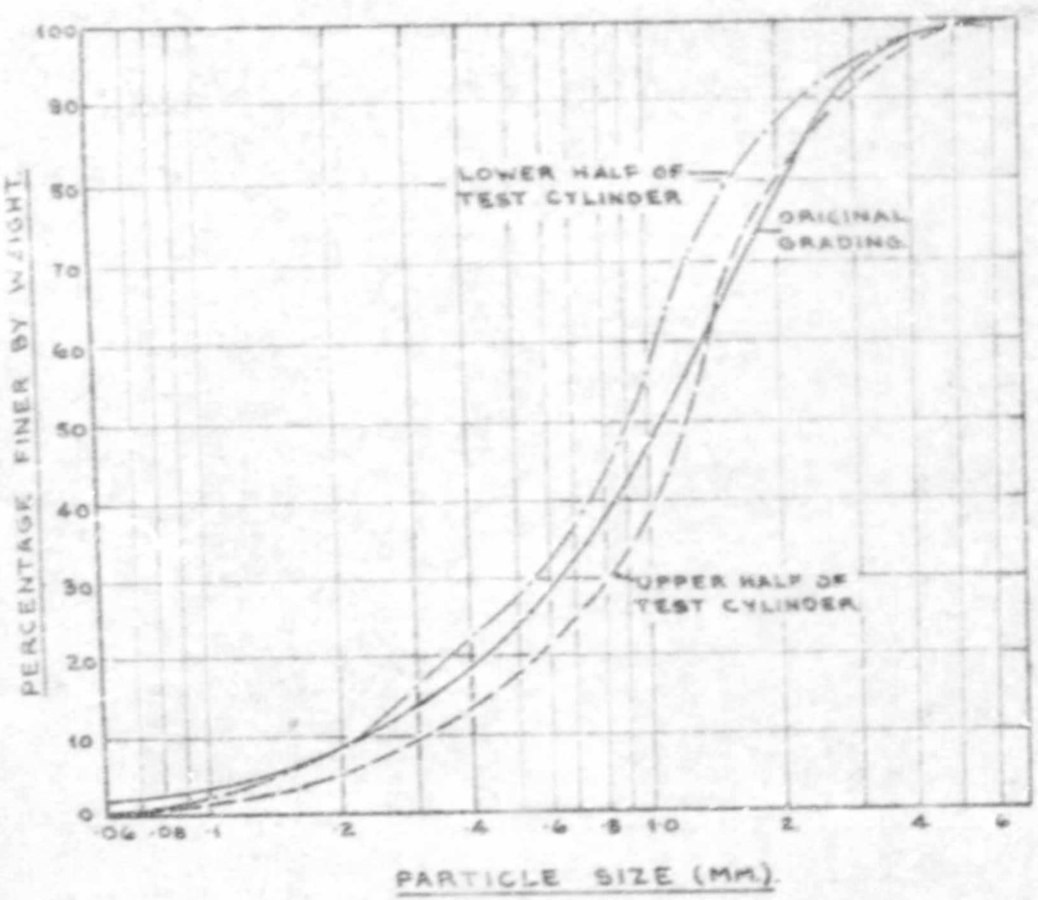
THE CHANGE OF GRADING OF FILTER SANDS.

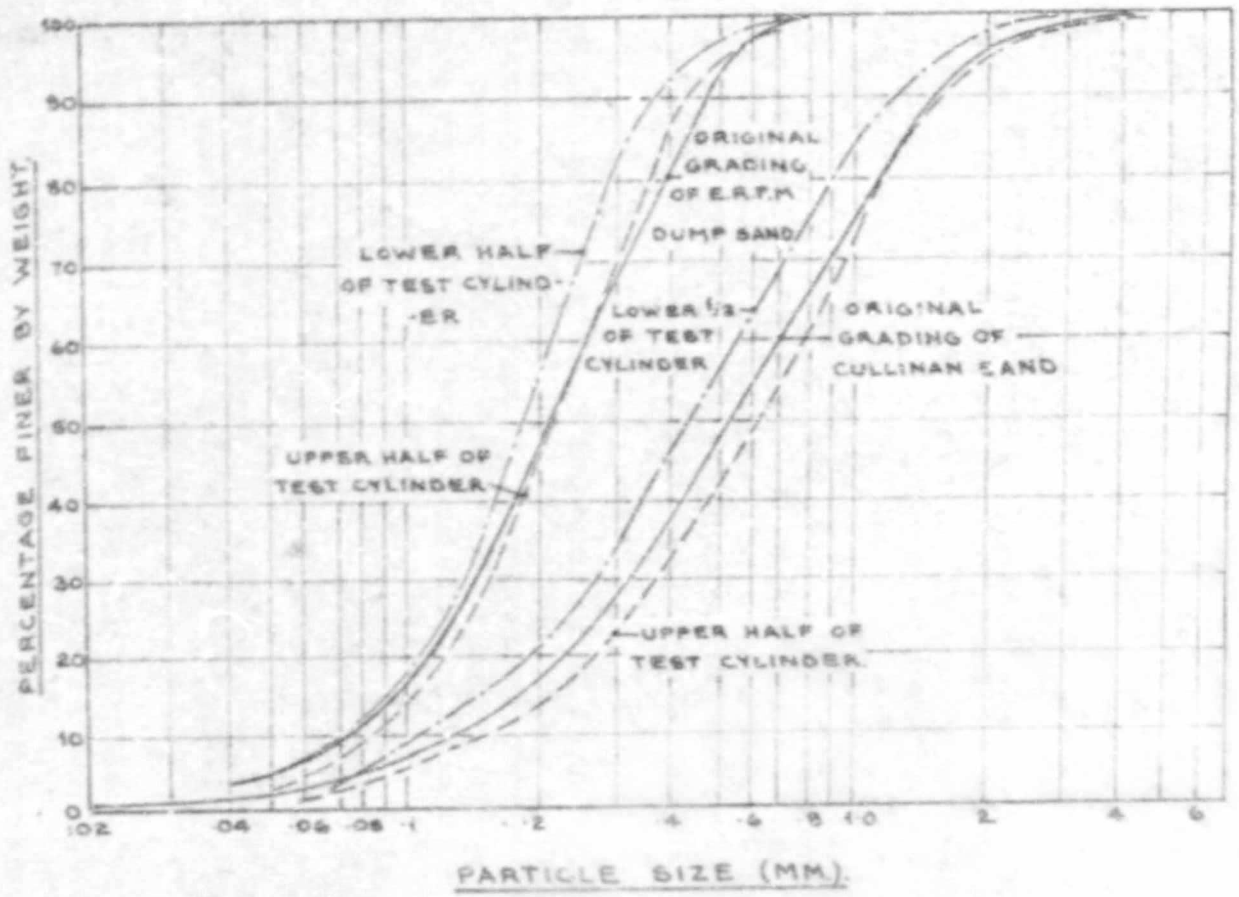
CHANGES BY MODE A.

THESE SETS OF CURVES ILLUSTRATE CHANGES OF GRADING DUE TO A PURELY INTERNAL RE-DISTRIBUTION OF PARTICLES WITH NO OVERALL LOSS OF FINE MATERIAL.



VAN RYN RIVER SAND

FINE	MEDIUM	COARSE	FINE
SAND			GRAVEL



CULLINAN SAND AND E.R.P.M. DUMP SAND

COARSE	FINE	MEDIUM	COARSE	FINE
SILT	SAND			GRAVEL

See Page 33

The curve for the lower portion of the cylinder, the sand becoming finer, moves to the left, while the curve for the upper portion of the cylinder, the sand becoming generally coarser, moves toward the right (both relative to the original grading of the sand). It is known, and can be easily demonstrated that the area beneath a grading curve on the semi-logarithmic plot is a measure of the Specific Surface Area of the sand sample. The area enclosed by the "hysteresis loop" therefore, will represent the change in Specific Surface Area between the top and bottom portions of the sample due to migration of fine particles within the sand in the direction of the hydraulic gradient. This means that the area of the loop should represent at least an approximate measure of the mass of fine particles which has migrated due to flow action. This type of failure appears to be the most common occurring in filter sands, as four samples out of nine exhibited the failure.

(b) It is possible for an overall loss of fine material from the sample to its surroundings to occur. This results in an overall coarsening of the sand, the grading curves for both upper and lower portions of the sand dropping below and moving to the right of their original position. The best illustration of this type of failure is found in the curves for the E.R.P.M. Ash and the Bartlett's Sand. The overall loss of fines was in the former case quite measurable, amounting to some 5% of the original dry weight of the sample.

The hysteresis loop again appears for this type of failure, but consists of two overlapping portions, both falling to one side of the original curve.

It will be observed that in the example cited, the material in the lower portion of the sample has undergone relatively little grading change, while the upper portion has undergone considerable change. This is probably because there was a steady replacement of fine material lost from the lower section by fines from the upper portion of the sample.

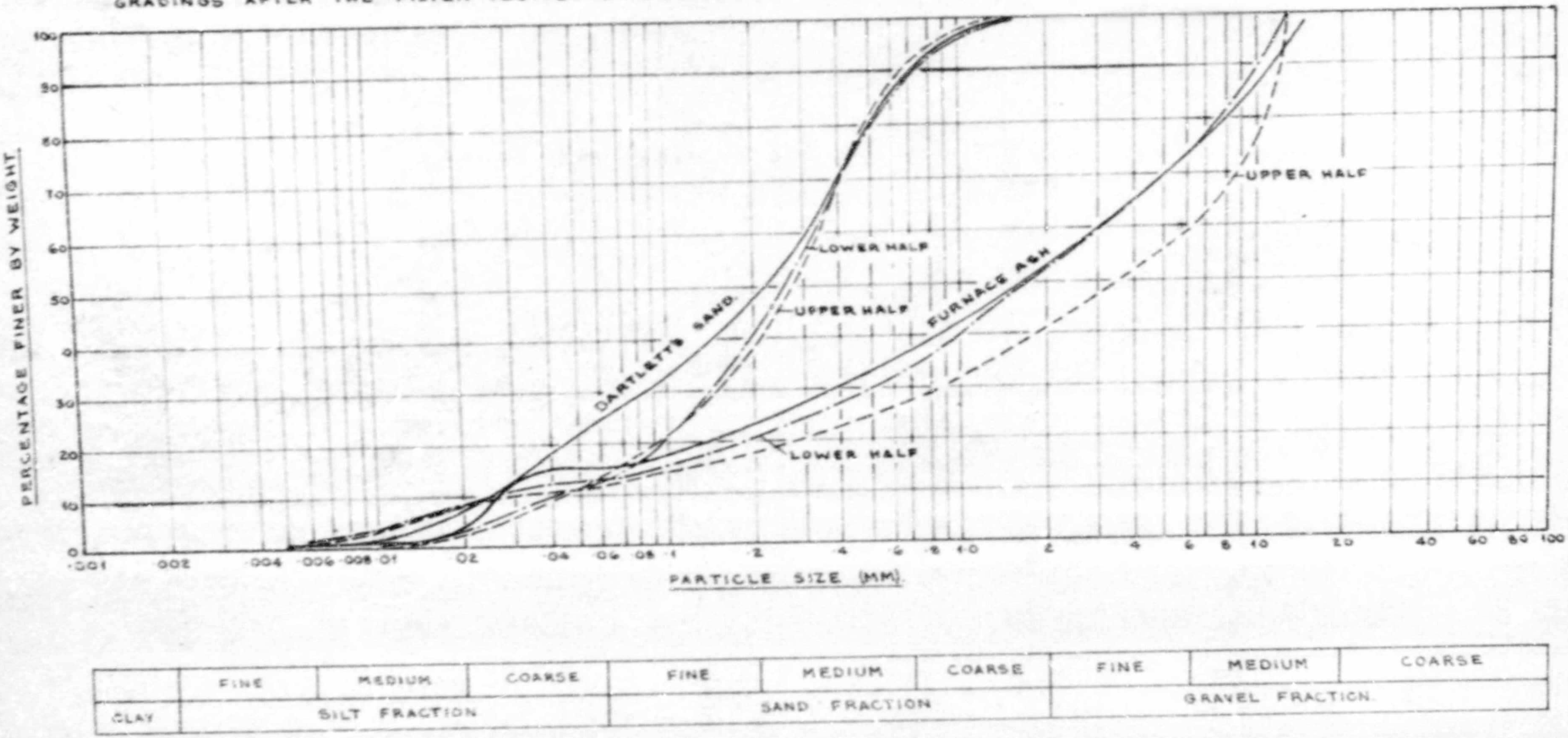
(c) It is possible for a physical reduction in the size of the individual particles to take place under the influence of the flowing water. This results in a generally finer sand, which is also more uniform. This mode of failure is illustrated by the behaviour of the sample of Decomposed Sandstone, in which the larger gravelly particles consisted of cemented aggregates of finer sand grains. These aggregations appear to have disintegrated wholly or partially during the filter test causing the grading curves of both upper and lower portions of the sample to 'rotate' anticlockwise. This movement has again formed an "hysteresis" loop in the 'coarse' portion of the grading curves representing an increase in Specific Surface Area due, not to the influx of finer particles from outside, but to the comminution of particles in situ.

(d) A fourth mode of failure is illustrated by the behaviour of the sample of Wit Deep Crusher Sand in which the lower portion of the sample became considerably finer (as evidenced by the large movement of the grading curve toward the left) while the upper portion of the sample appeared to remain relatively unchanged. The only explanation can be that the migration of fine material into the lower portion of the sample took place from the central region of the test cylinder leaving the upper region relatively unchanged. The central portion of the test cylinder was not subsequently resieved. In some of the special filter tests (to be described later) both upper and lower portions of the sample appeared to have become finer.

THE CHANGE OF GRADING OF FILTER SANDS.

CHANGES OF MODE 'B'.

THESE TWO SETS OF GRADINGS, FOR AN AEOLIAN SAND AND A FURNACE ASH, ILLUSTRATE A CHANGE OF GRADING BY AN OVERALL LOSS OF FINE MATERIAL FROM THE SOIL. ORIGINAL GRADINGS ARE SHOWN BY SOLID LINES, ALTERED GRADINGS AFTER THE FILTER TEST BY BROKEN LINES. THE POSITIONS OF THE SAMPLES IN THE TEST CYLINDERS ARE SHOWN.



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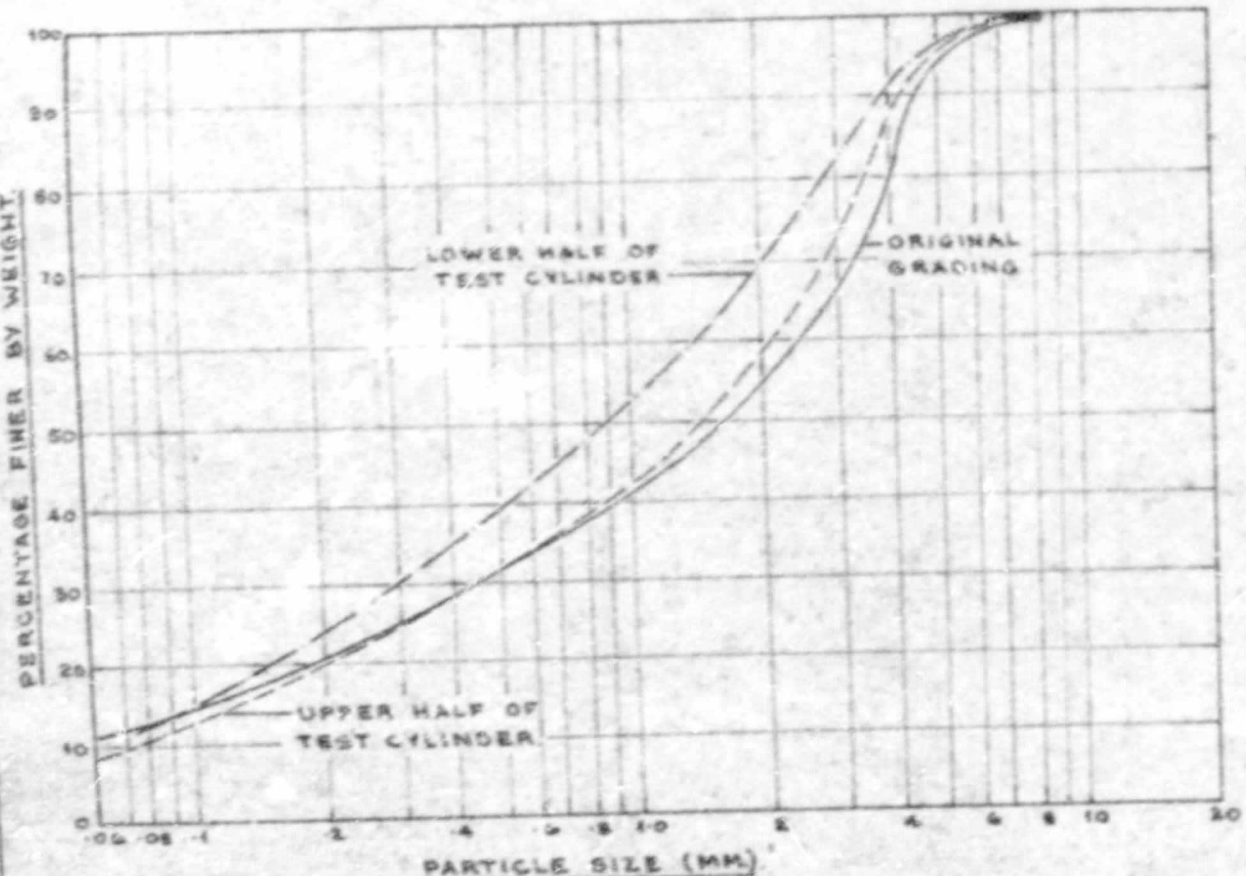
THE CHANGE OF GRADING OF FILTER SANDS.

CHANGES BY MODE C[illegible]

THESE CURVES SHOW A CHANGE OF G[illegible] RESULTING FROM MIG[illegible]ION OF FINE MATERIAL INTO THE [illegible]ER ZONE OF A SAMPLE FROM THE CENTRAL ZONE, THE UPPER Z[illegible]E REMAINING UNCHANGED.

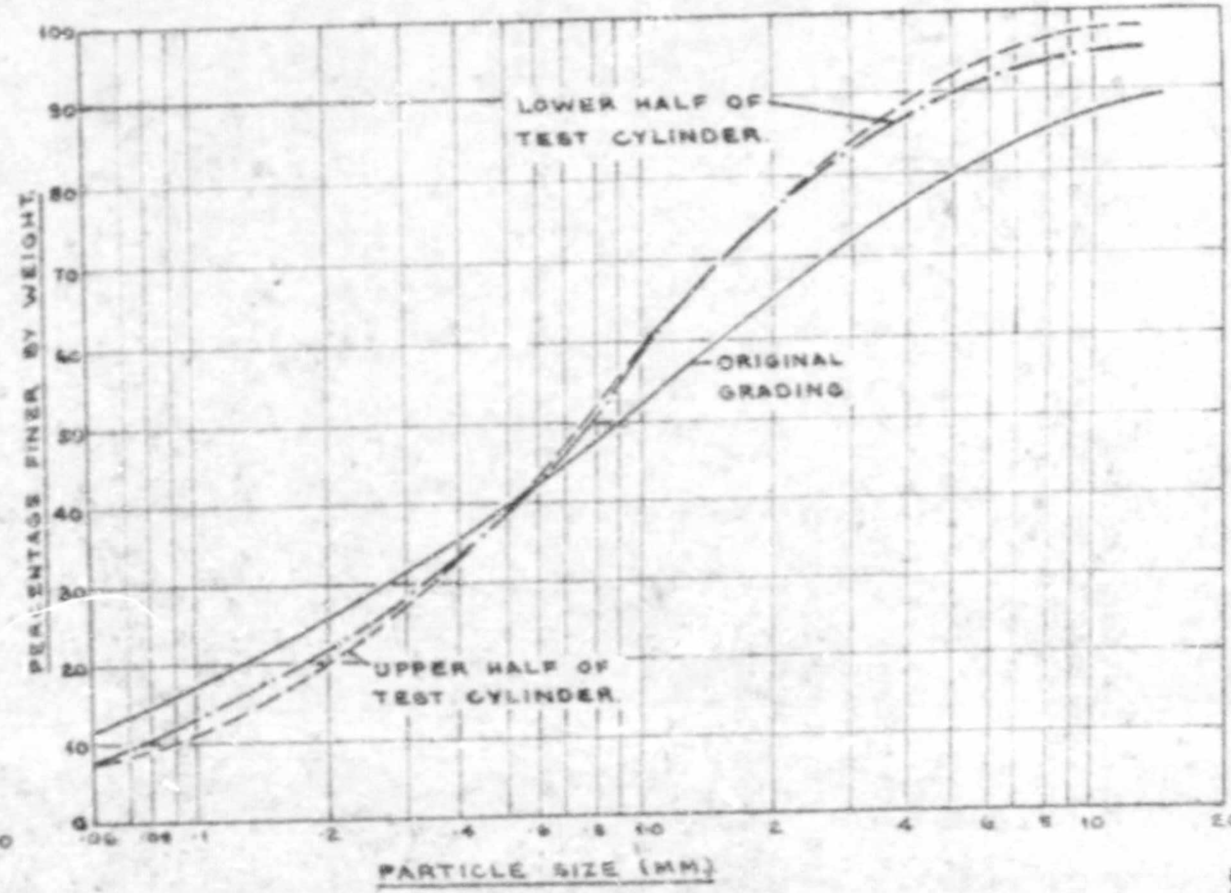


WITDEEP CRUSHER SAND.

FINE	MEDIUM	COARSE	FINE	MEDIUM
SAND			GRAVEL.	

CHANGES BY MODE D.

THESE CURVES SHOW A CHANGE OF GRADING DUE TO A REDUCTION IN THE SIZE OF THE SAND PARTICLES AND AN OVERALL LOSS OF FINES FROM THE SAMPLE.



DECOMPOSED SANDSTONE.

FINE	MEDIUM	COARSE	FINE	MEDIUM
SAND			GRAVEL.	

See Page 34

However, as in all cases the grading curve for the upper portion of the cylinder remained very close to the original curve, this anomaly may be entirely due to natural variation in the sand.

(e) Finally, the form of the grading curve may be altered in certain cases. In most of the experiments, although the positions of the grading curves were altered, their general shape and form remained substantially the same. In a few cases, however, considerable departures from the original form were observed. In the lower portion of the sample of Crusher Sand 'A', for example, the grading curve developed a flattish portion near the 50% mark indicating a dearth of particles of the corresponding sizes where none had been before. i.e. The sand was converted into a "gap-graded" sand. In the case of the Witbank Sand, the tendency was for the gradings of both upper and lower portions of the sample to become more regular and closer to the ideal 'Normal' grading curve.

It is not suggested that the five modes of failure described above are the only manners in which changes of grading in a sand may occur. They represent the observed modes which took place in this series of tests and were probably governed to some extent by the method of testing.

The appendix to this chapter contains seven pages illustrating the "before" and "after" grading curves for the remaining 7 sands tested by means of the standard filter test. The first two sands have undergone definite changes in grading while there was no significant change in the gradings of the remaining 5 sands.

(iii) CHARACTERISTICS OF SANDS WHICH ARE NOT A FILTER IN THEMSELVES - AS APPARENT FROM THEIR GRADING CURVES.

(a) The influence of the Origin of the Sand.

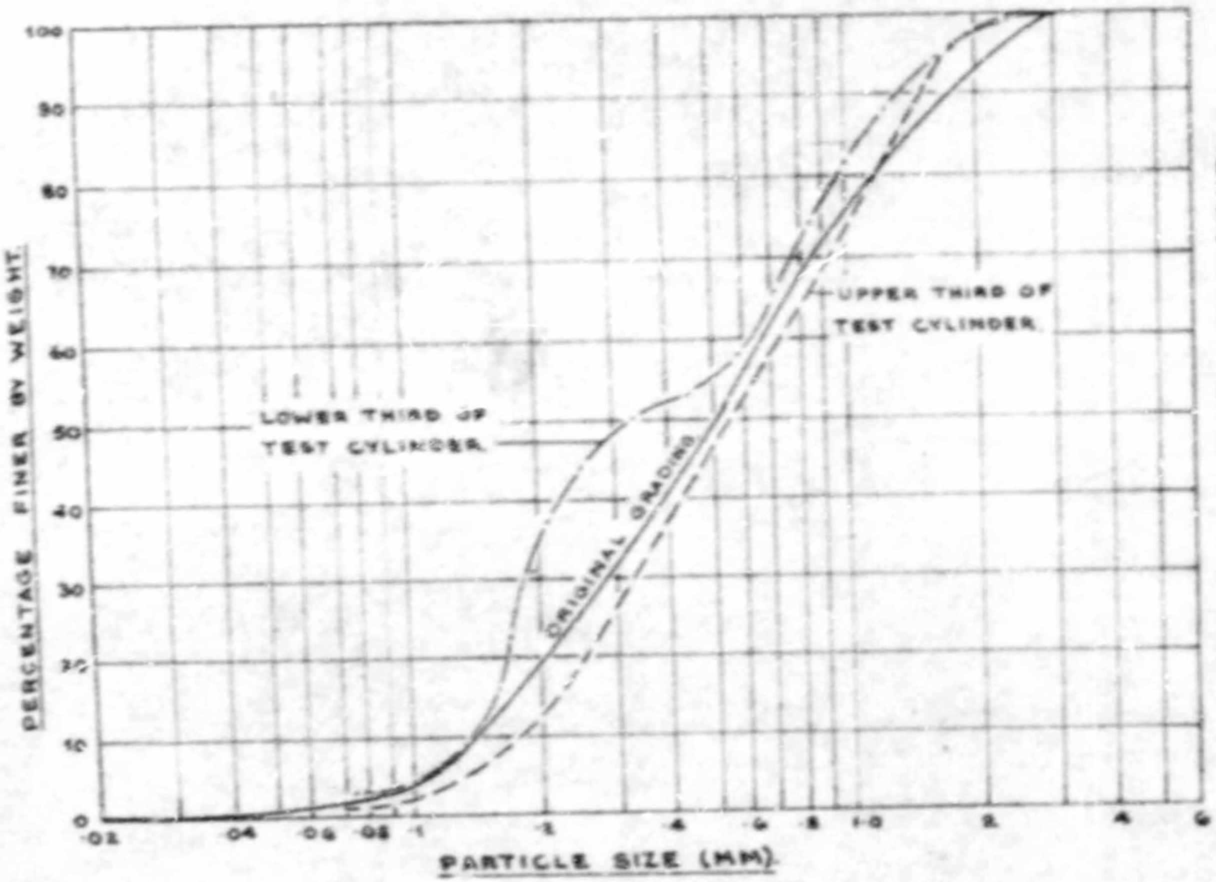
The origin of a sand appears to have an important influence on whether the sand will act as a filter in itself, or not. It is striking that most of the sands in which significant changes in grading did not occur during the course of the filter tests were sands which at a previous time during their history had been subjected to the action of percolating water. Of the six sands which did not fail, three were river sands and one was a crusher sand which had previously been in use in a slow sand sewage filter. In addition to this, one of the two remaining sands was an artificial sand composed of sieved fractions of river sand.

Of the nine sands which did fail, only two could be called river sands and these sands were actually taken from deposits of sand in ancient river channels - not from modern river beds.

The sands exhibiting the worst changes of grading were artificial crusher sands, sands from ancient aeolian deposits, now partially decomposed after deposition, and sands formed from decomposed rocks. It would therefore appear important when selecting a graded sand for use in a filter to choose a sand which in its recent past has been subjected to the action of flowing water in nature.

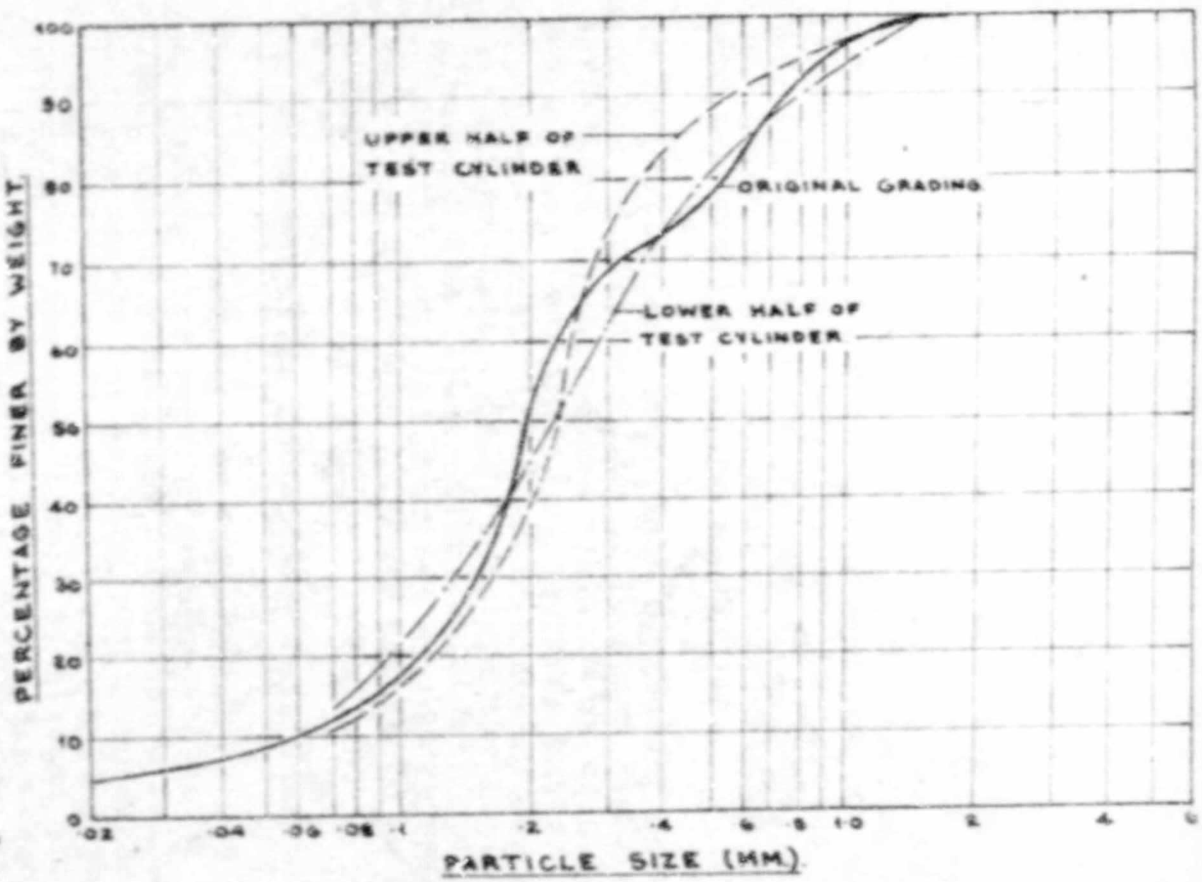
THE CHANGE OF GRADING OF FILTER SANDS. CHANGES OF MODE 'E'.

THIS PAIR OF SETS OF GRADING CURVES, FOR A CRUSHER SAND AND AN AEOLIAN SAND, ILLUSTRATES CHANGES OF GRADING BY AN INTERNAL REDISTRIBUTION OF PARTICLES LEADING TO ALTERED SHAPES OF THE GRADING CURVES. ORIGINAL GRADINGS ARE SHOWN BY SOLID LINES, ALTERED GRADINGS BY BROKEN LINES.



CRUSHER SAND A.

COARSE	FINE	MEDIUM	COARSE	FINE
SILT	SAND			GRAVEL



WITBANK AEOLIAN SAND.

COARSE	FINE	MEDIUM	COARSE	FINE
SILT	SAND			GRAVEL

See Page 35

(b) The Influence of the Original Grading of the Sand.

It has become almost standard practice in Soil Mechanics to judge the properties of a non-cohesive soil such as a filter sand purely on the basis of the particle size distribution of the sand. Not only is the grading of a sand an easily determined property, but experience has shown that grading is one of the most significant properties of any sand. Thus, especially in the design of filters, the practice has grown of basing a design entirely on properties deduced from the gradings of the sands used.

An inspection and comparison of grading curves for sands which act as filters in themselves and sands which do not act as filters in themselves will now be made. The grading curves have been drawn out on three bases: the non-cumulative, semi-logarithmic or grain-size frequency curve, the cumulative semi-logarithmic curve and the log.-log. cumulative curve. The illustrations which accompany this section portray the original gradings of the fifteen sands tested, classified according to their behaviour as filters within themselves.

The Non-Cumulative Semi-Logarithmic Curve:

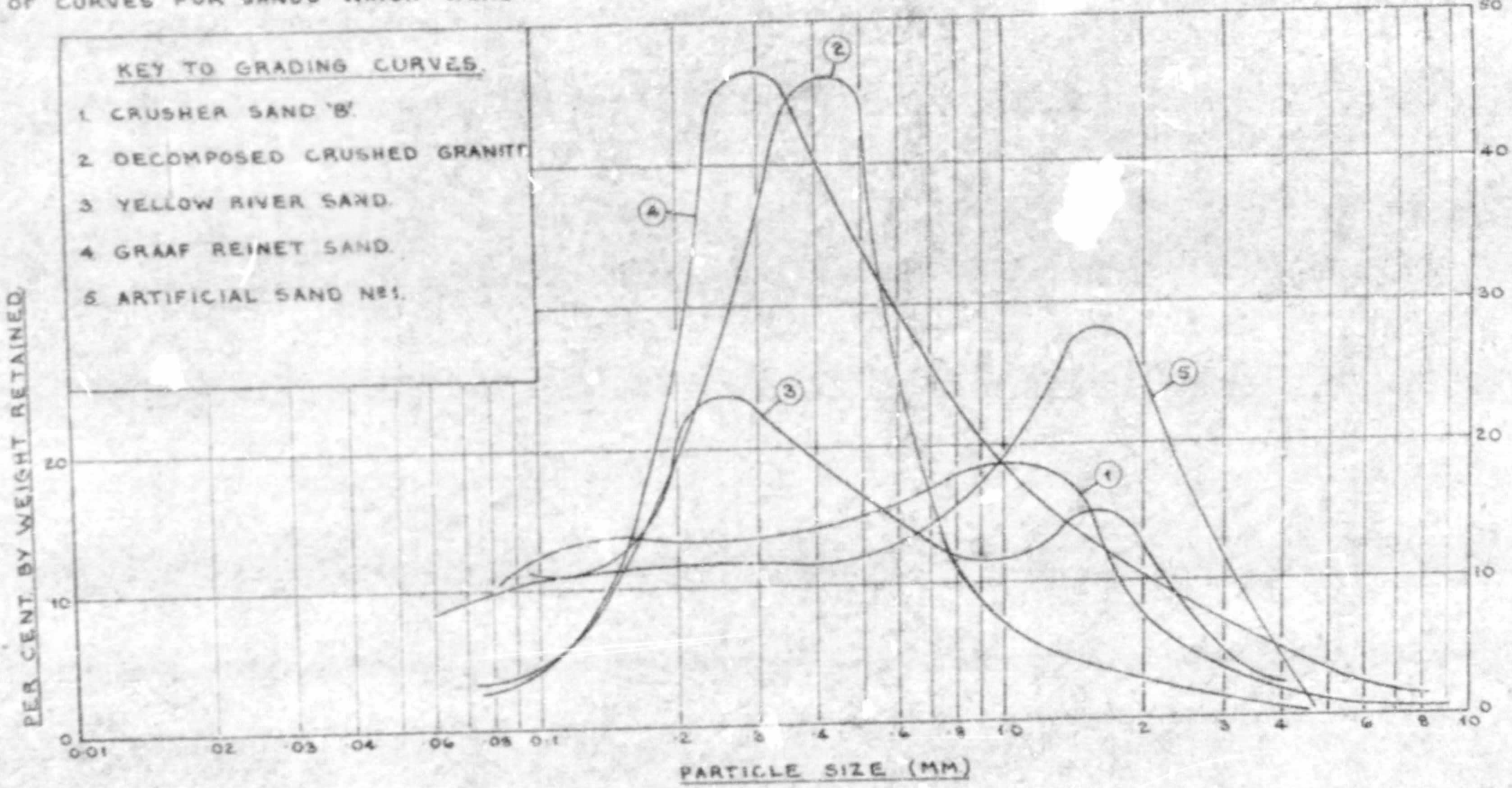
There is a tendency for sands which do not fail to have higher peaked, more regular grading curves on this plot. Uneven, widely spread peaks seem conducive to failure. It appears that the nearer the grading curve approaches the Gaussian curve with a small scatter or a combination of two or more such curves, the more likely is it that the sand will behave as a filter within itself. A very good example of this is a single sized sand. It is common knowledge that a single sized sand will not fail as a filter. It is possible though that a mixture of two or more single sized sands may fail to act as a filter if the ratios between successive mean particle sizes fall outside certain limits.

Consider for example a material consisting of a mixture of spherical particles of two sizes only. The larger spheres will tend to form a grain structure which will retain the smaller spheres (i.e. will filter them) unless the size of the smaller spheres falls below a certain limit which depends on the tightness with which the larger spheres are packed. It has been shown mathematically that for the tightest possible packing of the larger spheres of diameter D, the diameter of the smaller spheres must be less than 0.154D before they can penetrate the matrix of larger spheres. For the loosest possible packing of the larger spheres, the diameter of the smaller spheres must be less than 0.414D before they can wash out.

The table which appears below shows that these ratios of particle sizes do not hold for natural sands having multi-peaked non-cumulative grading curves. In the table D and d represent the particle size diameters corresponding to successive peaks of the grading curves. e.g. If a twin peaked curve is assumed to represent a mixture of two sands D and d represent in turn the mean particle sizes of the coarser and finer sands. The sands which failed would be expected to have smaller values of d/D, but this is not the case. The two sands which did not fail have values of d/D less than the theoretical limit of 0.154.

NON-CUMULATIVE SEMI-LOGARITHMIC GRADING CURVES FOR SANDS WHICH BEHAVE AS FILTERS WITHIN THEMSELVES.

A SET OF CURVES FOR SANDS WHICH WERE FOUND TO BE STABLE IN THE SPECIAL SERIES OF FILTER TESTS.



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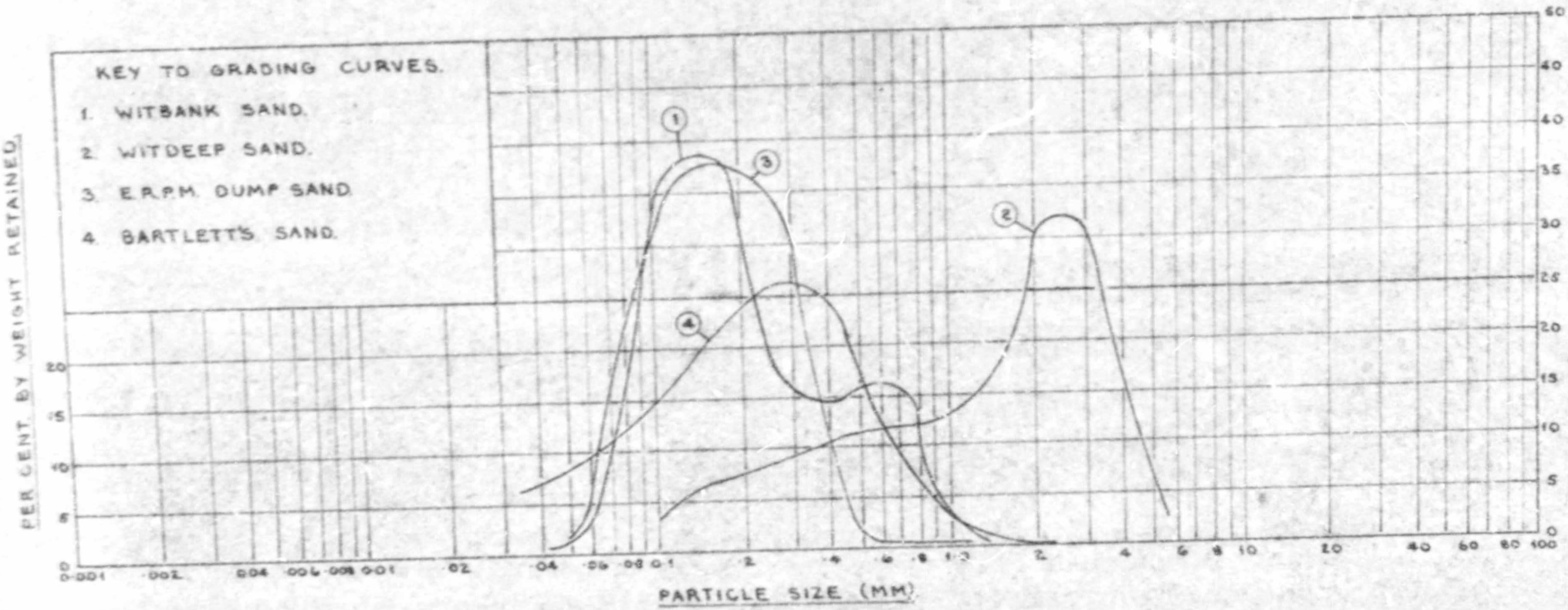
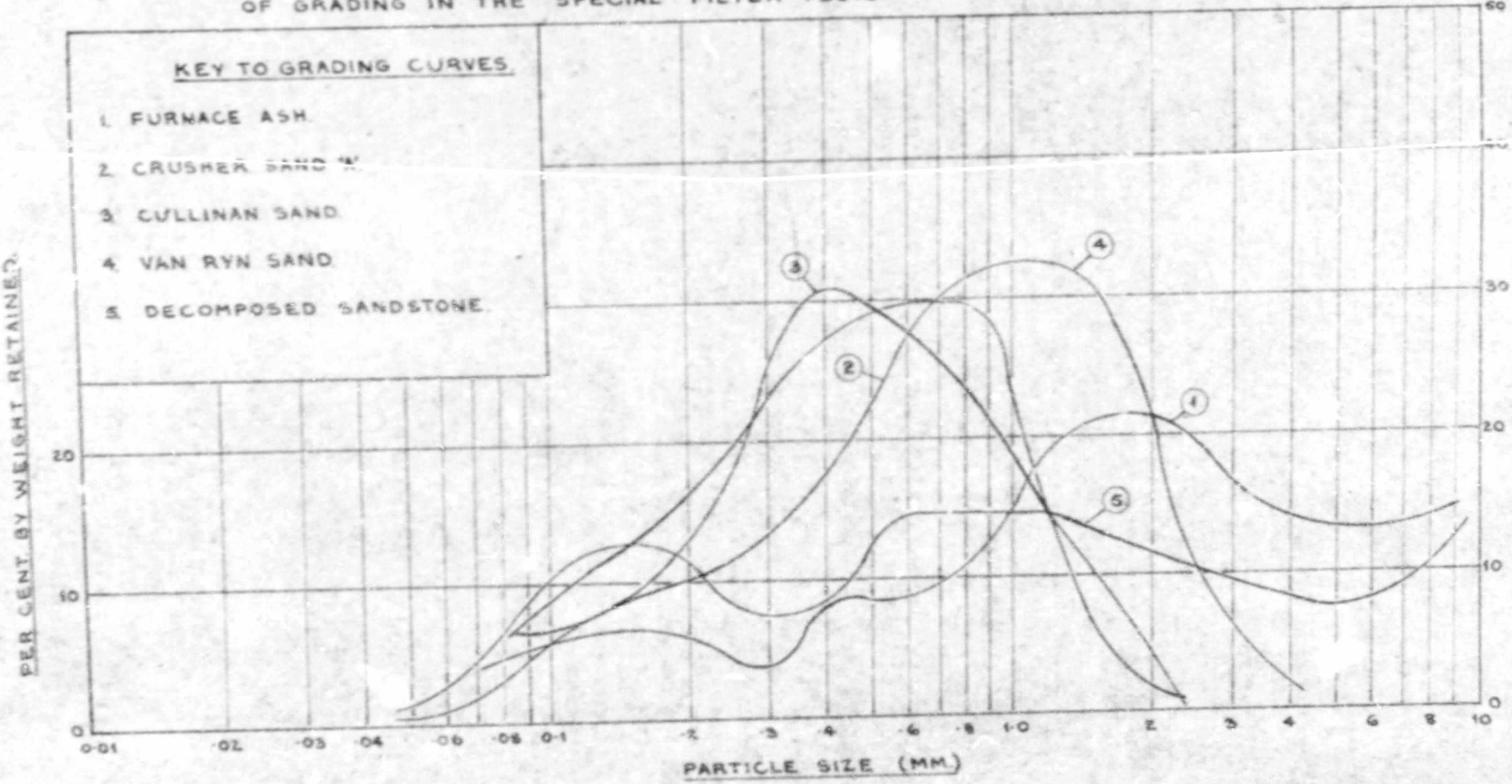
NON-CUMULATIVE SEMI-LOGARITHMIC GRADING CURVES FOR SANDS WHICH DO NOT BEHAVE AS FILTERS WITHIN THEMSELVES.

A SET OF CURVES FOR SANDS WHICH UNDERWENT EXTENSIVE CHANGES OF GRADING IN THE SPECIAL FILTER TESTS.



NON-CUMULATIVE SEMI-LOGARITHMIC GRADING CURVES FOR SANDS WHICH DO NOT BEHAVE AS FILTERS WITHIN THEMSELVES.

A SET OF CURVES FOR SANDS WHICH UNDER WENT EXTENSIVE CHANGES OF GRADING IN THE SPECIAL FILTER TESTS.



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Sands which did not fail	Sands which failed	D mm.	d mm.	d/D
Yellow River Sand		1.65	0.25	0.15
White River Sand		1.65	0.23	0.14
	Witbank Sand	0.59	0.15	0.25
	Decomposed Sandstone	0.80	0.15	0.19
	E.R.P.M. Ash	1.68	0.42	0.25

The Log.-Log. Cumulative Grading Curve:

On this plot the curves representing sands which behaved as filters within themselves have a tendency towards more regularity than those representing sands which failed. However, there is no clear-cut distinction between the curves, the majority of which are straight lines over most of their length and appear to follow the Rosin-Rammler relation fairly closely.

The Cumulative Semi-Logarithmic Curve:

The grading curves plotted on this basis once again exhibit a variety of shape and form for both sands which failed and sands which did not fail. Two points of interest may be gleaned from a comparative study of the grading curves:

Any grading curve can be partially described by two basic properties: position and scatter.

The position of a grading curve could be said to decide the grain size classification of the soil, e.g. clay, silt, sand or gravel, while the scatter gives a measure of the range of particle sizes covered by the grading curve on either side of the mean particle size.

A simple, easily obtained measure of position, much used in Soil Mechanics, is the percentage of soil fines passing the No. 200 Tylor sieve. Simple, symmetrical measures of scatter are the ratios D_{85}/D_{15} and D_{90}/D_{10}, which occur quite commonly in Soil Mechanics. From a statistical view-point these ratios are to be preferred to Hazen's Uniformity Coefficient $u = D_{60}/D_{10}$ because of their symmetry.

On studying the grading curves for the 15 sands used it was found that:

(i) Sands which do not behave as filters in themselves tend to contain a larger percentage of particles finer than a No. 200 sieve than do sands which behave as filters in themselves.

(ii) The scatter of grading curves for sands which failed tends to exceed, on the average, the scatter of grading curves for sands which did not fail.

These two statements were tested statistically.

(The appropriate calculations and theory are to be found in the section of this thesis dealing with the statistical analysis of grading curves).

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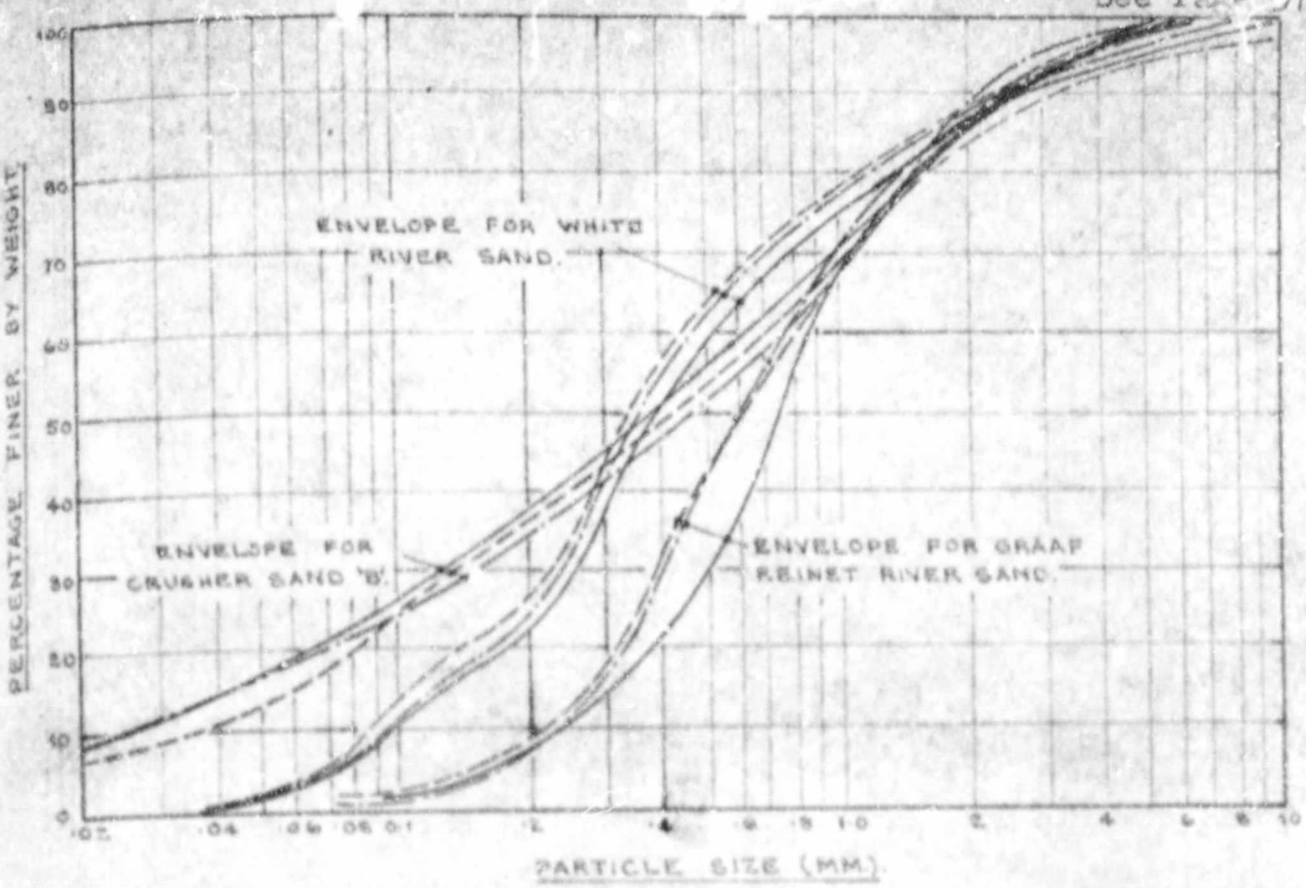
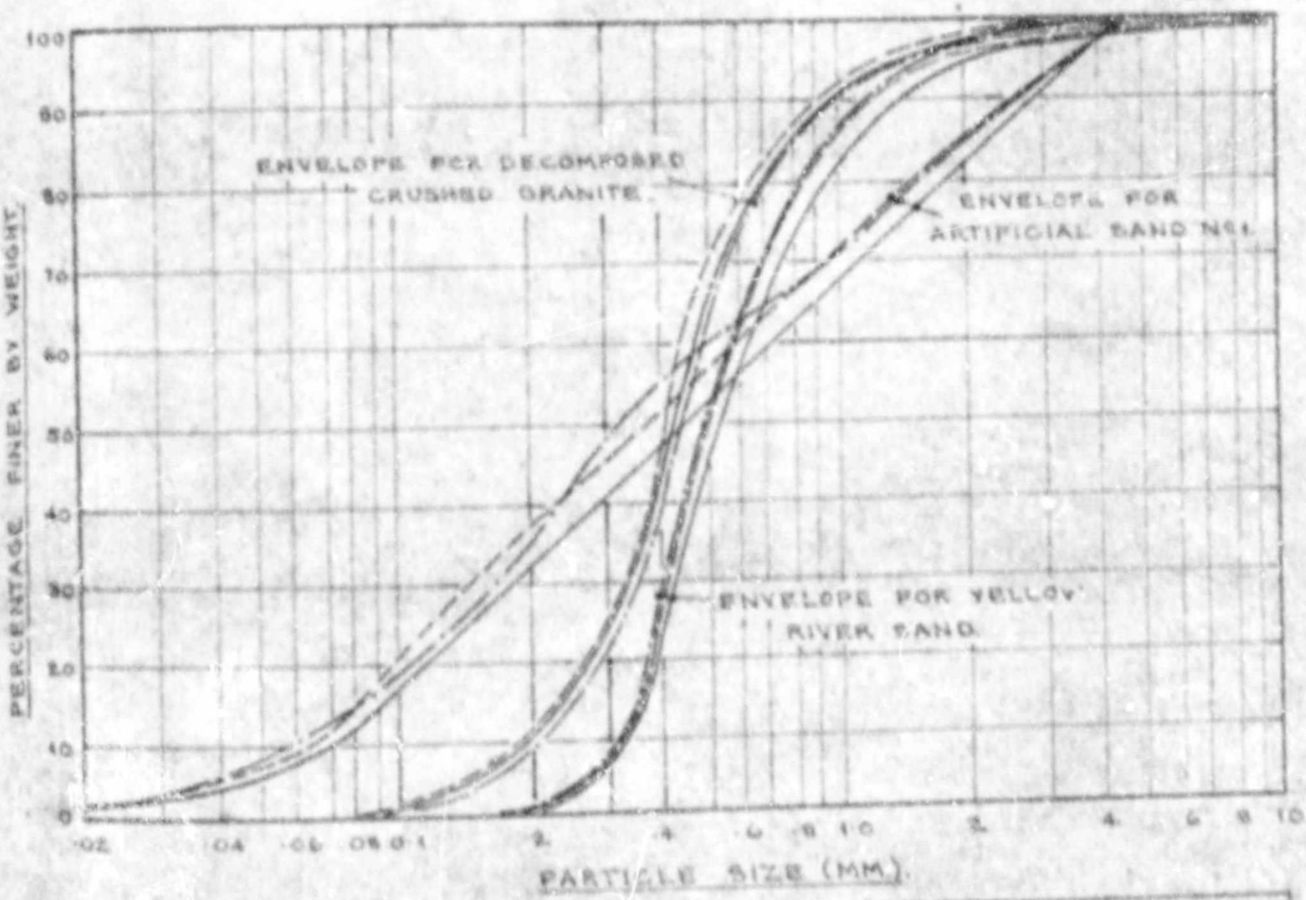


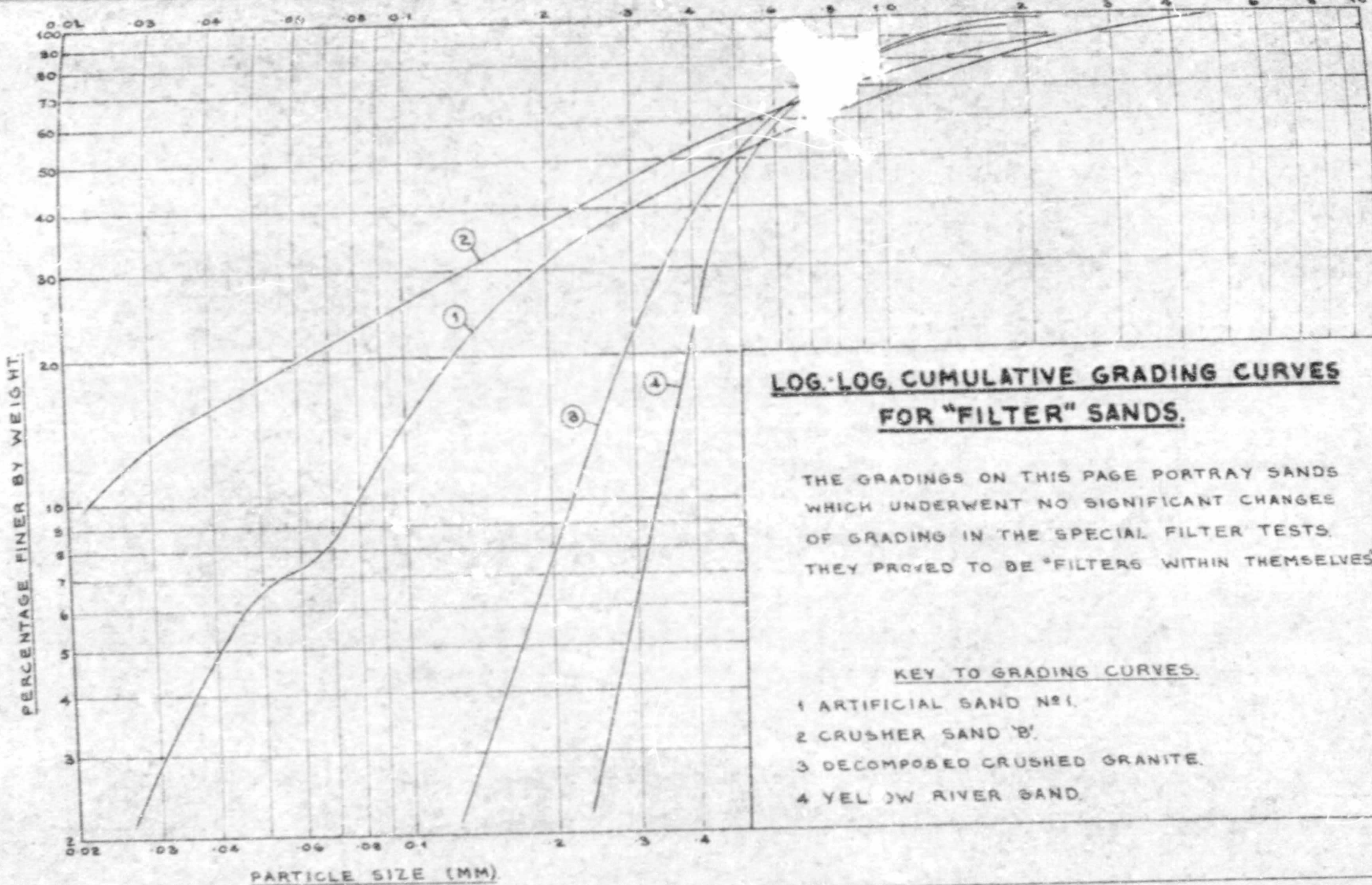


COARSE	FINE	MEDIUM	COARSE	FINE
SILT	SAND			GRAVEL

SANDS WHICH BEHAVED AS FILTERS WITHIN THEMSELVES.

THIS PAGE ILLUSTRATES THE SMALL CHANGES OF GRADING SUFFERED IN THE FILTER TEST BY SANDS WHICH ARE FILTERS [illegible]N THEMSELVES.

SOLID LINES DENOTE ORIGINAL GRADINGS, CHAIN DOTTED & BROKEN LINES GIVE GRADINGS OF UPPER & LOWER PORTIONS OF SAMPLES RESP.



LOG-LOG, CUMULATIVE GRADING CURVES
FOR "FILTER" SANDS.
THE GRADINGS ON THIS PAGE PORTRAY SANDS WHICH UNDERWENT NO SIGNIFICANT CHANGES OF GRADING IN THE SPECIAL FILTER TESTS. THEY PROVED TO BE "FILTERS WITHIN THEMSELVES".
KEY TO GRADING CURVES.
1 ARTIFICIAL SAND Nº1.
2 CRUSHER SAND 'B'.
3 DECOMPOSED CRUSHED GRANITE.
4 YEL OW RIVER SAND.
PERCENTAGE FINER BY WEIGHT.
PARTICLE SIZE (MM).

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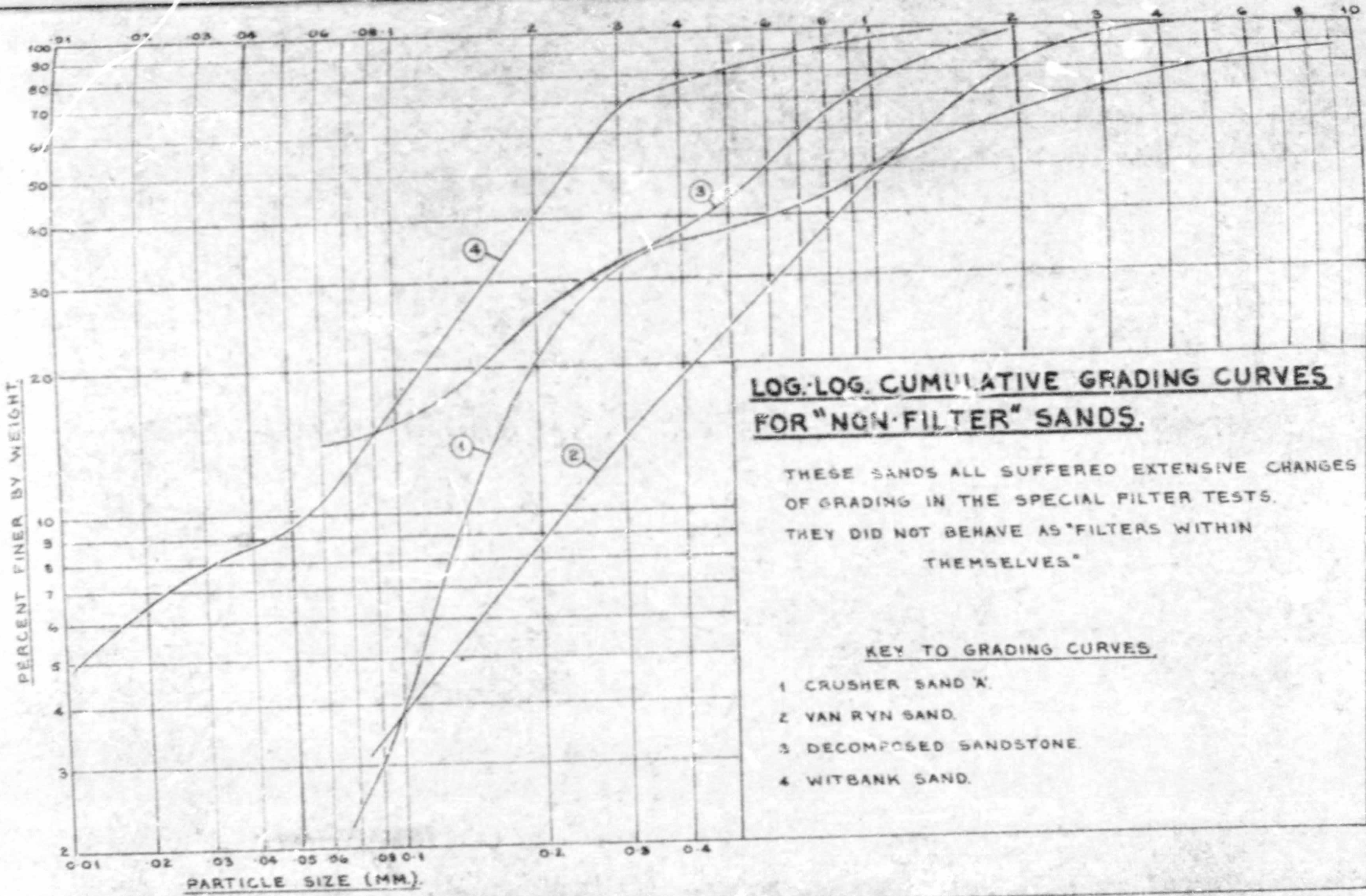
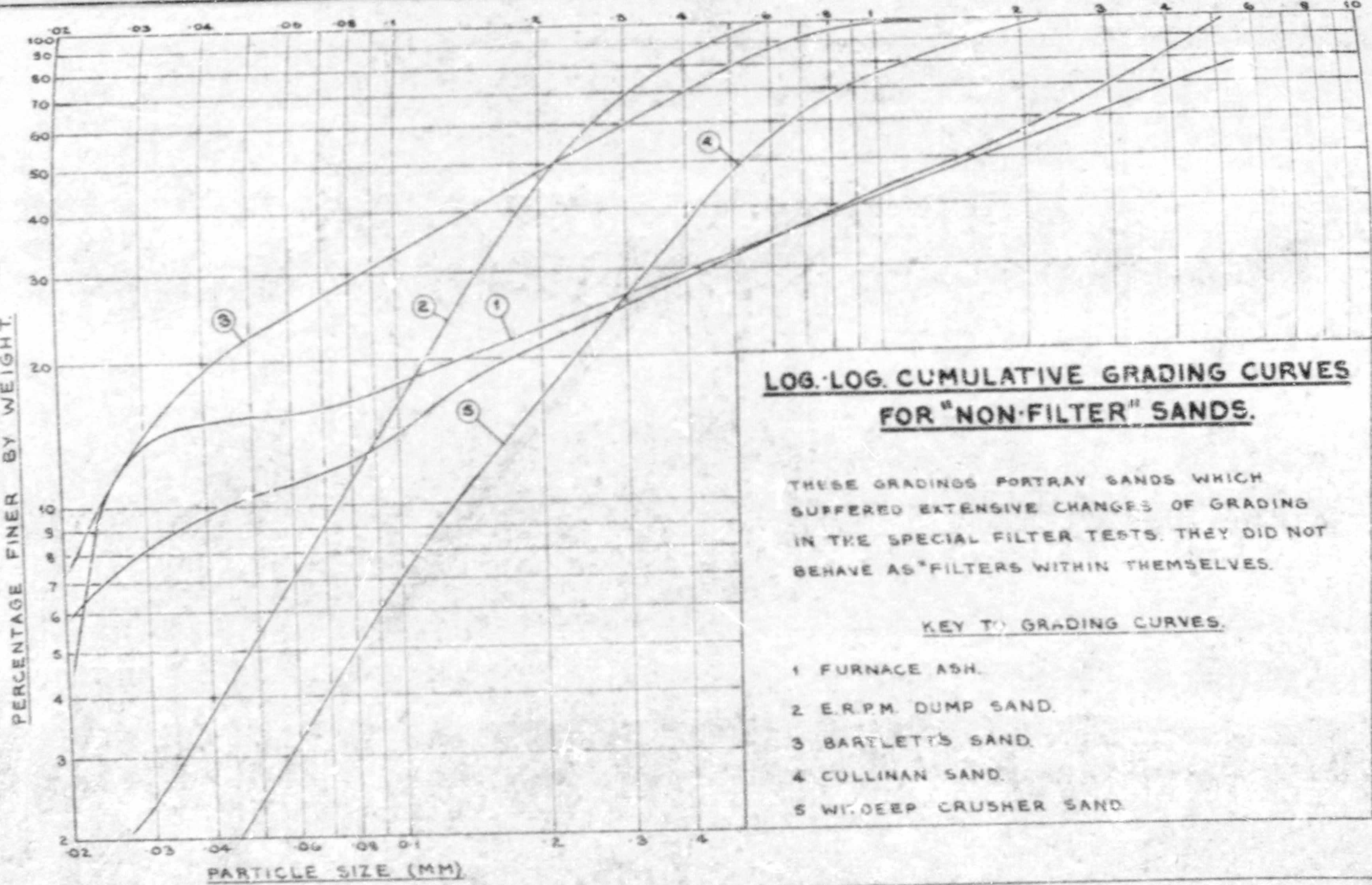

LOG-LOG. CUMULATIVE GRADING CURVES FOR "NON-FILTER" SANDS.
THESE SANDS ALL SUFFERED EXTENSIVE CHANGES OF GRADING IN THE SPECIAL FILTER TESTS. THEY DID NOT BEHAVE AS "FILTERS WITHIN THEMSELVES"
KEY TO GRADING CURVES.
1 CRUSHER SAND 'A'.
2 VAN RYN SAND.
3 DECOMPOSED SANDSTONE.
4 WITBANK SAND.
PERCENT FINER BY WEIGHT
PARTICLE SIZE (MM.)

See Page 37

See Page 37



LOG.-LOG. CUMULATIVE GRADING CURVES FOR "NON-FILTER" SANDS.

THESE GRADINGS PORTRAY SANDS WHICH SUFFERED EXTENSIVE CHANGES OF GRADING IN THE SPECIAL FILTER TESTS. THEY DID NOT BEHAVE AS "FILTERS WITHIN THEMSELVES.

KEY TO GRADING CURVES.

1 FURNACE ASH.
2 E.R.P.M. DUMP SAND.
3 BARTLETTS SAND.
4 CULLINAN SAND.
5 WIT.DEEP CRUSHER SAND.

It was found with a confidence of 74% that normal river, pit and crusher sands which do not behave as filters within themselves contain a larger percentage of particles finer than the No. 200 sieve. That is to say, on the average, 74 out of every 100 sands of this type which fail would contain a larger percentage of particles finer than the No. 200 sieve than would sands which do not fail.

The estimates of the mean percentages of particles finer than the No. 200 sieve calculated with a 60% confidence were:

	Sands which failed	Sands which did not fail
% < No. 200	11.23 ± 2.40	6.10 ± 3.04
No. of observations	9	6

It must be appreciated that these are average figures and in themselves do not mean very much. It cannot be said without qualification, for example, that if the percentage of particles of a sand finer than the No. 200 sieve exceeds 9.14 the sand will not behave as a filter within itself. The Crusher Sand 'B', for example, contained a percentage of 21.7 and yet behaved perfectly under test.

It should be noted that the paragraph above applies only to sands of the type dealt with in this thesis in which particle sizes usually ranged from gravel sizes downward. These conclusions cannot be applied to silts and clays. For silts and clays 75% and more of the sample may be finer than the No. 200 mesh sieve yet the soil may still behave as an (impervious) filter within itself.

It was also found that sands which did not behave as filters in themselves generally possessed larger ratios of D_{85}/D_{15} and D_{90}/D_{10} than did sands which did behave as filters within themselves. The corresponding levels of significance were:

for the ratio D_{85}/D_{15} : 72%.
for the ratio D_{90}/D_{10} : 78%.

As in the previous case the mean values for the ratios were estimated with 60% confidence limits to be:

	Sands which failed	Sands which did not fail
D_{85}/D_{15}	38.0 ± 15.7	16.5 ± 6.8
D_{90}/D_{10}	107.5 ± 49.1	32.1 ±15.6

It must be stressed once more that these are average figures and must be read in conjunction with the individual values of the ratios for the several sands. For example the values of D_{90}/D_{10} for the sands which failed range from 444 to 6.1, while those for the sands which did not fail vary from 113.6 to 4.4.

The various figures quoted above for the statistical mean values of the % <No. 200 sieve, D_{85}/D_{15} and D_{90}/D_{10} although they are subject to very wide variation and are perhaps too idealised and unrealistic could nevertheless be used as a guide in selecting sands for filter purposes.

On the evidence shown it would seem wise to suspect any river, pit or crusher sands for which the % <No. 200 sieve exceeded, say, 5%. It would also be wise to limit the value of D_{85}/D_{15} to 4 to 5 or alternatively the value of D_{90}/D_{10} to 6 to 7.

A glance at the values obtained for the fifteen typical sands used in this investigation will show that these requirements are very stringent and would probably be difficult to comply with in practice. In addition the figures quoted are rather arbitrary.

The best indication of whether a sand will behave as a filter within itself will of course still be the triple particle size analysis filter test described here. It should be pointed out at this stage (this will be amplified later) that some of the sands which behaved as filters within themselves failed by piping when employed as layers in a zoned filter designed to the Terzaghi filter design criteria; while others which did not behave as filters within themselves behaved perfectly when incorporated into a zoned filter.

REPORT ON THE SPECIAL FILTER TESTS INVESTIGATING THE EFFECTS OF EXPERIMENTAL PROCEDURE

In order to enable valid comparisons to be made of the test results for various types of sands, the standard testing procedure previously described was decided on and adhered to while carrying out the main series of fifteen filter tests. The imposition of a standard testing procedure, while simplifying the experimental work and facilitating conclusions, does limit the validity of the results.

In order to extend the scope of the results a series of additional tests were performed in which the standard testing procedure was varied, one 'parameter' at a time. The effects which were investigated were:

(i) The effect of the shape of the sand particles.
(ii) The effect of varying the initial density of the filter test samples.
(iii) The effects of initial layering of the sample due to segregation of fine material.
(iv) The effect of the direction of flow relative to gravity.
(v) The effect of variation in the hydraulic gradient across the sample.
(vi) The effects of neglect of the factors of air segregation and purity of the inflowing water.

(i) The Effect of Particle Shape

Theoretical considerations would lead one to expect that the shape of the sand particles would have a considerable influence on whether a sand behaves as a filter within itself or not. The effect of sub-angularity and to a greater extent angularity (for example in crushed rock and rock splinters) is to decrease density very materially in both the loose and dense conditions. This decrease in density of a sand composed of

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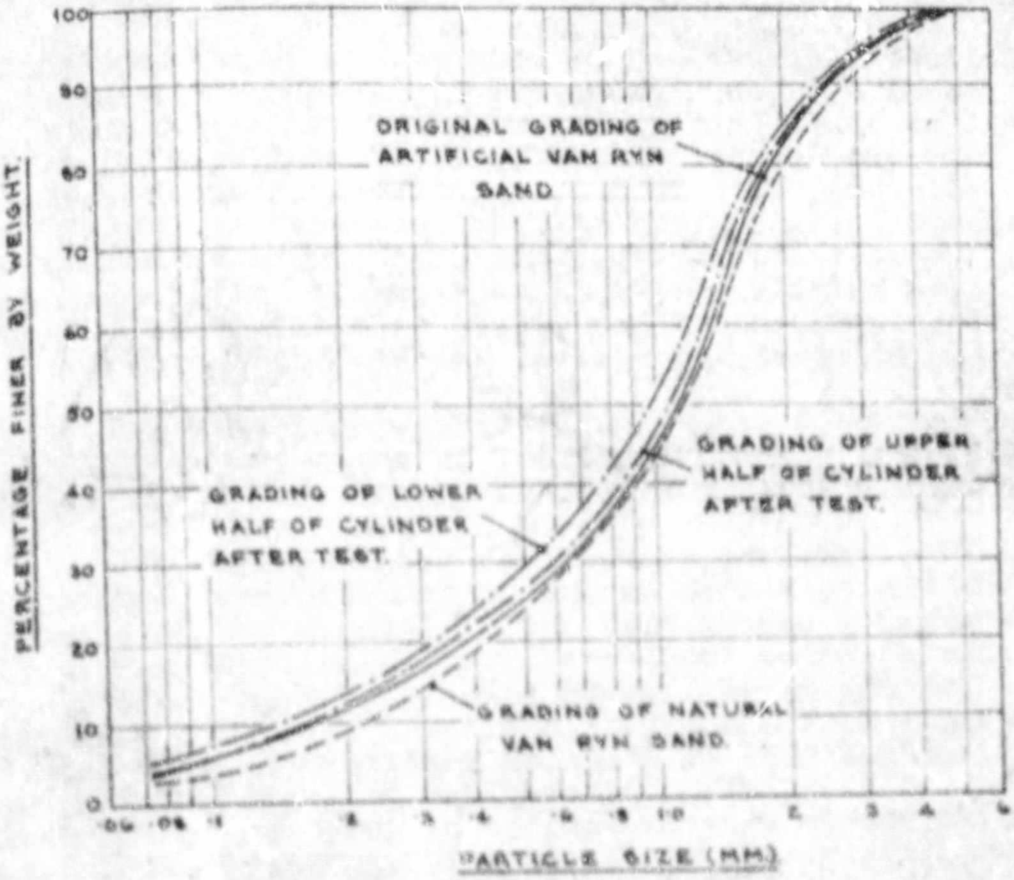
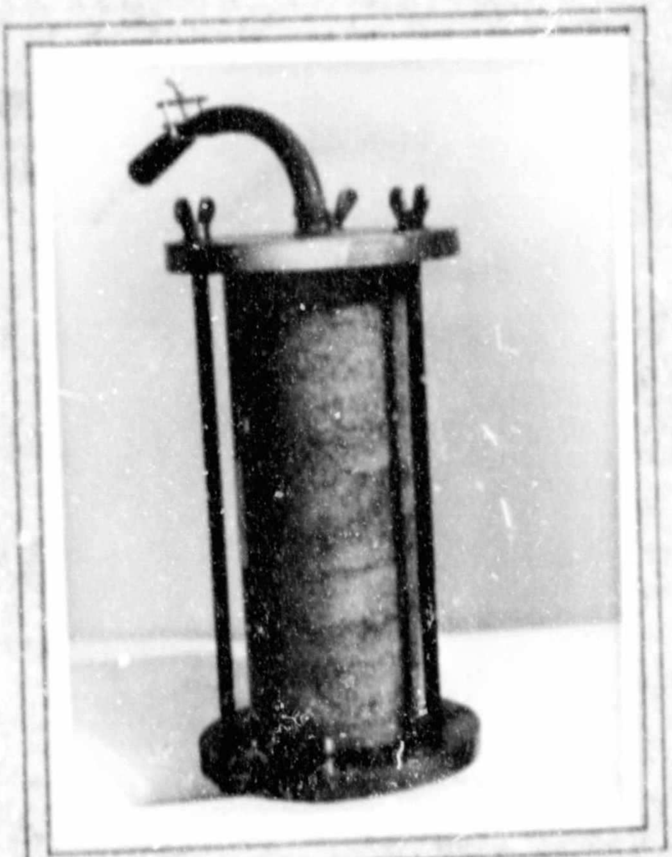


FINE	MEDIUM	COARSE	FINE
SAND			GRAVEL



THE EFFECT OF PARTICLE SHAPE ON CHANGES OF GRADING.

THESE CURVES SHOW THE LIMITED CHANGES OF GRADING SUFFERED BY AN ARTIFICIAL SAND COMPOSED OF ANGULAR FRAGMENTS IN THE FILTER TEST. THE PHOTOGRAPH SHOWS THE APPEARANCE OF THE TEST CYLINDER AT THE END OF THE TEST.

angular particles as compared with a sand of identical grading composed of rounded particles arises due to a looser packing of the sand grains. This looser packing leads to larger voids and channels within the sand which might be expected to facilitate the internal migration of soil particles by providing less restraint both to their initial movement and to their subsequent migration. On the other hand for the same void ratio, a sand with angular particles would be expected to be the more stable due to the greater frictional and interlocking restraint to internal particle migration.

To investigate this it was decided to compare the behaviour of two sands of identical grading, one composed of rounded particles, the other of flaky and angular fragments.

Van Ryn Sand was selected as one sand. It is composed of rounded to subrounded waterworn particles and when tested by means of the special filter test showed a failure of type (a), a well-developed 'hysteresis loop' being formed on the cumulative semi-log. grading chart. An artificial sand was now made up of sand fractions sieved out from a crushed Witwatersrand Quartzite consisting of very angular and flaky particles. After mixing, the artificial sand was resieved and its grading was found to correspond very closely with that of natural van Ryn sand. The two sands were tested using the standard procedure for this type of filter test.

It was found that the sand composed of angular particles showed less grading change than the natural van Ryn sand. The natural sand showed very significant grading changes with a well defined coarsening of the upper region of the sample due to the downward migration of fine material. The changes in the artificial sand were so small as to be hardly significant. The lower portion of the sample seemed to have become rather finer, but the upper portion had undergone no perceptible change.

The initial void ratio for the natural sand sample was 0.764. There was no measureable consolidation of the sample but due to loss of fines of 0.98% of the original soil weight, the final void ratio had increased to 0.776.

On the other hand the sample of artificial sand had an initial void ratio of 0.645 which decreased through consolidation to 0.630 with an accompanying loss of fine material of 0.78%.

These void ratios show that the two standard tests cannot directly be compared as contrary to common experience the density of the sand with rounded particles is less than that with angular particles. This very loose structure of the natural sand probably arose due to uplift of the sand during the initial saturating process as a result of the test cylinder not being completely full.

A better comparison can be obtained between the artificial sand and a sample of natural van Ryn sand which was lightly tamped into the test cylinder. This sample had an initial void ratio of 0.526 which increased due to a loss of fines of 0.47% to 0.535. There was no measureable consolidation. This sample showed grading changes of the same type and of only slightly smaller magnitude than the untamped sampl

As a result of these comparisons it would appear that the effect of frictional restraint due to angularity of the particles on the internal migration of the fine particles of an angular sand outweighs the effect of the increased void space.

As a result of this one test the indications are that for soils of the same grading and of comparable void ratios, a sand consisting of angular fragments tends to be more stable against change of grading than does a sand composed of rounded particles. This internal stability is probably due to a greater internal frictional and interlocking effect between angular, flaky particles than between rounded grains.

(ii) <u>The Effect of a Varying Initial Density</u>

The distribution of particle sizes and particle shape has been found to have a very important influence on the density of granular materials. Density is found to be influenced not only by the degree of fineness of a material and the range of particle sizes but by the distribution of particle sizes. Conversely, therefore, it seems reasonable to expect that the initial density of a filter sand before any flow has taken place through it would influence the stability of that sand against changes of grading due to internal particle migration. A sand placed with a low void ratio, for example, due to the smaller sizes of its internal voids and channels could be expected to have a more stable grading than the same sand in a very loose state.

As it is very difficult to control the void ratio of a sand, beyond placing with a standard compactive effort, in the standard procedure used for filter tests no control of the void ratio was attempted. The sand was simply poured into the test cylinders in the loosest possible state and allowed to consolidate under the pressure of the percolating water.

Additional tests were carried out on two sands to investigate the effects of varying initial density on the grading changes due to flow action. The two sands: van Ryn sand and Crusher Sand 'A' were rather similar in shape of grading curve as the superimposed curves for the two sands show. The van Ryn sand consisted of rounded waterworn particles while the crusher sand consisted of angular and flaky fragments. In each case the results of the standard filter tests conducted on loosely placed samples were compared with those of identical tests conducted on compacted samples.

For the van Ryn sand three samples were tested which were prepared as follows:

Method of Compaction	Initial Void Ratio	Final Void Ratio
No compaction	0.764	0.776
10 Blows, 10 oz Tamper, 1" layers	0.526	0.535
30 Blows, 10 oz Tamper, 1" layers	0.525	0.554

In no case was there any observable consolidation. The increases in overall void ratio during the course of the tests were due to loss of fine material from the samples. The grading envelopes for the various tests have been superimposed and it will be seen that there is little real difference between the envelopes for the various samples. However, the mode of failure is slightly different for the uncompacted sample as compared with the compacted samples.

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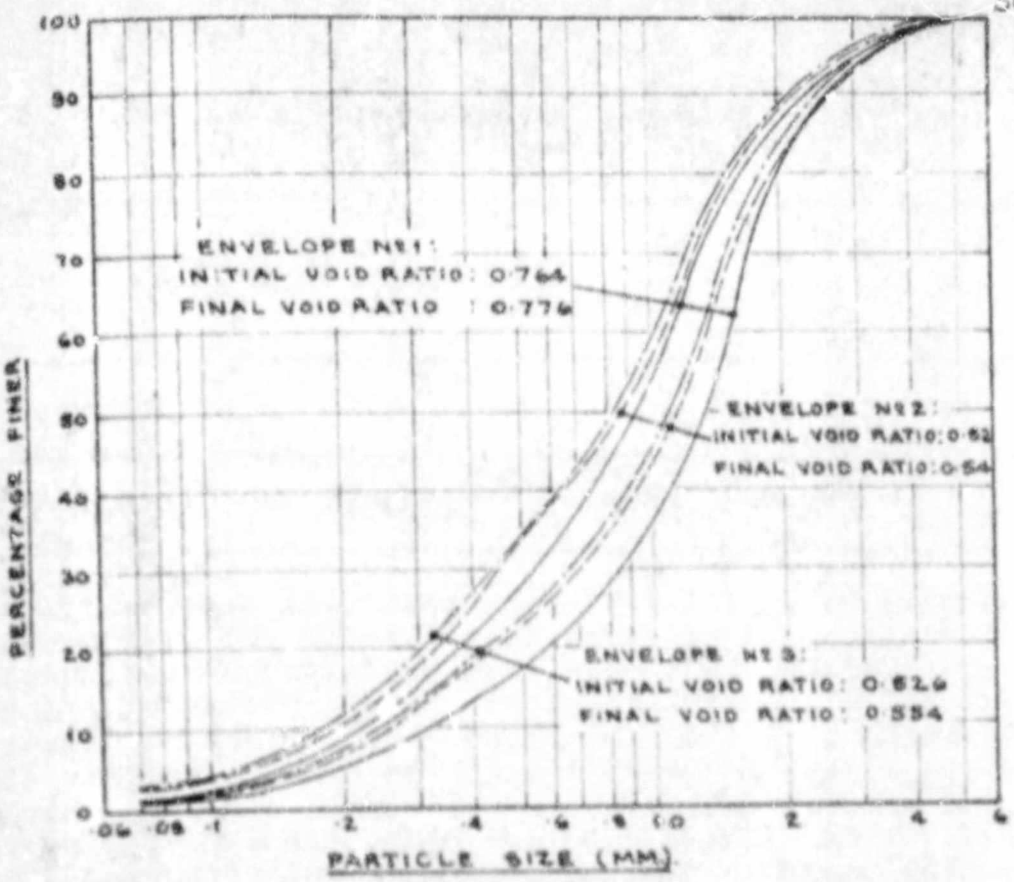
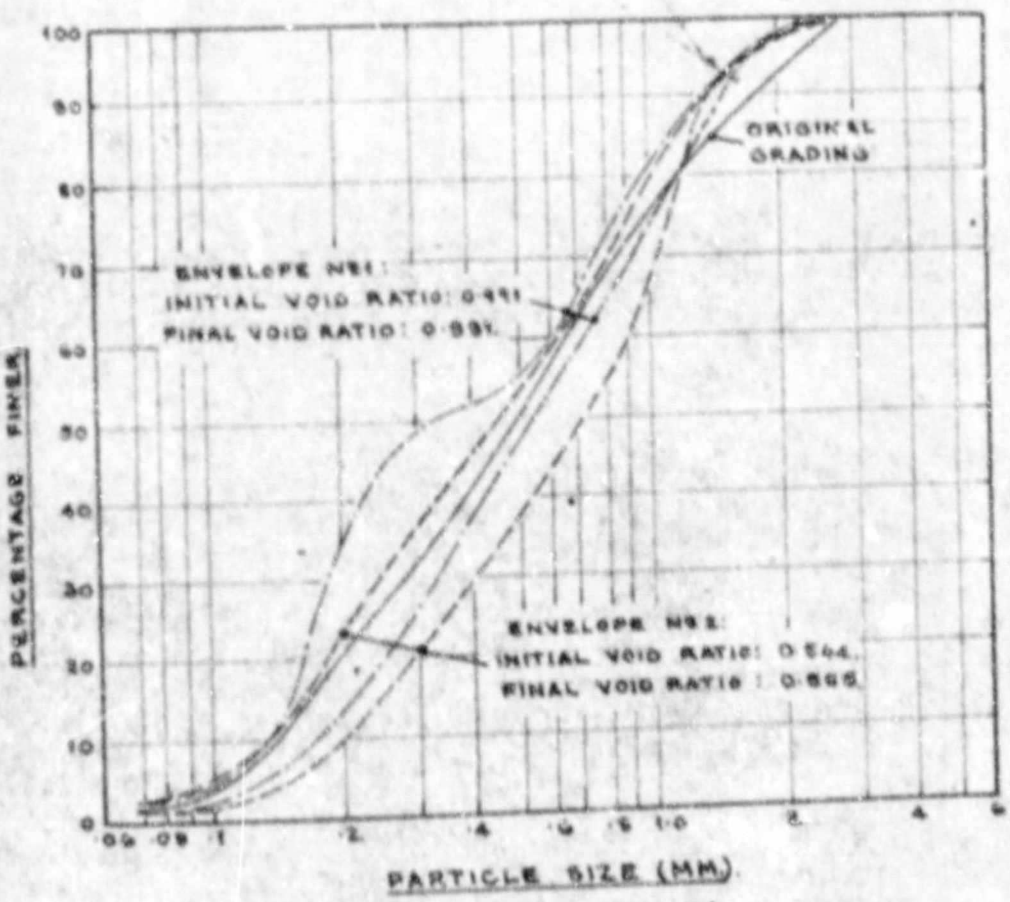


VAN RYN SAND.

CHANGES OF GRADING SUFFERED BY VAN RYN SAND WERE UNAFFECTED BY VARYING INITIAL DENSITY FOR ALL PRACTICAL PURPOSES.



CRUSHER SAND 'A'.

IN THIS CASE INITIAL DENSITY HAD NO CLEAR EFFECT, BUT APPEARED TO HAVE NO EFFECT ON THE MAGNITUDE OF GRADING CHANGES.

THE EFFECT OF VARYING INITIAL DENSITY ON CHANGES OF GRADING.

For the crusher sand only two samples were tested:

Method of Compaction	Initial Void Ratio	Final Void Ratio
No compaction	0.791	0.791
30 Blows, 10 oz. Tamper, 1" layers	0.564	0.555

In neither case was there any overall loss of material from the sample. The overall void ratio remained constant for the uncompacted sample as there was no visible consolidation. For the compacted sample, strangely enough, there was a decrease in overall void ratio due to slight consolidation. Both samples showed very significant changes of grading. The modes of failure were slightly different for the two cases. Although both samples had suffered a pure redistribution of the finer particles, the grading curve of the lower portion of the uncompacted sample also underwent a change of shape.

These two tests show that regardless of the shape of the particles constituting the sands the density at which the filter layer is placed does not appear to have much influence on the internal stability of the sand. In view of the known dependence of density on the shape of the grading curve, however, it may happen that for sands with grading curves of different shapes the behaviour might be entirely different.

Apart from the above considerations filter layers should be placed in as dense a state as possible to achieve a strong filter layer without any local zones of weakness. It was found in tests on large model filters (to be reported on later) that internal grading changes in a layer of sand were often initiated locally by the opening up of channels or 'pipes' through weak zones in the filter layers.

(iii) Initial Layering of the Sand

It was found that no matter how carefully the test cylinders were filled, some sorting of the sand took place. This caused segregation of the fine fraction of the sand at the bottom of each small layer and resulted in the completed sample being divided up by a series of closely spaced layers of fine material. The sand immediately underlying each fine layer was generally composed of the coarser grains and thus each layer of fines was, in effect, filtered by a layer of coarser material.

If this formation of 'filt r skins' proved practically unavoidable under laboratory conditions, it is extremely unlikely that any practical filter would escape the formation of this layering during the process of levelling the sand by raking, etc. The only obvious way of preventing layering would be to place the sand in a moist condition.

It now seems certain that when the percolation of water commences through any layer of artificially placed sand some changes of grading will occur due to a migration of fine material in the direction of flow. This movement will continue until a stable filter structure is established at all points