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THE EFFECT OF VERTICAL ALIGNMENT ON THE PERFORMANCE OF THE PRICE 622AA CURRENT METER

by

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Hydraulics Division
National Water Research Institute
Canada Centre for Inland Waters
Burlington, Ontario

July 1979

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MANAGEMENT PERSPECTIVE

The results of this study, which shows the Price current meter is very sensitive to its azimuth angle, were quite unexpected.

Bearing in mind the widespread use of this meter for recording the water resources of Canada, it is evidently important that operators and surveyors should be made aware of this characteristic of the meter. The results should be incorporated in operational manuals.

T. M. Dick
Chief
Hydraulics Division
17 August 1979

PERSPECTIVE - GESTION

Les résultats de cette étude qui démontre que le moulinet hydraulique Price est très sensible à son angle azimutal sont totalement inattendus.

Compte tenu de l'utilisation repandue de ce moulinet pour recenser les ressources hydrauliques du Canada, il est, de toute évidence, important que les opérateurs et les hydrographes soient informés de cette caractéristique du moulinet. Les résultats doivent être incorporés dans les guides d'exploitation.

T. M. Dick
Chef
Division de l'hydraulique
Le 17 août 1979

SUMMARY

Tests were conducted to study the performance of the Price 622AA current meter when placed normal to the flow but aligned at different angles above and below the horizontal plane. Results indicate that the meter behaves differently for angles above and below the true horizontal position. In order to keep errors below one percent, the Price meter should not be allowed to deviate by more than 2.5 degrees from true alignment above and below the horizontal plane. For all azimuth angles tested, the rate of rotation of the rotor was less than that obtained for the same meter when placed in true alignment.

SOMMAIRE

Des tests ont été faits pour étudier le rendement du moulinet hydraulique Price 622AA placé de façon perpendiculaire au courant, mais aligné à divers angles au-dessus et au-dessous du plan horizontal. Les résultats indiquent que le moulinet se comporte de façon différente, selon que les angles soient au-dessus ou au-dessous de la position horizontale vraie. Pour que les erreurs ne soient pas inférieures à un pour cent, le moulinet Price ne doit pas dévier de plus de 2.5 degrés de la véritable ligne d'alignement au-dessus et au-dessous du plan horizontal. Dans le cas de tous les angles azimutaux qui ont fait l'objet de tests, le taux de rotation de l'hélice était inférieur à celui qui avait été obtenu pour le même moulinet placé selon la véritable ligne d'alignement.

LIST OF NOMENCLATURE

N_o = revolutions per second for standard calibration

N_θ = revolutions per second for oblique calibration

V_o = towing speed for standard calibration

θ = vertical angle of alignment

ΔN = $N_\theta - N_o$

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1.0 INTRODUCTION

The Price current meter is the most commonly used instrument to measure stream flow discharge in North America. Therefore, it is important to know what factors influence the performance of this instrument. Studies to assess the effects of fluid properties (Engel, 1976) and the effects of misalignment of the meter in the horizontal plane (Engel, DeZeeuw, 1978) have already been done. This study was conducted to assess the response of the meter when it is misaligned both above and below its true horizontal (level) position.

This report is one in a series of seven, investigating the performance characteristics of the Price current meter. The results are intended to show only the performance tendency of the meter and as such do not provide information suitable for angular correction coefficients. Such information can only be obtained by exhaustive repetitive tests using many meters and is beyond the scope of this report. The experiments for this report were conducted under study number HRD 79-003.

2.0 EQUIPMENT AND APPARATUS

2.1 Meter Suspension

One Price 622AA type current meter number 1-179 was used in these tests. The meter was drawn at random from inventory and used with a 20 mm diameter solid steel rod assembly fastened to the rear of the towing carriage as shown in Figure 2.1.

2.2 Towing Tank

The tank, constructed of reinforced concrete, founded on piles, is 122 metres long and 5 metres wide. The full depth of the tanks is 3 metres of which 1.5 metres is below ground level. Normally, the water depth is maintained at 2.7 metres. Concrete was chosen for its stability, vibration reduction and to reduce possible convection currents.

At one end of the tank is an overflow weir. Waves arising from towed current metres and their suspensions are washed over the crest, reducing wave reflections. Parallel to the sides of the tank, perforated beaches serve to dampen lateral surface wave disturbances. The large cross section of the tank also inhibits the generation of waves by the towed object.

2.3 Towing Carriage

The carriage is 3 metres long, 5 metres wide, weighs 6 tons and travels on four precision machined steel wheels.

The carriage is operated in three overlapping speed ranges:

0.5 cm/sec -	6.0 cm/sec
5.0 cm/sec -	60 cm/sec
50 cm/sec -	600 cm/sec

In all speed ranges, the constant speed is well within a tolerance of ±1% of the mean. The maximum speed of 600 cm/sec can be maintained for 12 seconds within the specified tolerance. Tachometer generators connected to the drive shafts emit a voltage signal proportional to the speed of the carriage. A feedback control system uses these signals as input to maintain the constant speed within the specified tolerance.

2.4 Data Acquisition Module

For contact closure meters such as the Price 622AA, the pulses generated by the meter rotor are transmitted to a data acquisition module in the control room. Four channels are provided since four meters may be calibrated simultaneously.

A permanent record of velocity and distance is provided by a digital printout in the control room. For contact closure meters the number of revolutions of the meter rotor and time are also recorded on the printout. The printer can be engaged for several printing intervals from 1 to 10 seconds. The velocity and position of the carriage can also be monitored continuously on a visual display in the control room.

Time is measured with a crystal clock. The basic clock frequency is obtained from a 10 MHz oscillator contained within the frequency counter used to measure velocity. This frequency is divided down to provide a continuous 1 KHz clock which is used for overall synchronizaiton purposes. The KHz clock is further divided down to provide a clock frequency of 100 Hertz which is used for the measurement of the elapsed time between successive current meter pulses.

3.0 EXPERIMENTAL PROCEDURE

3.1 Meter Preparation

Prior to testing, the meter underwent the following inspection:

(a) the pentagear was checked to ensure it was operating freely

(b) the contact wire was cleaned and adjusted for tension to provide good contact

(c) all moving parts were lubricated.

Following the inspection, the meter was hung in a wind tunnel where it was spun for two hours to ensure that all moving parts were "run in".

3.2 Towing Tests

In each test, the meter was attached to the rod suspension and lowered into position 30 cm below the water surface. This depth was chosen to avoid surface effects and to create a minimum of drag on the steel rod and thus eliminate undue vibrations. The meter was set for a given angle above or below the true horizontal position using a jig as shown in Figure 3.1. In all cases, the suspended meter was placed near the centreline of the towing tank in accordance with test conditions set out by Engel (1977).

A tow of the meter with the towing carriage at a preset speed for a fixed angle of alignment was defined as a test. To begin a set of tests, the meter was set at the desired angle of alignment. The meter was then towed at different speeds, resulting in a total of 20 tests from a speed of 6 cm/s to 300 cm/s. Each time the meter was towed, care was taken that steady state conditions prevailed when measurements were recorded. The lengths of the waiting time between successive tests were in accordance with criteria established by Engel and DeZeeuw (1977) or better. For each test, the towing speed, revolutions of the meter rotor, time and angle of alignment were recorded. Water temperatures were not noted since temperature changes during the tests were small and do not affect the meter significantly (Engel, 1976).

Tests were conducted for horizontal aligment (0°) and angles of 5°, 10° and 15° above and below the horizontal position. The vertical angle is defined in Figure 3.2.

The data for all the tests are given in Table 3.1 for angles above the horizontal and Table 3.2 for angles below the horizontal position.

4.0 DATA ANALYSIS

4.1 Preliminary Considerations

In order to assess the performance of the Price meter, tests for oblique alignments were compared with the calibration for true alignment parallel to the direction of tow. The latter is called standard calibration and the tests for angles other than at 0° are referred to as oblique calibrations.

The standard calibration was examined first. Values of N_o/V_o (N_o=revolutions/s, V_o=towing speed in cm/s) were plotted versus V_o in Figure 4.1. Here the subscript o denotes the angle of 0°. This method of plotting was chosen because it best shows the characteristics of the meter calibration (Dickenson, 1967; Grindley, 1971; Engel, 1976). The values of N_o/V_o are virtually constant for speeds greater than 60 cm/s, whereas for speeds less than 60 cm/s, N_oV_o varies strongly with speed. In the speed range from 30 cm/s to 60 cm/s, the calibration is quite erratic and this condition prevails also for speeds less than 30 cm/s, although to a lesser degree. The erratic behaviour has to be attributed for the most part to the hydro-dynamic properties of the Price meter since the required waiting times between successive tows were carefully observed (Engel, DeZeeuw, 1977). In addition, the accuracy of the towing carriage is well within the variance of N_o/V_o indicated for speeds less than 60 cm/s.

4.2 Effect of Misalignment on Meter Response

Values of N_θ/V_o (subscript θ denotes alignment angle θ) were computed and are given in Table 4.1 for angles above the horizontal and Table 4.2 for angles below horizontal. The values of N_θ/V_o were then plotted versus V_o for angles above the horizontal on Figure 4.2 and on Figure 4.3 for angles below the horizontal. Superimposed on these figures was the standard calibration equation. This arrangement afforded a direct visual comparison between the oblique and standard calibrations over the full range of speeds tested.

In order to facilitate the comparison, average curves were sketched through the plotted points. This effectively reduced the analysis to consideration of the dominant deterministic response of the meter by removing the random component. These average curves were then used to assess the behaviour of the metre for the different conditions tested. Such a procedure was considered to be justified within the scope of this report.

An examination of Figures 4.2 and 4.3 shows that, except for the case of $\theta=15°$ above the horizontal, the oblique response curves have a shape very similar to that of the standard cuvė and are essentially parallel to the standard curve for speeds greater than 84 cm/s. In the case of $\theta=15°$ above the horizontal, the shape of the response curve is distinctly different at speeds below 180 cm/s with values of N_θ/V_o decreasing as the speed V_o decreases to about 50 cm/s. Thereafter N_θ/V_o increases as the speed V_o decreases to the lowest test value of 6 cm/s. In all cases, the meter response was slower when placed in oblique alignment. This difference was considerably greater when the meter was placed in an upward inclination and this difference noticeably increased when the angle θ was increased from 5° to 15°. When the angle of inclination was downward, the difference in the response rate increased only slightly for a change in θ from 5° to 15°.

In order to define the magnitude of the response changes of the meter, the differences between oblique and standard calibrations for the average curves in Figures 4.2 and 4.3 were computed. These differences expressed as percent error with respect to the standard calibration given by $(N_\theta-N_o)/N_o x100\%$ are presented in Table 4.3 for upward inclinations and Table 4.4 for downward inclinations.

The percent errors versus towing speed V_o were plotted in Figure 4.4 for upward inclinations and in Figure 4.5 for downward inclinations. The plots show that when $\theta=5°$ the error initially increases to -3.6% as V_o increases to 20 cm/s and then decreases to -2.3% as the towing speed increases to 80 cm/s. For values of V_o>80 cm/s, the error is constant at -2.3%. When the angle of alignment is 10°, the error increases to -7.0% as the speed increases from 6 cm/s to 80 cm/s. Thereafter the error remains fixed at -7.0% for all tested values of V_o>80 cm/s. When the value of $\theta=15°$, the variation of the error with towing speed is the most pronounced. The error increases to -15.3% as the V_o increases to 60 cm/s and then decreases again to -10.0% as V_o is increased to approximately 200 cm/s. For values of V_o>200 cm/s, the error remains constant at -10.0%. When the meter is aligned in a downward attitude, the effect expressed as percent difference is not as great as for the upward inclination. When the angle is 5°, the difference increases quite rapidly to an error of -2.0% at a speed V_o of about 50 cm/s and thereafter remains constant at -2.0% up to the maximum speed tested. When the angle is 10°, the increase in the percent difference is somewhat slower as V_o increases to reach the maximum vlaue of -2.7% at $V \approx 80$ cm/s and this difference also remains constant for $V_o > 80$ cm/s. It is interesting to note here that in the range of $6 < V_o < 70$, the error for $\Theta=10°$ is actually less than that at $\Theta=5°$, and becomes greater only when $V_o > 20$ cm/s. Finally, when $\Theta=15°$, the error again increases slowly with speed to the maximum of -2.9% when $V=80$ cm/s and maintains this value for $V_o > 80$ cm/s. In the range $6 < V_o < 80$ cm/s, the error at $\Theta=15°$ is always greater than that observed for the other two angles tested.

In order to obtain further insight into the variation of the meter response with alignment, values of the percent error were plotted versus Θ for several fixed values of V_o. Since for values of $V_o=200$ cm/s to 300 cm/s the values of the percent errors are constant for all values of Θ, then the variation of the error with Θ in this speed range can be given by one curve. This curve is given in Figure 4.6. The shape of the curve clearly shows the pronounced effects of a change in the angle of alignment on the performance of the Price current meter. From the overall shape of the curve, it is at once apparent that the meter responds differently for angles above the true horizontal (0°) and below (0°). The effect is always greater when the angle is above 0°. This difference is most likely attributable to the interference effected by the yoke and rod support of the meter, since ideally the rotor itself cannot differentiate between upward and downward misalignments. The curve also shows that the error is always negative over the range of angles tested, indicating that the meter will always undermeasure the velocity under these conditions. Data from Grindley (1971) who had conducted tests for $\Theta=20°$ above and below 0° were also plotted for $V>200$ cm/s and these two points agree with the general trend of the present test results.

Data were also plotted for values of $V_o=15$ cm/s, 30 cm/s, 60 cm/s, 84 cm/s and 108 cm/s. Smooth approximate curves were drawn through these points to estimate the trends for relative comparisons. These curves exhibit the same basic pattern with some variations. It is interesting to note for $\Theta=15°$ above 0° that as V_o decreases from $V_o=200$ cm/s to 60 cm/s inclusive, the error increases and when $V_o=30$ cm/s the error begins to decrease. A similar observation but to a lesser degree is made for values of Θ below 0°. This effect is particularly noticeable when the angle is 10° below the horizontal.

The error in measuring the towing speed with the towing carriage used in these tests is +1% at all speeds. In order to stay within this limit, it can be seen from Figure 4.7 that the Price meter should not be allowed to deviate from true alignment (0°) by more than 2.5° in either upward or downward direction. This applies for all speeds tested up to 300 cm/s.

5.0 CONCLUSIONS

5.1 The calibration of a Price meter is very sensitive to its vertical angle with respect to a horizontal plane.

5.2 To preserve an accuracy of ±1%, the meter must remain within an angle of ±2.5° from the horizontal.

5.3 The behaviour of the Price meter is unsymmetrical when not placed in a horizontal position. This is most likely due to the interference created primarily by the meter yoke and the rod suspension.

5.4 The Price meter is more sensitive to deviations in alignment above the horizontal compared to similar deviations below the horizontal.

5.5 The Price meter always underregistered for misalignments above and below the true horizontal position.

ACKNOWLEDGEMENTS

The writers wish to express their appreciation to Mr. C. Bil and Mr. J. Dalton who conducted the tests and performed some of the computations.

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TABLE 3.1 DATA OF TESTS FOR ANGLES ABOVE HORIZONTAL

V_o cm/s	N_o rev/s	N_Θ rev/s $\Theta=5°$	$\Theta=10°$	$\Theta=15°$
6	.079	.078	.050	.092
12	.169	.165	.155	.154
18	.256	.265	.243	.224
24	.344	.339	.327	.308
30	.447	.423	.408	.387
36	.529	.514	.497	.467
42	.618	.602	.579	.530
48	.711	.681	.661	.607
54	.799	.770	.742	.683
60	.890	.865	.830	.752
84	1.250	1.216	1.160	1.080
108	1.614	1.570	1.499	1.408
132	1.976	1.928	1.834	1.742
156	2.340	2.276	2.174	2.086
180	2.692	2.631	2.509	2.392
204	3.052	2.989	2.866	2.717
228	3.407	3.343	3.197	3.112
252	3.775	3.697	3.525	3.430
276	4.134	4.031	3.851	3.716
300	4.507	4.403	4.205	4.057

TABLE 3.2 DATA OF TESTS FOR ANGLES BELOW HORIZONTAL

V_o cm/s	N_o rev/s	N_Θ rev/s $\Theta=5°$	$\Theta=10°$	$\Theta=15°$
6	.079	.077	.068	.047
12	.169	.166	.165	.158
18	.256	.252	.256	.250
24	.344	.337	.341	.335
30	.447	.431	.439	.432
36	.529	.517	.525	.517
42	.618	.606	.613	.601
48	.711	.695	.698	.688
54	.799	.782	.788	.773
60	.890	.875	.883	.867
80	1.250	1.228	1.228	1.212
108	1.614	1.585	1.582	1.559
132	1.976	1.939	1.937	1.915
156	2.340	2.290	2.277	2.275
180	2.692	2.650	2.632	2.625
204	3.052	3.010	2.993	2.974
228	3.402	3.351	3.340	3.322
252	3.775	3.695	3.683	3.670
276	4.134	4.036	4.019	3.997
300	4.507	4.419	4.378	4.359

TABLE 4.1 COMPUTED REVOLUTIONS/METRE FOR ANGLES ABOVE HORIZONTAL

V_o cm/s	N_o/V_o rev/m	N_θ/V_o rev/m		
		$\theta=5°$	$\theta=10°$	$\theta=15°$
6	1.320	1.310	1.275	1.530
12	1.380	1.340	1.315	1.295
18	1.417	1.367	1.343	1.285
24	1.435	1.387	1.355	1.275
30	1.451	1.405	1.364	1.273
36	1.463	1.417	1.372	1.265
42	1.474	1.426	1.376	1.260
48	1.477	1.435	1.380	1.257
54	1.484	1.443	1.383	1.257
60	1.489	1.450	1.385	1.262
84	1.499	1.465	1.392	1.283
108	1.500	1.465	1.395	1.305
132	1.500	1.465	1.395	1.320
156	1.500	1.465	1.395	1.337
180	1.500	1.465	1.395	1.345
204	1.500	1.465	1.395	1.350
228	1.500	1.465	1.395	1.350
252	1.500	1.465	1.395	1.350
276	1.500	1.465	1.395	1.350
300	1.500	1.465	1.395	1.350

TABLE 4.2 COMPUTED REVOLUTIONS/METRE FOR ANGLES BELOW HORIZONTAL

V_o cm/s	N_o/V_o rev/m	N_θ/V_o rev/m $\theta=5°$	$\theta=10°$	$\theta=15°$
6	1.320	1.310	1.320	1.295
12	1.380	1.355	1.375	1.350
18	1.417	1.389	1.405	1.385
24	1.435	1.405	1.425	1.405
30	1.451	1.424	1.440	1.420
36	1.463	1.435	1.447	1.430
42	1.474	1.444	1.455	1.437
48	1.477	1.450	1.457	1.442
54	1.484	1.455	1.460	1.447
60	1.489	1.459	1.463	1.450
84	1.499	1.470	1.464	1.455
108	1.500	1.470	1.464	1.455
132	1.500	1.470	1.464	1.455
156	1.500	1.470	1.464	1.455
180	1.500	1.470	1.464	1.455
204	1.500	1.470	1.464	1.455
228	1.500	1.470	1.464	1.455
252	1.500	1.470	1.464	1.455
276	1.500	1.470	1.464	1.455
300	1.500	1.470	1.464	1.455

TABLE 4.3 ERRORS IN MEASURING FLOW SPEED FOR ANGLES ABOVE HORIZONTAL

V_o cm/s	$\Delta N/N_o$ %		
	θ=5°	θ=10°	θ=15°
6	- .76	-3.41	15.9
12	-2.90	-4.71	- 6.16
18	-3.53	-5.22	- 9.32
24	-3.35	-5.58	-11.15
30	-3.17	-6.00	-12.3
36	-3.14	-6.22	-13.5
42	-3.26	-6.65	-14.52
48	-2.84	-6.57	-14.90
54	-2.76	-6.81	-15.3
60	-2.62	-6.99	-15.3
84	-2.27	-7.14	-14.4
108	-2.33	-7.0	-13.0
132	-2.33	-7.0	-12.0
156	-2.33	-7.0	-10.9
180	-2.33	-7.0	-10.3
204	-2.33	-7.0	-10.0
228	-2.33	-7.0	-10.0
252	02.33	-7.0	-10.0
276	-2.33	-7.0	-10.0
300	-2.33	-7.0	-10.0

TABLE 4.4 ERRORS IN MEASURING FLOW SPEED FOR ANGLES BELOW HORIZONTAL

V_o cm/s	$\Delta N/N_o$ % θ=5°	θ=10°	θ=15°
6	- .76	0.00	-1.89
12	-1.81	-0.36	-2.17
18	-1.98	-0.85	-2.26
24	-2.09	-0.70	-2.09
30	-1.86	-0.76	-2.14
36	-1.91	-1.09	-2.26
42	-2.04	-1.29	-2.51
48	-1.83	-1.35	-2.37
54	-1.95	-1.62	-2.49
60	-2.01	-1.75	-2.62
84	-1.94	-2.33	-2.94
108	-2.00	-2.33	-2.94
132	-2.00	-2.33	-2.94
156	-2.00	-2.33	-2.94
180	-2.00	-2.33	-2.94
204	-2.00	-2.33	-2.94
228	-2.00	-2.33	-2.94
252	-2.00	-2.33	-2.94
276	-2.00	-2.33	-2.94
300	-2.00	-2.33	-2.94

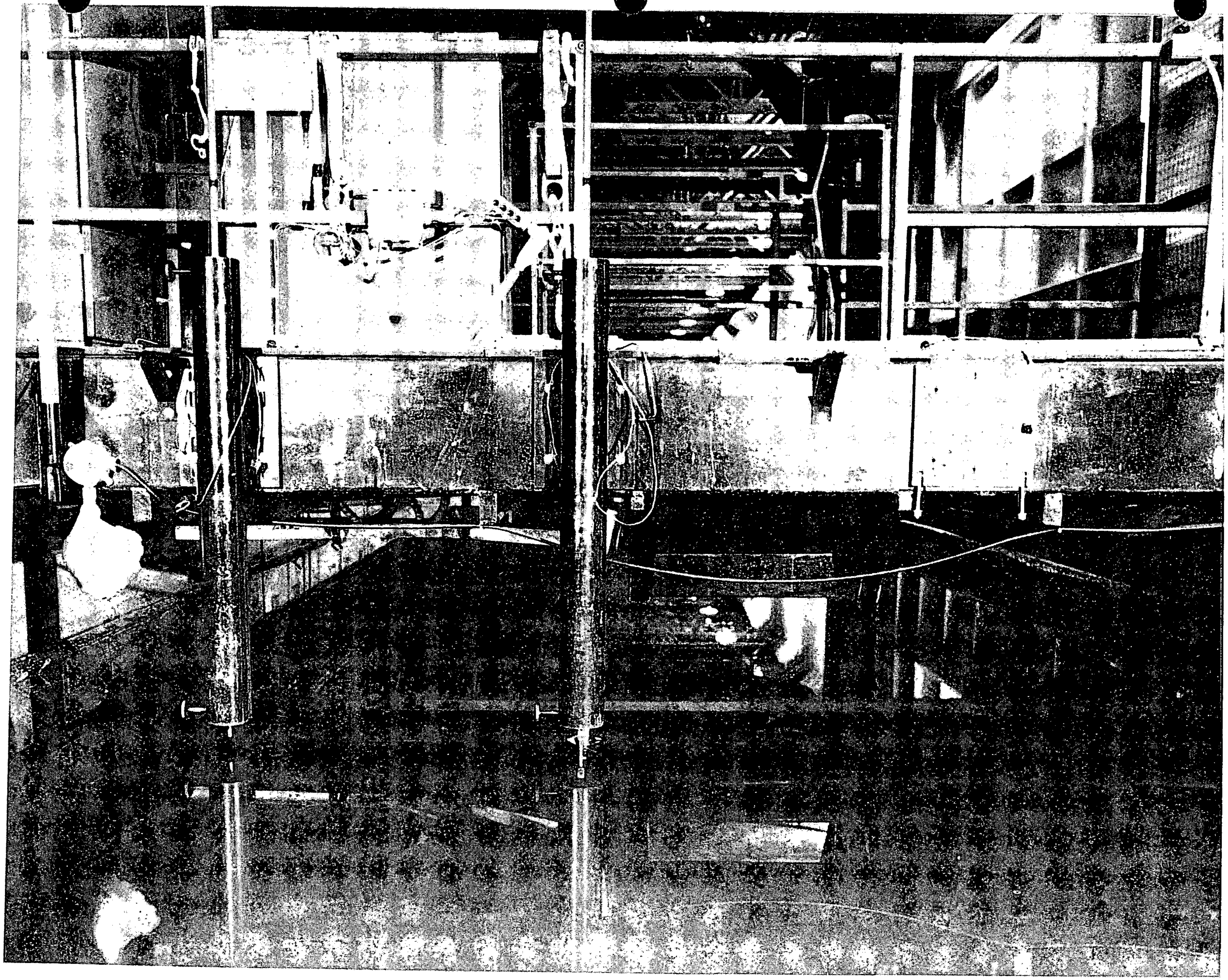

FIGURE 2.1 METER SUSPENDED AT REAR OF TOWING CARRIAGE

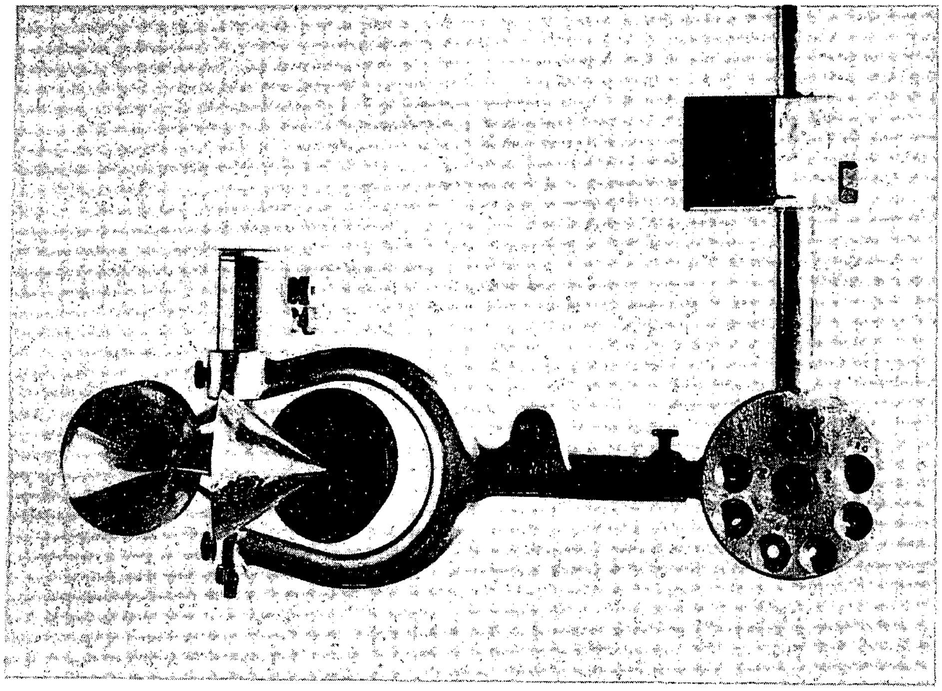

FIGURE 3.1 METER ATTACHMENT TO SUSPENSION ROD

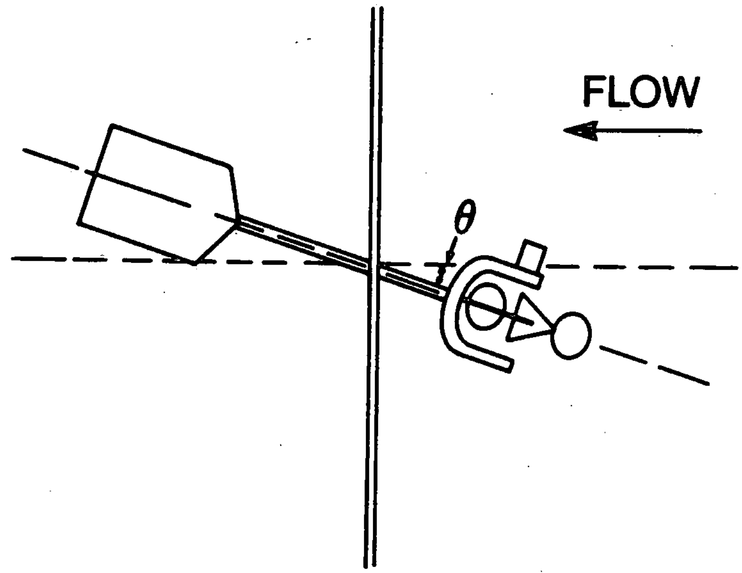

FIGURE 3.2 (a) ANGLE BELOW HORIZONTAL PLANE

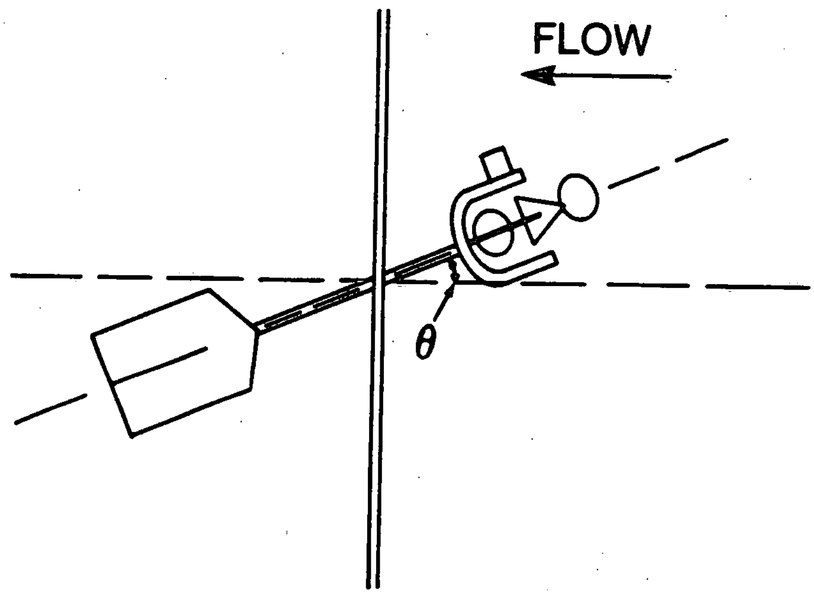

FIGURE 3.2 (b) ANGLE ABOVE HORIZONTAL PLANE

FIGURE 3.2 DEFINITION OF THE VERTICAL ANGLE

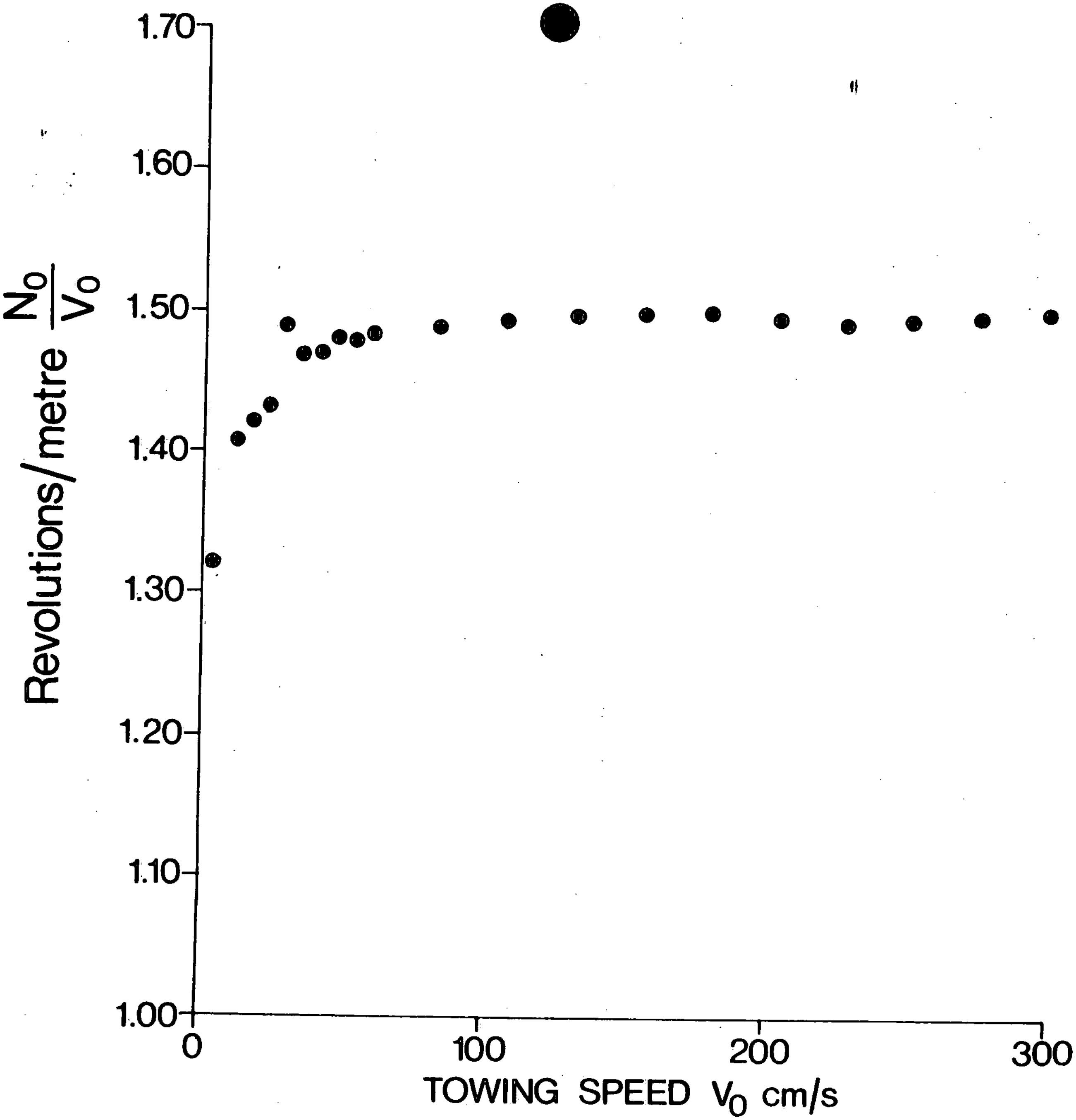

FIGURE 4.1 STANDARD CALIBRATION CURVE

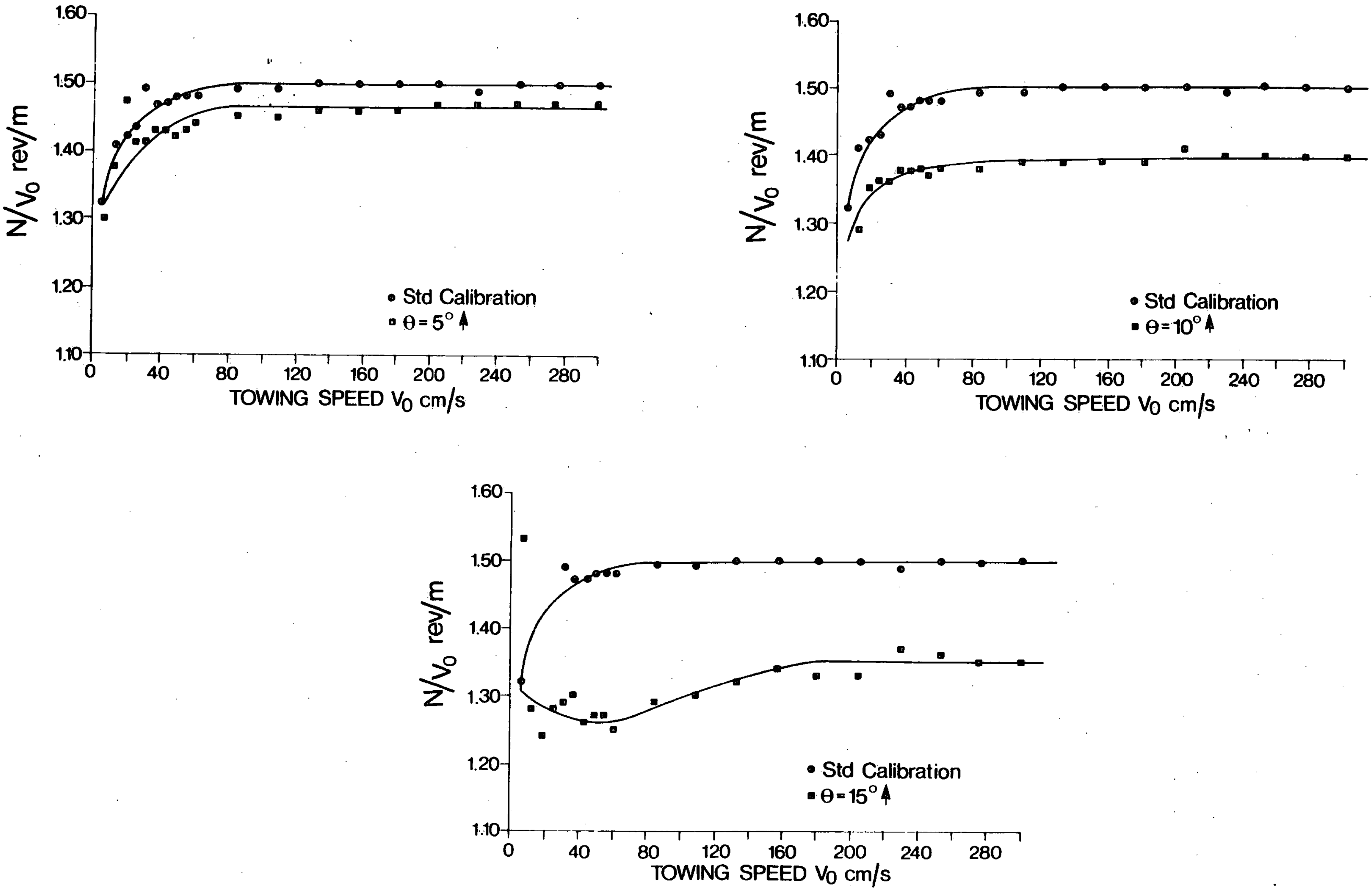

Figure 4.2 BEHAVIOUR OF PRICE METER FOR ANGLES ABOVE HORIZONTAL

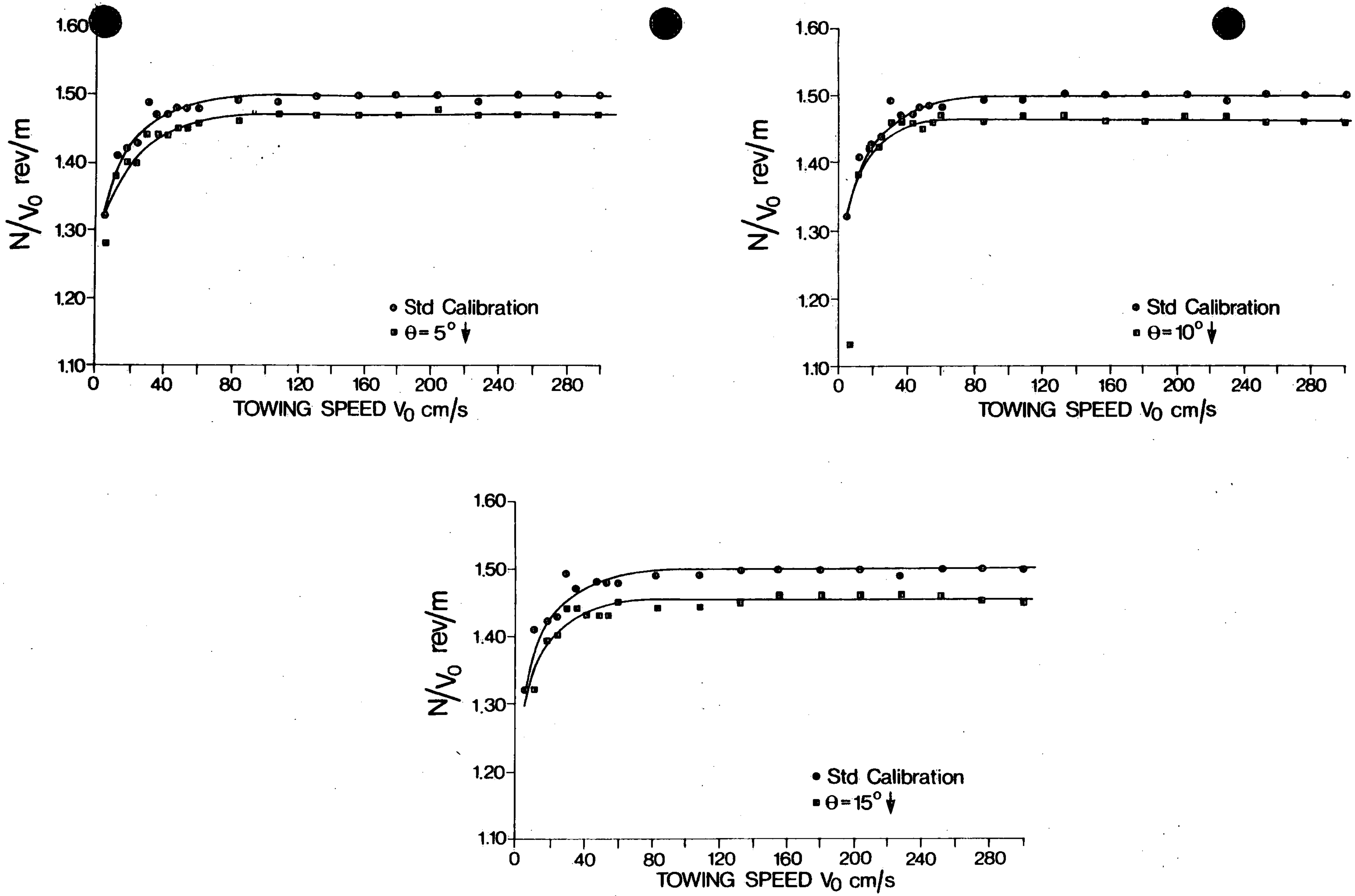

Figure 4.3 BEHAVIOUR OF PRICE METER FOR ANGLES BELOW HORIZONTAL

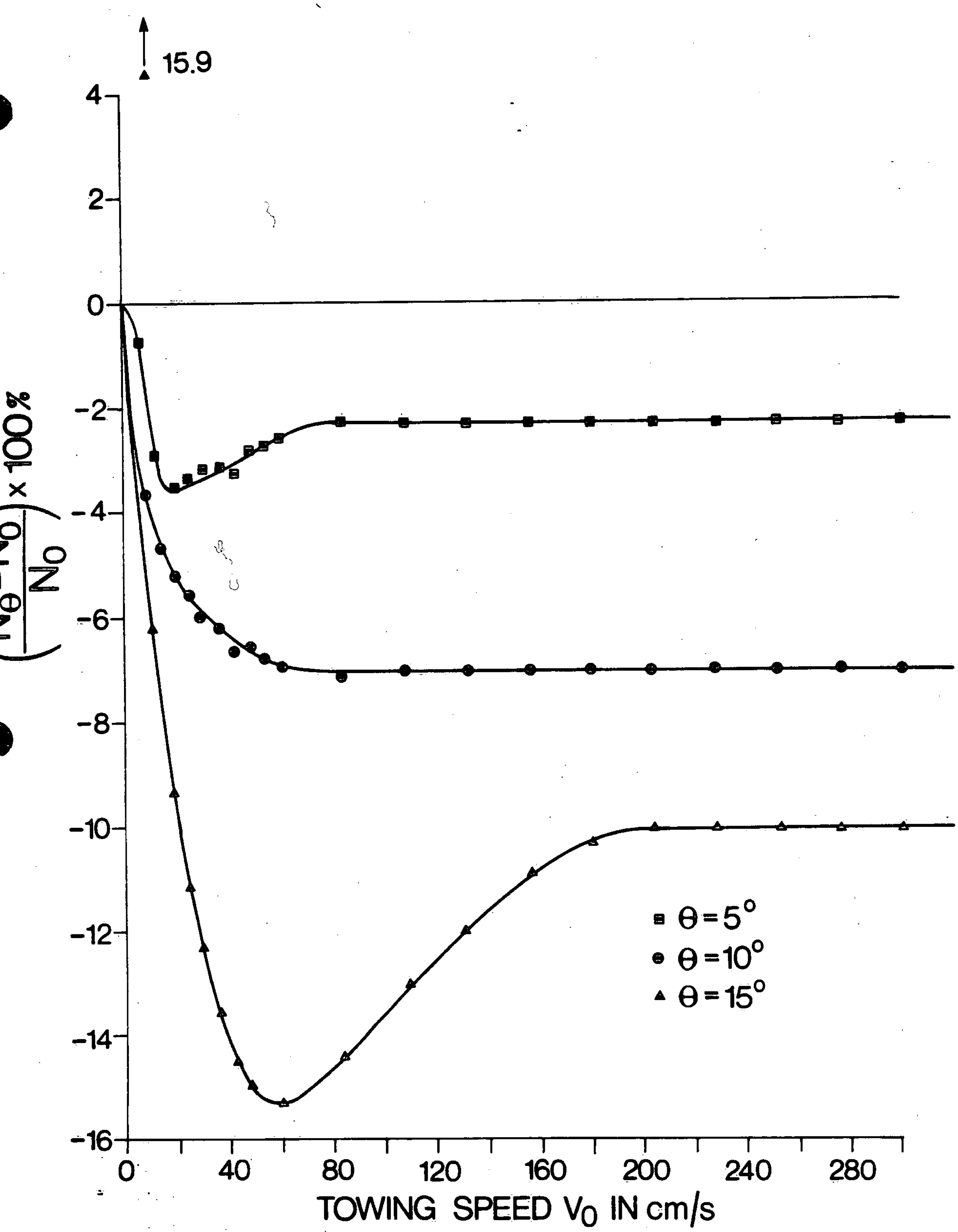

Figure 4.4 Error in meter response for angles above horizontal

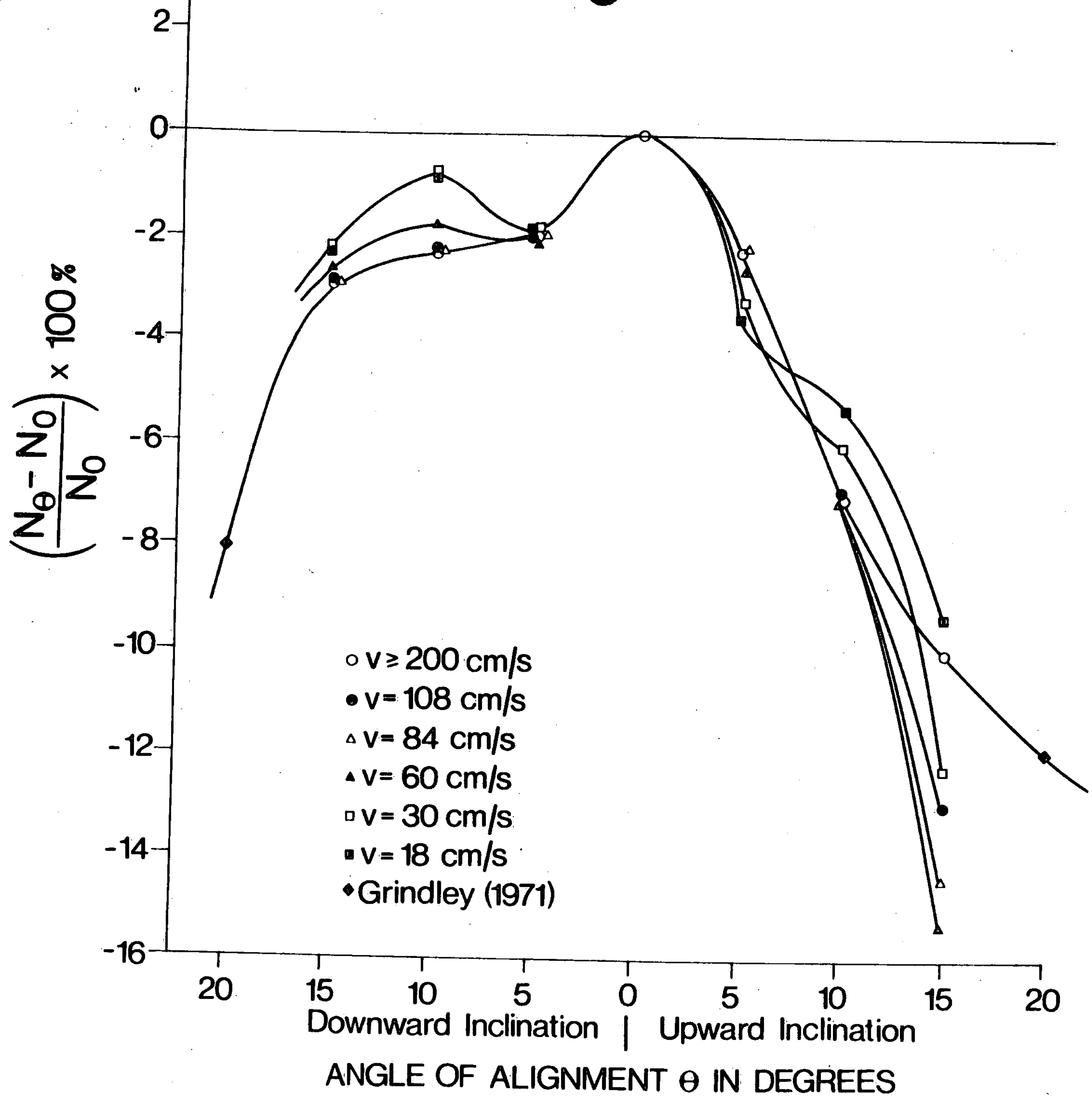

Figure 4.6 Variation of percent error with vertical alignment

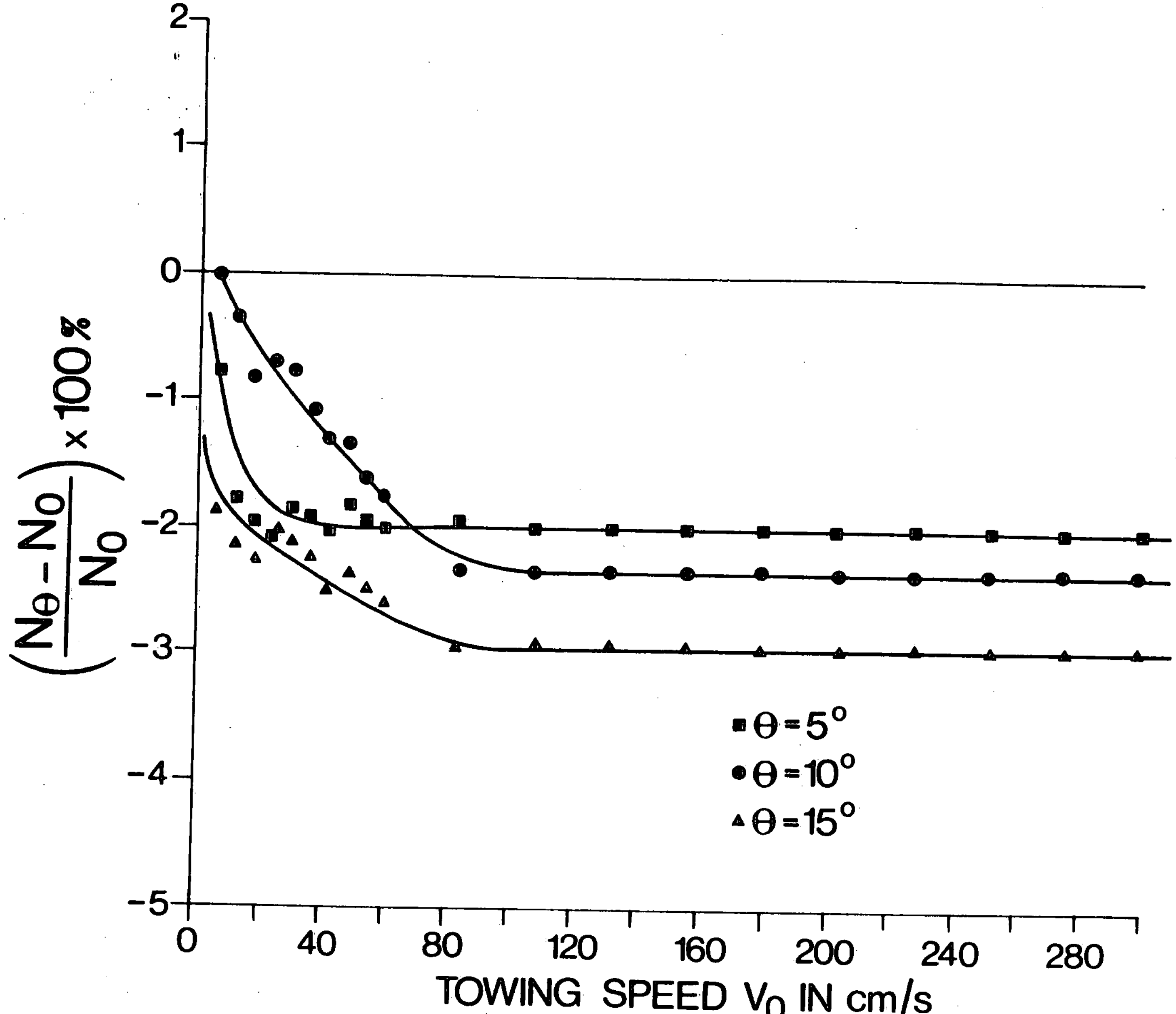

Figure 4.5 Error in meter response for angles below horizontal.