Response Prediction of Offshore Floating Structure using Artificial Neural Network


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Abstract:

For deep-water oil and gas exploration, spar platform is considered to be the most economic and suitable floating offshore structure. Analysis of spar platform is complex due to various nonlinearities such as geometric, variable submergence, varying pretention, etc. The Finite Element Method (FEM) is an important technique to deal with this type of analysis. However, FEM is computationally very expensive and highly time-consuming process. Artificial Neural Network (ANNs) can provide meaningful solutions and can process information in extremely rapid mode ensuring high accuracy of prediction. This paper presents dynamic response prediction of spar mooring line using ANN. FEM-based time domain response of spar platform such as surge, heave and pitch is trained by ANN. Mooring line top tension is predicted after 7200 sec (2 hours) of wave loading. The response obtained using ANN is validated by conventional FEM analysis. Results show that ANN approach is found to be very efficient and it significantly reduces the time for predicting long response time histories. Thus ANN approach is recommended for efficient designing of floating structures.

Keywords: Offshore floating structure, Spar platform, Artificial Neural Network, Dynamic response, Prediction, Mooring line tension, Deep water platforms.

1. INTRODUCTION

Due to global energy demand offshore industries is moving towards deep and ultra deep waters. For deep-water oil and gas exploration, spar platform is considered to be the most economic and suitable offshore structure. Spar platform is a complaint offshore structure used for deep-water applications of drilling, production, and storage of ocean deposits. The spar platform is a cylindrical deep draft floating hull, which allows the structure to buoy and be held in place by mooring lines. Analysis of
spar platform is complex due to various nonlinearities such as geometric, variable submergence, varying pretention, etc. FEM is an important technique to cope with this kind of analysis. Numerous studies have recently been performed in order to predict response of spar platform with different types of conventional methods. However, response analysis of spar platform by these methods is very complicated and time-consuming.

ANNs can provide meaningful solutions and can process information in extremely rapid mode ensuring high accuracy of prediction. Mazaheri & Downie\textsuperscript{1-2}, developed ANN modeling technique for prediction of floating production storage and offloading (FPSO) responses to arbitrary wind, wave and current loads. Elshafey et al.\textsuperscript{3-4} provided a tool for using deck acceleration measurements to predict the value of force and moment acting on offshore structure foundation. Hybrid ANN–FEM approach has been adopted for response analysis of FPSO, for random dynamic response of mooring lines and risers\textsuperscript{5}. Mandal et al.\textsuperscript{6} addressed the prediction of stress resultant deflection of fixed offshore platform under varying sea environments using neural networks. Yasseri et al.\textsuperscript{7} proposed a method for identifying the range of sea-states considered safe for the installation of offshore structures using FEM method and ANN. Simoes, et al.\textsuperscript{8} developed a neural network for prediction of mooring forces and analysis of dynamic behavior of FPSO and a shuttle ship in tandem configuration. Hong-yu & De-you\textsuperscript{9} proposed the grey neural network as adaptive predictive inverse controller, which was implemented for active control of jacket offshore platform. Cui & Zhao\textsuperscript{10} proposed neural network as an adaptive predictive inverse controller for active control of offshore platform under the combined action of random waves and winds.

The comprehensive existing literature review shows that response prediction of spar platforms using ANN has not been reported widely. Therefore, the main objective of present study is dynamic
response prediction of classic spar platform. It is observed that the proposed ANN approach is significantly faster than conservative FEM-analysis for dynamic response simulation of longer time histories.

2. FINITE ELEMENT METHOD

The finite element model is used to implement the fully coupled integrated spar platform. The analysis of spar platform considering actual physical coupling between the rigid vertical floating hull and mooring lines is carried out using FEM. Effect of mooring lines with spar can be captured well with numerical modeling. In actual field problems hydrodynamic loads due to wave and currents act simultaneously on spar platform and mooring lines. In finite element model, the entire structure will acts as a continuum. This model can handle all nonlinearities, loading and boundary conditions. The finite element code ABAQUS/AQUA is used to obtain the response of spar platform.

For this study a spar platform is selected in 1018 m deep water. Spar platform consist of major three parts such as spar hull, mooring lines and risers. The spar hull is modeled as rigid beams connecting with riser and mooring line at reaction points and fair leads respectively. Mooring tensions are assumed to be equally distributed in all the four mooring lines. The mooring lines are modeled as hybrid beam elements. It includes the nonlinearities due to low strain large deformation and fluctuating pretension. The axial tension maintains the catenary shape of the mooring lines.

In finite element analysis, 6m wave height and 14 sec wave period is considered as sea-state. These sea-states adequately cover the conditions of significant dynamic excitation for steady state. When the wave forces act on the entire structure, participation of mooring lines in the overall response is well represented.
3. ARTIFICIAL NEURAL NETWORKS

Artificial neural networks (ANNs) are an information-processing system encouraged by biological nervous systems, such as human brain. ANNs are able to learn from experience like people. An ANN is a combination of artificial neurons namely processing elements, nodes or units. Each processing element is fully interconnected to other processing elements by its connection weights. Processing element accepts its weighted inputs, which are summed with adjustable unit bias. The result of this combined summation is passed through the transfer function to produce the output of the processing element.

Fig. 1. Typical neural network architecture

Fig. 1 shows three layers of neural network having input, output and hidden layer with hyperbolic tangent function considered in present study. The responses such as surge, heave and pitch motion of spar platform are obtained from FEM. Non-linear dynamic motion time histories are used as input in ANN for training the network. Mooring line top tension time history is used in ANN as target for training, obtained from FEM. In this study FEM based response is trained by ANN for short simulation length. The ANN is capable to predict longer response time histories in dynamic analysis of spar mooring lines.

In a dynamic analysis output response depend upon not only on the current values but also on their previous values. Feed-forward neural networks with back-propagation algorithm are used to train ANN architecture. If the response of top tension differs from the desired output response, the network
generates an error. This error is utilized to adjust the connection weights between the target response and output response.

4. RESULTS AND DISCUSSION

Response time history of spar and mooring lines under regular wave are obtained after 1 hour of storm by FEM. The analysis of spar platform for deep water condition has been carried out up to a record length of 7200 sec (2 hours). The responses in terms of surge (longitudinal motion), heave (vertical motion), pitch (rotational motion) and mooring line top tension are plotted between 2000 to 3000 seconds which is shown in fig.2,3,4 and 5 respectively.

Fig.2. Surge time history
Fig.3. Heave time history
Fig.4. Pitch time history
Fig.5. Maximum Tension time history of mooring line

Statistical response of spar mooring lines is obtained from finite element analysis after 1 hour storm. Statistical analysis in terms of maxima, minima, means and standard deviation has also been shown in Table 1.

Table 1. Statistical response of spar mooring lines (After 1 h storm)

Response calculation of spar mooring line for 7200 sec using FEM requires minimum time of 15
hours on Dell Workstation Precision T7500. The computational efforts needed to predict spar platform response using ANN is very small compared to a complete finite element-based simulation. It takes just 20 min on Pentium (R) 4 CPU 3.0 GHz computer. Non-linear time histories of 7200 sec for surge, heave and pitch are used as input in ANN for training the network. Top tension time histories are used in ANN as target for training. A 7200 sec time histories have been used to train the neural network in the hidden layer with 10 neurons. Three kinds of target time steps have been randomly divided up to 7200 sec time series data.

Time series 5040 sec (70%) has been used for training, 1080 sec (15%) for validation and 1080 sec for testing (15%). Training set of data is used to adjust the network according to means square error. The validation set is used to minimize the data over fitting and testing set is for measuring the network performance during and after training. Consequently response/output of mooring line top tension is predicted after completing the training from 7201 sec to 14000 sec, that is more than 1 hour 53 min.

Fig.6. Maximum Tension time history of mooring line, FEM vs ANN

Fig. 6 shows the comparison between predicted ANN results and the time consuming FEM results 10300 sec to 10600 sec. The results of ANN have been well converged with the FEM outputs. The error in prediction for response histories of floating spar platform is presented in Fig. 7.

Fig.7. Error of ANN output
The back propagation neural network minimizes the error by trial and error process. It is observed that the combination between 4 sec delay for surge, heave and pitch motions and 10 neurons in the hidden layer quickly minimize the mean square error. From the analysis it is clear that the error is insignificant for the structural solution of floating spar platform.

5. CONCLUSIONS

Results show that ANN approach is found to be very efficient and it significantly reduces the time for predicting long response time-histories. The responses obtained from the ANN approach matches with the time consuming numerical solution and give a long duration prediction in simple manner. ANNs can deal with more data and requires less computing time for training. The study also reveals that an ANN can provide highly accurate predictions of mooring line top tension using the NARX algorithm. The research findings create high practical importance value for oil and gas industry. The trained architecture will help in designing more efficient and economical configuration of mooring systems.

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References

4. X. Zhou and S. Luan, 5th International Conference on Wireless Communications, Networking and


Figures and Tables

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Table 1. Statistical response of spar mooring line (After 1 h storm)

<table>
<thead>
<tr>
<th></th>
<th>Max</th>
<th>Min</th>
<th>Mean</th>
<th>Standard deviation</th>
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<tr>
<td>Wave Ht.=6m</td>
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<tr>
<td>Wave Pr.=14 sec</td>
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<tr>
<td>Surge (m)</td>
<td>16.194</td>
<td>-13.658</td>
<td>1.038</td>
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<tr>
<td>Heave (m)</td>
<td>2.374</td>
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<td>0.074</td>
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<td>Mooring line</td>
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<td>1.58E+07</td>
<td>1.63E+07</td>
<td>2.51E+05</td>
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<tr>
<td>Tension (N)</td>
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