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ON SIEVING AND SETTLING TECHNIQUES FOR SAND ANALYSIS

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SUMMARY

The basic differences between mechanical analysis of sand by Ro-Tap sieving and by settling in a sedimentation balance are discussed. The Groningen balance can continuously and rapidly record settling times of the grains (50–1,000 μ) of a 1.5-g sample with a maximum recording and reading error of about 2%.

The theory of sieving is not fully developed yet, nor has the theory of settling of sand-sized particles been adequately expressed by any mathematical law. The drag coefficient (C_D) and Reynolds number (Re) relation often used to derive diameter (d) from settling velocity (v) in this size range, are calculated from experimental data on diameter and velocity. Conversion of settling times to "sedimentation diameters" with the help of experimental curves for single, spherical quartz grains and their comparison with the corresponding "sieve diameters" are often found to be unsatisfactory in the case of natural sands, because shape and density variations of every individual grain in a sample can never be taken into account. Therefore, the use of settling velocity as a new grain parameter is advocated.

INTRODUCTION

Sieving is undoubtedly one of the earliest techniques developed for the mechanical analysis of sand-sized particles. On the other hand, it has also been recognised by many sedimentologists for a long time that the settling velocities of sedimentary particles represent more closely their behaviour under natural conditions of transportation and deposition than their sizes, as conventionally determined by the sieving method.

Thus, from time to time settling tubes have been built. Efforts have also been made by several investigators to express the settling times obtained in their settling tubes in terms of "equivalent diameter" (ODÉN, 1915), which has been more clearly defined and renamed by WADELL (1934) as the "sedimentation diameter". The latter is the expression for the diameter of a sphere of the same specific gravity and of the same terminal uniform settling velocity as a given particle in the same sedimentation fluid. Attempts have also been made to establish a relation between the Wadell "sedimentation diameter" and the conventional "sieve dia-

meter", defined as the geometric mean of the openings of the last sieve through which the particle has passed and the sieve on which it is retained (KENNEDY and KOH, 1961).

The purpose of the present paper is to discuss some of the basic differences between sieving and settling techniques which have been experienced through the use of a Ro-Tap with Tyler standard sieves and a sedimentation balance, designed and built at the Geological Institute, Groningen.

THEORY OF SIEVING

The theory of sieving, a technique so commonly used to separate sand-sized particles into different size grades, is not as simple as the practice of this method. KRUMBEIN and PETTIJOHN (1938) have attempted to express the theory of sieving in the simple, hypothetical case of a number of small spheres falling through *one* sieve at a particular time by the formula:

$$y = y_0 e^{-at}$$

where y is the number of spheres present on the sieve at a time t, y_0 is the original number of spheres on the sieve prior to sieving, and a is a constant of proportionality.

This constant of proportionality has been *experimentally determined* by MIZUTANI (1963), who has named it the "sifting coefficient" (K). Mizutani has also mathematically expressed the theory of sieving when a number of sieves is used. It should be noted that in both cases the mathematical expressions are derived on the *assumption* that the amount of sediment falling through a sieve is proportional to the amount retained on it at that moment.

It is clear that although the sieve diameter of a particle is postulated to be the same as its "nominal diameter" (defined by WADELL, 1932, as the diameter of a sphere having the same volume as the particle), this case is not attained in practice since the natural grains always depart in shape from true spheres. SAHU (1965) has stressed the fact that the intermediate diameter of a grain should determine whether it will pass through a particular sieve. The intermediate diameter (b) is a value between L and $L\sqrt{2}$, where L is the aperture for usual square mesh sieves. Thus, in the extreme case, grains having an intermediate diameter even 1.4 times the sieve opening can pass through it.

In practice, however, the case may be still more complicated. Precision measurement of apertures of unused sieves supplied by some well known manufacturers have shown a maximum error of 17%.

In an experiment conducted for better understanding of the behaviour of the individual size fractions during repeated sieving, a sample of sand was first sieved for 10 min in a sieve shaker and two of the fractions (500–400 μ and 400–300 μ) were then coloured red and violet, respectively, by aniline dyes. Mixing

of the individual size fractions and resieving for 10 min showed a grain distribution different from the original one although the weight of each size fraction was repeated fairly closely during the second sieving. Table I clearly shows that only 88% of the coloured grains reappeared on the sieves to which they originally belonged.

TABLE I

EXPERIMENTS ON THE BEHAVIOUR OF INDIVIDUAL GRAINS DURING REPEATED SIEVING

Size fraction (μ)	*Weight (mg)*		*Weight (%)*		*Coloured grains (%)*		
	first sieving	*second sieving*	*first sieving*	*second sieving*	*first sieving*	*second sieving*	
1000–750	2320	2310	4.8	4.8	—	—	
750–600	4186	4030	8.7	8.4	—	—	
600–500	5326	5330	11.1	11.1	—	6 red	
500–400	11236	11060	23.4	23.1	100 red	88 red,	6 violet
400–300	11944	12110	24.9	25.3	100 violet	6 red,	88 violet
300–200	9600	9570	20.0	20.0	—	—	6 violet
<200	3409	3480	7.1	7.3	—	—	
	48021	47890	100.0	100.0			

THEORY OF SETTLING

It is well known that for a particle of small size slowly settling in a fluid, all the resistance to fall is offered by the viscous forces within the fluid. In this case the Reynolds number given by $Re = dv\,\rho_2/\eta$, where d is the grain diameter, v is the velocity, ρ_2 is the fluid density and η is the viscosity of the fluid, is small. The lines of flow within the fluid are deformed to bend round the particle, the flow remaining laminar. Under such conditions the settling velocity of the particle can be expressed in terms of the Stokes' law, $v = C \cdot d^2$, where v is the velocity, d is the particle diameter. C being a constant, the settling velocities can be easily converted to particle diameter.

The upper limit of validity of this law is believed to lie between 25 μ and 60 μ diameter, i.e., between Reynolds numbers of 0.02 and 0.2, when water at 20° C is the fluid and quartz of $\rho = 2.65$ is the settling particle. Whatever the precise upper limit of Stokes' law may be, it is clear that the settling velocity of sand-sized particles is not guided by this law.

The validity of the three well known equations by Oseen (1910, as quoted by KRUMBEIN and PETTIJOHN, 1938), RUBEY (1933) and WADELL (1936) have been recently experimentally studied by BLANCHARD (1967). The limits of Rubey's and Oseen's equations pointed out by this author are $Re = 2$–12 and $Re = 0.02$–2, respectively, whereas Wadell's equation was not found to be applicable under the conditions tested by Blanchard.

The sedimentation balance designed at Groningen and described in the present paper is intended to measure settling times of sample sizes between 50 μ and 1,000 μ at 20°C, that is for Reynolds numbers between 0.1 and 160 approximately. Hence, none of the formulae mentioned above are valid for the whole size range covered by this equipment.

The attempts to derive the law of *single* particle fall outside the range covered by Stokes' equation, are generally based on Newton's law, equating the resisting force on a falling particle to the gravity force:

$$^1/_2 \, C_D \, A \, v^2 \, \rho_2 = {}^1/_6 \, \pi \, d^3 \, (\rho_1 - \rho_2) \, g$$

where C_D is the drag coefficient, or the coefficient of resistance dependent on interrelation of the physical properties of the particle and the fluid; A is the cross-sectional area of the particle, which is $^1/_4 \, \pi \, d^2$ for a sphere; ρ_1 and ρ_2 are the densities of the particle and the fluid, respectively; g is the acceleration due to gravity; d is the diameter of the particle.

It is customary for the hydraulic engineers to represent the relation between drag coefficient (C_D) and Reynolds number (Re) in the form of a graph. This graph, originally plotted by Schiller in 1932, has since been modified and reproduced by many authors, e.g., ROUSE (1950). This C_D–Re graph has found wide application among sedimentologists. The usual procedure adopted is that of "trial and error". Reynolds number and drag coefficient values are computed for some assumed values of grain diameter (velocity and other parameters being experimentally determined) and the computed values of C_D and Re are compared with those obtained from the curves. The diameters are continuously changed and figures recomputed till results matching with those derived from the graph are obtained.

A definite improvement of this tedious "trial and error" procedure has been provided by the U. S. HYDRAULIC LABORATORY (ST. PAUL), 1941, who published graphs of the correct fall velocities for quartz spheres of size range 0.01–10.0 mm, in water at five different temperatures. This graph has been used by many workers (e.g., POOLE, 1957; ROSFELDER, 1961) for the determination of grain sizes from fall velocities of particles.

Settling times of single quartz grains ($\rho = 2.65$) in water at 20°C, as experimentally determined in the Groningen sedimentation balance, are presented in Fig.1.

Corrections for various shape factors have been worked out by HEYWOOD (1938) and also by ZEIGLER and GILL (1959). However, these authors also depend on the experimentally determined C_D/Re relation for the derivation of settling velocities for different grain sizes.

A REVIEW OF SOME EARLIER SETTLING TUBES

One of the earliest sedimentation tubes designed for quick analysis of sand-sized particles was by VAN VEEN (1936), who designed an equipment to measure the volume of the particles settled in terms of the height of sediment accumulated after certain times at the narrowed bottom of a 200 cm long tube. Following Van Veen's idea later, Doeglas (DOEGLAS and SMITHUYSEN, 1941; DOEGLAS, 1946) constructed a sedimentation tube (200 cm long) in the Shell Laboratory, Amsterdam, which was capable of directly recording the weight percentage of the materials (about 4 g) settled on a balance pan at the bottom of the tube. The settling time/grain diameter relation was calculated from Sudry's formula (1912, quoted by DOEGLAS and SMITHUYSEN, 1941). The Doeglas equipment provided a reproducibility with an error of only 2% in the grain-size interval of 5–500 μ.

A more sophisticated version of the Doeglas sedimentation balance in which small movements of the balance beam were pneumatically amplified and continuously recorded, was constructed in the Shell Research Laboratory, Rijswijk (PLANKEEL, 1962). This equipment is capable of analyzing samples as small as 2g ranging in size from 63–2,000 μ. The apparatus contains a device for dropping the whole sample at the same time and also for precisely recording this time.

Another modification of the Doeglas sedimentation balance was constructed in the Scripps Institution of Oceanography (VAN ANDEL, 1964), in which the weight increase caused by sand settling on the balance pan is recorded continuously against time by a strain gauge and an amplifier–recorder system. A continuous cumulative size distribution curve from 62–2,000 μ, with a reproducibility of better than 2% is possible in this equipment.

In the sedimentation tube designed by EMERY as early as 1938, the amount (height) of sediment accumulated at the narrowed bottom of a 164-cm tube was read at predetermined times. Emery used this equipment to determine settling times of quartz grains of various Wentworth size grades at different temperatures. A continuous recording with a reproducibility error of 3% was possible with the original apparatus. The sample dropping device for the Emery settling tube was modified later by POOLE (1957), who, along with his collaborators (POOLE et al., 1951) have also investigated the usefulness, accuracy and reproducibility of the Emery tube. In this tube the reproducibility of the median diameter was found to range from 0.6–2.0% for materials between 62 μ and 1,000 μ sizes.

The rapid sediment analyzer developed at the Woods Hole Oceanographic Institution (ZEIGLER et al., 1960) depends on the technique of measuring pressure differential induced in a column of water by sediment settling through a measured distance. Very rapid analysis of samples ranging in sizes between coarse silt and fine gravels, with excellent reproducibility has been claimed by the authors.

The Woods Hole equipment was modified later (SCHLEE, 1966) to improve the pressure sensing device, the sediment introduction gate (combined with a

rotating disc system) and the diameters of the settling tube and of the sediment release chamber. The system was also calibrated in terms of Wentworth size grades so as to obtain the weight percentages of the individual size fractions.

THE GRONINGEN SEDIMENTATION BALANCE

The Groningen sedimentation balance was constructed in 1961 at a total cost of $ 1,700. It consists of an analytical balance of substitution weighing type fitted on top of a 204 cm high double-walled transparent plastic cylinder and an electrical recorder (Fig. 2). The balance, a Sartorius Selecta Ultra, which has a magnetic damping system, is capable of automatically weighing 1,000 mg. Its total capacity is 200 g and its sensitivity is less than 1.0 mg.

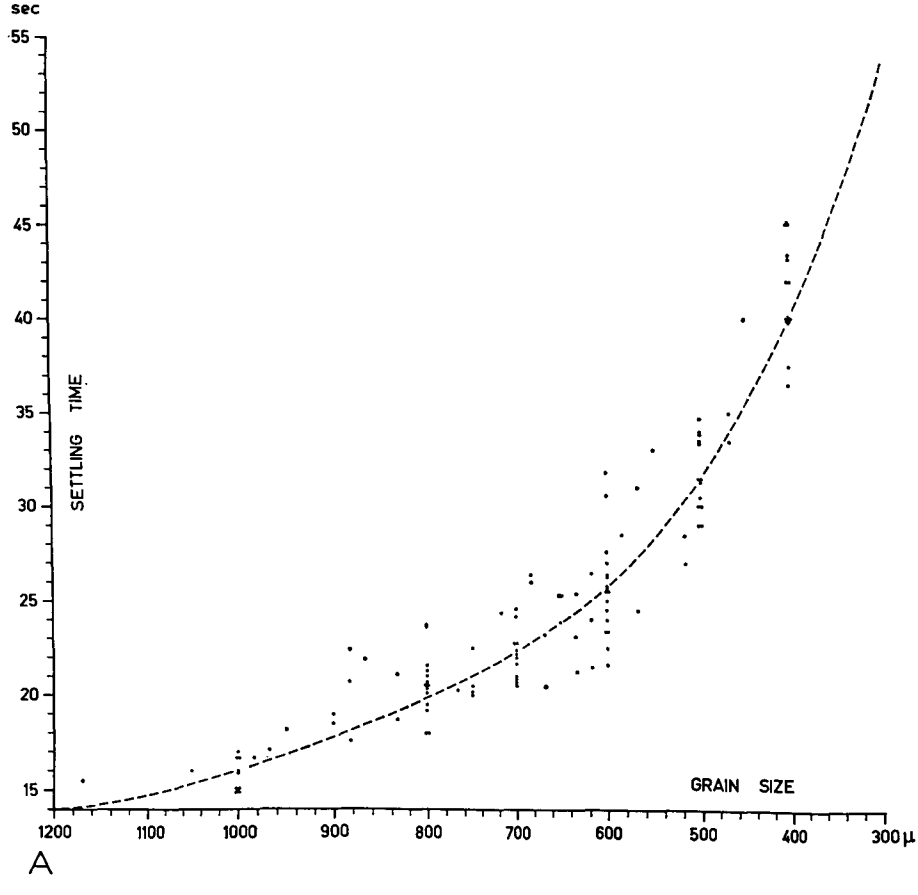
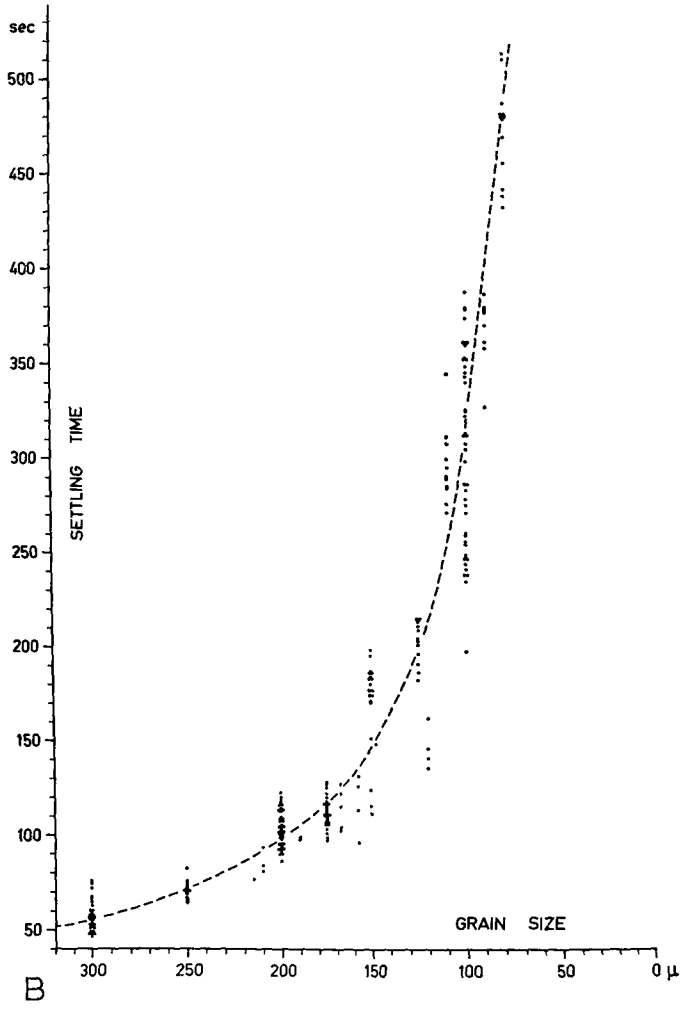


Fig.1. Settling times of single, natural quartz grains determined in the Groningen sedimentation balance. A. Settling times vs. grain diameters $> 300\ \mu$. B. (see p. 89) Settling times vs. grain diameters $< 300\ \mu$.

The balance has a special head with a light source and two photo-electric cells. Half of the light beam falls directly on one of the photo-electric cells, whereas the other half of the light beam is reflected by a prism into an optically conducting glass rod, passes through a slit in a frame mounted on top of the balance beam and is reflected back to the second photo-electric cell by a mirror. The difference in electrical outputs of the two cells is compared by a built-in potentiometer system and is subsequently recorded on paper at a speed of 1 inch/min (Fig. 3).

The total volume of the sedimentation cylinder is filled with 70 l of water. Distilled water is used since the air bubbles liberated by decompression of tap water tend to lift up the settling pan within the tube. The sedimentation pan (Fig. 2) is suspended from the balance pan with the help of two nylon threads



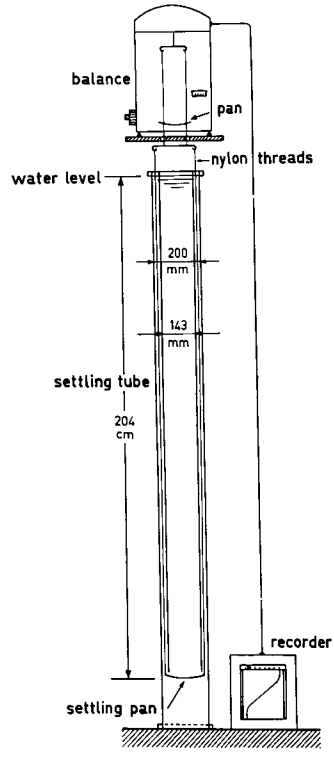


Fig.2. Schematic drawing of the Groningen sedimentation balance.

between the two walls of the tube. To reduce the influence of surface tension on the nylon threads, about 7 ml of "Teepol" detergent is added to the water. To prevent the growth of algae, daylight is screened off from the tube, when not in use. Screening and double walling of the sedimentation cylinder also help in maintaining a fairly constant temperature of the water column. To prevent the growth of fungi, 70 g of "Nipagin" ($NaOC_6H_4COOCH_3$) is added to the water.

The sample to be analysed is spread out on a moistened flat screen (50 μ) which is quickly turned over and lightly dipped into the water surface of the cylinder. Slight pressure on the water surface by the screen ensures recording of the beginning of the experiment (zero time-break on the record).

Grains coarser than 1,000 μ cause vibration in the suspension threads and those finer than 50 μ settle too slowly, thereby unduly lengthening the time of analysis of each sample. Therefore, the practical limit of analysis by this balance has been set between 50 and 1,000 μ. A sample of this size range is found to settle completely within 20 min, provided organic matter has been removed by chemical treatment. An additional reason for taking 50 μ as the lower limit for investigation by sedimentation balance is the increasing tendency with diminishing grain size

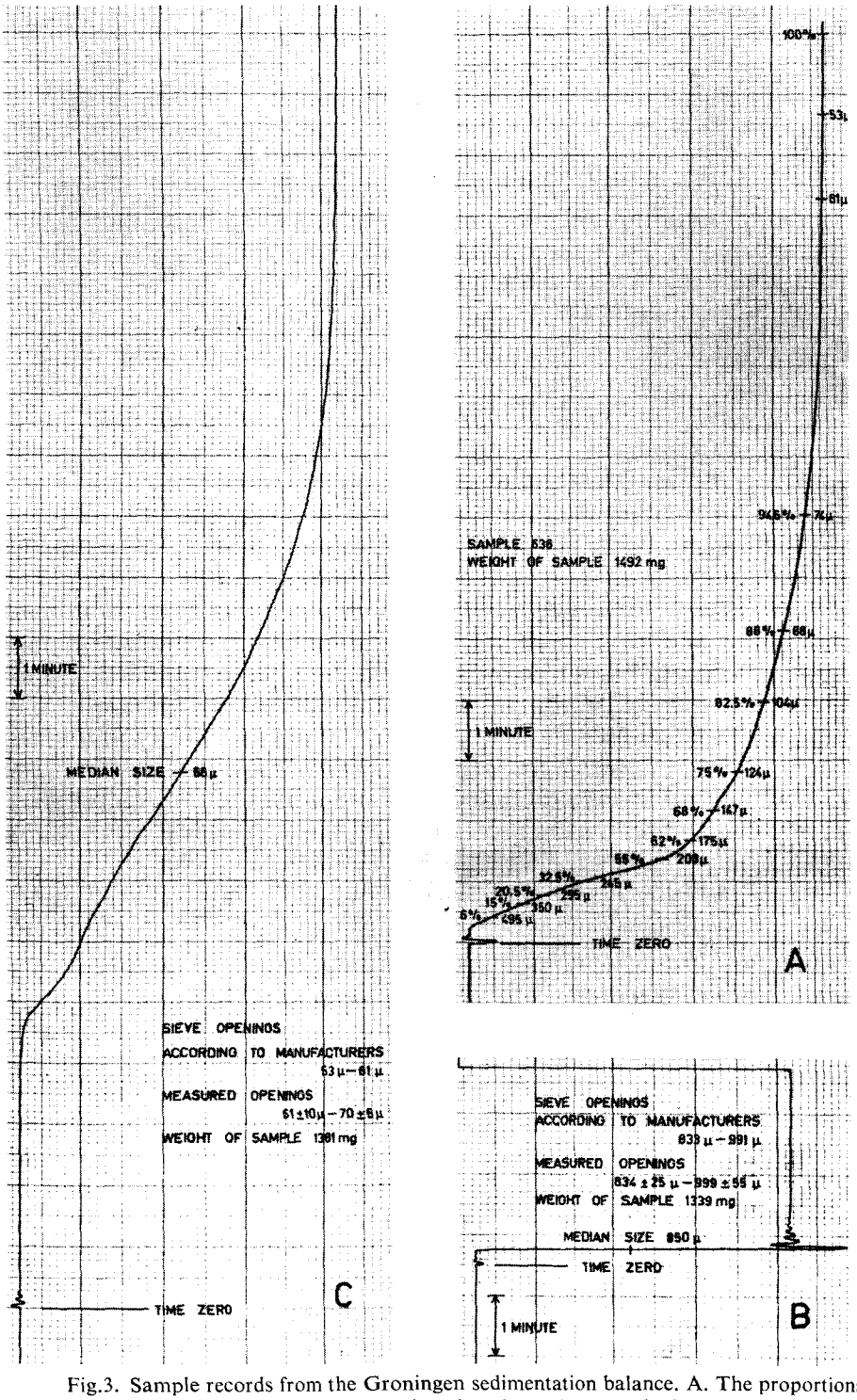


Fig.3. Sample records from the Groningen sedimentation balance. A. The proportions of size fractions interpreted on the assumption that the grains are all of spherical quartz. B. Sample record of natural sand sieved through coarse mesh sieves (833–991 μ). C. Sample record of natural sand sieved through narrow-range, fine mesh sieves (53–61 μ).

for settling convection to falsify the results (KUENEN, 1968).

The maximum sample size in this sedimentation balance is:

$\frac{2.65}{2.65-1.00} \times 1{,}000 = 1{,}600$ mg of quartz sand ($p = 2.65$) weighed in air.

For practical purposes it is advisable to have the sample size slightly smaller (about 1,500 mg). The settling pan needs cleaning after accumulation of about 200 samples. Tilting it with the help of the suspension threads allows the sediment to slide off. Removal of the sediment collected at the bottom is possible by unscrewing the base of the cylinder. Refilling by fresh water is necessary only after about a year of daily use of the balance.

In case the sample size is smaller than 1,600 mg, the end point on the recording paper is attained before the complete scale of the recorder is reached. In this case the pen of the recorder is first brought to the end point by adding small auxiliary weights (bits of paper) to the upper pan of the balance. Before starting the next analysis, the recorder pen is brought back to zero mark by a complete turn of the unit (1 g) control knob of the balance.

It is clear from the working principle described above, that this sedimentation balance allows every grain of a sample to fall through the *whole* column of water and hence the curve obtained is a direct record of the cumulative weight percentage of each size fraction. This method has a definite advantage over the principle of the Odén balance, in which settling takes place from a homogeneous suspension of the sample and the weight of each size fraction is determined either by tedious calculations or graphically by drawing tangents to the curve (KRUMBEIN and PETTIJOHN, 1938). Admittedly, the graphical method is subjective and is liable to considerable "operator error". Nevertheless, the method of interpretation of the settling times obtained from the Groningen balance in terms of sedimentation diameter also has its limitations.

COMPARISON BETWEEN SIEVING AND SETTLING TECHNIQUES

The definite advantages of sedimentation balance over the conventional sieving technique are rapidity of measurement, continuity and permanency of record and requirement of a small amount of sample for analysis. The equipment used at Groningen is at least 2½ times faster than the conventional system of sieving, using Tylers Ro-Tap with twelve sieves and electrical analytical balances for weighing. Routine analysis and computation (using size-time overlay) of at least ten samples are possible in this sedimentation balance in course of an 8-h working day. The balance requires only about 1.5 g of sample, which is much less than the 15–25 g (or more) generally used for sieving.

A difficulty experienced in the Groningen balance is the inertia of the recording system which prevents recording on paper of the first 5 mg, which is 0.3% of the sample.

An advantage of the sedimentation balance is that it records a sediment parameter (settling velocity) which is a more dependable representative of the particle behaviour under the natural processes of transportation and deposition than the intermediate grain diameter measured by the sieve.

A major disadvantage of most of the sedimentation balances is that unlike sieving, the various size fractions are not available for microscopical study at the end of the experiment. Moreover, although the actual time for settling in the balance is much shorter than the sieving time, microsplitting of the sediment for preparation of a representative sample of 1.5 g is a more time-consuming procedure than the preparation of a sample of much larger weight for sieving.

Estimation of possible errors

Repeated runs of the microsplit fractions of the same sample in the Groningen sedimentation balance showed a maximum error of 5% for coarse sediment (median = 220 μ) and 4% for the fine sediment (median = 79 μ). Maximum possible error in reproduction of results in the Groningen balance-recorder system is estimated to be slightly more than 1.5% according to the manufacturers estimate of reproducibility for the different components (balance = 0.02%, optical system = 1.0% and recorder = 0.5%). The possible reading error of the record is estimated to be 0.5%. Thus, the total possible maximum error of the balance system amounts to about 2.0%.

In case of sieving, repeated runs of the microsplit samples with the same set of apparatus show apparently better reproducibility (1.3% and 0.4% for coarse and fine sediments, respectively), but the actual error in measurement may be of a much larger magnitude due to large, observed manufacturing defects of the sieves.

Table II gives an estimate of the total possible maximum error in measurement by sieving and settling techniques. This total possible error also includes

TABLE II

ESTIMATE OF TOTAL POSSIBLE MAXIMUM ERROR (PERCENTAGES) IN SIEVING AND SETTLING METHODS

	Coarse sand (200–700 μ)		*Fine sand (50–200 μ)*	
	sieving	*settling*	*sieving*	*settling*
Splitting error	1.8	3.6	0.2	0.2
Manufacturing error	7.0	1.5	17.0	1.5
Operational and reading errors	0.4	0.5	0.4	0.5
Total	9.2	5.6	17.6	2.2
Observed reproducibility errors during reruns	1.3	5.0	0.4	4.0

considerable splitting errors. The figures for splitting error presented in this table are estimated from the experiments conducted by POOLE et al. (1951). Larger splitting errors have been assigned to the settling method for coarse sand, because preparation of a sample weighing only 1.5 g for the sedimentation balance requires a larger repetition (approximately double) of the splitting operation than the preparation of the much bigger sized samples for sieving.

The manufacturing errors of the sieves noted in Table II have been obtained by precision micrometer measurement of ten randomly chosen apertures in each sieve. Measurements were made in two directions normal to each other. The mean observed error was calculated for each sieve. Only the maximum values of these mean errors are noted in Table II. In case of the sieves measured, unidirectional (all too large) manufacturing errors were noted. Obviously, the total errors can have a compensating effect if some of the sieves have errors in opposite direction — but even then, the measurement would show large deviation from the actual distribution.

For the purpose of comparison of size distributions between two different samples, the manufacturing error may be eliminated to a great extent by using the same set of apparatus, but this practice is of no help when precise, absolute measurement of grain size or comparison with data from a different laboratory are intended.

In case of settling, the total possible error is much less, but this does not ensure better dependability of the technique for precision measurement of grain sizes since the settling time, particularly for the finer materials, is greatly affected by the particle shape.

Conversion of settling times to sieve diameters

Microsplit fractions of a number of samples of different size ranges have been analysed by sieving and by sedimentation balance techniques in the Groningen laboratory. The settling times have been converted to grain diameters — WADELL's (1934) "sedimentation diameter" — with the help of the conversion curves published by the U. S. HYDRAULIC LABORATORY (ST. PAUL) (1941). The results obtained for some representative, coarse, fine and medium-size ranged samples are shown graphically in Fig. 4.

These curves have been plotted on arithmetic paper to obtain undistorted view of the grain-size distributions.

Although the beginning of the curve is sharply defined by the "zero-time break", location of the end point (100% line) depends to some extent on the personal choice of the interpreter and affects all the intermediate percentage weight computations. The error caused in the balance-record interpretation in this case, is comparable to the apparent misrepresentation caused by setting a limit to sieving at a certain minimum sieve fraction and by computing the total size distribution on the assumption that this size represents 100%.

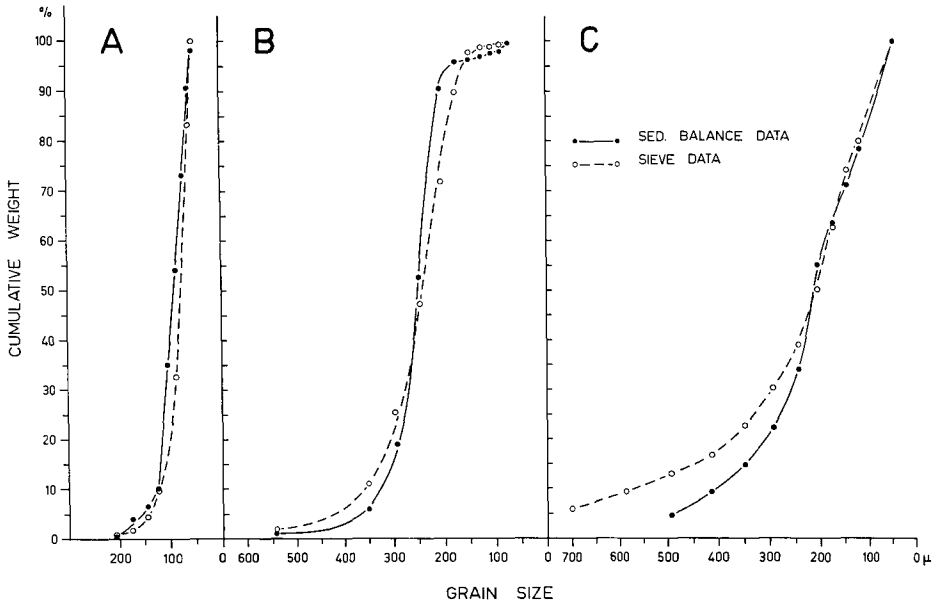


Fig. 4. Comparison of grain diameter obtained by sieving and settling techniques. A. Fine-grained sample. B. Medium-grained sample. C. Coarse-grained sample.

It is seen from Fig. 4 that for grain sizes larger than about 250 μ, the sedimentation-balance data usually shows lower cumulative weight percentages than the corresponding sieve data, whereas for grains smaller than 250 μ, the sedimentation balance shows larger weight percentages. Thus, in each sample, the median diameter obtained by sieve analysis is smaller by about 7–10 μ than the median value obtained from the balance record. For a sample of medium-size range (Fig. 4B) the balance shows a grain size 30 μ larger than the corresponding sieve data at the 84 percentile, while at 16 percentile, a difference of 20 μ in the opposite direction is observed.

This discrepancy was at first tentatively explained by the presence of slow settling mica flakes in the coarser fraction of the sample, and fast settling heavy minerals in the finer fractions.

Microscopical examination and heavy mineral separation, however, showed only a negligible amount of mica in the samples, and a very small amount (total amount being less than 0.2%) of heavy minerals. Hence, the factors responsible for the difference between the sieving and settling results, appear to lie in the very theory of conversion of one data into the other.

The relative effects of shape variations of grains on the sieving and settling techniques have been investigated by doing settling analysis on some coarse and fine sieve fractions. The results are shown in Fig. 3B, C. It is seen from Fig. 3B that the coarse sediments of a narrow size range (833–991 μ) settle almost at the

expected times calculated for spheres. Microscopic examination shows that these coarse grains were mostly equidimensional and well rounded. Impact of these coarse grains, which settle on the pan in quick succession, cause vibrations near the end point of the record (Fig. 3B).

In case of settling of the finer samples (53–61 μ), a considerable discrepancy is noticed between the sizes obtained from sieving and settling. Although the upper size limit of the sieve was 61 μ (measured size 70 $\pm$ 5 μ), grains as large as 102 μ are found to be present in the sample, when the sedimentation-balance record is interpreted in terms of grain diameter on the assumption of wholly spherical quartz grains (Fig.3 C). Microscopic measurement of a portion of this sieve fraction (53–61 μ) showed the maximum grain length to be as large as 185 μ. Elongate grains having intercepts of 105–160 μ are estimated to constitute about 10% of the total sample. Elongate grains having maximal intercepts of 85–100 μ form about 70% and equidimensional grains constitute only about 20% of the total. Since the actual length of the upper sieve opening (claimed to be 61 μ by the manufacturer) is found to be 70 $\pm$ 5 μ, this sieve would allow grains as big as 92–106 μ to pass through it diagonally. The still longer grains found in this sieve fraction must have passed through the sieve vertically. This experiment clearly shows the errors which can be introduced in the results of sieving by particle shape variation.

Close inspection of the settling cylinder during the experiment showed that most of the elongate grains settle either almost horizontally or slightly obliquely, and that they weave gently through the column of water during settling. Thus, the process of settling of the grain is controlled mostly by the larger diameter of the grain, whereas its intermediate diameter allows it to pass through a sieve of much narrower size.

Conversion of "sedimentation diameter" to "sieve diameter" with the help of the charts published by ZEIGLER and GILL (1959), and KENNEDY and KOH (1961), which take into consideration the "shape factor" of the grain, helps to minimize to a certain extent the differences between the two results, but even after these corrections, considerable difference remains between the two, apparently because the same shape corrections can never be applied to all the grains in the sample. Moreover, as POOLE (1957) has pointed out, the amount of labour involved and the inconclusiveness of the results do not justify use of shape correction in routine sedimentation analysis.

CONCLUSIONS

The only conclusion that can be drawn from the above observations is that neither sieving nor settling technique can produce an authentic measure of the grain-size distribution of a natural sand sample, where grains of varied shapes and densities are involved. The sieving technique is liable to a number of operational

defects (including the common manufacturing defects of sieves) and is also particularly affected by the shape variations of the grains. Only in the ideal case of spherical grains measured by faultless square, or preferably by round aperture sieves, can the diameter measured represent the "nominal grain diameter".

The settling technique, which has much smaller operational and manufacturing errors than the sieve, is also affected, though in an entirely different manner, by the shape and additionally by density variation of the grains. The sedimentation balance is intended to measure a grain parameter ("sedimentation diameter") which is basically different from the "sieve diameter". Moreover, only in the ideal case of a sample consisting of spherical quartz would the balance measure the "sedimentation diameter" of the grains.

The density and shape variations in natural sands are likely to introduce large errors in the conversion of settling times to sedimentation diameters. This is certainly not a very reliable procedure since the technique of conversion depends on the use of experimentally determined fall velocities of single, spherical quartz grains, but in practice shape corrections for every individual grain in a natural sand sample can never be taken into account.

Thus, the sedimentation balance should not be taken to be a replacement for the sieves, but should be looked upon as a tool for measuring, fairly accurately, a new grain parameter, the settling velocity. This parameter is a better guide of the particle behaviour in nature, especially under water, than the grain diameter. Sedimentologists are urged to use this parameter of settling velocity directly as a measure of the particle behaviour under natural conditions of transportation and deposition of the sediments, rather than first convert it into a measure of doubtful grain diameter, and then try to deduce the particle behaviour in nature from that assumed diameter.

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