MECHANICAL STUDIES OF TRAWL NET IN TAIWAN

by

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1. INTRODUCTION:

The marine fisheries of Taiwan yielded catch of 410,000 metric tons in 1967 and the amount of production by trawling exceeded to 216,000metric tons which corresponded to 53.8 per-cent of overall catoh. This(1) issillustrated in the following table.

Gear Type	Catch in Metric Tons	Per Total Catch in percentage
Trawls (Otter Bull Beam Drag)	216,000	53.85
Line	95,000	23.62
Purse seines	35,000	8,65
Lift net	20,000	5.18
Gill net	19,000	4.66
Set net	2,500	0.56
Other	14,000	3.50

It has only been in the past few years that the performance of traditional trawls and otber fishing techniques have begun to understood in engineering or mathematicaltterms. In Taiwan Republic of China, the emphasis has been placed ontrawling research because of relative mportance of the trawling techniques in this country.

So far, by use of a considerable amount of experimental work involving the measurements of tensions and gear geometries under full scall fishing conditions as well as the use of small scale models, an empirical understanding of the engineering behaviour of fishing gear has been possible. Theoretical studies that have been done in several countries, especial in Japan. have tended to be concentrated on hydrodynamic properties of Parts of [nets, rope, and other individual components of fishing

gears. In some cases these have been followed up by extensive use of controlled tanks test in order to determine certain characteristics like drag, developing force, buoyancy etc. These party digested and interpreted such as geometry and drag.
It must be emphasised that practical aims of this work is efficient catching of fish, ie, by utilitying the least cost in ships, manpower, equipment and its replacement, etc, for a particular yield of fish. Exactly how many fish should be caught must, of course, rest with the lows of demand, best use of fish stocks, and many other important issues. The engineering studies of equipment used in various parts of gears should, at the earliest possibie time, be communicated and applied to commercial fleets.
In the following sections therefore, the theory and principles involved in initial pattern are explained, and later, those for existiog experiments for gear designing suitable to the boats and possible increased productivity.
In the present study, the writer treats the hydrodynamic behavior of trawling gear with a series of model and full scale testings, This paper is divided into four Chapters, First, in Chapter 2 is presented the hydrodynamic characteristics of trawling gear. The experimentally by using the model andactual trawling are in Chapter 3. Chapter 4 contains the effect of upright board and the shape of net under operation with various kinds of pulling speed and resistance of trawling gear. The author wishes to express his deepest appreciation to Professor T. Kawakami, Department of Fisheries, Kyoto University, for his guidance and placing his original data with respect to Chapter 2. Sincere thanks are also due to Dr. Nomura, Fishing Gear Department, Tokai Regional Fisheries Research laboratory, for a serier of experiments has been carried out oy his technical services.

2. HYDRODYNAMIC CHARAGTERISTIC OF TRAWLING GEAR

The efficiency of a trawling gear is closely related to the shape under operation in various kinds of pulling speed, Recently, the mechanical behaviour of the gear in action could be assessed approximately by judging the tension and tilt angle of tow warps, or oy actual fishing results obtained with the gear. However, to design a trawling gear efficiently or oporate it effectively, an accurate knowledge is required of the mechanical properties of each part. In the following reviews, discussions will be developed on the hydrodynamic force acting on the towing warps, otter boards, and drag nets.

2-1. The behaviour of warps:

The warps take up shapes under tow that are in general curved, these curves depend upon warp length, water depth, warp diameter, warp weight in water per unit of length, towing speed, tension in the warp, and lateral distance or spread between the lower ends of the warps. The warp shape varies with towing speed because of he hydrodynamic water force that is tgenerated by moving the warp through the water and the magnitude of this water force depends upon the extent to whidh the warp vibrates.

The present section deals with fundamental differential equations, by which the form and tension of warp are expressed. In this initial theory has developed from a viewpoint that the warp is in equilibrium under. the tension acting on itself, assuming that the hydrodynamic force acting on the warp is negligible small as compared with the weight when the speed is reduced to zero, but the tension does not reduce to zero since it has to hold the warps taut, which can theoretically be shown to require a value equal to(depth of water)×(Weight of warp in water per unit length);e. g,(2)a 3.25 in circumference warp weighing 8.5 lb per fms requires a tension of 850 lb in 100 fms of water. The later, theory has expressed which neither the weight of the warp nor the tangential force of the hydrodynamic action can be neglected.

2-1-1. Theoretical consideration of the suspended warp:

We now consider a uniform warp suspended from two points and hanging under its own weight (Fig.1). Taking the y-axis positive upwards and the x-axis positive to the right, also letting W denote the weight per unit length of the warp and S the length of arc from the lowest point A to any point P (x, y), T the tenston in the direction of the tangent at the point P, the acute angle which this tangent makes with the horizontal, and To the horizontal tension at the lowest point A. Then, resolving vertically and horizontally the forces acting on the portion AP of the warp, we have

$$T = T\cos\varphi + T\sin\varphi$$
$$T\cos\varphi = T_o$$
$$T\sin\varphi = WS$$

Division gives

$$\tan\varphi = WS/T_o$$

T_o(3)$=Wa$, hence $S = a\tan\varphi$ (2-1-1)

From Fig. 2. $\frac{dx}{dS} = \cos\varphi = \frac{a}{\sqrt{a^2+S^2}}$

This is the differential equation of the warp, in order to solve this differential equation, write separate the variables :

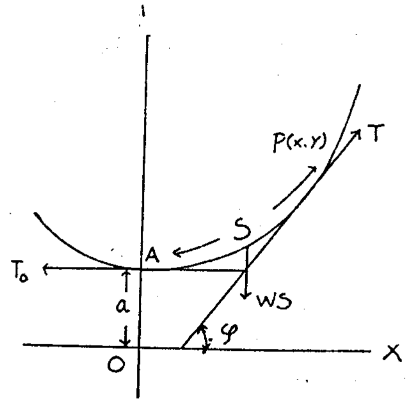


Fig. 1. The suspended warp

$$\frac{dx}{a}=\frac{dS}{\sqrt{a^2+S^2}}$$

Integrated to give

$$\frac{x}{a}=\log(S+\sqrt{a^2+S^2})+C$$

Vndèr the conditions that x=O, S=O, we get

$$\frac{x}{a}=\log(\frac{S+\sqrt{a^2+S^2}}{a}) \quad (2\text{-}1\text{-}2)$$

Using the same method integrating the differential equation of

$$\frac{dy}{dS}=\sin\varphi=\frac{S}{\sqrt{a^2+S^2}}$$

we have

$$y=\sqrt{a^2+S^2} \quad (2\text{-}1\text{-}3)$$

From(2) we have

$$S=\frac{a}{2}(e^{\frac{x}{a}}-e^{\frac{x}{a}})$$

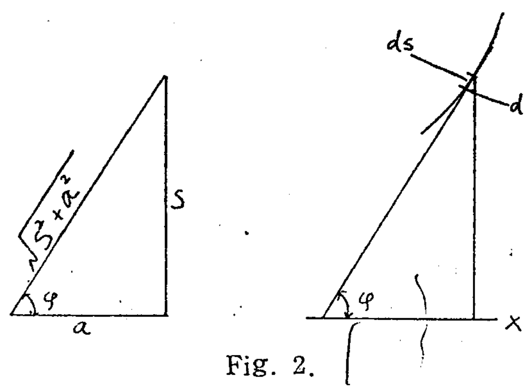


Fig. 2.

Substituting in(3), we get

$$y=\frac{a}{2}(e^{\frac{x}{a}}+\partial^{\frac{x}{a}}) \quad (2\text{-}1\text{-}4)$$

Which is the standard equation of a Catenary.

2-1-2 The equilibrium configuration and tension of a flexible of a warp in a uniform flow:

Professor T. Kawakami,(4)has made a analysis of the gear under way, the tensions the bottom of the warp is less than that at the top by a above quantity together with the component of force paralled to the warp that is produced by water flowing past it. For the case in which suppose the form of a warp in a uniform steady slow of velocity V (See Fig.3). Choose rectangular coordinates (x, y) whose origin is located at a point on the warp where the warp is normal to or paralled to the current measured positive up-stream and y-axis be directed vertically up-wards. Let S be the are length along the warp from the origin O to any pointP(x, y), on the warp. T and T be the tensions in the warp atthe points P and O respectively. The angle of inclination of warp against the stream is measured clockwise from the direction of the current to the direction of increasing S. Furthermore, let W be the weight of warp of unit length in water, and put $w'=W/R$. These forces may be resolved to and along the warp as shown in Fig. 4. then the equilibrium of the warp element dS requires:

$$\frac{dT}{dS}= -(c)F+W\sin\theta \quad (2\text{-}1\text{-}5)$$

$$T\frac{d}{dS}=(s)R\sin^2\theta+W\cos\theta \quad (2\text{-}1\text{-}6)$$

The solution of these differential equations can be written in a parametric form:

$$\tau=\frac{T}{T_o},\ \sigma=\frac{R}{T_o}S,\ \xi=\frac{R}{T_o}x,\ \eta=\frac{R}{T_o}y,\ f=\frac{F}{R},\ w=\frac{W}{R},\ (2\text{-}1\text{-}7)$$

From (2-1-7), we have:

$$d\xi=-\cos\theta\, d\theta \quad (2\text{-}1\text{-}8)$$

$$d\eta=\sin\theta\, d\theta \quad (2\text{-}1\text{-}9)$$

$$\frac{d\tau}{d\sigma}=-(c)f+w\sin\theta \quad (2\text{-}1\text{-}10)$$

$$\tau\frac{d\theta}{d\sigma}=(s)\sin^2\theta+w\cos\theta \quad (2\text{-}1\text{-}11)$$

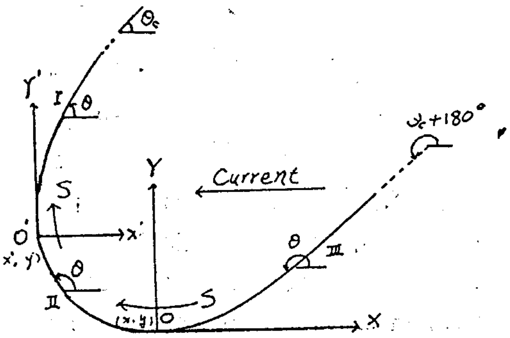


Fig. 3.
Configuration of a warp under water

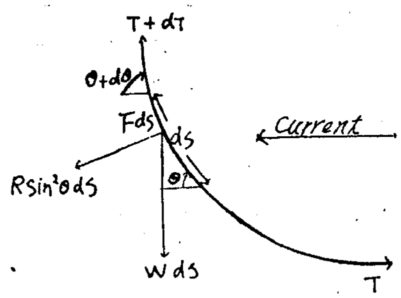


Fig. 4.
Forces acting on au warp subjected to flow of water

The different equations (2-1-10) and the (2-1-11) may be integrated with the condition that the origin point O, to give:

$$\log\tau=\int_0^\theta \frac{-(c)f+\omega'\sin\theta}{(s)\sin^2\theta+\omega\cos\theta}d\theta \quad (2\text{-}1\text{-}12)$$

$$\sigma=\int_0^\theta \frac{\tau}{(s)\sin^2\theta+\omega'\cos\theta}d\theta \quad (2\text{-}1\text{-}13)$$

Substituting in (2-1-8) and (2-1-9) we get

$$\xi=-\int_0^\theta \frac{\tau\cos\theta}{(s)\sin^2\theta+\alpha'\cos\theta}d\theta \quad (2\text{-}1\text{-}14)$$

$$\eta=\int_0^\theta \frac{\tau\cos\theta}{(s)\sin^2\theta+\omega'\cos\theta}d\theta \quad (2\text{-}1\text{-}15)$$

From (2-19) and (2-1-10) we have

$$d\tau=-(c)fd\sigma+\omega'd\eta \quad (2\text{-}1\text{-}16)$$

Integrating (2-1-16) under the condition that
$\sigma=0.\ \eta=0.\ \tau=1.$
to give
$\tau=1-(c)f\sigma+\omega'\eta$
From (2-1-11), under the condition that
θ =constant, we get
$(s)\sin^2\theta+\omega'\cos\theta=0$
That is to say the warp under a straight line and $d\theta=0$,
Suppose θ_c is a root of this equation
we have

$$\cos\theta_c=(s)\left[\frac{\omega'}{2}-\sqrt{\left(\frac{\omega'}{2}\right)^2+1}\right] \quad (2\text{-}1\text{-}17)$$

2-2-1. Otter Board forces and moment:

Theoretical treatments about the mechanical action of the otter board have been tried by TAUTI.(5), KOYAMA.(6), and CREWE.(7), Especially, about the behaviour of otter board KOYAMA has made a series of model and full scale experlments. KAWAKAMI(8), has presented the theoretical consideratlon about mechanical action of the flatboard as shown in Fig. 5. The lift L, drag D, and moment M, are defined as:

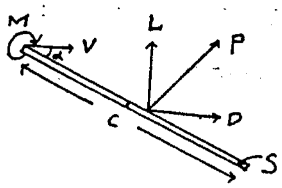


Fig.5. Otter board forces and moment

$$L=C_L\frac{\rho v^2\ 2}{S}C \quad (2\text{-}2\text{-}1)$$

$$D=C_D\frac{\rho v^2}{2}S \quad (2\text{-}2\text{-}2)$$

$$M=C_M\frac{\rho v^2}{2}S_c \quad (2\text{-}2\text{-}3)$$

Where the ρ is the density of fluid, S the area of the board, c the length of the board, V the current velocity, and CL, C_D and C_M are the lift, drag and moment coefficients respectively.

In Fig. 6. the mechanical actions of forces and the geometrical configuration may be symmetrical about the centre axis, Let F_1 be the tension of the warp, F_2 the tension of the hand rope, α the angle between the direction of towing and the board, and θ_1, θ_2 the angles of the center axis to the respective directions of the warp and the hand rope, the equation of equilibrium for the otter board can be written as:

$F_1\ \sin\theta_1+F_2\ \sin\theta_2=L(\alpha)$ (2-2-4)

$F_1\ \cos\theta_1+F_2\ \cos\theta_2=D(\alpha)$ (2-2-5)

Consider the polar coordinate about the joint of warp $Q(\psi_1, r_1)$ and the normal of the hand rope $R(\psi_2, r_2)$ we have:

$r_1\ F_1\ \sin(\alpha+\psi_1+\theta_1)+r_2F_2\ \sin(\alpha+\psi_2+\theta_2)=M(\alpha)$ (2-2-6)

Next, with regard to the configuration of trawl net the otter board and the hand rope in action as illustrated schematically in Fig.7.

The notation of the figure are difined as follows:

l_1 : length of warp

l_2 : length of hand rope.

θ_1 : angle between direction of F_1 and direction joint to that of towing

θ_2 : angle between the direction of F_2 and the direction normal to that towing

F_1 : tension of warp

F_2 : tension acting on wing tip of net

y : half distance between both dan-lenos

F : towing power

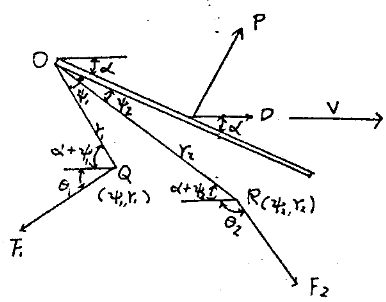


Fig.6.
Mechanical actions of forces and the geometrical configuration of the otter board

The character of net relations to F_2 and y are given as functions of the angle θ_2:

$F_2=f\ (\theta_2)$ (2-2-7)

$y=g\ (\theta_2)$ (2-2-8)

By the reference of the figure, we have

$y+l_2 \sin\theta_2 = l_1 \sin\theta_1$ (2-2-9)

Then consider the towing power F, we have

$F = 2F_1 \cos\theta_1$ (2-2-10)

Seven parameters are appeared in the equations (2-2-4) ~ (2-2-10)

However, resolved the simultaneous equations F, $F_1, F_2, \theta_1, \theta_2, F_2, \alpha$ and y may be fixed.

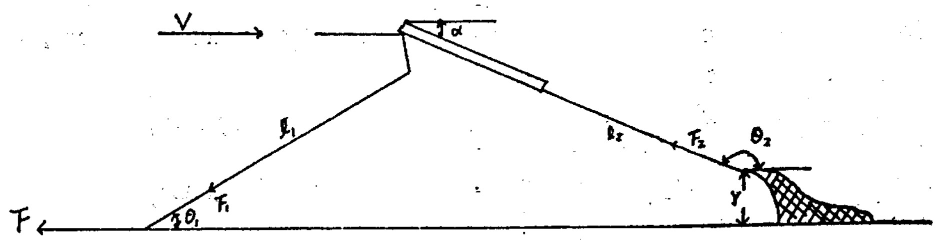


Fig.7. Schematic pattern of otter trawl gear under operating

2-2-2. Angle of attack:

Consider the half side of the otter board in action as shown in Fig.7. Let F_1 be the tension of the warp, F_2 the tension of the hand rope, α (angle of attack) the angle between the direction of towing and the board, and θ_1, θ_2 the angles of the center axis to respective directions of the warp and the hand rope, The magnitude of the hydrodynamic force, Po acting upon the otter board is given by

$$P_o = \frac{C_D}{2}\rho v^2 S \quad (2\text{-}2\text{-}11)$$

S is the area of the otter board, C_D the drag coefficient, ρ the density of water and V the current velocity.

This P_o is with respect the magnitude of force P_o acting upon the otter board with the attitude α to the current direction as follows:(9)

$$P\theta = P_o \frac{2\sin\alpha}{1+\sin^2\alpha} \quad (2\text{-}2\text{-}12)$$

By the reference of the figure the equation of equilibrium for the otter board can be written as

$$F_1 \cos\theta_1 = P_o \frac{2\sin\alpha_1}{1+\sin^2\alpha} + F_2 \quad (2\text{-}2\text{-}13)$$

$$F_1 \sin\theta_1 = P_o \frac{2\sin\alpha \cos\alpha}{1+\sin^2\alpha} - F_2 \tan\theta_2 \quad (2\text{-}2\text{-}14)$$

Dividing (2-2-14) by (2-2-13), we get

$$\tan\theta_1 \left(P_o \frac{2\sin^2\alpha}{1+\sin^2\alpha} + F\right) = P_o \frac{2\sin\alpha \cos\alpha}{1+\sin^2\alpha} - F_2 \tan\theta_2$$

Write separate the variables:

$$F_2 \tan\theta_2 = P_o \frac{2\tan\alpha\,(1-\tan\alpha \tan\theta_1)}{1+2\tan^2\alpha} - F_2 \tan\theta_1 \quad (2\text{-}2\text{-}15)$$

Assuming $\tan\alpha = x$, from the equation (2-2-5) can be written as:

$$f(x) = \frac{x\,(1-x\tan\theta_1)}{1+2x^2} \quad (2\text{-}2\text{-}6)$$

Under the condition of θ_2 be maximum, we have:

$$\frac{x\,(1-x\tan\theta_1)}{1+2x^3} = 0 \quad (2\text{-}2\text{-}7)$$

Differential the equation of (2-2-7) ,we get:

$$x=\frac{\sqrt{\tan^2\theta+2}}{2}+\frac{\tan\theta_1}{2}$$

That is to say: $\tan\alpha=\frac{\sqrt{\tan^2\theta_1+2}}{2}-\frac{\tan\theta_1}{2}$

2-3-1. Drag of the net:

The hydrodynamic force of relative velocity acting on a unit area of plane net, we have TAUTI law(10), as follows:

$$k_x=a\left(\frac{D}{L}\right)l_c\tan\varphi+\frac{bf(x)}{2}\left(\frac{D}{L}\right)^2\frac{l_c}{\cos\varphi\sin\varphi} \quad (2\text{-}3\text{-}1)$$

$$k_y=a\left(\frac{D}{L}\right)m_c\cot\varphi+\frac{bf(y)}{2}\left(\frac{D}{L}\right)^2\frac{m_c}{\cos\varphi\sin\varphi} \quad (2\text{-}3\text{-}2)$$

$$k_z=a\left(\frac{D}{L}\right)n_c\frac{1}{\cos\varphi\sin\varphi}+\frac{bf(z)}{2}\left(\frac{D}{L}\right)^2\frac{n_c}{\cos\varphi\sin\varphi} \quad (2\text{-}3\text{-}3)$$

where k_x, k_y and k_z, denote the coefficients of x.y. and z component of the force acting on the net, a is the drag coefficient, b is the drag coefficient of the knot, L is the length of bar, D is the diameter of twine, 2φ is the half angle between two adjacent bars of the mesh, As shown in Fig. 8. The direction of current to the area of plane net, the resistance under the condition with $l_c=\cos\theta$, $m_c=0$, $n_c=0$, is $k_d=k_x\cos\theta+k_z\sin\theta$

Substituting in (2-3-1) and (2-3-3) we get

$$k_d=a\left(\frac{D}{L}\right)\frac{1-\cos^2\theta\cos^2\varphi}{\cos\varphi\sin\varphi}+\frac{b}{2}\left(\frac{D}{L}\right)^2\frac{f(x)\cos^2\theta+f(z)\sin^2\theta}{\cos\varphi\sin\varphi}$$

When $\theta=\frac{\pi}{2}$ and $\theta=0$ we have

$$k_d\left(\frac{\pi}{2}\right)=a\left(\frac{D}{L}\right)\frac{1}{\cos\varphi\sin\varphi}+\frac{b}{2}\left(\frac{D}{L}\right)^2\frac{f(z)}{\cos\varphi\sin\varphi}$$

$$k_d(o)=a\left(\frac{D}{L}\right)\tan\varphi+\frac{b}{2}\left(\frac{D}{L}\right)^2\frac{f(x)}{\cos\varphi\sin\varphi}$$

hence $k_d\left(\frac{\pi}{2}\right)-k_d(O)=a\left(\frac{D}{L}\right)\cot\varphi+\frac{b}{2}\left(\frac{D}{L}\right)^2\frac{f(z)-f(x)}{\cos\varphi\sin\varphi}$

Assuming that the hydrodynamic force acting on the knot is negligibly small as compared with the drag force acting on the bar, we can be written as:

$$k_d\left(\frac{\pi}{2}\right)-k_d(O)=a\frac{D}{L}\cot\varphi$$

Then under the condition that $f(z)\fallingdotseq f(x)$

$$k_d-k_d(O)=a\left(\frac{D}{L}\right)\cot\varphi\sin^2\varphi$$

hence

$$\frac{k_d-k_d(O)}{k_d\left(\frac{\pi}{2}\right)-k_d(O)}=\sin^2\varphi$$

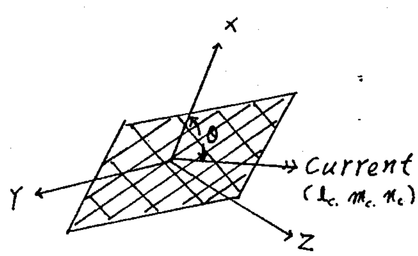


Fig. 8.
The force acting on the plane net

There are three kinds to find out the characteristic of the resistance of the bag net keeping a constant rate of slack to make an angle 2φ between adjacent bars of mesh, as shown in Fig.9. By the reference of the figure, the resistance of the bag net can be written as:

(1).

$$K_{d1} S_1 V^2 + K_{d2} r_2 V^2 = a\left(\frac{D}{L}\right)\frac{2V^2}{\cos\varphi\ \sin\varphi}(1-\cos^2\varphi\cdot\cos^2)S_1+(1-\cos^2\varphi\ \cos^2\theta)S_2$$

(2).

$$K_d = a\left(\frac{D}{L}\right)\frac{1-\cos^2\varphi\ \cos^2\theta}{\cos\varphi\ \sin\varphi}SV^2$$

(3).

$$K_d = 2a\left(\frac{D}{L}\right)\tan\varphi\ V^2(S_1+S_2)+a\left(\frac{D}{L}\right)\frac{1}{\cos\varphi\ \sin\varphi}V^2 S_3$$

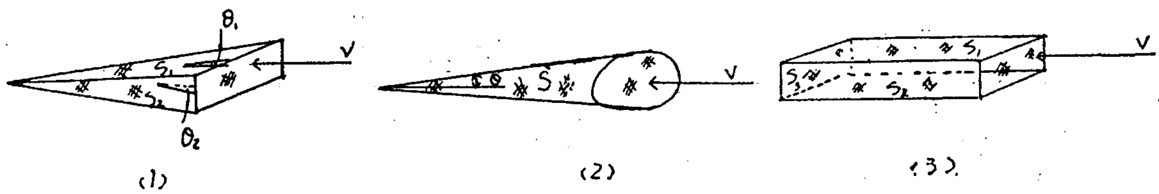
where S_1 is the area of upper or low webbing

S_2 is the area of side webbing

S_3 is the area of the webbing perpendicular to the current

θ_1 and θ_2 the angles between the direction of the current and the webbing.

It is seen that the resistance of the bag net woven from twines is represented by the total of the resistance of a unit plane net involved in the surface of the bag net.



Fig,9. The resistance of bag nets

2-3-2. The resistance of a rectangular strip net under a uniform current:

The mechanical and geometrical relations of the trawl net were expressed in tarms of nineteen equations (12), For the convenience of treatment, the variable designating force involved in these equations were divided by F,

Here F is given as follow:

$F = h\ S_h\ K_n$ (2-3-4)

Whe re h is the half depth of wing at the vicinity of net mouth and K_n is the hydrodynamic resistance acting on a unit area of the webbing employed to the gear, when it is normal to the current of velocity V. Iet φ be the half angle between adjacent bars of the mesh, k a constant proportional to drag coefficient of the netting twine, then K_n is given by:

$K_n = k\ V^2 \frac{D}{L} \sec\varphi\ \csc\varphi$ (2-3-5)

On the other hand KAWAKAMI(13) has developed the equilibrium configuration of a uniform current of water as follows:

Choose rectangular coordinates (x, y), the origin of which is located at a point of the edge line of the net, let y axis be paralled to the stream line, measured positive up stream as shown in Fig.10. Let S be the arc length along the edge line of the net, measured from the origin to any point P, then neglecting the apparent weight or buoyancy of the net in water, the equation of equilibrium can be written as

$$\frac{dT}{dS}=k\ h\ \sin^2\varphi\ \cos\theta \qquad (2\text{-}3\text{-}6)$$

$$T\frac{d}{dS}=k\ h\ \sin\theta \qquad (2\text{-}3\text{-}7)$$

Where the angle θ is measured positive anticlockwise from the direction of the current to the direction of increasing S, Let T_o be the tension of the net at the origin, The differential equations (2-3-6) and (2-3-7) may ce integrated with the condition that:

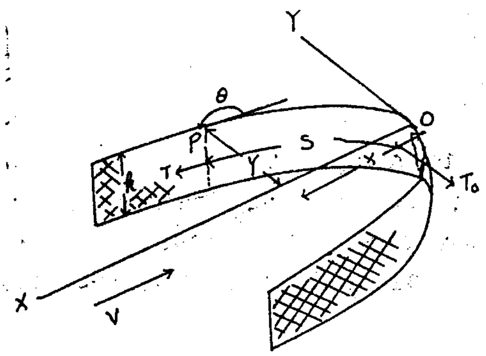


Fig. 10.
A rectangular strip net

$$\begin{cases} \frac{T}{T_o}=1,\ \frac{kh}{T_o}S=O, \\ \frac{kh}{T_o}x=O,\ \frac{kh}{T_o}y=O, \\ \text{for } \theta=\frac{\pi}{2} \end{cases}$$

to give $\frac{T}{T_o}=(\sin\theta)-\sin^3\varphi$

$$\frac{kh}{T_o}S=\int_{\frac{\pi}{2}}^{\theta}(\sin\theta)-(1+\sin^2\varphi)d\theta$$

$$\frac{kh}{T_o}x=\frac{1}{\sin^2\varphi}\left(\frac{T}{T_o}-1\right)$$

$$\frac{kh}{T_o}y=\int_{\frac{\pi}{2}}^{\theta}\frac{T}{T_o}d\theta$$

3. WAY OF EXPERIMENTS

3-1. Models test of trawl net:

The design of net used in the experiment is shown in Fig. 11. In the practical net that means in full scale the net's ropes, buoys and sinks are made of polyethylene, wire, glass and chain in material respectively, on the other hand in model net they are polyethylene, nylon, plastic and lead respectively. The model net was made according to the theory of designing and testing fishing nets in model(14) and the law of comparison of fishing net(15).

Mainratios between full scale and model used in this experiment are as follows:

Scale ratio: $\frac{\lambda'}{\lambda''}=\frac{1}{20}$

Ratio of mesh size (diameter of cord) : $\frac{D'}{D''}=\frac{L'}{L''}=\frac{0.5}{2.7}=\frac{1}{4.2}$

Corresponding speed: $\frac{V'}{V''}=\sqrt{\frac{D'}{D''}\cdot\frac{(\rho'-1)}{(\rho''-1)}}=\sqrt{\frac{1}{4.2}}$

$$V''=2.04V' \quad (\rho'=\rho''=0.92)$$

Ratio of buoyance or sinking power:

$$\frac{F'}{F''}=\left(\frac{\lambda'}{\lambda''}\right)^2\cdot\left(\frac{V'}{V''}\right)^2=\left(\frac{\lambda'}{\lambda''}\right)^2\cdot\left(\frac{D'}{D''}\right)^2=\left(\frac{1}{20}\right)^2\cdot\left(\frac{1}{4.2}\right)=\frac{1}{1680}$$

The experiment was conducted under two different conditions:

Experiment A was in such a condition as that the Danlono was 5.2cm and the experiment B was 12.5cm respectively. The model net is pulled with beam of 80cm length before the wings connected with two meter hand ropes, the beam has wheels, therefore, we are necessary to calculate with net under various speed, the resistance of model net will obtained by subtract the former value from the later.

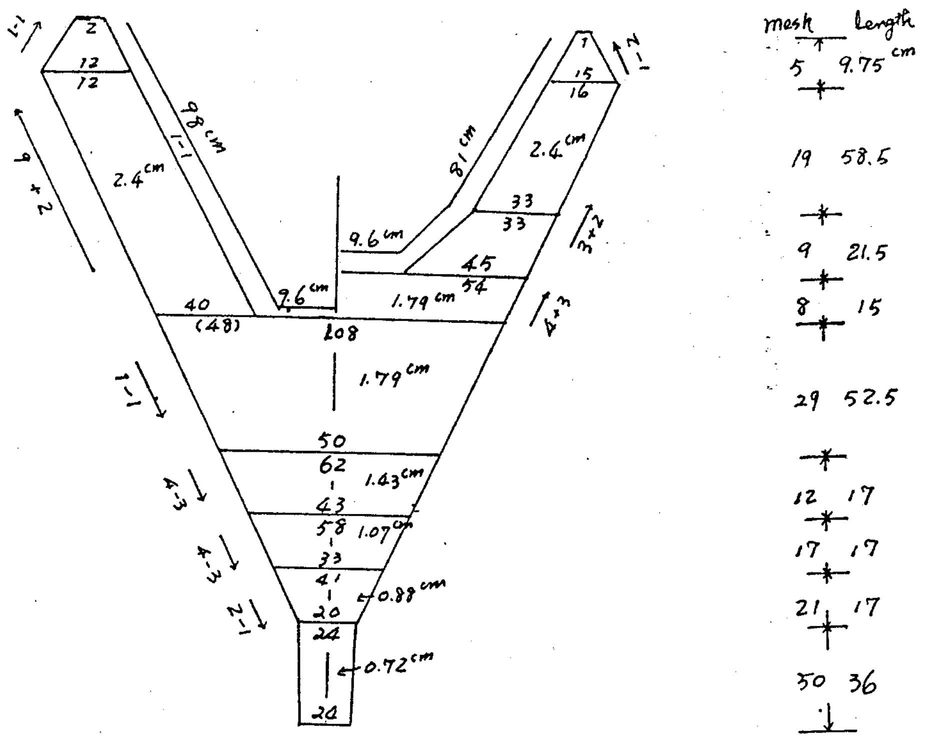


Fig. 11. Experimental Net

3-2. Methods and material of otter boards in actual trawling :

Several types with different profiles were designed, importance was given to the concave on the back side of the boards to allow rapid spreadand retrieving operation, the boards are rectangular sections which have badly finished surfaces because of the frame, reinforcement, nuts, etc. Restance to towing at a determined speed depends upon the area and angle of attack and is influenced by the finish of the surface and the density of the media. But, in the majority of cases, those factors are completely ignored. The dimension weight and angle of attack of the otter boards vary constderably not only in different locals but also in the same fishing port.

By applying elementary laws of mechanics it should be possible to construct accessory trawling equipment of improved efficiency, and for purposes of experiment we built three kinds of upright boards and one ordinary board which are made of iron sheet with steel pipes.

The specifications of the otter boards used in the experiments and the towing conditions are illustrated in the following tables, and the measurement for the tension and towing speed as shown in Fig. 12.

Specifications of the otter board

	Upright type	Ordinary type
Height×length	2×1.4(m)	1.52×2.14(m)
Ratio H/L	1.4	0.71
Area receiving	2.8m²	3.25m²
Weight in air	420 kg	340 kg
Center of gravity	22 cm before center line	17 cm before center line
Bracket of hanging	22 em before center line	27 cm before center line

Towing conditions

	Upright type	Ordinary type
Depth of sea	80–90(m)	80–90(m)
Bottom character	soft mud	soft mud
Warp length	300m	300m
length of hand rope	50m	50m
Towing speed	2–4 knot	2–4 knot

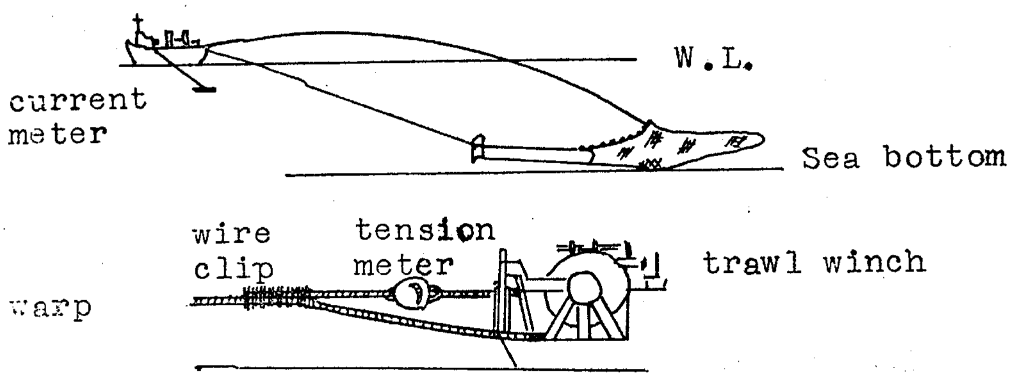


Fig. 12.
Measurement for the tension and towing speed

4. RESULTS AND DISCUSSION

4-1. The experimental equation between speed V(m/sec) and resistance R(kg) in the experiment are as follows:

$R=k\ V^n$

$\log 39=\log k-n \log 18.2$

$\log 218=\log k-n \log 62$

$k=0.67$

$n=1.41$

$R=0.67\ V\ 1.41$

The index number on V is smaller than 2 which is same result as the previous reports conducted by another person on model net experiment of trawling, Dickson, w(16). point out in his model experiment that the reason why the number on V is less than 2 is due to the changlng of shapes on model net according to the velocity. The relation between the pulling speed and the resistance of the net are shown in following tables and Fig. 13.

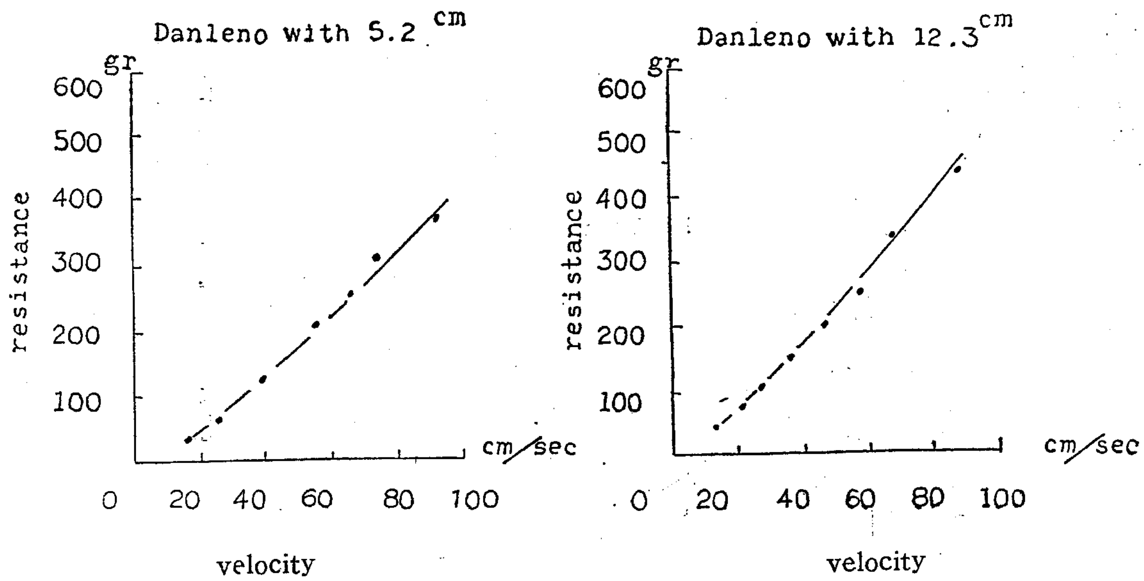


Fig. 13. The relation between the pulling speed and the resistance of net

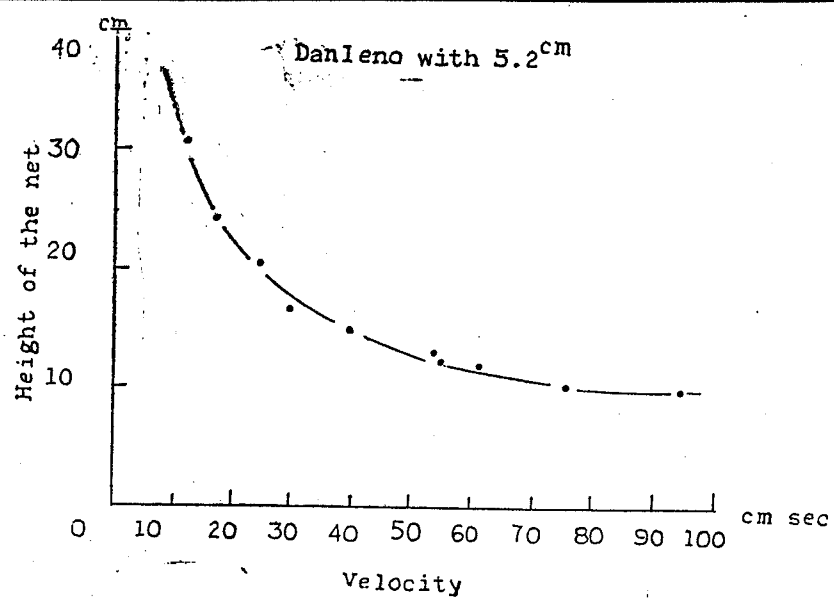
The relation between the pulling speed and the resistance of net with 5.2 cm Danlono and have not with the otter board

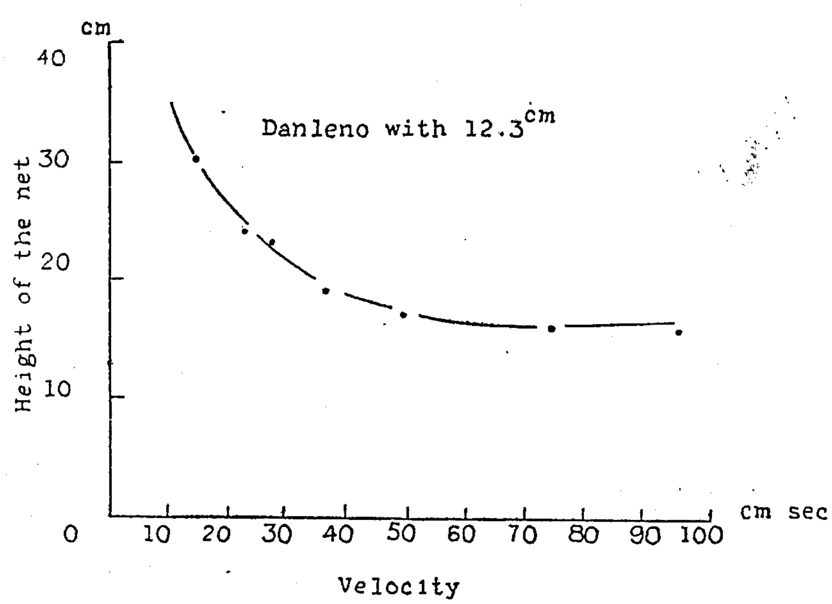
Ex. No.	Resistance Model (gr)	Resistance Full Scale (kg)	Velocity Model	Velocity Full Scale (cm sec)	Height of net Model (cm)	Height of net Full Scale (m)
1.	39	65.5	18.2	37	24	4.8
2.	63.7	113	25	51.7	20.5	4.1
3.	81.2	138	29.8	60.5	17	3.7
4.	119.1	200	40	81.2	15	3.0
5.	117.3	296	54	109	15	2.6
6.	188.9	318	57.1	116	12.5	2.5
7.	218.2	365	62	126	12	2.4
8.	257.1	415	67.4	137	12	2.4
9.	269.4	480	76.9	156	10	2.0
10.	350	590	95.2	193	10	2.0

The relation between the pullng speed and the resistance of net with 12.3cm Danlono and have not with the otter board

Ex. No.	Resistance Model (gr)	Resistance Full Scale (kg)	Velocity Model	Velocity Full Scale (cm sec)	Height of net Model (cm)	Height of net Full Scale (m)

11.	33.3	56	15.4	31.3	30.0	6.0
12.	59.7	100	23.5	45.7	24.0	4.8
13.	75.0	126	27.6	55.6	23.0	4.6
14.	114	191	36.6	74.2	19.0	3.8
15.	155	261	50.0	103	17.0	3.4
16.	214	360	57.9	116	17.0	3.4
17.	320	557	74.0	151	16.0	3.2
18.	420	705	95.0	193	16.0	3.2



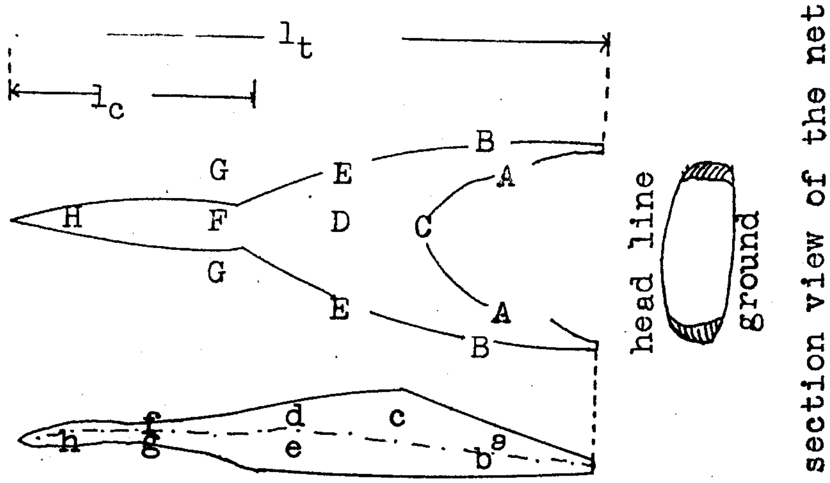


14. The relation between the height of net and the velocity of the speed in model

4-2. Fig. 14. shows the relation between the height of net and the velocity of the speed in the model under operation, and we can learn that the height is remarkable decreased according to the increasing of the velocity(17). If we connect into the velocity in practical net from result of this experiment we can say that the height of steady state when the velocity are 2 miles per hour.

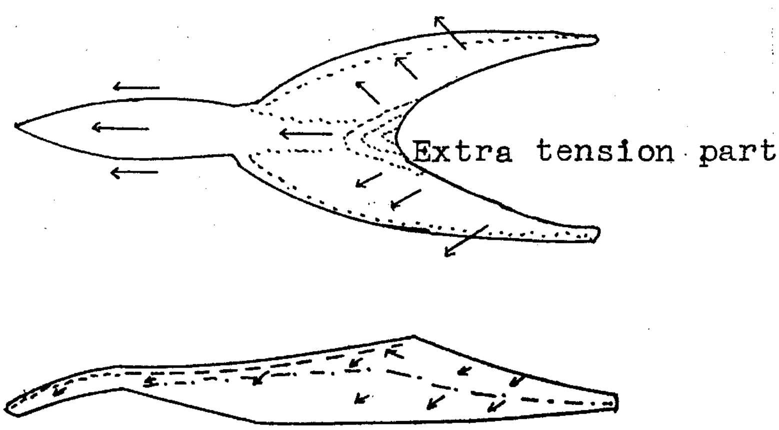
4-3. If we discuss about the hydrolic resistance of net we must know the state of changing of net shape. Suppose the Fig. 15 explains the simple marks on the net, the increase of towing speed the vertical spread of net mouth decrease and the part a appearance tends to out side with the 20 degrees dip to the horizontal but the part b appeared a good type and parts c to f made as a line.

Referring to Fig. 16. C part of the net is caused by choking up of water which cannot flow freely through the net. Under such circums tances the water flow to the cod-end is disturbed and causes gilling in the tapered body of fhe net(18).



l_t: length of the net
l_c: length of the codend

Fig. 15. Explains the simple marks on the net



------: explain the great resistance line

Fig. 16. Shape of conventional net in operation

4-4. Comparison of the performance of the boards of the two typesunder actual trawling :

By plotting log D and [log L against log V, respectively, (19) Fig. 17. are obtained which suggest that D and L can be expressed approximately by:

$D = K_D \; S \; V^2$

$L = K_L \; S \; V^2$

in which S is the area of the board, K_D snd K_L are the coefficients of resistance and developing force of the board, respectlvely, values of K_D, K_L and the ratio K_L/K_D are given in following tables, that the board of upright type presents far larger force to develop the net with some what less resistance than the ordinary type(20).

Coefficients of resistance K_D and developing force K_L of the otter board.

Coefficient	Upright type	Ordinary type
K_D	30.0	33.0
K_L	70.6	70.0

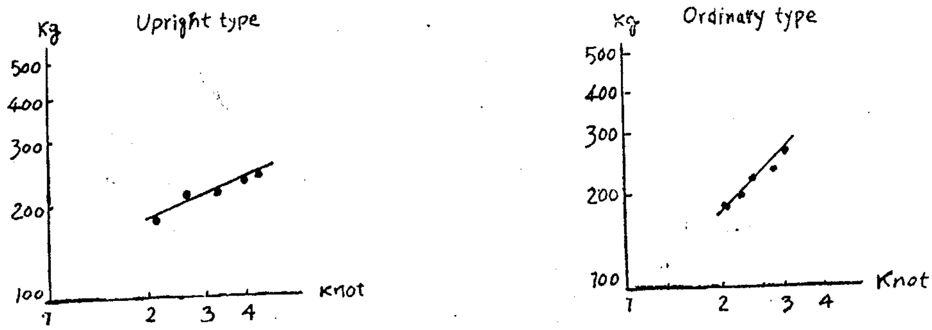


Fig. 17. (A).

Relationship between towing speed and vesistance of board

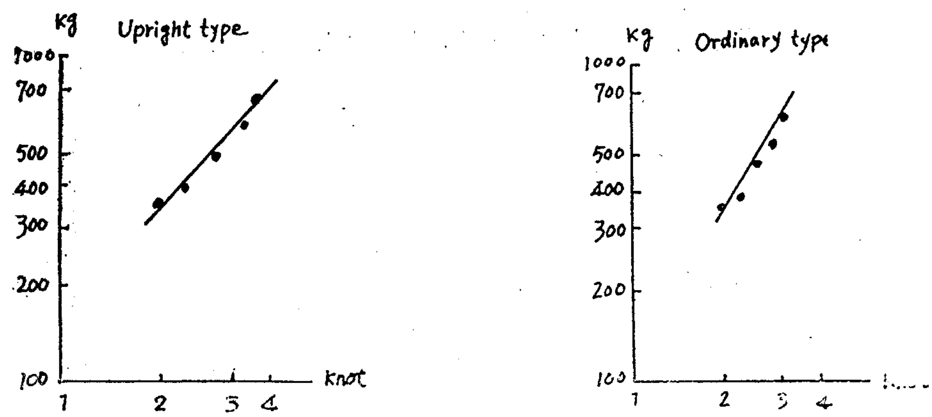


Fig. 17. (B).

Relationship between towing speed and developing force of otter board