

# Modeling Post-Tensioned Concrete Haunched Slabs (XCSH) in BrDR

Abdul Hamada, P.E.

Brad Shores, P.E.

2017 AASHTO Bridge RADBUG Meeting

8/15/2017

Kansas City, KS

# What is a XCSH?





# RCSH Uses Mild Steel + Concrete





**Maximum standard spans: 54'-72'-54'**





**Maximum standard spans: 71'-92'-71'**









# History of XCSH

- **Pre-1989: Need for longer span slab bridges**
- **1989: 1<sup>st</sup> PT, Sedgwick County, 45'-75'-45'**
- **1990-2000: 8 more PT's including 79'-102'-79'**
- **2000: Metric PT Standards developed for KDOT**
- **2006: Englification of Standards**
- **2013: Grout Improvements, Manual Update**
- **2017: Standard Update**

*30+ bridges constructed in 28 years*

# 2000: 85<sup>th</sup> St N over WVCFC





# Primary Structure Holding Up?

- 2011 NDT grout investigation two bridges no issues (low profile!)





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# 2016-2017 KDOT Standard Update

- "A" Spans: 50'-65'-50'
- "B" Spans: 55'-72'-55'
- "C" Spans: 62'-82'-62'
- "D" Spans: 71'-92'-71'
- 28' Roadway
- 32' Roadway
- 36' Roadway
- 40' Roadway
- 40' Roadway w/  
2' Offset Crown
- 44' Roadway



# 2016-2017 KDOT Standard Update

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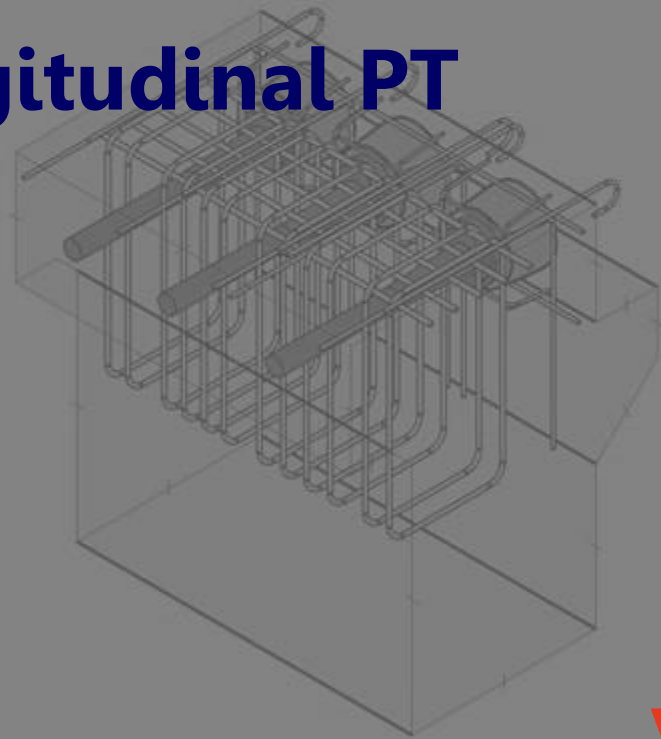
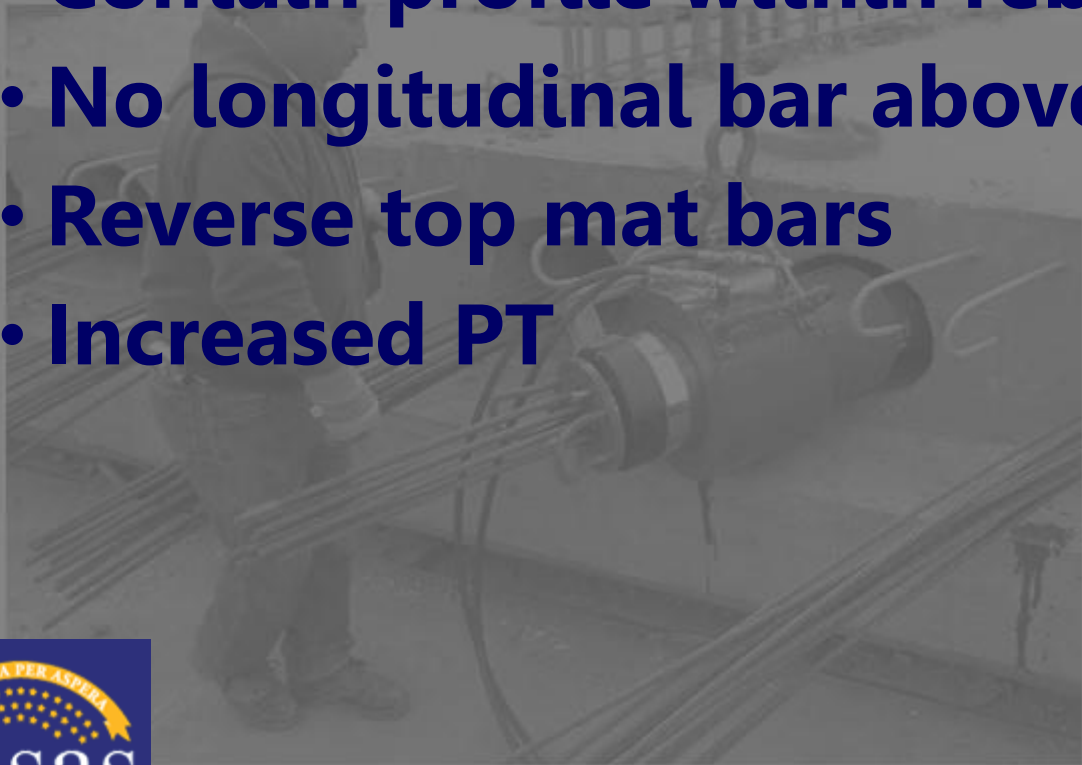
# 2016-2017 KDOT Standard Update

- **Tendon to Protection Level 2 (PL2)**
  - **PTI/ASBI M50.3-12 Guide Specification for Grouted Post-tensioning**
- **Review grout specification**
- **Detailing over the piers for longitudinal cracks**
- **AASHTO LRFD Bridge Design Specs, 7th edition, 2014**
  - **With Elastic Gains, 1.00 LL or Without Elastic Gains, 0.8 LL**
- **Load Rate BrR including SU trucks**



# Contain PT in Mild Steel

- 1.5" bottom mat clearance instead of 1.0"
- Contain profile within rebar mats
- No longitudinal bar above longitudinal PT
- Reverse top mat bars
- Increased PT



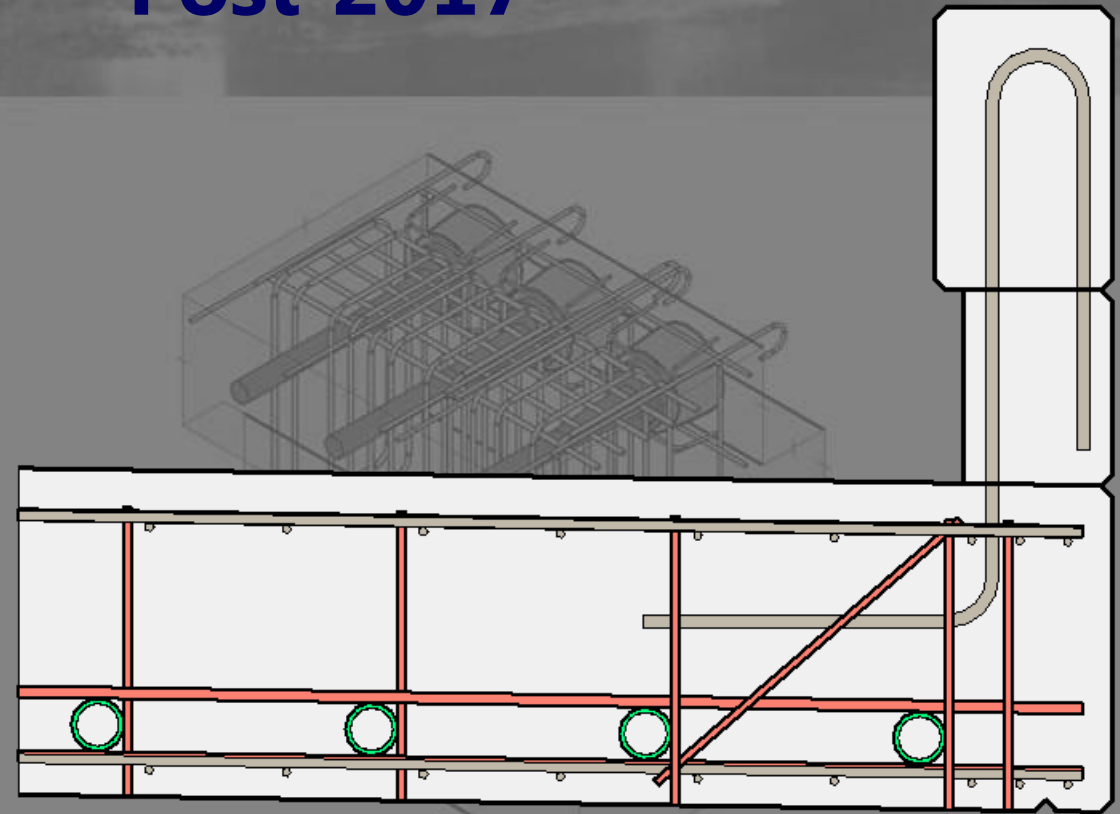


# Contain Low PT in Mild Steel

Pre-2017



Post-2017

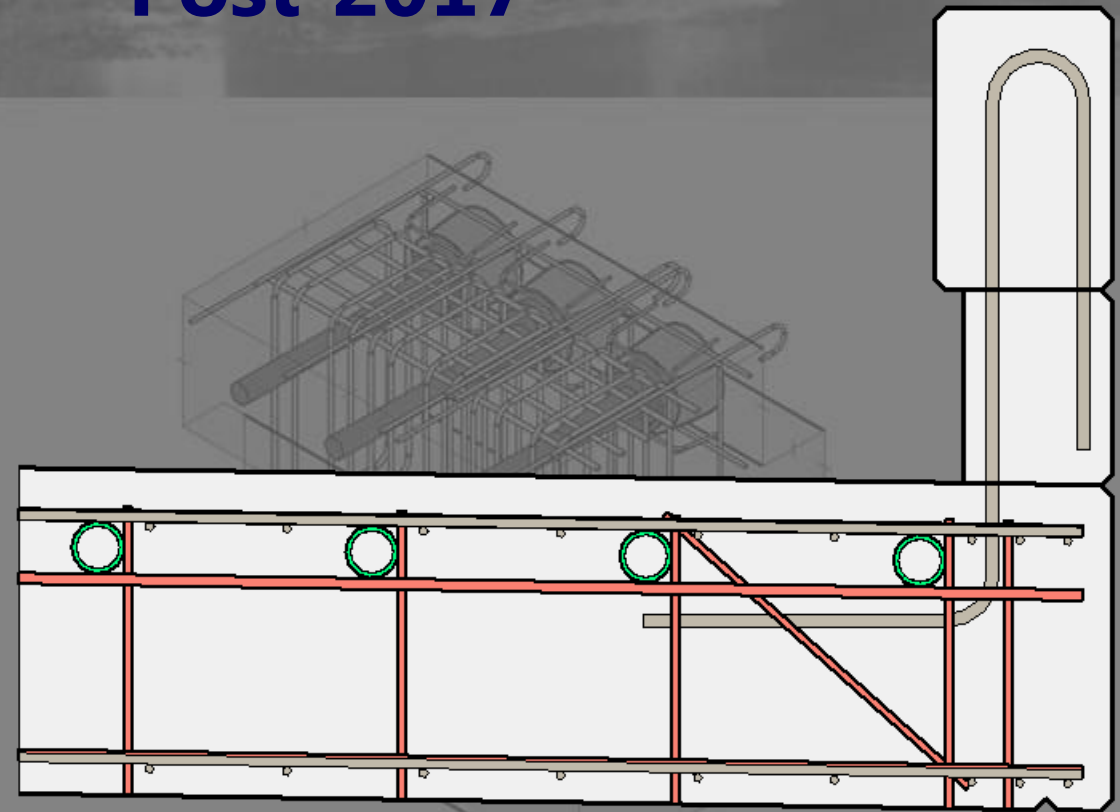


# Contain High PT in Mild Steel

Pre-2017



Post-2017



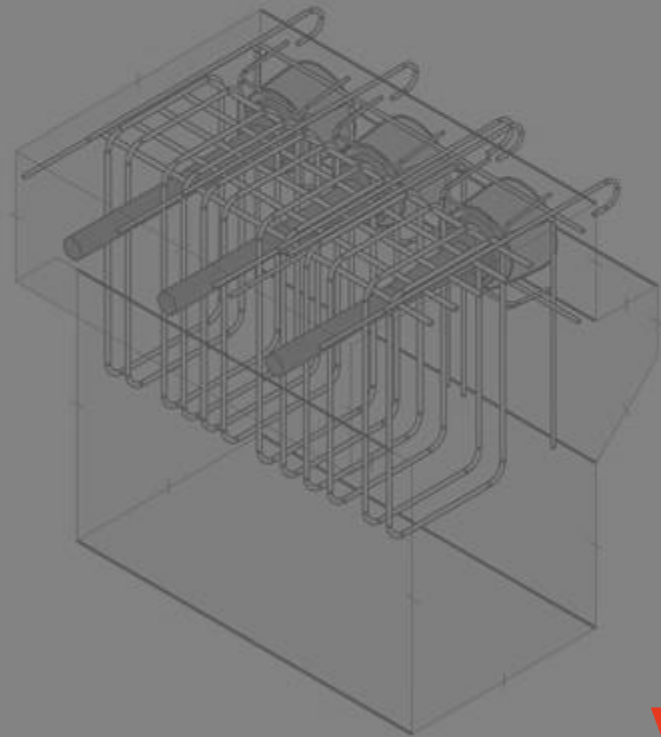
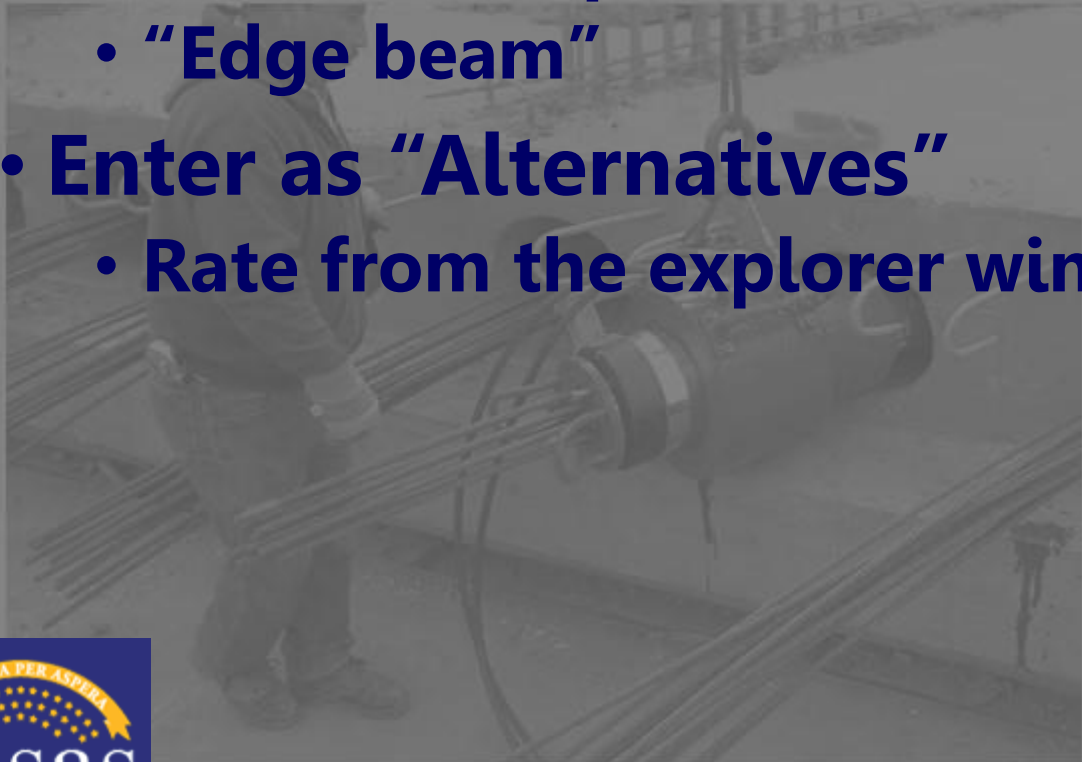


# BrR Scope

- Determine best Superstructure Definition for XCSH
- Create BrR files for previous standard configurations
  - 20 Configurations modeled in BrR
- Create BrR files for new standard configurations
  - 15 Configurations modeled in BrR
- Load Rate for 14 “LFR” trucks and 1 “LRFR” truck

# Approach – Our Code Interpretation

- For each configuration, model:
  - “Interior strip”
  - “Edge beam”
- Enter as “Alternatives”
  - Rate from the explorer window





# Strip Widths

- Interior strip width = Interior Duct Spacing = 1'-9"
- Edge beam width per AASHTO LRFD 4.6.2.1.4b

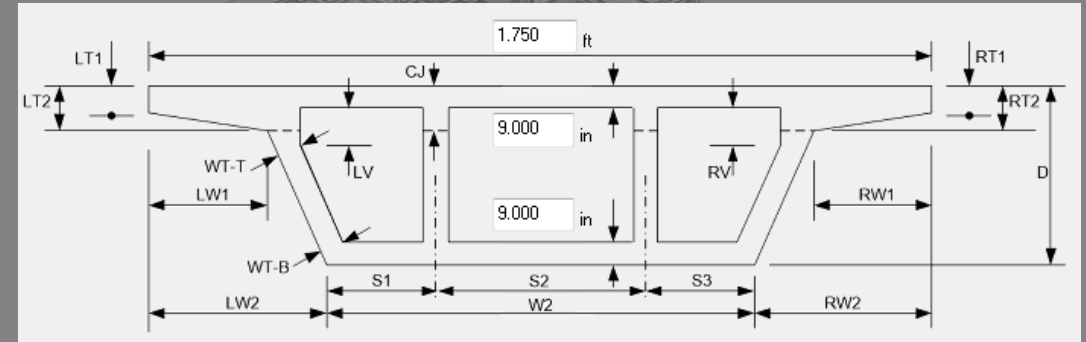
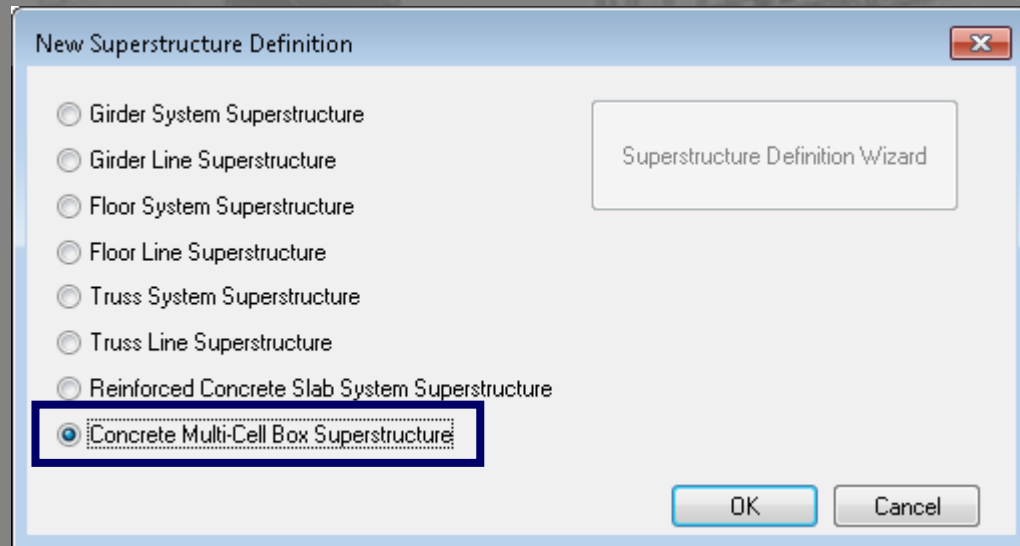
## *4.6.2.1.4b—Longitudinal Edges*

Edge beams shall be assumed to support one line of wheels and, where appropriate, a tributary portion of the design lane load.

Where decks span primarily in the direction of traffic, the effective width of a strip, with or without an edge beam, may be taken as the sum of the distance between the edge of the deck and the inside face of the barrier, plus 12.0 in., plus one-quarter of the strip width, specified in either Article 4.6.2.1.3, Article 4.6.2.3, or Article 4.6.2.10, as appropriate, but not exceeding either one-half the full strip width or 72.0 in.

# Superstructure Definition

- Superstructure Definition:
  - Concrete Multi-Cell Box Superstructure





# Structure Cross Sections: Define Two

The screenshot shows the 'Bridge Rating - [Structure Cross Section]' software interface. At the top, the menu bar includes File, Edit, View, Bridge, Substructure, Tools, Window, and Help. The toolbar contains various icons for file operations and analysis. The main window displays a cross-section diagram of a bridge with two cells. Key dimensions are highlighted with blue boxes: a width of 1.750 ft, and two vertical dimensions of 9.000 in. Below the diagram are two tables: 'Overall' and 'Cells'. The 'Overall' table lists dimensions in feet, and the 'Cells' table lists dimensions in inches. A 'Properties' dialog box is open at the bottom right, showing computed values for Area, Ixx, Iyy, and J.

Name: Equiv. Section 1      Number of cells: 2

Input Method:  Simple    Advanced  
Entry Method:  Width    Slope

Top slab concrete: Class 4A Concrete 5.0, 4.0    Other parts concrete: Class 4A Concrete 5.0, 4.0  
Top slab stress limit: P/S Limits    Other parts stress limit: P/S Limits

Overall		Cells	
	(ft)		(in)
D	1.833	LT1	11.000
CJ	0.917	LT2	11.000
LW1	0.000	RT1	11.000
LW2	0.000	RT2	11.000
RW1	0.000		
RW2	0.000		
LV	0.000		
RV	0.000		

W2 = 1.750 ft

Properties

Compute Properties

Area = 3.208 ft<sup>2</sup>  
Ixx = 0.8986 ft<sup>4</sup>  
Iyy = 0.8188 ft<sup>4</sup>  
J = 0.9362 ft<sup>4</sup>

OK   Apply   Cancel

Strip Width =  
Duct Spacing

Not equal;  
Arbitrary 4"x0"  
void required

Check section  
properties

# Superstructure Definition

The screenshot shows the 'Bridge Rating - [Concrete Multi-Cell Box Superstructure Definition]' window. The 'Definition' tab is active, displaying the following information:

- Name:** D44 Proposed (1'-9" Strip)
- Description:** New Approach to an equivalent 3 span Multi-Cell Concrete Box Girder Bridge. Adding an "arbitrary void" to get it to run. 1'-9" wide Interior Strip (1'-9" typical duct spacing). 2 cell: 10.5"-10.5" (half of "interior" strip width X 2).

At the bottom of the window, the 'Number of cells' is set to 2. The 'Span Lengths' table is as follows:

Span	Length (ft)
1	71.00
2	92.00
3	71.00

The 'Frame Connections' table is as follows:

Support	Frame Connection
1	<input type="checkbox"/>
2	<input type="checkbox"/>
3	<input type="checkbox"/>
4	<input type="checkbox"/>

The 'Structure Type' section has the following options:

- Frame structure simplified definition
- Integral with substructure
  - Consider substructure skew in FE section properties
- Not integral with substructure

The 'Post-tensioned' checkbox is checked.

2 Cells

Not integral with substructure



# Structure Cross Sections: Key Dim's

Bridge Rating - [Structure Cross Section]

File Edit View Bridge Substructure Tools Window Help

US Customary

Name: Equiv. Section 1 Number of cells: 2

Input Method:  Simple  Advanced  
 Entry Method:  Width  Slope

Top slab concrete: Class 4A Concrete 5.0, 4.0 Other parts concrete: Class 4A Concrete 5.0, 4.0  
 Top slab stress limit: P/S Limits Other parts stress limit: P/S Limits

Overall Cells Fillets

Top left web thickness: 7.000 in W2 = 1.750 ft  
 Bottom left web thickness: 7.000 in

Cell	S (ft)	Top Right Web Thickness (in)	Bottom Right Web Thickness (in)	Top Slab thickness (in)
1	0.875	7.000	7.000	9.000
2	0.875	7.000	7.000	9.000

Properties

Compute Properties

Area = 3.208 ft<sup>2</sup>  
 Ixx = 0.8986 ft<sup>4</sup>  
 Iyy = 0.8188 ft<sup>4</sup>  
 J = 0.9362 ft<sup>4</sup>

OK Apply Cancel

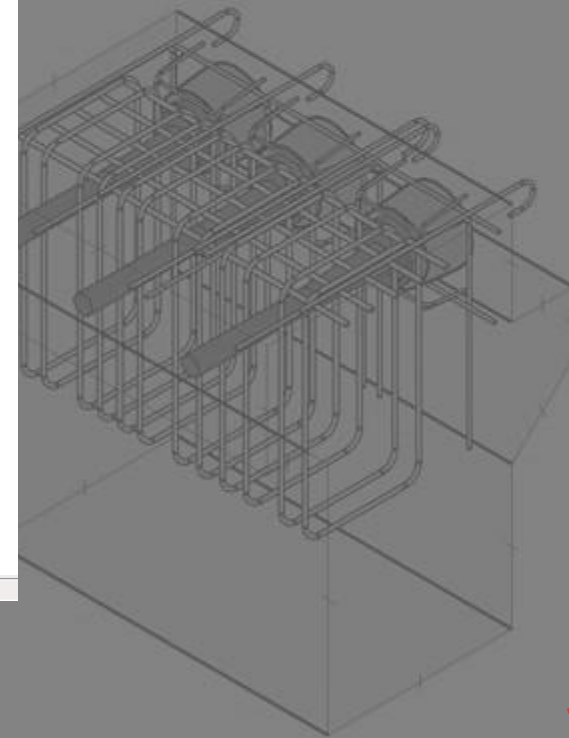
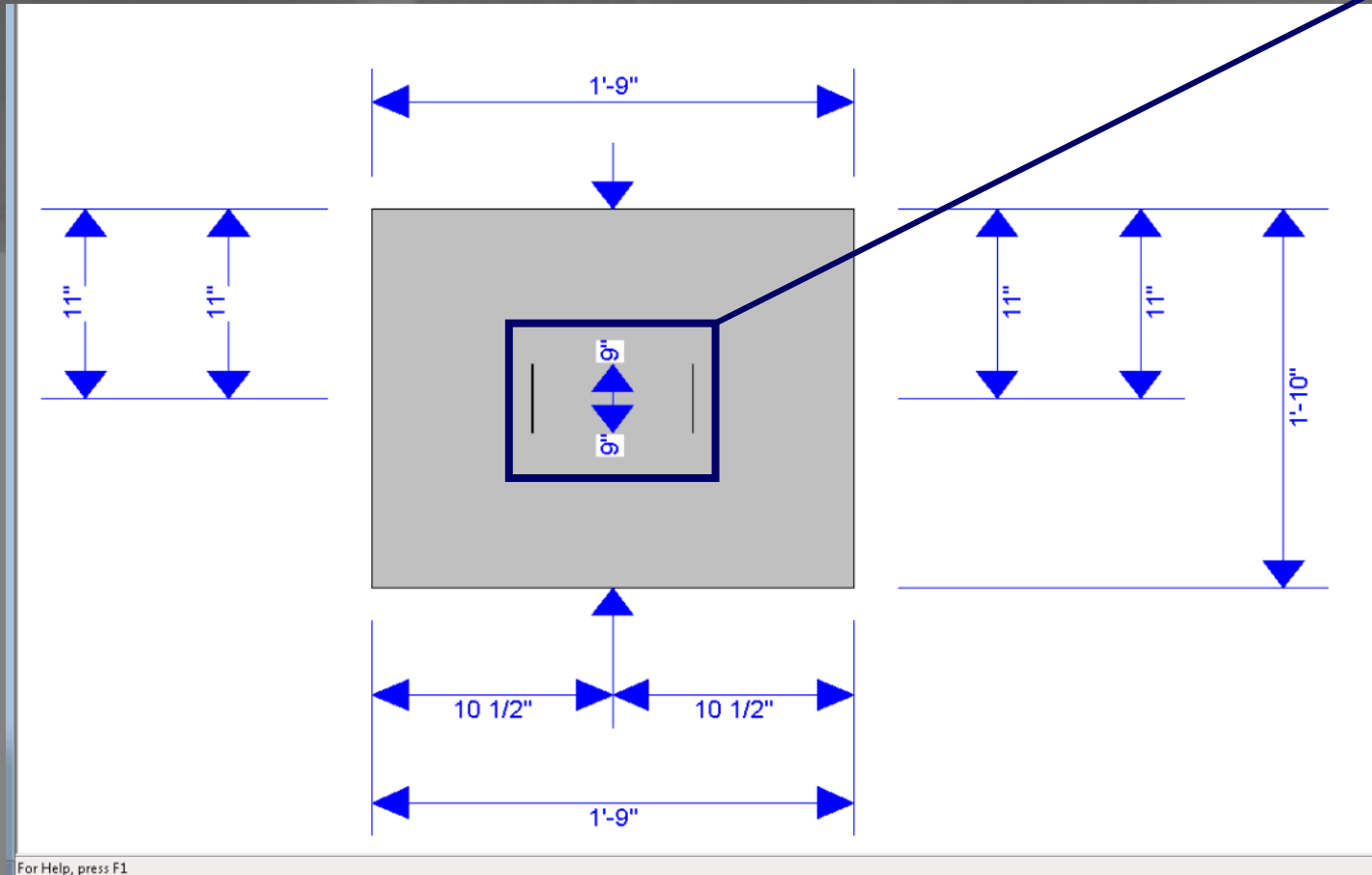
**S = Overall width / 2**

**Web thickness =**

**Overall width / 3**

# Section View

Arbitrary voids



For Help, press F1



# Cross Section Range Properties

BrR Bridge Rating - [Cross Section Ranges]

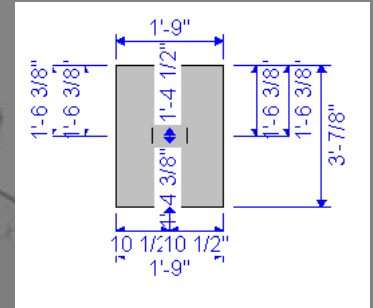
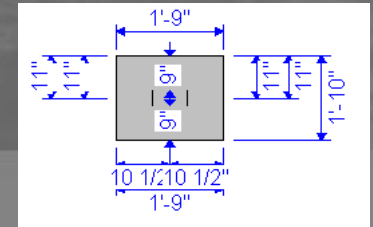
File Edit View Bridge Substructure Tools Window Help

Preliminary

Cross Sections Post Tensioning Effective Supports

Left end projection: 18.000 in Right end projection: 18.000 in

Start Section	End Section	Depth Vary	Solid Section	Support Number	Start Distance (ft)	Length (ft)	End Distance (ft)
Equiv. Section 1	Equiv. Section 1	None	<input type="checkbox"/>	1	0.000	25.000	25.000
Equiv. Section 1	Equiv. Section 2	Parabolic Concave	<input type="checkbox"/>	1	25.000	44.333	69.333
Equiv. Section 2	Equiv. Section 2	None	<input type="checkbox"/>	1	69.333	3.333	72.667
Equiv. Section 2	Equiv. Section 1	Parabolic Concave	<input type="checkbox"/>	2	1.667	44.333	46.000
Equiv. Section 1	Equiv. Section 2	Parabolic Concave	<input type="checkbox"/>	2	46.000	44.333	90.333
Equiv. Section 2	Equiv. Section 2	None	<input type="checkbox"/>	2	90.333	3.333	93.667
Equiv. Section 2	Equiv. Section 1	Parabolic Concave	<input type="checkbox"/>	3	1.667	44.333	46.000
Equiv. Section 1	Equiv. Section 1	None	<input type="checkbox"/>	3	46.000	25.000	71.000



# Tendon Profile Definitions

Bridge Rating - [Tendon Profile Definition]

File Edit View Bridge Substructure Tools Window Help

Preliminary

Profile Name: D44 Prop. Long. PT Tendon (12) Starting Span: 1 Start distance into start span: 0.000 ft  
Ending Span: 3 End distance from end span: 0.000 ft

Profile Post Tensioning Stress Limits

Inflection Point Entry Method  
 Percentage  Distance Assigned To: Box Unit

Span	Profile Type	Inflection Points			Vertical Offset					
		Left (ft)	Low (ft)	Right (ft)	Left End (in)	Measured From	Low (in)	Measured From	Right End (in)	Measured From
1	Type 3		28.400	17.750	11.313	Top	16.807	Top	5.780	Top
2	Type 1	23.000	46.000	23.000	5.780	Top	16.720	Top	5.780	Top
3	Type 4	17.750	42.600		5.780	Top	16.807	Top	11.313	Top

Bridge Rating - [Tendon Profile Definition]

File Edit View Bridge Substructure Tools Window Help

Preliminary

Profile Name: D44 Prop. Long. PT Tendon (12) Starting Span: 1 Start distance into start span: 0.000 ft  
Ending Span: 3 End distance from end span: 0.000 ft

Profile Post Tensioning Stress Limits

Prestress material: 0.6" (7W-270) LR Jacking end: Both Ends

Post-Tensioning Input Method  
 Jacking Force  Strands Jacking stress ratio: 0.750 Duct grouting: Grouted  
Duct diameter: 2.990 in

Jacking Force: 526.800 kip

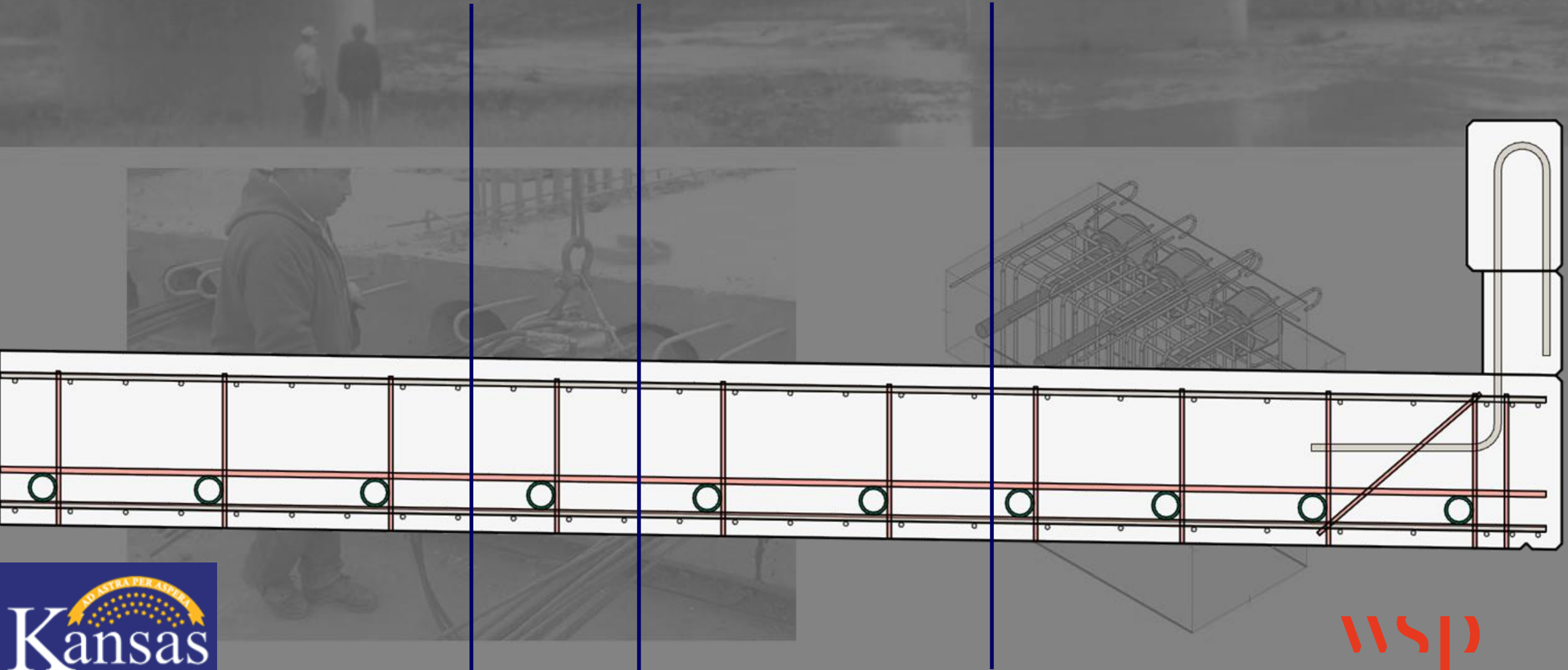
Number of ducts per web: 0

Duct	Strands per Duct
------	------------------

Specify jacking force rather than # of strands, especially for edge beam



# Tendon Profile Definitions







# Slab Reinforcement

Enter total # of bars as decimal  
# Bars Left Web = half total

Bridge Rating - [Slab Reinforcement]

File Edit View Bridge Substructure Tools Window Help

Preliminary

Type: Multi Cell Box

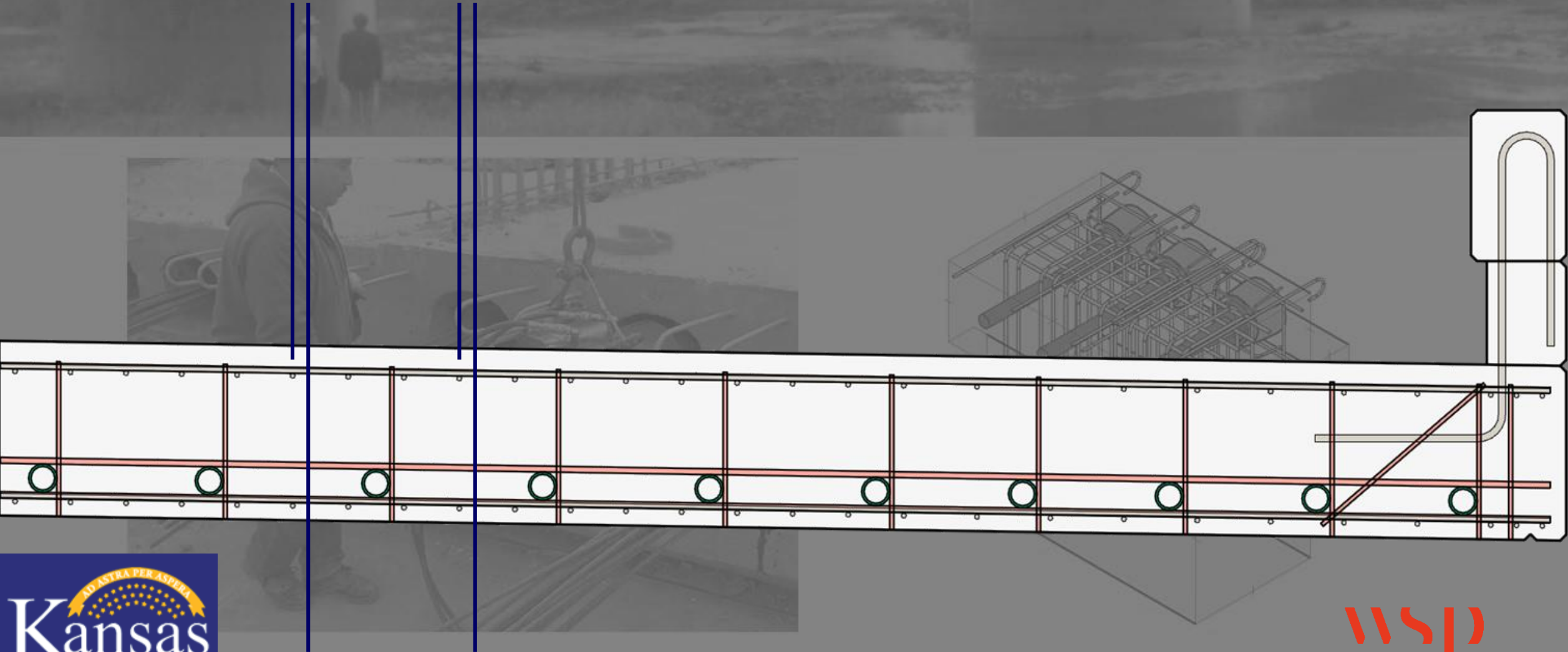
Transverse Reference Lines Cells - Top Slab Cells - Bottom Slab Overhangs

Cell	Material	Reference Point	Direction	Start Distance (ft)	Length (ft)	End Distance (ft)	Number of Bars	Number Bars for Left Web	Bar Size	Clear Cover (in)	Measured From	Bar Spacing (in)	Side Cover (in)	Start Fully Developed	End Fully Developed
All Cells	Grade 60	Support 1	Left	0.000	234.000	234.000	3	1.500	5	2.500	Top of Slab	7.000	2.688	<input type="checkbox"/>	<input type="checkbox"/>

Transverse Reference Lines Cells - Top Slab Cells - Bottom Slab Overhangs

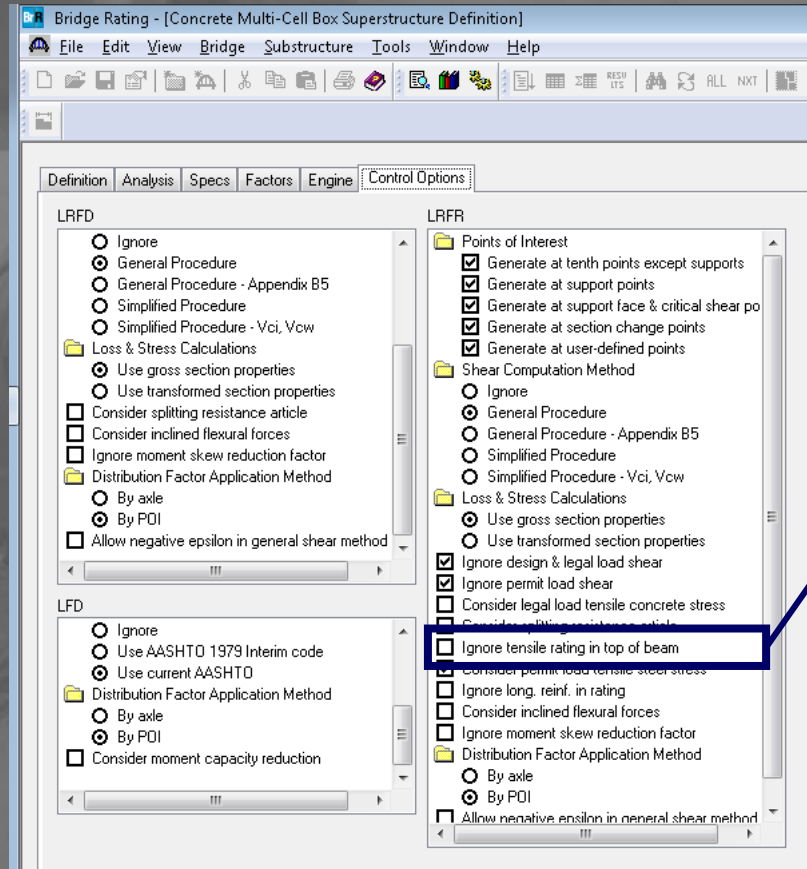
Cell	Material	Reference Point	Direction	Start Distance (ft)	Length (ft)	End Distance (ft)	Number of Bars	Number Bars for Left Web	Bar Size	Clear Cover (in)	Measured From	Bar Spacing (in)	Side Cover (in)	Start Fully Developed	End Fully Developed
All Cells	Grade 60 Epoxy	Support 1	Left	0.000	234.000	234.000	3	1.500	5	1.500	Bottom of Slab	7.000	2.688	<input type="checkbox"/>	<input type="checkbox"/>

# Slab Reinforcement





# Superstructure Definition



**KDOT ignores tensile rating in top of beam for P/S**

**Different for XCSH**

# P/S Limits

Bridge Rating - [Stress Limit Sets - Concrete]

File Edit View Bridge Substructure Tools Window Help

Name: P/S Limits

Description: Prestressed Conc Stress Limits

Concrete Material: Class 4A Concrete 5.0, 4.0

	LFD		LRFD	
Initial allowable compression:	2.280	ksi	2.470	ksi
Initial allowable tension:	0.185	ksi	0.185	ksi
Final allowable compression:	3.000	ksi	3.000	ksi
Final allowable tension:	0.000	ksi	0.212	ksi
Final allowable DL compression:	2.000	ksi	2.250	ksi
Final allowable slab compression:	3.000	ksi	3.000	ksi
Final allowable compression: (LL + 1/2(Pe + DL))	2.000	ksi	2.000	ksi

Can't enter one value for INV and one for OPER; conservatively used 0 for both

# P/S Losses

Bridge Rating - [Post Tension Losses]

File Edit View Bridge Substructure Tools Window Help

Name: P/S Losses

Loss Method: AASHTO Refined

Anchor Set: 0.38 in

Coefficient of friction: 0.23

Wobble coefficient: 0.0002 per ft

P/S transfer stress ratio:

Transfer time: 72.0 Hours

Age at deck placement: 50.0 Days

Final age: 27375.0 Days

Lump Sum Losses

Initial loss: ksi

Final loss: ksi

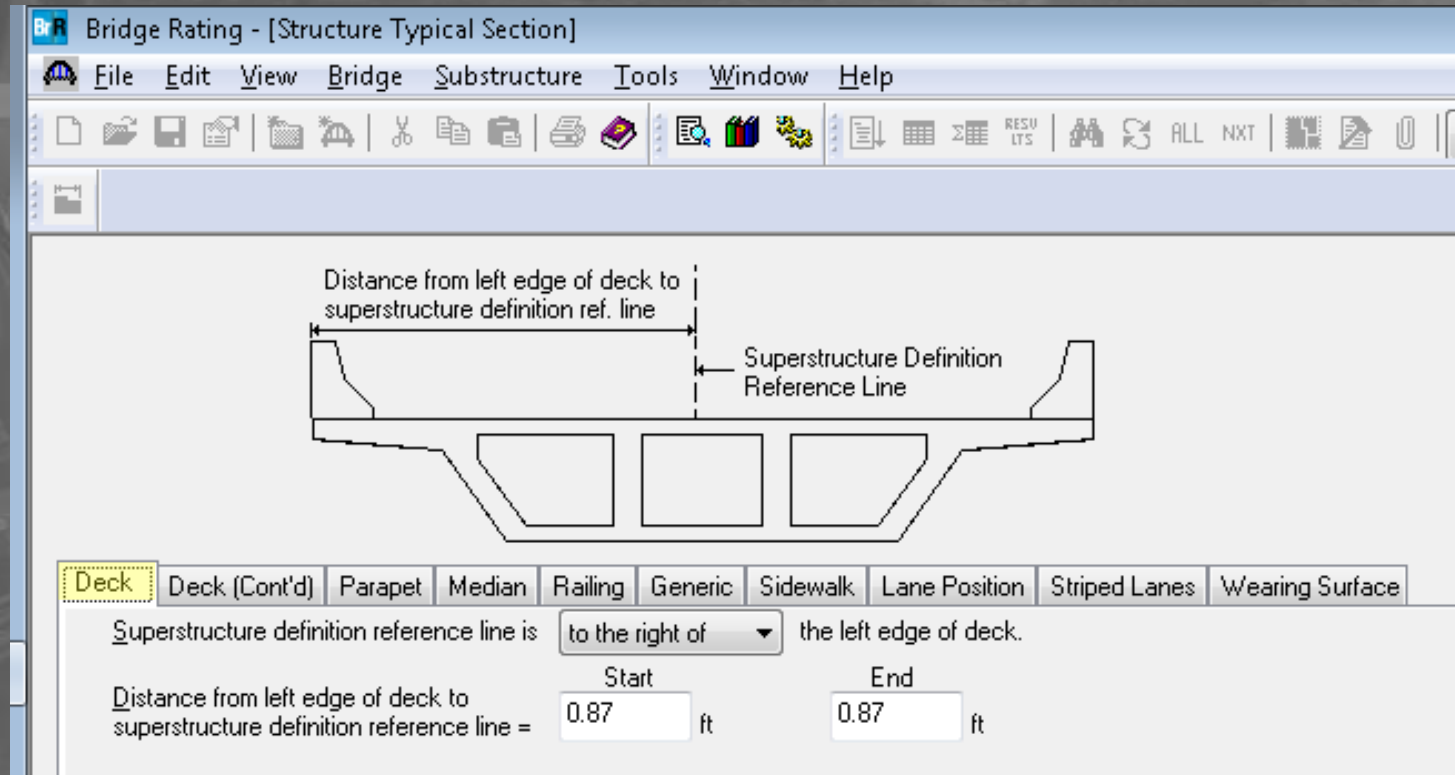
Approximate is not an option; use "AASHTO Refined"

Values from plans



# Structure Typical Section

- Deck



The screenshot displays the Bridge Rating software interface for a Structure Typical Section. The main window shows a cross-section of a bridge deck with three spans. A vertical dashed line is labeled "Superstructure Definition Reference Line". A horizontal double-headed arrow indicates the "Distance from left edge of deck to superstructure definition ref. line".

Below the diagram is a configuration panel for the "Deck" component. The panel includes a tabbed interface with the following tabs: Deck (Cont'd), Parapet, Median, Railing, Generic, Sidewalk, Lane Position, Striped Lanes, and Wearing Surface. The "Deck" tab is selected.

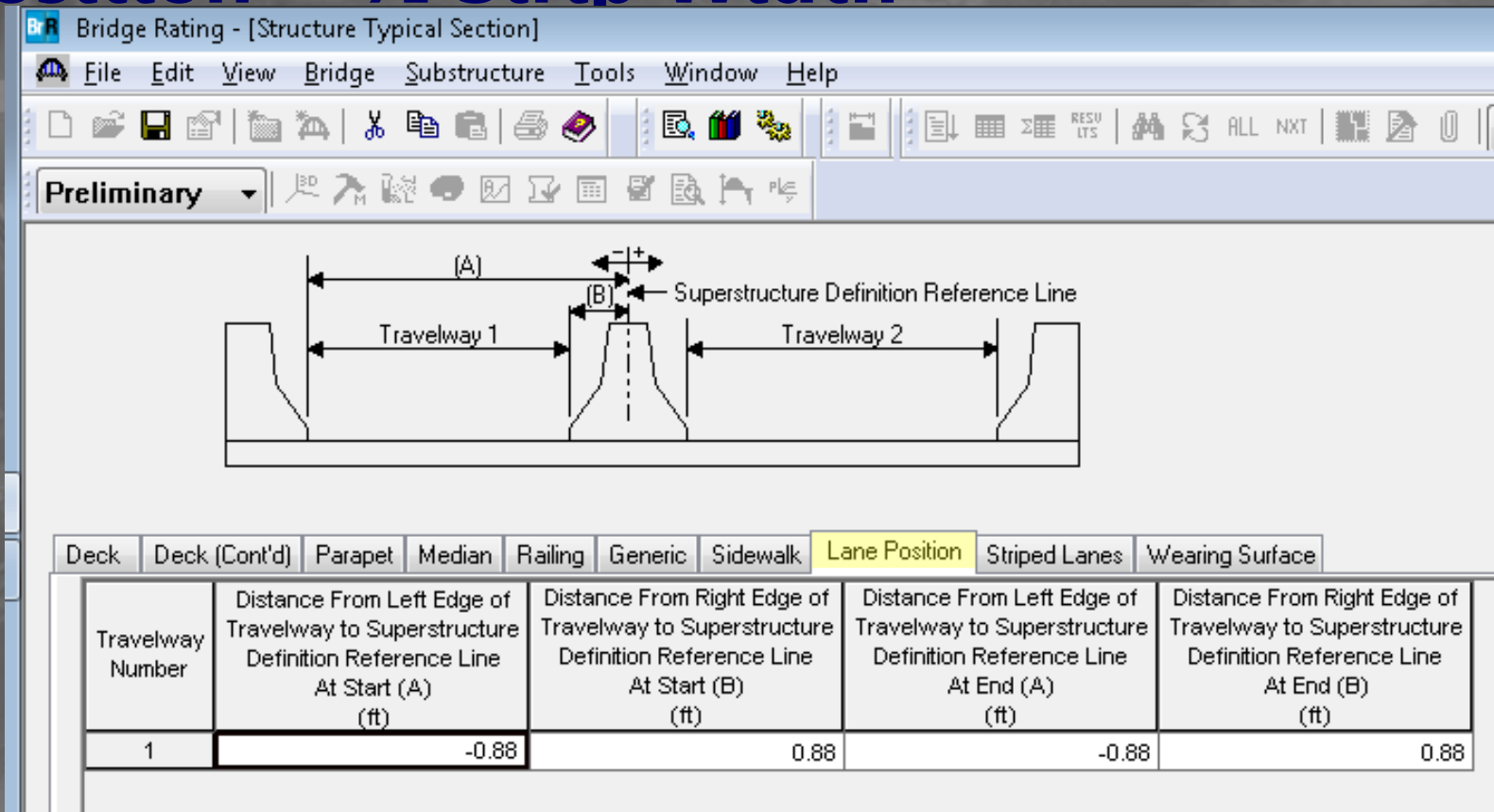
The configuration panel contains the following text and input fields:

Superstructure definition reference line is  the left edge of deck.

Distance from left edge of deck to superstructure definition reference line =  ft  ft

# Structure Typical Section

- Lane Position =  $\frac{1}{2}$  Strip Width



# Structure Typical Section

- FWS

The screenshot displays the Bridge Rating software interface. At the top, the title bar reads "Bridge Rating - [Structure Typical Section]". The menu bar includes "File", "Edit", "View", "Bridge", "Substructure", "Tools", "Window", and "Help". Below the menu bar is a toolbar with various icons for file operations and editing. A secondary toolbar shows a dropdown menu set to "Preliminary" and several icons for navigation and viewing. The main workspace contains a cross-sectional diagram of a bridge deck with three girders. A vertical dashed line is labeled "Superstructure Definition Reference Line". A horizontal dimension line above the deck is labeled "Distance from left edge of deck to superstructure definition ref. line". Below the diagram is a tabbed interface with the following tabs: "Deck", "Deck (Cont'd)", "Parapet", "Median", "Railing", "Generic", "Sidewalk", "Lane Position", "Striped Lanes", and "Wearing Surface". The "Wearing Surface" tab is active and contains the following configuration fields:

- Wearing surface material: SFOL
- Description: FWS 25 psf
- Wearing surface thickness = 2.0000 in  Thickness field measured (D'W = 1.25 if checked)
- Wearing surface density = 150.000 pcf
- Load case: DW

A "Copy from Library..." button is located at the bottom right of the configuration panel.



# Rail Definition

- Define weightless barrier

Bridge Appurtenances - Parapet

Name: Exterior Barrier

Description: 32" Open Kansas Corral Rail

All dimensions are in inches

Additional Load = 0.0000 kip/ft

12.0000 0.0000

Reference Line

0.0000

0.0000

0.0000

22.2720

Back Front

Roadway Surface

Parapet unit load = 0.0000 kcf

Calculated Properties

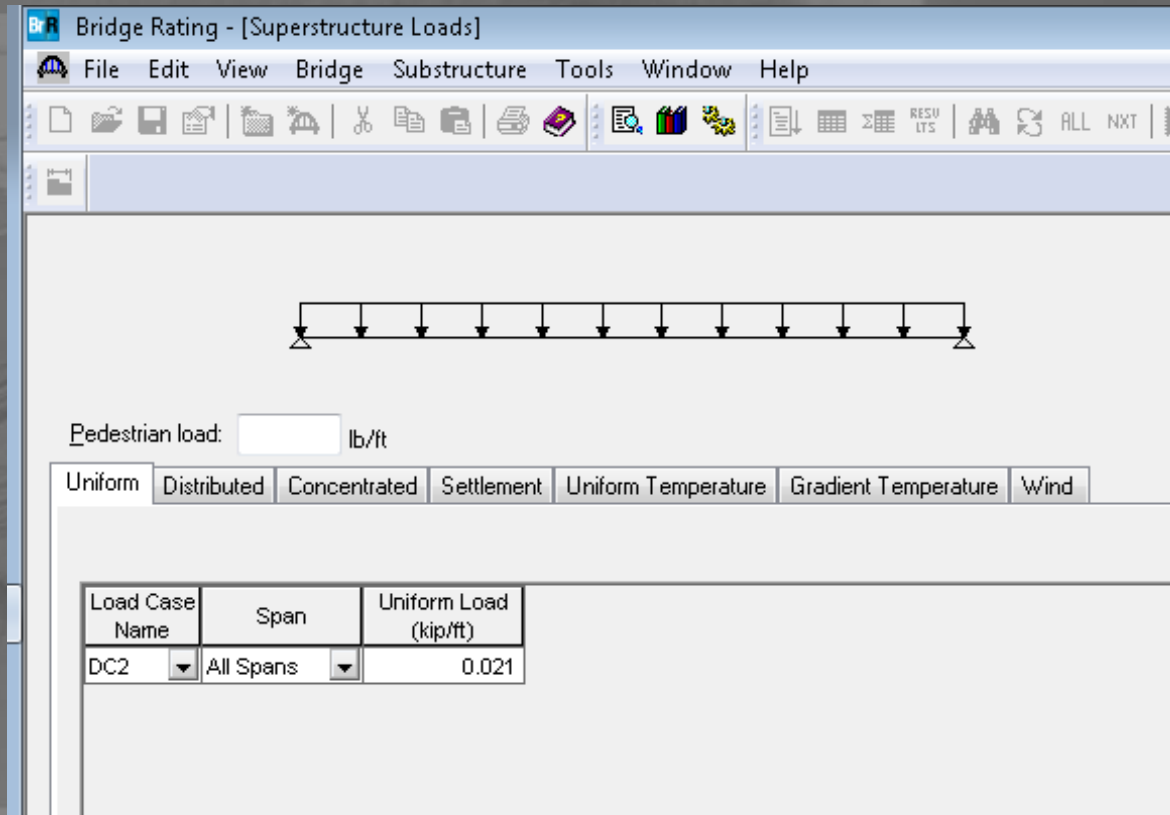
Net centroid (from reference line) = 6.000 in

Total load = 0.000 kip/ft

Copy from Library... OK Apply Cancel

# Superstructure Loads

- Barrier, proportioned to strip width

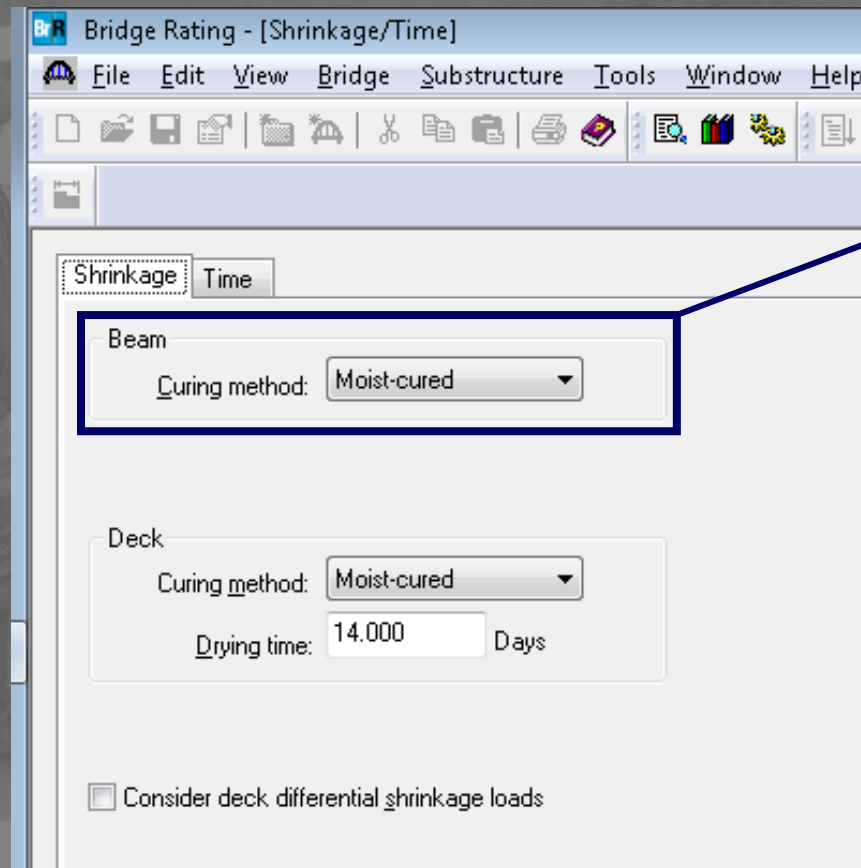


The screenshot shows the 'Bridge Rating - [Superstructure Loads]' software interface. It features a menu bar (File, Edit, View, Bridge, Substructure, Tools, Window, Help) and a toolbar with various icons. A diagram of a bridge span with a uniform load is displayed. Below the diagram, there is a 'Pedestrian load:' input field set to 0.021 lb/ft. A row of tabs includes 'Uniform', 'Distributed', 'Concentrated', 'Settlement', 'Uniform Temperature', 'Gradient Temperature', and 'Wind'. At the bottom, a table lists the load case details.

Load Case Name	Span	Uniform Load (kip/ft)
DC2	All Spans	0.021

# Shrinkage/Time

- Values as per KDOT



Bridge Rating - [Shrinkage/Time]

File Edit View Bridge Substructure Tools Window Help

Shrinkage Time

Beam

Curing method: Moist-cured

Deck

Curing method: Moist-cured

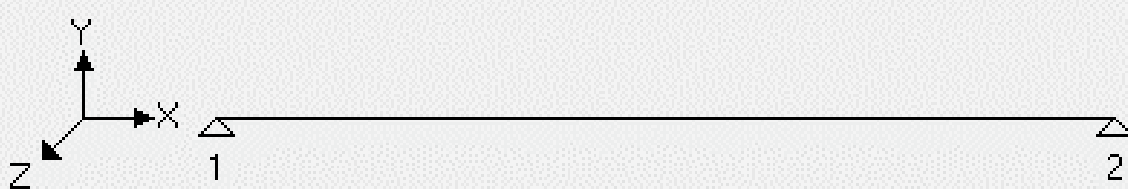
Drying time: 14.000 Days

Consider deck differential shrinkage loads

Except beam curing method



# Supports



The diagram shows a horizontal beam with two supports. Support 1 is a pin support at the left end, and support 2 is a roller support at the right end. A 3D coordinate system is shown with the X-axis pointing right, the Y-axis pointing up, and the Z-axis pointing out of the page.

General Elastic

Support Number	Support Type	Translation Constraints		Rotation Constraints
		X	Y	Z
1	Pinned	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
2	Pinned	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
3	Pinned	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
4	Roller	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>

# Live Load Distribution

- Hand calculate LLDF based on modeled width

Bridge Rating - [Live Load Distribution]

Standard: LRFD

Distribution Factor Input Method:  
 Use Simplified Method  Use Advanced Method  Use Advanced Method with 1994 Guide Specs

Allow distribution factors to be used to compute effects of permit loads with routine traffic

Lanes Loaded	Distribution Factor (Wheels)			
	Shear	Shear at Supports	Moment	Deflection
1 Lane	0.250	0.250	0.250	0.250
Multi-Lane	0.250	0.250	0.250	0.250

Bridge Rating - [Live Load Distribution]

Standard: LRFD

Distribution Factor Input Method:  
 Use Simplified Method  Use Advanced Method

Allow distribution factors to be used to compute effects of permit loads with routine traffic

Action: Moment

Support Number	Start Distance (ft)	Length (ft)	End Distance (ft)	Distribution Factor (Lanes)	
				1 Lane	Multi-Lane
1	0.00	234.00	234.00	0.095	0.132

Allow distribution factors to be used to compute effects of permit loads with routine traffic

Action: Shear

Support Number	Start Distance (ft)	Length (ft)	End Distance (ft)	Distribution Factor (Lanes)	
				1 Lane	Multi-Lane
1	0.00	234.00	234.00	0.095	0.132

# Load Rating Results

RATING SUMMARY - LFR						
TRUCK	INVENTORY RATING FACTOR			OPERATING RATING FACTOR		
	D Spans	C Spans	B Spans	D Spans	C Spans	B Spans
<b>H-20</b>	1.84	1.68	1.81	2.89	3.04	3.295
<b>Type 3</b>	1.68	1.77	1.76	2.80	3.00	2.944
<b>HS-20</b>	1.32	1.44	1.43	1.98	2.13	2.103
<b>Type 3S2</b>	1.38	1.47	1.55	2.23	2.45	2.507
<b>Type 3-3</b>	1.36	1.46	1.83	2.21	2.43	2.542
<b>Type T130</b>	1.56	1.75	1.63	2.14	2.34	2.654
<b>Type T170</b>	1.73	1.68	1.66	2.32	2.65	3.116
<b>HET</b>				1.17	1.28	1.27
<b>SU4</b>	1.53	1.50	1.61	2.56	2.74	2.684
<b>SU5</b>	1.39	1.42	1.52	2.27	2.43	2.387
<b>SU6</b>	1.36	1.30	1.38	2.07	2.24	2.207
<b>SU7</b>	1.30	1.25	1.29	1.91	2.07	2.06
<b>Type EV2</b>				2.40	2.57	2.517
<b>Type EV3</b>				1.62	1.73	1.696

RATING SUMMARY - LRFR						
TRUCK	INVENTORY RATING FACTOR			OPERATING RATING FACTOR		
	D Spans	C Spans	B Spans	D Spans	C Spans	B Spans
<b>AASHTO HL-93</b>	1.31	1.56	1.65	3.48	3.63	3.274



# Future Software Update

- Shear controls some of the LR's, unexpected for a slab bridge
- *"d" is the "distance from extreme compressive fiber to centroid of the prestressing force, or to centroid of negative moment reinforcing for precast girder bridges made continuous."*
- $V_{ci}$  calculated  $d$  from top of slab at interior support; should have been from bottom of slab
- BRDRSUP-1248 created to address issue

# Verification of Results

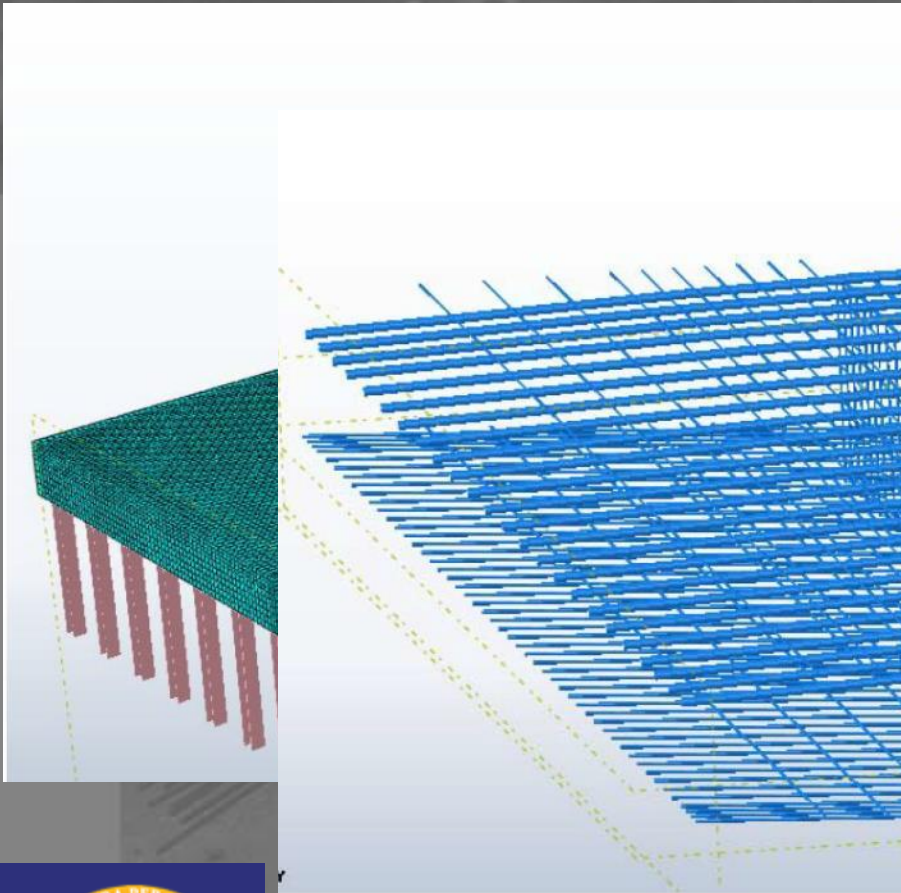


Figure 16: Rendering of the Reinforcement at the Pier Location

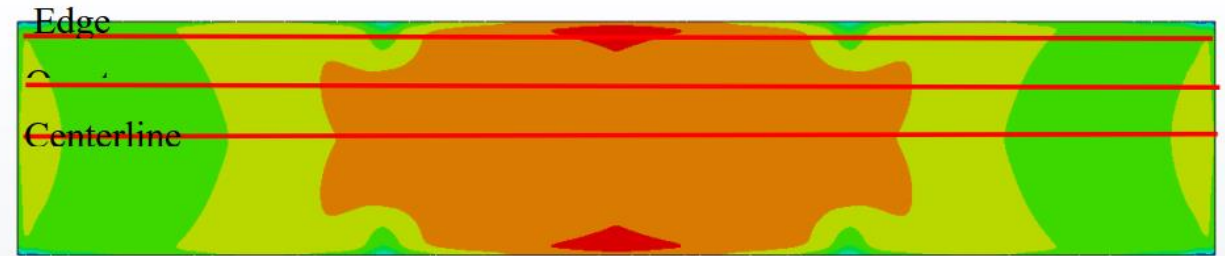
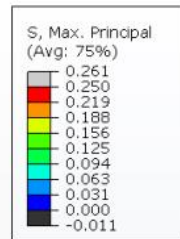


Figure 22: Maps of Principal Tension at the Top of the Deck due to Negative Temperature Gradient

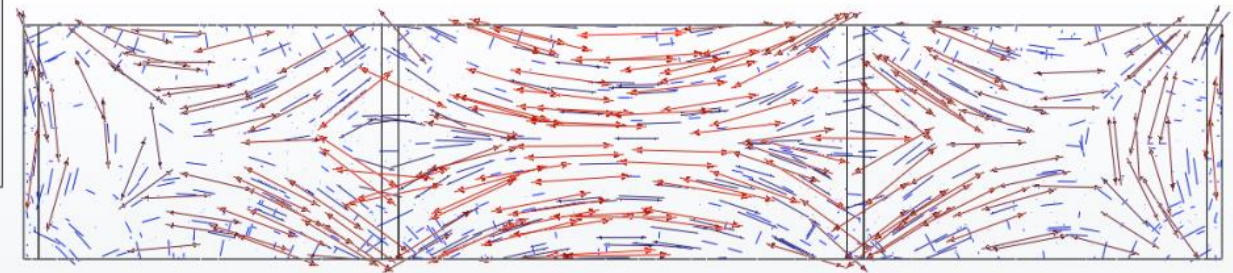
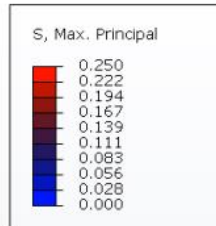


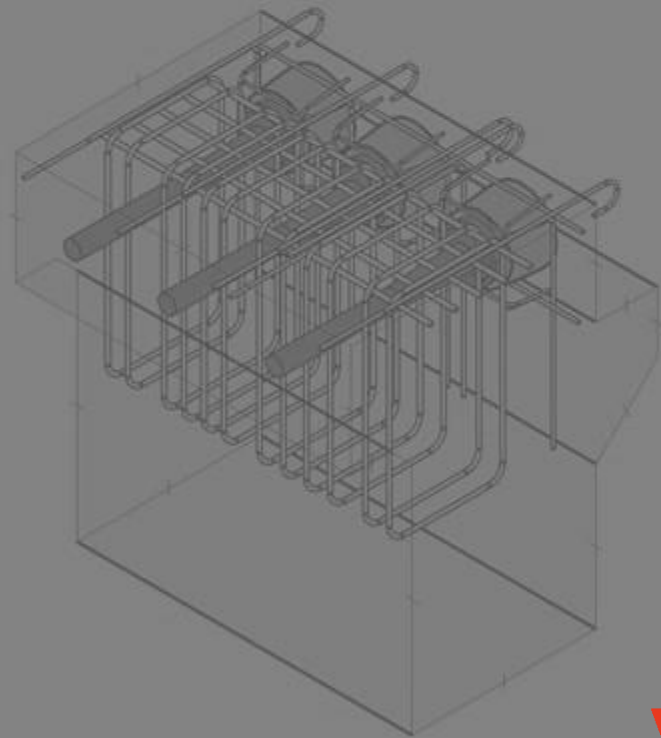
Figure 23: Directions of Principal Tension due to Negative Temperature Gradient

# Why XCSH?

- **Shallow superstructure, longer spans**
- **Cost Effective**
- **Durability**

## Challenges

- **Side Pockets**





# Side Pockets

- Drill and remove all loose material.
- Clean the surface and sandblast the pocket.
- Apply an epoxy bonding agent: Sikadur 32 Hi-Mod
- Use the non-shrink grout Sikagrout 212e
- Wait for grout to cure (14 days minimum)
- Sandblast the whole sides of the bridge, apply the water proofing membrane

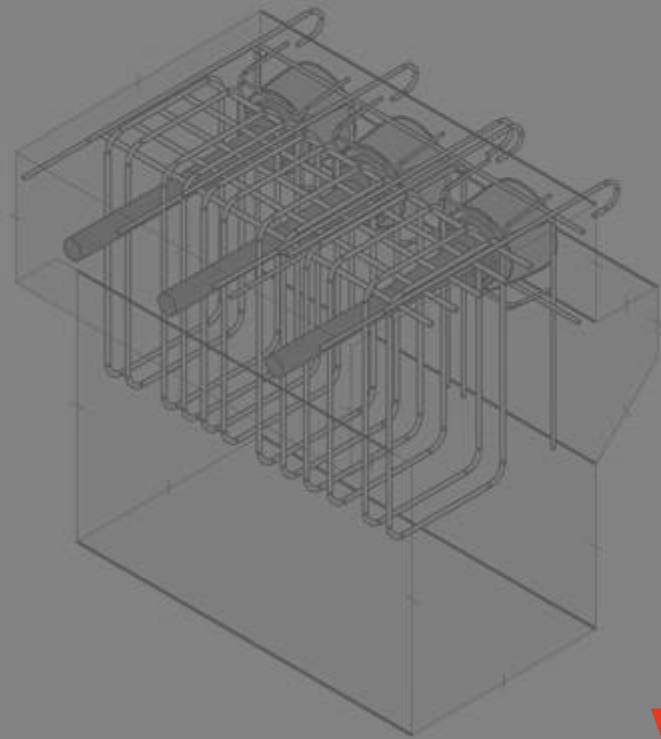






# Special Thanks

- **Mark Hoppe, P.E., KDOT**
- **John Jones, P.E., KDOT**
- **Dean Teal, P.E., KDOT**





# Questions?

