

# The Mechanical Study on the West Japan Small Type Tow Net

Akira KAKUI, Hideyuki NISHINOKUBI and kei NAKASAI

The mechanical characteristics of a four-seam trawl net being used in the west Japan district was studied on the basis of its construction. The authors, in this report, watched especially on the wing length of the net.

It was found that when the transversal distance between the danlenos exceeds the length of 13.6 cm in the model net and 408 cm in the practical net, the force acting on the net becomes smaller as the wing becomes longer at the towing speeds that are given in the practical fishing.

## Introduction

Many tow nets are being used in Kyushu area and Yamaguchi Prefecture. There are many different constructions among them. For instance, the wing length of the net being used in Nagasaki Prefecture is 10.7 m while that in Kagoshima Prefecture is 24.3 m.

Since, no mechanical study of the net has been made, there is no scientific basis to choose the best one among those practical nets. Therefore, in this paper, the authors intend to get the more effective net by mechanically analyzing the net that was modified from the standard net, which was presented by Kyushu-Yamaguchi Gyogyo Bunkakai<sup>1)</sup> (Kyushu-Yamaguchi Fisheries Branch Committee).

Now, in the case of researching the net, three principal factors, i. e., the transversal distance between the danlenos, the height of the net mouth, and the force acting on the net must be considered. There are other factors which influence upon the effectiveness of the net, however these three principal factors are the most important among them.

On the other hand, when the net is researched, the work of the plane net has to be investigated. The study to obtain the tension and the configuration of plane net was conducted by MIYAZAKI<sup>2)</sup> assuming that the configuration of the plane net were a catenary curve.

Another study to obtain the configuration of plane net was carried out by NAKASAI, SUZUKI and KAWAKAMI<sup>3)</sup> assuming that the configuration of the plane net could be approximated by a part of circular arcs of different curvatures or straight line.

On the basis of approximation mentioned in the latter, theoretical equations of the four-seam trawl net were presented by KAWAKAMI and NAKASAI<sup>4)</sup>, and a series of experiments were carried out in the ferro circulating water tank.

NAKASAI and FLORES<sup>5)</sup>, compared two-seam trawl net with four-seam trawl net, and got the results of the important working performance of the nets, such as elevation

of headline, spread of wings and total resistance, and showed the four-seam net to be more efficient than the two-seam net.

### Materials and Methods

The tow net in this paper is a kind of beam trawl and the model net employed in this study is shown in Fig. 1.

It is of box-shaped construction and made to a scale of one thirtieth of the natural size of the net. When the natural size of the net employed here was decided, the standard net that was presented by Kyushu Yamaguchi Gyogyo Bunkakai served as a reference.

The model net is composed of one kind of webbing and a constant rate of hang-in is made to make an angle of 90 degree ( $=2\varphi$ ) between the two adjacent bars.

The buoys made of plastic are attached only to the headline for the sake of simplicity of the theoretical equation, although there are two ways of attaching the buoys in the practical fishing nets, one is to attach both to the headline and to the seaming line of the square part and the other is to attach only to the headline.

Meanwhile, the theoretical values of the three principal factors were calculated concerning this model net at the experimental flow speeds and at the practical towing speeds.

The practical fishing net is towed at the towing speed in the range from 1 to 1.5 knots, and the flow speeds in the case of this model net were calculated according to TAUCHI's law.<sup>5)</sup>

The towing speeds are 91.1 cm/sec and 136.6 cm/sec in the case of this model net. Here we say these calculated flow speeds as the practical towing speeds. And at the time of the calculation of the practical towing speeds, the wing length was changed from 3.4 cm to 10.2 cm. Simultaneously, the experiment to verify the theoretical equations was carried out at the experimental flow speeds, and compared the observed values with the calculated ones.

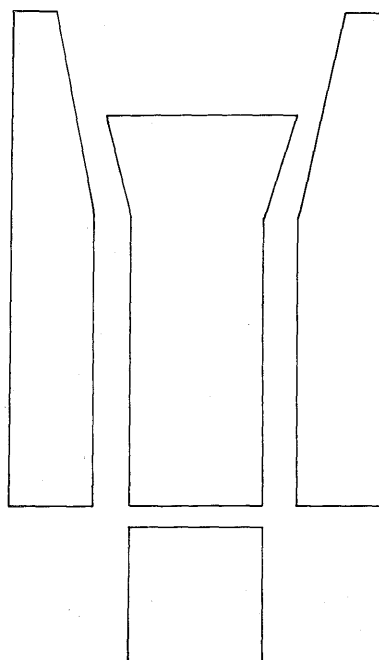


Fig. 1. Layout of experimental model net.

### Theoretical Analysis

The model net employed in this study is of box-shaped construction, and then, as the mechanical situations and the geometrical shape are symmetrical about the center line, let us treat the starboard side of the net and moreover confine discussion to the upper half of the net. The theoretical equations of the four-seam trawl net were obtained and the notations for the calculation are defined the same as in the preced-

ing paper<sup>4</sup>), and illustrated in Fig. 2.

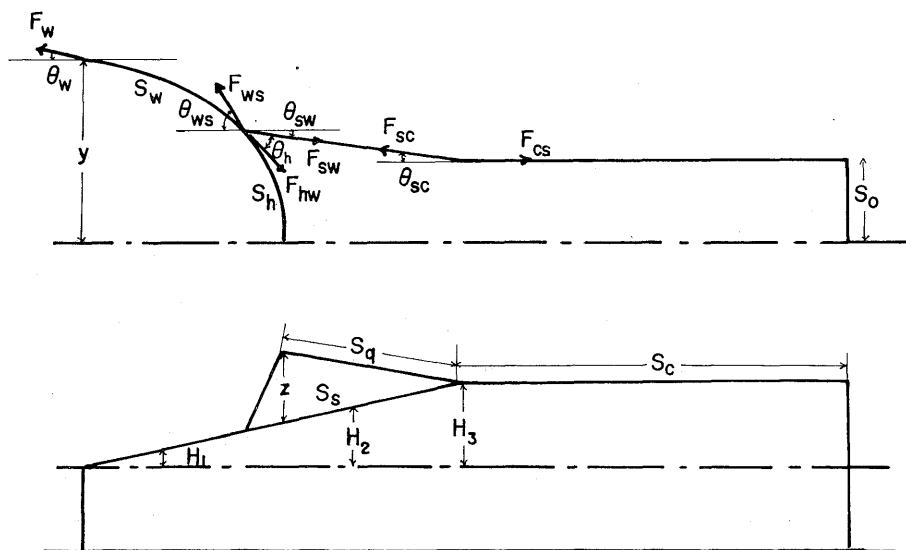


Fig. 2. Top view (upper) and side view (lower) of the model net.

**Theoretical equations of the four-seam trawl net**

wing

$$\frac{F_w}{F} (\theta_{ws} - \theta_w) = \frac{H_1}{H} \frac{S_w}{S} \frac{K_n}{K} \sin \theta_{ws} \tag{1}$$

$$\frac{F_w}{F} - \frac{F_{ws}}{F} = \frac{H_2}{H} \frac{S_w}{S} \frac{K_t}{K} \cos \theta_{ws} \tag{2}$$

$$\frac{Y_w}{S} = \frac{S_w}{S} \frac{\cos \theta_w - \cos \theta_{ws}}{\theta_{ws} - \theta_w} \tag{3}$$

Square, shoulder and codend

$$\theta_{sw} = \theta_{sc} \tag{4}$$

$$\frac{F_{sw}}{F} - \frac{F_{sc}}{F} = \frac{S_s}{S} \frac{K_t}{K} \cos \theta_{sc} \tag{5}$$

$$\frac{T_s}{T} = \frac{1}{2} \frac{S_q}{S} \left( 1 + \frac{S_o}{S} \right) \frac{K_t}{K} + \left( \frac{S_o}{S} \right)^2 \cot \varphi \frac{K_t}{K} + \frac{T_h}{T} \tag{6}$$

$$\frac{F_{cs}}{F} = \frac{H_3}{H} \frac{S_c}{S} \frac{K_t}{K} \frac{S_o}{S} (S_o - S_o \cot \varphi) + \frac{S_o}{S} \frac{H_3}{H} \frac{K_n}{K} \tag{7}$$

Headline

$$\frac{F_{hw}}{F} \sin \theta_e = \frac{T_b}{T} \frac{R}{S} \frac{S_h}{R} \tag{8}$$

$$\frac{T_b}{T} = \frac{T_s}{T} \tan \theta_e \tag{9}$$

$$1 = \frac{R}{S} \left( \frac{\pi}{2} - \theta_h \right) \tag{10}$$

$$\frac{Y_h}{S} = \frac{R}{S} \cos \theta_h \tag{11}$$

$$\frac{Z}{S_h} = \frac{R}{S_h} (1 - \sin\theta_h) \sin\theta_e \quad (12)$$

### Equilibrium condition at the seaming line

$$\tan\theta_{ws} = \frac{(F_{sw}/F) \sin\theta_{sw} + (F_{hw}/F) \sin\theta_h}{(F_{sw}/F) \cos\theta_{sw} + (F_{hw}/F) \cos\theta_h \cos\theta_e} \quad (13)$$

$$\left(\frac{F_{ws}}{F}\right)^2 = \left(\frac{F_{sw}}{F} \sin\theta_{sw} + \frac{F_{hw}}{F} \sin\theta_h\right)^2 + \left(\frac{F_{sw}}{F} \cos\theta_{sw} + \frac{F_{hw}}{F} \cos\theta_h \cos\theta_e\right)^2 \quad (14)$$

$$\frac{F_{cs}}{F} = \frac{F_{sc}}{F} \cos\theta_{sc} \quad (15)$$

### Transversal distance

$$\frac{Y_h}{S} = \frac{S_s}{S} \sin\theta_{sc} + \frac{S_o}{S} \quad (16)$$

$$\frac{Y}{S} = \frac{Y_w}{S} + \frac{Y_h}{S} \quad (17)$$

In order to get more generality in the solutions, the variables designating the forces in the equations were divided by  $H_2 S_h K_n (=F)$ , those designating force per unit area by  $K_n (=K)$ , and those representing the length by  $S_h (=S)$ , and in the theoretical equations of the four-seam trawl net,  $K_n$  and  $K_t$  are the forces acting on the unit area of the plane net by perpendicular current and parallel current, respectively.  $T_h$  is the resistance of the headline per unit length including the floats attached to it.

$\theta_h$  in the equation (6) is the angle made by the direction of flow and the direction of the tension in the headline, and that is the same as the angle made by the radius of circular arc  $S_h$  and the line connecting the two end points of the headline of the square.

And in case the values of the notations necessary for computation are given below, these theoretical equations can be solved when the variables - flow speed,  $\theta_h$  - are given as the initial conditions.

### Experiment

The model net, the dimensions of which are shown below, was employed in the experiment to verify the theoretical values.

$$\begin{aligned} H_1 &= 1.3\text{cm}, H_2 = 3.3\text{cm}, H_3 = 5.1\text{cm}, S_w = 6.8\text{cm}, S_s = 16.9\text{cm}, S_h = 8.5\text{cm} \\ S_c &= 23.7\text{cm}, S_q = 17.0\text{cm}, S_o = 5.1\text{cm}, D \text{ (diameter of twine)} = 0.03\text{cm} \\ L \text{ (bar length)} &= 0.8\text{cm}, T_b = 317.05, T_h = 0.2038V^2, K_t = 0.0225V^2, K_n = 0.045V^2. \end{aligned}$$

The model net has bamboo beam in front of the bridles. On the beam, there are two attachments connecting the lines from bridles and the distance between these attachments can be changed arbitrarily.

In this experiment, the distance was changed from 37.5 cm to 20 cm at interval of 2.5 cm to every series of flow speed of water.

The flow speed in the circulating water tank was changed from 4.7 cm/sec to 46 cm/sec.

The two lines attached to the beam are connected to the warp which goes through

the pulley to the strain gauge (Model 120T-500C, Kyowa Electronic Instruments Co., Ltd.). The strain gauge is connected to the amplifier (DPM-1N W6170, Kyowa Electronic Instruments Co., Ltd.) and the amplifier is connected to the oscillograph (TYPE WTR 281 WATANABE INSTRUMENTS CORP) by which the force acting on the net is recorded. Those instruments are in Fig. 3.

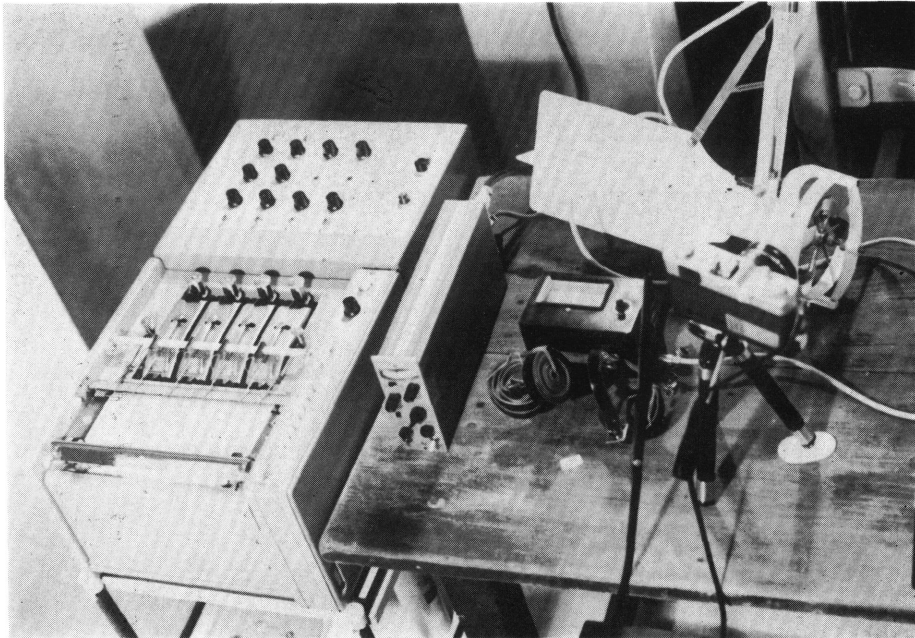


Fig. 3. Instruments; linear corder, amplifier flow meter and camera from left to right.

The height of the net mouth was pictured through the observation window at the side of the water tank and the transversal distance of the wing and the angle made by the direction of current and the wing were pictured from the top simultaneously.

### Computation

As the numerical computation is some what lengthy and tedious, the theoretical equations mentioned in the theoretical analysis were calculated by the computer (FACOM 270/20).

```

C   THEORETICAL EQUATIONS OF THE FOUR-SEAM TRAWL NET
    DIMENSION V(19)
    READ (5,100) (V(I), I=1,19), A, H1, H2, H3, SW, SS, SH, SC, SQ, SO,
    1  TB, BTH, BKT, BKN
    100 FORMAT (10F5.1/9F6.1/10F5.1/4F9.4)
    A=A*6.283186/360.
    A=COS(A)/SIN(A)
    DO 2 I=1,19
  
```

```
TH=BTH*V(I)**2
AKT=BKT*V(I)**2
```

- 10 -

```
AKN=BKN*V(I)**2
T=SH*AKN
F=H2*SH*AKN
TS=((SQ*(SH+SO)*AKT)/2.+SO**2*A*AKT+TH*SH)/(T*SH)
FCS=(H3*SC*AKT+SO*(SC-SO*A)*AKT+SO*H3*AKN)/F
QE=TB/(TS*T)
QE=ATAN(QE)
SE=SIN(QE)
CE=COS(QE)
IF (I. LE. 17) GO TO 11
```

- 20 -

```
DO 1 M=1,3
D=FLOAT(M)
SW=3.4*D
11 WRITE (6,200) V(I), AKN, SW
200 FORMAT (1H1, 5X, 2HV=, F7.3, 3X, 3HKN=, F7.3, 3X, 3HSW=, F5.1)
WRITE (6,300)
300 FORMAT (1H, 5X, 2HQH, 9X, 1HZ, 9X, 1HY, 8X, 2HQW, 13X, 2HFW)
DO 3 N=1,89
QH=FLOAT(N)
QH=(QH/360.)*6.283186
```

- 30 -

```
SQH=SIN(QH)
CQH=COS(QH)
R=1./(1.570797-QH)
YH=R*CQH
S1=(YH-SO/SH)*SH/SS
C1=SQRT(1.-S1**2)
FSC=FCS/C1
FSW=FSC+SS*AKT*C1/(SH*AKN)
Z=R*(1.-SQH)*SE
FHW=TB*R*SH/(T*H2*SE)
```

- 40 -

```
FWS=SQRT((FSW*S1+FHW*SQH)**2+(FSW*C1+FHW*CQH*CE)**2)
QWS=(FSW*S1+FHW*SQH)/(FSW*C1+FHW*CQH*CE)
QWS=ATAN(QWS)
CQWS=COS(QWS)
SQWS=SIN(QWS)
FW=FWS+H1*SW*AKT*CQWS/F
QW=QWSH1*SW*SQWS/(H2*SH*FW)
YW=SW*(COS(QW)-CQWS)/(QWS-QW)/SH
QW=QW*360./6.283186
Y=YH+YW
```

- 50 -

```
WRITE(6,400) N, Z, Y, QW, FW
```

```

400 FORMAT (1H, 5X, I2, 3F10.4, F15.4)
3 CONTINUE
  IF (I. LE. 17) GO TO 2
1 CONTINUE
2 CONTINUE
  STOP
  END

```

In this FORTRAN presentation, the dimensions and the flow speeds necessary for computation are read in the line 2, and the values of  $\theta_h$  are given by DO statement in the line 28 from one degree to 89 degree at interval of one degree.

In the line 2, the nineteen flow speeds are read and the seventeen of them are the experimental flow speeds, then the remaining two - eighteenth and nineteenth - are suitable to the practical towing speeds. Thereupon, for the purpose of the calculation of the theoretical values of the three principal factors at the experimental flow speeds, the seventeen values of  $V(I)$  are employed, and when the value of  $V(I)$  is the practical towing speed, that is indicated by IF statement in the line 20, the theoretical calculation is performed as to the three cases of the wing length.

The wing lengths are 3.4cm, 6.8cm and 10.2cm, respectively, and among those three values, 6.8cm is the real wing length of the model net.

### Characteristic curves of the small type tow net

The characteristic curves of the four-seam trawl net were drawn on the basis of the results of numerical computation.

Similar to the preceding paper<sup>4)</sup>, the important behavioral character of the tow net in practical operation is the relationship between the towing force applied to the net and its working performance at different towing speeds.

The theoretical relationship of the towing force ( $F_w/F$ ) to the towing angle ( $\theta_w$ ) is shown in Fig. 4.

In the figure, the notations from **a** to **q** indicate the flow speeds from 4.7 cm/sec to 46 cm/sec as shown below.

**a**=4.7, **b**=7.4, **c**=10.0, **d**=12.7, **e**=15.3, **f**=18.0, **g**=20.6, **h**=23.3, **i**=25.9, **j**=28.6,  
**k**=31.2, **l**=33.9, **m**=36.5, **n**=39.2, **o**=41.8, **p**=44.5, **q**=46.0

As the value of  $\theta_w$  becomes smaller, the difference between the values of  $F_w/F$  become smaller for each speed and the curves converge to one point.

The theoretical relationship of the elevation of headline ( $Z/S$ ) to the towing angle ( $\theta_w$ ) is shown in Fig. 5. As seen in the figure, almost the same tendency is shown at every flow speed, that is,  $Z/S$  becomes smaller as  $\theta_w$  becomes larger.

The theoretical relationship of the horizontal spread ( $Y/S$ ) to the towing angle ( $\theta_w$ ) is shown in Fig. 6., i. e., the horizontal spread becomes wider as the flow speed increases and the curves overlap at the flow speed faster than 28.6 cm/sec. And when the beam length is fixed,  $\theta_w$  becomes smaller as the flow speed becomes faster.

The theoretical relationship of the horizontal spread ( $Y/S$ ) to the towing force ( $F_w/F$ ) is shown in Fig. 7. At the lower flow speed, the force decreases abruptly as

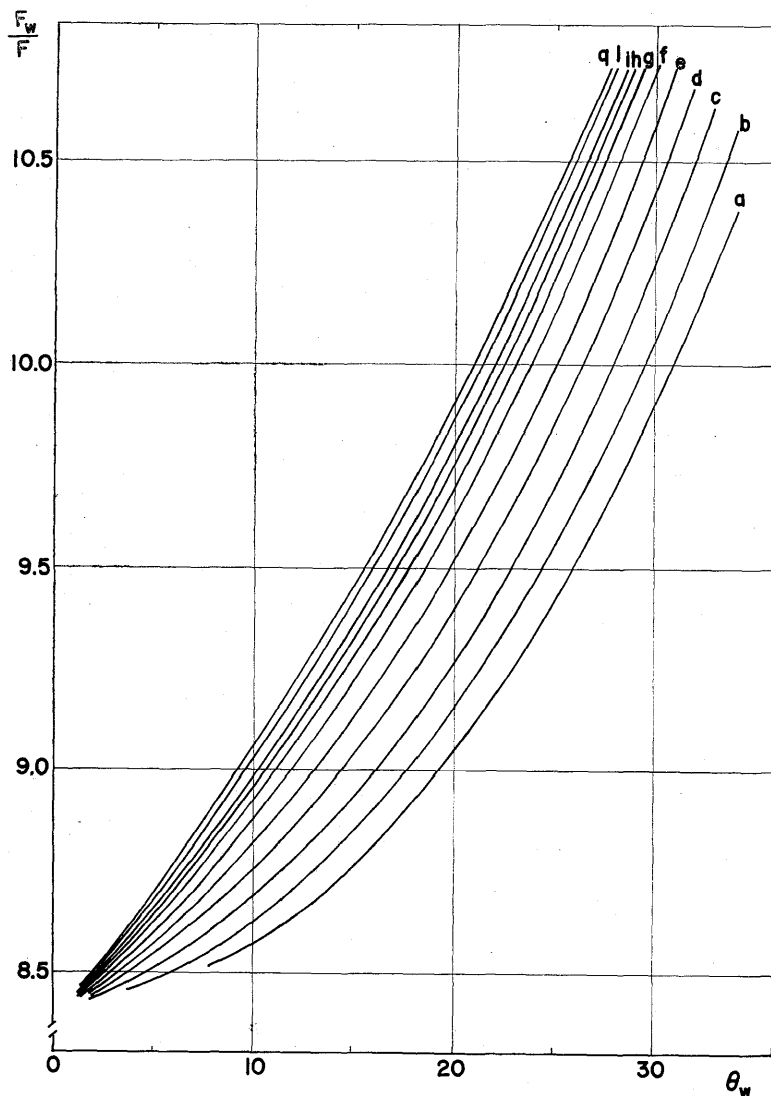


Fig. 4. The theoretical relationship of the towing force ( $F_w/F$ ) to the towing angle ( $\theta_w$ ).

the horizontal spread decreases.

The theoretical relationship of the horizontal spread ( $Y/S$ ) to the elevation of headline ( $Z/S$ ) is shown in Fig. 8.

Almost the same tendency is shown, i. e.,  $Z/S$  becomes smaller as the value of  $Y/S$  becomes larger.

### Result and Discussion

The values calculated theoretically were compared with the observed values. In all



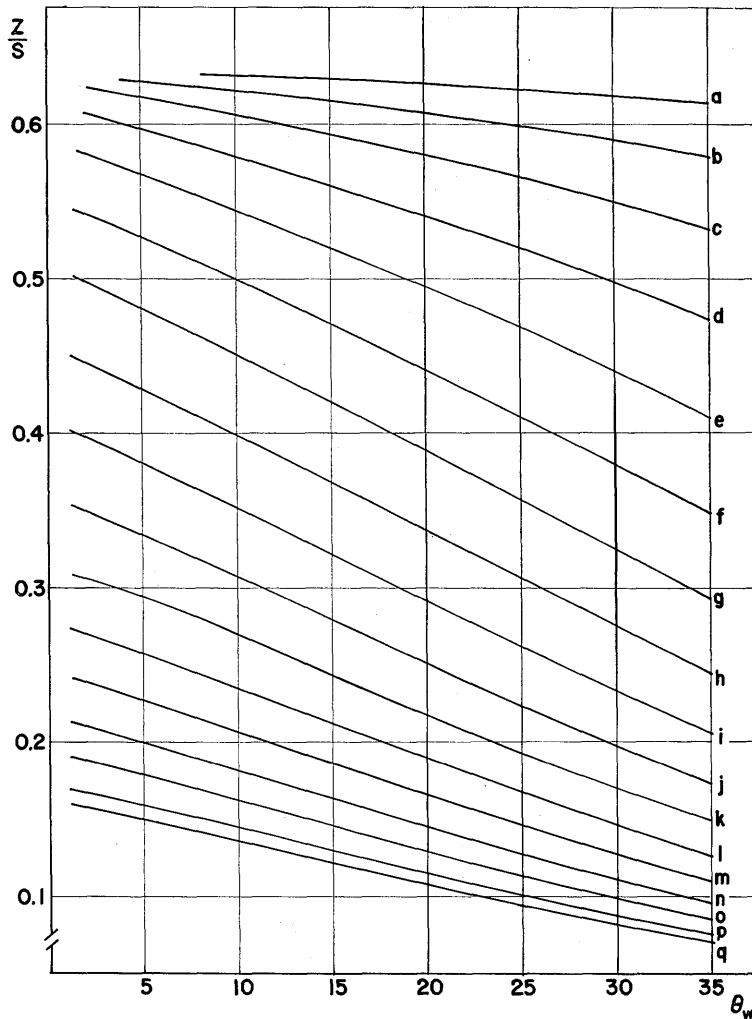


Fig. 5. The theoretical relationship of the elevation of headline ( $Z/S$ ) to the towing angle ( $\theta_w$ ).

the figures, the ordinate indicates the observed values and the abscissa indicates the calculated values.

In Fig. 9, the observed and calculated values of the towing force ( $F_w/F$ ) are shown. Generally the calculated values are bigger than the observed ones. It seems that more or less the cause is the friction of pulley. For instance, it was learned in a study of the friction of pulley that, when the tension of the model net is 90 g, the decrease due to the friction of pulley was about 10%.

Next, in regard to the comparison of the observed and calculated values of the elevation of headline ( $Z/S$ ) as shown in Fig. 10, the calculated values are bigger than the observed ones. It seems that the buoys were disproportional to the model net.

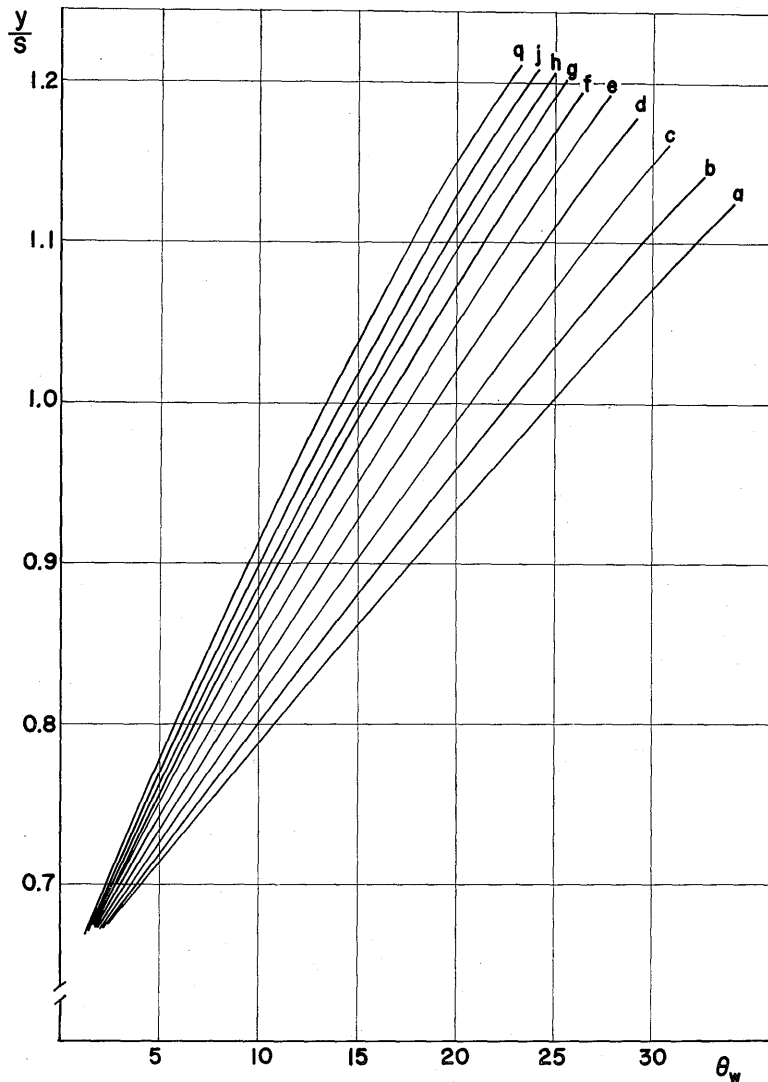


Fig. 6. The theoretical relationship of the horizontal spread ( $Y/S$ ) to the towing angle ( $\theta_w$ ).

The observed and calculated values of the horizontal spread ( $Y/S$ ) is shown in Fig. 11. Though the observed values are bigger than the calculated ones, a good agreement is shown at the faster flow speed. Furthermore, the theoretical relationship of the tow net at the practical towing speeds is shown in Figs. 12 and 13. In these figures,  $S_{w1}$ ,  $S_{w2}$  and  $S_{w3}$  indicate the three cases of the wing length as mentioned in the computation. The wing length in case of  $S_{w1}$ ,  $S_{w2}$  and  $S_{w3}$  was 3.4cm, 6.8cm and 10.2cm, respectively.

The theoretical relationship of the towing force ( $F_w/F$ ) to the horizontal spread ( $Y/S$ ) at the practical towing speeds is shown in Fig. 12. Generally, as the horizontal

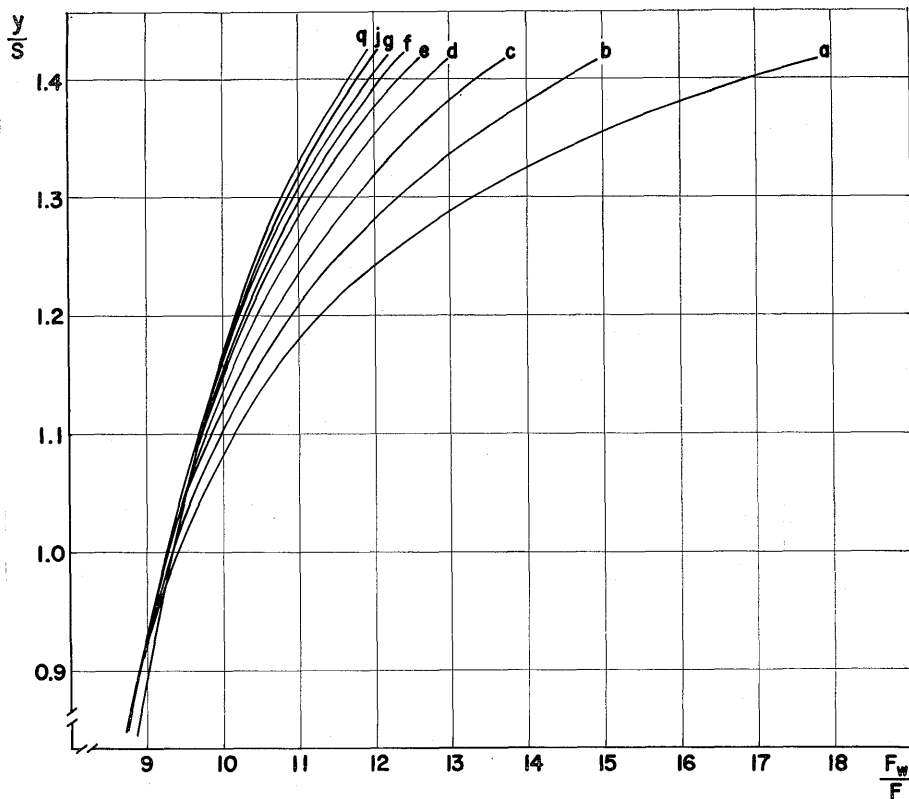


Fig. 7. The theoretical relationship of the horizontal spread ( $Y/S$ ) to the towing force ( $F_w/F$ ).

spread becomes wider, the force acting on the net becomes larger for each wing length.

And when the value of  $Y/S$  exceeds 0.8, or when the transversal distance between danlenos exceeds 13.6 cm in the model net or 408 cm in the practical net, the force acting on the net which has longer wings is smaller than the force acting on the net which has shorter wings. Certainly, when the value of  $Y/S$  exceeds 0.8, the force ( $F_w/F$ ) acting on the net is larger than 8.7, or it is equivalent to about 100 kg in the case of the practical net.

Next, in Fig. 13, the theoretical relationship of the elevation of headline ( $Z/S$ ) to the horizontal spread ( $Y/S$ ) at the practical towing speeds is shown. The lower graph indicates the relation of  $Z/S$  and  $Y/S$  at the practical towing speed of 1.5 knots and the upper one at 1 knot. Theoretically, the elevation of headline at 1.5 knots is nearly half of the elevation at 1 knot for each length of the wing.

After all, in conclusion, on the basis of the good coincidence of the observed and calculated values of the horizontal spread and the towing force, the theoretical

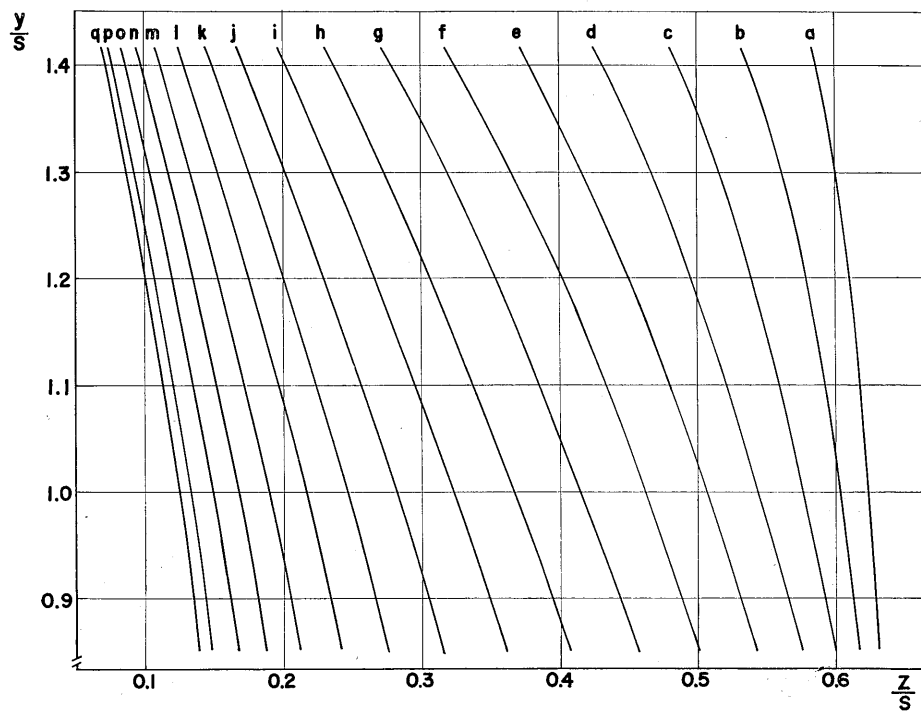


Fig. 8. The theoretical relationship of the horizontal spread ( $Y/S$ ) to the elevation of headline ( $Z/S$ ).

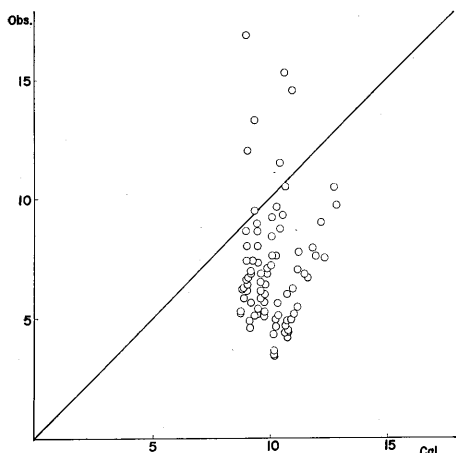


Fig. 9. The observed and calculated values of the towing force ( $F_w/F$ ).

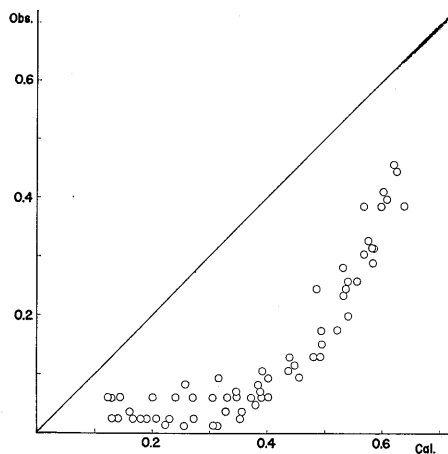


Fig. 10. The observed and calculated values of the elevation of headline ( $Z/S$ ).

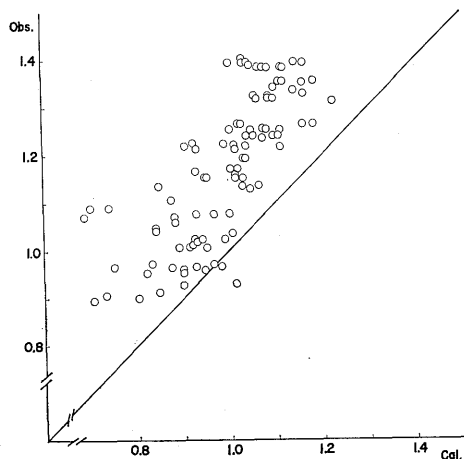


Fig. 11. The observed and calculated values of the horizontal spread (Y/S).

analysis at the practical towing speeds has enough validity. Thus when the transversal distance exceeds 408 cm, the wing length should be longer than 204 cm for less tension. However, generally speaking about a tow net whose wing length is fixed, the increase of the flow speed is followed by the decrease of the elevation of headline, the increase of the horizontal spread and the increase of the towing force.

Therefore detailed research about the relationship of the wing length, horizontal spread between the danlenos and horizontal spread at various points of the wing is needed.

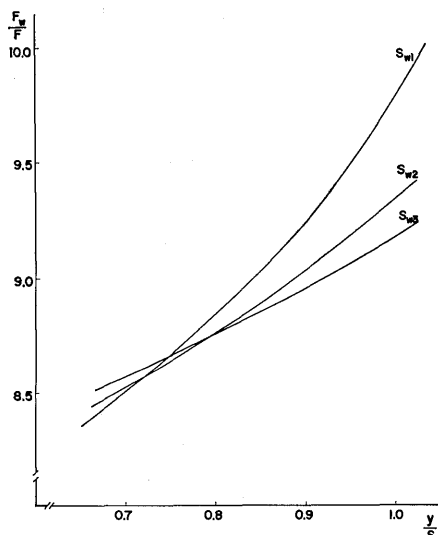


Fig. 12. The theoretical relationship of the towing force ( $F_w/F$ ) to the horizontal spread ( $Y/S$ ) at the practical towing speeds.

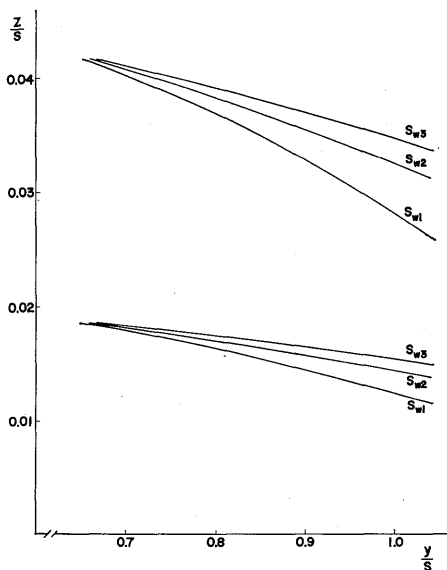


Fig. 13. The theoretical relationship of the elevation of headline ( $Z/S$ ) to the horizontal spread ( $Y/S$ ) at the practical towing speeds.

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