Southwest Windpower Inc.

Doc. # 0185

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27’ Air Tower Analysis

7/7/03

1. Introduction:

The following analysis covers tower stress and anchor loads for the Southwest Wndpower 27' Air Tower turbine tower due to wind loading. The tower is built from 1.9" OD schedule 40 steel pipe. The analysis covers the 27 ft tower. The construction of this tower can be seen in fig. 1. Wind drag on the tower is calculated with the use of 1997 UBC standard table. The Air turbine and electrical cable wt. is 10 lb and the thrust load at 100 mph is 80 lb.

The analysis is static only. FEA analysis was used to determine the support point reaction loads and tension in cables. The analysis and results follow.

2. Analysis

Guy wire diameter = .125"
Tower bottom section dimension OD = 1.9"
Tower top section dimension OD = 1.9"
Thrust load from turbine at 100 mph wind speed = 80 lb

The purpose of the analysis is to determine:
1. The factor of safety for the most heavily loaded portions of the tower for the given wind speed
2. Compliance with the 1997 UBC column loading for given loads.
3.The guy cable loads to determine support anchor loads.
4. Reaction loads at the tower base (Support requirements)

Quantify loads
Wind speed = 100 mph
Turbine Thrust = 80 lb

Wind Pressure Ref UBC 1997 section 1613
Exposure D was used as it represents the most severe exposure.

Definitions:

C_e = combined height, exposure and gust factor coefficient
C_q = pressure coefficient for the structure or portion of structure under consideration
I_w = Importance factor
P = design wind pressure
q_s = wind stagnation pressure at the standard height of 33 feet

The 1997 UBC design wind pressure equation

$P = C_e C_q I_w q_s$

Wind Pressure ref UBC 1997
Exposure D

$C_e := 1.52$ (taken along full height of tower)

Drag coefficient (C_q) on the tower is found in table 16H UBC 1997 and is equal to:

$C_q := .8$

Stagnation Pressure (q_s) at 100 mph per table 16F UBC 1997 is equal to:

$$q_s := 25.6 \cdot \frac{lbf}{ft^2}$$

Importance factor is found in Table 16K UBC 1997 and is equal to:

$I_w := 1$

$P := C_e \cdot C_q \cdot q_s \cdot I_w$

$$P = 31.13 \frac{lbf}{ft^2}$$

The projected area on the tower is equal to:

$H_{tower} := 27 \cdot ft$ $OD_{pipe} := 1.9 \cdot in$

$A_{projected} := H_{tower} \cdot OD_{pipe}$

$A_{projected} = 4.275\, ft^2$

Wind load on the tower is equal to:

$L_{wind} := A_{projected} \cdot P$

$L_{wind} = 133.079\, lbf$ $L_{ft} := \frac{L_{wind}}{27 \cdot ft}$ $L_{ft} = 4.929 \frac{lbf}{ft}$

The projected area of the guy wire is equal to:

$L_{guy} := 355 \cdot in$ $\qquad$ $OD_{guy} := .125 \cdot in$

$A_{guy} := L_{guy} \cdot OD_{guy}$

$A_{guy} = 0.308\ ft^2$

Wind Load on ..125 in diameter guy wire is:

$F_{guy} := A_{guy} \cdot P$

$F_{guy} = 9.593\ lbf$ $\qquad$ (neglected in analysis)

The cable is connected to the cable hanger by conventional means and looped back onto itself while it is clamped with cable clamps (3 ea. per cable)

The maxium load on the cable is 371 lbf. (axial Loads fig) Typical 1/8" 7X19 Galvanized cable strength = 2000 lbf

Factor of Safety = 5.4 OK

Analyzing the stresses in the guy/coupler extrusion:

Tensile load in the cable: $L_{cable} := 371 \cdot lbf$ (axial loads fig)

Width of tab: $W_{tab} := 1.204 \cdot in$

Thickness of tab: $T_{tab} := .322 \cdot in$

Diameter of cable hole: $D_{hole} := .413 \cdot in$

Cross section area:

$A_{tab} := W_{tab} \cdot T_{tab} - D_{hole} \cdot T_{tab}$ $\quad A_{tab} = 0.255\, in^2$

Stress in tab:

$\sigma_{tab} := \dfrac{L_{cable}}{A_{tab}}$ $\quad \sigma_{tab} = 1.457 \times 10^3\, psi$

Applying stress concentration factor: (fig A-26-1)

$ratio := \dfrac{D_{hole}}{W_{tab}}$ $\quad ratio = 0.343$

Stress concentration factor = 2.25

$\sigma_{conc} := 2.25\sigma_{tab}$ $\quad \sigma_{conc} = 3.277 \times 10^3\, psi$

$\sigma_{alumyld} := 35000 \cdot psi$ (6061-T6)

$FS_{tab} := \dfrac{\sigma_{alumyld}}{\sigma_{conc}}$ $\quad FS_{tab} = 10.679$ OK

UBC97-LRFD STEEL SECTION CHECK

```
Combo  : DSTL1
Units  : lb, in, F

Frame  : 2                 Design Sect: PIPE1-1/2SCH40
X Mid  : 0.000             Design Type: Column
Y Mid  : 12.000            Frame Type : Ordinary MRF
Z Mid  : 288.000           Sect Class : Seismic
Length : 72.000            Major Axis : 0.000 degrees counterclockwise from local 3
Loc    : 0.000             RLLF       : 1.000
HEQ Factor : 1.000

Area   : 0.799             SMajor : 0.326          AVMajor: 0.448          rMajor : 0.623
IMajor : 0.310             SMinor : 0.326          AVMinor: 0.448          rMinor : 0.623
IMinor : 0.310             ZMajor : 0.448          E      : 29000000.000
Ixy    : 0.000             ZMinor : 0.448          Fy     : 36000.000
```

STRESS CHECK FORCES & MOMENTS

Location	Pu	Mu33	Mu22	Vu2	Vu3	Tu
0.000	-36.838	-9533.664	0.000	-152.824	0.000	0.000

PMM DEMAND/CAPACITY RATIO

Governing Equation	Total Ratio		P Ratio		MMajor Ratio		MMinor Ratio	Ratio Limit	Status Check
(H1-1b)	0.658	=	0.002	+	0.657	+	0.000	1.000	OK

AXIAL FORCE DESIGN

	Pu Force	phi*Pnc Capacity	phi*Pnt Capacity
Axial	-36.838	12099.999	25887.601

MOMENT DESIGN

	Mu Moment	phi*Mn Capacity	Cm Factor	B1 Factor	B2 Factor	K Factor	L Factor	Cb Factor
Major Moment	-9533.664	14515.200	0.850	1.000	1.000	1.000	1.000	1.729
Minor Moment	0.000	14515.200	1.000	1.002	1.000	1.000	1.000	

SHEAR DESIGN

	Vu Force	phi*Vn Capacity	Stress Ratio	Status Check	Tu Torsion
Major Shear	152.824	8714.584	0.018	OK	0.000
Minor Shear	0.000	8714.584	0.000	OK	0.000

UBC97-LRFD STEEL SECTION CHECK
Combo : DSTL1
Units : lb, in, F

Frame : 2	Design Sect: PIPE1-1/2SCH40		
X Mid : 0.000	Design Type: Column		
Y Mid : 12.000	Frame Type : Ordinary MRF		
Z Mid : 288.000	Sect Class : Seismic		
Length : 72.000	Major Axis : 0.000 degrees counterclockwise from local 3		
Loc : 0.000	RLLF : 1.000		
HEQ Factor : 1.000			
Area : 0.799	SMajor : 0.326	AVMajor: 0.448	rMajor : 0.623
IMajor : 0.310	SMinor : 0.326	AVMinor: 0.448	rMinor : 0.623
IMinor : 0.310	ZMajor : 0.448	E : 29000000.000	
Ixy : 0.000	ZMinor : 0.448	Fy : 36000.000	

STRESS CHECK FORCES & MOMENTS

Location	Pu	Mu33	Mu22	Vu2	Vu3	Tu
0.000	-36.838	-9533.664	0.000	-152.824	0.000	0.000

PMM DEMAND/CAPACITY RATIO

Governing Equation	Total Ratio		P Ratio		MMajor Ratio		MMinor Ratio	Ratio Limit	Status Check
(H1-1b)	0.658	=	0.002	+	0.657	+	0.000	1.000	OK

AXIAL FORCE DESIGN

	Pu Force	phi*Pnc Capacity	phi*Pnt Capacity
Axial	-36.838	12099.999	25887.601

MOMENT DESIGN

	Mu Moment	phi*Mn Capacity	Cm Factor	B1 Factor	B2 Factor	K Factor	L Factor	Cb Factor
Major Moment	-9533.664	14515.200	0.850	1.000	1.000	1.000	1.000	1.729
Minor Moment	0.000	14515.200	1.000	1.002	1.000	1.000	1.000	

SHEAR DESIGN

	Vu Force	phi*Vn Capacity	Stress Ratio	Status Check	Tu Torsion
Major Shear	152.824	8714.584	0.018	OK	0.000
Minor Shear	0.000	8714.584	0.000	OK	0.000

TOWER CABLE ANCHOR DESIGN

DESCRIPTION:

Concrete anchor for the Southwest Windpower Air 27' and 45' Tower Models. Supporting cables from the tower are attached to the concrete anchor via and eye bolt and cable clamp arrangement.

LOADS:

Per Restrains Reactions fig., the maxium anchor loads are due to wind loading. They are 494 lbf in the vertical up direction and 359 lbf in the horizontal direction.

SOILS INFORMATION: NA

It is assumed the anchor will be located in sandy soil. The recommended UBC guidelines
for allowable soil bearing capacity are used to determine adequacy of the anchor to
support the loads. It is assumed that all fill is compacted.

Bearing strength is taken as 1500 PSF
Lateral bearing strength is taken s 150 PSF/ (ft depth)
Friction is taken as .25 X effective anchor weight.

ANCHOR WEIGHT:

Reference drawing R00003 for dimensions.

CONCRETE VOLUME:

$Base_{radius} := 1 \cdot ft$ $\qquad$ $Base_{thickness} := 8 \cdot in$

$V_{base} := Base_{radius}{}^{2} \cdot \pi \cdot Base_{thickness}$ $\qquad$ $V_{base} = 0.1\,m^{3}$

$Column_{width} := 8 \cdot in$ $\qquad$ $Column_{height} := 22 \cdot in$

$V_{column} := Column_{width}{}^{2} \cdot Column_{height}$ $\qquad$ $V_{column} = 0\,m^{3}$

$V_{total} := V_{base} + V_{column}$ $\qquad$ $V_{total} = 0.1\,m^{3}$

$$Concrete_{density} := 150 \cdot \frac{lbf}{ft^{3}}$$

$$Concrete_{weight} := V_{total} \cdot Concrete_{density}$$

$$Concrete_{weight} = 436.4\,lbf$$

OVER BURDEN VOLUME:

$Height := 16 \cdot in$

$V_{ob} := \left(\pi \cdot Base_{radius}{}^{2} \cdot Height\right) - Column_{width}{}^{2} \cdot Height$

$V_{ob} = 3.6\,ft^{3}$

$Density_{ob} := 75 \cdot \dfrac{lbf}{ft^{3}}$

$Weight_{overburden} := V_{ob} \cdot Density_{ob}$ $\qquad$ $Weight_{overburden} = 269.7\,lbf$

$Total_{weight} := Concrete_{weight} + Weight_{overburden}$

$Total_{weight} = 706.1\,lbf$ O.K.

$Anchor_{bearing} := \pi \cdot Base_{radius}{}^{2}$ $\qquad$ $Anchor_{bearing} = 3.1\,ft^{2}$

$Soil_{pressure} := \dfrac{Total_{weight}}{Anchor_{bearing}}$

$Soil_{pressure} = 224.8\,\dfrac{lbf}{ft^{2}}$ OK

LATERAL RESISTANCE:

$Lateral_{bearing1} := Height \cdot Column_{width}$ $\qquad Lateral_{bearing1} = 0.9\,ft^2$

$Lateral_{bearing2} := 2 \cdot Base_{radius} \cdot Base_{thickness}$ $\qquad Lateral_{bearing2} = 1.3\,ft^2$

Lateral allowable bearing = 150 PSF to 1', 300 PSF from 1' to 2'

$$Lateral_{resisting} := \left(Lateral_{bearing1} \cdot 150 \cdot \frac{lbf}{ft^2} \right) + Lateral_{bearing2} \cdot 300 \cdot \frac{lbf}{ft^2}$$

$Lateral_{resisting} = 533.3\,lbf$

$F_{vertical} := 494 \cdot lbf$

$Lateral_{friction} := \left(Total_{weight} - F_{vertical} \right) \cdot .25$

$Lateral_{friction} = 53\,lbf$

$Total_{lateral} := Lateral_{resisting} + Lateral_{friction}$

$Total_{lateral} = 586.4\,lbf$ $\qquad$ O.K.

REINFORCING STEEL:

$F_{vertical} = 494\,lbf$ $\quad F_{horizontal} := 359 \cdot lbf$ $\quad Column_{width} := 8 \cdot in$

$$\tau_{max} := \frac{F_{horizontal}}{Column_{width}^2} \qquad \tau_{max} = 5.6\,psi \qquad \text{OK}$$

$$\sigma_{max} := \frac{F_{vertical}}{Column_{width}^2} \qquad \sigma_{max} = 7.7\,psi \qquad \text{OK}$$

Minimum Reinforcement required:
Per UBC sec 1910.5.3 reinforcing steel area is to be 1.33 times greater than that required by analysis.

Load at the 8"x8" section = 494 lbf axial tension + maximum possible transfer moment to the base of that section = 359 lbf X 22" =658.2 lbf*ft.

Tensile load in the Rebar:

$M_r := 658.2 \cdot lbf \cdot ft$ $\quad width_{center} := 4 \cdot in$

$$Tensile_{rebar} := \frac{M_r}{width_{center}} + F_{vertical} \qquad Tensile_{rebar} = 2468.6\,lbf$$

Per UBC section 1909.2.2, tensile load:

$T_{UBC} := 1.33 \cdot Tensile_{rebar}$ $\quad T_{UBC} = 3283.2\,lbf$

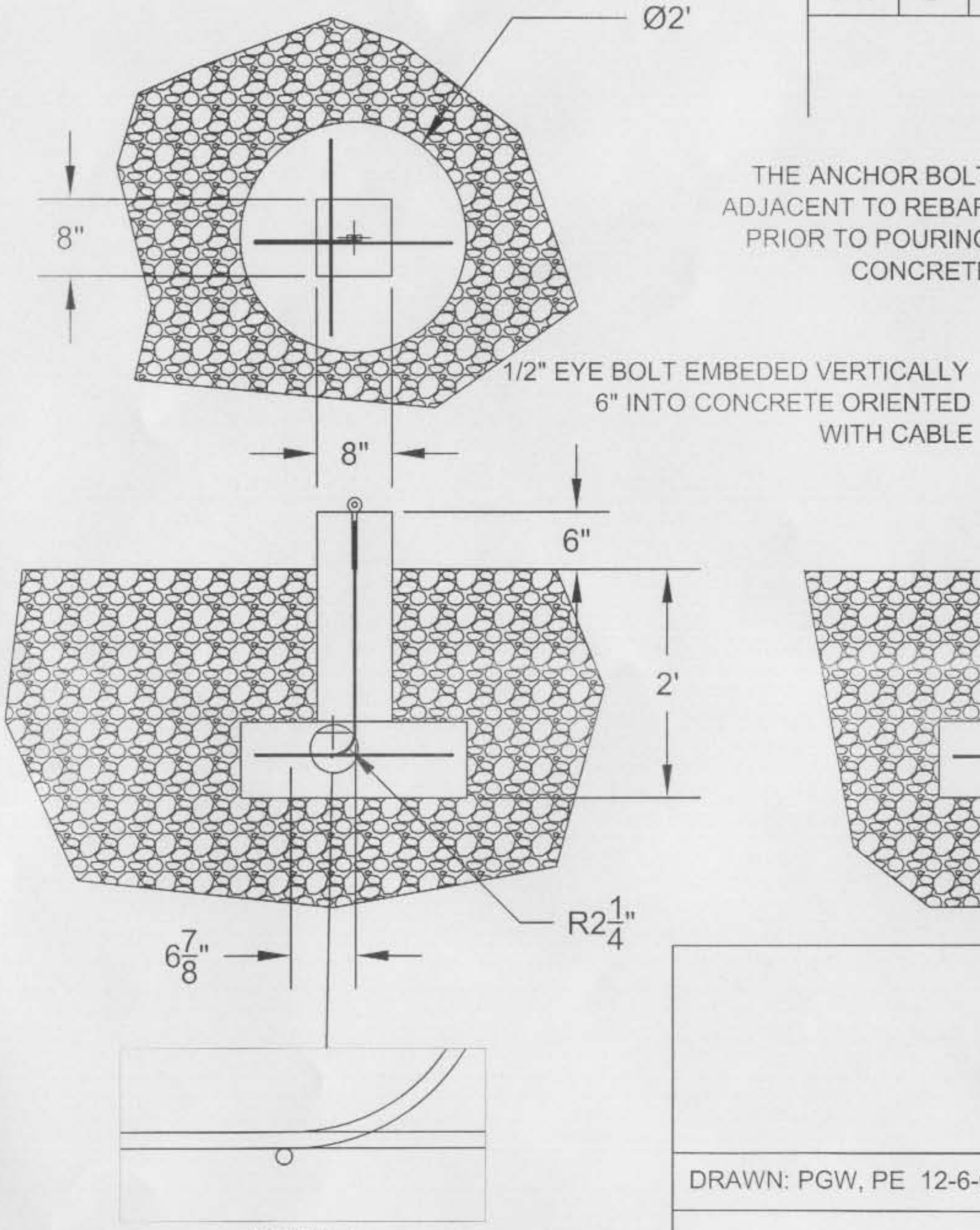
Required Rebar Area:

$$A_{rebar} := \frac{T_{UBC}}{40000 \cdot psi} \qquad A_{rebar} = 0.1\,in^2$$

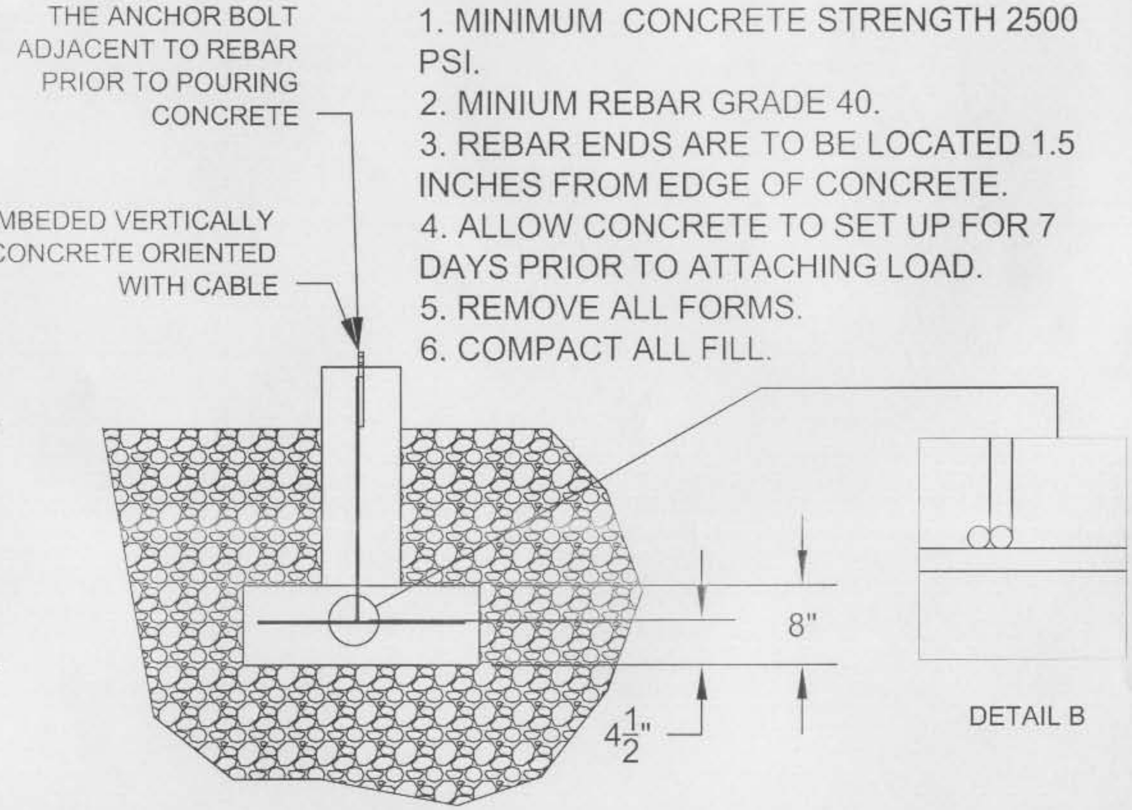
#4 rebar= $.196 \cdot in^2$ OK

Use one strand #4 centered in column section for base to column connection. Use two strands #4 in each direction perpendicular to each other in base as shown in drawing R00003. Per UBC table 19D use 1/2" Eyebolt embedded into concrete 6" deep tied adjacent to rebar.

REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED



NOTES:
1. MINIMUM CONCRETE STRENGTH 2500 PSI.
2. MINIUM REBAR GRADE 40.
3. REBAR ENDS ARE TO BE LOCATED 1.5 INCHES FROM EDGE OF CONCRETE.
4. ALLOW CONCRETE TO SET UP FOR 7 DAYS PRIOR TO ATTACHING LOAD.
5. REMOVE ALL FORMS.
6. COMPACT ALL FILL.



SOUTHWEST WINDPOWER

WIND SEEKER & AIR
27, 45, 47 AND 25 FOOT TOWER CABLE ANCHOR

DRAWN: PGW, PE 12-6-02	SIZE	FSCM NO.	DWG NO. R00003	REV C
	SCALE NONE		SHEET 1 OF 1	

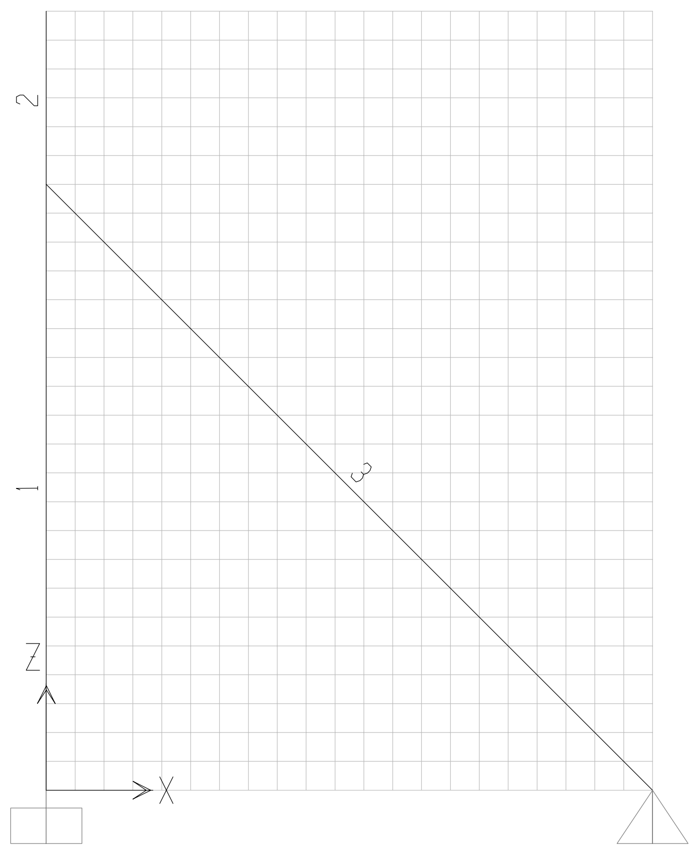
Conclusion:

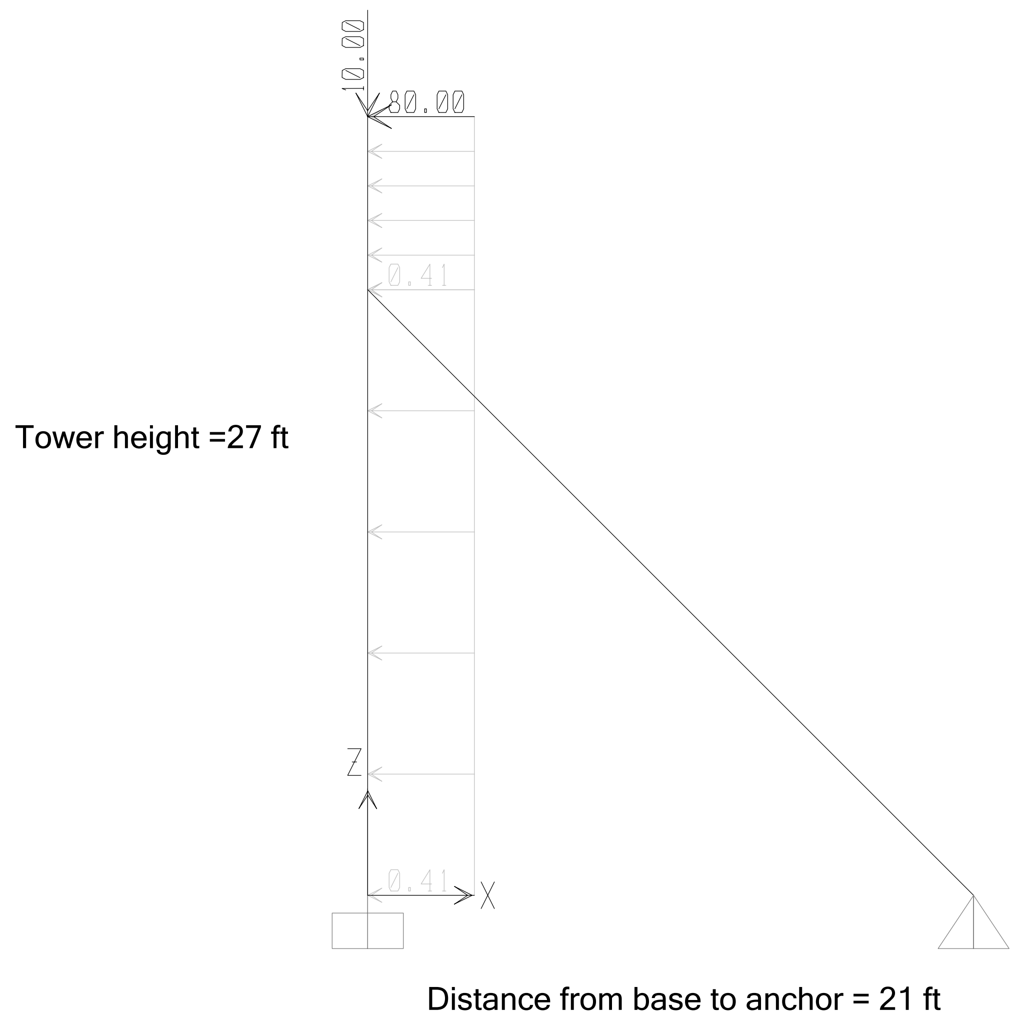
This analysis is a maximum load condition static analysis only; no fatigue analysis is contained herein. This analysis pertains to the 27 ft “Air” Turbine tower with construction and loading as described in appendix A, and does not address the operation of the turbine or the connection of the turbine to the tower. Loading conditions are at 100 mph. Proper assembly is assumed.

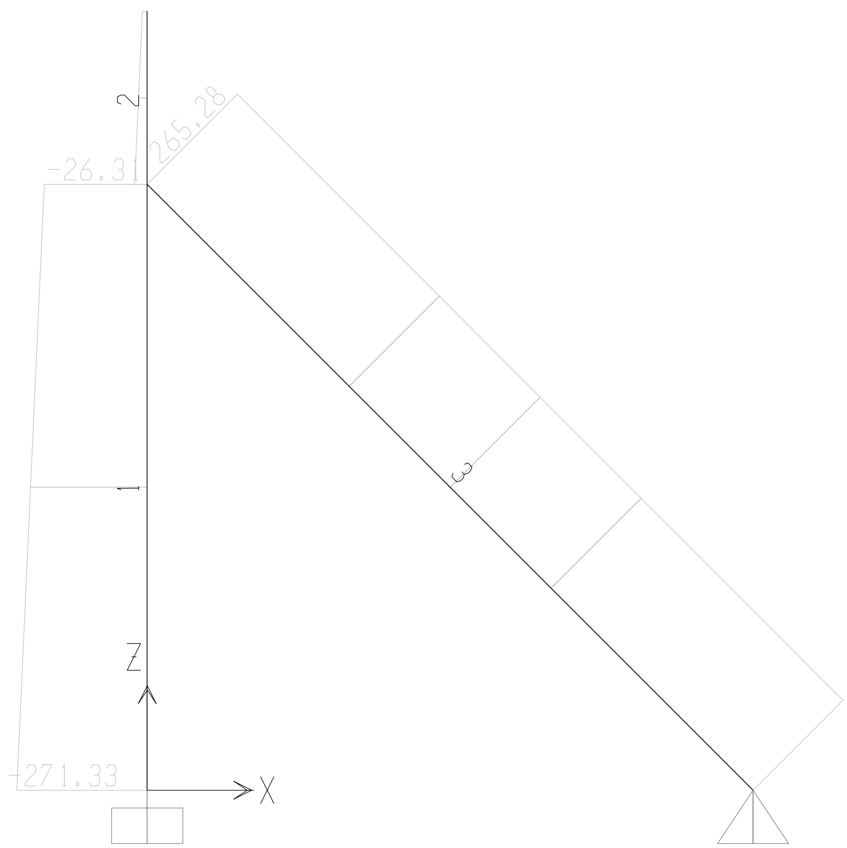
The sections of the tower were checked to see that it meets UBC requirements against buckling which it does. This requirement is the limiting factor for wind speed for the tower.

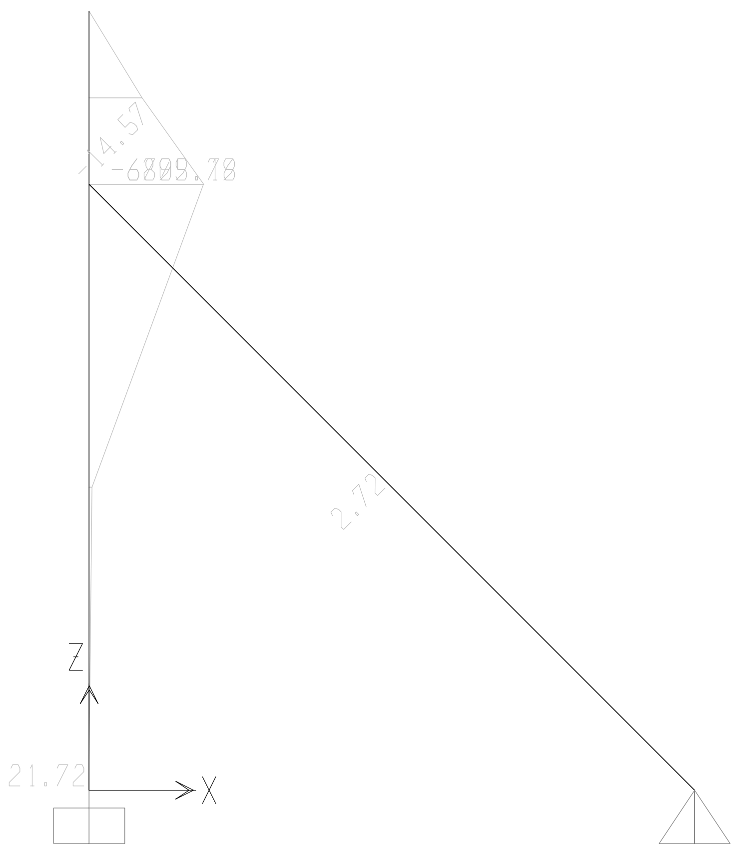
Guy wire stress is maximum in the top guy wire.

Appendix A


2
1
3
Z
X


10.00
80.00
0.41
Tower height =27 ft
Z
0.41
X
Distance from base to anchor = 21 ft


2
-26.31
265.28
1
3
Z
X
-271.33



14.57
-6805.78
-4709.10
2.72
21.72
Z
X

SAP2000

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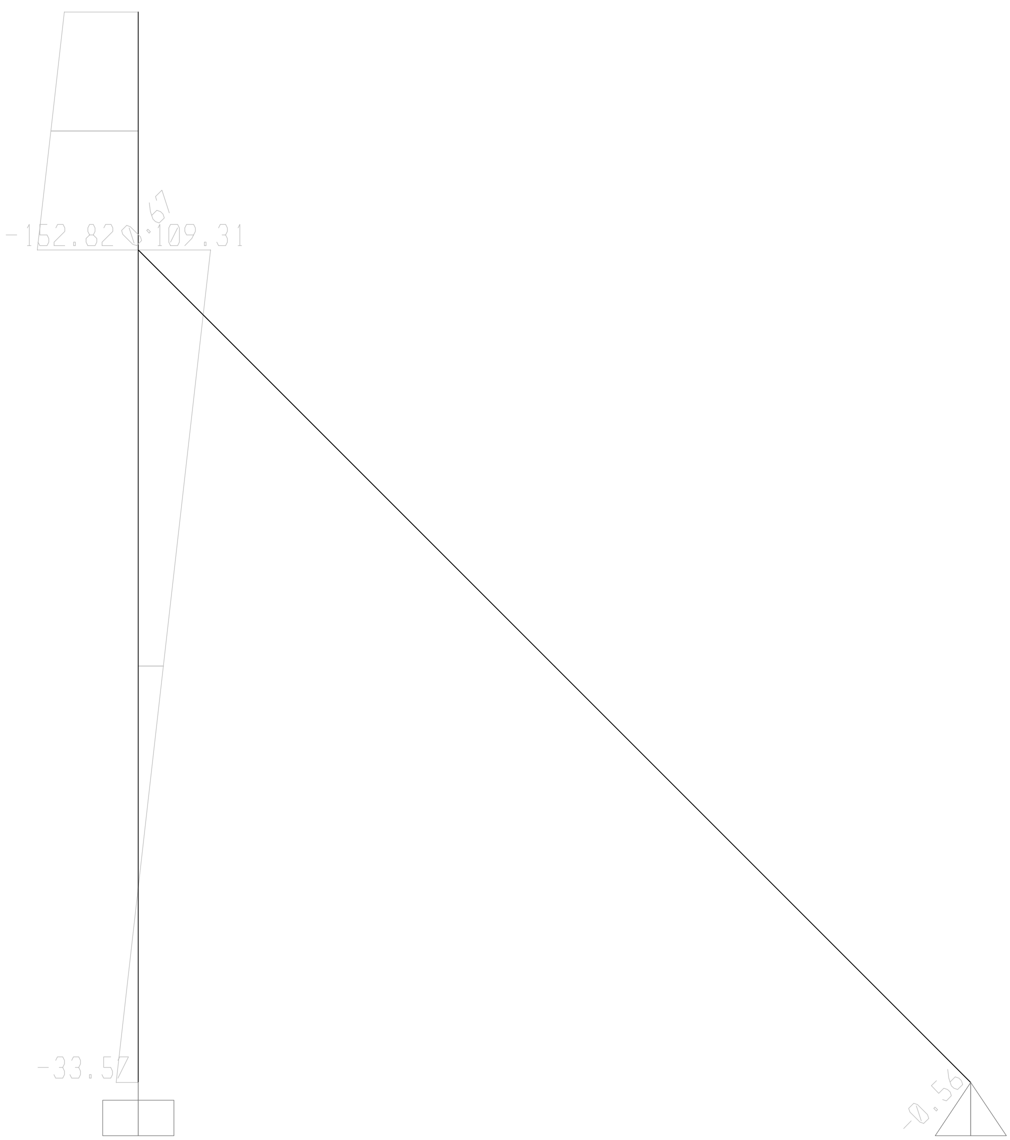
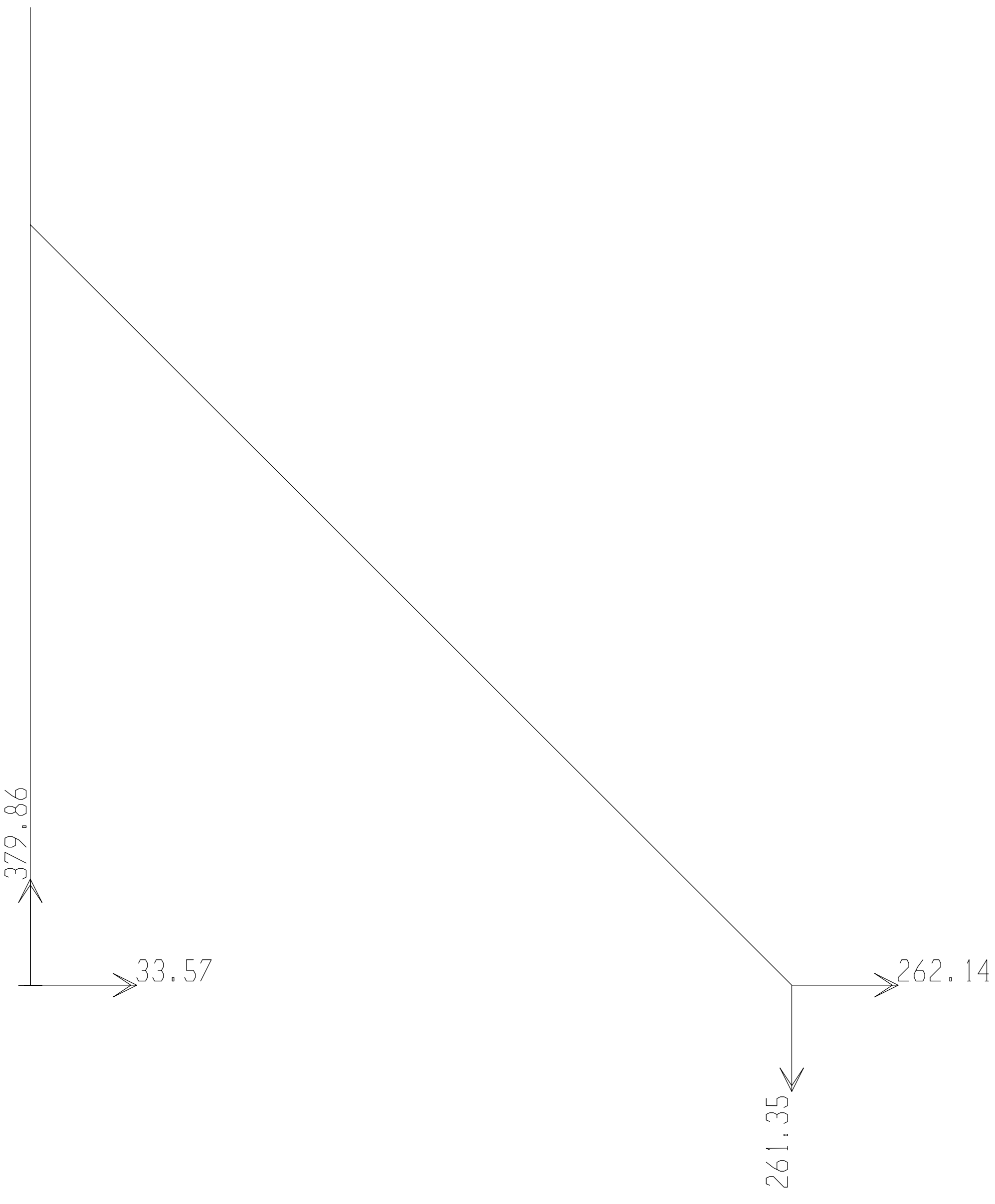


SAP2000 v8.1.2 - File:27ft air tower - Shear Force 2-2 Diagram (DSTL1) - lb, in, F Units



SAP2000 v8.1.2 - File:27ft air tower - Restraint Reactions (DSTL1) - lb, in, F Units

Table A-26 CHARTS OF THEORETICAL STRESS-CONCENTRATION FACTORS K_t*

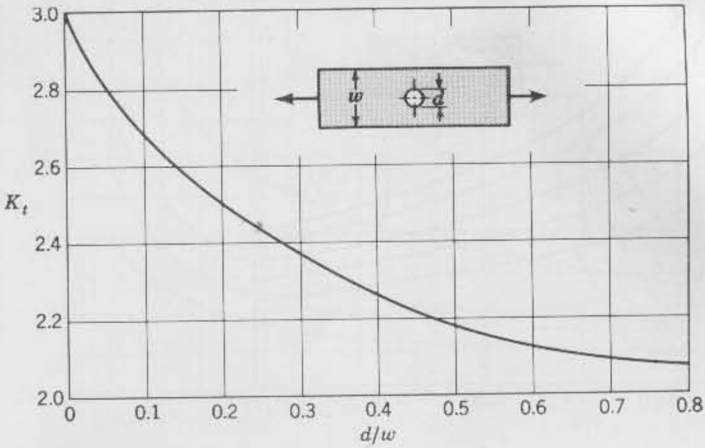


FIGURE A-26-1 Bar in tension or simple compression with a transverse hole. $\sigma_0 = F/A$, where $A = (w - d)t$, and where t is the thickness.

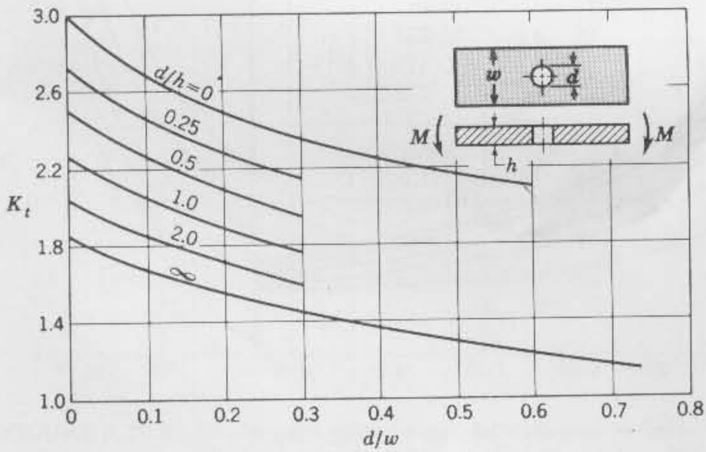


FIGURE A-26-2 Rectangular bar with a transverse hole in bending. $\sigma_0 = Mc/I$, where $I = (w - d)h^3/12$.

* Unless otherwise stated, these factors are from R. E. Peterson, "Design Factors for Stress Concentration," *Machine Design*, vol. 23, no. 2, February 1951, p. 169, no. 3, March 1951 p.161; no. 5, May 1951, p. 159; no. 6, June 1951, p. 173; no. 7, July 1951, p. 155; reproduced with the permission of the author and publisher.