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EXTREME ENVIRONMENTAL LOAD MODELS FOR WAVE AND CURRENT RESPONSE SURFACE METHOD

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The three most uncertain environmental design loads acting on offshore structures are wave height, current and wind velocity. If the reliability of structure is to be determined, then we need to have limit state function for load which requires that we should transform the environmental loads into load model. Load model, which predicts the load, will ultimately affect the design resistance and thus its final impact on cost could be large. Since, there are many offshore structures located in different offshore regions in Malaysia, the calibration of the environmental load model, should be evaluated to determine which model fits best. To obtain the environmental load model, response surface technique is generally applied. Load models suggested by DNV and ISO code are analysed to determine the best model fit for local conditions of Malaysia. Base shear, wave height and current velocity are used in a linear fit to determine polynomial response surface. The results showed that due to the geography of Malaysia different regions might have to use specific load models instead of a general load model for all regions.

Keywords: Offshore structures, Linear fit, Weibull distribution, Curve and surface fit.

1 INTRODUCTION

Offshore structures are designed to resist three kinds of loads, Environmental loads i.e., wave, currents and wind, Dead loads, i.e., weight of the structure, and Live loads, i.e., weight of consumable supplies and fluids in pipes and tanks. The extreme event considered for the design and assessment of old structures is recommended to have the probability of failure of 1E-2. The ultimate strength analysis requires that the resistance should be higher than the loads. Thus, higher anticipated loads will require higher resistance. Since, there are many offshore structures located in different offshore regions in Malaysia, the calibration of the environmental load model, should be evaluated to determine which model fits best for local conditions. This is because the environmental load model, used for calibration from Gulf of Mexico (GOM) and North Sea (NS) may or may not be reasonable for local geography of Malaysia (Sigurdsson *et al*. 1994, Atkins 2001, Wahab *et al*. 2015, Nichols 2014).

2 ENVIRONMENTAL LOADS

Environmental loads are severe and unpredictable due to uncertain whether condition and they can act with unexpected severity on offshore structures. The safety of offshore structures is achieved by taking into consideration hazards produced by rare wave, current and wind events. ISO 19902 code defines this rare and extreme event of 100 years. Present day design methods depend on all energy comes from a single direction which is a long-crested waves. However, sea waves in real are multidirectional as the energy comes from many directions simultaneously. Wave loads are unsteady and exert the largest force and it is producing main contribution to the hydrodynamic load. Currents can play important role in total forces acting on offshore structures. The current generated in the ocean is steady in nature and its effect tends to vary with the water depth. When extreme waves along with super-imposed current occur in same direction velocities from both can combine and produce large wave pressure. Normally wind load will not produce much effect, especially in the design conditions and it generally accounts for only 10% of the overall design load as used by DNV code.

2.1 Environmental Load Model

Many authors have studied response surface methodology to determine the reliability of offshore structures such as Gaspar *et al*. (2015), Gaspar *et al*. (2014), Gaspar *et al*. (2013) and Gaspar *et al*. (2012). The environmental load model is determined using response surface modeling using curve and surface fitting tool of MATLAB. The custom polynomial Equation for wave and current is defined to get the parametric values for the given coefficients. The first model is suggested by SHELL for the development of load factors for ISO 19902 code are shown in Eq. (1).

$$W = aH_{max}^2 + bH_{max} + cV_c^2 + dV_c + e \tag{1}$$

W = Load effects, H_{max} = variable annual maximum wave height, V_c = variable current speed, the coefficients of a, b, c, d and e are found from curve and surface by using least square method.

Response surface fit proposed by Heidman (1980) as shown in Equation (2) is used to get the load effects from Jacket base shear and wave heights Gerhard (2005). To establish the relationship between wave and current load and response of Jacket curve fitting is done to find the coefficients of the response surface Equation.

$$W = a_1 \left(H_{max} + a_2 V_c \right)^{a_3} \tag{2}$$

W = load effects, H_{max} = maximum wave height and V_c = current velocity. Coefficients a_1, a_2, and a_3 are found from the curve and surface. The third model was suggested during development of API LRFD code by Moses and Stahl (2000), as shown in Eq. (3),

$$W = X_{hydro}(a.H^b) \tag{3}$$

W= Environmental load model, X_{hydro} = Uncertainty model for base shear, H = maximum wave height, while coefficients a and b representing structure dependent parameter, fitted from analysis results of base shear and wave height.

2.2 Linear Polynomial Response Surface Fit

Table 1 contains the platform specific load parameters for one region of Malaysia, which shows the basic values of load variables used for conversion into random input for load values in FEM software. Using these values along with Weibull distribution, 100 random values is generated for wave, current and time period using MATLAB. These 100 random load values are used to get 100 stresses from FEM output file for each component. The corresponding 100 component output stresses are produced by FEM software. These are converted to load model using curve and surface fit. To get the environmental load effect for the reliability analysis, 100 stress values for wave, time period and current are determined using Weibull distribution using Table 1.

Table 1. Offshore jacket platform data.

Parameter	10 year	100 year	Weibull Distribution Parameter Scale	Weibull Distribution Parameters Shape
H_{max}	6.8 (m)	7.7 (m)	5.86	5.58
Tp	10.6 (s)	11.0 (s)	18.71	10.14
Current	0.78 (m/s)	0.94 (m/s)	0.62	3.71

Random variables obtained through Weibull distribution, are used to determine the base shear. The load is applied at each 45° i.e., from eight different directions as these jackets were four and six legged. From initial analysis, it was determined that 0° was producing maximum load effects. Therefore, this direction is selected for further analysis. The process is repeated until one hundred values of base shear are obtained. Base shear obtained is used for the response surface fit of the jacket platform. The relationship of the dependent and independent variables can be represented by curve fitting through the regression analysis, so that, we can understand how much uncertainty is present in the curve fit with random error. Curve fit also shows the accuracy of the analysis by displaying the value of R-square. Random variables such as wave height are assigned into x-axis, while base shear is set as the input of y-axis. Then, a model equation is inserted by choosing the custom equation option. Whenever the equation is applied, fitting tool will analyze the data from the set as the axis component. Coefficient of the model equation can be determined by using least-mean square method. Since the model equation applied is a two- parameter polynomial fit where the wave height and base shear are substituted into this equation, only coefficient will remain unknown and therefore it could be determined as the analysis is run. These coefficients are displayed together with the R-square. To evaluate effects of current velocity on load model surface fit tool is used which involves three dimension variables which are wave height, current velocity and base shear. Response surface of jacket platform can be analyzed based on this quadratic polynomial response surface fit. The accuracy is measured based on how close surface area created by data point linked to the surface created by equation. In the end sensitivity analysis is made to check the results obtained by using environmental load model and base shear from FEM software.

3 RESULT AND DISCUSSION

The coefficients are derived using the least square method. Data is analyzed at 95% confidence level. Here the design wave height and current speed used are based on 100 years as required by ISO/API codes. Figures 1-2 represent the surface fitting of Polynomial fit for model equations 1-2 and Figure 3 presents curve fitting of load model Eq. (3). The curve fitting for load model Eq. 1-2 is not shown here, but results are presented and compared against base shear. Figure 1 shows a plotted surface fitting of base shear vs. wave height and current velocity with the model of Eq. (1) and the coefficients are obtained where a= 0.1133, b= -0.4702, c= 0.1886, d= 4.199 and e= -0.1356. Now when current is not part of random variable a curve fit is made and the coefficients determined are a= 0.1304, b= -0.003236, c= 0.4719, d= -0.008059 and e= -0.8972. When model Eq. (2) is used with curve fitting i.e., no current is used then the coefficients determined are a_1=

0.4188, a_2= -0.003236 and a_3= 0.4719. When current is used as a variable and surface fit is used as shown in Figure 2, the coefficients determined are a_1= 0.02824, a_2= 6.099 and a_3= 2.141. Figure 3 illustrates a graph of base shear vs. wave height by the application of model Eq. (3) using curve fitting and has coefficients of a= 0.04354 and b= 2.498 and R^2 is 0.9923. Table 2 provides the parameters for wave and current for the platforms obtained from curve fitting. Now it is clear that Eq. (1) is providing the best fit model and this is due to the effects of current velocity are significant in this region of offshore Malaysia.

3.1 Environmental Load Model Analysis

The Environmental load applied to the structure is directly proportional to the base shear exerted on the platform. The closer the value of the environmental load model to base shear, more accurate will be the model for reliability analysis. Using Eq. (1), the base shear of the platform, when analyzed using the curve fit, is very close to its environmental load model since the R^2 displayed is 0.9969 as shown in Table 3. By comparing both average base shear and environmental load model of this platform, the average base shear is 3.06 MN and the maximum environmental load model is 3.09 MN which mean the difference between them are only 0.03. Hence, the relationship of base shear and environmental load model represented by the graph shows the high value of R^2. However, when it is analyzed by using surface fitting, the value of R^2 gives 0.9999 as shown in Figure 4 and Table 3 when current velocity is considered into the environmental random variables which shows that current velocity plays a significant role and it should be incorporated in developing the load model. The R^2 values for curve fit for Eq. (2), is 0.926 as recorded in Table 2. Figure 5 and Table 3 illustrates a fit plotted based on the base shear vs. environmental load model where the environmental load models are generated from the substitution of coefficient obtained from the surface fitting of Figure 2 into the Eq. (2). This is the lowest value among the three equations used and this shows that the second equation applied may not appropriate for this platform. Figure 5 also displays the function of the fit and its R^2 values which is 0.974 as recorded in Table 3. In Figure 6, a graph of base shear vs. environmental load model is plotted based on the environmental load model generated from the substitution of coefficients into Eq. (3). Those coefficients are obtained from the curve fitting of Figure 3. From Figure 6, the function of the fit can be found and its R^2 is recorded in Table 3. The value of the R^2 is 0.9927.

Table 2. Base shear vs. wave height and current velocity, R^2.

Curve fitting model			Surface fitting model	
1st	2nd	3rd	1st	2nd
0.9960	0.9961	0.9923	0.9999	0.9971

Table 3. Base shear vs. environmental load model, R^2.

Base shear vs. Environmental load model				
Curve fitting			Surface fitting	
1st equation	2nd equation	3rd equation	1st equation	2nd equation
0.9969	0.9260	0.9927	0.9999	0.9974

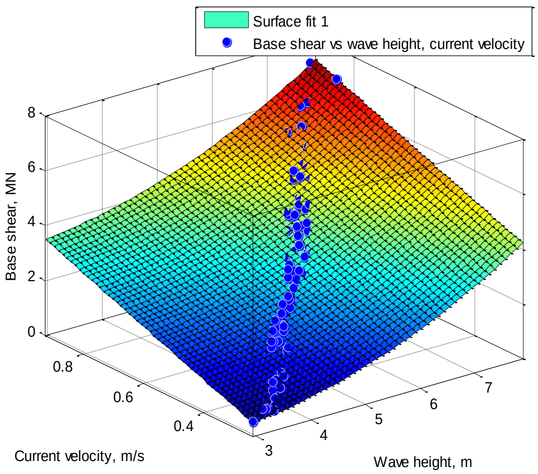

Figure 1. Base shear vs. wave height and current velocity Model 1_surface fit.

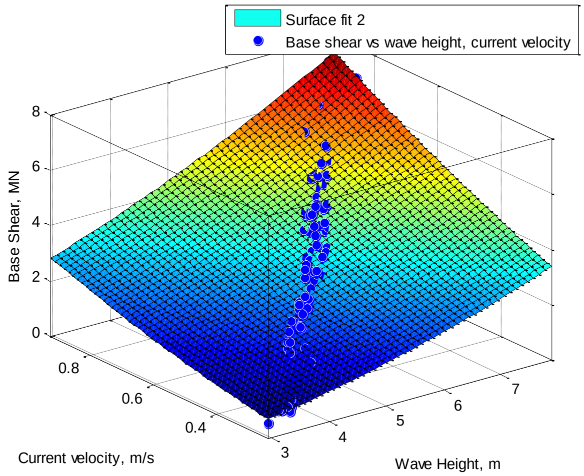

Figure 2. Base shear vs. wave height and current velocity Model 2_surface fit.

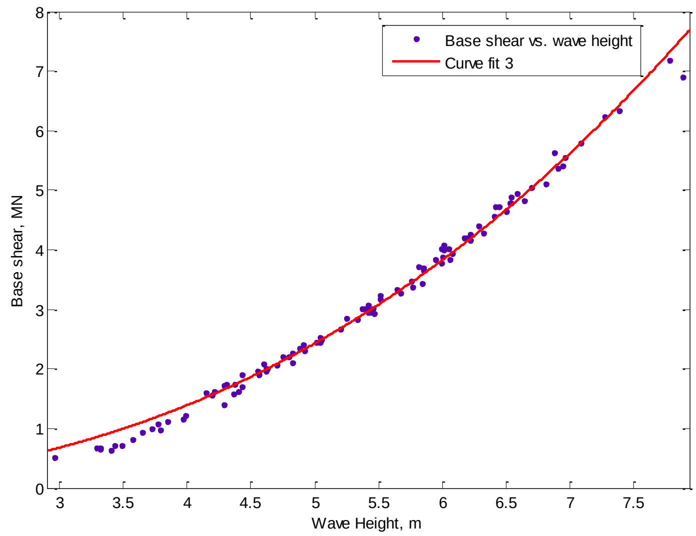

Figure 3. Base shear vs. wave height 3_curve fit.

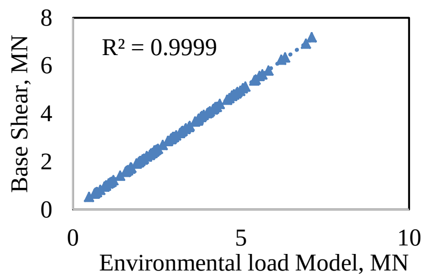

Figure 4. Base shear vs. environmental load Model 1 (Surface Fitting).

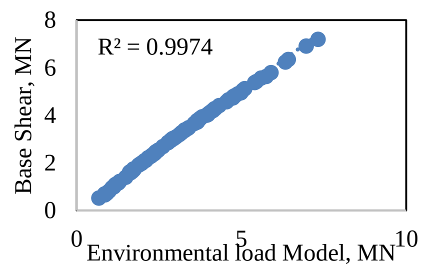

Figure 5. Base shear vs. environmental load Model 2 (Surface Fitting).

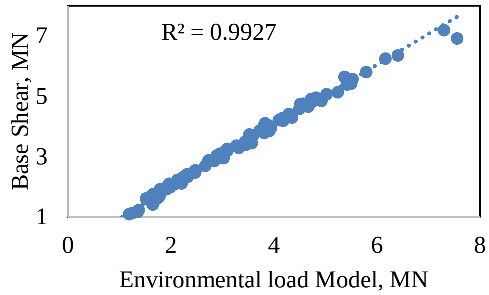

Figure 6. Base shear vs. environmental load Model 3 (Curve Fitting).

4 CONCLUSION

Wave height and current speed data from two platform specific locations are used. Regression analysis is used here to find the coefficients for response surface fit. Three polynomial models are used for converting the wave and current forces into the environmental load model. Best fit is assumed to predict as nearly as possible to the actual base shear from the analysis of jacket. The results show that first equation predicts very well to actual base shear and should be applied for the platforms lying in this region.

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References

Atkins, W.S., Consultants Ltd., Comparative evaluation of minimum structures and jackets. Health and Safety Executive, offshore technology report, UK, 2001.

Gaspar, B., Bucher, C., and Guedes Soares, C., Reliability analysis of plate elements under uniaxial compression using an adaptive response surface approach, *Ships and Offshore Structures*, 2015.

Gaspar, B., Naess, A., Leira B. J., and Guedes Soares, C., System Reliability Analysis by Monte Carlo Based Method and Finite Element Structural Models, *Journal of Offshore Mechanics and Arctic Engineering*, 2014.

Gaspar, B. and Guedes Soares, C., Hull girder reliability using a Monte Carlo based simulation method. *Probabilistic Engineering Mechanics*, 2013.

Gaspar, B., Naess, A., Leira B. J., and Guedes Soares, C., System reliability analysis of a stiffened panel under combined uniaxial compression and lateral pressure loads, *Structural Safety*, 2012.

Gerhard, E., "Assessment of existing offshore structures for life extension," Doctor of Philosophy, Department of Mechanical and Structural Engineering and Material Science, University of Stavanger, 2005.

Heideman, J., "Parametric Response Model for Wave/current Joint Probability," Report Submitted to *API TAC 88-20 for API LRFD*, 1980.

Nichols, N. W., Khan, R., Rahman, A. A., Akram, M. K. M., and Chen, K., Load resistance factor design (LRFD) calibration of load factors for extreme storm loading in Malaysian waters. Journal of Marine Engineering & Technology, 2014.

Moses, F. and Stahl, B., "Calibration issues in development of ISO standards for fixed steel offshore structures," *Journal of Offshore Mechanics and Arctic Engineering*, 2000.

Sigurdsson, G., Skallerud, B., Skjong, R., and Amdahl, J., Probabilistic collapse analysis of Jackets. OMAE conference, 1994.

Wahab, M. M. A., John, K. V., Liew, M. S., Nizamani, Z., and Kim, D. K., Structural reliability analysis using quadratic polynomial response surface methodology, OMAE, 2016.