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THE EFFECT OF COLUMBUS TYPE SOUNDING WEIGHTS ON THE PERFORMANCE OF THE PRICE CURRENT METER

by

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SUMMARY

Experiments were conducted in the towing tank at the National Water Research Institute to investigate the effect of the 15lb, 30lb, 50lb and 100lb Columbus type sounding weights on the performance of the Price 622AA current meter when used together with the WR2 hanger used by the Water Survey of Canada. The analysis showed that care must be taken that a meter is used with the same suspension configuration for which it is calibrated. Failure to do so may result in measurement errors of several percent at some speeds and errors in excess of ±0.5% above the original measurement accuracy of the meter at almost all speeds. The results obtained for all the suspension configurations possible with the four sounding weight sizes and WR2 hanger used in this study are described in detail.

SOMMAIRE

Des essais ont été effectués dans le bassin de traction de l'Institut national de recherche sur les eaux pour étudier les effets des lests de type Columbus de 15, 30, 50 et 100 livres sur le fonctionnement du courantomètre Price 622AA lorsque l'ensemble est soutenu par un support de type WR2 couramment utilisé par le service des Relevés hydrologiques du Canada. L'étude démontre que dans l'installation de mesure il faut utiliser le même dispositif de suspension que celui utilisé au moment de l'étalonnage du courantomètre. Les modifications au dispositif initial peuvent entraîner des erreurs relatives (en pourcentage) importantes à certaines vitesses et une marge d'erreur supplémentaire de ± 0,5% par rapport à la précision initiale du courantomètre et ce, pour presque toutes les vitesses. Les résultats obtenus pour les différentes combinaisons des éléments du dispositif de suspension, soit les quatre tailles de lest et le support de type WR2, sont présentés de façon détaillée.

MANAGEMENT PERSPECTIVE

Calibrations of Price current meters are done for a selected configuration of suspension and weight. If another configuration is used in the field, the calibration may be invalid to the point where the indicated water speed deviates sufficiently far from the true speed to be unacceptable.

One solution would be to prepare correction coefficients for other configurations of suspension and water. The other possibly better solution would be to have field equipment that could only be used with one configuration.

That is, select a small number of standard configurations and permit deviations from the standard configuration for only special circumstances.

The report could be used to develop correction tables for non standard arrangements of meters with weights and suspension system.

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PERSPECTIVE-GESTION

Les courantomètres Price sont étalonnés en fonction d'un dispositif de suspension et d'un lestage déterminés. Si les éléments du dispositif sont modifiés au moment de l'installation du courantomètre en profondeur, l'étalonnage risque d'être invalidé au point de produire des lectures inutilisables.

A titre de solution, on pourrait envisager de dresser des tables de coefficients de correction pour les différentes combinaisons d'éléments constituant les dispositifs de suspension. Pour mieux faire, on pourrait, au contraire, constituer des dispositifs établis dont les éléments ne pourraient être intervertis au moment de l'installation. Il s'agirait donc de déterminer un petit nombre de dispositifs types et de permettre les déviations par rapport à la norme dans des circonstances exceptionnelles seulement.

Les résultats de cette étude peuvent servir à dresser des tables qui permettent de compenser les erreurs liées à l'utilisation de dispositifs de suspension et de lestages inhabituels.

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1.0 INTRODUCTION

In North America, the most often used assembly to measure flow velocities in rivers consists of the Price 622AA current meter and Columbus type sounding weight attached to a standard hanger, which in turn is suspended with a steel cable as shown in Figure 1. The Columbus type sounding weights come in different sizes and are normally identified by their weight in air in even British units.

It is known that the presence of the sounding weight affects the performance of the meter rotor, however, information on such effects is very limited. Grindley (1971) found from experiments in a towing tank that for some propeller type meters, the effect of the Columbus type sounding weight decreased when the distance between the meter and the top of the sounding weight increased. Grindley's results, however, are not directly applicable, because propeller type meters and vertical axis type meters such as the Price 622AA, behave quite differently, Loquist (1975) developed a velocity field for potential flow around a 15 lb Columbus sounding weight which showed that the distance above the sounding weight as well as the position of the rotor relative to the nose of the sounding weight are important considerations. Kulin (1979), analyzing observed differences between calibrations of Price meters mounted on rods and cable suspensions, found that there was no single constant correction coefficient which, when applied to the results from the cable suspended meters, would account for the difference. Although, these findings indicate that the effect of the sounding weights varies with meter position relative to the sounding weights and velocity for a given sounding weight, the information is not conclusive.

Comprehensive knowledge of the effect of the Columbus type sounding weights on meter performance is important in determining efficient and correct calibration methods and measuring procedures for use in the field. For this purpose, available information is clearly too limited. In order to investigate the important aspects of the effects of cable suspensions, extensive tests were conducted in the towing tank of the National Water Research Institute. Some of the collected data are used in this report to reveal the effect of the Columbus type sounding weight when used in conjunction with the standard WR2 hanger used by the Water Survey of Canada. The results are intended to show only the behaviour of the Price meter and as such do not provide information suitable for correction coefficients. Such information can only be obtained from repeated tests using several meters and are beyond the scope of this report.

This report was prepared to provide information for the Water Survey of Canada and other users of this equipment.

2.0 EXPERIMENTAL EQUIPMENT

2.1 Meter Suspension

One Price 622AA type Current Meter number 1-061, drawn at random from inventory, was used in the tests, together with the standard 15 lb (6.8 kg), 30 lb (13.6 kg), 50 lb (22.7 kg) and 100 lb (45.5 kg) Columbus type sounding weights. The critical dimensions of the sounding weights are given in Figure 2. The meter was fitted with a special hanger which permitted positioning the meter above the top of each sounding weight at intervals as small as 1 cm. The hanger together with the Columbus type sounding weights are given in Figure 3.

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 as 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 meters 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 reduces the generation of waves by the towed object.

2.3 Towing Carriage

The carriage is 3 metres long, 5 metres wide, weighs 6 tonnes 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/sed	-	600 cm/sec

The maximum speed of 600 cm/sec can be maintained for 12 seconds. 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 specified tolerances.

2.4 Data Acquisition

2.4.1 Towing speed

The average speed data for the towing carriage is obtained by recording voltage pulses emitted from a measuring wheel. This wheel is attached to the frame of the towing carriage and travels on one of the towing tank rails, emitting a pulse for each millimeter of travel. The frequency of these pulses is measured using the 5323A Hewlett Packard automatic counter. The frequency is converted to speed in cm/s by dividing the frequency by 10 since the frequency of the pulses is the same as speed in mm/s. The automatic counter determines the frequency over very short time increments and therefore a large number of average velocity determinations are made as the towing carriage travels down the tank. These "speed samples" are processed directly by a Hewlett Packard 85 computer as they are produced. The computer determines the overall average towing speed and the standard deviation about this average to make sure that necessary tolerances are met.

2.4.2 Rate of revolution of the rotor

The Price meter is equipped with a contact closure mechanism which gives a voltage pulse for each complete revolution of the rotor. The pulses generated by the rotor are transmitted to a data acquisition module which begins counting the revolutions after the first pulse has been received. This ensures that all the pulses counted represent complete revolutions. In order to obtain the rate of rotation of the rotor in revolutions per second, time is measured simultaneously with the counting of the revolutions using a crystal clock.

3.0 EXPERIMENTAL PROCEDURE

3.1 Meter Preparation

Prior to testing, the meter underwent the following inspection:

a) the pentagear was checked to ensure that 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 Meter Position

The meter position on the hanger was defined as the distance "d" of the centerline of the rotor above the highest point of the sounding weight as shown in Figure 4a. Measuring the distance "d" along the hanger is tantamount to considering the meter position for zero speed when the hanger extends above the sounding weight perpendicular to its longitudinal axis. In reality, the flow deflects the meter assembly downstream so that the hanger is inclined at some angle, say θ, with the horizontal and the true distance of the meter above the top of the sounding weight is then $d\sin\theta$, as shown in Figure 4b. However, the angle θ is not known in practice and since it is a function of the submerged weight of the assembly, the effect of the deflection is implicitly included in the analysis.

3.3 Towing Tests

At the beginning of each test, a sounding weight was chosen and attached to the end of the experimental hanger given in Figure 3. The meter was then fastened to the hanger at the lowest position above the top of the sounding weight and the assembly suspended with a steel cable from the rear of the towing carriage at a depth of 100 cm below the water surface. This depth was chosen to avoid surface effects and to allow for the upward deflecton of the meter-sounding weight assembly due to drag forces exerted by the water. In all cases the suspended meter was placed near the centre line of the towing tank in accordance with test conditions set out by Engel (1977). A tow of the meter assembly with the towing carriage at a pre-set speed and the meter fastened at a given distance "d" above the top of the sounding weight was defined as a test. Once a meter assembly was prepared it was towed at speeds of 20, 40, 60, 80, 100, 125, 150, 175, 200, 225, and 250 cm/s resulting in a total of eleven tests for each meter position. Each time the meter was towed, care was taken that steady state conditions prevailed when measurements were recorded. The length of the waiting time between successive tests was in accordance with criteria established by Engel and DeZeeuw (1977) or better. For each test, the towing speed, revolutions of the meter rotor, meter position and type of sounding weight used were recorded. Water temperature were not noted because temperature changes during the tests were small and therefore do not affect the meter significantly (Engel, 1976).

3.4 Preliminary Data Analysis

For the purpose of this report values of N/V (N = rate of rotation of meter rotor cm rev/s, V = towing speed) were computed from the measured data and then plotted as N/V vs d with V as a parameter. Typical plots of N/V vs d for V = 100 cm/s for the four types of sounding weights used are given in Figure 5, together with the three meter positions above the sounding weight available on the WR2 hanger. These positions are identified as P_1, P_2, P_3, with the order of the subscripts increasing with distance from the sounding weight. From the plots values of N/V were obtained for the meter positioned at P1, P_2 and P_3 for given values of speeds V and size of sounding weight. These values are given in Tables 1 and 2. Table 1 shows the values of N/V when the meter is fastened on the WR2 hanger in the standard position for the corresponding size of sounding weight. Table 2 gives the values of N/V when the meter is fastened at the other two positions on the hanger for a given sounding weight.

4.0 PRELIMINARY CONSIDERATIONS

When a Price meter is placed into a two-dimensional flow, it was shown by Engel (1983) that the dimensionless rotor response of the meter could be expressed as:

$$\frac{ND}{V} = \frac{1}{\pi}\left[\frac{K-1}{K+1}\right] \tag{1}$$

where N = rate of rotation of the rotor in revolutions per second, D = effective diameter of the rotor, V = speed of the flow, π = 3.14..., and K represents a factor which must be obtained by calibrating the meter in a towing tank. In general, for a given fluid, K itself is a function of flow speed V, properties of the meter and suspension and this may be expressed as

$$K = f_K \text{ [V, rotor geometry, suspension type]} \qquad (2)$$

For a particular meter such as the Price 622AA the rotor geometry (i.e., diameter D, conical elements) are fixed and thus

$$K = f_{K_1}\text{[V, suspension type]} \qquad (3)$$

Therefore for present purposes the meter response may be expressed as

$$\frac{N}{V} = f_{K_2}\text{[V, suspension type]} \qquad (4)$$

The ratio N/V represents the meter response in revolutions of the rotor per meter of travel and is therefore a convenient variable to evaluate meter behaviour for different types of suspensions.

There are basically two types of suspensions that are used with the Price meter, namely rod suspension and cable suspension. When the rod suspension is used there is only one way that the meter is attached to the standard calibration rod. In this case the meter is mounted ahead of the free end of the steel rod with circular cross-section having a diameter of 20 mm as shown in Figure 6. In this way, the meter is virtually free from any peripheral effects and the respone curve should give a reasonable representation of the behaviour of the meter itself. For this case Equation (4) may be expressed in the particular form

$$\frac{N_R}{V} = f_R[V] \tag{5}$$

in which f_R denotes a function which is unique for a rod suspension with a particular meter. The curve of N/V vs V for this case was obtained by Engel and DeZeeuw (1978) for meter No. 1-061 tested in this study and is given in Figure 7.

When the sounding weight suspension is used, the effect of the suspension on the flow around the meter is due to the combined influence of the type of sounding weight used and the position of the meter above the sounding weight. This can be expressed in general terms by rewriting Equation (4) to give

$$\frac{N}{V} = f_{K_2}[V, Pn, Sw] \tag{6}$$

where n = position number, w = denomination of the sounding weight, P =- meter position and S denotes sounding weight. Equation (6) states that one can obtain different curves of N/V vs V by either varying the meter position while keeping the same sounding weight, changing the sounding weight while keeping the same meter position, or by changing both meter position and sounding weight simultaneously. There are twelve possible ways that the three available meter positions on the WR2 hanger and the four Columbus type sounding weights considered in this report can be combined as shown in Table 3. Four of the combinations correspond to standard suspension configurations used by the Water Survey of Canada.

The data from the towing tank tests are used to examine:

1. the response curves for the twelve possible combinations of meter position and sounding weight size;
2. the effect of changing a standard sounding weight suspension by keeping sounding weight size S_w fixed and changing the meter position P_n;
3. the effect of changing a standard sounding weight suspension by keeping the meter position P_n fixed and changing the sounding weight size S_w;
4. the effect of changing one standard sounding weight suspension with another standard sounding weight suspension.

5.0 RESPONSE CURVES FOR METER WITH SOUNDING WEIGHT SUSPENSIONS

The N/V vs V curve for a given type of suspension reveals the behaviour of the meter of the range of velocities measured. When a meter is suspended with a rod then the curve is specified by Equation (5) and the response is given in Figure 7. Because the meter is virtually removed from peripheral influences, this represents the response characteristics of the meter itself. The most desirable condition would be to have N/V = constant throughout the full measuring range. However, as shown in Figure 7, this condition is only approximately met for speeds greater than 60 cm/s. For speeds less than 60 cm/s the resistance in the rotor assembly, submerged weight of the rotor (Engel, DeZeeuw, 1984) and hydrodynamic properties of the rotors result in a decrease of N/V as V decreases from 60 cm/s. Clearly, any effects of the sounding weight suspension which causes a variation of N/V with V over a wider range than that given in Figure 7 are undesirable and must be minimized. The reason for this is that N/V is a measure of the slope of the N vs V calibration curve for the meter. Any variation of N/V with V means that the calibration curve is not linear. Alternately, one cannot ignore the possibility that the effect of a sounding weight may be beneficial by reducing the range of V over which N/V varies.

The response of the meter for the possible combinations of meter position and sounding weight type as specified in Table 3, according to Equation (6) is now examined and compared with the response of the meter itself as specified by Equation (5), referred to here as the reference curve, using data in Table 1 and 2.

5.1 Standard Sounding Weight Suspensions

Values of N/V from Table 1 were plotted versus V in Figure 8, 9, 10 and 11 for the four standard suspensions used by the Water Survey of Canada, together with the curve from Figure 7.

The plot in Figure 8 shows that, when the 15 lb standard suspension is used, values of N/V are always larger than those of the reference curve for speeds up to 180 cm/s. Thereafter, values of N/V are approximately the same as those of the reference curve up to the end of the measured speed range. The most dramatic difference occurs for speeds from 20 cm/s to 60 cm/s. In this range the meter response with the 15 lb sounding weight exhibits none of the natural tendencies of the meter rotor itself, which is a decreasing rate of increase in N/V as V increases from 20 cm/s to 60 cm/s. This difference must be attributed directly to the effect that the 15 lb sounding weight has on the flow field in the vicinity of the meter rotor at position P_1. In fact, the average trend of the meter response with this sounding weight is towards a gradual linear decrease in N/V as V increases over the full speed range. Such a behaviour is not desirable for a calibration, and thus, the standard suspension for the 15 lb sounding weight is not a very good configuration to use.

When the standard 30 lb suspension is used it can be seen from Figure 9, that the meter rsponse is virtually the same as that of the reference curve. The only point that differs significantly is at V = 60 cm/s, but this deviation may be due to the erratic behaviour of the Price meter rotor in the region of this speed (Engel, 1976). This means that the flow field around the meter due to the 30 lb sounding weight is virtually identical to that of the meter when attached .to the rod. For speeds greater than 80 cm/s values of N/V are almost constant and thus an accurate calibration can be obtained in this region. For speeds less than 80 cm/s, because N/V changes with V, it is more difficult to obtain a good calibration.

When the standard 50 lb suspension is used, the plot in Figure 10 shows that for speeds from 80 cm/s to 180 cm/s, the response of the meter rotor is identical with that of reference curve. When the speed is greater than 180 cm/s the effect of the 50 lb suspension is to slow the meter rotor down slightly for a given speed. However, the greatest effect of the suspension occurs for speeds less than 80 cm/s where the rate of rotation is always faster than that obtained with the reference curve, resulting in a unique variation of N/V with V. On the whole, for speeds from 80 cm/s to 250 cm/s, the response obtained with the 50 lb standard suspension makes it possible to obtain a good linear calibration equation. However, for speeds less than 80 cm/s, because the rate of change of N/V with V changes from positive to negative as V increases from 20 cm/s to 80 cm/s, this segment of the response curve is less suitable for calibrations than,for example, those obtained with the 15 lb and 30 lb standard calibration.

Finally, Figure 11 shows that the use of the 100 lb standard suspension increases the rate of rotation of the meter rotor at virtually all measured speeds, except again as observed for the 30 lb suspension, when V = 60 cm/s. When V = 60cm/s the value of N/V is identical to that of the reference curve. For speeds greater than 80 cm/s, N/V is again virtually constant and thus a good calibration is possible in this speed range. For speeds less than 80 cm/s the plot in Figure 11 indicates a response in which the rate of change of N/V is similar to that observed in Figure 9 with the 30 lb standard suspension. Therefore, the calibration with the 100 lb standard suspension should be as good as that obtained with the 30 lb standard suspension, with the advantage of having a slightly greater rate of rotation for a given V.

The four standard suspensions may now be ranked in the order of suitability for a good calibration as follows:

1. 100 lb standard suspension
2. 30 lb standard suspension
3. 50 lb standard suspension
4. 15 lb standard suspension

5.2 Non-Standard Suspension

Values of N/V from Table 2 were plotted versus V in Figures 12, 13, 14 and 15 for the remaining combinations of sounding weights and meter positions as given in Table 3, together with the reference curve from Figure 7.

The plots in Figure 12 show response curves for the two other possible meter positions on the WR2 hanger when the 15 lb sounding weight is used. When the meter is at position P_2, N/V is constant, with values slightly lower than the reference curve, for speeds greater than about 125 cm/s. However, for speeds less than 125 m/s, N/V varies with V, at first slightly, increasing as V decreases until when V = 100 cm/s, N/V decreases with the rate or change increasing as V decreases. In contrast to this, when the meter is at position P_3, the meter rotor response is more uniform, showing a slight linear decrease in N/V as V increases from about 40 cm/s to 250 cm/s, similar to that observed with the standard 15 lb suspension. It is for speeds less than 40 cm/s that there is a sudden decrease in N/V as V decreases to 20 cm/s. This marked change in the shape of the response curves for different meter positions above the 15 lb sounding weight clearly demonstrate the variability of the flow field around the sounding weight and the importance of specifying a given meter position when the meter is calibrated. It is also clear from Figures 8 and 12 that the best results are obtained when the suspension with the meter at position P_2 is used. Therefore, some thought should be given to replacing the present standard suspension with this configuration.

When the 30 lb sounding weight is used, the other two possible positions, besides the standard positions, are at P_1 and P_3. Figure 13 shows that when the meter is at position P_1 the rotor response appears to be adversely affected by the nearness of the sounding weight. This is reflected by the fact that N/V varies with V over most of the measured range from 20 cm/s to 200 cm/s. It is only for V > 200 cm/s that N/V is approximately constant. Clearly, position P_1 is not a good location for the meter with this size of sounding weight. When the meter is at position P_3, the response curve looks much more favourable. For speeds from 20 cm/s to 80 cm/s the curve is slightly better than the one for the standard suspension in Figure 9, because of a slightly more gradual increase in N/V as V increases. However, for speeds from 80 cm/s to 200 cm/s, values of N/V fluctuate and therefore this part of the curve is not as good as the one obtained with the standard suspension. Overall, the response curves indicate that the best results are obtained when the meter is at position P_2 (Figure 9) and therefore, the standard suspension should always be used with the 30 lb sounding weight.

When the 50 lb sounding weight is used, the standard position of the meter is at P_3. Comparison of the response curves in Figure 10 and Figure 14 reveals that the standard suspension does not provide the best results. This is contrary to what one might expect intuitively because at position P_3 the meter is the furthest distance from the sounding weight, again pointing out the complex influence the sounding weight has on the meter. Indeed, both curves in Figure 14 are preferable because of the shape of the repsonse curves for speeds less than 100 cm/s. When the meter is at position P_1, the average rate of change in N/V as V increases is more consistent than that obtained with the standard suspension. For speeds greater than 100 cm/s, N/V is again virtually constant at the same value obtained in Figure 10. When the meter is at position P_2 the shape of the rotor response in Figure 14, reveals a behaviour which is less conducive to obtaining an accurate calibration equation. For speeds from 40 cm/s to 250 cm/s, there is a slight average linear increase in N/V as V increases. The only change in this trend occurs for speeds from 20 cm/s to 40 cm/s, when there is a rapid increase in N/V. In comparison to the response curve for the standard suspension in Figure 10, the results obtained with the meter at position P_1 in Figure 14 are slightly superior. Considerations should therefore be given to designating the combination of position P_1 and 50 lb sounding weight as a standard suspension to replace the current standard suspension for which the meter is at position P_3.

The standard position with the 100 lb sounding weight is the same as that for the 50 lb sounding weight, namely, P_3. It is quite obvious from Figure 15 that the meter response with meters at positions P_1 and P_2 are inferior to the response obtained with the standard suspension in Figure 11. When the meter is at position P_1, there is a large decrease in N/V as V increases for speeds from 100 cm/s to 250 cm/s. When the meter is at P_2, Figure 15 shows that for speeds from 50 cm/s to 250 cm/s, there is an average trend or increasing N/V as V increases. Clearly, at both of these positions, the N vs V calibration curves would be nonlinear, therefore, both position P_1 and P_2 provide meter responses which are much inferior to that obtained with the standard suspension for which N/V is virtually constant for speeds greater than 80 cm/s.

6.0 EFFECT OF CHANGING METER POSITION WHEN A PARTICULAR SOUNDING WEIGHT IS USED

If one considers the meter in conjunction with a particular sounding weight size, then S_W is constant and Equation (6) may be reduced to

$$\frac{N}{V} = f_{S_W}[V, P_m] \qquad (7)$$

where f_{sw} denotes a function for a particular sounding weight size. For a particular standard suspension the meter position is also specified and for this case one may write

$$\frac{N_s}{V} = f_{St}[V] \tag{8}$$

where N_s = rate of rotation of the rotor when the standard suspension is used and f_{St} denotes a function. To obtain the relative response as a result of changing the meter position when a particular sounding weight is used one may combine Equations (7) and (8) to give

$$\frac{N}{N_s} = f_r[V,P_n] \tag{9}$$

where f_r denotes the function representing the relative response with respect to the meter rotor response obtained with the standard suspension. The relative error E can be obtained from the relationship

$$E = (\frac{N}{N_s} - 1)\ 100\% \tag{10}$$

and is compared with the obtainable calibration accuracy of ±0.5%.

6.1 Relative Response When 15 lb Sounding Weight is Used

Values of N/N_s were plotted versus V in Figure 16 resulting in two curves. These curves give a good idea of the error that can result when a meter is used in a position on the WR2 hanger for which it was not calibrated. It is quite clear that such errors can be considerable. When the meter is moved from P_1 (standard suspension) to position P_2, the error can vary from about -7% at 20 cm/s to -0.4% when V = 250 cm/s. Alternately, when the meter is placed at position P_3 the relative error varies from -5.5% at 20 cm/s to about -0.10% at a speed of 200 cm/s. In both cases there are considerable fluctuations between these extremes. Overall, the relative error at position P_3 is a little less, however, considering a calibration accuracy of ±0.5%, it is quite clear that the errors incurred by arbitrary positioning of the meter are unacceptable. Indeed, at position P_2, the meter under-registers by more than 0.5% over the full speed range tested, whereas at position P_3 the error exceeds 0.5% over most of the speed range. Clearly, a calibration provided with the standard 15 lb sounding weight suspension should never be used with the meter in any position other than P_1.

6.2 Relative Response When 30 lb Sounding Weight is Used

Values of N/N_S were plotted versus V in Figure 17. The two curves show that, as observed in Figure 16 for the 15 lb sounding weight, the effect of moving the meter is greatest for speeds less than 120 cm/s. When the meter is moved from Position P_2 (standard suspension) to P_1 the meter under-registers up to a speed of 120 cm/s with the maximum error being about -1.5% when V = 80 cm/s. For speeds greater than 120 cm/s, the meter at position P_1 tends to over-register to a maximum error of 0.8% when V ≃ 200 cm/s, and for V > 200 cm/s the error tends to be of the order of 0.2%. When the meter is moved to position P_3, it tends to over-register over virtually the full tested speed range with one exception, at V = 125 cm/s, when the meter under-registers slightly. For speeds greater than about 200 cm/s the error is about the same as that at position P_1, that is, about 0.2%. Considering the calibration accuracy of ±0.5%, this limit is exceeded by the meter at both position P_1 and P_3 for speeds up to 180 cm/s.

This provides sufficient evidence that when the 30 lb sounding weight is used, the meter must be calibrated in the same position at which it is to be used.

6.3 Relative Response When 50 lb Sounding Weight is Used

Values of N/N_S were plotted versus V in Figure (8), once again resulting in two curves. When the meter is moved from position P_3 (standard suspension) to P_1, the rotor under-registers in excess of the 0.5% calibration accuracy for speeds less than about 80 cm/s with the largest relative error being about -1.8%. For speeds greater than 80 cm/s the relative response fluctuates with meter primarily over-registering, but the error remaining within the calibration accuracy of 0.5%. When the meter is at position P_2, the rotor under-registers up to speeds slightly larger than 60 cm/s with the relative error being in excess of 0.5% only for speeds less than 40 cm/s. For speeds greater than 60 cm/s, the meter, on the whole, over-registers with the average trend increasing as V increases and relative errors being larger than those obtained at position P_1. For speeds greater than 180 cm/s the over-registration of the meter exceeds the 0.5% calibration tolerance, reaching a maximum relative error of 1% when V = 200 cm/s.

The results clearly show that when the 50 lb sounding weight is used, in order to have acceptable velocity measurements over the full operating range of the meter, it must be calibrated for the position on the WR2 hanger for which it is to be used.

6.4 Relative Response When 100 lb Sounding Weight is Used

Values of N/N_S were plotted versus V in Figure 19 resulting in two markedly different curves. When the meter was moved from position P_3 (standard suspension) to position p_1, the meter under-registers throughout the full speed range, with the error being about -2.5% when V = 20 cm/s, decreasing slightly to about -1.8% when V = 60 cm/s and thereafter decreasing to a maximum error of -5.0% when V = 250 cm/s. When the meter is placed at position P_2, the effect is less spectacular, but the meter still under-registers over the full speed range. When V = 20 cm/s the error is about -1.3% increasing slightly to -1.7% at V = 40 cm/s and thereafter the error tends to decrease slightly on average until when V = 250 cm/s, the minimum error of -0.2% is reached. Considering the calibration accuracy of ±0.5%, the relative error at position P_1 is well in excess of this tolerance throughout the speed range. When the meter is at position P_2 the 0.5% tolerance is exceeded everywhere except for a narrow speed range from 245 cm/s to 250 cm/s. It is clear from these results that interchanging the meter positions when the 100 lb sounding weight is used, while using the standard calibration obtained with the meter at position P_3, is not permissable.

7.0 EFFECT OF EXCHANGING SOUNDING WEIGHTS WHEN THE METER IS AT A PARTICULAR POSITION

The effect of the sounding weight is due to the combined influence of its size, shape and submerged weight. The size and shape affect the velocity field around the sounding weight, whereas the submerged weight as well as the shape affect the amount that the suspension assembly is deflected due to drag forces exerted by the flow. It is therefore of interest to examine the relative effect on a meter, when the sounding weight used with the meter at the corresponding standard position, is exchanged with a sounding weight of a different size. An example of this would be the case when a 30 lb sounding weight, for which the meter was calibrated at the standard position P_2 on the WR2 hanger, is exchanged for a 15 lb, 50 lb or 100 lb sounding weights, while the meter remains at position P_2.

If one considers the meter as being fixed at a particular position then one may reduce equation (6) to the form

$$\frac{N}{V} = f_{Pn}[V, Sw] \qquad (11)$$

where f_{Pn} denotes a function for fixed meter positions. For a given standard suspension the meter position is also fixed and for this case the meter response is specified by Equation (8). The relative response as a result of changing sounding weight size while the meter remains at a fixed position may then be obtained by combining Equation (8) and (11) to give

$$\frac{N}{N_s} = f_r[V, Sw] \qquad (12)$$

where f_r denotes the function for the relative response. The relative error as defined by Equation (10) is compared with the obtainable calibration accuracy of ±0.5%. The values of N/N_s are given in Tables 5 and 6.

7.1 Relative Response When Meter is at Position P_1

When the Price meter is calibrated with the 15 lb sounding weight, the standard position of the meter on the WR2 hanger is at P_1. Values of N/N_s were plotted versus V in Figure 20 resulting in three separate curves. The plot shows that as a result of exchanging the sounding weights, the meter under-registers at virtually all speeds, except in the vicinity of V = 200 cm/s and when V > 240 cm/s. At these speeds the meter over-registers slightly with the effects of the 30 lb and 50 lb sounding weights being virtually the same. In the range of $20 \leq V \leq 125$ cm/s, the meter response, when the 30 lb sounding weight is used, is considerably less than when the 50 lb sounding weight is used. However, when the speed is greater than 125 cm/s, the effect of these two sounding weights is reversed. When the 100 lb sounding weight is used, the results are quite close to those obtained with the 30 lb sounding weight up to speeds of 80 cm/s. For speeds greater than 80 cm/s, while there is a tendency for the meter responses for the 30 lb and 50 lb sounding weights to converge, when the 100 lb sounding weight is used there is a marked trend for the rate of rotation to decrease as the speed increases.

It is quite clear from Figure 20 that the errors that can be incurred by arbitrarily exchanging the 15 lb sounding weight are quite large. When the exchange is made with the 30 lb sounding weight the error ranges from 7.0% at V = 20 cm/s to 0.3% when V = 250 cm/s. Over the same speed range the error changes from -4.0% to 0.3% when the 50 lb sounding weight is used, while with the 100 lb sounding weight the error changes from -6.5% at V = 20 cm/s to -2.2% at V = 80 cm/s and then increases again to about -4.0%. Considering that the calibration accuracy is about ±0.5%, it is quite obvious that when a meter at position P_1 on the WR2 hanger is calibrated with the 15 lb sounding weight, one should not use this calibration with sounding weights of other sizes.

7.2 Relative Response When Meter is at Postion P_2

When the Price meter is calibrated with the 30 lb sounding weight, the standard position of the meter on the WR2 hanger is at P_2. Values of N/N_s were plotted versus V in Figure 21. The curves show that when the 30 lb sounding weight is exchanged for the 50 lb sounding weight, the meter over-registers over the full speed range. The error incurred exceeds the ±0.5% tolerance being exceeded primarily for speeds less than 75 cm/s reaching a maximum of about 1.6% and for speeds greater than 170 cm/s reaching a level of about 0.8%. It is therefore not recommended to replace the 30 lb sounding weight with the 50 lb sounding weight with the meter positioned at P_2. When the 15 lb sounding weight is used the meter under-registers for speeds less than 40 cm/s and speeds greater than 120 cm/s. In this case the incurred error exceeds the ±0.5% tolerance slightly by under-registration for speeds less than about 25 cm/s and for speeds greater than about 160 cm/s with the longest error being about -0.7%. Therefore, the effect of exchanging the 30 lb sounding weight with the 15 lb sounding weight, when the meter is at position P_2 is not too serious. The use of the 100 lb sounding weight results in an under-registration for speeds from about 30 cm/s to about 230 cm/s and an over-registration of the meter outside of this speed range. The incurred error exceeds the ±0.5% tolerance at various speeds throughout the tested speed range with the error varying between ±1%. Clearly, the 100 lb sounding weight should also not be used with a meter which has a standard calibration for the 30 lb sounding weight.

7.3 Relative Response When Meter is at Position P_3

When the Price meter is calibrated with the 50 lb sounding weight, the standard position of the meter on the WR2 hanger is at P_3. Values of N/N_S from Table 5 were plotted versus V in Figure 22 resulting again in three curves. The plot shows that the effect on the meter is greatest over-all when the 50 lb sounding weight is replaced with the 100 lb sounding weight. In this case the meter tends to under-register for speeds less than 70 cm/s and over-register for speeds greater than this. The error incurred exceeds the calibration accuracy of ±0.5% for speeds less than about 65 cm/s reaching a value of -0.8%, whereas for speeds greater than 75 cm/s, the ±0.5% tolerance is exceeded up to a maximum error of close to 1.2%. This shows that replacing the 50 lb sounding weight with the 100 lb sounding weight when the meter is at position P_3 is not advisable. When the 30 lb sounding weight is used, the meter under-registers for speeds less than 75 cm/s and in the range from 115 cm/s to 135 cm/s. At all other speeds the meter tends to over-register. The ±0.5% tolerance is exceeded for speeds less than 60 cm/s with the error reaching a value of -1.5% as well as for speeds from 85 cm/s to 105 cm/s and 145 cm/s to 160 cm/s reaching an error of 0.9% and 0.7% respectively. Clearly exchanging the 50 lb sounding weight with the 30 lb sounding weight should also not be recommended. Finally, when the 15 lb sounding weight is used, the meter tends to under-register for speeds less than 60 cm/s as well as for speeds from 110 cm/s to 200 cm/s. At all other speeds the meter rotor tends to turn fastr. For the 15 lb sounding weight the ±0.5% tolerance is exceeded for speeds less than about 38 cm/s reaching an error of -2.2%, while reaching an error of -0.7% for speeds greater than 200 cm/s. Although the ±0.5% tolerance is exceeded only at the extremes of the given speed range, replacing the 50 lb sounding weight with the 15 lb sounding weight is not recommended.

7.4 Relative Response When Meter is at Position P_3*

When the Price meter is calibrated with the 100 lb sounding weight, the standard position of the meter on the WR2 hangr is at P_3*. Values of N/N_s from Table 5 were plotted versus V in Figure 23 resulting in another set of three curves. The plot shows that when the 15 lb and 50 lb sounding weights are used in place of the 100 lb sounding weight, the meter response for speeds 40 cm/s to 200 cm/s is quite similar. However, for speeds less than 40 cm/s and greater than 200 cm/s, the effect of the two sounding weights is markedly different, with the 15 lb sounding weight inducing a much slower response in the meter. For both the 15 lb and 50 lb sounding weights the meter tends to over-register for speeds less than approximately 73 cm/s. For speeds greater than this, the two sounding weights cause the meter to under-register. For the 15 lb sounding weight the error incurred exceeds the ±0.5% tolerance at several intervals over the tested speed range, reaching a maximum negative error of -1.7% for

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* Position P_3 is standard position for both 50 lb and 100 lb sounding weights.

speeds greater than 230 cm/s and a maximum positive error of 1% when the speed is 60 cm/s. Based on these observations one must conclude that exchanging the 100 lb sounding weight with either the 15 lb or 50 lb sounding weight is not advisable. When the 30 lb sounding weight is used, the meter primarily under-registers except for two small speed intervals from 55 cm/s to 65 cm/s and 95 cm/s to 105 cm/s when the meter over-registers. On the whole the error incurred is negative and exceeds the ±0.5% tolerance only slightly at several points along the curve at a value of about -0.7%, except when the speed is near 120 cm/s where the error reaches a value of -1.1%. Therefore, one should not attempt to use the 30 lb sounding weight in place of the 100 lb sounding weight when the meter is at the position P_3.

8.0 EFFECT OF INTERCHANGING STANDARD SUSPENSIONS

It has been shown that both meter position and sounding weight size have an effect on the response of the meter. Each standard suspension consists of a specific combination of meter position and sounding weight size. This can be expressed in general terms by writing

$$\frac{N}{V} = f_s[V] \qquad (12)$$

in which f_s denotes the function for a particular combination of P_n and S_w comprising a standard suspension. For each standard suspension a calibration for the meter is supplied. It is now of interest to know what the effect would be on a velocity measurement if the calibration supplied with a particular standard suspension is used with the same meter but a different standard suspension. The effect of changing from one standard suspension to another can be assessed by determining the relative error from the ratio of the response of the meter with a given standard suspension to the response of the meter with a standard suspension for which the calibration is supplied. If the response of the meter with the supplied calibrtion is given by

$$\frac{N}{V} = f_c[V] \qquad (13)^c$$

where f_c denotes the function for the meter with the calibration, then the relative response can be expressed as

$$\frac{N_s}{N_c} = \bar{f}_{sc}[V] \qquad (14)$$

where f_{sc} denotes the function for the relative response. The relative error can then be obtained as given by Equation (10) and compared with the obtainable calibration accuracy of ±0.5%. The values of N_s/N_c are given in Table 7 and 8.

8.1 Relative Response when Changing From 15 lb Standard Suspension to Other Standard Sounding Weight Suspensions

Values of N_s/N_c were plotted versus V in Figure 24 resulting in three curves showing the effect of changing from the 15 lb standard suspension to each of the other three possible standard suspensions. The effect is most pronounced for speeds less than 80 cm/s for all three cases. When the change is made to the 30 lb suspension, the meter under-registers with a maximum error of -6.3% when V = 20 cm/s, with the error decreasing at first rapidly until when the speed is greater than 80 cm/s the decrease in the error becomes more gradual. When a speed of 244 cm/s has been reached the meter begins to over-register with the error increasing to 0.2% at V = 250 cm/s. Considering the calibration accuracy of ±0.5%, this tolerance is exceeded for all speeds less than 175 cm/s when the change is made to the 30 lb suspension.

When the 50 lb suspension is used, the effect is quite similar to that obtained with the 30 lb suspension for speeds greater than 80 cm/s. For speeds less than 80 cm/s, the error is less, but varies in a similar way from -3.1% when V = 20 cm/s, remaining negative until when V = 250 cm/s the error becomes positive at 0.1%. The relative error with the 50 lb suspension exceeds the ±0.5% calibration tolerance at all speeds less than about 180 cm/s except when the speed is near 40 cm/s. For speeds greater than 180 cm/s, the relative error is within the tolerance of ±0.5%.

When the meter is used with the 100 lb suspension the relative error falls between that obtained with the 30 lb and 50 lb standard suspensions for speeds less than 7 cm/s, and thereafter increases in a similar way as the speed increases above 70 cm/s. The meter under-registers for speeds less than 120 cm/s reaching a maximum error of -4.0% when V = 20 cm/s. When V = 120 cm/s the meter over-registers with the error increasing as speed increases up to 1.2% when V = 250 cm/s. The calibration accuracy of ±0.5% is exceeded for all speeds less than about 72 cm/s and all speeds greater than 180 cm/s.

It is clear from these results that the calibration obtained for a 15 lb standard suspension should never be used with any of the other three standard suspensions considered in this report.

8.2 Relative Response When Changing from 30 lb Standard Suspension to Other Standard Sounding Weight Suspensions

Values of N_S/N_C were plotted versus V in Figure 25 resulting in three curves, each revealing the error to be incurred when the 30 lb standard suspension is exchanged with another suspension for a given sounding weight size. Once again the overall effect is most pronounced for speeds less than 80 cm/s because in this range the rate of change in the relative error is greatest decreasing from the maximum at V = 20 cm/s in each case.

When the 15 lb suspension is used the meter over-registers for all speeds less than 240 cm/s and under-registers for speeds greater than 240 cm/s. The largest error is 6.7% when V = 20 cm/s and this decreases rapidly to .5% when V = 20 cm/s. For speeds greater than 80 cm/s the error declines more gradually to its minimum value of -0.2% when V = 250 cm/s. The errors obtained exceed the +0.5% calibration accuracy for all speeds less than 175 cm/s.

When the 50 lb suspension is used the relative error again declines rapidly up to a speed of 80 cm/s from its maximum value of 3.3% when V = 20 cm/s. For speeds greater than 80 cm/s the error increases and decreases gradually up to the end of the measured speed range at V = 250 cm/s where the error is quite small having a value of only -0.1%. For speeds less than about 78 cm/s the meter over-registers and exceeds the calibration tolerance of ±0.5% for speeds less than 62 cm/s. For speeds greater than 80 cm/s the error is well within the ±0.5% tolerance up to 250 cm/s.

When the 100 lb suspension is used the rate of decrease in N_S/N_C as V increases is the smallest of the three curves, beginning with a value of 2.5% when V = 20 cm/s, extending up to a speed of 100 cm/s where it reaches its lowest value of 0.6%. Thereafter, there is a slight increase to 1% when V = 125 cm/s and then remains virtually constant at this value up to the maximum speed of 250 cm/s. The meter over-registers and exceeds the ±0.5% tolerance at all speeds.

These results indicate that a meter which is calibrated with a 30 lb standard suspension should not be arbitrarily used with any of the other standard suspension configurations.

8.3 Relative Response When Changing From 50 lb Standard Suspension to Other Standard Sounding Weight Suspensions

Values of N_S/N_C were plotted versus V in Figure 26 resulting in another group of three curves. Overall, there is a marked difference in the trend of the curve for the 15 lb suspension and the curves for the 30 lb and 100 lb suspensions. In the first case there is a trend of declining values of N_S/N_C as V increases whereas for the other two curves the tendency is for N_S/N_C to increase over the tested speed range.

When the 15 lb suspension is used the relative error declines from the maximum of 3.3% when V = 20 cm/s to the minimum value of -0.1% when V = 250 cm/s. For speeds less than 240 cm/s the meter over-registers and under-registers for speeds greater than that. The calibration tolerance of ±0.5% is exceeded for speeds less than 190 cm/s.

When the 30 lb suspension is used the relative error decreases rapidly from -3% at V = 20 cm/s to 0.2% at 80 cm/s and thereafter fluctuates slightly between errors of -0.3% and 0.3% up to the maximum speed of 250 cm/s. The errors obtained exceed the calibration accuracy of ±0.5% for speeds less than 38 cm/s and for speeds from 46 cm/s to 186 cm/s.

When the 100 lb suspension is used values of N_S/N_C are virtually constant at -0.8% for speeds from 20 cm/s to 60 cm/s. Between 60 cm/s and 80 cm/s, there is a sudden change from an under-registration of -0.8% to an over-registration of 1%. For speeds greater than 80 cm/s the change in N_S/N_C is more gradual, increasing with some intermittent fluctuations, to 1.2% at V = 250 cm/s. The relative errors obtained when this suspension is interchanged with the 50 lb standard suspension, exceed the ±0.5% tolerance for speeds less than 64 cm/s and for all speeds greater than 75 cm/s.

It is quite obvious from the curves in Figure 26, that a calibration provided for a 50 lb standard suspension cannot be applied to any of the other standard suspensions.

8.4 Relative Response When Changing From 100 lb Standard Suspension to Other Standard Sounding Weight Suspensions

Values of N_S/N_C were plotted versus V in Figure 27. All three curves show an overall tendency for N_S/N_C to decline as V increases for speeds greater than 80 cm/s. For speeds less than 80 cm/s there are dramatic differences in the relative errors obtained with the other three standard suspensions.

When the 15 lb suspension is used there is a tendency, with some intermittent fluctuations, for the relative error to change from the maximum value of 4.2% at V = 20 cm/s to -1.2% when V = 250 cm/s. The curve shows that the meter over-registers for speeds less than 120 cm/s, except for small under-registrations when the speed is near 80 cm/s. When the speed is greater than 120 cm/s, the meter over-registers at all speeds up to 250 cm/s. The errors obtained exceed the calibration accuracy of ±0.5% for speeds less than 72 cm/s, when the speed is near 100 cm/s and for all speeds greater than 180 cm/s.

When the 30 lb standard suspension is used the relative error decreases from -2.4% at V = 20 cm/s to -1.3% when V = 80 cm/s. For speeds greater than 80 cm/s the error gradually increases again to a value of -1.0% when V = 250 cm/s. The meter under-registers at all speeds and exceeds the ±0.5% calibration accuracy for speeds less than 74 cm/s and speeds greater than 96 cm/s.

When the 50 lb suspension is used the relative error is virtually constant at 0.8% from V ≐ 20 cm/s to 69 cm/s and then changes rapidly to -1.0% as the speed increases to 80 cm/s. Thereafter the relative error fluctuates between -0.6% and -1.2% up to the maximum speed of 250 cm/s where the value is -1.1%. The meter over-registers for speeds less than 69 cm/s and under-registers for speeds greater than 69 cm/s. The calibration accuracy of ±0.5% is exceeded for speeds less than 64 cm/s and for all speeds greater than 75 cm/s.

These results clearly show that one cannot change from the 100 lb standard suspension to any of the other standard suspensions without having the appropriate calibration.

9.0 CONCLUSIONS

1. The response curve obtained with the 30 lb standard suspension as used by Water Survey of Canada is very similar to that obtained when the meter is fitted to a standard rod suspension.
2. Response curves obtained with the 15 lb, 50 lb and 100 lb standard suspension as used by Water Survey of Canada, differ significantly from that obtained with a standard rod suspension.
3. The response curves obtained with all other possible (non-standard) combinations of meter positions on the WR2 hanger and sounding weight size, differ significantly from the response curve obtained with the standard rod suspension.
4. The four standard sounding weight suspensions used by Water Survey of Canada may be ranked in the order of suitability for a good calibration as:
   1. 100 lb standard suspension
   2. 30 lb standard suspension
   3. 50 lb standard suspension
   4. 15 lb standard suspension
5. A calibration provided with 15 lb, 30 lb, 50 lb, and 100 lb standard sounding weight suspension should not be used with the meter in either of the two other possible positions on the WR2 hanger for each sounding weight size.
6. A calibration provided with a 15 lb, 30 lb, 50 lb, and 100 lb standard sounding weight suspension should not be used when the sounding weight for a given suspension is exchanged for any one or the other three sounding weight sizes.
7. A calibration provided with each of the 15 lb, 30 lb, 50 lb and 100 lb standard sounding weight suspension should not be used with any of the other three standard suspensions.

8. Failure to observe recommendations 5. through 7. may result in measurement errors of several percent in many cases and errors exceeding ±0.5% in virtually all cases.
9. The Price 622AA should always be calibrated with the same suspension configuration in which it is to be used.

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TABLE 1. Meter Response at Standard Positions

V cm/s	Meter Response N/V			
	15 lb P_1	30 lb P_2	50 lb P_3	100 lb P_3*
20	1.493	1.395	1.445	1.433
40	1.488	1.457	1.484	1.473
60	1.500	1.460	1.485	1.473
80	1.485	1.478	1.475	1.490
100	1.499	1.479	1.479	1.488
125	1.489	1.478	1.482	1.492
150	1.490	1.478	1.479	1.492
175	1.490	1.482	1.480	1.496
200	1.480	1.480	1.476	1.494
225	1.487	1.480	1.482	1.496
250	1.477	1.480	1.478	1.495

NOTE: P_1, P_2, P_3 denotes standard position on WR2 for the Given Weight

TABLE 2. Meter Response at Non Standard Positions on WR2 Hanger

V cm/s	N/V at Position P_n For a Given Sounding Weight Type							
	15 lb		30 lb		50 lb		100 lb	
	P_2	P_3	P_1	P_3	P_1	P_2	P_1	P_2
20	1.389	1.413	1.387	1.428	1.434	1.416	1.398	1.415
40	1.458	1.480	1.438	1.462	1.469	1.476	1.439	1.448
60	1.468	1.487	1.454	1.477	1.459	1.484	1.446	1.452
80	1.478	1.483	1.456	1.480	1.472	1.481	1.452	1.465
100	1.485	1.483	1.470	1.492	1.483	1.482	1.452	1.467
125	1.477	1.477	1.482	1.475	1.480	1.480	1.445	1.473
150	1.472	1.475	1.489	1.490	1.479	1.489	1.440	1.469
175	1.472	1.479	1.489	1.486	1.484	1.483	1.435	1.475
200	1.473	1.478	1.483	1.483	1.483	1.492	1.428	1.479
225	1.471	1.471	1.484	1.483	1.483	1.492	1.425	1.477
250	1.471	1.469	1.481	1.484	1.483	1.490	1.420	1.492

TABLE 3. Possible Combinations of Meter Position and Sounding Weight Size When WR2 Hanger is Used.

n \ w	15 lb	30 lb	50 lb	100 lb
1				
2				
3				

Standard Suspensions

Other Possible Combinations of Meter Position and Sounding Weight Size

n = meter position number

w = sounding weight denomination

TABLE 4. Effect of Changing Meter Position on WR2 Hanger

V cm/s	Relative Response							
	15 lb Sounding Weight		30 lb Sounding Weight		50 lb Sounding Weight		100 lb Sounding Weight	
	P_2/P_1	P_3/P_1	P_1/P_2	P_3/P_2	P_1/P_2	P_2/P_3	P_1/P_3	P_2/P_3
20	0.930	0.946	0.991	1.021	0.992	0.980	0.976	0.987
40	0.980	0.995	0.987	1.003	0.990	0.995	0.977	0.983
60	0.979	0.991	0.996	1.012	0.982	0.999	0.982	0.986
80	0.995	0.999	0.985	1.001	0.998	1.004	0.974	0.983
100	0.991	0.989	0.994	1.009	1.003	1.002	0.976	0.986
125	0.992	0.992	1.003	0.998	0.999	0.999	0.968	0.987
150	0.988	0.998	1.007	1.008	1.000	1.007	0.965	0.985
175	0.988	0.998	1.005	1.003	1.003	1.002	0.959	0.986
200	0.995	0.999	1.002	1.002	1.005	1.011	0.956	0.990
225	0.989	0.989	1.003	1.002	1.001	1.007	0.953	0.987
250	0.996	0.995	1.001	1.003	1.003	1.008	0.950	0.998

Example: P_2/P_1 denotes the case when the meter is moved to Position P_2 from standard position P_1.

TABLE 5. **Meter Response at Standard Positions**

V cm/s	Relative Response N/N_s					
	P_1			P_2		
	S_{30}/S_{15}	S_{50}/S_{15}	S_{100}/S_{15}	S_{15}/S_{30}	S_{50}/S_{30}	S_{100}/S_{30}
20	0.929	0.960	0.936	0.993	1.012	1.011
40	0.966	0.987	0.967	1.001	1.013	0.994
60	0.969	0.973	0.964	1.005	1.016	0.995
80	0.980	0.991	0.978	1.000	1.002	0.991
100	0.981	0.989	0.969	1.004	1.002	0.992
125	0.995	0.994	0.970	0.999	1.001	0.997
150	0.999	0.993	0.996	0.996	1.007	0.994
175	0.999	0.996	0.963	0.993	1.001	0.995
200	1.002	1.002	0.965	0.995	1.008	0.999
225	0.998	0.997	0.958	0.994	1.008	0.998
250	1.003	1.004	0.961	0.994	1.007	1.008

Example: S_{30}/S_{15} denotes the case when 30 lb sounding weight replaces the standard 15 lb sounding weight

TABLE 6. Effect of Exchanging Sounding Weights of Different Weights for a Given Meter Position on WR2 Hanger

V cm/s	Relative Response N/N_s					
	P_1			P_2		
	S_{15}/S_{50}	S_{30}/S_{50}	S_{100}/S_{50}	S_{15}/S_{100}	S_{30}/S_{100}	S_{50}/S_{100}
20	0.978	0.988	0.992	0.986	0.997	1.008
40	0.997	0.985	0.993	1.005	0.993	1.007
60	1.001	0.995	0.992	1.010	1.003	1.008
80	1.005	1.003	1.010	0.995	0.993	0.990
100	1.003	1.009	1.006	0.997	1.003	0.994
125	0.997	0.995	1.007	0.990	0.989	0.993
150	0.997	1.007	1.009	0.989	0.999	0.991
175	0.999	1.004	1.011	0.989	0.993	0.989
200	1.001	1.005	1.012	0.989	0.993	0.988
225	0.993	1.001	1.009	0.983	0.991	0.991
250	0.994	1.004	1.012	0.983	0.993	0.989

TABLE 7. **Effect of Changing From a Given Standard Suspension to Another**

V cm/s	Relative Response N_s/N_c					
	15 lb Standard Suspension			30 lb Standard Suspension		
	30 lb	50 lb	100 lb	15 lb	50 lb	100 lb
20	0.937	0.968	0.970	1.067	1.033	1.024
40	0.979	0.997	0.990	1.021	1.019	1.011
60	0.973	0.990	0.982	1.027	1.017	1.009
80	0.995	0.995	1.003	1.005	0.998	1.008
100	0.982	0.987	0.993	1.013	1.000	1.006
125	0.993	0.995	1.002	1.007	1.003	1.009
150	0.992	0.993	1.001	1.008	1.001	1.009
175	0.995	0.993	1.004	1.005	0.999	1.009
200	1.000	0.997	1.009	1.000	0.997	1.009
225	0.995	0.997	1.006	1.005	1.001	1.011
250	1.002	1.001	1.012	0.998	0.999	1.010

TABLE 8. Effect of Changing From a Given Standard Suspension to Another

V cm/s	Relative Response N_s/N_c					
	50 lb Standard Suspension			100 lb Standard Suspension		
	15 lb	30 lb	100 lb	15 lb	30 lb	50 lb
20	1.033	0.968	0.992	1.042	0.976	1.008
40	1.003	0.982	0.993	1.010	0.989	1.008
60	1.010	0.983	0.992	1.018	0.991	1.008
80	1.007	1.002	1.010	0.997	0.997	0.990
100	1.014	1.000	1.006	1.007	0.994	0.994
125	1.005	0.997	1.007	0.998	0.991	0.993
150	1.007	0.999	1.009	0.999	0.991	0.991
175	1.07	1.001	1.010	0.996	0.991	0.989
200	1.003	1.003	1.012	0.991	0.991	0.988
225	1.003	0.999	1.009	0.994	0.989	0.991
250	0.999	1.001	1.012	0.988	0.990	0.989

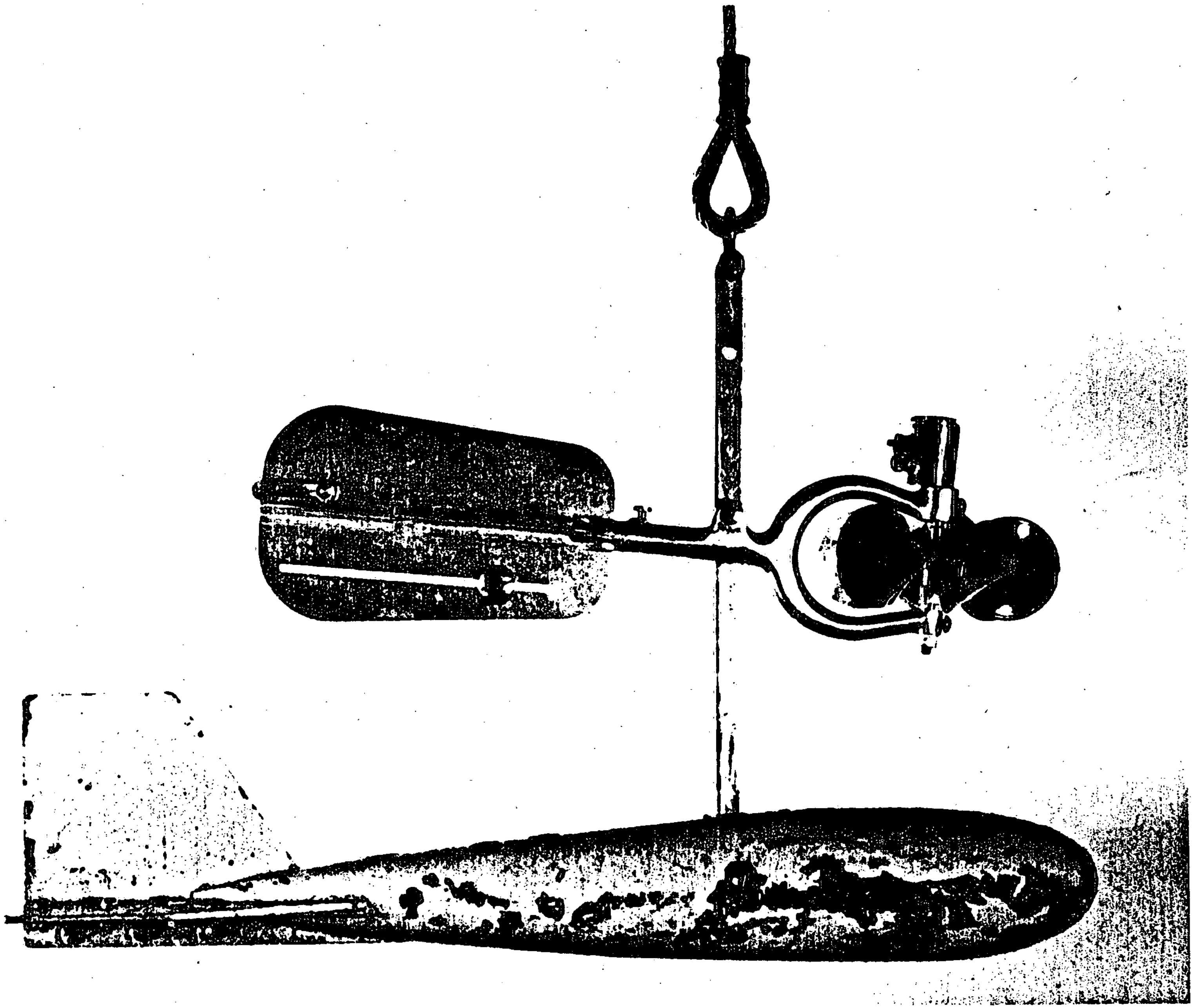
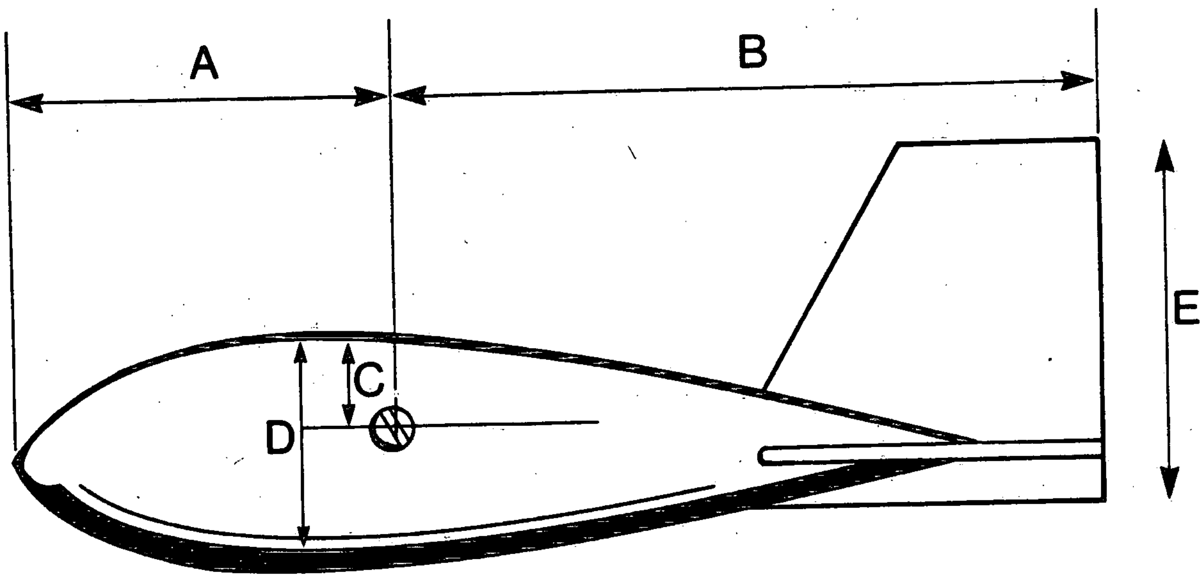


Figure 1 Standard assembly for Price 622 AA current meter and 30 lb Columbus sounding weight.



Side elevation of a Columbus pattern weight

Wt. (lb)	Length (mm)					
	A	B	A+B	C	D	E
15	179	322	501	26	67	102
30	184	362	546	30	79	152
50	206	376	582	39	98	178

Figure 2 Dimensions of various sizes of weight (mm)

Figure 3   Columbus weights and test hanger.

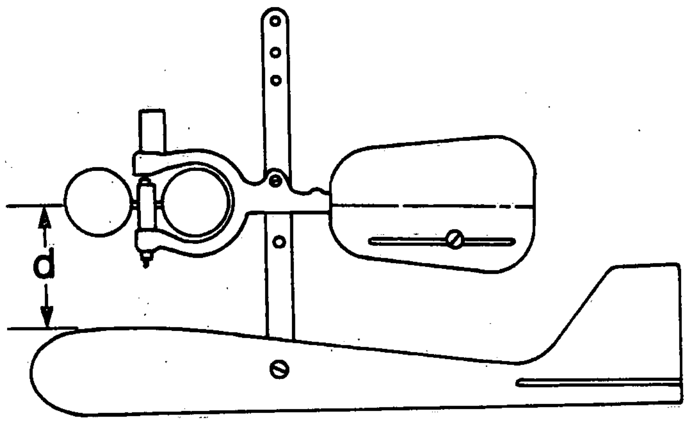


Figure 4a Adopted definition of meter position

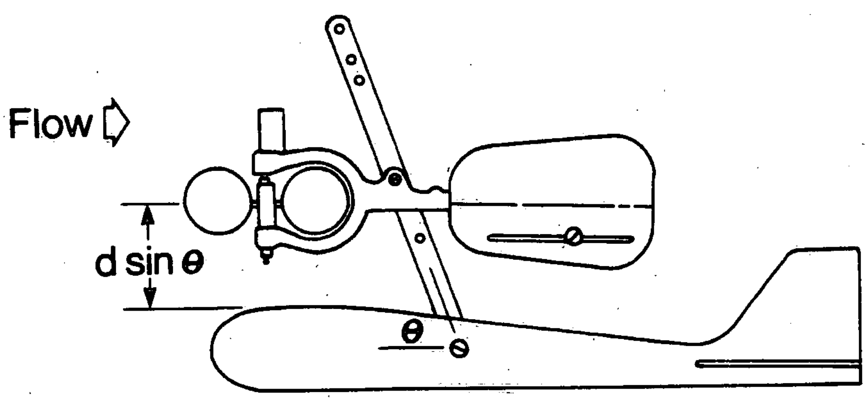


Figure 4b Actual meter position

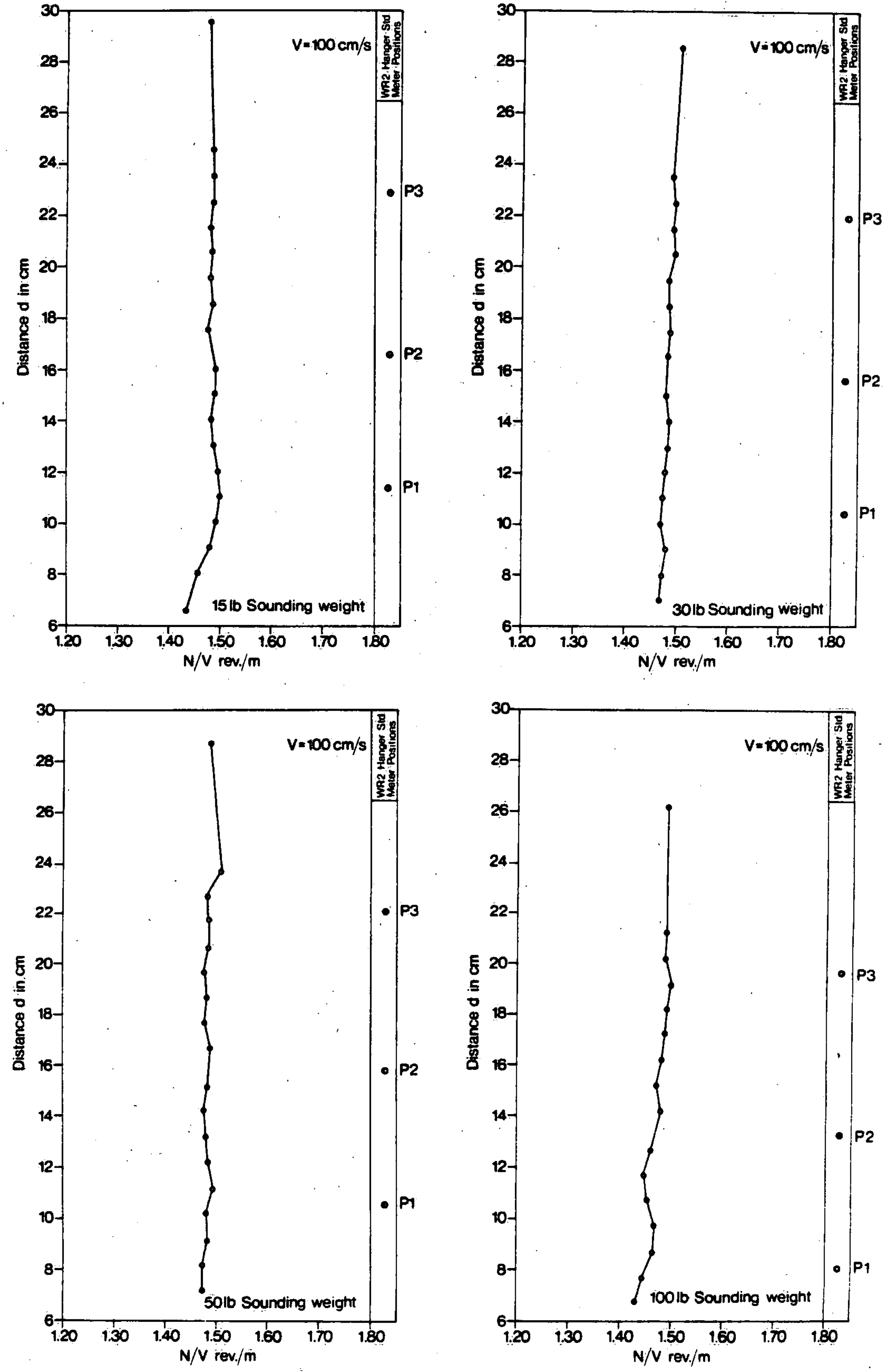


Figure 5 Typical plots of N/V versus d for each size of sounding weight.

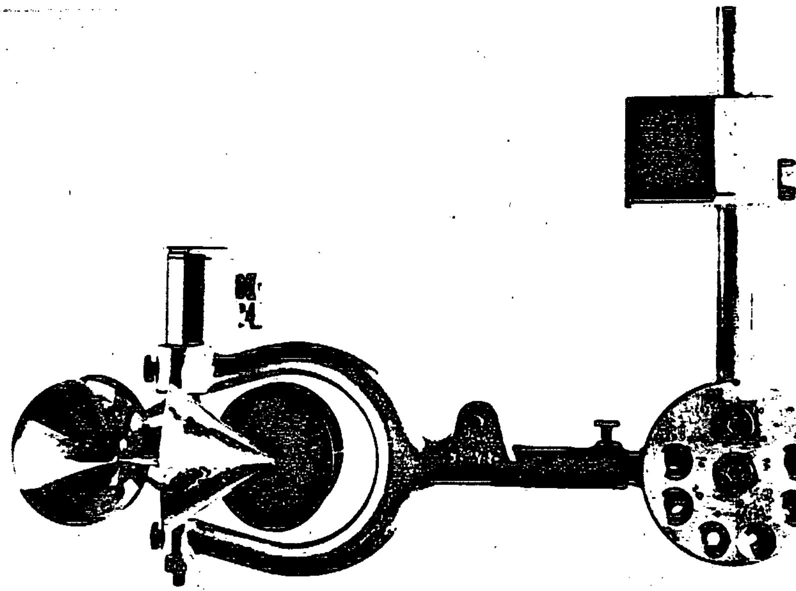


Figure 6 Price meter mounted on suspension rod

ENGEL/PM/84

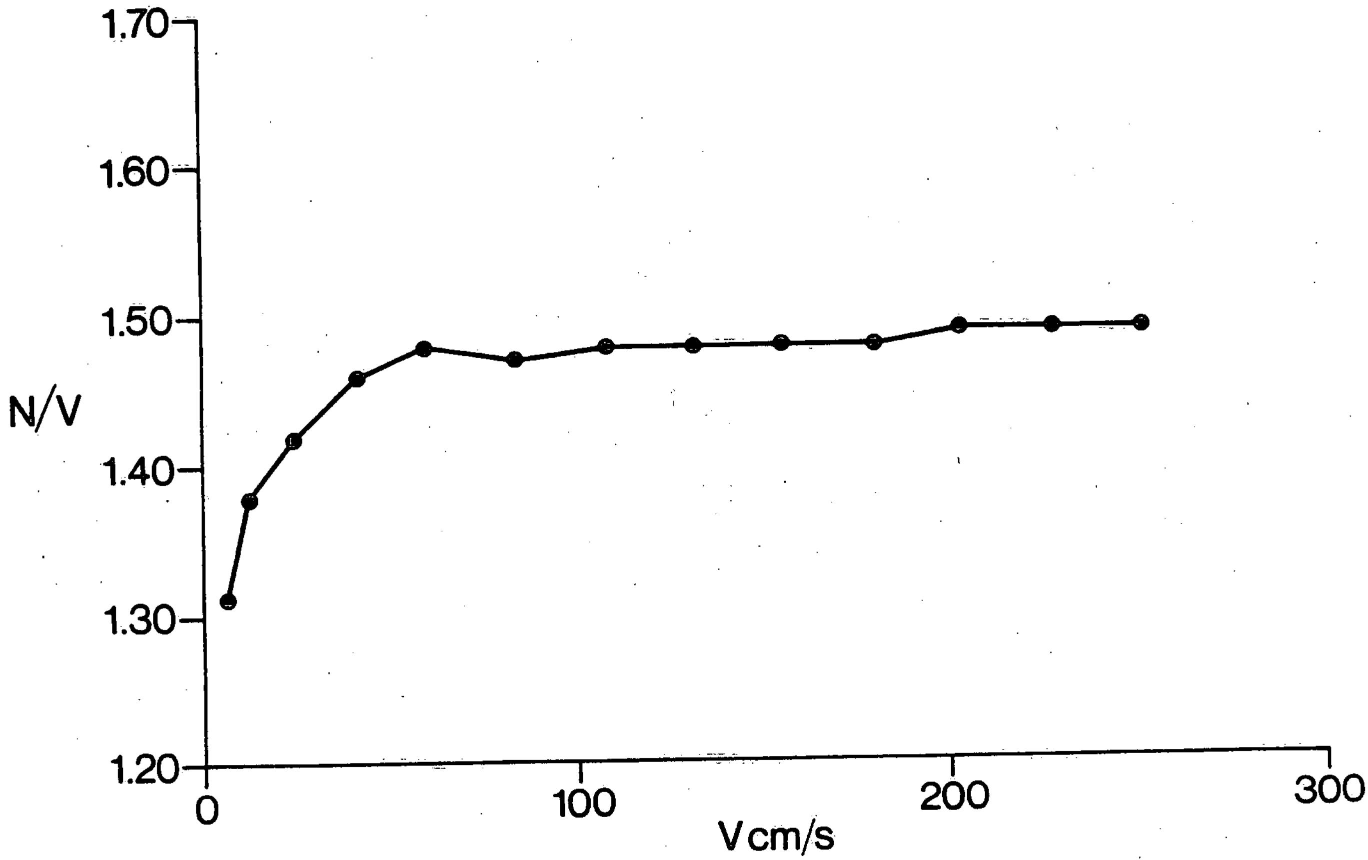


Figure 7 Standard calibration with rod suspension

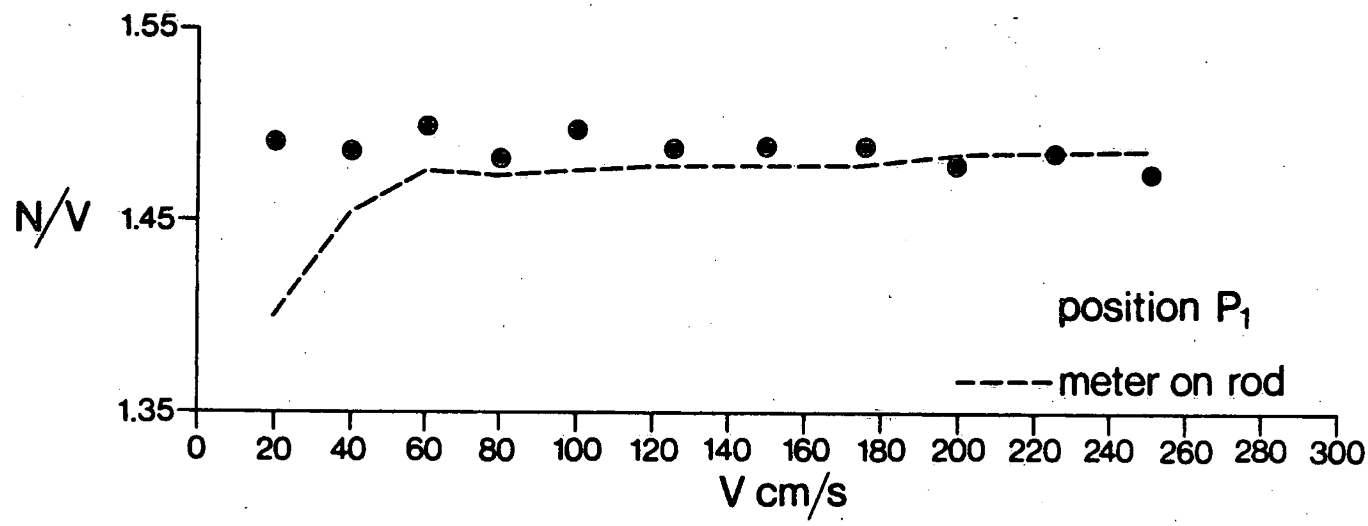


Figure 8 Rotor response with 15 lb standard suspension

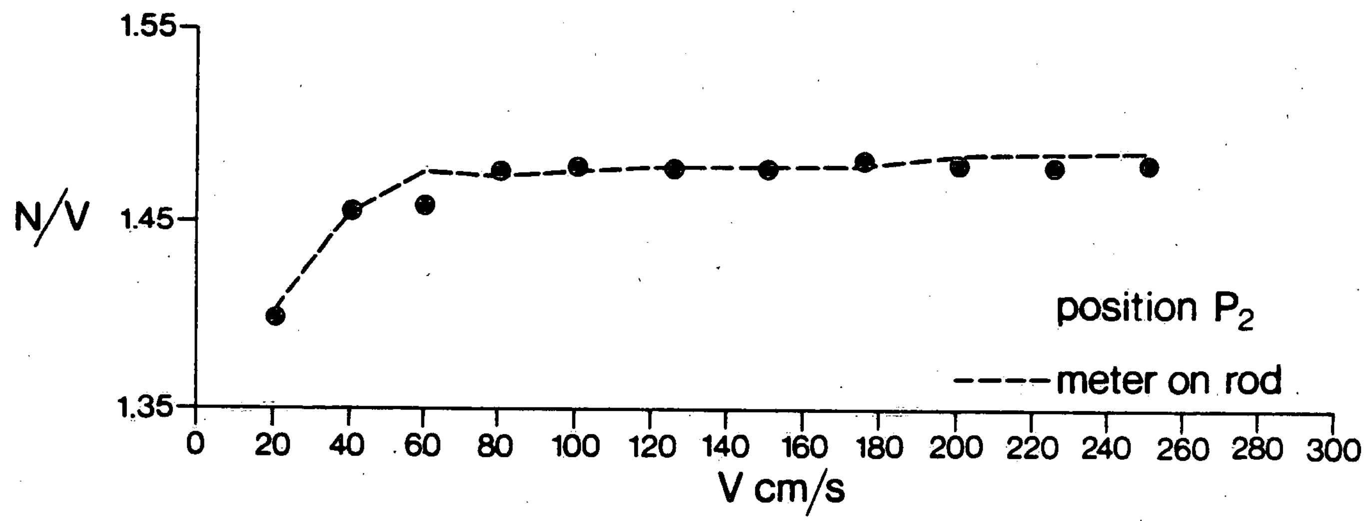


Figure 9 Rotor response with 30 lb standard suspension

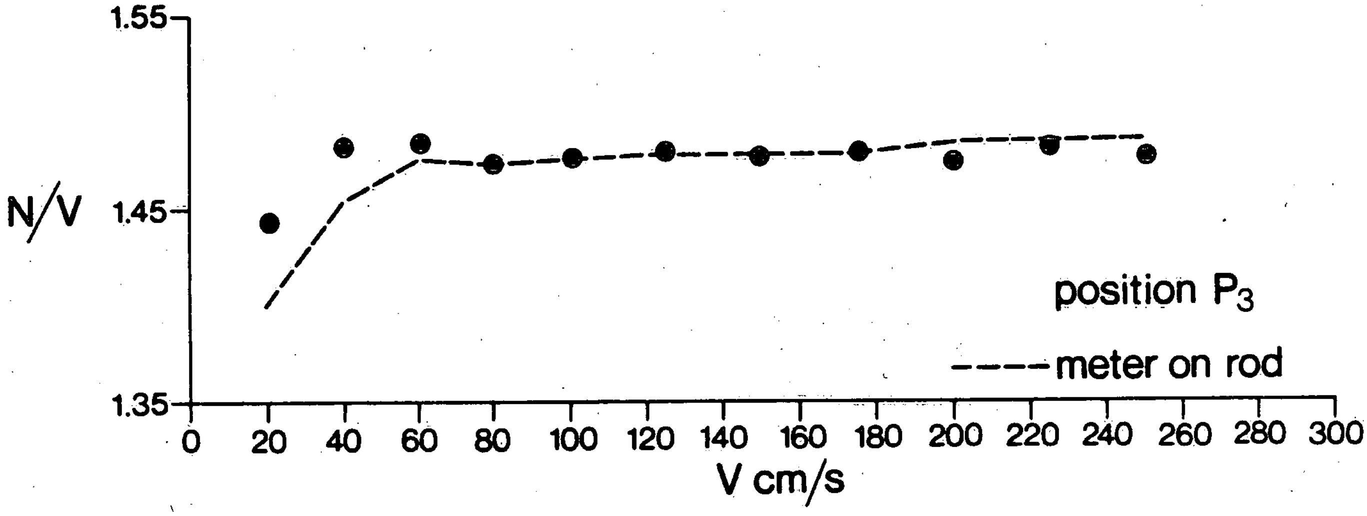


Figure 10 Rotor response with 50 lb standard suspension

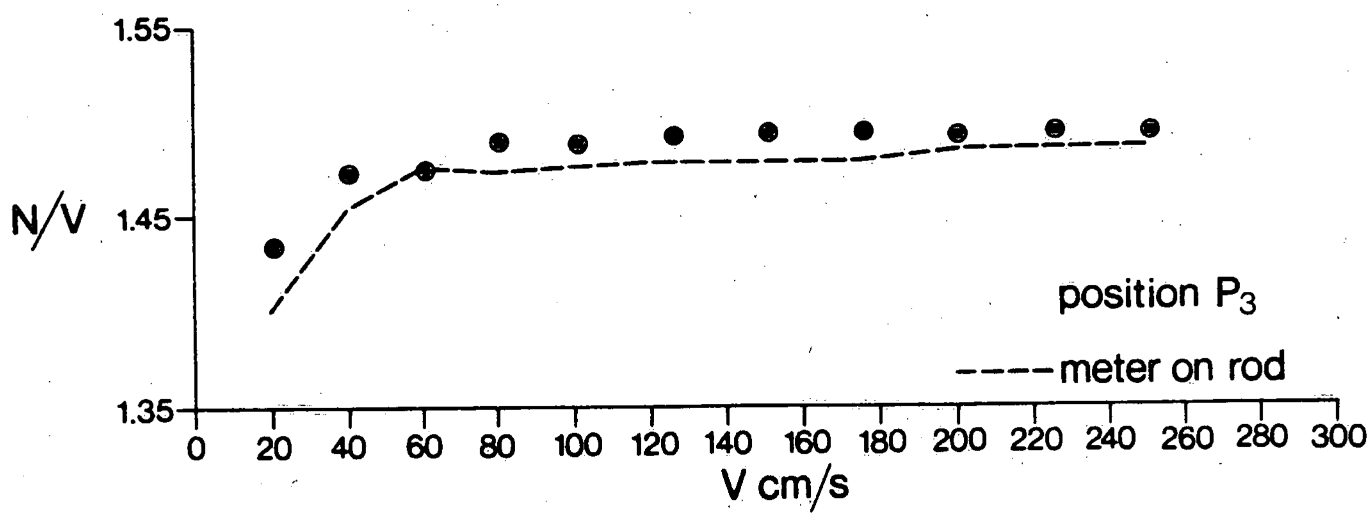


Figure 11 Rotor response with 100 lb standard suspension

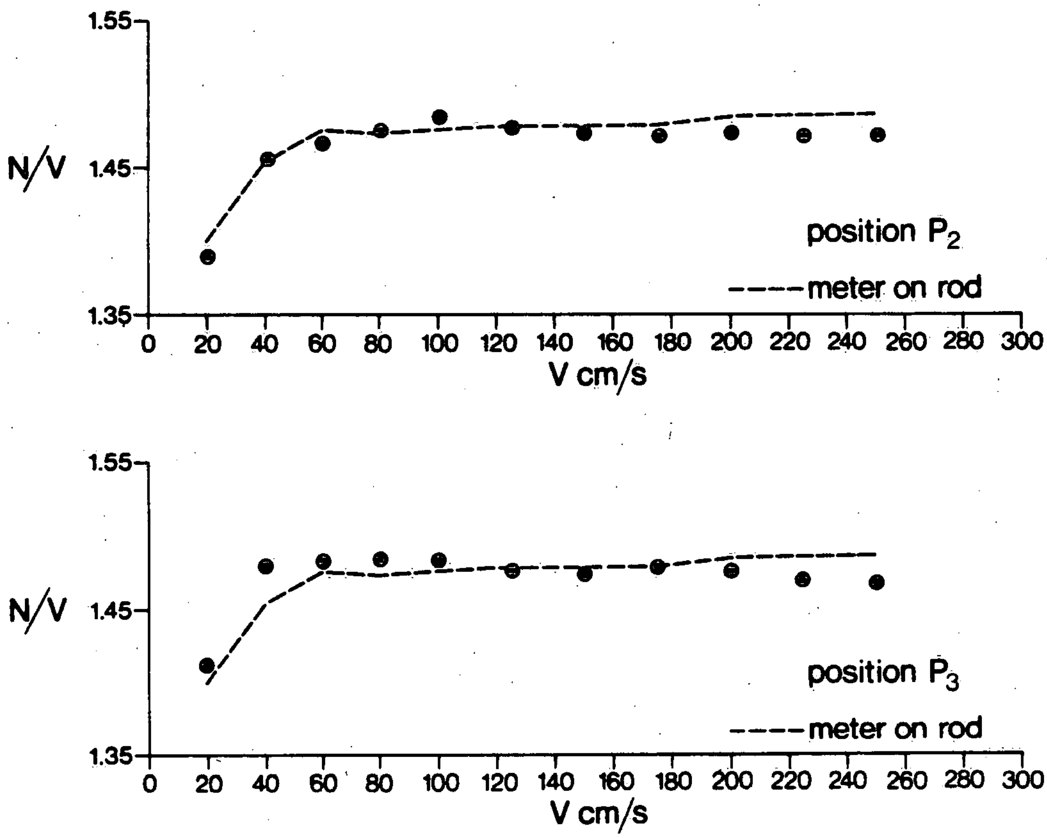


Figure 12 Rotor response with 15 lb sounding weight and meter at positions P_2 and P_3

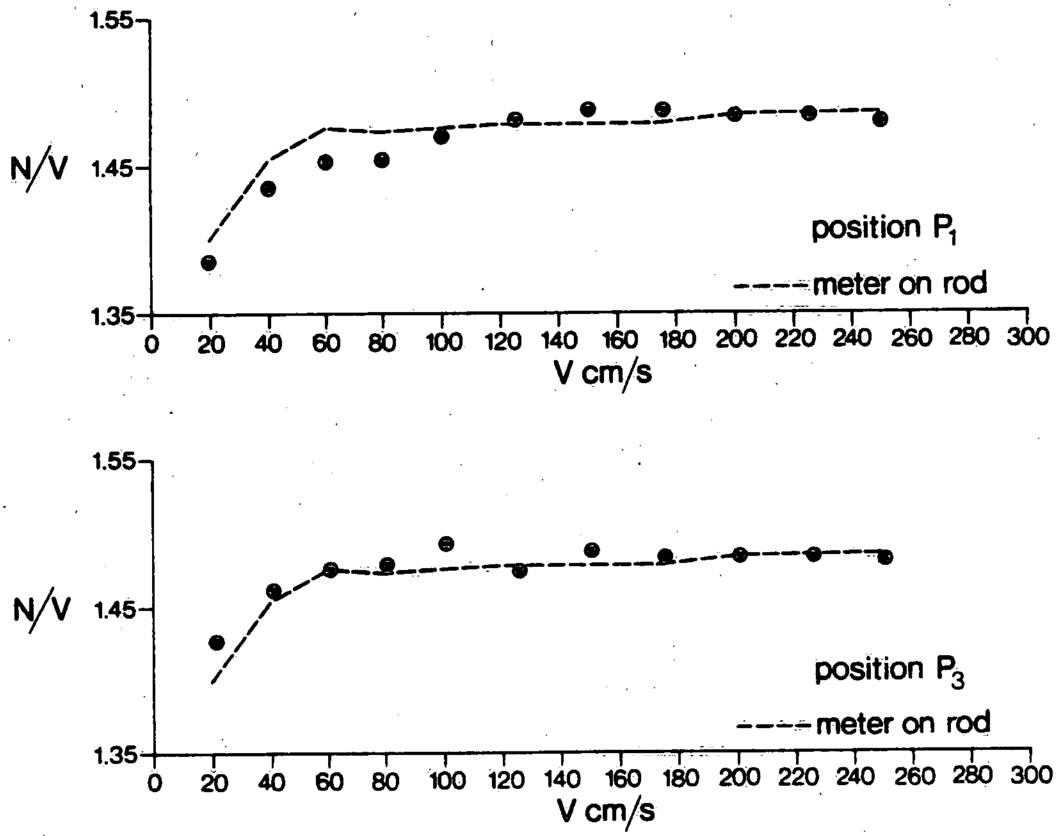


Figure 13 Rotor response with 30 lb sounding weight and meter at positions P_1 and P_3

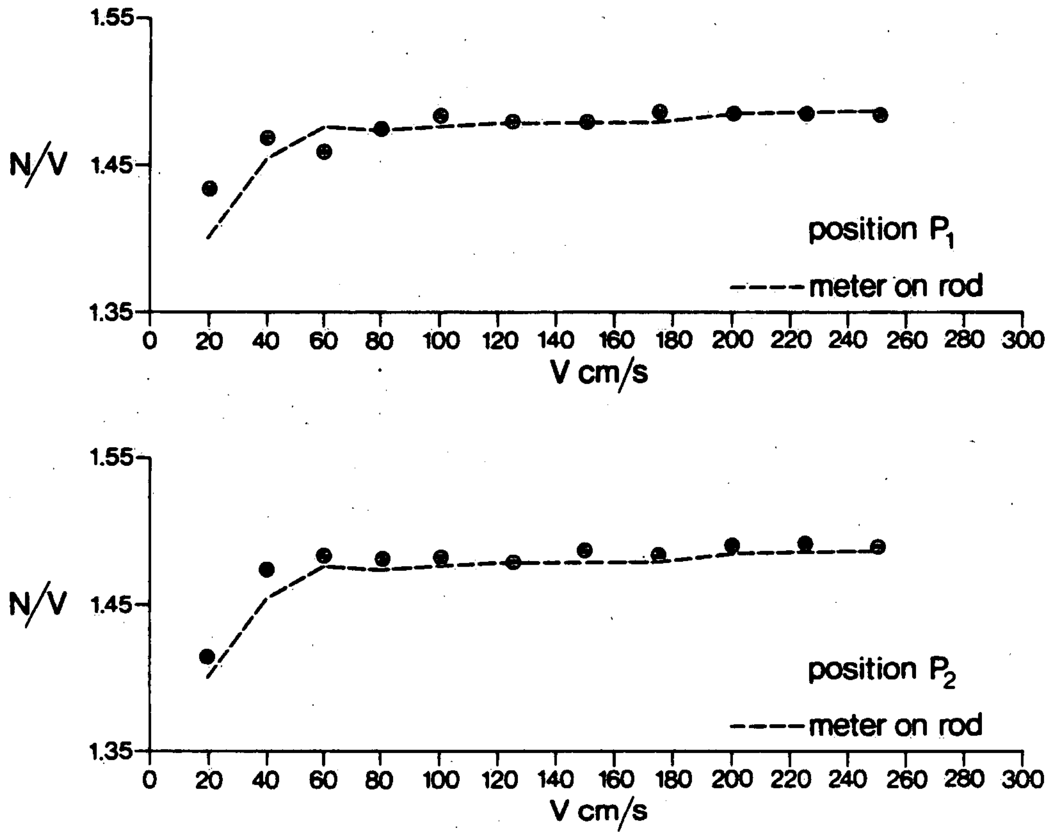


Figure 14 Rotor response with 50 lb sounding weight and meter at positions P_1 and P_2

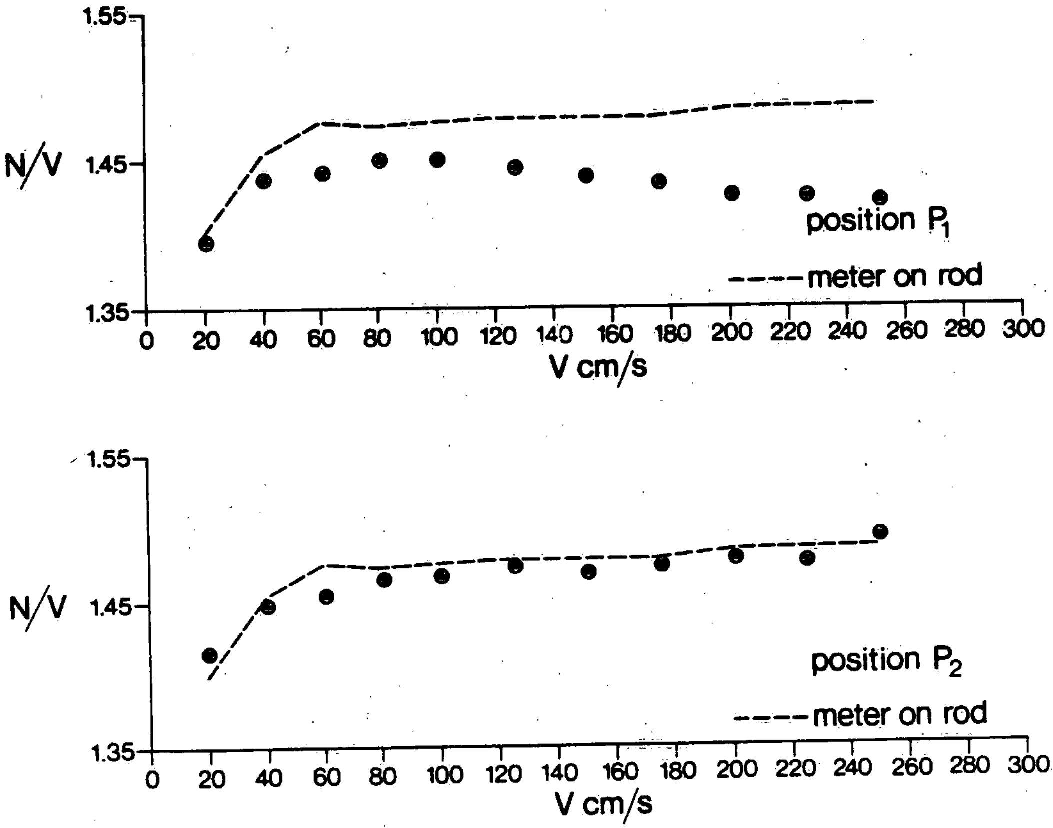


Figure 15 Rotor response with 100 lb sounding weight and meter at positions P_1 and P_2

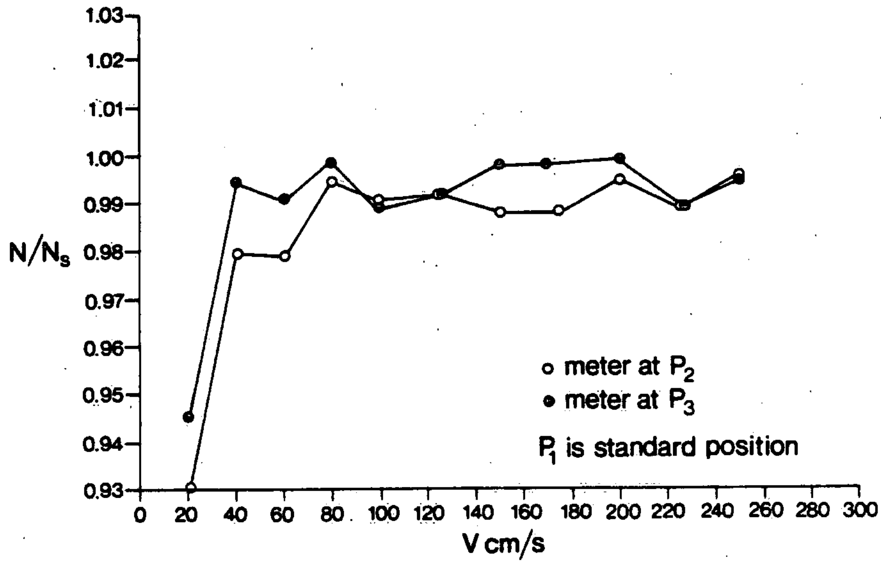


Figure 16 Effect of changing meter from standard position to position P_1 and P_2 when 15 lb sounding weight is used

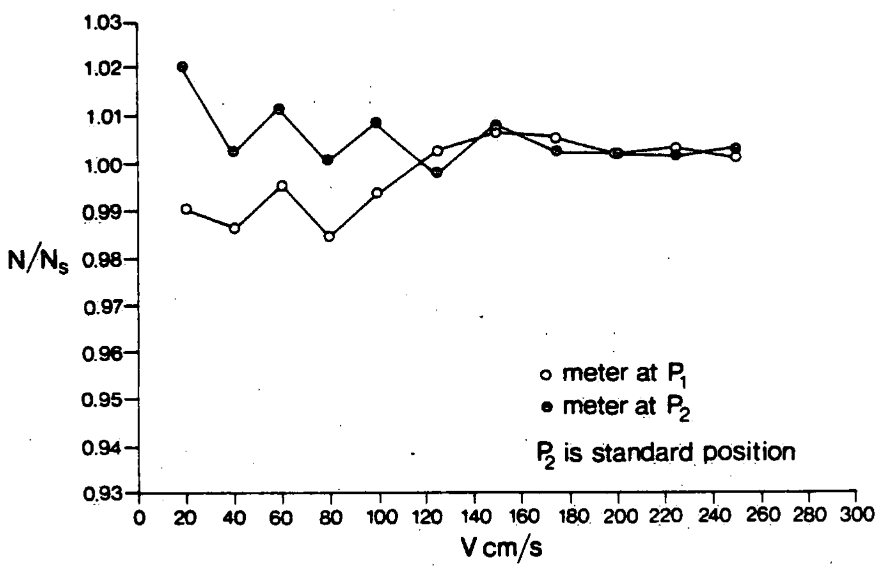


Figure 17 Effect of changing meter from standard position to position P_1 and P_3 when 30 lb sounding weight is used

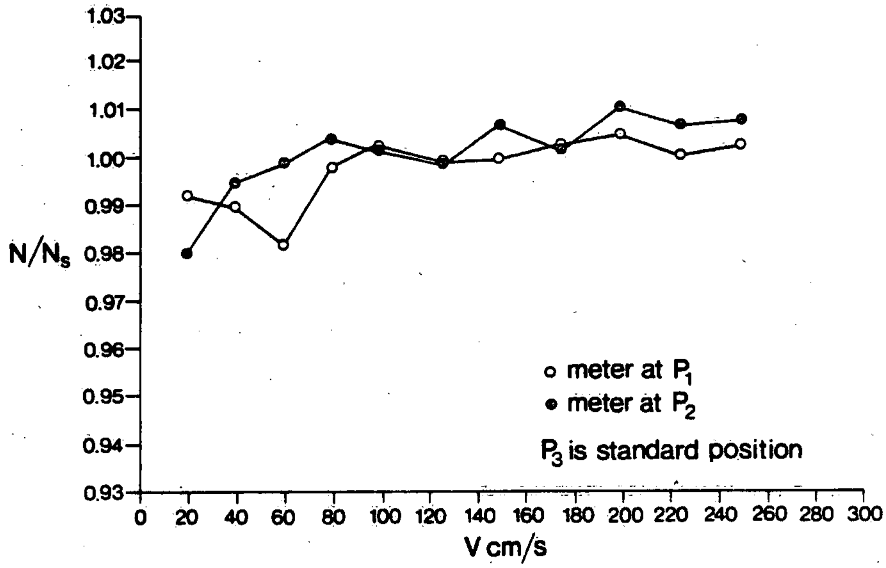


Figure 18 Effect of changing meter from standard position to position P_1 and P_2 when 50 lb sounding weight is used

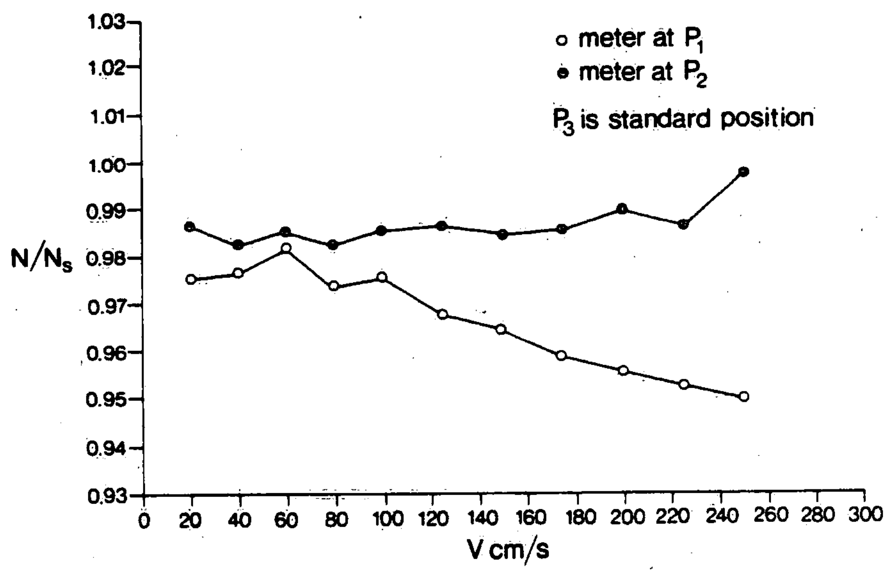


Figure 19 Effect of changing meter from standard position to position P_1 and P_2 when 100 lb sounding weight is used

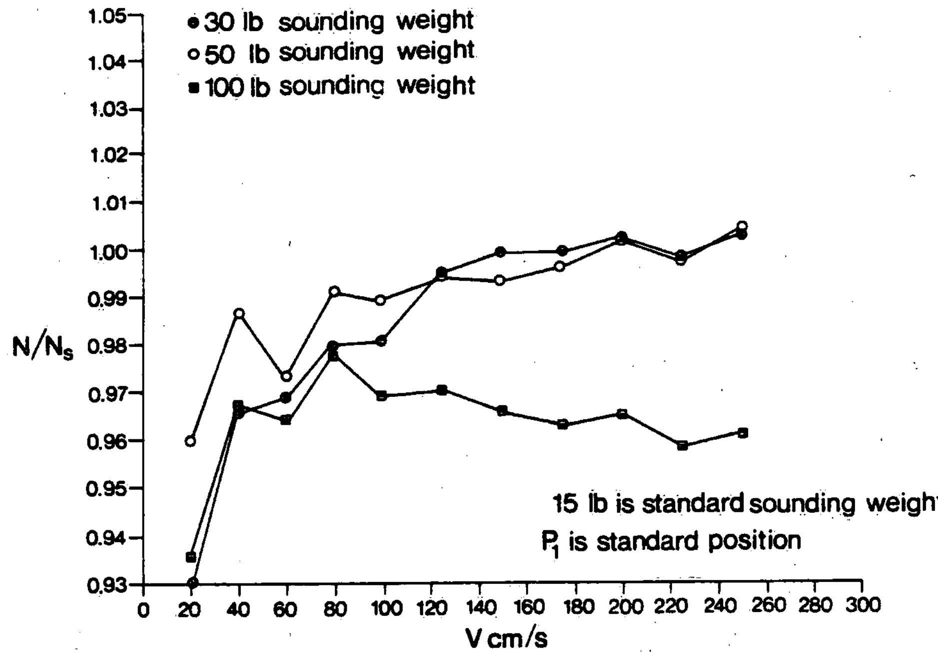


Figure 20 Effect of changing from 15 lb sounding weight to a sounding weight of different size

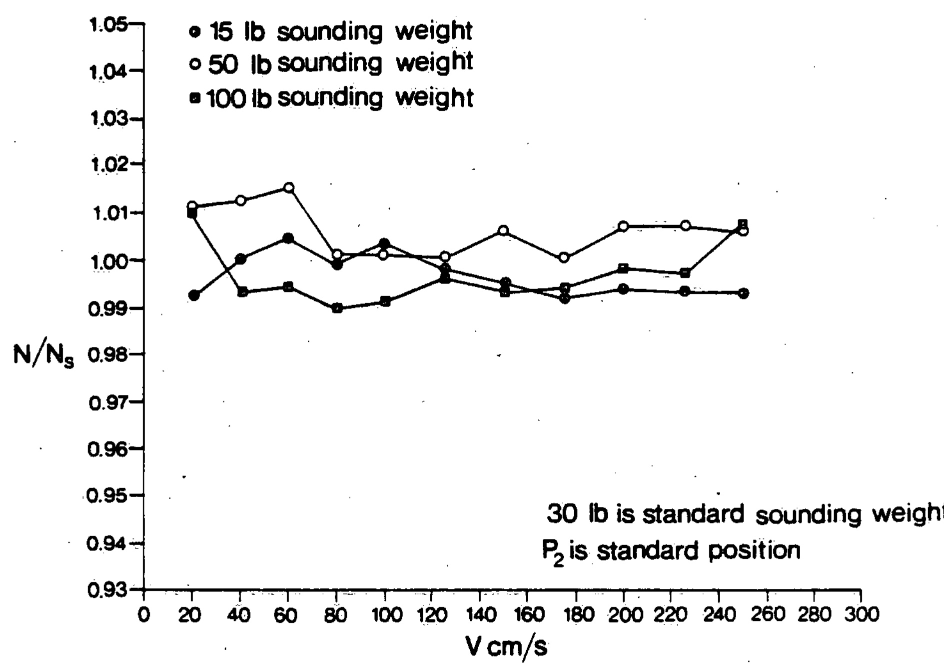


Figure 21 Effect of changing from 30 lb sounding weight to a sounding weight of different size

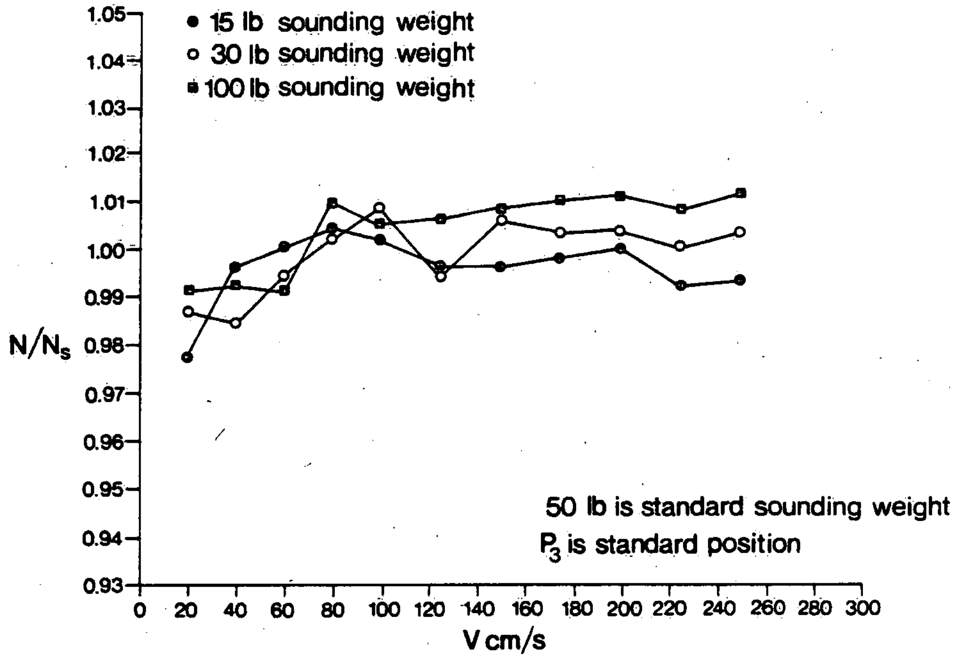


Figure 22 Effect of changing from 50 lb sounding weight to a sounding weight of different size

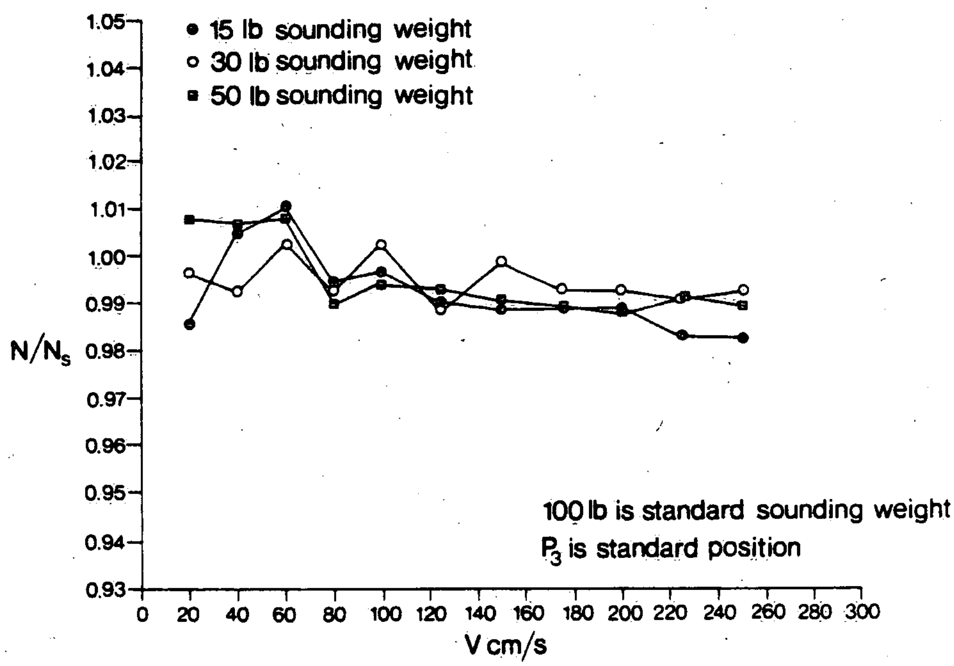


Figure 23 Effect of changing from 100 lb sounding weight to a sounding weight of different size

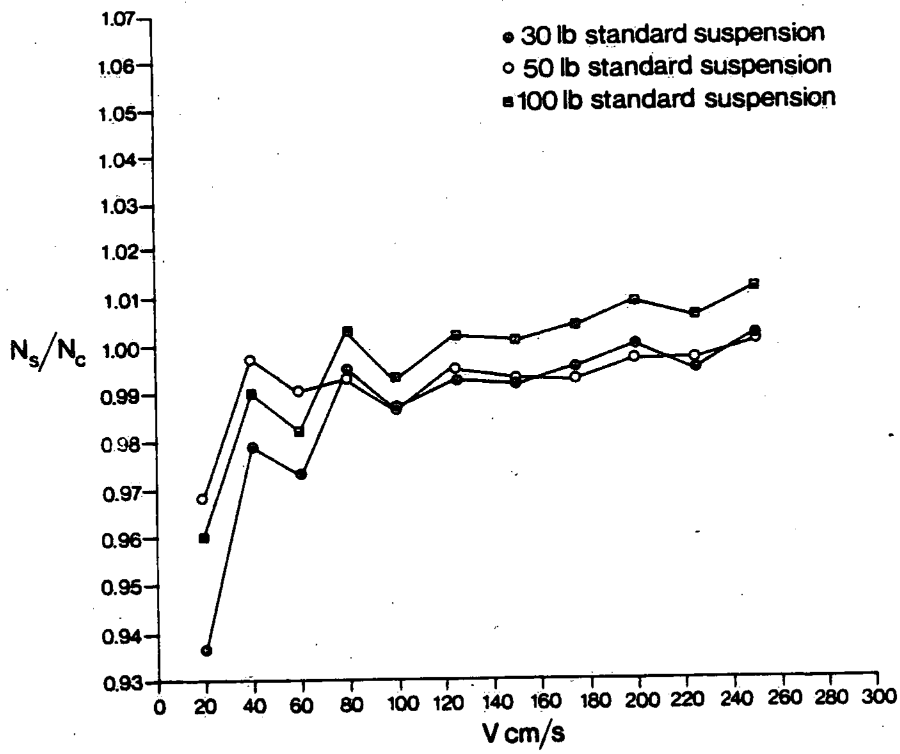


Figure 24 Effect of changing from 15 lb standard suspension to another standard suspension

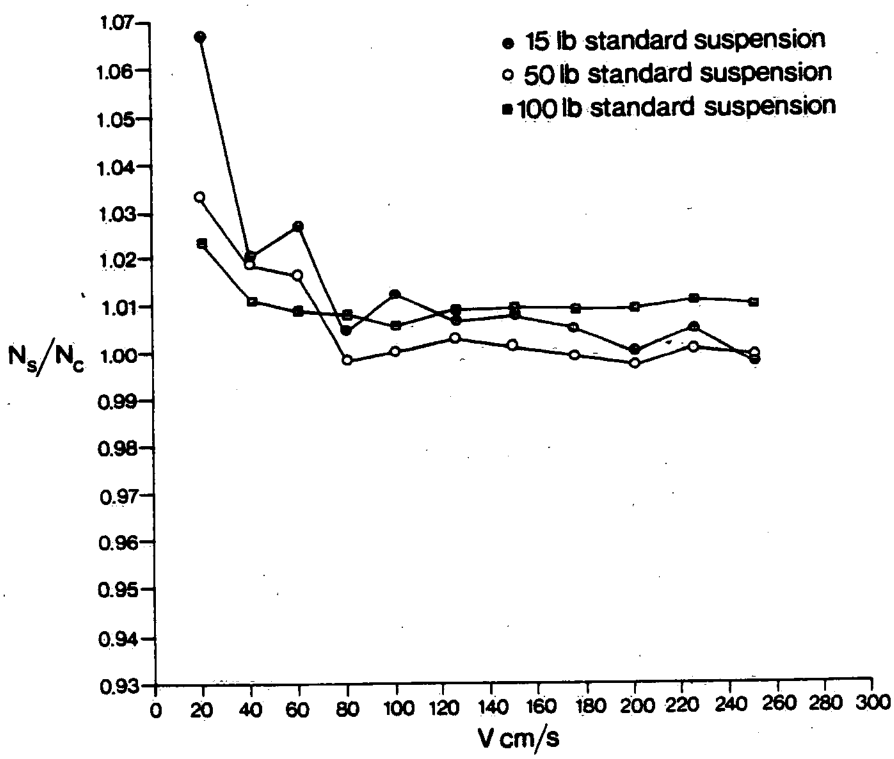


Figure 25 Effect of changing from 30 lb standard suspension to another standard suspension

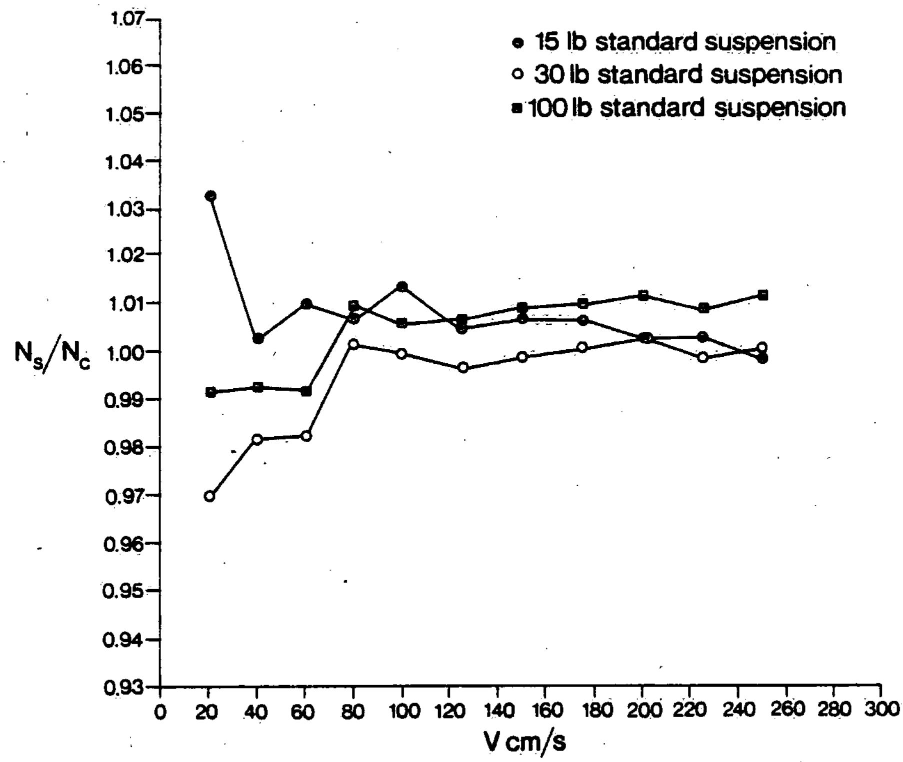


Figure 26 Effect of changing from 50 lb standard suspension to another standard suspension

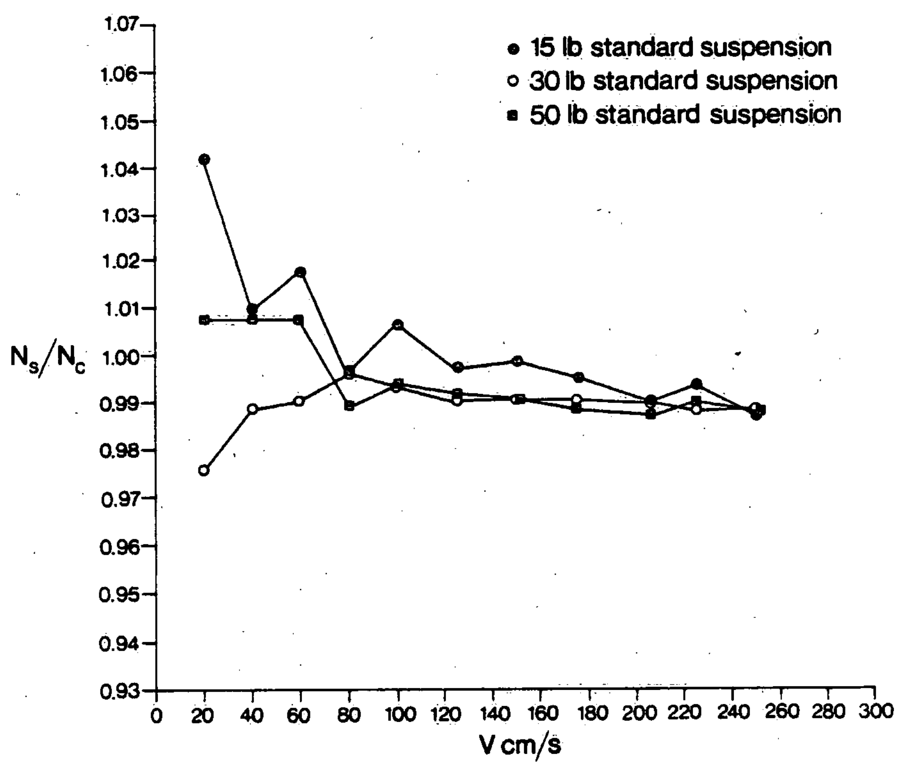


Figure 27 Effect of changing from 100 lb standard suspension to another standard suspension

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