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Research Article

INVESTIGATION OF FLUID-STRUCTURE INTERACTION BY USING SOLIDITY RATIO

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ABSTRACT
In this study, fluid-structure interaction problem is investigated by solidity ratio approach. In the first case (Case I) steady flow conditions are defined by using air as fluid. The wind forces acting on the space lattice systems are determined by considering the solidity ratio dictated by ANSI/TIA-222-G (Steel Antenna Towers and Antenna Supporting Structures) technical specification. Stability of wind tower is analyzed using SAP 2000 software program. In the second case (Case II) unsteady flow conditions are evaluated by utilizing water waves acting on lattice marine structures. Models are occurred two groups as three space frame structures and three porous media models. Hydrodynamic wave forces are represented by the Stoke's Second Order wave theory. Morison equation is employed to obtain lateral wave forces. The results of computational fluid dynamics are performed by using ANSYS-Fluent software. Solidity ratio is used to observe vortex effect that is based on turbulence around the structural members. The hydrodynamic forces acting on the marine structures are presented independent from configuration, depending on solidity ratio values.

Keywords: *Fluid-Structure Interaction, Hydrodynamic Forces, Solidity Ratio*

1. INTRODUCTION

Space lattice or frame structures such as wind turbine tower and jacket type oil platform are popular for many researchers due to new technological developments (TIA, 1996; Friez, 2011). Space frame towers located on land are generally subjected to variable wind drag forces throughout the height of the structure (Nizamani, 2015).The recent ANSI/TIA-222-G technical specification propose a different approach based on solidity ratio for lattice systems constructed on land. Solidity ratio is identified as the ratio of the surface areas of wind ward structural elements to the total surface area.

The offshore environment is characterized by the existence of a fluid inside and above the seabed. The hydrodynamic forces consisted of drag, inertia and liftforces are used as decisive in the design of offshore structures (Christensen et al., 2007; Kudale and Bhalerao, 2015; Dagli et al., 2018). Fluid-structure interaction is a multiphysics coupling between the laws of fluid dynamics and structural mechanics. The significant effects of hydrodynamic forces are complicated problems that are possible to solve by common technical methods (Kurian et al., 2010; Korobenko et al., 2013; Wei et al., 2014). This study proposes solidity ratio approach in environmental conditions for a simple and successful design for offshore structures.

Two cases are discussed in the paper. In Case I, wind forces acting on the space lattice systems are determined according to solidity ratio for presenting the methodology given by ANSI/TIA-222-G technical specification. In Case II, It has been studied with the 2 group structural models that can be classified as space frame structures and porous media models. Main top and base dimensions of all models are 6m × 6m with a height of 6m. Hydrodynamic analyses of 6 sub-models are performed by using Stokes Second Order wave theory. The fluid domain is designed as a rectangular prism and numerical simulations are utilized by the ANSYS-Fluent (ANSYS, 2013). The effects of solidity ratio on hydrodynamic forces are presented by graphs.

2. DESCRIPTION OF STRUCTURES

The space lattice structure is designed as similar to the one used in (Karadeniz, 2001) for Case I as given in Figure 1.

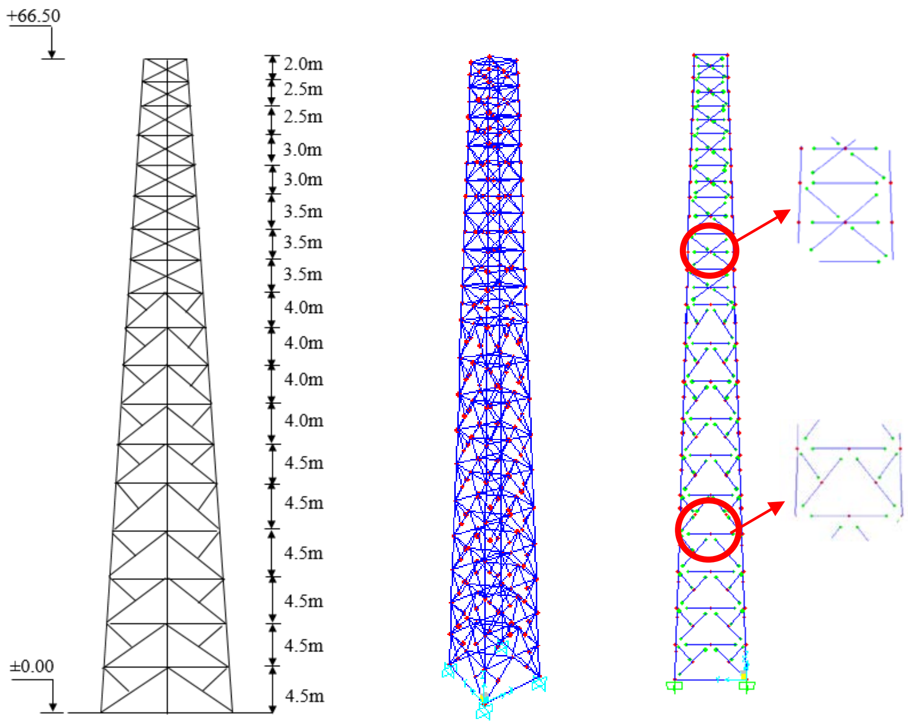
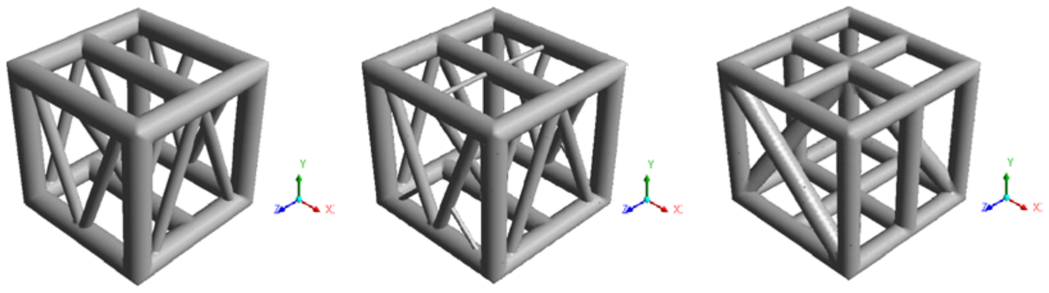


Fig. 1. The model of space lattice structure

The material properties are chosen to represent the steel, with Young's modulus of 21×107kN/m^2, Poisson's ratio of 0.3, and density of 78.50kN/m^3. Models are composed by uniform and homogeneous material. For steel, it is assumed that the material will comply with the associated Prandtl–Reuss flow rule and Von Mises yield criterion (Lee, 1999).

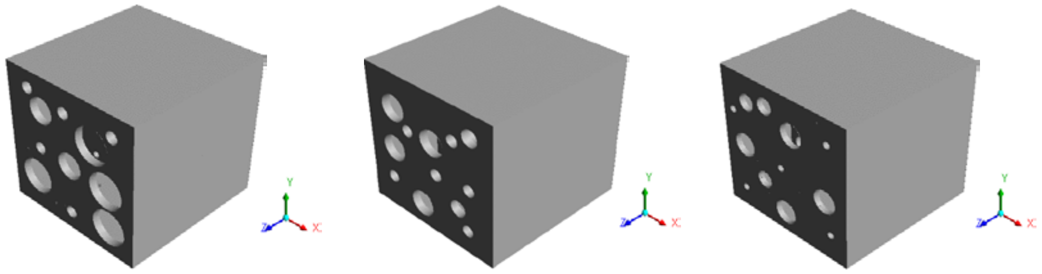
In Case II, 3 space frame structures and 3 porous media models are designed with %32, %34 and %36 solidity ratio (e) values. Solidity ratio values are selected as equal for two model groups. The values of solid volumes are presented as 70.11 m^3, 73.07 m^3, 78.76m^3 for %32, %34 and %36 solidity ratio values respectively.

The design of the space frame structures with different configurations according to solidity ratio values are shown in Figure 2a and porous media models are given by Figure 2b.



Model 1A, e=0.32 | Model 2A, e=0.34 | Model 3A, e=0.36

Fig. 2a. Configuration designs of space frame structures



Model 1B, e=0.32 Model 2B, e=0.34 Model 3B, e=0.36

Fig. 2b. Configuration designs of porous media models

The pinned conditions are assumed at seabed for all models. The space frame structures are composed of 3D solid tubular members.

2. DESCRIPTION OF FLUID DOMAIN

The fluid domain is modeled by the ANSYS-Fluent. The density and the dynamic viscosity of the seawater are considered as10.25 KN/m3, 0.0015 Ns/m2. The wave parameters are used to compute the hydrodynamic wave forces acting on structures. The wave height H, the water depth d and wave period T are major wave parameters (CERC., 2002; Ergin, 2010). These parameters are considered as 2.5m, 18.0m, 9.8s respectively in the present study. The equations of fluid particle velocity u and acceleration according to the Stoke's Second Order wave theory are given as below

$$u=\frac{HgT}{2L}\frac{\cosh\left[2\pi(y+d)/L\right]}{\cosh(2\pi d/L)}\cos\left(\frac{2\pi}{L}x-\frac{2\pi}{T}t\right)+\frac{3}{4}\left(\frac{\pi H}{L}\right)^2 c\frac{\cosh\left[4\pi(y+d)/L\right]}{\sinh^4(2\pi d/L)}\cos 2\left(\frac{2\pi}{L}x-\frac{2\pi}{T}t\right) \tag{1}$$

$$\dot{u}=\frac{Hg}{2}\frac{2\pi}{L}\frac{\cosh\left[2\pi(y+d)/L\right]}{\cosh(2\pi d/L)}\sin\left(\frac{2\pi}{L}x-\frac{2\pi}{T}t\right)+\frac{3}{8}\frac{2\pi}{L}\left(\frac{2\pi H}{T}\right)^2\frac{\cosh\left[4\pi(y+d)/L\right]}{\sinh^4(2\pi d/L)}\sin 2\left(\frac{2\pi}{L}x-\frac{2\pi}{T}t\right) \tag{2}$$

Where L stands for the wave length, g for acceleration of gravity, x,y for the axes of coordinate system, c for the velocity and t for time. Flow involves the free surface between two phases solved using VOF (Volume of Fluid) formulation (ANSYS, 2013). The effects of turbulence are modeled using RANS (Reynolds Averaged Navier Stokes Simulation). Realizable k-ε turbulence model is represented by the transport equations (Versteeg, 2007). The volume of the fluid domain includes prism layers and refined mesh contains around 500000 cells.

3. METHODOLOGY

Hydrodynamic drag forces F_R acting on space lattice and frame structures located on land can be calculated by ANSI/TIA-222-G technical specification independent from configuration, given as

$$F_R=q_z G_H\left[C_F A_E+\sum(C_A A_A)\right] \tag{3}$$

Where q_z is equivalent static pressure used in the determination of wind loads, G_H is the gust effect factor that is assumed as 1.11, C_F is the force coefficient for a structure and can be written as

$$C_F=4{,}0e^2-5{,}9e+4{,}0 \tag{4}$$

A_E is the projected area of structural components, C_A is the force coefficient for a lineer or discrete appurtenance and A_A is the projected area of an appurtenance. The solidity ratio e can be presented as

$$e=(A_F+A_R)/A_G \tag{5}$$

Here A_F and A_R refer to the projected area of flat and round structural components respectively. A_G is the gross area of one tower face or mounting frame. The values of solidity ratio according to height of space lattice are shown in Figure 3 for Case I.

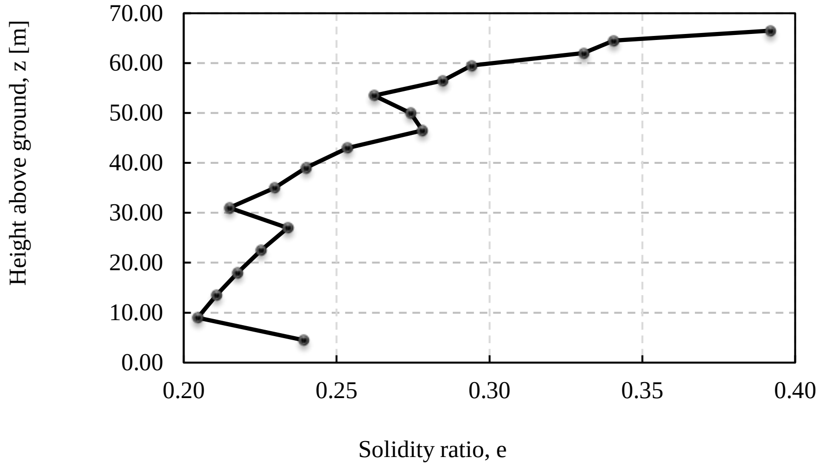


Fig. 3. The values of solidity ratio versus with height of space lattice tower

Figure 4 shows variation of the velocity pressure values.

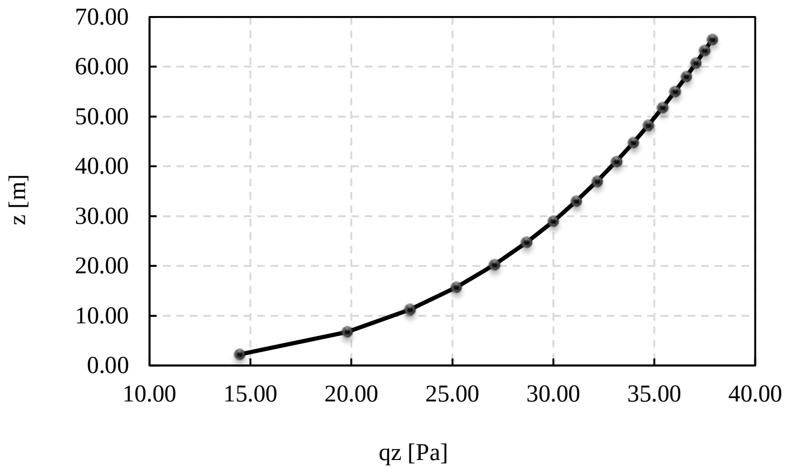


Fig. 4. The values of velocity pressure versus with height of space lattice tower

In the second approach, numerical simulations are also utilized in a 3D finite volume model in the framework of ANSYS-Fluent. The lateral total hydrodynamic forces (F_H) ($F_H=F_D+F_M$; F_D: drag force, F_M: inertia force) are performed for each model in Case II as examined by Figure 5.

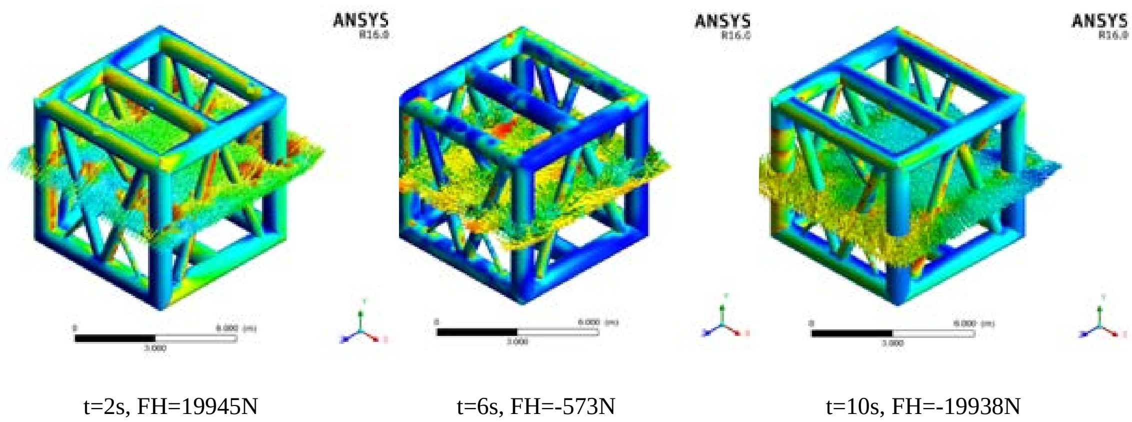


Figure 5. Time-varying hydrodynamic forces

4. NUMERICAL RESULTS

The values of wind pressures without ice are determined as 14.45 Pa between 37.87 Pa for Case I. The wind pressures are externally assigned to the tower and analyzed using SAP 2000 software program. The results are given by Figure 6.

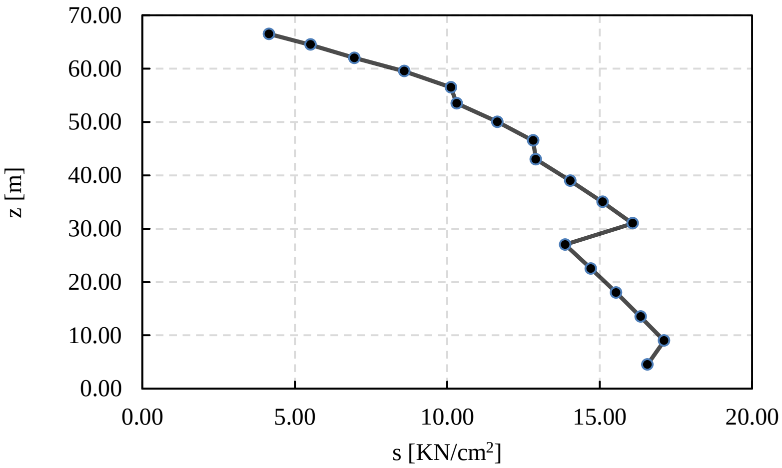


Figure 6. The distribution of the stress values for Case I

The hydrodynamic forces of space frame models are compared with the results of porous media models for the same solidity ratio values to define the relation between solidity and force. Figure 7 shows the comparison of horizontal hydrodynamic forces (F_H). for Model 1A and Model 1B. Solidity ratio value is assumed as 0.32. The hydrodynamic forces calculated by the analysis with ANSYS-Fluent program for Model 2A and 2B are given in Figure 8. These models are designed by considering the solidity ratio value as 0.34. The results are presented for Model 3A and 3B by Figure 9. The solidity ratio is taken into account as 0.36 in Figure 9.

According to the results, the hydrodynamic forces increase as the distance from the sea bed increases. The maximum positive values are determined as 31210N and 55405N for Model 1A-1B respectively.

The peak values of hydrodynamic forces are determined as 45540N, -46030N for Model 2A and 61660N, -65140N for Model 2B. For Model 3A the positive and the negative maximum values are 53064N, -54010N, for Model 3B the results are 63090N, -66180N.

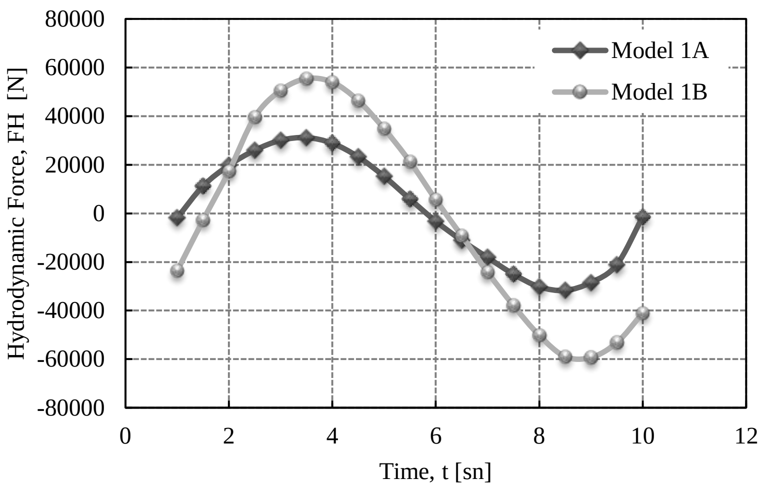


Figure 7. The comparison of the hydrodynamic forces (e=0.32)

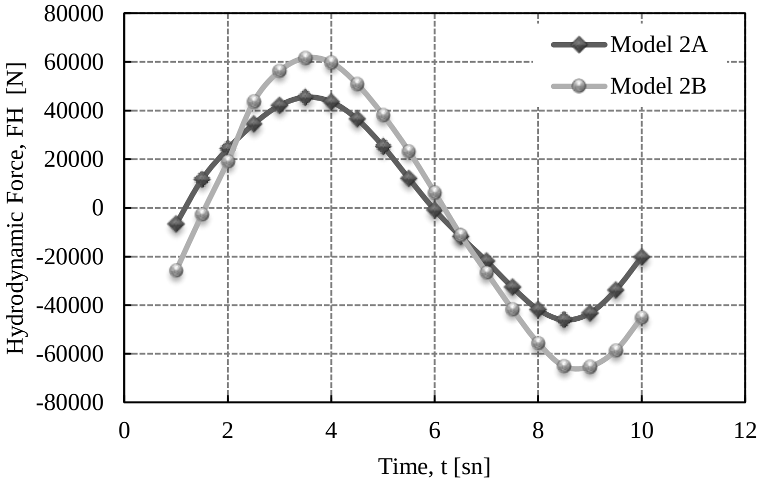


Figure 8. The comparison of the hydrodynamic forces (e=0.34)

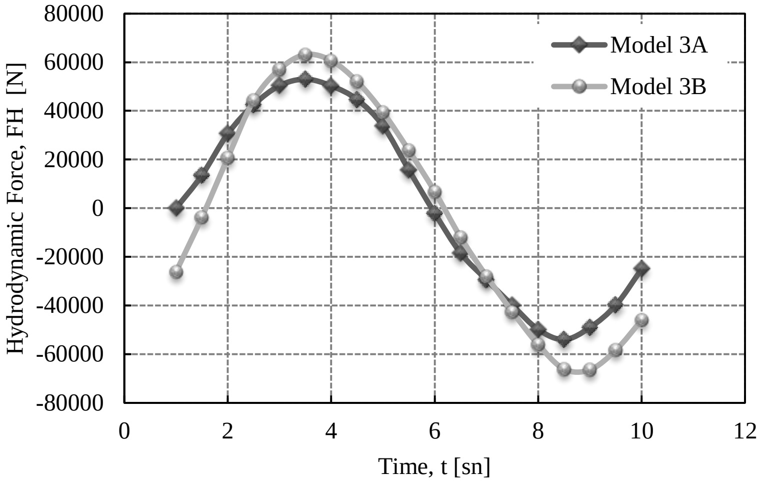


Figure 9. The comparison of the hydrodynamic forces (e=0.36)

It can be seen that the deviation between the hydrodynamic forces decrease as the values of solidity ratio increase. The mean deviation ratio is obtained as 26.1%. The design of configuration loose importance on lattice structures that have the high solidity.

5. CONCLUSIONS

In this study the validity of solidity ratio approach is evaluated for maritime conditions. The stability analyzes of the space lattice tower when it is subjected to wind forces is investigated utilizing ANSI/TIA-222-G (Steel Antenna Towers and Antenna Supporting Structures) technical specification in the first case. The stresses are obtained by using SAP 2000 software program.

In the second case this approach is utilized on the structures subjected by wave forces. 6 sub models are designed with different configurations according to solidity ratio values. Hydrodynamic wave forces represented by the Stoke's Second Order wave theory. Morison equation is employed to obtain lateral wave forces. The results of computational fluid dynamics are performed by using ANSYS-Fluent software.

The maximum hydrodynamic forces are calculated for Model 3A and 3B. When the results are evaluated, it is seen that the deviation of hydrodynamic forces between the frame and porous models decrease as the values of solidity ratio increase. The maximum deviations between the A-B models occurred at the wave crest and trough. This study demonstrated that the hydrodynamic forces can be determined free of its configuration when the solidity ratios have high values.

REFERENCES

A. Korobenko, M. C. Hsu, I. Akkerman, J. Tippmann, and Y. Bazilevs, “Structura lmechanics modeling and FSI simulation of wind turbines,” Mathematical Models and Methods in Applied Sciences, vol. 23, no. 2, pp. 249–272, 2013.

ANSYS Fluent Users Guide, ANSYS, Canonsburg, PA, USA, 2013.

CERC. (2002). Coastal engineering manual, Wave Mechanics, Part II, USA.

Christensen, E. D., Hansen, Yde, E. A. L., Tarp-Johansen, Gravesen, N. J. H., and Damsgaard, M. L., “Wave loads on offshore wind turbine foundations in shallow water: engineering models vs. refined flow modelling,” in Proceedings of the European Offshore Wind Conference, pp. 4–6, Berlin, Germany, December 2007.

Dagli, B. Y., Tuskan, Y., & Gökkuş, Ü. (2018). Evaluation of Offshore Wind Turbine Tower Dynamics with Numerical Analysis. Advances in Civil Engineering, 2018.

Ergin, A., 2009. Coastal Engineering. Metu Press. Turkey.

Friez, P.A., 2011. Offshore Structure Design and Construction. Ships and Offshore Structures. Encyclopedia of Life SupportSystems. UK.

Karadeniz, H. (2001). Uncertainty modeling in the fatigue reliability calculation of offshore structures. Reliability Engineering & System Safety, 74(3), 323-335.

Kudale, M. D. and Bhalerao, A. R., “Equivalent monochromatic wave height for the design of coastal rubble mound structures,” Aquatic Procedia, vol. 4, pp. 264–273, 2015.

Lee, M. M. K., (1999).Strength, stress and fracture analyses of offshore tubular joints using finite elements, Journal of Constructional Steel Research, vol. 51, no. 3, pp. 265–286.

Nizamani, Z., 2015. Environmental Load Factors and System Strength Evaluation of Offshore Jacket Platforms. Springer International Publishing, Switzerland.

Telecommunications Industry Association (TIA), 2005, Structural Standards For Steel Antenna Towers And Supporting Structures. USA, 120p.

Versteeg, H.K., 2007. Malalaseker, An introduction to Computational Fluid Dynamics. The Finite Volume Method. Pearson Education. Longman Scientific Technical. England.

Wei,K., Arwade, S. R., and Myers, A. T., “Incrementalwindwaveanalysis of thestructuralcapacity of offshore wind turbinesupportstructuresunderextremeloading,” EngineeringStructures, vol. 79, pp. 58–69, 2014.