Expanding the Geometric Limits for Composite Beams

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VIRGINIA TECH.

Acknowledgements

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Sponsors:

In-kind Support:

Organization

1. Introduction to Composite Beams
2. Geometric Limits on Composite Beams and Motivation
3. Research Program for Deck Up to 4.0 In. Deep
4. Investigating Effect of Edge Distance on Shear Studs
5. Summary, Conclusions and Recommendations

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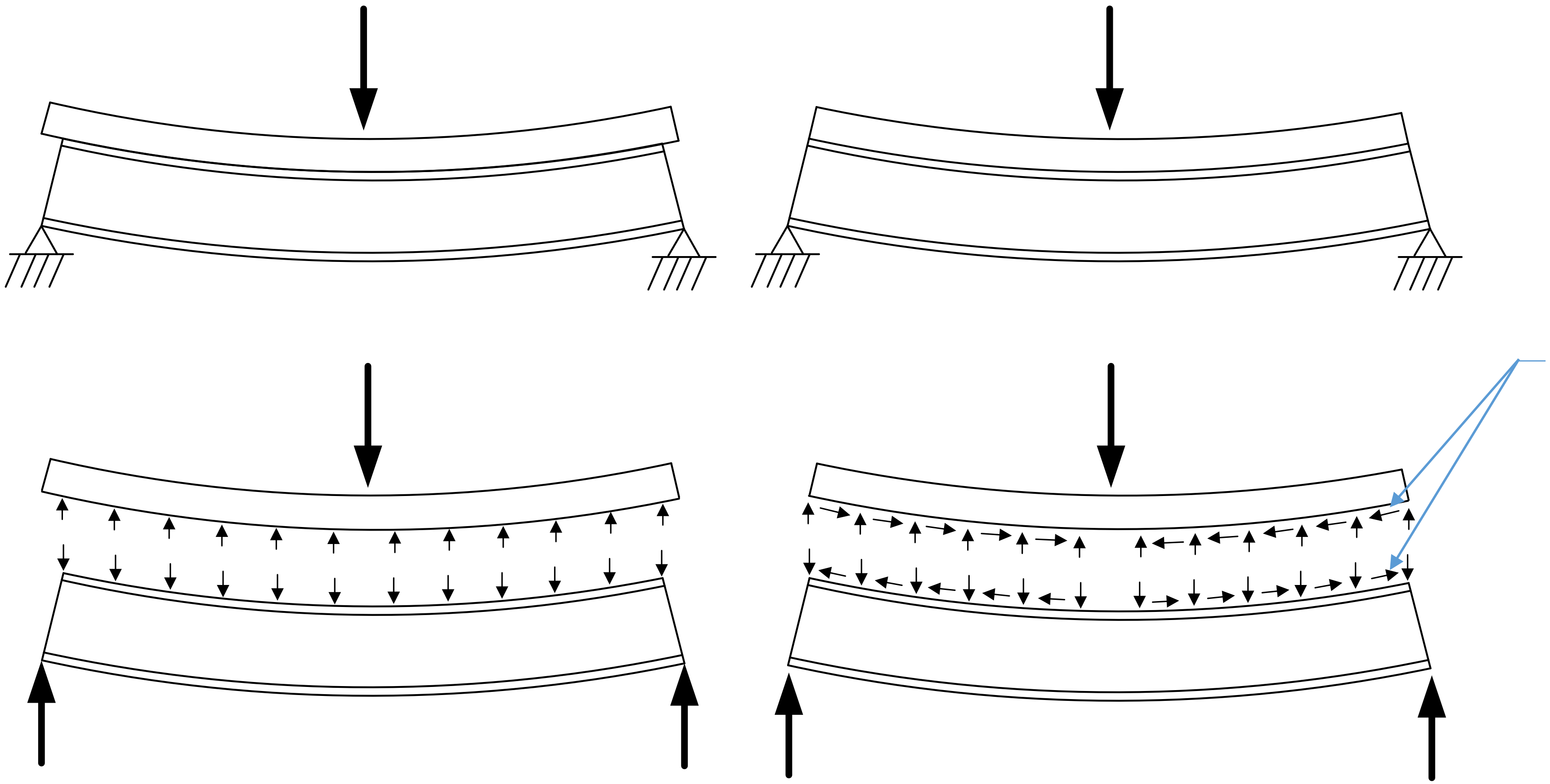
Basics of Composite Beam Design



a) Noncomposite Beam

b) Composite Beam

Composite beams have shear transfer between steel beam and concrete slab

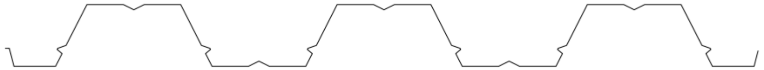
More efficient use of materials

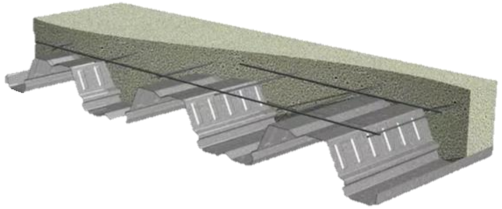
Headed shear studs are critical component

Types of Composite Floor Deck

Trapezoidal Deck

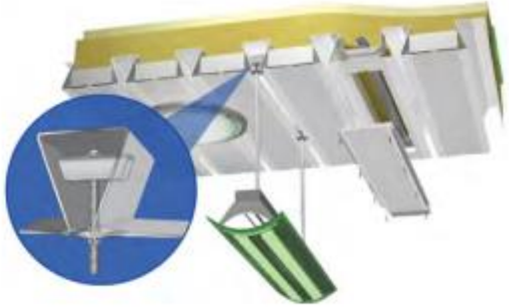
1.5” to 3” deep deck



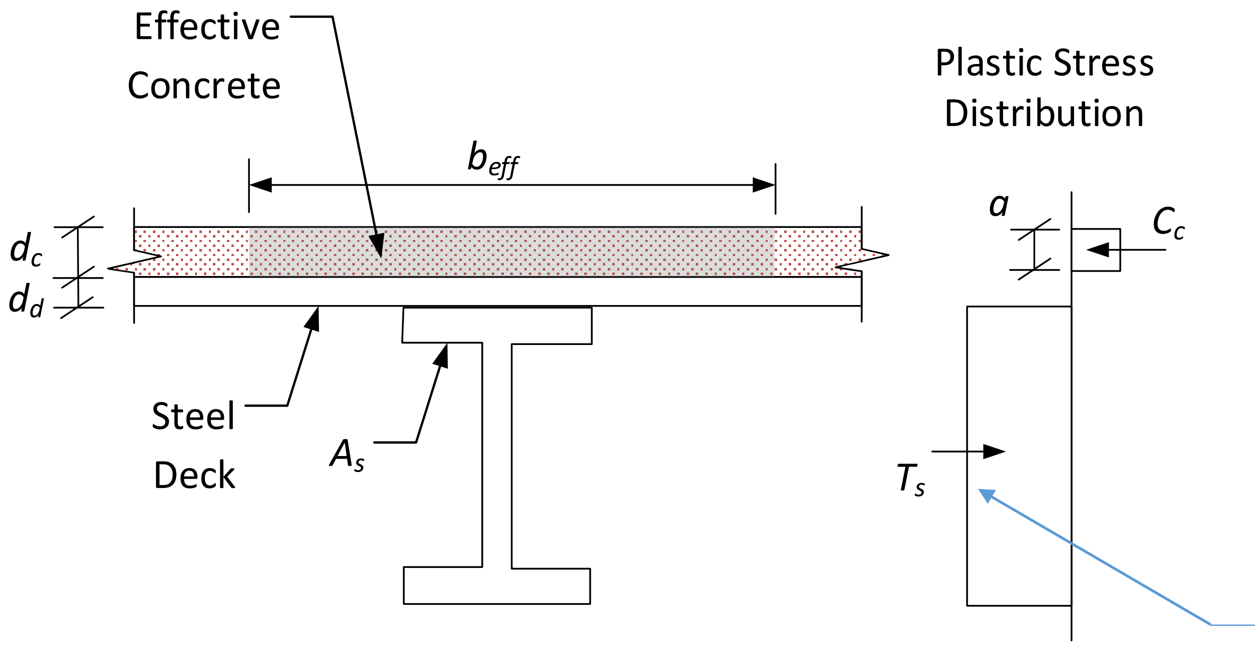


Dovetail Deck

2” to 4” deep deck



Full Composite Action



Composite Beam with
Deck Perpendicular

Shown for PNA
in concrete

If the shear transfer is sufficiently strong:

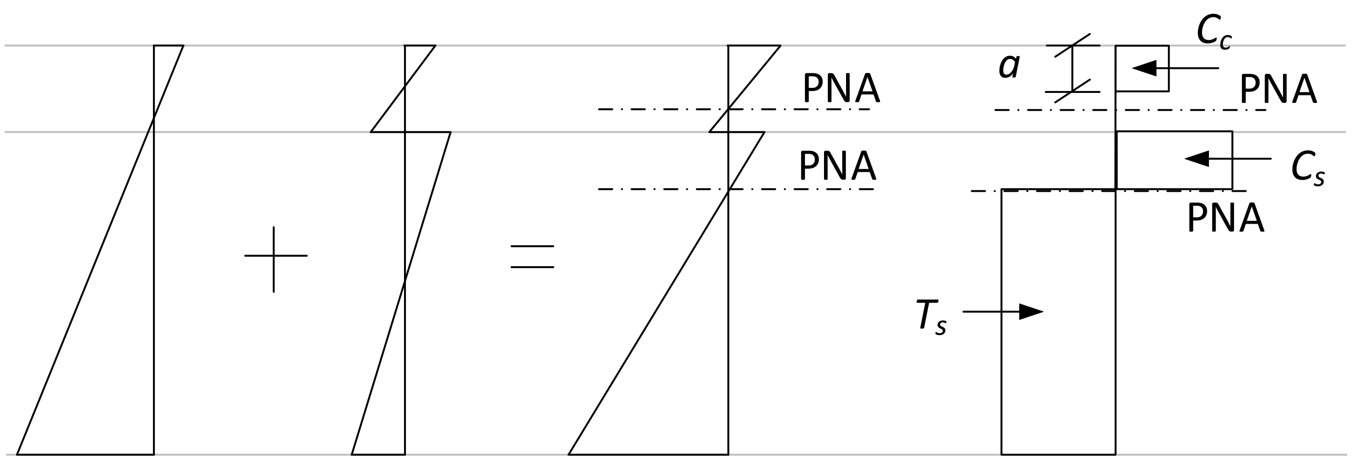
→ Can develop full plastic strength of steel or concrete

→ Call this "full composite action"

For this example stress distribution:

→ develops the full tension strength of the steel beam

Partial Composite Action



Strain up until Qn is reached (Composite)

Strain after Qn exceeded (Noncomposite)

Total Strain

Plastic Stress Distribution

- Two separate plastic neutral axes (PNA)
- ΣQn = sum of nominal shear stud strength between points of maximum moment and zero moment
- Given, ΣQn, can determine PNA locations, resultant forces, and Mn

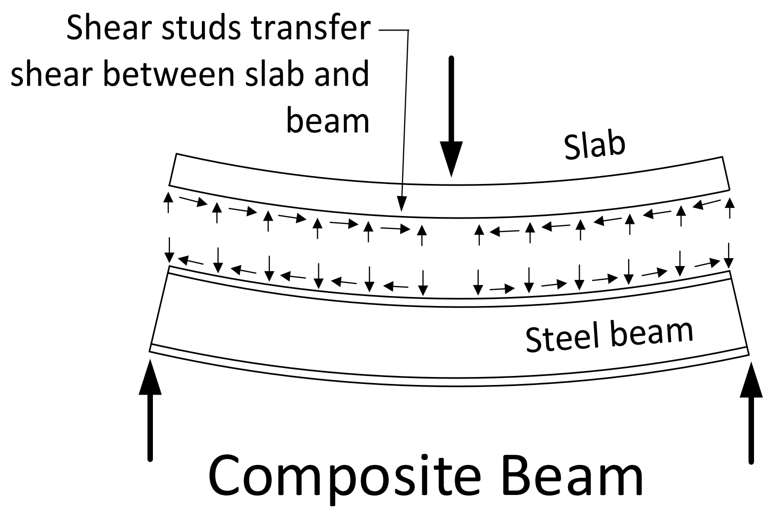
Role of Headed Shear Studs

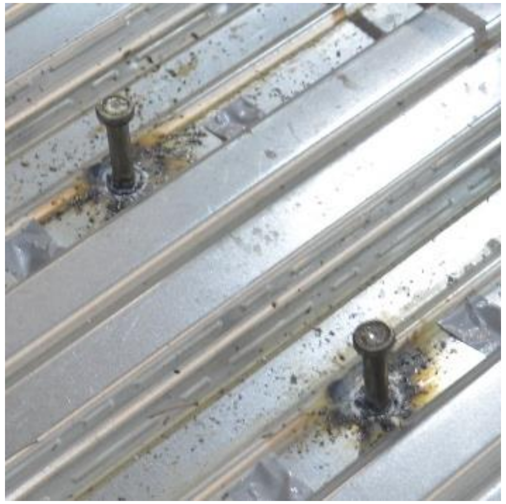
Critical applications

- Composite Beams
- Collectors

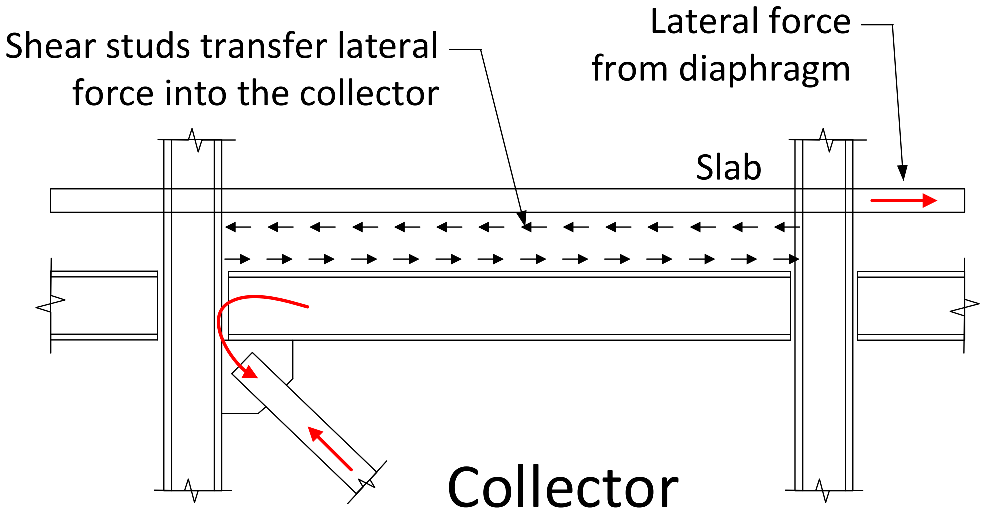
Key behavioral characteristics

- Strength
- Ductility



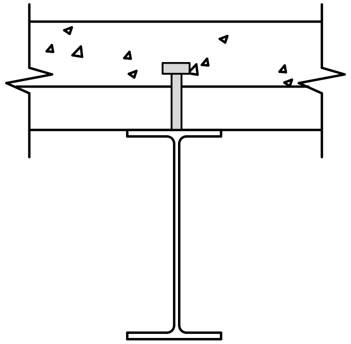


Headed shear studs welded to a beam through steel deck

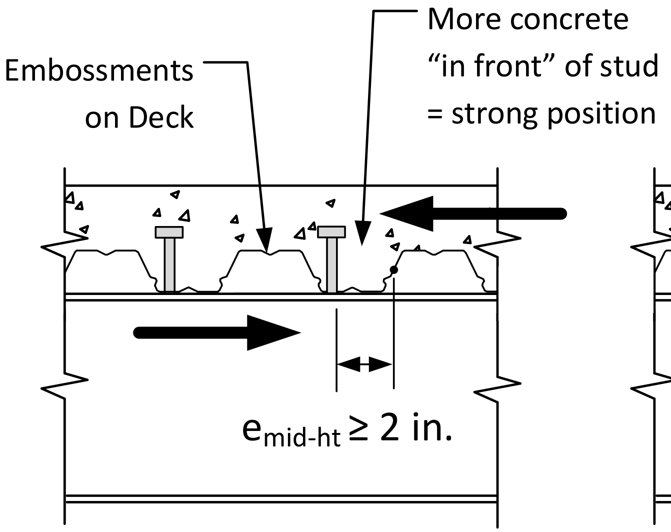


Definitions for Shear Stud Placement

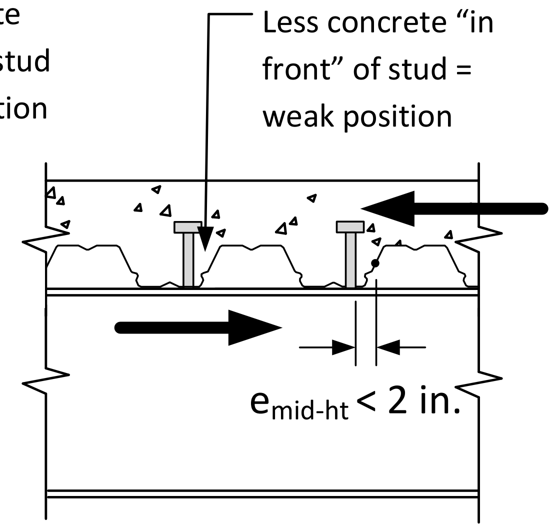
Deck Perpendicular to Beam



Cross-Section

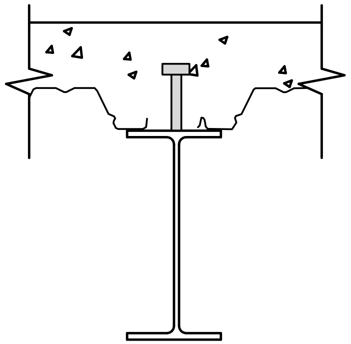


Strong Position

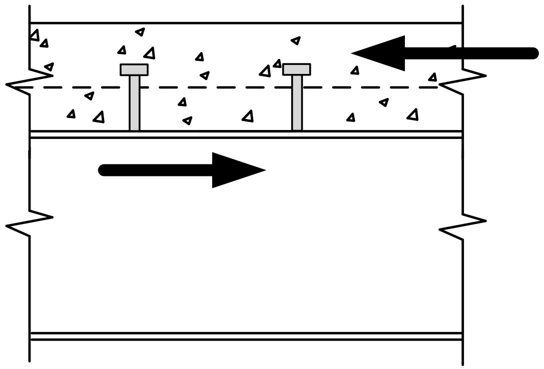


Weak Position

Deck Parallel to Beam

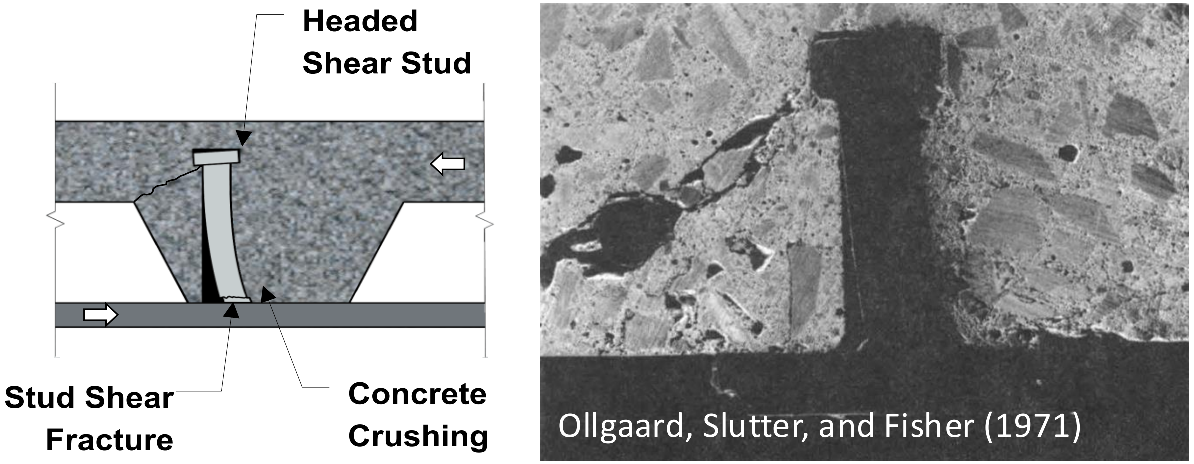


Cross-Section

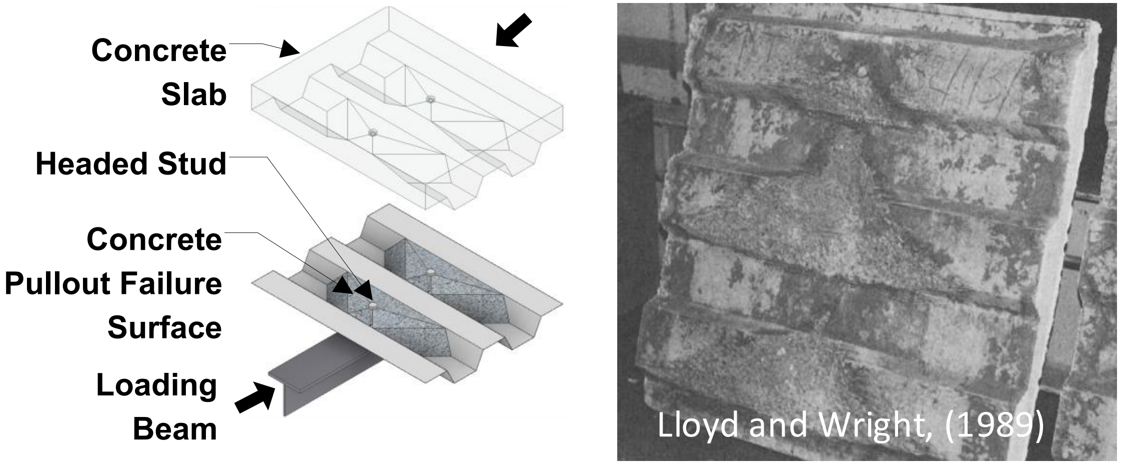


Common for girders

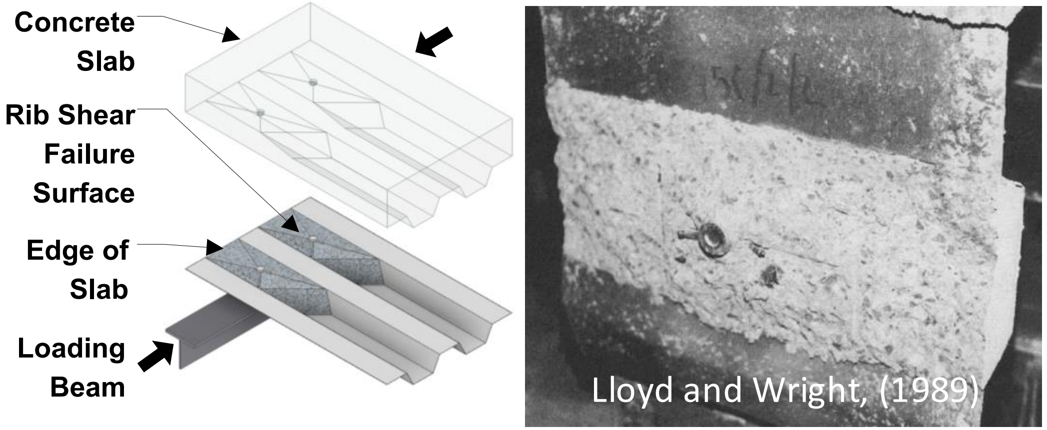
Headed Shear Stud Failure Modes – Can be Complex



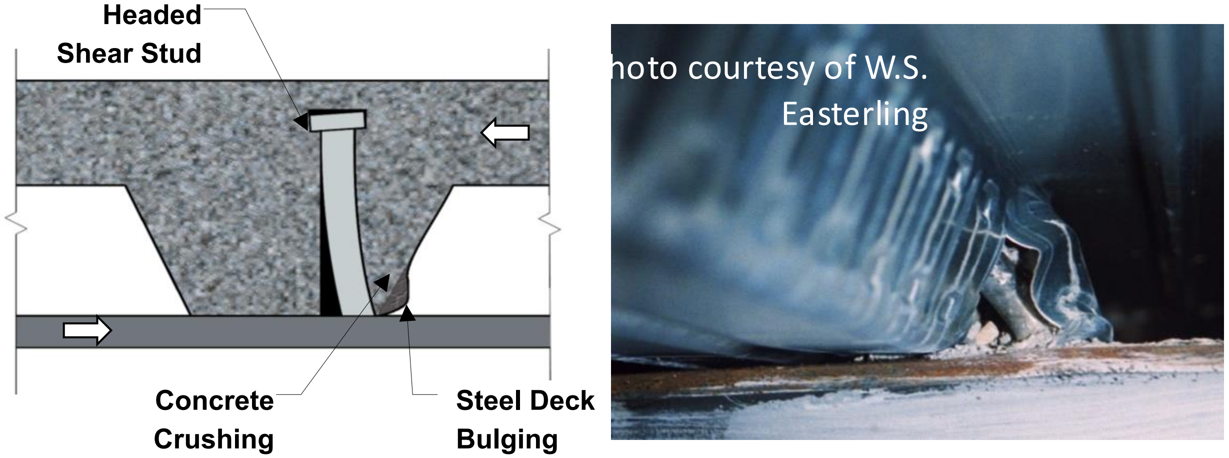
1. Stud Shearing Failure



2. Concrete Pullout Failure



3. Rib Shear Failure

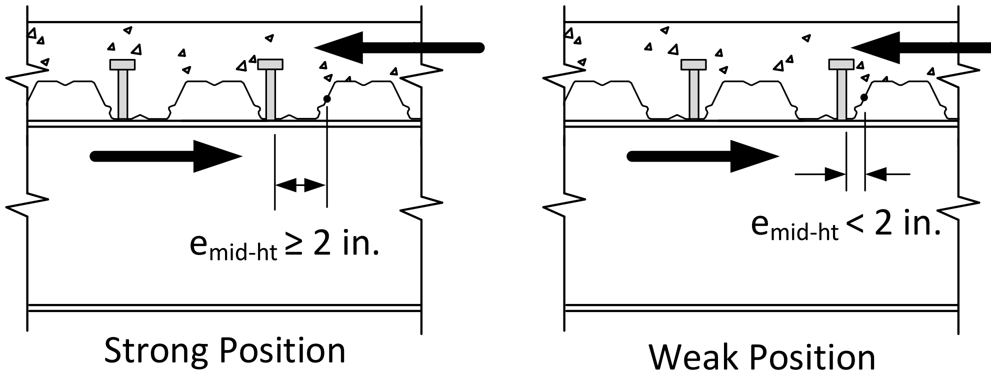


4. Deck Punching Failure

Predicting Strength of Shear Studs

Much Complexity → One empirical equation:
Headed Shear Studs – AISC 360-22 Section I8

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



Deck Perpendicular Cases

Condition	R_g	R_p
No Steel Deck	1.0	0.75
Deck Parallel	1.0 for $w_r/h_r \geq 1.5$ 0.85 for $w_r/h_r < 1.5$	0.75
Deck Perpendicular	1.0 for 1 stud per rib 0.85 for 2 studs per rib 0.7 for 3+ studs per rib	0.6 for weak position 0.75 for strong position

A_{sa} = Stud shank area
f'_c = Compressive strength of concrete
E_c = Modulus of elasticity of concrete
R_g = Group factor
R_p = Position factor
F_u = Ultimate stress of headed stud
w_r and h_r = Rib width and height

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Limits on Deck Depth

Limits on Deck Height

- AISC 360 Section I3.2c.1(a) limits composite beams to **deck not deeper than 3”**.
- Limit to 3” due to lack of data

Motivation for Deeper Deck

- Increasing the deck height = longer spans, fewer beams, reduced erection time and cost savings.
- 3.5” and 4” dovetail steel decks are already available.

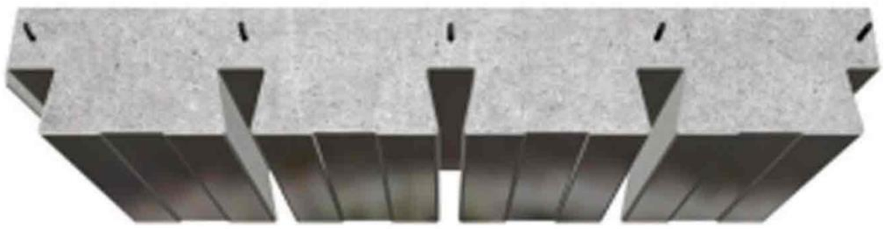
Cost/Benefit Study

- Principal at a structural engineering firm conducted a study
- Typical Data Center and Office Building – comparing 3.0” to 3.5” and 4.5” deck options
- Some findings:
  - 5% to 20% less beams
  - for data centers, dovetail deck eliminates Unistrut ceiling & conduit supports - much more efficient / cheaper

Trapezoidal concrete-filled steel deck

www.metaldeck.com

Dovetail (reentrant) concrete-filled steel deck



www.metaldeck.com

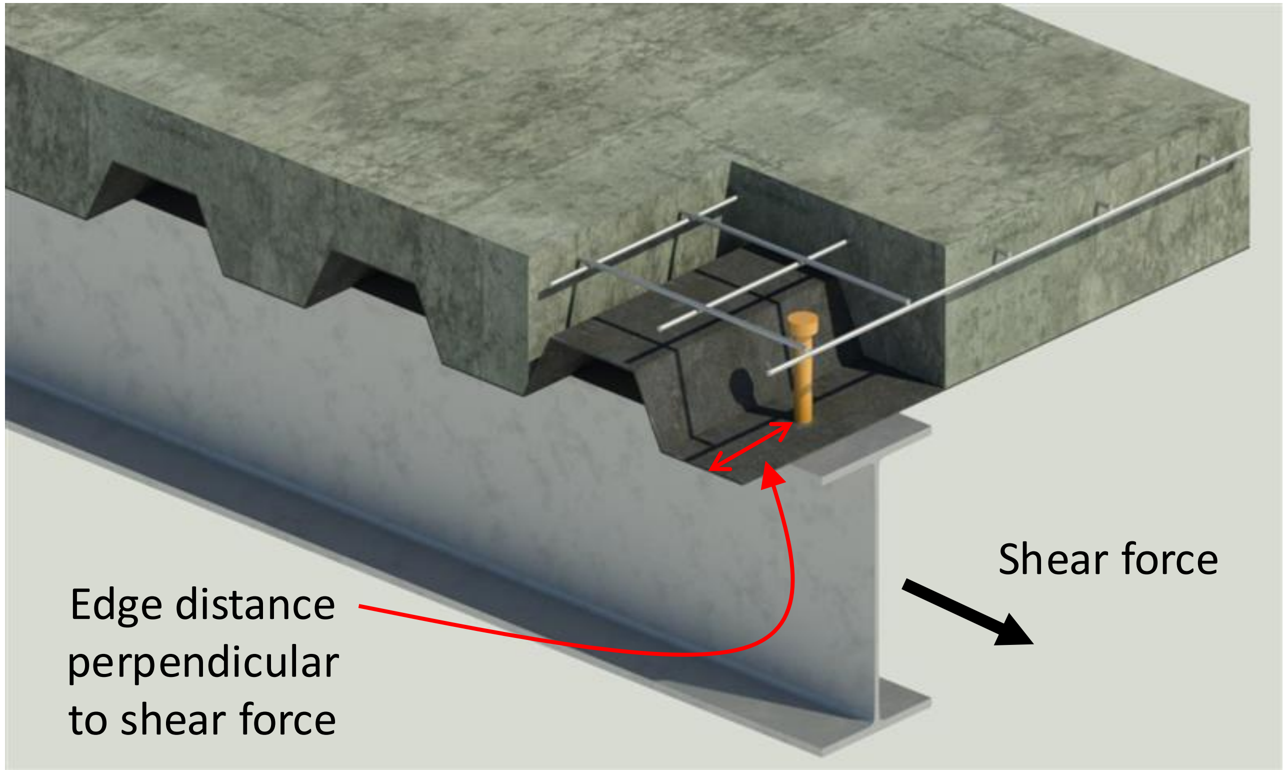
Why Not Deck Deeper than 4 in.?

<u>Tradeoff as deck gets deeper</u>

- Weight of individual sheets – handling by erectors
- Width of coverage.
  3.0” can have 36” coverage
  3.5 and 4.0 maybe 24” coverage
  At some depth, 12” coverage
- Shear stud solutions for deck deeper than 4.0” may be different.

→ Motivation: Desirable to expand limits for composite beams to 4.0 in. deck

Edge Distance Parallel to Shear Force



- **<u>No minimum edge distance</u>** given for steel anchors installed in the ribs of formed steel decks.
- **<u>No guidance</u>** provided in the commentary
- Reasons to believe <u>small edge distance reduces strength</u> (rib shear failure)

AISC 360-22 Section **I8.2d(b)**:

(b) Steel anchors shall have at least 1 in. (25 mm) of lateral concrete cover in the direction perpendicular to the shear force, except for anchors installed in the ribs of formed steel decks.

→ Motivation: Need limits on edge distance or reduction factor

Motivation and Scope

Research Questions:

- **What modifications are required for composite beam specifications to allow up to 4 in. deep deck?**
- **What is the minimum edge distance (parallel to direction of force) for which the shear stud strength prediction is accurate?**

Research Studies:

1. **Pushout tests, composite beam tests, and analysis to investigate effectiveness of shear studs with 3.5 in. and 4.0 in. deck.**
2. **Pushout test program to investigate effect of small edge distances on shear stud effectiveness.**

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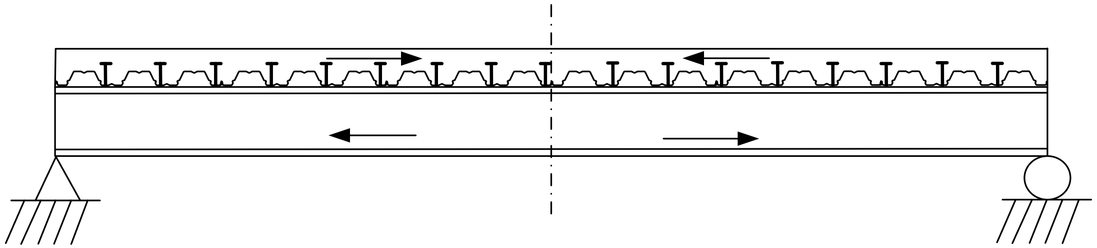
Overview of Study on 3.5 in. and 4.0 in. Deck

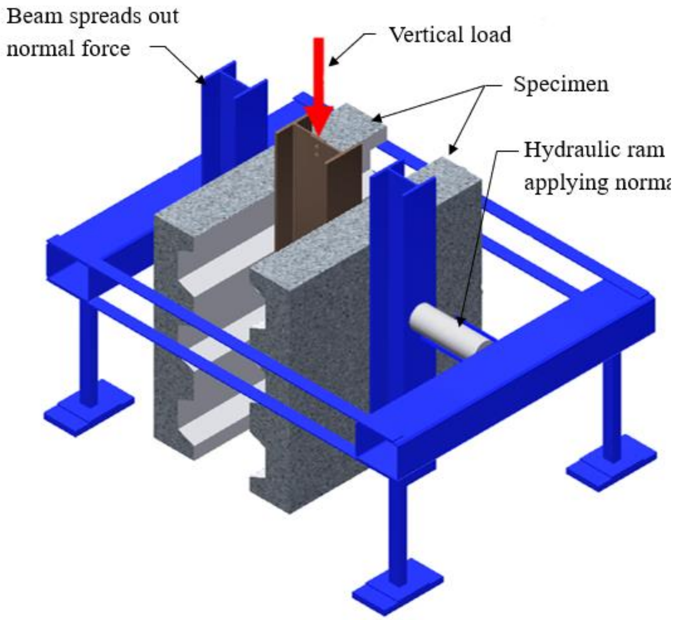
Objectives

- **Determine design requirements for composite beams with 3.5" and 4.0" deck.**
- **Provide experimental validation through pushout tests and composite beam tests.**

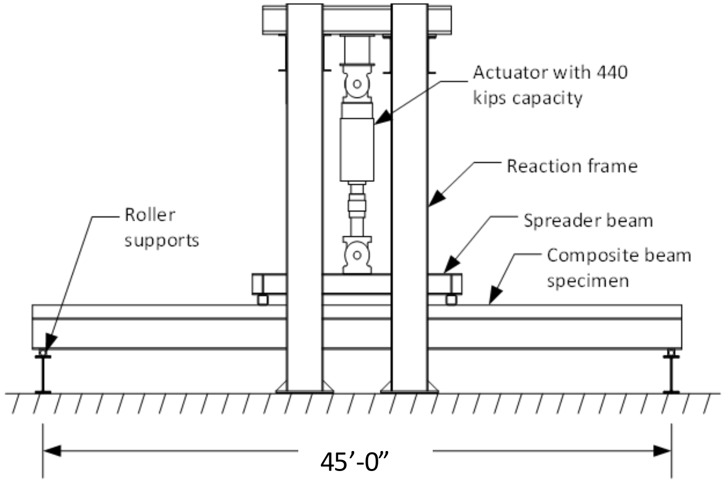
Parameters to Vary

- Both trapezoidal and dovetail deck
- Deck depth = 3.5" or 4.0", different manufacturers
- fc'=3ksi to 8 ksi, NW and LW concrete
- vary stud position





Pushout Test Setup



Composite Beam Test Setup

Scope of Work:

1. Approximately 100 pushout tests
2. Two composite beam tests with 45' span
3. Synthesize results, determine design requirements

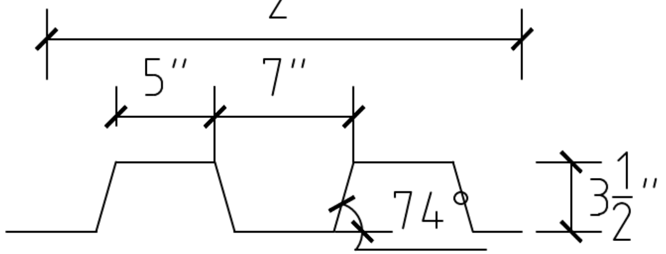
Pushout Test Matrix

Group Name	Number of Specimens	Deck Profile	Deck Manufacturer	Deck Profile Code	Specified Concrete Compressive Strength	Concrete Unit Weight	Stud Configuration
T3.0A-3N-W	5	3.0” Trapezoidal	Manufacturer A	TZ2	3 ksi	NW	Weak
T3.0A-3N-2ST	5	3.0” Trapezoidal	Manufacturer A	TZ2	3 ksi	NW	Two Staggered
T3.0A-8N-S	3	3.0” Trapezoidal	Manufacturer A	TZ2	8 ksi	NW	Strong
T3.5A-3N-S	3	3.5” Trapezoidal	Manufacturer A	TZ1	3 ksi	NW	Strong
T3.5A-3N-W	5	3.5” Trapezoidal	Manufacturer A	TZ1	3 ksi	NW	Weak
T3.5A-3N-2ST	3	3.5” Trapezoidal	Manufacturer A	TZ1	3 ksi	NW	Two Staggered
T3.5A-8N-S	3	3.5” Trapezoidal	Manufacturer A	TZ1	8 ksi	NW	Strong
T3.5A-8N-W	3	3.5” Trapezoidal	Manufacturer A	TZ1	8 ksi	NW	Weak
T3.5A-8N-2ST	3	3.5” Trapezoidal	Manufacturer A	TZ1	8 ksi	NW	Two Staggered
T3.5A-3L-W	5	3.5” Trapezoidal	Manufacturer A	TZ1	3 ksi	LW	Weak
T4.0C-4N-S	3	4” Trapezoidal	Manufacturer C	TZ3	4 ksi	NW	Strong
T4.0C-4N-W	3	4” Trapezoidal	Manufacturer C	TZ3	4 ksi	NW	Weak
T4.0C-4N-2ST	3	4” Trapezoidal	Manufacturer C	TZ3	4 ksi	NW	Two Staggered
T4.0C-4L-S	3	4” Trapezoidal	Manufacturer C	TZ3	4 ksi	LW	Strong
T4.0C-4L-W	3	4” Trapezoidal	Manufacturer C	TZ3	4 ksi	LW	Weak
T4.0C-4L-2ST	3	4” Trapezoidal	Manufacturer C	TZ3	4 ksi	LW	Two Staggered
D3.5A-3N-C	3	3.5” Dovetail	Manufacturer A	DT1	3 ksi	NW	Centered
D3.5A-3N-2C	3	3.5” Dovetail	Manufacturer A	DT1	3 ksi	NW	Two centered
D3.5B-3N-S	4	3.5” Dovetail	Manufacturer B	DT2	3 ksi	NW	strong
D3.5B-3N-W	3	3.5” Dovetail	Manufacturer B	DT2	3 ksi	NW	weak
D3.5A-8N-C	3	3.5” Dovetail	Manufacturer A	DT1	8 ksi	NW	Centered
D3.5A-8N-2C	3	3.5” Dovetail	Manufacturer A	DT1	8 ksi	NW	Two centered
D3.5B-8N-W	3	3.5” Dovetail	Manufacturer B	DT2	8 ksi	NW	weak
D3.5B-8N-2ST	3	3.5” Dovetail	Manufacturer B	DT2	8 ksi	NW	Two Staggered
D3.5A-3L-C	3	3.5” Dovetail	Manufacturer A	DT1	3 ksi	LW	Centered
D4.0D-4N-C	3	4” Dovetail	Manufacturer D	DT3	4 ksi	NW	Centered
D4.0D-4N-2C	3	4” Dovetail	Manufacturer D	DT3	4 ksi	NW	Two centered
D4.0D-4L-C	3	4” Dovetail	Manufacturer D	DT3	4 ksi	LW	Centered
D4.0D-4L-2C	3	4” Dovetail	Manufacturer D	DT3	4 ksi	LW	Two centered

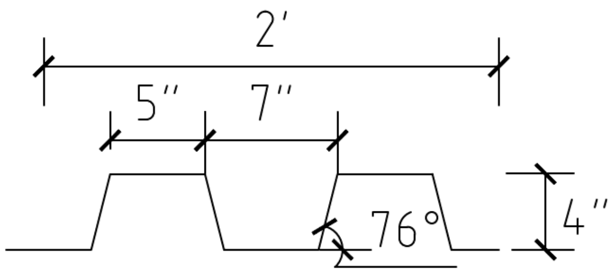
96 Total Pushout Specimens

Deck Profiles Included in the Study

Press-Braked Profiles



TZ1



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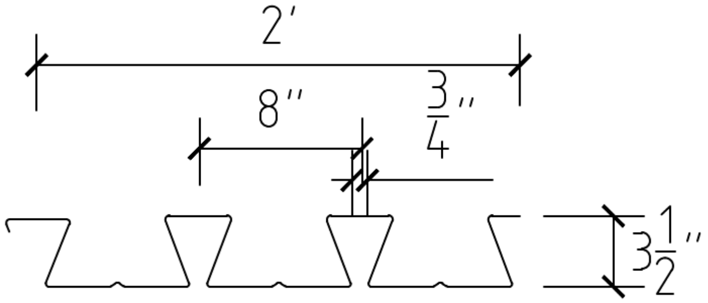
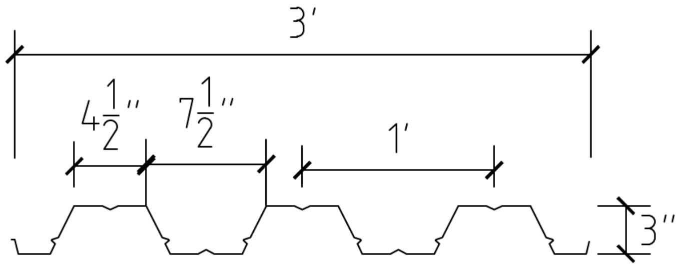
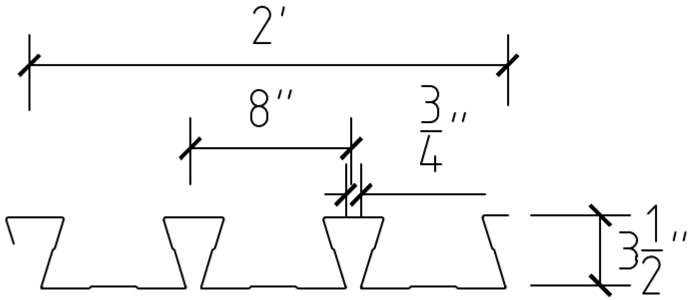


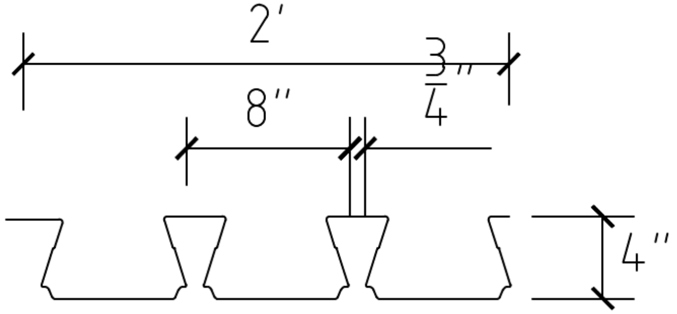
DT2



TZ2

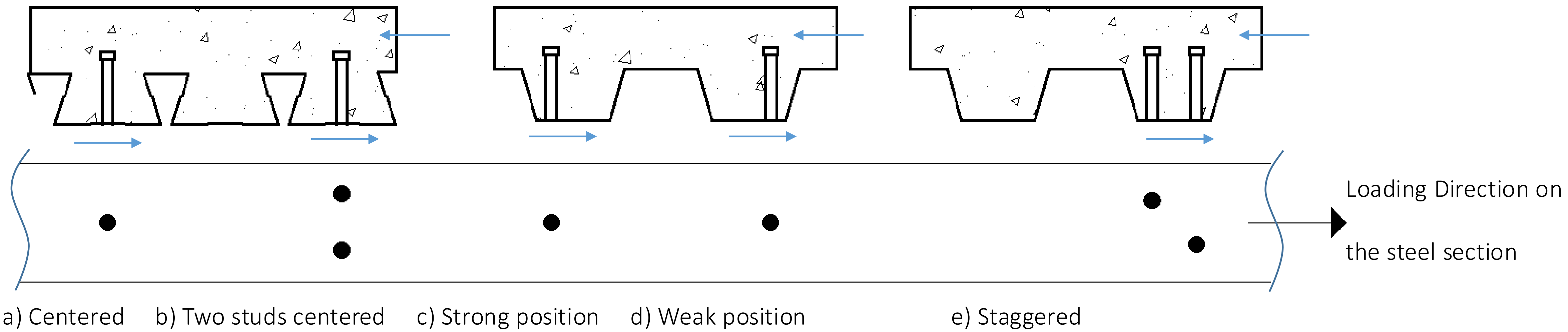


DT1



DT3

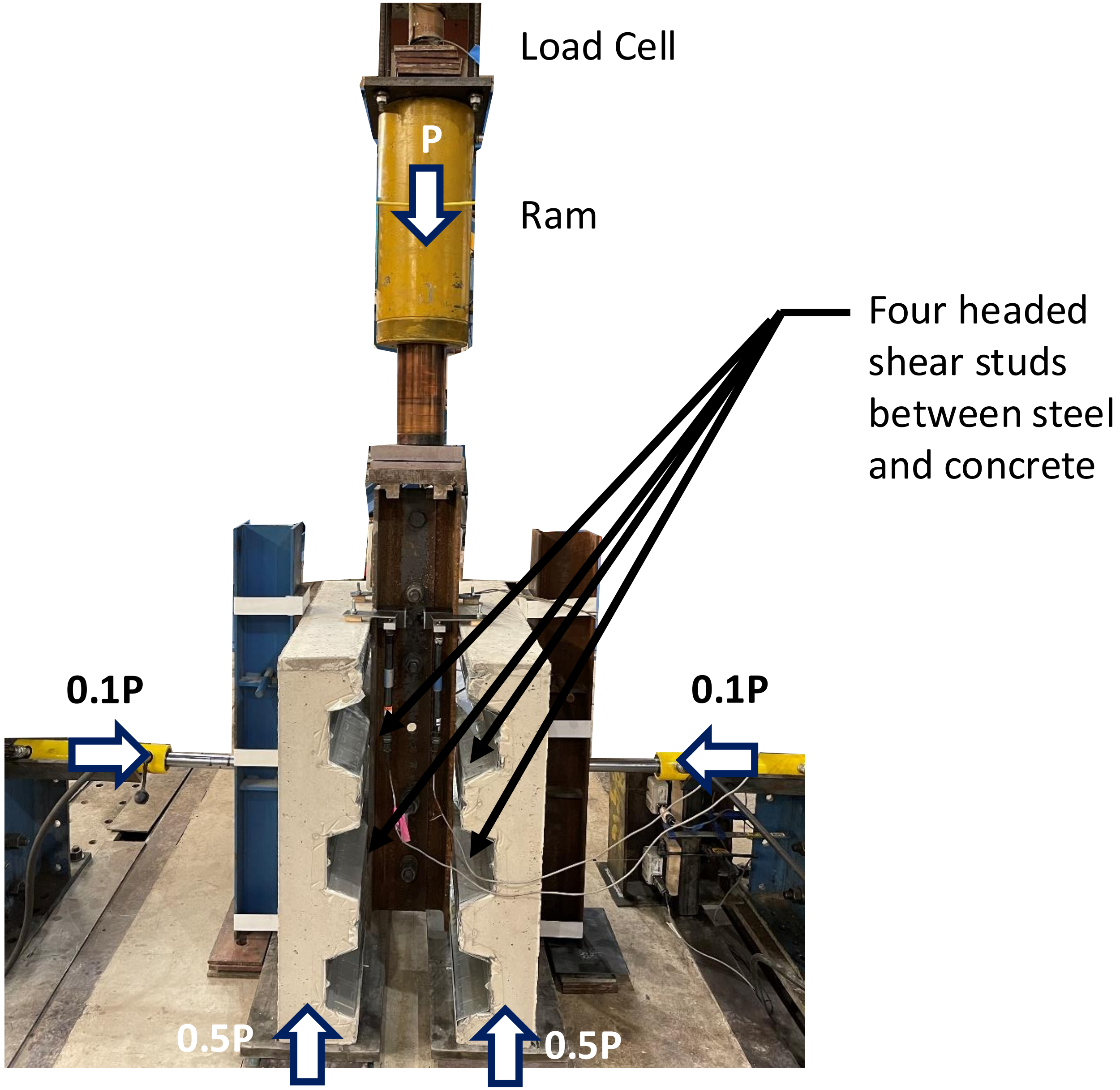
Headed Shear Stud Configurations

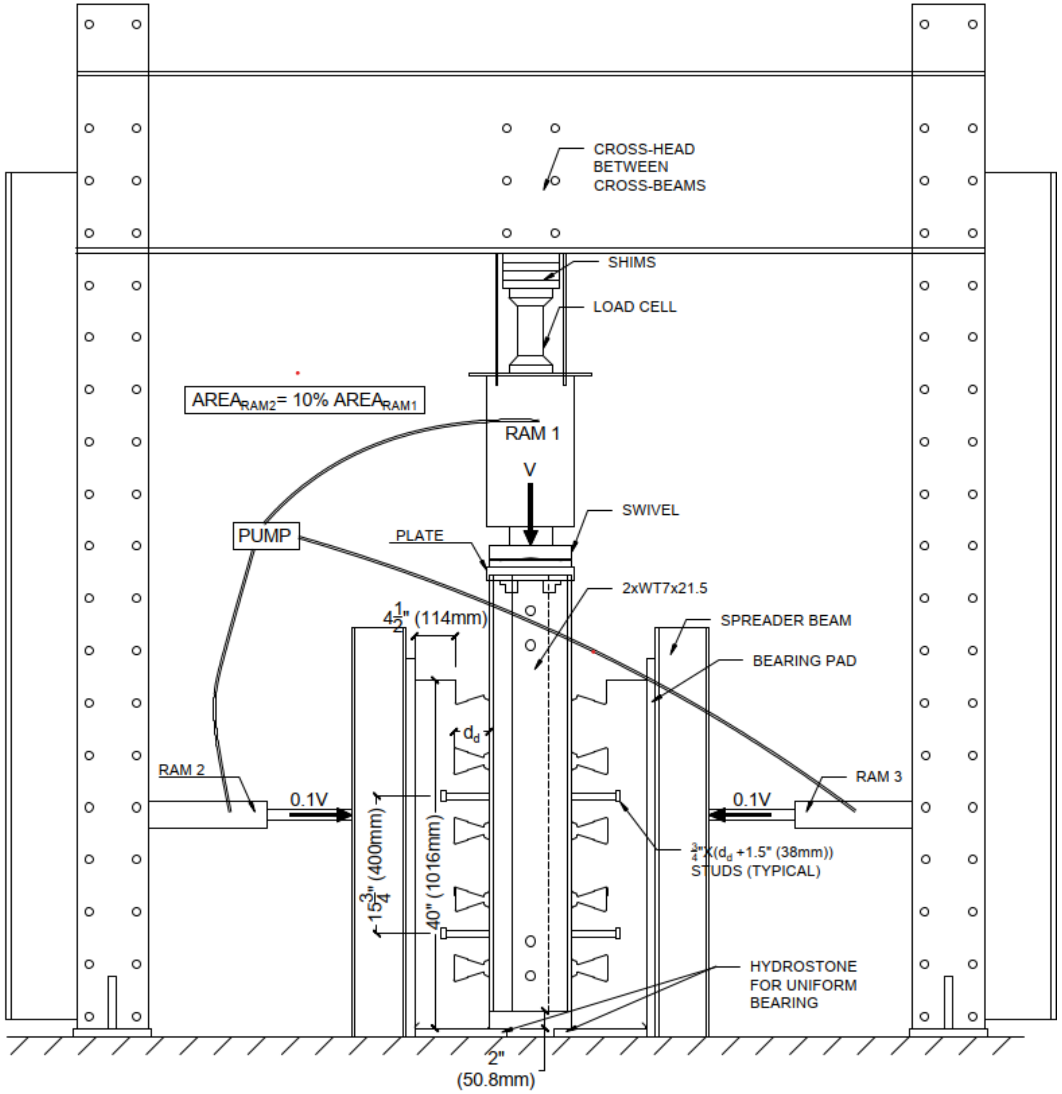


Hold constant:

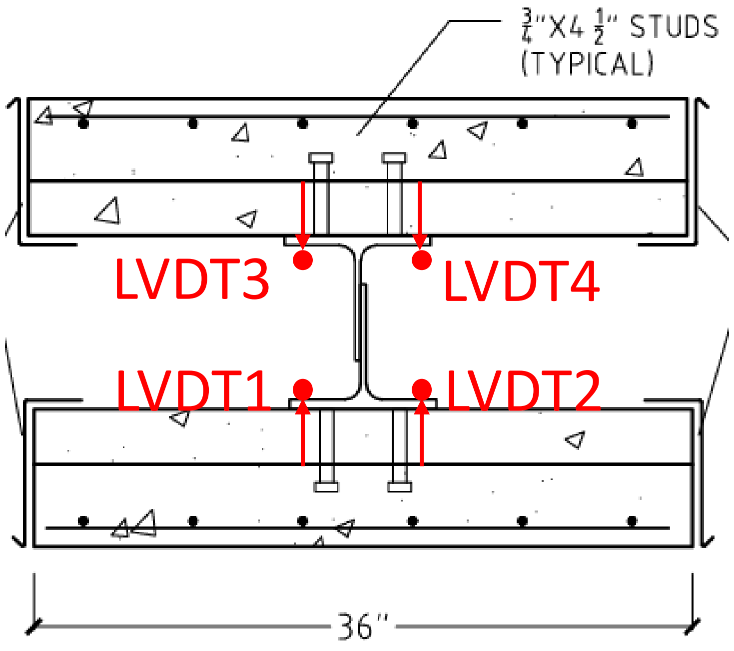
- ¾” headed shear studs
- Stud height = deck height + 1.5 in.
- Specified minimum ultimate strength = 65 ksi

Pushout Test Setup

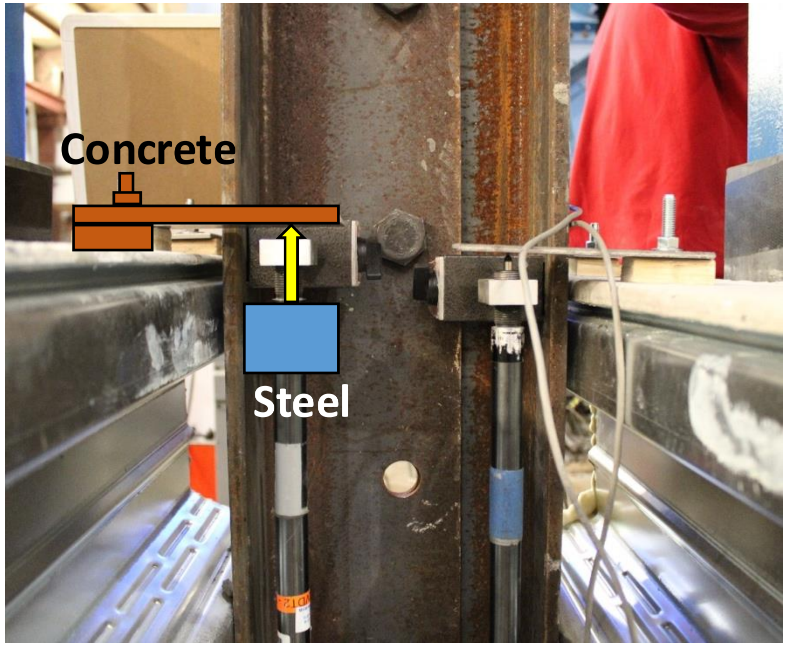




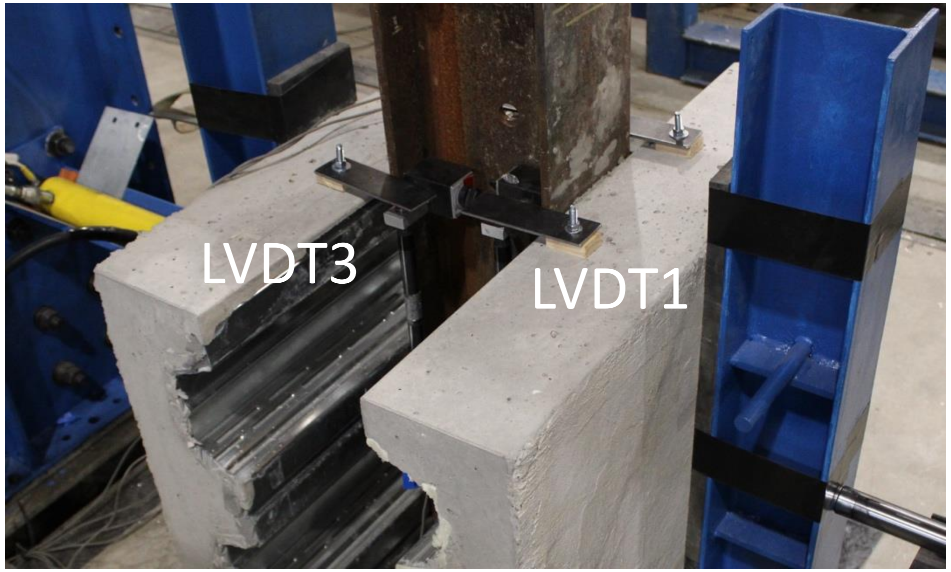
Instrumentation to Measure Slip



Top View



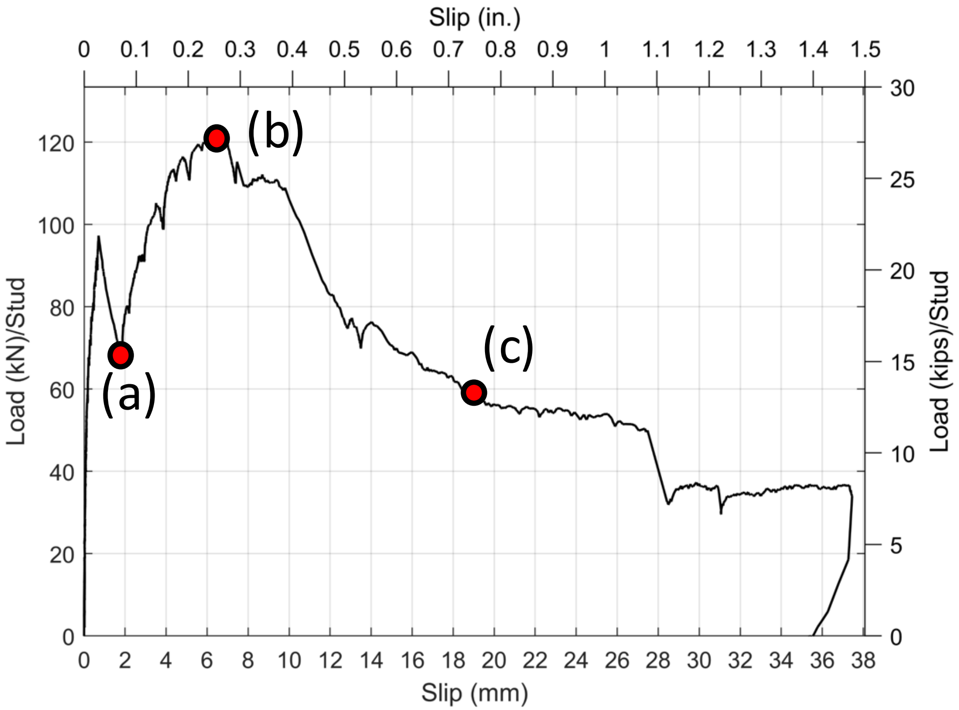
Four LVDT's to measure movement of concrete relative to steel section



Casting Specimens

Assembling Specimens

Failure Mode for Dovetail – Strong Position

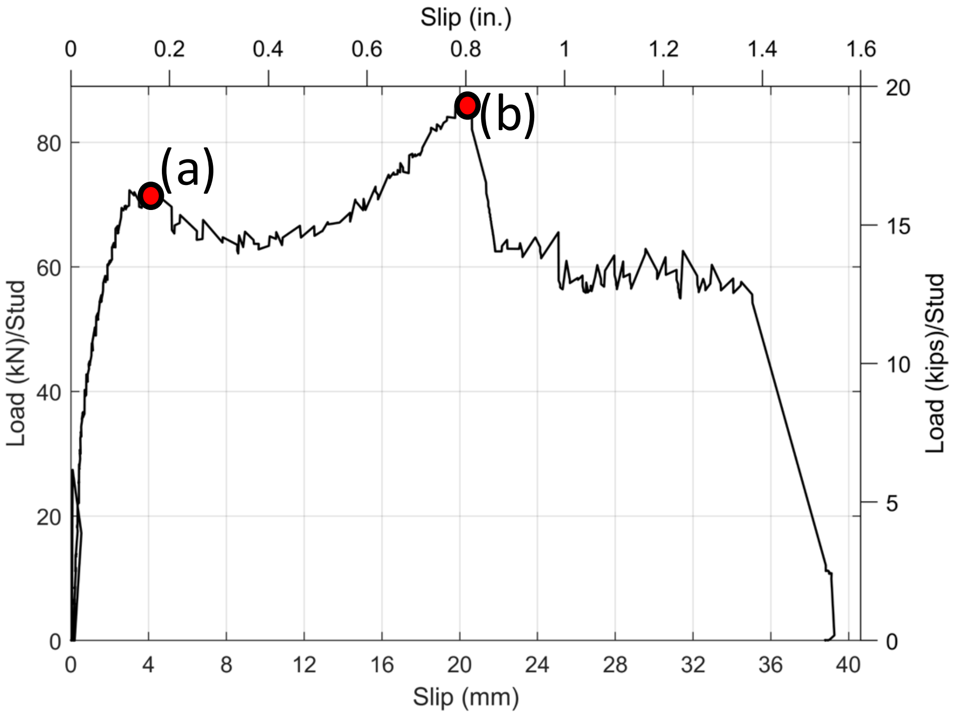


(a) When rib shear crack was formed

(b) At peak load

(c) After the test was ended

Failure Mode for Dovetail – Weak Position

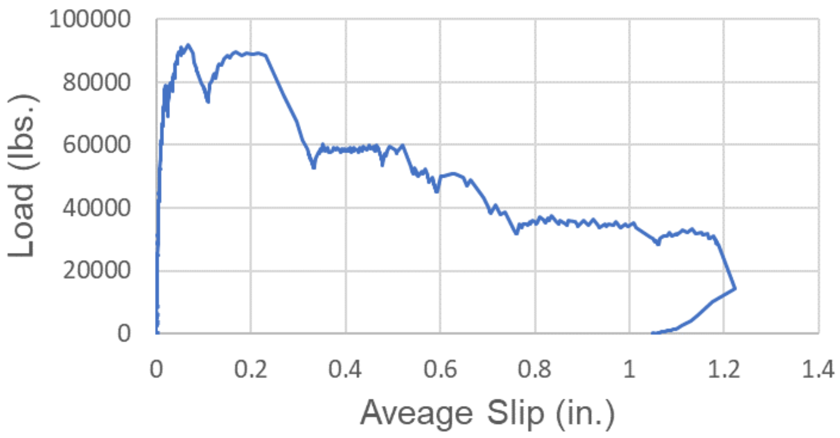


(a) Deck bulging

(b) Deck punching

Deck tearing at the bulge location

Concrete Cone Failure – Strong Position



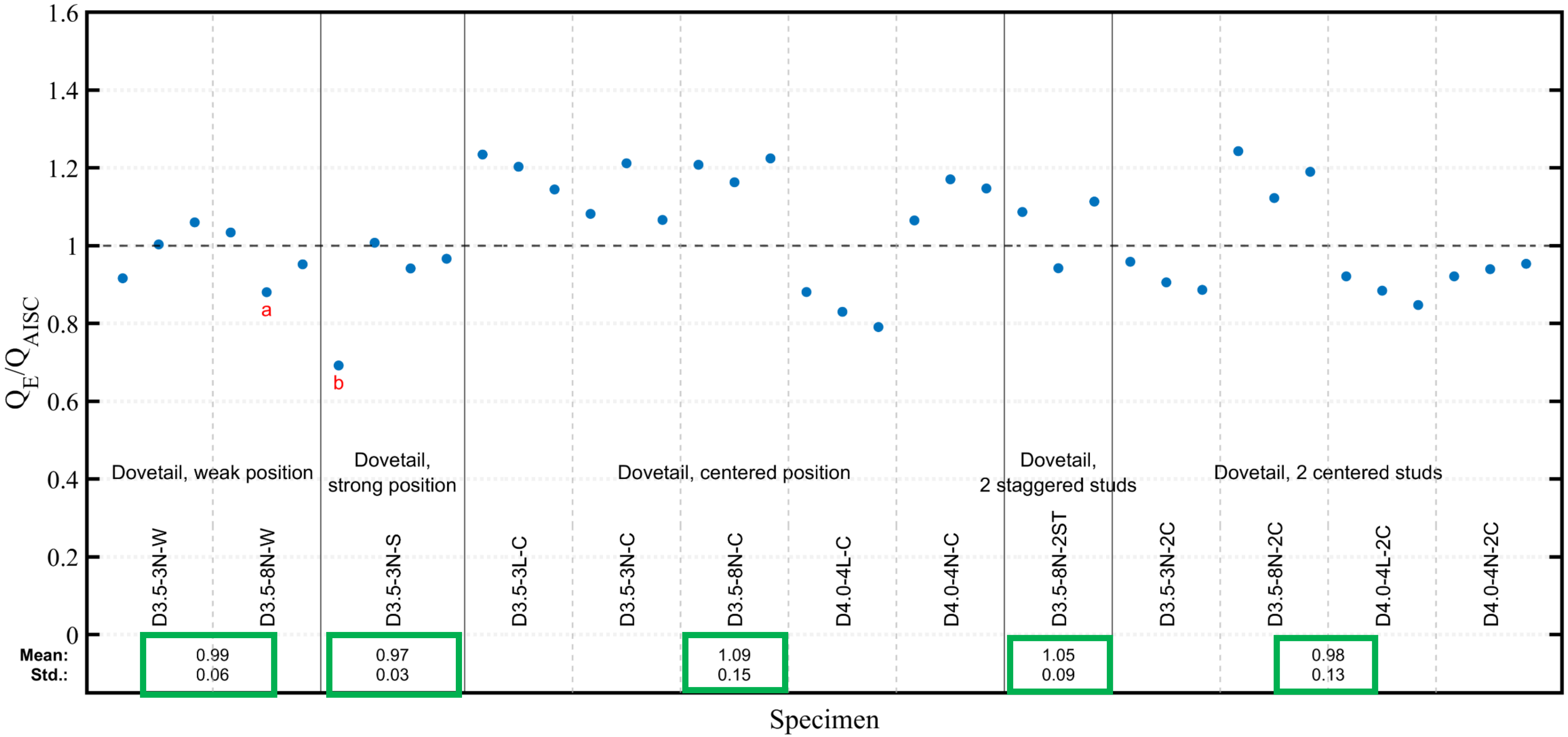
Typical Load vs. Slip Behavior

Plan View of Concrete Cone After Testing

Evidence of Concrete Cone During Test

Saw Cut After Testing

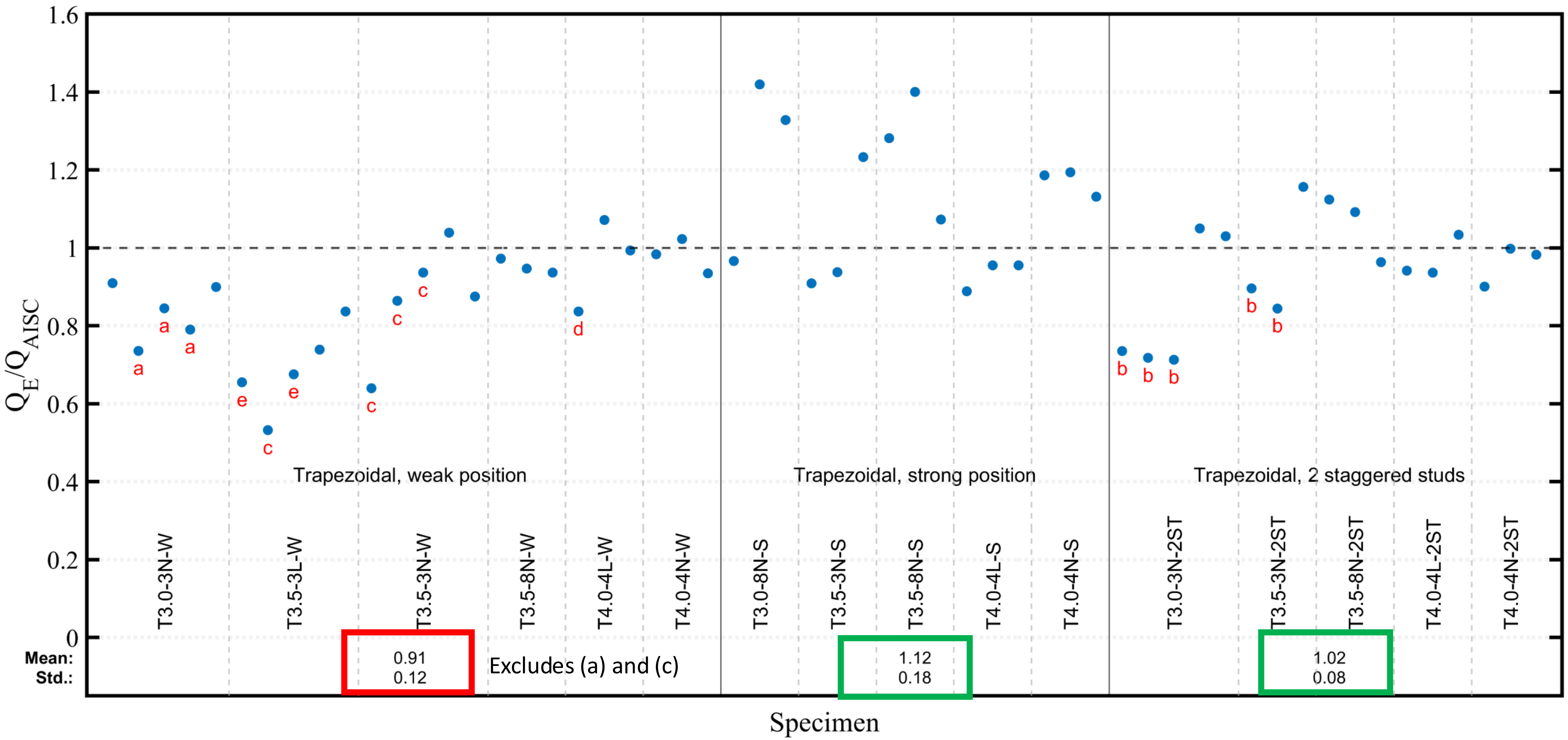
Dovetail Deck Strength Results



a Different failure modes between ribs – Deck Bulging and Deck Punching
b Non-uniform bearing likely using neoprene pad instead of grout under bearing surfaces
c Failure at seam between two over lapping deck
d Unequal slip measurement between LVDTs at peak
e Tested to predicted strength ratio below 0.75, but nothing unusual observed in those tests

- Accuracy of AISC prediction not correlated with concrete strength or LW
- Little data previously on studs with dovetail
- In general, good match with AISC Equation

Trapezoidal Deck Strength Results



a Different failure modes between ribs – Deck Bulging and Deck Punching

b Non-uniform bearing likely using neoprene pad instead of grout under bearing surfaces

c Failure at seam between two over lapping deck

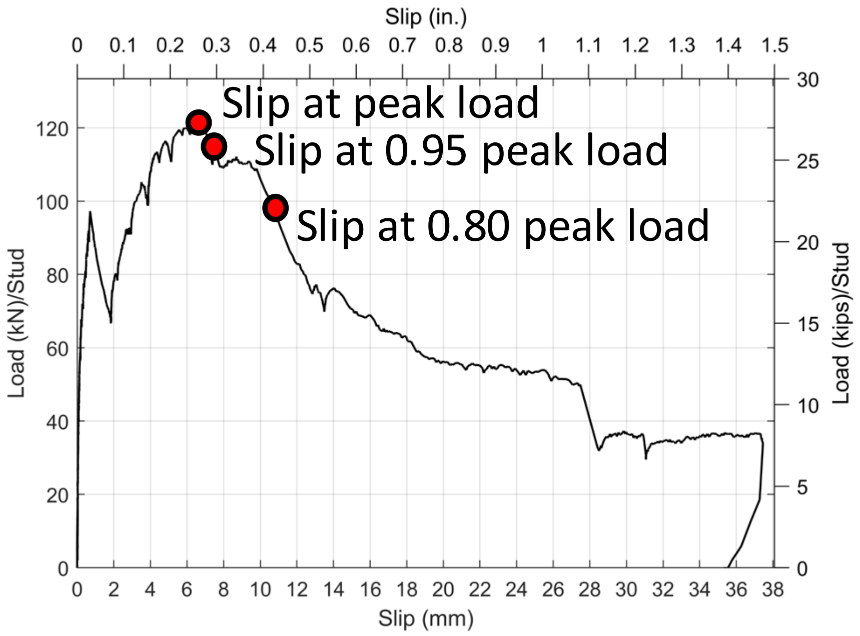
d Unequal slip measurement between LVDTs at peak

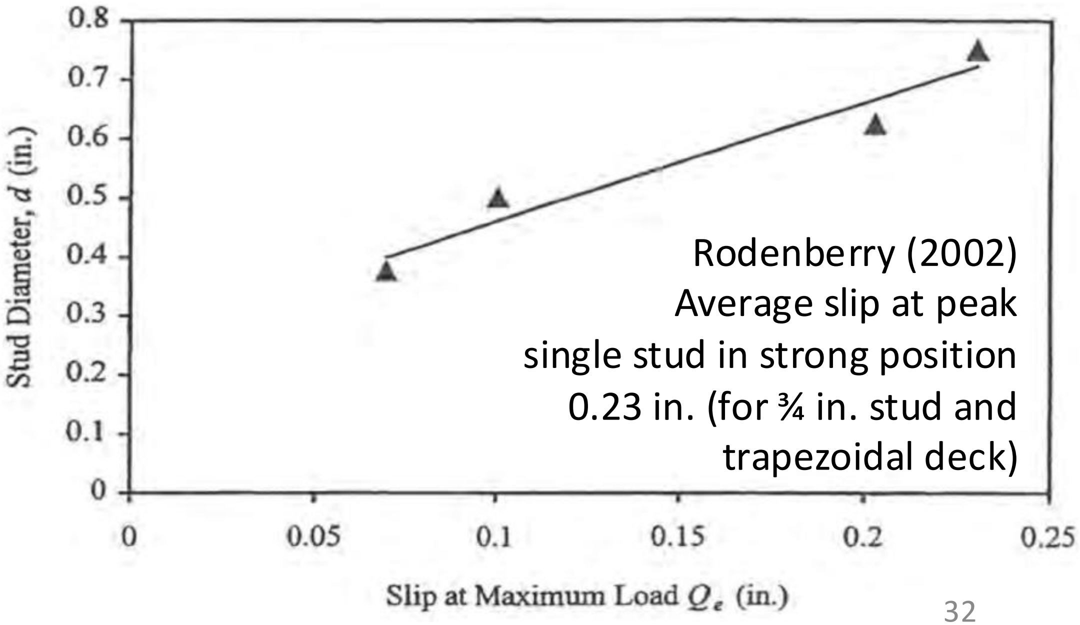
e Tested to predicted strength ratio below 0.75, but nothing unusual observed in those tests

- Some weak position specimens were faulty / repeated
- Weak position studs – better match with Roddenberry et al. (2002) test/pred.=1.12
- In general, good match with AISC Equation

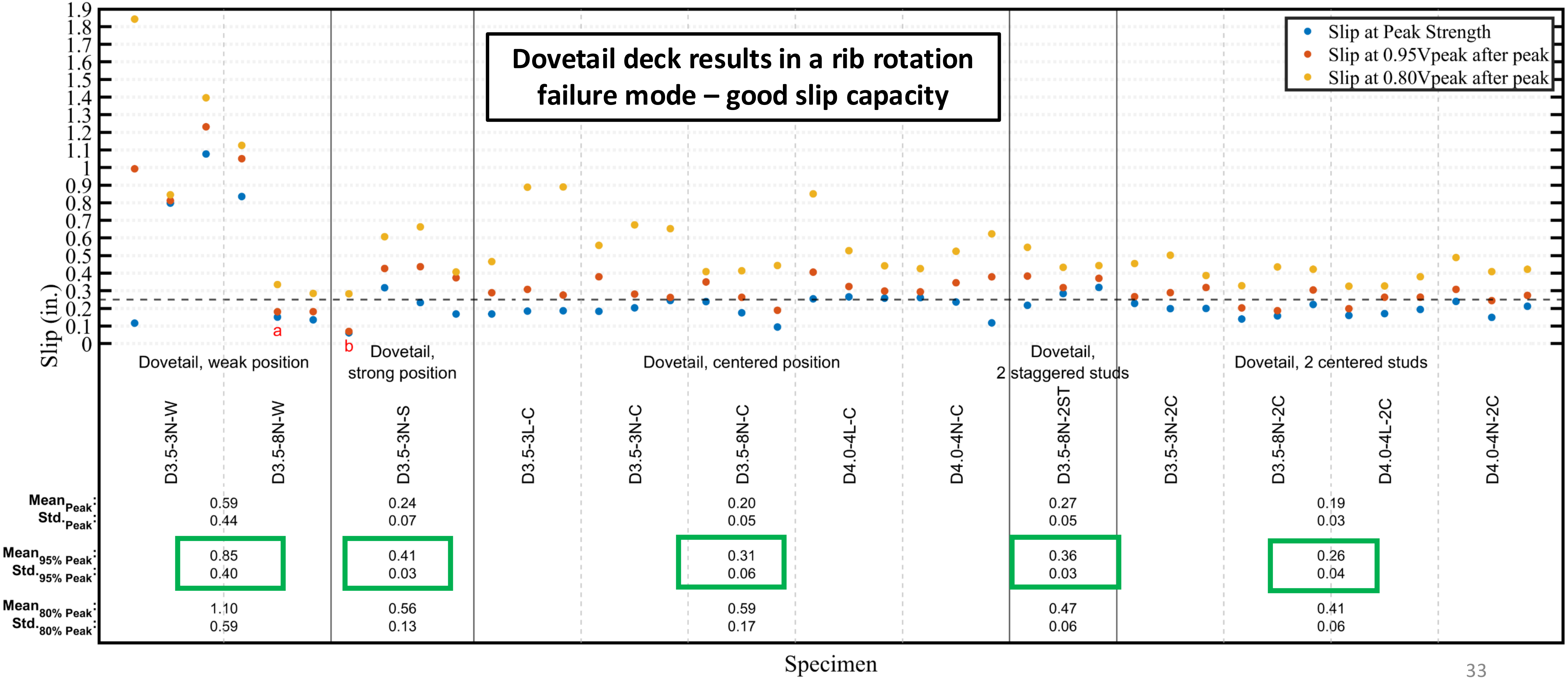
Slip Capacity – Expectations

- Slip capacity important – allows load sharing between studs
- AISC 360 Section I8.4 Performance based criteria is 0.25 in. when load drops to 95% of peak load
- Rodenberry (2002) slip capacity for ¾” studs in strong position = 0.23 in.





Dovetail Deck Slip Results



Trapezoidal Deck Slip Results

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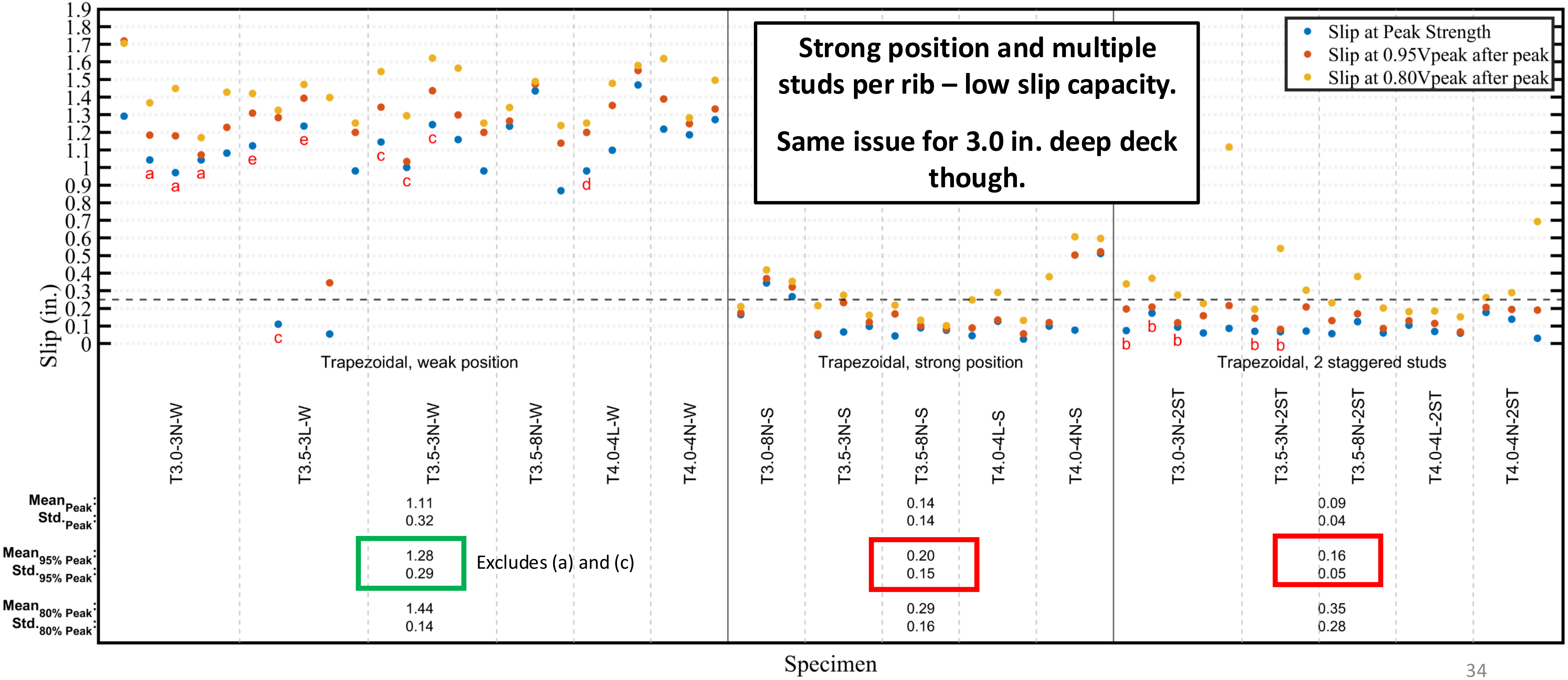
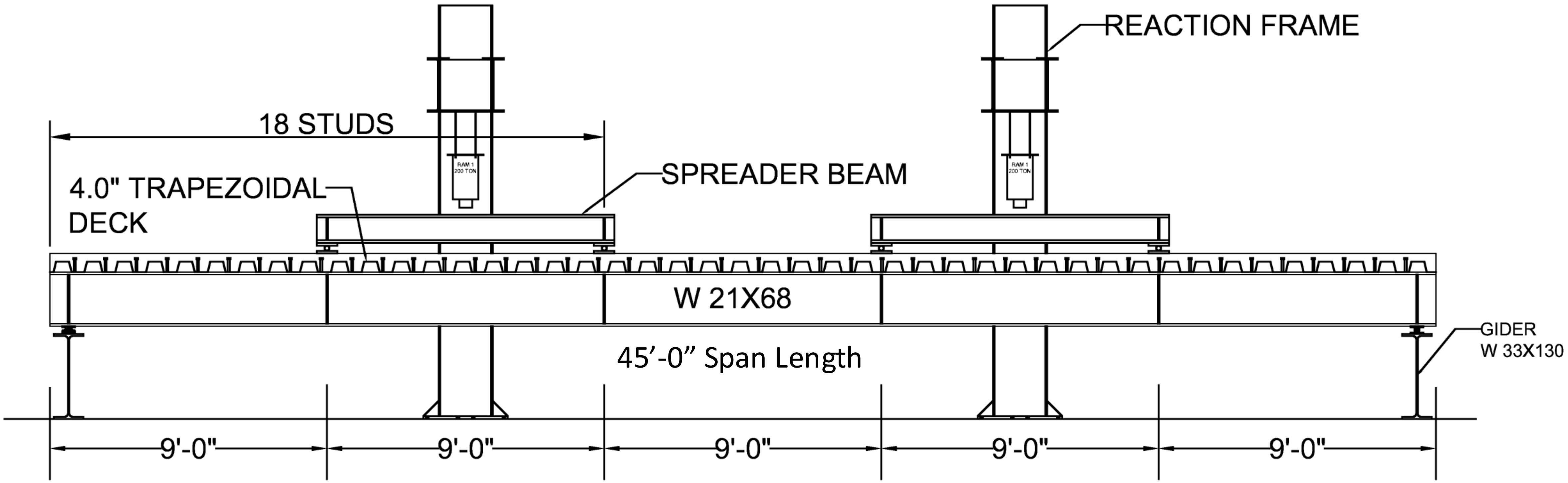


Composite Beam Tests for 4.0 in. Deck

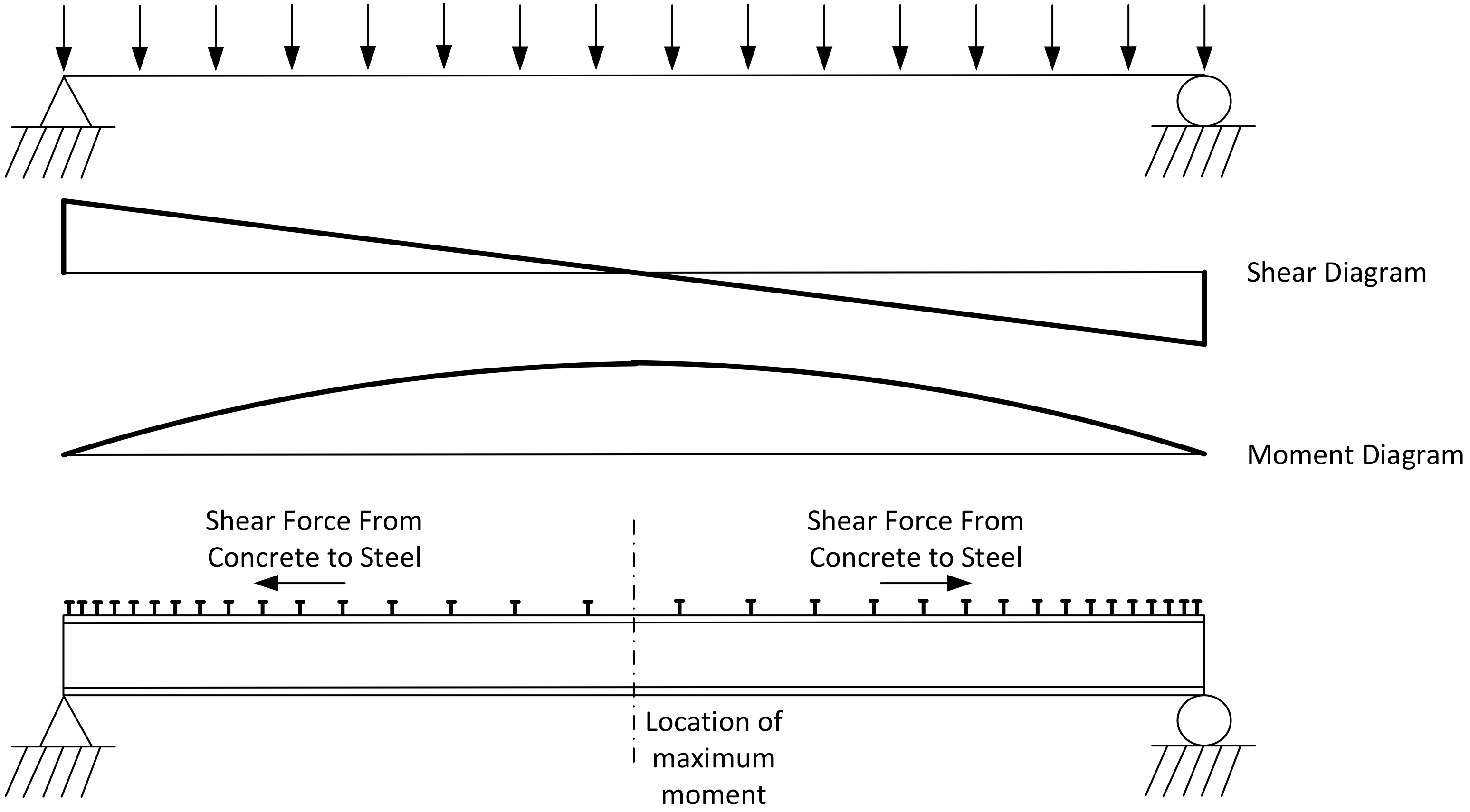


Test Matrix

Specimen Name	Deck Profile	Deck Depth	Slab Width
T4.0-4L-S-18	Trapezoidal	4.0 in.	7'-0"
D4.0-4L-C-20	Dovetail	4.0 in.	7'-0"

Shear studs in strong position
6 ksi LW concrete

Ideal Stud Distribution - Match Shear Diagram



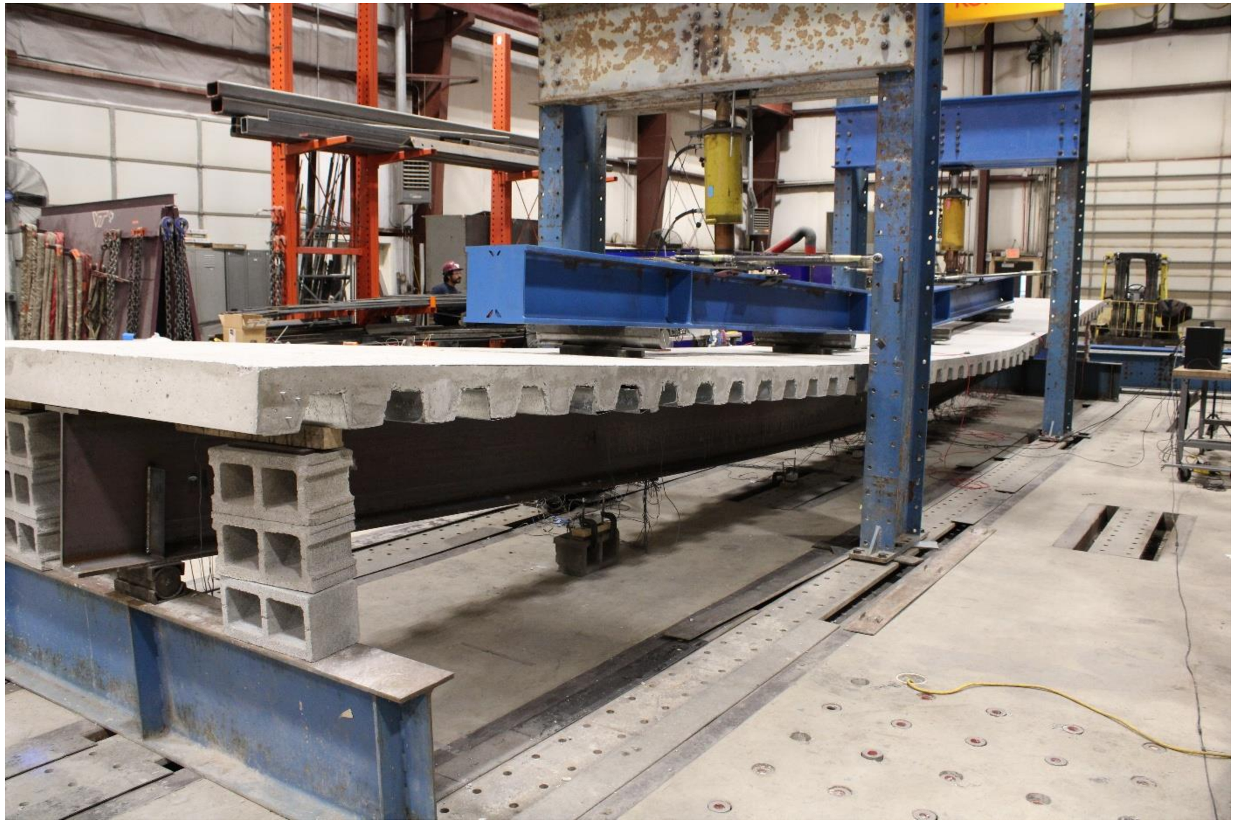
Stud Shear Force Demand if No Ductility:

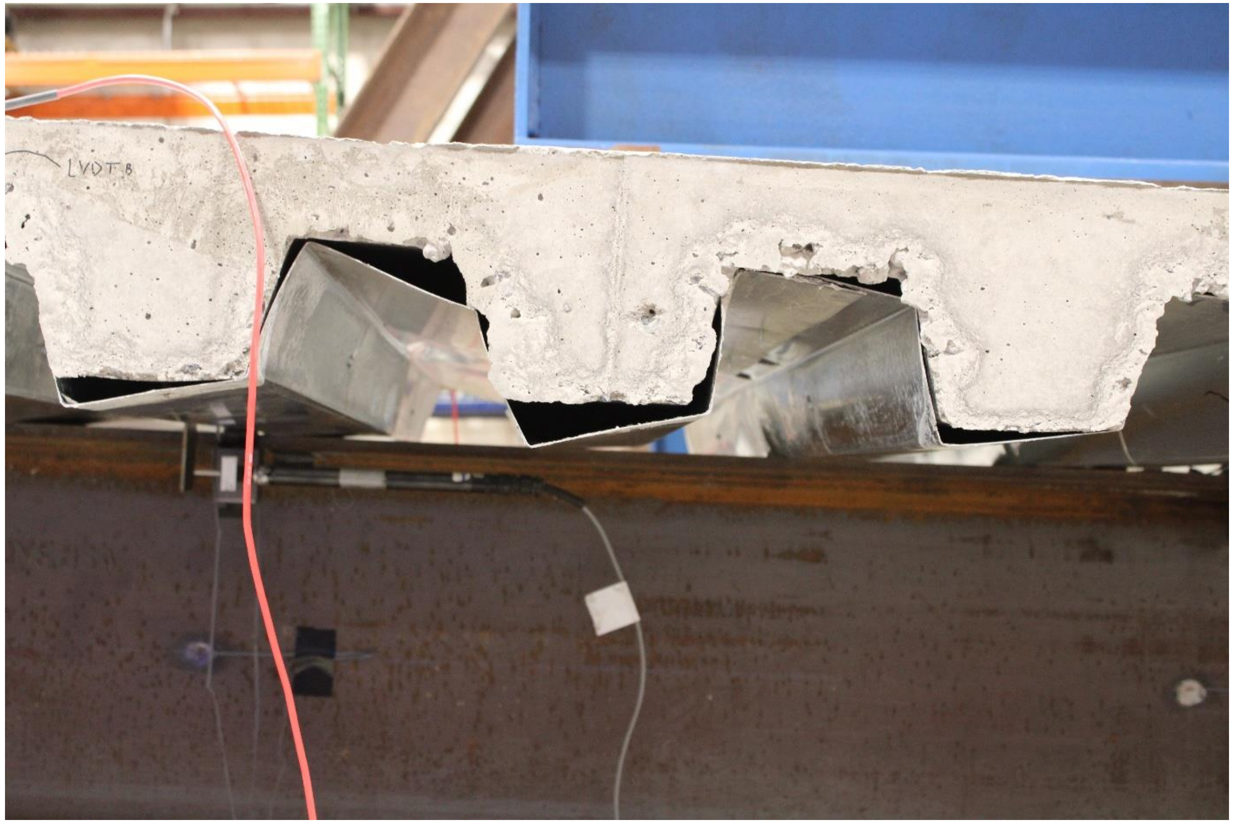
$$\frac{Q_n}{s} = \frac{V_x Q_{conc}}{I}$$

Q_n = Shear strength of one shear stud
s = shear stud spacing
V_x = beam shear
Q_{conc} = moment of the transformed concrete area about the composite NA
I = moment of inertia of composite section

- If studs have sufficient ductility (slip capacity), can distribute shear studs uniformly. Load spreads evenly among all studs.
- If insufficient ductility, uniformly distributed studs can fail progressively (unzip)

Preliminary Result From First Specimen





Organization

VIRGINIA TECH

1. Introduction to Composite Beams
2. Geometric Limits on Composite Beams and Motivation
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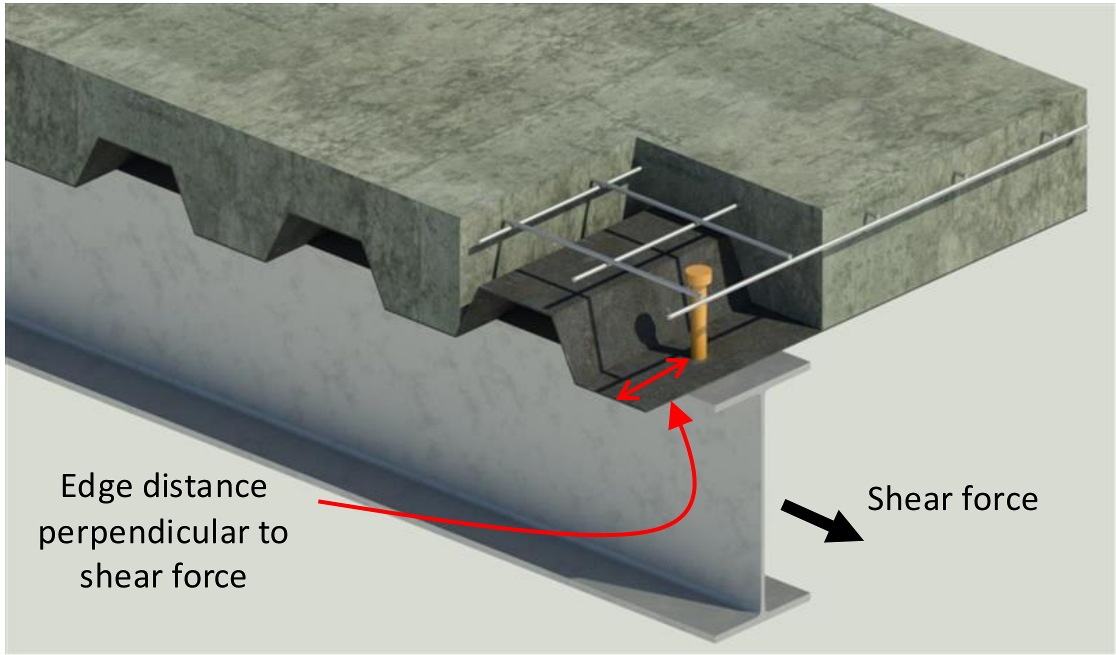
4. Investigating Effect of Edge Distance on Shear Studs
5. Summary, Conclusions and Recommendations

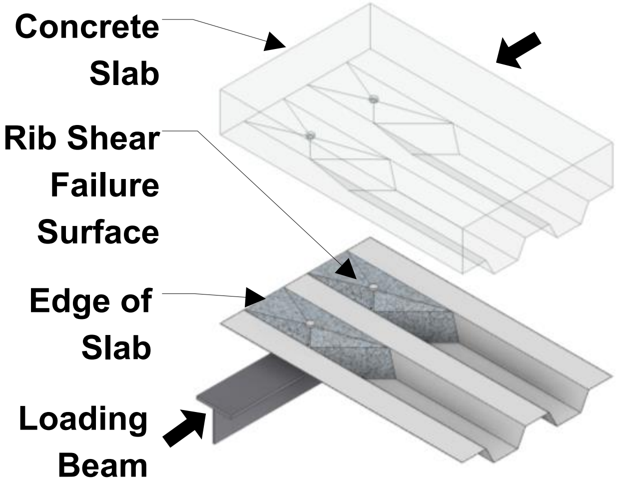
Effect of Edge distance for Shear Studs



AISC 360-22 Section **I8.2d(b)**:

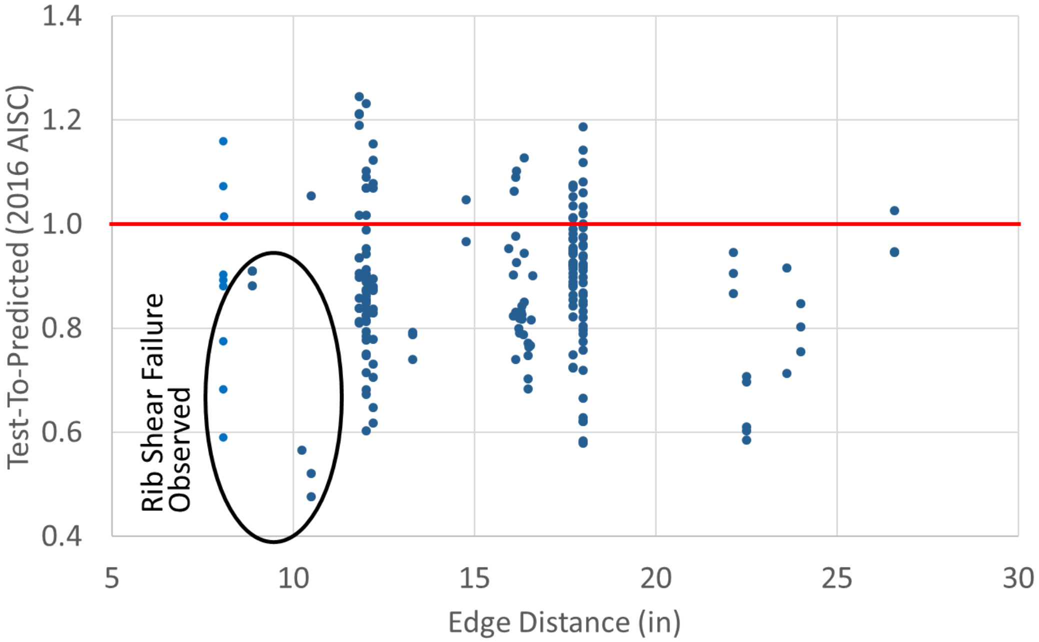
(b) Steel anchors shall have at least 1 in. (25 mm) of lateral concrete cover in the direction perpendicular to the shear force, except for anchors installed in the ribs of formed steel decks.

- **No minimum edge distance** given for steel anchors installed in the ribs of formed steel decks.
- **No guidance** provided in the commentary

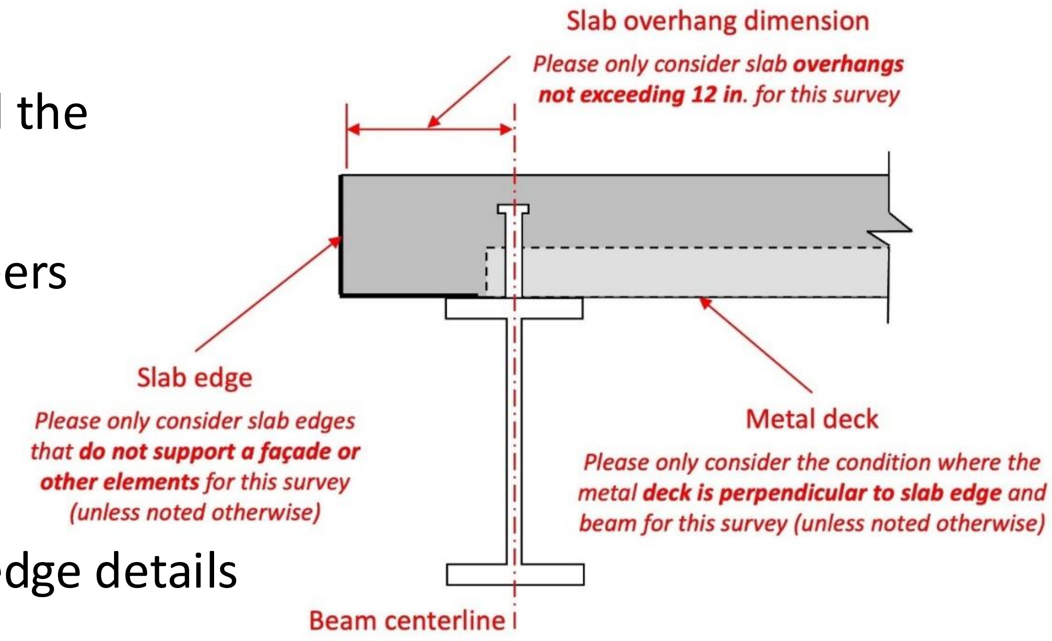


Rib Shear Failure Mode

reduced strength compared to typical push-out test



Industry Survey on Edge Details



Overview

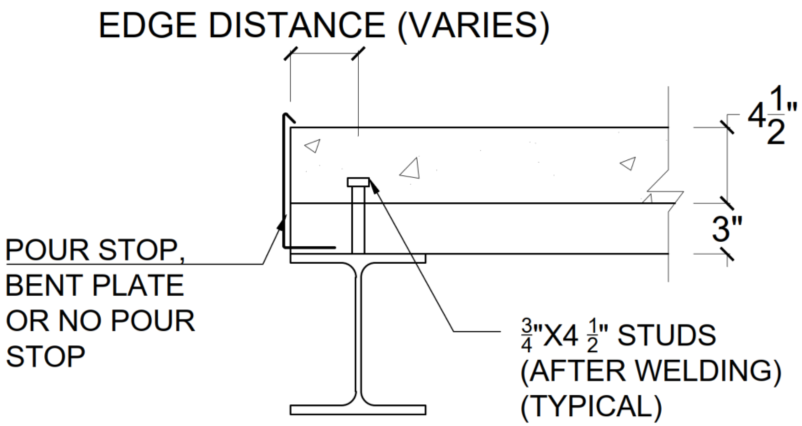
- Questions based on feedback from design engineers and the AISC Task Committee 5.
- Understand common practices used by structural engineers
- 34 respondents from United States

Key results

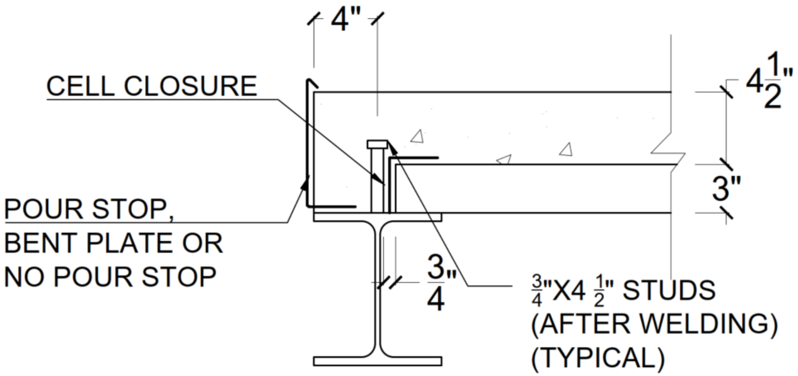
1. The survey showed large scatter in answers for typical edge details
2. Slab overhang < 6 in. is common
3. Half the respondents terminate the deck before the beam centerline
4. Light gauge pour stops for short overhangs with no edge loads; <6 in. Otherwise bent plates.
5. Half the respondents use additional reinforcement perpendicular to the slab edge, and many add reinforcement parallel to slab edge.

Al-Masarani, O., Kreitman, K., Eatherton, M.R., and Easterling, W.S. (2024) Survey Related To Edge Details in Concrete-filled Steel Deck Slabs, Virginia Tech Structural Engineering and Materials Report No. CE/VPI-ST-24/01

Testing Program for Edge Effects



Detail 1 – Deck extended to slab edge



Detail 2 – Deck stop just before the stud

Objectives:

Minimum edge distance for no reduction in strength for:

- Detail 1 – Pour stop, bent plate, or no formwork
- Detail 2 – Pour stop, bent plate, or no formwork

Limitations:

- Only single studs per rib were considered
- Does not consider effects of: multiple studs per rib, concrete strength, concrete type, stud diameter, and different types of deck

Test Program Description:

1. 41 Specimens
2. Conventional pushout test setup
3. 20 gage pour stop or 3/16” bent plate
4. Varied distances from center of stud to slab edge
5. Lightweight concrete with f'_c=4000 psi nominal
6. Studs installed in strong position, one stud per rib.

Test Matrix for Edge Effects

Edge Detail	Slab Closure	Edge Distance (in.)	Group	Number of Specimens
Detail 1	None	1 3/8	T3-4L-D1-1NPS	2
Detail 1	None	4	T3-4L-D1-4NPS	4
Detail 1	None	6	T3-4L-D1-6NPS	2
Detail 1	None	8	T3-4L-D1-8NPS	2
Detail 1	None	10	T3-4L-D1-10NPS	2
Detail 1	None	12	T3-4L-D1-12NPS	2
Detail 1	None	18	T3-4L-D1-18NPS	2
Detail 1	20 ga. PS	1	T3-4L-D1-1PS	2
Detail 1	20 ga. PS	2	T3-4L-D1-2PS	2
Detail 1	20 ga. PS	3	T3-4L-D1-3PS	2
Detail 1	20 ga. PS	4	T3-4L-D1-4PS	3
Detail 1	3/16 in. BP	4	T3-4L-D1-4BP	4
Detail 2	20 ga. PS	4	T3-4L-D2-4PS*	4
Detail 2	3/16 in. BP	4	T3-4L-D2-4BP*	4
Detail 2	None	4	T3-4L-D2-4NPS*	4

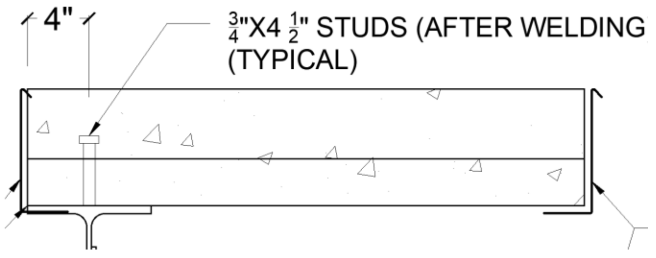
Material Properties:

- Nominal f'_c = 4000 psi
- Light Weight Concrete
- All studs welded in strong position

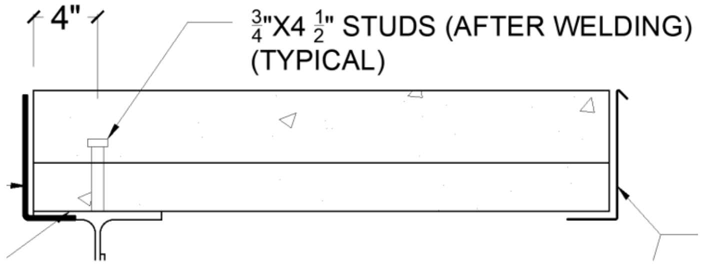
Key for Abbreviations and Notes:

- PS: 20 ga. Pour Stop
- BP: 3/16 in. Bent Plate
- None: Bare slab edge (no pour stop)
- *Two tests **with** deck puddle welded to the flange and two **without** puddle welding

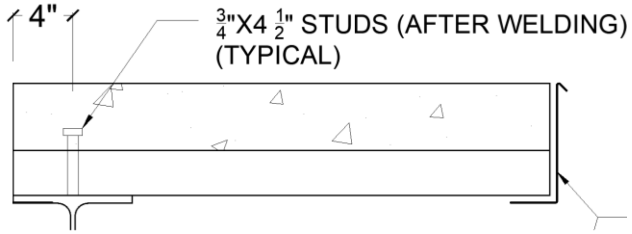
Edge Configurations Tested



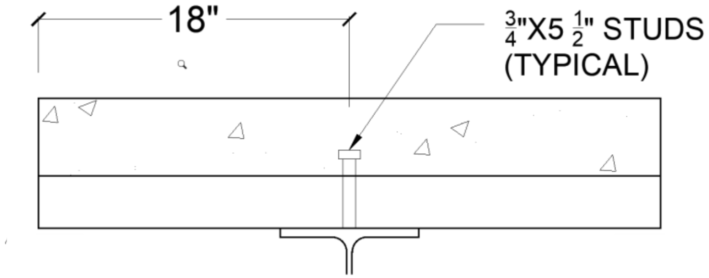
Detail 1 – 20 ga. pour stop with 4” edge distance



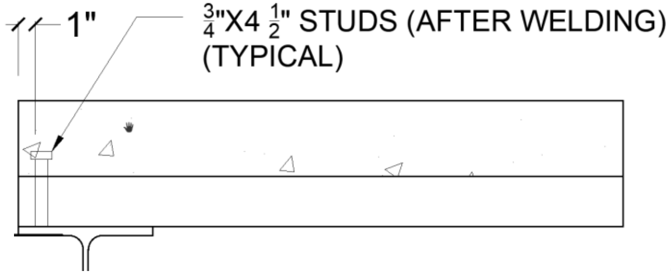
Detail 1 – 3/16” bent plate with 4” edge distance



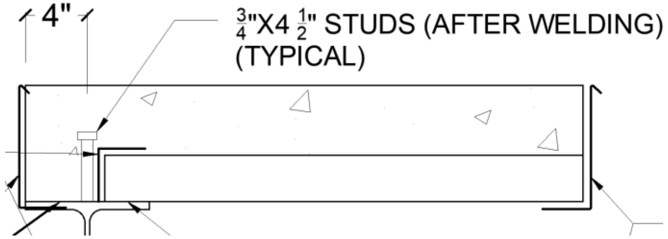
Detail 1 – no pour stop with 4” edge distance



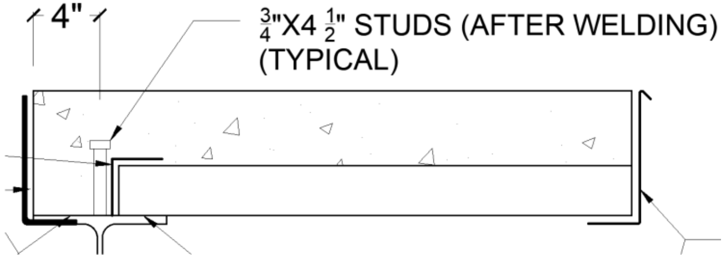
Detail 1 – no pour stop with 18” edge distance



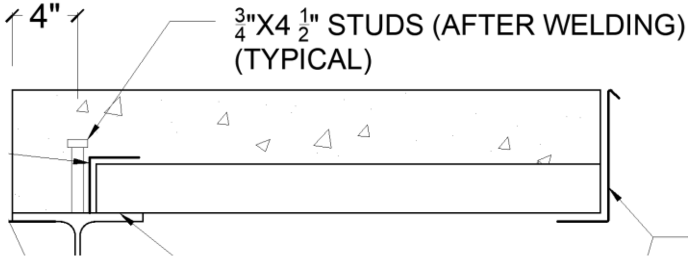
Detail 1 – 20 ga. no pour stop with 1” edge distance



Detail 2 – 20 ga. pour stop with 4” edge distance

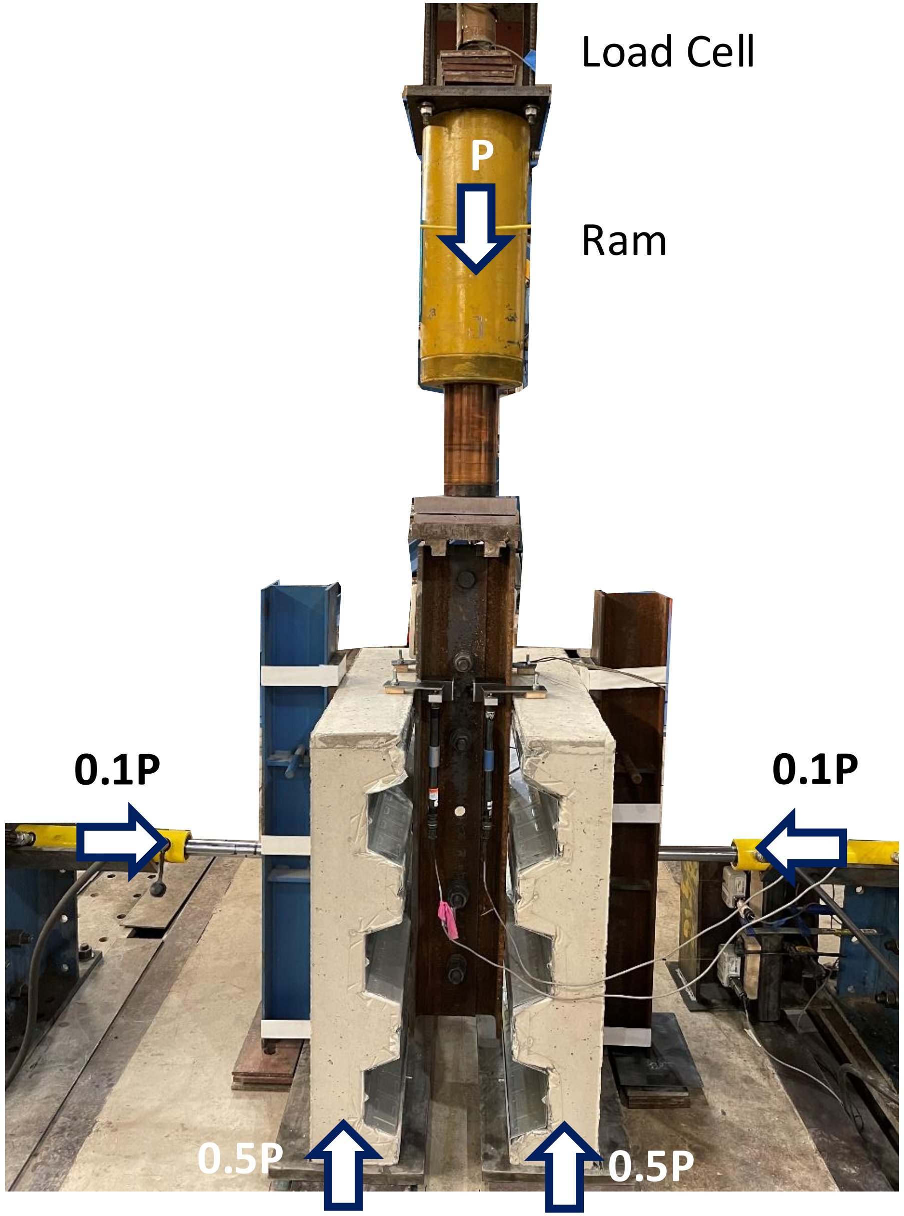


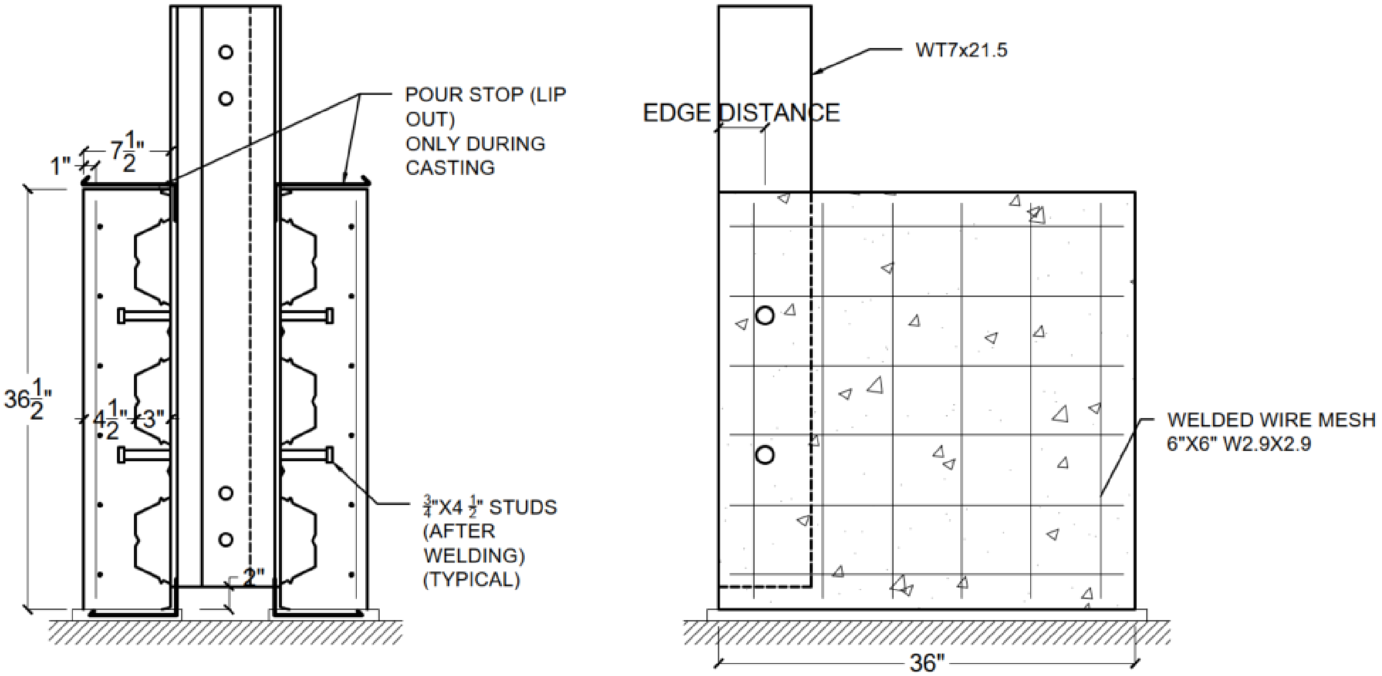
Detail 2 – 3/16” bent plate with 4” edge distance



Detail 2 – no pour stop with 4” edge distance

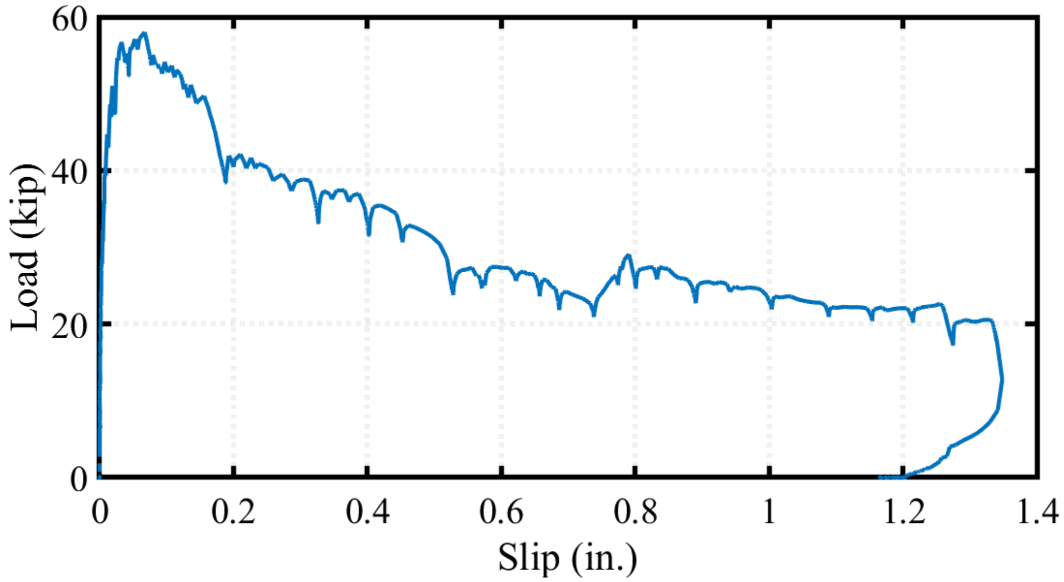
Pushout Test Setup





Typical Specimen

Example: Detail 1 With 1-3/8" Edge Distance No Formwork



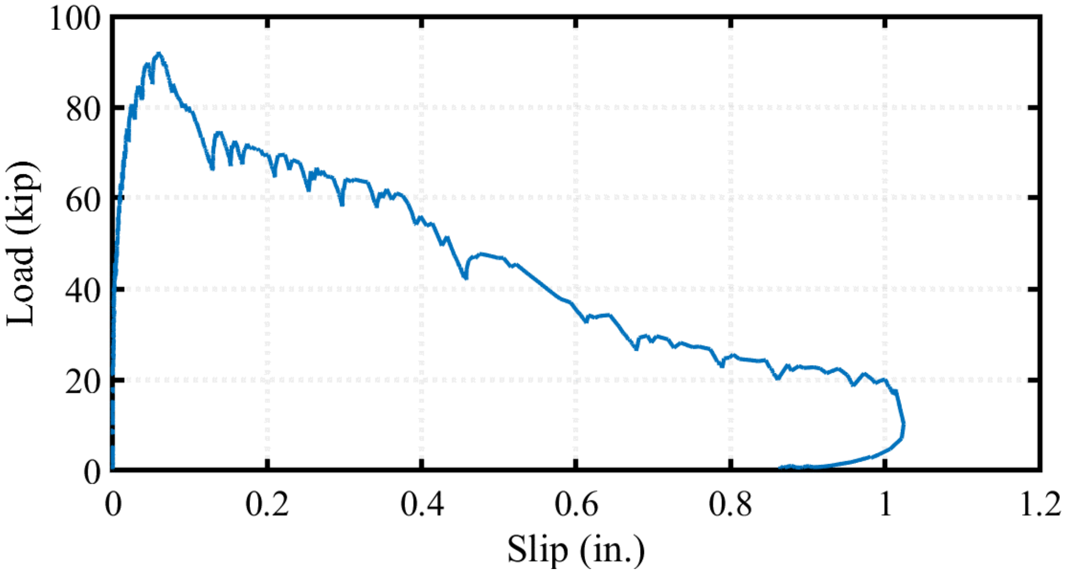
- Detail 1 – No formwork
- **1 3/8 in. edge distance**
- Strong position stud

$$\frac{\text{Tested Stud Strength}}{\text{Predicted Stud Strength as per AISC 360}} = \mathbf{0.65}$$

Rib Shear Failure

Edge distance = 1-3/8"
No stay in place formwork
→ NO GOOD

Example: Detail 1 With 8" Edge Distance
No Formwork



Rib Shear/Concrete Cone

Rib Shear

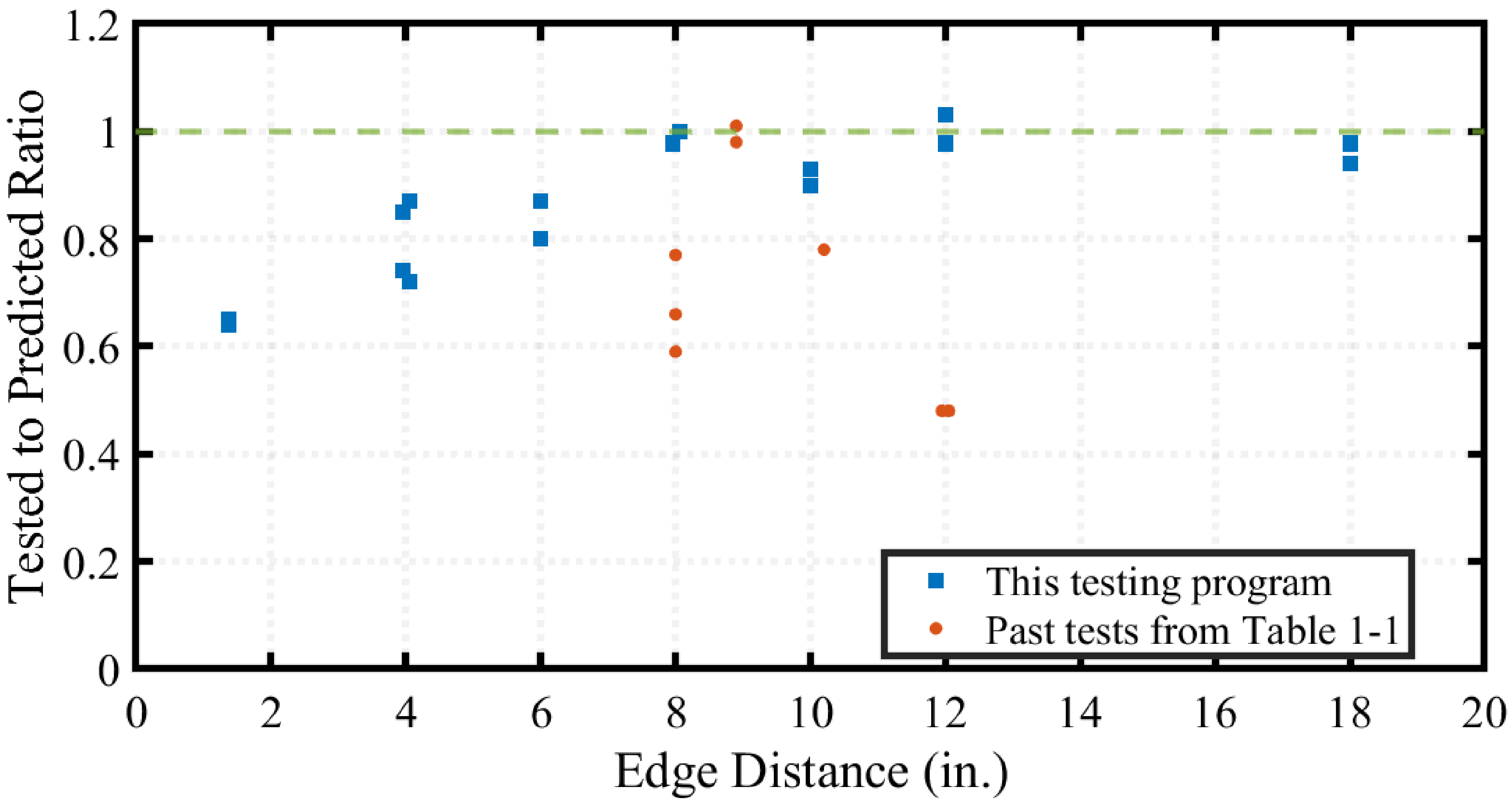
- Detail 1 – No formwork
- **8 in. edge distance**
- Strong position stud

$$\frac{\text{Tested Stud Strength}}{\text{Predicted Stud Strength as per AISC 360}} = \mathbf{1.0}$$

Increase edge distance to 8"
→ Strength is OK

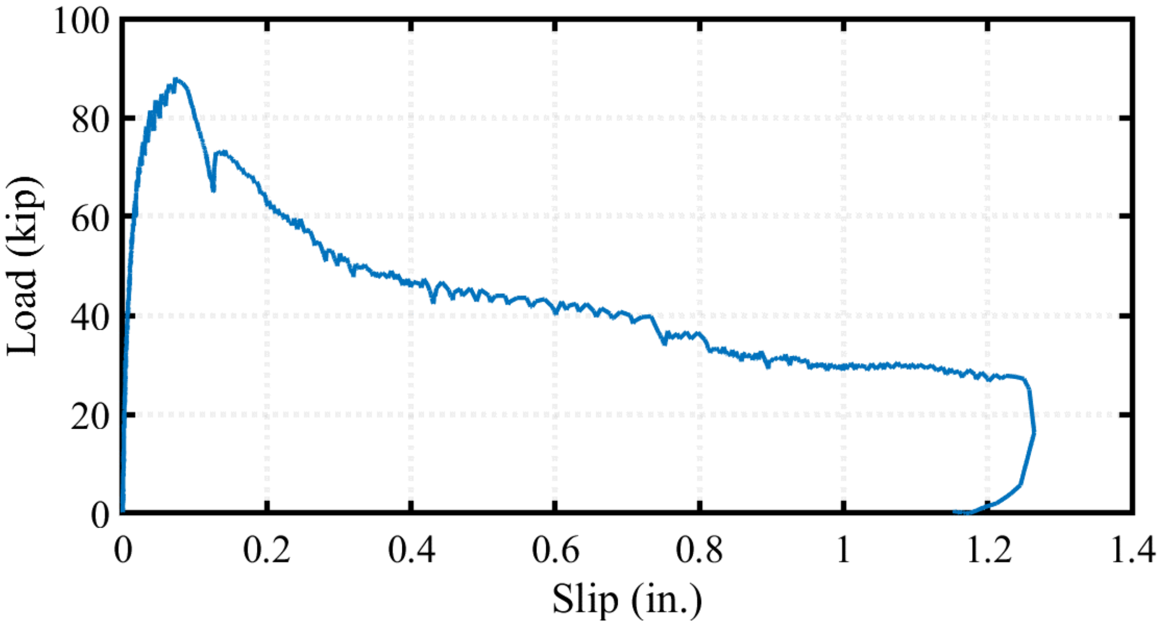
Results for Detail 1 - No Stay in Place Formwork

Edge Distance vs. Tested to Predicted Ratio for Studs with Bare Slab Edge



- Rib shear was observed in some cases for edge distance up to 18”
- For edge distance not less than 8”, test to predicted ratio close to 1.0

Example: Detail 1 with 1” Edge Distance Including 20 ga. Pour Stop



Stud with 1 in. edge distance – Before concrete casting

Localized damage around the stud

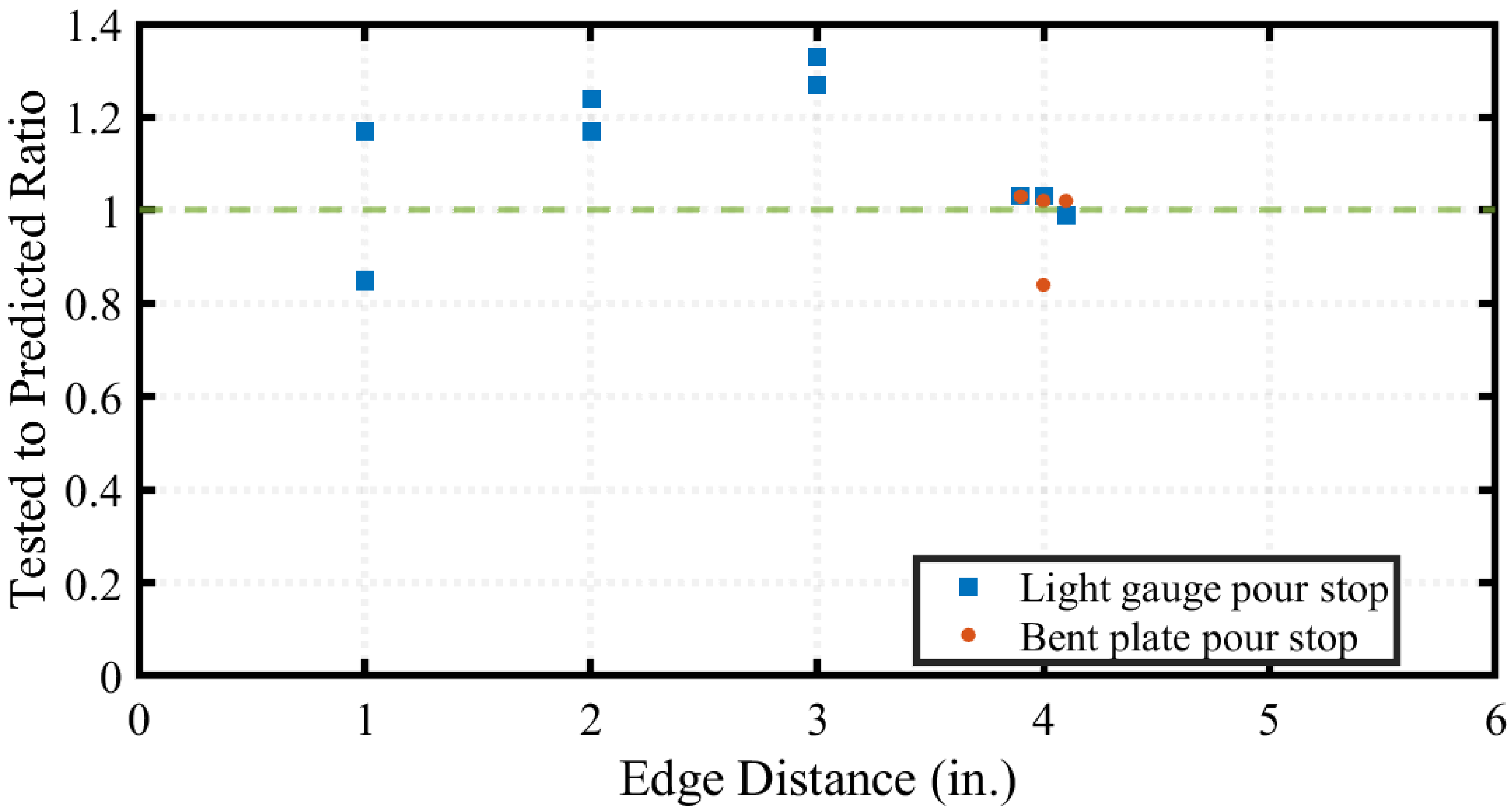
- **Detail 1 - 20 ga. Pour stop**
- **1 in. edge distance**
- Strong position stud

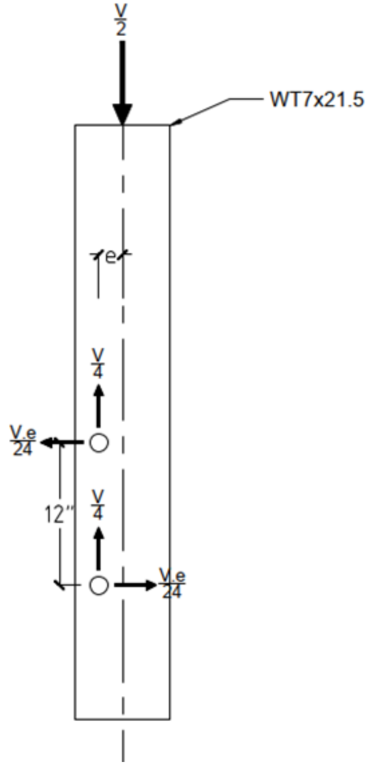
$$\frac{\text{Tested Stud Strength}}{\text{Predicted Stud Strength as per AISC 360}} = \mathbf{1.17}$$

1” edge distance, but add pour stop
→ Strength is OK

Results for Detail 1 - With Stay in Place Formwork

Edge Distance vs. Tested to Predicted Ratio for Studs with Pour Stop





- Stud eccentric compared to steel
- Complex stress states around studs
- May explain values > 1.0

- In presence of pour stop or bent plate, shear stud strength reasonably close to prediction

Overall Results for Detail 1

Slab Closure	Edge Distance (in.)	Specimen		Q_{AISC} (kip)	Q_E(kip)	Q_E/Q_{AISC}	Avg. Q_E/Q_{AISC}	Slip at peak (in.)	Failure Mode
None	1 3/8	T3-4L-D1-1NPS	a	22.2	14.3	0.64	0.65	0.04	RS
			b	22.2	14.5	0.65		0.07	RS
None	4	T3-4L-D1-4NPS	a	21.2	18.4	0.87	0.79	0.04	RS
			b	21.2	15.2	0.72		0.03	RS
			c	23.1	19.5	0.85		0.03	RS
			d	23.1	17.1	0.74		0.03	RS
None	6	T3-4L-D1-6NPS	a	23.1	18.5	0.80	0.84	0.03	RS/CC
			b	23.1	20.1	0.87		0.03	RS
None	8	T3-4L-D1-8NPS	a	23.1	23.0	1.00	0.99	0.06	RS/CC
			b	23.5	23.1	0.98		0.07	RS/CC
None	10	T3-4L-D1-10NPS	a	23.5	21.8	0.93	0.92	0.09	RS/CC
			b	23.5	21.2	0.90		0.10	RS/CC
None	12	T3-4L-D1-12NPS	a	23.5	23.0	0.98	1.00	0.10	RS/CC
			b	23.7	24.4	1.03		0.09	RS/CC
None	18	T3-4L-D1-18NPS	a	21.6	20.2	0.94	0.96	0.03	RS/CC
			b	21.6	21.2	0.98		0.05	CC
20 ga. PS	1	T3-4L-D1-1PS	a	18.9	16.1	0.85	1.01	0.04	RS
			b	18.9	22.0	1.17		0.07	RS
20 ga. PS	2	T3-4L-D1-2PS	a	18.9	22.0	1.17	1.20	0.04	RS
			b	18.9	23.40	1.24		0.06	RS
20 ga. PS	3	T3-4L-D1-3PS	a	18.9	25.1	1.33	1.30	0.04	RS
			b	18.9	24.0	1.27		0.06	RS
20 ga. PS	4	T3-4L-D1-4PS	a	20.7	21.3	1.03	1.02	0.06	RS
			b	21.2	21.1	0.99		0.02	RS
			c	21.2	21.9	1.03		0.02	RS
3/16 in. BP	4	T3-4L-D1-4BP	a	22.6	19.0	0.84	1.03	0.08	RS
			b	22.6	23.1	1.02		0.03	RS
			c	23.7	24.3	1.02		0.03	RS
			b	23.7	24.5	1.03		0.04	RS

Note:

- Q_{AISC}: AISC predicted load per stud
- QE: Experimental load per stud
- f'_c, w, E_c, A_s, F_u, R_g, R_p are defined in AISC 360 Section I8
- RS: Rib Shear
- CC: Concrete Cone

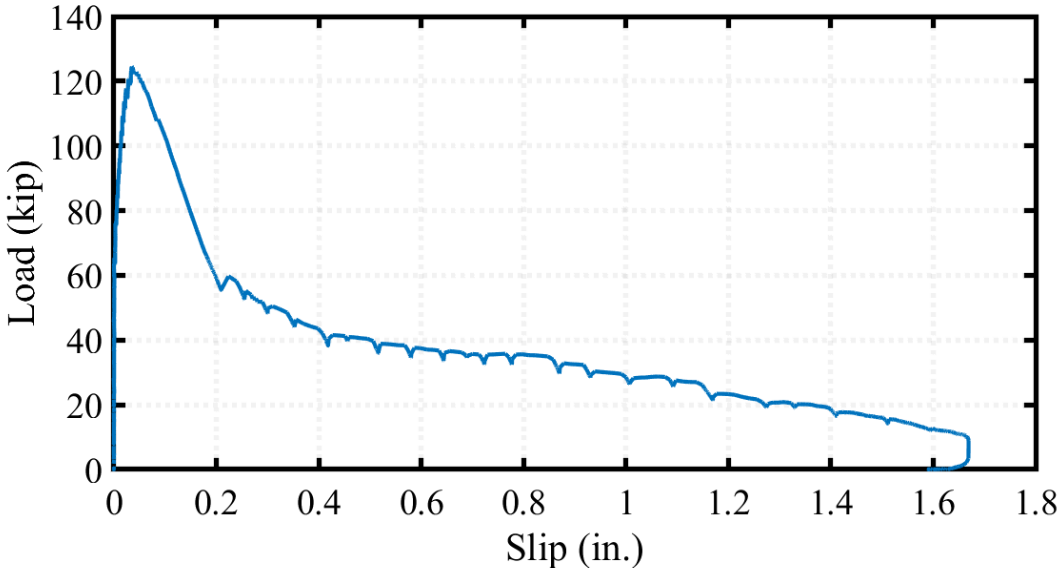
Constant:

- F_u = 76.2 ksi from mill cert
- ¾” headed shear stud x 4.5” after welding, A_s=0.44 in2
- 3” composite deck
- One stud in strong position, R_p=0.75, R_g=1.0
- Predicted shear stud strength controlled by concrete term

Conclusions:

- No formwork: 8 in. is minimum to achieve predicted strength
- With pour stop or bent plate: 1 in. is minimum to achieve predicted strength
- Low slip capacity

Example: Detail 2 with 4” edge distance, no formwork



- Detail 2 - No formwork
- 4 in. edge distance
- Puddle weld deck to steel, ¾ in. visible diameter at 12 in.

$$\frac{\text{Tested Stud Strength}}{\text{Predicted Stud Strength as per AISC 360}} = \mathbf{1.38}$$

Concrete Splitting

High test to prediction ratio – puddle weld is contributing

Overall Results for Detail 2

Slab Closure	Edge Distance (in.)	Puddle Weld?	Specimen		Q_{AISC} (kip)	Q_E(kip)	Q_E/Q_{AISC}	Avg. Q_E/Q_{AISC}	Slip at peak (in.)	Failure Mode
None	4	Yes	T3-4L-D2-4NPS	a	22.6	28.5	1.26	1.32	0.07	CS
				b	22.6	31.1	1.38		0.03	CS
		No		c	24.1	22.5	0.93	0.96	0.04	CS
				d	24.1	23.7	0.98		0.10	CS
20 ga. PS	4	Yes	T3-4L-D2-4PS	a	22.8	32.6	1.43	1.43	0.14	CS
				b	22.6	32.4	1.43		0.06	CS
		No		c	24.1	30.1	1.25	1.16	0.07	CS
				d	23.9	25.8	1.08		0.06	CS
3/16 BP	4	Yes	T3-4L-D2-4BP	a	22.6	34.9	1.54	1.55	0.07	CS
				b	22.6	35.3	1.56		0.05	CS
		No		c	24.1	26.1	1.08	0.94	0.06	CS
				d	23.9	19.0	0.79		0.20	CS

Note:

- Q_{AISC}: AISC predicted load per stud
- Q_E: Experimental load per stud
- CS: Concrete Splitting

Constant:

- F_u = 76.2 ksi from mill cert
- ¾” headed shear stud x 4.5” after welding, A_s=0.44 in2
- 3” composite deck
- One stud in strong position, R_p=0.75, R_g=1.0
- Predicted shear stud strength controlled by concrete term

Conclusions:

- 4” edge distance can achieve predicted strength
- For smaller edge distance with PS or BP, expect similar or better result as Detail 1
- With deck to support puddle welds, extra strength (typical in practice)

Organization

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Conclusions for Using 3.5 in. and 4.0 in. Deck with Composite Beams

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1. Approximately 100 pushout specimens with 3.5 in. and 4.0 in. deck.

2. Measured stud strength matches well with predicted strength using AISC 360 I8 for all groups except trapezoidal weak position. Average test/predicted ratio = 0.97 to 1.12 for all other groups. **<u>Prediction equation OK.</u>**

3. Tests with 3.5 in. and 4.0 in. trapezoidal deck and studs in weak position – test/predicted = 0.91 on average. Similar to results on 3.0 in. deck. Match with Roddenberry prediction is good (test/predicted = 1.12). **<u>Conclude OK.</u>**

4. Average slip capacities at 95% peak strength for trapezoidal weak position and dovetail deck are above 0.25 in. and **<u>therefore ok.</u>**

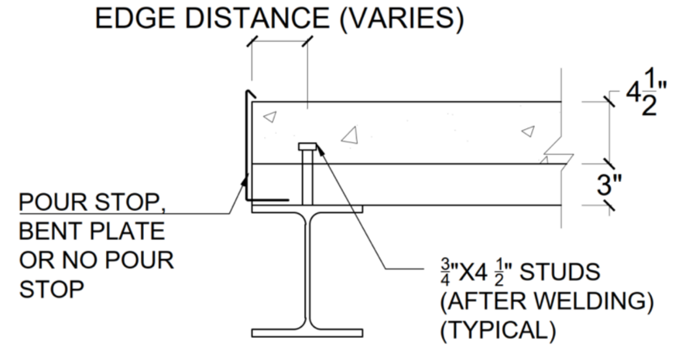
5. Average slip capacity at 95% peak strength for trapezoidal deck with strong position studs and multiple studs per rib is 0.20 in. and 0.16 in. Consistent with literature. **<u>Maybe slip capacity at 80% peak strength is better measure.</u>**

Conclusions for Edge Distances

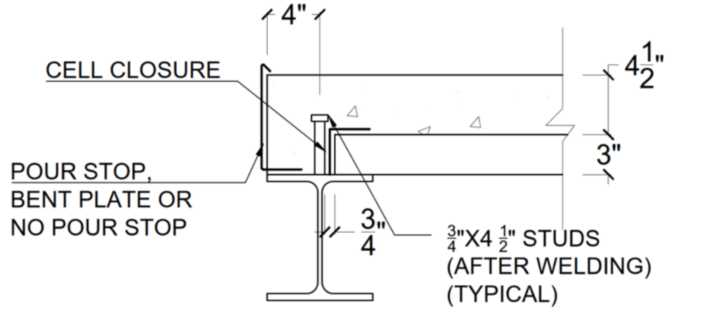
1. Recommended edge distances for single stud per rib:

	Edge condition	Min. Edge Distance (in.)
Detail 1	No stay in place formwork	8
Detail 2	No stay in place formwork	4
With stay in place pour stop or bent plate		1

Detail 1



Detail 2



2. Tests were not conducted with multiple studs per rib. Necessary edge distance for multiple studs per rib may be larger.

3. Slip capacity is small for studs near the slab edge. May need to consider stud ductility in calculating composite beam strength.

Thanks for Listening!