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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



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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

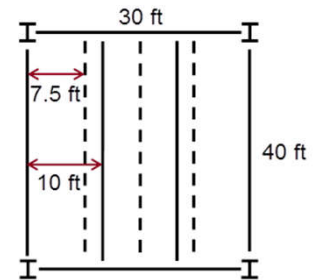


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Typical Interior Bay Design

- 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 ft²)



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

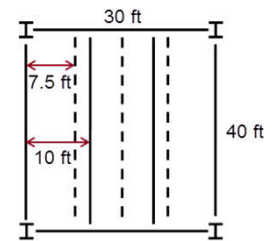
Floor Vibrations – *AISC Design Guide 11*



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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 / ft²
- 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 / ft²



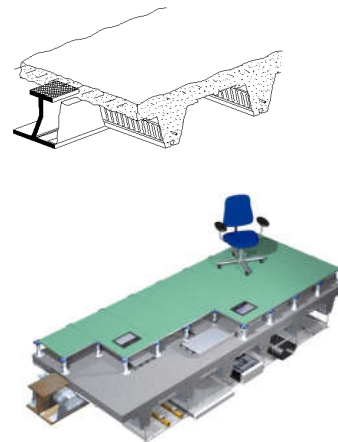
~13% reduction

Savings in fireproofing not included



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



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.

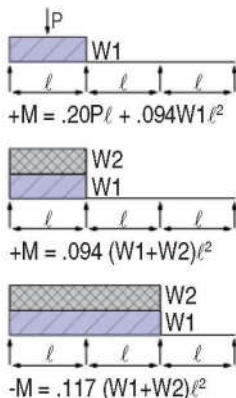


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Construction Load Stage

Triple Span Condition



Notes for Figures 1 and 2		LRFD Load Factors
P	= 150 pound concentrated load	1.4
I	= in ⁴ /ft - deck moment of inertia	
W1	= slab weight + deck weight	1.6
W2	= 20 pounds per square foot construction load	1.2
E	= 29.5 x 10 ³ psi	1.4
ℓ	= clear span length (ft.)	
W1 ₁	= 1.5 x slab weight + deck weight + slab weight + 30 + deck weight	

Dimensional check shows the need for the 1728 factor when calculating deflections using pound inch units.

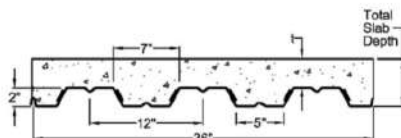
deck is evaluated as a continuous one-way member at the construction load stage



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				V _s lbs/ft	F _y ksi
			I _x in ⁴ /ft	S _x in ³ /ft	I _y in ⁴ /ft	S _y in ³ /ft		
2VLI22	0.0295	1.62	0.324	0.263	0.321	0.266	1832	50
2VLI20	0.0295	1.97	0.409	0.341	0.406	0.346	2096	50
2VLI19	0.0418	2.30	0.492	0.420	0.489	0.425	3180	50
2VLI18	0.0474	2.61	0.559	0.495	0.558	0.504	3606	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			Superimposed Live Load, PSF															
		1 SPAN	2 SPAN	3 SPAN	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"	
4.00 (f _c =200)	2VLI22	7'-4"	9'-6"	9'-9"	274	239	211	188	145	129	115	104	94	85	78	71	65	59	54	
	2VLI20	8'-7"	10'-10"	11'-2"	310	269	236	210	188	170	155	117	106	96	87	80	73	67	61	
	2VLI19	9'-9"	11'-11"	12'-4"	344	298	261	231	207	186	169	155	142	106	97	88	81	74	68	
	2VLI18	10'-9"	12'-9"	12'-9"	373	324	285	253	228	208	188	172	159	147	137	103	95	87	81	
39 PSF	2VLI16	11'-1"	13'-2"	13'-5"	400	376	330	292	261	235	214	195	180	166	154	143	109	100	93	



Construction Load Stage

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

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



Maximum Unshored Clear Span

Example

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

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

$$w_u = 1.2w_D + 1.6w_L$$

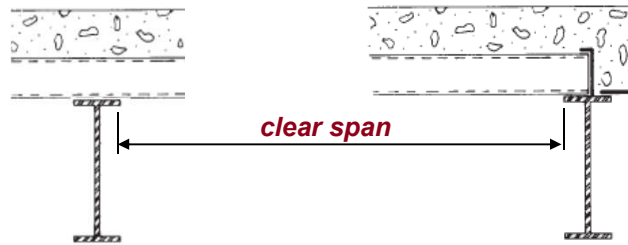
$$\ell = \sqrt{\frac{8\phi M_n}{1.2w_D + 1.6w_L}}$$

Other values determined for different limit states and span conditions.



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



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



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									
		1 SPAN	2 SPAN	3 SPAN	Clear Span (ft.-in.)									
4.00 ($t=2.00$) 39 PSF	2VLI22	7'-4"	9'-6"	9'-9"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	9'-6"	10'-0"
	2VLI20	8'-7"	10'-10"	11'-2"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	9'-6"	10'-0"
	2VLI19	9'-9"	11'-11"	12'-4"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	9'-6"	10'-0"
	2VLI18	10'-9"	12'-9"	12'-9"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	9'-6"	10'-0"
	2VLI16	11'-1"	13'-2"	13'-5"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	9'-6"	10'-0"

"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.



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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.



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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	2VLI22	7'-2"	9'-3"	9'-7"
	2VLI20	8'-5"	10'-7"	10'-11"
(t=3.25)	2VLI19	9'-6"	11'-8"	12'-1"
42 PSF	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										
		1 SPAN	2 SPAN	3 SPAN	Clear Span (ft)										
					6'-0	6'-6	7'-0	7'-6	8'-0	8'-6	9'-0	9'-6	10'-0	11'-0	
5.25 (t=3.25)	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		
42 PSF	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.)



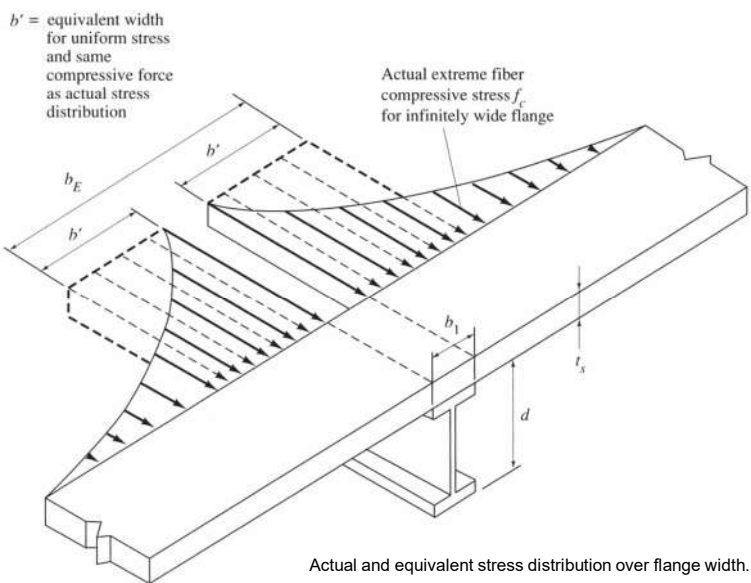
Composite Beams

13. 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.”

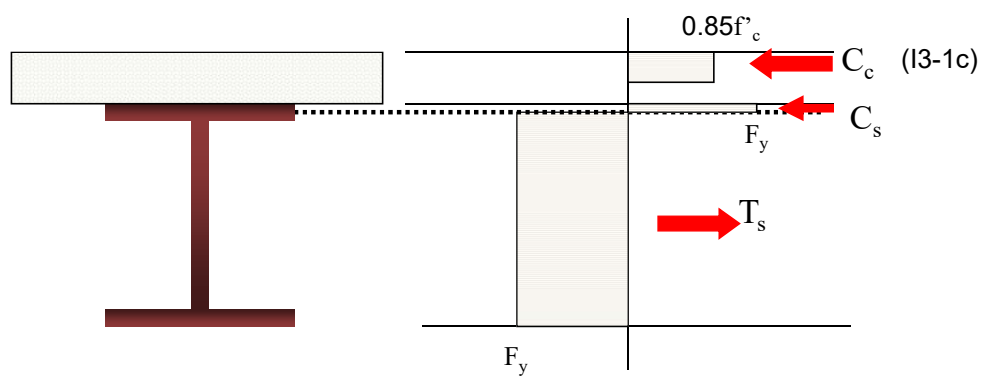


Effective Slab Width



+M Plastic Stress Distribution

Plastic Neutral Axis is in steel top flange



Partial Composite Action

- The steel headed stud anchors control. Thus,

$$\min(0.85 f'_c A_c, A_s F_y) > \sum Q_n$$

- 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.

$$\% \text{Composite Action} = \frac{\sum Q_n}{A_s F_y} \times 100$$

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

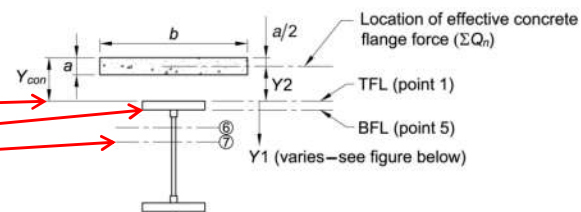


AISC Manual

Table 3-19 (continued)
Composite W-Shapes
Available Strength in Flexure,
kip-ft

$F_y = 50 \text{ ksi}$

Shape	IN./IN. λ_{FL}	IN. λ_{PL}	PNA	Y ₁	C ₁	R _n , kip-ft									
						1	2	3	4	5	6	7			
W16-W14	110	110	T1	0	0	1	1000	1000	1000	1000	1000	1000	1000	1000	1000
						2	1000	1000	1000	1000	1000	1000	1000	1000	1000
						3	1000	1000	1000	1000	1000	1000	1000	1000	1000
						4	1000	1000	1000	1000	1000	1000	1000	1000	1000
						5	1000	1000	1000	1000	1000	1000	1000	1000	1000
						6	1000	1000	1000	1000	1000	1000	1000	1000	1000
						7	1000	1000	1000	1000	1000	1000	1000	1000	1000



Y1 = Distance from top of steel flange to any of the seven tabulated PNA locations

$$\sum Q_n \text{ (at point 6)} = \frac{\sum Q_n \text{ (at point 5)} + \sum Q_n \text{ (at point 7)}}{2}$$

$$\sum Q_n \text{ (at point 7)} = 0.25 F_y A_s$$

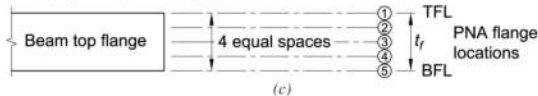


Fig. 3-3. Strength design models for composite beams.



AISC Manual

Table 3-19 (continued)
Composite W-Shapes
Available Strength in Flexure,
kip-ft

$F_y = 50$ ksi

Shape	M_p/Ω_b , $\phi_b M_p$ kip-ft		PNA ^c	γ_1^a in.	ΣQ_n^d kip
	ASD	LRFD			
W16x26	110	166	TFL	0	384
			2	0.0863	337
			3	0.173	289
			4	0.259	242
			BFL	0.345	194
			6	2.05	145
			7	4.01	96.0

W16x26		
PNA	ΣQ_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

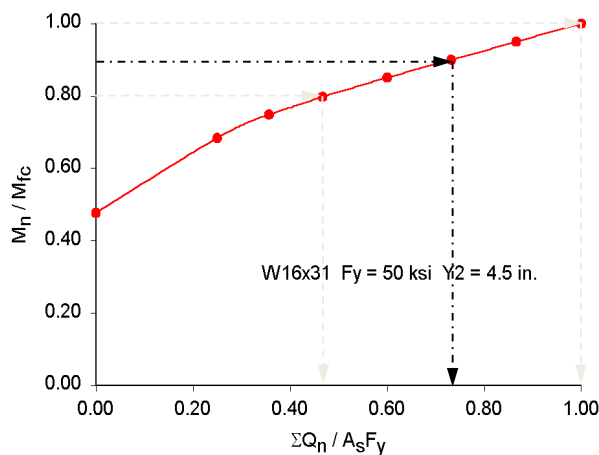
Percent composite action

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

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

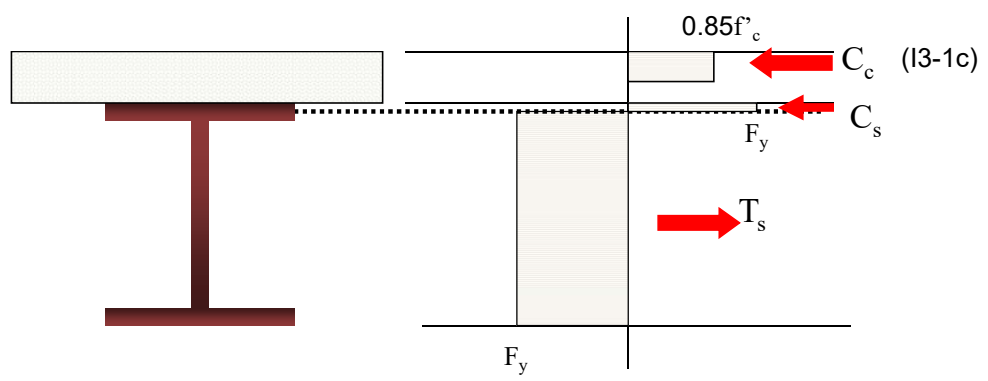


Normalized Moment vs. Shear Connection

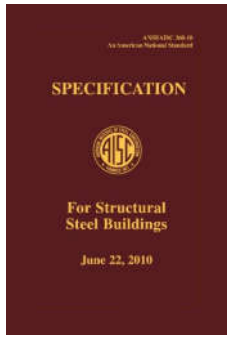
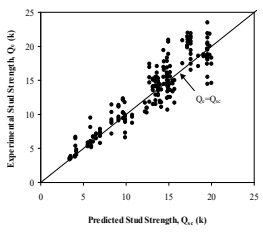


+M Plastic Stress Distribution

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*.

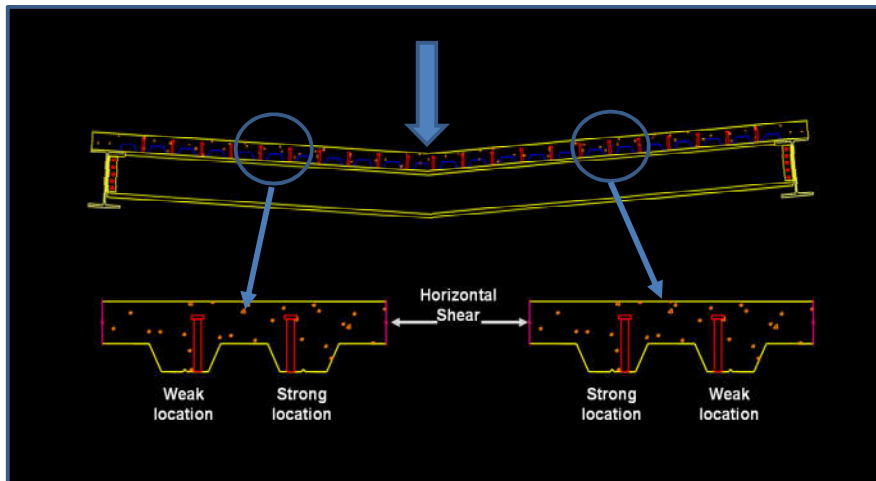
Condition	R_g	R_p
No decking	1.0	0.75
Decking oriented parallel to the steel shape		
$\frac{w_r}{h_r} \geq 1.5$	1.0	0.75
$\frac{w_r}{h_r} < 1.5$	0.85 ^[a]	0.75
Decking oriented perpendicular to the steel shape		
Number of steel headed stud anchors occupying the same decking rib:		
1	1.0	0.6 ^[b]
2	0.85	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 $e_{mid-rib} \geq 2$ in. (50 mm).



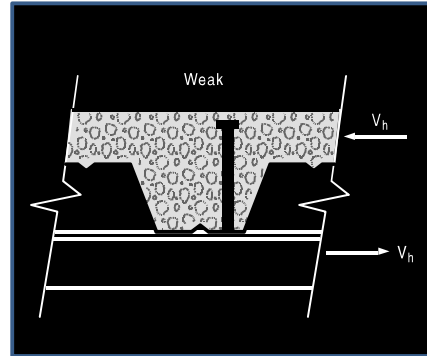
$$Q_n = 0.5 A_{sc} \sqrt{f'_c E_c} \leq R_g R_p A_{sc} F_u \quad (I8-1)$$

Strong vs. Weak Position Stud Anchors





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

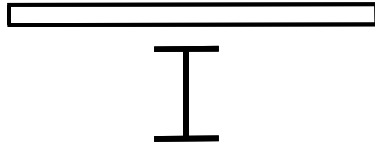
What is different between composite beams and composite girders?

- 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

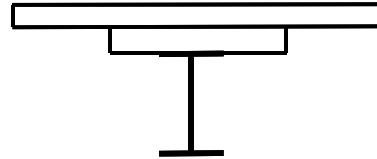


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Beam and Girder Cross Section for Flexural Strength



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.**

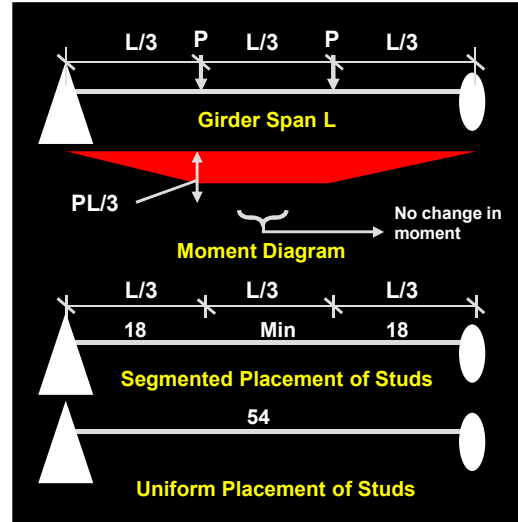


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Shear Connector Placement

Uniform vs. Segmented Placement of Shear Connectors

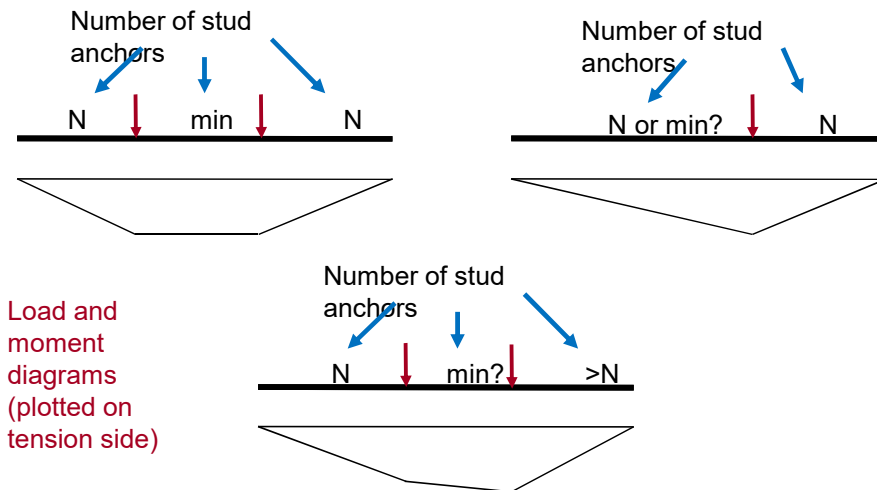
- Most girders supports several point loads from purlins
- For zone with zero moment gradient, no shear connectors are needed
- Only minimum number of studs are generally provided in this zone
- For uniform layout, significant additional studs are needed
- Additional studs do not add any value (no increase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



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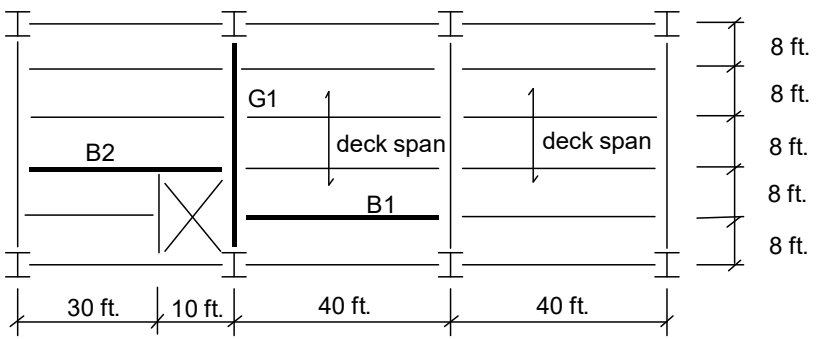
Stud Anchor Distribution



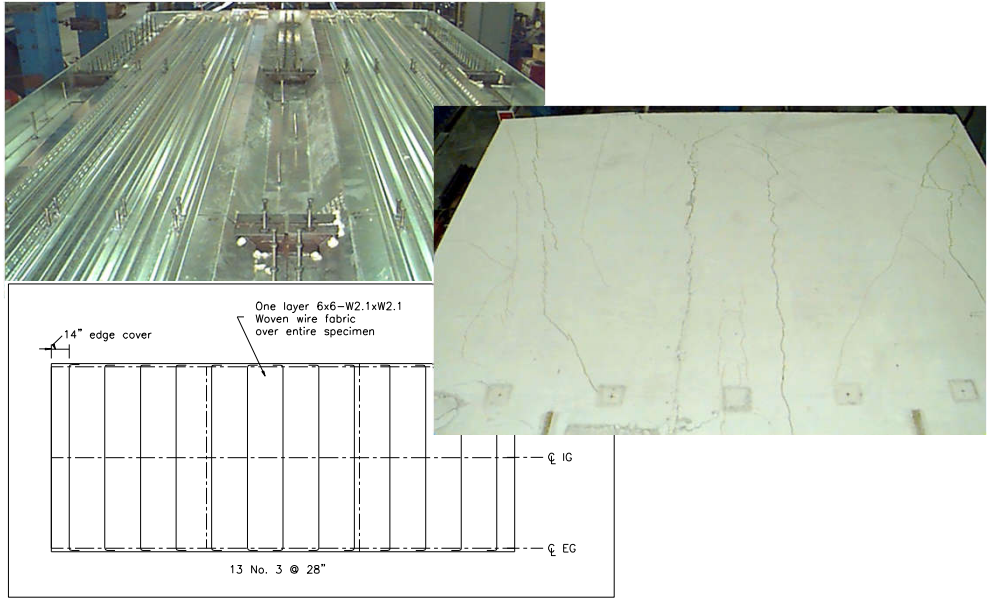
50



Cracking Over Girders

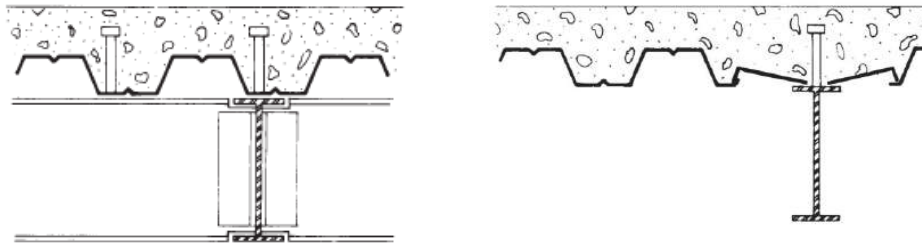


Cracking Over Girders



Bracing provided by floor diaphragm during construction

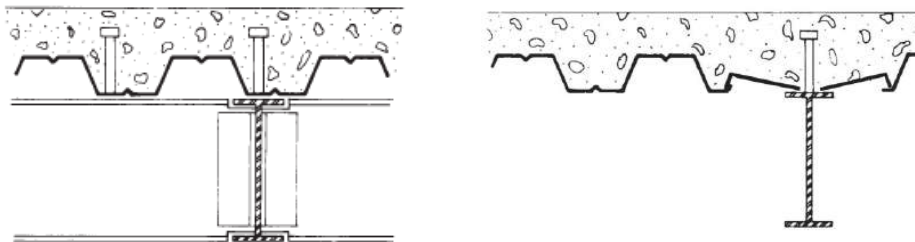
- Beams – deck attached on 12 in. centers – beam adequately braced laterally for construction loads
- Girders – *uncertain* construction detail



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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?

54

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.



55

AISC Specification and Commentary – Ch I

17. 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. 17.] COMPOSITE DIAPHRAGMS AND COLLECTOR BEAMS 16.1-405

17. 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

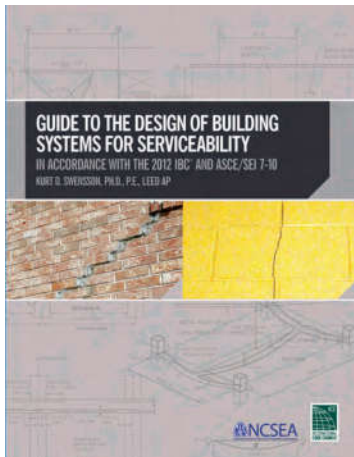
- Live Load, $\Delta_{LL} < L/360$
 - Limit max. based on occupancy/tenant considerations and total span length
 - Coordinate with architect any jointing requirements with non-structural elements (façade, slip track, etc.)
 - Consider floor vibrations
- Total Load, $\Delta_{tot} < L/240$
- Always evaluate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



60



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



62

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)



63

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?



64

Camber

Construction dead load consists of:

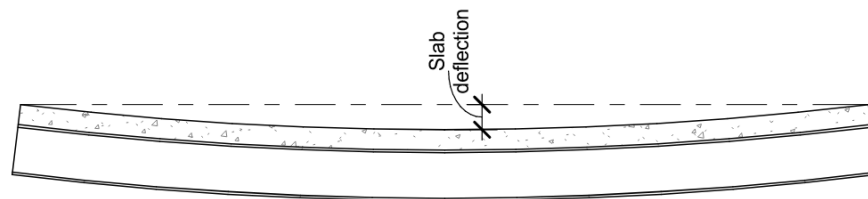
- Beam self-weight
- Deck self-weight
- Concrete self-weight (need to consider slab placement)

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.

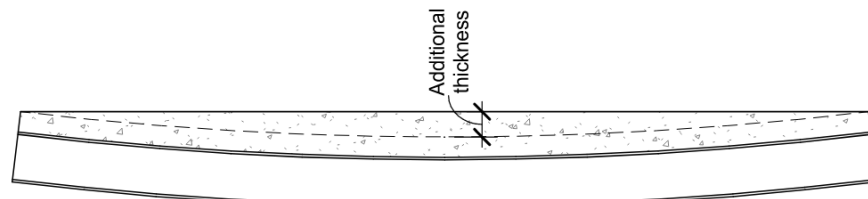


65

Camber



a) Pour concrete to a constant thickness



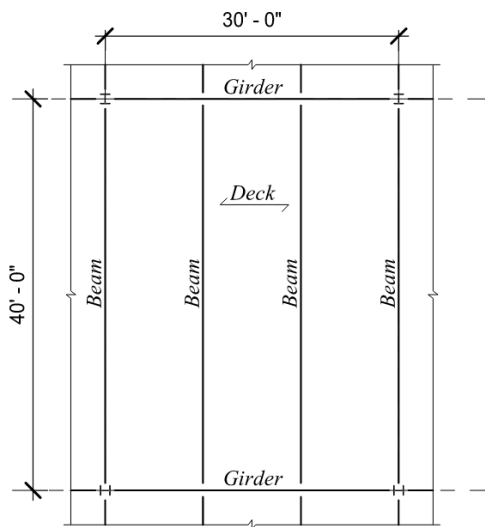
b) Pour concrete to a constant elevation

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



66

Estimate Additional Thickness



Mid-bay deflection:

$$\Delta_{\text{tot}} - \Delta_{\text{LL}} = \Delta_{\text{DL}}$$

$$L/240 - L/360 = L/720$$

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



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Example

Given:

W18x40 beam with (40) 3/4" 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"	3 1/4"	4 1/2"
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)	3/4" (74%)	1" (74%)	1 1/4" (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.



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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 (Δ_{DL}), but the post composite deflection limits (Δ_{LL} , Δ_{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

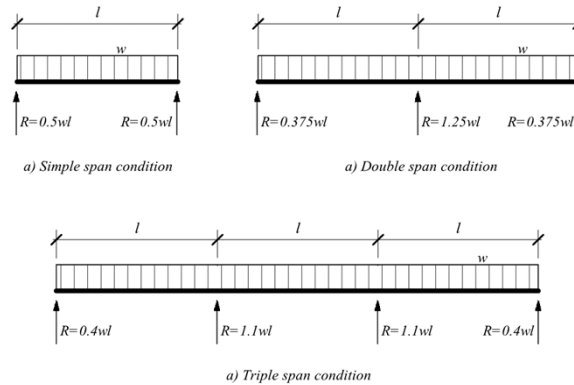


70



Other Camber Considerations

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



71

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)

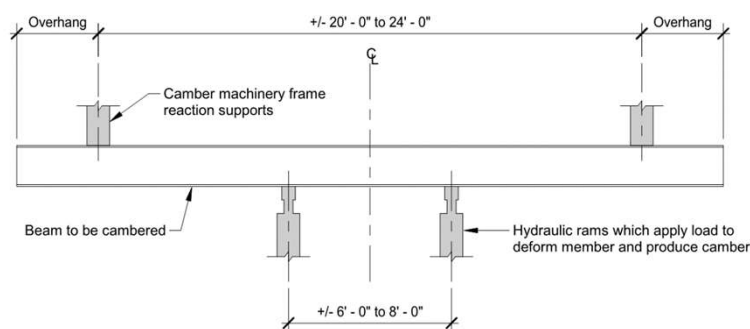
If beams spaced at 10'-0" o.c.,
this equates to a 2 psf savings



73

Members to Avoid Cambering

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



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Members to Avoid Cambering

- Beams that require a camber of less than $\frac{3}{4}$ "
 - Limited accuracy of cambering machines
 - COSP has (-0", + $\frac{1}{2}$ ") tolerance on specified camber (beams < 50 ft)
- Beams with webs less than $\frac{1}{4}$ " 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 \$\$\$)



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Members to Avoid Cambering

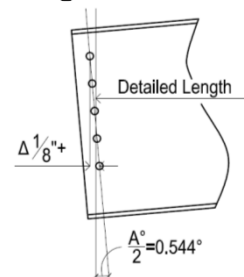
- Spandrel beams supporting brittle façade materials.
 - Brick/precast – design member with adequate stiffness
 - Curtainwall/metal stud/metal panel – coordinate with architect
- Beams that cantilever
 - Difficult/expensive to induce non-uniform or double curvature.
- Beams with holes in flanges between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



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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.

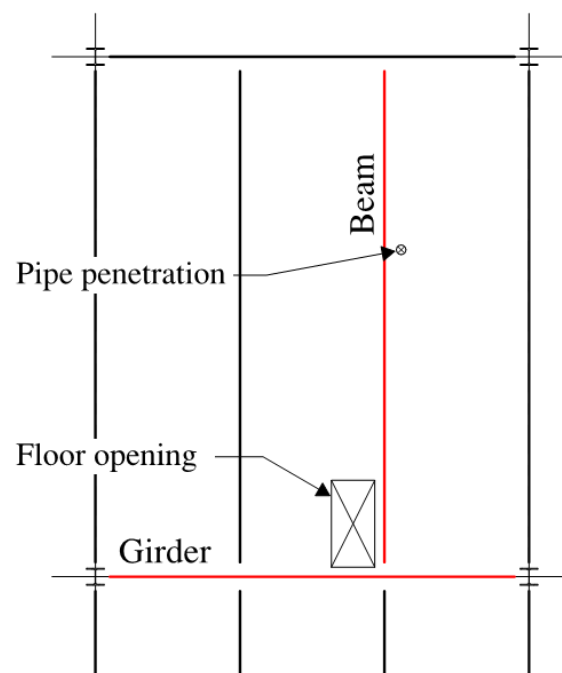
- a. True.
- b. False



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Slab Penetrations

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

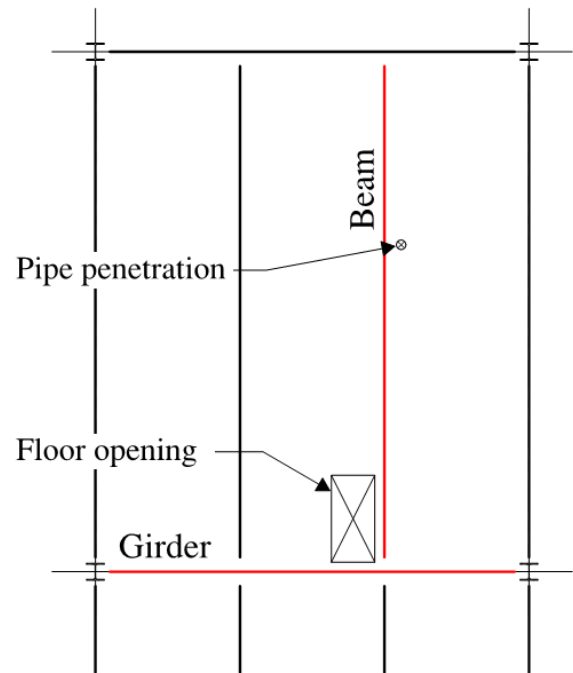


80



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

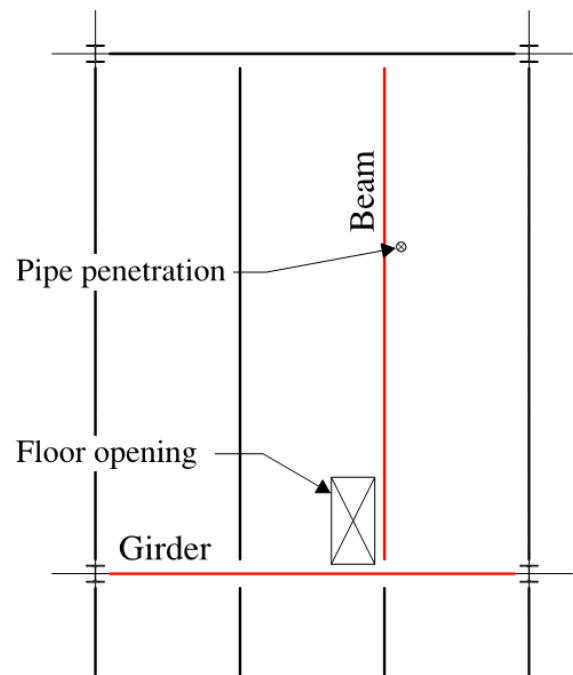
82



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:

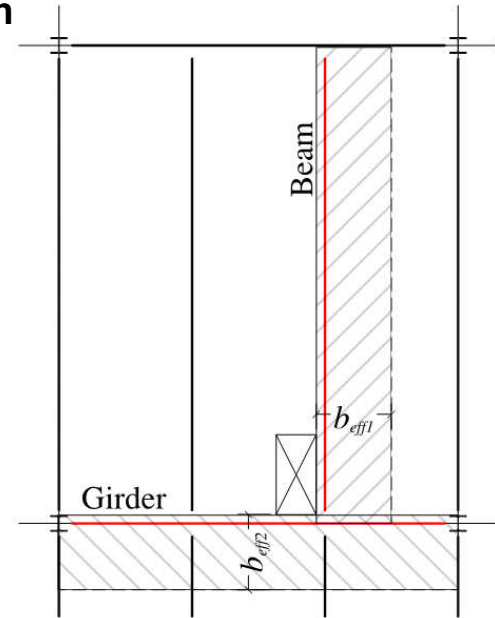
- One-eighth of the beam span, center-to-center of supports
- One-half the distance to the centerline of the adjacent beam
- The distance to the edge of the slab

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Slab Penetrations: Effective Flange Width

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

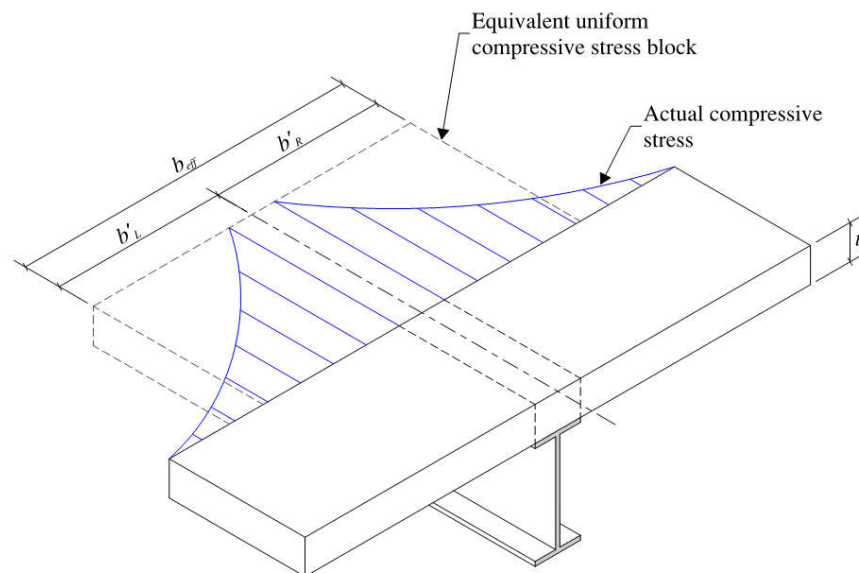


85



Slab Penetrations: Effective Flange Width

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

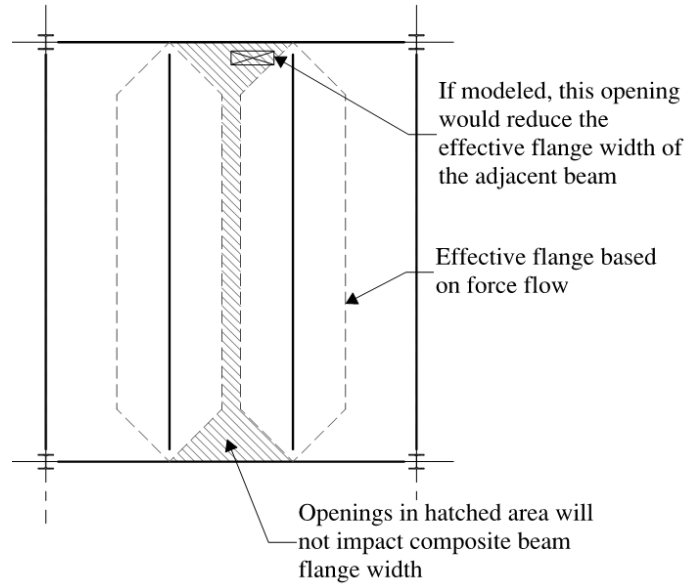


86



Slab Penetrations: Effective Flange Width

Only marginally helpful!

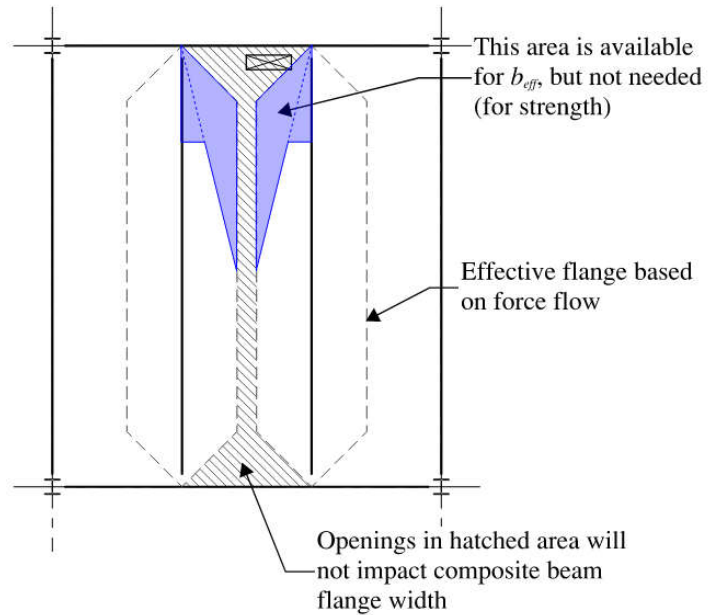


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Slab Penetrations: Interval Method

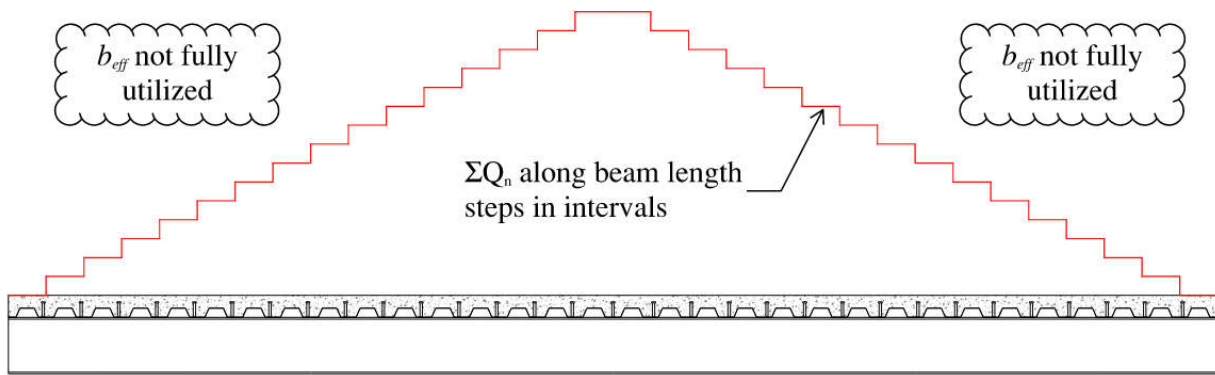
Can use interval method to show penetrations in the blue areas will not impact capacity.



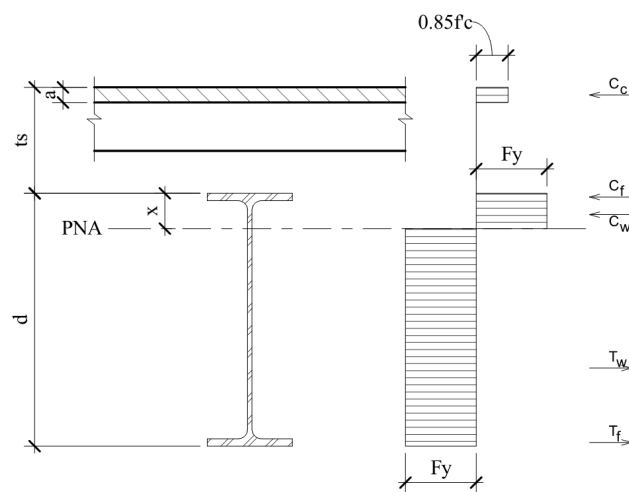
88



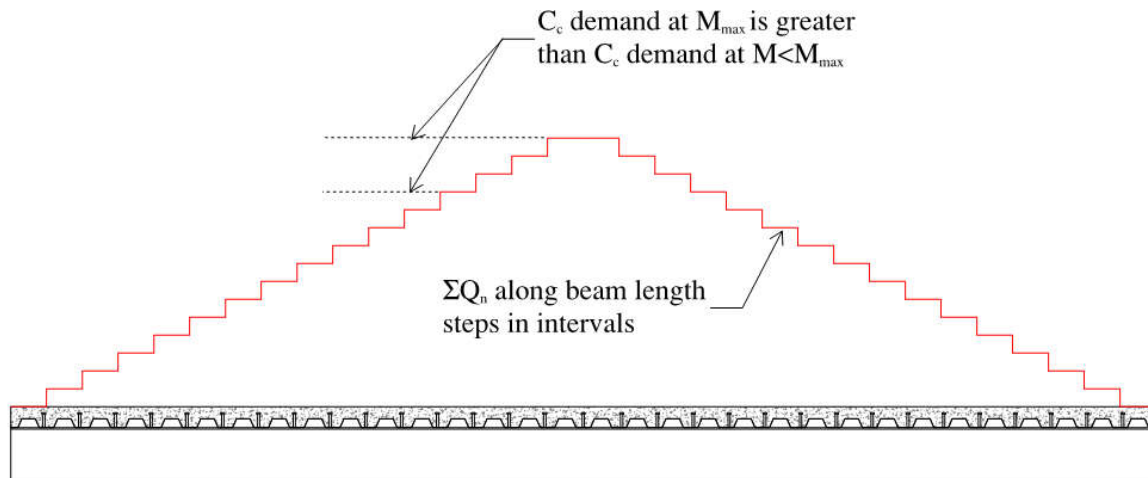
Slab Penetrations: Interval Method



Slab Penetrations: Interval Method



Slab Penetrations: Interval Method



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Slab Penetrations: Interval Method Example

Given:

W18x40, A992

$L = 40'-0''$

38 steel anchors ($\sim 1/\text{ft}$)

3" Composite Deck

4 1/2" Concrete above deck

$f'_c = 3 \text{ ksi NW}$

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:

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

$$L/8 = (40'-0'')/8 = 5'-0''$$

$$b'_L = b'_R = \text{Min. of}$$

$$TW/2 = (10'-0'')/2 = 5'-0''$$

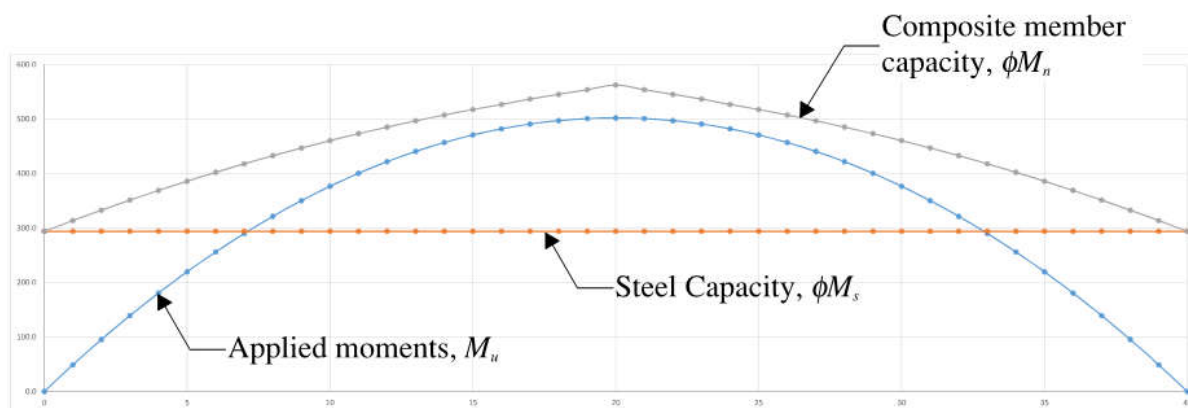
$$\text{Distance to EOS} = \text{N/A}$$

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



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Slab Penetrations: Interval Method Example

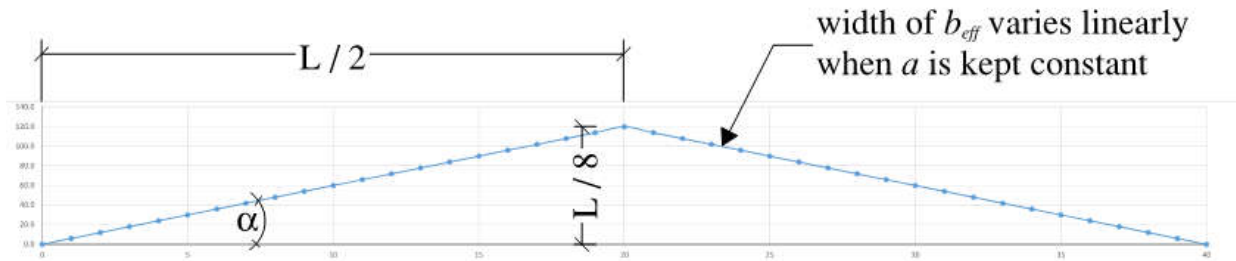


Where $\phi M_n > M_u$, full b_{eff} not required.
 Where $\phi M_s > M_u$, don't need any b_{eff} .



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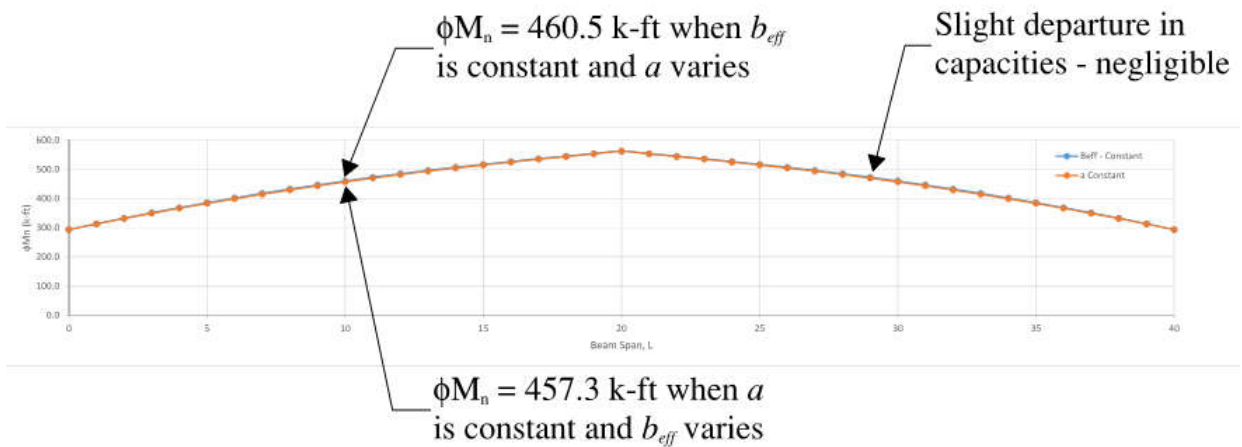
Slab Penetrations: Interval Method Example



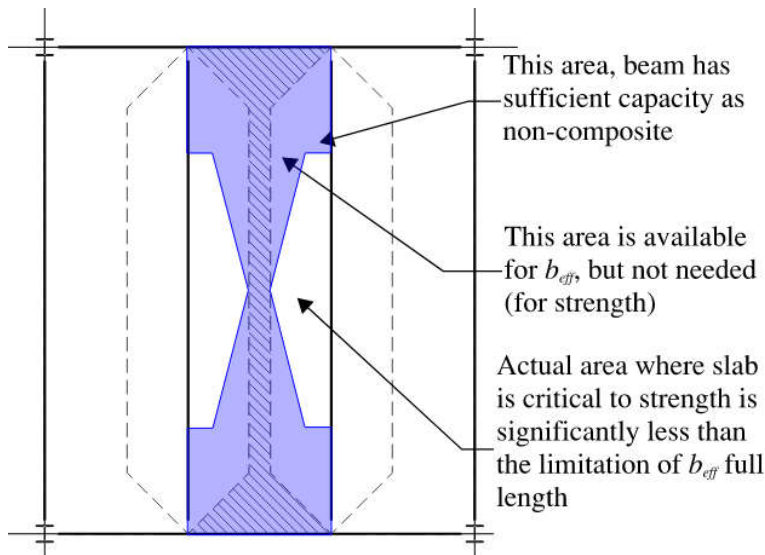
$$\tan(\alpha) = 0.25$$



Slab Penetrations: Interval Method Example



Slab Penetrations: Interval Method Example



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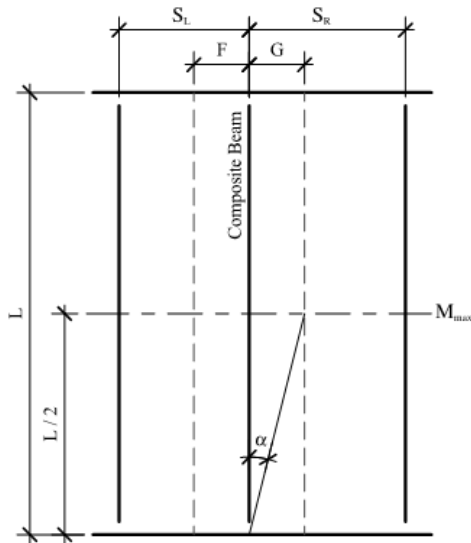
Slab Penetrations: Wiesner Method

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)

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Slab Penetrations: Wiesner Method



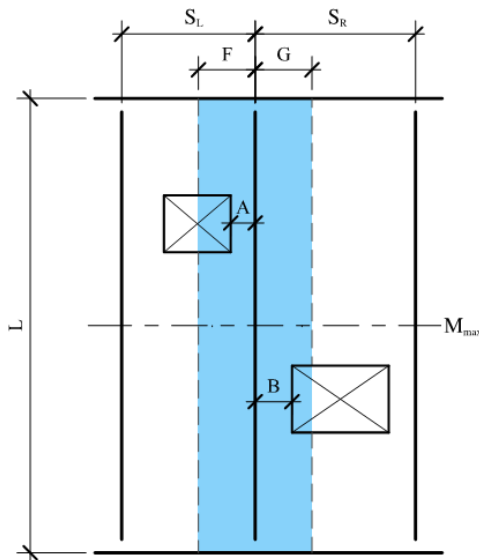
Wiesner's method uses the same angle, α , to limit shear stresses in the slab at discontinuities.

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

$$\alpha = 14 \text{ degrees}$$



Slab Penetrations: Wiesner Method

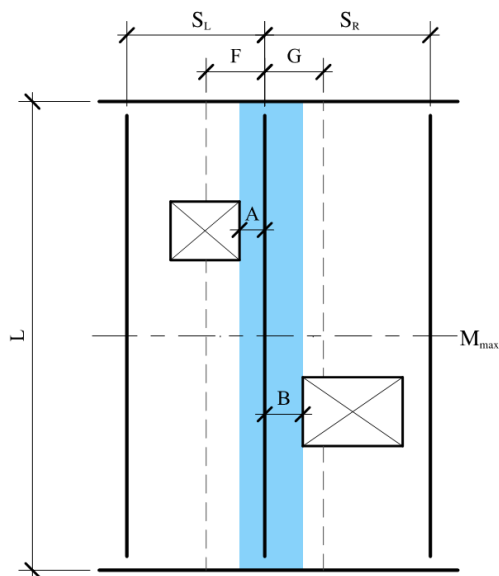


Without openings, you would have:

$$b_{eff} = F + G$$



Slab Penetrations: Wiesner Method

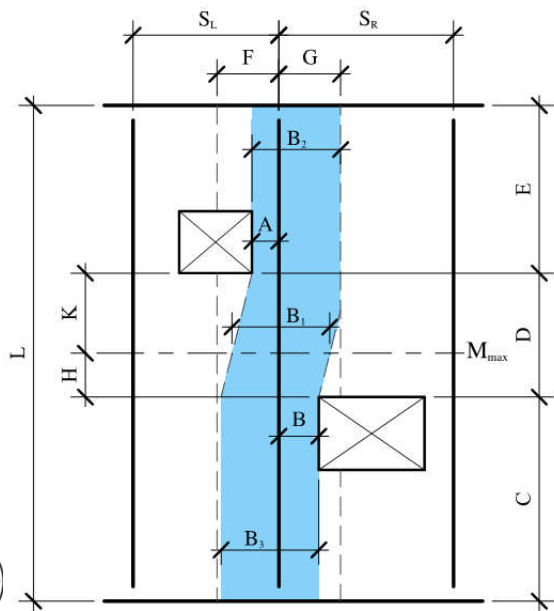


With openings, you have:

$$b_{eff} = A + B$$

unless a more robust analysis is performed

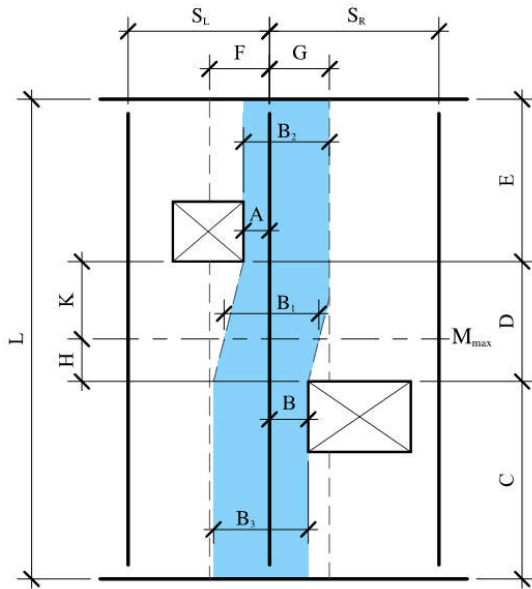
Slab Penetrations: Wiesner Method General Case



- Simple span beams
- M_{max} near mid-span
- One or two adjacent openings
- Openings do not align
- $A \ \& \ B > \frac{1}{2} b_f$ (beam flange)
- $H \ \& \ K > 0$
- No openings in adjacent spans



Slab Penetrations: Wiesner Method



Draw effective width diagram using $\alpha=14$ degrees for sloped lines

$$F = \min(S_L/2, L/8)$$

$$G = \min(S_R/2, L/8)$$

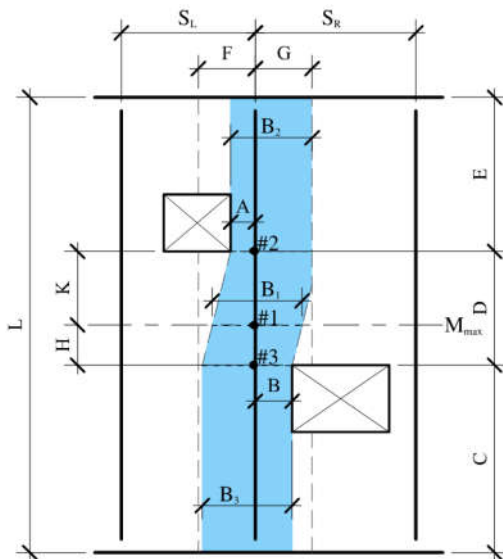
$$B_1 = A + B + \tan \alpha(H + K) \leq (F + G)$$

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

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



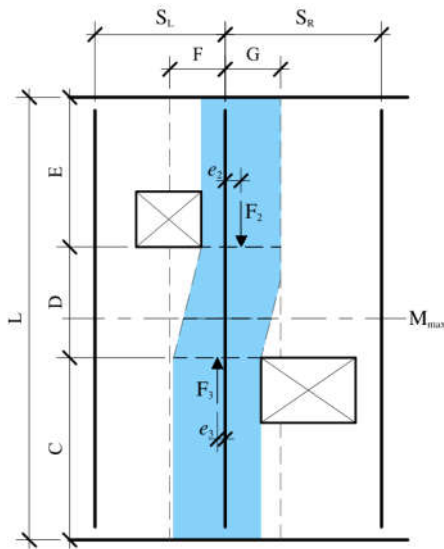
Slab Penetrations: Wiesner Method



- 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



$$F_2 = \sum Q_{n2}$$

$$F_3 = \sum Q_{n3}$$

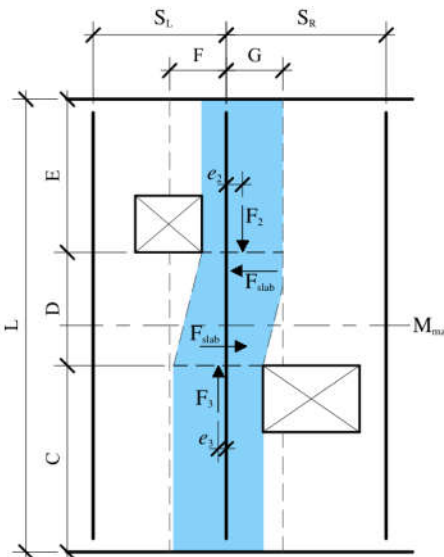
$$M_2 = F_2 e_2$$

$$M_3 = F_3 e_3$$

$$M_{slab} = \max(M_2, M_3)$$



Slab Penetrations: Wiesner Method



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

$$T_{slab} = 0.5 F_{slab}$$

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



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

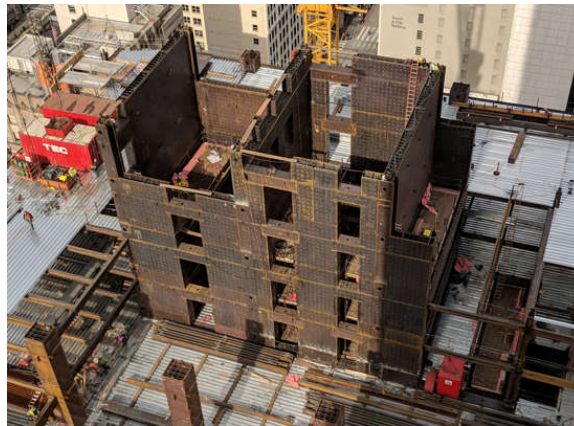
- Continued evolution of composite column requirements
 - AISC 360-10: Overhaul of composite column design provisions (CFTs) – focus on typical columns but introduced compact, non-compact, and slenderness concepts
 - AISC 360-16: Expanded composite columns to include more geometries – refined slender 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

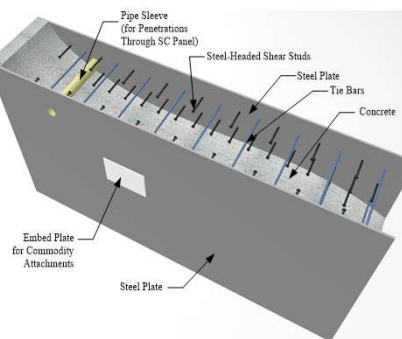
Magnusson Klemencic
Associates



111

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

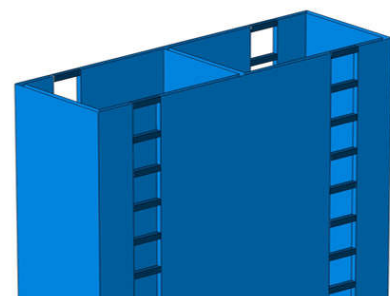


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New Development

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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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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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.



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!
- Completely fill out online form. Don't forget to check the boxes next to each attendee's name!



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