DESIGN AND ANALYSIS OF STEEL TOWER ATTACHMENTS FOR DOMESTIC WIND TOWER

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Abstract- *In recent year's renewable energy namely wind and solar is gaining popularity. The wind flow available in Indian terrain is now being utilized effectively to develop wind forms at suitable location based on availability of wind throughout the year. A wind turbine is a device which makes use of kinetic energy of wind and converts it into possible useful electrical energy through a mechanical integrity of mechanical machine elements. Enormous amount of research is picking up in recent years to develop a domestic wind turbine to produce power at low wind speed and meet the consumable require for household purpose.*

In the present work on such small effort is made to arrive at the fixity condition for a domestic wind turbine producing 0.9kw power ranging at low wind speed of 5 to 12m/s. The main intension of the project is to design a fixity at tower bottom and design the guy wires to establish stability in the tower and develop a methodology to understand interface of concrete steel and the bolt pretension in the tower components and successfully arrive at compression test for concrete M20 grade and consider for the analysis interfacing the bolts and guy wires to achieve the reliability for wind tower. The entire work is a blend of design using the standard course and design handbooks for the classical equation considered for design associates with simulation engineering through commercial ANSYS to simulate the performance and evaluation of fatigue life and fixity of the tower at bottom.

Keywords- wind tower, static analysis, I-section of plate, concrete block, gusset plate, FE models

1. INTRODUCTION

The wind energy in the nature is quite easily available and it is enormous. In day to-day technology, wind is an environment friendly and easily available source of energy, which can be used in a commercial scale. Basically kinetic energy is available in wind is in large amount of air moving over the earth's surface. Depending on our end use, blades of the turbine receive the efficiency of converting wind to other useful energy forms greatly depends on the efficiency with which the rotor interacts with the wind stream. It mainly consists of Foundation, nacelle, hub, blades, gearbox, generator, control system. Domestic wind turbines are carding in the renewable power at the low wind speed ranging from 0.5 to 1.5KW. Since wind is a seasonal activity the market is picking up with hybrid solar-wind turbines for continuous requirement of power. Domestic wind turbines are installed on roof top with a tower height ranging from 5m to 15m height. Though the blades are made of composite material with low weight and along with the hub, nacelle put together will weight maximum of 10 to 15kg. At low wind speed ranging 5 to 15m/sec, the force coming upon thetower holding the blade attachment exerts huge amount of bending and compression due to self-weight and tower accessories.

1.1 OBJECTIVES

The objective of this study is to model, both experimentally and analytically, the behavior of domestic wind tower foundations subjected to cyclic loading and to design the wind tower to withstand the calculated forces. To understand the steel concrete interface and loads acting on the tower base and to design the tower with greater stiffness at the roof top, the guy wires are fixed to the tower flange connected to the bottom of wind tower and also to simulate the performance and evaluation of fatigue life and fixity of the tower at bottom using the commercial ANSYS software.

2. METHODOLOGY

The steps involved in designing domestic wind turbine are:

1. Identification and theoretical calculation of loads acting on wind tower base.
2. To perform compression test on concrete block to determine concrete strength.
3. Design of gusset plate, I-section, bolts, guy wire and pin rod to withstand the calculated load as per the standard wind tower design requirement.
4. Creating a 3D model with the obtained dimensions using CATIA software.

5. To check whether the design withstands the calculated theoretical load using analysis software "ANSYS".
6. The installed gusset plate and I section plate at the bottom is analyzed along with concrete.
7. Analysis is done for different cases as with concrete and without concrete.

3. CALCULATIONS

ASSUMPTIONS

1. The tower base is under pure hinged condition.
2. UDL due to wind flow, tension in guy cable, weight of hub, nacelle, rotor and self-weight of tower are the forces acting on tower. All other forces are negligible.
3. The tower is uniform and homogeneous.
4. Weight of hub, rotor and blades are assumed as 15kg

Design wind speed, **$V_Z = V_b K_1 K_2 K_3 K_4$**

Where, V_b = 33m/s. (Normal wind speed in Bangalore)

K_1 =0.94 (Building and structures presenting a low degree of hazard to life and property in the event of failure, such as isolated towers in wooded areas, farm buildings other than residential buildings, etc.)

K_2=1.09. (Terrain category1 Class-A)

K_3=1.0. (For the slopes greater than 3 degree)

K_4 =1.0 (structures other than post cyclone importance and industrial structure)

Hence V_Z becomes,

$V_Z = 33\times0.94\times1.09\times1\times1$

$$V_Z = 33.82 m/s.$$

Design wind pressure, **$P_Z = 0.6V_Z^2$**

$P_Z = 0.6\times33.82^2$

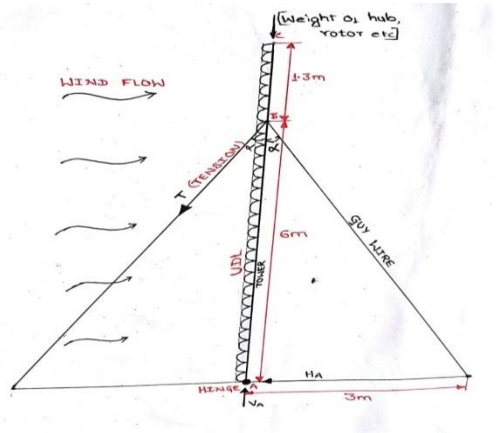
P_Z =686.275 N/m^2

By taking diameter of tower as 101.86mm,

$P_Z = 686.275\times0.1018$

P_Z =69.9 N/m

$$P_Z = 0.0699 \text{ KN}$$



From drawing of tower, $\alpha = \tan^{-1}(\frac{3}{6})$ =26.57

$\Theta = 90-\alpha$

$$\Theta = 63.43$$

Resolving of force.

$$T = 0.695 KN$$

Due to pretention in cable, tension is increased by 15%.

T= 0.695 + (0.15×0.695)

$$T = 0.798 \text{ KN}$$

$$V_A = 1.01 KN$$

$$H_A = 0.154 KN$$

3.1 Self-weight of tower

Density of steel =7.60g/cm^3

Outer diameter of tower =10.184cm

Inner diameter of tower =9.794cm

Area of tower = $(\pi (d_0^2-d_i^2))/4$ =6.27cm^2

Height of tower =730cm

Weight of Hub, rotor and blades = 15kg

From the equation,

$$\textbf{Density} = \frac{\textbf{Mass}}{\textbf{Volume}}$$

$$P = \frac{M}{V}$$

$$7.6 = \frac{M}{6.270\times730}$$

$$M = 34785.96g$$

$$M = 341.24N$$

Total vertical weight on PIN ROD = Self weight of tower + Weight of hub, rotor and blades + TsinΘ

=341.24 + (15×9.81) + 713.9

=1202.3N

Total horizontal force on PIN ROD = (0.0699×7.3) - T cosΘ

= 510.27 - 357

=153.27N

3.2 Calculations done on compression test.

To check the strength of concrete which has to be interfaced with steel attachments for the extra strength to the base of the wind tower.

Size of the cube =150mm x150mm x 150mm

Volume of the specimen =6× 0.15× 0.15× 0.15× 1.3 =0.026m^3

(Since wastage during experimentation, the volume should be increased by 30%)

Density of concrete = 2400kg/m^3.

WKT, ***MASS = DENSITY × VOLUME***

Also by mixed proportion, 1+ 1.5+ 3 = 5.5

Hence mass of cement = $\frac{1}{5.5}$ × 2400× 0.026 = 11.24 kg

Mass of sand = 1.5×11.24 = 16.86kg

Mass of course aggregate = 33.72kg

Since, $\frac{WATER}{CEMENT}$ ratio is 0.5.

Mass of water = 0.5× 11.24 =5.62kg

3.3 Compression test results

The mean design strength of the concrete cube =16.5N/ mm^2 (7 days)

Average compressive strength of the concrete cube =23.5N/mm^2 (28 days)

At various ages the compressive strength of the concrete
Concrete strength increases with the age.

The following table illustrates the strength of concrete at various ages in comparison with the strength at 28 days after casting.

Table –1: Strength of Concrete

Age	Strength per cent
1 day	16%
3 days	40%
7 days	65%
14 days	90%
28 days	99%

At 7 days and 28 days the compressive strength of different grades of concrete is as shown in the following table

Table-2: At 7 days and 28 days the compressive strength of different grades of concrete is as shown in the following table

Grade of Concrete	Minimum compressive strength N/mm^2 at 7 days	Specified characteristic compressive strength (N/mm^2) at 28 days
M15	10	15
M20	13.5	20
M25	17	25
M30	20	30
M35	23.5	35
M40	27	40
M45	30	45

4 CADD MODELS

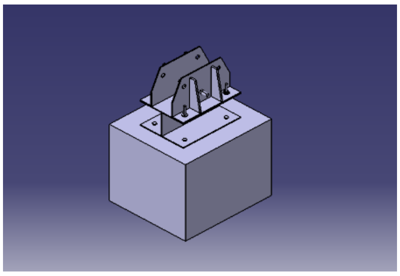


Fig-1 Isometric view of tower foundation without concrete

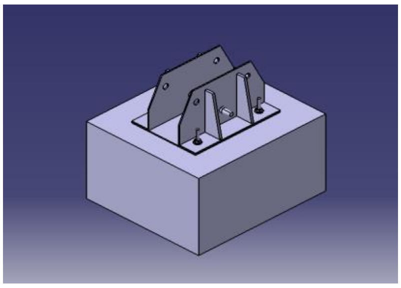


Fig-2 Isometric view of tower foundation with concrete

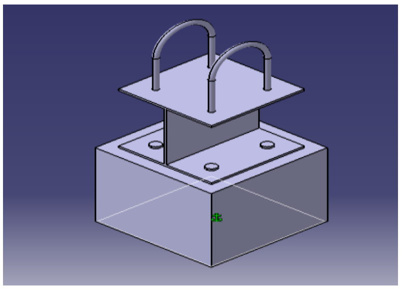


Fig-3 Isometric view of guy wire foundation without concrete

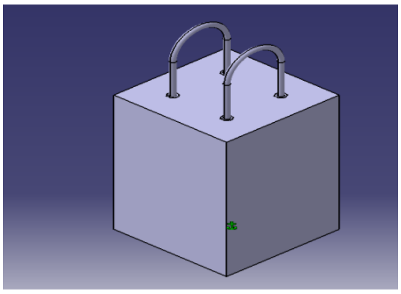


Fig-4 Isometric view of guy wire foundation with concrete.

4.1 ANALYSIS OF MODELS

Materials used: M20 grade concrete and structural steel

Once the models of foundation are done in CATIA software they are saved in stp format so that it can be inserted in ANSYS workbench for further analysis.

Basic steps involved in solving problems in Ansys are given below: -

Invent or model open. Ansys WB is started from inventor menu bar and linked to CAD geometry. Ansys Simulation takes the Inventor or Design Modeller model. Material of each (relevant) part defined and Engineering Data input for each material. Contacts between (relevant) parts defined & type of contact selected. Mesh of Finite Elements defined. Coordinate systems (defined if necessary).

1. Supports defined.
2. Loads defined.
3. Types of Solution defined.
4. Model is solved.
5. Results are reviewed.

Analysis of Gusset Plate without concrete

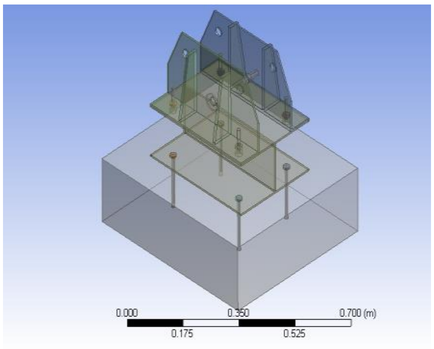


Fig-5 Model generated in Design Modeler

The above figure is a model generated in design modeler and it is an assembly of all the parts like plates, nuts, bolts gusset plates etc.

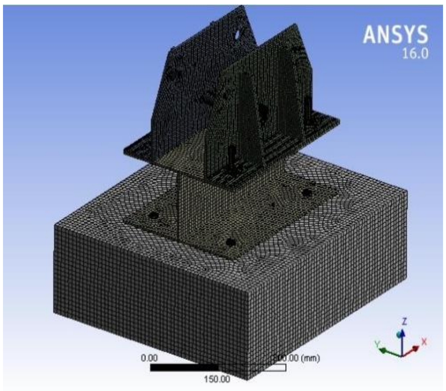


Fig-6 Meshed view of the model

Meshing has been done same for both with concrete and without concrete with same type of connections and element size has been given same.

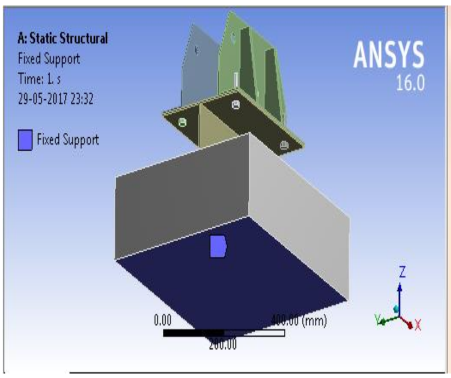


Fig-7 Fixed support provided at the bottom.

In the above figure it is shown that support is provided at the bottom which is fixed in order to give fixity at the tower bottom.

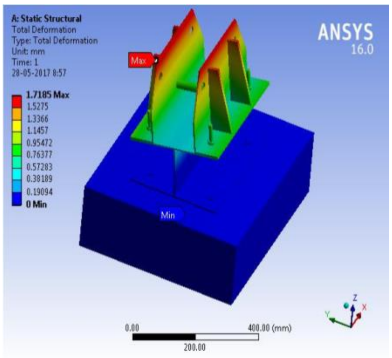


Fig: 8 Total deformation of Gusset plate assembly without concrete for pretension.

The above figure shows that gusset plate foundation without concrete subjected to loading under static structural with total deformation of 1.7185 maximum deformation which is safe for foundation.

Analysis of the gusset plate with concrete

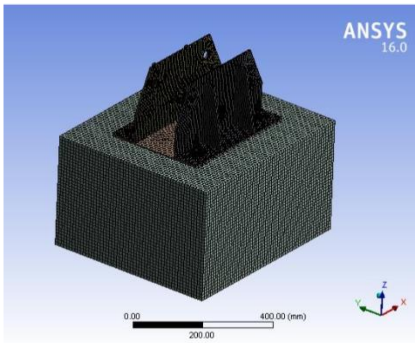


Fig-8 Meshed view of the assembly

In the above figure fine meshing has been done with element size of 10mm for concrete, 8mm for I section and 3 mm for bolts. Fine meshing allows for better application of loads and loads will be applied throughout the material.

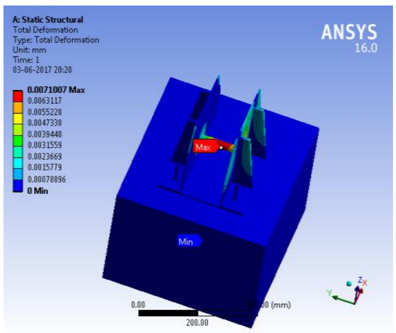


Fig- 9 Total deformation of Gusset plate assembly with concrete of 3000N preload.

The above figure shows that gusset plate with concrete subjected loading under with total deformation with minimum and maximum

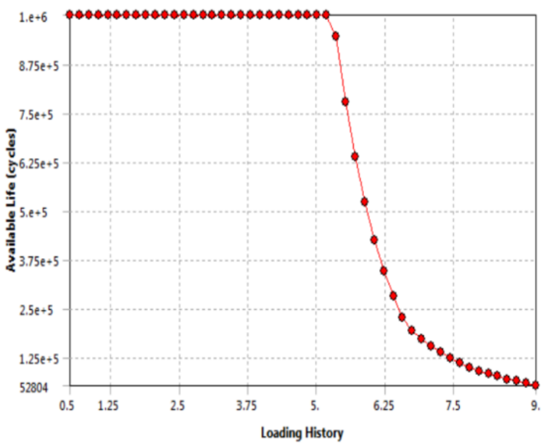


Fig-10 Fatigue sensitivity curve for gusset plate assembly with concrete.

Analysis of guy wire foundation without concrete

The procedure involved in solving the guy wire foundation without concrete is same as above. Specifications given in analyzing this assembly are given below.

Material: - Structural steel, concrete.

Type of connection: - Bonded.

Mesh: - Initially all parts are meshed using Hex Dominant method. Then each body is again meshed using sizing method. Element sizes given for different parts are

1. Concrete=10mm
2. I-section=8mm
3. Bolt, U-bolt=3mm
4. Support: - Fixed support at the base of the concrete block
5. Force on U-bolt: - Horizontal force=178.4N, vertically upward force=356.7N on both clamps
6. Bolt pretension: - 3000N.
7. Fatigue analysis type:- stress life based
8. Mean stress theory:- Goodman method
9. Stress component used for fatigue analysis:- Equivalent von misses stress

Same results will be generated even for this assembly.

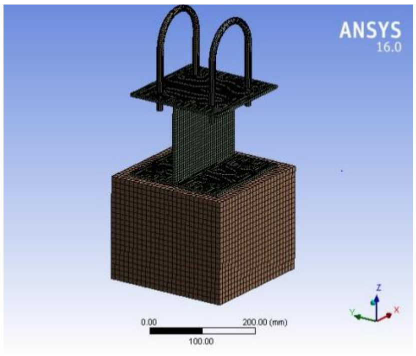


Fig-11 Meshed view of guy wire foundation without concrete

The above figure shows the guy wire foundation analysis under meshing without concrete. Here the observation is made to check how the foundation reacts to the loads calculated without the concrete and application of loads for material with finer meshing for concrete, I section, and U Bolts.

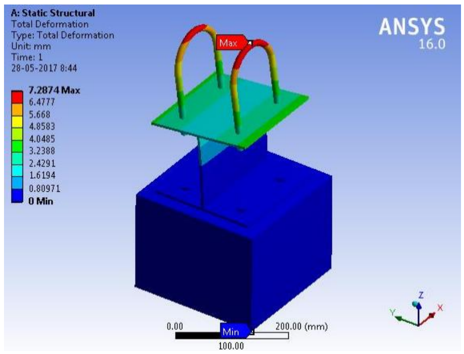


Fig-11 Total deformation of Guy wire foundation without concrete 3000N preload.

In the above figure total deformation of the guy wire is shown and deformation obtained is negligible and the foundation design is safe. Maximum and minimum deformation is as shown in the above figure.

Analysis of guy wire foundation with concrete

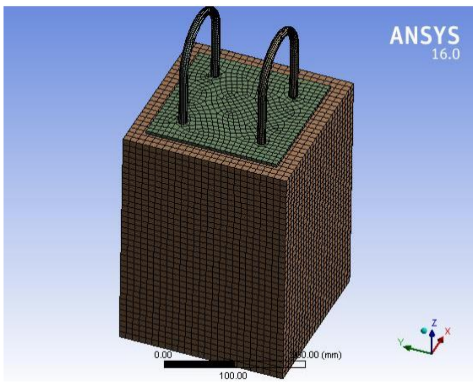


Fig: 12 Meshed view of guy wire foundation with concrete

The meshing of parts can be done by various methods. Initially all parts are meshed using Hex Dominant method. Then each body is again meshed using sizing method. This is done in order to get perfect meshing. Element sizes given for different parts are as follows.

1. Concrete=10mm
2. I-section=8mm
3. Gusset plate=5mm
4. Pin rod, nut, washer, bolt=3mm

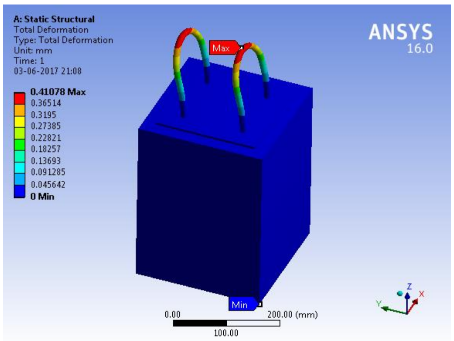


Fig: 13Total deformation of Guy wire foundation with concrete 3000N preload.

Guy wire helps the tower foundation with better stiffness along with this it is subjected with pretension of bolts for better preload for bolts with pretension of 3000N and deformation is negligible as shown in figure.

S-N CURVE:

Table-4: Stress and No. of cycles available in ansys.

	B	C
1	Cycles	Alternating Stress (MPa)
2	10	3999
3	20	2827
4	50	1896
5	100	1413
6	200	1069
7	2000	441
8	10000	262
9	20000	214
10	1E+05	138
11	2E+05	114
12	1E+06	86.2
*		

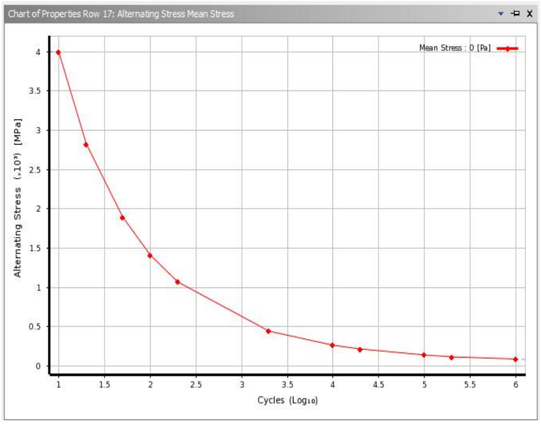


Figure: 14 S-N curves available in ANSYS

A SN-Curve is a plot of the magnitude of the alternating stress versus the number of cycles to failure for a given material.

5. RESULTS AND DISCUSSIONS

The preload which is calculated for M12 bolt, cause large amount of deformation and stress concentration. The calculated preload is practically not possible to apply on the bolts. Because, as labor can provide maximum load range of 8 to 10 kg. But as per calculated preload the labor should put 31kg of load during tightening. If he tries to put 30kgs of load then the concrete ends up with cracks. So, that the pretension given to the bolt is taken as 3000N, which is equal to around 8kgs.

The compression test conducted on M20 concrete provides the compression strength of concrete. By the result of compression test one can understand that the compression strength of concrete used in roof top tower foundation is 23.5N/mm^2. That means for one mm^2 of area, concrete can bear 20N of compressive load coming upon it.

The results of models which are analyzed by ANSYS software is divided into four cases as below:

CASE-01: The gusset plate without concrete.

1. Total deformation = 1.7178mm.
2. The equivalent (Von-mises) stress = 155.84MPa.
3. Safety factor = 15
4. Life = 1e6 cycles.

CASE-02: The gusset plate with concrete.

1. Total deformation = 0.0071007mm.
2. The equivalent (Von-mises) stress = 26.364MPa.
3. Safety factor = 15
4. Life = 1e6 cycles.

CASE-03: The U-bolt without concrete.

1. Total deformation = 7.2874mm.
2. The equivalent (Von-mises) stress = 122.7MPa.
3. Safety factor = 15
4. Life = 1e6 cycles.

CASE-04: The U-bolt with concrete.

1. Total deformation = 0.41078mm.
2. The equivalent (Von-mises) stress = 85.697MPa.
3. Safety factor = 15
4. Life = 1e6 cycles.

From all above results one can arrive to the conclusion that, the presence of concrete throughout the structure cause decreases in deformation and stress concentration to a greater extent.

From S-N graph the life of gusset plate assembly with full concrete at tower foundation has infinite life and the life of U-bolt assembly with full concrete at guy wire foundation has a life of 1e6 cycles. The infinite life means, the foundation can withstand more than 10^6 loading cycles. At any cycles more than 10^6 the foundation is going to fracture.

6. CONCLUSION

The load coming upon the towers are calculated and shear force diagram and bending moment diagrams are plotted. The diagrams will provide the information about the indication of more bending area on tower and presence of maximum shear force on tower.

Along with the UDL due to wind, tension in guy wire, reaction at hinge, the tower also has the force due to self-weight. Hence self-weight of tower is also calculated.

The theoretical pretension for M12 bolt is calculated. The obtained pretension results in more stress concentration and more deformation on structures. Hence pretension is taken below theoretically calculated pretension.

The compression test on concrete shows the compression strength of concrete. Hence compression test is conducted on M20 concrete.

The deformation and stress values are very less in the full concrete cases. But the structure without concrete allows more stress and large deformation of structures.

The S-N curve clearly indicates the life of the structure at foundation of tower.

All structures are having safety factor of 15. Hence the design of foundation is safe.

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