EFFECT OF TEMPERATURE AND BOUNDARY ON CURRENTMETER RATINGS

by

M G Hiranandani

and

P C Saxena

Technical Memorandum HLO :

September 1960

GOVERNMENT OF INDIA

CENTRAL WATER AND POWER RESEARCH STATION

Poona, India

Central Water and Power Research Station

Poona, India

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PREFACE

The present investigation for evaluating the effects of varying immersion positions of the currentmeter for its rating runs under water and of varying temperatures was initiated for the purpose of laying down standards for currentmeter calibrations and observations in the field.

The investigation has brought to light that currentmeter calibrations, for the range of temperatures tested, remain unaffected by normal temperature changes.

In regard to boundary effect, currentmeter observations in the field as well as calibrations in the rating tank will be subject to an error of less than 0.6% provided velocities are observed at a minimum distance of 12 inches at the sides as well as at the bottom.

The collaboration of Sarvashri C V Gole, Dy Director, G M Panchang, S V Chitale and P K Kulkarni, Chief Research Officers is gratefully acknowledged.

EFFECT OF TEMPERATURE AND BOUNDARY ON CURRENTMETER RATINGS

1. INTRODUCTION

Considerable research has been done in the last five decades or so towards improving the accuracy of measurement of velocities. An instrument known as the currentmeter with which most engineers of today are familiar was developed as a standard device for measuring velocities. This type of instrument generally falls under two categories:

i propeller-type currentmeters in which turning movement is obtained by the lift developed on the blades by water

ii cup-type currentmeters in which differential drag on cups in opposite directions rotates the cup assembly

The cup-type currentmeters(fig 1) are comprised of six hollow conical cups mounted on a vertical shaft held between bearings at the two ends. A set of guide vanes keeps the axis of the wheel perpendicular to the current and the entire assembly parallel to the direction of flow. The wheel is geared to a mono or penta contact arrangement for counting the number of its revolutions through a headphone or a counter by making or breaking a contact of the electrical circuit at the end of every one or five revolutions.

For very low velocities of $\frac{1}{2}$ foot per second and less the friction in the bearing of the currentmeter is comparable to the moving forces of water. The form of relation, therefore, of such low velocities with the corresponding number of the revolutions/sec is different from that for higher velocities. The general relation also called the rating curve, is evaluated for velocities more than $\frac{1}{2}$ ft/sec by calibrating the currentmeters in rating or towing tanks by towing them in still water at different velocities and counting the number of revolutions per second for each run.

2. NECESSITY OF PRESENT INVESTIGATION

The conditions with regard to temperature of water and boundary ie distance at which the currentmeter is held from the side or from the bottom may be different in actual streams as compared to that under which the currentmeter is calibrated in a towing tank.

No standardized procedure is so far known to have been prescribed in respect of specific temperature(s) to be maintained, or of holding the currentmeter at specified distance(s) from the bottom and/or from the sides for ensuring immunity from boundary effect during the course of calibration and actual observations in the field. Actually, there may be differences in either or both the factors on different oceasions. It may be noted that temperature variation over rivers is fairly wide in India, generally ranging between 5° to 40°C.

It was thought pertinent, therefore, to investigate the variations due to such extraneous differences of temperature or distances from bottom and sides on the rating tables or equations of rating curves obtaining for currentmeters. The information so procured would serve as a valuable guide for standardisation of conditions under which rating should be made and also for introducing appropriate corrections, if any, to the respective rating expressions of the currentmeters whenever the field conditions differed from those under which they might have been calibrated.

3. FACILITIES AVAILABLE

Facilities for calibrating currentmeters are well provided at the Ship Testing Tank at the CWPRS. The tank is 500 ft long, 12 ft wide and 7 ft deep. Sixty pound rails are laid to the curvature of the earth on either sides of the tank. A towing carriage with the facility

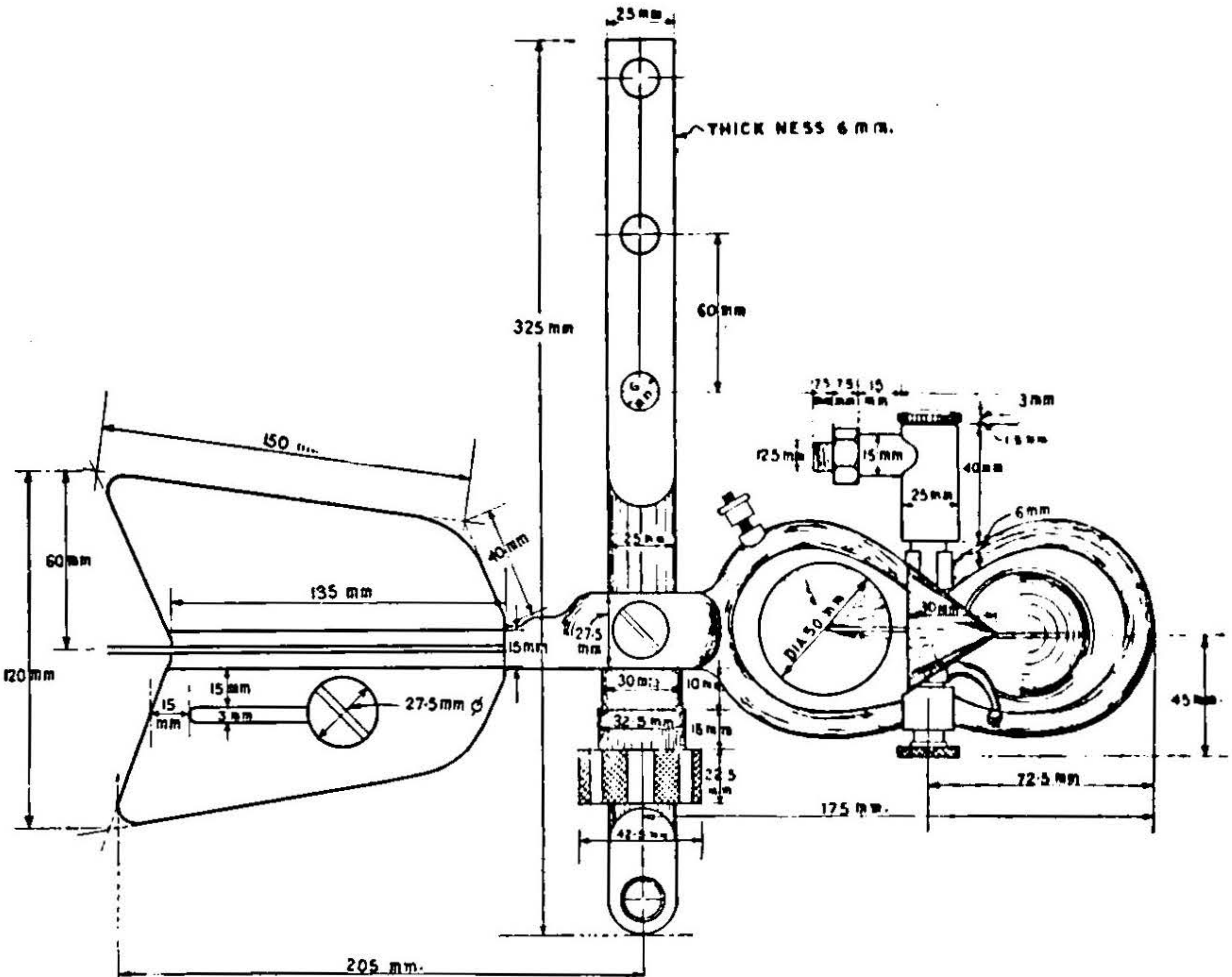

Fig 1 : Watts Currentmeter No. 91891 (not to scale)

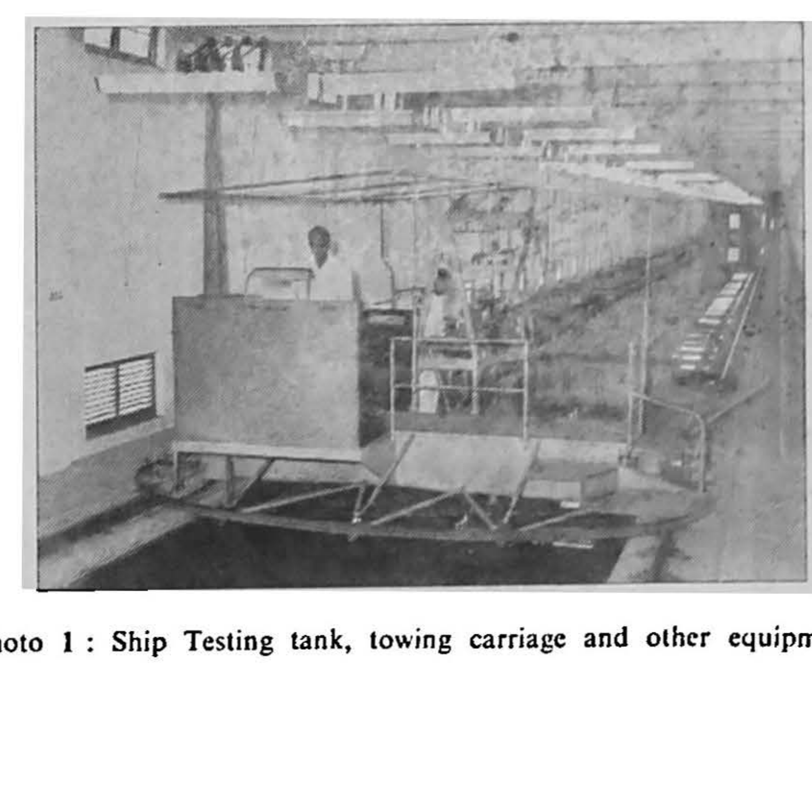

Photo 1 : Ship Testing tank, towing carriage and other equipments

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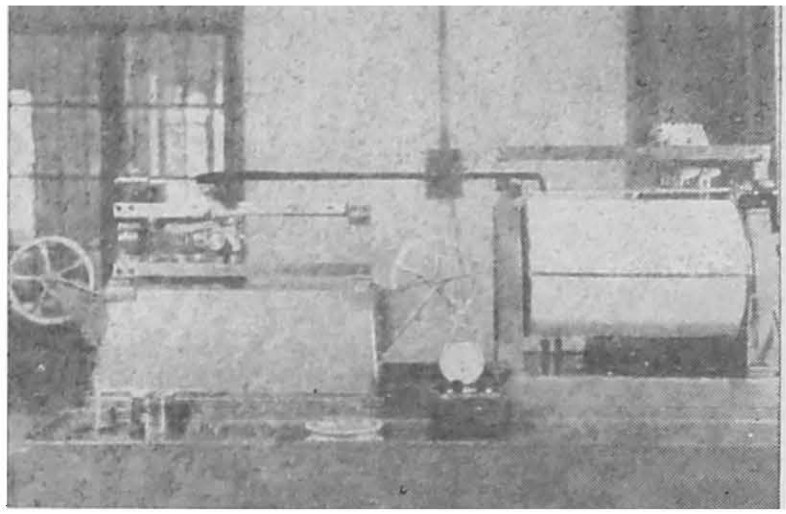

Photo 2 : Automatic recording equipment is shown at the right

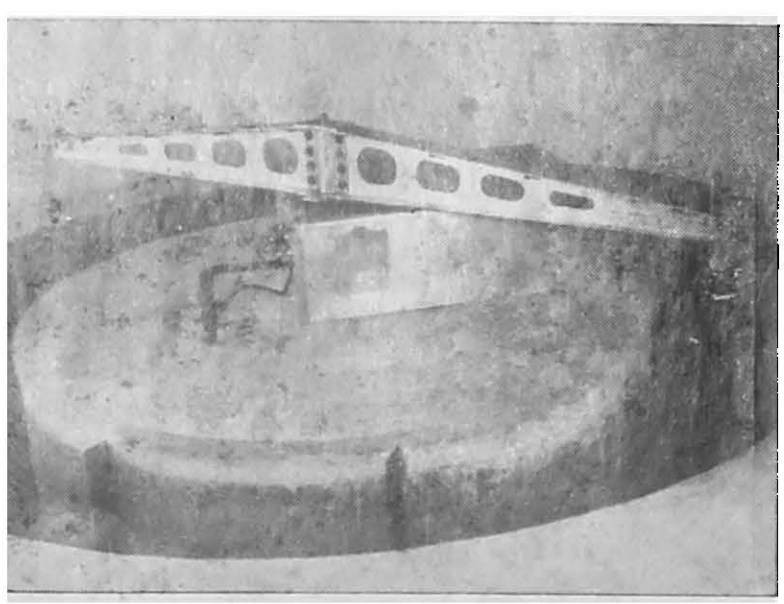

Photo 3 : Circular rating tank

of an Electronic Speed Control arrangement can run on the rails at any constant speed(s) between 0.2 to 20 ft(or .06 to 6m) per sec(photo 1). An Automatic Recorder(photo 2) fitted on board keeps the continuous data of the time, distance and the revolutions of the currentmeter wheel during the runs of the carriage.

The extent of boundary effects up to different distances was investigated by a series of experimental ratings made in this tank.

It was difficult to raise and lower the temperature of water over the desired range in the large tank. For the purpose of ratings under regulated temperature conditions, therefore, the experiments were confined to the SMALL-FIXED circular tank of rectangular section 15 inch wide and 17 3/4 inch deep having a central radius of 3 ft (photo 3). An arm provided at the centre of the tank rotates at different velocities through a gear box by a synchronous motor(fig 2). Baffles are provided at eight radial positions in the tank to prevent water from acquiring circular motion during calibrations.

The experimental calibrations made in the two tanks for evaluating the effects of controlled variations of temperature and boundary, their procedure, the data collected, their analysis and the conclusions drawn are described in the following paragraphs.

TEMPERATURE EFFECT

4. The procedure adopted for regulating the temperature(T) of water in the circular tank is described first.

Initially the temperature of water in the circular tank was brought down to about 3°C by adding ice. Water was then fully stirred to ensure uniformity of temperature and absence of differential currents on account of temperature difference. Care was taken that no circulation or residual velocity was present in the tank on account of stirring. Temperature of water was allowed to rise gradually to the room temperature of 23.6°C. It was noted that the time taken for each degree of rise of temperature was between 30-50 minutes. This ensured that the variation of temperature during the period of observation(3-5 minutes) was less than 0.1°C. Calibrations were next done with the rise of temperature from 3°C to room temperature as described above.

Temperatures of water higher than the room temperature were produced by heating water electrically at three different places and stirring it constantly to ensure uniformity of temperature. Actually, temperature readings of water were taken at 8 different points along the perifery of the tank, and all inter-se differences were within a variational latitude of 0.1°C.

5. OBSERVATION OF DATA

With these arrangements of temperature(T) control, a set of experimental calibrations were made of one pygmy-type Gurley currentmeter (No 541273)for assessing the effect of changing temperature of water. A 12-inch constant depth of water was maintained in the tank all through and the currentmeter immersed to a constant depth of 3 inches under water. The currentmeter was rated six times under six different controlled ranges of temperature of

5-6, 13-14, 20-21, 27-28, 34-35 & 39-40°C

covering between them nearly the full range of water temperatures in Indian streams. For each rating five sets of the R, V data were obtained at five speeds of

2.61, 1.44, .86, .51 and .29 ft/sec

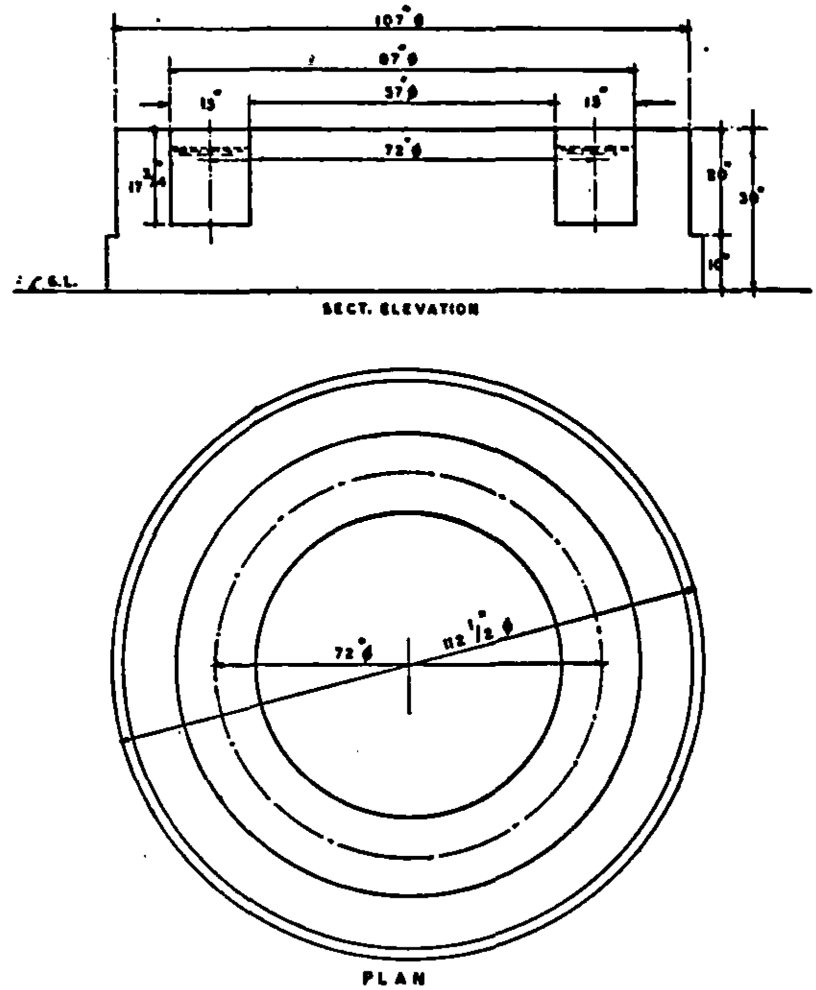

Fig 2 : Circular Tank for Midget Currentmeter

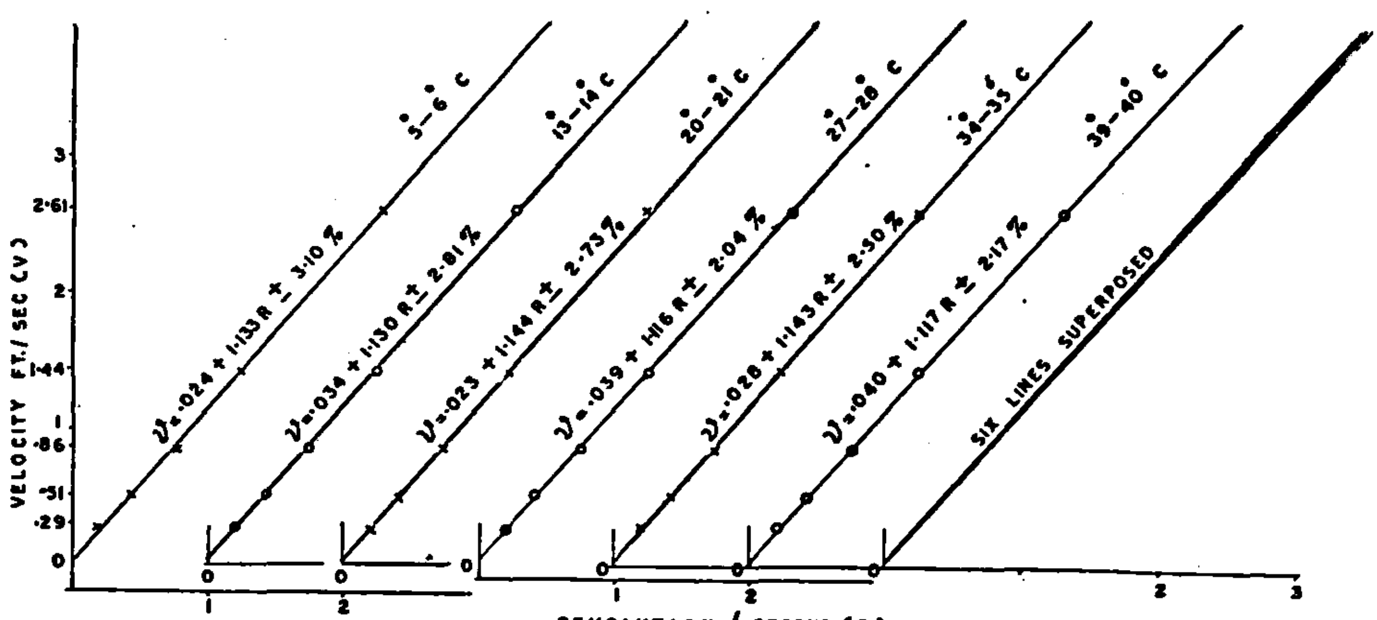

Fig 3 : Rating expressions ($V = a + bR$) for Pygmy type Gurley Currentmeter No. 541273 calibrated in circular tank at different temperatures

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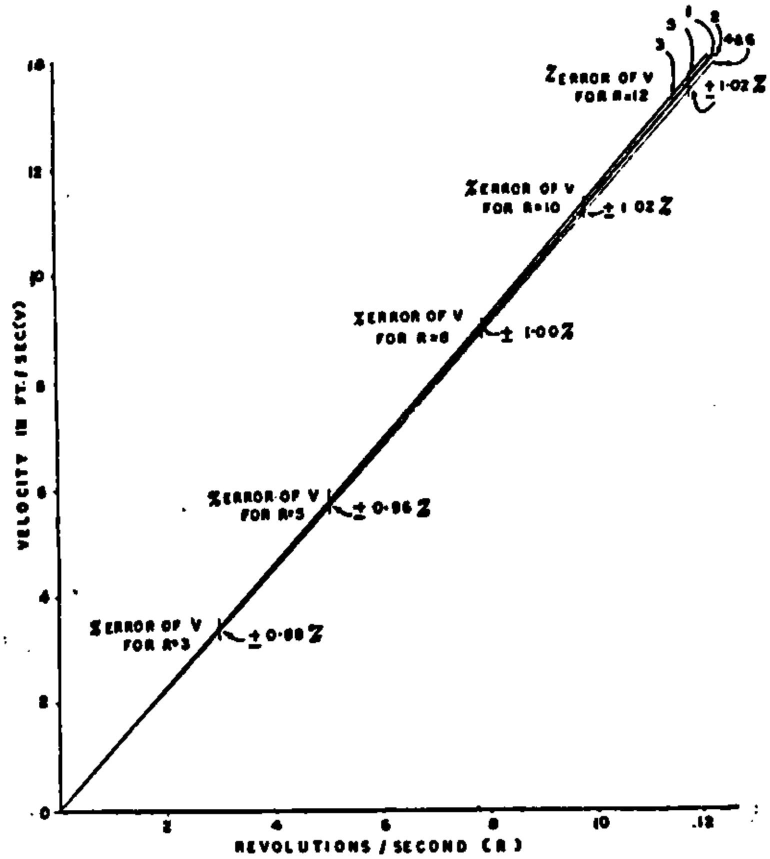

Fig 4 : Extensions of rating expressions for $V > 2{\cdot}16$ *ft / sec.* (*i e* outside observed range)

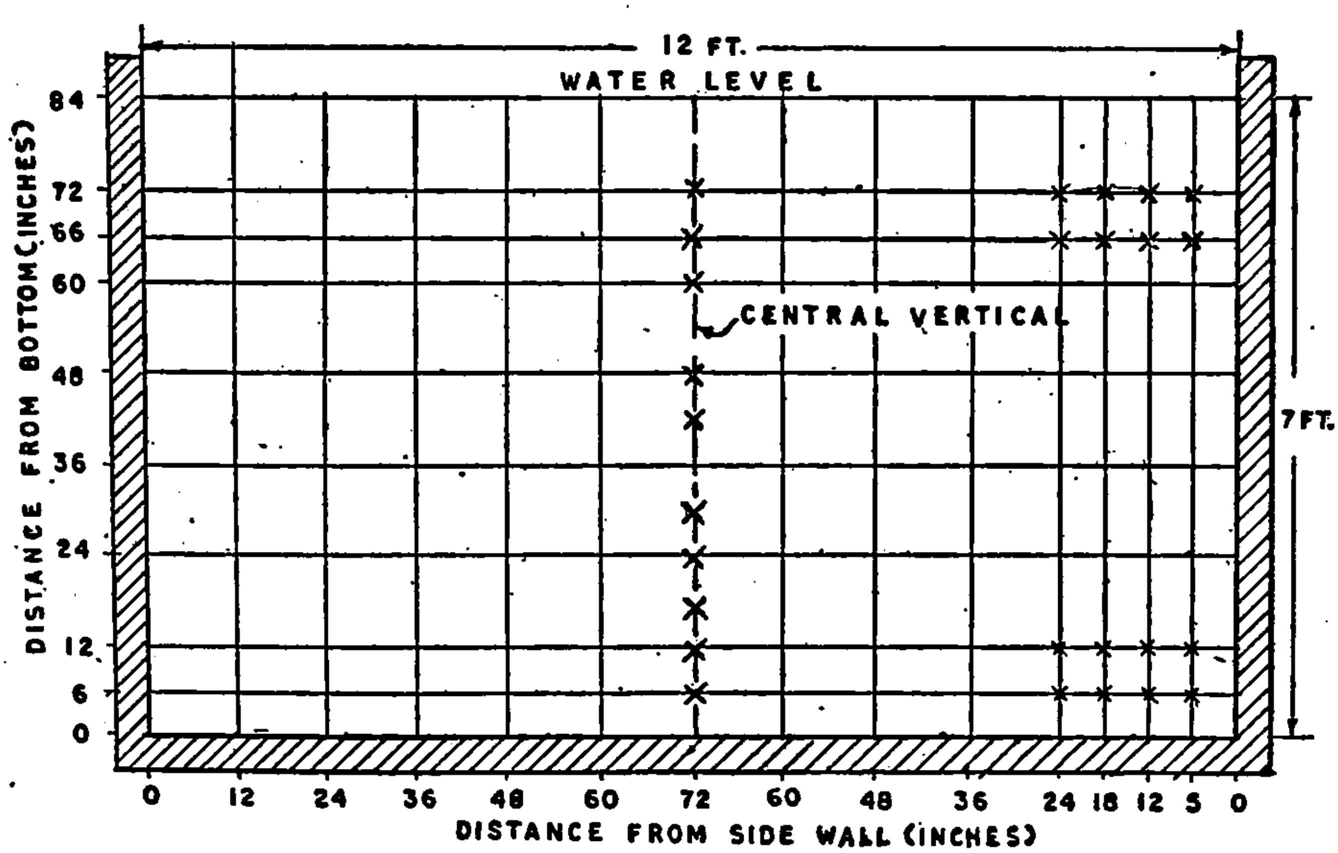

Fig 5 : Cross-section of Ship model testing tank showing immersion positions of Currentmeter for calibrations looking towards the end of the tank.

Observations of V and R were started only after the currentmeter had completed two revolutions of the circular tank and stable conditions were reached. Following procedure was adopted thereafter.

For each separate run of the currentmeter the time intervals taken for five complete rounds of the tank were observed repeatedly until their two successive values(t) were obtained as nearly identical. The number of revolutions recorded of the currentmeter wheel were also counted for equal intervals of time(t_o) until two successive counts(n) were steady. The values of V and R for the 30 runs so made with different combinations of the six constant temperature ranges and the five speeds were derived from

$$V = \frac{\text{Length of five rounds}}{t} \quad \text{and} \quad R = \frac{n}{t_o}$$

and set in Table 1 below:

Table 1 : Values of R

V \ T(°C):	5-6	13-14	20-21	27-28	34-35	39-40	Maximum % variation of R
1	2	3	4	5	6	7	8
2.61	2.270	2.270	2.250●	2.300+	2.250*	2.300●	2.22
1.44	1.256+	1.247	1.245	1.247	1.236*	1.242	1.62
0.86	0.772+	0.763	0.758	0.761	0.755*	0.761	2.25
0.51	0.430	0.422*	0.430+	0.423	0.424	0.423	1.89
0.29	0.206	0.201*	0.206	0.209+	0.206	0.208	3.98

● Obtained for V = 2.60 ft/sec
\+ Maximum value of R
* Minimum value of R

6. ANALYSIS OF DATA

The analysis of such data usually proceeds by fitting expressions of the type $V = f_1(R)$. . . . . . . $V = f_6(R)$ to the six sets of the data respectively for the six ranges of temperature values. Preliminary to this, however, plot of the (R,V) data vide fig 3 showed a fairly linear lie of the five points in all the batches separately. On evaluating exact expressions, the dispersions of the individual points about the respective lines are seen to go up to ±3%. Subject to this measure of observed variability, the six lines all drawn against a common pair of coordinate axes in fig 4 show themselves as very nearly coalescent over the length of the observed data. In other words the linear expressions descriptive of the R, V relations($.29 \leq V \leq 2.61$) are not appreciably different from each other for temperature variations between 5-40°C. Col 8 of Table 1 shows the maximum percentage variation of revolutions for different velocity values. It will be observed that this variation is of the order of about 2% except in the case of lowest velocity of 0.29 ft/sec, which is very small and boosts up the difference.

Thus the variation in revolutions for the range of temperature tested is within the tolerance limit for rating of currentmeters. Independent statistical analysis of variance carried out for evaluating the rating expressions also confirms that the effect of temperature variations from 5-40°C on the R, V data is not significant as under:

From variations of	Degrees of freedom	Sum of squares	Mean square	Standard Deviation ft/sec	Conclusion
Temperature	5	0.000809	0.000162	.013	Insignificant
Velocity	4	16.185443	4.046361	2.012	Significant
Error	20	0.002215	0.000111	.011	
Total	29	16.188467			

Thus the standard deviation measure of the velocity values due to temperature variations namely .013 ft/sec equals only about half percent for V = 2.6 ft/sec and 4.5% for V = .29 ft/sec.

7. EXTRAPOLATIONS

But the limitations particularly in respect of the small range of variation of the observed velocity data was rather serious. The inference drawn about the invariability of the V, R relation will have little importance, if similar invariability did not hold for the higher velocities as well. Higher velocity runs could not be made in the circular rating tank due to limitations already mentioned. Thus pending further observations an inductive approach was made to see if it could provide an answer.

Normally velocity encountered in stream gauging does not exceed 14 to 15 ft/sec. When the lines for the six sets of expressions in fig 4 are extended to a velocity of 14 ft/sec the maximum inter-se difference in the region of 14 ft velocity/sec is found to be sensibly small, limited to ±1% only.

Thus, despite the six expressions having been derived from observed data of only five points each from the lower values of V not exceeding 2.61 ft/sec, their divergence within a strictly narrow band in upper reaches of the R-V field indicates that in case of higher velocities also, the effect of Temperature on rating may not be of any consequence.

BOUNDARY EFFECT

8. EXPERIMENTAL PRECAUTIONS

Experiments were undertaken for investigation of boundary effects in the larger Ship Model Testing Tank. The following precautions were taken to ensure freedom from any experimental variations:

(1) The currentmeter was oiled and cleaned before each set of runs.

(2) Spin tests of the currentmeter was taken regularly before beginning each set of runs to ensure that friction in the bearings was minimum. While the spin

test gave a period of at least 90 seconds many ratings were carried out with spin-test values of 100 seconds and more up to 140 seconds. This ensured that the effect of friction at velocities of 1 ft/sec was negligible.

(3) The currentmeter was held tightly to the carriage by securing it at 2 points so that vibrations due to suspension of rod were reduced to the minimum.

(4)* Sufficient interval of time was allowed to lapse between two consecutive runs in order to induce stillness to the water mass in the tank and so ensure freedom from disturbance to the following run.

9. DESIGN OF THE EXPERIMENT

Twenty positions of immersing the currentmeter during its experimental runs in the tank comprised of points at four depths along each of the five selected verticals vide fig 5. All the 20 positions were selected from a half portion of the cross-section, as their symmetry about the central vertical suggests similar V-R behaviour over the second half also. The observations for any individual vertical will be capable of yielding separately information about the influence of the nearness of the bottom. Similarly the observations along any one depth

---

* When a run is taken in a tank for rating a currentmeter, waves and drift are generated. It takes certain time for this disturbance to reduce to a reasonably low value before next run can be taken. These intervals were actually decided from a separate experiment in which the absence of movements in water were checked by observing the reflection of 4.0 ft long fluorescent tube suspended about 13.0 ft from the surface of water. The movement of the image of the tube is greatly exaggerated, if the water has even the slightest movement. With a view to minimise the effect of any residual disturbance and make its effect equal on all calibrations, definite intervals were allowed between successive runs at different speeds as given below:

These were maintained in all the experiments that are described in the note.

Velocity (ft/sec)	1	1.5	2	2.5	3	4	5	6	7	8
Time interval (minutes)	3	3	3	5	5	6	9	11	14	16

on the five verticals can also yield information about the influence of the nearness of side wall; these may again differ for the 4 different depths. The advantage of this method of collection of data lies in the utilization of a large number of compounded observations to yield information on each feature of investigation and their interaction of differ- combinations. For example, whenever disproportionately increased bias due to depth is obtained along some verticals alone, the feature will be properly highlighted by the interaction mean square term in the analysis of variance.

10. OBSERVATIONS

A constant depth of 7-0 ft of water was maintained in the tank and a Watt currentmeter (No 91891) was used for the experimental ratings. Following series of tests were conducted:

(1) Currentmeter held in the centre of the tank and velocities observed at 6, 12, 66 and 72 inches above the bed

(2) Current meter held at 5, 12, 18 and 24 inches from the side wall of the tank and the velocity observations made in each case at 6, 12, 66 and 72 inches above the bed

(3) Additional tests with currentmeter at the centre of the tank and velocities observed at 6, 12, 18, 24, 30, 42, 48, 60, 66 and 72 inches above the bed

For evaluating rating expressions corresponding to 20 different positions replicate observations were made vide items (1)&(2) above. About 10 runs were made for each by running the carriage at different velocities between $0.95 < V < 8.44$ ft per second.

11. ANALYSIS OF DATA

The numerical values of the R and V for all the several runs are reproduced in Appendix 1 and shown plotted in fig 6. Straight line expressions evaluated by the method of least squares are drawn on the respective sets to show their goodness-of-fits. The average departures of individual points from the respective lines do not exceed about 3% except in a single case when it goes up to 6.9% for the extreme immersion position viz six inches from the bottom and five inches from the side of the tank. The large departure may more probably be ascribed to some mechanical maladjustment during the experiment rather than to the immersion position.

12. DIFFERENCES BETWEEN REPLICATE CALIBRATIONS

Replicate ratings for each different position were made solely to provide the measure of consistency between repeated calibrations, other things being equal.

The paired presentation of replicate lines in fig 6 discloses very effectively the varying degrees of their coalescence generally. These random differences between repeated calibrations usually provide the base for computing the upper limits which normal differences between calibrations for different positions should not exceed.

If there were no differences between replicate calibrations or between calibrations for different immersion positions of the currentmeter, the values by the 40 lines for R = 1 (and similarly 3 or 5) should all be identical. The format of Table 2 offers a means for examining as well as for computing the concrete differences between replicate calibrations or calibrations with positions of other features in common. Thus, for example a glance at the mean values line discloses the steadily-decreasing trend for decreasing depths of immersion of the currentmeter.

Nearly similar variation of the side effect is also perceivable in the series of the mean values in Table 2 for different horizontal distances from the side wall. Thus, when the currentmeter is closest

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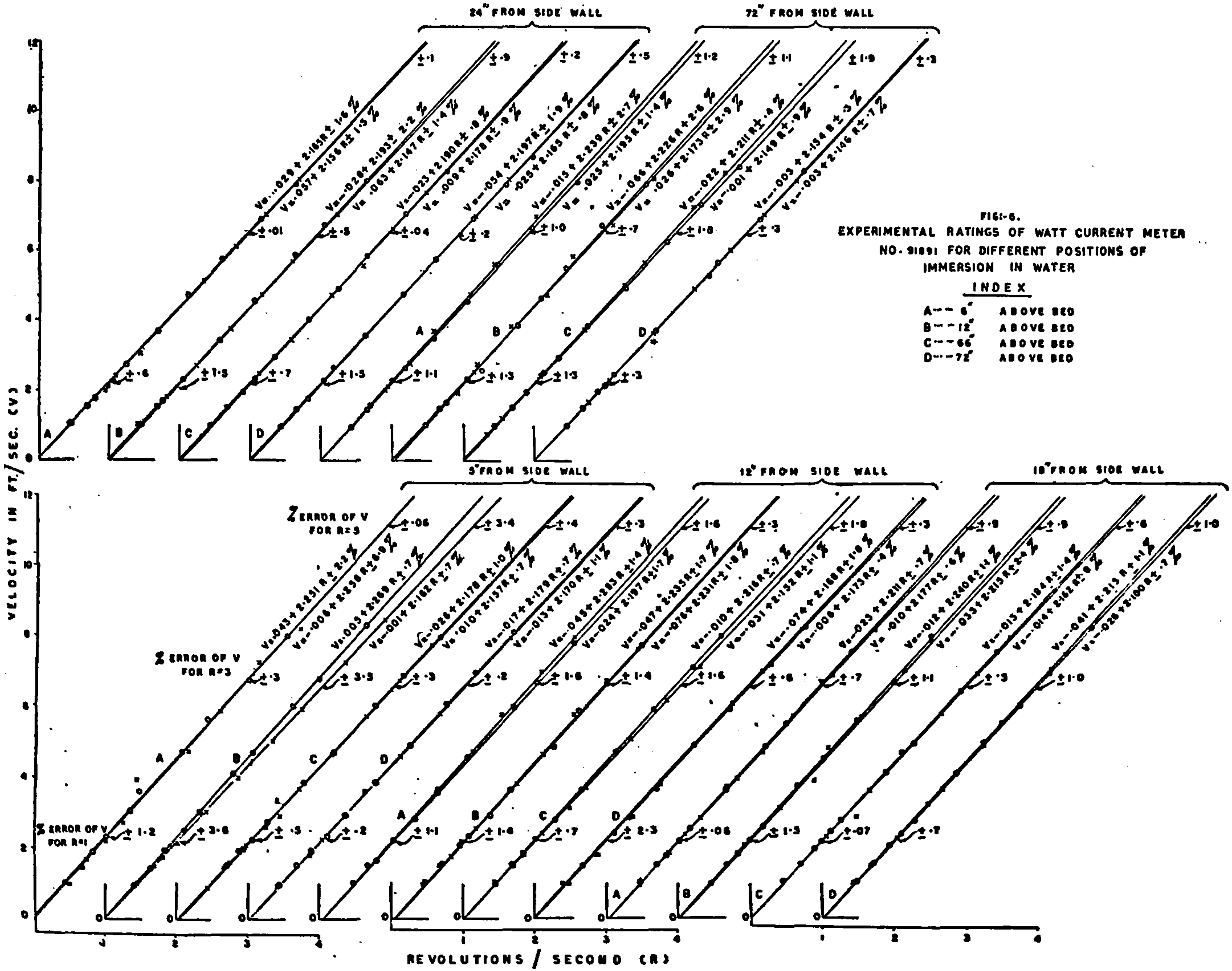

FIG. 6.
EXPERIMENTAL RATINGS OF WATT CURRENT METER NO. 91891 FOR DIFFERENT POSITIONS OF IMMERSION IN WATER

Table 2 : Values of V from rating expressions for different immersion positions of the currentmeter

Distance from side wall (inches)	R=1					R=3					R=5				
	DISTANCE FROM BOTTOM (INCHES)														
	6	12	66	72	Mean	6	12	66	72	Mean	6	12	66	72	Mean
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
5	2·293	2·273	2·167	2·162		6·795	6·810	6·481	6·519		11·297	11·348	10·794	10·876	
	2·253	2·161	2·151	2·137	2·202	6·770	6·485	6·506	6·497	6·608	11·287	10·809	10·862	10·837	11·014
12	2·173	2·154	2·206	2·169		6·567	6·616	6·637	6·520		10·961	11·077	11·068	10·870	
	2·207	2·186	2·184	2·242	2·190	6·713	6·652	6·488	6·579	6·597	11·218	11·118	10·793	10·915	11·003
18	2·185	2·228	2·176	2·154		6·606	6·709	6·500	6·515		11·028	11·190	10·823	10·815	
	2·187	2·180	2·174	2·175	2·182	6·541	6·610	6·542	6·605	6·578	10·894	11·041	10·910	11·035	10·974
24	2·194	2·165	2·187	2·190		6·525	6·551	6·542	6·520		10·855	10·936	10·898	10·849	
	2·213	2·210	2·166	2·144	2·184	6·524	6·504	6·546	6·538	6·531	10·835	10·798	10·925	10·933	10·879
72	2·220	2·160	2·150	2·143		6·609	6·612	6·448	6·434		10·999	11·063	10·747	10·725	
	2·224	2·199	2·189	2·152	2·180	6·703	6·545	6·611	6·460	6·553	11·182	10·892	11·033	10·769	10·926
Mean	2·215	2·192	2·175	2·169	2·188	6·635	6·609	6·530	6·519	6·573	11·056	11·027	10·885	10·868	10·959
Marginal random difference between two: Mean V's				·024	·026			·061		·068			·113		·126
Marginal random difference between two: Unit V's				·074				·192					·356		

From variations of	Degrees of freedom	Sum of squares (R=1)	Mean square (R=1)	Sum of squares (R=3)	Mean square (R=3)	Sum of squares (R=5)	Mean square (R=5)
Dist. from bottom	3	·012823	·004274 significant	·099995	·033332 significant	·275158	·091719 significant
Dist. from side	4	·002641	·000660	·031569	·007892	·101301	·025325
Residual I	32	·032216	·001007	·201933	·006310	·609967	·019061
Residual II	36	·034858	·000968 s=·031	·233502	·006486 s=·081	·711268	·022227 s=·149
Total	39	·047680	=±1·42%	·333498	=±1·23%	·986426	=±1·36%

to the side wall, higher velocities are again registered for same R's. But the side effect does not continue in a steady sense beyond a 5 inches distance. The casual differences noticed between the mean values for other distance of 12, 18 and 24 inches from the side wall are not larger than what may be expected between repeated calibrations for any random immersion position.

For the comparison of overall means for R = 1, R = 3 and R = 5 vide cols 6, 11 and 16(Table. 2) with the mean values for observations at 6 and 12 inches from the bottom vide cols 2, 3, 7, 8, 12 and 13 and at 5 and 12 inches from the side, vide items 1 and 2 of cols 6, 11 and 16 values are extracted as under:

		Mean velocity($\bar{V}$) and its difference for distance from: bottom 6"	bottom 12"	side wall 5"	side wall 12"	All distances mean velocity V_o
	$\bar{V}$	2.215	2.192	2.202	2.190	2.188
R = 1	Difference $\bar{V}-V_o$	.027	.004	.014	.002	
	% difference to V_o	1.23	.18	.64	.09	
	$\bar{V}$	6.635	6.609	6.608	6.597	6.573
R = 3	Difference $\bar{V}-V_o$	.062	.036	.035	.024	
	% difference to V_o	.94	.55	.53	.36	
	$\bar{V}$	11.056	11.027	11.014	11.003	10.959
R = 5	Difference $\bar{V}-V_o$	.097	.068	.055	.044	
	% difference to V_o	.89	.62	.50	.40	

Thus

(1) For the 6 inches position above bottom the mean velocity estimates may be subject to an upward variation between 0.9 to 1.23%.

(2) For the 12 inches position from bottom the effect remains between 0.18 to 0.62%.

(3) For positions of 5 inches from the side wall the mean velocities may be similarly subject to an upward bias ranging between 0.5 to 0.64%.

(4) For the 12 inches position from side wall the velocities will vary between 0.09 to .4%.

The broad inferences above are confirmed as correct by exact analyses-of-variance subjoined in Table 2.

The percentage standard error differences between the respective pairs of V's in Table 2 for all replicate calibrations are shown in fig 6. Their numerical magnitudes generally do not exceed 1.5% except for only one position(12 inches from bottom and 5 inches from side wall) when the replicates have a standard error equal to about 3.5%. But a minute scrutiny of the data has disclosed that the rating runs for one of the two sets for the supposed position of 12 inches from bottom might in all probability have been made at the 6 inches position.

Pooling the primary data of all depths positions for each fixed distance from the side wall separately the five mean lines respectively obtaining are drawn in fig 7. Similarly the 4 mean lines computed from all primary data for each of the 4 different depths irrespective of the positions distances from side wall are also shown as a separate set. The two sets of mean lines together provide a graphical demonstration of the larger dispersion due to the effects of different distances from the bed than of similar effects from the side wall. Obviously, further observations were necessary for investigating the depth at which the bottom effects were the least if not totally absent.

13. ADDITIONAL OBSERVATIONS ALONG CENTRAL VERTICAL

Fresh observations were therefore made as stated in para 11 supra with their scope limited to the central vertical only, as side effects had been found totally absent along three verticals close to the side wall and nearly absent at 5 inches distance. The primary data of the R, V values for the different rating runs made for 6 repeated calibrations for 10 different depths of immersion respectively at 6, 12, 18, 24,

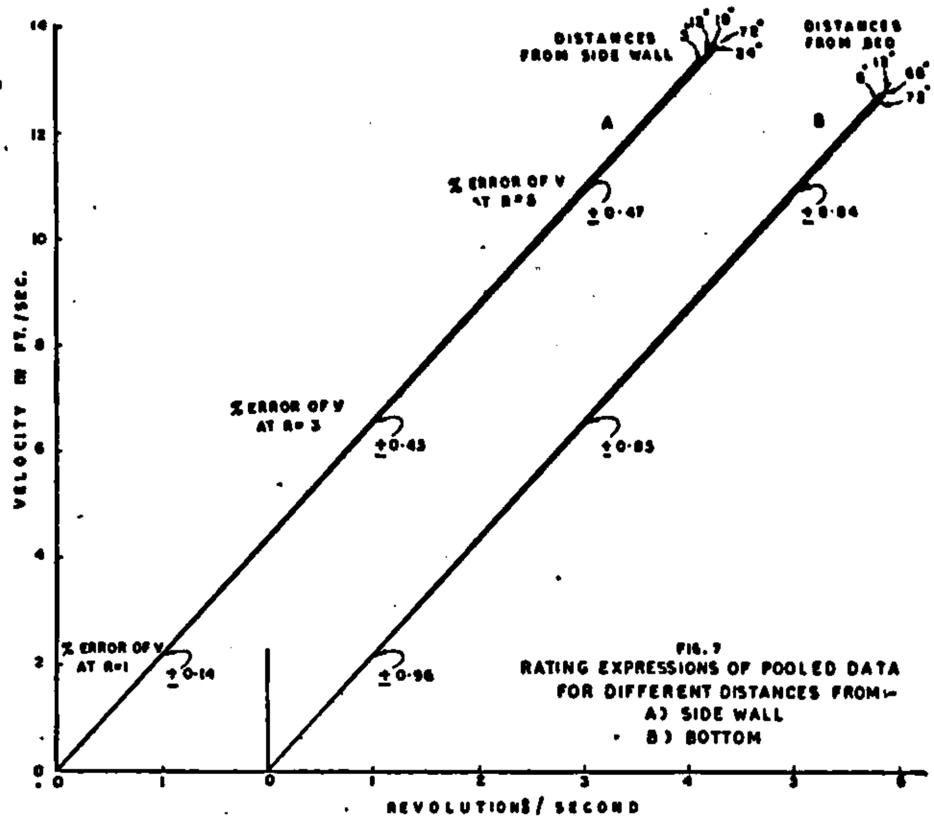

FIG. 7
RATING EXPRESSIONS OF POOLED DATA FOR DIFFERENT DISTANCES FROM:—
A) SIDE WALL
B) BOTTOM

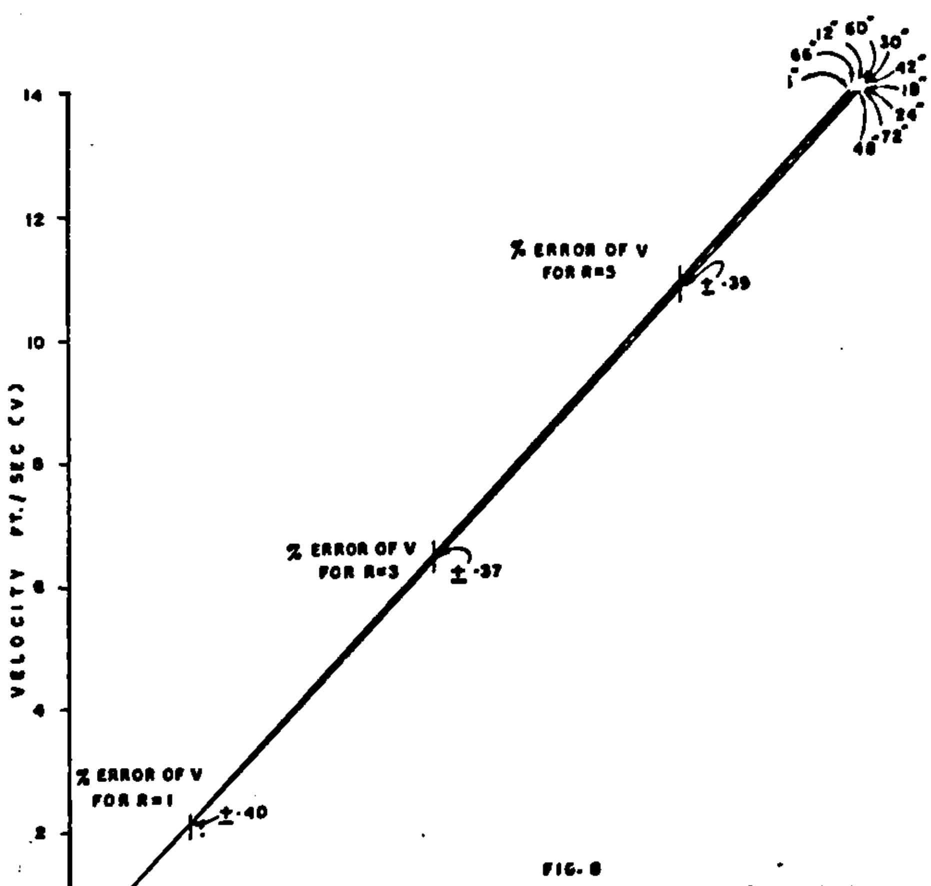

FIG. 8
RATING EXPRESSIONS FOR 10 IMMERSION POSITIONS ALONG CENTRAL VERTICAL

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Table 3 : Values of V from rating expressions for different immersion positions of currentmeter along central vertical

Distance from bottom (Inches)	R=1							R=3							R=5						
	REPLICATES																				
	1	2	3	4	5	6	Mean	1	2	3	4	5	6	Mean	1	2	3	4	5	6	Mean
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
6	2·220	2·223	2·182	2·159	2·181	2·188	2·192	6·609	6·618	6·544	6·552	6·562	6·539	6·571	10·999	11·013	10·906	10·946	10·943	10·891	10·950
12	2·160	2·199	2·159	2·226	2·168	2·183	2·183	6·612	6·545	6·463	6·548	6·551	6.515	6·539	11·063	10·892	10·767	10·870	10·933	10·847	10·895
18	2·154	2·214	2·142	2·180	2·174	2·197	2·177	6·468	6·585	6·452	6·482	6·538	6.544	6·512	10·781	10·957	10·763	10·784	10·902	10·890	10·846
24	2·157	2·199	2·165	2·185	2·181	2·180	2·178	6·519	6·513	6·489	6·512	6·519	6.494	6·508	10·881	10·826	10·813	10·839	10·857	10·809	10·838
30	2·179	2·188	2·181	2·177	2·208	2·194	2·188	6·584	6·564	6·557	6·480	6·520	6.497	6·534	10·990	10·940	10·933	10·782	10·832	10·801	10·880
42	2·176	2·150	2·141	2·195	2·210	2·145	2·169	6·471	6·456	6·442	6·661	6·678	6·453	6·527	10·766	10·763	10·743	11·127	11·146	10·761	10·884
48	2·158	2·159	2·173	2·173	2·192	2·158	2·169	6·469	6·466	6·457	6·498	6·641	6·469	6·500	10·781	10·768	10·741	10·824	11·090	10·779	10·830
60	2·171	2·209	2·156	2·158	2·157	2·135	2·164	6·538	6·573	6·534	6·524	6·535	6·454	6·527	10·904	10·937	10·912	10·890	10·914	10·718	10·890
66	2·150	2·189	2·213	2·180	2·159	2·185	2·179	6·448	6·611	6·629	6·562	6·532	6·590	6·562	10·747	11·033	11·046	10·944	10·904	10·995	10·945
72	2·143	2·152	2·201	2·175	2·153	2·178	2·167	6·434	6·460	6·532	6·558	6·482	6·540	6·501	10·725	10·769	10·864	10·942	10·811	10·901	10·835
Mean							2·177							6·528							10·879
Marginal random difference between two: mean V's							·022							·056							·099
unit V's							·053							·138							·242

From variations of	Degrees of freedom	Sum of squares	Meam square		Sum of squares	Mean square		Sum of squares	Mean square	
Distances	9	·004594	·000510		·032152	·003572		·100774	·011197	
Residual	50	·024808	.000496		·168112	·003362		·519691	·010394	
Total	59	·029402	·000498	s=·022 =±1·01%	·200264	·003394	s=·058 =±·89%	·620465	·010516	s=·102 =±·94%

30, 42, 48, 60, 66 and 72 inches are reproduced in Appendix II.

Table 3 shows three sets of V's as before for R = 1, 3 and 5 together with their respective analyses-of-variance. Study of mean value lines for the 3 sets of velocities shows that bottom effects do not perceivably continue beyond more than 12 inches as inferred from the mean value lines in table 2.

At the central vertical mean velocity at 6 inches above bottom may be subject to a maximum variation of 0.67% and the difference at 12 inches above bottom is not likely to exceed 0.27%.

Thus, the mean V's for only two positions distant from the bottom by not more than 12 inches are consistently higher than the rest. The higher mean V's uniformly obtaining for the position 66 inches from bottom seem to be more casual than systematic, as no similar tendency is observed for the positions 72 inches or 60 inches from the bottom.

Fig 8 shows the 10 mean lines separately evaluated for the 10 depths each by pooling all the respectively replicate ratings data. The compact lie of the 10 lines, indicates the very negligible bottom effects on currentmeter ratings at different heights above 12 inches along the central vertical.

14. CONCLUSIONS

From a set of observed data of experimental calibrations of a pygmy-type currentmeter with 2 inch diameter bucket wheel towed at a circular rating tank the following conclusions can be derived:

<u>Temperature effect</u>

i) Under constant temperature conditions, R-V relations are sensibly linear for $.89 < V < 2.61$ ft/sec subject to standard deviation random variations of 3%.

ii) Estimates of V deduced from different relations for $5^{o} < T < 40^{o}C$ have a $\pm$ standard deviation variability between them not exceeding 1%. In other words, R-V relations remain sensibly invariable to normal temperature changes.

iii) The variability measure between different R-V relations does not increase even when they may be extended beyond their observed range up to nearly V = 14 ft/sec. Thus, the invariability of the R-V relations to temperature changes is inferred also up to V = 14 ft/sec provided their linearities hold; the latter aspect is amply borne out by the voluminous data collected for the experiments in the larger towing tank.

The effect of the proximity of boundary was assessed with a Watt currentmeter having 5 inch diameter bucket wheel, in the large tank. The following conclusions were drawn:

<u>Boundary effect</u>

iv) The linearity of the R-V relations for $.75 < V < 8.5$ ft/sec holds for all positions of immersing the currentmeter in the towing tank, subject to $\pm$ standard deviation random variations of 3%.

v) Estimates of V from replicate ratings expressions, other conditions being equal, have a $\pm$standard deviation random variability between them not exceeding 1.5%.

vi) Estimates of V from rating expressions for different immersion positions more than 5 inches from side wall or 12 inches from bottom also have comparable $\pm$standard deviation variability and are less than 1.5%.

vii) For the 6 inches position above bottom the mean velocity estimates may be subject to an upward bias of from 0.9 to 1.2%. At the central vertical the bias is of the order of .67%.

For the 12 inches position from bottom the bias remains between .2 to .6%.

For positions of 5 inches from the side wall the mean velocities may be similarly subject to an upward bias ranging between .5 to .64%.

For the 12 inches position from side wall the bias varies between .1 to .4%.

viii) From conclusions (v) to (vii) it follows that current meter observations in the field as well as calibration in the rating tank will be subject to a negligible boundary effect(which will be less than 0.6%) provided the velocities are observed at a distance of not less than 12 inches from the sides as well as bottom.

ix) An error up to 1.2% may be expected if velocity observations are taken six inches above the bottom and 5 inches from the side.

APPENDIX I

Revolutions (R) / sec and velocity (V) ft / sec observed for experimental calibration runs of Watts type currentmeter No 91891

Distance from side wall (inches)	DISTANCE FROM BOTTOM (INCHES) 6				12				66				72			
	REPLICATE 1		2		1		2		1		2		1		2	
	R	V	R	V	R	V	R	V	R	V	R	V	R	V	R	V
	·44	·99	·50	1·00	·43	·98	0·46	1·01	·70	1·54	·44	·95	·46	1·01	·43	·98
	·66	1·47	·69	1·50	·64	1·47	0·69	1·51	·88	1·93	·68	1·49	·69	1·52	·69	1·47
	·85	1·93	·76	1·66	·86	1·95	0·82	1·79	·91	1·99	·76	1·61	·89	1·91	·87	1·81
	1·03	2·33	1·02	2·22	1·12	2·52	1·01	2·18	1·05	2·27	·96	2·10	1·10	2·38	1·03	2·24
5	1·35	3·06	1·28	2·74	1·33	3·02	1·41	3·03	1·28	2·74	1·26	2·65	1·35	2·89	1·35	2·90
	1·50	3·61	1·45	3·94	1·80	4·07	1·86	3·98	1·78	3·87	1·71	3·69	1·77	3·83	1·64	3·59
	2·07	4·71	2·16	4·70	2·07	4·67	2·34	5·01	2·19	4·67	2·17	4·66	2·24	4·83	2·12	4·54
	2·43	5·60	2·60	5·86	2·62	6·00	2·73	5·93	2·77	5·96	2·62	5·66	2·77	6·00	2·66	5·76
	3·01	6·73	3·16	7·26	2·97	6·76	3·34	7·24	3·16	6·83	3·11	6·78	3·17	6·91	3·14	6·84
	3·53	7·95	3·71	8·21	3·64	8·23	3·90	8·44	3·68	7·96	3·56	7·74	3·70	8·08	3·66	7·92
	·47	1·01	·46	1·02	·48	1·01	·44	·97	·43	·97	·43	1·02	·46	1·01	·40	1·03
	·67	1·50	·68	1·53	·69	1·51	·66	1·48	·68	1·52	·67	1·52	·68	1·49	·66	1·53
	·78	1·64	·81	1·74	·96	2·05	·83	1·77	·82	1·81	·81	1·76	·84	1·82	·87	1·87
	1·02	2·21	1·08	2·40	1·06	2·30	·98	2·15	1·03	2·28	1·13	2·44	1·11	2·40	1·06	2·49
12	1·32	2·80	1·26	2·72	1·38	2·91	1·20	2·57	1·30	2·82	1·50	3·17	1·33	2·86	1·36	2·91
	1·63	3·54	1·63	3·63	1·65	3·64	1·74	3·81	1·66	3·68	1·73	3·74	1·70	3·67	1·76	3·83
	2·02	4·52	2·11	4·66	2·25	4·83	2·13	4·63	2·14	4·73	2·36	5·11	2·25	4·90	2·26	4·95
	2·70	5·96	2·53	5·76	2·61	5·86	2·55	5·76	2·67	5·92	2·87	6·18	2·72	5·91	2·77	6·10
	3·05	6·64	3·10	6·93	3·03	6·67	3·02	6·75	3·24	7·14	3·31	7·17	3·30	7·18	3·20	7·02
	3·56	7·76	3·57	7·99	3·51	7·78	3·48	7·67	3·62	8·04	3·85	8·35	3·80	8·26	3·75	8·23
	·47	1·04	·45	1·00	·45	1·01	·46	1·02	·46	1·07	·46	1·00	·47	1·02	·45	·99
	·69	1·53	·68	1·49	·68	1·52	·68	1·52	·69	1·51	·69	1·50	·71	1·53	·68	1·48
	·83	1·79	·87	1·87	·83	1·84	·85	1·87	·90	1·94	·89	1·92	·95	2·05	·96	2·08
	1·01	2·20	1·12	2·44	1·00	2·21	·94	2·09	1·00	2·13	1·08	2·32	1·11	2·39	1·06	2·28
18	1·17	2·53	1·33	2·89	1·19	2·60	1·44	3·15	1·13	2·42	1·13	2·44	1·29	2·71	1·49	3·27
	1·68	3·70	1·83	3·99	1·66	3·80	1·89	3·91	1·27	2·76	1·68	3·64	1·88	4·09	1·69	3·66
	2·21	4·85	2·18	4·76	2·03	4·52	2·20	4·83	1·89	4·10	2·12	4·76	2·27	4·93	2·26	4·90
	2·51	5·50	2·61	5·74	2·51	5·57	2·58	5·75	2·28	4·91	2·69	5·85	2·77	6·03	2·51	5·58
	3·03	6·66	3·16	6·86	3·02	6·76	3·18	7·04	2·95	6·41	3·19	6·92	3·22	6·97	3·21	7·09
	3·45	7·65	3·77	8·20	3·56	7·99	3·57	7·90	3·47	7·52	3·66	7·99	3·78	8·22	3·41	7·51
	·46	1·02	0·41	1·01	·46	1·02	·41	1·03	·45	1·00	·45	1·00	·44	·98	·45	·99
	·69	1·52	·68	1·53	·70	1·52	·67	1·51	·68	1·49	·69	1·52	·67	1·47	·69	1·51
	·81	1·76	·94	2·02	·77	1·70	·83	1·84	·90	1·96	·73	1·54	·81	1·78	·81	1·73
	1·05	2·26	·99	2·16	1·06	2·29	1·07	2·30	1·08	2·35	·94	2·04	1·05	2·28	1·04	2·29
24	1·26	2·75	1·44	3·10	1·20	2·43	1·25	2·68	1·37	2·98	1·17	2·50	1·18	2·65	1·18	2·36
	1·71	3·70	1·69	3·68	1·57	3·42	1·75	3·78	1·82	4·04	1·59	3·47	1·65	3·58	1·74	3·77
	2·12	4·72	2·34.	5·19	2·08	4·55	2·17	4·71	2·27	4·88	2·18	4·71	2·17	4·71	2·18	4·72
	2·60	5·76	2·80	6·16	2·65	5·86	2·62	5·78	2·66	5·83	2·60	5·68	2·63	5·71	2·63	5·71
	3·17	6·92	3·24	7·02	3·06	6·72	3·25	7·04	3·21	7·01	3·02	6·60	3·16	6·88	3·18	6·95
	3·67	7·87	3·72	8·02	3·68	7·97	3·69	7·98	3·79	8·25	3·49	7·65	3·61	7·85	3·66	8·03
	·44	1·00	·46	1·01	·45	·99	·46	·99	·45	·97	·34	·76	·46	1·00	·46	·99
	·67	1·49	·69	1·52	·67	1·48	·69	1·49	·70	1·50	·55	1·20	·70	1·51	·70	1·49
	·70	1·56	·92	2·01	·77	1·62	·91	1·93	·91	1·93	·91	1·97	·92	1·96	·79	1·70
	1·03	2·28	·94	2·07	1·06	2·31	1·17	2·51	1·16	2·51	1·10	2·40	1·00	2·16	1·08	2·32
72	1·19	2·61	1·27	2·73	1·28	2·59	1·20	2·74	1·37	2·93	1·33	2·92	1·16	2·46	1·16	2·49
	1·59	3·50	1·59	3·67	1·77	3·85	1·69	3·84	1·78	3·83	1·71	3·73	1·73	3·73	1·70	3·64
	2·08	4·55	2·12	4·78	2·13	4·63	2·20	4·75	2·31	4·94	2·29	5·04	2·47	5·26	2·28	4·92
	2·50	5·61	2·47	5·61	2·47	5·51	2·57	5·82	2·90	6·24	2·58	5·69	2·64	5·64	2·77	5·99
	3·00	6·65	3·63	7·93	2·98	6·70	3·13	6·74	2·36	7·29	3·27	7·22	3·19	6·87	3·25	7·00
	3·63	7·93	3·06	6·96	3·61	7·89	3·72	8·02	3·91	8·34	3·71	8·20	3·82	8·19	3·71	7·98

APPENDIX II

Revolution (R)/ sec and velocity (V) ft/sec observed for experimental calibration runs of Watts type currentmeter No. 91891 at different depths along central vertical

Distance from bottom (Inches)	REPLICATE 1		2		3		4		5		6	
	R	V	R	V	R	V	R	V	R	V	R	V
6	·44	1·00	·44	1·01	·45	·98	·47	·99	·46	1·01	·45	1·00
	·67	1·49	·82	1·82	·68	1·47	·69	1·50	·69	1·53	·65	1·49
	·70	1·56	1·17	2·57	·86	1·85	·97	2·04	·86	1·85	·92	1·97
	1·03	2·28	1·67	3·66	1·10	2·35	1·21	2·57	1·05	2·28	1·06	2·29
	1·19	2·61	2·12	4·71	1·37	2·94	1·48	3·17	1·26	2·68	1·35	2·95
	1·59	3·50	2·62	5·84	1·63	3·59	1·91	4·12	1·81	3·93	1·85	4·02
	2·08	4·55	3·22	7·10	2·20	4·87	2·17	4·78	2·15	4·72	2·16	4·76
	2·50	5·61	3·48	7·63	2·53	5·72	2·62	5·88	2·53	5·64	2·57	5·64
	3·00	6·65			3·10	6·73	3·15	6·91	3·06	6·68	3·11	6·78
	3·63	7·93			3·67	7·87	3·82	8·25	3·57	7·75	3·64	7·91
12	·45	·99	·46	·99	·36	·78	·44	·99	·45	1·00	·46	1·00
	·67	1·48	·69	1·49	·79	1·72	·77	1·73	1·14	2·50	·75	1·65
	·77	1·62	·91	1·93	1·24	2·67	1·18	2·63	1·23	2·70	1·27	2·77
	1·06	2·31	1·17	2·51	1·48	3·19	1·60	3·53	1·71	3·64	1·68	3·65
	1·28	2·59	1·20	2·74	2·14	4·59	2·07	4·53	2·15	4·55	2·13	4·62
	1·77	3·85	1·69	3·84	2·75	5·93	2·61	5·75	2·63	5·80	2·67	5·80
	2·13	4·63	2·20	4·75	3·15	6·80	3·20	6·97	3·02	6·65	2·85	6·18
	2·47	5·51	2·57	5·82	3·76	8·10	3·60	7·82	3·56	7·77	3·43	7·44
	2·98	6·70	3·13	6·74								
	3·61	7·89	3·72	8·02								
18	·45	·98	·44	·99	·44	·95	·44	·97	·44	·98	·45	1.01
	·80	1·71	·67	1·48	·86	1·84	·79	1·72	·79	1·73	·78	1·72
	1·21	2·62	·72	1·58	1·29	2·75	1·30	2·81	1·28	2·76	1·23	2·68
	1·59	3·41	1·08	2·40	1·65	3·52	1·53	3·31	1·76	3·79	1·60	3·47
	2·24	4·83	1·24	2·69	2·26	4·82	2·17	4·67	2·08	4·52	2·20	4·78
	2·61	5·62	1·68	3·65	2·61	5·66	2·67	5·83	2·81	6·08	2·63	5·77
	3·06	6·61	2·00	4·60	3·24	6·94	3·19	6·89	3·20	6·96	3·15	6·91
	3·55	7·66	2·59	5·66	3·67	7·91	3·54	7·62	3·98	8·72	3·94	8·56
			2·98	6·59								
			3·61	7·82								
24	·45	·97	·42	·98	·44	·96	·46	·99	·45	·97	·45	·99
	·80	1·73	·87	1·97	·83	1·80	·86	1·92	·85	1·86	·77	1·67
	1·24	2·66	1·25	2·67	1·20	2·62	1·24	2·70	1·19	2·59	1·17	2·57
	1·71	3·68	1·70	3·67	1·78	3·83	1·73	3·75	1·54	3·34	1·80	3·90
	2·17	4·70	2·13	4·60	2·25	4·87	2·18	4·71	2·17	4·72	2·20	4·77
	2·75	5·93	2·71	5·91	2·60	5·62	2·76	5·98	2·43	5·25	2·54	5·51
	3·07	6·76	3·00	6·55	3·29	7·10	3·04	6·67	2·94	6·47	2·89	6·28
	3·66	7·91	3·65	7·91	3·76	8·16	3·72	8·06	3·80	8·20	3·64	7·85
30	·46	1·01	·46	1·02	·45	1·00	·44	·99	·44	·99	·45	1·00
	·67	1·46	·71	1·54	·90	1·98	·79	1·73	·76	1·70	·89	1·99
	1·04	2·24	1·01	2·19	1·23	2·68	1·08	2·35	1·13	2·48	1·22	2·64
	1·14	2·46	1·15	2·48	1·82	3·94	1·62	3·50	1·76	3·87	1·76	3·83
	1·30	2·84	1·29	2·89	2·19	4·75	2·06	4·47	2·07	4·52	2·19	4·75
	1·73	3·76	1·71	3·81	2·79	6·07	2·78	5·99	2·68	5·83	2·78	6·05
	2·30	5·04	2·31	4·99	3·24	7·13	3·31	7·15	3·13	6·82	3·19	6·91
	2·71	6·06	2·65	5·81	3·77	8·24	4·01	8·66	3·83	8·30	3·60	7·76
	3·13	6·83	3·27	7·14								
	3·77	8·25	3·61	7·90								

Height above bottom (Inches)	REPLICATE											
	1		2		3		4		5		6	
	R	V	R	V	R	V	R	V	R	V	R	V
42	·31	·69	·38	·81	·49	1·04	·34	·76	·36	·81	·51	1·09
	·49	1·08	·59	1·28	·68	1·47	·52	1·16	·35	·78	·64	1·37
	·81	1·78	·83	1·80	·85	1·80	·76	1·69	·61	1·34	·95	2·01
	1·06	2·31	1·50	3·21	1·09	2·34	1·00	2·21	·86	1·89	1·10	2·37
	1·20	2·61	1·70	3·64	1·31	2·79	1·25	2·76	1·03	2·26	1·25	2·66
	1·59	3·49	1·63	3·49	1·63	3·51	1·59	3·52	1·22	2·69	1·91	4·13
	2·73	5·86	2·22	4·79	2·21	4·71	2·11	4·68	1·60	3·53	2·16	4·63
	3·14	6·78	2·57	5·51	2·72	5·82	2·54	5·67	2·07	4·66	2·76	5·96
	3·68	7·93	3·14	6·77	3·18	6·83	3·01	6·70	2·58	5·74	3·16	6·78
			3·69	7·93	3·71	8·00	3·56	7·94	3·07	6·83	3·69	7·95
48	·32	·71	·37	·80	·39	·87	·37	·85	·37	·83	·39	·85
	·80	1·72	·59	1·30	·56	1·24	·58	1·27	·56	1·23	·63	1·36
	·99	2·16	·88	1·88	·78	1·72	·81	1·74	·79	1·74	·82	1·76
	1·22	2·62	1·00	2·18	1·04	2·26	1·06	2·28	1·02	2·23	1·08	2·33
	1·66	3·57	1·31	2·81	1·24	2·68	1·27	2·76	1·27	2·77	1·27	2·73
	2·22	4·77	1·76	3·80	1·66	3·59	2·22	4·84	1·63	3·55	1·71	3·71
	2·59	5·59	2·22	4·76	2·16	4·70	2·69	5·81	2·22	4·87	2·12	4·57
	3·11	6·71	2·70	5·83	2·69	5·65	3·19	6·92	2·62	5·79	2·73	5·91
	3·66	7·89	3·21	6·91	3·10	6·71	1·69	3·66	3·11	6·89	3·27	7·04
			3·69	6·96	3·60	7·78	3·73	8·08	3·59	7·98	3·75	8·08
60	·37	·84	·36	·81	·35	·81	·29	·65	·37	·81	·38	·82
	·65	1·43	·62	1·36	·56	1·23	·59	1·31	·64	1·39	·64	1·38
	·81	1·77	·90	1·95	·94	1·98	·92	1·97	·94	2·04	·87	1·83
	1·16	2·56	1·12	2·42	1·17	2·49	1·17	2·50	1·15	2·43	1·13	2·42
	1·25	2·76	1·30	2·79	1·38	2·92	1·40	2·97	1·43	3·10	1·33	2·80
	1·80	4·04	1·69	3·65	1·80	3·92	1·90	4·13	1·70	3·64	1·90	4·12
	2·20	4·81	2·17	4·71	2·28	4·98	2·21	4·80	2·22	4·82	2·21	4·72
	2·85	6·28	2·59	5·67	2·74	5·97	2·89	6·31	2·80	6·12	2·79	6·00
	3·23	7·08	3·12	6·79	3·17	6·90	3·23	7·02	3·08	6·70	3·30	7·09
	3·76	8·19	3·76	8·22	3·69	8·07	3·68	8·02	3·73	8·16	3·71	8·01
66	·45	·97	·34	·76	·47	1·01	·45	·98	·48	1·02	·45	1·00
	·70	1·50	·55	1·20	·67	1·48	·80	1·73	·68	1·51	·67	1·49
	·91	1·93	·90	1·97	·88	1·85	1·16	2·54	·89	1·90	·79	1·73
	1·16	2·51	1·10	2·40	1·06	2·61	1·58	3·44	1·05	2·33	1·17	2·54
	1·37	2·93	1·33	2·92	1·33	2·87	2·12	4·64	1·37	2·93	1·32	2·85
	1·78	3·83	1·71	3·73	1·72	3·78	2·72	5·94	1·76	3·69	1·73	3·80
	2·31	4·94	2·29	5·04	2·27	4·98	3·04	6·65	2·18	4·79	2·08	4·52
	2·90	6·24	2·58	5·69	2·65	5·83	3·78	8·27	2·85	6·29	2·76	6·06
	3·36	7·29	3·27	7·22	3·12	6·94			3·18	6·76	3·05	6·70
	3·91	8·34	3·71	8·20	3·61	7·98			3·62	7·97	3·60	7·94
72	·46	1·00	·46	·99	·44	1·04	·45	1·00	·46	·98	·44	·97
	·70	1·51	·70	1·49	·81	1·77	·89	1·91	·81	1·76	·72	1·56
	·92	1·96	·79	1·70	1·12	2·44	1·24	2·70	1·34	2·88	1·17	2·51
	1·00	2·16	1·08	2·32	1·61	3·50	1·62	3·53	1·72	3·69	1·68	3·69
	1·16	2·46	1·16	2·49	2·18	4·76	2·00	4·37	2·23	4·82	2·23	4·87
	1·73	3·73	1·70	3·64	2·59	5·65	2·56	5·60	2·73	5·91	2·72	5·92
	2·47	5·26	2·28	4·92	2·90	6·32	3·13	6·85	3·14	6·81	3·01	6·58
	2·63	5·60	2·77	5·99	3·72	8·08	3·58	7·82	3·73	8·03	3·68	8·00
	3·19	6·87	3·25	7·00								
	3·82	8·19	3·71	7·98								

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EFFECT OF TEMPERATURE AND BOUNDARY ON CURRENTMETER RATINGS by M G Hiranandani and P C Saxena, September 1960, pp 14+xiii-illus-tables (Technical Memorandum HLO 1)

Experimental ratings were made of currentmeters
- i at regulated temperature conditions in a small circular tank, and
- ii at different positions along cross-section of Ship Model Towing tank.

The differences between velocities for different temperatures from 5–40°C were estimated to have standard deviation not exceeding ± 1%.

Currentmeter observations in the field as well as calibration in the rating tank will be subject to negligible boundary effect (which will be less than 0·6%) provided the velocities are observed at a distance of not less than 12 inches from the sides as well as bottom. An error up to 1·2% may be expected if velocity observations are taken six inches above the bottom and 5 inches from the side.

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CWPRS TECHNICAL MEMORANDUMS

Subject Classification

Subject	Symbol
Water studies & Hydrology	HLO
Rainfall & Runoff	
Regeneration & Losses	
Quantity of Water	
Fluid Mechanics	FLM
Design of Hydraulic Structures	HYD
River Training & Flood Control	HYR
Irrigation, Drainage & Reclamation	IRD
Surface & subsurface irrigation	
Water requirements of crops	
Soil survey and crop pattern	
Drainage	
Reclamation	
Navigation	NAV
Ports, Harbours & Estuaries	
Inland Navigation	
Coastal Erosion	
Ships & Navigation Crafts	
Structural Design	STD
Soil Mechanics & Foundation Engineering	SFE
Investigations	
Stability, deformations & displacements of earth structures	
Foundation studies including geophysical	
Construction Materials & Practices	CMP
Concrete Technology	
Building & other Materials	
Instrumentation	IST
Model and Prototype comparisons	MPC
Other miscellaneous	MIS

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