THE EFFECTS OF VERTICAL MOTION ON THE PERFORMANCE OF CURRENT METERS

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The Effects of Vertical Motion on the Performance of Current Meters

By Kirk G. Thibodeaux and James C. Futrell, II

ABSTRACT

A series of tests to determine the correction coefficients for Price type AA and Price type OAA current meters, when subjected to vertical motion in a towing tank, has been completed. During these tests, the meters were subjected to vertical travel that ranged from 1.0 to 4.0 feet and vertical rates of travel that ranged from 0.33 to 1.20 feet per second while being towed through the water at speeds ranging from 0 to 8 feet per second. The tests show that type AA and type OAA current meters are affected adversely by the rate of vertical motion and the distance of vertical travel. The results of these tests show that when current meters are moved vertically, correction coefficients must be applied to the observed meter velocities to correct for the registration errors that are induced by the vertical motion. The type OAA current meter under-registers and the type AA current meter over-registers in observed meter velocity. These coefficients for the type OAA current meter range from 0.99 to 1.49 and for the type AA current meter range from 0.33 to 1.07. When making a current-meter measurement from a boat or a cableway, errors in observed current-meter velocity will occur when the bobbing of a boat or cableway places the current meter in vertical motion. These errors will be significant when the flowing water is less than 2 feet per second and the rate of vertical motion is greater than 0.3 foot per second.

INTRODUCTION

U.S. Geological Survey field personnel make numerous water velocity measurements using Price type AA current meters from small boats and cableways in accordance with Geological Survey Water-Supply Paper 2175 (Rantz and others, 1982). Water velocity measurements made from boats are subject to errors due to vertical movement of the boat caused by waves and from horizontal movement of the boat caused by winds. The water velocity measurements made from a cableway are subject to the same errors from the cable movement up and down when the cable car is moved to the next measuring section and from horizontal movement caused by winds. Because of these errors, it is stated (Rantz and others, 1982, p. 157-158) that "boat measurements are not recommended where velocities are slower than 1 ft/s (0.3 m/s) when the boat is subject to the action of wind and waves." However, in areas such as bays or estuaries, low-flow measurements from boats are usually made because other methods are not readily available. The errors induced from vertical motion of the Price type AA current meter were initially studied at the Colorado Agricultural College by Rohwer (1933) and further investigated by Kallio (1966).

This report presents the results of tests designed to determine effects of controlled vertical motion on current meters. The tests were performed in 1984 by the U.S. Geological Survey, Hydrologic Instrumentation Facility (HIF) in the Hydraulics Laboratory at the National Space Technology Laboratories, Mississippi. The HIF test data were collected from the controlled vertical motion tests of one cable-suspended Price type OAA current meter, one cable-suspended Price type AA current meter, and one cable-suspended pinned Price type OAA current meter from a platform that simulates a bobbing boat or cableway, while each current meter was being towed in the laboratory's tow tank facility.

The results of Kallio's studies are included in this report, but a direct comparison of Kallio's data and the data presented here cannot be made because Kallio's test data were not published with his report. Kallio concluded that the induced errors were a function of the rate of vertical motion of the meter. The HIF data shows that the errors were also a function of the vertical distance traveled by the meter during the bobbing motion. The HIF study serves to expand on Kallio's work, particularly at slower stream velocities.

APPROACH

Test Facility

Vertical motion tests of the Price type AA and OAA current meters were conducted in the Survey tow tank facility consisting of a tow tank that is 12 ft wide, 12 ft deep, and 450 ft long with a tow carriage that travels on rails atop the tank at speeds from 0.01 to 14 ft/s. The data-acquisition system of the tow carriage registers travel time, traveled distances, and the current-meter rotation data. The tow carriage has a speed accuracy of 0.01 percent at any speed based on the time and distance traveled. The accuracy of the time and distance acquisition equipment is traceable to the National Bureau of Standards.

Equipment Used

The equipment used for testing the Price type AA and OAA current meters consisted of a vertical motion generator, a 50-lb Columbus (50C)[1] sounding weight with hanger bar and a 0.125-in.-diameter Ellsworth[2] steel cable.

The vertical motion generator was assembled from a double-acting hydraulic cylinder with a directional valve, flow-control valve, pressure-check valve, and limit switches. The hydraulic cylinder was positioned horizontally on the deck of the tow carriage and mounted in a fabricated aluminum frame. This frame, in conjunction with rollers attached to the push rod of the hydraulic cylinder, prevented the rod from rotating as it moved back and forth. A cable fastened to the end of the cylinder rod redirected the horizontal rod motion to vertical cable motion by a series of pulleys. Sketches and photographs of the test assembly are shown in figures 1 through 3. Limit switches controlled the distance and direction traveled by the meter and were activated by the cylinder rod. The wave form of the moving current meter generated during testing was triangular in shape.

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[1] Columbus sounding weights were developed by the U.S. Geological Survey.

[2] Use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

DIAGRAM OF TEST RIG

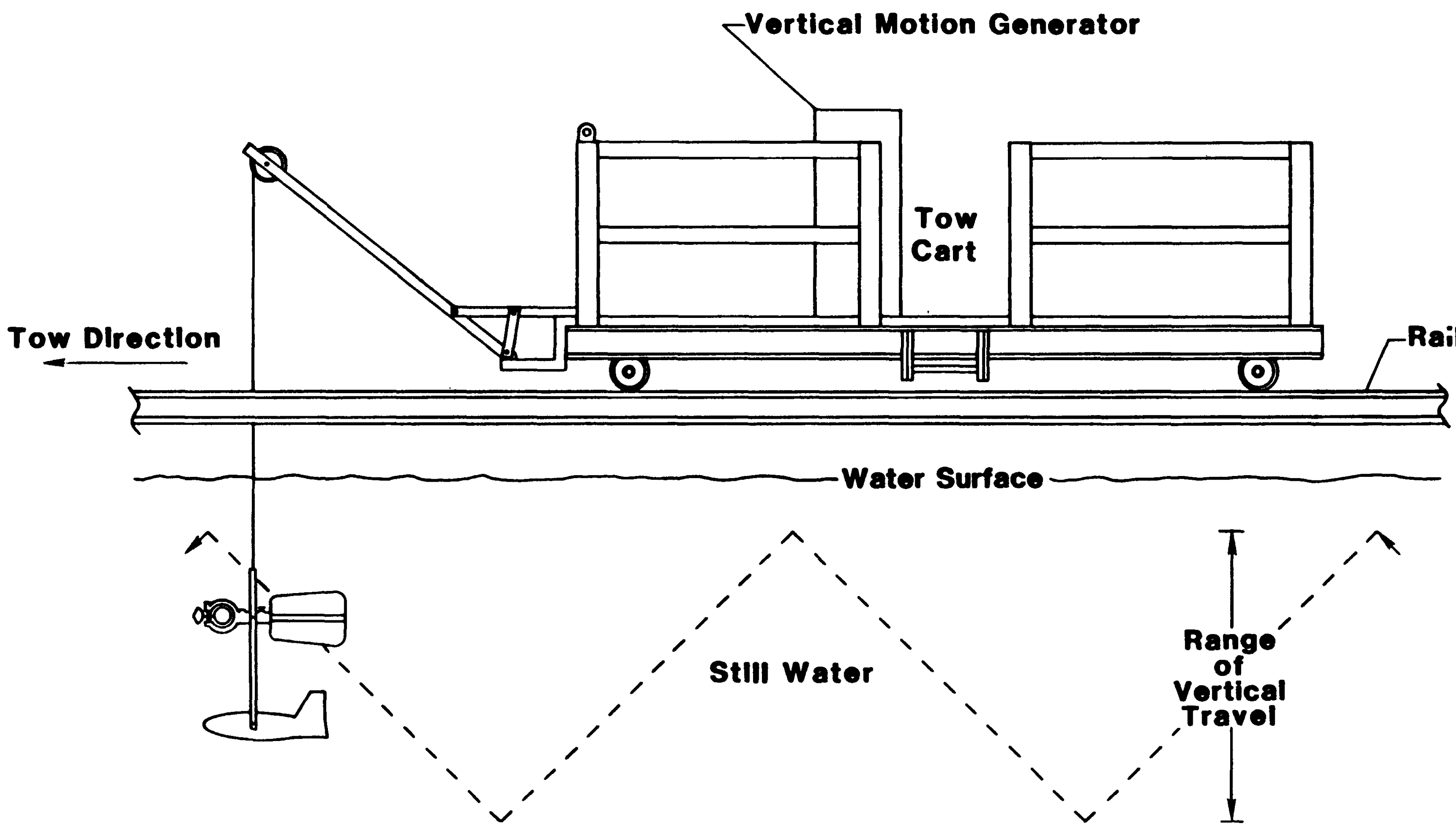

Figure 1.--U.S. Geological Survey test facility showing the travel of the meter.

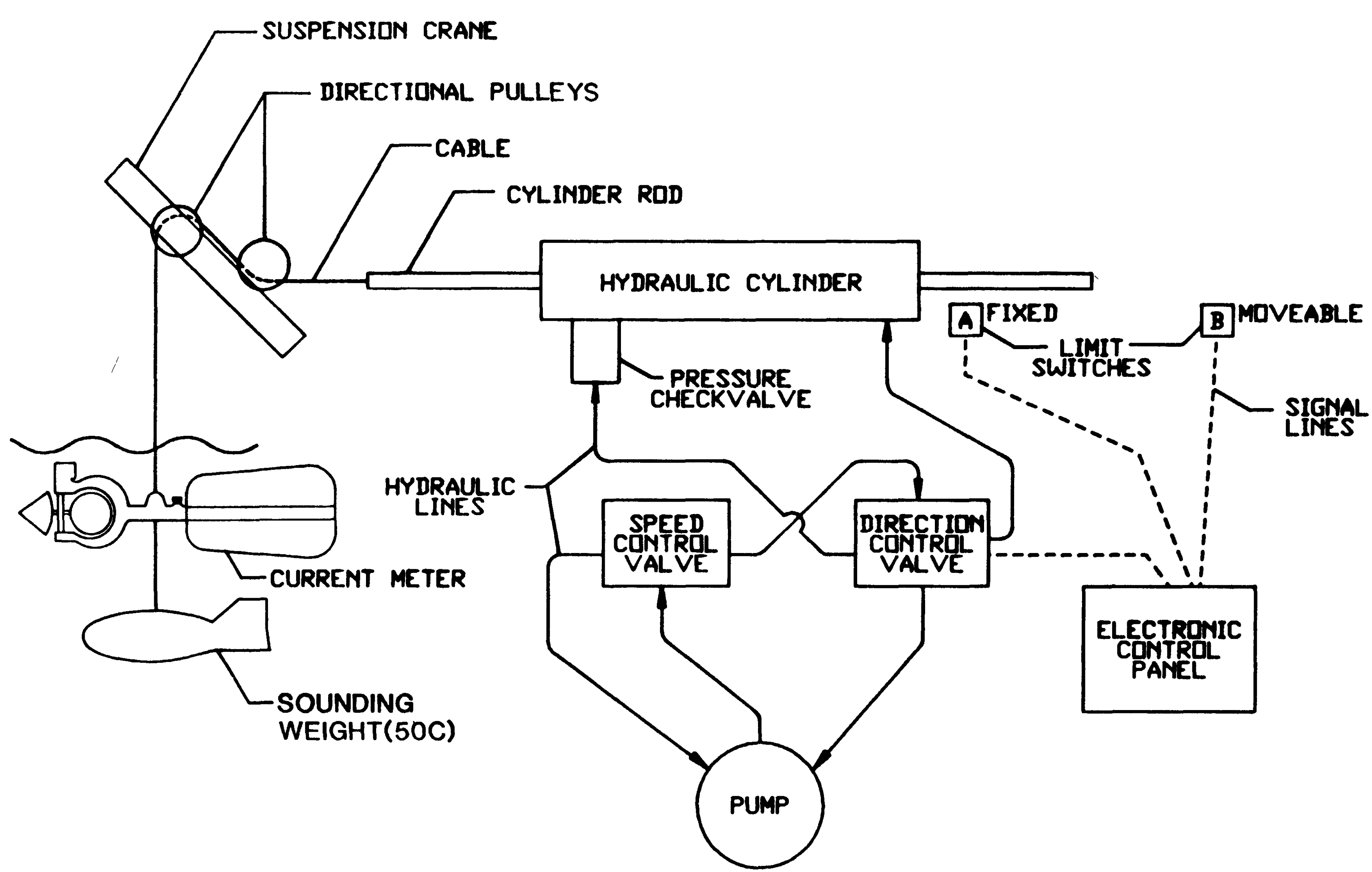

Figure 2.--Vertical motion generator installed on tow carriage of tow tank facility.

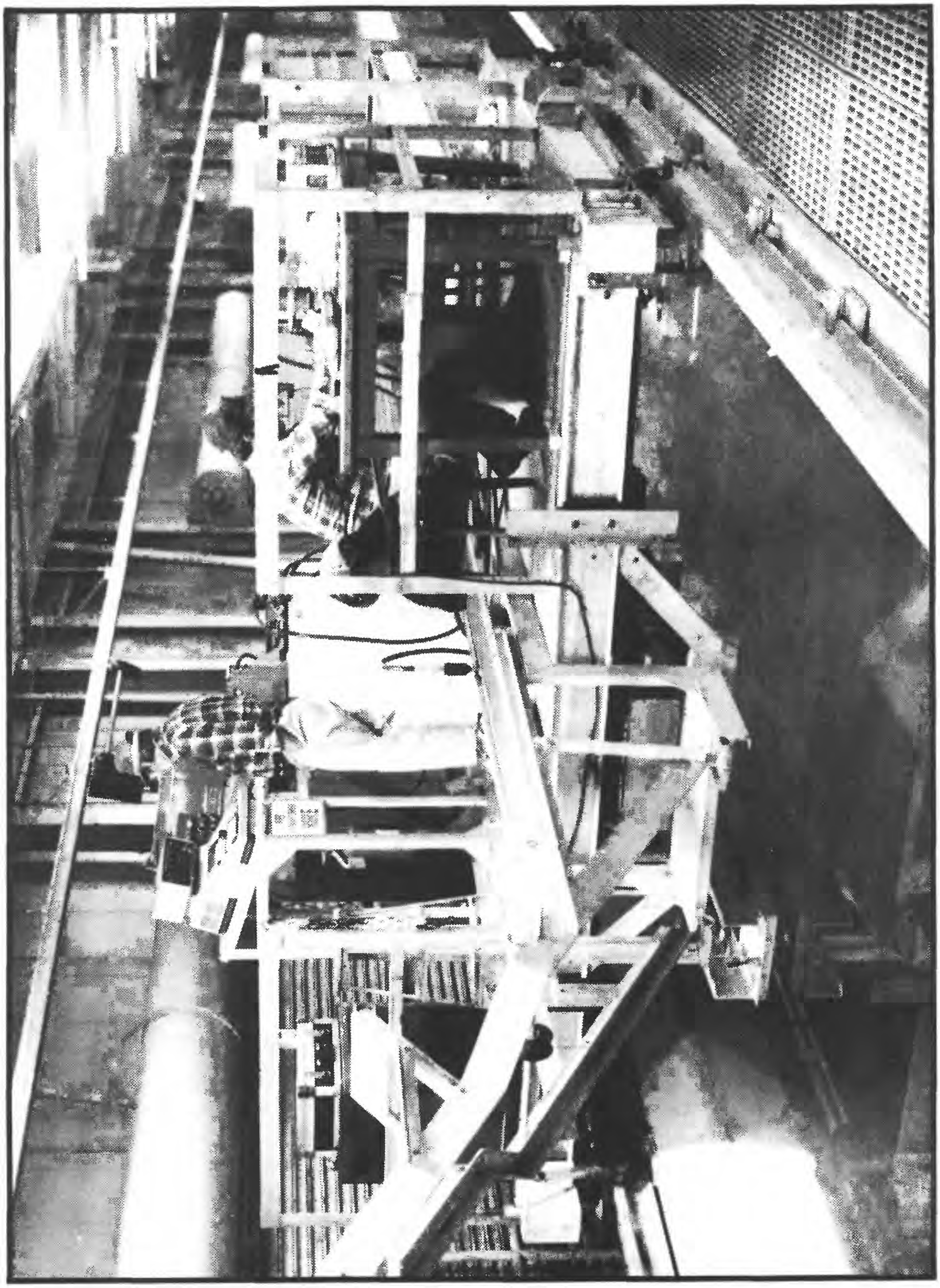

Figure 3.--U.S. Geological Survey test facility.

The adjustable pressure-check valve on the hydraulic cylinder was necessary to obtain equal pressure from the hydraulic pumping unit during the back and forth motion of the cylinder. This equal pressure ensured that the cylinder rod (and meter) moved at the same speed in up and down directions of travel.

TEST PROCEDURES AND RESULTS

A Price type AA current meter with a cat's-whisker sensor and a metal bucket wheel, and a Price type OAA current meter with an optic-head sensor and solid polymer bucket wheel were used in the tests. The optic-head sensor and solid polymer bucket wheel on the Price type OAA current meter weigh less than the cat's-whisker sensor and metal bucket wheel on the Price type AA current meter, thus requiring that the size of tail fin used to guide and balance the Price type OAA current meter be reduced to properly balance the current meter in the water. The Price type AA current meter used was similar to that used by Kallio (1966). This current meter was attached to the hanger bar of a 50C sounding weight and lowered into the water (fig. 4). The hydraulic cylinder was used to position the meter to the test depth. The vertical distance desired for the test was set by positioning and clamping one of the limit switches to the appropriate location on the cylinder frame. The cylinder's hydraulic controls were set in the automatic mode and the speed of travel was adjusted by the flow-control valve. The data from the two meters in vertical motion were analyzed to determine

1. the trends in their response to the various vertical motion tests, and

2. the correction coefficients that apply to the velocities measured with the current meter to correct those velocities to the true horizontal velocities.

The data collected for each current meter during a test include

1. horizontal distance traveled by the tow carriage after a uniform speed was established (ft),

2. time span for the traveled tow carriage distance(s),

3. current meter pulses (counts),

4. vertical distance traveled by meter (ft), and

5. time span for the vertical travel of the meter, top to bottom.

The horizontal distance traveled by the tow carriage (item 1) and the time span for the travel of the tow carriage over the distance (item 2) were used to calculate the true horizontal velocity of the tow carriage, which was also the true horizontal velocity of the meter.

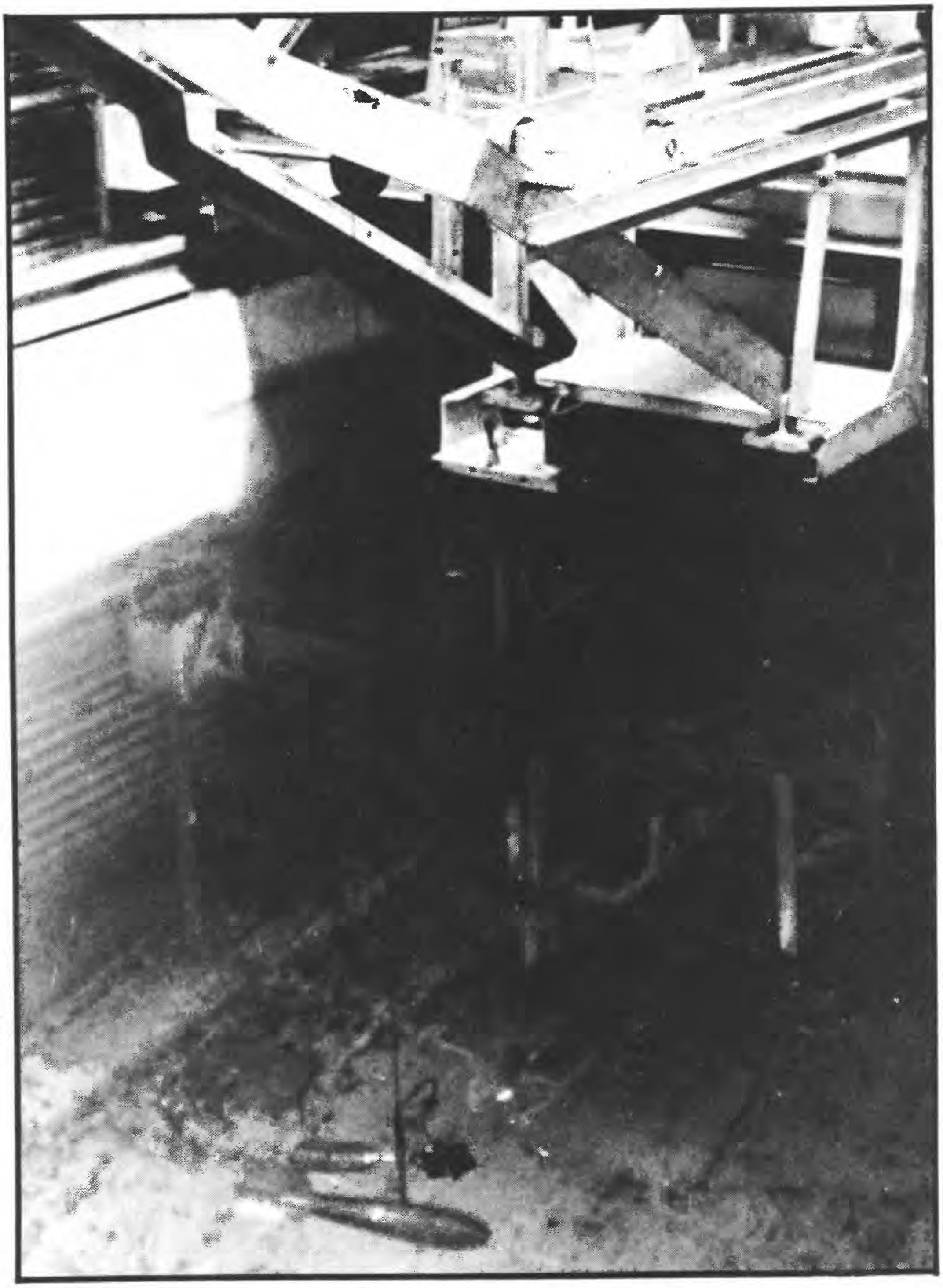

Figure 4.--Price type AA current meter suspended from test facility.

The adjustable pressure-check valve was set to obtain equal speeds for the up and down directions of meter travel and the vertical speed was verified by measuring, with a stopwatch, the time needed for the cylinder push rod to travel the set distance. The simulated stream velocity was obtained by controlling the speed of the tow carriage. The current meter data were collected during forward and reverse steady-state velocity runs in the tow tank to reduce any effects of induced currents in the tank. This data was collected while towing the current meter in still water. Vertical motion was induced to simulate the simple vertical movement of a boat on the water surface of a stream or the vertical oscillations of a cableway after movement of the cable car. The complex motions of a boat in a river, disturbances by other boat traffic, or live stream turbulence are not considered within this study. The following test points are listed:

- Vertical travel distance, in ft
  1.0, 2.0, 3.0, 4.0;

- Rate of vertical motion for each set of tests, in ft/s
  0.33, 0.66, 1.00, and 1.20; and

- Horizontal velocity at each rate of vertical motion, in ft/s;
  - For both meters: 0.00, 0.25, 0.75, 1.50, 2.00, 3.00, and 4.00;
  - Additional test points for the Price type OAA current meter: 6.00, 7.00, and 8.00.

The current-meter velocity was measured by using the tow-carriage rating system. A variable number of pulses was set into the data system of the tow carriage. After the carriage attained the desired speed, the operator initiated data collection. During data collection of the preset pulses, time and distance were measured. Items 2 and 3 (page 6) were used to calculate the velocity as measured by the current meter from the individual current-meter rating equations. These ratings were determined before the study and verified at the conclusion of the study. They are as follows:

Current meter	Rating equation	Range of use
Price type AA	$V = 2.180R + 0.020$	$V \leq 2.20$ ft/s
	$V = 2.170R + 0.030$	$V > 2.20$ ft/s
Price type OAA	$V = 2.418R + 0.024$	$V \leq 5.46$ ft/s
	$V = 2.442R - 0.030$	$V > 5.46$ ft/s

where: V = Velocity
R = Meter pulses/Time

The vertical distance traveled by the meter (item 4) and the time span for the vertical travel of the meter from top to bottom (item 5) were used to calculate the rate of vertical motion of the meter and the frequency of oscillation.

A distinct difference exists between the test results presented by Kallio and the test results presented here. The results of Kallio's (1966) study are presented in table 1 and are presented as registration errors, in percent of stream velocity induced by the rate of vertical motion in feet per second. The results of this study are presented in tables 2 through 9 and are presented as correction coefficients for the velocity measured by the current meter when errors are induced by vertical travel of the meter. These correction coefficients are necessary to make corrections to the observed meter velocities to determine the true stream velocities when the vertical motion of a boat or cableway induces errors in the observed velocities.

Table 1.--Registration errors for a Price type AA current meter, suspended by a cable, in percentage of stream velocity (Kallio, 1966, p. B8)

Stream velocity, in feet per second	Vertical motion, in feet per second						
	0.2	0.4	0.6	0.8	1.0	1.2	1.5
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

The data analyses for the Price type AA current meter have been presented independently from the Price type OAA current meter because the two meters are different in their response to vertical motion; however, the description of the figures and tables are the same.

Price Type AA Current Meter

The deviation of the Price type AA current-meter reading from the horizontal velocity of the tow carriage for each tested vertical travel distance was plotted in figures 5 through 8. Each figure contains four curves corresponding to each of the four rates of vertical motion. The four curves within each figure also provide the frequency of vertical motion if the rate of vertical motion is divided by the distance of vertical travel. The 45° diagonal line extending in the positive direction from the origin of the graph represents the reference line where the meter measurement equals the horizontal velocity obtained from the tow carriage. These figures demonstrate that in low stream velocities, as the vertical motion (and frequency) increases, the observed over-registration of the velocity reading from the current meter also increases.

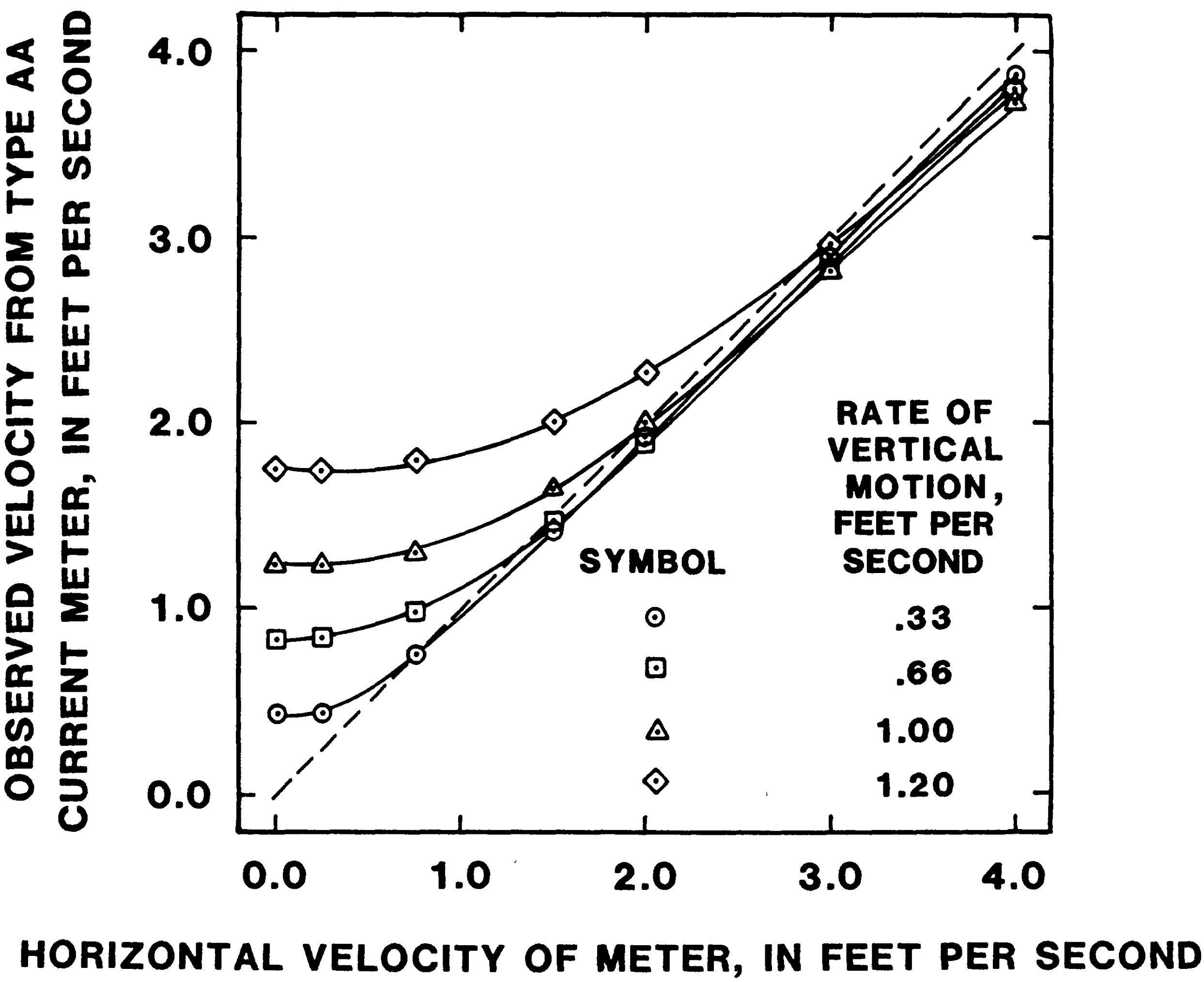

Figure 5.--Effect of different rates of vertical motion on the Price type AA current meter for a 1-ft vertical travel distance.

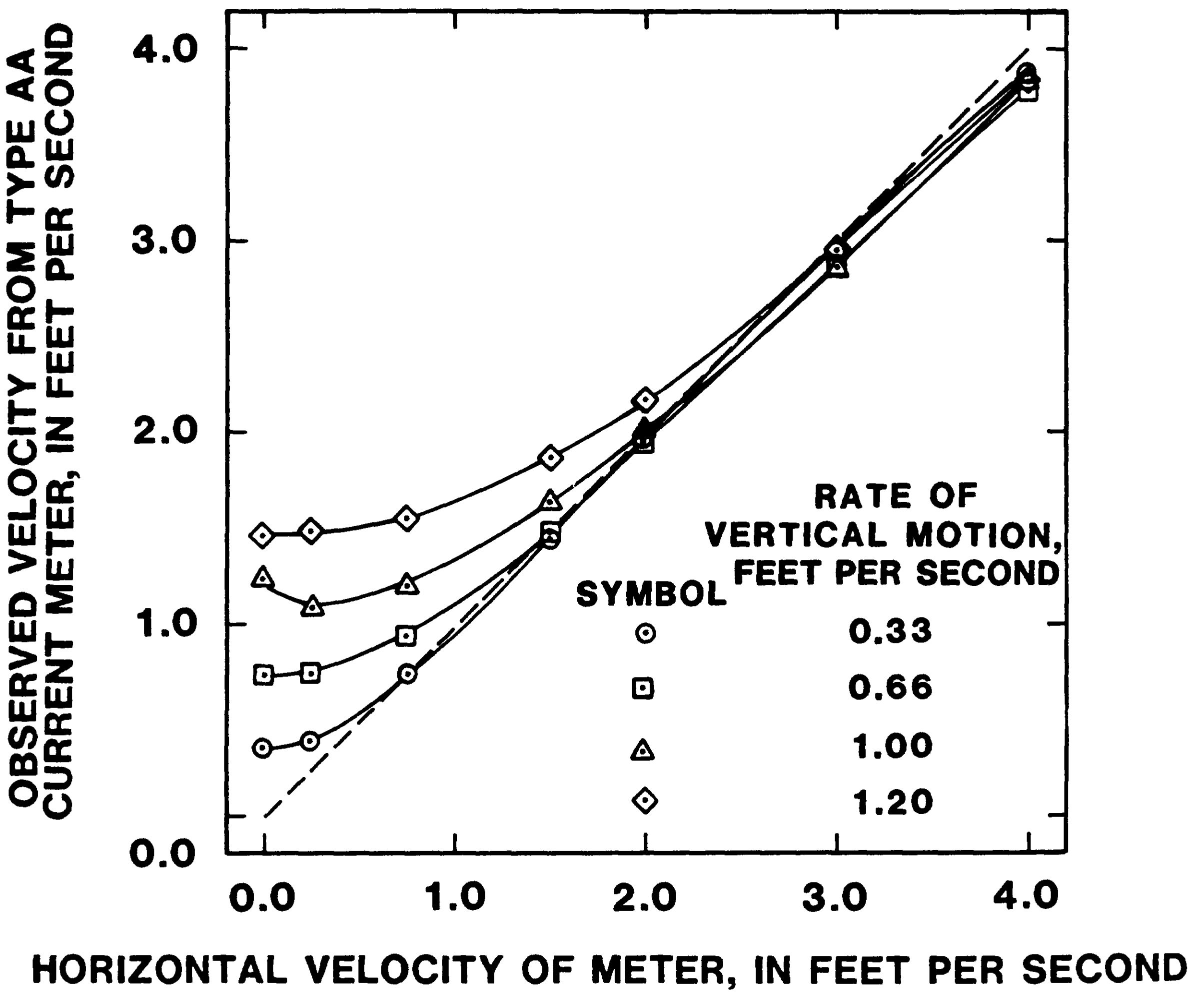

Figure 6.--Effect of different rates of vertical motion on the Price type AA current meter for a 2-ft vertical travel distance.

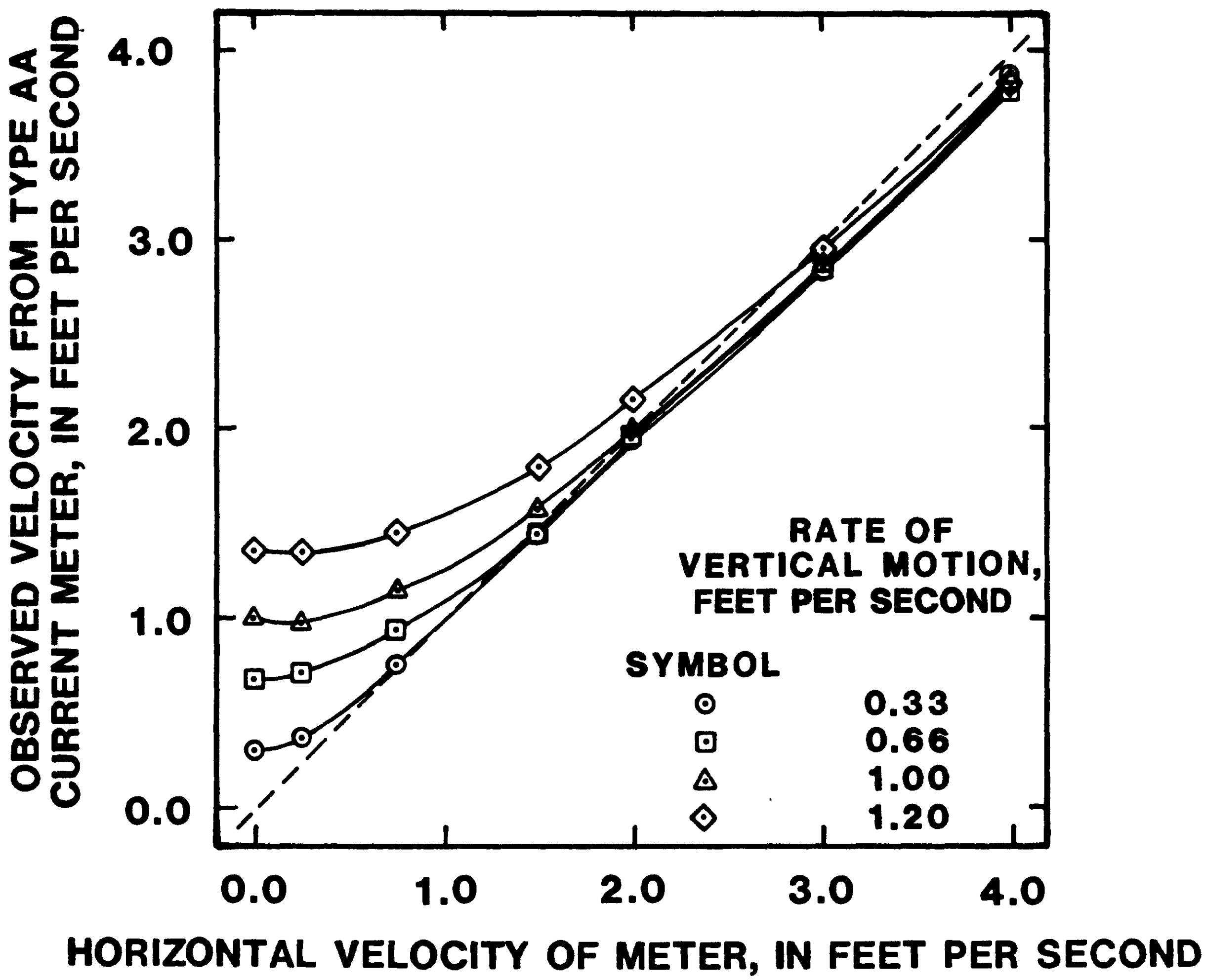

Figure 7.--Effect of different rates of vertical motion on the Price type AA current meter for a 3-ft vertical travel distance.

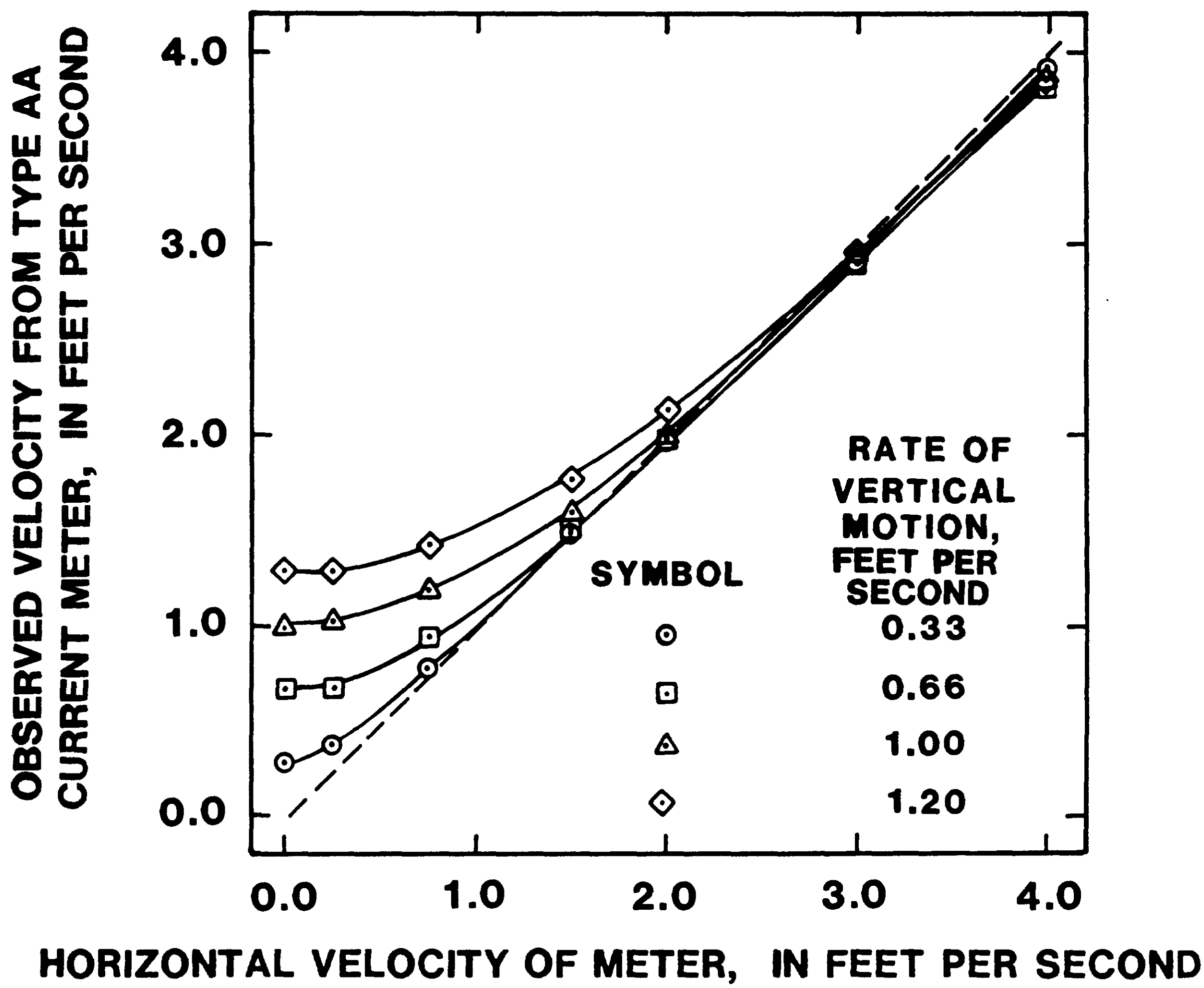

Figure 8.--Effect of different rates of vertical motion on the Price type AA current meter for a 4-ft vertical travel distance.

Figures 9, 10, 11, and 12 are different representations of figures 5, 6, 7, and 8, respectively, and are similar to those produced by Kallio (1966, p. B9). The curves in figures 9 through 12 were developed to obtain correction coefficients for the current meter and to obtain graphs similar to Kallio's. In these figures, the abscissa represents the rate of vertical motion and the ordinate represents both the horizontal velocity and the meter's observed measurement. The horizontal velocity is represented by a dashed reference line across the graph and the meter response is shown to deviate below (under-register) and then above (over-register) as the vertical rate of motion increases. The analysis by Kallio (fig. 13) shows this same trend. Figure 14 is a direct comparison of the average of the curves from figures 9 through 12 and selected curves by Kallio (fig. 13), showing this trend.

The correction coefficients shown in tables 2, 3, 4, and 5 were interpolated from figures 9, 10, 11, and 12, respectively. The interpolations were performed by entering the appropriate figures with the observed velocity from the current meter at the rate of vertical motion. The observed meter velocity was plotted by interpolating between the meter response lines while the horizontal velocity of the meter through the water was read from the ordinate scale. The correction coefficients were computed by dividing the horizontal velocities of the meter by the observed meter velocities.

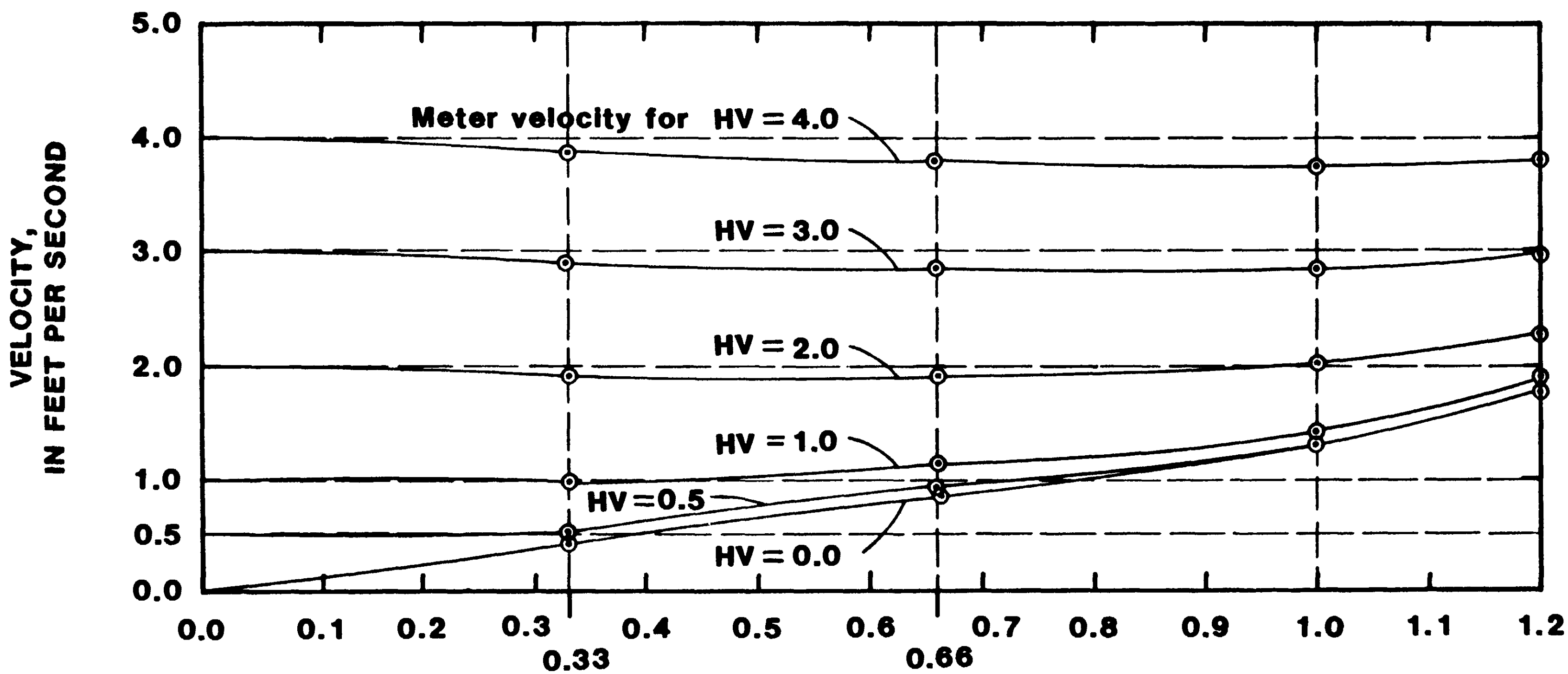

Figure 9.--Effect of vertical motion on the Price type AA current meter for a 1-ft vertical travel distance. The horizontal velocity (HV), the rate at which the current meter is towed down the tow tank, is represented by the dashed horizontal line.

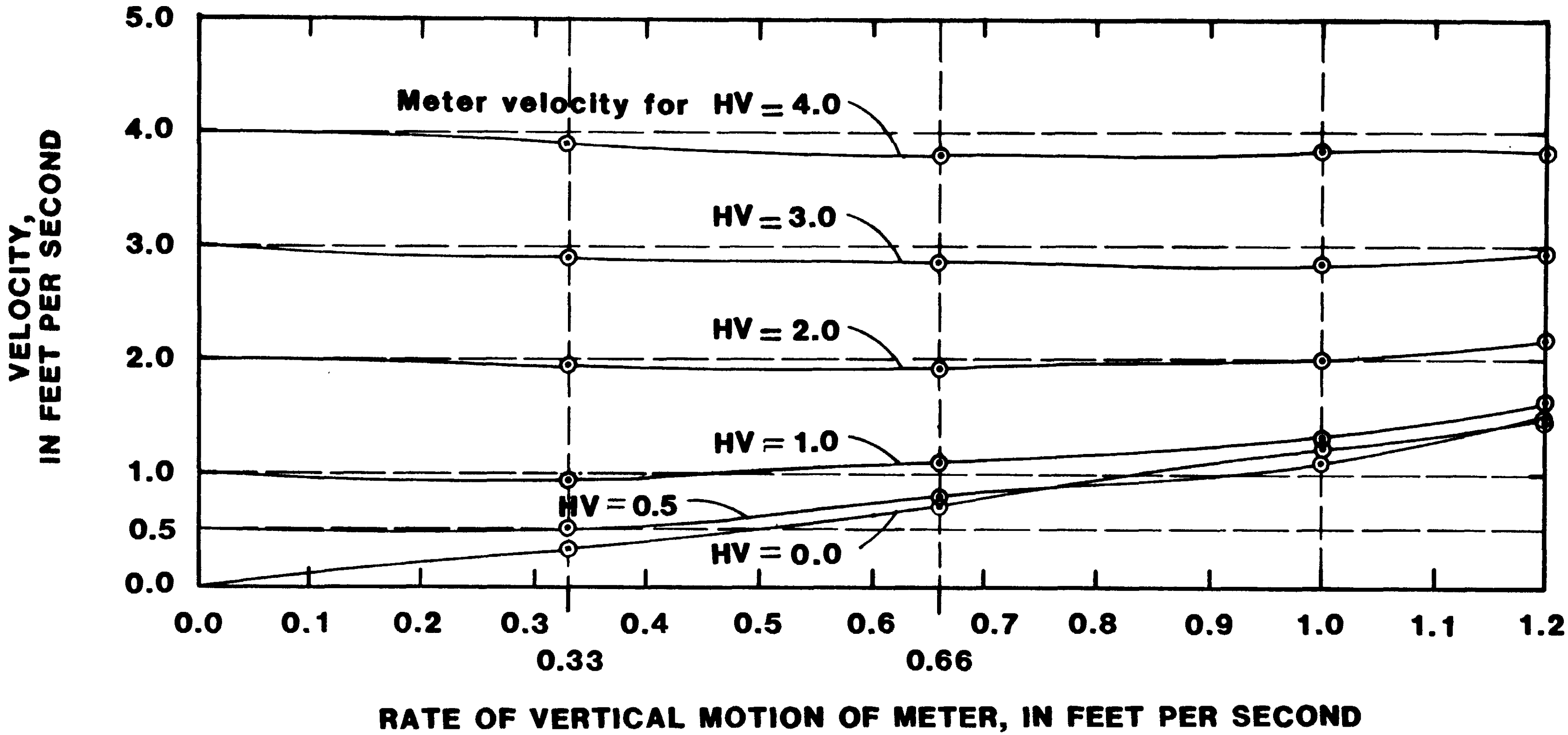

Figure 10.--Effect of vertical motion on the Price type AA current meter for a 2-ft vertical travel distance. The horizontal velocity (HV), the rate at which the current meter is towed down the tow tank, is represented by the dashed horizontal line.

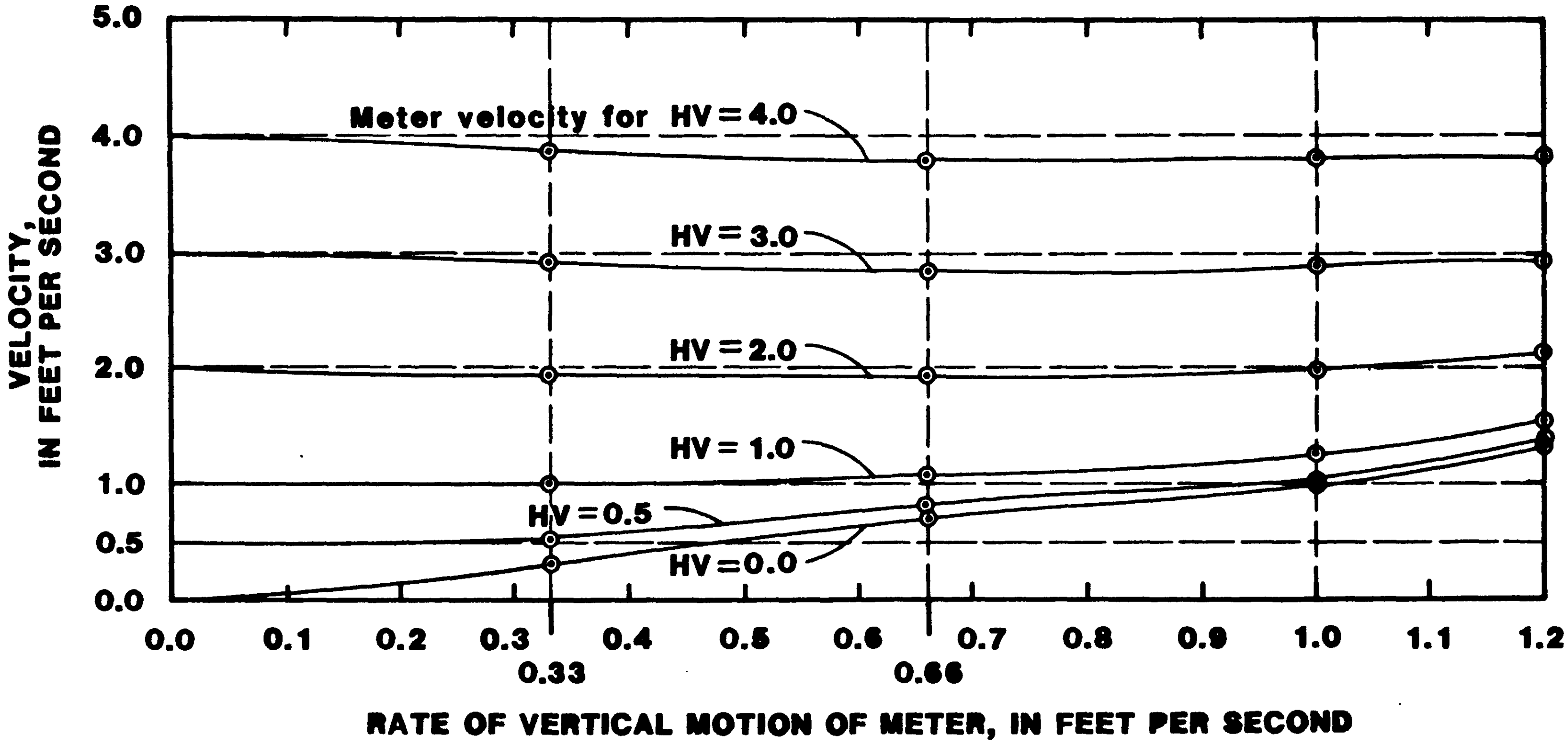

Figure 11.--Effect of vertical motion on the Price type AA current meter for a 3-ft vertical travel distance. The horizontal velocity (HV), the rate at which the current meter is towed down the tow tank, is represented by the dashed horizontal line.

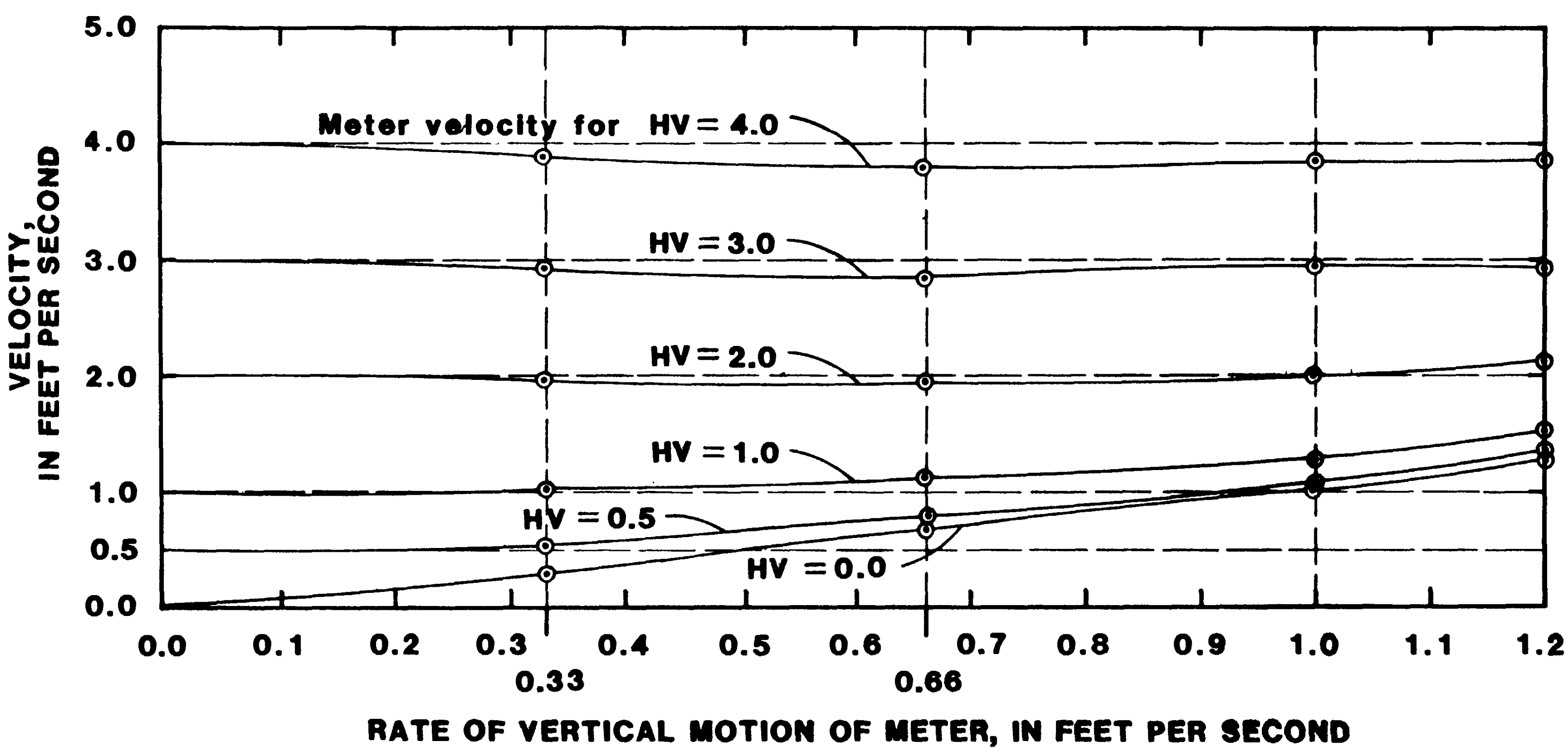

Figure 12.--Effect of vertical motion on the Price type AA current meter for a 4-ft vertical travel distance. The horizontal velocity (HV), the rate at which the current meter is towed down the tow tank, is represented by the dashed horizontal line.

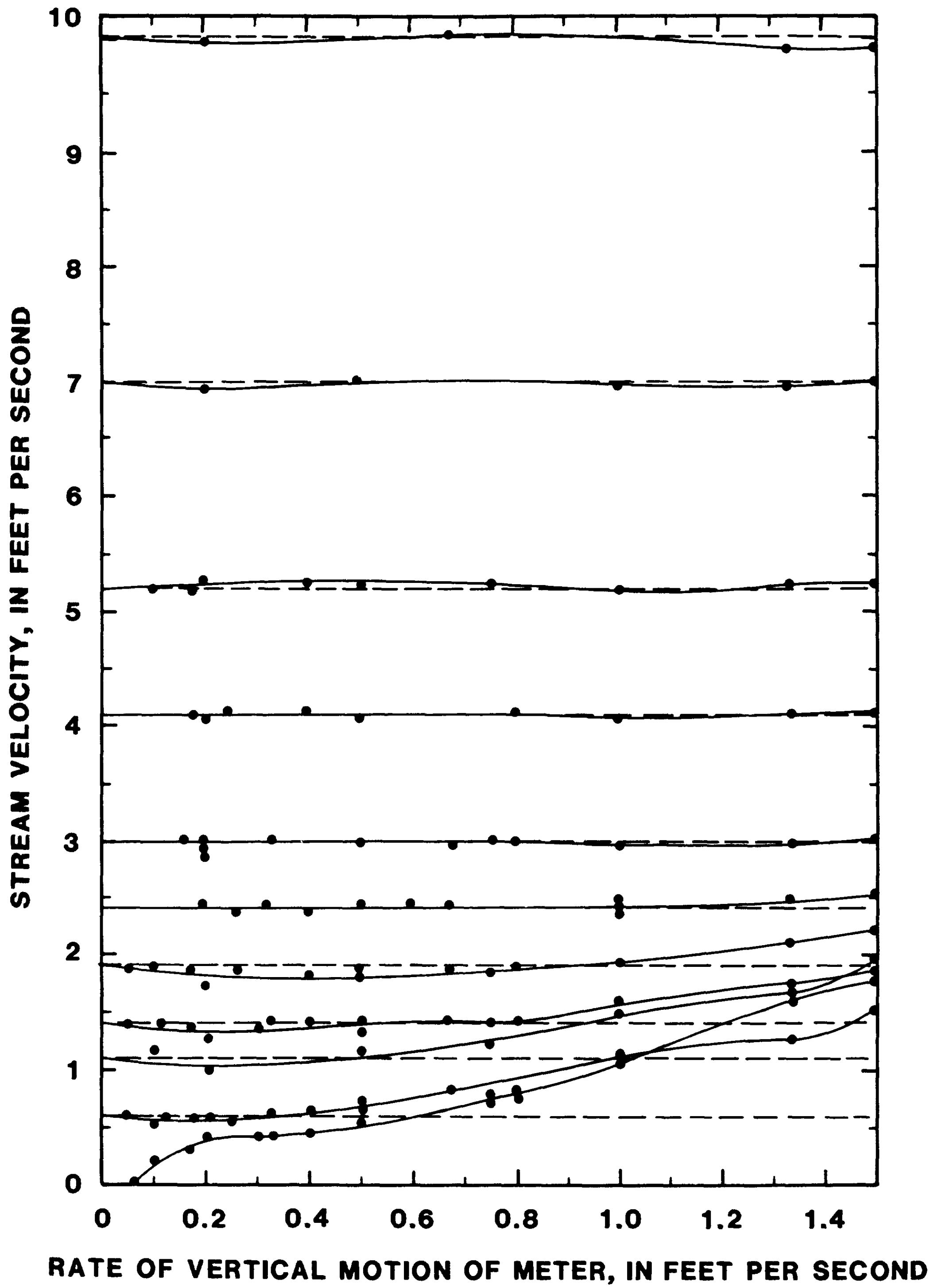

Figure 13.--"Effect of vertical motion on the Price type AA current meter suspended by a cable. The vertical intercept is the true stream velocity, and the departure from the dashed line through the intercept is the error in registration caused by the rate of vertical motion (abscissa). The true stream velocity for the lowest curve is zero." (N. A. Kallio, 1966, p. B9)

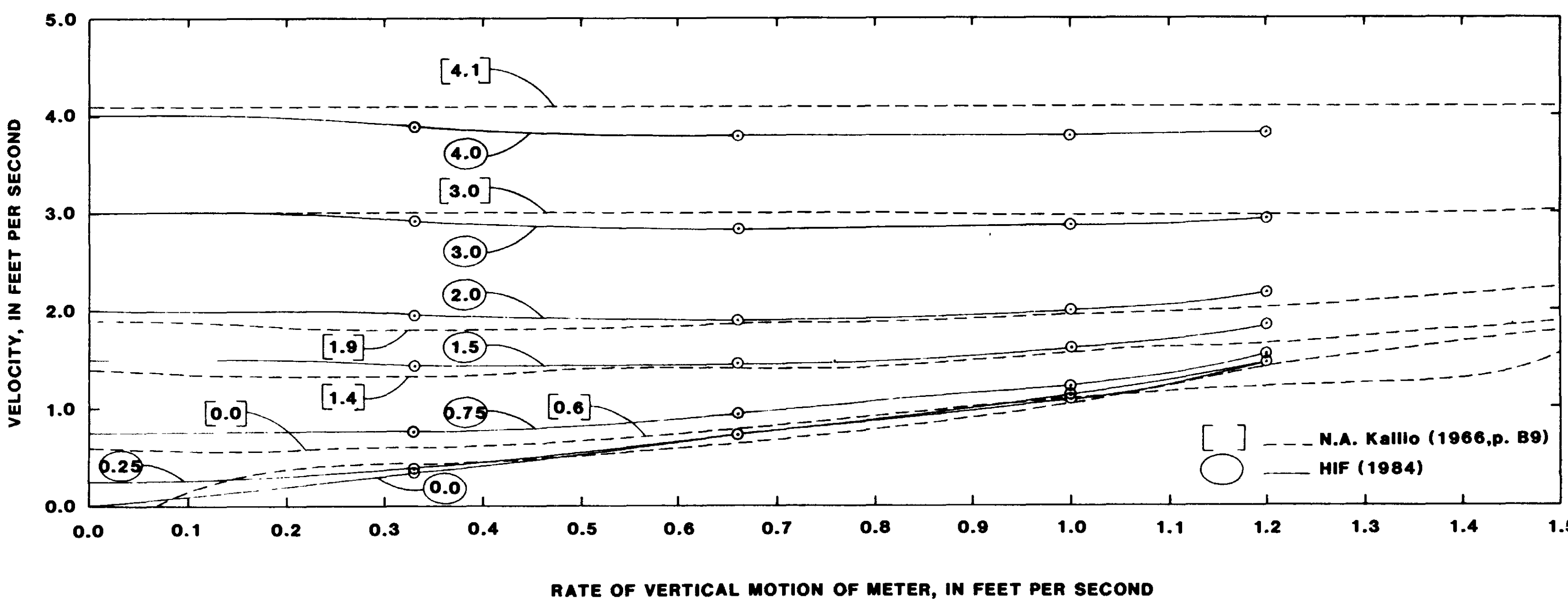

Figure 14.--Comparison of the effect of vertical motion on the Price type AA current meters as represented by the averaged HIF curves (fig. 9-12) and selected curves by Kallio (fig. 13).

Table 2.--Correction coefficients for Price type AA current meter with 1-ft vertical travel distance as determined from figure 9

Stream velocity, in feet per second	Vertical motion, in feet per second						
	0.25	0.33	0.50	0.66	0.75	1.00	1.20
0.25	--	--	--	--	--	--	--
.50	1.00	1.00	--	--	--	--	--
.75	1.00	1.04	0.67	--	--	--	--
1.00	1.00	1.05	1.04	0.75	0.57	--	--
1.50	1.01	1.05	1.06	1.00	.98	0.78	--
2.00	1.03	1.05	1.06	1.05	1.05	1.00	0.68
2.50	1.03	1.04	1.06	1.06	1.06	1.04	.94
3.00	1.03	1.03	1.05	1.06	1.06	1.06	1.02
3.50	1.03	1.03	1.05	1.06	1.06	1.07	1.04
4.00	1.03	1.03	1.05	1.06	1.06	1.07	1.06

Table 3.--Correction coefficients for Price type AA current meter with a 2-ft vertical travel distance as determined from figure 10

Stream velocity, in feet per second	Vertical motion, in feet per second						
	0.25	0.33	0.50	0.66	0.75	1.00	1.20
0.25	--	--	--	--	--	--	--
.50	1.00	0.86	--	--	--	--	--
.75	1.04	1.02	0.92	0.33	--	--	--
1.00	1.05	1.05	1.00	.83	0.73	--	--
1.50	1.03	1.03	1.03	.98	.96	0.86	0.43
2.00	1.03	1.03	1.04	1.04	1.03	1.00	.84
2.50	1.02	1.03	1.04	1.05	1.04	1.04	.97
3.00	1.02	1.03	1.04	1.05	1.05	1.05	1.02
3.50	1.02	1.03	1.04	1.05	1.05	1.05	1.04
4.00	1.02	1.03	1.04	1.05	1.05	1.04	1.05

Table 4.--Correction coefficients for Price type AA current meter with a 3-ft vertical travel distance as determined from figure 11

Stream velocity, in feet per second	Vertical motion, in feet per second						
	0.25	0.33	0.50	0.66	0.75	1.00	1.20
0.25	0.33	--	--	--	--	--	--
.50	1.00	0.89	0	--	--	--	--
.75	1.00	.98	.82	0.33	--	--	--
1.00	1.00	1.00	.95	.84	0.76	0	--
1.50	1.02	1.02	1.01	.99	.98	.89	0.56
2.00	1.03	1.03	1.04	1.04	1.04	1.01	.88
2.50	1.02	1.03	1.05	1.05	1.05	1.03	.98
3.00	1.02	1.03	1.05	1.06	1.05	1.04	1.02
3.50	1.02	1.03	1.04	1.05	1.05	1.05	1.04
4.00	1.03	1.03	1.04	1.05	1.05	1.06	1.05

Table 5.--Correction coefficients for Price type AA current meter with a 4-ft vertical travel distance as determined from figure 12

Stream velocity, in feet per second	Vertical motion, in feet per second						
	0.25	0.33	0.50	0.66	0.75	1.00	1.20
0.25	0.33	--	--	--	--	--	--
.50	1.00	0.90	0	--	--	--	--
.75	1.00	.98	.83	0.53	0	--	--
1.00	1.00	1.00	.94	.85	.80	0	--
1.50	1.01	1.02	1.00	.99	.98	.90	0.67
2.00	1.01	1.03	1.03	1.04	1.04	1.01	.92
2.50	1.02	1.03	1.04	1.05	1.04	1.02	1.00
3.00	1.02	1.03	1.05	1.06	1.04	1.03	1.03
3.50	1.02	1.03	1.05	1.05	1.05	1.04	1.03
4.00	1.03	1.03	1.05	1.05	1.06	1.05	1.04

The correction coefficients are in separate tables for each of the four vertical travel distances and can be used when the rate of vertical travel for that distance has been determined. They are unlike those in table 1 by Kallio (1966, p. B8), which give the registration error in the percentage of stream velocity. The correction coefficients presented here are to be multiplied by the meter measurement to obtain the stream velocity. The following example illustrates the use of the tables:

Example: The meter was vertically moving 2 ft from top to bottom in a period of 2 s. The meter reading (from the rating equation) was 3.0 ft/s. The stream velocity can be found as follows:

1. Vertical rate of travel $= \frac{2 \text{ ft}}{2 \text{ s}} = 1.00$ ft/s.

2. Enter table 3 (2-ft vertical distance) at 1.00 ft/s vertical rate of travel and 3.00 ft/s meter measurement. Locate the correction coefficient of 1.05.

3. Stream velocity = 1.05 x 3.00 ft/s = 3.15 ft/s.

Interpolation within the tables can be performed since the tables were developed by interpolating between the curves in figures 9 through 12.

The correction coefficients interpolated from figures 9 through 12 are shown also in graphical form in figures 15 through 18. Each graph shows curves of the correction coefficients versus the observed velocity of the type AA current meter. The four curves of each graph represent the vertical motion speeds 0.33, 0.66, 1.00 and 1.20 ft/s.

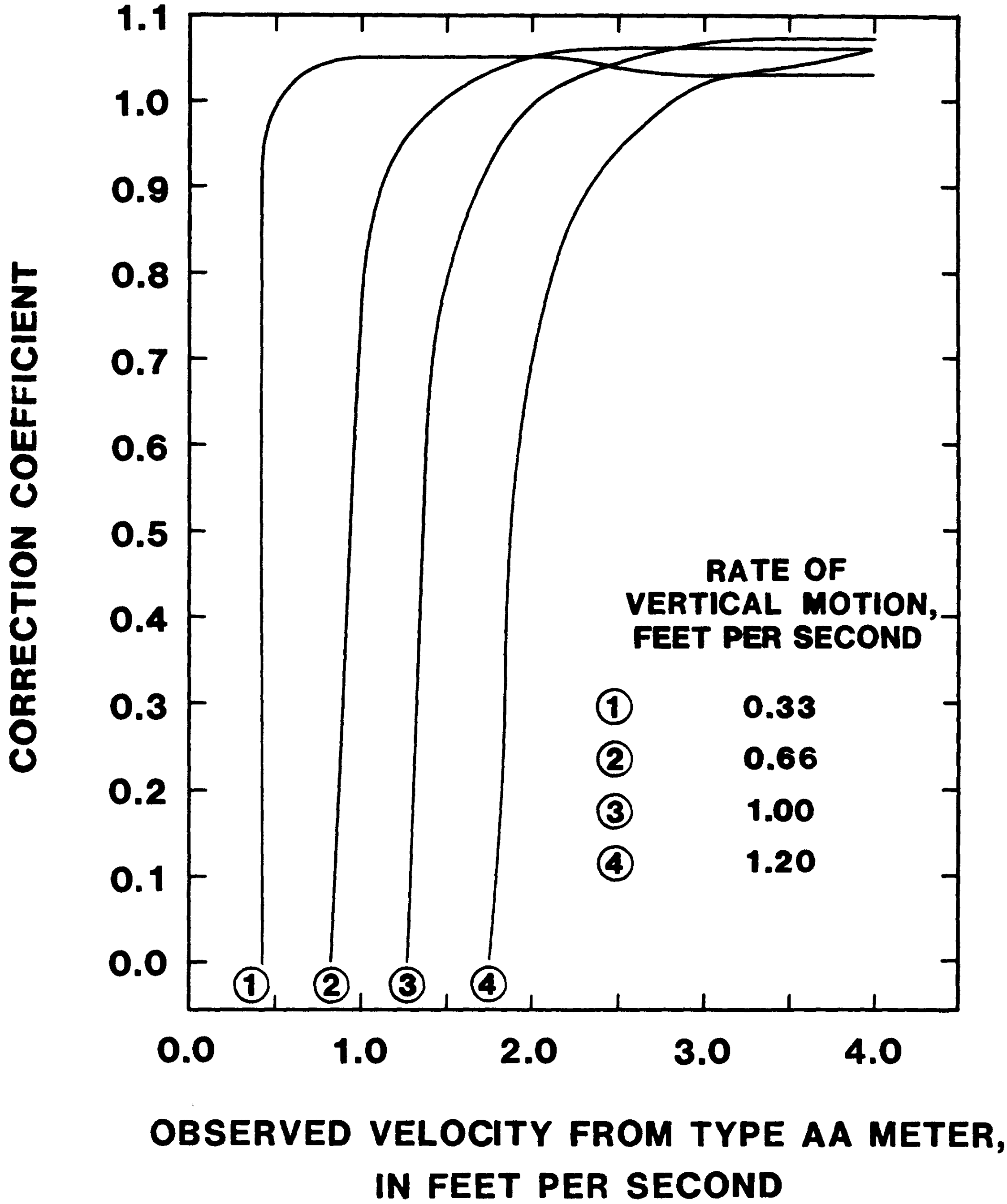

Figure 15.--Correction coefficient versus the observed velocity of the Price type AA current meter for a 1-ft vertical travel distance as determined from figure 9.

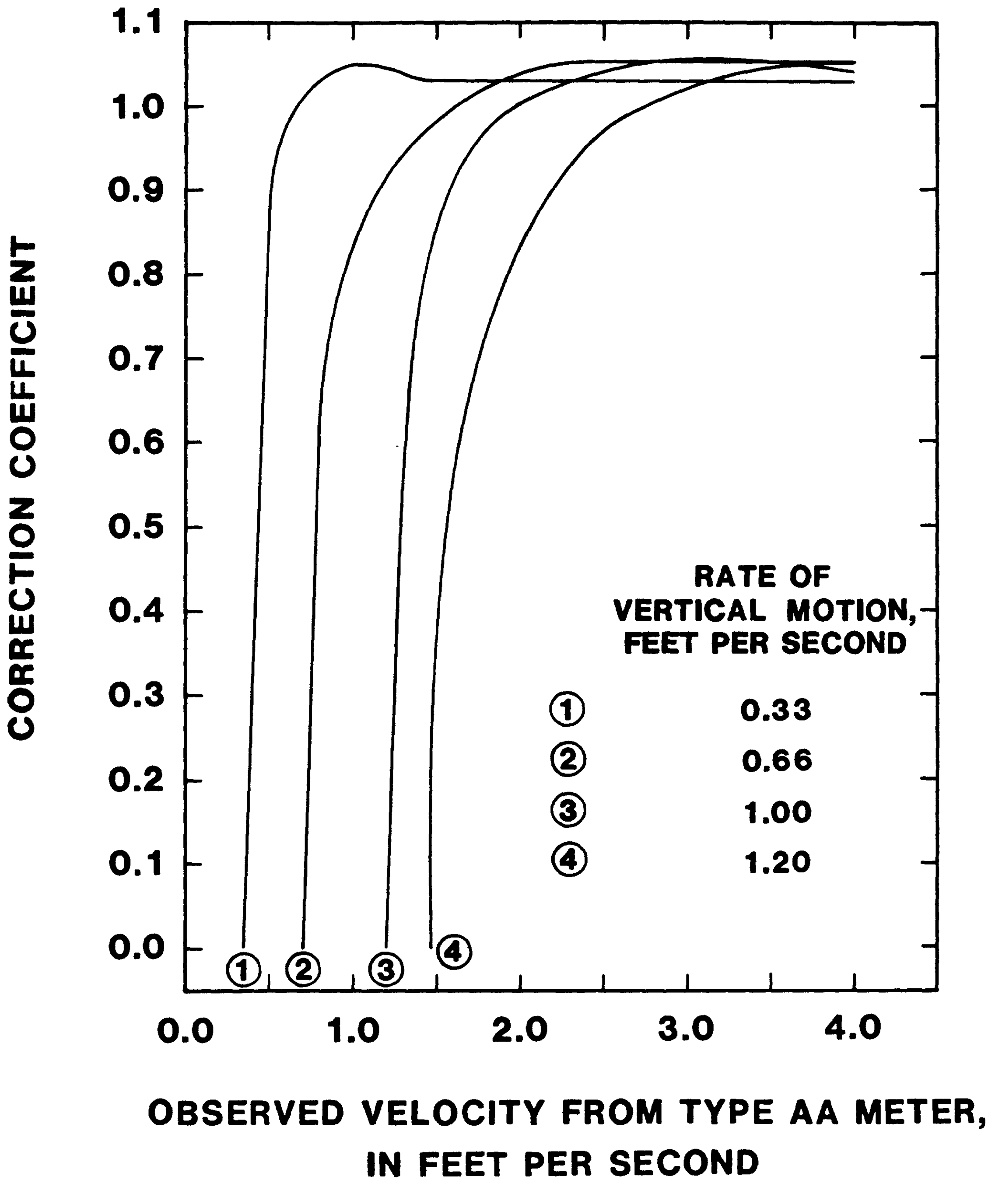

Figure 16.--Correction coefficient versus the observed velocity of the Price type AA current meter for a 2-ft vertical travel distance as determined from figure 10.

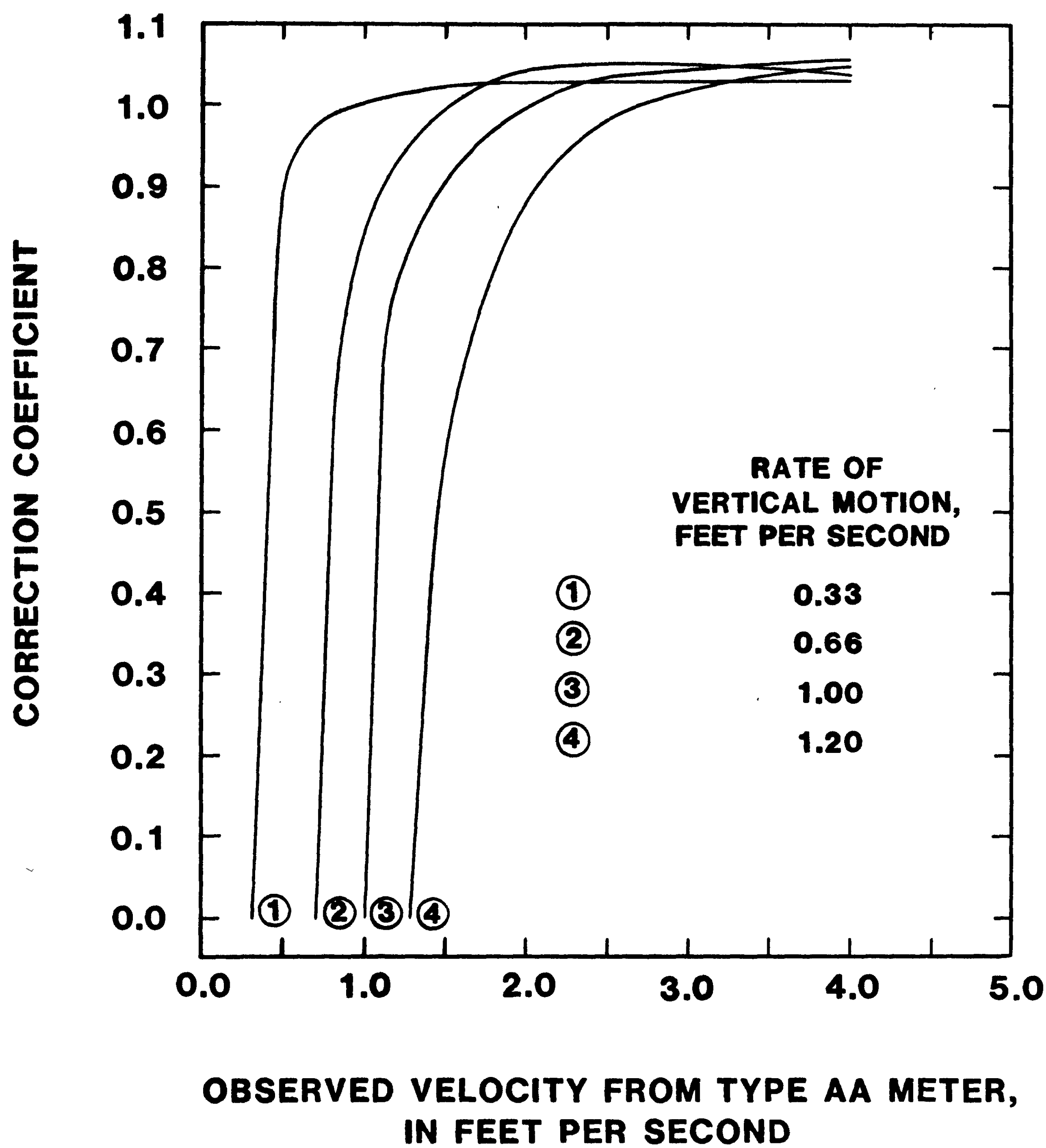

Figure 17.--Correction coefficient versus the observed velocity of the Price type AA current meter for a 3-ft vertical travel distance as determined by figure 11.

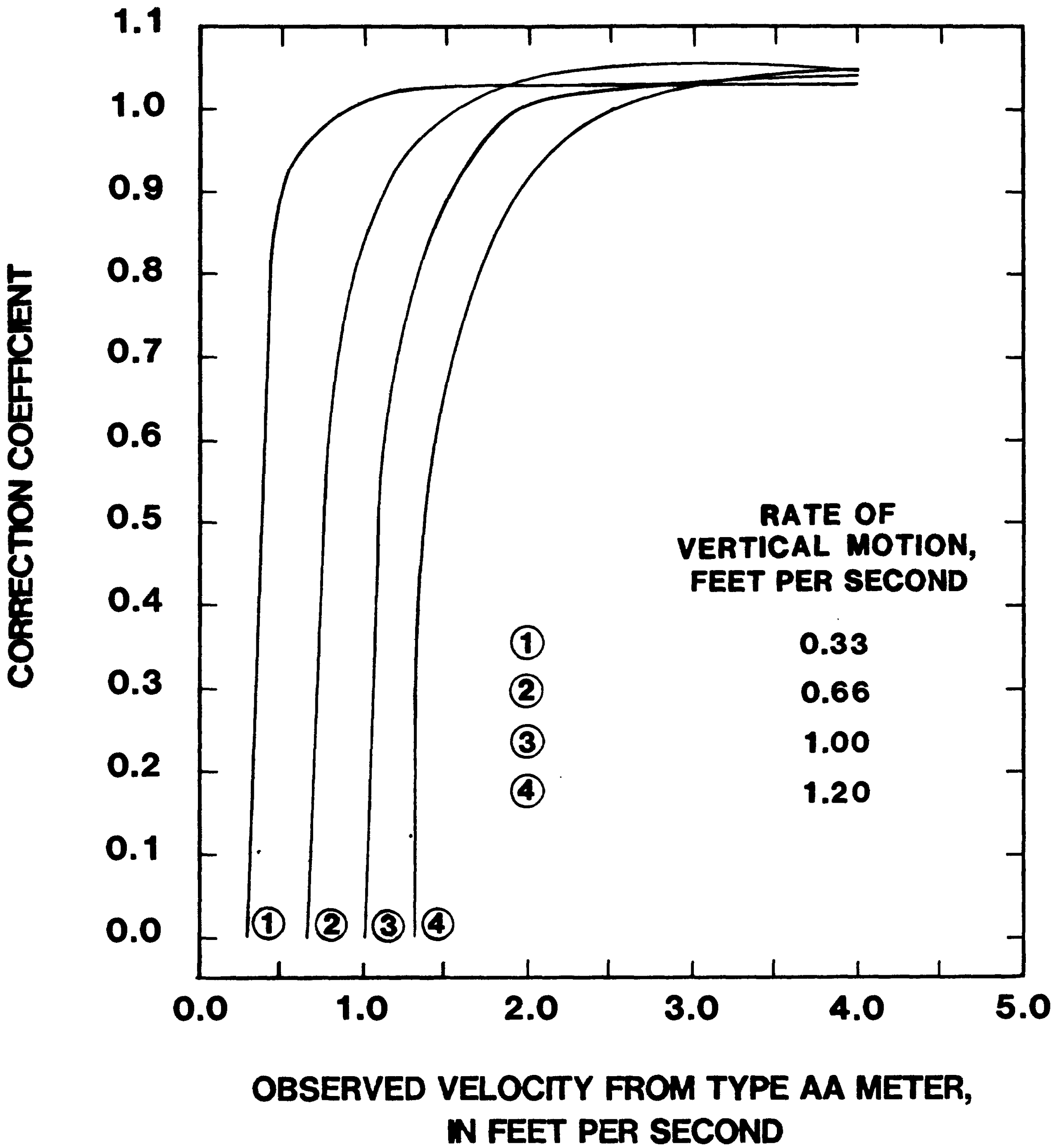

Figure 18.--Correction coefficient versus the observed velocity of the Price type AA current meter for a 4-ft vertical travel distance as determined from figure 12.

Price Type OAA Current Meter

The deviation of the Price type OAA current meter readings from the horizontal velocity for each tested vertical travel distance is plotted in figures 19 through 22. With the exception of a few over-registration points at low velocities, the meter generally under-registers with increasing error from increasing vertical rates of travel.

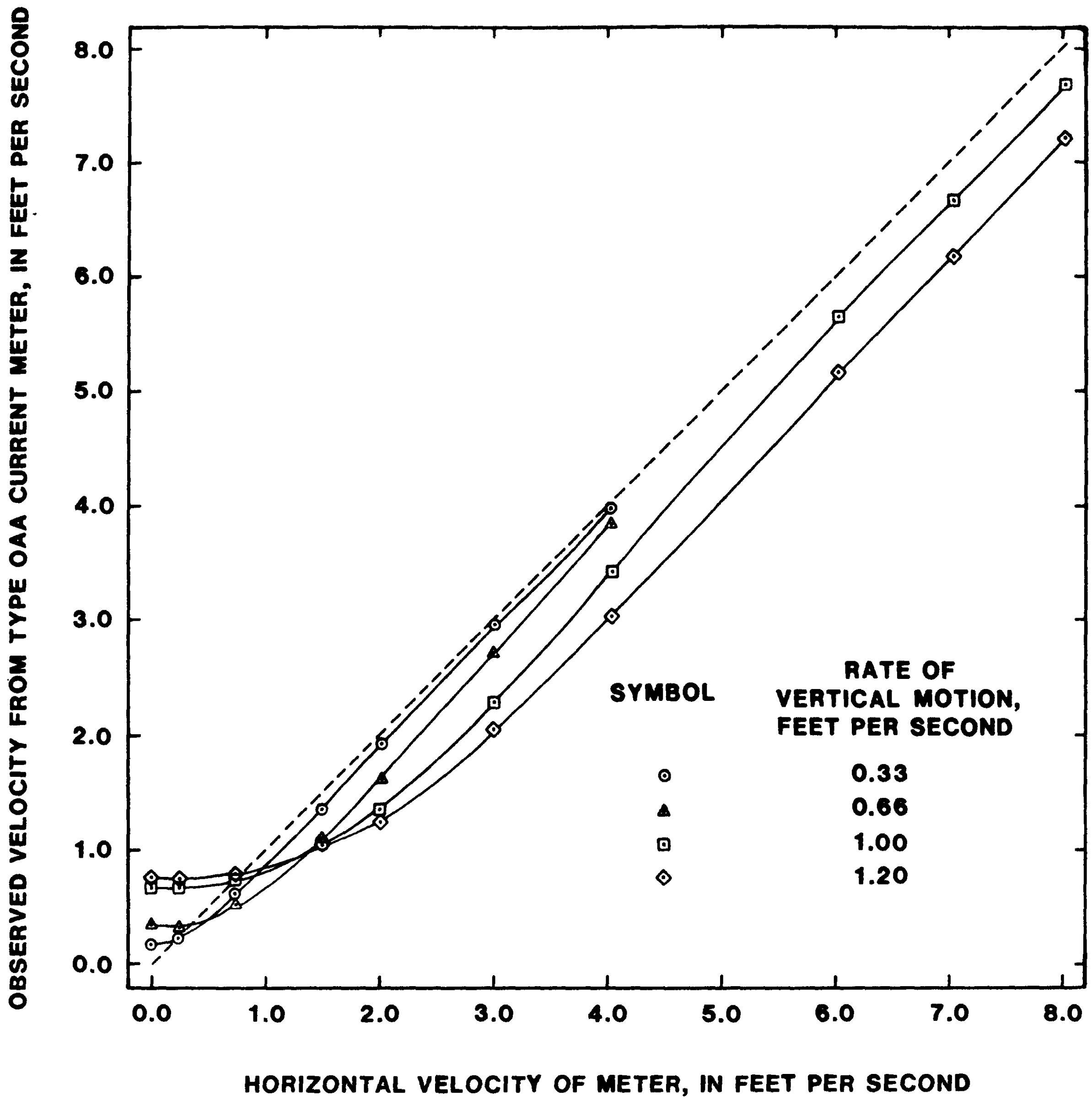

Figure 19.--Effect of different rates of vertical motion on the Price type OAA current meter for a 1-ft vertical travel distance.

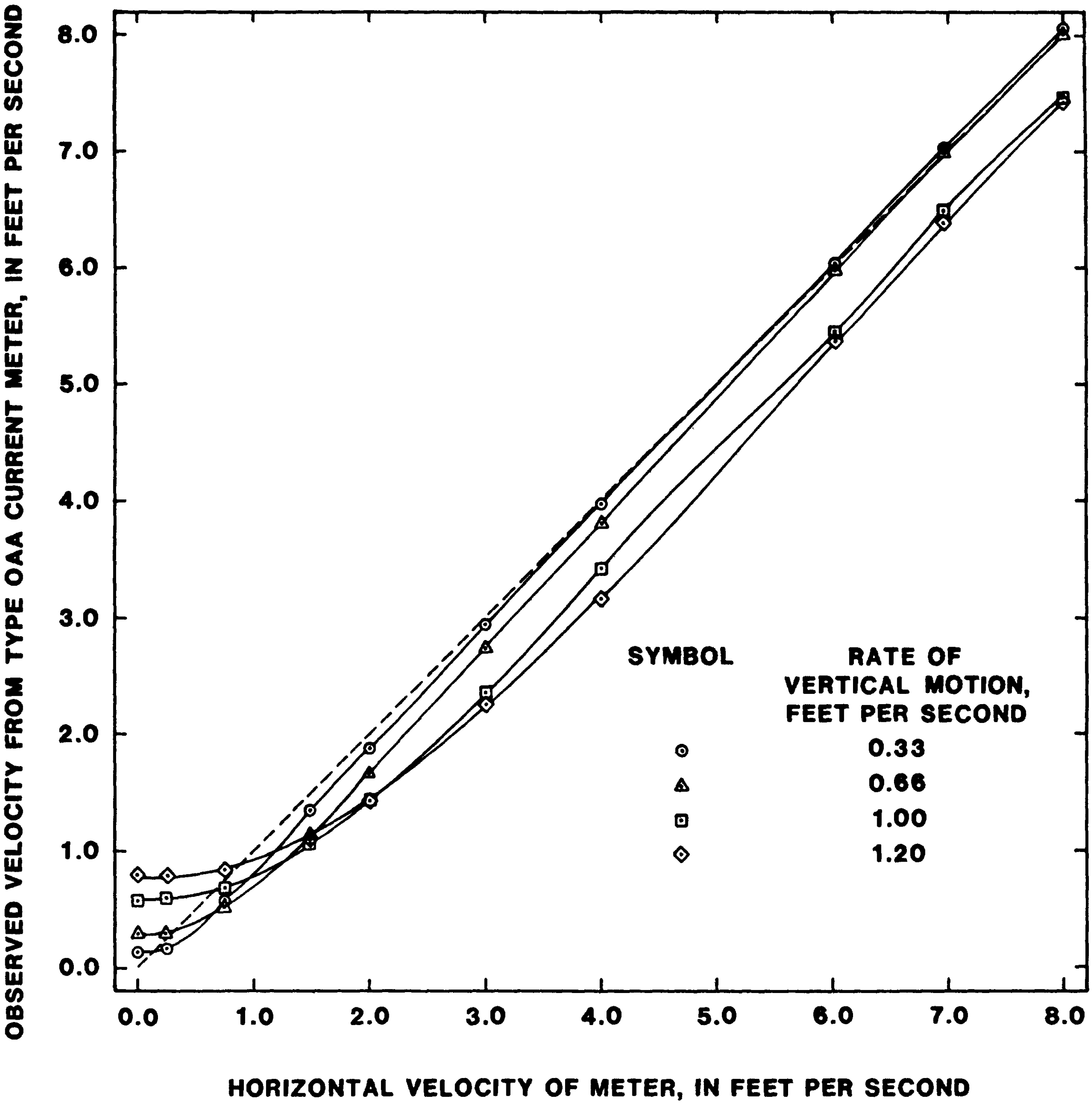

Figure 20.--Effect of different rates of vertical motion on the Price type OAA current meter for a 2-ft vertical travel distance.

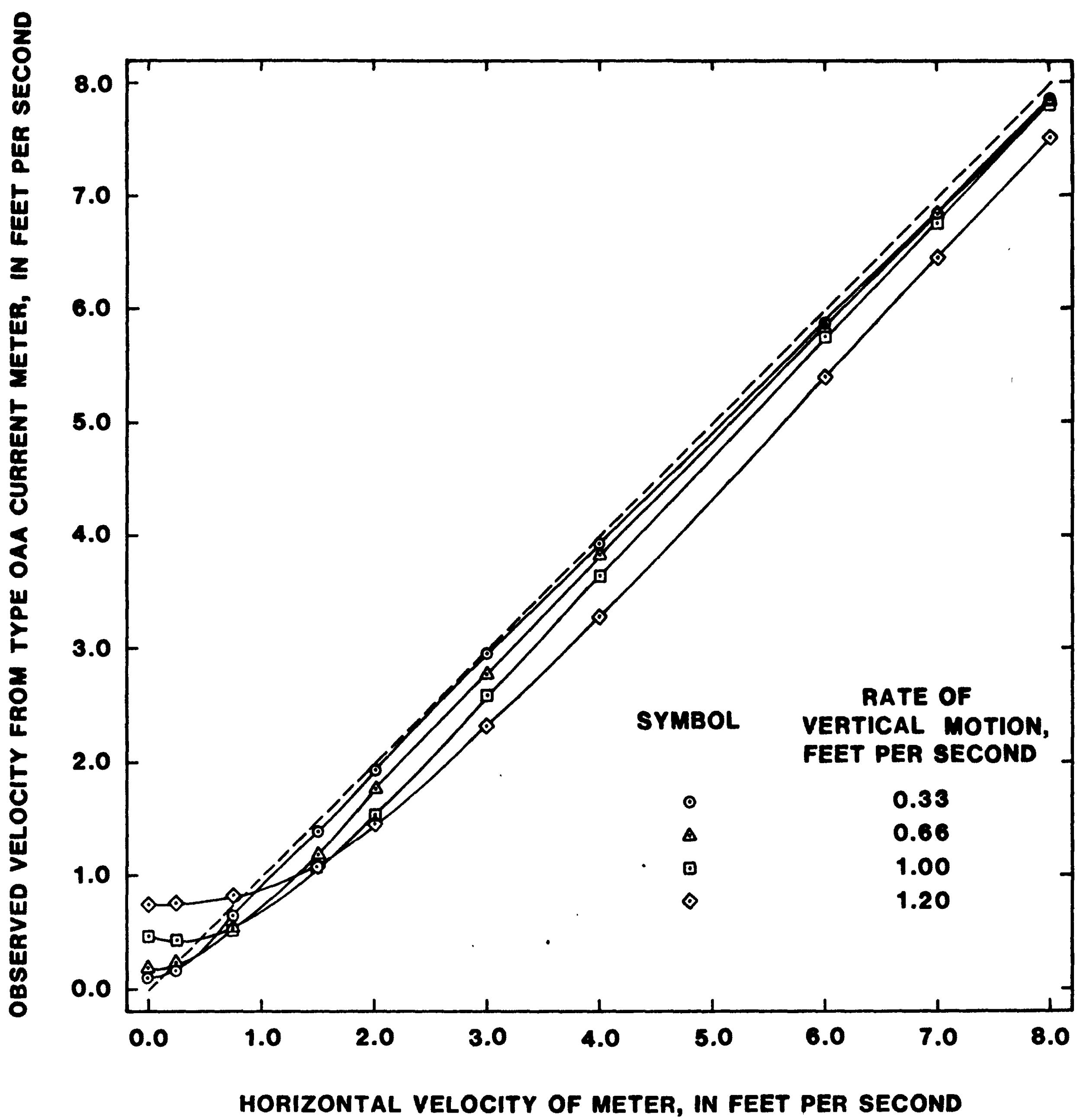

Figure 21.--Effect of different rates of vertical motion on the Price type OAA current meter for a 3-ft vertical travel distance.

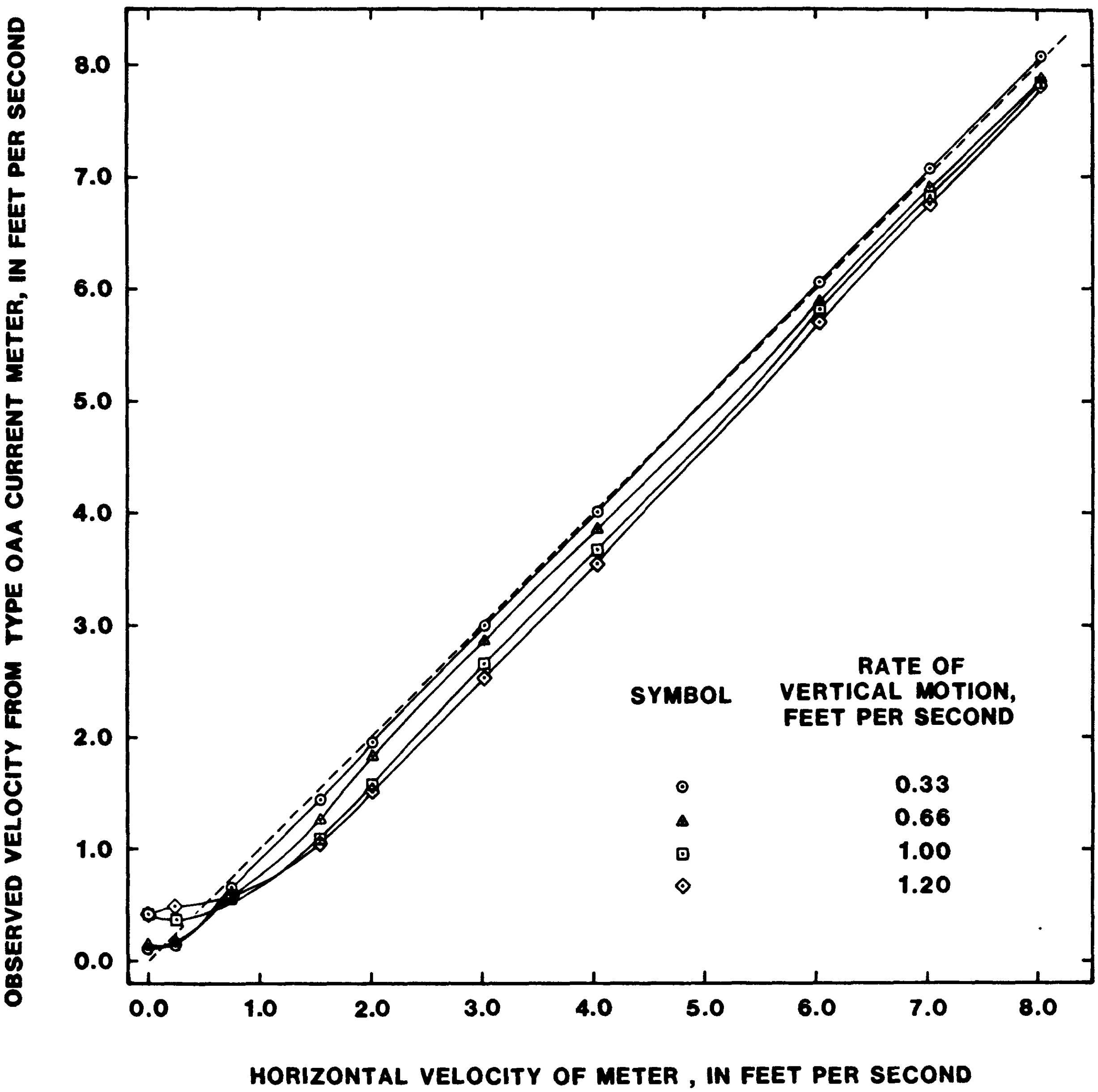

Figure 22.--Effect of different rates of vertical motion on the Price type OAA current meter for a 4-ft vertical travel distance.

From figures 23 through 26, which are presented in the form of figures 9 through 12, it can be concluded that the Price type OAA current meter exhibits less error at the larger vertical travel distances for a given rate of vertical travel. However, a substantial error exists at all horizontal velocities with vertical velocities greater than about 0.7 ft/s.

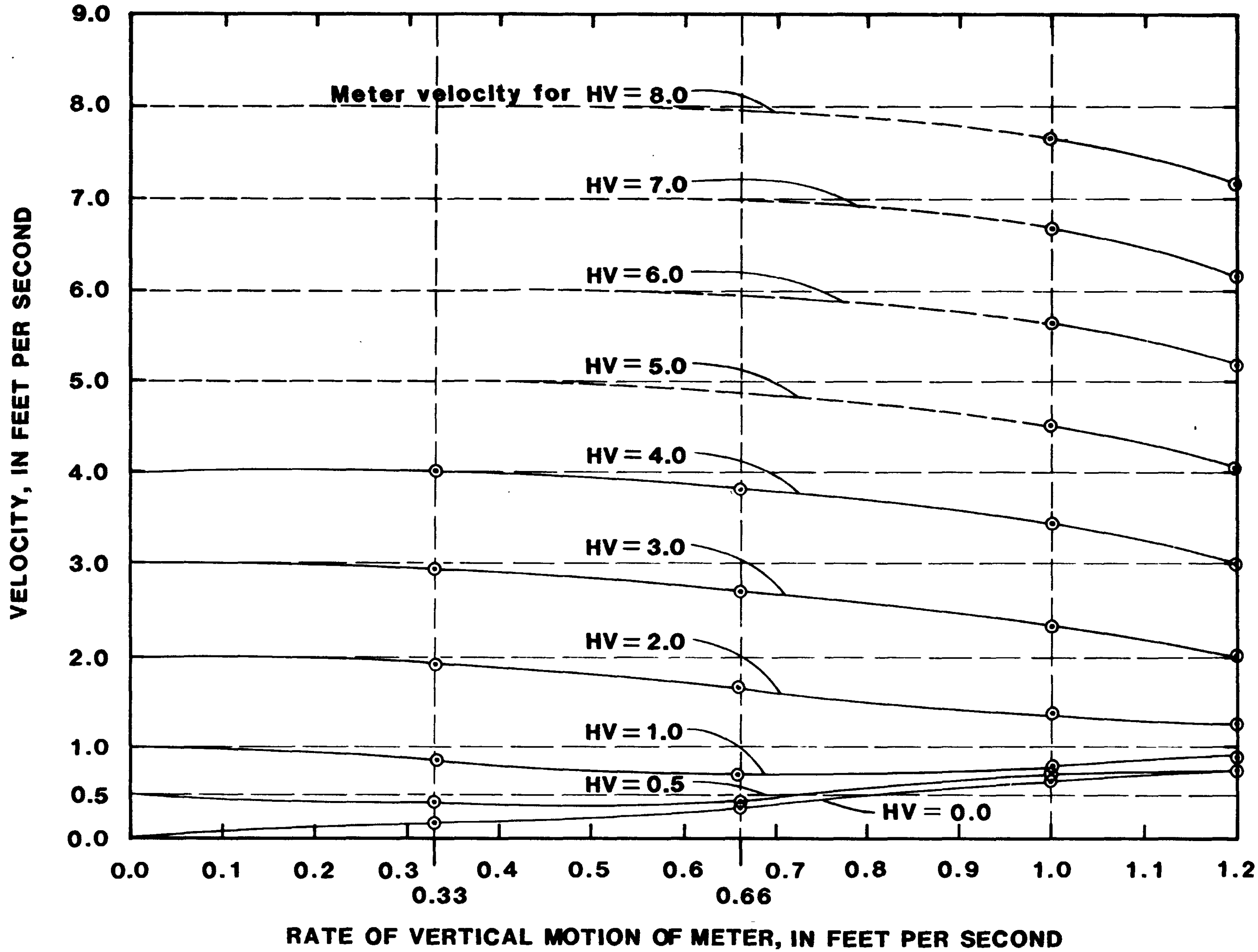

Figure 23.--Effect of vertical motion on the Price type OAA current meter for a 1-ft vertical travel distance. The horizontal velocity (HV), the rate at which the current meter is towed down the tow tank, is represented by the dashed horizontal line.

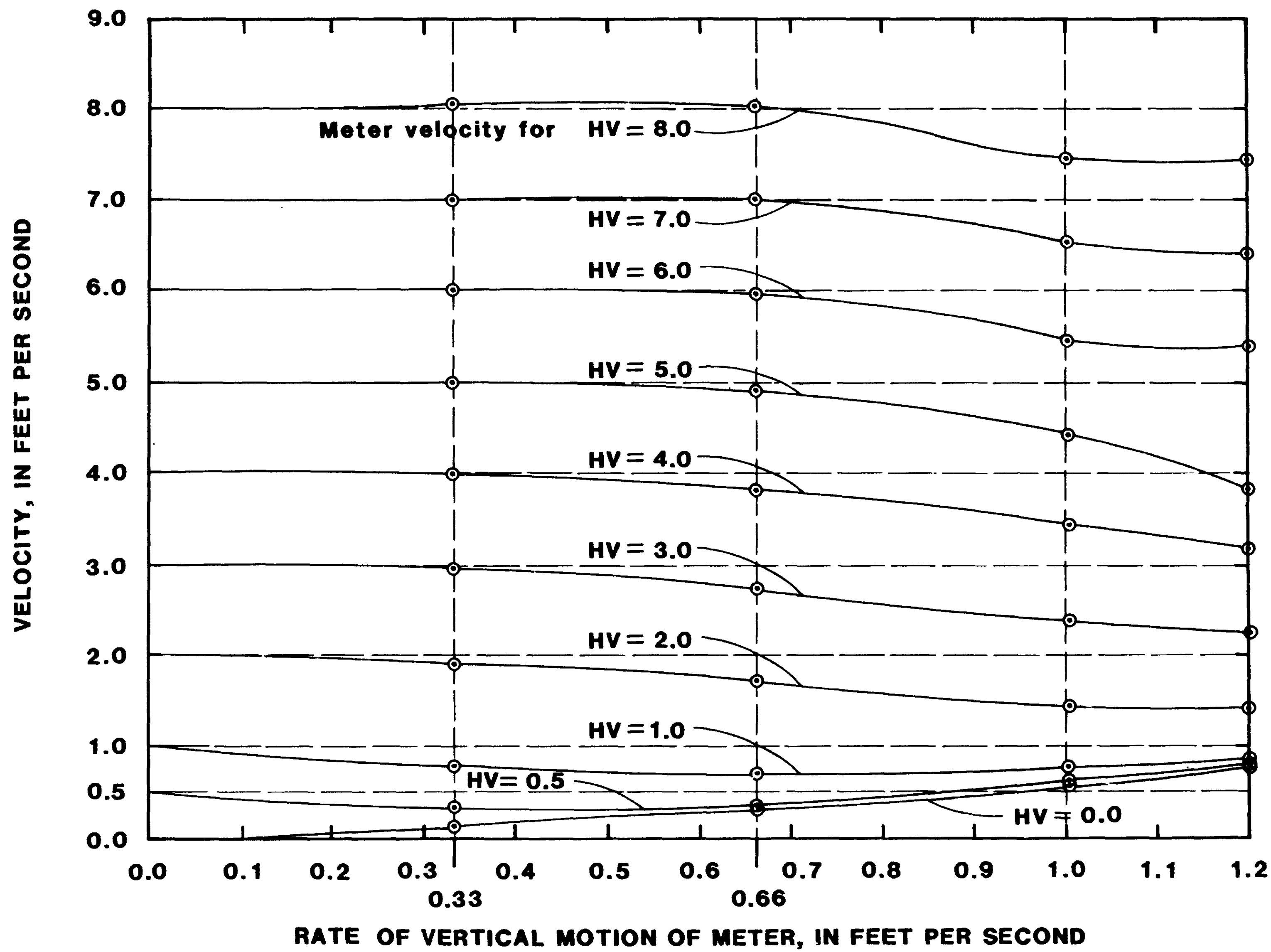

Figure 24.--Effect of vertical motion on the Price type OAA current meter for a 2-ft vertical travel distance. The horizontal velocity (HV), the rate at which the current meter is towed down the tow tank, is represented by the dashed horizontal line.

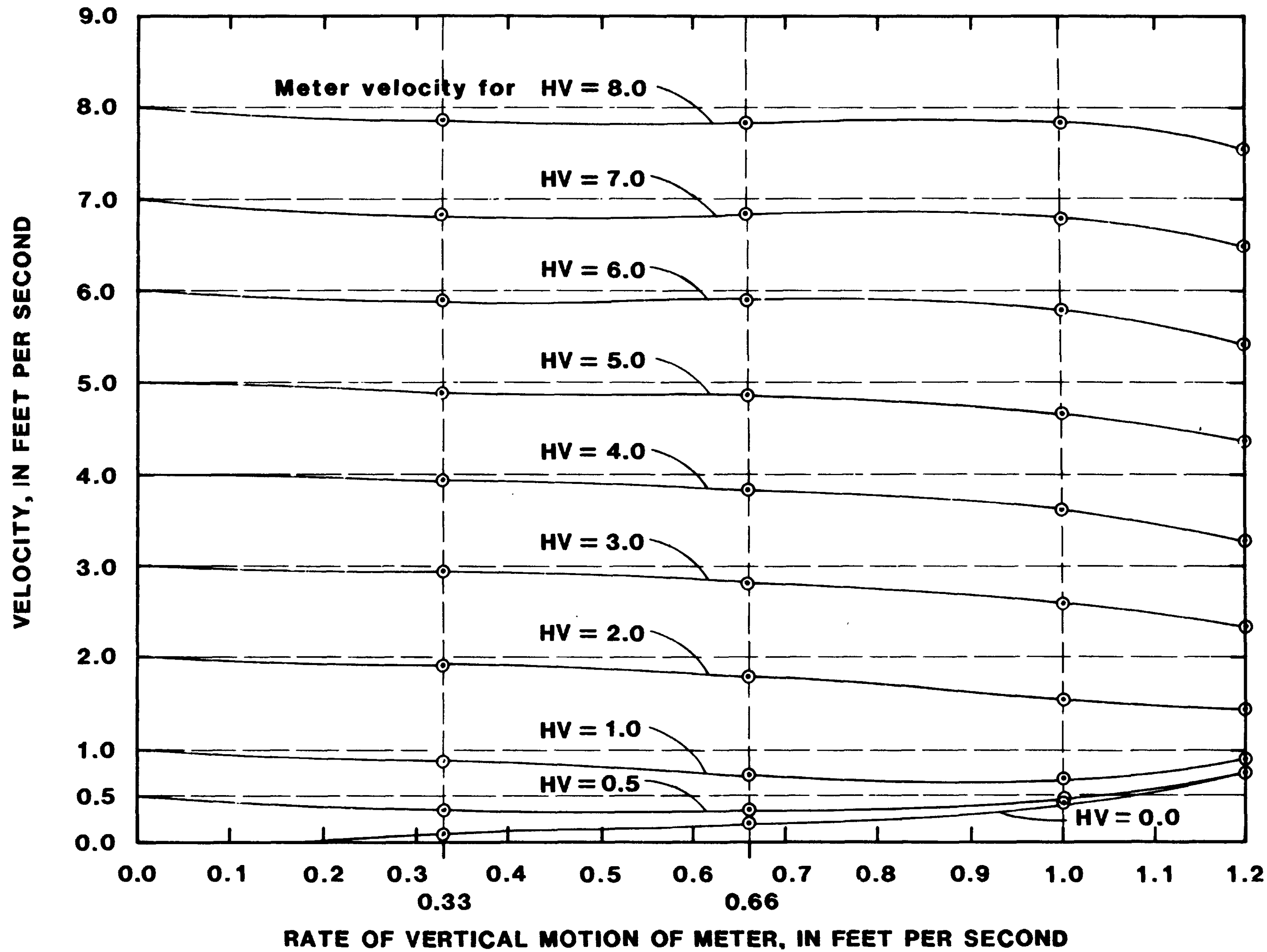

Figure 25.--Effect of vertical motion on the Price type OAA current meter for a 3-ft vertical travel distance. The horizontal velocity (HV), the rate at which the current meter is towed down the tow tank, is represented by the dashed horizontal line.

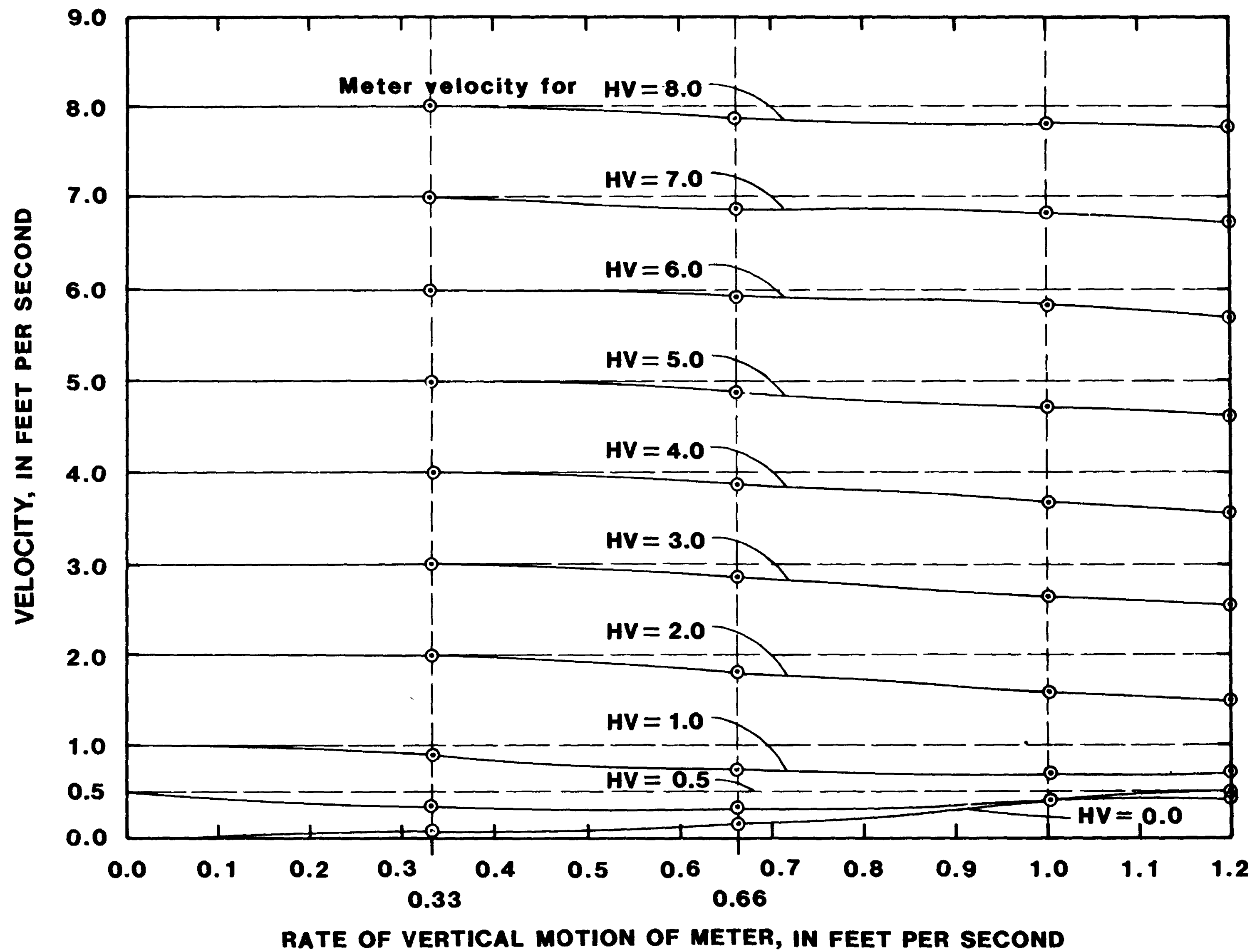

Figure 26.--Effect of vertical motion on the Price type OAA current meter for a 4-ft vertical travel distance. The horizontal velocity (HV), the rate at which the current meter is towed down the tow tank, is represented by the dashed horizontal line.

Tables 6 through 9 are organized to make corrections to the Price type OAA current meter when the vertical motion of the current meter has been determined. These tables were interpolated from figures 23 through 26 and are organized the same as tables 2 through 5. They are used in the same manner as described for the Price type AA current meter.

Table 6.--Correction coefficients for Price type OAA current meter with a 1-ft vertical travel distance as determined from figure 23

Stream velocity, in feet per second	Vertical motion, in feet per second						
	0.25	0.33	0.50	0.66	0.75	1.00	1.20
0.50	1.19	1.22	1.41	--	--	--	--
.75	1.11	1.19	1.39	1.40	1.48	--	--
1.00	1.07	1.14	1.27	1.32	1.39	1.46	--
1.50	1.04	1.08	1.15	1.23	1.30	1.44	1.56
2.00	1.02	1.05	1.10	1.17	1.20	1.34	1.50
2.50	1.01	1.03	1.07	1.12	1.15	1.27	1.40
3.00	1.00	1.02	1.05	1.09	1.11	1.20	1.33
3.50	1.00	1.01	1.03	1.06	1.08	1.16	1.28
4.00	1.00	1.00	1.02	1.05	1.07	1.13	1.24
4.50	1.00	1.00	1.02	1.04	1.06	1.11	1.20
5.00	1.00	1.00	1.01	1.03	1.04	1.09	1.17
5.50	1.00	1.00	1.00	1.02	1.03	1.07	1.15
6.00	1.00	1.00	1.00	1.01	1.02	1.06	1.14
6.50	1.00	1.00	1.00	1.01	1.01	1.05	1.13
7.00	1.00	1.00	1.00	1.00	1.01	1.05	1.12
7.50	1.00	1.00	1.00	1.00	1.01	1.05	1.11
8.00	1.00	1.00	1.00	1.00	1.01	1.04	1.11

Table 7.--Correction coefficients for Price type OAA current meter with a 2-ft vertical travel distance as determined from figure 24

Stream velocity, in feet per second	Vertical motion, in feet per second						
	0.25	0.33	0.50	0.66	0.75	1.00	1.20
0.25	1.40	1.50	1.00	--	--	--	--
.50	1.33	1.38	1.48	1.50	1.27	--	--
.75	1.26	1.26	1.36	1.40	1.41	--	--
1.00	1.18	1.18	1.24	1.30	1.34	--	--
1.50	1.08	1.09	1.13	1.20	1.23	1.37	1.38
2.00	1.04	1.05	1.08	1.15	1.19	1.30	1.36
2.50	1.02	1.03	1.06	1.12	1.16	1.25	1.32
3.00	1.01	1.02	1.05	1.09	1.12	1.20	1.28
3.50	1.00	1.01	1.03	1.06	1.09	1.17	1.30
4.00	1.00	1.00	1.02	1.05	1.07	1.15	1.28
4.50	1.00	1.00	1.01	1.03	1.05	1.13	1.21
5.00	1.00	1.00	1.01	1.02	1.04	1.12	1.15
5.50	1.00	1.00	1.00	1.01	1.03	1.10	1.11
6.00	1.00	1.00	1.00	1.01	1.02	1.09	1.10
6.50	1.00	1.00	1.00	1.00	1.01	1.07	1.09
7.00	1.00	1.00	1.00	1.00	1.01	1.07	1.08
7.50	1.00	1.00	1.00	1.00	1.01	1.07	1.07
8.00	.99	.99	.99	1.00	1.01	1.07	1.07

Table 8.--Correction coefficients for Price type OAA current meter with a 3-ft vertical travel distance as determined from figure 25

Stream velocity, in feet per second	Vertical motion, in feet per second						
	0.25	0.33	0.50	0.66	0.75	1.00	1.20
0.50	1.27	1.30	1.37	1.47	1.54	--	--
.75	1.15	1.20	1.26	1.39	1.46	1.49	--
1.00	1.10	1.14	1.19	1.27	1.33	1.40	--
1.50	1.05	1.06	1.10	1.15	1.19	1.31	1.39
2.00	1.03	1.03	1.06	1.10	1.13	1.22	1.32
2.50	1.02	1.02	1.04	1.08	1.10	1.16	1.28
3.00	1.02	1.02	1.03	1.07	1.08	1.13	1.25
3.50	1.01	1.02	1.03	1.06	1.07	1.11	1.21
4.00	1.01	1.02	1.03	1.05	1.05	1.10	1.17
4.50	1.02	1.02	1.03	1.04	1.04	1.08	1.14
5.00	1.02	1.03	1.03	1.03	1.04	1.06	1.12
5.50	1.02	1.02	1.02	1.02	1.02	1.05	1.11
6.00	1.02	1.02	1.02	1.02	1.02	1.04	1.10
6.50	1.02	1.02	1.03	1.02	1.02	1.04	1.08
7.00	1.02	1.02	1.03	1.03	1.03	1.03	1.07
7.50	1.02	1.02	1.02	1.03	1.02	1.02	1.06
8.00	1.02	1.02	1.02	1.03	1.02	1.02	1.06

Table 9.--Correction coefficients for Price type OAA current meter with a 4-ft vertical travel distance as determined from figure 26

Stream velocity, in feet per second	Vertical motion, in feet per second						
	0.25	0.33	0.50	0.66	0.75	1.00	1.20
0.25	1.20	1.50	1.33	--	--	--	--
.50	1.22	1.20	1.33	1.41	1.39	--	--
.75	1.10	1.15	1.26	1.33	1.37	1.41	1.42
1.00	1.05	1.09	1.18	1.24	1.27	1.33	1.40
1.50	1.02	1.03	1.09	1.14	1.17	1.26	1.33
2.00	1.00	1.00	1.05	1.10	1.12	1.19	1.24
2.50	1.00	1.00	1.03	1.07	1.09	1.14	1.18
3.00	1.00	1.00	1.02	1.05	1.07	1.11	1.15
3.50	1.00	1.00	1.01	1.04	1.06	1.09	1.13
4.00	1.00	1.00	1.01	1.04	1.05	1.08	1.11
4.50	1.00	1.00	1.01	1.03	1.04	1.07	1.09
5.00	1.00	1.00	1.01	1.02	1.03	1.05	1.07
5.50	1.00	1.00	1.01	1.02	1.02	1.04	1.06
6.00	1.00	1.00	1.01	1.02	1.02	1.03	1.05
6.50	1.00	1.00	1.01	1.02	1.02	1.03	1.04
7.00	1.00	1.00	1.01	1.02	1.02	1.03	1.04
7.50	1.00	1.00	1.01	1.01	1.02	1.02	1.03
8.00	1.00	1.00	1.01	1.01	1.02	1.02	1.02

Figures 27 through 30 are graphical representations of the correction coefficients interpolated from figures 23 through 26. These curves are slightly different than those of figures 15 through 18 for the Price type AA current meter in that the curves in the latter set of graphs do not extend to a correction coefficient of zero. The reason is that at low meter registration velocities the shape of the curves are sensitive to the small numbers used to calculate the correction coefficient.

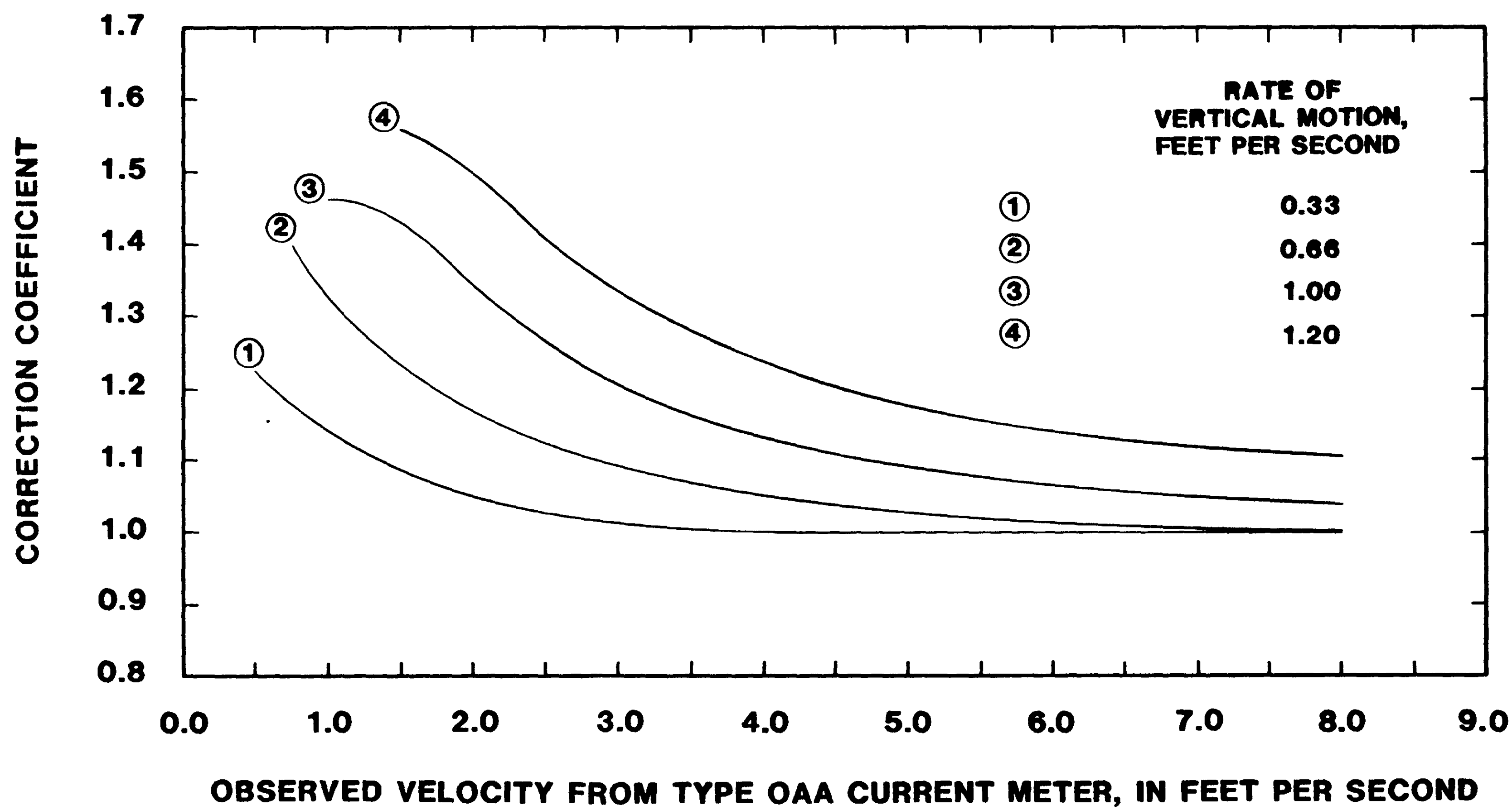

Figure 27.--Correction coefficient versus the observed velocity of the Price type OAA current meter for a 1-ft travel distance as determined from figure 23.

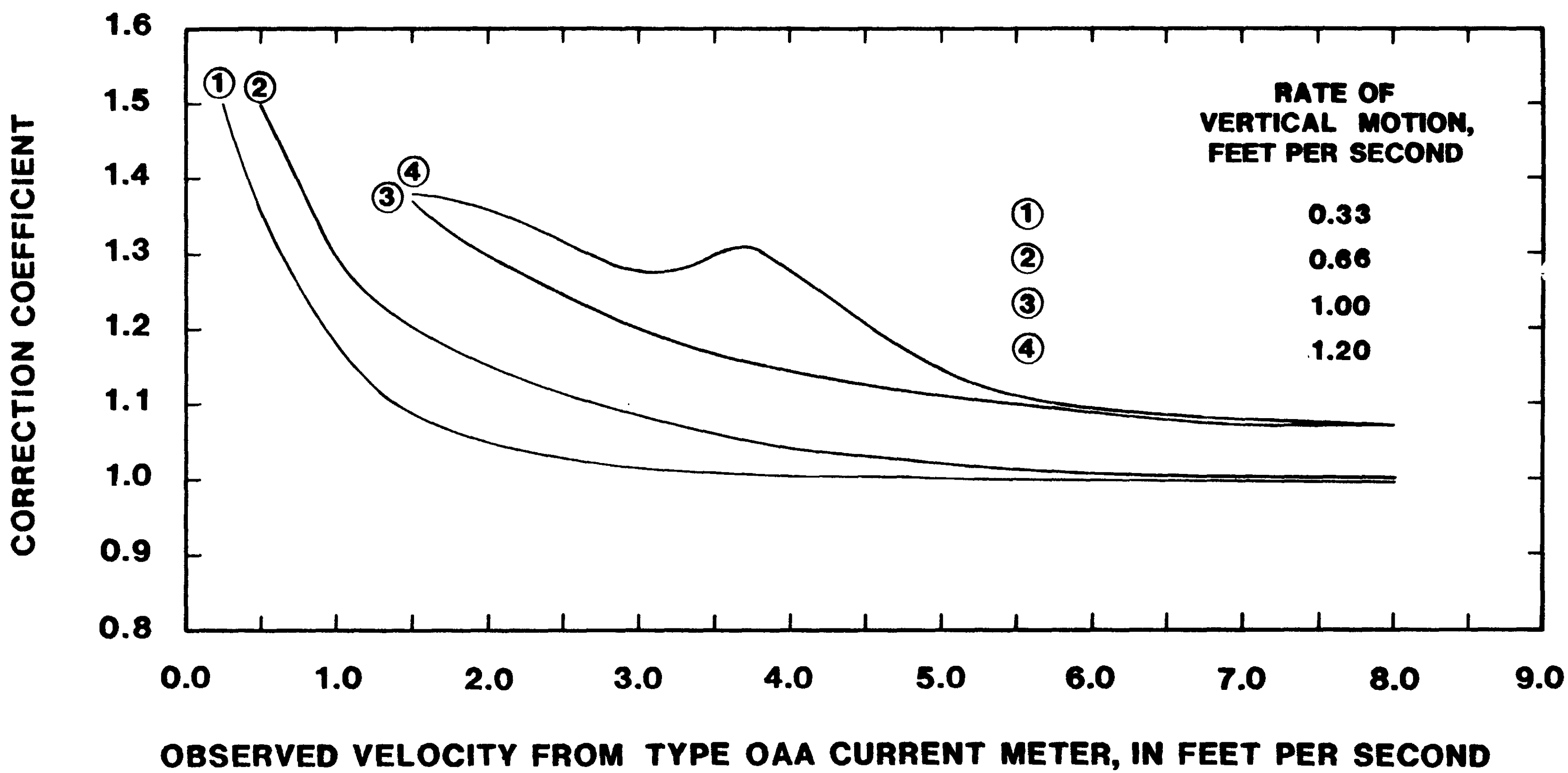

Figure 28.--Correction coefficient versus the observed velocity of the Price type OAA current meter for a 2-ft travel distance as determined from figure 24.

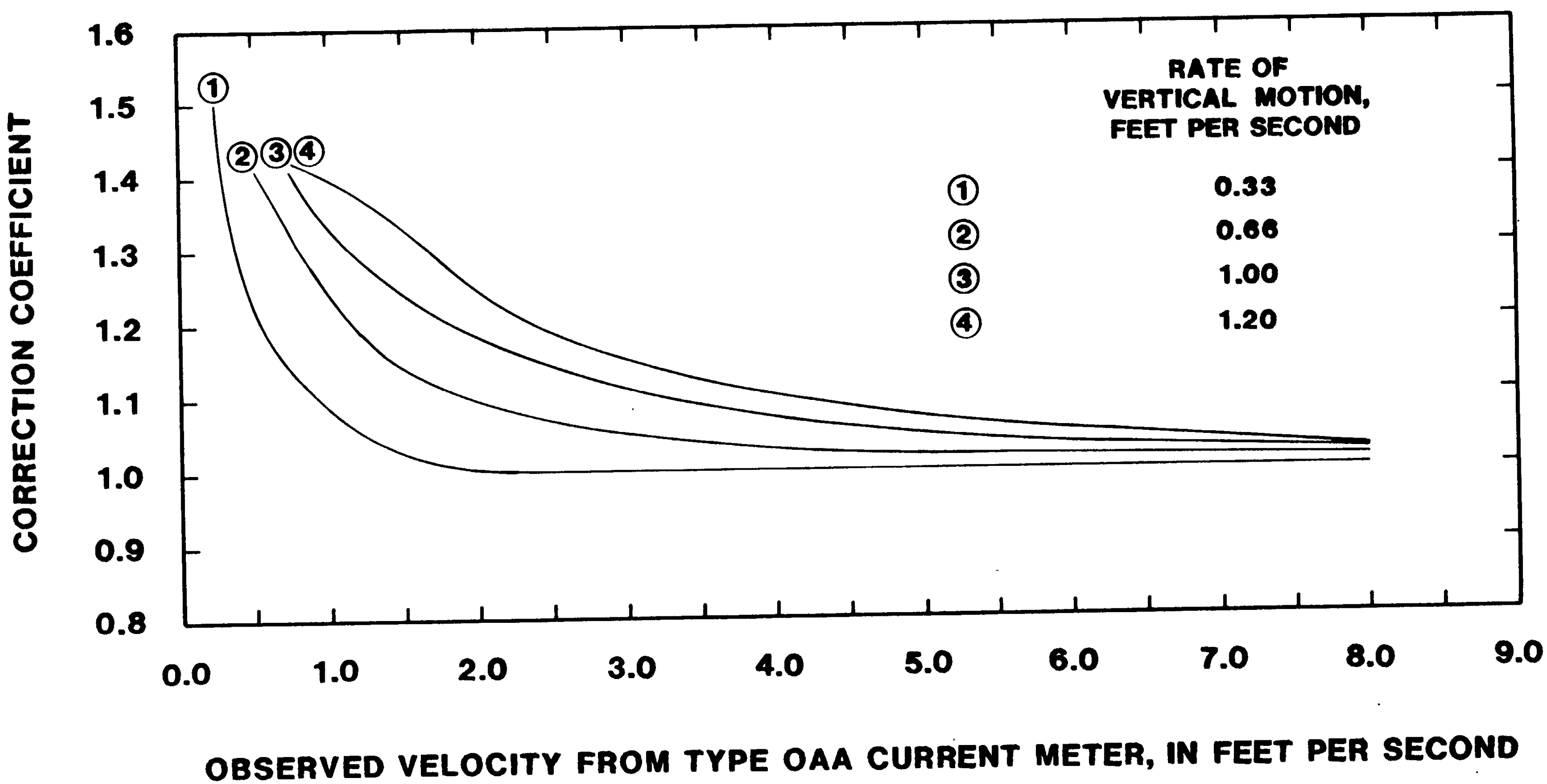

Figure 29.--Correction coefficient versus the observed velocity of the Price type OAA current meter for a 3-ft travel distance as determined from figure 25.

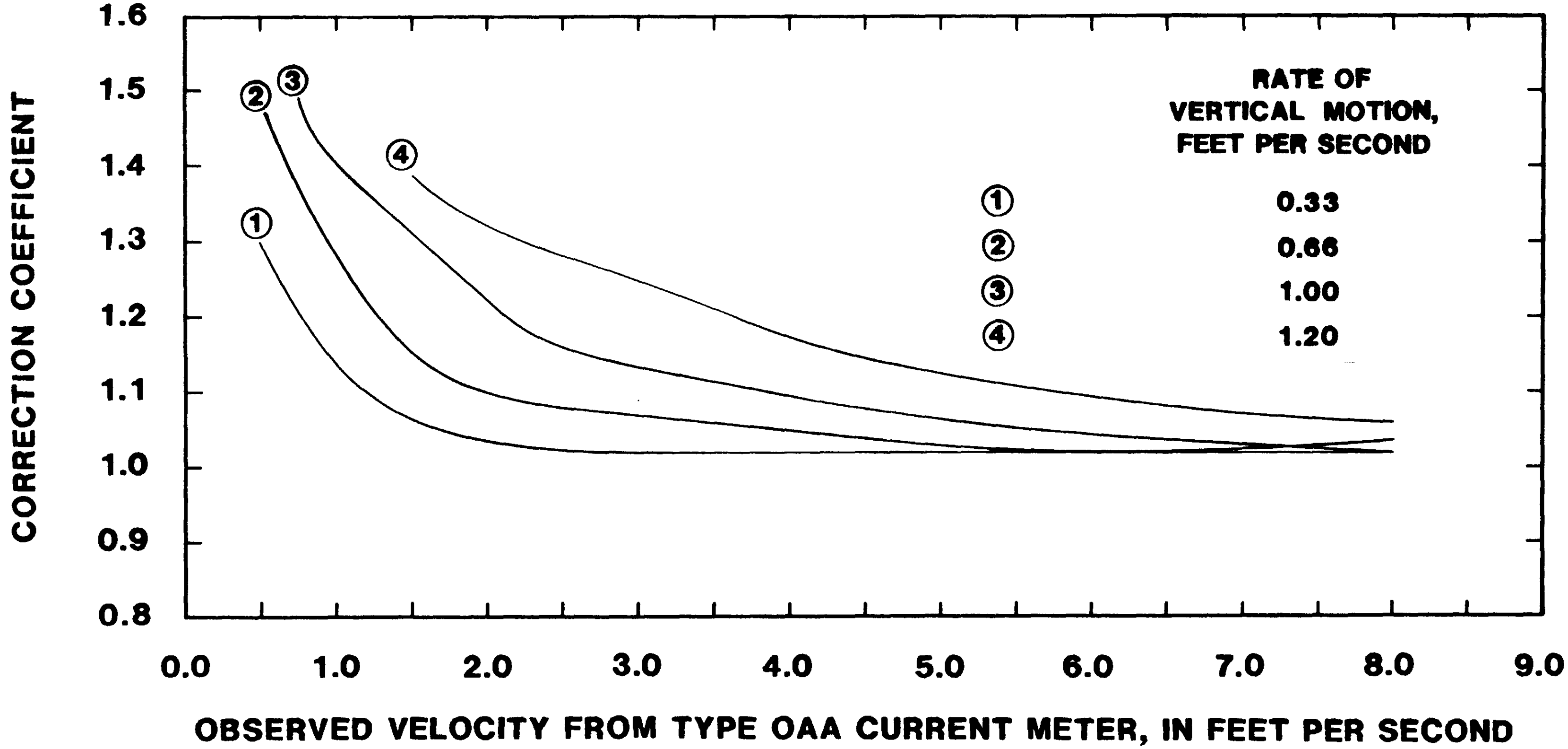

Figure 30.--Correction coefficient versus the observed velocity of the Price type OAA current meter for a 4-ft travel distance as determined from figure 26.

Price Type OAA Current Meter, Pinned

An additional test was performed using the Price type OAA current meter with the meter pinned in a horizontal plane to prevent vertical rotation of the meter about its suspension point during the vertical motion tests. This test was conducted to demonstrate the effects of vertical motion between a meter freely pivoting at its suspension point and a meter with a fixed, nonpivoting suspension point. The meter in its pinned configuration was tested under the same test points of rates of vertical motion, vertical travel distances, and towing speeds as used for the unpinned tests earlier defined.

The test data were plotted in the format of figures 19 through 22 for the unpinned configuration, and it was readily observed that the pinned meter's response was the same as the unpinned meter's response. Because of this same response trend, figures of the plotted data are not provided in this report. The correction coefficients for a pinned Price type OAA current meter are the same as for the unpinned meter detailed in tables 6 through 9.

SUMMARY AND CONCLUSIONS

This report presents the results of tests designed to determine effects of controlled vertical motion on current meters. The tests were performed in 1984 by the U.S. Geological Survey, Hydrologic Instrumentation Facility in the Hydraulics Laboratory at the National Space Technology Laboratories, Mississippi.

The results of these tests show that when current meters are moved vertically, correction coefficients must be applied to the observed meter velocities to correct for the registration errors that are induced by the vertical motion. The Price type AA and Price type OAA current meters are affected by both the rate of vertical motion and the distance of the vertical travel. The Price type OAA consistently under-registers to a higher degree than the Price type AA current meter at the higher rates of vertical motion. The response was the same whether the meter's suspension point was pinned or unpinned. The data indicate that the Price type OAA current meter exhibits less error than the Price type AA current meter at slow stream velocities (less than 2 ft/s) when under the influence of vertical motion.

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