II-76 THE RESISTING TORQUE OF THE PILE MOORING THE FLOATING BODY ON THE SURFACE WAVE

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1. The oscillation of the floating body is the fundamental subject in coastal hydraulics. Moored ships on long waves, submerged moored sphere in oscillatory waves were investigated recently. However when the floating body is moored to the pile somewhat tightly, the bodv oscillates around the mooring point but not around the center of floatation. This cause the additional torque of buoyancy. Moreover the resisting torque owing to the elastic deformation of the pile has to be taken into account. The stress of the pile can be calculated by this resisting torque of the pile.

2. When the direction of the waves is coincide with the axis of the floating body, the movement is solely pitching. In this case the maximum resisting torque M_{max} is calculated by the following equation.

$$M_{max} = \frac{E_s I_s}{l_s}\,\theta_{max} = \frac{E_s I_s}{l_s}\cdot\frac{P}{\sqrt{(\omega^2-n^2)^2+4K^2n^2}} \qquad (1)$$

In this equation, E_s, I_s and l_s is the modulus of elastisity, the moment of inertia and the length of the pile respectively. θ_{max} is the maximum tilting angle of the waterline, P is the amplitude of the external torque, ω is the natural circular frequency of the body and n is that of the wave. And they are expressed as follows;

$$P = w_0\frac{aB}{m^2}\cdot\frac{g}{I_0+I'}\,(1-Kmd\cdot H)\cdot\sqrt{\{\sin(ml)-ml\cos(ml)\}^2+\{1-\cos(ml)-ml\sin(ml)\}^2} \qquad (2)$$

$$K = \frac{gK_1}{2(I_0+I')} \qquad (3)$$

$$\omega^2 = \frac{g}{I_0+I'}\left(W\cdot\overline{GM}+\frac{E_s I_s}{l_s}+w_0\frac{BL^3}{4}\right) \qquad (4)$$

In which, w_0 is the specific weight of water, a is the amplitude. m is the circular wave number $2\pi/\lambda_0$ and B,L,d are the breadth, length and the draft of the floating body. I_0 and I' are the moment of inertia of the body and the added moment of enertia. K is the coefficient of the virtual mass torque, k_1 is the coefficient of the resistance of the motion, W is the displacement and $\overline{GM}$ is the longitudinal metacentric height.

3. When the direction of the wave has the angle φ_0 to that of the axis of the floating body, yawing is accompanied with pitching.

For pitching, the apparent circular wave number can be assumed as $m' = m\cos\varphi_0$.

Pressure torque caused by the pressure difference due to the phase shift between the exposed side and the sheltered side of the wave movement is the external torque. Maximum resisting torque of the pile is the tortion torque and can be expressed as follows;

$$M_{max} = \frac{KG}{l_s}\,(B\varphi + C\varphi)_{max} \qquad (5)$$

$$B\varphi = (D_{sn}^2+D_{cn}^2)^{1/2}\Big/\sqrt{(\omega_2^2-n^2)^2+4K_2^2n^2} \qquad (6)$$

$$C\varphi = (C_{mn}^2+D_{mn}^2)^{1/2}\Big/\sqrt{(\omega_2^2-4n^2)^2+16K_2^2n^2} \qquad (7)$$

in which, KG is the tortional rigidity and ω_2 is the natural circular frequency of yawing. D_{sn}, D_{cn}, C_{mn} and D_{mn} are functions of I_y, I'_y, $mB \sin\varphi_o$, and $mL \cos\varphi_o$.

4. When waves attack the floating body at right angle, rolling is accompanied beside pitching and yawing. For pitching,

$$P \doteq w_0 \frac{aB}{m^2} \cdot \frac{g}{I+I} \cdot (1-Kmd\cdot H) \frac{m^2 L^2}{2} \quad (8)$$

can be obtained. And another simple expressions for D'_{cn} and C'_{mn} are derived for yawing in which case D_{sn} and D_{mn} can be ommitted.

For rolling, same expression as equation (1) can be used, but

$$P = \frac{g}{I_r} \cdot W \cdot \overline{GM_r} \cdot am \quad (9)$$

in which I_r is the moment of inertia of the floating body around the horizontal axis of it, $\overline{GM}_r$ is the transversal metacentric radius.

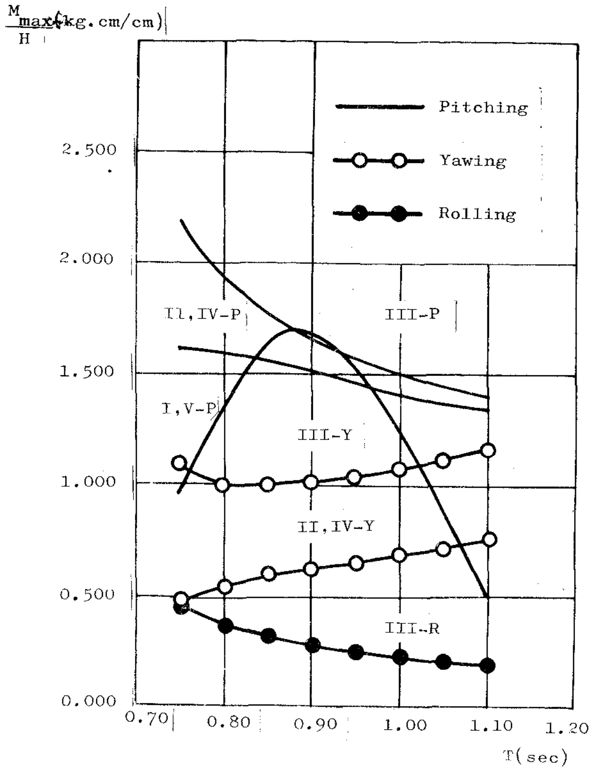

Fig.1 Relations between M_{max}/H vs. T

Fig. 1 shows the relationship between the ratio of the maximum torque to the wave height H and the wave period T calculated for a 3000-t pump dredger on the surface wave of the wave height of 2 meters. P, Y and R are for pitching, yawing and rolling respectively. Wave direction is identified by I for the stern wave, by V for the bow wave, by II for the 45° stern wave, by IV for the 45° bow wave and by III for the shipside wave. Curve of **I,V-P** shows that maximum torque happens in the vicinity of the wave period of 0.93 sec when the wave length is twice the ship length. It can be said that the resonance effect is far less effective as the natural period of pitching is 0.61 sec. This may be called the buoyancy effect.

This buoyancy effect becomes weak and the apparent wave length to the floating body tends to be longer as the wave direction has wider angle to the bodies axis causing the wave period of the peak resisting torque to shift to the shorter period.

As for yawing, external force is the result of the pressure difference of both sides of the ship due to the phase difference of waves. So, if the breadth is much smaller than the wave length, the resisting torque is not sensible to the wave period, but to that of the natural period. The natural period of yawing is 2.29 sec in this case. Curves of yawing tells this fact.

This is also the case of rolling shown in III-R as the natural period of rolling is 0.34 sec. These analysis was certified by experiments in the Tohoku University.