CHAPTER 12

BASIC SYSTEMS OF WIND WAVE FIELD

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The study of wind waves is usually carried out in the following manner. At the first moment a homogenous wind field with the constant speed directed from the shore to the basin is occured over the water surface restricted by a straight shore line. It is required to calculate statistic wave characteristics as functions of time and distance from the shore. When solving the problem in such a way the explorers [1-6] usually came to a conclusion of the system development of gravitational waves with a main energy maximum the amplitude and period of which rise in process developing from small magnitudes to limiting values.

Some explorers noted that the two-or three-wave systems under the conditions of constant wind are available. The first results of this theory were obtained by L.Ph. Tytov. In studies of stereophotographs of sea waves he noted and discribed quantitatively two types of waves: "prevailing" and "large". [7]. It is possible to show that the first type of waves has a phase speed that is less than wind speed, and the second one is equal to wind speed. At a later time G.Neumann [6] generalizing results of ocean observations has come to the conclusion that under the action of constant wind three "specific" wave systems which have phase speeds less, equal and 1.2 more than the speed of wind are developed. However, Tytov's and Neumann's results didn't receive a progress, and later on they were substituted by the conception of continuous wave spectrum with one energy maximum [3-6]. Nevertheless, the opinions of availability of two-or three-wave systems as a typical feature of wind rough sea [8,9] were published in the press. Spectra with two or three maxima were obtained by some explorers, but whether particular emphasis was not placed upon this phenomenon by them, or they didn't explain this correctly considering that the second maximum is condi-

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tioned by non-linear effects [12,13].

In practice in deep-water basin under the action of constant wind two main, but not one gravitational wave systems having substantial distinctive features are developed regularly. Under natural conditions this phenomenon appears particularly in water-basin at small distance from the shore with gentle off-shore wind when wave lengths of two main systems difference several times, and the interferences came from the neighbour basin areas are practically absent. In Fig.1 examples of frequency spectra and oscillogram models of waves providing visual proof of the availability of two vibratory processes are shown. On the spectra two maxima with phase speeds equal and less than wind speed are clearly defined. A system with phase speed equal to wind speed is called as a resonance one, and a system with phase speed less than wind speed is called as a pre-resonance one. In Fig.2 the relationships of main parameters of two systems where C_i/v and $g\sigma_i/v^2$ are independent on gx/v^2 are shown, and where

- C_i - system phase speed
- σ_i - root-mean-square deviation of rough sea elevation
- V - wind speed on upper boundary of water layer
- g - gravity acceleration
- x - distance to leeward shore

Value $i=1$ complies with the resonance system, and $i=2$ with the pre-resonance one. Observation data and laboratory measurements were obtained by means of statistic analysis of wave recordings. Phase speed was determined from the position of the energy maximum on the frequency scale, and the root-mean-square deviation σ_i from the area under the spectral density curve of each system. Maximum relative errors of measurements of dimensionless parameters are not more than $\pm 25\%$.

Data from Fig.2 points out to the following regularities of observed systems. The phase speed of resonance system is equal to wind speed, and the pre-resonance speed rises rapidly when moving away from the shore and reaches the 0.8-0.9 limit of wind speed approximately. The pre-resonance system reaches an energy saturation rather rapidly, and the resonance one continues to develop. At an early stage of process development the energy of pre-resonance system is more than the energy of resonance one, and vice versa at the later stages. A resonance system appears at some distance from the shore (the more distance, the more speed of wind), and reaches energy saturation at a rather great distances from the shore (under condition of necessary duration of wind action). At the main stage the energies of both systems are increased in direct proportion to the distance from the shore. It is rather noteworthy that pre-resonance system doesn't occur with the equation $gx/v^2=0$, as it was known earlier, but with the value $gx_0/v^2>0$ where x_0 - critical distance from leeward shore independing on physical characteristics of turbulent viscous underlayer of air flow when transiting from the land to the sea. This new regularity is shown in Fig.2 with dashed lines for various parameter values of gx_0/v^2.

Physical cause of resonance system development consists in such phenomenon that among the whirlwinds occuring in turbulent frontier layer and carried by the wind there are always such ones the horizontal dimensions of which are close to the length of gravitational waves spreading at a speed of wind. These whirlwinds are exactly responsible for the initiation and development of a resonance system. Physics of a pre-resonance system development was studied by many explorers [1-3, 10]. The pre-resonance system occurrence is due to the whirlwind movements in turbulent viscous under-layer of wind flow. This system is developed in such a manner that the induced field of pressure in the air flow gives the growth of waves on the reverse communication scheme until the supplied energy to be balanced by a dissipation.

Apart from two main systems the third, a super-resonance one with the phase speed more than wind speed is developed. Physical cause of initiation and development of this system consists in non-linear interaction of two main systems. According to Phyllips' a frequency of wave interaction (the amplitude of which is linearly increasing with time) is equal to doubled lesser frequency minus another one [10]. When taking as $C_2=0.8$ v in accordance with Fig.2 $C_3=1.3$ v may be obtained for super-resonance system which is in agreement with the Neumann's results [6]. An energy of the third system is commensurable with the energy of both another systems at the later stages of their process development. In consequence of three systems availability long-period waves with differential frequencies are developed as it is confirmed by the spectral analysis data [5].

The given facts and considerations may explain the rough sea process of the wind waves in a new fashion from the united point of view. At a laboratory, lakes and ponds one system is dominant (pre-resonance); in the seas two systems (resonance and pre-resonance), in the oceans--three systems (super-resonance, resonance and pre-resonance) [20].

Besides, the studies of wave pressures and loads of irregular standing waves upon sea breakwater of vertical type in full-scale conditions were conducted.

In the Soviet Union as it was reported earlier [22] a hydraulic research station constructed at the head of sea breakwater of vertical type is in operation.

Synchronous recording of sea level and wave pressure on various levels at a breakwater and also wave parameters in approaches to the structure are provided by measuring procedures.

Oscillogram models of waves and wave loads fixed on a wave recording buoy (I) and at a breakwater (II) are presented in Fig.3. On the oscillograms there are the following recordings: (1 and 3) fluctuations of sea level recorded by electrocontact wave-recorder on a buoy and at a breakwater respectively; (2.4-10) wave pressure fluctuations measured by pressure transmitter on a buoy at 2.8 m depth and at a breakwater of +1.3; +0.4; -0.6; -2.9; -7.3; -9.5 and-11.2 elevations respectively; time marks were equal 1 sec.

In Fig.3 the data was initial for computer calculations of the total wave load at a breakwater (Fig.4).

In Fig.4 the values R_i^+ and R_i^- are of positive and negative loads in wave crest and trough phases respectively, and R_i is a"range" of wave load.

Materials of observed measurements allowed for obtaining of new data on probability structure of wave field pressure and wave loads at a breakwater [21].

On the basis of observed wave analysis and wave pressure recordings at a vertical type breakwater it is shown that the rough surface of sea at a breakwater may be represented in form of the limited number totality of the frequency spectrum components (no more than 3-5). On the frequency scale these components comply with energy maxima in wind wave spectrum. Squares of amplitude's components are proportional to their dispersions, and in this case the sum of dispersions is equal to dispersion of the total process.

Changing continuous frequency spectrum of sea level at a breakwater from e (μ) to discrete spectrum with frequencies μ_i of main energy-carrier maxima in the spectrum, and appropriate dispersions σ_i^2, where

$$\sigma_3^2 = \sum_i \sigma_i^2 \qquad (1)$$

is a dispersion of a total dispersion process of water level at a breakwater, and an energy-carrier interval of the i-component is characterized by (μ_i', μ_i'').

Such scheme for three components as illustration is showed in Fig.5.

Dispersion of wave load for i - component in linear approximation will be given as [23]

$$(\sigma_R^2)_i = 2g\rho \int_{\mu_i'}^{\mu_i''} e(\mu) \frac{th^2 K_i H}{K_i^2} d\mu \tag{2}$$

where K_i - wave number related to the frequency of energy maximum of i-component by equation

$$\mu_i^2 = gK_i \, th \, K_i H \tag{3}$$

(H-depth at a breakwater, ρ - water density).

The total load on a breakwater is formed as a result of effect upon it by i-components (i=3-5) of wave field.

So, the dispersion of load to be

$$\sigma_R^2 = \frac{4(g\rho)^2}{\varkappa^2} \sum_i \frac{(\sigma_\zeta^2)_i}{K_i^2} th^2 K_i H \tag{4}$$

where σ_ζ^2 - dispersion of sea level for i-component connected with its frequency spectrum by equation

$$(\sigma_\zeta^2)_i = \frac{1}{g\rho} \int_{\mu_i'}^{\mu_i''} e(\mu) d\mu \tag{5}$$

($\varkappa^2$ - wave reflection coefficient from breakwater).

The given method of wave load determination was used for calculation of maximum wave load upon, the breakwater in the port of Sheskharis on given measured parameters of wave frequency spectrum at a breakwater.

The calculations were carried out for 11 instances at heights of $h_{1\%}$=0.9-2.2 m, $\bar{\tau}$=4.4-7.8 sec and relative depths of H/λ =0.17-0.45.

For given wave parameters and relative depths the rated values of positive and negative loads of one per cent security accounts for 4.6-15.8 t/m.

A correlation between rated loads and measured ones shows that for mentioned wave parameters and relative depths the rated loads exceed the measured ones both in case of wave crests coming to a breakwater, and troughs. In some instances the exceeding reaches 15-18 per cent.

Adequate agreement between the rated and measured wave load values indicates that the probability sampling of theoretical model which may be used in engineering practice was made correctly.

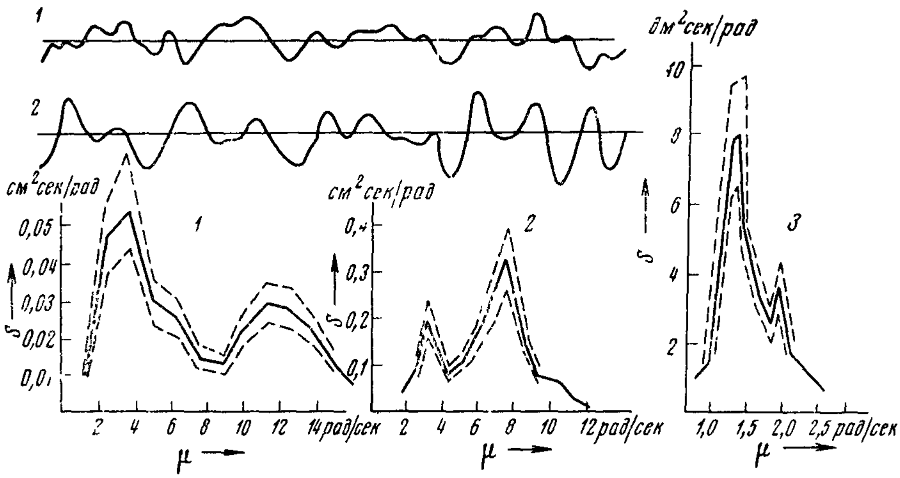

Fig.1. Oscillogram models of waves and frequency spectra $e(\mu)$ for the following stages of wind wave development:

1 - in an initial stage [20] ; 2 - in an early stage [20] ; 3 - in the later stage [18].
Confidence limit of 90% probability are showed by dashed line

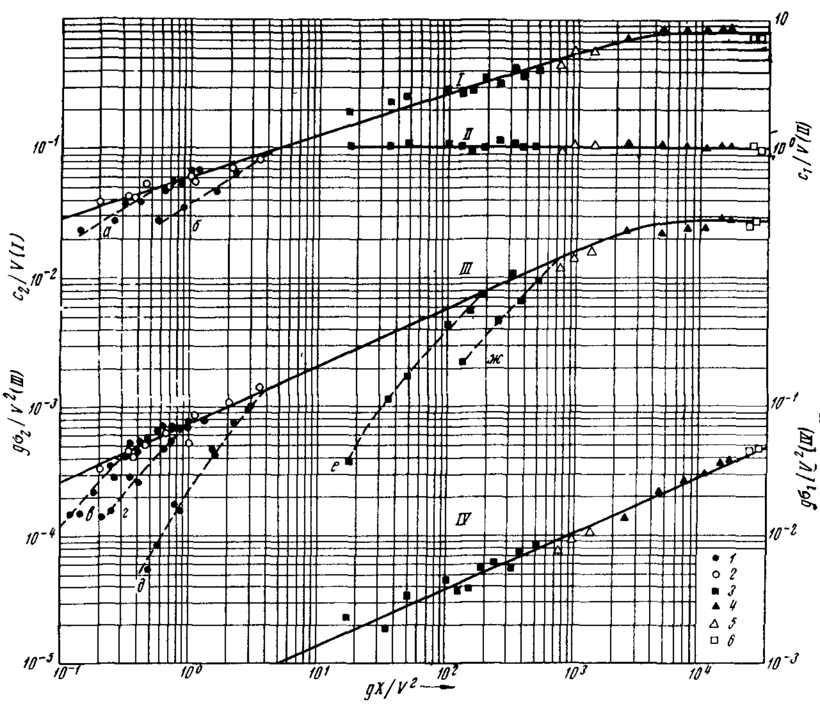

Fig. 2. Relationships C_2/V(I), C_1/V(II), $g\sigma^2/V^2$(III), $g\sigma_1/V^2$(IV) on gx/V^2 obtained from laboratory data:

1- [15]; 2- [14];

from observation data:

3- [16,17]; 4- [10]; 5,6- [18,19].

The initial stages of wave growth in gx_o/V^2 parameters of pre-resonance system are showed by dashed line;

а - $gx_o/V^2=6.9\times10^{-3}$, V=9 m/sec.;

б - 7.6×10^{-2}, 6 m/sec.;

в - 6.5×10^{-4}, 15 m/sec.;

г - 6.9×10^{-5}, 9 m/sec.;

д - 7.6×10^{-2}, 6 m/sec.;

е - 7.7, 3.2 m/sec.;

ж - 3.7×10, 2 m/sec.

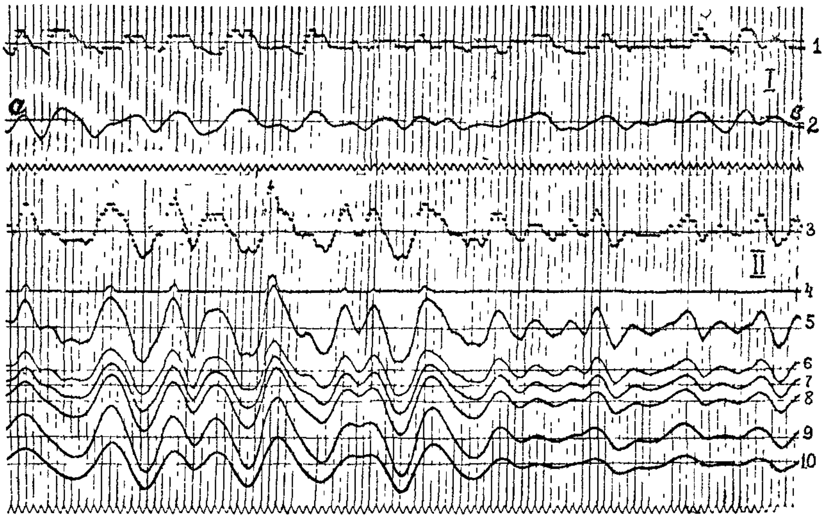

Fig.3. Oscillogram models of waves and wave loads at breakwater (II) and in approaches to it (I)

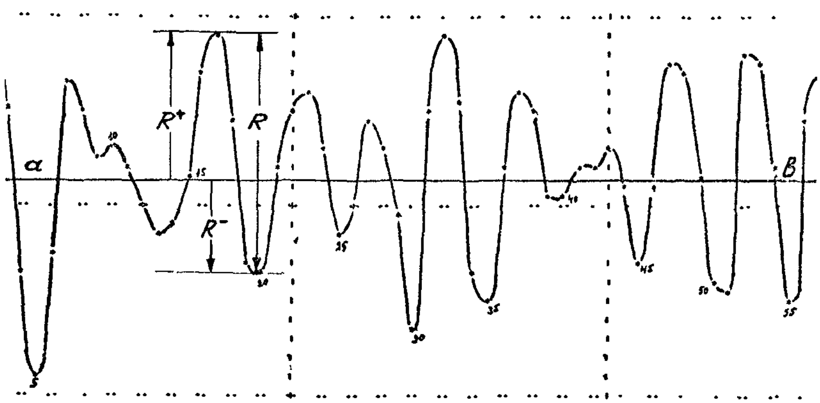

Fig. 4. Scheme of changes of measured total wave loads at breakwater

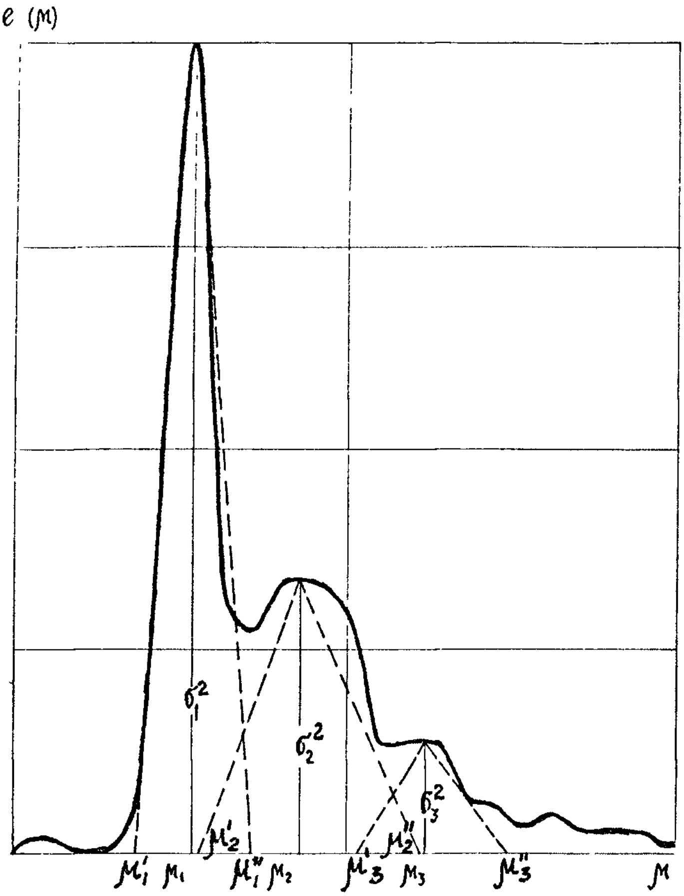

Fig.5. Approximation diagram of sea-level frequency spectrum (solid line) with three components of wave field (dashed line)

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