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FATIGUE ANALYSIS OF ARTICULATED SUPPORT FOR OFFSHORE WIND TURBINE

Navin.S.S[1], Vivek Philip[2]

[1]PG Student, Department of Civil Engineering, SAINTGITS College of Engineering, Kottayam, Kerala, India
[2]Assistant Professor ,Department of Civil Engineering, SAINTGITS College of Engineering, Kottayam, Kerala, India

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Abstract -Offshore wind moves at higher speeds than onshore winds, thus allowing wind turbines to yield more electricity. With over 7500 kilometers of coastline and 500 GW of offshore wind power potential in India, there is a strong case to consider offshore wind as an energy source both from the perspective of energy security and climate change. Articulated support platform is a type of compliant structure for offshore wind turbine and is suited for sea depth of around 200 m. Previous researches show that articulated platforms are well suited for supporting the offshore wind turbine under environmental loads. Floating wind turbines, have been shown to experience much higher fatigue and ultimate loading than onshore or fixed bottom offshore turbines, and could therefore benefit greatly from load reduction techniques. Fatigue analysis of such platforms supporting offshore wind turbine are not yet investigated. The main objective is to obtain critical stresses to perform a fatigue analysis of a three legged articulated tower.

Key Words: Fatigue analysis, universal joint, articulated structure, ANSYS, Response Analysis

1. INTRODUCTION

Offshore wind moves at speeds greater than onshore winds allowing turbines to generate more electricity. Offshore wind should be considered as an important source of potential energy because India has about 7500 kilometres of coastline and 500 GW of offshore wind power potential. Compliant structure technology has the ability to move large wind turbines in offshores where the wind is stronger and consistent. Articulated support platform is a type of compliant platforms, suited for sea depth of around 200 m. Articulated/universal joints are connected to the sea bed, by allowing them to move freely under the action of current, waves and wind. Single hinged, multi-hinged, multi-legged are types of articulated support platforms. A multi-leg articulated tower has three or more columns parallel to one another. Multi legged articulated platforms has better stability and it could be investigated for its ability to support deep water offshore wind turbines. These type of towers are connected to the sea bed through a universal joint offering position restrain, but no restrain against rotation. By the buoyancy force acting on it, it can be held vertical. It must safely withstand the offshore environment, which includes the combined effects of wind and wave loads, for an offshore support structure to be viable for wind turbines. When compared to fixed platforms, compliant platforms are lighter and have greater responses compared to fixed supports. The research aims to study the fatigue characteristics of a universal joint which is supporting the structure by using the critical stresses obtained by analysing the offshore structure.

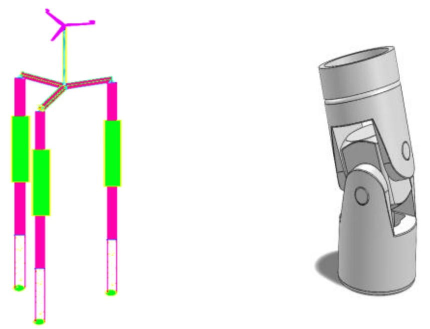


Figure 1 a)articulated tower b)universal joint

2. LITERATURE REVIEW AND OBJECTIVES OF THE STUDY

Articulated tower technology was developed in the early of 1970s for oil exploration. A number of experimental and analytical investigations on different types of articulated towers have been carried out in the past. Studies on articulated tower supporting offshore wind turbine were done recently by Anitha Joseph et.al (2013), Vivek Philip et.al (2015), Jiss.K.Abraham et.al (2015), Nimmy Lancelot (2016)
Said Fawad Mohammadi, Nelson Szilard Galgoul, Uwe Starossek, Paulo Mauricio Videiro, (2015), performed Fatigue analysis of a fixed type offshore structure having jacket supporting system.
Sebastian Kelma, Peter Schaumann, (2015), performed Probabilistic fatigue analysis of jacket support structures for offshore wind turbines exemplified on tubular joints.

Literature Gap

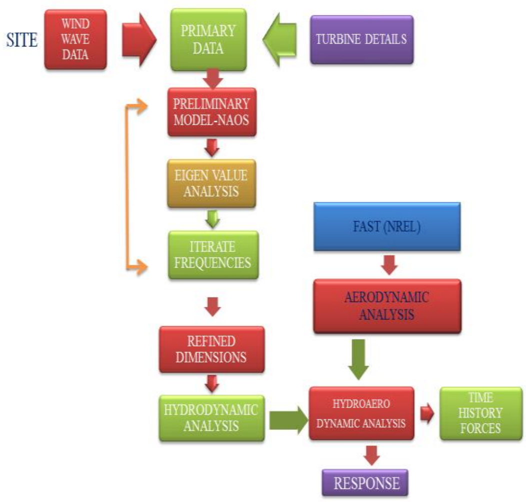
Previous researches show that articulated platform is well suited for supporting offshore wind turbine but Fatigue life assessment on such platforms supporting offshore wind turbine are not yet investigated. The primary aim of the present investigation is to study the fatigue life of articulated joint on a three legged platform supporting offshore wind turbine in Indian coastal conditions.

Objectives

1. To perform Coupled Aero hydrodynamic analysis of Articulated tower supporting offshore wind turbine by coupling NAOS (Nonlinear Analysis of Offshore Structures developed by NREL) with FAST(Fatigue, Aerodynamics, Structures and Turbulence) to obtain the critical points where stresses are maximum.
2. To model critical joints in SOLIDWORKS software and applying associated time history forces from NAOS to obtain stress variations.
3. To obtain critical stresses to perform a fatigue analysis using ANSYS.

3. METHODOLOGY

Using the wind and wave data from site and the turbine details, a preliminary model is developed in NAOS (Nonlinear Analysis of Offshore Structures, developed at Department of Ocean Engineering, IIT Madras). Eigen value analysis is done in NAOS to iterate frequencies. The frequencies are checked whether they are well away from normal sea frequencies; otherwise dimensions and mass are adjusted to control the natural frequency. With the refined dimensions, aerodynamics is carried out in NREL FAST (Fatigue, Aerodynamics, Structures and Turbulence, developed by National Renewable Energy Limited (NREL)) and coupled with hydrodynamics done in NAOS. Then the critical forces are obtained from non-linear time domain analysis and applied to the universal joint modelled in SOLIDWORKS and analyzed in ANSYS WORKBENCH for fatigue assessment.



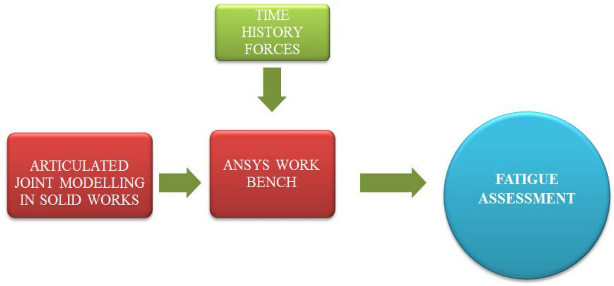


Figure2 Methodology

4. PRELIMINARY DESIGN

a) Environmental conditions: The site for the offshore articulated tower is located at 7° 17' 46.02" N 77° 33' 6.51" E at a water depth of 180 m in the Indian Ocean about 85km's from Kanyakumari, Tamil Nadu. The wave at site has found properties of wave height of 7m and wave period of 12seconds.

b) Wind Turbine and Tower: The wind turbine used is the "NREL offshore 5-MW Baseline Wind Turbine ", which is a conventional three-bladed upwind variable speed, variable blade pitch-to-further-controlled turbine. The gross properties of the NREL offshore 5-MW Baseline Wind Turbine were given as per Jonkman (2009). For ease of modelling an equivalent mass distribution as suggested by Vivek Philip (2013) in correlation with 5MW wind turbine and tower.

c) Preliminary dimensioning: The basic form of the three Legged Articulated support for wind turbine for present investigation is given in Fig3. The basic criteria's to be satisfied in design of a articulated tower as suggested by Kirk & Jain(1977) are that the buoyant force should be 1.5 times greater than total weight of structure and the ratio of restoring moment to overturning moment should be greater than 1.5 thereby ensuring the proper restoring when deflected and attaining of stability. The dimensions of buoyancy chamber, ballasting height, tower diameter, thickness etc. were fixed by trial and error process s in MS – Excel.

5. FINITE ELEMENT MODELLING AND EIGEN VALUE ANALYSIS IN NAOS

a) Numerical modelling: The tower was modelled with 5 beam element for each leg, 3 beam element for support beam, and 12 beam elements for tower. 3D general springs are provided at top of legs joining with beam. 3D coupled springs were provided for water-piercing elements and turbine mass was included as point mass at tower top.

b) Eigen Value Analysis: Eigen value analysis was done in NAOS to find the natural frequencies and corresponding mode shapes. Modes with time period less than 4seconds are of more stiffness and hence are called rigid modes and

modes with time period greater than 25seconds are of lower stiffness and hence are soft modes. Our aim in preliminary design is to keep the rigid modes less than 4seconds and soft modes greater than 25seconds to avoid resonance with sea frequencies and turbine frequency.
First three modes (surge, sway and yaw) are soft modes with frequencies, much greater than 25seconds. Other modes are insignificant.

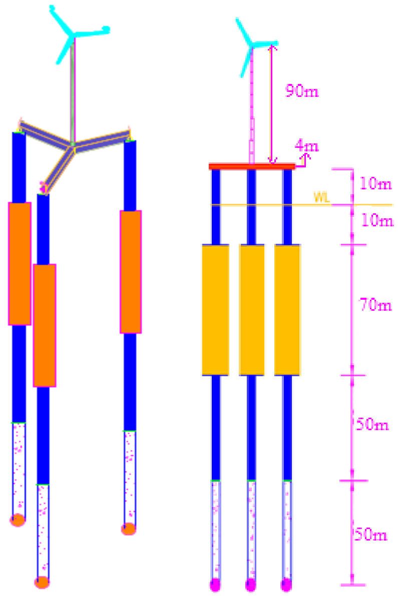


Figure 3 Final proposed structure

Coupled Dynamic Analysis

Non-Linear coupled dynamic analysis was done in NAOS (Nonlinear Analysis of Offshore Structures, developed at Department of Ocean Engineering, IIT Madras), coupling the time series of wind force obtained from NREL FAST (Fatigue, Aerodynamics, Structures and Turbulence, developed by National Renewable Energy Limited (NREL)). Analyses were done for several parameters and critical conditions.

6. TIME HISTORY FORCES

The type of analysis is Non-linear time history analysis. Investigations were carried out for time history forces corresponding to critical points .Three elements where selected corresponding to nodes 1, 2 and 3 and time history forces where computed from NAOS. Maximum values from time history forces where applied in universal joint model in order to compute fatigue life of the joint. Time history forces give the forces and moments corresponding to time in two coordinate systems " i " and " j ". Time history forces are as follows:

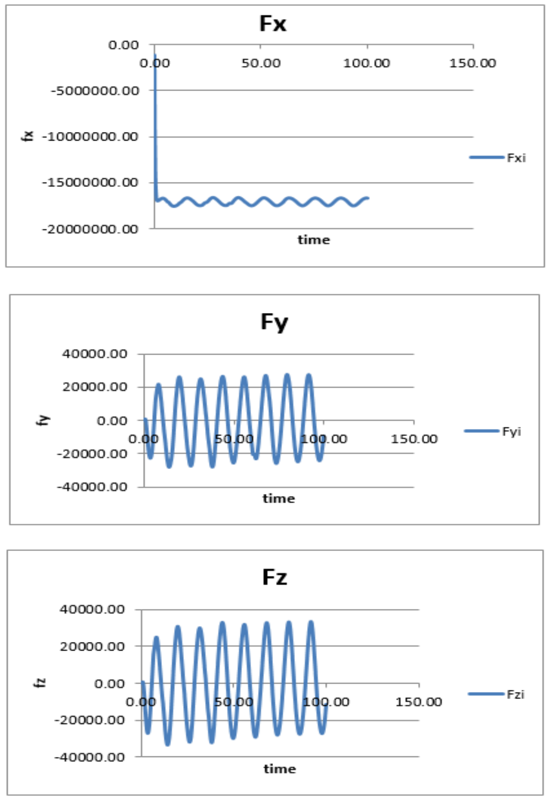


Figure 4 Time varying forces on x, y & z coordinates on element 1

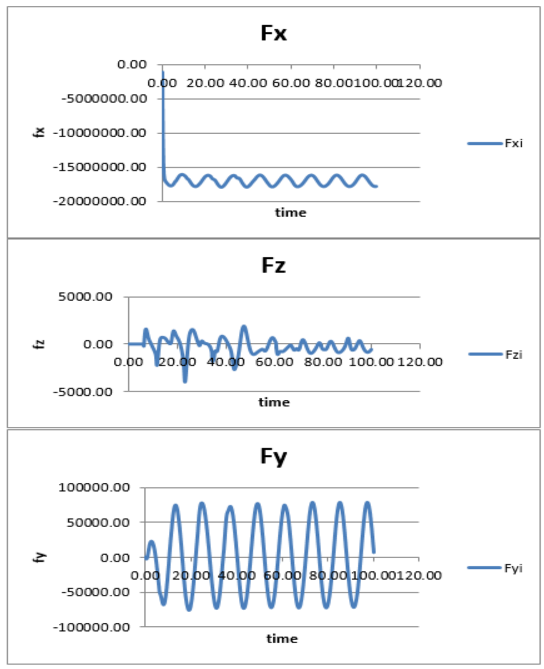


Figure 5 Time varying forces on x, y & z coordinates on element 2

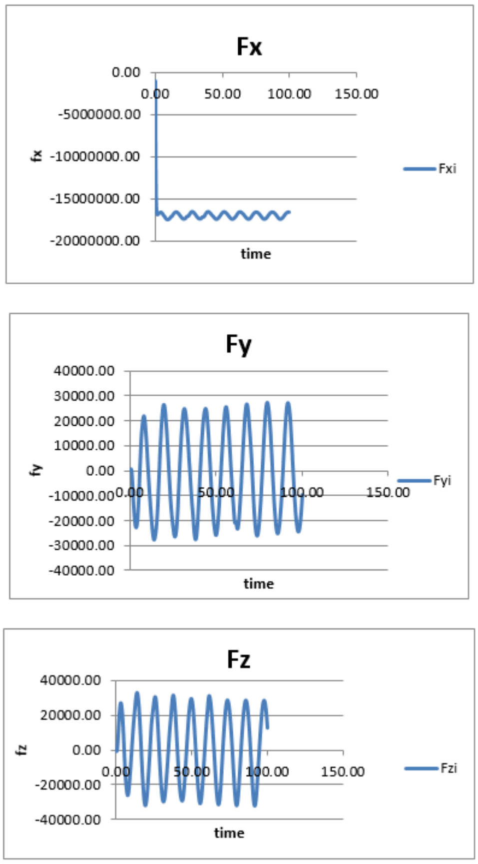


Figure 6 Time varying forces on x, y & z coordinates on element 3

Figures 4, 5, 6 shows the graphical representation of various forces with respect to time i.e. Forces along x, y and z directions acting on three legs of structure at nodes 1, 2 and 3 are plotted against time. Maximum forces obtained from node 1 are Fx = -1750000000 N, Fy= 25000 N, Fz= 37500 N. Maximum forces obtained from node 2 are Fx = -1750000000 N, Fy= - 4000 N, Fz= 75000 N. Maximum forces obtained from node 3 are Fx = -1750000000 N, Fy= 25000 N, Fz= 37500 N.

7. ANALYSIS

With the advancement in the finite element analysis (FEA) modelling, model based design of mechanical structures is replacing the traditional trial and error approach. Here the finite element analysis of joint is done in ANSYS WORKBENCH software there are three steps

1. Pre-processing
2. Processing
3. Post-processing

Pre-processing

After modelling and assembling the joint in SOLIDWORKS and importing to ANSYS WORKBENCH meshing is carried out. Tetrahedral meshing approach is employed for the meshing of the solid region geometry. Tetrahedral meshing produces high quality meshing for boundary representation of solid structural model. Since the tetrahedral is found to be the best meshing technique divide the whole model into several parts and mesh one by one in different mesh densities.

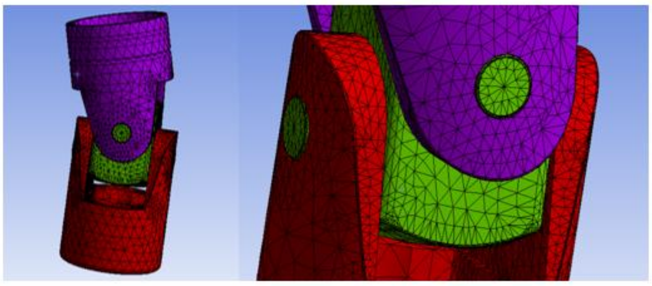


Figure 7 Meshing in ANSYS WORKBENCH

Processing

After pre-processing, Loads & boundary conditions are applied as shown in figure. Boundary conditions: 1.76e + 007N, 37500N, 25000N forces in global coordinate system applied at top of yoke and constraint at lower side.

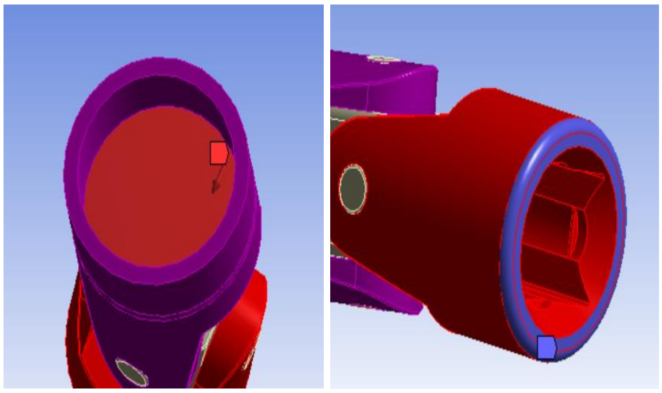


Figure 8 boundary conditions applied

Post- processing

After successfully completed the process, the results can be viewed. The three important results are noted and they are: 1.Vonmises stress
2. Major stresses
3. Fatigue – life, damage, safety factor

Maximum Vonmises stress = 347.44 MPa, Major Principal Stress = 301 MPa.

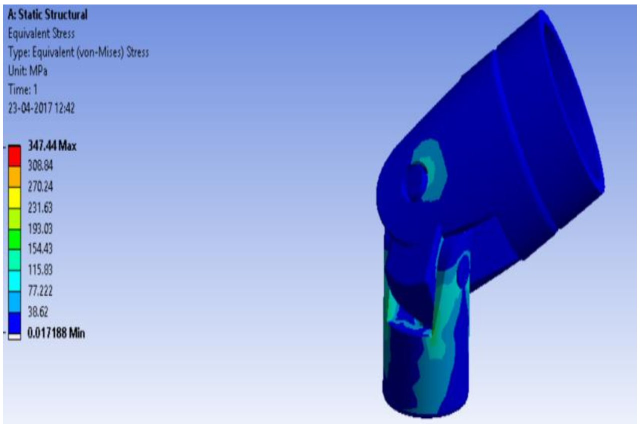


Figure 9 Equivalent Stress

Fatigue tool in ANSYS workbench gives numerous results such as the information about life, damage, safety factor, fatigue sensitivity etc. Fatigue life of the structure is minimum at joints and it can withstand only up to 59529 cycles.

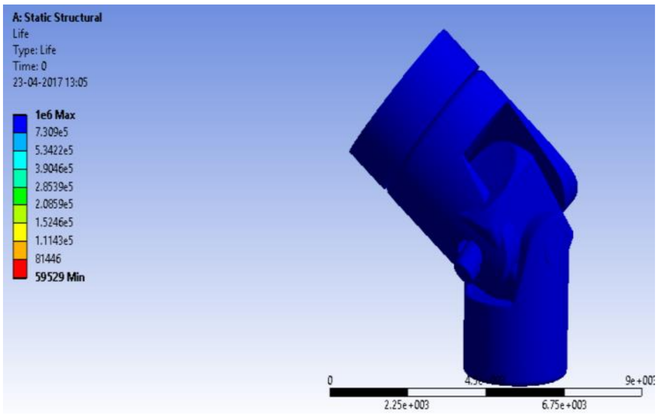


Figure 10 fatigue life

Joint connection i.e. trunnion will fail after completing 59529 cycles as shown in figure.

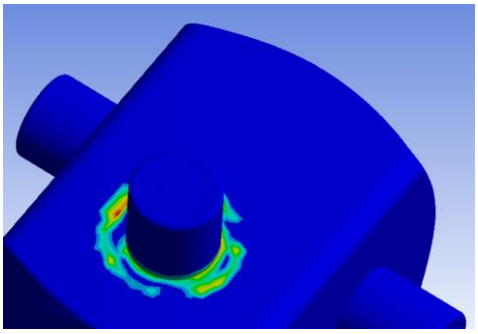


Figure 11 critical section in joint

Maximum damage value 16811 occurs at trunnion. Safety factor 0.589 occurs at joint in trunnion.

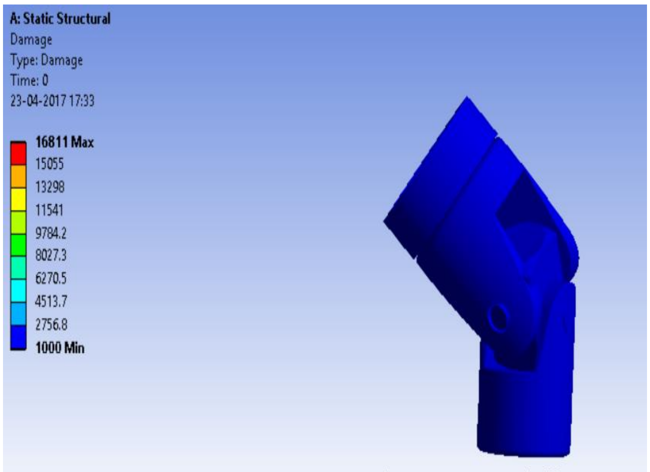


Figure 12 damage

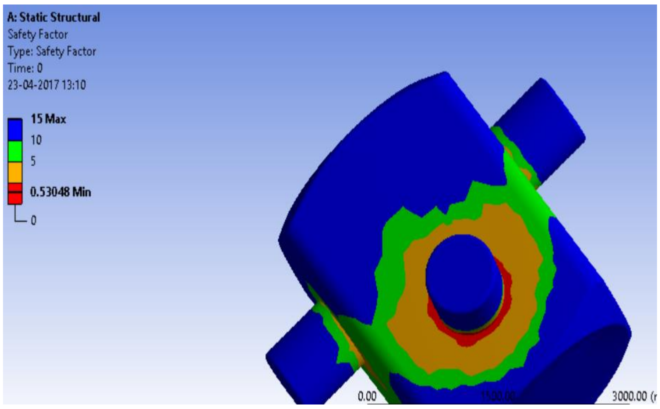


Figure 13 safety factor

8. CONCLUSION

Preliminary proportioning of the investigated structure was carried out in MS- Excel as a trial and error procedure. Eigen value analysis of the proposed three legged articulated support structure shows that surge, sway and yaw are soft modes with time period very much higher than 25seconds. Heave, pitch, roll motions are rigid modes with very low time periods (<4seconds). No modes associated with rigid body motions are found in the range 4 to 25 seconds. Also here the soft modes (surge, sway and yaw) have timeperiod much greater than 25seconds which is expected for a structure to be stable. Boundary conditions applied for joints are 1.76e + 007N, 37500N, 25000N (nodes 1 & 3) and 1.76e + 007N, - 4000 N, 75000 N (node 2) forces applied at the top of top yoke and constrained at bottom yoke. Fatigue assessment is an important tool in predicting the life of a structure The maximum load is taken by the trunnion and minimum load is taken by yoke parts in universal joint. Maximum Fatigue life is for yoke part and up to 59529 cycles trunnion can withstand. Fatigue damage value is maximum for trunnion. Joint is safe under given load conditions up to 59529 cycles and for getting an expanded life span the dimensions of the universal joint can be changed , then the fatigue life of the structure will be more.

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