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DESIGN AND STRUCTURAL ANALYSIS OF WIND TURBINE TOWER

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Abstract - *The wind turbines are used to convert the wind energy into electrical energy. Wind turbines are mounted at the top of the vertical structure called "Wind Tower". Increasing demand of high power generation in is compelling the towers to be made taller and stiffer, so as to catch strong winds at higher altitudes. It mainly focuses on designing a wind tower for Uttar Kannada, the Western Ghats of Karnataka State, which is one of the potential sources of wind energy. The main objective is to find the high strength material for wind turbine tower. Geometric design of the 2MW power generation wind turbine tower is carried out in CATIA V5 and analyzed in ANSYS Workbench 19.2 for structural steel, Alloy steel 4130, and Alloy steel 6150 materials. Structural analysis, modal analysis and fatigue life estimation is performed and results are validated. Hence From the results we can conclude that Alloy steel 6150 is safe and economic for design when compare to other materials.*

Key Words: **Wind energy, Power generation, High strength, CATIA V5, ANSYS Workbench.**

1. INTRODUCTION

As the growth of the economy of the country increases, the energy requirement also increases. Burning of the fossil fuels will affect the environment by releasing greenhouse gas, to avoid the environmental pollution, we need to reduce dependency on fossil fuels, and hence few alternative method of generation power is needed. Therefore, to meet the demand of the power requirement and also being friendly to the environment these renewable energy resources are used for power generation like wind energy, solar energy, tidal energy etc. Wind is the one of the renewable energy resources which pays a major role and freely available resources for the power generation. The cost of the electricity produce from the wind energy has successfully reduced to over the past 15 years in the wind industries. Over the past few decades, the wind industries for power generation had been built all over the world.

Due to the shortage of electricity is getting common in the busy dynamic worlds. Over all about 40% world population has no access between the modern energy services. The demand in the electricity in India is going to be expected three times more than the expected demand over the year 2005 to 2030. In the year 2011, India had new record in installing more than 3GW of new capacity wind towers between the months of January to December. As of September 2014, India total capacity of installed renewable energy accounts for 12.45%, up from 2% in 1995. From the above it is clear that the next few years, we could see major increase in wind farm activities.

1.1 Wind tower failures

As the number turbines towers increases, the number of accidents occurring is also increasing day to day from the survey in the recent decades. From the last 20 year's survey shows that, with an average of 16 accidents per year from 1995-99 inclusive; 48 accidents per year from 2000-2004 inclusive; 108 accidents per year from 2005-09 inclusive, and 155 accidents per year from 2010-14inclusive. As official information releases up to 31 December 2014.

1.1.1 Foundation failure

There are three types of cracking are occurred in the wind tower foundation; one type is the cracking of the mortar grout between the connection flange and the concrete foundation. This type of cracking occurs in the foundation by the negligence in the workmanship and also in poor selection of material. The second type is the cracks which are observed in the high pedestals, i.e. pedestals with a height of about 4 to 8 m. The cracks are caused by poor structural design. This cracks are leads to foundation failure in the concrete steel interface by crack propagation due to the cyclic loading on the tower, further soil bearing force also causes the foundation failure.

1.1.2 Tower failure in flange fillet and welded region

Due to the uneven loading failure occurs in the flange result in bending stress in the fillets, weld, and tower shell. The weld region may fail due to the high bending stress in the fillet region which leads to structural failure.

2. LITERATURE SURVEY

Murtagh, Basu et.al [1] In this paper the authors has studied the vibration of the wind turbine towers effects the soil structure interface in the model. They have identified that the incorporating the flexibility of the soil in the model which determines a considerable amount of damping in the wind tower system. This suggests the calculations of natural frequency that do not consider damping due to soil structure interaction which may lead to the un realistic and un economical design.

Silva, Arora et.al [2] In this paper the authors have discussed on the dynamic analysis of reinforced concrete slender structures. This is based on the nonlinear model with experimental data. Furthermore, optimization of constraints has been transcribed in this model and applied it to the optimal design of reinforced concrete wind turbine towers.

B Gencturk, A Attar et al [3] In this paper the authors have discussed on the design optimization of lattice wind turbine towers subjected to earthquake forces. The selection of height and size of the turbine is one of the key aspects in optimizing the cost of installation wind tower based on the wind farm location. For about 10 towers size and combinations of height is compared and validated based on the cost. The analysis is carried out in the case study of the earthquake region and seismic forces which are also involved in the tower analysis. The obtained results data will provide direct insight on the selection of the optimal tower considering height and size of the turbine despite from the effect of total number of towers in the farm and location.

B Song, J C Wuet.al [4] in this paper the authors have discussed on comparative analysis on dynamic response of wind turbine tower in different sites. In this comparative analysis authors have considered the height of the tower about 50m and 88.5m tall respectively based on the mountain and offshore different types of environmental condition in different sites. By maintaining the Japanese standard behavior of bearing and combinations of loads are analyzed for various kinds of turbine towers. Dynamic response of the structure is studied for higher levels of earth quick conditions based on the height, displacement and quality of the towers. So, from the conclusion we come to know that dynamic response of the structure is majorly affected by height of the tower in different sites. Where if the height increases by 177% then the maximum displacement would get increased by 231%. The largest impact on the structure which are high rise and great in flexibility in the far field seismic waves.

Hani M et.al [5] In this paper the authors have discussed on structural design optimization of wind turbine towers. The main body of the tower is constructed from uniform assembly parts with the effective design constraints like area, height and radius of gyration. Here determination of 5 design optimization methods is tested. The last one is regarding on reduction of vibration level by normal mode method which is applied to obtained force response for different types of excitations in the wind towers.

Umesh K N, Bharath P et.al [6] In this paper the authors have carried out wind tower analyses of the stress, strain and fatigue life behavior of the welded fixture for the bolted ring flange connection of loading were estimated using finite element analysis. The thickness of the shell and number of bolts in the wind tower are optimized in few specific joints in the tower with the objective of reduction in weight and cost of the tower structure.

S Jerath and S Austin [7] In this paper the authors have studied on response of wind turbine towers to seismic loading at different damping ratios. A 65KW wind towers are subjected to lenders earthquake is compared with the results obtained experimentally and ANSYS FEM. The damping ratio of 0.86 is obtained, it is compared numerically and experimental methods with different effects sizes of the turbine, peak acceleration etc. and their response are studied and determined. The maximum Von-misses stress is observed in the base of the wind turbine tower and peak acceleration, maximum deformation is observed on the top of nacelle.

Ajay R.Vaghela and G.S. Doiphode [8] In this paper the authors have investigated on the door opening analysis of wind turbine steel tubular tower. The main aim of the project work is to investigate the load cases in the door opening region where usually creates high stress based on different thickness of the material at the lower tower parts. The door opening in the lower tower is used for the services and maintenance inside the turbine towers. Static structural analysis is done to the door opening section because high stresses are noticed due to the load from the top of tower is determined by using finite element model software ANSYS. Hence, due to the application of high stress development of cracks can be found near the door opening and are visualized by simulation.

C.C. Baniotopoulos, G. Nikolaidis et.al [9] In this paper the authors have carried out a design of large-scale wind turbine towers in seismic areas. For simulation of the wind tower structure response, two models have been created one is linear geometric model of the whole structure and the other is finite element modal of the whole wind turbine tower structure assembly consist of flange connections, door opening, foundation etc. The tower has been designed for the following wind loading and seismic loading conditions by applying material properties and boundary conditions to the tower. An additional investigation is carried out for limit load and buckling analysis for the whole large scale wind towers and there are three methods proposed by Eurocodes for local buckling design have been compared.

Chethan M, Bharath V G et.al [10] In this paper authors have investigated on the structural evaluation of steel adapter and door type ring stiffness in wind turbine tower. The consumption of steel in the wind towers has reached around 3.5 million tons over period of 2007 to 2009. Design optimization of the steel tower is being improved to reduce the overall total cost of the wind turbine tower from 20% to 10% by using different unique assembly technique and also by utilizing different types of high-grade steel. Further investigation is going on the improvement of existing flange to overcome the un avoidable imperfections in the assembly joint.

Bhattacharya [11] In this paper author has studied on the soil structure interaction considering the offshore dynamic properties of the wind tower. From the discussion author concluded that by avoiding resonance conditions considering the effects and type of the soil, the off shore tower majorly depends on the maximum frequency which is observed in the wind tower analysis.

3. PROBLEM DEFINATION

The major difficulties in designing a wind turbine tower which concerns in mutual interaction between the vibration, aerodynamics, aero elastics & controls faced by mediated design loads based on various environmental factors. The overall net load comes from the turbine tower head assembly & these loads are transmitted to the foundation via tower. The fundamental goal of the work is to design an economic wind turbine tower which possesses good strength and structural stability. In this assessment, material optimization is done to the tower by linear structural analysis to find structural safety in the wind turbine tower, finding six initial modes and corresponding Natural frequency by using modal analysis and fatigue life estimation of the wind turbine tower to identify most appropriate material for future investigation.

3.1 Objective

To achieve the successful working stability of wind turbine tubular tower, by avoiding the failure due to various environmental impacts, the following regions of the tower should be consider and make analysis with the worst conditions of environmental impact.

1. To design of bolts and flanged tower segment connections for wind turbine tower.
2. To investigate the wind tower for Structural steel, Alloy steel 4130, and Alloy steel 6150 materials based on their geometry.
3. To analyze the mechanical properties of the materials, focus on the stress.
4. To study the different modes and their natural frequency in vibration condition by Modal analysis.
5. To study the load distribution on the wind turbine tower by Structural analysis.
6. To study the Fatigue life estimation for the wind turbine tower.

Table -1: Material Properties

Materials	Structural steel	Alloy steel 4130	Alloy steel 6150
Density(kg/m^3)	7850	7850	7850
Modulus of elasticity(Gpa)	200	190	210
Poisson's Ratio	0.3	0.27	0.3
Yield strength(Mpa)	250	460	415

4. METHODOLOGY

4.1 Geometry model using CATIA V5

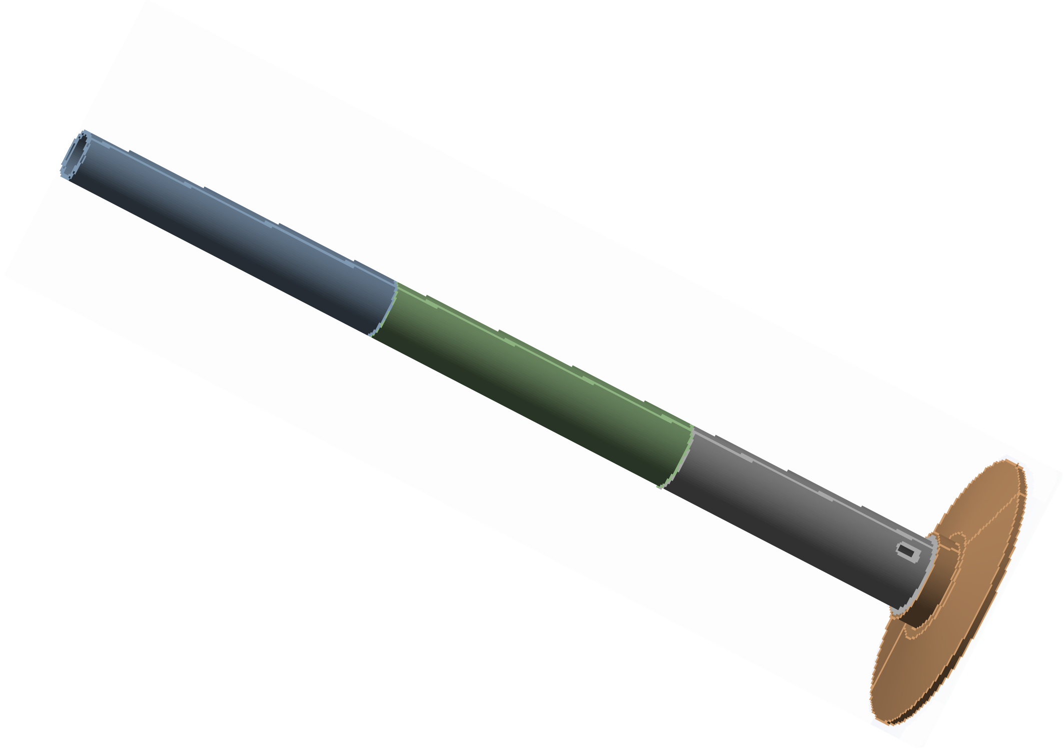

Figure 1 FEM model of wind tower

The fundamental essential of FEA is the geometry which is designed by the tool CATIA V5. Figure 1 shows three dimensional (3D) model of tapered cylindrical tubular tower with increasing diameter and thickness towards the base is developed using the software CATIA V5.

4.2 Meshed Model using ANSYS Workbench 19.2

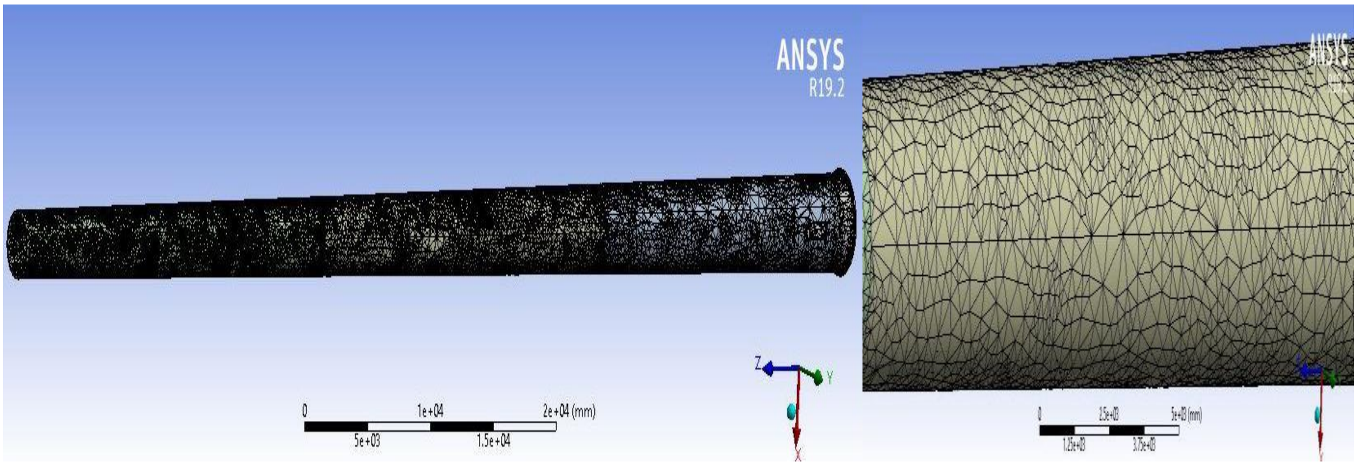

Figure-3: Tetrahedron element mesh model of the wind turbine tower

The figure 2 shows tetrahedron element meshing for all standard region of the wind turbine tower. This cell shape consists of 4 triangular faces and is one of the 3D types of mesh. The Solid 187 element is used for meshing. A tetrahedron surface mesh is always quick and easy to create.

Meshed Parameters

- Total number of nodes :-505194
- Total number of elements:-259796
- Degree of freedom:-6

4.3 LOADS AND BOUNDARY CONDITIONS

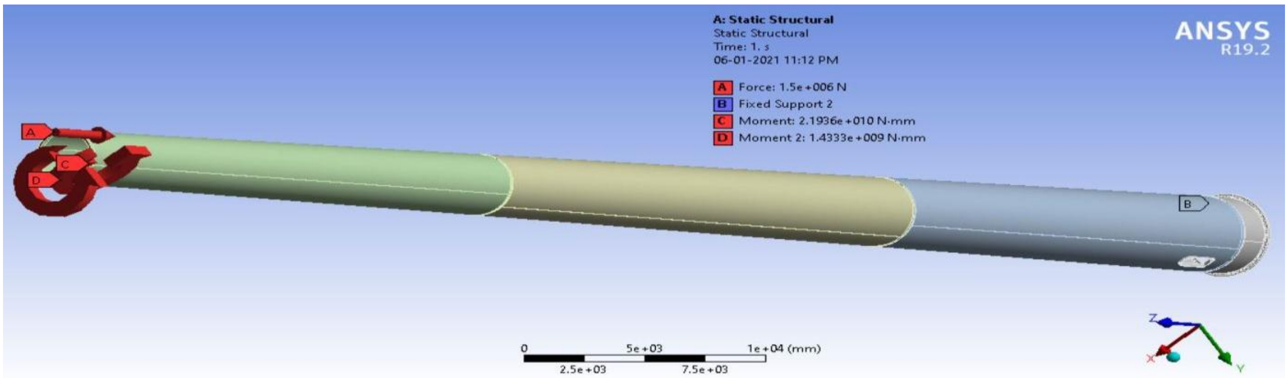

Figure-3: Load and moment applied on wind turbine tower

Figure 3 shows the wind turbine tower Fixed in bottom portion, compressive load 1500KN applied on the tower top section, bending moment 2.1936e^{+10}N-mm applied in the Z-axis on top of the tower, Torsional moment 1.4333e^{+9}N-mm applied in Y-axis on top of the tower.

5. STRUCTURAL ANALYSIS

A structural analysis is done to a designed wind turbine tower model. When the load applied to a designed FE model, the model gets deformed and the effect of load distributed all over the wind turbine tower model. The load creates an internal forces and reaction to restore the model into state of equilibrium. Structural analysis calculates deformation, maximum principal stress, minimum principal stress and Von-misses stress under the effect of applied loads.

5.1 Structural steel wind turbine tower

a) Equivalent stress

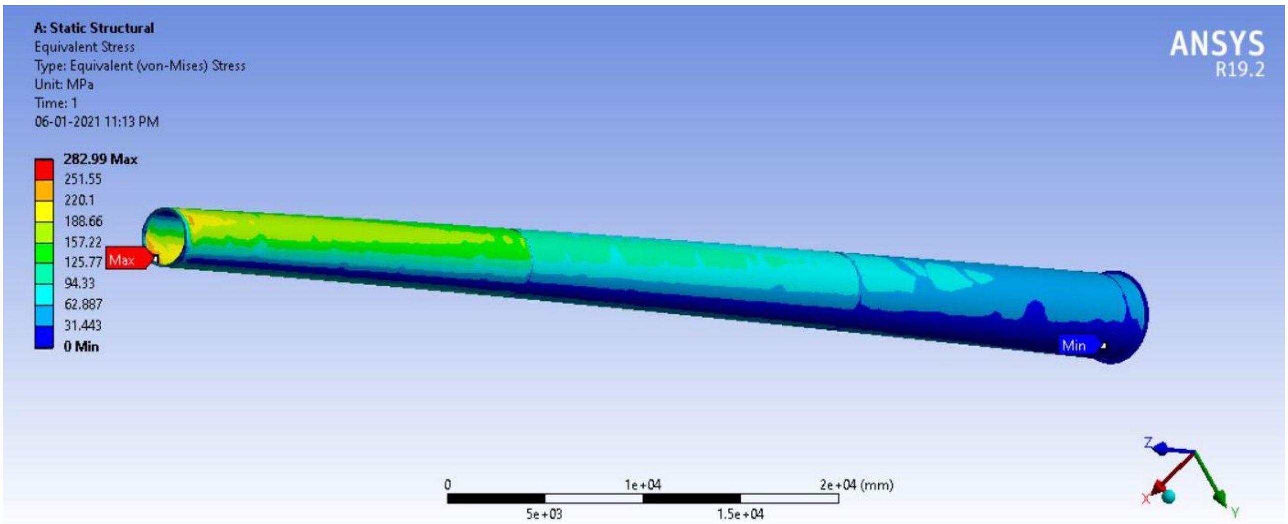

Figure-4: Equivalent stress in Structural steel

Figure 4 shows the equivalent stress developed in wind turbine tower, the maximum stress developed due to the application of load and moment is 282.99Mpa which shows red in colour, it is occurred in top portion of wind turbine tower.

b) Maximum principal stress

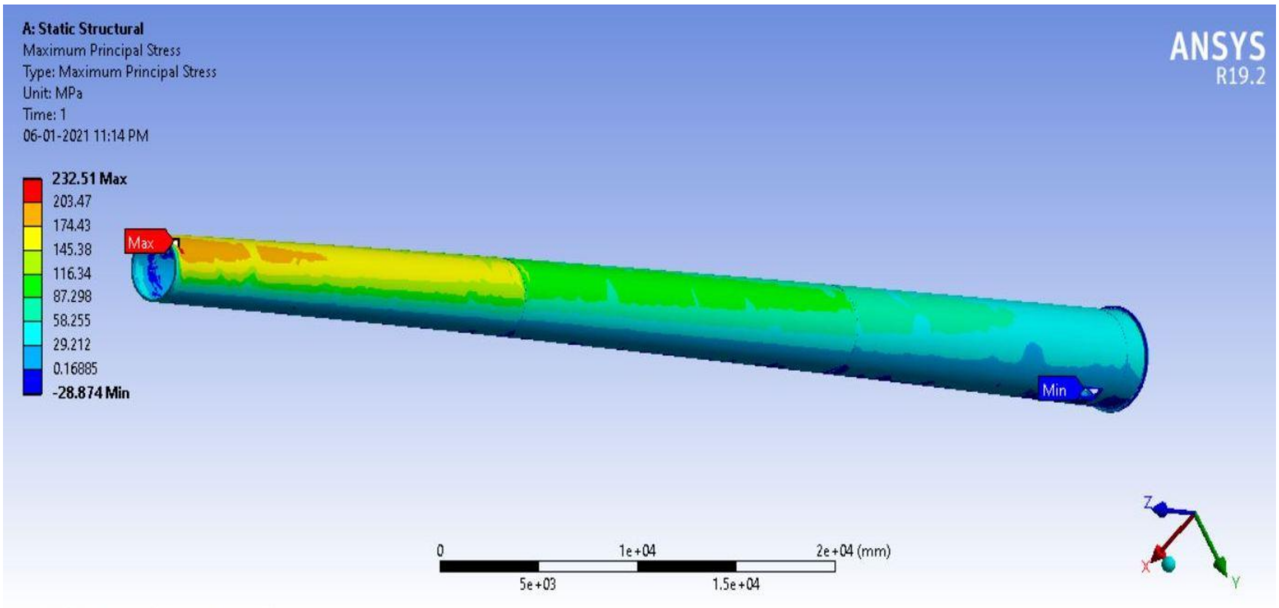

Figure-5: Maximum principal stress in structural steel

Figure 5 shows the maximum principal stress developed in wind turbine tower, the maximum stress developed due to the application of load and moment is 232.51Mpa which shows red in colour, it is occurred in the top portion of the wind turbine tower.

c) Minimum principal stress

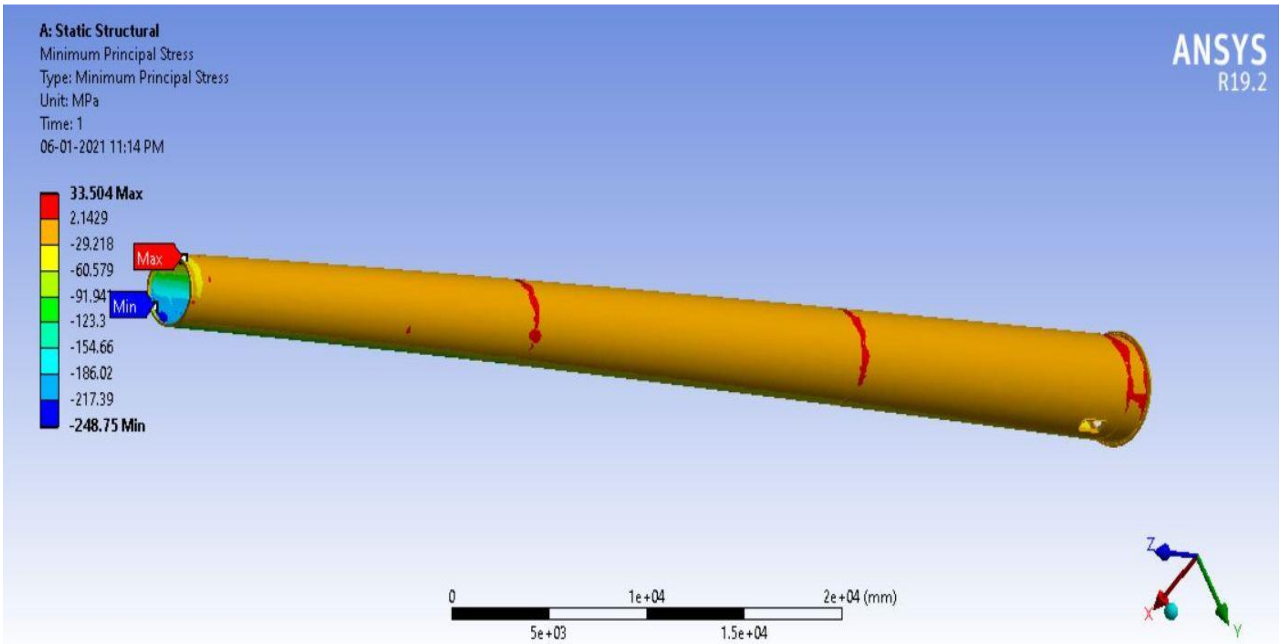

Figure-6: Minimum principal stress in structural steel

Figure 6 shows the minimum principal stress developed in wind turbine tower, the minimum stress developed due to application of load and moment is -248.75Mpa which show blue in colour, it is occurred in the top portion of the inner surface of the wind turbine tower.

d) Total deformation

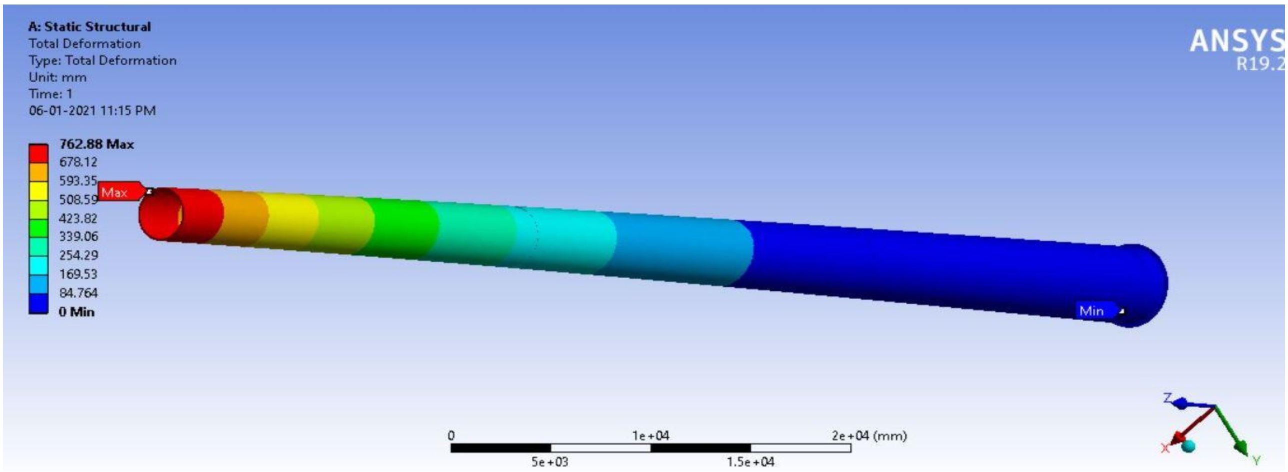

Figure 7: Total deformation due to stress in structural steel

Figure 7 shows the total deformation of the wind turbine tower, the maximum total deformation of 762.88mm is observed which shows red in colour, it is occurred in the top portion of the wind turbine tower.

e) Factor of safety

Factor of Safety (FOS) = (Tensile Ultimate Strength)/(Working Stress)

FOS = 460/282.99

FOS = 1.625

The tensile ultimate strength of the Structural Steel is 460Mpa; from the analysis result working stress obtained is 282.99Mpa, so from the calculation the factor of safety of Structural steel is 1.6 which is greater than the 1.5 standard safety factor.

5.2 Alloy steel 4130 wind turbine tower

a) Equivalent stress

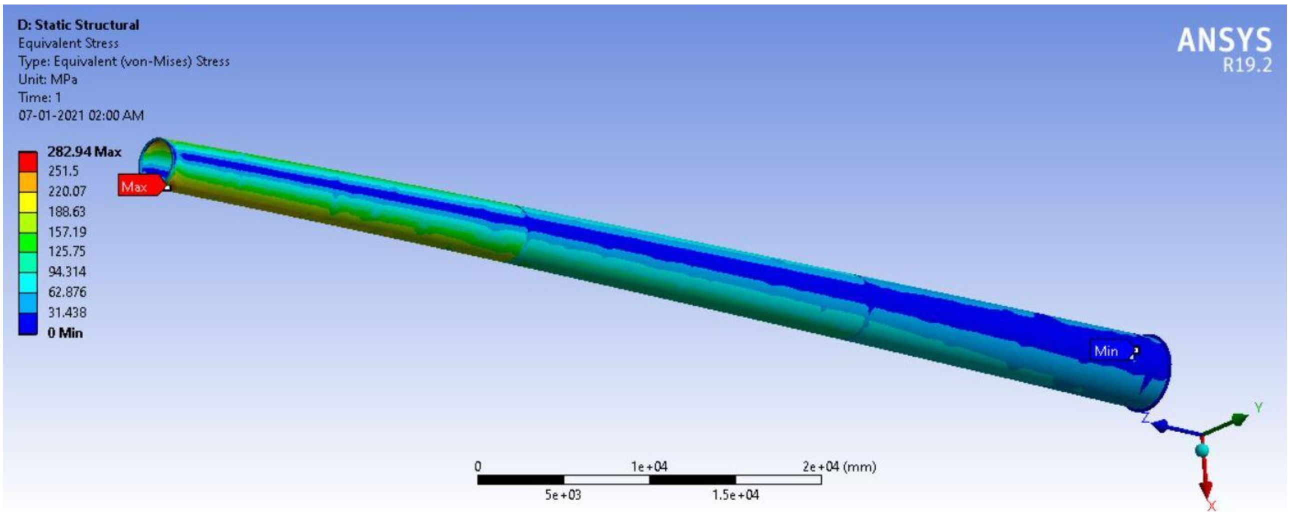

Figure-8: Equivalent stress in Alloy steel 4130

Figure 8 shows the equivalent stress developed in wind turbine tower, the maximum stress developed due to the application of load and moment is 282.94Mpa which shows red in colour, it is occurred in top portion of wind turbine tower.

b) Maximum principal stress

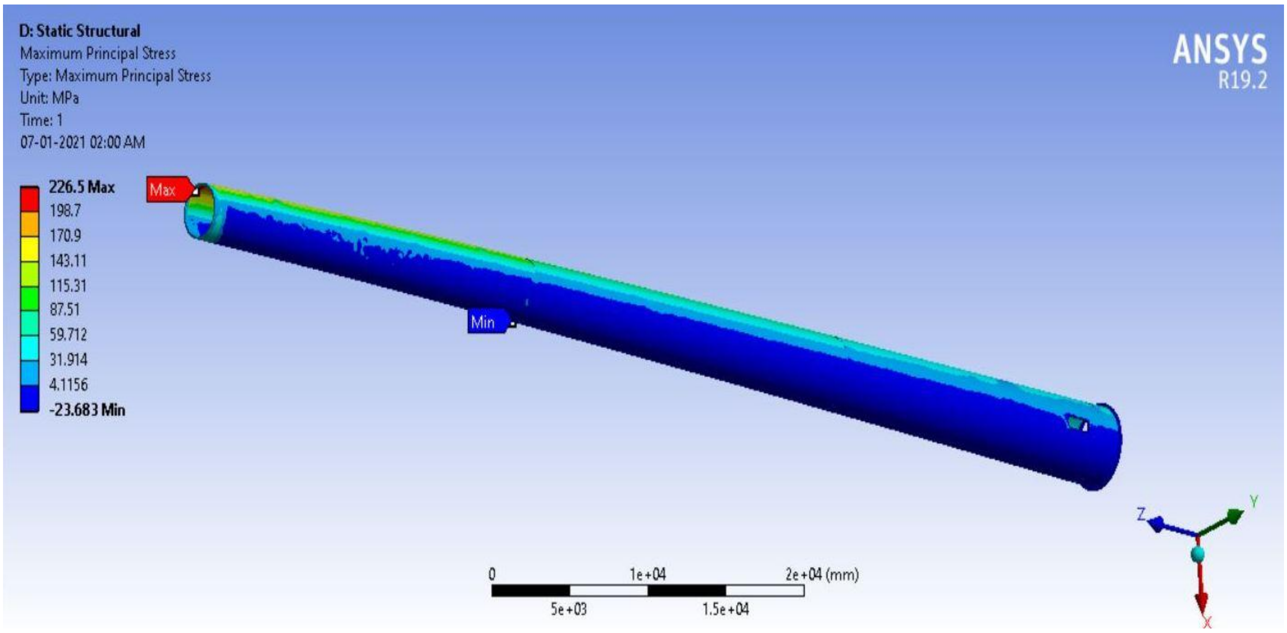

Figure-9: Maximum principal stress in Alloy steel 4130

Figure 9 shows the maximum principal stress developed in wind turbine tower, the maximum stress developed due to the application of load and moment is 226.5Mpa which shows red in colour, it is occurred in the top portion of the wind turbine tower.

c) Minimum principal stress

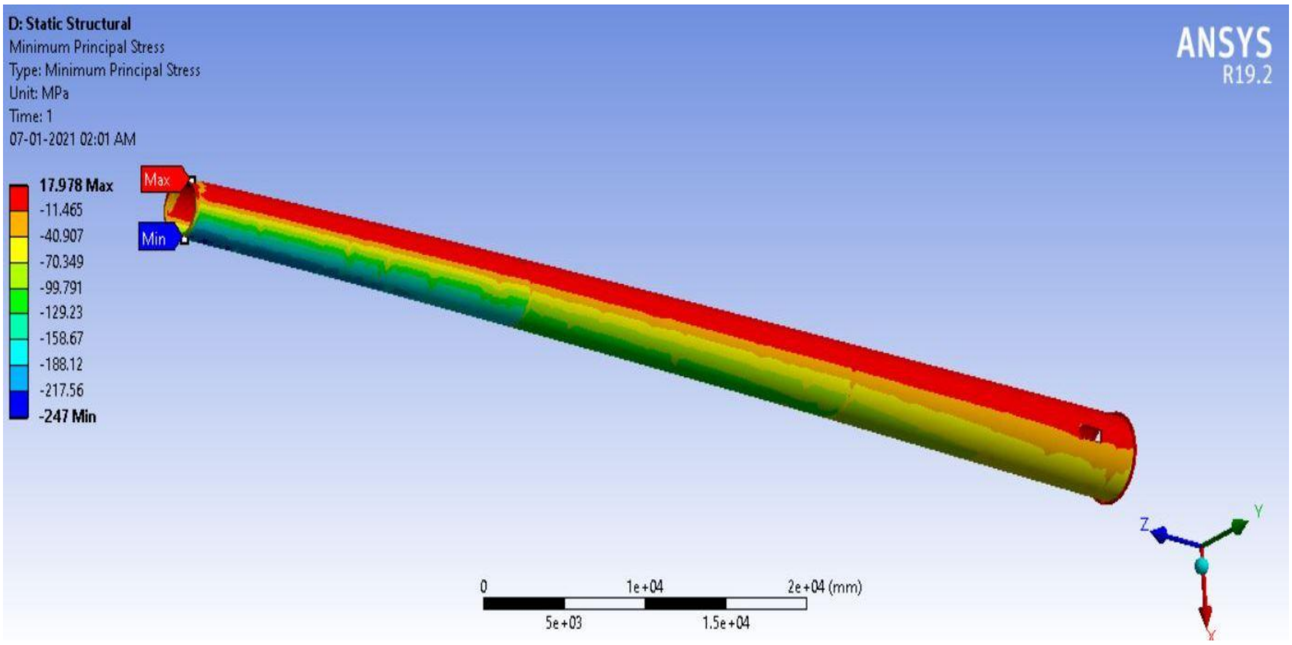

Figure-10: Minimum principal stress in Alloy steel 4130

Figure 10 shows the minimum principal stress developed in wind turbine tower, the minimum stress developed due to the application of load and moment is -247Mpa which shows blue in colour, it is occurred in the top portion of the wind turbine tower.

d) Total deformation

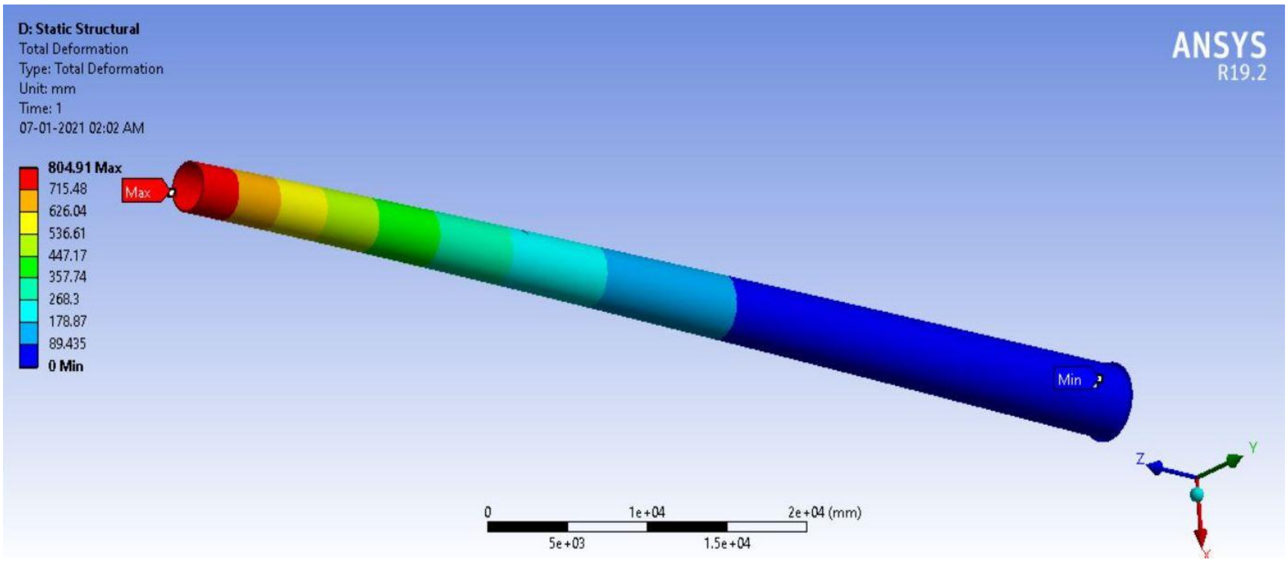

Figure 11: Total deformation due to stress in Alloy steel 4130

Figure 11 shows the total deformation of the wind turbine tower, the maximum total deformation of 804.91mm is observed which shows red in colour, it is occurred in the top portion of the wind turbine tower.

e) Factor of safety

Factor of Safety (FOS) = (Tensile Ultimate Strength)/ (Working Stress)

FOS = 560/282.94

FOS = 1.979

The tensile ultimate strength of the Alloy Steel 4130 is 560Mpa; from the analysis results working stress obtained is 282.94Mpa, so from the calculation the factor of safety of Alloy steel 4130 is 1.979 which is greater than the 1.5 standard safety factor.

5.3 Alloy steel 6150 wind turbine tower

a) Equivalent stress

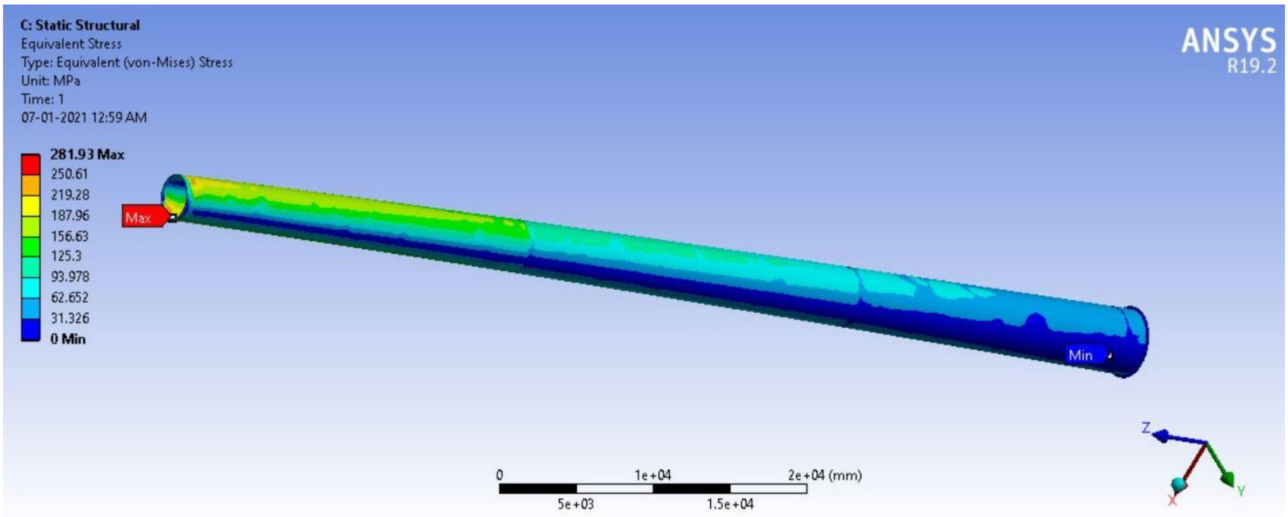

Figure-12: Equivalent stress in Alloy steel 6150

Figure 12 shows the equivalent stress developed in wind turbine tower, the maximum stress developed due to the application of load and moment is 281.93Mpa which shows red in colour, it is occurred in top portion of wind turbine tower.

b) Maximum principal stress

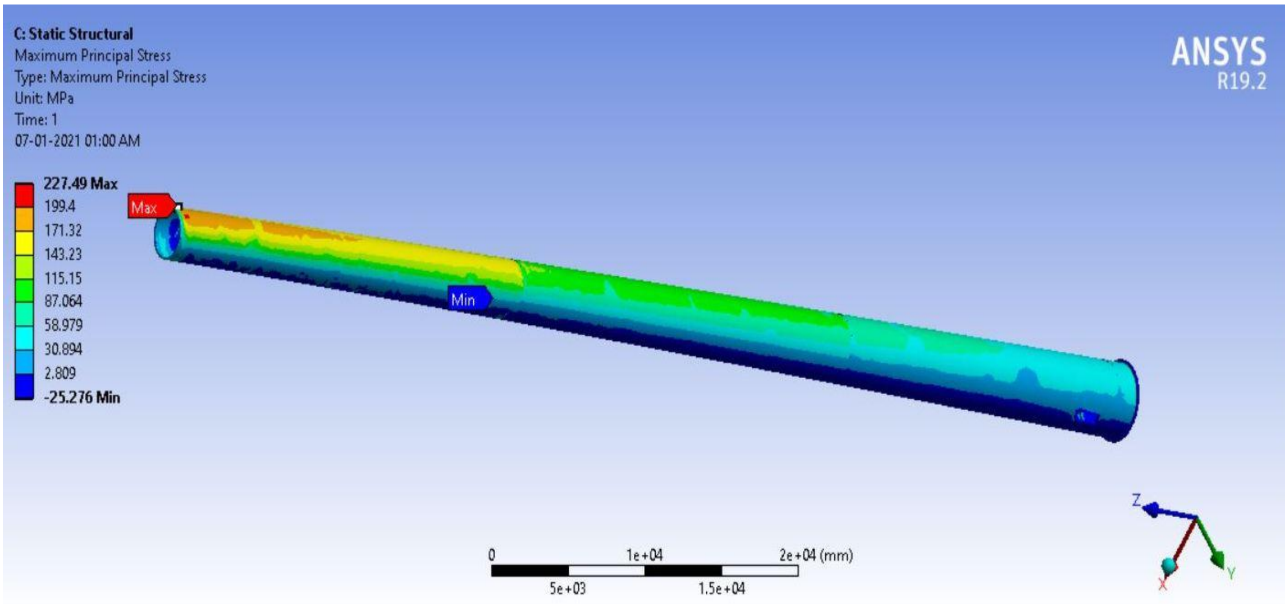

Figure-13: Maximum principal stress in Alloy steel 6150

Figure 13 shows the maximum principal stress developed in wind turbine tower, the maximum stress developed due to the application of load and moment is 227.49Mpa which shows red in colour, it is occurred in the top portion of the wind turbine tower.

c) Minimum principal stress

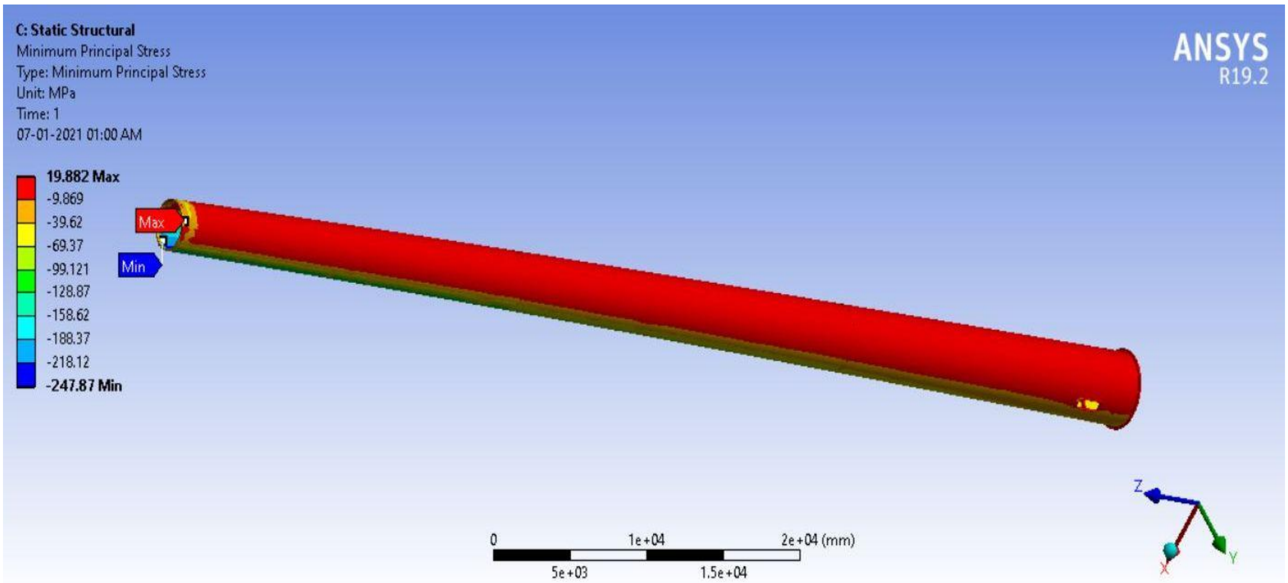

Figure-14: Minimum principal stress in Alloy steel 6150

Figure 14 shows the minimum principal stress developed in wind turbine tower, the minimum stress developed due to the application of load and moment is -247.87Mpa which shows blue in colour, it is occurred in the top portion of the wind turbine tower.

d) Total deformation

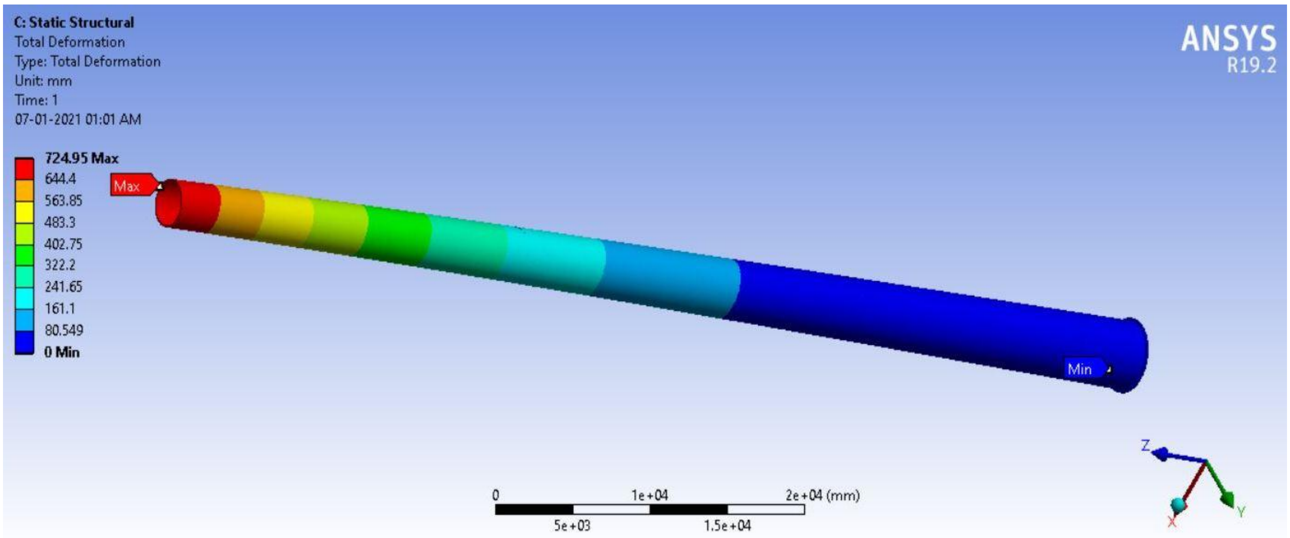

Figure 15: Total deformation due to stress in Alloy steel 6150

Figure 15 shows the total deformation of the wind turbine tower, the maximum total deformation of 724.95mm is observed which shows red in colour, it is occurred in the top portion of the wind turbine tower.

e) Factor of safety

Factor of Safety (FOS) = (Tensile Ultimate Strength)/(Working Stress)

FOS = 670/281.93

FOS = 2.376

The tensile ultimate strength of the Alloy Steel 6150 is 670Mpa; from the analysis results working stress obtained is 281.93Mpa, so from the calculation the factor of safety of Allot steel 6150 is 2.376 which is greater than the 1.5 standard safety factor.

6. MODAL ANALYSIS

6.1 Alloy steel 6150 wind turbine tower

Mode 1

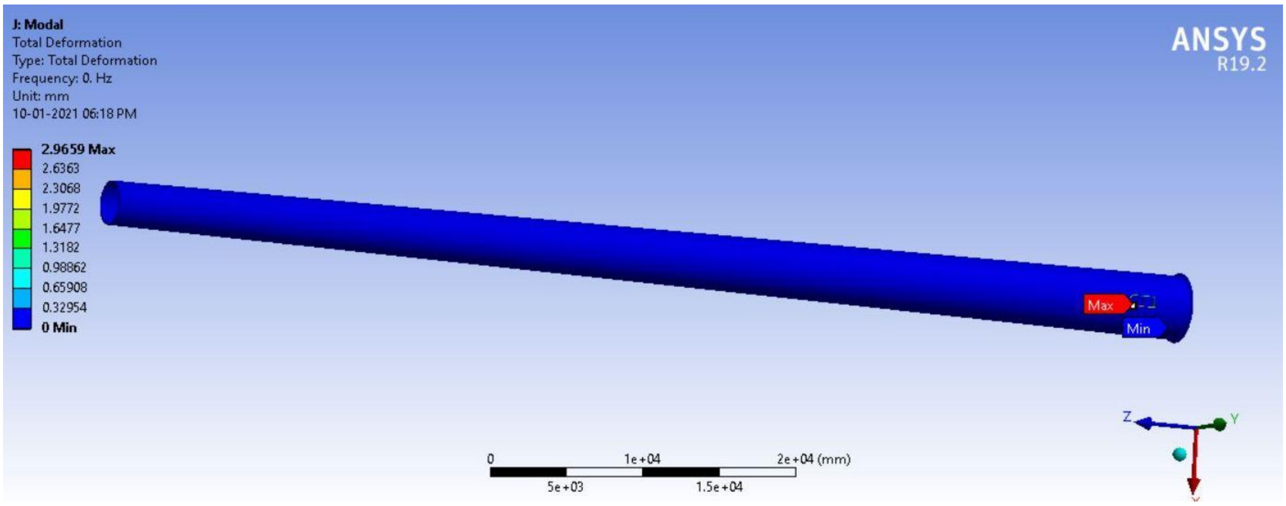

Figure 16: Mode 1 Frequency of Alloy steel 6150

In figure the value of frequency of the Alloy steel 6150 for the mode 1 is 0HZ. The maximum deformation caused due to the vibration in the wind turbine tower is 2.9659mm, shown red in colour which can be observed near the bottom of the tower and the minimum deformation can be observed blue in colour.

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Mode 2

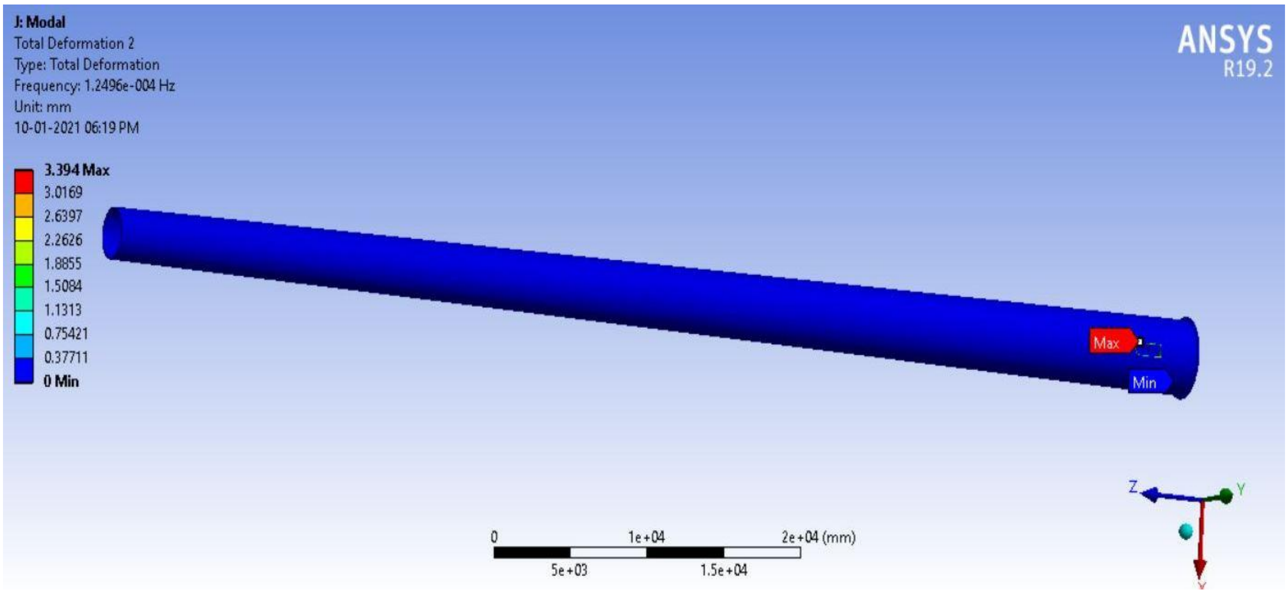

Figure-17: Mode 2 Frequency of Alloy steel 6150

In figure the value of frequency of the Alloy steel 6150 for the mode 2 is 1.2496e^{-4} HZ. The maximum deformation caused due to the vibration in the wind turbine tower is 3.394mm, shown red in colour which can be observed near the bottom of the tower and the minimum deformation can be observed blue in colour.

Mode 3

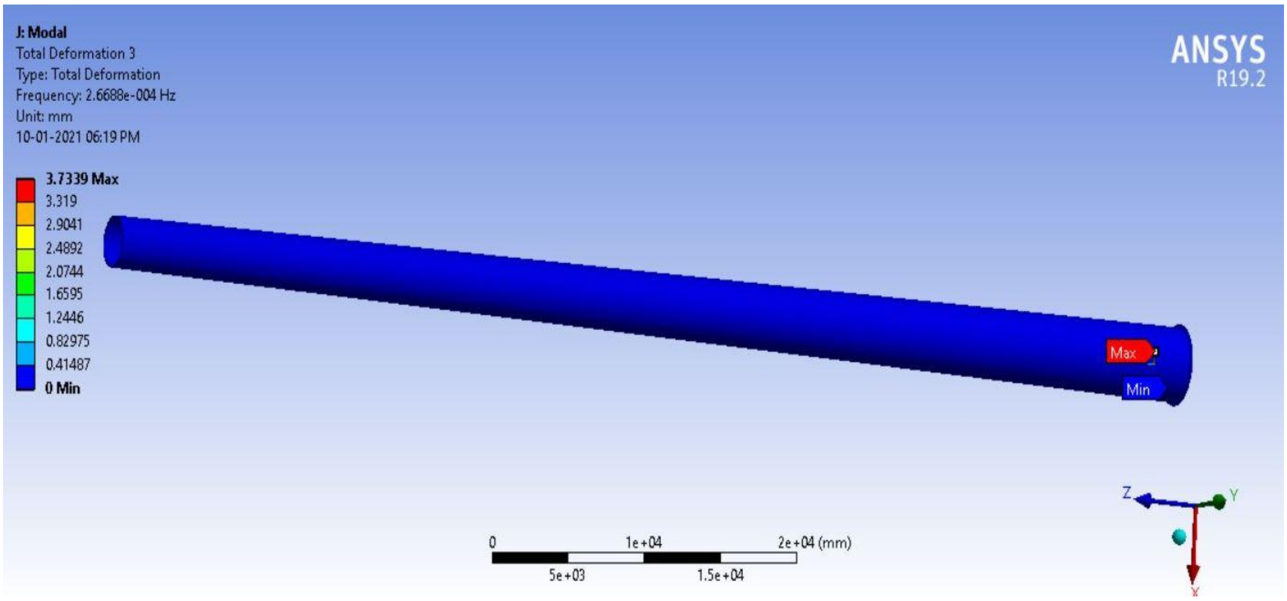

Figure 18: Mode 3 Frequency of Alloy steel 6150

In figure the value of frequency of the Alloy steel 6150 for the mode 3 is 2.6688e^{-4} HZ. The maximum deformation caused due to the vibration in the wind turbine tower is 3.7339mm, shown red in colour which can be observed near the bottom of the tower and the minimum deformation can be observed blue in colour.

Mode 4

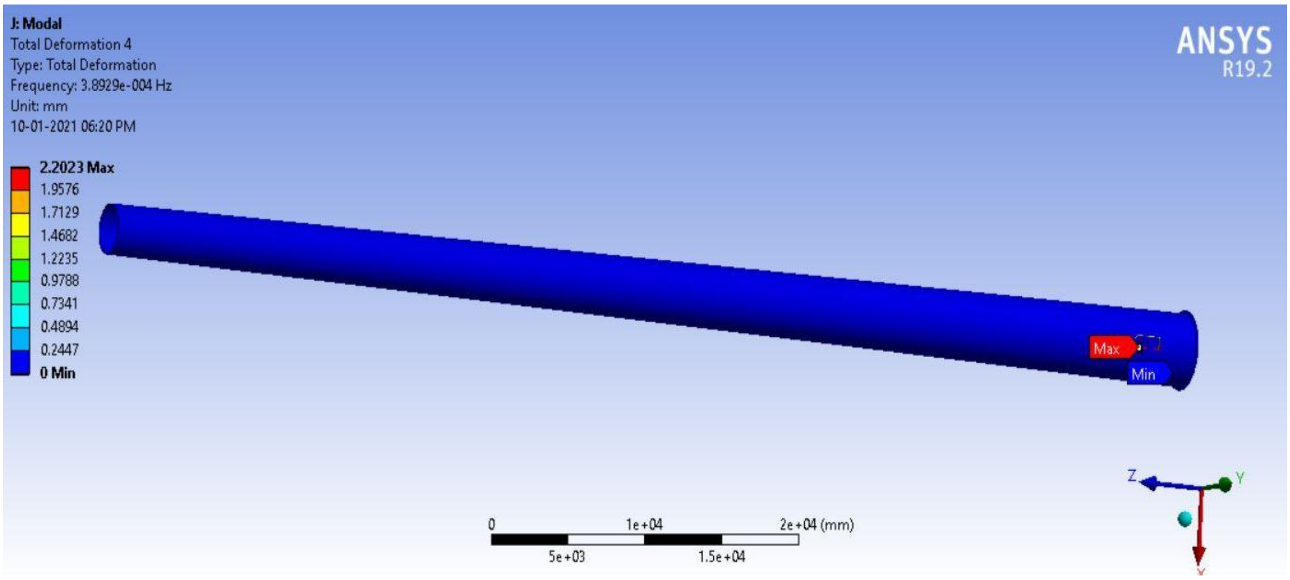

Figure-19: Mode 4 Frequency of Alloy steel 6150

In figure the value of frequency of the Alloy steel 6150 for the mode 4 is 3.8929e^{-4} HZ. The maximum deformation caused due to the vibration in the wind turbine tower is 2.2083mm, shown red in colour which can be observed near the bottom of the tower and the minimum deformation can be observed blue in colour.

Mode 5

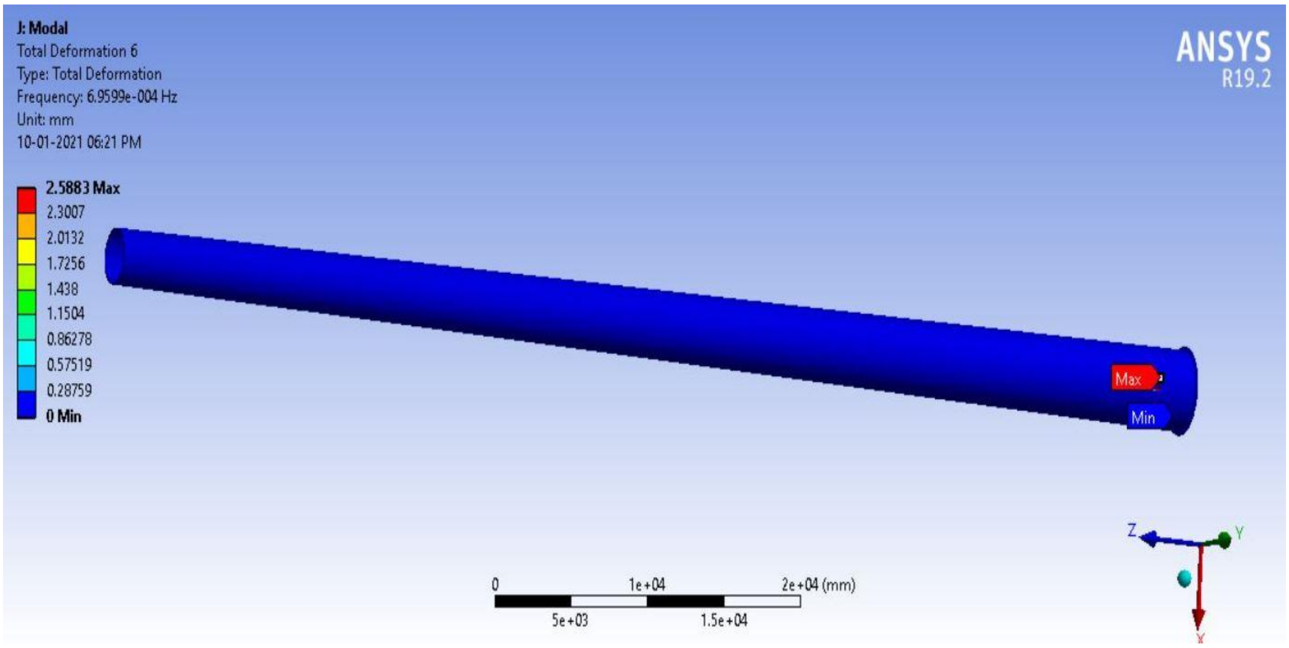

Figure 20: Mode 5 Frequency of Alloy steel 6150

In figure the value of frequency of the Alloy steel 6150 for the mode 5 is 6.9599e^{-4} HZ. The maximum deformation caused due to the vibration in the wind turbine tower is 2.5883mm, shown red in colour which can be observed near the bottom of the tower and the minimum deformation can be observed blue in colour.

Mode 6

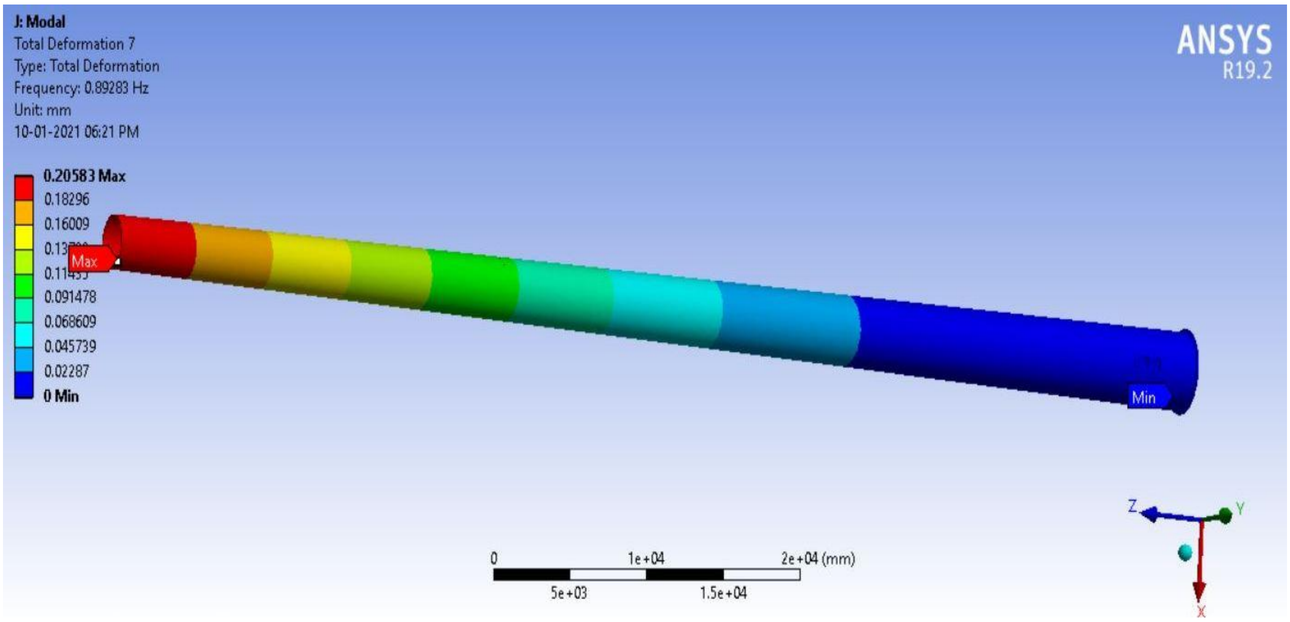

Figure-21: Mode 6 Frequency of Alloy steel 6150

In figure the value of frequency of the Alloy steel 6150 for the mode 6 is 0.89283 HZ. The maximum deformation caused due to the vibration in the wind turbine tower is 0.20583mm, shown red in colour which is occurred in top portion of the tower and the minimum deformation can be observed blue in colour, which is occurred in lower portion of the tower.

7. Fatigue analysis on Alloy steel 6150wind turbine tower

In materials science, fatigue is the wearying of a material caused by recurrently applied loads. The nominal maximum stress values that cause such damage may be much less than the strength of the material classically quoted as the ultimate tensile stress limit, or the yield stress limit.

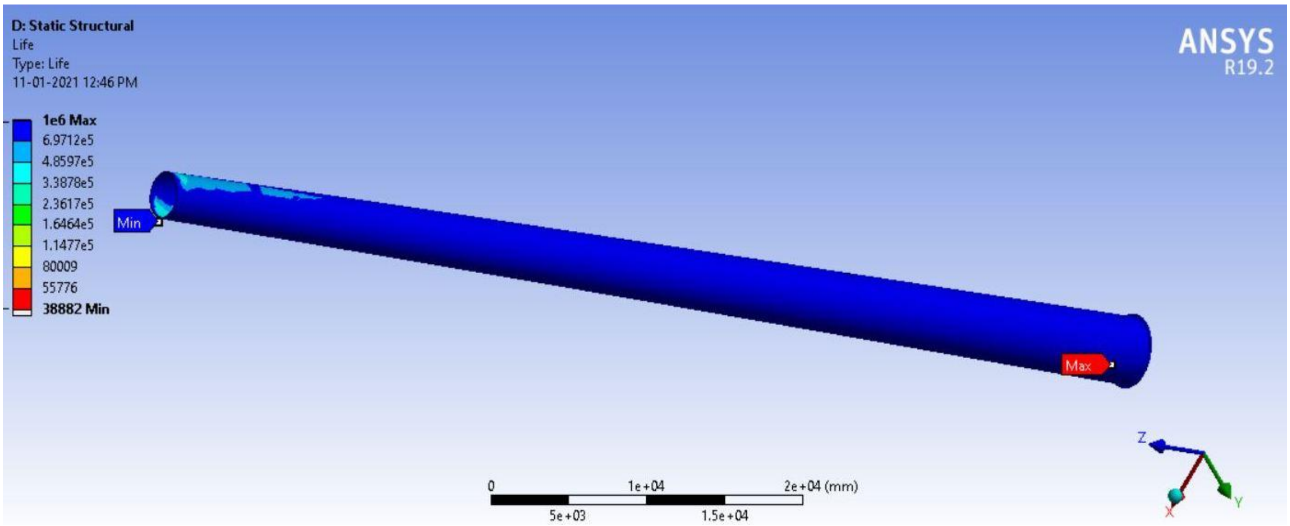

Figure 22: Fatigue analysis on Alloy steel 6150

Figure 22 shows the Fatigue estimation using Finite element approach for the Alloy steel 6150 wind turbine tower, the maximum life cycle can be observed in above figure is 100000 cycles, show blue in colour at the top of the wind tower.

8. Comparative Analysis

Table 2: Comparison b/w wind turbine tower with different materials

Materials	**Structural steel**	**Alloy steel 4130**	**Alloy steel 6150**
Equivalent stress	282.99Mpa	282.94Mpa	281.93Mpa
Maximum Principal Stress	232.51Mpa	226.5Mpa	227.49Mpa
Minimum Principal Stress	248.75	247Mpa	247.87Mpa
Total deformation	762.88mm	804.91mm	724.95mm

9. Graphical Representation

9.1 Equivalent stress of Wind Turbine Tower Using Structural Steel, Alloy Steel 4130, and Alloy Steel 6150 Materials

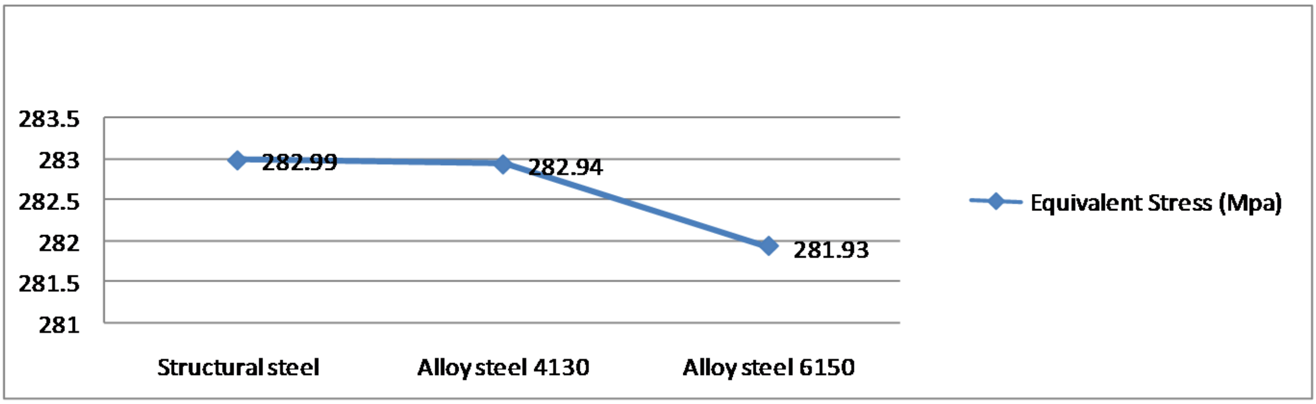

Figure 23: Equivalent stress v/s materials

The graph clearly shows the equivalent stress values of Structural Steel, Alloy steel 4130, and Alloy Steel 6150 wind turbine tower. In the above graph X- direction represents the different materials and Y- direction represents the equivalent Stress (Mpa). The highest equivalent stress of 282.99Mpa is observed for Structural steel wind turbine tower and lowest equivalent stress of 281.93Mpa is observed for Alloy steel 6150 wind turbine tower.

9.2 Maximum Principal Stress of Wind Turbine Tower Using Structural Steel, Alloy Steel 4130, and Alloy Steel 6150 Materials.

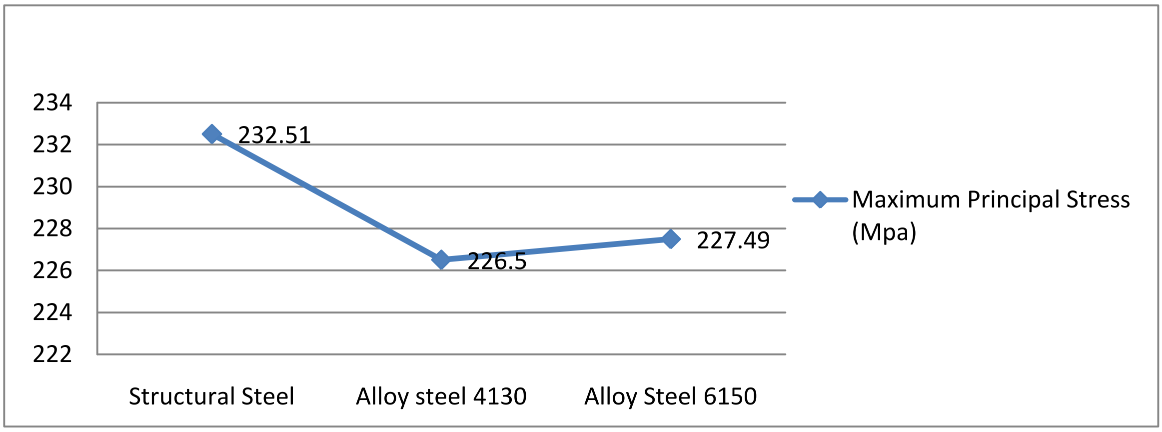

Figure 24: Maximum principal stress v/s materials

The graph clearly shows the maximum principal stress values of Structural Steel, Alloy steel 4130, and Alloy Steel 6150 wind turbine tower. In the above graph X- direction represents the different materials and Y- direction represents the maximum principal stress. The highest maximum principal stress of 232.51Mpa is observed Structural steel wind turbine tower and lowest maximum principal stress of 226.5Mpa is observed for Alloy steel 4130 wind turbine tower.

9.3 Maximum Principal Stress of Wind Turbine Tower Using Structural Steel, Alloy Steel 4130, and Alloy Steel 6150 Materials.

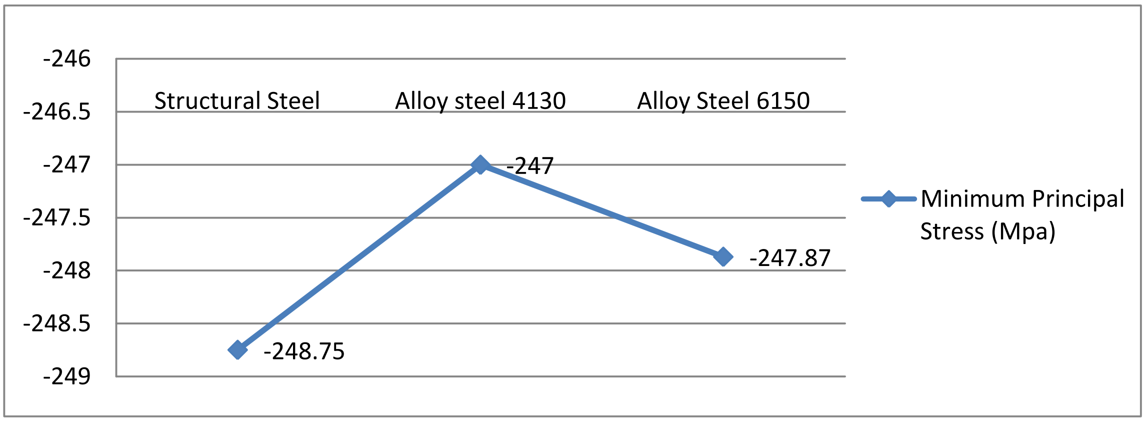

Figure 25: Minimum principal stress v/s materials

The graph clearly shows the minimum principal stress values of Structural Steel, Alloy steel 4130, and Alloy Steel 6150 wind turbine tower. In the above graph X- direction represents the different materials and Y- direction represents the minimum principal stress. The highest minimum principal stress of -248.75Mpa is observed for Structural steel wind turbine tower and lowest minimum principal stress of -247.87Mpa is observed for Alloy steel 6150 wind turbine tower.

9.4 Total Deformation of Wind Turbine Tower Using Structural Steel, Alloy Steel 4130, and Alloy Steel 6150 Materials.

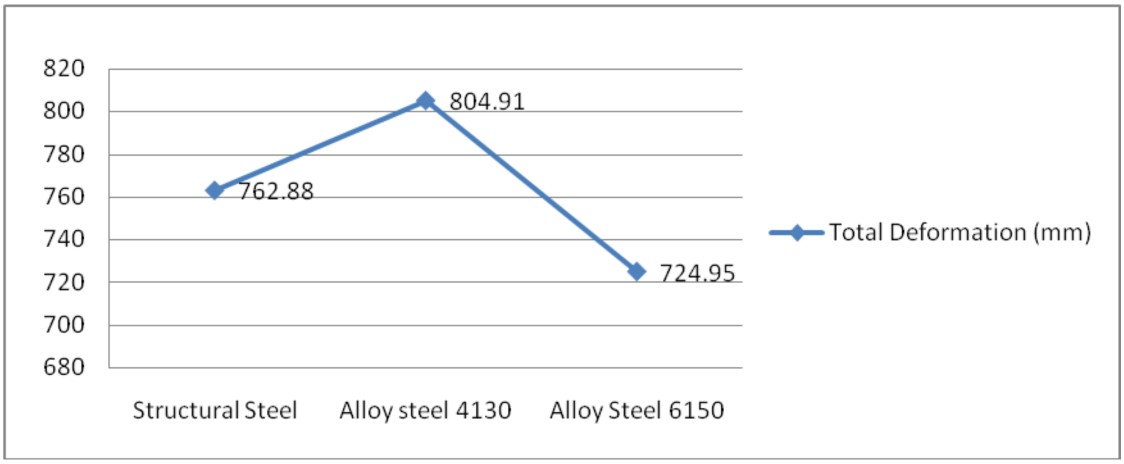

Figure 26: Total deformation v/s materials

The graph clearly shows the total deformation values of Structural Steel, Alloy steel 4130, and Alloy Steel 6150 wind turbine tower. In the graph X- direction represents the different materials and Y- axis shows the total deformation. The highest total deformation of 804.91mm is observed for Alloy steel 4130 wind turbine tower and lowest total deformation of 724.95mm is observed for Alloy steel 6150 wind turbine tower.

10. Conclusions

- The design of the wind turbine tower with the materials used for its manufacturing holds a major role in the wind turbine energy generation, since turbine is placed on the top of the tower.

- The S355 high grade steel material is used, in the present 2MW capacity wind turbine tower for energy generation, its yield stress is 355Mpa and tensile ultimate stress is 470Mpa. New materials are used to improve the strength of the tower.
- The analysis of the wind turbine towers is carried out by Structural steel, Alloy steel 4130, and Alloy steel 6150 materials.
- Studying the structural analysis results of the Structural steel wind turbine tower, Alloy steel 4130 wind turbine tower, and Alloy steel 6150 wind turbine tower. It can be concluded that Equivalent stress of the Alloy steel 4130 and Alloy steel 6150 values are less when compare to the yield stress values of the Alloy steel 4130 and Alloy steel 6150 materials, so we can say that design is safe for both the materials.
- Based on the results we can say that, maximum principal stress of the Alloy steel 6150 wind turbine tower is less when compare to Structural steel wind turbine tower and Alloy steel 4130 wind turbine tower.
- Based on the results we can say that, total deformation of the Alloy steel 6150 wind turbine tower is less the compare to Structural steel wind turbine tower and Alloy steel 4130 wind turbine tower.
- From the economic aspects we can say that Alloy steel 6150 wind turbine tower is less expensive when compare to Alloy steel 4130 material.
- Based on the above points it can be concluded that Alloy steel 6150 wind turbine tower is better strength when compare to Alloy steel 4130 wind turbine tower and Structural steel wind turbine tower.

11. References

1. MURTAGH, P. J., BASU, B., and BRODERICK, B. Along-wind response of a wind turbine tower with blade coupling subjected to rotationally sampled wind loading. Engineering Structures, Volume 27, Issue 8, July 2005.

2. Marcelo A. Silva, J.S.Arora, Dynamic Analysis of Pre-Cast RC Telecommunication Towers using a Simplified Model. Volume 2006, Received 15 January 2005; Revised 27 March 2006; Accepted 4 April 2006.

3. B. Gencturk, A. Attar, and C. Tort "Design Optimization of Lattice Wind Turbine Towers Subjected to Earthquake Forces" Volume 2014 Structures Congress ASCE 2014.

4. B. Song, and J. C. Wu Comparative Analysis on Dynamic Response of Wind Turbine Tower in Different Sites International Efforts in Lifeline Earthquake Engineering ASCE 2014.

5. Hani M. Negma, Karam Y. Maalawi Structural design optimization of wind turbine towers.Volume 74, Issue 6, 1 February 2000.

6. Umesh K N, Bharath P et.al carried out wind tower analyses of the stress and strain behavior of the welded fixture. International Journal of Mechanical And Production Engineering, ISSN: 2320-2092, Volume- 4, Issue-10, Oct.-2016.

7. S. Jerath and S. Austin Response of Wind Turbine Towers to Seismic Loading At Different Damping Ratios Structures Congress. Volume 8, Issue 3, September 2017.

8. Ajay R.Vaghela1 'Door opening analysis of wind turbine steel tubular tower. International Journal of Research in Engineering and Technology Volume: 03 Issue: 05 | May-2014.

9. C.C. Baniotopoulos, G. Nikolaidis et.al design of large-scale wind turbine towers in seismic areas and design of the prototype of large tubular steel wind turbine tower in earthquake areas.

10. Chethan M C,Bharath V G, Harish H, Dr .K Kumar 'Structural Evaluation of Steel Adapter and Door Type Ring Stiffener in Wind Turbine Tower for Certification' International Journal of Engineering Research & Technology (IJERT) ISSN: 2278- 0181 www.ijert.org Vol. 3 Issue 7, July–2014.

11. Bhattacharya has studied the dynamic properties of off-shore wind turbine considering soil structure interaction. Wind and Structures, Vol. 14, No. 2 (2011).

12. Anh Tuan Tran1, Milan Veljkovic, Carlos Rebelo and Luis Simoes da,'Resistance of door openings in towers for wind turbines', Greece, 12–14 June 2013.

13. Manouchehr Hassanzadeh, 'Cracks in onshore wind power foundations Causes and consequences', Elforsk rapport 11:56 January 2012.

14. Asian, S., Ertek, G., Haksoz, C., Pakter, S., & Ulun, S. (2017). Wind turbine accidents: A data mining study. IEEE Systems Journal, 11(3).

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