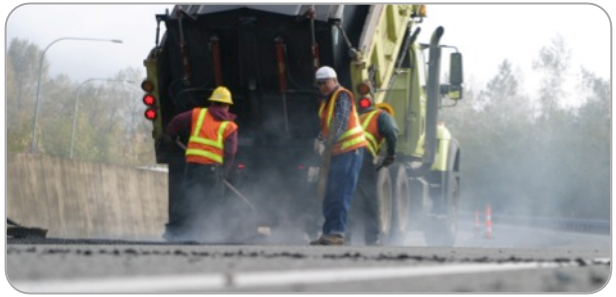
Evaluation of Common Design Policies for Precast Prestressed I-Girder Bridges







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- Publications
  - PCI Aspire Magazine Winter 2013
  - PCI Journal Fall 2013

Introduction

- Purpose
  - Quantify the sensitivity of primary design parameters to common design policies
- Which Design Parameters?
  - Span Capability
  - Girder Spacing
  - Prestressing Requirement
- Which Policies?
  - Section Properties (LRFD 5.9.1.4, BDM 5.6.2I)
  - Allowable Tension (LRFD 5.9.4.2.2, BDM 5.2.1C)
  - Continuity for Superimposed Dead and Live Loads (LRFD 5.14.1.4, BDM 5.6.2)

Design Policies

- AASHTO provides minimum design requirements for safe highway bridge structures
- Bridges designed using more stringent policies will obviously be stouter and more costly when compared to bridges designed only to the minimum requirements
- Influence of design policies are some combination of
  - Reduction in span capability (increase in number of spans/piers)
  - Reduction in girder spacing (increase in number of girder lines)
  - Increase in prestressing level (increase in release strength and shear and moment capacities)

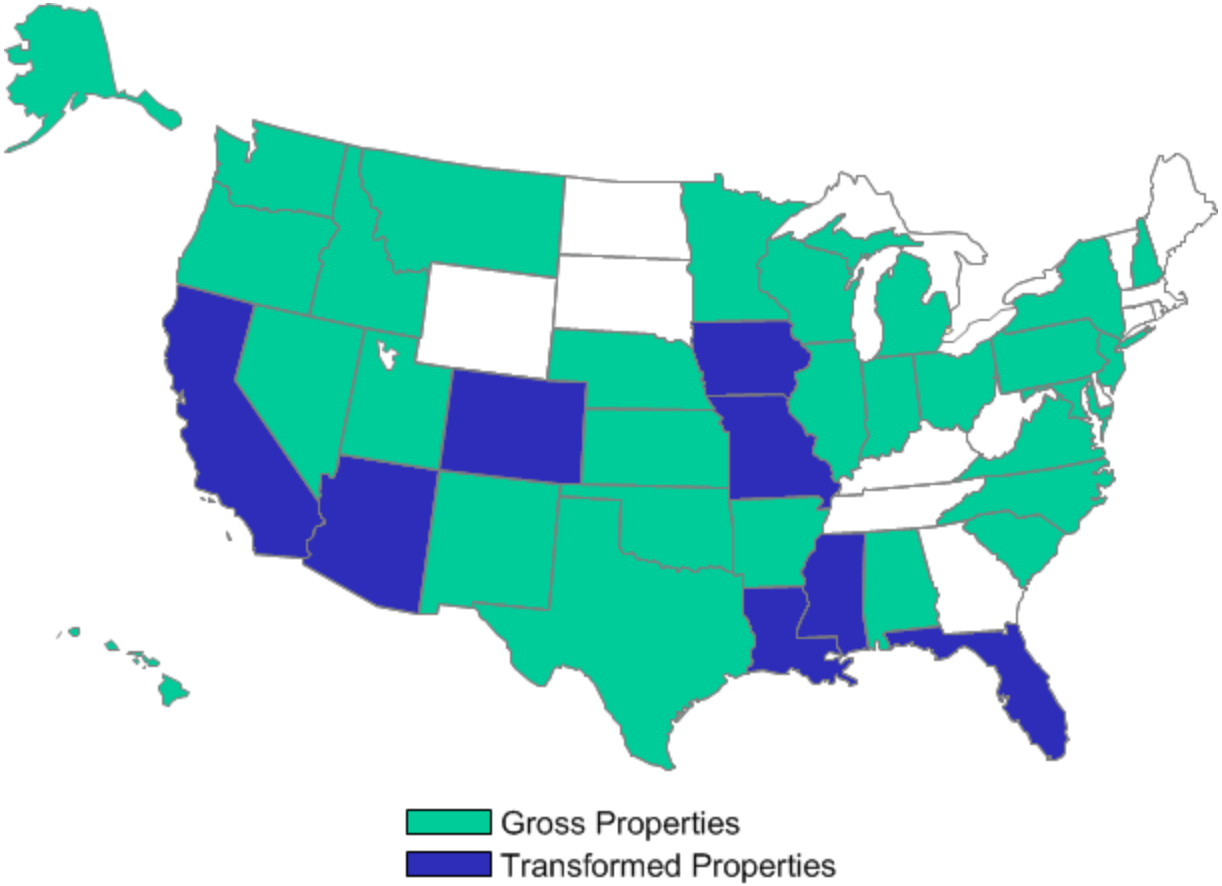
Design Policy Survey

- Survey of state DOTs – 38 respondents

- What type of section properties does your state use?
- What allowable tension stress does your state use?
- What continuity policy does your state use?
- What prestress loss method does your state use?

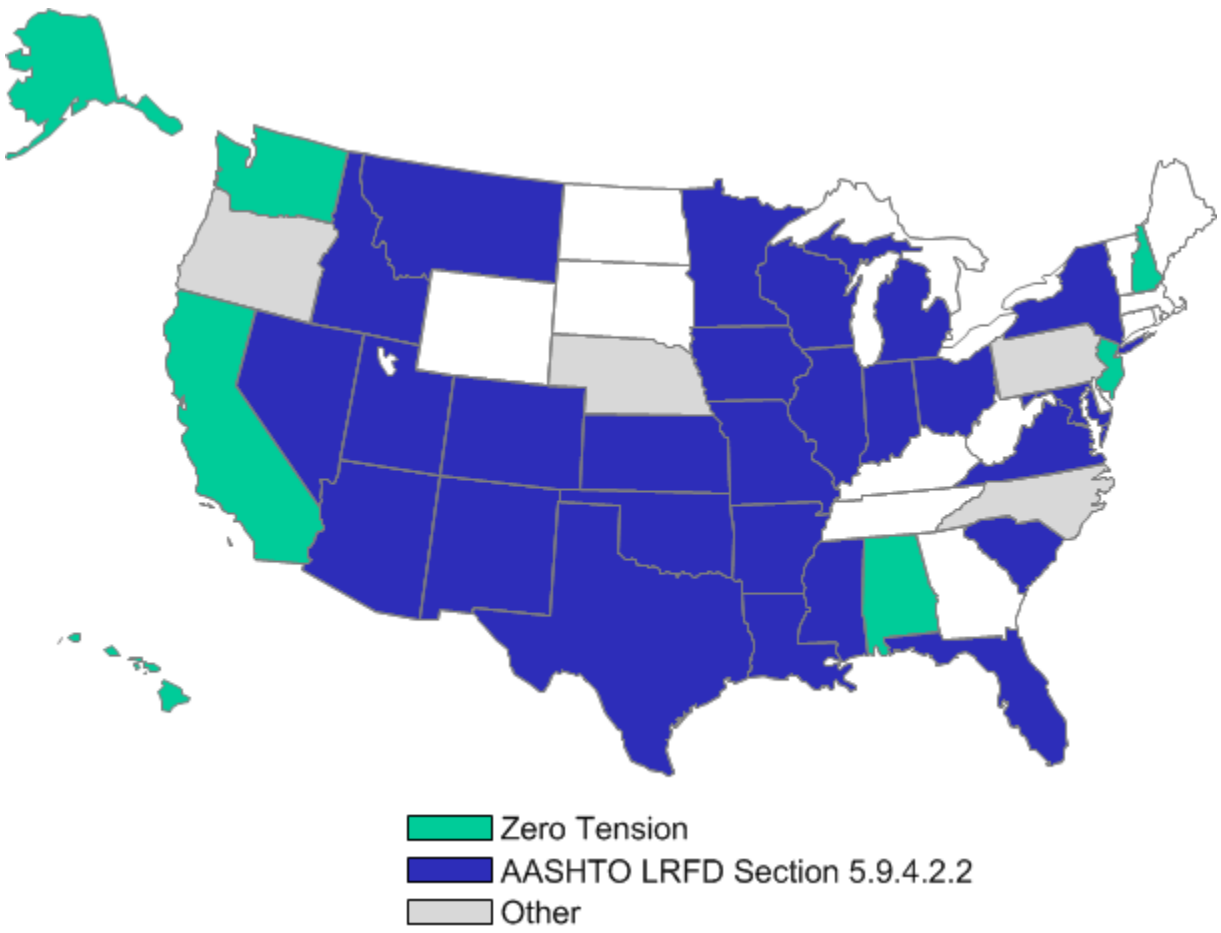
Section Properties Policy

- 29 Gross
- 9 Transformed



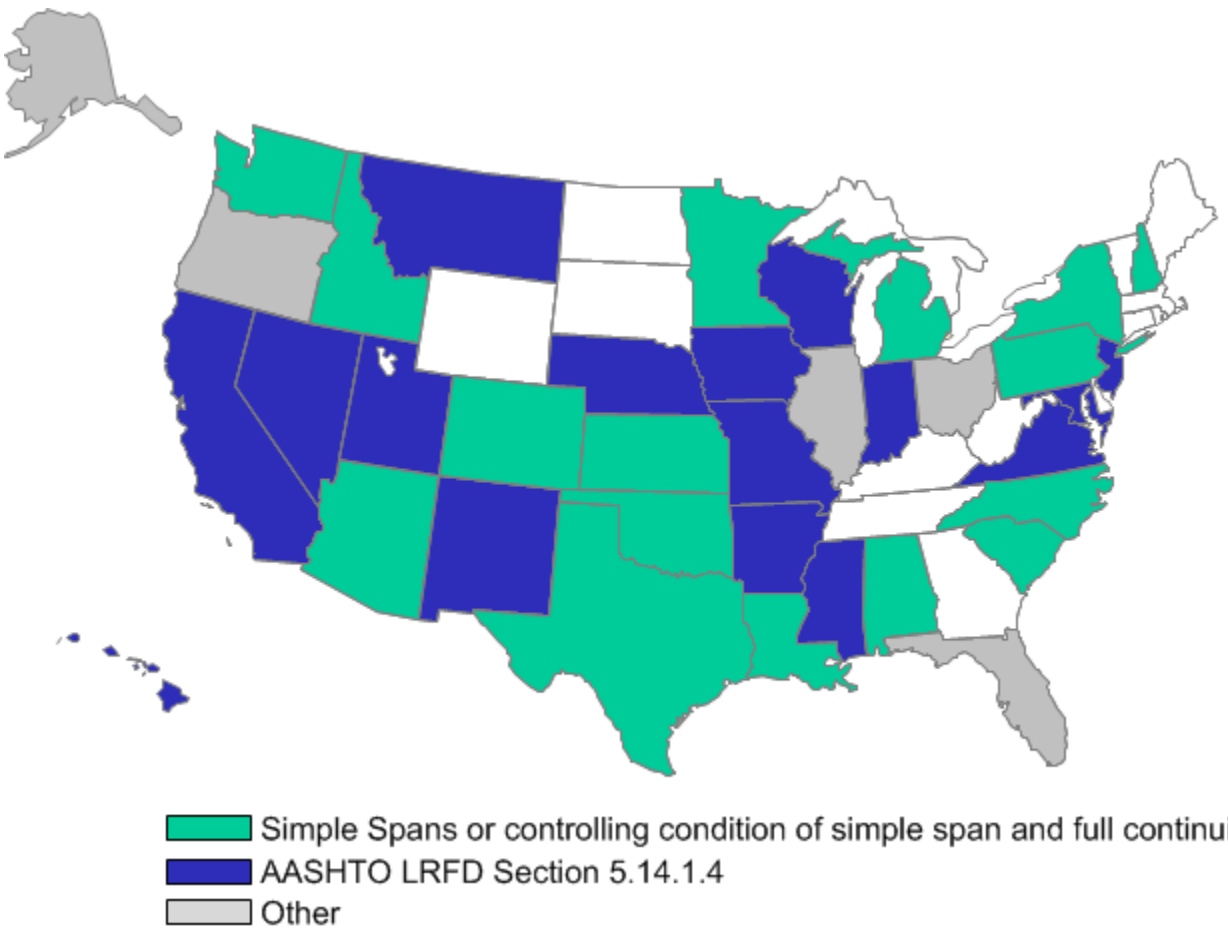
Allowable Tension Policy

- 7 Zero Tension
- 27 per AASHTO
- 4 Other



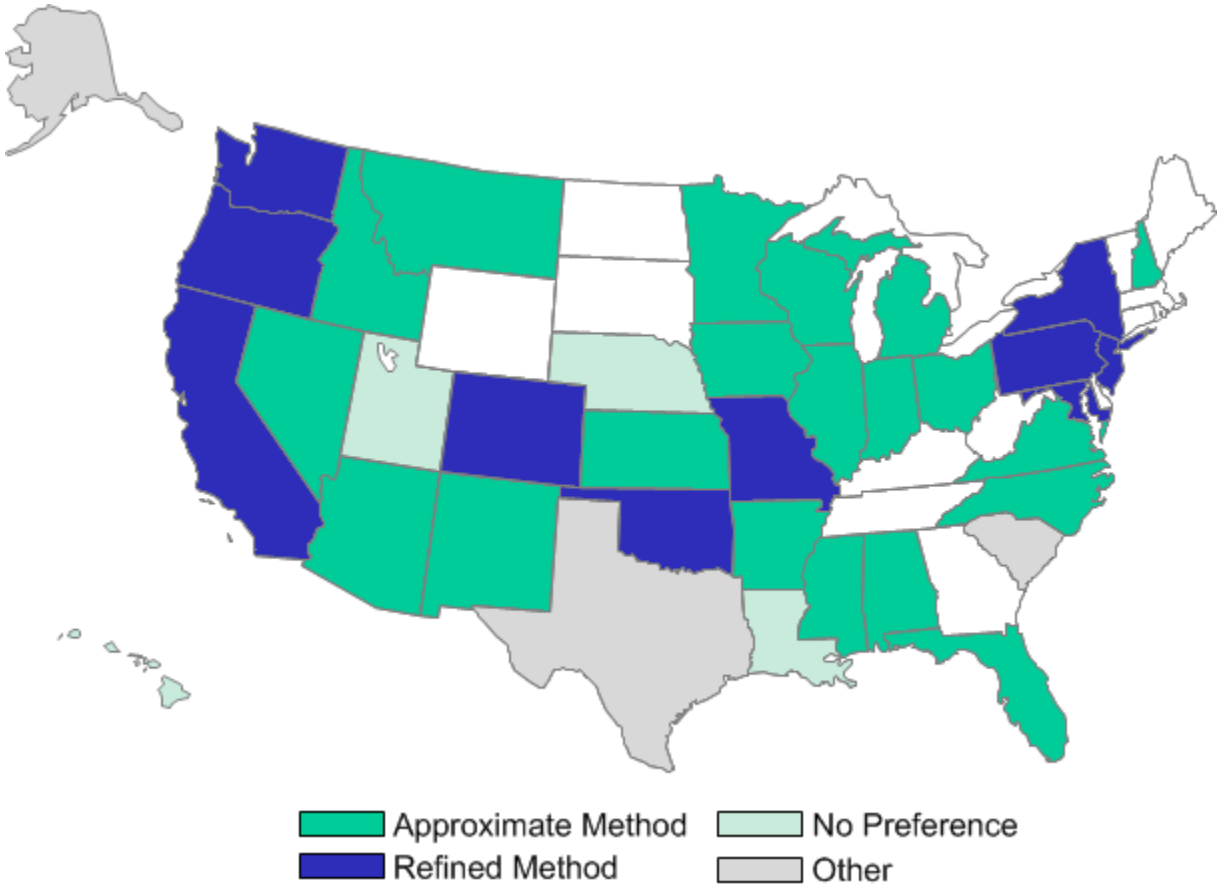
Continuity Policy

- 16 Simple Span
- 17 per AASHTO
- 5 Other



Prestress Loss Policy

- 20 Approximate
- 10 Refined
- 5 No Preference
- 3 Other



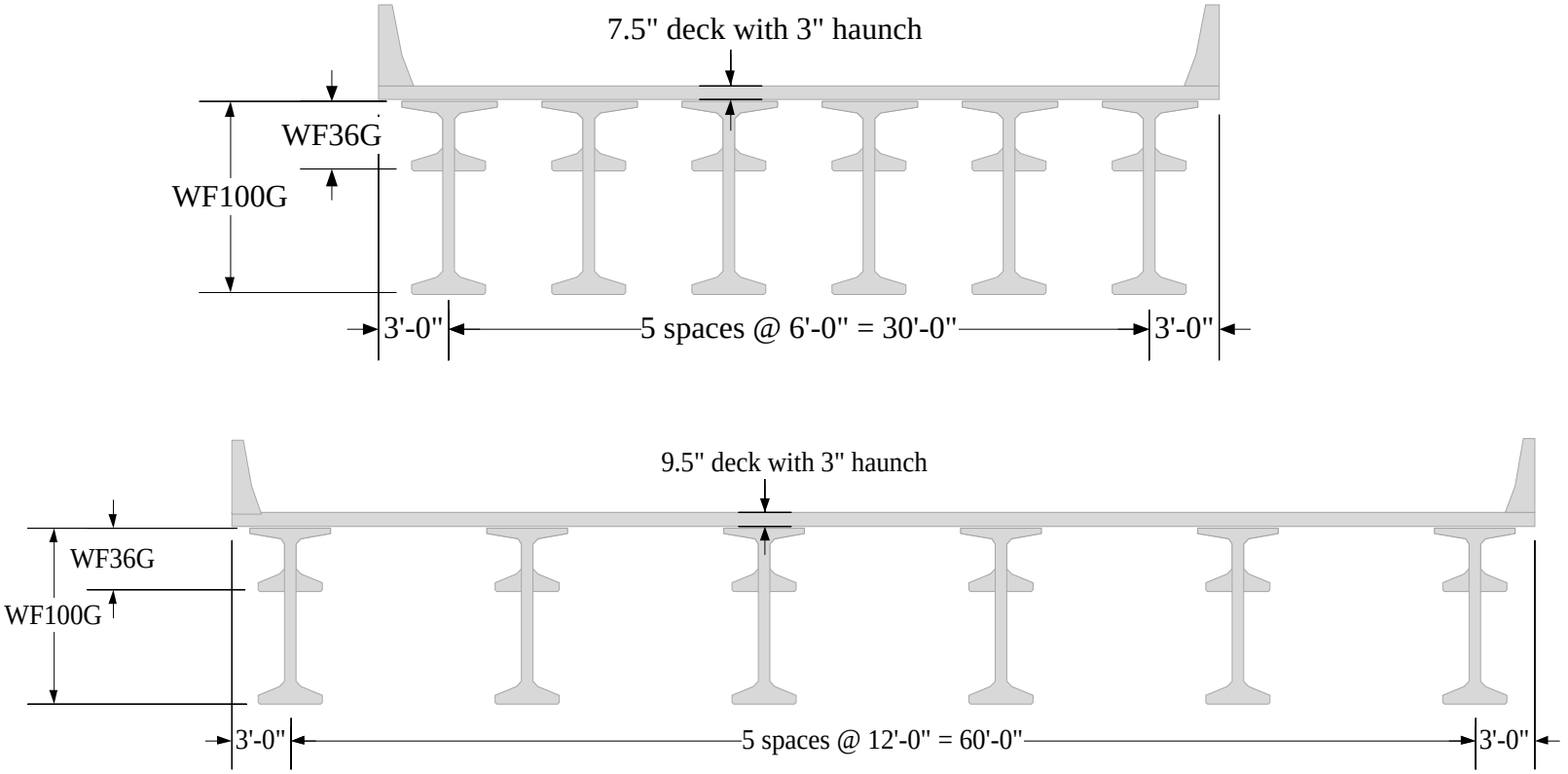
Research Approach

- Study typical bridge configurations using WF-Series girders at 6 ft and 12 ft spacing
- Assume design is controlled by tensile stress limitations in the Service III limit state

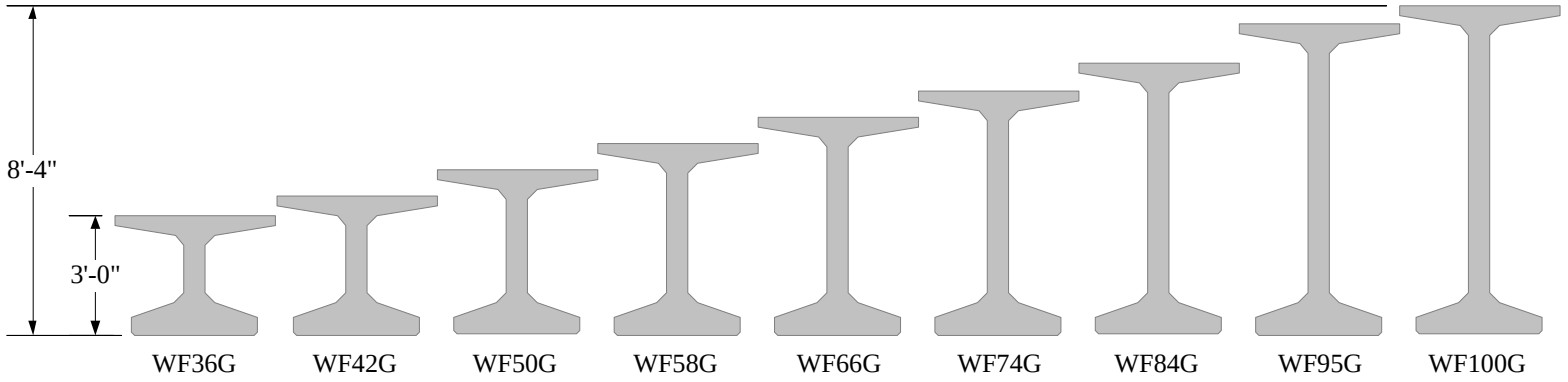
$$f_b - \frac{P_e}{A} - \frac{P_e e_{ps}}{S_b} \leq K_t \sqrt{f_c'}$$

- Determine baseline by using AASHTO criteria and various levels for prestressing to determine span capabilities
- For each design policy and all three design policies together
  - Baseline girder spacing and prestressing, determine span capability
  - Baseline span capability and prestressing, determine girder spacing
  - Baseline span capability and girder spacing, determine prestressing

Typical Bridge Configurations



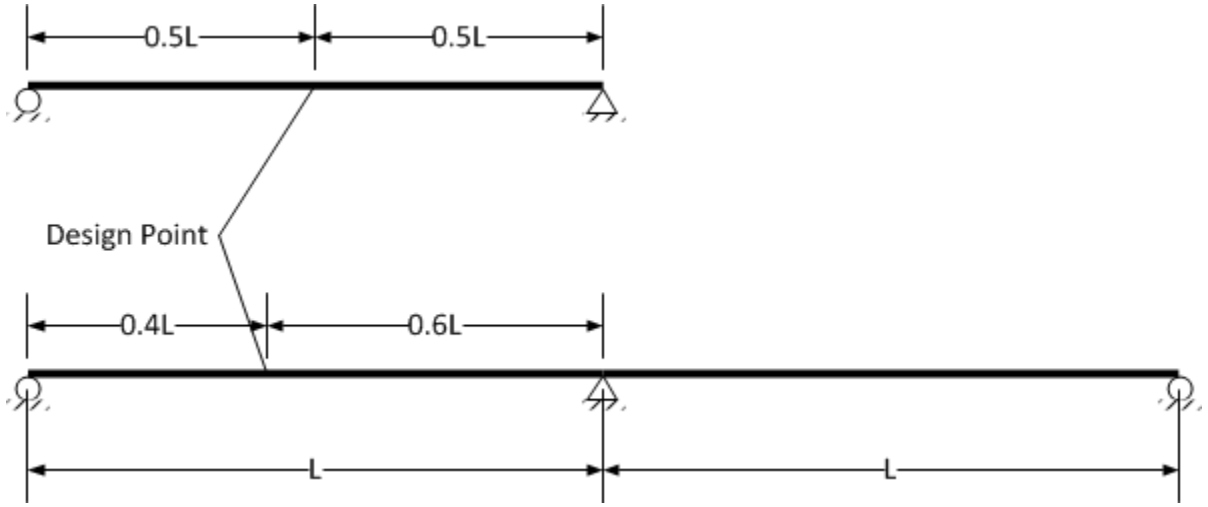
WSDOT WF-Series Girders



Gross Section Properties

Girder	Height (in)	Area (in^2)	Y_b (in)	Y_t (in)	I (in^4)	S_b (in^3)	S_t (in^3)
WF36G	36	691	17.5	18.5	124772	7115	6758
WF42G	42	728	20.4	21.6	183642	9020	8486
WF50G	50	777	24.2	25.8	282559	11700	10931
WF58G	58	826	28.0	30.0	406266	14527	18637
WF66G	66	875	31.8	34.2	556339	17493	16269
WF74G	74	824	35.7	38.3	734356	20595	19153
WF83G	82.625	976	39.8	42.8	959396	24088	22418
WF95G	94.5	1049	48.9	45.6	1328995	29148	27175
WF100G	100	1083	48.3	51.7	1524912	31589	29480

Span Configurations



Material Properties

Girder Release Strength, f'_{ci}	7.0 ksi
Girder 28-day Strength, f'_c	9.0 ksi
Deck 28-day Strength, f'_c	4.0 ksi
Concrete Density for computing dead load	0.165 kcf
Concrete Density for computing modulus of elasticity	0.155 kcf
Prestressing strand	0.6” diameter, Grade 270, Low Relaxation Strand
Superimposed Dead Loads (Traffic Barrier)	0.100 kip/ft/girder

- 0.570 ksi is average allowable tensile stress for concrete strengths between 4.0 and 15.0 ksi. Corresponds to f'_c = 9.0 ksi
- $0.19\sqrt{9.0\ ksi} = 0.570\ ksi$

Time Dependent Prestress Losses

- Losses computed by LRFD Approximate Method in this study
- Approximate method has excellent correlation with refined method for Slab on I-Girder bridge systems (NCHRP Report 496)
- Approximate method depends on prestressing
- Refined method depends on all design parameters considered
  - Requires net and transformed section properties

Baseline

- Transformed section properties
- Allowable tension = 0.570 ksi
- Simple spans made continuous

Girder	# Strands	Span Capability (ft)	
		6 ft Spacing	12 ft Spacing
WF36G	50	125.47	100.11
WF42G	50	137.80	110.20
WF50G	55	158.71	127.48
WF58G	55	171.72	138.54
WF66G	60	190.40	154.37
WF74G	60	201.09	163.79
WF83G	65	219.01	179.31
WF95G	70	239.77	197.62
WF100G	70	245.49	202.91

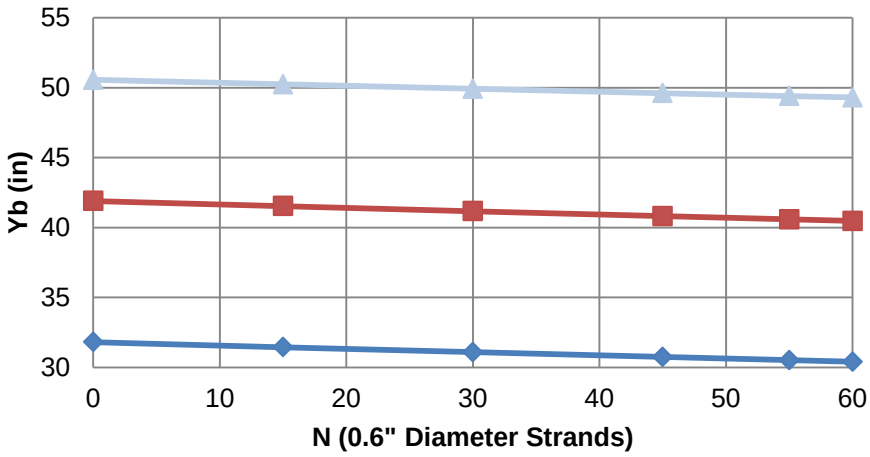
Section Properties Policy

- Gross section properties
- Allowable tension = 0.570 ksi
- Simple spans made continuous

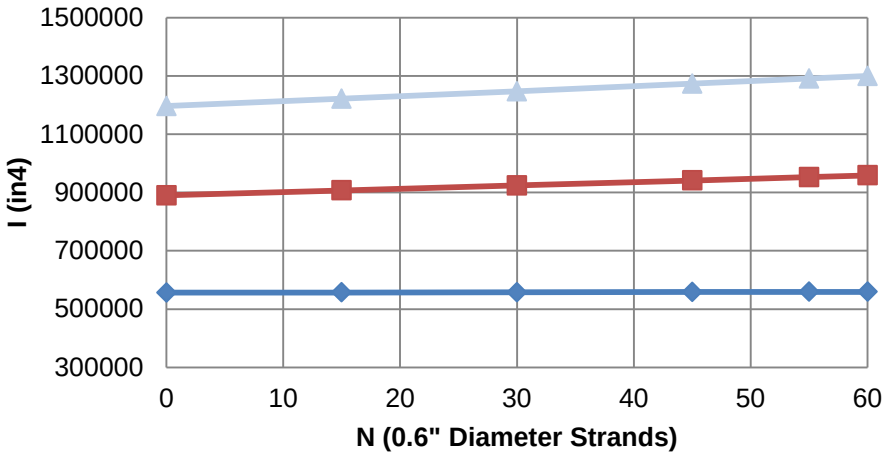
Transformed Section Properties

- Theoretically correct
- Transform strand into equivalent girder concrete
  - $A_t = A_g + A_{ps}\left(\frac{E_{ps}}{E_c} - 1\right) = A_g + A_{ps}(n-1)$
- Transformed bottom section modulus, S_{bt}, is greater than S_b based on gross section properties
  - Lower final tension stress at the bottom of the girder
- Elastic losses and gains are implicit in prestress loss calculations
- More cumbersome to compute
- Properties are time-dependent (at release $n = \frac{E_{ps}}{E_{ci}}$, at final $n = \frac{E_{ps}}{E_c}$)
- Vary along the length of a girder due to position of harped strands
- Must be recomputed when number of strands change during design iterations

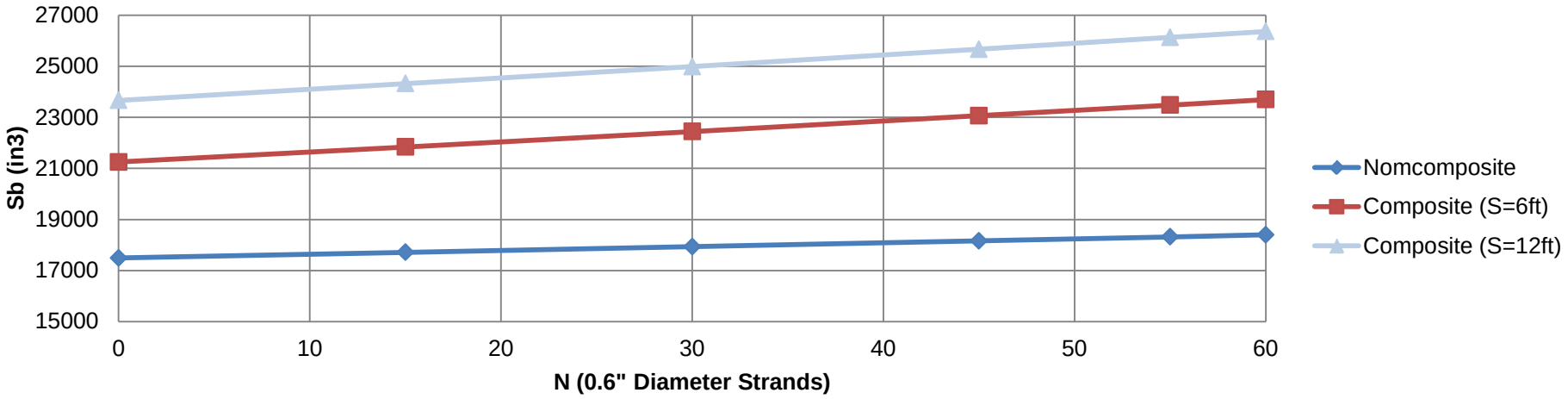
WF66G Bottom Centroid



WF66G Moment of Inertia

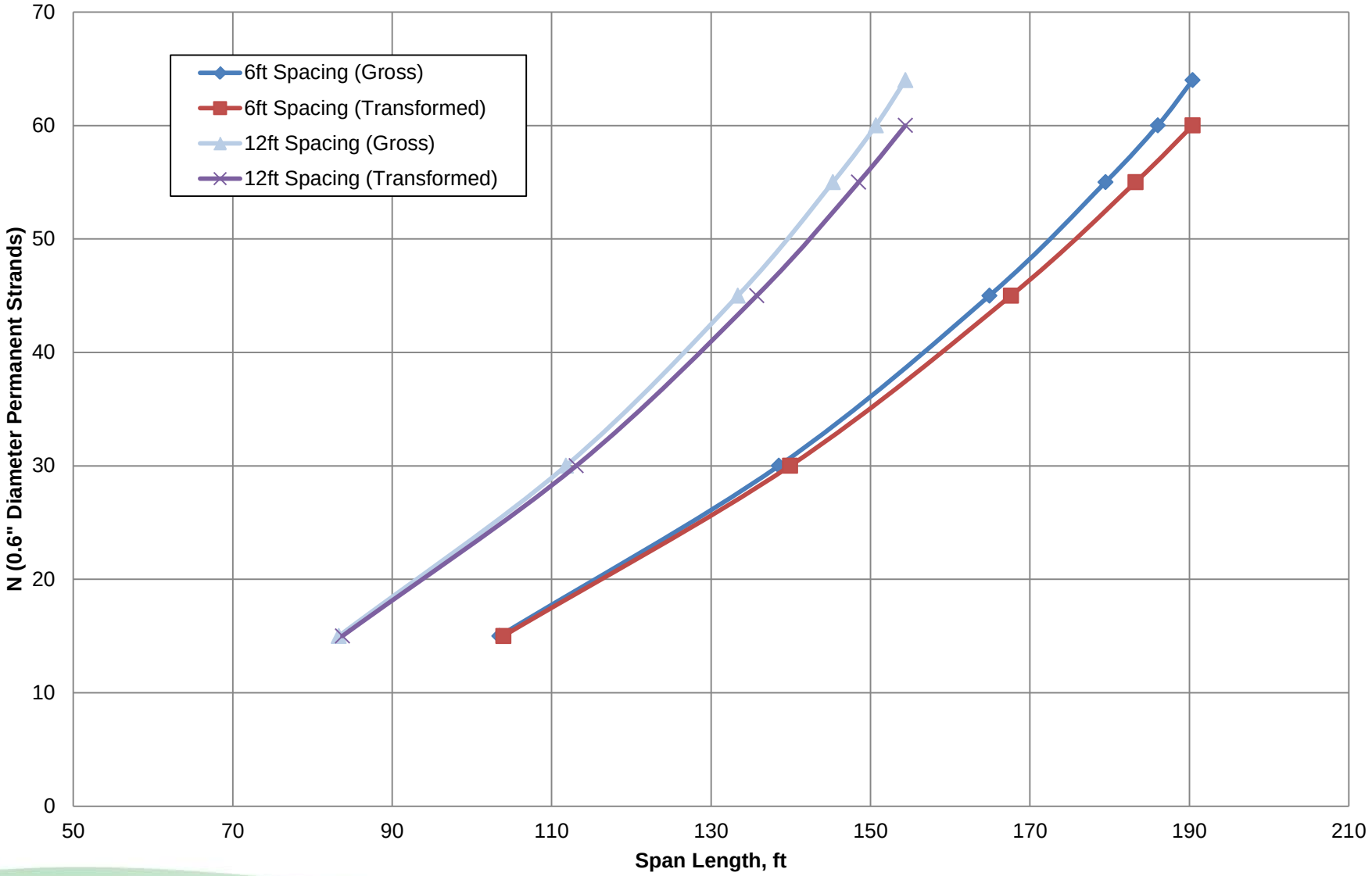


WF66G Bottom Section Modulus

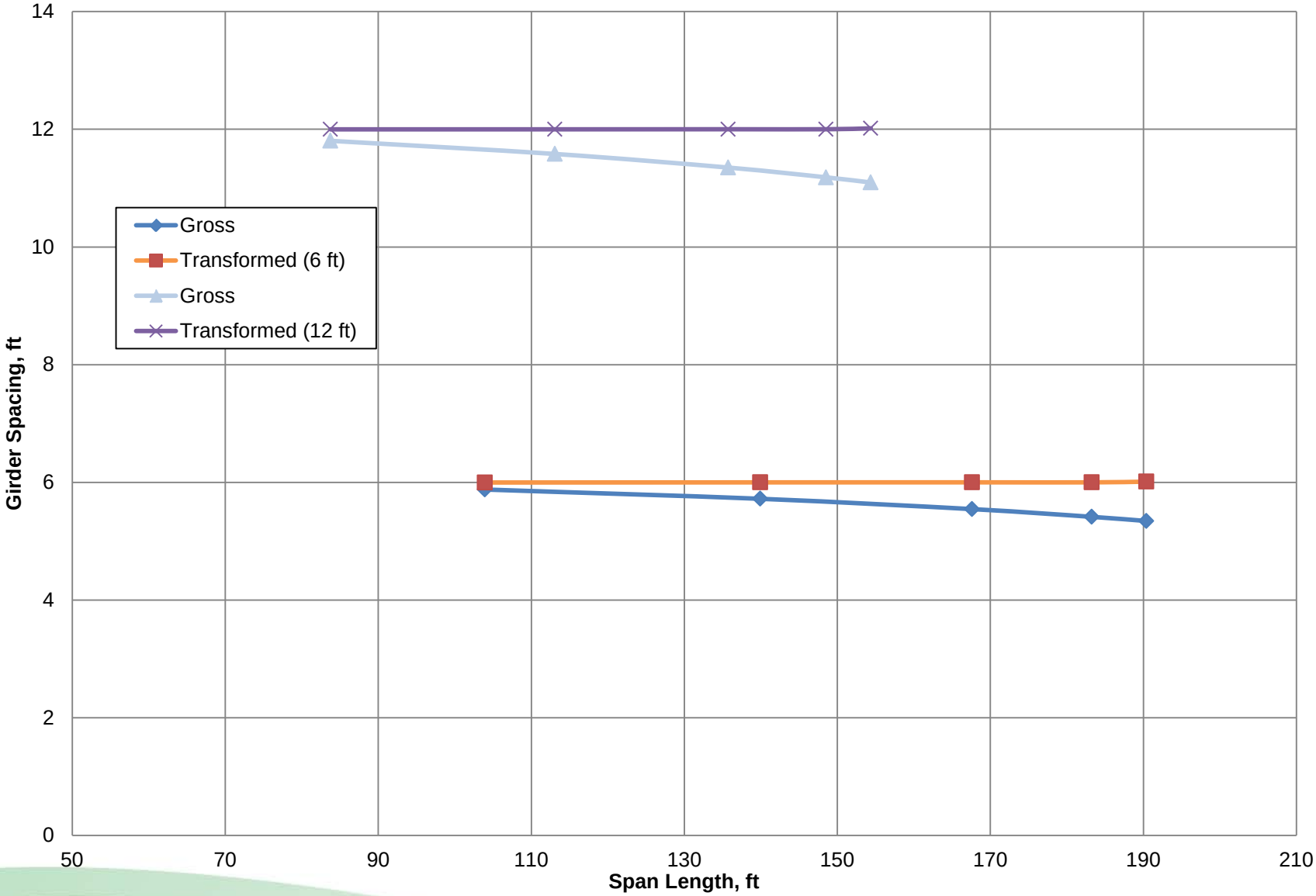


All strands located 5.0” from bottom of girder

WF66G Span Capability Comparison



WF66G Girder Spacing Comparison



Section Properties Policy
Baseline Comparison (6 ft Spacing)

Girder	Span Capability (ft)	% Reduction	Girder Spacing (ft)	% Reduction	# Strands	% Increase
WF36G	121.74	3.0%	5.25	12.6%	54	8.0%
WF42G	134.10	2.7%	5.31	11.6%	54	8.0%
WF50G	154.53	2.6%	5.30	11.7%	59	7.3%
WF58G	167.74	2.3%	5.36	10.7%	59	7.3%
WF66G	186.03	2.3%	5.34	10.9%	64	6.7%
WF74G	196.97	2.0%	5.40	10.0%	64	6.7%
WF83G	214.58	2.0%	5.38	10.3%	69	6.2%
WF95G	235.18	1.9%	5.39	10.2%	74	5.7%
WF100G	241.10	1.8%	5.42	9.7%	74	5.7%

Section Properties Policy
Baseline Comparison (12 ft Spacing)

Girder	Span Capability (ft)	% Reduction	Girder Spacing (ft)	% Reduction	# Strands	% Increase
WF36G	97.11	3.0%	10.96	8.7%	54	8.0%
WF42G	107.19	2.7%	11.04	8.0%	54	8.0%
WF50G	124.02	2.7%	11.02	8.1%	59	7.3%
WF58G	135.18	2.4%	11.11	7.4%	59	7.3%
WF66G	150.66	2.4%	11.10	7.5%	64	6.7%
WF74G	160.24	2.2%	11.17	6.9%	64	6.7%
WF83G	175.47	2.1%	11.16	7.0%	69	6.2%
WF95G	193.61	2.0%	11.17	6.9%	74	5.7%
WF100G	199.04	1.9%	11.21	6.5%	74	5.7%

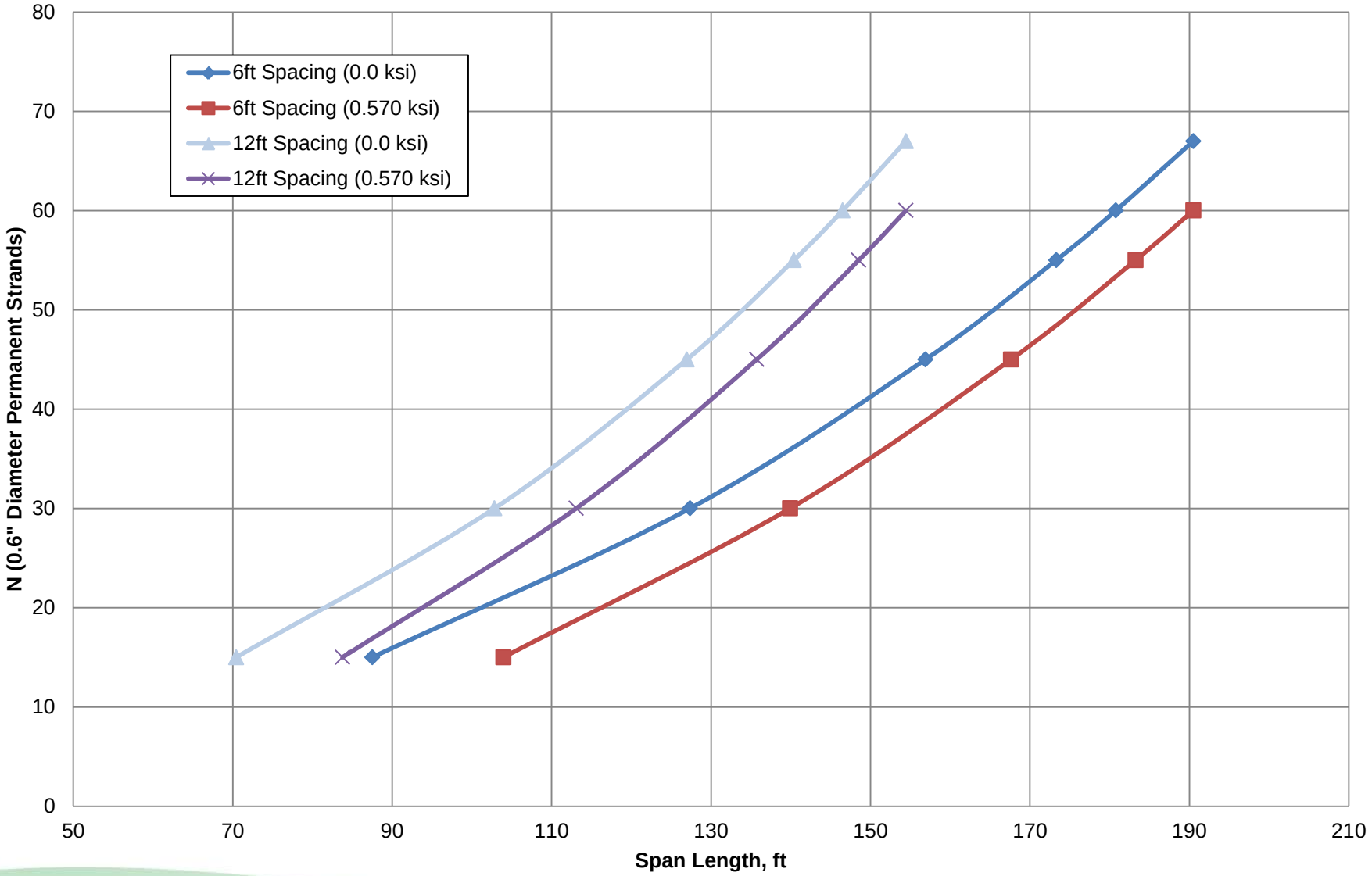
Allowable Tension Policy

- Transformed section properties
- Allowable tension = 0.0 ksi
- Simple spans made continuous

Allowable Tension

- Service III Limit State
- AASHTO LRFD 5.9.4.2.2
  - $0.19\sqrt{f_c'}$ for no worse than moderate corrosion conditions
  - $0.0948\sqrt{f_c'}$ for severe corrosive conditions
  - $0.19\sqrt{9.0\ ksi} = 0.570\ ksi$
- WSDOT BDM 5.2.1C
  - 0.0 ksi

WF66G Span Capability Comparison



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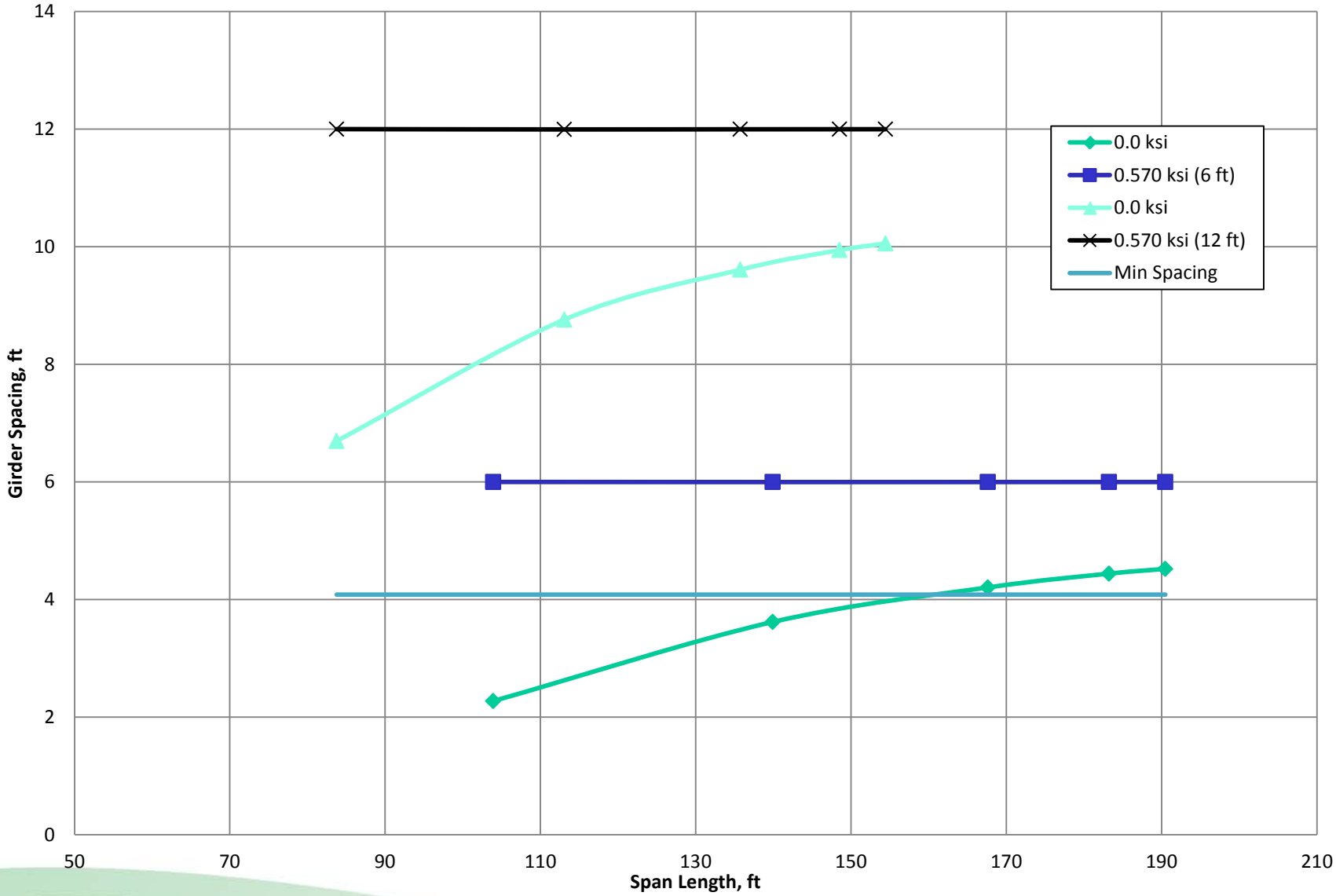
WF66G Girder Spacing Comparison



Allowable Tension Policy
Baseline Comparison (6 ft Spacing)

Girder	Span Capability (ft)	% Reduction	Girder Spacing (ft)	% Reduction	# Strands	% Increase
WF36G	118.93	5.2%	4.65	22.5%	56	12.0%
WF42G	130.42	5.4%	4.59	23.5%	57	14.0%
WF50G	150.57	5.1%	4.60	23.4%	62	12.7%
WF58G	162.65	5.3%	4.51	24.8%	62	12.7%
WF66G	180.76	5.1%	4.52	24.6%	67	11.7%
WF74G	190.64	5.2%	4.44	26.0%	68	13.3%
WF83G	208.05	5.0%	4.44	26.0%	73	12.3%
WF95G	228.08	4.9%	4.41	26.5%	78	11.4%
WF100G	233.34	4.9%	4.36	27.3%	78	11.4%

Allowable Tension Policy
Baseline Comparison (12 ft Spacing)

Girder	Span Capability (ft)	% Reduction	Girder Spacing (ft)	% Reduction	# Strands	% Increase
WF36G	94.88	5.2%	10.16	15.3%	56	12.0%
WF42G	104.27	5.4%	10.08	16.0%	57	14.0%
WF50G	120.89	5.2%	10.12	15.7%	62	12.7%
WF58G	131.16	5.3%	10.02	16.5%	62	12.7%
WF66G	146.48	5.1%	10.06	16.2%	67	11.7%
WF74G	155.19	5.2%	9.97	16.9%	68	13.3%
WF83G	170.25	5.1%	9.99	16.7%	73	12.3%
WF95G	187.89	4.9%	9.98	16.9%	78	11.4%
WF100G	192.77	5.0%	9.92	17.3%	78	11.4%

Continuity Policy

- Transformed section properties
- Allowable tension = 0.570 ksi
- Simple span analysis for all loads

Continuity Requirements

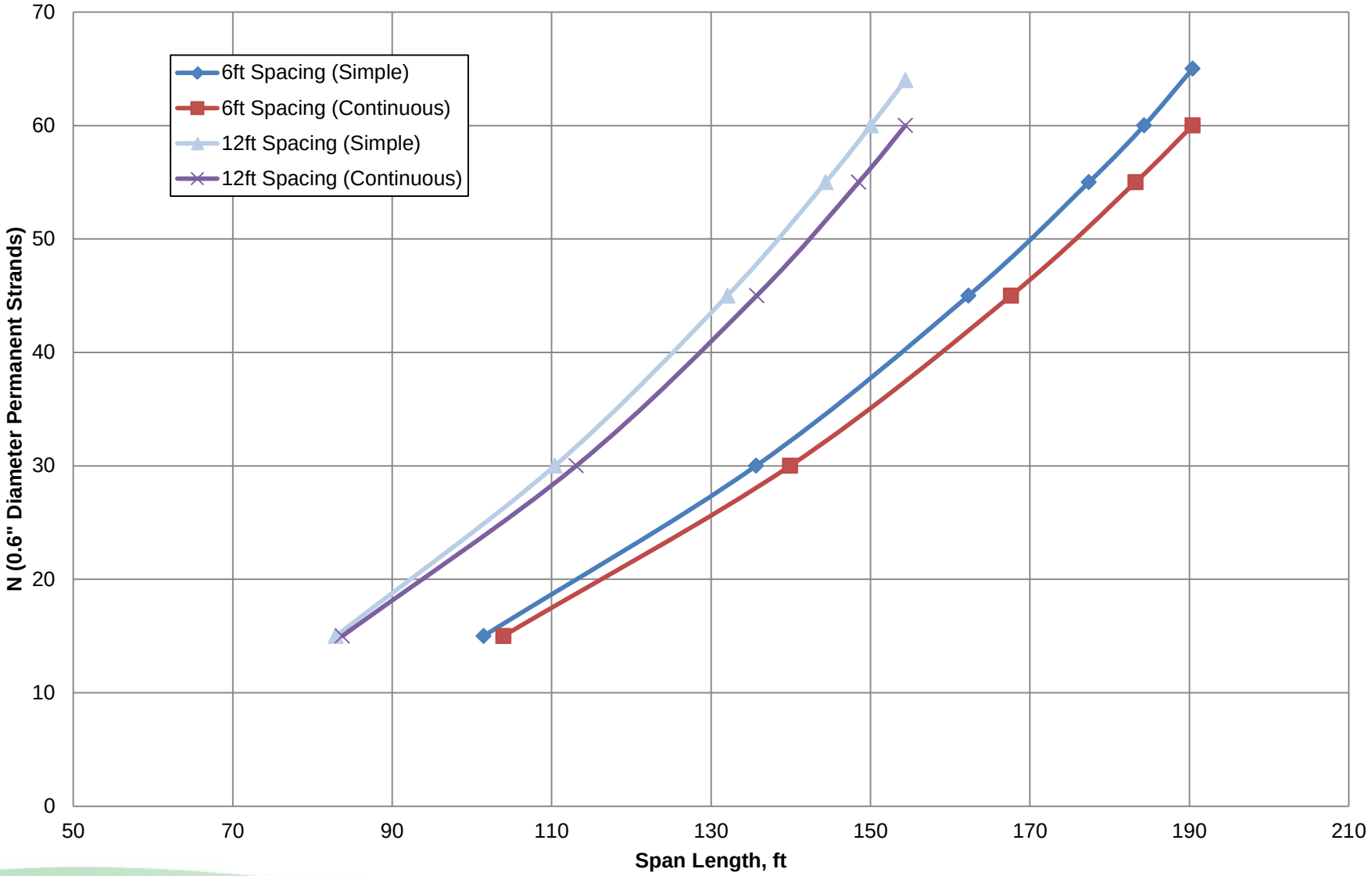
- This study assumes continuity is established when the girder age is at least 90 days so that restraint moment does not need to be computed (LRFD 5.14.1.4.4)

- When girder age is less than 90 days, continuity diaphragms are partially effective and girders should be treated as simple spans for all loads in the service limit states.

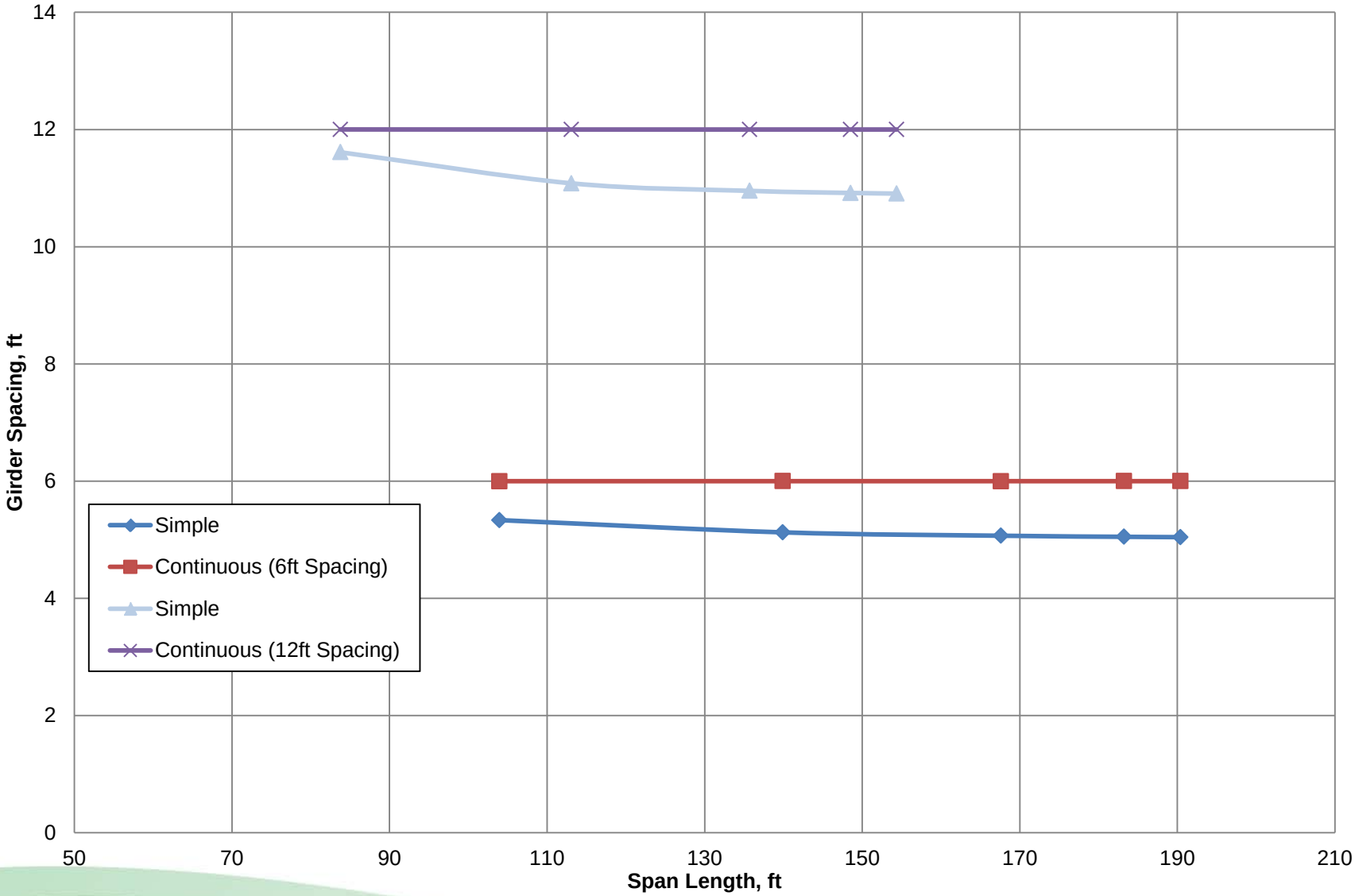
- WSDOT specifies a minimum age of 10 days for girder erection and 30 days for deck casting.

- Reduction in continuity effectiveness if deck rebar yields during permit overload situations. Yielding of reinforcement is permissible for permit load ratings (MBE 6A.5.4.2.2b).

WF66G Span Capability Comparison



WF66G Girder Spacing Comparison



Continuity Policy
Baseline Comparison (6 ft Spacing)

Girder	Span Capability (ft)	% Reduction	Girder Spacing (ft)	% Reduction	# Strands	% Increase
WF36G	121.82	2.9%	5.21	13.2%	54	8.0%
WF42G	133.59	3.1%	5.16	14.0%	54	8.0%
WF50G	153.69	3.2%	5.11	14.9%	60	9.1%
WF58G	166.25	3.2%	5.08	15.4%	60	9.1%
WF66G	184.33	3.2%	5.04	15.9%	65	8.3%
WF74G	194.70	3.2%	5.02	16.3%	65	8.3%
WF83G	212.12	3.1%	5.00	16.7%	70	7.7%
WF95G	232.33	3.1%	4.97	17.2%	76	8.6%
WF100G	237.92	3.1%	4.96	17.4%	76	8.6%

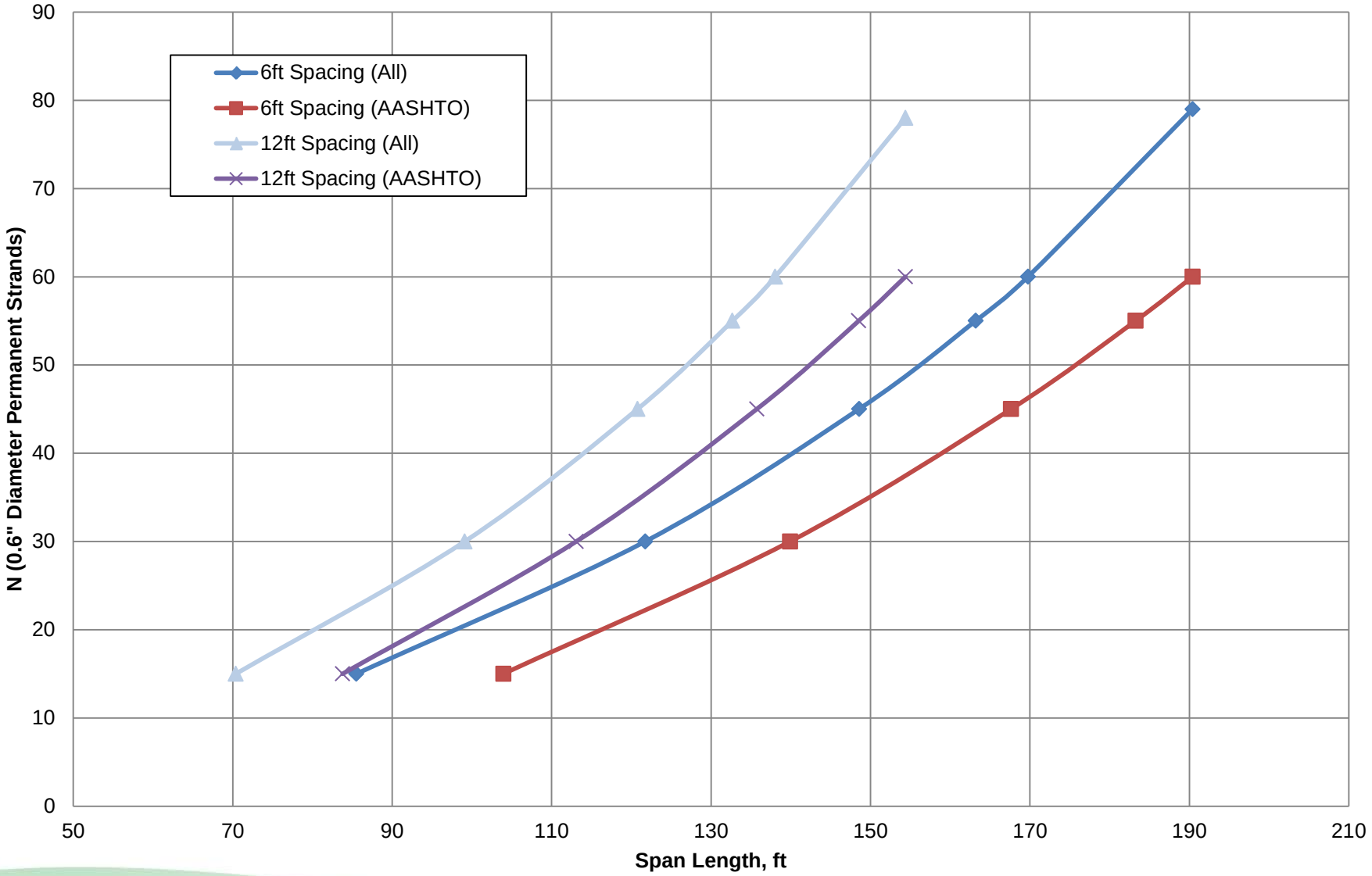
Continuity Policy
Baseline Comparison (12 ft Spacing)

Girder	Span Capability (ft)	% Reduction	Girder Spacing (ft)	% Reduction	# Strands	% Increase
WF36G	98.07	2.0%	11.24	6.3%	53	6.0%
WF42G	107.64	2.3%	11.13	7.2%	53	6.0%
WF50G	124.14	2.6%	11.02	8.2%	59	7.3%
WF58G	134.77	2.7%	10.96	8.7%	59	7.3%
WF66G	150.04	2.8%	10.91	9.1%	64	6.7%
WF74G	159.14	2.8%	10.88	9.4%	65	8.3%
WF83G	174.18	2.9%	10.84	9.7%	70	7.7%
WF95G	191.98	2.9%	10.81	9.9%	75	7.1%
WF100G	197.13	2.8%	10.80	10.0%	75	7.1%

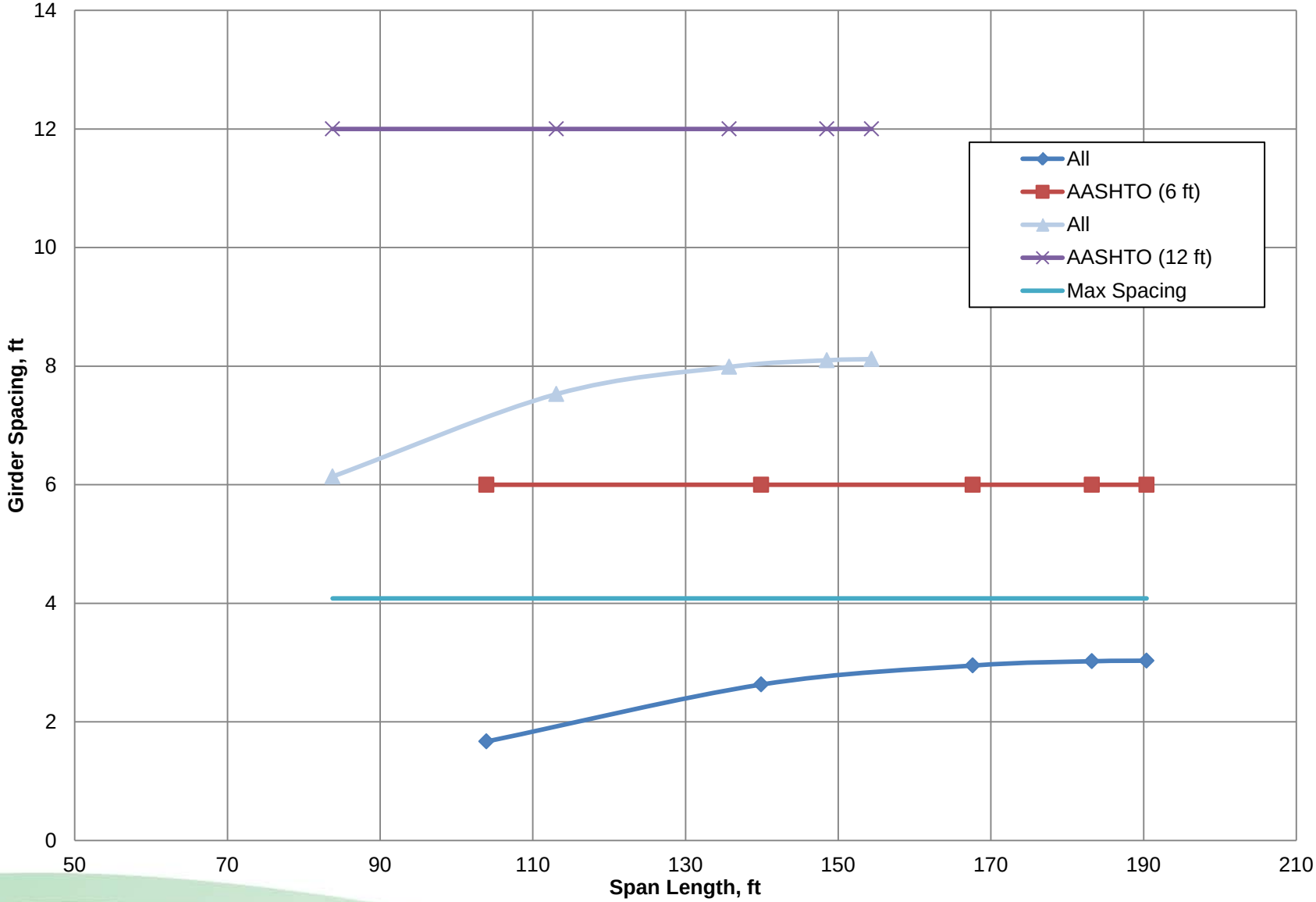
Combined Design Policies

- Gross section properties
- Allowable tension = 0.0 ksi
- Simple span analysis for all loads

WF66G Span Capability Comparison



WF66G Girder Spacing Comparison



Combined Design Policies
Baseline Comparison (6 ft Spacing)

Girder	Span Capability (ft)	% Reduction	Girder Spacing (ft)	% Reduction	# Strands	% Increase
WF36G	111.59	11.1%	3.23	46.2%	67	34.0%
WF42G	122.44	11.1%	3.18	46.9%	66	32.0%
WF50G	141.07	11.1%	3.12	47.9%	73	32.7%
WF58G	152.78	11.0%	3.08	48.7%	72	30.9%
WF66G	169.74	10.9%	3.03	49.5%	79	31.7%
WF74G	179.49	10.7%	2.99	50.2%	78	30.0%
WF83G	195.94	10.5%	2.94	50.9%	85	30.8%
WF95G	215.10	10.3%	2.88	51.9%	91	30.0%
WF100G	220.40	10.2%	2.85	52.5%	90	28.6%

Girder spacing less than top flange width

$f'_{ci} > 7.0$ ksi

Combined Design Policies
Baseline Comparison (12 ft Spacing)

Girder	Span Capability (ft)	% Reduction	Girder Spacing (ft)	% Reduction	# Strands	% Increase
WF36G	90.07	10.0%	8.44	29.6%	65	30.0%
WF42G	98.79	10.4%	8.34	30.5%	65	30.0%
WF50G	113.98	10.6%	8.23	31.4%	72	30.9%
WF58G	123.79	10.6%	8.16	32.0%	72	30.9%
WF66G	138.03	10.6%	8.12	32.3%	78	30.0%
WF74G	146.52	10.5%	8.07	32.8%	78	30.0%
WF83G	160.67	10.4%	8.04	33.0%	84	29.2%
WF95G	177.46	10.2%	7.99	33.4%	90	28.6%
WF100G	182.31	10.2%	7.96	33.6%	90	28.6%

$f'_{ci} > 7.0$ ksi

Sensitivity of Design Parameters

- Span Capability is least sensitive
- Girder Spacing is most sensitive
- Designing with Gross Properties has least overall influence
- Designing with Reduced Allowable Tension has greatest overall influence

Benefits of Conservative Design Policies

- Historical increase in live load
  - HS15 → HS20 → HS25 → HL93
- Increasing use of overload trucks
- Increase in number of traveling lanes
  - Reduction in lane width from 12ft to 10ft
- Periodic changes in bridge design specifications
  - ASD → LFD → LRFD
- Reserve capacity for girders damaged by over height collisions
- Uncracked concrete under service conditions
- Increased shear capacity
- Reduced life cycle cost

Conclusions

- Conservative design policies can be an inexpensive insurance policy against future events including increasing legal loads, changing specifications, and unforeseen physical distress to the structure

- User costs due to temporary loss of use of a structure can be significant

- Premium is a one-time expense for as little as half a dozen strands to one line of girders which is typically a negligible percentage of overall project costs.