Study on the effect of Offshore Five-Legged Jacket Structure with X, Y and Z Bracings

Emmanuel Zaviyo[1], **Dr. Hari G**[2]

[1]*M. Tech in Structural Engineering and Construction Management, APJ Abdul Kalam Technological University, Saintgits College of Engineering, Kerala, India*
[2]*Professor, Department of Civil Engineering, APJ Abdul Kalam Technological University, Saintgits College of Engineering, Kerala, India*

***

Abstract - The number of offshore platforms within the world is growing annually, most of them are of fixed jacket-type platforms with a depth range from 30 to 200 m to explore and produce oil and gas. The extreme offshore environmental conditions have a serious impact on the analysis, design and construction of offshore structures. Environmental impacts caused due to global warming has led the increase in alternative renewable energy sources which has led to a demand in offshore wind turbines across the world. Offshore wind turbines are usually supported on monopole or jacket structures. The structures which support these offshore wind turbines need to be studied to make better structural performance and to reduce deformations against applied loads. This study investigates the deformations of offshore jacket type structures with five legs (Penta base) with X, Y and Z configuration. Here in this study only dynamic analysis is performed. The numerical investigations were done on ANSYS software to determine the maximum deformations of the structure. The loading parameters were based on Taiwan sea conditions. The results showed that structures with K bracings produced minimum deformation followed by X brace and maximum deformation was obtained for Z braced structures. The minimum deformation was obtained for a Penta base structure with K brace.

Key Words: *Jacket Structure, Offshore Wind Turbine, Penta base.*

1. INTRODUCTION

The number of offshore platforms within the world is growing annually, most of them are of fixed jacket-type platforms with a depth range from 30 to 50m to explore and produce oil and gas. The extreme offshore environmental conditions have a serious impact on the analysis, design and construction of offshore structures. Over the traditional conditions that land based structures meet, offshore structures have added complexity to their location within the ocean environment where the consequences of hydrodynamic interaction and dynamic response become major concerns in their design. Environmental impacts caused due to global warming has led the increase in alternative renewable energy sources which has led to a demand in offshore wind turbines across the world. Offshore wind turbines are usually supported on monopole or jacket structures. Jacket structures are provided for a water depth of 30m to 50m.Monopile foundations have been commonly used to support offshore wind turbine generators but this type of foundation encounters economic and technical limitations for larger depths in water depths exceeding 30 m. Offshore wind farm projects are increasingly turning to alternative multipod foundations like tetrapod, jacket and tripods supported on shallow foundations to reduce the environmental effects of piling noise. However, the characteristics of these foundations under dynamic loading or long-term cyclic wind turbine loading are not fully understood. Design of offshore platforms, although their occurrence probability is low. Offshore structures should be designed for severe environmental conditions and rigorous requirements should be defined for the optimum performance.

2. LITERATURE REVIEW

Argyriadis *et al.* (2007) integrated the analysis of wind turbine behavior and structural dynamics of a complex support structure (jacket) under combined wind and wave loads in the time domain. The result showed that this method was effective.

Hillmer *et al.* (2007) studied the design of a rotor blade for an offshore wind turbine with an installed power exceeding 5 MW to 10 MW, using a traditional approach used in local industry. Results showed the annual yield and weights which were reported by applying the procedure from the guidelines of Germanischer Lloyd Wind Energy theory.

Asgarian and Lesani (2009) conducted pushover analysis of fixed offshore jacket platforms with the application of fiber elements which are capable of post buckling behavior of braces. Results showed that the non-linear sub have the most compatibility with the base case.

Golafshani *et al.* (2011) studied a novel probabilistic framework named Probabilistic incremental Wave Analysis (PIWA) to assess performance of jacket offshore platforms under extreme waves. The results indicated that the main advantage of PIWA is reflected in decoupling of the wave hazard and structural analysis through an intermediate variable known as the wave height intensity measure.

Bhattacharya *et al.* (2013) conducted experiments on a series of small-scale tests of a complete National Renewable Energy laboratory wind turbine model on three types of foundations: monopiles, symmetric tetrapod and asymmetric tripod. Results showed that the multipod foundations exhibit two closely spaced natural frequencies corresponding to the rocking modes of vibration in two principle axes.

Li *et al.* (2013) conducted study on Pearl River Tower, located in Guangzhou, has 71 stories and rises about 310 m and investigated wind loads on tall building and wind speed up factors in the tunnels for wind power generation based on wind tunnel tests and wind climate data analysis. The wind induced pressures and overall forces on building model with a geometric scale of 1:15. The study obtained comparative analysis and discussions of the results for four cases.

Damgaard *et al.* (2013) evaluated the first natural frequency and modal damping of offshore structures. The analysis showed distinctly time-dependent cross-wind dynamic properties. Based on the numerical analysis, the variation is believed to be caused by sediment transportation at sea be level and varying performance of tower oscillation dampers.

Alati *et al.* (2015) investigated the seismic response of a horizontal axis wind turbine on two bottom-fixed support structures for transitional water depths of 30 to 60m, a tripod and a jacket, both resting on pile foundations. The results showed that earthquake loading may cause a significant increase of stress resultant demands, even for moderate peak ground accelerations, and that fully coupled nonlinear time-domain simulations on full system models are essential to capture relevant information on the moment demand in the rotor blades, which cannot be predicted by analyses on simplified models allowed by existing standards.

Ishwarya *et al.* (2016) conducted a nonlinear pushover analysis of a 3D model of a jacket offshore platform for North Sea conditions and concluded that the type of bracing does not play a role in seismic design of jacket platform considering soil structure interaction.

Chen *et al.* (2016) investigated the various existing types of offshore jacket substructures along with a proposed twisted-tripod jacket type. The results showed that the proposed jacket structures possess excellent structural behavior and few structural nodes and components competitive with the patented twisted jacket structures, while still maintaining the advantages of low material usage similar to the three-leg jacket structures. The study also provided alternatives for the initial selection and design of offshore wind turbine substructures for green energy applications.

Park *et al.* (2016) suggested a hybrid structure to reduce the wave forces by composing a multicylinder having different radii near free surface and a gravity substructure at the bottom of the multicylinder. The structural strength and deformation were evaluated to derive an ultimate structural safety of the hybrid substructure for various soil conditions and the results showed that the first few natural frequencies of the substructure are heavily influenced by the wind turbine.

Tenghiri *et al.* (2019) conducted a structural design and analysis of 11 kW small wind blades. The study revealed that the rotor blades will be safe against fatigue for a design lifetime of 20 years. This study shows that simple and reliable aero elastic models are still needed for fatigue analysis of small wind blades.

Velarde *et al.* (2019) investigated the sensitivity of fatigue loads with respect to primary structural, geotechnical and ocean parameters for a 5 MW offshore wind turbine installed on a gravity-based foundation. The Results showed that parameter significance rankings vary according to which design load case is considered. In general, uncertainties in the fatigue loads are highly influenced by turbulence intensity and wave load uncertainties, while uncertainties in soil property suggest significant nonlinear or interactive effects.

Boudounit *et al.* (2019) proposed a structural design for the development of a composite blade of 48m length for an offshore wind turbine. Parametric studies were performed with the ABAQUS finite element analysis software to determine and propose a particular structure configuration, which can effectively withstand extreme load conditions.

Raheem *et al.* (2020) conducted in place analysis to check whether structural members have the capability to support the loads in operating and storm conditions and concluded that in-place analysis is required for reliable design of offshore platform.

Oguclu (2020) Conducted Computational Fluid Dynamics (CFD) model is designed to investigate the structural analysis of a helical Vertical Axis Wind Turbine (VAWT). The main objective of this study was to determine that the strength of the turbine blade against bending caused by increased wind speeds is sufficient for the selected turbine blade material.

Rajasri *et al.* (2020) Conducted structural analysis to implement and demonstrate a fully automated (self-start) system to optimize a vertical axis wind turbine (VAWT) aero foil cross- section. Results showed that composite material Glass fiber made blade profile generated to be effective in durability, High strength and stiffness, Light weight and corrosion resistant.

3. METHODOLOGY

The research methodology adopted is shown in Fig -1.

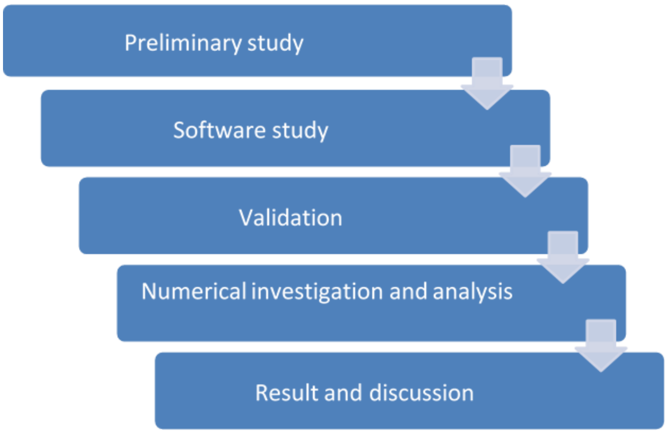

Fig -1: Research Methodology

4. DETAILS OF STRUCTURE

The study is carried out on jacket structures for supporting heavy wind turbines, mainly the NREL 5-MW baseline wind turbine in the Taiwan sea conditions with an average water depth of 50m. The turbine design and tower specifications are not of much importance in the study, however the weight of the structures that the jacket structures support and the loads acting on the turbine and moments generated were taken into account for the study. The structures were modelled in Creo Parametric software and finite element analysis was done in ANSYS software to find out the deformation of the structures for the applied loads. The beam element method was adopted for analysis, of all the analysis done the soil structure interaction was neglected and the structures was assumed to be fixed in all six degrees of freedom at the base. The analysis of the current study was limited to static study only, however dynamic analysis such as modal analysis, time-domain analysis and fatigue analysis are equally important and require a detailed study in the future. The material properties of the structure are shown in Table -1.[6]

Table -1: Material Properties

Material	Density	Young's Modulus	Poisson's ratio	Yield Stress
Structural Steel A36	7800 kg/m^3	200Gpa	0.3	250Mpa

The dimensions of the structure are shown in Table -2.

Table -2: Dimensions of the structure

Sl No	Specification	Dimensions in meter
1	Diameter of leg	1.80
2	Diameter of brace	0.90
3	Thickness of leg	0.04
4	Thickness of brace	0.03
5	Total height of structure	70.5
6	Water level	50.5

5. LOADS ON THE STRUCTURE

The loads considered for the study are as follows.[6]

- The self-weight of the baseline wind turbine machine and tower is 1.859 MN
- The side wind load is 16.644 kN
- The wind load moment is 733.584 kN-m
- The wind load is 32.73D N/m = 58.914 (D is the diameter of the tubular structural member)
- The wave load is 509.9PaThe current load 8.08D N/m = 14.544N (D is the diameter of the tubular structural member).

6. LOADING DIAGRAM OF STRUCTURES

The modelled structure, meshing diagram and loading diagrams of 5- legged jacket structures with X, K and Z bracings are as follows.

6.1 Penta base structure with X bracing

The modelled structure, meshing diagram and loading diagram of Penta base structure with X bracings are shown in Fig -2, Fig -3, Fig -4 respectively.

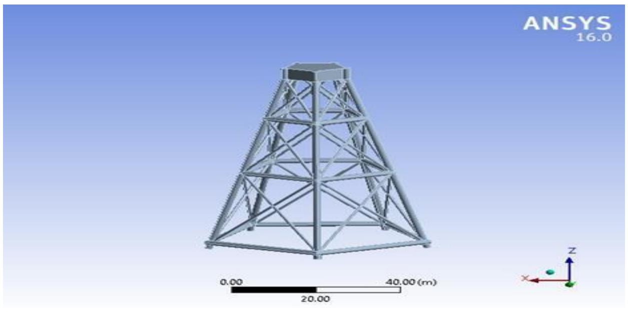

Fig - 2: Modelled structure of Penta base with X brace

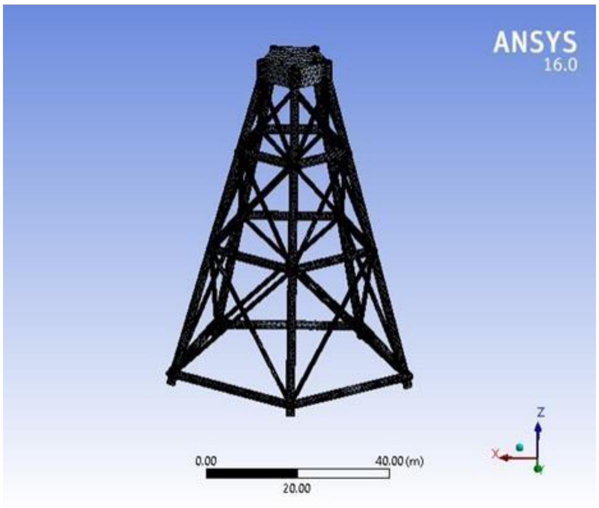

Fig -3: Meshing diagram of Penta base with X brace

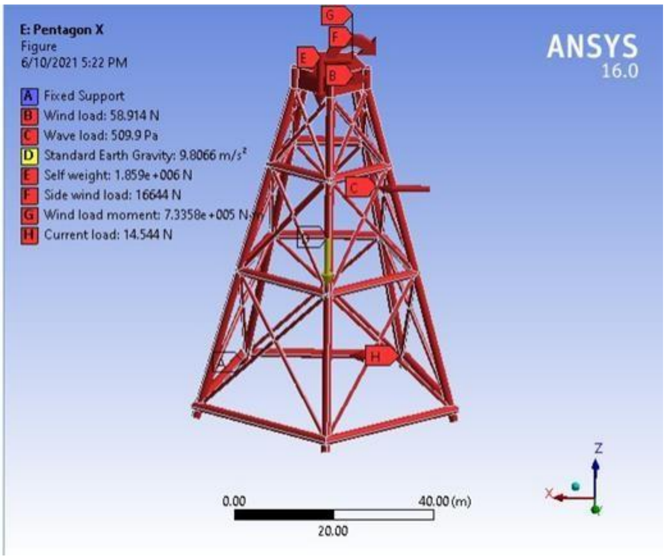

Fig -4: Loading diagram of Penta base structure with X brace

6.2 Penta base structure with K brace

The modelled structure, meshing diagram and loading diagram of Penta base with K brace are shown in Fig – 5, Fig -6 and Fig -7 respectively.

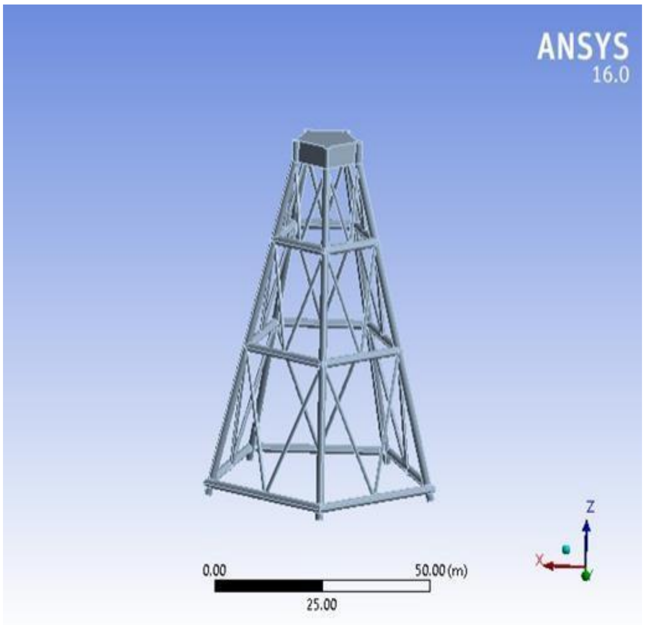

Fig -5: Modelled Penta base structure with K brace

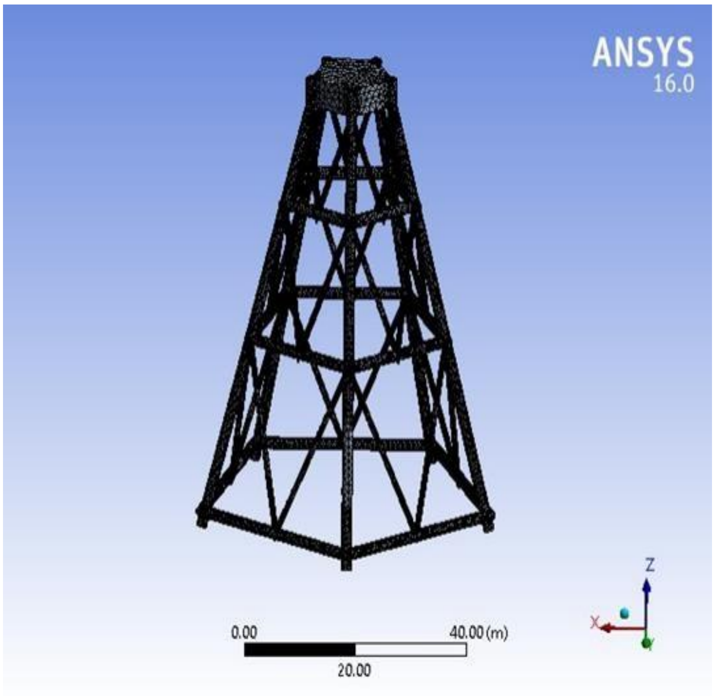

Fig -6: Meshing diagram of Penta base structure with K brace

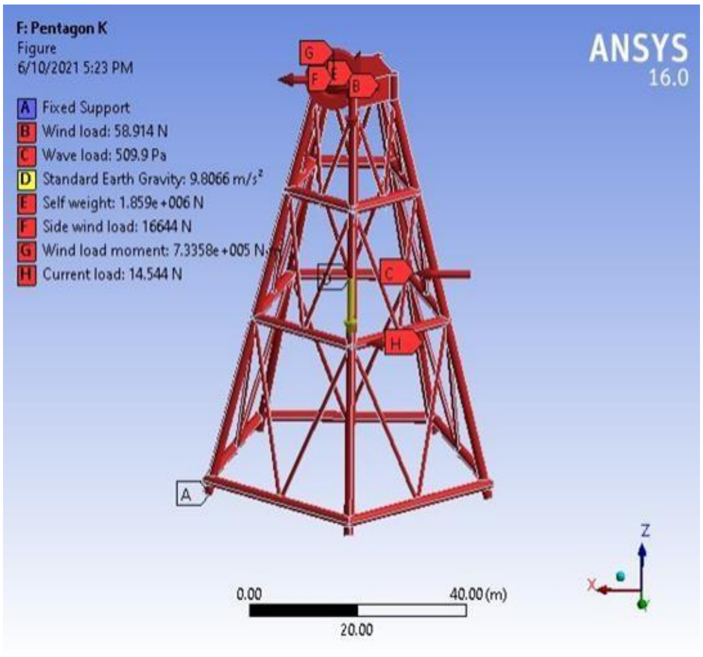

Fig -7: Loading diagram of Penta base structure with K brace

6.3 Penta base structure with Z brace

The modelled structure, meshing diagram and loading diagram of Penta base structure with Z bracings are shown in Fig -8, Fig -9 and Fig -10 respectively.

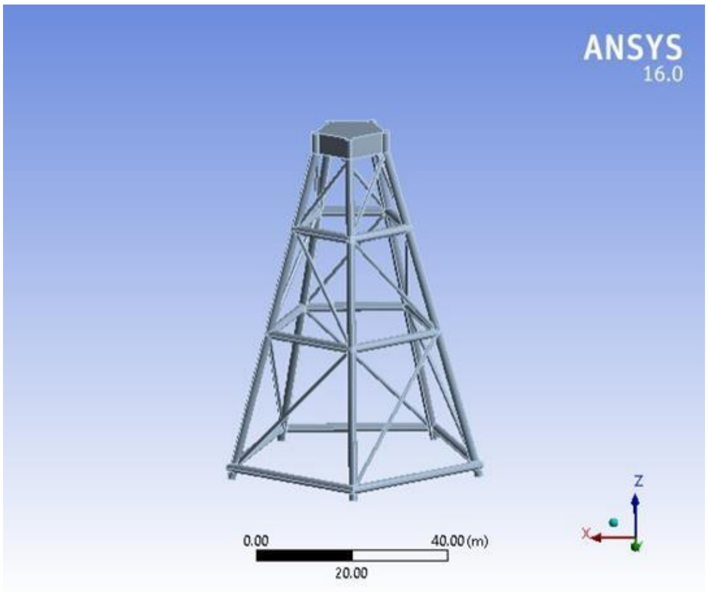

Fig -8: Modeled Penta base structure with Z brace

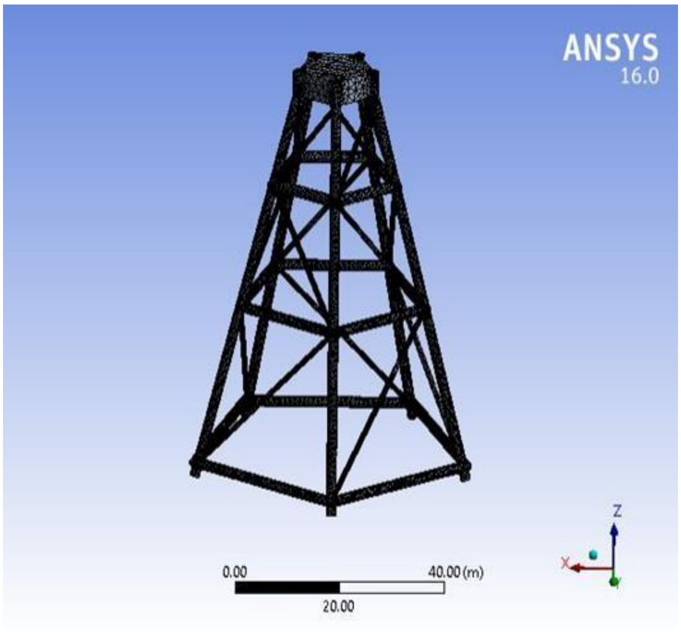

Fig -9: Meshing diagram of Penta base structure with Z brace

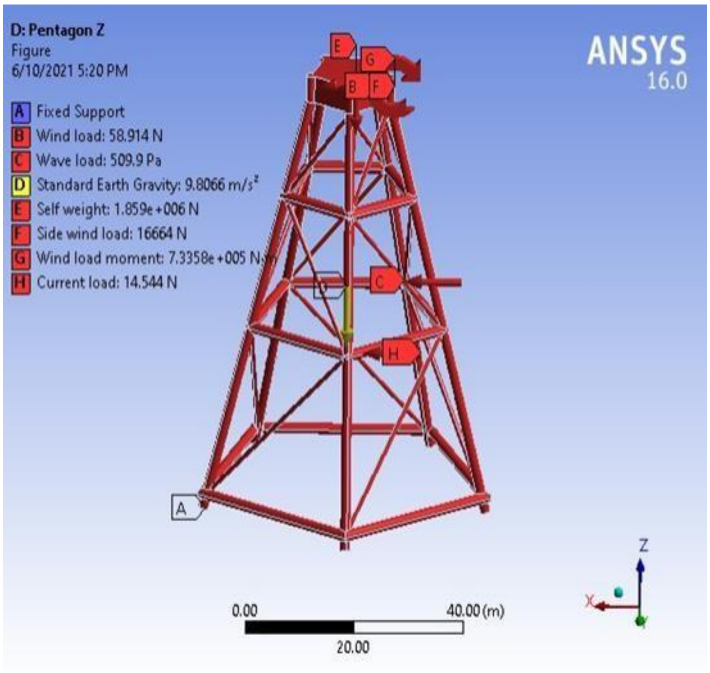

Fig -10: Loading diagram of Penta base with Z brace

7 RESULTS AND DISCUSSIONS

7.1 Results of Penta base structure with X brace

The maximum deformation of Penta base structure with X brace for the applied loads was found to be 8.489mm. The deformation diagram of Penta base structure with X brace is shown in Fig -11.

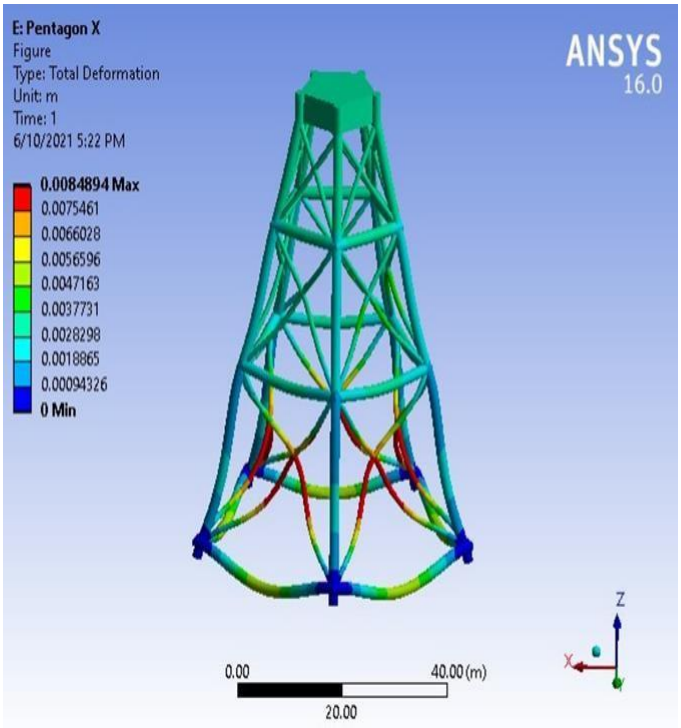

Fig -11: Total deformation of Penta base structure with X brace

7.2 Results of Penta base structure with K brace

The maximum deformation of Penta base structure with K brace for the applied loads was found to be 7.3455 mm. The deformation diagram of Penta base structure with K brace is shown in Fig -12.

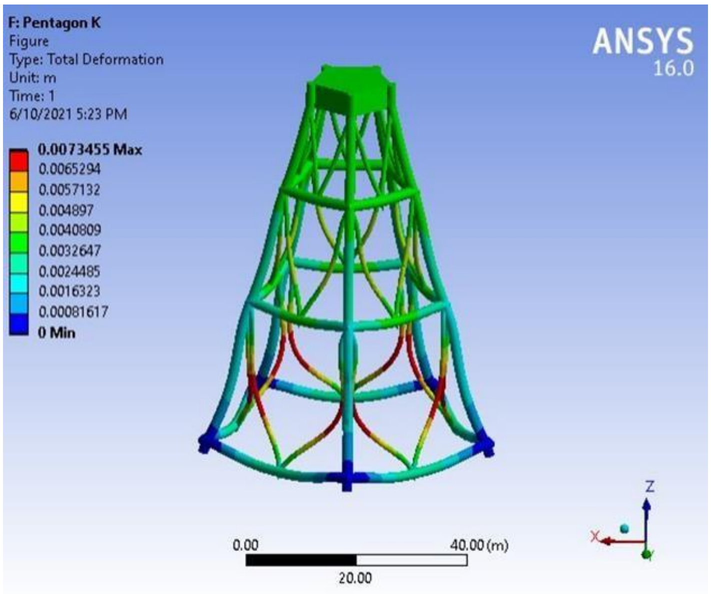

Fig -12: Total deformation of Penta base structure with K brace

7.3 Results of Penta base structure with Z brace

The maximum deformation of Penta base structure with Z brace for the applied loads was found to be 26.971 mm. The deformation diagram of Penta base structure with Z brace is shown in Fig -13.

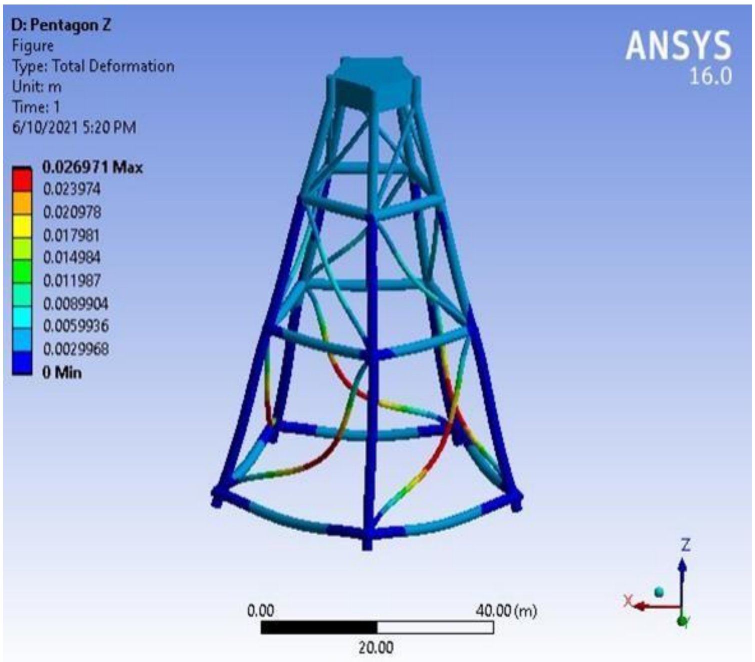

Fig -13: Total deformation of Penta base structure with Z brace

7.4 Comparison of deformations of Penta base structures with X, K and Z brace

The deformations of Penta base structures with X, Y and Z bracings are shown in table 6.1 and the comparative graphical representation is shown in fig 6.4. The deformation and graphs are shown in Table -3 and Chart -1 respectively.

Table -3: Deformation of Penta base structures

Bracing Type	Deformation (mm)
X	8.489
K	7.3455
Z	26.971

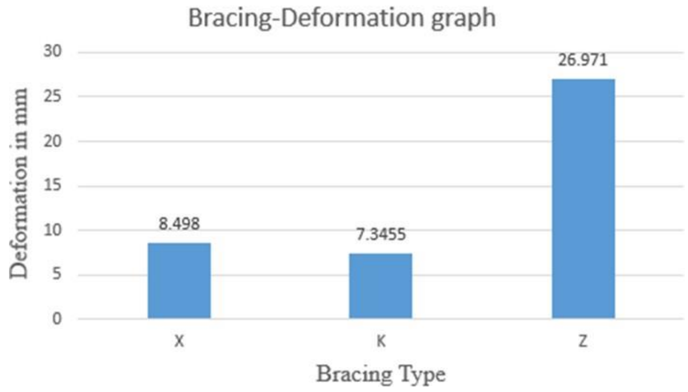

Chart -1: Deformation graph for Penta base structures

From the results it is observed that for Penta base jacket structures the deformation of K bracing is less followed by X and Z. Z bracing has the largest deformation.

8 CONCLUSIONS

Dynamic analysis was performed on Penta base structure with X, K and Z bracings to obtain the respective deformations for the applied loads. From the results obtained from the analysis the following conclusions were made:

- For the applied load conditions the Penta base structures produced minimum deformation.
- Throughout the study for the different bracing arrangement for the various leg configurations the K bracing had the lowest deformation, followed by X brace and the maximum deformation was for Z brace.
- The minimum deformation was obtained for Penta base structure with K brace, a deformation of 7.3455mm.

REFERENCES

1. Alati, N, G. Failla and F. Arena (2015) Seismic analysis of offshore wind turbines on bottom-fixed support structures, *Phil Trans. R. Soc. A* 373: 20140086, http://dx.doi.org/10.1098/rsta.2014.0086.
2. Argyriadis, K., S. Kimon and M. Klose (2007) Analysis of Offshore Wind Turbines with Jacket Structures, *The Seventeenth International Offshore and Polar Engineering Conference*, Lisbon, Portugal.
3. Asgarian, B. and M. Lesani (2009) Pile soil structure interaction in pushover analysis of jacket offshore platforms using fiber elements, *Journal of constructional steel research*, 65, 209-218.
4. Bhattacharya, S., N. Nikitas, J. Garnsey, N.A. Alexander, J. Cox, D. Lombardi, D. M. Wood and D.F.T. Nash (2013) Observed dynamic soil–structure interaction in scale testing of offshore wind turbine foundations, *Soil dynamics and earthquake engineering*, 54, 47- 60.
5. Boudounit, H., M. Tarfaoui and D. Saifaoui (2019) Structural Design and Analysis of a 5MW Offshore Wind Turbine Blades Under Critical Aerodynamic Loads, *14e Congrès de Mécanique* 16, 11-15.
6. Chen, I. W., B. L. Wong, Y. H. Lin, S. W. Chau and H. H. Huang (2016) Design and analysis of jacket substructures for offshore wind turbines, *Energies*, 9, 264, doi:10.3390/en9040264.
7. Cristian, S. I., P. Mihail and B. Bogdan (2014) study of offshore structure design related to ansys stress, displacement and vibration modes, *Constanta Maritime University Annals*, 15, 22, 97-100.
8. Damgaard, M., L. B. Ibsen, L. V. Andersen and J. K. F. Andersen (2013) Cross wind modal properties of offshore wind turbines identified by full scale testing, *Journal of Wind Engineering and Industrial Aerodynamics*, 116, 94-108.
9. El Moumen, A., M. Tarfaoui, O. Hassoon, K. Lafdi, H. Benyahia and M. Nachtane (2018) Experimental study and numerical modelling of low velocity impact on laminated composite reinforced with thin film made of carbon nanotubes. *Applied Composite Materials*, 25, 2, 309-320.
10. Golafshani, A. A., H. Ebrahimian, V. Bagheri and T. Holmas (2011) Assessment of offshore platforms under extreme waves by probabilistic incremental wave analysis, *Journal of constructional steel research*, 67, 759-769.
11. Hillmer, B., T. Borstelmann, P. A. Schaffarczyk and L. Dannenberg (2007) Aerodynamic and Structural Design of MultiMW Wind Turbine Blades beyond 5MW, *Journal of Physics: Conference Series* 75, Doi:10.1088/1742-6596/75/1/012002.
12. Ishwarya, S., M. Arockiasamy and R. Senthil (2016) Inelastic Nonlinear Pushover Analysis of Fixed Jacket-Type Offshore Platform with Different Bracing Systems Considering Soil- Structure Interaction, *Journal of Shipping and Ocean Engineering*, 6, 241-254.

13. Kong, C., J. Bang and Y. Sugiyama (2005) Structural investigation of composite wind turbine blade considering various load cases and fatigue life, *Renewable Energy*, 30, 11, 2101-2114.
14. Li, Q. S., F. B. Chen, Y. G. Li and Y. Y. Lee (2013) Implementing wind turbines in a tall building for power generation: A study of wind loads and wind speed amplifications, *Journal of Wind Engineering and Industrial Aerodynamics*, 116, 70–82.
15. Jonkman, J. M. (2009) Dynamics of offshore floating wind turbines model development and verification, *Wind Energy*, 12, 5, 459–492.
16. Minguez, E. L., A. J. Kolios, and F. P. Brennan (2011) Multicriteria assessment of offshore wind turbine support structures, *Renewable Energy*, 36, 11, 2831–2837.
17. Mostapha, T., M. Nachtane and H. Boudounit (2019) Finite element analysis of composite offshore wind turbine blades under operating conditions, *Journal of Thermal Science and Engineering Applications*, 3, 17, 11-18.
18. Nachtane, M., M. Tarfaoui, D. Saifaoui, A. El Moumen, O. H. Hassoon and H. Benyahia (2018) Evaluation of durability of composite materials applied to renewable marine energy: Case of ducted tidal turbine. *Energy Reports*, 4, 31-40.
19. ÖĞÜÇLÜ, O. (2020) Structural Design and Stress Analysis of a Helical Vertical Axis Wind Turbine Blade, *Sakarya University Journal of Science*, 24, 6, 1151-1161.
20. Park, M. S., Y.J. Jeong, Y. J. You and Y. K. Hwang (2016) Safety Evaluation of a Hybrid Substructure for Offshore Wind Turbine, *Hindawi Publishing Corporation*, http://dx.doi.org/10.1155/2016/8089426.
21. Rajasri, A., A. Ragi and S. Nalla (2020) Modeling and structure analysis of Vertical Axis Wind Turbine, *International Journal of Innovative Technology and Exploring Engineering*, 9, 3, 80-84.