Mechanical Studies on the Mid-water Trawl Gear in Operation

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Abstract

The estimation of the working depth of mid-water trawl net has been obtained by considering that the towing warp in operation takes geometrically a part of a circular arc and was verified by a series of experiments.

This time, the gear was analyzed on the basis of the equilibrium of hydrodynamic forces, and six equilibrium equations of the state in operation were obtained.

Seven diagrams were obtained by calculation of these equations for the convenience of practical use, and the equilibrium of hydrodynamic forces of the mid-water trawl net in operation was realized.

Introduction

Preceedingly, the authors have published a method of estimation of the working depth of mid-water trawl net by a chart1) which is calculated by considering that the towing warp in operation takes geometrically a part of a circular arc. By a series of experiments, 1,2,3) the authors obtained satisfactory results. But in those papers, all cases were analyzed geometrically, and equilibrium of hydrodynamic forces of the gear was not taken into consideration.

This simple estimation of the working depth of gear is practically quite convenient for the completed gear, but, in case of planning or construction of the gear under various conditions, analysis on dynamical force of the gear would be of great importance.

The present authors, therefore, have made an analysis on the mechanism of towing operation of mid-water trawl gear on the basis of the equilibrium of hydrodynamic forces.

Theoretical Consideration

I. Basic Consideration

It can be considered that there are three conditions which would influence the equilibrium of gear in operation, i.e., the net, the towing warp, and the towing velocity.

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Exactly speaking, the drag of the gear is related to the net and towing velocity; the weight in water per unit length of the warp, the length of the warp, and the drag per unit length of the warp when the warp is normal to the stream are related to the shape of the towing warp in operation; and the ratio of the weight in water per unit length of the warp and the drag of the gear also have influence upon the equilibrium of the gear.

Before proceeding further, suppose the form of a cable towing through the water as shown in Fig. 1, that is, choose a rectangular coordinates \((x, y)\) whose origin \(O\) is located at the point on the cable where the cable is normal to the direction of motion. Let the \(x\)-axis be taken as positive towards the direction of motion and \(y\)-axis be directed vertically upward. Let \(S\) be the length of the arc along the cable from the origin \(O\) to any point \(P(x, y)\), \(T\) and \(T_0\) be the tensions of the cable at the points \(P\) and \(O\), respectively. Denote the drag per unit length of the line by \(R\) when the cable is normal to the stream and it is expressed as

\[
R = \frac{1}{2} C_D \rho V^2 D
\]

where \(C_D\) is the drag coefficient of the cable, \(\rho\) the density of fluid, \(V\) the speed of the motion, and \(D\) the diameter of the cable. Let \(F\) be the drag per unit length of the line when the line is parallel to the stream. Podé\(^{40}\) gave the solution of equilibrium.

![Fig. 1. Cable configuration and forces acting on an element of cable in the coordinate system.](image-url)
equation by a nondimensional parametric form as follows;

\[ \frac{T}{T_0} = \tau (\theta), \]
\[ \frac{RS}{T_0} = \sigma (\theta), \]
\[ \frac{Rx}{T_0} = \xi (\theta), \]
\[ \frac{Ry}{T_0} = \eta (\theta), \]

where, \( \tau, \sigma, \xi, \) and \( \eta \) are transcendental functions of angle, \( \theta \), between the cable and the direction of motion, and numerical values have already been computed and tabulated for the value \( \theta \) from 0 to 90 degrees.

In this study, the equation (3) is not so important, and therefore, it is omitted. We focus our attention to the other three equations, (1), (2), and (4).

Another special interest is the values of the angle \( \theta = \theta_c \), which is called the critical angle. When the cable is towed by itself, that is, the line is simply trailed without any towed body at the end of the line, the configuration of the cable in the water will be a straight line inclined to the stream at such an angle \( \theta = \theta_c \), as shown in Fig. 2.

![Fig. 2. Cable configuration and forces acting on an element of cable when the cable is towed by itself.](image)

II. General Consideration

As shown in Fig. 3, all parameters related to the point where the warp is attached to the net and the point where the warp intersects the water surface are distinguished by subscriptions \( n \) and \( s \), respectively. Let \( W \) be the weight in water per unit length of the warp, \( L \) the length of the towing warp, \( h \) the working depth of the gear, \( T \) the tension in the warp at an arbitrarily chosen point, \( \theta \) the inclined angle, \( W_n \) the weight in water of the net, \( R_n \) the drag of the net, and \( T_V \) the towing force of the vessel. Then, we have
where $w$ is the ratio of the weight in water per unit length of the warp to the drag of the gear, i.e., $W/R$, and is a function of the critical angle $\theta_c$.

By these equations, for example, if the net size, warp size, and towing speed are given, the size of the gear, i.e., the weight of the otter boards can be estimated.

For simple and easy usage, equations (a) and (b) were calculated with consultation to the tables by Pode, and were put into the form of diagrams. But as the relationships are different by the critical angles $\theta_c$, one diagram must be chosen according to the critical angle of the warp in use which is derived from the ratio of the weight in water per unit length of the warp to the drag of the gear.

These diagrams thus obtained were shown in Figs. 4-1, 4-2, 4-3, 4-4, 4-5, 4-6, and 4-7. Drawn in the figures are the contour lines of $\theta_s$ and $\theta_n$ which denote the angle between the warp and the horizontal plane at the sea surface and at the connecting point to the net; the magnitude of both angle is jointly indicated in degree in the
Fig. 4.1. Theoretical relationship between $h/L$ and $WL/T_3$ for the angles $\theta_3$ and $\theta_4$, in the range of 5° to 10° of the critical angle.
Fig. 4-2. Theoretical relationship between $h/L$ and $WL/T_s$ for the angles $\theta_s$ and $\theta_n$ in the range of $10^\circ$-$15^\circ$ of the critical angle.
Fig. 4-3. Theoretical relationship between \( h/L \) and \( WL/T_s \) for the angles \( \theta_s \) and \( \theta_n \) in the range of 15°-20° of the critical angle.
Fig. 4-4. Theoretical relationship between $h / L$ and $WL / T_s$ for the angles $\theta_s$ and $\theta_p$ in the range of $20^\circ$-$25^\circ$ of the critical angle.
Fig. 4.5. Theoretical relationship between \( \frac{h}{L} \) and \( \frac{WL}{T_s} \) for the angles \( \theta_s \) and \( \theta_n \) in the range of 25°-30° of the critical angle.
Fig. 4-6. Theoretical relationship between $h / L$ and $WL / T_s$ for the angles $\theta_s$ and $\theta_n$ in the range of 30°-35° of the critical angle.
Fig. 4-7. Theoretical relationship between $h/L$ and $WL/T_s$ for the angles $\theta_s$ and $\theta_H$ in the range of $35^\circ$-$40^\circ$ of the critical angle.
Conclusion

In order to verify the diagrams, the data of the experiment which was carried out in the former paper was used.

The comparison of the calculated value with the experimental one is shown in Fig. 5.

As seen in the figure, both values agree satisfactorily with each other. By this diagram, not only the ratio of the depth to the length of the warp, \( h / L \), is obtained immediately, but also \( WL/T_s \) is obtained on the abscissa.

Since the tension of the towing warp in operation was not measured in the course of experiment, \( WL/T_s \) is not verified. However, as the depth of the gear is obtained from the diagram quite exactly and as \( WL \) is known from the construction and towing condition of the gear, the tension of the towing warp in operation \( T_s \) can be calculated. With the given value of \( T_s \), \( W_H \) and \( R_H \) were calculated by the equations (a) and (f). \( W_H \) is plotted against the speed of the vessel as shown in Fig. 6.

Before calculation of \( W_H \) it was considered that \( W_H \) would be a constant value such as the approximated value of the weight of the otterboard, i.e., 331kg in water (380kg in air), and the value was indicated by dotted line in the figure. The calculated value of \( W_H \) seems to have a tendency to be larger than the weight of the gear when towing speed is relatively low and smaller with the increase of towing speed. The reason why the value of \( W_H \) varies with the towing speed may be attributed to the attitude (or pose) of the otter-boards when the gear is towed, i.e., when the towing speed is small the boards have tendency to sink and apparent weight of the boards become large, and contrarily when the towing speed increases the boards have tendency to rise upward and apparent weight of the boards become small.
The resistance of the gear, $R_n$, was expected to be proportional to some power of $V$, but the calculated value of $R_n$ was gained scatteringly and no systematical results were obtained.

After all, the equilibrium equations of hydrodynamical force of the mid-water trawl net in operation are realized and the diagrams which were prepared upon calculation of the cable equations will be useful for operations of mid-water trawl.

References