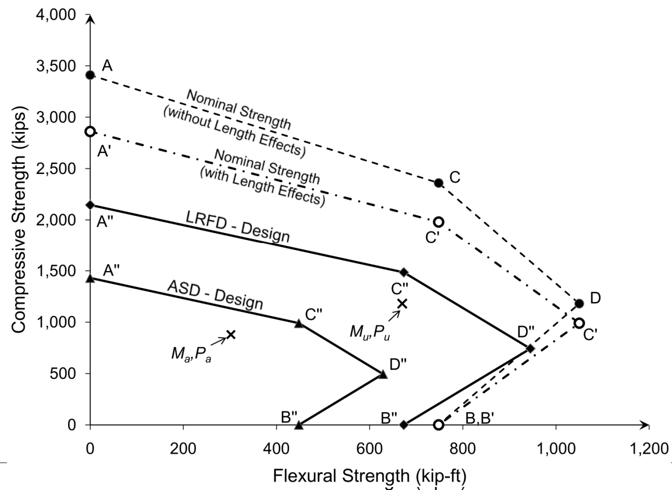
82

I5: Combined Forces

- **Plastic Stress Distribution Method 2**



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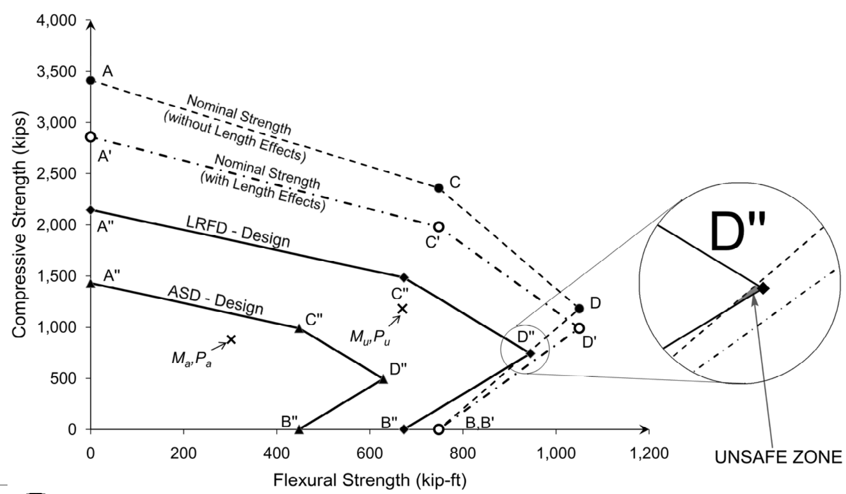
83

I5: Combined Forces

- **Plastic Stress Distribution Method 2**



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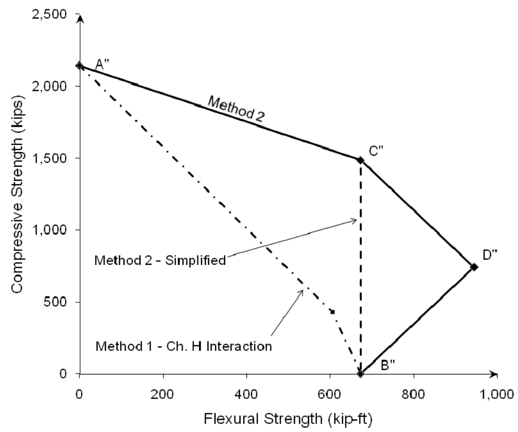
84

I5: Combined Forces

- **Plastic Stress Distribution Method 3**
- "Simplified" Version of Method 2



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I5: Combined Forces

- **Plastic Stress Distribution Method 3**
- "Simplified" Version of Method 2

If $P_r < P_C$

$$\frac{M_{rx}}{M_{Cx}} + \frac{M_{ry}}{M_{Cy}} \leq 1 \qquad \text{(C-I5-1a)}$$

If $P_r \geq P_C$

$$\frac{P_r - P_C}{P_A - P_C} + \frac{M_{rx}}{M_{Cx}} + \frac{M_{ry}}{M_{Cy}} \leq 1 \qquad \text{(C-I5-1b)}$$

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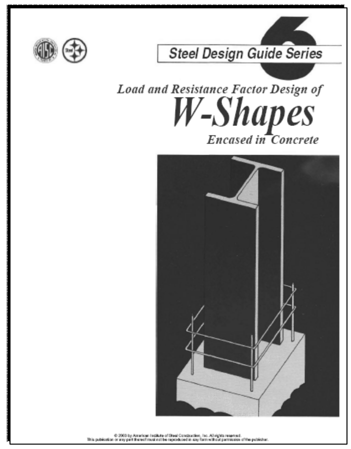
I5: Combined Forces

- **Plastic Stress Distribution Method 4**
  - AISC Design Guide 6
  - Based on 1986 LRFD
  - 5, 8ksi Normal Wt Conc.
  - 1-4% Rebar Patterns



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87

I5: Combined Forces

- **Research Basis?**
  - Mechanics Based Formulations Supplemented by Numerical Modeling Validated by Research

$$EI_{eff} = E_s I_s + 0.5 E_s I_{sr} + C_1 E_c I_c$$

  - Recent Testing in MAST (Multi-Axial Subassemblage Testing) Lab at University of Minnesota to Help Fill in the Gaps

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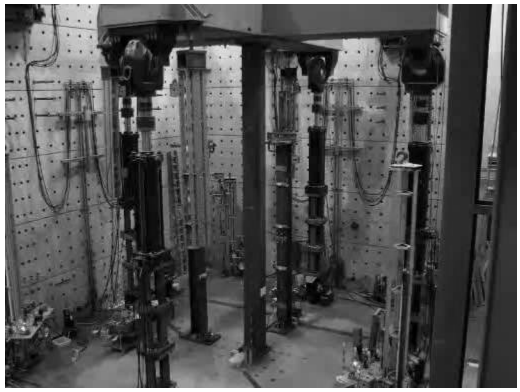
88

I5: Combined Forces

- **Research Basis?**



Material shown from NEESR project supported by the National Science Foundation under Grant No. CMMI-0619047, the American Institute of Steel Construction, the Georgia Institute of Technology, and the University of Illinois at Urbana-Champaign. In-kind funding was provided by Atlas Tube Inc. and LeJeune Steel Co.

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I6: Load Transfer

- **2010 Chapter I**
  - I1: General Provisions
  - I2: Axial Force
  - I3: Flexure
  - I4: Shear
  - I5: Combined Flexure and Axial Force
  - **I6: Load Transfer**
  - I7: Composite Diaphragms and Collector Beams
  - I8: Steel Anchors
  - I9: Special Cases

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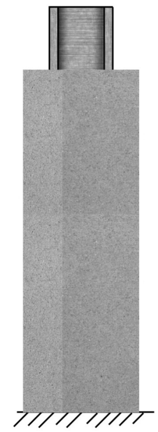
I6: Load Transfer

- **What Is Load Transfer?**



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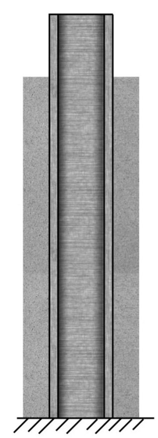
91

I6: Load Transfer

- **What Is Load Transfer?**



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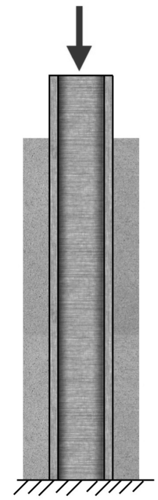
92

I6: Load Transfer

- **What Is Load Transfer?**

1. Force Introduction (I6.1)



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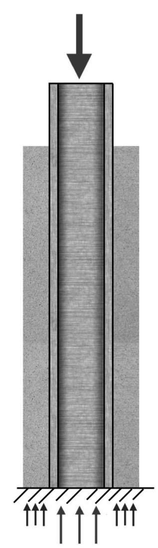
93

I6: Load Transfer

- **What Is Load Transfer?**

1. Force Introduction (I6.1)
2. Force Allocation (I6.2)



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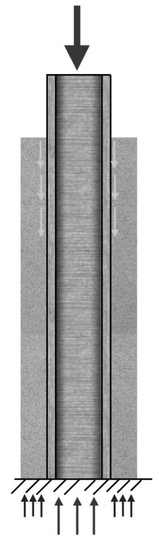
94

I6: Load Transfer

- **What Is Load Transfer?**

1. Force Introduction (I6.1)
2. Force Allocation (I6.2)
3. Force Transfer (I6.3)



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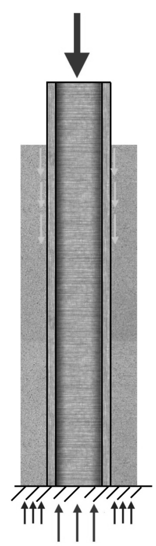
95

I6: Load Transfer

- **What Is Load Transfer?**

1. Force Introduction (I6.1)
2. Force Allocation (I6.2)
3. Force Transfer (I6.3)
4. Detailing Provisions (I6.4)



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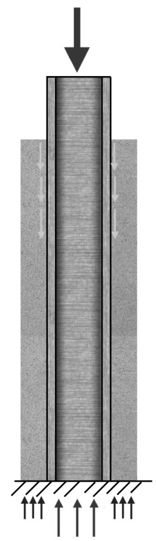
96

I6: Load Transfer

- **What Is Load Transfer?**



1. **Force Introduction (I6.1)**
2. Force Allocation
3. Force Transfer
4. Detailing Provisions

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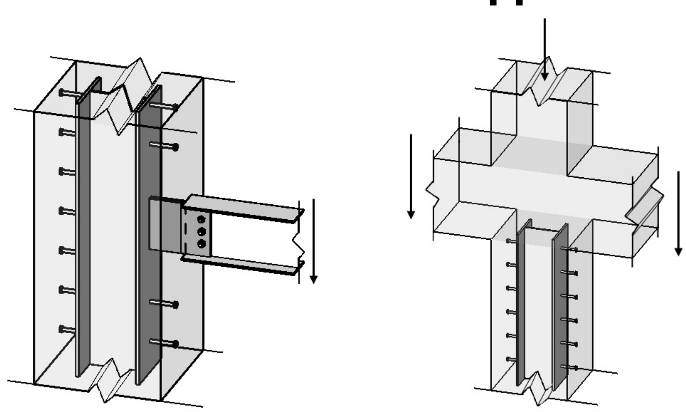
I6: Load Transfer

- **How is External Force Applied?**



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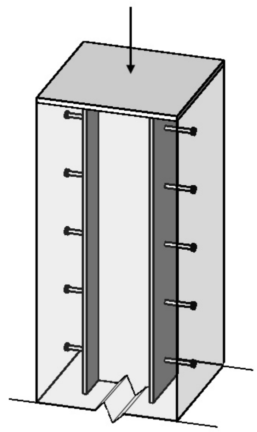
I6: Load Transfer

- **How is External Force Applied?**



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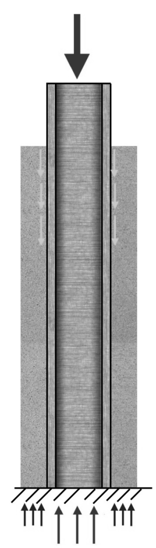
I6: Load Transfer

- **Force Allocation**

1. Force Introduction (I6.1)
2. **Force Allocation (I6.2)**
3. Force Transfer (I6.3)
4. Detailing Provisions (I6.4)



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I6: Load Transfer

- **Force Allocation Requirement:**

The applied external forces shall be distributed within the composite section based on the same ratio of steel section strength to reinforced concrete section strength as represented by the plastic capacity model.

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101

I6: Load Transfer

- **Plastic Model**

Encased Composite Columns

$P_{no} = A_s F_y + A_{sr} F_{ysr} + 0.85 A_c f'_c$ (Eq. I2-4)

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I6: Load Transfer

- **Plastic Model**

Encased Composite Columns

$P_{no} = \mathbf{A_s F_y} + A_{sr}F_{ysr} + 0.85A_c f'_c$ (Eq. I2-4)

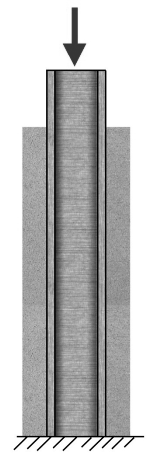
I6: Load Transfer

- **Plastic Model**

Encased Composite Columns

$P_{no} = A_s F_y + \mathbf{A_{sr}F_{ysr} + 0.85A_c f'_c}$ (Eq. I2-4)

I6: Load Transfer



- **Example**

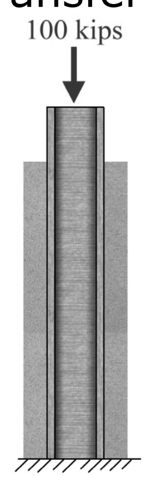
$P_{no} = A_s F_y + A_{sr} F_{ysr} + 0.85 A_c f'_c$

Say: $A_s F_y$ = 67% of Total P_{no}

There's always a solution in steel.

105

I6: Load Transfer



- **Example**

$P_{no} = A_s F_y + A_{sr} F_{ysr} + 0.85 A_c f'_c$

Say: $A_s F_y$ = 67% of Total P_{no}

There's always a solution in steel.

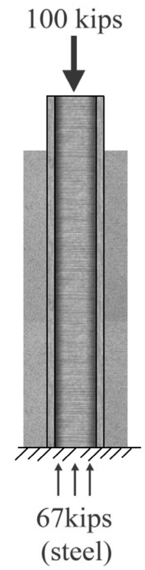
106

I6: Load Transfer

- **Example**

$P_{no} = A_sF_y + A_{sr}F_{ysr} + 0.85A_cf'_c$

Say: A_sF_y = 67% of Total P_{no}



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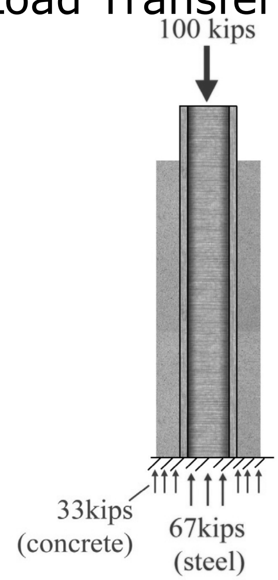
107

I6: Load Transfer

- **Example**

$P_{no} = A_sF_y + A_{sr}F_{ysr} + 0.85A_cf'_c$

Say: A_sF_y = 67% of Total P_{no}



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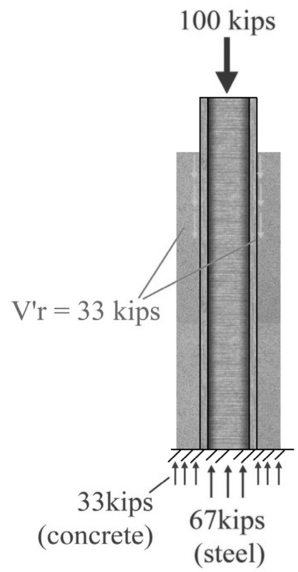
108

I6: Load Transfer

- **Example**

$P_{no} = A_sF_y + A_{sr}F_{ysr} + 0.85A_cf'_c$

Say: A_sF_y = 67% of Total P_{no}



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109

I6: Load Transfer

- **Example**

$P_{no} = A_sF_y + A_{sr}F_{ysr} + 0.85A_cf'_c$

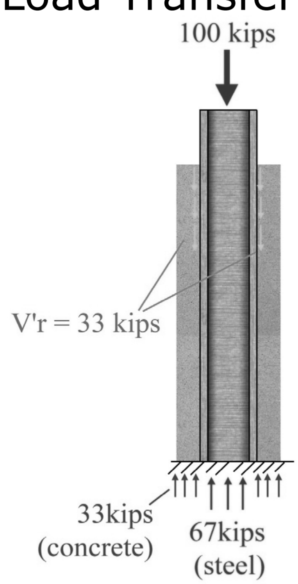
Say: A_sF_y = 67% of Total P_{no}

$V'_r = P_r\,(1 - A_sF_y/P_{no})$ Eq. I6-1

(For External Force Applied to Steel Only)

$V'_r = P_r\,(A_sF_y/P_{no})$ Eq. I6-2

(For External Force Applied to Concrete Only)



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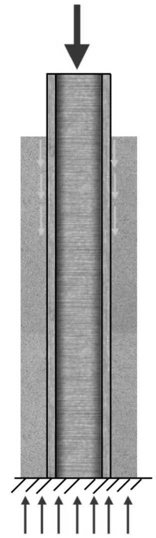
110

I6: Load Transfer

- **Force Transfer**



1. Force Introduction (I6.1)
2. Force Allocation (I6.2)
3. **Force Transfer (I6.3)**
4. Detailing Provisions

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111

I6: Load Transfer

- **Mechanisms for Force Transfer**

Filled Sections

- Direct Bearing (I6.3a)
- Shear Connection (I6.3b)
- Bond (I6.3c)

Encased Sections

- Direct Bearing
- Shear Connection

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112

I6: Load Transfer

- **Mechanisms for Force Transfer**

Filled Sections	Encased Sections
• Direct Bearing (I6.3a)	• Direct Bearing
• Shear Connection (I6.3b)	• Shear Connection
• Bond (I6.3c)	

$\phi R_n \geq V'_r$ (LRFD)

$R_n / \Omega \geq V'_r$ (ASD)

R_n = Mechanism Strength

V'_r = Longitudinal Shear

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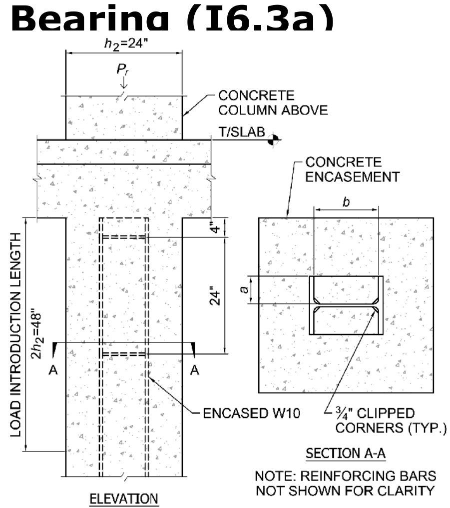
I6: Load Transfer

- **Direct Bearing (I6.3a)**



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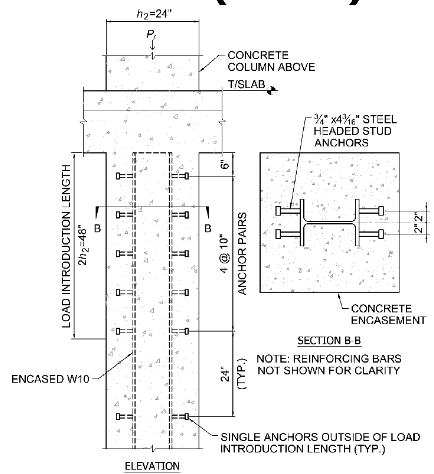
114

I6: Load Transfer

- **Shear Connection (I6.3b)**



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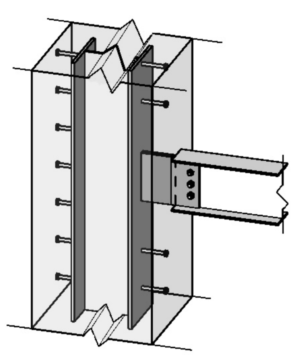
I6: Load Transfer

- **Shear Connection (I6.3b)**



- What Strength to Use?
- What Resistance or Safety Factor is Appropriate?
- Study of Available Data Conducted by Pallares and Hajjar to Answer these Questions – this became basis for I8.3: Steel Anchors in Composite Components.

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116

I6: Load Transfer

- **Bond (I6.3c)**
  - Applicable to Filled Columns Only
  - 60 psi Nominal Bond Strength (F_{in})

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117

I6: Load Transfer

- **Bond (I6.3c)**
  - Applicable to Filled Columns Only
  - 60 psi Nominal Bond Strength (F_{in})

For Rectangular Filled Columns:

$R_n = B^2 C_{in} F_{in}$ $\phi=0.45$ (LRFD)

$\Omega=2.31$ (ASD)

B = Width of Section at Loaded Face

C_{in} = 4 if connection away from ends of member, 2 if at end of member

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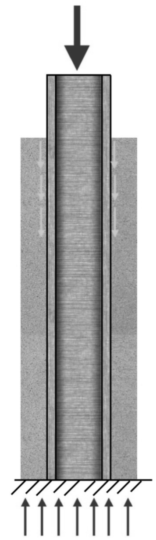
118

I6: Load Transfer

- **Detailing Provisions**

1. Force Introduction (I6.1)
2. Force Allocation (I6.2)
3. Force Transfer (I6.3)
4. **Detailing Provisions (I6.4)**



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I7: Composite Diaphragms

- **2010 Chapter I**
  - I1: General Provisions
  - I2: Axial Force
  - I3: Flexure
  - I4: Shear
  - I5: Combined Flexure and Axial Force
  - I6: Load Transfer
  - **I7: Composite Diaphragms and Collector Beams**
  - I8: Steel Anchors
  - I9: Special Cases

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I7: Composite Diaphragms

- **Pointer to Commentary Discussion**
  - Composite Diaphragms
  - Collector Beams (Drat Struts)

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121

I7: Composite Diaphragms

- **Notes on Composite Collector Beams**
  - Beware the "Noncomposite" Composite Beam

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122

I7: Composite Diaphragms

- **Notes on Composite Collector Beams**
  - Beware the "Noncomposite" Composite Beam
  - Generally Unnecessary to Superimpose Horizontal Shears

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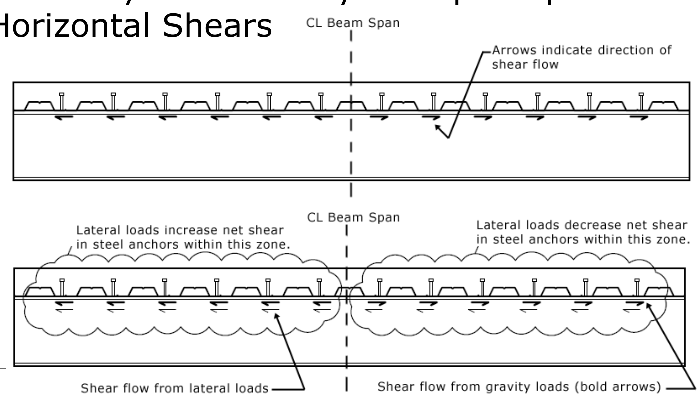
I7: Composite Diaphragms

- **Notes on Composite Collector Beams**
  - Beware the "Noncomposite" Composite Beam
  - Generally Unnecessary to Superimpose Horizontal Shears



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I7: Composite Diaphragms

- **Notes on Composite Collector Beams**
  - Beware the "Noncomposite" Composite Beam
  - Generally Unnecessary to Superimpose Horizontal Shears
  - Check Interaction of Flexure and Axial Load

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I8: Steel Anchors

- **2010 Chapter I**
  - I1: General Provisions
  - I2: Axial Force
  - I3: Flexure
  - I4: Shear
  - I5: Combined Flexure and Axial Force
  - I6: Load Transfer
  - I7: Composite Diaphragms and Collector Beams
  - **I8: Steel Anchors**
  - I9: Special Cases

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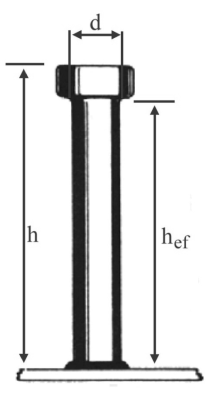
I8: Steel Anchors

- **Two Main Categories**
  - I8.2: Steel Anchors in Composite Beams
  - I8.3: Steel Anchors in Composite Components
    - -I8.3a: Shear
    - -I8.3b: Tension
    - -I8.3c: Interaction

There's always a solution in steel. 127

I8: Steel Anchors

- **Shear Connection Strength (I8.3)**

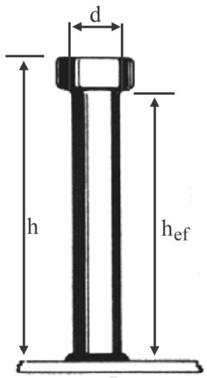


- $h_{ef}/d > 4.0$: 81% of Anchors Failed in Steel
- $h_{ef}/d > 4.5$: 85% of Anchors Failed in Steel
- $h_{ef}/d > 5.5$: 98% of Anchors Failed in Steel

There's always a solution in steel. 128

I8: Steel Anchors

- **Shear Connection Strength (I8.3)**



- $h_{ef}/d > 4.0$: 81% of Anchors Failed in Steel
- $h_{ef}/d > 4.5$: 85% of Anchors Failed in Steel
- $h_{ef}/d > 5.5$: 98% of Anchors Failed in Steel

2010 AISC Specification: Allows Strength Determination by Steel Strength Alone If $h/d>5.0$

$$R_n = A_{sc}F_u \quad \text{Eq. I8-3}$$

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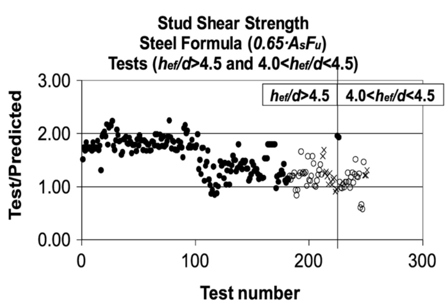
129

I8: Steel Anchors

- **Shear Connection Strength (I8.3)**



e. $F_u = 65$ ksi. 224/251 tests. Avg.: 1.541/1.501. St.D.: 0.336/0.353.

From Pallares and Hajjar, 2010

$$R_n = A_{sc}F_u \quad \text{Eq. I8-3}$$

$\phi=0.65$ (LRFD)

$\Omega=2.31$ (ASD)

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130

I8: Steel Anchors

- **Tension and Interaction**

Loading Condition	Normal Weight Concrete	Lightweight Concrete
Shear	$h/d = 5$	$h/d = 7$
Tension	$h/d = 8$	$h/d = 10$
Shear+Tension	$h/d = 8$	N/A+

h/d = ratio of steel headed stud anchor shank length to the top of the stud head, to shank diameter

+ Refer to ACI 318 Appendix D for the calculation of interaction effects of anchors embedded in lightweight concrete.

I9: Special Cases

- **2010 Chapter I**
  - I1: General Provisions
  - I2: Axial Force
  - I3: Flexure
  - I4: Shear
  - I5: Combined Flexure and Axial Force
  - I6: Load Transfer
  - I7: Composite Diaphragms and Collector Beams
  - I8: Steel Anchors
  - **I9: Special Cases**

Questions?

End of Part 1:

Any Questions?

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133

NEW COMPOSITE DESIGN PROVISIONS

IN THE 2010 AISC SPECIFICATION

PART II: DESIGN EXAMPLES

There's always a solution in steel.

134

Outline

- **Outline**
  - Layout and Scope of Design Examples
  - Review of Select Design Problems

There's always a solution in steel.

135

Why Update?

- **Why the Update?**

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136

Why Update?

2005 Design Examples

- I-1: Composite Beam Design
- I-2: Filled Composite Column in Axial Compression
- I-3: Encased Composite Column in Axial Compression
- I-4: Encased Composite Column in Axial Tension
- I-5: Filled Composite Column in Axial Tension
- I-6: Filled Composite Member Design for Shear
- I-7: Combined Axial and Flexural Strength (Encased)

Why Update?

- **Why the Update?**
  - "Fill in the Gaps" and restore order

Why Update?

- I-1: Composite Beam Design
- I-2: Composite Girder Design
- I-3: Concrete Filled Member Force Allocation/Load Transfer
- I-4: Concrete Filled Member in Axial Compression
- I-5: Concrete Filled Member in Axial Tension
- **I-6: Concrete Filled Member with Combined Loading**
- I-7: Concrete Filled Box Column with Noncompact/Slender Elem.
- I-8: Encased Composite Member Force Allocation/Load Transfer
- I-9: Encased Composite Member in Axial Compression
- I-10: Encased Composite Member in Axial Tension
- I-11: Encased Composite Member with Combined Loading
- I-12: Steel Anchors in Composite Components

There's always a solution in steel.

139

Why Update?

- **Why the Update?**
  - "Fill in the Gaps" and restore order
  - Provide more detailed guidance for the most commonly used composite members

There's always a solution in steel.

140

Why Update?

- I-1: Composite Beam Design
- **I-2: Composite Girder Design**
- I-3: Concrete Filled Member Force Allocation/Load Transfer
- I-4: Concrete Filled Member in Axial Compression
- I-5: Concrete Filled Member in Axial Tension
- I-6: Concrete Filled Member with Combined Loading
- I-7: Concrete Filled Box Column with Noncompact/Slender Elem.
- I-8: Encased Composite Member Force Allocation/Load Transfer
- I-9: Encased Composite Member in Axial Compression
- I-10: Encased Composite Member in Axial Tension
- I-11: Encased Composite Member with Combined Loading
- I-12: Steel Anchors in Composite Components

There's always a solution in steel.

141

Why Update?

- **Why the Update?**
  - "Fill in the Gaps" and restore order
  - Provide more detailed guidance for most commonly used composite members
  - Cover new provisions from the 2010 Specification

There's always a solution in steel.

142

Why Update?

- I-1: Composite Beam Design
- I-2: Composite Girder Design
- **I-3: Concrete Filled Member Force Allocation/Load Transfer**
- I-4: Concrete Filled Member in Axial Compression
- I-5: Concrete Filled Member in Axial Tension
- I-6: Concrete Filled Member with Combined Loading
- **I-7: Filled Box Column with Noncompact/Slender Elem.**
- **I-8: Encased Composite Member Force Allocation/Load Transfer**
- I-9: Encased Composite Member in Axial Compression
- I-10: Encased Composite Member in Axial Tension
- I-11: Encased Composite Member with Combined Loading
- **I-12: Steel Anchors in Composite Components**

Why Update?

- **Why the Update?**
  - "Fill in the Gaps" and restore order
  - Provide more detailed guidance for most commonly used composite members
  - Cover new provisions from the 2010 Specification
  - Available Online Now at:

    www.aisc.org/designexamples

Review

- **Review of Select Problems**
  - I-2: Composite Girder
  - I-8: Encased Member Force Allocation/Transfer

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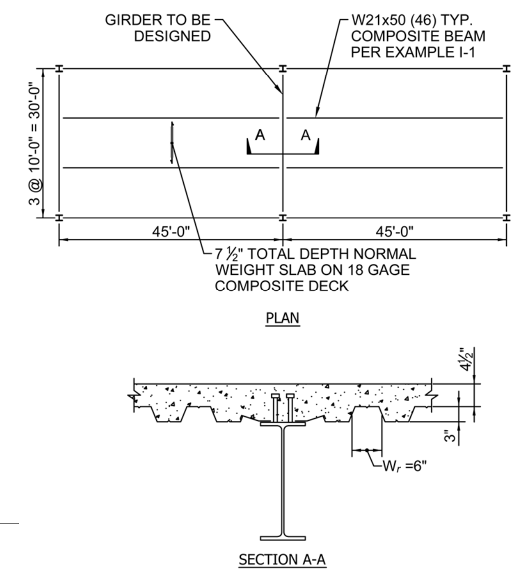
Girder Design

- **Problem Statement**



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Girder Design

- **Steps for Composite Beam Design**

1. Determine Loads
2. Check Noncomposite Flexural Strength
3. Check Noncomposite Deflection Limits
4. Check Composite Flexural Strength
5. Check Composite Deflection Limits

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Girder Design

- **Why 7 ½"?**

Restrained Assembly Rating	Type of Protection	Concrete Thickness & Type (1)	U.L. Design No. (2,3,4)
2 Hr. (continued)	Sprayed Fiber	2" NW&LW	859 *
		2 1/2" NW&LW	822 *
			825 *
			831 *
			832 *
			833 *
			847 *
			858 *
			861 *
			870 *
			871 *
		2 1/2" LW	862 *
		2 1/2" NW	864 *
		3 1/4" LW	860 *
	Unprotected Deck	3 1/4" LW	733 #
			826 #
			840 #
			902 #
			907 #
			913 #
			916 #
			918 #
			919 #
			920 #
		4 1/2" NW	902 #
			916 #
			918 #
			919 #

There's always a solution in steel. 148

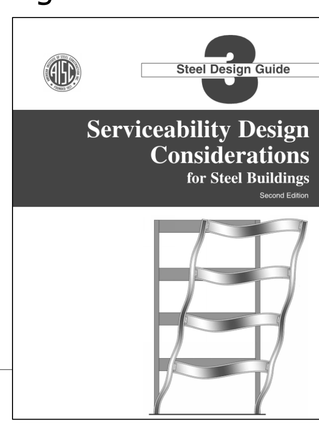
Girder Design

- **Select Loading (Dead)**
- Dead Load = 75 psf (from deck catalog)+beam and girder weights
- What about concrete ponding?

There's always a solution in steel. 149

Girder Design

- **Select Loading (Dead)**
- Dead Load = 75 psf (from deck catalog)+beam and girder weights
- What about concrete ponding?
- AISC Design Guide 3 Recommends increasing slab weight by 10% (after Ruddy, *Engineering Journal*, 3Q, 1986)



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Girder Design

- **Select Loading (Construction Live)**
- 20psf?

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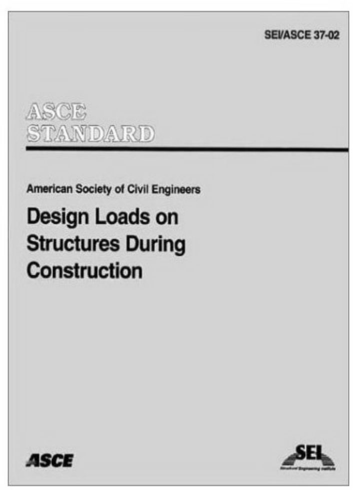
151

Girder Design

- **Select Loading (Construction Live)**
- 20psf?
- ASCE 37-02 "Design Loads on Structures During Construction"

  "Light Duty" Operational Class which includes "Concrete transport and placement by hose"

  =25psf



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152

Girder Design

- **Steps for Composite Beam Design**

1. Determine Loads
2. Check Noncomposite Flexural Strength
3. Check Noncomposite Deflection Limits
4. Check Composite Flexural Strength
5. Check Composite Deflection Limits

There's always a solution in steel.

153

Girder Design

- **Check Noncomposite Flexural Strength**
- Does the deck brace the beam?

There's always a solution in steel.

154

Girder Design

- **Check Noncomposite Flexural Strength**
- Does the deck brace the beam?
- For deck running perpendicular to the beam…

There's always a solution in steel.

155

Girder Design

- **Check Noncomposite Flexural Strength**
- Does the deck brace the beam?
- For deck running perpendicular to the beam…

YES

"Shear Diaphragm Bracing of Beams I: Stiffness and Strength Behavior"

"Shear Diaphragm Bracing of Beams II: Design Requirements"

Helwig and Yura, ASCE Journal of Structural Engineering, March 2008

There's always a solution in steel.

156

Girder Design

- **Check Noncomposite Flexural Strength**
- Does the deck brace the beam?
- But what about deck parallel to the girder?

There's always a solution in steel.

157

Girder Design

- **Check Noncomposite Flexural Strength**
- Does the deck brace the beam?
- But what about deck parallel to the girder?

  Maybe…

There's always a solution in steel.

158

Girder Design

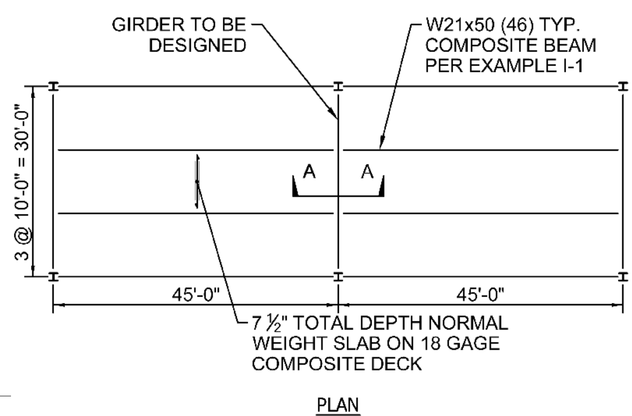
- **Check Noncomposite Flexural Strength**
- Does the deck brace the beam?
- But what about deck parallel to the girder?

There's always a solution in steel.

159

Girder Design

- **Check Noncomposite Flexural Strength**
- Design Example uses distance between filler beams as unbraced length.



There's always a solution in steel.

160

Girder Design

- **Steps for Composite Beam Design**

1. Determine Loads
2. Check Noncomposite Flexural Strength
3. Check Noncomposite Deflection Limits
4. Check Composite Flexural Strength
5. Check Composite Deflection Limits

There's always a solution in steel.

161

Girder Design

- **Check Noncomposite Deflection Limits**
- AISC Design Guide 3 Recommends L/360 or 1.0 in. under precomposite dead load

There's always a solution in steel.

162

Girder Design

- **Check Noncomposite Deflection Limits**
- AISC Design Guide 3 Recommends L/360 or 1.0 in. under precomposite dead load
- Could introduce camber to meet these limits
  - Camber 80% precomposite Dead Load
  - Reduce to nearest ¼ in., with ¾ in. minimum
  - Be careful with steel anchor cover

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163

Girder Design

- **Check Noncomposite Deflection Limits**

2005 Specification: "Stud shear connectors, after installation, shall extend not less than 1 ½ in. above the top of the steel deck and there shall be at least ½ in. of concrete cover above the top of the installed studs.

There's always a solution in steel.

164

Girder Design

- **Check Noncomposite Deflection Limits**

2005 Specification: “Stud shear connectors, after installation, shall extend not less than 1 ½ in. above the top of the steel deck and there shall be at least ½ in. of concrete cover above the top of the installed studs.

2010 Specification: “Steel headed stud anchors, after installation, shall extend not less than 1 ½ in. above the top of the steel deck and there shall be at least ½ in. of ***SPECIFIED*** concrete cover above the top of the steel headed stud anchors.”

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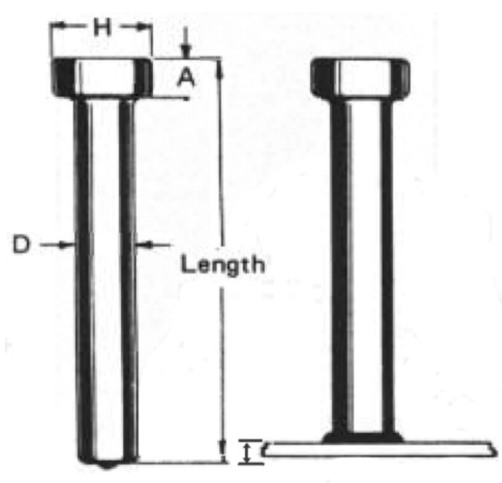
Girder Design

- **Steel Anchor Length**



Reference: www.nelsonstud.com

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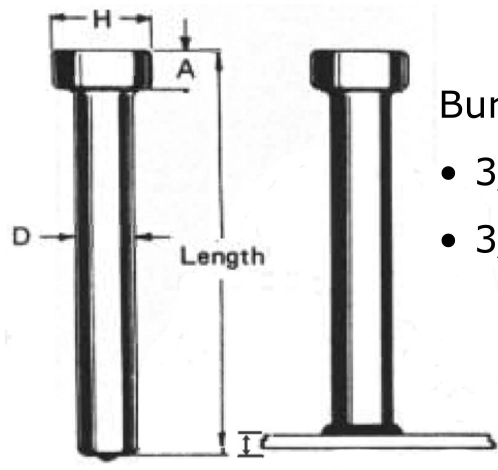
Girder Design

•Steel Anchor Length



Burn off Values:

- 3/16″ to Bare Steel
- 3/8″ through Deck

Reference: www.nelsonstud.com

There's always a solution in steel. 167

Girder Design

- **Steps for Composite Beam Design**

1. Determine Loads
2. Check Noncomposite Flexural Strength
3. Check Noncomposite Deflection Limits
4. Check Composite Flexural Strength
5. Check Composite Deflection Limits

There's always a solution in steel. 168

Girder Design

- **Determine Composite Flexural Strength**

There's always a solution in steel.

169

Girder Design

- **Determine Composite Flexural Strength**
- Method 1: Manual Tables

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170

Girder Design

- **Determine Composite Flexural Strength**
- Method 1: Manual Tables
- Method 2: Direct Calculation w/Chapter I

Girder Design

- **Determine Composite Flexural Strength**
- Method 1: Manual Tables
- Method 2: Direct Calculation w/Chapter I
- *Method 3: Push "Go" in Ram…RISA…etc…*

Girder Design

- **Determine Composite Flexural Strength**
- Method 1: Manual Tables

Table 3-19 (continued)
Composite W-Shapes
Available Strength in Flexure, kip-ft

W36

F_y = 50 ksi

Shape	M_p/Ω_b	$\phi_b M_p$	PNA[c]	Y1[a]	$\sum Q_n$	Y2[b], in.							
	kip-ft					2		2.5		3		3.5	
	ASD	LRFD		in.	kip	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
W36×210	2080	3120	TFL	0	3100	3140	4720	3220	4840	3300	4960	3370	5070
			2	0.340	2680	3100	4660	3160	4760	3230	4860	3300	4960
			3	0.680	2270	3050	4580	3100	4660	3160	4750	3220	4830
			4	1.02	1850	2990	4490	3030	4560	3080	4630	3130	4700
			BFL	1.36	1440	2920	4390	2960	4440	2990	4500	3030	4550
			6	5.04	1100	2840	4260	2860	4300	2890	4350	2920	4390
			7	9.03	774	2690	4040	2710	4070	2730	4100	2750	4130

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173

Girder Design

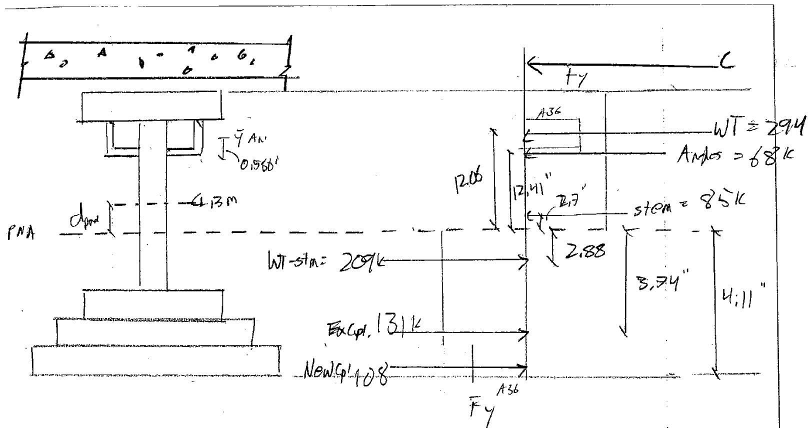
- **Determine Composite Flexural Strength**
- Method 2: Direct Calculation w/Chapter I

There's always a solution in steel.

174

Girder Design

- **Determine Composite Flexural Strength**
- Method 2: Direct Calculation w/Chapter I



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175

Girder Design

- **Composite Percentage**

$$\%\ \text{Composite} = \frac{\sum Q_n}{MIN\begin{cases} A_s F_y & \leftarrow \text{Steel Yielding} \\ 0.85 f'_c A_c & \leftarrow \text{Concrete Crushing} \end{cases}}$$

There's always a solution in steel.

176

Girder Design

- **Composite Percentage**
- No Minimum Specification Requirement

There's always a solution in steel.

177

Girder Design

- **Composite Percentage**
- No Minimum Specification Requirement
- Design Aids Limited to 25%

There's always a solution in steel.

178

Girder Design

- **Composite Percentage**
- No Minimum Specification Requirement
- Design Aids Limited to 25%
- Commentary recommends 50% minimum

There's always a solution in steel.

179

Girder Design

- **Composite Percentage**
- No Minimum Specification Requirement
- Design Aids Limited to 25%
- Commentary recommends 50% minimum

Less than 50% composite action requires…

There's always a solution in steel.

180

Girder Design

- **Composite Percentage**
- No Minimum Specification Requirement
- Design Aids Limited to 25%
- Commentary recommends 50% minimum

Less than 50% composite action requires…

…Large Rotations

There's always a solution in steel.

181

Girder Design

- **Composite Percentage**
- No Minimum Specification Requirement
- Design Aids Limited to 25%
- Commentary recommends 50% minimum

Less than 50% composite action requires..

…Large Rotations

…Can Result in Very Limited Ductility

There's always a solution in steel.

182

Girder Design

- **Composite Percentage**
- No Minimum Specification Requirement
- Design Aids Limited to 25%
- Commentary recommends 50% minimum

Less than 50% composite action requires..

…Large Rotations

…Can Result in Very Limited Ductility

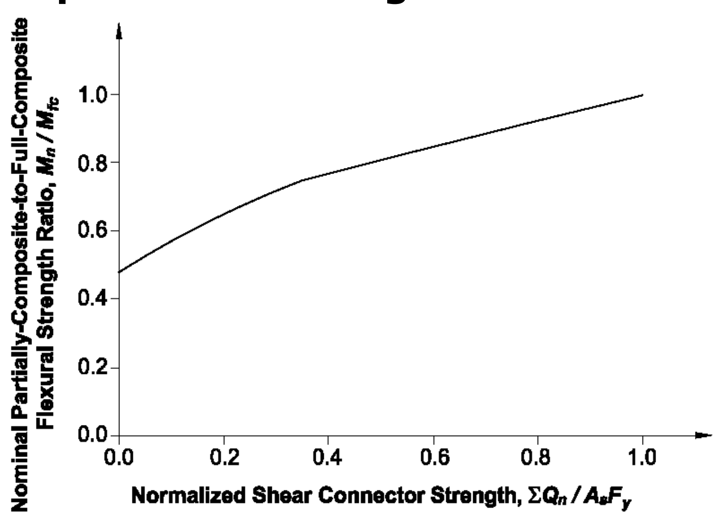
…Premature Departure from Elastic Behavior

There's always a solution in steel.

183

Girder Design

- **Composite Percentage**



There's always a solution in steel.

184

Girder Design

- **Determine Composite Flexural Strength**
  - Step 1: Determine Concrete Compressive Force

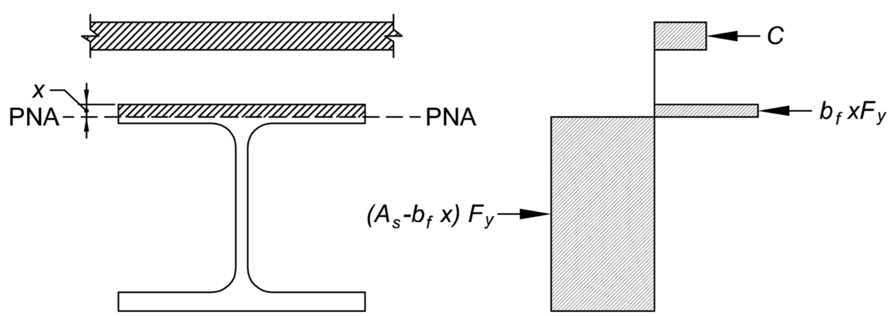
$$C = MIN \begin{cases} A_s F_y & \leftarrow \text{Steel Yielding} \\ 0.85 f'_c A_c & \leftarrow \text{Concrete Crushing} \\ \sum Q_n & \leftarrow \text{Stud Anchor Strength} \end{cases}$$

There's always a solution in steel.

185

Girder Design

- **Determine Composite Flexural Strength**
  - Step 2: Calculate Plastic Neutral Axis (ΣF_x)



(NTS)

$$\sum F_{\text{above PNA}} = \sum F_{\text{below PNA}}$$

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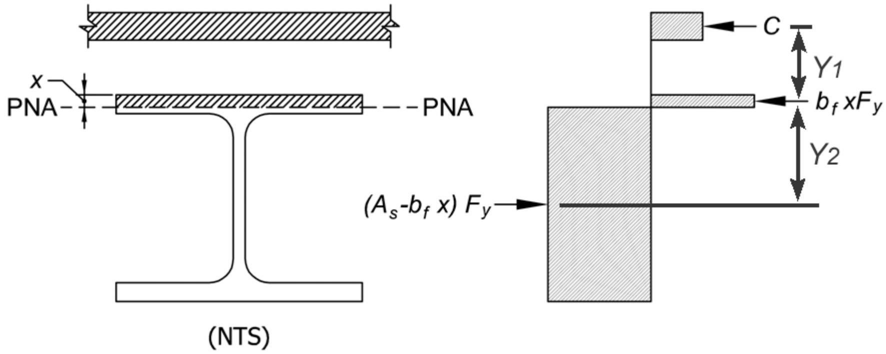
186

Girder Design

- **Determine Composite Flexural Strength**
  - Step 3: Calculate Nominal Flexural Strength (ΣM)



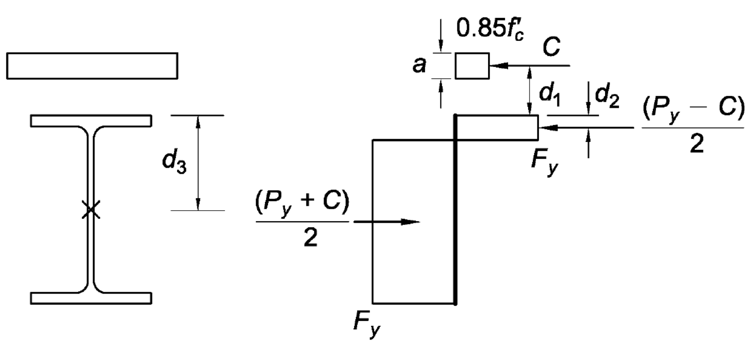
$$M_n = C(Y_1) + (A_s - b_f x)(F_y)(Y_2)$$

There's always a solution in steel.

187

Girder Design

- **Determine Composite Flexural Strength**
  - 2010 Commentary condenses this method into Commentary Figure C-I3.3 and Eq. C-I3-10



$$M_n = C(d_1 + d_2) + A_s F_y (d_3 - d_2)$$

There's always a solution in steel.

188

Girder Design

- **Steps for Composite Beam Design**

1. Determine Loads
2. Check Noncomposite Flexural Strength
3. Check Noncomposite Deflection Limits
4. Check Composite Flexural Strength
5. Check Composite Deflection Limits

There's always a solution in steel. 189

Girder Design

- **Check Composite Deflection Limits**
- AISC Design Guide 3 recommends L/360 or 1.0 in. for Live Loads applied after composite action has been achieved (allows 50% reduction in design Live Load)
- IBC 2009 Table 1604.3 requires L/360 under full design live load

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Girder Design

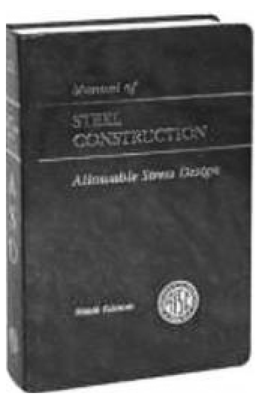
- **Check Composite Deflection Limits**

So what moment of inertia should be used?

Girder Design

- **Check Composite Deflection Limits**

So what moment of inertia should be used?

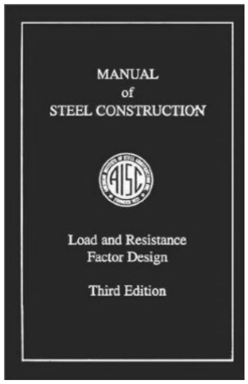


$$I_{eff} = I_s + \sqrt{\left(V_h^{'} / V_h\right)}\left(I_{tr} - I_s\right)$$

Girder Design

- **Check Composite Deflection Limits**

So what moment of inertia should be used?



$$I_{eff} = I_s + \sqrt{\left(\Sigma Q_n / C_f\right)}\left(I_{tr} - I_s\right)$$

"for realistic deflection calculations, I_{eff} should be taken as 0.80 I_{eff} or 0.75 $I_{eff.}$

As an alternative…"

$$I_{LB} = I_s + A_s\left(Y_{ENA} - d_3\right)^2 + \left(\Sigma Q_n / F_y\right)\left(2d_3 + d_1 - Y_{ENA}\right)^2$$

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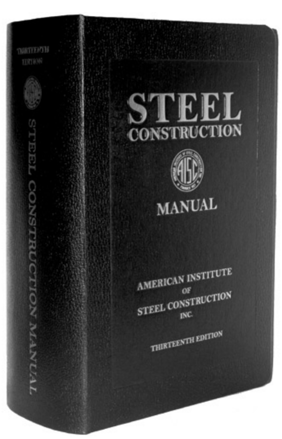
193

Girder Design

- **Check Composite Deflection Limits**

So what moment of inertia should be used?



- Retained I_{LB} Method from 3rd Ed.
- I_{eff} should be taken as $0.75I_{equiv}$

$$I_{eff} = I_s + \sqrt{\left(\Sigma Q_n / C_f\right)}\left(I_{tr} - I_s\right)$$

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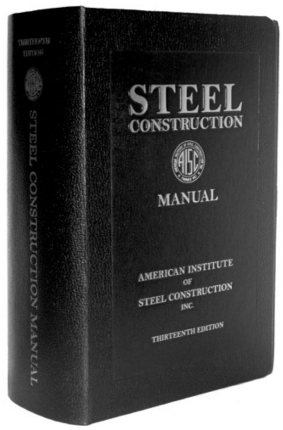
194

Girder Design

- **Check Composite Deflection Limits**

So what moment of inertia should be used?



- Retained I_{LB} Method from 3rd Ed.
- I_{eff} should be taken as $0.75I_{equiv}$

~~$I_{eff} = I_s + \sqrt{\left(\sum Q_n / C_f\right)}\left(I_{tr} - I_s\right)$~~

$$I_{equiv} = I_s + \sqrt{\left(\sum Q_n / C_f\right)}\left(I_{tr} - I_s\right)$$

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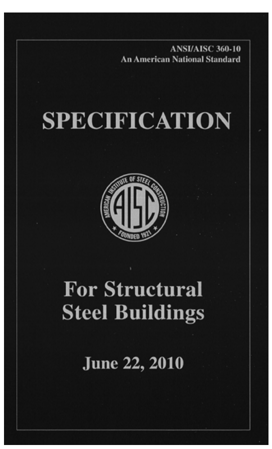
Girder Design

- **Check Composite Deflection Limits**

So what moment of inertia should be used?



- Retained I_{LB} Method from 3rd Ed.
- I_{eff} should be taken as $0.75I_{equiv}$

$$I_{equiv} = I_s + \sqrt{\left(\sum Q_n / C_f\right)}\left(I_{tr} - I_s\right)$$

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Girder Design

- **Check Composite Deflection Limits**

So which method is "correct"?

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197

Girder Design

- **Check Composite Deflection Limits**

So which method is "correct"?

- Neither are perfect…

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198

Girder Design

- **Check Composite Deflection Limits**

  So which method is "correct"?

  - Neither are perfect…
  - Design Example compares both methods and takes the HIGHER moment of inertia.
  - Subject of ongoing research

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199

Review

- **Review of Select Problems**
  - I-2: Composite Girder
  - I-8: Encased Member Force Allocation/Transfer

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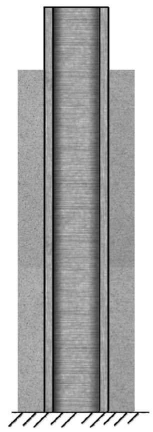
200

Load Transfer

- **What Is Force Allocation/Load Transfer?**



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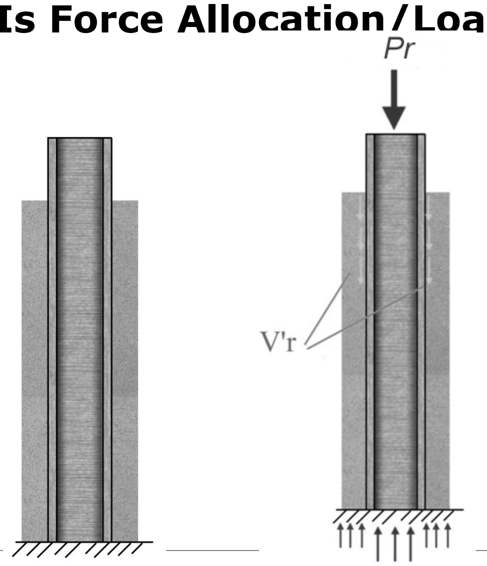
201

Load Transfer

- **What Is Force Allocation/Load Transfer?**



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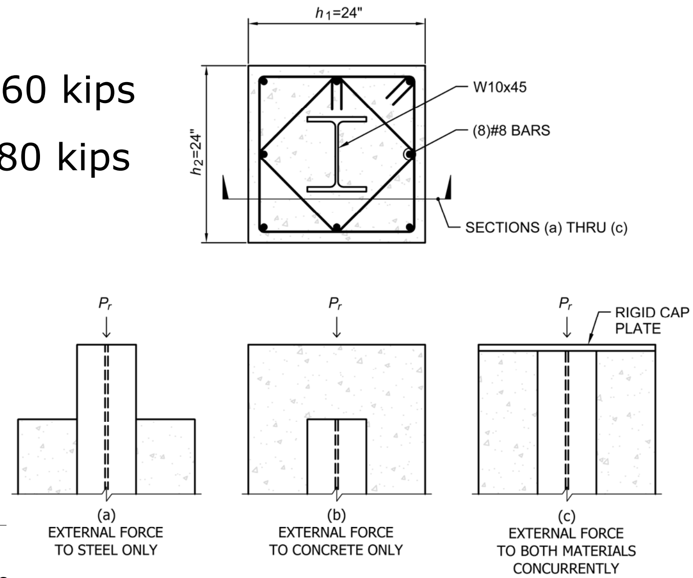
202

Load Transfer

- **Problem Statement**

P_D=260 kips

P_L=780 kips



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203

Load Transfer

- **Real World**

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204

Load Transfer

- **Calculate Longitudinal Shear**

$$P_u = 1.2(260\text{ kips}) + 1.6(780\text{ kips})$$
$$= 1{,}560\text{ kips}$$

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205

Load Transfer

- **Calculate Longitudinal Shear**

$$P_u = 1.2(260\text{ kips}) + 1.6(780\text{ kips})$$
$$= 1{,}560\text{ kips}$$

- Allocation based on Plastic Strength Model

$$P_{no} = F_y A_s + F_{ysr} A_{sr} + 0.85 f_c' A_c = 3{,}410\text{ kips}$$
$$F_y A_s = 665\text{ kips} \quad \leftarrow \text{Steel Only}$$
$$F_{ysr} A_{sr} + 0.85 f_c' A_c = 2{,}742\text{ kips} \leftarrow \text{Concrete Only}$$

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206

Load Transfer

- **Calculate Longitudinal Shear**

$$V_r' = P_u\left(1 - \frac{F_y A_s}{P_{no}}\right) \qquad (\textit{Spec}\text{ Eq. I6-1})$$

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207

Load Transfer

- **Calculate Longitudinal Shear**

$$V_r' = P_u\left(1 - \frac{F_y A_s}{P_{no}}\right) \qquad (\textit{Spec}\text{ Eq. I6-1})$$

$$= P_u\left(\frac{P_{no} - F_y A_s}{P_{no}}\right)$$

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208

Load Transfer

- **Calculate Longitudinal Shear**

$$V_r' = P_u\left(1 - \frac{F_y A_s}{P_{no}}\right) \quad (\textit{Spec}\ \text{Eq. I6-1})$$

$$= P_u\left(\frac{P_{no} - F_y A_s}{P_{no}}\right)$$

$$= P_u\left(\frac{\text{Member Strength - Steel Only}}{\text{Member Strength}}\right)$$

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209

Load Transfer

- **Calculate Longitudinal Shear**

$$V_r' = P_u\left(1 - \frac{F_y A_s}{P_{no}}\right) \quad (\textit{Spec}\ \text{Eq. I6-1})$$

$$= P_u\left(\frac{P_{no} - F_y A_s}{P_{no}}\right)$$

$$= P_u\left(\frac{\text{Member Strength - Steel Only}}{\text{Member Strength}}\right)$$

$$= P_u\left(\frac{\text{Concrete Strength}}{\text{Member Strength}}\right)$$

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210

Load Transfer

- **Calculate Longitudinal Shear**

$$V_r' = P_u\left(\frac{\text{Concrete Strength}}{\text{Member Strength}}\right)$$

$$= 1{,}560 \text{ kips}\left(\frac{2{,}742 \text{ kips}}{3{,}410 \text{ kips}}\right)$$

$$= 1{,}255 \text{ kips}$$

For force Applied to Steel Only

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211

Load Transfer

- **Calculate Longitudinal Shear**

$$V_r' = P_u\left(\frac{A_s F_y}{P_{no}}\right)$$ (*Spec* Eq. I6-2)

$$= P_u\left(\frac{\text{Steel Strength}}{\text{Member Strength}}\right)$$

$$= 1{,}560 \text{ kips}\left(\frac{665 \text{ kips}}{3{,}410 \text{ kips}}\right)$$

$$= 304 \text{ kips}$$

For force Applied to Concrete Only

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212

Load Transfer

- **Mechanisms for Force Transfer**

Encased Sections

- Direct Bearing (I6.3a)
- Shear Connection (I6.3b)

Filled Sections

- Direct Bearing (I6.3a)
- Shear Connection (I6.3b)
- Bond (I6.3c)

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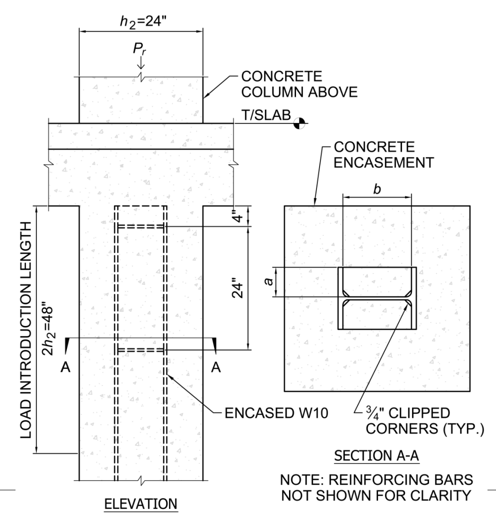
Load Transfer

- **Direct Bearing**



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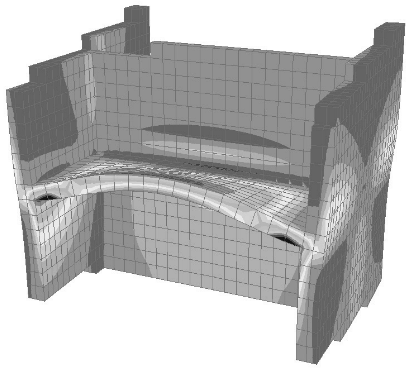
Load Transfer

- **Direct Bearing**



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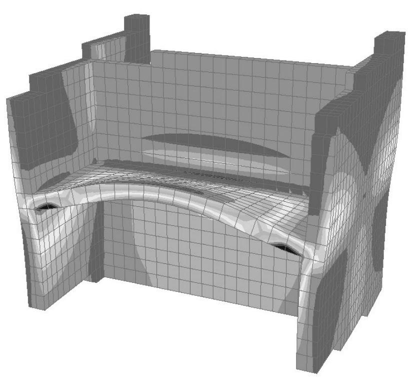
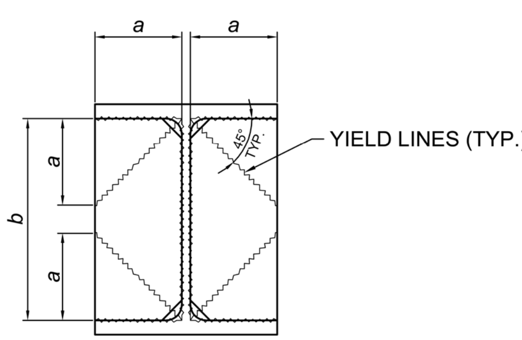
215

Load Transfer

- **Direct Bearing**





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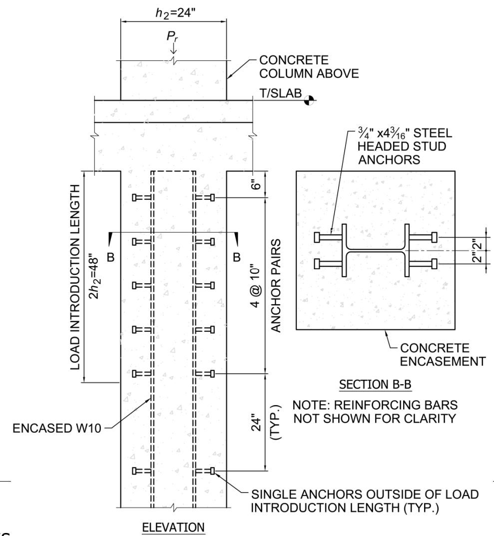
216

Load Transfer

- **Shear Connection**



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217

Load Transfer

- **Shear Connection**

Use I8.3 – Steel Anchors in Composite Components

Loading Condition	Normal Weight Concrete	Lightweight Concrete
Shear	$h/d = 5$	$h/d = 7$
Tension	$h/d = 8$	$h/d = 10$
Shear+Tension	$h/d = 8$	N/A[+]

h/d = ratio of steel headed stud anchor shank length to the top of the stud head, to shank diameter

[+] Refer to ACI 318 Appendix D for the calculation of interaction effects of anchors embedded in lightweight concrete.

$$Q_{nv} = F_u A_{sa}$$

$$\phi_v = 0.65$$

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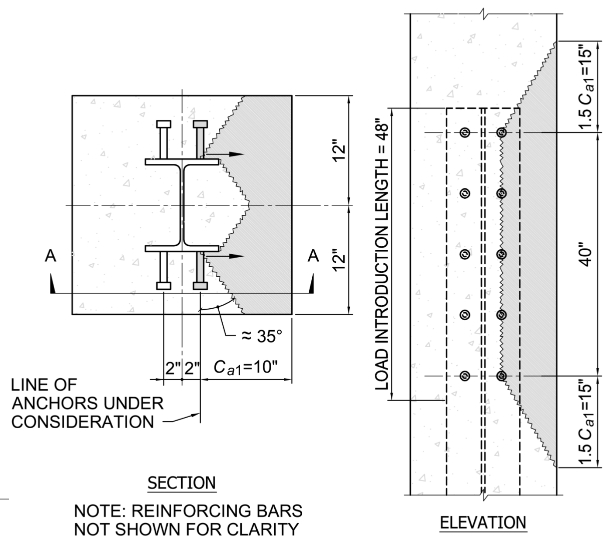
218

Load Transfer

- **Notes on Section I8.3**
  - h/d ratio, head geometry, and spacing limitations in Spec. preclude concrete pryout in shear
  - They do NOT preclude concrete breakout towards a free edge (generally not a problem with composite columns)
  - Commentary warns against the possibility of edges parallel to the line of force breaking out

Load Transfer

- **Shear Connection**



Load Transfer

- **Shear Connection**

$$V_{cbg} = 2\left[\frac{A_{Vc}}{A_{Vco}}\Psi_{ec,V}\Psi_{ed,V}\Psi_{c,V}\Psi_{h,V}V_b\right]$$

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221

Load Transfer

- **Shear Connection**

$$V_{cbg} = 2\left[\frac{A_{Vc}}{A_{Vco}}\;{}_{ec,V}\;{}_{ed,V}\;{}_{c,V}\;{}_{h,V}V_b\right]$$

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222

Load Transfer

- **Load Introduction Length**

  2005 Specification: "The shear connectors shall be distributed along the length of the member **at least** a distance of 2.5 times the depth of the encased composite column…

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Load Transfer

- **Load Introduction Length**

  2005 Specification: "The shear connectors shall be distributed along the length of the member **at least** a distance of 2.5 times the depth of the encased composite column…

  2010 Specification: "Steel anchors…shall be distributed within the load introduction length, which **shall not exceed** a distance of two times the minimum transverse dimension of the [composite column]…

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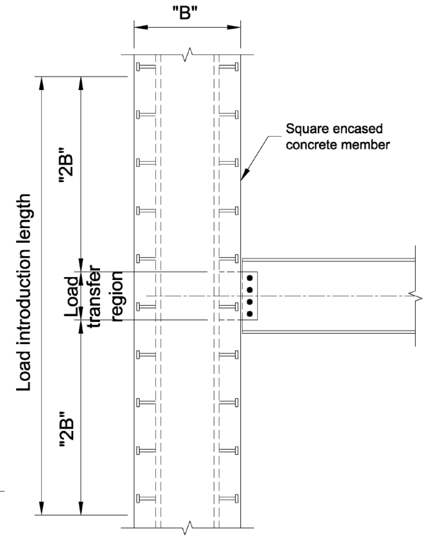
Load Transfer

- **Load Introduction Length**



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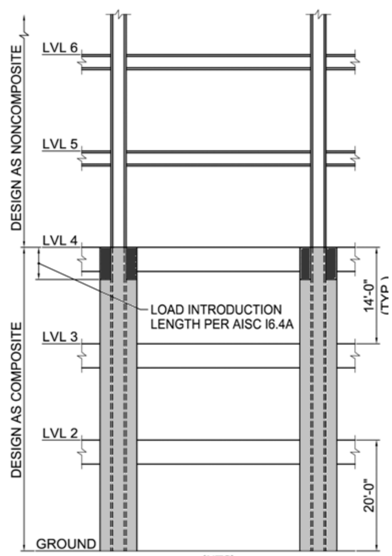
225

Load Transfer



(a) STANDARD LOAD INTRODUCTION LENGTH

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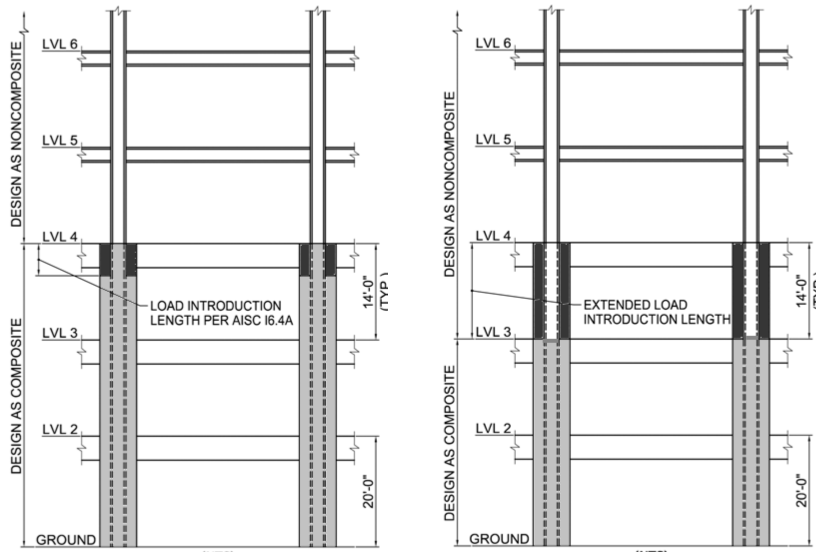
226

Load Transfer



(NTS)
(a) STANDARD LOAD INTRODUCTION LENGTH

(NTS)
(b) EXTENDED LOAD INTRODUCTION LENGTH

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Summary

- **Summary & A Look Forward**
  - 2010 Specification and Design Examples Greatly Expanded / Reorganized
  - Main Revisions to Reinforcing Detailing / Local Buckling / Load Transfer / Shear Provisions / Collector Beams / Steel Anchors
  - Problems Provided for Each Member Type (Beams, Filled Columns, Encased Columns) for Each Action (Compression, Tension, Shear, Combined)
  - 2010 Specification Available Now at www.aisc.org
  - 14th Edition Manual Available Now at www.aisc.org

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Questions?

End of Part 2:

Any Questions?

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