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Theoretical Studies on the Mechanical Characteristics of Two-seam Trawl Net

Kei NAKASAI and Efren Ed. C. FLORES

The mechanical characteristics of a two-seam trawl net was studied theoretically on the basis of its construction and geometrical configuration in operation. A model net was constructed and tested in a circulating water tank to verify theoretical results. Good coincidence of the observed and calculated values for horizontal spread and towing force of the model net is presented.

Introduction

This study was conducted in line with the series of studies on the mechanical character of drag nets by T. KAWAKAMI and K. NAKASAI1, 2, 3, 4, 5). T. KAWAKAMI1) started the study with a rectangular strip of net examining its equilibrium configuration and distribution of tension. Then he modified the strip of net by adding a bag at the center, producing a mechanically simple model drag net2). Results of the theoretical analysis proved to be valid being in agreement with the experimental results of the model net under investigation.

With an understanding of the mechanical characteristics of a simple drag net, a four-seam drag net3, 4, 5) of similar construction to that of the two-boat trawl of Japanese type was studied. Here, the mode of transmission of tension in the webbing is different from that of the previous model. With modification in consideration of the change in construction, the results of the theoretical computations on the mechanical characteristics, such as the height of the net mouth, showed a good coincidence with experimentally observed values of the model net.

This paper deals with the investigation of a two-seam drag net using the same theoretical considerations, with further modifications, given to four-seam net. The model net used is of the construction resembling that of the two-seam trawl net employed in otter trawling.

Theoretical Analysis

For the sake of simplicity, the model net treated here is constructed as a cylinder as shown in Fig. 1. The configuration of relatively minor part of the net is approximated to a part of a circular arc of various curvatures or to a straight line if possible.
The experimental model net is composed of three different kinds of webbing, $N_1$, $N_2$ and $N_3$ and a constant rate of hang-in is made on the frame line so as to make an angle of $90^\circ \left( =2\phi \right)$ between two adjacent bars. As the mechanical situation and the geometrical shape are symmetrical about the center line, $C$, let us treat the starboard side of the net and moreover confine our discussions to the upper half of the net. The notations are defined according to the following and illustrated in Fig. 2.
1. WING

The wing consists of two different kinds of webbing, \( N_1 \) and \( N_2 \). The forward section, \( N_1 \), is of larger mesh than the rear section, \( N_2 \), but both are of the same depth, \( H \). The webbing of the wing is framed by three lines, i.e., headline, ribline and groundline. Therefore the tension on the upper half of the webbing is directed to both the headline and the ribline in equal proportion.

Accordingly, for the forward wing, let \( f_{wh} \) and \( f_{wwh} \) be the tensions at the forward and rear ends of the headline and \( f_{wm} \) and \( f_{wwm} \) be the tensions at the forward and rear ends of the ribline, respectively. And let \( \beta_{wh} \) and \( \beta_{wwh} \) be their respective angles on the headline, and \( \beta_{wm} \) and \( \beta_{wwm} \) on the ribline deviating from the direction of current. With \( L_w \), the length of the forward wing, and \( y_{wh} \) and \( y_{wwm} \), the transversal distances of the headline and ribline from their extremities to the center line, \( C \), then the following relation may be obtained:

\[
f_{wh} (\beta_{wwh} - \beta_{wh}) = \frac{1}{2} H L_w K_{n1} \sin \beta_{wwh}, \tag{1}
\]
\[
f_{wh} - f_{wwh} = \frac{1}{2} H L_w K_{t1} \cos \beta_{wh}, \tag{2}
\]
\[
y_{wh} = L_w \frac{\cos \beta_{wh} - \cos \beta_{wwh}}{\beta_{wwh} - \beta_{wh}}, \tag{3}
\]
\[
f_{wm} (\beta_{wwm} - \beta_{wm}) = \frac{1}{2} H L_w K_{n1} \sin \beta_{wwm}, \tag{4}
\]
\[
f_{wm} - f_{wwm} = \frac{1}{2} H L_w K_{t1} \cos \beta_{wm}, \tag{5}
\]
\[
y_{wm} = L_w \frac{\cos \beta_{wm} - \cos \beta_{wwm}}{\beta_{wwm} - \beta_{wm}}, \tag{6}
\]

where \( K_{n1} \) and \( K_{t1} \) are the values for \( K_n \) and \( K_t \) of the webbing \( N_1 \), respectively.

The similar relations will be valid for the rear section of the wing. Let \( f_{wsh} \).
and $f_{w\text{m}}$ respectively be the tensions on the headline and ribline at the rear ends of this section, and also let $\beta_{w\text{h}}$ and $\beta_{w\text{m}}$ respectively be their angles of incidence of the current to the plane of the webbing. With $L_{w\text{w}}$, the length of this section, $\gamma_{w\text{h}}$ and $\gamma_{w\text{m}}$ respectively be the transversal distances of the headline and ribline from their extremities to the center line, and as the depth, $H$, is constant, we have

$$f_{w\text{h}}(\beta_{w\text{h}} - \beta_{w\text{h}}) = \frac{1}{2} H \ L_{w\text{w}} \ K_{n2} \ \sin \ \beta_{w\text{h}},$$

$$f_{w\text{h}} = \frac{1}{2} H \ L_{w\text{w}} \ K_{12} \ \cos \ \beta_{w\text{h}},$$

$$\gamma_{w\text{h}} = L_{w\text{w}} \ \frac{\cos \ \beta_{w\text{h}} - \cos \ \beta_{w\text{h}}}{\beta_{w\text{h}} - \beta_{w\text{h}}},$$

$$f_{w\text{m}} \ (\beta_{w\text{m}} - \beta_{w\text{m}}) = \frac{1}{2} H \ L_{w\text{w}} \ K_{n2} \ \sin \ \beta_{w\text{m}},$$

$$f_{w\text{m}} = \frac{1}{2} H \ L_{w\text{w}} \ K_{12} \ \cos \ \beta_{w\text{m}},$$

$$\gamma_{w\text{m}} = L_{w\text{w}} \ \frac{\cos \ \beta_{w\text{m}} - \cos \ \beta_{w\text{m}}}{\beta_{w\text{m}} - \beta_{w\text{m}}},$$

where $K_{n2}$ and $K_{12}$ are the values for $K_n$ and $K_i$ of the webbing $N_2$, respectively.

2. SQUARE, SHOULDER and BAG NET

Between the bases of both wings in the upper front of bag net, this net has a "Square" of trapezoidal shape as shown in Fig. 3. The front edge of the square is hung to the headline of length $L_h$ to which floats of buoyancy $T_b$ per unit length are attached.

For the sake of simplicity, the shoulder is assumed to be on the same cylindrical plane with the square making an angle of $\beta_{\text{scm}}$ against the current. This is designated by

$$\beta_{\text{scm}} = \beta_{\text{scm}}.$$  (13)

Moreover, the shoulder and the wing are assumed to be on the same against the current. Then we have

$$\beta_{\text{scm}} = \beta_{\text{wcm}}.$$  (14)

Next, assume that half of the tension of the square is directed to the ribline and the remaining tension to the headline. Then denoting the tension on the ribline by $f_{\text{wcm}}$ at the front edge and $f_{\text{scm}}$ at the rear edge, and the length by $L_s$, we have approximately

$$f_{\text{wcm}} - f_{\text{scm}} = \frac{1}{2} H \ L_s \ \sin \ \phi \ K_{12} \ \cos \ \beta_{\text{scm}}.$$  (15)
where \(2\phi\) is the angle of mesh opening.

The bag net is made up of two kinds of webbing, \(N_2\), the front section (Belly) and \(N_3\) the rear section (Cod end).

The force that acts horizontally on the headline, \(L_h\), is estimated by the same principle as in the previous papers \(^2,^3\), and may be approximately given by

\[
T_s L_h = \frac{1}{2} (L_h^2 \tan \phi + H L_s \sin \phi) \ K_{i2} + \frac{1}{4} \ ((H + L_o) \ (L_h \tan \phi - L_s \sin \phi) + L_o^2 \tan \phi) \ K_{i2} + T_h L_h, \quad (16)
\]

where \(T_h\) is the resistance of the headline per unit length including the floats attached to it.

The remaining resistance will act on the ribline. Thus we have

\[
f_{erm} = \frac{1}{4} \ ((H + L_o) \ (L_h \tan \phi - L_s \sin \phi)) \ K_{i2} + L_o \ (L_o - (L_h + L_o) \tan \phi) \ K_{i2}
+ L_o^2 L_o K_{n3} + \frac{\pi}{4} L_o^2 K_{n3}, \quad (17)
\]

where \(K_{n3}\) and \(K_{i3}\) are the values of \(K_n\) and \(K_i\) for the webbing \(N_3\), respectively.

3. **HEADLINE**

   The equations for the headline are all the same as the previous paper \(^3\).

   Then we have

\[
f_{h\alpha} = \frac{T_h}{R} \sin \beta_e \quad (18)
\]

\[
T_h = \tan \beta_e \quad (19)
\]

\[
L_h = R (\frac{\pi}{2} - \beta_h) \quad (20)
\]

\[
y_h = r \cos \beta_h \quad (21)
\]

\[
Z = R (1 - \sin \beta_h) \sin \beta_e \quad (22)
\]

4. **EQUILIBRIUM CONDITIONS AT THE HEADLINE AND RIBLINE**

   The equilibrium equations on the headline at the rear wing can be presented as

\[
f_{\alpha\beta} \cos \beta_{\alpha\beta} = f_{\alpha\omega} \cos \beta_h \cos \beta_e, \quad (23)
\]

\[
f_{\alpha\beta} \sin \beta_{\alpha\beta} = f_{\alpha\omega} \sin \beta_h, \quad (24)
\]

and at the ribline from the wing to the shoulder, we have

\[
f_{\omega\alpha} \cos \beta_{\omega\alpha} = f_{\omega\omega} \cos \beta_{\omega\omega}, \quad (25)
\]

\[
f_{\omega\alpha} \sin \beta_{\omega\alpha} = f_{\omega\omega} \sin \beta_{\omega\omega}, \quad (26)
\]

and in addition, at the ribline from the shoulder to the bag net, we have

\[
f_{\alpha\epsilon} = f_{\epsilon\omega} \cos \beta_{\epsilon\omega}, \quad (27)
\]

5. **TRANSVERSAL DISTANCE**
As regards the transversal distance between the danlenos, we have geometrically

\begin{align}
Y_h &= y_{wh} + y_{wm} + y_h, \\
Y_m &= y_{wm} + y_{wmm} + y_m,
\end{align}

where

\[ y_m = L, \sin \beta_{em} + L_0. \]

**Numerical Computation**

Thirty (30) equations which contain forty-seven (47) variables are thus obtained. If, however, the twine, mesh size, hang-in ratio, float attached to the headline as well as the towing speed are given, we can evaluate the following parameters:

\[ K_{n1}, K_{n2}, K_{n3}, K_{t1}, K_{t2}, K_{t3}, \phi, T_h \text{ and } T_b. \]

From the layout of webbings we have numerical values of \( L_w, L_{ww}, L_h, L_s, L_c, L_0, \) and \( H. \)

Hence the following thirty-one (31) variables will remain undetermined:

\[ f_{wh}, f_{wm}, f_{wmm}, f_{wxh}, f_{wsm}, f_{wsw}, f_{xem}, f_{xsm}, T_s, \]

\[ \beta_{wh}, \beta_{wm}, \beta_{wmm}, \beta_{wxh}, \beta_{wsm}, \beta_{xem}, \beta_{xsm}, \beta_h, \beta_e, \]

\[ y_{wh}, y_{wm}, y_{wmm}, y_{wxh}, y_{wsm}, y_{xem}, y_{xsm}, y_h, y_m, R, Z. \]

Then if one of them is given, or a relation between these variables representing the towing condition is given, we can completely determine all unknowns by solving these equations simultaneously. In order to get more generality in the solutions, the variables designating the forces in the equations should be divided by \( H L_h K_{n2} (=f), \) those designating force per unit area by \( K_{n2} (=K), \) and those representing the length by \( L_h (=L) \) or by \( H. \) Thus a set of dimensionless equations is obtained corresponding to the above equations as follows:

\begin{align}
\frac{f_{wh}}{f} (\beta_{wh} - \beta_{wh}) &= \frac{1}{2} \frac{L_w}{L} \frac{K_{n1}}{K} \sin \beta_{wsh}, \\
\frac{f_{wh}}{f} - \frac{f_{wsh}}{f} &= \frac{1}{2} \frac{L_w}{L} \frac{K_{t1}}{K} \cos \beta_{wsh}, \\
\frac{y_{wh}}{L} &= \frac{L_w}{L} \cos \beta_{wh} - \cos \beta_{wsh}, \\
\frac{f_{wm}}{f} (\beta_{wm} - \beta_{wmm}) &= \frac{1}{2} \frac{L_w}{L} \frac{K_{n1}}{K} \sin \beta_{wsm}, \\
\frac{f_{wm}}{f} - \frac{f_{wmm}}{f} &= \frac{1}{2} \frac{L_w}{L} \frac{K_{t1}}{K} \cos \beta_{wsm}, \\
\frac{y_{wm}}{L} &= \frac{L_w}{L} \cos \beta_{wmm} - \cos \beta_{wm}, \\
\frac{f_{wsh}}{f} (\beta_{wsh} - \beta_{wmm}) &= \frac{1}{2} \frac{L_w}{L} \sin \beta_{wsh},
\end{align}
\[
\begin{align*}
\frac{f_{wuh}}{f} - \frac{f_{wsh}}{f} &= \frac{1}{2} \frac{L_{wu}}{L} \frac{K_2}{K} \cos \beta_{wuh}, \quad (38) \\
\frac{y_{wuh}}{L} &= \frac{L_{wu}}{L} \frac{\cos \beta_{wuh} - \cos \beta_{wsh}}{\beta_{wuh} - \beta_{wsh}}, \quad (39) \\
\frac{f_{wuh}}{f} (\beta_{wuh} - \beta_{wsh}) &= \frac{1}{2} \frac{L_{wu}}{L} \sin \beta_{wuh}, \quad (40) \\
\frac{f_{wuh}}{f} - \frac{f_{wsh}}{f} &= \frac{1}{2} \frac{L_{wu}}{L} \frac{K_2}{K} \cos \beta_{wuh}, \quad (41) \\
\frac{y_{wuh}}{L} &= \frac{L_{wu}}{L} \frac{\cos \beta_{wuh} - \cos \beta_{wsh}}{\beta_{wuh} - \beta_{wsh}}, \quad (42) \\
\beta_{wuh} &= \beta_{wsh}, \quad (43) \\
\beta_{wsh} &= \beta_{wuh}, \quad (44) \\
\frac{f_{wuh}}{f} - \frac{f_{wsh}}{f} &= \frac{\sqrt{2}}{4} \frac{L_3}{L} \frac{K_2}{K} \cos \beta_{wsh}, \quad (45) \\
T_e &= \frac{1}{2} \left( 1 + \frac{\sqrt{2}}{2} \frac{H}{L} \frac{L_3}{L} \frac{K_2}{K} \right) + \frac{1}{4} \left\{ \left( \frac{H}{L} + \frac{L_3}{L} \right) \left( 1 - \frac{\sqrt{2}}{2} \frac{L_2}{L} \right) + \left( \frac{L_2}{L} \right)^2 \right\} \frac{K_2}{K} + \frac{T_h}{T}, \quad (46) \\
\frac{f_{wsh}}{f} &= \frac{1}{4} \left\{ \left( 1 + \frac{L}{L} \frac{L_3}{L} \frac{K_2}{K} \right)^2 \left( 1 - \frac{\sqrt{2}}{2} \frac{L_2}{L} \right) + \left( \frac{L_2}{L} \right)^2 \frac{K_2}{K} + \frac{L_3}{L} \frac{K_3}{K} + \frac{\pi}{4} \left( \frac{L_2}{L} \right)^2 \frac{K_3}{K} \right\}, \quad (47) \\
\frac{f_{wsh}}{f} \sin \beta_e &= \frac{T_h}{T} \frac{R}{L} \frac{L}{H}, \quad (48) \\
\frac{T_h}{T} &= \frac{T_e}{T} \tan \beta_e, \quad (49) \\
1 &= \frac{R}{L} \left( \frac{\pi}{2} - \beta_h \right), \quad (50) \\
\frac{y_h}{L} &= \frac{R}{L} \cos \beta_h, \quad (51) \\
\frac{Z}{L} &= \frac{R}{L} \left( 1 - \sin \beta_h \right) \sin \beta_e, \quad (52) \\
\frac{f_{wsh}}{f} &= \frac{f_{wsh}}{f} \cos \beta_e, \quad (53) \\
\frac{f_{wsh}}{f} &= \frac{f_{wsh}}{f}, \quad (54) \\
\frac{f_{wsh}}{f} \sin \beta_{wsh} &= \frac{f_{wsh}}{f} \sin \beta_h, \quad (55) \\
\frac{f_{wsh}}{f} \sin \beta_{wsh} &= \frac{f_{wsh}}{f} \sin \beta_{wsh}, \quad (56) \\
\frac{f_{wsh}}{f} \sin \beta_{wsh} &= \frac{f_{wsh}}{f} \sin \beta_{wsh}, \quad (57) \\
\frac{y_{wsh}}{L} &= \frac{L}{L} \sin \beta_{wsh} + \frac{L_3}{L}, \quad (58) \\
\frac{Y_h}{L} &= \frac{y_{wsh}}{L} + \frac{y_{wsh}}{L} + \frac{y_h}{L}, \quad (59)
\end{align*}
\]
\[
\frac{Y_m}{L} = \frac{y_{w_m}}{L} + \frac{y_{w_w}}{L} + \frac{y_m}{L}.
\]  

(60)

Practical procedure of numerical calculation is the same as in the preceding paper\textsuperscript{3}.

**Characteristic Curve of Trawl Net**

The characteristic curve of the two-seam net was drawn on the basis of the results of numerical computations. Similar to the preceding paper\textsuperscript{3}, the important behavioral character of trawl net in practical operation is the relationship between the towing force applied to the net and its working performance at different

![Graph](image)

*Fig. 4. Theoretical relationship of horizontal spread (Y/L) to towing force (magnitude $f_{w}/f$, angle $\beta_w$).*
towing speed indicated by the value of $K$ or the resistance of webbing $N_2$.

The theoretical relationship of horizontal spread of the wing end ($Y/L$) to the towing force (magnitude $f_w/f$, and angle $\beta_w$) is shown in Fig. 4. In the figure, the relationship of $Y/L$ to $\beta_{wh}$ is drawn in bold line and to $\beta_{wm}$ in dot dash line, and also $f_{wh}/f$ to $\beta_{wh}$ in bold line while $f_{wm}/f$ to $\beta_{wm}$ in dot dash line which is seen nearly parallel to the abscissa. The relationship between $f_w/f$ (sum of $f_{wh}/f$ and $f_{wm}/f$) and $\beta_w$ is shown in broken line in the figure.

The relationship of the sectional horizontal spreads which is shown in Fig. 5, i.e., $y_h/L$, $y_{wo}/L$ and $y_w/L$, is not constant at different $\beta_w$. Up to $\beta_w$ 25°, $y_h/L > y_{wo}/L > y_w/L$; $\beta_w$ 25° to 35°, $y_{wo}/L > y_h/L > y_w/L$; $\beta_w$ 35° to 63°,

![Fig. 5. Theoretical relationship of sectional horizontal spread ($y_w/L$), ($y_{wo}/L$) and ($y_h/L$) to towing angle ($\beta_w$).](image)

![Fig. 6. Theoretical relationship of angle of force at headline ($\beta_{wh}$) to angle of force at ribline ($\beta_{wm}$).](image)
The wing under towing condition does not stand vertically to the bottom as shown in Fig. 6 by the result of numerical computation. In the case of towing direction below 45°, $\beta_{wh}$ is smaller than $\beta_{wm}$, that is, the headline is deviated inward from the vertical line of the ribline. On the contrary, in the case of towing direction above 45°, $\beta_{wh}$ is larger than $\beta_{wm}$, that is, the headline is deviated outward from the vertical line of the ribline.

The theoretical relationship of the elevation of headline ($Z/L$) to the angle of forces $\beta_{wh}$ and $\beta_{wm}$ is shown respectively in Figs. 7 and 8. And also the
theoretical relationship between the elevation of headline and horizontal spread $Y_h/L$ and $Y_w/L$ is shown in Figs. 9 and 10, respectively.

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Fig. 8. Theoretical relationship of the elevation of headline ($Z/L$) to angle of force ($\beta_{wm}$).
Fig. 9. Theoretical relationship of the horizontal spread $(Y_h/L)$ to the headline elevation $(Z/L)$.

Fig. 10. Theoretical relationship of ribline horizontal spread $(Y_m/L)$ to headline elevation $(Z/L)$.

Experiment

To verify the above calculated values, experiments of the model net were carried out in a circulating water tank with an effective area of 80cm by 2 m. The performance of this tank was already described in a previous paper$^{6}$.

The dimensions of the model net used for computation of observed values
were as follows:

\[ D = 0.03 \text{cm}, \quad L_1 = 1.0 \text{cm}, \quad L_2 = 0.8 \text{cm}, \quad L_3 = 0.5 \text{cm}, \]
\[ \frac{D}{L_1} = 0.03, \quad \frac{D}{L_2} = 0.0375, \quad \frac{D}{L_3} = 0.06, \quad \phi = 45^\circ, \]
\[ H = 4.0 \text{cm}, \quad L_w = 14.2 \text{cm}, \quad L_{ww} = 13.7 \text{cm}, \quad L_h = 9.7 \text{cm}, \]
\[ L_s = 8.0 \text{cm}, \quad L_c = 11.4 \text{cm}, \quad L_{cc} = 7.0 \text{cm}, \quad L_o = 4.0 \text{cm}, \]
\[ T_h = 0.1429 V^2, \quad T_b = 222.26, \]
\[ K_{t1} = 0.018 V^2, \quad K_{t2} = 0.0225 V^2, \quad K_{t3} = 0.036 V^2, \]
\[ K_{n1} = 0.036 V^2, \quad K_{n2} = 0.045 V^2, \quad K_{n3} = 0.072 V^2. \]

The wing ends of the net were attached to a bamboo bridle (danleno) whose legs were then connected to a bamboo beam (0.4 cm in diameter and 52 cm in length). The bamboo bridle kept the wings upright, whereas the bamboo beam kept the spread of the net.

The length, \(2Y_{bb}\), between the two points of connection of the bridle legs on the beam can be controlled arbitrarily. From these two points of attachment, two lines are connected to a warp. The warp goes through the pulley of the L-Bar and is connected to a strain gauge (Model 120 T-500 C, Kyowa Electronic Instruments Co., Ltd.) as shown in Fig. 11. The strain gauge was then connected to an oscillograph (Model WTR 281, Watanabe Instruments Corp.) where the resistance of the model net was recorded. A current meter (Model CM-IB, Toho Dentan Co. Ltd.) was mounted just overhead the model net.

Fig. 11. Arrangement of model net under test in experimental tank.
The net was subjected to water flows ranging from 10 cm/sec to 47 cm/sec and data were recorded at 8 intervals. The spread of the net was changed by adjusting $Y_{bb}$ at intervals of 5 cm for every series of water flows.

The beam was also subjected to a series of water flows and its resistance was subtracted from the corresponding resistance of the model net with its accessories.

Pictures were taken for every water flow measurement from the top and from the side through the observation window, simultaneously. A transparent bottom box was mounted on the water surface just above the model net to eliminate wave motion which distorts the picture taken from the top.

The top view pictures were projected to measure $Y$, $y_w$, $y_{ww}$, $y_h$, $\beta_w$, $\beta_{ww}$, $\beta_{ws}$ and $\beta_{tw}$. The side view picture were also treated the same way to measure $Z$ and $\beta_e$.

**Result and Discussion**

Since the observed values of $\beta_w$ ranged only from $5^\circ$ to $25^\circ$, this portion was magnified together with the theoretical curve as shown in Fig. 12. The observed $Y/L$ values were plotted thereon showing a good agreement with the theoretical

![Graph](image-url)

**Fig. 12.** Observed and calculated values of horizontal spread ($Y/L$) in relation to towing force ($\beta_w$).

**Fig. 13** Observed and calculated values of sectional headline horizontal spread ($y_w/L$, $y_{ww}/L$, $y_h/L$) in relation to towing force ($\beta_w$).
curve.

$Y/L$ is a transversal distance of the wing extremities and this alone does not show the general configuration of the entire headline. A headline of known $Y/L$ may have a "V" or "U" configuration. To get a clear picture of the headline configuration, the observed values of the sectional horizontal spreads, $y_w/L$, $y_{ww}/L$ and $y_h/L$ were also plotted on their corresponding theoretical curves and this too presented a good agreement as shown in Fig. 13.

It was observed that the general configuration of the headline was not maintained at different $\beta_w$ as predicted by the theoretical curves. Within the experimental range of $\beta_w$, the observed and calculated values coincided. Fig. 14 shows some representative reproduction of actual headline configurations of the model net at different $\beta_w$ ($5^\circ$, $10^\circ$, $25^\circ$) which agree with corresponding theoretical values.

The observed values of the elevation of the headline ($Z/L$) is less than the calculated values, and the difference increases at higher water velocities as shown in Fig. 15. The seaming line at the sides of the square are considered to influence the force distribution on the square which exerts force on the headline. It is suggested that the tension applied on the headline at the square section needs further detailed examination.

For the towing force ($f_w/f$) at less than $20^\circ$ towing angle ($\beta_w$), the calculated and observed values as shown in Fig. 16 are in agreement although the latter cluster above and below the characteristic curve. However, at $\beta_w$ more than
20°, the observed values become larger than the calculated values.

The good coincidence of the observed and calculated values for the horizontal spread and towing force of the model net shows the validity of the theoretical approach in studying the mechanical characteristics of two-seam trawl net.

Expenses for executing this study were partly defrayed by the Ministry of Education of Japan.

Fig. 16. Observed and calculated values of the towing force (\(f_{\text{tr}}/f\)) in relation to the towing angle \(\beta_{\text{t}}\).

Reference


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