CHAPTER 13

THE LOSSES OF INNER ENERGY IN SEA WAVES

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As it is known Lamb in his time suggested that energy losses in waves stipulated by liquid viscosity should be calculated by a formular:

$$W_{\nu} = 2\pi^2 \rho g \frac{h^2}{\lambda^2} \nu \tag{1}$$

where ν is kinematic viscosity coefficient

The following prototype observations and laboratory experimental data showed that actual losses tens and hundreds times exceed those calculated by this formular. This can be explained by the turbulent character of according to Lamb, suggested to substitute the turbulent viscosity coefficient determined depending on wave parameters (instead of the kinematic viscosity one). The best known are the suggestions of Dobroklonsky who puts forward the following dependence for turbulent viscosity coefficient:

$$\nu_t = 2{,}51 \cdot 10^{-2} \frac{h^2}{\tau} \quad (cm^2 sec^{-1})$$

and Bouden: $\nu_t = 2{,}8 \cdot 10^{-5} \frac{h \cdot \lambda}{\tau} \quad (cm^2 sec^{-1})$

Even these dependences give nearly 100 times divergence

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in calculation.

Considering suggestions of other investigators one can find out more than 300 times discrepancy. Such variability testifies that recommended functional connections betwee wave parameters and turbulent viscosity coefficient are not correct.

Modern knowledge on liquid structure can explain these discrepancies.

A number of latest works in this field bring to conclusion that the main kinematic elements of water are particles consisting of several hundreds of molecules. If we cease to consider water particles as some part of continuous medium without definite dimensions, and begin to consider it as the transfer and deformation of real particles, we can notice that the conventional division of motion to laminar and turbulent is not complete.

As we know, any fluid motion which can be described as periodical or which is to some extent a regular vorfex model is not a turbulent flow is that the turbulent pulsations by their nature are of chaotical character. At present, when considering waves, the majority of experts find turbulent and laminar regimes in them by analogy with water flows. In fact, looking at real waves during storms, when it is even difficult to determine their characteristic owing to chaotical combination of crests and troughs, one can suppose turbulent nature of motion. If we consider two-dimentional waves in laboratory chute, however, strict regularity of surface periodical fluctuations becomes evident; pressures and velocities at a point vary strictly periodically as well. Not a single experimenter could find high-frequency pulsations characteristic for turbulent regime in swell waves and standing ones.

Therefore, it should be admitted that regular wave motion itself is not turbulent. On the other hand, due to periodical velocity and pressure variations at a point, it could not be considered as laminar.

Fluid pressure is the motion of material particles having definite geometrical dimentions at each moment. It can be supposed that with laminar motion there are either no particle deformations or they result from outer actions (the change of distance between boundary surfaces, for instance). With turbulent motion the particle deformations undoubtedly take place which can be seen from variations of all parameters measured. These deformations have accidental character which is characteristic for turbulent motion. With wave motion particle deformations occur strictly periodically and that causes particular properties of wave flow. Therefore, it seems expedient to consider the wave motion as the third main type of fluid motion. Comparing various types of fluid motion we can see clear indications of difference between them.

Laminar motion.

1. There are no particle deformations or they are connected with external local actions (broadening or narrowing boundary surfaces).

2. Motion has laminated character, separate jets move parallel each other without mixing.

3. Velocity value and direction at each point of area occupied by moving fluid with set motion are constant.

4. Inner energy losses are stipulated by fluid molecular viscisity.

5. Energy losses due to friction are proportional to the first degree of velocity.

Turbulent motion.

1. Particle deformations are of accidental character with high frequencies.

2. Particle motion has chaotical character; fluid continuously mixed.

3. Value and direction of velocity at any point are

continuously varying. It has frequencies of hundreds of hertz. Variations are of accidental character.

4. Inner energy losses are stipulated by mixing in the thickness of final fluid masses (by turbulent viscosity).

5. Energy losses due to friction are proportional to the velocity in degree 1,75 - 2.

Wave motion.

1. Particle deformations are strictly periodical with low frequencies.

2. Particle perform oscillatory motions along definite trajectories. This motion is accompanied by laminated "orbital" motion reducing when the depth increases. Particles are not mixed.

3. Value and direction of velocity at any point periodically vary. Frequency is equal to wave period. The fluctuations of velocities are strictly regular.

4. Inner energy losses are stipulated by molecular v viscosity and particle deformation losses.

5. Though some authors suppose that the losses due to friction are proportional to the square velocity, this problem should be specially studied.

One should distinguish real waves and that we call wave motion. Wave motion itself, as any other, is an abstraction. Under wave motion we understand one of the components of real fluid motion namely: oscillatory particle motion along definite trajectories and connected with them periodical deformations of particles, without breaking the nearest order between particles. Real waves are the result of summing up turbulent motion to the system of wave motions. Cutting to minimum the effect of external turbulizing factors, it is possible to get more or less pure wave motion in laboratory. The effect of turbulency becomes quite essential for storm waves in open weakens for ocean swells' waves the relation between wave motion and turbulent one will vary in behalf of the first one. To estimate this phenomenon properly it is rather useful to divide motion to its compounds: wave and turbulent ones.

With wave motion the fluid particles are subjected to the periodical deformations. Analysing these deformations one can obtain [1] equations for swell waves in Lagrange variables:

$$x = x_o + r \sin \varphi + k r^2 \left(\frac{\sigma t}{2} + \frac{1}{4} \sin 2\varphi \right) \qquad (2)$$

$$y = y_o + r \cos \varphi + k r^2 \left(\frac{1}{2} + \frac{1}{4} \cos 2\varphi \right)$$

where: $\varphi = \sigma t - k x_o$,

x and y varying particle coordinates,

x_o and y_o - coordinates of particles at rest,

$\sigma = \frac{2\pi}{\tau}$, $k = \frac{2\pi}{\lambda}$, $r = \frac{h}{2} e^{\frac{-2\pi y_o}{\lambda}}$,

h, λ and τ - height, length and wave period correspondingly.

Now let's define deformation energy losses. If we take two moments $t_1 = 0$ and $t_2 = t$ and consider the position of two closely situated particles, the distance change between them during t will be:

$$dx - dx_o = - kr \cos\varphi \; dx_o - \frac{k^2 r^2}{2} \cos 2\varphi \; dx_o \qquad (3)$$

Relative deformation of each centimeter of infinitely small fluid layer is:

$$\varepsilon = \frac{dx - dx_o}{dx_o} = - k r \cos\varphi - \frac{k^2 r^2}{2} \cos 2\varphi \qquad (4)$$

Then the rate of deformation will be:

$$\frac{d\varepsilon}{dt} = k \sigma r \sin\varphi + \sigma k^2 r^2 \sin 2\varphi \qquad (5)$$

R.N.Ivanov in his works [2] on film extension based on a great number of experiments showed that the force of resistance to film extension is proportional to velocity. If these conclusions be spread to the case of infinitely small fluid layer deformations considered, the energy absorbed by 1 cm^2 of this layer may be obtained in the form of:

$$dW_d' = a\rho \frac{\partial \varepsilon}{\partial t} d\varepsilon \quad , \tag{6}$$

where a - proportionality constant factor, which can be called deformation dissipation coefficient.

Substituting all the values in formular (6) we obtain the following expression:

$$dW_d' = a\rho \, (k \sigma \, r \sin \varphi + k^2 \sigma \, r^2 \sin 2\varphi) \, dt \tag{7}$$

As the particle deformation sign changes in a half of a period (half a period goes compression and the other half - extension), integrating expression (7) when $x_o = 0$ for a half a period and doubling it we obtain energy losses by an infinitely small fluid layer, whose area is 1 cm^2 for the whole period:

$$W_d' = \pi \, a \, \rho \, \sigma \, (k^2 r^2 + k^4 r^4) \tag{8}$$

To obtain energy loss values over all water thickness, we integrate expression (8) over the depth:

$$W_d = \int_0^{-\infty} W_d' \, dy_o = \frac{1}{2} \pi \, a \, \rho \, k \, \sigma \, r_o^2 \, (1 + \frac{k^2 r_o^2}{2})$$

Or substituting values k , σ and r_o we get:

$$W_d = \frac{a \rho \pi^3 h^2}{2 \lambda \tau} \left[1 + \frac{1}{2} (\frac{\pi h}{\lambda})^2 \right]$$

i.e. , energy loss value of disturbed fluid related to 1 cm^2 of surface during the period. Obviously, energy losses during a second will be equal to:

$$W_d = \frac{a \rho \pi^3 h^2}{2 \lambda \tau^2} \left[1 + \frac{1}{2} \left(\frac{\pi h}{\lambda} \right)^2 \right] \tag{9}$$

Coefficient dimension a from formular (9) $cm^2\ sec^{-1}$ - coincides with the dimension of kinematic viscosity coefficient and hence from the dimention condition we may assume the following dependence:

$$a = m \frac{h \lambda}{\tau} \tag{10}$$

Generally, it seems possible to consider that inner energy losses in waves can be represented as:

$$W = W_\nu + W_d + W_t \tag{11}$$

where: W_ν - kinematic viscosity losses

W_d - particle deformation losses

W_t - turbulency losses.

Taking into account Lamb dependence (1) we can write down:

$$W = 2 \pi^2 \rho\ g \frac{h^2}{\lambda} (\nu + \nu_d + \nu_t) \tag{12}$$

where ν, ν_d and ν_t the coefficients of kinematic viscosity, deformation energy dissipation and turbulent viscosity, correspondingly.

Comparing (12) and (9) we get:

$$\nu_d = m_1 \frac{h \lambda}{\tau} \left[1 + \frac{1}{2} \left(\frac{\pi h}{\lambda} \right)^2 \right] \tag{13}$$

where m_1 is an empirical coefficient.

If determining coefficient ν_d experimentally it turns out that it varies with depth as the turbulent viscosity coefficient does, this may be taken into account by exponential dependence for m_1. In the latter case we have to integrate equation (8) to make the numerical coefficient more exact.

As the waye turbulency depends on external turbulizing factors, when looking for functional dependence for ν_t , the wind parameters (velocity and action duration) should be taken into account first of all. The existing dependencies for ν_t accounting only wave parameters do not meet this condition and therefore they give results differing 300 times and more from each other.

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