# TOWER LOAD TEST PLAN DEVELOPMENT USING PLS-TOWER

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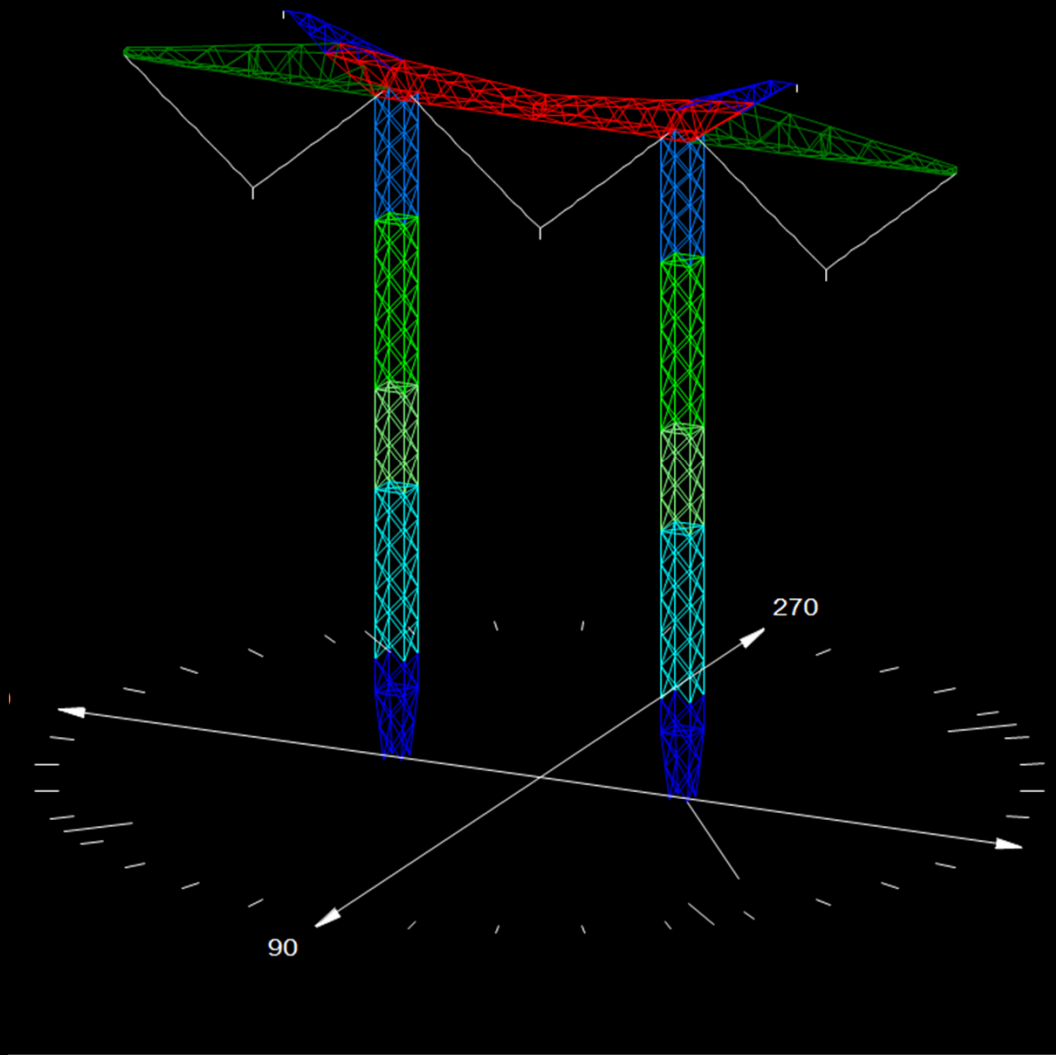



ATUG Conference| June 2026

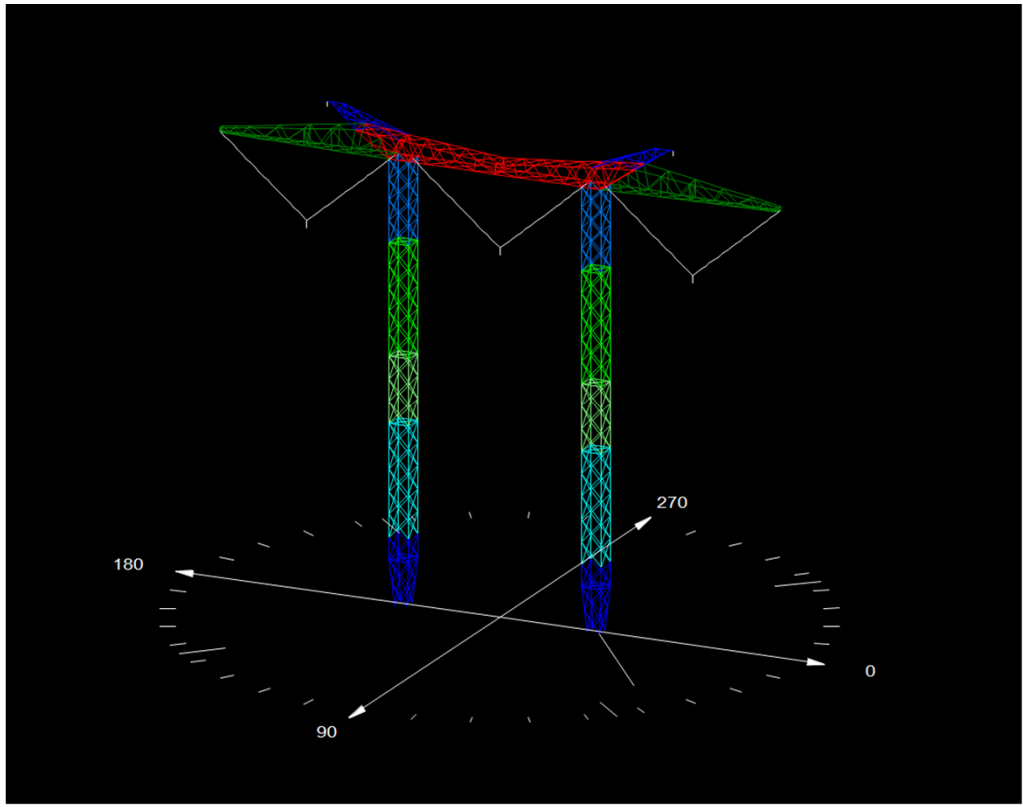
# Purpose and Learning Objectives

The purpose of this program is to provide an overview of how we develop a load test plan using PLS-Tower for lattice tower testing.

At the end of this presentation you will be able to:

- *Use PLS-Tower to develop load test plan*
- *Use PLS-Tower to analyze the tower given the mechanical strength of steel*
- *Use PLS-Tower to select test load cases*
- *Use PLS-Tower to determine how to apply wind loading during testing*

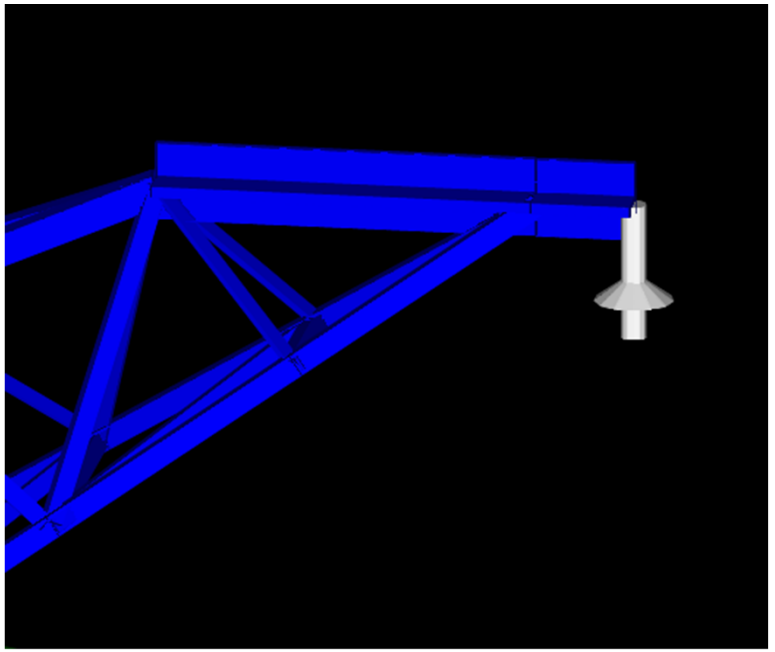
# General Process Overview

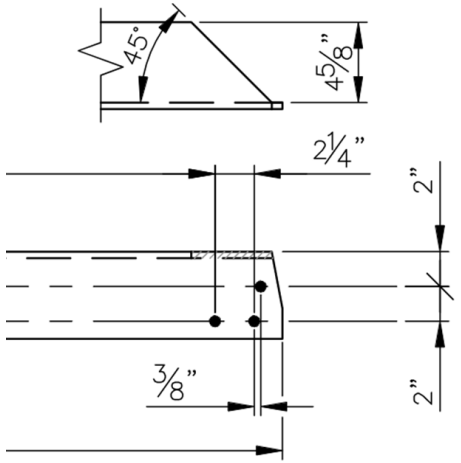



- Use PLS-Tower to Analyze Tower Design
  - Verify usages of member
- Use PLS-Tower to prepare for tower test
  - Determine governing load case in main chord members
  - Select load cases for load test
  - Determine wind load rigging
  - Determine anticipated deflections
- Pre-load test procedures (ASCE 10-15 Ch. 6)
  - Tower vendor to submit heat lot mechanical strength test of steel
  - Attach strain gages to tower (If needed)
- Post test procedures
  - Compare deflections
  - Perform mechanical strength test of main chord members and varying other member sizes
  - Compare initial analysis to tested mechanical strength values and strain gage results

# Why Test Tower Designs?

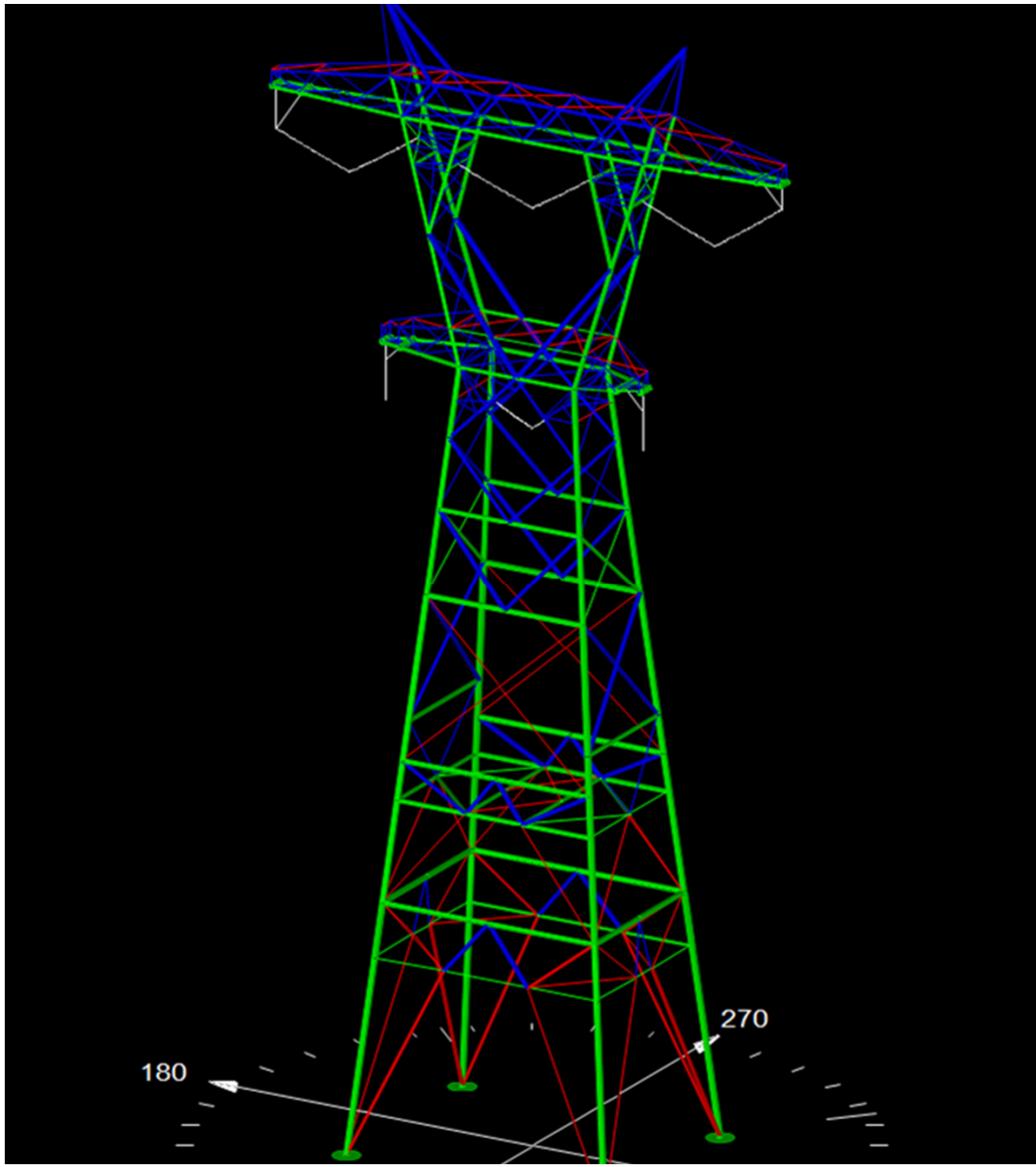
- Framing eccentricities
  - Excessive bending
- Stress concentrations
  - Member cuts, clip, notches, etc. added during member detailing
- Unforeseen load paths
  - Unstable mechanism
    - Adequate redundant bracing
  - Member detailing at Connections
- Verification of design model
  - Deflections
  - Permanent deformations
    - Connections & Members
  - Towers can be tested to destruction





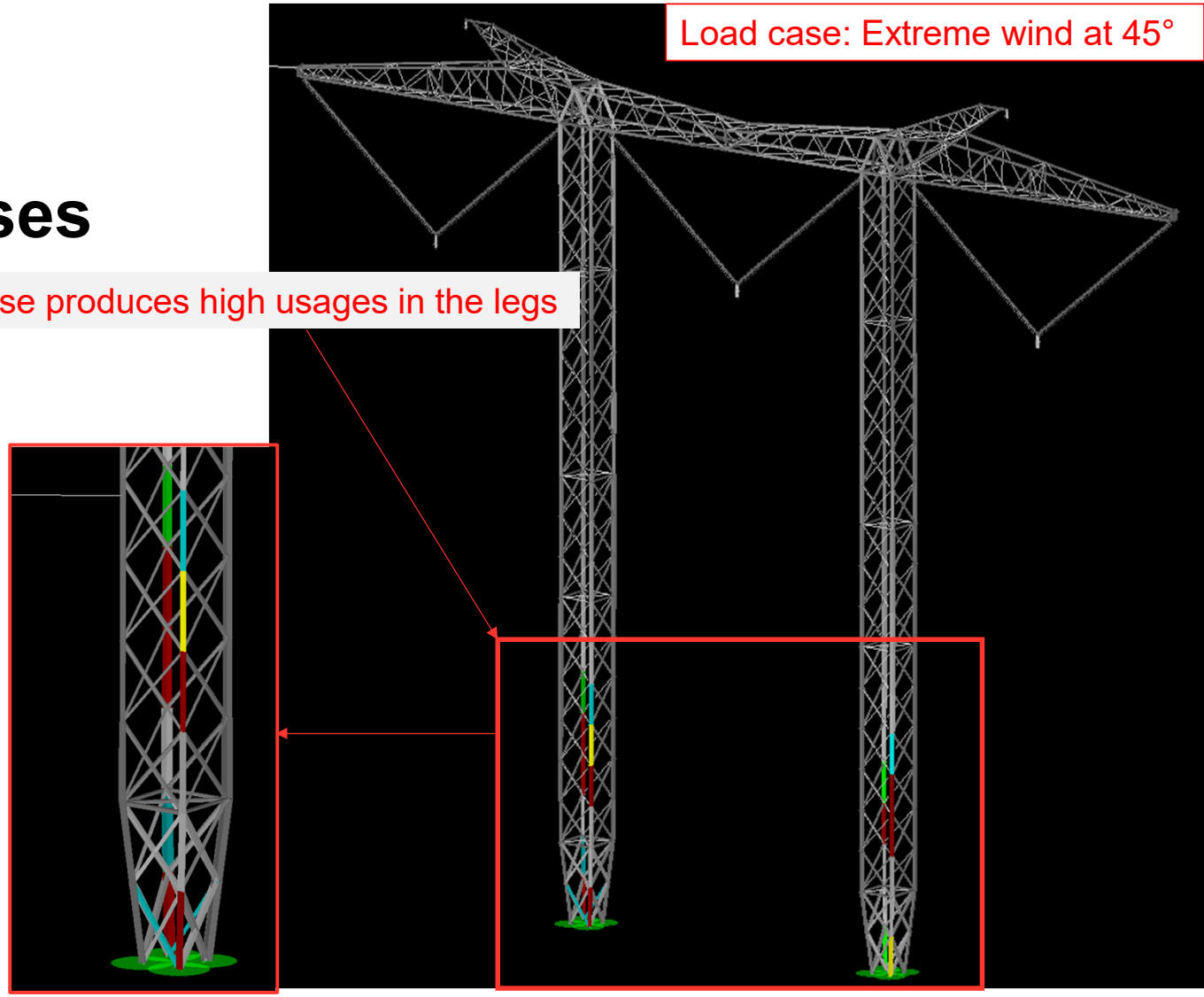
# PLS-Tower Design Analysis (Pre-load test)

- Identify governing load cases for main chord members
  - Shield wire peak, crossarms, bridge, k-frame, legs, etc.
- Determine load cases for testing
  - Typically consist of 6-10 load cases
  - Load cases typically considered:
    - Code Cases
    - Max vertical, transverse, and longitudinal loadings
    - Quartering wind cases
    - Torsional conditions (i.e. Broken wire, differential ice, etc.)



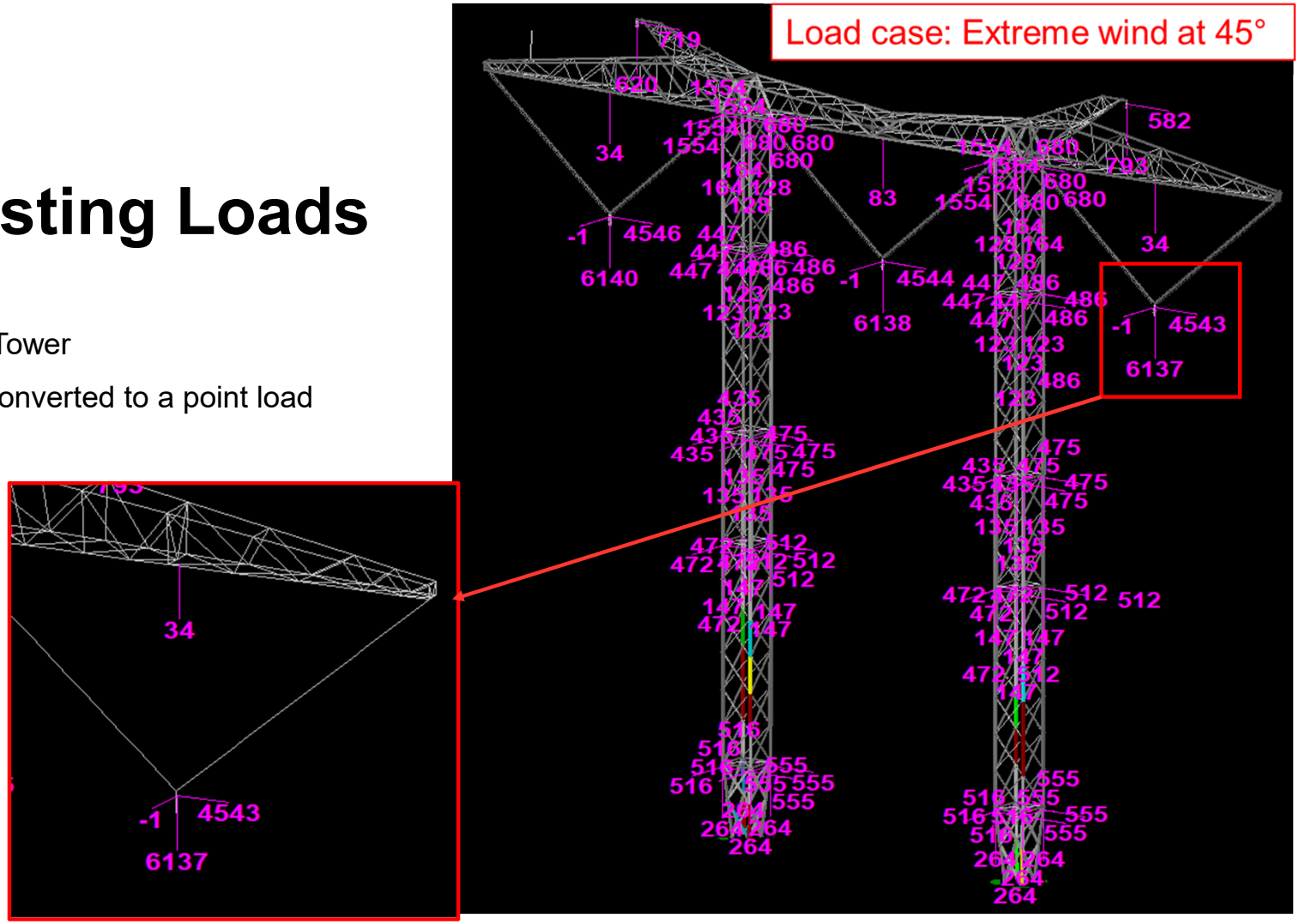
# Selecting Load Cases

- Additional load cases that should be considered:
  - Load cases that produce high usages in critical areas of the tower (i.e. Shield wire peak, crossarms, bridge, k-frame, legs, etc.)
- Test from least impactful load cases to most impactful load cases



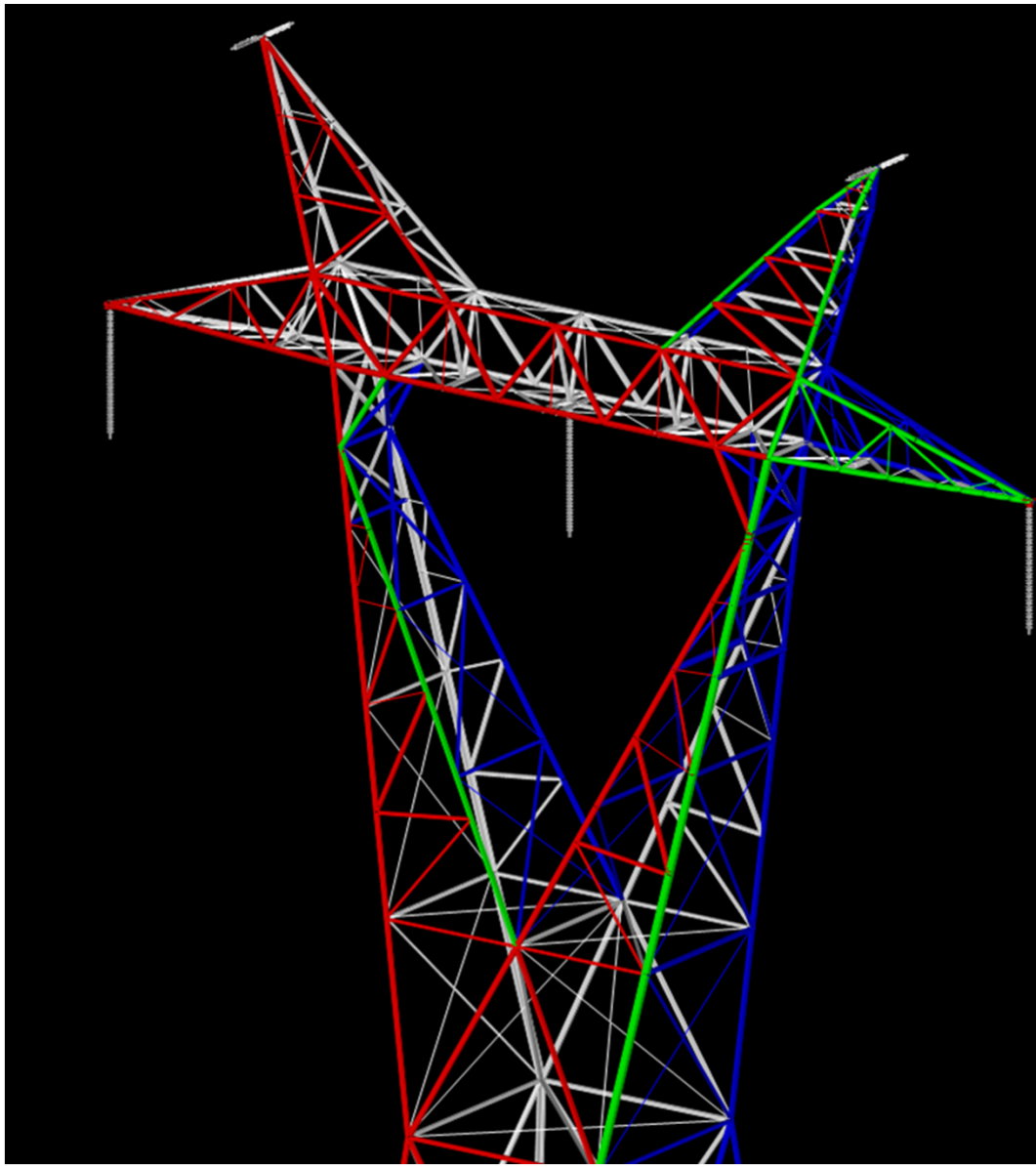
# Determine Testing Loads

- Load case vectors from PLS-Tower
- Wind loading will have to be converted to a point load application



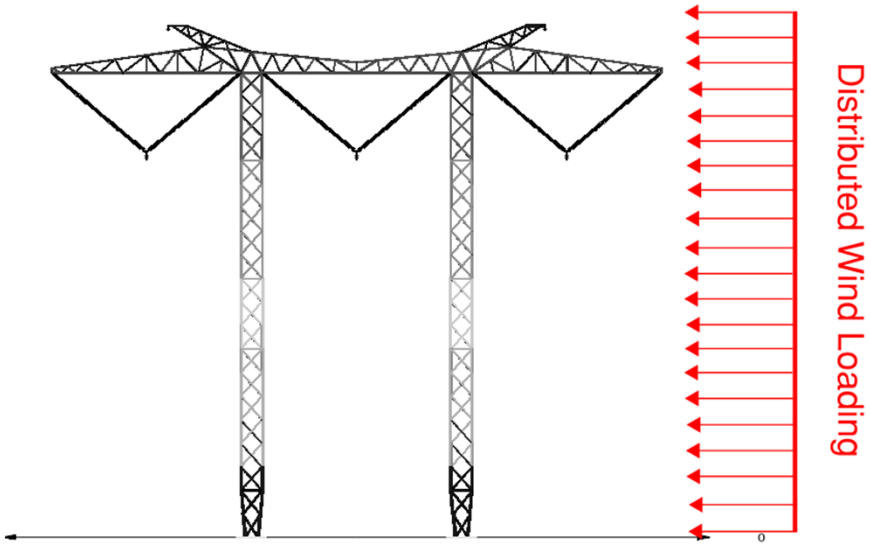
# Applied Load Calculation: K-frame Towers

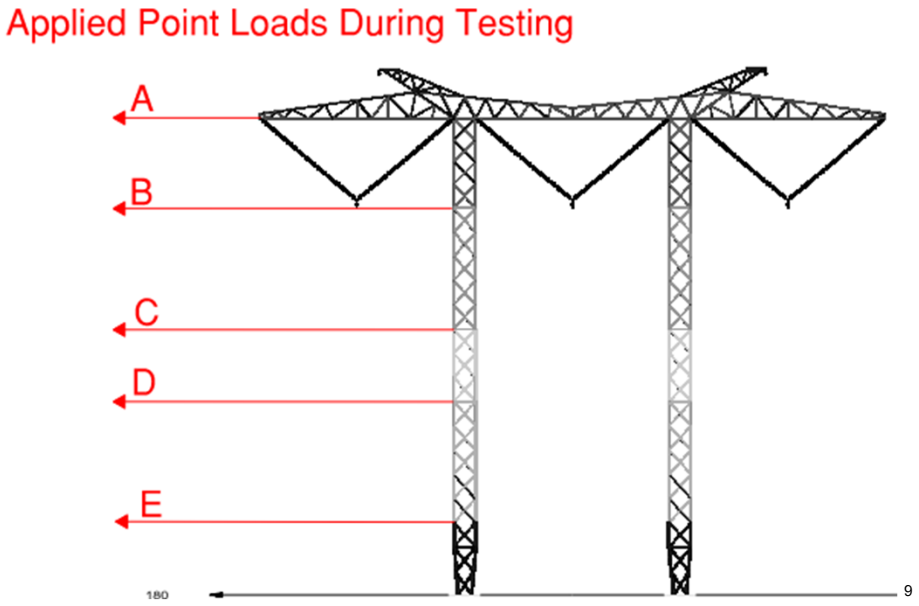
- Wind Face Assignments
  - Wind on face model need the wind faces adjusted in PLS-Tower
  - Load cases with the “Wind on all” wind model do not have this issue
  - Wind models using $C_d$ from code do not have this issue



# Wind Loading Application During Testing

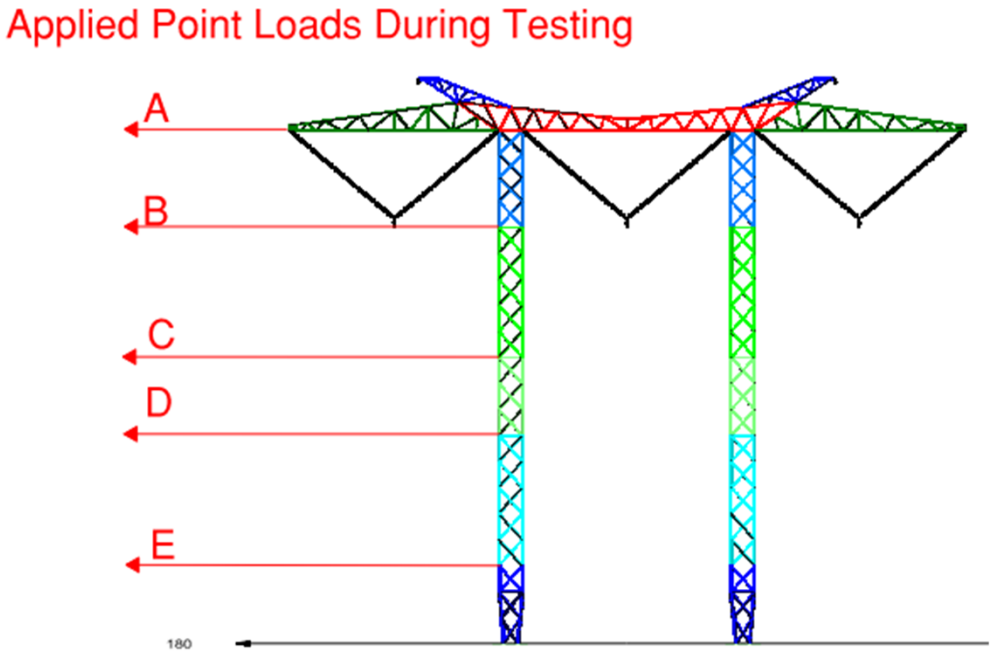
- Wind loading will be applied as point loads at multiple locations
- Design model analyzed using a distributed wind loading



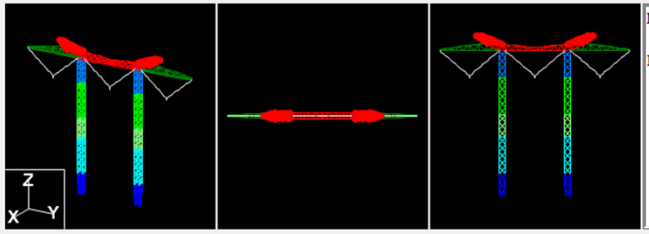
# Applied Point Load Calculation (Step 1)

- Set Sections in PLS-Tower to where load cables will attach
- Rigging cables will preferably attach at diaphragm members
  - Avoid loading redundant members



# PLS-Tower Sections Table

Sections



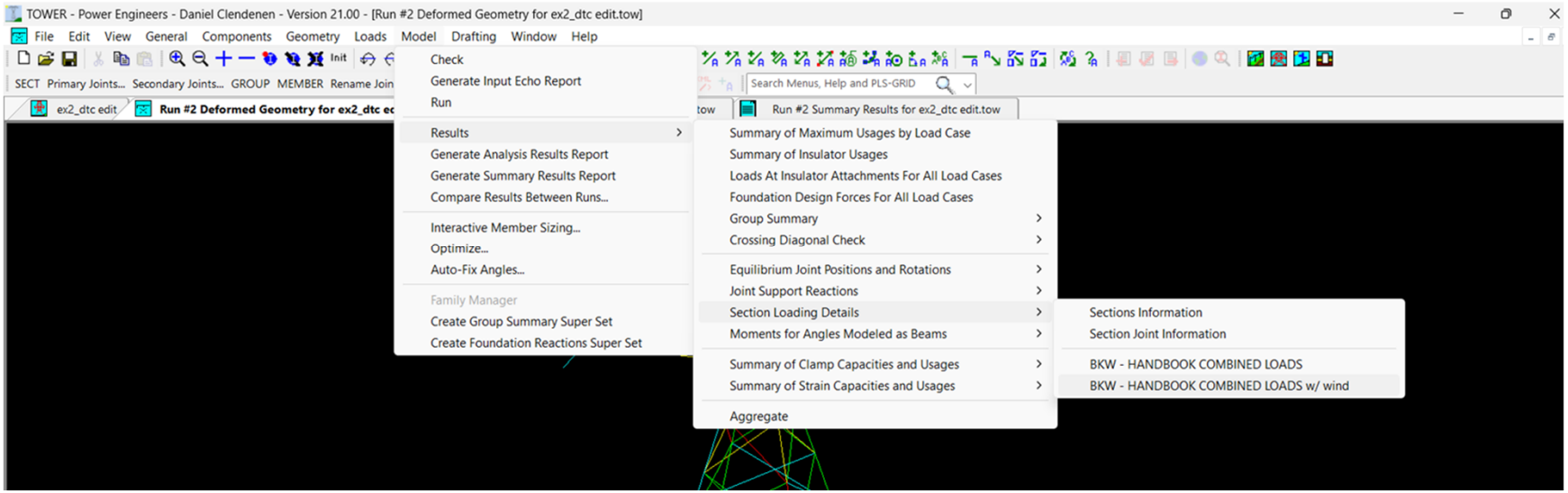
Model Check Report

No errors or relevant warnings detected.

| | Section Label | Section Color | Joint Defining Section Bottom | Dead Load Adjust. Factor | Transverse Drag x Area Factor For Face | Longitudinal Drag x Area Factor For Face | Transverse Area Factor (CD From Code) | Longitudinal Area Factor (CD From Code) | Af Flat Factor For Face EIA Only | Ar Round Factor For Face EIA Only | Transverse Drag x Area Factor For All | Longitudinal Drag x Area Factor For All | SAPS Angle Drag x Area Factor | SAPS Round Drag x Area Factor | Adjustment Type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | GWP | | | 1.160 | 3.200 | 3.200 | 1.000 | 1.000 | 0.000 | 0.000 | 1.600 | 1.600 | 1.000 | 1.000 | None |
| 2 | BR | | | 1.160 | 3.200 | 3.200 | 1.000 | 1.000 | 0.000 | 0.000 | 1.600 | 1.600 | 1.000 | 1.000 | None |
| 3 | XArm | | | 1.160 | 3.200 | 3.200 | 1.000 | 1.000 | 0.000 | 0.000 | 1.600 | 1.600 | 1.000 | 1.000 | None |
| 4 | Top_Mast_End | | | 1.160 | 3.200 | 3.200 | 1.000 | 1.000 | 0.000 | 0.000 | 1.600 | 1.600 | 1.000 | 1.000 | None |
| 5 | Common_Mast | | | 1.160 | 3.200 | 3.200 | 1.000 | 1.000 | 0.000 | 0.000 | 1.600 | 1.600 | 1.000 | 1.000 | None |
| 6 | 25` Common_Mast | | | 1.160 | 3.200 | 3.200 | 1.000 | 1.000 | 0.000 | 0.000 | 1.600 | 1.600 | 1.000 | 1.000 | None |
| 7 | CrossBrace | | | 1.160 | 3.200 | 3.200 | 1.000 | 1.000 | 0.000 | 0.000 | 1.600 | 1.600 | 1.000 | 1.000 | None |
| 8 | 5`Ext | | | 1.160 | 3.200 | 3.200 | 1.000 | 1.000 | 0.000 | 0.000 | 1.600 | 1.600 | 1.000 | 1.000 | None |
| 9 | 10`Ext | | | 1.160 | 3.200 | 3.200 | 1.000 | 1.000 | 0.000 | 0.000 | 1.600 | 1.600 | 1.000 | 1.000 | None |
| 10 | 15`Ext | | | 1.160 | 3.200 | 3.200 | 1.000 | 1.000 | 0.000 | 0.000 | 1.600 | 1.600 | 1.000 | 1.000 | None |
| 11 | 20`Ext | | | 1.160 | 3.200 | 3.200 | 1.000 | 1.000 | 0.000 | 0.000 | 1.600 | 1.600 | 1.000 | 1.000 | None |
| 12 | 25`Ext | | | 1.160 | 3.200 | 3.200 | 1.000 | 1.000 | 0.000 | 0.000 | 1.600 | 1.600 | 1.000 | 1.000 | None |
| 13 | 30`Ext | | | 1.160 | 3.200 | 3.200 | 1.000 | 1.000 | 0.000 | 0.000 | 1.600 | 1.600 | 1.000 | 1.000 | None |
| 14 | 35`Ext | | | 1.160 | 3.200 | 3.200 | 1.000 | 1.000 | 0.000 | 0.000 | 1.600 | 1.600 | 1.000 | 1.000 | None |
| 15 | 40`Ext | | | 1.160 | 3.200 | 3.200 | 1.000 | 1.000 | 0.000 | 0.000 | 1.600 | 1.600 | 1.000 | 1.000 | None |
| 16 | Bot_Mast | | | 1.160 | 3.200 | 3.200 | 1.000 | 1.000 | 0.000 | 0.000 | 1.600 | 1.600 | 1.000 | 1.000 | None |
| 17 | Bot_12.5`Mast | | | 1.160 | 3.200 | 3.200 | 1.000 | 1.000 | 0.000 | 0.000 | 1.600 | 1.600 | 1.000 | 1.000 | None |

# Applied Point Load Calculation (Step 2)

- To determine wind load at each section (from PLS-Tower):
  - Run analysis
  - Results>Section Loading Details
    - “Sections Information” contains section area and other helpful section dimensions
    - Load case options give the wind load in terms of a force
      - “Tran Wind Load (lb)”
      - “Long Wind Load (lb)”



Sections Information

| | Section Label | Top Z (ft) | Bottom Z (ft) | Joint Count | Member Count | Tran. Face Top Width (ft) | Tran. Face Bot Width (ft) | Tran. Face Gross Area (ft^2) | Long. Face Top Width (ft) | Long. Face Bot Width (ft) | Long. Face Gross Area (ft^2) | CoG X (ft) | CoG Y (ft) | CoG Z (ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | GWP | 108.500 | 102.985 | 42 | 76 | 0.00 | 4.50 | 14.271 | 78.34 | 44.61 | 373.290 | 0.000 | 0.000 | 106.327 |
| 2 | BR | 104.000 | 98.500 | 65 | 195 | 4.50 | 4.50 | 24.750 | 64.86 | 49.11 | 313.418 | 0.000 | 0.000 | 100.522 |
| 3 | XArm | 104.000 | 98.500 | 80 | 198 | 4.50 | 4.50 | 23.864 | 64.86 | 129.32 | 566.235 | 0.000 | 0.000 | 99.597 |
| 4 | Top_Mast_End | 98.500 | 80.000 | 40 | 96 | 4.50 | 4.50 | 83.250 | 49.11 | 49.11 | 908.535 | 0.000 | 0.000 | 89.387 |
| 5 | Common_Mast | 0.000 | 0.000 | 0 | 0 | 0.00 | 0.00 | 0.000 | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6 | 25` Common_Mast | 80.000 | 55.000 | 48 | 132 | 4.50 | 4.50 | 112.500 | 49.11 | 49.11 | 1227.750 | 0.000 | 0.000 | 68.343 |
| 7 | CrossBrace | 0.000 | 0.000 | 0 | 0 | 0.00 | 0.00 | 0.000 | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 |
| 8 | 5`Ext | 0.000 | 0.000 | 0 | 0 | 0.00 | 0.00 | 0.000 | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 |
| 9 | 10`Ext | 0.000 | 0.000 | 0 | 0 | 0.00 | 0.00 | 0.000 | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 |
| 10 | 15`Ext | 55.000 | 40.000 | 32 | 84 | 4.50 | 4.50 | 67.500 | 49.11 | 49.11 | 736.650 | 0.000 | -0.000 | 48.153 |
| 11 | 20`Ext | 0.000 | 0.000 | 0 | 0 | 0.00 | 0.00 | 0.000 | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 |
| 12 | 25`Ext | 40.000 | 15.000 | 48 | 132 | 4.50 | 4.50 | 112.500 | 49.11 | 49.11 | 1227.750 | 0.000 | 0.000 | 28.177 |
| 13 | 30`Ext | 0.000 | 0.000 | 0 | 0 | 0.00 | 0.00 | 0.000 | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 |
| 14 | 35`Ext | 0.000 | 0.000 | 0 | 0 | 0.00 | 0.00 | 0.000 | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 |
| 15 | 40`Ext | 0.000 | 0.000 | 0 | 0 | 0.00 | 0.00 | 0.000 | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 |
| 16 | Bot_Mast | 15.000 | 0.000 | 32 | 84 | 4.50 | 2.75 | 58.750 | 49.11 | 47.36 | 727.900 | 0.000 | -0.000 | 7.331 |
| 17 | Bot_12.5`Mast | 0.000 | 0.000 | 0 | 0 | 0.00 | 0.00 | 0.000 | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 |

Done

Section Load Case Information (Code) - [Int_Susp_Ext Wind_BI+,C BI+]

| | Section Label | Z of Top (ft) | Z of Bottom (ft) | Ave. Elev. Above Ground (ft) | Res. Adj. Wind Pres. (psf) | Tran Adj. Wind Pres. (psf) | Tran Angle Face Area (ft^2) | Tran Gross Area (ft^2) | Tran Soli-dity Ratio | Tran Angle Drag Coef | Tran Wind Load (lbs) | Long Adj. Wind Pres. (psf) | Long Angle Face Area (ft^2) | Long Gross Area (ft^2) | Long Soli-dity Ratio | Long Angle Drag Coef | Long Wind Load (lbs) | Ice Weight (lbs) | Total Weight (lbs) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | GWP | 108.50 | 102.99 | 138.44 | 21.81 | 21.81 | 7.80 | 14.27 | 0.546 | 3.200 | 544.4 | 0.00 | 22.77 | 373.29 | 0.061 | 3.200 | 0.0 | 0 | 1067 |
| 2 | BR | 104.00 | 98.50 | 133.95 | 21.81 | 21.81 | 17.80 | 24.75 | 0.719 | 3.200 | 1242.5 | 0.00 | 62.94 | 313.42 | 0.201 | 3.200 | 0.0 | 0 | 4906 |
| 3 | XArm | 104.00 | 98.50 | 133.95 | 21.81 | 21.81 | 24.50 | 23.86 | 1.027 | 3.200 | 1665.9 | 0.00 | 67.79 | 566.24 | 0.120 | 3.200 | 0.0 | 0 | 4082 |
| 4 | Top_Mast_End | 98.50 | 80.00 | 121.95 | 21.81 | 21.81 | 46.18 | 83.25 | 0.555 | 3.200 | 3223.9 | 0.00 | 42.94 | 908.54 | 0.047 | 3.200 | 0.0 | 0 | 2765 |
| 5 | Common_Mast | 0.00 | 0.00 | 32.70 | 21.81 | 21.81 | 0.00 | 0.00 | 0.000 | 3.200 | 0.0 | 0.00 | 0.00 | 0.00 | 0.000 | 3.200 | 0.0 | 0 | 0 |
| 6 | 25` Common_Mast | 80.00 | 55.00 | 100.20 | 21.81 | 21.81 | 63.24 | 112.50 | 0.562 | 3.200 | 4414.4 | 0.00 | 57.63 | 1227.75 | 0.047 | 3.200 | 0.0 | 0 | 3884 |
| 7 | CrossBrace | 0.00 | 0.00 | 32.70 | 21.81 | 21.81 | 0.00 | 0.00 | 0.000 | 3.200 | 0.0 | 0.00 | 0.00 | 0.00 | 0.000 | 3.200 | 0.0 | 0 | 0 |
| 8 | 5`Ext | 0.00 | 0.00 | 32.70 | 21.81 | 21.81 | 0.00 | 0.00 | 0.000 | 3.200 | 0.0 | 0.00 | 0.00 | 0.00 | 0.000 | 3.200 | 0.0 | 0 | 0 |
| 9 | 10`Ext | 0.00 | 0.00 | 32.70 | 21.81 | 21.81 | 0.00 | 0.00 | 0.000 | 3.200 | 0.0 | 0.00 | 0.00 | 0.00 | 0.000 | 3.200 | 0.0 | 0 | 0 |
| 10 | 15`Ext | 55.00 | 40.00 | 80.20 | 21.81 | 21.81 | 43.69 | 67.50 | 0.647 | 3.200 | 3050.0 | 0.00 | 40.33 | 736.65 | 0.055 | 3.200 | 0.0 | 0 | 3006 |
| 11 | 20`Ext | 0.00 | 0.00 | 32.70 | 21.81 | 21.81 | 0.00 | 0.00 | 0.000 | 3.200 | 0.0 | 0.00 | 0.00 | 0.00 | 0.000 | 3.200 | 0.0 | 0 | 0 |
| 12 | 25`Ext | 40.00 | 15.00 | 60.20 | 21.81 | 21.81 | 71.57 | 112.50 | 0.636 | 3.200 | 4996.1 | 0.00 | 65.96 | 1227.75 | 0.054 | 3.200 | 0.0 | 0 | 4835 |
| 13 | 30`Ext | 0.00 | 0.00 | 32.70 | 21.81 | 21.81 | 0.00 | 0.00 | 0.000 | 3.200 | 0.0 | 0.00 | 0.00 | 0.00 | 0.000 | 3.200 | 0.0 | 0 | 0 |
| 14 | 35`Ext | 0.00 | 0.00 | 32.70 | 21.81 | 21.81 | 0.00 | 0.00 | 0.000 | 3.200 | 0.0 | 0.00 | 0.00 | 0.00 | 0.000 | 3.200 | 0.0 | 0 | 0 |
| 15 | 40`Ext | 0.00 | 0.00 | 32.70 | 21.81 | 21.81 | 0.00 | 0.00 | 0.000 | 3.200 | 0.0 | 0.00 | 0.00 | 0.00 | 0.000 | 3.200 | 0.0 | 0 | 0 |
| 16 | Bot_Mast | 15.00 | 0.00 | 40.20 | 21.81 | 21.81 | 53.35 | 58.75 | 0.908 | 3.200 | 3724.5 | 0.00 | 50.30 | 727.90 | 0.069 | 3.200 | 0.0 | 0 | 5987 |
| 17 | Bot_12.5`Mast | 0.00 | 0.00 | 32.70 | 21.81 | 21.81 | 0.00 | 0.00 | 0.000 | 3.200 | 0.0 | 0.00 | 0.00 | 0.00 | 0.000 | 3.200 | 0.0 | 0 | 0 |

Done

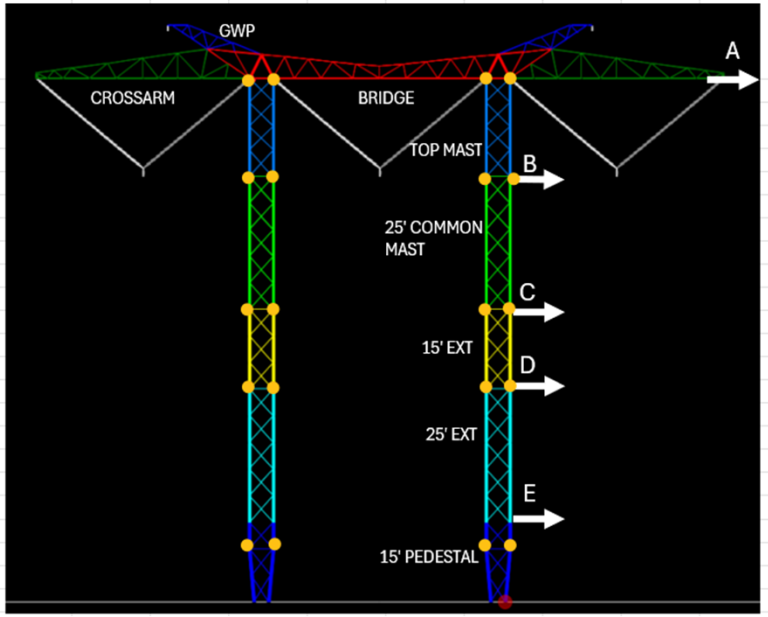
# Example Load Calculation

How many joints will this load be applied?

Total loading divided by number of applied joints

| Wind Area | | LC68 Int_Susp_Ext Wind_BI+,C BI+ 1 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Tower Section | Area per face [sq_ft] | Wind Pressure [psf] | Load / Section [lbs] | # of Joints Applied to | Total Load Distribution [lbs] | Load Distribution | Load Point [lbs] | Load Label | Joint Lables |
| GWP | 11.82 | 69.792 | 825.4 | 8 | | | | | |
| Bridge | 17.8 | 69.792 | 1242.5 | 8 | | | | | |
| Crossarm (*) | 24.5 | 69.792 | 1665.9 | 8 | | GWP + Bridge + Crossarm + | | | |
| Top Mast | 46.18 | 69.792 | 3223.9 | 8 | 5346 | 1/2 Top Mast | 668 | A | 6P |
| 25' Common Mast | 63.24 | 69.792 | 4414.4 | 8 | 3819 | 1/2 Top Mast + 1/2 25' Common Mast | 477 | B | Y2P, Y2.1P |
| 15' Ext | 43.69 | 69.792 | 3050 | 8 | 3732 | 1/2 25' Common Mast + 1/2 15' Ext | 467 | C | 3HP, 3H.1P |
| 25' Ext | 71.57 | 69.792 | 4996.1 | 8 | 4023 | 1/2 15' Ext + 1/2 25' Ext | 503 | D | 3EP, 3E.1P |
| 15' Pedestal | 53.35 | 69.792 | 3724.5 | 8 | 4360 | 1/2 25' Ext + 1/2 15' Pedestal | 545 | E | 2OP, 2O.1P |
| Total | | | 21280 | | 21280 | | | | |

(*) Section "Crossarm" has a 1.027 Trans Solidity Ratio



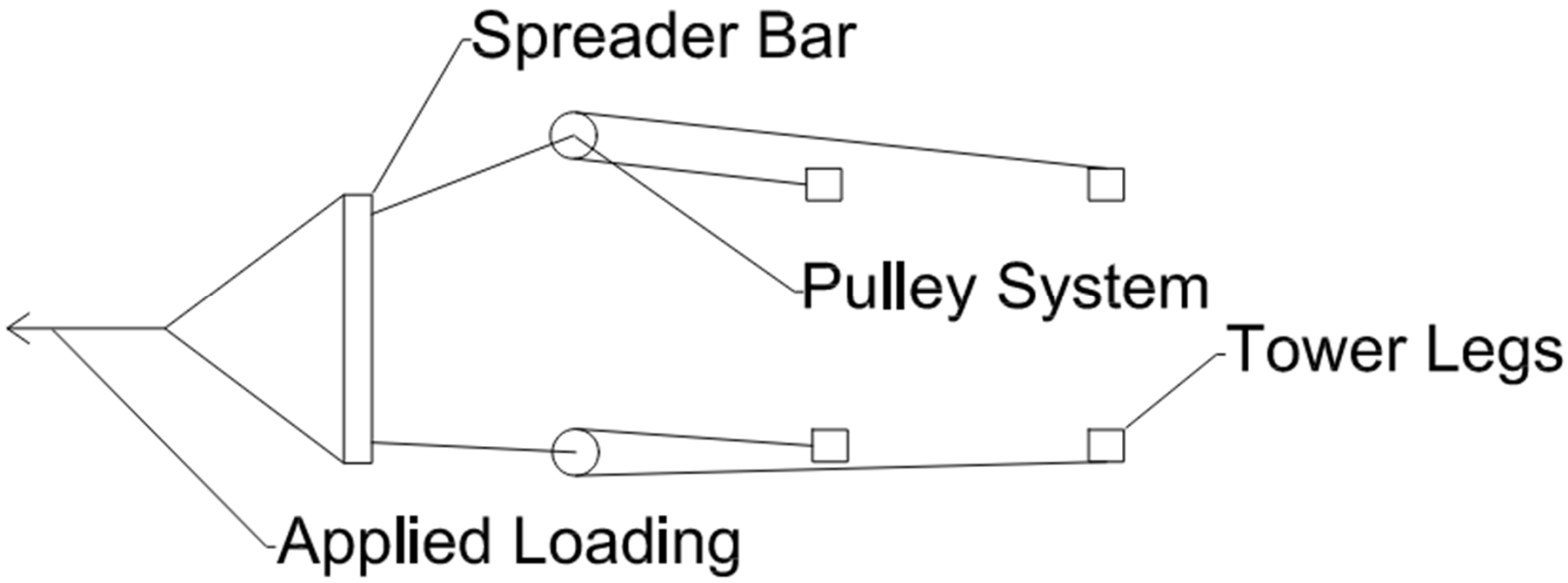

Pulled from PLS-Tower Section Data

Total Loading Applied Accounting for Tributary Widths

# How will the loadings be applied?

- Loads calculated will be applied to each leg typically
  - Spreader bar and pulley system is used
- Wind loading is typically applied at increments:
  - 50%
  - 75%
  - 85%
  - 95%
  - 100%
- In some cases, towers will be tested to destruction.

# Spreader bar and Pulley System Example

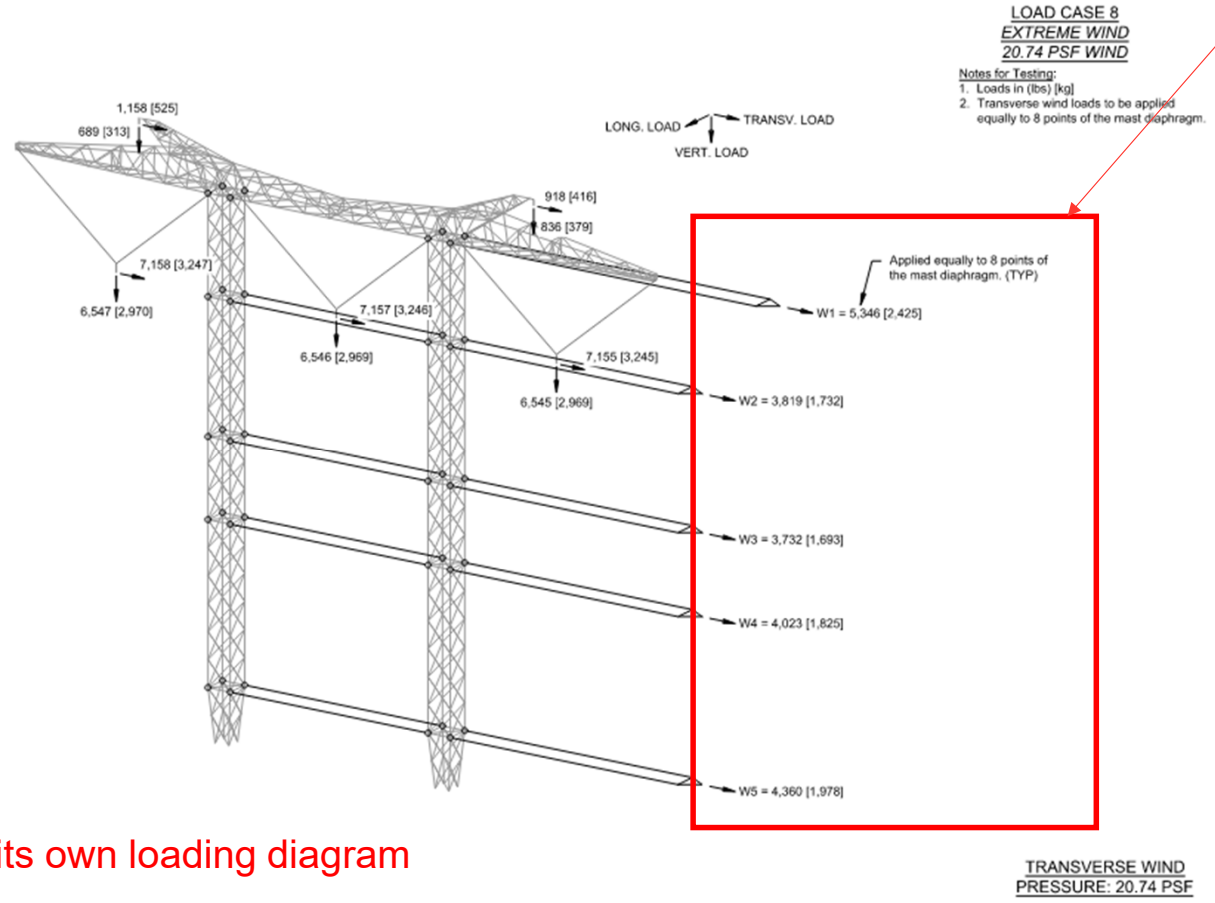


# Applied Point Load Calculation Verification

- Distributed wind model:
  - Applies wind pressure to wind face
  - Section factors and member surface area are accounted for
- Point Load Application:
  - Calculated load applies at clamp insulator locations
  - LCA file will not consider wind pressure
- Re-run analysis
  - Verify member usages at attachment points
  - Verify stresses in legs at the bottom of the tower are similar
  - Re-distribute section loadings as necessary

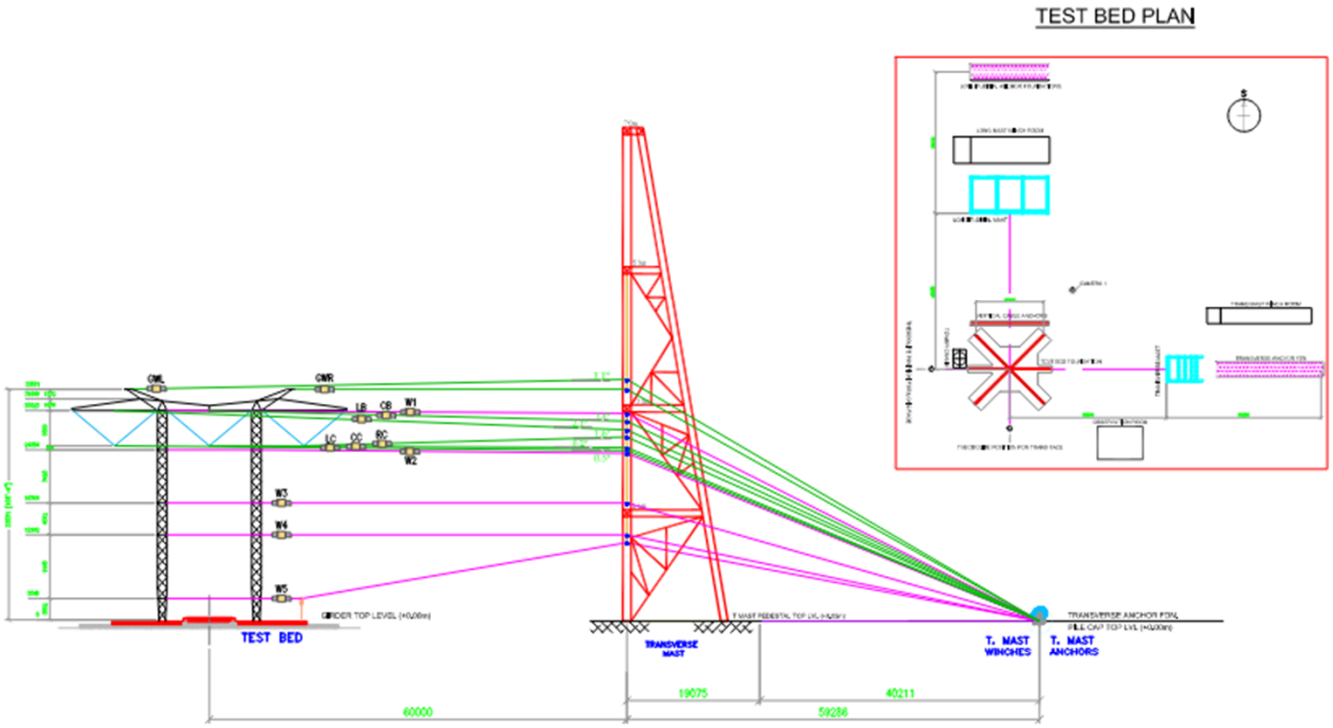
# Tower Test Preparation (Load Rigging)

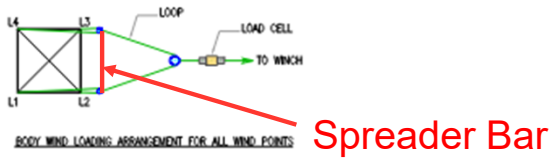
Wind loading application




Each load case will have its own loading diagram

# TRANSVERSE RIGGING DIAGRAM

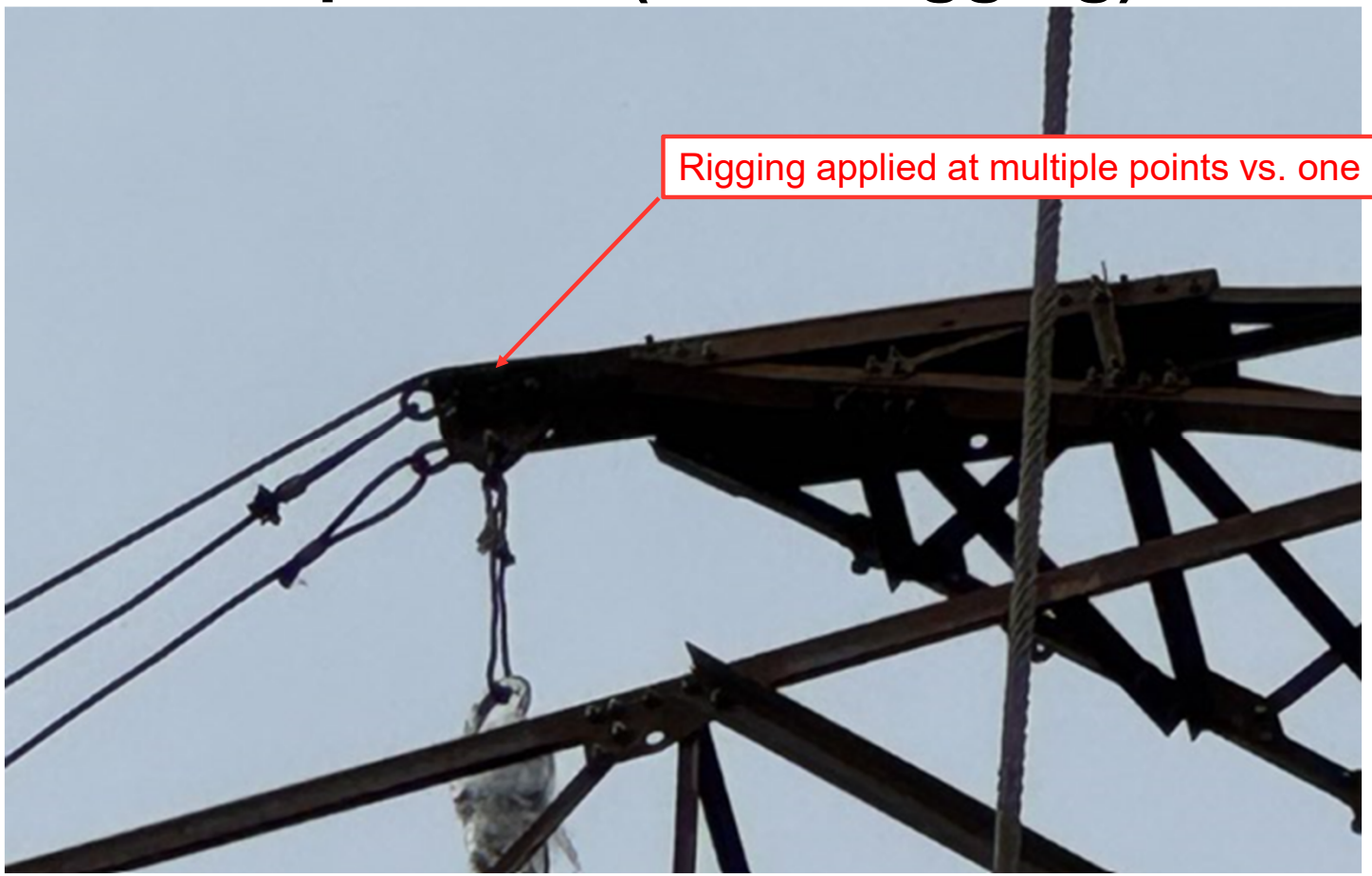


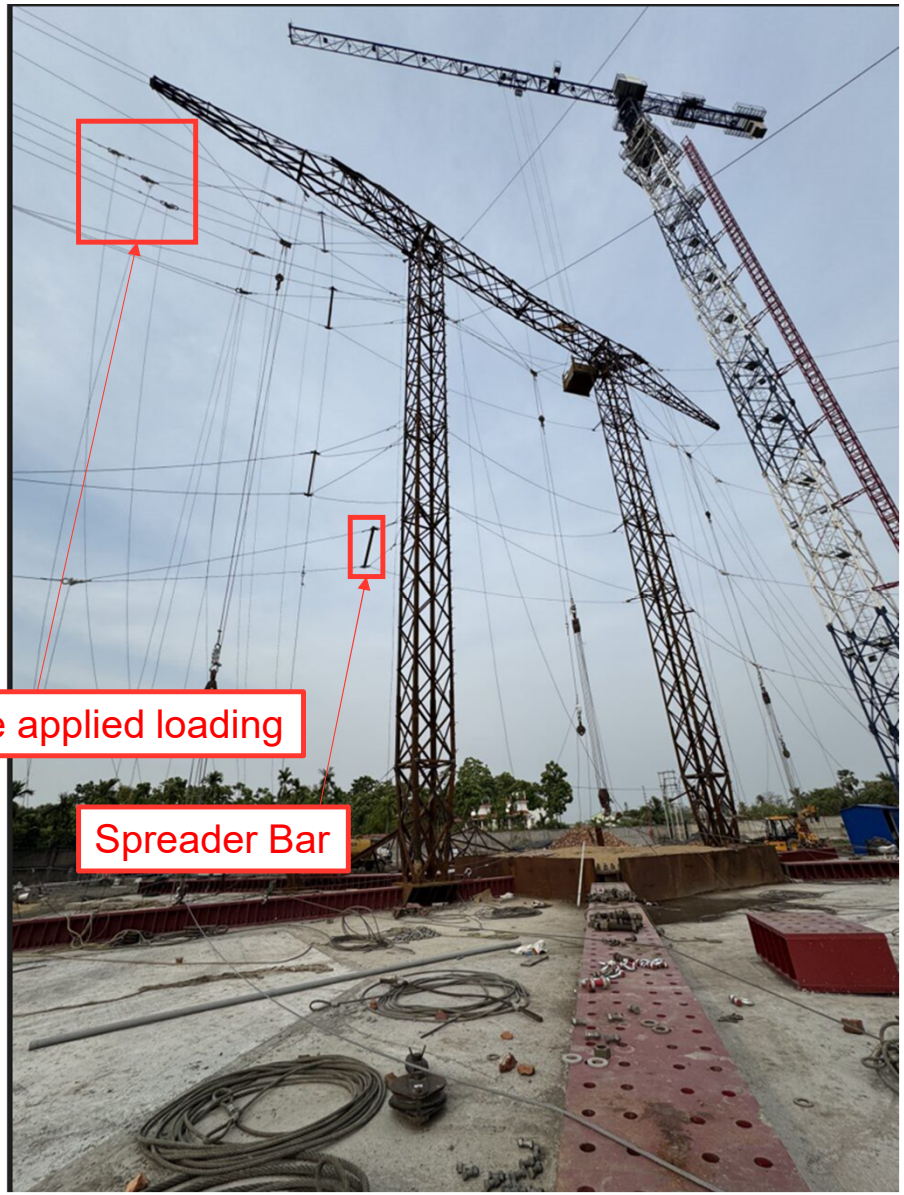

BODY WIND LOADING ARRANGEMENT FOR ALL WIND POINTS

NOTES:-
1. ALL DIMENSIONS ARE IN MM UNLESS MENTIONED
2. LOAD CELL POSITIONS ARE ONLY FOR REPRESENTATION

# Tower Test Preparation (Load Rigging)



# Tower Test Preparation (Load Rigging)



# Tower Test Preparation (Load Rigging)

# Tower Test Preparation (Materials)

- Review mechanical strength test of steel
  - Comes from heat lot certificate submitted by fabricator
    - Ultimate Stress
    - Yield Stress
    - Modulus of Elasticity
- ASCE 10-15 limits
  - Yield Stress
- Steel strength used in the test should align with the steel strength used in design
- Supplied by Vendor

# ASCE 10-15 Steel Strength Limits

- ASCE10-15
  - 6.3 & C6.3
- Adjust steel yield of main chord members to match actual steel yield

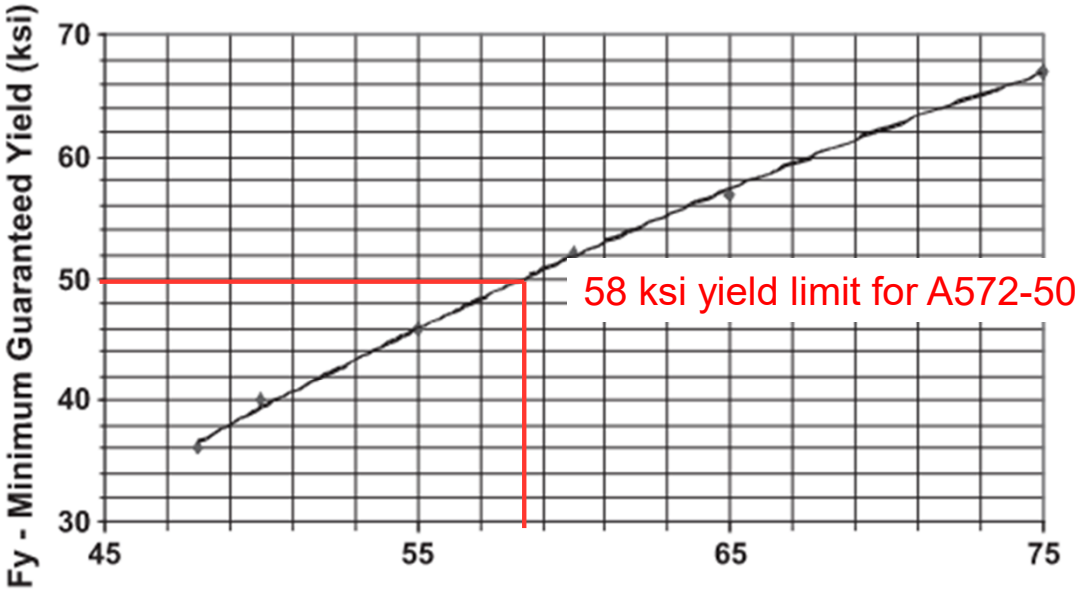



FIG. C6-1. Maximum Overstrengths for Members of Prototype (1 ksi = 6.89 MPa)

# PLS-Tower Loading Comparison

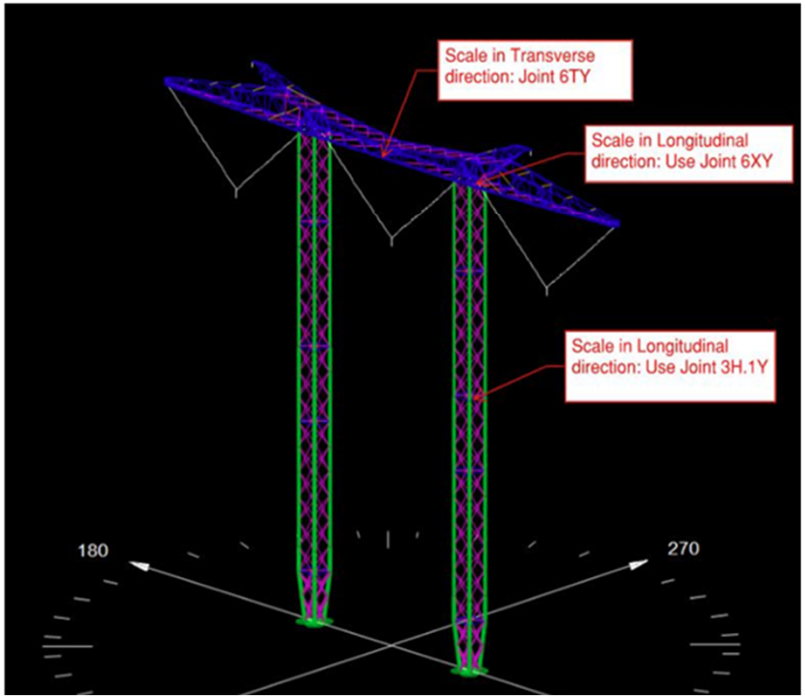
- The tower analysis will determine the focus during testing
  - Areas of high usage are the focus
- PLS-Tower loading comparison:
  - Load test results ≈ Results seen in PLS-Tower
    - The exception would be areas not covered by the PLS-Tower analysis
- Identify if the tower has additional capacity
  - On the final load test case (Only for destructive load test):
    - Load tower to 100% of capacity
      - During testing, watch the members with 100% (or higher) usage

# What's Next After the Load Test?

- PLS-Tower loading comparison:
  - Inspect steel members (if not testing to destruction)
    - Connection damage can be hidden by bolts (bolt hole elongation)
  - Perform mechanical strength test on members
    - Performed by test facility
      - Compare results to initial strength test
  - Compare actual deflections to estimated deflections
  - If strain gages are used:
    - Compare the stress from the strain gage readings to the PLS-Tower calculated values
      - Strain gages are attached to main chord members
      - Prone to error and typically does not produce meaningful results

| Transverse Deflection | | | |
|---|---|---|---|
| Load Case | Joint | PLS Tower Model [cm] | Field deflection [cm] |
| LC8 | 6TY | 34.53 | 38 |
| LC9 | 6TY | 4.694 | 3 |
| LC10 | 6TY | 21.97 | 23 |

| Longitudinal Deflection | | | |
|---|---|---|---|
| Load Case | Joint | PLS Tower Model [cm] | Field deflection [cm] |
| LC8 | 6XY | 0.00 | 25 |
| LC8 | 3H.1Y | 0.00 | 10 |
| LC9 | 6XY | 64.85 | 58 |
| LC9 | 3H.1Y | 24.25 | 47 |
| LC10 | 6XY | 31.94 | 44 |
| LC10 | 3H.1Y | 12.04 | 23 |




LC8: Extreme Wind @ 0°
LC9: Failure Containment Broken Wire (Outside Conductor)
LC10: Extreme Wind @ 45°

-In most cases Field Deflection>PLS Tower Deflection

# THANK YOU

# ANY QUESTIONS?