REPORT L

VISUAL ACCUMULATION TUBE FOR SIZE ANALYSIS OF SANDS

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VISUAL ACCUMULATION TUBE FOR SIZE ANALYSIS OF SANDS

B. C. Colby[1] and R. P. Christensen[2]
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SYNOPSIS

The visual-accumulation-tube method was developed primarily for making size analyses of the sand fractions of suspended-sediment and bed-material samples. Because the fundamental property governing the motion of a sediment particle in a fluid is believed to be its fall velocity, the analysis is designed to determine the fall-velocity-frequency distribution of the individual particles of the sample. The analysis is based on a stratified sedimentation system in which the sample is introduced at the top of a transparent settling tube containing distilled water. The procedure involves the direct visual tracing of the height of sediment accumulation in a contracted section at the bottom of the tube. A pen records the height on a moving chart. The method is simple and fast, provides a continuous and permanent record, gives highly reproducible results, and accurately determines the fall-velocity characteristics of the sample.

The apparatus, procedure, results, and accuracy of the visual-accumulation-tube method for determining the sedimentation-size distribution of sands are presented in this paper.

INTRODUCTION

The visual-accumulation-tube method for the size analysis of sands was developed as a part of a general series of investigations entitled "A Study of Methods Used in Measurement and Analysis of Sediment Loads in Streams" and sponsored by the Subcommittee on Sedimentation, Inter-Agency Committee on Water Resources (formerly Federal Inter-Agency River Basin

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Committee[3]). The developmental work was carried on at the St. Anthony Falls Hydraulic Laboratory, University of Minnesota, by the active cooperation of the U. S. Geological Survey and the Corps of Engineers, U. S. Army; financial assistance was given by the U. S. Bureau of Reclamation.

Size analyses of sands have been made for many years. With recent added attention to sediment-transport problems in streams, the emphasis has shifted toward the determination of fall velocity or sedimentation size instead of physical size or volume of the individual grains. In fluvial sediment problems, the fall velocity of an individual particle in water appears to be the most significant and fundamental measurement of particle size.[4,5] None of the size-analysis methods previously available for sands were sufficiently economical and at the same time sufficiently accurate in establishing the fall velocity distribution that would be found if each particle of the sample was dropped individually. The many sedimentation-size analysis methods that did determine the rate of fall of the sample actually indicated a settling velocity that was affected by concentrations of material, space limitations, and other influences inherent in the combination of sample, fluid, and apparatus.

The VA-tube method for analysis of sands was developed to meet two principal requirements:

1) The method must be fast, inexpensive, and adaptable for use by personnel having little scientific training.
2) Results must be based on the fall velocity of the individual particles composing the sample.

Direct measurement of the fall velocity of the individual particles was not practical for routine size analyses. However, a velocity-frequency distribution may be obtained by allowing a sand sample to settle through a definite length of water column. Sediment is introduced at the top of a column of distilled water, and the rate of sediment accumulation is measured at the bottom. This general settling-velocity method is not new; Benningsen,[6] Kennedy,[7] Werner,[6] Emery,[6] Travis,[8] and others[6] have used similar sedimentation-

3. "Measurement and Analysis of Suspended Sediment Loads in Streams," by M. E. Nelson and P. C. Benedict, Trans., ASCE, Vol. 116, 1951, pp. 917-918.
4. "Development of a Stratified-Suspension Technique for Size-Frequency Analysis," by H. J. Skidmore, Thesis, Dept. of Mechanics and Hydraulics, Iowa State University, 1948, p. 2.
5. "A Study of Methods Used in Measurement and Analysis of Sediment Loads in Streams," Subcommittee on Sedimentation, Inter-Agency Committee on Water Resources, Report No. 7, Corps of Engrs., U. S. Dept. of the Army, St. Paul District, St. Paul, Minn., 1943, pp. 14-15.
6. "A Study of Methods Used in Measurement and Analysis of Sediment Loads in Streams," Subcommittee on Sedimentation, Inter-Agency Committee on Water Resources, Report No. 4, Corps of Engrs., U. S. Dept. of the Army, St. Paul District, St. Paul, Minn., 1941, pp. 74-76, 144-146.
7. "Report on the Deposit, and Scour of Silt in the Main Line, Sirhind Canal, and on the Silt Experiments 1893-1898," by R. G. Kennedy, Punjab Public Works Dept. of Irrigation Br. Paper No. 9.
8. "Measurement of Average Particle Size by Sedimentation and Other Physical Means," by P. M. Travis, Am. Soc. for Testing Materials, Bull. No. 102, 1940, pp. 29-32.

size methods. Their analyses determined the quantities of sediment that settled the length of the water column within given intervals of time, and each time interval corresponded to a definite settling velocity.

The velocity-frequency distributions obtained by the general settling-velocity method differed from those for the fall velocity of the individual particles for three reasons: (1) The sample could not be introduced at the top of the water column so that all particles would start to settle from the same elevation at the same time and without mutual interference. (2) The rate of fall of each particle was affected by the nearness of the tube walls, the influence of adjacent particles, and the density currents set up in the fluid. In addition, the effects varied because of the contracting and contracted sections of sedimentation tube which were a part of most systems of this type. (3) Whether the accumulation of sediment was measured in place at the bottom of the sedimentation tube or was removed for measurement, inaccuracies were inherent in determining the quantity settled out of suspension at given time intervals.

Usually the velocities obtained in any of the many sedimentation systems have been accepted without critical investigation as equal to, or at least representative of, the fundamental fall velocity of the particles. Emery[9] calibrated his fall velocity apparatus with quartz sands of established sieve-size distributions. This procedure does not meet the needs of the present investigation of fall velocity. His calibration showed that quartz particles of the smaller sand sizes fell much faster in the Emery tube than would quartz spheres of the same sieve sizes. The coarse sand particles did not show the same degree of difference.

A more exacting study of fall velocity was made for the VA-tube development. For the finer sand sizes, in the range 62 to 125 microns, the velocities in the VA-tube were about 40% greater than those of the same particles falling along. The difference between rates of fall under the two conditions gradually reduced to zero at the coarse or very coarse sand sizes.

For the VA-tube development the fall velocity of the individual particle in water has been accepted as the fundamental measurement of particle size. "Standard fall velocity" may be defined as the terminal uniform settling velocity of the particle falling alone in quiescent distilled water of infinite extent and at a standard temperature of 24°C. This is the ideal fall velocity for the VA-tube development. However, a standard temperature is not generally accepted, and not all determinations of fall velocity can be made at 24°C. The settling velocity of a sand particle may be determined at another temperature and converted to that at 24°C by the relation for quartz spheres.[10] Unpublished data[11] support theoretical considerations which indicate that determinations within normal ranges of laboratory temperatures, if converted by the relation for spheres, will yield fall velocities essentially the same as

9. "Rapid Method of Mechanical Analysis of Sand," by K. O. Emery, Jour. Sed. Petrology, Vol. 8, No. 3, pp. 105-110.
10. "A Study of Methods Used in Measurement and Analysis of Sediment Loads in Streams," Subcommittee on Sedimentation, Inter-Agency Committee on Water Resources, Report No. 4, Corps of Engrs., U. S. Dept. of the Army, St. Paul District, St. Paul, Minn., 1941, Fig. 5.
11. "Preliminary Report on the Fall Velocity of Missouri River Sand" by L. C. Fowler, Missouri River Div., Corps of Engineers, U. S. Army.

those in water at 24°C. "Fall velocity" will be used herein as the terminal uniform settling velocity of a particle falling alone in quiescent distilled water of infinite extent. A quantitative expression for fall velocity must be accompanied by a statement of the temperature at which it applies.

The actual settling velocity of particles in the VA-tube was not the same as the fall velocity of the individual particles. Sedimentation theory was inadequate to define the relation between the two. Therefore, a calibration procedure was substituted for theoretical definition so that the effects of mutual interference of particles, size limitations of the system, and volume-weight relations did not require separate determinations.

The instrumentation and techniques for the VA-tube method possess several advantages over previous processes of the same type, but the really significant improvement lies in this calibration which makes possible the direct determination of the fall-velocity distribution of the sample. The calibration was accomplished by analyzing hundreds of sand samples for which the fall-velocity characteristics had previously been established. The preparation of such samples was made possible by new techniques for determining the fall-velocity frequency distribution of sand samples.

As a concession to those accustomed to a linear-size designation, the term "fall diameter" is introduced. The fall diameter of a particle is the diameter of a sphere that has a specific gravity of 2.65 and also has the same terminal uniform settling velocity as the particle when each is allowed to settle alone in quiescent distilled water of infinite extent and at a temperature of 24°C. The temperature qualification in the definition is necessary only for precision; within the normal range of laboratory temperatures the effect of temperature on fall diameters is usually negligible.

Twelve sets of the VA-tube apparatus were delivered to various sedimentation laboratories in 1954. In some of these laboratories, the method has been in routine use for several months and has been considered satisfactory. Improvements in apparatus and technique can undoubtedly be made as the result of further field experience.

Visual-Accumulation-Tube Method

Samples Suitable for Analysis

Samples whose particles are mainly in the range of sand sizes are suitable for analysis in the VA-tube. The weight of the samples may be as small as 0.05 gm for fine sands and as large as 15 gm for samples with a normal size distribution. If many coarse particles, larger than a sieve diameter of 1 or 2 mm, are present in a sample, they are removed by sieving. If any clay or much silt (sizes under 62 microns) is contained in a sample, it is removed before VA-tube analysis. Some coarse silt does not affect the accuracy of results, but appreciable quantities of silt require additional time for making the analysis. The clay and silt fractions should be separated from the sand by sieving or by sedimentation processes, but the division need not be at a precise size.

Samples for analysis should be relatively free of organic matter and in such condition that the grains will fall as individual particles and not in aggregates. The sand particles should be thoroughly soaked in water before analysis so that every particle is completely wetted; they should be contained in not more than 40 ml of water at a temperature no lower than that of the water in the sedimentation tube.

Visual-Accumulation Tube

The apparatus for the VA-tube method of analysis consists of the following main parts as shown in Fig. 1:

1) A glass funnel, or tube-and-funnel combination, about 10 in. long.
2) A rubber tube that connects the funnel and the main sedimentation tube and that together with a special clamping mechanism serves as a valve.
3) A glass sedimentation tube. Tubes are of 2 lengths. A 180-cm tube has a 140-cm section of 2-in. inside diameter, a 20-cm contracting section, and a 20-cm accumulation section of 10-mm inside diameter. This long tube is used for the analysis of bed, beach, or other sands of coarse sizes when a sufficient quantity of the material is available. A 120-cm tube has an 80-cm section of 1-in. inside diameter; a 20-cm contracting section; and a 20-cm accumulation section with an inside diameter of 2.1, 3.4, 5.0, or 7.0 mm. The short tube is suitable for the analysis of suspended-sediment samples that contain only small quantities of sand that is mostly less than 1 mm in diameter. An elastic plug is inserted in the lower end of the accumulation section to close the tube.
4) An electrically operated tapping mechanism that strikes against the glass tube and helps keep the accumulation of sediment uniformly packed and level on top.
5) A special VA-tube recorder which consists of: (1) A carriage that can be moved vertically by a hand-operated mechanism and on which are mounted a recording pen and an optical instrument consisting of a 2-power telescope eyepiece with a horizontal cross hair. (2) A cylinder that carries a chart and rotates at a constant rate during the analysis.
6) The recorder chart is a printed form on which the pen draws a continuous record of the accumulation.

Plans and specifications are available for all items of the visual-tube equipment. The cost of the complete visual-tube apparatus is about $500, or approximately that of a set of sieves and sieve shaker.

Selection of Tube Size

A necessary preliminary to analysis is the choice of the proper tube size for a given sample. Frequently, two sizes or more would be satisfactory. The quantity of sand and the upper particle-size limit in a sample are used as guides in selecting the tube size. Table 1 indicates the limitations on sand samples suitable for analysis in each size of tube. If the pertinent characteristics of samples are not known from previous experience with the sampled stream, the sample to be analyzed may be compared with a set of synthetic samples. For instance, a sample may be analyzed in a 2.1-mm tube if it does not exceed in quantity or particle size a synthetic sample containing about 0.8 gm of sand with a maximum particle size of 250 microns.

The maximum particle sizes shown in Table 1 are those that should not be exceeded by a significant percentage of the sample. The percentage of excess may be greater if the sample is small in relation to the capacity of the tube or if the analysis of the coarser portion is not highly important.

Normally, the best results are obtained if the total height of accumulation in the bottom of the tube is between 1 and 4 in. If a sample has a very limited size range or the material is predominantly coarse, better results are obtained with maximum heights less than 4 in. If a satisfactory tube size is not selected the first time, the sample can be rerun in another size of tube.

Table 1.--Guide to Selection of Tube Size

Sample		Maximum particle size		Sedimentation tube	
Dry weight (gm)	Volume of sand (ml)	Fall diameter (microns)	Sieve diameter (microns)	Length (cm)	Size (mm)
0.05- 0.8	0.03-0.5	250	250	120	2.1
0.4 - 2.0	0.2 -1.2	350	400	120	3.4
0.8 - 4.0	0.5 -2.4	500	600	120	5.0
1.6 - 6.0	1.0 -4.0	700	1,000	120	7.0
5.0 -15.0	3.0 -9.0	--	2,000	180	10.0

However, the choice of a suitable tube is not difficult because the usable limits of the respective tubes overlap considerably.

Methods of Analysis

The authors and their assistants have analyzed many samples with the visual-accumulation tube. These analyses required less than 10 minutes if the particles in the sample had fall diameters greater than 62 microns. More samples could be analyzed per hour than by sieving. If silt was present, the analysis took a longer time. For those who might be interested, the step-by-step procedure used by the authors is as follows:

1) The proper chart for the chosen length of tube is selected and, after notes to identify the sample, operator, and analysis are written on the chart, it is placed on the drum. (The 180-cm tube requires a different chart than the 120-cm tubes because of the greater distance through which the sample must settle.)
2) The recorder pen is oriented on the zero-accumulation and zero-time lines of the chart.
3) The recorder is adjusted to bring the horizontal hair in the eyepiece level with the top of the tube plug where the accumulation of sediment begins.
4) When the apparatus, including the proper sedimentation section, is assembled, the tube is filled with distilled water to just above the valve. The temperature of the water in the tube is recorded, and the valve is closed. The water need not be changed for succeeding analyses.
5) The electrical tapping mechanism is started; this operation also closes the electrical circuit to a switch at the valve so that opening the valve starts rotation of the cylinder.
6) The sand sample is washed into the funnel above the closed valve and is stirred briskly for 10 seconds.
7) The valve is immediately and fully opened. Because opening the valve automatically starts the cylinder, the chart time and the settling of the particles in the tube begin simultaneously.
8) The operator watches through the eyepiece and, as soon as the first particles reach the bottom of the tube, he moves the carriage vertically at a rate that keeps the horizontal hair on a level with the top of the accumulation of sediment. This procedure continues until the pen has passed the 62-micron size on the chart. Then rotation of the cylinder automatically stops. If material is still falling, the tracking operation is continued, at least intermittently, until the maximum height of accumulation is determined.

9. While the pen stands at the maximum height of accumulation, the cylinder is rotated by hand to extend the line of maximum accumulation across the chart.
10. After the valve is closed, the sample is drained into a beaker by removing the tube plug. If necessary, the valve is opened slightly to drain out the sample. The plug is replaced.
11. The chart is removed from the recorder.

Calibration

The settling velocity of sediment particles varies with many factors including the size of sedimentation column, the presence of other particles, and the manner of introducing the sample. In the VA-tube method, the finer sands fall as much as 40% faster than individual particles, while the coarser sizes are affected to a lesser degree. A fall diameter of 250 microns corresponds to a fall velocity of 3.44 cm/sec when the particle falls alone in distilled water at 24°C and corresponds to a settling velocity of about 4.4 cm/sec when the particle falls in the visual tube in the presence of other particles in water at 24°C. Results expressed in terms of the fall diameter of the individual particles were, therefore, obtainable only by calibration of the VA-tube method. A satisfactory calibration required analysis of hundreds of sand samples for each of which the fall-diameter distribution had been previously determined.

Determination of Fall-Diameter Distribution

Test samples of known fall-diameter distribution were needed for calibrating the VA-tube method. There was no available method for satisfactorily compositing samples having known fall-diameter distributions; therefore, one was developed that was based on the fall velocities of the individual particles. The primary concept was simple and obvious, and other investigators had pointed the way. Carey and Stairmand[12] had developed a photographic method for determining the fall velocity of individual grains in samples composed of particles smaller than 100 microns. Serr[13] had determined the sedimentation-diameter distribution for sands of sizes larger than about 140 microns by an individual dropping of many representative particles from each of several sieve fractions.

The essentials of the procedure developed for determining the fall-diameter distribution for sands were as follows: A bulk sample of sand was sieved, 10 gm at a time, until the desired quantity of material of each sieve fraction had been obtained. The sieve-size distribution based on the total weight of each fraction was recorded. Then each sieve fraction was carefully split and resplit until about 100 representative particles remained. The particles from a sieve fraction were dropped individually in distilled water, and the fall velocity of each was determined and converted into fall diameter

12. "Size Analysis by Photographic Sedimentation," by W. F. Carey and C. J. Stairmand, Inst. of Chem. Engr., London, Trans., Vol. 16, 1938, pp. 57-62.
13. "A Comparison of the Sedimentation Diameter and the Sieve Diameter for Various Types of Natural Sands," by E. F. Serr, III, Thesis in Irrigation Engr., Colorado A & M College, Fort Collins, Colo., 1948.

by using the relation of the diameter of a quartz sphere to its settling velocity in water.[10] The fall diameters of the particles were cubed to approximate their relative volumes and weights. A fall diameter was chosen at about the median division of a summation of the cubed diameters arranged in order of size. A summation was made of all cubed diameters smaller than the median, and this sum was expressed as a percentage of the total of all the cubed diameters. For example, assume that the sum for particles smaller than 305 microns was 48% of the sum for the sieve fraction 250 to 350 microns. If, in the recorded sieve size distribution for the bulk sample, 50% was finer than 250 microns and 10% was in the 250 to 350 fraction, then 50 plus 4.8 or 54.8% of the total sample had fall diameters smaller than 305 microns. Extending this process to all the sieve fractions completed the fall-diameter distribution for the sample.

Fig. 2 shows the fall-diameter distribution and the sieve-diameter distribution for a sand sample. A sieve-size distribution curve is defined only at the sizes of sieves actually used. A fall-diameter distribution curve, obtained by the method above is defined only at the approximately median sizes chosen to divide the fractions. Common practices which introduce errors are (1) the use of average or mean figures between defined points on size-distribution curves, and (2) the substitution of particle counts that are unweighted for distributions by weight.

Four comments that pertain to the method of determining fall-diameter distributions are justified.

1) The cube of the fall diameter was assumed to be proportional to the weight of the particle. This relationship is not always exact, but for a a group of particles, the cube more adequately represents the volume and weight than would the first power of the fall diameter. Even use of the first power of the fall diameter would not seriously alter the results if the range of sizes for a fraction was small.
2) The previously cited process for computing the size distribution required modification if a significant percentage of material in the sieve fractions coarser than 350 microns had fall diameters less than 305 microns or if a significant percentage of material in the sieve fractions finer than 250 microns had fall diameters greater than 305 microns. The necessity for modification was readily apparent and was infrequent except for very coarse sieve fractions. By extra computations the weight equivalent of offending material was transferred from the original sieve fraction to the proper side of the 305-micron size.
3) Splits of 100 particles from each of about 8 sieve fractions were generally adequate to determine the fall-diameter distribution. The fall-diameter distribution curve should have a shape similar to that for the sieve-diameter distribution, and any inconsistency in the results of a split was immediately obvious from a plot of the size distribution. If inconsistencies were minor, the results for adjacent sieve fractions were averaged when drawing the final distribution curve; but, if any large discrepancy was found, the split was rechecked or repeated. In the example cited, if the 48% smaller than the cube of 305 microns should actually have been 40% (an extreme variation) the percentage finer would have been changed only from 54.8% to 54.0%. Errors in individual splits (1) were independent of those for other splits, (2) were not subject to cumulative errors, and (3) generally applied to small fractions of the total sample.

4) Within the temperature range from 20°C to 30°C, the effect of temperature on the settling velocity of a particle of sediment in water was considered to be essentially the same as that on the velocity of a sphere that has a specific gravity of 2.65.

Test Samples of Known Fall-Diameter Distribution

The process for determining the fall-diameter distribution of a sand is a laborious one, and applying it directly to many sands in order to calibrate the visual-tube method would not have been feasible. However, many test samples could be composited from the sieve fractions of any one sand for which the fall-diameter distribution had been determined. In this manner a large supply and variety of test samples were obtained.

The original relative weights of the various sieve fractions were composited into samples having the same sieve- and fall-diameter distributions as those in the original sand. These samples were made up in a variety of total weights, and duplicate samples could be compounded in any or all of the weights. Different relative weights of the various sieve fractions were used to obtain test samples of different size-frequency distributions. The fall-diameter distribution was readily computed for each of these samples by the same methods used for the original sand. In the former illustration 48% of the sieve fraction 250 to 350 microns was finer than a fall diameter of 305 microns. If a test sample was made up in which 60% of the sample was from sieve sizes finer than 250 microns and 20% was from the 250 to 350 sieve fraction, then 60 plus (48 x 20/100) or 69.6% of the test sample was finer than a fall-diameter of 305 microns. Extending the process to the other sieve fractions completed the fall-diameter distribution for the test sample, and percentages finer than desired division sizes could be determined from a plotting of the distribution.

Method of Calibration

Nearly 300 analyses of samples with predetermined fall-diameter distributions were available for the calibration of the VA-tube method. The calibration was incorporated in two charts, one for the 120-cm tubes and one for the 180-cm tubes.

Each analysis produced a curve of sediment accumulation with time. (See Fig. 3.) Because the percentage finer than each division size was already known for a calibration sample, the percentage of the total accumulation that should occur at each division size was known. The point on the chart at which the proper percentage of the accumulation occurred for a given division size indicated the location at which the division-size line must be placed to divide the accumulation at the proper percentage. Assume that 40% of a calibration sample was finer than 125 microns. Then the intersection of the pen trace with the elevation for 60% of the total accumulation fixed the distance from the time origin at which the proper percentage for the 125 micron size was obtained. Consequently, for the temperature of analysis, each analysis established a point on the chart for each division size in the sample. A series of analyses of known samples supplied a group of points tending to define the proper location of each division-size line. The distance of a division-size line from the time origin of the chart is a measure of the time for that division size of particle to fall in the VA-tube.

Analyses at other temperatures provided information for adjustments for temperature. Actually there were not enough analyses to define completely the effect of temperature on the time of fall, but the effect of changes in

temperature was considered proportional to the effect on the fall velocities of spheres—an assumption that could not be much in error for the relatively narrow range of temperatures encountered in the analyses.

Average times from all analyses in the 120-cm tube could be satisfactorily combined into one chart provided that the previously stated limits (Table 1) of sample quantity and particle size were regarded. The chart for the 120-cm tubes is shown in Fig. 4. A second chart was prepared for the 180-cm tube.

The calibrated charts show analyses directly in the desired terms of fall-diameter distribution by weight, which is equivalent to fall-velocity distributions by weight. Therefore, the calibration automatically covers the effects of such conditions as particle concentration and size, methods of introducing the sample, size limitations of the system, and the fact that accumulation is measured in terms of height or volume instead of weight.

The charts were designed to give the best average results for sands similar to those used in calibration. If much work is to be done with a given sand, especially one that may have highly unusual qualities, then a check calibration should be made for that sand if extremely accurate results are required.

Results from Analysis

Size Distribution from the Chart

In the VA-tube analytical procedure, the pen trace on the chart is a curve for which time is the abscissa and height of accumulated sediment is the ordinate. The curve is a continuous record of the size distribution of the sample. According to custom, analytical results are expressed as percentages of the sample finer (or coarser) than specified division sizes; one common series of these sizes is shown on the chart for the 120-cm tube in Fig. 4. The various temperature lines and the spread between them are required by, and indicate the magnitude of, temperature effects on the analyses. These temperature effects are in proportion to those for spheres of specific gravity 2.65.

The percentages finer than those sizes shown on the recorder chart were found from the chart by use of a scale that when placed at a convenient angle would divide the total accumulation into 100 equal parts. (See Fig. 4.) Briefly, the procedure is as follows: The intersections of the accumulation curve and the division-size lines for the temperature of analysis are marked. Points are interpolated along the curve for temperatures between the positions of the plotted size lines. The zero percent of the scale is placed on the total-accumulation line, and the 100% on the zero-accumulation line. The scale is moved horizontally to the intersection of the curve with the size-temperature line. The percentage finer that the division size is represented by the portion of the total accumulation that lies above the curve and may be read directly on the scale.

Several modifications of the method for reading percentages from the chart are possible. Horizontal lines may be drawn through the intercepts on the curve, and all percentages may be read from one position of the scale. If 10% of material coarser than that analyzed in the visual tube was removed from the sample prior to analysis, then the 90% mark may be used on the zero-accumulation line to show readings directly in percentages of the total sample. Similarly, if 40% of the original sample was removed as silt and clay before visual-tube analysis, the 40% mark may be used on the total-accumulation line to obtain direct readings in percentages of the total sample. The scale may be reversed to show readings in percentages coarser.

Accuracy of Method

The fall-diameter distributions of the samples analyzed for calibration of the visual-tube method were predetermined from individual particle drops. The fall-diameter distributions obtained from the visual-tube analyses were compared with the predetermined fall-diameter distributions to define the accuracy summary shown in Table 2. The data are in terms of differences in percentage finer figures. If, for example, the known amount finer than 125 microns was 40% by weight and the analysis showed 38%, then the difference is -2% and any percentage between 38 and 42 would be within 2% accuracy. Over 75% of the results for all division sizes were within 2% of the known distribution. The accuracy is shown for the various tube sizes, for different sand mixtures classified according to predominant size, and for several fall diameters.

Analyses in the various sizes of tube were about equally accurate except that the accuracy in tubes having a 2.1-mm accumulation section was comparatively low. The reduction in accuracy may have been due to the restricted size, but it probably reflected difficulties in compounding duplicate samples and in analyzing the small quantities of the samples for this small tube.

The accuracy differed somewhat for the various sand mixtures that were analyzed. The very coarse sands contained only a small range of sizes and, consequently, had high concentrations of material at some of the division sizes; the accuracy was lower for these sands. Any small difference in chart time, fall velocity, or calibration produced much greater errors in percentage of the total sample if the concentration of particles was high at a division size.

Variations in accuracy at the different fall diameters were probably not significant except that the high concentrations of material at the 1000-micron size resulted in lower accuracy. At other division sizes the proportion of samples having high concentrations was small. The accuracy at the 62-micron size tended to be high because in many samples the concentration at this size was rather low.

Although Table 2 was based on a large number of analyses there may be occasional samples that can not be analyzed with the same accuracy. The effect of specific gravities much different from 2.65 has not been evaluated, except that samples containing some relatively light-weight material showed no identifiable reduction in accuracy. Several samples composed of one or two sieve fractions have been analyzed but no general evaluation of accuracy has been made for these samples. Analysis of a single sieve fraction produces problems of high and rapidly changing concentrations which are undesirable.

SUMMARY

The visual-accumulation-tube method is rapid, economical, and accurate for obtaining the sedimentation-size distribution of sand samples. The significant technical advance is the development and calibration of an instrument that records results in terms of the fall velocity of the individual particles of the sample.

The fall velocity of the individual particles is one of the most fundamental properties governing the action of sediment in a fluid. The VA-tube method is an improved means of establishing this fundamental property of sands.

An average calibration for the VA-tube was based on analyses of hundreds of samples of known fall-diameter distribution by weight. The calibration provided for normal variations in sand samples; in extremely unusual circumstances, the calibration should be rechecked.

For samples containing only sand sizes, the VA-tube method is a faster means of determining size distribution than the standard sieving method. Therefore, it may justify consideration outside the field of purely sedimentation problems.

The method has been used satisfactorily by several laboratories over a period of many months.

A 16-mm film is available for showing the apparatus and for demonstrating the analytical procedures of the VA-tube method.

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Table 2.--Accuracy of the visual-tube method

Qualification	Observations within given limits, %					Total observations
	Within 1%	Within 2%	Within 3%	Within 5%	Within 10%	
SEDIMENTATION TUBE						
Diameter of accumulation section, mm:						
2.1	36.9	64.2	81.0	95.5	100.0	179
3.4	56.8	80.5	92.4	99.7	100.0	384
5	54.2	75.7	90.7	99.3	100.0	432
7	62.0	84.3	95.2	100.0	100.0	166
a 10	50.9	77.0	88.7	98.1	100.0	318
b 4 and 9	59.4	82.1	95.1	100.0	100.0	224
All observations	53.8	77.5	90.7	98.9	100.0	1,703
SAND MIXTURE						
Predominant size:						
Very coarse sand	44.4	61.1	77.7	94.4	100.0	18
Do	33.3	52.8	63.9	86.1	100.0	36
Coarse sand	50.0	81.2	92.2	100.0	100.0	64
Do	48.2	83.9	92.9	100.0	100.0	56
Do	51.7	81.7	93.3	100.0	100.0	60
Do	52.3	75.0	93.8	100.0	100.0	128
Medium sand	59.4	81.2	95.0	100.0	100.0	160
Do	55.2	79.6	92.5	99.6	100.0	496
Fine sand	62.0	87.5	96.0	99.5	100.0	200
Do	44.3	63.0	82.1	98.0	100.0	246
Very fine sand	53.3	82.2	91.1	98.5	100.0	135
Do	62.5	76.9	89.4	98.1	100.0	104
All observations	53.8	77.5	90.7	98.9	100.0	1,703
FALL DIAMETER						
Division size, microns:						
1,400	72.2	80.6	88.9	97.2	100.0	36
1,000	25.0	58.3	75.0	86.1	100.0	36
700	56.6	79.2	89.3	100.0	100.0	159
500	46.4	75.2	94.1	100.0	100.0	153
350	45.4	70.3	87.6	99.5	100.0	185
250	53.8	78.8	93.9	100.0	100.0	212
175	50.4	80.7	92.9	98.7	100.0	238
125	49.2	75.6	88.2	99.2	100.0	238
88	56.5	74.4	87.9	98.2	100.0	223
62	71.3	87.0	95.1	99.1	100.0	223
All observations	53.8	77.5	90.7	98.9	100.0	1,703

a 180-cm sedimentation tube; other sizes refer to 120-cm tubes.
b Experimental tube not used for routine analyses.

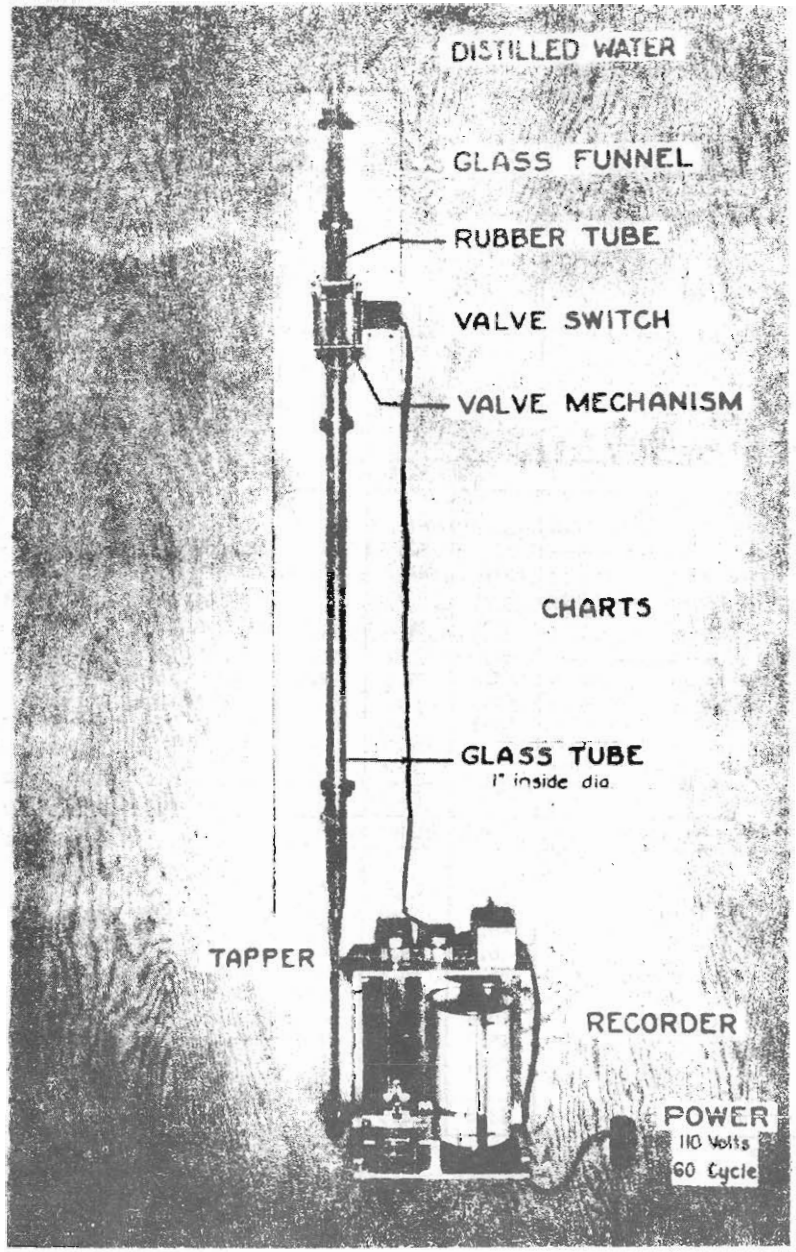


Fig. 1—Visual-Accumulation-Tube Apparatus

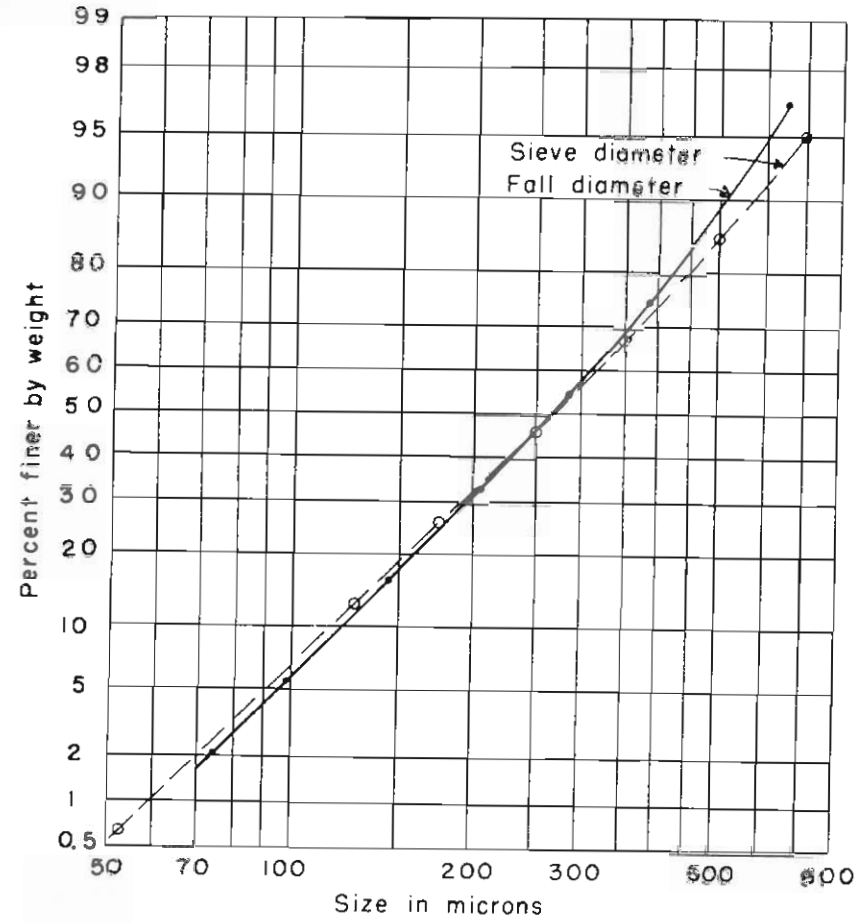
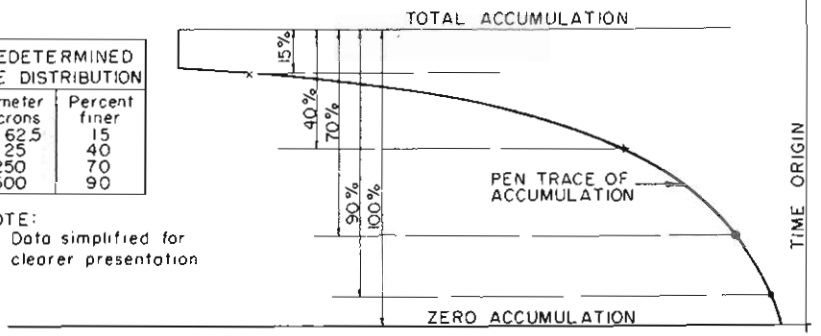


FIG. 2—FALL- AND SIEVE-DIAMETER DISTRIBUTION

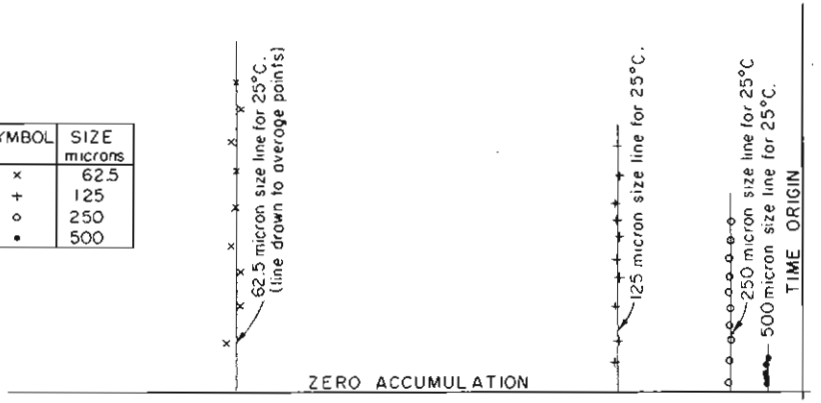
PREDETERMINED SIZE DISTRIBUTION	
Diameter microns	Percent finer
62.5	15
125	40
250	70
500	90

NOTE:
Data simplified for clearer presentation



A--CALIBRATION POINTS FROM A SINGLE ANALYSIS

SYMBOL	SIZE microns
×	62.5
o +	125
•	250
	500



B--CALIBRATION POINTS FROM SEVERAL ANALYSES AT 25°C

FIG. 3--FUNDAMENTALS OF CALIBRATION METHOD

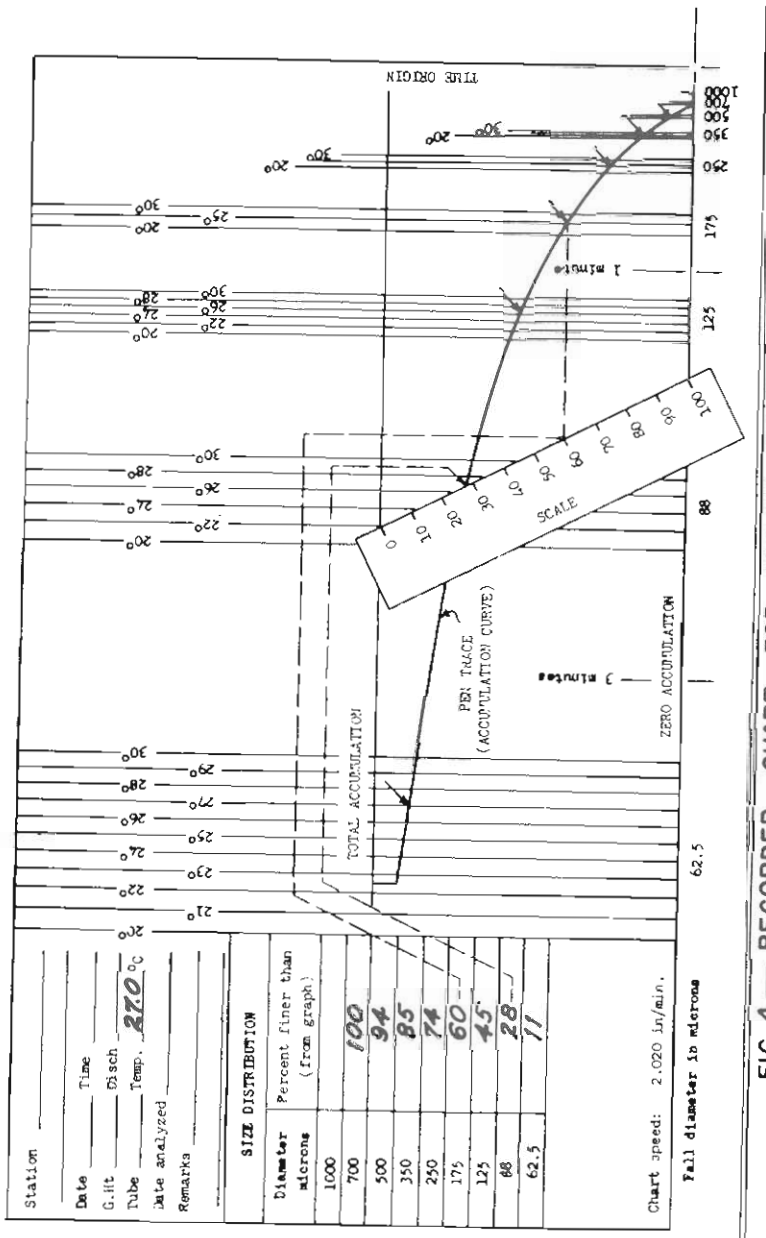


FIG. 4 — RECORDER CHART FOR 120-CM TUBE SHOWING METHOD OF READING SIZE DISTRIBUTION