Journal Homepage: -www.journalijar.com
INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)
ISSN NO. 2320-5407
Article DOI:10.21474/IJAR01/8460
DOI URL: http://dx.doi.org/10.21474/IJAR01/8460

RESEARCH ARTICLE

A NEW APPROACH FOR THE CALCULATION OF HYDRODYNAMIC FORCES ACTING ON LATTICE STEEL STRUCTURES.

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Manuscript Info

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Manuscript History
Received: 02 December 2018
Final Accepted: 04 January 2019
Published: February 2019

Key words:-
Ann, ansys-fluent, hydrodynamic force, solidity ratio, stokes second order wave theory.

Abstract

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Thewindforcesactingonthespacelatticestructures are determinedbyconsideringthesolidity ratio dictatedby ANSI/TIA-222-G (Steel AntennaTowers and AntennaSupportingStructures) technicalspecification. This governing methodology for the steady flow conditions was investigated for its applicability for unsteady flow conditions at marine environment. The relation between the solidity ratio and hydrodynamic forces was investigated by utilizing 5 models. The solidity ratio was identified as the ratio of the surface areas of wave ward structural members to the total surface area. ANSYS-Fluent software was used for evaluating the performances of models.Hydrodynamic wave forcesrepresentedbytheStoke'sSecondOrder wave theory. Morisonequationwasemployedtoobtain lateral wave forces. Artificial Neural Network (ANN) with the Levenberg-Marquardt optimization algorithm was used to determine the relation between hydrodynamic forces and various dimensionless parameters: solidity ratio *(e)*,$H/(gT^2)$, $d/(gT^2)$, (z_s/d), (t/T) and project area of sector *(A)*. The performance of the evaluated ANN model indicated that, hydrodynamic forces can be obtained successfully by implementing the solidity ratio.

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Introduction:-

Space-lattice system towers located on land are generally exposed to variable wind drag forces throughout the height of the structure (Nizamani, 2015). The effect of wind forces increases with the height of structure (Kurç et al., 2012). Additionally, these forces create a compression and vacuum effect and vortices at upstream and downstream depending on the structural geometry. The forces acting on the members of lattice structure are often calculated with the extensive dynamic analysis. The recent ANSI/TIA-222-G technical specification is considered as different approach for space-lattice towers constructed on land. According to the technical specification, the area between the layers of space-lattice or frame towers is called as a "sector". the lateral forces are determined with a function based on a solidity ratio defined as the ratio of the surface areas of wind ward structural elements to the total surface area.

Space lattice or frame structures are popular solutions for the offshore projects such as wind turbine tower and jacket type oil platform (TIA, 2005; Friez, 2011). Usually, the structural members under the sea level are exposed to hydrodynamic forces due to the currents and waves (Kurian et al., 2010). The total lateral hydrodynamic force is composed of drag and inertia forces. The drag and the inertia wave forces are calculated with water particle

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velocities and accelerations due to wave theories which can change by depth, wave height and wave period (Chakrabarti, 2005; Dean &Dalrymple, 2007). The site of this study has also expanded considerably by applying the various solution methods to different structural design and environmental conditions. Elshafey et al. (2009) investigated the dynamic response of a scaled model of a jacket offshore structure subjected to random wave loads theoretically and experimentally. The effects of structure's weight and the characteristics of the wave loading have been examined by using a finite element model which represented the dynamic response. This study demonstrated an excellent agreement between the experimental and theoretical results. Bea et al. (1997) proposed a simplified procedure to evaluate the storm loadings acting on the offshore platforms. They determined the ultimate limit state lateral loading capacities of these platforms by cross comparing the simplified analyses results and three-dimensional, linear, and nonlinear analyses. Foster (1970) developed a response model for deep-ocean tower structures subjected to wave forces. Analytical solution of the problem was achieved using a discrete-system semi-linear technique. Raheem and Aal (2013) investigated the response of fixed offshore structure with considering distribution of displacement, axial force and bending moment along the legs. Wave and current kinematics were generated by 5th order Stokes wave theory. This study proved that the nonlinear analysis of an offshore platform subjected to extreme wave prevailed its design.

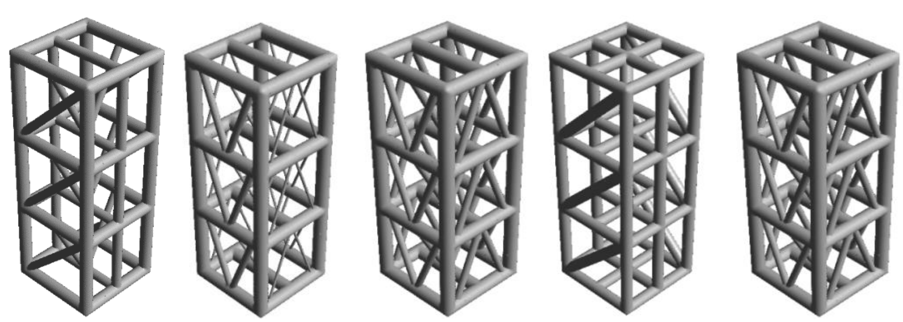
The aim of this study is to propose a novel approach for calculating hydrodynamic forces acting on the space lattice and space frame structures independent from configuration. The validity of solidity ratio approach has been questioned in marine conditions. The solidity ratio has been used to observe vortex effect that was based on turbulence around the structural members. It was studied with the structural models as CSR (Constant Solidity Ratio). Both structural models consisted of 3 sectors and designed according to 5 different solidity ratio e values. The solidity ratios were assumed as constant throughout the sectors. Hydrodynamic analyses of 5 sub-models were performed by considering 2 marine environment conditions which were valid under Stokes Second Order wave theory. Data set was obtained to define the relation between solidity ratio and hydrodynamic forces with ANSYS-Fluent software. Then, Artificial Neural Networks (ANN) was used to train the data set that was obtained from the analysis results of ANSYS-Fluent. Water depth d, wave height H, the distance from center of sector to seabed z_s, wave period T, the time when hydrodynamic force is obtained t, solidity ratio value e and structure surface area A were determined as variable parameters. These parameters were simplified as H/gT^2, d/gT^2, t/T, z_s/d. The reliability of the results was controlled by using test model T_1. It has been emphasized that this simplified method can contribute to the development of space lattice and space frame structures.

Methodology:-

The effect of hydrodynamic forces on space lattice and frame offshore structures was investigated by using the ANSYS-Fluent analysis program (ANSYS, 2013). The modeled structures were composed of 3D solid tubular members. The structural models were subjected to wave loads represented by the Stokes Second Order Wave Theory. This flow involves the free surface between two phases solved using VOF (Volume of Fluid) formulation (ANSYS, 2013). VOF model depends on Euler-Euler approach.

Structural Models

Main top and base dimensions of the CSR models were 6m × 6m with a height of 18 m. The solidity ratio values were assumed as 0.25, 0.30, 0.32, 0.34 and 0.36 to be constant and equal in each 3 sectors. The structural models are shown in Figure 1.



CSR1 e=0.25 CSR2 e=0.30 CSR3 e=0.32 CSR4 e=0.34 CSR5 e=0.36

Figure 1:-Structural models

The CSR sub-models were named as CSR-1, CSR-2, CSR-3, CSR-4 and CSR-5 with the varying solidity ratios of 0.25, 0.30, 0.32, 0.34, and 0.36 respectively. These models were divided into 4 designs regarding their geometries (Reedy, 2012). CSR-3 and CSR-5 models had the same geometry but their solidity ratios were deviated because of the variable profile dimensions used in design.

Fluid Domain

The fluid domain was modeled as a rectangular prism by the ANSYS-Fluent. The dimensions of the domain were 20 x 25 x 40 m in directions *x*, *y*, and *z*, respectively. The volume of the fluid domain includes prism layers around the members to solve the boundary layer more efficiently and refined mesh contains around 2.75 million cells.

The density and the dynamic viscosity of the seawater were considered as 10.25 KN/m3, 0.0015 Ns/m^2. Lateral hydrodynamic wave forces were calculated with water particle velocities u and accelerations $\dot{u}$ in accordance with Stokes Second Order Wave Theory, as presented below

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

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

Where, g isacceleration of gravity, d is the water depth$H$ is wave height and T is wave period and L is wave length (Yüksel&Çevik, 2009; Ergin, 2009). In this study the wave conditions were considered as respectively*: $d = 18.0m$, $T = 12.0s$, $H = 1.40m$*. The lateral total hydrodynamic forces (F_H), (F_H=F_D+F_M; F_D: drag force, F_M: inertia force) were determined for CSR models.

ANN Model Training

The total hydrodynamic forces acting on each sector of CSR models were obtained with ANSYS-Fluent. The data set consisting of 504 values was generated by recording hydrodynamic forces for 0.5s intervals to12s. The parameters of fluid and structure, that have an influence on hydrodynamic forces, are presented as inputs of the data set for training model (Öztemel, 2003; Şen, 2004). These inputs are determined as X_1; (H/gT^2), X_2; (d/gT^2), X_3; (z_s/d), X_4; (t/T), X_5; e, X_6; A and output is consisted of Y; F_H. The data set prepared to define the relation between input and output was shown in Figure 2.

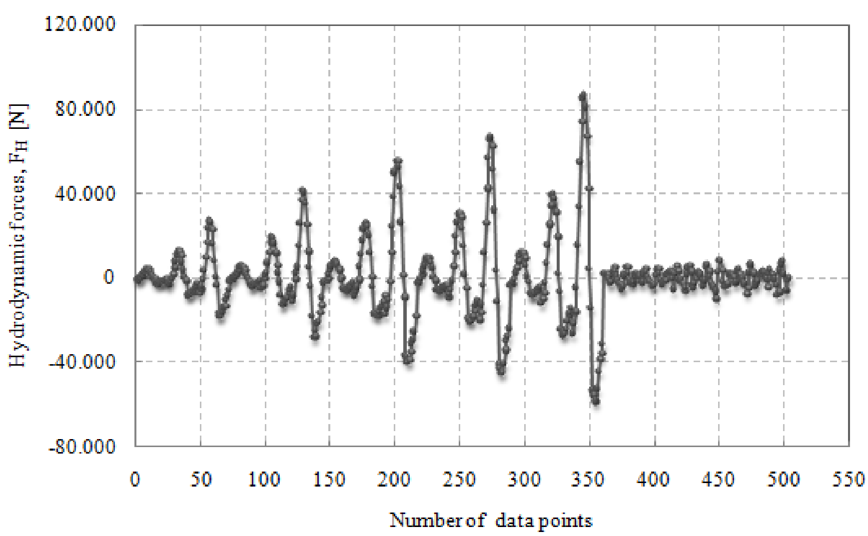


Figure 2:-Data set of ANN training model

Models were generated using a network containing single hidden layer variable hidden neurons (8 to 16). Tangent hyperbolic activation function and Levenberg-Marquardt *(LM)* optimization algorithm were used (Cığızoğlu, 2005; Tayfur, 2012).

The performance of the ANN model was evaluated by T_1 test model consists of 3 sectors with a fixed solidity ratio of 0.34 and the dimensions of each sector were 6 m x 6 m x 6 m in directions *x*, *y*, and *z*, respectively. T_1 test model was analyzed considering D_{T1}environmental conditions. In D_{T1}, parameters were taken into account as respectively: *d = 18.0 m*, *T = 8.80 s*, *H = 1.30 m*. The hydrodynamic forces calculated by the analysis with ANSYS-Fluent program are given in Figure 3.

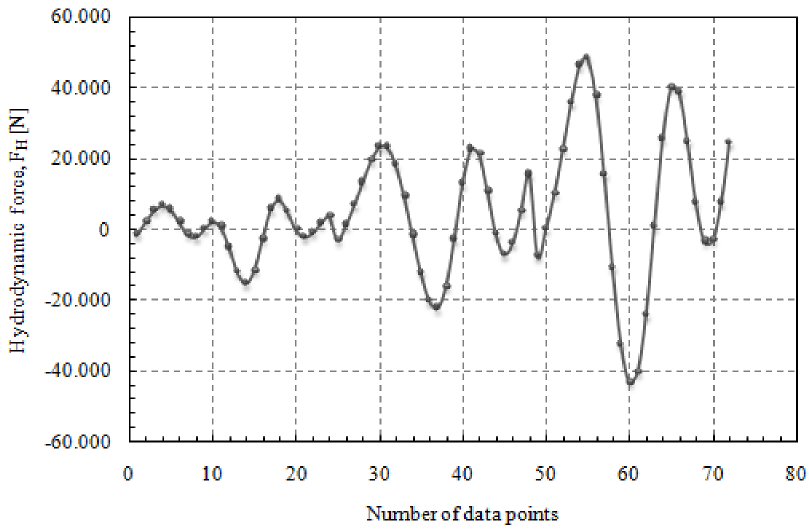


Figure 3:-Data set of T_1test model

Numerical Results:-

The hydrodynamic forces acting on T_1 test model were estimated by implementing the ANN model. The scatter diagrams of forces that were determined with ANSYS-Fluent analyses and estimated with ANN training model are given in Figure 4.

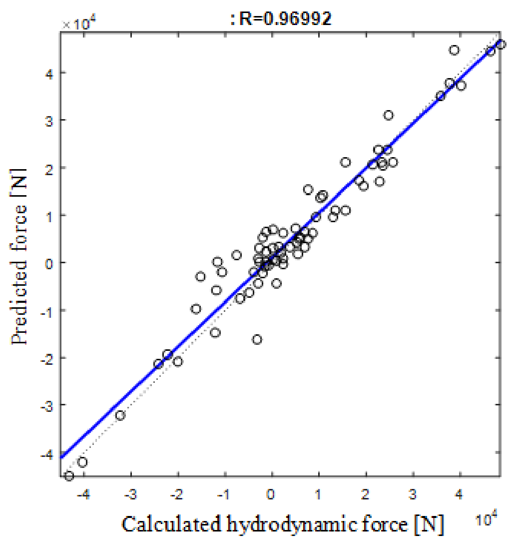


Figure4:-The scatter diagram of the test model

According to the results, the value of correlation coefficientwas determined as 0.969. The actual and predicted forces were compared in Figure 5 for T_1test model.

As seen in Figure 5, estimated and actual values are compatible with each other.

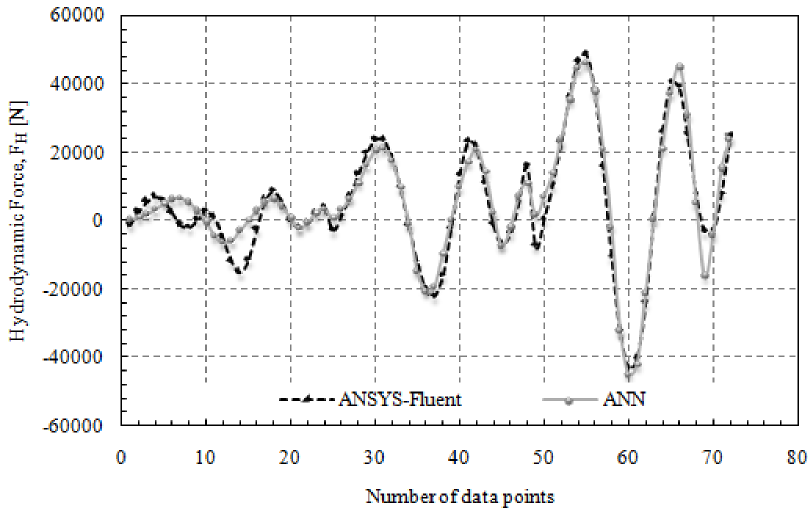


Figure5:-The comparison of the ANSYS and ANN results for the T_1 test model

The maximum positive value of hydrodynamic forces was determined as 46349N withANSYS-Fluent and estimated as 44520N with ANN. The maximum negative value of hydrodynamic force has been determined as -40412N with ANSYS-Fluent, as 42065N with ANN. In general, the deviation band varies from 25.2% to 3.4%.

Conclusions:-

In this study the validity of solidity ratio approach was evaluated for maritime conditions. In order to calculate hydrodynamic forces including different solidity ratios and wave parameters, both ANSYS-Fluent and Artificial Neural Network (ANN) were used. Hydrodynamic analyses of 5 sub-models of CSR (Constant Solidity Ratio) types were implemented for variable marine conditions under prevailing Stokes Second Order wave theory. The data obtained from the analysis of the models were divided for the training and testing phases of the ANN. The test data-set was named as T_1.

The mean deviation ratio was obtained as 15.6% for the T_1 test model. The results indicate that, there was a significant deviation between the sectors for both models because of the variability of the distance between the center of a sector and the sea bed. However, when the results are evaluated as sectoral basis, it is seen that the model yield relatively consistent results.

This study demonstrated that the hydrodynamic forces acting on a space lattice and space-frame structures can be determined free of its configuration. This proposed methodology for interrelating the solidity ratio and the corresponding hydrodynamic forces allows the designer to assert a reliable and practical way of structural analysis for the offshore structures instead of complex and long-term analysis.

References:-

1. ANSYS Fluent Users Guide, pp. 2692, (2013).
2. Bea, R.G., Mortazavi, M.M., Loch, K.J., “Evaluationof storm loadings on and capacities of offshore platforms”, Journal of Waterway, Port, Coastal and Ocean Engineering ASCE. 123(2), 73-81, (1997).
3. Chakrabarti, S.K., “Handbook of Offshore Engineering”, Elsevier Science, USA, 1321p, (2005).
4. Cığızoğlu, H.K., Kişi, Ö., “Flow prediction by three back propagation techniques using k-fold partitioning of neural network training data”, Hydrology,Nordic., 36(1), 49-64, (2005).
5. Dean, R.G., Dalrymple R.A., “Water Wave Mechanics for Engineers and Scientists”, Advanced Series on Ocean Engineering, World Scientific Publishing Co. Pte. Ltd., USA, (2007).

6. Elshafey, A.A., Haddara M.R., Marzouk, H., “Dynamic response of offshore jacket structures underrandom loads”, Marine Structures, 22, 504-521, (2009).
7. Ergin, A., “Coastal Engineering”, Metu Press, Turkey, (2009).
8. Foster, E.T., “Model for Nonlinear Dynamics of Offshore Towers”, Civil Engineering Database, American Society Of Civil EngineersAsce Lıbrary, USA, (1970).
9. Friez, P.A., “Offshore Structure Design and Construction”, Ships and Offshore Structures. Encyclopedia of Life Support Systems, UK, (2011).
10. Kurç, Ö., Kayışoğlu, B., Shojaee, S.M.N., Uzol, O., “yüksek binalarda rüzgar etkilerinin rüzgar tüneli deneyleriyle tespiti”, Teknik Dergi, 389, 6163-6186, (2012).
11. Kurian,V.J.;Narayanan,S.P.;Ganapathy,C., “Towers for offshore wind turbines”, The 10th Asian International Conference on Fluid Machinery, AIP Conference Proceedings, Kuala Lumpur-Malaysia, (2010).
12. Nizamani, Z., “Environmental Load Factors and System Strength Evaluation of Offshore Jacket Platforms”, Springer International Publishing, Switzerland, (2015).
13. Öztemel, E., “YapaySinirAğları”, PapatyaYayıncılık, İstanbul, (2003).
14. Raheem, S.E.A., Aal, E.M.A.A., “Finite element analysis for structural performance of offshore platforms under environmental loads”, Key Engineering Materials, 159, 569-570, (2013).
15. Reedy. M.E., “Offshore Structures Design, Construction and Maintenance”, Gulf Professional Publishing, United Kingdom, (2012).
16. Şen, Z., “YapaySinirAğlarıİlkeleri”, Su VakfıYayınları, İstanbul, (2004).
17. Tayfur, G., “Soft Computing in Water Resources Engineering”, WIT Press, Southampton, (2012).
18. Telecommunications Industry Association (TIA), “Structural Standards For Steel Antenna Towers And Supporting Structures”, USA, 120p., (2005).
19. Yüksel, Y., Çevik E.Ö., “KıyıMühendisliği”, Beta BasımYayım, İstanbul, (2009).