Boardman to Hemingway Transmission Line Project

Lattice Towers: A Case Study

PLS 2026 Users Group

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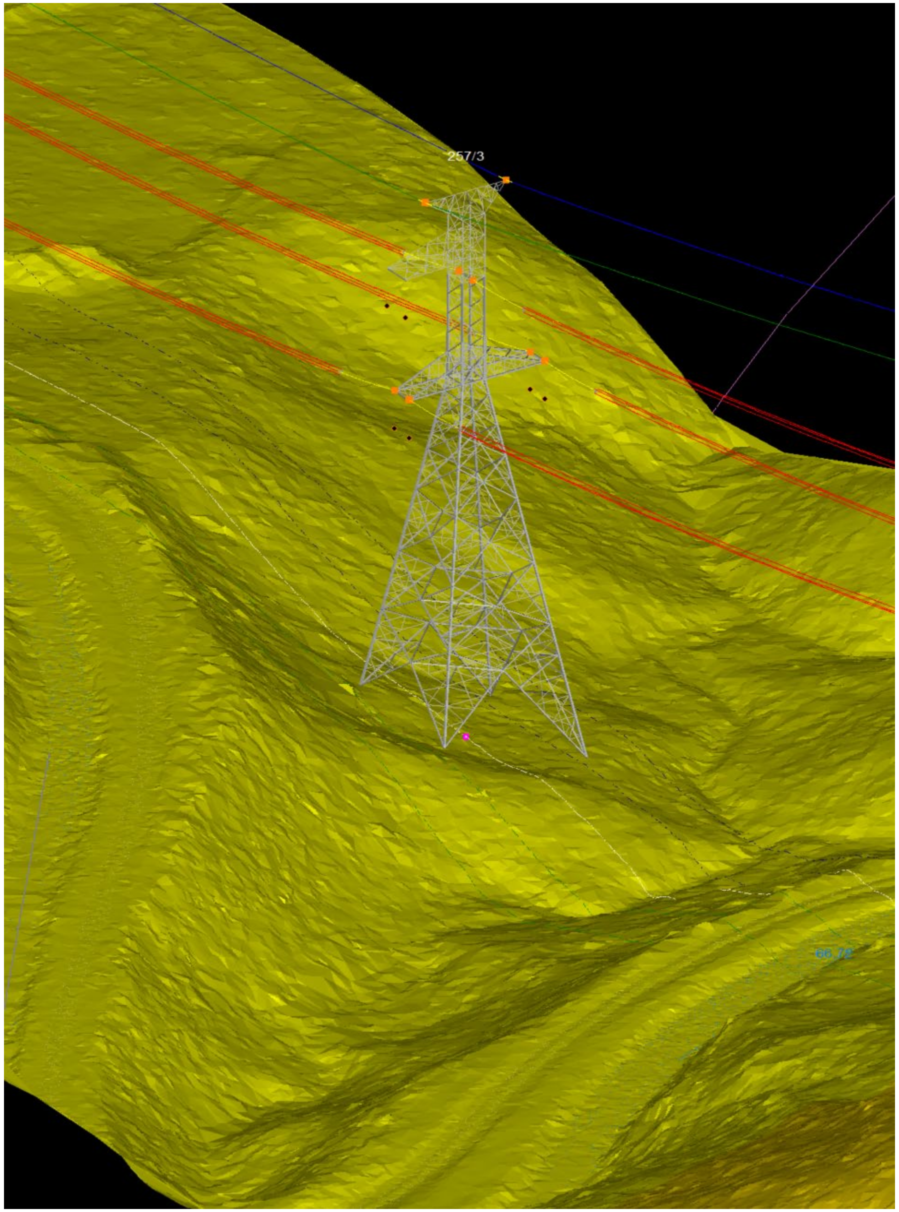
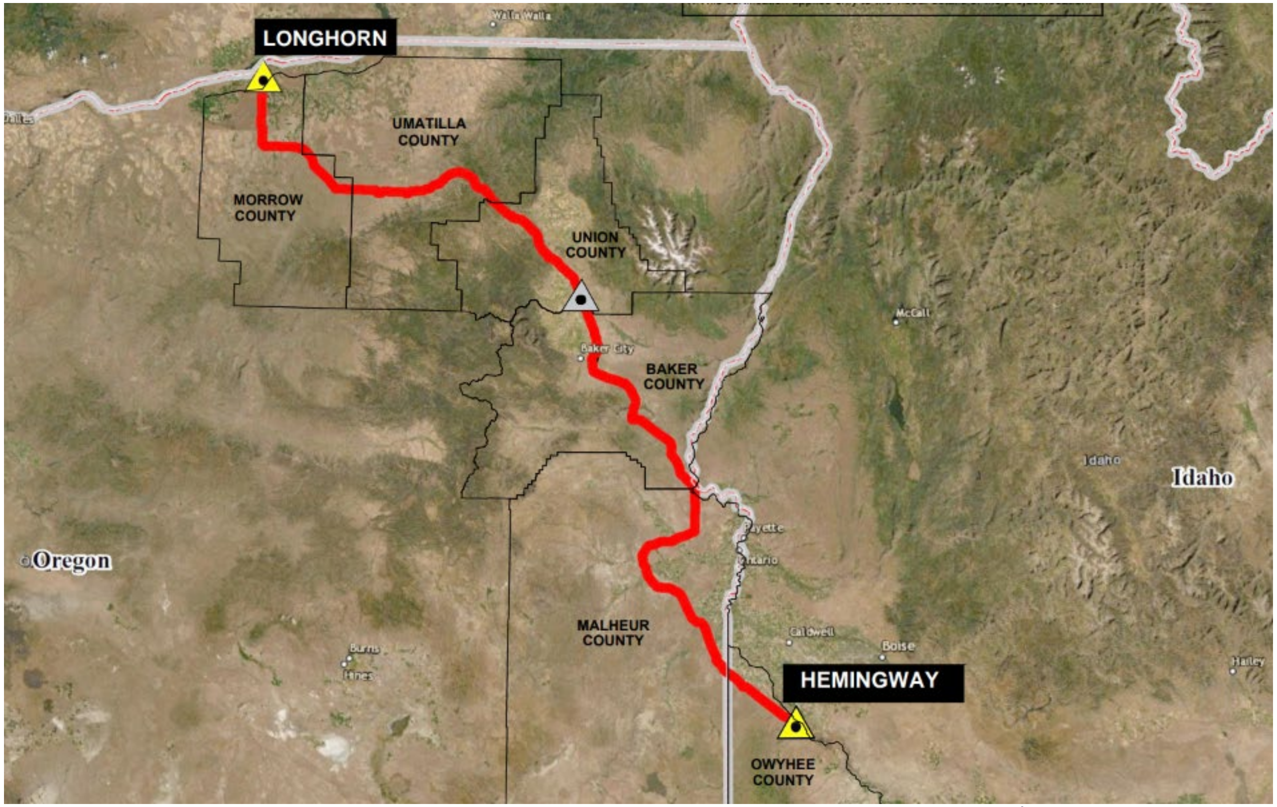
Presentation Outline

- **Project Overview**
- Lattice Tower Overview
  - Modifications
  - Load Case Development
  - Testing
- Lattice Tower Modeling
  - Developing preliminary models
  - Models change over design life
  - Family Manager
- Leg Extensions Design
  - PLS-CADD automatic spotting
  - Requirements
  - results



Project Overview

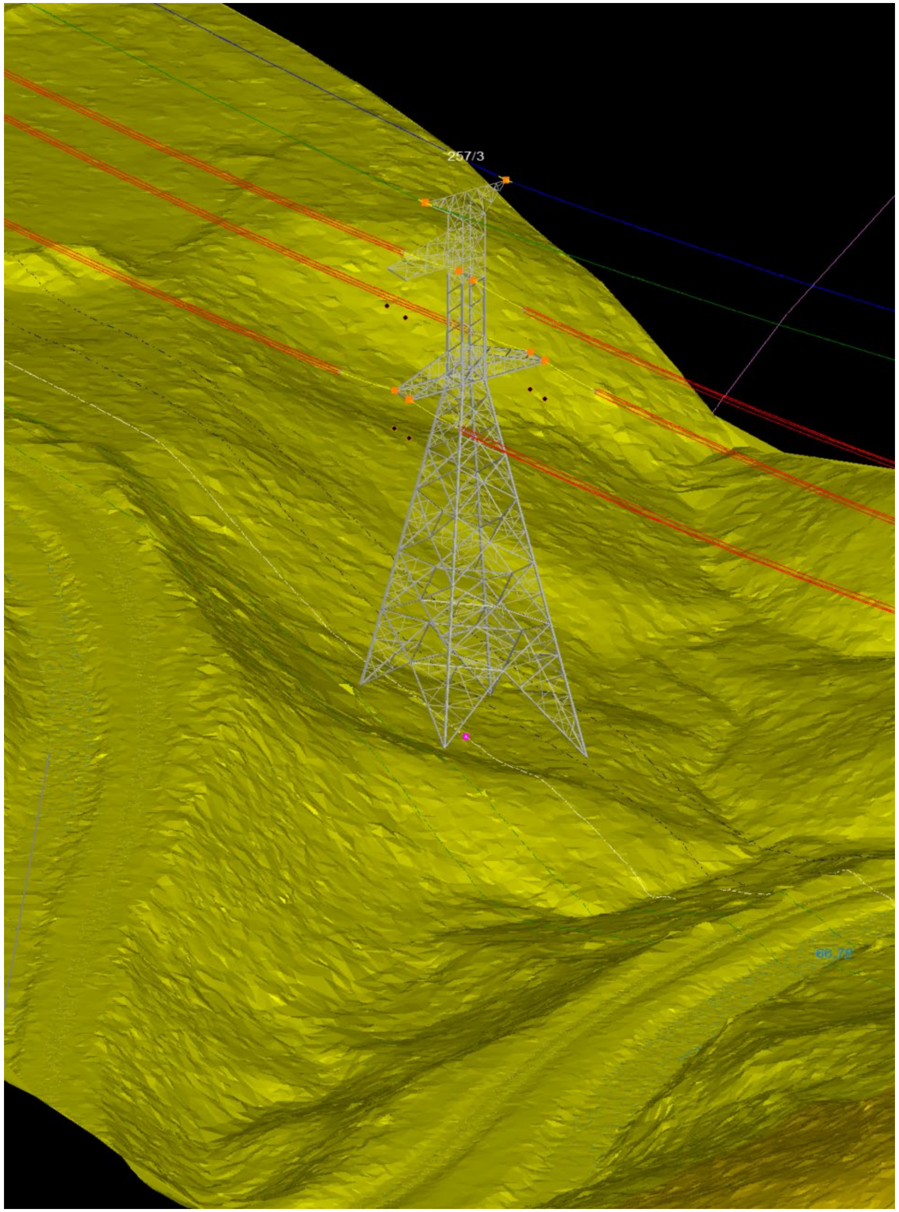
- Idaho Power, Boardman (BPA “Longhorn”) to Hemingway 500kV
  - 300 miles, ~1150 lattice towers, 120 tubular steel
    - 225 miles “as the crow flies”
  - Permitting
    - 2008-2020
  - Design:
    - 2021-2025
  - Construction:
    - 2025-2028



Project Overview

Presentation Outline

- Project Overview
- **Lattice Tower Overview**
- Lattice Tower Modeling
- Leg Extensions Design



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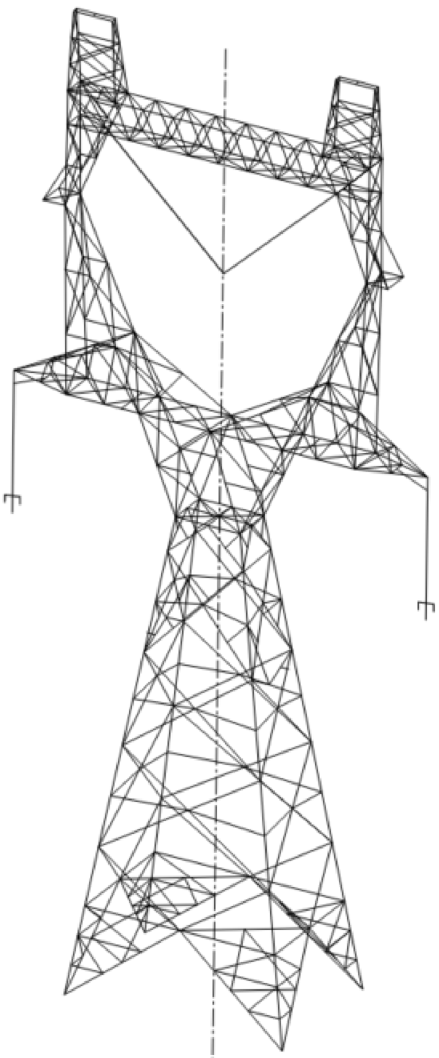
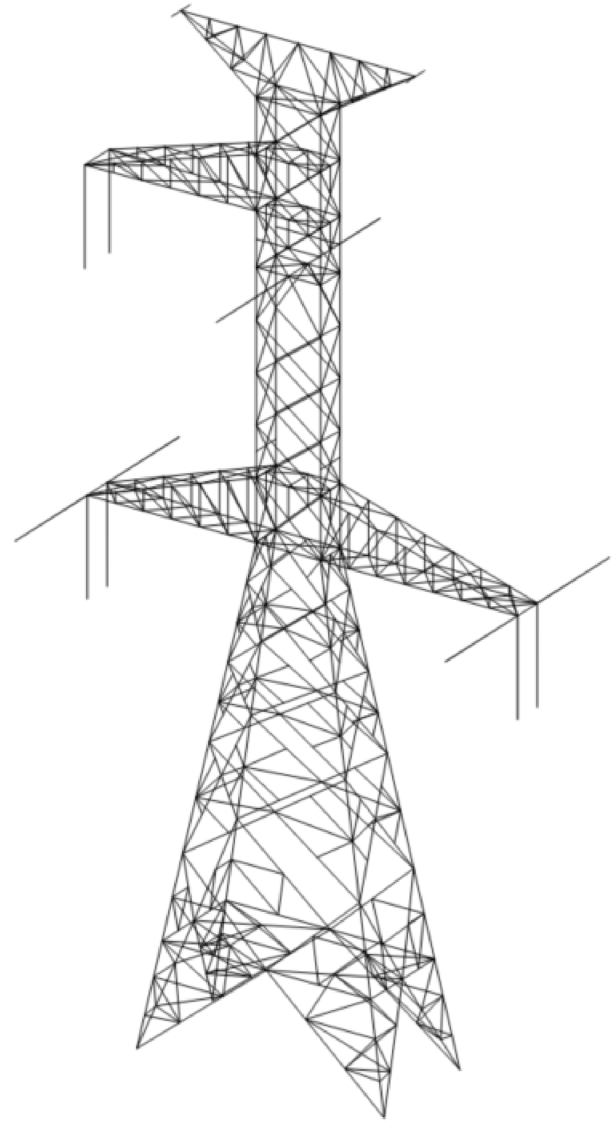
Lattice Towers: Overview

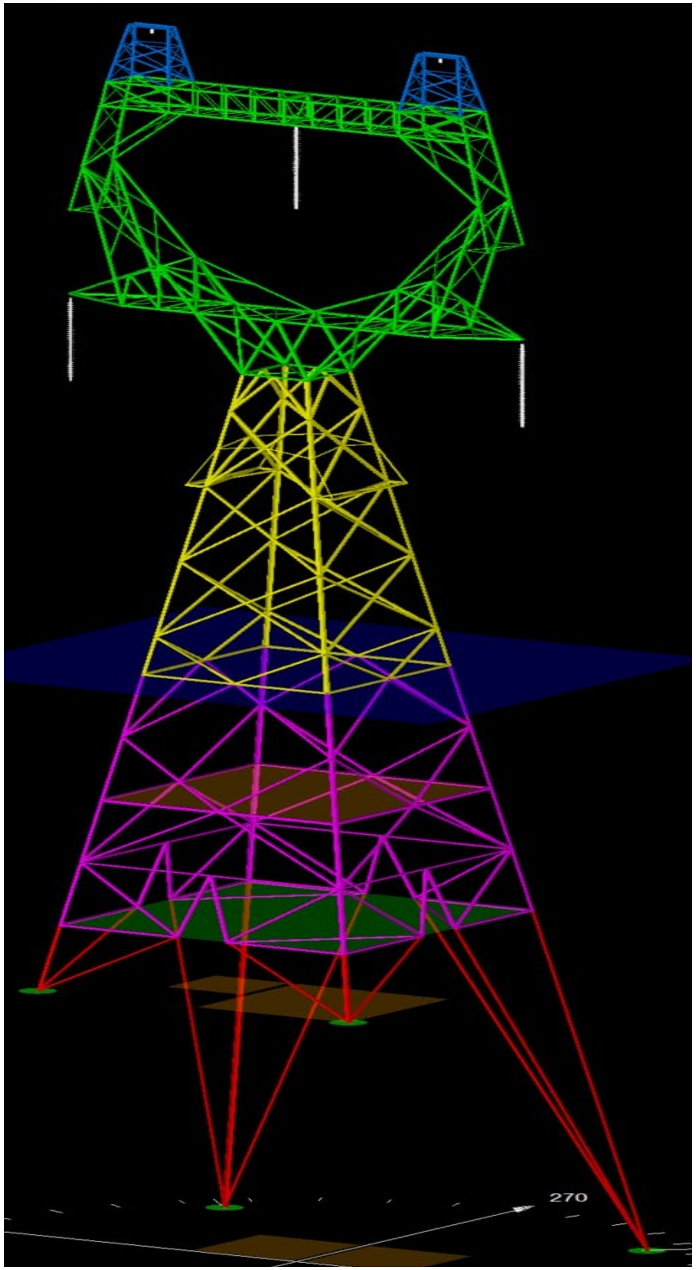
- Modified BPA 248 Series
  - Freestanding
  - Delta
  - 3Bundle Conductor
    - Deschutes ACSR/TW
  - 2x OPGW
  - 3x Tangents
    - Light 248M
    - Medium 248A
    - Heavy 248B
  - 2x Deadends
    - Standard 248D
    - Corner 248G
- Modeled in BPA ATADS
  - Proprietary
  - Not compatible with PLS





Lattice Towers: BE & LE

- Typical Tower has:
  - Common Component (CC)
    - Static Peak
    - Cage
  - 3 Body Configurations (BE)
    - 60 (base common body)
    - 80 (+20 body extension)
    - 100 (+20 +20 body extension)
  - Leg Extensions (LE)
    - Range: 5 to 50 feet
    - 2.5ft increments
  - Height Range:
    - 107 ft to 205ft



Lattice Tower: Why Modifications?

- Almost every large 500kV Project has unique requirements:
  - Different Insulators
    - Hardware, OPGW, Details
    - Helicopter Erection
  - Different Line Arrangement
    - Structure Types
    - Optimization
  - Load Cases
    - Standards Change
    - Different Utility Requirements
  - Testing
    - Prototype test fitment
    - Full scale loading
  - Construction Means & Methods
  - Foundations
- 12 month effort in conjunction with SANPEC & SAE / KEC

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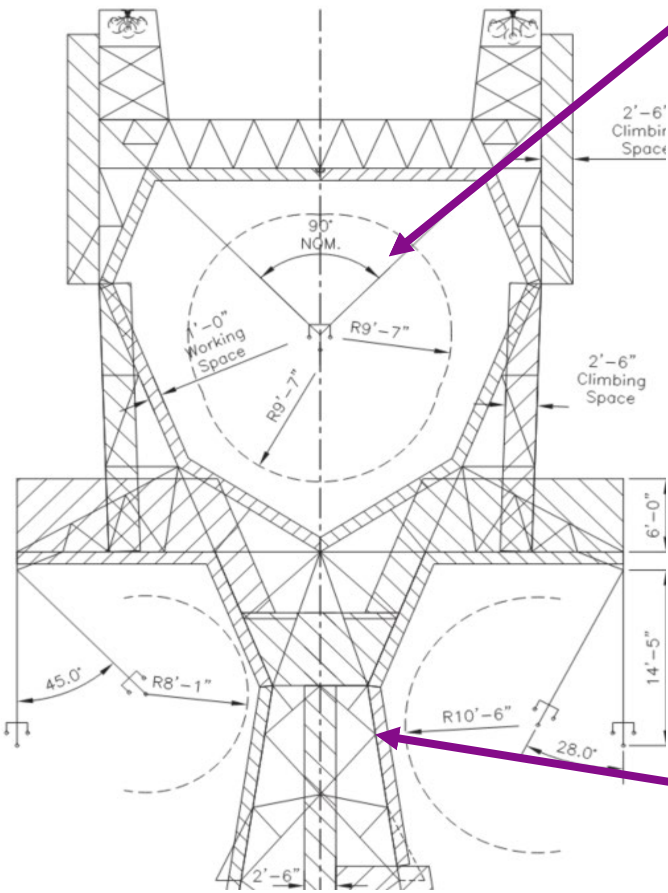
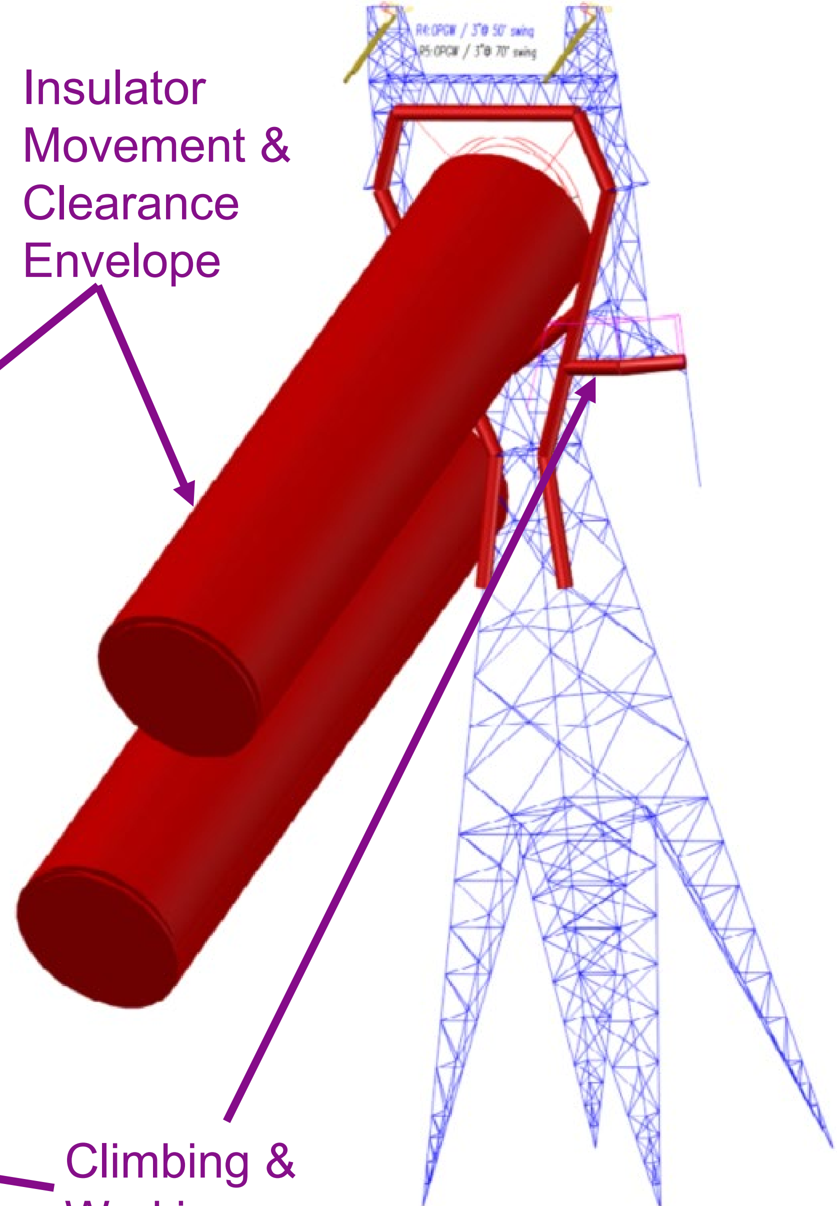
Insulators

- 2D vs 3D swing/clearance
  - suspension

Insulator Movement & Clearance Envelope





Climbing & Working Space

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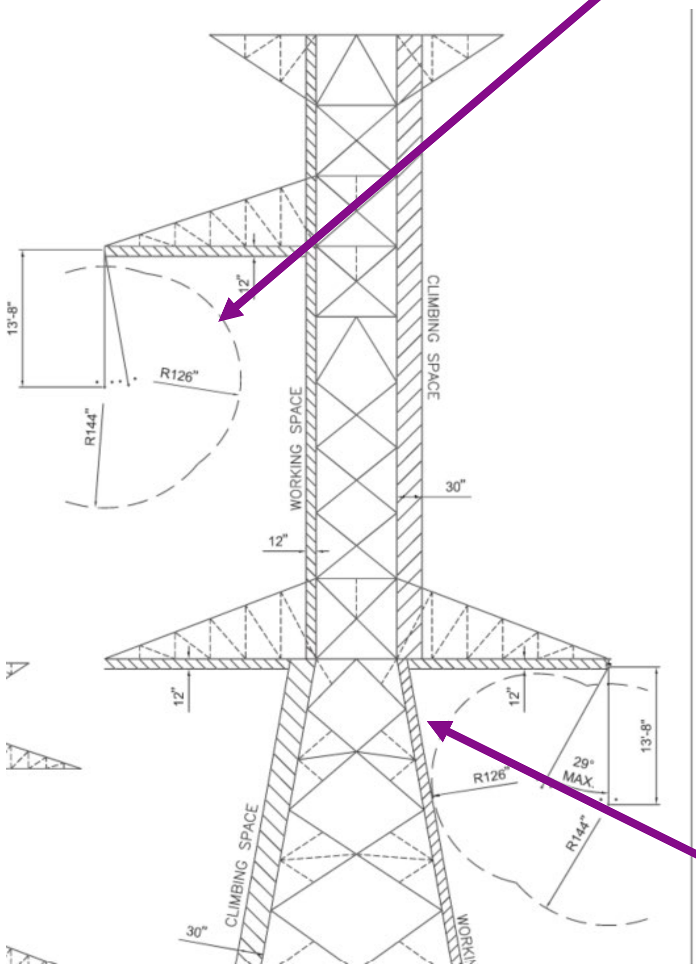
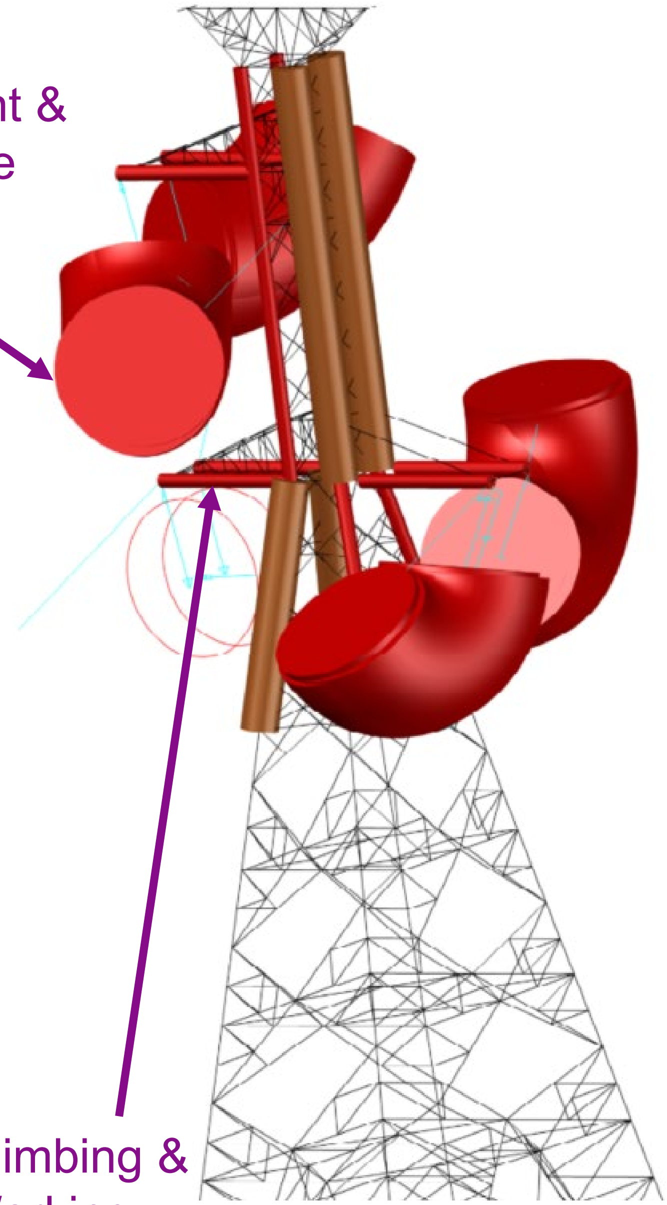
Insulators Cont'd

- 2D vs 3D swing/clearance
  - strain





Insulator Movement & Clearance Envelope

Climbing & Working Space

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Insulators Cont'd

- BPA Design: 40kip bell
  - Metric standard (20mm)
  - Procurement Issues
- Project: larger 50kip bell
  - ANSI standard (52-11)
  - Procurement Simplicity
  - Strength requirements

BPA Suspension

ITEM NO.	DESCRIPTION	CATALOG ID	RATED STRENGTH (LBS)	QUANTITY
1	SHACKLE, ANCHOR, 7/8" DIA, 3 3/4" X 1 3/8" OPENING, 1" BOLT DIA	606727	60,000	1
2	OVAL EYE - BALL, 20MM BALL, 2-1/2" X 1" INSIDE DIM, 4 3/4" LENGTH	605218	40,000	1
3	INSULATOR, PORCELAIN, 20 MM BALL/SOCKET, 6 1/4" HT X 11" DIA	505475	40,000	22
	INSULATOR, TOUGHENED GLASS, 20 MM BALL/SOCKET, 6 1/4" HT X 11" DIA	505476		
4	SUSPENSION ASSEMBLY, TRIPLE BUNDLE, SINGLE I-STRING, 20MM BALL/SOCKET, FOR ACSR/TW DESCHUTES AND ACSR BUNTING	607590	40,000	1
	LENGTH "L" (NOMINAL)			14' 4.5"
	WEIGHT (NOMINAL)			458 LBS

B2H Suspension

GLOBAL ITEM NO.	ASSEMBLY ITEM NO.	DESCRIPTION	IPC CATALOG ID NO.	MFG.	MFG. PART NO.	WT. EA. (LBS)	ASSEMBLY QTY.
1038	1	ANCHOR SHACKLE, WIDE THROAT, FORGED STEEL, GALV, 60 KIP	-	PLP	AS-60WBNKCM	3.5	1
1051	2	BALL EYE, FORGED STEEL, GALV, 52-11, 50 KIP	-	PLP	BE-50CM	1.6	1
1042	3	INSULATOR, GLASS, 6-1/8 IN X 11 IN, ANSI 52-11, 50 KIP	4782	SEDIVER	N21/156DC	14.1	22
1043	4	SOCKET Y-CLEVIS, FORGED STEEL, GALV, ANSI 52-11, 50 KIP	-	PLP	SYC-50CM	5	1
1044	5	YOKE PLATE, TEE CONFIG, CUT STEEL, GALV, 50 KIP	-	PLP	YPT-66278C	33.8	1
1052	6	Y-CLEVIS EYE, FORGED STEEL, GALV, 30 KIP	-	PLP	YC-9034CM	3	3
1047	7	CLAMP, SUSPENSION, ALUM, 1.81 IN - 2.36 IN, 25 KIP	-	PLP	ALS-238BNKCM	7	3
1048	8	ROD, ARMOR, EHV, ALUM, 1.27 IN - 1.327 IN, 99.5 IN LONG, 0.365 IN DIA	-	PLP	AR-0508	13.5	3
1066	9	CORONA RING, ALUMINUM	-	PLP	CR-022	11.6	1
1062	10	SHIELD NUT, 7/8"	-	PLP	SN-78	0.2	1
1063	11	SHIELD NUT, 3/4"	-	PLP	SN-34	0.2	3
1065	12	SHIELD NUT, 5/8"	-	PLP	SN-58	0.2	3

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Insulators Cont'd

- Additional Bells (Strain)
- New Hardware

BPA Strain

ITEM NO.	DESCRIPTION	CATALOG ID	RATED STRENGTH	QUANTITY
1	SHACKLE, ANCHOR, 1 5/8" DIA, 7 1/8" X 2 5/8" OPENING, 1 3/4" BOLT DIA	606738	200,000	3
2	LINK, CHAIN, 1 5/8" DIA, 12" X 2 1/4" INSIDE DIM	606220	200,000	1
3	LINK, SHEAVE SUPPORT, 13 1/2" X 1 7/8" INSIDE DIM, 1 7/16" DIA, 1 7/8" EYE DIA, 1 7/16" RIG HOLE DIA	606304	200,000	1
4	YOKE, DEADEND, TRIPLE BUNDLE	607318	200,000	1
5	SHACKLE, ANCHOR, 1" DIA, 4 5/16" X 1 5/8" OPENING, 1 1/8" BOLT DIA	606730	80,000	3
6	OVAL EYE - BALL, HOT LINE, LONG REACH, 20MM BALL, 1" X 1 1/2" INSIDE DIM, 24" LENGTH	605270	40,000	3
7	INSULATOR, PORCELAIN, 20 MM BALL/SOCKET, 6 1/4" HT X 11" DIA	505475	40,000	90
	INSULATOR, TOUGHENED GLASS, 20 MM BALL/SOCKET, 6 1/4" HT X 11" DIA	505476		
8	SOCKET - CLEVIS, HOT LINE, 20MM SOCKET, 1 1/8" BOLT DIA, 16 5/8" LENGTH	606931	40,000	3
9	GRADING RING, 17" RING I.D.	602366		2
10	SPREADER ASSEMBLY, TRIPLE BUNDLE, 30" X 21 1/4" X 21 1/4' SPACING	607304		1
11	DEAD END ASSEMBLY, COMPRESSION, 15° PAD	*		3
12	JUMPER TERMINAL, COMPRESSION, 15° PAD	*		3
	LENGTH "L" (NOMINAL)			23' 10.5"
	WEIGHT (NOMINAL)			1973 LBS

B2H Strain

GLOBAL ITEM NO.	ASSEMBLY ITEM NO.	DESCRIPTION	IPC CATALOG ID NO.	MFG.	MFG. PART NO.	WT. EA. (LBS)	ASSEMBLY QTY.
1041	1	ANCHOR SHACKLE, LONG, FORGED STEEL, GALV, 150 KIP	-	PLP	AS-150LBNKCM	15	2
1055	2	EYE-EYE TURNBUCKLE, FORGED STEEL, GALV, 185 KIP	-	PLP	TB-EE-2-24CM	85.3	1
1045	3	YOKE PLATE, TEE-CONFIG , CUT STEEL, GALV, 150 KIP	-	PLP	YPT-66286CM	106	2
1059	4	BALL CLEVIS LINK, FORGED STEEL, GALV, 50 KIP	-	PLP	BCL-50WBNKCM	4.7	3
1042	5	INSULATOR, GLASS, 6-1/8 IN X 11 IN, ANSI 52-11, 50 KIP	4782	SEDIVER	N21/156DC	14.1	96
1054	6	SOCKET CLEVIS LINK, FORGED STEEL, GALV, 50 KIP	-	PLP	CSL-50BNKCM	6.1	3
1069	7	CORONA RING, ALUMINUM	-	PLP	CR-026	24.8	1
1056	8	JAW-JAW TURNBUCKLE, FORGED STEEL, GALV, 76 KIP	-	PLP	TB-JJ-114-12BNKCM	22	3
1057	9	COMPRESSION DEAD-END, ALUMINUM	-	VARIES	SEE LH 1-9	VARIES	3
1053	10	Y-CLEVIS EYE LINK, FORGED STEEL, GALV, 50 KIP	-	PLP	OYCL-50-15D5CM	7.8	1
1062	11	SHIELD NUT, 7/8"	-	PLP	SN-78	0.2	4
1064	12	SHIELD NUT, 1-1/8"	-	PLP	SN-118	0.2	6

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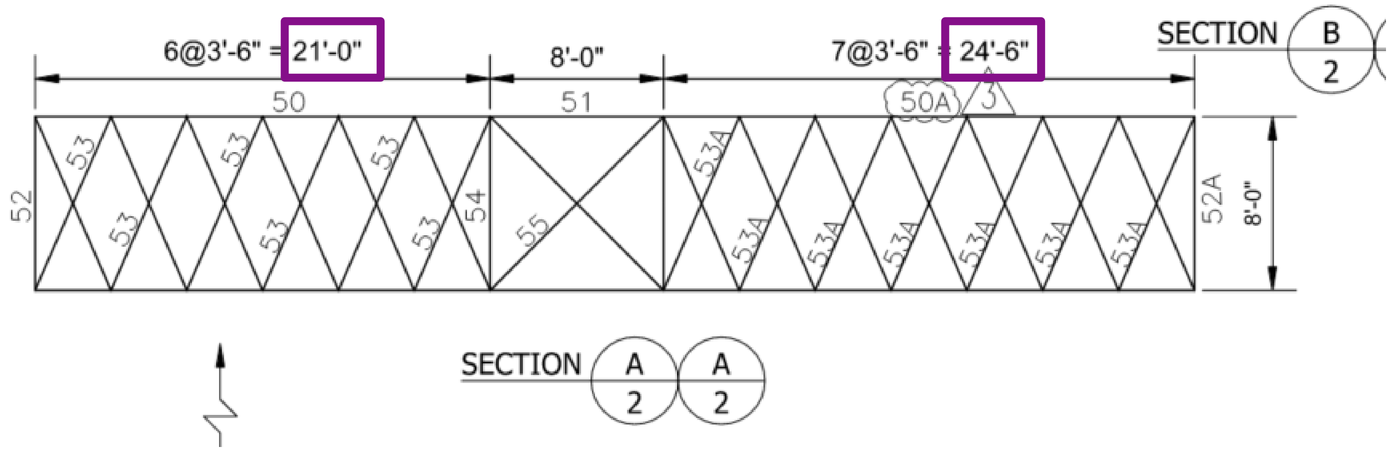
Insulators Cont'd

- RESULT: modified tower arm lengths



- RESULT: new swing angles

CONDUCTOR CLEARANCE

1 MAXIMUM SWING AT 6psf WIND = 38° 3

MAXIMUM SWING AT 2psf WIND = 14°

CONDUCTOR SLOPE = 16° UP TO 20° DOWN 4

CLEARANCE TO STEEL AT 6psf INSULATOR SWING = 97"

CLEARANCE TO SURFACE OF WORKING AND CLIMBING SPACES AT 2psf INSULATOR SWING = 126"

WORKING SPACE = 12"

CLIMBING SPACE = 30"

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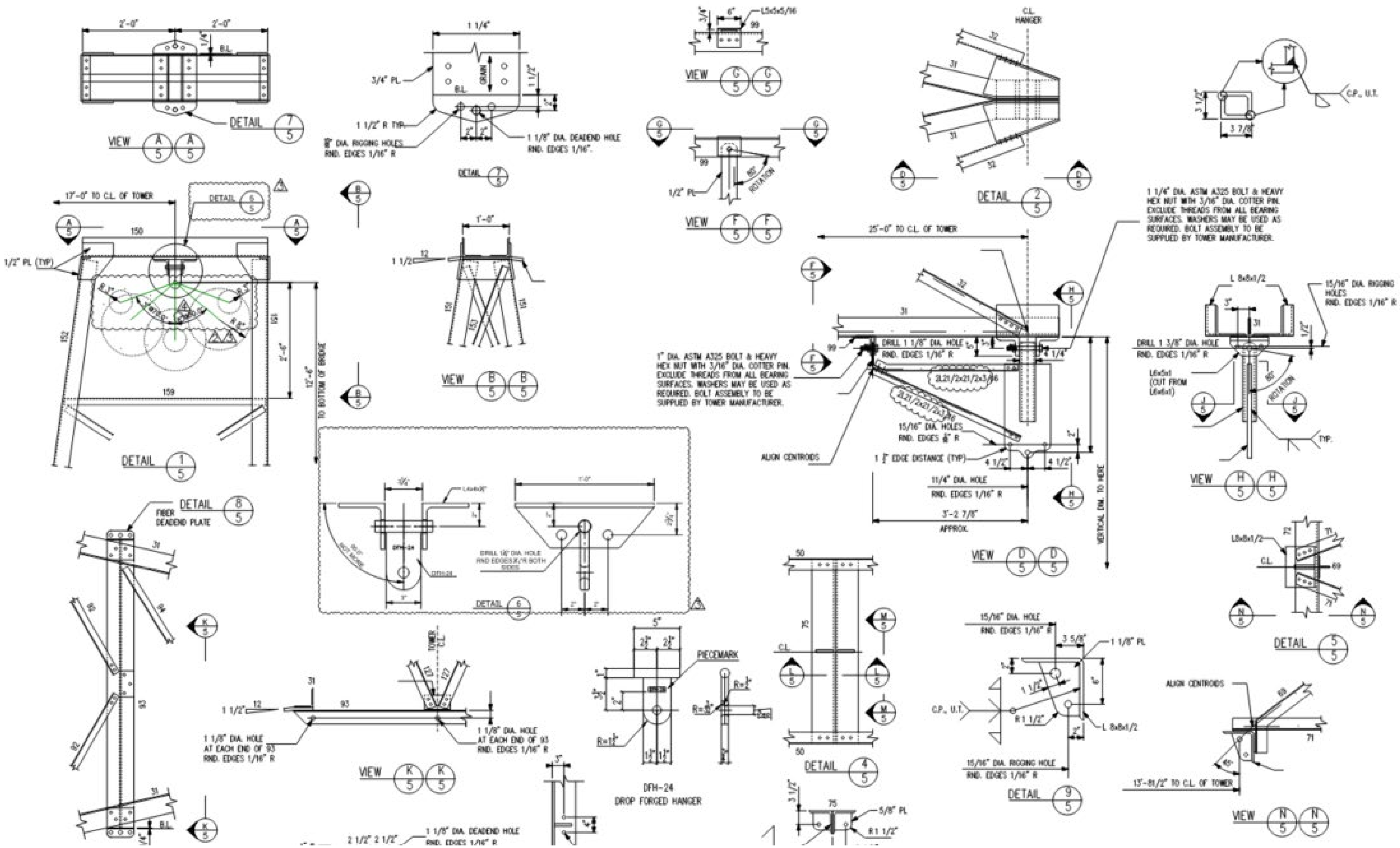
Hardware

- Check/Modify all details as needed



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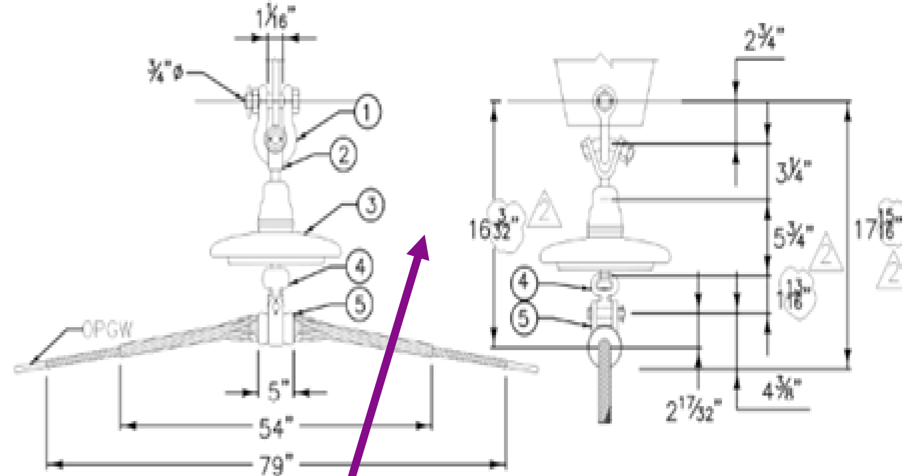
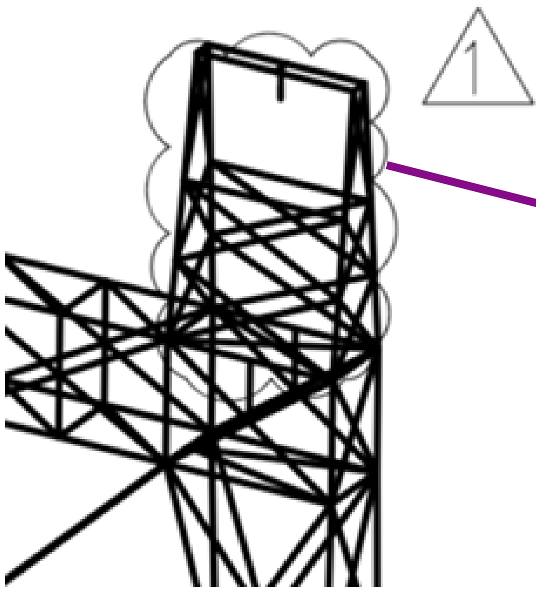
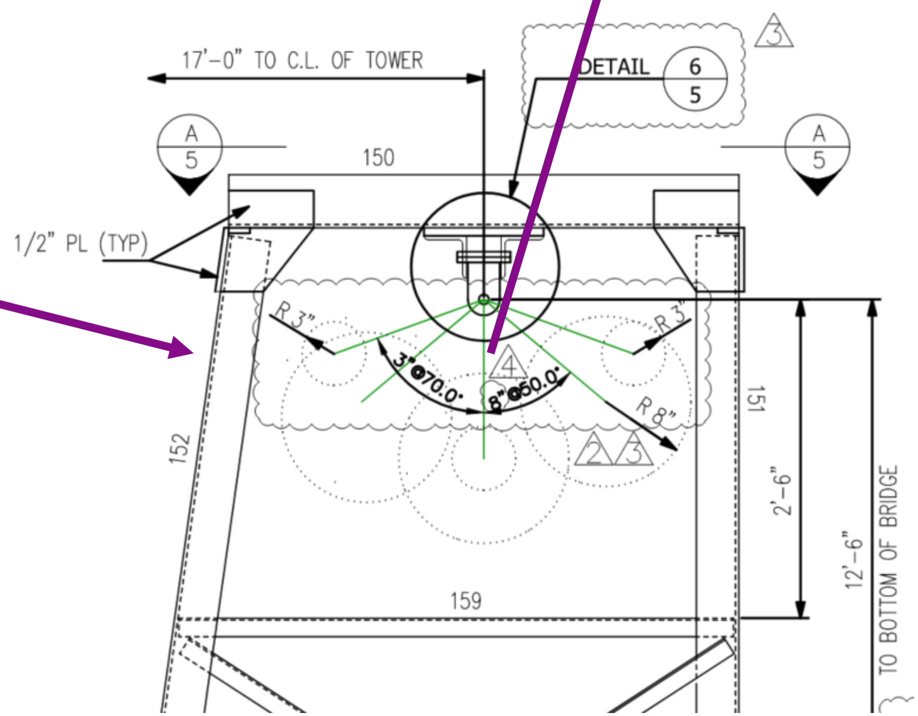
OPGW

- BPA Tower design: 2x 32Fiber
- Project Requirements: 2x 96Fiber
  - Insulation Requirements
- Result: Static Peak Redesign



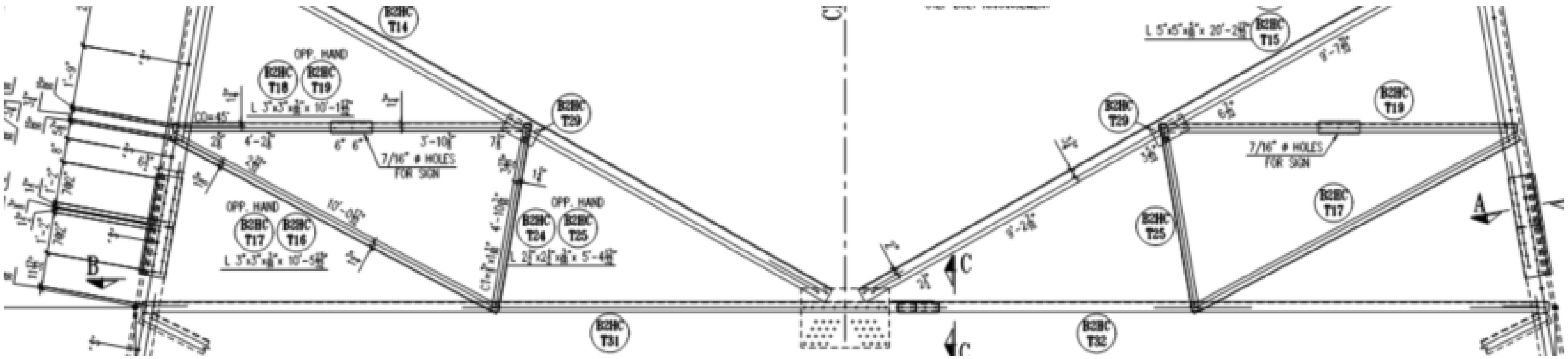




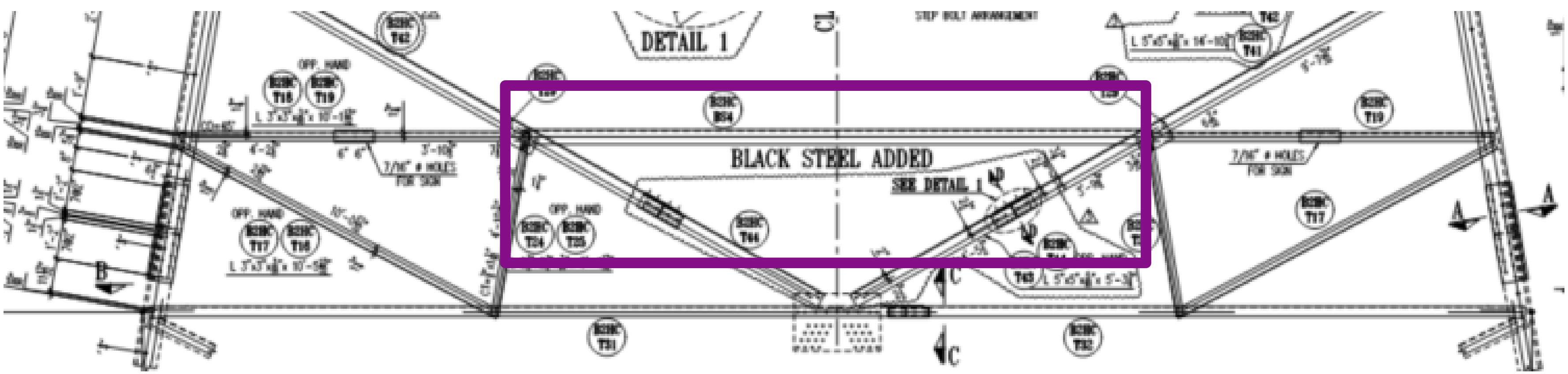
Helicopter Erection

- Requires modification of tower details (splices & temporary members)

Original:



Modified:



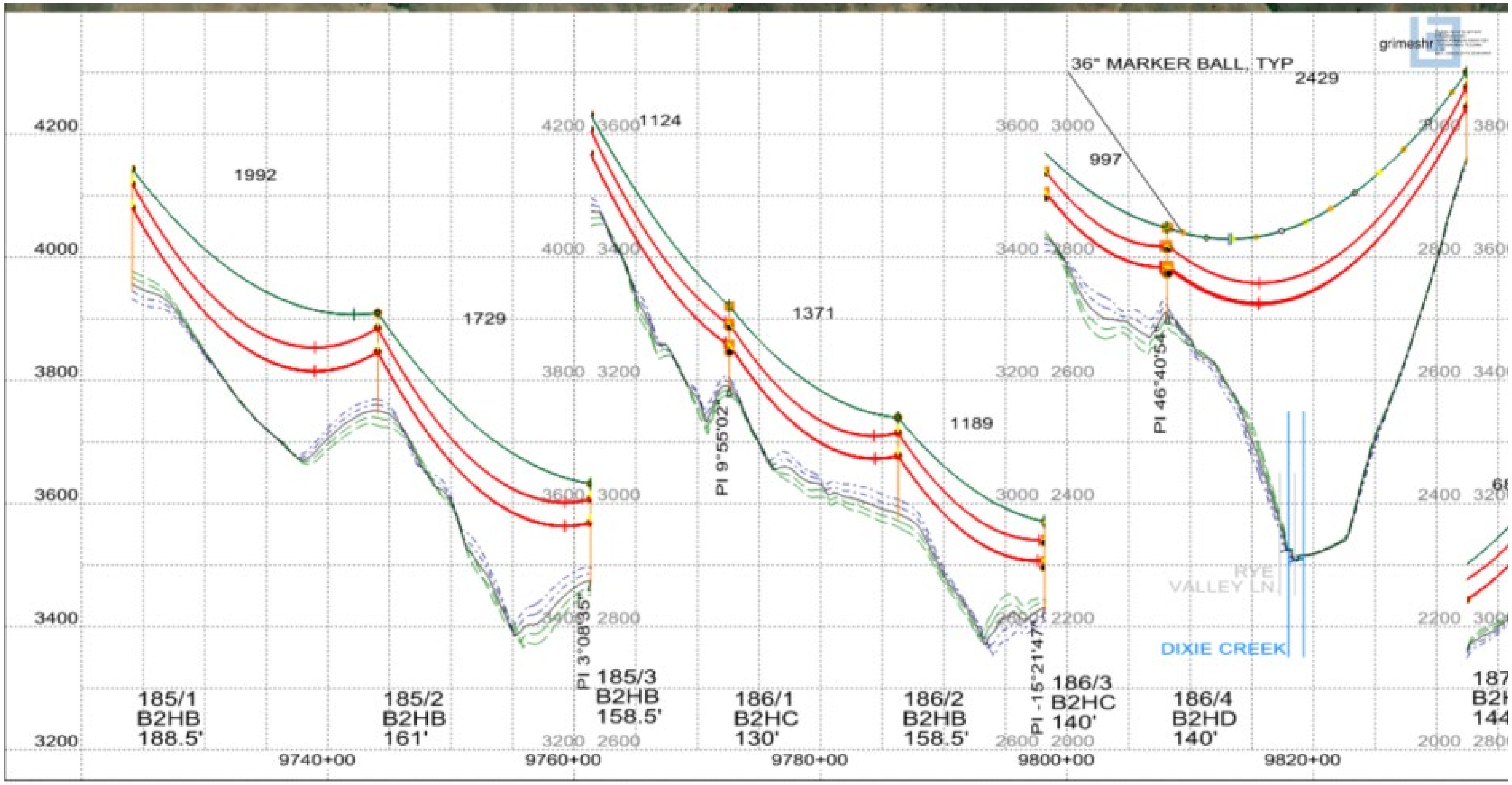
Different Line Configuration

- B2H project required many more deadends than “normal”
  - Many “medium” PIs (6°-30°)
    - Due to routing requirements
- 248 Series has no optimal design
  - Heaviest Tangent “248B”: 6° max
  - Standard Deadend “248D”: 0-60°
    - “Full Containment”
  - No Running Angle
  - No “Light” Deadend
- Pull Length Limitations
    - 16,000 ft max due to conductor reel length

PI (Line Angle)	Minimum Structure TYPE	Qty Count	% of Total
None	248M (Tan)	935	73%
0°<LA<=3°	248A (Tan)	90	7%
3°<LA<=6°	248B (Tan)	46	4%
6°<LA<=30°	**248D (DE)**	**119**	9%
30°<LA<=60°	248D (DE)	73	6%
60°<LA<=90°	248G (DE)	6	<1%

Different Line Configuration Cont'd

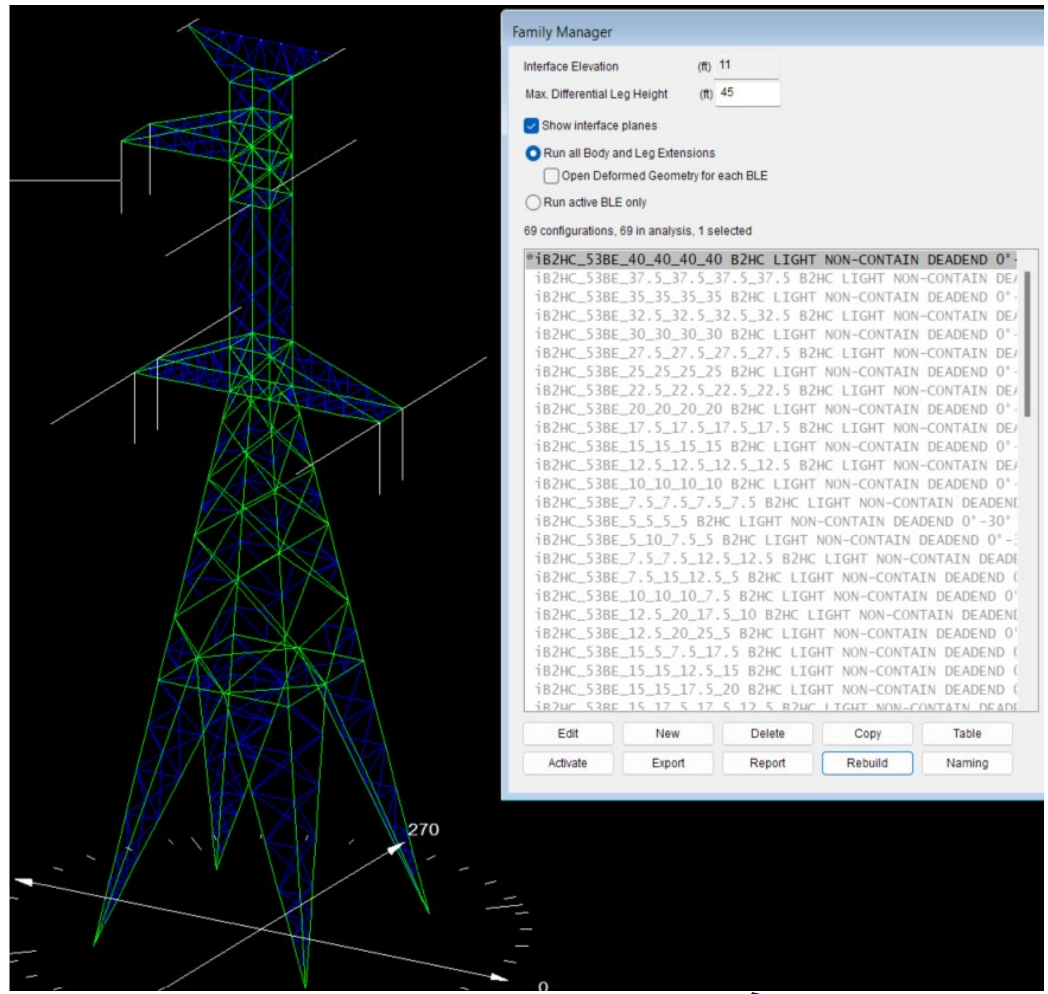
- Uplift structures (requires Deadend)
  - Mountainous terrain for ~30% the project.
  - Total 250 deadend out of 1270 structures. (20%)



Different Line Configuration Cont'd

- Developed new "248C" tower:
  - 0°-30° Light angle Deadend
  - Non-containment Loading
  - Same footprint as D tower
- Approx 140 "C" towers used
  - Average 11,000lbs lighter
  - $3+ million saved

STRUCTURAL DESIGN TYPE 'B2HC' TOWER Idaho Power Company, Boise, ID BDMN - HMWY 500 kV LINE #853			
SAE TOWERS MEXICO S. de R. L. de C. V. ENGINEERING			
Made by M. H. C. (SAE BR) Chkd. by R. P. G. (SAE BR)	Completed	REC. APPR.	SCALE: 1"=1'-0"
Reference- based on BPA 248D tower design drawing #318345			
CONTRACT NUMBER- -----	DRAWING NUMBER- B2HC-01		Rev. No. 4



Load Case Development

- Towers are inherently complex
  - Individual members controlled by different cases
  - Tension or Compression can control
- Why do we end up with 100s of LC?
  - (max 1000)

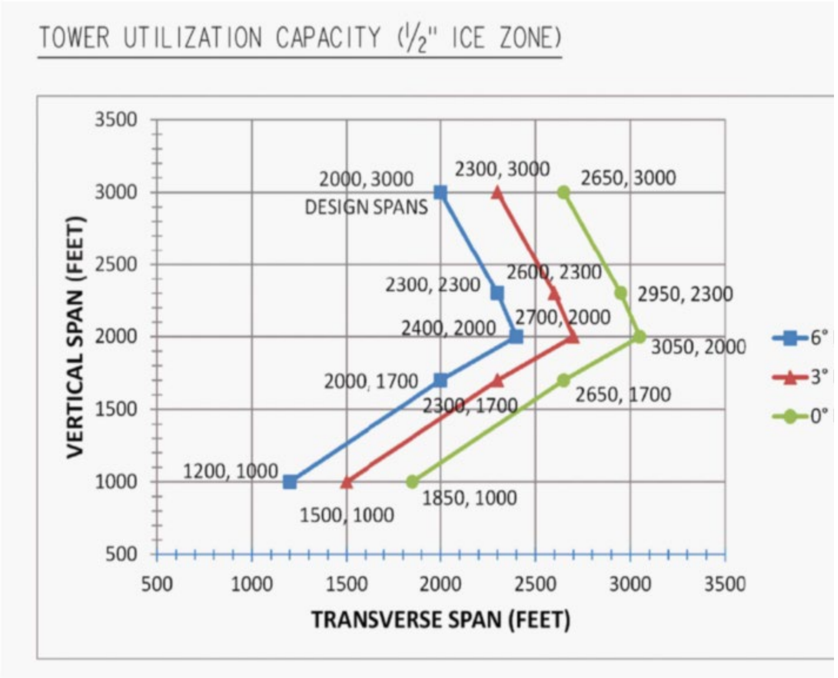
B2HA	Interaction Point Details			
1/2" ICE	Pt	Wind Span	Weight Span	Line Angle
1*	1	2000	3000	6
2*	2	2300	2300	6
3*	3	2400	2000	6
4*	4	2000	1700	6
5*	5	1200	1000	6
1*	6	2300	3000	3
2*	7	2600	2300	3
3*	8	2700	2000	3
4*	9	2300	1700	3
5*	10	1500	1000	3
1*	11	2650	3000	0
2*	12	2950	2300	0
3*	13	3050	2000	0
4*	14	2650	1700	0
5*	15	1850	1000	0

B2*	DESIGN CONDITION	IN	ALL WIRES INTACT
B2*	DESIGN CONDITION	BRG1 +L	LEFT GROUNDWIRE AHEAD BROKEN (G1B: V=T=L=0)
B2*	DESIGN CONDITION	BRG1 −L	LEFT GROUNDWIRE BACK BROKEN (G1A: V=T=L=0)
B2*	DESIGN CONDITION	BRG2 +L	RIGHT GROUNDWIRE AHEAD BROKEN (G2B: V=T=L=0)
B2*	DESIGN CONDITION	BRG2 −L	RIGHT GROUNDWIRE BACK BROKEN (G2A: V=T=L=0)
B2*	DESIGN CONDITION	B1G1G2 +L	BOTH GROUNDWIRE AHEAD BROKEN (G1B, G2B: V=T=L=0)
B2*	DESIGN CONDITION	B1G1G2 −L	BOTH GROUNDWIRE BACK BROKEN (G1A, G2A: V=T=L=0)
B2*	DESIGN CONDITION	BRC1 +L	MIDDLE CONDUCTOR AHEAD BROKEN (C1B: V=T=L=0)
B2*	DESIGN CONDITION	BRC1 −L	MIDDLE CONDUCTOR BACK BROKEN (C1A: V=T=L=0)
B2*	DESIGN CONDITION	BRC2 +L	LEFT CONDUCTOR AHEAD BROKEN (C2B: V=T=L=0)
B2*	DESIGN CONDITION	BRC2 −L	LEFT CONDUCTOR BACK BROKEN (C2A: V=T=L=0)
B2*	DESIGN CONDITION	BRC3 +L	RIGHT CONDUCTOR AHEAD BROKEN (C3B: V=T=L=0)
B2*	DESIGN CONDITION	BRC3 −L	RIGHT CONDUCTOR BACK BROKEN (C3A: V=T=L=0)
B2**	DESIGN CONDITION	DE +L	ALL AHEAD WIRES BROKEN (C1B, C2B, C3B, G1B, G2B: V=T=L=0)
B2**	DESIGN CONDITION	DE −L	ALL BACK WIRES BROKEN (C1A, C2A, C3A, G1A, G2A: V=T=L=0)
B2***	DESIGN CONDITION	DEG2C1C3 +L	RIGHT GROUNDWIRE, MIDDLE CONDUCTOR, & RIGHT CONDUCTOR AHEAD BROKEN (G2B, C1B, C3B: V=T=L=0)
B2***	DESIGN CONDITION	DEG2C1C3 −L	RIGHT GROUNDWIRE, MIDDLE CONDUCTOR, & RIGHT CONDUCTOR BACK BROKEN (G2A, C1A, C3A: V=T=L=0)
B2***	DESIGN CONDITION	DEG2C2C3 +L	RIGHT GROUNDWIRE, LEFT CONDUCTOR, & RIGHT CONDUCTOR AHEAD BROKEN (G2B, C2B, C3B: V=T=L=0)
B2***	DESIGN CONDITION	DEG2C2C3 −L	RIGHT GROUNDWIRE, LEFT CONDUCTOR, & RIGHT CONDUCTOR BACK BROKEN (G2A, C2A, C3A: V=T=L=0)
B2***	DESIGN CONDITION	DEG2C1C2 +L	RIGHT GROUNDWIRE, LEFT CONDUCTOR, & MIDDLE CONDUCTOR AHEAD BROKEN (G2B, C2B, C1B: V=T=L=0)
B2***	DESIGN CONDITION	DEG2C1C2 −L	RIGHT GROUNDWIRE, LEFT CONDUCTOR, & MIDDLE CONDUCTOR BACK BROKEN (G2A, C2A, C1A: V=T=L=0)
B2***	DESIGN CONDITION	DEG1C1C3 +L	LEFT GROUNDWIRE, MIDDLE CONDUCTOR, & RIGHT CONDUCTOR AHEAD BROKEN (G1B, C1B, C3B: V=T=L=0)
B2***	DESIGN CONDITION	DEG1C1C3 −L	LEFT GROUNDWIRE, MIDDLE CONDUCTOR, & RIGHT CONDUCTOR BACK BROKEN (G1A, C1A, C3A: V=T=L=0)
B2***	DESIGN CONDITION	DEG1C2C3 +L	LEFT GROUNDWIRE, LEFT CONDUCTOR, & RIGHT CONDUCTOR AHEAD BROKEN (G1B, C2B, C3B: V=T=L=0)
B2***	DESIGN CONDITION	DEG1C2C3 −L	LEFT GROUNDWIRE, LEFT CONDUCTOR, & RIGHT CONDUCTOR BACK BROKEN (G1A, C2A, C3A: V=T=L=0)
B2***	DESIGN CONDITION	DEG1C1C2 +L	LEFT GROUNDWIRE, LEFT CONDUCTOR, & RIGHT CONDUCTOR BACK BROKEN (G1A, C2A, C3A: V=T=L=0)
B2***	DESIGN CONDITION	DEG1C1C2 −L	LEFT GROUNDWIRE, LEFT CONDUCTOR, & MIDDLE CONDUCTOR AHEAD BROKEN (G1B, C2B, C1B: V=T=L=0)

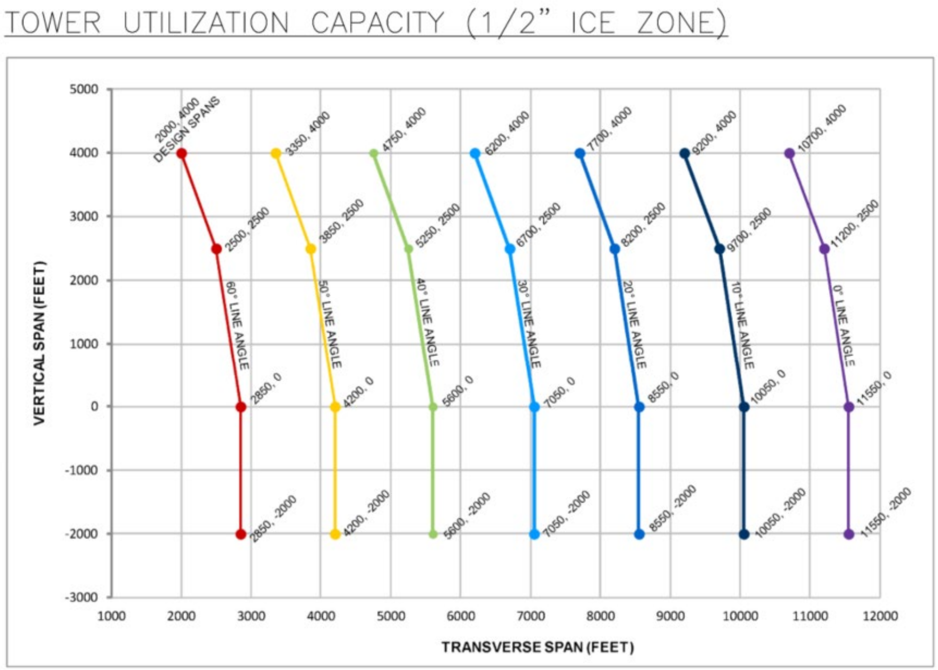
Load Cases Interaction Diagram

- Original Tower designs based on BPA standards
  - BPA developed Interaction Diagrams of Permissible Span Lengths
  - Must model each point on each diagram, not just largest

248A Medium Tangent

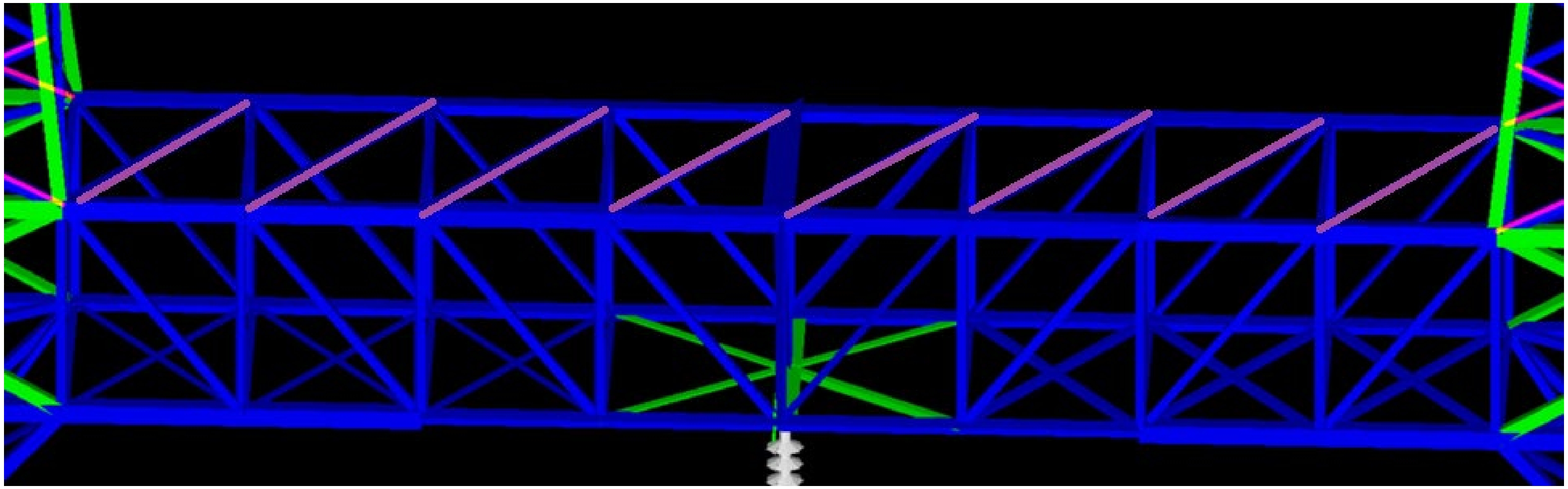


248D Standard Deadend



Load Cases Other Considerations

- Develop loads for intact, broken wire iterations
  - For deadends: multiple wires broken, and all wires broken
- Consider wind applied on different angles of tower
- Fall protection loading, Construction & Rigging Loading
- If tower is not completely symmetric, must iterate +/-T and +/-L



Load Cases Results (248D, 100-95%)

- Notice the variety of load cases controlling design (248D)

	Group Label	Angle Type	Angle Size	Steel Strength (ksi)	Max Usage %	Usage Cont-rol	Max Use In Comp. %	Comp. Force (kips)	Comp. Control Load Case	Comp. Control Model
1	93L7.5	SAE	8x8x1	50.0	99.28	Tens	92.14	-654.239	DM_1_DE -L -T	B2HD_93BE_42.5_12.5_7.5_32.5
2	93L10	SAE	8x8x1	50.0	98.86	Tens	94.54	-649.336	DM_1_DE -L -T	B2HD_93BE_47.5_22.5_10_27.5
3	93L15	SAE	8x8x1	50.0	98.81	Comp	98.81	-645.478	DM_1_DE +L	B2HD_93BE_15_40_50_22.5
4	93L45	SAE	8x8x1	50.0	98.46	Comp	98.46	-595.653	DM_1_DE +L	B2HD_93BE_45_45_45_45
5	9	SAE	8x8x1	50.0	98.17	Tens	92.70	-651.752	DM_1_DE -L -T	B2HD_93BE_42.5_12.5_7.5_32.5
6	13	SAE	6x6x5/8	50.0	98.17	Comp	98.17	-282.043	B1_1_DE_20 +L	B2HD_93BE_42.5_12.5_7.5_32.5
7	93L35	SAE	8x8x1	50.0	97.95	Comp	97.95	-602.788	DM_1_DE +L	B2HD_93BE_35_45_40_30
8	56	SAE	5x5x3/8	50.0	97.80	Tens	81.05	-96.756	B2_4_DE_0 -L (L-0) -T	B2HD_93BE_15_40_50_22.5
9	93L25	SAE	8x8x1	50.0	97.65	Comp	97.65	-615.453	DM_1_DE -L -T	B2HD_93BE_45_37.5_25_30
10	rc1	SAE	2-1/2x2-1/2x3/16	50.0	97.13	Comp	97.13	-5.323	B2_1_BRC2 -L	B2HD_93BE_50_50_50_50
11	7	SAE	8x8x1	50.0	96.74	Tens	89.07	-626.262	DM_1_DE -L -T	B2HD_93BE_42.5_12.5_7.5_32.5
12	51	SAE	6x6x1/2	50.0	96.71	Comp	96.71	-189.287	B2_1_DEG1C1C2_60 +L (L-3)	B2HD_93BE_15_40_50_22.5
13	43-801	SAE	2-1/2x2-1/2x3/16	50.0	96.70	Redun	96.70	-4.834	A1_1_IN	B2HD_93BE_45_37.5_25_30
14	93L32.5	SAE	8x8x1	50.0	96.53	Comp	96.53	-609.934	DM_1_DE +L	B2HD_93BE_32.5_37.5_47.5_40
15	93L22.5	SAE	8x8x1	50.0	96.41	Comp	96.41	-626.287	DM_1_DE -L	B2HD_93BE_15_40_50_22.5
16	93L40	SAE	8x8x1	50.0	96.07	Comp	96.07	-607.766	DM_1_DE -L	B2HD_93BE_47.5_45_37.5_40
17	93L42.5	SAE	8x8x1	50.0	95.89	Comp	95.89	-593.867	DM_1_DE +L	B2HD_93BE_42.5_42.5_42.5_42.5
18	12	SAE	8x8x3/4	50.0	95.35	Comp	95.35	-350.904	B1_1_DE_20 +L	B2HD_93BE_42.5_12.5_7.5_32.5
19	57	SAE	4x4x3/8	50.0	95.35	Tens	63.98	-58.544	B2_4_DEG2C2C3_60 +L (L-2)	B2HD_93BE_30_32.5_12.5_7.5
20	56A	SAE	5x5x1/2	50.0	95.25	Tens	69.06	-108.338	B2_4_DE_0 +L (L-0)	B2HD_93BE_42.5_12.5_7.5_32.5
21	93L12.5	SAE	8x8x1	50.0	95.24	Tens	94.08	-636.004	DM_1_DE +L	B2HD_93BE_12.5_35_37.5_15

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Load Cases Results (248D, 95-90%)

	Group Label	Angle Type	Angle Size	Steel Strength (ksi)	Max Usage %	Usage Cont-rol	Max Use In Comp. %	Comp. Force (kips)	Comp. Control Load Case	Comp. Control Model
23	53	SAE	3x3x3/16	50.0	94.68	Comp	94.68	-29.234	B2_4_BRC3 +L	B2HD_93BE_30_32.5_12.5_7.5
24	8	SAE	8x8x1	50.0	94.68	Tens	88.93	-625.233	DM_1_DE -L -T	B2HD_93BE_42.5_12.5_7.5_32.5
25	93L20	SAE	8x8x1	50.0	94.63	Comp	94.63	-631.404	DM_1_DE +L	B2HD_93BE_20_40_45_22.5
26	53A	SAE	3x3x3/16	50.0	94.55	Comp	94.55	-29.193	B2_4_BRC2 +L -T	B2HD_93BE_30_32.5_12.5_7.5
27	93L5	SAE	8x8x1	50.0	94.32	Tens	90.97	-629.716	DM_1_DE -L -T	B2HD_93BE_25_12.5_5_17.5
28	84	SAE	3x3x3/16	50.0	94.14	Comp	94.14	-10.944	B2_4_IN -T	B2HD_93BE_50_50_50_50
29	93L47.5	SAE	8x8x1	50.0	94.05	Comp	94.05	-595.983	DM_1_DE +L	B2HD_93BE_47.5 47.5 47.5 47.5
30	1	SAE	8x8x7/8	50.0	94.01	Comp	94.01	-518.911	B2_1_DEG2C1C3_60 -L (L-2)	B2HD_93BE_15_40_50_22.5
31	54	SAE	5x5x3/8	50.0	93.68	Tens	88.15	-102.740	B2_4_BRC2 -L -T	B2HD_93BE_30_32.5_12.5_7.5
32	37	SAE	5x5x5/16	50.0	93.53	Comp	93.53	-48.843	B2_1_DEG1C1C2_60 +L (L-3)	B2HD_93BE_47.5_22.5_10_27.5
33	93L37.5	SAE	8x8x1	50.0	93.52	Comp	93.52	-604.006	DM_1_DE -L -T	B2HD_93BE_47.5_45_37.5_40
34	59	SAE	3x3x3/16	50.0	93.51	Comp	93.51	-27.483	B2_4_BRC2 -L	B2HD_93BE_15_40_50_22.5
35	30T	SAE	6x6x3/8	50.0	92.50	Tens	80.68	-128.271	B2_4_DEG1C1C2_60 -L (L-3)	B2HD_93BE_30_32.5_12.5_7.5
36	25T	SAE	3-1/2x3-1/2x5/16	50.0	92.50	Comp	92.50	-56.624	B2_1_BRG1 +L	B2HD_93BE_30_32.5_12.5_7.5
37	23T	DAE	3-1/2x3-1/2x1/4	50.0	92.47	Comp	92.47	-85.301	B2_1_BRG2 +L -T	B2HD_93BE_30_32.5_12.5_7.5
38	43-802	SAE	2-1/2x2-1/2x3/16	50.0	92.40	Redun	92.40	-5.464	A1_1_IN	B2HD_93BE_45_37.5_25_30
39	93L27.5	SAE	8x8x1	50.0	92.30	Comp	92.30	-610.824	DM_1_DE +L	B2HD_93BE_27.5_37.5_40_32.5
40	5	SAE	8x8x1	50.0	91.66	Tens	84.81	-587.026	DM_1_DE -L -T	B2HD_93BE_42.5_12.5_7.5_32.5
41	43-8	SAE	3x3x3/16	50.0	91.59	Redun	91.59	-4.941	A1_1_IN	B2HD_93BE_45_37.5_25_30
42	16	SAE	5x5x5/16	50.0	91.31	Tens	78.31	-93.543	B1_2_BRG12 +L	B2HD_93BE_50_50_50_50
43	93L17.5	SAE	8x8x1	50.0	91.23	Tens	90.26	-616.748	DM_1_DE +L	B2HD_93BE_17.5_40_27.5_10
44	93L50	SAE	8x8x1	50.0	91.18	Comp	91.18	-595.651	DM_1_DE +L	B2HD_93BE_50_50_50_50
45	93D15	SAE	5x5x5/16	50.0	91.00	Comp	91.00	-47.725	DM_4_BRC2 +L	B2HD_93BE_15_40_50_22.5
46	6	SAE	8x8x1	50.0	90.92	Tens	83.30	-585.685	DM_1_DE -L -T	B2HD_93BE_42.5_12.5_7.5_32.5
47	2	SAE	8x8x7/8	50.0	90.24	Tens	86.26	-534.672	B2_1_DEG2C1C3_60 -L (L-2)	B2HD_93BE_47.5_22.5_10_27.5

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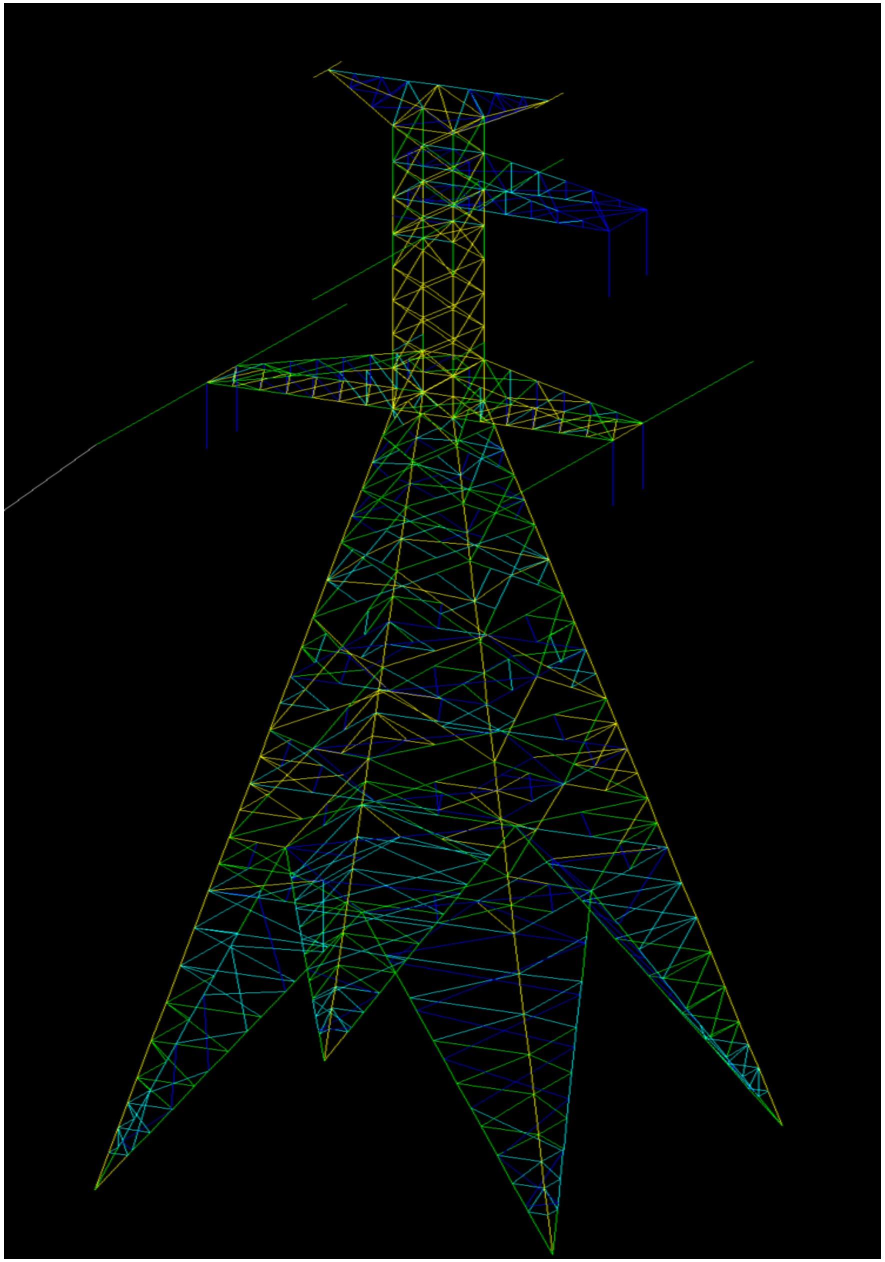
Load Cases Results (Utilization)

- Efficient, well utilized tower
  - Yellow = 75-100%
- Runtime: 30-45 minutes
  - all family manager iterations
  - all load case iterations
- No “surprises” in PLS-CADD
  - PLS-CADD generated loads:
    - Actual individual line angles
    - Unbalanced tensions
    - Finite Element
    - Concentrated Loads



Fitup Testing

- Prototype Fit Test (never perfect on paper)
  - 7 tower types
    - 2 extended bodies
    - 30-50 unique leg extensions per type
    - ~1500 pages of detail/erection drawings

Fitup Testing Cont'd

Full Scale Load Testing

- Test each tower type
  - Tallest configuration
  - 10 load cases each type
  - Test up to 110%

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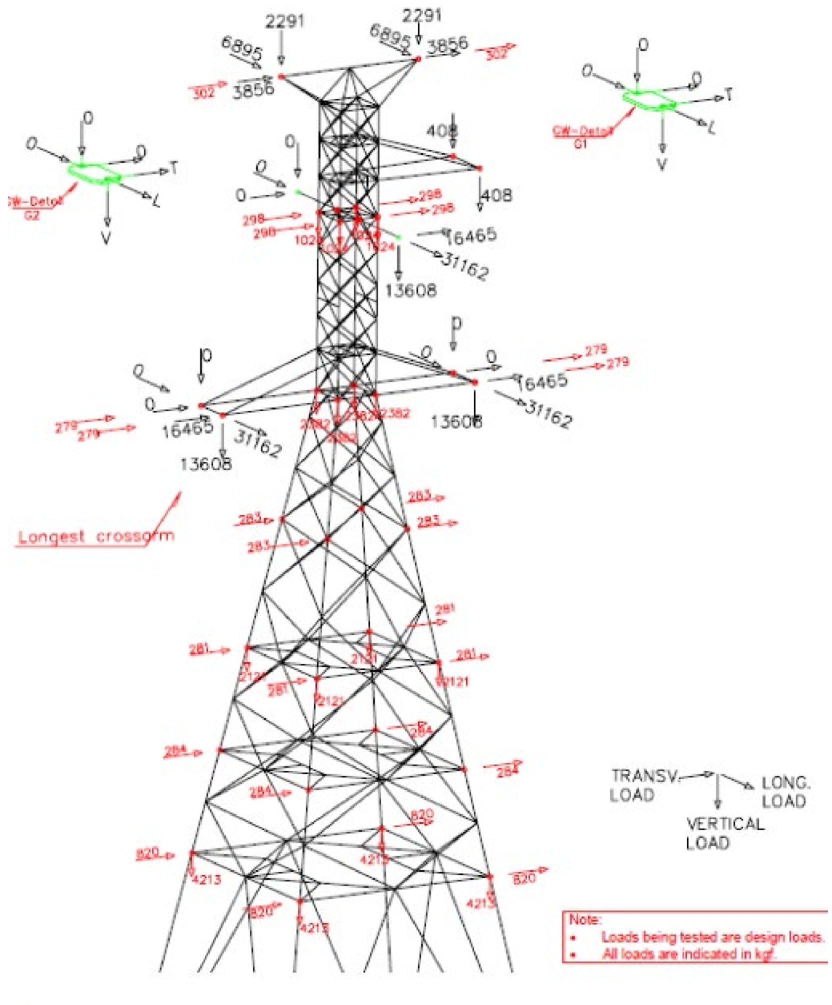
Full Scale Load Testing Cont'd



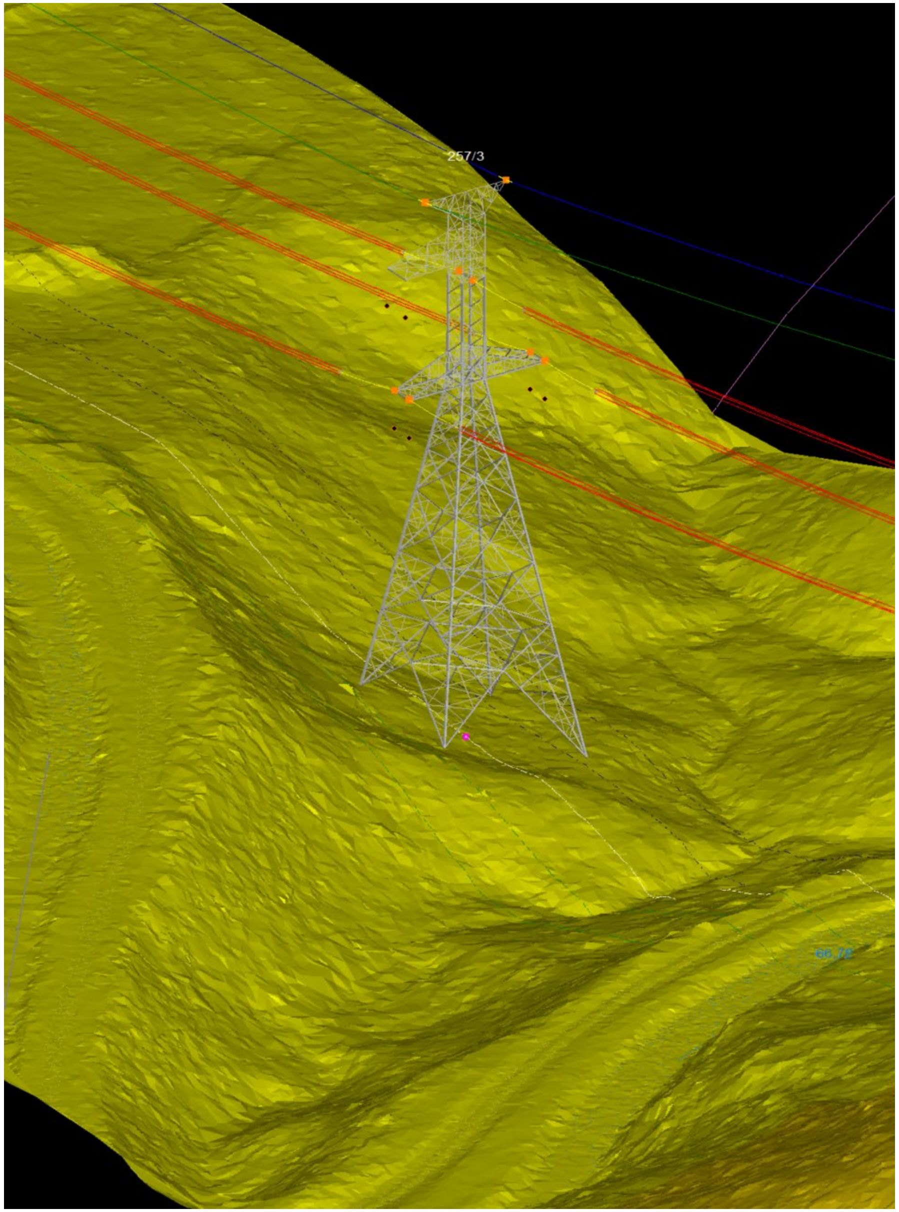
LC 11
32_1_DE_40-L(L-1)-T(56.6MPH wind on 1" Radial Glaze Ice / Full

Full Scale Load Testing Cont'd

- 248D Tower Leg
  - 109% compression
  - Was further strengthened
- All other structures nominal

Presentation Outline

- Project Overview
- Lattice Tower Overview
- **Lattice Tower Modeling**
- Leg Extensions Design

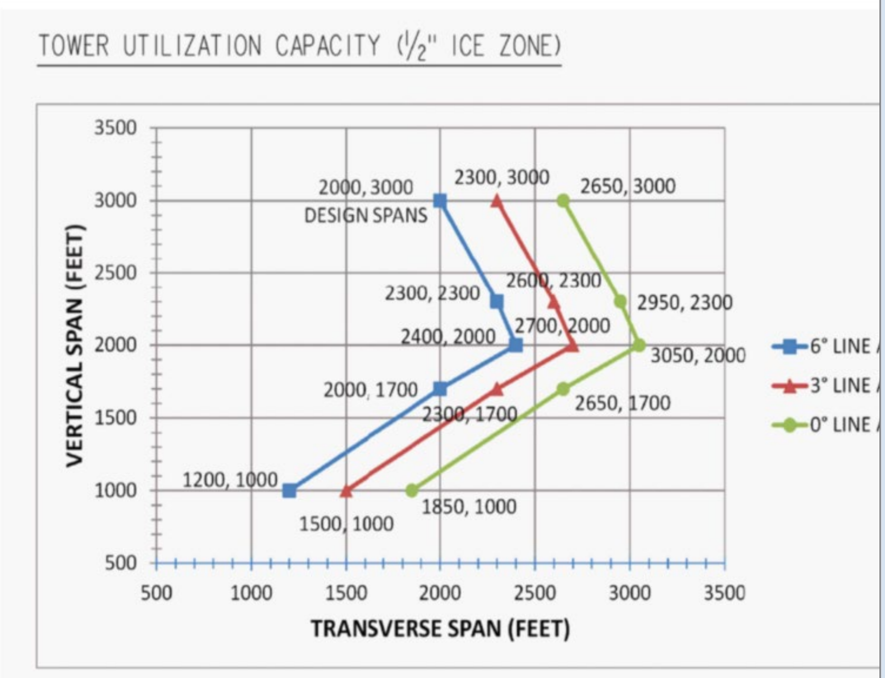


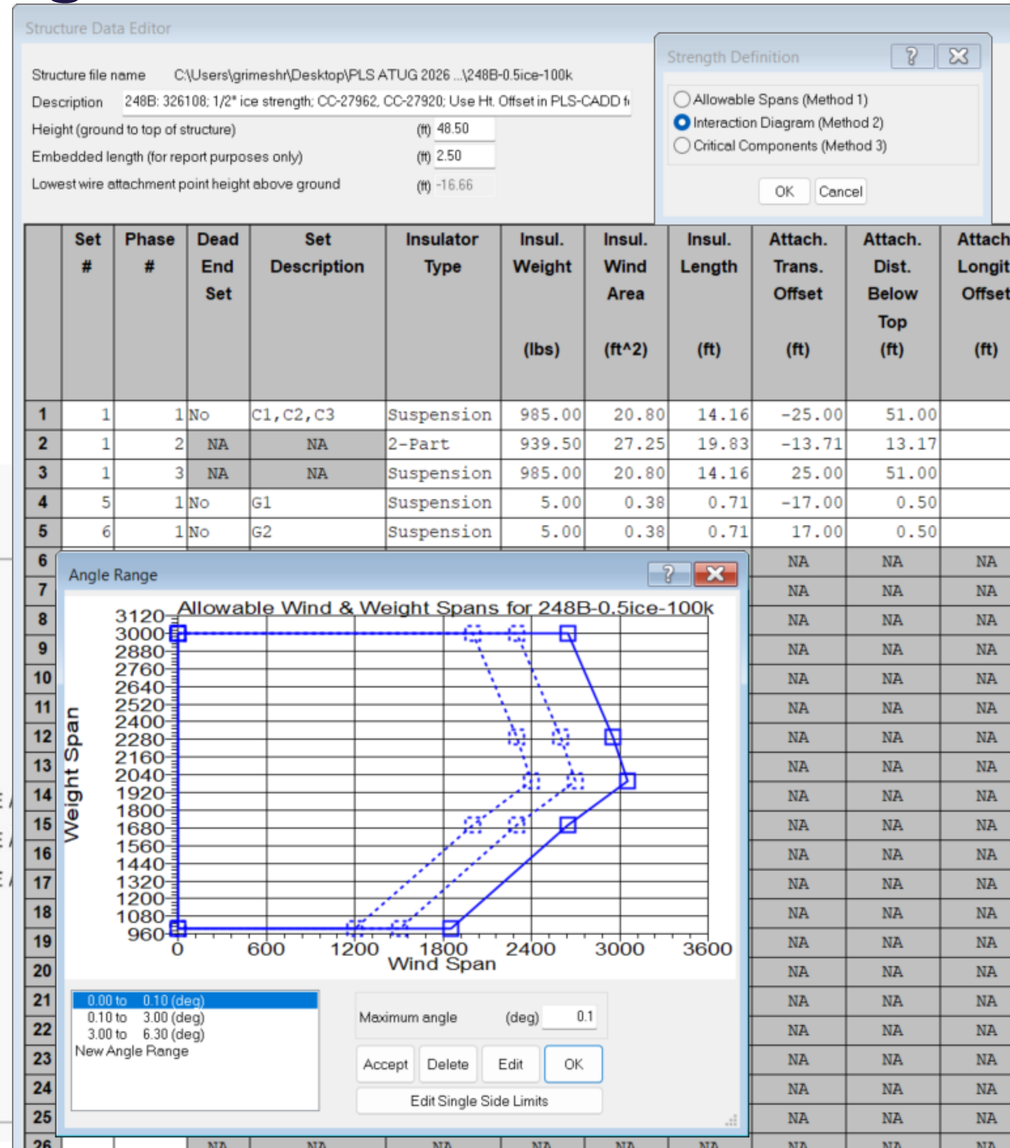
Lattice Tower Modeling

- BPA ATADS, not compatible with PLS-TOWER
- Developed Method 2 “interaction diagram” models first
  - Preliminary 10% - 60% design stages
- Intermediate method 4 models
  - 60-90% design stages
  - Final tower models from SAE/KEC not available till after 90% phase
  - Developed using ATADS -> TOWER model conversion
  - Not for structural analysis, only for:
    - Insulator strength check
    - Leg Extension Design
    - Staking / Footprint
- Final SAE/KEC complete & accurate tower models inserted at 100%.
  - Don’t want any “surprises” at this point!

Lattice Tower Modeling: METHOD 2

- Interaction Diagram





	Set #	Phase #	Dead End Set	Set Description	Insulator Type	Insul. Weight (lbs)	Insul. Wind Area (ft^2)	Insul. Length (ft)	Attach. Trans. Offset (ft)	Attach. Dist. Below Top (ft)	Attach. Longit. Offset (ft)
1	1	1	No	C1,C2,C3	Suspension	985.00	20.80	14.16	-25.00	51.00	
2	1	2	NA	NA	2-Part	939.50	27.25	19.83	-13.71	13.17	
3	1	3	NA	NA	Suspension	985.00	20.80	14.16	25.00	51.00	
4	5	1	No	G1	Suspension	5.00	0.38	0.71	-17.00	0.50	
5	6	1	No	G2	Suspension	5.00	0.38	0.71	17.00	0.50	
26			NA	NA	NA	NA	NA	NA	NA	NA	NA

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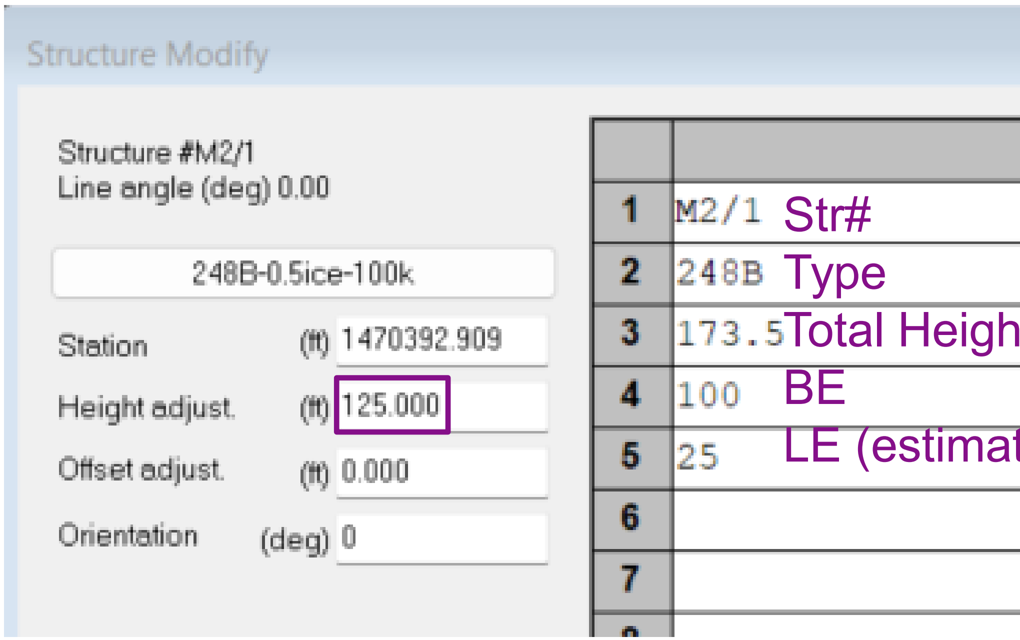
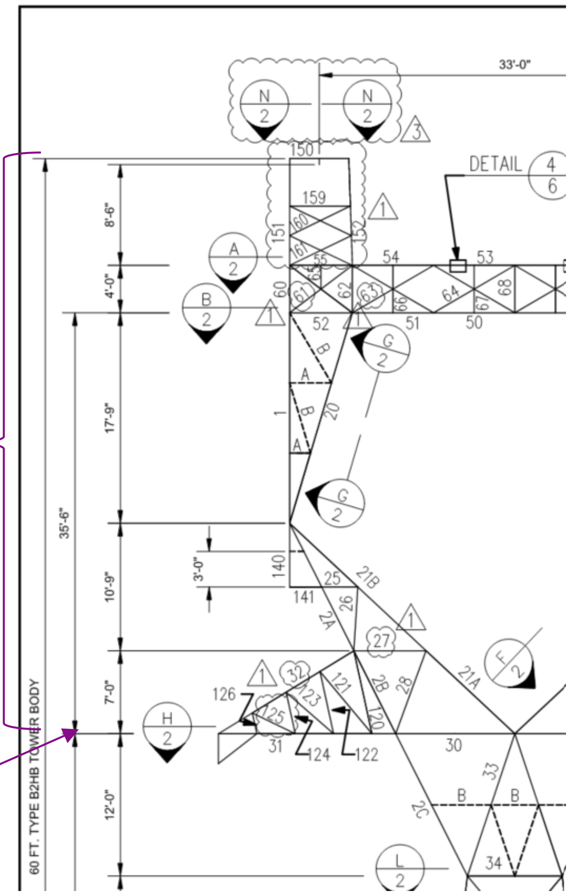
Lattice Tower Modeling: METHOD 2 Cont'd

- Carefully track height of tower
  - Common (C) + Body & Body Extension (BE) + Leg Extension (LE)
  - Aim for middle third of Leg Extension Range
  - Give yourself buffer



Str#
Type
Total Height
BE
LE (estimate)

C = 48.5



Z=0 (for M2)

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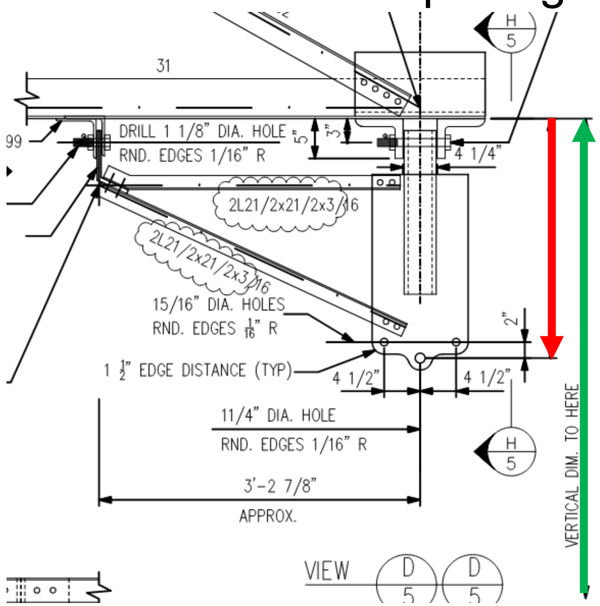
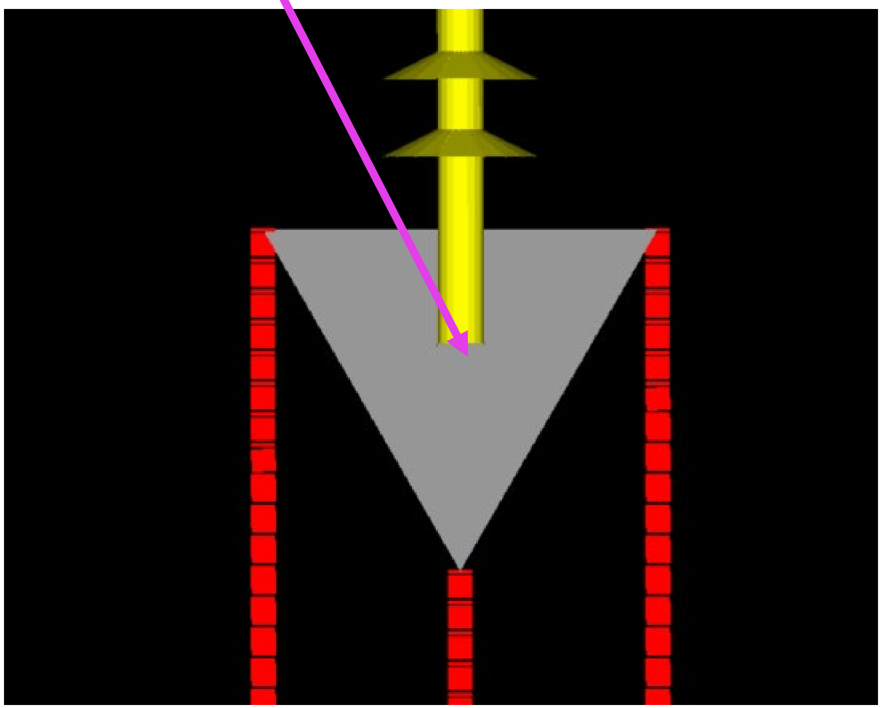
Lattice Tower Modeling: METHOD 2 Cont'd

- Must get insulator attachment points exact
  - Triple Bundle modeling: PLS defaults to centroid of triangle
    - Affects Insulator length
  - Clearance Line and Blowout
    - Use centroid of bundle
  - Survey point clearance
    - Checks to all wire bundles
  - Also account for drop vangs

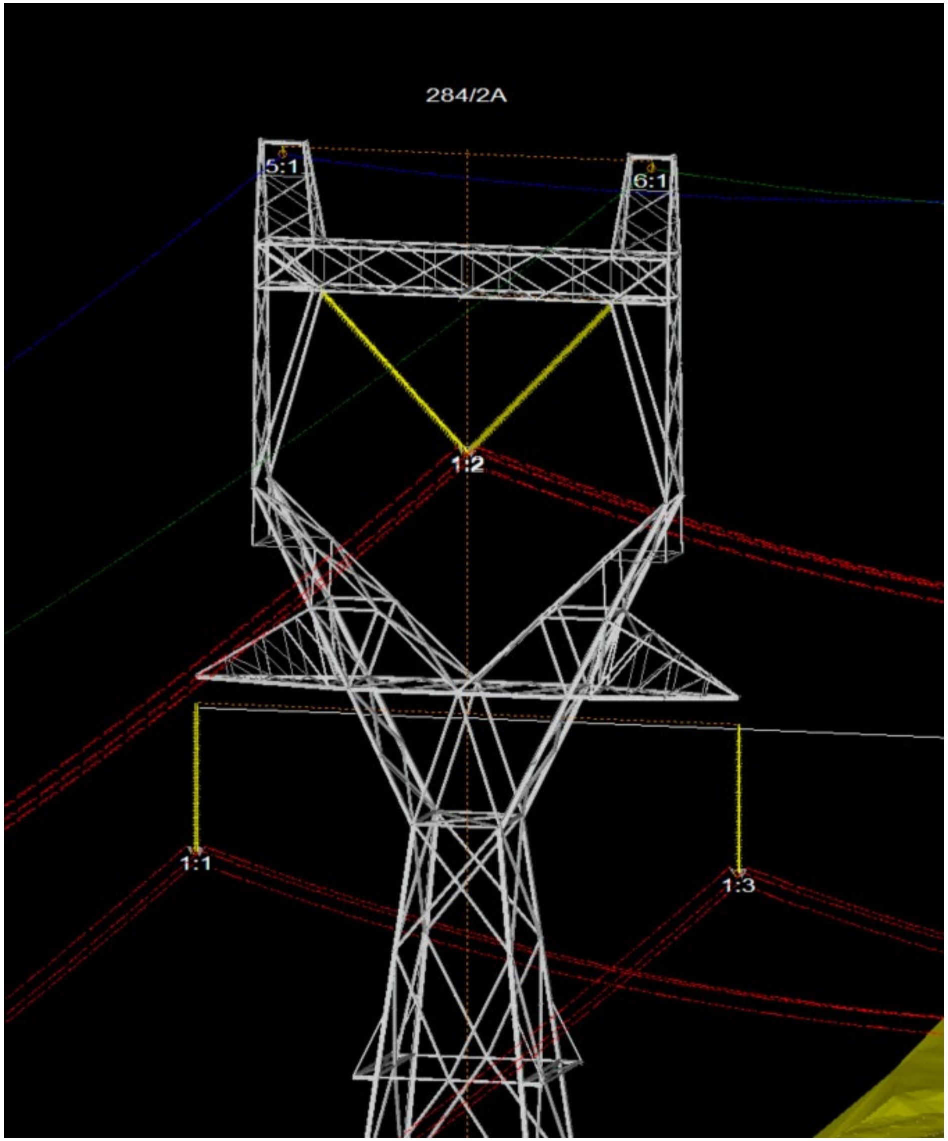




Tower Crossarm Elev
vs
Attachment Elev

Lattice Tower Intermediate Method 4

- GOALS
- design LE using PLS-CADD
  - Leg Optimizer Tool
  - Determine impact footprints
  - Insulator analysis
    - Method 2 doesn't check
- Hold wires in correct spot
  - Same as Method 2
  - Manage heights
    - Dependent on foundations
- Not for structural analysis
  - Still must be stable



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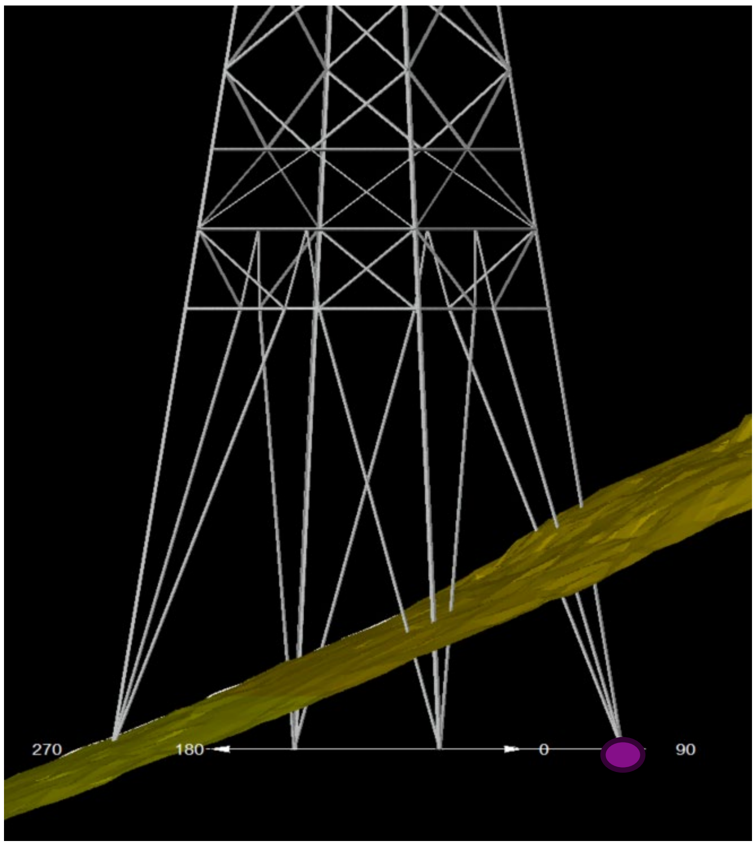
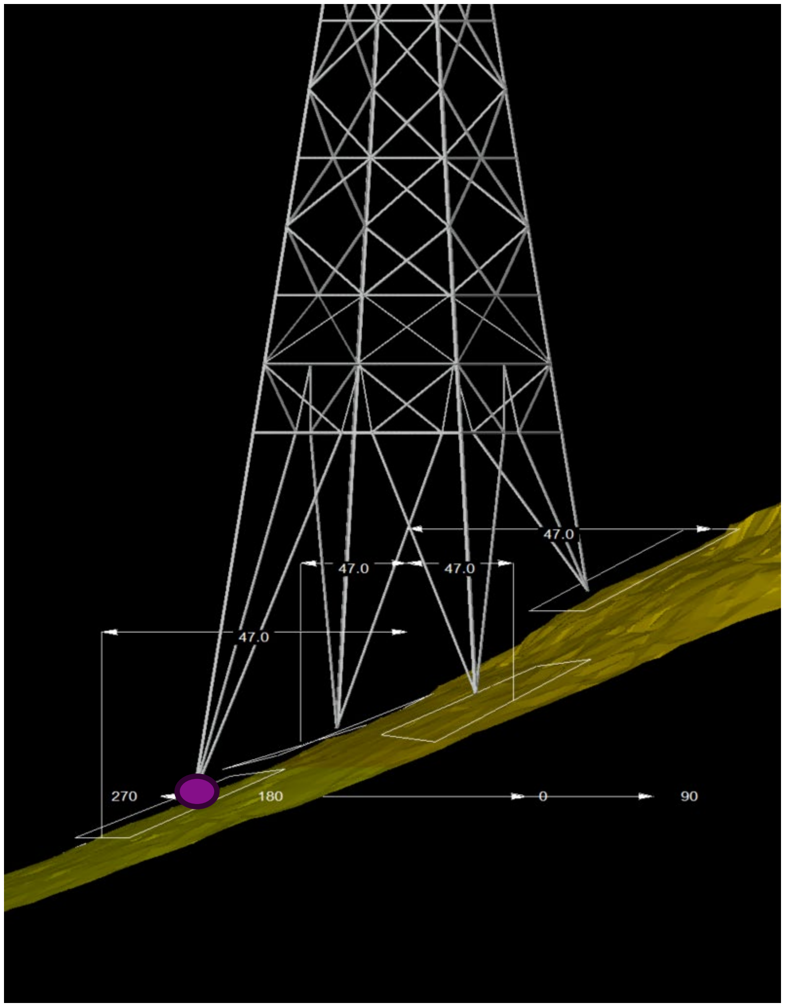
Lattice Tower Method (4) Cont'd





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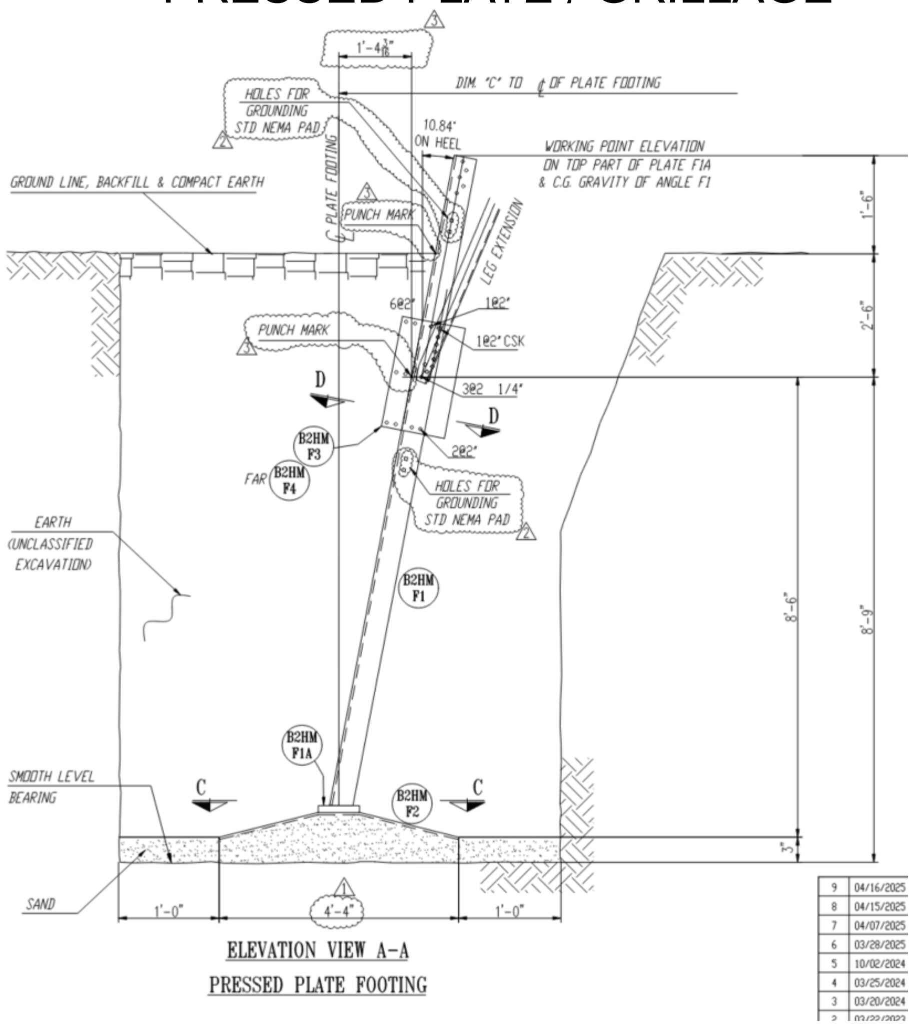
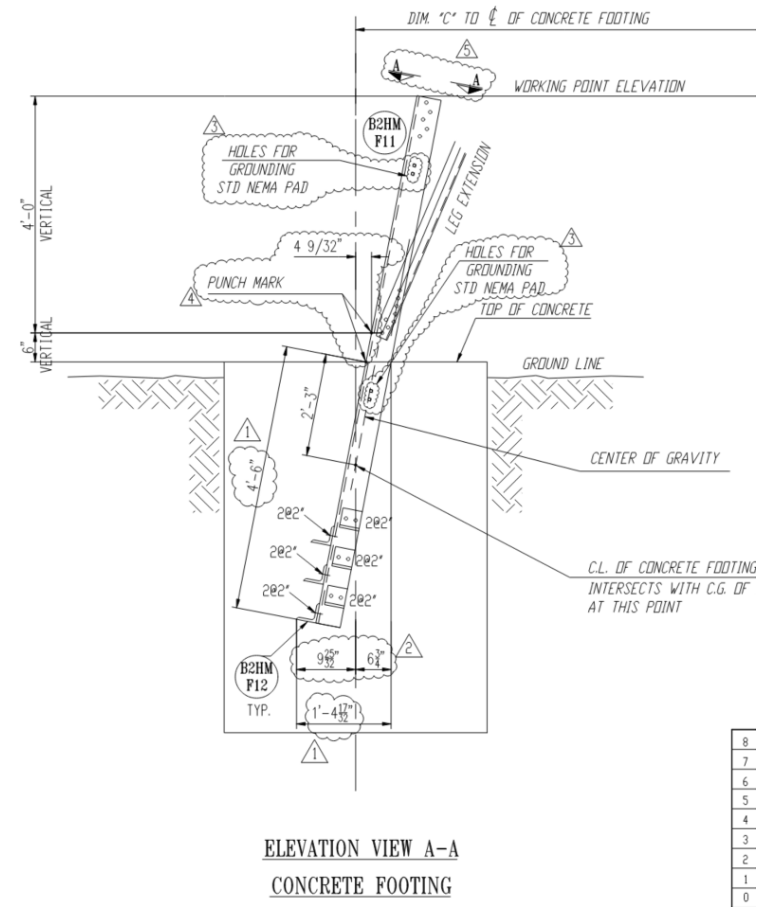
Lattice Tower Method (4): Foundation

- Must think about foundations as that affects LE length
  - PRESSED PLATE / GRILLAGE CONCRETE DRILLED PIER





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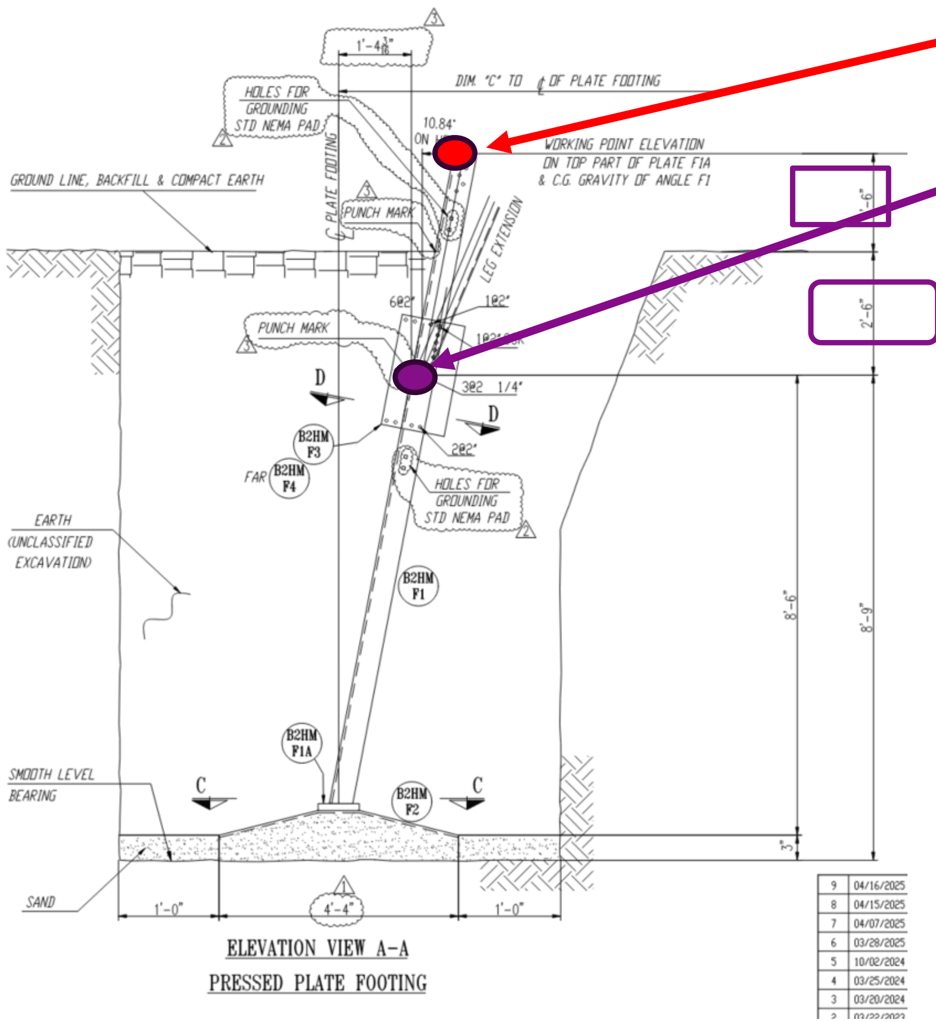
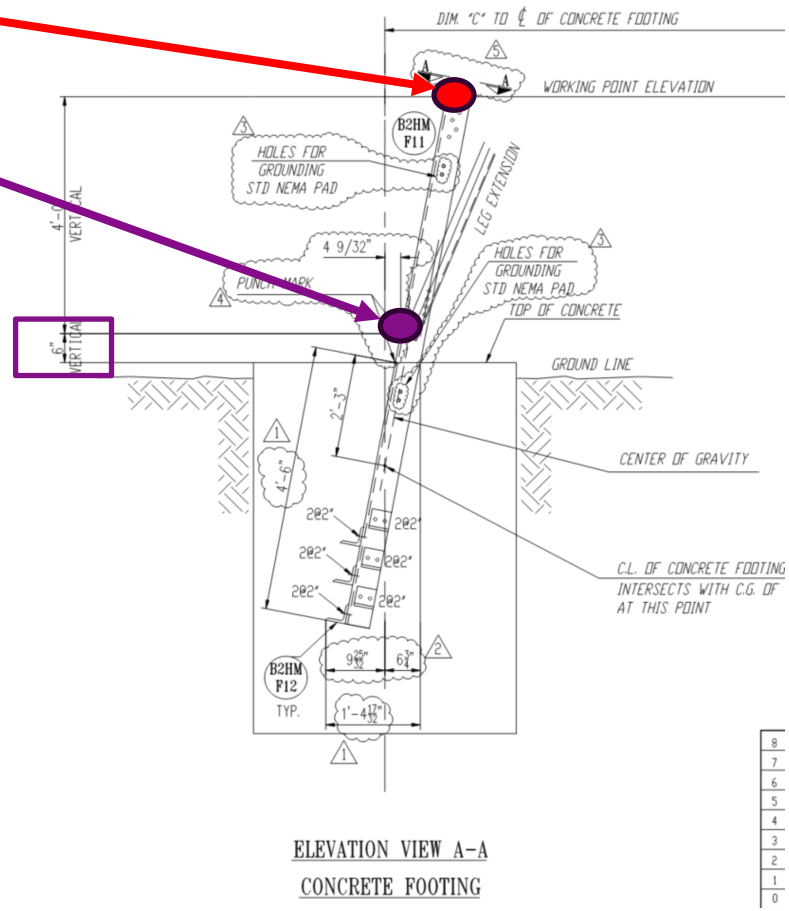
Lattice Tower Method (4): Foundation Cont’d



- Pressed Plate / Grillage
  - Working Point Elev (WPE)
    - 4’ above tower joint
  - Tower joint below ground
  - Max Elev: -2.5’ AGL
    - Relies on sufficiently burying the Plate/Grillage
    - Weight soil
  - Min Elev: - 4.0’ AGL
    - Don’t want stub/WPE buried

Lattice Tower Method (4): Foundation Cont’d

- Concrete (Drilled Pier) Footing
  - Working Point Elev (WPE)
    - 4’ above tower joint
  - Tower joint above ground
  - Max Elev: +4.5’ AGL
    - Max Conc Reveal +4ft
  - Min Elev: +1.5’ AGL
    - Min Conc Reveal +1ft



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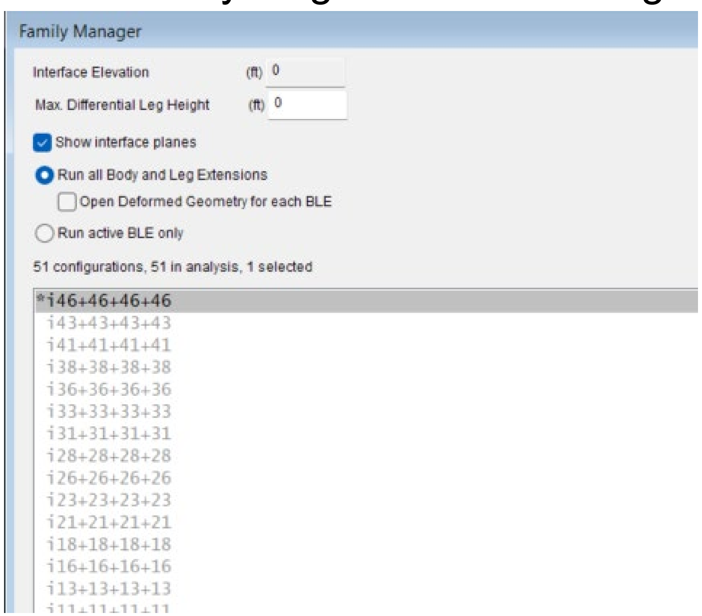
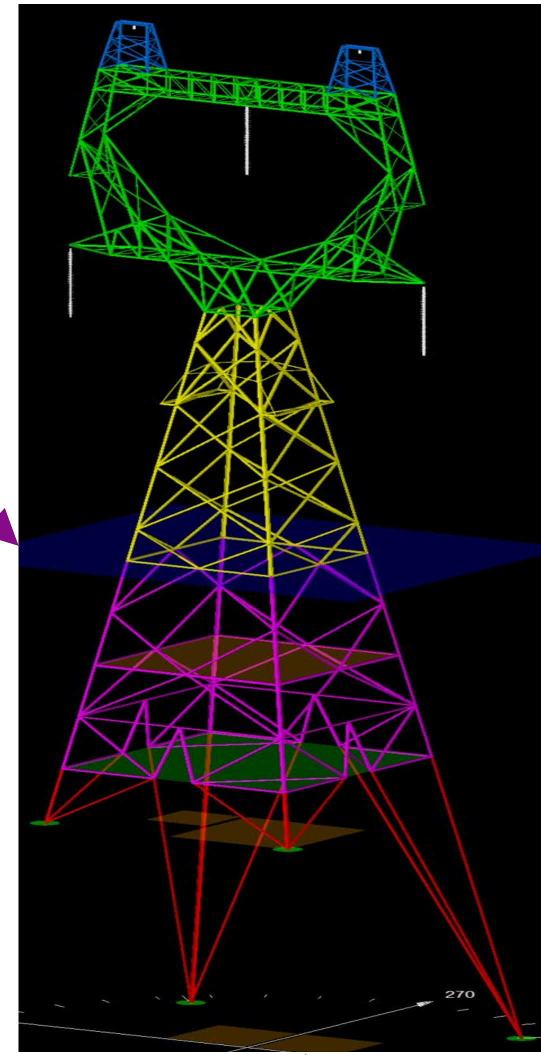
Lattice Tower Method (4): Requirements

- Must have family manager properly setup
  - One line for each LE
  - Default to Largest
  - Z=0 must be set at “interaction plane”
    - Everything above stays same
    - Everything below can change (BE, LE)



Z=0



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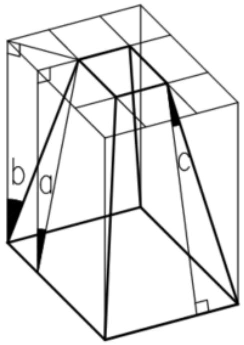
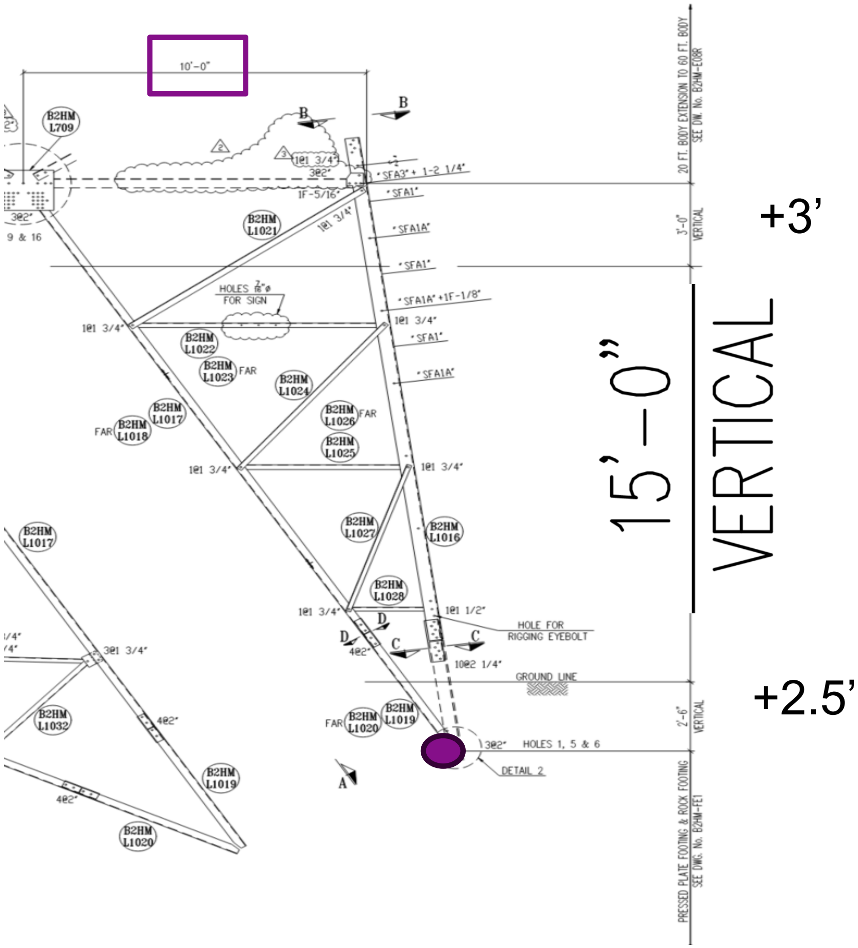
Lattice Tower Method (4): Requirements Cont'd

- Leg actual heights
  - What it's called vs actual length
- X/Y of corners
  - Sets impact footprint
  - Calculated by slope of Tower



VERTICAL SLOPE (a)= 7.7118924127°
LEG SLOPE (b)= 10.8413403585°
IN FACE SLOPE (c)= 7.6429693807°



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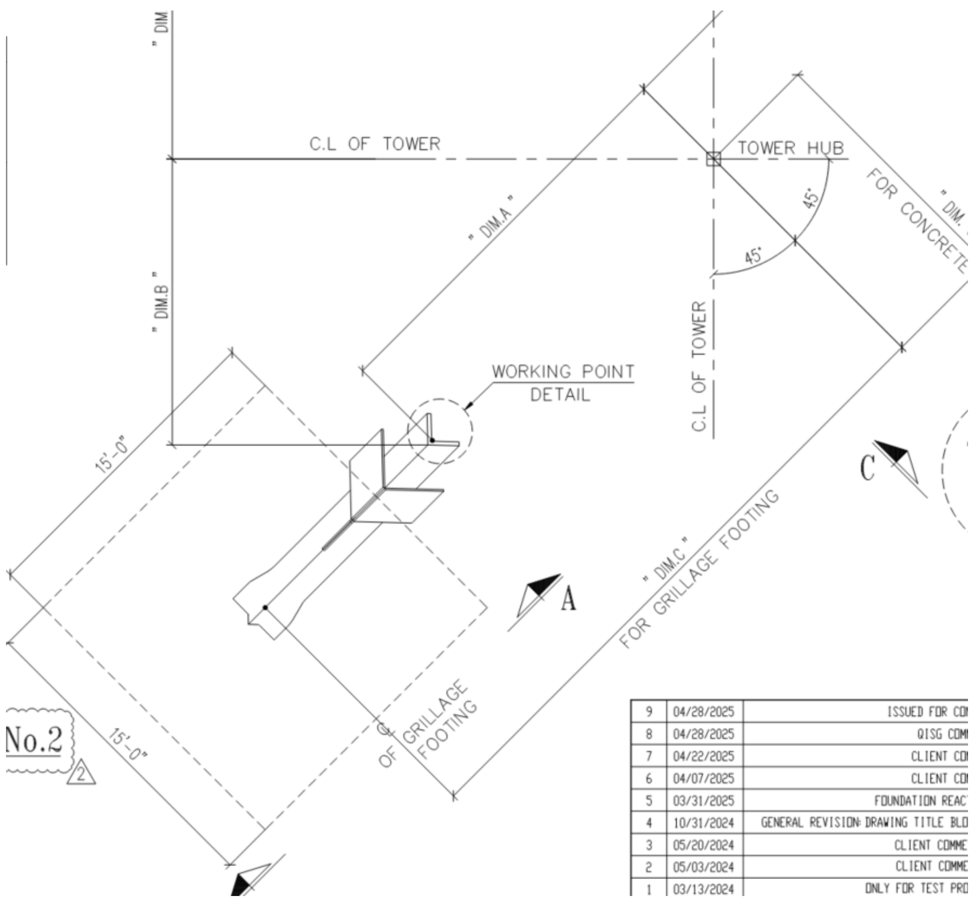
Lattice Tower Method (4): Requirements Cont'd



UNDER 93 ft TOWER (53 ft BASIC TOWER + 20 ft B.E + 20 ft B.E)				
LEG EXT'N	DIM.A	DIM.B	DIM.C	DIM.C
			GRILLAGE FOOTING	CONCRETE FOOTING STUB
5'–0"	29.739	21.138	33.551	31.973
7'–6"	30.372	21.586	34.185	32.607
10'–0"	31.006	22.034	34.819	33.241
12'–6"	31.640	22.482	35.452	33.874
15'–0"	32.274	22.931	36.086	34.508
17'–6"	32.908	23.379	36.720	35.142
20'–0"	33.541	23.827	37.354	35.776
22'–6"	34.175	24.275	37.988	36.410
25'–0"	34.809	24.724	38.621	37.043
27'–6"	35.443	25.172	39.255	37.677
30'–0"	36.076	25.620	39.889	38.311
32'–6"	36.710	26.068	40.523	38.945
35'–0"	37.344	26.517	41.157	39.578
37'–6"	37.978	26.965	41.790	40.212
40'–0"	38.612	27.413	42.424	40.846
42'–6"	39.245	27.861	43.058	41.480
45'–0"	39.879	28.310	43.692	42.114
47'–6"	40.513	28.758	44.326	42.747
50'–0"	41.147	29.206	44.959	43.381

Lattice Tower Method (4): Requirements Cont'd

- One model per BE
  - PLS "optimum spotting" Leg optimizer tends towards longest LE
    - Takes a lot longer with multiple BE
  - Recall want to hit middle of LE range.

248A60-50k.tow

248A60-100k.tow

248A80-50k.tow

248A80-100k.tow

248A100-50k.tow

248A100-100k.tow

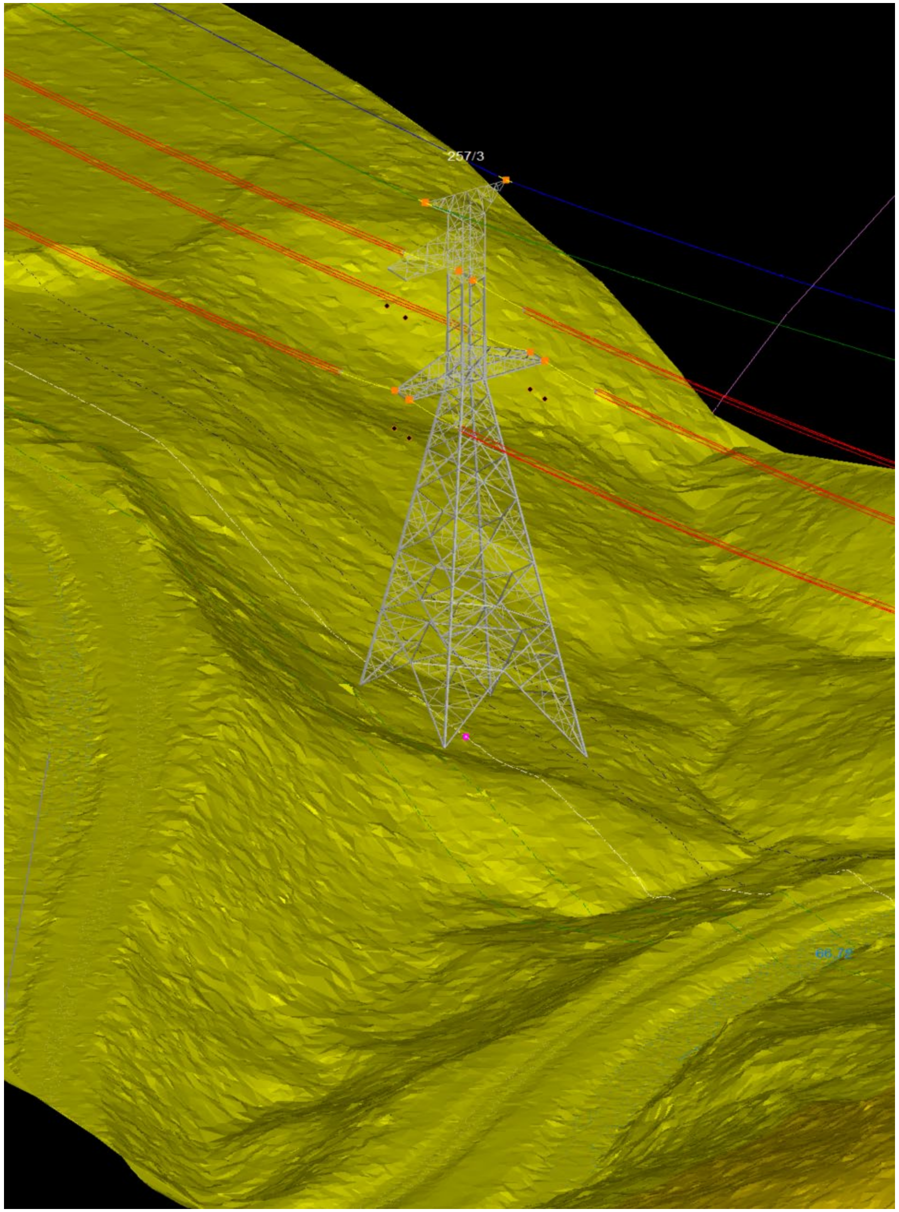
248D53-150k.tow

248D73-150k.tow

248D93-150k.tow

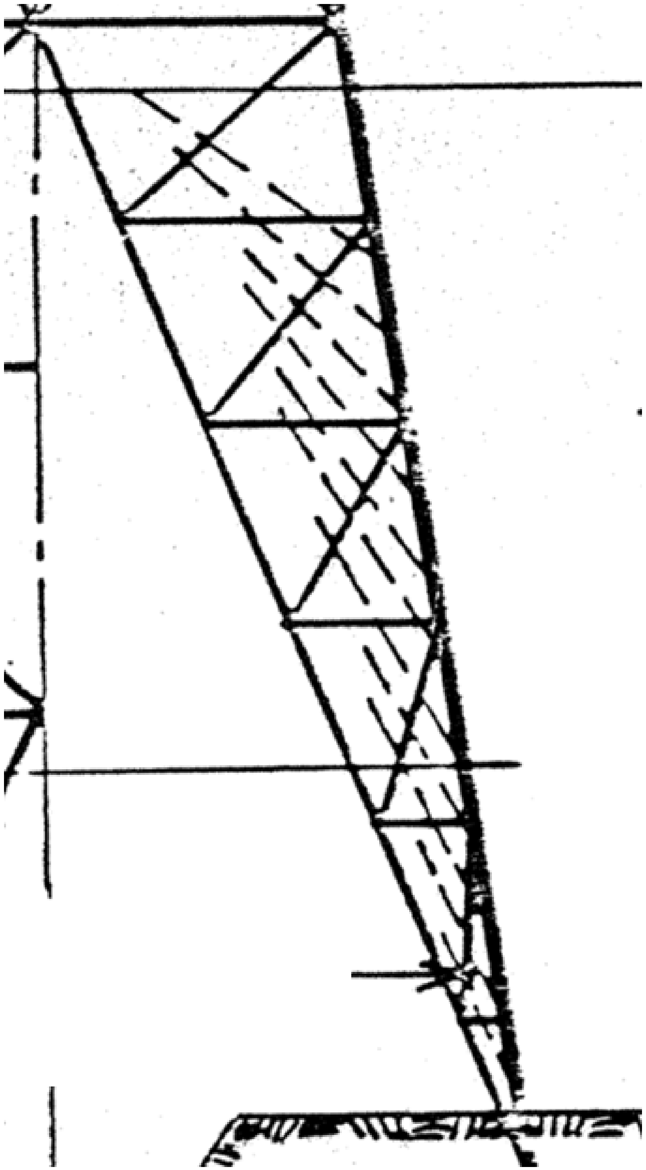
Presentation Outline

- Project Overview
- Lattice Tower Overview
- Lattice Tower Modeling
- **Leg Extensions Design**



Leg Extension Design: Problem

- Changing leg length moves leg footprint
  - Due to slope of tower
    - changes elevation @ TIN surface
    - changes leg length needed
    - changes elevation @TIN surface
    - ...
- Could do a handful manually
  - Guess & Check
  - This Project has 1150 towers
    - 4600 Leg Extensions
  - A person: one every 5-10 minutes
  - Leg Optimizer: hundreds over lunch



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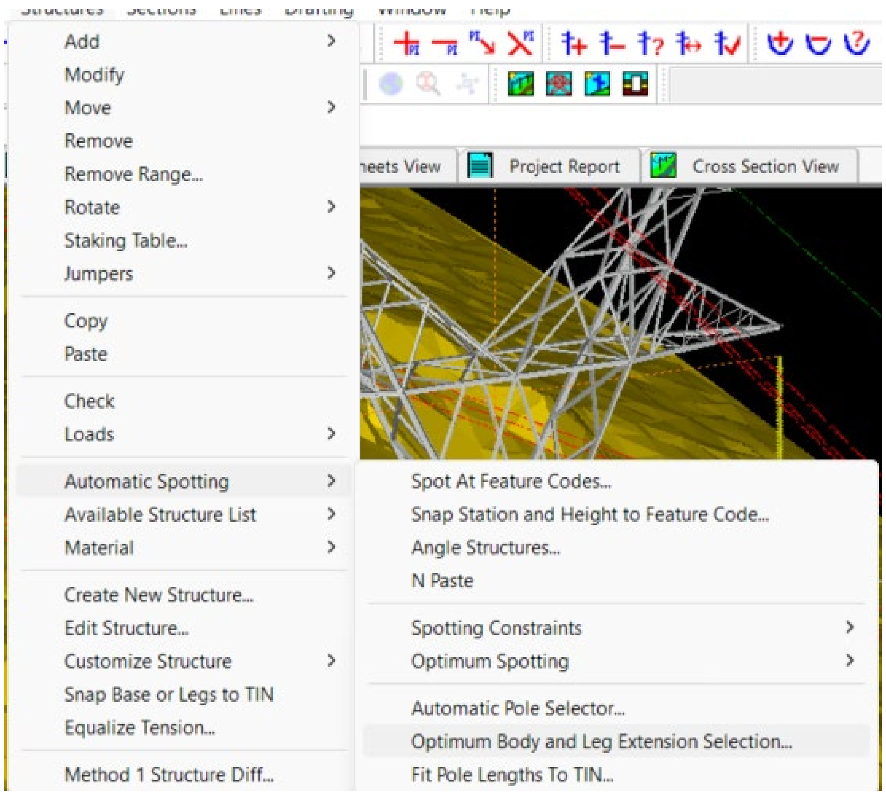
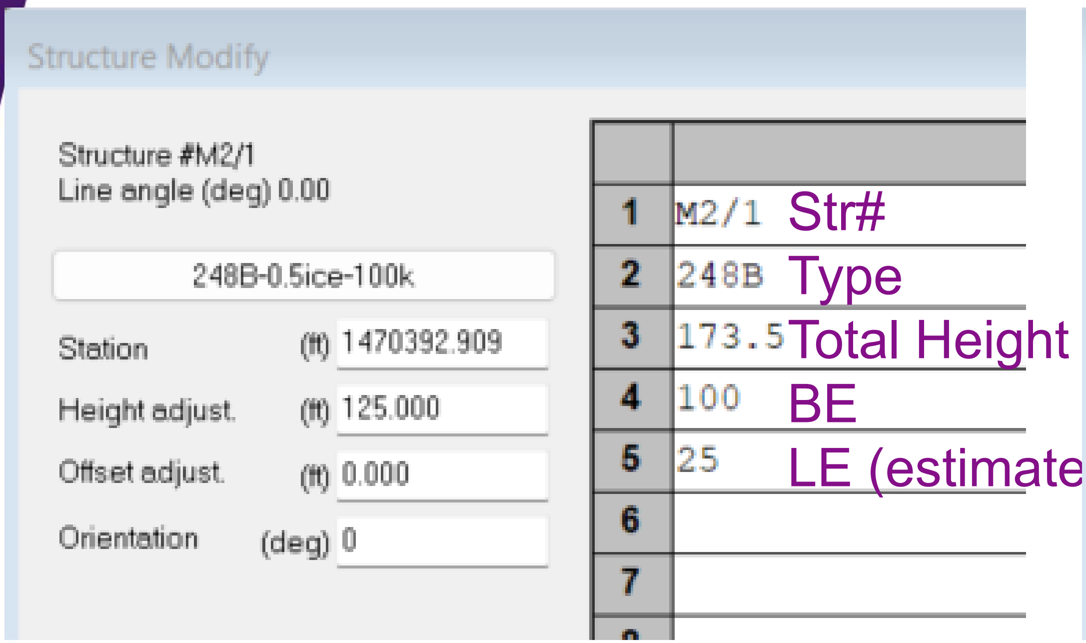
Leg Extension Design: PLS-CADD Solution

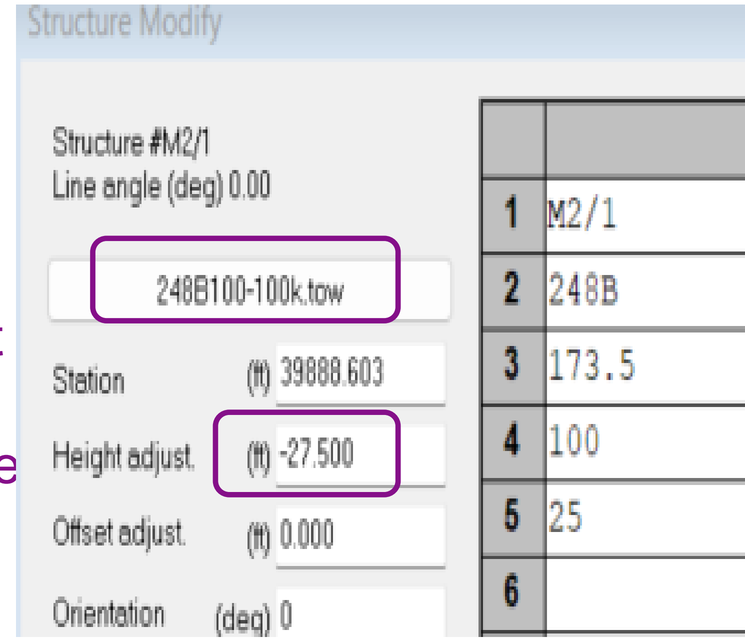
- Solution: PLS-CADD “automatic spotting” Leg Extension Selector
  - Experimental ~V18
  - Fully Functional ~V21
- What you need
  - Method 4 structures
    - (as previously discussed)
  - Good TIN surface
  - New Line edit
    - Estimate BE
    - longest LE set
    - Height offset to match M2
  - Organizational Discipline
    - Consistent File-naming
    - Structure Comment Fields
    - Excel is your friend



Leg Extension Design: Prepare

– Before (m2): (m4)





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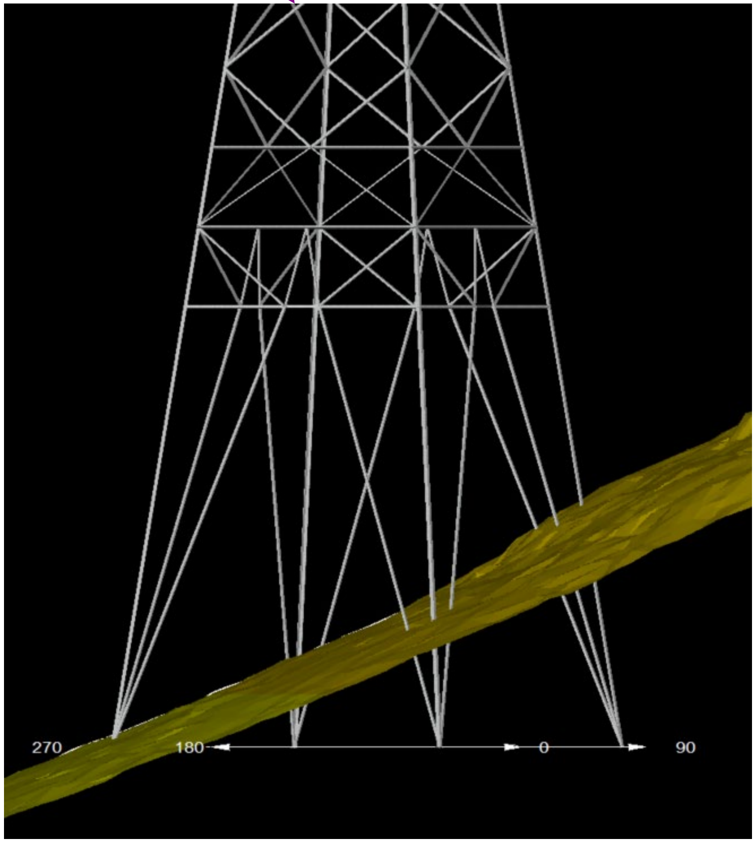
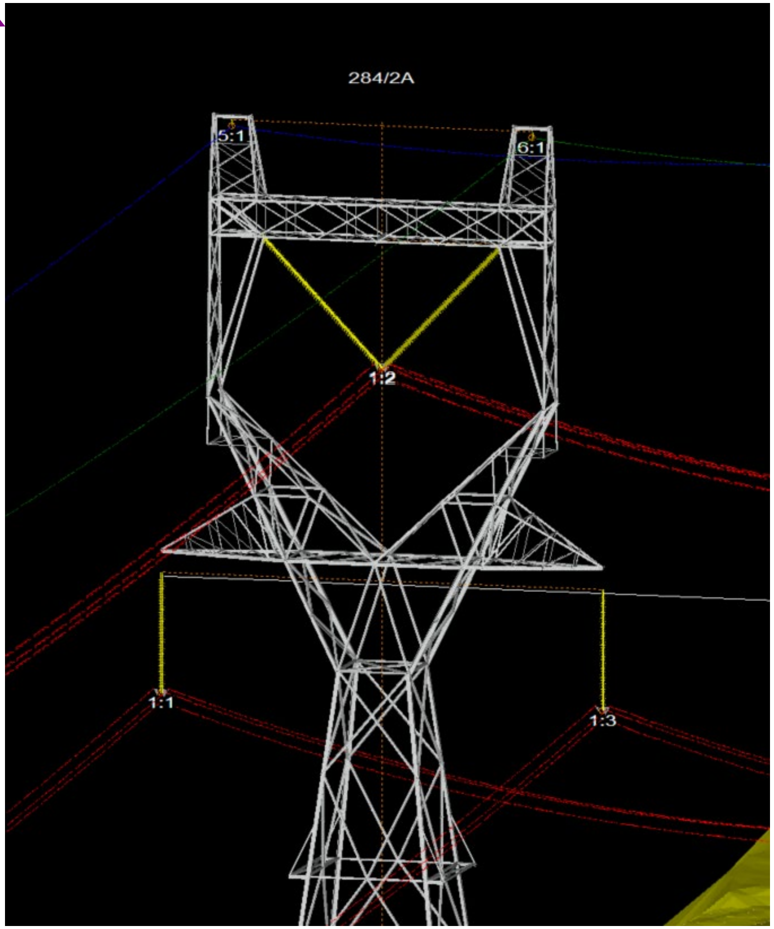
Leg Extension Design: Before

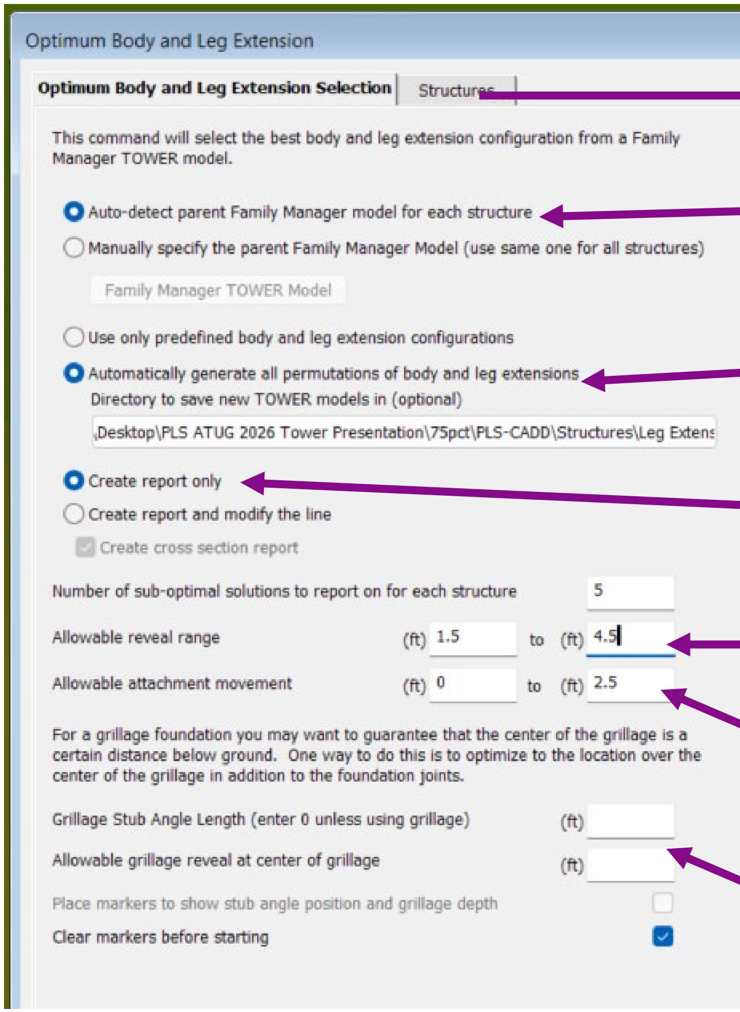
Before (m4)

(m2+m4)

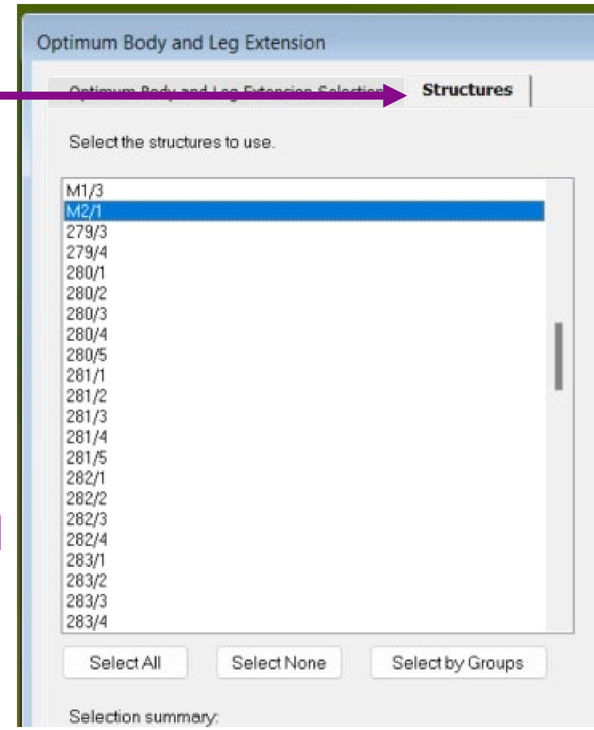




Leg Extension Design: Optimum Leg Menu



Applicable Structures



M4 models populated

Uneven terrain

Do first before modifying model

Foundation Dependent

TIN surface never perfect, limited LE iterations (consider impact to design)

Newer feature to assist with grillage

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Leg Extension Design: Optimizer Report

Leg Reveal, all okay
If a solution cannot be found, RED warning

Height change

Old filename

New Filename

Optimum Body and Leg Extension Selection

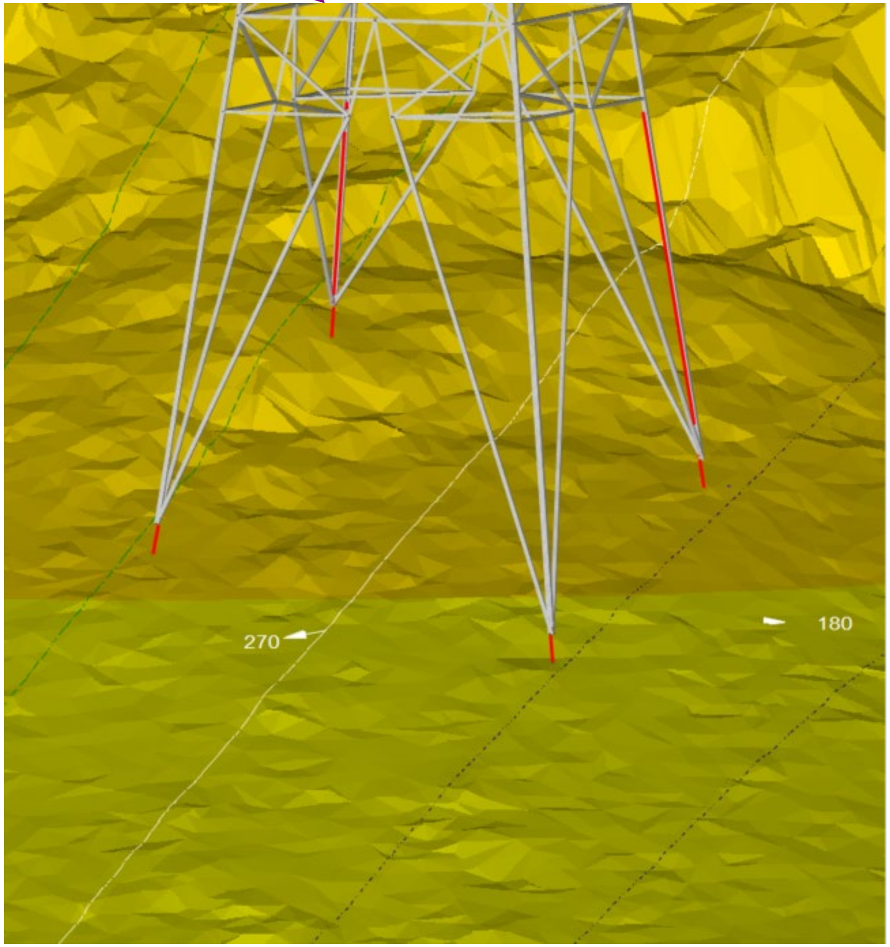
Structure Number	Existing Structure Name	Existing Structure Height (ft)	Existing Structure Weight (lbs)	New Structure Name	New Structure Height (ft)	New Structure Weight (lbs)	Attachment Height Change (ft)	Height Adjust (ft)	Reveal Leg 1 (ft)	Reveal Leg 2 (ft)	Reveal Leg 3 (ft)	Reveal Leg 4 (ft)	Notes
M2/1	248B100-100k.tow	201.0	56125	248B100-100k+NB+21+28+28+23.tow	173.5	50275	0.00	-0.00	4.11	3.10	2.83	2.10	

Sub-Optimum Body and Leg Extension Selection

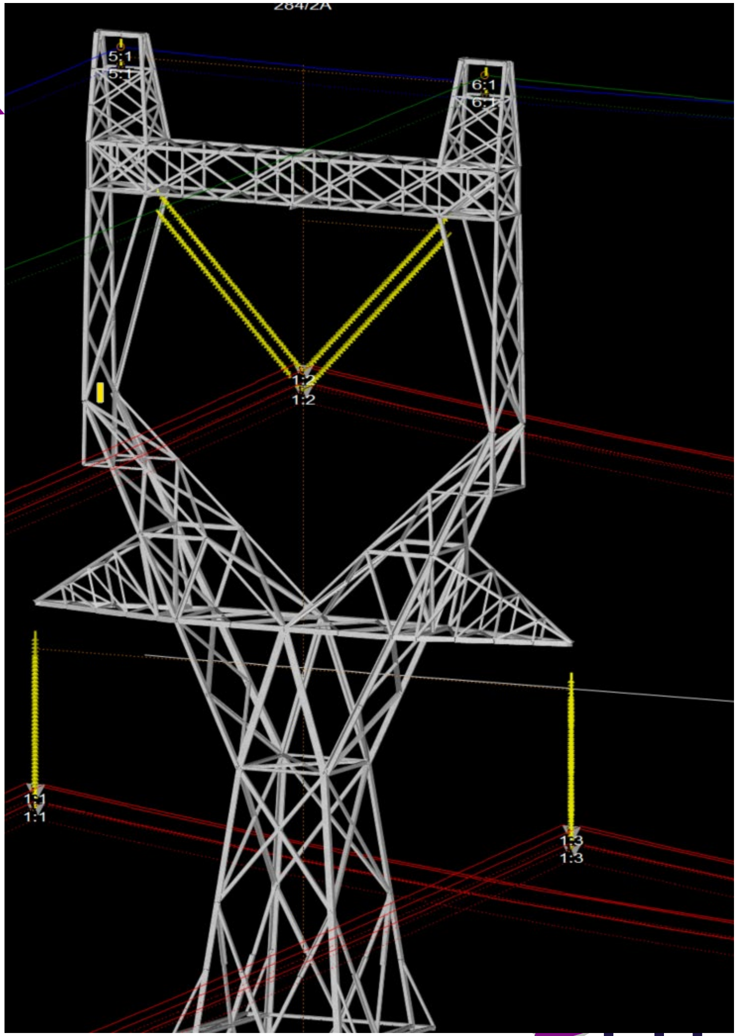
Structure Number	Existing Structure Name	Existing Structure Height (ft)	Existing Structure Weight (lbs)	New Structure Name	New Structure Height (ft)	New Structure Weight (lbs)	Attachment Height Change (ft)	Height Adjust (ft)	Reveal Leg 1 (ft)	Reveal Leg 2 (ft)	Reveal Leg 3 (ft)	Reveal Leg 4 (ft)	Notes
M2/1	248B100-100k.tow	201.0	56125	248B100-100k+NB+23+30+30+23.tow	176.0	50626	1.13	-1.37	2.68	1.79	1.50	3.23	
M2/1	248B100-100k.tow	201.0	56125	248B100-100k+NB+23+30+28+23.tow	176.0	50508	0.84	-1.66	2.39	1.50	3.67	2.94	
M2/1	248B100-100k.tow	201.0	56125	248B100-100k+NB+23+28+30+23.tow	176.0	50508	1.13	-1.37	2.68	4.23	1.50	3.23	
M2/1	248B100-100k.tow	201.0	56125	248B100-100k+NB+23+28+28+23.tow	173.5	50390	0.00	-0.00	1.55	3.10	2.83	2.10	

Leg Extension Design: Success

After (m4)



(m2+m4)



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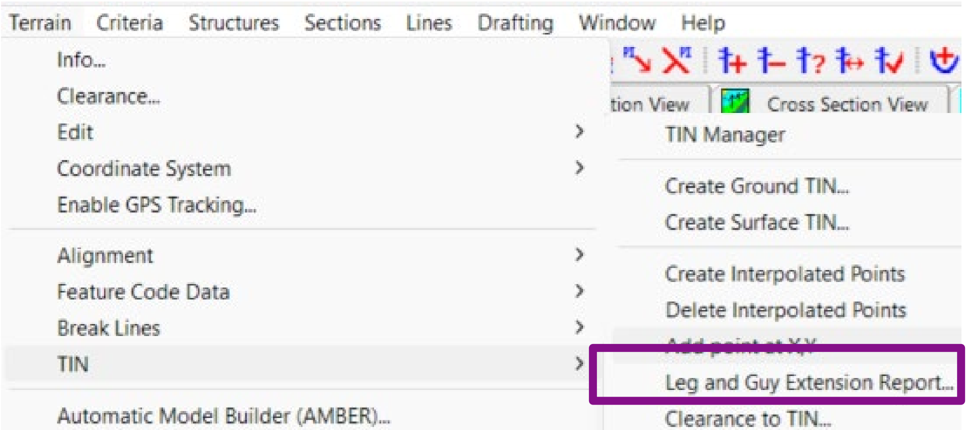
Leg Extension Design: Verify

- Using Leg

& Guy Extension Report



Reval

Structure Number	Member Label or Type	From Joint	To Joint	Member Length (ft)	Member Top Z (ft)	Member Bottom X (ft)	Member Bottom Y (ft)	Member Bottom Z (ft)	TIN Z at Member Bot. XY (ft)	Reveal at Member Bot. XY (ft)	Slope Intersect X (ft)	Slope Intersect Y (ft)	Slope Intersect Z (ft)	Intersect Addl. Len Required (ft)	Intersect Total Len Required (ft)	OK or NG
M1/1	AL80P	120P	1000P	21.003	2664.09	2311911.62	666633.85	2643.59	2642.43	1.16	2311911.36	666633.87	2642.43	1.19	22.20	OK
	LX_AL80P	121P	LX_1000P	26.126	2664.09	2311938.23	666657.44	2638.59	2637.59	1.00	2311938.25	666657.67	2637.56	1.05	27.18	OK
	LXY_AL80P	122P	LXY_1000P	26.126	2664.09	2311961.73	666629.72	2638.59	2636.46	2.13	2311962.23	666629.68	2636.34	2.30	28.43	OK
	LY_AL80P	123P	LY_1000P	21.003	2664.09	2311934.10	666607.33	2643.59	2641.87	1.72	2311934.07	666606.96	2641.89	1.74	22.75	OK
M1/2	AL100P	140P	1000P	41.494	2626.32	2313089.32	665234.86	2585.82	2584.82	1.00	2313089.09	665234.87	2584.80	1.05	42.54	OK
	LX_AL100P	141P	LX_1000P	38.932	2626.32	2313125.41	665264.93	2588.32	2587.13	1.19	2313125.43	665265.20	2587.13	1.22	40.15	OK
	LXY_AL100P	142P	LXY_1000P	33.810	2626.32	2313154.42	665229.49	2593.32	2590.55	2.77	2313155.02	665229.44	2590.61	2.78	36.59	OK
	LY_AL100P	143P	LY_1000P	36.371	2626.32	2313120.04	665199.83	2590.82	2588.90	1.92	2313120.01	665199.41	2588.92	1.95	38.32	OK
M1/3	73LP	104P	1000P	31.980	2661.72	2313871.11	664304.84	2630.72	2628.92	1.80	2313870.67	664304.71	2628.91	1.86	33.84	OK
	LX_73LP	105P	LX_1000P	34.560	2661.72	2313891.66	664344.49	2628.22	2626.94	1.28	2313891.56	664344.81	2626.93	1.33	35.89	OK
	LXY_73LP	106P	LXY_1000P	34.560	2661.72	2313931.49	664323.34	2628.22	2627.22	1.00	2313931.74	664323.42	2627.21	1.04	35.60	OK
	LY_73LP	107P	LY_1000P	31.980	2661.72	2313910.16	664284.11	2630.72	2628.93	1.79	2313910.29	664283.68	2628.93	1.85	33.83	OK
M2/1	BL100P	1601P	5000P	23.341	2799.92	2315581.95	664113.35	2776.92	2774.74	2.18	2315581.67	664113.12	2774.79	2.16	25.50	OK
	LX_BL100P	1602P	LX_5000P	30.952	2799.92	2315584.87	664148.56	2769.42	2768.13	1.29	2315584.73	664148.73	2768.10	1.34	32.30	OK
	LXY_BL100P	1603P	LXY_5000P	30.952	2799.92	2315620.89	664144.63	2769.42	2768.42	1.00	2315621.03	664144.74	2768.40	1.03	31.98	OK
	LY_BL100P	1604P	LY_5000P	23.341	2799.92	2315616.15	664109.62	2776.92	2774.19	2.73	2315616.44	664109.26	2774.24	2.72	26.06	OK

Leg Extension Design: Result

Individual Files

Structures > Leg Extension > Individual Files

View ⌄ ···

Name

- 248M60-50k+NB+13+10+10+13.tow
- 248M60-50k+NB+15+18+18+15.tow
- 248M60-50k+NB+31+33+31+31.tow
- 248D73-150k+NB+21+26+24+19.tow
- 248D73-150k+NB+24+21+21+21.tow
- 248D73-150k+NB+11+24+24+11.tow
- 248D73-150k+NB+24+26+21+19.tow
- 248D73-150k+NB+26+26+26+24.tow
- 248D73-150k+NB+26+26+29+26.tow
- 248D53-150k+NB+13+21+18+11.tow
- 248D53-150k+NB+13+26+36+24.tow
- 248D53-150k+NB+21+24+24+21.tow
- 248A100-50k+NB+18+23+23+21.tow
- 248A100-50k+NB+21+21+21+26.tow
- 248A100-50k+NB+21+23+21+21.tow
- 248A100-50k+NB+21+23+23+21.tow
- 248A100-50k+NB+26+18+21+21.tow
- 248A100-50k+NB+28+33+48+38.tow
- 248A100-50k+NB+13+23+28+18.tow
- 248A100-50k+NB+33+43+46+30.tow
- 248A100-50k+NB+41+38+33+36.tow
- 248A100-50k+NB+48+48+51+51.tow
- 248B80-100k+NB+36+28+28+33.tow

	Structure Number	t ft	Height Adjust. (ft)	fs ju ft	nt ng le	X Easting (ft)	Y Northing (ft)	r a ft	TIN Z Elevation (ft)	e ft	in ng e	:	w k r e	Structure Name
11	272/1	9	-8.600			2288530.352	686677.784	6	2947.386	1		N	9	248M100-50k+NB+36+41+36+30.tow
12	272/2	0	-7.310			2289340.918	686010.699	2	2907.802	1		N	9	248M100-50k+NB+36+41+38+33.tow
13	272/3	1	-7.060			2290280.986	685237.035	0	2847.080	7		N	9	\248M80-50k+NB+38+41+46+43.tow
14	272/4	8	-5.000			2291102.884	684560.624	5	2900.334	3		N	9	\248A60-50k+NB+26+23+26+26.tow
15	273/1	1	-4.710			2292430.396	683468.100	1	2854.681	4		N	9	248B100-50k+NB+41+41+38+38.tow
16	273/2	5	-10.230			2293866.750	682286.000	1	2909.141	0	9	N	0	248D93-150k+NB+54+51+44+46.tow
17	273/3	5	-6.650			2295021.000	681696.000	6	3160.836	2	4	N	7	248B80-100k+NB+41+36+33+41.tow
18	274/1	7	-7.500			2296045.764	681031.593	6	3007.856	0		N	4	248A100-50k+NB+33+43+46+30.tow
19	274/2	7	-0.060			2297338.091	680193.711	3	2854.103	6	3	N	1	248D53-150k+NB+21+24+24+21.tow
20	274/3	3	-5.000			2298425.939	679222.744	9	2802.489	7		N	7	248A100-50k+NB+13+23+28+18.tow
21	274/4	0	-8.360			2299485.363	678277.147	0	2764.470	9		N	7	\248A80-50k+NB+33+38+43+38.tow
22	275/1	9	-4.240			2300622.363	677262.309	0	2718.260	1		N	7	248A100-50k+NB+26+28+28+26.tow
23	275/2	0				2301520.539	676460.635	8	2777.508	5		N	7	\248A60-50k+NB+26+26+28+26.tow
24	275/3	5	-5.500			2302490.921	675594.514	3	2700.093	1	6	N	0	248D73-150k+NB+11+24+24+11.tow
25	275/4	6	-7.320			2303041.979	674874.611	2	2674.482	1		N	3	\248M80-50k+NB+38+46+46+38.tow
26	276/1	7	-4.860			2303836.375	673836.810	0	2693.080	6		N	3	\248M80-50k+NB+33+38+38+36.tow
27	276/2	3	-4.130			2304428.690	673063.010	1	2683.760	6		N	3	\248M80-50k+NB+28+38+36+26.tow
28	276/3	9	-6.1[illegible]			2305123.107	672155.822	7	2723.307	4		N	3	\248M60-50k+NB+23+26+23+20.tow
29	276/4	3	-5.55[illegible]			2305774.957	671304.244	3	2702.633	3		N	3	\248M80-50k+NB+21+26+26+21.tow
30	276/5	6	-7.410			2306577.299	670256.064	1	2635.491	5	3	N	5	248D93-150k+NB+26+28+31+26.tow
31	277/1	0	-5.240			2307022.934	668701.991	0	2775.990	4	5	N	4	248D73-150k+NB+29+29+29+26.tow
32	277/2	5	-10.030			2307899.380	667577.236	1	2808.371	9	5	N	8	248D53-150k+NB+13+26+36+24.tow
33	277/3	4	-5.000			2308954.698	667592.588	8	2664.388	1		N	6	\248A80-50k+NB+36+38+38+36.tow
34	277/4	5	-3.290			2309966.942	667607.313	6	2653.546	6		N	6	les\248M60-50k+18+18+18+18.tow
35	278/1	1	-10.500			2311095.268	667623.727	0	2564.920	9	7	N	9	248D73-150k+NB+26+34+31+24.tow
36	M1/1	0	-7.150			2311936.119	666631.834	9	2640.609	0		N	3	248A80-100k+NB+26+31+31+26.tow

Heights Adjusted

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Questions