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The investigation of filter sands and the establishment of a criterion for the condition that a sand is a filter in itself

Blight, Geoffrey Eustace

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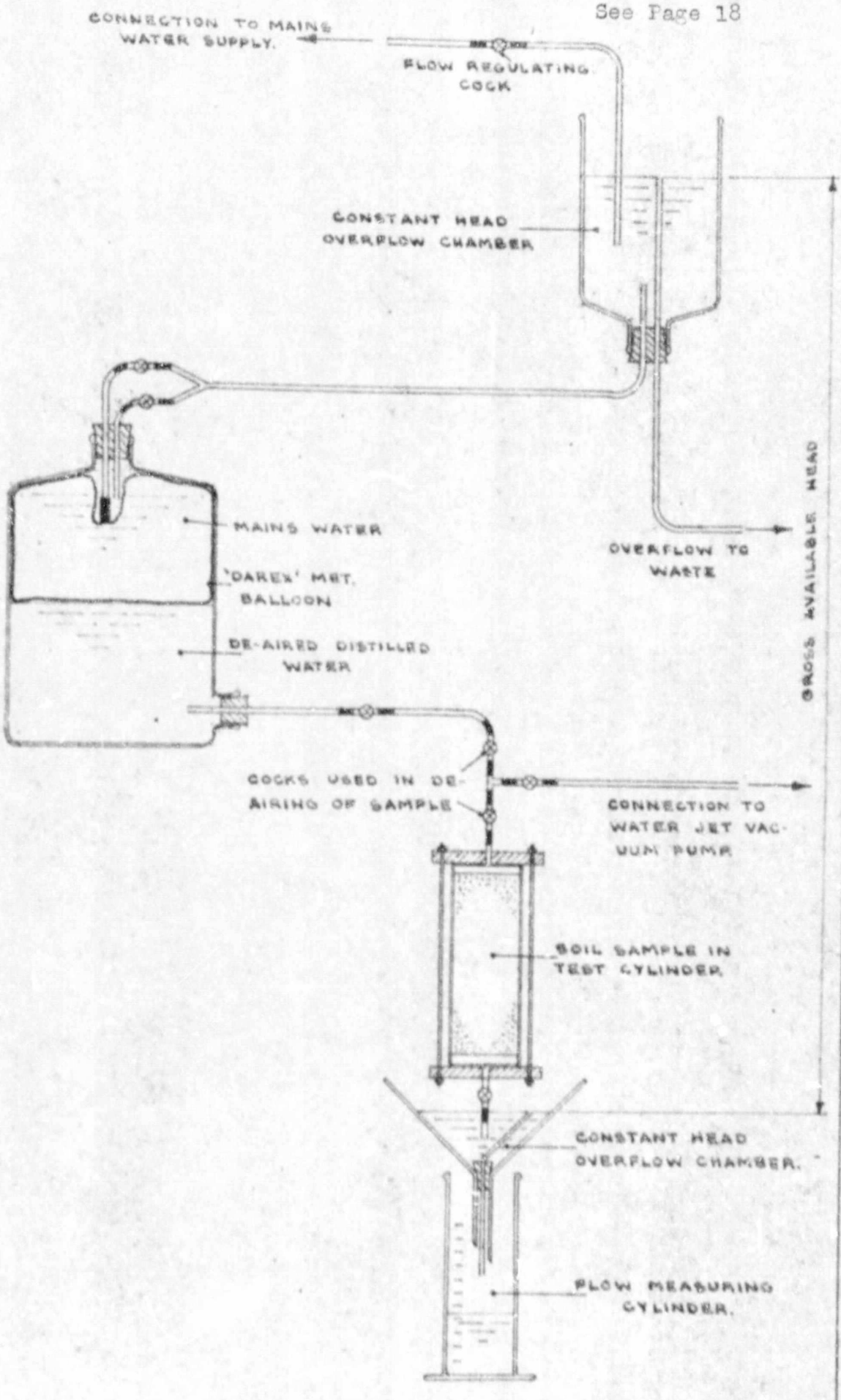
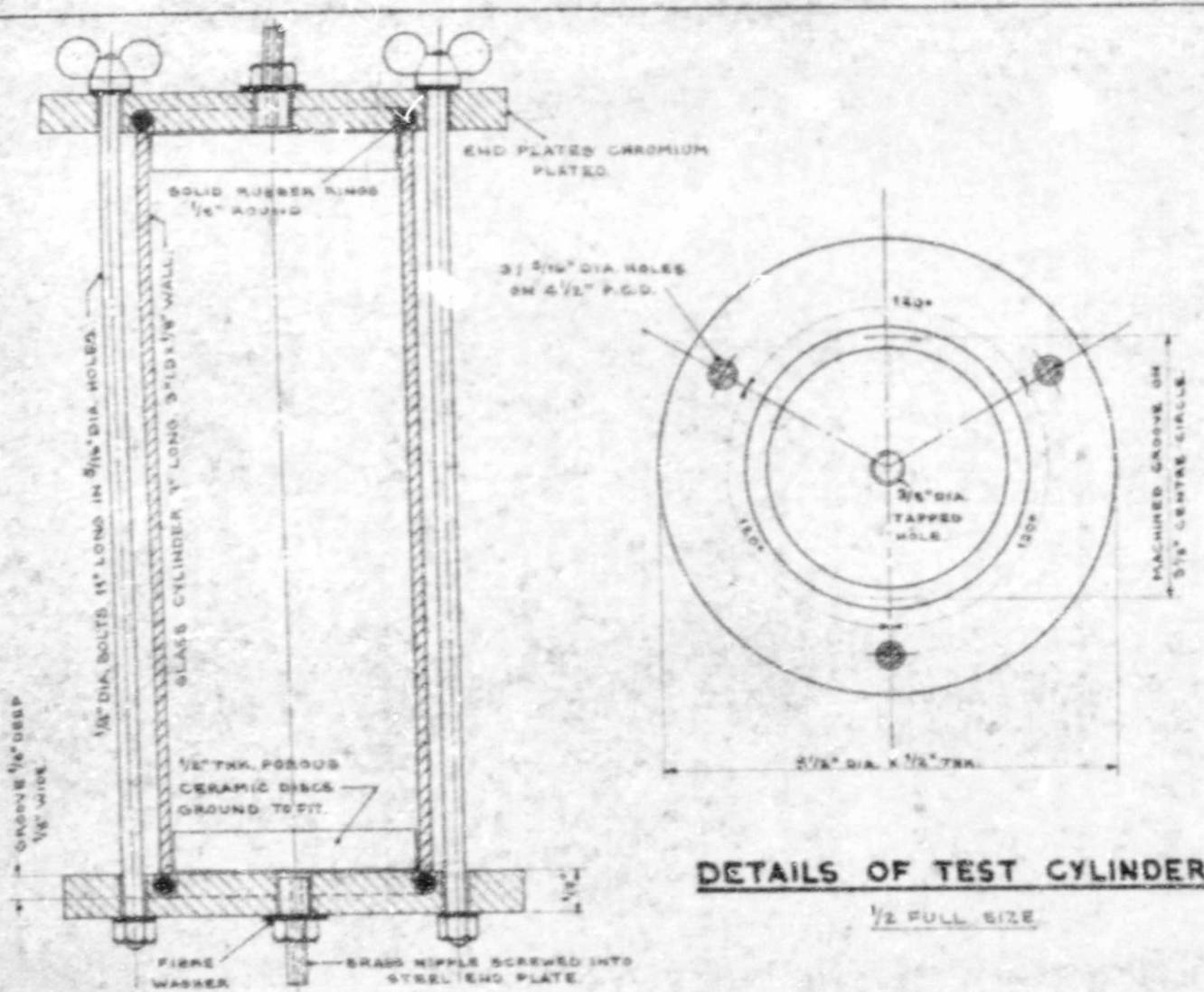


DIAGRAM SHOWING LAYOUT OF APPARATUS USED IN SPECIAL FILTER TESTS.

USED IN CONJUNCTION WITH WATER DE-AIRING APPARATUS FOR ALL PERCOLATION TESTS ON SANDS.



DETAILS OF TEST CYLINDER

1/2 FULL SIZE



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TEST CYLINDERS USED IN SPECIAL FILTER TEST SERIES.

THIS ILLUSTRATION SHOWS: ON THE LEFT — A DETAILED DRAWING OF A TEST CYLINDER.
ON THE RIGHT — A PHOTOGRAPH OF A CYLINDER READY FOR USE.

The discharge from the test cylinder fed into a second overflow type constant head chamber, the overflow from which constituted the discharge through the cylinder of soil and was measured by means of a measuring cylinder.

The total head causing flow was measured as the difference between the levels of the water in the two constant head chambers. This head was used to calculate hydraulic gradients and coefficients of permeability.

In the latter stages of the test when the de-aired distilled water supply was exhausted and the feed was switched to tap water, a connection was taken directly from the upper constant head chamber to the test cylinder.

Water De-Airing Apparatus:

The water de-airing apparatus used in this investigation and described here is a modification of an apparatus developed at the Harvard Graduate School of Engineering.

The assembly of the de-airing apparatus is shown in the diagram. The distilled water reservoir was connected by rubber and glass tubing to the top of the de-airing column which provided a constant height of fall for the water. The distilled water entered the de-airing column through a capillary nozzle made by drawing out a piece of glass tubing. The nozzle introduced the water into the column at a slow rate in the form of a fine even spray.

The de-airing column was packed with marbles which acted as launders causing the water to trickle down in a thin film of large surface area. It has been found that water trickling with a large surface area exposed gives up its dissolved air more readily than a spray falling freely. The spray nozzle thus acted merely as a check on the rate of flow of water through the apparatus and helped disperse the falling water over the cross-section of the column.

From the de-airing column the water fell into a large glass carboy which was also evacuated and helped further to delay the passage of water through the apparatus.

From the auxiliary neck at the bottom of this carboy, the water passed into the bottom of the de-aired water reservoir. This reservoir consisted of a 20 litre carboy containing a "Darex J 350" meteorological balloon which was completely emptied and evacuated before commencing the de-airing process. The de-aired distilled water occupied the body of the bottle, the balloon hanging limply inside it. When empty, the balloon was slightly larger than the inside volume of the bottle so that at no time could any tension develop in the membrane of the balloon.

Two connections were taken from the neck of the de-aired distilled water reservoir, one from the inside of the bottle and one from the inside of the balloon. These two connections could be closed independently by means of screw pinch-cocks beyond which the connections were united by means of a glass 'Y'.

The connection from the base of this Y was taken via a vacuum guage to a water trap, a water vapour trap filled with calcium chloride and thence to an electrically driven high vacuum pump of the oil filled eccentric roller type.

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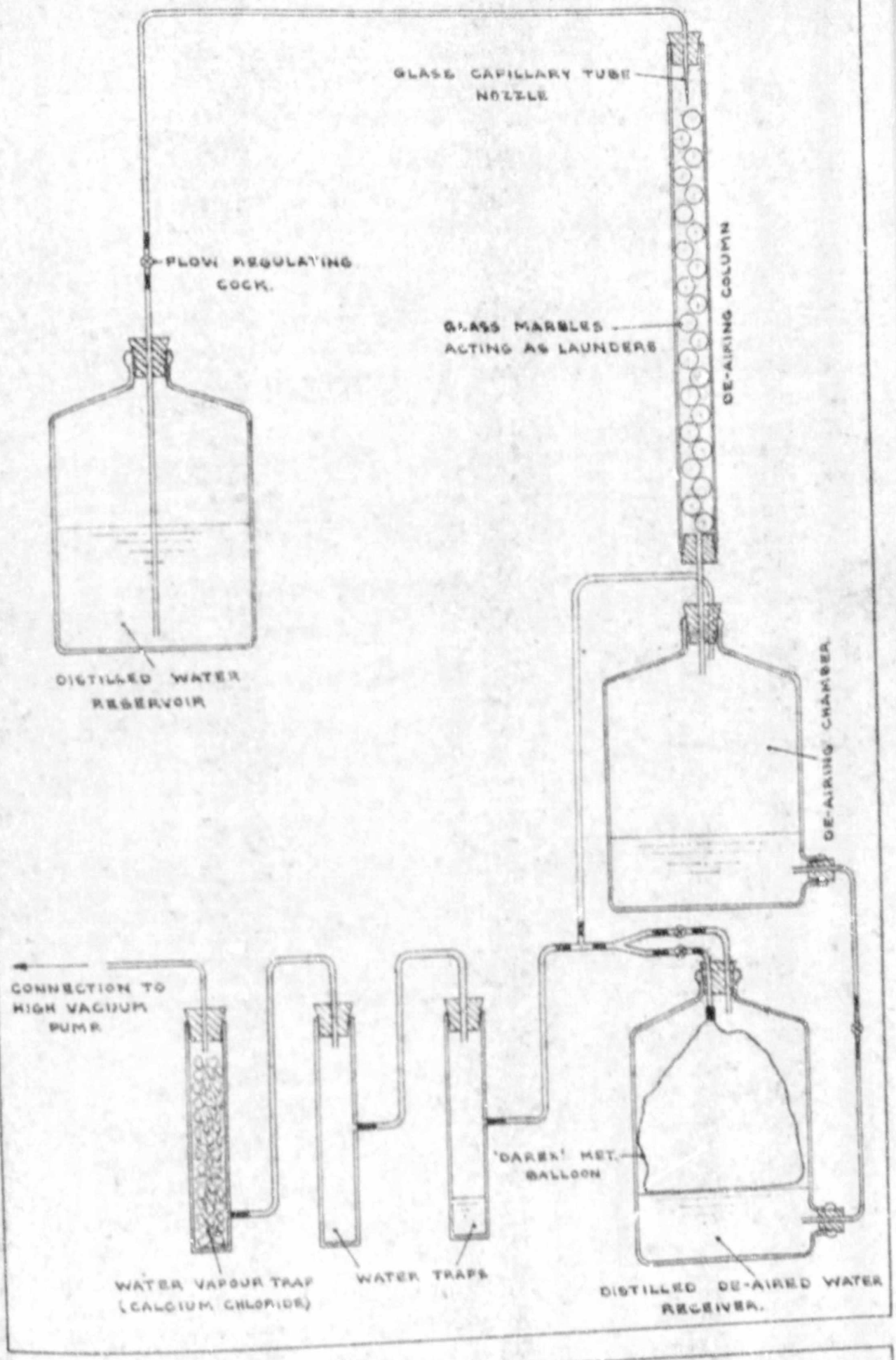


DIAGRAM SHOWING ARRANGEMENT OF WATER DE-AIRING PLANT.

USED TO PREPARE DE-AIRED DISTILLED WATER FOR USE IN THE SPECIAL FILTER TESTS.

DESCRIPTION OF THE TESTING PROCEDURE ADOPTED IN THIS INVESTIGATION.

The testing procedure may be described under two general headings:

(i) Routine testing used to establish the basic properties of the sand (in this case the particle size distribution). Under this heading come:

(a) Sieving Analyses.
(b) Hydrometer Analyses.
(c) Specific Gravity Determinations.

(ii) Special testing to establish the hydraulic properties of the sand. This consists of the special filter test using de-aired distilled water.

In each case standard methods of testing were adopted which experience has shown to give the most reliable results in a manner most economical of both time and effort. These methods of testing are not generally recommended for application to any type of soil, but for cohesionless and slightly cohesive sandy materials they have proved adequate.

To facilitate the testing routine standard result sheets were drawn up. These were found to ease the labour of both testing and reduction of results.

(i) Procedure in Routine Testing.

(a) Sieve Analysis

Sieve analyses were carried out on air dried samples of the sands.

The procedure was as follows:

1. A nest of STANDARD TYLER TEST SIEVES was selected and each sieve carefully cleaned with a brass wire brush to remove any loosely jammed soil particles from the sieve meshes. The sieves were then weighed to an accuracy of ± 0.1 gramme.

The successive sieve sizes were selected so that successive sieve openings were approximately in the ratio 1 : 2. The usual sieve nests used were:

Series (a)	Series (b)
0.371"	0.371"
4	4
8	10
14	20
28	35
48	60
100	100
200	200

These two ranges were found to give a good distribution of points on the grain size curve.

The largest sieve used depended on the coarseness of the soil being tested.

SIEVE ANALYSIS.

SOIL SAMPLE: Bartlett's Pit Sand

LOCATION: Barkway

SAMPLE Nº: 3

TEST Nº: 3

DATE: 12th March, 1956

REMARKS: Sample air dried, sieved 5 minutes in "Rot-Tap" shaker.

SOIL SAMPLE WEIGHT

WT. CONTAINER + DRY SOIL (GM)	1564·1
WT. CONTAINER (GM)	749·7
WT. DRY SOIL (GM)	814·4
SPECIFIC GRAVITY	2·64

SIEVE Nº	SIEVE OPENING MM.	SIEVE WEIGHT GM.	DRY SIEVING		WET SIEVING				
			WT. SIEVE + SOIL GM.	WT. SOIL RETAINED GM.	WT. SIEVE + SOIL GM.	WT. SOIL RETAINED GM.	PERCENT RETAINED	CUM. % RETAINED	PERCENT FINER
8	2·362	488·9	503·7	14·8	490·7	1·8	0·2	0·2	99·8
14	1·165	378·9	426·1	47·2	393·3	14·4	1·7	1·9	98·1
28	0·589	440·3	605·1	164·8	547·0	106·7	12·6	14·5	85·5
48	0·295	364·0	617·8	253·8	578·0	221·0	26·2	40·7	59·3
100	0·147	405·5	604·1	198·6	573·5	168·0	19·9	60·6	39·4
200	0·074	417·0	489·9	72·8	5 114	94·4	11·2	71·8	28·2
PAN		378·6	492·1	85·5					
				845·5					

HYDROMETER ANALYSIS.

SOIL SAMPLE: Bartlett's Pit Sand — < Nº 200

SAMPLE Nº: 3

TEST Nº: 3

DATE: 12th April, 1956

HYDROMETER Nº: 0085 H 3

SOIL SAMPLE WEIGHT

WT. CONTAINER + DRY SOIL	97·61 gm
WT. CONTAINER	24·46 gm
WT. DRY SOIL	73·15 gm
SPECIFIC GRAVITY	2·64
MENISCUS CORRECTION	gm.

$N = \frac{G}{G-1} \cdot \frac{V}{W_s} \cdot \delta_w (T - T_w) \times 100\% = 2.20 (R - R_w)$. N' = % FINER Nº 200 = N

D (IN MM.) $= \sqrt{\frac{18\mu}{\gamma_s - \gamma_w}} \sqrt{\frac{Z_R}{t}} = .0105 \sqrt{\frac{Z_R}{t}}$ N' = 0·292 N

DATE	TIME	ELAPSED TIME t MIN.	$R = 10^3(m-1)$	$R_w = 10^3(T_w - 1)$	TEMPERATURE °C.	R − R_w	N %	Z_R CM.	$\sqrt{Z_R/t}$	D MM.	N' %
12/4/56		1/4	38	−0·2	20·5	38·2	82·8	6·0	5·65	·059	28·4
		1/2	33			38·2	72·5	9·3	4·31	·045	20·4
		1	26			25·2	56·9	11·2	3·34	·035	16·0
		2	17·5			17·7	39·6	13·3	2·58	·027	11·2
	0901	2	17·8	0·0	20·5	17·5	28·4	14·9	1·93	·020	7·2
		4	11·5	−0·1	20·7	11·6	15·4	16·1	1·42	·015	4·3
		8	7·0	0·0	20·7	7·0	8·8	17·0	1·03	·011	2·5
		16	4·0	0·0	20·5	4·0	5·5	17·3	0·786	·0082	1·6
	0930	28	2·5	0·0	20·4	2·5	3·7	17·7	0·454	·0047	1·0

STANDARD FORMS FOR PARTICLE SIZE DISTRIBUTION TESTS.

THE STANDARD FORMS SHOWN HERE WERE USED THROUGHOUT THE LABORATORY TESTING PROGRAMME.

2. A sample was next weighed out to 0.1 gm. The usual sample size used was about 600 grammes.

3. The sieve nest was provided with a pan and the soil sample was poured in. The sieves were next placed in the 'RO-TAP' MECHANICAL SIEVING MACHINE and sieved for a period of 5 minutes.

4. The sieves were now separated and each sieve and contents was weighed. The pan and contents was also weighed and the contents of the pan (< #200 sieve) were transferred to a bottle for future hydrometer analysis.

5. The contents of each sieve were then washed using a copious quantity of water in a fairly strong jet.

During this process, the pan was discarded and the sieves were arranged in order of decreasing size of opening. As soon as the wash water in one sieve was clear, it was removed and the succeeding sieve also washed.

The washed sieves were dried in an oven, cooled, and then reweighed.

6. The weights of soil retained on each sieve in the dry sieving process and the weight of fines in the pan were added to obtain the dry weight of the soil used.

The weights of soil retained after the washing process were used in the calculation of the percent retained, the cumulative percent retained, and the percent finer and hence in the plotting of the GRAIN SIZE DISTRIBUTION CURVE.

Notes on the Method:

(i) A comparison of the weight of the soil sample obtained by weighing in a dish before sieving and that obtained by adding the weights of soil retained on the sieves and in the pan after dry sieving, gave an indication of the amount of soil lost from the sieves during the sieving process.

(ii) The use of the soil sample weight obtained from the dry sieving also eliminated some of the errors incurred in the weighing of the sieves as the same scale was used for all weighings in any one test.

(iii) The use of a mechanical sieve shaker and a standard sieving time eliminated any errors from sample to sample due to differences in sieving technique.

(b) Hydrometer Particle Size Analysis.

An Hydrometer Particle size analysis was carried out on the < #200 SIEVE fraction of each soil analysed to give a combined particle size analysis together with the sieve analysis.

1. The soil sample weight was determined by weighing the sample in a small aluminium dish on a beam balance to ± 0.01 gm.

The sample was then mixed with distilled water and transferred to a 1000 ml. measuring flask using a funnel and a jet of distilled water obtained by blowing into one tube of an aspirator bottle filled with distilled water. Great care was taken to ensure that no soil was lost in the transfer.

2. The following deflocculating agents were now added:

2 ml. Sodium Oxalate (saturated solution).
2 ml. Sodium Silicate (saturated solution).

The above solutions in their respective concentrations were found to give the best results for the fine fraction of sands in general. This procedure was standard during all tests.

3. The measuring cylinder was now half filled with distilled water and the soil-water mixture was thoroughly mixed up and agitated by shaking the cylinder - its mouth being closed by the palm of the hand.

Because of the nature of the samples tested (they were all in the form of a fine powder thoroughly broken up by the dry sieving process in the Mechanical Sieve), it was not found necessary to disperse the soil particles in the water by mixing with a cocktail shaker as is usually done.

The measuring cylinder was now topped up with distilled water to the 1000 ml. mark using a pipette.

4. The hydrometers used were of a special streamlined type and were stored alongside the cylinder containing the soil-water suspension in a similar cylinder containing distilled water.

5. The rise of the meniscus against the stem of the hydrometer above the surface of the distilled water was noted in terms of divisions of the hydrometer and constituted the meniscus correction. Hereafter readings were taken of the top of the meniscus on the hydrometer stem only.

The temperature of the soil suspension was now noted.

6. The cylinder containing the sample was well shaken up and placed on the bench, the stopwatch was started, the hydrometer was inserted in the settling soil suspension and readings were taken at intervals of ¼, ½, 1, 2 mins. This was repeated three times thus obtaining 4 sets of readings in the range 0 to 2 mins. The hydrometer was now removed from the cylinder and placed in the cylinder of distilled water. The sample was shaken up again, the watch was started and the suspension allowed to settle. Just before 2 mins. had elapsed, the temperature of the soil suspension was read, the reading of the hydrometer in the distilled water was noted and the hydrometer was inserted in the soil suspension and a reading taken at 2 mins. The hydrometer was then immediately removed and replaced in the storage cylinder. Thereafter readings were taken after the lapse of 4, 8, 16, 30, 60 etc. mins. until no difference could be observed between hydrometer readings in the distilled water and in the soil suspension.

7. The calculation of the particle sizes was carried out as shown on the accompanying standard result sheet. All readings after the 2 min. reading were corrected for immersion by using a calibration chart.

The success of this method of hydrometer analysis for materials of the type tested is indicated by the fact that very seldom did the curves obtained by sieving and hydrometer work not match up well.

The samples used were very small varying between 20 and 30 grammes. This proved very successful as tests seldom ran for more than two hours total time.

(c) Specific Gravity Determinations

Specific Gravities were measured as the result of three independent determinations which were made under conditions as closely similar as possible. The procedure was as follows:

1. In order to ensure an absolutely dry pycnometer flask, each flask before use was rinsed with alchohol and then evacuated until all the alchohol had evaporated and a perfectly dry flask resulted.

2. The flask was next weighed clean, dry and empty and with its stopper in position to an accuracy of 0.1 gramme.

3. The air-dried sample of the sand to be tested was next introduced into the pycnometer using a funnel made of filter paper. The usual size of sample was approximately 250 gm.

4. Using a funnel, sufficient distilled water was now added to the flask to saturate the sample and cover it to a depth of about ½ inch. The flask was now again evacuated and boiled under vacuum at room temperature to expell all air entrapped in the sample. The contents of the flask were swirled around during this process to facilitate the escape of the air. The duration of this boiling (under a vacuum of about 23½ inches of mercury) was usually about 5 minutes or until no more air was observed to be coming off.

More distilled water was then added to bring the water level to just below the neck of the flask when the boiling procedure was repeated.

The contents of the flask were then topped up to the graduation mark on the neck by means of a large pipette.

The temperature of the contents was noted.

The pycnometer flask was stoppered and with its contents weighed to the nearest 0.1 gramme.

5. The flask was emptied, rinsed, and then filled with distilled water up to the graduation mark. The temperature was again noted and the stoppered flask weighed.

6. From the results of the weighings, the Specific Gravity was calculated.

7. The Specific Gravity of the sand concerned was taken as the mean of the 3 independent determinations.

Notes on the Method:

(i) To obviate as much as possible errors in weights due to balance defects, the same balance was used for all weighings.

(ii) The tests were carried out in a part of the laboratory in which the air temperature varied very little. The distilled water was also stored in this section of the

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SPECIFIC GRAVITY TEST.

TEST Nº 3 SAMPLE Nº 3

DATE 11th April 1936

SOIL SAMPLE Brickfield Estate LOCATION Berkeley

REMARKS Sample air dried. W_2 & W_4 determined by quick weighing in pycnometer.

DETERMINATION Nº		1	2	3	4
BOTTLE Nº		G	F	J	
WT. BOTTLE + WATER + SOIL	W_1	1395.8 gm	1379.6	1414.2	
TEMPERATURE	T°	26.8°C	26.4°C	25.3°C	
WT. BOTTLE + WATER	W_2	1241.3 gm	1210.8	1268.6	
EVAPORATING DISH Nº		G	F	J	
WT. DISH + DRY SOIL		486.5	484.0	613.4	
WT. DISH		265.6	220.9	266.0	
WT. DRY SOIL	W_3	214.9	263.1	247.4	
SPECIFIC GRAVITY OF WATER AT T°	G_T	0.997	0.997	0.997	
SPECIFIC GRAVITY OF SOIL	G_s	2.64	2.64	2.63	

$$G_s = \frac{G_T W_3}{W_3 - W_1 + W_2}$$

SPECIFIC GRAVITY G_s 2.64

STANDARD FORM USED FOR SPECIFIC GRAVITY TESTS.

laboratory. The result of this was that the temperature readings in (4) and (5) seldom varied by more than ± 0.2°C. This variation would have negligible effects on the specific gravity of the water and the volume of the pycnometer.

(iii) As the accuracy of the S.G. determinations depends on the determination of a small difference between two large weights, this difference was increased in relative value as much as possible by using a large sample size.

(iv) The method of determining the dry weight of the sample by direct weighing in the pycnometer is more accurate than the usual method of collecting the soil-water mixture in an evaporating dish and weighing after evaporating to dryness in an oven. Not only does it eliminate possible errors due to loss of soil in the transfer from pycnometer to drying dish, but as the weight is determined on an air-dried sample, the method eliminates errors of loss of weight of the soil in oven drying due to volatile or organic constituents.

(v) The pycnometers used were of 1000 millilitres nominal capacity.

(ii) Procedure in Special Testing

(a) Operation of Water De-Airing Apparatus:

The water de-airing apparatus was operated as follows:

1. The lead to the distilled water reservoir was closed by a pinchcock and the vacuum pump was switched on until a vacuum of over 20 in. of mercury had developed inside the apparatus.

2. The pinchcock on the water supply tube was now regulated to give an even gentle spray at a suitable rate from the spray nozzle.

3. When the vacuum had built up to its maximum value (about 26 in. of mercury) the pump was switched off and the apparatus allowed to run on its own. It was found that the vacuum fell off very slowly and under normal conditions if the pump was run for five minutes every half hour this sufficed to keep the vacuum above 20 in. of mercury.

4. When the carboy was filled to the neck the water supply and the vacuum were shut off and disconnected.

During testing the delivery tube leading from the carboy was connected directly to the inlet side of the soil sample and the tube from the balloon directly to the constant head chamber.

(b) Procedure in Special Filter Tests

On arrival in the laboratory all samples of sand were air-dried and then thoroughly mixed before being bagged for storage.

Preliminary testing consisted of determining an accurate particle size distribution for the sand using combined sieve and hydrometer particle size analysis. This was carried out in the manner described previously.

SPECIAL FILTER TEST.

SOIL SAMPLE Bartlett's Pit Sand
LOCATION Bottesford
SAMPLE Nº 3
TEST Nº 19
DATE 22nd August, '36
TIME OF START 12.09
MEASURING CYLINDER Nº 3
HEAD CAUSING FLOW 278 cm.

PERMEAMETER Nº & AREA 44.1 cm²

SOIL SPECIMEN WEIGHTS

INITIAL	WT. DISH + SAND (i)	2390.4 gm
	WT. DISH + SAND (ii)	1169.9 gm
	INITIAL WT. DRY SAND	1110.5 gm
FINAL	WT. CYLINDER + DISH + SAND	1826.0 gm
	WT. CYLINDER + DISH	733.0 gm
	FINAL WT. DRY SAND	1093.0 gm

PARTICLE SPECIFIC GRAVITY 2.64
INITIAL SAMPLE LENGTH 19.8 cm.
INITIAL VOID RATIO 1.071
WT. FINES LOST 0.69% - 7.7 gm
FINAL VOID RATIO 0.820
REMARKS Sheet 1 of 2
Migration of fines clearly visible at start of test. Vide sheet 2 for end of test

SUB-TEST Nº	SAMPLE LENGTH CM.	HYDRAULIC GRADIENT	TIME HOURS	ELAPSED TIME HOURS	TIME OF COLLECTION SECS.	DEPTH OF WATER COLLECTED CM.	ACCUMULATED FLOW CC.	FLOW RATE CC. SEC.$^{-1}$	PERMEABILITY AT TEMP. T CC. SEC.$^{-1}$	TEMPERATURE T°C.	VISC. AT T° / VISC. AT 20°	PERMEABILITY AT 20°C.	VOID RATIO.
1	17.8	15.6	12.09	0.031	225.1	18.1	630	2.80	4.07×10^{-3}	19.1	1.02	4.15×10^{-3}	0.865
2	17.7	15.7	12.14	0.114	222.2	16.9	568	2.65	3.82×10^{-3}	19.3	1.02	3.90×10^{-3}	0.865
3	17.7	15.7	12.18	0.182	222.4	18.9	659	2.96	4.27×10^{-3}	19.4	1.01	4.36×10^{-3}	0.855
5	17.6	15.8	12.28	0.345	201.8	18.7	648	3.15	4.56×10^{-3}	19.2	1.02	4.65×10^{-3}	0.843
8	17.5	15.9	12.55	0.796	200.2	17.7	616	3.08	4.39×10^{-3}	19.1	1.02	4.48×10^{-3}	0.831

STANDARD FORM FOR SPECIAL FILTER TEST.

THIS PAGE ILLUSTRATES THE STANDARD FORM WHICH WAS USED THROUGHOUT THE LABORATORY WORK FOR THIS TEST.

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Samples were prepared for the special filter tests by the following procedure:

1. The porous plates which were to be used were weighed to the nearest 0.1 gramme. The permeameter was assembled by placing the glass cylinder upright on the lower end plate (with the screw nipple removed) and with the lower porous plate in position.

2. An evaporating dish containing the requisite sand was weighed to the nearest 0.1 gramme. The sand was loosely poured into the cylinder in sections approximately 1 cm. in thickness, each layer being levelled off gently before placing the next. In this way the initial void ratio of the sand was kept to as high a value as it would probably ever be in a carelessly constructed filter layer.

3. Once the glass cylinder was full and the upper porous plate was in position, the material remaining in the dish was reweighed. The difference between the weights obtained in steps (2) and (3) being the initial weight of soil in the test cylinder.

4. The assembly of the permeameter was now completed by the addition of the upper end plate, the securing bolts and the screw nipples. The test cylinder was now placed in its supporting rack.

After the test cylinders were packed, it was necessary to saturate the samples in such a manner that no air would be entrapped in the voids of the sand or in the connecting tubing. This was accomplished as follows:

5. The tap water supply was adjusted until the upper constant head chamber was overflowing steadily. By opening the pinch cocks all air in the tubing between this chamber and the de-aired distilled water reservoir was replaced by water and the tap water supply was connected to the inlet of the balloon contained in the de-aired water reservoir.

6. A rubber tube leading to a water jet vacuum pump was next connected to the free arm of the glass T-piece inserted between the test cylinder and the de-aired water reservoir. The lower constant head chamber was filled with distilled water.

7. The jet pump was turned on and with the lead from the test cylinder to the lower constant head chamber closed, the cylinder and connecting tubing was evacuated. The lead to the lower constant head chamber was now gradually opened and the sand sample in the test cylinder was permitted to saturate from the bottom upward. When the water appeared in the glass T-piece, the test cylinder was isolated from the jet pump and the tubing between the pump and the de-aired distilled water supply was filled with water.

8. The lead to the pump was now clamped and with the system completely full of water the test was ready to start.

9. The initial length of the sand sample was now carefully measured using a steel rule and the flow was started.

At intervals during the course of the permeability test readings were taken as follows:

10. The overflow from the lower constant head chamber was diverted into a measuring cylinder and simultaneously a stop watch was started. While the flow was collecting in the measuring cylinder the temperature of the outflowing water was

taken and the length of the soil sample was measured. The overflow was now diverted from the measuring cylinder, the watch being simultaneously stopped.

11. From these observations values of the permeability (reduced to a temperature of 20°C) and the void ratio of the sample were obtained at a series of times after the commencement of the flow.

12. Once the de-aired distilled water supply was exhausted, a switch was made to tap water and the test was continued for the remainder of a 24 hour period, a permeability reading being taken immediately before discontinuation of the test.

13. After discontinuing the test, the glass cylinder containing the sand sample and porous end plates was placed on end in a small evaporating dish care being taken to avoid the loss of any soil. The dish and contents were then placed in an oven and dried.

14. The cooled oven dry cylinder of sand was next weighed to the nearest 0.1 gm. and the sand sample was split into three approximately equal portions (designated:upper, middle and lower thirds) care being taken to avoid destruction of the particle size distribution of the sand in the various portions of the cylinder as established by the percolating water.

15. The empty cylinder, dish and porous plates were then reweighed and hence the final weight of the sand sample and the loss of weight due to migration of fines out of the sample was determined.

16. The porous plates were reweighed in order to determine whether they had become clogged by fine material.

17. Finally, particle size analyses were carried out on each of the three fractions of the original soil sample in order to determine what grading changes had taken place during the filter test.

NOTES ON THE SPECIAL APPARATUS AND TESTING PROCEDURE

The Water De-Airing Apparatus:

This apparatus is used, on a vastly larger scale by the mining industry in a process involving the de-airing of cyanide solution. In that case it works extremely well and hence it could be anticipated that the smaller model would also perform well. The vacuum obtained in the apparatus is very high being approximately 23 in. of mercury whereas the prevailing atmospheric pressure in Johannesburg is only 24.4 in. of mercury.

It has been found that such an apparatus is capable of reducing the dissolved oxygen content of water from approximately 6.4 cc. per litre to only 0.5 cc. per litre in one operation if the water supply is preheated. As oxygen and nitrogen dissolve in about equal proportions in water under a given pressure, the oxygen content is proportional to the air content. The value of 6.4 cc. per litre corresponds to water at room temperature and atmospheric pressure. As preheating was not used it is unlikely that the oxygen content was reduced so low. Nevertheless the water was sufficiently "air-starved" to be effective in giving a high degree of saturation in the samples.

The operation of the apparatus was very convenient as the process is continuous and needs little supervision. Also, the receiving vessel could be used directly in the filter test apparatus and no problem of transferring de-aired water from one vessel to another arose.

The Filter Test and Apparatus

The apparatus and testing procedure developed for these tests proved successful in providing the information desired.

No direct measurements of the degree of saturation of samples under test were made. Immediately after saturating the samples it was generally found that there were few remaining air bubbles visible in the test cylinder. In every case, within a short time after the flow of the de-aired distilled water had started, no air bubbles were visible and the test cylinders flowed full. The change-over to tap water did not appear to have any appreciable effect over a period of some hours on the accumulation of air within the sample, in any case there were no visible bubbles. However, the permeability at the end of 24 hours had always dropped off from its earlier value, and this was possibly caused by a loss of head due to air segregation in the pores of the sample.

In each and every case of these tests an immediate consolidation of the sample took place as soon as flow started in a downward direction. Thereafter consolidation proceeded at a very slow rate and its magnitude was usually too small to measure.

In almost every case, the only visible loss of fine material from the test cylinders occurred during the first few minutes of downward flow when the issuing water was discoloured. This condition soon passed and the water cleared rapidly. The decision to limit the duration of the filter tests to 24 hours was mainly justified by this observation of the rapidity with which the main changes of grading took place. In certain cases it was possible to see the change in grading which had taken place, the upper section of the sample being noticeably coarser than the lower section. In one case, that of the E.R.P.M. Furnace Ash, the movement of particles within the soil sample was plainly visible for a long period after the commencement of the flow.

The hydraulic losses in the filter test circuit did not appear to be unduly high and no correction was made to the available head to take account of these losses. The complete circuit with an empty test cylinder, but with the porous plates in place appeared to offer very little resistance to flow.

The overflow type constant head chambers proved very successful and were very sensitive.

CHAPTER IV

THE EFFECTS OF PERCOLATING WATER ON THE GRADING OF A FILTER SAND

Introduction:

Before proceeding to discuss the effects of percolating water on zoned or layered filters, consider what effect water has on the gradings of single sands. The methods of testing and the apparatus used have all been described in the preceding chapter.

For an analysis of the changes of grading a knowledge of various types of grading curve is required and the more common and useful methods of drawing particle size distribution curves will be described before analysing the various mechanisms of changes of grading. After this the characteristics of sands which do not behave as filters within themselves will be studied and a description and report will be given of a number of special tests which were carried out to investigate various minor effects.

Finally, after marshalling all the available information recommendations will be given for the selection of sands which are required to behave as filters within themselves.

Introductory - The Scope of the Investigation

The soils used in this investigation embrace a wide range of types of sands which could possibly be used in the construction of graded or zoned filters. Of the fifteen samples used, five are river sands - a type of sand most suitable and most commonly used for filter construction in Southern Africa and overseas at present. Five sands are crushed sands which are not used to a very large extent in filter construction overseas (Europe and North America) due to the plentiful supply there of good natural river sands. In South Africa, however, good river sands are expensive and in short supply and crusher sands are coming into increasing use as filter media. At present this is the case principally in the Gold Mining industry where their use is mainly for protective filters for slimes dams and on municipal works where crusher sands are being increasingly used in the construction of sewage purification filters.

The remaining types of sand are not in common use in filter construction, but have been used in the past and will conceivably be used in the future. Two samples of sand from ancient Kalahari dune deposits were used. These sands occur quite commonly in Southern Africa and are distributed over wide areas. The deposits are already extensively worked to provide 'pit sand' for building purposes and will no doubt, sooner or later be required for filter construction.

One sample of a sand formed from a decomposed sandstone was used. It is not known whether such a sand has been used previously in Southern Africa for filter construction, but a similar sand is being used for the protective filters of a large earth dam now under construction.

One sample of a waste ash was also used. This material appears at first sight to be a good, stable, permeable material and might quite conceivably be chosen for a filter layer.

It is considered that the sands used in this investigation cover a wide enough range of types, gradings and geological origins for any conclusions arrived at to be of fairly general application. The number of samples tested (fifteen) may not appear large, but due to the laborious testing programme called for, this was the largest number of samples which could be handled in the time available for the investigation. Because of the small sample number extensive use has been made of statistical methods of estimation in an attempt to obtain more certain results.

Full descriptions of the sands used will be found in the accompanying SOIL SAMPLE INDEX.

SOIL SAMPLE INDEX

SAMPLE NO.	CLASSIFICATION	SOIL SAMPLE	DESCRIPTION
1	Crusher Sand	Crusher Sand 'A' Roodepoort	Crushed Witwatersrand Quartzite. Light grey to white quartzite fragments.
2	do	Crusher Sand 'B' Roodepoort	Crushed Witwatersrand Quartzite containing large % yellow silty fines. Large Particles angular and flaky.
3	do	Witdeep Sand Boksburg	Crushed Witwatersrand Quartzite. Grey in colour. Contains undecomposed pyrite and large % grey fines.
4	do	E.R.P.M. Dump Sand Boksburg	Very finely crushed Quartzite. Yellow in colour due to decomposed pyrite. Sand fairly uniform.
5	do	Granite Filter Sand Nelspruit	Crushed 'Old' Granite. Partially decomposed after crushing due to use in sewage slow sand filter.
6	do	Crushed Norite Pretoria	Crushed Norite: Sound unweathered crystalline Norite. Dark grey in colour.
7	do	Crushed Beaufort Sandstone Graaf Reinet	Finely crushed Beaufort Sandstone. Uniform fine grained hard greyish white sandstone.
8	do	Crushed Granite Nelspruit	Crushed Sound and hard 'Old' Granite: Coarsely crystalline pink and white hard granite.
9	do	Witwatersrand Quartzite	Crushed Witwatersrand Quartzite.
10	do	Artificial Van Ryn Sand	Artificial Van Ryn Sand made up of angular and flaky crushed quartzite particles.
11	River Sand	Cullinan Sand Olifantsfontein	Clean fawn River Sand, fairly uniform. Consists of subrounded quartz particles.
12	do	Van Ryn Sand Benoni	Clean, uniform sand from old river deposit. Subrounded pinkish fawn quartzite particles.

SAMPLE NO.	CLASSIFICATION	SOIL SAMPLE	DESCRIPTION
13	River Sand	Jukskei River Sand Johannesburg	Uniform coarse waterworn yellow sand. Grains mostly quartz but with some felspar.
14	do	Graaf Reinet River Sand	Dirty sand consisting of rounded waterworn particles of Beaufort Shale. Grey-blue to drab in colour.
15	do	White River Sand	Fine clean white river sand containing coarser yellow agate pebbles.
16	do	Yellow River Sand Virginia	Well graded clean water worn yellow river sand. Grains mostly quartz and chalcedony.
17	Aeolian Sand	Bartlett's Sand Boksburg	Fine grained medium to dark brown sand with large silt content. Kalahari dune deposit.
18	do	Witbank Sand Witbank	Fine Reddish brown sand. Kalahari dune deposit, partially decomposed in situ.
19	Artificial Sand	Artificial Sand No. 1	Well graded artificial sand composed of rounded orange brown river sand particles.
20	Ash	E.R.P.M. Furnace Ash Boksburg	Pink Furnace Ash grading from large clinkers to fly ash.
21	Decomposed Sandstone	Decomposed Sandstone Boksburg	Decomposed reddish brown sandstone containing aggregates of particles cemented by purple iron and manganese salts.
22	Slimes (Silt)	Delmore Slimes Germiston	Finely ground yellow Witwatersrand Quartzite.

(i) COMMON METHODS OF CONSTRUCTING GRADING CURVES

There are a number of ways of drawing grading curves for soils and artificial crushed aggregates all of which have their own peculiar advantages. Only three types of curve have been considered here:

The Non-Cumulative Semi-Logarithmic or Grain Size Frequency Curve,
The Cumulative Semi-Logarithmic Curve,
The Cumulative Log.-Log. Curve.

Consider two sands which have geometrically similar particle size distributions but mean particle sizes which are not equal. Only with a logarithmic particle size scale will the grading curves be congruent and have the same shape although displaced from each other either towards the fine or coarse particle size range.

(a) The Non-Cumulative Semi-Logarithmic Curve:

Here the percentage by weight retained on the individual sieves or the percentage by weight corresponding to an individual hydrometer reading are plotted as ordinates against the logarithms of the particle sizes as abscissae. This method gives a curve closely related to the statistical Histogram. The area of a strip located above an arbitrary grain size range, e.g. 0.1 mm.to 0.2 mm. represents the quantity of soil particles within this range as a percentage of the total dry weight.

The typical curve obtained from a single crushing operation carried out on a structurally homogeneous rock such as an igneous rock is a single peaked, bell-shaped curve. The illustration shows a typical curve for a jaw crusher fed with a sound, hard norite. These curves may be symmetrical or skewed either towards the fine or coarse particle size ranges depending on the characteristics of the crushing operation.

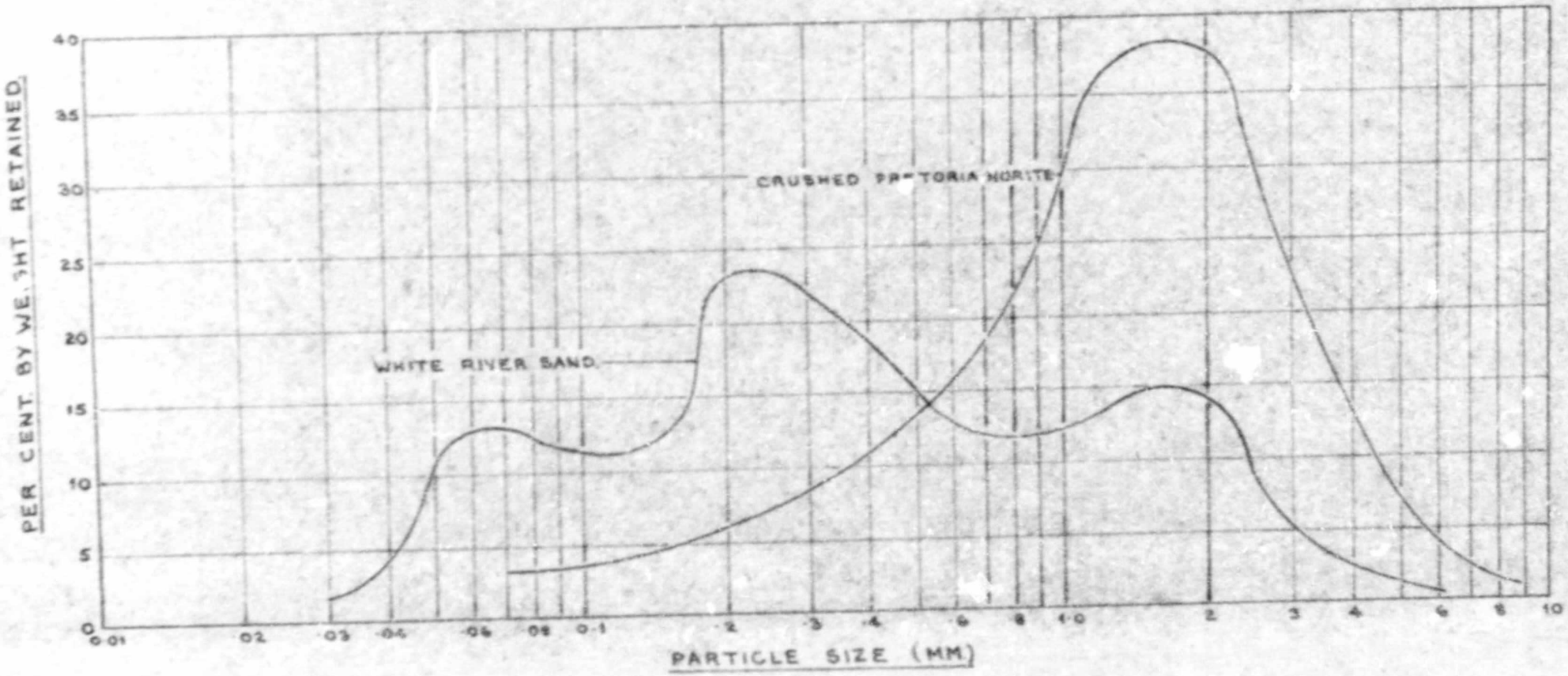
In natural soils it frequently happens that the products of two or more processes of comminution are deposited together in the form of a more or less intimate mixture. Each process will be characterised by its own particular curve and the resultant curve for the mixture will be multi-peaked. The grain size frequency curve is the only form of grading curve which exhibits this property. Thus the grain size frequency curve can reveal a lot of unsuspected information about the origin of an apparently completely homogeneous soil. The illustration shows a triple peaked grain size frequency curve for a sand which was apparently a homogeneous river sand, and would have been expected to have only one peak.

(b) The Cumulative Semi-Logarithmic Curve:

Here cumulative percentages by weight of particles finer than a given size are plotted as ordinates against the logarithm of the particle size as abscissae. This is for most purposes the most convenient representation of the results of a particle size analysis, and has been adopted in this thesis for most purposes. It is analogous to the ogive of statistical literature. A great deal of information as to the constitution and grain size characteristics of the sand can be readily read off this graph.

TYPICAL NON-CUMULATIVE SEMI-LOGARITHMIC GRADING CURVES.

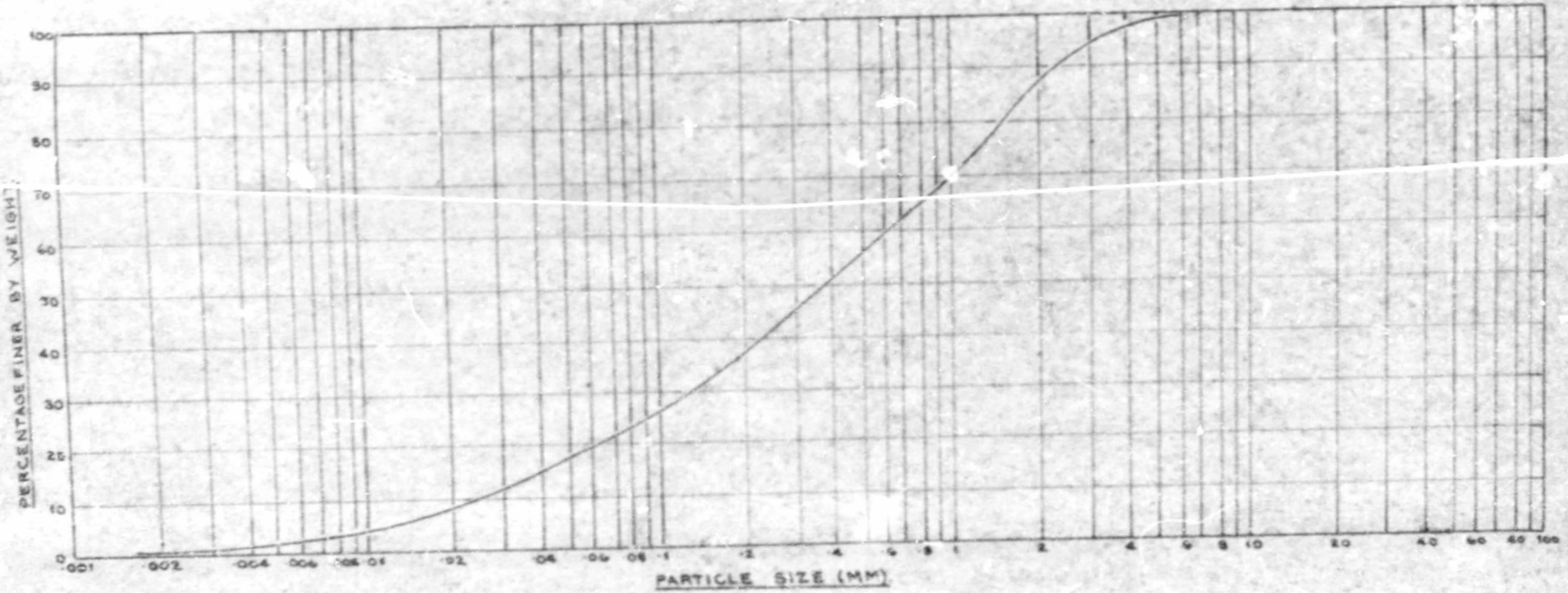
TWO CURVES ARE SHOWN. A NATURAL RIVER SAND WITH 3 PEAKS SHOWING A COMBINATION OF 3 DISTINCT GRADINGS & A SINDLE PEAKED CURVE FOR A CRUSHER RUN NORITE.



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TYPICAL CUMULATIVE SEMI-LOGARITHMIC GRADING CURVE.

THIS IS A TYPICAL CURVE FOR A FINE CRUSHER SAND (A CRUSHED QUARTZITE).



	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE
CLAY	SILT FRACTION			SAND FRACTION			GRAVEL FRACTION		

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Neither of the above two curves are simple in form and it is seldom that specimens of either can be adequately described by a mathematical expression.

(c) The Cumulative Log.-Log. Curve

This curve is similar to the cumulative semi-logarithmic curve except that the cumulative percentages are plotted to a logarithmic scale. This curve generally has a simpler form than the previous two and is usually a straight line over much of its length. This has been found to be characteristic of most materials that have been broken down by natural causes and also of many crushed and ground products. Continuity of the curve must be destroyed by any selective action to which a material may have been subjected and deviations from a straight line are to be expected at both the upper and lower size limits due to errors in sampling, size measurement, etc.

The straight line portion of the curve can be described mathematically by:

$$\log y = n \log x + \log a$$

Where x = size of sieve aperture.
y = corresponding cumulative percentage by weight of material passing the sieve.
n and a are constants.

This implies that on natural scales the grading can be described by: $y = ax^n$.

Another expression which takes into account the deviations from a straight line at either extremity is the Rosin-Rammler relation which is extensively used for crushed coal

$$\% \text{ oversize } x = 100\, e^{-\left(\frac{x}{\bar{x}}\right)^n}$$

The illustration shows two curves for typical sands and a curve representing the Rosin-Rammler relation with $n = 1$ and $\bar{x} = 0.10$ mm.

(ii) THE APPARENT MECHANISM OF GRADING CHANGES

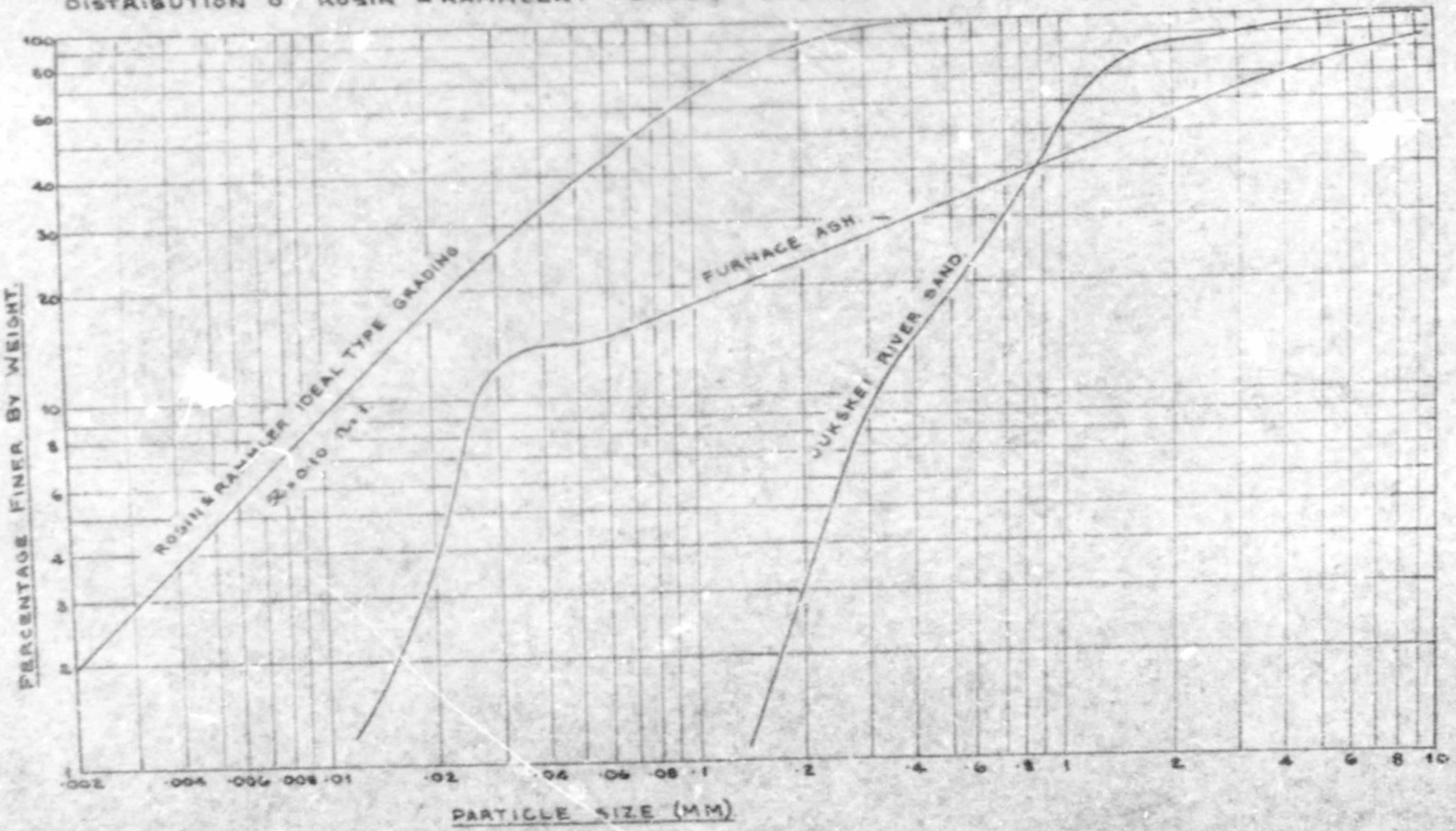
A study of the changes in the semi-logarithmic grading curves brought about by the action of percolating water has revealed five basic mechanisms of grading change in filter sands. These five modes in which the grading of a filter sand may change have been further illustrated by a visual inspection of the test cylinders of sand after subjection to flow action.

Grading changes appear to have occurred as a result of:

(a) A redistribution of fine particles within the mass of the sand without appreciable loss of fine material from the sample as a whole. This results, generally, in a coarsening of the grading of the upper portion of the sample together with a corresponding increase in the percentage of fine material contained by the lower portion of the sample. This action is very well illustrated by the accompanying photograph and the corresponding grading curves, both of which are for the same sample of van Ryn Sand. It will be seen that this mode of failure results, in general, in the formation of an "hysteresis loop" on the grading chart between the grading curves for the upper and lower portions of the sand in the test cylinder.

TYPICAL LOG.-LOG. CUMULATIVE GRADING CURVES.

3 CURVES ARE SHOWN: A COARSE RIVER SAND, A FURNACE ASH AND AN IDEAL PARTICLE SIZE DISTRIBUTION OF ROSIN & RAMMLER: PERCENT OVERSIZE $R = 100\,e^{-(x/\bar{x})^n}$



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Author Blight Geoffrey Eustace
Name of thesis The Investigation Of Filter Sands And The Establishment Of A Criterion For The Condition That A Sand Is A Filter In Itself. 1958

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