

PERFORMANCE OF ICE METER AND WEIGHT ASSEMBLIES

by Verne R. Schneider and James C. Futrell II

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PERFORMANCE OF ICE METER AND WEIGHT ASSEMBLIES

by Verne R. Schneider and James C. Futrell, II

ABSTRACT

The performance of three ice meters and weight assemblies was evaluated in a towing tank. Each meter was rated individually on a rod suspension. Each meter was then re-rated on a cable suspension, with the appropriate weight assembly. Vertical and veer cable angles were measured along with meter yaw angle. The effect of the weight assembly on the rod-suspension rating for each meter was illustrated by computing a correction coefficient which ranged between 0.88 and 1.10 depending on the weight system used and the fluid velocity. A slush-n-all type weight assembly least affected the meter rating and was the most stable in all flow conditions.

INTRODUCTION

The U.S. Geological Survey is responsible for the measurement of streamflow throughout the United States. The measurement of flow under ice-covered streams is of special concern to the Survey in the northern states, including Alaska, and to counterpart Canadian agencies throughout Canada. Environment Canada and the Survey have begun a cooperative program to compare the performance of various equipment and techniques for the measurement of flow under ice cover. As part of this program, the Survey undertook a brief study to evaluate selected ice meters and weights. The intent was to evaluate the performance of the meters and weights for cable or rod suspension, while rating the meters in a towing tank. Two types of meter, and three types of weight assemblies were rated in various combinations, and observations were made of misalignment angles and overall hydrodynamic stability of meters and weights.

METER MISALIGNMENTS AND CAUSES

Spinning-rotor type meters are generally designed to measure a single component of fluid velocity while aligned with the flow. Most meters used to measure velocity in open channels have devices to orient themselves both vertically and horizontally into the flow. The Price AA current meter, for example, has tail fins to align the meter. Ice meters commonly do not have self-orienting features. Systematic errors in the velocity readings occur when the meter is misaligned, for any reason, with the flow.

A meter is misaligned horizontally when it turns as if to broadside itself in the flow; it is vertically misaligned when the force of the flow moves the whole suspension assembly downstream from the fixed suspension point; and it is misaligned by a tilt angle off vertical that occurs when the force of the flow moves the whole suspension assembly laterally out from under the fixed suspension point.

The foregoing three types of misalignment characterize a three-dimensional problem that can be completely described in terms of its three constituent planar angles. Thus, horizontal misalignment is described by yaw angle, measured in a horizontal plane; vertical misalignment is described by pitch angle, measured in a vertical plane oriented with the flow direction; and tilt misalignment is described by roll angle, measured in a vertical plane oriented transverse to the flow direction. These three component misalignment angles are diagramed in figure 1.

A variety of causes may combine to produce any one or all of the described misalignments. Commonly, with cable-suspended equipment the cable can be seen to drift away from the vertical -- in both downstream and lateral directions -- due to the force of the flow. Such cable drift can be described and measured in terms of an observable vertical angle and veer angle, as shown in figure 2, even though the associated precise meter misalignments are not known. Residual torsional stresses in the cable can also contribute to yaw misalignment.

Rod or cable-suspended ice meters are subject to some combination of meter misalignment errors, which can occur throughout most of the range in fluid velocities. However, for moderate flow velocities, the meter will usually perform reliably when the slush-n-all weight assembly is employed.

IDEAL ICE METER AND WEIGHT ASSEMBLY

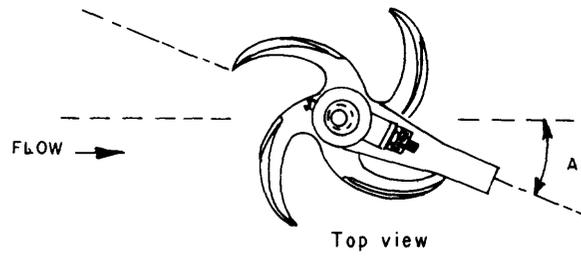
Characteristics of an ideal rotor-type ice meter and weight assembly are listed as follows:

A. Meter:

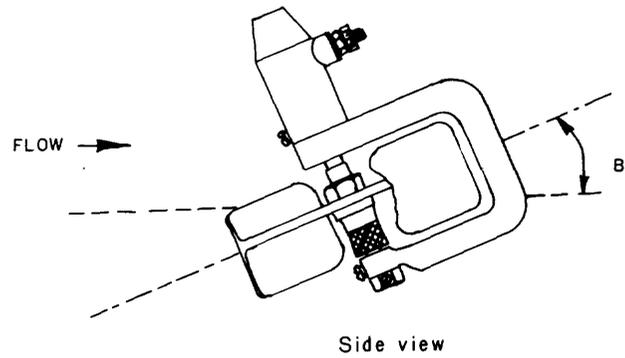
- (1) Suitable for cable or ice rod suspension.
- (2) Near frictionless revolution counting (rotation pick-up) system.
- (3) Matches a standard rating to within 1 percent throughout the desired fluid-velocity range.
- (4) Operates normally in flowing water at $+0.1^{\circ}\text{C}$ within 30 seconds after 1 hour of exposure to air temperature at -40°C .
- (5) All parts highly impact resistant.
- (6) Operates linearly over a velocity range from 0.05 to 4.5 ft/s.
- (7) Non-stick surfaces to repel slush ice or freezing water.
- (8) Fits through a 6-inch diameter hole drilled through the ice cover.
- (9) Capable of a simple field check (such as a spin test) to verify calibration.

B. Suspension Assembly:

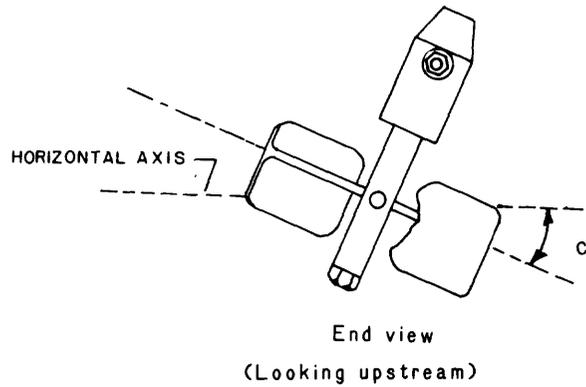
- (1) Same as A-5, A-7, and A-8.
- (2) Easy to handle while wearing heavy mittens.
- (3) Capable of self alignment with flow streamline to eliminate yaw, pitch, and roll angle misalignments.



(a) Yaw angle

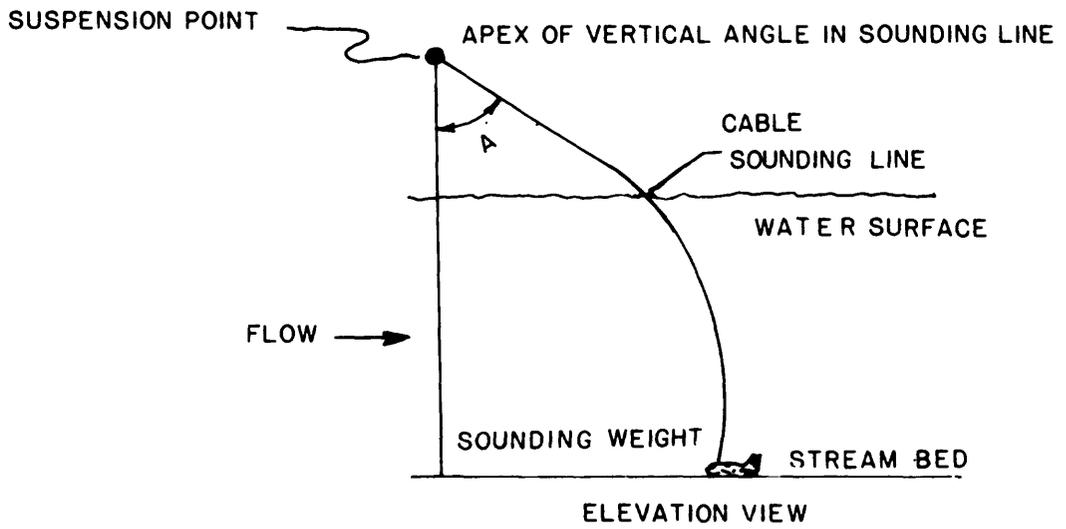


(b) Pitch angle

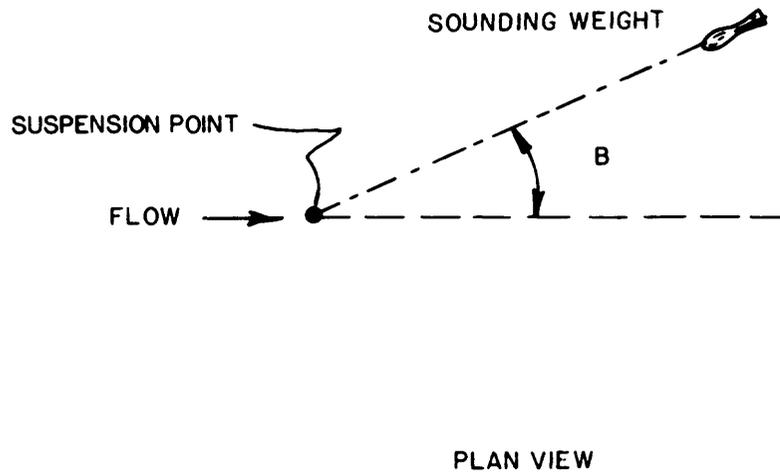


(c) Roll angle

Figure 1.--Fundamental meter misalignment angles.



(a) Vertical angle



(b) Veer angle

Figure 2.--Cable suspension angles that cause meter misalignment.

C. Weight:

- (1) Same as A-5, A-7, A-8, B-2, and B-3.
- (2) Possible tip-tilt feature to accommodate (A-8).

TOW-TANK TEST PROGRAM

The following ice meters and weights, were used in tow-tank tests at the Survey's Gulf Coast Hydroscience Center:

U.S. GEOLOGICAL SURVEY

1. Vane ice meter No. I-0017 and weight assembly (fig. 3)

ENVIRONMENT CANADA

2. WSC winter meter No. 6-117 (fig. 4)
 - a. Pancake weight assembly (fig. 5)
 - b. Slush-n-all weight assembly (fig. 6)

Environment Canada loaned the Canadian WSC winter meter and weights to the Survey.

Data Collection Procedure

Meter ratings were made for the combinations of equipment and suspension types as summarized in table 1.

Table 1.--Test combinations, ice meters and weights

Type meter	Type weight assembly	Type suspension		
		Carriage rod		Cable
		Meter only	Meter and weight	Meter and weight
Vane ice No. I-0017.	Vane ice meter.	X	X	X
WSC winter No. 6-117.	Pancake ---	X	---	X
WSC winter No. 6-117.	Slush-n-all ---	X	---	X

The cable rating of the vane ice meter and weight assembly was made for 3 different depth settings in the tow tank. The selected depths were 2.2, 6.6, and 8.8 ft (see tables 2, 3, and 4 respectively). The cable rating of the WSC winter meter was made at a depth of 6.6 ft with both the pancake and slush-n-all weight assemblies.

Ten to twelve velocity points were obtained for each meter and weight combination, generally ranging from 0.5 to 10 ft/s. Meter readings were taken in both the forward and reverse carriage-travel directions and the results averaged to determine the rating curve. Measurements of cable vertical and veer angles as well as meter yaw angles were made. General observations were made of the stability of the meter and weight assembly and their performance when cable-

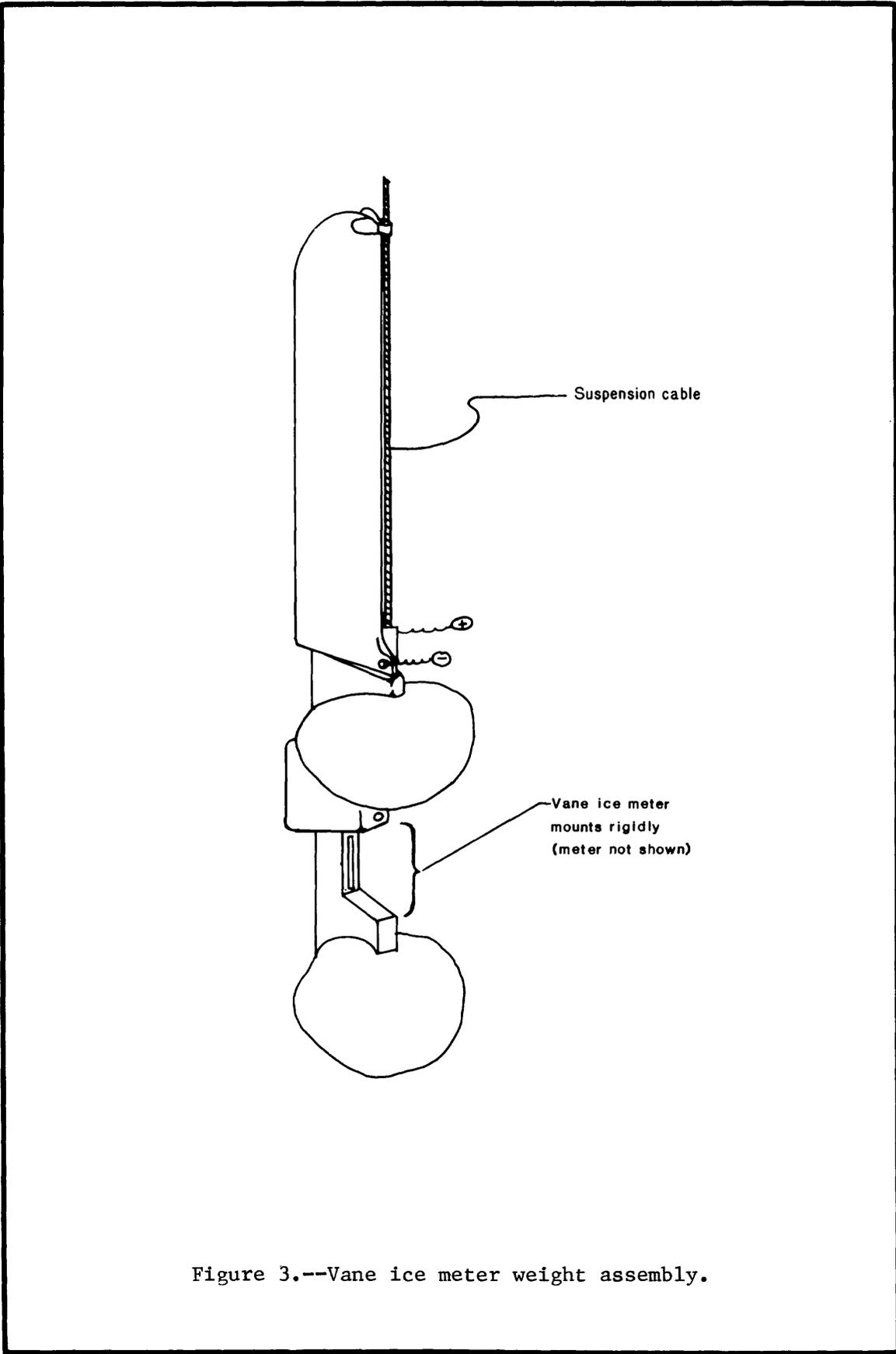


Figure 3.--Vane ice meter weight assembly.

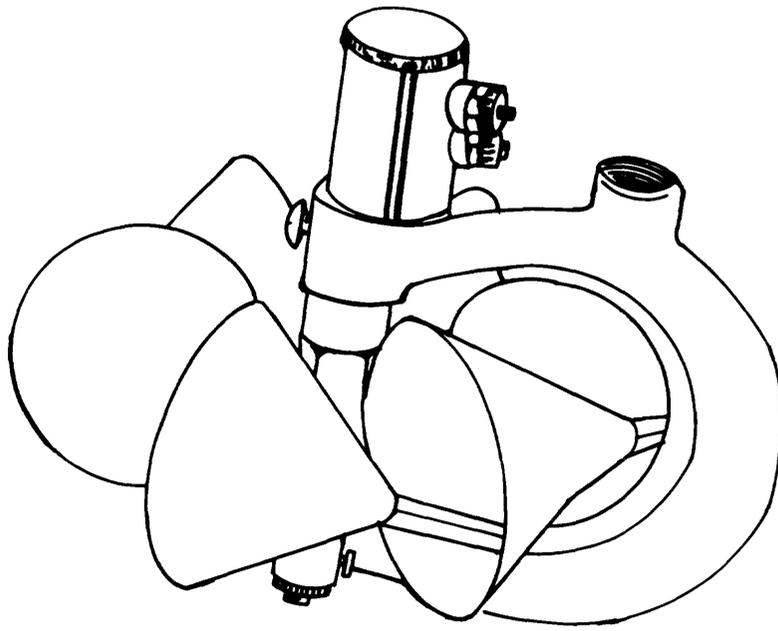


Figure 4.--WSC winter meter.

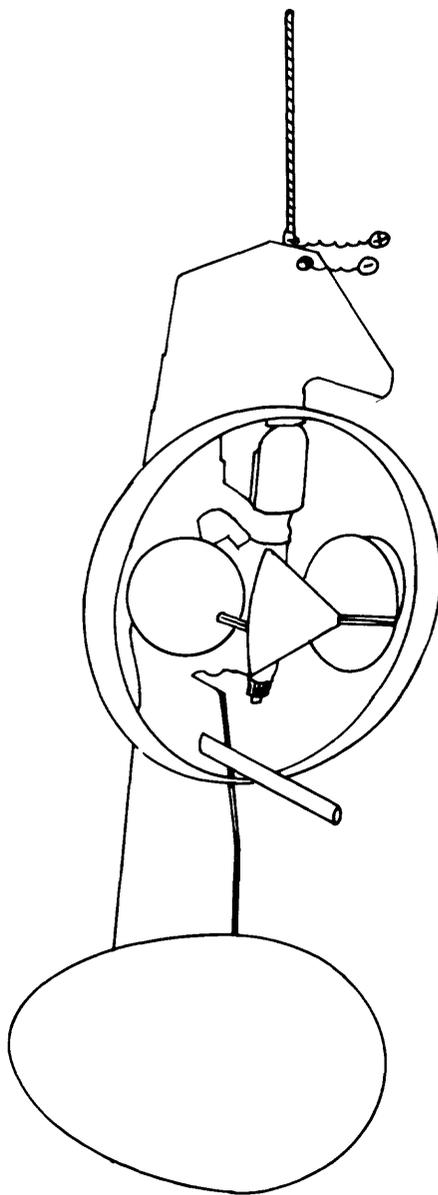


Figure 5.--Pancake weight assembly.

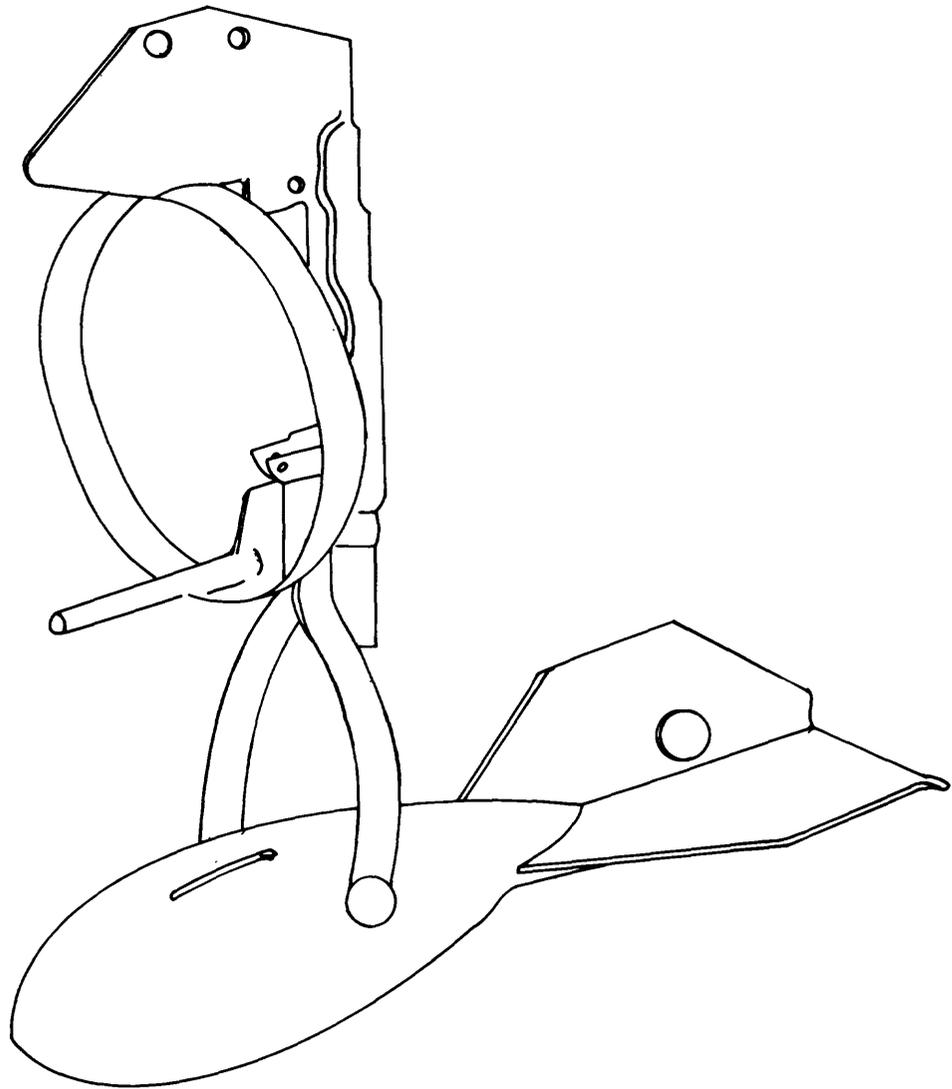


Figure 6.--Slush-n'-all weight assembly.

Table 2.--Cable rating for vane ice meter with vane ice weight assembly, 2.2 foot depth

[Yaw angle correction = 1.00]

Velocity ft/s	Towing direction	Cable veer angle degrees	Cable vertical angle degrees	Notes
0.51	Forward	0	0	--
	Reverse	0	0	--
0.76	Forward	1	0	Weight swims in a sinusoidal pattern.
	Reverse	1	0	
1.10	Forward	0	0	--
	Reverse	0	0	--
1.50	Forward	0	0	--
	Reverse	0	2	--
2.22	Forward	0	2	Cable strums.
	Reverse	0	3	Do.
3.00	Forward	0	3	Do.
	Reverse	0	4	
3.99	Forward	1	6	Do.
	Reverse	1	8	Do.
5.98	Forward	1	16	Do.
	Reverse	1	17	Do.
6.98	Forward	1	22	Weight bobs and vibrates violently.
	Reverse	(1)	(1)	
7.96	Forward	1	26	Do.
	Reverse	(1)	(1)	Do.
8.96	Forward	2	26	Do.
	Reverse	(1)	(1)	Do.
10.08	Forward	2	28	Top of ice weight out of water;
	Reverse	(1)	(1)	weight bounces on water surface in the tow tank.

¹ At this velocity, the cable touches the tow carriage for the reverse run; therefore, no data are available.

Table 3.--Cable rating for vane ice meter with vane ice weight assembly, 6.6 foot depth

[Yaw angle correction = 1.00]

Velocity ft/s	Towing directions	Cable veer angle degrees	Cable vertical angle degrees	Notes
0.50	Forward	0	0	Cable strums.
	Reverse	0	0	Do.
0.76	Forward	1	0	--
	Reverse	1	0	--
1.11	Forward	1	0	--
	Reverse	1	0	--
1.50	Forward	1	0	Cable strums.
	Reverse	1	0	Do.
2.22	Forward	0	3	Do.
	Reverse	0	5	Do.
3.00	Forward	0	10	Do.
	Reverse	0	11	Do.
3.99	Forward	0	18	Do.
	Reverse	0	19	Do.
5.98	Forward	0	25	Do.
	Reverse	(1)	(1)	Do.
6.97	Forward	2	35	--
	Reverse	(1)	(1)	--
7.96	Forward	3	37	--
	Reverse	(1)	(1)	--
8.95	Forward	1	40	--
	Reverse	(1)	(1)	--
10.21	Forward	1	45	--
	Reverse	(1)	(1)	--

¹ At this velocity, the cable touches the tow carriage for the reverse run, therefore, no data are available.

Table 4.--Cable rating for vane ice meter with vane ice weight assembly, 8.8 foot depth

[Yaw angle correction = 1.00]

Velocity ft/s	Towing direction	Cable veer angle degrees	Cable vertical angle degrees	Notes
0.51	Forward	0	0	--
	Reverse	0	0	--
0.76	Forward	0	0	--
	Reverse	0	0	--
1.11	Forward	1	0	--
	Reverse	1	0	--
1.50	Forward	0	0	Cable strums
	Reverse	0	0	Do.
2.22	Forward	0	0	Do.
	Reverse	0	0	Do.
3.00	Forward	0	10	Do.
	Reverse	0	15	Do.
3.99	Forward	0	21	Do.
	Reverse	(1)	(1)	Do.
5.98	Forward	0	34	Do.
	Reverse	(1)	(1)	Do.
6.97	Forward	0	37	Do.
	Reverse	(1)	(1)	Do.
7.98	Forward	0	42	Do.
	Reverse	(1)	(1)	Do.
8.95	Forward	0	45	No cable strumming
	Reverse	(1)	(1)	Do.
10.22	Forward	1	49	--
	Reverse	(1)	(1)	--

¹ At this velocity, the cable touches the tow carriage for the reverse run, therefore, no data are available.

suspended. All of these cable-suspension data are summarized in tables 2 to 6.

As already mentioned, a rotor-type meter is designed to measure a single component of fluid velocity when perfectly aligned with the flow streamline. In the tow-tank setup, therefore, the meter is rated by mounting it in a fixed and perfect alignment -- yaw, pitch, and roll angles all zero -- on a rod that is rigidly secured to the towing carriage. The rating is established by running the carriage at selected speeds and measuring the rotor spin velocity for each speed.

In the tow-tank test procedures, no attempt was made to relate cable vertical and veer angles to meter misalignments of yaw, pitch and roll. About all that can be said is that when such cable angles are not zero there will be some form of meter misalignment, and meter accuracy will be degraded.

Data Analysis Procedure

Preliminary analysis of the rating data indicates that a rating equation consisting of two intersecting straight lines would reasonably approximate most of the plotted points. This is in accord with current rating practice for vane-ice and Price type AA meters. A computer program, incorporating least squares techniques, is used to fit trial combinations of lines to each data set by progressively varying the number of points in the lower and upper lines (3 points in the lower line and n-3 points in the upper line; 4 points in the lower line and n-4 points in the upper line, and so forth). The standard error of estimate is calculated for each trial pair of lines. The pair with the lowest standard error is selected as the rating for the meter and weight to which the data set belong. The rating equations and the corresponding standard errors are summarized in table 7.

The resultant equations are presented in the form

$$V = M_1 R + b_1 \quad (V_{bp}) \quad M_2 R + b_2 \quad (1)$$

where V is the fluid velocity, in feet per second
 V_{bp} is the fluid velocity at the breakpoint or
the intersection of the upper and lower lines
 M_1 and M_2 are the slopes of the lower and upper lines,
respectively,
 b_1 and b_2 are the Y coordinate-axis intercepts of the
lower and upper lines, and
 R is the meter rotor speed, in revolutions per second.

FACTORS THAT AFFECT THE METER RATING

In the stream gaging process, accurate velocity measurements are essential in order to calculate discharge. In this paper, selected factors are identified that affect the accuracy of the meter in making velocity measurements. These factors can be grouped for discussion purposes under test procedures and cable

Table 5.--Cable rating for WSC winter meter with pancake weight, 6.6 foot depth

[Yaw angle correction = 1.00]

Velocity ft/s	Towing direction	Cable veer angle degrees	Cable vertical angle degrees	Notes
0.52	Forward	0	0	--
	Reverse	0	0	--
0.78	Forward	1	0	--
	Reverse	1	0	--
1.13	Forward	1	0	Weight swims in a sinusoidal pattern.
	Reverse	2	0	
1.53	Forward	4	0	Do.
	Reverse	4	0	Do.
2.26	Forward	1	0	Do
	Reverse	1	0	Do.
3.06	Forward	0	2	--
	Reverse	0	2	--
4.07	Forward	0	5	--
	Reverse	0	5	--
6.10	Forward	0	10	--
	Reverse	0	10	--
7.10	Forward	0	15	--
	Reverse	0	15	--
8.12	Forward	0	20	--
	Reverse	0	20	--
9.14	Forward	0	25	--
	Reverse	0	(1)	--
10.23	Forward	2	30	--
	Reverse	2	(1)	--

¹At this velocity, the cable touches the tow carriage for the reverse run, therefore, no data are available.

Table 6.--Cable rating for WSC winter meter with slush-
n-all weight, 6.6 foot depth

[Yaw angle correction = 1.00]

Velocity ft/s	Towing direction	Cable veer angle degrees	Cable vertical angle degrees	Notes
0.76	Forward	0	0	
	Reverse	0	0	
1.11	Forward	0	0	
	Reverse	0	0	
1.50	Forward	0	0	
	Reverse	0	0	
2.22	Forward	0	0	
	Reverse	0	0	
3.01	Forward	0	4	
	Reverse	0	4	
4.00	Forward	0	6	
	Reverse	0	6	
5.99	Forward	0	13	
	Reverse	0	13	
6.99	Forward	2	16	
	Reverse	2	16	
7.98	Forward	2	19	
	Reverse	2	19	
8.99	Forward	3	24	
	Reverse	3	(1)	
10.24	Forward	5	30	
	Reverse	5	(1)	

¹ At this velocity, the cable touches the tow carriage
for the reverse run, therefore, no data are available.

Table 7.--Summary of meter rating equations

Meter type	Meter no.	Suspension type	Weight type	Depth of meter	Standard error	Fluid velocity equation	Equation number
Vane	I-0017	Rod ¹	None	1.2	0.015	$V = 2.482R + 0.056 (2.317)2.316R + 0.206$	2
Vane	I-0017	Rod ¹	Vane Ice	2.0	0.022	$V = 2.075R + 0.053$	3
Vane	I-0017	Cable	Vane Ice	2.2	0.026	$V = 2.377R - 0.003 (1.844) 2.123R + 0.194$	4
Vane	I-0017	Cable	Vane Ice	6.6	0.051	$V = 2.151R + 0.072$	5
Vane	I-0017	Cable	Vane Ice	8.8	0.059	$V = 2.164R + 0.066$	6
WSC	6-117	Rod ¹	None	1.2	.008	$V = 2.197R + 0.048 (1.650) 2.145R + 0.086$	7
WSC	6-117	Cable	Pancake	6.6	.026	$V = 2.242R + 0.051 (7.426) 2.475R - 0.715$	8
WSC	6-117	Cable	Slush-n-all	6.6	.018	$V = 2.232R + 0.067 (6.234) 2.581R - 0.897$	9

¹Tow-tank-carriage rod.

suspension characteristics, but all bear upon meter misalignments in the flow regime.

Test Procedures

When rating a current meter, the proper procedure is first to calibrate the meter on a fixed-rod type suspension without any weights. Previous tests have shown that when the meter is at least 1.2 ft below the water surface, the rating is not affected by the surface. The effect of weight proximity to the meter is then evaluated, through multiple runs at different separation-distance settings, until the minimum distance at which the weights do not affect the meter rating is determined. A good example of the end result is the Price AA meter used with Columbus type weights. Its hanger strap (for the meter/weight assembly) is drilled at several different positions to allow the meter to be mounted with any one of several weights. For a given weight, the meter is mounted at a specified and recommended point on the hanger strap. All such points were determined by tests in a tow tank.

For the tests identified in table 7, the meters alone were first rated suspended from a fixed-rod type of mount. Meter and weight assemblies were then suspended from a cable or fixed rod and rerated. Comparisons of results were made generally by computing "correction" coefficients to convert meter-only rating data from one type of suspension or test procedure to another type of suspension or test procedure. The coefficients are simply the velocity ratios -- for specific meter rotor speeds -- where the velocities are computed from the rating equations in table 7.

A preliminary step in the test program was to determine the basic effect of the ice-weight assembly for the cable suspension on the rating for the vane ice meter for the rigid-rod type suspension. This was accomplished by first rating the meter alone (eq 2 in table 7), followed by a rating for the combined meter and weight assembly (eq 5 in table 7). The effect is then computed as "correction" coefficients, which are the velocity ratios -- for specific meter rotor speeds -- for the meter-and-weight assembly rating (eq 5) divided by the meter-alone rating (eq 2). The results are plotted as figure 7. In this case, the correction coefficient would be applied to the rigid-rod rating to construct a cable suspension rating. The correction coefficient can be seen to range from 0.88 at 2.2 ft/s to 0.91 at 8.0 ft/s. In other words, the meter rotates approximately 9 to 12 percent faster when mounted with the vane ice weight than it does when mounted by itself on a rigid rod. Furthermore, the correction factor varies with velocity.

For comparison purposes, the vane ice meter and weight assembly was cable suspended and rated at 3 different initial depths in the tow tank (2.2, 6.6, and 8.8 feet). As the carriage speed (fluid velocity) increased, the cable vertical angle -- and hence the meter pitch angle -- increased so that the submerged depth of the meter decreased. In this position, the proximity of the meter to the water surface may effect the rating. In figure 8, these results are

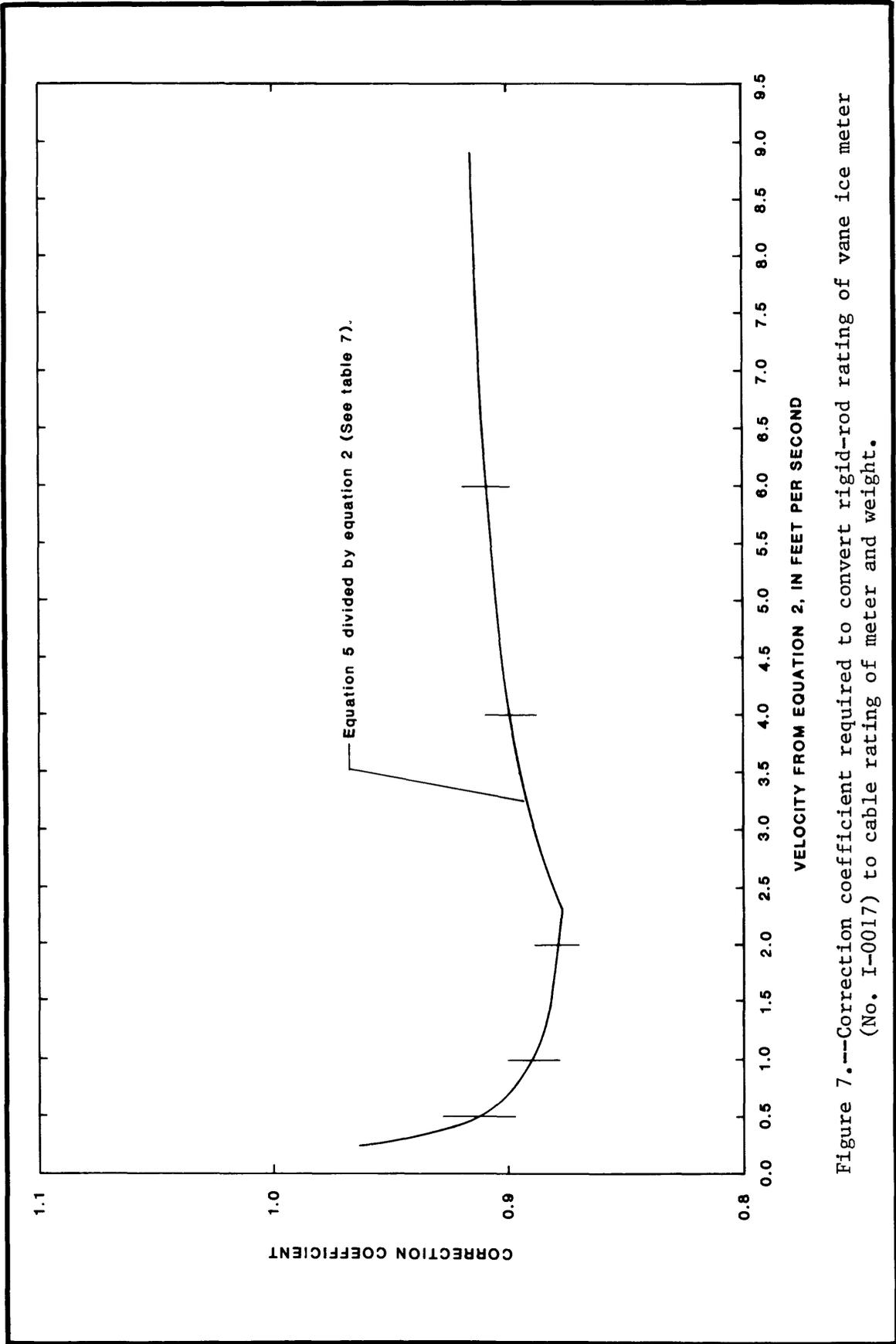


Figure 7. ---Correction coefficient required to convert rigid-rod rating of vane ice meter (No. I-0017) to cable rating of meter and weight.

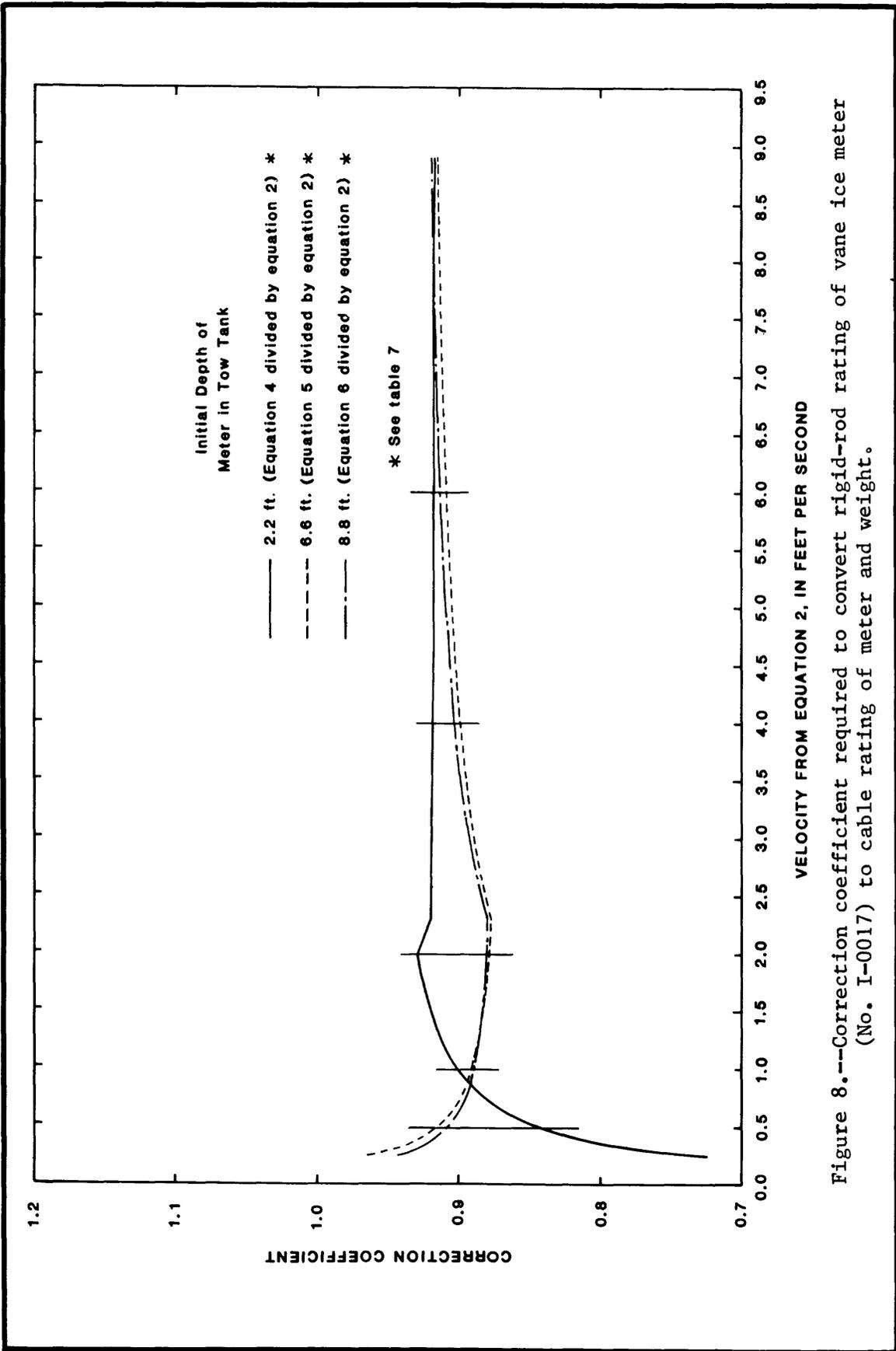


Figure 8.--Correction coefficient required to convert rigid-rod rating of vane ice meter (No. I-0017) to cable rating of meter and weight.

compared. The results show that the ratings are virtually identical at 6.6 and 8.8 ft, but that at 2.2 ft the proximity of the water surface affects the rating. Therefore, all cable ratings were made starting with an initial depth of 6.6 ft.

The effect of cable rating (for 6.6 ft depth) versus rod rating of the vane ice meter and weight can be seen in figure 9. For some reason the cable suspension of this meter and weight assembly has slightly less affect on the flow field than the rigidly mounted rod suspension of the same assembly. The meter rotates between 5 to 10 percent slower for the rod suspension than for a cable suspension. The reason for this difference is not known.

The pancake and slush-n-all weights have a relatively smaller effect on the velocity readings of the WSC meter as shown in figure 10. For the pancake weight, the meter rotates between 2 to 5 percent slower for a cable suspension than for a rod suspension. For the slush-n-all weight and meter assembly, the meter rotates 3 to 9 percent slower. Note that for the pancake weight the coefficient is nearly constant over the velocity range of most interest (0 to 4 ft/s).

Cable Suspension Characteristics

A variety of factors peculiar to cable suspensions are observed in judging overall meter performance. These factors are identified in table 8, and in addition to cable vertical and veer angles are seen to include cable strumming, vibration of the meter and weight assembly, and swimming of the whole assembly.

Cable strumming is caused by the alternate shedding from the submerged cable of clockwise and counter-clockwise fluid vortices. The frequency of the vortex shedding, f , has been found to be proportional to the ratio of the fluid velocity, V , and the cable diameter, D , that is,

$$f = S \frac{V}{D}$$

(Berteaux, 1976, p. 277-279). The constant of proportionality, S (Strouhal number) varies with the Reynolds number. Therefore, an oscillatory motion develops, normal to the free stream velocity. This high-frequency-flow induced vibration is commonly referred to as strumming. Large diameter cables are more susceptible to strumming. Although strumming itself does not affect the meter rating, it does increase the cable drag from 50 to 100 percent, which in turn may significantly increase the cable vertical angle. Strumming was observed for the vane ice meter and weight assembly for velocities ranging from 2.2 to 6.0, 1.5 to 6.0 and 1.5 to 8.0 ft/s for the 2.2, 6.6 and 8.8 ft depths, respectively.

Vibration and swimming are other forms of hydrodynamic instabilities associated primarily with the meter/weight assembly. Vibration was observed when the vane ice meter assembly was towed at the 2.2 ft depth at the relatively high velocities of 6 to 9 ft/s. It was judged to be caused by the interaction of the meter assembly with the water surface. Vibration should not be a general problem affecting ice measurements.

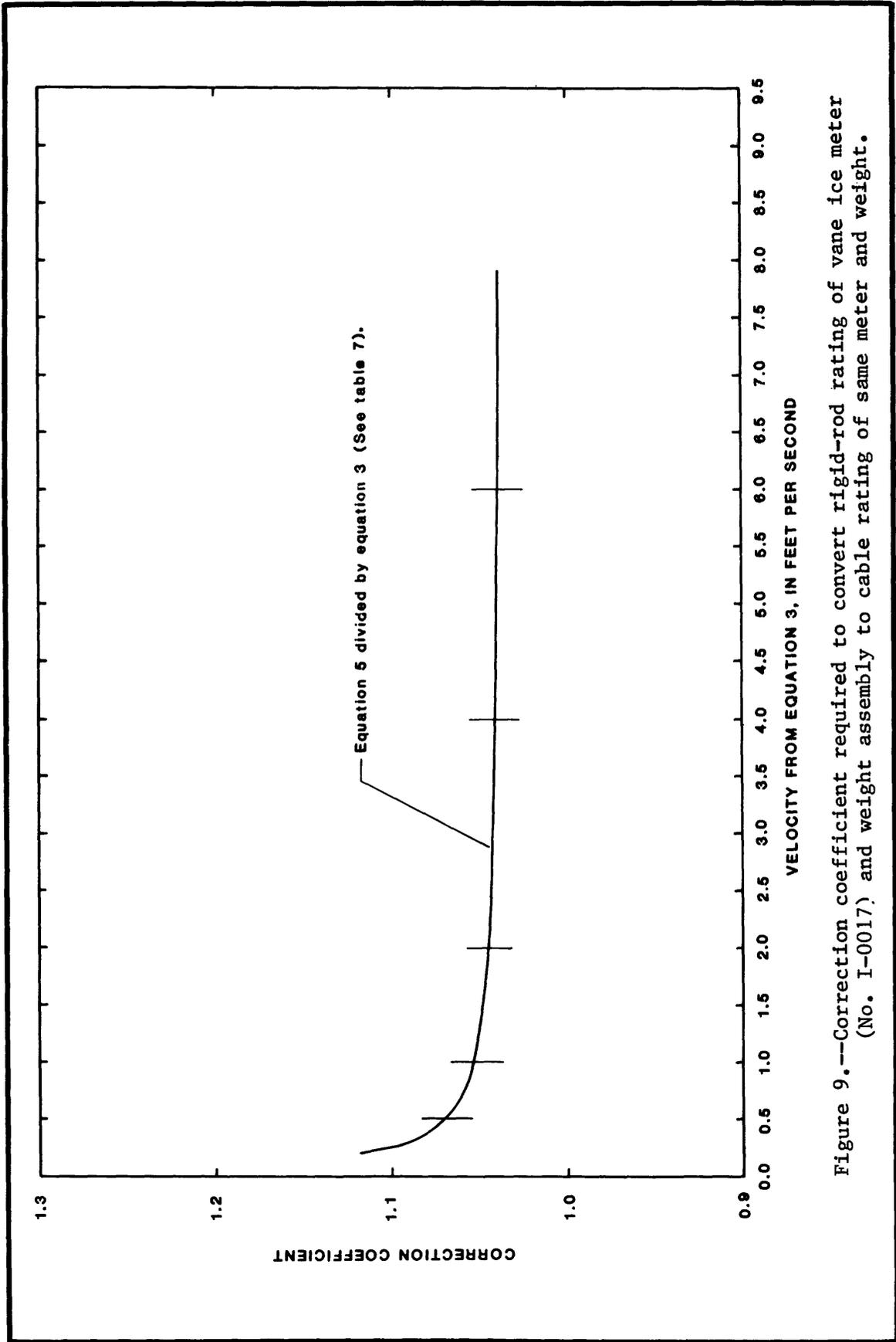


Figure 9.--Correction coefficient required to convert rigid-rod rating of vane ice meter (No. I-0017) and weight assembly to cable rating of same meter and weight.

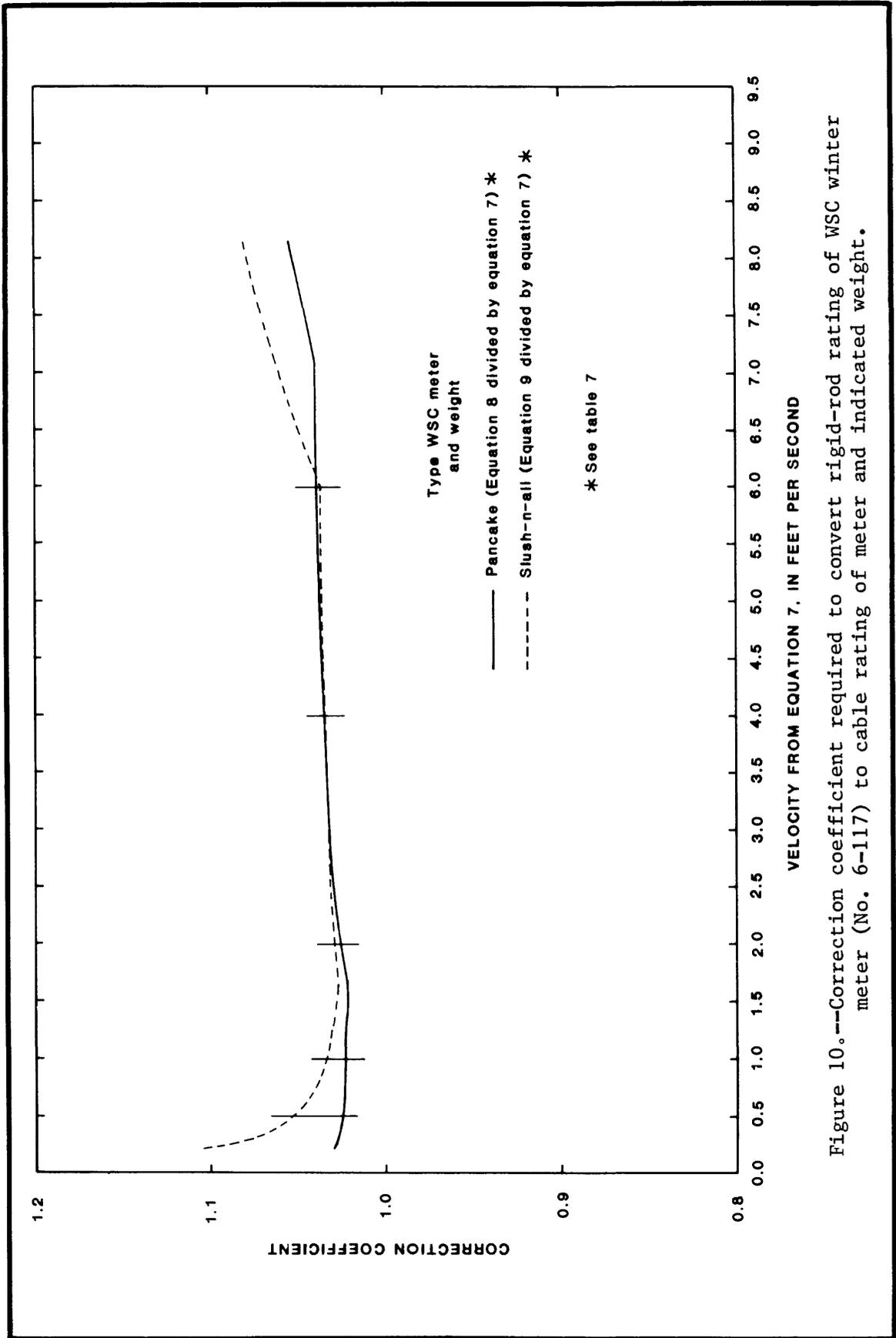


Figure 10.--Correction coefficient required to convert rigid-rod rating of WSC winter meter (No. 6-117) to cable rating of meter and indicated weight.

Table 8.--Performance comparison of meter and weight assemblies

[Yaw angle correction = 1.00]

CABLE SUSPENSION

Meter and weight assembly	Strumming, velocity range (ft/s)	Vibrating or swimming velocity range (ft/s)	Cable vertical angle exceeds 5° for velocities greater than shown ft/s	Cable veer angle exceeds 4° for velocities greater than shown ft/s	Yaw angle velocity range ft/s	Acceptable results
Vane ice meter and weight assembly 8.8 ft depth.	1.5-8.0	--	2.0	--	--	None
Vane ice meter and weight assembly 6.6 ft depth	0.5 and 1.5-6.0	--	2.2	--	--	None
Vane ice meter and weight assembly 2.2 ft depth	2.2-6.0	0.8, and 6.0-9.0	4.0	--	--	None
WSC winter meter with pancake weight 6.6 ft depth	--	1.1-2.3	4.0	--	--	None
WSC winter meter with slush-n-all weight 6.6 ft depth	--	--	4.0	9.0	--	None

ROD SUSPENSION

Meter Type	Recommended use, minimum velocity ft/s
Vane ice meter	0.5
WSC winter meter	0.25

Swimming usually occurred over a fairly narrow velocity range. In these tests, the vane assembly was observed to swim at a velocity of 0.8 ft/s at 2.2 ft depth while the WSC winter meter with pancake weight was observed to swim over the velocity range of 1.1 to 2.3 ft/s at 6.6 ft depth. Swimming of the meter/weight assembly is its movement, in a sinusoidal pattern, perpendicular to the towed direction. The movement is limited by the available cable length. The effect on the rating is not known but considered small.

Cable vertical angle is caused by the fluid drag on the cable and meter assembly. The magnitude of the angle is related to the balance of forces on the cable and meter assembly. Therefore, any factor affecting the force balance will affect vertical angle. Ideally the meter should hang directly below the cable suspension point with a zero vertical angle. When vertical angle is not zero, the depth and position of the meter may be in error. The acceptable vertical angle will change with changes in the local stream-channel geometry. For comparison purposes, the fluid velocity at which the cable vertical angle exceeds 5° is given in table 8. The vertical angle of 5° is exceeded for the vane ice meter assembly at velocities of 4.0, 2.2, and 2.0 ft/s for depths of 2.2, 6.6, and 8.8 ft respectively. It is exceeded for the pancake and slush-n-all assemblies at 4.0 ft/s for depths of 6.6 ft. This angle increases with depth as shown for the vane ice meter assembly, probably because of the drag on the extra length of cable. One would expect total drag to increase with the length of exposed cable. Since vertical angle cannot be measured under ice, the meter and weight assembly should be designed and limited to uses that will insure that the vertical angle is small.

Cable veer angle appears to be caused by nonsymmetry of the weight and meter assembly. Tests conducted by the Survey have shown that in some instances the meter cup rotation is sufficient to create a nonsymmetrical configuration and induce cable veer. Veer is not a problem for any of the ice meter assemblies at velocities usually encountered under ice. When veer angle is large, it causes an error in the lateral, longitudinal, and vertical positioning of the meter and it may -- at sufficiently large values -- induce a meter roll angle.

Meter yaw angle can be caused by the failure of the entire cable, meter, and weight assembly to align the meter with the flow streamline. There are various reasons for this. The Ellsworth-type reverse lay steel sounding cable generates a torsional force, when loaded. This force varies with line length, sounding weight size, and external twists exerted on the assembly. The vanes of a cable-suspended Price current meter combined with the vanes of a Columbus sounding weight, tend to counteract this torsional cable force when exposed to flowing water. When the velocity of the flowing water exerts sufficient pressure on the meter and weight vanes the meter aligns with the flow and the yaw angle approaches zero.

Meter response varies with yaw angle and may be different depending upon the direction of the angle. In these tests, the alignment of the meter and weight assembly was observed before each run. Yaw angles were eliminated by carefully aligning the meter with the flow streamline. The alignment was necessary for velocities below 1.5 ft/s. Since some ice meter assemblies have no vanes and therefore are limited in ability to align themselves with the flow, it is important that the meter be oriented correctly before lowering it into the flow. Even then, because of poor visibility, and the variation of the induced torsional force in different cable lengths, significant yaw angles may exist which adversely affect the accuracy of the measurement.

The velocities measured with all meters require correction if the meter was rated on a rod. The corrections for the meters used in this study are shown in figures 7 to 10. The corrections are lowest and nearly constant for the pancake and slush-n-all weight assemblies with the WSC meter. The WSC winter meter with slush-n-all weight was the only cable suspended assembly which did not have a problem in the velocity range from 0.25 to 4.0 ft/s.

On the other hand, both the vane ice meter and the WSC winter meters tested successfully on a rod suspension. The results show no problems at velocities greater than 0.5 and 0.25 ft/s respectively. At velocities below 0.5 ft/s, the vane ice meter rating is nonlinear and, like all rotating element type meters, it stalls at some point between 0 and 0.5 ft/s. The WSC winter meter rating may be nonlinear below 0.25 ft/s and it stalls between 0 and 0.25 ft/s. The stall point for both meters is a function of the fluid flow and the meter condition. Each meter is individually rated to the stall speed of the bucket wheel.

SUMMARY AND CONCLUSIONS

These tests have shown that, while the ideal ice meter was not tested, with care, good quality data may be obtained with any of the meters. However, since the cable suspension of the vane ice meter has a large variable correction coefficient, the vane ice meter is now recommended for use only on a rod.

The slush-n-all and pancake-type weights had the least effect on the rotation of the current meter. Furthermore, their correction coefficients were nearly independent of velocity over the range of interest.

The correction coefficients derived in this report are for use only with the Vane ice meter No. #I-0017 and WSC winter meter No. #6-117. A general set of coefficients could be derived if a sufficiently large sample of meters was tested.

REFERENCES

Berteaux, H. O., 1976, Buoy engineering: New York, John Wiley and Sons, Inc., p. 277-279.