


The slide features a large, light blue watermark of the Indiana Department of Transportation seal in the background. The seal contains icons for an airplane, a train, a truck, and a car. The text is centered within a dark blue rounded rectangle.

INDOT Bridge Evaluation

Jennifer L. Hart, P.E.



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The slide features a large, light blue watermark of the Indiana Department of Transportation seal in the background. The text is centered within a dark blue rounded rectangle.

Who We Are Today

- INDOT Bridge Evaluation Team
- INDOT Bridge Design Engineers – Provide added support
- 3 On-Call Load Rating Consultant Teams (~30 Engineers)
- 21 Indiana LPA Consultants performing load ratings on behalf of the State of Indiana



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To Serve and Protect

- Maintain Indiana Policies Regarding Load Rating
- Owners of Load Rating Data
 - Business Owners Load Rating ITAP Applications
 - BRADIN – Authoritative Source for All Load Rating Data
 - Load Rating Request Application (LRR)
- Provide Oversight for County Load Ratings
- Maintain State BrR Models for Integration with Oversize Overweight Permitting System
- Manual Review of all Permits > 200,000 lbs
- Provide Departmental Support
 - Bridge Asset Management
 - Bridge Design
 - Bridge Inspection



INDOT Bridge Rating Application Database of Indiana

Bridge: 002680
 Bridge: (937-35-05206) BNBL

Rating Method	Rating Value
IS Inventory Rating Method	LF8 - Load Factor Rating
IS Inventory Rating	25
IS Operating Rating Method	LF8 - Load Factor Rating
IS Operating Rating	47 800

In Service	Submitted	Scheduled By	Revision Date	Created Date
✓	10/24/2017 12:08 S.	System, BridgeApp	10/24/2017 12:08 S.	10/24/2017 12:08 S.



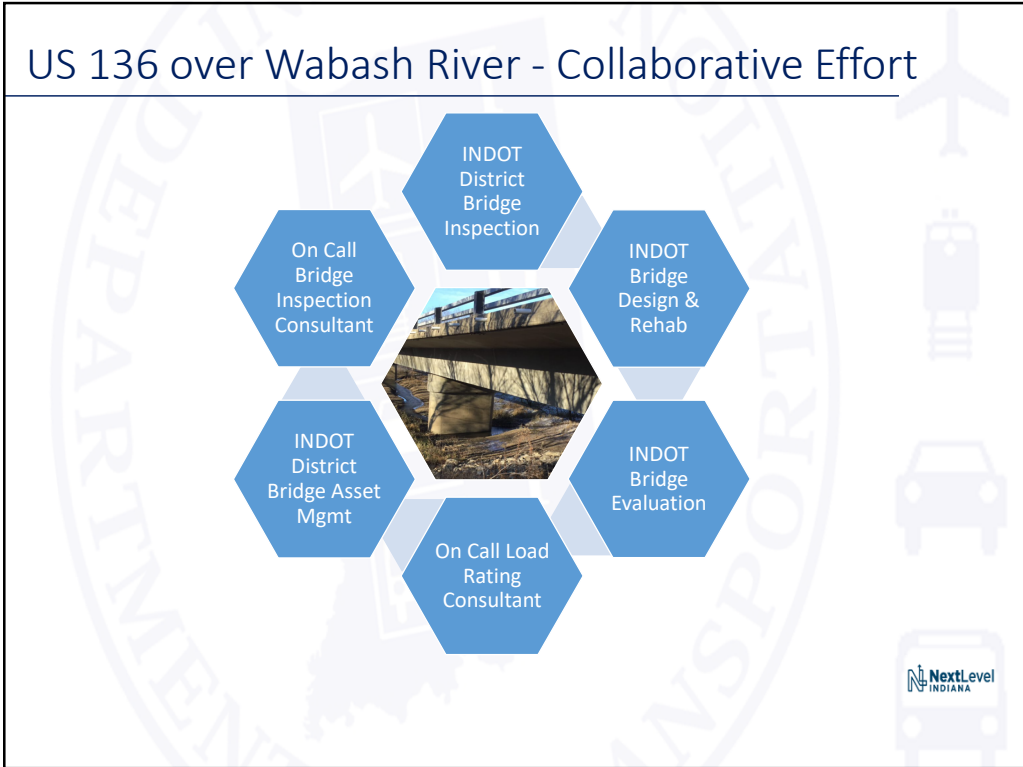
3

Bridge Evaluation Team Support


- INDOT Asset Engineers Project Scoping Review ~ **150 per year**
- Routine Load Rating Review ~ **600 per year**
 - ~250 Design project development load rating review
 - ~200 Updates in response to construction completion
 - ~150 Production model review in support of OSOWPS
- Updates to load rating models in response to INDOT Bridge Inspection notification ~ **25 per year**
- Overweight (>200,000 lb) Permit Evaluation ~ **1,000 per year**



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US 136 over Wabash River


Load Rating, Refined Capacity Analysis and Special Inspection of an Existing Segmental Post-Tensioned Bridge

Jennifer Hart, PE
 Load Rating Division Supervisor
 Indiana Department of Transportation

Amy Huebschman, PE
 Structures Services Lead
 EMCS, Inc.


Douglas Crampton, PE, SE
 Principal
 Wiss, Janney, Elstner Associates, Inc.





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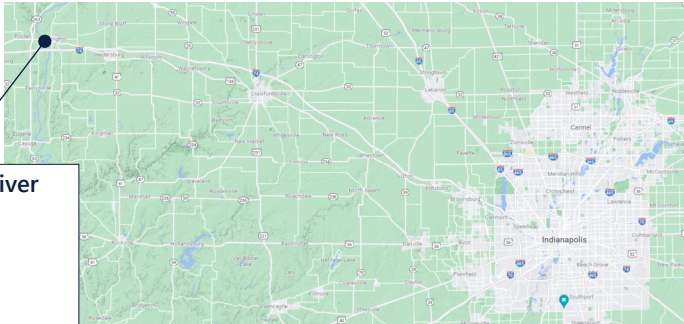



US 136 over Wabash River

PROJECT OVERVIEW


US 136 over Wabash River
136-86-06086 C
NBI. 026790

Covington, IN
Crawfordsville District

emcsinc | **WJE**

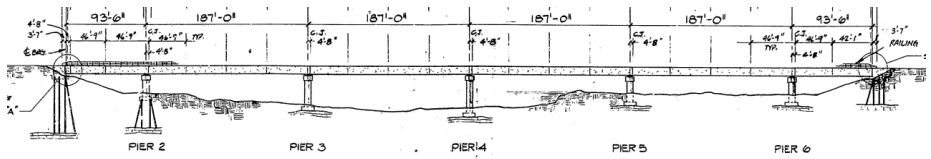
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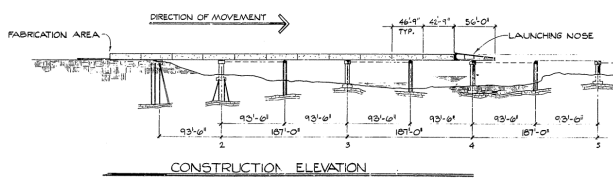
US 136 over Wabash River

PROJECT OVERVIEW

Six Span Continuous Segmental Concrete Bridge, **Constructed in 1975**



Originally Designed with 6'-6" Long Segments, Modified to Span Launching Method with 46'-9" long segments.




- Stage I Prestressing (PT) = Tensioned during Staged Construction
- Stage II Prestressing (PT) = Tensioned after Final Position from Inside Box

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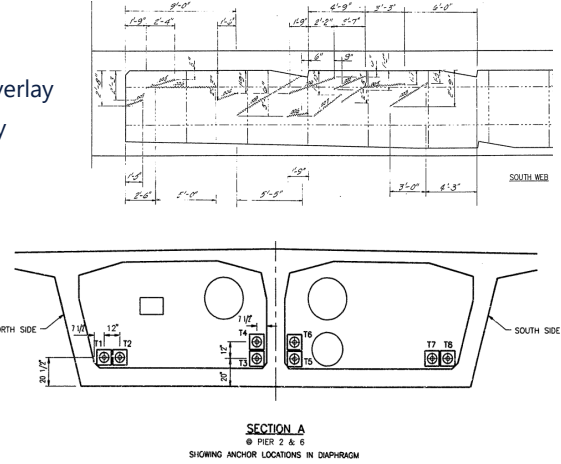
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US 136 over Wabash River


PROJECT OVERVIEW

1. Rehab A (1992) – Web Cracking Repair & Wearing Surface
 - Epoxy Crack Injection
 - Additional PT Tendons
2. Rehab B (2009) – Polymeric Deck Overlay
3. Rehab C (2020) – Rigid Deck Overlay



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US 136 over Wabash River

Introduction to Load Rating (LRFr)

Load rating is the process in determining the safe load carrying capacity of bridges.

- INDOT Bridge Inspection Manual, PART 3: LOAD RATING (July 2021)
- AASHTO, Manual for Bridge Evaluation 3rd Ed. Section 6
- AASHTO Bridge Design Specifications, 8th Edition

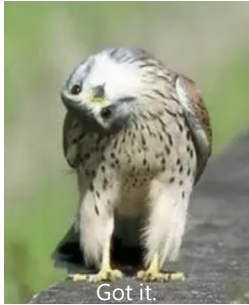
$$C \geq (\gamma_{DC})(DC) + (\gamma_{DW})(DW) + (\gamma_P)(P) + (\gamma_{LL})(LL)$$


$$RF = \frac{C - (\gamma_{DC})(DC) - (\gamma_{DW})(DW) \pm (\gamma_P)(P)}{(\gamma_{LL})(LL + IM)}$$

(6A.4.2.1-1)


$C = \phi_c \phi_s \phi R_n$

System, Condition, LRFr
Resistance Factor





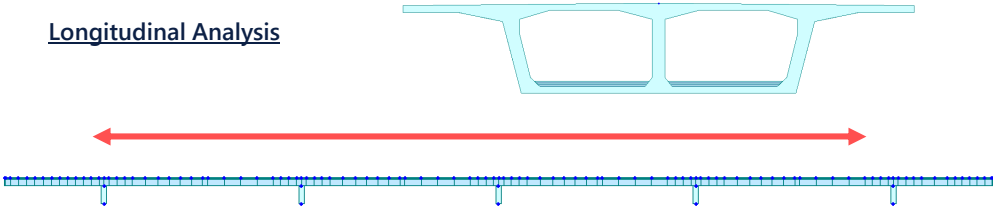
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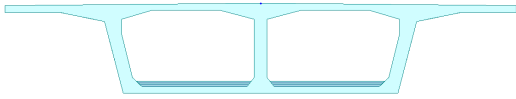


US 136 over Wabash River

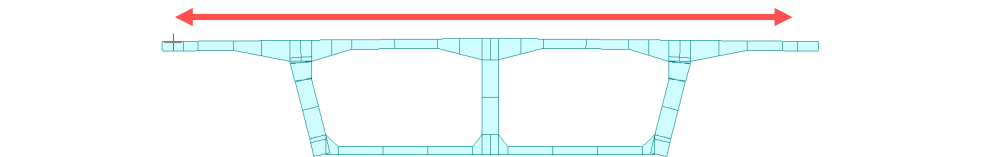
FEM Analysis

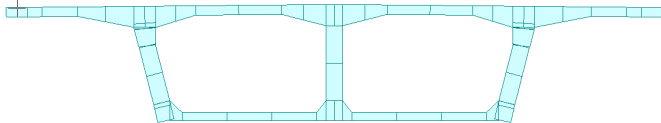
Longitudinal Analysis







Transverse Analysis





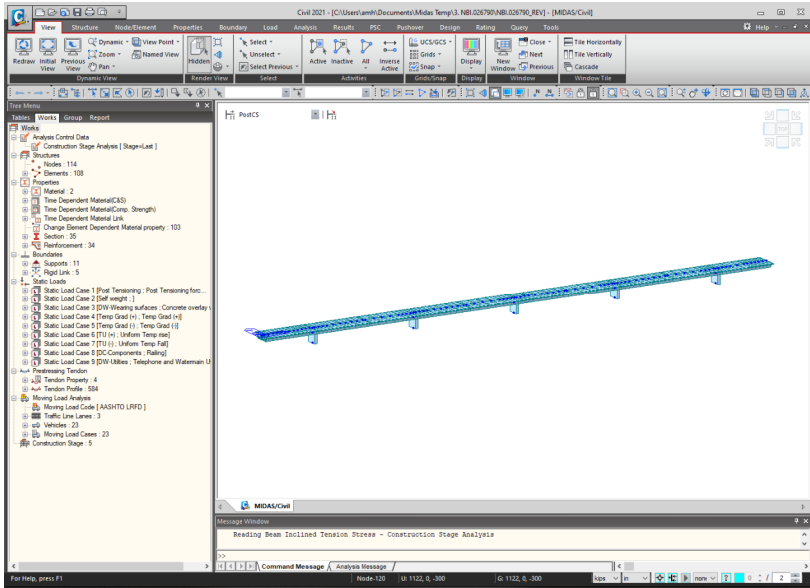



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FEM Analysis – General Setup MIDAS



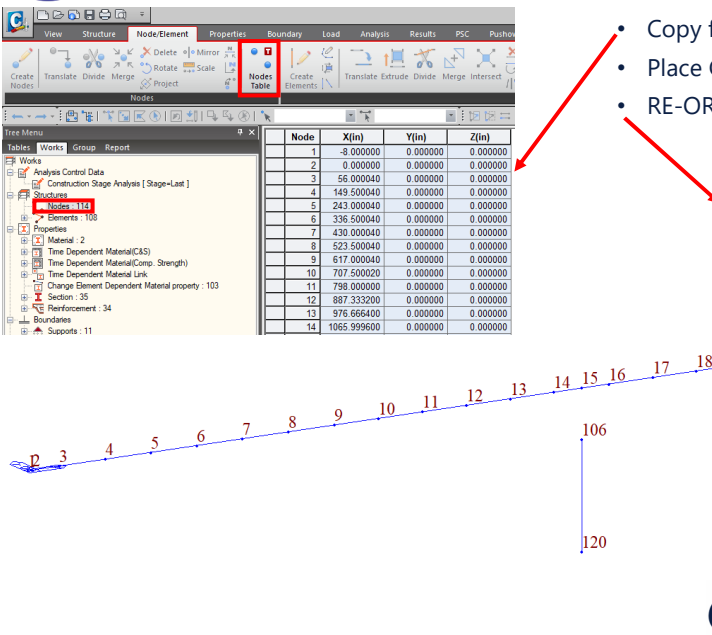


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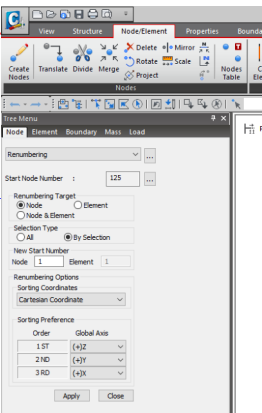
FEM Longitudinal Analysis




Node	X(in)	Y(in)	Z(in)
1	-8.000000	0.000000	0.000000
2	0.000000	0.000000	0.000000
3	56.000040	0.000000	0.000000
4	149.500040	0.000000	0.000000
5	243.000040	0.000000	0.000000
6	336.500040	0.000000	0.000000
7	430.000040	0.000000	0.000000
8	523.500040	0.000000	0.000000
9	617.000040	0.000000	0.000000
10	707.500020	0.000000	0.000000
11	798.000000	0.000000	0.000000
12	887.333200	0.000000	0.000000
13	976.666400	0.000000	0.000000
14	1065.999600	0.000000	0.000000


NODES –

- Copy for Excel – Suggested
- Place Graphically
- RE-ORDER





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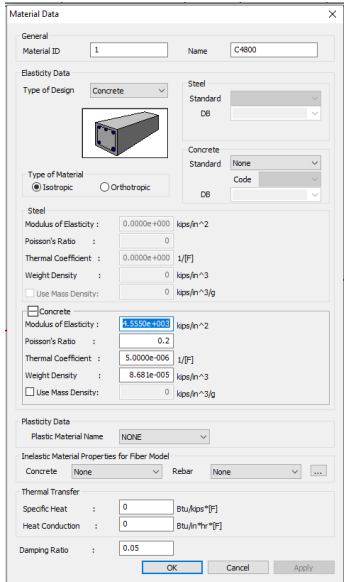
FEM Longitudinal Analysis


Material Data –

- Concrete Strength (4.8 ksi)
- Tendons (270 ksi)
- Time Dependent Materials (CR & SH)
- Time Dependent (Comp. Strength)


After Sections Created

- Link Dependent Material Property (to Section)
- Change Element Dependent Property – Program Calculates the h and V/S for sections





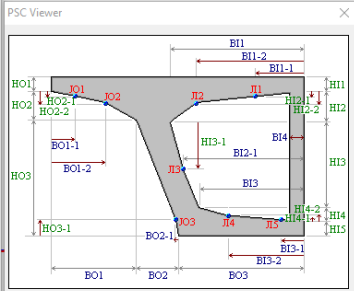
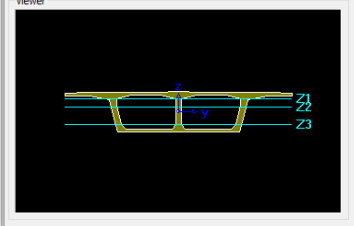
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FEM Longitudinal Analysis

Section Input –

Section ID: 1

Name: TYP

Joint On/Off: JO1, JO2, JO3, JI1, JI2, JI3, JI4, JI5

Section Type: 2 Cell


Shear Check: Z1: 80.437 in, Z2: Centroid, Z3: 17.000 in

Web Thick. for Shear (total): t1: 74.984 in, t2: 44.111 in, t3: 42.933 in


Offset: Center-Top

Outer dimensions: HO1: 7.5 in, HO2: 9.75 in, HO2-1: 0 in, HO2-2: 0 in, HO3: 78 in, HO3-1: 0 in

Inner dimensions: HI1: 17.4999 in, HI2: 0 in, HI2-1: -9.9996 in, HI2-2: -9.996 in, HI3: 63.4375 in, HI3-1: 15.25 in, HI4: 0 in, HI4-1: -9.996 in, HI4-2: -9.9996 in, HI5: 17.000 in



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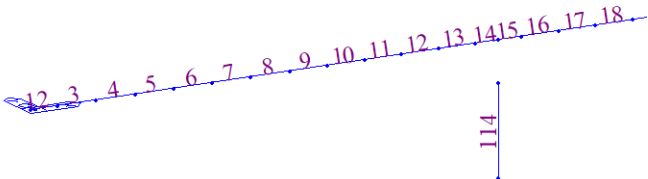
US 136 over Wabash River

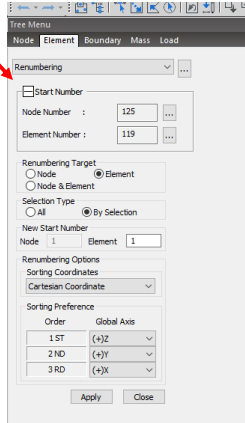
FEM Longitudinal Analysis


ELEMENTS –

Element	Type	Sub Type	Material	Property	B-Angle (deg)	Node1	Node2	Node3	Node4
70	BEAM		1	26	0.00	70	71	0	0
71	BEAM		1	2	0.00	71	72	0	0
72	BEAM		1	2	0.00	72	73	0	0
73	BEAM		1	27	0.00	73	74	0	0
74	BEAM		1	28	0.00	74	75	0	0
75	BEAM		1	29	0.00	75	76	0	0
76	BEAM		1	1	0.00	76	77	0	0
77	BEAM		1	1	0.00	77	78	0	0
78	BEAM		1	1	0.00	78	79	0	0
79	BEAM		1	1	0.00	79	80	0	0
80	BEAM		1	1	0.00	80	81	0	0

- Copy for Excel – Suggested
- Place Graphically
- RE-ORDER w/ NODES








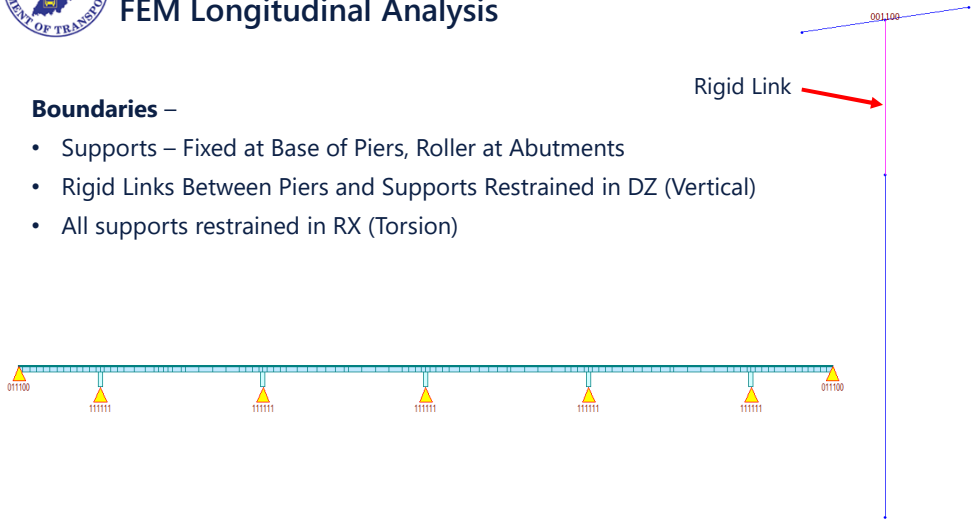
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US 136 over Wabash River
FEM Longitudinal Analysis



Boundaries –


- Supports – Fixed at Base of Piers, Roller at Abutments
- Rigid Links Between Piers and Supports Restrained in DZ (Vertical)
- All supports restrained in RX (Torsion)



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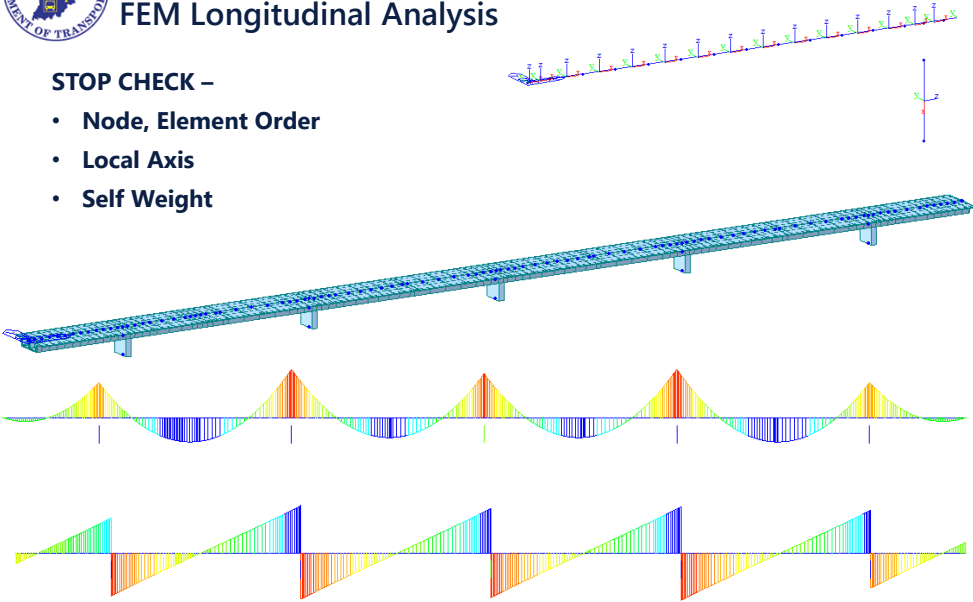
17

US 136 over Wabash River
FEM Longitudinal Analysis




STOP CHECK –

- Node, Element Order
- Local Axis
- Self Weight



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US 136 over Wabash River

FEM Longitudinal Analysis

Prestressing Tendons –

- Tendon Material Properties
- Tendon Profiles entered for each Tendon – EXCEL
- Tendon profile geometry specific to the starting Assigned Element – ORDER

Add/Modify Tendon Property

Tendon Name: Stage 1 HS-13

Tendon Type: Internal(Post-Tension)

Material: 2 A416-270(normal)

Total Tendon Area: 1.836009672 in²

Duct Diameter: 2.00004 in

Relaxation Coefficient: CEB-FIP 2010 rho1000: 3.5 %

Class 1: Slow

Ultimate Strength: 270.244 kips/in²

Yield Strength: 227.574 kips/in²

Curvature Friction Factor (μ): 0.3

Wobble Friction Factor (K = μ x k): 3.81e-005 1/in

Unintentional Angular Displacement (k): 0.000127 rad/in

External Cable Moment Magnifier: 0 kips/in²

Anchorage Slip (Draw in): Begin: 0.4 in, End: 0.4 in

Bond Type: Bonded, Unbonded

Add/Modify Tendon Profile

Tendon Name: 1AL Group: Default

Tendon Property: Stage 1 Tendons

Assigned Elements: 1to103

Input Type: 2-D, 3-D


Curve Type: Spline, Round

Transfer Length: User defined Length


Debonding Data: Debonded Length: Begin: 0, End: 0

Profile Reference Axis: Straight, Curve, Element

	x(ft)	y(ft)	z(ft)	Ry(deg)	Rz(deg)
1	0.4583	14.208	-0.9110	0.00	0.00
2	935.20	14.208	-0.9110	0.00	0.00
3					



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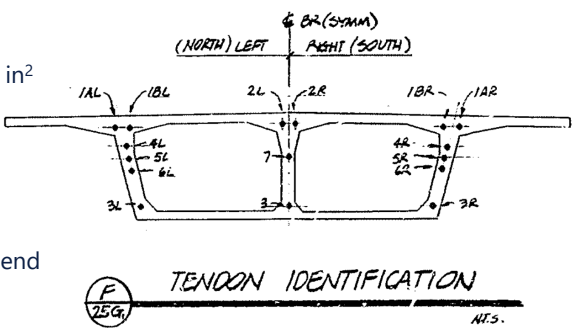


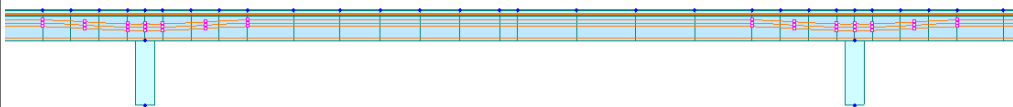
US 136 over Wabash River


FEM Longitudinal Analysis

Tendons –


- Stage 1 Tendons – 16
- E5-12, 12 Strands, A = 0.153 in²
- A416-270 Stress Relieved
- Strand geometry in Excel
- Strands mirrored about the centerline of section
- Strands were modeled from end to end







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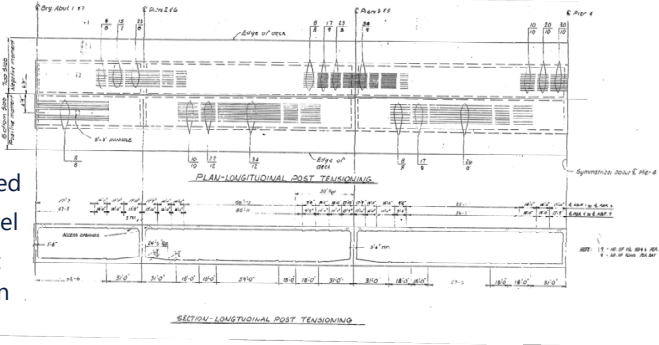



US 136 over Wabash River


FEM Longitudinal Analysis

Tendons –


- Stage 2 Tendons – **560**
 - “SG4” 4 Strands, $A = 0.153 \text{ in}^2$
 - A416-270 Stress Relieved
 - Strand geometry in Excel
 - Strands mirrored about the centerline of section
 - Repetitive







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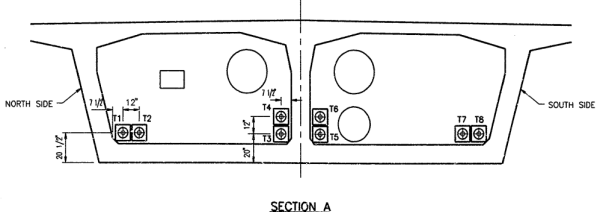


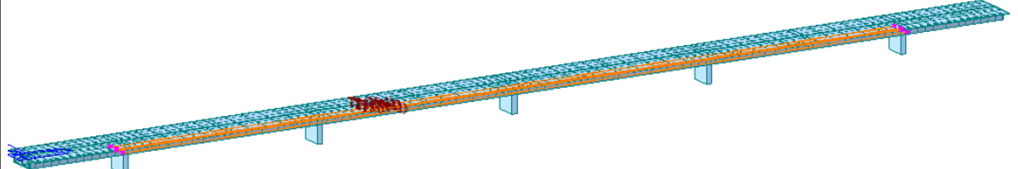
US 136 over Wabash River


FEM Longitudinal Analysis

Tendons –


- 1992 Rehab B Tendons – **8**
 - 6-7 Strands, $A = 0.217 \text{ in}^2$
 - A416-270 Stress Relieved
 - Strand geometry in Excel
 - Strands mirrored about the centerline of section







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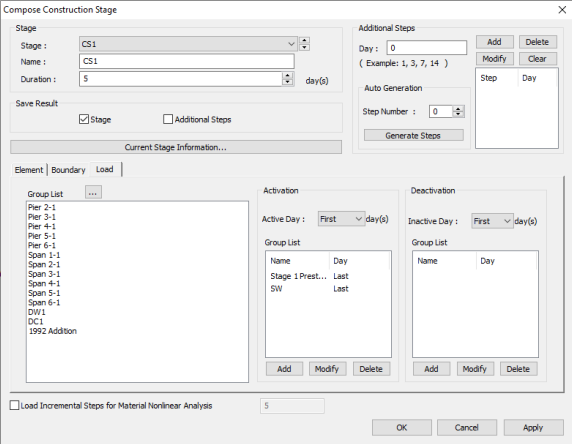


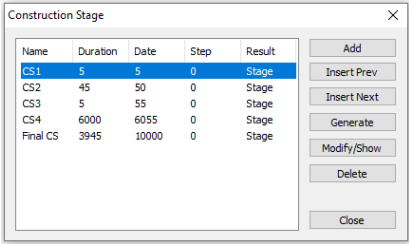
US 136 over Wabash River

FEM Longitudinal Analysis


Construction Analysis –

- Use GROUP for Elements, Boundaries, and Loads






Name	Duration	Date	Step	Result
CS1	5	5	0	Stage
CS2	45	50	0	Stage
CS3	5	55	0	Stage
CS4	6000	6055	0	Stage
Final CS	3945	10000	0	Stage



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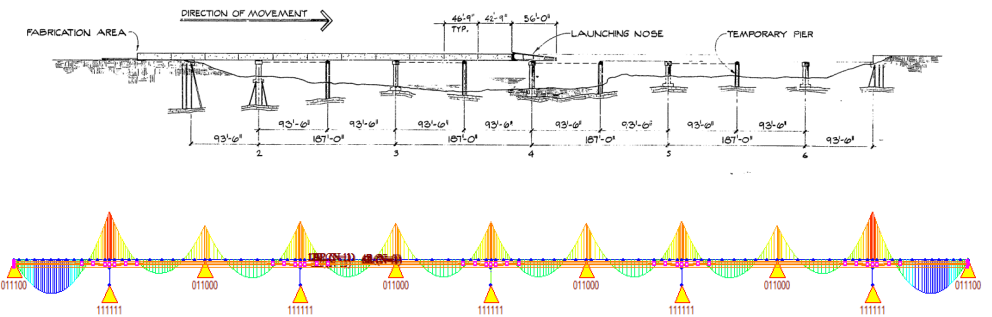



US 136 over Wabash River

FEM Longitudinal Analysis


Construction Analysis –

- CS 1 = Cast All Segments, Construct Piers, Temporary Piers, Stress Stage 1 Tendons, SW





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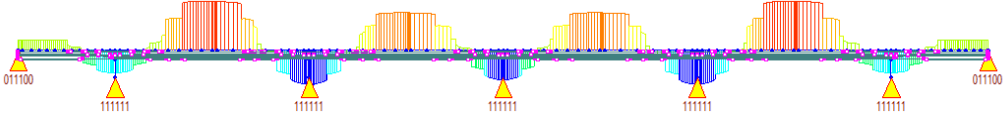


US 136 over Wabash River

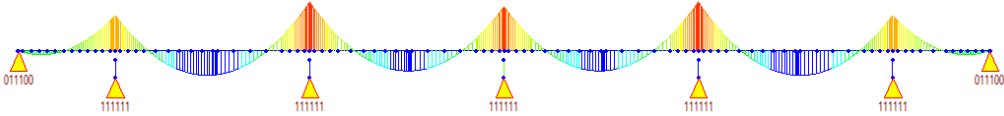
FEM Longitudinal Analysis

Construction Analysis –


- CS 2 = Stress Stage 2 Tendons, Remove Temporary Piers




- CS 3 = Add DC 2 and DW (End of Original Construction)



- CS 4 = Rehab A, Stress Rehab Tendons (Day 6000) – (1992-1975) x 365 ~ 6000 days
- Final CS = Current Conditions**



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US 136 over Wabash River


FEM Longitudinal Analysis

Static Loads


- Load Tables, Copy Excel
 - DC – Self Weight, DC Components
 - DW – Utilities (Watermain), Wearing Surface

Elem	BM LD Type	Load Case	Load Type	Dist-I(ft)	Dist-J(ft)	Direction	Proje	D1	D2	D3	D4	P1	P2	P3	P4	Unit	Group
1	Beam Load	DC-Compo	Distributed	22.50	22.50	Global Z	No	0.00	1.00	0.00	0.00	-140.00	-140.00	0.00	0.00	lb/ft	DC1
1	Beam Load	DC-Compo	Distributed	-22.50	-22.50	Global Z	No	0.00	1.00	0.00	0.00	-140.00	-140.00	0.00	0.00	lb/ft	DC1
2	Beam Load	DC-Compo	Distributed	22.50	22.50	Global Z	No	0.00	1.00	0.00	0.00	-140.00	-140.00	0.00	0.00	lb/ft	DC1
2	Beam Load	DC-Compo	Distributed	-22.50	-22.50	Global Z	No	0.00	1.00	0.00	0.00	-140.00	-140.00	0.00	0.00	lb/ft	DC1
3	Beam Load	DC-Compo	Distributed	22.50	22.50	Global Z	No	0.00	1.00	0.00	0.00	-140.00	-140.00	0.00	0.00	lb/ft	DC1
3	Beam Load	DC-Compo	Distributed	-22.50	-22.50	Global Z	No	0.00	1.00	0.00	0.00	-140.00	-140.00	0.00	0.00	lb/ft	DC1
4	Beam Load	DC-Compo	Distributed	22.50	22.50	Global Z	No	0.00	1.00	0.00	0.00	-140.00	-140.00	0.00	0.00	lb/ft	DC1
4	Beam Load	DC-Compo	Distributed	-22.50	-22.50	Global Z	No	0.00	1.00	0.00	0.00	-140.00	-140.00	0.00	0.00	lb/ft	DC1
5	Beam Load	DC-Compo	Distributed	22.50	22.50	Global Z	No	0.00	1.00	0.00	0.00	-140.00	-140.00	0.00	0.00	lb/ft	DC1
5	Beam Load	DC-Compo	Distributed	-22.50	-22.50	Global Z	No	0.00	1.00	0.00	0.00	-140.00	-140.00	0.00	0.00	lb/ft	DC1

- Temperature Gradient – Beam Section Temp Loads
- Uniform Temperature



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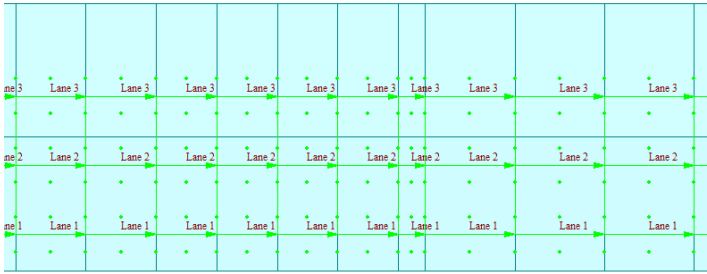


US 136 over Wabash River

FEM Longitudinal Analysis

Live Load Trucks & Lanes–

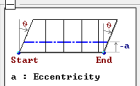
- Live Load Lanes for Load Rating – Worst Case Modeled for Max Torsion and Optimized
- Per AASHTO MBE 6A.5.11.4,5 **“the number of live load lanes may be taken as the number of striped lanes. However, load shall be positioned so as to create maximum effects,”**



Traffic Line Lanes

Lane Name: Lane 1

Traffic Lane Properties



Lane Width: 120 in
 Eccentricity: 0 in
 Wheel Spacing: 72 in

Centrifugal Force
 Left Wheel of Vehicle Moving Forward: 0.5 W

Transverse Lane Optimization
 Allowable Width: 120 in

Vehicular Load Distribution
 Lane Element Cross Beam
 Cross Beam Group: _____


Slew: Start 0 [deg] End 0 [deg]

Moving Direction
 Forward Backward Both


Select by
 2 Points Picking Number
 0, 0, 0 in
 0, 0, 0 in

Operations

No	Elem	Eccen (in)	Span Start	CE
7	7	201	F	0.5
8	8	201	F	0.5
9	9	201	F	0.5



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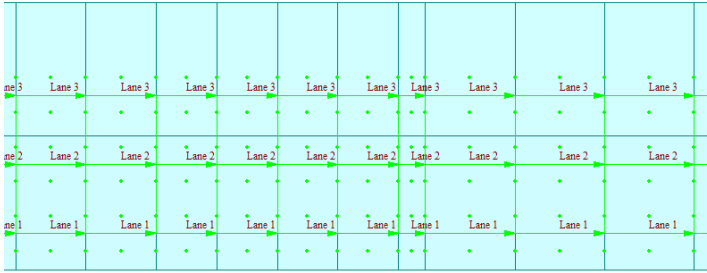


US 136 over Wabash River

FEM Longitudinal Analysis

Live Load Trucks & Lanes –

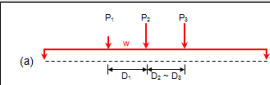
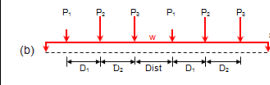
- Design Loads (Inventory and Operating)
 - HL-93, HS20, H20
- Emergency Vehicles
 - EV2, EV3
- Legal Vehicles
 - H-20, HS-20
 - AASHTO Type 3, 3-3, 3S2
 - Lane – Type, NRL
 - SU4, SU5, SU6, SU7
 - Alt. Military
- Permits (Superload)
 - 11 Axle
 - 13 Axle
 - 14 Axle
 - 19 Axle (305k & 481k)



Define Standard Vehicular Load

Standard Name: AASHTO LRFD Load


Vehicular Load Properties
 Vehicular Load Name: HL-93TRK
 Vehicular Load Type: HL-93TRK
 Dynamic Load Allowance: 33 %

Lane Support-Neg. Moment/ Reaction	Application
Not assigned	a
Assigned	a, b

No	Load(kips)	Spacing(in)	W	r	Dist.
1	8	168	0.05333333	90	%
2	32	168		600	in
3	32	360			

Add Centrifugal Force



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FEM Longitudinal Analysis

Typical FE Analysis Results

- My, Moments – DC, DW, PS, TG, TU, LL
- Fz, Shears – DC, DW, PS, TG, TU, LL
- Mx, Torsions – DC, DW, PS, TG, TU, LL

- Results → Moving Tracer → Beam Force Moments (Max Moment Node 44)

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US 136 over Wabash River

FEM Longitudinal Analysis **PSC Box Bridge Design**

Reinforcement - 34

- 1: TYP (PSC) [Longitudinal-0, Shear-0]
- 2: P SEG (PSC) [Longitudinal-0, Shear-0]
- 3: Tapered - 1 (PSC) [Longitudinal-0, Shear-0]
- 4: Tapered - 2 (PSC) [Longitudinal-0, Shear-0]
- 5: Tapered - 11 (PSC) [Longitudinal-0, Shear-0]
- 6: Tapered - 12 (PSC) [Longitudinal-0, Shear-0]
- 7: Tapered - 13 (PSC) [Longitudinal-0, Shear-0]
- 8: Tapered - 21 (PSC) [Longitudinal-0, Shear-0]
- 9: Tapered - 22 (PSC) [Longitudinal-0, Shear-0]
- 10: Tapered - 23 (PSC) [Longitudinal-0, Shear-0]
- 11: Tapered - 11 (PSC) [Longitudinal-0, Shear-0]
- 12: Tapered - 12 (PSC) [Longitudinal-0, Shear-0]
- 13: Tapered - 13 (PSC) [Longitudinal-0, Shear-0]
- 14: Tapered - 21 (PSC) [Longitudinal-0, Shear-0]
- 15: Tapered - 22 (PSC) [Longitudinal-0, Shear-0]
- 16: Tapered - 23 (PSC) [Longitudinal-0, Shear-0]
- 17: Tapered - 11 (PSC) [Longitudinal-0, Shear-0]
- 18: Tapered - 12 (PSC) [Longitudinal-0, Shear-0]
- 19: Tapered - 13 (PSC) [Longitudinal-0, Shear-0]
- 20: Tapered - 21 (PSC) [Longitudinal-0, Shear-0]
- 21: Tapered - 22 (PSC) [Longitudinal-0, Shear-0]
- 22: Tapered - 23 (PSC) [Longitudinal-0, Shear-0]
- 23: Tapered - 11 (PSC) [Longitudinal-0, Shear-0]
- 24: Tapered - 12 (PSC) [Longitudinal-0, Shear-0]
- 25: Tapered - 13 (PSC) [Longitudinal-0, Shear-0]
- 26: Tapered - 21 (PSC) [Longitudinal-0, Shear-0]
- 27: Tapered - 22 (PSC) [Longitudinal-0, Shear-0]
- 28: Tapered - 23 (PSC) [Longitudinal-0, Shear-0]
- 29: Tapered - 23 (PSC) [Longitudinal-0, Shear-0]

Section Manager

Target Section & Element

Section: 34

- 1: TYP
- 2: P SEG
- 3: Tapered - 1
- 4: Tapered - 2
- 6: Tapered - 11
- 7: Tapered - 12
- 8: Tapered - 13
- 9: Tapered - 21
- 10: Tapered - 22
- 11: Tapered - 23
- 12: Tapered - 11
- 13: Tapered - 12
- 14: Tapered - 13
- 15: Tapered - 21
- 16: Tapered - 22
- 17: Tapered - 23
- 18: Tapered - 11
- 19: Tapered - 12
- 20: Tapered - 13
- 21: Tapered - 21
- 22: Tapered - 22
- 23: Tapered - 23
- 24: Tapered - 11
- 25: Tapered - 12
- 26: Tapered - 13
- 27: Tapered - 21
- 28: Tapered - 22
- 29: Tapered - 23

Longitudinal Reinforcement Shear Reinforcement

Diagonal Reinforcement

- Pitch: 12 in
- Angle: 90 [Deg]
- Aw: 1.96 in²

Steel Bar for Web

- Pitch: 0 in
- Angle: 90 [Deg]
- Aw: 0 in²
- Ps: 0 kpsi

Torsional Reinforcement


- Pitch: 0 in
- Aw: 0 in²
- At: 0 in²

Enclosing Stirrup

- Cover Thickness: 0 in
- Include Flange/Cantilever:

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FEM Longitudinal Analysis PSC Box Bridge Design

PSC Design Parameters

Design Code : AASHTO-LRFD17

Input Parameters

Tendon Type

Low Relaxation Tendons

Stress Relieved Tendons

Prestressing Bars

Exposure Factor for Crack Width

Class I (1.0)

Class II (0.75)

User

Corrosive Condition

Severe Moderate/Mild

Flexural Strength

Code Strain Compatibility

Construction Type

Segmental Non-Segmental

Output Parameters

At Construction Stage/Service Loads

Stress by Construction Stage

Stress by Service Load Combinations

Stress in Prestressing Tendons

Principal Stress by Construction Stage

Principal Stress by Service Load Combinations (Max Shear)

Principal Stress by Service Load Combinations (Max Torsion)

Crack Check

At Factored Loads

Flexural Strength Check

Shear Strength Check

Combined Shear and Torsion Check

Select All Unselect All

OK Cancel



Load Combinations

General | Steel Design | Concrete Design | SRC Design | Composite Steel Girder Design


Load Combination List

No	Name	Active	Type	Description
1	STR1	Strength	Add	
2	SVC III	Service	Add	
3	SVC I Permit	Service	Add	

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US 136 over Wabash River

FEM Design and Rating

PSC DESIGN Results

- Verified MIDAS Moment Capacity – Design Report, Separate Structure Positive and Negative M
- Verified Calculated Stresses – Section Properties
- Partially Verified Shear and Torsion Capacity – Spacing Definition Issues

Result Tables

Elem	Part	Positive/Negative	LCom Name	Type	CHK	M _{uy} (in*kips)	M _{cr} (in*kips)	M _{ny} (in*kips)	PhiM _{ny} (in*kips)	Ratio (M _{uy} /PhiM _{ny})	PhiM _{ny} /min(1.33M _{uy} , M _{cr}) (ksi)	F _y (ksi)
4	J[5]	Negative	STR1	MY-MIN	OK	0.0000	349896.9770	581093.8247	581093.8247	0.0000	larger than 100	500.000
5	J[6]	Negative	STR1	MY-MIN	OK	0.0000	350760.5375	581479.9742	581479.9742	0.0000	larger than 100	500.000
6	J[7]	Negative	STR1	MY-MIN	OK	0.0000	352011.1230	581905.5608	581905.5608	0.0000	larger than 100	500.000
7	J[8]	Negative	STR1	MY-MIN	OK	-34891.6130	353568.5316	582500.7576	582500.7576	0.0599	12.5540	500.000
8	J[9]	Negative	STR1	MY-MIN	OK	-83390.9436	452209.3022	790702.6918	790702.6918	0.1055	7.1292	500.000
9	J[10]	Negative	STR1	MY-MIN	OK	-142745.3564	457244.3272	792419.4143	792419.4143	0.1801	4.1739	500.000
10	J[11]	Negative	STR1	MY-MIN	OK	-214425.0330	569971.2069	952940.4582	952940.4582	0.2250	3.3415	500.000
11	J[12]	Negative	STR1	MY-MIN	OK	-297254.3136	585399.2183	934037.6870	934037.6870	0.3182	2.3626	500.000
12	J[13]	Negative	STR1	MY-MIN	OK	-392869.6024	670759.1661	1122646.4890	1122646.4890	0.3499	2.1485	500.000
13	J[14]	Negative	STR1	MY-MIN	OK	-506893.8699	678448.4430	1123315.4284	1123315.4284	0.4512	1.6662	500.000
14	J[15]	Negative	STR1	MY-MIN	OK	-588035.9786	642023.7290	1182298.2238	1064068.4014	0.5526	1.6574	500.000

Design Excel Report

Design Code	Element	Node(U)
AASHTO-LRFD2017	53	J

Section Properties



- Gross section					
H	97.975 (in)	A _y	1.270E+04 (in ⁴)	S _y	4.144E+05 (in ³)
B	557.993 (in)	I _y	1.814E+07 (in ⁴)	S _x	3.348E+05 (in ³)
C _{yp}	43.782 (in)				
C _{yp}	54.193 (in)				
- Transformed section					
H	97.975 (in)	A _y	1.323E+04 (in ⁴)	S _y	4.388E+05 (in ³)
B	557.993 (in)	I _y	1.868E+07 (in ⁴)	S _x	3.428E+05 (in ³)
C _{yp}	42.971 (in)				
C _{yp}	55.004 (in)				

Materials

- Concrete				
f _c (ksi)	E _c (ksi)	t _c =0.20*f _c (ksi)	β ₁	
4.800	3991.963	0.438	0.810	


* β₁ : 0.85 if f_c is lower than 4ksi, the others are 0.85-0.05/(f_c-4.0)≥0.65

- Prestressing steel information

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US 136 over Wabash River

FEM Design - Capacities

1. ϕM_n , Strain Compatibility
 - AASHTO 5.6.2
2. T_n , Torsion – Investigation Not Required
 - AASHTO 5.7.2.1 $T_u > 0.25\phi T_{cr}$
3. ϕV_n , Shear, Segmental
 - AASHTO 5.12.5.3.8

$$V_n = V_c + V_s$$

$$V_n = 0.379\lambda\sqrt{f'_c} b_v d$$


$$V_c = 0.0632K\lambda\sqrt{f'_c} b_v d$$

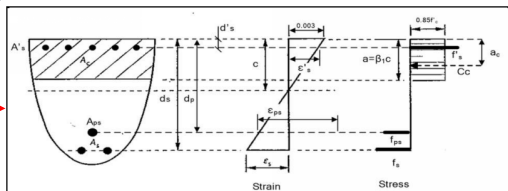
$$V_s = \frac{A_v f_y d}{s}$$

$$K = \sqrt{1 + \frac{f_{pc}}{0.0632\lambda\sqrt{f'_c}}} \leq 2.0$$


b_v = effective web width taken as the total minimum width of all webs within the depth d

d = 0.8h or the distance from the extreme compression fiber to the centroid of the prestressing reinforcement, whichever is greater (in)





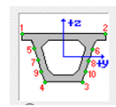
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FEM Design - Capacities

1. Flexural Stress – Mc/I , M/S
2. Principal Stress – Stress at the Neutral Axis of the section for tension evaluated
 - Principal Stresses are **NEVER ADDITIVE**
 - Determine the Center of the Mohr's Circle for Permanent Loads from MIDAS (Node 7 & 8)

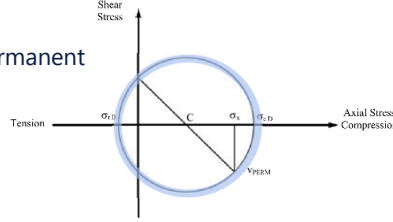



$$c = \frac{(\sigma_x + \sigma_y)}{2}$$

σ_y = Vertical Compressive Stress = 0 in most cases


- Determine Radius of Mohr's Circle under Permanent Loads

$$r_P = \sqrt{[(c - \sigma_y)^2 + (v_{PERM})^2]}$$





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US 136 over Wabash River

FEM Design - Capacities

- Determine Allowable Principal Tensile Stress = $3.5 \cdot (f'_c)^{0.5}$ and Max Allowed Mohr's Circle Radius

$$R_{MAX} = (c + \sigma_{TMAX}) = \left(\frac{\sigma_x + \sigma_y}{2} \right) + \left(\phi_{SERVICE} \cdot n \cdot \sqrt{f'_c} \right)$$

- Determine the Max Shear Capacity available for resisting loads

$$V_{CAP} = V_{LLMAX} + V_{PERM} = \sqrt{R_{MAX}^2 - (\sigma_x - c)^2}$$

- Determine Rating Factor

$$RF = \frac{V_{CAP} - V_{PERM}}{V_{1LL}}$$

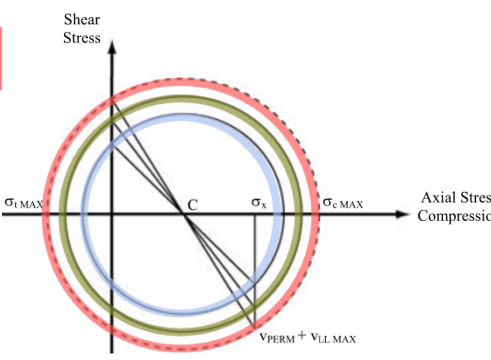




Figure B.3 – Mohr's Circle for All Permanent Loads + Max Live Load (for $\sigma_v = 0$)

Ref. Florida Post Tensioned Bridges, FINAL Report, Vol. 10 A, Appendix B



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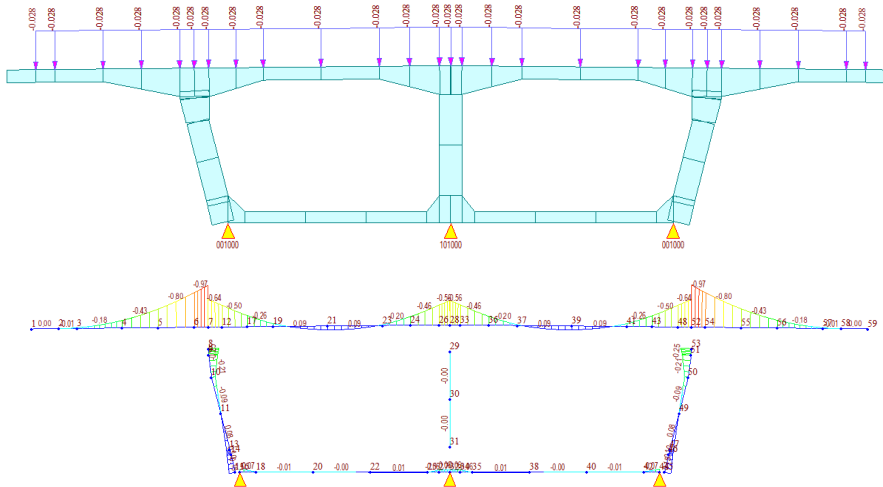



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FEM Transverse Analysis


Transverse DC Analysis

- 1 ft thick Elements, DC & DW Applied





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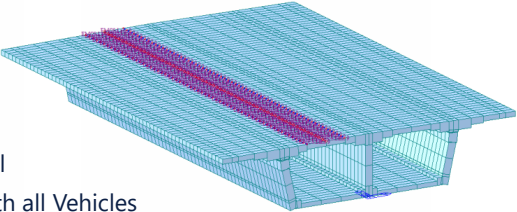


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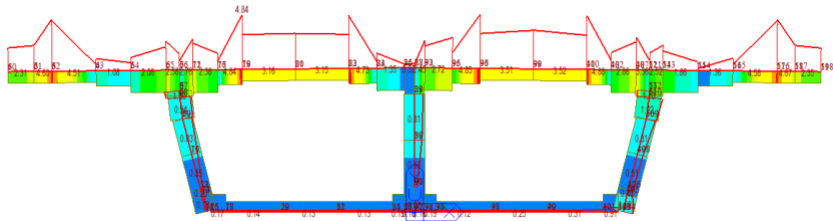
FEM Transverse Analysis

Transverse DC Analysis


- Plate Element Extruded x 100
- Fixed supports at faces of 3D Model
- Multiple Surface Lanes modeled with all Vehicles
- Section Cut at Center to get LL Envelopes




Lane 1 Max M, HL-93



Section Results Max M, HL-93



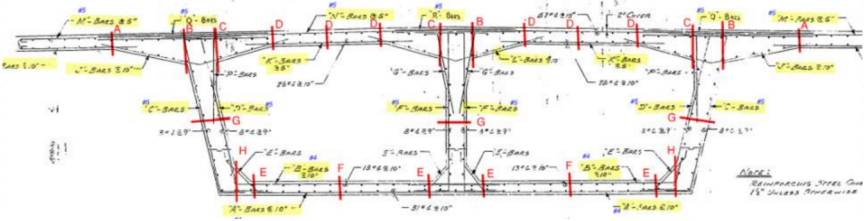
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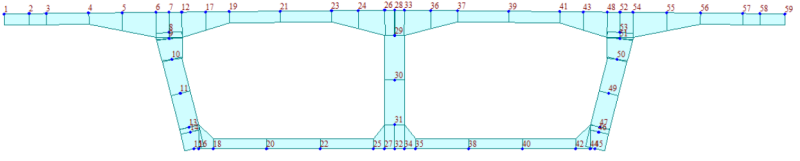



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FEM Transverse Analysis


- Section Capacity, Hand Calculations. RC Strain Compatibility, Section A through H
- No Post Tensioning







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Load Rating Calculations


- MIDAS Resulting Rating Factors were Inconsistent
- Rating Calculated Outside of Program Excel – Independent check in Mathcad


$$RF = \frac{C - (\gamma_{DC})(DC) - (\gamma_{DW})(DW) \pm (\gamma_P)(P)}{(\gamma_{LL})(LL + IM)} \quad (6A.4.2.1-1)$$

$$C = \phi_c \phi_s \phi R_n$$


$\phi_s = 1.15$ System Factor, more than 4 Tendons per web
 AASHTO MBE 6.A.5.11.6-1

$\phi_c = 0.95$ Inspection Report, Fair Condition
 AASHTO MBE 6.A.4.2.3-1





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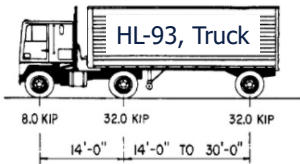
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Load Rating Combinations

Design Load Rating: Inventory, HL-93, HS20, H20


1. Strength I, $\gamma_{DC} = 1.25, \gamma_{DW} = 1.25, \gamma_P = 1.0, \gamma_{LL} = 1.75$, Flexure - ϕM_n
2. Strength I, $\gamma_{DC} = 1.25, \gamma_{DW} = 1.25, \gamma_P = 1.0, \gamma_{LL} = 1.75$, Shear / Torsion - ϕV_n
3. Service III, $\gamma_{DC} = 1.0, \gamma_{DW} = 1.0, \gamma_P = 1.0, \gamma_{LL} = 1.0$, Flexural Tensile Stress = -100 psi, $3*(f'c)^{0.5}$
4. Service III, $\gamma_{DC} = 1.0, \gamma_{DW} = 1.0, \gamma_P = 1.0, \gamma_{LL} = 1.0, \gamma_{LL} = 1.0$, Flexural Compressive Stress = $0.6f'c$
5. Service III, $\gamma_{LL} = 1.0$, Principal Stress = $3.5*(f'c)^{0.5}$

- Bridge Cast in 46'-9" Segments, with a segmental "Type B Joint", having no continuous reinforcement or epoxy. Utilized more conservative allowable stress per AASHTO Guide Specification for Segmental Bridges and previous practice. AASHTO Table 5.9.2.3.2b-1 utilized for locations within CIP segments, $3*(f'c)^{0.5} = 0.0948*(f'c)^{0.5}$
- Principal Stress, per AASHTO 5.9.2.3.3, $3.5*(f'c)^{0.5} = 0.110*(f'c)^{0.5}$
- Wearing Surface assumed Field Measured





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Load Rating Combinations

Design Load Rating; Operating, HL-93, HS20, H20

1. Strength I, $\gamma_{DC} = 1.25$, $\gamma_{DW} = 1.25$, $\gamma_P = 1.0$, $\gamma_{LL} = 1.35$, Flexure - ϕM_n
2. Strength I, $\gamma_{DC} = 1.25$, $\gamma_{DW} = 1.25$, $\gamma_P = 1.0$, $\gamma_{LL} = 1.35$, Shear / Torsion - ϕV_n
3. Service III, $\gamma_{DC} = 1.0$, $\gamma_{DW} = 1.0$, $\gamma_P = 1.0$, $\gamma_{LL} = 1.0$, Flexural Tensile Stress = 0 psi, $6^*(f'c)^{0.5}$
4. Service III, $\gamma_{DC} = 1.0$, $\gamma_{DW} = 1.0$, $\gamma_P = 1.0$, $\gamma_{LL} = 1.0$, $\gamma_{LL} = 1.0$, Flexural Compressive Stress = $0.6f'c$
5. Service III, $\gamma_{LL} = 1.0$, Principal Stress = $3.5^*(f'c)^{0.5}$
 - Bridge Cast in 46'-9" Segments, with a segmental "Type B Joint", having no continuous reinforcement or epoxy. Utilized more conservative allowable stress per AASHTO Guide Specification for Segmental Bridges and previous practice. AASHTO Table 5.9.2.3.2b-1 utilized for locations within CIP segments, $6^*(f'c)^{0.5} = 0.19^*(f'c)^{0.5}$
 - Principal Stress, per AASHTO 5.9.2.3.3, $3.5^*(f'c)^{0.5} = 0.110^*(f'c)^{0.5}$
 - Wearing Surface assumed Field Measured



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US 136 over Wabash River

Load Rating Combinations

Legal Load Rating (Both Routine Commercial and Specialized Hauling) –
H-20, HS-20, EV2, EV3 AASHTO Type 3, 3-3, 3S2, NRL, Lane Type, SU4, SU5, SU6, SU7, Alt. Milt.


1. Strength I, $\gamma_{DC} = 1.25$, $\gamma_{DW} = 1.25$, $\gamma_P = 1.0$, $\gamma_{LL} = 1.45$, (1.3 EV) Flexure - ϕM_n
2. Strength I, $\gamma_{DC} = 1.25$, $\gamma_{DW} = 1.25$, $\gamma_P = 1.0$, $\gamma_{LL} = 1.45$, (1.3 EV) Shear / Torsion - ϕV_n
3. Service III, $\gamma_{DC} = 1.0$, $\gamma_{DW} = 1.0$, $\gamma_P = 1.0$, $\gamma_{LL} = 1.0$, Flexural Tensile Stress = 0 psi, $6^*(f'c)^{0.5}$
4. Service III, $\gamma_{DC} = 1.0$, $\gamma_{DW} = 1.0$, $\gamma_P = 1.0$, $\gamma_{LL} = 1.0$, Flexural Compressive Stress = $0.6f'c$
5. Service III, $\gamma_{DC} = 1.0$, $\gamma_{DW} = 1.0$, $\gamma_P = 1.0$, $\gamma_{LL} = 1.0$, Principal Stress = $3.5^*(f'c)^{0.5}$
 - Bridge Cast in 46'-9" Segments, with a segmental "Type B Joint", having no continuous reinforcement or epoxy. Utilized more conservative allowable stress per AASHTO Guide Specification for Segmental Bridges and previous practice. AASHTO Table 5.9.2.3.2b-1 utilized for locations within CIP segments, $6^*(f'c)^{0.5} = 0.19^*(f'c)^{0.5}$
 - Principal Stress, per AASHTO 5.9.2.3.3, $3.5^*(f'c)^{0.5} = 0.110^*(f'c)^{0.5}$
 - Wearing Surface assumed Field Measured





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US 136 over Wabash River


Load Rating Combinations

Permit Load Rating ("Special", Single Trip, Mixed with Traffic) –
Superload 11 Axle, 13 Axle, 14 Axle, 19 Axle (305k & 481k)

1. Strength I, $\gamma_{DC} = 1.25$, $\gamma_{DW} = 1.25$, $\gamma_P = 1.0$, $\gamma_{LL} = 1.35$, Flexure - ϕM_n
2. Strength I, $\gamma_{DC} = 1.25$, $\gamma_{DW} = 1.25$, $\gamma_P = 1.0$, $\gamma_{LL} = 1.35$, Shear / Torsion - ϕV_n
3. Service III, $\gamma_{DC} = 1.0$, $\gamma_{DW} = 1.0$, $\gamma_P = 1.0$, $\gamma_L = 1.0$, Flexural Tensile Stress = 0 psi, $6*(f'_c)^{0.5}$
4. Service III, $\gamma_{DC} = 1.0$, $\gamma_{DW} = 1.0$, $\gamma_P = 1.0$, $\gamma_{LL} = 1.0$, Flexural Compressive Stress = $0.6f'_c$
5. Service III, $\gamma_{DC} = 1.0$, $\gamma_{DW} = 1.0$, $\gamma_P = 1.0$, $\gamma_{LL} = 1.0$, Principal Stress = $3.5*(f'_c)^{0.5}$

SUPERLOAD - 19 AXLES LOADING
(W = 480.09K)

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US 136 over Wabash River

Initial Load Rating Results


Legal Load Rating (Both Routine Commercial and Specialized Hauling) –
H-20, HS-20, EV2, EV3 AASHTO Type 3, 3-3, 3S2, NRL, Lane Type, SU4, SU5, SU6, SU7, Alt. Milt.

1. Strength I, Flexure – ϕM_n	
a. Longitudinal	1a. $RF_{min} = 7.69$ OK
b. Transverse	1b. $RF_{min} = 1.01$ OK
2. Strength I, Shear – ϕV_n	2. $RF_{min} = 0.66$ NG ←
3. Service III, Flexural Tensile Stress	3. $RF_{min} = 2.99$ OK
4. Service III, Flexural Compressive Stress	4. $RF_{min} = 3.14$ OK
5. Service III, Principal Stress	5. $RF_{min} = 0.99$ NG ←

NEXT STEPS:

- Check Again
- Narrow Rating Results Location
- Refine Model
- Collaborate Data / Direction

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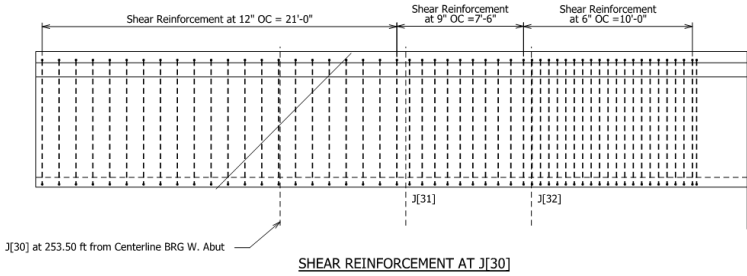


US 136 over Wabash River

Initial Load Rating Results

Find all Locations NOT Rating and Narrow Down the Problem

- Shear Controlled, Approximately 27ft off either side of Piers 3 and 5
- At this location, the shear stirrups transition from 9 in to 12 in
- Addition nodes, suggestion that including counting all bars along the inclined crack path will not fix.




J[30] at 253.50 ft from Centerline BRG W. Abut


SHEAR REINFORCEMENT AT J[30]

→

Collaborate Data / Direction




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US 136 over Wabash River

What's Next?

1. Load Posting?





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 **US 136 over Wabash River**

What's Next?

1. Load Posting?
2. Repair / Retrofits?



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What's Next?

1. Load Posting?
2. Repair / Retrofits?
3. More Refinements?
 - Material Properties
 - Field Verification



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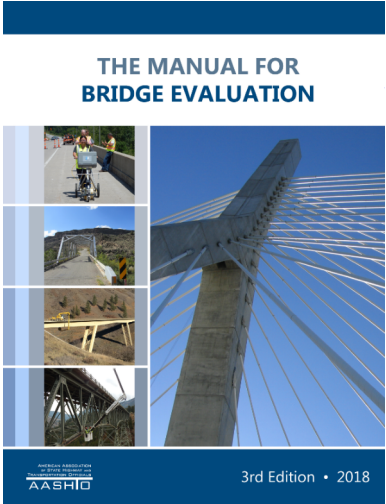
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Material Property Refinements

6.A.5.2.1 Concrete


Where the quality of the concrete is uncertain, cores should be taken for mechanical property testing.

Cores may also be taken where the initial load capacity based on design concrete strength is considered inadequate.





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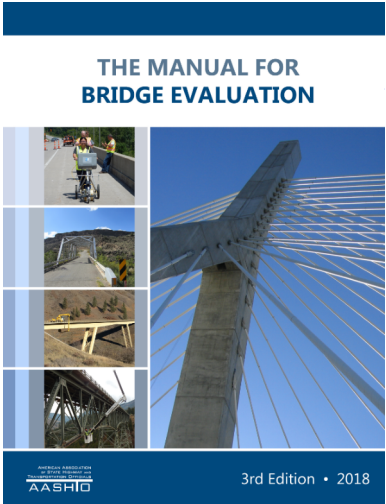



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Material Property Refinements

6.A.6.2.1 Structural Steels

In cases where the initial evaluation suggests load capacity inadequacies, or there is doubt about the nature and quality of a particular material, the mechanical properties can be verified by testing. Mechanical properties of the material should be determined based on coupon tests.






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 **US 136 over Wabash River**
Field Verification Examples

Material Sampling

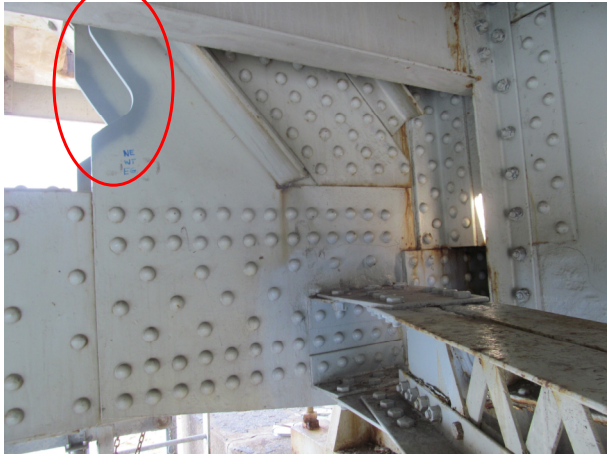
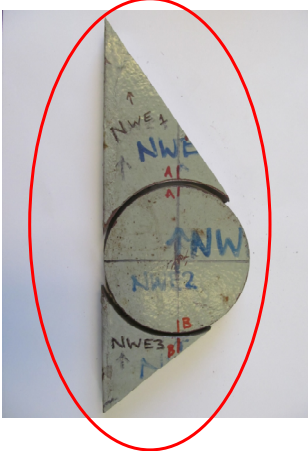


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 **US 136 over Wabash River**
Field Verification Examples

Material Sampling

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US 136 over Wabash River

Field Verification Examples

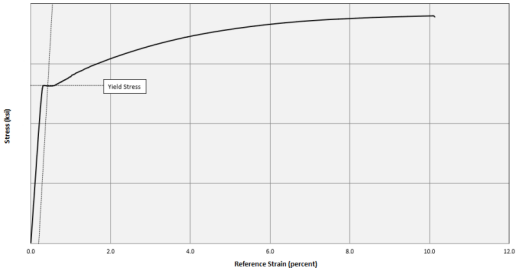
Material Sampling




WJE
Wiss, Janney, Elstner Associates, Inc.
Engineers • Architects • Material Scientists

Tensile Testing

Tensile Orientation	Longitudinal	Transverse	Longitudinal
Tensile Strength, psi	63,500	63,000	61,000
Yield Strength, psi (Yield Point (.2% Offset))	37,200 33,800	41,500 36,000	-- 33,900





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US 136 over Wabash River

Field Verification Examples

Ground Penetrating Radar (GPR)







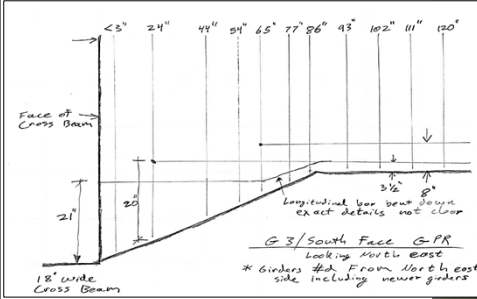
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Field Verification Examples

Ground Penetrating Radar (GPR)



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Field Verification Examples

Inspection Openings





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US 136 over Wabash River


Field Verification Examples

Reinforcing Bar Samples



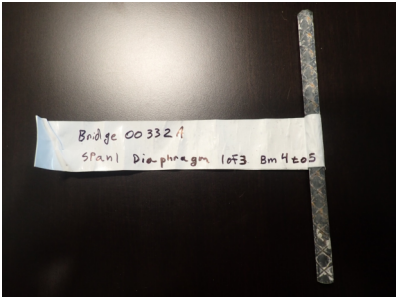

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US 136 over Wabash River


Field Verification Examples

Reinforcing Bar Testing





TENSILE TESTING

	East Wall North End	West Wall South End	West Wall North End
Specimen Orientation	Longitudinal	Longitudinal	Longitudinal
Specimen Type	.250	.250	.250
Tensile Strength, psi	71,500	70,500	72,000
Yield Strength, psi (Yield Point) ¹ (.2% Offset)	47,300 45,500	44,100 43,100	49,400 45,700



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Field Verification Examples


Condition Factors

Table 6A.4.2.3-1—Condition Factor: ϕ_c


Structural Condition of Member	ϕ_c
Good or Satisfactory	1.00
Fair	0.95
Poor	0.85

If section properties are obtained accurately, by actual field measurement of losses rather than by an estimated percentage of losses, the values specified for ϕ_c in Table 6A.4.2.3-1 may be increased by 0.05 ($\phi_c \leq 1.0$).



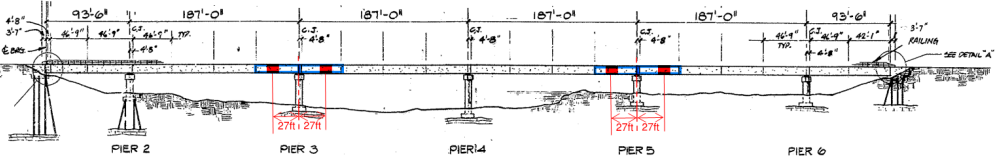


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US 136 over Wabash River

US 136 Field Verification



- Visual Inspection
- Ground Penetrating Radar
- Concrete Core Samples
- Concrete Strength Testing




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 **US 136 over Wabash River**
US 136 Field Verification

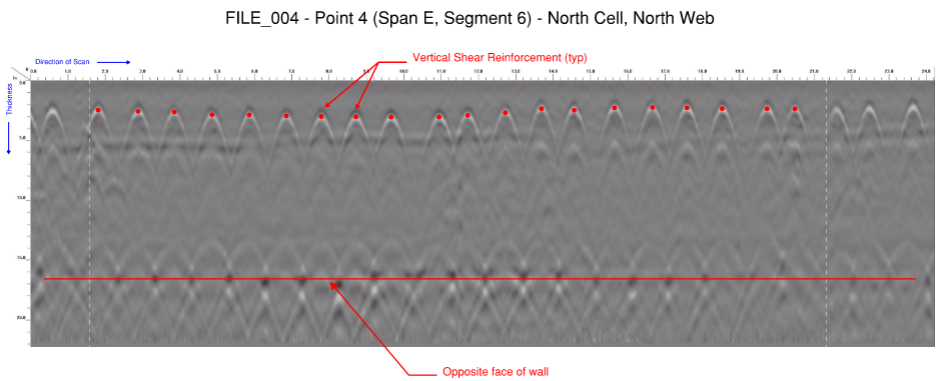



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 **US 136 over Wabash River**
US 136 Field Verification

FILE_004 - Point 4 (Span E, Segment 6) - North Cell, North Web



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 **US 136 over Wabash River**
US 136 Field Verification



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 **US 136 over Wabash River**
US 136 Material Sampling





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US 136 over Wabash River


US 136 Material Sampling



Sample ID	Corrected Compressive Strength (psi)	Section	Web
CORE 1	7,360	Point 4 (Span E)	Center
CORE 2	8,250	Point 4 (Span E)	North
CORE 3	7,920	Point 4 (Span E)	North
CORE 4	9,580	Point 3 (Span D)	North
CORE 5	7,910	Point 3 (Span D)	North
CORE 6	8,260	Point 3 (Span D)	Center
CORE 7	6,440	Point 2 (Span C)	Center
CORE 8	7,080	Point 2 (Span C)	North
CORE 9	8,610	Point 1 (Span B)	North
CORE 10	9,210	Point 1 (Span B)	South
CORE 11	8,060	Point 1 (Span B)	South
CORE 12	8,270	Point 1 (Span B)	Center
CORE 13	8,070	Point 2 (Span C)	South
CORE 14	8,250	Point 2 (Span C)	South
CORE 15	8,570	Point 3 (Span D)	South
CORE 16	8,610	Point 4 (Span E)	South
CORE 17	8,630	Point 4 (Span E)	South



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US 136 Material Sampling

Group	Concrete Compressive Strength (psi)		
	Mean (μ)	Standard Deviation (σ)	AASHTO MBE ($\mu - 1.65\sigma$)
All Samples	8,181	744	6,954
Above Construction Joint	7,995	886	6,533
Below Construction Joint	8,347	595	7,366
Point 1 (Span B)	8,538	502	7,709
Point 2 (Span C)	7,460	853	6,053
Point 3 (Span D)	8,580	719	7,393
Point 4 (Span E)	8,154	531	7,277

$\mu - 1.65\sigma = 6,053 \text{ psi (Material Testing)}$
 $f'_c = 4,800 \text{ psi (Design Drawings)}$



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US 136 over Wabash River

Updated Load Rating Results


Legal Load Rating – Strength I, Shear – ϕV_n


Previous: $RF_{min} = 0.66$ NG

↓


Update
Concrete Strength

Updated: $RF_{min} = 1.008$ OK
Posting Consideration
No Longer Necessary





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US 136 over Wabash River

Questions?

If you ask me anything I don't know,
I'm not going to answer.

-Yogi Berra



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