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Modal Analysis of the Wind Turbine Planned to be Built in Mamurdağı Ground Conditions Using Finite Element Method

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Abstract **–** In the present study, steel structural wind turbine tower with design configurations is analysed using ABACUS CAE 2022 FEM modelling. Tower of 73m heights is considered and investigated with dynamic parameters, mechanical design options. Structural and dynamic analyzes of the wind turbine, which is thought to be built in the Mamurdağ location of Samsun İlkadım District, has been tried to be analyzed using the Finite Element Method.The main purpose of this study is to numerically examine the dynamic behavior of the wind turbine under the existing ground conditions of Mamurdağı for the Wind Turbine. The turbine preferred as a model in this study is the 73m high 800Kw wind turbine belonging to Enocon Company. Modeling was made in the light of the technical data of the relevant company. While the numerical model was being created, the blades of the wind turbine and the nacelle-rotor system were not modeled, but the actual weight, corresponding to approximately 81 tons was applied as a load to the system. In the last part of the article, the dynamic properties of this 73m high tower are examined to obtain the natural frequencies and mode shapes. As a result of the analysis, 5 different mode shapes, frequency and period values of the wind turbine planned to be built were obtained. According to the modal analysis results of the wind turbine, the result of the dominant frequency was obtained as 0.72327 (cycles/time). First Mode is in the y-x plane so this is the lateral movement in this direction.

Keywords – Wind Turbine, Mode Shapes; Finite Element Method; Modal Analysis; Frequencies

I. Introduction

In todays world with the development of technology, the increasing energy demands are reaching different dimensions day by day. The fact that a large part of the energy need is obtained from fossil fuels and the existence of a certain amount of reserves of these fuels has led human beings to new and renewable energy sources [27]. One of the most important renewable energy sources is wind energy. Today, it is an energy type that shows the fastest development in technology and usage area and its economy can compete with conventional energy sources.Since the process of generating electrical energy from wind energy is independent of carbon production, that is, it does not cause atmospheric pollution, this source is also described as "clean energy". For this reason, it is very important to spread the use of wind energy, which is one of the renewable energy sources. The general definition of wind turbines is that they are energy converters that convert the kinetic energy in the moving air into electrical energy in energy conversion. It consists of a system connected to the rotor part and support towers that also support the power transmission and control systems[26]. Since it is a renewable energy source, the use of wind energy minimizes greenhouse gas emissions, which we know about the harmful effects on the environment. In this case, the rate of environmental degradation decreases. Wind energy is a clean and affordable solution to meet a large part of this energy demand. At present, wind energy is widely used, and the basic technology is developing very quickly. Wind speed and direction are the two main parameters in determining the wind energy potential [11].

1.1. Turkey's Wind Energy Potential

It has been determined from the researches that our country has a wind energy potential of 48,000 MW. It is understood from the studies that the total area corresponding to this value corresponds to approximately 1.30% of the surface area of our country [21]. Wind energy, which comes to mind first when it comes to a renewable and clean energy source, is a resource that should not be ignored with its low cost, easy technology and endless potential [9]. Due to the fact that it is a clean and unlimited power source that is completely formed by the sun, wind power is an air flow phenomenon that arises from the formation of different temperature and pressure differences as a result of the sun's heating of the atmosphere on the earth's surface. This weather condition, called wind, is actually high between two adjacent pressure regions. It is the air flow that moves from the center of pressure to the center of low pressure. This event, which is caused by the pressure difference of the winds, is caused by some situations; reasons such as the earth's rotation around its own axis, surface friction, local heat dissipation, different atmospheric events in front of the wind, and the topographic structure of the land. Wind is expressed by two parameters: speed and direction. Wind speed increases with height, and its theoretical strength varies in proportion to the cube of its speed. Figure 1.

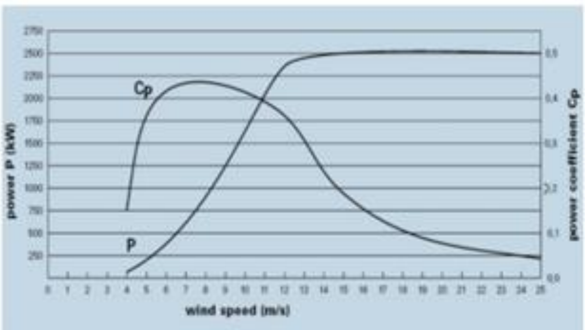


Fig. 1. Power-Wind Graph

The following equations are used to calculate the wind data. It is the wind energy potential that has a certain mass and kinetic energy. The strength of the instantaneous wind is expressed by the following equation: Not all of the instantaneous energy in wind turbines is converted into electrical energy.

The amount of power converted into electrical energy in wind turbines:

$$p = \frac{1}{2} * \rho * v^3 * C_p * A \qquad (1)$$

P=Power(Watt)

ρ= Air Density (kg/m^3)

V^3=Wind Speed(m/sec)

C_p=Power Coefficient

A=Swept Area (m^2)

In 2007, there were developments for wind energy potential in Turkey. Türkiye Wind Energy Potential Atlas Figure 2 as can be seen; It is possible to reach all kinds of detailed information, especially wind source information, through this map. (fighting forest fires, monitoring air pollution concentrations, mountain and sea sports, maritime activities, agricultural practices, etc.). In the wind potential calculations made in Turkey, it is accepted that 5MW wind power plants per square kilometer can be established in areas where the wind speed is 7.5m/s and above at 50m heights from the ground level. According to these assumptions, the light wind energy potential in Turkey has been determined as 47,850 MW.

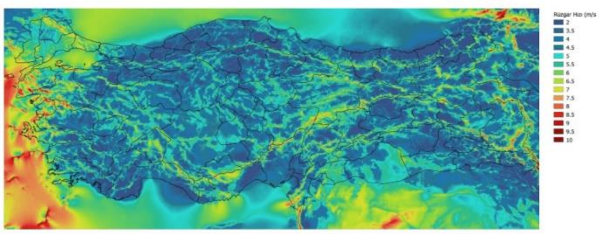


Fig.2. Turkey Wind Energy Potential Atlas

As of the end of June 2022, our installed power based on wind energy is 10,976 MW, its ratio in the total installed power is 10,81%, and the change in installed power over the years and its ratio in the total installed power are given in the graphs below Fig 3.

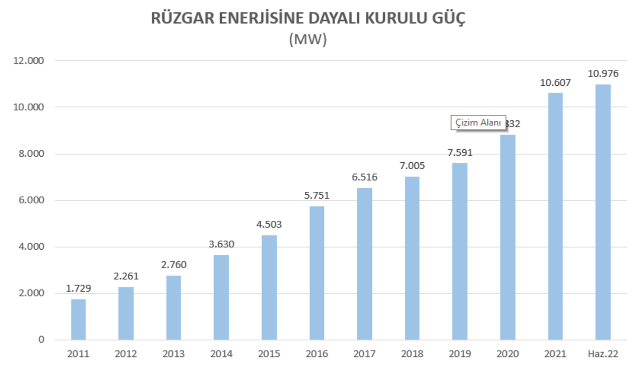


Fig. 3. Installed Power Based on Wind Energy

In these studies, primarily analytical models of the structures are created. The dynamic behavior of structures, towers and other structural systems when exposed to earthquakes is generally studied with analytical and experimental models. Knowing the dynamic parameters of the structures provides us with information about the situation that may occur before or after the structure. Experimental behavior of structures is investigated with experimental studies in structures vibrating with various factors [2] Investigation of the dynamic behavior of any structure can be investigated theoretically by constructing a finite element model and experimentally by using modal analysis methods [2, 10, 17]. In the literature review related to this publication, many studies using the finite element method have been reached. In some studies, such as some of the publications using the finite element method and guiding the author's work are as follows on the use of the finite element method were used [2, 10, 17] With all these knowledges, some these new studies has been carried out. Researchers have conducted many study on new methods [15,12, 7, 14, 6] The author also refers to these studies about the wind towers structures made. Looking at the literature studies, the researchers carried out a different number of studies using the finite element method [20, 1, 16, 4,8). Today, some authors have conducted various studies using FEM analysis of the structural response of tubular steel wind türbine with various design configurations. [8, 26, 19, 13, 4]

1.2 Wind Turbine

Machines that use wind energy to obtain mechanical or electrical energy are called wind turbines.Turbines have three main parts. These are the turbine housing, the propellers and the tower.Propeller blades, propeller hub and propeller shaft are also called rotor.The propeller shaft is connected to the gearbox.The shaft connecting the gearbox to the generator is also called the generator shaft.Generators used in wind turbines are called aerogenerators. Generator, gearbox and brake assemblies are located in the body, also called the Nacelle (Fig.4). In this Abaqus programme we are not modeling the Nacelle.This part will be represented in our model as a lumped mass and its value added the reference point in tower model and the magnitude of mass as 81 tons.

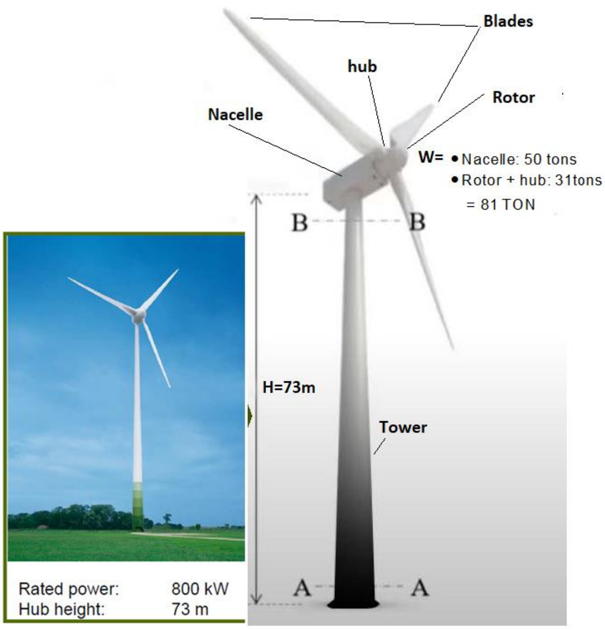


Fig. 4. Wind Turbine Components

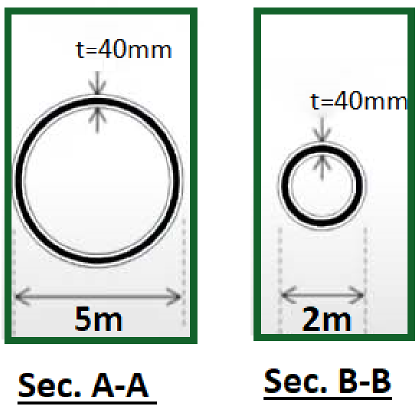


Fig. 5. Wind Tower Sections

Number of Eigenvalues requested for our model and we chose the first 5 modes.Fig.(10-14).In this paper, steel structural wind turbine tower with design configurations is analysed using FEM modelling.In Abaqus programme we create the part of wind turbine using solid elements to model the tower 73 meter tower with circular section.In the "Edit Base Extrusion" tab of the Abaqus programme the tower height of the wind turbine is 73m and the tower contraction angle is entered as θ=1.4312 degrees (Fig.6). In abaqus programme tower section will be Shell homegenous and Shell thickness is 40mm (Table 2) and the material is steel (Fig.5). Size for our part is the global size that actually chose approxiamately global size:700 mm that seems reasonable.A more refined mesh in order to capture the bending stiffness better we will use this 700mm mesh and used quadratic elements (Fig.17)

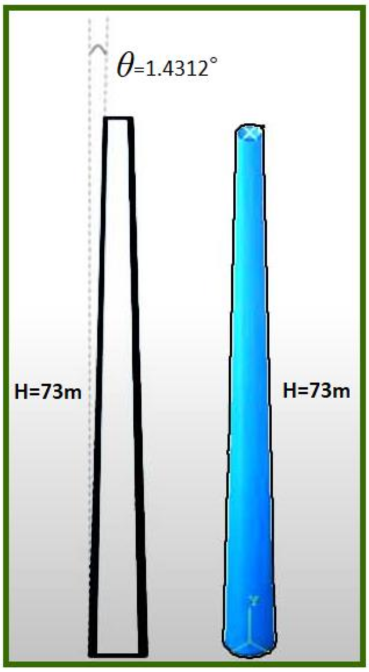


Fig 6. Wind Turbine Model

Structural and dynamic analyzes of the wind turbine, which is thought to be built in the Gürgendağ location, which is located in a region with winds at an altitude of approximately 1100 meters within the borders of Samsun İlkadım district has been tried to be analyzed using the Fig.7.

The main purpose of this study is to numerically examine the dynamic behavior of the wind turbine under the existing ground conditions of Mahmurdağı for the Mahmurdağı Wind Turbine.For this purpose, Türkiye Earthquake Hazard Map [18] data from AFAD website was used (Fig.8). The turbine preferred as a model in this study is the 73m high 800Kw wind turbine belonging to Enorcon Company [22]. Modelling was made in the light of the technical data of the relevant company. While the numerical model was being created, the blades of the wind turbine, the nacelle-rotor system were not modeled, but the actual weight, corresponding to approximately 81 tons, was applied as a load to the system. In the last part of the article, the dynamic properties of this 73m high tower are examined to obtain the natural frequencies and mode shapes.

As a result of the analysis, 5 different mode shapes, frequency and period values of the wind turbine planned to be built were obtained. Abaqus analysis completed step is presented in Fig.15.

Fig 17. Wind Tower Turbine Mesh in Abaqus CAE

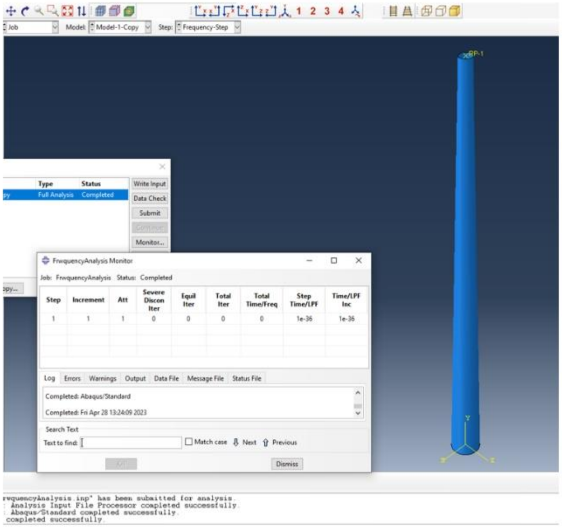


Fig 15. Abaqus Analysis Completed Step

Fig.7. Mamur Dağı Wind Turbine Settlement

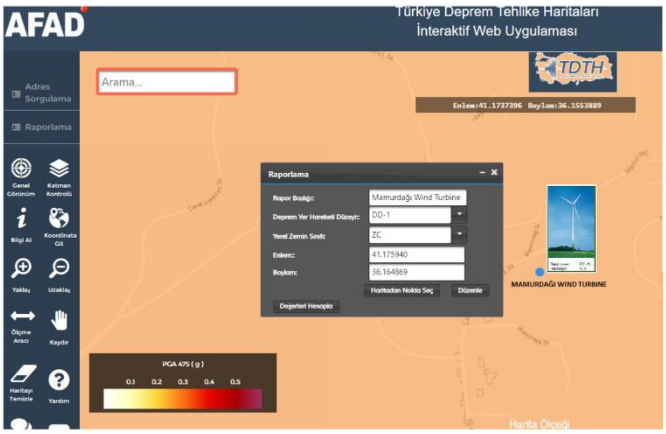


Fig 8. Ground Conditions of Mamurdağı, İlkadım,Samsun,(AFAD, Türkiye Earthquake Hazard Map

II. MATERIALS AND METHOD

Finite Element Analysis (FEA) reaches the desk of the engineering analyst as a software package. Unless that software has been designed to exploit the true generality of the method, the analyst will become frustrated by the gap between the method's theoretical potential and the unnecessary limitations imposed by the software. This is where Abaqus shines.

Abaqus is truly a general-purpose finite element-based software package [25]. In this study, a steel wind tower model was created and modal analysis was carried out with the finite element method. In the application of the finite element method, the ABACUS CAE 2022 package program, which is used in the field of academic and engineering applications all over the world, was used.In abaqus programme we need to define for the material propertis is the density,Young's moduluss and Poisson's Ratio is presented in Table1.

2.1.Description of Mamurdağı Wind Turbine

Table 1. Material properties of structural steel of the wind tower

Material property	**Elastisite Modulus(Gpa)**	**Density (g/cm^3)**	**Poisson's ratio**
Steel	205	7.85	0.3

Table 2. Wind Tower Dimensions

Height of Tower (m) 73 m	**Shell Thicknesses of Tower (mm)**	**Wind Tower Diameter (m)**
Sec. A-A	40mm	5m
Sec. B-B	40mm	2.5m

III. RESULTS AND DISCUSSION

The model steel wind turbine was first analysed with the finite element method using ABACUS CAE 2022 CAE 2022 [25], In Abaqus program it was chosen the create inertia tab and type the point in tower model and was added the magnitude of mass as 81 tons to the system and the same analyses were repeated and the results were compared. In this study, the following materials properties were taken in the analysis; Material grade: steel; the modulus of elasticity as E = 2.0x105MPa, material density ρ = 7.85kg / m3 and Poisson ratio υ = 0.3 as seen Table 1.

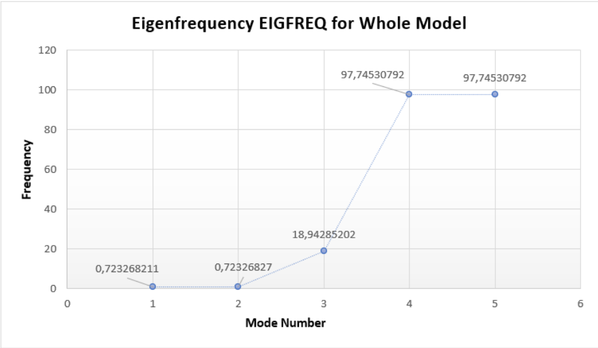


Fig 9. Eigenfrequency for Wind Turbine Model

In Fig. (10-14), mode shapes and frequency values are presented separately in the relevant graphics in the light of the analysis data of the wind turbine.

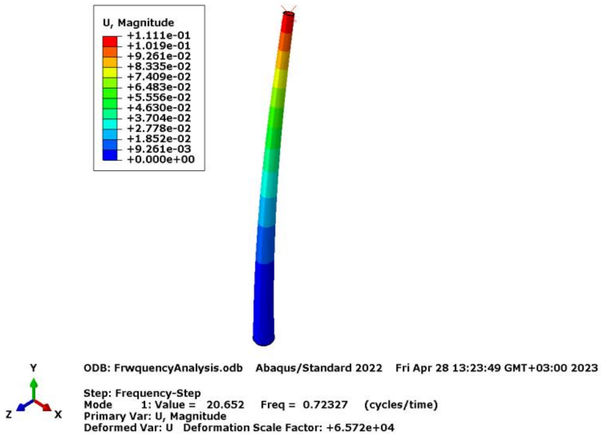


Fig 10. 1. Mode shape (Period value = 0.72327 s)

Mode 1 is translational mode shape.

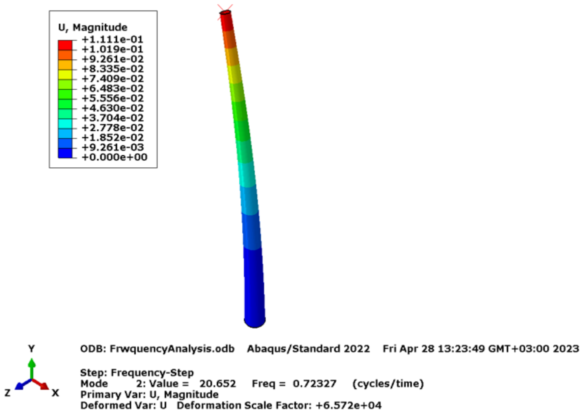


Fig 11. 2. Mode shape (Period value = 0.72327 s)

Mode 2 is translational mode shape.

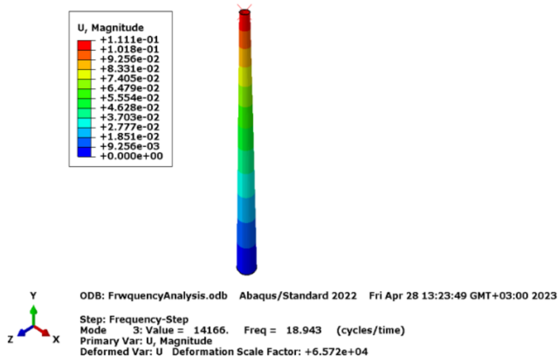


Fig 12. 3. Mode shape (Period value = 18.943 s)

Mode 3 is the elongation mode shape along the Y axis.

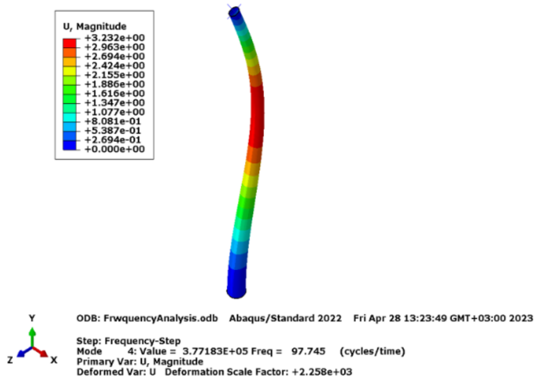


Fig. 13. 4. Mode shape (Period value = 97.745 s)

Mode 4 is torsional mode shape.

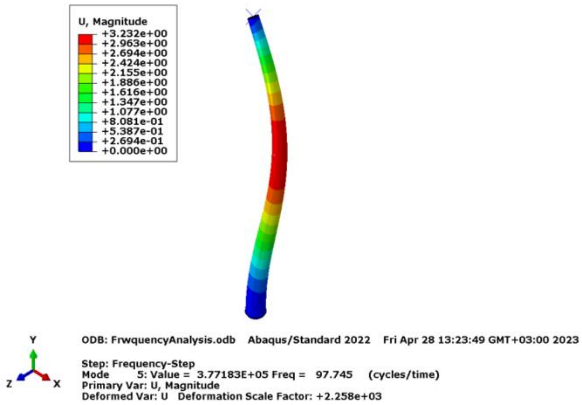
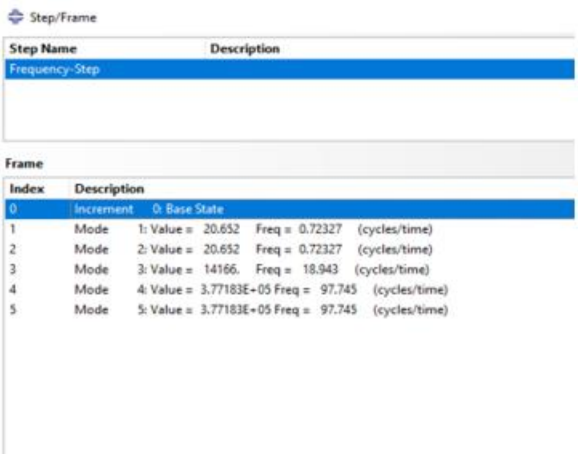


Fig. 14. 5. Mode shape (Period value = 97.745 s)

Mode 5 is torsional mode shape.

Table 3. Frequencies of Wind Turbine Model



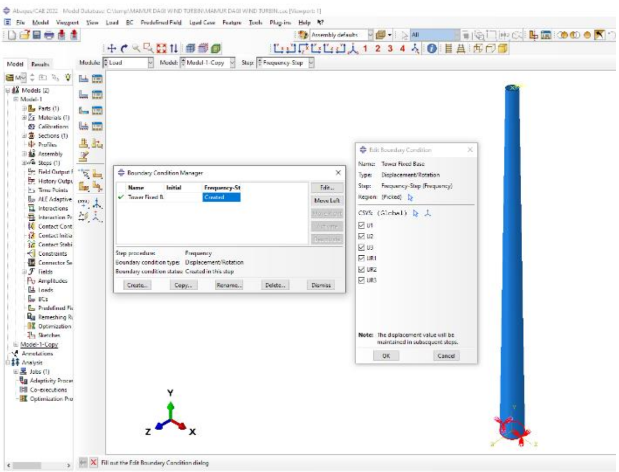


Fig.16. Abaqus Edit Boundary Condition Step

IV. CONCLUSION

In the model wind turbine, the result of the dominant frequency was obtained as 0.72327 (cycles/time). First Mode is in the y-x plane so this is the lateral movement in this direction. This is the Translational mode shape that is a cantilever with a lumped mass so this is the main mode. Mode 1 Value:20.652, and Period is :1.38sn.

In the model wind turbine, the result of the 2nd Mode frequency was obtained as 0.72327 (cycles/time). Mode 2 is Translational mode shape in the y-z direction. The result of the 3rd Mode frequency was obtained as 18.943(cycles/time). Mode 3 is the elongation mode shape along the Y axis.

Mode 4 and 5 is torsional mode shapes. These ar[11 both higher modes of wind turbines. Mode shapes like a wave in the middle of the tower. A plot of the mode number and the frequency was presented in the Fig.9. As a result, it can be said that the natural frequencies and mode shapes have been obtained by including the mass of nacelle-rotor system at the top of tower in order to study the effect of the tower design on its own dynamic behaviour. If interpretation is to be made according to the results of this study, if the entire wind turbine system is to be examined, the mass of the wind turbine should be taken into account, because the mass of the nacelle-rotor system can constitute more than 28% of the total mass.

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