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A Study on Photoelectric Current Meters

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1. Introduction

Hydraulic phenomena are so confused both in the sea and in the river that several problems remain completely unsolved. To solve the problem, it is important to observe several factors relating to the phenomena. Current velocity is one of these factors but its observation is difficult. There have been many studies on measuring current velocity, in which only a few devices are used for routine work[1]. Precise measurement of current velocity has developed recently, especially for weak current velocity. And this remarkable improvement is found in neutral buoyant float for deep sea[2)~4)], and current meters for coastal regions[5)~7)]. This article is on a current meter for coastal flow, the principle of which is different from those of the other devices, that is, using smoke of Tellurium[8] and a photoelectric system.

2. Review of principles for measuring current velocities

Methods to determine current velocity have two classes from the view point of hydrodynamics : Euler's method and Lagrange's method. The latter is a method to track the motion of a water particle, and the former to observe the motion of a water particle passing at a fixed station at a certain time.

The use of floating bodies, drifting bottles or wreck boards, belong to the Lagrange's method and the use of a current meter belongs to the Euler's method. G. E. K. which is a combined system of the two methods has been widely used in recent years. G. E. K. is fit generally for observation of surface currents in a deep sea region, but it is taken to be difficult to apply to shallow water because of the effect of the electric earth current and of the electric conductivity of the sea water. There is, however, an opposit report to it : G. E. K. is a good instrument for tidal observation in coastal regions.

There have been many current meters devised for oceanographic observation[9)~12)], but a few can be used for routine works and some of them are not used at present, although they have historical values. Some are only for research, which may not be able to be applied to general uses. One of methods for measuring weak current is thermoelectric one, which is in use not only for experimental study in laboratory, but for practical oceanographic observations[13] at present.

3. Device of a photoelectric current meter[14]

The device of a current meter for coastal flow has been developed, and the principle is different from those in the above section. The model of the

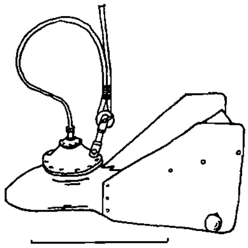

Fig. 1. Photoelectric current meter, *I-O* type.

current meter devised at first which is named *I-O* type is shown in Fig. 1. The current meter has some attachments, i. e., a source of smoke, a straight circular pipe and two phototransistors as detectors. The procedure for measuring current velocity is shown below. At first the axis of the pipe is set parallel to the current direction, and a kind of smoke or dye-mark, for which metallic Tellurium is used, is introduced into the pipe. To detect the smoke in a certain part of the pipe, a phototransistor is applied. And to determine the time of the smoke passing the two parts of the pipe, the two phototransistors as detectors set on the side of the pipe at a certain distance are used. The relation between the current velocities in the field and the current velocities in the pipe, which are determined by dividing the distance l by the time t, should be determined. A trial was carried out to test the practical applicability of this principle for measuring current velocity in coastal regions.

When the method above mentioned is applied, it needs a mechanism to issue a kind of smoke in saline water. For this purpose, smoke of metallic Tellurium is applicable. The mechanism to issue the smoke is such that when a lump of metallic Tellurium is used as a kathode in saline water which is electrically conductive, powders of purified Tellurium are produced from the surface of the lump just like black smoke. Quantity of the issuing smoke decreases with decrease in water temperature and salinity. Therefore, application of this mechanism is not suitable for fresh water.

The relation of the current velocities in the field and in the pipe is studied not only from the experimetal view point but also the theoretical one. The relation is derived and written as

$$\left(\frac{u}{u_t}\right)^2=\frac{1}{2}\left(1+\frac{64L/d}{R_e}\right) \tag{1}$$

where

$$R_e=\rho\frac{u_t d}{\mu}$$

and u and u_t are the current velocities in the field and in the pipe respectively, and L and d are the length and the inside diameter of a straight circular pipe respectively. The results which are obtained through the experiments in the flume at the Disaster Prevention Research Institute, Kyoto University, are shown in Fig. 2, in which the inside diameter is taken as one of parameters. These experimental results demonstrate the effect of the length of the pipe in relation to the current velocities in the flume or the field and in the pipe. The above theoretical equation is shown by a curve of full line in Fig. 3, in which the other curve is added that is deduced from the results of experiments. The theoretical result is in good agreement with the experimental results. From the relation shown in Fig. 3 regarding the

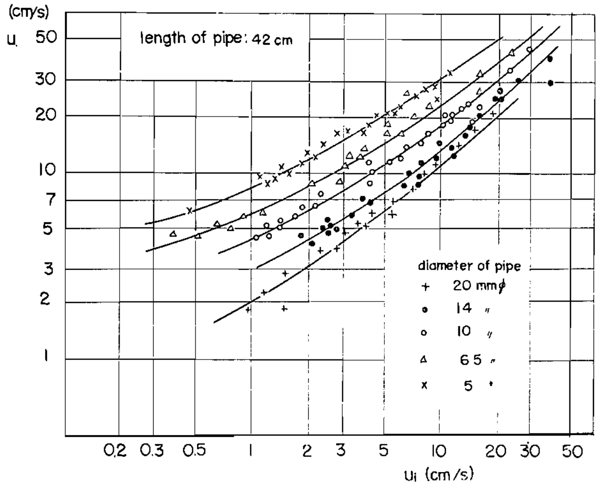

Fig. 2. Relations between u and u_i obtained from the flume expeiiments.

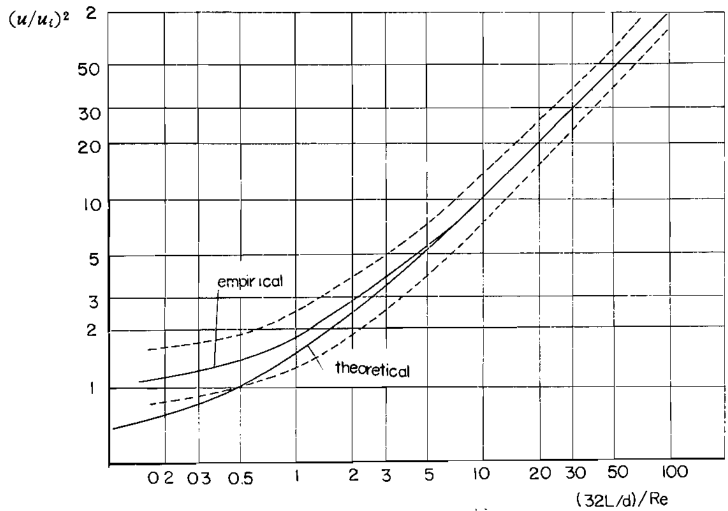

Fig. 3. Relations between $(u/u_i)^2$ and $(32L/d)/R_e$ from the flume experiments and the theoretical result (the experimental results are in the band limitted by the two dotted curves).

condition of the flume or the field, the length and the inside diameter are taken as 35 cm and 2.0 cm respectively. As seen in Fig. 1, the current meter *I-O* type contains the pipe, so that there may be structural or shape effect on the relation between u and u_i. To find whether this effect is remarkable or not, experiments were carried out in the oceanographic experimental tank at the Geophysical Institute, Kyoto University. The results of the experiments did not give data to find a significant effect of the shape or the structure. On the other hand, the errors should be noted when current velocities are measured with the axis of the pipe of current meter deflecting from the direction of current in the field. The results of experiments in the flume showed that it may be sufficient that the deflection is less than 10° if observational errors are admitted as much as 5 per cent of the observed current velocity.

4. Directional characteristics of current meters

In the practice of the above mentioned method, a current vane is attached as in Fig. 1. If the vane is deflected initially at an angle to the current direction, the vane oscillates about the direction. Assuming the deflection θ at time t and θ_0 at time $t=0$, the equation of oscillation of the vane is given by

$$I\frac{d^2\theta}{dt^2}+k\frac{d\theta}{dt}+n^2\theta=0 \tag{2}$$

where I is the moment of inertia around the suspended axis of the current meter, k and n^2 are constants determined by the current field and the scale of the current meter. This equation gives an oscillation with the following logarithmic damping factor Λ and period of free oscillation T :

$$\Lambda=\pi\frac{k}{2n\sqrt{I}}, \quad \text{and} \quad T=\frac{2\pi\sqrt{I}}{n} \tag{3}$$

Time constant, i. e., index of rapidity of damping of θ, is given by

$$(T/2\Lambda)=(2I/k)$$

It will be easily found that any current meter turns to the actual current direction after a certain lapse of time in a uniform current field. The coefficient k of the second term in the equation (2) may be determined by the torque on the suspended point and frictional resistance of fluid acting on the current meter. A wanted value Λ of the current meter may be obtained by determining suitable values of k and I. Although there is not always such a field of uniform flow in the sea, by making use of Λ and T, it is possible to know how rapid the current meter responds to a change of the direction of the current and indicates the direction of the actual current. In Table 1 are shown Λ, $T\cdot u$, $(T/2\Lambda)\cdot u$ and n^2/u^2 which are calculated for several current meters : k and n^2 are calculated refering to the terms of

TABLE 1.
Directional characteristics of current meters.

current meter	Λ	$T\cdot u$ (cm)	$(T/2\Lambda)\cdot u$ (cm)	n^2/u^2 (g)
Ekman	0.835	514	308	978
photoelectric				
I-O type	0.490	410	418	1340
I-R type	0.772	318	206	2240
N type	1.77	115	32.5	32.5

Sanuki's formula for wind vanes in a uniform wind[15], when the density of air is replaced by that of water.

Now simple current field is taken, which is expressed by $u=u_0(1+s\cdot e^{i(\omega t+\varepsilon)})$, where u_0 is a constant current velocity, and a fluctuation of current velocity is expressed by use of amplitude s, frequency ω and phase lag ε. Under this condition, the solution of the equation (2) is given by

$$\theta=\theta_0 \exp\left\{-2(\Lambda+\sqrt{\Lambda^2-\pi^2})\left(\frac{t}{T}-i\frac{s}{\omega T}e^{i(\omega t+\varepsilon)}\right)\right\} \times\left\{A'\int\exp\left[4\sqrt{\Lambda^2-\pi^2}\left(\frac{t}{T}-i\frac{s}{\omega T}e^{i(\omega t+\varepsilon)}\right)\right]dt+C\right\} \tag{4}$$

where A' and C are determined to satisfy an initial condition. Real current in the field is confused because of the existence of turbulence. An example of observation of the current direction in the Ebisugawa Waterway (Kyoto) is shown in Fig. 4, in which the trend calculated theoretically is also found in the observed variation of current direction. This observation is carried out by using the current meter *I-O* type shown in Fig. 1.

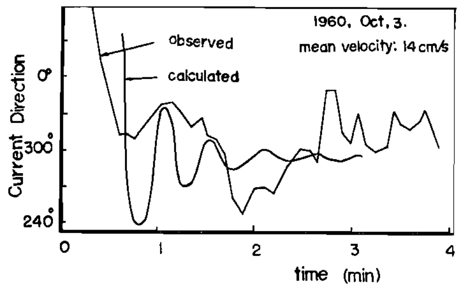

Fig. 4. Variations of current direction in the Ebisugawa Waterway (Kyoto) by use of the photoelectric current meter, *I-O* type

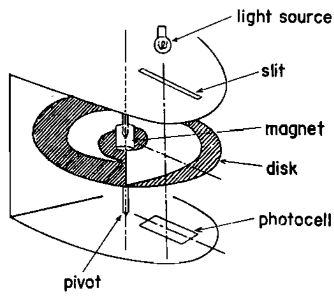

Fig. 5. A measuring unit for current direction using a photocell and a photoelectric system.

Adding to the consideration of the current vane, a device of detecting and transmitting the current direction, for which a magnetic needle or magnet is used as a reference of the north-south line[16][17], is necessary. This application is simple and useful for observation by use of current meters. A device mounted on the current meter *I-O* type is an application of the photoelectric system shown in Fig. 5. This device consists of a light source, a narrow slit and a disc with a magnet at the center of it which has a spiral slit above a photocell rotating around the pivot. By means of this device it becomes possible to detect any deflection from the azimuth of the magnet or the north-south line through the photoelectric system. Of course, the error was checked and it was found that the error caused by the existence of the frame of the current meter had turned out to be as insignificant as could be disregarded for the practical uses.

5. Photoelectric current meter *I-O* type

A photoelectric current meter *I-O* type is constructed with the considerations as above mentioned. An electric circuit is used to issue the smoke and to detect the current velocity and the current direction. The circuit is shown schematically in Fig. 6. Table 2 shows an example of tidal observation carri-

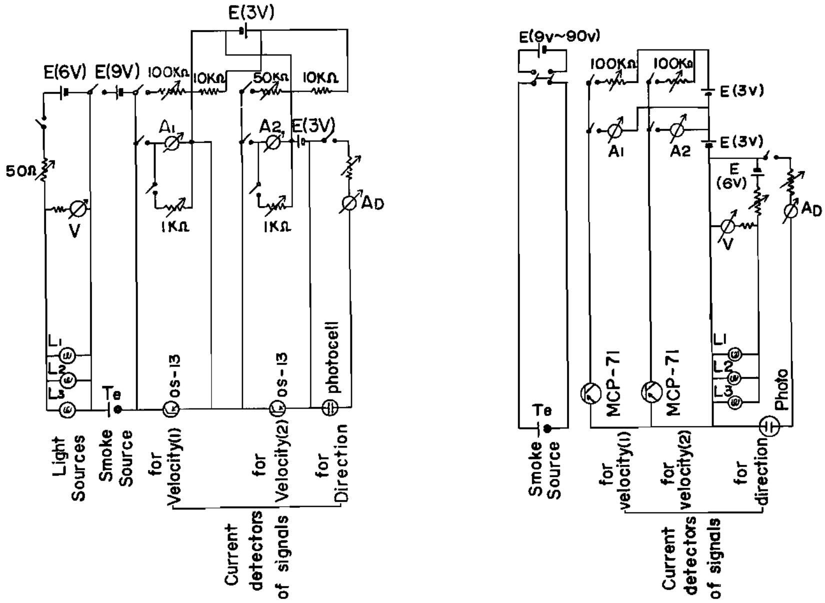

Fig. 6. Schema of the electric system in the photoelectric current meter.

TABLE 2.
Results of trial by the photoelectric current meter *I-O* type at Koganoura where the water depth was about 5m.

date	time	depth (m)	current velocity (cm/s)	current direction (degree)
1960. 8. 24	10. 00	0. 5	1. 2	85
	10. 22	3	1. 6	18
	10. 24	0. 5	1. 7	5
	10. 40	4. 9	0. 5	15

ed out as a trial at Koganoura, a small inlet at the south of Tanabe Bay, Wakayama. Scale of Koganoura is approximately 400 m in breadth and 1 km in length.

6. Further study on the current meter

The photoelectric current meter is improved and refined. Application of a thrust bearing at the suspension point is tried to lessen the effect of torsion of the lead-wire and to widen the area of the current vane. Fig. 7 shows the profile of the reformed current meter. On the other hand, an application of

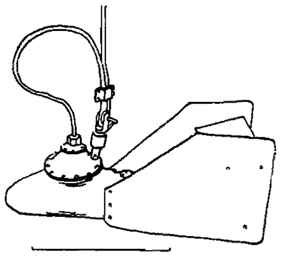

Fig. 7. Photoelectric current meter, *I-R* type.

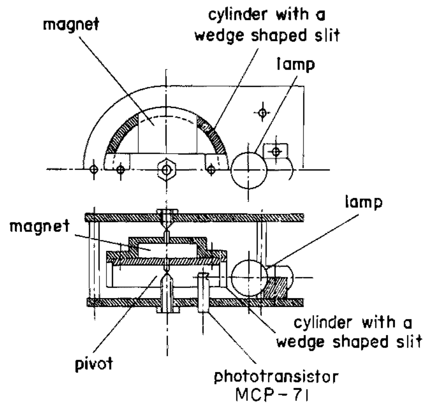

Fig. 8. A measuring unit for current direction using a phototransistor and a photoelectric system.

phototransistor is introduced as a measuring unit of current direction, which is seen in Fig. 8. In this device a cylinder with a wedge shaped slit is applied instead of the disc in Fig. 5. The most simplified one of the current meters is planned and constructed as shown in Fig. 9. A trial to use the current meters shown in Fig. 7 (*I-R* type) and Fig. 9 (*N* type) was carried out at the Oceanographic Tower Station of Kyoto University. The results of the trial are shown in Fig. 10.

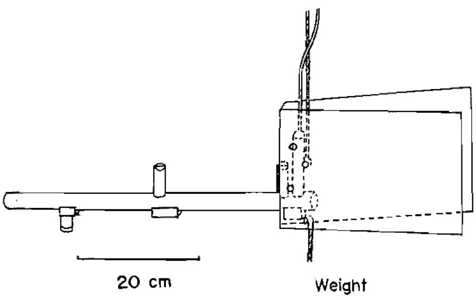

Fig. 9. Photoelectric current meter, *N* type.

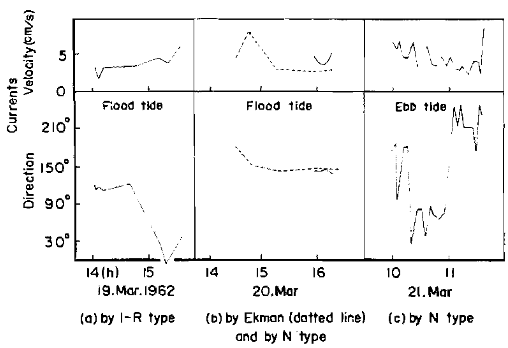

Fig. 10. Results of trials by the photoelectric current meters, *I-R* type and *N* type at the Oceanographic Tower Station of Kyoto University.

The fluctuations of the currents seem to be irregular. If these results are sure, it may be an excellent method that is introduced in this article for studying regular and irregular motions of the sea water compared with the other methods[18)19)]. From these trials and experiences, there will be found some limits or conditions in the practical application of the photoelectric current meter in the field, that is to say: (1) calm of the sea condition, (2) current velocity below 20 cm/s, and (3) station fixed to the ground etc. The limitations are not only in natural conditions but in the principle and mechanism of the current meters, for example, secondary flow induced in the pipe and mechanism of issuing the smoke.

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