Oblique Wind on Structures

an inconvenient truth

By: George T Watson, Staff Engineer

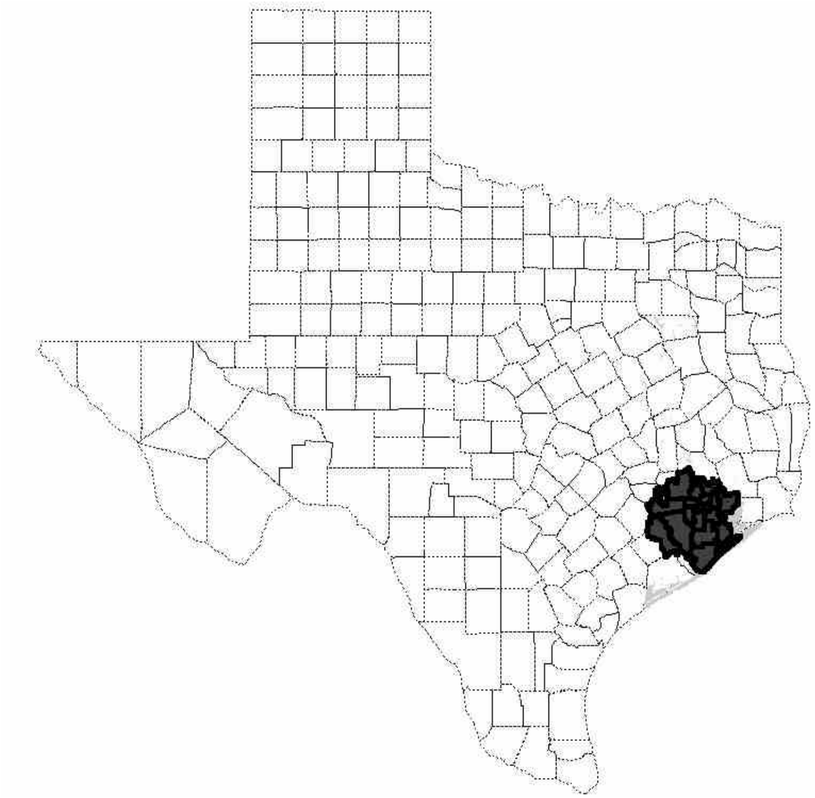
CenterPoint Energy

formerly Reliant Energy

formerly Houston Industries Inc.

formerly Houston Lighting & Power

Small Service Area (2.5%)
Big Electrical Load (25%)



Texas Peak Load for 2006 was 62,000mw

CNP Peak Load for 2006 was 15,700mw

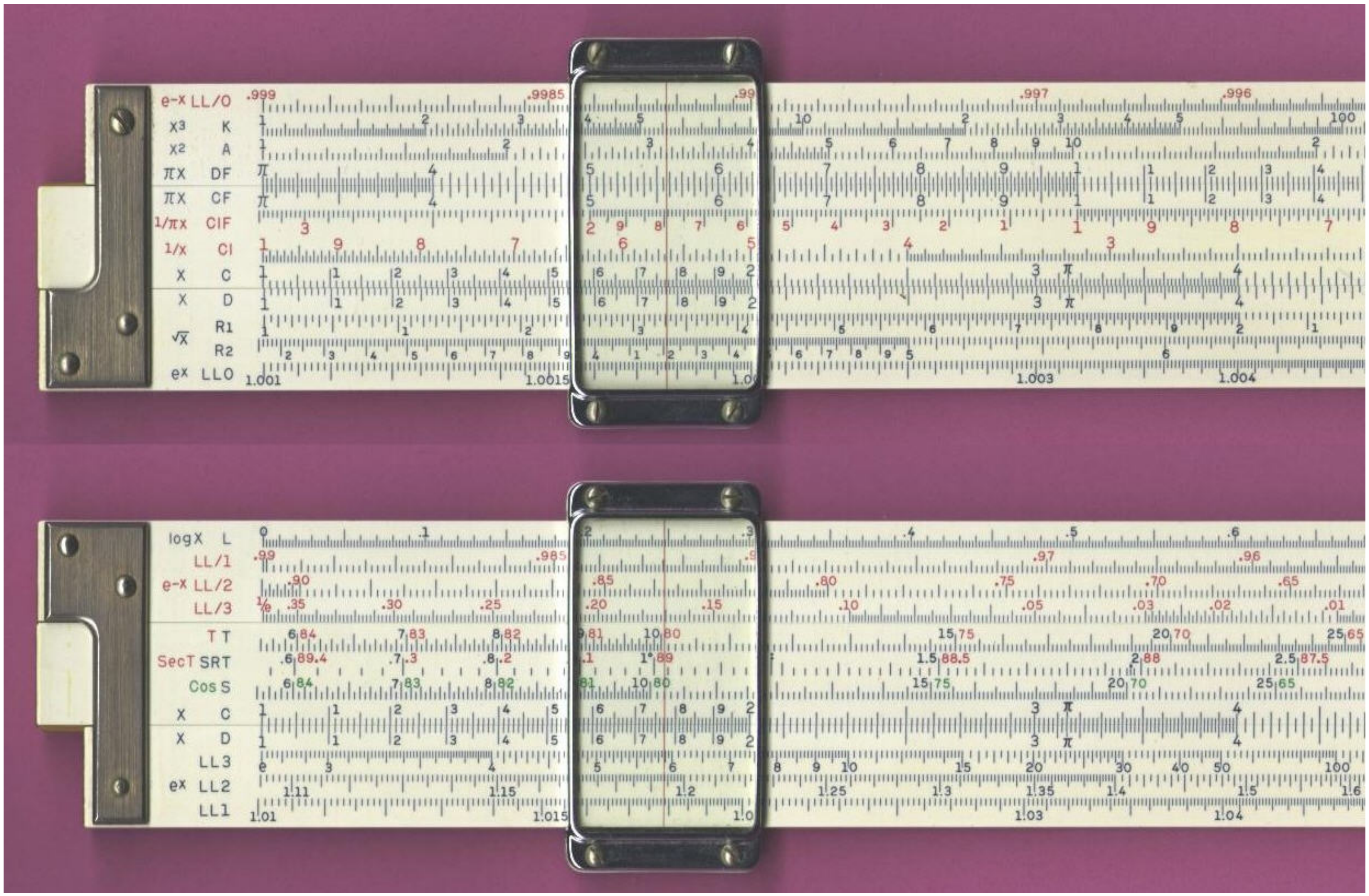
(25% of Texas Total)

Typical Houston house

with 11 Car Garage (now for sale)

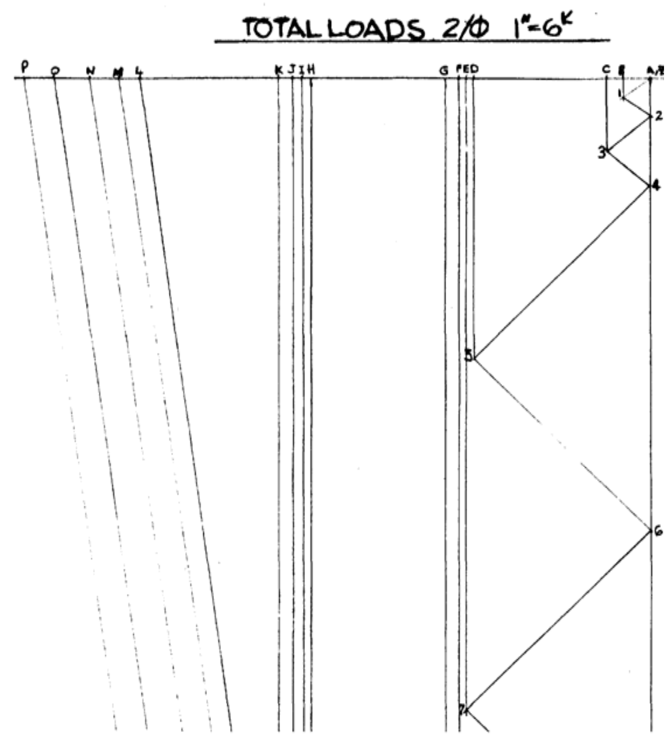
61,000 Square Feet on an 11 Acre Lot

Ancient Tower Design Tools



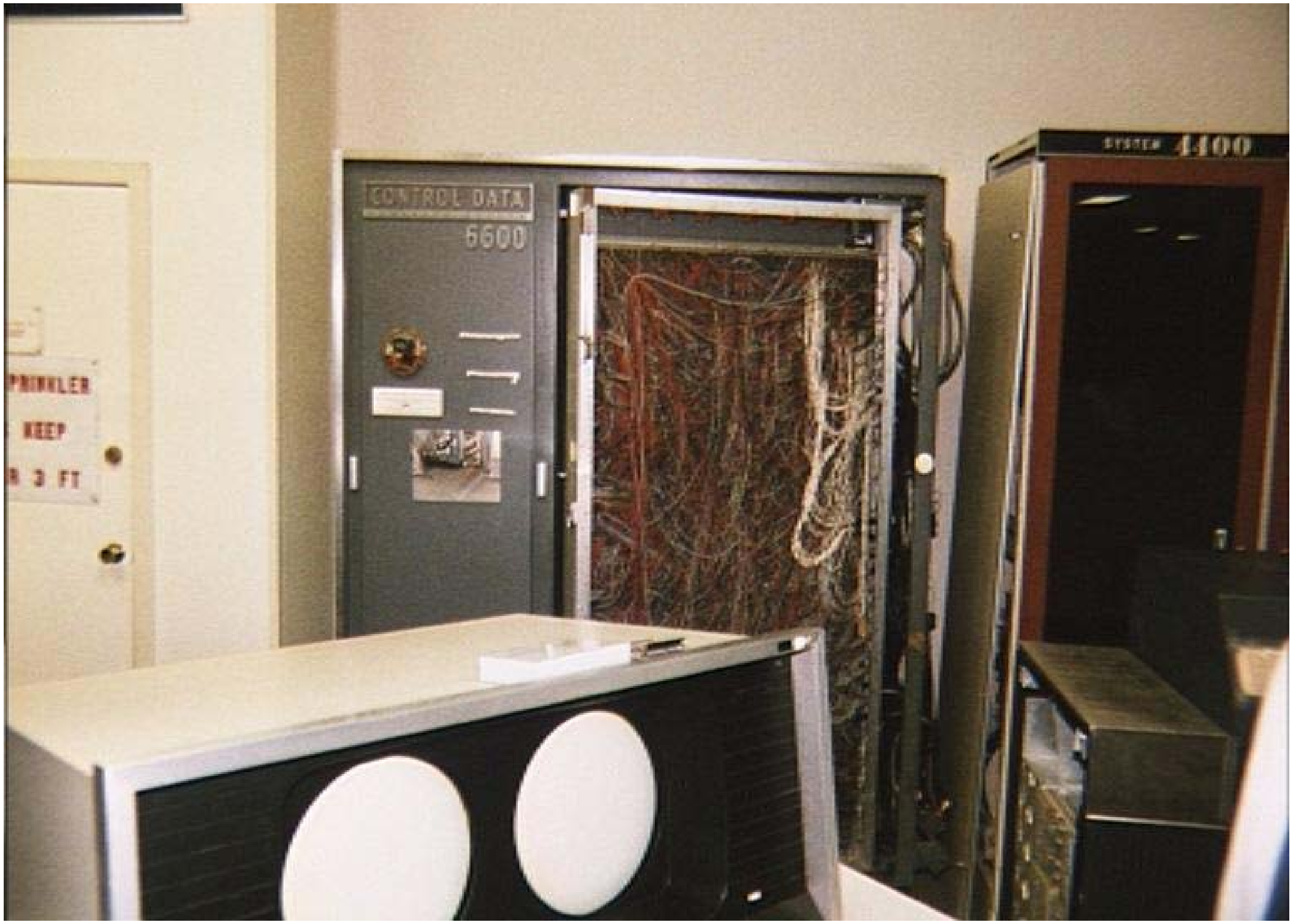
Early Stress Analysis

- Graphical Method of Joints
- Many Assumptions to Allow Analysis
- Multiple Load Cases Very Time Consuming



Calculator from 1973 ($2,000)

1976 Tower Design on CDC 6600



2007 NESC Code

252D Simultaneous Application of Loads

Where a combination of vertical, transverse, or longitudinal loads may occur simultaneously, the structure shall be designed to withstand the simultaneous application of these loads.

Note: Under the extreme wind conditions of Rule 250C, an oblique wind may require greater structural strength than that computed by Rules 252B and 252C.

2007 NESC Code

Rules 261A1c, 261A2e, and 261A3d

All structures including those below 18 m (60 ft) shall be designed to withstand, without conductors, the extreme wind load in Rule 250C applied in any direction on the structure.

Do You Have a Problem?

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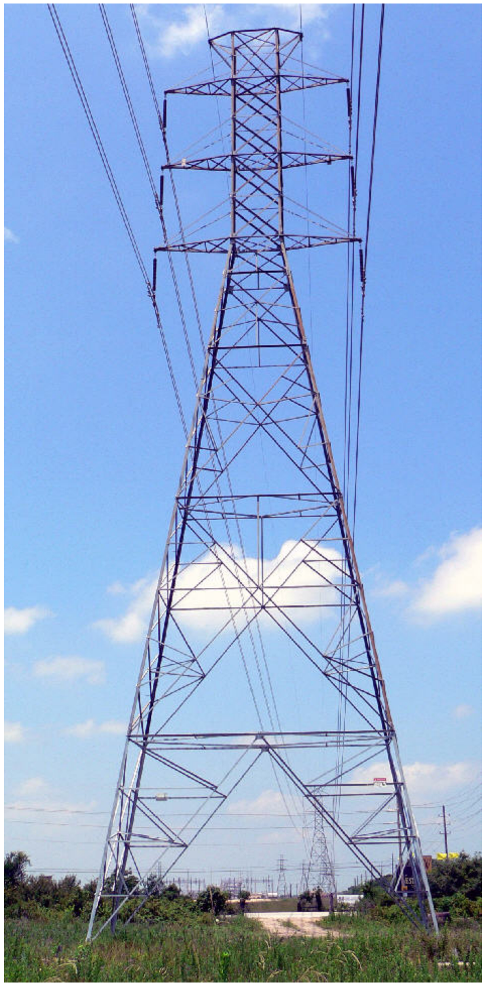
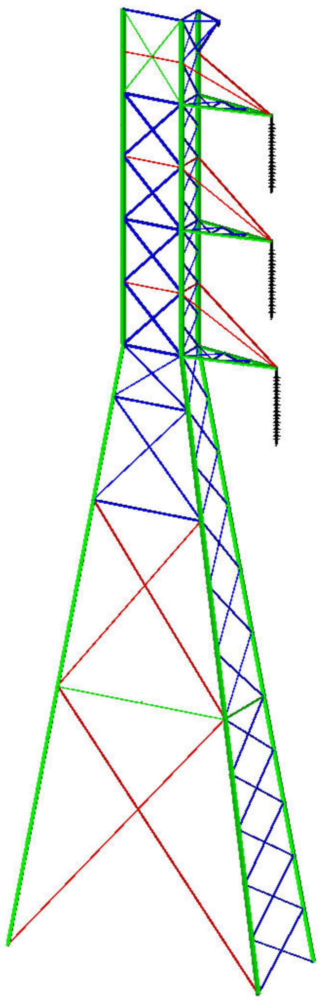
Rectangular Tangent Towers Can be Susceptible to Oblique Wind Leg Overload



An Example to Consider

All Redundants must be Accounted for in the Drag Area Calculations

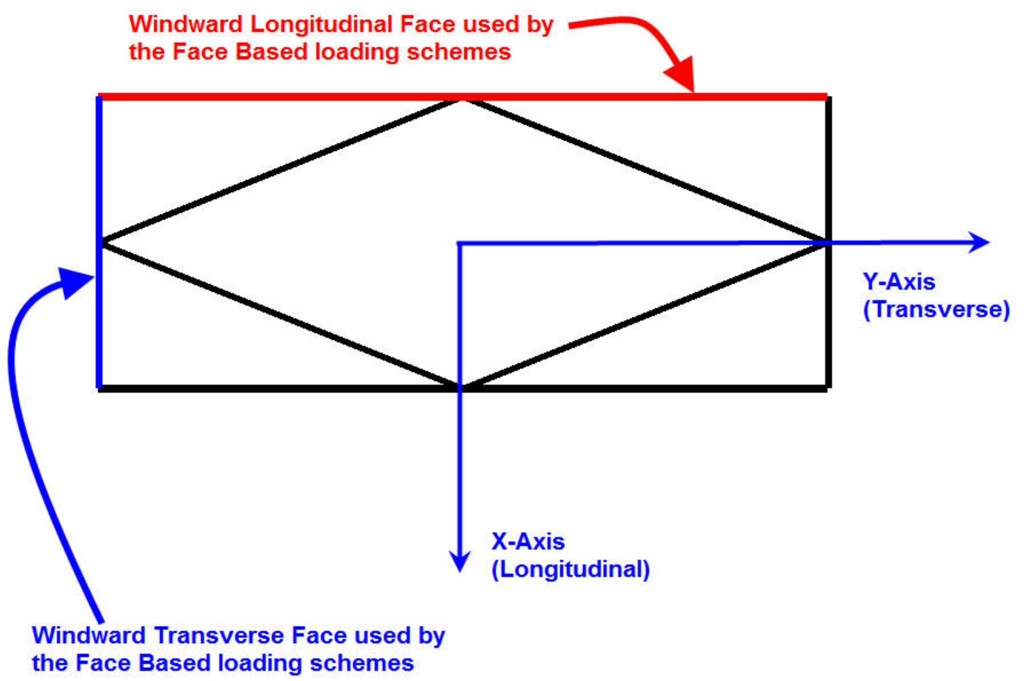


Tower Base is 26’ x 10’

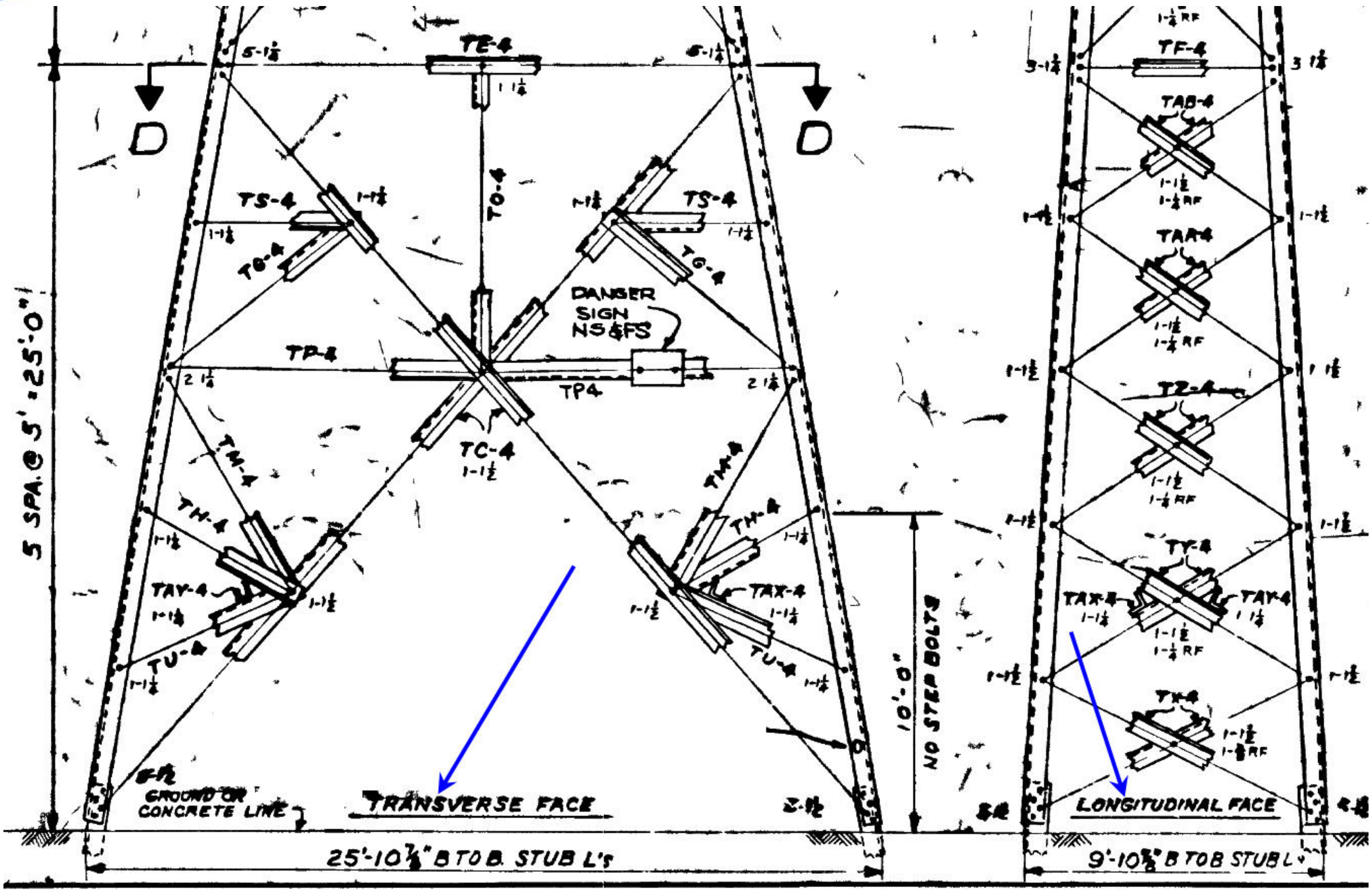
(8mx3m)

PLS-TOWER Face Designation

The windward transverse face is that on which a positive transverse wind (in the positive Y-direction) would blow.

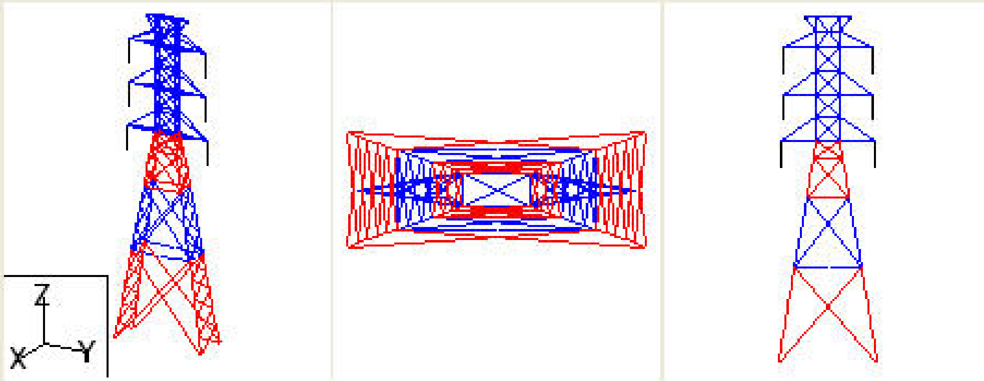


Common Face Designation



Adjust Drag Factors

Sections



Model Check Report

No errors or relevant warnings detected.

Adjust Drag Factors

	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)
1	Cage		11P	1.310	3.200	3.200	1.000	1.000
2	Body3		14S	1.310	3.200	3.636	1.000	1.136
3	Body2		17S	1.310	3.200	4.114	1.000	1.286
4	Body1		22P	1.310	3.200	4.960	1.000	1.550
5								

DESIGN CONDITIONS:

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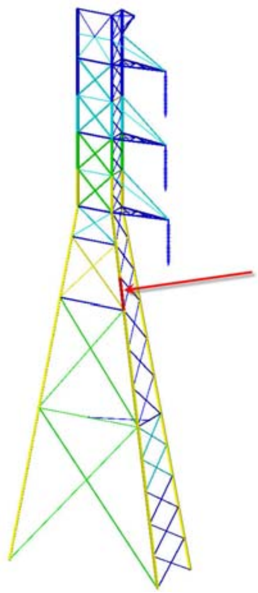
- No Line Angle
- NESC 2007 Wind Load Convention
- 140 mph Hurricane Wind (63 m/sec)
- 2 Circuits of 795 ACSR Drake Wire (2 per Phase)
- Span Length = 777.5 feet (237 meters)

Legs are at 100% for Wind Normal

Group Summary (Compression Portion):

Group Label	Group Desc.	Angle Type	Angle Size	Steel Strength (ksi)	Max Usage %	Max Use In Comp. %	Comp. Control Member	Comp. Force (kips)	Comp. Control Load Case	
TA5	LEG1	SAE	3.5X3.5X0.25	36.0	94.85	94.85	9P	-49.789	Hurricane	
TB4	**LEG2**	**SAE**	**4X4X0.25**	**50.0**	**100.00**	**100.00**	**13P**	**-65.480**	**Hurricane**	**NG**
T4	LEG3	SAE	4X4X0.3125	50.0	98.69	98.69	15P	-74.161	Hurricane	



Add Wind at Oblique Angles

Structure Loads Criteria

	Description	Weather case	Cable condition	Wind Direction	Bisector Wind Dir (deg)
1	Hurr -90	Hurricane	Initial RS	BI+	-90.00
2	Hurr -89	Hurricane	Initial RS	BI+	-89.00
3	Hurr -88	Hurricane	Initial RS	BI+	-88.00
4	Hurr -87	Hurricane	Initial RS	BI+	-87.00
5	Hurr -86	Hurricane	Initial RS	BI+	-86.00
6	Hurr -85	Hurricane	Initial RS	BI+	-85.00
7	Hurr -84	Hurricane	Initial RS	BI+	-84.00
8	Hurr -83	Hurricane	Initial RS	BI+	-83.00
9	Hurr -82	Hurricane	Initial RS	BI+	-82.00
10	Hurr -81	Hurricane	Initial RS	BI+	-81.00
11	Hurr -80	Hurricane	Initial RS	BI+	-80.00

Legs Overstressed by 21%

Group Summary (Compression Portion):

Group Label	Group Desc.	Angle Type	Angle Size	Steel Strength (ksi)	Max Usage %	Max Use In Comp. %	Comp. Control Member	Comp. Force (kips)	Comp. Control Load Case	
TA5	LEG1	SAE	3.5X3.5X0.25	36.0	108.57	108.57	10Y	-56.991	Hurr -28,I	NG
TB4	LEG2	SAE	4X4X0.25	50.0	121.46	121.46	13Y	-79.531	Hurr -30,I	NG
T4	LEG3	SAE	4X4X0.3125	50.0	118.05	118.05	16Y	-88.706	Hurr -35,I	NG

- At 35 degrees from Normal, Bottom Legs are overloaded
- At 30 degrees from Normal, Middle Legs are overloaded

Lacing Overstressed by 33%

Group Summary

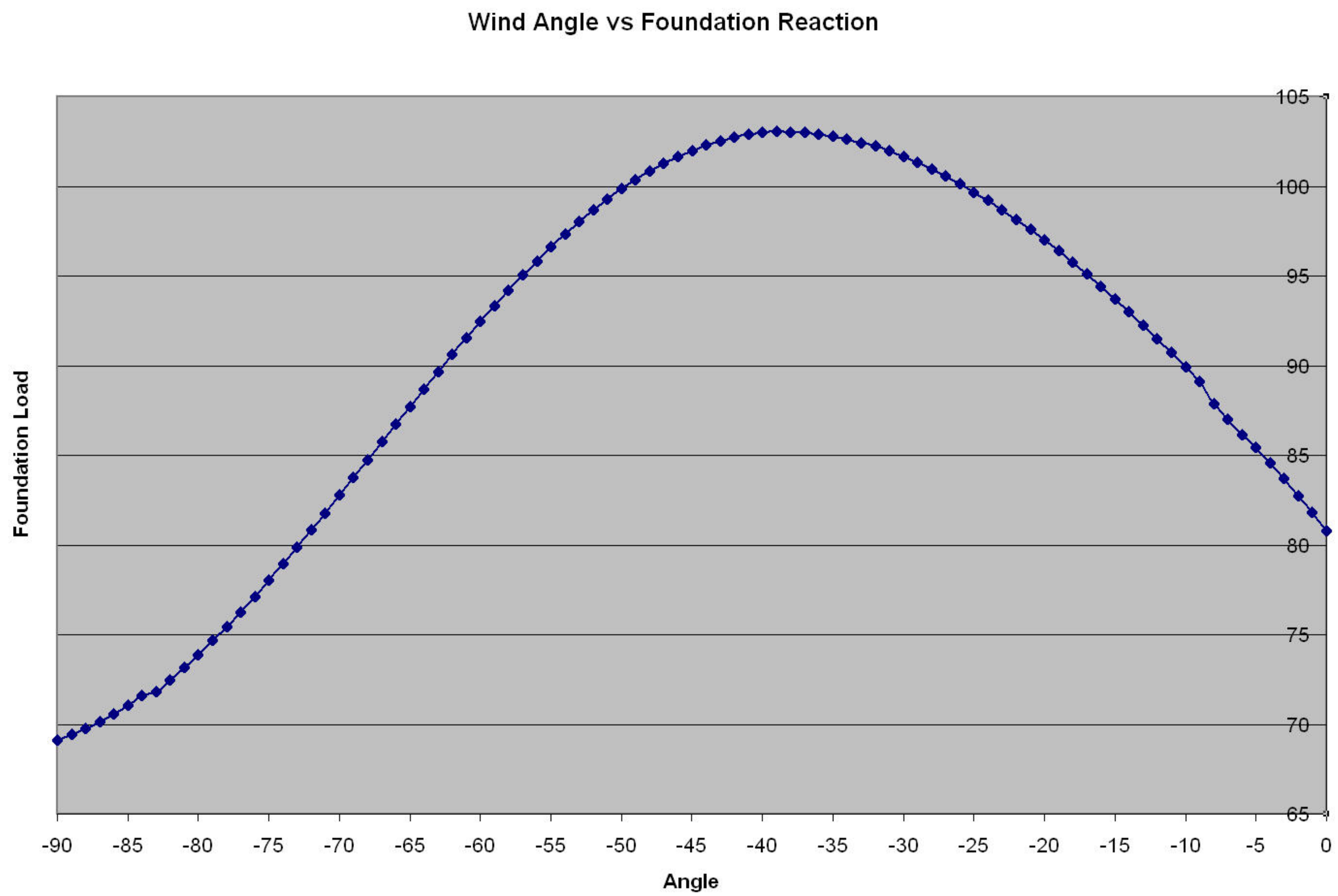
	Group Label	Group Desc.	Angle Type	Angle Size	Steel Strength (ksi)	Max Usage %	Max Use In Comp. %	Comp. Control Member	Comp. Force (kips)	Comp. Control Load Case
11	TE4	TGIR8	SAE	1.75X1.75X0.1875	36.0	133.18	133.18	32X	-7.620	Hurr -58,I BI+ (140mph)

Group Summary

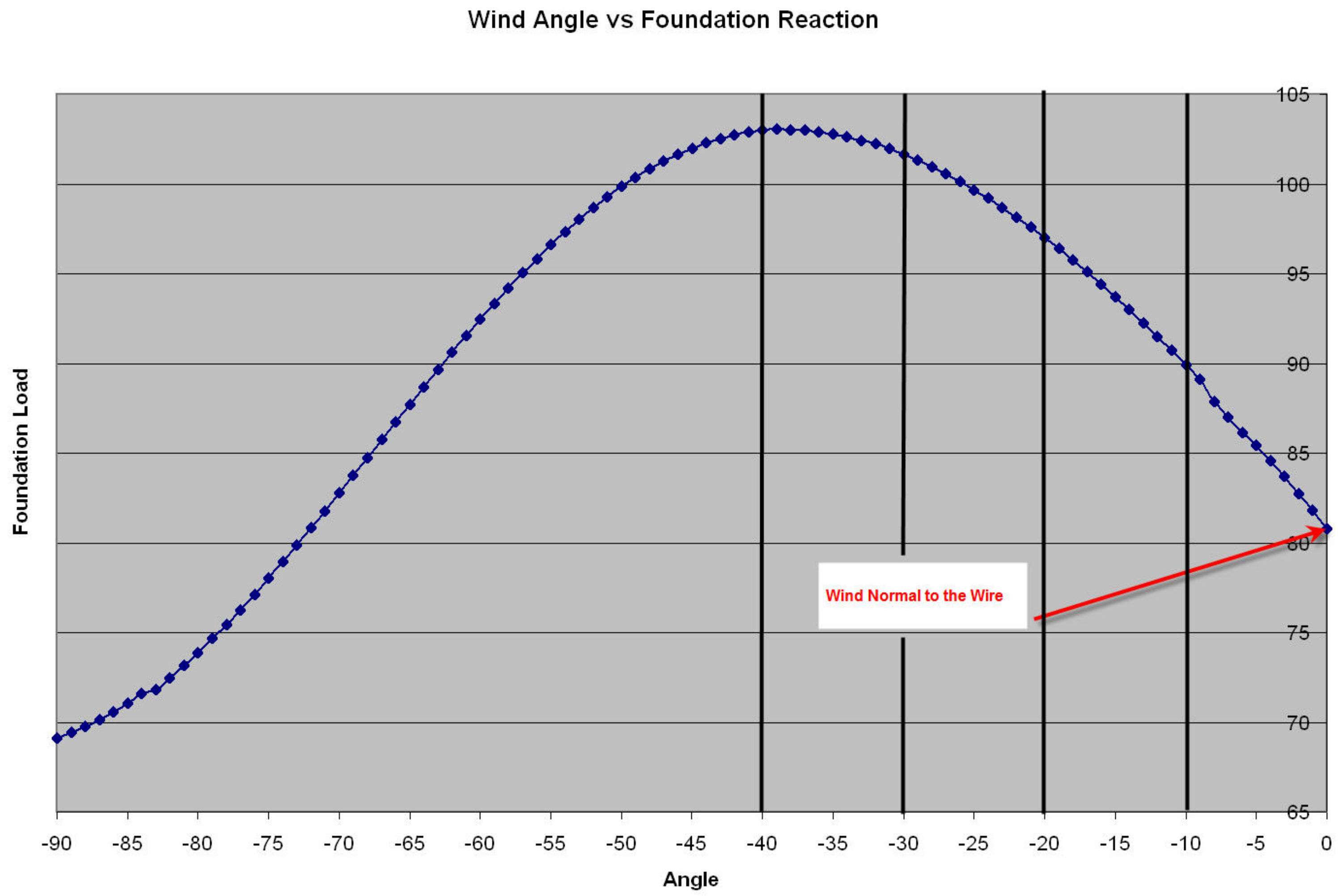
	Group Label	Group Desc.	Angle Type	Angle Size	Steel Strength (ksi)	Max Usage %	Max Use In Comp. %	Comp. Control Member	Comp. Force (kips)	Comp. Control Load Case
35	TAB4	LONG13	SAU	1.75X1.25X0.1875	36.0	110.49	110.49	66P	-3.401	Hurr -61,I BI+ (140mph)
36	TAA4	LONG14	SAU	1.75X1.25X0.1875	36.0	122.34	122.34	67X	-3.378	Hurr -59,I BI+ (140mph)

- At 58, 59, and 61 degrees from Normal, Lacings are overloaded

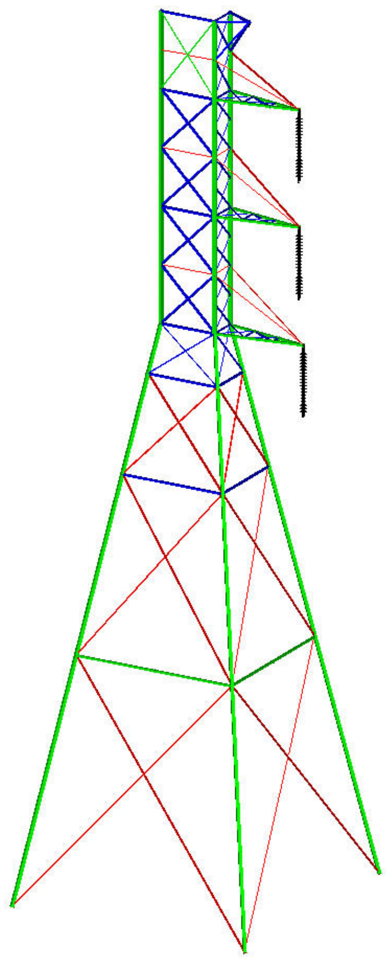
Graph of Foundation Loads



Run 10 Degree Increments



Square Base Towers Behave Better than Rectangular Base



Tower Base is 26’ x 26’

(8mx8m)

DESIGN CONDITIONS:

- No Line Angle
- NESC 2007 Wind Load Convention
- 140 mph Hurricane Wind (63 m/sec)
- 2 Circuits of 795 ACSR Drake Wire (2 per Phase)
- Span Length = 750 feet (229 meters)

Square Base Tower Legs are Overstressed by less than 7%

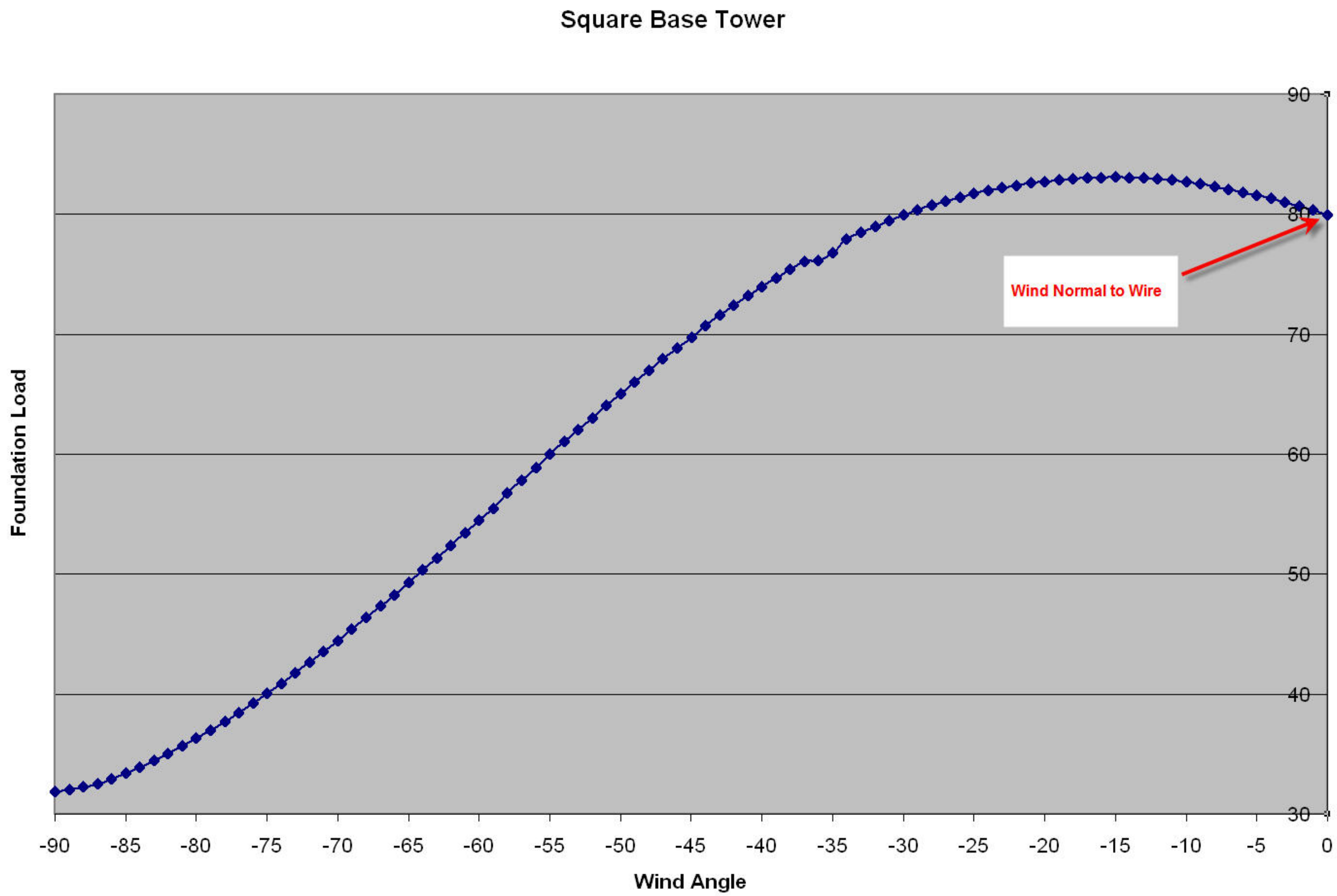
Group Summary (Compression Portion):

Group Label	Group Desc.	Angle Type	Angle Size	Steel Strength (ksi)	Max Usage %	Max Use In Comp. %	Comp. Control Member	Comp. Force (kips)	Comp. Control Load Case	
TA5	LEG1	SAE	3.5X3.5X0.25	36.0	102.58	102.58	10Y	-53.848	Hurr -35,I	NG
TB4	LEG2	SAE	4X4X0.25	50.0	106.71	106.71	12Y	-69.186	Hurr -35,I	NG
T4	LEG3	SAE	4X4X0.3125	50.0	103.87	103.87	14Y	-77.417	Hurr -14,I	NG

- At 35 degrees from Normal, Middle Legs are overloaded by 6.71%

- At 14 degrees from Normal, Bottom Legs are overloaded by 3.87%

Foundation Loads



But My Line is in Nixa, Missouri (90mph, Heavy Ice)

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- The previous examples were for the Texas Gulf Coast or Florida.

- Do I need to consider Oblique Wind outside of Hurricane Zones?

DESIGN CONDITIONS:

- No Line Angle
- NESC 2007 Wind Load Convention
- 90 MPH Wind (40 m/sec)
- NESC Heavy Ice District
- 2 Circuits of 795 ACSR Drake Wire (3 per Phase)
- Span Length = 1302 feet (397 meters)

Legs are at 100% for NESC 250B

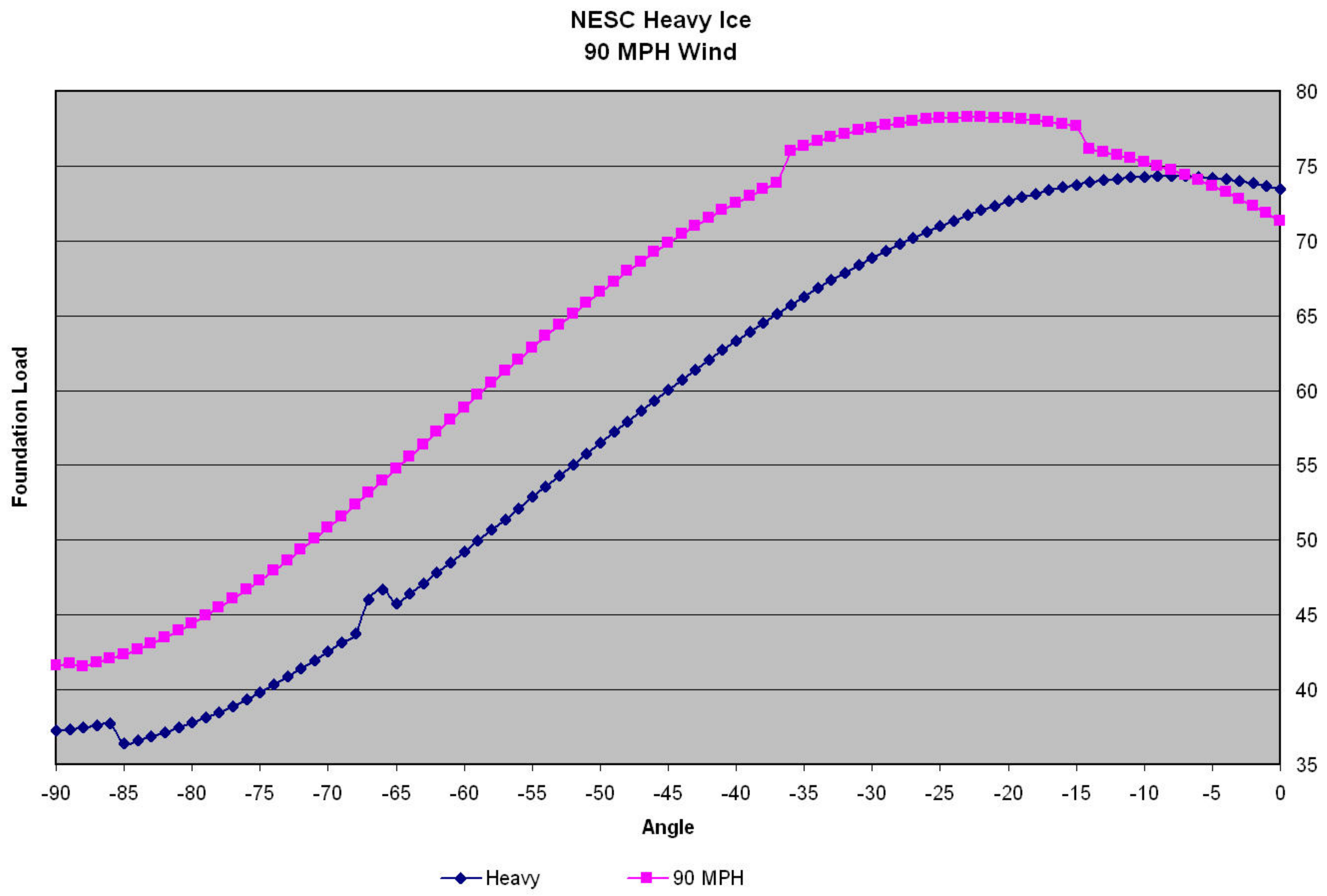
Group Summary (Compression Portion):

Group Label	Group Desc.	Angle Type	Angle Size	Steel Strength (ksi)	Max Usage %	Max Use In Comp. %	Comp. Control Member	Comp. Force (kips)	Comp. Control Load Case
TA5	LEG1	SAE	3.5X3.5X0.25	36.0	99.94	99.94	10X	-52.460	NESC 250B
TB4	LEG2	SAE	4X4X0.25	50.0	97.84	97.84	13P	-64.065	NESC 250B
T4	LEG3	SAE	4X4X0.3125	50.0	95.41	95.41	15P	-71.694	NESC 250B

Leg Loads Maximum for NESC 250B

Heavy Ice (1/2” Radial and 40 MPH wind)

Foundation Reaction
NESC Heavy and 90 MPH Wind



Analysis Results:

- Based on this particular 26’x10’ Tower Model
- Oblique Wind Cases Never Controlled Leg Design
- Foundation Loads were Slightly Higher for Oblique Winds at 90 MPH

ATLANTA, GEORGIA

- No Line Angle
- NESC 2007 Wind Load Convention
- 100 MPH Wind (45 m/sec)
- NESC Medium Ice District
- 2 Circuits of 795 ACSR Drake Wire (3 per Phase)
- Span Length = 1135 feet (346 meters)

Normal 100 mph Wind Results

Group Summary (Compression Portion):

Group Label	Group Desc.	Angle Type	Angle Size	Steel Strength (ksi)	Max Usage %	Max Use In Comp. %	Comp. Control Member	Comp. Force (kips)	Comp. Control Load Case
TA5	LEG1	SAE	3.5X3.5X0.25	36.0	95.01	95.01	9XY	-49.875	Hurricane
TB4	LEG2	SAE	4X4X0.25	50.0	99.99	99.99	13P	-65.468	Hurricane
T4	LEG3	SAE	4X4X0.3125	50.0	98.12	98.12	15XY	-73.719	Hurricane

Legs at 99.99% for Wind Normal to Wires

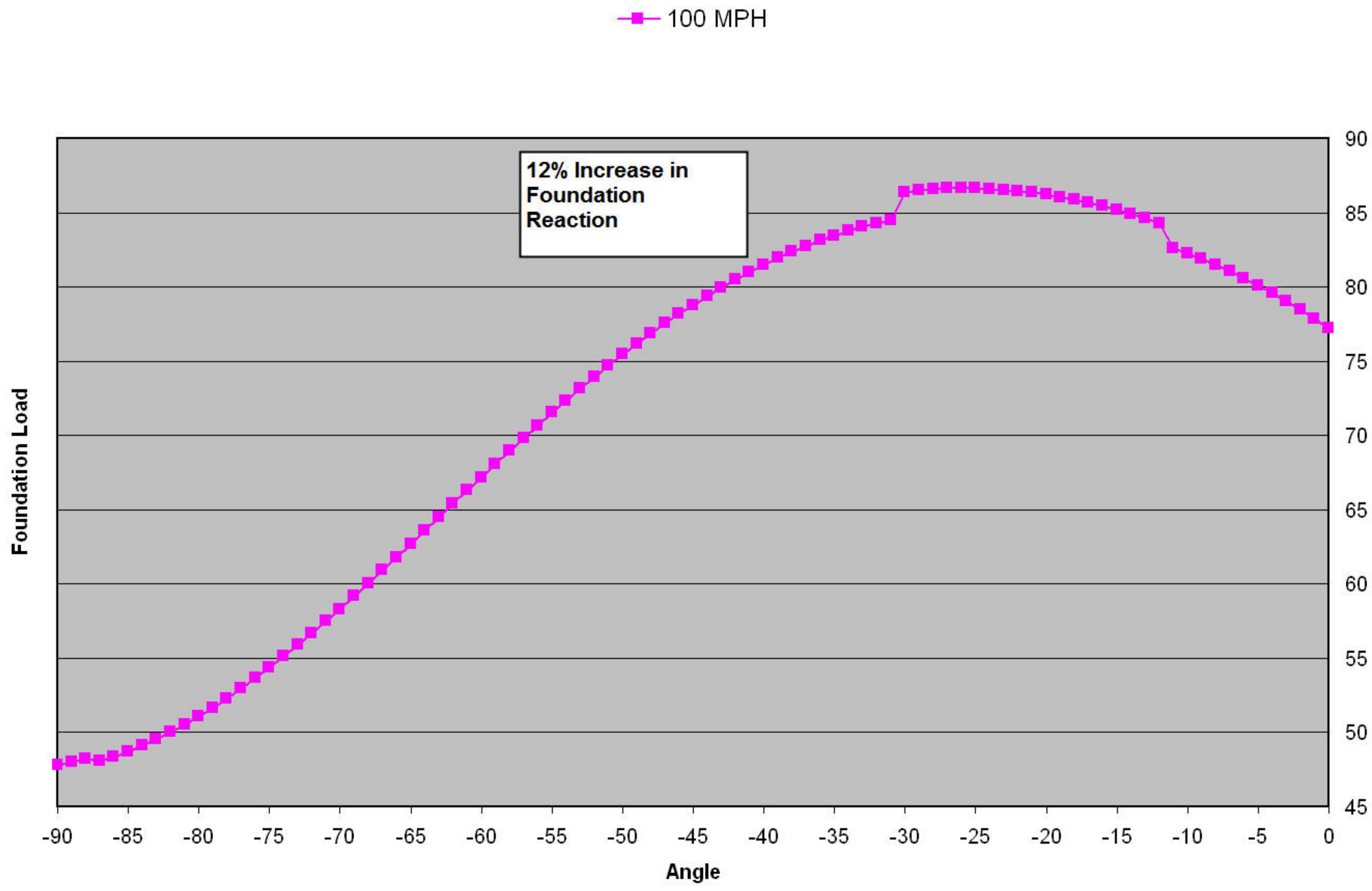
Oblique 100 mph Wind Results

Group Summary (Compression Portion):

Group Label	Group Desc.	Angle Type	Angle Size	Steel Strength (ksi)	Max Usage %	Max Use In Comp. %	Comp. Control Member	Comp. Force (kips)	Comp. Control Load Case	
TA5	LEG1	SAE	3.5X3.5X0.25	36.0	98.05	98.05	10Y	-51.468	Hurr -13,I	
TB4	LEG2	SAE	4X4X0.25	50.0	103.54	103.54	13Y	-67.792	Hurr -11,I	NG
T4	LEG3	SAE	4X4X0.3125	50.0	102.55	102.55	15Y	-77.044	Hurr -11,I	NG

At 11 degrees from Normal, Legs are overloaded by 3.5%

Foundation Reaction
100 MPH Wind



BUT I DO NOT USE LATTICE TOWERS

I HAVE WOOD H-FRAME LINES

(Wood is always Good)

DO I HAVE A PROBLEM?

Wood Is always Good?

Concrete H-Frame Failure

Hurricane Lilly damage in Louisiana.

H-Frame Structure

Class 2 Wood Pole

Pole Length = 100’ (30m)

Height = 88’ (27m)

H-Frame Analysis

- No Line Angle
- NESC 2007 Wind Load Convention
- 140 MPH Wind (63 m/sec)
- NESC Light Ice District
- 1 Circuit of 795 ACSR Drake Wire (1 per Phase)
- Span Length = 443 feet (135 meters)

H-Frame Analysis

Summary of Wood Pole Usages:

Wood Pole Label	Maximum Usage %	Load Case	Segment Number	Weight (lbs)
Pole	99.07	Hurricane NL-,I NA- (140mph)	17	5843.6
RPol	99.07	Hurricane NL+,I NA+ (140mph)	17	5843.6

140 MPH Wind Normal to Wires

H-Frame Analysis

Summary of Wood Pole Usages:

Wood Pole Label	Maximum Usage %	Load Case	Segment Number	Weight (lbs)	
Pole	271.26	Hurr -90,I BI+ (140mph)	18	5843.6	NG
RPol	271.29	Hurr -90,I BI+ (140mph)	18	5843.6	NG

271% Overstress on Pole at 90° oblique angle with no Wire on Structure

(Wind Along Line, NESC Rule 261A2e)

Too Many Iterations

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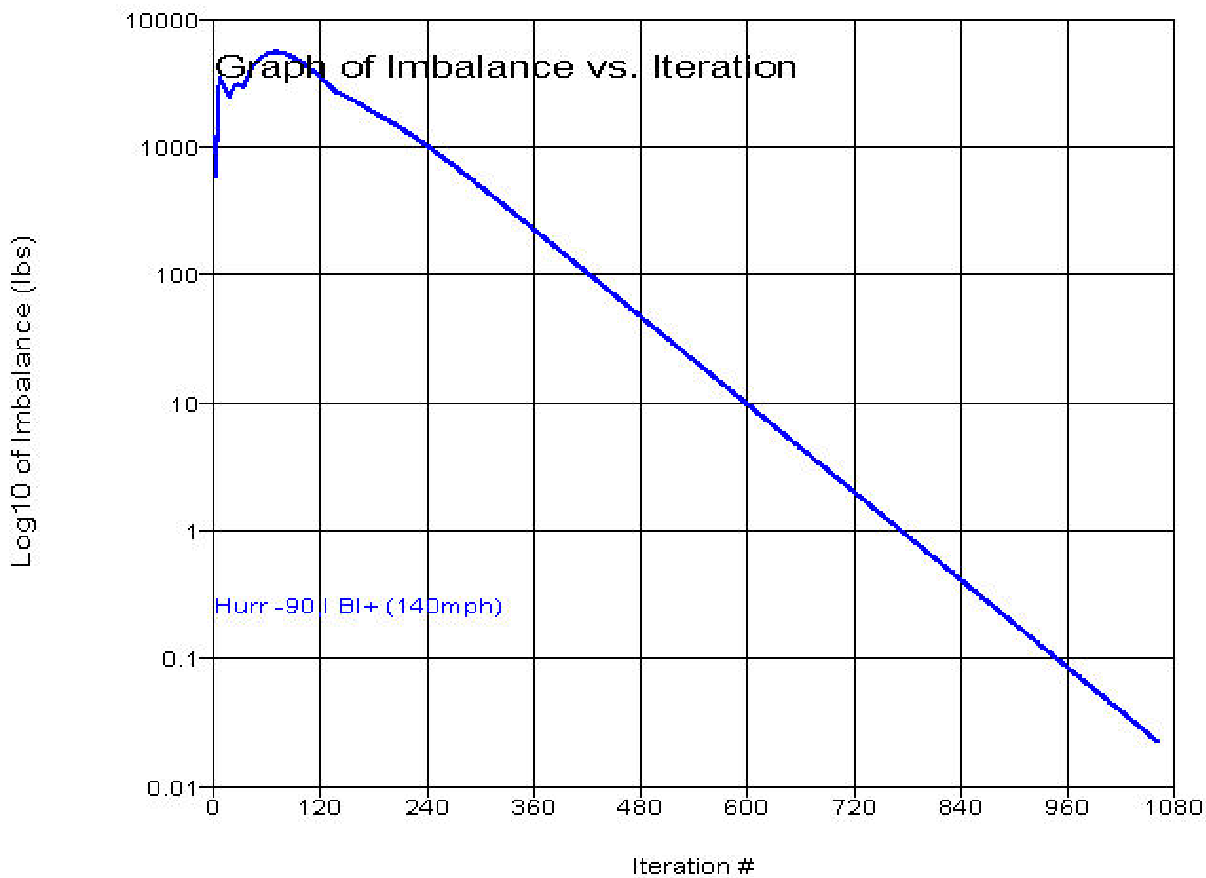
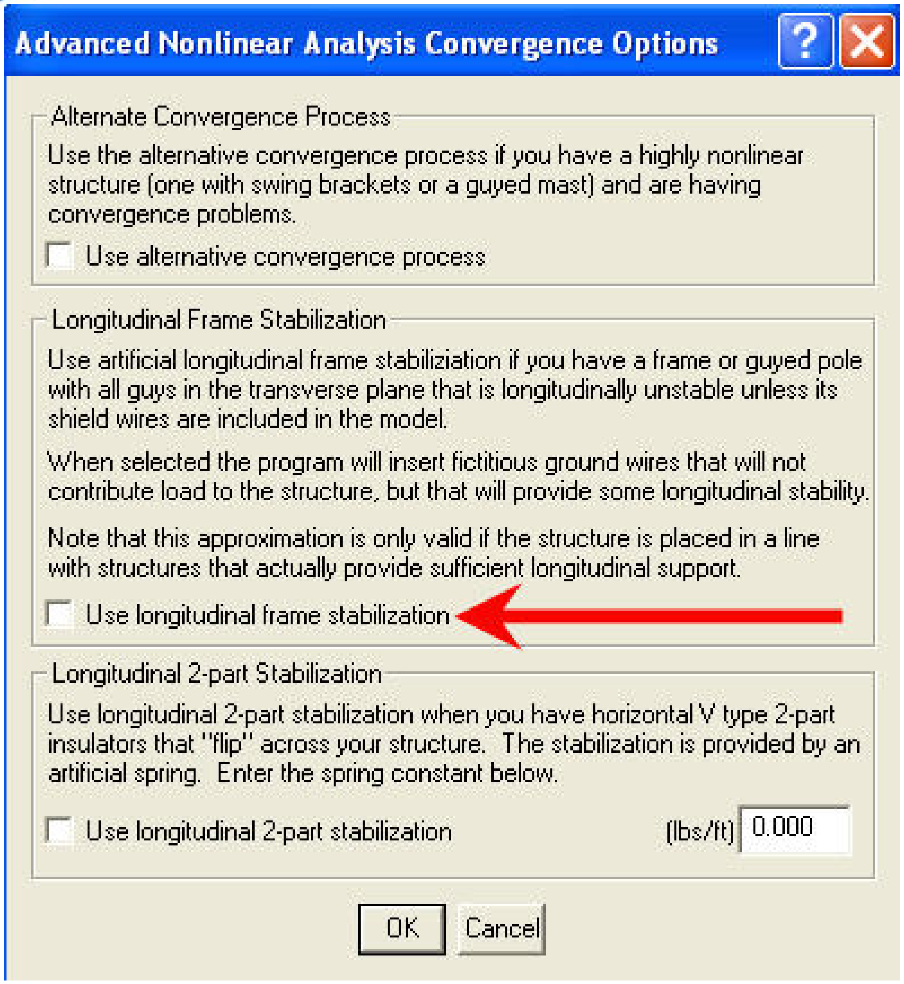
*** Analysis Results:

Maximum element usage is 271.29% for Wood Pole "RPol" in load case "Hurr -90,I BI+ (140mph)"   NG



*** Analysis Results for Load Case No. 1 "Hurr -90,I BI+ (140mph)" - Number of iterations in SAPS 1062

Frame Stabilization



General-General Data-Conv. Options

Check this box if you have OHGW attached to the poles for the load case.

Uncheck this box when no wire is on the structure for Rule 261A load cases

90 MPH H-Frame Analysis

- No Line Angle
- NESC 2007 Wind Load Convention
- 90 MPH Wind (45 m/sec)
- NESC Medium Ice District
- 1 Circuit of 795 ACSR Drake Wire (3 per Phase)
- Span Length = 770 feet (235 meters)

H-Frame Analysis

Summary of Wood Pole Usages:

Wood Pole Label	Maximum Usage %	Load Case	Segment Number	Weight (lbs)
Pole	99.84	Hurricane NL-,I NA- (90mph)	17	5843.6
RPol	99.84	Hurricane NL+,I NA+ (90mph)	17	5843.6

90 MPH Wind Load Normal to Wires

H-Frame Analysis

```
Summary of Wood Pole Usages:

 Wood Pole Maximum                    Load Case Segment Weight
      Label Usage %                               Number   (lbs)
----------------------------------------------------------------------
       Pole  150.74 Hurr -90,I BI+ (90mph)        16 5843.6   NG
       RPol  150.82 Hurr -90,I BI+ (90mph)        16 5843.6   NG
```

151% Overstress on Pole at 90° oblique for 90 MPH Wind Load (45 m/s) with no wire on structure.

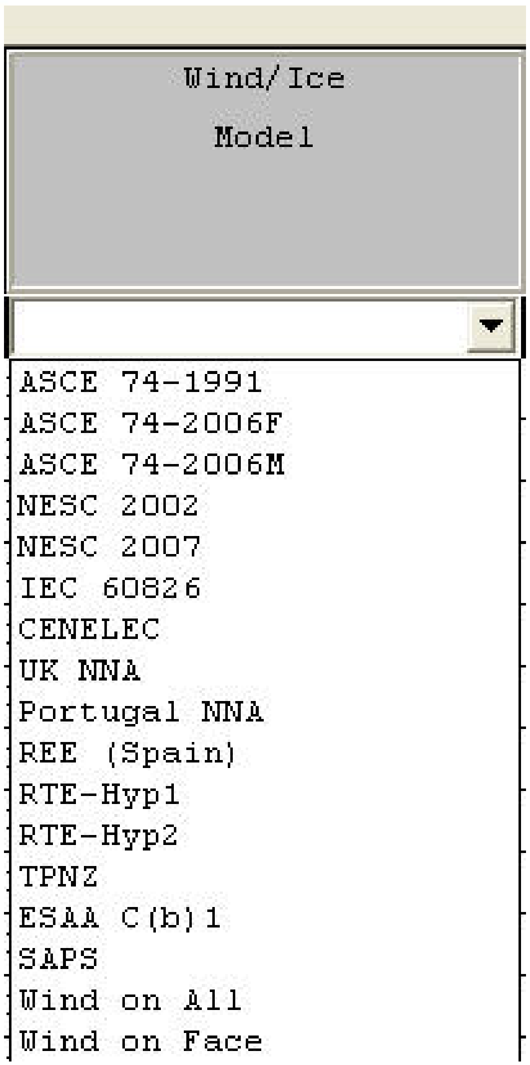
Oblique Wind Conclusions

- 90 MPH did not show a significant increase in Foundation and Leg Loads for Towers
- 100 – 150 MPH Winds do show a significant increase in Foundation and Leg Loads
- Research is Based on a Specific 26'x10' Tower
- 10° Increments in Wind Angle can effectively bracket the maximum value
- Your Results May Vary

Oblique Wind Conclusions
H-Frame

- Longitudinal Wind May Be a Big Problem for 90MPH to 150MPH Winds with no wire on structure
- Oblique Wind is a Problem in 100 – 150 MPH Zones
- Analysis Considered New Wood Poles
- In-Line Guys Solve the Oblique Wind Problem

PLS-CADD WIND FACTORS



Available Wind on Tower Methods

- Code Based Methods do include any factors in the codes listed
- WIND ON ALL does not include any factors for flat
- WIND ON FACE does not include any factors for flat or shielding
- ASCE 74-1991 based on Fastest Mile wind speed
- ASCE 74-2006M and ASCE 2006F are proposed methods

PLS-TOWER DRAG FACTORS

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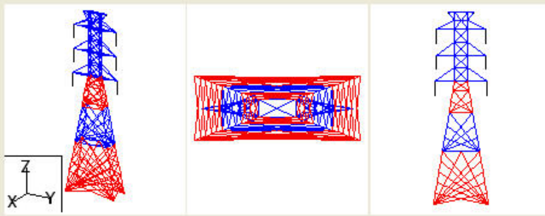
Sections



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	Force Solid Face
1	Cage		11P	1.310	3.200	3.200	1.000	1.000	0.000	0.000	1.600	1.600	1.600	1.000	None
2	Body3		14S	1.310	3.200	3.636	1.000	1.136	0.000	0.000	1.600	1.818	1.709	1.000	None
3	Body2		17S	1.310	3.200	4.114	1.000	1.286	0.000	0.000	1.600	2.057	1.829	1.000	None
4	Body1		22P	1.310	3.200	4.960	1.000	1.550	0.000	0.000	1.600	2.480	2.040	1.000	None

Geometry – Sections – Define Table

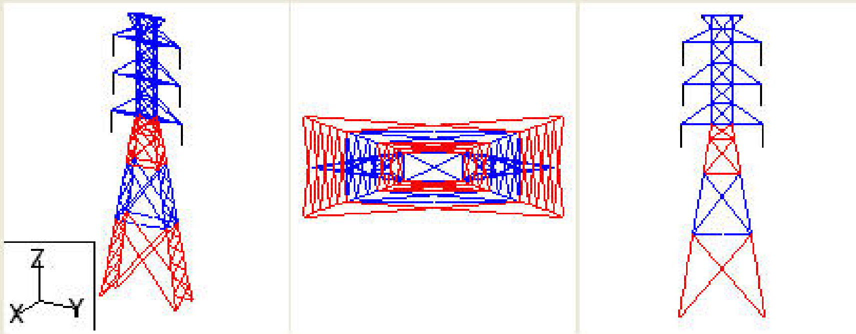
Modify Drag Factors to account for missing redundants

PLS-TOWER DRAG FACTORS

- Changing Wind Methods can be Dangerous
- If columns are blank, no wind on tower will be applied when that column becomes active

PLS-TOWER DRAG FACTORS

Sections



Model Check Report

No errors or relevant warnings detected.

Adjust Drag Factors

	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)
1	Cage		11P	1.310	3.200	3.200	1.000	1.000
2	Body3		14S	1.310	3.200	3.636	1.000	1.136
3	Body2		17S	1.310	3.200	4.114	1.000	1.286
4	Body1		22P	1.310	3.200	4.960	1.000	1.550
5								

CD From Code is used for NESC 2002, NESC 2007 and ASCE 74-2006F

PLS-TOWER DRAG FACTORS

	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
1	Cage		11P	1.310	3.200	3.200
2	Body3		14S	1.310	3.200	3.636
3	Body2		17S	1.310	3.200	4.114
4	Body1		22P	1.310	3.200	4.960

Factor For Face is used by the “WIND ON FACE” method and does not include any height adjustments

PLS-TOWER DRAG FACTORS

Transverse Drag x Area Factor For All	Longitudinal Drag x Area Factor For All
1.600	1.600
1.600	1.818
1.600	2.057
1.600	2.480

Factor For All is used for "WIND ON ALL" method and does not include height adjustments

PLS-TOWER DRAG FACTORS

SAPS Angle Drag x Area Factor
1.600
1.709
1.829
2.040

- SAPS Angle Factor is used for the SAPS method and the ASCE 74-2006M method for non-round members
- The shape factor for angles is NOT included and must be added
- Method is based in Fluid Mechanics and does not account for any shielding

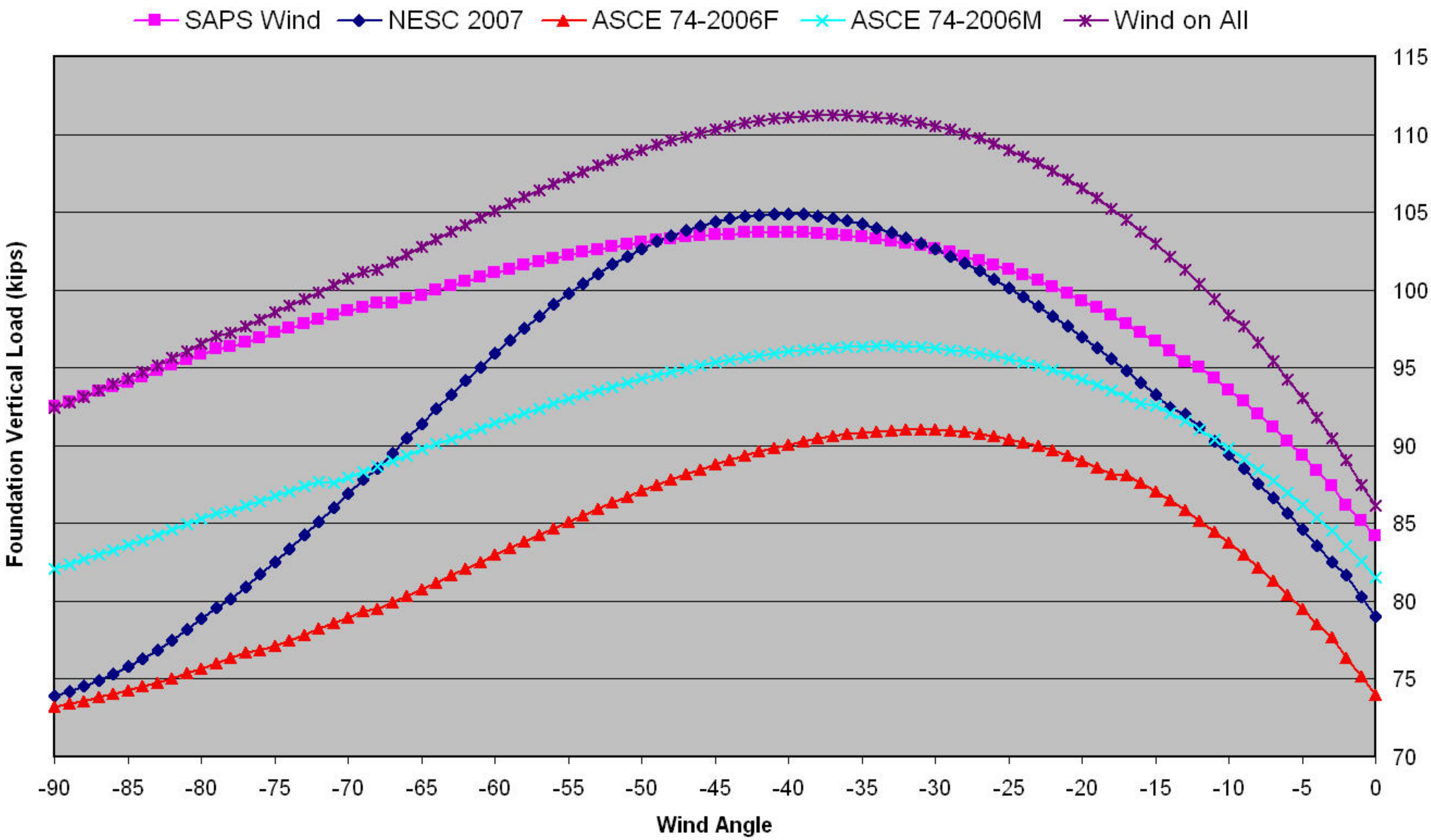
PLS-TOWER DRAG FACTORS

SAPS Round Drag x Area Factor
1.000
1.000
1.000
1.000

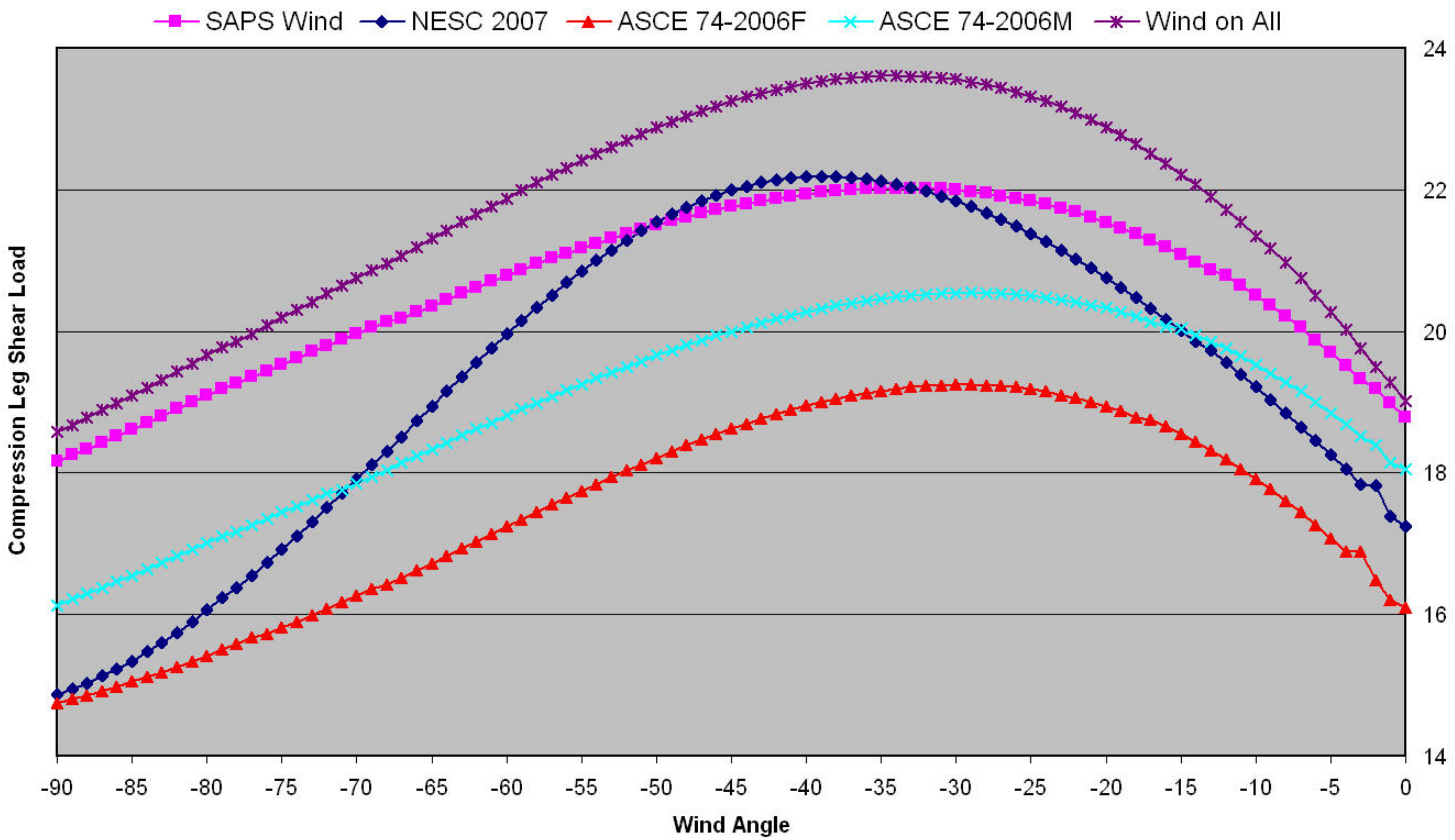
SAPS Round Factor is used for the SAPS method and the ASCE 74-2006M method for round members

Method is based in Fluid Mechanics and does not account for any shielding

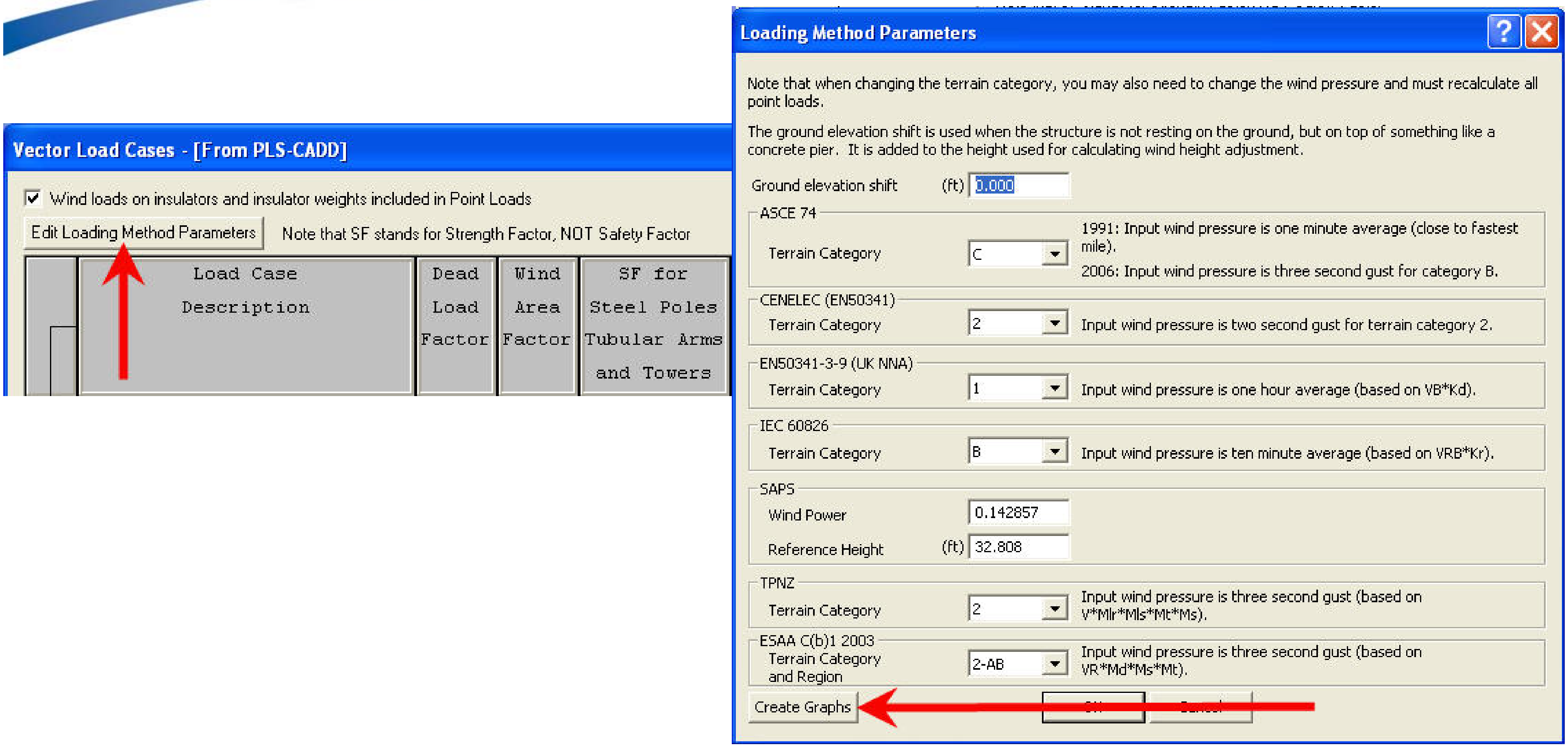
WIND METHOD COMPARISON
Foundation Loads



WIND METHOD COMPARISON
Shear Load



Wind Method Graphs



Wind On Tower Methods

Wind Method Comparison

METHOD	Gust Response	Wind Pressure on Tower	Drag Coeff
SAPS Wind	NOT APPLICABLE	User Defined	User Defined Constant
NESC 2007	Variable with Height	Constant at 2/3 Height	3.2 x User Defined
ASCE 74-2006F	Variable with Height	Variable with Section Height	Variable with Solidity
ASCE 74-2006M	Variable with Height	Variable with Member Height	User Defined Constant
Wind on All	NOT APPLICABLE	Constant	User Defined Constant

PLS-CADD Criteria File

CenterPoint Energy

Weather Cases

See Criteria/Code Specific Wind and Terrain Parameters for more information on height adjustments and gust response factors

	Description	Air Density Factor (Q) (psf/mph^2)	Wind Velocity (mph)	Wind Pressure (psf)	Wire Ice Thickness (in)	Wire Ice Density lbs/ft^3)
11	Hurricane	0.00256	140	50.176	0	0
12	NESC LIGHT	0.00256	59.2927	9	0	0
13	NESC Medium	0.00256	39.5285	4	0.25	57
14	NESC Heavy	0.00256	39.5285	4	0.5	57
15	Rule 250 D	0.00256	30	2.304	0.5	57

PLS-CADD Criteria File

Structure Loads Criteria

	Description	Weather case	Cable condition	Wind Direction	Bisector Wind Dir (deg)
26	Hurr -90	Hurricane	Initial RS	BI+	-90.00
27	Hurr -80	Hurricane	Initial RS	BI+	-80.00
28	Hurr -70	Hurricane	Initial RS	BI+	-70.00
29	Hurr -60	Hurricane	Initial RS	BI+	-60.00
30	Hurr -50	Hurricane	Initial RS	BI+	-50.00
31	Hurr -45	Hurricane	Initial RS	BI+	-45.00
32	Hurr -40	Hurricane	Initial RS	BI+	-40.00
33	Hurr -30	Hurricane	Initial RS	BI+	-30.00
34	Hurr -20	Hurricane	Initial RS	BI+	-20.00
35	Hurr -10	Hurricane	Initial RS	BI+	-10.00
36	Hurr 10	Hurricane	Initial RS	BI+	10.00
37	Hurr 20	Hurricane	Initial RS	BI+	20.00
38	Hurr 30	Hurricane	Initial RS	BI+	30.00
39	Hurr 40	Hurricane	Initial RS	BI+	40.00
40	Hurr 45	Hurricane	Initial RS	BI+	45.00
41	Hurr 50	Hurricane	Initial RS	BI+	50.00
42	Hurr 60	Hurricane	Initial RS	BI+	60.00
43	Hurr 70	Hurricane	Initial RS	BI+	70.00
44	Hurr 80	Hurricane	Initial RS	BI+	80.00
45	Hurr 90	Hurricane	Initial RS	BI+	90.00

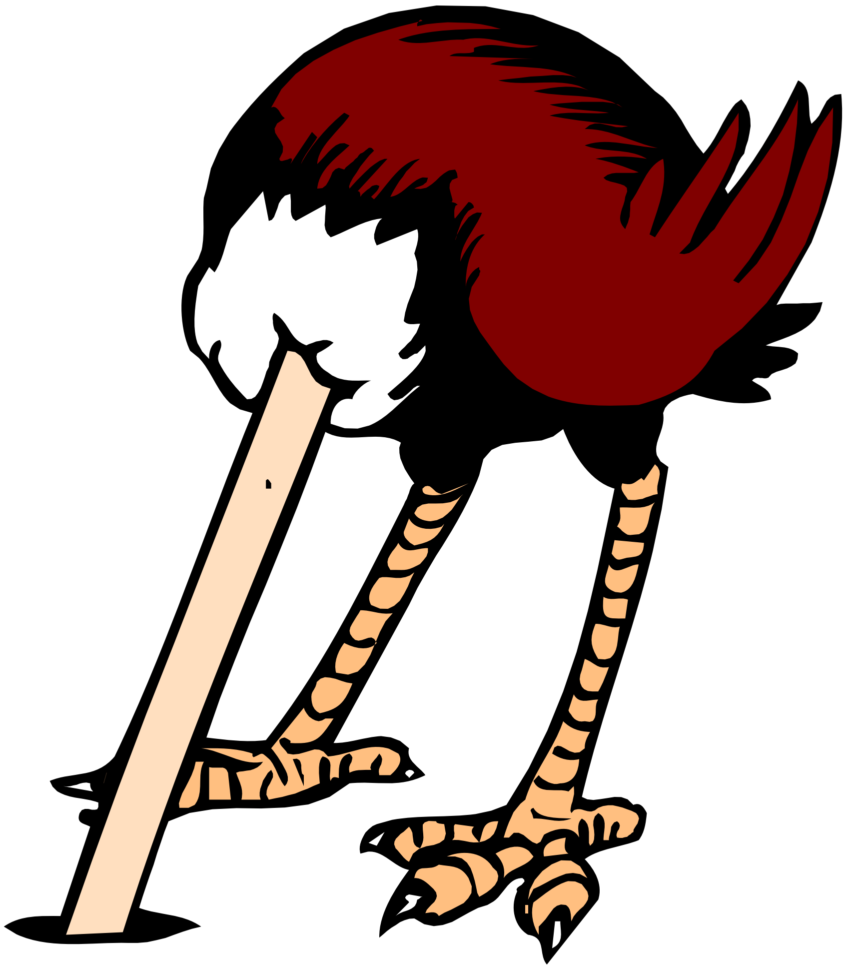
Structure Loading Criteria.

39 wind cases added to this table will provide oblique wind on structures.

Do You Have a Problem?

"I Don't Have a Problem. All my structures are fine when the wind blows in the direction I want it to."

Do You Have a Problem?



"I Don't Have a Problem. My wood H-Frame line is in Missouri in the 90 mph zone."

Do You Have a Problem?

"I don't have time to evaluate all the wind cases. The cost savings now will pay for the restoration later."

Do You Have a Problem?

"We have had structures in the field for 50 years and have not seen any failures yet. Besides, the wind does not blow on the bottom 60 feet."

QUESTIONS?

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