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Wave Climate at Hong-do and Mara-do Sea Areas

by
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홍도와 마라도 해역에서의 파후에 대하여

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Abstract

In this paper the statistical characteristics of the waves at Hong-do and Mara-do are examined. The wave scatter diagrams of H_s and T_z and $H_{1/3}$ and $T_{1/3}$ at two locations are given and various statistical characteristics of the ocean waves are examined. If the sea is not narrowband, the modified Rayleigh distribution introduced by Longuet-Higgins can be used for the individual wave height distribution. However the modified Rayleigh distribution has not been widely used due to the inconvenience of determining the empirical constant. In this paper a simple method to determine the empirical constant for the modified Rayleigh distribution is proposed. Extreme waves based on the measured wave data are estimated. There is no significant difference depending on the distribution functions. However the estimations of the extreme waves from H_s and $H_{1/3}$ show considerable difference.

요 약

이 논문에서는 홍도와 마라도에서의 파랑의 통계적 특성을 살펴보았다. 두 지역에서의 스펙트럼법과 시계열에서 얻은 유의파고를 이용하여 파고주기결합분포를 얻었으며 여러 가지 통계적인 특성을 살펴보았다. 주파수의 대역폭이 협대역이 아닌 경우에 개별 파고분포에 롱기히긴스가 제안한 수정레일리분포를 사용할 수 있다. 그러나 이 분포함수는 경험상수를 결정해야하는 불편함 때문에 널리 사용되지 않고 있었다. 본 논문에서는 수정레일리분포의 경험상수를 결정하는 간단한 방법을 제안하였다. 설계파고의 추정에서 서로 다른 분포함수 선택에 따른 영향은 크지 않다. 그러나 스펙트럼법과 시계열에서 얻은 파랑자료 사용에 따라서 한계파고의 추정치는 큰 차이를 보인다.

Keywords: ocean waves, individual wave height distribution, extreme wave height, korean waters, wave climate

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1. Introduction

The ocean waves acting on the ocean structures are so complicated that it is very difficult to define characteristics of an individual wave. Therefore the stochastic analysis is needed to estimate the characteristics of the ocean waves. Longuet-Higgins [1952] applied the result of Rice [1944] to the ocean waves and found various statistical properties. Cartwright [1958] expressed the probability density function of the extreme waves. There have been lots of researches thereafter. In general one assumes the symmetry of the wave profile with respect to the mean surface and employs the Gaussian distribution of the wave elevation.

The significant wave height is defined by

$$H_s = 4\sqrt{m_o} \tag{1}$$

where m_o is the variance of sea surface elevation. The average of the zero up-crossing period is defined by

$$T_z = \left(\frac{m_o}{m_2}\right)^{1/2} \tag{2}$$

where m_2 is the second moment of the wave spectrum. The average crest-to-trough height and the average up-crossing period of the highest one-third waves will be referred as $H_{1/3}$ and $T_{1/3}$. The significant steepness is defined by

$$s_s = \frac{2\pi H_s}{gT_z^2} \tag{3}$$

Rice (1952) defined the bandwidth parameter as

$$\varepsilon = \left(1 - \frac{m_2^2}{m_o m_4}\right)^{1/2} \tag{4}$$

However the bandwidth parameter ε is not appropriate to describe the ocean wave spectrum since the fourth moment of the theoretical wave spectrum becomes infinity and the fourth moment of the measured wave spectrum also depends on the cut-off frequency.

Longuet-Higgins [1980] defined the bandwidth parameter as

$$\nu = \left(\frac{m_o m_2}{m_1^2} - 1\right)^{1/2} \tag{5}$$

This parameter does not contain the fourth moments. For the Pierson-Moskowitz spectrum ν =0.425 and for the JONSWAP spectrum with γ=3.3, σ_A=0.7 and σ_B=0.9, ν=0.39. If the spectrum is narrowband, $\nu=0$.

In this paper the statistical characteristics of the waves at two locations in the sea area of Korea are examined. One is at Hong-do and the other is at Mara-do. Wave scatter diagrams and various statistical characteristics are to be examined. Estimations of the extreme wave heights based on the measured wave data will be made.

2. Statistical Wave Characteristics

In this paper wave data report which was published by the office of harbor and maritime transportation [1996] is used. In this report wave data from eight locations in the sea area of Korea are given. Among eight locations, Hong-do and Mara-do wave stations are selected because these two locations provide wave data for a whole year without missing too much data. The water depth at Mara-do station is 110 m, and that at Hong-do station is 40 m. Mara-do station is located at 2.5 km south of Mara-do and Hong-do station is located 1.8 km northwest of Hong-do. At both locations directional wave riders are used and wave elevations are measured every 3 hours.

Table 1 Scatter diagram of h_s and t_z. Total number of observation is 2477. Hong-do, 1995.

H_s \ T_z	2 - 2.5	2.5 - 3.0	3.0 - 3.5	3.5 - 4.0	4.0 - 4.5	4.5 - 5.0	5.0 - 5.5	5.5 - 6.0	6.0 - 6.5	6.5 - 7.0	7.0 - 7.5	7.5 - 8.0	sum
5.5-6.0												3	3
5.0-5.5												1	1
4.5-5.0										1	6		7
4.0-4.5									5	10	6		21
3.5-4.0									4	5			9
3.0-3.5							1	23	25	6			55
2.5-3.0							37	54	10	1			102
2.0-2.5					2	31	88	24	4	1			150
1.5-2.0				1	59	97	55	5	1				218
1.0-1.5			6	83	186	86	43	5					409
0.5-1.0		32	128	261	206	51	16	3	1				698
0-0.5	20	164	259	191	127	28	11	3	1				804
sum	20	196	393	536	580	293	251	117	51	24	12	4	2477

Table 2 Scatter diagram of h_s and t_z. Total number of observation is 2278. Mara-do, 1995.

H_s \ T_z	2.5 - 3.0	3.0 - 3.5	3.5 - 4.0	4.0 - 4.5	4.5 - 5.0	5.0 - 5.5	5.5 - 6.0	6.0 - 6.5	6.5 - 7.0	7.0 - 7.5	7.5 - 8.0	8.0 - 8.5	8.5 - 9.0	9.0 - 9.5	9.5 - 10.0	sum
6.0-6.5													1			1
5.5-6.0																0
5.0-5.5												1		1		2
4.5-5.0									1	2	1					4
4.0-4.5									0	1						1
3.5-4.0								6	3						1	10
3.0-3.5							3	8	6	4	3					24
2.5-3.0						6	21	10	12	3						52
2.0-2.5				1	12	50	38	16	6			3				126
1.5-2.0			1	27	82	73	38	9	3	1	2	3				239
1.0-1.5		5	97	224	155	121	42	16	5	3						668
0.5-1.0	18	168	233	211	109	71	33	12	2	3						860
0-0.5	26	73	83	68	21	12	4	4								291
sum	44	246	414	531	379	333	179	81	38	17	6	7	1	1	1	2278

Table 1 and 2 give wave scatter diagrams based on H_s and T_z at Hong-do and Mara-do respectively. Significant wave heights and zero up-crossing periods are grouped with 0.5 intervals and are rounded to the nearest 0.5 m and 0.5 s. The first column and the first row represent the intervals of wave heights and periods of each group. Generally wave scatter diagram becomes narrow for high waves. In table 2 we can see some wave data with long period and relatively low wave height. This phenomenon can be seen clearly in table 3 and 4 which are wave scatter diagrams based on $H_{1/3}$ and $T_{1/3}$. This might be due to the swell.

Table 5 shows the upper bound and the average

Table 3 Scatter diagram of $H_{1/3}$ and $T_{1/3}$. Total number of observation is 2431. Hong-do, 1995.

$H_{1/3}$ \ $T_{1/3}$	3.0 -3.5	3.5 -4.0	4.0 -4.5	4.5 -5.0	5.0 -5.5	5.5 -6.0	6.0 -6.5	6.5 -6.5	7.0 -7.5	7.5 -8.0	8.0 -8.5	8.5 -9.0	9.0 -9.5	9.5 -10	sum
5.5-6.0													1	1	2
5.0-5.5														1	1
4.5-5.0												1	2	1	4
4.0-4.5									1		5	7	2		15
3.5-4.0										4	11	5			20
3.0-3.5								2	10	16	6				34
2.5-3.0							2	27	42	15	5				91
2.0-2.5					3	18	38	43	34	3	1		1		141
1.5-2.0				4	32	69	62	33	11	3					214
1.0-1.5			22	75	107	88	64	27	6	3					392
0.5-1.0	5	73	123	184	170	83	30	8	1		2			2	681
0 -0.25	11	151	267	207	83	51	23	17	13	5	4	3	1		836
sum	16	224	412	470	395	309	219	157	118	49	34	16	7	5	2431

Table 4 Scatter diagram of $H_{1/3}$ and $T_{1/3}$. Total number of observation is 2246. Mara-do, 1995.

$H_{1/3}$ \ $T_{1/3}$	3.5 -4.0	4.0 -4.5	4.5 -5.0	5.0 -5.5	5.5 -6.0	6.0 -6.5	6.5 -6.5	7.0 -7.5	7.5 -8.0	8.0 -8.5	8.5 -9.0	9.0 -9.5	9.5 -10	10- 10.5	10.5 -11	11- 11.5	11.5 -12	12- 12.5	sum
5.5-6.0													1	1					2
5.0-5.5																			0
4.5-5.0											1	1				1			3
4.0-4.5									1			1							2
3.5-4.0									2	4	3	1						1	11
3.0-3.5									7	4	4	1		1					17
2.5-3.0					1	1	2	11	8	7	3	2		1	1				37
2.0-2.5			1	1	4	11	19	35	31	9	5	2							118
1.5-2.0				15	29	50	53	31	19	10	3	2		1	1	1	3	1	219
1.0-1.5		8	58	112	138	119	74	47	25	11	4	6	1	2					605
0.5-1.0	32	93	166	193	168	112	52	33	14	7	10	7	4	1	2				894
0-0.5	11	54	70	60	76	29	17	9	4	4	3				1				338
sum	43	155	295	381	416	322	217	166	111	56	36	23	6	7	5	2	3	2	2246

of the significant steepness based on H_s. As the wave height becomes higher the significant steepness seems to be bounded. The significant steepness shows maximum value 0.080 where H_s is about 2 m. Most of the significant steepness has a maximum value that is greater than 0.0508 or 1/19.7. Considering that the fully developed Pierson-Moskowitz spectrum gives a constant significant steepness of 0.0508, this suggests that the sea is not fully developed and still under the effect of the local wind. Most of the average significant steepness, however, is less than 0.0508.

Table 5 Upper bound of the significant steepness S_s and the average per each H_s group

	Hong-do		Mara-do	
H_s	S_s max	average	S_s max	average
6.25	-	-	0.052	0.052
5.75	-	-	-	-
5.25	0.056	0.056	0.049	0.044
4.75	0.067	0.062	0.067	0.058
4.25	0.070	0.060	0.052	0.052
3.75	0.062	0.057	0.062	0.047
3.25	0.076	0.059	0.063	0.044
2.75	0.064	0.050	0.064	0.047
2.25	0.080	0.051	0.080	0.047
1.75	0.080	0.049	0.080	0.038
1.25	0.076	0.044	0.076	0.035
0.75	0.064	0.029	0.064	0.026
0.25	0.032	0.012	0.021	0.010

Table 6 Upper bound of the significant steepness S_s and the average per each $H_{1/3}$ group

	Hong-do		Mara-do	
$H_{1/3}$	S_s max	average	S_s max	average
5.75	0.043	0.041	0.039	0.037
5.25	0.035	0.035	-	-
4.75	0.040	0.036	0.040	0.033
4.25	0.052	0.040	0.045	0.039
3.75	0.040	0.036	0.040	0.030
3.25	0.046	0.038	0.035	0.027
2.75	0.045	0.035	0.053	0.030
2.25	0.052	0.032	0.064	0.034
1.75	0.050	0.031	0.041	0.018
1.25	0.044	0.025	0.044	0.019
0.75	0.046	0.019	0.034	0.012
0.25	0.015	0.006	0.011	0.005

Table 6 shows the significant steepness based on $H_{1/3}$ and $T_{1/3}$. Table 8 shows smaller values of the significant steepness than those of the spectral analysis. This is due to the difference in the definition between T_z and $T_{1/3}$.

Table 7 The average values of the ratios $H_{1/3}/H_s$, $T_{1/3}/T_z$ and the bandwidth parameter per each wave height group. n_i is the number of observations. Hong-do, 1995.

$H_{1/3}$	n_i	$H_{1/3}/H_s$	$T_{1/3}/T_z$	ν
5.75	3	0.925	1.24	0.29
5.25	1	0.829	1.257	0.34
4.75	7	0.912	1.217	0.35
4.25	21	0.964	1.259	0.39
3.75	9	0.941	1.26	0.45
3.25	55	0.941	1.239	0.43
2.75	98	0.962	1.267	0.50
2.25	147	0.953	1.249	0.51
1.75	217	0.959	1.257	0.57
1.25	404	0.958	1.248	0.61
0.75	682	0.962	1.259	0.68
0.25	787	0.944	1.342	0.83
	average	0.954	1.283	0.69

Table 8 The average values of the ratios $H_{1/3}/H_s$, $T_{1/3}/T_z$ and the bandwidth parameter per each wave height group. n_i is the number of observations. Mara-do, 1995.

$H_{1/3}$	n_i	$H_{1/3}/H_s$	$T_{1/3}/T_z$	ν
6.25	1	0.892	1.137	0.32
5.75	-	-	-	-
5.25	2	1.015	1.217	0.42
4.75	4	0.935	1.237	0.39
4.25	1	0.847	1.228	0.40
3.75	10	0.983	1.286	0.47
3.25	24	0.897	1.255	0.36
2.75	52	0.922	1.270	0.45
2.25	126	0.951	1.285	0.50
1.75	237	0.946	1.285	0.56
1.25	662	0.950	1.298	0.63
0.75	838	0.960	1.330	0.73
0.25	289	0.961	1.423	0.85
	average	0.954	1.322	0.68

Table 7 and 8 show the average values of the ratios $H_{1/3}/H_s$, $T_{1/3}/T_z$ and the bandwidth parameter v. If the sea is true narrowband, $H_{1/3}$ is equal to H_s. Generally the sea, however, is not true narrowband. In the table one can see that $H_{1/3}$ is less than H_s. The total average value of the ratio $H_{1/3}/H_s$ is 0.954. The ratio $T_{1/3}/T_z$ is greater than the unity and $T_{1/3}$ is 28% larger than T_z in general. This difference in the wave period can affect the design condition greatly, because the water particle velocity is function of wave period as well as wave height. One can see that the bandwidth parameter v becomes smaller as the wave height becomes high.

3. Individual Wave Height Distribution

If the sea is not narrowband, one cannot use the Rayleigh distribution for the individual wave height distribution. Forristall [1978] showed that 2-parameter Weibull distribution could be fitted for the wave data. Longuet-Higgins [1980], however, also found that the same data can be fitted with same accuracy with a Rayleigh distribution with reduced root mean square value. The modified Rayleigh distribution by Longuet-Higgins is given by

$$p(H)=\frac{H}{4K^2m_o}\exp(-H^2/8K^2m_o) \tag{6}$$

Here K is an empirical constant and does not have exact physical meaning. For a small amplitude waves K is equal to 1.0 and eq. (6) reduces to the original Rayleigh distribution. The data set used by Forristal corresponds to K=0.925.

The modified Rayleigh distribution has almost the same form as the original Rayleigh distribution except the constant K. Therefore the modified Rayleigh function has all the advantages of the original distribution. In order to determine the constant, however, one has to fit the modified Rayleigh distribution function to the individual wave heights probability distribution. Therefore the modified Rayleigh distribution is difficult to use practically. In this section a simple method to determine the constant K is suggested.

Let a the wave height corresponding to the $1/n^{th}$ highest wave. Then one has the following relation.

$$\int_a^\infty p(H)dH=\frac{1}{n} \tag{7}$$

The average of the $1/n^{th}$ highest wave heights as follows.

$$H_{1/n}=\frac{\int_a^\infty Hp(H)dH}{\int_a^\infty p(H)dH} \tag{8}$$

After evaluating eq. (8) one obtains the following equation.

$$\frac{H_{1/n}}{(8K^2m_o)^{1/2}}=(\ln n)^{1/2}+\frac{n\sqrt{\pi}}{2}\left[1-erf[(\ln n)^{1/2}]\right] \tag{9}$$

From eq. (9) one can have an expression for K.

$$K=\frac{\sqrt{2}}{(\ln n)^{1/2}+\frac{n\sqrt{\pi}}{2}erfc[(\ln n)^{1/2}]}\frac{H_{1/n}}{4\sqrt{m_o}} \tag{10}$$

If we recall the definition of the significant wave height in eq. (1) and take n equal to 3, one can obtain the following simple relation.

$$K=\frac{H_{1/3}}{H_s} \tag{11}$$

Most wave riders used in Korean waters provide H_s and $H_{1/3}$, hence the empirical constant K can be directly determined by eq. (11).

From Table 7 and 8 one can find that average value of K is 0.95 and K=0.925 and 0.89 for the highest H_s group for Hong-do and Mara-do respectively. It is noted that K becomes smaller as wave height becomes higher. Carter et. al (1986) suggested that the K = 0.9 for the extreme waves.

4. Extreme Wave Estimation

From the measured wave data one can estimate the n-year return period wave height. First the significant wave height with n-year return period H_{sn} is estimated using a proper long term probability distribution function. The modified Rayleigh distribution is used for the probability distribution of the individual wave height.

If one assumes that wave height is independent, the probability that all N_z waves are less than h is given by

$$P(H_M < h) = [P(H < h)]^{N_z} \qquad (12)$$

Then the most probable highest wave height becomes the mode of this distribution.

$$H_{\max} = KH_s\left[\frac{\ln N_z}{2}\right]^{1/2} \qquad (13)$$

One can assume the relation between H_{sn} and T_{zn} using the significant steepness.

$$T_{z_n} = \left(\frac{2\pi H_{s_n}}{gS_s}\right)^{1/2} \qquad (14)$$

The storm duration is assumed to be 3 hours and the average number of waves in this periods can be calculated by

$$N_z = \frac{10800}{T_z} = 1.35\times 10^4\left(\frac{S_s}{H_{s_n}}\right)^{1/2} \qquad (15)$$

Although the storm duration is assumed to be 3 hours, eq. (15) is not quite sensitive to the storm duration. Eq. (15) can be used without any modification up to the strom duration of 6 hours.

Using eq. (13) and (15) the n-year return period wave height is calculated by

$$H_n = KH_{s_n}\left\{4.755 + \frac{1}{2}\ln\left[\frac{S_s}{H_{s_n}}\right]\right\}^{1/2} \qquad (16)$$

In estimating the extreme wave heights two types of the probability distribution functions are used. One is the Fisher Tippett type 1 distribution (FT-1) and the other is the 3-parameter Weibull distribution. The FT-1 distribution is sometimes known as the Gumbel distribution or the Frechet distribution. These distributions are given by following equations.

FT-1 distribution:

$$P(H) = \exp\left\{-\exp\left[-\frac{H-\varepsilon}{\theta}\right]\right\} \qquad (17)$$

Weibull distribution:

$$P(H) = 1-\exp\left[-\left(\frac{H-\varepsilon}{\theta}\right)^{\alpha}\right] \qquad (18)$$

where α is a shape parameter, θ is a scale parameter and ε is a location parameter of the distribution functions.

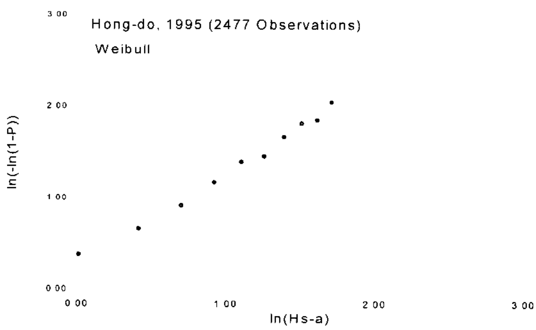

Fig. 1 Cumulative probability distribution of H_s at Hong-do, 1995 based on Weibull distribution ($a=\varepsilon$)

From Fig.1 to Fig. 8 one can see that each distribution fit to the data point fairly well. Extrapolation results are summrized in Table 9 to Table 14. One can see that the estimation from the Weibull distribution is a little higher than that from the FT-1 distribution. But there is no significant difference. The estimation based on H_s is quite different from that on $H_{1/3}$. Generally the estimations from $H_{1/3}$ give smaller wave heights.

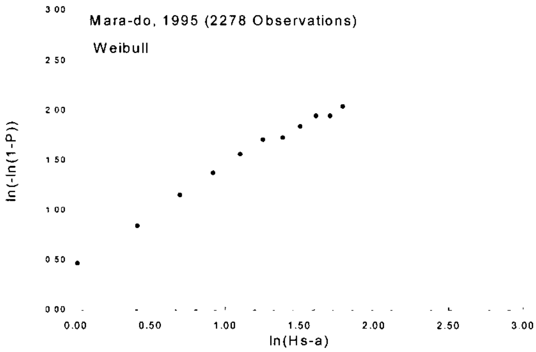

Fig. 4 Cumulative probability distribution of $H_{1/3}$ at Mara-do, 1995 based on Weibull distribution $(a=\varepsilon)$

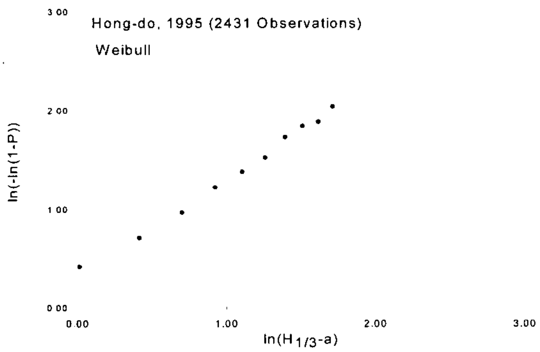

Fig. 2 Cumulative probability distribution of $H_{1/3}$ at Hong-do, 1995 based on Weibull distribution $(a=\varepsilon)$

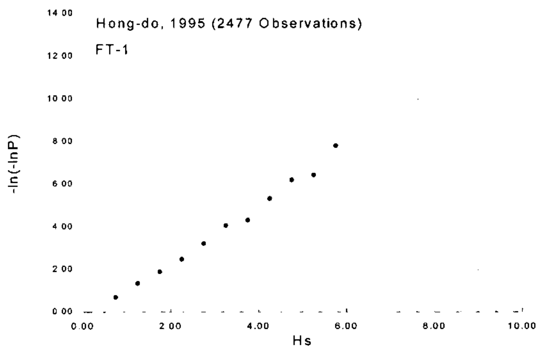

Fig. 5 Cumulative probability distribution of H_s at Hong-do, 1995 based on FT-1 distribution

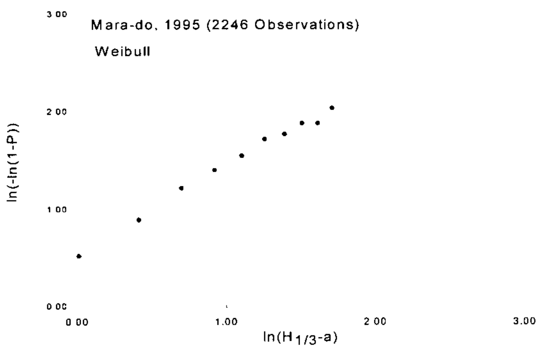

Fig. 3 Cumulative probability distribution of H_s at Mara-do, 1995 based on Weibull distribution $(a=\varepsilon)$

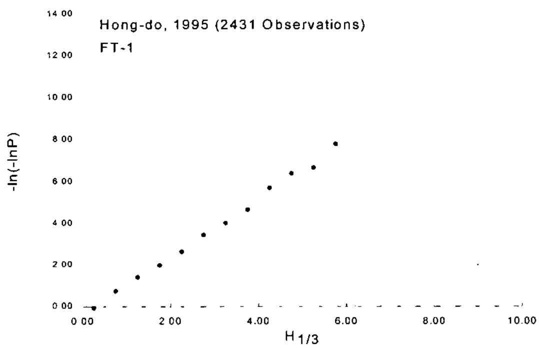

Fig. 6 Cumulative probability distribution of $H_{1/3}$ at Hong-do, 1995 based on FT-1 distribution

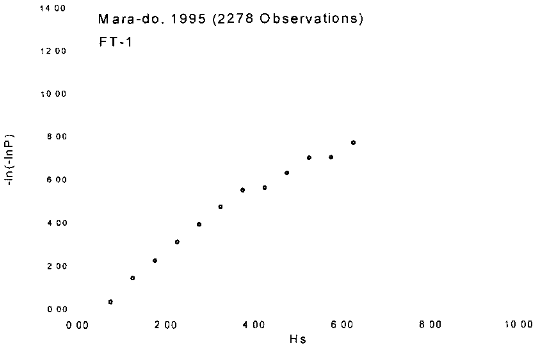

Fig. 7 Cumulative probability distribution of H_s at Mara-do, 1995 based on FT-1 distribution

Table 10 Estimation of the extreme wave height based on the the FT-1 distribution. R is the return period. Estimations based on H_s-T_z and $H_{1/3}$-$T_{1/3}$ are compared. Mara-do, 1995.

FT-1	H_s-T_z		$H_{1/3}$-$T_{1/3}$	
R	50	100	50	100
H_{sn}	9.234	9.863	8.979	9.598
S_s	1/18	1/18	1/25	1/25
K	0.9	0.9	0.9	0.9
H_n	15.50	16.51	14.90	15.89

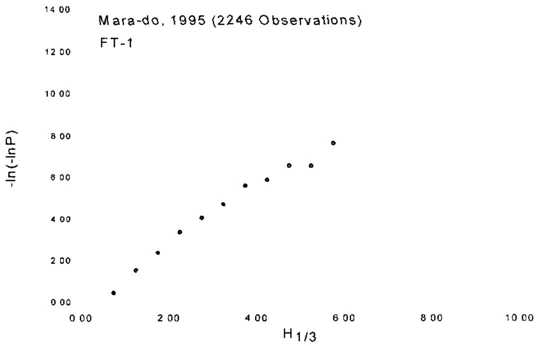

Fig. 8 Cumulative probability distribution of $H_{1/3}$ at Mara-do, 1995 based on FT-1 distribution

Table 11 Estimation of the extreme wave height based on the Weibull distribution. R is the return period. Estimations based on H_s-T_z and $H_{1/3}$-$T_{1/3}$ are compared. Hong-do, 1995.

Weibull	H_s-T_z		$H_{1/3}$-$T_{1/3}$	
R	50	100	50	100
H_{sn}	9.099	9.632	8.664	9.17
S_s	1/17	1/17	1/20	1/20
K	0.9	0.9	0.9	0.9
H_n	15.31	16.17	14.52	15.33

Table 9 Estimation of the extreme wave height based on the FT-1 distribution. R is the return period. Estimations based on H_s-T_z and $H_{1/3}$-$T_{1/3}$ are compared. Hong-do, 1995.

FT-1	H_s-T_z		$H_{1/3}$-$T_{1/3}$	
R	50	100	50	100
H_{sn}	8.999	9.53	8.788	9.283
S_s	1/17	1/17	1/20	1/20
K	0.9	0.9	0.9	0.9
H_n	15.15	16.01	14.72	15.52

Table 12 Estimation of the extreme wave height based on the Weibull distribution. R is the return period. Estimations based on H_s-T_z and $H_{1/3}$-$T_{1/3}$ are compared. Mara-do, 1995.

Weibull	H_s-T_z		$H_{1/3}$-$T_{1/3}$	
R	50	100	50	100
H_{sn}	9.315	10.027	9.001	9.697
S_s	1/18	1/18	1/25	1/25
K	0.9	0.9	0.9	0.9
H_n	15.63	16.78	14.94	16.05

Table 13 Comparison of various periods for the highest waves. H_m is maximum wave height. T_m is the wave period corresponding to H_m. T_l is the average period. Hong-do, 1995.

H_s	T_z	H_m	T_m	T_l	T_m/T_l	T_m/T_z	T_l/T_z
4.76	7.02	9.13	9.80	7.98	1.23	1.40	1.14
5.97	7.69	8.30	9.83	8.20	1.20	1.28	1.07
4.38	6.90	8.11	9.49	7.39	1.28	1.38	1.07
5.62	7.69	8.02	10.31	7.38	1.40	1.34	0.96
5.95	7.84	7.52	11.67	7.94	1.47	1.49	1.01
4.10	6.56	7.37	8.98	7.19	1.25	1.37	1.10
5.43	7.69	7.35	8.87	8.11	1.09	1.15	1.05
4.30	6.67	7.23	7.77	7.11	1.09	1.16	1.07
4.82	7.41	7.13	8.89	7.82	1.14	1.20	1.06

Table 14 Comparison of various periods for the highest waves. H_m is maximum wave height. T_m is the wave period corresponding to H_m. T_l is the average period. Mara-do, 1995.

H_s	T_z	H_m	T_m	T_l	T_m/T_l	T_m/T_z	T_l/T_z
6.47	8.89	10.63	11.68	8.42	1.39	1.31	0.95
5.08	8.16	9.36	9.85	8.94	1.10	1.21	1.10
3.99	6.06	7.72	7.64	6.51	1.17	1.26	1.07
4.76	7.27	7.16	8.74	8.01	1.09	1.20	1.10
5.05	9.09	7.08	10.8	9.77	1.11	1.19	1.07
4.71	6.90	6.92	9.80	7.55	1.30	1.42	1.09
2.94	6.67	6.71	8.14	7.70	1.06	1.22	1.15
4.90	7.69	6.54	9.28	8.16	1.14	1.21	1.06

Longuet-Higgins [1980] theoretically explained that the period of the highest waves tends to the average period T_l. But the measured wave data show that the period of the highest waves is higher. Also the expected zero up-crossing period of the highest individual waves in a sea state is considerably in excess of the mean zero up-crossing period [Tucker, 1991]. Table 13 and 14 show the same trends.

The wave period T_m corresponding to the maximum wave is up to 47% greater than the average period T_l. Also T_m is far greater than T_z. Therefore the period of the extreme wave is much higher than T_z or T_l. From the Table 11 and 12 extreme wave period may be approximately estimated as 1.4 times the T_z at Hong-do and 1.3 times the T_z at Mara-do.

5. Conclusion

In this paper wave scatter diagrams for Hong-do and Mara-do are given based on the measured wave data in 1995. From the significant steepness it can be concluded that the sea is not fully developed for the extreme wave condition. A new method to determine the empirical constant K in the modified Rayleigh distribution is suggested. The average value of K is 0.95. For the higher waves it is 0.925 for Hong-do and 0.89 for Mara-do. Extreme wave height with return period of 50 and 100 years are computed based on the measured wave data. There is no significant difference between the result form the FT-1 and the Weibull distributions. The estimation based on H_s is quite different from that on $H_{1/3}$. Generally the estimations from $H_{1/3}$ give smaller wave heights. Extreme wave period is estimated as 1.4 times the T_z at Hong-do and 1.3 times the T_z at Mara-do.

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