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A Study of Generation of Shallow Water Waves over the Continental Shelf

By

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Abstract

The observations of shallow water waves have been continued over the continental shelf of New Jersey Bight for two years since 1973, to investigate the annual condition of ocean waves. The observed results of shallow water waves represent that the most spectra are going to grow up along the slope of f^{-4}, or at least milder slope than that of f^{-5}, which is generally recognized as a spectrum of deep water waves.

The proposed spectral formula of shallow water waves on a basis of Pierson and Moskowitz spectrum (1964) was established by using the dimensional analysis of these data over the continental shelf. A comparison between the observed spectracted spectra and the calculated spectra from the proposed equation give us a comparatively good agreement and show the availability of the proposed spectrum formula in this case.

1. Introduction

The prediction of wind generated waves in the ocean is quite important not only for the problems of the ship navigation and the coastal engineering, i. e. harbor construction against the incident waves and, also for the process analysis of wind generated waves and the mechanism of the swell to the current.

The previous works for the ocean wave prediction were seperated into two methods: the significant wave method and the spectral method. Sverdrup and Munk (1927) produced an imaginative and useful wave prediction scheme, which has come to be known as the significant wave method. The significant wave method is of considerably more than historical interest as it continues in wide use today. The relationships were derived between steepness, $R=H_S/L$ (wave height/wave length) and wave age $m=C/U$ (wave phase speed/wind speed) and between the non-dimensional quantities gF/u^2, gT/u and R and m. However, it simply cannot provide an adequately detailed description of the sea surface. The significant wave method fundamentally fails to provide a suitable framework for self improvement.

The application of spectral concepts to the description of ocean surface waves by Pierson and Marks (1952) signalled the beginning of a new era in ocean wave prediction. Indeed, the so-called spectral method of wave prediction was already outlined in the paper by St. Danis and Pierson (1953) on the basis of the pioneering studies of Pierson (1952), Neumann (1952), Longuett-Higgins (1952), and

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Pierson, Neumann, and James (1953).

Attempts to marry the significant wave method by the use of parameterized spectral forms have been done along the line such as those by Deacon (1949), Barber and Ursell (1948) and more lately, Pierson (1952) and Neumann (1952). The complex sea surface can be approximated by the sum of an infinite number of sine waves of infinitesimally small amplitude added in random phase. This has been shown theoretically by Pierson (1952), and observation verify this property to be a close approximation. Thus the sea surface can be represented by a spectrum, showing the energy of the frequency components. Then the wind blows over the water, a characteristic spectrum develope, the extent of which depends upon the fetch length and the wind parameters of velocity and duration. Neumann (1954) has shown the total energy present in a wave train can be represented by an energy spectrum which relates wave energy to wave frequency for a given wind velocity.

Since the spectrum grows from the low period end of the spectrum toward the high-period end, the area under the co-cumulative spectrum, for given velocity which is integrated from a particular frequency to infinite, is a measure of the energy in wave train. As the duration of a given wind velocity increases over a long enough fetch, the E value increases until a limiting value is reached, at which point no further energy can be added to the wave train. The sea at this point is called a fully developed sea, which means that all periods and heights maintained by that particular wind are present.

The quantity E is equal to the sum of the square of the individual sinusoidal amplitudes in the total spectrum. Since the wave system is approximately Gaussian, an approximate relationship between E and the average height, the significant height can be determined from the theoretical work of Longuet-Higgins (1952). According to Longuet-Higgins (1952), this relationship results in the following values:

$$\begin{aligned} A &= \text{average height} = 1.77\sqrt{E} \\ A_{1/3} &= \text{significant height} = 2.83\sqrt{E} \\ A_{1/10} &= \text{average 1/10 height} = 3.60\sqrt{E}. \end{aligned} \tag{1}$$

A more complete discussion of the above theory can be found in a manual on wave forecasting by Pierson, Neumann and James (1953).

As wave propagate from deep water into shallow water, they are modified by their interaction with the bottom topography. Significant change occurs in the sea-surface spectrum as it propagates from deep to shallow water. These changes are a combined result of non-dissipative forces (retraction, shoaling) and dissipative-generative forces (bottom friction, wind generation, wave breaking).

Two mechanisms are involved in the generation of waves by wind. The turbulent-pressure spectrum in the wind is converted over the water surface and generates waves. The wave components whose phase speeds match the wind speed tend to grow by a "resonant" interactions. This mechanims was first proposed by Phillips (1957). It governs the wave growth in the early phases of generation. Once the water surface is distrubed, it in turn disturbs the air flow, which tends to follow the waves and induce even more water and air disturbance. The "instability" phase was first proposed by Miles (1957). The wind-generation mechanisms can be expressed in the form

$$G=(\alpha+\beta E) , \tag{2}$$

where α represents the Phillips mechanism and β represents the Miles mechanism. Several forms of this have been proposed by Phillips (1966), Hasselmann (1960) Barnett (1968), Snyader and Cox (1966) and Inoue (1966). All of the formulas proposed for α can be shown to be equivalent of the wave equation in deep water is assumed (i. e. $\omega^2=gk$). In shallow water this relationship is not valid. The term is relatively more straightforward. Snyder and Cox recommended $\beta=s(kW-\omega)$ where s is the ratio of the density of air to water. Barnett (1968) recommended a slight change in the ratio to yield

$$\beta=5sf\,(W\cos\delta/c-0.90) . \tag{3}$$

In the steady state, say under an offshore wind that has been blowing steadily for some period of time, the spectral growth is given by $dE(f\cdot\varphi)/dx=G/V_g\cos\varphi$, wherer V_g is the group velocity. The frame work of spectral wave prediction models can be traced through the work of Celci et al. (1956). Hasselmann (1960), Pierson et al. (1966) and Barnett (1968). These models are based on the numerical integration of the energy balance equation

$$\frac{\partial}{\partial t}E(f,\varphi,x,t)+V_g(f,\varphi)\nabla E(f,\varphi,t,x)=-G , \tag{4}$$

where E is the directional wave spectrum defined as a function of frequency, f,

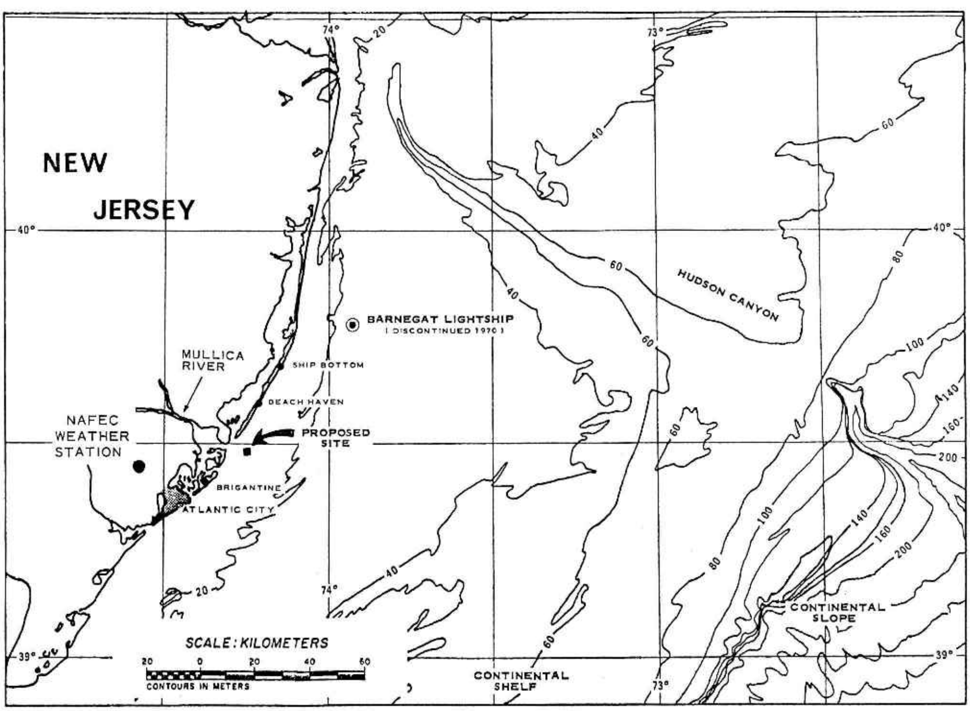


Fig. 1. Regional chart of proposed site of wave observation, which is located 4.5 km off the southern coast of New Jersey.

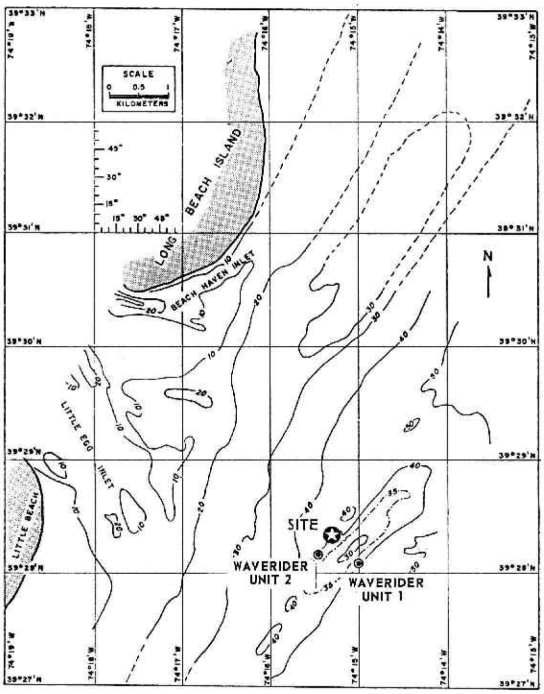


Fig. 2. Chart showing site and waverider positions.

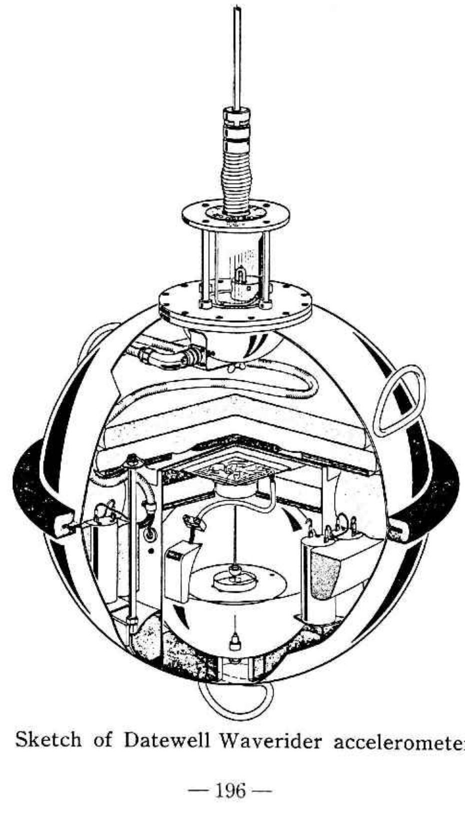


Fig. 3. Sketch of Datewell Waverider accelerometer buoy.

direction, φ, position x and time, t. The source function G, represents all physical processes that transfer energy to or from the spectrum.

In shallow water wave case, bottom friction dissipation can be considered to include the work done against turbulent shear stress induced at the bed by the water particle motions (turbulent bottom friction). The bottom friction can be represented by the low

$$\tau_i=\rho\cdot c_f\cdot u_i\cdot|\boldsymbol{u}| \tag{5}$$

The total dissipation of the wave field is then given by

$$\Phi=-<\tau,\ u_i>=\rho c_f<|\boldsymbol{u}|^3>\ . \tag{6}$$

$<\ >$ denotes mean values averaged over the ensemble of all possible wave field with the given wave spectrum and repeated subscripts mean summation over the field i-1, 2.

The determination of the dissipation function Φ has made. The dissipation function $\Phi(f)$ is given by Hasselmann (1965), and Hasselman and Collins (1968).

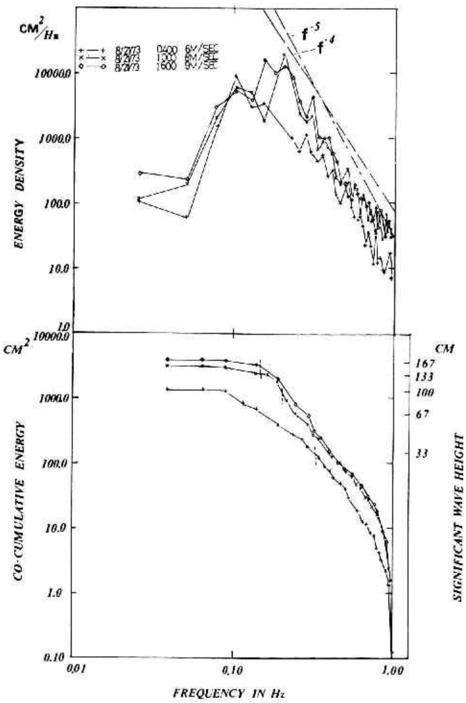
In the present paper, the empilical analyses will be made by using the spectral method combined with the significant wave method on the basis of P.N.J. method and the co-cumulative spectra will be calculated for the comparison between the empilical and theoretical analyses, which is derived by Pierson and Moskowitz spectrum in deep water. However, before the discussion of both analyses, the spectrum formula of shallow water waves should be drived from the arrangements of the observed waves spectra. A few papers (Goda, 1974) reported the differences of wave spectrum in shallow water from one of the deep water, specially the gradient of generating spectral slope in equilibrium range might correspond to the milder slope than f^{-5}.

After settlement of the formula of shallow water waves, modulated from Pierson and Moskowitz spectrum, two kind of simulations will be attempted to establish the prediction method of the shallow water waves on the assumption of given winds field over the generating area of the sea. One of the simulations is made for the comparison between the empilical spectrum of wind waves and those of the theoretical calculations on the basis of the formula modified from Pierson and Moskowitz spectrum. This simulation means that the wind waves will be just generated in the shallow water region. The simulated spectrum derived from the established formula can be calibrated for the confidence or accuracy with respect to the spectral shape and energy.

2. Instrumentation and observation

The wave observations were made by EG&G Environmental Engineering Services during the months of May 1973 thrugh August 1947, near the proposed site which is located 4.5 km off the southeastern coast of New Jersey, just offshore of little Egg Inlet at 39° 28′ 20″ N Latitude, 74° 15′ 20″ W Longitude (Figs. 1 and 2).

The wave observations described in this paper were all made with the Datawell Waverider accelerometer buoy (Fig 3). This instrument consists of a spherical stainless-steel shell containing a high-resolution accelerometer for measuring accelerations in the vertical direction. The buoy is slack-moored in



Figs. 4~11 The wind generating waves spectra and co-cumulated spectra during the comingstorm from August 1973 to March 1974.

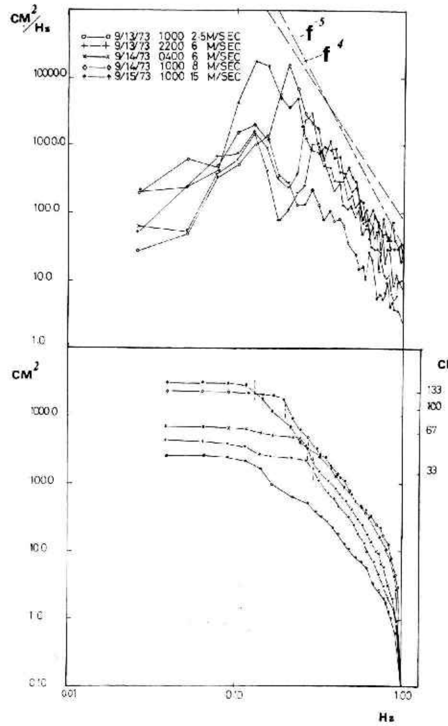


Fig. 5

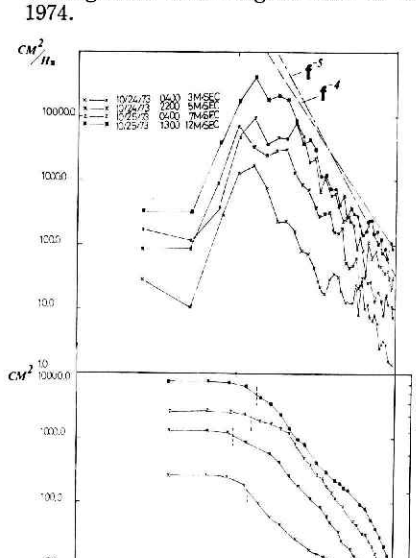


Fig. 6

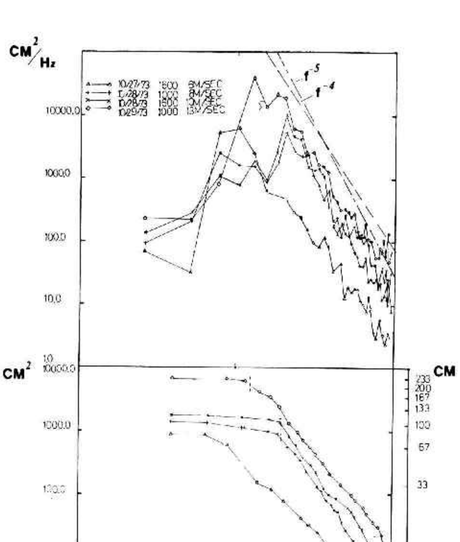


Fig. 7

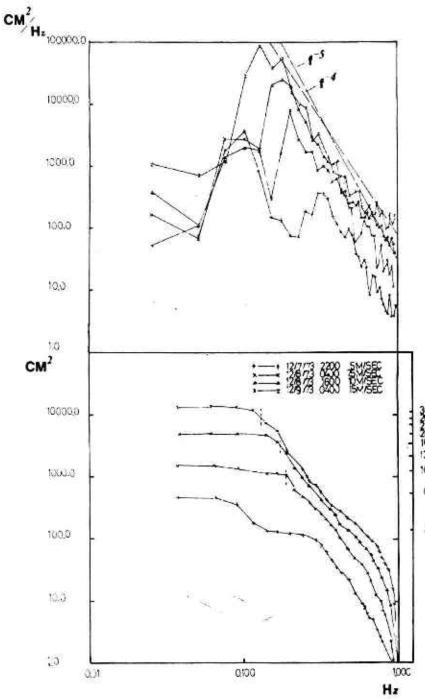


Fig. 8

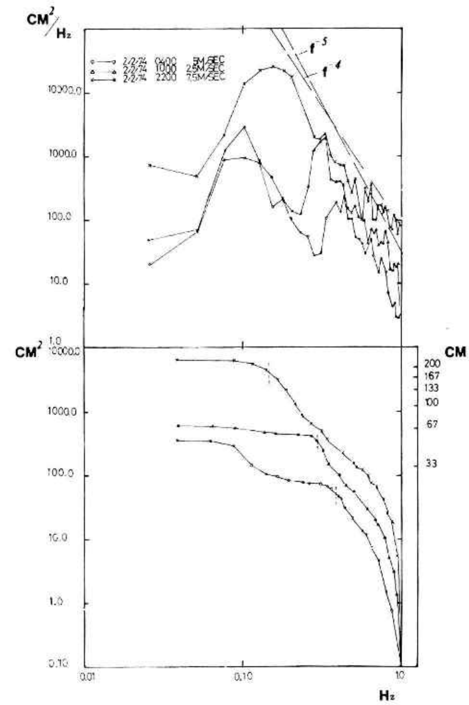


Fig. 9

Period			Wind Direction	Min./Max. Wind Speed (M/S Knot)		Min./Max. Sgn. Height (M)
	1973					
July 24 10:00	to	July 28 22:00	225°	0 -	9M 18K	0.5 - 1.3
Aug. 20 04:00	to	Aug. 22 22:00	90°	3 -	10M 20K	1.2 - 1.8
Sep. 13 04:00	to	Sept. 15 22:00	135°	2 -	17M 34K	0.5 - 1.5
Oct. 23 04:00	to	Oct. 27 16:00	45°	0 -	13M 26K	0.4 - 2.5
Oct. 26 16:00	to	Oct. 29 22:00	90°	2 -	20M 40K	0.7 - 2.7
Dec. 7 04:00	to	Dec. 9 16:00	20° → 45°	4 -	15M 30K	0.6 - 3.3
Dec. 19 04:00	to	Dec. 22 22:00	135°	2 -	15M 30K	0.6 - 2.4
	1974					
Jan. 25 22:00	to	Jan. 28 04:00	220°	2 -	13M 26K	0.3 - 1.8
Feb. 1 22:00	to	Feb. 4 22:00	45° → 0°	2 -	7M 14K	0.3 - 2.43
Feb. 21 22:00	to	Feb. 24 22:00	180°	2 -	15M 30K	0.2 - 1.5
March 1 04:00	to	March 6 22:00	225°	2 -	15M 30K	0.3 - 2.2
March 7 04:00	to	March 9 22:00	45°	2 -	11M 22 K	0.5 - 1.8

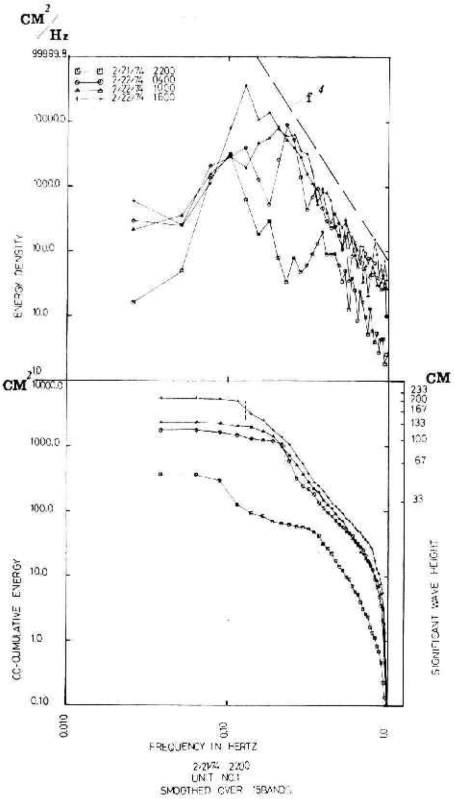


Fig. 10

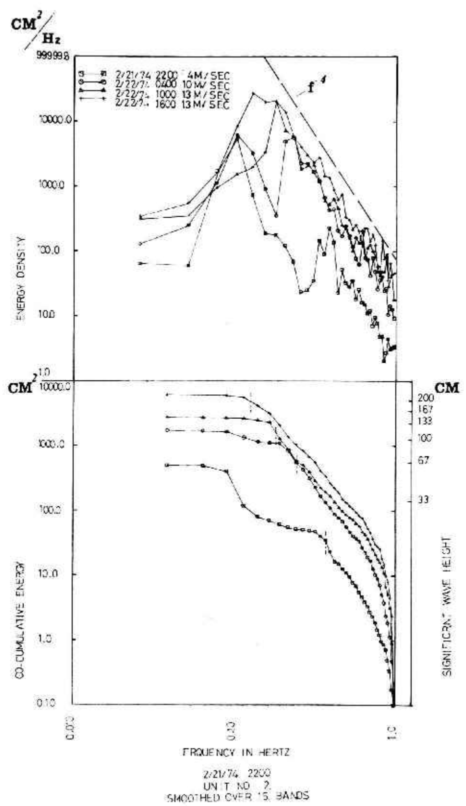


Fig. 11

the water and follows the movement of the water surface quite closely (the manufacturer states a maximum discrepancy between buoy motion and surface motion of 1.5%). Special construction of the accelerometer reduces the Waverider's response to horizontal accelerations to less than 3%.

The waverider has an effective response within a frequency range of 0.06 to 0.8 Hz. At 0.06 Hz the waverider will response to within 3% of true, while at 0.03 Hz this is reduced to 30%. The low-frequency cut-off characteristics are determined by the electronic circuitry used to time-integrate the accelerometer output. The high-frequency cut/off of 0.8 Hz is related to the physical size of the buoy and is discussed by Briscoe and Goudriaan (1972).

The vertical acceleration signal is twice integrated with respect to time (within the buoy) to yield the surface displacement. The displacement signal is converted to a frequency-modulated (FM) form for telemetering to a shore-based receiver located at a distance of some 7 miles from the buoy. Upon reception, the signal is demodulated to produce a time-varying voltage proportinal to the surface displacement (1 volt is equal to 1 meter of displacement). This voltage is then recorded via a strip chart recorder.

The original wave records were obtained with the Waverider System in the form of pen-and ink strip charts. The digitizing process of transferring data prints from the strip chart to computer-compatible magnetic tape. Values of the

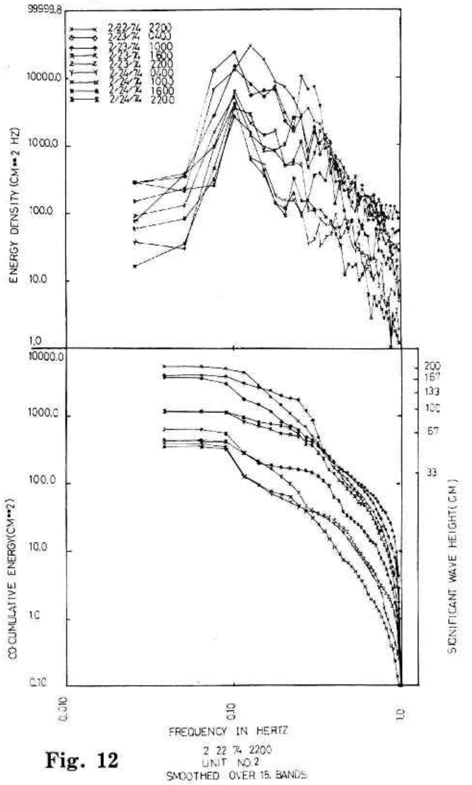


Fig. 12

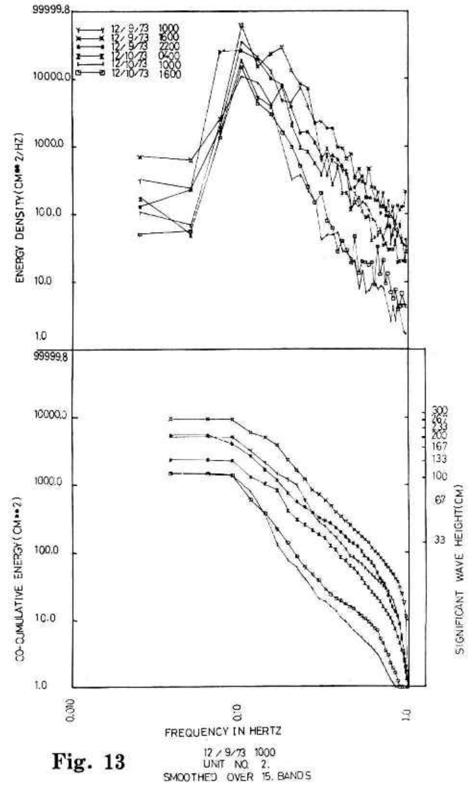


Fig. 13

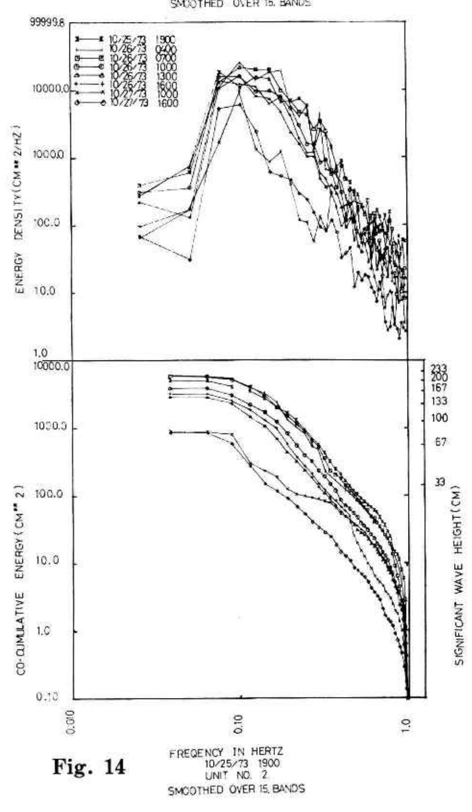


Fig. 14

Figs. 12~14 The time series decay process of wind waves corresponding to the generating spectra and co-cumulated spectra.

surface displacement are read off the chart at 0.508 second intervals (0.5 min on the chart's time axis). Plots of the digitized data were generated for each wave record to the same scale as the original strip charts.

A limitation in the resolution of the data points obtained in this manner stems from the inabitility of the digitizer operator to trace over the original wave record with absolute accuracy. Careful digitization will reproduce the original record to within 0.3 millimeter, on the average. Since the scale of the chart displacement axis is 1:100 (1 centimeter equals 1 meter) resolution limitation of 13 centimeters approximately is placed on the digitized displacement values.

The sampling interval of 0.508 second between data points is small enough to prevent aliasing problems, since the high frequency cut-off of the waverider system is approximately 0.8 Hz From the sampling theorem (in the time domain), this value results in a maximum possible sampling interval of $\Delta t \leq 1/2\,F_c = 0.625$ second. The low frequency cut-off of the waverider system is approximately 0.05 Hz.

From August 1973 to March 1974, the wave observation program consisted of making a 10-minute wave record every 6 hours. Throughout the period covering the collection of data, the Waverider system was moored in water approxiately 11 meters deep.

3. Wind Wave Analysis

During the observation periods, about twelve storms and hurricanes had visited the observation site offshore of New Jersey. The storms had generated the heavy wave field in this area. On the wave analyses, twelve samples that the maximum significant hieghts of waves are higher than 2 meters and the averaged maximum speed of wind attaines to more than 10 meters/second at 10 meters above the sea surface of observation site, are chosen as in Table 1. Unfortunately though, the directional property of the wind wave was not measured in this period. The typical wave fields can be separated into 3 types on the assumption of dependence of wave direction on one of wind. One of which is the wave group arriving to the observation site from offshore (east to west) in fully developed waves in deep water. The second group is shallow water waves propagating on the continental shelf due to the storms in the direction of about 200 degrees. The third group is also shallow water waves coming from

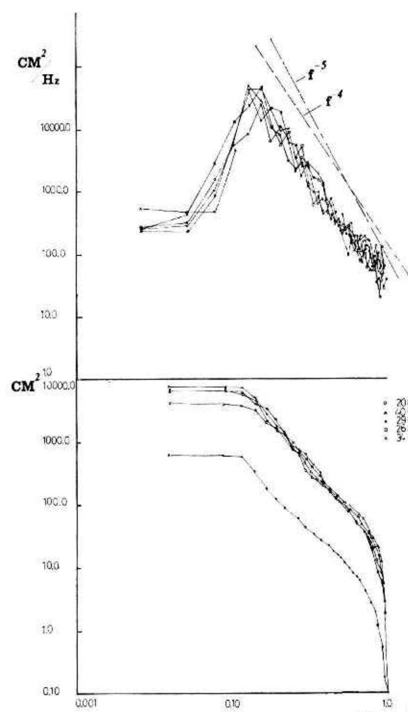


Fig. 15 Representative spectra which are already grown up and almost saturated in the shallow water. The slopes of the wave spectra has a f^{-4} or at least milder than f^{-5},

approximately 45 degrees on the continental shelf.

Figures 4 thru 11 illustrate the wind generating waves spectra and co-cumulated spectra during the coming storm from August 1973 to March 1974. Figures 12 to 14 show the time series decay process of wind waves corresponding to the generating spectra and co-cumulative spectra except August sample. In these spectra, the first group in which the waves are coming from offshore in the direction of approximately 90° is shown in Figures 4 and 7. The second group propagating on the continental shelf is shown in Figures 5 and 10. The third group is shown in the remaining figures.

The wind generating process of every case except October 24, has a good similarity that, before the storm will visit the observation site, the swell in the frequency range of about 0.1 Hz (as due length 150 m) has existed. When the wind begins to blow over the area, the wind generated waves are developing along the slope of f^{-4} (the problem of the slope will be discussed in the following chapter) where f is a frequency of the spectrum and the total energy of co-cumulative spectrum increases. As the wind generated waves are dveloping by storm on Miles mechanism some of the swell spectra in samples dissipate their energies and shift their dominant frequencies from about 0.1 Hz to higher frequency ranges as in Figures 7, 8 and 9. In this case, interaction between the swell and the wind generated waves might be created and some of the swell energy might be transferred to the wind waves. Another example of which swell energy keeps or sometimes increases his level, even during generating, the wind waves are represented in Figures 4, 5 and 10. The coupling phenomena between the wind waves and the swell strongly depends on the directionalties of the long and short waves. On the assumption that the dircetionality of the swells depend on the wind profile of a few days before, the wind generated waves will develop, the wind waves-swell coupling will be produced by the inverse direction between the both waves and the swell energy will be transferred to wind waves by the radiation stress mechanism (Longuett-Higgins 1960) for the cases of Figures 7 (October 26 to 29), 8 (December 7 to 9) and 9 (February 1 to 4), because the averaged directions of these wind profiles show the variabilities on the comparison of wind directions during the period of generating wind waves and the angles between both winds are more than 90°. On the other hand, the samples of Figure 4 (August 24 to 18), 5 (September 13 to 15) and 10 (February 1 to 4) show almost the same directions, otherwise the angles between both winds is almost less than about 90°. In these cases, the exchanges of the energy between the bind waves and the swell might not happen and individually both waves will be developing.

After one or two days from the beginning of wind blowing, the wind waves are fully developed and becomes almost the swell of which frequency limit is about 0.1 Hz and the significant wave height driven by Equation 1 is lower than 2.33 meters as in Figures 4 to 13.

4. A Prposed Spectral Form For Fully Developed Wind Sea

The wave prediction for fully developed sea in shallow water is quite different from the case of waves in deep water. The two methods are usually available for the prediction of wave field. One is a numerical simulation by using the Equation 4 for a given wind field. Another is the calculation of the proposed spectral form for fully developed case in shallow water. Pierson and Moskowitz

(1964) developed a proposed spectral formula after analizing the data for the spectra of fully develped sea obtained by Moskowitz (1964) for wind speeds from 10.29 to 20.58 meters/second through the dimension-less method as follows,

$$E(\omega)d\,\omega=\alpha\,g^2\omega^{-5}\,e^{-\beta(g/u_\omega)^4}\,d\,\omega\ . \tag{8}$$

This spectral form is given by using the dimension less parameters, α and β, where α is 8.10×10^{-3} and β is 0.74. U is a wind speed of anemometer.

This proposed spectral form is comparatively in a good agreement with the empilical spectra in deep water and is available for the estimation of wave spectrum. However, slope of the Pierson and Moskowitz spectrum has a f^{-5} in equilibrium range, which is a little different from the observed spectrum in shallow water as a few reports (Goda 1974, etc.) had already suggested. The theory of Phillips (1958) suggests that the wave, if high and if having a spectrum with $f^{-4.5}$ or f^{-4} in the denominator, would break and dissipate their energy in low frequency component. The analysis of Kitaigrodskii supports this assumption. Hamada (1964) has also shown that a form such as f^{-6} would cause vortexes and dissipation by viscosity, again forming a return to the f^{-5} form.

As recognized in Figure 4 through 11, the slopes of the wave spectra in shallow water has a f^{-4} or at least milder than f^{-5}. Some of the spectra which

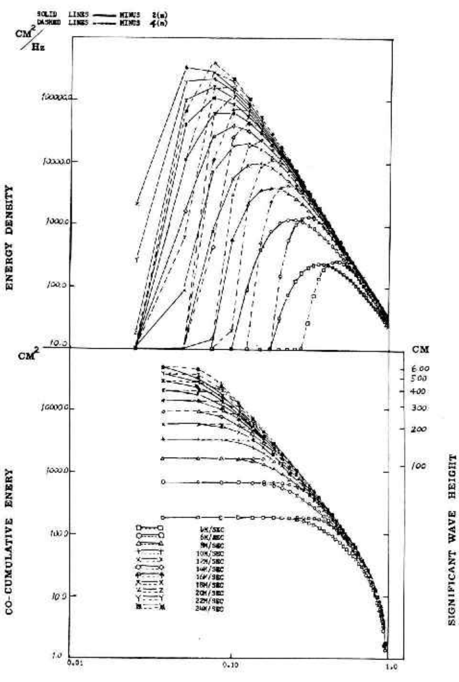


Fig. 16 The power spectra and co-cumulated spectra calculated from Eqs. (11) and (12), that depend on defference of spectral width. Solid lines the case of $n=-2$ and dashed lines $n=-4$.

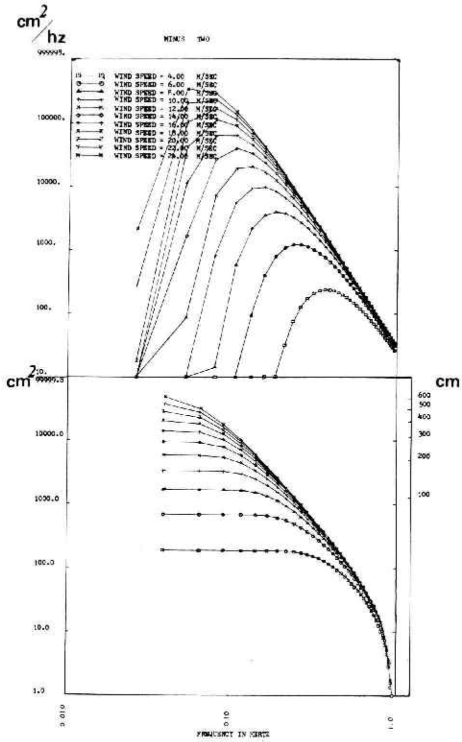


Fig. 17 Thhe power spectra and co-cumulated spectra calculated from Eq. (11) for the case of $A=0.0081$, and $B=1.962$.

are already grown up and almost saturated in the shallow water are put in a figure as shown in Figure 5. The slope of real spectra in this area, offshore of New Jersey, are clearly concluded to correspond to f^{-4}.

In order to establish the proposed spectral formula, the other possible factors in Equation 8 should be estimated. Bretsdneider (1963) has also suggested spectra of the form shown by Equation 8. The exponential term can be thought of as a high-pass filter acting on the limiting form proposed by Phillips (1958), and the question is which of these possible forms would give the best fit to the curves presented in Figure 15.

In shallow water, spectrum would be satisfied by following eguation,

$$E(\omega)\,d\,\omega=\alpha\,g^2\omega^{-4}\,e^{-\beta}\left(\frac{g}{U\omega}\right)^n d\,\omega \tag{9}$$

Then Equations 11, and 12 for various numbers of n will be simulated through the comparison of peak value, spectral width and slope between the empilical and analytical spectra.

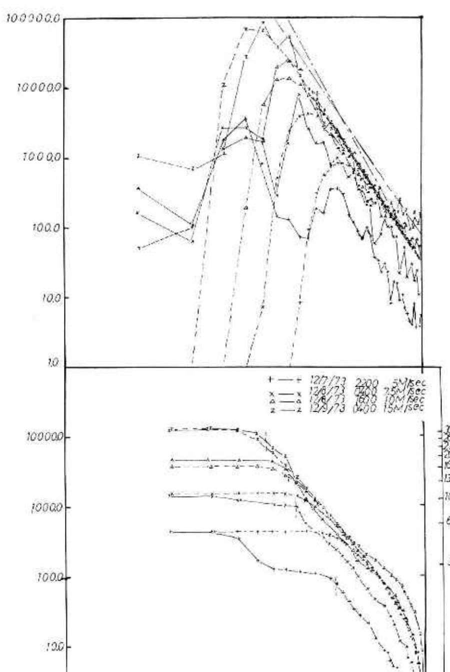


Fig. 18 The comparisons between the empirical and calculated spectra using Eq. (15) with real wind speeds. Solid lines represent the empirical spectra and dashed lines the calculated ones.

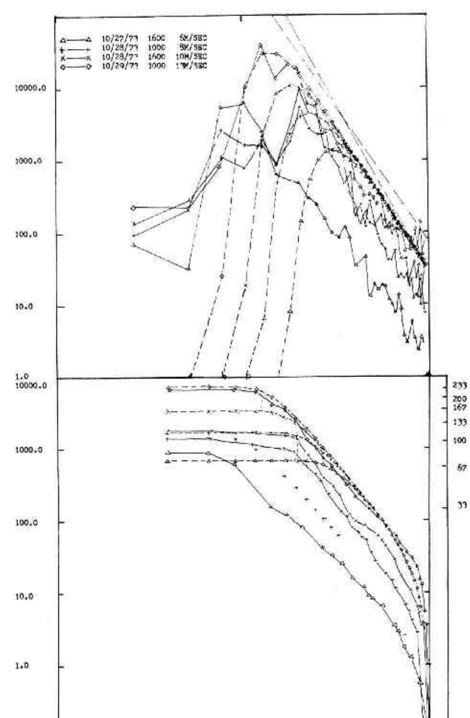


Fig. 19 The comparisons between the empirical and calculated spectra using Eq, (15) with real wind speeds. Solid lines represent the empirical spectra and dashed lines the calculated ones.

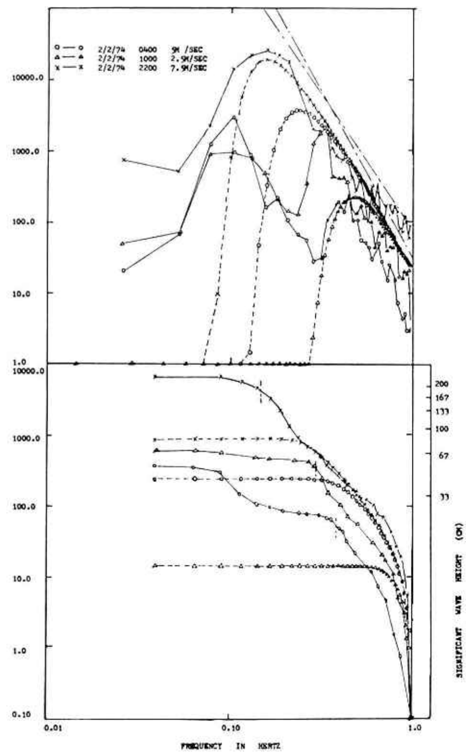


Fig. 20 Most empirical spectra can be recognized to be similar to the calculated spectra except the low frequency, i.e., the swell.

$$E(f)=Af^{-4}\exp\left[-\frac{B}{U^2}\left(\frac{1}{f^2}\right)\right] \tag{10}$$

$$E(f)=Af^{-4}\exp\left[-\frac{B}{U^4}\left(\frac{1}{f^4}\right)\right] \tag{11}$$

These possible forms are plotted in Figures 16, and 17, fitted so as to pass through the peak of the set of given curves. Moreover, the patameter n for the appearance of f^{-n} in the exporential terms would be derived from the following equation.

$$\frac{d}{df}E(f_{\max})=0$$

$$\frac{\sqrt{n}\ \beta g^n}{U^n f^n_{\max}}-2=0 \tag{12}$$

Then for given values of wind velocity U and maximum $f_{\max}$ in each spectrum, the number n can be decided. However, this number is quite smaller than the value given by the comparison between the empilical spectra and calcurated spectra with random n values. Finally, the most adequate value of n would be settled as $n=4$.

On the other hand, new parameter which can define the steepness and the maximum frequency of spectrum would be available so as to pass through the peak of empilical spectra and put it in the proposed spectral form as follows:

$$\begin{aligned} E(\omega)\,d\omega &= \alpha\, g^2\omega^{-4}\exp\left[-\beta\left(\frac{g}{U\cdot\omega/\gamma}\right)^4\right] \\ &= \alpha\, g^2\omega^{-4}\exp\left[-\beta\left(\frac{g\cdot\gamma}{U\cdot\omega}\right)^4\right] \end{aligned} \tag{13}$$

the value of γ would approximately stay in the range of 1.08 to 1.55 for $n=4$ and 1.10 to 1.81 for $n=2$. However. for the purpose of forecasting of the longer waves in shallow water, it would be clearly recognized that value of $n=4$ is much better. Though the steepness of the forward (low frequency) face cannot be determined more sharply than the sample for the value of $n=2$, the proposed spectrum formula would be finally defined as in the following equation:

$$E(\omega)\,d\omega=8.10\times10^{-3}\cdot g^2\cdot\omega^{-4}\cdot\exp\left[-2.371\left(\frac{g}{U\omega}\right)^4\right]\cdot d\omega \tag{14}$$

Figures 18 through 20 represent the comparison between the empilical and calcurated spectra using equation (15) with real wind speeds. Almost empilical spectra can be recognized to be similar to the calcurated spectra except the range of low frequency, i. e., the swell component. Also, fortunatly or unfortunatly the cocumulated spectra, for examples of December 7 and October 27, show the same energy levels even in the low-frequency component. As already discussed in Section 3, the every wave spectra of this observation site contains the swell component in low-frequency component, and the interaction between the wind waves and the swell would be produced. On the discussion of the wind waves generation, the coupling effect of swell and wind waves might be separated to be another story, because of the problem of directionarity between both waves and the non-linearity of coupling effects.

As a conclusion, by these inter-calibration between the two kinds of spectrum, the equation (15) would be so available for the prediction of the wind waves in the shallow water, at least in the frequency component of wind generating waves.

5. Coclusion

The prediction problems of shallow water waves consists of investigations of the generation and dissipation processes, especially the bottom friction dissipation, non-linear interaction or white-cape and breaking. However in this work, it is very hard to perform the process analysis of wind wave generation, because there are many unknown data, which are absolutely necessary for the process analysis, for instance at least two stations waves-measurements at fixed stations to compare with each other, and measurements of air-fluctuation, etc. Hence only a characteristics of shallow water waves close to the coast are available to investigate and report.

When the wind begins to blow over the shallow water region, the wind generated waves are growing up along the slope of f^{-4} and almost data of that observation period show that the slope of f^{-4} will be remained up to the saturation stage of shallow water wave growth, on the contrary of the slope of f^{-5} in equilibrium range of deep water waves. Also it seems to happen that as the wind generated wave are growing up by storm energy on the Phillips-Miles mechanism, some of the swell energy, which was still remained after a last wave generation, are dissipating their energy and shift their dominant frequencies from about 0.1 Hz to higher frequency ranges and on the other words, interaction between the swell and wind generated waves might be created and some of the swell energy should be transferred to wind waves.

On the other hand, the establishment of prediction scheme of wind waves generation in shallow water was tried with same method by Pierson and Moskowitz (1964), who had developed a proposed spectral formula after analizing the data for the spectra of fully developed sea. Their proposed spectral formula is comparatively in a good agreement with the empilical spectra in deep water and is available for the estimation of wave spectrum.

In shallow water region, the proposed formula of wind wave generation should be defferent from that of deep water and the proposed spectrum formula was finally determined by the dimension-analysis as in the following equation,

$$E(\omega)\,d\omega=8.10\times10^{-3}\,g^2\,\omega^{-4}\exp\left[-2.371\left(\frac{g}{U\omega}\right)^4\right]\cdot d\omega$$

The comparison between the observed and calcurated spectra using above equation were made and almost empilical spectra can be recognized as to be similar to the calcurated spectra except the frequency, i.e., the swell component.

The problems of dissipation mechanism by bottom friction, non-linear wave-wave interaction and white cape and wave breaking are still remained in this work and the observations of wind waves with respect to the dissipation processes will become most important.

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大陸棚上の浅海域における風浪の発達に関する研究

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1973 年より 2 年間，ニュージャージーバイトの大陸棚上で浅海域の風浪の観測が，その年間の海況条件を調べる目的の一つとして行なわれた．観測された浅海域の風浪の結果は次のようなものである．即ち大部分の風浪のスペクトルは f^{-4} の勾配に沿って発達するか，少なくとも深海波のスペクトルとして一般に考えられている f^{-5} よりもゆるやかな勾配に沿って発達していることがわかった．

Pierson と Moskowitz (1964) が提案した深海波のスペクトルを基礎として浅海波のスペクの式が以上の観測された大陸棚上の風浪の資料を有次元解析することによって完成された．この提案されたスペクトルの式を用いて計算した結果と観測されたスペクトルの比較は比較的よい一致を与え，この観測された大陸棚上での風浪のスペクトルの式は有用であることが示された．