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Load Rating of the Bonners Ferry Bridge: A Case Study of Evaluating Post-Tensioned Steel Girders

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Presented by:
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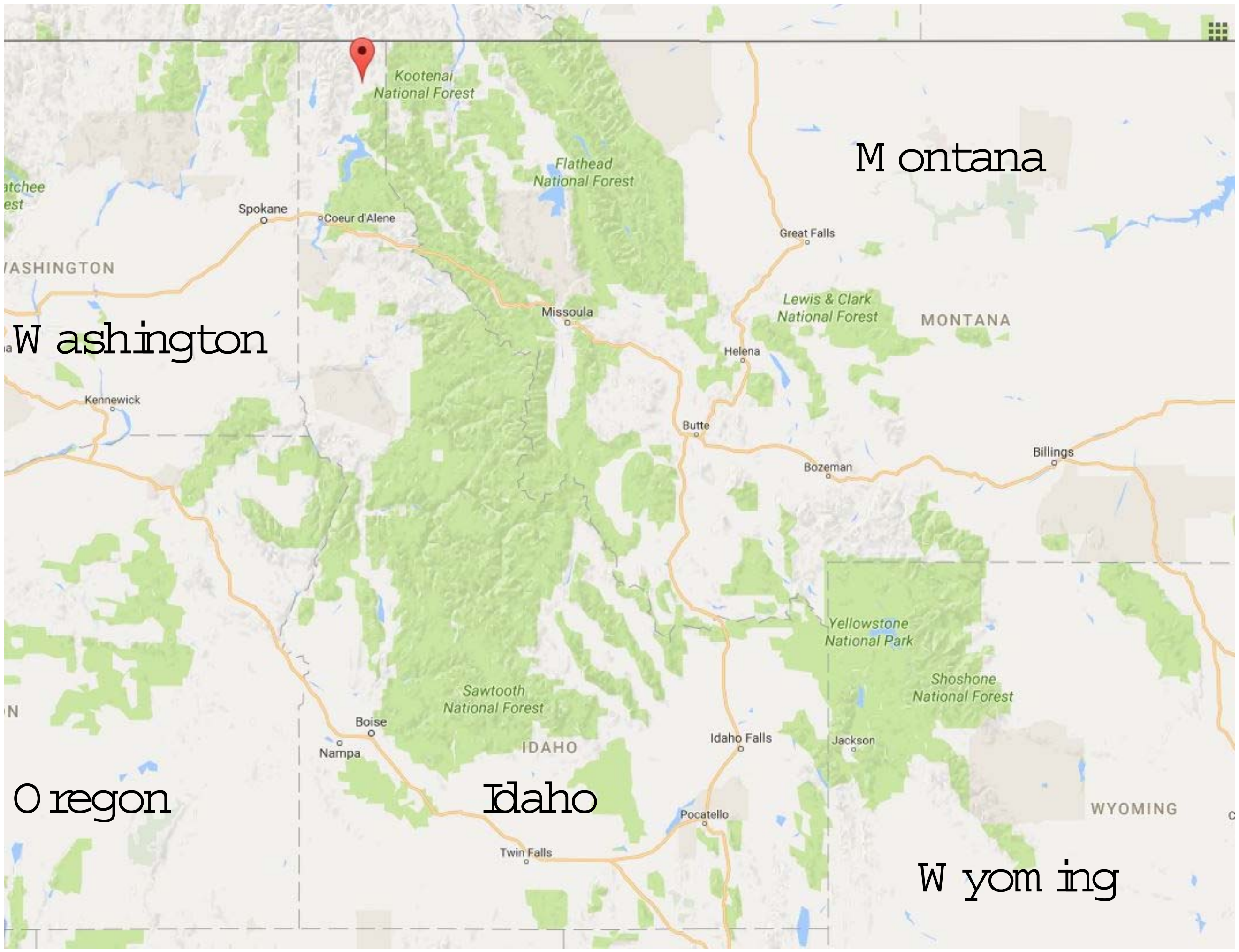
Michael Baker International

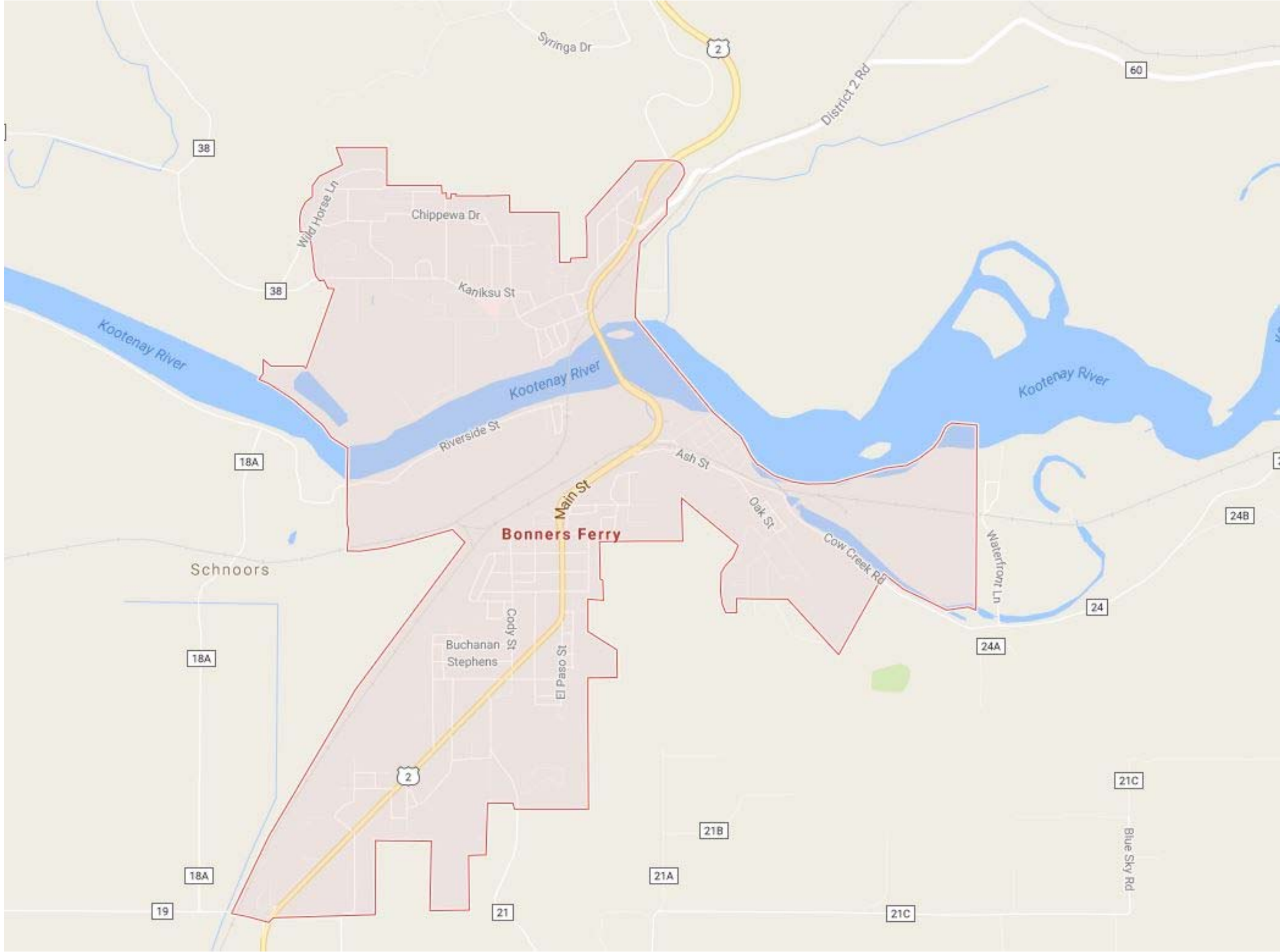
Outline

- Project location and bridge type
- Post-tensioning configuration
- Applicability to BrR
- Structural analysis
- Strength evaluation
- Results
- Load rating tool
- Conclusions

Bridge Location



Bridge Location

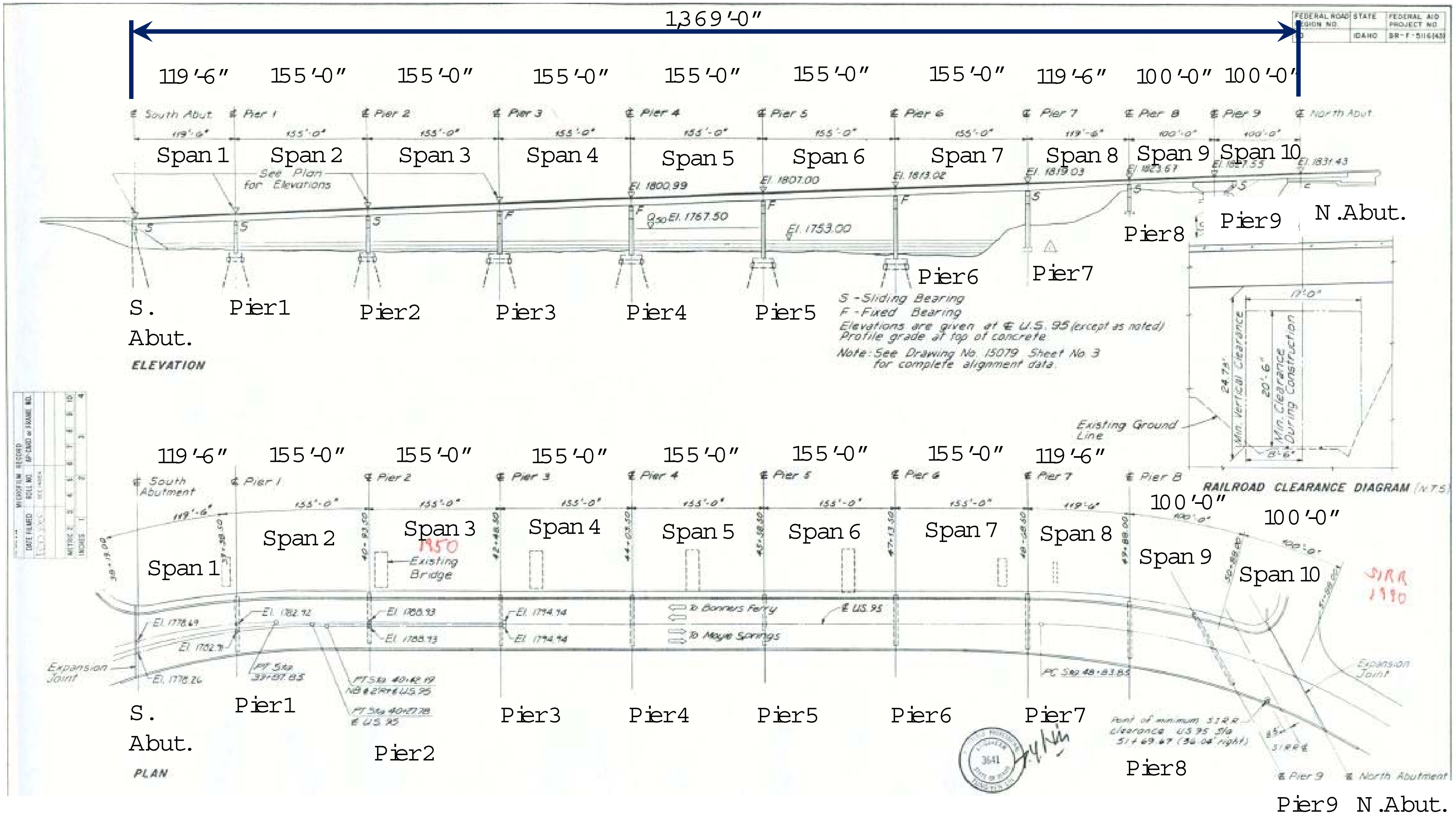


Bridge Location

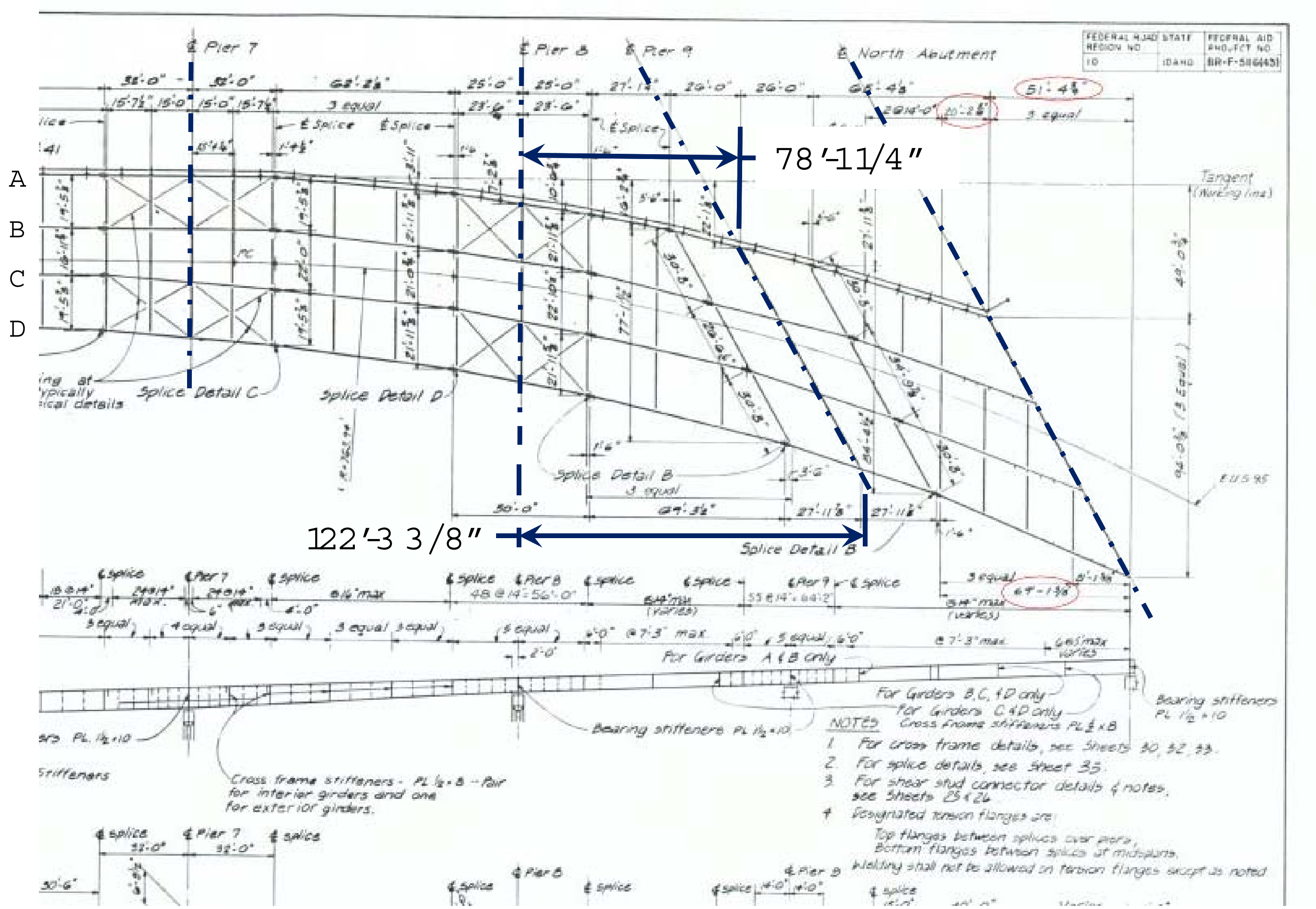
Bridge History

- Opened in 1984
- Longitudinally post-tensioned steel plate girders
- Transversely post-tensioned deck
- 20% reduction in steel
- Deck and superstructure condition rating of 7

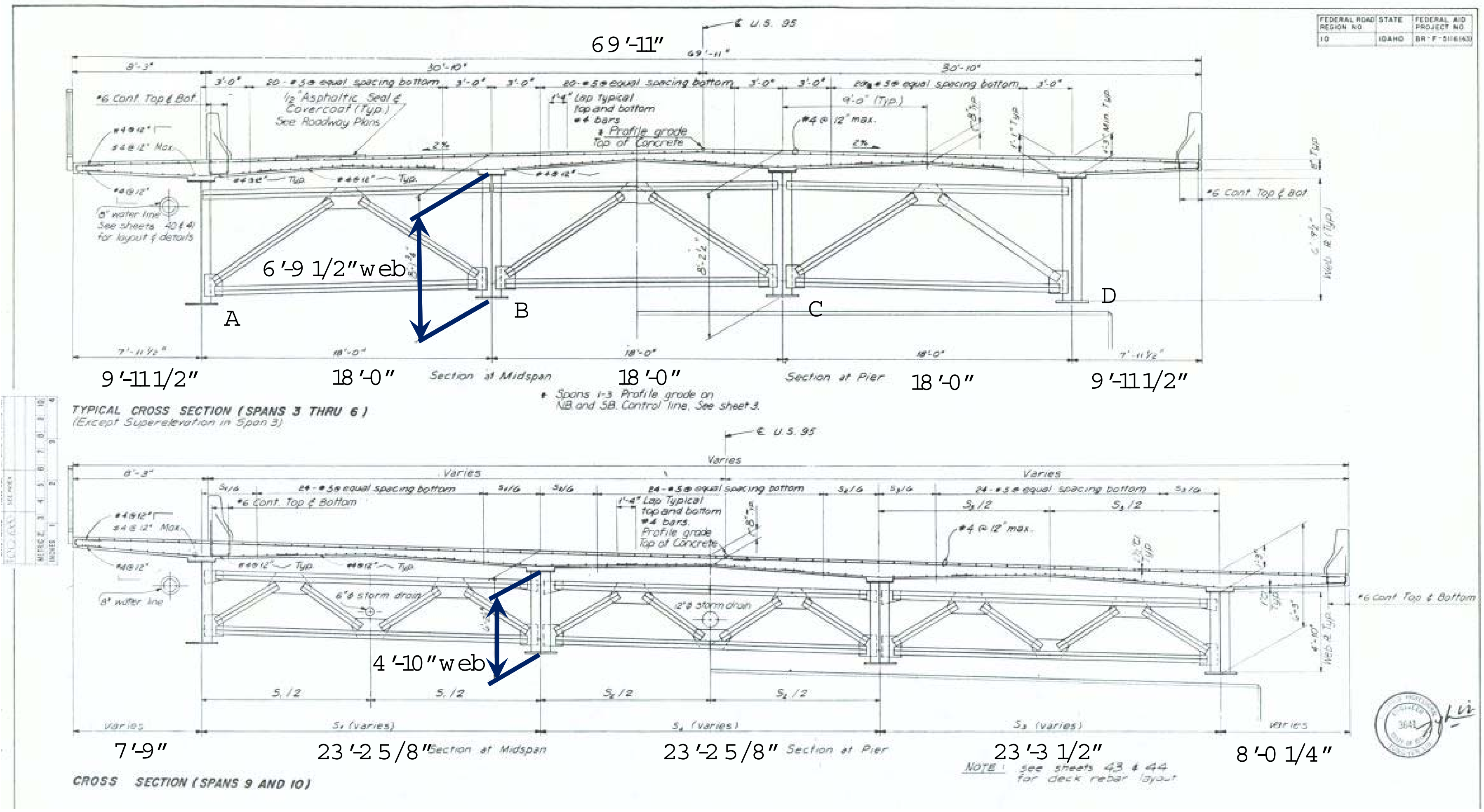
Plan and Elevation



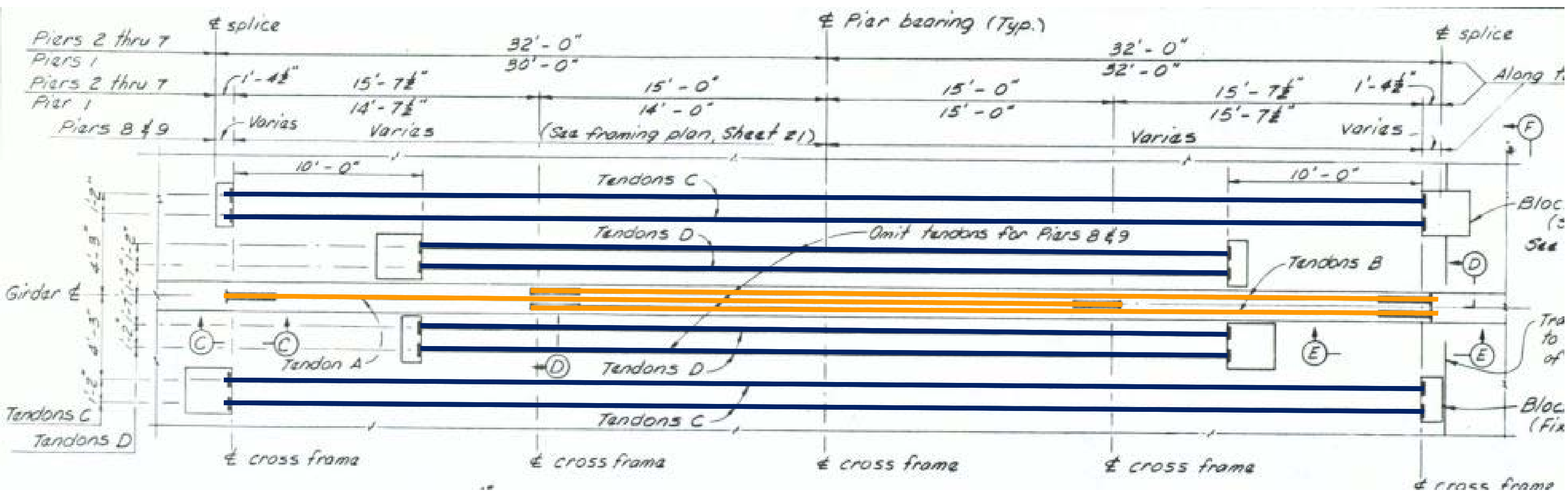
Spans 8 -10


A
B
C
D
78'-1 1/4"
122'-3 3/8"
℄ Pier 7
℄ Pier 8
℄ Pier 9
℄ North Abutment
Splice Detail C
Splice Detail D
Splice Detail B
Tangent (Working line)
NOTES
1 For cross frame details, see Sheets 30, 32, 33.
2 For splice details, see Sheet 35.
3 For shear stud connector details & notes, see Sheets 25 & 26.
4 Designated torsion flanges are:
Top flanges between splices over piers,
Bottom flanges between splices at midspans.
Welding shall not be allowed on torsion flanges except as noted
For Girders A & B only
For Girders B, C, & D only
For Girders C & D only
Bearing stiffeners PL 1/2 x 10

Transverse Section



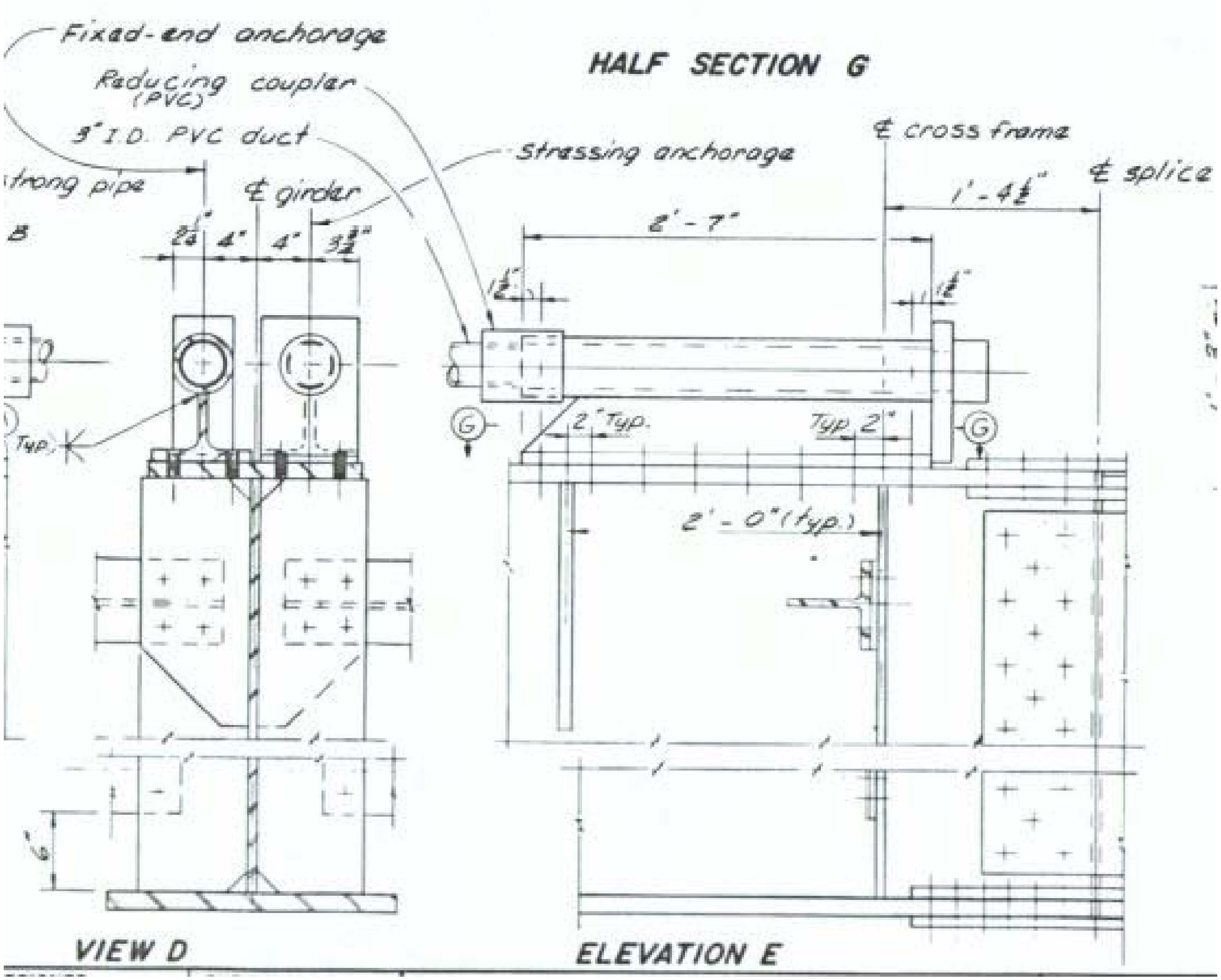
Longitudinal Girder and Deck Tendons



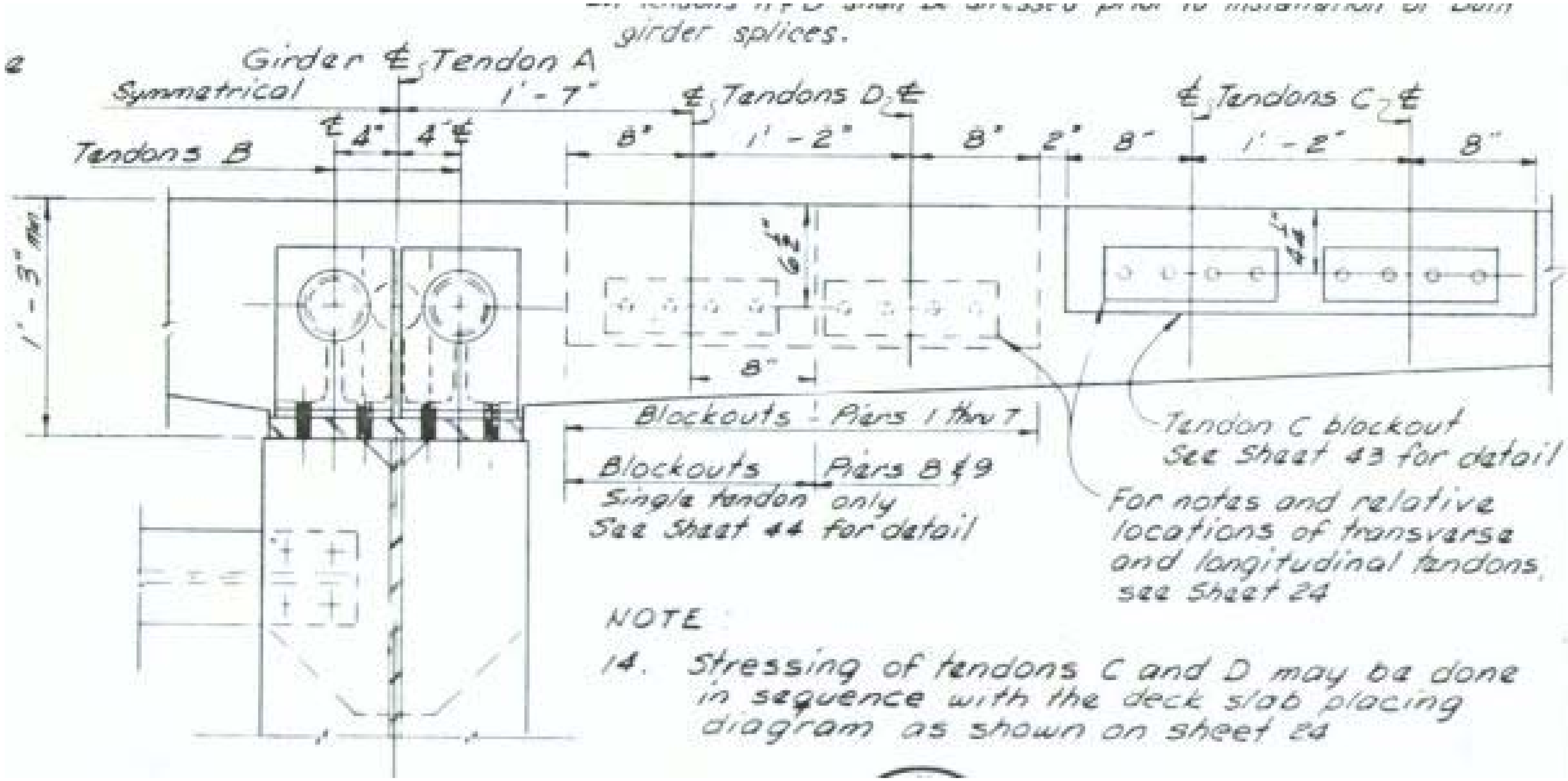
Tendon A and B force after long-term losses = 197 kips
(5 – 0.6" diameter strands – girder tendons)

Tendon C and D force after long-term losses = 159 kips
(4 – 0.6" diameter strands – deck tendons)

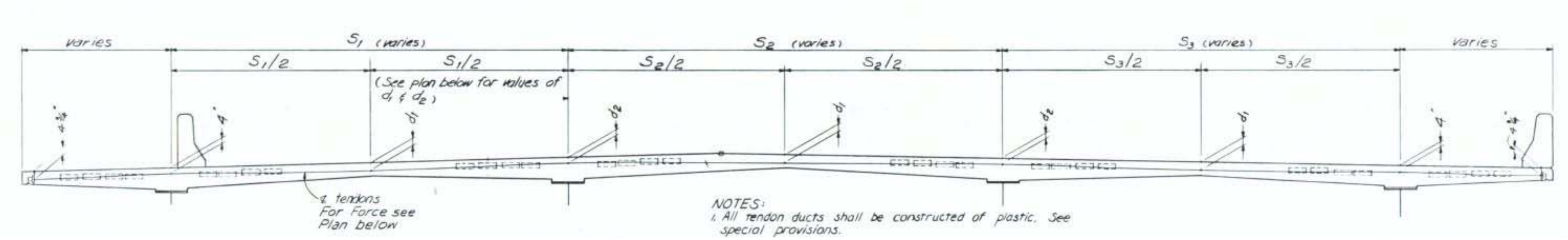
Longitudinal Tendon Details



Longitudinal Tendon Details



Transverse Tendons



- 4 – 0.6" diameter strands in 1" x 2" plastic ducts
- 30" typical tendon spacing

Applicability to BrR

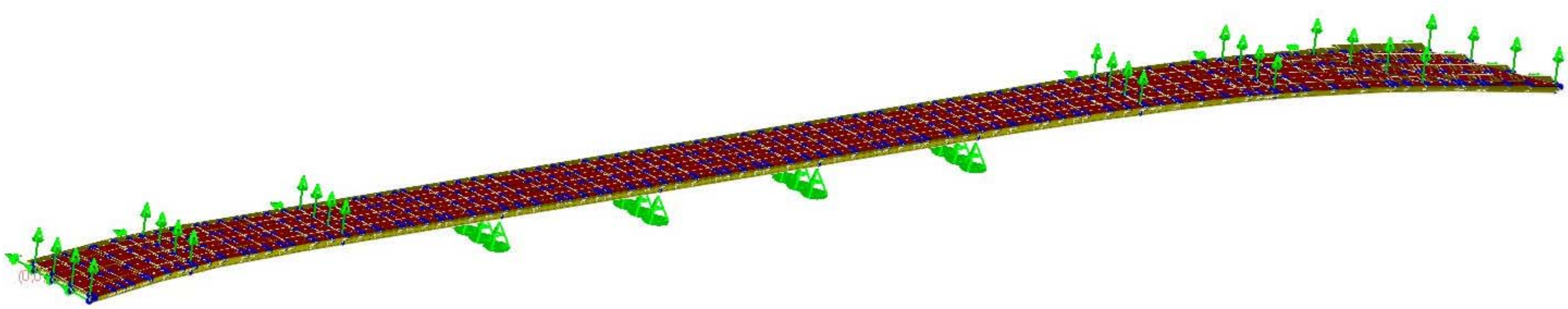
- Longitudinally post-tensioned steel plate girders and post-tensioned deck slabs are not supported
- Girder spacing would be okay for 3D analysis

General Load Rating Procedure

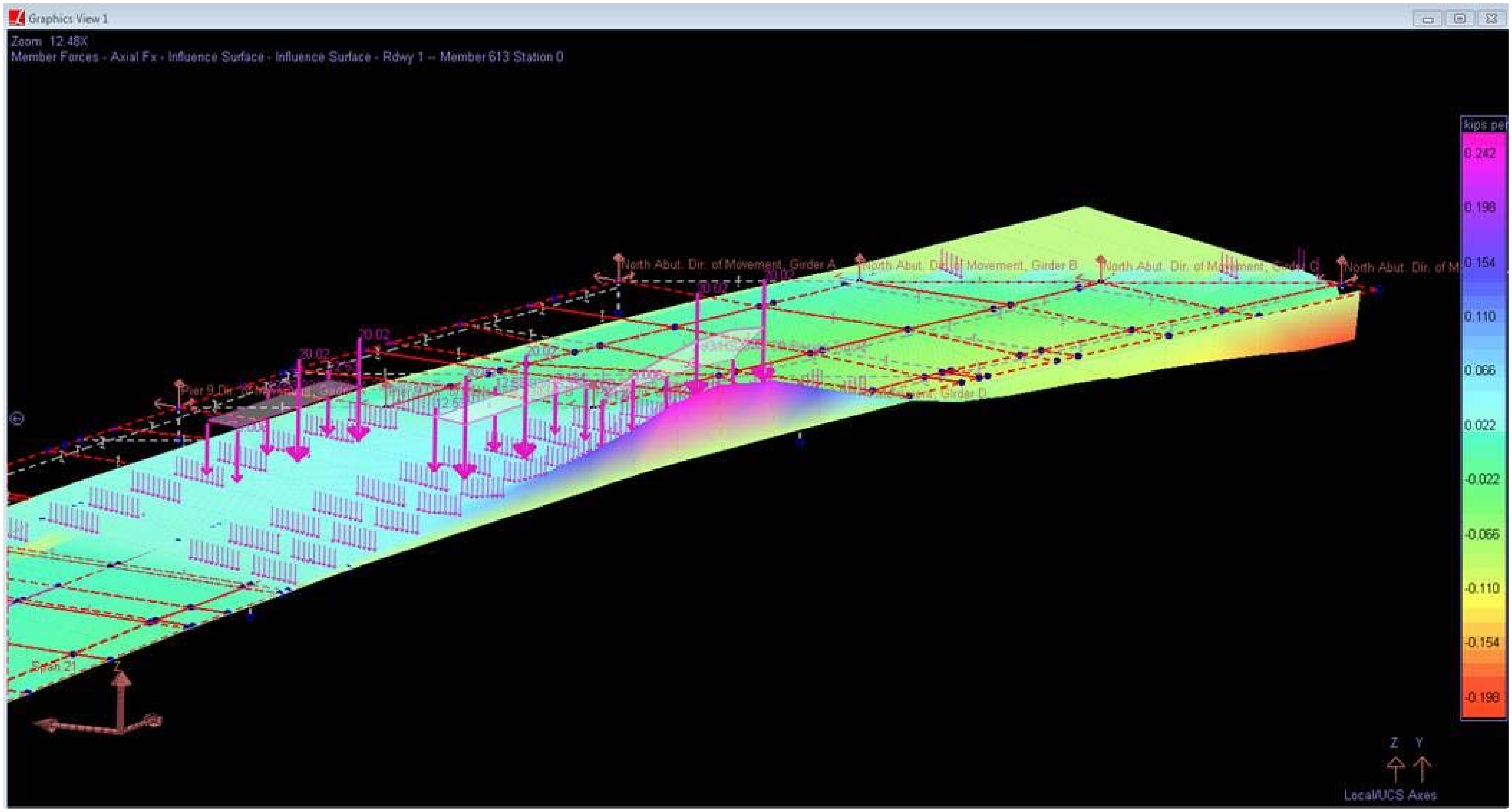
- Model bridge using general purpose FEA software
- Identify points of interest using spreadsheet post-processing
- Provide required design, legal, and permit ratings
- Extract influence lines for points of interest
- Develop an automated load rating tool that can load rate user-defined permit vehicles

Larsa Model

- 3D grillage model with construction staging
- Girders modeled with single lines of beam elements
- Flange lateral bending stresses estimated (C6.10.1)
- Live loads applied to shell elements
- Loads move transversely across deck using influence surfaces



Larsa Model


Graphics View 1
Zoom 12.48X
Member Forces - Axial Fx - Influence Surface - Influence Surface - Rdwy 1 -- Member 613 Station 0
kips per
0.242
0.198
0.154
0.110
0.066
0.022
-0.022
-0.066
-0.110
-0.154
-0.198
Local/UCS Axes

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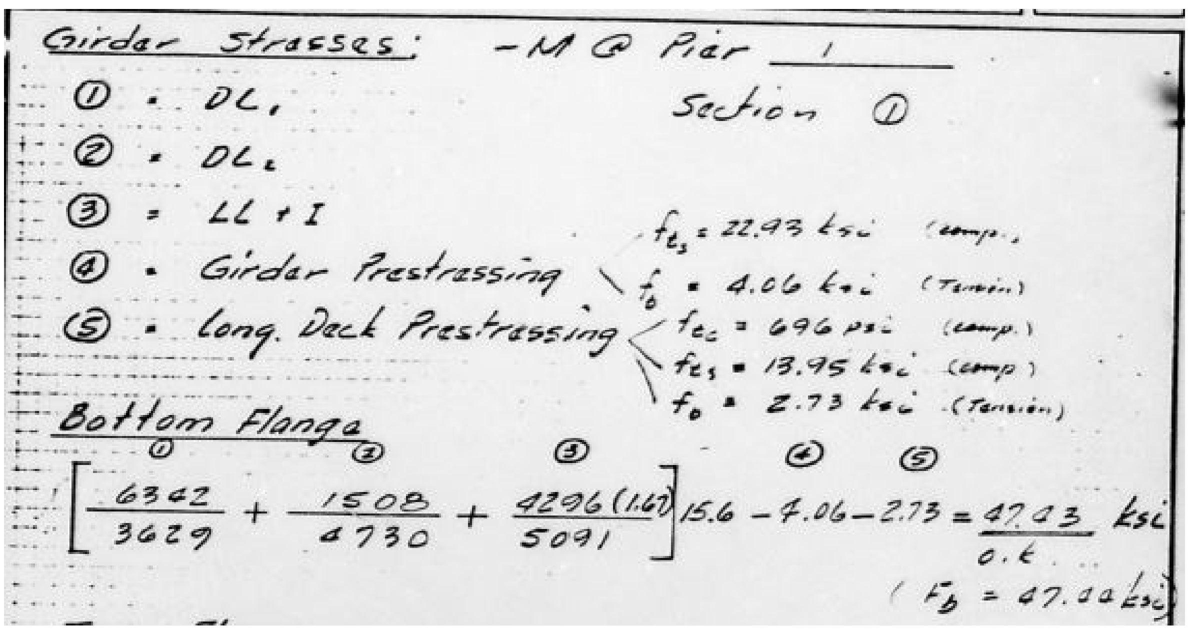
Strength Evaluation

- Designed with load factor design
- Stress from post-tensioning after losses added to loads and compared with resistance



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LRFR Load Rating

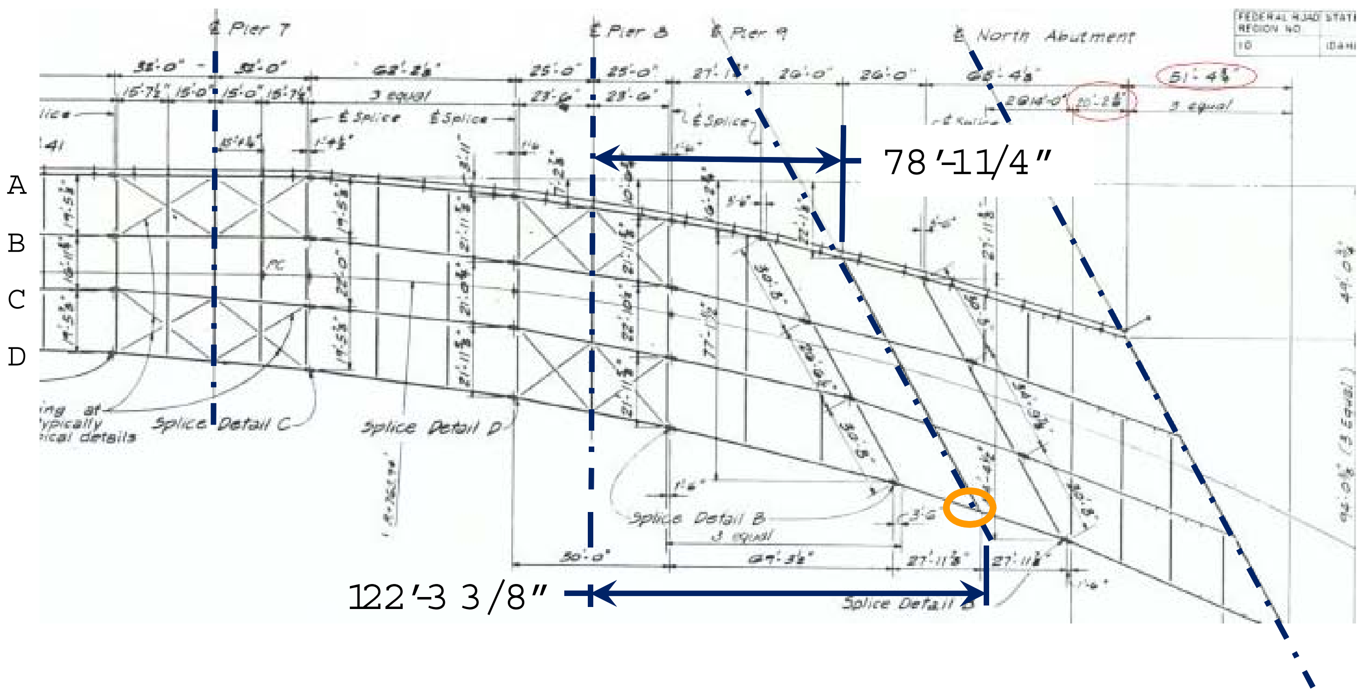
- Initially followed a similar approach for Strength limit states
- Low ratings in Girder D over Pier 9

Summary of Code Check Results Sorted by Demand/Capacity Ratio

Moment Magnification?	Yes
Constructibility Check?	Yes

Element to Check				Total Factored Loads with Noncomposite Moment Magnification									
Maximum Demand/Capacity Ratio Rank	Element	Element Part (i.e. i,j,2/4)	Element + Part	Factored Axial Force A_x (kips)	Factored Horizontal Shear V_y (kips)	Factored Vertical Shear V_z (kips)	Factored Torsion M_x (kip-ft)	Factored Moment M_y (kip-ft)	Factored Moment M_z (kip-ft)	Maximum Demand/Capacity Ratio	Top Flange Stress	Bottom Flange Stress	Controlling
1	21109	J	21109_J	-1015.73	-40.26	552.82	-219.03	-12747.33	-1056.39	1.95	Tension	Compression	Composite Com
2	21110	I	21110_I	-1003.99	52.17	-581.53	36.26	-12548.38	-1057.21	1.93	Tension	Compression	Composite Com
3	21092	J	21092_J	-949.32	-19.80	520.93	-173.18	-11229.19	-414.99	1.92	Tension	Compression	Composite Com
4	21093	I	21093_I	-937.73	14.54	-531.76	129.84	-11143.10	-421.50	1.90	Tension	Compression	Composite Com
5	21092	I	21092_I	-949.46	-20.77	506.97	-173.95	-10185.19	-387.63	1.74	Tension	Compression	Composite Com
6	21091	J	21091_J	-942.41	-19.27	502.38	-89.44	-10270.25	-374.45	1.70	Tension	Compression	Composite Com
7	20108	J	20108_J	-978.38	20.25	543.75	-144.10	-11185.81	110.20	1.66	Tension	Compression	Composite Com
8	20109	I	20109_I	-978.33	-3.99	-556.22	-53.95	-11143.46	28.74	1.65	Tension	Compression	Composite Com
9	20093	I	20093_I	-955.40	-26.37	-503.71	46.45	-9811.19	467.93	1.65	Tension	Compression	Composite Com
10	20092	J	20092_J	-951.05	21.81	509.94	4.05	-9810.44	466.29	1.65	Tension	Compression	Composite Com
11	21108	J	21108_J	-1015.12	-34.18	523.40	-208.91	-10728.36	-882.16	1.65	Tension	Compression	Composite Com
12	21109	I	21109_I	-1015.89	-38.59	523.37	-212.25	-10727.25	-883.10	1.65	Tension	Compression	Composite Com
13	20091	J	20091_J	-945.33	19.15	483.93	-40.51	-8699.45	410.55	1.51	Tension	Compression	Composite Com
14	21111	I	21111_I	-1002.57	41.95	-533.13	25.43	-9758.17	-741.78	1.50	Tension	Compression	Composite Com
15	21110	J	21110_J	-1005.72	47.23	-532.82	32.39	-9753.99	-733.48	1.50	Tension	Compression	Composite Com
16	20092	I	20092_I	-951.96	16.55	489.83	33.36	-8791.27	394.76	1.48	Tension	Compression	Composite Com
17	21069	J	21069_J	-2153.31	-4.41	604.95	-30.41	-13079.68	53.75	1.46	Tension	Compression	Composite Com

Girder D over Pier 9



Girder D over Pier 9 – HL93 Inventory (initial assumption of uncracked section)

- σ_{nc_top} = 45.5 ksi
- $\sigma_{n\_composite\_top}$ = 1.6 ksi
- $\sigma_{3n\_composite\_top}$ = 1.4 ksi
- σ_{pt_top} = -2.3 ksi
- $\underline{\sigma_{top\_total}}$ = 46.1 ksi
- $\phi_f F_{nt}$ = 50 ksi
- D/C = 0.92

- σ_{nc_bottom} = -24.6 ksi
- $\sigma_{n\_composite\_bottom}$ = -21.6 ksi
- $\sigma_{3n\_composite\_bottom}$ = -4.0 ksi
- σ_{pt_bottom} = -1.9 ksi
- $\underline{\sigma_{bottom\_total}}$ = -52.3 ksi
- $\phi_f F_{nc}$ $-1/3 f_l$ = -42.5 ksi
- D/C = 1.23

However, top of slab stress is 60% above f_r. Therefore, compute stresses using cracked section properties instead.

Girder D over Pier 9 – HL93 Inventory

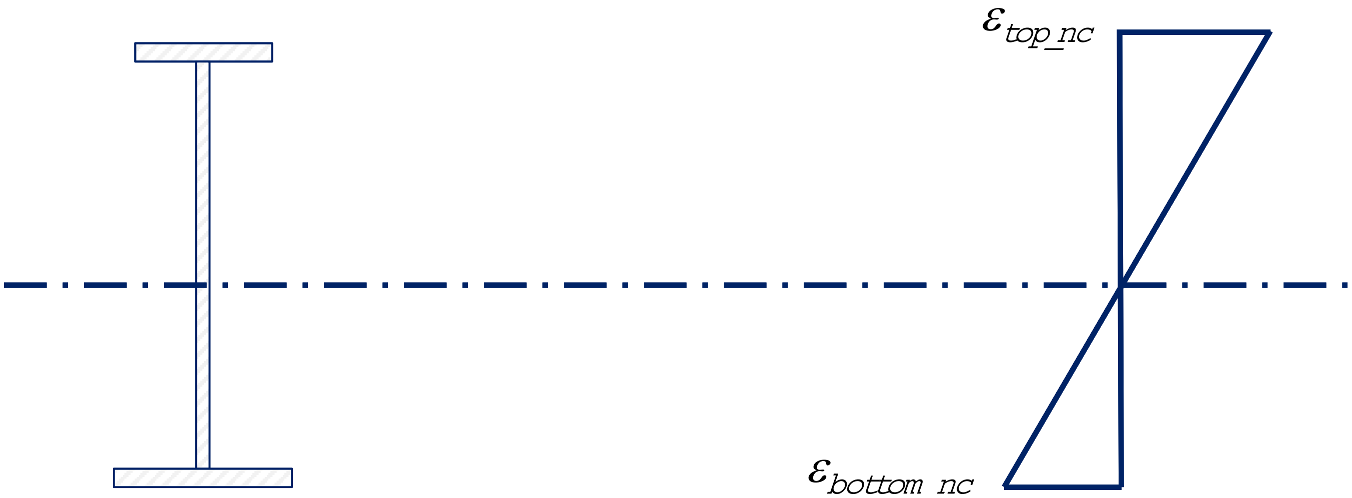
- σ_{nc_top} = 45.5 ksi
- $\sigma_{cracked\_top}$ = 49.6 ksi
- σ_{top_total} = 95.1 ksi
- $\phi_f F_{nt}$ = 50 ksi
- D/C = 1.90

- σ_{nc_bottom} = -24.6 ksi
- $\sigma_{cracked\_bottom}$ = -29.6 ksi
- σ_{bottom_total} = -54.2 ksi
- $\phi_f F_{nc}$ - $1/3 f_l$ = -42.5 ksi
- D/C = 1.28

Ultimate Moment Strength

- For Girder D over Pier 9, results are very sensitive to cracked section assumption
- Using strain compatibility provides a more consistent approach
- Strain compatibility in conjunction with maximum factored stress in bottom compression flange is consistent with AASHTO LRFD steel and prestressed concrete

Strain Compatibility Procedure

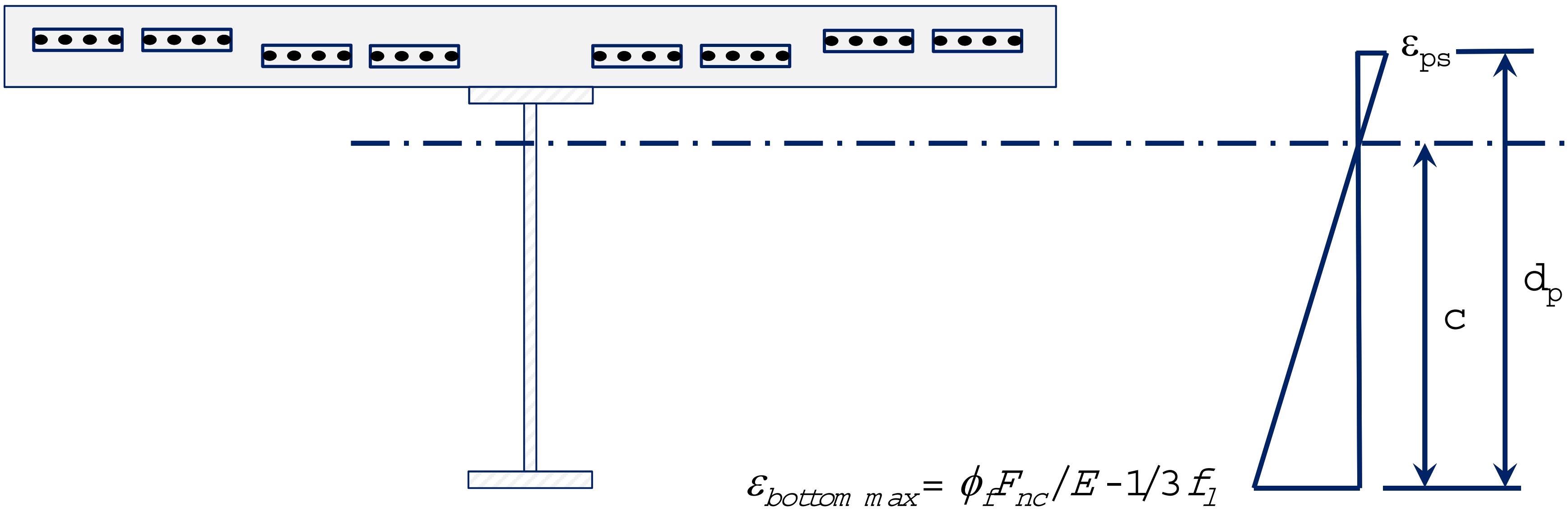


1. Find strain in extreme fibers due to factored noncomposite dead load applied to noncomposite girder

2. Find additional strain that when added to compression flange will cause buckling: $\varepsilon_{bottom\_max} = \varepsilon_{bottom\_nc} + \varepsilon_{additional}$

$$\varepsilon_{bottom\_max} = \phi_f F_{nc} / E - 1/3\, f_l$$

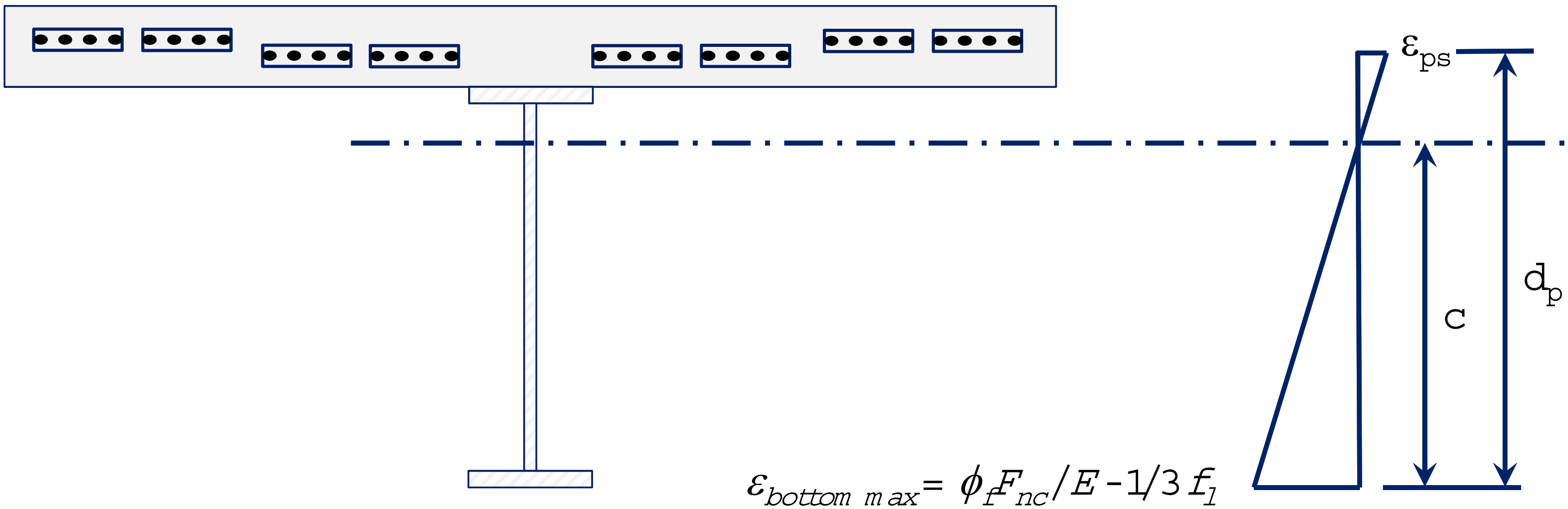
Strain Compatibility Procedure



3. Choose a value for $f_{ps} = f_{pe} + f_s$, set internal tension equal to internal compression and solve for neutral axis location c

4. Use c and $\varepsilon_{additional} = \varepsilon_{bottom\_max} - \varepsilon_{nc}$ to find ε_s, additional strain in prestressing steel due to composite loads

Strain Compatibility Procedure



5. Using ε_s, calculate f_s, the additional stress in the prestressing steel due to composite loads

Strain Compatibility Procedure

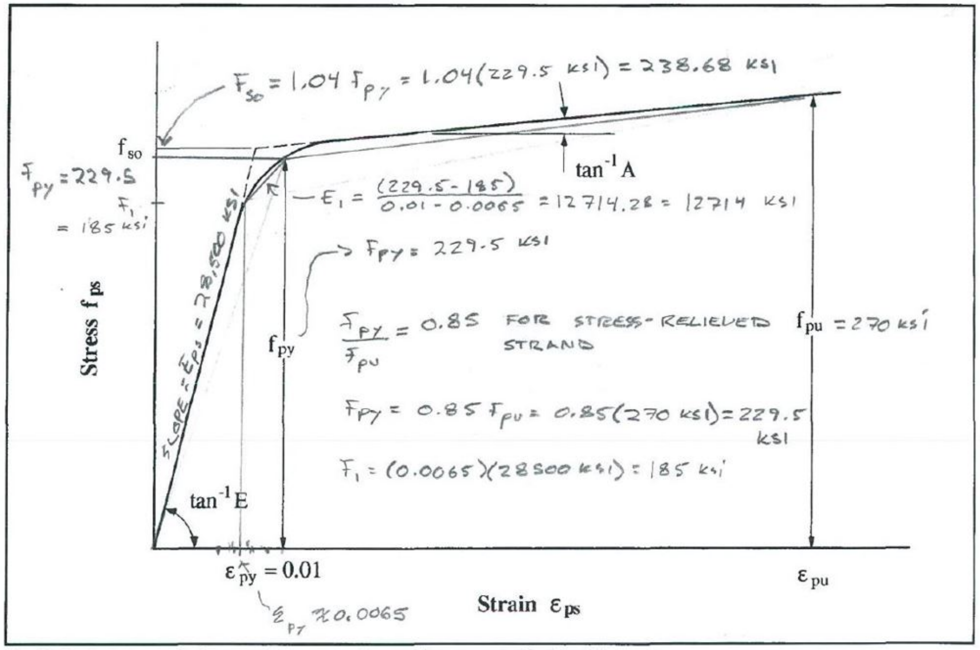


Fig. B. Typical stress-strain curve for prestressing steel represented by Eq. (2).

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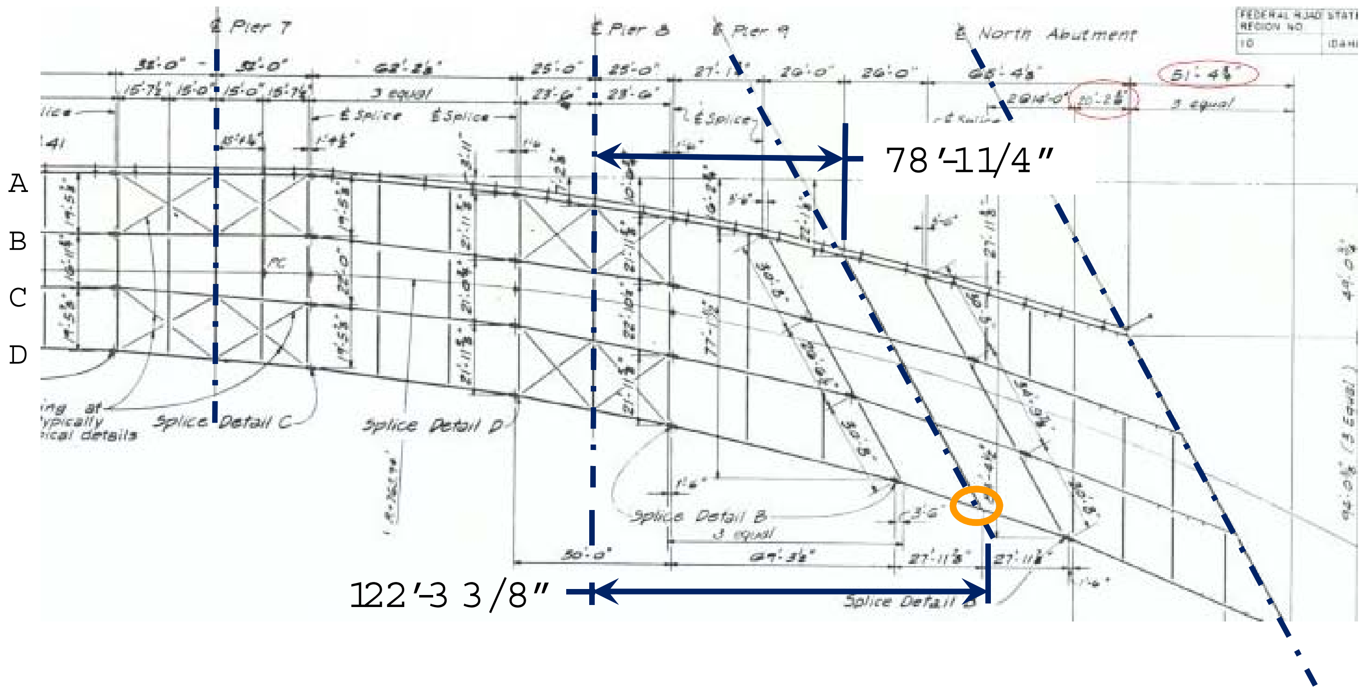
6. Iterate the value chosen for f_{ps} until $f_{pe} + f_s = f_{ps}$. Bilinear stress-strain relationship used for prestressing steel

7. Check internal force equilibrium and sum internal moments to find moment capacity.

Girder D over Pier 9 – HL93 Inventory

- $M_u = 12{,}904$ k-ft
- $\phi M_{n\_strain\_compatibility} = 11{,}134$ k-ft
- D/C = 1.16

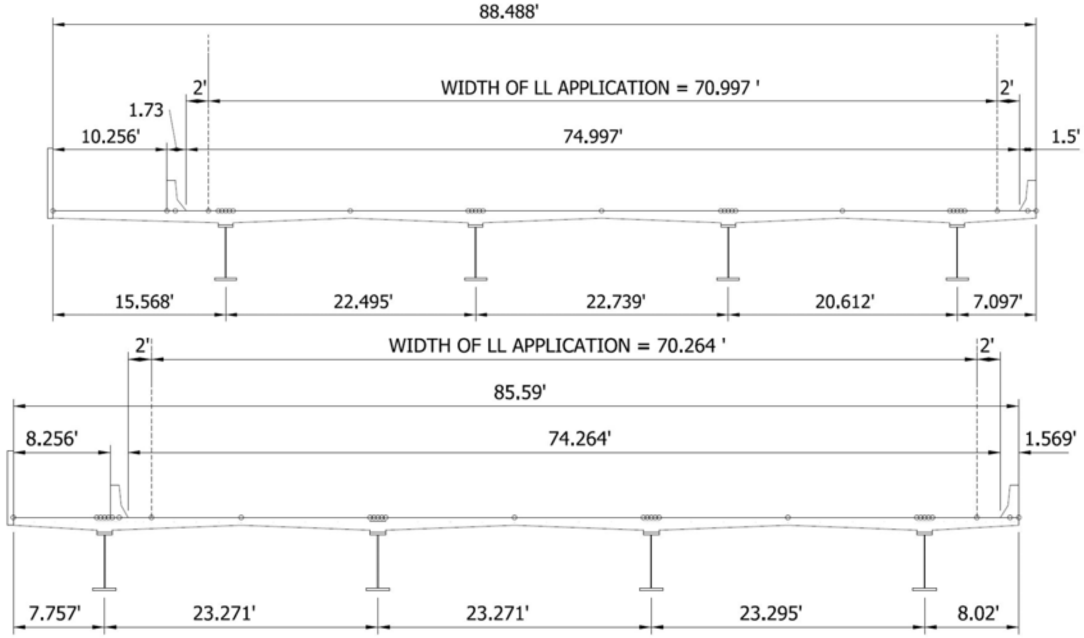


Service II Check

- LRFD Service Limit State provisions
- Stresses from post-tensioning after losses added as loads
- $\sigma_{tf} < 0.95 R_h F_{yt}$ (6.10.4.2.2-1)
- $1/3\sigma_l + \sigma_{bf} < 0.95 R_h F_{yc}$ (6.10.4.2.2-1)

Transverse Analysis

- AASHTO Equivalent Strip Method and influence lines
- Typical deck, and widened deck cross-sections
- Rated for Strength I, II and Service III

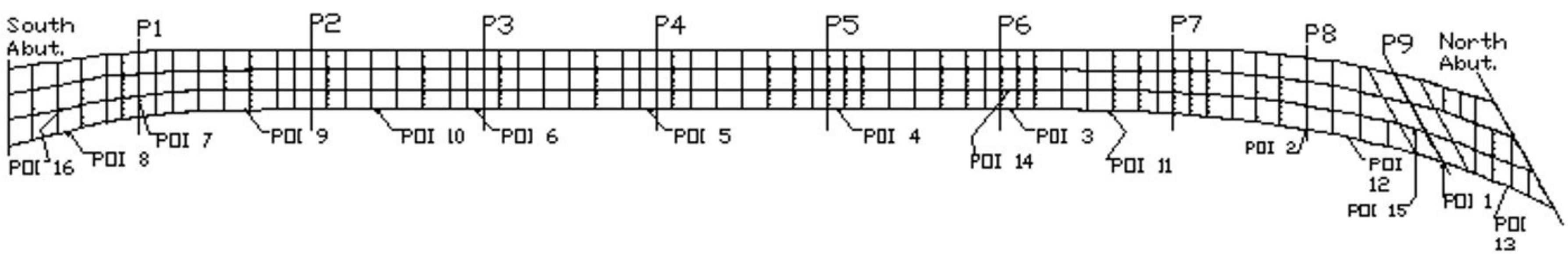


Results

- Longitudinal rating, Girder D over Pier 9, governs
- HL-93 Strength I Inventory Rating = 0.74
- HL-93 Service II Inventory Rating = 1.21
- HL-93 Strength I Inventory Rating, Transverse Analysis = 1.37
- HL-93 Service III Rating Transverse Analysis = 1.47

Automated Load Rating Tool

- User-defined permit vehicles can be input
- Option to load only one interior lane with permit
- Deterioration from field inspections can be input
- Impact factor can be specified
- Strain-compatibility iterations are automated



Automated Load Rating Tool

Assumed Factored Flange Lateral Bending Stress: 15.00 ksi
(AASHTO LRFD 7th Ed. Section C6.10.1)

Average Daily Traffic (ADT): 9800 **Truck Percentage (%):** 9% **Average Daily Truck Traffic (ADTT):** 882

Conditon Factor: 1.0
System Factor: 1.0

LANE CONFIGURATION: *Legal*
Legal will utilize the striped lane configuration with the user input truck configuration.

TRUCK CONFIGURATION:
Auto Populate Truck Data: HL-93

Axle Weights:		*Axle Spacing:*	
Axle 1:	*8.00 k*	*Axle 1 to Axle 2:*	*14.00 ft*
Axle 2:	*32.00 k*	*Axle 2 to Axle 3:*	*14.00 ft*
Axle 3:	*32.00 k*	*Axle 3 to Axle 4:*	
Axle 4:		*Axle 4 to Axle 5:*	
Axle 5:		*Axle 5 to Axle 6:*	
Axle 6:		*Axle 6 to Axle 7:*	
Axle 7:		*Axle 7 to Axle 8:*	
Axle 8:		*Axle 8 to Axle 9:*	
Axle 9:		*Axle 9 to Axle 10:*	
Axle 10:		*Axle 10 to Axle 11:*	
Axle 11:		*Axle 11 to Axle 12:*	
Axle 12:		*Axle 12 to Axle 13:*	
Axle 13:		*Axle 13 to Axle 14:*	
Axle 14:		*Axle 14 to Axle 15:*	
Axle 15:		*Axle 15 to Axle 16:*	
Axle 16:		*Axle 16 to Axle 17:*	
Axle 17:		*Axle 17 to Axle 18:*	
Axle 18:		*Axle 18 to Axle 19:*	
Axle 19:		*Axle 19 to Axle 20:*	
Axle 20:			

PRINCIPAL STRESS ALLOWABLE PRESSURE COEFFICIENTS (k)

Inventory: *3.50*
Operating: *4.50*

Principal Stress Allowable Pressure = k√(f'c). Default values = 3.5, 4.5 (Inv, Opr) based on AASHTO LRFD Bridge Design Specifications, 7th Editin Table 5.9.4.2.2-1

MEMBER DETERIORATION:

	----- *Section Loss Present (in.)* -----			Deck	
Point of Interest & Description	Top Flange	Bottom Flange	Web	Top Spall (in)	Bottom Spall (in)
POI 1 Girder D over Pier 9:	*0%*	*0%*	*0%*	*0.00*	*0.00*
POI 2 Girder D over Pier 8:	*0%*	*0%*	*0%*	*0.00*	*0.00*
POI 3 Girder D over Pier 6:	*0%*	*0%*	*0%*	*0.00*	*0.00*
POI 4 Girder D over Pier 5:	*0%*	*0%*	*0%*	*0.00*	*0.00*
POI 5 Girder D over Pier 4:	*0%*	*0%*	*0%*	*0.00*	*0.00*
POI 6 Girder D over Pier 3:	*0%*	*0%*	*0%*	*0.00*	*0.00*
POI 7 Girder C over Pier 1:	*0%*	*0%*	*0%*	*0.00*	*0.00*
POI 8 Girder D @ Mid Span betw S. Abut. and Pier 1:	*0%*	*0%*	*0%*	*0.00*	*0.00*
POI 9 Girder D @ Mid Span betw Pier 1 and Pier 2:	*0%*	*0%*	*0%*	*0.00*	*0.00*
POI 10 Girder D @ Mid Span betw Pier 2 and Pier 3:	*0%*	*0%*	*0%*	*0.00*	*0.00*
POI 11 Girder D @ Mid Span betw Pier 6 and Pier 7:	*0%*	*0%*	*0%*	*0.00*	*0.00*
POI 12 Girder D @1/3 Span betw Pier 8 and Pier 9:	*0%*	*0%*	*0%*	*0.00*	*0.00*
POI 13 Girder D @ 1/3 Span betw Pier 9 and N. Abut.:	*0%*	*0%*	*0%*	*0.00*	*0.00*
POI 14 Girder C over Pier 6:	*0%*	*0%*	*0%*	*0.00*	*0.00*
POI 15 Girder C over Pier 9:	*0%*	*0%*	*0%*	*0.00*	*0.00*
POI 16 Girder C @ Mid Span betw S. Abut. and Pier 1:	*0%*	*0%*	*0%*	*0.00*	*0.00*
POI 17 Tranverse Slab, between Girder A and Girder B:	*0%*	*0%*	*0%*	*0.00*	*0.00*
POI 18 Tranverse Slab, @ Girder B:	*0%*	*0%*	*0%*	*0.00*	*0.00*
POI 19 Tranverse Slab, between Girder B and Girder C:	*0%*	*0%*	*0%*	*0.00*	*0.00*
POI 20 Tranverse Slab, between Girder C and Girder D:	*0%*	*0%*	*0%*	*0.00*	*0.00*

PERFORM RATING

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Automated Load Rating Tool

BRIDGE LOAD RATING INFORMATION:

Controlling LRFR Inventory Load Rating = 0.74	Controlling Location = POI 1 - Girder D over Pier 9	Limit State = BENDING
Controlling LRFR Operating Load Rating = 0.96	Controlling Location = POI 1 - Girder D over Pier 9	Limit State = BENDING

INDIVIDUAL ELEMENT LOAD RATING INFORMATION:

		Strength Load Rating Factor		Service Rating Factor & Stresses				Controlling Rating (Tons)	
Point of Interest & Description		Inventory Rating	Operating Rating	Inventory Rating	Operating Rating	INV Applied (ksi)	INV Allowed (ksi)	Inventory Rating	Operating Rating
POI 1	Girder D over Pier 9	**0.74**	**0.96**	1.21	1.54	**43.75**	47.50	**26.74**	**34.66**
POI 2	Girder D over Pier 8	**0.88**	1.14	1.32	1.67	41.45	47.50	31.75	41.15
POI 3	Girder D over Pier 6	1.15	1.49	1.33	1.69	41.53	47.50	41.34	53.59
POI 4	Girder D over Pier 5	1.20	1.56	1.43	1.81	39.96	47.50	43.37	56.22
POI 5	Girder D over Pier 4	1.18	1.53	1.41	1.79	40.23	47.50	42.44	55.02
POI 6	Girder D over Pier 3	1.18	1.53	1.40	1.77	40.45	47.50	42.59	55.21
POI 7	Girder C over Pier 1	1.19	1.55	1.44	1.83	40.38	47.50	42.99	55.73
POI 8	Girder D @ Mid Span betw S. Abut. and Pier 1	6.22	8.07	1.38	1.79	39.03	47.50	49.66	64.56
POI 9	Girder D @ Mid Span betw Pier 1 and Pier 2	**0.98**	1.27	1.46	1.90	37.34	47.50	35.13	45.54
POI 10	Girder D @ Mid Span betw Pier 2 and Pier 3	1.03	1.33	1.56	2.02	36.15	47.50	36.91	47.85
POI 11	Girder D @ Mid Span betw Pier 6 and Pier 7	**1.00**	1.29	1.42	1.84	38.87	47.50	35.96	46.61
POI 12	Girder D @1/3 Span betw Pier 8 and Pier 9	1.06	1.37	1.62	2.11	34.36	47.50	38.06	49.33
POI 13	Girder D @ 1/3 Span betw Pier 9 and N. Abut.	1.03	1.33	1.53	1.99	37.02	47.50	36.97	47.93
POI 14	Girder C over Pier 6	1.23	1.59	1.45	1.84	40.09	47.50	44.19	57.28
POI 15	Girder C over Pier 9	**0.84**	1.09	1.32	1.67	42.06	47.50	30.41	39.42
POI 16	Girder C @ Mid Span betw S. Abut. and Pier 1	5.90	7.65	1.32	1.71	40.60	47.50	47.42	61.64
* POI 17	Tranverse Slab, between Girder A and Girder B	1.37	1.78	1.47	NA	-0.05	0.42	49.31	63.92
* POI 18	Tranverse Slab, @ Girder B	1.73	2.25	1.47	NA	0.12	0.42	52.84	80.85
* POI 19	Tranverse Slab, between Girder B and Girder C	1.80	2.34	2.05	NA	-0.46	0.42	64.93	84.17
* POI 20	Tranverse Slab, between Girder C and Girder D	1.41	1.83	1.55	NA	-0.15	0.42	50.92	66.01

Conclusions

- 3D analysis revealed unexpected performance issues at skewed support
- Strain compatibility useful for obtaining additional capacity with post-tensioned steel
- Longitudinal rating, Strength I over Pier 9 controls
- Automated load rating tool will facilitate future permit evaluations

Thank You!

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Questions?