Southwest Windpower Inc.

Doc. # 0186

Southwest Windpower Inc.

45’ Air Tower Analysis

7/7/03
1. Introduction:

The following analysis covers tower stress and anchor loads for the Southwest Windpower 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:

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

The 1997 UBC design wind pressure equation

\[ P = C_e C_q I_w q_s \]
Wind Pressure ref UBC 1997
Exposure D

\( C_e := 1.62 \)  \( ( \text{taken along full height of tower} ) \)

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:

\( q_s := \frac{25.6 \text{ lbf}}{\text{ft}^2} \)

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

\( I_w := 1 \)

\[ P := C_e C_q q_s I_w \]

\[ P = 33.178 \frac{\text{ lbf}}{\text{ft}^2} \]

The projected area on the tower is equal to:

\( H_{\text{tower}} := 45 \text{ ft} \quad \text{OD}_{\text{pipe}} := 1.9 \text{ in} \)

\( A_{\text{projected}} := H_{\text{tower}} \times \text{OD}_{\text{pipe}} \)

\( A_{\text{projected}} = 7.125 \text{ ft}^2 \)

Wind load on the tower is equal to:

\( L_{\text{wind}} := A_{\text{projected}} P \)

\( L_{\text{wind}} = 236.39 \text{ lbf} \quad L_{\text{ft}} := \frac{L_{\text{wind}}}{45 \text{ ft}} \quad L_{\text{ft}} = 5.253 \frac{\text{ lbf}}{\text{ft}} \)
The projected area of the guy wire is equal to:

\[ L_{\text{guy}} := 565 \text{ in} \quad \text{OD}_{\text{guy}} := .125 \text{ in} \]

\[ A_{\text{guy}} := L_{\text{guy}} \cdot \text{OD}_{\text{guy}} \]

\[ A_{\text{guy}} = 0.49 \text{ ft}^2 \]

Wind Load on .125 in diameter guy wire is:

\[ F_{\text{guy}} := A_{\text{guy}} \cdot P \]

\[ F_{\text{guy}} = 16.272 \text{ lbf} \quad \text{(neglected in analysis)} \]
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 maximum 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: \( L_{\text{cable}} := 435 \text{ lbf} \) (axial loads fig)

Width of tab: \( W_{\text{tab}} := 1.204 \text{ in} \)

Thickness of tab: \( T_{\text{tab}} := .322 \text{ in} \)

Diameter of cable hole: \( D_{\text{hole}} := .413 \text{ in} \)

Cross section area:

\[
A_{\text{tab}} := W_{\text{tab}} \cdot T_{\text{tab}} - D_{\text{hole}} \cdot T_{\text{tab}} \quad A_{\text{tab}} = 0.255 \text{ in}^2
\]

Stress in tab:

\[
\sigma_{\text{tab}} := \frac{L_{\text{cable}}}{A_{\text{tab}}} \quad \sigma_{\text{tab}} = 1.708 \times 10^3 \text{ psi}
\]

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

\[
\text{ratio} := \frac{D_{\text{hole}}}{W_{\text{tab}}} \quad \text{ratio} = 0.343
\]

Stress concentration factor = 2.25

\[
\sigma_{\text{conc}} := 2.25 \sigma_{\text{tab}} \quad \sigma_{\text{conc}} = 3.843 \times 10^3 \text{ psi}
\]

\[
\sigma_{\text{alumyl}} := 35000 \text{ psi} \quad (6061\text{-T6})
\]

\[
FS_{\text{tab}} := \frac{\sigma_{\text{alumyl}}}{\sigma_{\text{conc}}} \quad FS_{\text{tab}} = 9.108 \quad \text{OK}
\]
### UBC97-LRFD STEEL SECTION CHECK

#### Combo: DSTL1
- **Units:** lb, in, F
- **Design Sect:** PIPE1-1/2SCH40
- **Location:** 126.000
- **RLLF:** 1.000
- **HEQ Factor:** 1.000

#### Details:
- **Area:** 0.799
- **SMajor:** 0.326
- **AVMajor:** 0.448
- **AVMajor:** 0.448
- **rMajor:** 0.623
- **IMajor:** 0.310
- **SMinor:** 0.326
- **AVMinor:** 0.448
- **rMinor:** 0.623
- **ZMajor:** 0.448
- **E:** 29000000.000

#### Stress Check Forces & Moments

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<th>Pu</th>
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<th>Mu22</th>
<th>Vu2</th>
<th>Vu3</th>
<th>Tu</th>
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#### PMM Demand/Capacity Ratio

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<tr>
<th>Governing Equation</th>
<th>Total Ratio</th>
<th>P</th>
<th>MMajor Ratio</th>
<th>MMinor Ratio</th>
<th>Ratio Limit</th>
<th>Status</th>
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#### Axial Force Design

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<td>Force</td>
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<td>Capacity</td>
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UBC97-LRFD STEEL SECTION CHECK

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 combo : DSTL1
 frame type : Ordinary MRF

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AXIAL FORCE DESIGN

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MOMENT DESIGN

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SHEAR DESIGN

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### UBC97-LRFD STEEL SECTION CHECK

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

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<tbody>
<tr>
<td>X Mid</td>
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<td>Y Mid</td>
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<table>
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**Area**: 0.799  
**SMajor**: 0.326  
**AVMajor**: 0.448  
**rMajor**: 0.623  
**IMajor**: 0.310  
**SMinor**: 0.326  
**AVMinor**: 0.448  
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### STRESS CHECK FORCES & MOMENTS

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### PMM DEMAND/CAPACITY RATIO

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### AXIAL FORCE DESIGN

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### MOMENT DESIGN

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### SHEAR DESIGN

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<th>Tu</th>
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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 maximum 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 as 150 PSF/ (ft depth)
Friction is taken as .25 X effective anchor weight.

ANCHOR WEIGHT:

Reference drawing R00003 for dimensions.
CONCRETE VOLUME:

\[ V_{\text{base}} := \pi \cdot \text{Base}_\text{radius}^2 \cdot \text{Base}_\text{thickness} = 0.1 \text{m}^3 \]

\[ V_{\text{column}} := \text{Column}_\text{width}^2 \cdot \text{Column}_\text{height} = 0 \text{m}^3 \]

\[ V_{\text{total}} := V_{\text{base}} + V_{\text{column}} = 0.1 \text{m}^3 \]

\[ \text{Concrete}_\text{density} := \frac{150}{\text{ft}^3} \]

\[ \text{Concrete}_\text{weight} := V_{\text{total}} \cdot \text{Concrete}_\text{density} = 436.4 \text{ lbf} \]
OVER BURDEN VOLUME:

Height := 16 in

\[ V_{ob} := \left( \pi \cdot \text{Base}_\text{radius}^2 \cdot \text{Height} \right) - \text{Column}_\text{width}^2 \cdot \text{Height} \]

\[ V_{ob} = 3.6 \text{ ft}^3 \]

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

Weight_{overburden} := V_{ob} \cdot \text{Density}_{ob} \quad \text{Weight}_{overburden} = 269.7 \text{ lbf}

Total_{weight} := \text{Concrete}_{weight} + \text{Weight}_{overburden}

Total_{weight} = 706.1 \text{ lbf} \quad \text{O.K.}

Anchor_{bearing} := \pi \cdot \text{Base}_\text{radius}^2 \quad \text{Anchor}_{bearing} = 3.1 \text{ ft}^2

Soil_{pressure} := \frac{\text{Total}_{weight}}{\text{Anchor}_{bearing}}

Soil_{pressure} = 224.8 \frac{\text{lbf}}{\text{ft}^2} \quad \text{OK}
LATERAL RESISTANCE:

\[
\text{Lateral}_{\text{bearing}1} := \text{Height} \cdot \text{Column width} \quad \text{Lateral}_{\text{bearing}1} = 0.9 \text{ft}^2
\]

\[
\text{Lateral}_{\text{bearing}2} := 2 \cdot \text{Base radius} \cdot \text{Base thickness} \quad \text{Lateral}_{\text{bearing}2} = 1.3 \text{ft}^2
\]

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

\[
\text{Lateral}_{\text{resisting}} := \left( \text{Lateral}_{\text{bearing}1} \cdot 150 \cdot \frac{\text{lbf}}{\text{ft}^2} \right) + \text{Lateral}_{\text{bearing}2} \cdot 300 \cdot \frac{\text{lbf}}{\text{ft}^2}
\]

\[
\text{Lateral}_{\text{resisting}} = 533.3 \text{lbf}
\]

\[
F_{\text{vertical}} := 494 \cdot \text{lbf}
\]

\[
\text{Lateral}_{\text{friction}} := \left( \text{Total weight} - F_{\text{vertical}} \right) \cdot .25
\]

\[
\text{Lateral}_{\text{friction}} = 53 \text{lbf}
\]

\[
\text{Total}_{\text{lateral}} := \text{Lateral}_{\text{resisting}} + \text{Lateral}_{\text{friction}}
\]

\[
\text{Total}_{\text{lateral}} = 586.4 \text{lbf} \quad \text{O.K.}
\]
REINFORCING STEEL:

\[ F_{\text{vertical}} = 494 \text{ lbf} \quad F_{\text{horizontal}} := 359 \cdot \text{lbf} \quad \text{Column width} := 8\cdot\text{in} \]

\[ \tau_{\text{max}} := \frac{F_{\text{horizontal}}}{\text{Column width}^2} \quad \tau_{\text{max}} = 5.6 \text{ psi} \quad \text{OK} \]

\[ \sigma_{\text{max}} := \frac{F_{\text{vertical}}}{\text{Column width}^2} \quad \sigma_{\text{max}} = 7.7 \text{ psi} \quad \text{OK} \]

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:

\[ M_r := 658.2 \cdot \text{lbf} \cdot \text{ft} \quad \text{width}_{\text{center}} := 4\cdot\text{in} \]

\[ \text{Tensile}_{\text{rebar}} := \frac{M_r}{\text{width}_{\text{center}}} + F_{\text{vertical}} \quad \text{Tensile}_{\text{rebar}} = 2468.6 \text{ lbf} \]

Per UBC section 1909.2.2, tensile load:

\[ T_{\text{UBC}} := 1.33 \cdot \text{Tensile}_{\text{rebar}} \quad \text{T}_{\text{UBC}} = 3283.2 \text{ lbf} \]

Required Rebar Area:

\[ A_{\text{rebar}} := \frac{T_{\text{UBC}}}{40000 \cdot \text{psi}} \quad A_{\text{rebar}} = 0.1 \cdot \text{in}^2 \]

\#4 rebar= .196 \cdot \text{in}^2 \quad \text{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.
THE ANCHOR BOLT ADJACENT TO REBAR PRIOR TO POURING CONCRETE

1/2" EYE BOLT EMBEDDED VERTICALLY 6" INTO CONCRETE ORIENTED WITH CABLE

NOTES:
1. MINIMUM CONCRETE STRENGTH 2500 PSI.
2. MINIMUM 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
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
Tower height = 45 ft

Distance from base to anchor is 24 ft
### Table A-26 CHARTS OF THEORETICAL STRESS-CONCENTRATION FACTORS $K_t$\(^*\)

<table>
<thead>
<tr>
<th>$d/w$</th>
<th>$K_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.0</td>
</tr>
<tr>
<td>0.1</td>
<td>1.4</td>
</tr>
<tr>
<td>0.2</td>
<td>1.8</td>
</tr>
<tr>
<td>0.3</td>
<td>2.2</td>
</tr>
<tr>
<td>0.4</td>
<td>2.6</td>
</tr>
<tr>
<td>0.5</td>
<td>3.0</td>
</tr>
</tbody>
</table>

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

* Reproduced by courtesy of the Reynolds Metal Company. Specify sheet, wire, and plate by stating the gauge number, the gauge name, and the decimal equivalent in parentheses. \( 
+ \) Reflects present average unit weights of sheet steel.

### FIGURE A-26-2** Rectangular bar with a transverse hole in bending. $\sigma_0 = Mh/2I$, 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.