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Modal Analysis of Prestressed Concrete Structural System for Wind Turbine Tower

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Abstract

The wind is almost seasoned and efficient of all renewable energies. The wind turbine tower (WTT) with a horizontal axis. It supported on steel, concrete, pre-stressed, hybrid, tower. As the turbine size grows up, the is heightened to generate spadesful of electricity power. The hybrid tower consists of pre-stressed concrete in the bottom and steel at the top. The parts of the steel tower have to be reasonably rigid, this design requirements raise the cost of a construction lifetime and decrease maintenance condition. To solve and improve this problem, a new proposed of the prestressed concrete (PC) structural system for the horizontal axis (WTT). The introducing tower is designed as an octagon section with internal ribs in the bottom along the hight of the tower with reducing in dimensions at different hight. The aerodynamic principle ware considered in optimizing the transverse profile of the tower. 100 m height of the tower system for the 3.6-megawatt turbine was designed using FE software (ANSYS).

Keywords: concrete structures; tall building; horizontal axis wind generators; Prestressed techniques; tower systems of the wind turbine; finite element analysis; ANSYS.

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1. Introduction

A wind turbine's maximum output power can be determined in from the energy

transformation law:

$$\rho = 1/2 \cdot \rho \cdot A \cdot v^3 \cdot cp. \quad (1)$$

Where:

ρ = air density

A = area sweep,

v^3 = speed of the wind

c_p = Power coefficient

The power value is a maximum power allowed for the generator installed and it should be included in the control system that this power is below high wind [1] . The cause of increasing tower size is the need to increase the output of electric power. It's required in the strength and stiffness to enhance structure load capacity, which will cause an increase in the dimension of the tower sections [2]. Concrete is a competitive choice for towers, as concrete towers have more advantages than steel towers, ease in erection and analysis, fewer maintenance cost, good dynamic behavior and best transport option[3]. The biggest problem with steel (WTT) is that the maximum capacity of wind farms is reduced. The main problem with conical steel (WTT) is the maximum diameter of onshore (WTT) is limited to transportation issues: in general, the large diameter permitted to circulate on roadways it's less than 4.5 m, due to free height of the bridges. Reference [3] studied A new support structure system of pre-stressed concrete (PC) wind-turbine support system with octagon tower sections of the wind-generators support system that proposed with internal stiffeners on all sides. The findings of the research in an optimized design in the condition of a (PC) tower and the principle design of the initial pre-stressed force in the tower. It appears that the price decreased by fifty percent for a totally optimized tower. The Research resulted is lightweight, reduce the construction duration and maintenance expenses.

Reference [4] proposed a system of a triangular section and consists of a column for all corners of the cross-section. The hight rise structure has an aerodynamic transverse section to decreasing the area exposed to wind force, therefore reducing the overall weight and straining actions applied, for 3.6 megawatts the different heights of hup were examined dual their total performance was compared with the traditional conical metallic tower having the same hight. The research resulted that concrete is more economical than steel (WTT) for 3.6 MW.

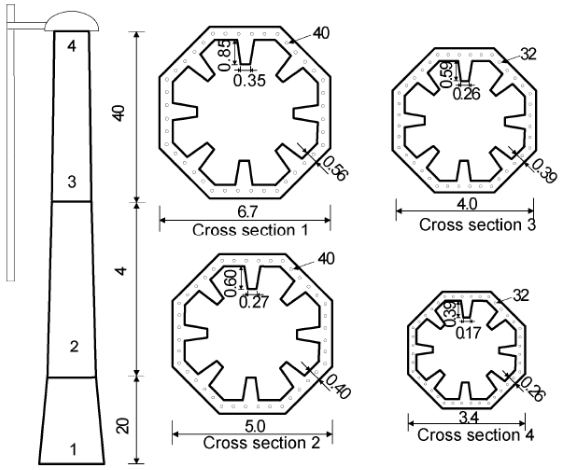

Figure 1: Wang and Ran proposed system

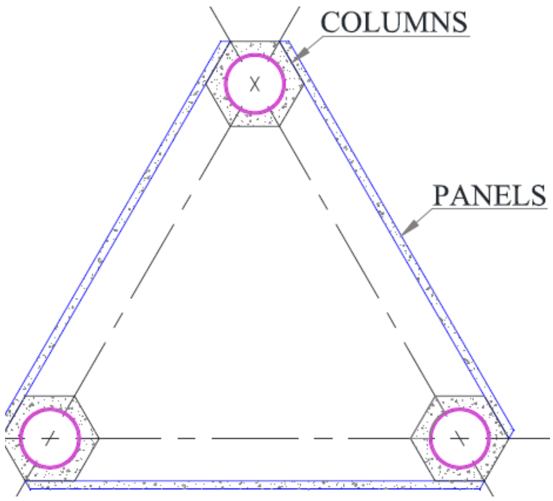

Figure 2: lofty' proposed system

The previous studies established the concrete tower as a more economical and durable choice to steel when the tower for heights exceed 80 m, Therefore it was favored that the concrete (WTT) particularly when the hub height be 100 m, Despite the existence of these studies however it may disregarded for the necessary concerns such as challenge of implementation, quantity of (PC) that required, capacity to make adjustments in the used section, capacity to use easy sections can be modified at the peak and the decrease costs, In this study goals to strengthen two parts of (PC) wind-turbine support structure system. This advance part has much fewer weight sections, and the effect of the construction method on the design, to achieve fast erection time by simply concrete forming and casting by decreasing the complexity of the (PC) and precast concrete sections.

2. Materials and Methods

The design process followed in this study to design the (WTT) is according to ASCE 7-10, the ACI 318 and the IEC (2005), (NREL) (LaNier, M.W., 2005)[5]. Fig. 3 represents the flow chart of the design process (WTT).

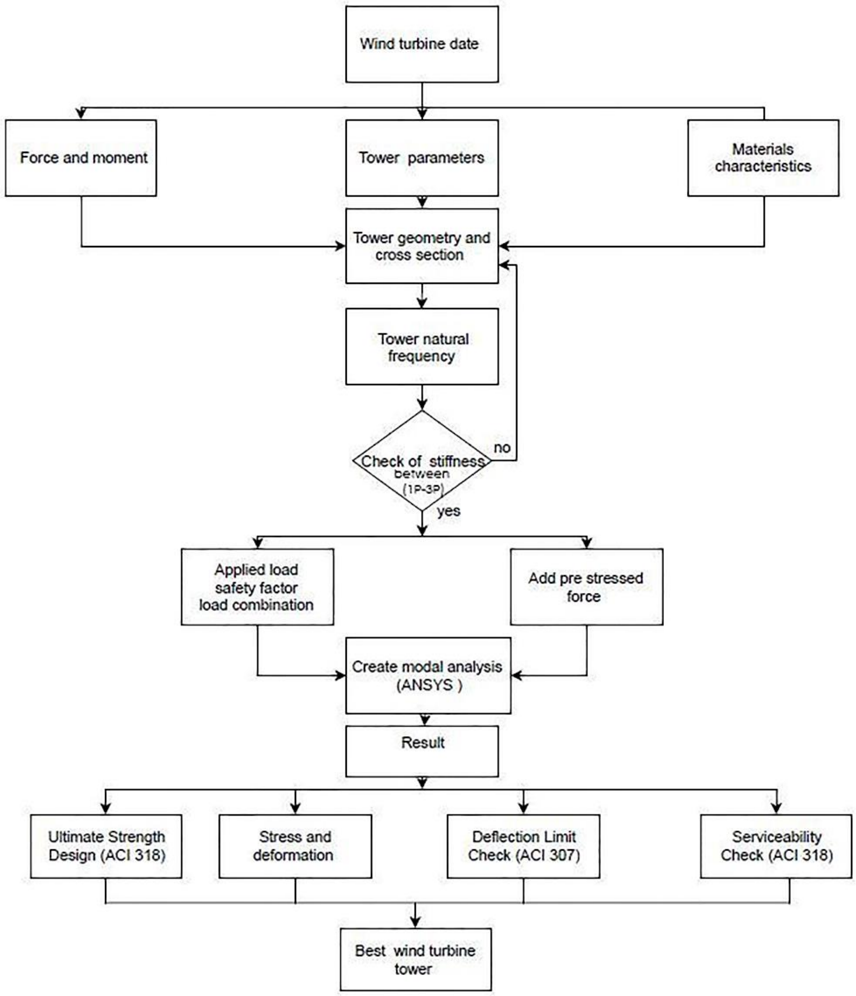

Figure 3: Flow Chart Design Process of Wind Turbine *Tower*

Determination height of the (WTT) based on the wind profile and turbulence are both main parameters and the (IEC class I, II and III) conditions that assist in the choice of the (WTT) height., The criteria of determining the section dimensions of the(WTT) based on the stiffness and strength of tower, The stiffness of (WTT) depends on the rotation frequency (1P) and the frequency of the blade (3P) of the blade, the design of (WTT), where the turbine tower is the first mode shape frequency above (3P) the case called stiff-stiff or below (1P) called soft-soft or above (1P) and below (3P) called soft-stiff, the last case is the most comical and favorable to the designer [6].

In this study the height of the structure system for (WTT) is proposed, The tower is 100m consists of octogen and circular segments, The segments length varies from 10 to 20 in height, The segments are delivered to the location and all those conforming to smaller.

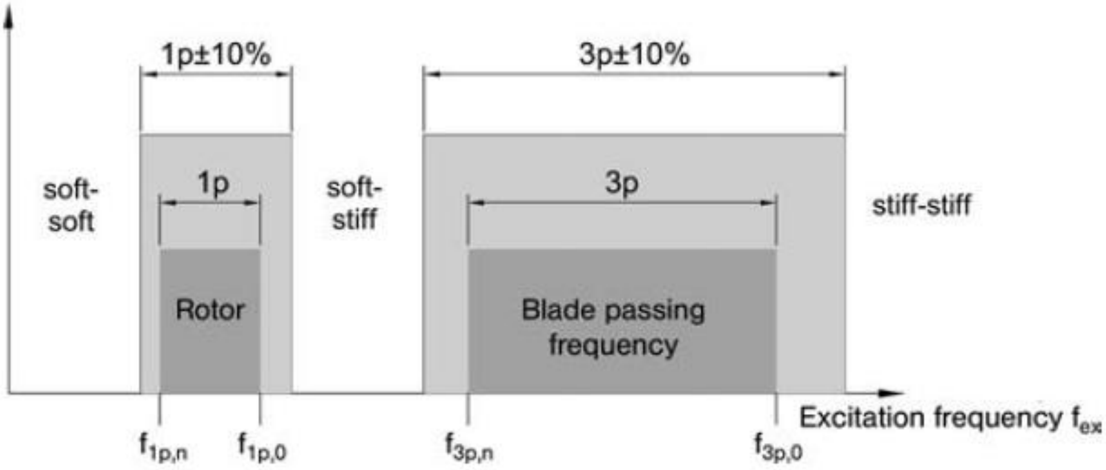

Figure 1: Natural frequency analysis of loadbearing *structure*

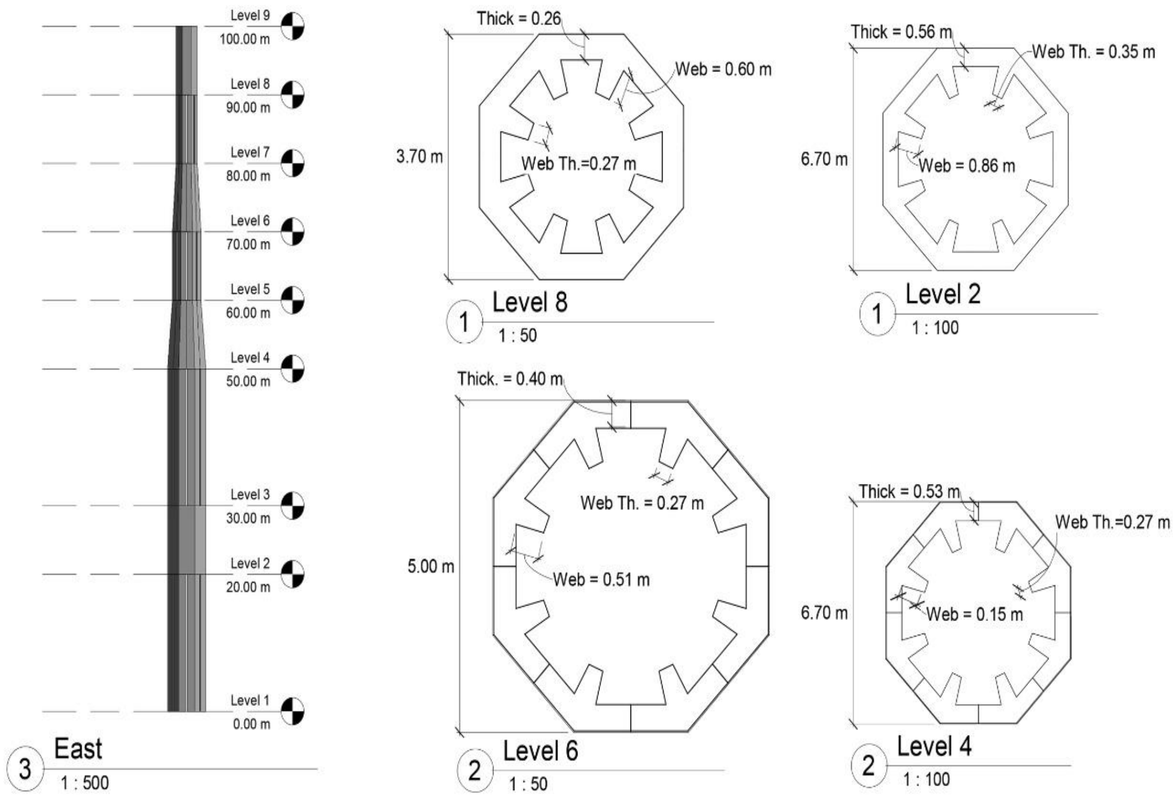

Figure 5: the newly proposed system

The tower was modeled as a fixed cantilever, and the reactions of the generators are applicable to the tipping tower. The service lifetime of the structure is 50 years, the concrete characteristics are FC $\geq$ 60 MPa, ratio of water to cement $\leq$ 0,50, Reinforcement minimum cover = 30 mm, Minimum sheathing cover of (PC) = 40 mm, Typical values of the materials used for construction are fy=500 MPa for steel reinforcement, fps=1860 MPa for prestressing strands. Maximum concrete stresses permitted for quasi-permanent loads are 0.45 fC and regular loads are 0.60 fC. Tendons. IEC sets initial wind turbine specifications and is not meaning to be used a full design [7]. The wind turbine classified into3 categories (Class I, II, III), the classes may be further subdivided into classifications A, B, and C, as shown by the disturbance component of the wind. Wind generators standard groups (IEC, 2005).

Table 1: Standard groups of wind turbines

Wind turbine class	**I**	**II**	**III**	**S**
$\boldsymbol{V_{REF}}$**(m/s)**	50	42.5	37.5	Values specified by designer
$\boldsymbol{I_{REF}}$ **- A**	0.16			
$\boldsymbol{I_{REF}}$ **- B**	0.14			

Table 2: Practical date for 3.5 megawatts Wind generator (M.W. LaNier, 2005)

Rated power	3.5 MW
Rotor Dimeter	108.4 m
Rotor speed	13.2 rpm
Upper component Mass (incl. nacelle, hub and blades)	314912 kg
Tower height	100 m
Wind category	IIB
Average wind speed	10 m/s
Extreme wind speed (E W M)	59.5 m/s
Gust wind speed (EOG)	35.1 m/s

2.1 Direct wind static pressure of the tower

It was determined by ASCE 7- 10 specification:

$$v_z = (\frac{z}{zhub})^{(\alpha\ i)} \times v_{hub} \quad (2)$$

$$q_z = 0.613 \times k_z \times k_{zt} \times k_d \times v^2 \quad (3)$$

$$F_z = q_z \times C_f \times G_f \times A_f \quad (4)$$

To analyze the supporting system, the (WTT) reactions must be determined and then applied on the tower either dynamically or as an amplified static load, The generator (WTT) used in this study rated power at 3.6 M. W, Static turbine loads have been obtained from technical studies published by (N R E L) (Malcolm, D.J. & Hansen, A.C., 2006) & (Lanier, M.W., 2005). The IEC wind conditions that are extreme wind model (EWM) and extreme wind operation gust (EOG). The gust wind speeds for the EWM and EOG models were 59.5 m/s and 35 m/s respectively at 3 seconds.

Table 3: The Wind Turbine Load [5]

	E W M	E O M
Horizontal Force (kN)	1086	1199
Overturn Moment (KN/m)	16767	9913
Twisting (KN/m)	5961	1597
Tower Axial Force (KN)	3155	3129

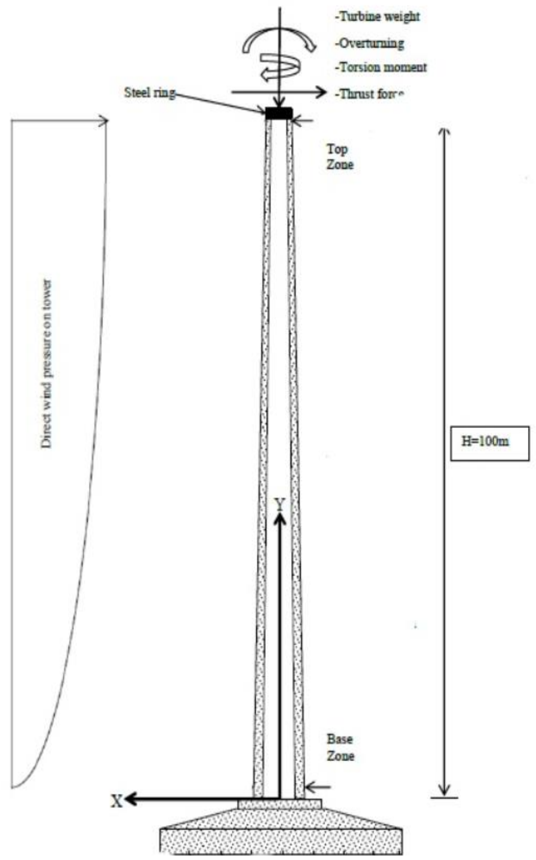

Figure 6: Illustration of Loads Action on Wind Turbine Support System

3. Results and discussion

The use of the finite element method to analyze pre-stressed (WTT), The tower modeled was calibrated to predict and expect the deformation and stress at the tower along its height, the initial pre-stressed force, reaction in the different directions, the natural frequency of the tower, mode shape after applying a prestressed force, the failure mechanism of the tower, and the predicted failure load, The resulted model frequencies were compared a with previously studied models. ASCE gives the load factor ultimate of limit state (ULS) designee 1.6 the use of the finite element method to analyze pre-stressed (WTT), A pre-stressed (WTT) model to calibrated a predict and expect the deformation and stress at the tower along its height, the initial pre-stressed force, reaction in the different directions, ASCE gives the load factor ultimate of limit state (ULS) designee 1.6 factor of safety according to ASCE condition for all loads, wind turbine loads, this safety factor are modified to completely with IEC conditions, The serviceability limit state (SLS) should simulate an operation condition under normal wind condition.

Ultimate load combination :

0.9D + 1.6W + 1.35TWL

Working load combination :

0.6(1.0D + 1.0W + 1.0TWL)

Where:

TWL= wind-induced generator loads,According to ASCE specifications.

3.1 Fundamental Natural Frequency of the Tower

The (WTT) should be designed with adequate separation between the turbine operating frequencies and the tower natural frequencies to avoid any resonance, The previous table and images illustrate a value of turbine frequencies in the different mode shapes and the first frequency of the first mode shape (WTT), this frequency of turbines under optional case is result of harmonic load including (frequencies of rotor operational and frequency of blade). The 3.6 MW turbine rotor the concrete structure for the turbine 3.6 with rotor speed 13.2 rpm for 1P to 3P (0.220 -. 660) HZ of the first frequency of first mode shape (WTT).

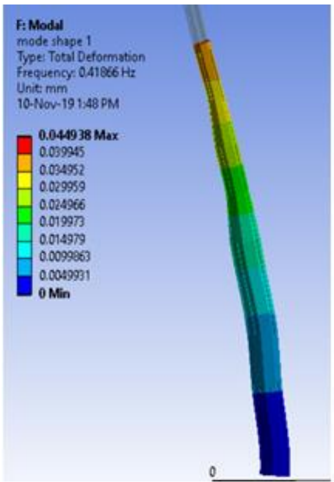

Figure 7(a): Tower Mode Shape

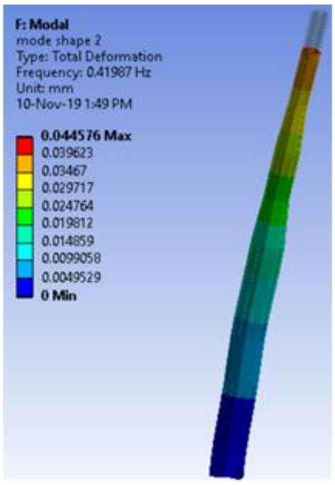

Figure 7(b): Tower Mode Shape

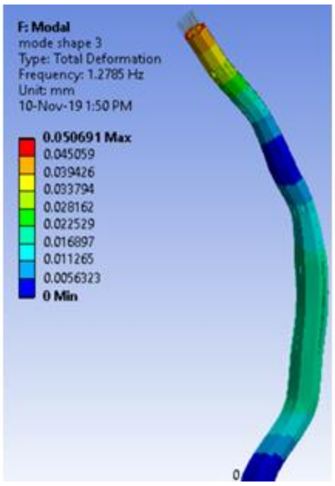

Figure 7(c): Tower Mode Shape

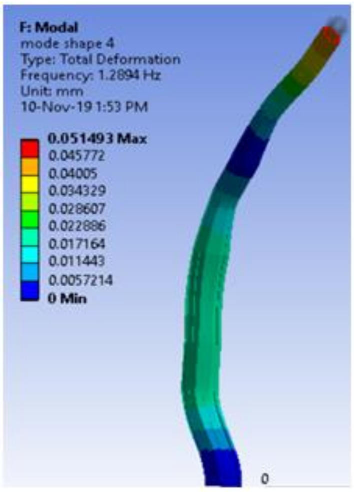

Figure 7(d): Tower Mode Shape

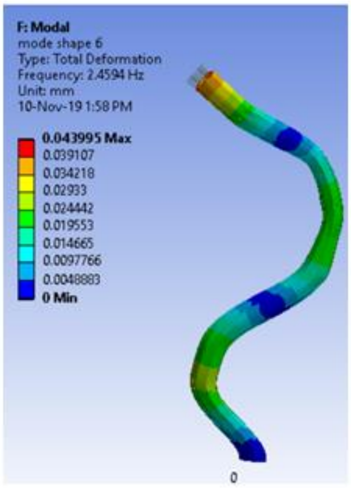

Figure 7(e): Tower Mode Shape

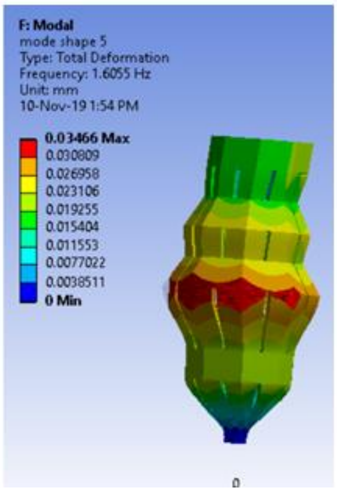

Figure 7(a): Tower Mode Shape

3.2 Tower top deflection

The (WTT) was assumed as a cantilever beam, The tower top deflection will be calculated by applying uniformly distributed loads of the wind with the height of the tower, The calculated results give the deflection of the (WTT) according to fixed free cantilever equation, The top deflection of the tower should be less than 1% of the tower length, The maximum deflection of the (WTT) is founded from the static structural analysis of the tower using ANSYS workbench is 304.35 mm.

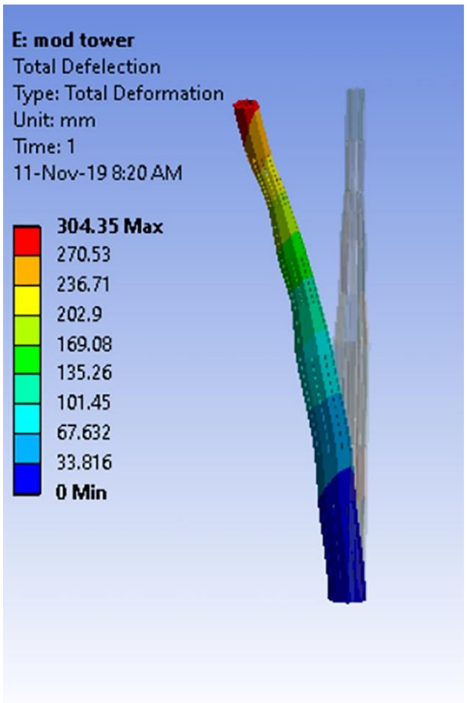

Figure 8: Tower Deflection

4. Conclusion

The suggested structural system is considered an important design feature of the concrete wind turbine tower, providing a focus on (PC) towers and how to reduce the value of pre-stressing due to sustainable loads and wind turbine loads, the(PS) reaction because of turbine reaction on the tower tip and the wind loads along of the tower. The proposed system achieves the development goals and targets by reducing the size, strengthening steel, pre-stressing strength, removing the need for post-tensioning tendons, retaining quick erection time, optimal (WTT) aesthetics and simulation.

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