Studies on the Mechanical Characters of Patti-ami—I. On the Tensions on Head Line and Foot Rope

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(Received Dec. 16, 1966)

In the coastal waters of Japan, a two-boat drag net called Patti-ami (or Batti-ami) is in use for catching anchovy, sand lance, etc. This net is operated in all depths of water from the bottom to the surface. In case of mid-water operation, the net is suspended from floats on the water surface. Ise and Mikawa bays are one of the main fishing grounds of this fishery, where about seventy pairs of boats are operated. As shown in Fig. 1 the net used in this waters consists of three parts, namely, wing, bag and intermediate parts. The wing is composed of four or five different kinds of webbings of large-sized mesh and its length reaches 200 m or more. The bag net whose mouth circumference length is about 45 m is made up of minnow netting (moji-ami in Japanese, small meshed textile like woven netting of warp and woof). The intermediate part, through the mediation of which the above two parts are connected, is constructed of upper, lower and side nets. The amount of webbing used in this part is considerably small as compared with those used in other two parts.

In constructing the net, each chief fisherman pays attention to several points, such as the mode of connecting and sewing the webbing, the ratio of slackenning of web-

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bing. There exist, however, some differences of opinion among them on the way of making an effective net. Such a state is caused by the fact that the relation between the net design and the net form in action has not yet been clarified sufficiently.

This paper, as the first step to get the detailed knowledge of the relation mentioned above, deals with the variation of the tensions on the head line and the foot rope resulted from the change of the mode of connecting the wing with the bag net.

Experiments

The model net used in this study is reduced to 1/90 of the full scale of a certain typical net excepting the length of wing which is shortened less than its calculated length owing to the scale of the experimental tank. Mesh and twine sizes of the model net are determined arbitrarily (not necessarily suppose a full-scale net). The layout of webbings and the main scales are shown in Fig. 2. As shown in this figure the wing of the model net consists of two different kinds of webbings, the forward part is of larger mesh than the rear part.

As to the mode of connection between the wing and the bag net, the following two cases were chosen: (1). The case which the centre line of the wing is on a level with the lateral centre line of the bag net; (2). The case which the centre line of the wing is 3.5 cm above the lateral centre line of the bag net (Fig. 3).
In each case, the net was set in the experimental tank of circulating type so as to hold the constant distance of wing tips (52 cm). Then the tensions on the head line and the foot rope under various current velocities were measured and the net form were photographed from above and side. For the measurements of the tensions in the net the circular-arc-shaped pick-up on which the strain gage is stucked was used. This pick-up was set on the front end of the head line or of the foot rope. The tensions detected by pick-up was led to the pen oscillograph to be recorded (Fig.

![Fig. 5. Tensions on the head line (—×—) and the foot rope (—•—).](image)

![Fig. 6. The relationship between the velocity of current and the resisting force of the bag net. Different marks ○, × and • denote the case where the ratios of the mouth height to the mouth width are 1.0, 0.75 and 0.54 respectively.](image)
4). The results of measurements are shown in Fig. 5. It can be seen from this figure that in the case (1) the size of tension on the head line is nearly equal to that on the foot rope, but in the case (2) the size of tension on the head line is smaller than that on the foot rope. As regards the net form, we can find the differences between the two cases as well; that is, the mouth height of net, which means the vertical distance from the forward end of the upper net to the lower net, is larger in the case (2) than in the case (1) but the mouth height of the bag net shows contrary relation.

Since the bag of the model net is made of gauzy netting of extremely fine mesh, TAUTI’s formula for the resistance of netting, which will be employed in the subsequent analysis, will be inapplicable to this part. Thus we measured experimentally the resistance of the bag net for three kinds of mouth shape. The result is shown in Fig. 6, from which we can find only a little differences in resistance for these three mouth shapes and the relation between resistance R and current velocity V can be generally expressed as $R = 0.155V^2$ (in g.wt, cm/sec unit).

**Consideration on Analytical Method**

KAWAKAMI and others, who had continued a series of analytical studies on the drag net, showed that the distribution of tension in a gear or the height of net mouth in working condition could be predicted by numerical computation. Subsequently, KAWAKAMI simplified the principle of theoretical analysis by approximating the configurations of the wing to circular arcs of different radii.*

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* Unpublished
net is transmitted to the head line and the foot rope of the rear part of the wing through the upper net, the lower net and the rear wing net. The ratio of the force transmitted to the head line to that transmitted to the foot rope is equal to the ratio of the circumferential length of the bag net mouth connected with the upper net and the upper half of the wing net to that connected with the lower net and the lower half of the wing net; 2. The force acting on the rear end of the upper net (lower net) is transmitted by half to its forward end which is concentrated to the tail end of the head line (foot rope). Thus this transmitted force acts concentrically on this tail end.

As the mechanical situations and the geometrical shape may be symmetrical about the centre line, we consider the stabord side of net. The top and side view of the net with the geometrical and mechanical quantities is shown in Fig. 7.

As shown in Fig. 2, the depth of the forward part of the wing is tapered down near the extremity. We replace the shape of this part with trapezoid whose dimensions are equivalent to original one. Its mean depth is 2h₁. The rear part of the wing has the depth of 2h₂. Now, let us confine our discussion to the upper half of the wing and assume that the resisting force acting on the webbing of the upper half is transmitted directly to the head line. Let S₁ and S₂ be the length of the head line of the forward and rear parts whose configurations are approximated to a part of circular arcs of different radii. Let F₁, F₂ and F₃ be the tensions at the forward end of the head line, at the joining point of two parts and at the rear end of the head line respectively and let θ₁, θ₂ and θ₃ be respectively their angles deviated from the direction of current. Let y₁ and y₂ be the transversal distance between the extremities across the current in the forward part and that in the rear part respectively. Let R₁ and R₂ be respectively the forces acting on the head line of the rear part and on the tail end of the head line in the direction of current, both of which are due to the resisting force of the bag net. Then if we assume that the upper half of the wing has constant depth h₁, h₂ and moreover if we neglect the resistance of the webbing of the intermediate part and of the head line including the floats as compared with that of the wing and the bag net, the equations of equilibrium can be written approximately as

\[ F₁(θ₂−θ₁)=h₁S₁K₁₁ sin θ₁, \]
\[ F₁−F₂=h₁S₁K₁₁ cos θ₁, \]
\[ F₂(θ₃−θ₂)=h₂S₂K₁₂ sin θ₂+R₁ sin θ₂, \]
\[ F₂−F₃=h₂S₂K₁₂ cos θ₂+R₁ cos θ₂, \]
\[ F₃ cos θ₃=R₂ \]

and the following two relations are obtained geometrically:

\[ y₁=S₁\frac{cos θ₁−cos θ₂}{θ₂−θ₁}, \]
\[ y₂=S₂\frac{cos θ₂−cos θ₃}{θ₃−θ₂}, \]
In the equations (1)-(4), $K_n1$ and $K_t1$ are the resisting force acting on a unit area of the webbing of the forward part when it is normal and parallel to the current of velocity $V$ respectively and $K_n2$ and $K_t2$ are the values of $K_n$ and $K_t$ for the webbing of the rear part respectively. According to TAUTI's formula\(^4\) neglecting the resistance of knot, $K_n$ and $K_t$ are given respectively by

\[
K_n = kV^2D/L \sec \varphi \csc \varphi ,
\]

\[
K_t = kV^2D/L \tan \varphi ,
\]

where $D$ and $L$ are the diameter of the netting twine and the bar-length of the mesh respectively, $2\varphi$ the angle between the adjacent bars of mesh, $V$ the velocity of current, and $k$ the coefficient of resistance of netting twine.

If we divide all the forces by $K_n1h_1S_1$ and all the lengths by $S_1+S_2$, respectively, in the preceding equations (1)-(7), we get 7 dimensionless equations.

By the same procedure we can get the similar equations for the lower half of the wing. As shown in Fig. 3, two cases were chosen as the mode of connection between the wing and the bag net. Accordingly we have 4 sets of dimensionless equations.

Now, as an example, we show a set of dimensionless equations for the upper half of the wing in the case (1):

\[
\frac{F_1}{F} \cdot (\theta_2-\theta_1) = \sin \theta_1 , \quad (1')
\]

\[
\frac{F_1-F_2}{F} = 0.172 \cos \theta_1 , \quad (2')
\]

\[
\frac{F_2}{F} \cdot (\theta_4-\theta_3) = 0.954 \sin \theta_2 , \quad (3')
\]

\[
\frac{F_3-F_2}{F} = 0.571 \cos \theta_3 , \quad (4')
\]

\[
\frac{F_3}{F} \cos \theta_4 = 0.105 , \quad (5')
\]

\[
\frac{y_1}{S} = 0.814 \frac{\cos \theta_4-\cos \theta_2}{\theta_4-\theta_2} , \quad (6')
\]

\[
\frac{y_2}{S} = 0.186 \frac{\cos \theta_2-\cos \theta_3}{\theta_2-\theta_3} , \quad (7')
\]

where $F$ and $S$ are equated to $K_n1S_1h_1$ and $S_1+S_2$ respectively.

**Results Obtained by Computation**

In the above dimensionless equations (1')-(7'), if $\theta_4$ is given, the other 7 dimensionless parameters can be obtained numerically by solving these equations simultaneously. Thereupon, we calculate the values of $y_1/S$ and $y_2/S$ for the different values of $\theta_4$. In the foregoing experiment the distance $y(=y_1+y_2)$ was fixed and the distance $y_1$ and $y_2$ can be measured easily from the photograph. Thus, using these values, we can decide:
the value of $\theta_1$ first and successively the values of the other dimensionless parameters in the experimental conditions. These values are listed in Table 1 together with those of the foot rope. Similarly we can get these values for the case (2), but here we show only the values of $F_1/F$: 0.723 for the head line and 1.05 for the foot rope.

Table 1. Calculated values of eight dimensionless parameters for the case (1).

<table>
<thead>
<tr>
<th></th>
<th>$F_1/F$</th>
<th>$F_2/F$</th>
<th>$F_3/F$</th>
<th>$\theta_1$</th>
<th>$\theta_2$</th>
<th>$\theta_3$</th>
<th>$y_1/S$</th>
<th>$y_2/S$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head line</td>
<td>0.870</td>
<td>0.700</td>
<td>0.174</td>
<td>$10^\circ 37'$</td>
<td>$22^\circ 46'$</td>
<td>$53^\circ 0'$</td>
<td>0.230*</td>
<td>0.113*</td>
</tr>
<tr>
<td>Foot rope</td>
<td>0.894</td>
<td>0.725</td>
<td>0.251</td>
<td>$10^\circ 57'$</td>
<td>$23^\circ 07'$</td>
<td>$51^\circ 0'$</td>
<td>0.233*</td>
<td>0.112*</td>
</tr>
</tbody>
</table>

* The values in the parentheses are the experimental ones.

Fig. 8. The relation between the calculated values and the experimental values of $F_1$.

The marks are the same as those in Fig. 5.

The comparisons of the observational values of $F_1$ under various current velocities with the calculated ones are shown in Fig. 8. In each case, the coincidence of both values is tolerably satisfactory. Thus, the assumptions and the method of treatment above-mentioned seem to be of practical use.

The writer wishes to express his hearty thanks to Prof. T. KAWAKAMI, D. Agr., of Kyoto University for his kind guidance and revision.

References
4) M. TAUTI: ibid., 3, 1 (1934).