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"A COMPARATIVE ANALYSIS OF OFFSHORE WINDMILL SUPPORTING STRUCTURE"

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Abstract – *Wind turbines are devices that capture the kinetic energy of the wind and transform it into electricity. The present study sets up competitive analysis of jacket support structure for 3.6MW and 5MW offshore wind turbine (OWT), which is placed at water depth of 40m. The offshore structure design required because it is constantly subjected to dynamic load such as wind load wave load, earthquake load. The analysis process of support structure including tower, transition piece, jacket substructure, is carried out by creating modeled in SAP2000. The forces and moments due to wave and wind are calculation by using the API RP 2A-WSD. In this paper analysis and results are obtained in the form of deflection, axial force and base shear.*

Key Words: *Offshore Wind Turbine Tower, Wave load, Wind Load, Earthquake Load, Deflection, Base Shear, Axial Force.*

I. INTRODUCTION

Wind turbines are the key machines in generating renewable energy, a sustainable practice that has the potential in the future to reduce or eliminate the dependence on fossil fuels to produce electricity. Wind turbines provide enough electricity to meet the needs of the country's electricity demand. Compared with onshore wind turbines, offshore wind energy presents several advantages such as higher wind speeds, lower turbulence intensity, decreased visual and noise effects for humans and the possibility to transport larger turbines.

Offshore structures may be analyzed using static or dynamic analysis methods. Static analysis methods are sufficient for structures, which are rigid enough to neglect the dynamic forces associated with the motion under the time-dependent environmental loadings. On the other hand, structures which are flexible due to their particular form and which are to be used in deep sea must be checked for dynamic loads. Dynamic analysis is particularly important for waves of moderate heights as they make the greatest contribution to fatigue damage and reliability of offshore structures. The dynamic response evaluation due to wave forces has significant roles on the reliable design of the offshore structure. [10]

For the design and analysis of fixed offshore structures, the calculation of the dynamic load (i.e., wind load earthquake load and wave loads) on vertical members is always of major concern to engineers, especially in important structure like offshore wind mill foundation design which passes almost 50% of entire offshore windmill.

For the design of offshore structures' supporting system have been designed as per the American Petroleum Institute (API). American Petroleum Institute (API) RP2A-LRFD, 1993 provisions provide characterization of environmental load and design requirement for fixed offshore support structure for use in design, describe analytical methods to determine the forces induced in the support structure system by wave motions, and give guidance for sizing and configuring steel elements for the design forces. The environmental loads are consist earthquake loads, wind, wave and current loads. Design methods for structures, members or components under static loads to avoid failure, collapse, buckling are well defined in codes and standards, such equivalent codes in other countries, whilst for offshore structures the design code used almost invariably is API RP2A (API 1993).

In this paper comparative analysis has been came at for 3-Legged Jacket supporting system and 4-Legged Jacket support structure of NREL 3.6MW and 5MW offshore wind turbine at a water depth of 40 m. The wind loads, wave loads, blade load earthquake load and the combination of loads are applied on structure. For dynamic analysis of offshore windmill structure, widely used program SAP2000 is used by using SAP2000 and then results are obtained in the form of the Base Shear, Axial Force, and Deflection at top of the tower. Gross property for the NREL 3.6MW and 5MW reference wind turbine is mention in Table -1.

Table 1 **Gross property for the NREL 3.6MW and 5MW reference wind turbine**

Parameter	Unit	Value of 3.6MW	Value of 5MW
Design Tip speed ration	-	7.56	8
Average wind speed at hub height	m/s	7.8	7.8
Number of blade	-	3	3
Density of air	kg/m3	1.225	1.225
Rotor speed	m/s	14	12
Rotor diameter	m	108	120
Rotor radius	m	54	60
Rated wind speed at turbine rated Power (V_{rated})	m/s	11.71	11.71
Weight of blade	kN	178.33	288.05
Weight of hub	kN	690.66	1110.94

II. THE JACKET TYPE SUPPORT STRUCTURE MODELING

In this paper, 3-Legged and 4-Legged jacket-type support structure used to support the NREL 3.6MW and 5MW offshore wind turbine at a specific water depth of 40 m. The transition piece, which is connected with the bottom of the tower and the top of the jacket legs, is modeled using a 4.0 m thick concrete block of M40 grade concrete for both 3-Legged and 4-Legged jacket-type support structure.

The Fe345 Grade steel is used in structure which have density of 78.5 kg/m^2, Young's modulus of 200GPa, Poisson's ratio of 0.3 and yielding strength of 350MPa, remains same for tower as well as support structure.

Table-2 shows the geometric dimension of tower with its global height, outer diameter and thickness. The Section property of support 3-Legged and 4-Legged jacket-type support structure for 5MW tower is mention in Table-3; similarly Table-4 shows the section property of 3.6MW tower.

Table 2 **Tower Cross Section Property for 5MW and 3.6MW**

Global Height (m)	Outer Diameter (m)	Thickness (mm)
50	5.79	30
60	5.5	30
70	5.21	30
80	4.92	30
90	4.63	30
100	4.34	30
110	4.052	28
120	3.764	26
130	3.476	24
140	3.188	22
150	2.9	20

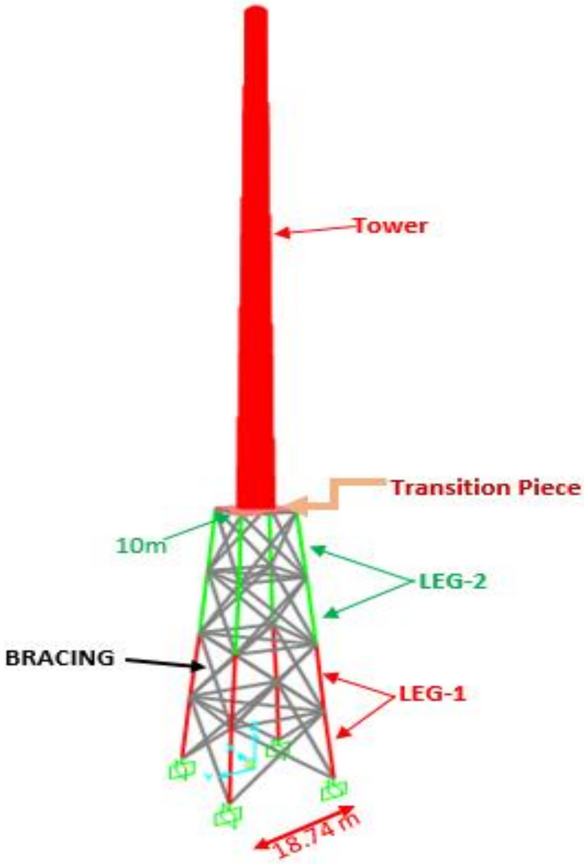

Figure 1 **OWT Modal**

Table 3 **Support Structure property of 5MW**

Capacity	Property	Outer Diameter (m)	Thickness (mm)
4-Leg	Leg-1	1.4	35
	Leg-2	1.35	30
	Bracing	0.85	25
3-Leg	Leg-1	1.9	40
	Leg-2	1.85	35
	Bracing	1.25	30

Table 4 **Support Structure property of 3.6MW**

Capacity	Property	Outer Diameter (m)	Thickness (mm)
4-Leg	Leg-1	1.3	35
	Leg-2	1.3	30
	Bracing	0.85	25
3-Leg	Leg-1	1.65	40
	Leg-2	1.65	35
	Bracing	1.2	30

III. Design Load:

1.1 Wave Load:

Several theories for the description of the shape and kinematics of regular waves exist. Regular wave theories used for calculation of wave forces on fixed offshore structures are based on the three parameters water depth (d), wave height (h) and wave period (T) as obtained from wave measurements adapted to different statistical models, are shown in Figure-2.

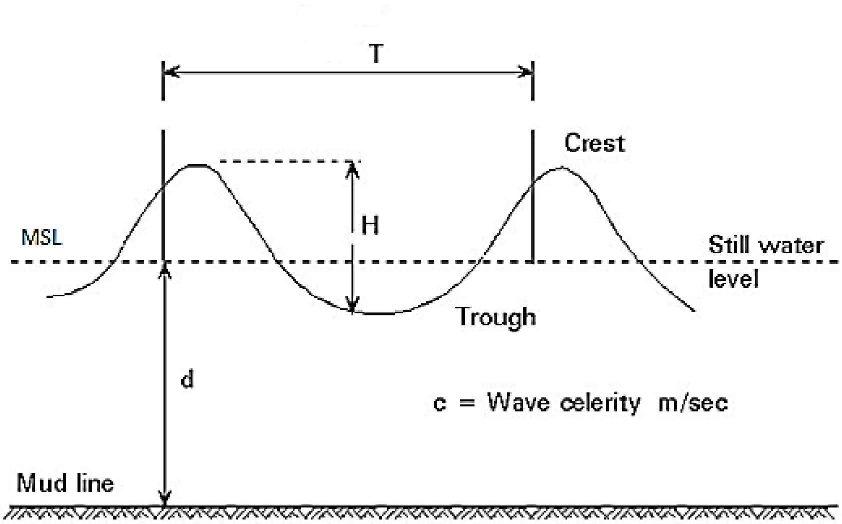

Figure 2 **Wind and tidal Current Profile**

Wave forces on individual structural elements can be calculated using Morison equation, based on hydrodynamic drag and mass coefficients (Cd, Cm) and particle velocity and acceleration obtained by the chosen wave theory. This description assumes the waveform whose wave height (h) is small comparison to its wavelength (L), and water depth (d). According to Morison's equation, the intensity of wave force per unit length on the structure is calculated. Table-5 shows the detail for wave load parameter which are consider for current study.

Table 5 **Detail for Wave Load Calculation**

Definitions	1-year return period wave for operating conditions
Water depth (MSL)	30 m
LAT (from MSL)	-2 m
HAT (from MSL)	2 m
Tide	1m
H_{max}	5m
T_p	6.5

1.2 Blade Load:

For the Turbine load on the rotor shaft code EN-61400-2:2006 is used. As per EN-61400-2: 2006, Rotor Wind Thrust is calculated on the upwind side or downwind side of rotor. It Calculate Thrust in X-direction on wind side, torsional moment along Z-axis and bending moment along Y axis,

$$\Delta F_{x\text{-shaft}} = \frac{3 * \lambda\ design * Q\ design}{2 * R}$$

$$\Delta M_{x\text{-shaft}} = Q_{design} + 2\ m_r g e_r$$

$$\Delta M_{shaft} = 2\ m_r g L_{rb} + (R/6) * \Delta F_{x\text{-shaft}}$$

Figure 3 indicates the axis of forces generated on turbine due to blade rotation,

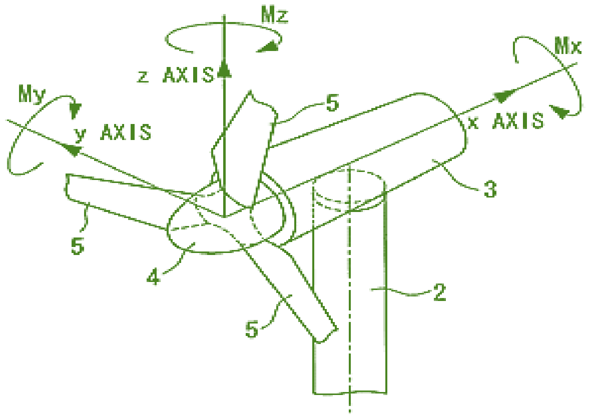

Figure 3 **Turbine Load**

Table 6 shows the load moment obtain after considering all the parameters of 3.6MW and 5MW Wind turbine data. This load and moment will act at top the tower

Table 6 **Turbine Load**

Parameters	5MW	3.6MW
F_X	995.2229299	644.9
F_Z	1399	869
M_Y	13269.63907	7265.62
M_X	4976.11465	3070.97
M_Z	9952.229299	5374.20

1.3 Wind Load:

When a structure is placed in the path of the moving air so that wind is stopped or is deflected from its path, then all or part of the kinetic energy is transformed into the potential energy pressure. Wind Load Calculation is carried out as per IS: 875-(Part-3) - 2015 by using Basic wind speed and wind load criteria is given for Indian Region.

Following parameter are for wind load calculations,
Basic Wind Speed= 50m/s
K1= Probability Factor= 1
K2= Terrain Category-1
K3= Topography Factor= 1
K4 =Importance Factor for Cyclonic Region= 1.30
Wind load is applied on structure in form of the uniform area load.

1.4 Seismic Load
Seismic Load on Offshore Wind is calculated as per IS: 1893(Part 1): 2016. Mass modal analysis method is used for the calculation of seismic load acting on OWTs. For the seismic load calculations following parameters are consider,
Z= Zone factor= 0.36
I= Impotence factor= 1.5
R= Reduction Factor= 5
SAP2000 program has capacity to generate auto earthquake load based on defined parameters.

Analysis:

1.1 Modal Analysis:

The design of the turbine support structure is firstly conditioned by its natural frequencies. Principally in the first mode of vibration. The dynamic characteristics condition imposes avoidance of resonance between rotor movement and natural frequency of the tower during operation. The frequency limit is range between the 0.2 Hz to 0.8 Hz. If it is **less than**

0.2Hz then its match with blade frequency and if it is greater than 0.8Hz then it is match with rotor frequency so in both case, this criteria then it creates the resonance and it is harmful to tower structure. Natural frequency of 5MW and 3.6MW wind turbine is shown in Figure-4.

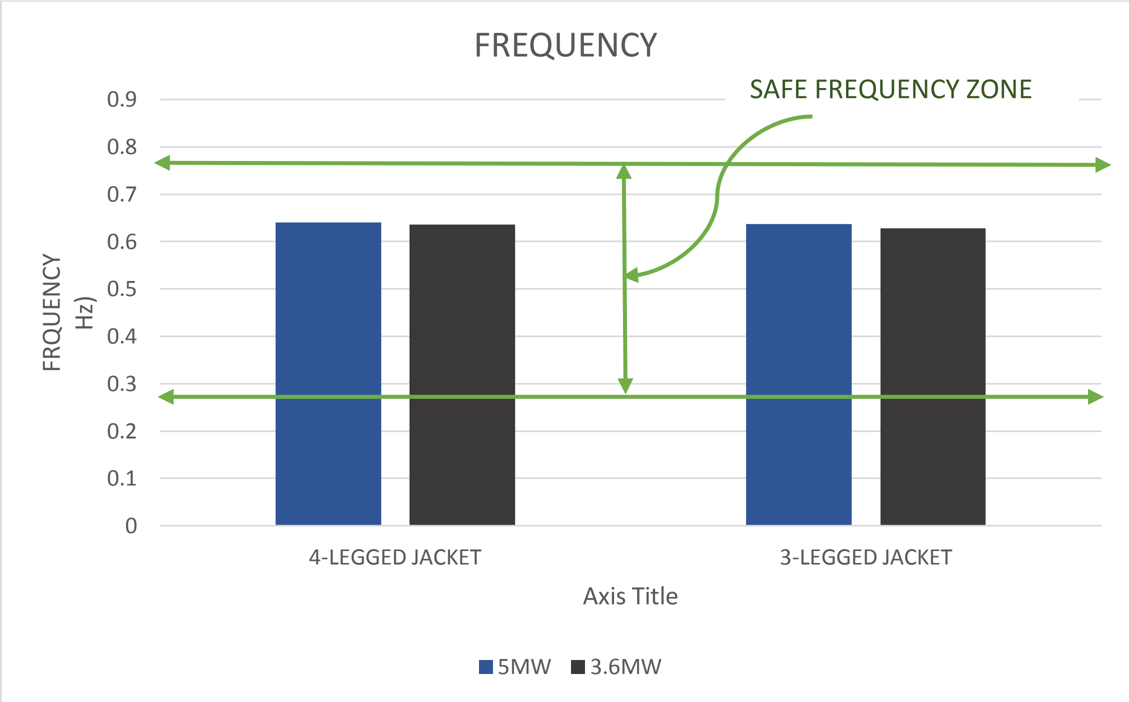

Figure 4 **Frequency**

1.2 Deflection

To have a better understanding of the behavior jacket type offshore windmill, the analysis was conducted for a 40m water depth for the earthquake, wind and wave forces; combination of loads. Deflection is carried out at every 10m height of wind tower, and result shows the max deflection occurred at top of the tower which is shown in Figure-5 and Figure-6 represent deflection of OWT.

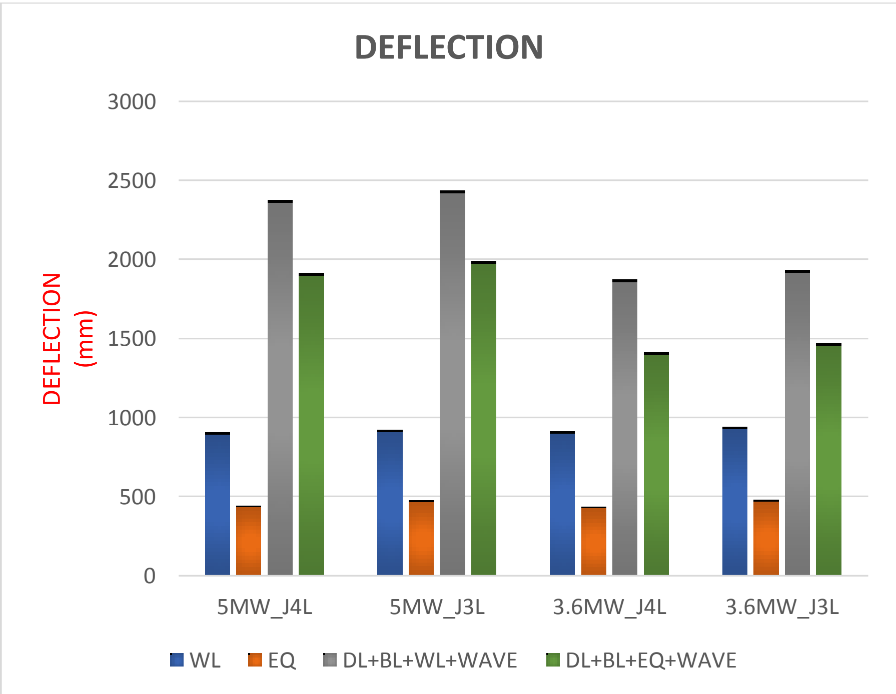

Figure 5 **DEFLECTION OF OWTs**

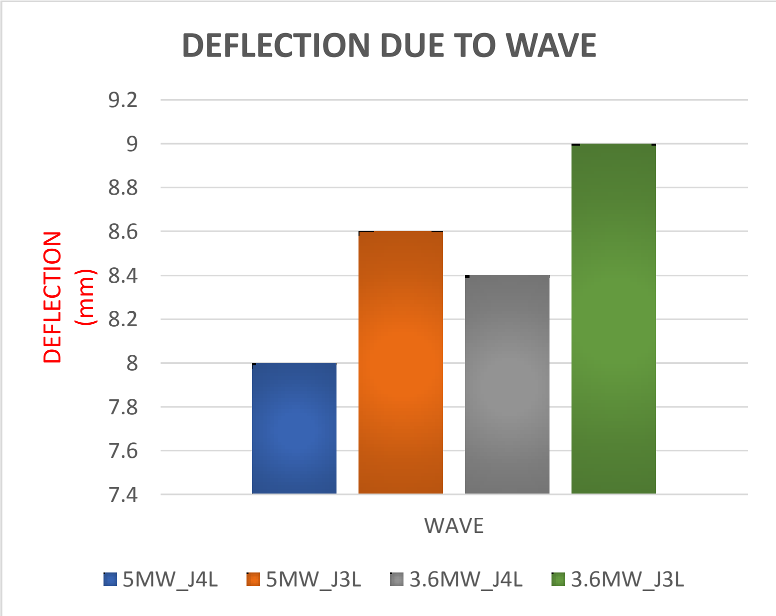

Figure 6 **Deflection of OWTs due to wave load**

Higher deflection has been observed in 5MW than 3MW. But in case of wave load, higher deflection is observed for 3-Legged turbine structure.

1.3 Base Shear

Base shear is an estimate of the maximum expected lateral force that will occur due to loads acting on structure at the base of a structure. The comparison of the base shear for the different capacity tower is shown in Figure-7.
Base shear forces comparison shown in figure to figure. As it is cited, base shear decrease with the decrease of the turbine weight at the tower top.

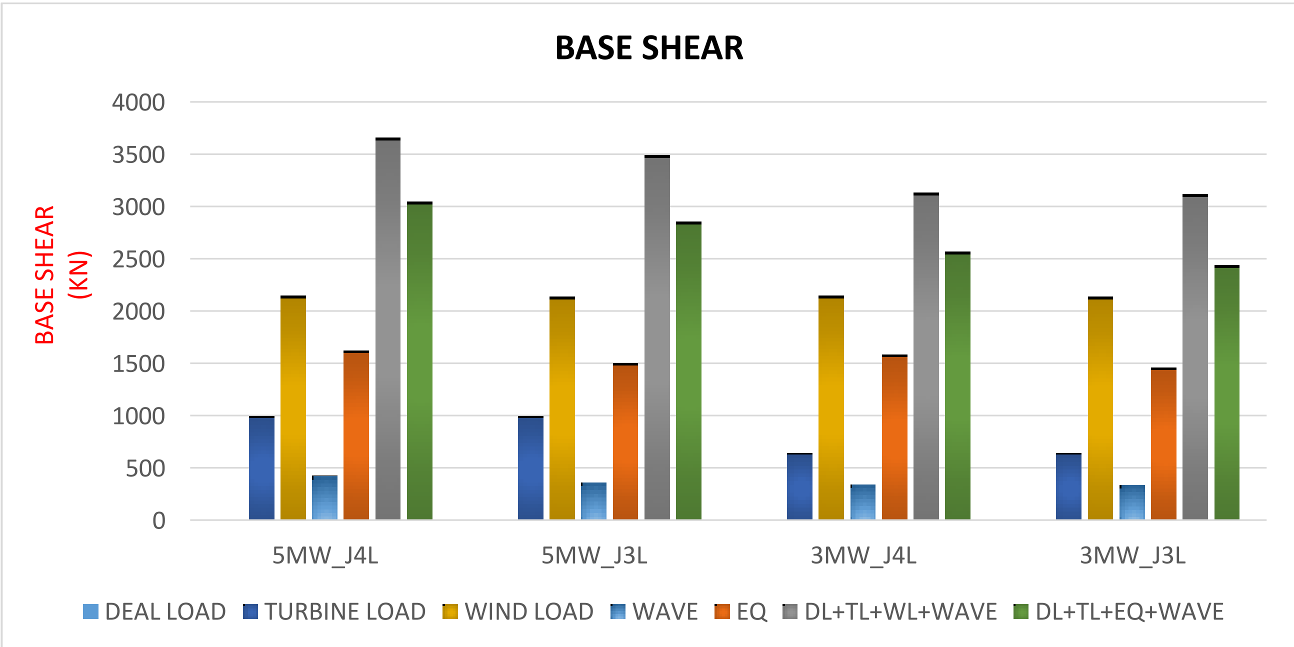

Figure 7 **Base Shear**

1.4 AXIAL FORCE:

The support structure of offshore wind turbines is subjected to significant dynamic loading. It is important to understand the dynamic nature for foundation design. When an offshore wind turbine is based on a jacket substructure, the external loads are transmitted into the seabed soil through the jacket piles in form of axial forces. In this paper the characteristics of the axial loads due to dynamic loading in support structure is carried out, in the form of tension and compression force. Axial force effect in J4L windmill is shown in Figure-8 and effect in J3L windmill is shown in Figure-9.

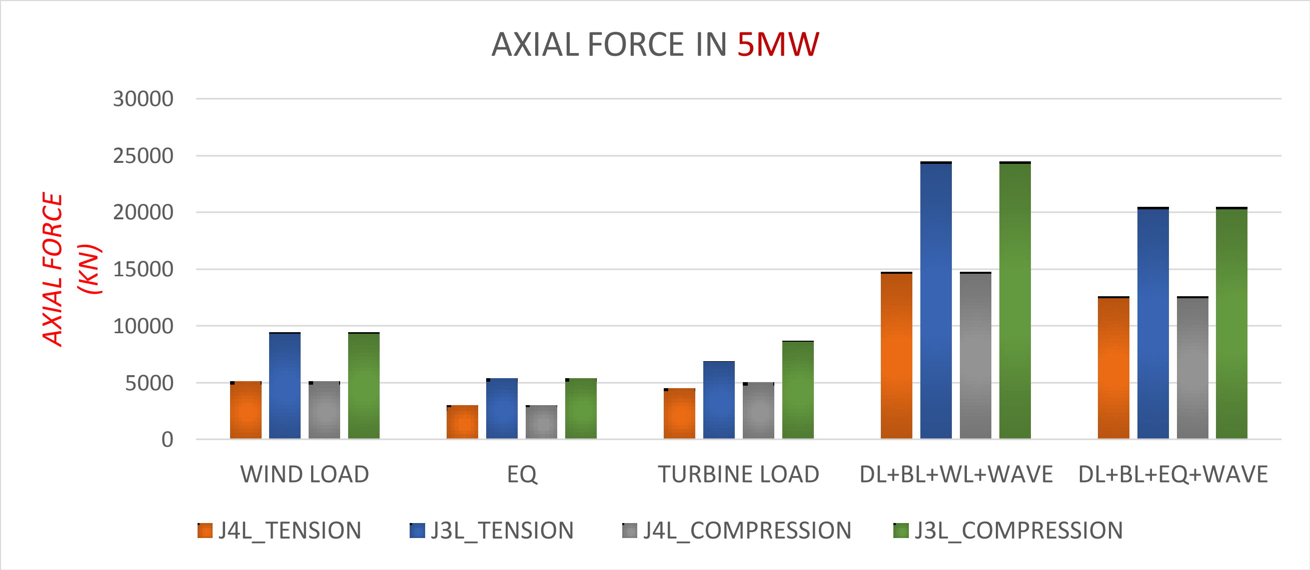

Figure 8 **AXIAL FORCE IN J4L OWT**

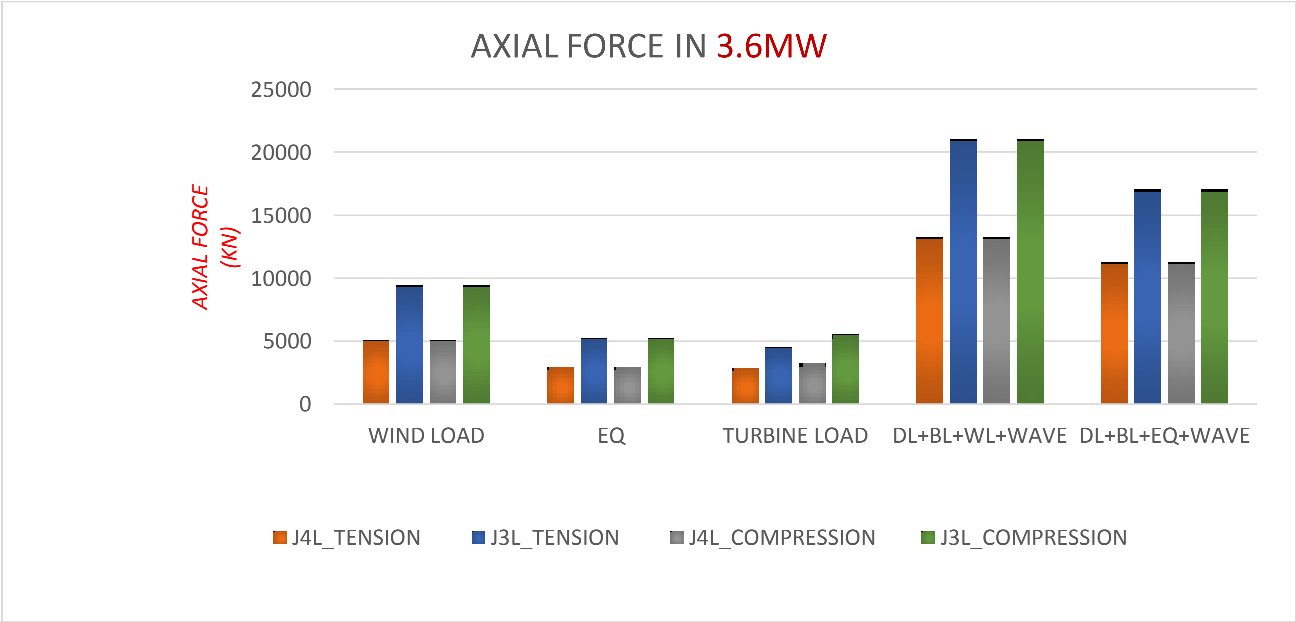

Figure 9 **AXIAL FORCE IN 3.6MW OWT**

From the axial force comparison, it is clear that the same compression and tension are obtain due to coupling action. 3-legged structure develops larger axial forces than the 4-Legged Structure and it is higher almost 1.5 higher.

IV. CONCLUSION:

The offshore windmill support structural analysis is used to obtain displacement response under varying external dynamic loadings such as individual and combination of wind load, wave load, turbine load, earthquake load. Analysis of OWTs is carried out in the form of Deflection, Axial Force, base Shear and Modal analysis.

From analysis following considerations are drawn. Here, **natural frequency** of all support structure is **in-between 0.2 to 0.8Hz** so that resonance will not acquire.

The dynamic loads at the top of support structure will obviously create higher fatigue damage. After the analysis, it is clearly seems that max deflection is found on the top tower; it shows that deflection in 3-Legged jacket structure is higher than the 4-Legged jacket structure in both 3.6MW and 5MW OWTs.

The present result shows that Axial Force and Base Shear is higher in 3-Legged jacket support structure compare to 4-Legged Jacket Structure.

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