Steel Structures

M.Sc. Structural Engineering

SE-505

Lecture # 5

Composite Steel-Concrete Construction

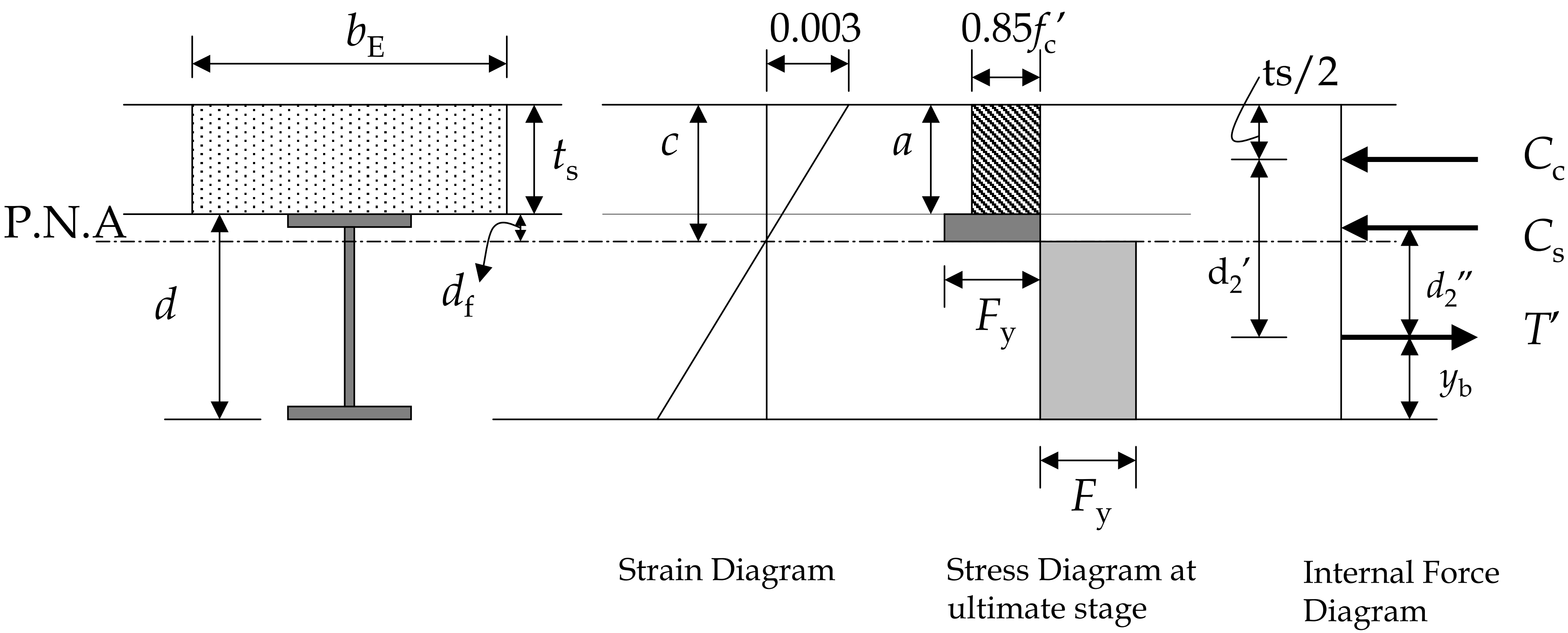
Steel Structures

Strength Design (contd…)

Positive Moment Strength Based on Plastic Stress Distribution

Case-II Plastic N.A. Outside the Slab

Rare case. When b_E is very small



Steel Structures

Strength Design (contd…)

Positive Moment Strength Based on Plastic Stress Distribution

Case-II Plastic N.A. Outside the Slab

$$C_c = 0.85 f_c' \times b_E \times t_s$$

$$C_s = A_s' F_y$$

A_s' = Area of steel section in compression

$$T' = (A_s - A_s')F_y$$

A = Total area of steel section

Steel Structures

Strength Design (contd…)

Case-II Plastic N.A. Outside the Slab

$$T' = A_s F_y - A_s' F_y$$

$$T' = A_s F_y - C_s$$

$$C_s = A_s F_y - T'$$

For longitudinal equilibrium

$$T' = C_c + C_s$$

$$A_s F_y - C_s = C_c + C_s$$

$$C_s = \frac{A_s F_y - C_c}{2}$$

Steel Structures

Strength Design (contd…)

Case-II Plastic N.A. Outside the Slab

Steps for Capacity Calculation

1. Find position of N.A.
2. Calculate tension and compression area.
3. Locate centroid of tension area.
4. $d_2' = d + t_s/2 - y_b$
5. $d_2'' = d - d_f/2 - y_b$ [If P.N.A is within the top flange]

Steel Structures

Strength Design (contd…)

Case-II Plastic N.A. Outside the Slab

Steps for Capacity Calculation

$$M_n = C_c \times d_2' + C_s \times d_2''$$

$\phi_b = 0.9$ $\Omega_b = 1.67$

When P.N.A. is within steel section (flange or web) some portion of section is in compression. But there is no concern of flange local buckling or LTB as it is continuously braced. Web local buckling can be checked.

Steel Structures

Strength Design (contd…)

Example: determine the flexural capacity of the shown composite section. Use A36 steel and concrete of $f_c' = 20$ MPa.

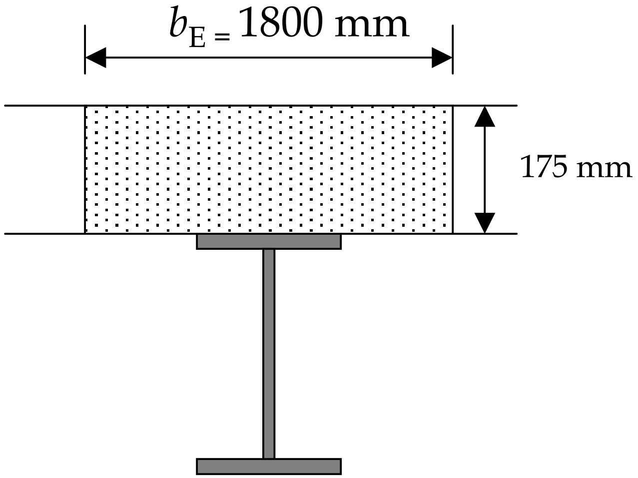
W 920 x 253

$A = 32{,}300\ mm^2$, $d = 919$ mm

$b_f = 306$ mm, $t_f = 27.9$ mm

$t_w = 17.3$ mm , $h/t_w = 47.8$ mm,

$b_f/2t_f = 5.5$



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Strength Design (contd…)

Solution

Assuming the N.A. within the slab

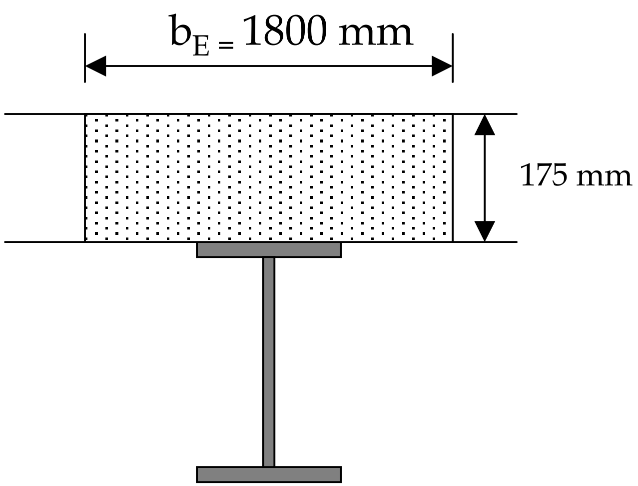
$$a = \frac{A_s F_y}{0.85 f_c' b_E}$$

$$a = \frac{32,300 \times 250}{0.85 \times 20 \times 1800} = 264$$

$$c = \frac{a}{\beta_1} = \frac{264}{0.85}$$

$$c = 310\ mm > t_s$$

N.A. is outside the slab.



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Strength Design (contd…)

Solution

The above value of "c" is now invalid.

$$C_c = 0.85 f_c' b_E t_s$$

$$= \frac{0.85 \times 20 \times 1800 \times 175}{1000}$$

$$= 5355 \ kN$$

$$C_s = \frac{(A_s F_y - C_c)}{2}$$

$$= \frac{(32,300 \times 250 / 1000 - 5355)}{2}$$

$$= 1360 \ kN$$

Steel Structures

Strength Design (contd…)

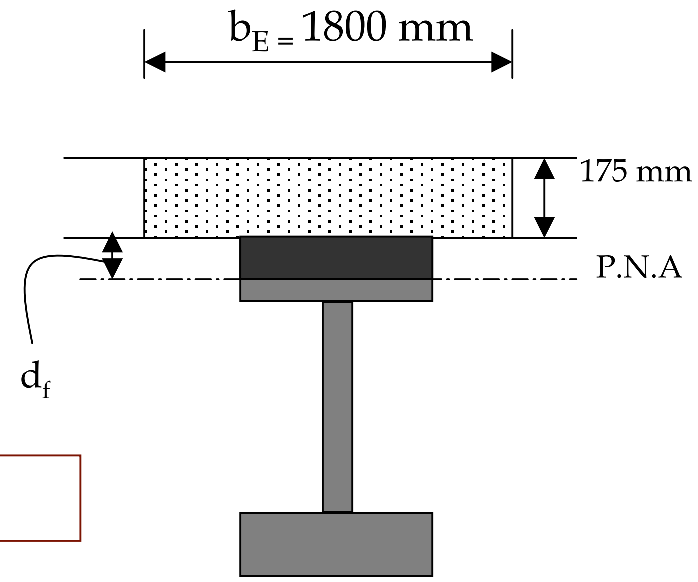
Check location of N.A, by first making some assumption.

1. N.A. is within the flange of N.A.

$$b_f \times d_f \times F_y = C_s$$

$$d_f = \frac{C_s}{b_f \times F_y} = \frac{1360 \times 1000}{306 \times 250}$$

$$= 17.8 mm < t_f$$



So N.A. is within the flange of W-Section

If N.A. is outside flange,

t_w × depth outside flange = $C_s - b_f \times t_f \times 250/1000$

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Strength Design (contd…)

Now we need to calculate d_2'

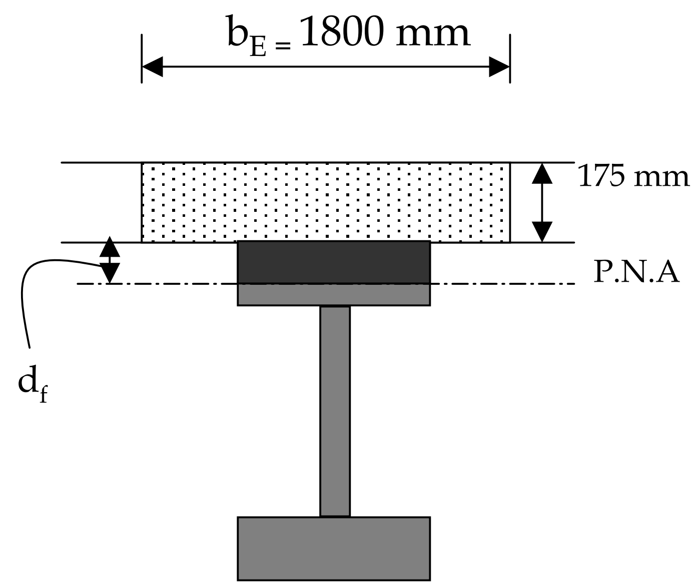
$$d_2' = d + \frac{t_s}{2} - y_b$$

y_b is the location of centroid of the area below N.A.

Area in tension:

$$A_T = 32{,}200 - 306 \times 17.8$$
$$= 26853\ mm^2$$

$$y_b = \frac{A \times d/2 - b_f \times d_f \times (d - d_f/2)}{A_T}$$
$$= 368 mm$$



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Strength Design (contd…)

Now we need to calculate d_2'

$$d_2' = d + \frac{t_s}{2} - y_b$$

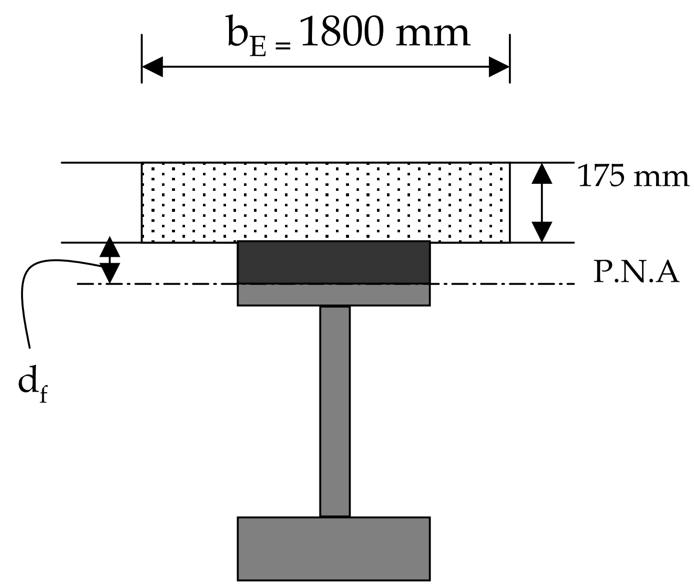
$$d_2' = 919 + \frac{175}{2} - 368 = 638.5mm$$

$$d_2'' = d - \frac{d_f}{2} - y_b$$

$$d_2'' = 542.1mm$$

$$\phi_b M_n = \phi_b \left(C_c \times d_2' + C_s \times d_2'' \right)$$

$$\phi_b M_n = {0.90\left(5355 \times 638.5 + 1360 \times 542.1\right)} \big/ {1000} = 3740 \ \ kN - m$$



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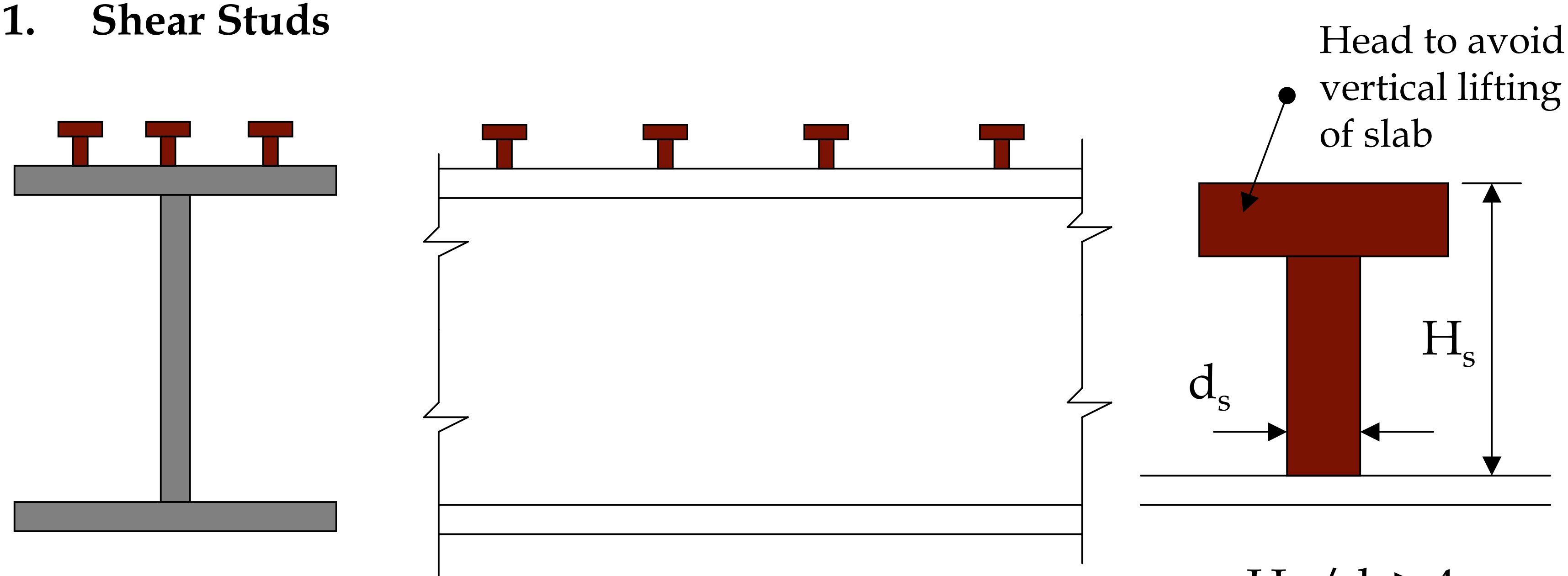
Shear Connectors

"Mechanical shear connectors are required for the full transfer of longitudinal shear except for concrete encased beam".

1. Shear Studs



Shear Connector

$H_s / d_s \geq 4$

[AISC I1.3]

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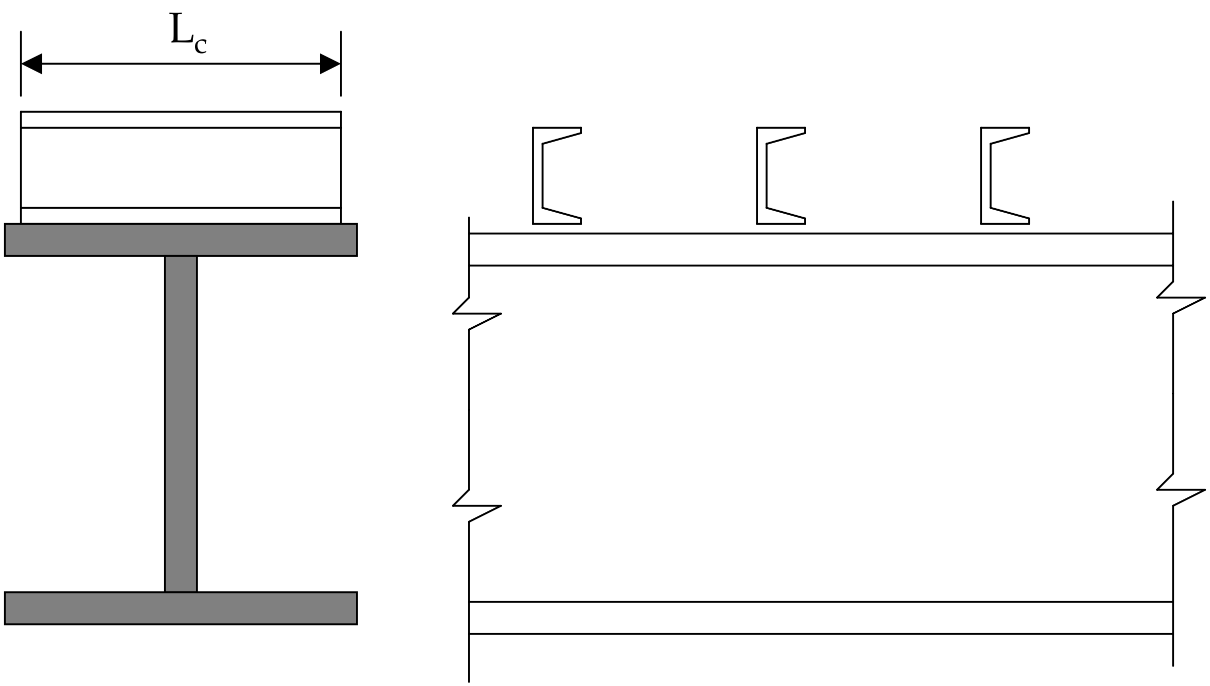
Shear Connectors (contd…)

2. Channel Connectors



L_c = Length of channel section

AISC suggests only studs and channels

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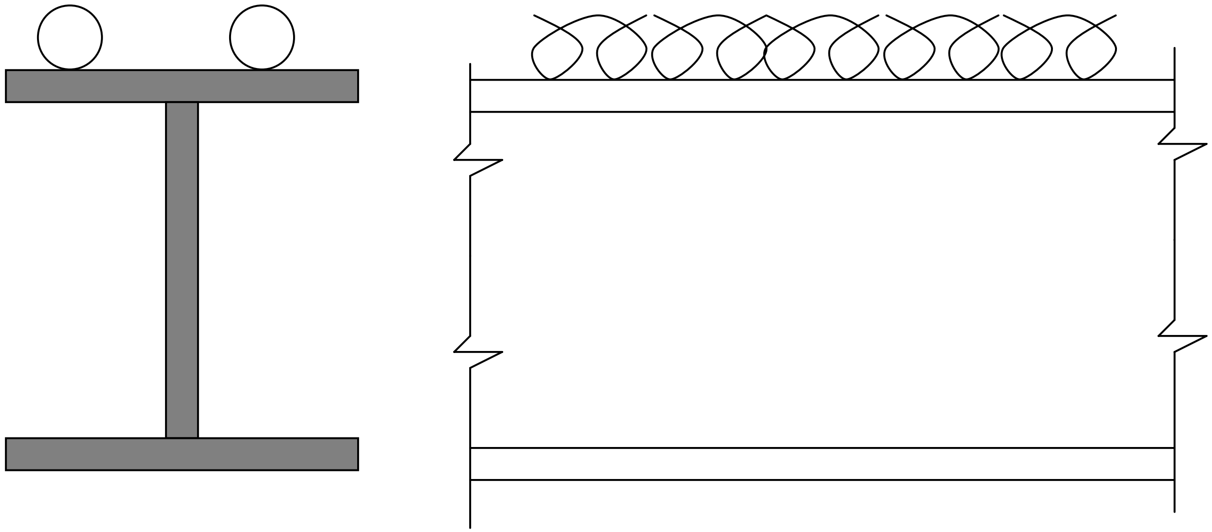
Shear Connectors (contd…)

3. Spiral Connectors



Not suggested by AISC

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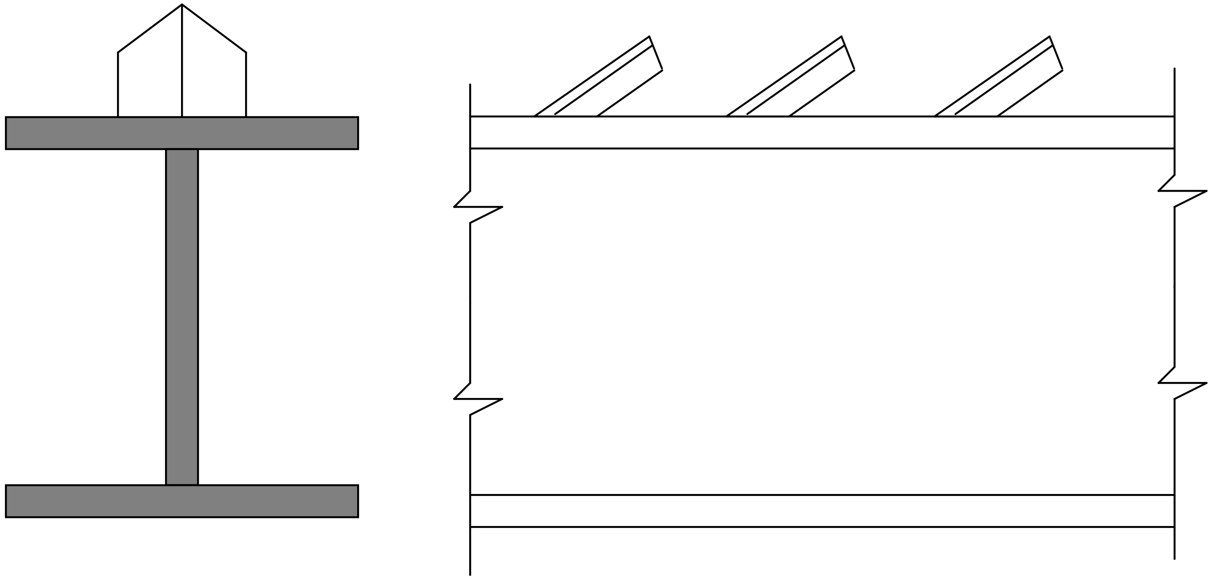
Shear Connectors (contd…)

4. Angle Connectors



Not suggested by AISC

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Shear Connectors (contd…)

Horizontal Shear Force for which Connectors are to be Designed For Positive Moment Sections

AISC I3 Shear force shall be smallest of the following limit states

1. Concrete crushing $V' = 0.85 f_c' A_c$
2. Tensile Yielding of the steel section $V' = A_s F_y$
3. Strength of shear connectors $V' = \Sigma Q_n$

A_c = Area of concrete slab within effective width

A_s = Area of concrete steel cross section

Q_n = nominal strength of one connector

ΣQ_n = strength of total number of connectors between the point of max. positive moment and the point of zero moment.

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Shear Connectors (contd…)

Horizontal Shear Force for which Connectors are to be Designed For Negative Moment Section

AISC I3 Shear force shall be lesser of the following limit states:

1. $V' = A_r F_{yr}$ Tensile yielding of the slab reinforcement.
2. $V' = \Sigma Q_n$ Strength of shear connectors

A_r = Area of reinforcement in slab parallel to beam with in effective width of slab

F_{yr} = minimum specified yield strength of steel reinforcement.

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Shear Connectors (contd…)

AICS I3 Strength of Stud Connector

$$Q_n = 0.5 A_{sc} \sqrt{f_c' E_c} \leq R_g R_p A_{sc} F_u$$

$$H_s / d_s \geq 4$$

A_{sc} = Area of shear connector

E_c = M.O.E of concrete in MPa

F_u = specified minimum tensile strength of a stud shear connector

Usually, dia of stud = 12 to 25 mm, H_s = 50 to 200 mm

R_g and R_p are equal to 1.0 in case no decking is used. For different types of decking, the values are given in AISC specification.

Steel Structures

Shear Connectors (contd…)

AISC I3 Strength of Channel Connector

$$Q_n = 0.3\left(t_f + 0.5t_w\right)L_c\sqrt{f_c' E_c}$$

L_c = Length of channel connector

t_f and t_w are for the channel

Steel Structures

Shear Connectors (contd…)

AICS I3.2d.(5) Required Number of Shear Connector

(between max. and zero moment section)

$$\text{Number of Shear Connectors} = \frac{\text{Horizontal Shear Force}}{Q_n}$$

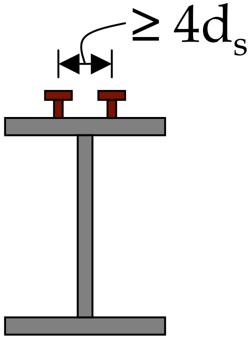
Steel Structures

Shear Connectors (contd…)

AICS I3.2d.(6) Shear Connector Placement and Spacing

Shear connectors required on each side of maximum BM (+ve or –ve) shall be distributed uniformly between that point and the adjacent point of zero moment.

- Minimum cover for the shear connector is 25 mm.
- Diameter of stud should not be greater than 2.5 t_f
- $s_{min} = 6d_s$ (longitudinal direction)
- s_{max} = lesser of $8t_s$ and 915 mm (all directions)
- $s_{min} = 4d_s$ (transverse direction)



Steel Structures

Spans and Proportions of Composite Sections

For steel building frames economical span = 7.5 m to 15 m

Bridges

- For Simple span, > 12m is economical
- For Continuous span, > 18 m is economical

Steel plate may be attached with bottom flange of steel beam to increase tensile capacity.

Approximate Minimum Depth of Steel Beam (Not AISC requirement)

- Steel beams without cover plate, L/24 for static load
- Steel beams without cover plate, L/20 for moving load

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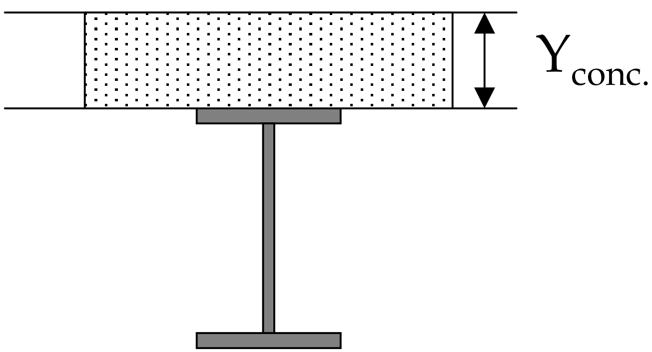
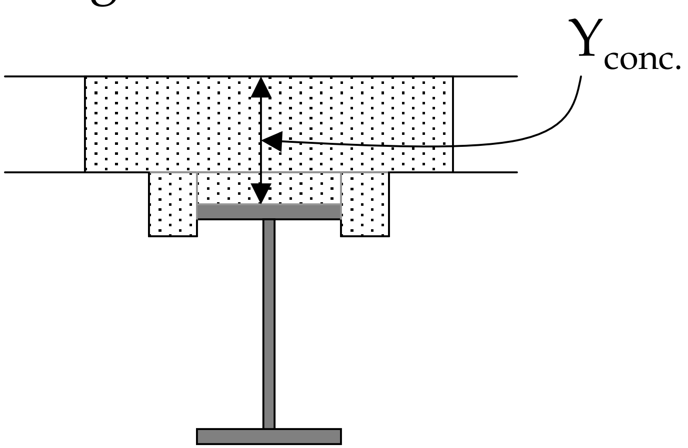
Estimate of Self Weight

$$\text{Self weight} = \left[\frac{M_{u\,(N-mm)}}{\left(d/2 + Y_{conc.} - a/2 \right) \phi F_y} \right] \times 0.00785 \quad \text{kg/m}$$

$Y_{conc.}$ = Distance from top of steel section to top of concrete slab

a =depth of stress block, 50mm for initial guess





Steel Structures

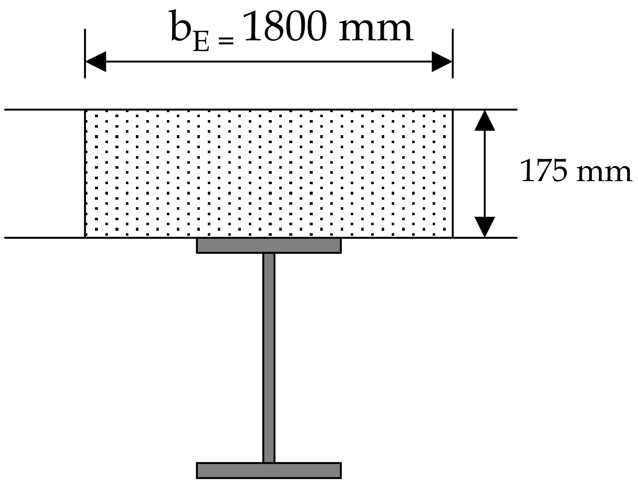
Example:

Determine the number of 20mm dia x 80mm shear stud connectors made of A36 steel to develop fully composite section shown in figure. Assume that the applied loading is uniform and beam is simply supported. fc′=20 MPa.

W 920 x 253

A = 32,300 mm^2

H_s = 80 mm, d_s = 20 mm



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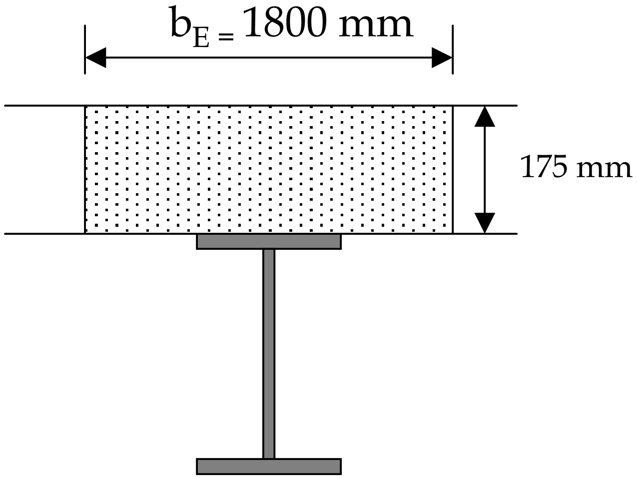
Solution (contd…)

$H_s / d_s = 4$ O.K.

<u>Strength of One Stud</u>



$$Q_n = 0.5 A_{sc}\sqrt{f_c' E_c} \le R_g R_p A_{sc} F_u$$

$$A_{sc} = \frac{\pi}{4} 20^2 = 314 mm^2$$

$$E_c = 4700\sqrt{f_c'} = 4700\sqrt{20} = 21019 MPa$$

$$R_g R_p A_{sc} F_u = 1 \times 1 \times 314 \times 400 / 1000 = 125.6 kN$$

$$Q_n = {0.5 \times 314\sqrt{20 \times 21019}} \Big/ {1000} = 101.79 kN < 125.6 kN$$

Steel Structures

Solution (contd…)

Horizontal Shear Force (between +ve max. and zero BM)

V' is lesser of

$$0.85 f_c' A_c = \frac{0.85 \times 20 \times (1800 \times 175)}{1000} = 5355 kN$$

$$A_s F_y = \frac{32{,}300 \times 250}{1000} = 8075 kN$$

ΣQ_n Not used here because we are designing studs and don't know the number of studs, in fact, we are going to calculate them.

$$V' = 5355\ kN$$

Steel Structures

Solution (contd…)

Number of Shear Connectors (between +ve max. and zero BM)

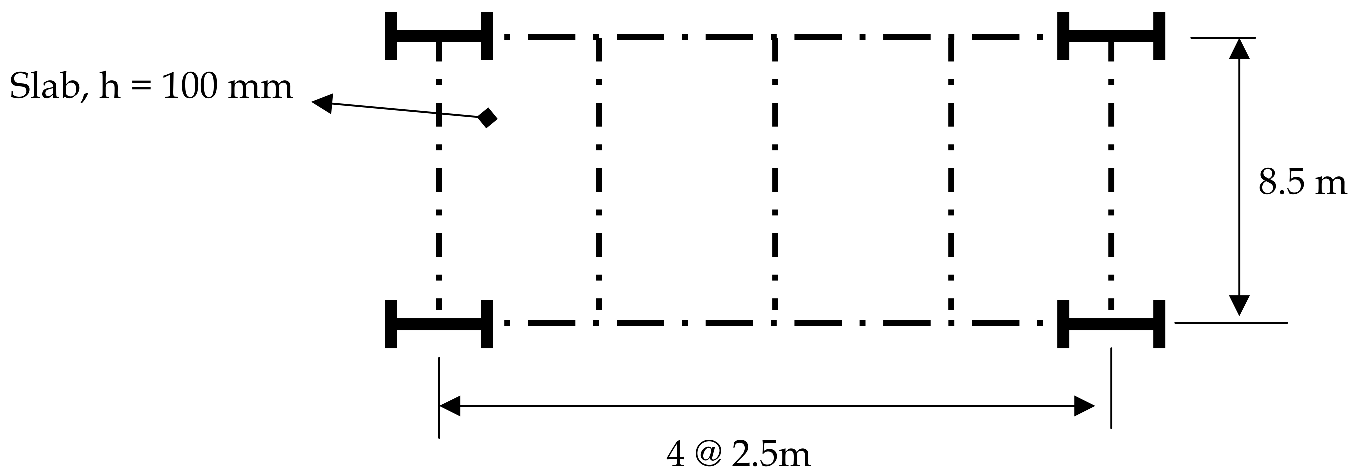
$$= \frac{V'}{Q_n} = \frac{5355}{101.79} \cong 53$$

2 studs at each cross section and at 27 locations in half span ($L/2$) .

Steel Structures

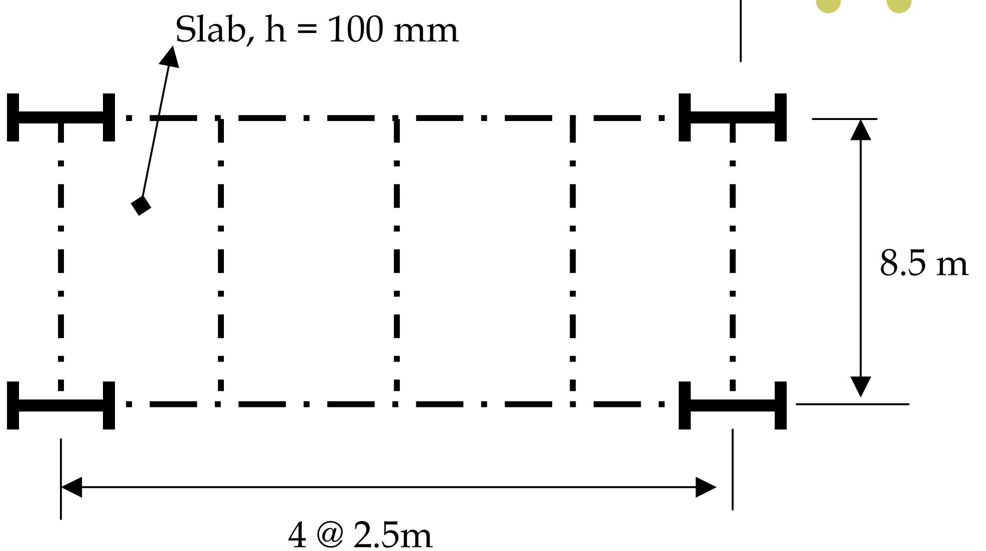
Example:

Design an interior composite beam for the floor plan shown in fig. assuming that no shoring will be used during construction. Use A36 steel, fc′ = 20 MPa, 100 mm slab thickness, flooring, false ceiling and partition load = 155 kg/m^2, live load = 750 kg/m^2 and construction live load = 100 kg/m^2. The beam is having shear connection with the main beam. Try minimum depth section.



Steel Structures

Solution



$$d \cong \frac{L}{24} = \frac{8500}{24} = 354\,mm$$

Use W 360

$$\text{Slab Weight} = \left(\frac{100}{1000} \times 2400\right) \times 2.5 = 600\,kg/m$$

$$\text{Other dead loads} = 155 \times 2.5 = 388\,\text{kg/m}$$

Assumed Self weight = 10% of other dead loads

$$= 0.1(600 + 388) = 99\,\text{kg/m}$$

Steel Structures

Solution (contd…)

Total Dead Load $= 600 + 388 + 99 = 1087 \text{ kg / m}$

Live Load $= 750 \text{ kg / m}^2$

$= 750 \times 2.5 = 1875 \text{ kg / m}$

Total Factored Load $= (1.2 \times 1087 + 1.6 \times 1875) \times \frac{9.81}{1000}$

$w_u = 42.23 \text{ kN/m}$

$$M_u = \frac{42.23 \times 8.5^2}{8} = 381.41 \text{kN - m}$$

Steel Structures

Solution (contd…)

Approximate Self weight $= \left[\dfrac{M_{u\,(N-mm)}}{\left(d/2 + Y_{conc.} - a/2 \right) \phi F_y} \right] \times 0.00785 \;\; kg\,/\,m$

$$= \left[\frac{381.41 \times 10^6}{\left(360/2 + 100 - 50/2 \right) 0.90 \times 250} \right] \times 0.00785$$

$$= 52.18\, kg\,/\,m < 99\, kg\,/\,m$$

We are on safer side, can be revised also.

Assuming N.A. to lie within the slab

$$(A_s)_{req} = \left[\frac{M_u}{\phi_b F_y \left(d/2 + t_{s.} - a/2 \right)} \right]$$

$$= \left[\frac{381.41 \times 10^6}{0.90 \times 250 \times \left(360/2 + 100 - 50/2 \right)} \right] = 6648 \;\; mm^2$$

Steel Structures

Solution (contd…)

Trial Section

W 360 x 57.8, $A = 7230\ mm^2$

$d = 358$ mm, $I = 16000 \times 10^4\ mm^4$, $b_f = 172$ mm

Effective Slab Width

b_E is smaller of

1. $L/4 = 8500/4 = 2125$ mm
2. $s = 2500$ mm

$b_E = 2125$ mm

Steel Structures

Solution (contd…)

Checking the Position of N.A

$$a = \frac{A_s F_y}{0.85 f_c' b_E} = \frac{7230 \times 250}{0.85 \times 20 \times 2125} = 50mm$$

Coincidently same as assumed value

$$c = \frac{a}{\beta_1} = \frac{50}{0.85} = 58.9mm < t_s$$

O.K. N.A. is within slab

$$\phi_b M_n = \phi_b A_s F_y \left(\frac{d}{2} + t_s - \frac{a}{2} \right)$$

$$= 0.90 \times 7230 \times 250 \left(\frac{358}{2} + 100 - \frac{50}{2} \right) \Big/ 10^6$$

$$= 413.2kN - m > M_u = 381.41kN - m$$

O.K.

Steel Structures

Solution (contd…)

Local Stability Check

$$\frac{h}{t_w} = 39.6 < \lambda_p = 107$$ O.K. (For flexure stress in web)

For A36 Steel

$$\frac{h}{t_w} = 39.6 < \lambda_p = 69.5$$ O.K. (To get maximum Shear Strength)

$$\frac{b_f}{2t_f} = 6.6 < \lambda_p = 10.8$$ O.K. Not compulsory to be checked

Steel Structures

Solution (contd…)

Shear Strength Check

$$V_u = \frac{42.23 \times 8.5}{2} = 179.5kN$$

$$\phi_v V_n = \phi_v \left(0.6F_y\right) \times d \times t_w$$

$$= 0.9\left(0.6 \times 250\right) \times 358 \times 7.9 / 1000$$

$$= 381.8kN > 179.5kN$$ O.K.

Steel Structures

Solution (contd…)

Flexural Strength Check at Construction Stage

Actual Self Weight = 57.8 kg/m

Wet slab weight = 600 kg/m (included in Live Load)

Construction live load = 100 x 2.5 = 250 kg/m

$$w_u = (1.2 \times 57.8 + 1.6 \times 850) \times \frac{9.81}{1000}$$

$$= 14.02 kN/m$$

O.K.

$$M_u = \frac{14.02 \times 8.5^2}{8} = 126.7 kN - m$$

$$\phi_b M_p = 0.9 Z_x \times F_y = 225 KN - m > M_u$$ O.K.

Steel Structures

Solution (contd…)

Design of Shear Connectors

V′ is lesser of

$$0.85 f_c' A_c = 3612.5 kN$$

$$A_s F_y = 1807.5 kN$$

$$\boxed{V_{uh} = 1807.5 kN}$$

If we use 20mm Φ x 80mm, cover at the top will be 20 mm, which is less than 25 mm so, let we use

$$15\text{mm}\Phi \times 60\text{mm}$$

Steel Structures

Solution (contd…)

$$A_{sc} = \frac{\pi}{4} \times 15^2 = 176.7 mm^2$$

$$E = 21019 MPa$$

$$Q_n = 0.5 A_{sc} \sqrt{f_c' E_c} \leq A_{sc} F_u$$

$R_g = R_p = 1.0$

$$Q_n = \frac{0.5 \times 176.7 \sqrt{20 \times 21019}}{1000} \leq \frac{176.7 \times 400}{1000}$$

$$= 57.28 kN \leq 70.6 kN$$

$$\boxed{Q_n = 57.28 kN}$$

Steel Structures

Solution (contd…)

Number of Shear Connectors b/w M_{max} & zero moment section. $= \frac{V'}{Q_n} = \frac{1807.5}{57.28} = 32$

Transverse Spacing

$b_f = 172$ mm

$s_{min} = 4d_s = 4 \times 15 = 60$ So two rows are easily possible

Longitudinal Spacing

$$s = \frac{8500/2}{32/2} = 265 \text{ mm}$$

$$s_{min} = 6d_s = 90\text{mm} < 265 \quad \text{O.K.}$$

$$s_{max} = \text{lesser of } 8t_s \text{ and } 915 \text{ mm}$$

$$= 800mm > 265 \quad \text{O.K.}$$

Total no. of connectors = 2 x 32 + 2 = 66 2 additional

Concluded