Evaluate the Prediction of Wave Parameters Using Parametric Methods in the South Coast of the Mediterranean Sea

Hassan Salah

Offshore Structures Engineering Specialist, Offshore Department, ENPPI Co., Egypt

Abstract: ***The wave parameters are the important factor in the offshore and near-shore activities. The choice of the appropriate parametric method for wave parameters calculation has a significant impact on the design of maritime structures (such as; fixed offshore platform, marine terminal jetty, harbor, ... etc.) from the cost point of view. Several parametric methods have been used to predict wave parameters that have been based on data from certain areas of the sea. These methods are still used in many Coastal areas such as the coast of Egypt. Therefore, evaluating the performance of these methods based on the measured data of the coast of Egypt is very important because of many recent discoveries of oil and gas. In this study, P-M, SPM and CEM methods were used to predict the 3 hourly significant wave height (Hs) and significant wave period (Ts). The data used in evaluation are significant wave heights (Hs), significant wave periods (Ts), wind speed (u) and fetch length (F). This data measured in the offshore area of Alexandria and Port Said located on the southern coast of the Mediterranean Sea. This study aims to find optimal parametric method that we can used safely in the prediction of wave parameters of this region. The results indicated that the P-M method with some modification in the significant wave period equation gave the best results in the prediction of wave parameters than other methods.***

Keywords: Mediterranean Sea, Wave parameters, Parametric method and Offshore and near-shore

1. Introduction

The wave parameters are considered the dominant factor in a variety of offshore and nearshore activities such as shoreline changes, oil and gas drilling, maritime structures design and installation, ..etc. For this propose, there are several empirical and numerical methods described in many literatures, such as; P-M (Pierson and Moskowitz, 1964), SMB (Bretschneider, 1970), JONSWAP (Hasselmann et al., 1973), (Donelan, 1980), Shore Protection Manuel (SPM, 1984), Goda (2003) and Coastal Engineering Manuel (CEM, 2008) [8].

These methods were developed based on the dimensionless parameters to predict the wave parameters such as; wave height and wave period depending on the fetch length and wind speed. These simplified methods are particularly preferred for solving of the practical engineering problems in the early stages of the marine projects (e.g. during the conceptual design stage).

Although these methods have been developed for different seas to predict wave parameters, they are still used until today for various engineering purposes especially in Egypt. As results of the emergence of many gas discoveries in the deep water of the coast of Egypt, we need to evaluate the performance of these methods because of their significant impact on the design of offshore structures and also on the vessels movement [9], [10].

In this paper, the 3 hourly significant wave heights (H_s), significant wave periods (T_s), fetch data (F) and wind speed (u) were used to evaluate the performance of these parametric methods and their applicability to the northern coast of Egypt.

This paper is organized as follows: the next section introduces parametric methods used in this study. Section 3 describes the study area and data description. Section 4 presents measures used to evaluate the performance of methods. Section 5 presents the results and discussion. Finally, conclusions are reported in the last section.

2. Parametric Methods

2.1 Pierson-Moskowitz Method

The Pierson-Moskowitz spectrum (1964) is often used as a model spectrum for a fully developed sea, an idealized equilibrium state reached when duration and fetch are unlimited. This spectrum is based on a subset of 420 selected wave measurements recorded by British ocean weather ships during the five-year period (1955-1960) [11].

The Pierson-Moskowitz spectrum can be written directly in terms of the wind speed:-

$$S(f) = \frac{\alpha g^2}{(2\pi)^4 f^5} e^{-0.74(g/2\pi u f)^4} \qquad (1)$$

The following relationships can be developed from the Pierson-Moskowitz spectrum (Ochi, 1982) [11], [12]:-

$$H_s = \frac{0.21u^2}{g} \qquad (2)$$

$$f_p = \frac{0.87g}{2\pi u} \qquad (3)$$

Where;
Hs is significant wave height.
u is the wind speed at 10 m (standard elevation).
f_p is the peak frequency, which equal to 1/Tp.

Goda (1978) has shown that significant wave period *Ts* remain within a range of 0.87 *Tp* to 0.98 *Tp* [11], [13].

2.2 SPM method

In this method, significant wave height (Hs) and peak frequency (f_p) are associated with the wind speed, fetch and duration. In the fetch limited case, SPM method suggested a parametric model expressed as:

$$\frac{gH_s}{U_A{}^2} = 0.0016\left(\frac{gF}{U_A{}^2}\right)^{1/2} \quad (4)$$

$$\frac{gT_p}{U_A} = 0.2857\left(\frac{gF}{U_A{}^2}\right)^{1/3} \quad (5)$$

$$\frac{gt_{min}}{U_A} = 68.8\left(\frac{gF}{U_A{}^2}\right)^{0.67} \quad (6)$$

For fully developed sea condition:

$$\frac{gH_s}{U_A{}^2} = 0.2433 \quad (7)$$

$$\frac{gT_s}{U_A} = 8.134 \quad (8)$$

Where;
Hs is significant wave height.
Tp is the peak wave period.
t_{min} is the wind duration
UA is the wind stress factor (m/s) which is defined as:

$$U_A = 0.71(U_{10})^{1.23} \quad (9)$$

Where;
U_{10} is the wind speed at 10 m above the sea surface (m/s).

The relationship between the significant wave period (*Ts*) and the peak period (*Tp*) is defined as [5]:

$$T_s = 0.95\,T_p \quad (10)$$

Equations from (8) to (14) were formulated based on the Joint North Sea Wave Project (JONSWAP) field data (Hasselmann et al., 1973) [5].

2.3 CEM method

CEM method was built on some adjustment in the JONSWAP spectral method [7]. In the CEM method (CEM, 2008), the equation for prediction of dimensionless wave height and period are:

$$\frac{gH_s}{U_*{}^2} = 0.0413\left(\frac{gF}{U_*{}^2}\right)^{1/2} \quad (11)$$

$$\frac{gT_p}{U_*} = 0.751\left(\frac{gF}{U_*{}^2}\right)^{1/3} \quad (12)$$

Where,
U_* is the friction velocity (m/s) is estimated as:

$$U_* = U_{10}(C_D)^{0.5} \quad (13)$$

Where;
U_{10} is the wind speed at 10 m above the sea surface (m/s).
C_D is the drag coefficient is defined as:

$$C_D = 0.001(1.1 + 0.035U_{10}) \quad (14)$$

and wind duration will be equal to:

$$t_{min} = 77.23\,\frac{F^{0.67}}{U_{10}{}^{0.34}\,g^{0.33}} \quad (15)$$

For fully developed sea condition:

$$\frac{gH_s}{U_*{}^2} = 2.11 * 10^2 \quad (16)$$

$$\frac{gT_s}{U_*} = 2.398 * 10^2 \quad (17)$$

3. Study Area and Data Description

3.1 Alexandria

Alexandria is the second largest city and a major economic center in Egypt, and stretches more than 50 kilometers along the shore from Abu Qir Bay to Sidi Krir along the coast of the Mediterranean Sea in the north central part of Egypt. The analysis of wave data for Alexandria region showed that about 80 % of significant wave height are less than or equal 1.80 m with corresponding significant wave period less than or equal 8 second. Furthermore, the waves are dominantly arriving from NW direction with percentage of occurrence reaches 65 %.

3.2 Port Said

Port Said is an Egyptian city extending about 30 kilometers along the coast of the Mediterranean Sea, north of the Suez Canal. The city was established in 1859 during the building of the Suez Canal. The analysis of wave data for Port Said region showed that about 85 % of significant wave height are less than or equal 1.60 m with corresponding significant wave period less than or equal 7 second. Furthermore, 55 % of wave's data for this region are dominantly arriving from NW direction.

3.3 Data description

The wave data and wind speed were measured from the beginning of January 2012 to the end of December 2012 at the offshore area for both Alexandria and Port Said regions located on the northern coast of Egypt, south-east of the Mediterranean sea (Figure 1). This data provided by Egyptian Navy, Meteorological and Oceanographic Division. The 3 hourly significant wave heights (H_s) and significant wave periods (T_s) accompanied with wind speed (u) and fetch (F) were used in this study based on the available hourly observations data.

Figure 1: Study area location (Google map)

4. Measures of Results Accuracy

Two measures scatter index (SI) and bias were used in this study to evaluate the accuracy results:-

$$SI = \frac{RMSE}{\bar{O}} \quad (18)$$

$$Bias = (\bar{P} - \bar{O}) \quad (19)$$

In all the above measures, the O_i's represent the observation value, the P_i's represent the predicted value, n is the total number of observations, $\bar{O}$ is the mean of O_i and $\bar{P}$ is the mean of P_i.

5. Results and Discussions

In this study, to evaluate the performance of the above parametric methods and applicability on the study area, significant wave height and period were predicted using the data of year 2012 for both Alexandria and Port Said regions. Predicted and measured values were compared and evaluate through the statistical measures mentioned in section 4.

To evaluate the parametric methods, the checks be made between fetch, duration, and fully developed limitations to estimate the wave height and period to fit the data of the study area. Many design situations require iteration between these approaches and the appropriate averaged durations [5]. These approaches were applied using data available to these regions and we found that the fully developed sea condition was the appropriate approach to the study area, which yielded satisfactory results.

5.1 Alexandria results

Table-1 shows the errors statistics of wave parameters of Alexandria data set in the fully developed sea condition. As can be seen, the SPM method has the highest SI% and bias with the prediction of significant wave height (H_s) which are equal to 43.23 % and -0.22 m respectively. On the other hand, P-M method has lowest SI% and bias (12.31 % and 0.09 m respectively). Comparison of error statistics for all parametric methods revealed that the P-M method is generally more skillful, in the prediction of wave height, than the other ones, while SPM method is the poorest method.

For the prediction of significant wave period (T_s), P-M method has the highest SI% and bias (37.08 % and 1.12 sec respectively) while the SPM method is considered to be more accurate than the others which gave the lowest scatter index (6.15%).

The correlation between observed and predicted for H_s is shown in figures from 2 to 4. Figure 2 (for P-M method) showed that the correlation between the predicted and observed for H_s gives better results with high accuracy for all wave height values than the correlation shown in figures 3 and 4 below.

Figure 3 and 4 (for SPM and CEM methods respectively) showed that the correlation between the predicted and observed for H_s gives good results with high accuracy for significant wave height up to 3.5 m, while the wave height more than 3.5 m decreasing in accuracy. For waves larger than 3.5 m, the values of SPM method have a greater deviation from the reference line than the values of CEM method. Therefore, CEM method is more accurate in their results than SPM method. Although the accuracy of results decrease with increasing significant wave height (for H_s> 3.5 m), they are still within acceptable range as the most of data of H_s for Alexandria region is less than or equal to 1.8 m.

5.2 Port Said results

Table-2 displays the errors statistics of wave parameters of Port Said data in the fully developed sea condition. It's obvious that the SPM method has highest SI% and bias in the prediction of significant wave height (H_s) which equal to 29.63 % and -0.11m respectively. On the other hand, P-M method has the lowest SI% (11.36 %). Comparison of all parametric methods revealed that the P-M method is more accurate than other methods in Port Said region, while SPM method is the poorest method.

For the prediction of significant wave period (T_s), P-M method has the highest SI% and bias (30.76 % and 0.98 sec respectively) while the CEM method has the lowest values of SI% and bias (5.35 % and 0.02 sec respectively) indicating that the CEM is the best method to be used in the prediction of significant wave period for Port Said region.

Table 1: Error statistics of parametric methods for Alexandria

Methods	No. of Data	H_s		T_s	
		SI%	Bias (m)	SI%	Bias (sec)
P-M	2874	12.31	0.09	37.08	1.12
SPM	2874	43.23	-0.22	6.15	0.27
CEM	2874	22.7	-0.12	7.23	0.07

Table 2: Error statistics of parametric methods for Port Said

Methods	No. of Data	H_s		T_s	
		SI%	Bias (m)	SI%	Bias (sec)
P-M	2836	11.36	0.08	30.76	0.98
SPM	2836	29.63	-0.11	5.96	0.26
CEM	2836	15.11	-0.07	5.35	0.02

The correlation between observed and predicted for H_s is shown in figures from 5 to 7. Figure 5 (for P-M method) displayed that the correlation between the predicted and observed for H_s gives better results with high accuracy for all wave height values than the correlation shown in figures 6 and 7.
Figure 6 and 7 (for SPM and CEM methods respectively) showed that the correlation between the predicted and observed for H_s gives satisfactory results with high accuracy for significant wave height up to 3.0 m, while the wave height more than 3.0 m decreasing in accuracy. For SPM method, the waves larger than 3.0 m have a greater deviation from the reference line than the values of CEM method. So, CEM method is more accurate in their results than SPM method. Although the accuracy of results decrease with increasing significant wave height (for H_s> 3.0 m), they are still within the acceptable range as the most of data of H_s for Alexandria region is ≤ 1.60 m.

5.3 Modification of P-M method

As seen in section 5.1 and 5.2 above, the P-M method gives the highest accuracy in the results with the prediction of significant wave height relative to the other parametric methods, while its results with the significant wave period prediction are less accurate than the others. Consequently, the P-M method has been modified with regard to the prediction of significant wave period to improve its performance and obtain better results. The P-M equation (3) was then modified to be formulated as:-

$$f_p = \frac{0.645g}{2\pi u} \tag{20}$$

Where the value of significant wave period (Ts) will be taken equal to 0.92 of peak frequency (f_p) to be within the range of 0.87 T*p* to 0.98 T*p* (Goda, 1978) [11], [13].

Table 3 and 4 present the results of significant wave period prediction based on the use of the modified P-M equation (20) in a comparison with the results of P-M based on equation (3) mentioned in tables 1 and 2.

As can be seen using the modified equation leads to lower error in the prediction of significant wave period. For Alexandrian region (Table-3), the MSE and scatter index of the Ts decreased from 2.36 sec and 37.08% to 0.30 sec and 10.38% respectively and also leads to unbiased predictions. For Port Said region (Table-4), the values of MSE and SI decreased from 1.50 sec and 30.76% to 0.15 sec and 7.61% respectively with very low biased value (-0.12 sec).

It can be seen that the accuracy of the modified method has been improved to give results close to SPM method for the Alexandria area in Table 1 and CEM method for Port Said area in Table 2 above. Consequently, P-M method for equations (3) and (20) give high accuracy in the prediction of wave parameters of the study area.

Figures 8 and 9 present the results of P-M method in time series form for the significant wave period (Ts) based on the use of equations (3) and (20) respectively for Alexandria region.

The figures showed that the prediction by using the modified P-M equation (Eq. 20) was more accurate in the results than the original P-M (Eq. 3). It is clear that the trend of Ts in figure 9 (by Eq. 20) has high accuracy in its results than the trend in figure 8 (by Eq. 3). The same for Port Said region, the trend of Ts in figure 11 has high accuracy in its results than the trend of Ts in figure 10.

6. Conclusions

The evaluation of the prediction of wave parameters in the Mediterranean offshore area using different parametric methods is presented in this paper. P-M, SPM and CEM methods were used to predict the wave parameters (Hs and Ts).

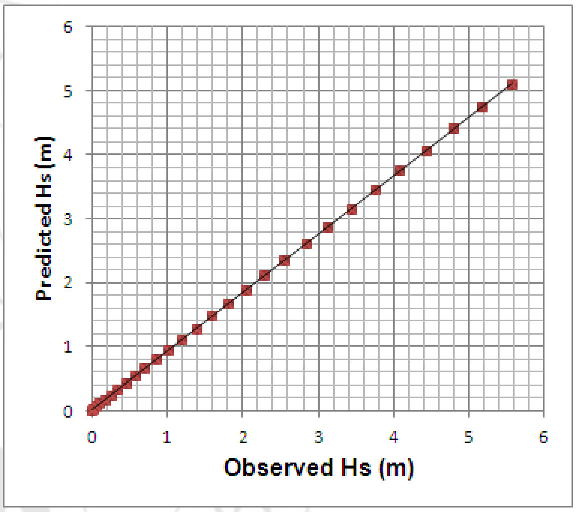

Figure 2: Correlation of predicted and observed Hs by P-M method for Alexandria

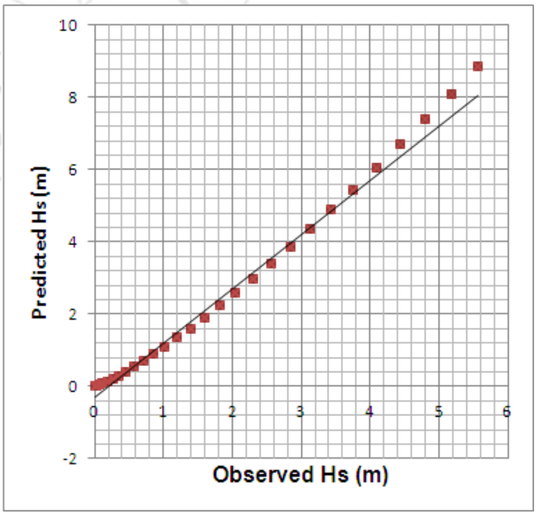

Figure 3: Correlation of predicted and observed Hs by SPM method for Alexandria

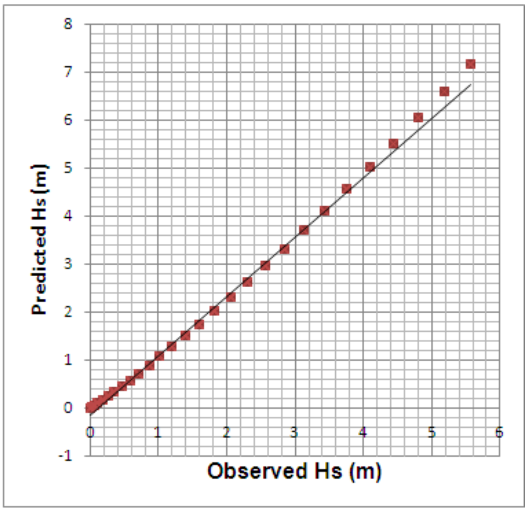

Figure 4: Correlation of predicted and observed Hs by CEM method for Alexandria

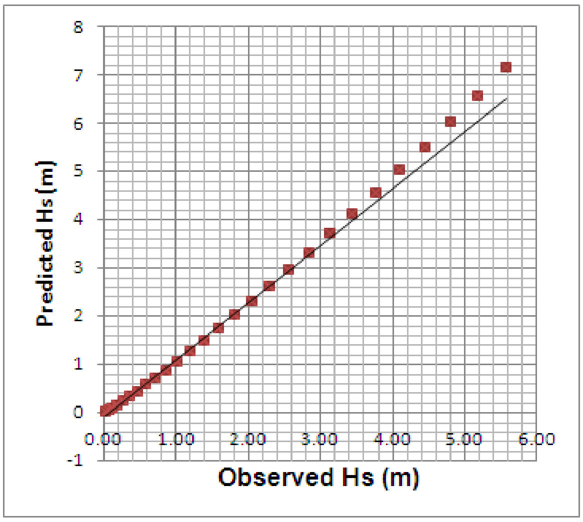

Figure 7: Correlation of predicted and observed Hs by CEM method for Port Said

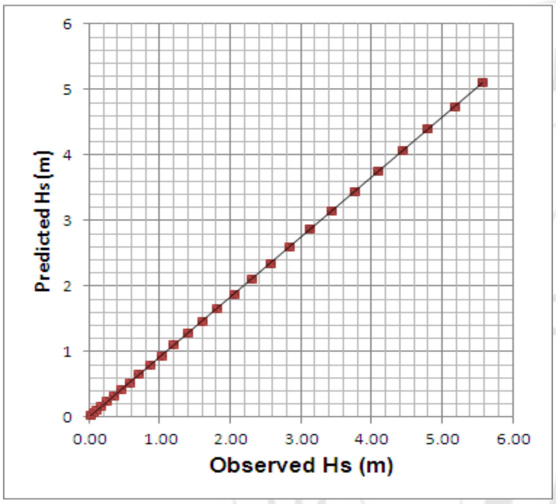

Figure 5: Correlation of predicted and observed Hs by P-M method for Port Said

Table 3: Error statistics of the Modified P-M for significant wave period (Ts) against P-M by Eq. (3) for Alexandria

Methods	No. of Data	T_s	
		SI%	Bias (sec)
P-M (from Table 1)	2874	37.08	1.12
Modified P-M	2874	10.38	-0.02

Table 4: Error statistics of the Modified P-M for significant wave period (Ts) against P-M by Eq. (3) for Port Said

Methods	No. of Data	T_s	
		SI%	Bias (sec)
P-M (from Table 2)	2836	30.76	0.98
Modified P-M	2836	7.61	-0.12

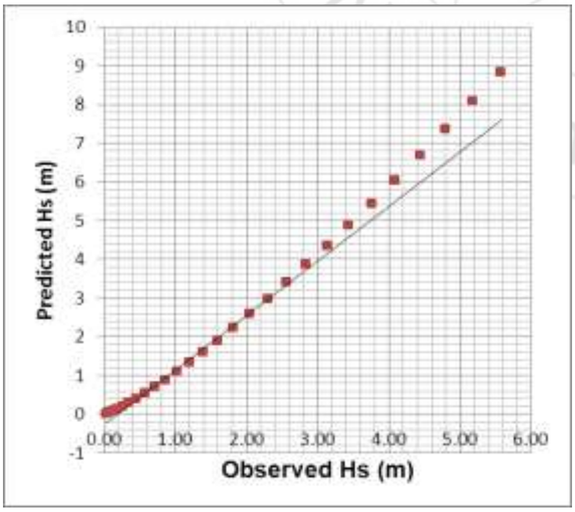

Figure 6: Correlation of predicted and observed Hs by SPM method for Port Said

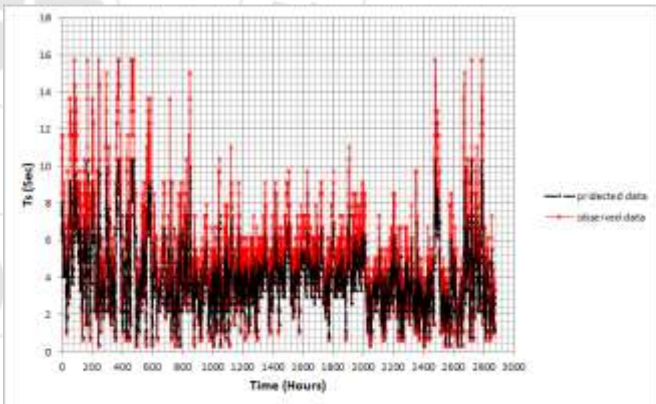

Figure 8: Comparison of predicted Ts values by Eq. (3) and observed values for Alexandria region

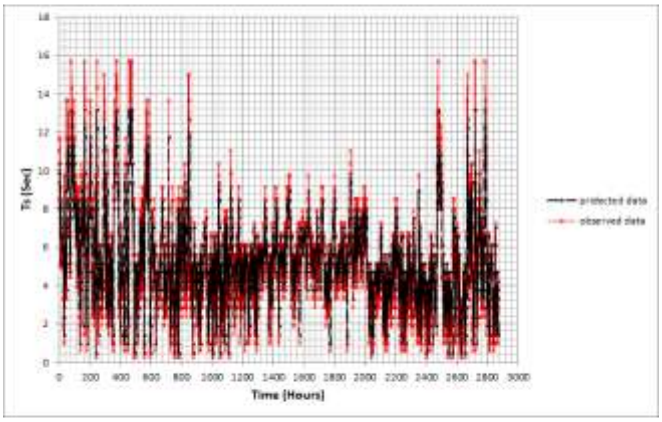

Figure 9: Comparison of predicted Ts values by Eq. (20) and observed values for Alexandria region

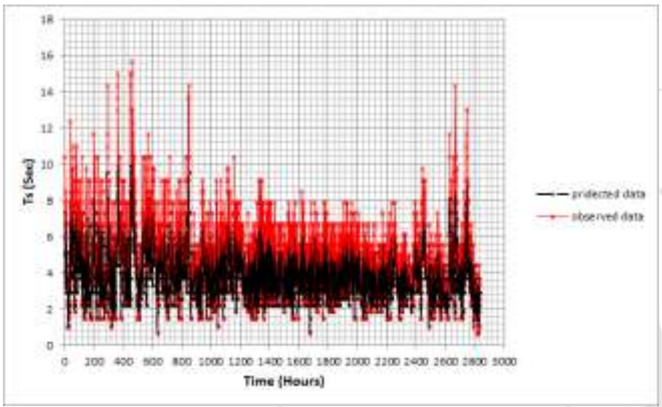

Figure 10: Comparison of predicted Ts values by Eq. (3) and observed values for Port Said region

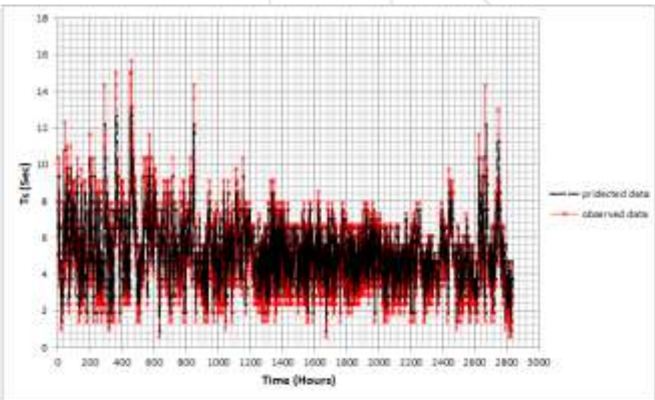

Figure 11: Comparison of predicted Ts values by Eq. (20) and observed values for Port Said region

Data from the beginning of January 2012 to the end of December 2012 based on 3 hourly significant wave heights (H_s), significant wave periods (T_s) and wind speed (u) were used in the analysis.

In this study, fetch limited, duration limited and fully developed sea conditions were investigated to determine the wave parameters to fit the data of study area. We concluded that the fully developed sea condition was the appropriate approach to the study area.

Since CEM method is the latest method, it is expected to be the most accurate in their results. However, the results showed that the CEM method is poorer than P-M method for Hs prediction. The scatter index for CEM and P-M methods are 43.23% and 12.31% respectively (for Alexandria region) while 29.63% and 11.36% respectively (for Port Said). Therefore, we recommend using the P-M method to predict wave parameters for the study area.

In addition to the above, the analyses of this study were concluded the following points:-

- About 80% ~ 85% of the significant wave height data of the study area does not exceed 1.6m ~ 1.8m. Furthermore, about 55% ~ 65% of the wave data are dominantly coming from NW direction.
- P-M method has a high convergence between the predicted and observed values for Hs with all wave height values (correlation coefficient close to one) while the SPM and CEM methods have a high convergence with wave height up to 3.5m and then decrease in its accuracy with wave height larger than 3.5m.
- The prediction of Ts using P-M method was investigated and modified to improve its performance and rely on its results.

Finally, this study concluded that the prediction of wave parameters using P-M method (with the modification of significant wave period equation) was significantly accurate in its results and also very suitable for the study area compared to other methods.

Because the parametric methods used to predict wave parameters have a significant impact on design as well as ships movement, the author hopes to study many of the areas in the Mediterranean basin using parametric methods and compared to this study to find the best method for the Mediterranean basin to be used.

References

[1] Pierson, W. J. and L. Moskowitz, 1964. A proposed spectral form for fully developed wind-seas based on the similarity theory of S. A. Kitaigorodskii. J. Geophys. Res., 69(24), 5181–5190.

[2] Bretschneider, C.L., 1970. Wave forecasting relations for wave generation. Look Lab/Hawaii, 1(3), 31–34.

[3] Hasselmann, K., Barnett, T.P., Bouws, E., Carlson, H., Cartwright, D.E., Enke, K., Weing, J.A., Gienapp, H., Hasselmann, D.E., Kruseman, P., Meerburg, A., Muller, P., Olbers, K.J., Richter, K., Sell, W., Walden, W.H., 1973. Measurements of wind wave growth and swell decay during the Joint North Sea Wave Project (JONSWAP). Deutsche Hydrograph, Zeit, Erganzung-self Reihe, A 8 (12).

[4] Donelan, M.A., 1980. Similarity theory applied to the forecasting of wave heights, periods and directions. Proceedings of the Canadian Coastal Conference (National Research Council of Canada), pp. 47– 61.

[5] SPM, 1984. Shore Protection Manual. Coastal Engineering Research Center, Waterway Experiment Station, Corps of Engineers, Department of the Army, Vicksburg, MS.

[6] Goda, Y., 2003. Revisiting Wilson's formulas for simplified wind-wave prediction. Journal of Waterway, Port, Coastal and Ocean Engineering 129 (2), 93–95.
[7] CEM, 2008. Coastal Engineering Manual. Department of the army, US Army corps of Engineers, Washington, DC 20314-1000, Manual No. 1110-2-1100 (Change 2), 1 April 2008.
[8] Tamer Elgohary; Amir Mubasher and Hassan Salah, 2017. Significant deep Wave Height Prediction by Using Support Vector Machine Approach (Alexandria As case of study). 135| International Journal of Current Engineering and Technology, Vol.7, No.1 (Feb 2017).
[9] Mohamed Abdel-Aziz Younes, 2015. Natural Gas Geochemistry in the Offshore Nile Delta, Egypt. http://dx.doi.org/10.5772/60575.
[10] Adem Akpinar, Mehmet Özger, Serkan Bekiroglu and Murat Ihsan Komurcu, 2014. Performance evaluation of parametric models in the hindcasting of wave parameters along the south coast of Black Sea. Indian Journal of Geo-Marine Sciences, Vol. 43(6), pp. 905–920.
[11] WMO, 1988. Guide to wave analysis and forecasting. World Meteorological Organization WMO no. 702, Geneva, Switzerland.
[12] Ochi, M.K., 1982. Stochastic Analysis and Probabilistic Prediction of Random Seas. Advances in Hydroscience, Vol. 13, pp. 218–375.
[13] Goda, Y., 1978. The observed joint distribution of periods and heights of sea waves. Proc. 16th Coastal Engineering Conference, Hamburg, Germany, 227–246.

Author Profile

Hassan Salah A. El-Hameed, B.Sc. degree in Civil Engineering, currently I work as an Offshore Structural Engineer Specialist in **ENPPI Petroleum Company** in Egypt, one of the international engineering companies in the field of oil and gas industry. Before Oil and Gas field, I worked for 4 years as a teacher at faculty of engineering and 2 years as a site engineer for several mega projects. I have published in the abroad. Area of interest and investigation is development and application of the marine and Civil engineering works, especially in Oil and Gas field (i.e. Marine terminal jetties, Fixed and Floating offshore terminals, Mooring analysis, Port design, ...etc.).