EXPERIMENTAL VERIFICATION FOR DIFFERENTIAL EQUATIONS OF SWEEP LINE*

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In the preceding paper,¹⁾ differential equations about the form and tension of sweep line were dealt with.

In order to verify the theory, an experimental study has been carried out and the results obtained are discussed in the present paper. Moreover, the validity of the assumption, appeared in the theory, that the tangential and normal components of frictional force per unit length of rope are independent of the direction of motion is also checked experimentally.

Experimental

The experimental apparatus is essentially similar to that outlined in the previous paper.²⁾ In order to increase the precision in experiments, the apparatus was slightly modified. Efforts were made to minimize the friction of pulleies, through which a hauling thread is connected to the body to be dragged.

Prior to proceed the experimental study concerning the from and tension of rope, it must be of importance to check the validity of the assumption that the tangential and normal components of frictional force per unit length of rope, which have been denoted previously¹⁾ by K_t and K_n , respectively, are independent of the inclination angle of it. For the sake of simplicity, rigid rods were used instead of flexible rope. Two smoothly painted wooden rods of diameter 0.77 cm. and length 17.50 cm., and a bamboo rod were combined to form a frame of an isosceles triangle as shown in Fig. 1. If this triangular frame is pulled on a horizontal sand plane, by a thin thread connected to the apex A made by two wooden rods, it moves to the towing direction, canceling the lifts acting on two wooden rods. As the rods were connected each other by means of aluminium pipes, which could be easily

Fig. 1. Showing a triangular frame of wooden rods.

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

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bent, the apex angle could be varied arbitrarily according to the length of the bamboo rod. Thus, the drag acting on wooden rods was measured at the towing speed of about 1 cm./sec., with attack angles varied at every 10° between 0 and 90° . Here, the thin bamboo rod had no influence upon this measurement, as the rod did not contact with the sand surface.

Now, we proceed to the next problem. In the whole course of experiments, a uniform flexible nylon twine of 3 mm. in diameter was used as a model of sweep line. The twine was laid on a horizontal plane of dry sand in such a form as shown in Fig. 1 of the reference,¹⁾ letting $\alpha = \pi/2$, $\overline{AB} = 80$ cm. and $\overline{BC} = 100$ cm. Then, the end of twine was dragged by a thin thread at slow speeds in the range of 1.23 to 1.66 cm./sec. At a regular interval 5 cm. of dragged distance, the towing force was measured and the pattern assumed by the twine was photographed simultaneously from the top. We thus obtained the experimental data as to the tension and the shape of the twine. On the other hand, the value of K_t is measured, by pulling the definite length 100 cm. of twine, which is originally laid along the towing direction.

Results and Discussion

With the consideration of equilibrium as to the wooden rod mentioned above, the drag K_θ , at an attack angle of $(\pi/2 - \theta)$, per unit length of the rod is given by

$$K_\theta = K_n \cos \theta + K_t \sin \theta.$$

Dividing the expression by K_n , we have

$$K_\theta/K_n = \cos \theta + \kappa \sin \theta, \quad (1)$$

which shows that the ratio K_θ/K_n is a function of θ , if $\kappa (= K_t/K_n)$ is constant. This expression should be verified experimentally. In the case of the rigid rod, the value of K_n is easily obtained. On the other hand, the value of K_t is considered to estimate rather largely than its intrinsic value, owing to the sand heap appeared at the front

end of rod. In Fig. 2 is shown the relation between θ and the observed value of K_θ/K_n , an upward trend of plots, as appeared in the range of $\theta = 80 \sim 90^\circ$, is explained by the above reason. Using the observed value of K_θ/K_n for $\theta = 60^\circ$, where the sand heap is not yet found, we obtain $\kappa = 0.3$ in terms of the equation (1). The calculated values of K_θ/K_n for this value of κ are also illustrated in the same figure. The calculated and the observed value

Fig. 2. Relationship between θ and K_θ/K_n . Curve shows calculated value for $\kappa = 0.3$.

agree with each other within experimental error. Consequently, we may consider that the assumption mentioned above is verified in the range of slow speeds.

In the latter experiment, the value of K_t for the twine used has been given to be 0.0440 gr./cm. In order to compare the theoretical with the experimental, it is required to determine the value of K_n . Contrary to the rigid rod, it is very difficult to measure the value of K_n in the case of the flexible twine. Returning to the equations (5) and (6) of the reference,¹⁾ and substituting $\theta=\pi/2$, we have

$$\frac{Y_t}{X_t} \Big|_{\theta=\pi/2} = \frac{e^{\pi/2 \cdot \kappa} - \kappa}{\kappa e^{\pi/2 \cdot \kappa} + 1} \quad (2)$$

It is noted that the ratio $Y_t/X_t|_{\theta=\pi/2}$ should be a constant depending only upon the value of κ . Accordingly, the plot of Y_t against X_t , experimentally obtained, should give a straight line through the origin, with a slope given by the right-hand member of equation (2). This requirement is found to be satisfied with the data above, as shown in Fig. 3. which gives $Y_t/X_t|_{\theta=\pi/2}=0.7$. Moreover, from Fig. 4,

Fig. 3. Plots of Y_t against X_t , experimentally obtained. The slope of straight line gives 0.7. The marks $\odot$ and $\circ$ show duplicate experiments.

Fig. 4. Ratio $Y_t/X_t|_{\theta=\pi/2}$ plotted as a function of κ .

which shows the relation between the value of the right-hand member of equation (2) and κ , the value of κ is found to be 0.85 and thus in turn the value of K_n is determined to be 0.0517 gr/cm.

Once the values of K_t and K_n have been determined, it is possible to compute the values of T_o and in turn T_t as a function of l . Under the experimental condition that $\overline{BC}=100$ cm., the length of the linear part $\overline{RC}$, which connects the terminal point R of the curve and the rope end C as shown in Fig. 1 of the reference,¹⁾ and the frictional force acting tangentially upon this part, $K_t \times (\overline{RC})$, are calculated as a function of l . Sum of $K_t \times (\overline{RC})$ and T_t gives the tension T_o at the twine end. If the frictions acting on the thin hauling thread and the pulley are negligibly small as compared with the towing force, the calculated value of T_o should agree, in successive stages of towing, with the measured towing force. This requirement is also satisfied as

shown in Fig. 5, in which the calculated and observed values of towing force T_e , including the calculated values of T_o and T_t , are plotted against l . In Fig. 6. the

Fig. 5. Calculated and observed values of tension T_e plotted against towed distance l .

Fig. 6. Characteristic values, S_t , X_t and Y_t , of curve plotted as functions of towed distance l .

calculated values of S_t , X_t and Y_t are plotted against l together with their experimental ones. They agree with each other, from the nature of fact that the relation between T_o/K_n and l has been based on the experiment. Moreover, as seen in the figure, S_t , X_t and Y_t have linear relations, respectively, against l . This means the fact that the patterns assumed by the twine, in the course of towing, are geometrically similar, as pointed out previously.¹⁾

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References

- 1) SUZUKI, O.: *Bull. Jap. Soc. Sci. Fish.*, **28**, 985 (1962).
- 2) KAWAKAMI, T. and O. SUZUKI: *ibid.*, **25**, 413-416 (1959).