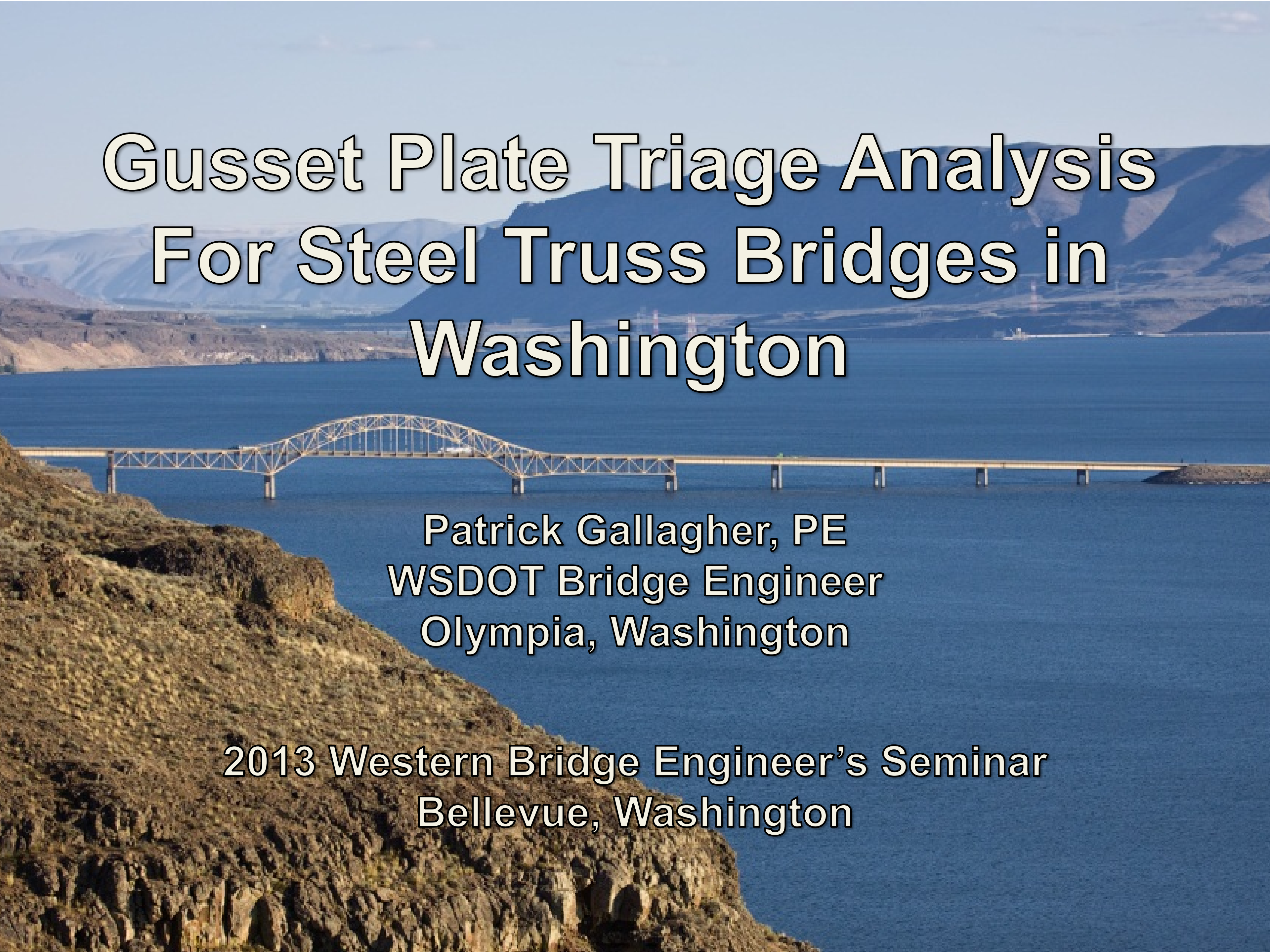

Gusset Plate Triage Analysis For Steel Truss Bridges in Washington

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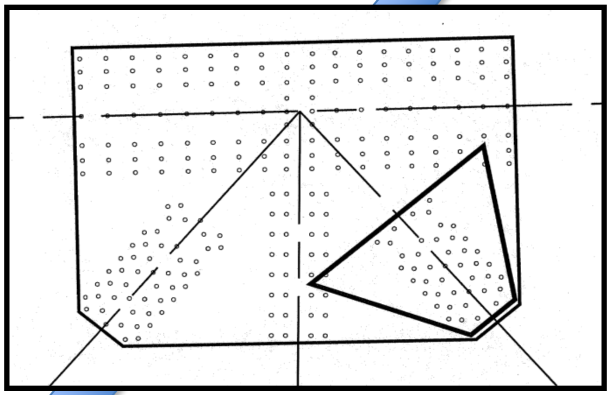
2013 Western Bridge Engineer’s Seminar
Bellevue, Washington

OUTLINE

- Why?
- Bridge Inventory
- Triage Method
- Triage Example
- Application
- What's Next



THE MOTIVATION

- Load Rating is a bit of a reaction based program.
  - An engineer is always allowed to check areas of concern. However, tradition and lack of concern has left gusset plates off of the usual list of items to check.
- Minneapolis, 2009 demonstrated a need to analyze quickly a lot of trusses quickly.

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WSDOT’S TRUSS INVENTORY

- 130+ steel trusses owned by WSDOT
  - A total of 27.6 miles of truss on WSDOT’s system, and local agencies have more.
  - Sizes range from the very small to the very large.
  - Types range from simple to very complex.
    - Simple span, continuous, drop spans, erection stresses built in.
  - Not every bridge has good plans.
- Modeling
  - Boundary Conditions
    - Global and Local
  - Lane Configuration
- This is a daunting task to evaluate!

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THE TRIAGE PLAN

- Identify if a gusset will control a rating.
  - Other methods are available, FHWY, finite element, compare to the current AASHTO Design Code.
- Almost every bridge is deemed okay with the triage method and the rating is not governed by the gussets. We need to identify which ones are not okay, and fast!

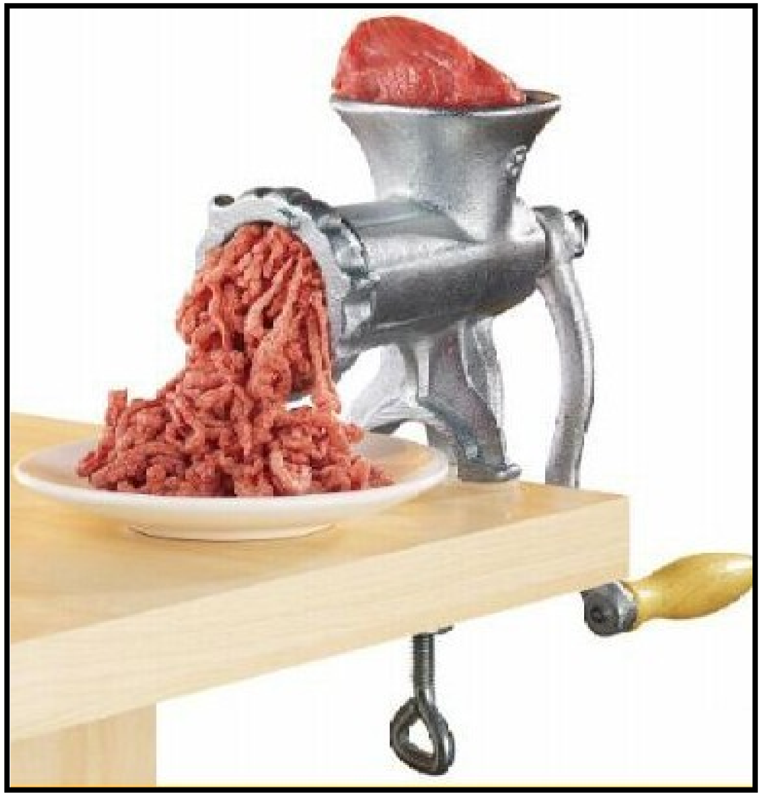
SIEVE ANALOGY

- SIEVE 1:
  - With the Triage Method, if the Rating Factors are higher than those currently listed, then the analysis is done.
- SIEVE 2:
  - If the gusset ratings are lower than those currently listed, then the FHWA Method is used.
- SIEVE 3:
  - If RFs are still very low, more detailed analysis tools could be utilized.
- SIEVE 4:
  - If more detailed analysis yields low RFs, then the low RFs are used for rating the bridge.

Most bridges are deemed okay within "Sieve 1." This takes minimal analysis effort.

DEVELOPMENT OF TRIAGE METHOD

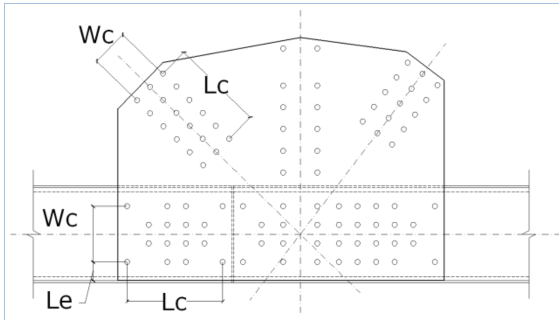
- UW Research
- BPO Involvement
- Standardizing calcs is critical. With so many engineers to do the work, and so few to review, and so few to maintain the load ratings, uniformity is key.



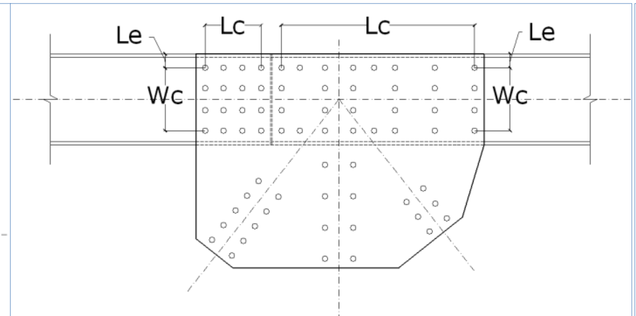
THE TRIAGE METHOD

- Three failure modes considered:
  - Gusset Yielding
  - Gusset Buckling ~ Compression Members Only
  - Rivet Shear
- If the connection is milled to bear, compression on both sides, no evaluation necessary. Tension against Milled to bear requires an evaluation.
- All plates crossing a joint are considered
  - Gussets, Wind Plates, Splice Plates
- Stress reversals require a separate evaluation for each direction.
  - Stress reversal = 2.17 LL > 1.3 DL

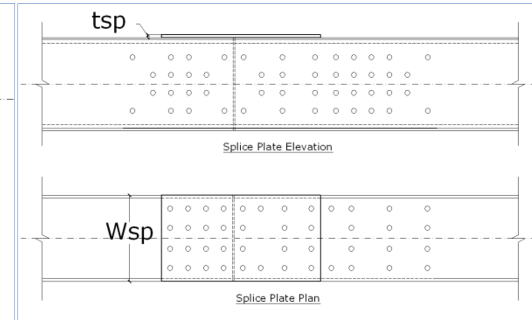
THE TRIAGE METHOD



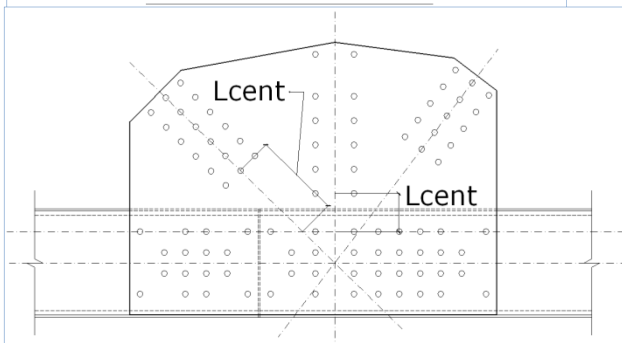
Gusset Plate Elevation



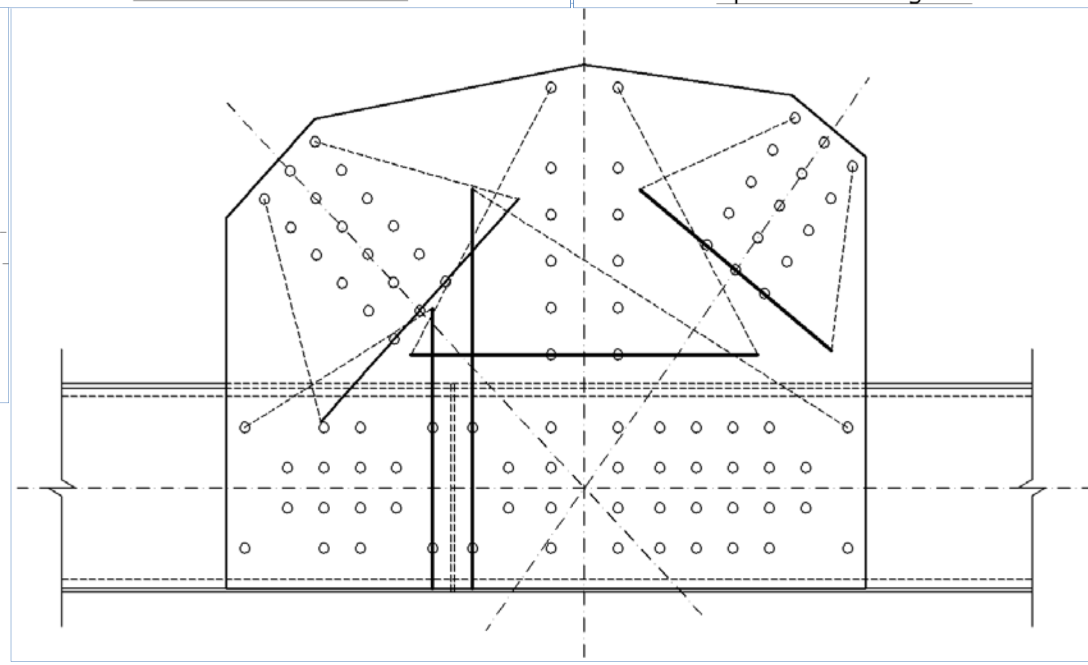
Wind Brace Elevation



Splice Plate Diagram

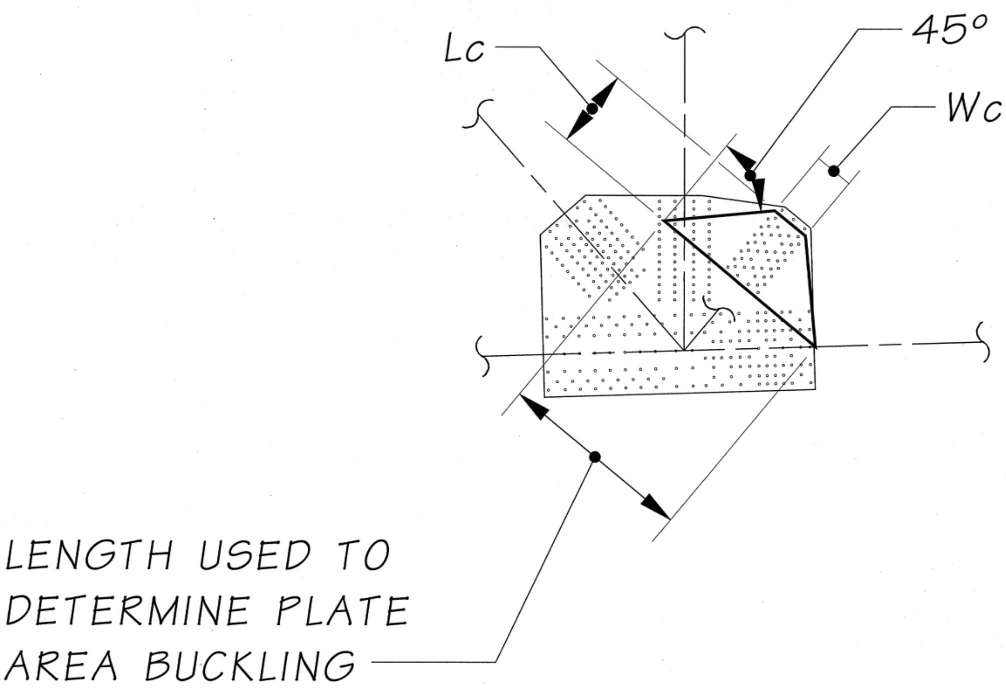


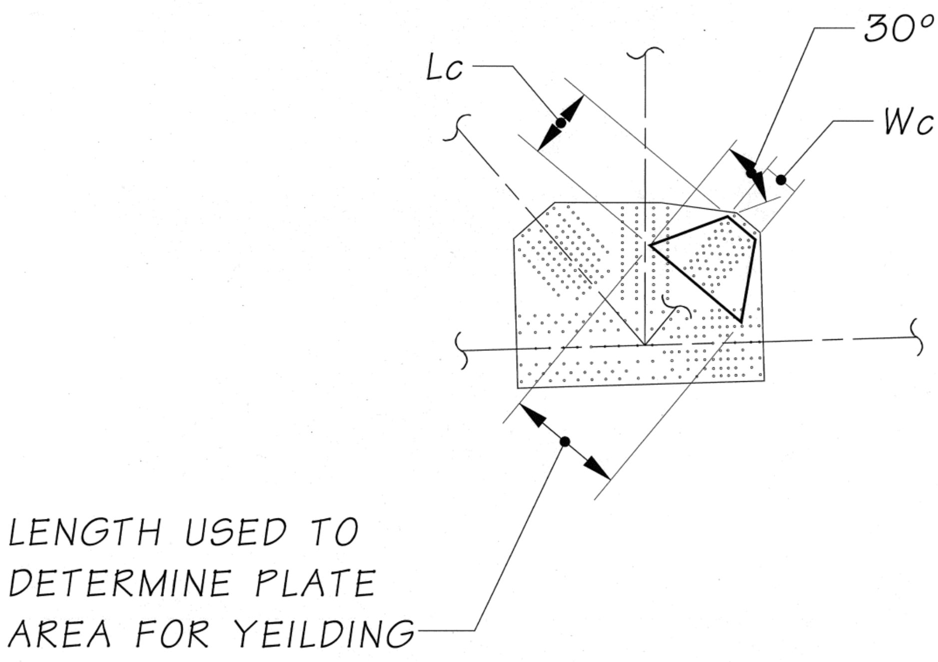
Gusset Plate Elevation



LENGTHS USED FOR AREA CALCS

THE TRIAGE METHOD





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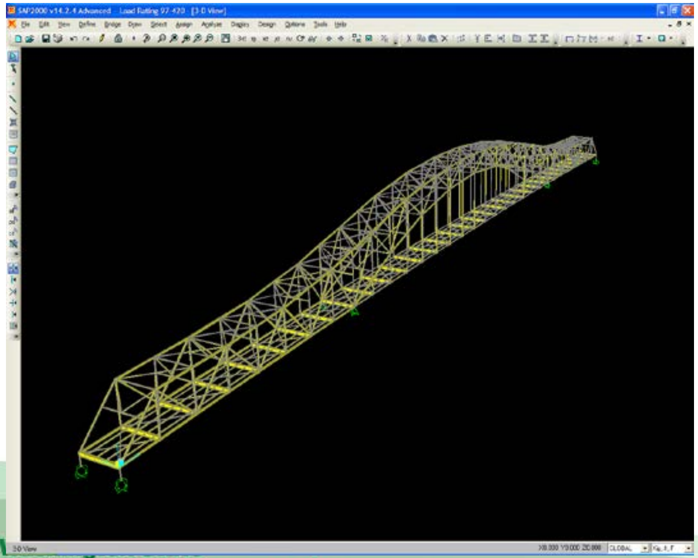
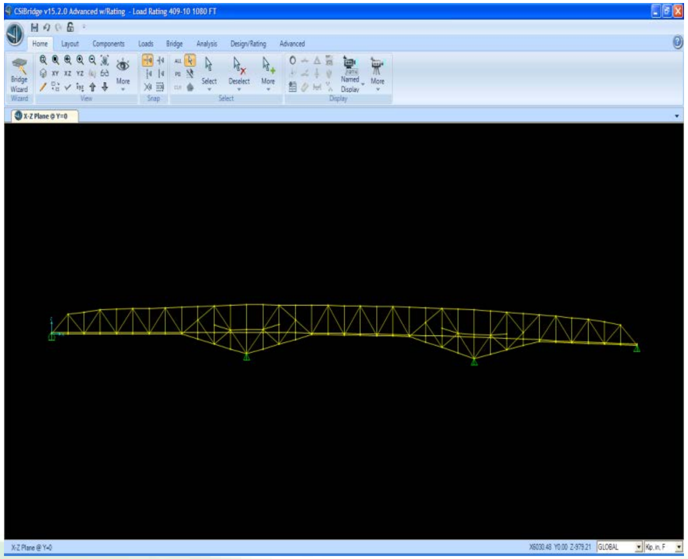
MODELING ~ METHODS

- CSI used for analysis
  - Original analysis condition considered.
  - Verified model against original dead loads.
  - Modeled idealized boundary conditions.
- 2D or 3D models used.
  - 2D quicker, 3D more useful later, but rarely.



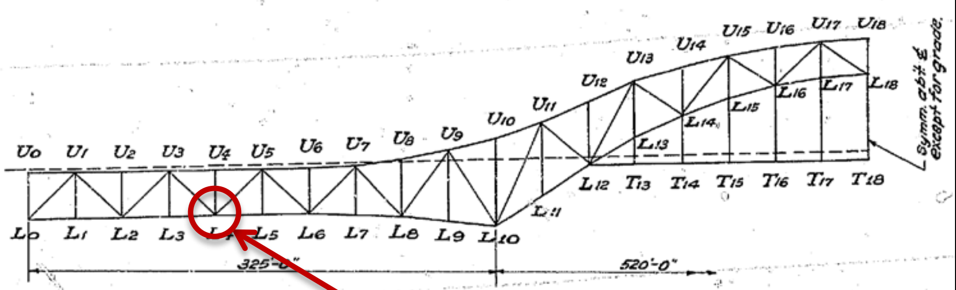


EXAMPLE ~ VANTAGE BRIDGE

130 mi.

BRIDGE LOCATION

TRIAGE EXAMPLE ~ MATERIALS



STRUCTURAL STEEL NOTES

All stresses are given in kips.
Total design stress shown is 80% of total stress when wind is included or for erection stress alone, and 66 2/3 % for erection plus erection wind.
Erection and Erection Wind Stresses are for cantilever condition only. Contractor shall submit stresses for other stages of erection.
(5) Indicates number of inches taken out of each component part of the member for rivet and hand holes.
"A"-denotes Low Alloy Steel.
All rivets shall be 7/8"φ except 3/4"φ in flanges of 12" [.
Minimum rivet spacing shall be 3".
All truss verticals, floor beams and rail posts shall be vertical.
All reaming according to the Standard Specifications 1957 of the State of Washington Department of Highways except:
Truss members shall be reamed to geometric angles,
Stringers and Laterals shall be fabricated to geometric lengths.
The normal temperature shall be 64°F.

MATERIAL SPECIFICATIONS

Structural Carbon Steel A.S.T.M. A-7
Structural Low Alloy Steel A.S.T.M. A-242
Structural Rivet Steel A.S.T.M. A-141
High Strength Bolts A.S.T.M. A-325 & A.A.S.H.O. 2.10.20
All welding shall conform to the current Specifications of the American welding Society for Welded Highway and Railway Bridges.

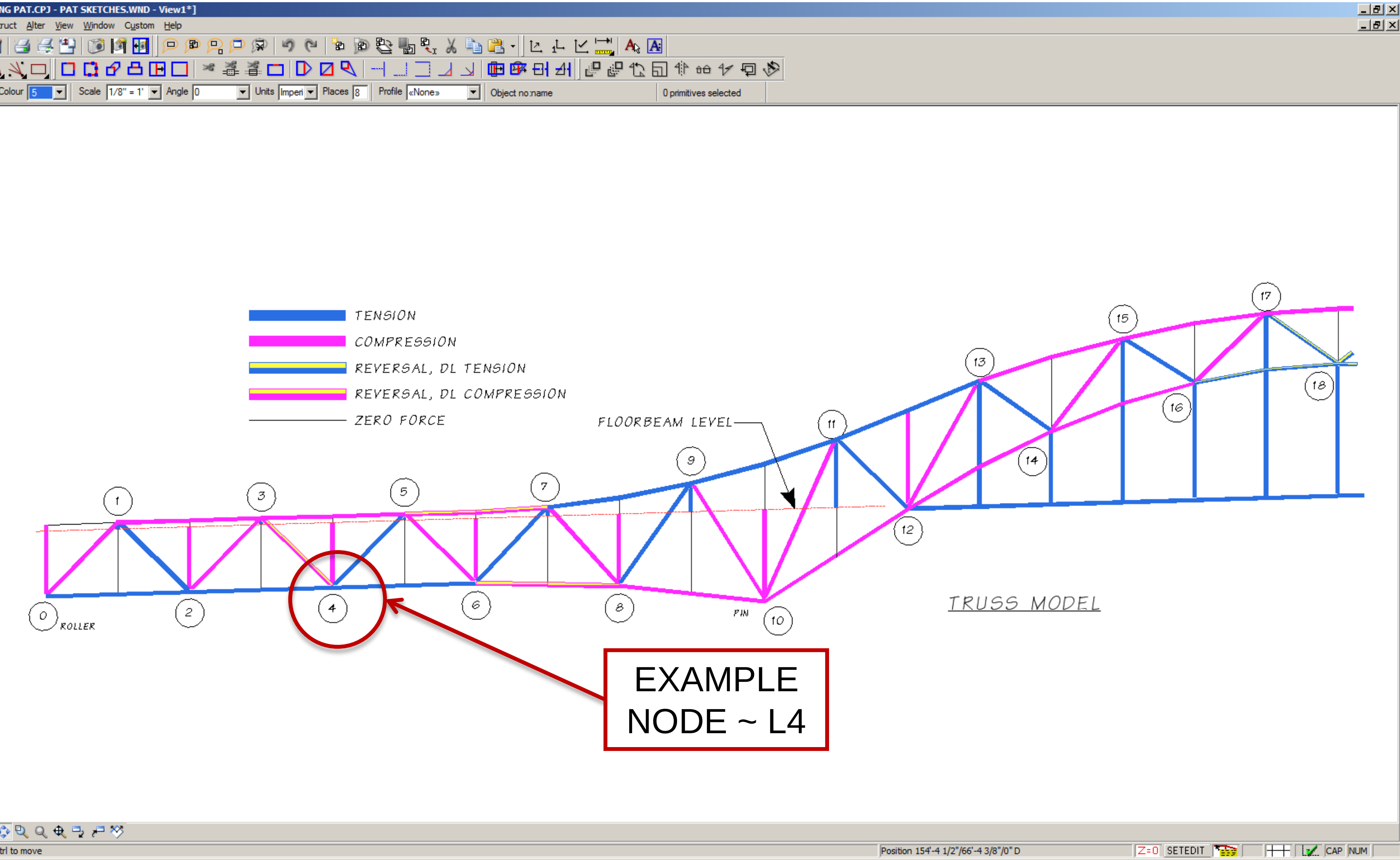
GENERAL NOTES

ASTM A-7 ~ fy = 33ksi
ASTM A-242 ~ fy = 50ksi
ASTM A-141 ~ fy = 24-32 ksi

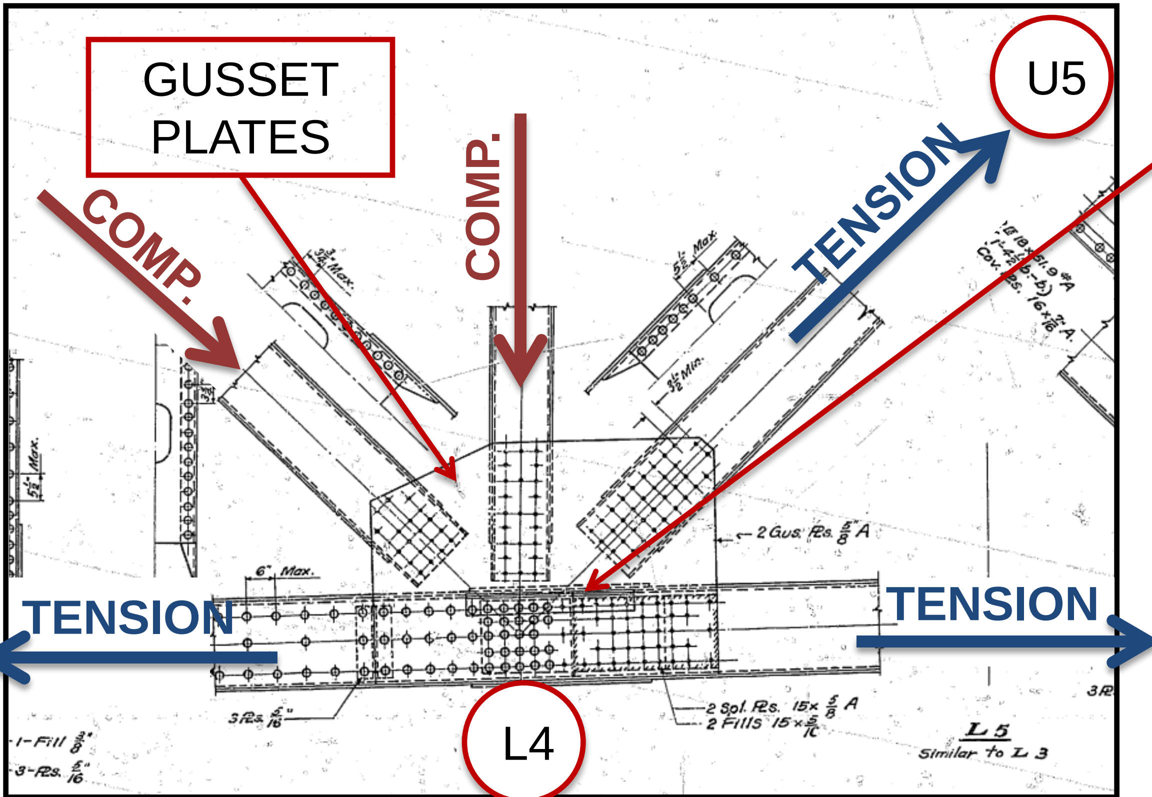
For rivets, fy varies depending upon connection length per the 2011 Interim to the 2010 MBE Article 6A.6.12.5.

EXAMPLE NODE ~ L4

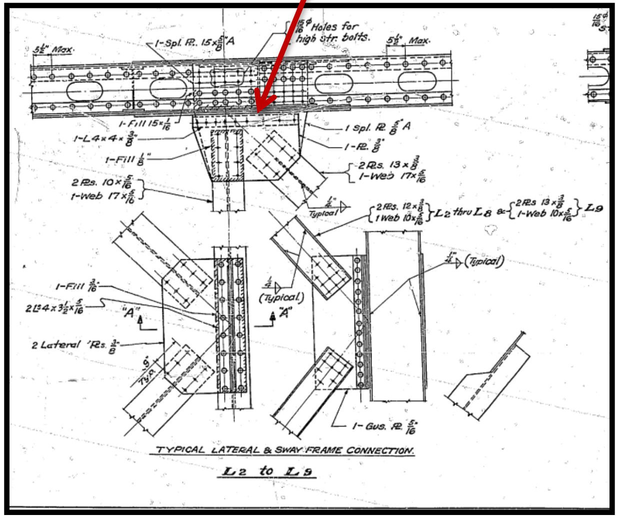
TRIAGE EXAMPLE ~ FORCES



TRIAGE EXAMPLE ~ AS-BUILTS



AS-BUILT ~ NODE L4



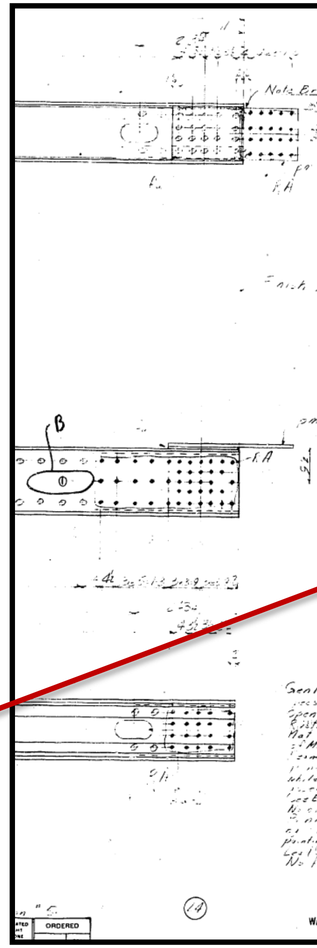
AS-BUILT ~ NODE L4

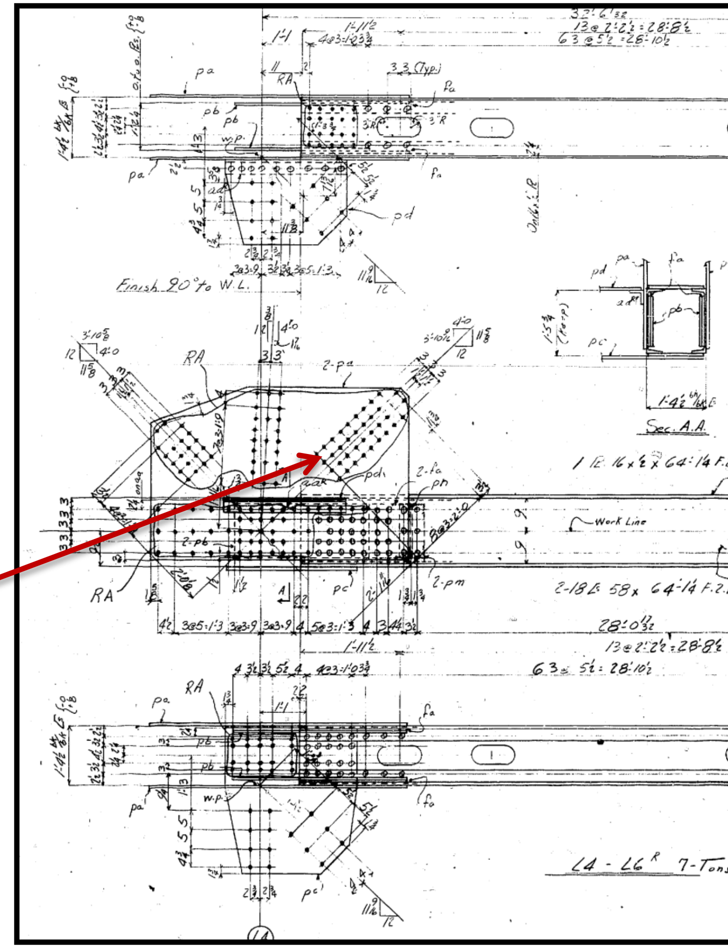
CONSIDER L4-U5 FOR OUR EXAMPLE

TRIAGE EXAMPLE ~ SHOP DRAWINGS

Often times the As-Builts are not correct. For determining exact plate sizes and connection geometry, the shop drawings are the only reliable tool.

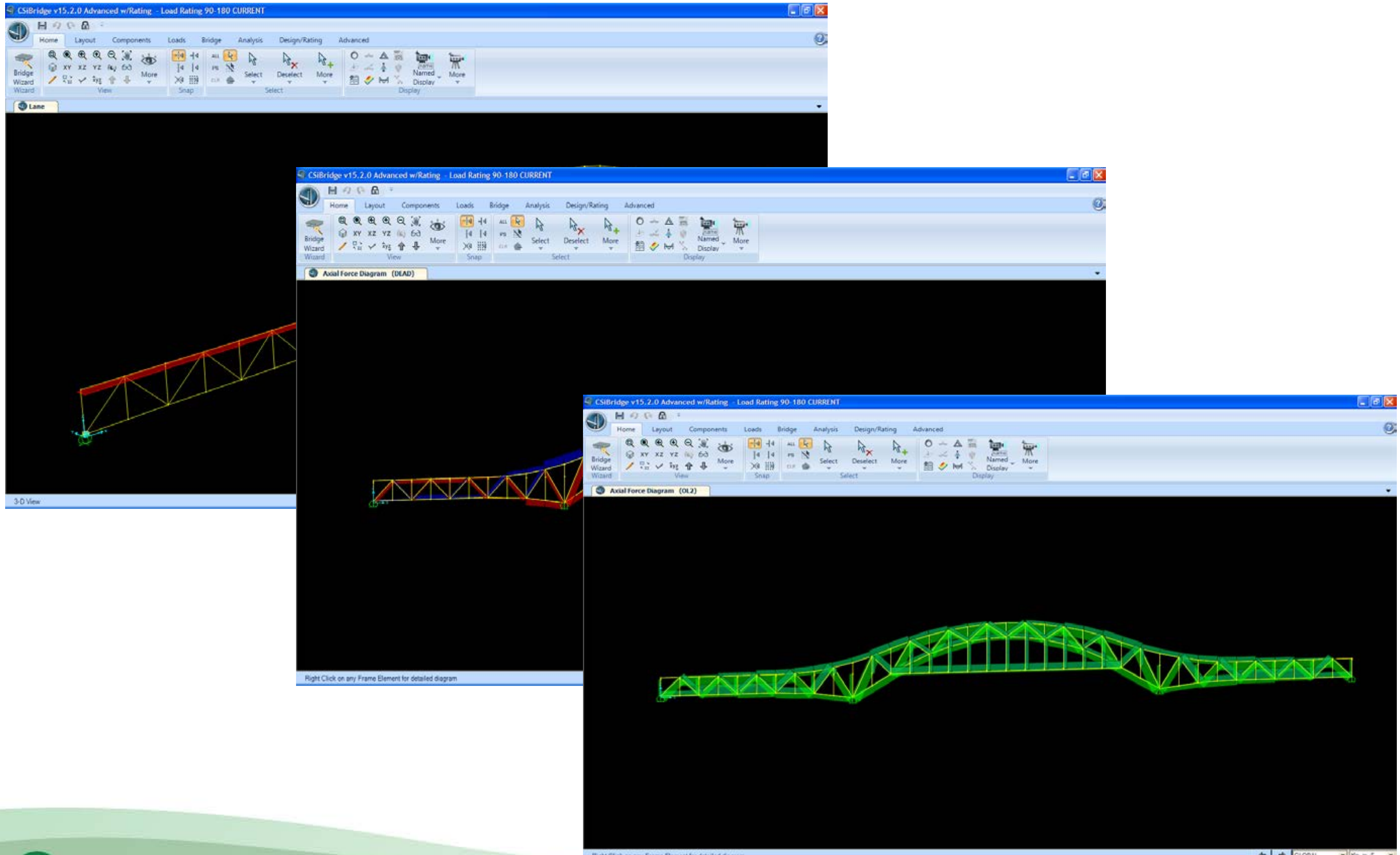
CONNECTION CONSIDRED ~ L0-U5





SHOP DRAWINGS ~ NODE L4

MODELING ~ VANTAGE



MODELING RESULTS

- Member 1028 = L4-U5

MEMBER END FORCES:															
	LANE DISTRIBUTION FACTORS:	LANE 2	LANE 3	LANE 4	TOTAL										
	1080 FT SPAN	0.4064	0.6713	0.8583	1.9360										
		2 LANES	3 LANES	4 LANES											
	Multiple Presense Factor	1.00	0.90	0.75											
TABLE: Element Forces - Frames ~ THREE LANES CONTROL											STRESS REVERSAL CONSIDERATION CHECK:				
Frame	OutputCase	DEAD	UNIT LANE		LANES 2, 3, 4		TRIAGE INPUTS		LEGAL IN LEFT		IF 2.17* opposing LL >> 1.3*DL, THEN BOTH				
			Tension	Comp.	Tension	Comp.	Tension	Comp.	FOR OL IN RIGHT		DIRECTIONS OF LOAD ARE CONSIDERED.				
			(kips)	(kips)	(kips)	(kips)	(kips)	(kips)	T. (kips)	C. (kips)					
1028	DEAD	314.7					HS-20 CHECK					1.3DL =	409.1	kips	
	HS-20 TK		50.0	-34.6	87.1	-60.2	Chord?	N				2.17 opposing LL =	-193.0	kips	
	HS-20 18K		75.9	-36.6	132.3	-63.8	CONTROLING HS-20					CHECK:	No reversal check required.		
	HS-20 26K		81.9	-40.8	142.6	-71.0	142.64	-71.05	54.7	-35.7					
	TYPE 3		35.2	-24.4	61.4	-42.6	61.39	-42.57							
	TYPE 3S2		46.4	-31.6	80.8	-55.1	80.78	-55.06							
	TYPE 3-3		49.1	-33.4	85.6	-58.2	85.62	-58.16							
	NRL		53.9	-36.8	94.0	-64.2	93.97	-64.20							
	LEGAL LANE		56.4	-33.5	98.2	-58.4	98.25	-58.43							
	OL1		65.2	-44.9	113.7	-78.2	50.39	-30.14	NOTE:						
	OL2		118.5	-79.3	206.4	-138.1	91.52	-53.20	OL for triage input						

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ANALYSIS

Gusset Plate Inputs & Summary

Sheet Information									
Rated By	Company	Date	Bridge ID	Gusset ID	Number of Connections	Include Rivets?	Condition Factor, ϕc	Redundancy Factor, ϕs	Comments
Patrick Gallagher	WSDOT Bridge	12/19/2012	90/180	L4	5	Y	1	1	Live load distribution considered in the reactions input below.
								ϕs equals 1 for LFR	

Forces entered into spreadsheet shall be based on a single lane distribution.

LL Distribution Factors		
AASHTO & Legal Trucks	OL Trucks	Legal Truck w/OL
1.000	1.000	1.000

LL Distribution factor for Design & Legal truck shall be based on the number of lanes multiplied by the appropriate reduction factor.
LL Distribution factor for one OL placed in lane closest to truss multiplied by the appropriate reduction factor.
LL Distribution factor for Legal Truck w/OL assumes legal loads are placed in lanes adjacent to OL truck multiplied by the appropriate reduction factor.

LL Input and RF Summary									Operating RF for LFR only	
Load Case ID	Live Loads					Minimum RF	Controlling Connection ID	Controlling Resistance Type		
	Truck Type	Overload?	γ_{LL}	Impact Factor (I)	Rating Method				γ_{LL}	Minimum RF
HS-20	HS-20	N	2.17	0.0943	LFR	1.66	L4-L3	Rivets	1.3	2.77
TYPE 3	TYPE 3	N	2.17	0.0943	LFR	2.65	L4-U4	Rivets	1.3	4.43
TYPE 3S2	TYPE 3S2	N	2.17	0.0943	LFR	2.52	L4-U4	Rivets	1.3	4.21
TYPE 3-3	TYPE 3-3	N	2.17	0.0943	LFR	2.63	L4-L3	Rivets	1.3	4.40
NRL	NRL	N	2.17	0.0943	LFR	1.69	L4-U4	Rivets	1.3	2.81
LEGAL LANE	LEGAL LANE	N	2.17	0.0943	LFR	2.26	L4-L3	Rivets	1.3	3.77
OL1	OL1	Y	1.3	0.2	LFR	4.68	L4-U4	Rivets	1.3	4.68
OL2	OL2	Y	1.3	0.2	LFR	3.01	L4-L3	Rivets	1.3	3.01

Plate Material & Dimension Inputs

Gusset Plate Properties		Wind Gusset Plate Properties		Splice Plate Properties		Rivet Properties	
Fy_gp (ksi)	50	Fy_wp (ksi)	33	Fy_sp (ksi)	50	Fu_r (ksi)	24
Thickness, tgp (in)	0.625						
Num Plates, np	2						

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ANALYSIS

Triage Procedure Connection Inputs

Rated By	*Patrick Gallagher*
Company	*WSDOT Bridge*
Date	*#########*
Bridge ID	*90/180*

Connection Information					
Connection ID	Chord or Web?	Splice PL's?	Wind Bracing GP?	Comp. or Tension?	Milled to Bear, Y/N?
L4-U5	Web	N	N	Tension	

Gusset Plate Connection			
Wc (in)	9	2*Lc tan 30 + Wc	36.71
Lc (in)	24	Is Plate Width < 2*Lc tan 30 + Wc?	N
Le (in)			
Plate Width (in)		Plate Width valid only for web members and when < 2*Lc tan 30 +Wc	

Individual Splice Plate Dimensions		
Splice ID	Wsp (in)	tsp (in)

Wind Brace GP Dimensions				
Brace ID	Wc (in)	Lc (in)	Le (in)	twp (in)

Summary of Yielding Resistance Calculations				
Agp_wb (in^2)	45.89	»		
Awp (in^2)	0.00		Rn (k)	1324.8
ΣAspi (in^2)	0.00			

Buckling Resistance Inputs

Buckling Input	Summary of Buckling Resistance Calculations					
Centroidal Length, L_cent (in)	L_Whit45 (in)	Ig (in^4)	Ag (in^2)	φc	»	
	57.00	2.319	71.25	1		Rn (k)
Whitmore Length Manual Input (in)	rs (in)	L_cent (in)	λ	K		N/A
	0.180	0.000	0.000	1.0		

Does the L_Whit45 exceed the actual width of the plate?

-

Rivet Input				Rivet Resistance
Rivet Diameter, D_r (in)	# of Single Shear Rivets, nss	# of Double Shear Rivets, nds	»	Rn (k)
0.875	72	0		1039.1

Rating Factors

Controlling Resistance (k)	Resistance Type
1039.1	Rivets

Dead Load Rating Method			
Rating Method	LFR	»	Factored DL (k)
γDL	1.3		409.11
Dead Load (k)	314.7		

Rating Method	LRFR	»	Factored DL (k)
γDL_C			0
DL_C (k)			
γDL_W			
DL_W (k)			

Controlling Legal Load for OL rating	
Maximum Legal Load	54.68950305

Maximum force due to legal load based on one lane distribution

Controlling RF	

LL Input and Connection RF Summary						Resistance Type		
	Live Loads					Yielding	Buckling	Rivets
Load Case ID	Truck Type	γLL	Impact Factor (I)	Rating Method	Member LL (k)	RF	RF	RF
HS-20	HS-20	2.17	0.0943	LFR	142.641576	2.70	N/A	1.86
TYPE 3	TYPE 3	2.17	0.0943	LFR	61.3899792	6.28	N/A	4.32
TYPE 3S2	TYPE 3S2	2.17	0.0943	LFR	80.7759216	4.77	N/A	3.28
TYPE 3-3	TYPE 3-3	2.17	0.0943	LFR	85.621536	4.50	N/A	3.10
NRL	NRL	2.17	0.0943	LFR	93.9728592	4.10	N/A	2.82
LEGAL LANE	LEGAL LANE	2.17	0.0943	LFR	98.245224	3.92	N/A	2.70
OL1	OL1	1.3	0.2	LFR	50.39439786	10.56	N/A	6.93
OL2	OL2	1.3	0.2	LFR	91.51606584	5.82	N/A	3.82

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SUMMARY OF NODES

RATING FACTORS

TRUCK	L0		L2		L4		L6		L8		L10		L12		L13		L14		L15		L16		L17		L18		MIN. RATING FACTORS		MIN. RATING FACTORS ALL SPANS	
	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating		
AASHTO 1	2.52	4.20	2.83	4.73	2.65	4.43	2.43	4.06	2.15	3.59	4.08	6.81	3.25	5.43	2.50	4.17	2.50	4.17	2.47	4.12	2.50	4.16	1.28	2.14	2.49	4.15	1.28	2.14	Inventory	Operating
AASHTO 2	1.85	3.09	2.07	3.45	2.52	4.21	1.88	3.14	1.57	2.63	2.89	4.83	2.48	4.15	2.37	3.96	2.37	3.96	2.30	3.84	2.32	3.87	1.22	2.03	2.36	3.95	1.22	2.03	1.28	2.14
AASHTO 3	1.71	2.85	1.93	3.22	2.59	4.33	1.74	2.91	1.45	2.43	2.63	4.38	2.34	3.91	2.53	4.23	2.34	3.91	2.43	4.05	2.18	3.63	1.30	2.17	2.49	4.16	1.30	2.17	1.22	2.03
NRL	1.62	2.70	1.77	2.95	1.69	2.81	1.55	2.58	1.38	2.30	2.59	4.33	2.11	3.52	1.59	2.65	1.59	2.65	1.57	2.62	1.59	2.65	0.81	1.36	1.58	2.64	0.81	1.36	1.30	2.17
Legal Lane	1.50	2.50	1.59	2.65	2.22	3.71	1.55	2.59	1.30	2.17	1.89	3.15	2.10	3.50	2.77	4.63	2.09	3.49	2.54	4.24	1.81	3.02	1.39	2.31	2.07	3.46	1.30	2.17	0.81	1.36
OL1	NA	3.98	NA	3.74	NA	4.68	NA	3.57	NA	3.23	NA	6.84	NA	5.70	NA	3.78	NA	3.78	NA	3.71	NA	3.78	NA	1.39	NA	3.76	NA	1.39	1.30	2.17
OL2	NA	2.04	NA	1.88	NA	2.94	NA	1.84	NA	1.65	NA	3.24	NA	3.11	NA	3.02	NA	3.02	NA	2.85	NA	2.82	NA	1.11	NA	2.88	NA	1.11	NA	1.39
Inventory (HS20)	1.06		1.14		1.63		1.12		0.95		1.15		1.49		1.85		1.47		1.82		1.18		0.95		1.36		0.95		NA	1.11
Operating (HS20)		1.77		1.91		2.73		1.87		1.58		1.92		2.49		3.08		2.46		3.04		1.97		1.58		2.27		1.58	0.90	
																														1.51

RATING FACTORS

TRUCK	U1		U3		U5		U7		U8		U9		U10		U11		U13		U15		U17		L4, L6, L16 REV.		U6 REV.		MIN. RATING FACTORS	
	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating
AASHTO 1	2.90	4.84	2.25	3.75	3.51	5.86	2.93	4.90	5.62	9.39	2.41	4.03	7.58	12.65	4.40	7.34	2.84	4.74	2.47	4.12	2.13	3.55	4.94	8.25	5.95	9.93	2.13	3.55
AASHTO 2	2.13	3.55	1.68	2.81	2.61	4.36	2.15	3.58	3.95	6.59	2.30	3.83	5.30	8.85	4.20	7.00	2.47	4.13	2.30	3.84	1.99	3.32	3.76	6.28	4.17	6.97	1.68	2.81
AASHTO 3	1.98	3.30	1.57	2.62	2.43	4.06	1.98	3.31	3.58	5.98	2.27	3.79	4.81	8.03	4.05	6.76	2.33	3.89	2.24	3.74	2.10	3.51	3.53	5.90	3.79	6.32	1.57	2.62
NRL	1.84	3.07	1.46	2.43	2.27	3.79	1.88	3.14	3.53	5.89	1.53	2.56	4.75	7.93	2.80	4.67	1.80	3.01	1.57	2.62	1.35	2.26	3.24	5.40	3.73	6.23	1.35	2.26
Legal Lane	1.71	2.86	1.47	2.46	2.11	3.52	1.78	2.96	2.56	4.27	1.80	3.00	2.69	4.48	3.02	5.03	2.09	3.49	2.00	3.34	1.81	3.02	3.42	5.70	2.81	4.69	1.47	2.46
OL1	NA	4.70	NA	3.55	NA	6.10	NA	4.69	NA	8.64	NA	3.62	NA	11.72	NA	7.53	NA	4.44	NA	3.71	NA	3.05	NA	8.13	NA	9.28	NA	3.05
OL2	NA	2.44	NA	1.89	NA	3.22	NA	2.41	NA	4.10	NA	2.55	NA	5.55	NA	4.83	NA	3.10	NA	2.85	NA	2.36	NA	4.45	NA	4.40	NA	1.89
Inventory (HS20)	1.28		1.12		1.45		1.29		1.55		0.90		1.35		1.58		1.48		1.41		1.18		2.71		1.76		0.90	
Operating (HS20)		2.13		1.88		2.43		2.16		2.58		1.51		2.26		2.64		2.48		2.35		1.97		4.73		2.94		1.51

RATING FACTORS

TRUCK	U3, U5, U17 REV.		L8 REV.		L17 REV.		L18 REV.		Tie Splice		MIN. RATING FACTORS	
	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating	Inventory	Operating
AASHTO 1	4.94	8.25	10.96	18.29	7.97	13.31	6.11	10.20	3.92	6.54	3.92	6.54
AASHTO 2	3.76	6.28	8.27	13.80	5.77	9.64	4.55	7.60	2.73	4.55	2.73	4.55
AASHTO 3	3.53	5.90	7.80	13.01	5.33	8.90	4.24	7.07	2.46	4.11	2.46	4.11
NRL	3.24	5.40	6.90	11.52	5.01	8.36	3.97	6.63	2.45	4.09	2.45	4.09
Legal Lane	3.42	5.70	6.82	11.38	4.58	7.64	3.63	6.06	1.68	2.81	1.68	2.81
OL1	NA	8.13	NA	19.06	NA	15.22	NA	11.56	NA	5.49	NA	5.49
OL2	NA	4.45	NA	10.15	NA	7.59	NA	6.11	NA	2.56	NA	2.56
Inventory (HS20)	2.39		5.08		3.38		2.48		0.98		0.98	
Operating (HS20)		3.99		8.48		5.64		4.13		1.64		1.64

CONTROLING RF W/O GUSSETS:

AASHTO 1 = 1.10
AASHTO 2 = 1.05
AASHTO 3 = 1.12
NRL = NA ~ Pre 2011
Legal Lane = 1.00
OL1 = 1.08
OL2 = 0.92
HS20 Inventory = 0.31
HS20 Operating = 0.52

OTHER PORTIONS HAVE LOWER RFS, GUSSETS DO NOT CONTROL. RATING COMPLETE

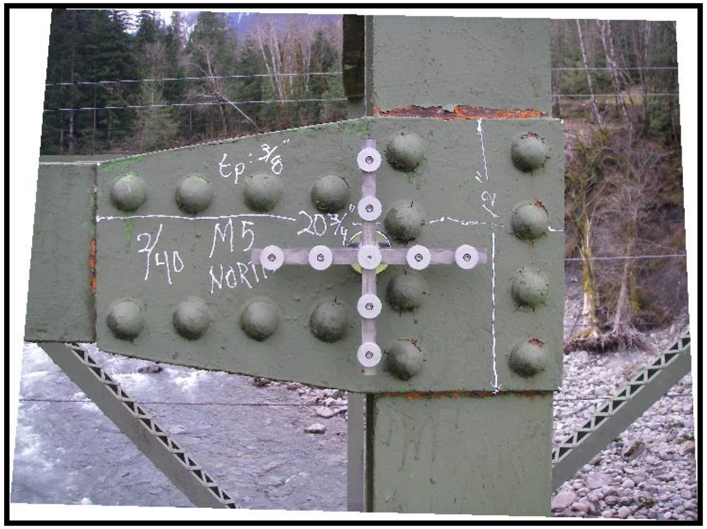
APPLICATION ~ SO WHAT?

- SIEVE 1:
  - If the Rating Factors are higher than those currently listed, then the analysis is done.
- SIEVE 2:
  - If the gusset ratings are lower than those currently listed, then the FHWA Method is used.
- SIEVE 3:
  - If RFs are still very low, more detailed analysis tools could be utilized.
- SIEVE 4:
  - If more detailed analysis yields low RFs, then the low gusset RFs are used for rating the entire bridge.

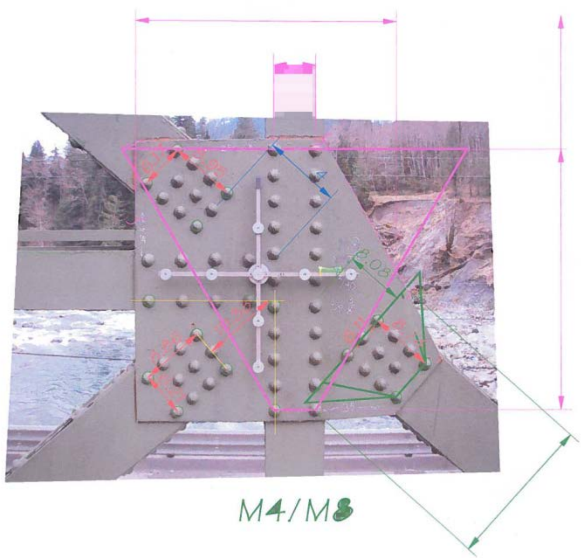
OTHER FACTORS

- Know the spreadsheet and how it works.
  - Not everything fits into the mold of that spreadsheet.
    - Stacked gussets, varying material strengths, varying rivet diameters, triple shear rivets.
- Know what you’re trying to achieve.
  - Lift span bridges are closed under live load.
  - Understand erection stresses and how they were managed.
- Know how truss bridges function.
  - Truss engineering is a dying art. Learn how they work.
  - If it should be a zero force member, make it one.
  - Hanger members should all have the same loads.
  - Understand drop spans and cantilever spans.

NO AS-BUILTS?



U3/U9



M4/M8

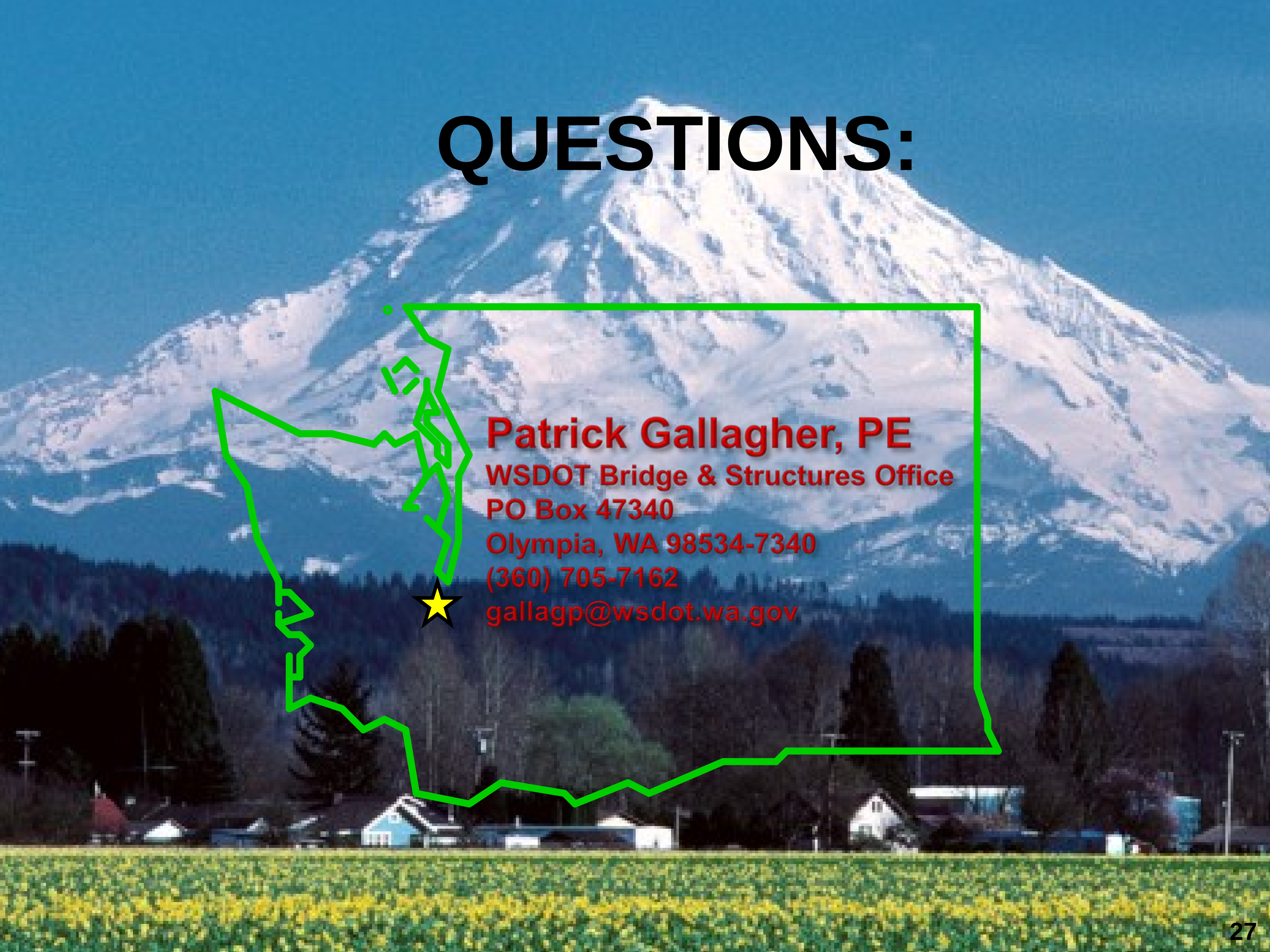
WHAT'S NEXT?

- Once the ratings are updated for gussets, maintaining those records will be ongoing.
- Inspection practices have been adjusted to account for gussets.
- More effort and discussion will be given to bridge maintenance.
- The timeliness is excellent. With a huge design and construction package being completed, maintenance is a natural place to turn efforts towards.

FUTURE OF INSPECTION

- Gusset plates are now their own BMS Element.
- Bridge inspections have been including field verification of gusset thicknesses.
- Truss ratings include gusset ratings.

Washington State
Department of Transportation



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