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An Improved Version of ETS-Regression Models in Calculating the Fixed Offshore Platform Responses

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Abstract: An offshore structural design should accurately calculate wave loads and structural responses acting on slender cylinders. The hydrodynamic drag-dominated force was always challenging, hence the hydrodynamic wave loading became a complex solution; it led to a nonlinear relation between the wave force and responses caused by the diffracted and radiated waves, which was included in Morison's equation. For more consistency in the structural assessment, the linearised drag-inertia force was considered in model development, such as an improved version of the efficient time simulation regression (ETS-Reg) procedure that was introduced. The study aimed to improve the prediction of structural responses using the predetermined linear, polynomial, and cubic regression models. These simulations were performed focusing on high sea state conditions without wave-induced current effects. In order to evaluate the level of accuracy, the recent ETS-Reg models were compared and validated using the Monte Carlo time simulation (MCTS) method. An amended ETS-Reg model, known as the ETS-Reg_{LR} model, was also compared with the previous results obtained using the conventional ETS-Reg models (ETS-Reg_{SE}), leading to better structural response calculations.

Keywords: offshore structure; time simulation; regression model; extreme structural responses; Monte Carlo time simulation



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1. Introduction

Based on the presumptions of potential flow nearby small structure bodies, Morison's equation (ME) was adequate to represent the hydrodynamic behavior (Mukhlas et al., 2016). The ME represented the total load as a sum of two contributions: nonlinear drag and linear inertia forces. It formed a way to express the equation in order to determine additional damping (drag force) and added mass (inertia force) [1]. However, difficulties in hydrodynamic response analysis were continuously complicated phenomena that were often considered non-Gaussian characteristics [2]. Therefore, the nonlinear drag term was always an issue that influenced the consistency of offshore structural response estimation.

The linearisation of the nonlinear force expression was a common technique for resolving this inconsistency. This approach was initially introduced by [3,4], and continued by other researchers for calculation improvement in their studies [5–8]. As stated by [9], a relative study of the linear and nonlinear forms of the wave-induced force from Morison's equation was conferred and derived. In different techniques, the nonlinear drag term in Morison's equation was also linearised by least square methods [10].

Following the prior findings, the recent practice also implemented a similar approach by linearising the wave force component in Morison's equation as a modified model of development. This paper is an extended version of the previous paper by [11,12], who

offered a striking finding in the development of the empirical regression model. In fact, a simplified approach was found through the efficient time simulation regression (ETS-Reg) procedure in order to assess the complex hydrodynamical wave load-induced responses. As reviewed in that paper, the structural response of the structure was calculated based on applying the ETS-Reg_{SE} model.

However, the earlier ETS-Reg procedure was developed based on surface elevation as the primary input parameter for model development, which is why the structural response estimation was always an under-predicted phenomenon. For that reason, a proposed probabilistic model was utilised to simulate the more accurate structural responses by applying an improved version of the ETS-Reg procedure to obtain reliable results. The amended ETS-Reg_{SE} model, known as the ETS-Reg_{LR} model, was presented by introducing linearised responses as the revised input parameter in model development. As the same practice was implemented in [12,13], this recent paper consisted of three regression models: linear, polynomial, and cubic were improved in predicting the structural responses.

A parametric analysis was conducted to clarify the distinction between the wave loads-induced responses determined by the ETS-Reg_{SE} and ETS-Reg_{LR} models. These ETS-Reg models were measured in 100-year extreme response models, which consider low and high-sea sea state conditions with no current impacts. Both ETS-Reg models were compared and validated using the benchmark Monte Carlo time simulation (MCTS) method to examine the level of accuracy.

2. Platform Specifications and Wave Modelling Analysis

This section may be divided into two subheadings. Firstly, it consists of the test structure model accompanied by specific descriptions, which is similar to a fixed jack-up platform. Secondly, the evaluation of the offshore structural responses is calculated numerically regarding ocean wave hydromechanics. Lastly, the MCTS procedure is used as a reference to predict the extreme values of the short-term probability distribution.

2.1. Test Structure Specifications and Offshore Platform Models

The calculation of structural responses was based on the given features of offshore platforms. An ocean structure is subjected to the buildup of organic marine growths. The fluid flow behaviours around naturally roughened circular cylinders with a drag coefficient (C_d) and inertia coefficient (C_m) are equal to 1.05 and 1.20, respectively. Hydrodynamic coefficients are influenced by marine growths and natural roughness. Specifications of the jacket structural model admitted in this study were at an ocean depth of 110 m in the North Sea. These legs had a diameter of 1.5 m and a thickness of 0.04 m [14].

Figure 1 presents a fixed platform comprised of a four-legged platform that is a large-diameter tubular leg frame pile fixed to the seabed. The scattered load on each leg was designated by 30-point loads that reached a total number of nodal loads [15,16]. The total mass was 17,665 tonnes, and the square cross-section jacket measured 38 m × 35 m (plan view) on the platform deck.

Waves from the environment mostly caused the structural loads. The actual data were used to assess two configurations: offshore platforms and environmental met-ocean. Atkins Ltd. (Epsom, UK) provided the structural data and the Health and Safety Executive (Bootle, UK) granted environmental data for Forties Field in the North Sea region. Based on ocean wave hydromechanics, the fast Fourier transform (FFT) mathematical tools were used to simulate the wave hydrodynamics of sea surface elevation, wave loadings on slender structures, and their corresponding structural responses.

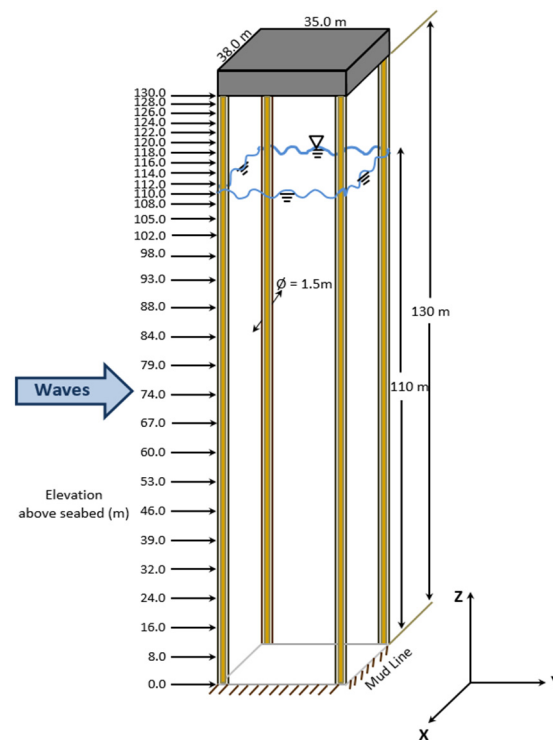


Figure 1. Schematic diagram of the offshore structure.

2.2. Numerical Simulation of Offshore Structural Responses

Simulations were used to bring a numerical model of a calculation scheme into the real world using computer capabilities. Currently, in the presence of advanced software availability [17,18], stochastic analysis is feasible to carry out a robust time-domain analysis where the complicated wave loads were integrated into a numerical ocean model [19]. In the wave scheme shown below, artificial ocean waves could be simulated as associated with several ocean wave models [20].

Generic Spectrum: According to wave [21], the generic spectrum model could be used to generate waves. The wave spectrum, such as the P-M spectrum, was used in this current study, as described by Equation (1):

$$S_{\eta}(f)_{PM} = \frac{H_s^2}{4\pi T_z^4 f^5} \exp\left(-\frac{1}{\pi T_z^4 f^4}\right) \quad (1)$$

where S_{η} is the surface elevation frequency spectrum, H_s is the significant wave height (m), T_z is the mean zero up-crossing period (s), f is wave frequency (Hz), and π is a mathematical constant of 3.142.

Linear Random Wave Theory: Transforming the wave spectrum $S_{\eta}(f)$ to wave elevation $\eta(t)$ could be performed by an inverse FFT (IFFT) method. According to linear random wave theory (LRWT), an irregular sea could be described as a superposition of many different regular waves [22], as represented by Equation (2):

$$\eta(t) = \sum_{i=1}^{NW=N/2} A_i \cos(2\pi f_i t - k_i x - \phi_i) \quad (2)$$

where η is the water surface elevation, NW is the total wave number used, x is the distance from wave origin, t is time, f_i is set of wave frequency, k is wave number, ϕ_i random phase angle (0 to 2π), and A_i wave amplitudes.

Water Particle Kinematics: LRWT was the method used for simulating the visualisation of water particle kinematics in various nodes of offshore structures [23–25]. The water particle equations were defined by using Equations (3) and (4):

$$u(x, t) = A_i 2\pi f_i \frac{\cosh(k_i(z+d))}{\sinh(k_i d)} \cos(k_i x - \omega_i t) \quad (3)$$

$$\dot{u}(x, t) = A_i (2\pi f_i)^2 \frac{\cosh(k_i(z+d))}{\sinh(k_i d)} \sin(k_i x - \omega_i t) \quad (4)$$

where u is the water particle velocity, u' is the water particle acceleration, x is the horizontal direction, z is the elevation above the seabed, t is time, d is water depth, k_i is wave number, ω_i is angular frequency, $2\pi f$ (rad/s), and A_i wave amplitudes.

Morison's Equation: For this fixed offshore platform, Morison-based analysis was more suitable, since the wave-induced horizontal force per unit length was on a vertical submerged cylinder [26]. Morison's equation (ME) was the sum of a nonlinear drag and a linear inertial form, stated by Equation (5):

$$F_{wave}(z, t) = \frac{1}{2} \rho C_D D \overbrace{(u - \dot{x})|u - \dot{x}|}^{r_{drag}} + \frac{\pi}{4} \rho C_M D^2 \overbrace{\dot{u}}^{r_{inertia}} \quad (5)$$

where F_{wave} is wave load, F_{drag} is drag force, $F_{inertia}$ is inertia force, C_d is drag coefficient, C_m is inertia coefficient, ρ is water density, D is cross-sectional area of the cylinder section, and x' is the structure velocity.

Linearisation of Morison's Equation: This method was known as a modification of Morison's equation. The linearisation was to simplify the calculation based on the absolute velocity and acceleration technique, which minimises the error between the original nonlinear and linear form [27]:

$$r_{L,drag} = \alpha_1 u_1 + \alpha_2 u_2 + \alpha_3 u_3 + \cdots \alpha_n u_n \quad (6)$$

$$r_{L,inertia} = \beta_1 \dot{u}_1 + \beta_2 \dot{u}_2 + \beta_3 \dot{u}_3 + \cdots \beta_n \dot{u}_n \quad (7)$$

For simplification, the common approach was to utilise the least square error (LSE) method in order to determine factors for the equivalent linear form. By minimising $E[e^2]$ and $E[e'^2]$, the α and β coefficients were determined as follows:

$$e = r_{drag} - r_{L,drag} = r_{drag} - \alpha_1 u_1 + \alpha_2 u_2 + \alpha_3 u_3 + \cdots \alpha_n u_n \quad (8)$$

$$e' = r_{inertia} - r_{L,inertia} = r_{inertia} - \beta_1 \dot{u}_1 + \beta_2 \dot{u}_2 + \beta_3 \dot{u}_3 + \cdots \beta_n \dot{u}_n \quad (9)$$

where $r_{L,drag}$ and $r_{L,inertia}$ are linearised drag and inertia force.

Structural Responses: With reference to those mentioned above, the wave load of quasi-static response for base shear (BS) and overturning moment (OTM), respectively, could be calculated as follows:

$$BS = \sum_{i=1}^{NS} (F_i \times \Delta l_i) \quad (10)$$

$$OTM = \sum_{i=1}^{NS} (F_i \times \Delta l_i \times z_i) \quad (11)$$

where NS is number of nodal loads, F_i is Morison load per unit length at node i , Δl_i is length of the element associated with node i , and z_i is the elevation of node i from the seabed, as illustrated in Figure 1.

2.3. Evaluation of Short-Term Probability Distribution of Extreme Offshore Structural Responses Using MCTS Method

A simple approach used to find the extreme value of short-term probability distribution was the MCTS method [28,29]. This procedure could be analysed based on ocean wave hydromechanics (numerical modelling) in the preceding section in order to predict a response record (beginning with a simulated surface elevation record), as shown in Figure 2. Next, the technique was repeated as many times as necessary to acquire a large number of extreme response records. The simulated extreme values were then ranked from smallest to largest.

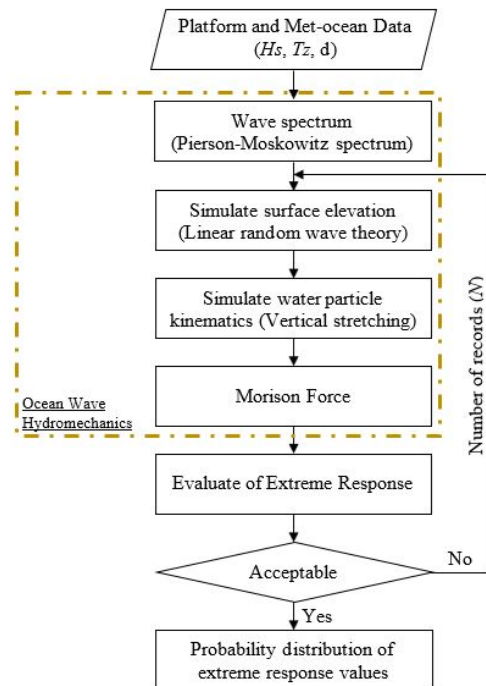


Figure 2. Procedure of the evaluation of extreme structural responses using the MCTS procedure.

Following Equation (12), the plotting position equation for the Gumbel distribution [30] was adopted to determine the probability distribution value for each ranking extreme value. The short-term probability distribution of responses was computed in this study using a record of 10,000 responses with a length of 128 s.

$$P(i \leq x_i) = p_i = \left(\frac{i - 0.44}{n + 0.12} \right), \quad i = 1, 2, 3, 4 \dots n \quad (12)$$

where i is the rank of the order statistic associated with p_i of the data point, n is the total number of points.

3. Development of Improved ETS-Regression Procedures

According to [11,12], an ETS-Regression (ETS-Reg) model was developed relying on two main variables between their input variables (extreme surface elevation) and its corresponding output variables (extreme responses), so-called the ETS-Reg_{SE} model. Based on this excellent duo-relationship, there was a possibility to build regression models from the relationship between input–output parameters. This straightforward model could be used to predict time-consuming 100-year structural responses. However, the ETS-Reg model is restricted to particular sea state conditions, with the level of accuracy decreasing as the significant wave height, $H_s = 5$ m.

In this current paper, the improvement of ETS-Reg models would be extended using the revised input variable of linearised responses, known as the ETS-Reg_{LR} model. Follow-

ing the same approach of previous ETS-Reg procedures, the recent model development was also introduced to several regression models (linear, polynomial, and cubic). In this study, the least-squares Pearson's correlation–regression approach was preferred for the development of the regression models alongside the hindcast data obtained [31], as illustrated in Figure 3. According to the least square error (LSE) procedure, the line (linear regression model) and curve-fitting (nonlinear regression model) techniques would be used to derive simple functions. Therefore, the unknown model coefficients for each model were solved by Cramer's rule [32].

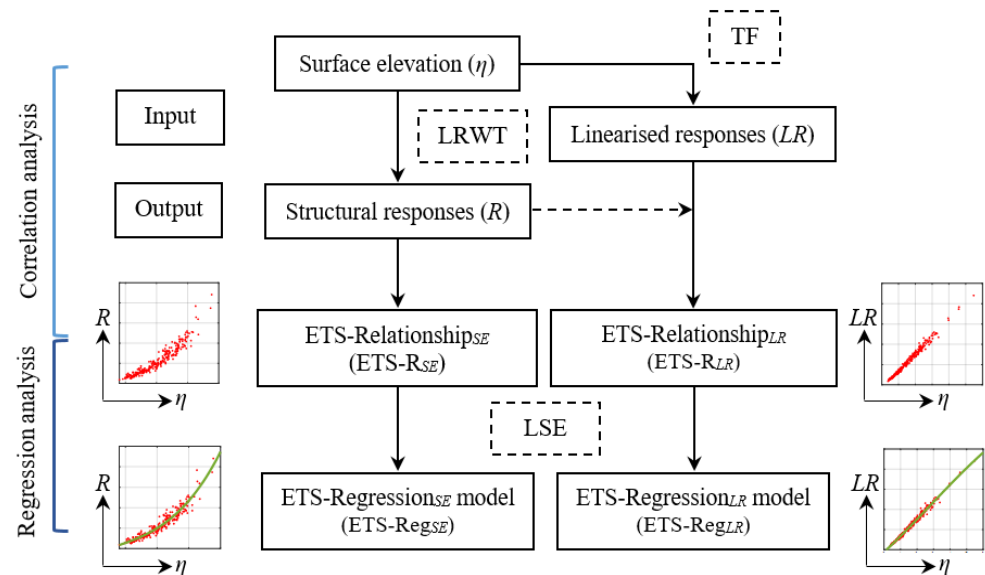


Figure 3. Assessment the relationship using Pearson's correlation–regression analysis.

3.1. Relationships of ETS- R_{SE} and ETS- R_{LR}

The pioneer ETS method was presented by [15] and offered the advantage of a relationship between extreme values of surface elevation and responses. Therefore, an extended ETS method, known as the ETS-Reg model, was introduced. Regarding Pearson's correlation analysis, Table 1 shows the intensity of the relationship via correlation- r values for both the ETS (ETS- R) relationships with different input parameters at low and high-sea sea state conditions. The ETS-Relationship-based surface elevation (SE) input is the term given to this type of ETS- R_{SE} , in the meanwhile, the ETS-Relationship-based linearised response (LR) as the revised input was named ETS- R_{LR} . In this preliminary analysis, the wave conditions of $H_s = 5$ and 15 m without the effect of currents were selected in order to examine the establishment of relationships.

Table 1. The coefficient of correlation between two categories of ETS relationships (scatterplot) for the conditions of low and high sea states (H_s) without current ($U = 0.0$ m/s) impacts regarding the total quasi-static base shear and overturning moment responses.

Type of ETS-Reg (correlation- r)	Base Shear		Overturning Moment	
	ETS- R_{SE}	ETS- R_{LR}	ETS- R_{SE}	ETS- R_{LR}
	r	r	r	r
Significant wave height, $H_s = 15$ m (high sea state)				
	0.9408	0.9931	0.9376	0.9922
Significant wave height, $H_s = 5$ m (low sea state)				
	0.8444	0.9626	0.8360	0.9528

According to the findings in Table 1, the strength of the relationship became less proportional to decreasing sea state conditions. Secondly, the relationship based on linearised responses (ETS- R_{LR}) as the input parameters observed higher correlation- r values instead of surface elevation (ETS- R_{SE}). The cubic-based regression model had the highest correlation- r -value among the regression model types when compared to the two other types, linear and polynomial.

3.2. Regression Models of ETS-Reg $_{SE}$ and ETS-Reg $_{LR}$

Figure 4a demonstrates the relationship between extreme surface elevations proportional to the extreme base shear responses for high sea state conditions without the impact of currents. As a result, in terms of total quasi-static base shear responses, an effective coefficient of correlation ($r = 0.9408$) was acquired where this ETS- R_{SE} relationship was considered for the development of the ETS-Reg $_{SE}$ model. Figure 4b shows that the improvement of the relationship scatterplot offered a strong correlation coefficient ($r = 0.9931$) rather than the ETS- R_{SE} relationship. The improved relationship was based on the updated input parameter of linearised responses, which is the output of the linearised ME (refer Figure 3). Thus, the ETS-Reg $_{LR}$ model development was based on the ETS- R_{LR} relationship. The amended version of the ETS-Reg $_{SE}$ model, known as the ETS-Reg $_{LR}$ model, made a significant improvement in both relationship and model development.

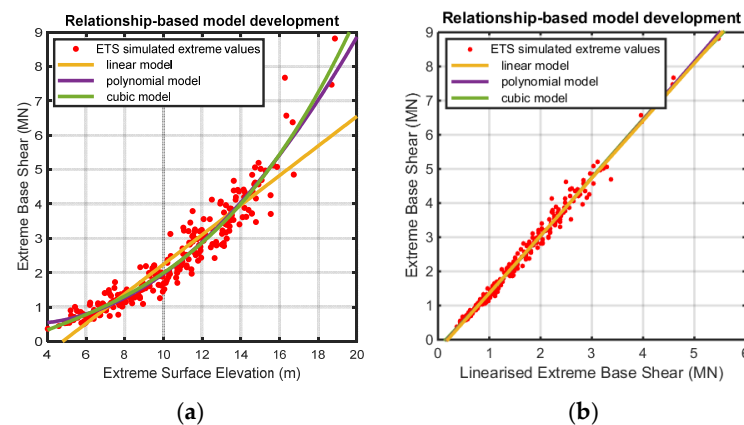


Figure 4. (a) ETS-Reg $_{SE}$ model based on the ETS- R_{SE} relationship. (b) ETS-Reg $_{LR}$ model based on the ETS- R_{LR} relationship. For the cases of total quasi-static base shear responses, $H_s = 15$ m, $T_z = 13.75$ s, $U = 0$ m/s. (a) ETS- R_{SE} and its ETS-Reg $_{SE}$ model. (b) ETS- R_{LR} and its ETS-Reg $_{LR}$ model.

For low sea state conditions without the effect of currents, Figure 5a shows the coefficient of correlation ($r = 0.8360$) was obtained in terms of total quasi-static overturning moment responses, and this ETS- R_{SE} relationship was considered for the formation of the ETS-Reg $_{SE}$ model. Figure 5b demonstrates that the improved ETS- R_{SE} relationship scatterplot increased the coefficient of correlation up to $r = 0.9528$. Thus, this enhanced correlation was also derived from the linearised responses as the input parameter, which improved model development.

Table 2 demonstrates the coefficient of determination (r^2) involving the linear, polynomial, and cubic regression models. According to the relationship pattern in Figure 3, the relationship between ETS-Reg $_{LR}$ was far more significant than the relationship between ETS-Reg $_{SE}$, which indirectly improved all ETS-Reg models. Overall, the ETS-Reg $_{LR}$ models were satisfactory, rather than the ETS-Reg $_{SE}$ models, particularly when applying the linearised responses as the input variable in the relationship instead of surface elevation.

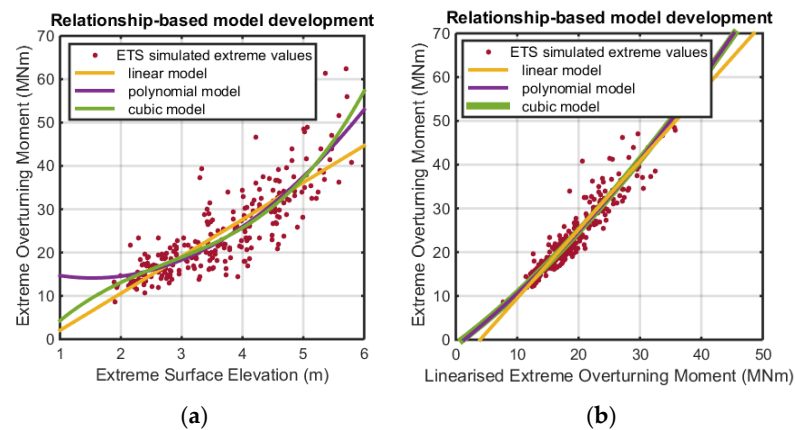


Figure 5. (a) ETS-Reg_{SE} model based on the ETS-R_{SE} relationship. (b) ETS-Reg_{LR} model based on the ETS-R_{LR} relationship. For the cases of total quasi-static overturning moment responses, $H_s = 5$ m, $T_z = 7.94$ s, and $U = 0$ m/s. (a) ETS-R_{SE} and its ETS-Reg_{SE} model. (b) ETS-R_{LR} and its ETS-Reg_{LR} model.

Table 2. Types of ETS-Reg models regarding the coefficient of determination for the low and high sea state (H_s) conditions without current ($U = 0.0$ m/s) impacts regarding total quasi-static base shear and overturning moment responses.

ETS-Reg Models	Base Shear		Overturning Moment	
	ETS-Reg _{SE}	ETS-Reg _{LR}	ETS-Reg _{SE}	ETS-Reg _{LR}
	r^2	r^2	r^2	r^2
Significant wave height, $H_s = 15$ m (high sea state)				
Linear	0.8851	0.9862	0.8792	0.9844
Polynomial	0.9284	0.9863	0.9304	0.9845
Cubic	0.9296	0.9864	0.9317	0.9846
Significant wave height, $H_s = 5$ m (low sea state)				
Linear	0.7131	0.9265	0.6988	0.9078
Polynomial	0.7360	0.9291	0.7345	0.9103
Cubic	0.7377	0.9292	0.7386	0.9105

Similar to the relationship findings (correlation- r values), the ETS-Reg_{LR} based on the cubic model was better than the ETS-Reg_{SE} cubic model. The r -squared of the ETS-Reg_{LR} cubic model was 0.9864, which was much higher than the ETS-Reg_{SE} cubic model, equal to 0.9296. Due to this evidence, the ETS-Reg_{LR} cubic model was expected to influence the accuracy level of the probability distribution of a 100-year extreme response prediction.

4. Derivation of Short-Term Probability Distribution of Extreme Offshore Structural Responses

The short-term probability distribution of ETS-Reg models would be compared to the benchmark of MCTS probability distribution for the 100-year extreme responses.

4.1. Preliminary Analysis of Extreme Responses by Three Types of ETS-Reg Models

In order to provide a good result, the level of accuracy regarding three types of ETS-Reg model development was required to be examined with the benchmark of MCTS procedures. This prediction would be plotted on the 100-year short-term probability distribution of extreme responses. Table 3 demonstrates the ETS-Reg procedures with linear, polynomial, and cubic-based regression models used in calculating the predicted 100-year responses (P100) for high sea states without current impact.

Table 3. ETS-Regression of different empirical models in calculating the P_{100} -year short-term responses for total base shear quasi-static responses and without current. $H_s = 15$ m ($P_{100}MCTS = 11.1459$ mega Newton (MN)).

Method	Prediction		Responses Ratio	
	ETS-Reg _{SE}	ETS-Reg _{LR}	$\frac{ETS-Reg_{SE}}{MCTS}$	$\frac{ETS-Reg_{LR}}{MCTS}$
Linear	12.0808	11.4266	1.0839	1.0252
Polynomial	10.4922	11.3804	0.9413	1.0210
Cubic	10.0723	11.3220	0.9037	1.0158

As observed in Table 3, the prediction of 100-year extreme responses between the ETS-Reg_{SE} and the ETS-Reg_{LR} model was examined with the MCTS method. The benchmark of the MCTS method predicted was 11.1459 (≈ 11.15) MN. As shown in Figure 6, the comparison of ETS-Reg_{LR} models among linear, polynomial, and cubic types was validated for the probability distribution of 100-year extreme responses. Since the strength of relationships and model development via correlation- r alongside r -squared values were related, it affects the accurate prediction of 100-year responses obtained. It could be observed that the regression-based cubic model was only preferred for validation purposes compared to linear and polynomial models.

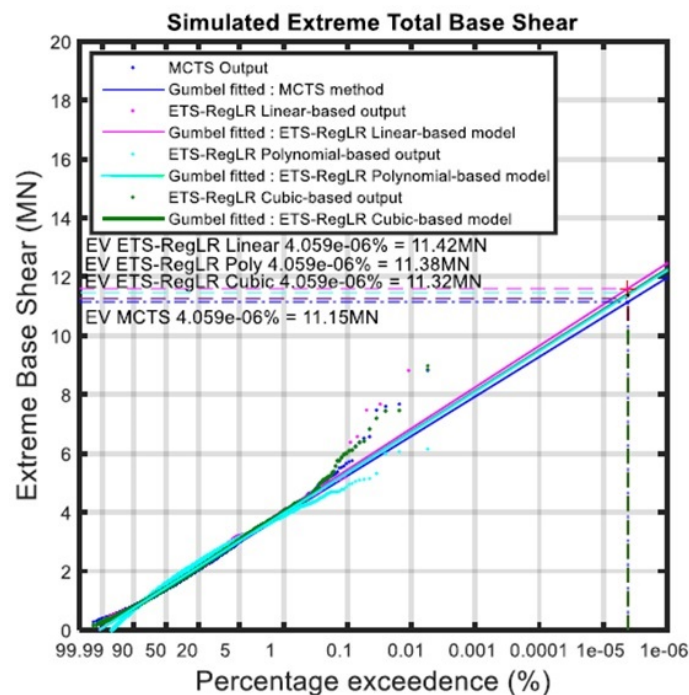


Figure 6. Comparison and validation of ETS-Reg linear, polynomial, and cubic models with the MCTS method. $N = 10,000$, total quasi-static base shear responses; $H_s = 15$ m, $T_z = 13.75$ s, and $U = 0.00$ m/s.

4.2. Level of Accuracy of Extreme Responses by ETS-Reg Models

Syed Ahmad et al. [13] studied that the accuracy level based on ETS-Reg_{SE} models corresponded precisely to the relationship results, as presented in Part 1 in [12]. Similar to the previous study, the 100-year response reduced significantly as the high H_s decreased to the low H_s in terms of measured accuracy ranges. In the current findings, Table 4 shows the MCTC methods' deviation ratio of 100-year extreme responses had comparable diversity to ETS-Reg_{SE} and ETS-Reg_{LR} models. The result shows that an improvement was made by the ETS-Reg_{LR} model, with an accuracy range of 96–99 percent. In contrast, the accuracy

level of the ETS-Reg_{SE} models was made approximately 77–93 percent. Thus, the increment results show an improved approach with the ETS-Reg_{LR} model for more accurate structural response calculation.

Table 4. Comparison of the MCTS method with the ETS-Reg_{SE} and ETS-Reg_{LR} models for 100-year responses with the low and high sea state (H_s) conditions without current ($U = 0.0$ m/s) impacts.

Responses	Base Shear			Overturning Moment		
	Ratio			Ratio		
Methods	MCTS (MN)	ETS-Reg _{SE} / MCTS	ETS-Reg _{LR} / MCTS	MCTS (MNm)	ETS-Reg _{SE} / MCTS	ETS-Reg _{LR} / MCTS
Significant wave height, $H_s = 15$ m (high sea state)						
Total responses	11.1459	0.9037	1.0158	983.7499	0.9316	1.0087
Significant wave height, $H_s = 5$ m (low sea state)						
Total re-sponses	0.9795	0.8037	1.0453	93.0112	0.7740	1.0464

As pre-analysis studied in Section 4.1, the ETS-Reg models were developed based on cubic regression models. Figure 7 displays the predictions by ETS-Reg_{SE} and ETS-Reg_{LR} cubic-based models were 10.0723 and 11.3220 MN, respectively. The analysis was considered for the high sea state regarding the total quasi-static base shear responses. Based on these different outcomes, the ETS-Reg_{LR} proved that the ratio response was 1.0158 compared to the ETS-Reg_{SE} equal to 0.9037. That meant the ETS-Reg_{LR} model provided the highest level of accuracy with a minimal error value of around 1.58% in predicting the 100-year extreme responses as validated by the MCTS method. As expected, the improved relationship significantly impacted the model accuracy of ETS-Reg_{LR}, which was the most accurate result.

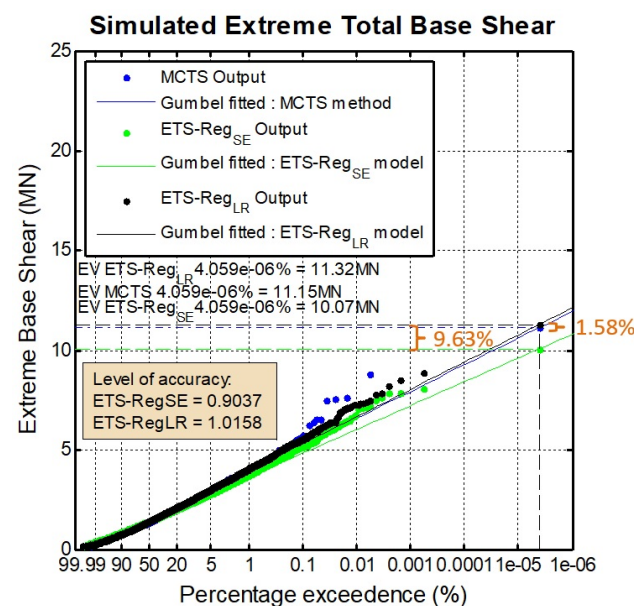


Figure 7. Comparison and validation of ETS-Reg models with the MCTS method. $N = 10,000$, total quasi-static base shear responses; $H_s = 15$ m, $T_z = 13.75$ s, and $U = 0.00$ m/s.

The result was an underestimated value for the low waves, with a significant percentage error when the validation between the MCTS method and ETS-Reg_{SE} models was examined. With the presence of the ETS-Reg_{LR} model to improve this particular sea state, the error was reduced from 22.6 to 4.64 percent. Figure 8 demonstrates that the predictions by ETS-Reg_{SE} and ETS-Reg_{LR} models were 71.9907 and 97.3269 MNm, respectively. Therefore, the improvement of the relationship associated with the regression model

development significantly influenced predicting the 100-year extreme responses, which contributed to a better level of accuracy.

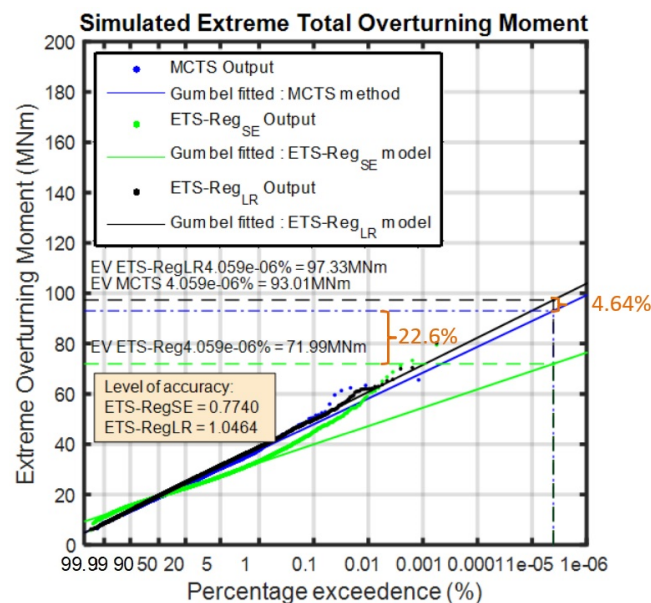


Figure 8. Comparison and validation ETS-Reg models with the MCTS method. $N = 10,000$, total quasi-static overturning moment responses; $H_s = 5$ m, $T_z = 7.94$ s, and $U = 0.00$ m/s.

5. Conclusions

This study has concluded the improved version of ETS-Regression model development output based on the short-term 100-year of extreme offshore structural responses, and the results are summarised as follows:

- In the current study, the comparison of the probability distribution of quasi-static extreme responses values was validated between the MCTS and ETS-Regression method. This study was considered for a single sea state without the current impact. Moreover, the structures exposed to the load intermittency in the splash zone were included.
- The simplified development of the ETS-Reg model offered another approach to boost numerical calculation based on the probabilistic time domain. Applying this method could reduce computational demand as required by the MCTS method. Due to its accuracy, the ETS-Reg models proved equivalent to the MCTS method used in the probability distribution of extreme responses.
- This ETS-Regression method provided: (i) no need for extensive simulations, and (ii) no requirement to pass through several procedures of calculations in order to estimate 100-year extreme responses.
- The ETS-Reg_{SE} model was based on the input of surface elevation, whereas the ETS-Reg_{LR} model was based on the input of linearised responses as the revised input parameter of ETS-Relationship. Thus, the prediction of 100-year responses by ETS-Reg_{LR} had better accuracy when compared to ETS-Reg_{SE} for high sea state conditions without a current impact.
- As revealed in Table 4, this result shows that accurate structural response values could be achieved using the linearised response as the new input variable of relationships in developing the regression models.
- The ETS-Reg_{LR} model was good at predicting the 100-year-old extreme responses with a 96% to 99% level of accuracy level in comparison to its benchmark of the MCTS procedure. In contrast, the ETS ETS-Reg_{SE} model produced a lower level of accuracy of 77% to 93%.
- Further research is necessary to consider the wave current since it substantially impacts the drag component of the Morison force.

- The simulation used in this work was also restricted to a single sea state. It is well recognised that the sea surface is not stationary in actual conditions and that a wide range of sea states can be used to characterise it. Therefore, using the long-term distribution to determine the 100-year responses to design the structure is advised.
- The most significant loading source for offshore structural design is typically the load caused by wind-generated random waves. A nonlinear wave analysis, such as Stokes wave theory, solitary wave theory, cnoidal wave theory, stream function, or standing wave theory, is recommended to approximate a realistic ocean wave for an accurate prediction of the severe offshore structure response.

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