Effect of Vertical Motion On Current Meters

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By N. A. KALLIO

RIVER HYDRAULICS

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A study of the effect of vertical movement on the registration of three types of current meters

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ABSTRACT

The effect of vertical motion on the performance of current meters at various stream velocities was evaluated to determine whether accurate discharge measurements can be made from a bobbing boat.

Three types of current meters—Ott, Price, and vane types—were tested under conditions simulating a bobbing boat. A known frequency and amplitude of vertical motion were imparted to the current meter, and the related effect on the measured stream velocity was determined. One test of the Price meter was made under actual conditions, using a boat and standard measuring gear. The results of the test under actual conditions verified those obtained by simulating the vertical movements of a boat.

The tests show that for stream velocities below 2.5 feet per second the accuracy of all three meters is significantly affected when the meters are subjected to certain conditions of vertical motion that can occur during actual field operations. Both the rate of vertical motion and the frequency of vertical oscillation affect the registration of the meter.

The results of these tests, presented in the form of graphs and tables, can be used as a guide to determine whether wind and stream flow are within an acceptable range for a reliable discharge measurement from a boat.

INTRODUCTION

Streamflow is usually measured by observing the depth and velocity at selected verticals in a cross section of a stream. The velocity is measured with a current meter attached to a rod or suspended on a cable from a bridge, cableway, or boat.

The accuracy of a steamflow measurement depends on the performance of the current meter, as well as on the number of observations of depth and velocity that are made in a given cross section. The performance of the common types of current meters has been thoroughly tested in various towing tanks, and Townsend and Blust (1960, p. 14) showed that comparative measurements of discharge with Price, Ott, and Neyrpic current meters in a turbulent stream agree within 0.2 percent of the mean. Similar comparisons of the performance of the Price and Ott meters for 19 pairs of discharge measurements of the Mississippi River at Vicksburg by Carter and Anderson (1963, p. 108) showed a mean difference of 0.15 percent and a maximum difference of 2.76 percent. These tests and comparisons attest to the accuracy and reliability of discharge measurements made with current meters suspended from a stationary structure; however, the performance of current meters subjected to vertical motion, as where suspended from a bobbing boat, has not been thoroughly investigated.

The effect of vertical motion on velocity registration by the Price current meter, and thus on the accuracy of discharge measurements made from a boat on a windy day, has often been a subject of conjecture. Hydrographers have observed that the Price meter responds positively (same direction as if recording stream velocity) if moved vertically in still water, regardless of the direction, frequency, or rate of vertical movement.

C. J. Chappell (written commun., 1959) stated that several tests were conducted by U.S. Geological Survey personnel in August 1939 to determine the effect of vertical motion on the Price current meter. The tests were limited to a single stream velocity of 2.5 feet per second. The results of those tests indicated underregistration if the rate of vertical motion was less than 0.75 fps and increasing overregistration if the rate of vertical motion was more than 0.75 fps. These results led to the conclusion that the rate of vertical motion determines whether the Price meter overregisters or underregisters, but this conclusion is not in agreement with the observations mentioned previously—that the meter always responds in a positive direction regardless of the direction, frequency, or rate of vertical movement in still water. One could assume, therefore, that in flowing water, some element of oscillatory motion must have a retarding effect on the registration of stream velocity by the Price meter, though the more significant effect is toward overregistration.

This report describes and presents the results of an investigation of the effect of vertical oscillation (simulated movement of a bobbing boat) on the performance of the Price, vane-type, and Ott current meters. The meters were tested within a range of frequency and amplitude of vertical oscillation that might be expected while measuring discharge from a boat. The effect of frequency of oscillation, as well as the rate of vertical motion, was evaluated.

Tests were conducted mostly in the rating flume at the Bonneville Hydraulic Laboratory of the Corps of Engineers U.S. Army. Several tests were also conducted in uniform streamflow from bridges spanning the Willamette and Columbia Rivers in Oregon. Some tests conducted in the Willamette River were later duplicated (same stream velocity) in the rating flume, and results were practically identical. All the tests, with the exception of one where a meter was suspended from a boat, were performed under simulated conditions of vertical motion.

The effect of moving a current meter up and down in uniform flow is not the same as holding a current meter motionless in turbulent flow. The assumption, therefore, should not be made that the effect of vertical motion on current meters, as presented herein, applies to current meters held motionless in turbulent flow.

For cable suspension, the meters were attached to a standard C-type sounding weight and suspended with a 0.10-inch sounding cable. For rod support, the meters were attached rigidly to a ⅝-inch metal pipe.

TESTING THE EFFECT OF VERTICAL MOTION

CURRENT METERS TESTED

The Price standard and Pygmy current meters are commonly used by the U.S. Geological Survey in measuring streamflow. The meters function similarly to an anemometer and have six conical cups that form a wheel which has an axis of rotation normal to streamflow. The standard Price meter shown in figure 1 was used for testing.

The U.S. Geological Survey designed and built the vane-type meter (see fig. 2) for use in measuring streamflow under ice cover. This meter is the same as the Price meter except that in place of conical cups it has curved vanes that are not as easily clogged by snow and ice. Figure 3 shows three adaptations of the vane-type meter. Vertical-motion tests were conducted mainly with meter A. Meter B was also tested, but on a cable (same suspension as for Price and Ott) instead of on the rod shown. Meter C is identical to A but is equipped with specially designed weights and tailpiece to allow suspension by a cable through an augered hole in ice cover.

The Ott meter is a screw-type meter having its axis of rotation parallel to streamflow. Standard equipment for cable-suspension includes a buoyant 39-inch tailpiece having a detachable horizontal fin which serves as a vertical stabilizer and counterbalance. The meter can be attached to the hanger bar with one pin, which al-

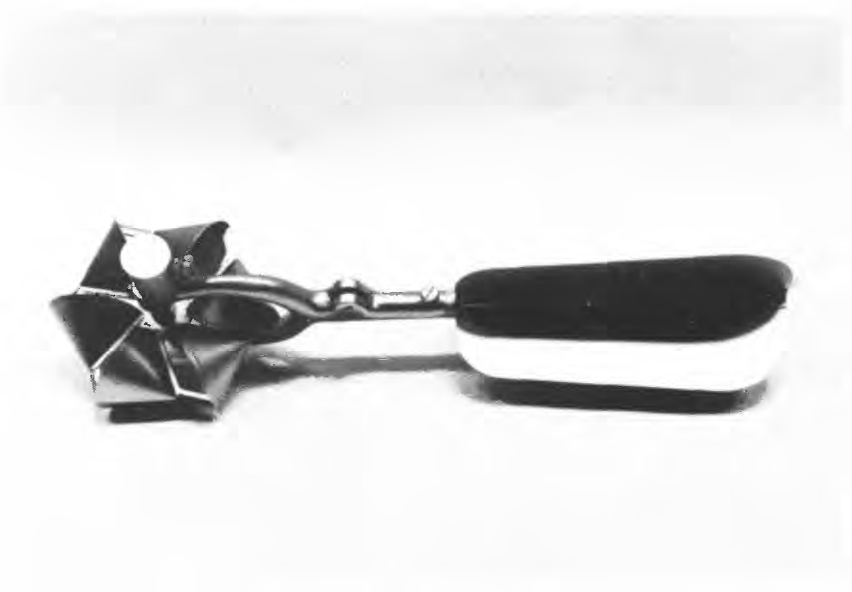

FIGURE 1.—Standard Price current meter.

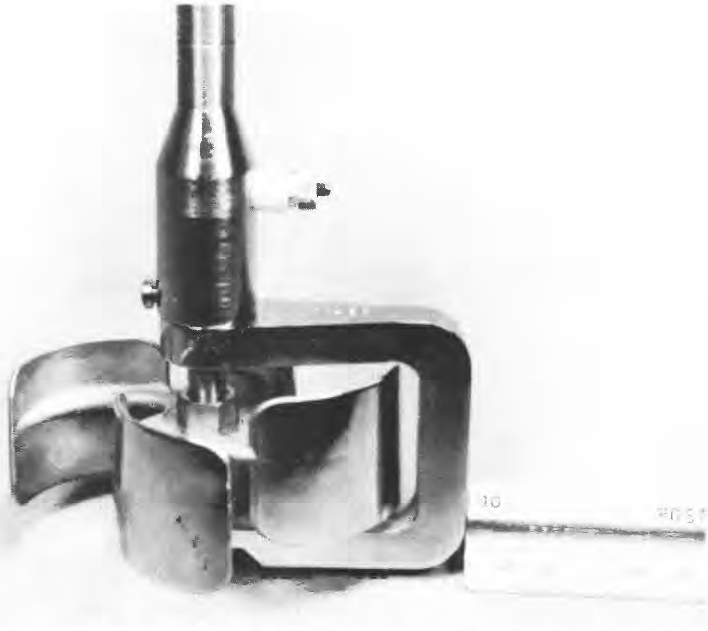

FIGURE 2.—Vane-type current meter adapted for supporting by a rod. Photograph furnished by Plans and Operations Section of U.S. Geol. Survey, Columbus, Ohio.

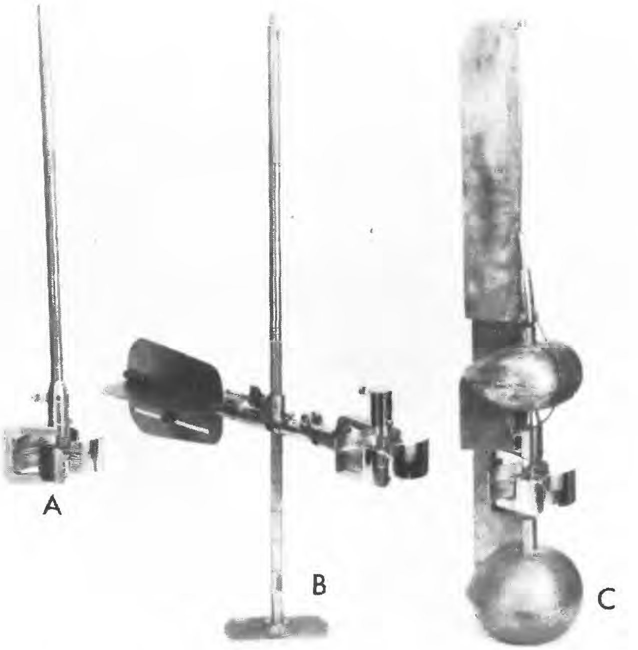

FIGURE 3.—Three adaptations of the vane-type meter: *A*, for supporting by a rod from ice cover or a boat; *B*, for supporting by a rod while wading or for suspending by a cable; *C*, for suspending by a cable through an augered hole in ice cover.

lows considerable pivot action about the pin, or it can be attached rigidly with two pins. Several types of rotors (propellers) are available for use with the Ott meter. Figure 4 shows an Ott meter with a cosine rotor (8646–A) and a standard tailpiece having a detachable stabilizer fin. This rotor is designed to register the cosine component of angular flow up to a 45° angle from the meter axis.

TEST PROCEDURE UNDER SIMULATED CONDITIONS

The vertical bobbing of a boat was simulated by the use of either a sounding reel (U.S. Geol. Survey type A) for cable suspension or a length of ⅝-inch pipe provided with guides and adjustable stops for rod suspension.

The meter was raised and lowered manually with these devices, and the cycle period of the vertical movements was timed with a stopwatch. Various periods and amplitudes of vertical motion were used, each carefully controlled and recorded so that the vertical

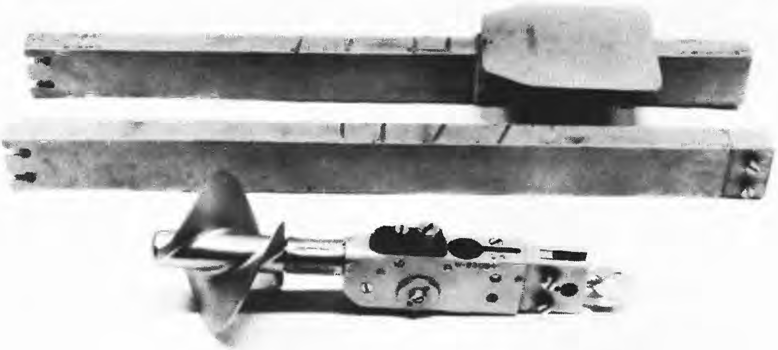

FIGURE 4.—Ott current meter with rotor 8646–A and standard tailpiece with stabilizer fin.

velocity of the meter could be computed. The amplitudes ranged from a minimum of +0.1 to —0.1 foot to a maximum of +2.0 to —2.0 feet. The cycle periods ranged from 1 to 30 seconds. Various combinations of periods and amplitudes were used in the tests to ensure that the simulated motion would encompass the unpredictable oscillations of a boat and to disclose any tendency of a meter to be affected by frequency of change in vertical direction as well as by the rate of vertical motion.

During tests conducted in the rating flume, the current meter was suspended near middepth from a tow cart, and the revolutions were counted electrically in a circuit synchronized with solenoids that expelled a dart at the beginning and at the termination of each run. The towing speed (control velocity) was determined from the time interval and distance between darts. During tests conducted from bridges, a stationary control meter was suspended at the same elevation (midpoint of vertical oscillation) and about 2 feet laterally from the meter being tested. The registrations (revolutions) of both the test and control meters were recorded simultaneously on a chronograph.

Prior to each series of tests from bridges, the stream velocity was measured at various depths within the vertical range of test oscillations to assure that the vertical distribution of stream velocity was approximately uniform. The registered velocities of the control and test meters, both held stationary at the same depth, were then compared. If a disagreement was evident, the subsequent registrations were adjusted by the amount of the difference. Some disagreement in the registration of the two meters was noted during a few of the tests and presumably caused either by differing stream velocity within the lateral distance between meters or by calibration error. The test-meter registration was also adjusted for any variation in stream velocity as recorded continuously by the control meter during each series of tests.

TEST RESULTS FOR SIMULATED CONDITIONS

Figures 5, 6, and 7 show, in feet per second, the relation between the vertical motion (abscissa) and the stream velocity (ordinate). The intercept on the ordinate axis (where the plotted line for a given observed velocity intercepts the ordinate axis) for each curve represents the true stream velocity, and the difference between the dashed horizontal line through the intercept and any given point on the curve is the overregistration or underregistration caused by the indicated rate of vertical motion. Each test point, shown as a small dot, indicates the test-meter registration during an interval of time (40–60 seconds) when the meter was being moved up and down at a constant amplitude and cycle period (frequency). The amplitude and cycle period are not identified on these graphs because of lack of space. Data extracted from these graphs, partly by interpolation, are shown in tabular form in table 1. The curves and the table indicate that each of the three meters tested is affected to some degree by vertical motion.

PRICE METER

Figure 8 shows an expanded plot of typical tests of the Price meter at a stream velocity of 1.4 fps. Each test point represents a known cycle period and amplitude of vertical motion, as identified by numbers and symbols, at a constant stream velocity. The position of each test point on the plot indicates the effect of that vertical motion on the registered stream velocity. Note that the test points farthest on the negative side (less than control velocity as registered by control meter) represent oscillations of relatively small amplitude or high frequency, whereas those near control velocity or on the positive side represent relatively large amplitude or low frequency. This distribution of test points indicates that the frequency of oscillation and the rate of vertical motion affect the Price meter registration of stream velocity. Vertical movement causes a positive effect (overregistration), whereas changes in

TABLE 1.—*Registration errors, in percentage of stream velocity*

Stream velocity (ft per sec) \ Vertical motion (ft per sec)	0.2	0.4	0.6	0.8	1.0	1.2	1.5
Price current meter [Suspended by a cable]							
0.5	−2.0	+10	+36	+72	+120	+150	+210
1.0	−3.0	−1.0	+10	+24	+40	+50	+56
1.5	−6.7	−6.7	−4.0	+1.3	+8.0	+25	+27
2.0	−2.5	−2.5	−2.5	−2.0	0	+4.0	+14.0
2.5	0	0	0	0	0	+ .8	+4.0
3.0	0	0	0	0	−2.3	−2.0	0
4.0	0	0	0	0	−1.3	−1.3	0
5.0	+ .4	+1.0	+ .6	0	− .2	0	+ .8
7.0	− .7	− .4	0	+ .1	− .4	− .7	− .4
10.0	− .5	− .3	0	0	− .3	− .7	−1.3
Vane-type current meter [Suspended by a rod]							
0.5	+4.0	+6.0	+20	+44	+72	+100	+160
1.0	+5.0	+10	+12	+10	+11	+15	+26
1.5	+3.3	+8.7	+10	+6.7	+3.3	+3.3	+10
2.0	+2.0	+6.5	+9.0	+9.5	+8.5	+6.0	+7.5
2.5	+2.0	+4.4	+6.4	+7.6	+8.0	+7.2	+6.4
3.0	−1.7	+3.7	+5.3	+6.7	+7.3	+7.7	+6.7
4.0	+1.2	+ .8	+ .3	+1.0	+2.5	+3.8	+3.3
5.0	−1.0	−2.6	−2.8	−2.0	− .4	− .2	−2.0
7.0	− .7	− .7	− .3	0	0	+ .3	− .4
Ott current meter [Cosine rotor 8646–A, standard tailpiece without vertical stabilizer, and two-pin attachment to cable hanger]							
0.5	0	+6.0	+10	+20	+30	+44	+70
1.0	0	0	0	+4.0	+9.0	+15	+30
1.5	0	0	0	+1.3	+4.0	+7.3	+17
2.0	0	0	0	+ .5	+2.0	+4.5	+9.5
2.5	0	0	0	0	+1.6	+2.8	+6.4
3.0	0	0	0	+ .3	+1.0	+2.3	+6.0
4.0	0	0	+ .5	+1.0	+1.8	+2.5	+3.8
5.0	+ .4	+ .6	+ .4	+ .6	+1.0	+1.4	+2.0
7.0	0	0	0	0	+ .3	+ .7	+1.4

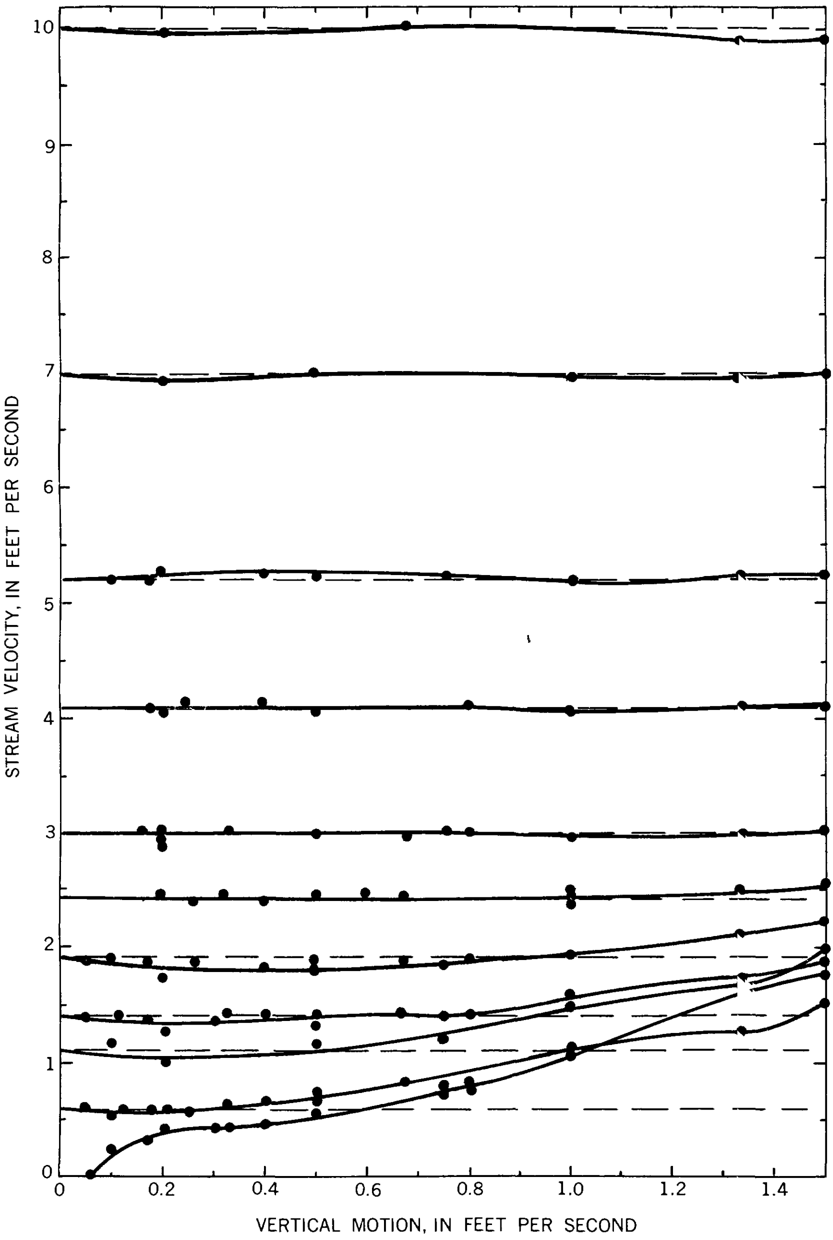

FIGURE 5.—Effect of vertical motion on the Price current meter suspended by a cable. The vertical intercept is the true stream velocity, and the departure from the dashed line through the intercept is the error in registration caused by the rate of vertical motion (abscissa). The true stream velocity for the lowest curve is zero.

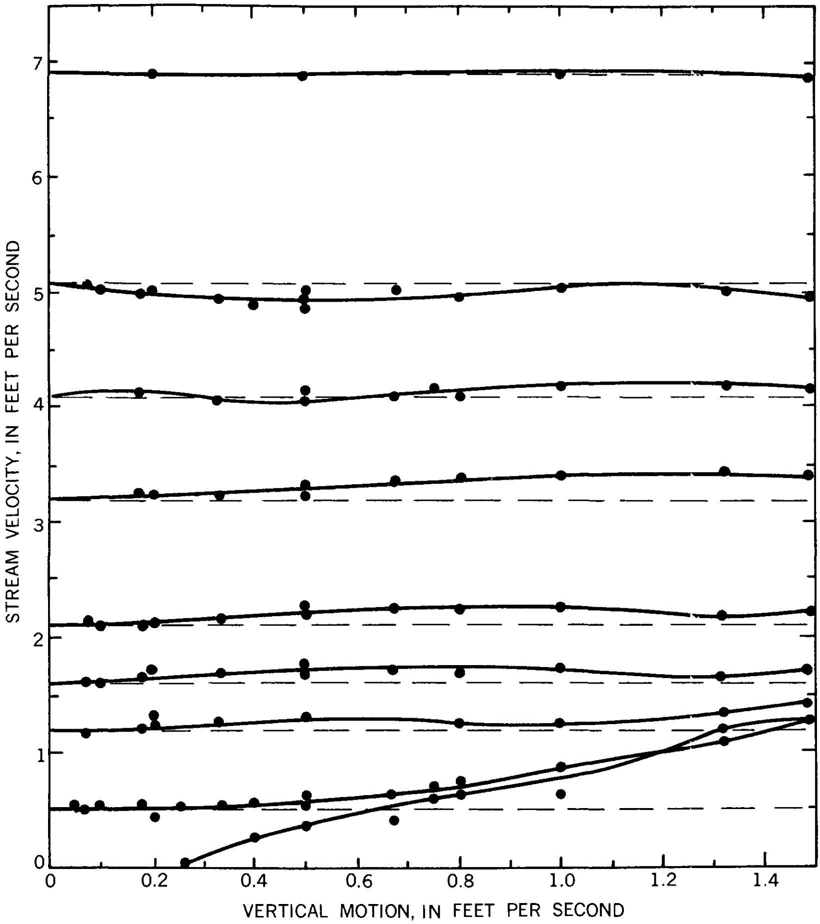

FIGURE 6.—Effect of vertical motion on the vane-type current meter supported by a rod. The true stream velocity for the lowest curve is zero.

vertical direction cause a negative effect (underregistration). The negative effect varies directly with the frequency of changes in direction and probably has a retarding effect whenever the meter is oscillated up and down in flowing water, but it is the dominant factor only at small amplitude in stream velocities between 0.5 and 2.4 fps.

Because of the horizontal fins on the sounding weight and the tailpiece of the current meter, the cable-suspended meter and sounding weight are poorly balanced hydrodynamically when moved vertically and they, therefore, tend to pivot about their hanger pins when moved up and down. Some freedom for pivoting

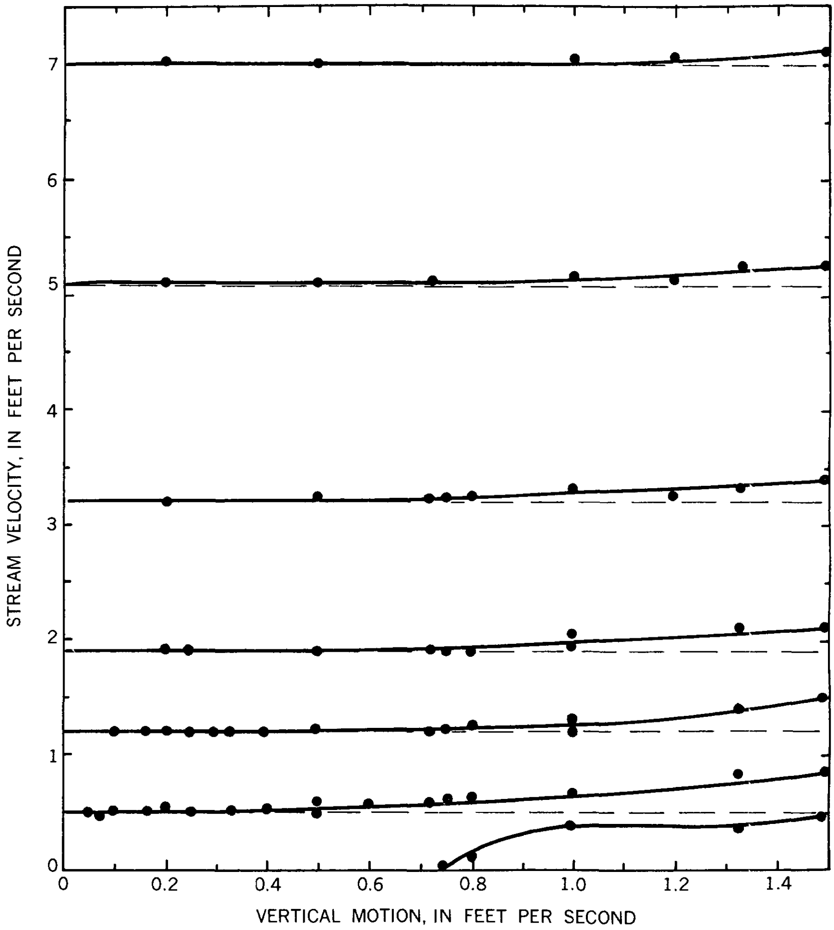

FIGURE 7.—Effect of vertical motion on the Ott current meter suspended by a cable and equipped with rotor 8646–A and a standard tailpiece without stabilizer. The true stream velocity for the lowest curve is zero.

is provided in the hanger-bar attachment of both the meter and the weight, but during higher rates of vertical oscillation, the limits of that freedom are exceeded. As a result, the hanger bar begins to tilt forward on downward movement of the weight and meter and backward on upward movement. The combined pivoting and tilting tends to head the meter in the direction of vertical motion.

In an effort to evaluate the effect of pivoting and tilting on the registration of the Price meter, several tests were conducted with the meter attached to a rod. Figure 9 shows the results of these tests. Comparison with test results for cable suspension (fig. 5)

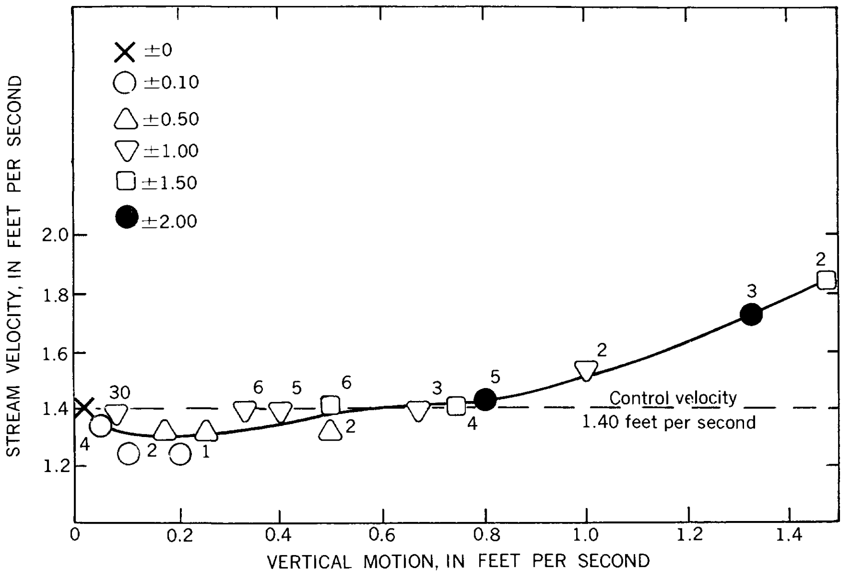

FIGURE 8.—Expanded test plot for Price current meter in a stream velocity of 1.40 feet per second. The symbols show the various amplitudes in feet, of simulated wave motion for which the meter was tested. The numbers indicate cycle periods in seconds. Curve drawn through the points represents the average deviation from true velocity for various combinations of amplitude and cycle period.

indicates that the pivoting and tilting of the cable-suspended meter increase the registration at most of the stream velocities tested.

VANE-TYPE METER

The vane-type meter is used mostly for measuring streamflow under ice cover and in open water where slush ice is flowing. Figure 6 shows that the rod-suspended meter overregisters significantly from 0 to 4 fps and underregisters at 5 fps stream velocity if subjected to vertical motion. Meter-calibration tests at 5 fps stream velocity indicated some rating instability, which may account for part of the underregistration at this velocity.

The meter (meter B, fig. 3) was also tested while suspended by a cable. Figure 10 shows that the effect of vertical motion is very similar to the effect on the rod-supported meter except that the cable-suspended meter underregistered at 0.5 fps stream velocity if the vertical motion was between 0 and 0.6 fps. The pivoting and tilting observed during the tests of the Price meter also occurred during these tests, but comparison of figures 6 and 10 does not indicate any overregistration from that cause.

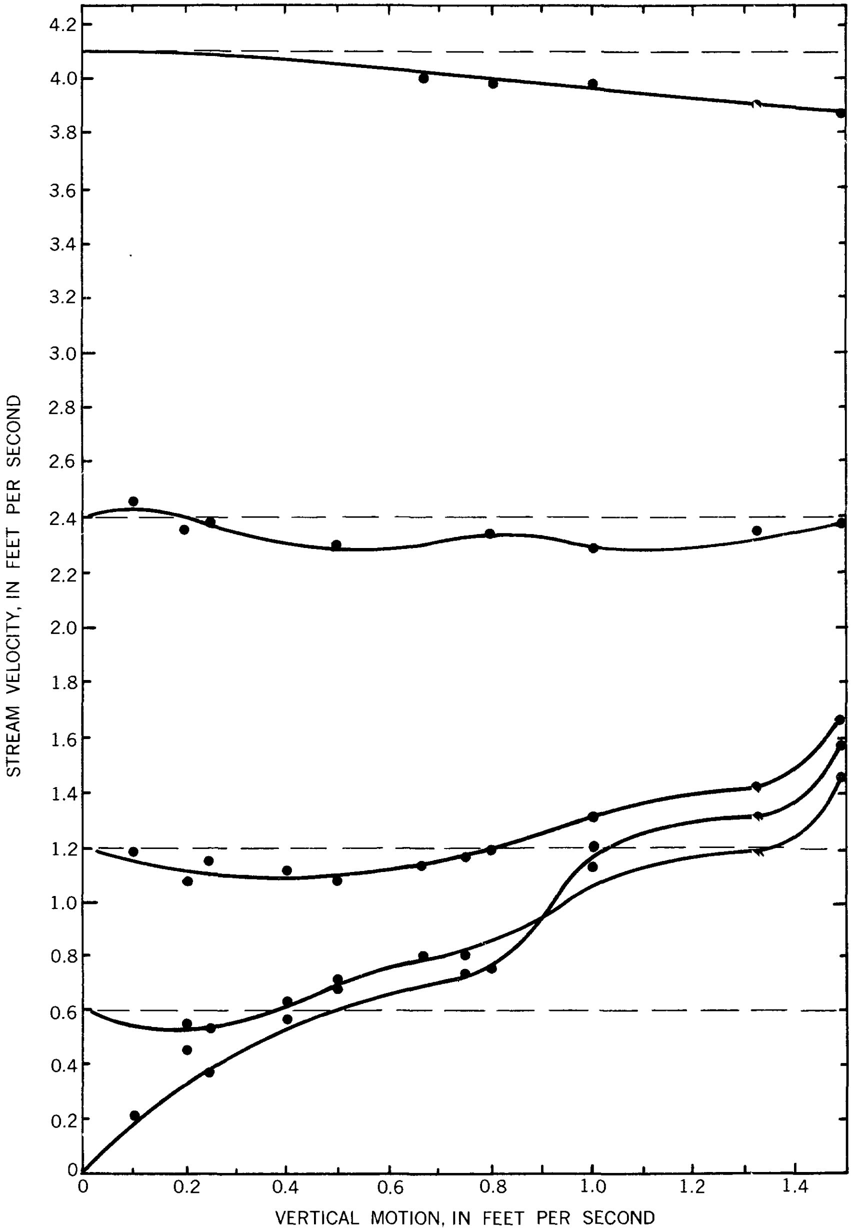

FIGURE 9.—Effect of vertical motion on the Price current meter supported by a rod. The true stream velocity for the lowest curve is zero.

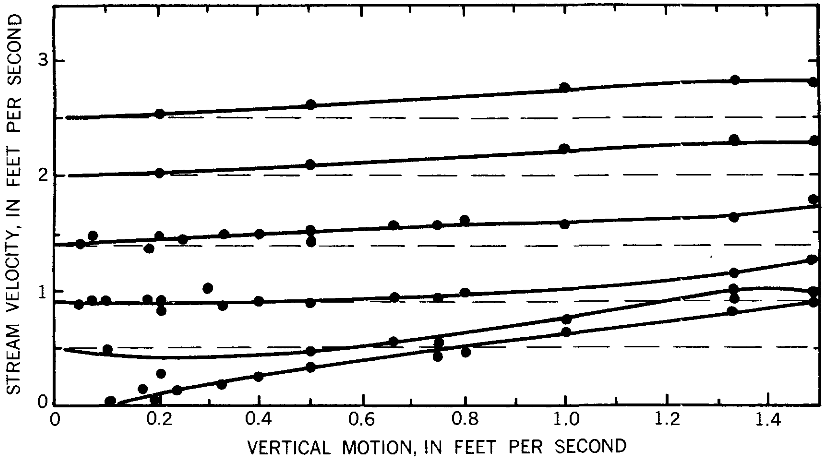

FIGURE 10.—Effect of vertical motion on the vane-type current meter suspended by a cable. The true stream velocity for the lowest curve is zero.

OTT METER

Figure 7 shows that the Ott meter overregisters if subjected to vertical motion but to a lesser extent than the Price or vane-type meters. The cosine property of the rotor (8646–A) used in these tests has been tested, with favorable results, in the Bureau of Standard's rating flume. Vertical motion tests, therefore, were expected to show no overregistration at rates of vertical motion less than stream velocity (resultant angle of flow less than 45° from meter axis) because it was assumed that the cosine property would cancel any tendency of the meter to overregister. The curves shown in figure 7 tend to verify that assumption up to a stream velocity of about 1.0 fps. At higher stream velocities, however, the meter begins to overregister at less than a 45° angle of flow.

Because the Ott meter has such a long tailpiece, it is even less well balanced hydrodynamically than the Price meter in vertical movement; consequently, it tilts more if moved up and down. The two-pin attachment fixes the meter rigidly to the hanger bar and eliminates the possibility of pivoting, but, as explained for the Price meter, the hanger bar tilts forward and backward during higher rates of vertical oscillation. The Ott meter was tested mostly without the stabilizer fin because the fin would cause the meter to tilt even more. Because a hydrographer has the option of removing the fin, it probably would not be used when measuring

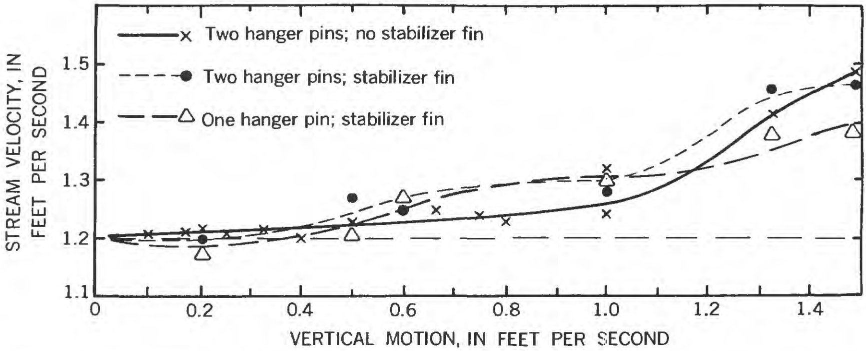

FIGURE 11.—Effect of vertical motion on the Ott current meter suspended by a cable. The curves show the comparative effect of one- and two-pin attachment to the hanger bar, and the effect of the stabilizer fin.

velocity from a bobbing boat; the two-pin attachment to the hanger bar would generally be used.

Figure 11 shows the results of vertical motion tests with and without the stabilizer fin and with one- and two-pin attachment to the hanger bar. The two-pin attachment without stabilizer fin caused the least amount of tilting, whereas the one-pin attachment with stabilizer fin caused the most. No significant increase in overregistration, however, is indicated by an increased amount of tilting.

To determine the effect of vertical motion when tilting is not a factor, the Ott meter was tested while attached to a rod. Figure 12 shows that the meter still overregisters, and comparison with figure 7 indicates that overregistration was reduced slightly by elimination of the tilt factor.

Vertical-motion tests were also conducted with the Ott meter using rotor 8406–1 and a modified tailpiece. (See fig. 13.) The short tailpiece (not standard Ott equipment) was designed to improve the hydrodynamic balance of the meter and thereby reduce the tilting. The meter was tested from a suspended cable, and no tilting was observed except at rates of vertical motion exceeding 1.0 fps. Rotor 8406–1 has considerably greater pitch than cosine rotor 8646–A and is apparently designed for low stream velocities. The results of these tests (fig. 14) show significant underregistration for the slow-velocity rotor at all stream velocities. Comparison of test data for the two Ott rotors shows that rotors of various pitch designs can vary considerably in their response to vertical motion, and this fact indicates that a rotor could possibly be designed which would not register vertical motion.

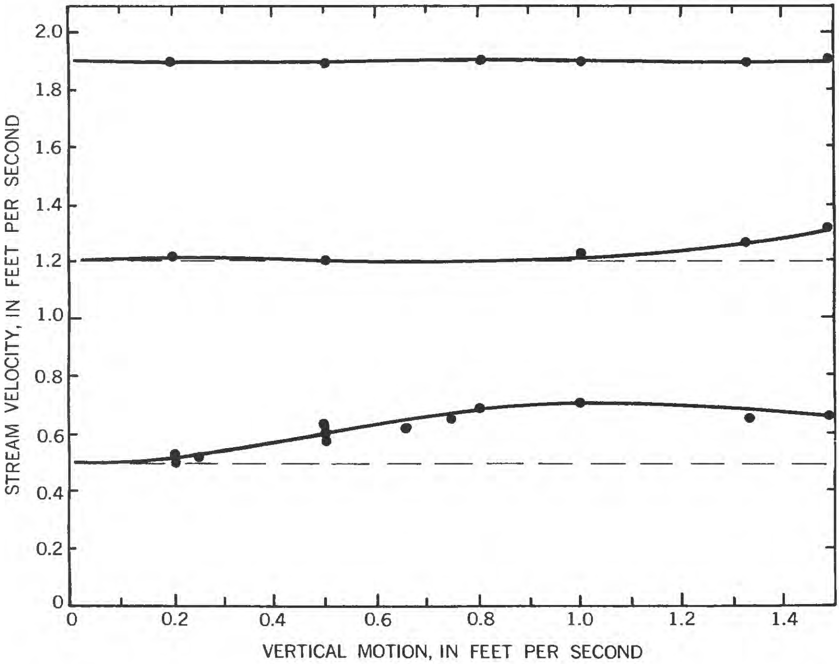

FIGURE 12.—Effect of vertical motion on the Ott current meter supported by a rod and equipped with rotor 8646–A.

TEST UNDER ACTUAL CONDITIONS

Results of the foregoing tests represent the effect on registration of current meters when subjected to various combinations of man-induced wave motion in various stream velocities. To corroborate the results of these simulated studies, a Price meter was suspended from a 14-foot boat having standard U.S. Geol. Survey equipment and was tested under actual conditions.

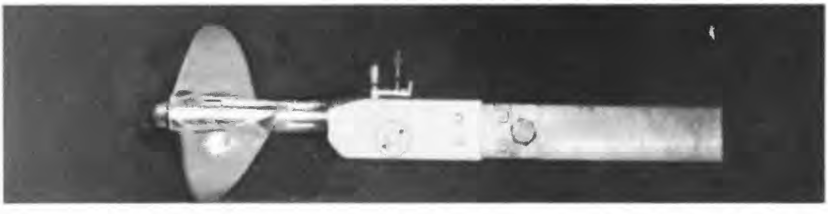

FIGURE 13.—Ott current meter with rotor 8406–1 and modified tailpiece.

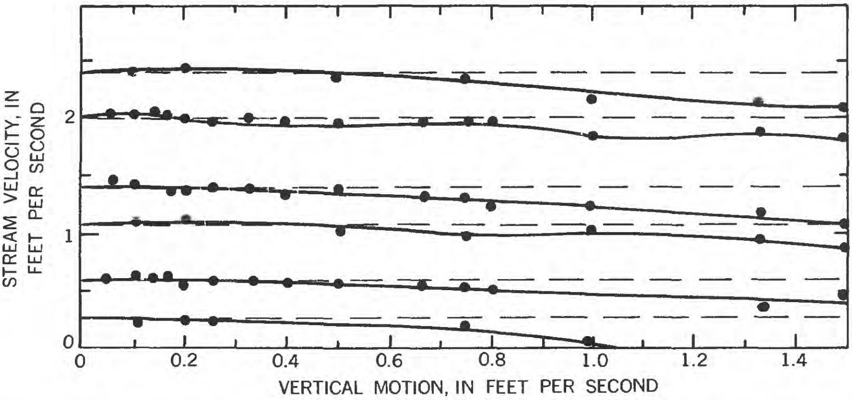

FIGURE 14.—*Effect of vertical motion on the Ott current meter suspended by a cable and equipped with rotor 8406–1 and a short tailpiece.*

The boat, positioned beneath a bridge which spans the Columbia River at Hood River, Oreg., was restrained from horizontal movement by a cable attached to piers 200 feet apart but was free to move up and down. One Price meter (test meter) was suspended from a standard boat measuring boom which extended 2 feet over the bow of the boat, and a control meter (Price) was suspended from the bridge at the same elevation, but 3 feet laterally from the test meter. The revolutions of both meters and the vertical movements of the boat were simultaneously recorded on a chronograph, as shown in figure 15. The wind was variable and the velocity was estimated to be 5–30 miles per hour. There were no "white caps"—thus wind conditions were relatively calm for the Columbia River gorge.

RESULTS OF TEST UNDER ACTUAL CONDITIONS

Figure 16 shows the chronological sequence of vertical motion of the test meter and the registration of stream velocity by both the test meter and the control meter. The data were computed and plotted for 10-second intervals by summing the number of revolutions of the rotor for each meter at 10-second intervals and converting that to velocity and by summing the vertical distances the meter traveled, as recorded on the chronograph (without regard to direction) for each 10-second interval, and dividing by 10 to obtain the velocity of vertical motion. Even with a mild wind, which is common during many discharge measurements, the

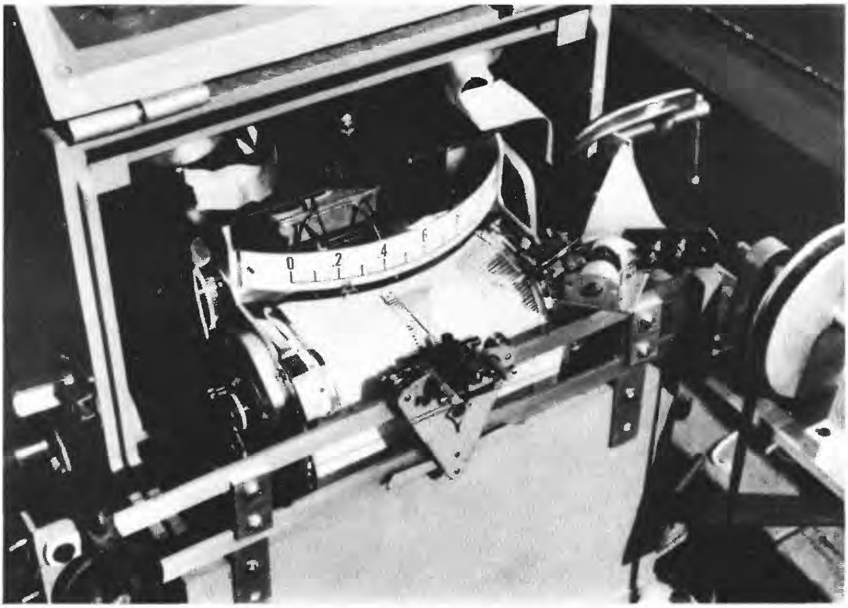

FIGURE 15.—Chronograph equipped for recording revolutions of two current meters and the vertical movement of a boat.

Price meter overregistered nearly 8 percent on the average and more than 30 percent at times.

The results from the tests made from the boat agree very favorably with the results of tests from simulated wave motion. Underregistration began to occur when the vertical motion decreased to less than 0.5 fps, which agrees with the test results for 1.1 fps stream velocity shown in figure 5. The magnitude of overregistration and underregistration also agrees with the amounts shown in figure 5 for corresponding rates of vertical motion.

CONCLUSIONS

The results obtained from the tests during this study indicate that the performance of each of the three current meters tested is significantly affected by vertical motion in lower stream velocities. Discharge measurements made at low stream velocities, therefore, can be in error by a significant amount.

The results shown in figures 5, 6, and 7 and table 1 can be used as a guide in deciding whether wind and streamflow are within an acceptable range for a reliable discharge measurement from a boat. The rate of vertical motion of a boat can be approximated

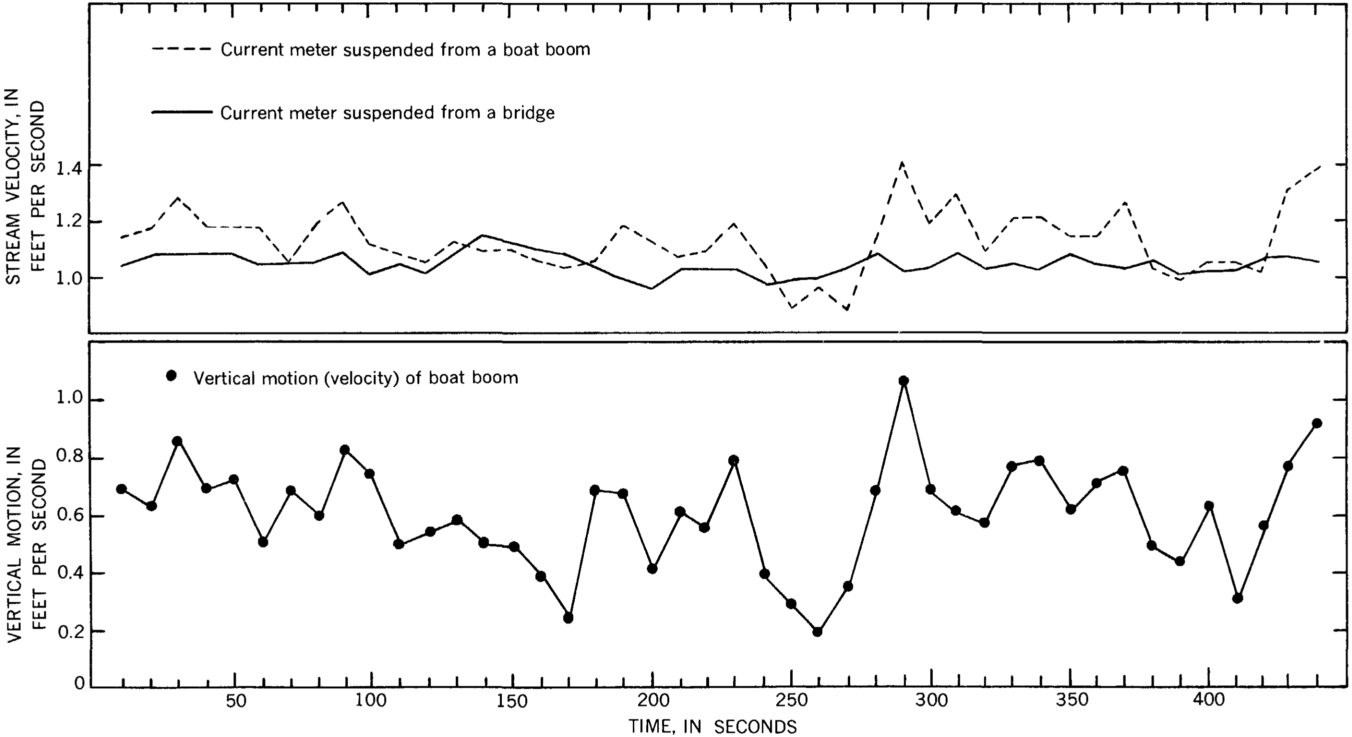

FIGURE 16.—Comparison of registered velocities by two Price current meters—one suspended from a bridge and the other from a boat beneath the bridge.

by measuring its vertical movement (twice the average distance from lowest to highest positions) with a sounding or anchor line and then multiplying by the number of cycles (frequency) per second. During the boat test performed for this study, the frequency of vertical motion remained relatively constant; only the amplitude varied.

In stream velocities above 2.5 fps, the effect of vertical motion on the Price meter becomes insignificant within the range of vertical motion tested in this study. The underregistration of the Price meter at low rates of vertical motion is caused by relatively high frequency of vertical oscillation rather than the rate of vertical motion. Measurement of velocities from a small boat in choppy water may result in underregistration in the velocity range from 0.5 to 2.4 fps.

The vane-type meter overregisters significantly in steram velocities up to 4 fps if subjected to vertical motion. Underregistration at 5 fps may have been caused partly by rating instability, which is suggested by a variation in several calibration checks made at this stream velocity.

The results shown for the Ott meter in figures 7, 11, and 12 and in table 1 apply only to rotor type 8646–A. The rotor overregisters significantly in stream velocities up to 4 fps if the rates of vertical motion exceed 0.8 fps. At stream velocities of 1.0 fps and less, however, it overregisters at lower rates of vertical motion. Where the meter is used with other types of rotors, the effect of vertical motion, as shown by the test results for rotor 8406–1 (fig. 14), is likely to be different. The variation in the effect on rotors of different design indicates that a rotor could be designed which would not be affected by vertical motion.

LITERATURE CITED

Carter, R. W., and Anderson, I. E., 1963, Accuracy of current meter measurements: Am. Soc. Civil Engineers, Jour. Hydraulics Div., v. 89, no HY 4, Proc. Paper 3572, p. 105–115.

Townsend, F. W., and Blust, F. A., 1960, A comparison of stream velocity meters: Am Soc. Civil Engineers, Jour. Hydraulics Div., v. 89, no. HY 4, Proc. Paper 2438, p. 11–19.

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