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Statistical Wave Parameters Offshore Jeddah Coast

SAAD M. ABDELRAHMAN
Marine Physics Dept., Faculty of Marine Science
King Abdulaziz University, Jeddah, Saudi Arabia

ABSTRACT. Waves offshore Jeddah were measured by a pressure-type gauge deployed 7 km off the coast. Narrow banded wave records were considered and analyzed by two different methods; individual wave and Tucker-Drapper methods. Similar results are obtained by both methods. Statistical representative wave parameters show significant wave height around 1.2 m with significant period 6.7 sec, root mean square wave height of 0.80 m, mean height of 0.70 m and an average wave length of 128 m.

The observed representative wave parameters are correlated and compared favorably with those predicted by the theoretical formulation. Further analysis including the relative frequency of occurrence and the probability density function of wave heights and periods provides confirmation of the applicability of the Rayleigh distribution to describe well the random waves offshore Jeddah coast.

Introduction

Water waves are considered the primary force for most coastal changes and nearshore processes. Waves with period that varies from 1-30 sec are considered the most energetic band among waves (Kinsman, 1965). These wind waves and their energy flux are responsible for generating longshore currents and sediment transport which affect the stability of the coastal zone (Thorton and Abdelrahman, 1991). Underestimating the wave parameters may lead to severe coastal problems and, therefore, any successful design for the coastal works depends basically on our understanding of the prevailing wave conditions.

A preliminary literature survey shows that there is only limited wave information offshore Jeddah. General wave information for the Red Sea are described in the

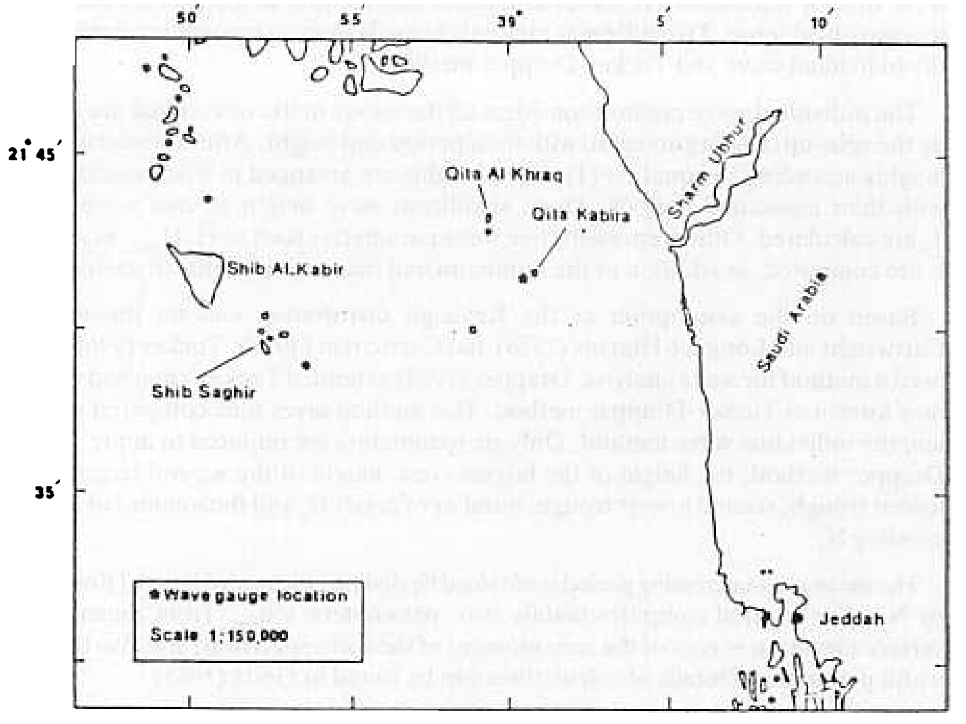

FIG. 1. A map showing the location of the wave gauge offshore Jeddah.

For each record of 10-minute, mean sea level was first drawn by visual adjustment (Goda, 1985) then individual waves were identified by applying zero-up crossing method. Individual wave period T^* and height H^* were determined and tabulated for each record. Wave periods were scaled by appropriate scale while the actual wave heights (H) were transferred according to the following relationship, (Earle and Bishop, 1984).

$$H = n \cdot S \quad H^* \quad \cosh kh \tag{1}$$

where n is a constant when applying the linear wave theory (1.2 as suggested by Horikawa and Isobe, 1980), S is a sensitivity coefficient given in the instrument manual, k is the wave number and h is the water depth. The wave length and then the wavenumber were calculated from the dispersion relationship following the explicit solution suggested by Wu and Thornton (1986). Each record is then written in a tabular form containing the observed individual heights, periods and wave lengths.

It is assumed that the 10-minutes record represent adequate length for statistical analysis. Narrow banded records with sufficient well developed waves are considered for detailed statistical analysis while records dominated by low frequency oscillations (broad banded) are excluded. The idea of the analysis is to express the can be constructed to demonstrate the observed frequency of occurrence and their distribution. It is common to normalize the wave height by a representative wave height such as H_{rms} or $\bar{H}$ and the wave period by $\bar{T}$.

The wave height distribution was studied by Longuet-Higgins (1952) and shown to give Rayleigh distribution provided that the frequency band is relatively narrow. The wave height probability density function P, for a normalized wave height ($H/\bar{H}$), is given as:

$$P(H/\bar{H}) = \frac{\pi}{2}\frac{H}{\bar{H}^2} \text{EXP} \left[-\frac{\pi}{4}\left(\frac{H}{\bar{H}}\right)^2 \right] \qquad (4)$$

which is entirely specified by H. If the wave height is normalized by H_{rms} then

$$P(H/H_{rms}) = 2\frac{H}{H^2_{rms}} \text{EXP} \left[-\left(\frac{H}{H_{rms}}\right)^2 \right] \qquad (5)$$

and for the wave period distribution of a fully developed sea is;

$$P(P/\bar{T}) = 2.7\frac{T^3}{\bar{T}^4} \text{EXP} \left[0.675\left(\frac{T}{\bar{T}}\right)^4 \right] \qquad (6)$$

where $P(T/\bar{T})$ is the wave period density distribution function and the period is scaled by $\bar{T}$.

III. Results and Discussion

Observed narrow banded 25 records, that are dominated by gravity waves, were selected for the analysis. Computer programs were developed to calculate the statistical wave parameters by the two adopted methods; individual wave and Tucker-Drapper method. Wave parameters; H_s, H_{rms}, $\bar{H}$, $\bar{T}$ and H_{max} are computed by both methods while significant wave period T_s, $\bar{L}$ and H_{10} are only calculated by individual wave method. The maximum wave height by Tucker-Drapper method represents the maximum height over the time interval between records; *i.e.* two hours, while it is merely the maximum recorded height in the other method.

Summary of the statistics of the representative wave parameters is given in Table 1 that includes; mean, median, minimum, maximum, variance, standard deviation and the standard error. Both methods of analysis are expected to give the same mean zero-up crossing period; $\bar{T} = 9.26$ sec. Significant wave period T_s is calculated 6.65 sec by Individual method as shown in Table 1. In general, the mean zero-up crossing wave period is expected to be of longer period since the measurements were taken during summer (Swell type). However, significant wave period is commonly comparable to the peak spectral period (SPM, 1984) where the most energetic band is located. It is also added that the range of the observed wave heights and periods lie within the ones obtained by hindcasting in Abdelrahman (1993).

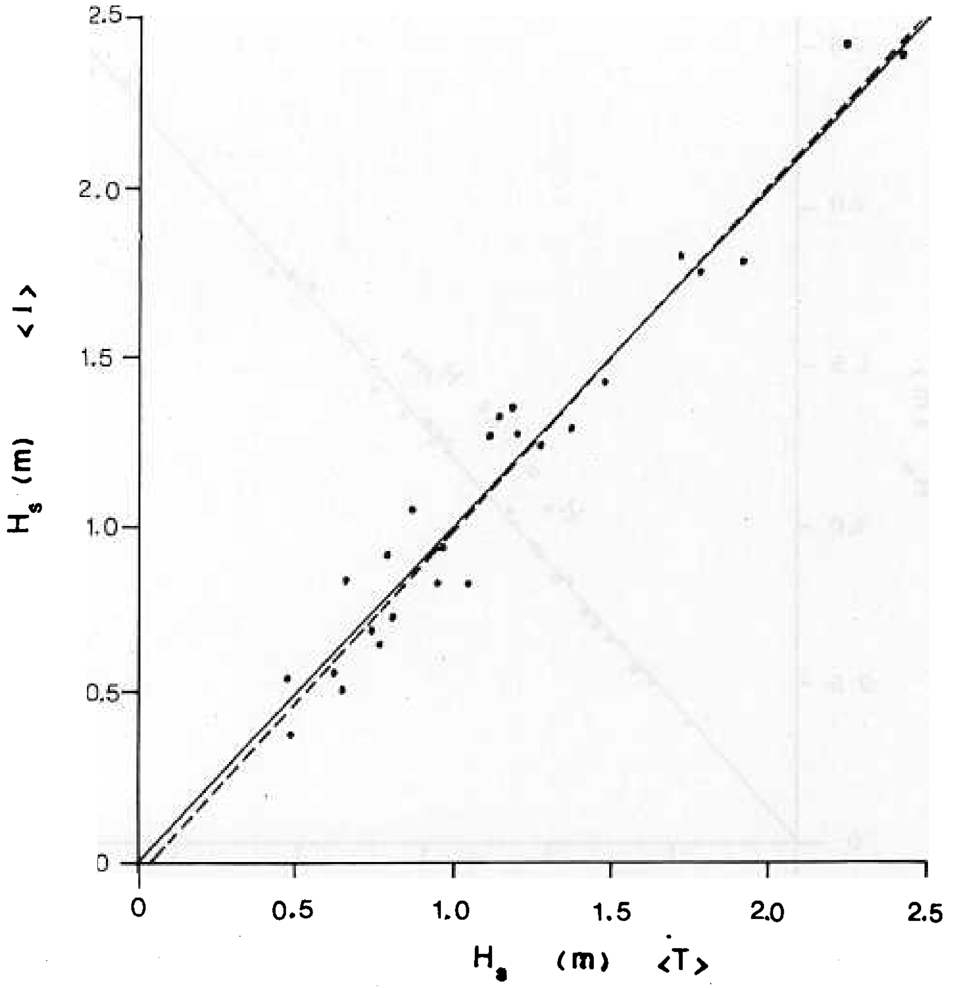

FIG. 2. Measured significant wave height H_s by individual wave method (I), plotted against Tucker-Drapper (T) statistic H_s. The best fit regression line (----) agrees well with the 45° line (——).

Statistical based wave height parameters obtained by the individual wave method (observed data) are plotted against each other to verify the applicability of the Rayleigh distribution. Fig. 3 shows the best line fit to H_s against H_{rms}. The resulting equation is comparable with the theoretical equation (equation 3). The intercepts of the best fit lines are small and can be neglected (order of 2 cm). Linear aggression and the resulting equations between representative parameters are given in Table 2. The good agreement between the observed and theoretical relationships are found in Table 2.

Further analysis is carried out to examine the tendency of the observed data to follow the Rayleigh density function. Wave heights and periods are scaled with the associated parameters $\bar{H}$, H_{rms}, $\bar{T}$ for each record. Then, histograms including all the scaled recorded waves (1678 waves) are constructed, superposed on them the probability density function of Rayleigh distribution given by equations 4 and 5. Fair agreement between the observed and theoretical distributions are shown in Fig. 4, 5 and 6 and the validity of Rayleigh distribution is confirmed. The Rayleigh distribution appears to describe qualitatively the measured wave height that is why the central moments such as $\bar{H}$ and H_{rms} are predicted well by theoretical function. The application of a linear model (Rayleigh distribution) seems to be reasonable since typical wave steepness in this data set, based on mean values, are less than 1%. Part of the reason of the deficit in $P(T/\bar{T})$ is because of the shortness of the records' length (10 min) and the dependence of the distribution on $\bar{T}$ which seems to be biased in this data towards longer period when compared with the significant wave period.

It is worth-mentioning that despite the fact that the sensor was bottom mounted in relatively shallow water area where waves are partially subjected to shoaling and reflection effects, the obtained pattern agrees with the suggested Rayleigh distribution. This is to say that the wave height distribution appear to follow Rayleigh under a much wider range of conditions than the strict assumptions of deep water and

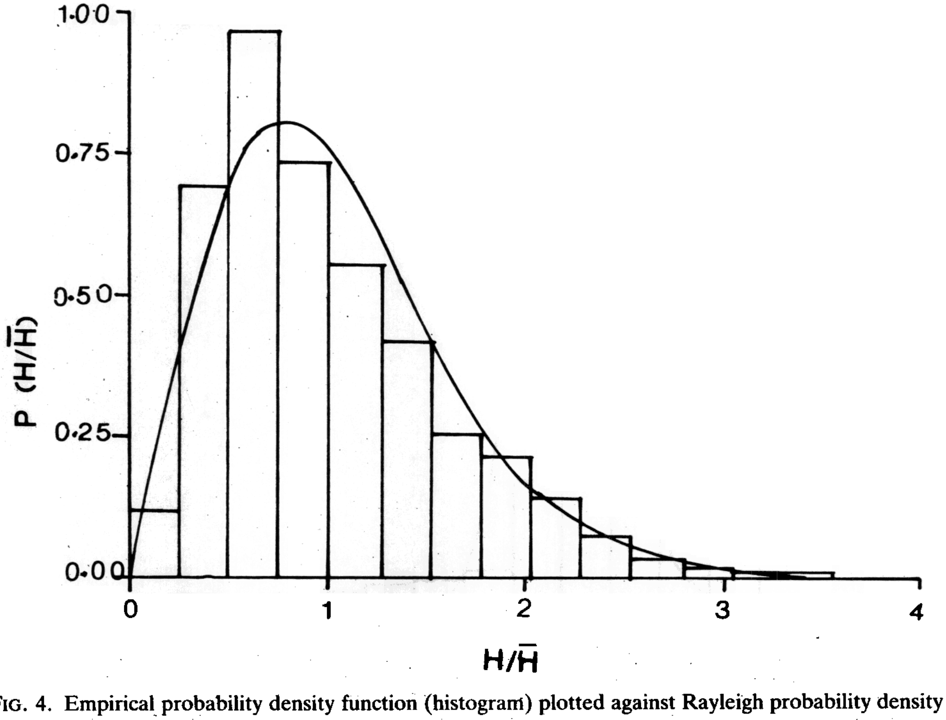

FIG. 4. Empirical probability density function (histogram) plotted against Rayleigh probability density function for wave heights normalized by average wave height.

Gaussian (linear) process would imply. Thornton and Guza (1983) obtained a nearly Rayleigh distribution even within the surf zone.

IV. Conclusion

Waves are measured offshore Jeddah by a pressure type gauge. Main findings can be summarized as follow :

1. Tucker-Drapper method gives reliable wave results despite the fact that it takes less time and effort compared with individual wave method. This may suggest the use of Tucker-Drapper method to efficiently analyze wave records in the central part of the Red Sea.
2. Analysis of narrow banded records show the following features during the recording period :
   a. Significant wave period varies from 5.1 second to 9.8 second with a mean period of 6.7 second. Longer period of 9.3 second is obtained as mean zero-up crossing by the two methods. However, significant wave period may correspond to the spectral peak band.
   b. An average wave length of 128 m is obtained by the use of an explicit solution for each recorded wave.
   c. Mean values for different wave height give $\bar{H}$ = 0.70 m, H_{rms} = 0.80 m, H_s = 1.15 m and short terms variation in H_{max} ranges from 3.91 m (max. recorded) to 4.5 m (max. calculated for two hour intervals).
   d. Relationship between observed representative wave heights are highly correlated with the associated theoretical relationships derived from the Rayleigh distribution as given by Longuet-Higgins (1952).
   e. Further analysis that includes empirical and theoretical probability density function provides a confirmation to the applicability of the Rayleigh distribution.

A final conclusion can be drawn that the observed waves offshore Jeddah coast are reasonably well described by Rayleigh distribution. This results improves our knowledge of the wave characteristics in the central part of the Red Sea. Moreover, it provides a reliable wave statistics based on measured data which may help in future studies.

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المتغـــيرات الإحصـــائية للأمـــواج أمـــام شاطيء جـــدة

سعد مصباح عبد الرحمن

قسم الفيزياء البحرية ، كلية علوم البحار ، جامعة الملك عبد العزيز

جـــدة - المملكة العربية السعودية

المستخلص . تم قياس الأمواج البحرية أمام شاطيء جدة وعلى بعد ٧ كم من الشاطيء بواسـطة جهـاز يعتمد على التغير في الضغط الناشيء عن مرور الأمواج . ولقد اختيرت سجلات الأمواج ذات المدى المتقارب في الترددات لإجراء التحليل عليها . واستُخدمت طريقتان لتحليل السجلات : الأولى طريقة الأمواج الفردية ، والثانية تسمى طريقة Tucker-Drapper ، وقـد وجد أن نتائجهما متقاربة . ولقد أوضحت التحاليل أن قيم المتغيرات الإحصائية للأمواج كما يلي :

ارتفاع الموجة المميز حوالي ١,٢٠م مع زمن موجة مميز ٦,٧ ثانية ، وجذر متوسط مجموع مربعات الارتفاع هو ٠,٨٠م ، والارتفاع المتوسط هو ٠,٧٠م ، ومتوسط الطول الموجي هو ١٢٨م .

وقـد وجـد أن هذه القيم لسجلات الأمواج المقاسة تتفق مع مايتم توقعه باستخدام العـلاقات النظرية . وعلاوة على ذلك فقد حسبت معدلات التكرار والتوزيع الاحتمالي لارتفاعات الأمواج والأزمنة ، ووجد أنها تتبع توزيع ريليه Rayleigh الاحتمالي ، والذي وجد أنه يصف الأمواج العشوائية أمام شاطيء جـدة بصورة جيدة .