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A Proper Unidirectional Wave Spectrum Model For Chabahar Bay at The North of Oman Sea

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Abstract
The objective of present paper is to announce an appropriate unidirectional wave spectrum model for Chabahar bay at the north of oman sea. primitive investigations had been conducted on the field data, showing that they may suffer unphysical data. Hence, in the first step, using known methods the errors were discovered and modified. Then, The research is concentrated on appraisal of standard wave spectrum models in the region. wave spectrum models such as JONSOWAP, PM, Ochi-Hubble and ITTC indicated that considering standard coefficient, Ochi-Hubble spectrum is not appropriate for field spectrums with two peaks. Also it was seen that ITTC model demonstrates a great fit with field spectrums that have one peak. Then by using GRG nonlinera method coefficients were proposed for ITTC and Ochi-Hubble models in order to increase their accuracy.

Keywords: Chabahar bay; Oman Sea; JONSWAP; ITTC; P-M; Ochi-Hubble.

Introduction
Having information about the wave spectrum and the sea wave parameters is one of the requirements of engineering activities such as analysis and design of ports and coastal structures. In addition, studies on sediment, morphology and environment of coasts depend strongly on wave spectrum and its features such as significant wave height, peak period and spectrum frequency range. There are different well-known wave spectra; each useful under certain circumstances. These are models extracted based on field data at specified regions and wisely or blindly extended overseas. Even though, such approach of implementing a standard spectrum model is practical, however, error is its inherence. Various researchers have suggested different spectral models that some of them have been introduced by Chakrabarty [1].
In 1953, the first two-parameter spectral model was proposed by Newman. Then, different models were introduced for fully developed sea conditions by Philips in 1958, Bretschneider in 1959, Pierson-Moskowitz in 1964 [2], and different models were introduced for growing sea conditions by Jonswap in 1973 [3] and Ochi-Hubble in 1976 [4] for spectrums with two peaks, but in practice several spectral models are more applicable in coastal engineering and marine structures that PM and JONSWAP spectral models can be named. Each spectral models presented above are derived and introduced based on the different data and conditions that may have not a good adaptation with waves spectrum of other regions.
In view of the above, it can be concluded that it is still difficult to choose a spectrum which can express the wave behavior generated in the Oman sea.
In this paper, field spectrum of the mentioned region are compared with the standard ITTC, PM, Ochi-Hubble and JONSWAP wave spectrum model and then an appropriate spectral model is introduced for this region.

Measurement
In the current study, the raw data measured by the AWAC device based on the data measured by AST method have been studied in four stations. In AST method, a short acoustic pulse encountered water surface vertically and the time difference between the transmission and reflection is used to generate a time series of water level changes. Table 1 and Figure 1 show details and map of data measuring stations in Chabahar bay region.

Table 1. Measurement details of wave data stations in Chabahar bay region

station No.	depth (meter)	measurement time interval		measurement point coordination (UTM)	
		Start	End	X	Y
1	30	2006/08/27	2007/06/14	263397	2595937
2	10	2006/08/25	2007/09/20	257785	2799179
3	11	2006/08/30	2007/09/02	245745	2799632

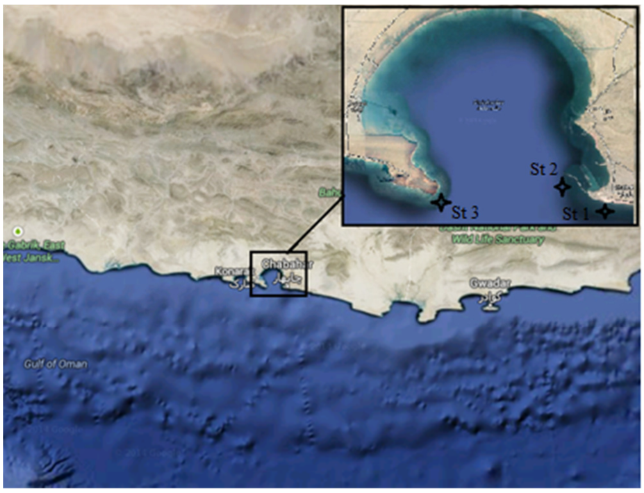

Figure 1. The locations of measuring stations

Before analyzing the data, a series of operations should be done related to standardize or eliminate unreasonable data. The purpose of monitoring and filtering data is to eliminate the errors in recording data or the data that should be excluded due to the type of analysis [5]. There are many types of error in recording of data that Gap and Spike can be pointed out as the most common errors. Also, errors due to the device operation such as vibrations (vessels collision to buoy) can also cause the error. Common errors in recording data have been described as follows:

Spike: the height of wave changes irrationally and does not follow its pre and post process.

Gap: no data have been recorded in a time interval and therefore the values of this interval are shown as zero or irrational numbers.

Among the data measured, three different groups of data can be observed including data without errors, data with low errors and data with high errors. In the data with low errors, the errors should be replaced by interpolation such as Cubic Spline method [6]. In this paper, some errors observed were over 2 percent and consecutively, so they can be considered as time series with high errors that should be eliminated from the analysis [6].

Performance of standard spectral models

After extracting dominant events at each station, comparisons could be made between observed spectra and those presented by standard models at this step.

Actually, different spectra could be used to answer this main question in ocean engineering that what would be an appropriate presentation of ocean waves. Perhaps the simplest is that proposed by Pierson and Moskowitz in 1964 (PM)[2] under fully developed sea condition. PM and ITTC; later introduced by International Towing Tank Conference[7]; models follow a general form as Eq.1; in which their coefficients are presented in Table 2:

$$S(f)=\frac{A}{f^5}.e^{\left(-B/f^4\right)} \tag{1}$$

Table 2. Coefficients of PM and ITTC models in Eq.1

PM	ITTC
$A=0.0081g^2(2\pi)^{-4}$	$A=0.312H_s^2 f_p^{-4}$
$B=0.0324g^2/\left[(2\pi)^4 H_s^2\right]$	$B=1.25 f_p^{-4}$

Here, f is frequency in Hz, g is the acceleration of gravity in m/s^2, f_p is peak frequency in Hz and H_s is significant wave height in m.

Also JONSWAP model can be considered as the most widely known spectral model. The equations of this model are as follows.

$$S(f)=\frac{\alpha g^2}{(2\pi)^4} f^{-5} e^{-1.25\left(f_p/f\right)^4} \gamma^{e^{-\left[\frac{(f-f_p)^2}{2\sigma^2 f_p^2}\right]}} \tag{2}$$

For values γ, σ and α relations (3) to (5) are presented.

$$\begin{cases} \gamma=5 & for \quad T_p/\sqrt{H_s}\le 3.6 \\ \gamma=\exp(5.75-1.15T_p/\sqrt{H_s}) & for \quad 3.6\le T_p/\sqrt{H_s}\le 5 \\ \gamma=1 & for \quad T_p/\sqrt{H_s}\ge 5 \end{cases} \tag{3}$$

$$\sigma=\begin{cases} 0.07 & f< f_p \\ 0.09 & f\ge f_p \end{cases} \tag{4}$$

$$\alpha = 0.076\left(\frac{gF}{W^2}\right)^{-0.22} \quad or \quad \alpha = 0.0081 \tag{5}$$

Hasselman et al to facilitate the use of this model for coefficient γ independent of relation (3) have provided values between 1 and 7 that for the general use number 3.3 is recommended value as used in this study for the standard version of JONSWAP spectrum..

Ochi and Hubble in 1976, Kumar et al in 2008 and Mazaheri and Ghaderi in 2011 [8], modified α and γ based on data recorded in different areas.

In continuation of other researchers, a six-parameter spectrum developed by Ochi and Hubble (1976) is the only wave spectrum which exhibits two peaks, one associated with underlying swell (lower frequency components) and the other with locally generated waves (higher frequency components). It is defined as:

$$S(\omega) = \frac{1}{4}\sum_{j=1,2}\frac{\left(\frac{4\lambda_j+1}{4}\omega_{p_j}^4\right)^{\lambda_j}}{\Gamma(\lambda_j)}\cdot\frac{H_{s_j}}{\omega^{4\lambda_j+1}}\exp\left[-\frac{4\lambda_j+1}{4}\left(\frac{\omega_{p_j}}{\omega}\right)^4\right] \tag{6}$$

where H_{s1}, ω_{01}, and λ_1 are the significant wave height, modal frequency, and shape factor for the lower frequency components while H_{s2}, ω_{02}, and λ_2 correspond to the higher frequency components and Γ is gamma function. For the most probable values of H_{s1}, ω_{01}, λ_1, H_{s2}, ω_{02}, λ_2 it can be shown as table 3:

Table 3.The most probable values for the parametrs of Ochi-Hubble model

H_{s_1}	H_{s_2}	ω_{p_1}	ω_{p_2}	λ_1	λ_2
$0.84H_s$	$0.54H_s$	$0.70\exp(-0.046H_s)$	$1.15\exp(-0.039H_s)$	3.00	$1.54\exp(-0.62H_s)$

At this step, statistical performance of well-known standard models, i.e., Pierson and Moskowitz (PM), JONSWAP and ITTC models has been examined for field spectrums that have two peaks and Ochi-Hubble for field spectrums that have one peak. Results are summarized in Table 2 which R^2 is Correlation factor and N(Error) is normalized error.

Table 2. Performance of standard wave spectra in modeling the enviroment

One Peak					
station No.	spectral model	R^2	N(Error)	$\Delta fp^{(Hz)}$	$\Delta A^{(m2)}$
1	JONSWAP	٠.٨١	35%	0	0.270
	PM	٠.٣٩	21%	0.10	0.012
	ITTC	٠.٨٦	10%	0	0.013
2	JONSWAP	٠.٨٤	30%	0	0.390
	PM	0.٢٥	14%	0.08	0.012
	ITTC	0.٩١	7%	0	0.012
3	JONSWAP	٠.٨٧	41%	0	0.450
	PM	٠.٢٥	25%	0.12	0.014
	ITTC	٠.٩٢	15%	0	0.012
Two Peaks					
1	Ochi-Hubble	0.42	49%	0.12	0.21
2	Ochi-Hubble	0.34	53%	0.08	0.16
3	Ochi-Hubble	0.41	42%	0.10	0.18

It should be reminded that, f_p entered directly to JONSWAP and ITTC models. So, Δf_p=0.0 is not a great achievement for them. However, ITTC results are more promising than two other spectra. Here, Although JONSWAP is sometimes weaker in modeling sea states, but having f_p as one of its inputs pushes one to go further.

Figure 2 compares an observed spectrum with JONSWAP, PM and ITTC models. It should be noted that the reported values are just the average ones. Consequently they might be larger in some cases than others, as is the case for aforementioned figure.

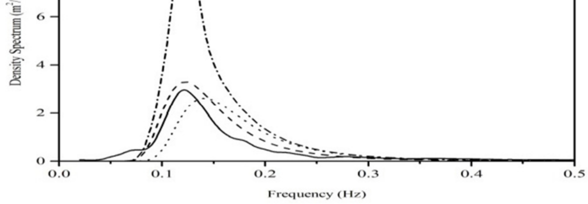

Figure 2. Comparison of an observed spectrum (one peak) with selected models

Also figure 3 compares an observed spectrum that has two peak with Ochi-Hubble model.

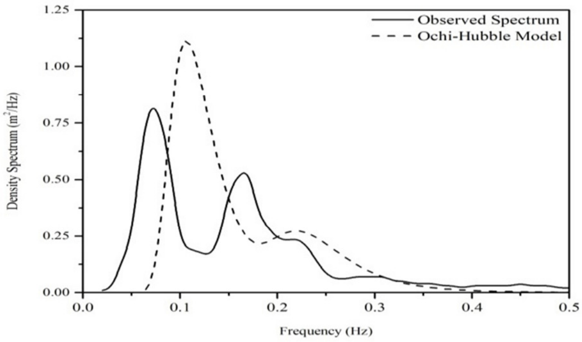

Figure 3. Comparison of an observed spectrum (two peaks) with Ochi-Hubble model

Calibration of standard spectral models

In this section, to achieve higher accuracy the coefficients of both ITTC and Ochi-Hubble models are modified for the region. PM and JONSWAP models are excluded from the list due to their lack of performance In this study.

However, both of ITTC and Ochi-Hubble models are non-linear. Therefore, to obtain optimal coefficients, nonlinear methods should be used. Methods of Lagrangian and Generalized Reduced Gradient (GRG) nonlinear are nonlinear programming methods. Most methods for solving nonlinear programming problems include the linearization of problem and using linear programming technique.

One of the disadvantages of Lagrangian method is the possibility of non-convergence of the problem. Therefore the best current general algorithm is using the Generalized Reduced Gradient (GRG) algorithm which is an extension of the Wolfe algorithm which can accommodate both a nonlinear objective function and nonlinear constraints [9]. It should be noted that such a combination has been found the best is a trial and error procedure.

Calibration of ITTC model

To increase accuracy, GRG nonlinear algorithm results in coefficients presented in Table 3. a general form of ITTC model is assumed as below:

$$S(f)=\frac{A}{f^5}.e^{\left(-B/f^4\right)}$$
$$A=a\frac{H_s^2}{T_p^4}\quad \& \quad B=\frac{b}{T_p^4} \tag{7}$$

In this case, the calibration procedure has been also successful when considering N(Error) decline of more than 80% as well as R^2 increase of up to 5%. Besides, the calibration procedure plays a beneficial role even with such a small change in constant coefficients.

Table 3.coefficients of standard ITTC model and its calibrated version

ITTC model		calibrated ITTC model	
a	b	a	b
0.31	1.25	0.33	1.22
N(Error)=0.10 R^2=0.90 $\Delta A=0.012^{m^2}$ $\Delta f_p=0^{Hz}$		N(Error)=0.02 R^2=0.95 $\Delta A=0.001^{m^2}$ $\Delta f_p=0^{Hz}$	

Figure 4 shows ITTC performance as developed from a standard version to a calibrated version.

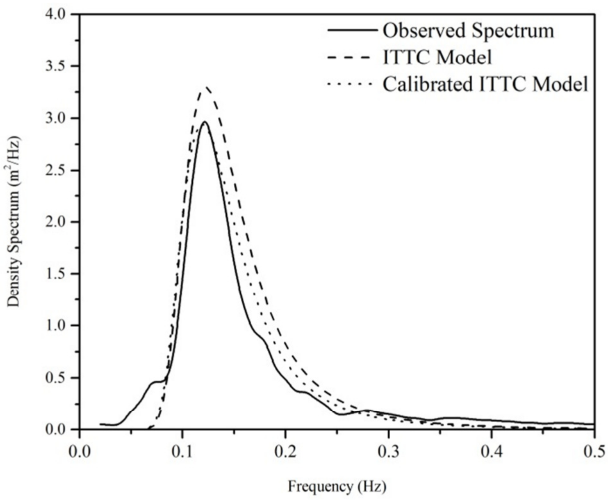

Figure 4.Comparison of an observed spectrum with different versions of ITTC model

Calibration of Ochi-Hubble model

The above scenario is repeated just by using Ochi-Hubble spectrum. For the mentioned spectrum, it could be parameterized by introducing 9 potential coefficients a to i for a calibration, as below:

$$S(\omega)=\frac{1}{4}\sum_{j=1,2}\frac{\left(\frac{4\lambda_j+1}{4}\omega_{p_j}^4\right)^{\lambda_j}}{\Gamma(\lambda_j)}.\frac{H_{s_j}}{\omega^{4\lambda_j+1}}\exp\left[-\frac{4\lambda_j+1}{4}\left(\frac{\omega_{p_j}}{\omega}\right)^4\right]$$

$$\begin{aligned} H_{s_1}&=aH_s\\ H_{s_2}&=bH_s\\ \omega_{p_1}&=c\exp(dH_s)\\ \omega_{p_2}&=e\exp(fH_s)\\ \lambda_1&=g\\ \lambda_2&=h\exp(iH_s) \end{aligned} \tag{8}$$

The results in calibration of constants a to i for the spectrum reported in Table 4. , the calibration procedure has been also successful when considering N(Error) decline of more than 75% as well as R^2 increase of up to 100%.

Table 4.coefficients of standard Ochi-Hubble model and its calibrated version

The coefficients of standard Ochi-Hubble model								
N(Error)=0.48 Average R^2=0.40 ΔA=0.18$^{m^2}$ Δf_p=0.10^{Hz}								
a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*
0.84	0.54	0.70	-0.046	1.15	-0.039	3	1.54	-0.062
The coefficients of calibrated Ochi-Hubble model								
N(Error)=0.12 Average R^2=0.80 ΔA=0.09$^{m^2}$ Δf_p=0.02^{Hz}								
a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*
0.45	0.62	0.45	-0.039	0.95	-0.046	1.92	1.26	-0.062

Figure 5 shows the great change in Ochi-Hubble performance as developed from a standard version to a calibrated version.

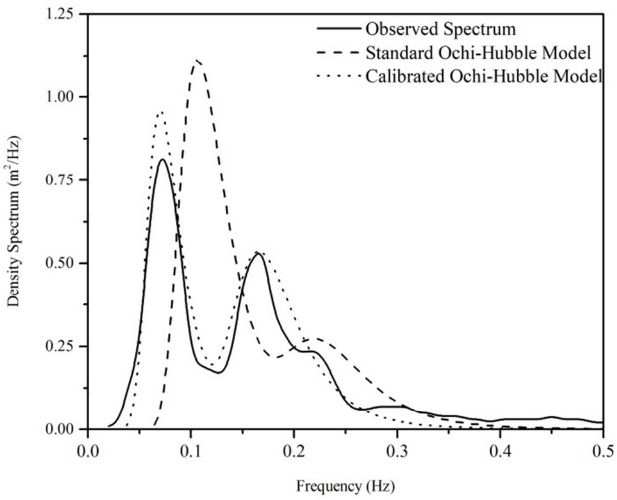

Figure 5.Comparison of an observed spectrum with different versions of Ochi-Hubble model

Conclusion

In this study, observed spectra in Chabahar bay at the north of oman sea have been studied with respect to performance of standard well-known spectral models. Results showed that for observed spectrun with one peak standard ITTC model is extremely more appropriate in this regions when compared with PM and JONSWAP models and for observed spectrum with two peaks standard Ochi-Hubble model performance is not appropriate and should be calibrated.

In order to catch a calibrated version and increasing the accuracy, the constant values of ITTC and Ochi-Hubble models changed by applying GRG algorithm. Briefly, a new version of ITTC model introduced as the best practical unidirectional spectra which is greatly capable of handling spectrum (with on peak) modeling at this region and for Spectrums with two peaks results show that the modified Ochi-Hubble model proposed in this study is appropriate.

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