DETERMINATION OF THE SETTLING VELOCITIES OF COHESIVE MUDS

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SUMMARY

Standard methods used at the Hydraulics Research Station to measure the settling velocities of cohesive muds in the laboratory and in the field are described. Details are given of the apparatus required, and of the experimental methods used. Worked examples are included to illustrate the calculation of the results.

INTRODUCTION

1 The settling velocity distribution of a cohesive mud in suspension is a complex function of a large number of factors, including particle size, mineralogical composition, suspended concentration, salinity, temperature and flow turbulence. For this reason the various methods of determining the settling velocity tend to give differing results, depending upon which of the above factors they include.

2 The simplest type of mud suspension is obtained in the laboratory when the mud particles are dispersed by a de-flocculant, and allowed to settle in distilled water under quiescent conditions. Since the specific gravity of these basic mud particles can be measured, the settling velocity results can be used to obtain the diameters of the equivalent spherical particles, to give an equivalent size grading of the basic mud particles. Although this method is very useful for classifying the particular mud it does not give any quantitative measure of how the mud would behave in natural conditions. It also does not give the true geometric dimensions of the mud particles, since their settling velocity also depends largely on their shape, which is generally plate-like rather than spherical.

3 As a step towards obtaining the settling velocity of the mud in suspension in natural conditions, a large sample of the water (containing the sediment in suspension) can be obtained, and taken back to the laboratory. There the mud is brought into suspension again by stirring or shaking, and allowed to settle under quiescent conditions. The basic mud particles will now probably form mud flocs, generally with a higher settling velocity than in the dispersed state. However, the specific gravity of the flocs varies greatly with the degree of flocculation, and is virtually impossible to measure while the flocs are in suspension. For this reason the settling velocity results cannot be used to obtain the size grading of the mud flocs in the suspension.

4 Since a sample of the actual water is used for the above method, the effects of suspended concentration and salinity are automatically included in the settling velocity determination. However the natural turbulence in the flow is replaced by a different, artificial turbulence generated in the laboratory. A more realistic measurement of the settling velocity would be obtained if the natural turbulence was somehow reproduced.

5 Turbulence is both difficult to measure in a river or estuary, and difficult to reproduce satisfactorily in the laboratory. For these reasons it is best to obtain an undisturbed sample of the suspension, and to measure the settling velocity of the mud flocs immediately. Because the sample is undisturbed, the flocs sizes and specific gravities are those determined by the flow turbulence, and the effect of salinity, suspended concentration and temperature are also automatically included.

6 Detailed descriptions of the methods used by the Hydraulics Research Station, Wallingford, for determining each of the three types of settling velocity outlined above are given below.

DETERMINATION OF THE SETTLING VELOCITY AND SIZE GRADING OF DISPERSED PARTICLES

The standard method used at HRS, Wallingford, is the *bottom withdrawal method.* The results give the settling velocity grading curve for a suspension of dispersed, de-flocculated mud particles: this curve can then be used to give the equivalent spherical particle size grading of the basic mud particles.

Apparatus 7 The apparatus consists of a pyrex glass tube about 1.20 m long and 25 mm internal diameter. One end is tapered to an outlet tube of internal diameter 8 mm, as shown in Fig 1. A piece of soft rubber tubing is attached to the outlet tube and is closed by a spring clip. The tube is calibrated along its length in centimetres, but because of the taper at the bottom, the zero of the centimetre scale is determined as follows. With the outlet clip closed, enough water is added to bring the level in the tube above the tapered portion. This water level is then marked. A known volume of water (we suggest 250 ml) is now added to that already in the tube, and the new water level marked. From the difference in water levels and the known volume of water added, the volume of water required to fill a 50 mm length of tube is calculated. The tube is then emptied by opening the spring clip, and the clip closed again. The volume of water required to fill 50 mm of the tube is now added, and the water level marked with the figure 5. A linear centimetre scale between 0.05 and 1.00 m is then marked on the tube, making special marks at 1.00, 0.86, 0.72, 0.58, 0.44, 0.30, 0.15 and 0.05 m.

Sample preparation 8 The following sample preparation is used by HRS when all of the sample is less than 0.075 mm diameter.

Mix sample thoroughly, and withdraw a suitable representative quantity (about 1-2 g dry weight).

Add 20 ml of 100 vol hydrogen peroxide and stand till reaction ceases, adding more peroxide if necessary. Use of a large beaker is recommended. The hydrogen peroxide destroys the organic content of the sample.

Rinse sides of beaker and boil to remove excess peroxide. Allow to stand, and siphon off supernatant solution when it has cleared.

Add 5 ml of 10% sodium hexametaphosphate, dilute to 250 ml, and bring to boil. This deflocculates the sample, and disperses the mud particles.

When cool, proceed with the settling test.

Method 9 Add about 100 ml distilled water to the clean tube, and then add the sample prepared as above. The dry weight of mud in the tube should be greater than 0.1 g, but should not exceed about 4 g because of particle interference at suspended concentrations above about 8000 mg/l.

Fill up to the 1.00 m mark with distilled water if necessary.

10 The suspension in the tube has now to be thoroughly mixed and we suggest the following simple method.

A rubber bung or cork is placed in the top end of the tube, and the suspension thoroughly mixed by repeatedly turning the tube upside down, the air bubble acting as a mixing device. After about 20 or 30 inversions, a stopwatch is started on the last inversion as soon as the air bubble has left the lower end of the tube. The tube is immediately placed in a rack and fixed in a vertical position. After about 90 seconds the spring clip is carefully opened, and enough of the suspension is withdrawn under gravity into a 100 ml centrifuge tube (pre-weighed) to bring the water level down to the 0.86 m mark. The timing should be such that the spring clip is closed at exactly 100 seconds. The temperature of this first withdrawn sample only is recorded. Further withdrawn samples are taken after 3, 6, 12, 30 and 90 minutes at water levels of 0.72, 0.58, 0.44, 0.30 and 0.15 m. After 180 minutes a sample is withdrawn to bring the water level down to the 0.05 m mark, and then the last 0.05 m withdrawn as a separate sample. There should now be eight withdrawn samples in their respective centrifuge tubes.

11 For a total sediment quantity in the settling tube exceeding 1 gram, the sample tubes are centrifuged, the overlying water syphoned off, and the tubes dried in an oven at about 120°C. After cooling in a desiccator,

the tubes are re-weighed to find the dry weight of sediment in each withdrawn sample, and the results entered as shown in the example in Table 1.

12 For a total sediment quantity less than 1 gram, the suspended sediment in the centrifuge tubes is filtered on a glass fibre or membrane filter, dried, and the weight of sediment again found.

Calculation of results

13 Referring to the example in Table 1, columns 1 to 6 are self-explanatory. Column 7, the cumulative weight of sediment, is the summation of column 6, beginning at the bottom. For instance, the cumulative weight at time 30 minutes (tube no 5) is the total of the sediment weights of tubes 6, 7 and 8. Column 8, the depth factor, is used to correct the cumulative weights and times to those required for a full 1.00 m height of settling of each withdrawn sample. This depth factor is therefore 1.00/Column 2. Column 9 is then the corrected cumulative weight (column 7 multiplied by column 8), and column 10 is the corrected time (column 3 x column 8). The percentages in column 10 are the true corrected weights in column 9 divided by the total sediment weight (0.9640 grams in the example).

Graphical interpretation of results

14 The percentage weights (column 11) are plotted against corrected time (column 10) on logarithmic graph paper, as shown in Fig 2.

15 The settling velocity of dispersed particles (and also of mud flocs) in water depends greatly on the water temperature, mainly because of the large changes in viscosity. To compensate for these variations, the settling velocities of particles are usually quoted at a standard temperature (20^{o}C is used by HRS). The times required to settle 1.00 m are given in Table 2 for particles of differing standard settling velocities, and for a range of water temperatures.

16 The temperature of the first withdrawn sample is therefore rounded off to the nearest degree, and the times required at that temperature read from Table 2. These times are then marked along the time axis, as in Fig 2 for a temperature of 25^{o}C.

17 A piece of tracing paper or thin perspex sheet is now laid on the graph paper, and horizontal lines drawn at the 0 and 100% cumulative weight levels. The vertical lines are then drawn, one at time 1.0, and the other at time e (2.718) minutes (e is the base of Naperian logarithms). The distance between these two lines is therefore log e – log 1. The tracing paper is now moved horizontally, keeping the two horizontal lines at the 0 and 100% levels, until the right hand vertical line coincides with one of the times obtained from Table 2. The tangent to the curve is now drawn at this point (marked T on Fig 2), to intercept the left hand vertical line, and the percentage at which the intersection occurs is read from the cumulative percentage scale. This then gives the percentage by weight of the suspension which has a settling velocity less than that defined by the time at T. In Fig 2 for instance, the time T is 547 minutes, and the tangent intersects the left hand line at 16%. From Table 2, a time of 547 minutes at 25^{o}C gives a standard (20^{o}C) settling velocity of 0.0271 mm/s. For dispersed mud particles, where the specific gravity is known, usually about 2.65, the particle sizes can be calculated. At the bottom of Table 2 these particle sizes, corresponding to the standard settling velocities at the top of the table, are given. For instance, the particle size corresponding to a standard settling velocity of 0.0271 mm/s is found to be 5.5 micrometres (μm). This means that 16% by weight of the total sediment is under 5.5 μm in diameter.

18 The tracing paper is then moved, and the right hand line placed in turn on each of the selected times previously marked on the axis. The size grading curve is then obtained by plotting the percentage undersize against the diameter, on semi-logarithmic paper, plotting the diameter on the logarithmic scale, as shown in Fig 3.

DETERMINATION OF THE SETTLING VELOCITY OF A SUSPENSION OF MUD FLOCS IN THE LABORATORY

The standard method used in this laboratory is again the bottom withdrawal method. The results give the settling velocity grading curve for a suspension of mud flocs at the same concentration and salinity as found in the river or estuary. However, it is important to realise that the flocculation process is also a function of the laboratory test conditions – for example, different size grading curves are obtained if bottom withdrawal tubes of different lengths are used. It is essential therefore to adopt a standard method for these tests.

Apparatus 19 The bottom withdrawal tube is identical in all respects to that used for determining the size grading of dispersed mud particles, as described in the previous section.

Sample preparation 20 The sample of the suspension taken from the river or estuary should be large enough to permit two tests to determine the settling velocity, if necessary, ie a sample volume of at least 1 litre. This sample should be returned to the laboratory as soon as possible, before any decomposition of the organic material begins. In the laboratory the only sample preparation necessary is to thoroughly mix the suspension, to bring all the material which has deposited at the bottom of the container back into suspension again. If a number of samples at concentrations less than about 200 mg/l are expected, then in order to be able to determine the settling velocities accurately, a larger diameter settling tube should be used. A tube of internal diameter 50 mm would enable measurements to be made on suspended concentrations down to 50 mg/l. There should always be at least 0.1 g of mud in suspension in the tube (see paragraph 9).

Method 21 The clean sedimentation tube is filled with the thoroughly mixed suspension sample, filling up to the 1.00 m mark. The suspension in the tube is then mixed again by repeatedly turning the tube over and over, and the stop-watch started on the last inversion just as the air bubble leaves the bottom, as before. Samples are withdrawn from the bottom of the tube at the same times (100 seconds, 3, 6, 12, 30, 90 and 180 minutes), and the same water levels (0.86, 0.72, 0.58, 0.44, 0.30, 0.15 and 0.05 m) as before.

The samples are dried and weighed as before.

Calculation of results 22 The calculation of the results is identical to the example in Table 1 which was explained previously.

Graphical interpretation of the results 23 This is very similar to that used in the first method, "Determination of the settling velocity and size grading of dispersed mud particles".

The percentage weights (column 11 in Table 1) are plotted against corrected time (column 10) on semilogarithmic paper, as Fig 2. The temperature of the first withdrawn sample is rounded to the nearest degree, and the required times at that temperature obtained from Table 2. These times are then plotted along the axis of the graph.

24 A piece of tracing paper is placed over the graph, and horizontal lines drawn at the 0 and 100% levels. Vertical lines are also drawn at 1 and e minutes. The tracing paper is then moved horizontally until the right hand line coincides with one of the times on the axis, keeping the horizontal lines on the 0 and 100% levels. The tangent to the curve is drawn at this selected time, and the percentage at which it intercepts the left hand vertical line is read off the scale. This then gives the percentage of material under the standard (20°C) settling velocity defined by the selected time. This settling velocity is obtained from Table 2, as explained previously. However, the specific gravity of the suspended mud flocs is not known, and is virtually impossible to measure, since it varies greatly depending on the degree of flocculation

of the suspension. These standard settling velocities *cannot* therefore be converted to floc sizes.

25 The graph paper is moved on again, horizontally, and the right hand vertical line placed on each selected time in turn, and the percentages determined. The settling velocity grading curve is obtained by plotting the percentage under a given standard settling velocity against that settling velocity, as shown in Fig 4. The suspended concentration, salinity, temperature and height of settling tube used should all be indicated on the grading curve.

26 Occasionally the settling velocities at the actual temperature are required, rather than those corrected to a standard temperature of 20^{o}C. In this case the times given in Table 2 at the actual temperature (rounded to the nearest degree) are plotted along the axis, and the percentages corresponding to those times determined as before. However the settling velocity for these times is not obtained from Table 2, but is calculated by dividing 1.00 m by the actual time, expressing the result in mm/s (see below).

DETERMINATION OF THE SETTLING VELOCITIES OF MUD FLOCS IN A TURBULENT SUSPENSION

27 The basic purpose of this method is to obtain an undisturbed sample of the turbulent suspension, and to then determine the settling velocities immediately by the bottom withdrawal method, similar to that used in the laboratory. The results almost invariably give higher settling velocities than are obtained by laboratory methods, and various tests have shown that these higher values closely represent the settling velocities of the mud flocs as they exist in the river or estuary.

Apparatus 28 The apparatus is necessarily fairly complicated, since it has to perform both as a suspension sampling tube (with minimum disturbance to the suspension) in the river or estuary, and then as a bottom withdrawal sedimentation tube on board the survey boat.

29 A photograph of the instrument is shown in Plate 1, and the main parts are shown in Fig 5. The actual sampling tube is a 1 metre long, 50 mm diameter perspex tube, which is supported in a concentric 90 mm diameter perspex tube. At each end of the sampling tube a rubber sleeve or sock is fitted, being held by a conical grip. The free end of the sock or sleeve is fitted to the outside tube, so that by rotating the inner tube relative to the outer one, a seal is obtained at each end by the twisting of the rubber sleeves. This relative rotation is caused by the spring unit, which consists of a helical spring wound inside a split drum. One part of the drum – the stator, is fixed to the outer tube, and the other part – the rotor – to the inner tube. The spring is wound up and held by a piston-operated plunger. When this plunger is withdrawn, the rotor and inner sampling tube rotate through about three-quarters of a turn, to form the seals at both ends.

30 The whole tube assembly is hung in a frame, and is pivotted near its centre. The stabilising ring is adjusted so that the tube hangs vertically in air, and lies horizontally in water. It also ensures that the sampling tube is always pointing directly into the direction of flow.

Method 31 Only a general description of the method will be given here, but a detailed, step-by-step, account of the procedure is given in the Appendix. The detailed description can then be easily detached or reproduced for easy reference during the surveys.

a) During the survey

32 The spring unit on the sampling instrument is first wound up and set, and the rubber sleeves at each end correctly fitted. The whole assembly

is then placed in its frame, and the pipe carrying water down to the piston, which operates the spring, is connected up. The tube in its frame is then lowered down into the water to the required depth. It is then held at that depth for a short time, to allow the flow through it to become established. A small quantity of water is then pumped down the pipe with a small hand pump. The water pressure operates the piston, which withdraws the plunger, releasing the spring, which then rotates the inner tube and twists the rubber sleeves at each end to form a seal. The tube now contains a sample of the turbulent suspension, and it is hauled back up to the water surface. As it is pulled out of the water, it automatically swings to the vertical position, and a stopwatch is started at this time, or else the accurate time is noted. The sampling tube assembly is then taken out of its frame (disconnecting the water pipe) and placed in a stand on board the survey boat, Plate 2.

33 Samples can now be withdrawn from the bottom of the tube by turning the whole spring unit (after releasing the wing-screw which fixes the stator to the outer tube), which untwists the rubber sleeves at both ends. The first sample is taken 3 minutes after the tube swung to the vertical position, and about 250 ml of the suspension is allowed to drain into a sample bottle, taking care not to lose any by splashing etc. Further samples, each of 250 ml, are then taken at 6, 10, 15, 25, 40 and 60 minutes, and any remaining water left in the tube is also withdrawn after 60 minutes, making 8 withdrawn samples in all. The temperature of the first withdrawn sample only is measured.

34 The sampling tube holds 2 litres of suspension, so that the 8 withdrawn samples should ideally be exactly 250 ml each. However it is very difficult to withdraw precise volumes, so that although every effort should be made to obtain a total of 8 withdrawn samples, they need not necessarily be of equal volume. The laboratory analysis can correct for this. All the withdrawn samples are labelled to indicate which tests they belong to, and are returned to the laboratory.

35 The settling velocity of mud flocs depends on the suspended concentration, and this is likely to vary both with time and depth so that no two determinations of settling velocity at the same site are likely to give equal values. The best approach therefore is to attempt to obtain undisturbed samples at as widely differing concentrations as possible, and to plot the settling velocities against the concentration. This can usually be achieved by taking samples at widely differing depths, from as near the bed as possible to as near the surface as possible. In an estuary it can also be achieved by sampling at different stages of the tide. However it should be realised that the flow turbulence must also vary to some extent both at different depths and at different stages. Ideally one would like to have a wide range of concentrations at identical turbulence levels.

b) In the laboratory

36 When the withdrawn samples are returned to the laboratory, the volumes of the suspensions they contain are measured, and the suspended mud filtered off, washed, and dried. Filtering can be done through cellulose membrane or glass fibre filters. (If the suspended concentrations are very high, larger diameter filters or several small ones can be used.) The withdrawn sample number, filter weight, filter weight with sediment, calculated sediment weight, and sample volume are all recorded, as shown in the example in Table 3. The total of all the sample volumes should be about 2.0 to 2.1 litres, unless there has been some leakage or spillage.

Calculation of results 37 Referring to Table 3, column 6 is the height in the sampling tube occupied by the volume of suspension in the given withdrawn sample. It is therefore obtained by the volume divided by the cross-sectional area of of the tube (2030 mm^2). Column 7 is the depth of fall, or the depth through which the mud has settled, and is obtained by the summation of column 6, beginning at the bottom. For instance, the depth of fall for sample no 5 is the total of the heights of samples 6, 7, 8. Column 8 is the time at which the samples were withdrawn, measured from the time at which the sampling tube swung to the vertical. The recommended times for these withdrawn samples are 3, 6, 10, 15, 25, 40 and 60 minutes. However it is sometimes difficult to keep exactly to these times during a survey, in which case the actual time, not the recommended time, should be entered in column 8.

38 Column 9 is the summation of the sediment weights in column 4, beginning at the bottom. For instance the cumulative weight of sample no 5 is the total of the sediment weights in samples 6, 7 and 8.

39 Column 10 is the depth factor, which for this method is used both to correct the weights and times for the different depths of settling of each withdrawn sample, but also to correct for the fact that the total calculated height of water in the sampling tube may not be exactly 1.000 m. The depth factor is therefore 1.00/depth of fall for each sample (column 7). In Table 3 for instance, the depth factor for sample no 5 in 1.000/0.379 which is 2.64.

40 Column 11 is the corrected cumulative weights for each sample, and is obtained by multiplying column 9 by column 10. Column 12 is simply column 11 expressed as a percentage of the total corrected weight (which is 0.5180 in this example). The corrected time, column 13, is column 8 multiplied by the depth factor, column 10. Columns 14 and 15 are the results of the graphical interpretation, described below.

41 The concentration of the suspension sample can be obtained by dividing the actual total sediment weight by the total volume, that is 0.5395 g/2109 ml, or 256 mg/l in Table 3.

Graphical interpretation of the results

42 This proceeds in a very similar manner to that described on page 4, except that whenever this suspension sampling tube is used it is generally the actual settling velocity at the measured water temperature which is required, rather than the standard (20^{o}C) settling velocity.

43 The corrected cumulative percentage, column 12 is plotted against the corrected times, column 13, on semilogarithmic paper, as shown on Fig 6. The recorded water temperature is rounded to the nearest degree, and the required settling times read from Table 2 at this temperature. These times are then plotted along the time axis.

44 A piece of tracing paper is laid on the graph paper, and two horizontal and two vertical lines drawn as before. The tracing paper is then moved horizontally until the right hand vertical line coincides with one of the selected times marked on the axis, such as time T on Fig 6. The tangent to the curve is then drawn at this time, and the percentage at which it intersects the left hand vertical line is read from the scale. This is then the percentage of the mud flocs in the suspension sample which have a settling velocity less than that defined by the time T. The settling velocity is obtained by dividing the corrected total depth of fall, 1.00 m, by the time T, expressing the result in mm/s. For instance, time T on Fig 6 is 42.2 minutes, so that the corresponding settling velocity is 1.00 m/42.2 minutes, which is 0.4 mm/s. The percentage and the settling velocity are recorded in columns 15 and 14.

45 The graph paper is again moved horizontally to each selected time in turn, and the percentages and settling velocities determined. The settling velocity grading curve is then obtained by plotting percentage under a given settling velocity against that settling velocity, in the same way as Fig 4.

46 The settling velocities obtained by the above method are for the actual temperature of the suspension sample. If instead the standard (20^{o}C)

settling velocities are required, then the value corresponding to the time T is obtained from Table 1 at the recorded temperature, as shown on page 4.

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TABLES

TABLE 1

Example of sedimentation tube result sheet
T = 24.8^{o}C

1	2	3	4	5	6	7	8	9	10	11
Tube No	Height (m)	Time	Weight of tube + sample (g)	Weight of tube (g)	Weight of sample (g)	Cumulative weight (g)	Depth factor	Weight in 1.00 m suspension (g)	Corrected time (min)	%
						0.9640	1.000	0.9640		100.0
1	0.86	100 s	66.6800	66.5175	0.1625	0.8015	1.163	0.9322	1.94	96.7
2	0.72	3 min	66.5791	66.4241	0.1550	0.6465	1.389	0.8980	4.17	93.2
3	0.58	6 min	67.6784	67.5212	0.1572	0.4893	1.724	0.8436	10.3	87.5
4	0.44	12 min	67.1532	66.9886	0.1646	0.3247	2.273	0.7380	27.3	76.6
5	0.30	30 min	73.8796	73.7008	0.1788	0.1459	3.333	0.4863	100	50.5
6	0.15	90 min	73.1364	73.0001	0.1363	0.0096	6.667	0.0640	600	6.6
7	0.05	180 min	65.2502	65.2414	0.0088	0.0008	20	0.0160	3600	1.7
8		+180 min	73.3064	73.3056	0.0008					

TABLE 2

Time in minutes required for particles or flocs of given settling velocity to fall 1.00 m in water of different temperature

Temperature °C	Settling velocity at standard (20°C) temperature, in mm/s												
	8.13	4.90	3.50	1.75	0.873	0.438	0.218	0.108	0.0545	0.0271	0.0136	0.00632	0.00341
5			7.21	14.41	28.9	57.7	115.7	233	463	931	1851	3696	7405
6			6.99	13.98	28.1	55.9	112.3	226	449	903	1795	3584	7181
7			6.78	13.55	27.2	54.2	108.8	219	435	875	1741	3476	6964
8			6.58	13.15	26.4	52.6	105.6	212	422	849	1689	3373	6757
9			6.39	12.77	25.6	51.1	102.5	206	410	825	1641	3276	6563
10	2.60	4.35	6.21	12.41	24.9	49.6	99.6	200	398	801	1594	3182	6373
11	2.54	4.25	6.03	12.06	24.2	48.2	96.8	195	387	779	1549	3093	6197
12	2.48	4.15	5.87	11.73	23.5	46.9	94.2	189	377	758	1507	3008	6026
13	2.42	4.05	5.71	11.41	22.9	45.6	91.6	184	366	737	1466	2926	5862
14	2.36	3.95	5.55	11.11	22.3	44.4	89.2	179	357	717	1427	2849	5706
15	2.30	3.85	5.41	10.82	21.7	43.3	86.8	175	347	699	1389	2774	5557
16	2.25	3.76	5.27	10.54	21.1	42.2	84.6	170	338	681	1354	2703	5414
17	2.20	3.67	5.14	10.27	20.6	41.1	82.4	166	330	663	1319	2633	5276
18	2.15	3.58	5.01	10.01	20.1	40.0	80.4	162	321	647	1286	2568	5144
19	2.10	3.49	4.88	9.76	19.6	39.1	78.4	158	314	631	1254	2504	5017
20	2.05	3.40	4.76	9.53	19.1	38.1	76.5	154	306	615	1224	2443	4895
21	2.01	3.33	4.65	9.30	18.7	37.2	74.6	150	299	601	1194	2385	4777
22	1.97	3.26	4.54	9.08	18.2	36.3	72.9	147	292	586	1166	2328	4664
23	1.93	3.19	4.43	8.87	17.8	35.5	71.2	143	285	573	1139	2274	4556
24	1.89	3.12	4.33	8.66	17.4	34.6	69.5	140	278	559	1113	2221	4450
25	1.85	3.05	4.23	8.47	17.0	33.9	68.0	137	272	547	1087	2171	4350
26	1.82	3.00	4.14	8.28	16.6	33.1	66.4	134	266	534	1063	2122	4252
27	1.79	2.95	4.05	8.09	16.2	32.4	65.0	131	260	523	1039	2075	4158
28	1.76	2.90	3.96	7.92	15.9	31.7	63.5	128	254	511	1017	2030	4067
29	1.73	2.85	3.87	7.74	15.5	31.0	62.2	125	249	500	995	1986	3979
30	1.70	2.80	3.79	7.58	15.2	30.3	60.8	122	243	489	973	1944	3894
	100	75	62.5	44.2	31.2	22.1	15.6	11.0	7.8	5.5	3.9	2.76	1.95

Particle diameter in micrometres (μm), for spheres of specific gravity 2.65

TABLE 3

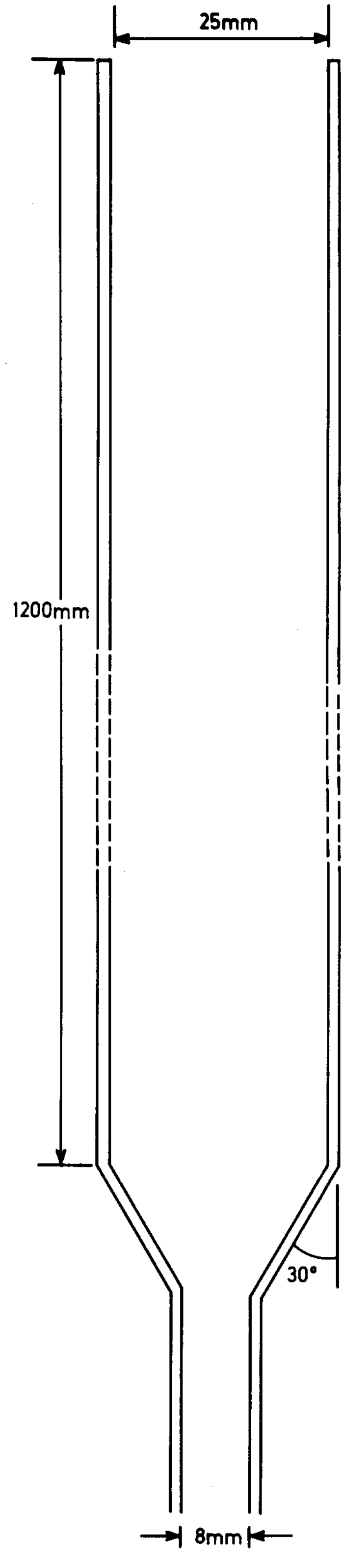
Example of field settling tube results
T = 16°C

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sample No + Bottle No	Filter			Sample volume (ml)	Height of sample (m)	Depth of fall (m)	Time (min)	Cumulative weight (g)	Depth factor	Cumulative weight whole tube (g)	%	Corrected time (min)	Fall velocity (mm/s)	%
	Weight (g)	Weight + solids (g)	Solids (g)											
						1.041		0.5395	0.96	0.5180	100.0	0	0.04	16.0
1, 1417	0.1260	0.3482	0.2222	247	0.122	0.919	3	0.3173	1.09	0.3455	66.5	3.27	0.10	21.0
2, 2273	0.1259	0.2390	0.1131	250	0.123	0.796	6	0.2042	1.26	0.2562	49.6	7.56	0.20	26.5
3, 1413	0.1246	0.2044	0.0798	282	0.139	0.657	10	0.1244	1.52	0.1892	36.4	15.2	0.40	33.0
4, 1403	0.1265	0.1782	0.0517	318	0.157	0.500	15	0.0727	2.00	0.1454	28.0	30.0	1.00	47.5
5, 1950	0.1238	0.1546	0.0308	245	0.121	0.379	25	0.0419	2.64	0.1106	21.4	66.0	2.00	65.0
6, 4253	0.1276	0.1488	0.0212	255	0.126	0.253	40	0.0207	3.96	0.0820	15.8	158.4	4.00	84.0
7, 1958	0.1246	0.1372	0.0126	249	0.123	0.130	60	0.0081	7.70	0.0623	12.0	462.0		
8, 1409	0.1267	0.1348	0.0081	263	0.130		60+							

Total 2109

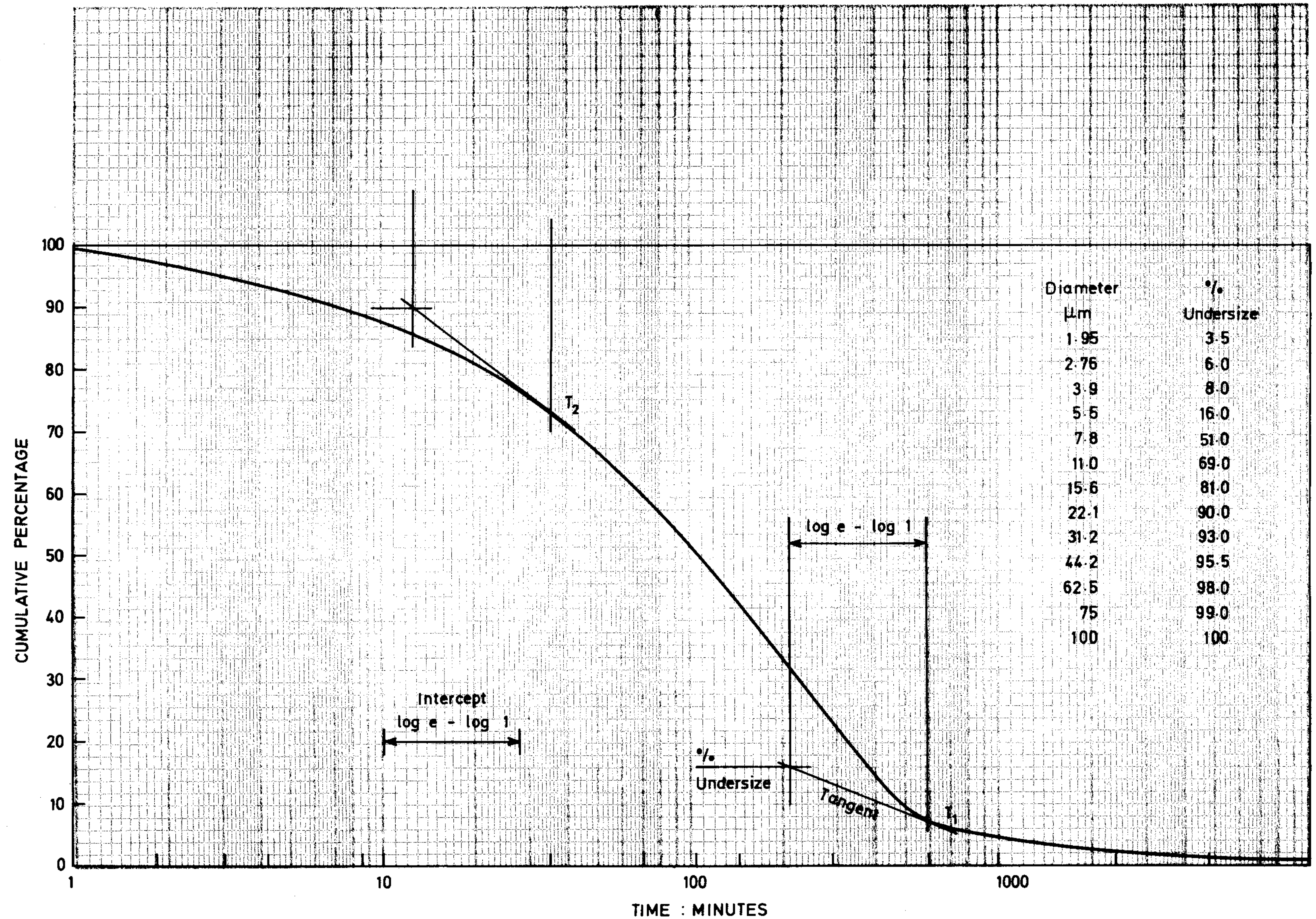
Concentration $[\frac{0.5395}{2109} \times 10^6]$ ppm = 256 ppm

FIGURES



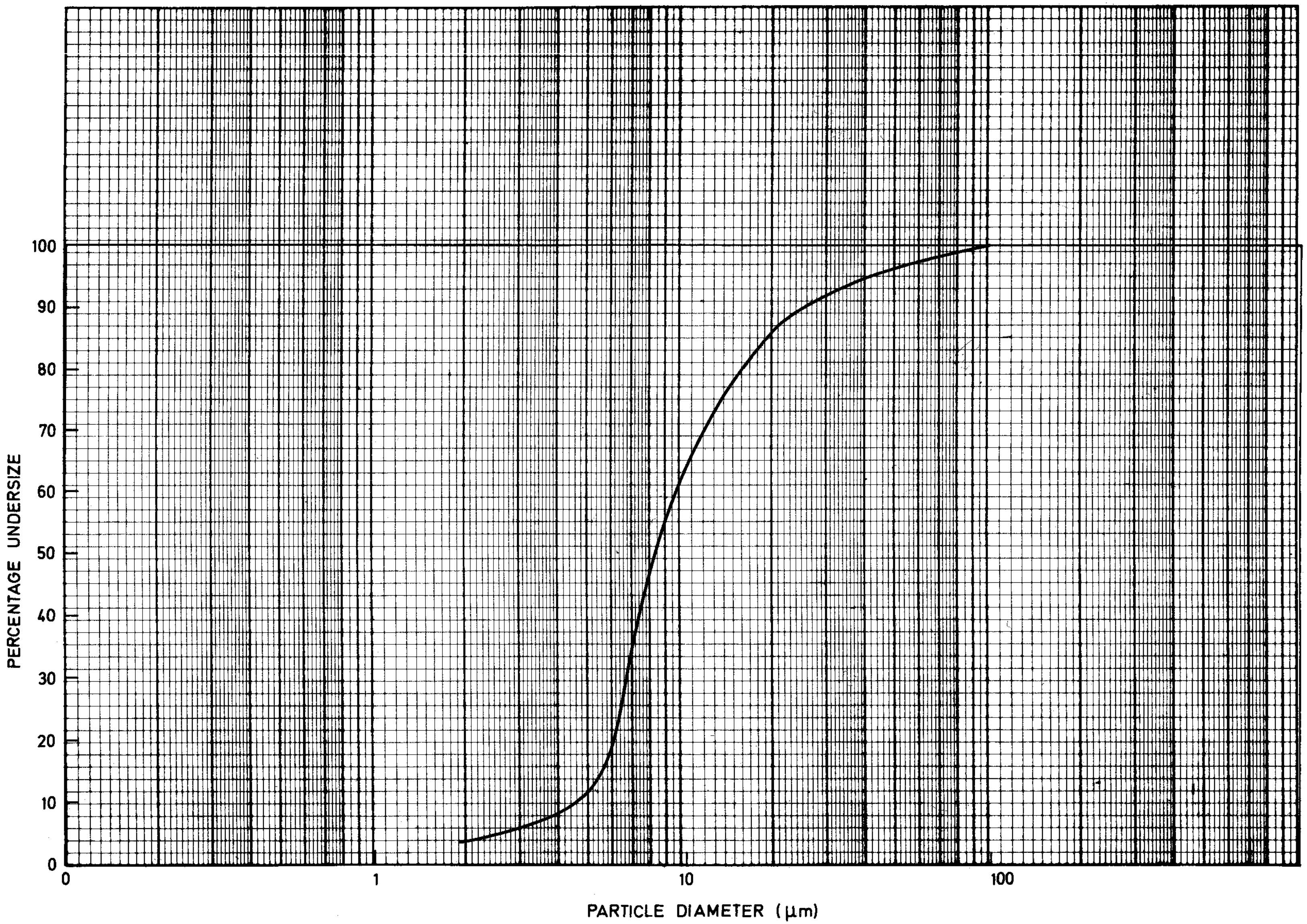
LABORATORY SEDIMENTATION TUBE

FIG 1



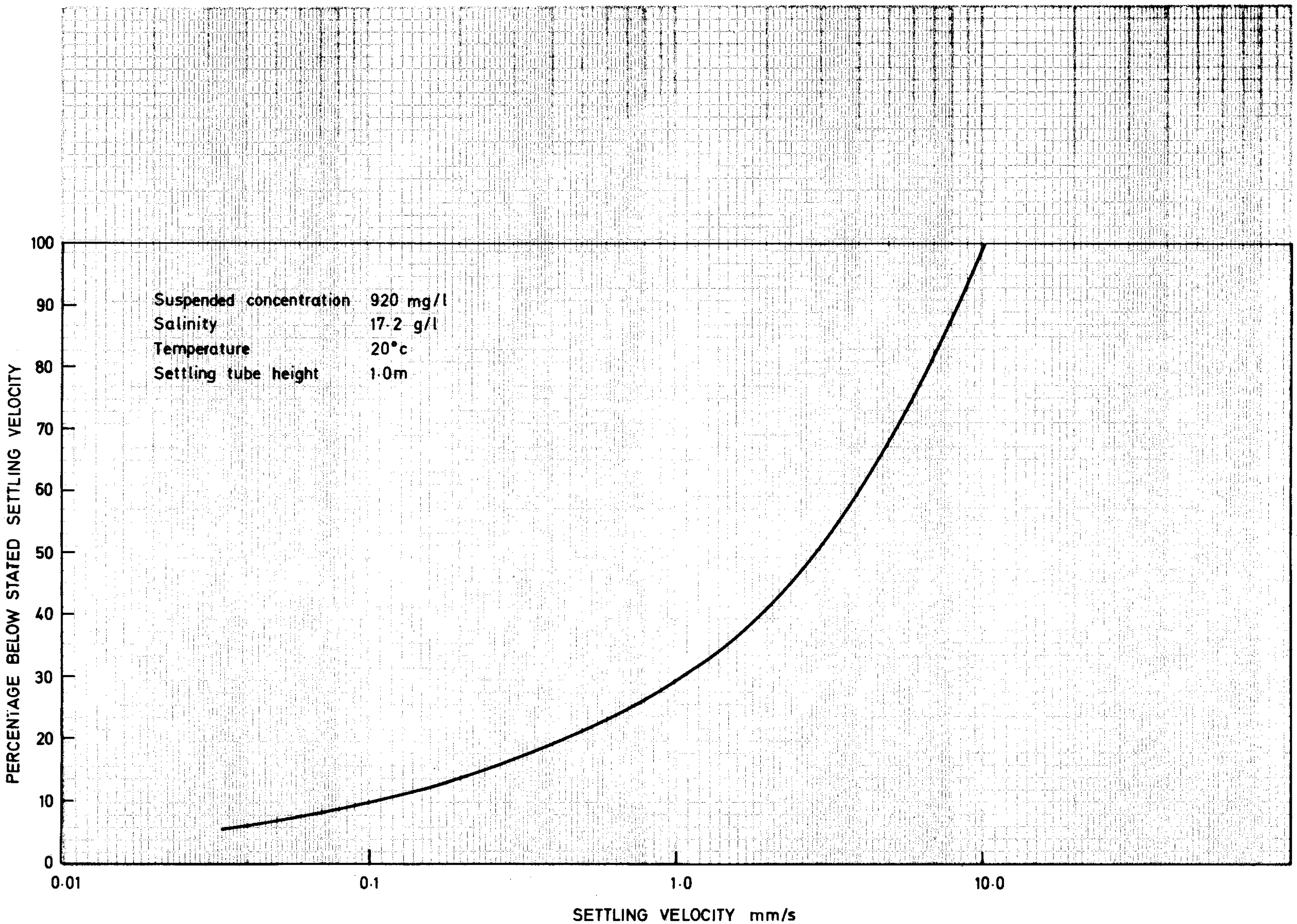
PLOT OF CUMULATIVE PERCENTAGE AGAINST CORRECTED TIME (for example of Table 1)

FIG 2



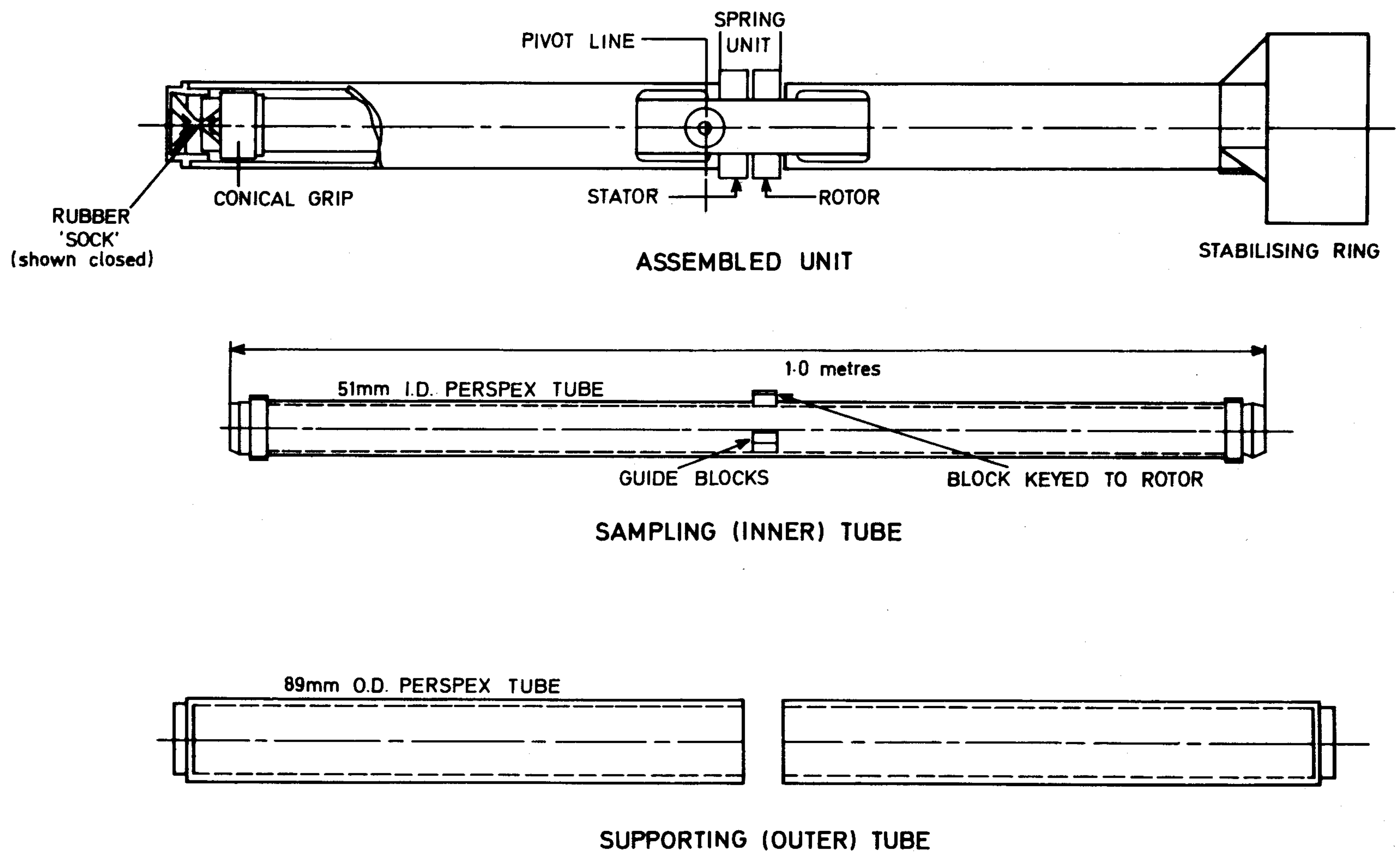
FINAL SIZE DISTRIBUTION FROM SEDIMENTATION TUBE (for example of Table 1)

FIG 3



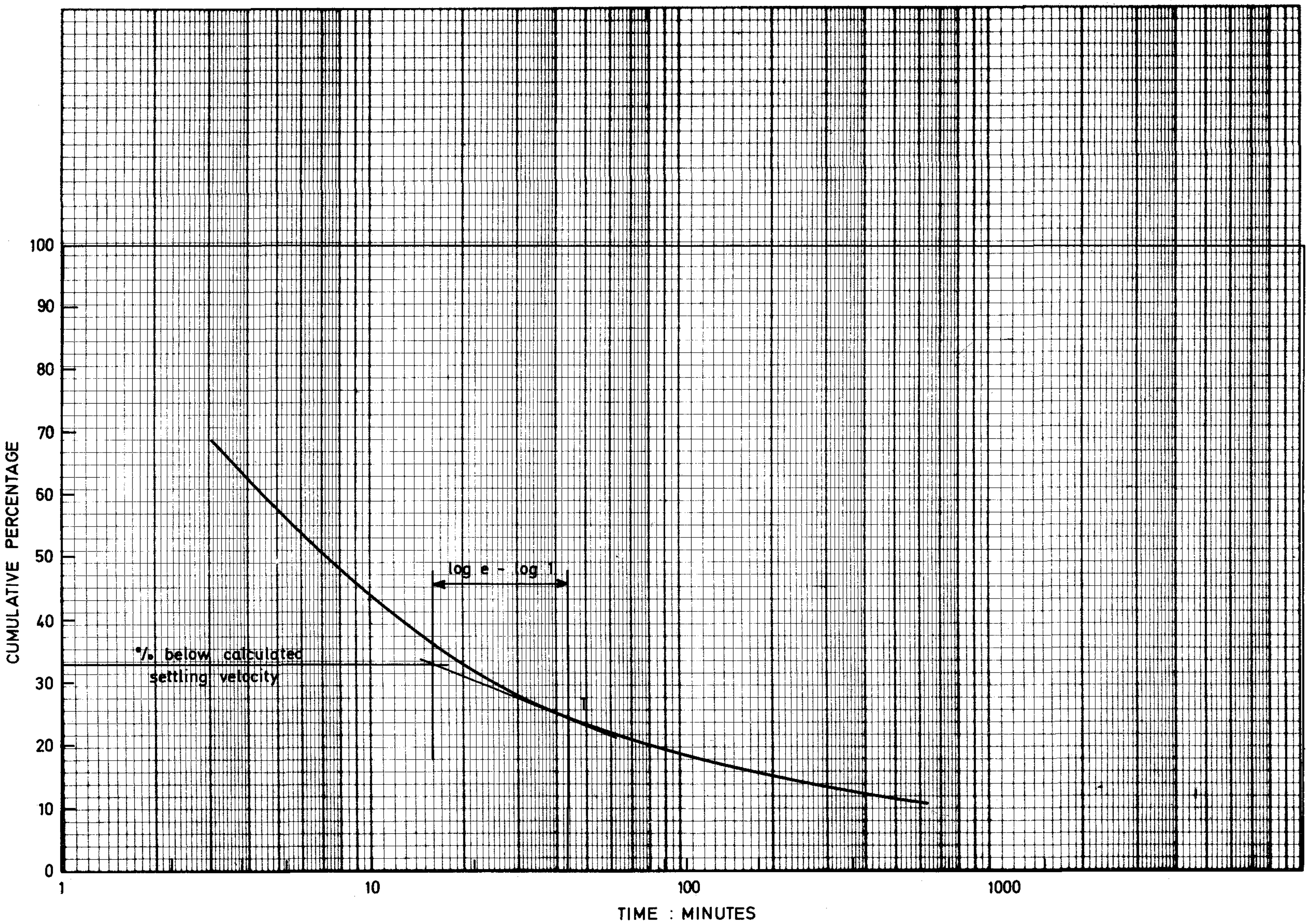
TYPICAL SETTLING VELOCITY DISTRIBUTION

FIG 4



OUTLINE DRAWING OF SAMPLING INSTRUMENT

FIG 5



PLOT OF CUMULATIVE PERCENTAGE AGAINST CORRECTED TIME (for example of Table 3)

FIG 6

PLATES

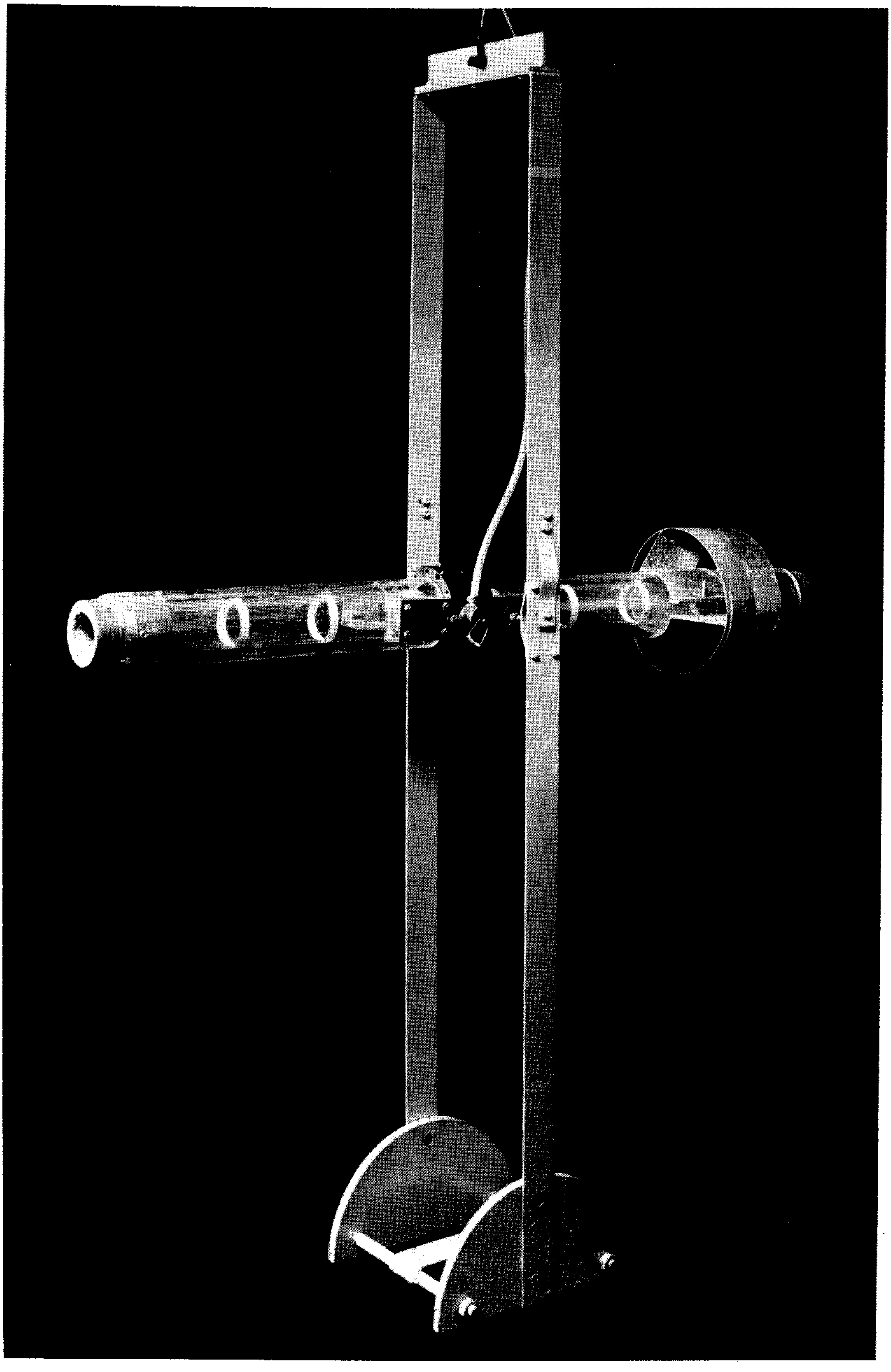


PLATE 1 Settling velocity sampling tube in submerged position

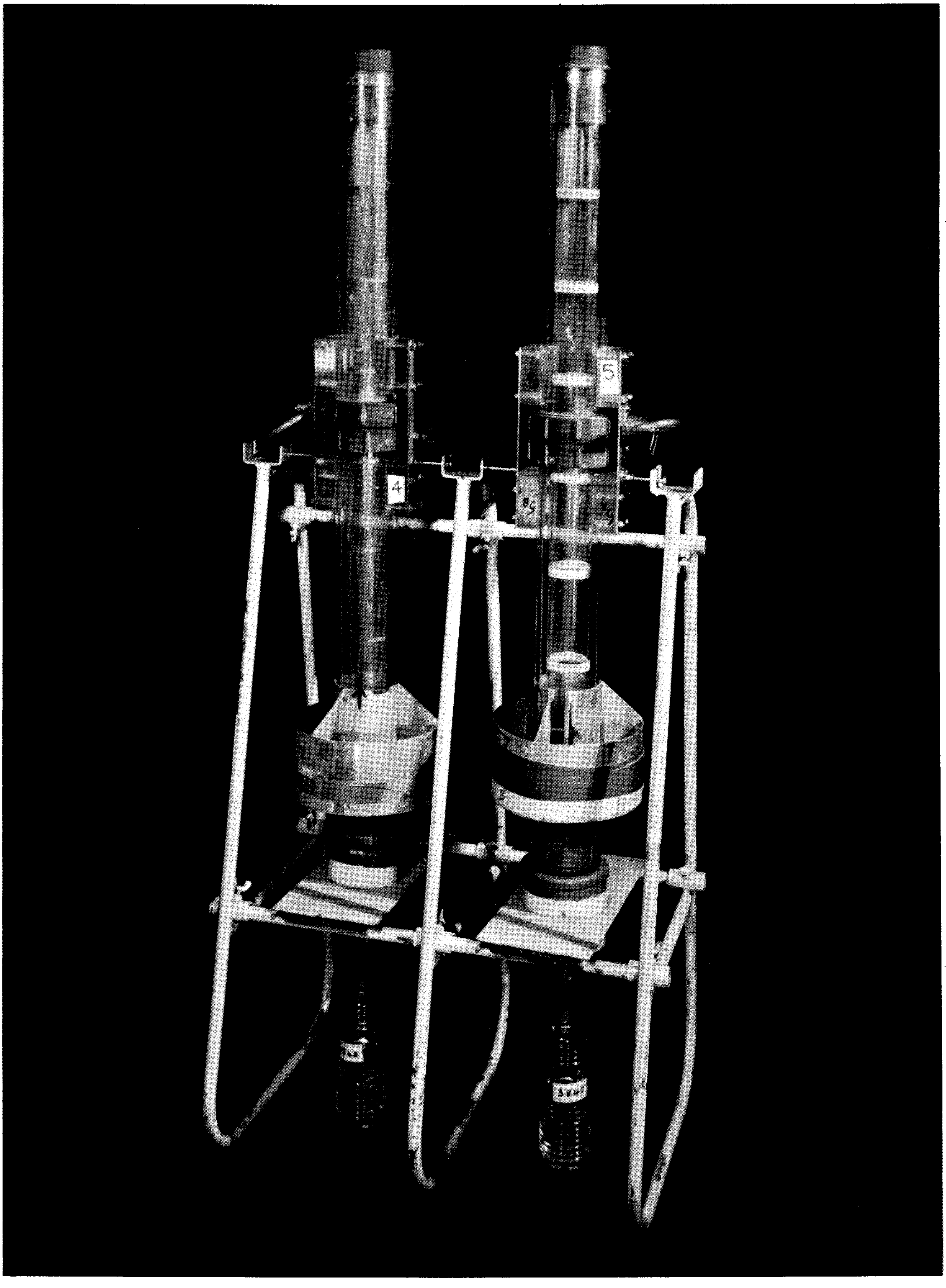


PLATE 2 Settling velocity sampling tubes in sedimentation position

APPENDIX

APPENDIX I

Instructions for the settling velocity sampling tube

Preparation

The following preparations are made at the beginning of a day's surveying:—

1 *Place the sampling tube in the stand.*
With the tube vertical, the stabilising ring should be at the bottom, and the piston operated plunger towards the left.

2 *Check that the rubber sleeves have been fitted.*
The rubber sleeves should already have been fitted to both ends of the inside tube. If not, see instructions for fitting sleeves (page A3).

3 *Set the wing-screw in the hole.*
Rotate the spring unit until the hole in the lower half is opposite the wing screw, and screw in.

4 *Wind up the spring unit.*
Place the spanner provided into the small holes in the top of the spring unit. Rotate the top half anti-clockwise as far as the spanner will allow. Depress the piston-operated plunger by hand to engage one of the bars on the spring unit. Re-position the spanner, and wind on. Carry on winding until hole on top half of spring unit is opposite plunger. Push plunger into hole. Please take care not to damage with the spanner the end of the spring which just sticks through the top half of spring unit.

5 *Attach bottom rubber sleeve.*
Insert three fingers of each hand into the rubber sleeve, and stretch over outer tube, pulling it some distance down the tube. Roll back spare rubber to provide extra grip on brass end-piece. Check that rubber is taut and smooth, and that aperture is central. If not, try again.

6 *Attach top rubber sleeve.*

7 *Test the operation of the sampling tube.*
Pull the plunger quickly out of its hole. The top half of the spring unit and the inner tube should rotate about three-quarters of a turn very rapidly, and the rubber sleeves at both ends of the tube should have been twisted to make a seal. Test the tautness of the rubber in this position.

8 *Rewind the spring unit.*

9 *Check position of stabilising ring.*
The red horizontal line and vertical arrow on the stabilising ring should match up with the red horizontal line and vertical arrow on the sampling tube.

10 *Connect lowering cable and water pipeline to lowering frame.*

11 *Prime the hand pump.*
Place suction pipe in bucket of water, and operate pump until all the air is expelled from the water pipeline.

Taking a suspension sample

1 *Check that spring unit is wound up, and that rubber sleeves at both ends are in the open position.*

2 *Place sampling tube in lowering frame.*
Piston operated plunger should be on opposite side of frame to the water pipeline. Screw in retaining screws.

3 *Connect up water pipeline.*
The connection need only be finger tight.

4 *Lower the sampling tube into the water.*
The tube is lowered until its horizontal axis is at the required depth.

5 *Operate the hand pump.*
Not more than 30 seconds before the appointed time, give two short, sharp strokes to the hand pump. This should release the spring unit, and close both ends of the tube. A sample of the suspension has therefore been obtained.

6 *Haul the tube back on board, as follows:–*
Pull the tube up to the water surface. Hold it just below the surface for a few seconds until the appointed time, and then pull gently out of the water. Make a note of the time. (See example in Table A1.)
The tube should now swing to the vertical position, with the stabilising ring at the bottom. Hold the tube just above the water surface while the water drains out of the outer tube, and then pull on board the survey boat. Occasionally the tube may swing to the upside-down vertical position, due to some small impulse, such as a wave, just as it leaves the water. If this begins to happen, replace in water just below surface, and try again.

7 *Disconnect water pipeline, and unscrew retaining screws.*

8 *Place sampling tube in stand, gently.*
The stabilising ring must be at the bottom.

Taking bottom withdrawal samples

1 *Samples are taken at set times of 3, 6, 10, 15, 25, 40 and 60 minutes.*
(If the sample is expected to contain a large percentage of fine sand, the sampling times are set at 1, 3, 5, 8, 13, 20 and 30 minutes.)

2 *As soon as the sampling tube is in the stand, number first sample bottle, and place under bottom of tube, together with funnel.*
This ensures that none of the sample is lost due to slight leaks etc.

3 *Unscrew wing screw just before set time.*

4 *At set time, open both ends of tube, and release about 250 ml of the water into the sample bottle, and then close again.*
Tube is opened by turning whole spring unit by hand in anti-clockwise direction. Open fairly wide so that all mud deposited on bottom rubber sleeve is flushed out. Make sure that no water is lost by splashing out of funnel, bottle etc. Tube is closed again by turning spring unit clockwise until hole is again opposite wing-screw. (If sampling tube is leaking slightly, turn further if necessary, engaging wing-screw on one of the bars. Do not however go beyond the hole a second time.) At no time during the settling process should the sampling tube be moved from the vertical position. Take care not to move the tube while withdrawing samples from the bottom.

5 *Screw wing-screw into hole again.*

6 *Label bottle for next sample, and replace full sample bottle.*
The next sample bottle must be placed in position as soon as the full bottle is removed, so that no water is lost due to leaks from the tube. Place the top on the full bottle.

7 *Note the number of the full sample bottle, and the time at which it was filled. (See example in Table A1.) For the first sample, note also its temperature.*

8 *Take further samples at the stated times.*

9 *After last sample at 60 minutes, release any remaining water into another sample bottle(s). Note the number of this bottle also.*

10 *Prepare tube for next test.*
Screw wing-screw into hole. Wind up spring-unit. Check that rubber sleeves are open, and are still in good condition. Flush tube through with water.

11 *During the settling process the tube should be kept as free from vibration as possible.*

Operation of two or more sampling tubes simultaneously

To avoid, as far as possible, the clashing of times of various operations when using two or more tubes simultaneously, the survey programme should be planned so that the appointed times for suspension samples in the different tubes are 20 minutes apart. For instance, the suspension sample might be taken at 1100 hours in tube no 1, at 1120 hours in tube no 2, 1140 hours in tube no 3, and so on.

A typical programme for two-tube operation is given below:

Time minutes	Sampling Tube No 1	Sampling Tube No 2
0	Take suspension sample A	
3	Take bottom withdrawal bottle sample A/1	
6	Bottle sample A/2	Prepare for suspension sample
10	Bottle sample A/3	
15	Bottle sample A/4	
20		Take suspension sample B
23		Take bottom withdrawal bottle sample B/1
25	Bottle sample A/5	
26		Bottle sample B/2
30		Bottle sample B/3
35		Bottle sample B/4
40	Bottle sample A/6	
45		Bottle sample B/5
60	(2) Bottle sample A/7 (3) Remaining water A/8	(1) Bottle sample B/6
80		Bottle sample B/7 Remaining water B/8

At time 60, three bottle samples have to be taken, and they should be done in the order indicates, that is:– 1. Bottle B/6, 2. Bottle A/7, 3. Bottle A/8.

The next suspension sample in tube no 1 is then taken at time 80, or later if desired.

On completion of survey

1 Release spring unit, so that spring is in the unwound position.

2 Release rubber sleeves at both ends of the sampling tube, so that the rubber is slack. Push loose rubber sleeves inside inner tube.

3 Store in a dark place, so that the rubber sleeves last as long as possible. Each sleeve should probably last about two weeks once it has first been used.

4 Any damaged or worn rubber sleeves should be replaced in the laboratory or workshop if possible, although it can be done anywhere.

Replacement of rubber sleeves

1 Release spring unit, and release rubber sleeves at both ends.

2 At the end at which a new rubber sleeve is required, unscrew the two small screws which hold the brass end-piece in position.

3 Remove the brass end-piece, and withdraw the inside tube by about 30 cm or so.

4 Turn the knurled ring anti-clockwise to unscrew, and remove.

5 Remove the cone-ring, if this did not come off with the knurled ring, and remove the worn rubber sleeve.

6 Stretch the new rubber sleeve over the inner tube, so that it covers the threaded brass end-piece on the inner tube. Fold back the rubber so that it forms a double thickness over about half the length of the brass end-piece, especially on the tapered portion.

7 Replace the cone-ring.

8 Replace the knurled ring, and screw down tight.

9 Pull the free end of the rubber to slightly stretch the rubber, and re-tighten the knurled ring. Repeat, gradually stretching the rubber more and more, until the knurled ring will screw down no further. Pull fairly hard on the rubber sleeve to check that it will not slip out. It is better to find this out now, rather than during a test.

10 Slide inner tube back into outer tube, checking that keybar on the inside of the spring unit fits into slot in one of the grey blocks fixed near the centre of the inner tube.

11 Replace brass end-piece on outer tube, and match up screw holes.

12 Replace 2 screws holding end-piece.

Checking the balance of the sampling tube

The correct balance of the sampling tube is most important when the tube is being used in low velocities, less than about 0.5 m/s. At higher velocities the stabilising fin will correct any tendency to deviate from the horizontal position under water.

1 To check the balance, immerse the tube in still water in its lowering frame. If it is correctly balanced it will adopt a horizontal position once all the air has escaped from the outer tube.

2 If necessary; correct the balance by loosening the clamping screw, and slide the stabilising ring in the required direction. The red arrows on the tube and ring should however still be in line – this controls the vertical balance.

3 When the balance is correct again, tighten up the clamping screw, and mark the new stabilising ring position.

Additional notes

1 Lead weights are provided for attachment to the lowering frame, to counteract the drag forces on the tube at high velocities. At velocities in excess of 1.0 m/s the drag forces increase substantially, and the tube and frame become very difficult to handle.

2 Although not normally necessary, a strip of adhesive tape may be wound around the rubber sleeves where they are attached to the outer tube. This provides an additional safeguard against the sleeve sliding off the end. Note however that the adhesive tape cannot easily be detached from the rubber sleeve without damaging it.

TABLE A1
Typical field sheet for sampling tube

SETTLING VELOCITY SAMPLING TUBE

Date: 16.5.73 | Location: Bristol Avon/Seamills

Sample No: 04S | Tube No: 6

Tube sample taken at: 1015 BST | Depth of sample: 0.8 m below surface

Temperature of first sample: 11°C

Time after sample taken in minutes	Clock time	Withdrawn sample bottle number
0	1015	–
3	1018	1417
6	1021	2273
10	1025	1413
15	1030	1403
25	1040	1950
40	1055	4253
60	1115	1958
60+	–	1409

Comments:

APPENDIX II

Instructions for assembling the sampling tubes after unpacking

The settling velocity sampling tubes and the equipment that goes with them will normally be shipped in a dismantled state. Each case will usually contain the parts for two complete sampling tubes and the associated stand.

Assembling the stand

1 After unpacking the case, identify the following parts:—

i) Three stand frames – these are made of tubular steel, and are shaped rather like the letter 'A'.

ii) Three crossbars – these are tubular steel rods about 60 cm long.

iii) Two funnel plates.

2 The assembly of the stand is best carried out while looking at the photograph in Plate 2. Each crossbar slides into the holes on the main 'A' frames, and is clamped in position by turning the wing screw. The three frames are identical, so it does not matter which order they are placed in. They should be clamped in position to give two equal gaps (see Plate 2).

3 After assembling the stand, turn it around if necessary so that the crossbar at the top of the stand is towards the back. Place the two funnel plates on the bottom two crossbars with one in each space. When the sampling tubes are later placed in the stand they should be in a vertical position. If they are not quite vertical, check to see whether turning the funnel plate back-to-front will make the tube more vertical.

Assembling the sampling tubes

1 After unpacking the case identify the following parts which make up two complete tubes:—

i) Four outer, larger diameter perspex tubes. The two longer ones are bottom outer tubes, and the two shorter ones are the top outer tubes.

ii) Two inner, smaller diameter perspex tubes, about 95 cm long.

iii) Two spring recoil units – these are brass assemblies about 12 cm diameter and 7 cm long.

iv) Four brass sideplates about 24 cm long and 5 cm wide. Two of the side plates have the release piston mounted on them: these are the left side plates. The other two side plates have a wind screw mounted on them: these are the right side plates.

v) Four brass end pieces: these are brass parts about 9 cm diameter.

vi) Two stabilising fins. These are made of an aluminium alloy, and consist of two concentric cylinders joined by three fins.

2 Take a stabilising fin and stand it on end on a bench or table. The fin should rest on the outside cylinder, with the smaller cylinder uppermost. Take one outer bottom perspex tube, and lower into the centre of the fin. Slide the fin up or down the tube until the top of the fin matches up with the line marked on the outer tube. Tighten the clamping screw on the fin.

3 Remove the 8 washers and nuts from the top of the outer tube. Stand the tube on the table again. Take a left side plate (one with a release piston on it) and fit it on to the four screw-studs on the side of the perspex tube. The pivot rod and the piston should be on the side

furthest away from the axis of the tube, and the pivot should be below the piston. Place a nut and washer loosely on each of the bottom two screw-studs.

4 Take a right hand side-plate (one with a wing-screw mounted on it) and place it over the four studs on the other side of the perspex tube. Again the wing-screw and the pivot rod should be on the side furthest away from the axis of the tube, and the pivot rod should be below the wing-screw. Place a nut and washer loosely on each of the bottom two studs.

5 Take a spring unit, and slide over the top end of the perspex tube.

6 Check that the piston on the left side plate is fully withdrawn and the wing-screw on the right side plate is fully screwed out.

7 Take one top outer perspex tube. Remove all 8 nuts and washers. Place the end of the tube between the two side plates, and match up the screw studs with the holes in the side plates. Push the side plates into place, and place a nut and washer on each of the four top screw studs. Tighten to finger-tight.

8 Now tighten up all four bottom nuts, again to finger tight.

9 Lay the sampling tube flat on the bench or table, and place a nut and washer on each of the eight remaining screw-studs. Tighten up all 16 nuts with a spanner.

10 Take one of the inner perspex tubes. Mounted on this tube are three grey plastic blocks, which divide the tube into two unequal lengths. The shorter length of tube is the top and the longer length is the bottom.

11 Unscrew the knurled ring at the top of the inner tube, and remove the ring and also the cone ring. Feed the top end of the inner tube into the bottom of the outer tube, continuing until the inner tube is wholly inside the outer tube.

12 Take one brass endpiece, and remove the two small retaining screws. Place the endpiece in the bottom end of the outer tube, and screw in the two retaining screws.

13 If it is decided not to fit the rubber sleeves at this time, withdraw the inner tube about 30 cm or so out of the top end of the outer tube, and replace the cone ring and the knurled ring. Lower the inner tube back into the outer tube and place another endpiece in position at the top end of the outer tube, screwing in the two small retaining screws.

14 If it is decided instead to fit the rubber sleeves at this stage, place the sampling tube in the stand, with the stabilising fin at the bottom, and the piston towards the left. Withdraw the inner tube about 30 cm or so out of the top end of the outer tube. Fit the rubber sleeve according to the instructions on page A4, following through instructions 6 to 12.

15 Turn the sampling tube upside down in the stand, and fit the rubber sleeve to this end of the tube, again following the instructions on page A4, but this time beginning at instruction 2. Replace the sampling tube the correct way up in the stand (Plate 2).

16 It is probably a good idea to check the operation of the sampling tube at this stage, as described on page A1, instructions 3 to 7. If a sufficient depth of water is available, such as a tank, then it is also a good idea to check the balance of the tube, as described on page A4.

17 After these checks have been carried out, release the spring unit and the rubber sleeves, and push the loose rubber sleeves inside the inner tube. The sampling tube can the be stored until it is required.