Prediction of Green Water Events for FPSO in Irregular Waves using ANN Model

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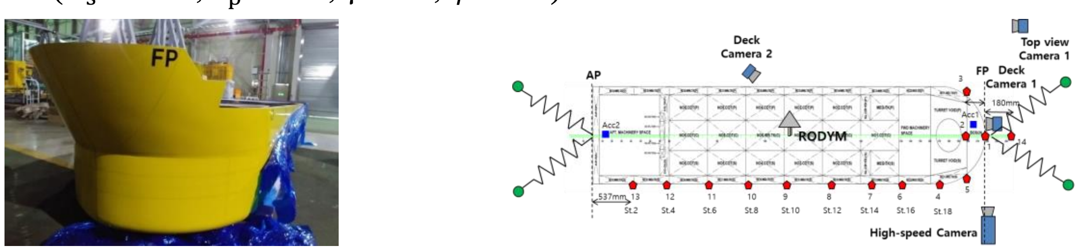
1 INTRODUCTION

Green water event in severe sea sate is a critical issue with respect to the safety of sailing ships and offshore structures. At the design stage, it is required to examine the occurrence of green water events under extreme wave conditions. In general, the linear diffraction analysis method has limitations in accurately predicting relative wave motion and green water events. Thus, a modified approach based on the linear diffraction method was also introduced in combination with nonlinear incident wave information [1, 2]. However, even though nonlinear incident waves were used, it is still difficult to accurately predict the nonlinear relative wave motion responses. In this study, prediction models based on artificial neural network (ANN) were developed to predict peak values of the relative wave motion and occurrence of green water events. Section 2 describes the experiments of KFPSO, while Section 3 introduces the developed ANN models. Finally, in Section 4, it was analyzed whether the prediction performance of the linear diffraction method is improved by the ANN model.

2 EXPERIMENTAL DESCRIPTIONS

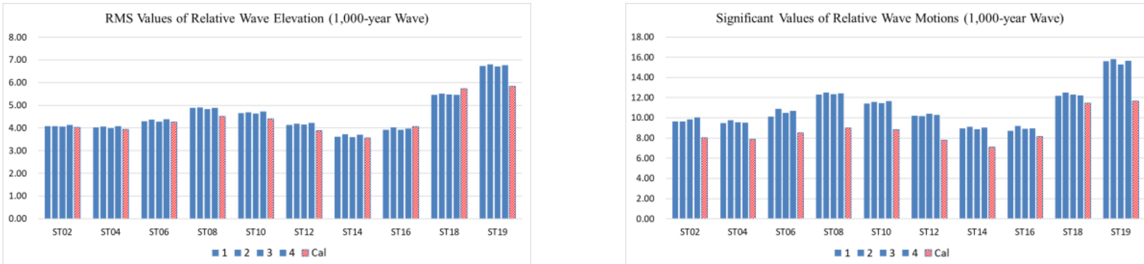
A model test for a KFPSO was performed by Park et al. [3]. The scale ratio was 1:60, and the LBP, breadth, and draft of the scaled model are 5.37 m, 1.033 m, and 0.292 m, respectively. The freeboard height was approximately 0.21m. Fig. 1 shows the front and top views of the KFPSO model. As shown in Fig. 1(b), the relative wave motion was measured at 14 positions. The irregular wave condition for the model test is a 1000-year return period wave based on the JONSWAP spectrum(H_s: 17.5m, T_p: 17.0s, γ: 2.93, ψ: 150°).



(a) (b)

Figure 1: (a) Front view and (b) top view of the KFPSO

Fig. 2 compares the RMS (root mean square) and significant values for the RWM (relative wave motion) measured on the side of the KFPSO. The largest statistical values are found at the ST19 (Loc.05), which is located closest to the bow. The relative wave motion tended to decrease from the bow section to the midship, and the lowest values were found at ST14. The relative wave motion increased again after ST14, forming the second-highest RWM values at the ST08 (Loc.10) position. In addition, It can be observed that the linear diffraction method underestimated the relative wave motion more than the experimental results, which is mainly due to the nonlinearity of relative wave motion. Thus, in this study, we tried to develop an ANN-based prediction model for relative wave motion by focusing on two positions of Loc.05 and Loc.10.

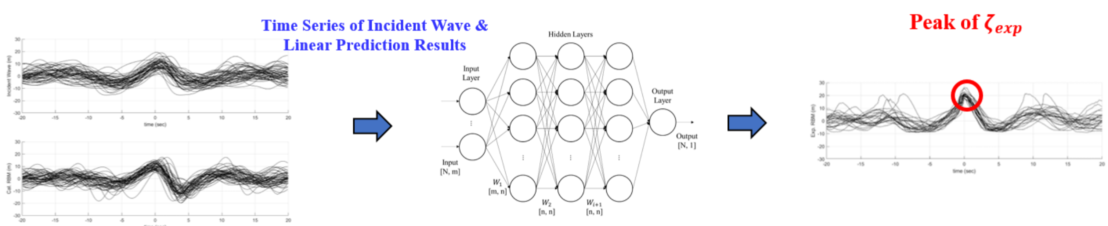


(a) (b)

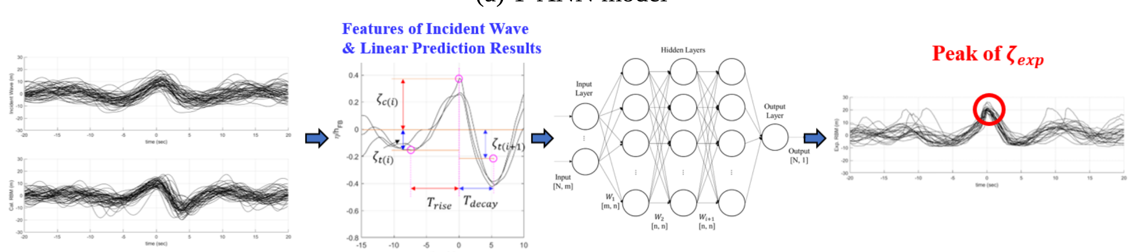
Figure 2: (a) RMS values and (b) Significant values of relative wave motion according to measurement position

3 ANN-BASED PREDICTION MODEL

In this study, two ANN-based prediction models were applied to predict the relative wave motion and occurrence of Green water events. The first ANN model, which is called as 'T-ANN model', was designed to utilize the time series of the incident wave and linear RWM calculation as input data, as shown in Fig. 3(a). In this case, the time series was sampled by setting a time window symmetrically around the location where the RWM peak occurred. Then, to train the ANN model, the sampled time series was given to the input layer, while the positive amplitude of RWM peak was assigned to the output layer of the T-ANN model. Note that the undisturbed incident wave was directly measured from the model test at the locations that are the same as the center and bow of the KFPSO. The linear RWM time series were constructed by combining the measured incident wave and the frequency-domain diffraction analysis result.



(a) T-ANN model



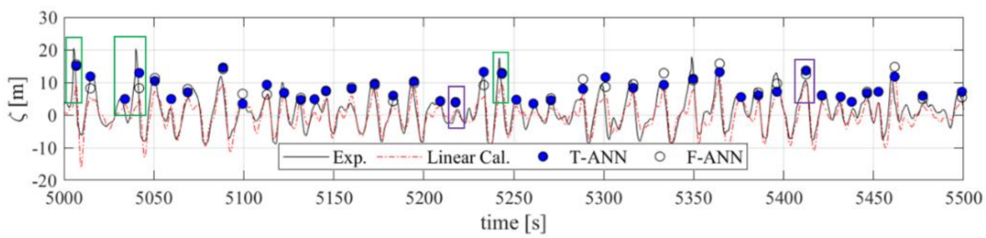
(b) F-ANN model

Figure 3: Schematic diagram for ANN prediction models

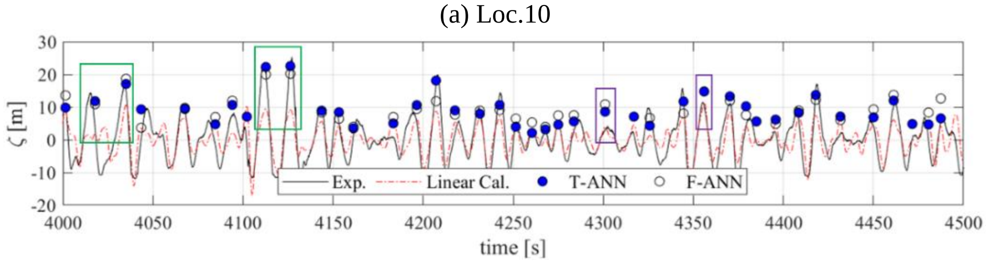
The second ANN model was built using the local parameters extracted from the incident wave and linear RWM calculation rather than directly using the time series, as shown in Fig. 3(b). This model is named 'F-ANN model', where a total of 10 parameters in Table 1 were considered as input candidates. Here, 8 parameters were selected from the incident wave characteristics, while 2 parameters are related to the linear RWM calculation. The forward selection process was performed to determine the final input parameters for the F-ANN model. As a result, the ANN model for Loc.05 uses 9 input variables except for V_{rise}, while the ANN model for Loc.10 receives only 4 input variables ($\zeta_C', V_{decay}, H', \tau$).

Table 1: Parameters of incident wave and relative wave motion

Name	Parameters	Name	Parameters
Wave height	$H' = (\eta_{c(i)} - \eta_{t(i)})/\mathrm{h}_{FB}$	Wave steepness	$\nabla\mathrm{C} = \dfrac{2\pi(\eta_{c(i)} - \eta_{t(i)})}{gT_{\mathrm{rise}}(\eta) \cdot T_{\mathrm{down}}(\eta)}$
Rise velocity	$V_{rise} = (\eta_{c(i)} - \eta_{t(i)})/T_{rise}(\eta)$	Kurtosis	$\mathrm{K_t} = \dfrac{1}{\eta_{rms}^4} \cdot \dfrac{1}{N}\sum_{i=1}^{N}(\eta_i - \bar{\eta})^4$
Decay velocity	$V_{decay} = (\eta_{c(i)} - \eta_{t(i+1)})/T_{decay}(\eta)$	Skewness	$\mathrm{S_k} = \dfrac{1}{\eta_{rms}^3} \cdot \dfrac{1}{N}\sum_{i=1}^{N}(\eta_i - \bar{\eta})^3$
Vertical asymmetry factor	$\tau = \dfrac{T_{rise}(\eta)}{T_{\mathrm{rise}}(\eta) + T_{\mathrm{decay}}(\eta)}$	Atiltness	$\mathrm{A_t} = \dfrac{\frac{1}{N-1} \cdot \sum_{i=1}^{N-1}(\dot{\eta}_i - \bar{\dot{\eta}})^3}{\left[\frac{1}{N-1} \cdot \sum_{i=1}^{N-1}(\dot{\eta}_i - \bar{\dot{\eta}})^2\right]^{3/2}}$
RWM peak	$\zeta_C' = \zeta_{c(i)}/\mathrm{h}_{FB}$	RWM steepness	$\nabla C_{\zeta_c} = \dfrac{2\pi(\zeta_{c(i)} - \zeta_{t(i)})}{gT_{\mathrm{rise}}(\zeta) \cdot T_{\mathrm{down}}(\zeta)}$



(a) Loc.10

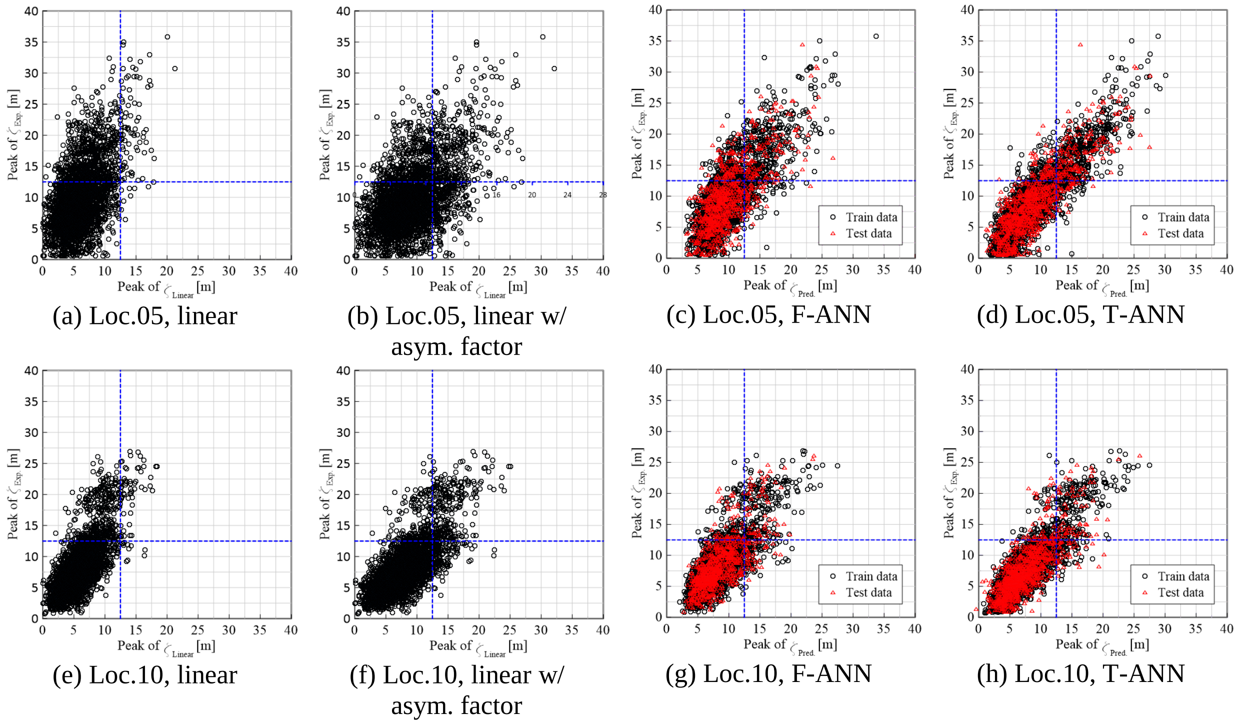


(b) Loc.05

Figure 4: ANN prediction results at (a) Loc.05 and (b) Loc.10 for test time series

4 Results and discussions

Fig. 4 shows the prediction results by the ANN model overlaid with the experimental RWM time series. Overall, the two ANN models predict the peak values of RWM with good accuracy, even for the test time series that were not used for training. In particular, regarding some high RWM values (marked with green boxes), the prediction accuracy is greatly improved with the ANN models, whereas the linear calculation was significantly underestimated. These high relative wave motions can lead to Green water events. However, it was also found that at some points (marked with purple boxes), the ANN models slightly overestimated the RWM peak values.



(a) Loc.05, linear (b) Loc.05, linear w/ asym. factor (c) Loc.05, F-ANN (d) Loc.05, T-ANN

(e) Loc.10, linear (f) Loc.10, linear w/ asym. factor (g) Loc.10, F-ANN (h) Loc.10, T-ANN

Figure 5: Scatter plots of prediction results of each model for Loc.05(top) and Loc.10(bottom)

Fig. 4 shows the scatter plots of the predicted results from various models versus experimental values as for the RWM peak values. The two graphs from the left are based on linear calculations without and with asymmetric factors, while the two graphs from the right are plotted based on the ANN prediction models. It can be observed that both ANN models show much less error (narrower variance) than the linear calculations. This implies that the ANN models predict the peak values of the relative wave motion by correcting the nonlinearity rather than the linear calculation result. Among the ANN models, the T-ANN model based on the time series itself has a higher predictive performance than the F-ANN model using some features extracted from the time series.

6 Conclusion

In this study, ANN-based prediction models were developed for the prediction of relative wave motion and green water events in irregular waves. Model test data for KFPSO were directly used to construct the ANN models. It is found that the ANN models significantly improve the prediction performance for relative wave motions compared to the linear calculations. In addition, the ANN model based on the time series was more accurate than the feature-based ANN model.

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