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Efficacy of Twisted Jacket for Offshore Wind Turbine Foundation

Makwana Krishna Arvind*1, Prof. Ravindra Desai**
**1Applied Mechanics Dept, Walchand College of Engineering, Sangli, Maharashtra, India*
*** Applied Mechanics Dept, Walchand College of Engineering, Sangli, Maharashtra, India*
Corresponding Auther : Makwana Krishna Arvind

ABSTRACT

With the increase in demand of offshore wind energy, the need for offshore structures for supporting wind turbine is increasing. These structures can be floating and moored to the seabed or a fixed structure with its foundation on the seabed. In this paper, a jacket and 3-legged twisted Jackets with twisting angles 0°, 30°, 60° & 90° used for supporting 5 MW NREL wind turbine is statically analyzed for a site selected is in the Indian sea near Rameshwaram, in Tamilnadu. The structure is designed based on the procedure followed in oil and gas industry which conforms to the API-RP2A WSD (2007). The structure includes the jacket, transition piece and the tower. The structure is modeled in Bentley SACS v7 within which the static structural analysis is carried out. The preliminary analysis meets the requirements specified in the codes API RP 2A and DNV-OS-J101.

Keywords - Offshore wind turbine, static, twisted jackets, SACS.

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I. INTRODUCTION

The offshore wind energy is one of the most important renewable energy resources which can cover worldwide energy demands. The available land based wind energy is already been explored to its maximum potential in many regions and thus offshore wind gains importance. While the limited areas on land with high wind potential are identified and being utilized, the offshore sector is still to be developed, with the necessity to establish an availability chart for the offshore wind energy and the economics of harnessing such energy. Even though offshore wind energy has numerous bottlenecks in implementation the overall performance and efficiency of the new generation wind turbines producing power in MW could offset the disadvantages. A higher capital investment is required for offshore wind turbines because of the costs associated with marinization of the turbine and the added complications of the foundation, support structure, installation, and decommissioning. The short construction period and low operation and maintenance cost make the wind energy more attractive. Many developed countries have achieved 20-30% dependency on renewable sources where as in India it is less than 12%. Centre for Wind Energy Technology (C-WET), Chennai, India is the primary nodal agency associated with wind energy. Preliminary studies and reports exists stating that there are many potential offshore wind sites in Indian waters and these areas till date remains untapped. India has a coastline of about 7,600 km and in order to harness the wind energy effectively, primarily the offshore wind potential should be estimated by installing offshore wind mast at potential sites.[2]

The offshore wind turbines are installed far off the coast preferably and the water depths wherein these structures can be varying from shallow to deep. National Renewable Energy Laboratory (NREL), USA has classified 0-30 m as shallow water, 30-60 m a transitional waters and greater than 60 m as deepwater for installing offshore wind turbine. However the concept of deepwater for offshore industries is greater than about 1000 m. In shallow water, the wind turbine is fixed on the substructures. Tripods, jackets, and truss-type towers, monopiles and gravity base serves as substructure. Most of the fixed wind turbines are applied for water depth 20-30m, and the support structure are typical monopiles and tripod structures. In order to extend the application of Offshore Fixed Wind Turbine (OFWT) in deep water where winds are stronger and steadier a stronger support structures like jacket and gravity base are proposed to withstand the met-ocean loads as well as dynamic loads from the wind turbine though this may prove to be expensive compared to floating structures. In deeper waters the wave and current loads will increase significantly and the jacket

substructure which could provide adequate ultimate strength capacity becomes a good alternative. Many of the proposed concepts utilize designs borrowed from the oil and gas industry. The offshore wind energy can be viable only when the substructure cost is optimized, for which there is need to develop economical design and construction methods for installation of substructure for wind turbine. While the viability of each substructure varies from case to case, the optimal option shall be identified for each location.

A recently-designed new jacket substructure was invented and patented by Keystone Engineering Inc., called the inward battered guide structure (IBGS), or “twisted jacket” foundation. A number of advantages of the IBGS have been suggested, such as the fabrication costs are approximately 20% less expensive than traditional offshore wind turbine jackets, it has fewer nodes and components compared to a traditional jacket, it is safer and easier to manufacture than a traditional jacket, it is more compact, allowing for more structures to be transported, and it has less offshore welding and underwater work, greatly reducing commercial and schedule risks, etc. [1].

This study compares several jacket substructures on the basis of stresses induced in members. In total, 5 substructures including 4 twisted jackets with various degrees of twisting were modelled and analysed. Stress analysis using beam element models were performed. The results provide insights into development of a novel design for offshore wind turbine substructures.

In this paper, the static analysis of a substructure jacket supporting an offshore wind turbine is presented. The analysis is carried out for a water depth of 50 m at an area near to Rameswaram in Tamil Nadu, India. The jacket structure including the tower was modelled using Bentley SACS v7 and analysis was carried out. Steel is a material which has high strength per unit mass. Steel as a construction material is one of the very important materials used in the industry, the reason is because of its characteristics and properties that it has.

II. INTRODUCTION TO STRUCTURE

The access to energy is a very important matter in the modern society, but even more important is how the energy is provided. There is almost unlimited ways of how to provide energy and each method has got their own benefits and disadvantages. The method should be efficient, and in addition not affect the environment in a bad manner, where the latter is playing a very important role for the energy production today. Today we are talking about the importance of having a sustainable development, which means that global changes should be progressive without precluding forthcoming generations to satisfy their needs . One major example of sustainable development in the energy industry is renewable energy, meaning that the source is not consumed but just used once, ready to be used again. One of the bigger challenges for today’s society is the change from non renewable energy sources, such as fossil fuel consumption to renewable sources such as wind power. Today, almost one third of Sweden’s energy originates from fossil fuels and less than 1% comes from wind power. The situation is not specific for Sweden, but more of a trend valid for most countries. The use of wind to produce energy is a very old tradition. As early as 3000 years ago China and Japan built wind mills, and later on in the 13th century wind power were spread to Europe. In the 19th century wind power was one of the largest sources of energy. Wind mills were used in several areas, such as grinding seed, pumping water and operating sawmills etc. Today’s situation is different with only a few percent of the total energy production origin from wind power. Wind turbines today involves very advanced technology, but the basic principle is that the wind forcing a rotor, via the rotor blades, to rotate and this rotation creates electricity via a generator [5]

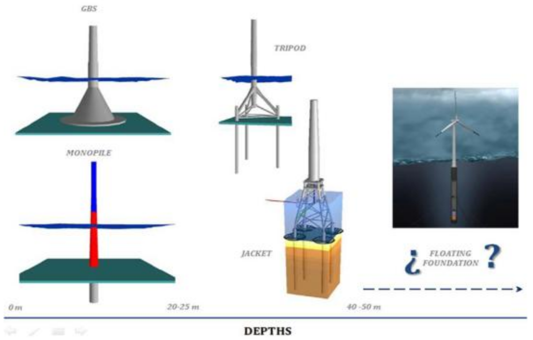
A. Types Of Foundations

This epigraph contents, firstly, a discussion about the foundations currently used and, secondly, a thought about the foundations forecasted to be used in the future. First offshore wind facilities were built in locations close to the coast with foundations below 25 meters and with favourable geotechnical properties, mainly sand. Most of them were founded on steel monopile foundations and gravity based structures foundations. As time passed, these facilities were extending to greater depths which, added to an increasing size of wind turbine generators, led to other, more complex foundation solutions appearing, such as tripod and jackets (Fig. 2) [5].

1) Steel monopiles

Steel monopiles are deep and individual foundations that, by means of their driving or/and drilling in the ground, achieve the load transmission. They are competitive foundations for small and medium size wind turbine generators, although can be competitive also for some big wind turbine generators. Their mass production and their installation are easy, being the most difficult question to find suitable vessels for their transportation and installation.

Fig. 1: Foundations types regarding the seabed depth



2) Gravity Based Structures

Gravity ased Structures (also called GBS) are able to maintain the stability facing any conditions, only by means of the own weight of the structure. These foundations are competitive when environmental loads are relatively limited and when the own weight of the structure are significant. The shape of the structures is used to concentrate their weight in the base, looking for a reduced diameter in the medium sea level, achieving so to reduce the hydrodynamic actions due to the wave and the currents. Although the most usual shape is the conical one, these structures can adopt other shapes. The typical diameter in the base of conical GBS is around 30-40 m, although this magnitude depends on several determining factors.

3) Tripods

Tripods are steel tubular foundations inspired in the oil platform. These foundations have been short tested up to this moment, but their future is too promising. The diameters of the tubes forming part of them are, generally, between 1.5 & 2m. In particular, jackets used for offshore wind farms are tubular lattice with four legs that, due to the small diameters of the tubes, are little exposed to the wave and the currents; then, they are appropriate for severe maritime weather. And, on the other hand, tripods have a central column below the wind turbine tower, following the monopole philosophy somehow, but connected by means of a tubular structure to three inferior legs.

4) Jacket foundation

The jacket foundation concept is characterized by a number of main legs which are stiffened by transverse braces. The legs are typically connected to the soil by piles or in more recent designs also by suction buckets. Aerodynamic, hydrodynamic and gravity loads are mainly transferred as axial loads through the members of the structure, but the members also experience certain shear forces, bending moments and even torsion. The transfer of global loads into the soil differs significantly from monopiles. Shear forces and torsion moments are transferred as lateral loads into the seabed. Axial loads and overturning moments are mainly transferred as axial compressive and tensile forces. In case of the overturning moments this is achieved by load couples in opposite directions at the individual legs, utilizing the distance of the legs in the footprint as lever arms. The connection between the tower and jacket is established by a transition piece. In contrast to monopiles, the jacket does also carry secondary steel structures like boat landings and access ladders. Compared to monopiles, jackets are expected to become economic feasible for larger water depths as reflected by numerous publications. Jacket foundations are currently most common in combination with piles. Successful installation of this prototype and initial lessons learned indicate promising prospects for the suction bucket as a feasible alternative to piles. However, suction buckets are sensitive to tensile loading. Therefore, one of the main advantages for jackets compared monopiles, i.e. the relatively low mass, might lead to problems for the geotechnical design in case of suction buckets.

III. METHODS AND MATERIALS

In order to evaluate the Maximum stresses induced in the structures using linear static analysis for fixed Jacket structures with various twisting angles, different sample structures were adopted the details of these structures are given in next section.

The finite element analysis software SACS is utilized to create model and run all analyses. The software accepts the seastate data of specific site conditions viz. Wind speed, Wave height, Wave period, Current speed and direction.[5]

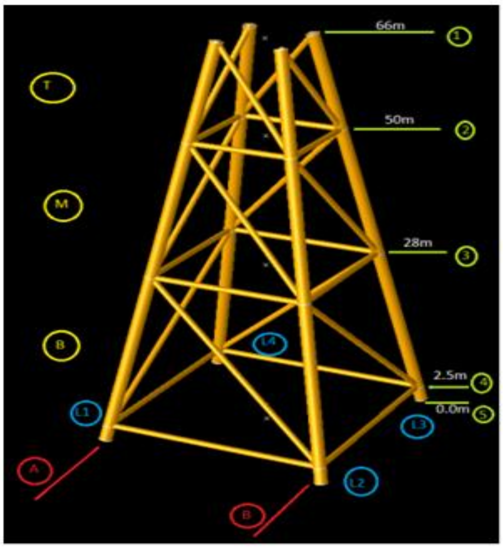


Fig. 2: Z-bracing Jacket model from SACS

A. DETAILS OF MODELS

Twisted Jackets

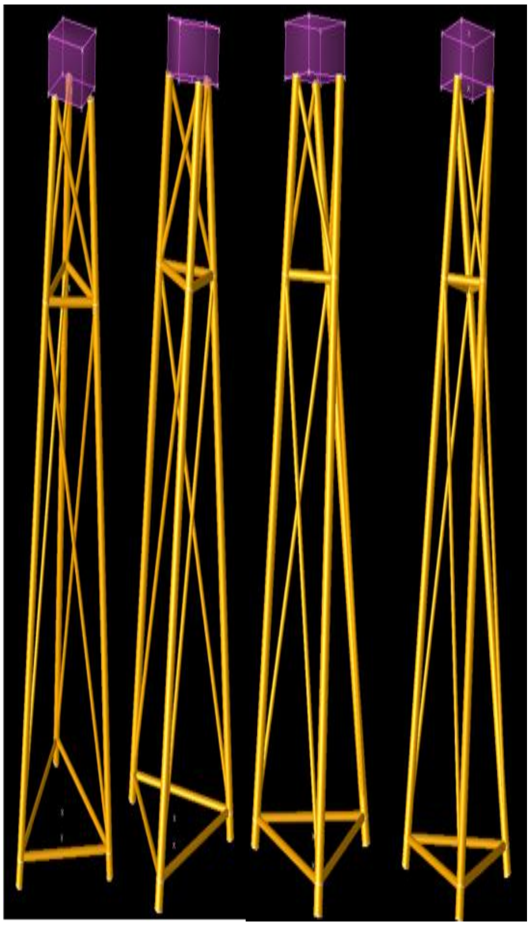


Fig. 3: Modified Twisted Jacket models in SACS with 0◦, 30◦, 60◦ & 90◦ twisting angles

as well as Extreme 100 years return period. Fig. shows the load acting on Jacket in 45° degree direction for extreme condition. All structures were assumed to be made of structural steel A36, where in

beam element method was employed for stress analysis. The overall load combination applied on the whole offshore wind turbine structure is complex in nature and site specific. Since the focus of the present study was on the investigation of the modified substructures and the comparison of those proposed structures with other existing structures, for simplicity and without loss of generality, only permanent load-like mass of the structures and environmental loads, such as wind, wave and current loads, were considered in the analysis. Other environmental loadings, such as tidal, seismic and ice loads, as well as soil conditions and temperature effect, were not taken into account. Two load combinations were considered: normal condition with simplified (2D) loads and extreme condition comprehensive (3D) loads.[1]

Twisted Tripod Jacket Substructure (MJ)				
Jacket	**MJ0**	**MJ30**	**MJ60**	**MJ90**
Total Height	66.00m	66.00 m	66.00 m	66.00 m
Length of Leg	66.86m	66.97 m	67.28 m	67.68 m
Length of Top Brace	17.23m	17.15 m	16.93 m	16.63 m
Length of Middle Brace	50.85m	51.10 m	51.12 m	50.89 m
Length of Top Horizontal Brace	11.07m	10.70 m	9.61m	7.87m
Length of Bottom Horizontal Brace	24.41m	24.38 m	24.32 m	24.16 m
Thickness of Horizontal Brace	0.03m	0.03m	0.03m	0.03m
Thickness of Top Brace	0.06m	0.06m	0.06m	0.06m
Thickness of Middle Brace	0.06m	0.06m	0.06m	0.06m
Thickness of Leg	0.04m	0.04m	0.04m	0.04m
Diameter of Horizontal Brace	0.90m	0.90m	0.90m	0.90m
Diameter of Top Brace	0.90m	0.90m	0.90m	0.90m

Table. 1: Specifications of four Modified Jacket

IV. FORMULATION OF CRITICAL LOADS

A. Load Conditions

Waves are omnidirectional. API RP2A mentions that the maximum wave height for a 1-year or 100-year storm is applied on the eight directions by the same values applied to the platform. Therefore the 8 loading conditions were used in 0°, 45°, 60°, 90° direction for normal average 1 year period the simulations, the density, Young modulus, Poisson's ratio and yield stress is were set to 7800 kg/m3, 200 GPa, 0.3 and 250 MPa, respectively. Material was assumed linear elastic for all analyses, except for global buckling analysis. The

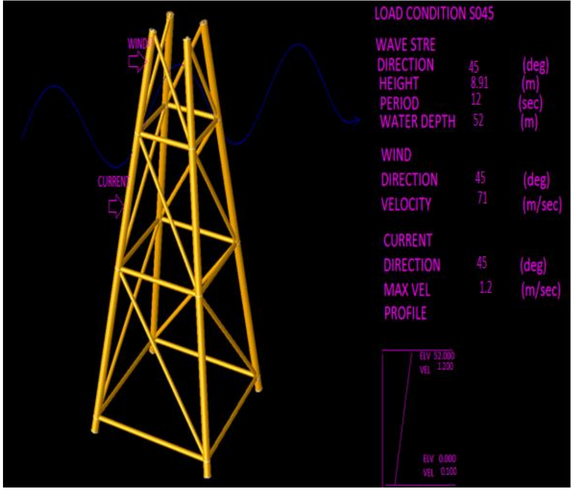


Fig.4: Extreme Load condition in 45degree direction on Jacket

Loading data of wind speed, wave height, Tamil Nadu are taken from Feasibility studies on Offshore Wind Development in India by National Institute of Ocean Technology, Chennai, India. Following are the loads for Normal average condition and Extreme condition for 100 year return period.[3]

Table 2: Loading data of Rameshwaram Site TN

Load Conditions	Normal	Extreme
Wind Speed	9.7m/s	71m/s
Wave Height	0.3m	8.91m
Wave Period	4s	12s
Current Speed	0.1m/s	1.2m/s

B. 5MW NREL Baseline Wind Turbine:

5MW NREL Baseline Wind Turbine was used for analysing the jacket in 50m depth. The following are the specification of the Upwind Turbine.

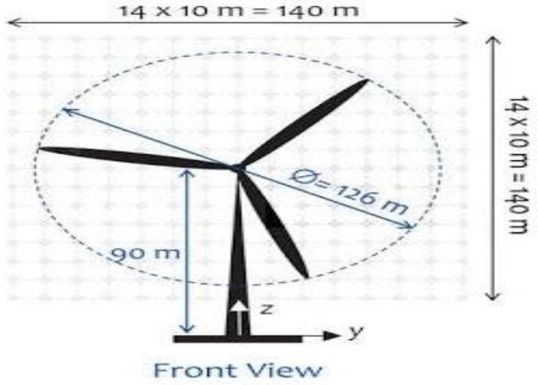


Fig.5: NREL 5-MW Baseline Wind Turbine

Table 3: Gross Properties Chosen for the NREL 5-MW Baseline Wind Turbine

Rating	5MW
Rotor Orientation, Configuration	Upwind, 3 Blades
Control	Variable Speed, Collective Pitch
Drivetrain	High Speed, Multiple-Stage Gearbox
Rotor, Hub Diameter	126m, 3m
Hub Height	90m
Cut-in, Rated, Cut-Out Wind Speed	3m/s, 11.4m/s, 25m/s
Cut-In, Rated Rotor Speed	6.9rpm, 12.1rpm
Rated Tip Speed	80m/s
Overhang, Shaft Tilt, Precone	5m, 5°, 2.5°
Rotor Mass	110,000kg
Nacelle Mass	240,000kg
Tower Mass	347,460kg
Coordinate Location of Overall CM	(-0.2m, 0.0m, 64.0m)

wave period, current period for Rameshwaram –

V. VALIDATION OF PAPER RESULTS

The 4-legged Z-braced jacket structure is used to validate by applying all wind, wave and current load in one direction (X-direction) for simplicity by computing the forces substituting the values in above mentioned formulas. The following image shows the Loads acting on the jacket and indicates the member with maximum Von Mises stresses with red color as shown in fig.

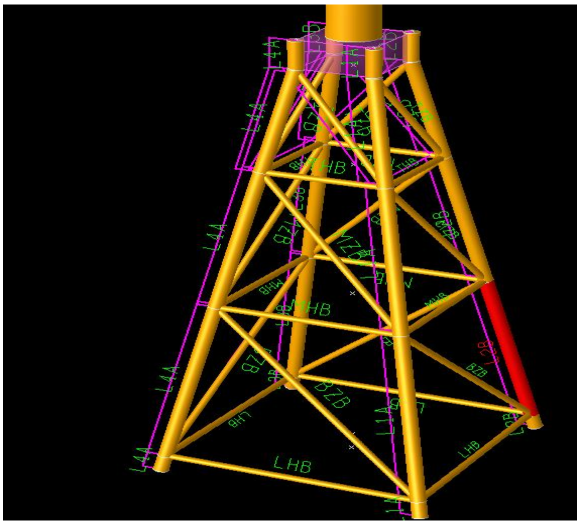


Fig. 6: Loads acting on Jacket with indicating member with max. Von-Mises stress

The value for max. stress given by software is compared with the computed model from paper and found difference of 4.6% as shown in the following table. This error is mainly because of incomplete data provided in the paper.

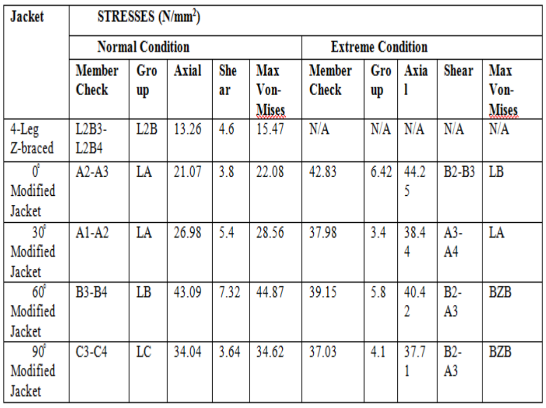
Table 4: Comparison of Max Von Mises stresses

Max. Von Mises Stress Comparision		
From Software	From paper	%Difference
17.6N/mm^2	18.48N/mm^2	4.6%

VI. RESULTS AND DISCUSSIONS

All the Five Jackets were statically analysed for the given site conditions. All substructures were initially designed with the assumed dimensions. Stress analyses describe in Section 3 were then performed to determine the maximum von Mises stresses in the structures. The dimensions of the structures were taken from one of the paper which were iteratively modified so that the maximum stresses generated in all designed structures, under identical load and boundary conditions, fell at a similar level. The computed stresses for each member of different jackets are compared using Maximum stresses for both normal and extreme conditions as shown in the following table and it is observed that three leg twisted jacket with more twisting with same loading and environmental conditions are able to take maximum stresses as compared to normal jacket

Table 5: Max. Stresses in members of Jackets in Normal and Extreme conditions



Jacket	STRESSES (N/mm^2)									
	Normal Condition					Extreme Condition				
	Member Check	Group	Axial	Shear	Max Von-Mises	Member Check	Group	Axial	Shear	Max Von-Mises
4-Leg Z-braced	L2B3-L2B4	L2B	13.26	4.6	15.47	N/A	N/A	N/A	N/A	N/A
0^0 Modified Jacket	A2-A3	LA	21.07	3.8	22.08	42.83	6.42	44.25	B2-B3	LB
30^0 Modified Jacket	A1-A2	LA	26.98	5.4	28.56	37.98	3.4	38.44	A3-A4	LA
60^0 Modified Jacket	B3-B4	LB	43.09	7.32	44.87	39.15	5.8	40.42	B2-A3	BZB
90^0 Modified Jacket	C3-C4	LC	34.04	3.64	34.62	37.03	4.1	37.71	B2-A3	BZB

VII. CONCLUSION

1) This paper presented the study of various types of offshore substructures along with the analysis of different types of proposed Jacket structures
2) The results revealed that all structures were safe under the provided load combinations.
3) The MJ-structures were expected and proven to possess excellent structural behavior similar to the patented twisted jacket structures, while still maintaining the advantage of low material usage, similar to the three-leg jacket structures.
4) Although the design of offshore wind turbine substructures is site dependent and requires additional dynamic and fatigue analysis with many specific site load combinations, the results obtained in this study shall provide alternatives for the initial selection and design of offshore wind turbine substructures.

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