Southwest Windpower Inc.

Doc. # 0186

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45’ Air Tower Analysis

7/7/03

1. Introduction:

The following analysis covers tower stress and anchor loads for the Southwest Wndpower 45' Air Tower turbine tower due to wind loading. The tower is built from 1.9" OD schedule 40 steel pipe. The analysis covers the 45 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

$C_e := 1.62$ (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:

$I_w := 1$

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

$$P = 33.178 \frac{lbf}{ft^2}$$

The projected area on the tower is equal to:

$H_{tower} := 45 \cdot ft$ $OD_{pipe} := 1.9 \cdot in$

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

$A_{projected} = 7.125\, ft^2$

Wind load on the tower is equal to:

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

$L_{wind} = 236.39\, lbf$ $L_{ft} := \frac{L_{wind}}{45 \cdot ft}$ $L_{ft} = 5.253 \frac{lbf}{ft}$

The projected area of the guy wire is equal to:

$L_{guy} := 565 \cdot in$ $OD_{guy} := .125 \cdot in$

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

$A_{guy} = 0.49\,ft^2$

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

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

$F_{guy} = 16.272\,lbf$ (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 435 lbf. (axial Loads fig) Typical 1/8" 7X19 Galvanized cable strength = 2000 lbf

Factor of Safety = 4.6 OK

Analyzing the stresses in the guy/coupler extrusion:

Tensile load in the cable: $L_{cable} := 435 \cdot lbf$ (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:

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

Stress in tab:

$\sigma_{tab} := \frac{L_{cable}}{A_{tab}}$ $\sigma_{tab} = 1.708 \times 10^3\,psi$

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

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

Stress concentration factor = 2.25

$\sigma_{conc} := 2.25\sigma_{tab}$ $\sigma_{conc} = 3.843 \times 10^3\,psi$

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

$FS_{tab} := \frac{\sigma_{alumyld}}{\sigma_{conc}}$ $FS_{tab} = 9.108$ OK

UBC97-LRFD STEEL SECTION CHECK

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

Frame  : 1                Design Sect: PIPE1-1/2SCH40
X Mid  : 0.000            Design Type: Column
Y Mid  : 12.000           Frame Type : Ordinary MRF
Z Mid  : 126.000          Sect Class : Seismic
Length : 252.000          Major Axis : 0.000 degrees counterclockwise from local 3
Loc    : 126.000          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
126.000	-644.682	2990.696	0.000	11.985	0.000	0.000

PMM DEMAND/CAPACITY RATIO

Governing Equation	Total Ratio		P Ratio		MMajor Ratio		MMinor Ratio	Ratio Limit	Status Check
(H1-1a)	0.908	=	0.619	+	0.289	+	0.000	1.000	OK

AXIAL FORCE DESIGN

	Pu Force	phi*Pnc Capacity	phi*Pnt Capacity
Axial	-644.682	1041.542	25887.601

MOMENT DESIGN

	Mu Moment	phi*Mn Capacity	Cm Factor	B1 Factor	B2 Factor	K Factor	L Factor	Cb Factor
Major Moment	4719.904	14515.200	0.850	1.578	1.000	1.000	1.000	1.570
Minor Moment	0.000	14515.200	1.000	1.857	1.000	1.000	1.000	

SHEAR DESIGN

	Vu Force	phi*Vn Capacity	Stress Ratio	Status Check	Tu Torsion
Major Shear	11.985	8714.584	0.001	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  : 372.000           Sect Class : Seismic
Length : 240.000           Major Axis : 0.000 degrees counterclockwise from local 3
Loc    : 240.000           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
    240.000        -405.826   -6002.367      0.000      80.369       0.000       0.000

PMM DEMAND/CAPACITY RATIO
    Governing         Total          P      MMajor      MMinor       Ratio      Status
    Equation          Ratio      Ratio       Ratio       Ratio       Limit       Check
    (H1-1a)           0.778  =   0.353  +    0.424  +    0.000       1.000          OK

AXIAL FORCE DESIGN
                         Pu     phi*Pnc     phi*Pnt
                      Force    Capacity    Capacity
    Axial          -405.826    1148.300   25887.601

MOMENT DESIGN
                         Mu      phi*Mn       Cm       B1       B2        K        L       Cb
                     Moment    Capacity   Factor   Factor   Factor   Factor   Factor   Factor
    Major Moment  -6926.933   14515.200    0.850    1.154    1.000    1.000    1.000    2.370
    Minor Moment      0.000   14515.200    1.000    1.358    1.000    1.000    1.000

SHEAR DESIGN
                         Vu      phi*Vn      Stress      Status          Tu
                      Force    Capacity       Ratio       Check     Torsion
    Major Shear      80.369    8714.584       0.009          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  : 3                Design Sect: PIPE1-1/2SCH40
X Mid  : 0.000            Design Type: Column
Y Mid  : 12.000           Frame Type : Ordinary MRF
Z Mid  : 516.000          Sect Class : Seismic
Length : 48.000           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	-29.225	-6029.184	0.000	-139.216	0.000	0.000

PMM DEMAND/CAPACITY RATIO

Governing Equation	Total Ratio		P Ratio		MMajor Ratio		MMinor Ratio	Ratio Limit	Status Check
(H1-1b)	0.416	=	0.000	+	0.415	+	0.000	1.000	OK

AXIAL FORCE DESIGN

	Pu Force	phi*Pnc Capacity	phi*Pnt Capacity
Axial	-29.225	17885.375	25887.601

MOMENT DESIGN

	Mu Moment	phi*Mn Capacity	Cm Factor	B1 Factor	B2 Factor	K Factor	L Factor	Cb Factor
Major Moment	-6029.184	14515.200	0.850	1.000	1.000	1.000	1.000	1.710
Minor Moment	0.000	14515.200	1.000	1.001	1.000	1.000	1.000	

SHEAR DESIGN

	Vu Force	phi*Vn Capacity	Stress Ratio	Status Check	Tu Torsion
Major Shear	139.216	8714.584	0.016	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:

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

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

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

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

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

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

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

$Concrete_{weight} = 436.4\, lbf$

OVER BURDEN VOLUME:

$Height := 16 \cdot in$

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

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

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

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

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

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

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

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

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

LATERAL RESISTANCE:

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

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

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

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

$Lateral_{resisting} = 533.3\,lbf$

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

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

$Lateral_{friction} = 53\,lbf$

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

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

REINFORCING STEEL:

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

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

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

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:

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

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

Per UBC section 1909.2.2, tensile load:

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

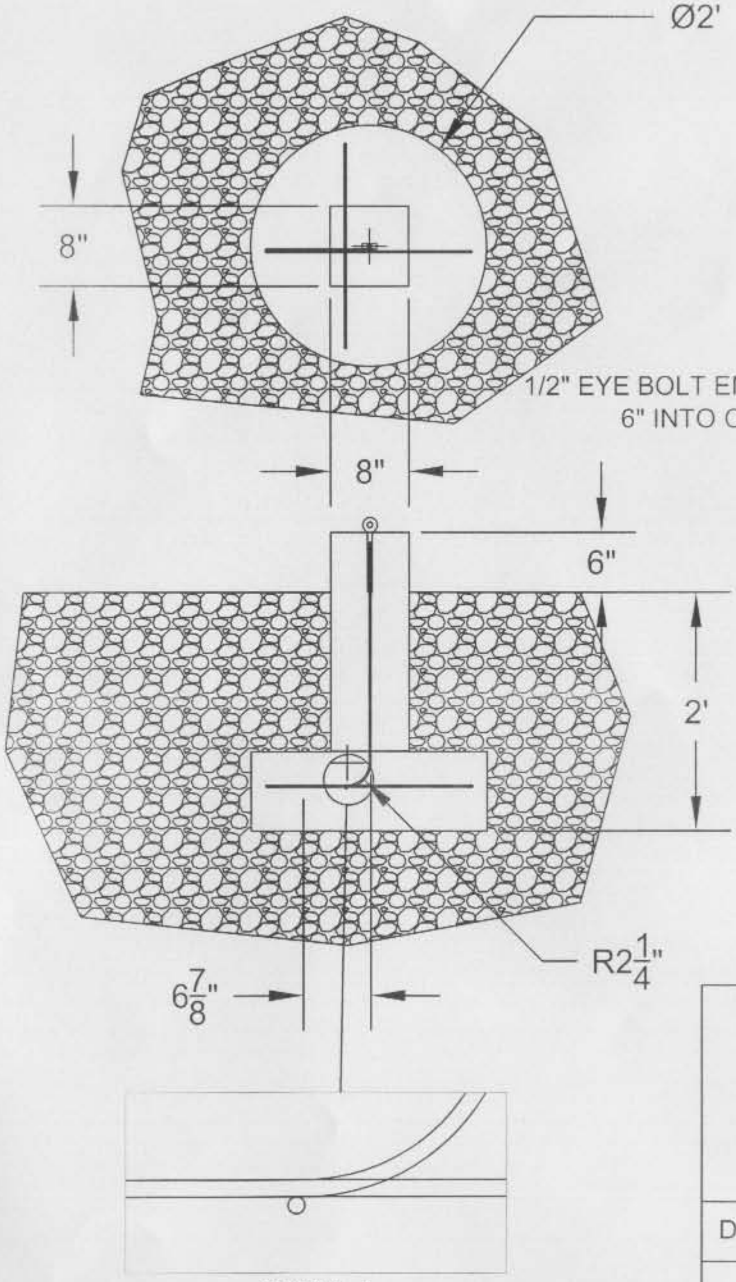
Required Rebar Area:

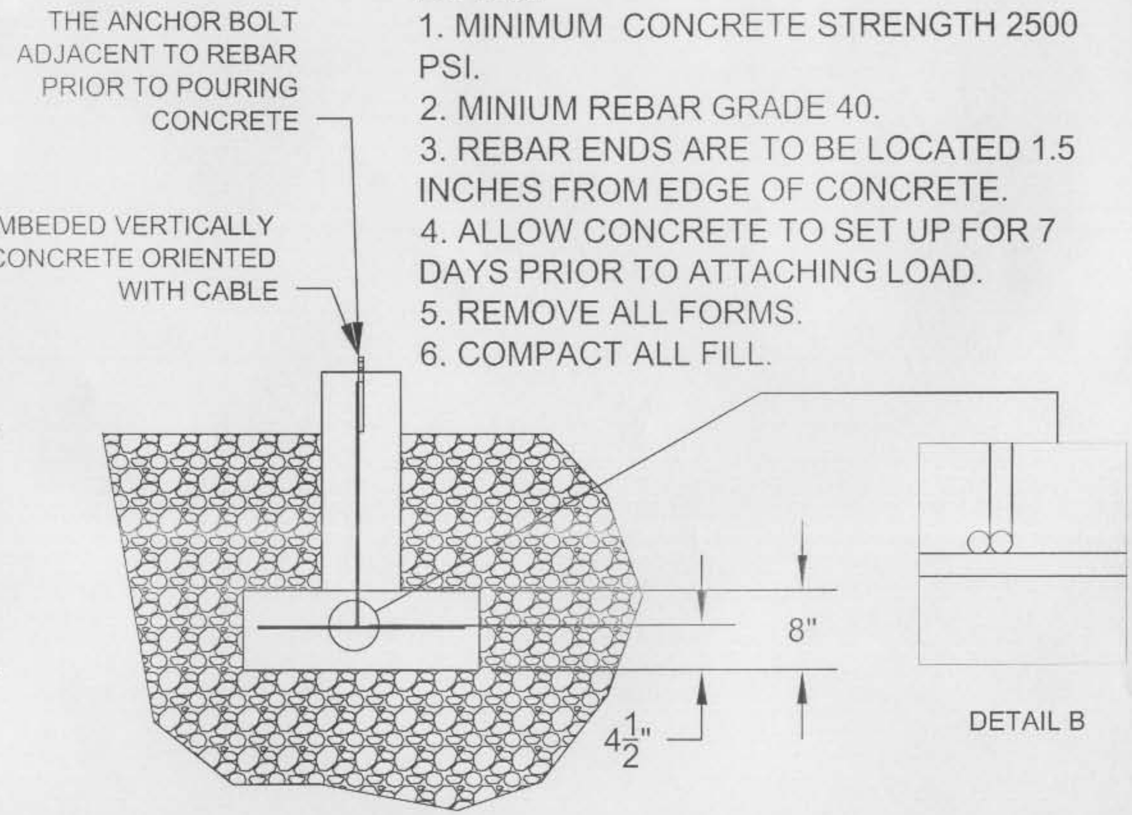
$$A_{rebar} := \frac{T_{UBC}}{40000 \cdot psi} \qquad A_{rebar} = 0.1\,in^2$$

#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

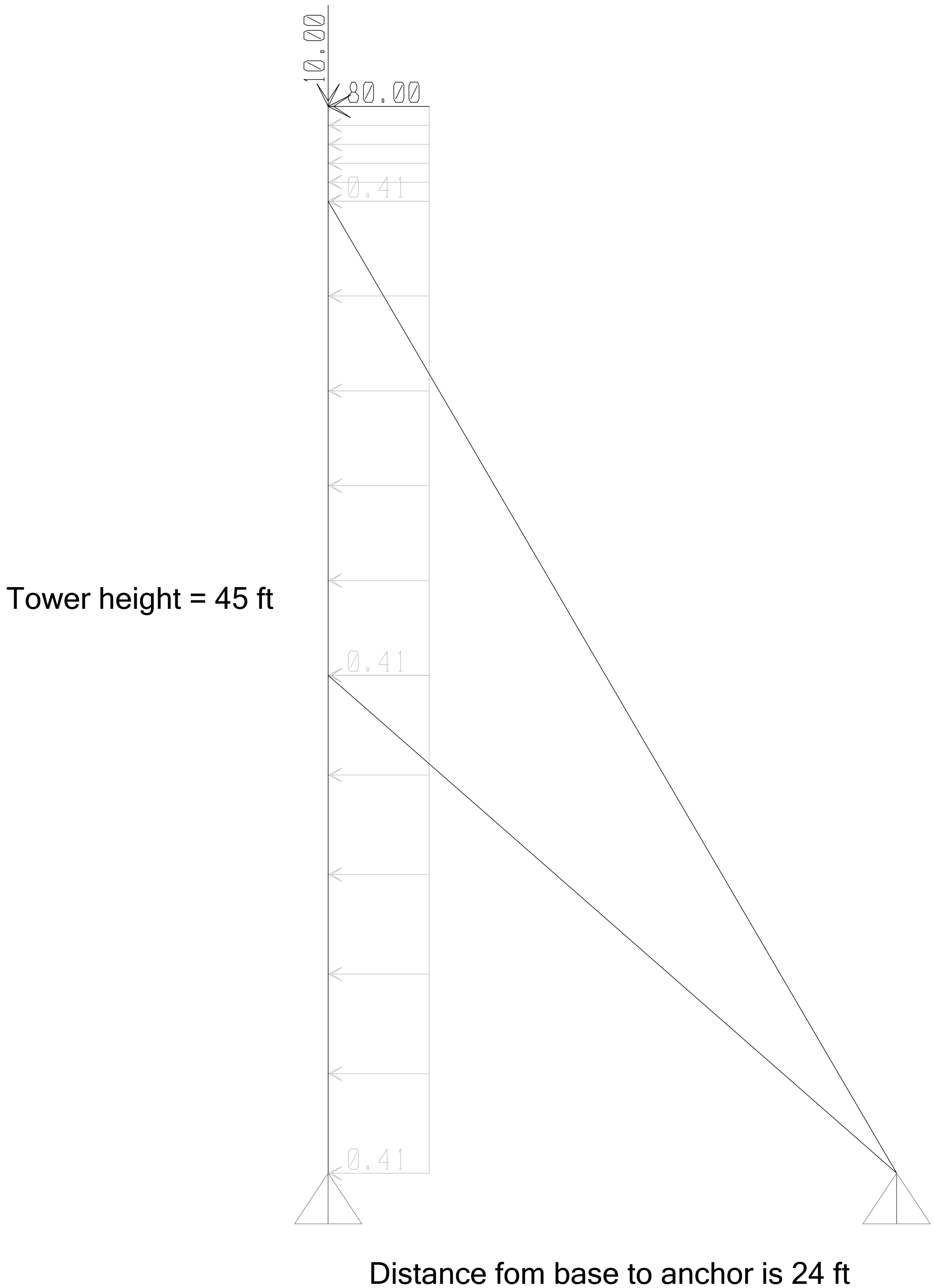
Conclusion:

This analysis is a maximum load condition static analysis only; no fatigue analysis is contained herein. This analysis pertains to the 45 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.

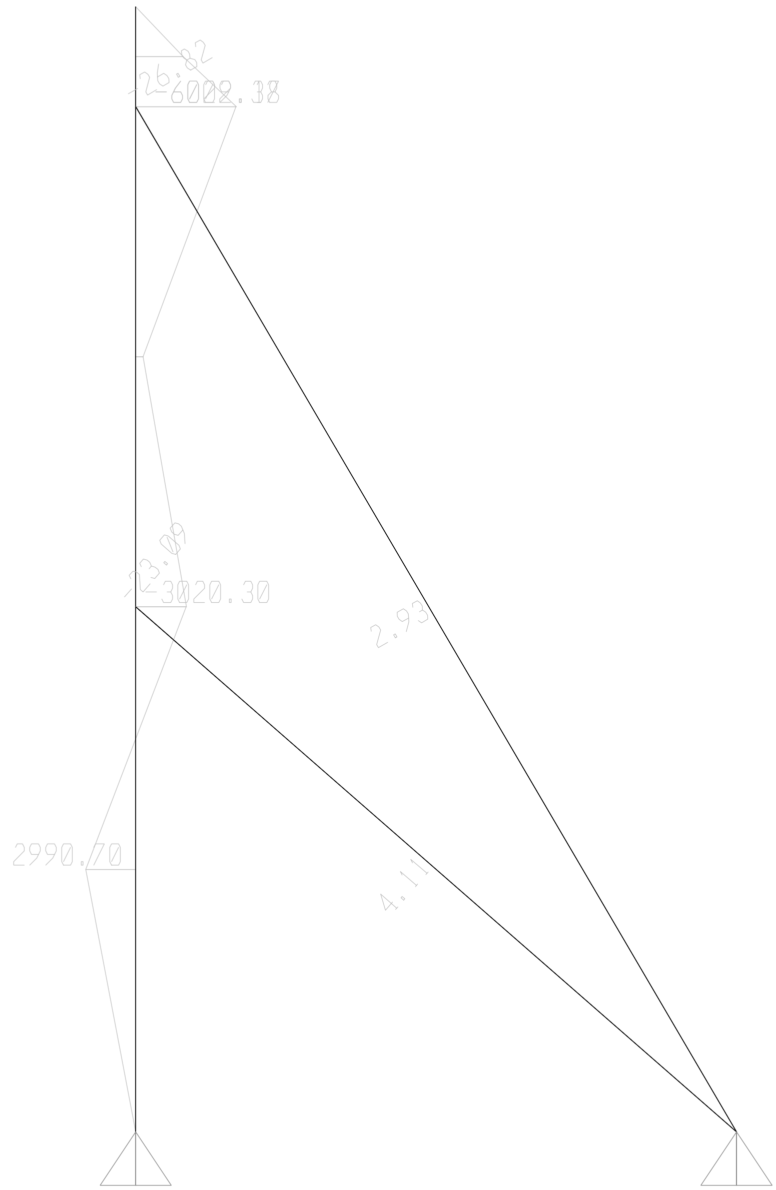
The sections of the tower were checked to see that it meets UBC requirements against buckling which it does. This requirement is the limiting factor for wind speed for the tower.

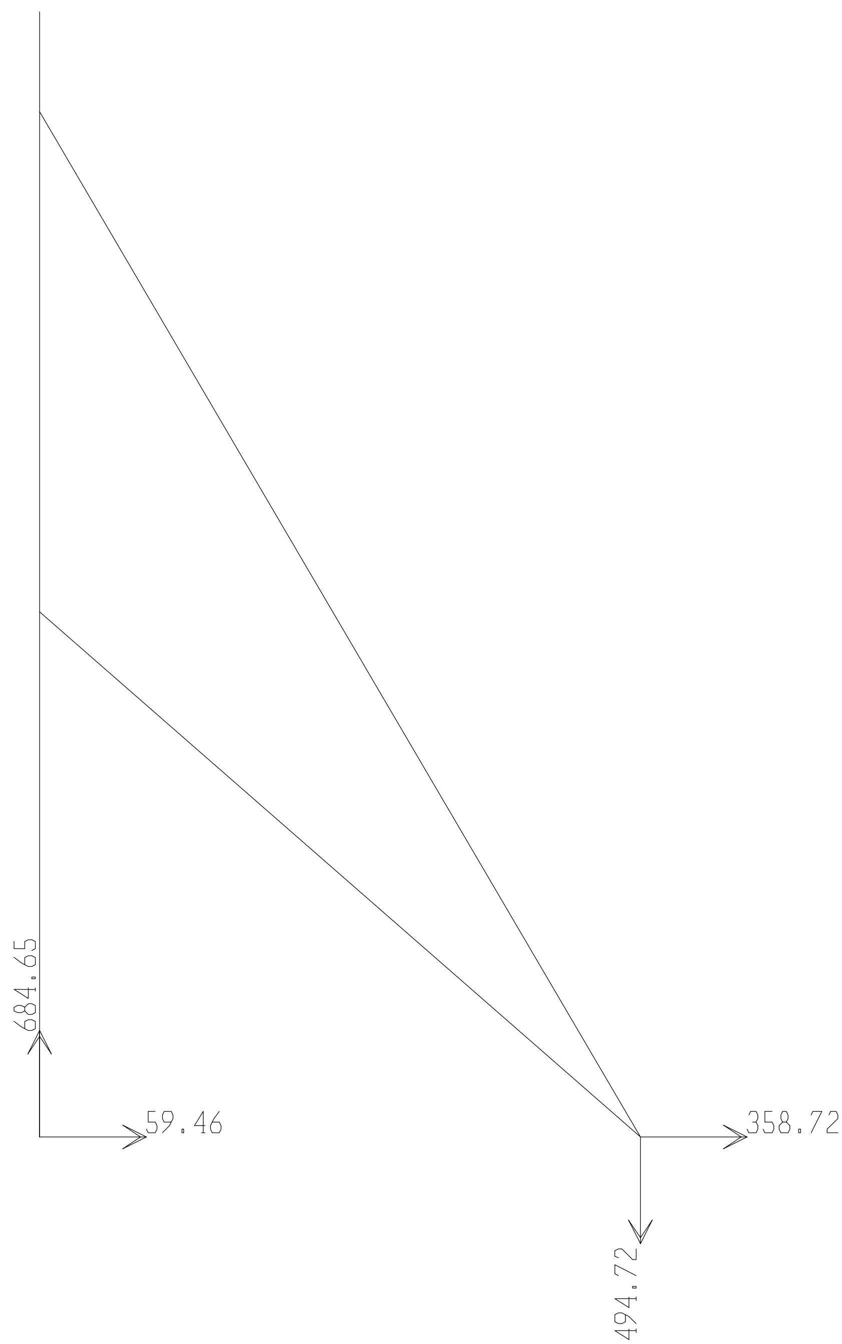
Guy wire stress is maximum in the top guy wire.

Appendix A


10.00
80.00
0.41
Tower height = 45 ft
0.41
0.41
Distance fom base to anchor is 24 ft

SAP2000 v8.1.2 - File:45ft air tower - Axial Force Diagram (DSTL1) - lb, in, F Units


26.82
6002.38
23.09
3020.30
2.93
2990.70
4.11



SAP2000 v8.1.2 - File:45ft air tower - Restraint Reactions (DSTL1) - lb, in, F Units

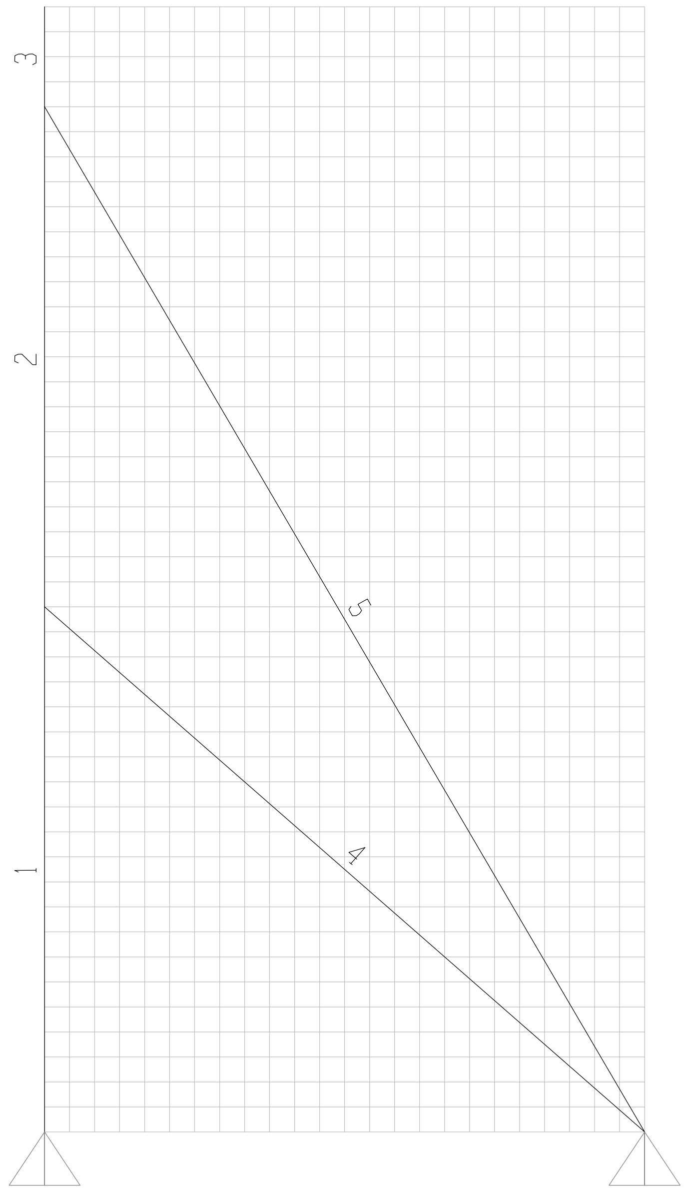

3
2
1
5
4

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

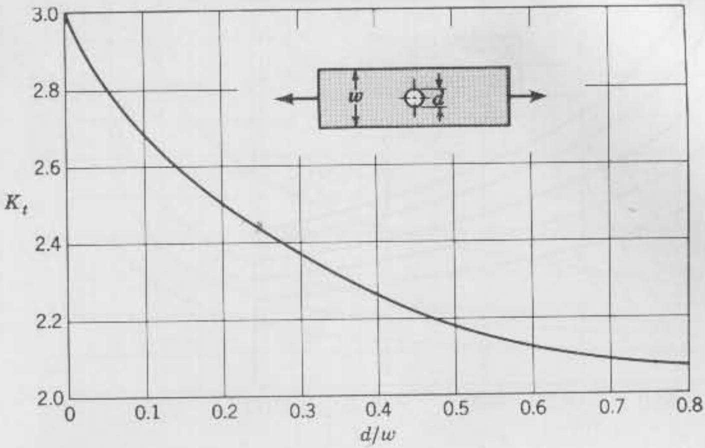


FIGURE A-26-1 Bar in tension or simple compression with a transverse hole. $\sigma_0 = F/A$, where $A = (w - d)t$, and where t is the thickness.

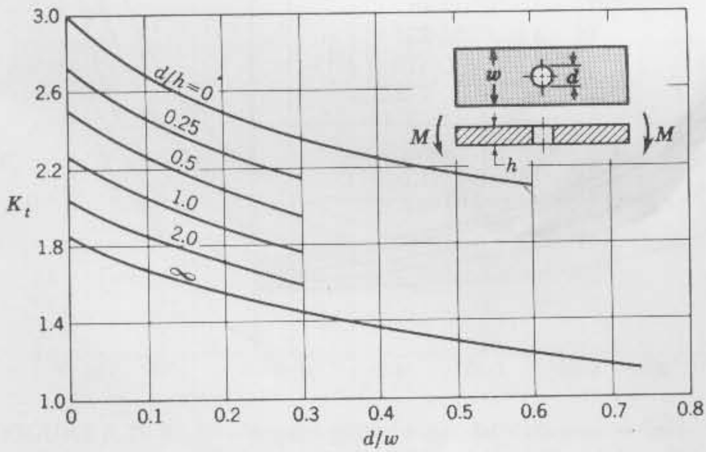


FIGURE A-26-2 Rectangular bar with a transverse hole in bending. $\sigma_0 = Mc/I$, where $I = (w - d)h^3/12$.

* 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.