Photo: 2020 Prize Bridge National Winner, Major Span – Gov Cuomo/Tappen Zee (New York) – Photo Credit: New York State Thruway Authority

Medium/Long Span Bridge Design - LRFD Simon

Devin Altman, PE – Bridge Steel Specialist (Steel Solutions Center)

Steel Bridge Essentials: Designing Cost Effective & Resilient Bridges

Smarter.
Stronger.
Steel.

Devin Altman (Steel Solutions Center)

- Bridge Steel Specialist in the Steel Solutions Center (SSC) for the NSBA, a division of the AISC. He represents the steel bridge industry on matters of steel bridge design, fabrication and construction. Devin's role with NSBA is to provide technical assistance, tools, and resources for steel bridge owners, designers, fabricators, university programs, and technical committees.
- 17 years of bridge industry experience, spent over 15 years in the bridge consulting profession as a bridge engineer and project manager, with 12 years at CH2M Hill/Jacobs working on a wide range of projects includings design, load ratings, rehabilitation, complex analysis, and construction of a wide variety of structure types located throughout the USA and Internationally.
- B.S. in Mathematics from The Evergreen State College
- Master of Engineering degree in Structural Engineering and Construction Engineering Management from Oregon State University
- Registered Professional Engineer in Oregon

NATIONAL STEEL BRIDGE ALLIANCE NSBA FOUNDED 1995

Smarter.
Stronger.
Steel.

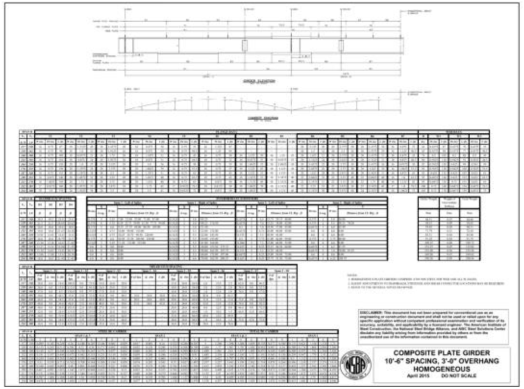
Learning Objectives

- Understand how to develop the required inputs for LRFD Simon and your bridge
- Learn how to use the LRFD Simon User's Guide for further clarification when needed
- Understand how to interpret LRFD Simon output and increase resistance if needed
- Learn about LRFD Simon in general and when it is appropriate for design/analysis and when it is not
- Understand how to use NSBA Continuous Span Standards as a starting point

Overview of the Design Tools Used Today

Continuous Span Standards

- Example steel girder design drawing detail/spec
- 5 girder bridge cross-sections with balanced design
- Per AASHTO LRFD BDS 7^{th} Edition (update out soon)

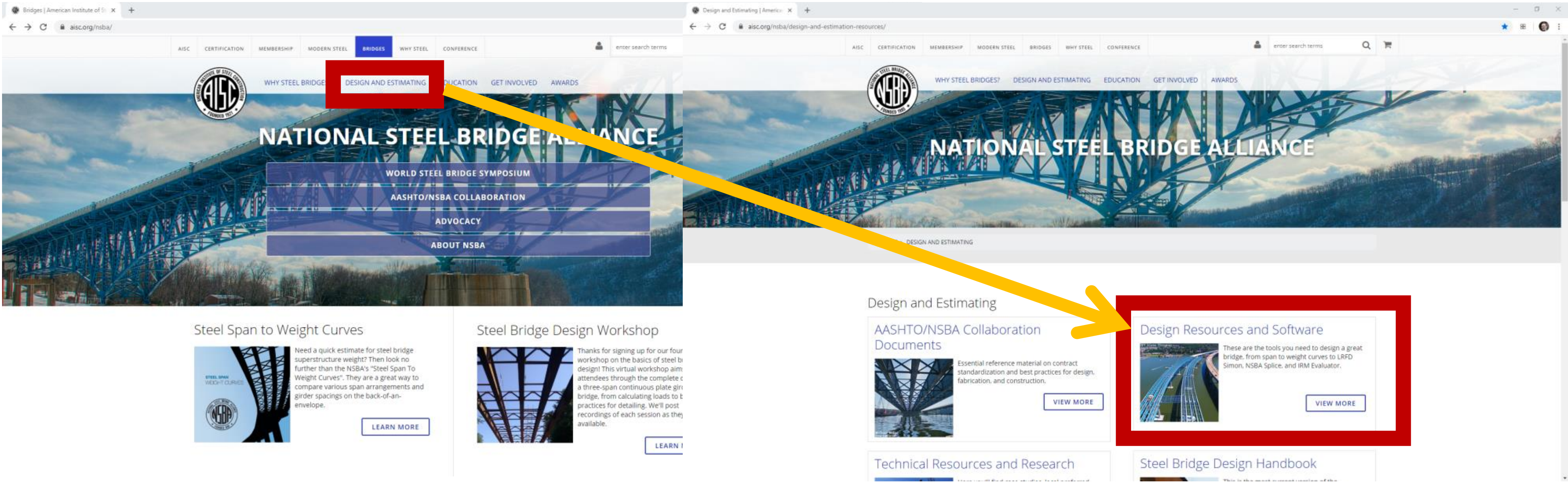


LRFD Simon

- Line girder analysis software
- Design mode, analysis mode, web depth optimization
- Per AASHTO LRFD BDS 9^{th} Edition

Where Can I Find These Free Design Tools

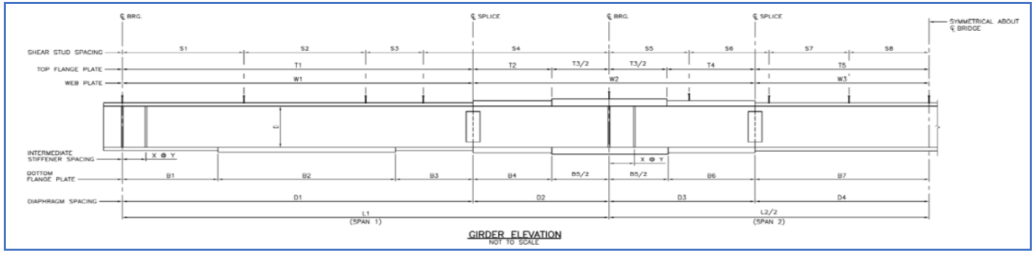
https://www.aisc.org/nsba



Continuous Span Standards

- **Assist Engineers During the TS&L Phase:**
  - ➢ LRFD Simon input files included
  - ➢ Flange plate sizes and lengths
  - ➢ Web plate sizes and lengths
  - ➢ Diaphragm spacing
  - ➢ Stiffener locations
  - ➢ Girder weights
  - ➢ Shear connector spacing
  - ➢ Camber tables

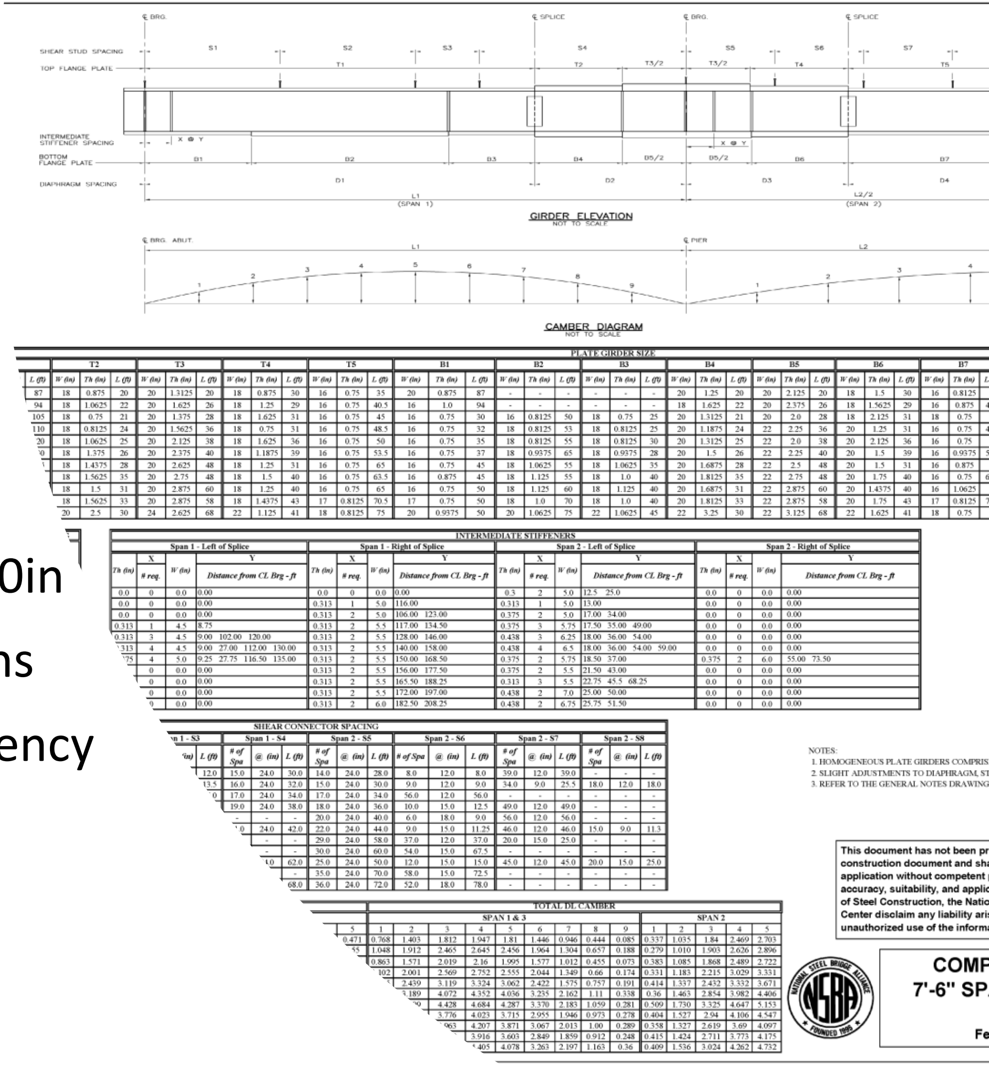
NSBA National
Steel Girder Standards
(Available in Early 2023)



Continuous Span Standards

Preliminary designs include:

- Center Span: 150 ft – 300 ft
- End Spans: 78% of center span
- Girder Spacing: 7ft – 6in to 12ft – 0in
- Homogeneous and hybrid solutions
- Web depth to suite material efficiency
- AASHTO 7th Edition LRFD
- 88 Unique Solutions



LRFD Simon

Named After Singer/Songwriter Paul Simon (Bridge over Troubled Water)

- Originally Developed in the Late 1960’s by U.S. Steel Corporation in Cooperation with Wisconsin Department of Transportation
- Late 2021 Release Satisfies AASHTO LRFD BDS 9th Edition
- Design Run Option
- Analysis Mode
- Free Software
- NSBA & AISC Support

LRFD Simon

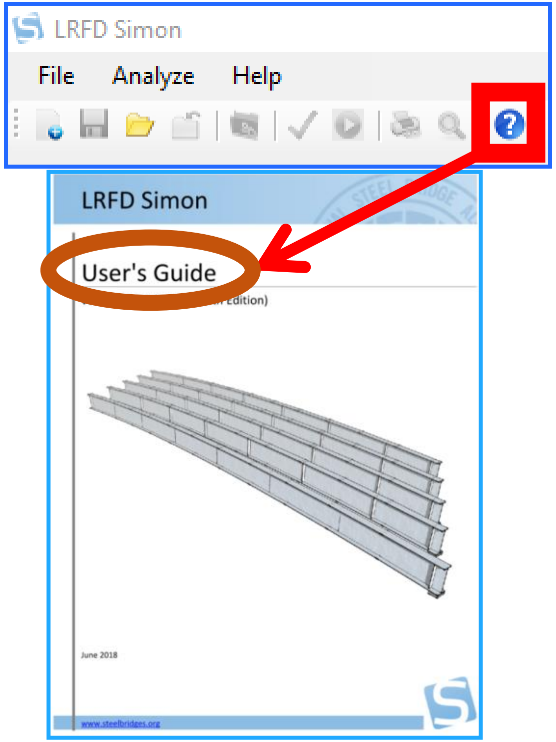
Analysis and Design Program

- Powerful Line-Girder Analysis & Design Software
- I-Girder and Box Girders Bridges
- Linear and Parabolic Haunches
- AASHTO LRFD Bridge Design Specification – 9th Edition
- Straight Bridges with Minimal Skew (i.e. equal to or less than 20 deg.)
- Help Develop Cost Estimates with Tabulated Quantities in Report

LRFD Simon

Analysis and Design Program

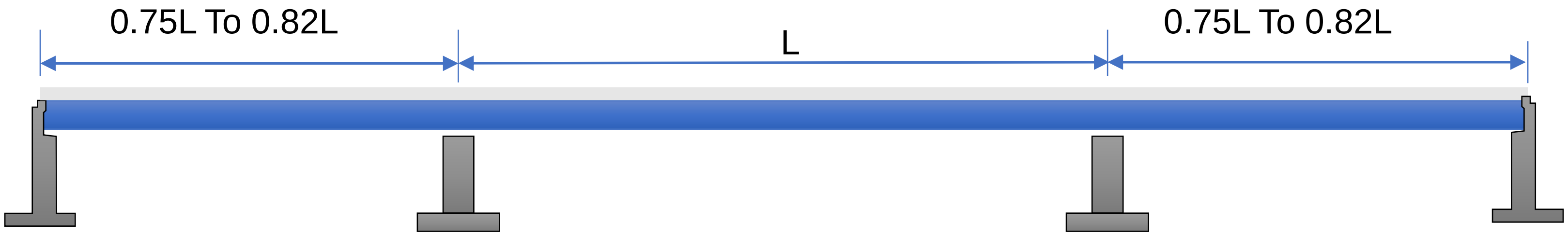
- Independently Design One Solution for both Interior and Exterior Girders
- Analyze both Interior and Exterior Girders
- Capable of Modeling Various Bridge Geometries and Design Loading Configurations
- Generates Service and Strength Moments, Shears, Deflections, and Bearing Reactions
- Helpful User's Guide Manual Written by Mike Grubb & Associates



Keep in Mind Before We Get Started

Span Layouts

- Try to layout span arrangements with maximum positive moments being nearly equal in each span
- End spans ideally 75% - 82% of center span

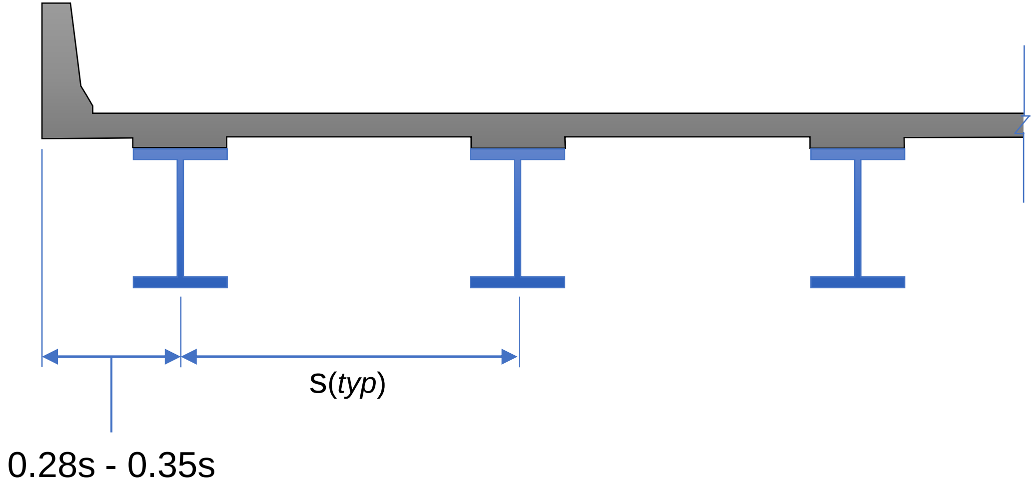


Balanced Span Arrangement

Keep in Mind Before We Get Started

Girder Spacing & Deck Overhangs

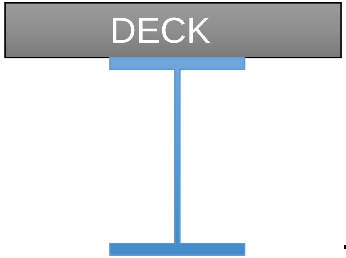
- Total factored moment tends to be larger in exterior girders (subject to lateral bridge deck overhang truck impact loads)
- Limit size of deck overhangs accordingly



Keep in Mind Before We Get Started

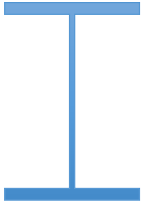
Proportioning – Web Depth

- Optional Span-to-Depth Ratio (AASHTO BDS Section 2.5.2.6.3)



Simple Spans	0.040L
Continuous spans	0.032L

<u>Suggested Minimum Overall Depth for Composite I-beam</u>



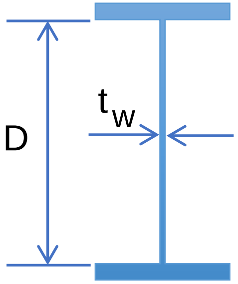
Simple Spans	0.033L
Continuous spans	0.027L

<u>Suggested Minimum Depth for I-beam</u>

Keep in Mind Before We Get Started

Proportioning – Web Thickness

- Web Thickness (AASHTO BDS Section 6.10.2.1)



Without Longitudinal Stiffeners	$\frac{D}{t_w} \leq 150$
With Longitudinal Stiffeners	$\frac{D}{t_w} \leq 300$

- ½" minimum thickness preferred by fabricators

Keep in Mind Before We Get Started

Proportioning - Flanges

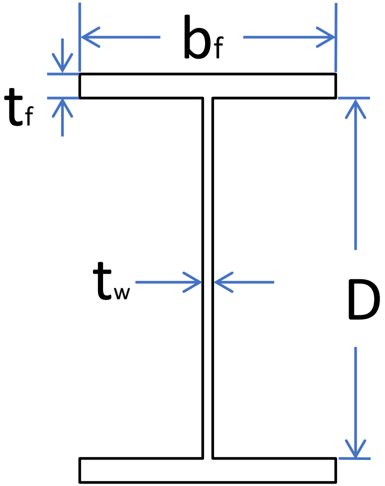
- Proportioning Requirements (AASHTO BDS Section 6.10.2.2):

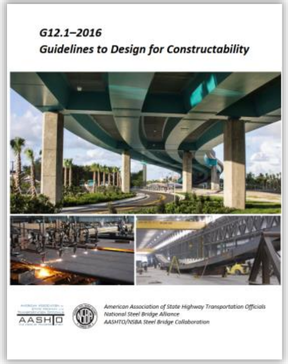
$$\frac{b_f}{2t_f} \leq 12$$

$$b_f \geq \frac{D}{6}$$

$$t_f \geq 1.1\, t_w$$

$$0.1 \leq \frac{I_{yc}}{I_{yt}} \leq 10$$





Fabricators prefer: $b_f \geq 12$ in.; $t_f \geq 0.75$ in.

Keep in Mind Before We Get Started

Field-Section Lengths for Steel I-Girders

- Shipment by truck is the most common means
  - 215 ft. Possible, 80 ft. Comfortable, 80 – 150’ typical
  - Over 100 Tons Possible (20 Tons - No Permit)
  - 16 ft. Width and 10 ft. Height (depending on truck and route)
  - Girder under 9’ deep can usually be shipped vertical to anywhere

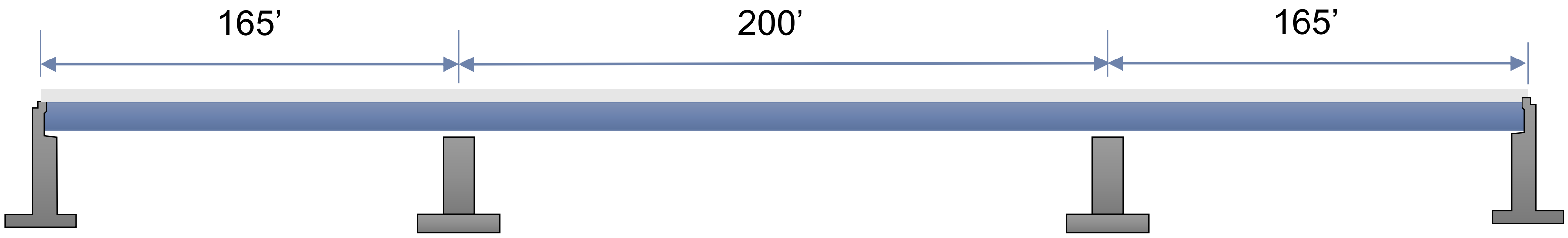


LRFD SIMON

3-Span Continuous Example

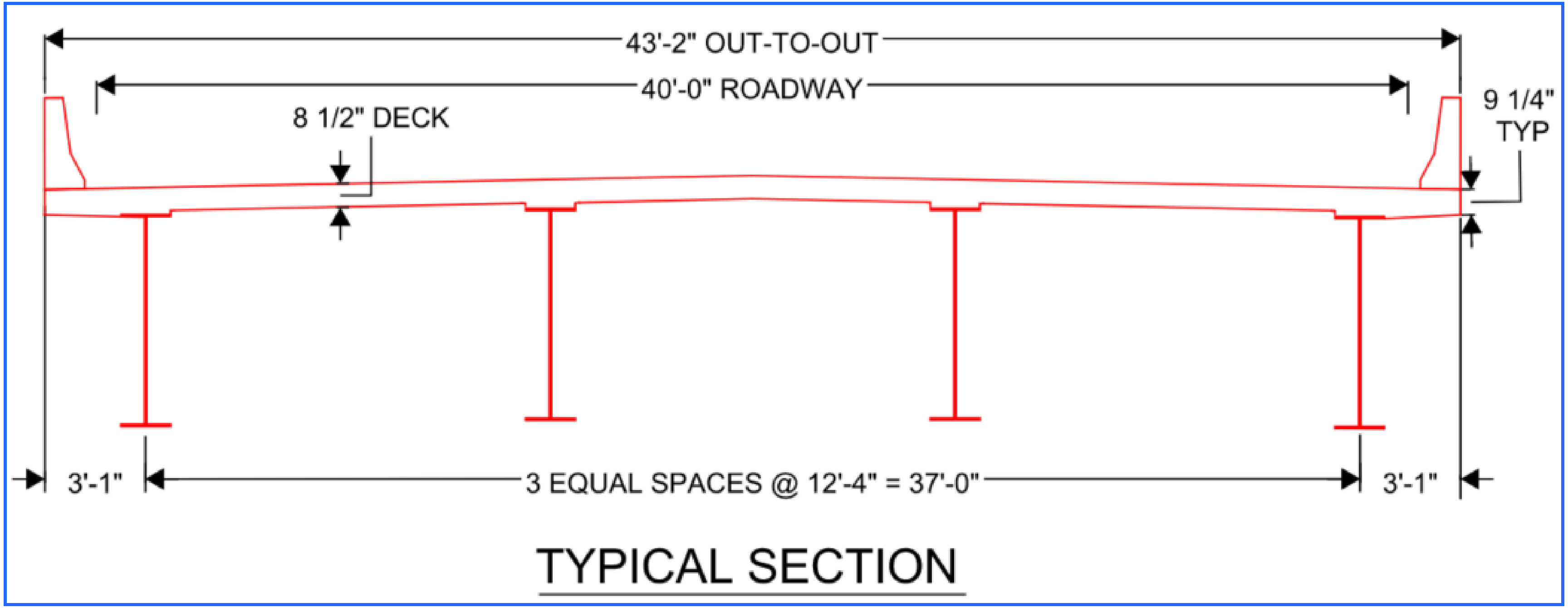
What if Your Span Layout is This?

The Continuous Span Standards Come with LRFD Simon Inputs



What if Your Cross-Section is This?

The Continuous Span Standards Come with LRFD Simon Inputs



Everything is Different Should I Start Over?

No, But We Still Need to Do the Hard Work and Develop the Design

- Generate Load Demands
- Compare Continuous Span Standards Loading Assumptions with Project
- Does Superstructure Depth Work for Project Constraints
- Overhang:Girder Spacing = 0.25 (Lower than Ideal)
- Verify and Check Everything (Assume it is All Wrong)

Continuous Span Standards

The Continuous Span Standards serve as a guide to state, county, and local highway departments in the development of suitable and economical steel bridge superstructures. Included are 88 unique solutions for three-span bridges with center spans between 150'-0" and 300'-0", girder spacings between 7'-6" and 12'-0", and plate girder designs utilizing both homogenous and hybrid steel options. These solutions were developed using the latest version of the AISC/NSBA LRFD Simon software v10.2 with the input files provided as part of the download.

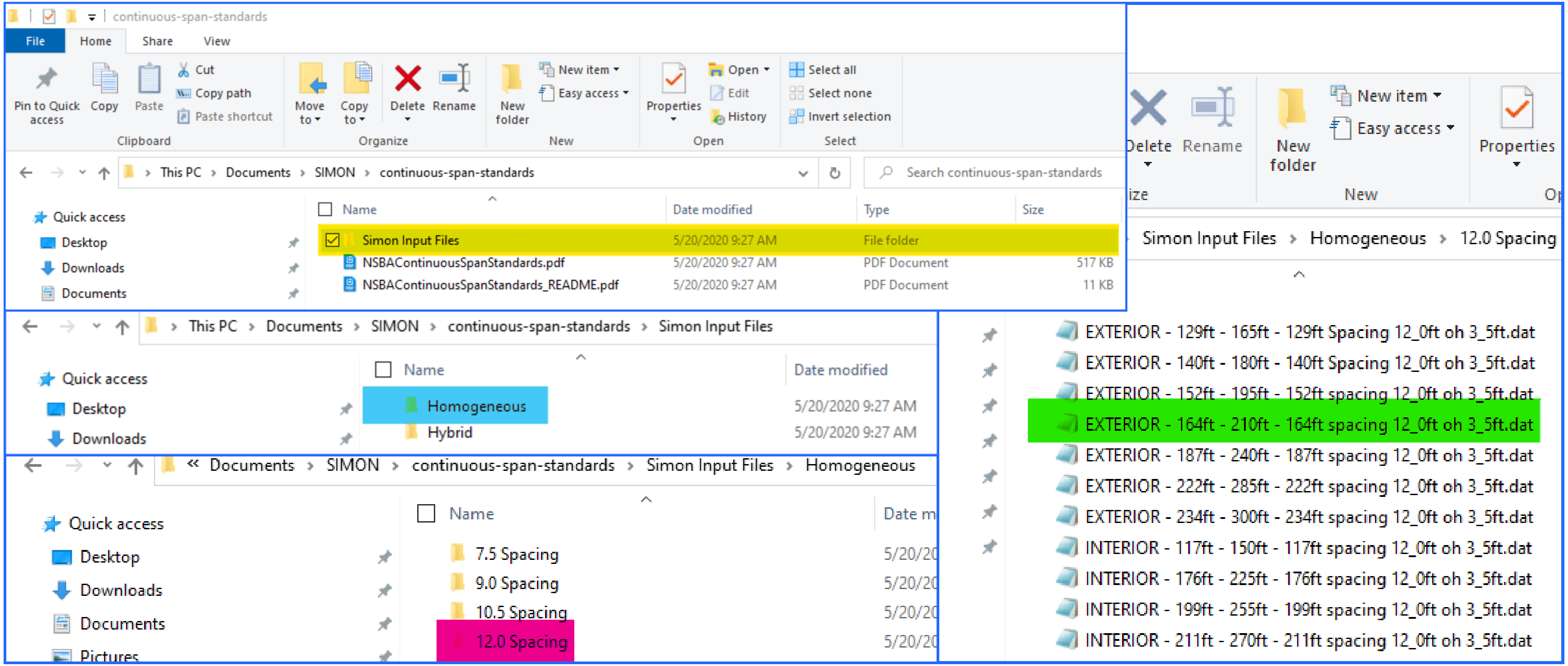
The Simon input files were provided because the NSBA understands bridge span arranges almost never match an idealized solution (ends span lengths at 78% of center span length). In providing the files, the NSBA has integrated two of its most successful resources into one powerful preliminary design tool. Find a span arrangement that most closely matches the bridge's geometry and begin editing from that file. This saves time and allows for more exploration of girder depths and steel strength options.

Included on each conceptual solution are tables presenting girder plate sizes, diaphragm spacings, intermediate stiffener sizes and locations, shear connector spacings, camber, and girder weights.

DOWNLOAD THE CONTINUOUS SPAN STANDARDS

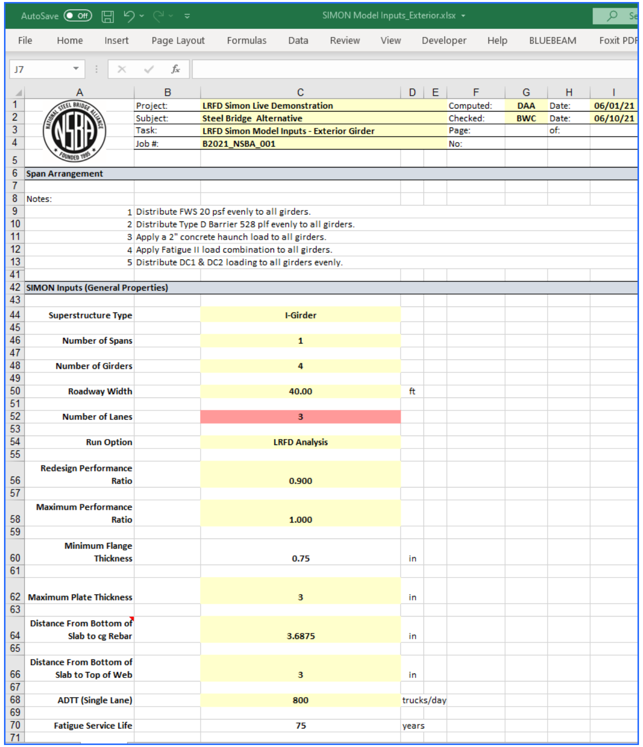
Grab LRFD Simon File Similar to Your Bridge

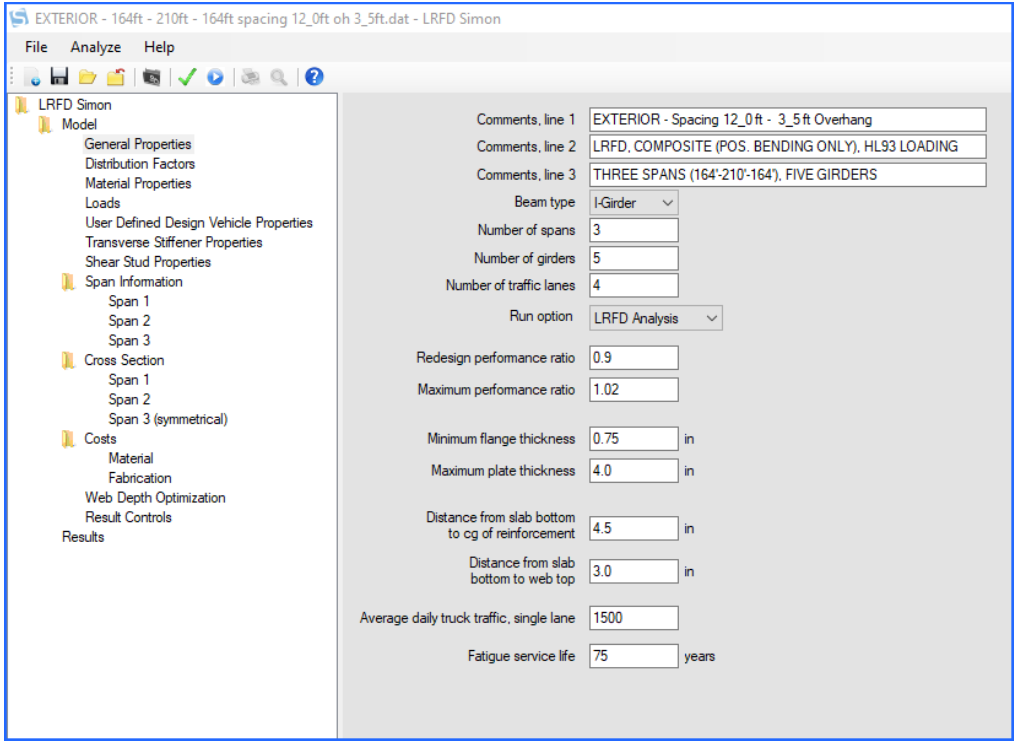
Our Girder Material is ASTM A709 50W, Homogeneous (Not Hybrid)



Design Girders with Project Design Criteria

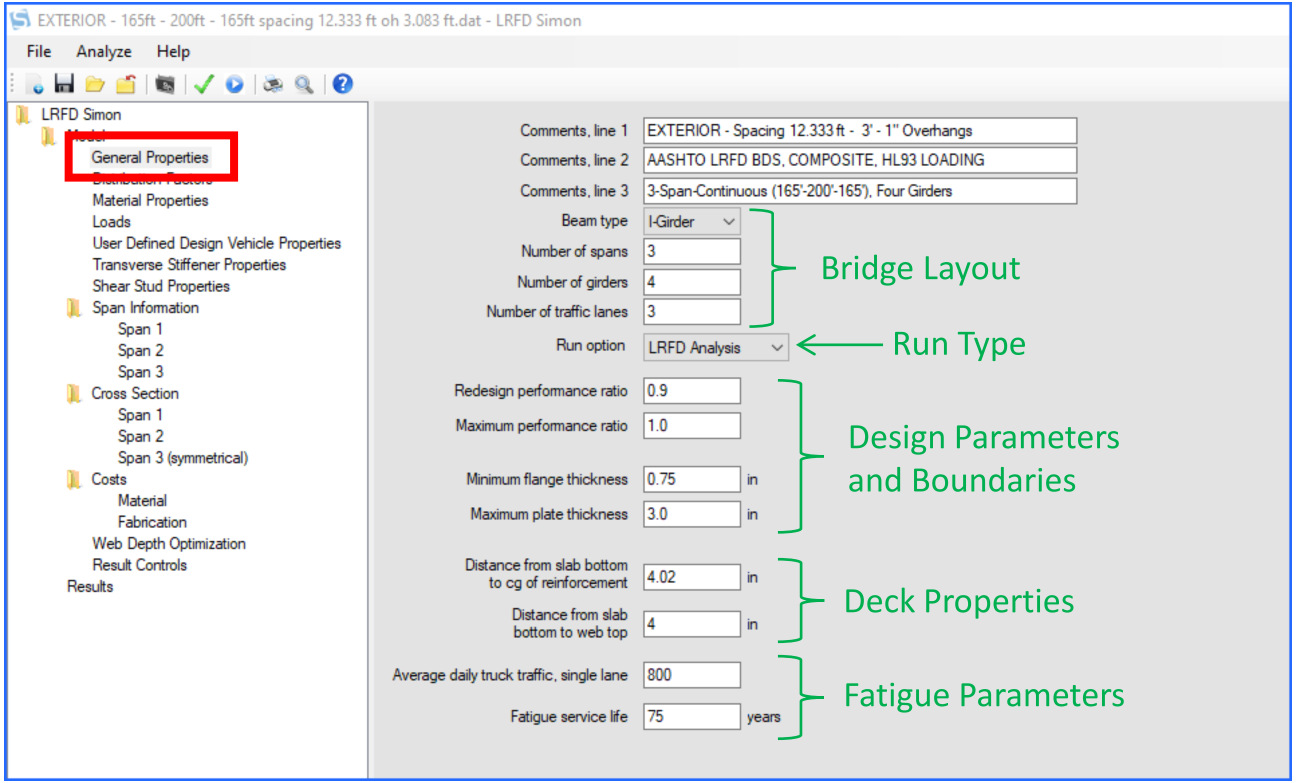
I Recommend Using Excel or MathCAD Spreadsheet for Girder Design





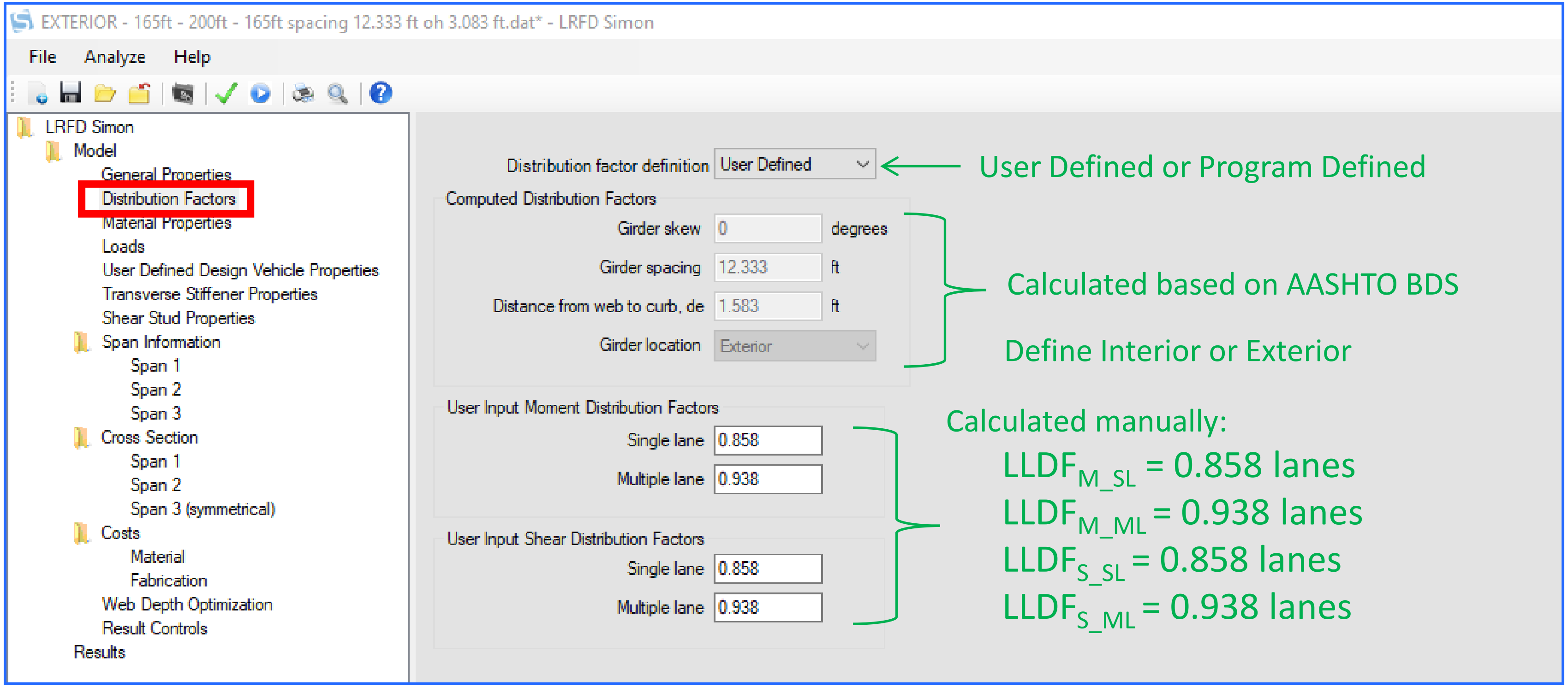
General Properties – Exterior Girder

Vet & Update LRFD Simon Inputs for Project Requirements



Distribution Factors – Exterior Girder

Vet & Update LRFD Simon Inputs for Project Requirements

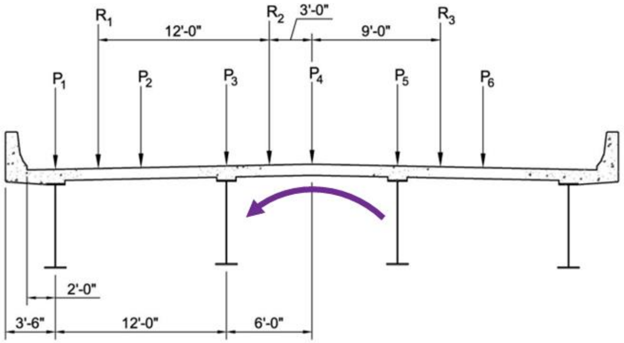


Distribution Factors – Exterior Girder

AASHTO LRFD BDS Special Analysis (C4.6.2.2.2d - Commentary)

- Assuming the entire cross-section rotates as a rigid body about the longitudinal centerline of the bridge, distribution factors for the exterior girder are also computed for one, two and three lanes loaded using the following formula

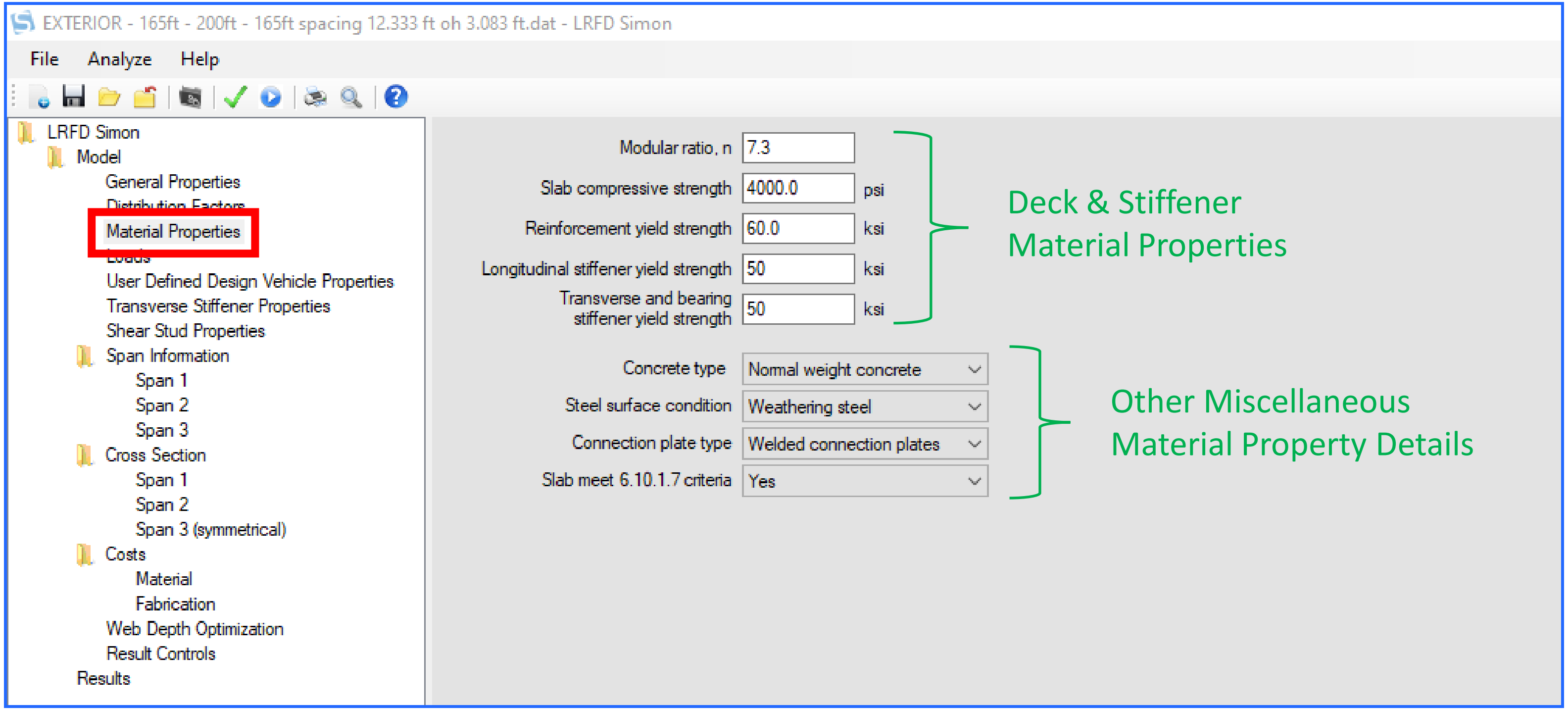
$$R = \frac{N_L}{N_b} + \frac{X_{ext}\sum^{N_L} e}{\sum^{N_b} x^2} \quad \text{(C4.6.2.2.2d-1)}$$



- SIMON Now Computes this LLDF
  (Other Design Software May Not, Verify)

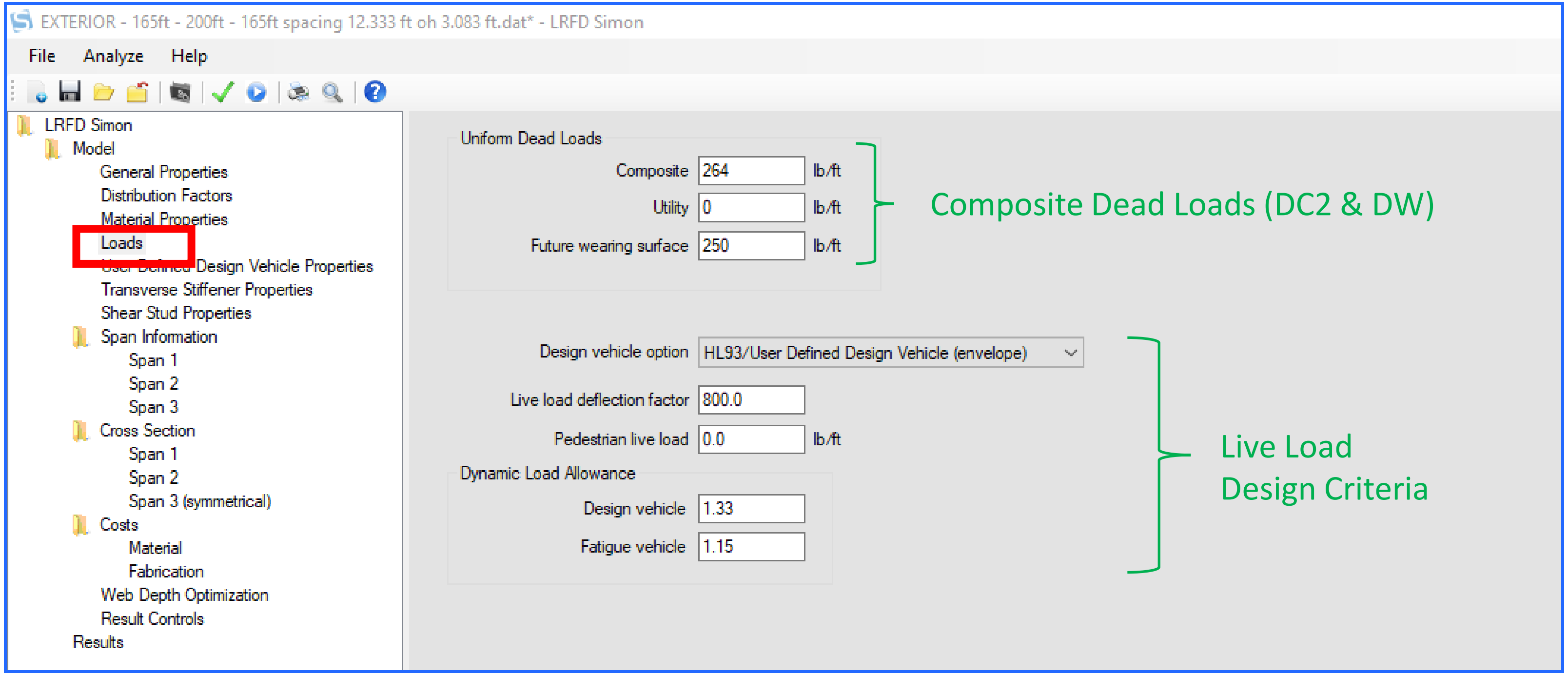
Material Properties – Exterior Girder

Vet & Update LRFD Simon Inputs for Project Requirements



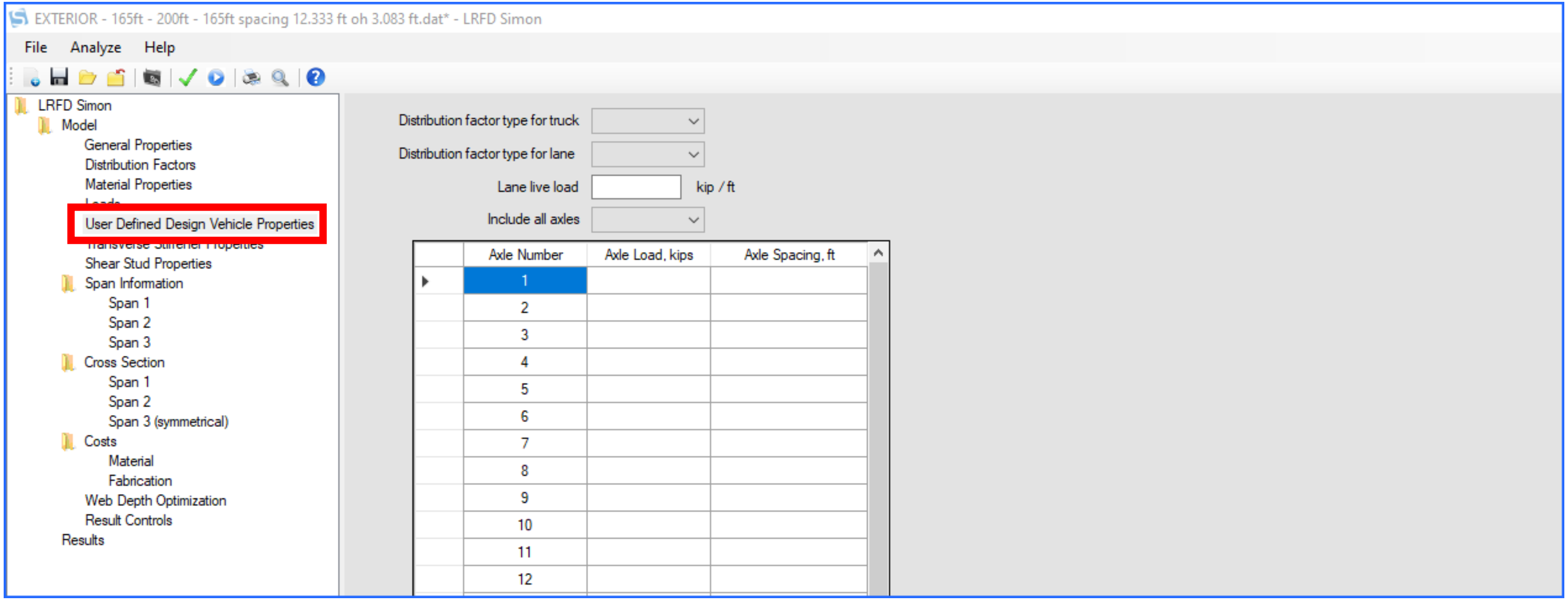
Loads – Composite DL (Distribute Equal) & LL

Vet & Update LRFD Simon Inputs for Project Requirements



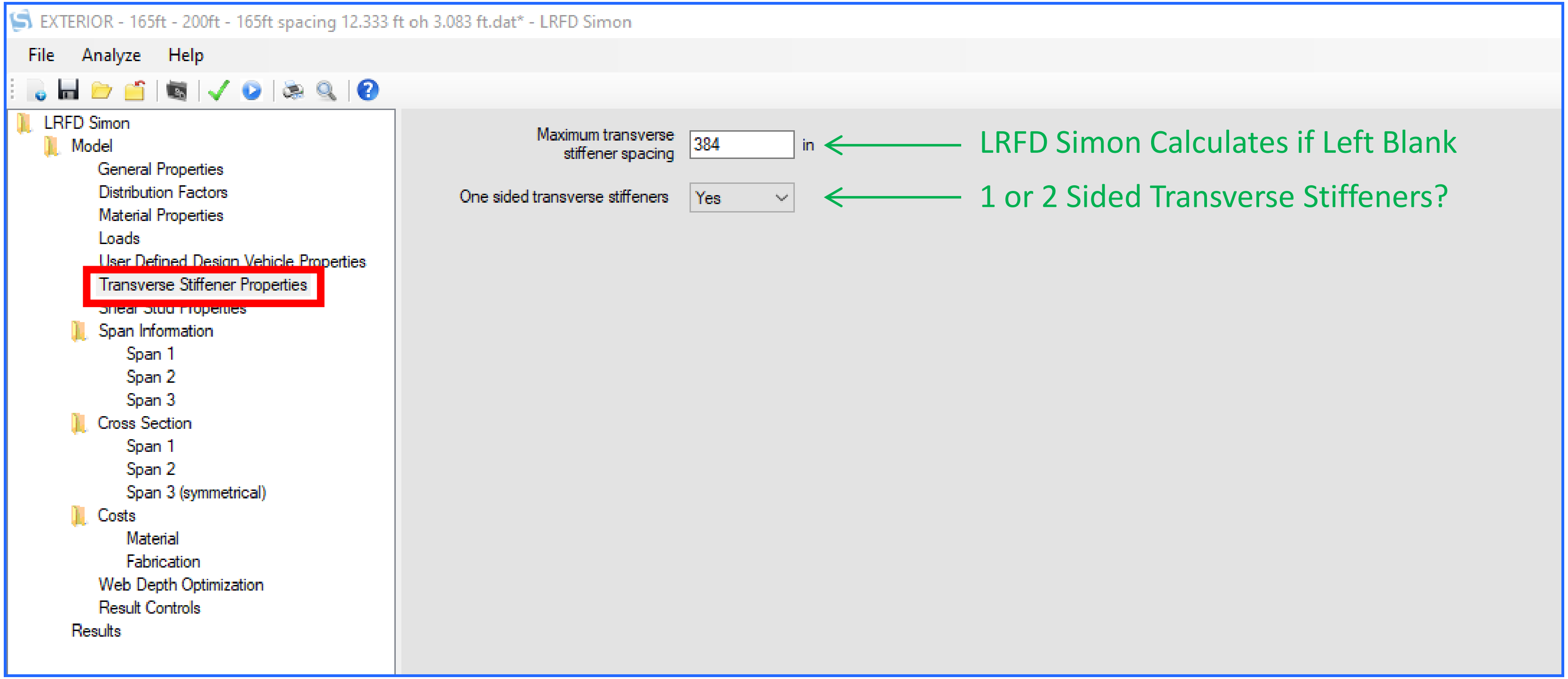
User Defined Vehicle (None for Example)

Up to 40 Axles for Strength II Permit/Superloads/Emergency Vehicles



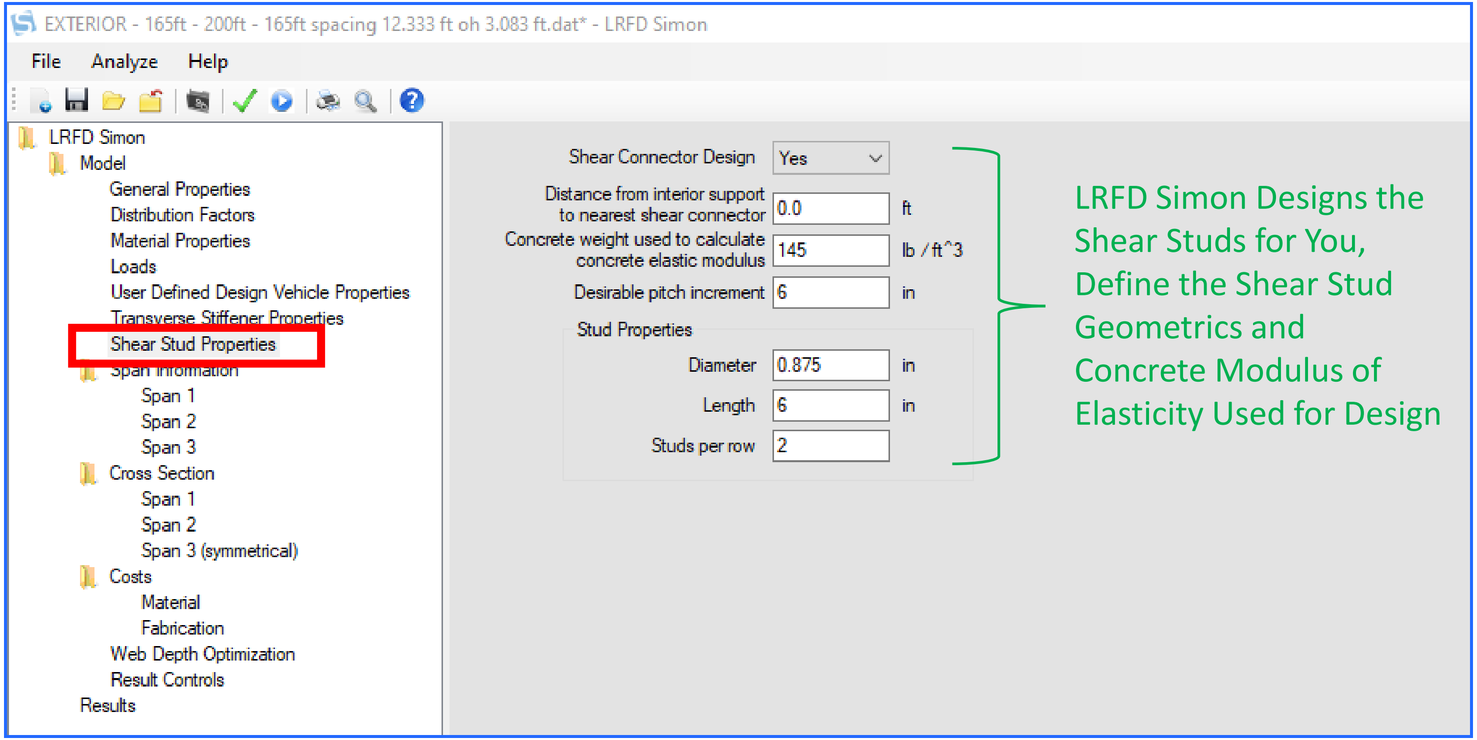
Transverse Stiffener – Exterior Girder

Vet & Update LRFD Simon Inputs for Project Requirements

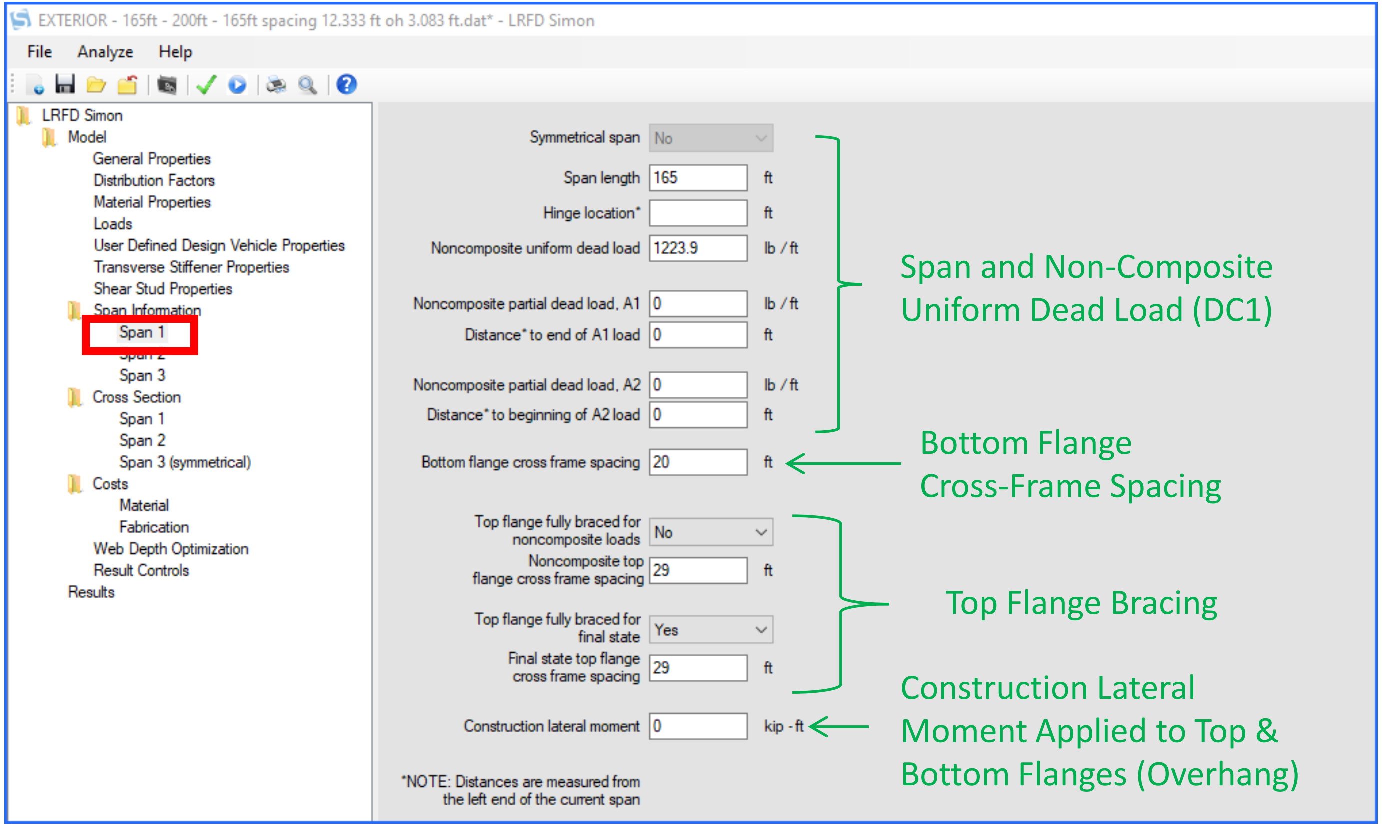


Shear Studs – Exterior Girder

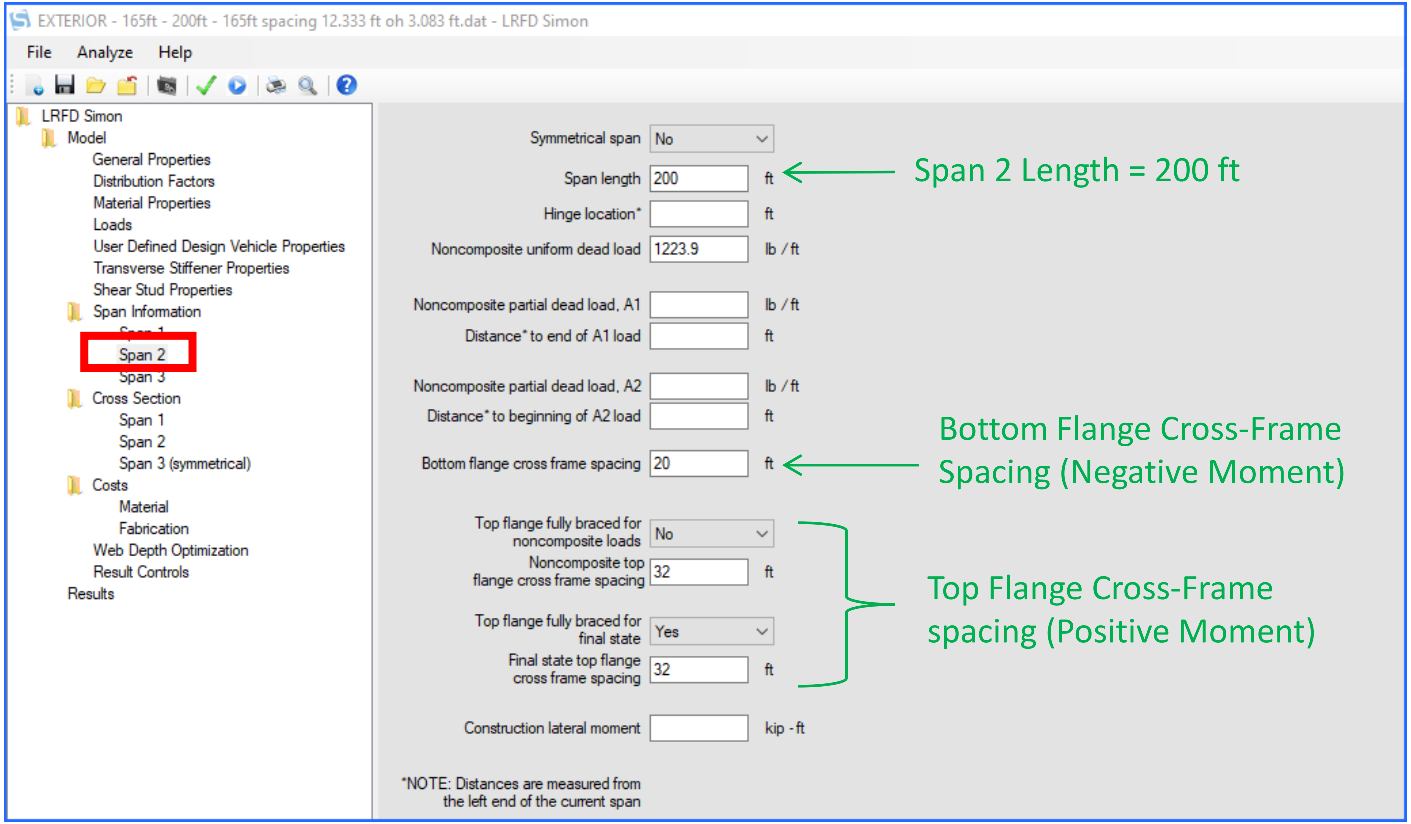
Vet & Update LRFD Simon Inputs for Project Requirements



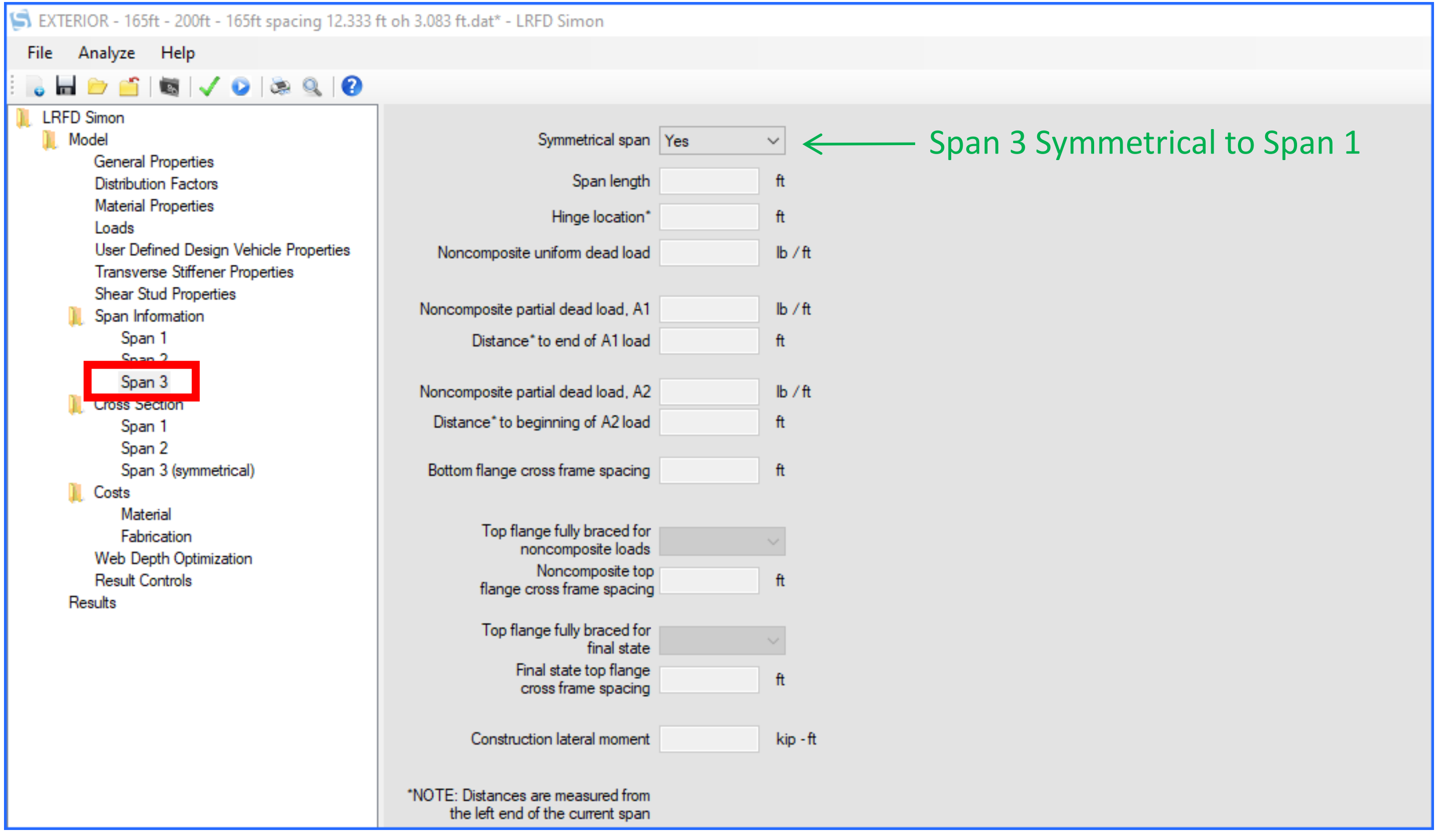
Span Information – Span 1



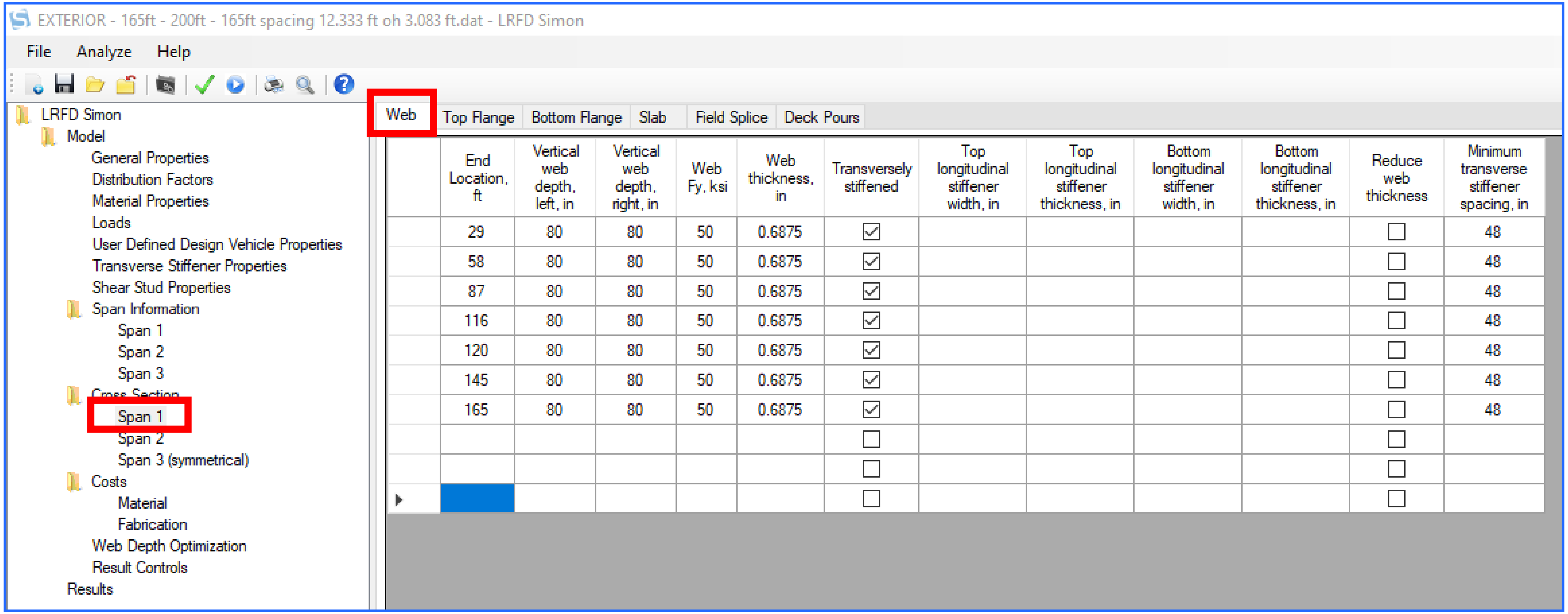
Span Information – Span 2



Span Information – Span 3

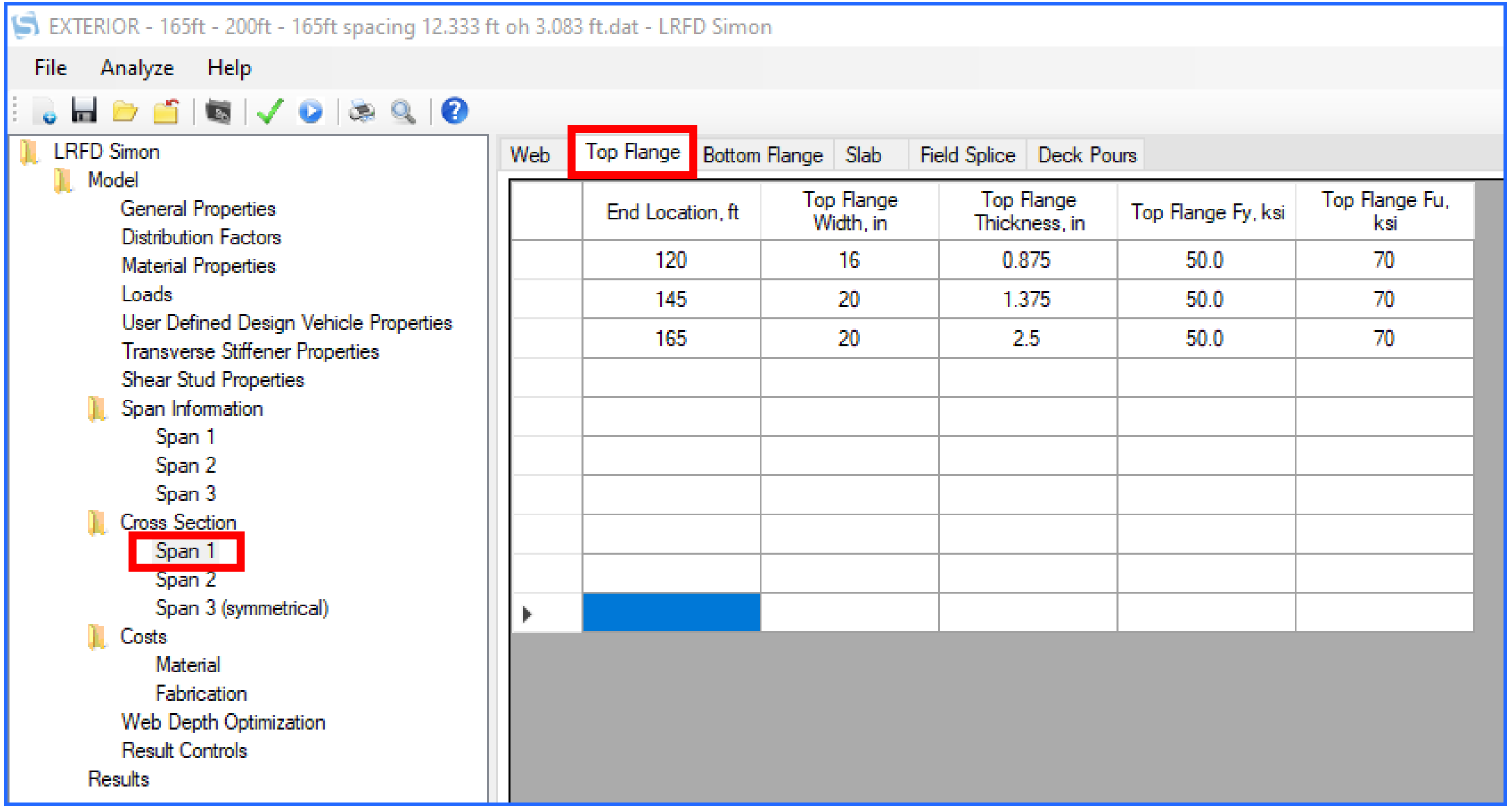


Cross Section Data – Span 1 – Web



End Location, ft	Vertical web depth, left, in	Vertical web depth, right, in	Web Fy, ksi	Web thickness, in	Transversely stiffened	Top longitudinal stiffener width, in	Top longitudinal stiffener thickness, in	Bottom longitudinal stiffener width, in	Bottom longitudinal stiffener thickness, in	Reduce web thickness	Minimum transverse stiffener spacing, in
29	80	80	50	0.6875	☑					☐	48
58	80	80	50	0.6875	☑					☐	48
87	80	80	50	0.6875	☑					☐	48
116	80	80	50	0.6875	☑					☐	48
120	80	80	50	0.6875	☑					☐	48
145	80	80	50	0.6875	☑					☐	48
165	80	80	50	0.6875	☑					☐	48
					☐					☐	
					☐					☐	
					☐					☐	

Cross Section Data – Span 1 – Top Flange



End Location, ft	Top Flange Width, in	Top Flange Thickness, in	Top Flange Fy, ksi	Top Flange Fu, ksi
120	16	0.875	50.0	70
145	20	1.375	50.0	70
165	20	2.5	50.0	70

Cross Section Data – Span 1 – Bott. Flange

EXTERIOR - 165ft - 200ft - 165ft spacing 12.333 ft oh 3.083 ft.dat - LRFD Simon

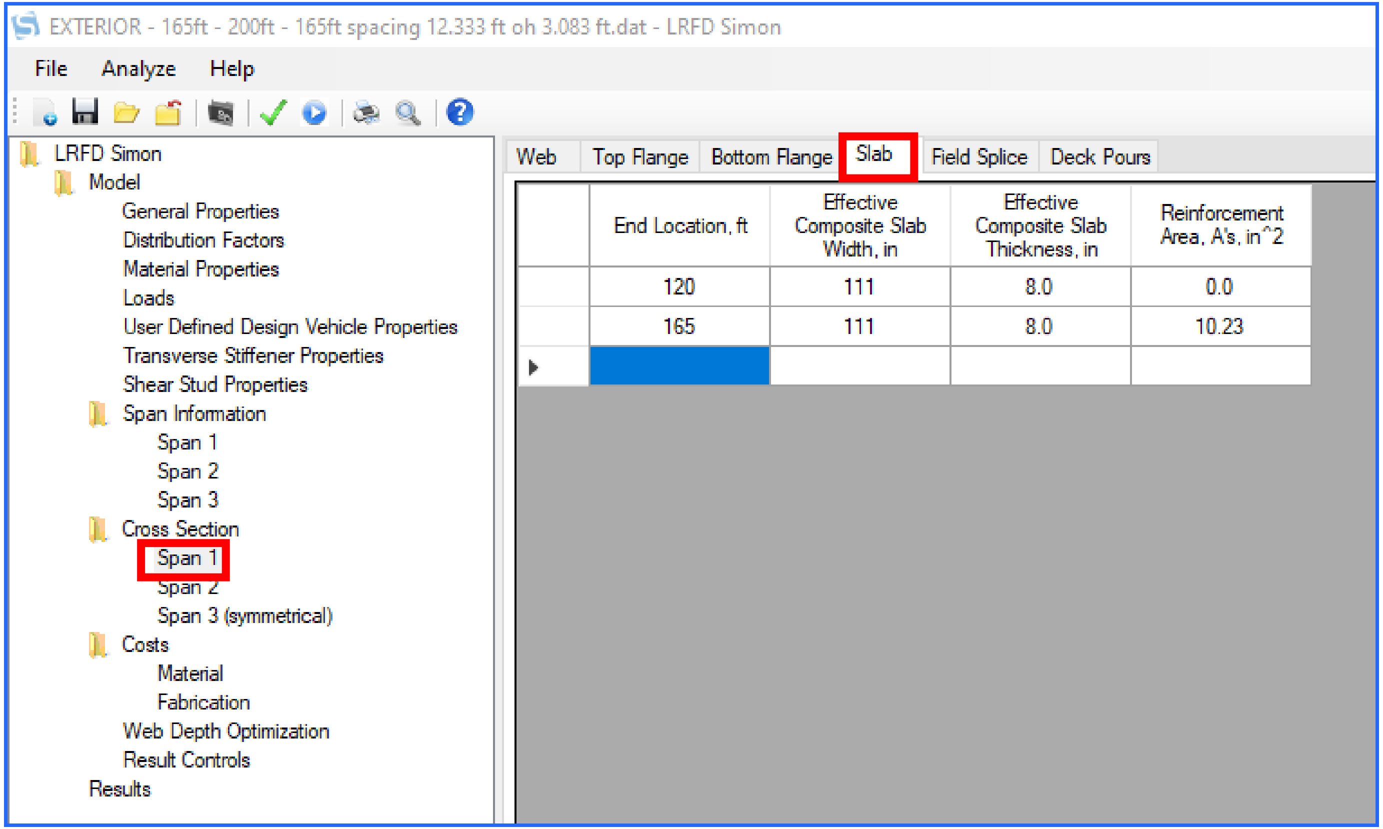
File Analyze Help

- LRFD Simon
  - Model
    - General Properties
    - Distribution Factors
    - Material Properties
    - Loads
    - User Defined Design Vehicle Properties
    - Transverse Stiffener Properties
    - Shear Stud Properties
    - Span Information
      - Span 1
      - Span 2
      - Span 3
    - Cross Section
      - Span 1
      - Span 2
      - Span 3 (symmetrical)
    - Costs
      - Material
      - Fabrication
    - Web Depth Optimization
    - Result Controls
  - Results

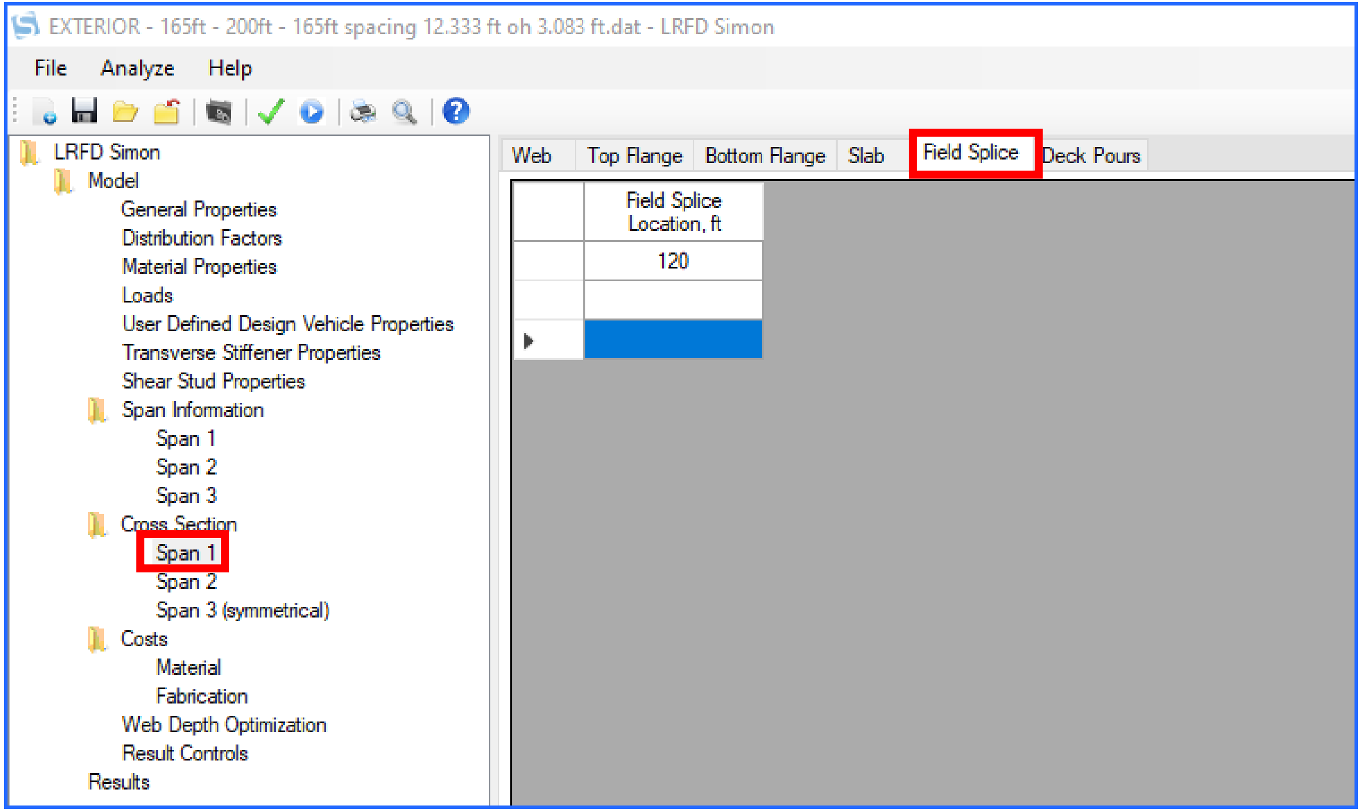
Web | Top Flange | Bottom Flange | Slab | Field Splice | Deck Pours

End Location, ft	Bottom Flange Width, in	Bottom Flange Thickness, in	Bottom Flange Fy, ksi	Bottom Flange Fu, ksi
40	16	0.875	50.0	70
120	16	1.5	50.0	70
145	22	1.5	50.0	70
165	22	3	50.0	70

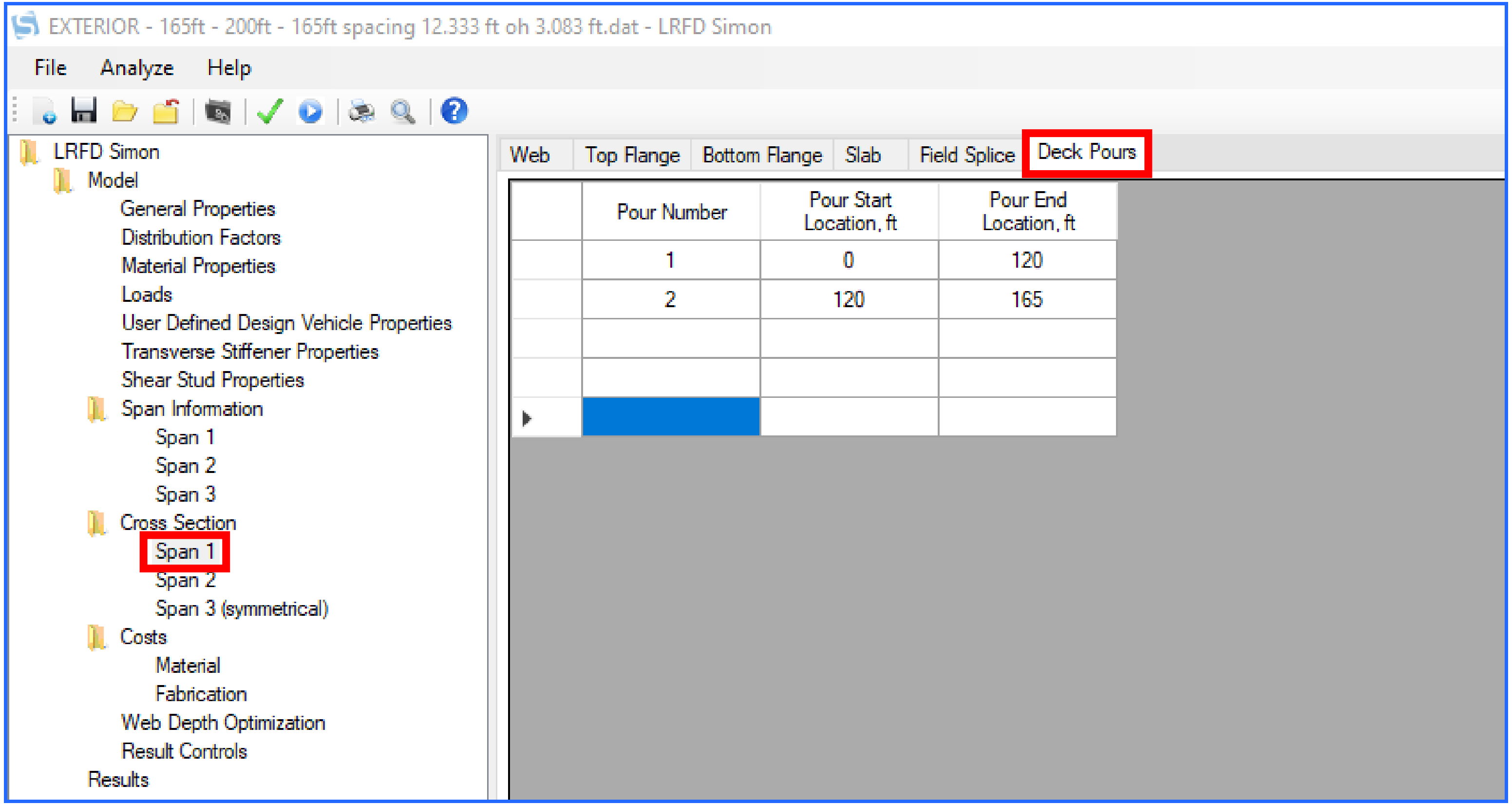
Cross Section Data – Span 1 – Deck Slab



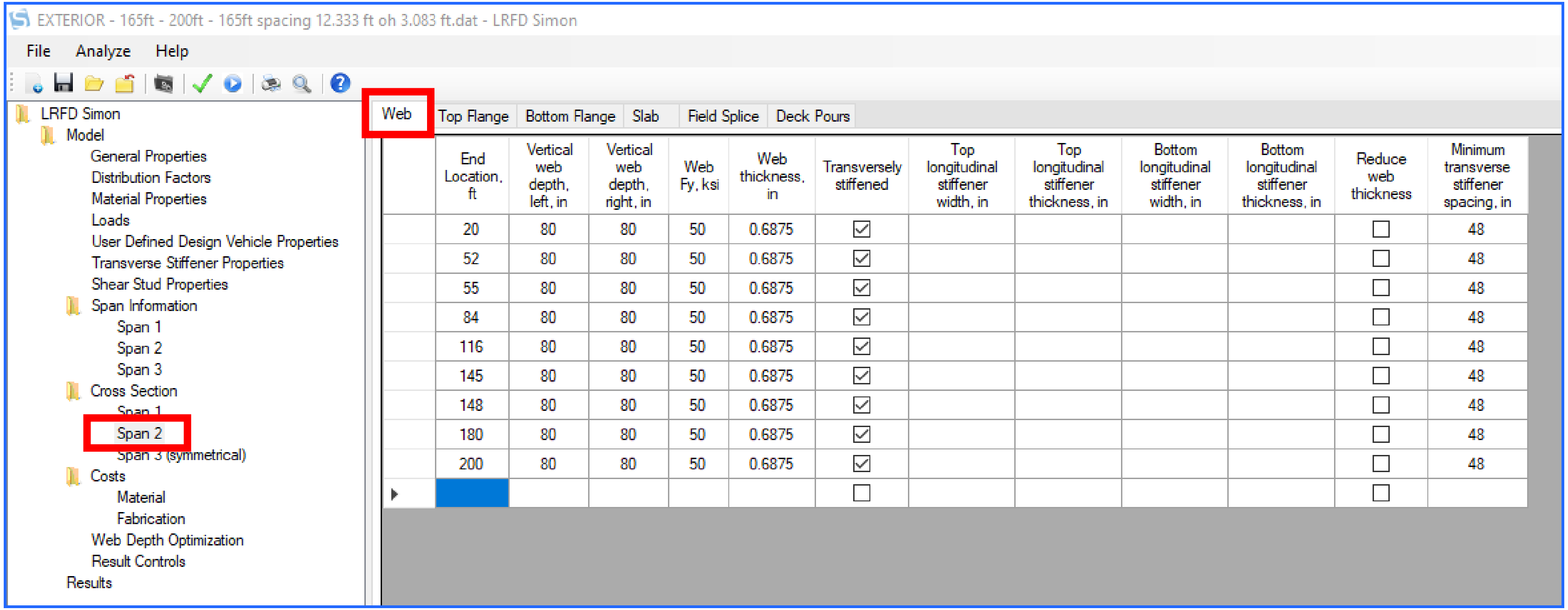
Cross Section Data – Span 1 – Field Splice



Cross Section Data – Span 1 – Deck Pours

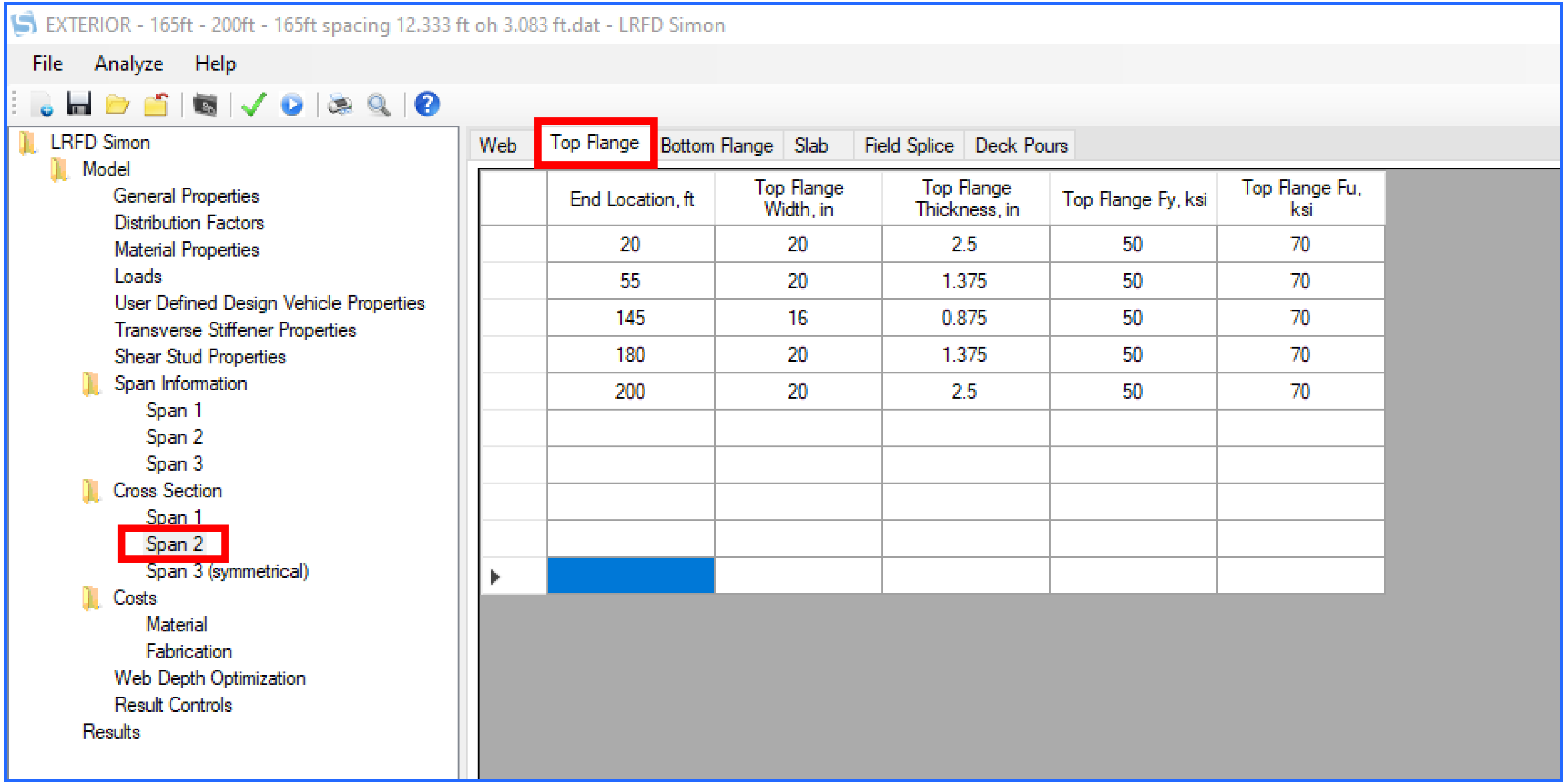


Cross Section Data – Span 2 – Web



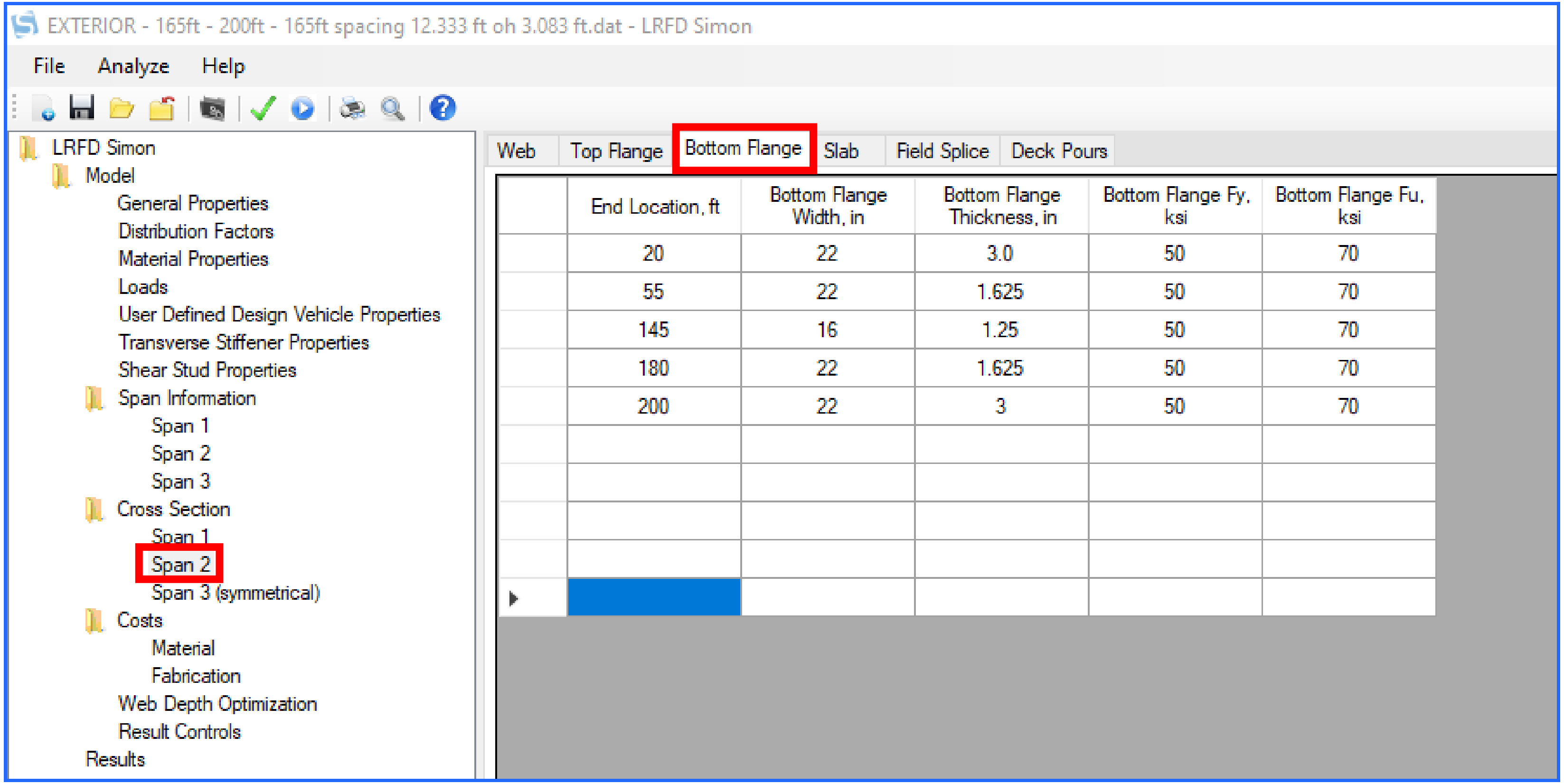
End Location, ft	Vertical web depth, left, in	Vertical web depth, right, in	Web Fy, ksi	Web thickness, in	Transversely stiffened	Top longitudinal stiffener width, in	Top longitudinal stiffener thickness, in	Bottom longitudinal stiffener width, in	Bottom longitudinal stiffener thickness, in	Reduce web thickness	Minimum transverse stiffener spacing, in
20	80	80	50	0.6875	☑					☐	48
52	80	80	50	0.6875	☑					☐	48
55	80	80	50	0.6875	☑					☐	48
84	80	80	50	0.6875	☑					☐	48
116	80	80	50	0.6875	☑					☐	48
145	80	80	50	0.6875	☑					☐	48
148	80	80	50	0.6875	☑					☐	48
180	80	80	50	0.6875	☑					☐	48
200	80	80	50	0.6875	☑					☐	48
					☐					☐	

Cross Section Data – Span 2 – Top Flange



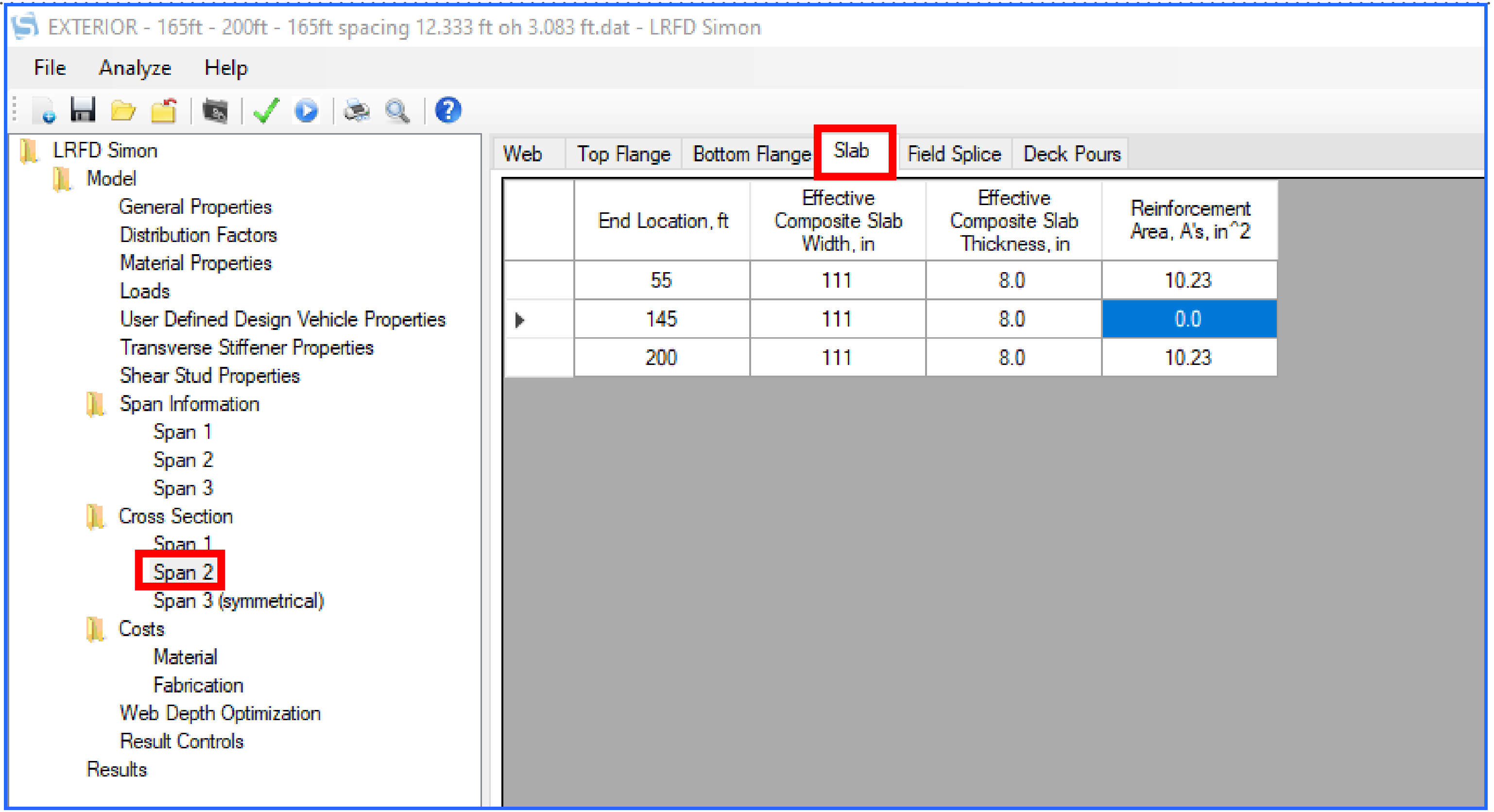
End Location, ft	Top Flange Width, in	Top Flange Thickness, in	Top Flange Fy, ksi	Top Flange Fu, ksi
20	20	2.5	50	70
55	20	1.375	50	70
145	16	0.875	50	70
180	20	1.375	50	70
200	20	2.5	50	70

Cross Section Data – Span 2 – Bott. Flange

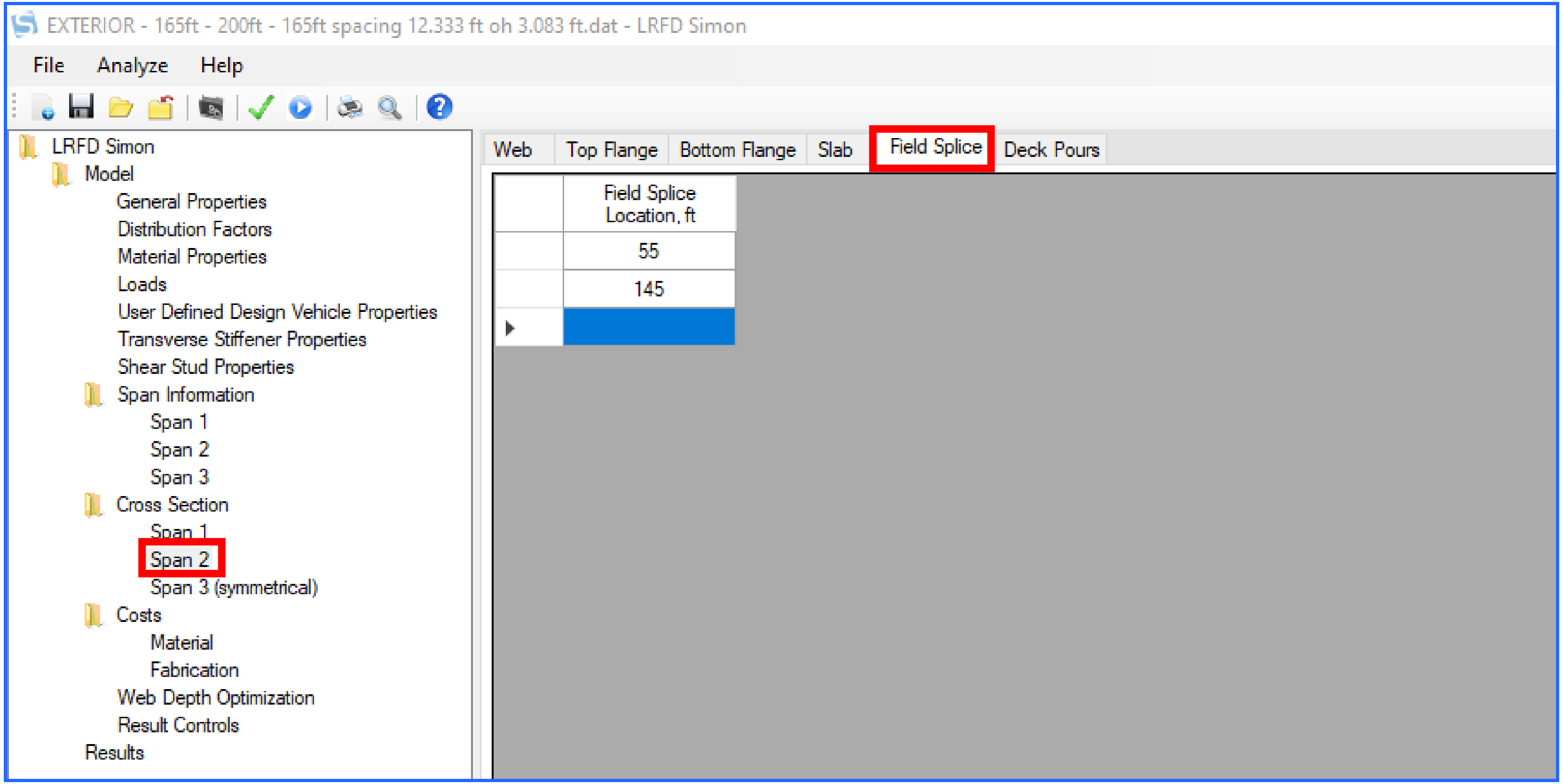


End Location, ft	Bottom Flange Width, in	Bottom Flange Thickness, in	Bottom Flange Fy, ksi	Bottom Flange Fu, ksi
20	22	3.0	50	70
55	22	1.625	50	70
145	16	1.25	50	70
180	22	1.625	50	70
200	22	3	50	70

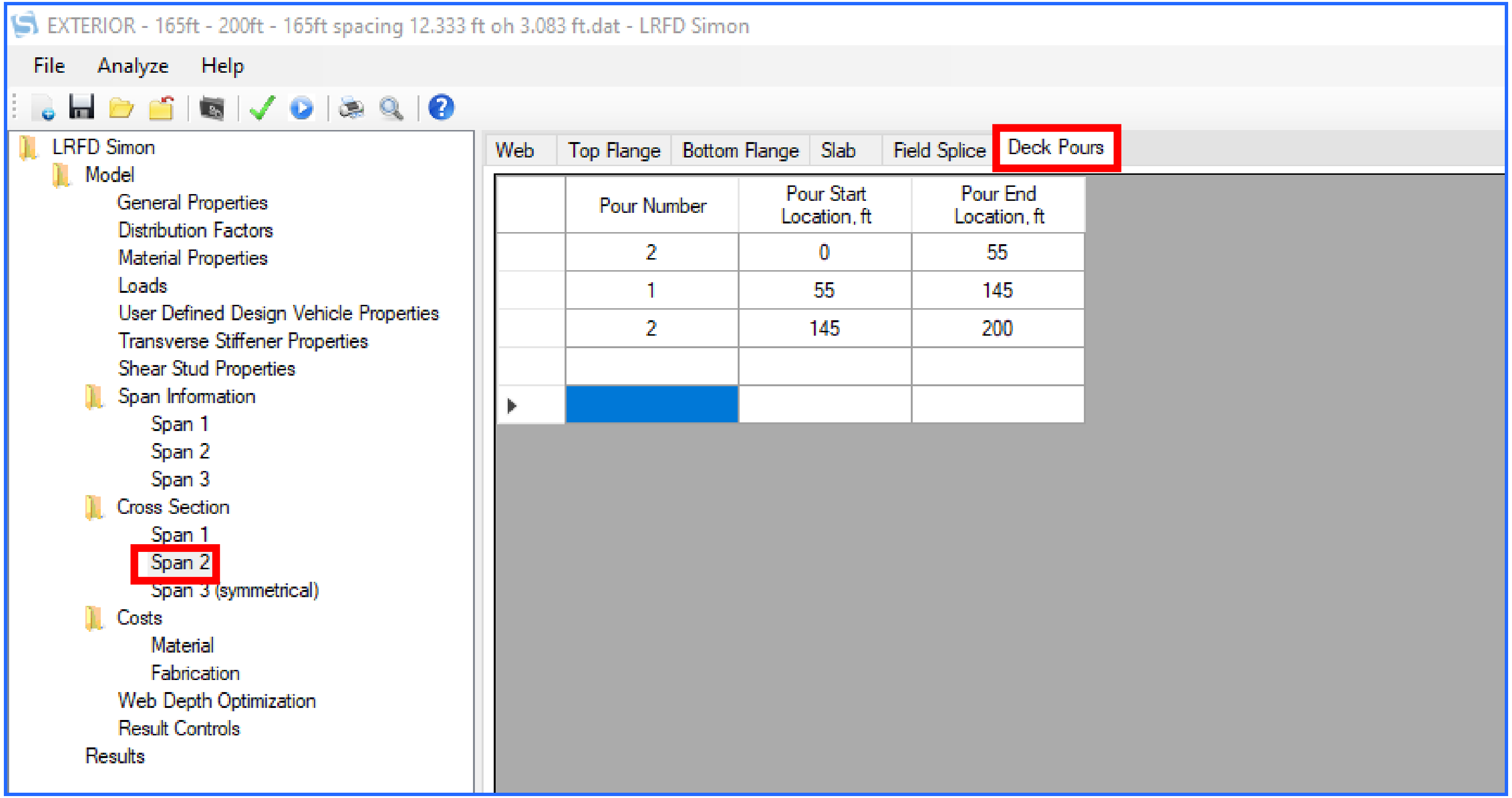
Cross Section Data – Span 2 – Deck Slab



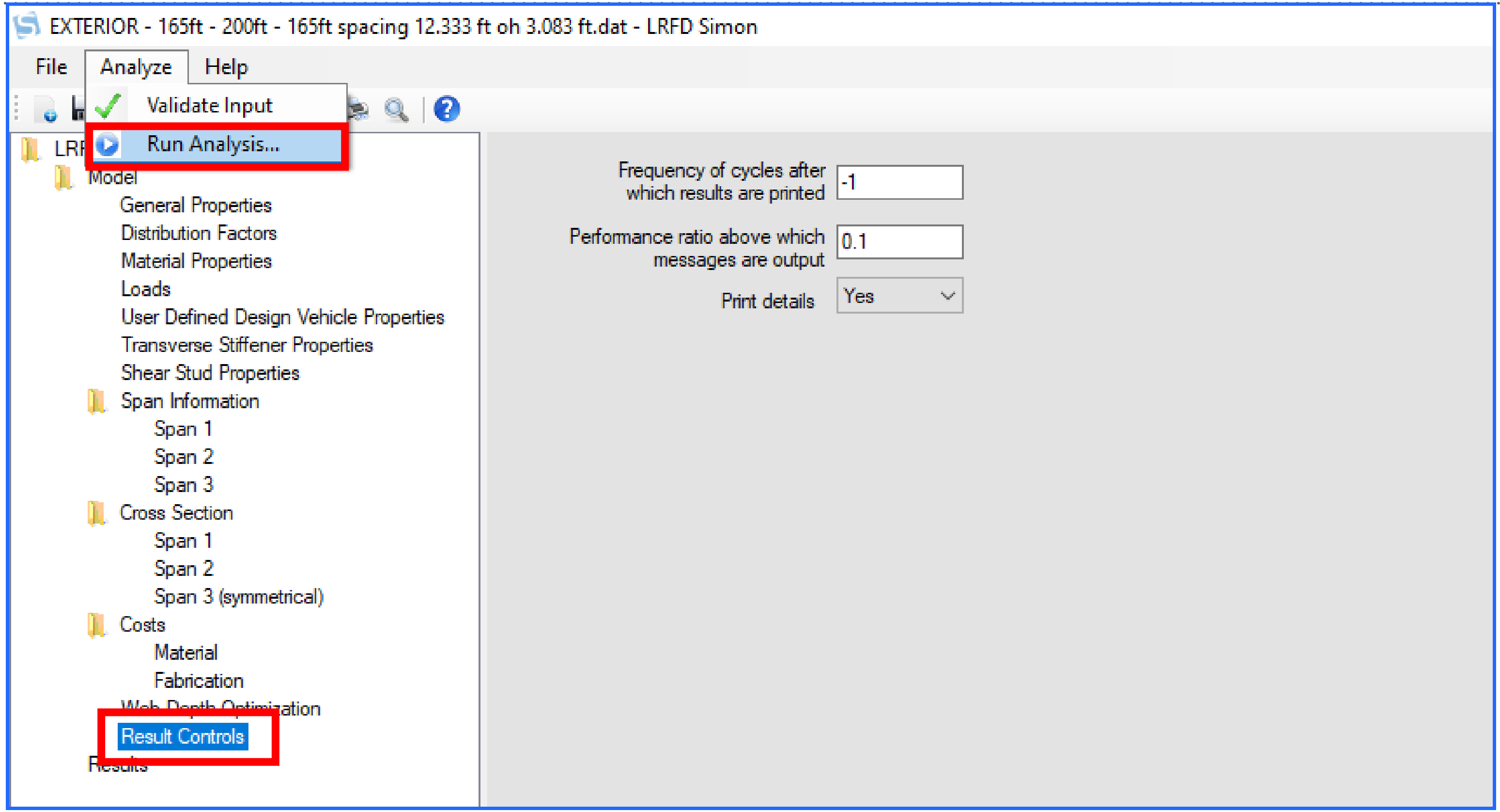
Cross Section Data – Span 2 – Field Splice



Cross Section Data – Span 2 – Deck Pours

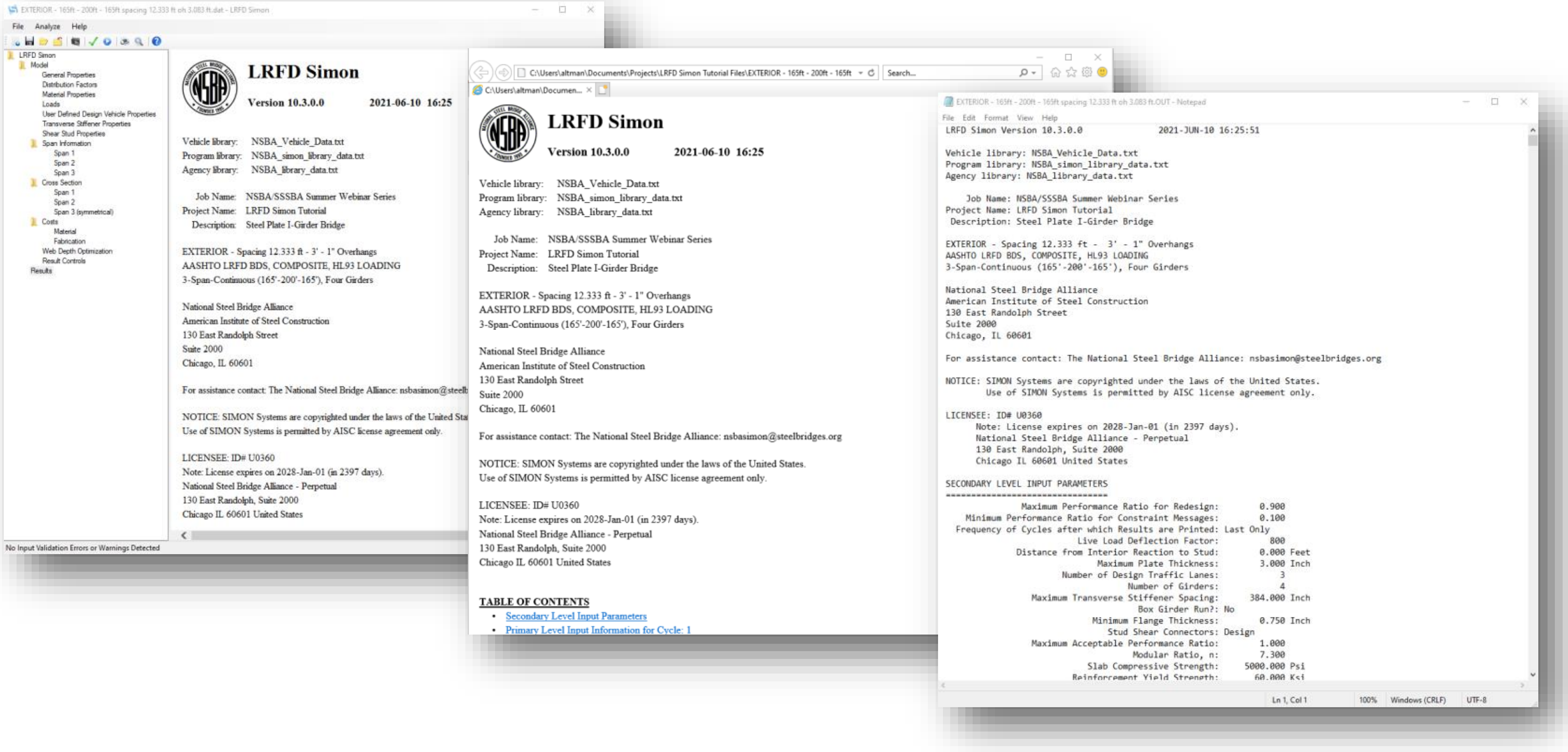


LRFD Simon – Run the Analysis



LRFD Simon – Results File

Results Files in SIMON, .XML, and .OUT (notepad)



LRFD Simon – Results Review

Moments Results

Span: 1

Point	Girder	Other DC1	Comp DL	Utility	FWS
0.0	0.0	0.0	0.0	0.0	0.0
0.1	146.0	915.0	160.3	0.0	154.2
0.2	247.8	1534.4	269.7	0.0	259.3
0.3	305.4	1858.3	328.1	0.0	315.5
0.4	315.8	1886.6	335.5	0.0	322.6
0.5	276.0	1619.3	292.0	0.0	280.8
0.6	186.1	1056.5	197.5	0.0	189.9
0.7	45.9	198.1	52.1	0.0	50.1
0.8	-145.6	-955.9	-144.3	0.0	-138.7
0.9	-389.1	-2405.4	-391.6	0.0	-376.6
1.0	-697.5	-4150.6	-690.0	0.0	-663.4

Span: 1

Point	HL93		USER DEFINED DESIGN VEHICLE		ENVELOPE		FATIGUE	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1	1490.5	-255.2	0.0	0.0	1490.5	-255.2	622.0	-97.1
0.2	2551.7	-510.4	0.0	0.0	2551.7	-510.4	1038.3	-194.3
0.3	3206.7	-765.7	0.0	0.0	3206.7	-765.7	1299.9	-291.4
0.4	3507.5	-1020.9	0.0	0.0	3507.5	-1020.9	1385.1	-388.5
0.5	3466.3	-1276.1	0.0	0.0	3466.3	-1276.1	1345.3	-485.7
0.6	3119.8	-1531.3	0.0	0.0	3119.8	-1531.3	1221.0	-582.8
0.7	2465.4	-1786.6	0.0	0.0	2465.4	-1786.6	958.2	-679.9
0.8	1554.3	-2459.4	0.0	0.0	1554.3	-2459.4	588.4	-777.1
0.9	692.3	-2988.1	0.0	0.0	692.3	-2988.1	217.1	-874.2
1.0	600.5	-4087.4	0.0	0.0	600.5	-4087.4	241.2	-971.4

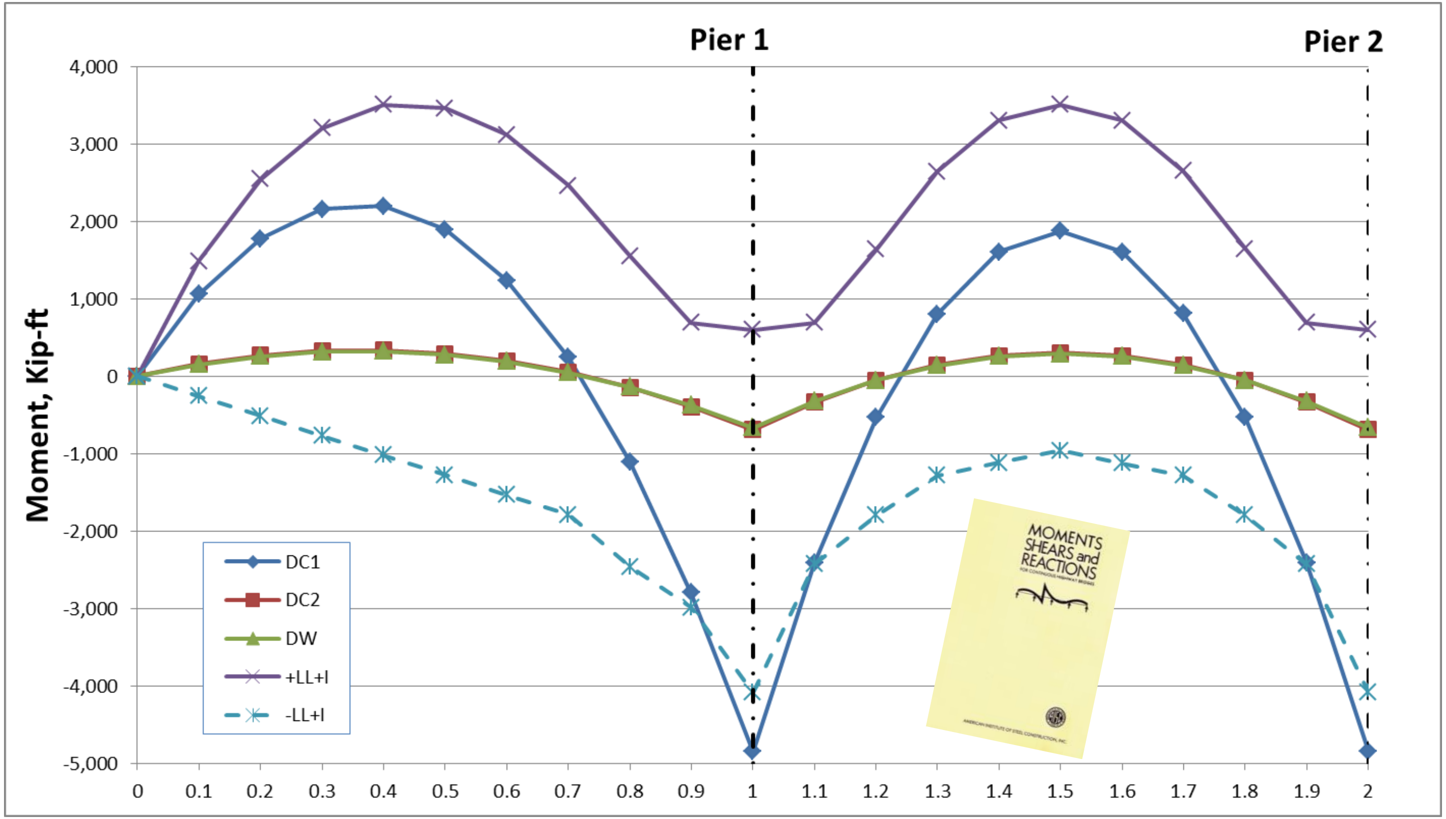
Span: 2

Point	Girder	Other DC1	Comp DL	Utility	FWS
0.0	-697.5	-4150.6	-690.0	0.0	-663.4
0.1	-339.5	-2072.3	-331.6	0.0	-318.9
0.2	-76.1	-455.9	-52.9	0.0	-50.9
0.3	108.4	698.7	146.1	0.0	140.5
0.4	218.9	1391.5	265.6	0.0	255.3
0.5	256.0	1622.4	305.4	0.0	293.6
0.6	219.6	1391.5	265.6	0.0	255.4
0.7	109.8	698.8	146.1	0.0	140.5
0.8	-74.8	-455.7	-52.9	0.0	-50.9
0.9	-338.8	-2072.1	-331.6	0.0	-318.8
1.0	-697.4	-4150.3	-689.9	0.0	-663.4

Span: 2

Point	HL93		USER DEFINED DESIGN VEHICLE		ENVELOPE		FATIGUE	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
0.0	600.5	-4087.4	0.0	0.0	600.5	-4087.4	241.2	-971.4
0.1	692.0	-2428.0	0.0	0.0	692.0	-2428.0	245.9	-694.8
0.2	1642.3	-1795.5	0.0	0.0	1642.3	-1795.5	683.2	-590.8
0.3	2650.9	-1279.9	0.0	0.0	2650.9	-1279.9	1071.8	-486.8
0.4	3303.6	-1120.3	0.0	0.0	3303.6	-1120.3	1305.4	-382.8
0.5	3511.4	-961.6	0.0	0.0	3511.4	-961.6	1361.2	-279.4
0.6	3304.6	-1121.5	0.0	0.0	3304.6	-1121.5	1305.7	-383.5
0.7	2653.0	-1281.5	0.0	0.0	2653.0	-1281.5	1072.8	-487.6
0.8	1645.5	-1798.2	0.0	0.0	1645.5	-1798.2	684.5	-591.7
0.9	693.2	-2430.3	0.0	0.0	693.2	-2430.3	246.3	-695.8
1.0	600.5	-4086.8	0.0	0.0	600.5	-4086.8	241.2	-970.0

LRFD Simon – Results Review



LRFD Simon – Results Review

Shear Results

Span: 1

Point	Girder	Other DC1	Comp DL	Utility	FWS
0.0	12.0	75.9	13.3	0.0	12.8
0.1	8.8	54.8	9.6	0.0	9.3
0.2	5.7	33.7	6.0	0.0	5.8
0.3	2.5	12.6	2.4	0.0	2.3
0.4	-1.0	-8.5	-1.3	0.0	-1.2
0.5	-4.6	-29.6	-4.9	0.0	-4.7
0.6	-8.2	-50.8	-8.6	0.0	-8.2
0.7	-11.8	-71.9	-12.2	0.0	-11.7
0.8	-15.5	-93.0	-15.8	0.0	-15.2
0.9	-19.3	-114.1	-19.5	0.0	-18.7
1.0	-24.8	-135.2	-23.1	0.0	-22.2

Span: 2

Point	Girder	Other DC1	Comp DL	Utility	FWS
0.0	23.9	132.0	22.8	0.0	21.9
0.1	17.3	105.6	18.2	0.0	17.5
0.2	12.8	79.2	13.7	0.0	13.1
0.3	8.4	52.8	9.1	0.0	8.8
0.4	4.2	26.4	4.6	0.0	4.4
0.5	0.0	0.0	0.0	0.0	0.0
0.6	-4.2	-26.4	-4.5	0.0	-4.4
0.7	-8.4	-52.8	-9.1	0.0	-8.7
0.8	-12.8	-79.2	-13.6	0.0	-13.1
0.9	-17.4	-105.6	-18.2	0.0	-17.5
1.0	-23.9	-131.9	-22.7	0.0	-21.9

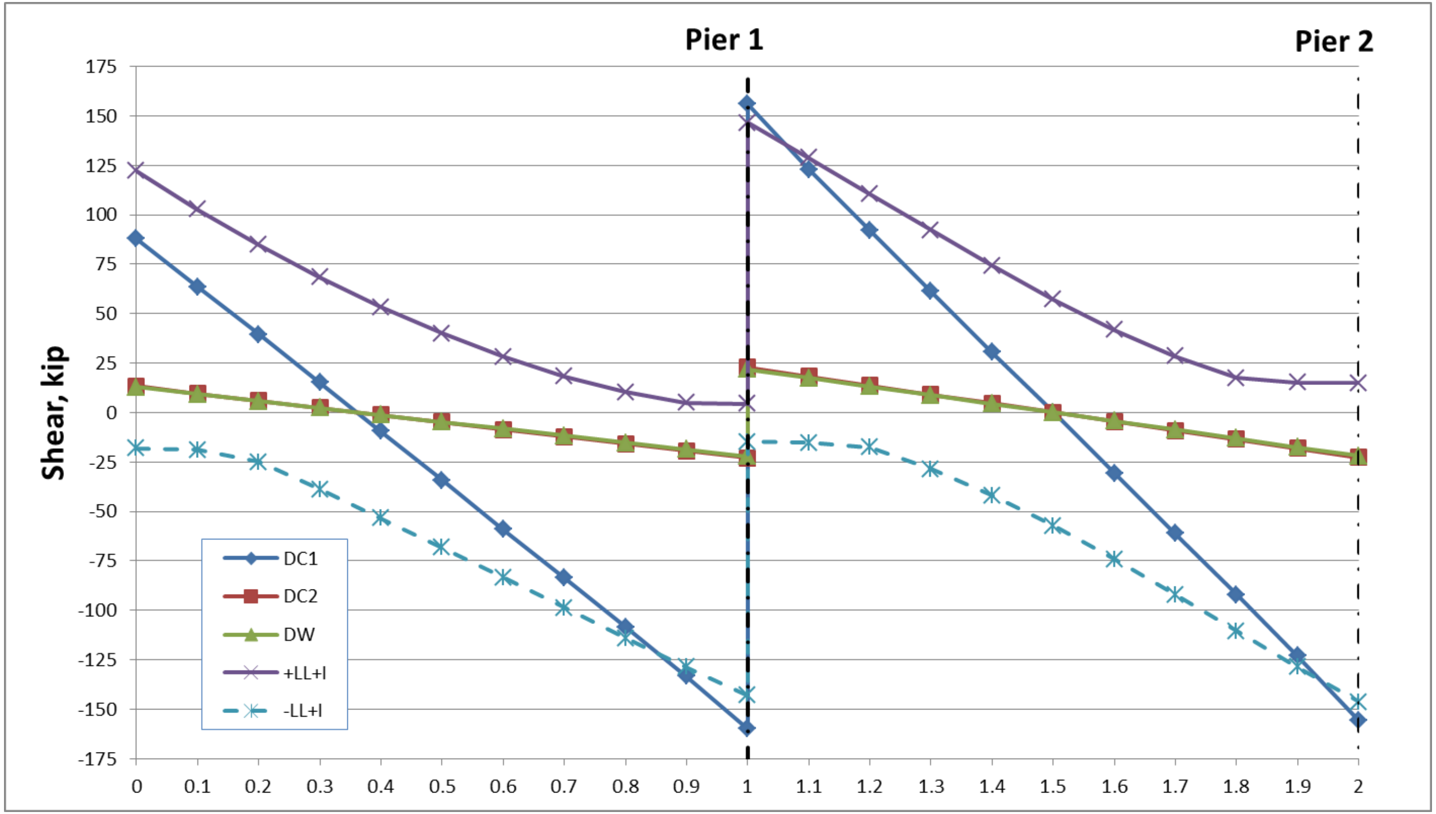
Span: 1

Point	HL93		USER DEFINED DESIGN VEHICLE		ENVELOPE		FATIGUE	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
0.0	122.1	-18.2	0.0	0.0	122.1	-18.2	52.0	-6.9
0.1	102.7	-18.8	0.0	0.0	102.7	-18.8	44.4	-6.9
0.2	84.8	-25.1	0.0	0.0	84.8	-25.1	37.1	-7.8
0.3	68.3	-38.9	0.0	0.0	68.3	-38.9	30.1	-13.2
0.4	53.3	-53.4	0.0	0.0	53.3	-53.4	23.5	-20.6
0.5	39.9	-68.3	0.0	0.0	39.9	-68.3	17.4	-27.8
0.6	28.2	-83.5	0.0	0.0	28.2	-83.5	11.9	-34.7
0.7	18.3	-98.8	0.0	0.0	18.3	-98.8	7.1	-41.1
0.8	10.2	-114.0	0.0	0.0	10.2	-114.0	3.9	-47.0
0.9	5.0	-128.8	0.0	0.0	5.0	-128.8	1.7	-52.2
1.0	4.3	-143.0	0.0	0.0	4.3	-143.0	1.7	-56.7

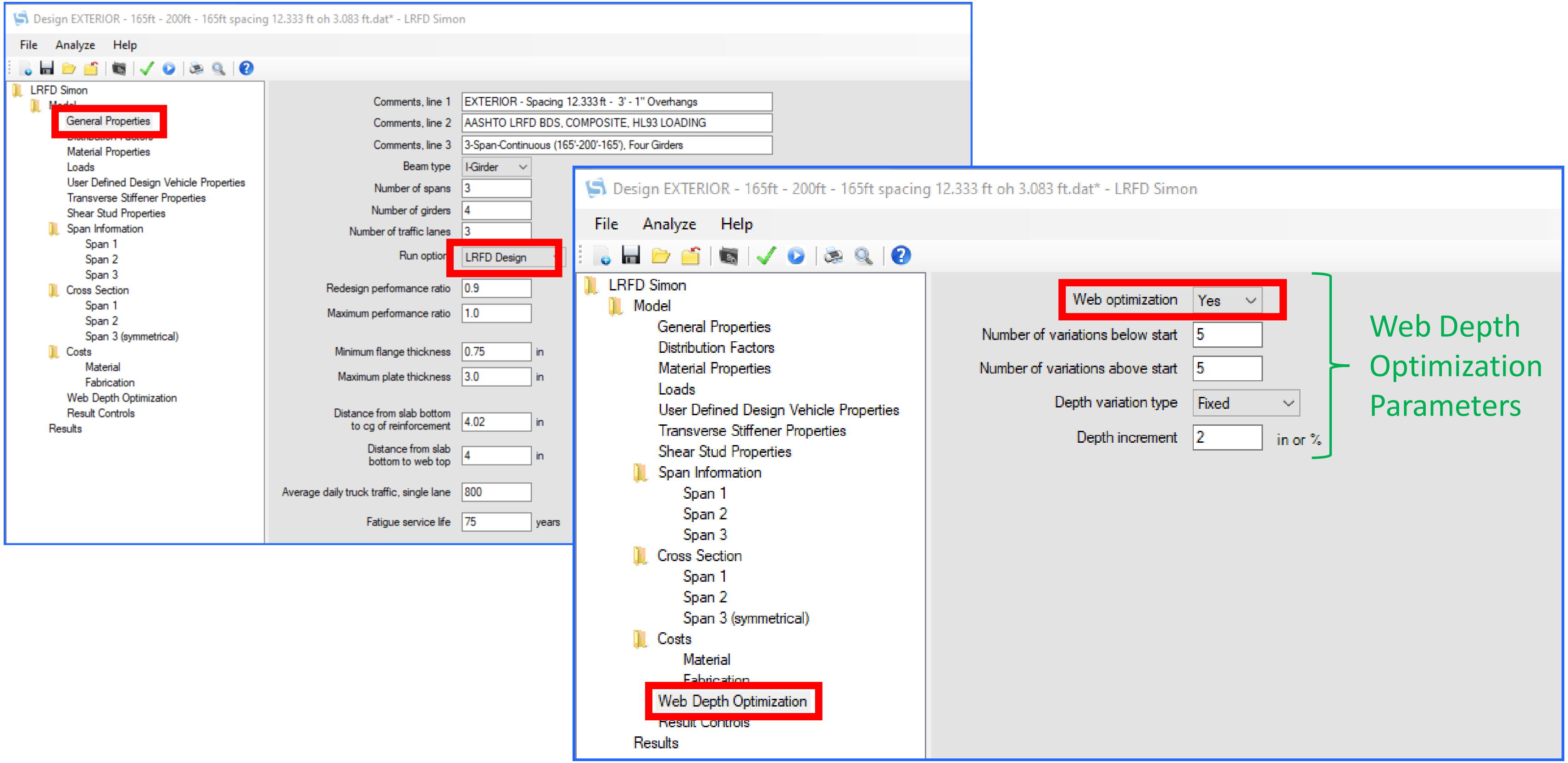
Span: 2

Point	HL93		USER DEFINED DESIGN VEHICLE		ENVELOPE		FATIGUE	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
0.0	146.4	-14.8	0.0	0.0	146.4	-14.8	57.0	-5.9
0.1	128.8	-15.2	0.0	0.0	128.8	-15.2	51.5	-5.9
0.2	110.5	-17.5	0.0	0.0	110.5	-17.5	45.1	-5.9
0.3	92.1	-28.5	0.0	0.0	92.1	-28.5	38.1	-10.1
0.4	74.2	-41.9	0.0	0.0	74.2	-41.9	30.8	-16.4
0.5	57.2	-57.2	0.0	0.0	57.2	-57.2	23.4	-23.4
0.6	41.9	-74.1	0.0	0.0	41.9	-74.1	16.4	-30.7
0.7	28.5	-92.1	0.0	0.0	28.5	-92.1	10.1	-38.1
0.8	17.5	-110.5	0.0	0.0	17.5	-110.5	5.9	-45.1
0.9	15.2	-128.8	0.0	0.0	15.2	-128.8	5.9	-51.5
1.0	14.8	-146.4	0.0	0.0	14.8	-146.4	5.9	-57.0

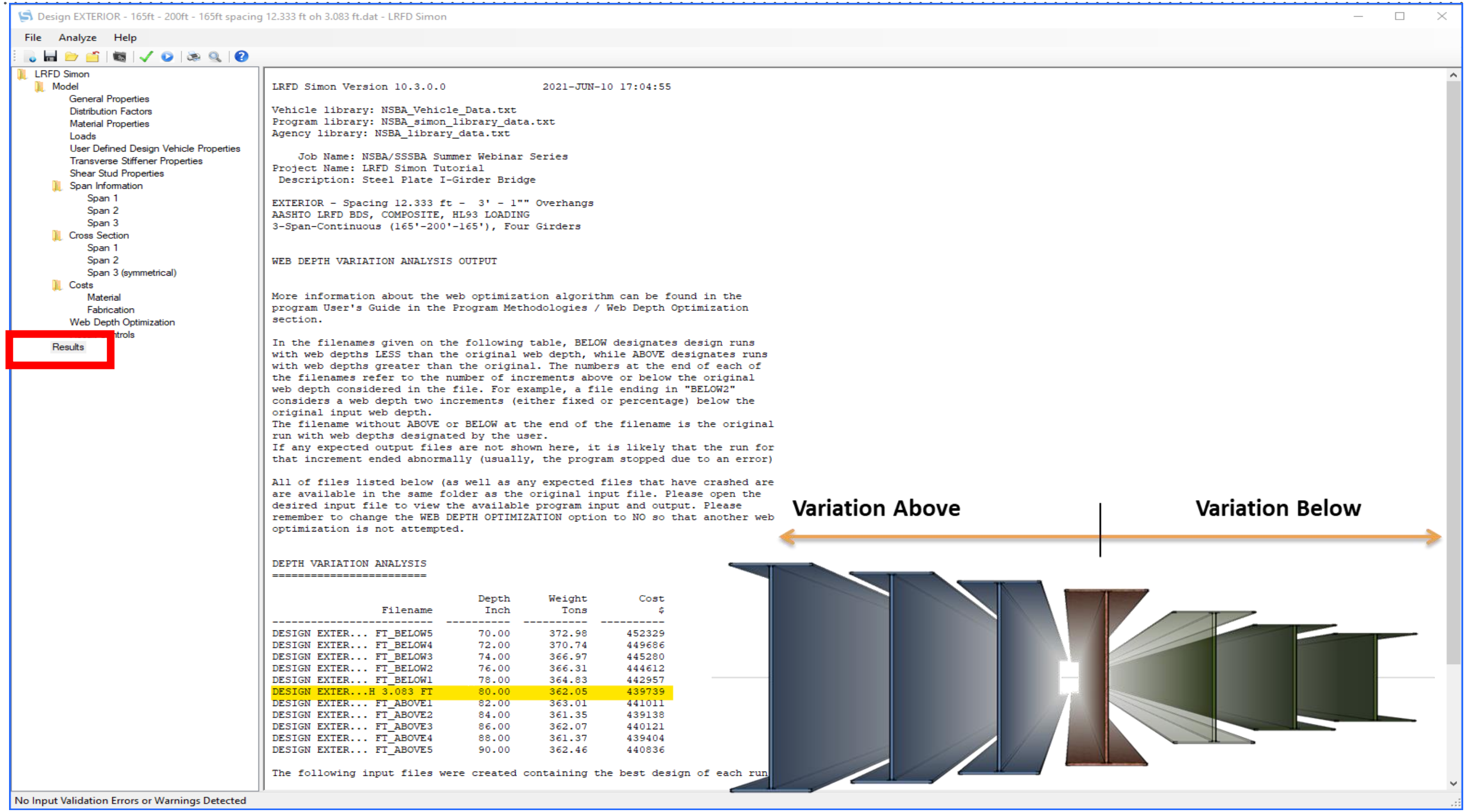
LRFD Simon – Results Review



Simon – Web Depth Optimizer (Design Mode)



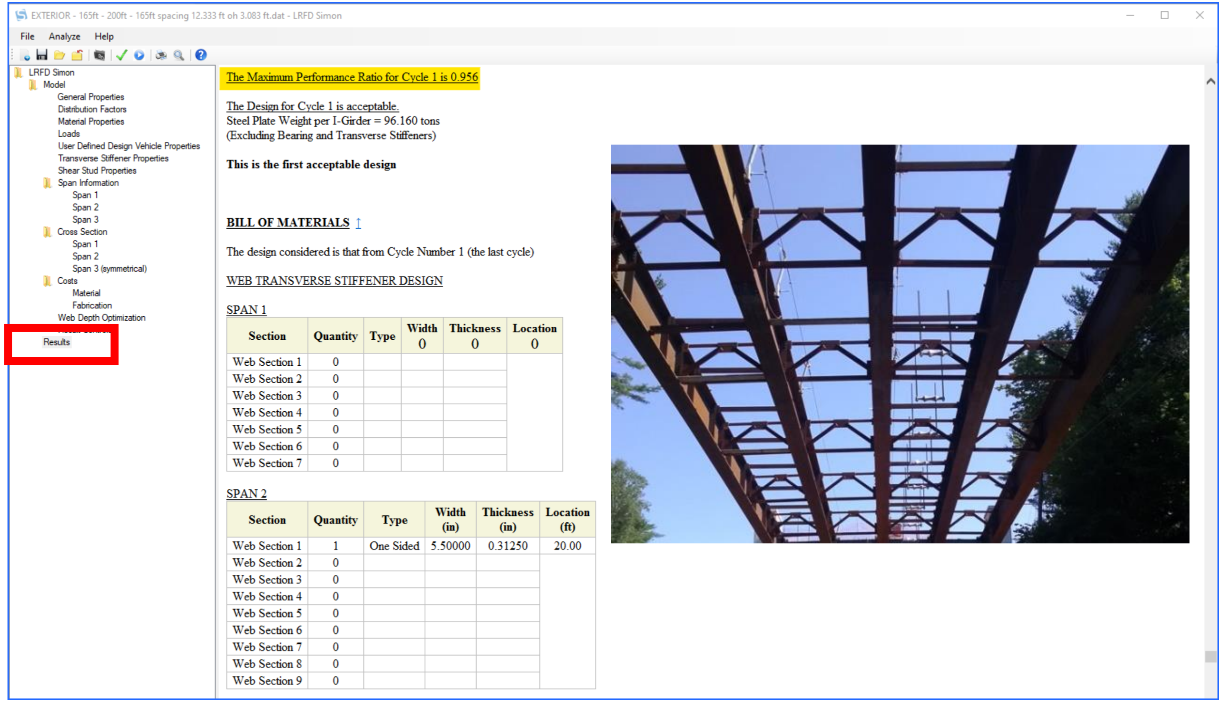
Simon – Web Depth Optimizer Results



LRFD Simon – Results Review

All Performance Ratios Should Be Less Than 1.0

- Highest P.R. is 0.956
- Verify Interior Girder Design is Adequate
- Could Refine Further to Optimize Sections for Fabrication and Costs
- If Results P.R. More Than 1.0, Revise & Rerun
- Adjust Web Thickness and Stiffeners for Shear
- Adjust Flange Thickness & CF Locations for Flexure & Fatigue

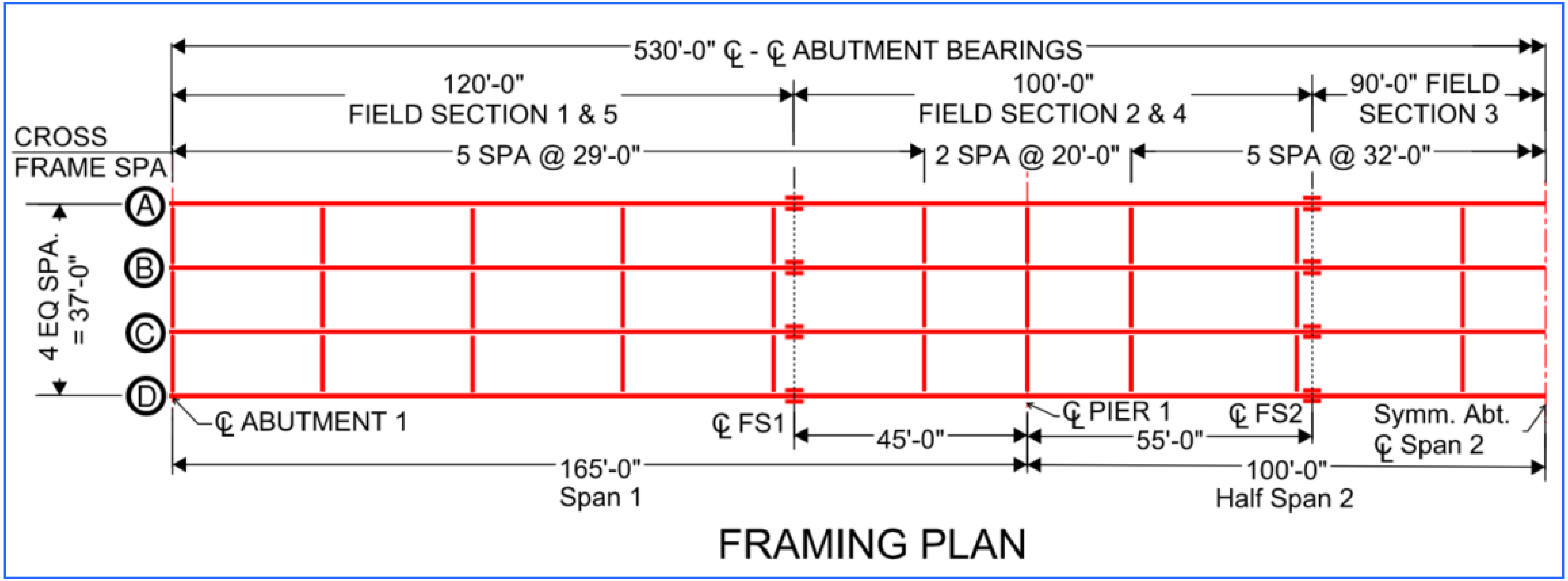


Section	Quantity	Type	Width 0	Thickness 0	Location 0
Web Section 1	0				
Web Section 2	0				
Web Section 3	0				
Web Section 4	0				
Web Section 5	0				
Web Section 6	0				
Web Section 7	0				

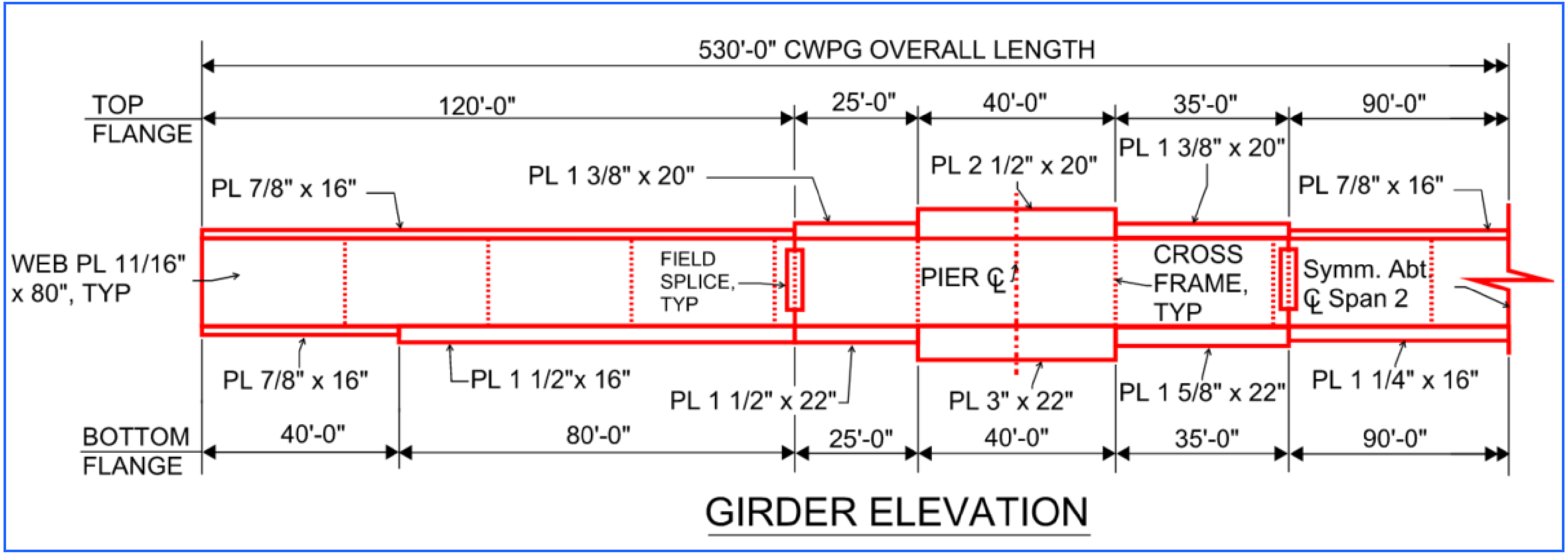
SPAN 2

Section	Quantity	Type	Width (in)	Thickness (in)	Location (ft)
Web Section 1	1	One Sided	5.50000	0.31250	20.00
Web Section 2	0				
Web Section 3	0				
Web Section 4	0				
Web Section 5	0				
Web Section 6	0				
Web Section 7	0				
Web Section 8	0				
Web Section 9	0				

LRFD Simon Design Results



LRFD Simon Design Results



Thank You! **The National Steel Bridge Alliance**

Devin Altman, PE (altman@aisc.org); 503.349.1106

Smarter.
Stronger.
Steel.