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 occurred 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 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 described quantitatively two types of waves: "prevailing" and "large". 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-

1/ Prof., Dr. Phys.-Math. Sc., State Research Project Inst. of Sea Transport, USSR, Moscow.
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 \(g\sigma_i^2/v^2\) are independent on \(g\sigma/v\) are shown, and where

\[
\begin{align*}
C_i & \quad \text{system phase speed} \\
\sigma_i & \quad \text{root-mean-square deviation of rough sea elevation} \\
v & \quad \text{wind speed on upper boundary of water layer} \\
g & \quad \text{gravity acceleration} \\
x & \quad \text{distance to leeward shore}
\end{align*}
\]

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 \(\sigma_i\) 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 neces-
sary duration of wind action). At the main stage the
energies of both systems are increased in direct propor-
tion to the distance from the shore. It is rather note-
worthy that pre-resonance system doesn't occur with the
equation $gx/v^* = 0$, as it was known earlier, but with the
value $gx_0/v^* > 0$ where $x_0$ - critical distance from lee-
ward shore independent of 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 $gx_0/v^*$. Physical cause of resonance system development con-
sists in such phenomenon that among the whirlwinds occu-
ring 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 exact-
ly responsible for the initiation and development of a
resonance system. Physics of a pre-resonance system de-
velopment was studied by many explorers [7-3, 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 indu-
ced field of pressure in the air flow gives the growth of
waves on the reverse communication scheme until the sup-
plied energy to be balanced by a dissipation.

Apart from two main systems the third, a super-re-
sonance one with the phase speed more than wind speed is de-
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 increa-
sing with time) is equal to doubled lesser frequency mi-
nus another one [10]. When taking as $C_0 = 0.8 v$ in ac-
cordance with Fig. 2 $C_1 = 1.3 v$ may be obtained for super-re-
sonance system which is in agreement with the Neumann's
results [6]. An energy of the third system is commensu-
able with the energy of both another systems at the la-
ter stages of their process development. In consequence
of three systems availability long-period waves with dif-
ferential 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-reso-
nance) [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 $e(\mu)$ to discrete spectrum with frequencies $\mu_i$ of main energy-carrier maxima in the spectrum, and appropriate dispersions $\sigma_i^2$, where

$$\sigma_i^2 = \sum \sigma_i^2$$

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 $(\mu_i^2, \mu_i^2)$.

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 \[ (\sigma_R^2)_i = 2 \pi \rho \int_{\mu} e^{(\mu)} \frac{\theta^2 K_i^2}{K_i^2} d\mu \]

where \( K_i \) - wave number related to the frequency of energy maximum of i-component by equation
\[ M_i^2 = gK_i th K_i H \]

(H - depth at a breakwater, \( g \) - 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
\[ \sigma_R^2 = \frac{4(\pi \rho)^2}{\chi^2} \sum_i \frac{(\sigma_i^2)_i}{K_i^2} th^2 K_i H \]

where \( \sigma_i^2 \) - dispersion of sea level for i-component connected with its frequency spectrum by equation
\[ (\sigma_i^2)_i = \frac{1}{\pi \rho} \int e^{(\mu)} d\mu \]

\( \chi^2 \) - 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 \( h_{1/2} = 0.9-2.2 \text{ m} \), \( T = 4.4-7.8 \text{ sec} \) and relative depths of \( H/\lambda = 0.17-0.45 \).

For given wave parameters and relative depths the rated values of positive and negative loads of one percent 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 $C_2/V(I)$, $C_4/N(II)$, $\frac{\sigma}{N^2}(III)$, $\frac{\sigma_1}{N^2}(IV)$ 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 $gx_o/N^2$ parameters of pre-resonance system are showed by dashed line;
- $a - gx_o/N^2=6.9x10^{-3}$, $V=9$ m/sec.;
- $b - 7.6x10^{-2}$, 6 m/sec.;
- $c - 6.5x10^{-4}$, 15 m/sec.;
- $d - 6.9x10^{-5}$, 9 m/sec.;
- $e - 7.6x10^{-2}$, 6 m/sec.;
- $f - 7.7$, 3.2 m/sec.;
- $g - 3.7x10$, 2 m/sec.
WIND WAVE FIELD

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)
References

1. Шулейкин В.В. Физика моря, изд., М., 1969.
2. Титов Л.Ф. Ветровые волны. Л., 1969.
13. Давидан И.Н. Тр. координационных совещаний по гидротехнике. 50, 1969.
18. Ржеплинский Г.В. и др. Тр. Гос. океаногр. ин-та, 93, 1968.
23. Крылов Ю.М. Линейная теория взаимодействия нерегулярных трёхмерных волн с жесткой вертикальной стенкой. Тр. СоюзморНИИпроекта, вып. 27(33), М., "Транспорт", 1969.