NATIONAL ACADEMIES Sciences Engineering Medicine

TRB TRANSPORTATION RESEARCH BOARD

TRB Webinar: Using 0.7-inch Strands for Better Bridge Design

March 20, 2023

3:00 – 4:00 PM

NOVEMBER 2022 UPDATE

PDH Certification Information

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

You must attend the entire webinar.

Questions? Contact Andie Pitchford at TRBwebinar@nas.edu

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ENGINEERING RCEP REGISTERED CONTINUING EDUCATION PROGRAM

Purpose Statement

For the first time, AASHTO Load-and-Resistance Factor Design (LRFD) Bridge Design Specifications will permit the use of 0.7-inch strands. The use of 0.7-inch strands could cut down on the number of strands in a girder, reduce the number of girders in a bridge, achieve longer spans, and allow the use of shallower girders for the same span length. This webinar will present the results of a multi-year, multi-organizational research program leading to AASHTO's revision. Presenters will discuss the benefits and considerations of moving to 0.7-inch strands, compared to 0.6-inch strands. Presenters will also share the challenges to application and special attention to end region detailing..

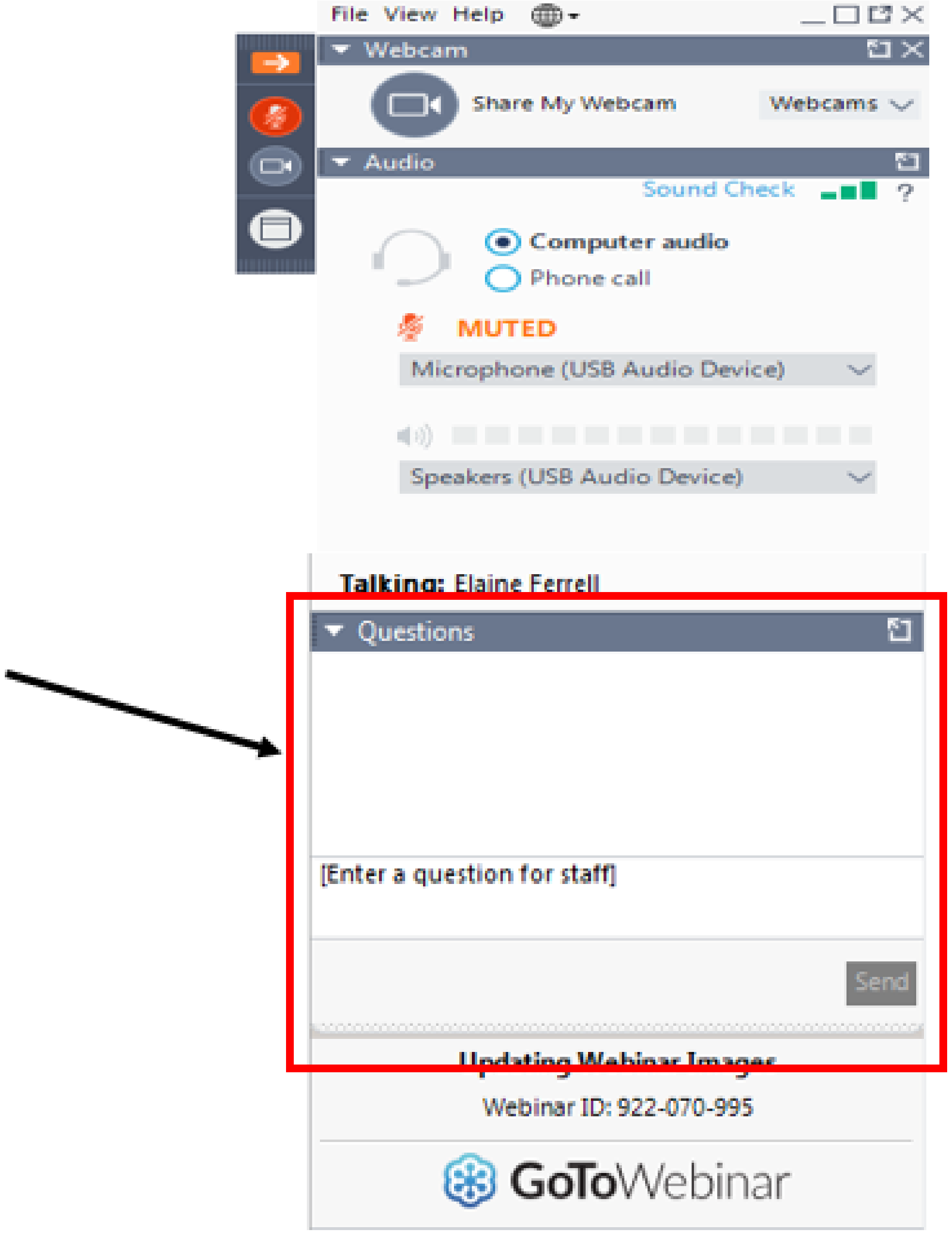
Learning Objectives

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

- (1) Determine the cases for which 0.7-inch strands offer advantages over 0.6-inch strands
- (2) Detail the end regions when 0.7-inch strands are used
- (3) Identify the research leading to the revisions to AASHTO LRFD Bridge Design Specifications

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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0.7-in. Strands – Applications and Detailing Requirements

Outline

Background and motivations for using 0.7-in. strands

Part 1: Design parametric study

Part 2: Full-scale girder tests

Background

- Current practice
  - Seven-wire prestressing strands conform to ASTM A416 /AASHTO M203
  - Grade 270 low-relaxation strand is typical
  - 0.6-in. strands have been industry standard since the mid 1990s
- Seven-wire, 0.7-in. Grade 270 low relaxation strands have primarily been used as cable or strand roof anchors in the mining/tunneling industries.
- Prior to NCHRP 12-109 project (*Use of 0.7-in. Diameter Strands in Precast Pretensioned Girders*), 0.7-in. strands were not permitted in *AASHTO LRFD Bridge Design Specifications*.

Motivations for using 0.7-in. strands

- The cross-sectional area of 0.7-in. strands is 35% larger than 0.6-in. strand: 0.294 in.^{2} for 0.7-in. vs. 0.217 in.^{2} for 0.6-in.
- 0.7-in. strands in conjunction with higher-strength concrete have the potential to:
  1. reduce the required number of strands in a girder for the same span, alleviating congestion
  2. allow increased girder spacing, reducing the total number of girders required for a bridge, shortening construction time and cost as well as reducing overall embodied energy
  3. increase span length, potentially eliminating the central pier in typical two-span bridges or reducing the number of piers in longer-span bridges
  4. allow shallower girders be used, which benefits replacement projects that must maintain or increase existing clearances beneath the bridge

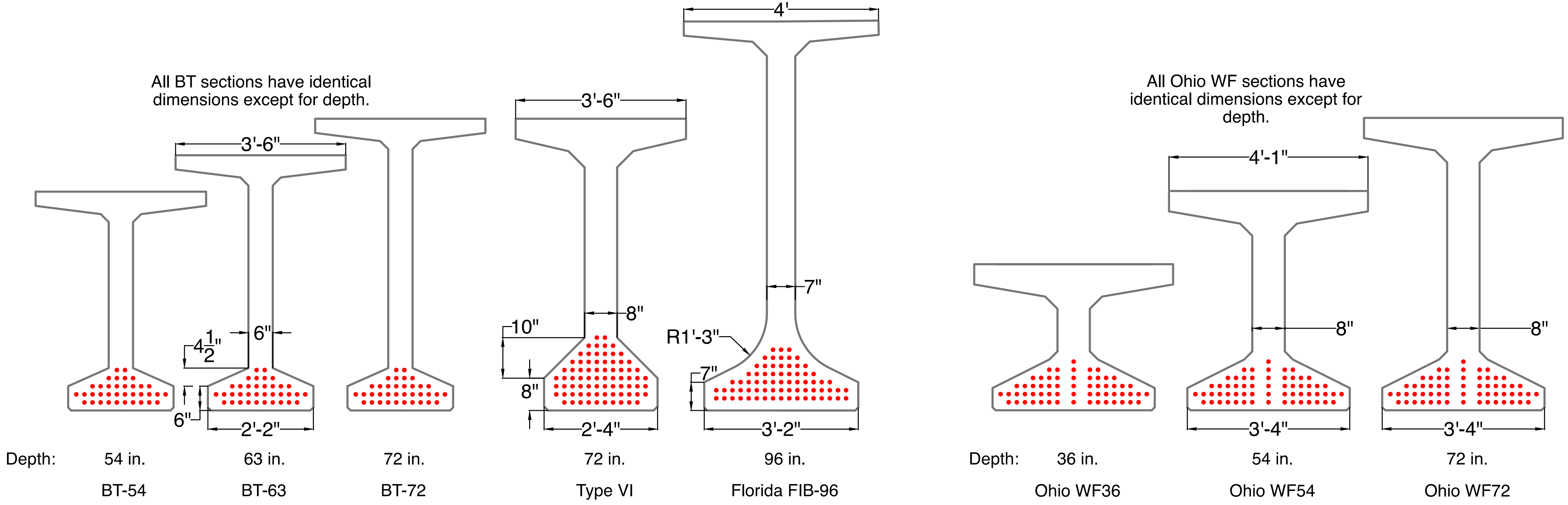
Part 1: Design parametric study

Overall information

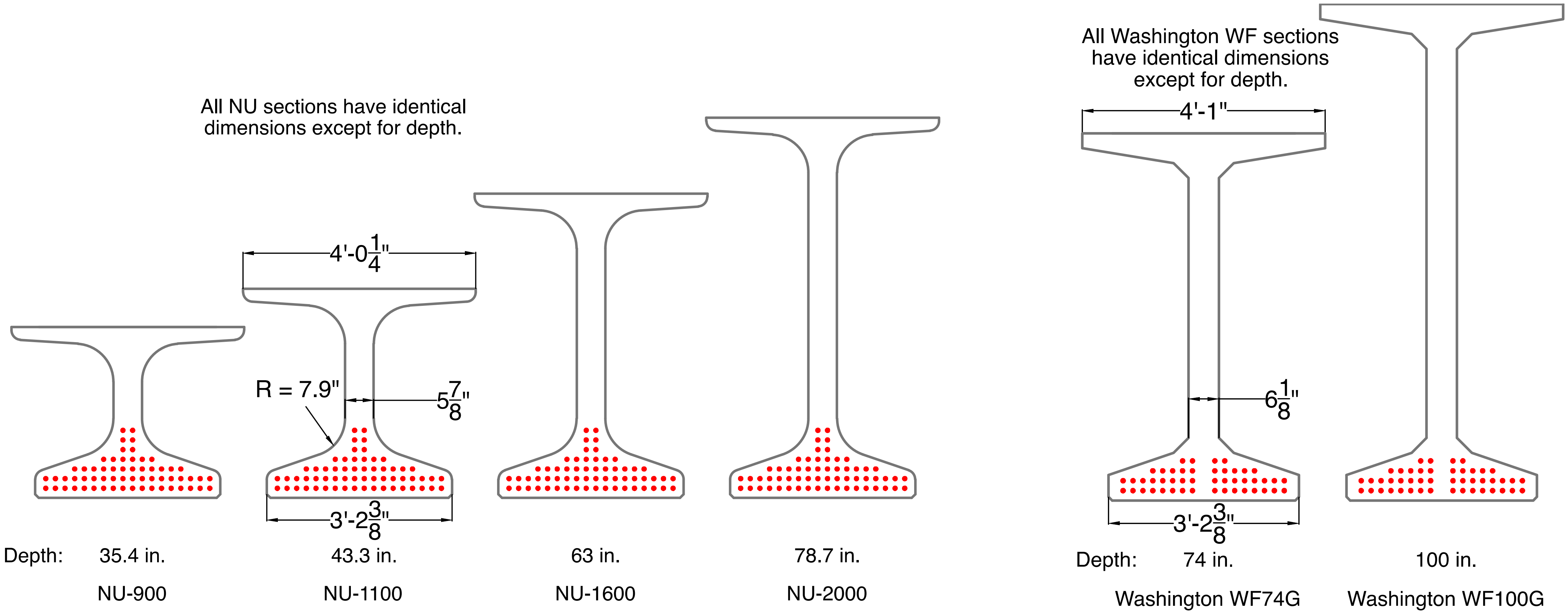
- 584 pretensioned girder design cases (interior girders)
- Design objective was to maximize the girder span meeting all requirements of *AASHTO LRFD Bridge Design Specifications*.
- Stability considerations will be addressed in the second part.

Parameter	Range
NWC design f'_c	10, 15, 18 ksi (f'_{ci} = 8, 9, 10.8 ksi)
LWC design f'_c	10 ksi (f'_{ci} = 8 ksi)
Strand diameter	0.6 in., 0.7 in.
Girder spacing	Single web girders: 6, 8, 10, 12 ft
	Double web girders: 12, 14, 16 ft
Number of spans	One simple span

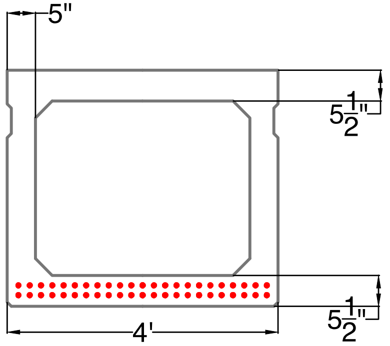
Cross sections



Cross sections

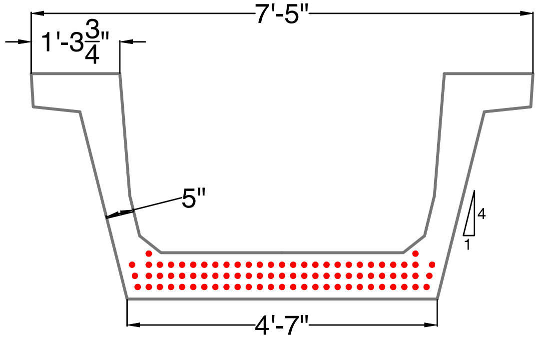


Cross sections



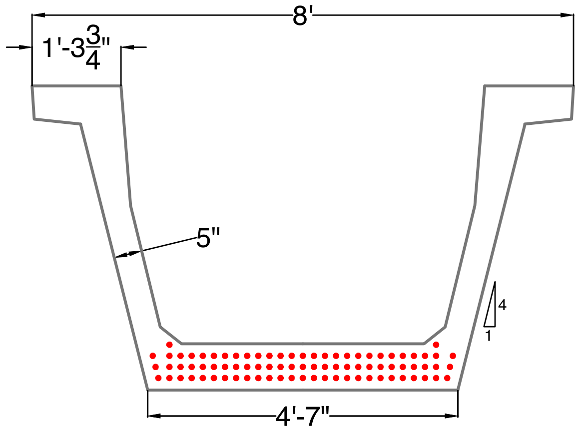
Depth: 42 in.

BIV-48



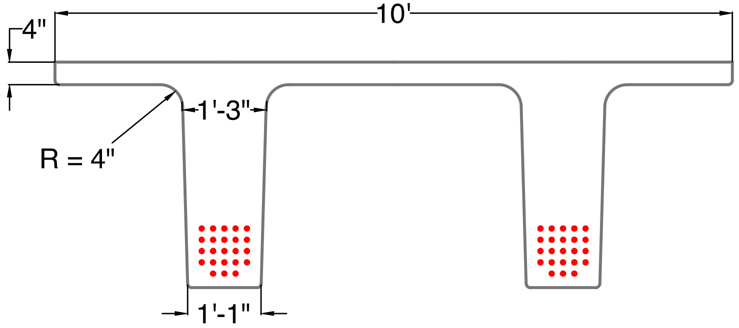
Depth: 40 in.

U-40



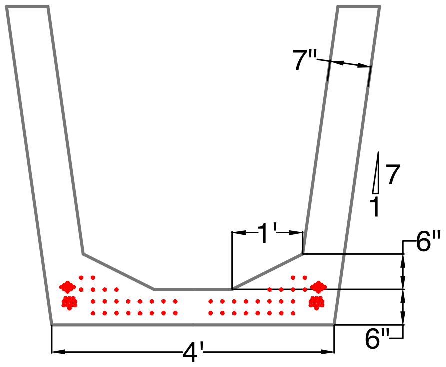
54 in.

U-54



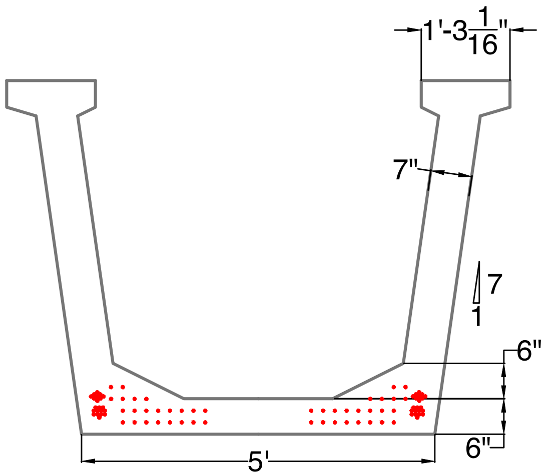
Depth: 40 in.

NEXT 40D



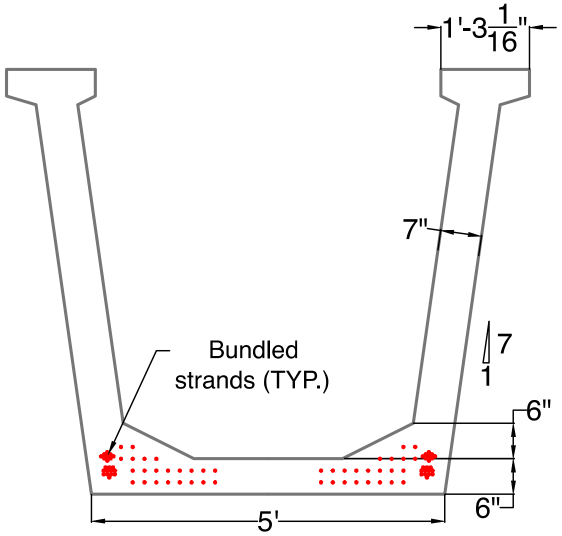
Depth: 54 in.

U54G4



60 in.

UF60G5



72 in.

UF72G5

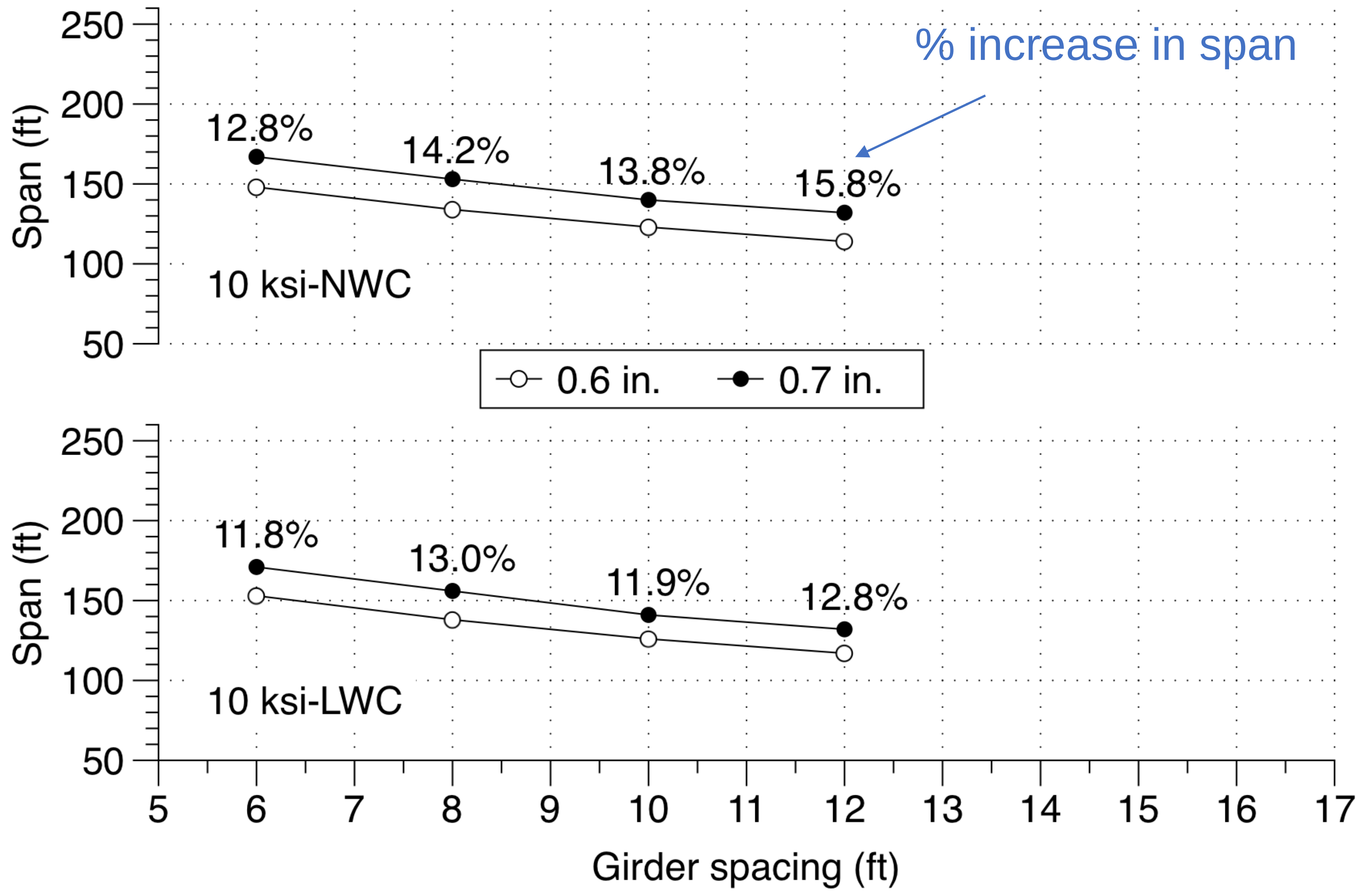
Loads

- DC
  - LWC = 0.125 kcf
  - NWC = 0.145 kcf for $f'_c \leq 5$ ksi
  - NWC = 0.140 + 0.001 f'_c for $f'_c > 5$ ksi
  - Add 0.005 kcf for reinforcement
  - 0.6 klf for rail/barrier walls (distributed equally across all girders)
  - 2-in. haunch over the entire top flange (not included in capacity calculations)
- DW
  - 2-in. thick wearing surface (0.150 kcf)
- HL-93

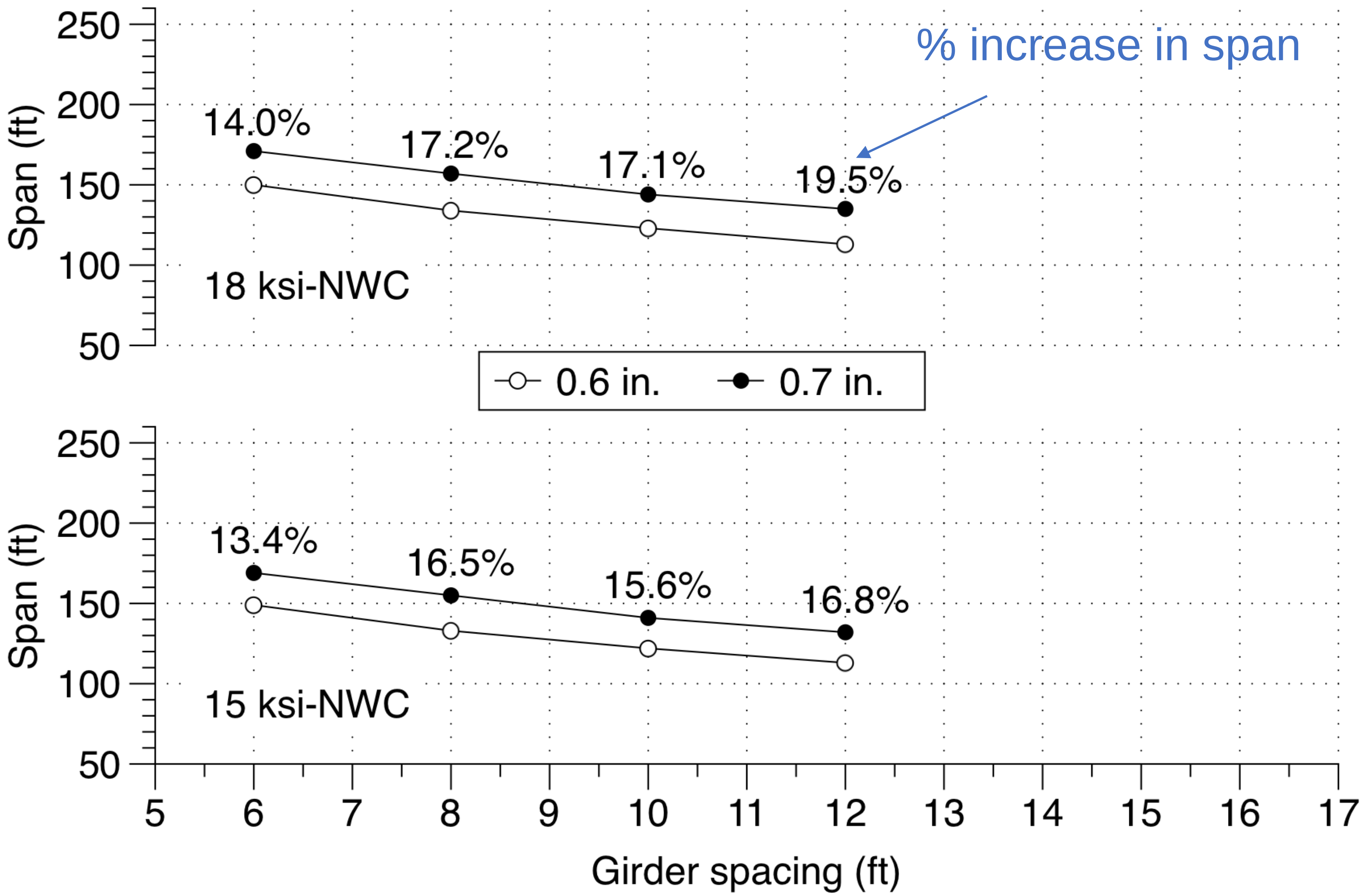
Reinforcement

- Debonding within current AASHTO limits
- Harp points
  - 8 or fewer strands: 15 ft on either side of girder centerline
  - > 8 strands: second harp points at 19 ft on either side of girder centerline
  - Limited to 1/3 of total strands
  - Slope is limited to
    - 1-on-8 for 0.6-in. strands
    - 1-on-11 for 0.7-in. strands
- Four top strands stressed to 15 kips each
  - These strands were included in the calculations

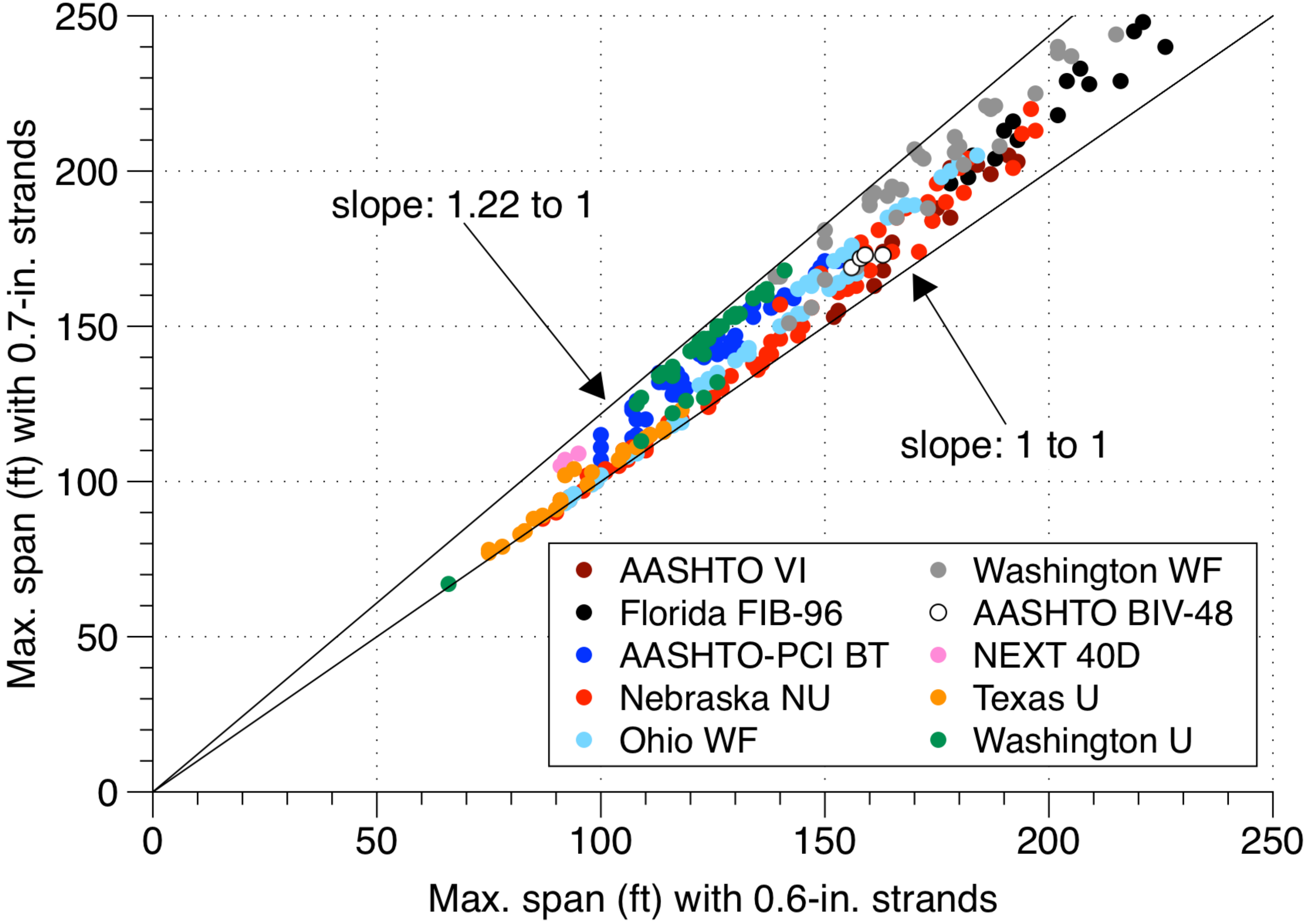
Results: Increase in span length with 0.7-in strand (BT-72)



Results: Increase in span length with 0.7-in strand (BT-72)



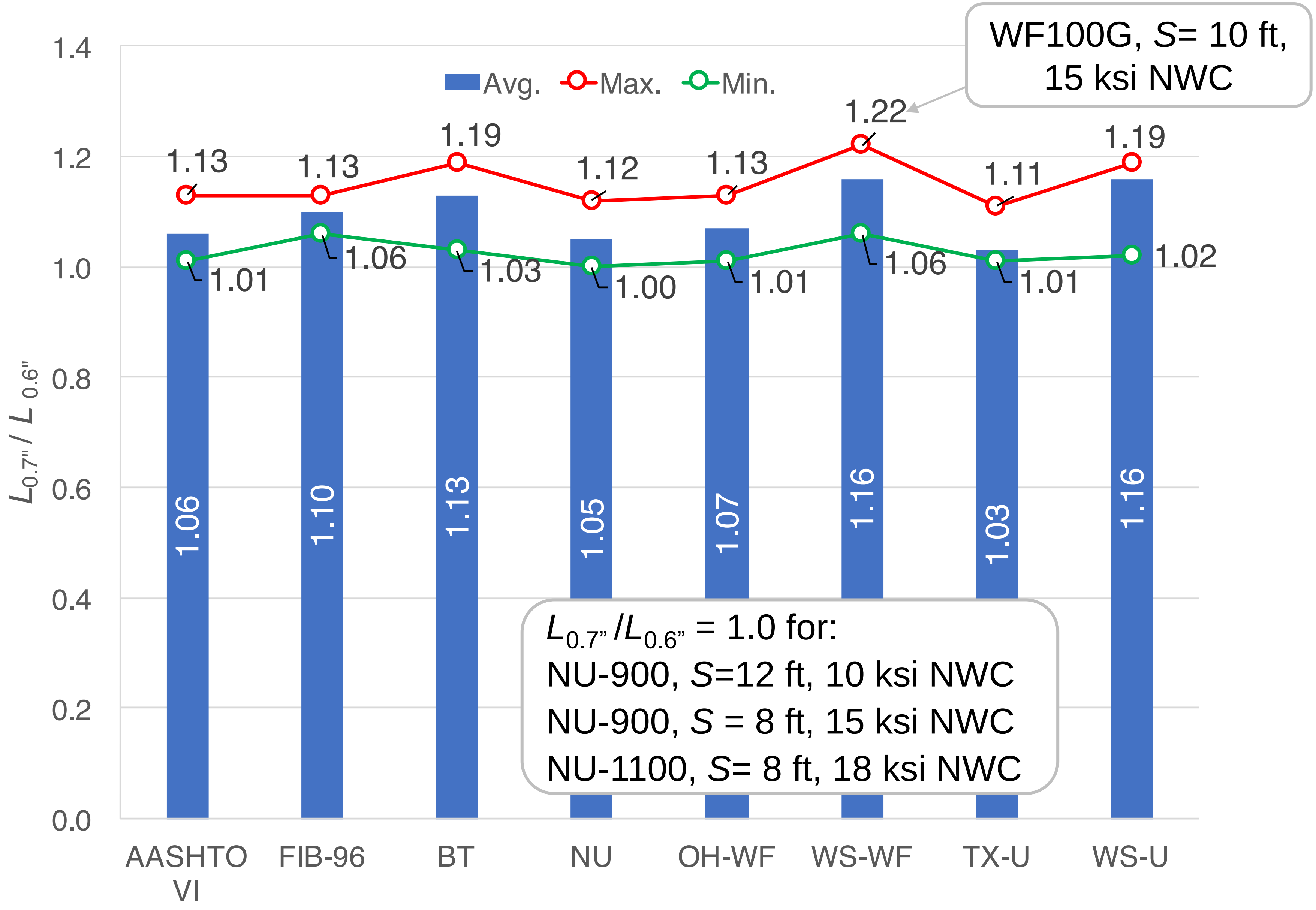
Results: Span increases



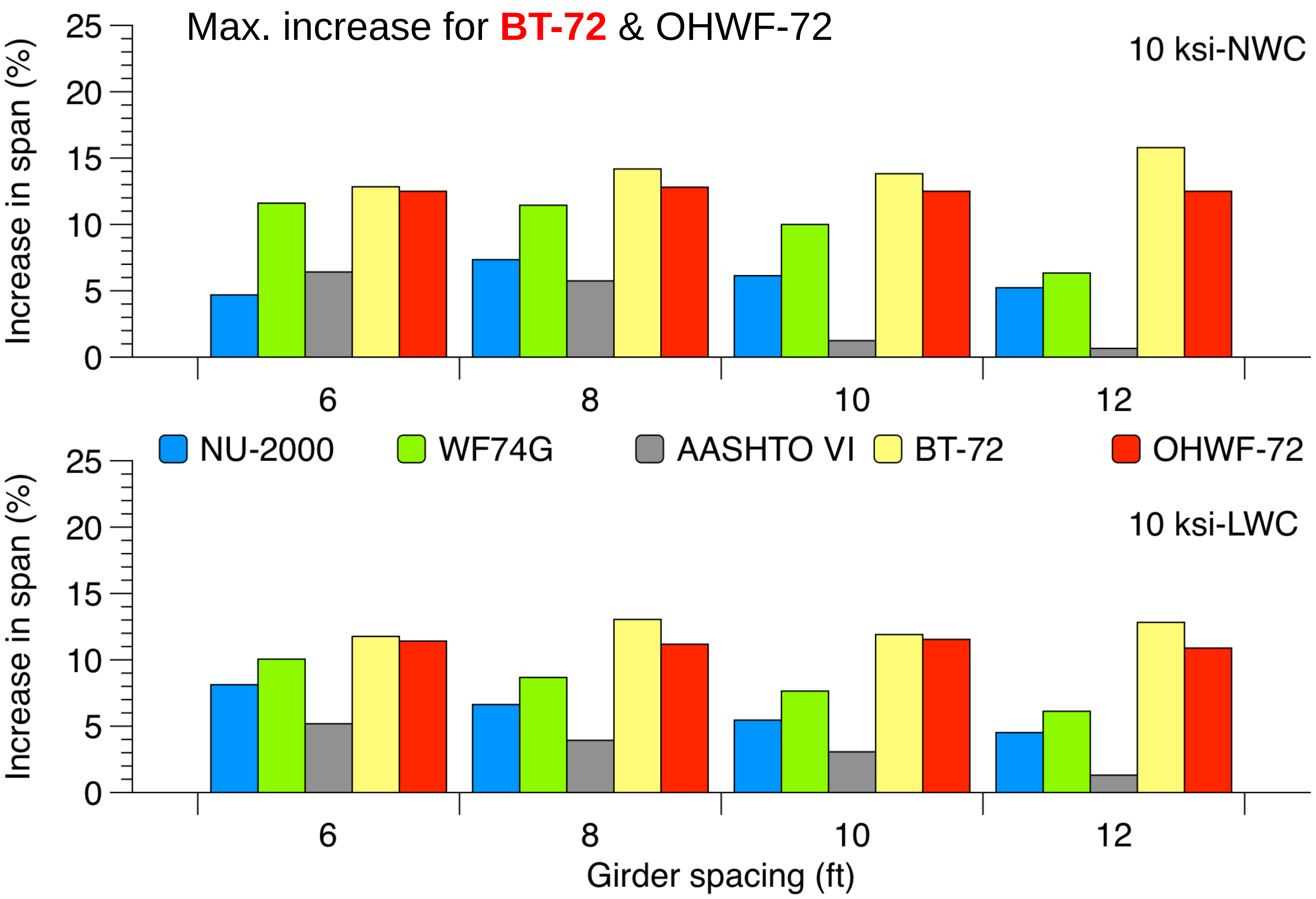
$$\frac{A_{0.7''}}{A_{0.6''}} = 1.35$$

$$\left(\frac{L_{0.7''}}{L_{0.6''}}\right)_{avg.} = 1.09$$

Results: Span increases



Results: Single-web girders



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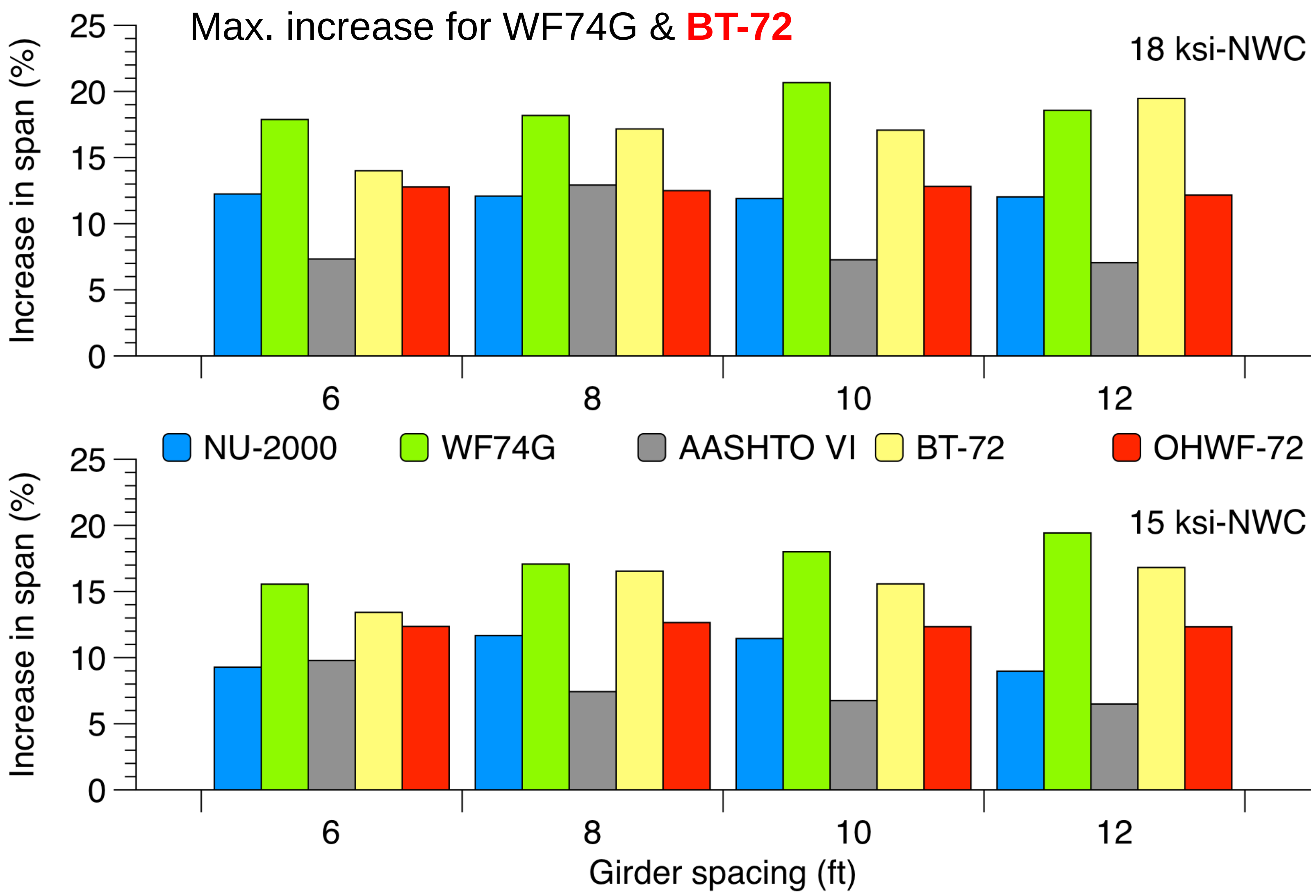
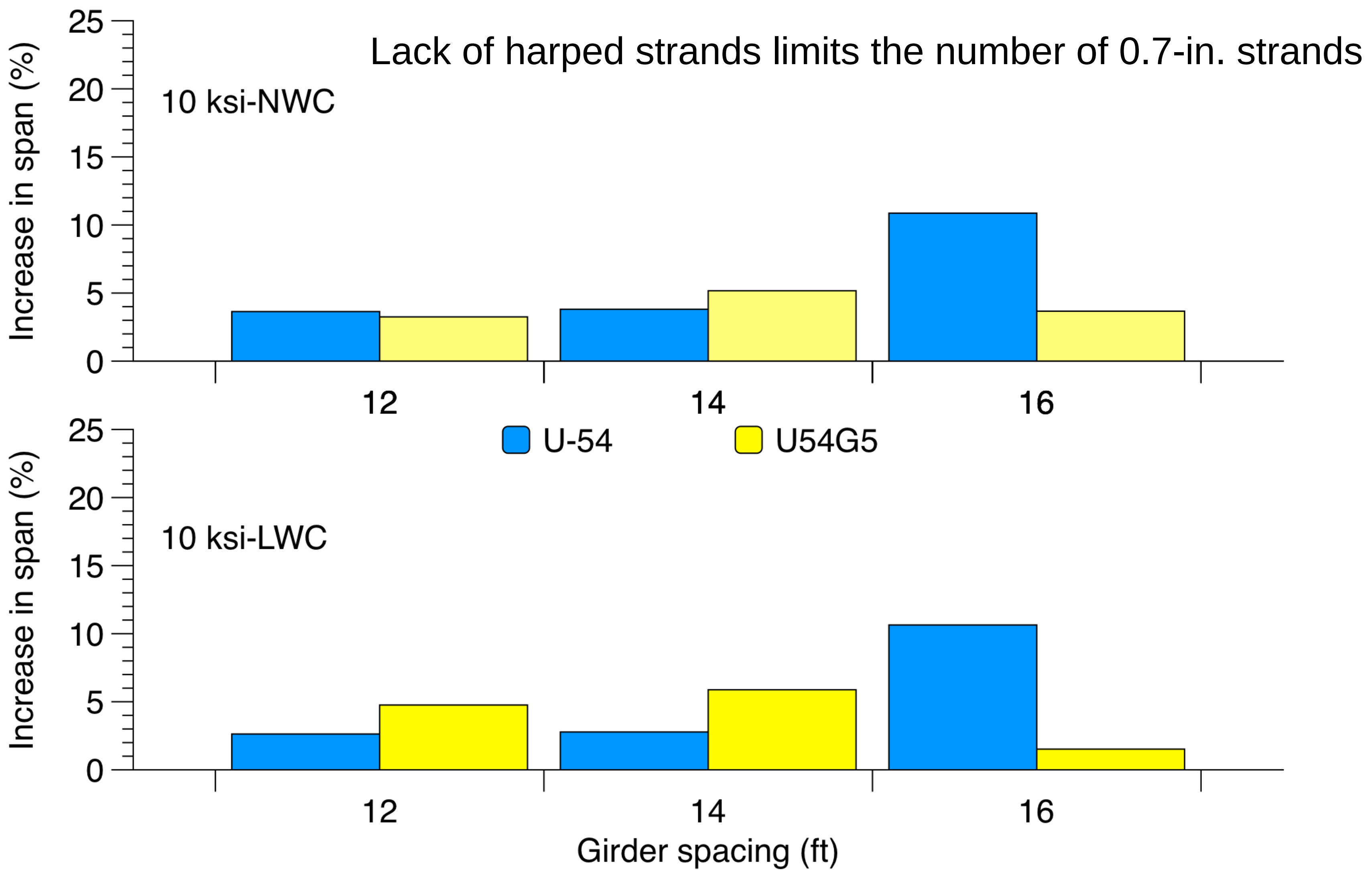
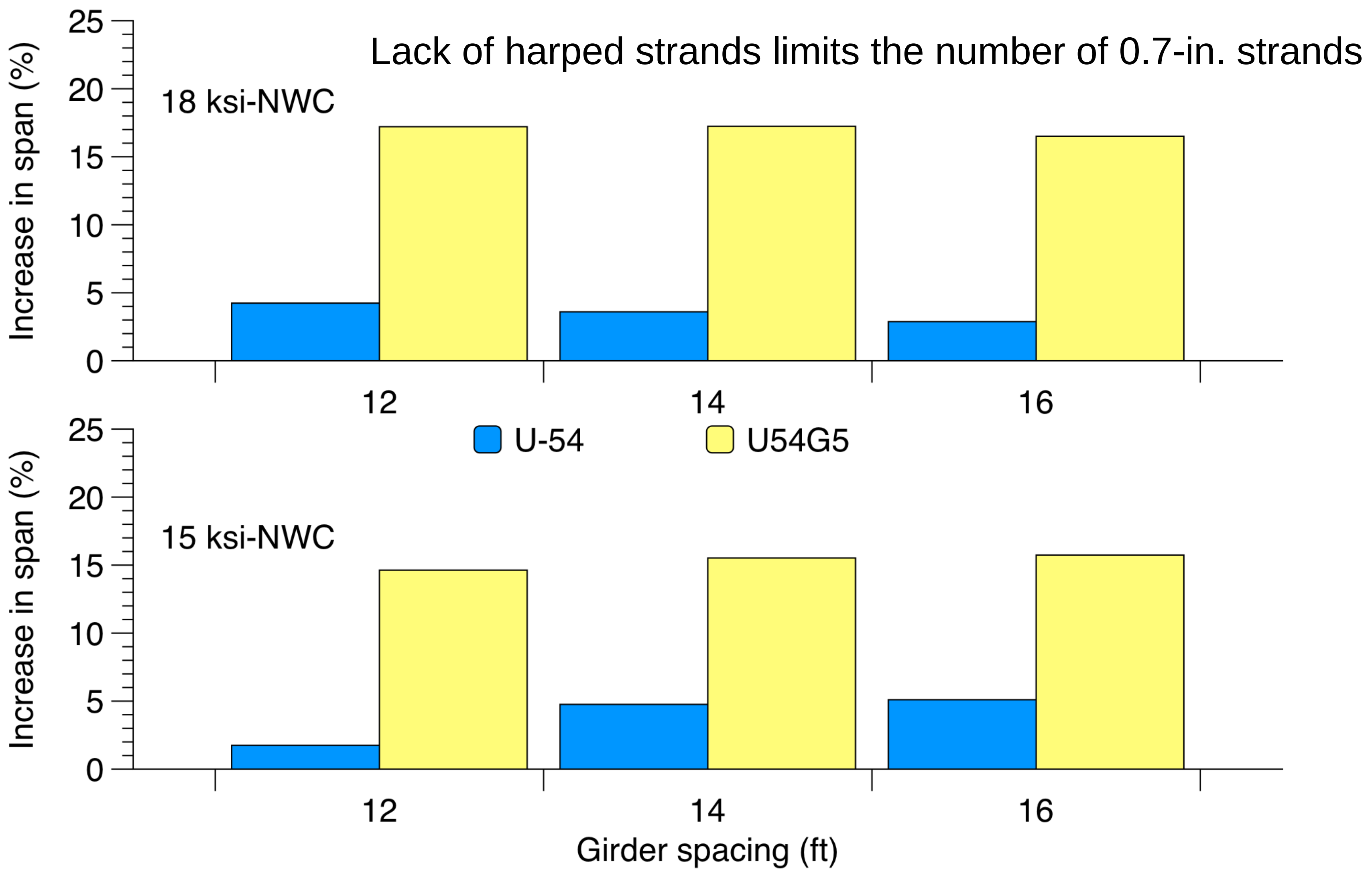


Results: Double-web girders

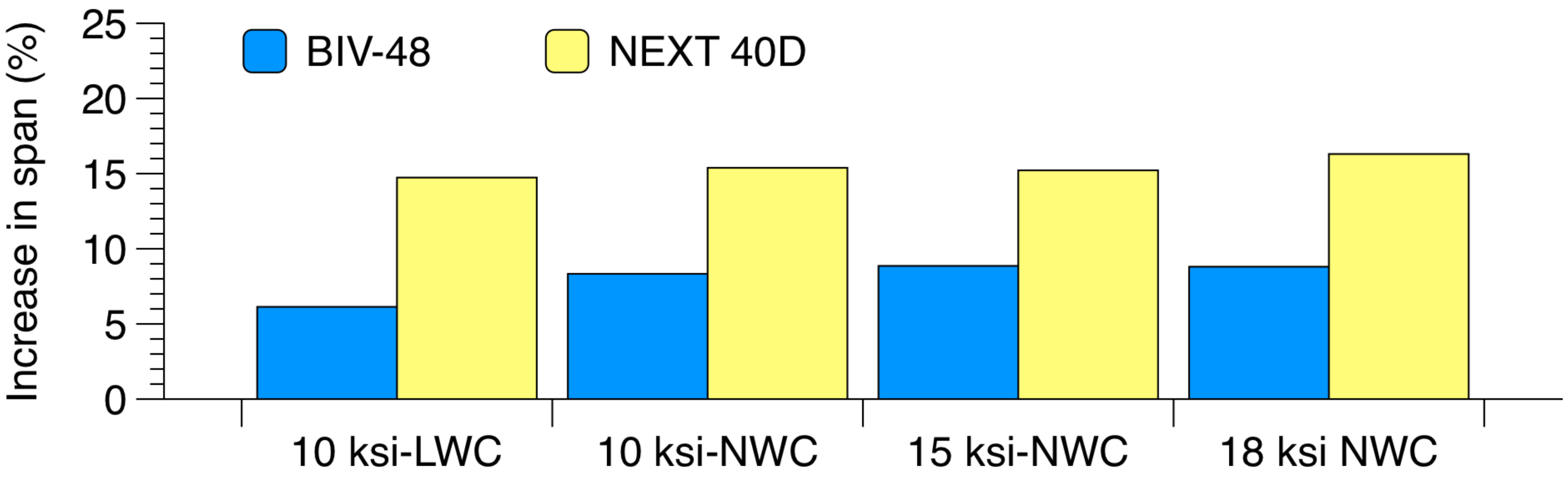


Results: Double-web girders

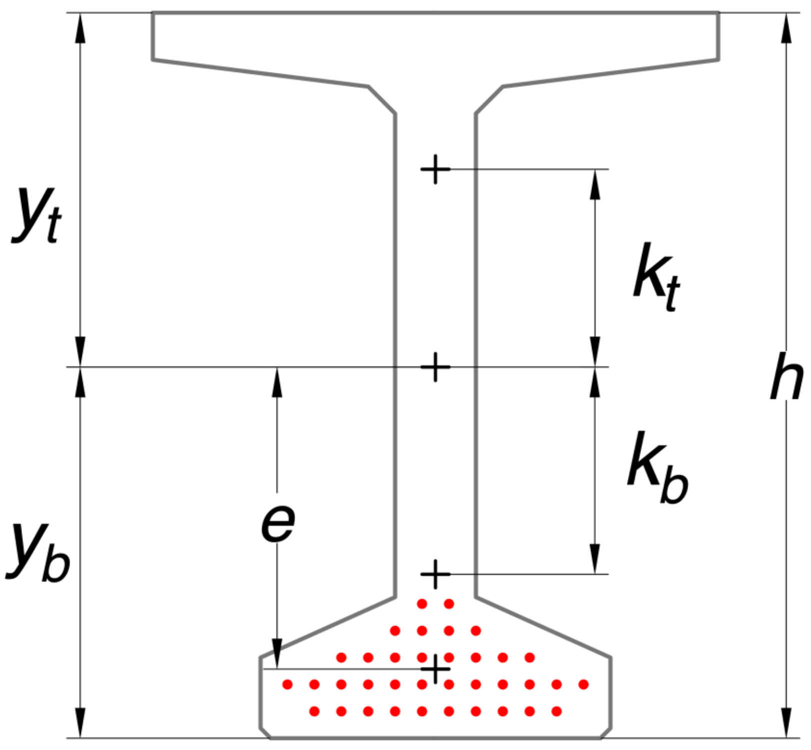


Results

NEXT 40D benefits the most in comparison to BIV-48



Girder "efficiency"



e = distance between centroid of cross section and centroid of prestressing steel

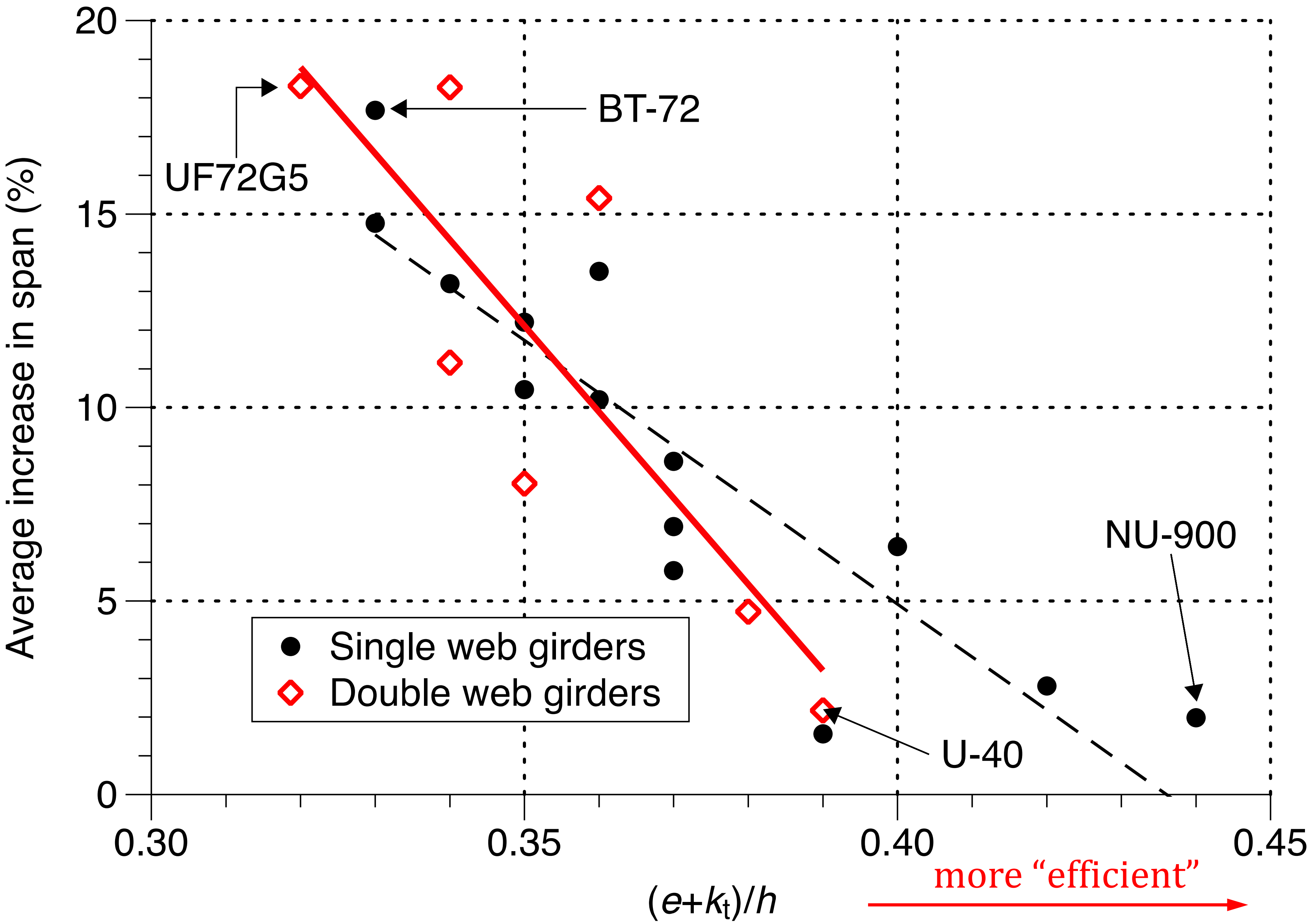
k_t = distance between centroid of cross section and top kern point = S_b/A

Top kern point is the uppermost location at which compression resultant can be placed while maintaining zero tension at the bottom face.

The section becomes more efficient as $e+k_t$ increases.

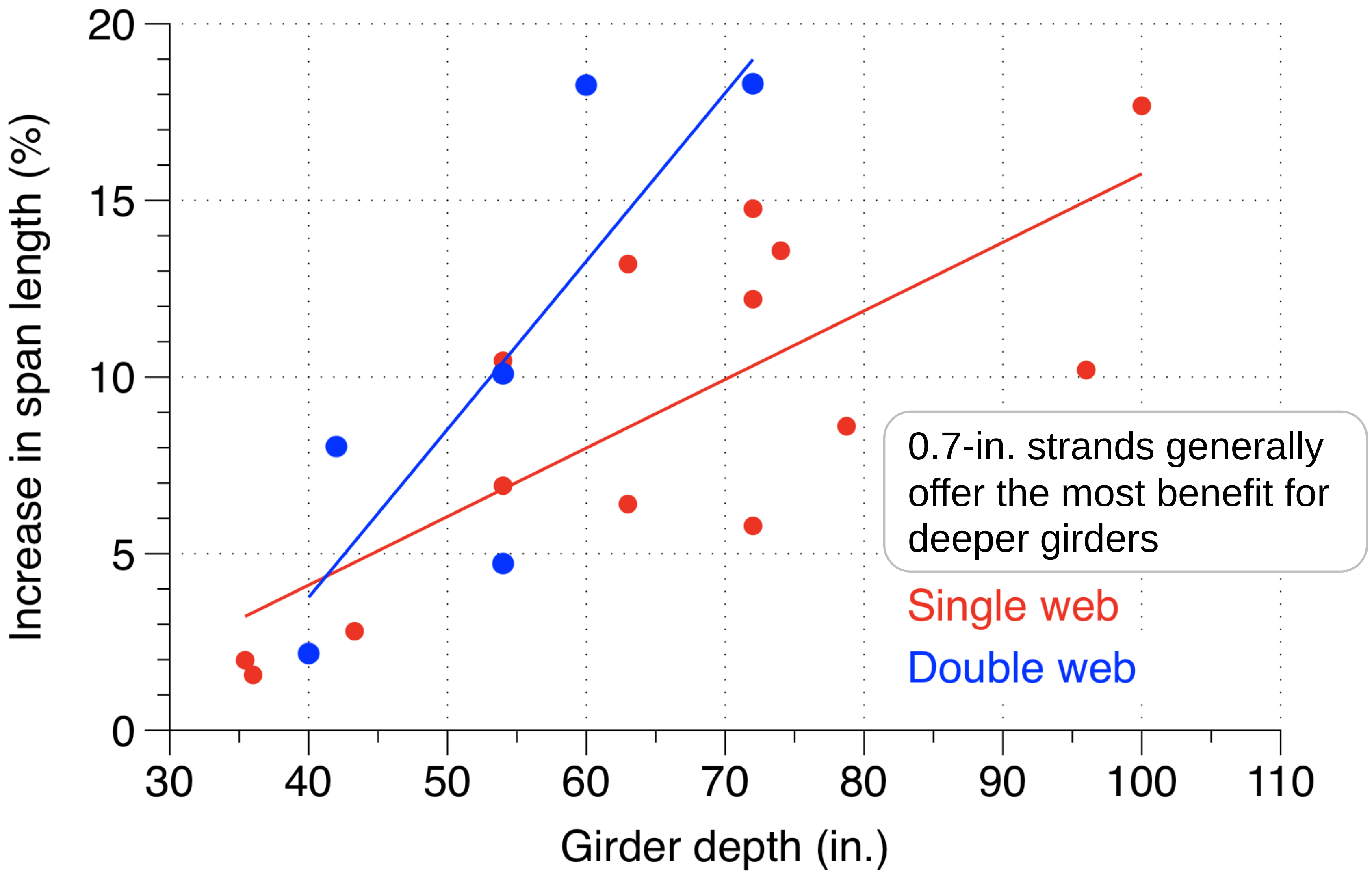
Efficiency is in terms of requiring less prestressing force to carry a given load over a given span.

Girder "efficiency"



Girder shape affects $(e+k_t)/h$

Results: Influence of girder depth



Splitting resistance (AASHTO Article 5.9.4.4.1)

"The factored splitting resistance of pretensioned anchorage zones provided by reinforcement in the ends of pretensioned beams shall be taken as:

$$P_r = f_s A_s$$

where:

f_s *= stress in steel not to exceed 20.0 ksi*

A_s *= total area of reinforcement located within the distance h/4 from the end of the beam (in.2)*

h = overall dimension of precast member in the direction in which splitting resistance is being evaluated (in.)"

Splitting reinforcement:

No. 5 bars spaced at 2 in. had to be extended to $h/3$ for

30% (86 out of 292) of the cases using 0.6-in. strands

43% (126 out of 292) of the cases using 0.7-in. strands

Some states, e.g., Washington, allow extension beyond $h/4$.

Summary and observations from parametric study

- The final increase in span length is less than the ratio of area of 0.7-in. strand to area of 0.6-in. strand.
  - A one-to-one replacement of 0.6-in. strands with 0.7-in. strands is not possible (e.g., stress limits at release)
- For some girder shapes, girder spacing, and concrete strengths, the span length did not increase when 0.6-in. strands are replaced by 0.7-in. strands.
- Some shapes are better suited for 0.7-in. strands (e.g., NEXT 40D vs. BIV-48). Less “efficient” girders benefit more from the use of 0.7-in. strands.
- The use of 0.7-in. strands generally increases the span length of deeper girders than shallower girders.
- Release stress limits could impede the benefits of 0.7-in. strands if harping is not possible or permitted (e.g., Texas U girders).

Part 2: Full-scale girder tests

Primary objectives of full-scale girders

12 full-scale (single-web and double-web) girders were fabricated and tested to

1. evaluate transfer length
2. examine development length, particularly for partially debonded strands
3. understand flexural and shear behavior
4. investigate potential interaction between 0.7-in. strands spaced on a 2-in. grid
5. evaluate current detailing requirements for end region vertical splitting reinforcement and bottom flange confinement reinforcement
6. study the applicability of current design procedures to cases with 0.7-in. strands

Both ends of 5 girders were tested. Therefore, 17 sets of data were obtained.

Transfer length

Girder	Shape	Debonding ratio	Measured		Calculated
			End A	End B	NCHRP
G1	T-beam	0	$46d_b$	$37d_b$	$58d_b$
G2	T-beam	0.33	$48d_b$	$34d_b$	$51d_b$
G3	BTB-35	0	-	-	$40d_b$
G4	BTB-35	0.14	$36d_b$	$30d_b$	$41d_b$
G5	BTB-35	0.43	$33d_b$	$20d_b$	$41d_b$
G6	BTB-35	0.33	$31d_b$	$22d_b$	$42d_b$
G7	BTB-35	0.33	$19d_b$	$20d_b$	$42d_b$
G8	BTB-35	0.33	$31d_b$	$12d_b$	$42d_b$
G9	BI-36	0.36	$41d_b$	$37d_b$	$43d_b$
G10	BI-36	0.36	-	-	$43d_b$
G11	NU-1100	0.40	$27d_b$	-	$40d_b$
G12	NU-1100	0.40	$23d_b$	$30d_b$	$40d_b$
		average (COV)	$33.5d_b$ (0.282)	$26.9d_b$ (0.326)	

AASHTO

$$l_t = 60d_b$$

NCHRP 12-60

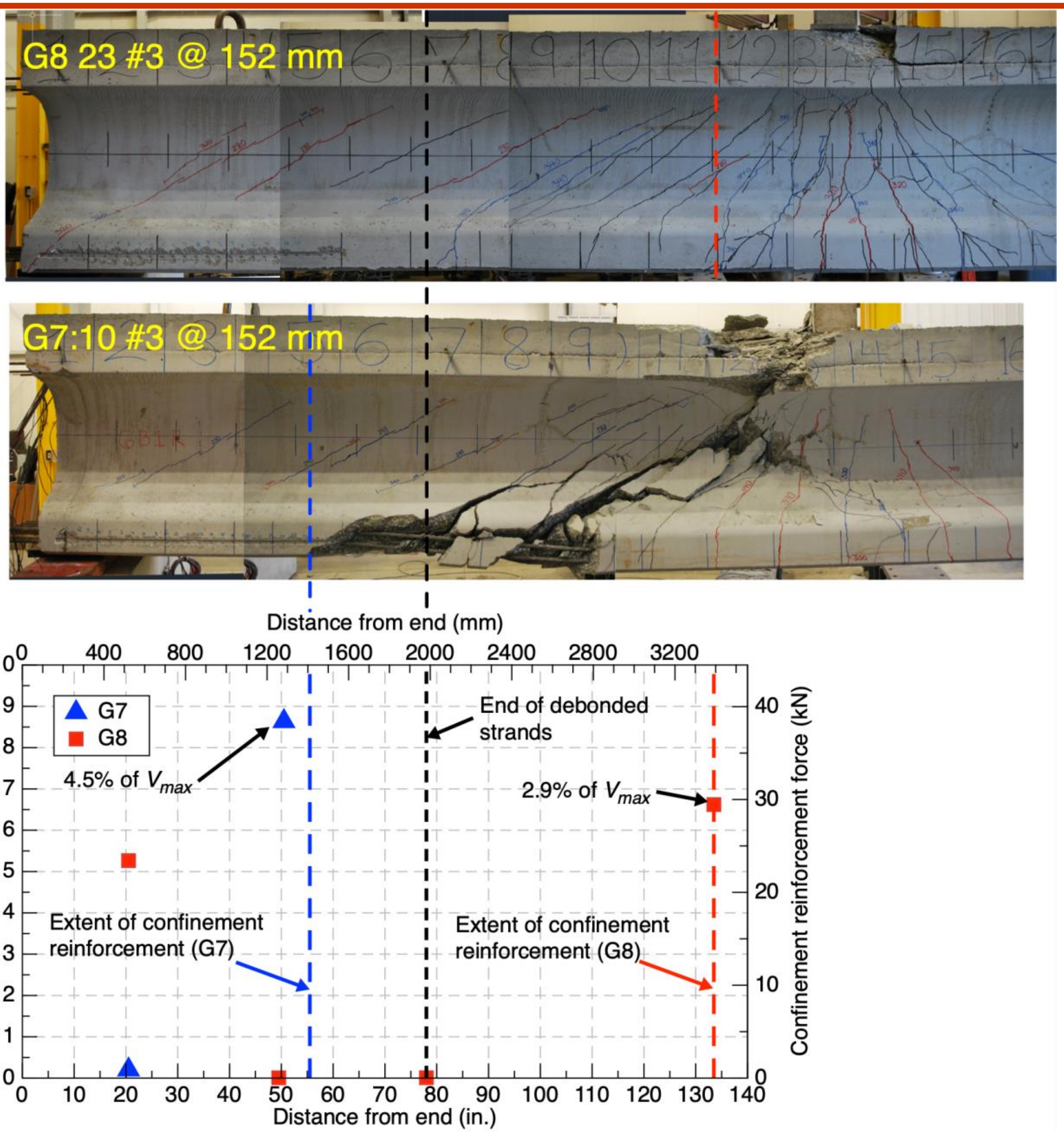
$$l_t = \left(\frac{120}{\sqrt{f'_{ci}}}\right) d_b \geq 40d_b$$

Confinement reinforcement (AASHTO Article 5.9.4.4.2)

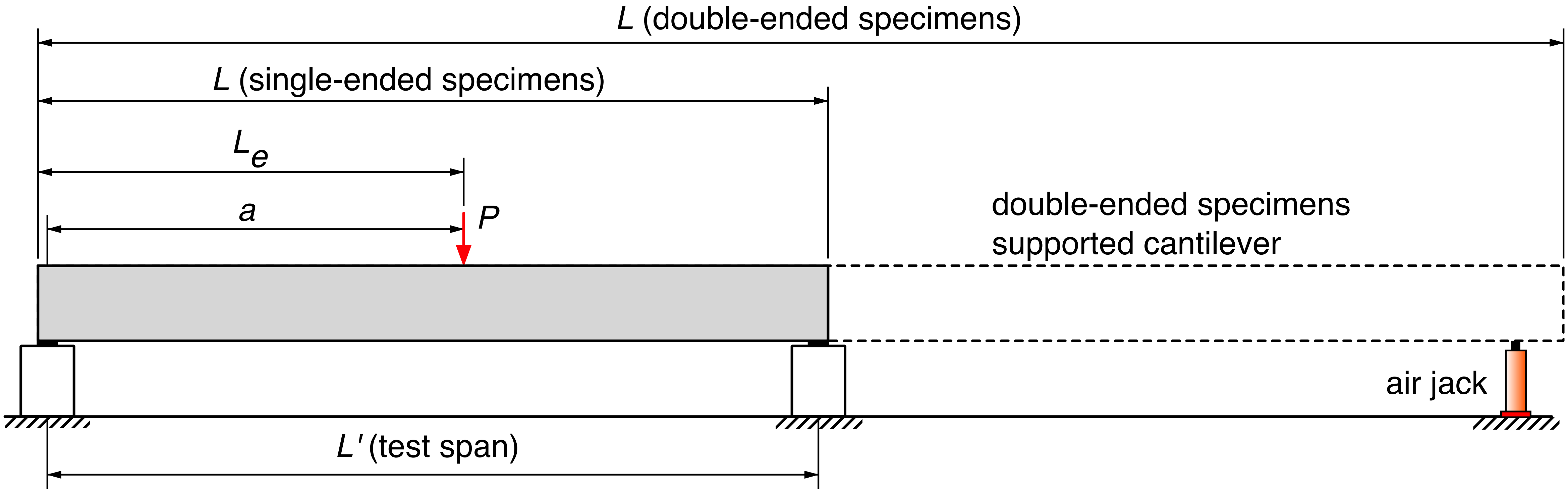
"For the distance of 1.5d from the end of the beams other than box beams, reinforcement shall be placed to confine the prestressing steel in the bottom flange. The reinforcement shall not be less than No. 3 deformed bars, with spacing not exceeding 6.0 in. and shaped to enclose the strands.

For box beams, transverse reinforcement shall be provided and anchored by extending the leg of stirrup into the web of the girder."

Influence of extension of confinement reinforcement



Location of applied load (L_e)



Measured vs. calculated capacity

Test ID	Test/Calculated		L_e/AASHTO l_d	L_e/NCHRP l_d
	AASHTO l_d	All strands		
G1a	1.16	1.04	0.92	1.67
G1b	1.59	1.18	0.56	1.01
G2a	1.61	1.11	0.37	0.68
G2b	1.58	0.94	0.29	0.54
G3a	1.27	0.70	0.52	1.09
G3b	1.80	0.99	0.52	1.09
G4a	1.14	0.88	0.46	0.98
G4b	1.25	0.96	0.46	0.98
G5a	1.11	0.77	0.40	0.72
G5b	1.05	0.73	0.40	0.72
G6	1.40	1.09	0.63	1.14
G7	1.11	0.94	0.57	1.03
G8	1.21	1.02	0.62	1.03
G9	1.38	0.99	0.72	1.09
G10	1.15	1.02	0.57	1.01
G11	1.32	1.02	0.63	1.16
G12	1.20	0.98	0.54	1.00

AASHTO: standard methods and $l_{d,AASHTO}$

All strands: Response 2000

$$l_{d,AASHTO} = \kappa\left(f_{ps} - \frac{2}{3}f_{pe}\right)d_b$$

κ =1.6 for full-length bonded strands

κ =2.0 for partially debonded strands

$$l_{d,NCRHP\ 12-60} = \left(\frac{120}{\sqrt{f'_{ci}}} + \frac{225}{\sqrt{f'_c}}\right)d_b \geq 100d_b$$

Meet current requirements but not the proposed revision

	AASHTO l_d	All strands
Average	1.36	1.04
COV	22.3%	7.4%

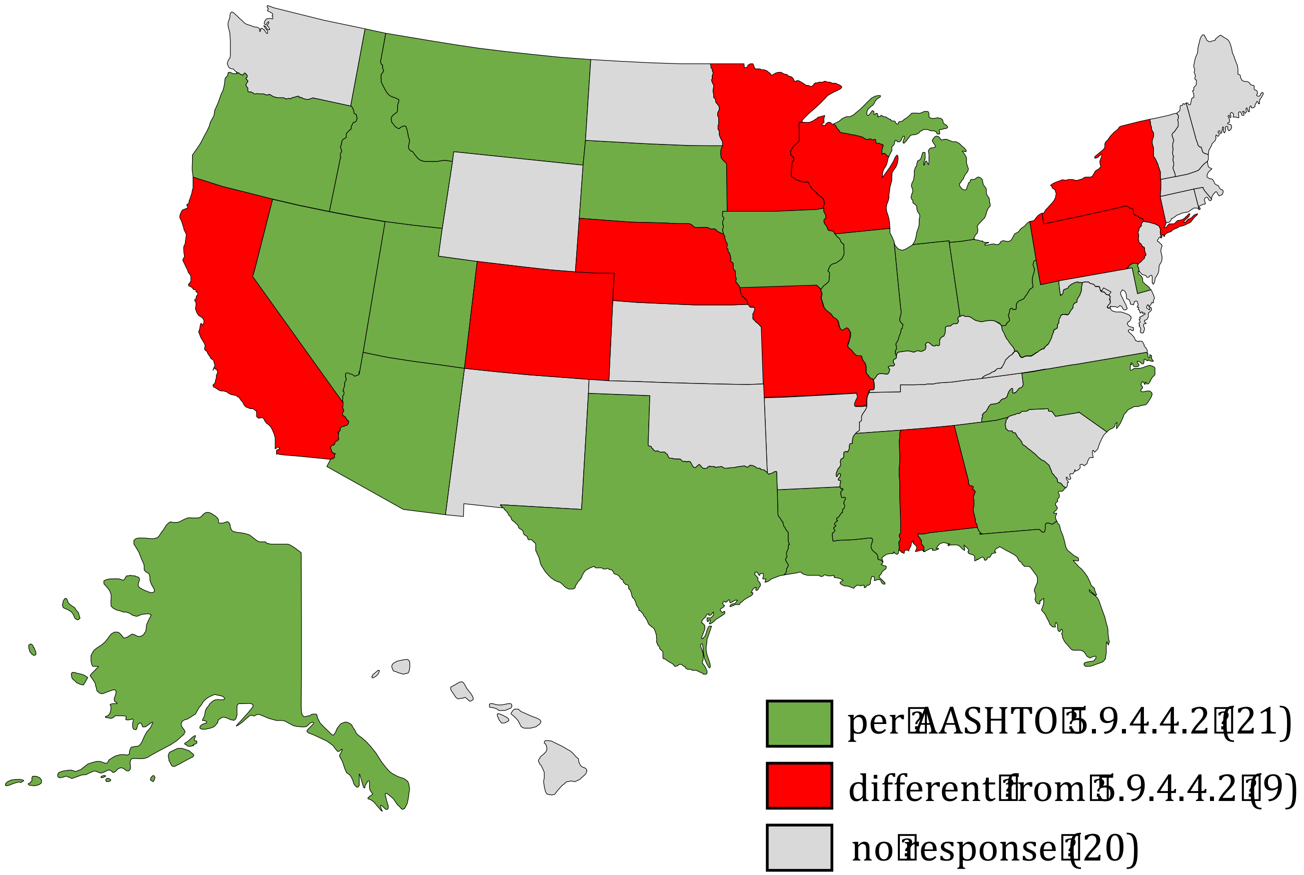
Summary and conclusions from full-scale girder tests

- Current design, including the calculation of flexural and shear capacities and all required stress checks, are adequate for girders using 0.7-in. strands
- Transfer and development lengths are less than those prescribed by the *AASHTO LRFD Specification*. NCHRP 603-prescribed transfer and development lengths are more representative of the data measured.
- No deleterious effects were found by using 0.7-in. strands spaced at 2 in. center-to-center.

Summary and conclusions from full-scale girder tests

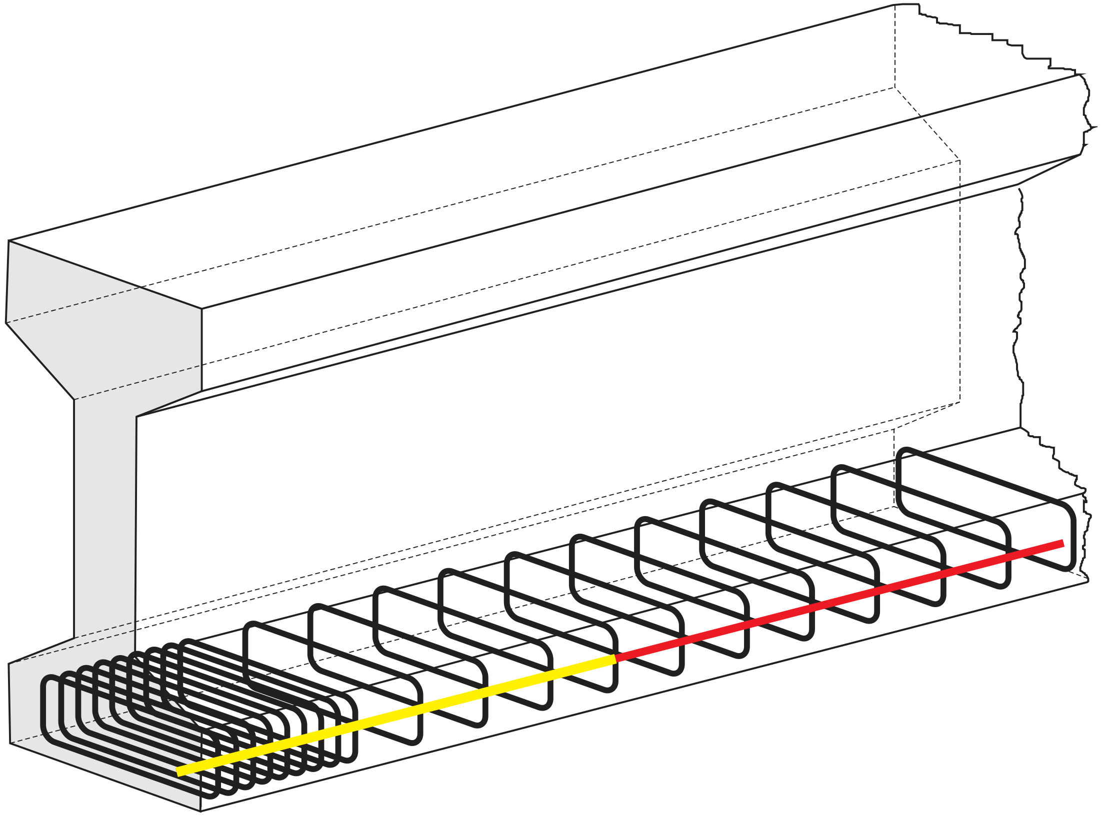
- AASHTO LRFD Article 5.9.4.4.1 splitting reinforcement is sufficient for 0.7-in. strands to resist bursting stresses at release.
  - For cases with many 0.7-in. strands, the required splitting reinforcement should be permitted to be extended beyond the current $h/4$ limit to avoid congestion.
- The minimum required amount of confinement reinforcement of AASHTO Article 5.9.4.4.2 was found to be enough to confine 0.7-in. strands.
  - Extension of bottom flange confinement reinforcement to $1.5d$ beyond the end of the girder is adequate for cases with no debonded strands.
  - The minimum bottom flange confinement reinforcement must be extended to at least $1.5d$ beyond the termination of the longest debonded length of 0.7-in. strands.

Survey responses regarding AASHTO Article 5.9.4.4.2



- NY and PA: require No. 4 bars rather than No. 3 bars
- CA, CO, MO, and NE: confinement reinforcement is extended over the entire beam length
- PA: confinement reinforcement is extended over 1/3 the beam length
- DE and WV standard details: use overall beam height rather than depth
- DE standard details: confinement reinforcement is extended 1.5 times beam height for 0.5-in. strands and 2 times beam height for 0.6-in. strands

Girder End Region Detailing



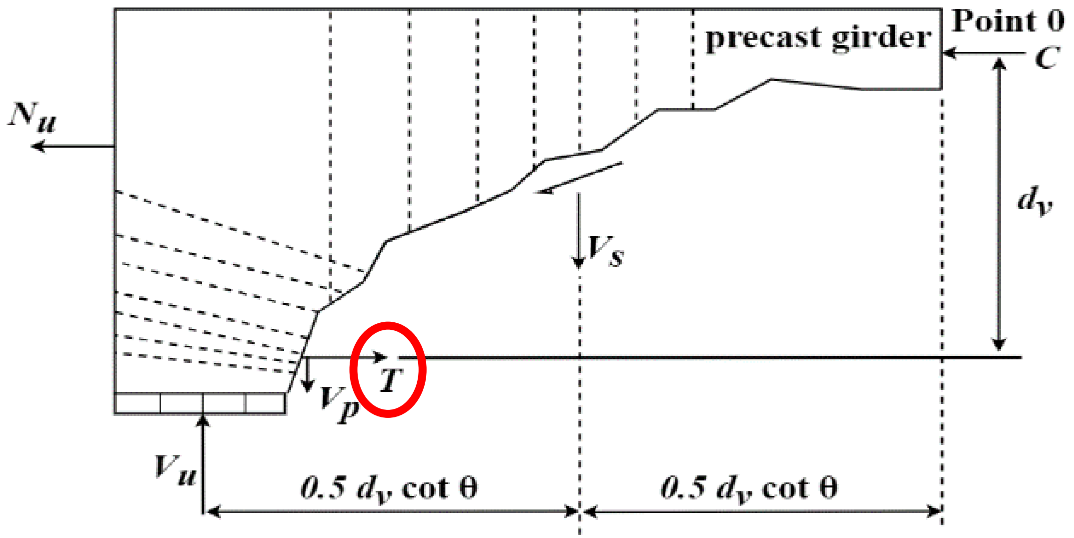
Girder End Region Detailing

With increased **total** prestress force, comes…

greater potential requirement for partial debonding of strand in order to mitigate top-of-flange tension at girder end.

Resulting in…

greater potential for inadequate tension capacity at critical section for shear.



With 0.7-in. strand, in some cases, additional non-prestressed reinforcement may be required to augment the $A_s f_y$ term.

$$T = \sum A_s f_y + \sum A_{ps} f_{ps} \geq \frac{|M_u|}{d_v \phi_f} + 0.5\frac{N_u}{\phi_c} + \left(\left|\frac{V_u}{\phi_v} - V_p\right| - 0.5V_s\right)\cot\theta$$

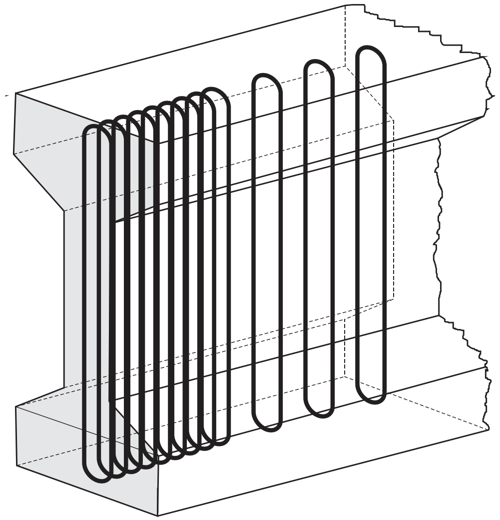
[*AASHTO LRFD* (9e) Article 5.7.3.5]

Girder End Region Detailing

With increased **total** prestress force, comes…

greater potential for “splitting”

With 0.7-in. strands, there is potential for greater congestion but nothing that cannot be reasonably accommodated.



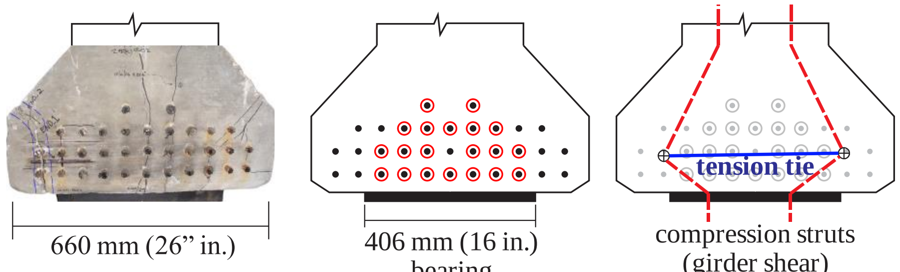
web reinforcement to resist 4% of prestress force at transfer

[*AASHTO LRFD* (9e) Article 5.9.4.4.1]

Girder End Region Detailing

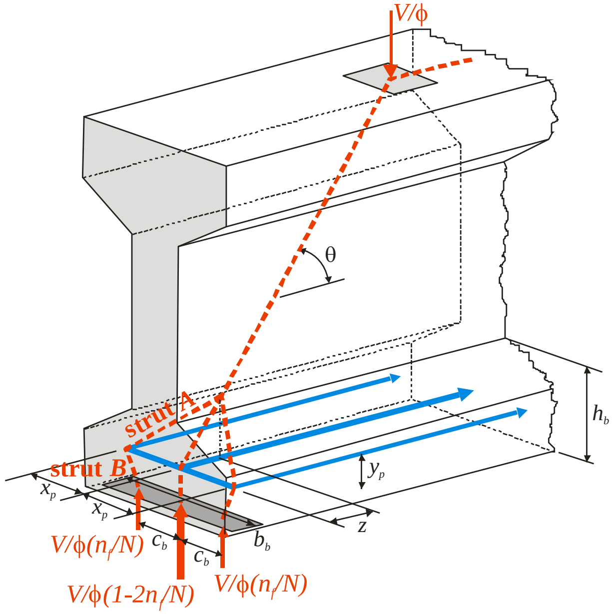
With increased **total** prestress force, comes…

greater potential for "bursting" across flange



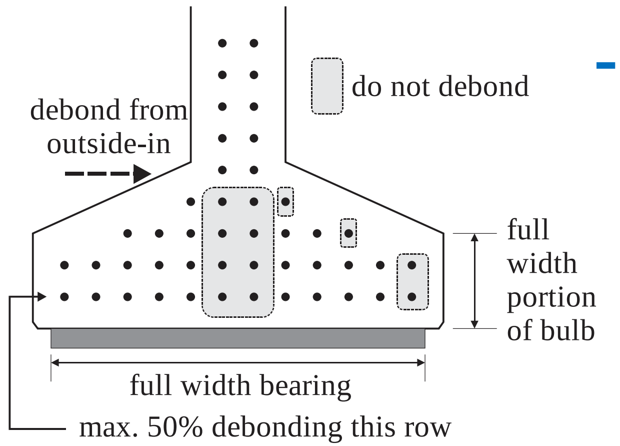
▲
Llanos, G., Ross, B., and Hamilton, H.R. (2009) Shear Performance of Existing Prestressed Concrete Bridge Girders. *Report. No. BD 545-56*, Florida Department of Transportation, Tallahassee, FL.

With 0.7-in. strands, there is potential for greater congestion although this can be mitigated with good debonding practice



Strut-and-tie approach

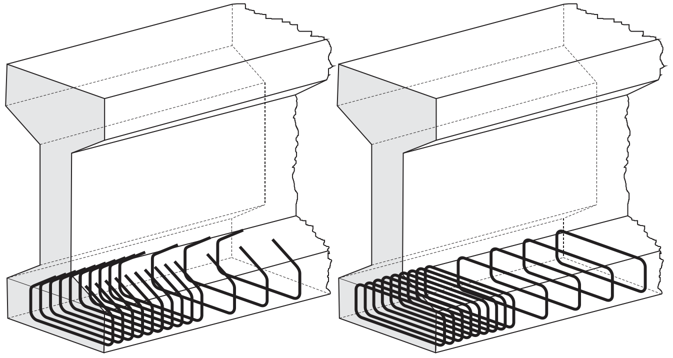
NCHRP *Report 849* and Harries et al. (2019) *ASCE JBE*



Detailing guidance

[*AASHTO LRFD* (9e) Article 5.9.4.3.3]

NCHRP *Report 849* and Bolduc et al. (2023) *PCI J.*



Flange confinement in addition to

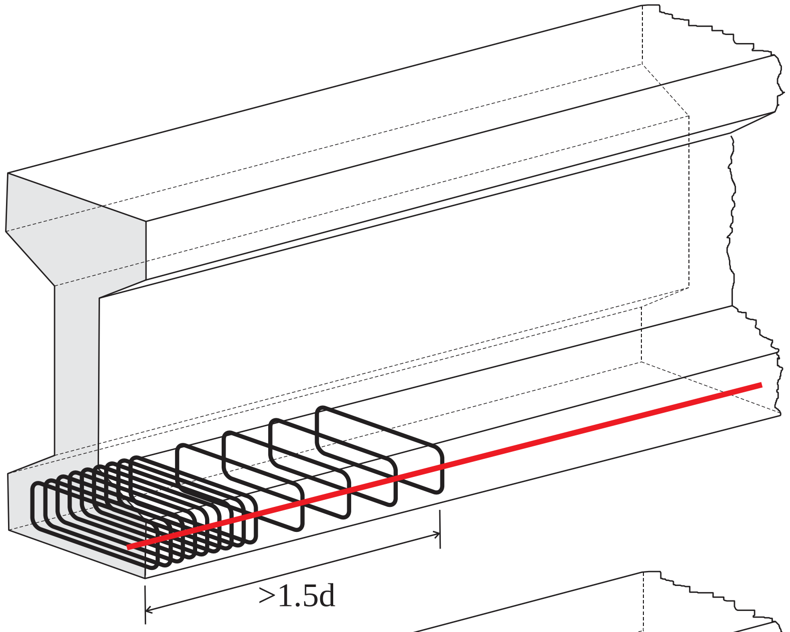
AASHTO LRFD (9e) Article 5.9.4.4.2

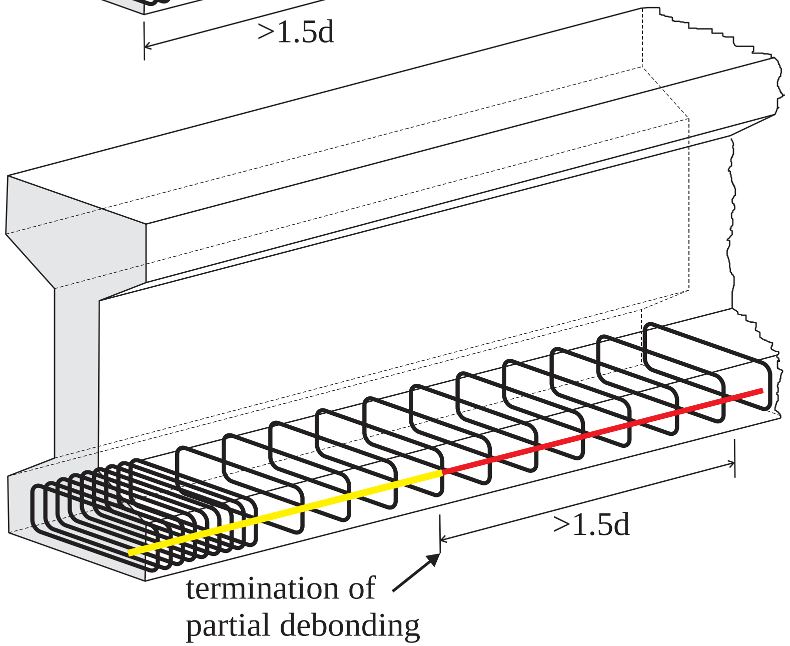
NCHRP *Report 849* and Harries et al. (2019) *ASCE JBE*

Girder End Region Detailing

As partial debonding extends further into span, flange confinement should follow.

AASHTO LRFD (9^{e}) Article 5.9.4.4.2





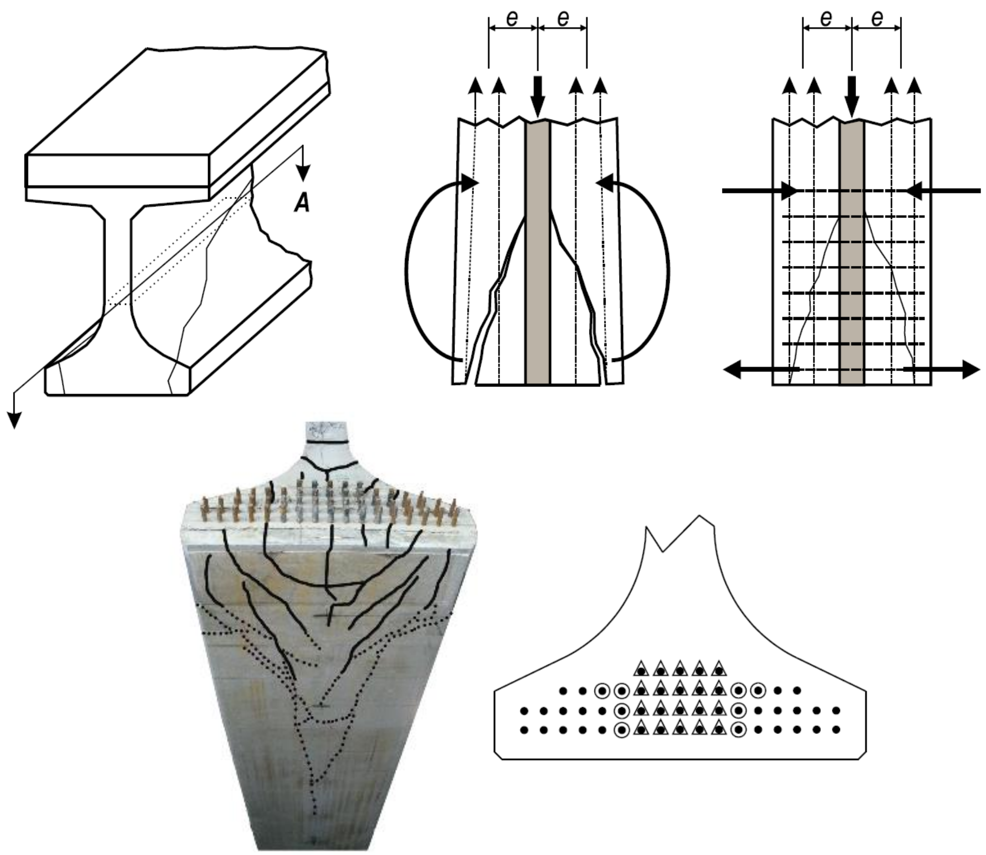
Some states (including CA, CO, DE, MO, NE, WV) require flange confinement over the entire beam length. PA requires confinement over 1/3 the beam length. This is a recommended detail and may help to address other issues (vehicle impact).

Reinforcement should be placed to confine the prestressing steel in the bottom flange for a distance of at least 1.5d ***beyond the termination of the longest partially debonded length***

Girder End Region Detailing

With increased **total** prestress force, comes…

greater potential for “peeling” or “lateral splitting”



▲

Ross, B.E. (2012) *Function and Design of Confinement Reinforcement in Pretensioned Concrete I-Girders*, PhD Dissertation, University of Florida.

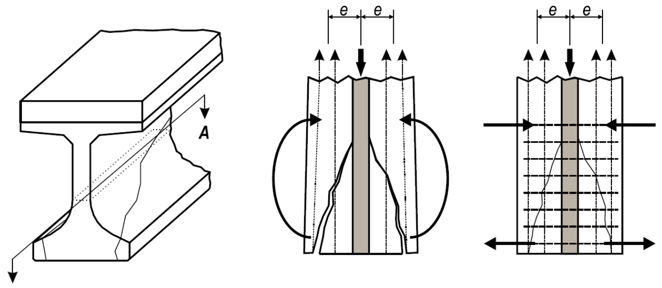
Girder End Region Detailing

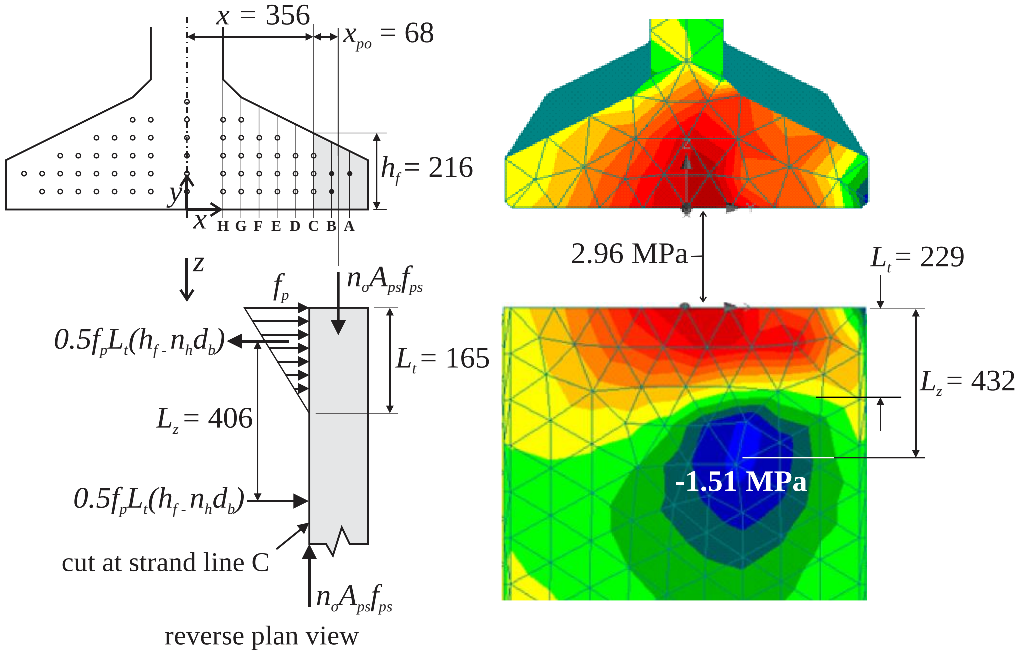
Peeling stresses are not unique to heavily prestressed girders or to larger 0.7-in. strands. Shapes having wide flat flanges exhibit large predicted peeling stresses.

Peeling stresses can be mostly mitigated by debonding strands in the recommended pattern of “from the outside in”.

Similarly, releasing/cutting strands in a uniform manner mitigates peeling stresses. For conventional release operations, a symmetric top-down method should not result in significant peeling stress.

Prestressed girder end region detailing requirements aimed at providing adequate flange confinement and strand anchorage at the ultimate limit state should be adequate to control peeling stresses – even those resulting from the inadvertent use of a poor release sequence.





NCHRP *Report 994*

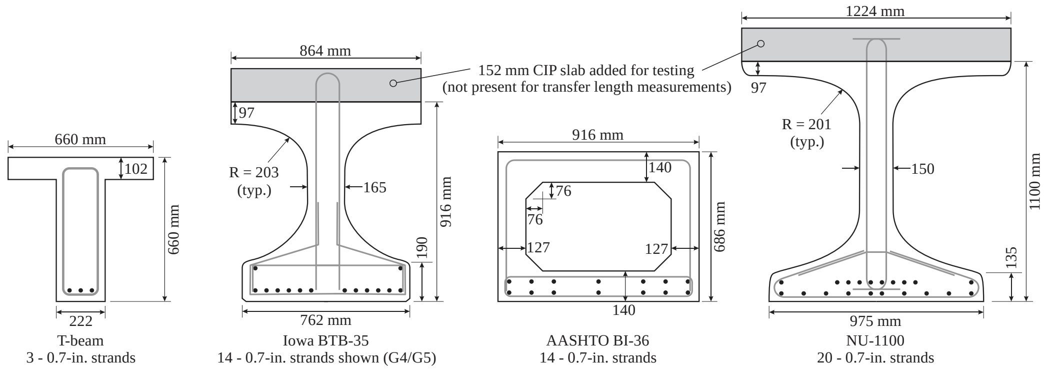
Transfer Length

Transfer length was measured during prestress strand release of 12 experimental girders.

The mean transfer length of 0.7-in. strands was found to be $\mathbf{30.4}\boldsymbol{d_b}$. 5th percentile (95% confidence) was $53.4d_b$.

Both lower than $60d_b$ specified by *AASHTO LRFD* (9e)

Mean transfer length values were better-predicted using equations proposed by *NCHRP Report 603* which yielded a mean transfer length of $44d_b$



Overestimation of transfer length underestimates concrete tensile stresses at prestress transfer. This may result in unanticipated cracking. A two-tier approach is proposed:

1. use a reduced transfer length – $40d_b$ is proposed – to check tensile stresses at prestress release;
2. use a longer development length – $60d_b$ – to determine girder load-carrying capacity.

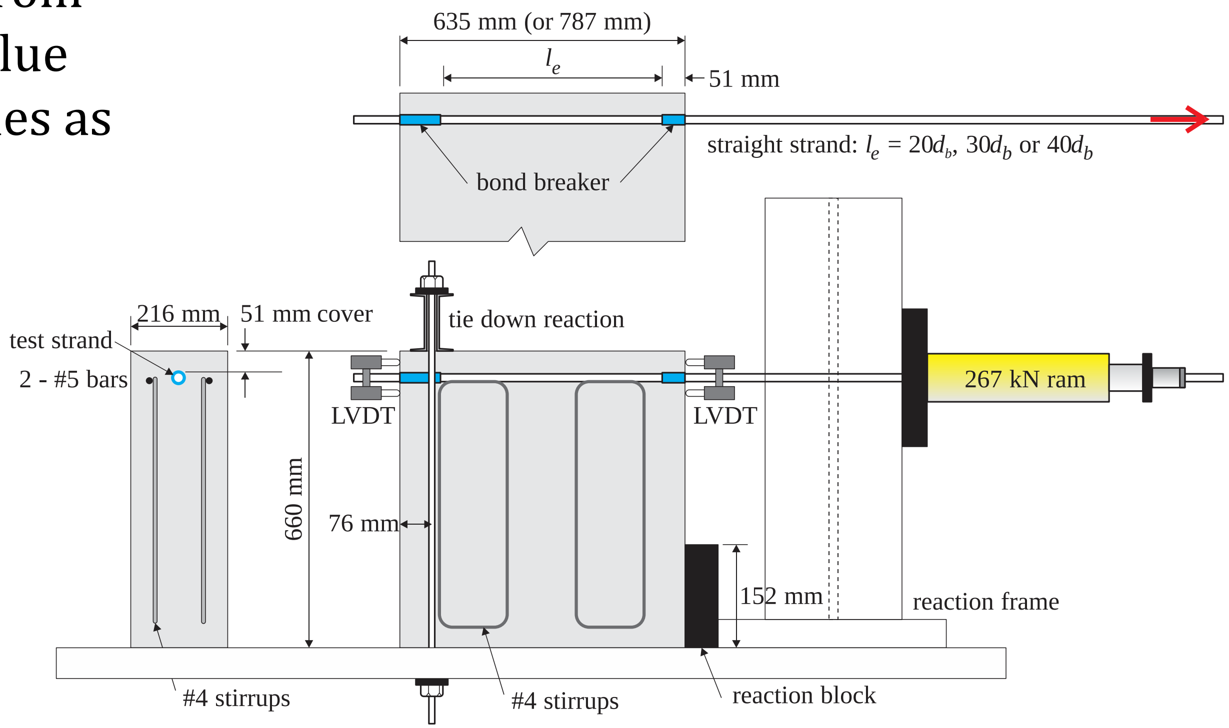
Bond and Development Length

Bond performance of the 0.7-in. strand used in the experimental program, established using the **ASTM A1018** test, was found to be adequate and comparable to the range of the values reported by others.

Based on the bond characteristics determined from **ASTM A944** beam end tests, no extrapolated value of development length exceeded $106d_b$ and values as low as $40d_b$ were observed.

AASHTO LRFD (9[e]) would require a minimum development length of $136d_b$

0.7-in strand do not appear to have any different bond characteristics than extant strand 0.5-in. and 0.6-in.



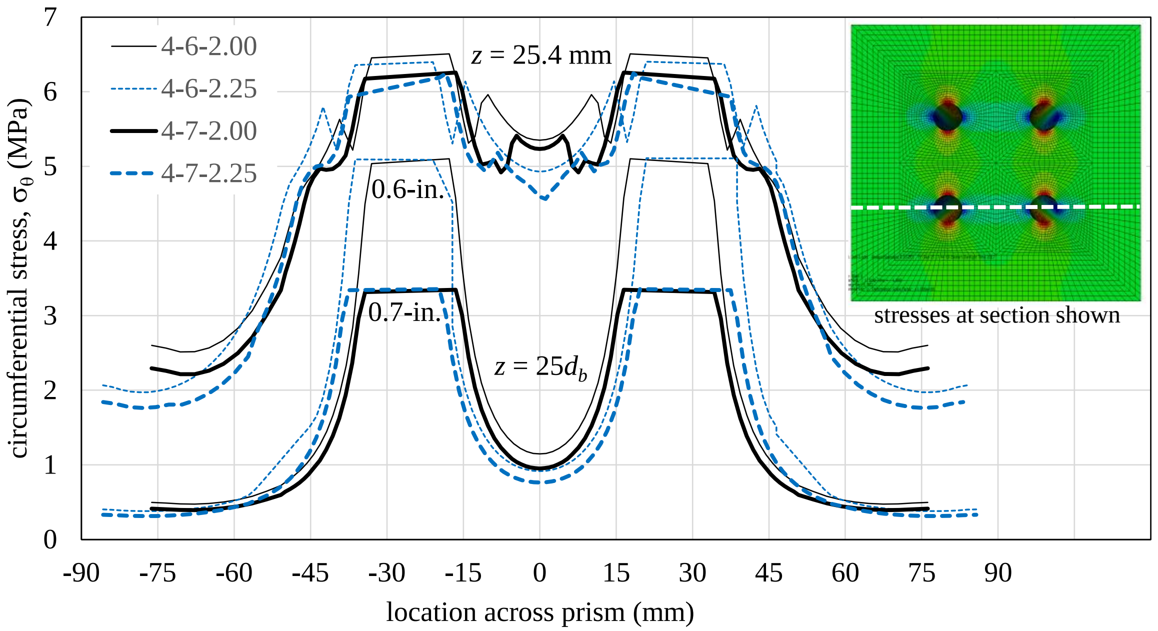
Strand Spacing

For many practical reasons, it is desirable to permit 0.7-in. strands to be located with **2 in. on-center spacing**.

A comparative numeric study indicated that stresses at the strand-to-concrete interface are only marginally affected when strand diameter is increased to 0.7-in. from 0.6-in.

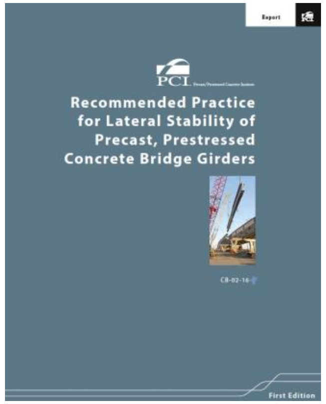
Larger strands exhibit a lower dilation ratio (Hoyer effect) and therefore lower circumferential stresses develop upon release.

Critically, no instance of excessive slip or cracking at prestress release has been observed in (admittedly limited) practice.

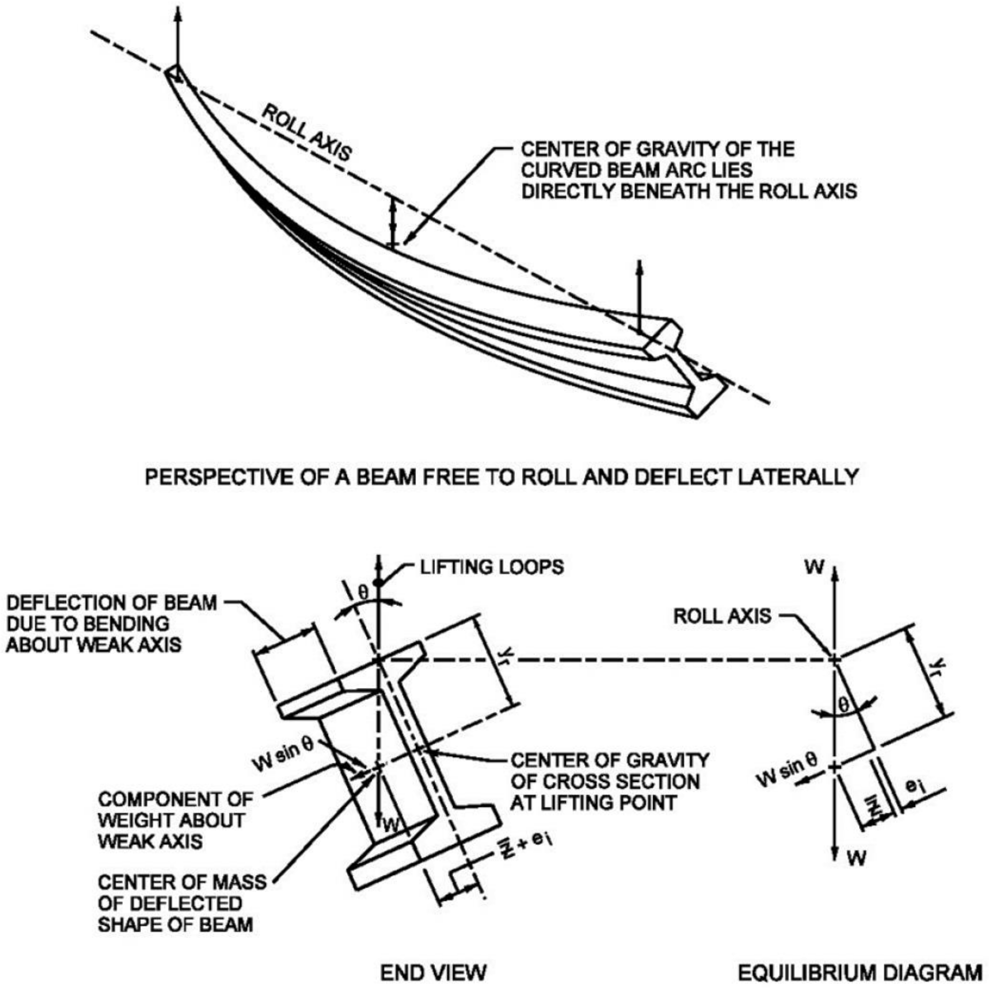


Since it is envisioned that use of 0.7-in. strands will likely be accompanied with higher strength concrete and potentially greater confinement requirements, the 2 in. on-center spacing is likely adequate.

Long-span Girder Stability



PCI Recommended Practice for Lateral Stability of Precast, Prestressed Concrete Bridge Girders (CB-02-16)



Loooonnnngggg Span Stability

West, C. (2019) Prestressed Concrete Girders Achieve Record Lengths. *Aspire*, Fall, 56–57.

West (2019) reports that in order to achieve a record **223 ft span**, a WF100G girder section was modified by widening the top flange 12 inches to improve stability during handling.

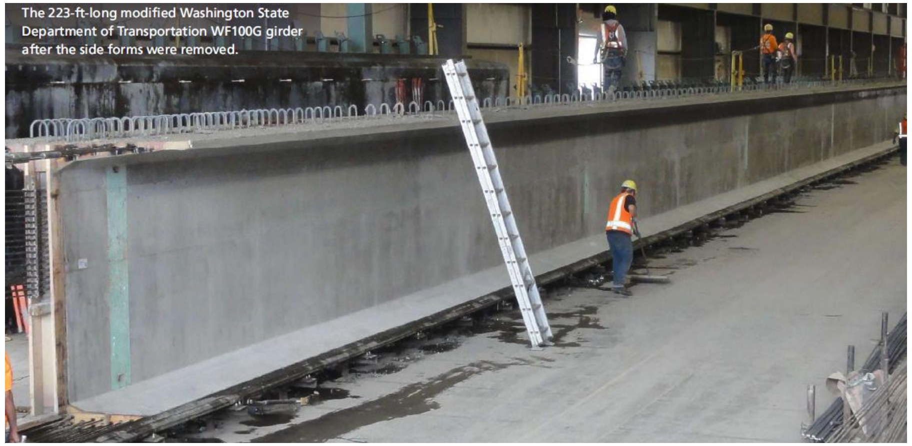
WF 100G

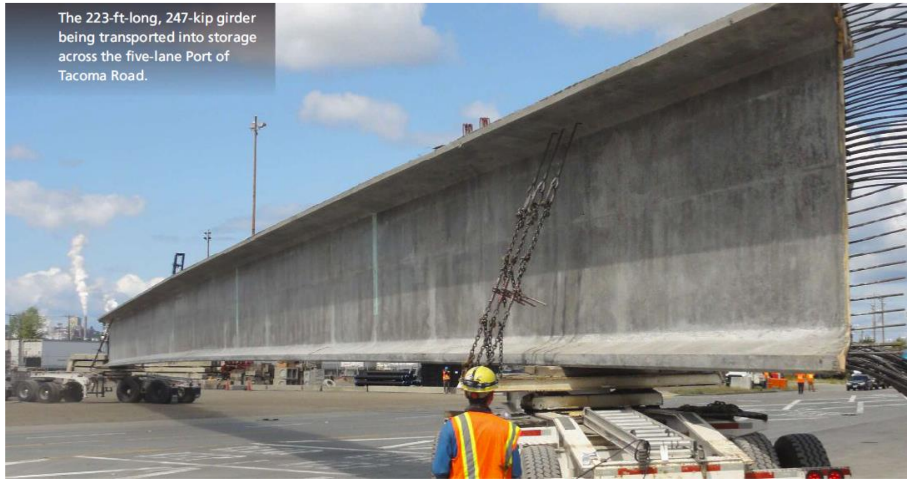
46 straight 0.6-in. strand	cgs at midspan = 6.7 in.
35 harped 0.6-in. strand	cgs at end = 79.5 in.
10 temporary top 0.6-in. strands	

'redesigned' using 0.7-in. strand:

WF 100G

32 straight 0.7-in. strand	cgs at midspan = 5.4 in.
28 harped 0.7-in. strand	cgs at end = 83.5 in.
10 temporary top 0.6-in. strands	

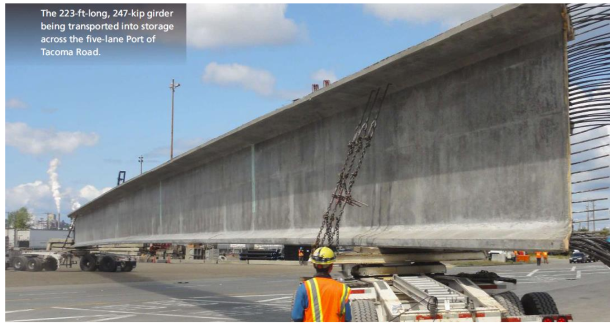




Looooonnnngggg Span Stability

	WF100G			WF100G-MOD			WF100G			WF100G-MOD		
	0.6-in. strands			0.6-in. strands			0.7-in. strands			0.7-in. strands		
	49 in top flange			61 in top flange			49 in top flange			61 in top flange		
	FS_{cr}	FS'	FS_{roll}	FS_{cr}	FS'	FS_{roll}	FS_{cr}	FS'	FS_{roll}	FS_{cr}	FS'	FS_{roll}
	1.0	1.5	1.5	1.0	1.5	1.5	1.0	1.5	1.5	1.0	1.5	1.5
Lift from bed	1.57	1.57	-	1.83	1.83	-	1.53	1.53	-	1.76	1.76	-
On dunnage	1.43	2.63	1.79	1.65	2.87	1.93	1.18	2.63	1.78	1.42	2.86	1.93
Transportation	**0.78**	1.90	1.55	**0.95**	2.11	1.70	**0.64**	1.89	1.55	**0.81**	2.11	1.70
Lift in field	1.55	1.55	-	1.78	1.78	-	1.51	1.51	-	1.72	1.72	-
Place on bearings	1.32	**1.21**	**0.65**	1.53	**1.43**	**0.76**	1.29	**1.21**	**0.65**	1.50	**1.43**	**0.76**

As is required for much shorter girders than those considered here, end braces must be installed immediately upon placement on bearings in order provide safety against rollover.



Loooonnnngggg Span Stability

	WF100G 0.6-in. strands 49 in top flange			WF100G-MOD 0.6-in. strands 61 in top flange			WF100G 0.7-in. strands 49 in top flange			WF100G-MOD 0.7-in. strands 61 in top flange		
	FS_{cr}	FS’	FS_{roll}	FS_{cr}	FS’	FS_{roll}	FS_{cr}	FS’	FS_{roll}	FS_{cr}	FS’	FS_{roll}
	1.0	1.5	1.5	1.0	1.5	1.5	1.0	1.5	1.5	1.0	1.5	1.5
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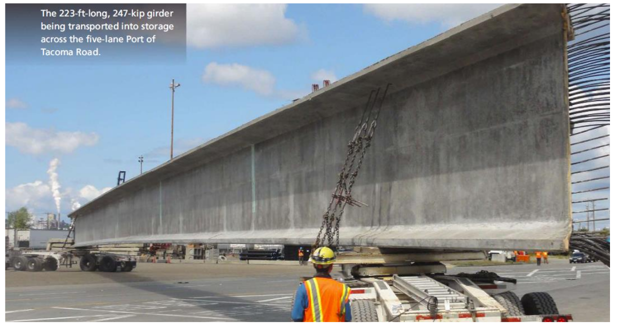
Use of 0.7-in. strands decreases stability marginally → lower cgs results in greater camber



Loooonnnngggg Span Stability

	WF100G			WF100G-MOD			WF100G			WF100G-MOD		
	0.6-in. strands			0.6-in. strands			0.7-in. strands			0.7-in. strands		
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	FS_{cr}	FS’	FS_{roll}	FS_{cr}	FS’	FS_{roll}	FS_{cr}	FS’	FS_{roll}	FS_{cr}	FS’	FS_{roll}
	1.0	1.5	1.5	1.0	1.5	1.5	1.0	1.5	1.5	1.0	1.5	1.5
Lift from bed	1.57	1.57	-	1.83	1.83	-	1.53	1.53	-	1.76	1.76	-
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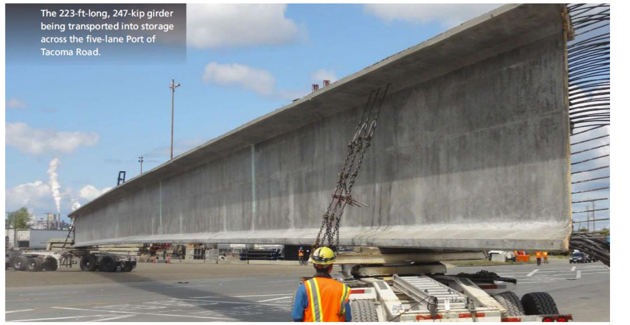
Increasing top flange width 12 in. improves stability dramatically.

This increases I_y by 40%! and $I_{y,top\ flange}$ by 74%



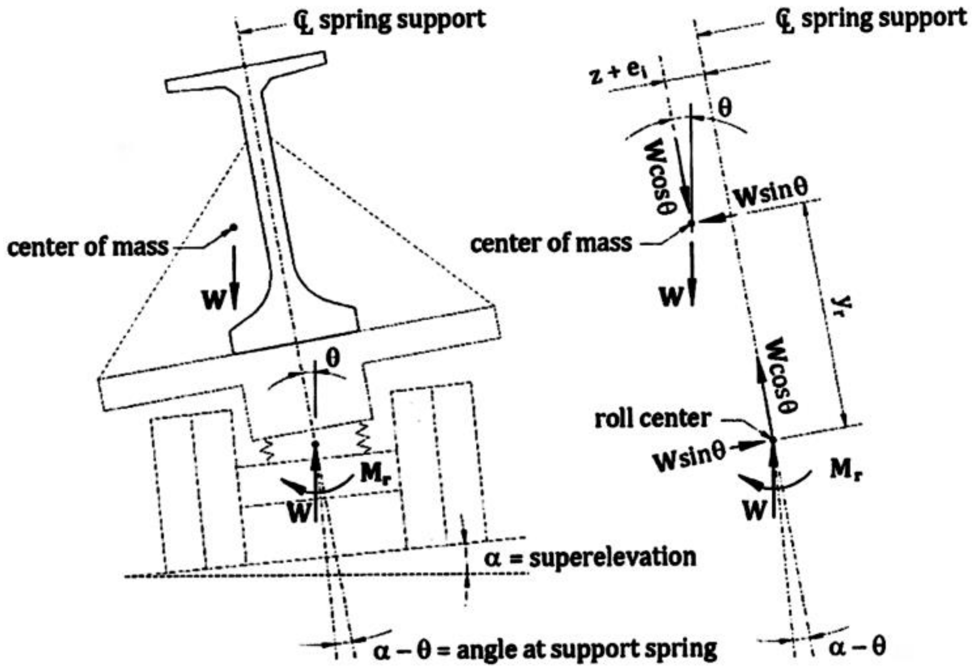
Loooonnnngggg Span Stability

	WF100G			WF100G-MOD			WF100G			WF100G-MOD		
	0.6-in. strands			0.6-in. strands			0.7-in. strands			0.7-in. strands		
	49 in top flange			61 in top flange			49 in top flange			61 in top flange		
	FS_{cr}	FS’	FS_{roll}	FS_{cr}	FS’	FS_{roll}	FS_{cr}	FS’	FS_{roll}	FS_{cr}	FS’	FS_{roll}
	1.0	1.5	1.5	1.0	1.5	1.5	1.0	1.5	1.5	1.0	1.5	1.5
Transportation	**0.78**	1.90	1.55	**0.95**	2.11	1.70	**0.64**	1.89	1.55	**0.81**	2.11	1.70

Girder is susceptible to cracking at transportation stage.

Increasing length of “overhang” beyond support point from 20 ft to 37 ft increases both WF100G-MOD ratios F_{cr} > 1.0, although this may be impractical for road transport

Increasing hauling rig stiffness (K_q), decreasing hauling rig velocity (V_{el}), and/or decreasing eccentricity of support (y_{seat}, z_{max}, h_{roll}) all can improve transportation stability



▲PCI CB-02-16

Loooonnnngggg Span Stability

Additional analyses were conducted and are reported in *NCHRP Report 994*. Conclusions are as follows:

The use of 0.7-in. strand, which may result in longer spans, will increase the susceptibility of girders to instabilities.

As is required for much shorter girders, end braces must be installed immediately upon placement on bearings in order provide safety against rollover.

Refining hanging (lift points) and dunnage support locations can optimize resistance to stability effects.

Increasing the width of the top flange of a girder – thereby increasing I_y/I_x – has a pronounced effect on improving stability.

Providing stiffer transportation or dunnage support – assuming this is possible – improves stability.

Girders having relatively thin bottom flanges (BT sections) are more susceptible to rollover while supported on dunnage or in transportation; such girders are not well suited for long spans.

Girders considered:
223 ft WF100G
223 ft WF100G-MOD
207 ft WF100G
207 ft WF100G-MOD
181 ft WF 74G
135 ft BT-72
185 ft OHWF-72
223 ft FIB-96
223 ft FIB-96-MOD
220 ft NU-2000

MOD indicates 12 in. added to top flange width

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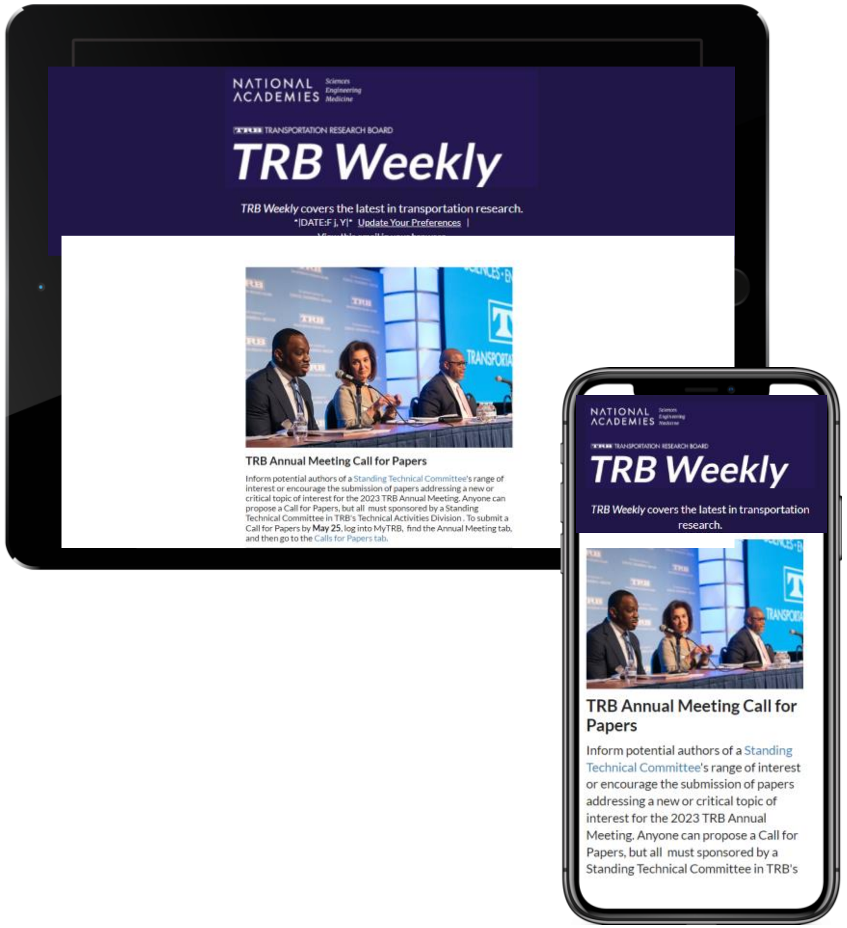

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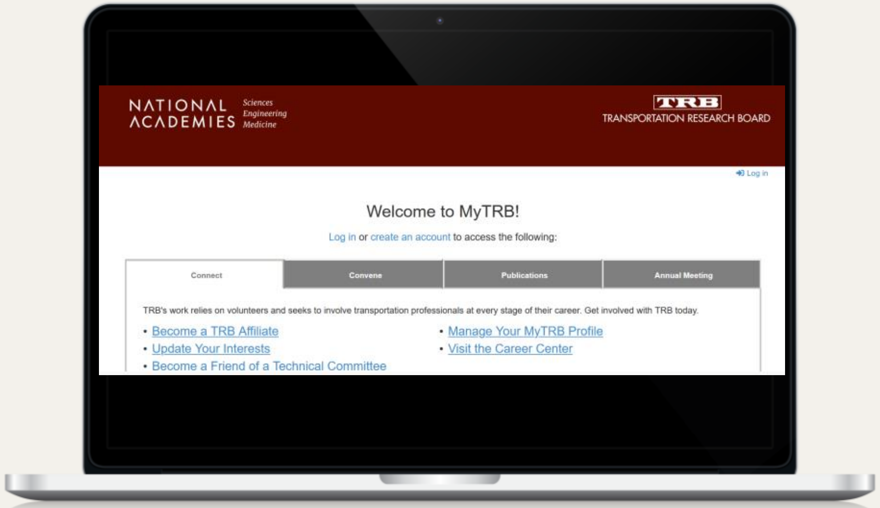

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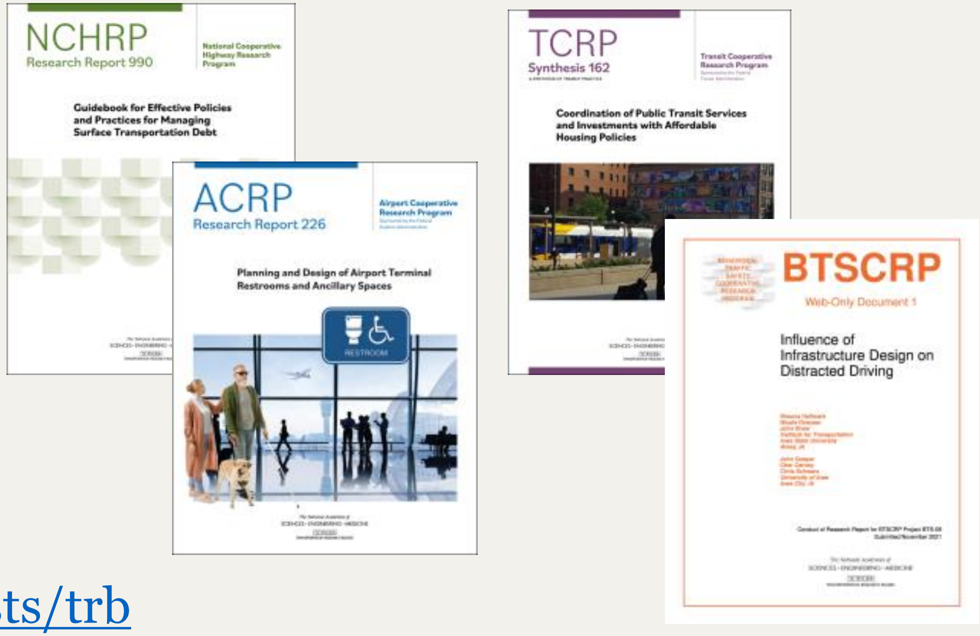

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