CE591 Lecture 10: Composite Beams; Shear Connectors; Metal Decking

- Metal Deck, Shear Connectors
- Shear Studs and Metal Deck
  - Capacity, $Q_n$
  - Limits on Spacing, etc.
- Calculation of Positive Design Flexural Strength
Metal Deck
Thickness – 16 to 22 gage (~0.064” to ~0.034”)
Puddle welds
AISC I3.2c – steel deck shall be anchored to all supporting members at a spacing not to exceed 18” (can be from combination of shear studs and puddle welds)

Deck manufacturers may specify placement
“Button-punching” deck

BUTTON PUNCH

WELD AFTER CLINCHING

SCREW OR WELD

SCREW OR WELD

SCREWS MAY BE PLACED AT AN ANGLE IF MALE LEG IS SHORT
Shear Connectors

From Geschwindner, Unified Design of Steel Structures, 2nd ed.
Shear studs (steel headed stud anchor) and ferrules
Typically 3/4” or 7/8” diameter
(3/4” required with metal deck)

Height ~ 2” – 8”
Placing shear studs
Welded wire fabric (WWF)
Welded wire fabric

diameter of wire, 10 gage, \( d \sim 1/8" \)

W1.4 x 1.4
6 x 6

Spacing (inches)
May add reinforcement across girders
AISC C-I3.2 – “where … longitudinal cracking detrimental to serviceability is likely to occur, slab should be reinforced transverse to the supporting steel section ...”

\[ A_r \geq 0.002A_c \]
Fig. C-I3.1. Longitudinal shear in the slab [after Chien and Ritchie (1984)].
Shear Studs and Metal Deck

Ribs parallel to axis of beam  Ribs perpendicular to axis of beam
Composite Floor System Design Techniques, 2013 NASCC
Will Jacobs, Sam Easterling
media.aisc.org/NASCC2013/N14a.mp4
Ideally – rigid, no slip

Reality – stud can deform, concrete crushes, get some slip
Strength of stud connectors for composite beams

\[ Q_n = 0.5 A_{sa} \sqrt{f'_c E_c} \leq R_g R_p A_{sa} F_u \]

\( R_g = \text{Group effect factor} \)
\( R_p = \text{Position effect factor} \)

No metal deck? \( \Rightarrow \)
\[ R_g = 1.0 \]
\[ R_p = 0.75 \]
Solid slab strength

\[ Q_n = 0.5A_{sc} \sqrt{f'_c E_c} \leq A_{sc} F_u \]

Based on Push-out tests

(Easterling, 2007)
\[
\frac{Q_u}{A_s} = 0.5 \sqrt{f'_c E_c}
\]

Graph showing the relationship between \(\frac{Q_u}{A_s}\) (in KSI) and \(\sqrt{f'_c E_c}\) (also in KSI), with data points for different stud diameters and concrete types.
$H_s = \text{length of stud after welding}$

$H_s \geq h_r + 1-1/2''$

$H_s \geq 4d_s$

AISC I3.2c and I8.2
AISC Specification Equations

\[ SRF = \frac{0.85}{\sqrt{N_r}} \left( \frac{w_r}{h_r} \right) \left( \frac{H_s}{h_r} - 1.0 \right) \leq 1.0 \]

Stud reduction factor – based on beam tests

From AISC-LRFD 3rd edition
AISC Predicted Strength, $Q_N$

Experimental Stud Strength, $Q_e$

$Q_e = Q_N$

- △ S Studs
- ◇ 2S Studs
- ○ W Studs
W16x31  $F_y = 50$ ksi  $y_2 = 4.5$ in.
(Easterling, 2007)
Slab/Beam Interface (Friction)

Conclusions:

- Stud strength in solid slabs ($1.0A_{sc}F_u$) greater than strength from direct shear tests ($0.7A_{sc}F_u$)
- Eliminating concrete to structural steel interface with sheet steel reduces the strength ($\sim 0.88 A_{sc}F_u$)

* Steel deck, regardless of profile, reduces the friction at the beam / concrete interface

(Easterling, 2007)
Web embossments not shown
Weak Position Stud Failure

(Easterling, 2007)
**Shear Connectors**

\[ Q_n = 0.5 A_{sc} \sqrt{f'_c E_c} \leq R_g R_p A_{sc} F_u \]

\[ R_g = \text{stud group factor} \]

*0.85 if thru deck and \( \frac{w_r}{h_r} < 1.5 \); 1.0 if \( \frac{w_r}{h_r} \geq 1.5 \)*
Shear Connectors

\[ Q_n = 0.5 \, A_{sc} \sqrt{f'_c E_c} \leq R_g \, R_p \, A_{sc} \, F_u \]

\( R_p = \) position adjustment factor

\( R_p = 0.6-0.75 \)

No Deck

\( R_p = 0.75 \)

Deck
\( e_{\text{mid-ht}} \) = distance from edge of stud shank to steel deck web, measured at mid-height of the deck rib, and in the load bearing direction (i.e., direction of max moment for simply supported beam)

\[ e_{\text{mid-ht}} \geq 2\text{in} \quad e_{\text{mid-ht}} < 2\text{in} \]

\( R_p = 0.6 - 0.75 \)

\[ R_p = 0.75 \quad R_p = 0.6 \]

Fig. C-I8.1. Weak and strong stud positions [Roddenberry et al. (2002b)].
Shear Connectors

\[ Q_n = 0.5 A_{sc} \sqrt{f'_c E_c} \leq R_g R_p A_{sc} F_u \]

\[ R_p = 0.6 \quad R_p = 0.75 \]
**User Note:** The table below presents values for $R_g$ and $R_p$ for several cases. Capacities for steel headed stud anchors can be found in the Manual.

<table>
<thead>
<tr>
<th>Condition</th>
<th>$R_g$</th>
<th>$R_p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>No decking</td>
<td>1.0</td>
<td>0.75</td>
</tr>
<tr>
<td>Decking oriented parallel to the steel shape</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\frac{w_r}{h_r} \geq 1.5$</td>
<td>1.0</td>
<td>0.75</td>
</tr>
<tr>
<td>$\frac{w_r}{h_r} &lt; 1.5$</td>
<td>0.85**</td>
<td>0.75</td>
</tr>
<tr>
<td>Decking oriented perpendicular to the steel shape</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of steel headed stud anchors occupying the same decking rib</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.0</td>
<td>0.6+</td>
</tr>
<tr>
<td>2</td>
<td>0.85</td>
<td>0.6+</td>
</tr>
<tr>
<td>3 or more</td>
<td>0.7</td>
<td>0.6+</td>
</tr>
</tbody>
</table>

$h_r = \text{nominal rib height, in. (mm)}$

$w_r = \text{average width of concrete rib or haunch (as defined in Section I3.2c), in. (mm)}$

** for a single steel headed stud anchor

$^+ \text{this value may be increased to 0.75 when } e_{mid-ht} \geq 2 \text{ in. (51 mm)}$
Control of Shear Stud Placement in the Field

The use of the “strong position” value of 0.75 for $R_p$ requires confidence in the control of shear stud placement in the field. Will you have that control?

(Easterling, 2007)
(Easterling, 2007)
Composite Girder Details

CELL CLOSURE

$R_p$ for beam or girder?

Composite Girder Details

CELL CLOSURE

$R_p$ for beam or girder in weak position

Composite Floor System Design Techniques, 2013 NASCC
Will Jacobs, Sam Easterling
media.aisc.org/NASCC2013/N14a.mp4
Limits

$w_r \geq 2''$

$\geq 2'' \geq \frac{1}{2}''$

$\leq 3''$

$H_s \geq 1-1/2''$

AISC I3.2c – $d_s \leq \frac{3}{4}''$ (based on test results)
When nominal

\[ h_r \geq 1-1/2" \]

(AISC I3.2c)

Deck rib permitted to be split longitudinally and separated to form a concrete haunch

For one stud,

\[ w_r \geq 2" \]

+ \(4d_s\) for each additional stud
Limits, cont’d.

2 $d_s$ (recommended)

≥4 $d_s$

≥6 $d_s$ (in general)

≥4 $d_s$
(for ribs perpendicular to beam)

≤ 8 $t_s$
and ≤36”
(in any direction)

5½” minimum flange width for 2 rows of studs (for ¾” stud)
8½” minimum flange width for 3 rows of studs (for ¾” stud)
Limits, cont’d.

\[ d_s \leq 2.5t_f \]

Unless stud placed over web
Limits, cont’d.

AISC I8.2d
Lateral cover of 1” for shear connectors, except in ribs of formed steel decks

≥1/2” req’d, ~1” typ.
Calculation of $\phi M_n$

Ribs perpendicular to axis of beam

AISC I3.2c
Concrete below top of deck (in ribs) shall be neglected for section properties and calculation of $A_c$ (strength, etc.)
Calculation of $\phi M_n$

Ribs parallel to axis of beam

AISC I3.2c
Concrete below top of deck (in ribs) is permitted be included for section properties ($I_x$)

and SHALL be included in calculation of $A_c$ (strength)
Lateral bracing during construction (concrete placement)

- With puddle welds / studs / combination at no more than 18” o.c.
- Beams are fully laterally braced
- Girders are perhaps not braced by the deck
  - Depends on girder – filler beam detail
  - Recommend using filler beam spacing as unbraced length at construction stage
Composite Girder Details