BEHAVIOUR OF SWEEP LINE IN PAIR-TRAWLING*

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(Received July 17, 1962)

In the previous papers^{1),2)} differential equations about the form and tension of sweep line have been treated and the experimental data for the case of a uniform nylon twine have been analyzed in terms of the theory presented.

In pair-trawling, it has been pointed out³⁾ that the sweep line, in earlier stages of towing, shows two different kinds of behaviour. The first pattern, which appears in the process from the layout of rope to the stage that the deformation of rope propagates to the wing tip of net by towing, can be reduced to the case treated previously.^{1),2)} In the second process, the inclination angle of a rope to the towing direction at wing tip varies as a function of the towed distance.

In the present work on the sweep line of pair-trawl, accordingly, the focal point on this study is in the second process. As an extension of the previous theory,¹⁾ the behaviour of sweep line in the process will be discussed on the assumption that the resistance of net is constant throughout the course of towing.

Theoretical Consideration

According to one of the most popular patterns of layout in pair-trawling, a uniform rope is laid, on a horizontal plane of sand, in such a form that it makes three sides $\overline{DA}$, $\overline{AB}$ and $\overline{BC}$ of a rectangle (Fig. 1). Here, assume that a net is attached to the rope at the mid-point O of the side $\overline{AB}$. If both ends C and D of the rope is pulled to a definite direction $\overline{BC}$ and $\overline{AD}$, the pattern assumed by both sides of rope will change symmetrically with respect to the central line. At a certain instant of towing process, the deformation of rope will propagate to the point O . The behaviour of rope in this course has been discussed previously.^{1),2)} In the subsequent process of towing, the rope will be bent at the point O , owing to the resistance of net. As the rope is towed on further, an included angle made by the both sides of rope at the point O

Fig. 1. Form of sweep line in pair-trawling.

* Studies on the kinematic behaviour of the ground rope of the trawl net-V.

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will decrease, and the net starts to move when the towing component of tension on the rope at the point O exceeds the resistance of net.

Now, referring to Fig. 1, take the y -axis to the direction of the part $\overline{AB}$ of rope originally laid, and choose the origin at the mid-point O of the originally laid rope. We may confine our discussion to the left half of the curve by consideration of symmetry. Denote by T_n the tension acting on the rope at the point O, θ_n the angle of inclination of T_n to the positive direction of the y -axis. Then, T_t be the tension acting on the rope at the point R, at which the curve comes in contact with the line $\overline{BC}$ as shown in Fig. 1; here, from the initial condition that $\overline{OB}$ is perpendicular to $\overline{BC}$, the inclination angle of T_t to the positive y -axis keeps $\pi/2$. The same mechanical relation as discussed in the preceding papers^{1), 2)} should hold also in this case. Hence, we have the relation between the tensions, T_n and T_t , acting on the rope at the respective points, O and R,

$$\frac{T_t}{T_n} = e^{\kappa(\pi/2 - \theta_n)}, \quad (1)$$

where $\kappa = K_t/K_n$, denoting by K_t and K_n the tangential and the normal component of frictional force per unit length of rope, respectively. Moreover, the arc length $s_r (= \widehat{OR})$ of the curve is given by

$$s_r = \frac{T_n}{K_n} \frac{1}{\kappa} (e^{\kappa(\pi/2 - \theta_n)} - 1). \quad (2)$$

In order to obtain the coordinates of the point R, some attentions should be paid. In the reference¹⁾ cited above, we have defined the y -axis of the rectangular coordinates system to the direction of tension acting on rope at the origin. As a consequence, the values of x and y , expressed by the equations (5) and (6) of the reference¹⁾, give the lengths in direction of $\overline{OM}$ and $\overline{MR}$, respectively, as in Fig. 1. The present coordinate axes can be obtained by rotating the above mentioned coordinate system about the origin to the positive sense as far as the angle θ_n . Therefore, the projections, x_r and y_r , of s_r to the present coordinate axes become

$$x_r = x \cos \theta_n + y \sin \theta_n,$$

$$y_r = y \cos \theta_n - x \sin \theta_n.$$

Substitution of x and y , given from (5) and (6) of the reference¹⁾, into the above expressions gives:

$$x_r = \frac{T_n}{K_n} \frac{1}{\kappa^2 + 1} [e^{\kappa(\pi/2 - \theta_n)} \kappa - (\kappa \sin \theta_n - \cos \theta_n)], \quad (3)$$

$$y_r = \frac{T_n}{K_n} \frac{1}{\kappa^2 + 1} [e^{\kappa(\pi/2 - \theta_n)} - (\kappa \cos \theta_n + \sin \theta_n)]. \quad (4)$$

The equation (4) is rewritten to a dimensionless form,

$$\frac{K_n}{T_n} y_r = \frac{1}{\kappa^2 + 1} [e^{\kappa(\pi/2 - \theta_n)} - (\kappa \cos \theta_n + \sin \theta_n)]. \quad (5)$$

The right-hand member of the above equation is a function of θ_n , for the given value of κ . Then, if the value of $y_r (= \overline{OB})$ is determined according to the experimental condition, the values of K_n/T_n and thus in turn T_n can be obtained as functions of θ_n . Moreover, Fig. 1 gives geometrically the towed distance l of the rope end:

$$l = x_r + y_r - s_r. \quad (6)$$

The equation (6) gives l as a function of θ_n , and in reverse the towing component $T_n \sin \theta_n$ acting at the wing tip can also be given as a function of l . Here, denoting by R_n the resistance of net in motion, we have, as the condition under which the net starts to move

$$\frac{R_n}{2} = T_n^* \sin \theta_n^*, \quad (7)$$

where T_n^* and θ_n^* are the tension of rope at the point O and its inclination angle, respectively, when the net starts to move. If the value of R_n is known, the values of θ_n^* and T_n^* are determined in terms of the equation (7). It is seen theoretically that the rope will be towed keeping the same stationary pattern as assumed when the net starts to move, if R_n keeps a constant value in the whole course of towing.

Experimental

The outline of experimental apparatus has been illustrated previously.⁴⁾ A uniform flexible twine of 3 mm. in diameter was laid at first, on a horizontal plane of dry sand, in such a form as shown in Fig. 1, letting $\overline{AD} = \overline{BC} = 120$ cm. and $\overline{AO} = \overline{OB} = 30$ cm. A small lead ball of weight 1.70 gr. was attached to the twine at the point O, in place of the net. In order to keep the distance between the both ends C and D of twine to be constant, a thin bamboo rod of definite length 60 cm. was connected to each end of the twine. Thus, the both ends were pulled simultaneously at speeds in the range of 1.25 to 1.66 cm/sec. In the first experiment, the towing force was measured at a regular interval 5 cm. of dragged distance, and then the form assumed by the twine was photographed from the top. Here, the bamboo rod has no influence upon the measured towing force, as the rod is kept afloat off the sand surface in motion by the taut hauling thread. In the second experiment, the measurements were made at a regular interval 1 cm. of towed distance between 14 and 21 cm., which was presumed to be the range to be treated in the present study. In the experiment, the towing force was measured rather larger than its intrinsic value, owing to the slight contact of bamboo rod with the sand surface.

Results and Discussion

According to the preceding experiment,²⁾ the values of K_t and K_n of the twine

used have been known to be 0.0440 gr./cm. and 0.0517 gr./cm., respectively. Substitution of the value $\kappa=0.8500$, together with $y_r(=\overline{OB})=30$ cm. derived from the experimental condition, into the equation (5) gives the relationship between θ_n and T_n , as shown in Fig. 2. On the other hand, the frictional resistance R_n of the lead ball is determined independently and is found to be 2.1100 gr., then we get $\theta_n^*=30^\circ$, by combining the equation (7) and the result given in Fig. 2.

Fig. 2. Tension T_n plotted as a function of θ_n .

Fig. 3. Calculated and observed values of tension T_e plotted against towed distance l . The marks $\odot$ and $\circ$ show duplicate experiments.

experimental condition $\overline{BC}=120$ cm., the tangential frictional force $K_t \times (\overline{RC})$ acting on the linear part $\overline{RC}$ of rope is calculated as a function of l , and thus the tension $T_e [=T_t + K_t \times (\overline{RC})]$ at the end of twine is also determined as a function of l . In Fig. 3 the calculated and observed values of T_e , including the calculated value of T_t , are plotted against l , the both values of T_e agree with each other within experimental

Substituting $\theta_n=0^\circ$ and $T_n=0.9070$ gr., given from Fig. 2, to the equations (2), (3) and (4), the towed distance when the deformation of rope propagates to the point O is determined to be 15.34 cm. by means of the equation (6). Similarly, the towed distance when the ball starts to move is determined to be 20.06 cm. In the region $l=0 \sim 15.34$ cm., the data about the form and the tension of the twine treated have already been obtained by the previous experiment,²⁾ accordingly, the data may be used in the present study. Now we proceed to our calculation in the range $l=15.34 \sim 20.06$ cm., in which the angle θ_n varies with l . Since the relation between θ_n and T_n has been given and, moreover, l can be expressed in terms of θ_n , we can get the relation between l and T_n . Then the tension T_t acting on the twine at the point R can be expressed as a function of l . From the

error. The characteristic values, s_r , x_r and y_r , of the pattern assumed by the twine can also be obtained as functions of l . In Fig. 4 are shown these relations, including the dragged distance d of the ball, together with their experimental ones. They agree satisfactorily with each other.

The author is indebted to Prof. T. KAWAKAMI for his valuable advice and revision.

Fig. 4. Calculated and observed values of s_r , x_r , y_r and d plotted against l .

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