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**Composite Construction 101: Fundamentals, Practical Implementation, and New Thrust Areas**
June 11, 2020

Smarter. Stronger. Steel.

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## AISC Live Webinars

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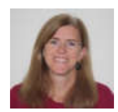
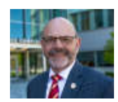
**Composite Construction 101: Fundamentals, Practical Implementation, and New Thrust Areas**



Susan Burmeister, P.E.
S2B Structural Consultants PLLC
Springfield, Virginia



W. Samuel Easterling, PhD, PE
James L. and Katherine S. Melsa Dean of Engineering
Iowa State University
Ames, Iowa

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Composite Construction 101: Fundamentals, Practical Implementation, and New Thrust Areas

- Fundamentals - Overview of composite construction in floors
- Practical Implementations
- New Thrust Areas

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## The Deck is Important

30 story building

- Very little time by the Structural Engineer to design
- Deck production time was approximately 4 days
- Detailing/design time by deck manufacturer personnel was 6 months for two people.

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The cost of fabricating and erecting steel is a major component of the overall cost and should be considered at all stages of design and early in the process

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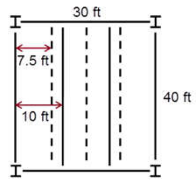
## Typical Interior Bay Design

- 30 ft x 40 ft bay
- Compare steel deck spans of 7.5 ft and 10 ft
- Costs
  - Structural steel - $1.25 / lb  ($2500 per ton)
  - Shear studs - $2.50 per stud
  - Fabrication / erection - $700 - $1,500 per beam
  - Steel deck - $1300 per ton (2 in., 20 ga - $130 per square)
    - $100 per square to install ("square" = 100 ft$^2$)

*Consult your local fabricator for current costs*

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## Typical Interior Bay Design

*Design basics*

- Office loads – 50 psf live
  20 psf partition
  8 psf mech & ceiling
- Deflection limits – span / 240 initial dead load
  span / 360 live load
- Use 1 headed steel anchor per ft

Floor Vibrations – *AISC Design Guide 11*

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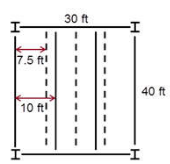
## Typical Interior Bay Design

- 7.5 ft deck span – 2 in. deep deck (3 filler beams)
  Beams – W18x35  L = 40 ft,  Girders – W21x62  L = 30 ft
  Cost - $1000/bm fabrication/erection - $14.63 / ft$^2$
- 10 ft deck span – 2 in. deep deck (2 filler beams)
  Beams – W18x40  L = 40 ft,  Girders – W21x57  L = 30 ft
  Cost - $1000/bm fabrication/erection - $12.73 / ft$^2$

**~13% reduction**

***Savings in fireproofing not included***

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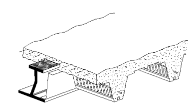
## Steel Construction Institute

- *Design Guide for Vibrations of Long Span Composite Floors*
- Evaluated several buildings in the UK with composite floors, two of which use deep deck with the Slimfloor system
- Floors deemed acceptable, based both on analysis, field measurements and occupant perception



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## Recommendation

- Use the largest deck span allowed based on the choice of slab depth.
- Early interactions with the project architect may result in being able to consider different slab depths

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## Composite Slab Design

**Construction Load Stage**

*Fresh concrete*

*Construction load*

**Service Load Stage**

*Superimposed load*

*Vibration*

*Fire resistance*

**Strength** **Serviceability**

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## Composite Slab Design

**Construction Load Stage**

*Fresh concrete*

*Construction load*

**Service Load Stage**

*Superimposed load*

*Vibration*

*Fire resistance*

**Strength** **Serviceability**

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## Steel Deck Design

**Construction Load Stage**

**Strength**

**AISI S100 - *North American Specification for the Design of Cold-formed Steel Structural Members***

**Serviceability**

**Deflection - Steel Deck Institute - span / 180** *or 3/4 in.*

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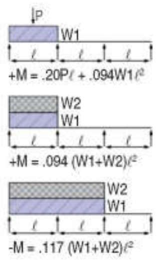
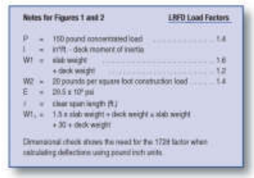
## Construction Load Stage

**Triple Span Condition**




***deck is evaluated as a <u>continuous one-way member</u> at the construction load stage***

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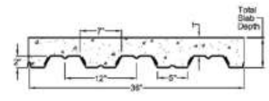
**VULCRAFT**

## 2 VLI

Maximum Sheet Length 42'-0
Extra Charge for Lengths Under 6'-0
ICBO Approved (No. 3415)




Interlocking side lap is not drawn to show actual detail.

**STEEL SECTION PROPERTIES**

| Deck Type | Design Thickness in. | Deck Weight psf | Section Properties $I_p$ in⁴/ft | $S_p$ in³/ft | $I_n$ in⁴/ft | $S_n$ in³/ft | $V_a$ lbs/ft | $F_y$ ksi |
|---|---|---|---|---|---|---|---|---|
| 2VLI22 | 0.0295 | 1.62 | 0.334 | 0.263 | 0.321 | 0.266 | 1633 | 50 |
| 2VLI20 | 0.0358 | 1.87 | 0.409 | 0.341 | 0.406 | 0.346 | 2888 | 50 |
| 2VLI19 | 0.0418 | 2.30 | 0.492 | 0.420 | 0.489 | 0.426 | 3190 | 50 |
| 2VLI18 | 0.0474 | 2.81 | 0.559 | 0.495 | 0.558 | 0.504 | 3608 | 50 |
| 2VLI16 | 0.0598 | 3.29 | 0.704 | 0.653 | 0.704 | 0.653 | 3618 | 40 |

**(N=9.35) NORMAL WEIGHT CONCRETE (145 PCF)**

| TOTAL SLAB DEPTH | DECK TYPE | SDI Max. Unshored Clear Span 1 SPAN | 2 SPAN | 3 SPAN | Superimposed Live Load, PSF Clear Span (ft.-in.) 5'-6 | 6'-0 | 6'-6 | 7'-0 | 7'-6 | 8'-0 | 8'-6 | 9'-0 | 9'-6 | 10'-0 | 10'-6 | 11'-0 | 11'-6 | 12'-0 | 12'-6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2VLI22 | 7'-4 | 9'-6 | 9'-9 | 274 | 239 | 211 | 188 | 145 | 129 | 115 | 104 | 94 | 85 | 78 | 71 | 65 | 59 | 54 |
| 4.00 | 2VLI20 | 8'-7 | 10'-10 | 11'-2 | 310 | 269 | 236 | 210 | 188 | 170 | 155 | 117 | 106 | 96 | 87 | 80 | 73 | 67 | 61 |
| (t=2.00) | 2VLI19 | 9'-9 | 11'-11 | 12'-4 | 344 | 298 | 261 | 231 | 207 | 186 | 169 | 155 | 142 | 106 | 97 | 88 | 81 | 74 | 68 |
| 39 PSF | 2VLI18 | 10'-9 | 12'-9 | 12'-9 | 373 | 324 | 285 | 253 | 228 | 206 | 188 | 172 | 159 | 147 | 137 | [illegible] | 95 | 87 | 81 |
| | 2VLI16 | 11'-1 | 13'-2 | 13'-5 | 400 | 376 | 330 | 292 | 261 | 235 | 214 | 195 | 180 | 166 | 154 | 143 | 133 | [illegible] | 93 |

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## Construction Load Stage

**(N=9.35) NORMAL WEIGHT CONCRETE (145 PCF)**

| TOTAL SLAB DEPTH | DECK TYPE | SDI Max. Unshored Clear Span 1 SPAN | 2 SPAN | 3 SPAN | Superimposed Live Load, PSF Clear Span (ft.-in.) 5'-6 | 6'-0 | 6'-6 | 7'-0 | 7'-6 | 8'-0 | 8'-6 | 9'-0 | 9'-6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2VLI22 | 7'-4 | 9'-6 | 9'-9 | 274 | 239 | 211 | 188 | 145 | 129 | 115 | 104 | 94 |
| 4.00 | 2VLI20 | 8'-7 | 10'-10 | 11'-2 | 310 | 269 | 236 | 210 | 188 | 170 | 155 | 117 | 106 |
| (t=2.00) | 2VLI19 | 9'-9 | 11'-11 | 12'-4 | 344 | 298 | 261 | 231 | 207 | 186 | 169 | 155 | 142 |
| 39 PSF | 2VLI18 | 10'-9 | 12'-9 | 12'-9 | 373 | 324 | 285 | 253 | 228 | 206 | 188 | 172 | 159 |
| | 2VLI16 | 11'-1 | 13'-2 | 13'-5 | 400 | 376 | 330 | 292 | 261 | 235 | 214 | 195 | 180 |

***Spans are back calculated based on controlling Strength (flexure, shear, web crippling) or Deflection (span/180 or ¾ in.)***

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## Maximum Unshored Clear Span

***Example***

***single span condition, flexural limit state***
***$w_D$ = slab + deck***
***$w_L$ = construction live load (20 psf)***
***$\phi M_n$ = flexural strength determined from AISI NAS***

$$\phi M_n = M_u = \frac{w_u \ell^2}{8}$$

$$w_u = 1.2 w_D + 1.6 w_L$$

$$\ell = \sqrt{\frac{8\phi M_n}{1.2 w_D + 1.6 w_L}}$$

***Other values determined for different limit states and span conditions.***

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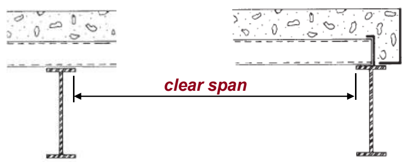
**Construction and Service Load Stage**

***Note: Both the "Maximum Unshored Clear Span" and "Superimposed Live Load" are based on the clear span noted below. Typically would use center-to-center spans, unless the particular design is "close." In such a case, it is perfectly acceptable to use the actual clear span***

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## Steel Deck Design

**Service Load Stage**

### Strength

Manufacturers load tables (SDI method, test programs, other)

**Serviceability**

Deflection – designer's criteria
Floor vibrations – AISC Design Guide 11

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## Composite Slab Flexural Strength

- Strength based on simple span composite slabs – no negative moment reinforcement over the supports
- Behavior is that of a one-way slab because of the deck geometry and lack, typically, of reinforcement transverse to the deck ribs.
- When loaded you should expect to see flexural cracks
- Construction loading (material staging) on composite slab will often induce cracks over beams or girders

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## Construction Material Staging

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## Service Load Stage

(N=9.35) NORMAL WEIGHT CONCRETE (145 PCF)

| TOTAL SLAB DEPTH | DECK TYPE | SDI Max, Unshored Clear Span | | | Superimposed Live Load, PSF Clear Span (ft.-in.) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 SPAN | 2 SPAN | 3 SPAN | 5'-6 | 6'-0 | 6'-6 | 7'-0 | 7'-6 | 8'-0 | 8'-6 | 9'-0 | 9'-6 |
| 4.00 (t=2.00) 39 PSF | 2VLI22 | 7'-4 | 9'-6 | 9'-9 | 274 | 239 | 211 | 188 | 145 | 129 | 115 | 104 | 94 |
| | 2VLI20 | 8'-7 | 10'-10 | 11'-2 | 310 | 269 | 236 | 210 | 188 | 170 | 155 | 117 | 106 |
| | 2VLI19 | 9'-9 | 11'-11 | 12'-4 | 344 | 298 | 261 | 231 | 207 | 186 | 169 | 155 | 142 |
| | 2VLI18 | 10'-9 | 12'-9 | 12'-9 | 373 | 324 | 285 | 253 | 228 | 206 | 188 | 172 | 159 |
| | 2VLI16 | 11'-1 | 13'-2 | 13'-5 | 400 | 376 | 330 | 292 | 261 | 235 | 214 | 195 | 180 |

*"Superimposed Live Load" explained in next slide*



## Service Load Stage

### LRFD Design Approach

$$\phi M_n = M_u = 1.2M_D + 1.6M_L$$

$$M_L = \frac{\phi M_n - 1.2M_D}{1.6}$$

$$M_L = \frac{w_L \ell^2}{8}$$

$$w_L = \frac{8(\phi M_n - 1.2M_D)}{1.6\ell^2}$$

The loads in the load tables are "service loads" (i.e. unfactored loads.) The total superimposed load on the slab is compared with the value given in the load table. The load table values are reported as "live" load because as noted in the calculation shown, the 1.6 factor has been carried through.



## Composite Slab – Example

- Select a composite slab for the conditions described below
- Bay is 30 ft x 30 ft.
- Building occupancy requirements dictate a two-hour fire rated assembly.
- The desire is to use an unprotected deck.
- Lightweight aggregate is readily available for the job so a 3.25 in. lightweight concrete cover thickness is selected, with a 5.25 in. total slab thickness specified by the architect.



## Composite Slab – Example

- With the objective to have the deck span as far as possible within the given constraints, start by trying a 15 ft deck span (1 filler beam.)
- We observe that for a 5.25 in. LWC slab, the maximum unshored clear span is 13 ft – 3 in. – therefore N.G.
- Next try a 10 ft deck span (2 filler beams).
- Select deck type 2VLI20, which has a maximum unshored clear span of 10 ft – 11 in. for a 3 span configuration.

## Vulcraft 2VLI – Load Table

(N=14.15) LIGHTWEIGHT CONCRETE (110 PCF)

| TOTAL SLAB DEPTH | DECK TYPE | SDI Max. Unshored Clear Span | | |
|---|---|---|---|---|
| | | 1 SPAN | 2 SPAN | 3 SPAN |
| 5.25 (t=3.25) 42 PSF | 2VLI22 | 7'-2 | 9'-3 | 9'-7 |
| | 2VLI20 | 8'-5 | 10'-7 | 10'-11 |
| | 2VLI19 | 9'-6 | 11'-8 | 12'-1 |
| | 2VLI18 | 10'-6 | 12'-7 | 12'-7 |
| | 2VLI16 | 10'-9 | 12'-10 | 13'-3 |



## Composite Slab – Example

*The applicable design loads at the service load stage are:*

*Live = 50 psf*

*Partition = 20 psf*

*superimposed dead = 15 psf*

**mechanical and ceiling = 10 psf*

*total "superimposed load" = 95 psf*

***Check 2VLI20 at 10 ft clear span for 95 psf***



## Vulcraft 2VLI – Load Table

(N=14.15) LIGHTWEIGHT CONCRETE (110 PCF)

| TOTAL SLAB DEPTH | DECK TYPE | SDI Max. Unshored Clear Span | | | Superimposed Live Load, PSF Clear Span (ft.-in.) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 SPAN | 2 SPAN | 3 SPAN | 6'-0 | 6'-6 | 7'-0 | 7'-6 | 8'-0 | 8'-6 | 9'-0 | 9'-6 | 10'-0 |
| 5.25 (t=3.25) 42 PSF | 2VLI22 | 7'-2 | 9'-3 | 9'-7 | 334 | 294 | 262 | 209 | 187 | 168 | 152 | 138 | 126 |
| | 2VLI20 | 8'-5 | 10'-7 | 10'-11 | 377 | 331 | 293 | 263 | 237 | 190 | 171 | 155 | 142 |
| | 2VLI19 | 9'-6 | 11'-8 | 12'-1 | 400 | 366 | 324 | 289 | 260 | 236 | 216 | 198 | 156 |
| | 2VLI18 | 10'-6 | 12'-7 | 12'-7 | 400 | 400 | 355 | 319 | 288 | 263 | 241 | 222 | 205 |
| | 2VLI16 | 10'-9 | 12'-10 | 13'-3 | 400 | 400 | 400 | 367 | 330 | 300 | 274 | 252 | 232 |

***2VLI20 with 5.25 in. LWC slab on a 10 ft clear span has a maximum superimposed live load capacity of 142 psf > 95 psf so ok. (What is the actual clear span? Depends on the beam flange width, but probably between 9 ft – 4 in. and 9 ft 6 in. Therefore could use up to 155 psf for superimposed live load if needed.)***

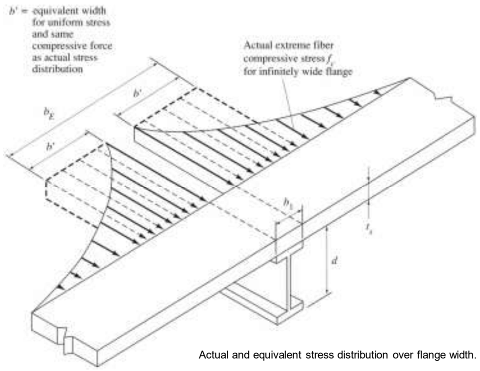


## Composite Beams

**I3. Flexure**

"This section applies to three types of composite members subject to flexure: composite beams with steel anchors consisting of steel headed stud anchors or steel channel anchors, concrete encased members, and concrete filled members."

## Effective Slab Width




Actual and equivalent stress distribution over flange width.

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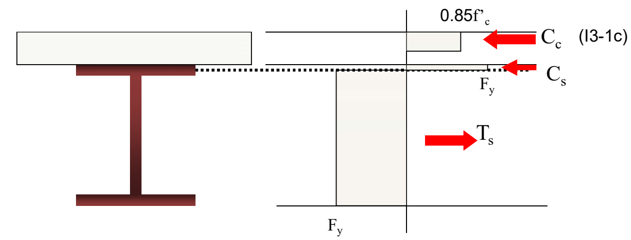
## +M Plastic Stress Distribution

Plastic Neutral Axis is in steel top flange

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## Partial Composite Action

- The steel headed stud anchors control. Thus,

$$\min\left(0.85 f_c' A_c,\ A_s F_y\right) > \Sigma Q_n$$

- The behavior will be characterized by slip between the steel and concrete at the ultimate load and there will be a PNA in the concrete and the steel.

$$\%Composite\ Action = \frac{\Sigma Q_n}{A_s F_y} \text{ x } 100$$

- Ductility requirements must be considered – result is that minimizing %composite action (e.g. 25%) is not recommended

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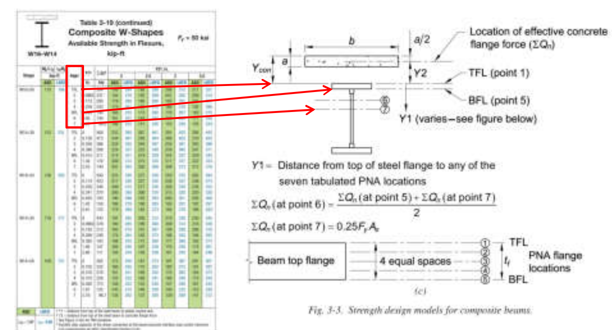
## AISC Manual

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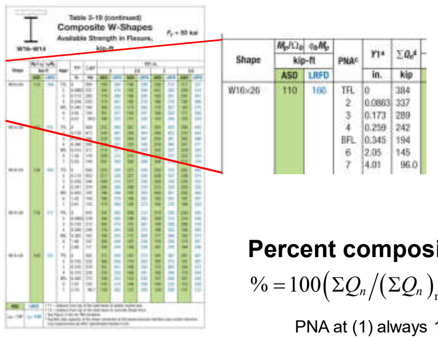
## AISC Manual




| W16x26 | | |
|---|---|---|
| PNA | $\Sigma Q_n$ | % |
| TFL | 384 | 100 |
| 2 | 337 | 87.8 |
| 3 | 289 | 75.3 |
| 4 | 242 | 63.0 |
| BFL | 194 | 50.5 |
| 6 | 145 | 37.8 |
| 7 | 96.0 | 25.0 |

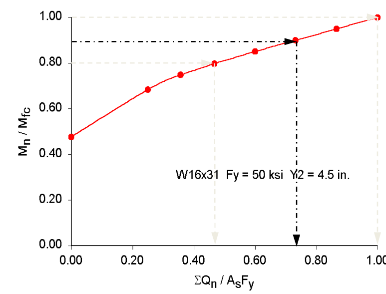
**Percent composite action**

$$\% = 100\left(\Sigma Q_n / (\Sigma Q_n)_{max}\right)$$

PNA at (1) always 100%
PNA at (7) always 25%
PNA at (6) always half way between (5) and (7)



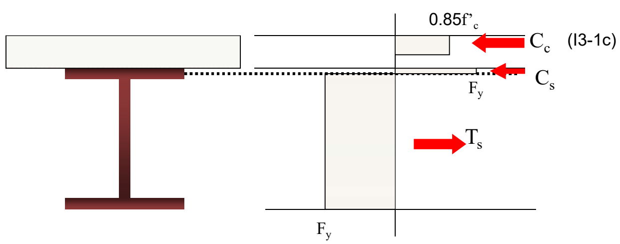
## Normalized Moment vs. Shear Connection





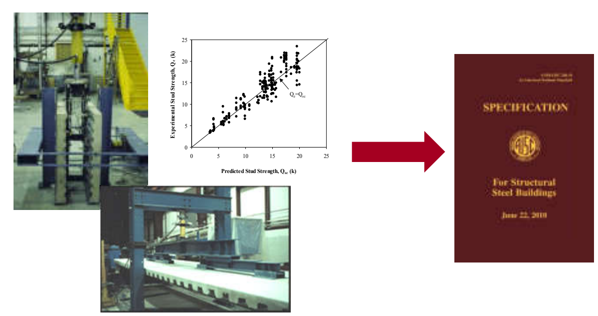

## +M Plastic Stress Distribution

Plastic Neutral Axis is in steel top flange






## Research to Practice



## AISC *Specification* – Ch I8.2a

**User Note:** The table below presents values for $R_g$ and $R_p$ for several cases. Available strengths for steel headed stud anchors can be found in the AISC *Steel Construction Manual*.

| Condition | $R_g$ | $R_p$ |
|---|---|---|
| No decking | 1.0 | 0.75 |
| Decking oriented parallel to the steel shape | | |
| $\frac{w_r}{h_r} \geq 1.5$ | 1.0 | 0.75 |
| $\frac{w_r}{h_r} < 1.5$ | 0.85[a] | 0.75 |
| Decking oriented perpendicular to the steel shape<br>Number of steel headed stud anchors occupying the same decking rib: | | |
| 1 | 1.0 | 0.6[b] |
| 2 | 0.85 | 0.6[b] |
| 3 or more | 0.7 | 0.6[b] |

$h_r$ = nominal rib height, in. (mm)
$w_r$ = average width of concrete rib or haunch (as defined in Section I3.2c), in. (mm)
[a] For a single steel headed stud anchor
[b] This value may be increased to 0.75 when $e_{mid\text{-}ht} \geq 2$ in. (50 mm).

$$Q_n = 0.5A_{sc}\sqrt{f'_c E_c} \leq R_g R_p A_{sc} F_u \qquad \text{(I8-1)}$$

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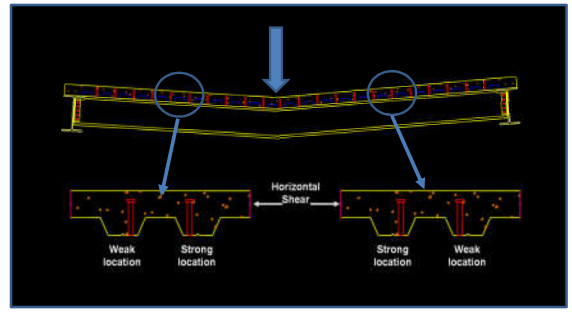
## Strong vs. Weak Position Stud Anchors

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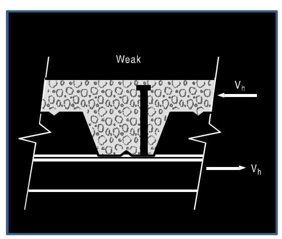
## Weak Position Stud Failure

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## Control of 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?

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## Composite Girders

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## Composite Girders

What is different between composite beams and composite girders?

- Deck is parallel to steel shape in a "girder" which enables the concrete within the rib to be used in the flexural strength calculation
- Non-uniform stud anchor distribution is more common and should be considered for economical considerations
- Greater flexibility in location for placing stud anchors on girders
- Cracking over girders may create a serviceability concern

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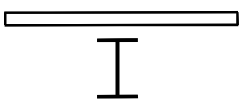
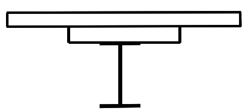
## Beam and Girder Cross Section for Flexural Strength



**Beam – deck is perpendicular to cross section**



**Girder – deck is parallel to cross section**

*Note – not a requirement to use additional concrete*

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## 2c. Required Number of Steel Anchors

The number of anchors required between the section of maximum bending moment, positive or negative, and the adjacent section of zero moment shall be equal to the horizontal shear as determined in Sections I3.2d.1 and I3.2d.2 divided by the nominal shear strength of one steel anchor as determined from Section I8.2a or Section I8.2b. **The number of steel anchors required between any concentrated load and the nearest point of zero moment shall be sufficient to develop the maximum moment required at the concentrated load point.**

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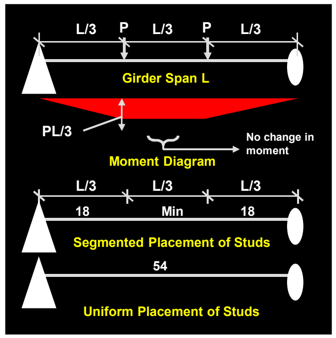
## Shear Connector Placement

**Uniform vs. Segmented Placement of Shear Connectors**

- Most girders supports several point loads from purlins
- For zone with zero moment gradient, no shear connectors are needed
- Only minimum number of studs are generally provided in this zone
- For uniform layout, significant additional studs are needed
- Additional studs do not add any value (no increase in strength for the given load pattern)

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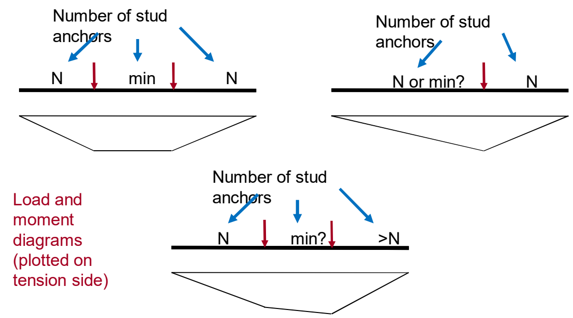
## Stud Anchor Distribution

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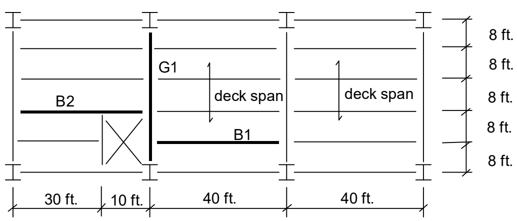
## Cracking Over Girders

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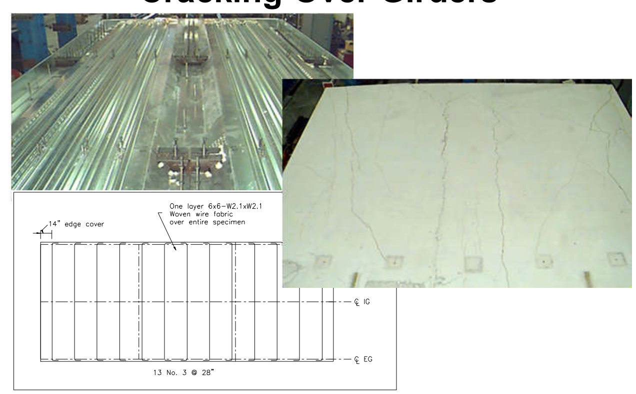
## Cracking Over Girders



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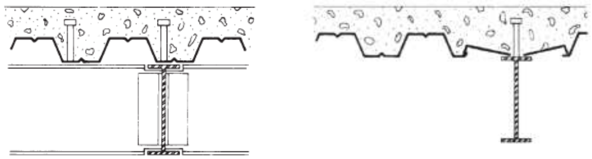
## Bracing provided by floor diaphragm during construction

- Beams – deck attached on 12 in. centers – beam adequately braced laterally for construction loads
- Girders – *uncertain* construction detail



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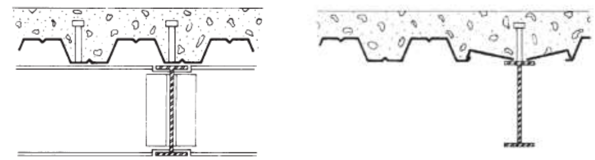
## Bracing provided by floor diaphragm during construction

- **Girders – *uncertain* construction detail**
  - Figure at left – full lateral support for girder for checking girder under construction loads
  - Figure at right - use filler beam spacing as unbraced length for checking girder under construction loads – i.e. ignore the diaphragm bracing effect



***Which detail will you have during construction?***

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## Key Point!!!

- Load table values – SDI DDM03 or manufacturer load tables – represent strengths for the *field* of the composite diaphragm
- Edge connectors must be detailed to resist required strength.

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## AISC *Specification* and Commentary – Ch I

**I7. COMPOSITE DIAPHRAGMS AND COLLECTOR BEAMS**

Composite slab diaphragms and collector beams shall be designed and detailed to transfer loads between the diaphragm, the diaphragm's boundary members and collector elements, and elements of the lateral force-resisting system.

**User Note:** Design guidelines for composite diaphragms and collector beams can be found in the Commentary.

Comm. I7.] COMPOSITE DIAPHRAGMS AND COLLECTOR BEAMS **16.1**-405

**I7. COMPOSITE DIAPHRAGMS AND COLLECTOR BEAMS**

In composite construction, floor or roof slabs consisting of composite metal deck and concrete fill are typically connected to the structural framing to form composite diaphragms. Diaphragms are horizontally spanning members, analogous to deep

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## Diaphragm Resources

- Steel Deck Institute *Diaphragm Design Manual, Third Edition* (SDI DDM03)
- Manufacturers' design catalogs
- AISI North American Standard for the Design of Profiled Steel Diaphragm Panels
- NIST Technical Brief on Composite Diaphragms

  http://www.nehrp.gov/pdf/nistgcr11-917-10.pdf
- AISC Seminar – Steel Design after College (2006)
  recording available at below link (refer to Part 3)

  https://www.aisc.org/education/continuingeducation/education-archives/steel-design-after-college/

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Composite Construction 101: Fundamentals, Practical Implementation, and New Thrust Areas

- Fundamentals - Overview of composite construction in floors
- Practical Implementations
- New Thrust Areas

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## Serviceability

*Many a wise old man says, with steel, design for serviceability first, then check the structure for strength*

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## Beam Deflections

- Live Load, $\Delta_{LL}$ < L/360
  - Limit max. based on occupancy/tenant considerations and total span length
  - Coordinate with architect any jointing requirements with non-structural elements (façade, slip track, etc.)
  - Consider floor vibrations
- Total Load, $\Delta_{tot}$ < L/240
- Always evaluate at service load levels

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## Deflection / Span limits


- Deflection/span ratios have been in the codes for more than a century
- Deflection/span ratios developed when typical floor spans were 20-ft and roof spans were 40-ft
- Deflection/span ratio limits apply 2-dimensional criteria to a 3-dimensional problem
- The designer must use discretion when applying deflection/span limits

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## Deflection Considerations

1. Design beams with adequate stiffness to limit deflection (total and LL)
2. Shore beams during construction
   - ✓ Adds cost and time to project
   - ✓ Increase in floor cracks when shores removed
3. Include a leveling topping in the project cost
   - ✓ Adds cost
   - ✓ Best when used in isolated areas only
4. Camber beams

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## Camber

- ASTM A6 – permissible out of straightness (1/8" per 10 ft) can occur anywhere along the member length (natural or mill camber)
- Member Curvature – modifying member geometry by introducing in-plane arch or out-of-plane sweep for architectural appearance or function. (AISC Design Guide 33, *Curved Member Design*)
- Camber – induce a slight upward curvature on a member through the fabrication process to optimize the final member deflected geometry. (AISC Design Guide #36 – pending late 2020)

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## Camber

Q: How does one decide how much to camber the beam?

A: Rule of Thumb: Camber beams for 80% of the construction dead load deflection

Q: What does that actually mean?

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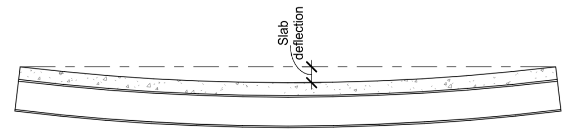
## Camber

Construction dead load consists of:
- Beam self-weight
- Deck self-weight
- Concrete self-weight (need to consider slab placement)

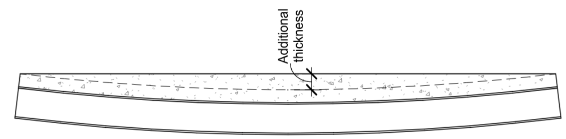
Superimposed dead load is typically ignored for camber unless it is “heavy” (ex: plaza loading – soil, pavers, topping slab, etc.) In this case, camber may not “come out” until later in construction.



## Camber




*a) Pour concrete to a constant thickness*

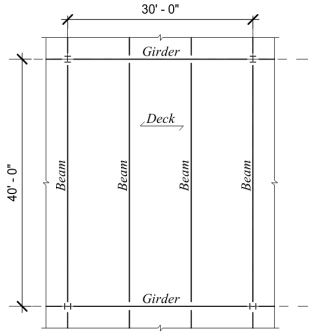



*b) Pour concrete to a constant elevation*

Structural engineer should specify which method was used in design on the contract documents.



## Estimate Additional Thickness




Mid-bay deflection:
$\Delta_{tot} - \Delta_{LL} = \Delta_{DL}$
L/240 – L/360 = L/720

Girder (30’-0”) L/720 = 0.5”
Beam (40’-0”) L/720 = 0.67”
Deck (10’-0”) L/720 = 0.17”

Extra concrete at mid-bay: 1.33”
Roughly 50% over whole bay

If NW concrete, add 8-9 psf to slab
If LW concrete, add 6-7 psf to slab



## Example

Given:
W18x40 beam with (40) ¾” dia. Headed studs — 10 psf SDL
L=40’ spaced at 10’ o.c. — 70 psf LL
Poured to constant thickness slab

| | Case 1 – Light Slab | Case 2 – “Average” Slab | Case 3 – Heavy Slab |
|---|---|---|---|
| **Floor deck** | 2” composite deck, 20 GA | 2” composite deck, 20 GA | 3” composite deck, 20 GA |
| **Concrete type** | 3,000 psi, lightweight(1) | 3,000 psi lightweight(1) | 3,000 psi normal weight(2) |
| **Slab thickness above flutes** | 2” | 3¼” | 4½” |
| **Slab self-weight** | 30 psf | 42 psf | 80 psf |
| **Pre-composite DL deflection** | 1.007” | 1.357” | 2.467” |
| **80% of DL deflection** | 0.806” | 1.086” | 1.974” |
| **Specified camber (%DL)** | ¾” (74%) | 1” (74%) | 1¾” (71%) |
| **Net DL deflection** | 0.257” (L/1870) | 0.357” (L/1344) | 0.717” (L/670) |
| **DL % of Total Load** | 27% | 34% | 50% |

(1) Light weight concrete is assumed to have a dry unit weight of 110 pcf.
(2) Normal weight concrete is assumed to have a dry unit weight of 150 pcf.

## Camber vs Floor Flatness

Expectation that camber of composite beams will produce flat floors should be no more other structural systems.

Camber can be used to reduce the initial dead load deflection ($\Delta_{DL}$), but the post composite deflection limits ($\Delta_{LL}$, $\Delta_{TOT}$) used in design are unchanged.

Case 3 on previous has a DL deflection of 0.717”

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## Other Camber Considerations

- Beam simple end connections will provide some restraint
- AISC Code of Standard Practice 6.4.4
  - Beam $\leq$ 50’ – camber tolerance is (-0”, +1/2”)
  - Beam > 50’ – camber tolerance is (-0”, +1/2”) plus 1/8” for each additional 10 ft
  - Beams received by fabricator with 75% of camber do not require additional cambering
- Camber inspection must be performed in the fabrication shop

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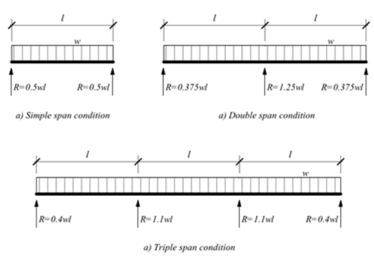
## Other Camber Considerations

BEWARE: Deck continuity during construction results in beam loads different than assumed during beam design.

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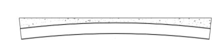
## Camber Amount

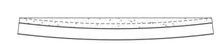
If beam camber is too much and slab elevation is poured constant:

- Reduced shear connector/reinforcement cover
- Shear connectors may project above top/slab
- Fire rating may be reduced
- Reduced slab depth for $I_{eff}$ used to determine deflections

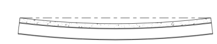


If beam camber is too little and slab elevation is constant:

- Increase in concrete required to make pour (extra $$$)
- Potentially could have utilized a reduced beam size (extra $$$)



If the slab thickness is kept constant, most these issues can be avoided, but your floor will be less flat.



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## Camber Benefits

Material economy

- Without camber, beam design depends on stiffness to prevent excessive deflection resulting in heavier beams

  Example:
  Given a 4 ½" concrete slab over 3" deck (7 ½" total)
  SDL = 15 psf
  LL = 70 psf

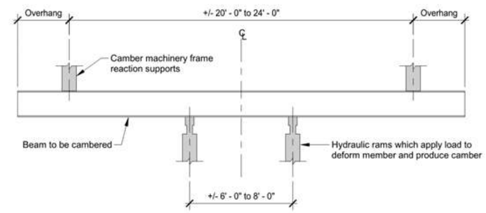
  Beam with Camber: W18x35(30)
  Beam without Camber: W24x55(34)

If beams spaced at 10'-0" o.c., this equates to a 2 psf savings



## Members to Avoid Cambering

- Beams less than 25-ft long
  - Shop machines have rams at 6'-8' apart with reaction points 20'-24' apart






## Members to Avoid Cambering

- Beams that require a camber of less than ¾"
  - Limited accuracy of cambering machines
  - COSP has (-0", +½") tolerance on specified camber (beams < 50 ft)
- Beams with webs less than ¼" thick
  - Thin webs tend to cripple when beam flanges loaded to yield.
- Large or heavy beams (exceeding +/- 100 plf)
  - "Typical" fabrication shop machines are limited in capacity
  - May have to send beam out to another shop (adds $$$)
  - May have to use heat camber (adds $$$)

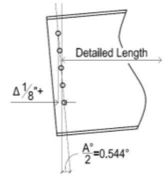


## Members to Avoid Cambering

- Spandrel beams supporting brittle façade materials.
  - Brick/precast – design member with adequate stiffness
  - Curtainwall/metal stud/metal panel – coordinate with architect
- Beams that cantilever
  - Difficult/expensive to induce non-uniform or double curvature.
- Beams with holes in flanges between machine reaction points.
  - Since flanges are loaded to yield, can result in fracture at bolt holes

## Members to Avoid Cambering

- Beams with moment connections, bracing connections, or special connections for torsional restraint
  - Difficult/expensive fit up for non-straight beams
- Beams that are part of an inverted "V" (Chevron) bracing
  - Difficult/expensive fit up of bracing connection
  - Influence of brace gusset plate on beam stiffness




END SLOPE - W21x44 x 40ft - Camber 2"
NTS

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## Members to Avoid Cambering

- Beams with non-symmetric or non-prismatic cross section
  - Irregular cross-section lends to twist when strained
- Beams with welded cover plates
  - Heat from welding will alter/relax the camber
- Beams serving as crane girders
  - Beam should have stiffness based on crane design requirements.

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## Poll Question

When selecting the amount of camber to design for a beam, you should always use 80% of the construction dead load.

a. True.

b. False

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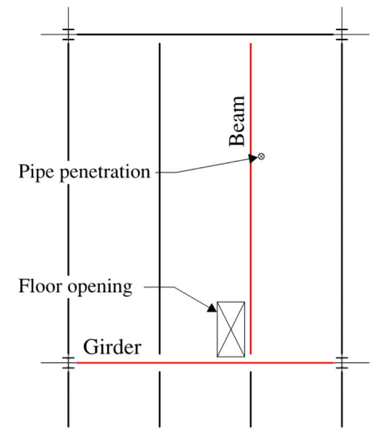
### Slab Penetrations

How much do floor openings and penetrations truly impact the capacity of the highlighted members?

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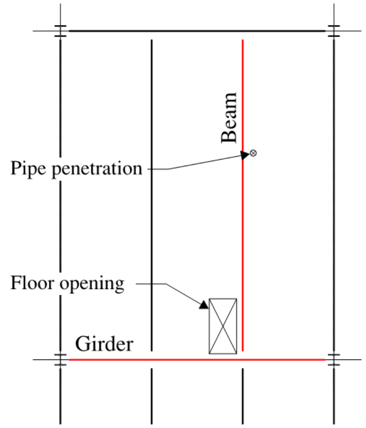
**Slab Penetrations**

Small openings, like the pipe penetration, that are less than 12” in all directions are usually considered negligible provided there are not multiple small penetrations clustered together in close proximity.

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**Slab Penetrations**

Pipe clusters should be treated like one larger floor opening

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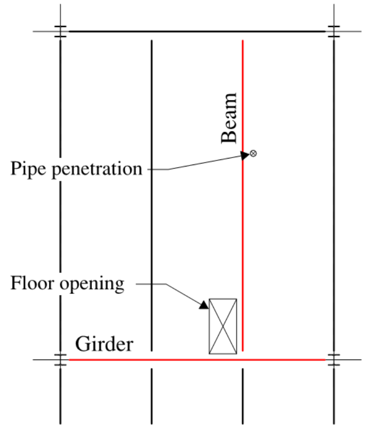
**Slab Penetrations**

Options for Evaluating:

- Compare opening size & location to a standard effective flange profile
- Interval Method
- Wiesner Method – General or Special

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**Slab Penetrations: Effective Flange Width**

(I3.1a) The effective width of the concrete slab shall be the sum of the effective widths for each side of the beam centerline, each of which shall not exceed:

- One-eighth of the beam span, center-to-center of supports
- One-half the distance to the centerline of the adjacent beam
- The distance to the edge of the slab

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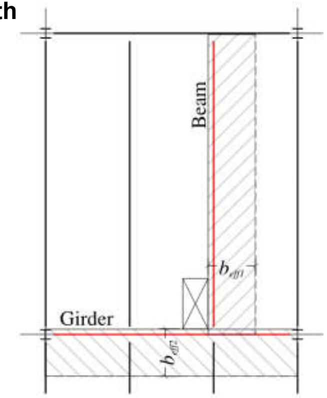
## Slab Penetrations: Effective Flange Width

Typical design approach is to reduce the effective beam width used in analysis

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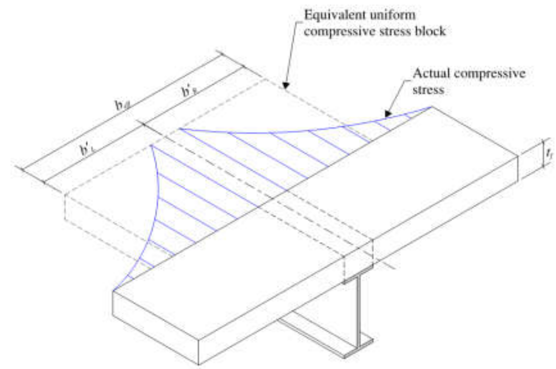
## Slab Penetrations: Effective Flange Width

$$b_{eff} = b'_L + b'_R$$

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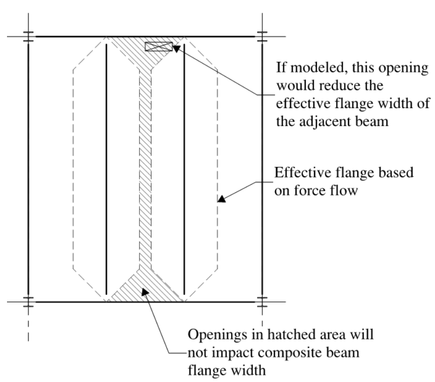
## Slab Penetrations: Effective Flange Width

Only marginally helpful!

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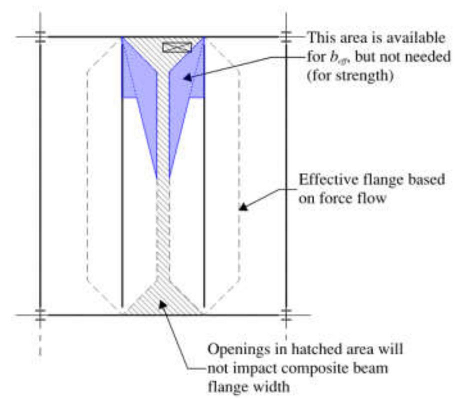
## Slab Penetrations: Interval Method

Can use interval method to show penetrations in the blue areas will not impact capacity.

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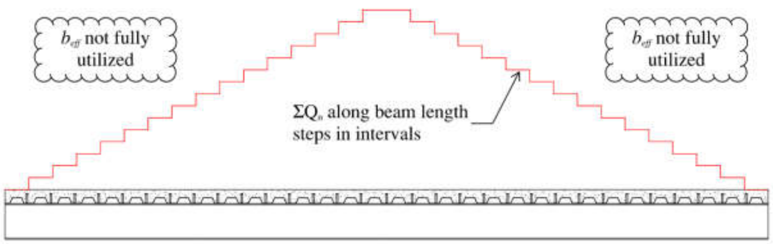
## Slab Penetrations: Interval Method

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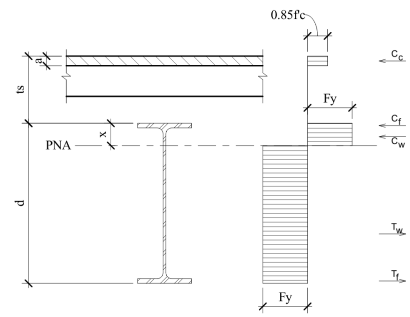
## Slab Penetrations: Interval Method

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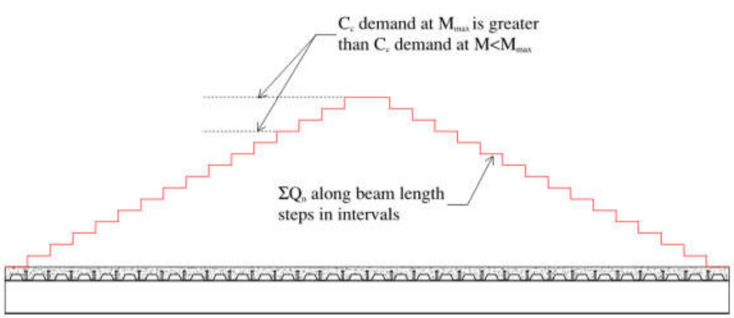
## Slab Penetrations: Interval Method

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## Slab Penetrations: Interval Method Example

Given:
W18x40, A992
L= 40'-0"
38 steel anchors (~1/ft)
3" Composite Deck
4 ½" Concrete above deck
$f'_c$ = 3 ksi NW
Beams spaced @ 10'-0"

Loads:
DL (slab) = 75 psf
SDL = 25 psf
LL = 80 psf NR

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## Slab Penetrations: Interval Method Example

Determine the available effective width for the beam:

$$b_{eff} = b'_L + b'_R$$

$b'_L = b'_R =$ Min. of
- $L/8 = (40'\text{-}0")/8 = 5'\text{-}0"$
- $TW/2 = (10'\text{-}0")/2 = 5'\text{-}0"$
- Distance to EOS = N/A

$$b_{eff} = (5'\text{-}0") + (5'\text{-}0") = 10'\text{-}0" \quad (120")$$

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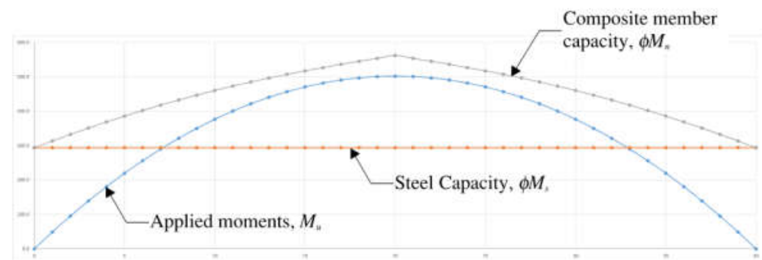
## Slab Penetrations: Interval Method Example




Where $\phi M_n > M_u$, full $b_{eff}$ not required.
Where $\phi M_s > M_u$, don't need any $b_{eff}$.

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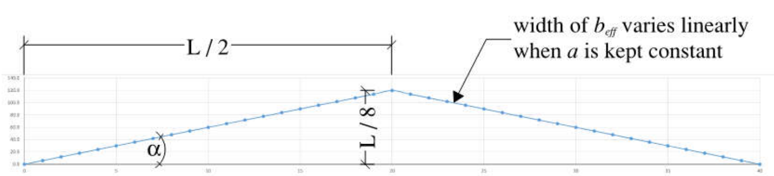
## Slab Penetrations: Interval Method Example




$$\tan(\alpha) = 0.25$$

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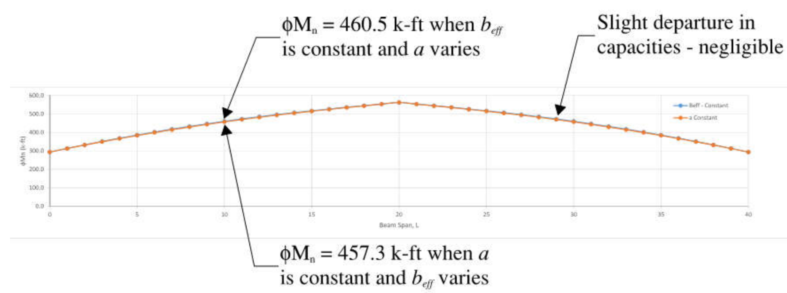
## Slab Penetrations: Interval Method Example

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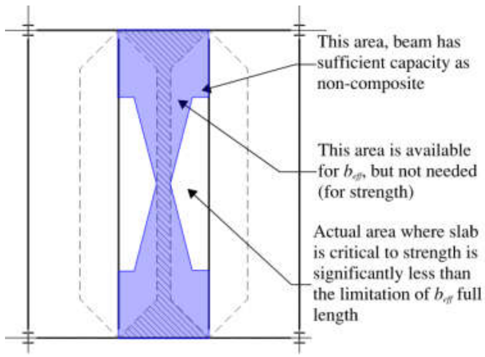
## Slab Penetrations: Interval Method Example





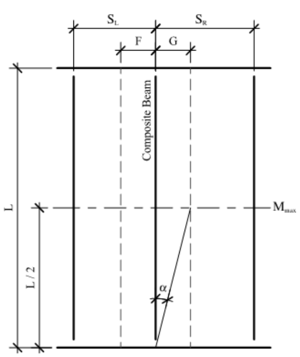

## Slab Penetrations: Wiesner Method

Wiesner, K.B., "Composite Beams with Slab Openings", Modern Steel Construction, March, 1996, pp 26-30

- Outlines procedure for allowing the effective flange of a composite beam to "snake around" openings which encroach on the effective flange width. (General Case)
- Outlines procedure for neglecting certain openings that are within the effective flange limits. (Special Case – see published article)



## Slab Penetrations: Wiesner Method

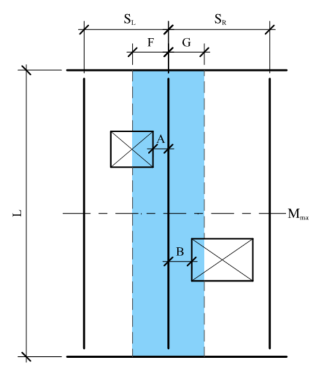



Wiesner's method uses the same angle, $\alpha$, to limit shear stresses in the slab at discontinuities.

$$\tan(\alpha) = 0.25$$
$$\alpha = 14 \text{ degrees}$$



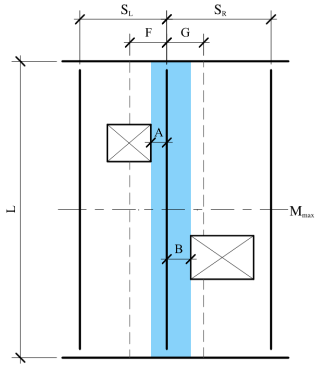
## Slab Penetrations: Wiesner Method




Without openings, you would have:

$b_{eff} = F + G$

## Slab Penetrations: Wiesner Method



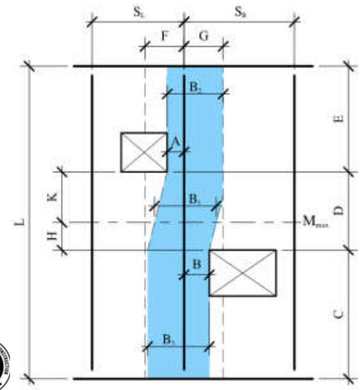

With openings, you have:

$b_{eff} = A + B$

unless a more robust analysis is performed



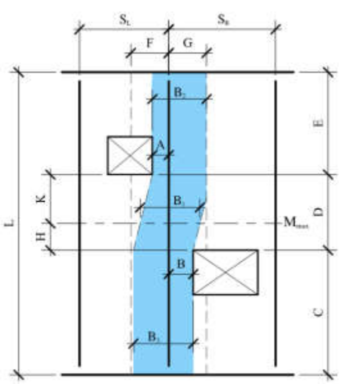
## Slab Penetrations: Wiesner Method General Case




- Simple span beams
- $M_{max}$ near mid-span
- One or two adjacent openings
- Openings do not align
- A & B > ½ $b_f$ (beam flange)
- H & K > 0
- No openings in adjacent spans



## Slab Penetrations: Wiesner Method




Draw effective width diagram using α=14 degrees for sloped lines

$$F = \min\left(\frac{S_L}{2}, \frac{L}{8}\right)$$

$$G = \min\left(\frac{S_R}{2}, \frac{L}{8}\right)$$

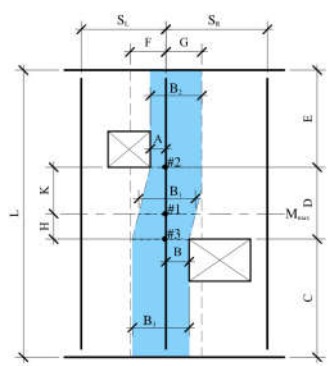
$$B_1 = A + B + \tan\alpha(H + K) \le (F + G)$$

$$B_2 = A + B + \tan\alpha(H + K) \le (A + G)$$

$$B_3 = A + B + \tan\alpha(H + K) \le (B + F)$$

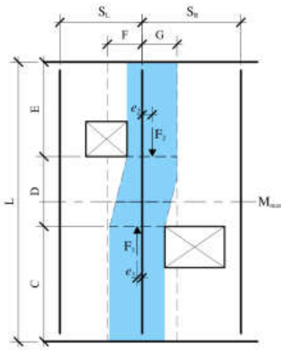


## Slab Penetrations: Wiesner Method




- Design composite beam for $M_{max}$ at point #1 using $B_1$
- Check design for moment at point #2 using $B_2$
- Check design for moment at point #3 using $B_3$
- Check deflection of the beam using a weighted average of the 3 effective widths

**Slab Penetrations: Wiesner Method**



$$F_2 = \sum Q_{n2}$$
$$F_3 = \sum Q_{n3}$$
$$M_2 = F_2 e_2$$
$$M_3 = F_3 e_3$$
$$M_{slab} = \max(M_2, M_3)$$

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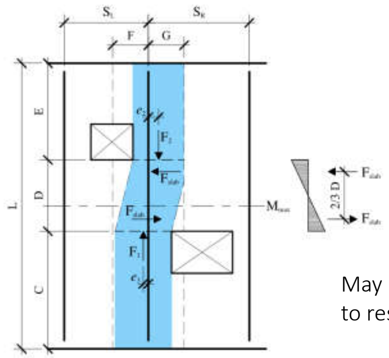
**Slab Penetrations: Wiesner Method**



$$F_{slab} = \frac{M_{slab}}{\frac{2}{3}D}$$
$$T_{slab} = 0.5F_{slab}$$

May need to add reinforcing into the slab to resist $T_{slab}$

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**Poll Question**

Which of the following can be used to evaluate the impact of slab penetrations on the composite beam behavior?

a. Compare the opening to the standard effective flange width.
b. Compare the aspect ratio of the opening dimensions to the bay where the slab penetration occurs.
c. Use the interval method to evaluate whether or not the opening falls outside the bounds of where the slab concrete is required for beam strength.
d. All of the above.
e. a. and c.

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Composite Construction 101: Fundamentals, Practical Implementation, and New Thrust Areas

- Fundamentals - Overview of composite construction in floors
- Practical Implementations
- New Thrust Areas

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## New Development

- Coordination of conflicting composite provisions with ACI 318

ACI 318-19 has removed composite provisions from the concrete specification and references the AISC documents for composite design requirements

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## Ongoing Development

- Continued evolution of composite column requirements
  - AISC 360-10: Overhaul of composite column design provisions (CFTs) – focus on typical columns but introduced compact, non-compact, and slenderness concepts
  - AISC 360-16: Expanded composite columns to include more geometries – refined slender column provisions
  - AISC 360-22: Miscellaneous clean-up, including reinforcing requirements
  - The end???
- AISC is in the process of updating *Design Guide 6: Load and Resistance Factor Design of W-Shapes Encased in Concrete* to incorporate new provisions for expanded range of members

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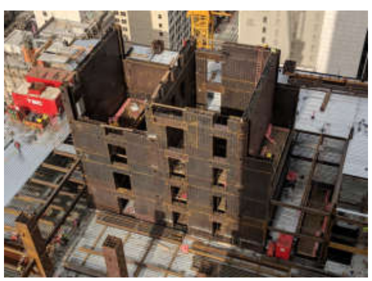
## New Development

- New provisions for composite shear walls (SpeedCore).



Ranier Square
Seattle, WA

Magnusson Klemencic
Associates

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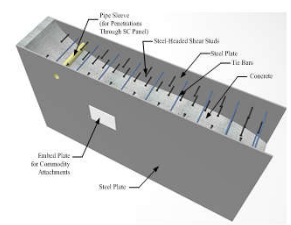
## New Development

- AISC 360-22 Specification expected to address:
  - Stiffness modifiers for calculating required strengths for use with the Direct Analysis method.
  - Guidance on how to determine the axial, flexural, and shear capacity
  - Requirements for detailing the tie bars, shear connectors, and plates

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**New Development**

- AISC 341-22 Seismic Provisions will address:
  - Requirements expected to provide significant inelastic deformation capacity
  - Min./Max. percent of plate steel used in cross-section
  - Steel boundary element construction requirements
  - Seismic connection requirements

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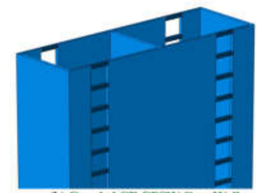
**New Development**

Steel-Plate Composite Walls: Structural Performance

- Similar to conventional RC walls
  - (stiffness, strength, and deformation capacity)
- Excellent seismic strength and ductility
- Excellent strength for impact and blast loads
- Excellent behavior for thermal loading and fire



(b) Coupled CF-CPSW Core Walls

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**Ongoing Development**

- Utilizing higher strength material properties in composite design
  - Coordinate with higher concrete limits in ACI 318
  - Increase steel strength in select composite members, including certain seismic systems
  - More movement in this direction anticipated for the 2028 code cycle

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**Ongoing Development**

- Introduction of Performance Based Alternative for the design of shear connection
- Allows use of shear connection validated by testing criteria
- Must demonstrate adequate strength, ductility, and stiffness

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**Ongoing Development**

- Exploring the potential for deeper decks and larger diameter stud anchors
- Additional testing required - not to be included in 2022 Specification
- AISC is collaborating with SDI

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# AISC Live Webinars

## Course Description

Composite Construction 101:
Fundamentals, Practical Implementation, and New Thrust Areas
Jun 11, 2020

Understanding the design and behavior of composite floor systems is critical to the success and economy of building projects. This webinar will present an overview of the fundamentals of composite design, as well as an introduction to the latest composite framing alternatives. It will also cover recent updates to the composite design provisions of the AISC *Specification*.

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## AISC Live Webinars

### Learning Objectives

- Describe the design process for composite floor systems to safely resist construction loads.
- Describe how to design a composite floor system for strength, serviceability, and fire resistance during the service life of a building.
- Explain how the concrete placement method can affect the design of composite beams. Identify the benefits and limitations of cambering beams as related to concrete placement.
- List the design options for composite beams adjacent to slab penetrations.

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## PDH Certificates

- You will receive an email on how to report attendance from: registration@aisc.org.
- Be on the lookout: Check your spam filter! Check your junk folder!
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