

Composite Sections (Steel Beam + Conc. Slab)

- Composite Sections by LRFD
- Analysis Methods



Photo by Mike Greenwood, 2009. Used with permission

Composite Design

Steel W section with concrete slab
“attached” by shear studs.

The concrete slab acts as a wider and
thicker compression flange.

Strength increase by 33% to 50%

Deflection reduced by 70% to 80%

Can attain either longer spans or smaller
members – more economical in long spans

Smaller floor depth, therefore reduced
overall building heights and weights

Reduced DL of system, reduction of other
material vertically (façade, walls, plumbing,
wiring, etc.)



Shear Studs

Also called Nelson studs after the company that originated them.



From AISC DigiLib

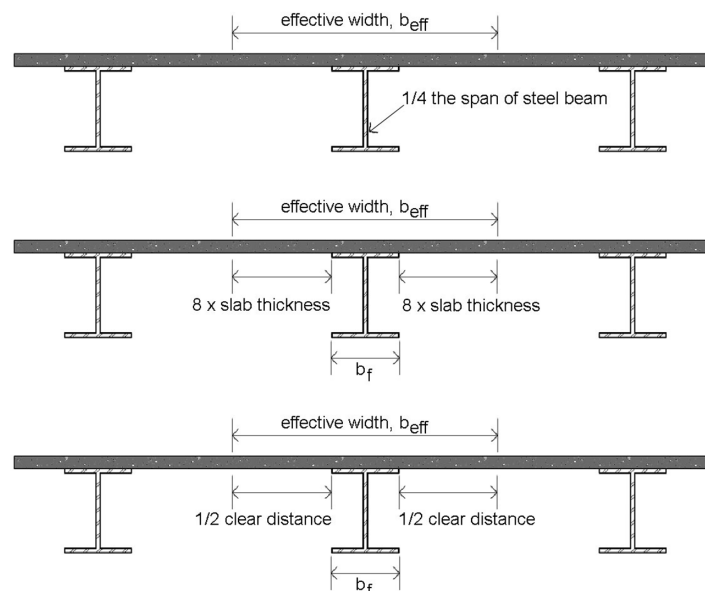
Can be spot welded through light gage decking onto W section

Effective Flange Width, b_e

Slab on both sides:

b_e is the **least** total width :

- Total width: $\frac{1}{4}$ of the beam span
- Overhang: $8 \times$ slab thickness
- Overhang: $\frac{1}{2}$ the clear distance to next beam (i.e. b_e is the web on center spacing)

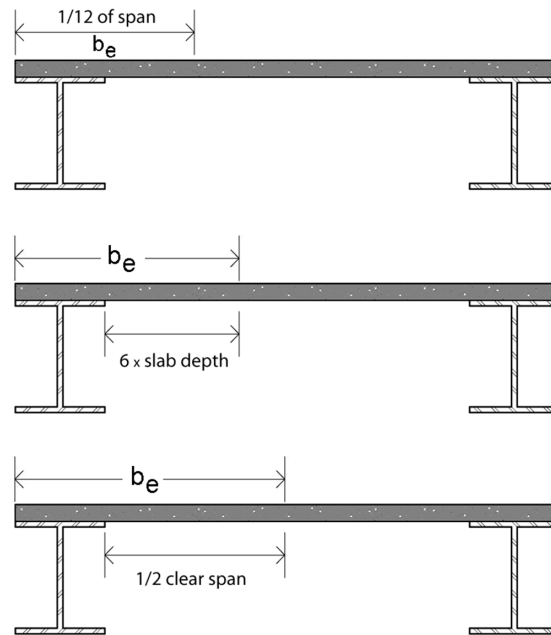


Effective Flange Width, b_e

Slab on one side:

b_e is the **least** total width (i.e. overhang + steel flange) :

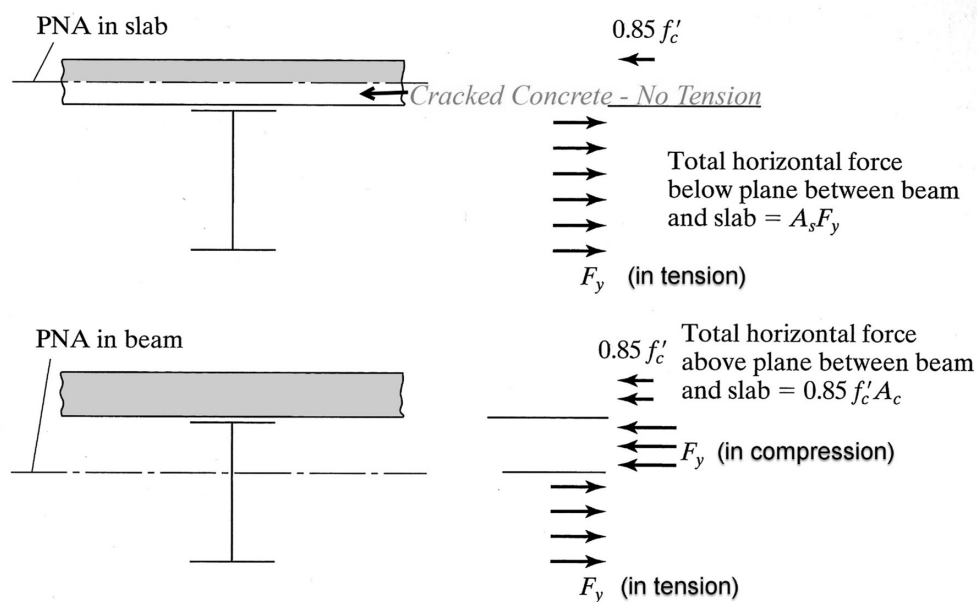
- Total width: 1/12 of the beam span
- Overhang: 6 x slab thickness
- Overhang: $\frac{1}{2}$ the clear distance to next beam



Analysis Procedure (LRFD)

Case 1 – Plastic Neutral Axis (PNA) within slab

Case 2 – PNA within steel section

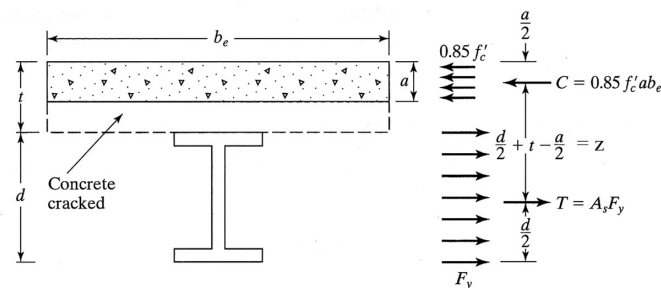


Analysis Procedure (LRFD)

Case1 – PNA within slab

Given: Slab and beam geometry
W-section size and steel grade
(floor loads)

Find: pass/fail or capacities



1. Define effective flange width, b_e
2. Calculate the effective depth of the concrete stress block, a
3. If a is within concrete slab, the full steel section is in tension and:
 $M_p = T z$
 $M_n = M_p = A_s F_y (d/2 + t - a/2)$

4. $M_u \leq \phi M_n$

$$T = C$$

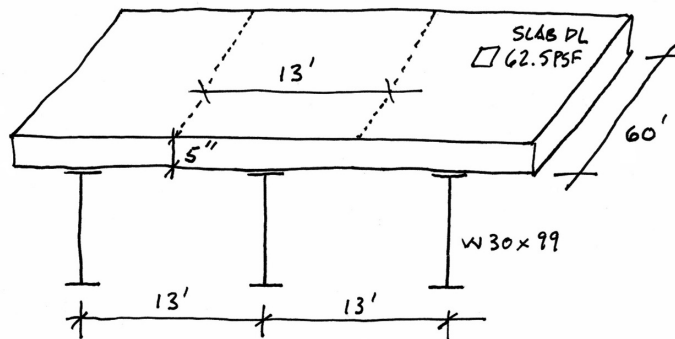
$$A_s f_y = 0.85 f'_c a b_e$$

$$a = \frac{A_s f_y}{0.85 f'_c b_e}$$

Non-composite vs. Composite Sections

Given:

- $DL_{slab} = 62.5 \text{ psf} = 812.5 \text{ plf}$
- $DL_{beam} = 99 \text{ plf}$
- $LL = ?$
- W 30x99
- $F_y = 50 \text{ ksi}$
- $f'_c_{conc} = 4 \text{ ksi}$



Find: Load Capacity

For this example, floor capacity is found for two different floor systems:

1. Find capacity of steel section independent from slab

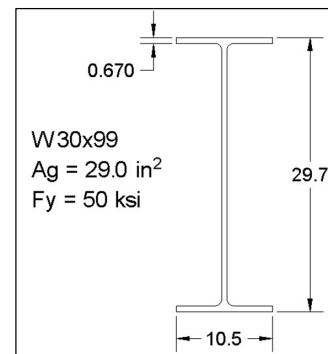
vs.

2. Find capacity of steel and slab as a composite section

WEIGHT of SLAB

$$\frac{5''}{12} 150 \text{ PCF} = 62.5 \text{ PSF}$$

$$13' \times 62.5 \text{ PSF} = 812.5 \text{ PLF}$$



Part 1 Non-composite Capacity Analysis

(Example part 1 - steel beam alone - LRFD)

WEIGHT of SLAB

$$\frac{5''}{12} 150 \text{ PCF} = 62.5 \text{ PSF}$$

$$13' \times 62.5 \text{ PSF} = 812.5 \text{ PLF}$$

Given:

- $DL_{\text{slab}} = 62.5 \text{ psf} = 812.5 \text{ plf}$
- $DL_{\text{beam}} = 99 \text{ plf}$
- W 30x99

1. Find section modulus, Z_x in the steel W-section chart.
2. Calculate $M_n = F_y Z_x$.
3. $M_u \leq \phi M_n$
4. Find w_u from moment equation
5. Subtract the DL to find the remaining LL.
6. Calculate LL capacity in PSF.

$$W30 \times 99 \quad Z_x = 312 \text{ in}^2$$

$$M_n = F_y Z_x = 50(312) = 15600 \text{ in-K} \\ = 1300 \text{ ft-K}$$

$$\phi M_n = M_u = 0.9(1300) = 1170 \text{ ft-K}$$

$$M_u = \frac{w_u l^2}{8} = \frac{w_u (60)^2}{8} = 1170 \text{ ft-K}$$

$$w_u = 2.6 \text{ KLF} = 2600 \text{ PLF}$$

$$w_u = 1.2(w_{DL}) + 1.6(w_{LL}) = 2600 \text{ PLF}$$

$$w_u = 1.2(812.5 + 99) + 1.6(w_{LL}) = 2600 \text{ PLF}$$

$$w_{LL} = 941.3 \text{ PLF}$$

$$LL = 941.3 \text{ PLF} / 13' = 72.4 \text{ PSF}$$

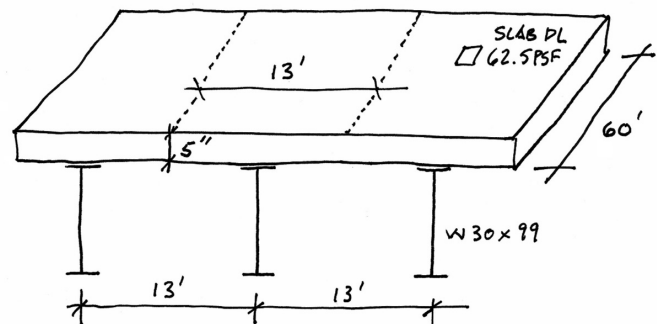
Composite Analysis Procedure

(Case1 – PNA within slab)

Given: Slab and beam geometry
W-section size and steel grade
(floor loads)

Find: pass/fail or capacities

1. Determine effective flange width, b_e
2. Calculate the effective depth of the concrete stress block, a
3. If a is within concrete slab, the full steel section is in tension and:
 $M_n = M_p = A_s F_y (d/2 + t - a/2)$
4. $M_u \leq \phi M_n$
5. Use M_u to calculate factored loads with appropriate beam moment equation.



WEIGHT of SLAB

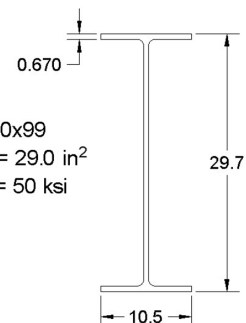
$$\frac{5''}{12} 150 \text{ PCF} = 62.5 \text{ PSF}$$

$$13' \times 62.5 \text{ PSF} = 812.5 \text{ PLF}$$

W30x99

$A_g = 29.0 \text{ in}^2$

$F_y = 50 \text{ ksi}$



Composite Capacity Analysis

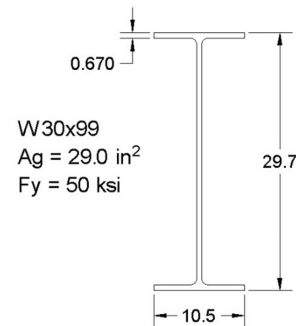
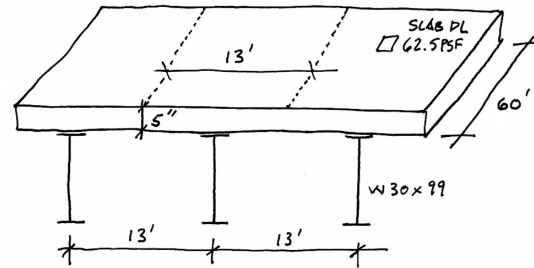
(Example part 2 - composite steel beam and slab)

Given:

- $DL_{slab} = 62.5 \text{ psf} = 812.5 \text{ plf}$
- $DL_{beam} = 99 \text{ plf}$
- $LL = ?$
- W 30x99
- $F_y = 50 \text{ ksi}$
- $f'_c_{conc} = 4 \text{ ksi}$

Find:

capacity of steel and slab as a composite section

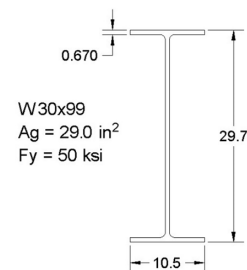
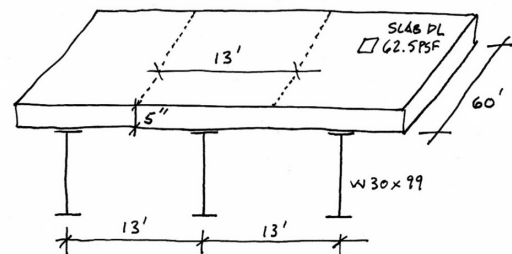
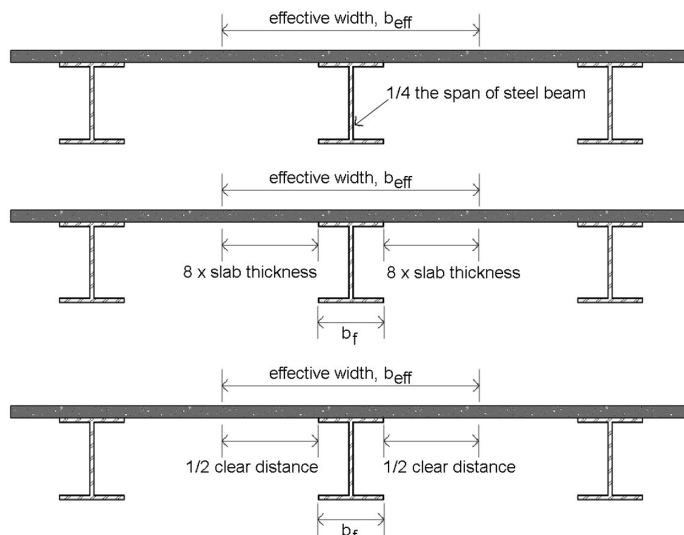


Part 2 Composite Capacity Analysis

1. Determine effective flange width, b_e

b_e is the **least** total width :

- Total width: $\frac{1}{4}$ of the beam span
- Overhang: 8 x slab thickness
- Overhang: $\frac{1}{2}$ the clear distance to next beam (i.e. b_e is the web on center spacing)



b_e is the **least** total width :

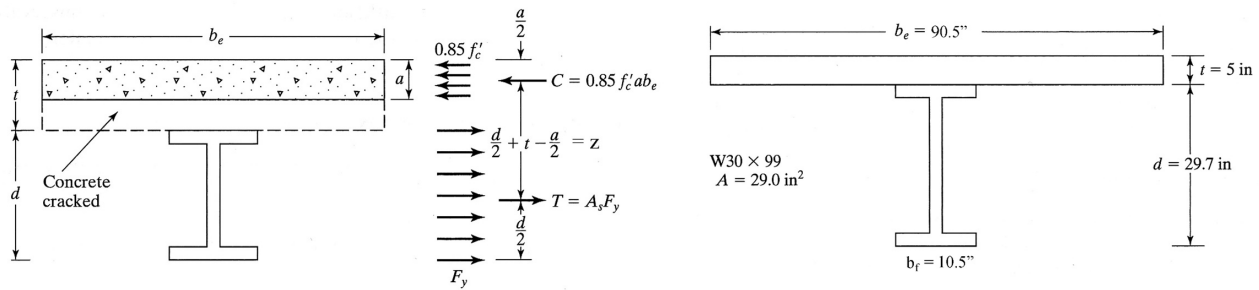
$$b_e \text{ ①} = \frac{1}{4} 60' = 15' = 180''$$

$$b_e \text{ ②} = 8(5') \times 2 + 10.5 = 90.5'' \leftarrow$$

$$b_e \text{ ③} = 13' = 156''$$

$$\therefore b_e = 90.5''$$

Part 2 - Composite Capacity Analysis cont.



- Calculate the effective depth of the concrete stress block, a

$$a = \frac{A_s F_y}{0.85 f'_c b_e} = \frac{29.0(50)}{0.85(4)(90.5)} = 4.712''$$

$$4.712'' < 5'' \therefore \text{WITHIN SLAB}$$

- If a is within concrete slab, the full steel section is in tension and:

$$M_n = M_p = A_s F_y (d/2 + t - a/2)$$

- $M_u \leq \phi M_n$

$$M_n = M_p = T \times z$$

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

$$M_n = 29.0 \text{ in}^2 (50 \text{ ksi}) \left(\frac{29.7}{2} + 5 - \frac{4.712}{2} \right)$$

$$M_n = 25366 \text{ in-k} = 2114 \text{ ft-k}$$

$$\phi M_n = 0.9(2114) = 1902 \text{ ft-k} = M_u$$

Composite Analysis cont.

- $M_u \leq \phi M_n$

- Find total factored w_u .

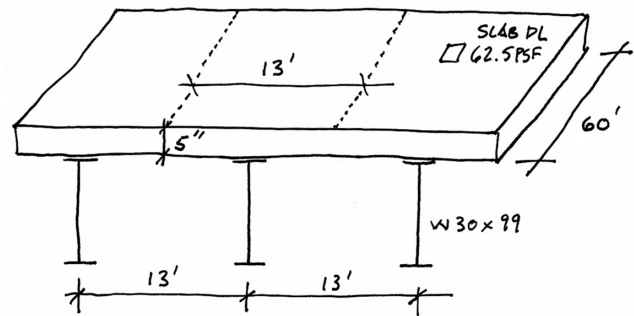
- Subtract the factored w_{DL} to find w_{LL}

- Calculate the LL in PSF based on the w_{LL} .

Conclusion:

Non-composite LL = 72.4 PSF

Composite LL = 150 PSF



WEIGHT of SLAB

$$\frac{5''}{12} 150 \text{ PCF} = 62.5 \text{ PSF}$$

$$13' \times 62.5 \text{ PSF} = 812.5 \text{ PLF}$$

$$M_u = 1902 = \frac{w_u l^2}{8} = \frac{w_u 60^2}{8}$$

$$w_u = 4,227 \text{ PLF} = 1.2(w_{DL}) + 1.6(w_{LL})$$

$$w_u = 4227 \text{ PLF} = 1.2(911.5) + 1.6(w_{LL})$$

$$w_{LL} = 1958 \text{ PLF}$$

$$LL = 1958 \text{ PLF} / 13' = 150 \text{ PSF}$$

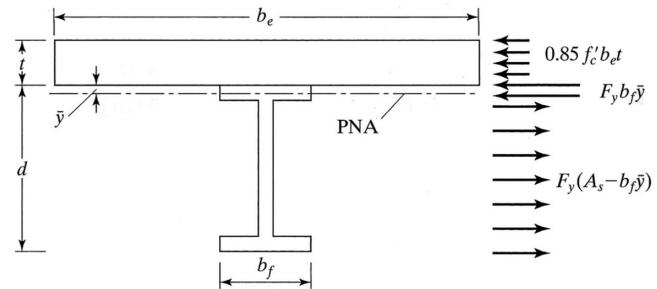
Composite Analysis Procedure

(Case 2 – PNA within W-section)

Given: Slab and beam geometry
W-section size and steel grade
(floor loads)

Find: pass/fail or capacities

1. Determine effective flange width, b_e
2. Calculate the effective depth of the concrete stress block, a .
3. If a is within steel section, the part below the Plastic Neutral Axis (PNA) is in tension and everything above the PNA is in compression (the steel and the concrete)
4. Check if PNA falls within flange or web of the W-section
5. Find $\bar{y}$ by equating $T = C$
6. $M_n = M_p = C_1(z_1) + C_2(z_2) + T(z_3)$
7. $M_u = \phi M_n$



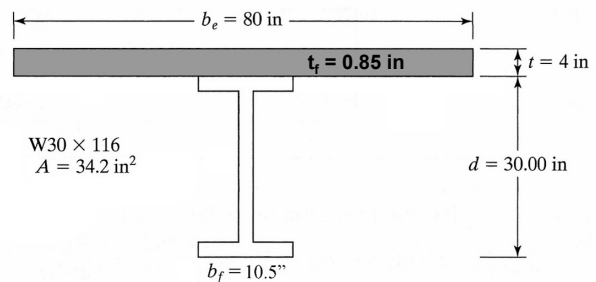
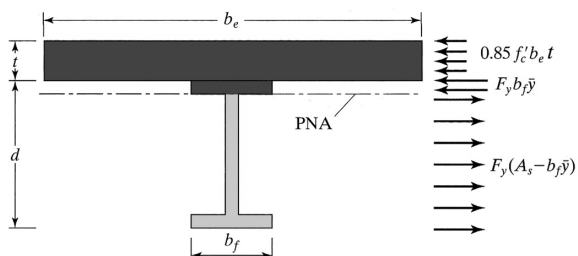
Composite Analysis Example

(Case 2 – PNA within W-section)

Given: Slab and beam geometry
W-section size and steel grade
(floor loads)

Find: moment capacity

1. Determine effective flange width, b_e
2. Calculate the effective depth of the concrete stress block, a .
3. Check if PNA is within upper flange. Assume PNA is at top of web. Check C and T . If C is greater than T , then PNA is within the top flange.



$$a = \frac{A_s f_y}{0.85 f'_c b_e} = \frac{34.2 \text{ in}^2 (50 \text{ ksi})}{0.85 (4 \text{ ksi}) (80 \text{ in})} = 6.29 \text{ in}$$

$6.29 \text{ in} > 4 \text{ in} \therefore \text{BELOW SLAB}$

$$C_1 = 0.85 f'_c b_e t$$

$$C_1 = 0.85 (4 \text{ ksi}) (80 \text{ in}) (4 \text{ in}) = 1088 \text{ K}$$

$$C_2 = F_y b_f t_f = 50 \text{ ksi} (10.5 \text{ in}) (0.85 \text{ in}) = 446.25 \text{ K}$$

$$C = C_1 + C_2 = 1088 \text{ K} + 446.25 \text{ K} = 1534 \text{ K}$$

$$T = F_y (A_s - b_f t_f) = 50 (34.2 - 8.925) = 1263.7 \text{ K}$$

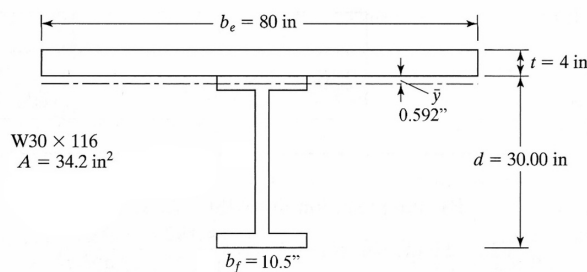
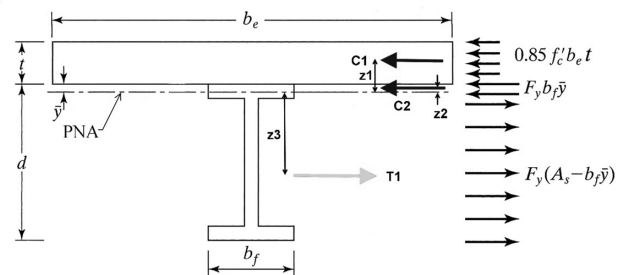
$$\sum F_u = 0 = T - C \therefore T = C$$

Since horizontal forces should sum to zero, T should equal C . So C should be less than 1534 and T greater than 1263. Therefore, the PNA must be higher and within the flange.

Composite Analysis Procedure

(Case 2 – PNA within W-section)

3. If a is within steel section, only the part below the PNA is in tension and the top is in compression with all concrete
4. Check if PNA falls within flange or web of the W-section
5. Find $\bar{y}$ by equating $T = C$



$$T = C$$

$$(A_s - b_f \bar{y}) F_y = 0.85 f'_c b_e t + b_f \bar{y} \times F_y$$

$$A_s F_y - 0.85 f'_c b_e t = 2 (b_f \bar{y} F_y)$$

$$\bar{y} = \frac{A_s F_y - 0.85 f'_c b_e t}{2 b_f F_y}$$

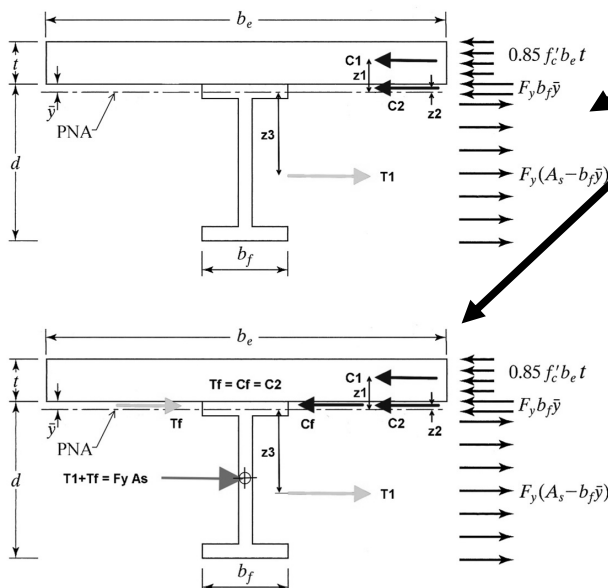
Composite Analysis Procedure

(Case 2 – PNA within W-section)

5. Find $\bar{y}$ by equating $T = C$
6. $M_n = M_p = C_1(z_1) + C_2(z_2) + T(z)$
7. $M_u = \phi M_n$

$$\bar{y} = \frac{34.2 \text{ in}^2 (50 \text{ ksi}) - 0.85 (4 \text{ ksi}) (80 \text{ in}) (4 \text{ in})}{2 (10.5 \text{ in}) (50 \text{ ksi})}$$

$$\bar{y} = 0.592 \text{ in} \quad t_f = 0.85 \text{ in for W30x116}$$



$$\sum M_{@PNA} = C_1(z_1) + C_2(z_2) + T_1(z_3)$$

$$= C_1(z_1) + 2C_2(z_2) + A_s F_y \left(\frac{d}{2} - \bar{y} \right)$$

$$M_n = M_p = \overbrace{0.85 f'_c b_e t}^{C_1} \left(\frac{t}{2} + \bar{y} \right) + \overbrace{2 F_y b_f \bar{y}}^{C_2} \left(\frac{d}{2} \right) + \overbrace{F_y A_s}^T \left(\frac{d}{2} - \bar{y} \right)$$

$$M_n = 0.85 (4 \text{ ksi}) (80 \text{ in}) 4 \text{ in} \left(\frac{4 \text{ in}}{2} + 0.592 \text{ in} \right) + 2 (50 \text{ ksi}) (10.5 \text{ in}) (0.592 \text{ in}) \left(\frac{30 \text{ in}}{2} \right) + (50 \text{ ksi}) (34.2 \text{ in}^2) \left(\frac{30 \text{ in}}{2} - 0.592 \text{ in} \right)$$

$$= 27650 \text{ in} \cdot \text{K}$$

$$= 2304 \text{ ft} \cdot \text{K}$$

MOMENT CAPACITY :

$$M_u = \phi M_n = 0.9 (2304 \text{ ft} \cdot \text{K}) = 2074 \text{ ft} \cdot \text{K}$$