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VIBRATION TEST IN AIR ON A 200 TON TUGBOAT AND ESTIMATE OF VIRTUAL INERTIA COEFFICIENT*

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Abstract. An experimental study on the vibration measurement in air on board 200ton tugboat was carried out and by the test on the same ship in water the virtual inertia coefficient in two node vertical vibration was estimated referring the tests of the model ship. Both results in actual ship and that in model showed good agreement.

Introduction

Since the water surrounding a ship is considered to be ideal fluid in ship hull vibration, the virtual inertia coefficient in the vibration of the model ship may be assumed to be identical with that of the corresponding actual ship. It is therefore needless to attempt vibration test on actual ship in air. However, since the natural frequency of the vibration of a model ship is much higher than that of actual ship, there are some questions whether or not the water surrounding the model ship follows to the vibratory motion of the model or whether there is an effect of surface tension in the small model ship as suggested by Dr. F. M. Lewis in his paper of 1929. Clarifying such physical mechanisms mentioned above, the authors attempted to obtain the inertia coefficient through the vibration tests in air and water on a 200 ton tugboat and compared the result with that obtained from 1/25 scale model ship. The three-dimensional correction factor of the virtual mass in the two node vertical vibration of the tugboat are also determined by the experiments and calculations.

1. Vibration test on board 200 ton tugboat in air and in water

The principal dimensions of the tugboat and the conditions in the vibration tests are shown in table I. The tugboat was vertically excited by gear wheels with excentric mass which is driven by D.C. motor of 1/4 H.P. The exciting force is 180 kg in 700 rpm of two wheels 20 cm in diameter each having excentric mass. The above exciter was installed at the after perpendicular on a deck. A portable mechanical accelerometer was used for measuring the natural frequency of vertical vibration of the hull in the fundamental mode, and also for measuring the accele-

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Table I. Principal dimensions of 200ton tugboat.

length	P.P	L	25.5	M
length	O.A	L	28.4	〃
breadth	Md.	B	7.8	〃
depth	Md.	D	3.75	〃
draught		d	2.85	〃
condition in vibration test:				
		$d(f)$	1.20	M
		$d(a)$	3.15	〃
		$d(m)$	2.20	〃
		L/B	3.27	〃
		B/d	3.55	〃
displacement			197	tons

rations at ten points on deck moving the accelerometer the mode curves were made. The vibration test in air was carried out using the above-mentioned exciter and accelerometer, when the 200 ton tugboat was being suspended in air for having on board the deck of a cargo ship. The test in water was taken place when the ship floated in dock.

Photo. 1. View of 200 ton tugboat in suspended state.

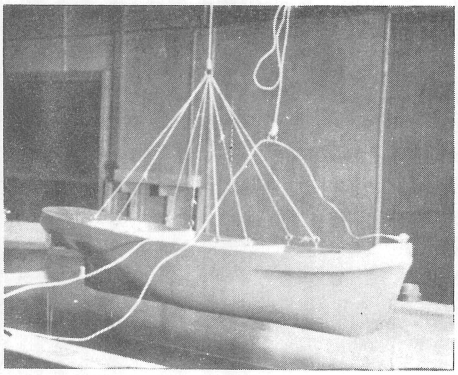

Photo. 2. Model ship suspended in air.

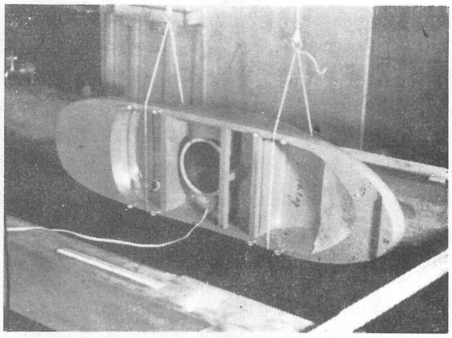

Photo. 3. Model ship in the state of free-free bar.

On the other hand, in order to confirm the effect of supporting points of a suspended ship and of the shallow water in dock on the natural frequency and the vibration mode of the ship hull, a wooden model ship of 1/25 scale was prepared and some experiments were carried out.

General views of the tugboat in the state of suspension and the model ship in two states of measurements in air are shown in photographs 1, 2 and 3 respectively.

2. Experimental results

2.1. Test results on boad ship

Fig. 1 and table II show the results of measurements of two-node vertical vibration of the 200ton tugboat in air and in water. As be seen in the figure, the

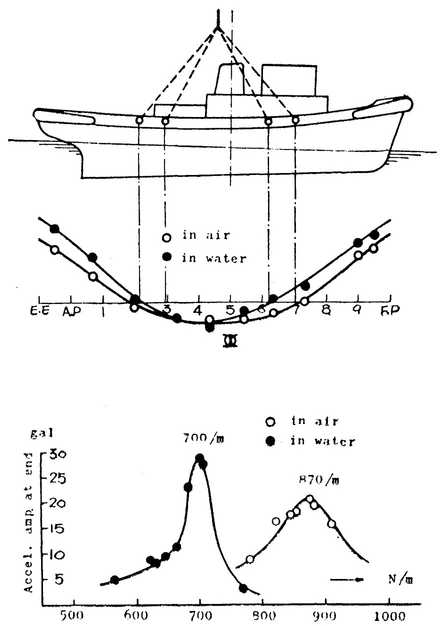

Fig. 1. Experimental results of vibration measurements on board 200 ton tugboat in air and water.

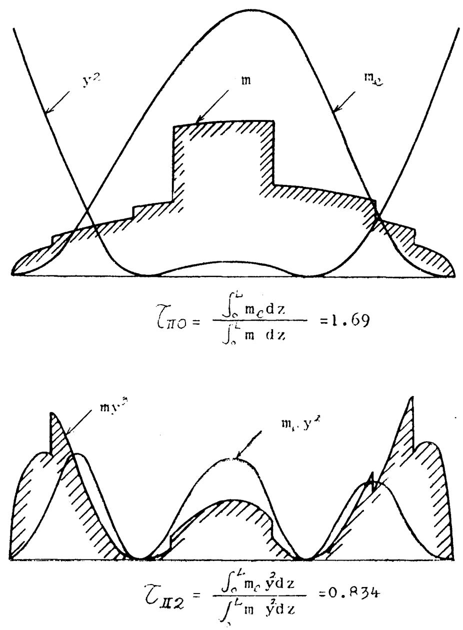

Fig. 2. Distributions of m, m_c, y^2 and kinetic energies in two node vertical vibration of 200 ton tugboat.

natural frequency in air is higher than that in water true to our expectation. The nodal points of the measured modes in water are located nearer to midship than that in air. It is to be noted that the damping coefficient of the vibration of the hull in water is smaller than that in air.

With regard to the virtual inertia coefficient of water, the τ-value agrees with that obtained by the model ship, and the three-dimensional correction factor, namely, J-value which was obtained from the ratio of the result of experiment on actual ship to two-dimensional strip calculation is determined.

Table II. Results of measurements on board ship and model ship.

<table>
<tr><th colspan="2">items</th><th>in water</th><th>in air</th><th>remarks</th></tr>
<tr><td rowspan="3">natural frequency of two node vertical vibration on actual ship, per min.</td><td>measured</td><td>700</td><td>870</td><td></td></tr>
<tr><td>corrected for shallow water</td><td>712</td><td>—</td><td>see Fig. 4</td></tr>
<tr><td>corrected for suspension</td><td>—</td><td>887</td><td>see Fig. 3</td></tr>
<tr><td colspan="2" rowspan="2">measured on model ship per sec.</td><td rowspan="2">250</td><td>305</td><td>hanging state</td></tr>
<tr><td>311</td><td>free-free state</td></tr>
<tr><td colspan="2">logarithmic derement of damping coefficient, δ_2, on actual ship</td><td>0.158</td><td>0.343</td><td>$\delta_2=\frac{C}{L_m}$, $C=4.04$ [5]</td></tr>
<tr><td colspan="2">max. acceleration of vibration, a (gal) on actual ship</td><td>25.8</td><td>21.0</td><td>$a=\frac{g\pi F}{\Delta_1\delta_2}\phi$, $\phi\doteqdot4$, [6]</td></tr>
<tr><td colspan="2">exciting force, F(kg), on actual ship</td><td>180</td><td>278</td><td>at A.P</td></tr>
<tr><td rowspan="3">virtual inertia coefficient, τ_2,</td><td>measured on actual ship</td><td colspan="2">0.524</td><td></td></tr>
<tr><td>measured on model ship</td><td colspan="2">0.510</td><td></td></tr>
<tr><td>two-dimensional calculation</td><td colspan="2">0.834</td><td>($\tau_{II0}=1.69$)</td></tr>
<tr><td rowspan="4">three-dimensional correction factor, J_2,</td><td>by experiments</td><td colspan="2">0.628</td><td>$\tau_{2exp}/\tau_{II2\ cal}$</td></tr>
<tr><td>by Kruppa</td><td colspan="2">0.574</td><td>ellipsoid [3]</td></tr>
<tr><td>by Taylor</td><td colspan="2">0.490</td><td>ellipsoid of revolution [1]</td></tr>
<tr><td>by Prohaska</td><td colspan="2">0.564</td><td>$J_2=0.38\sqrt[3]{L/B}$ [2]</td></tr>
</table>

It should be noted that since the virtual inertia coefficient is defined by the ratio of kinetic energies of virtual mass and of ship hull, the square of a velocity amplitude or the mode of vibration should be taken into account for two-dimensional calculation of virtual inertia coefficient, as already referred to the previous paper of one of the authors [7]. The results of energy distributions mentioned above in the translational motion and two-node vertical vibration are respectively shown in figure 2.

The J-value made in the present study closely approaches to that obtained from and ellipsoid with the same L/B and B/d values as actual ship under water line. The theoretical investigation on J-value of the ellipsoid was recently presented by C. Kruppa [3] and the numerical computation with respect to the results of measurements of the mode of the vibration in the present experiment was carried out by the courtesy of Dr. C. Kruppa. The J-value obtained from J. L. Taylor [1] and C. W. Prohaska's empirical results [2], both in the ellipsoid of revolution, are also shown in table II.

In regard to the logarithmic decrements of the two node vertical vibration of the hull of the tugboat in water, the empirical expression [5] almost represents that of experiments. The force-amplitude relationship was also obtained as a special type ship. The result of response factor [6] is shown in table II, Some corrections for obtaining the above results in actual ship will be verified by the following model experiments.

2.2. Experimental studies on model ship

Since measurements of vibration on actual ship in air are resulted in the state of hanging by eight points at gunwale close to the nodes of hull vibration, as was shown in photograph 1, and Fig. 2, it is necessary to correct these restriction of support into free-free vibration of the hull. In the model tests, the first experiment was carried out in the same hanging state as actual ship as shown in photograph 2. As the second experiments, the model was hung with its hull turned sideways and the test was carried out in air as usual as seen in photograph 3. The results of the above measurements made in air and in water are shown in Fig. 3. As will be seen in the figure, a little effects of restraint of supporting points on the natural frequency and on the nodal points of the mode of the vibration may be clarified in these differences and the correction for this effect will be applicable to the result of measurement on actual ship.

The effects of shallow water as well as that of wall effects on the natural

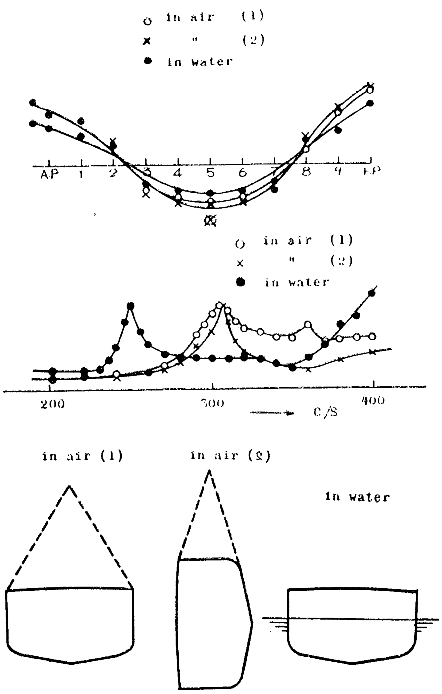

Fig. 3. Experimental results of vibration measurements on the model ship of 200 ton tugboat.

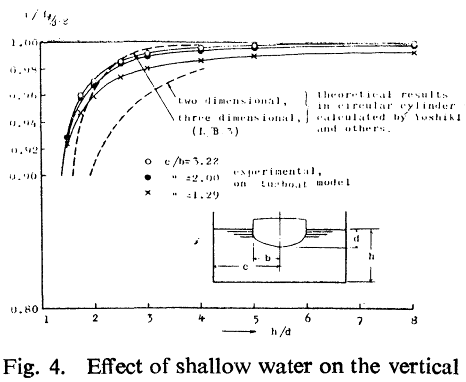

Fig. 4. Effect of shallow water on the vertical vibration of 200 ton tugboat model.

frequency should be also corrected in the present experiments. The model test on the effects of shallow water and wall upon the natural frequency was carried out in a small water tank. The results are shown in Fig. 4. The theoretical results on the vibration of a circular cylinder in the three- and two-dimensional flow which were calculated by M. Yoshiki and others [4] are plotted in the same figure. There is a remarkable agreement between experimental results and the theoretical calculation for a circular cylinder in the three dimensional flow as will be seen in the figure. The natural frequency measured in the present study was corrected according to the effects of shallow water and wall from the curve in Fig. 4.

The inertia coefficient of the virtual mass in the vibration is determined by the natural frequencies in air and in water with a coefficient ν as follows [7],

$$\tau = \frac{f_a^2}{f_w^2} \cdot \nu - 1 ,$$

where, ν is calculated from the locations of the nodal points of vibration modes in air and in water, the modes and curvature, the distribution of rigidity and that of mass of ship hull (see table III). If we assume that the mode of the two node vertical vibration is to be in the second degree parabola as is usually assumed in ellipsoid, and the mass distribution is in parabolic form, both symmetrically about the midship, the ν-value will be obtained with ratio of distances between two nodal points of vibration modes in air and in water, μ, in variable and distance, α_w, in

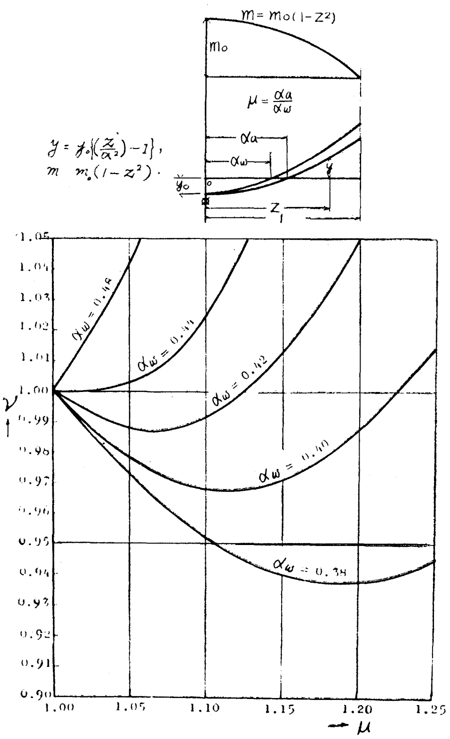

Fig. 5. Correction factor ν-value for various α_w and μ.

Table III. Locations of nodal points in two node vertical vibration in air and in water and correction factor ν.

	α_a	α_w	μ	ν
in actual ship, measured	0.520	0.410	1.13*	0.982
hanging state in model ship	0.500			
free-free state	0.455	0.400	1.11	0.968

* corrected for α_w by the model test

parameter as will be seen in Fig. 5. By the use of ν-value and the natural frequencies in air and in water, the inertia coefficient in the two node vertical vibration is determined from the vibration measurements on board ship or model ship in air and in water using the above formula.

Conclusions

Brief conclusions will be drawn from the present experimental study as follows:

The results of measured virtual inertia coefficient of the two node vertical vibration of actual ship and of its model ship almost agreed. The virtual inertia coefficient in the vibration of a ship hull may be therefore determined by the vibration test of the corresponding model ship.

In the calculation of virtual inertia coefficient by the strip method, it is to be noted that a square of amplitude should be multiplied by corresponding virtual mass and mass of the hull of each strip for obtaing the kinetic energies of water and ship hull, which was noted by one of the authors in previous paper [7].

The damping coefficient obtained by measurement on actual ship in water agrees with that obtained by empirical one, though it is seen larger in air than that in water even in the model ship. The cause for this phenomenon is supposed that for the restriction in hanging state.

The authors wish to express their gratitude to Dr. C. Kruppa of Portsmouth England for his assistance in carrying out the numerical calculation of J-value of the ellipsoid by the use of the results of measured vibration mode and other given data of the tugboat which was tested in the present investigation.

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