NATIONAL ACADEMIES *Sciences Engineering Medicine*

TRB TRANSPORTATION RESEARCH BOARD

TRB Webinar: **Incorporating Unbonded Post-Tensioning in Concrete Bridges**

November 19, 2025

1:00PM – 2:30 PM

PDH Certification Information

1.5 Professional Development Hours (PDH) – see follow-up email

You must attend the entire webinar.

Questions? Contact Andie Pitchford at TRBwebinar@nas.edu

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Program. Credit earned on completion of this program will be reported to RCEP at RCEP.net. A certificate of completion will be issued to each participant. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the RCEP.

ENGINEERING RCEP REGISTERED CONTINUING EDUCATION PROGRAM

Purpose Statement

This webinar will explore the analytical and experimental evaluation of post-tensioned concrete bridge elements, including both flexural and shear behavior, and provide design recommendations for the use of unbonded tendons.

Learning Objectives

At the end of this webinar, participants will be able to:

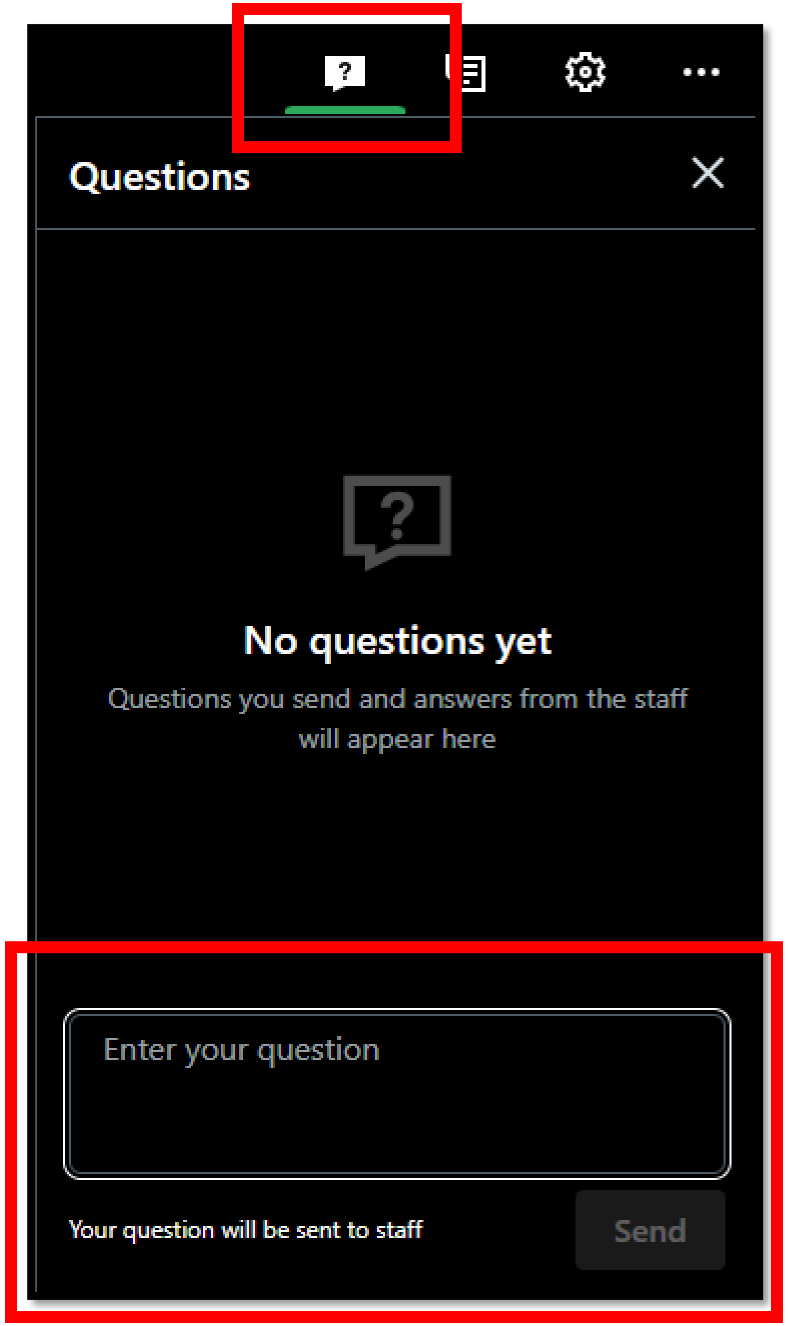
(1) Understand the behavior of structures incorporating unbonded tendons

(2) Determine the flexure and shear strength of structures incorporating unbonded tendons

(3) Implement the findings of research on members with unbonded strands into practice

Questions and Answers

- Please type your questions into your webinar control panel
- We will read your questions out loud, and answer as many as time allows



Today's presenters

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MODJESKI and MASTERS

Incorporating Unbonded Post-Tensioning in Concrete Bridges

Purdue University
University at Buffalo
Modjeski and Masters

TRB Webinar
November 19, 2025

Post-Tensioning

- Benefits
  - Efficient use of materials
  - Longer spans
  - Curved girders
  - Improved durability

- Issues
  - Problems with grouting
    - Contaminated grouts
    - Construction processes
  - Inspection
  - Replaceability

NCHRP 12-118 Objective

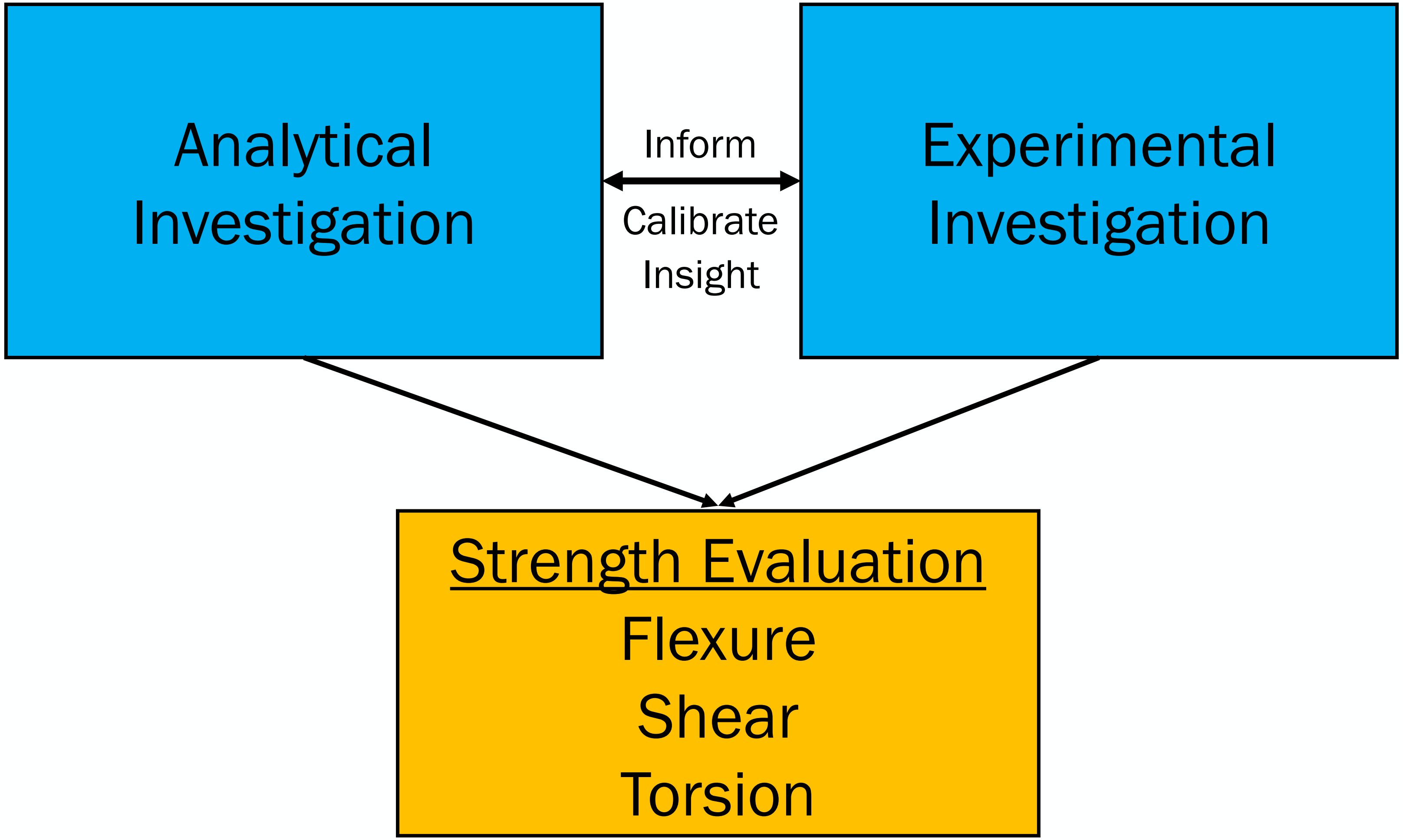
The objective of this research is to propose revisions to

1) the *AASHTO LRFD Bridge Design Specifications* design procedures for post-tensioned concrete bridge elements with unbonded tendons or a combination of bonded (pretensioned or post-tensioned) and unbonded tendons, and

2) the *AASHTO LRFD Bridge Construction Specifications* as needed.

The research shall address both internal and external tendons.

Research Program



Shear Behavior

Past Research

<u>Moore et al. (2015)</u>

- Focus: Shear strength with bonded web tendons
- Findings:
  - Web width not reduced for presence of grouted duct
  - No influence of duct material
  - AASHTO – duct diameter correction factor

<u>Skelton and Hamilton (2021)</u>

- Focus: Shear strength with unbonded web tendons
- Findings:
  - Increase in duct diameter to web width ratio decreases shear strength
  - AASHTO is adequate, conservative

<u>Han et al. (2022)</u>

- Focus: Shear strength with unbonded web tendons
- Findings:
  - Similar capacities and failure mechanisms for bonded/unbonded web tendons
  - Provided recommendations to AASHTO for shear strength of webs with unbonded tendons

Total Depth = 70”

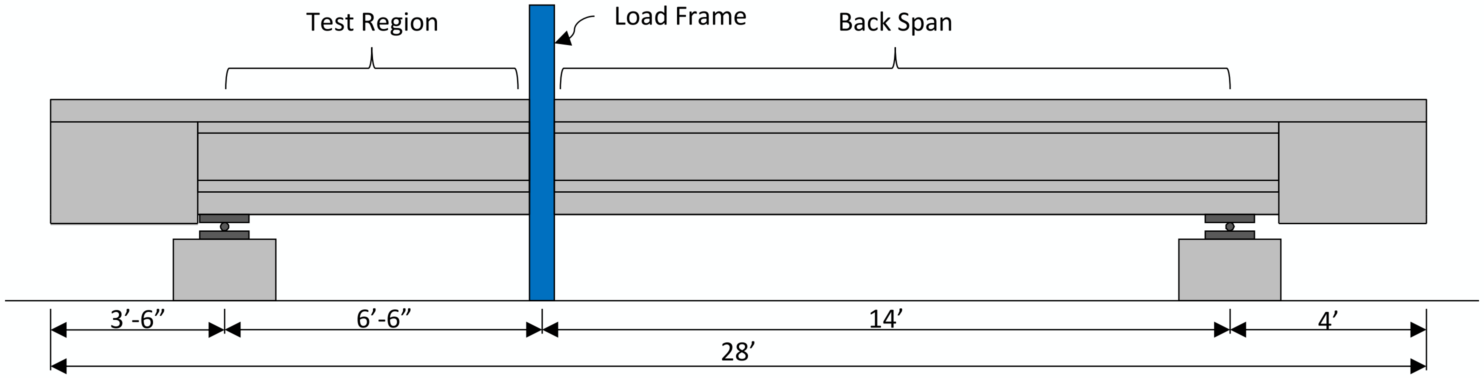
Total Depth

Total Depth = 62”

Shear Test Series

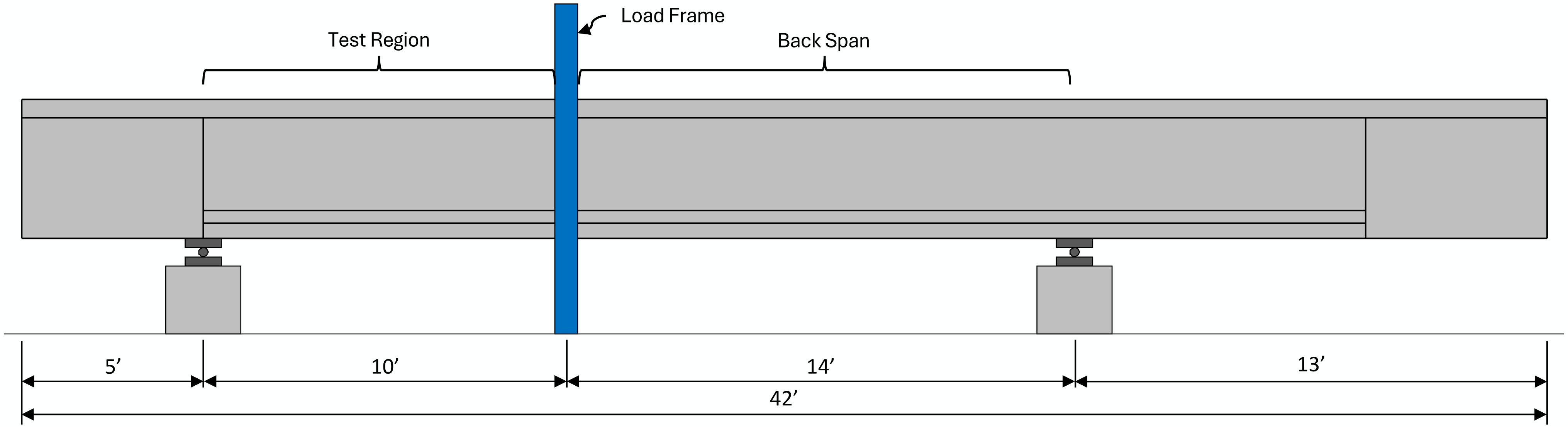
Test Series 1

a/h = 2.8

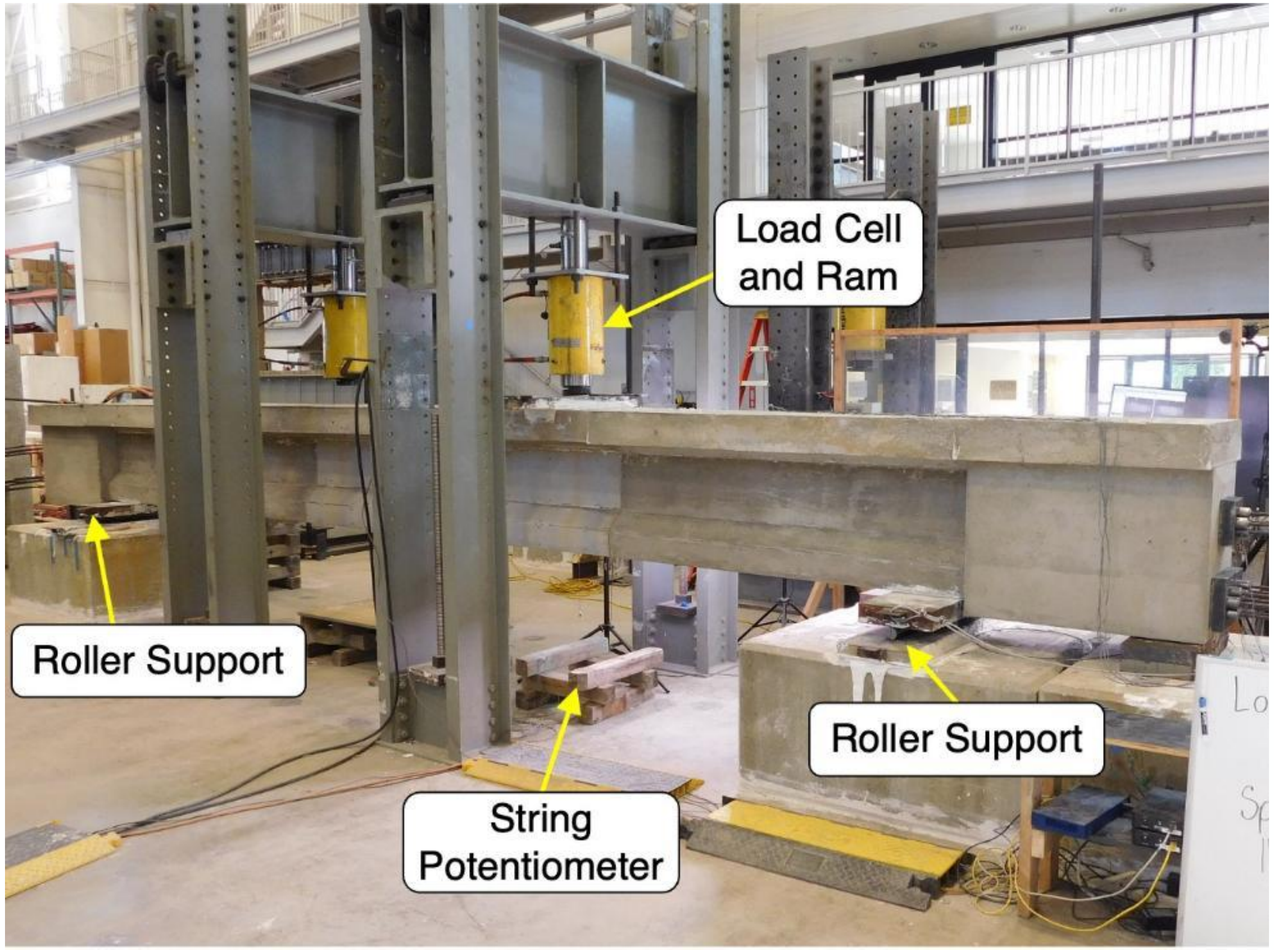


Test Series 2

a/h = 2.6



Shear Specimen Setup

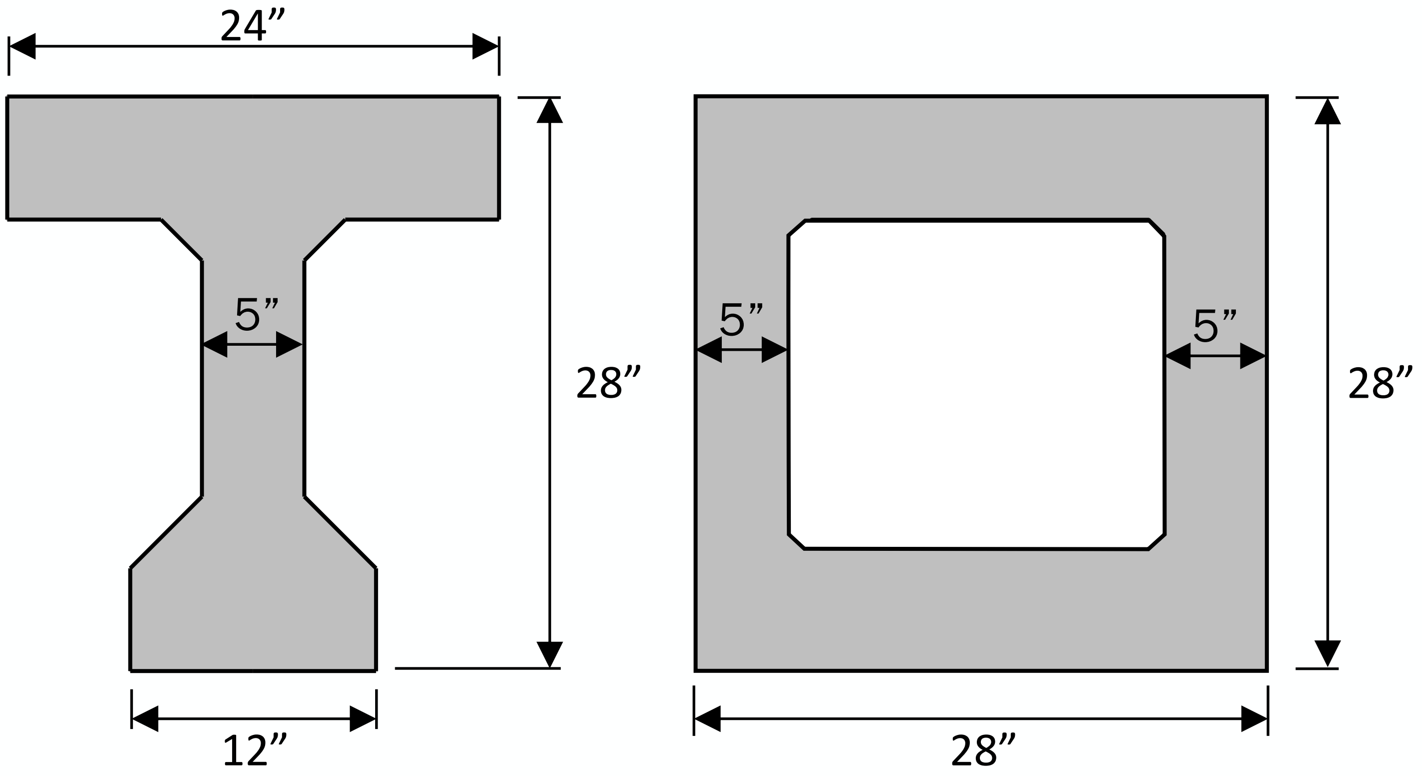


Test Series 1

- Primary test series
- 25 specimens
- Isolated variables

Variables include:

- Duct diameter to web width ratio
- Number of tendons in the web
- Transverse reinforcement ratio
- Grouted/ungrouted tendons
  - Web
  - Bottom flange
- Girder section (bulb-tee/box)

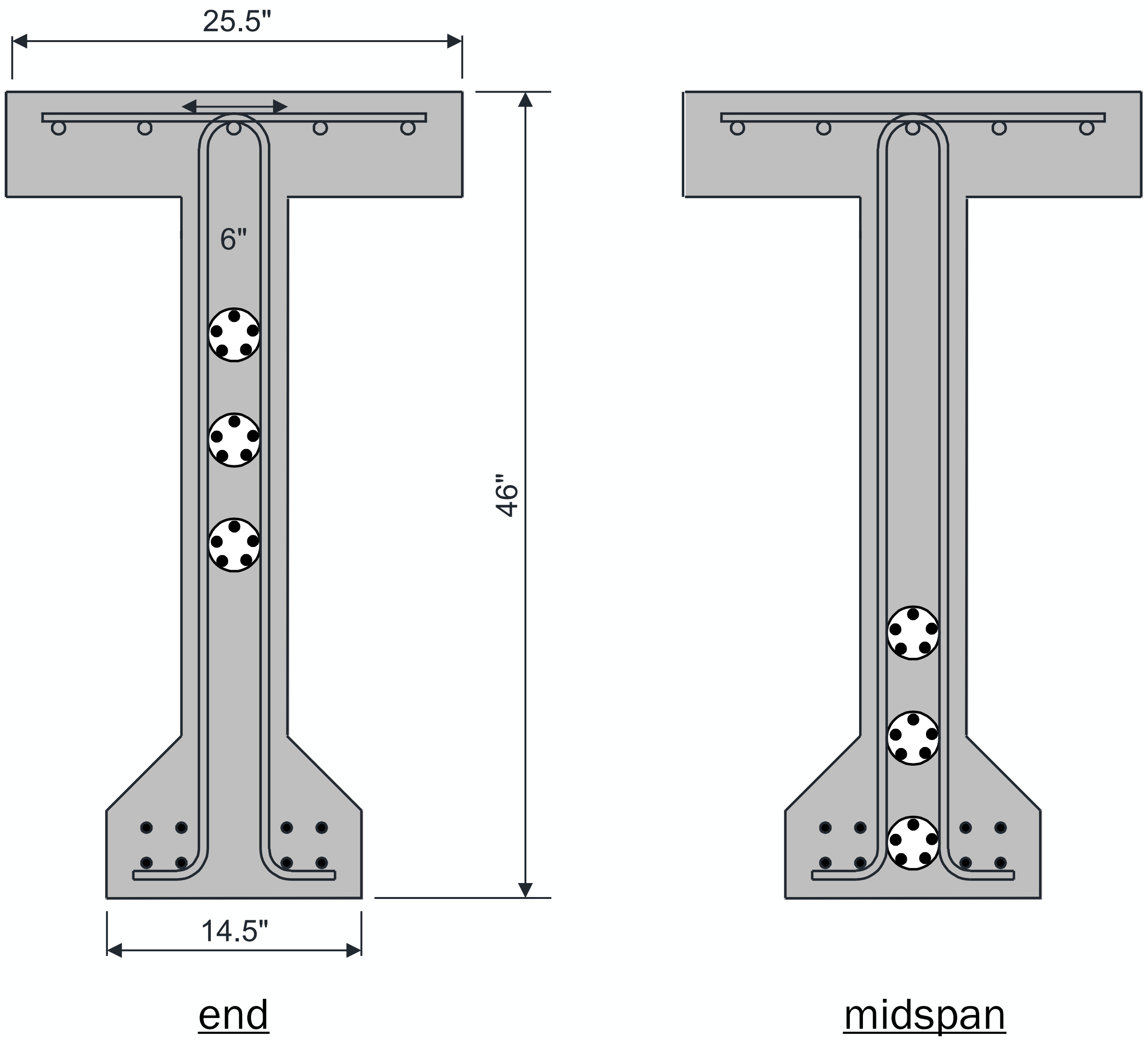


Test Series 2

- Validation test series
- 4 specimens
- Draped tendons

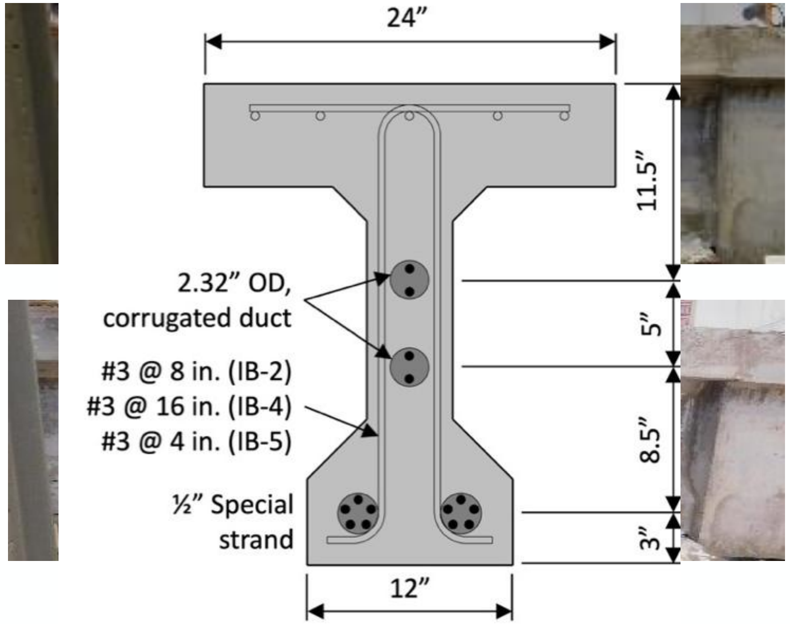
Variables include:

- Transverse reinforcement ratio
- Grouted/ungrouted tendons

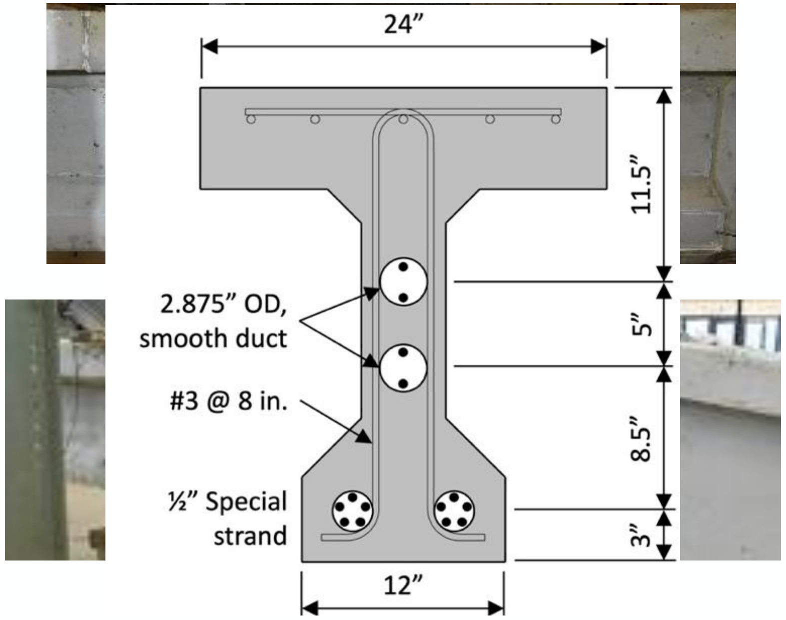


Shear Behavior

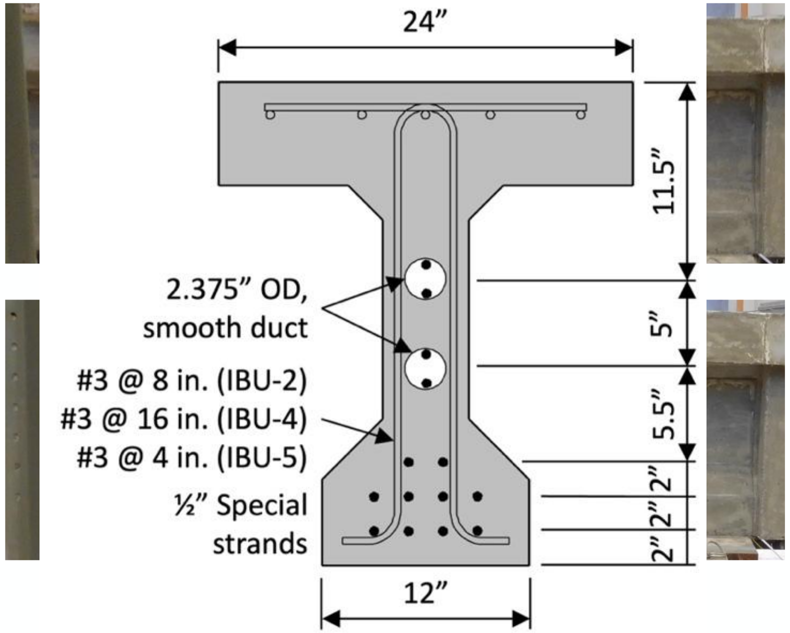
Bonded (IB-2)



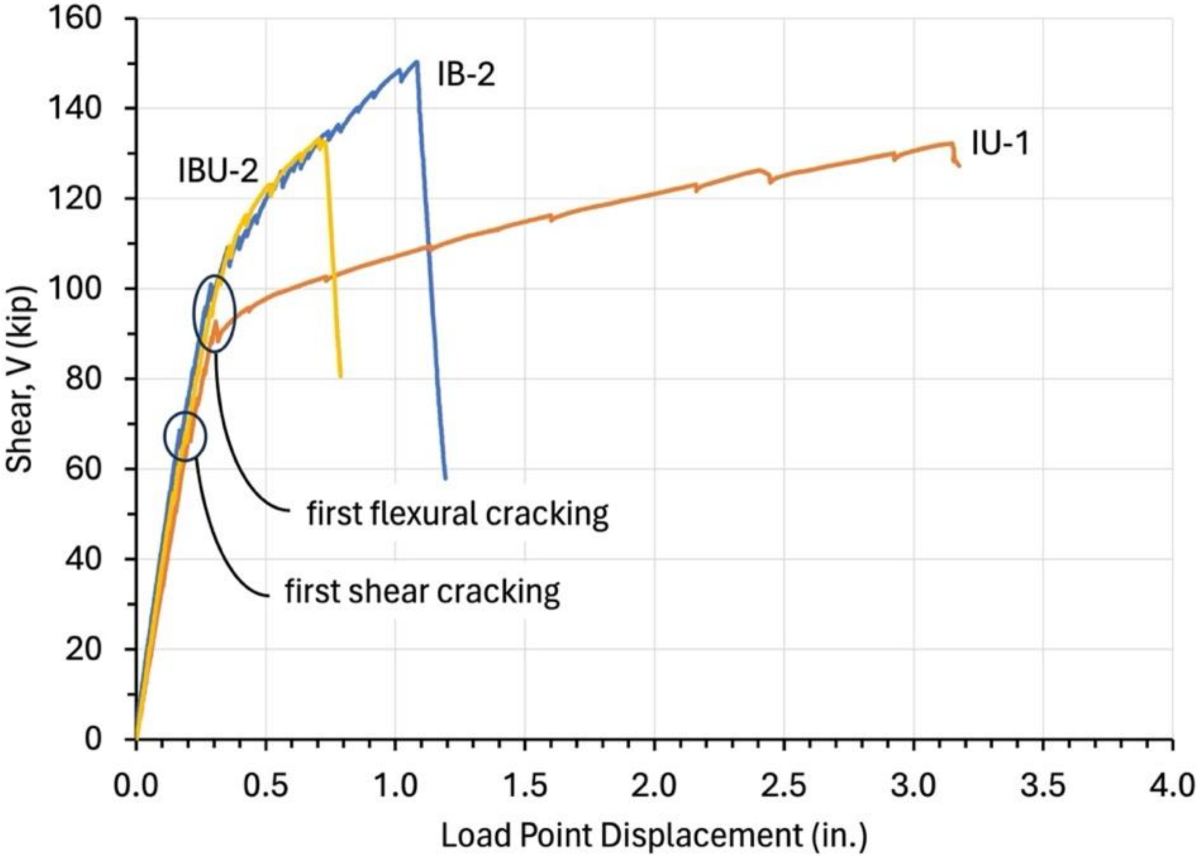
Unbonded (IU-3)



Bonded/Unbonded (IBU-2)

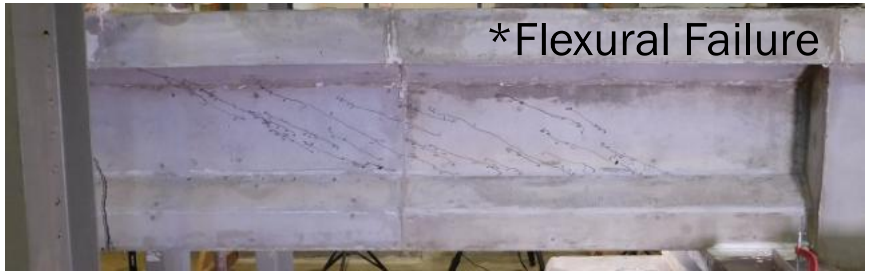


Influence of Bond

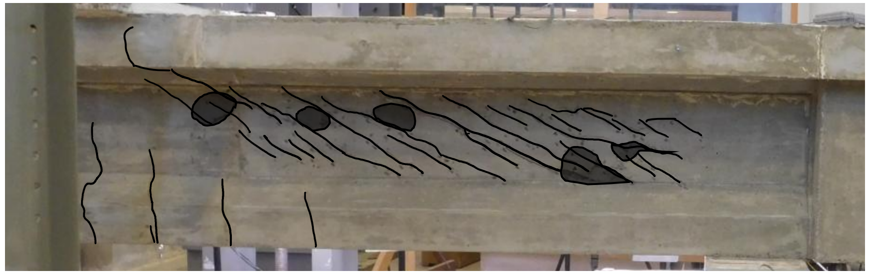


Bonded (IB)

Unbonded (IU)

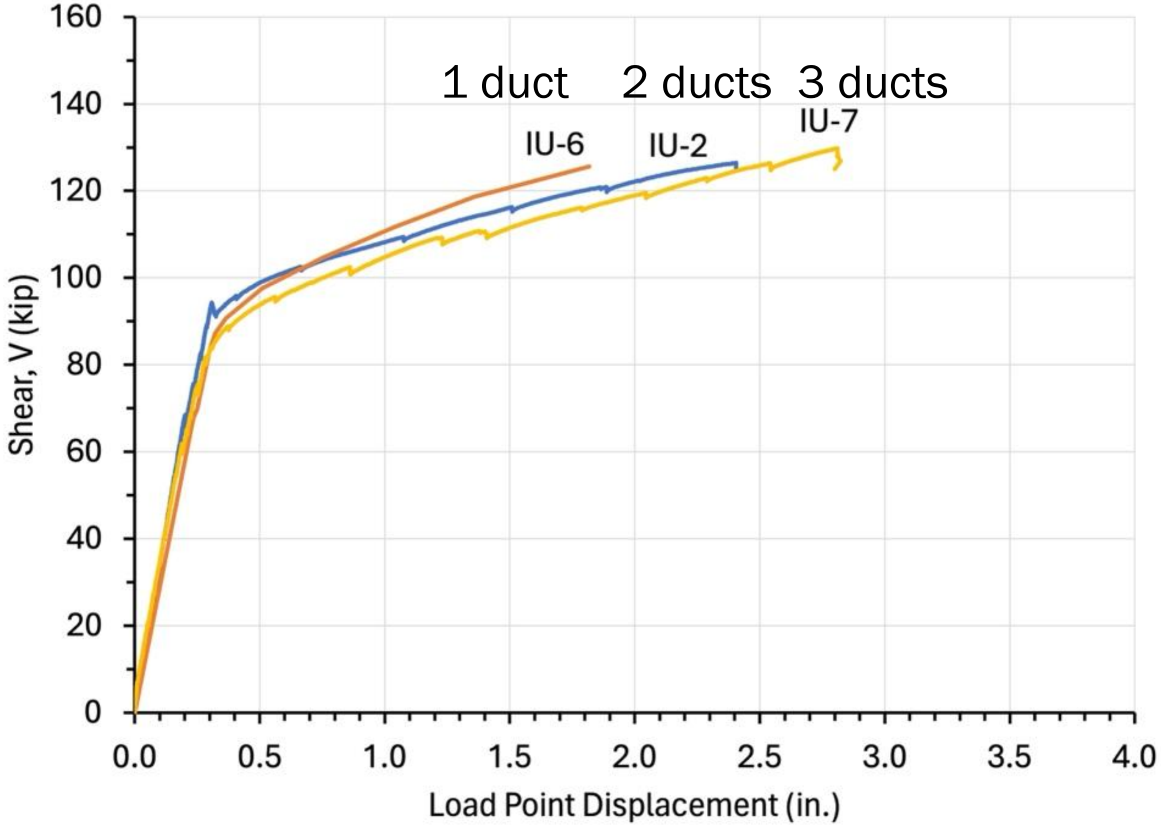


Bonded/
Unbonded (IBU)



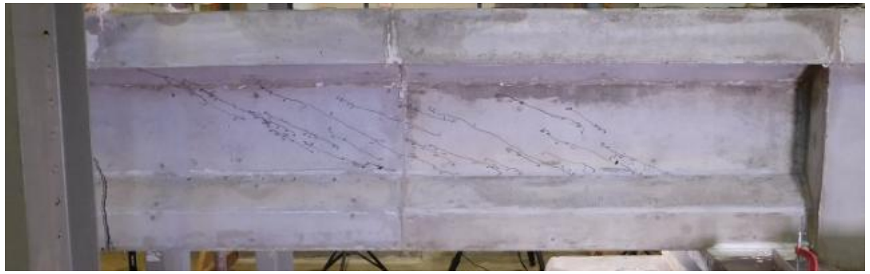
Influence of Ducts in Web

Internal Unbonded Group (IU)



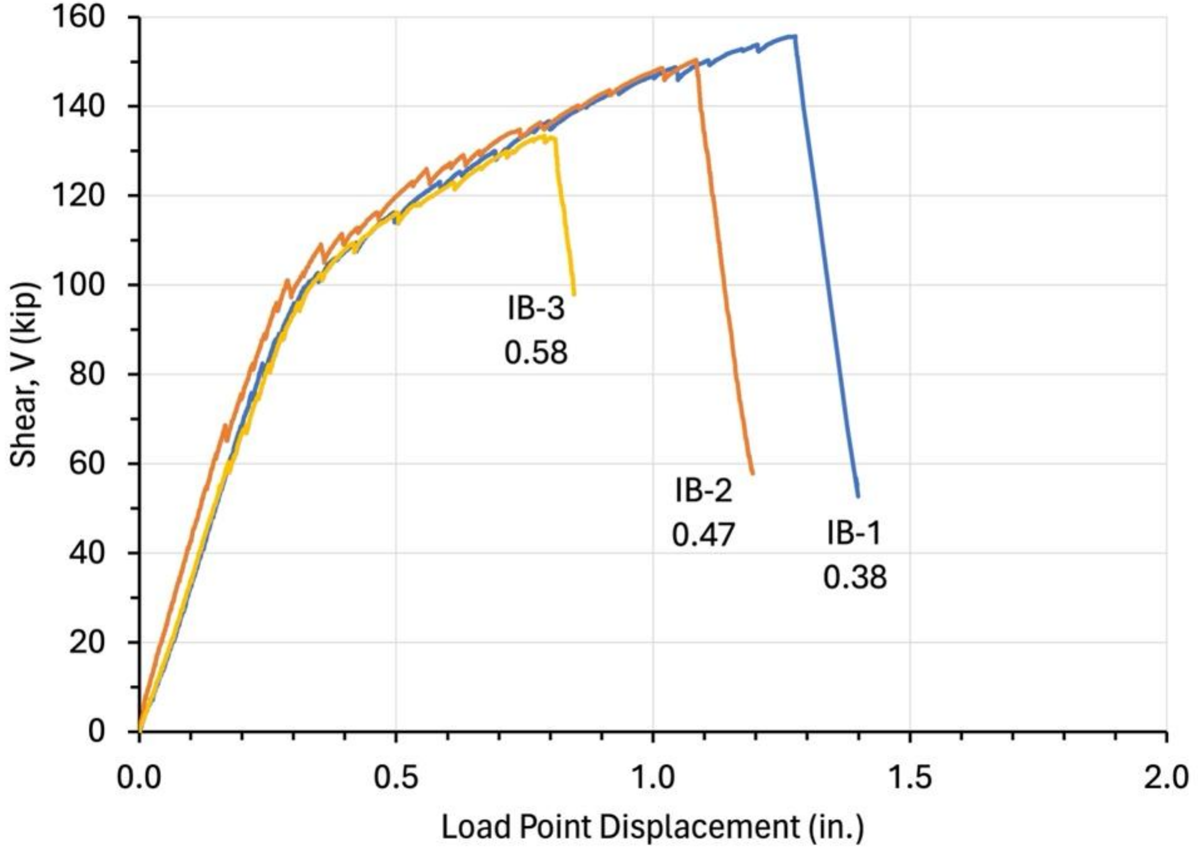
1 duct in web

2 ducts in web



3 ducts in web

ϕ_{duct}/b_w - Internal Bonded (IB)

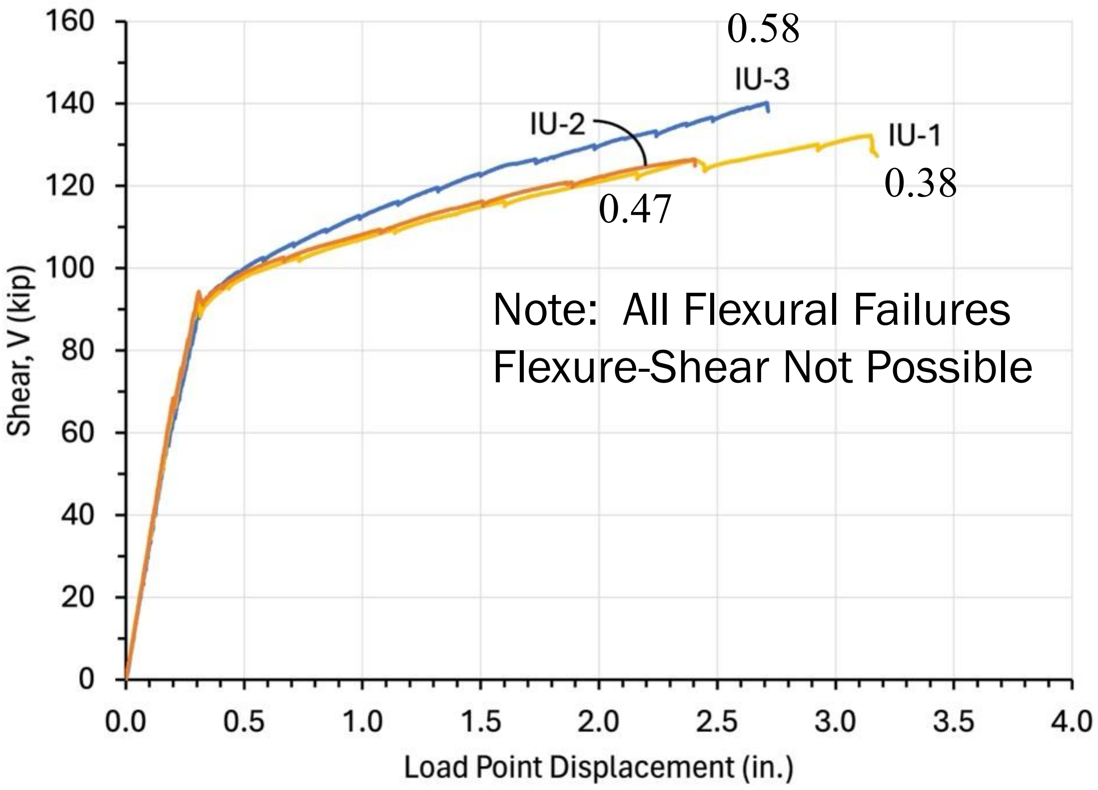


$\phi_{duct}/b_w = 0.38$

$\phi_{duct}/b_w = 0.47$

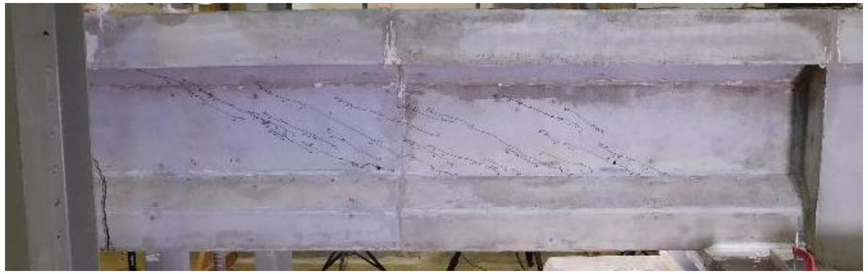
$\phi_{duct}/b_w = 0.58$

ϕ_{duct}/b_w - *Internal Unbonded (IU)*



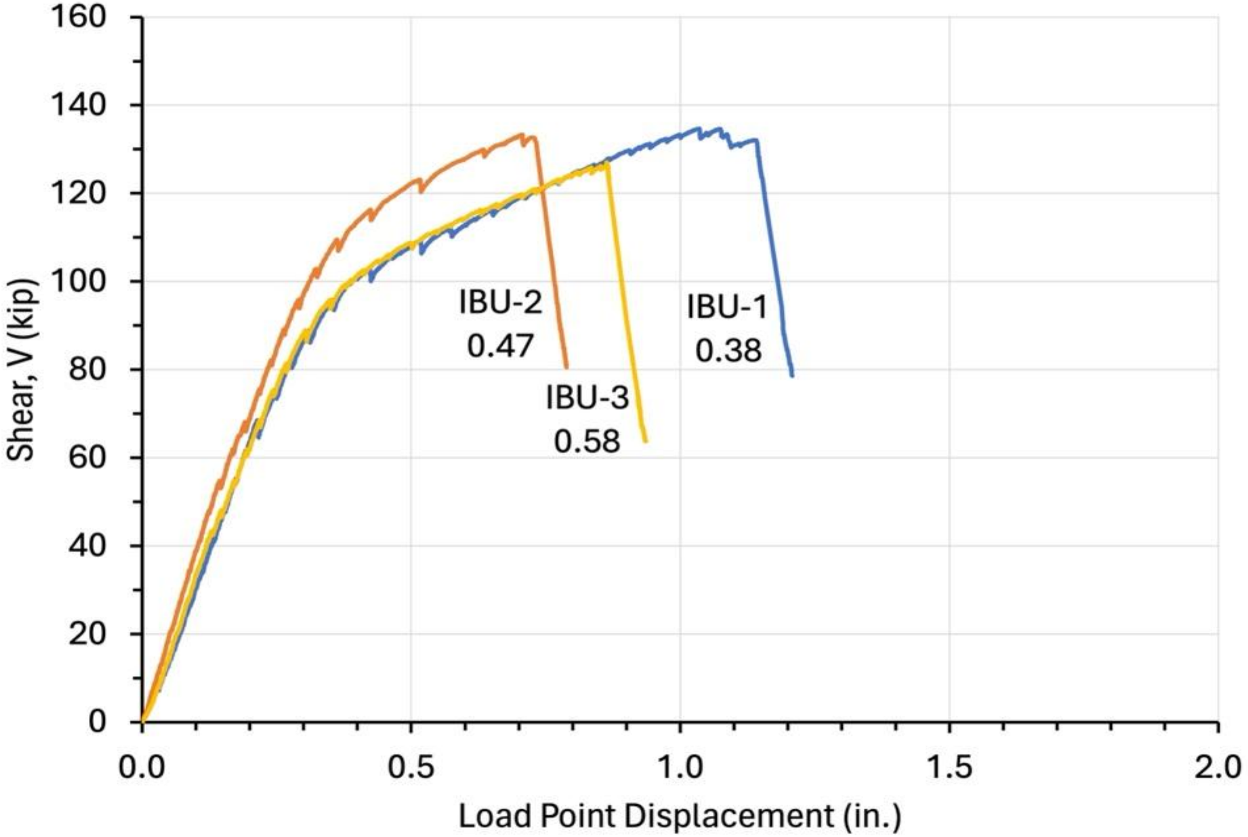
$\phi_{duct}/b_w = 0.38$

$\phi_{duct}/b_w = 0.47$



$\phi_{duct}/b_w = 0.58$

ϕ_{duct}/b_w - Internal Bonded/Internal Unbonded (IBU)

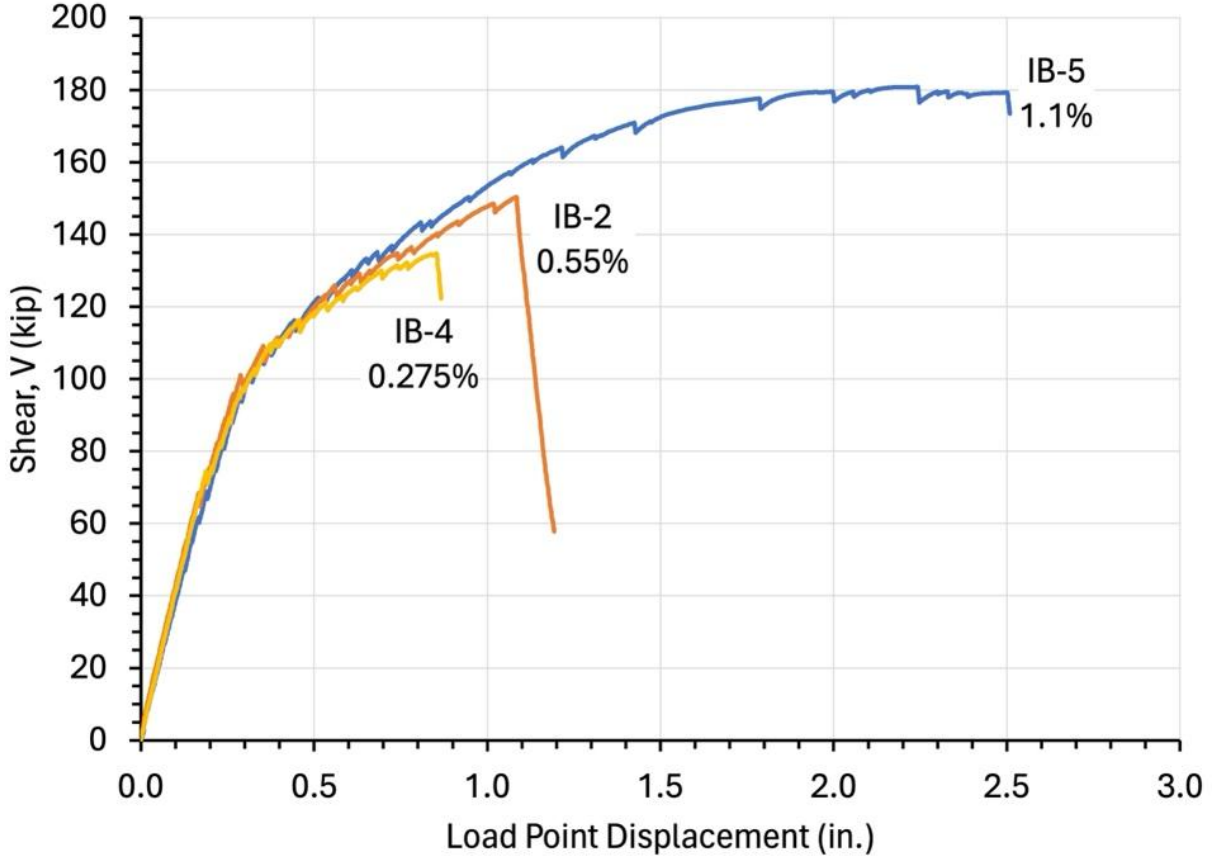


$\phi_{duct}/b_w = 0.38$

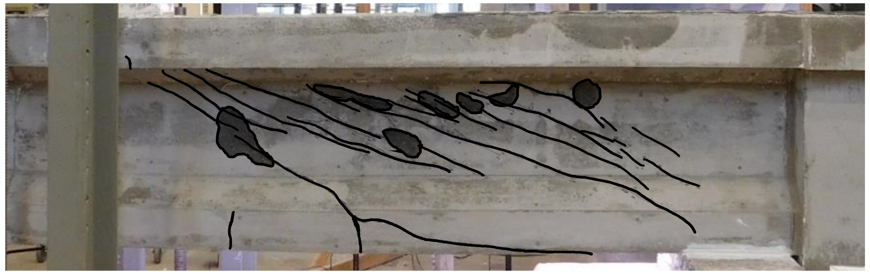
$\phi_{duct}/b_w = 0.47$

$\phi_{duct}/b_w = 0.58$

ρ_v - Internal Bonded (IB)



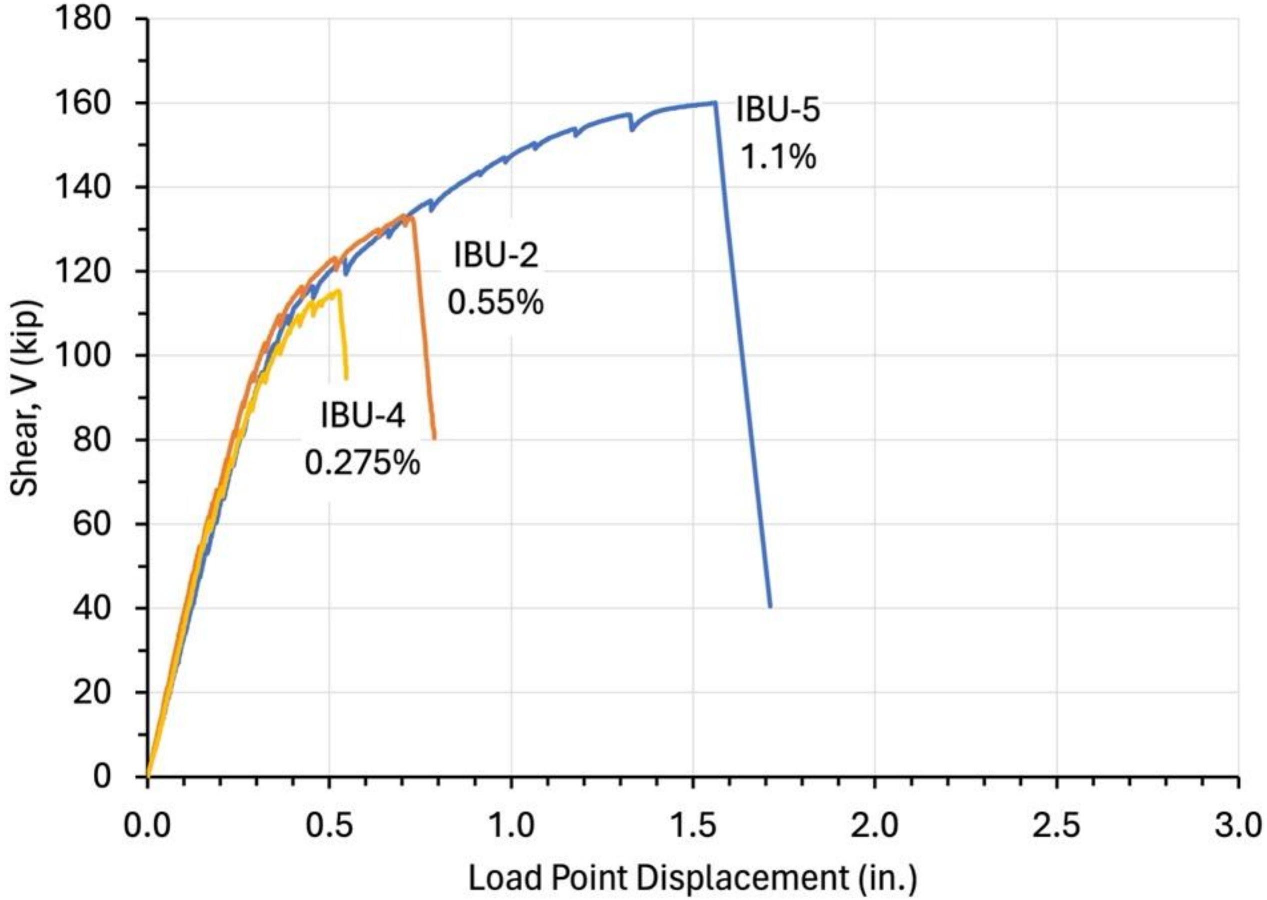
ρ_v= 0.275%



ρ_v= 0.55%

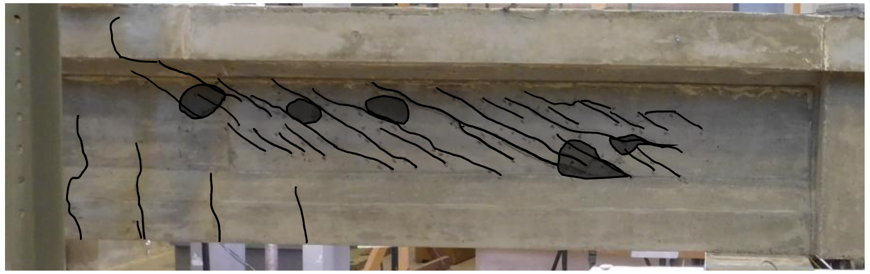
ρ_v= 1.1%

ρ_v - Internal Bonded/Internal Unbonded (IBU)

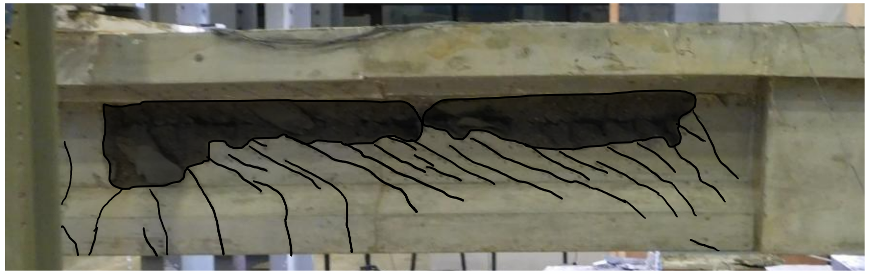


ρ_v= 0.275%

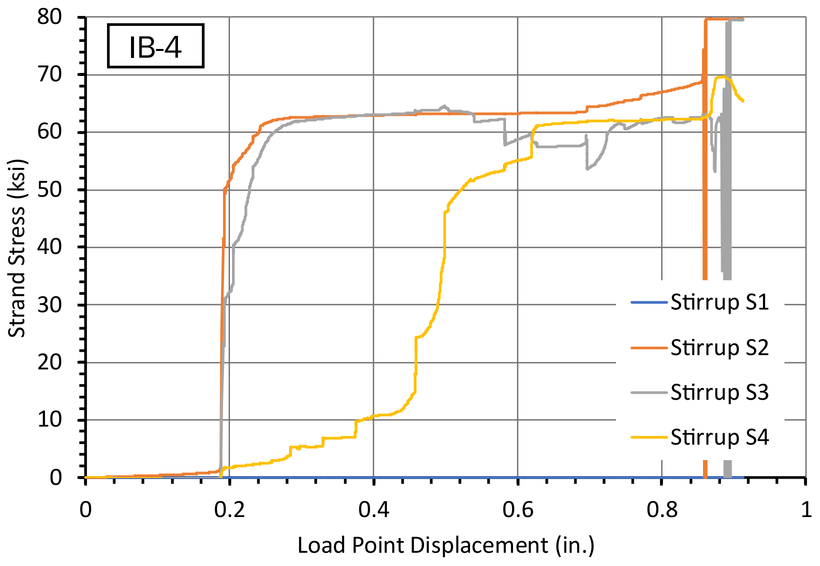
ρ_v= 0.55%



ρ_v= 1.1%

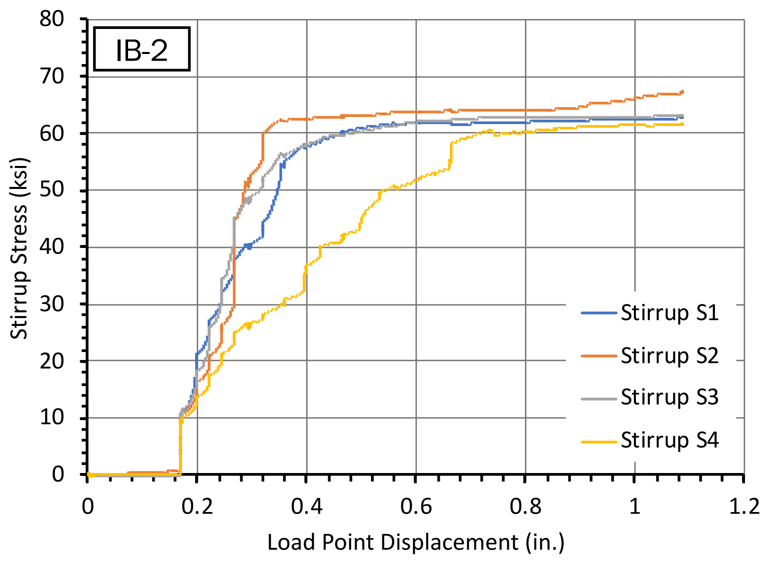


Stirrup Stresses – Bonded PT



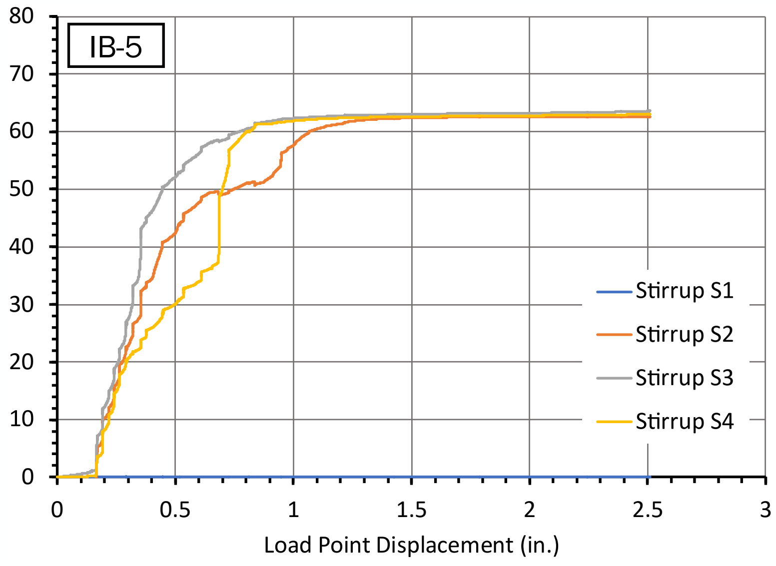
#3 @ 16”

ρ_v= 0.275%



#3 @ 8”

ρ_v= 0.55%



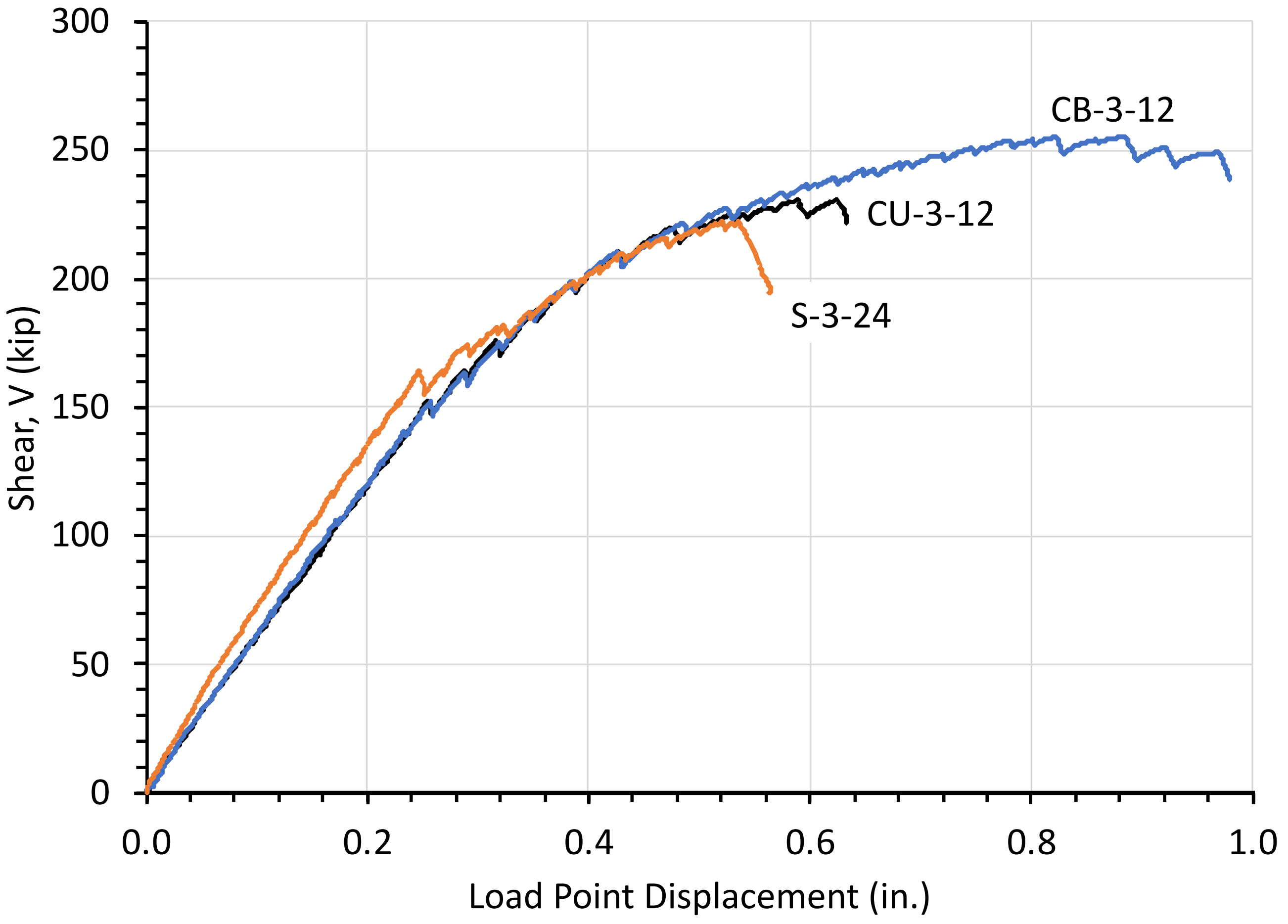
#3 @ 4”

ρ_v= 1.1%

Experimental Findings - Test Series 1

- Bond type of web tendons did not significantly influence shear capacity
- Increase in duct diameter decreases shear capacity
  - Crushing at top duct
- Number of tendons in web does not influence shear capacity
- Flexure-Shear failure not possible with all unbonded strands
- Increase in transverse reinforcement increases shear capacity
  - Stirrups can reach yield in the test region

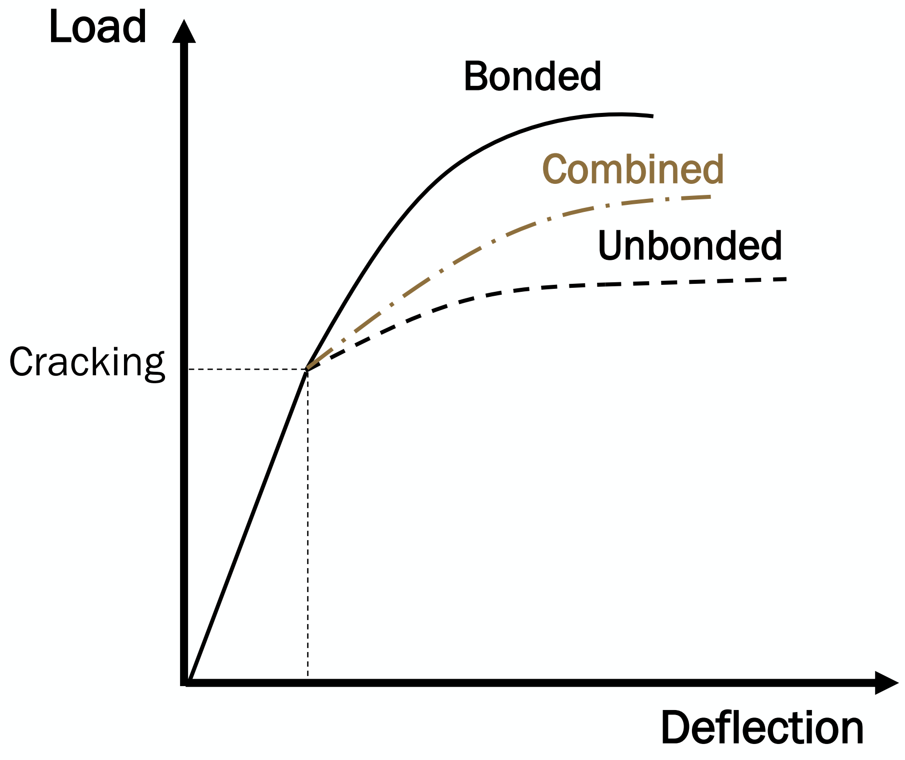
Test Series 2 Results

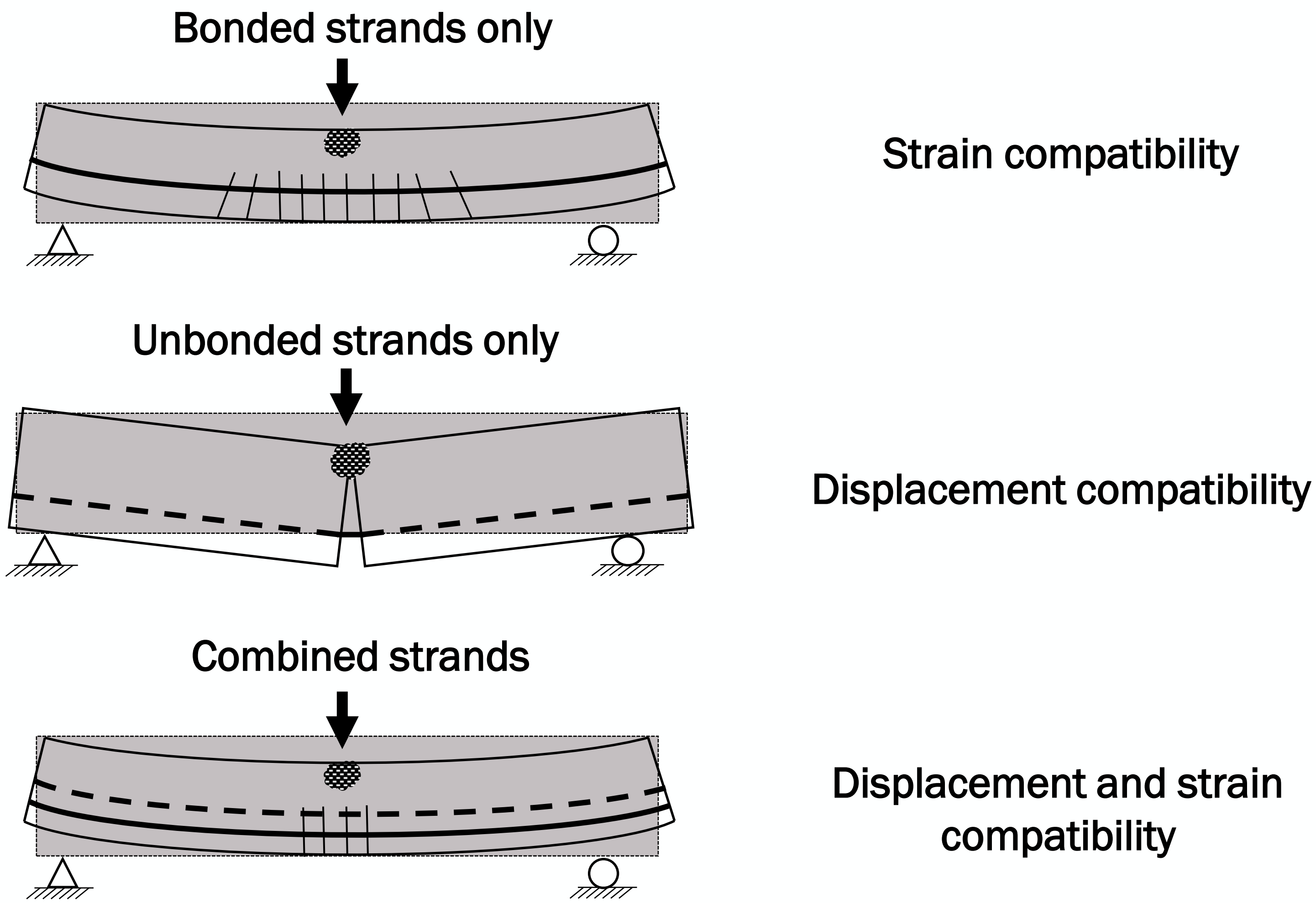


- Confirmed findings of Test Series 1
- Bonded tendons resulted in a slightly higher shear strength
- Increasing transverse reinforcement ratios increases the shear strength

Flexure Behavior

Flexure Response with Bonded and/or Unbonded Strands

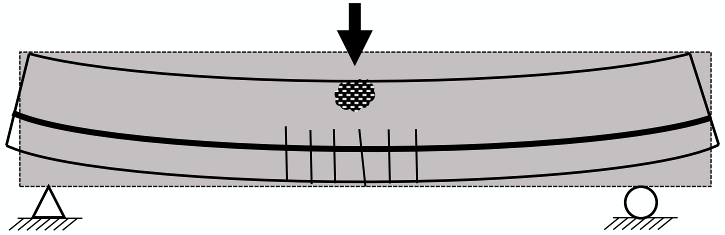




Current Design Practice and Knowledge Gaps

AASHTO LRFD Bridge Design Specifications (2024):

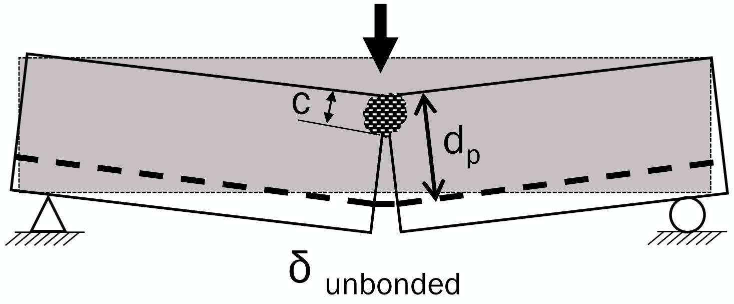
Bonded Members



$$f_{psb} = f_{pu}\left(1 - k\frac{c}{d_p}\right)$$

- Based on strain-compatibility
- Derived by Loove (1988) and Naaman (1989)

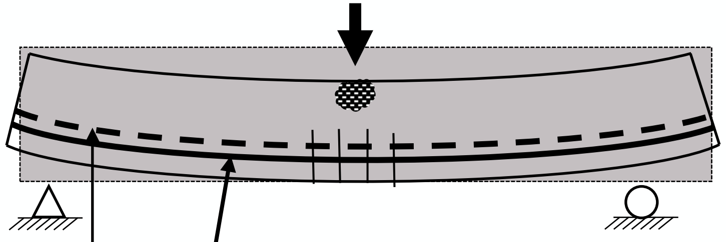
Unbonded Members



$$f_{psu} = f_{pe} + 900\left(\frac{d_{ps}-c}{L_e}\right) \leq f_{py}\ \text{(ksi)}$$

- Empirical multiplier based on 8 specimens by Tam and Pannell (1976)
- Derived by MacGregor (1989)

Combined Members



$$f_{psb} = f_{pu}\left(1 - k\frac{c}{d_p}\right)$$

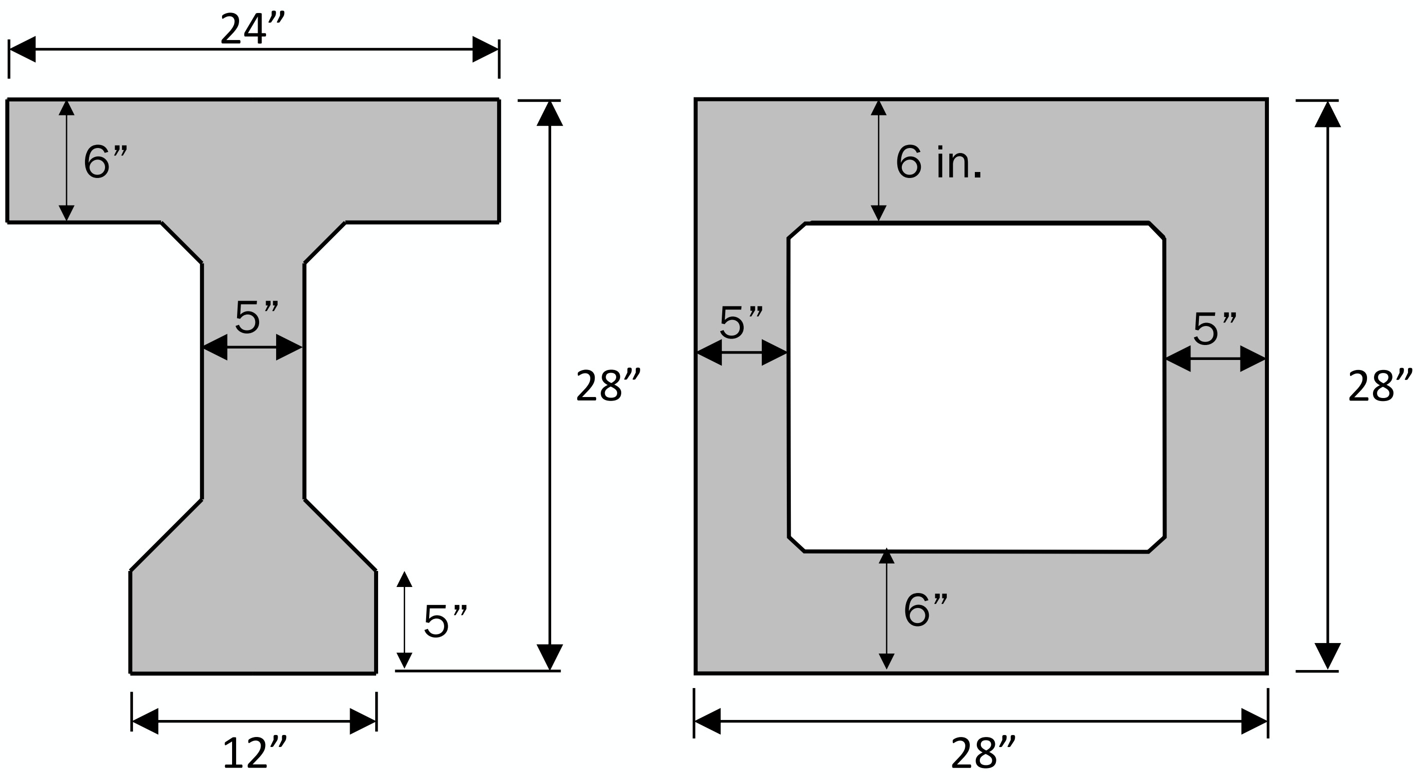
$$f_{psu} = f_{pe}$$

- Stress increase in unbonded strands is ignored.

- Is the multiplier **900** reasonable for members with unbonded strands?
- Is $f_{psu} = f_{pe}$ reasonable for members with combined strands?

Experimental Program

Flexure Specimens

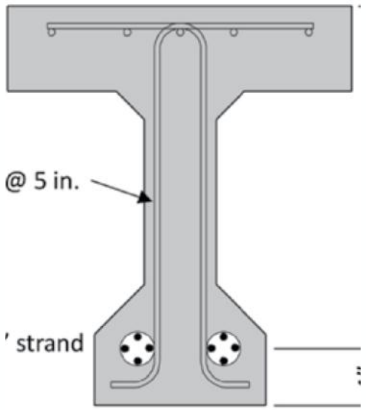


Variables:

- Ratio of bonded to total prestressed reinforcement
- Total prestressed reinforcement area

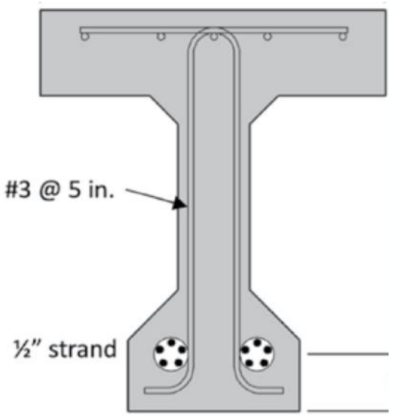
Specimens

Internal unbonded



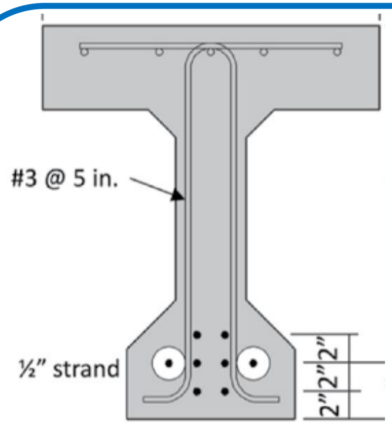
$\mathbf{A_{ps} = 1.2\ in^2}$

$A_{ps,bonded} = 0\%$



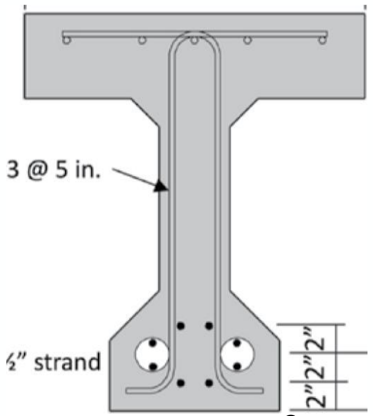
$\mathbf{A_{ps} = 1.5\ in^2}$

$A_{ps,bonded} = 0\%$



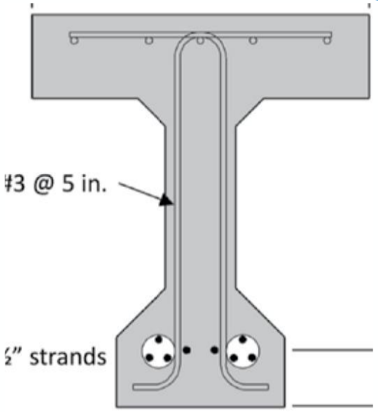
$A_{ps} = 1.2\ in^2$

$\mathbf{A_{ps,bonded} = 75\%}$



$A_{ps} = 1.2\ in^2$

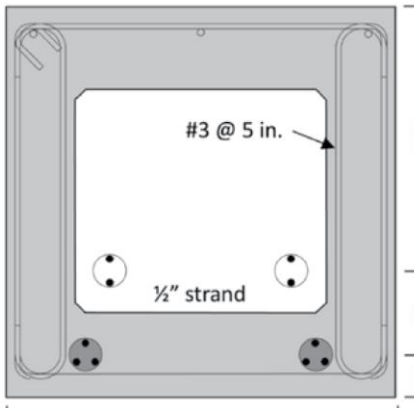
$\mathbf{A_{ps,bonded} = 50\%}$



$A_{ps} = 1.2\ in^2$

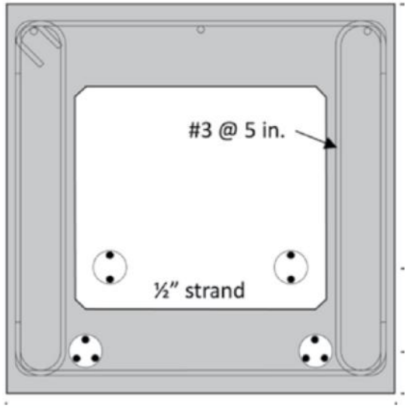
$\mathbf{A_{ps,bonded} = 25\%}$

Internal bonded and internal unbonded



$A_{ps} = 1.5\ in^2$

$\mathbf{A_{ps,bonded} = 60\%}$



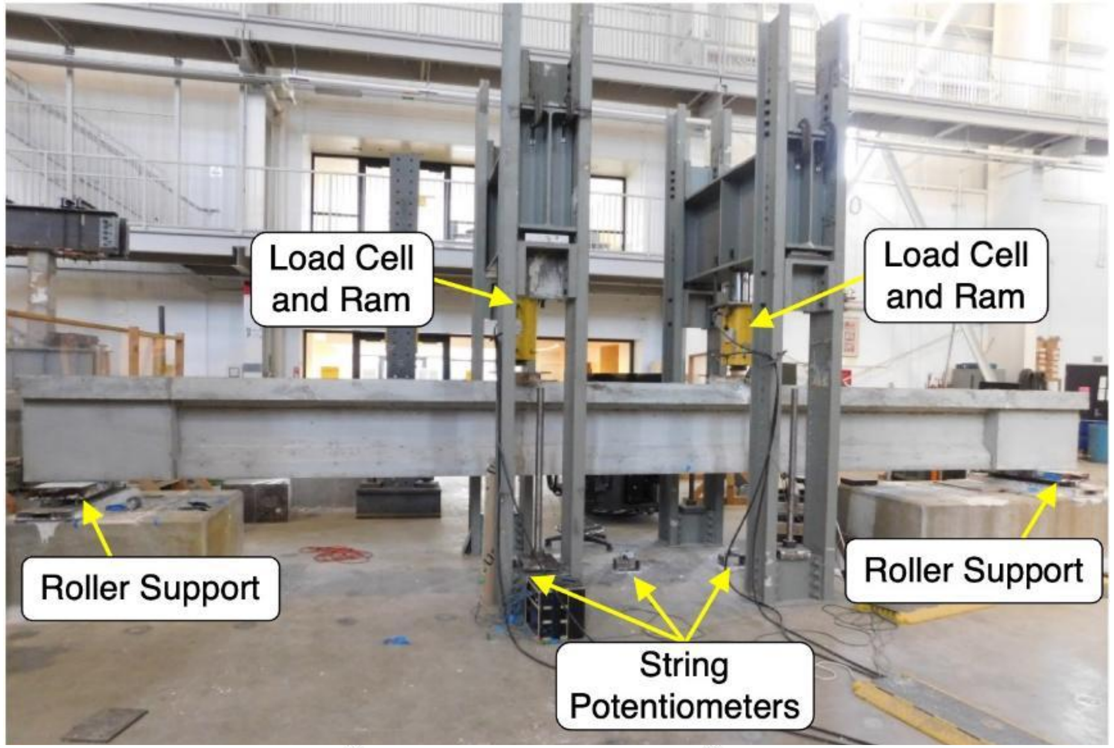
$A_{ps} = 1.5\ in^2$

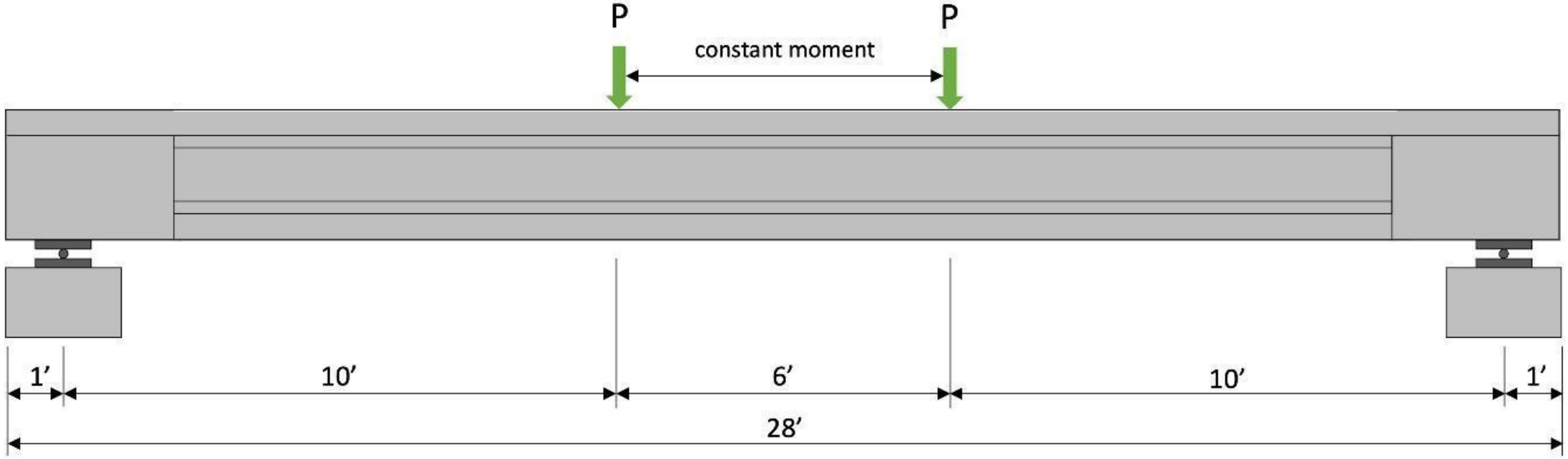
$\mathbf{A_{ps,bonded} = 0\%}$

Internal bonded and external

Internal unbonded and external

Flexure Tests





Crack Distribution

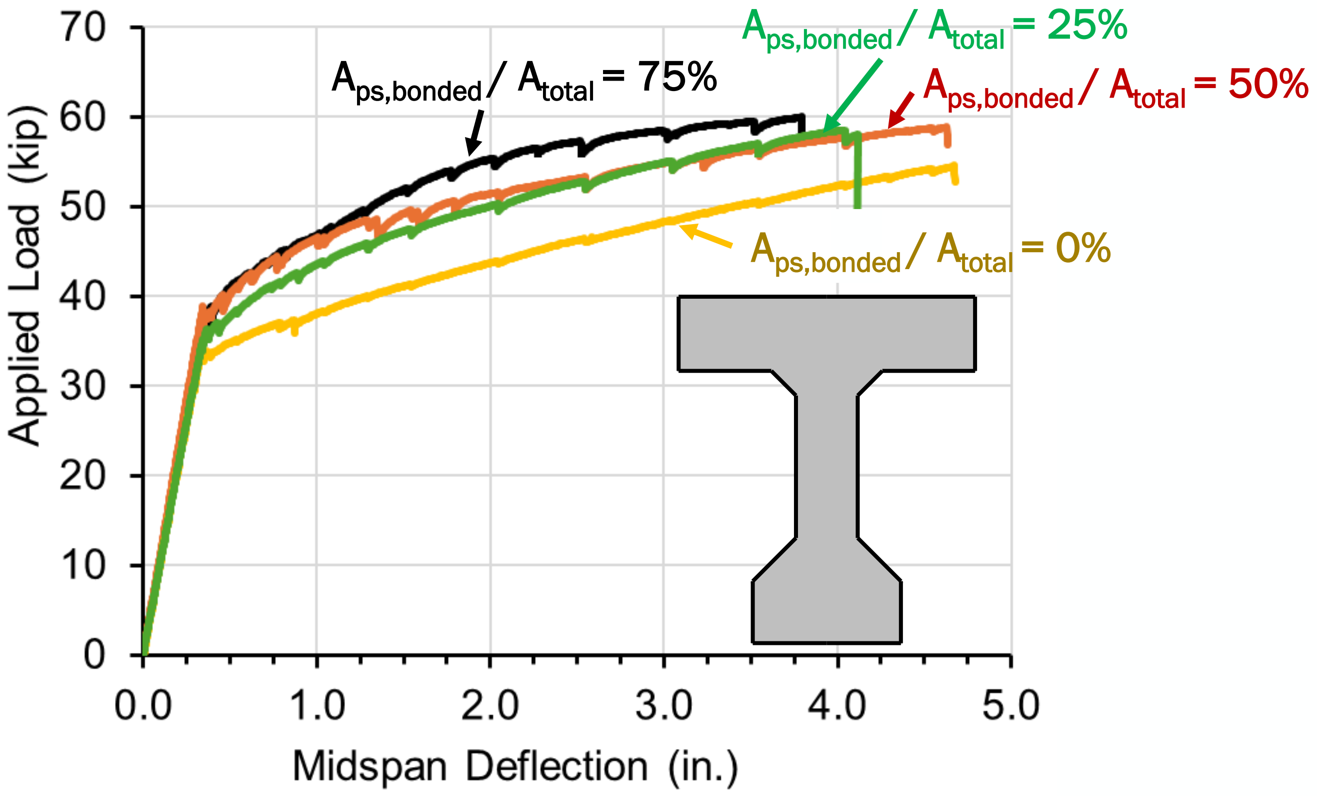
$A_{ps,bonded} / A_{total} = 75\%$

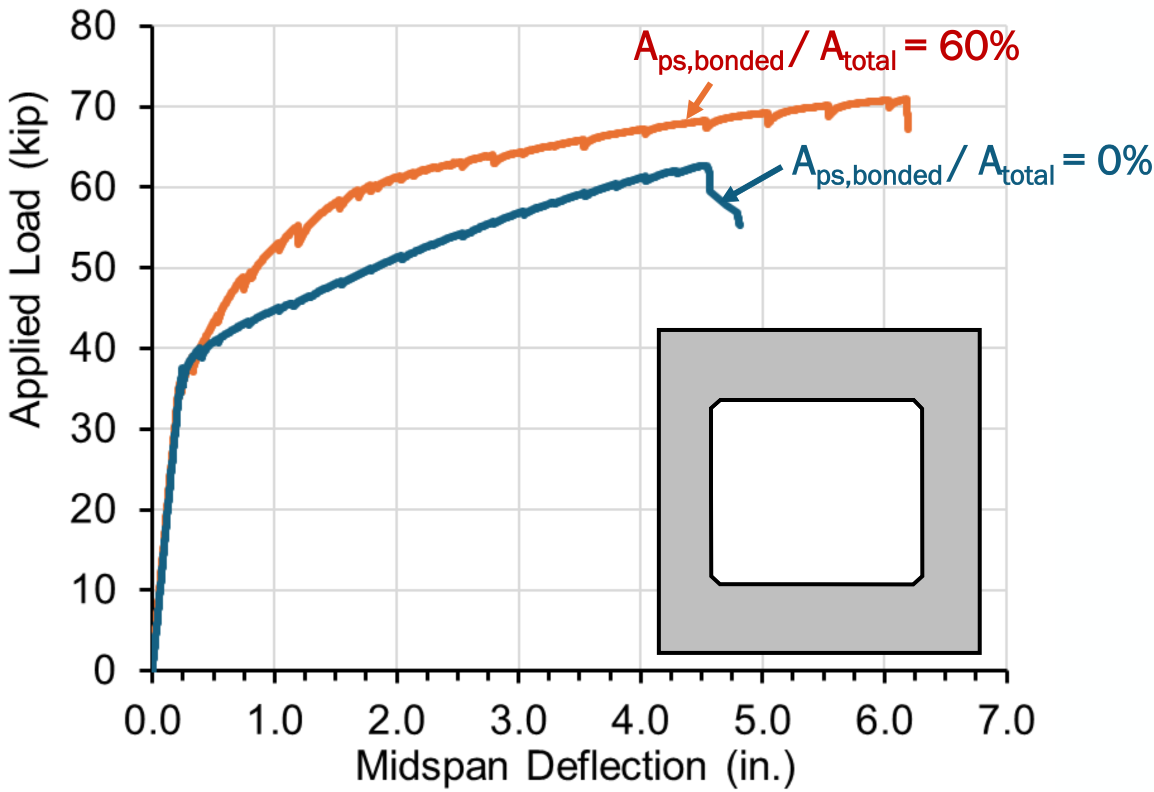
$A_{ps,bonded} / A_{total} = 0\%$

Larger bonded strand area leads to:

- narrower and closely spaced cracks.

Load-Deflection Response



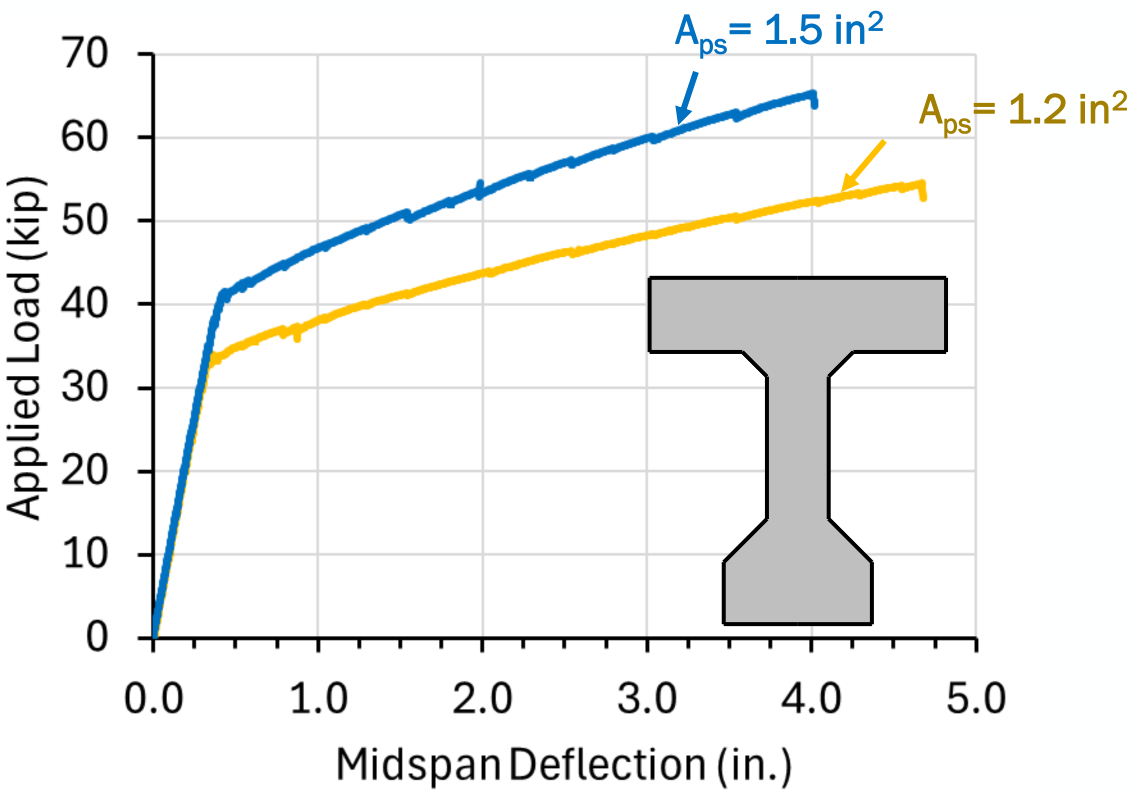


Varying bonded strand ratios, constant A_{ps} = 1.2 in^2

Higher ratios of bonded to total strands leads to:

- higher flexure strength
- higher post-cracking stiffness

Load-Deflection Response

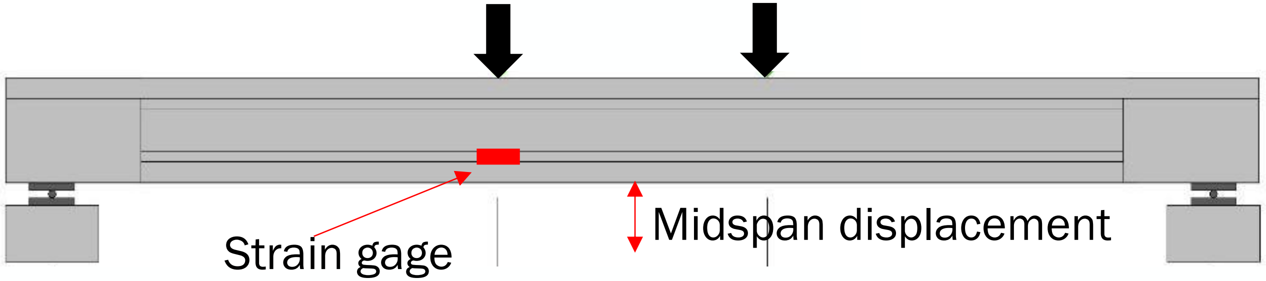


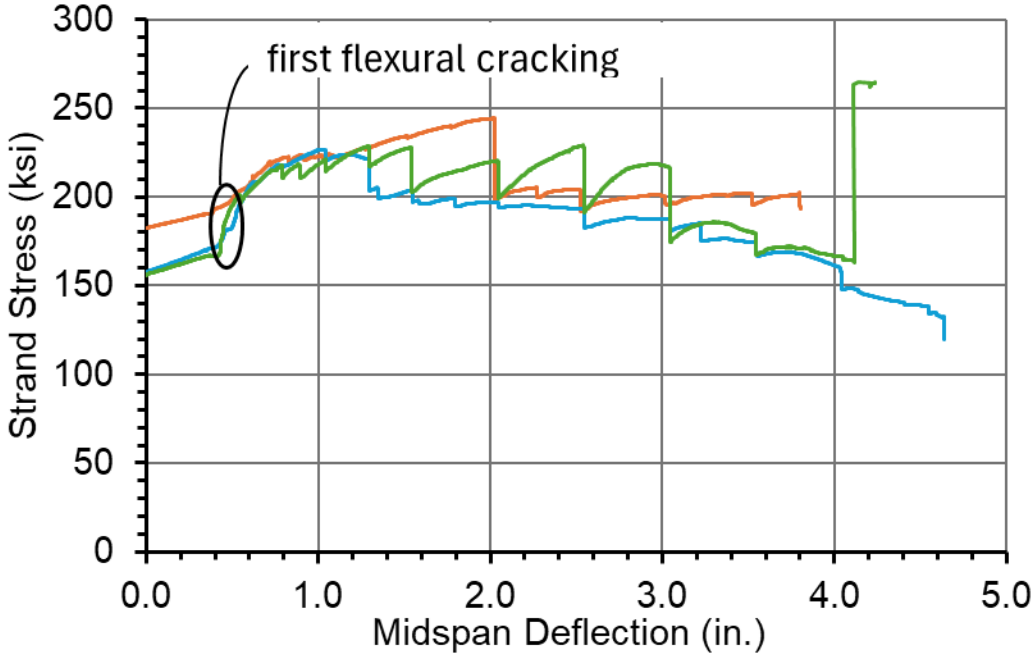
Varying total strand area, constant bonded strand

Higher total strand area leads to:

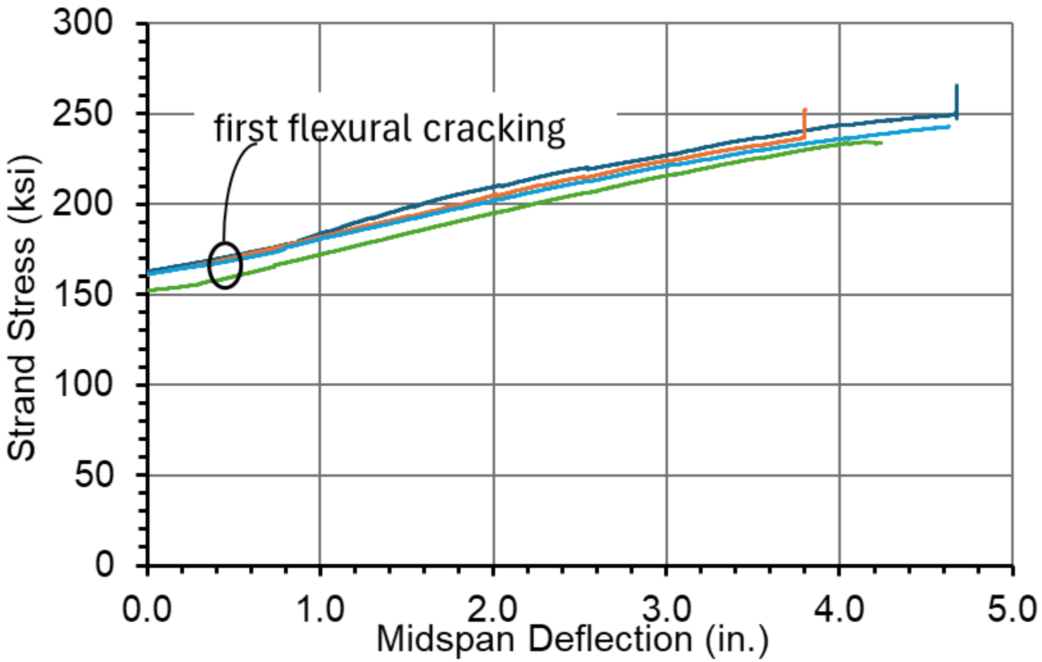
- higher flexure strength

Strand Stresses





Bonded Strands



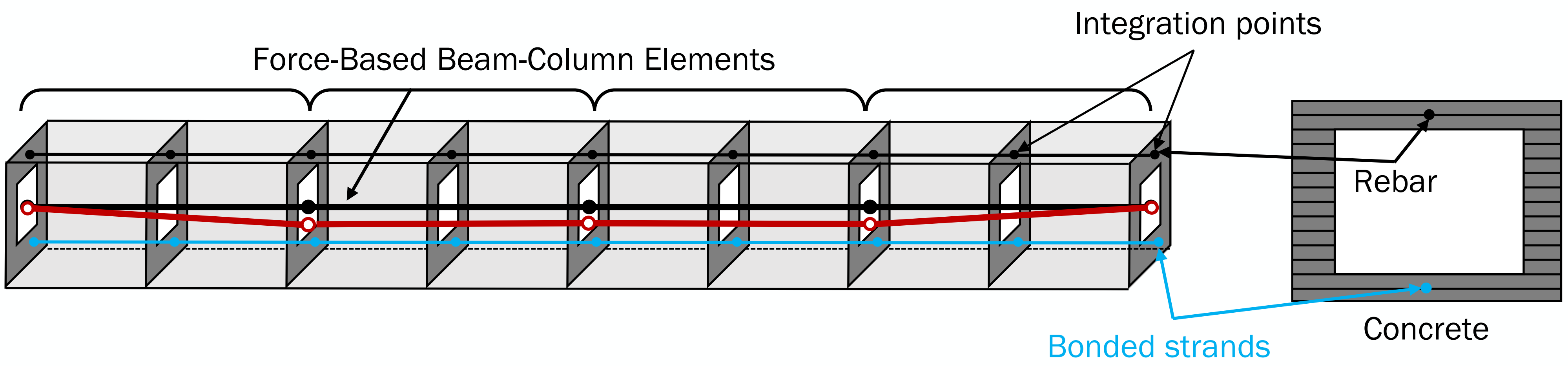
Unbonded Strands

Strand stress increase depends on bond type:

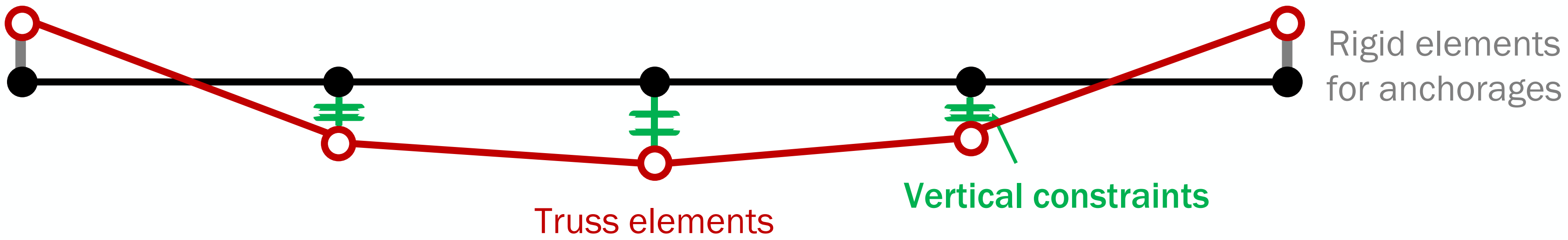
- Bonded – Increased significantly at cracking
- Unbonded – Increases at a nearly constant rate

Analytical Program

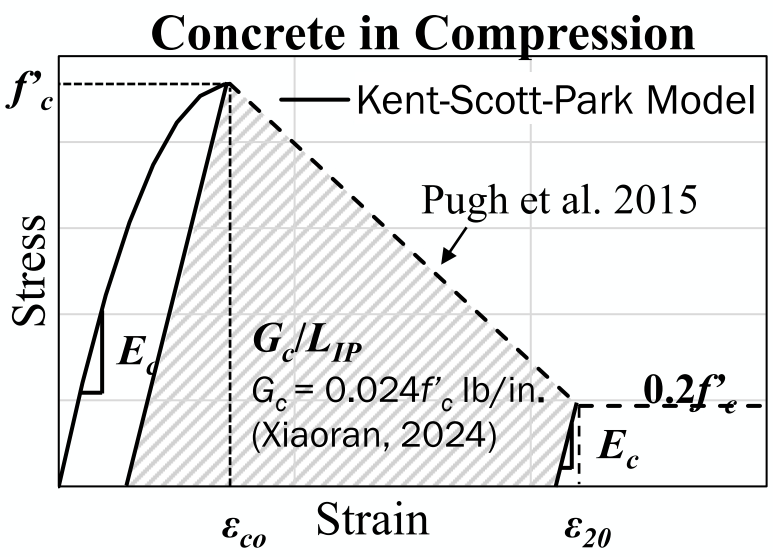
Sectional Analysis Models

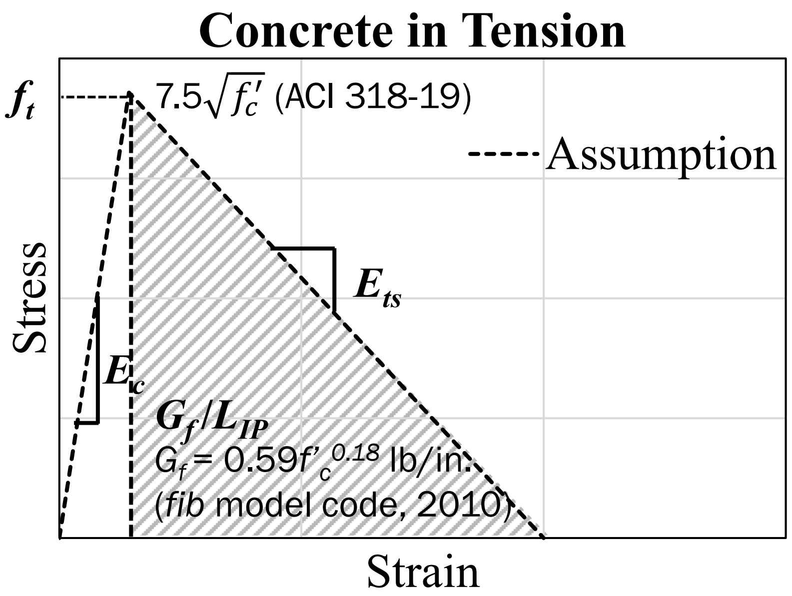


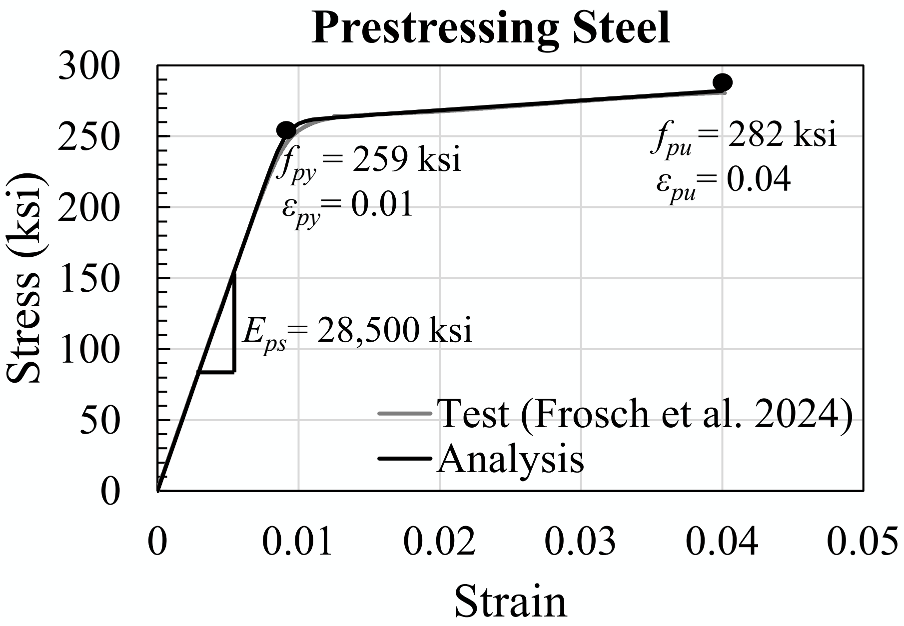
Unbonded Strands

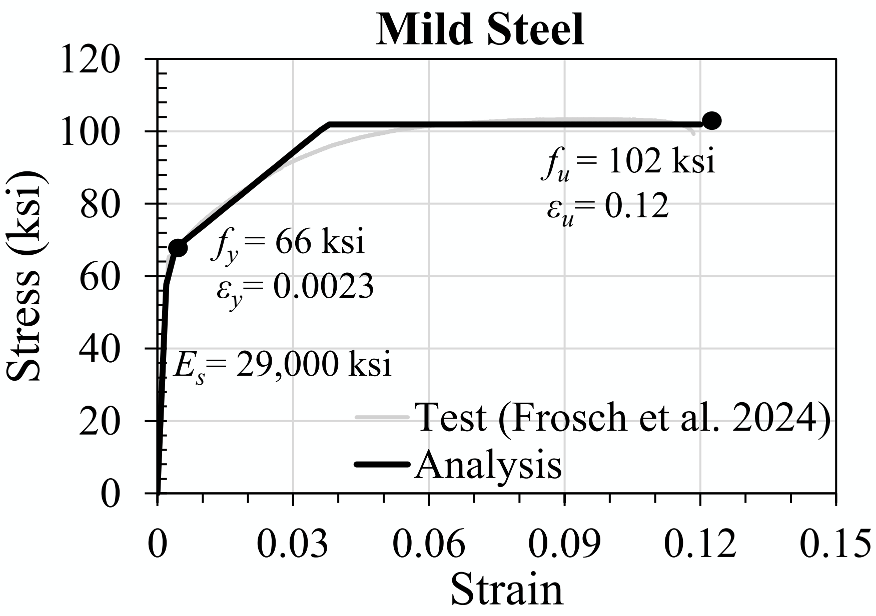


Material Models

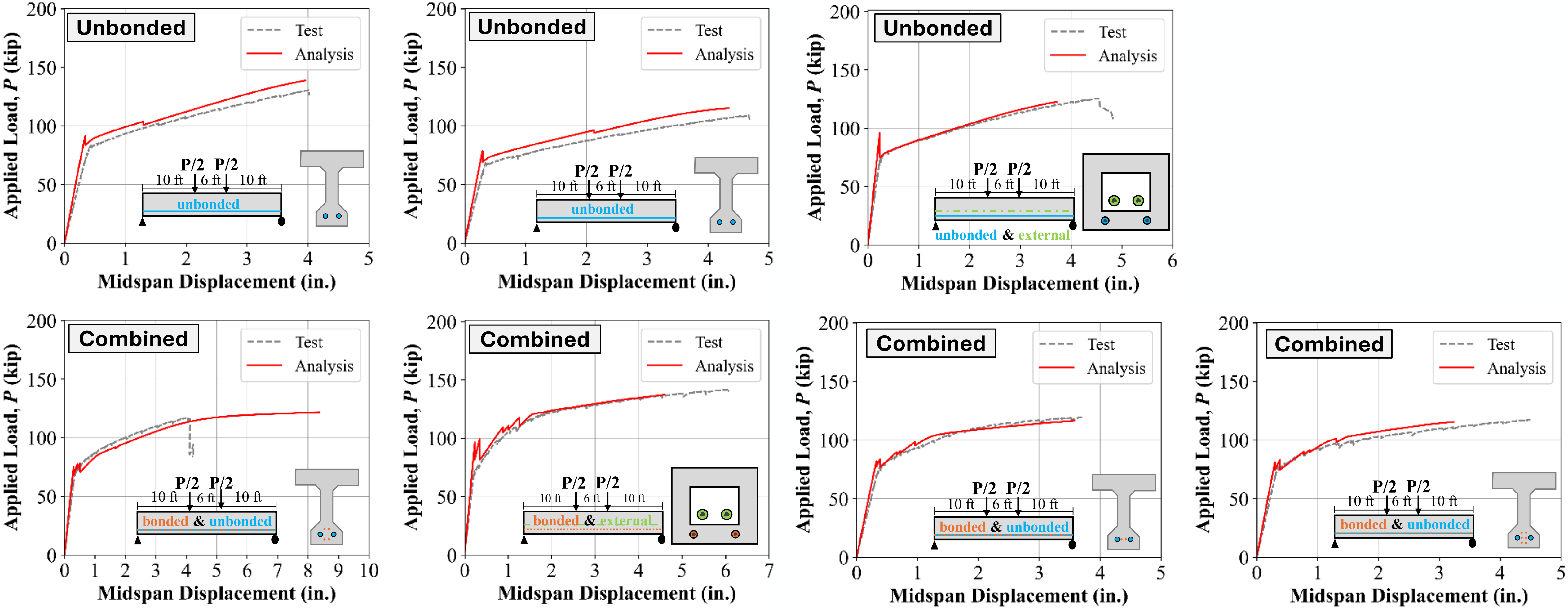




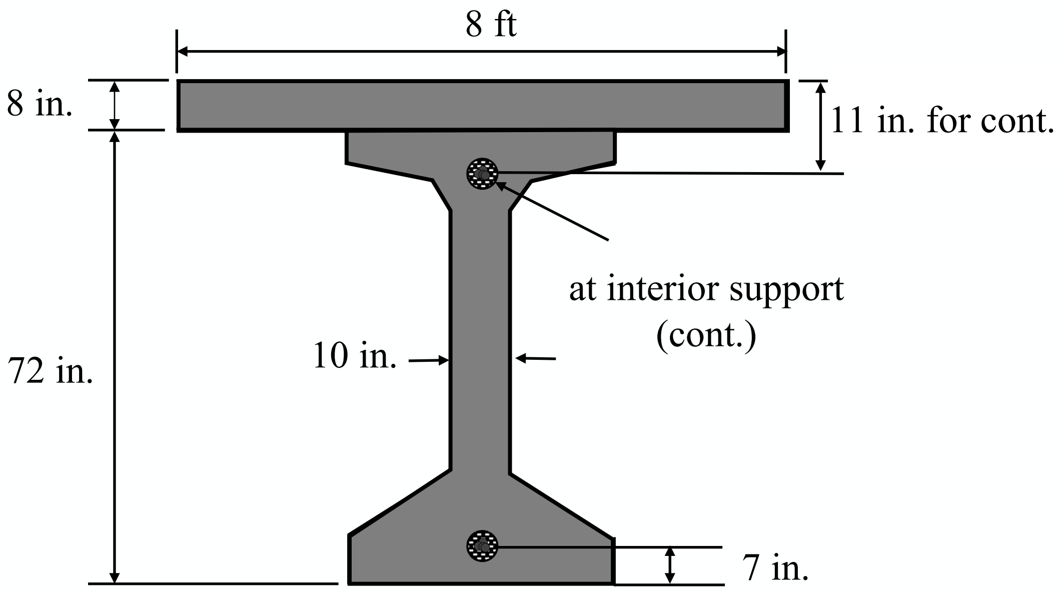




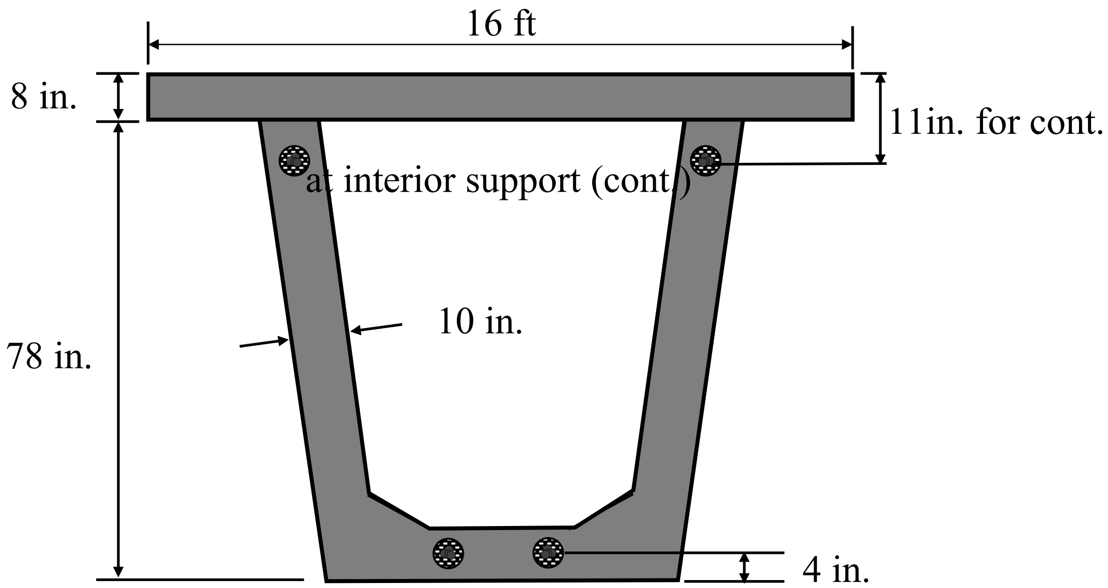
Model Validation



Cross-Sections Analyzed



AASHTO Type IV Bulb tee
(with 10 in. web)



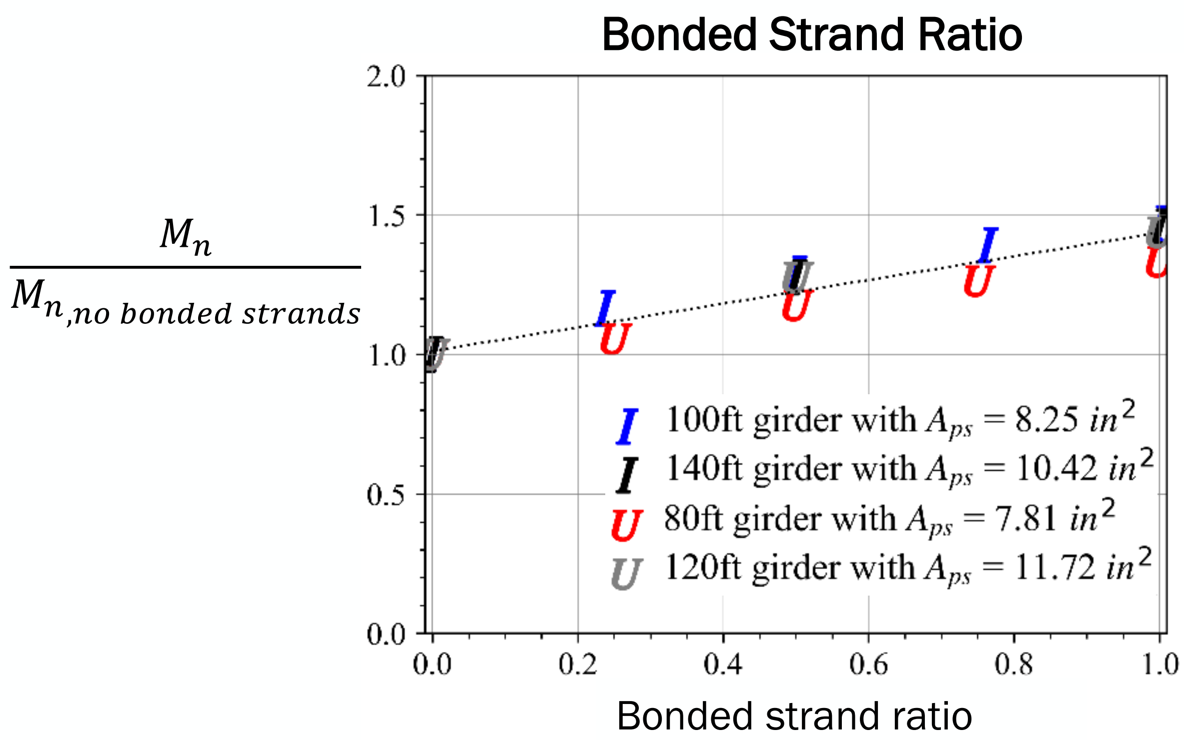
Washington DOT U78G5
(with 10 in. web)

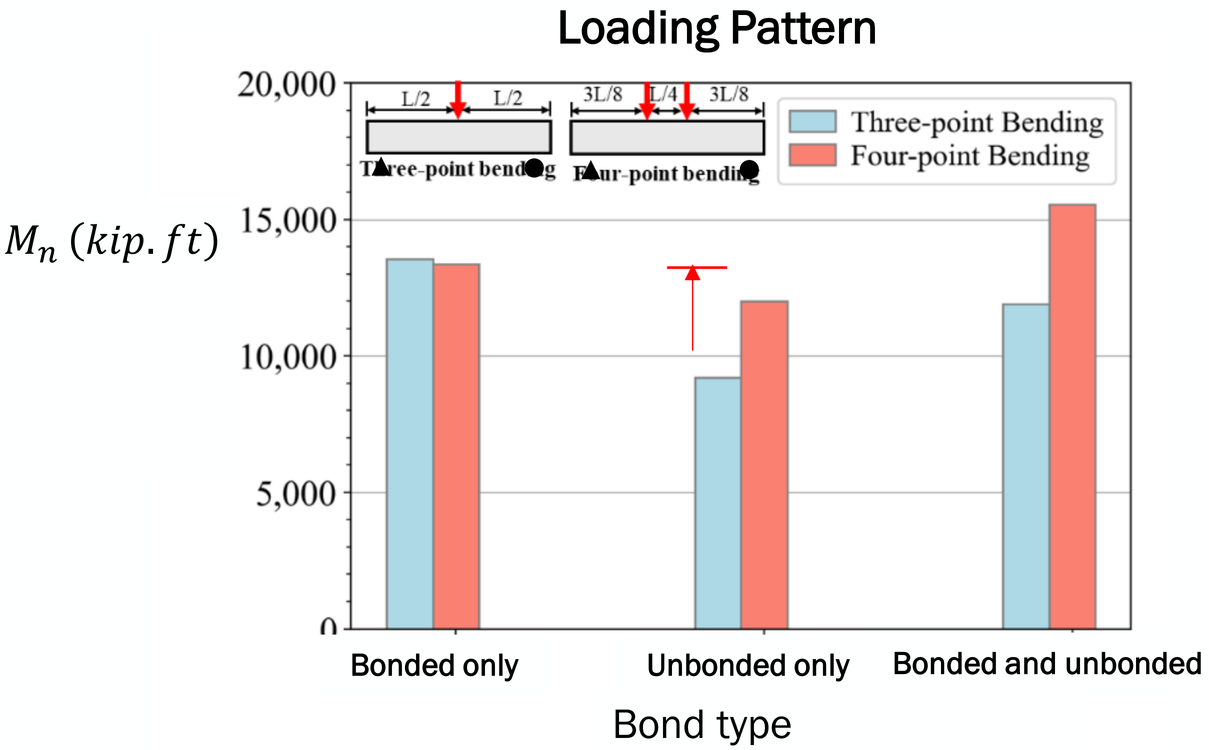
Parameters

Type	Simply supported girders	Continuous girders
Beam section type	• Bulb tee • U-shaped	• Bulb tee • U-shaped
Strand bond & location	• Bonded (IB) • Unbonded (IU) • Bonded & unbonded (IBU) • Bonded & external (IBE) • Unbonded & external (IEU)	• Bonded (IB) • Unbonded (IU) • Bonded & unbonded (IBU) • Bonded & external (IBE) • Unbonded & external (IEU)
Span length	• 80 ft – 140 ft	-
A_{ps}	• 7.81 in^2 – 11.72 in^2	-
A_{bonded}/A_{total}	• 0–100% (bonded strand) • 0–50% (mild reinforcement)	-
Loading type	• 3-point vs. 4-point bending	-
Strand profile	• Straight vs. parabolic (internal) • Straight vs. harped (external)	-
Concrete strength	• 8 ksi vs. 15 ksi	-

81 beams were analyzed

Impact of Parameters





- Capacity increases linearly with bonded prestress area ratio.
- For members with unbonded or combined strands, a constant moment region leads to higher capacity.

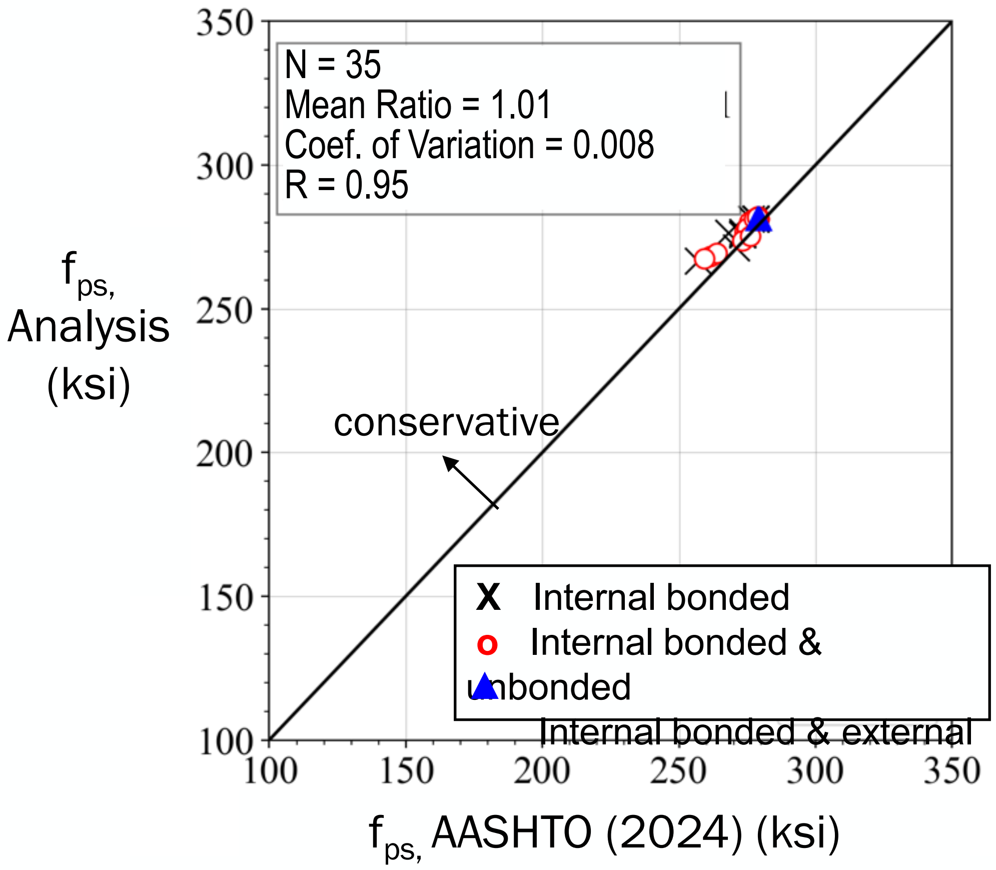
(Shown for simply supported girders only for clarity)

Evaluating Design Equations using Analysis Results

f_{ps} Predictions for Bonded Strands

AASHTO (2024) equation:

$$f_{ps,bonded} = f_{pu}\left(1 - k\frac{c}{d_p}\right)$$



AASHTO equation for bonded strands predicts f_{ps} well for:

- Members with bonded strands only
- Members with combined strands

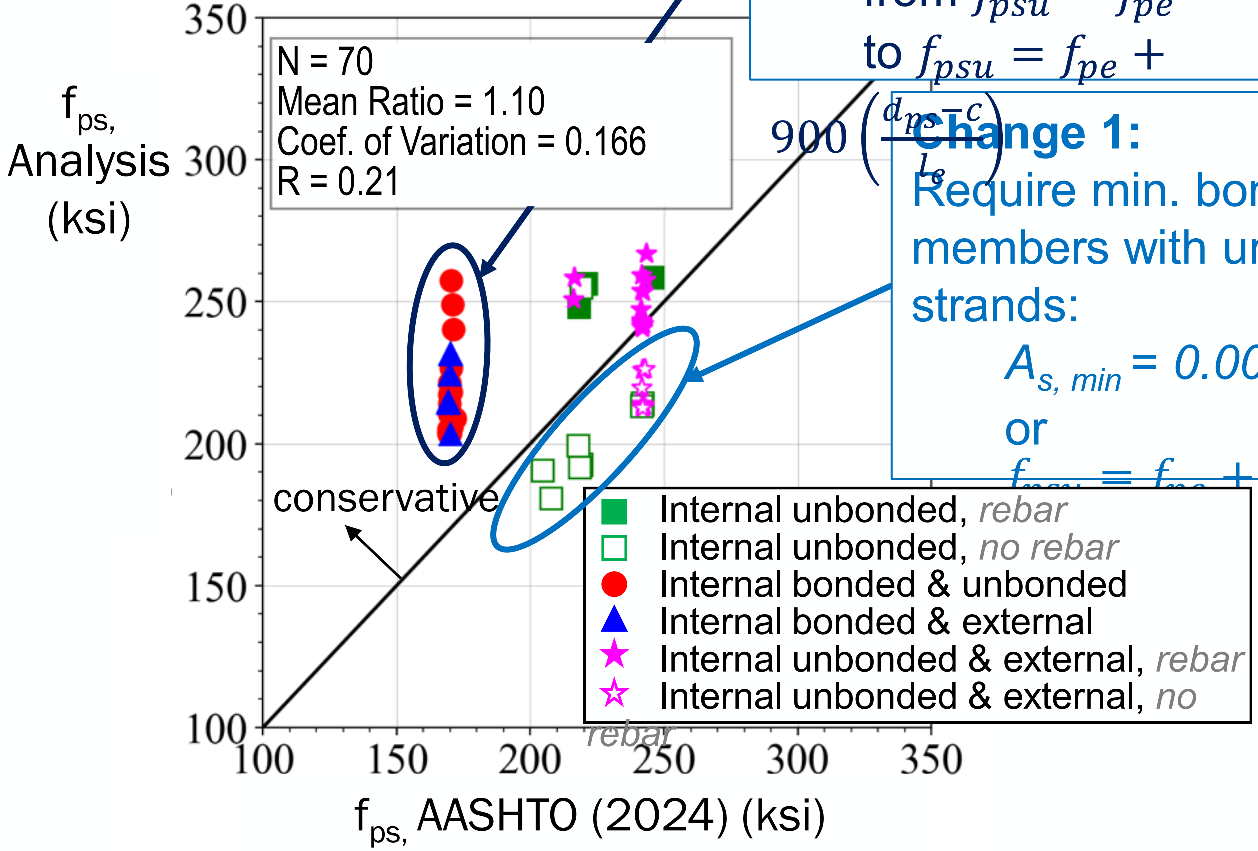
Evaluating Design Equations using Analysis Results

f_{ps} Predictions for Unbonded Strands

AASHTO (2024) equation:

For unbonded strands only: $f_{psu} = f_{pe} + 900\left(\frac{d_{ps} - c}{l_e}\right)$

For combined strands: $f_{psu} = f_{pe}$



Change 2:
Change unbonded strand stress equation in combined strands:
from $f_{psu} = f_{pe}$
to $f_{psu} = f_{pe} + 900\left(\frac{d_{ps}-c}{l_e}\right)$

Change 1:
Require min. bonded rf. area for members with unbonded strands:
$A_{s,\ min} = 0.004A_{ct}$
or
$f_{psu} = f_{pe} + 500\left(\frac{d_{ps}-c}{l_e}\right)$

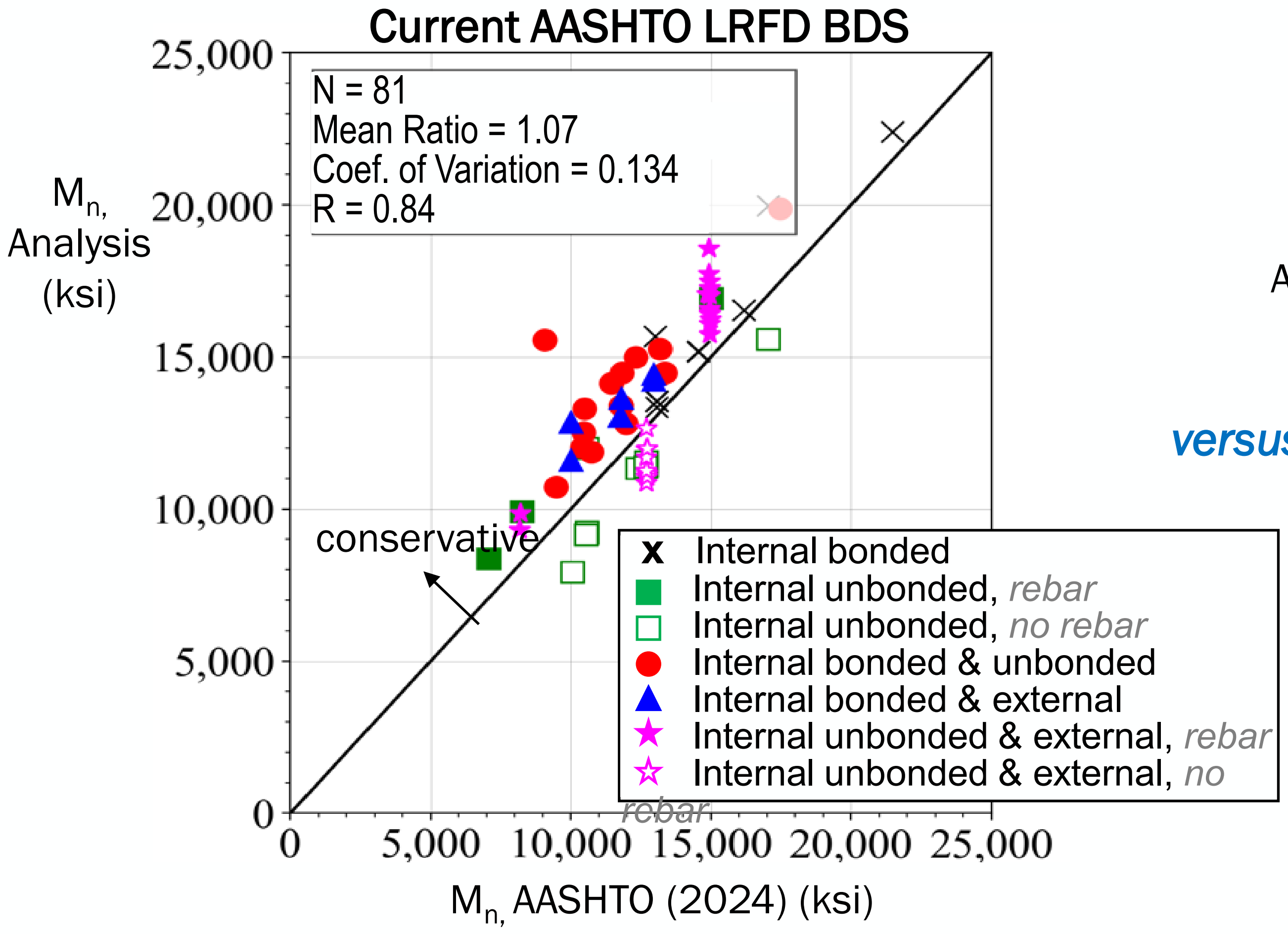
- AASHTO equation for unbonded strands does *not* predict f_{ps} well for members with no bonded reinforcement.
- Assuming $f_{psu} = f_{pe}$ leads to very conservative predictions for members with combined strands

Evaluating Design Equations using Analysis Results

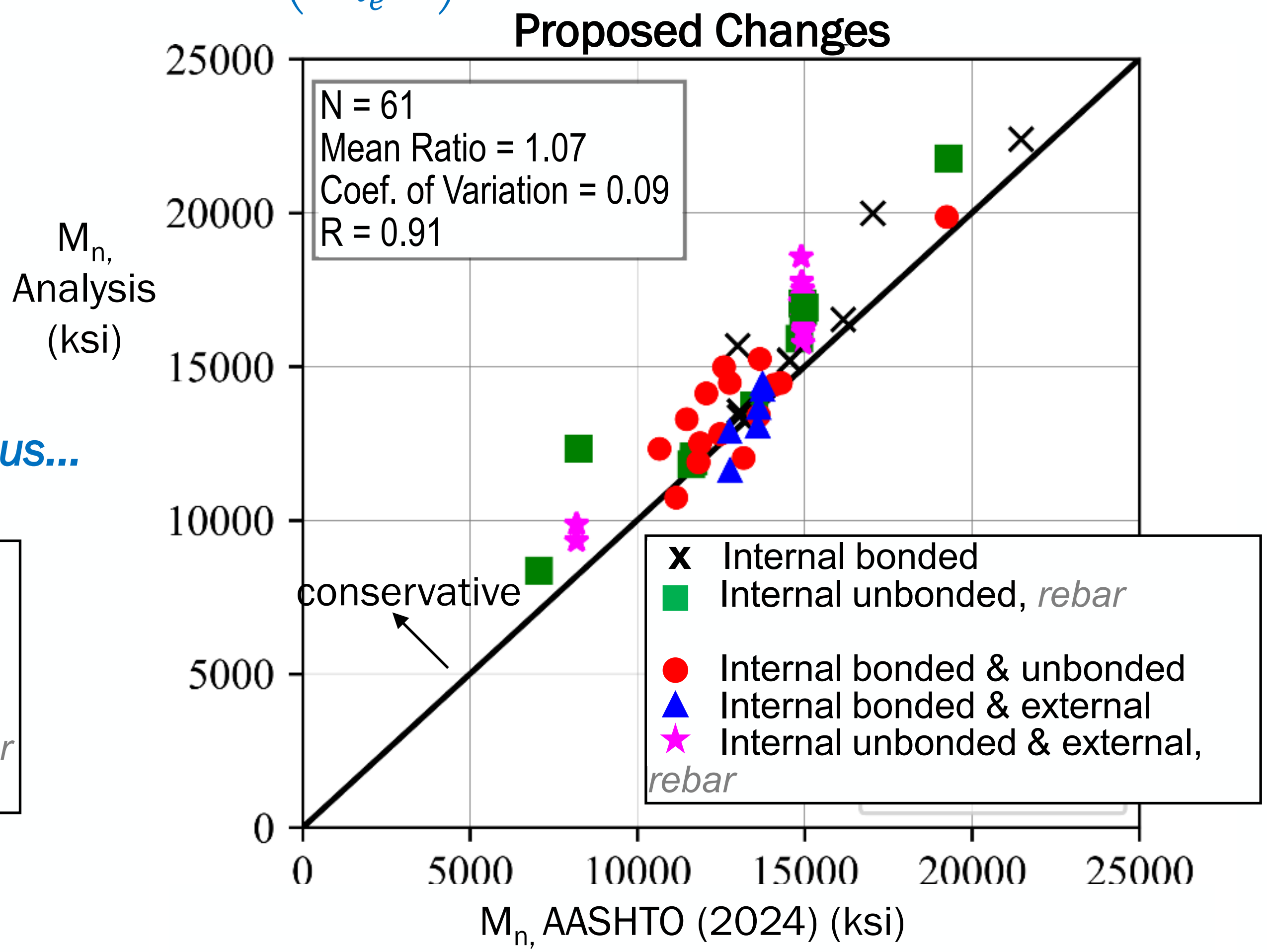
M_n Predictions

For unbonded strands only: $f_{psu} = f_{pe} + 900\left(\frac{d_{ps} - c}{l_e}\right)$ *and* $A_{s,\,min} = 0.004A_{ct}$

For combined strands: $f_{psu} = f_{pe} + 900\left(\frac{d_{ps} - c}{l_e}\right)$



versus...



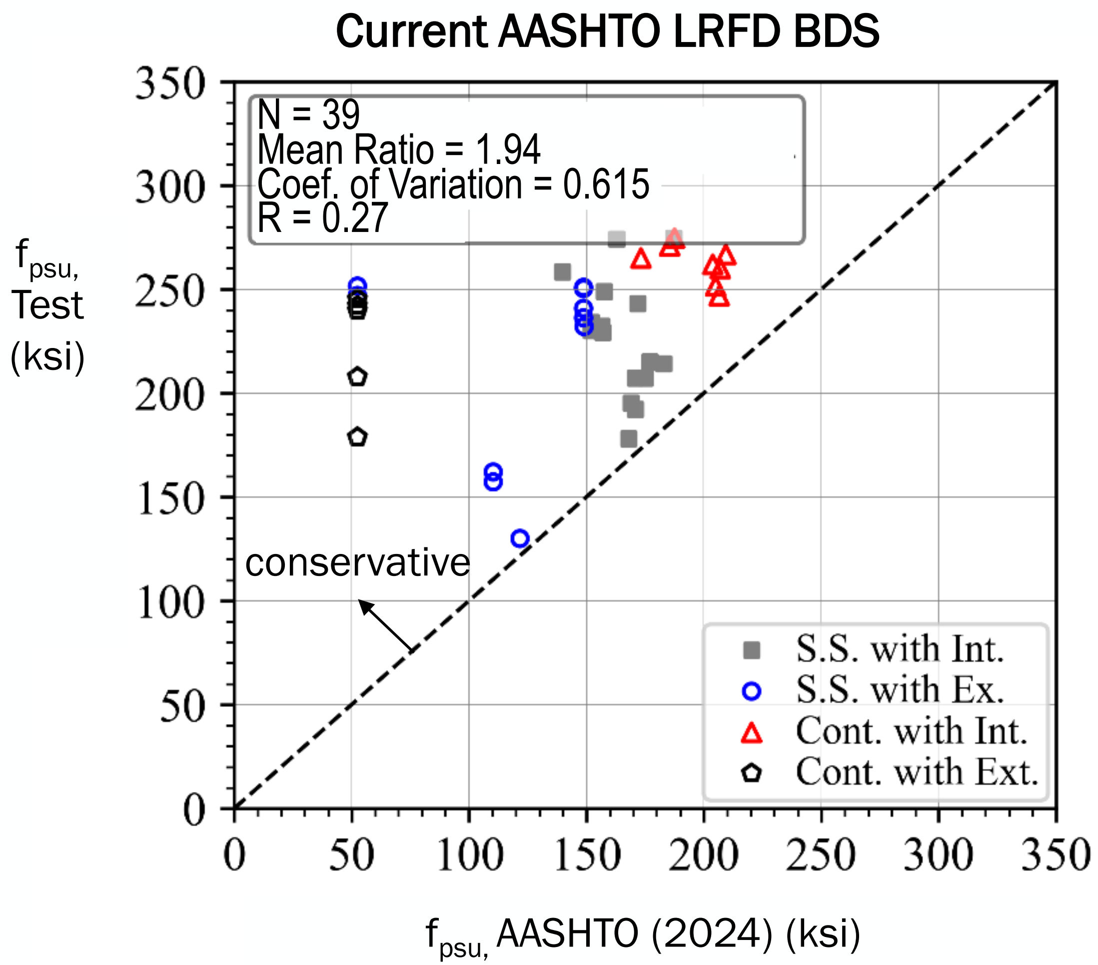
Test Data on Members with Combined Strands

Reference	No. of beams	Continuity	Unbonded strand type	Beam depth, in	Span length, ft	No. of loads along span
Mutsuyoshi et al. (1995)	1	Simply supported	Exterior	13	20	2
Kosa et al. (1997)	4	Simply supported	Exterior	39	32.8	2
Aravinthan et al. (2005)	7	Simply supported, Continuous	Exterior	6	16.4	2
Yoo and Ha (2010)	2	Simply supported	Exterior	15	9.8	2
Brenkus et al. (2017)	2	Simply supported	Interior	62	39	1-2
Abu-Obeidah (2017)	4	Simply supported	Interior	10	10	2
Abu-Saibia (2018)	8	Continuous	Interior	10	10	2
Consolazio et al. (2022)	7	Simply supported, Overhang	Interior	44	45-75	1
Frosch et al. (2024)	4	Simply supported	Interior or Exterior	28	26	2

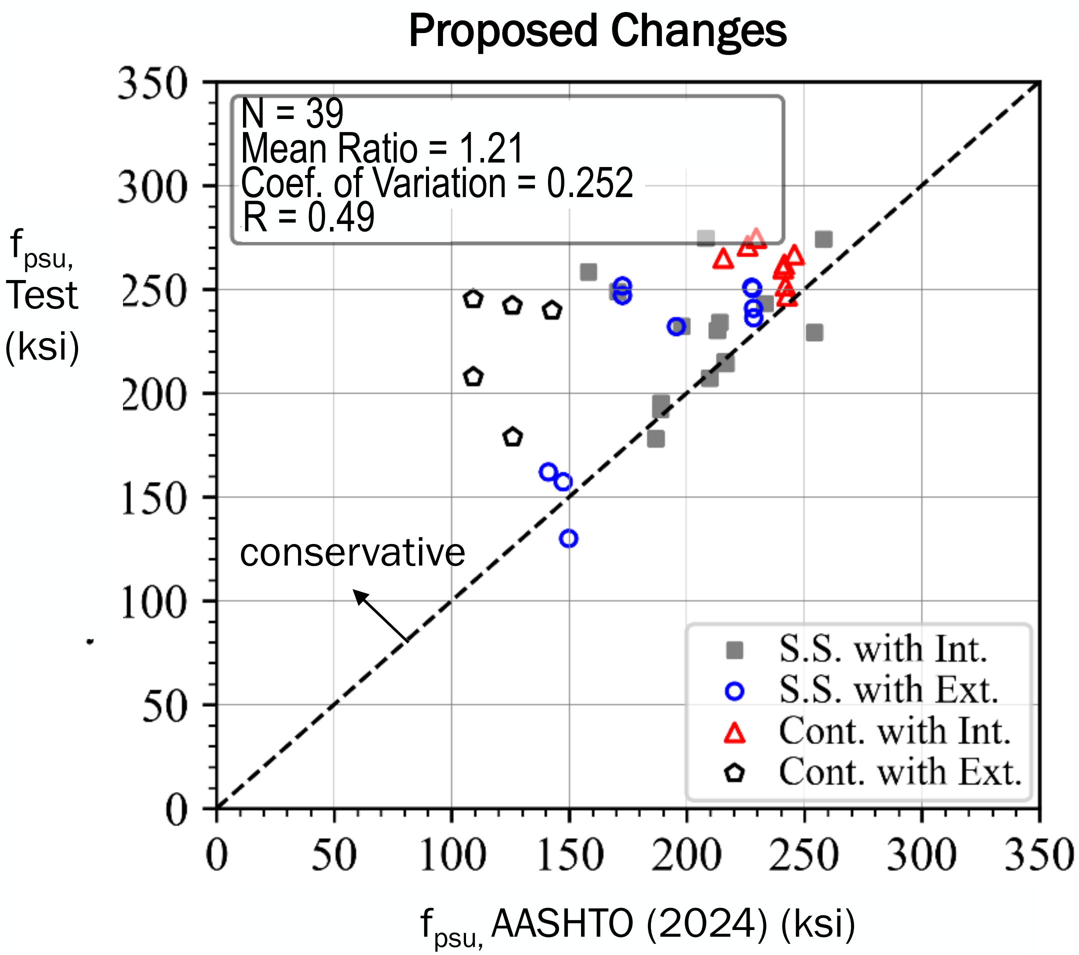
Total = 39 specimens

Evaluating Design Equations using Test Data

f_{ps} Predictions for Members with Combined Strands



versus...



Conclusions on Flexure

- **Bonded strands only**

  AASHTO predicts the capacity well:

$$f_{psb} = f_{pu}\left(1 - k\,\frac{c}{d_p}\right)$$

- **Unbonded strands only**

  AASHTO predictions are unconservative:

  unless there is no bonded reinforcement.

$$f_{psu} = f_{pe} + 900\left(\frac{d_{ps} - c}{l_e}\right)$$

- **Combined strands**

  AASHTO predictions are conservative:

$$f_{psb} = f_{pu}\left(1 - k\,\frac{c}{d_p}\right)$$
$$f_{psu} = f_{pe}$$

Proposed AASHTO Changes

Flexure Recommendations

- Provide minimum area of bonded tensile reinforcement (Article 5.6.3.1.2)

$$A_s \geq 0.004 A_{ct}$$

A_{ct} = area of that part of cross section between the flexural tension face and centroid of gross section

- Added commentary explaining reasoning for minimum bonded requirement

Research (NCHRP 12-118, 2024) has indicated that Eq. 5.6.3.1.2-1 can produce unconservative results if no bonded reinforcement is present. The minimum required bonded reinforcement, either prestressed or nonprestressed, should be located approximately an equivalent distance from the neutral axis as the main tensile reinforcment to be effective.

Flexure Recommendations

Article 5.6.3.1.3b

Current Weighted Average:

$$M_n = (A_{psb} + A_{psu}) f_{ps.avg} \left(d_p - \frac{a}{2} \right)$$

Proposed Change:

$$M_n = A_{psb} f_{psb} \left(d_{pb} - \frac{a}{2} \right) + A_{psu} f_{psu} \left(d_{pu} - \frac{a}{2} \right)$$

A_{psb} = area of bonded prestressing steel (in.^{2})
A_{psu} = area of unbonded prestressing steel (in.^{2})

f_{psb} = stress in bonded prestressing steel (ksi)
f_{psu} = stress in unbonded prestressing steel (ksi)

Flexure Recommendations

Article 5.6.3.1.3b

- Combined strands (bonded and unbonded)

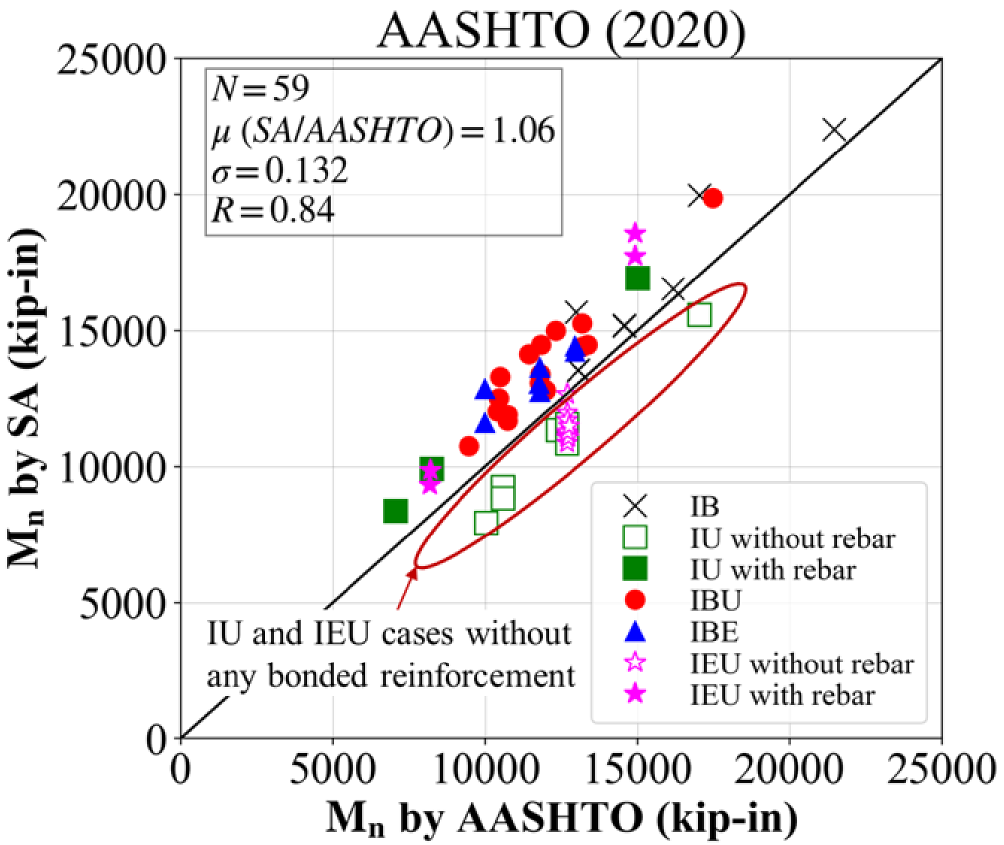
Bonded:

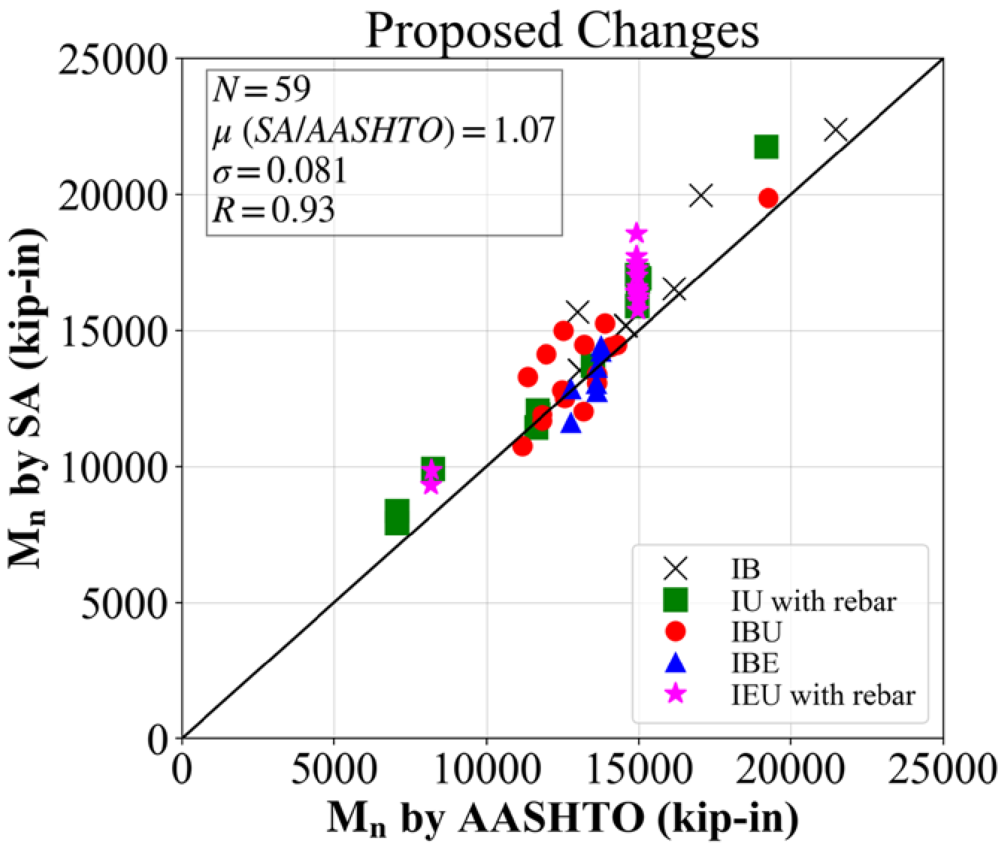
$$f_{psb} = f_{pu}\left(1 - k\,\frac{c}{d_p}\right)$$ *or* *by strain compatibility*

Unbonded:

$$f_{psu} = f_{pe} + 900\left(\frac{d_{ps} - c}{l_e}\right)$$ *or* $$f_{psu} = f_{pe}$$

Flexural Capacity





Minimum bonded reinforcement $\geq 0.004A_{ct}$

Unbonded strand stress increase for combined cases

Proposed Changes to Shear Capacity

- Revise web width used in the shear strength upper limit (Eq. 5.7.3.3-2), subtracting the duct width whether bonded or unbonded
- For the modified compression field theory shear strength (Eq. 5.7.3.3-1), the full web width should be used without reduction for duct widths
- Define new variable, b_w, to clarify when the width is reduced, and when it is not
- Removal of the duct factor, λ_{duct}, in both shear and torsion provisions

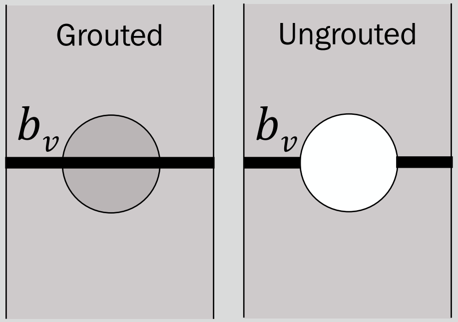
Shear Recommendations

2020 Specification (9th ed.)

Lesser of:

$$V_n = V_c + V_s + V_p$$

$$V_n = 0.25 f'_c b_v d_v + V_p$$



for grouted ducts: $b_v = b_w$

for ungrouted ducts: $b_v = b_w - \emptyset_{duct}$

$$V_c = 0.0316 \beta \lambda \sqrt{f'_c}\, b_v d_v$$

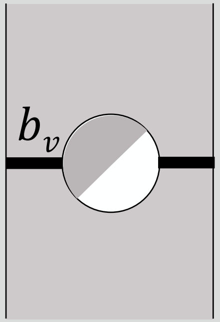
$$V_s = \frac{A_v f_y d_v (\cot\theta + \cot\alpha)\sin\alpha}{s}$$ ~~λ_{duct}~~

~~$\lambda_{duct} = 1 - \delta\left(\frac{\phi_{duct}}{b_w}\right)^2$~~

Proposed Revision (Article 5.7.3.3)

$$V_n = V_c + V_s + V_p$$

$$V_n = 0.25 f'_c b_v d_v + V_p$$



for ALL ducts: $b_v = b_w - \emptyset_{duct,\,OD}$

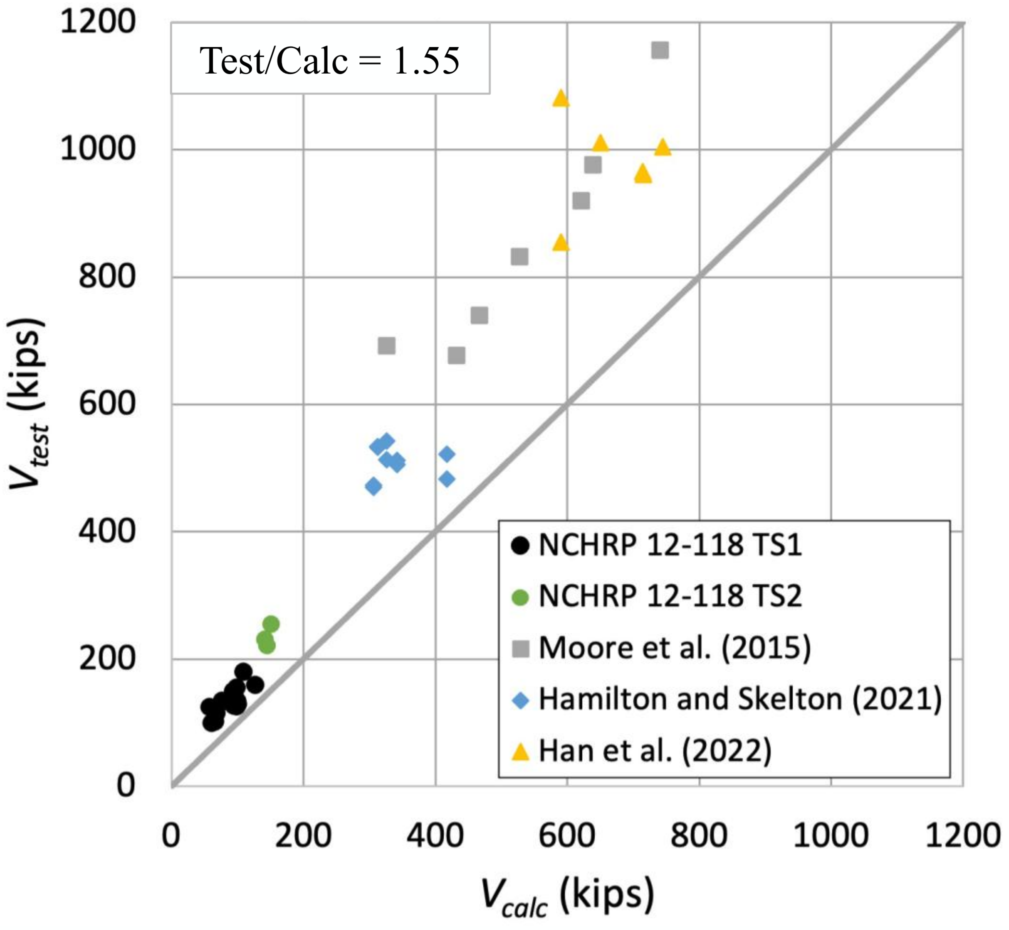
$$V_c = 0.0316 \beta \lambda \sqrt{f'_c}\, b_w d_v$$

$$V_s = \frac{A_v f_y d_v (\cot\theta + \cot\alpha)\sin\alpha}{s}$$

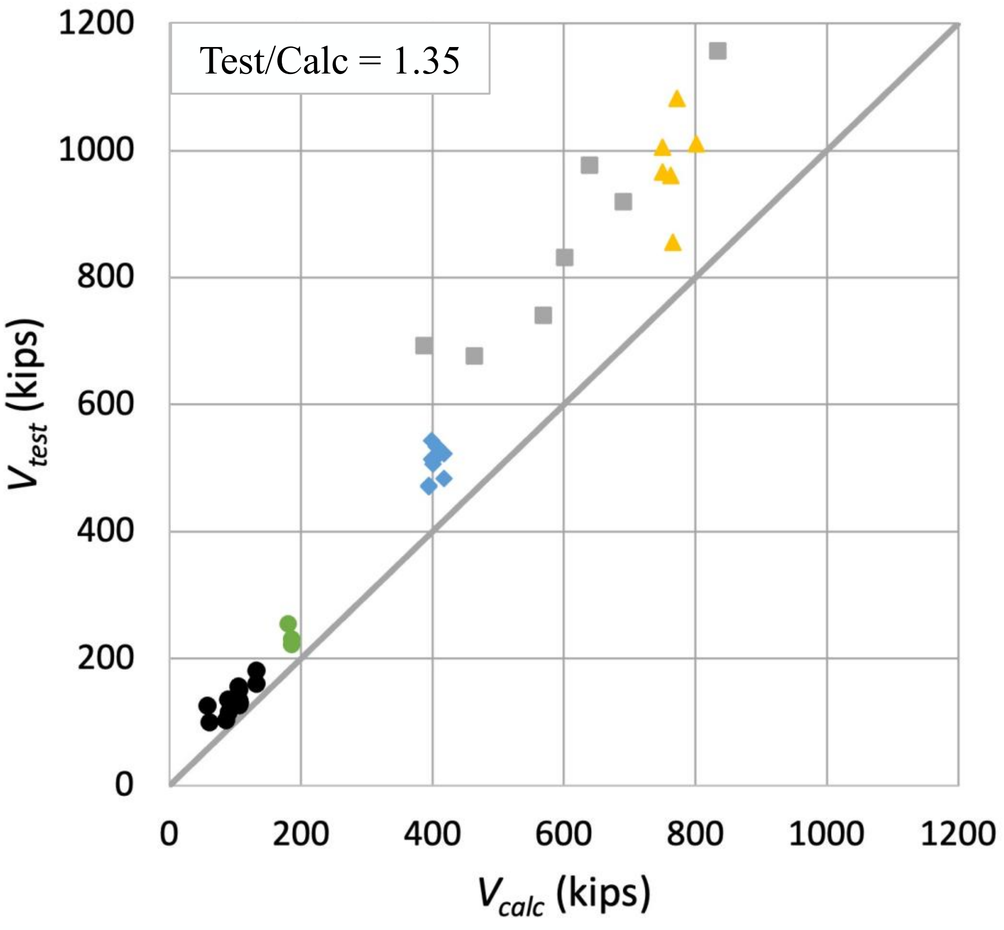
Proposed Changes to Commentary C5.7.3.3

Post-tensioning ducts in the web reduce the area of concrete that resists shear stresses. The reduced cross-section results in higher stresses at the location of the ducts and can result in compression failure of the web. Research (Moore et al., 2015, Han et al., 2022, and NCHRP 12-118, 2024) has shown that the effective width of the web is reduced by the dimension of the duct for both bonded and unbonded tendons. Therefore, shear strength is limited by this failure mechanism which is accounted for by the reduced web width b_v in Eq. 5.7.3.3-2. While the effective web width b_v is used in Eq. 5.7.3.3-2 to prevent crushing, the entire web width b_w is used in Eq. 5.7.3.3-3 as the entire web engages the shear transfer mechanism (Han et al., 2022 and NCHRP 12-118, 2024).

Shear Capacity



AASHTO (2020)



Proposed Changes

Proposed Changes to AASHTO Construction Specs

- Current specifications do no accommodate flexible filler (only grouted ducts)
- Article 8.16.3.3 - add language referencing flexible filler
- Articles 10.4.1.2 and 10.8.3 - discuss requirements for smooth black PE ducts, reference flexible filler

Thank You

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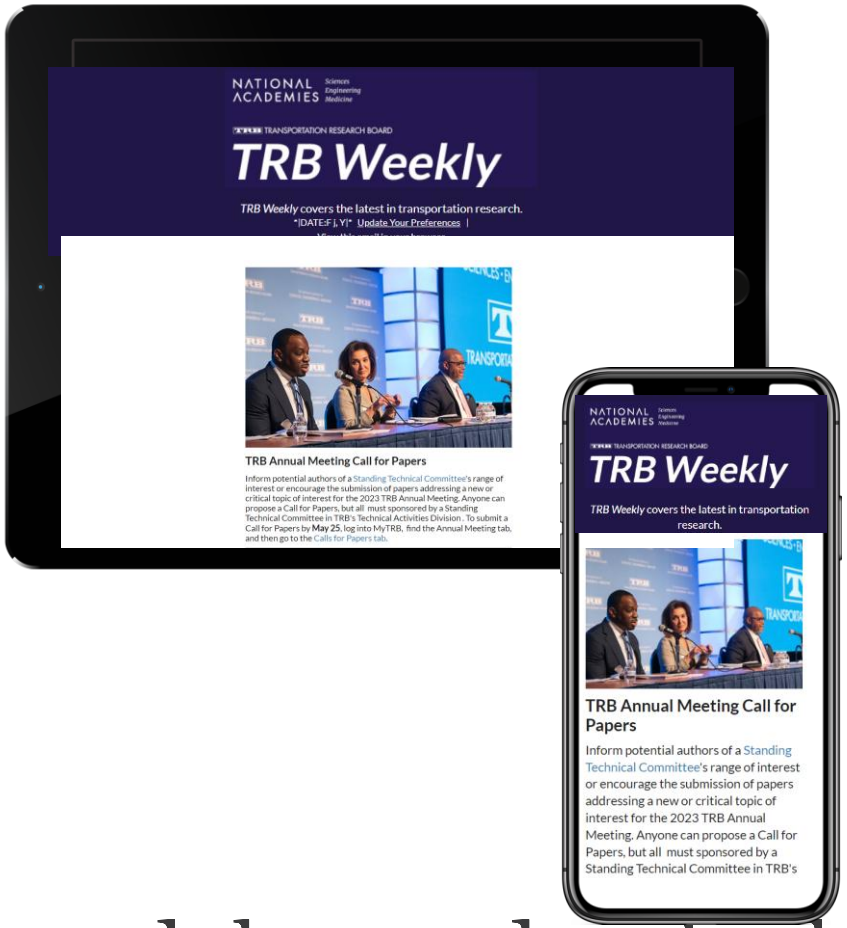

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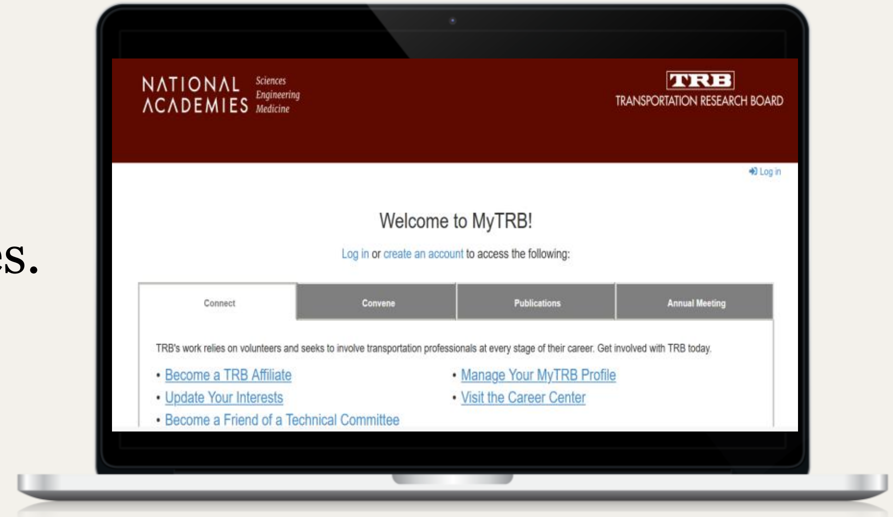

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