Composite Sections (Steel Beam + Slab)

- Composite Sections by LRFD
- Analysis Methods

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.

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: $6 \times$ 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)
Case 1 – 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:
   \[ M_p = T \frac{a}{T} \]
   \[ M_n = M_p = A_s F_y \left( \frac{d}{2} + t - \frac{a}{2} \right) \]

4. $M_u \leq \phi M_n$

Non-composite vs. Composite Sections

Given:
- $D_{L, \text{slab}} = 62.5$ psf
- $D_{L, \text{beam}} = 99$ plf
- $L = ?$
- W 30x99
- $F_y = 50$ ksi
- $f'_c \text{ conc} = 4$ ksi

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
Part 1 Non-composite Capacity Analysis
(steel beam alone - LRFD)

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.

---

Composite Analysis Procedure
(Case 1 – 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.
Part 2 - Composite Capacity Analysis
(composite steel beam and slab)

Given:
- $D_{L_{slab}} = 62.5$ psf
- $D_{L_{beam}} = 99$ plf
- $LL = ?$
- $W_{30x99}$
- $F_y = 50$ ksi
- $f'_c_{conc} = 4$ 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: $8 \times$ slab thickness
   - Overhang: $\frac{1}{2}$ the clear distance to next beam
     (i.e. $b_e$ is the web on center spacing)
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:
   \[ Mn = Mp = \frac{A_s F_y (d/2 + t - a/2)}{0.85 F_y (d/2 + t - a/2)} \]

4. \( Mu \leq \phi Mn \)

Composite Analysis cont.

4. \( Mu \leq \phi Mn \)

5. Find total factored \( w_u \).

6. Subtract the factored \( w_{DL} \) to find \( w_{LL} \).

7. Calculate the LL in PSF based on the \( w_{LL} \).

Conclusion:
Non-composite LL = 72.4 PSF
Composite LL = 150 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. \( M_n = M_p = C_1(z_1) + C_2(z_4) + T(z_3) \)
7. \( M_u = \Phi \cdot M_n \)

---

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. 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.

\( C_1 = 0.85 f_c b_e t \)
\( C_1 = 0.85 (4,000)(0.85) = 342 \text{ ksi} \)
\( C_2 = f_y b_f t_f = 50,000 (10.5)(0.85) = 446.25 \text{ ksi} \)
\( C = C_1 + C_2 = 1088 + 446.25 = 1534 \text{ ksi} \)
\( T = F_y (A_v - b_f t_f) = 50 (34.2 - 8.925) = 1263.7 \text{ ksi} \)

\[ \Sigma F_x = 0 = T - C \therefore T = C \]

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)

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. Find $\bar{y}$ by equating $T = C$

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

Composite Analysis Procedure (Case 2 – PNA within W-section)

4. Find $\bar{y}$ by equating $T = C$

5. $M_n = M_p = C_1(z_1) + C_2(z_2) + T(z)$

6. $M_u = \phi M_n$

Moment Capacity: $M_u = 0.9 (8304 ' k) = 2074 ' k$