AN INVESTIGATION TO DETERMINE THE PRACTICAL APPLICATION OF NATURAL BANK GRAVEL AS A PROTECTIVE FILTER FOR AN EARTH EMBANKMENT

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Cambridge, Mass.
August 30, 1940

Professor George W. Swett
Secretary of the Faculty
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Dear Sir:

Submitted herewith is a thesis entitled, "An Investigation To Determine The Practical Application Of Natural Bank Gravel As A Protective Filter For An Earth Embankment," in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering from the Massachusetts Institute of Technology.

Yours respectfully,

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I. INTRODUCTION

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I. INTRODUCTION

General Problem. - In all types of earthwork construction the use of gravel filters for drainage of water-bearing soils is very common practice. Whether in highway or railroad subgrades, earth levees or the more complicated structure, the earth fill dam, gravel filter drains are depended upon to a large extent to dispose of excess and undesirable water and thus to help insure stability of the structure. Engineers for years have depended upon experience to determine the proper gradation of the gravel in the filter to protect any given sand emplacement, sometimes with unsatisfactory results. Definite criteria concerned with a relation between the grain size distribution of the filter and the layer to be protected are at present lacking. Research to establish definite relations in this respect will result in the elimination of the failure of drainage filters and without doubt economies in the construction of protective filters. Several agencies are now concerned with a research of this type, but a limited amount of data has as yet been published. It is hoped that this investigation will contribute towards a clearer understanding of filter protection and will outline a method for testing proposed filter materials.

Object of Thesis. - The authors proposed to determine some controlling relations between the grain size distribution of a protective gravel filter and the base material, or layer to be protected, that would govern the selection of the filter material to give a safe and satisfactory drainage combination.

It was decided to use only materials from borrow pits at the site of an earth fill dam actually under construction. Base material was to be sampled from the pervious shell borrow area and used directly while the protective filter material, taken run-of-the-bank from the gravel borrow area, was to be studied with various grain size distribution. In this manner the authors hoped to arrive at limiting grain size distributions of filter material below which the specific base would be held stable and above which the same base would fail by washing into the filter.

Summary of Conclusions.

1. Natural run-of-the-bank filter material provides a satisfactory protection for the pervious base layer with materials obtained from the site of the specific project selected.

2. For protection of the base material by a filter, the ratio of the 15% size of the filter to the 15% size of the base should not exceed 32 and the ratio of the 15% size of the filter to the 50% size of the base should not exceed 15.

3. Both of the above-mentioned ratios of the grain sizes, between filter and base, at the limit of protective stability, tend to decrease slightly with an increase in the uniformity coefficient of the filter material.

4. Compaction of the base material to any value above 60% has no noticeable effect upon the stability.

5. A thickness of filter layer about 1-1/2 times the thickness of base layer provides a satisfactory test arrangement.

6. Satisfactory test results can be obtained by subjecting the samples to either downward or upward flow.

7. There is no advantage in using de-aired water for protective filter stability tests other than in the determination of permeability.

II. SCOPE OF INVESTIGATION

II. SCOPE OF INVESTIGATION

Considerable search was made for material covering any investigation work carried out on protective gravel filters. The Soil Mechanics Section of the Office of the Chief of Engineers, U. S. Army, The Waterways Experiment Station, Vicksburg, Mississippi, and the Soil Mechanics Department of Massachusetts Institute of Technology were helpful with suggestions. A letter from the Binghamton Engineer District and another from an independent investigator, both on file at Massachusetts Institute of Technology, indicated some work on filters had been carried out, but was inconclusive and not in line with our research. The only published paper was a recent report by G. E. Bertram,(1) which proved of invaluable assistance, especially in regard to laboratory technique. The Soils Laboratory of the Boston District at Concord, New Hampshire, has proceeded with considerable research in this line, and some very helpful suggestions were obtained from the staff of that laboratory.

In approaching the problem in hand, the investigations outlined in Bertram's report were carefully considered. Bertram, in referring the percent of sizes to the usual cumulative grain size diagrams, wherein the percent finer by weight of a soil sample is plotted against grain size on semi-log scale, concluded that: protection could not be maintained if the ratio of the 15% size of the filter material to the 15% size of the base material exceeded approximately 9, and if the ratio of the 15% size of the filter to the 85% size of the base exceeded approximately 6. Bertram also states that K. von Terzaghi, in an

(1) "An Experimental Investigation of Protective Filters," by G. E. Bertram, Publication of the Graduate School of Engineering, Harvard University, January 1940.

unpublished report on Bou-Hanifia Dam, North Africa, established the following criteria for drainage filters: the ratio of the 15% size of the filter to the 15% size of the base should be at least 4, and the ratio of the 15% size of the filter to the 85% size of the base should not be greater than 4. Both the above sets of criteria, as far as the authors were able to determine, were established by using an essentially uniform soil which was by no means a natural gradation of base material. This investigation attempts to broaden these criteria, or rather to establish criteria to cover the non-uniformly graded base material. So broad a scope must be limited to a specific base material as would occur in a specific construction project.

The selection of run-of-the-bank filter and base materials was made by visits to five earth fill dam projects under construction. These included the Franklin Falls Dam, Franklin, New Hampshire, and the Blackwater River Dam, Contoocook, New Hampshire, being built under the direction of the Boston District, U. S. Engineer Department, and Knightville Dam, Knightville, Massachusetts; Birch Hill Dam, South Royalston, Massachusetts; and Surry Mountain Dam, Surry, New Hampshire, being built under the direction of the Providence District, U. S. Engineer Department. About three hundred pounds of representative run-of-the-bank filter material was obtained from borrow pits actually inspected at Knightville, Birch Hill, and Surry Mountain Dams. Photographs Nos. VI, VII, and VIII show these borrow areas. Sufficient representative base material was also obtained from the pervious shell borrow areas at each of these three sites.

All the materials were analysed and typical mechanical analysis curves for the base and filter materials at each site were drawn up as shown on Plates Nos. I, II, and III. It was decided to use the Surry Mountain material exclusively in all the tests since it appeared that a wider variation existed between the base and filter materials from that site, and that the filter material contained a larger proportion of the coarser sizes, both of which facts would lead to a broader series of tests.

The Surry Mountain materials are typical of glacial deposited sands and gravels throughout a large part of New England. The grains are to a large extent irregular in shape but for the most part rounded. Most of the deposits are of granitic origin, there being a small amount of micas and schists. Photograph No. V shows clearly typical grain shapes encountered.

Tests were carried out in what was endeavored to be the most practical manner to follow in any soils laboratory. For each test a separate sample was taken from the material supply and analysed, thus simulating the taking of samples for study in the field and giving a variation in the grain size distribution within a relatively narrow range (Plate B). All the analyses were obtained with standard sieves.

It was decided to run all of the tests in cylinders in the belief that conditions of contact between base and filter and opportunities for failure in a prototype would be simulated quite closely, with the added advantage of facility of operation of test. New clear transparent Lucite cylinders were required for visibility. 2", 4", and 6" tubes were obtained, the 2", however, being discarded immediately as being too small to hold a representative sample of filter in which grain sizes ran larger than 1". The 4" and 6" sizes were believed to be large enough in area to permit free distribution of all grain sizes encountered. All the 4" tubes were cut to 8" in length as no advantage in using longer lengths could be found. There were no cases in any of the tests in which a longer test cylinder would have changed the results.

It was noted in Bertram's report that, in cases of failure by the base entering the voids of the filter, the failure took place within a very short time, less than thirty minutes. Accordingly, it was planned to run all the tests for about two and one-half hours to check this point and to allow sufficient time for any delayed failures. The average time of all routine tests was considerably greater than four hours.

Practically all of the tests were carried out using ordinary tap water supplied from the city mains at about fifty pounds per square inch pressure. Although considerable air collected in the samples during the test, it was believed that the erosive hydraulic action against the grains would not be altered due to that fact. Several tests were run with de-aired water under otherwise exactly similar conditions with no apparent changes in the behavior of the samples. The supply of de-aired water under best conditions would have limited the length of a routine 4" cylinder test to about an hour and twenty minutes.

Endeavors were made to procure all data from each test that would have any bearing whatsoever in analysing the results, whether or not its application was immediately apparent. The permeability of all samples was determined when practicable and in all cases was taken with de-aired water rather than tap water to avoid inconsistencies due to the formation of air bubbles in the sample. Permeability was ordinarily calculated only over the length of base material since the resistance to flow of the filter could be considered negligible with respect to that of the base. Temperature readings of the water used were taken at intervals during the test and the average recorded. Void ratios of base and filter were computed from the dry weights of materials, specific gravities, and volume of container. The compaction was found from the void ratio.

Although in any properly designed earth structure the hydraulic gradient at any point should be less than unity, it was the practice in this investigation to use as high a gradient as was feasible with the equipment used, in order to hasten any incipient failure and locate any weaknesses in the sample. For the most part a gradient of twenty was used, calculated only on the length of base material when the filter was very pervious relative to the base.

Most of the tests were conducted with downward flow through the base and then the filter with the thought that gravity would tend to assist failure. It was desired to afford the sample as much opportunity as possible to fail without exceeding conditions that might arise in nature. Two check tests were carried out with upward flow to determine if the flotation effect thus obtained would have an adverse effect, but it was found that the results checked the downward flow conditions.

In line with the practical aspects of the investigation the determination of failure or stability of tests was made largely by visual observations. It was found in all cases that if failure occurred, it was very definite with a decided erosion of the base into the filter voids. The decision as to stability or failure was checked by running grain size analyses on portions of the base and filter after test and comparing with the analyses before test.

It was decided to approach the investigation as a whole by checking the stability of the base with natural run-of-the-bank filter material followed by tests in which the finer sizes of the filter were successively screened out and wasted until a filter condition was obtained into which the base just failed. A limiting size range between base and filter was thus to be established. To cover the possibility of various coarse grain distributions in the filter borrow, artificial gradings of filter were to be built up and limiting conditions established for each of several constant uniformity coefficients. The "uniformity coefficient" refers to the constant recommended by Hazen in studies of water supply filter sands, that is, the ratio of the 60% size to the 10% size on the usual grain size distribution graph plotted on semi-log paper.

It was hoped that results of this study might lead to some conclusions regarding the economics of using run-of-the-bank filter material as opposed to using processed material, but it is considered that more exhaustive investigation, especially as regards the drainage feature of the run-of-the-bank material, must be undertaken before such comparisons can be intelligently made.

III. PROCEDURE

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III. PROCEDURE

Apparatus. - The equipment designed and constructed for use in these tests consisted of:

1. Brass frames.
2. Rubber tamper.
3. Constant head device.
4. Supply pipes and supporting framework.
5. Permeameter standpipes.
6. Sample evacuator.
7. Tailwater trough.
8. Loading block, screens, and cloths.
9. Various forms for recording data.

1. The brass frames (Photograph No. III) were composed of three principal parts: the rods, the perforated disks, and the annular rings or collars. The rods were made from 1/4" diameter stock, threaded for 2" at each end and fitted with hexagonal and wing nuts. Rods were cut in 10" and 18" lengths to accommodate both the 8" and 16" Lucite testing cylinders. The perforated disks were made from sheet brass, 1/8" thick, by simply cutting out a circular disk 8" in diameter and drilling 1/4" holes. The holes were drilled with centers on concentric circles, staggering the centers radially so as to obtain maximum drainage while reducing the rigidity of the disk as little as possible. The distance from center to center of holes was about 3/4". Three holes were drilled 120 degrees apart near the edge of the disks to accommodate the rods. By inserting and fastening the rods in the perforated disk, a very satisfactory stand for the Lucite tube was obtained. The tube was placed on this stand and held firmly in place by means of the annular ring and the brass rods.

2. The rubber tamper was made from a 2" rubber stopper by drilling a hole through the center and fitting a wooden handle. This device gave ample weight and had the advantage of not scratching the Lucite tube when packing the sample.

3. The constant head device (Plate No. IV and Photograph No. II) was constructed by capping both ends of a 5" brass tube 5" in length with sheet copper, leaving an air vent in the top to insure atmospheric pressure. Four holes were tapped in the bottom of the tank and 1/2" brass nipples inserted. All connections were made watertight by soldering. Any nipple could thus be connected with the supply, leaving the others for use as outlets to the samples. A hole was tapped near the top of the tube and a 1/2" nipple inserted in a similar manner, with a 90-degree elbow placed at each end. The elbow on the inside was turned up to give a level overflow opening and the one on the outside turned down to discharge the overflow into a small copper funnel below it. This funnel was connected to a rubber tube which led to a waste sink. The funnel, which made the overflow visible, was found necessary in order to regulate the main supply quickly. The apparatus was mounted upon a slotted board in such a manner that it could be raised up and down and fastened at any desired position. A meter stick was fastened alongside the slot in such a position that by means of a pointer rigged on the tank the head on the sample could be read directly. The constant head device as a whole was very satisfactory.

4. The supply pipes were made of 3/8" glass tubing as far as possible. These were bent into various angles and designs to fit the set-up. All connections were made using flexible rubber hose which had the advantage of easy control by use of pinchcocks. The supply tubes were supported and held in position by clamps and vertical brass rods (see Photograph No. I). Once in position it was only necessary to change the clamps when a different length of Lucite tube was used. A glass Y was used to connect the supply tube, the permeameter standpipe,

and the tube leading to the sample into a unit. Between the Y and the glass tube in the large rubber stopper, a T connection was placed (Plate No. IV). If the supply tube from the constant head device was fully opened, enough velocity was obtained to force out all air bubbles, the bubbles either going out the T connection or rising up the permeameter standpipe.

5. The permeameter standpipes were simple glass tubes calibrated and marked in 10 cm. lengths for a length of 50 cm. and mounted in a vertical position in such a manner that the supply from the constant head device could be cut off and a rubber hose leading from the de-aired water supply connected to the Y. The de-aired water could be run directly into the standpipe, then cut off while making the permeability test upon the sample. The areas of the permeameter standpipes varied from 4.60 sq. cm. to 4.85 sq. cm. All calibrations were made by the water volume method.

6. The sample evacuator was an entirely original device made up to fit this particular problem. It consisted essentially of sealing the upper portion of the loaded test cylinder by closing a pinchcock directly above the T and connecting the horizontal leg of the T (Plate No. IV) to a vacuum pump; and of sealing the lower end of the cylinder by means of a rubber gasket between the Lucite tube and brass plate, and a rubber suction cup on the lower side of the perforated brass plate. Suction cup and gasket were treated with glycerin to help prevent leakage. When vacuum was applied through the cylinder, the suction cup pulled snugly against the plate and the apparatus became air tight. A flask was inserted in the vacuum line to prevent any particles from entering the vacuum pump. The suction cup was made

of a rubber stopper inserted through the center of a piece of rubber gasket material 6-1/2" in diameter. A small glass tube pierced the stopper in the cup and led into a length of rubber tubing. During evacuation of air from the sample, this tubing was clamped with a pinchcock, and during saturation of the sample de-aired water was admitted very slowly through this tube; the water being drawn in by maintaining a vacuum in the cylinder with the vacuum pump.

7. The tailwater trough was a 12" by 30" rectangular tank 6" deep, constructed of heavy galvanized iron with wooden framework to furnish rigidity. This trough was placed directly in a sink so the water would drain off when it overflowed. By calibrating the position of the scale on the constant head device with the overflow level of the trough, the head on the samples could be readily obtained.

8. To facilitate packing of the sample in an inverted position, a cylindrical spacing block, about 1-1/4" long, was turned out to fit inside the 4" Lucite tube. This block was inserted into the lower end of a test cylinder. A closely fitted brass disk, 1/16" thick, perforated with 1/8" holes, was laid directly above, and then in turn, a 50-mesh screen and a piece of cloth. The base material was packed directly on this arrangement which provided a firm tamping base, the screens and cloth preventing any fines from escaping during packing. When the tube was restored to its upright position after being completely loaded, the spacer block was removed. The space then existing above the small perforated brass disk was almost completely filled by the large rubber stopper. The thin space between stopper and screens was filled with uniform gravel to disperse the incoming water and create a firm solid unit when the brass rods were tightened. A #20 or

#10 mesh screen cut to fit inside the tube was placed just between the filter and lower perforated brass plate to prevent any grains from lodging in the 1/4" perforations.

9. After the first tests, forms were designed and mimeographed to be used for recording data. It was found that these expedited the recording and insured that all necessary observations were made.

Besides the apparatus designed and constructed for these tests, the following standard equipment of the laboratory was used:

1. Lucite tubes.
2. Sample splitter.
3. Sieving machine.
4. Jet pump.
5. Drying ovens.
6. Scales.
7. Compaction test apparatus.
8. System for de-airing water.
9. Various flasks, evaporating dishes, and containers.

1. The Lucite tubes were of the common variety, 2", 4", and 6" nominal diameters. These were cut into lengths of 8" and 16" to be used as desired. The tubes, being transparent, furnished an excellent means of observing the actions of the materials during the test. It was found that the tubes possessed sufficient strength and did not easily break.

2. The sample splitter was a commercial device built in the form of a trough with alternate chutes opening on opposite sides and discharging into separate containers. When a sample was poured into this trough, an equal division of material was made, one-half entering each container. This splitter would not pass material larger than 1" in diameter. An equal distribution of material this size or larger was made by hand after the finer sizes had passed through.

3. The sieving machine was an electrically operated commercial apparatus known as the "Rotap." It was designed to operate using six sieves and a pan. The machine was equipped with an automatic starting and timing device. Sieves ranging from 3" mesh to 250 mesh per inch were available. These included special sieves designated #B, #C, #D, and #E with openings of 26.67 mm., 18.85 mm., 13.35 mm., and 9.423 mm., respectively.

4. The jet pump was similar to those used in many laboratories, consisting of a water faucet with a tube tapped near the outlet. A vacuum of about 700 mm. could be obtained with this device. In addition, a mechanical vacuum pump and trap was available. The water jet pump was found satisfactory for the purpose of these experiments.

5. The drying ovens were electrically heated and automatically controlled. Ample oven space was available for complete drying of all samples at all times.

6. The weighing scales used were of the balance type and were graduated to read to the nearest gram. Fractions of a gram could be read by estimating the position of the pointer.

7. The compaction apparatus consisted of the standard Proctor test equipment.

8. The system for de-airing water was similar to the procedure developed by Professor Gordon M. Fair of the Department of Sanitary Engineering, Harvard Graduate School of Engineering, described by Bertram. Heated water was sprayed into a tube through a nozzle. By keeping a vacuum in this tube the air was removed from the water spray during a fall of about 4 feet. From this tube the de-aired water entered carboys where it was stored for use (Plate No. V). The capacity

of the system was from 4 to 5 gallons per hour. A storage capacity of 60 gallons was available. Atmospheric pressure was maintained in the carboys by use of balloons as described in Bertram's report. Routine tests conducted by the laboratory staff showed the dissolved oxygen content to be about 3 to 5 parts per million. Similar tests on tap water showed a dissolved oxygen content of 15 to 16 parts per million at the same temperature.

Method of Testing. - The materials to be used in the tests were shipped from the field in canvas bags of about 30 lb. normal capacity. In the laboratory enough was selected to satisfy the requirements of all tests and thoroughly mixed, using the sample splitter, until homogeneous materials for both base and filter were obtained. These were placed in canvas bags, labeled, and stored for future use. From representative samples of each material, specific gravity and compaction tests were run. Results checked previous tests by the laboratory staff upon similar samples from the same locations.

The compaction test was performed using a brass cylinder of known weight and volume. First, the dry material was placed into the cylinder as loosely as possible, striking off the top level, and weighing. Knowing the weight, volume, and specific gravity, the void ratio and density was computed. This test was repeated three times, the results checking very closely. The test was again carried out, placing the dry material in the metal container in about 2 cm. layers, packing as tightly as possible with a metal tamper, and compacting to maximum density with a metal block and rawhide hammer. Terming the loose state 0% compaction, and the dense state 100% compaction, curves were drawn for the base and filter materials, plotting void ratio and pounds per cubic foot as ordinates and percent compaction as abscissae, a straight line being drawn from the 0% compaction point to the 100% compaction point. From these curves, knowing the void ratio of a material, the percent compaction could be read.

At the beginning of a test lengths of base and filter were chosen, and the approximate amount of materials necessary were weighed out. The entire amount of materials were analysed, using the "Rotap" sieving machine, and a grain size distribution curve plotted upon semi-log paper. After sieving, the material was thoroughly mixed to reproduce its original state.

The packing of the sample in the Lucite tube was accomplished as follows: the frame was assembled placing the brass rods through one of the perforated disks and tightening. About 1-1/2" of the threaded length was passed through the disk to allow plenty of room for the rubber stopper and collar which would be assembled later. This formed a stand supported by the three ends of the rods. Next, the Lucite tube was placed on the stand, the wooden spacer block inserted. The perforated brass screen, the 50-mesh screen and cloth were placed directly upon the block in the order named. The collar was lowered against the tube. The top set of wing nuts were made up bringing enough pressure on the tube to prevent slipping during packing. The base material was placed gently on the cloth a spoonful at a time until a layer of about one centimeter was in the tube. The material was then packed as tightly as possible with the rubber tamper. The entire base was packed in this manner taking care to put representative material in each layer. After finishing a layer, the surface was roughened before placing the next to avoid segregation between layers. When all of the base material was packed, the surface was leveled with the tamper. The length of the sample was determined to the nearest millimeter by averaging several measurements with a steel scale. A red pencil line was drawn around the tube at the level of the finished surface. The filter material was placed directly upon the base material with care to insure the proper distribution of the larger sized particles. If this precaution is not closely observed, the grain size distribution of the filter is meaningless. The filter was packed to the top of the tube arranging the surface to be as near the level of the edges of the tube as possible. The length of filter was measured and recorded.

The collar was removed and a 10-mesh screen was placed directly against the filter. Any sand or grit on the end of the tube was wiped off and a coat of glycerin applied. A soft rubber gasket treated with glycerin was placed over the end of the tube in such a manner that it surrounded the wire screen and covered the edges of the tube. The perforated brass plate was placed against the rubber gasket taking care not to disturb its position. The wing nuts were tightened, bringing pressure through the plate to the gasket and screen. The entire apparatus was then inverted gently. Any subsidence of the base taking place during this step was noted. The top plate was removed and the spacer block lifted out. A thin layer of uniform gravel, passing a #4 screen and retained on a #6 screen was placed upon the perforated brass screen to distribute the water. The large rubber stopper was inserted tightly into the top of the tube. The brass collar was placed in position on the stopper and drawn tight with the rods and wing nuts. The sample in this state was ready for evacuation.

The large soft rubber washer of the suction cup was rested upon a 5" brass ring and thoroughly coated with glycerin. The testing cylinder apparatus was gently lowered upon the suction cup so that all of the perforations in the bottom disk were covered by the cup. The washer was pressed against the disk by hand, the glycerin giving enough cohesion to make it stick tightly. The T connection was clamped tightly at the top end and the horizontal end connected to the vacuum line. The tube leading to the bottom of the sample through the suction cup was clamped at its end and placed in a beaker of de-aired water. Full vacuum was gradually applied to the sample. The sample was allowed to evacuate dry for a period of 5 to 10 minutes. No action of the grains of the material could be noticed during this period, but the force of the vacuum was indicated by the collapsing of the soft rubber hose connection at the upper end of the T. The gasket at the bottom of the sample was observed to detect any minor leaks. If any were found, they could usually be stopped with a few drops of glycerin. When it was believed the air had been removed from the sample, the pinchcock at the end of the evacuator tube was opened slightly, allowing de-aired water to enter the sample. The water was admitted very slowly for a period of about 20 to 30 minutes. When the sample was completely saturated, the vacuum was gradually closed, at the same time increasing the pinchcock opening on the de-aired water supply. When the tube leading to the vacuum was completely closed, the water rose through the T connection, giving a state of thorough saturation at atmospheric pressure. This was a critical stage because immediately after the vacuum was completely closed the particles of the base material that were unsupported were free to drop into the filter. The amount of material settling depended upon the filter material and the size of the voids therein.

By closing all pinchcocks the entire apparatus could be handled without fear of admitting air or losing the water from the sample. The sample was placed into the overflow tank where the suction cup was removed, taking care to save any grains that may have passed the screen and the perforated disk. The apparatus was placed upon a 5" ring in an evaporating dish and supported by wooden blocks on the bottom of the trough at such a height that the bottom of the sample was barely covered with water. The apparatus was clamped to one of the vertical brass supporting rods in order to obtain rigidity. The permeability of the sample was obtained before the test began. A supply tube of the de-aired water system was connected to the Y. The pinchcock between the Y and the sample being closed, the de-aired water was fed directly into the permeameter standpipe. Any air in the Y or T connections was removed by opening the horizontal leg of the T and letting the water run through until all bubbles were removed. By closing off the de-aired water supply and opening the line leading to the sample, the set-up became similar to that used in all falling head permeability tests. The time necessary for the head to fall a distance of 50 cm. was taken with a stop watch. At least three runs were made on each sample. The head in the standpipe was measured to the closest millimeter. All data were recorded on a form prepared for this purpose.

Permeability having been determined, the line leading to the sample was closed and the de-aired water supply tube removed, replacing it with one of the supply tubes from the constant head device. The valve controlling the supply to the constant head device was opened, allowing considerable flow to waste. This was done to prevent exhaustion of the supply tank of the constant head device when water was allowed to enter the sample. Any air in the supply tubes was exhausted as before. The pinchcock on the line leading to the sample was opened gradually until full flow was obtained. At this point the sample was closely observed, because the stability or instability of a sample was nearly always indicated during the first few minutes of testing. The remaining data including temperatures and head were taken.

The tests were run for a period of time necessary to establish a condition of failure or stability. The index of either condition was determined visually. If sand grains could be seen trickling down among the particles of the filter and continued to do so until a considerable part of the base had moved, then a condition of failure was pronounced. If there was very little movement at the beginning of the test, and no movement during about two hours of run, a stable condition was considered to exist.

When a test had run long enough for the condition to be determined, the water was shut off and the sample removed by entering at the top and observing the appearance of the base material. A length of about 4 cm. of the base was scooped out to be analysed and compared to its original grain size distribution. About 8 cm. of the filter was removed from the bottom of the tube. These materials were placed in the ovens and analysed when completely dry.

Calculations consisting of gradient, permeability, void ratios, percent compaction, uniformity coefficients, grain sizes, and grain size ratios were made. All grain sizes were read directly from the curves. Data being taken, computations recorded, and comments made, the test records were filed.

All tests were performed in the manner outlined above with a few variations in size of sample, direction of flow, and the use of de-aired water instead of tap water. These variations entered only in the tests which were re-run to check tests performed in the normal manner. The tests varying in size of sample were Nos. 1, 6-B, 7-B, and 18. In tests Nos. 2, 6-B, and 7-B, upward flow was used. Tests Nos. 1, 6-A, 15-A, and 19 were run wholly or in part using de-aired water. The changes in the technique were made in an effort to determine the effect of varying these items upon the stability. In all cases, once the limiting size range of base and filter had been established by the normal procedure, the results obtained by the check tests were practically identical with the original.

IV. ANALYSIS OF TESTS

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IV. ANALYSIS OF TESTS

The following discussions outline in chronological order all the tests carried out in this investigation. The peculiarities of each test and the reasons therefor, together with the decisions prompting subsequent tests, are related.

Test No. 1: The first step in this particular research, the authors believed, was to determine the stability of the run-of-the-bank filter material itself with water flowing through it. It was desired to determine if under any conditions the fines would wash out or if the grain size distribution would change in any manner. Accordingly, the sample was set up as noted in the Appendix, the filter material while subjected to downward flow resting directly on a layer of uniform gravel, passing #D and retained on #E screen. A very small amount of fines settled out into the gravel layer. All of these appeared to come from the lower 3 cm. of the filter, the resulting natural gradation retaining all the fines above this zone.

Test No. 2: It was considered that in the previous test the uniform gravel layer might have acted as an efficient filter and prevented the settlement of an appreciable amount of fines, so it was decided to run a slightly different test to determine the inherent stability of the run-of-the-bank filter. In this case the flow was reversed, emerging through the unrestrained top of the filter layer. The sample was subjected to an excessive gradient, resulting in failure by uplift. The test proved useless.

Test No. 3: Since test No. 2 was so unsatisfactory, a third was arranged to check the stability of the natural filter. This time the filter sample was packed in the bottom of the tube and supported by a #10 screen and the perforated brass plate. The upper part of the tube was merely filled with uniform gravel to make the apparatus rigid and disperse the downward flow of the water. Only 14 grams of fines, or slightly over 1% of the filter sample, washed through, all of this material coming from the lower 0.5 cm. of sample. Analysis of the upper two-thirds of filter sample indicated very slight change in the proportion of fines. The variance in curves (see Appendix) must have been due to failure of a portion of the sample to be representative of the whole. In the first three tests the gradient and permeability determinations were calculated only from the length of filter material.

Test No. 4: From the very slight losses of fines in tests Nos. 1 and 3, it was concluded that the run-of-the-bank filter material was stable within itself. Since fines of the filter would not wash out, it seemed impossible that fines of a base material protected by the natural filter could wash through. However, a test was set up with the base material above and natural filter below and subjected to downward flow. In this case the gradient and permeability of the sample was calculated over the entire length since each material appeared to be nearly as pervious as the other. This combination gave not the slightest indication of washing or failing.

Test No. 5: It was planned at the beginning of the investigation to test the base with natural filter material from which fines below successively larger screen openings had been removed. To carry out that plan, a series of tests called Group I was to be made. This test was accordingly set up, in which all fines of the filter passing the #4 screen were discarded. The base evidently was not packed well as only 58% compaction was obtained. When the sample was inverted after packing, a considerable amount of fines from the base fell into several rather large voids in the filter adjacent to the base. It is felt that these large voids were caused by non-representative distribution of sizes in packing the filter due to inexperience. This settlement of base material loosened and disturbed the entire length of base above. At the end of the run there was such a decided settlement of base that the combination was called a failure. However, since analysis of the upper portion of base after test indicated such a slight change from the original, and that change in a finer rather than a coarser direction, it was felt failure resulted principally from the excessive disturbance when the sample was inverted.

Test No. 5-A: It was decided to repeat the previous test, this time taking special care to tamp the base properly and obtain representative distribution of grain sizes throughout the filter layer. All other conditions were as nearly identical with test No. 5 as practicable. The sample was saturated very slowly and carefully. This time no disturbance or movement within the base was noted and the set-up proved to be very stable, indicating that failure of the previous test was no doubt due to faulty preparation. The test was run for only a short time as stability seemed assured when no settlement of fines occurred in the first half hour.

Test No. 6: This was next in the sequence of sieving fines out of the natural filter material. In this case all fines passing #3 screen were discarded. This combination proved to be stable which further checked the conclusions drawn in regard to No. 5-A. A very limited amount of settlement occurred and this above a filter void that was larger than normal. The length of test, 6-1/2 hours, was considered to have allowed more than sufficient time for any failure to occur.

Test No. 7: In this case the filter used was obtained by wasting all the fines passing a #E screen. The base was packed dry in the usual manner and the filter material placed in the tube with care. When the tube was inverted, complete failure by settlement of the dry base into the filter voids occurred. Failure was so drastic that it was considered useless to run any water through the sample. It was immediately decided to repeat the test, so the material was reclaimed by screening out and recombining the correct particle proportions of filter and base.

Test No. 7-A: This test utilized the materials reclaimed from the previous test. The base was packed in this instance in about 1 cm. layers of dry material, each layer then slightly moistened to obtain some apparent cohesion. The base material remained intact when the tube was inverted but immediately sloughed down into the filter when the saturating water reached it from below. The settlement and disturbance of the base was so pronounced that no permeability test was taken. The complete failure of the last two tests indicated that the end point in the process of screening fines from the natural filter had been reached.

Test No. 6-A: Since in the process of screening fines from the filter, test No. 6 was the last in the sequence to be stable, it was thought best to run a check test. De-aired water was used in this case to determine any differences in behavior of the sample from that previously noted with tap water. The combination was stable. The only peculiarity noted by using de-aired water was that no air collected in the sample. The short time of run was necessitated by the limited supply of de-aired water.

Test No. 8: The next series of tests planned, Group II, was to determine the limits of stability with filter material made up of uniform gravel screened out from the same natural filter material used in the first group of tests. To start with, gravel passing the #C screen and retained on the #D screen was arbitrarily chosen. The routine procedure was followed with the result that the combination appeared stable even though there was slight settlement of the base during the early part of the test. Since stability seemed assured, the test was unwisely run for a relatively short time. The percentage of fines in the filter after test (see Appendix) led to some doubt as to certainty of the decision of stability.

Test No. 9: The uniform gravel used in the previous test apparently giving a stable set-up, the next larger size of uniform gravel, passing #B and retained on #C screen, was tried. This resulted in complete failure during saturation of the sample. Results of tests Nos. 8 and 9 led to the belief that the limiting size ranges for stability with uniform gravels had been reached.

Test No. 10: The next group of tests decided upon was to use two sizes of uniform gravel, equal weights of each size being taken, which would give a filter uniformity coefficient slightly higher than that of the previous group. The same uniformity coefficient for filter was to be used throughout this group, building up filters from uniform gravel to relatively coarser or finer gradations as desired. The filter for the first test in this group, called Group III, was made up of equal parts of uniform gravel such that all passed the #B screen, 50% was retained on #C, and 100% retained on #D. The base, packed dry and then slightly moistened to give some apparent cohesion, held up when inverted and sloughed only slightly during saturation. However, considerable settlement occurred early during the test run, and the combination was considered a complete failure.

Test No. 11: The composition for the filter in this case was built to correspond to a curve having the same uniformity coefficient as the previous one but with a finer gradation. It consisted of grains passing the #B screen, 25% being retained on the #C, 75% on the #D, and 100% on the #E screen. Failure occurred in this case during the first five minutes of test, with increasing settlement of base during the next four hours.

Test No. 12: In order to make full use of equipment available, the investigators decided to set up tests in a fourth group before research for Group III was completed. Group IV called for a filter gradation of uniform gravel over three screen sizes, which would give a uniformity coefficient somewhat larger than in Group III and considerably larger than in Group II. The first test in this group had a filter composed of uniform gravel sizes, all of which passed the #B screen, 33.3% of which was retained on #C, 66.7% retained on #D, and 100% retained on #E. This composition of filter very closely resembled that of tests Nos. 7 and 7-A which resulted in complete failure, so it was expected test No. 12 would also fail. Contrary to expectations, the test held to such an extent as to be considered stable, although a slight amount of base worked into the filter voids. A check test on this combination was indicated.

Test No. 13: A third test was required under Group III to establish a stable condition. Accordingly, a filter was prepared in which all gravel passed the #C screen, 50% was retained on #D, and 100% was retained on #E. The net result was a complete failure but was peculiar in that definite indications of settlement of the base did not appear for about an hour and a half. Observations during the early part of test showed only slight movements of base particles.

Test No. 8-A: The failure of the previous test, No. 13, in which the filter gradation was finer throughout than in test No. 8 led to doubt as to the conclusions regarding stability of No. 8, which was run only a short time. A check test, No. 8-A, was accordingly set up. This time the result was, as expected, a complete failure. Because of this situation, further tests were required under Group II to establish a stable condition.

Test No. 14: In Group IV, since test No. 12 was considered stable, a slightly coarser gradation of filter was built up with approximately the same uniformity coefficient as test No. 12. The combination failed.

Test No. 15: Proceeding in an endeavor to find a stable combination under Group III, this test was run with a filter gradation somewhat finer than test No. 13. Only very slight readjustments of particles could be noted in the base during saturation. Stability was soon reached and maintained throughout the test. The result of this test defined the limiting filter conditions for stability under Group III.

Test No. 12-A: This set-up was prepared to check the questionable results of test No. 12. The samples as prepared showed remarkable similarity. In this test the base was packed dry rather than moist as in No. 12, because no advantage seemed to be obtained by the moistening process. Test No. 12-A showed definite indications of failure when inverted and during saturation. The run resulted in complete failure, which carried out the original expectations for this gradation of filter.

Test No. 16: This test under Group II established the stable condition desired. It was prompted by the failure of test No. 8-A. The filter in this case was a uniform gravel passing a #D screen and retained on #E. It was packed and carried out in the routine manner and run for a longer than average period. The set-up was very stable, and analysis after test showed practically no change in gradation whatever.

Test No. 17: The final filter arrangement under Group III turned out to be a gradation of gravel, passing the #B screen and retained on the #3 screen, so that an effective size of 9.0 mm. and a uniformity coefficient of 1.67 was obtained. This combination was very stable, and it was therefore concluded that the limits of stability for the Group III uniformity coefficient had been outlined.

Tests Nos. 15-A, 16-A, and 17-A: It was considered undesirable to base ultimate conclusions on only a single stable test in each of Groups II, III, and IV. Accordingly, check tests were run on tests Nos. 15, 16, and 17, duplicating as closely as possible representative packing of materials and the conditions obtained in the original tests.

All three checked the previous results. In test No. 15-A, de-aired water was used for the first forty-five minutes with no change in behavior from the original test.

Test No. 18: The gravel bedding material in use at the Surry Mountain Dam was selected, washed and screened gravel from the same borrow areas as the filter material used in all prior tests. By comparing a representative mechanical analysis curve of this material with those of some previous tests, it was concluded that this selected material would prove a safe filter for the regular base. To check this conclusion a test was set up. In this instance a 6" Lucite cylinder, 16" long, was used, the purpose being to determine whether larger area of contact between filter and base would affect results. A special brass head was utilized in place of a rubber stopper because of the large area. Otherwise, the regular test routine was simply changed slightly to accommodate the larger tube. As expected, the set-up proved very stable.

Test No. 19: In line with the practice of checking stable tests, another test was run on the same class of material as that used in test No. 18. This time the regular 4" diameter tube, 8" long, was used. De-aired water was again used for about forty minutes during the early part of test, but as usual the effect on the sample was no different from the effect of tap water. The stability of the test proved the conclusions derived from test No. 18. These last two tests were classed as Group V.

Test No. 7-B: Upon completion of the program outlined, it was observed that practically all conclusions had been drawn from tests in 4" cylinders, with downward flow, and that no tests were run for an extended period of time. Therefore, to check results, it was decided to set up a large cylinder using upward flow. It was felt that the buoyant action of the upward flow might create a slightly different effect on the base. With upward flow, the possible disturbance to the base upon inverting after packing was avoided, a factor which does not existi in placement of materials in the field. Materials were chosen to reproduce those of tests Nos. 7 and 7-A. The test failed before the full gradient of about 10 was reached. The test was continued for about 25 hours to determine the extent of failure over a protracted period. At completion of test, practically the entire base had migrated into the filter voids and considerable amounts of the filter had dropped into the base layer. Failure of this test further checked the conclusions of tests Nos. 7 and 7-A.

Test No. 6-B: Since a failure test was checked using the large cylinder and upward flow, it was decided to run a check on a stable condition in the same group. Materials in tests Nos. 6 and 6-A were duplicated. Although the test ran continuously for practically two days, no indication of any movement in the base was noted whatsoever. Apparently the conclusions drawn from the smaller tubes and downward flow were justified.

V. RESULTS

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V. RESULTS

Presentation of results. - The following tabulation and graphs illustrate the results of this investigation of protective filters:

Plate A: The pertinent data and the results of all tests conducted are listed herein. Group I includes tests using run-of-the-bank filter material in the natural state and with fine particles below certain sieve sizes wasted. Groups II, III, and IV consist of tests using a filter made up of uniform gravel sizes such that the uniformity coefficient for the filter material in each group is essentially constant. The uniformity coefficient is the ratio of the 60% size to the 10% size. Group V is comprised of tests on selected screened gravel adopted for use in the construction of a specific earth fill dam.

In the next to the last column, entitled "Ratios," the ratio of the 15% size of the filter material to the 15% size of the base material, and the ratio of the 15% size of the filter to the 50% size of the base are tabulated. The percent sizes are taken from the ordinary cumulative grain size curves in which the percent finer by weight of a soil sample is plotted against grain size on a semi-log scale. The final column, headed "Comments," lists the result of each test.

Plate B: The critical grain size distribution zone of the filter material outlining the failure and stability conditions for each group and the spread of the grain size distribution of the base material are shown hereon.

Plates C, D, E, F, and G: These show a compilation of grain size distributions of filter and base materials used in tests under Groups I, II, III, IV, and V, respectively.

Plate H: This plate shows graphically the relations found to exist between the grain size distribution of the base material and various protective filter combinations investigated. The varying uniformity coefficient of the filter was chosen as ordinate. The ratios of the 15% size of the filter to the 15% size of the base, and the 15% size of the filter to the 50% size of the base which define the relation of the grain sizes between the filter and base materials were used as abscissae.

Test No.	Time		Temperature °C	Gradient	Cylinder Size		Permeability	FILTER							BASE								Ratios		Comments
	Hrs.	Min.			A(cm)^2	L(in.)	$k_{10} \times 10^{-4}$ cm/sec.	Weight g.	Length cm.	Void Ratio e.	Effective Size mm.	Uniformity Coefficient	15% Size mm.	Sieve Sizes	Weight g.	Length cm.	Void Ratio e.	Percent Compaction	Effective Size mm.	Uniformity Coefficient	15% Size mm.	50% Size mm.	15:15	15:50	
GROUP I																									
1	4	0	33.5	7.0	67.6	16	227	2587	18.5	0.323	0.35	12.0	0.45	Natural run of bank.	-	-	-	-	-	-	-	-	-	-	Very stable.
2	0	10	20.8	20.1	67.3	8	-	767	5.7	0.370	0.37	16.8	0.46	Natural run of bank.	-	-	-	-	-	-	-	-	-	-	Failure by uplift.
3	7	0	21.1	14.2	67.3	8	99.5	1282	9.2	0.325	0.35	17.7	0.44	Natural run of bank.	-	-	-	-	-	-	-	-	-	-	Stable.
4	10	30	20.8	8.3	67.3	8	168	1294	9.2	0.308	0.35	25.7	0.45	Natural run of bank.	745	6.4	0.567	66	0.25	3.40	0.28	0.63	1.6	0.72	Very stable.
5	3	0	20.1	24.6	67.1	8	352	1355	11.9	0.618	6.2	3.10	7.1	Wasting below #4.	608	5.3	0.589	58	0.22	3.20	0.25	0.60	28.4	11.8	Failure.
5-A	1	15	20.3	21.4	67.1	8	243	1289	11.2	0.595	6.3	2.90	7.2	Wasting below #4.	717	6.1	0.549	71	0.24	3.54	0.29	0.58	24.8	12.4	Very stable.
6	6	30	20.1	20.7	67.1	8	250	1281	10.8	0.548	8.2	2.20	9.2	Wasting below #3.	751	6.3	0.527	79	0.23	4.35	0.28	0.67	32.9	13.7	Stable.
6-A	0	40	28.0	20.4	67.1	8	287	1223	10.8	0.622	8.1	2.35	9.0	Wasting below #3.	748	6.2	0.507	85	0.23	3.65	0.29	0.62	31.0	14.5	Stable.
6-B	43	45	20.0	5.63	159.3	16	-	9460	33.7	0.557	8.0	2.25	9.0	Wasting below #3.	2010	7.1	0.525	80	0.27	3.26	0.32	0.63	28.1	14.3	Very stable.
7	0	0	-	-	67.1	8	-	1237	10.8	0.608	10.9	2.01	11.7	Wasting below #E.	714	6.1	0.558	69	0.25	3.20	0.29	0.60	40.3	19.5	Complete failure (dry).
7-A	1	30	20.3	20.4	67.1	8	-	1184	10.5	0.628	11.0	2.00	11.8	Wasting below #E.	757	6.4	0.538	75	0.25	3.28	0.29	0.60	40.7	19.7	Failure.
7-B	25	0	20.0	10.2	159.3	16	-	10007	37.1	0.620	11.0	2.09	11.7	Wasting below #E.	991	3.6	0.573	64	0.24	3.08	0.28	0.57	41.8	20.5	Complete failure.
GROUP II																									
8	1	15	19.8	21.4	67.1	8	384	1246	11.1	0.642	14.0	1.16	14.0	Passing #C, retained on #D.	734	6.1	0.509	85	0.24	3.40	0.29	0.61	48.3	22.9	Stable.
8-A	3	0	19.9	21.4	67.4	8	-	1227	11.4	0.716	13.8	1.19	14.0	Passing #C, retained on #D.	721	6.0	0.517	82	0.24	3.70	0.30	0.64	46.7	21.9	Complete failure.
9	-	-	-	-	67.1	8	-	1097	10.8	0.813	19.8	1.16	20.0	Passing #B, retained on #C.	733	6.2	0.535	76	0.22	4.77	0.28	0.70	71.4	28.6	Complete failure.
16	7	10	20.6	20.3	67.4	8	181	1206	10.8	0.653	10.0	1.17	10.1	Passing #D, retained on #E.	782	6.4	0.497	89	0.22	3.54	0.27	0.59	37.4	17.1	Very stable.
16-A	7	40	20.5	20.3	67.4	8	222	1205	10.5	0.607	10.0	1.16	10.1	Passing #D, retained on #E.	776	6.4	0.507	86	0.25	3.40	0.30	0.62	33.7	16.3	Stable.
GROUP III																									
10	4	30	20.8	21.0	67.1	8	337	1172	11.2	0.758	14.4	1.41	15.0	Passing #B, 50% retained on #C, 100% retained on #D.	752	6.2	0.502	87	0.22	3.82	0.26	0.59	57.7	25.4	Complete failure.
11	8	30	21.3	21.3	67.1	8	302	1254	11.4	0.676	12.0	1.41	12.3	Passing #B, 25% retained on #C, 75% retained on #D, 100% retained on #E.	732	6.1	0.515	83	0.25	3.84	0.29	0.64	42.4	19.2	Complete failure.
13	3	15	21.5	20.3	67.4	8	172	1220	10.7	0.618	10.3	1.41	10.6	Passing #C, 50% retained on #D, 100% retained on #E.	774	6.4	0.513	84	0.22	3.45	0.27	0.57	39.2	18.6	Complete failure.
15	4	0	20.4	20.7	67.1	8	265	1244	10.6	0.568	8.5	1.41	8.8	Passing #C, 25% retained on #D, 75% retained on #E, 100% retained on #3.	771	6.3	0.490	91	0.22	3.54	0.27	0.59	32.6	14.9	Stable.
15-A	3	20	29.0	19.6	67.4	8	201	1225	10.5	0.584	8.6	1.40	8.9	Passing #C, 25% retained on #D, 75% retained on #E, 100% retained on #3.	784	6.5	0.519	84	0.24	3.41	0.28	0.61	31.7	14.6	Stable.
GROUP IV																									
12	4	30	21.2	21.4	67.4	8	211	1256	10.9	0.602	10.7	1.65	11.2	Passing #B, 33.3% retained on #C, 66.7% retained on #D, 100% retained on #E.	742	6.1	0.500	88	0.23	3.70	0.28	0.61	40.3	18.5	Stable.
12-A	5	15	20.4	21.0	67.4	8	286	1239	10.7	0.595	11.0	1.64	11.6	Passing #B, 33.3% retained on #C, 66.7% retained on #D, 100% retained on #E.	770	6.3	0.494	90	0.22	3.36	0.27	0.56	43.0	20.7	Complete failure.
14	7	0	21.5	20.3	67.1	8	330	1232	10.9	0.627	12.3	1.71	15.0	Passing 1-1/2", 16.7% retained on #B, 50% retained on #C, 83.3% retained on #D, 100% ret. on #E.	773	6.4	0.509	85	0.24	3.41	0.29	0.58	44.8	22.4	Failure.
17	4	30	20.7	20.7	67.1	8	164	1271	10.7	0.547	9.0	1.67	9.3	Passing #B, 16.7% retained on #C, 50% retained on #D, 83.3% retained on #E, 100% ret. on #3.	780	6.5	0.510	84	0.25	3.40	0.29	0.62	32.0	15.0	Very stable.
17-A	9	15	20.6	20.0	67.1	8	223	1263	10.7	0.557	9.0	1.66	9.4	Passing #B, 16.7% retained on #C, 50% retained on #D, 83.3% retained on #E, 100% ret. on #3.	777	6.5	0.524	80	0.24	3.33	0.29	0.61	32.4	15.4	Stable.
GROUP V																									
18	6	30	20.5	19.4	159.3	16	183	9693	34.2	0.544	5.2	3.18	6.2	Selected, screened gravel.	1890	6.7	0.532	78	0.26	3.00	0.31	0.61	20.0	10.2	Stable.
19	3	0	20.5	20.0	67.4	8	236	1336	10.9	0.509	5.5	3.64	6.8	Selected, screened gravel.	764	6.2	0.483	93	0.24	5.00	0.29	0.79	23.5	9.2	Stable.

PLATE A

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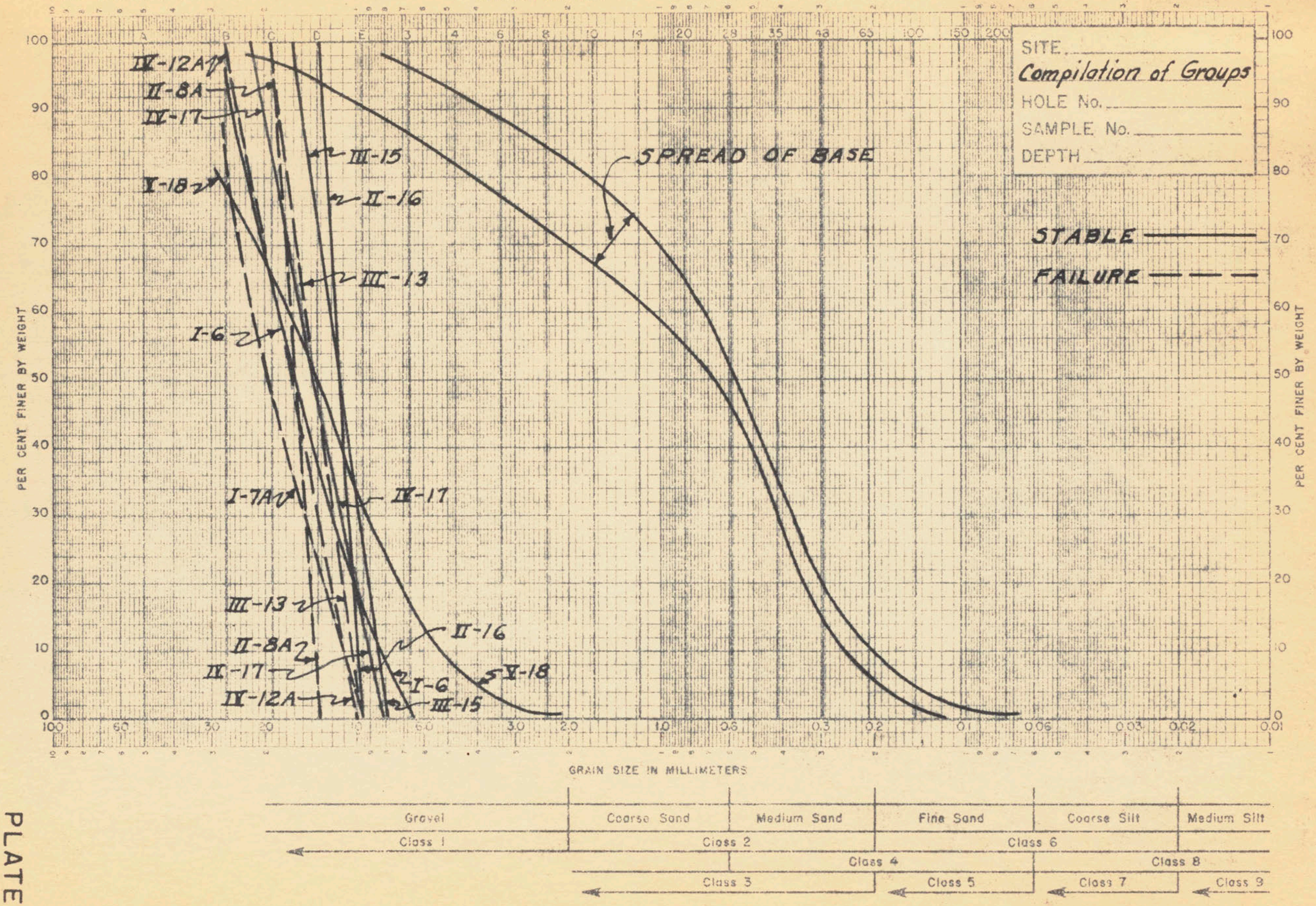

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MECHANICAL ANALYSIS

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PLATE B

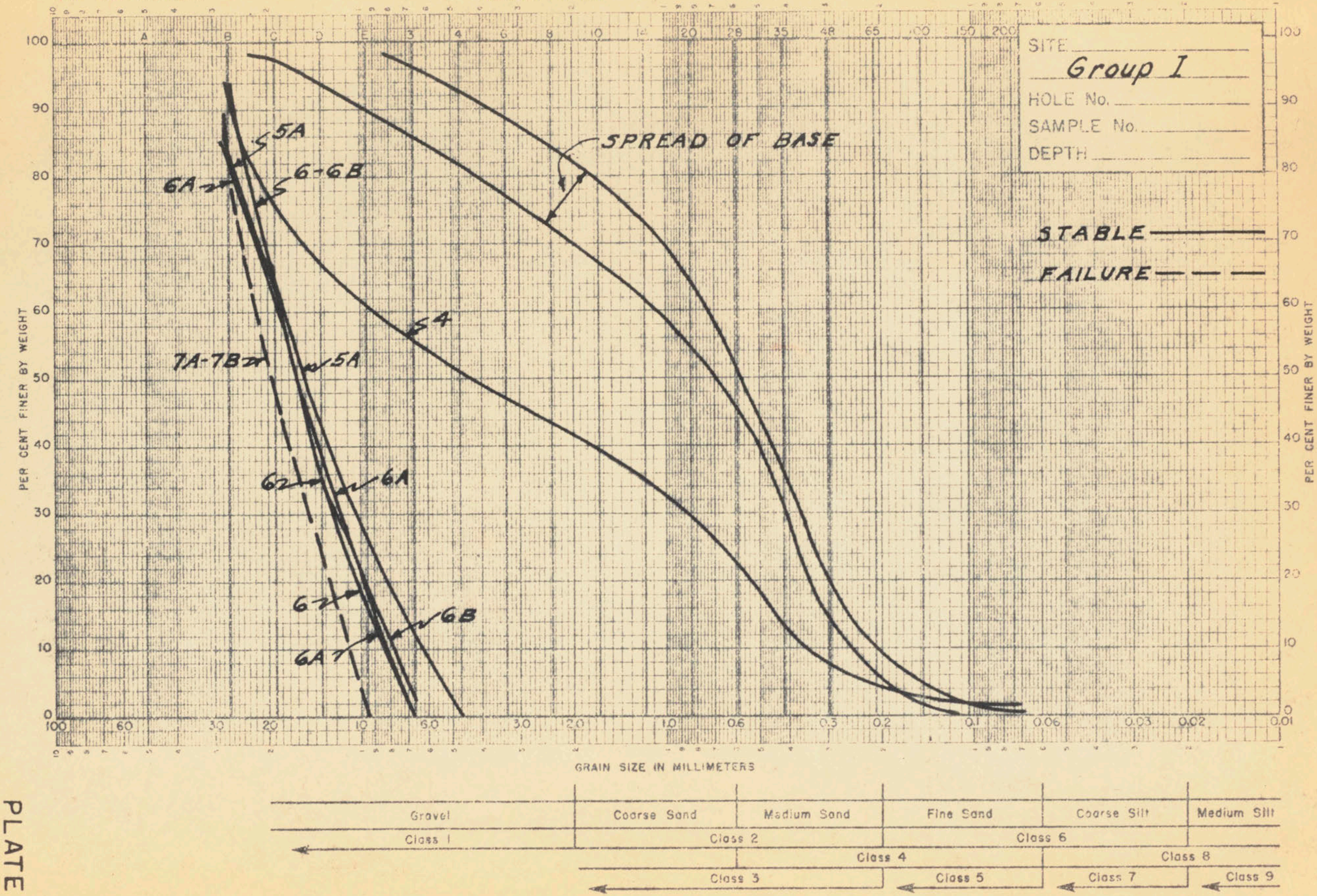

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PLATE C

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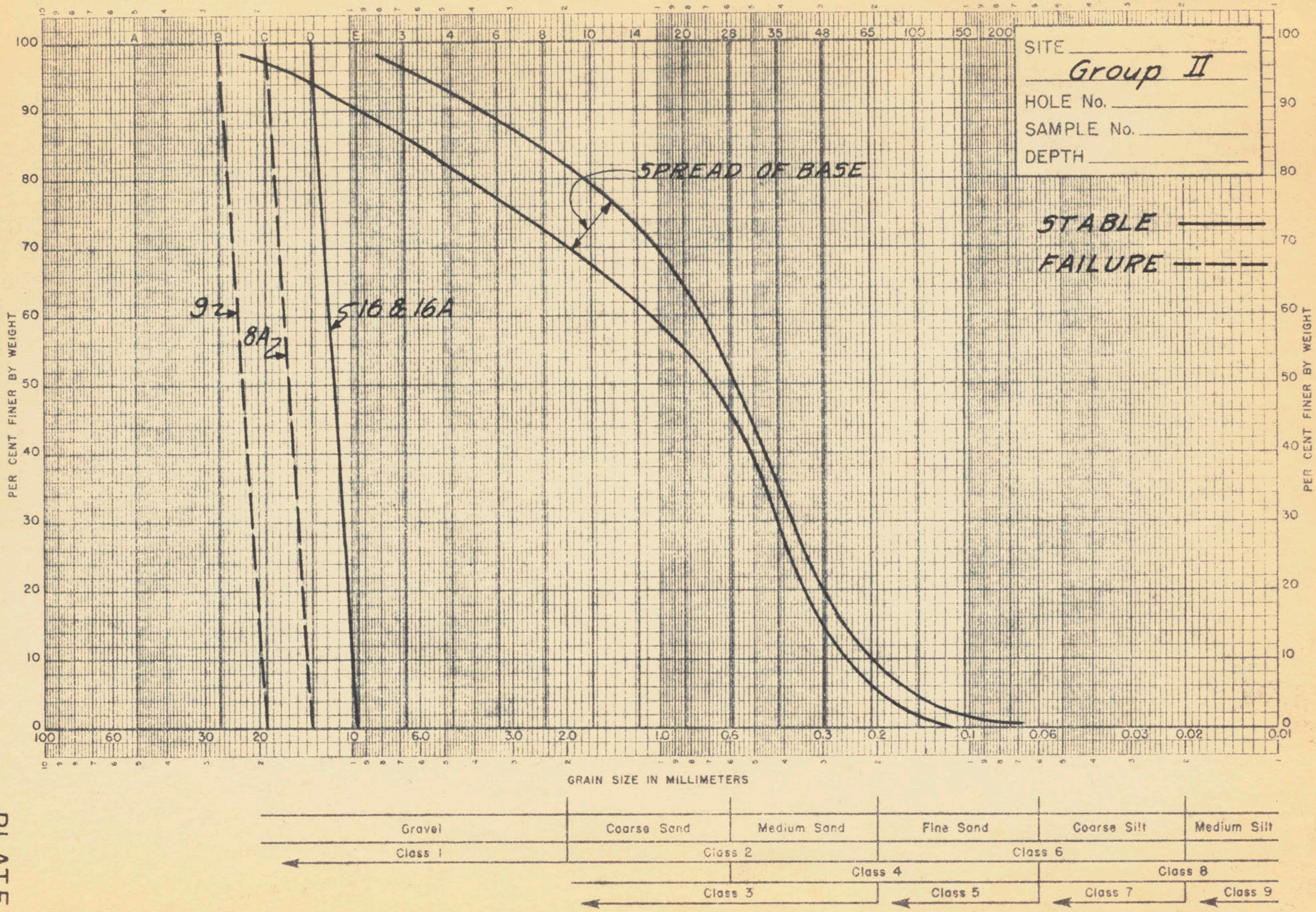

PLATE D

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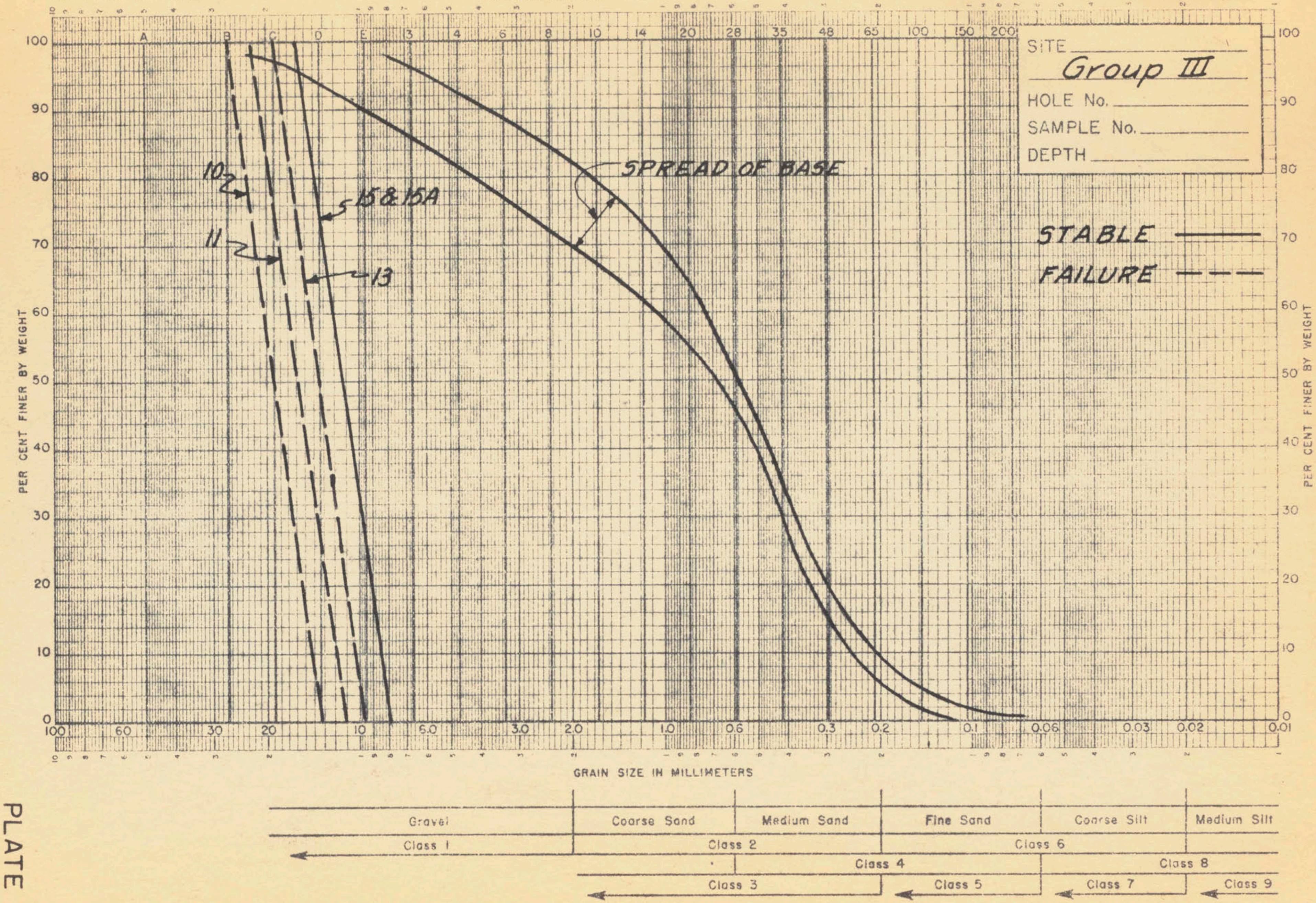

PLATE E

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MECHANICAL ANALYSIS

PROVIDENCE, R. I.

S. L. FORM NO. 58

U. S. GOVERNMENT PRINTING OFFICE 192621

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY

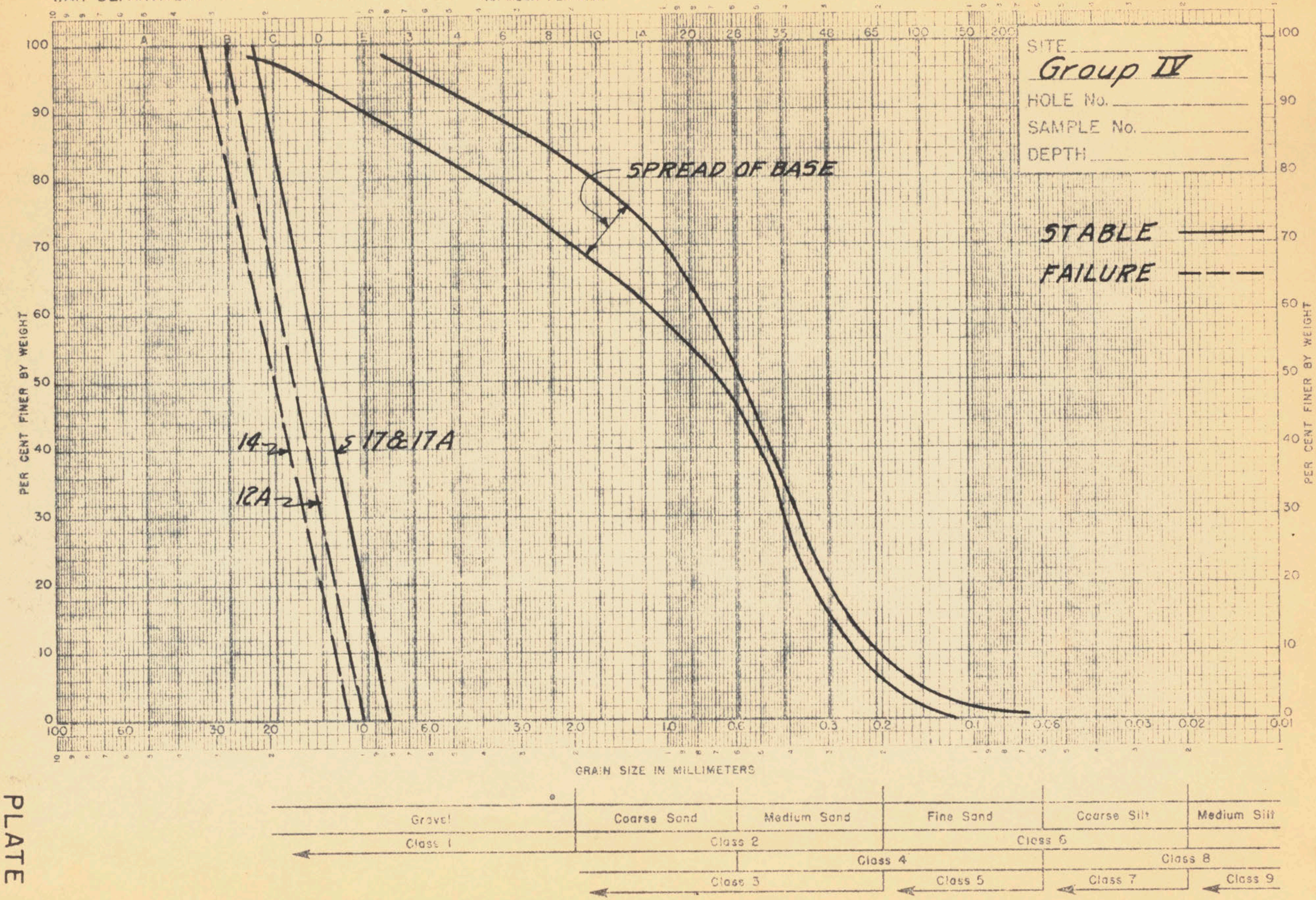


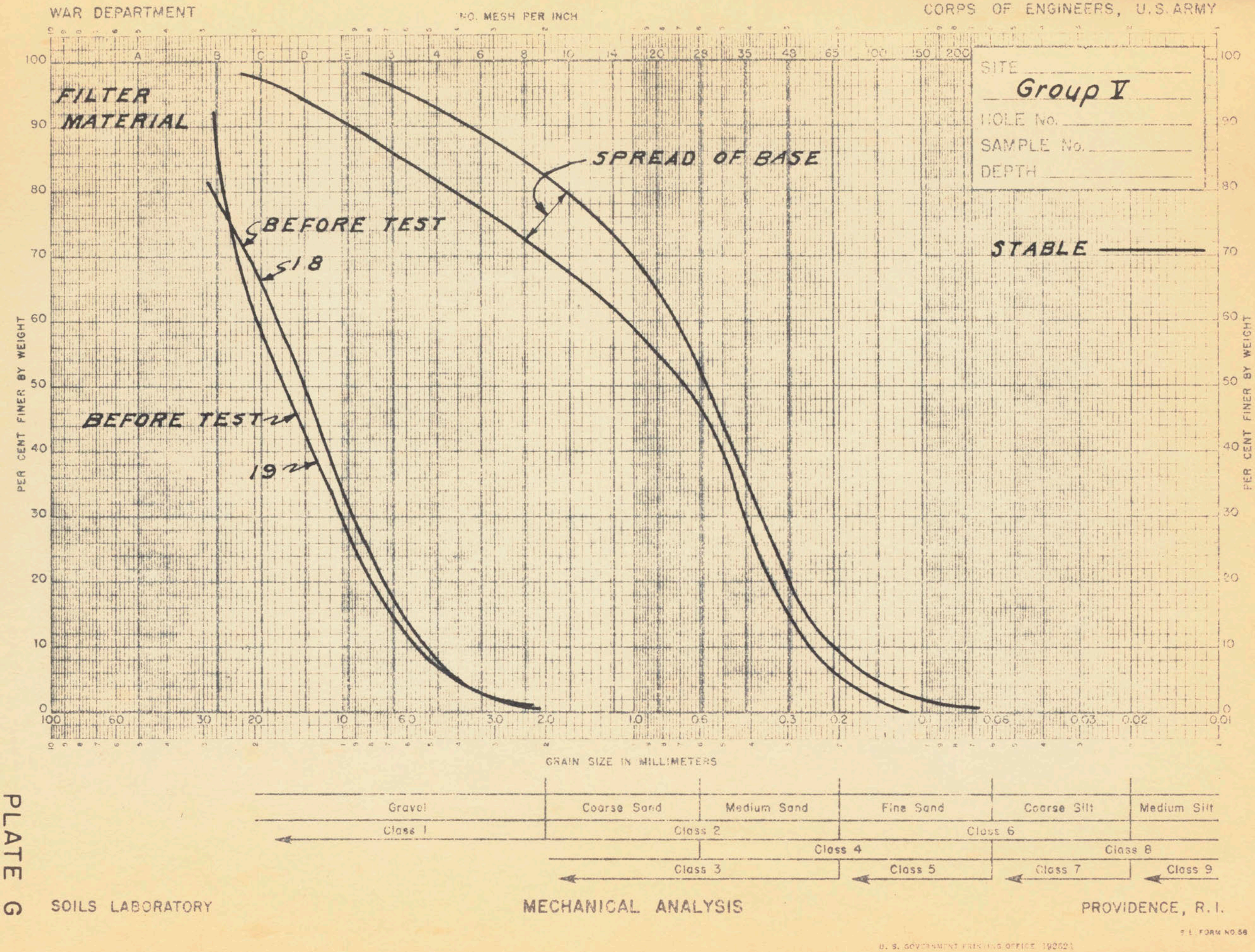
PLATE F

SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R. I.

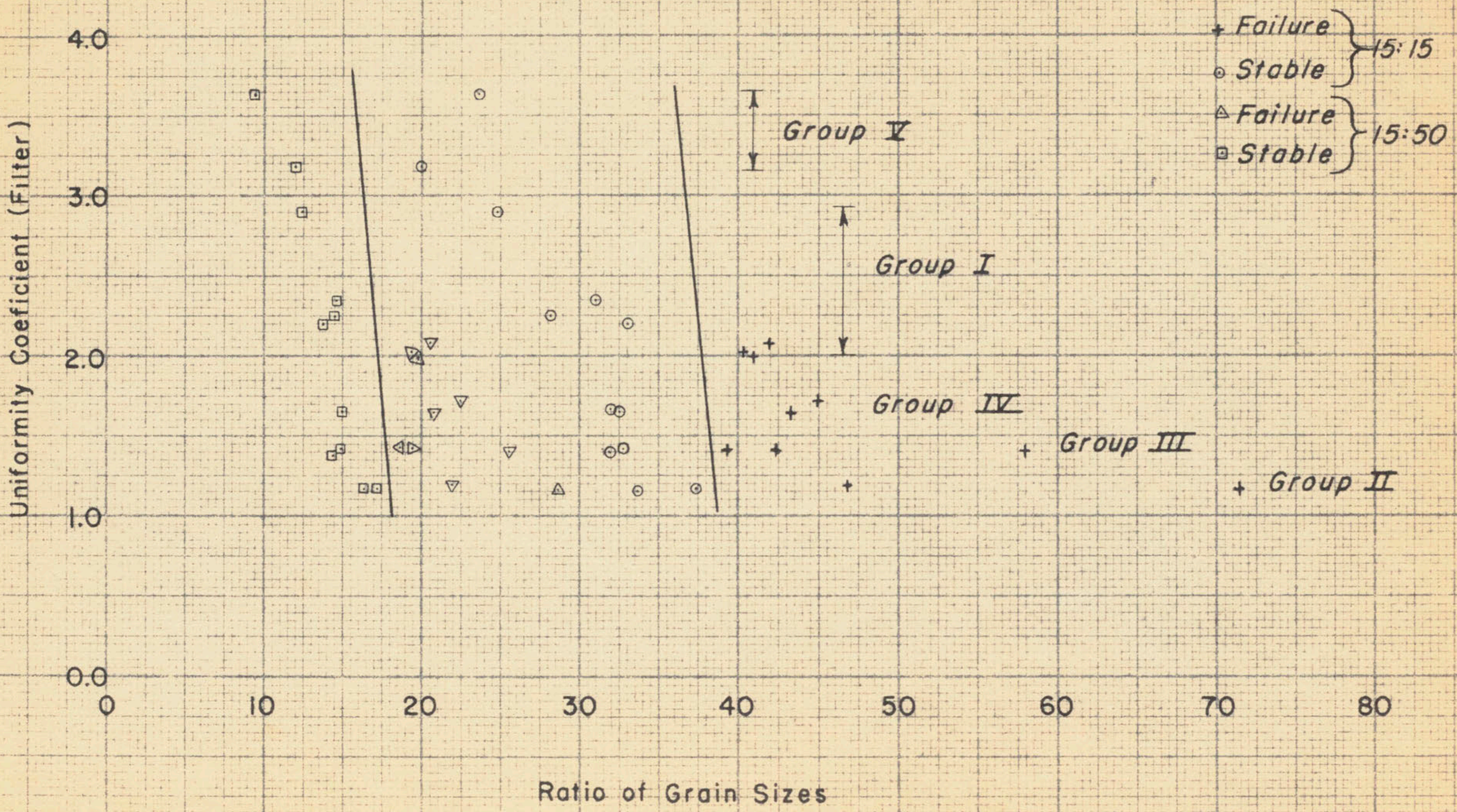
S. L. FORM NO. 58



WAR DEPARTMENT
NO. MESH PER INCH
CORPS OF ENGINEERS, U.S. ARMY
SITE
Group V
HOLE No.
SAMPLE No.
DEPTH
FILTER MATERIAL
BEFORE TEST
18
SPREAD OF BASE
STABLE
BEFORE TEST
19
PER CENT FINER BY WEIGHT
GRAIN SIZE IN MILLIMETERS
Gravel
Coarse Sand
Medium Sand
Fine Sand
Coarse Silt
Medium Silt
Class 1
Class 2
Class 6
Class 4
Class 8
Class 3
Class 5
Class 7
Class 9
SOILS LABORATORY
MECHANICAL ANALYSIS
PROVIDENCE, R.I.

PLATE G

PLATE H



GRAIN SIZE RELATIONS

Discussion of Results. - It was decided in comparing the grain sizes of filter and base to follow the principles suggested by Terzaghi and later used by Bertram. Accordingly, the criteria adopted consisted of the ratio of the 15% sizes of filter to base, and the ratio of the 15% size of filter to the 50% size of the base. The 50% size of base varied within narrow limits while the 85% size, chosen by Terzaghi, fluctuated to such an extent as to be misleading for comparative purposes. The 50% size also indicated the average grain size of the base material. Therefore, in this study it was found more satisfactory to use the 50% size of the base. It was noted that both of these ratios for the limiting condition of stability were considerably higher than those obtained by Bertram. It seems logical that these ratios, obtained with the non-uniform gradation of base material used in this investigation, would be larger than corresponding ratios obtained with uniform base materials. In a non-uniform material the finer particles are necessarily retained in place by the coarser particles.

Interesting results were obtained by plotting the uniformity coefficients of the filter against the grain size relations (see Plate H). It was noted that the limit of stability falls within a definite range of each of the grain size ratios. The existence of a critical zone between stability and failure is clearly demonstrated in each group. The trend of this critical zone covering all groups studied shows that both ratios tend to decrease with an increase of the uniformity coefficient of the filter. A study of the graph (Plate H) indicated that for stability the ratio of the 15% size of the filter to the 15% size of the base should not exceed 32, and the ratio of the 15% size of the filter to the 50% size of the base should not exceed 15. It may be noted that for any particular combination of materials a slightly different value may be chosen.

It is believed that research on filter material as a protection for this specific base material was complete. The spread of the base material and the limiting stability zone of the filter is illustrated on Plate B. It is the opinion of the authors that any filter material whose distribution curve lies to the right of this critical zone will give full protection for this base material.

Results of tests as to stability or failure were determined largely by visual observation. In all cases a certain small amount of fines fell from the base into the voids of the filter. This was to be expected because the base material was cohesionless and because many of the voids in the filter were larger than the finest grains of the base material. In all tests where failure occurred, it was very pronounced. Failure consisted of a continuous erosion of base material into the filter voids with a complete alteration of the original grain size distribution of the base. In cases of failure a definite indication of erosion of base into the filter was always observed during the early part of the test. Once started, the erosion continued throughout the length of test. The thickness of the filter layer used in these tests was found to be ample to establish definite failure conditions. In no case was it felt that plugging of the filter was a decisive factor since base material entering the filter invariably dropped to the bottom of the tube leaving a practically clean reach of filter directly below the base.

The only requirement as to size of sample tested was that the area be large enough to obtain representative distribution of the various particle sizes in the filter material. The area of the 4" diameter tubes was considered adequate. Check tests run in tubes having approximately 2-1/2 times this area substantiated this decision.

The use of de-aired water is recommended for permeability testing to avoid the inconsistent results due to collection of air in the test sample. In testing solely for filter protection, tests with both de-aired water and ordinary tap water indicated no particular advantage for either.

In all conditions investigated, a gradient, calculated on the thickness of the base layer and very considerably higher than would be encountered in actual practice, was used in order to create extremely adverse effects. With the above conditions and making use of periods of testing up to approximately 44 hours, observations indicated that a definite state of failure or stability is established within the first two hours. It seems reasonable to assume that high gradients compensate for relatively short periods of testing.

From the results of the majority of tests run with downward flow and the two check tests run with upward flow, the conclusion was reached that with a large gradient the direction of flow is immaterial.

Although permability determinations were made on the basis of the original thickness of the base layer in practically all tests, any relationship between the values obtained and the void ratios was too erratic to determine. It is believed that the range of base materials, the presence of the filter, and the partial failure of the base material in some tests materially distorted the permeability values.

Neither the permeability nor the compaction of the base appeared to have any direct effect upon the stability of the sample. Compaction of the base in practically all cases exceeded 60%, giving densities that are considered entirely satisfactory for this type of soil in good construction practice.

It is realized that investigations covered by this report include only a small portion of the field of research concerning protective filters, but it is felt that the procedure outlined will prove satisfactory in determining a safe protective filter for a given base material.

All original test data is filed at the Soils Laboratory of the Providence District, United States Engineer Department, Providence, Rhode Island.

APPENDIX

Plates Nos. I - VII

Photographs Nos. I - VIII

Test Data Tests Nos. 1 - 19

WAR DEPARTMENT

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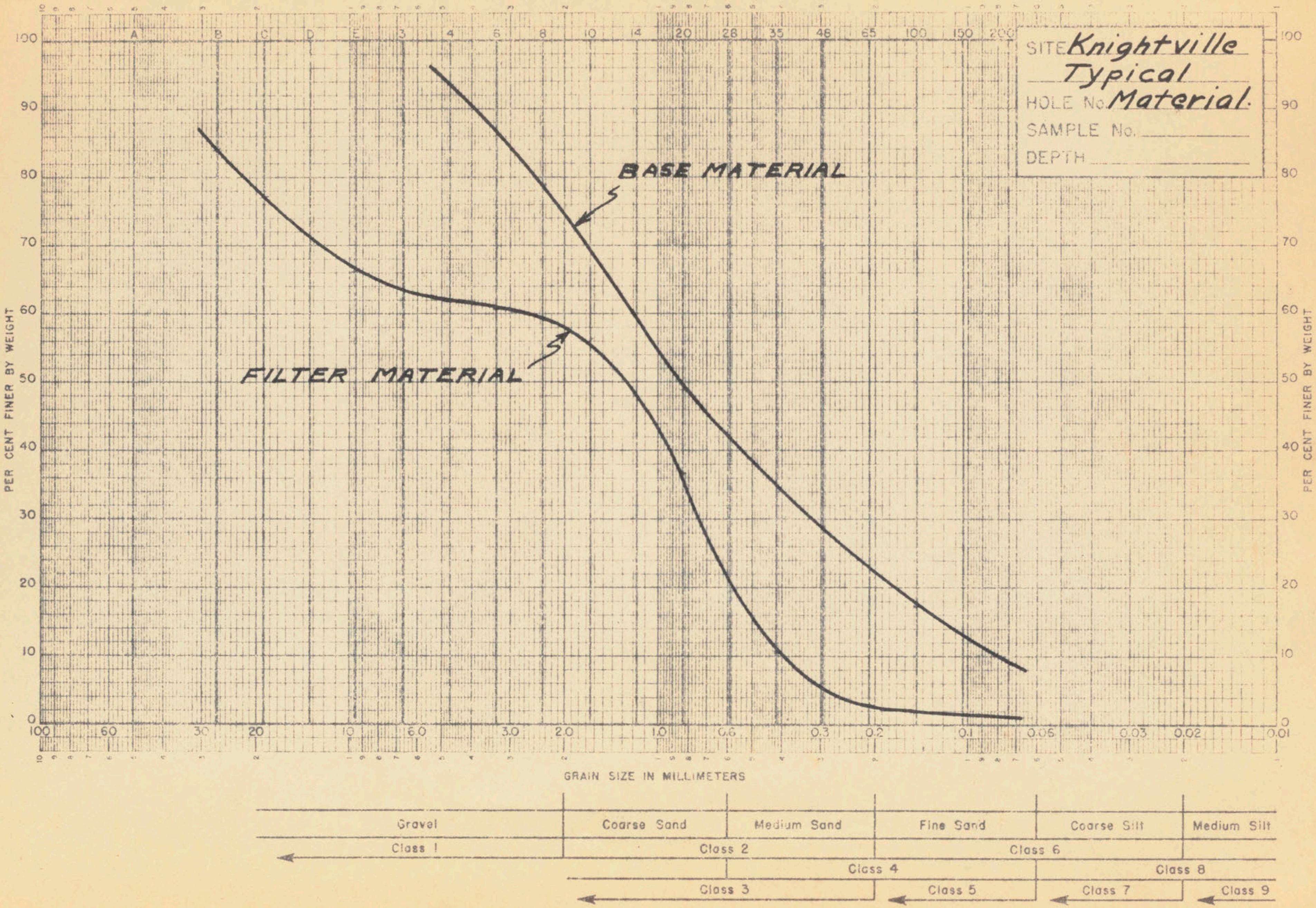


PLATE NO. I

SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

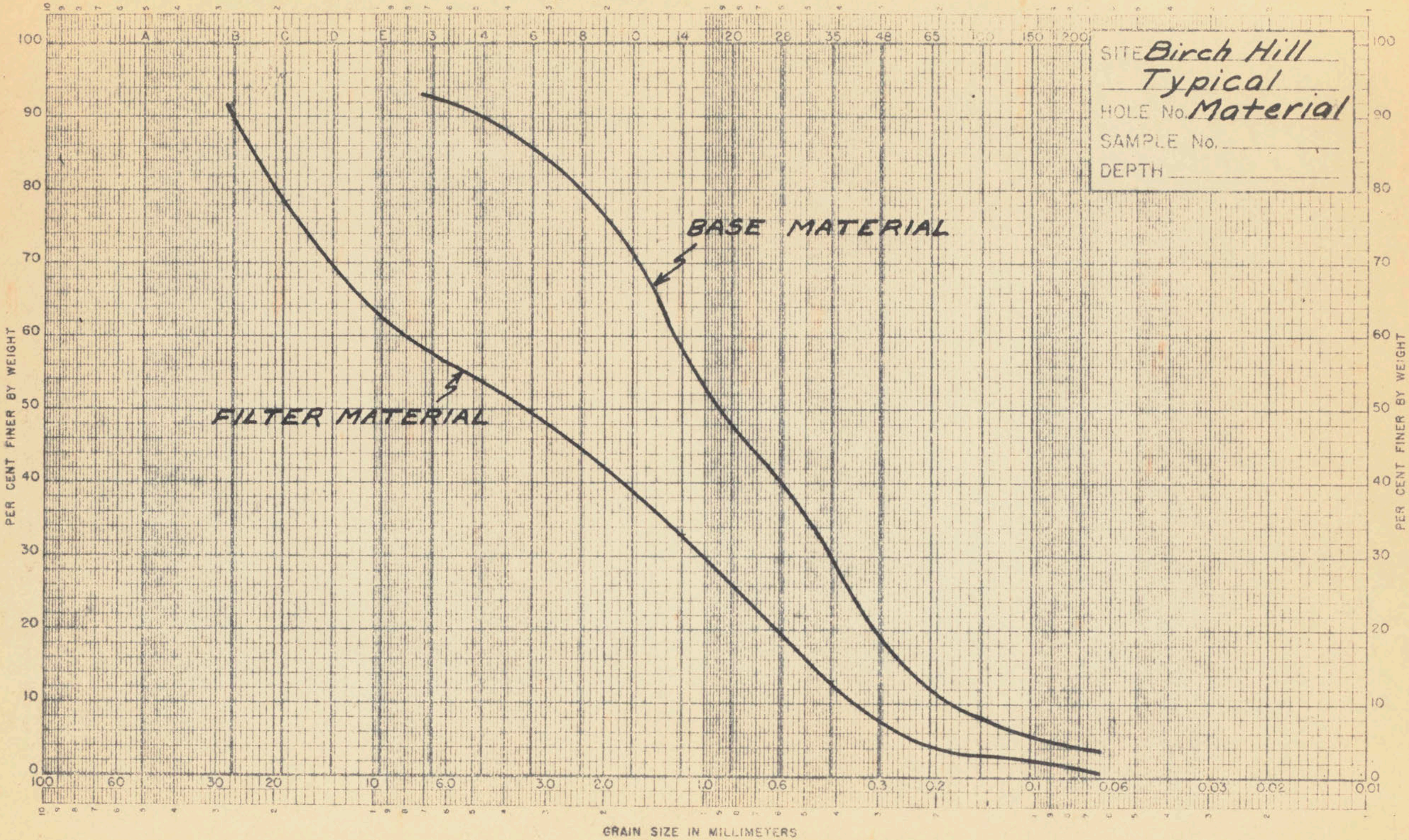
S.L. FORM NO 58

U. S. GOVERNMENT PRINTING OFFICE 190521

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY

PLATE NO. II



Gravel	Coarse Sand	Medium Sand	Fine Sand	Coarse Silt	Medium Silt
← Class 1	Class 2		Class 6		
		Class 4		Class 8	
	← Class 3		← Class 5	← Class 7	← Class 9

SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S.L. FORM NO. 58

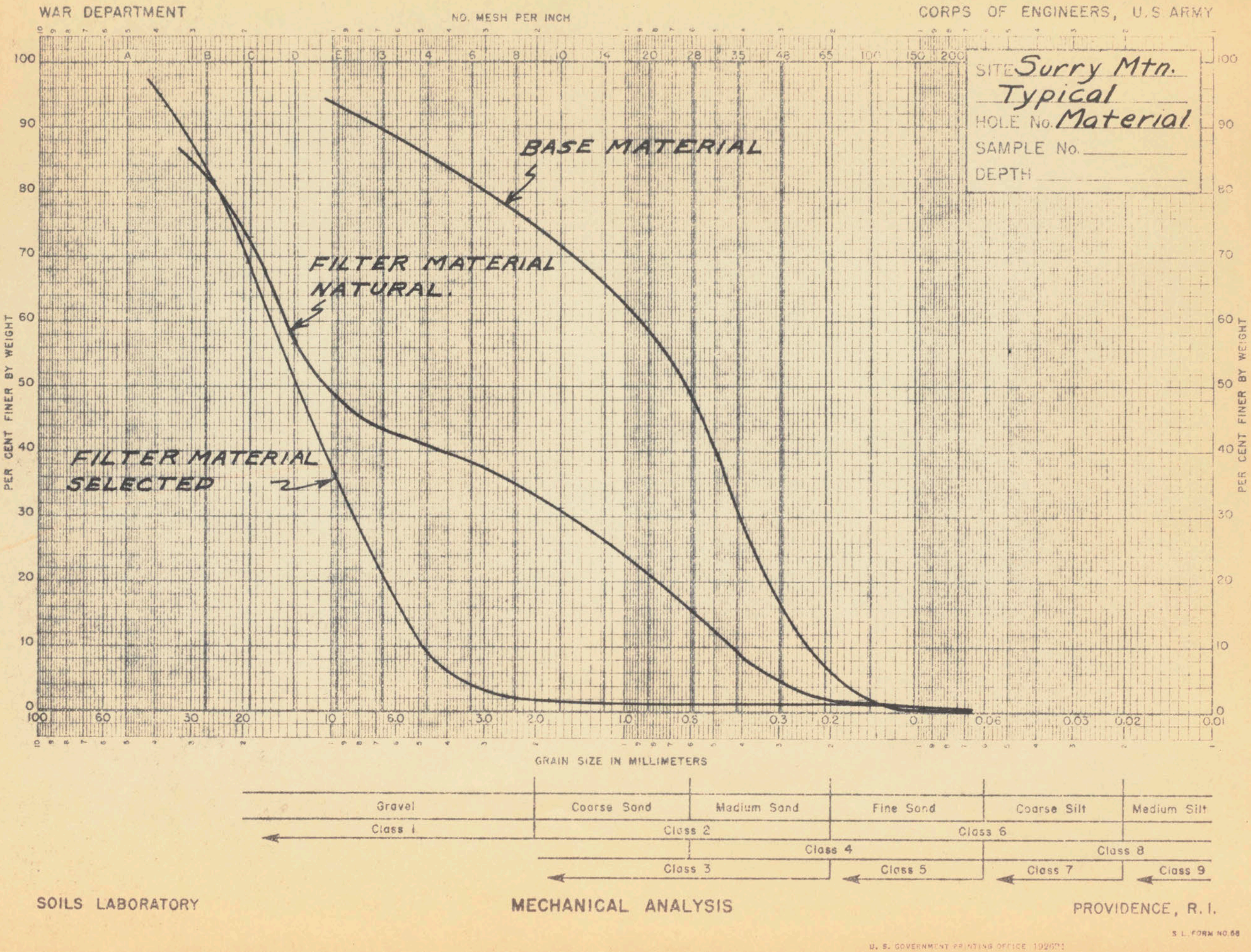

WAR DEPARTMENT
CORPS OF ENGINEERS, U.S ARMY
NO. MESH PER INCH
SITE Surry Mtn. Typical
HOLE No. Material
SAMPLE No.
DEPTH
BASE MATERIAL
FILTER MATERIAL NATURAL.
FILTER MATERIAL SELECTED
PER CENT FINER BY WEIGHT
GRAIN SIZE IN MILLIMETERS
Gravel
Coarse Sand
Medium Sand
Fine Sand
Coarse Silt
Medium Silt
Class 1
Class 2
Class 3
Class 4
Class 5
Class 6
Class 7
Class 8
Class 9
SOILS LABORATORY
MECHANICAL ANALYSIS
PROVIDENCE, R. I.
S. L. FORM NO. 68
U. S. GOVERNMENT PRINTING OFFICE

PLATE NO. III

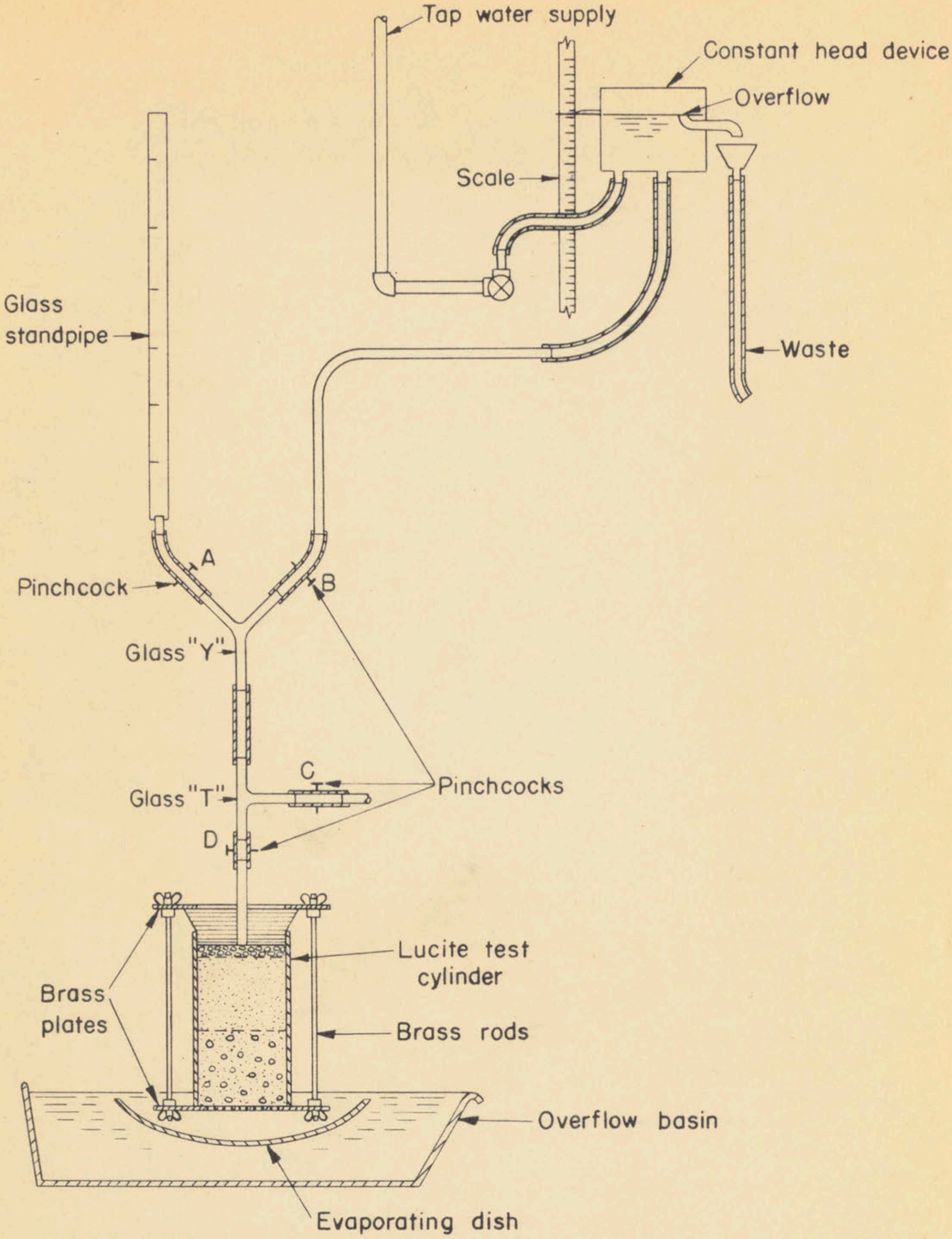
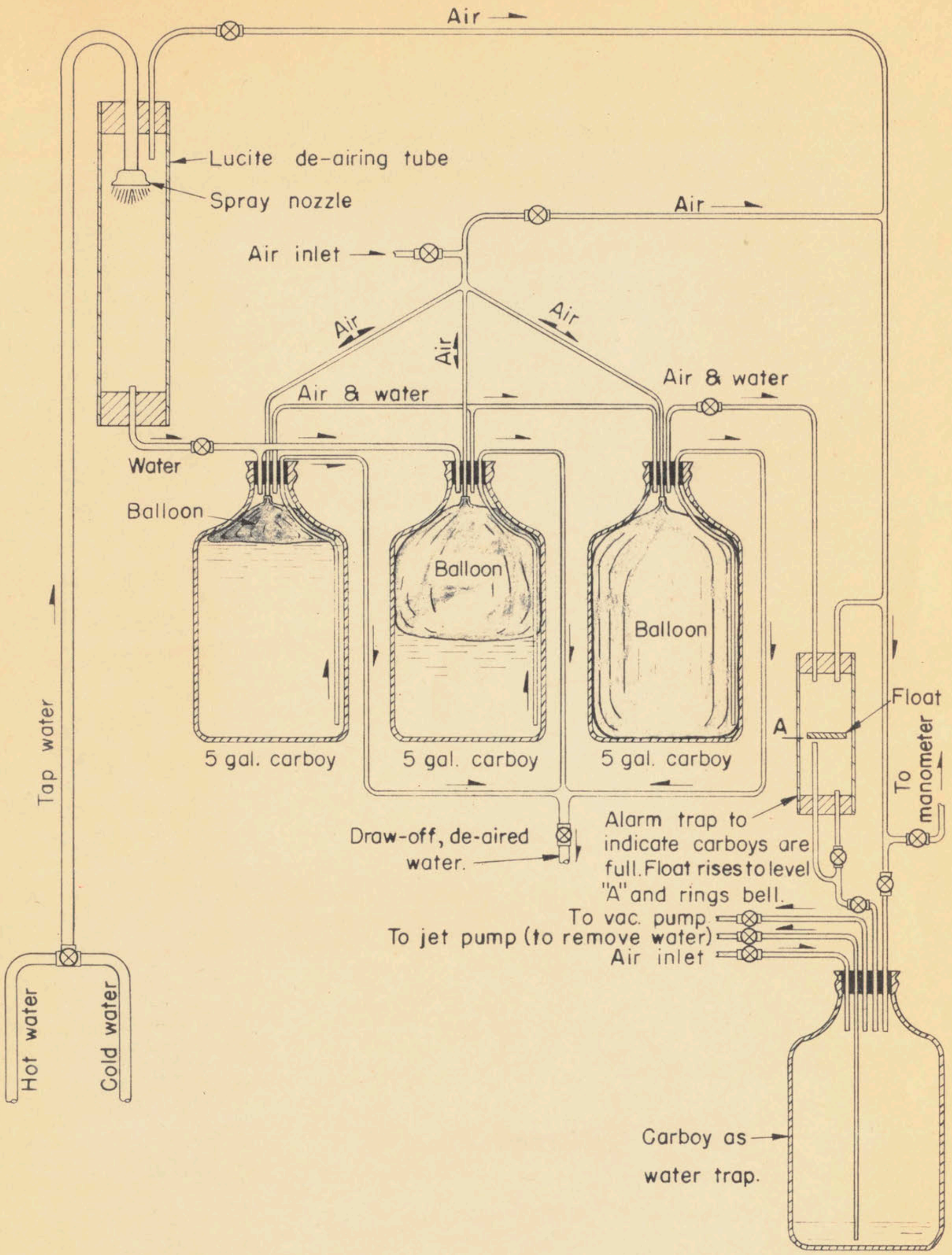


DIAGRAM OF FILTER TEST APPARATUS



ASSEMBLY OF DE-AIRING APPARATUS

PLATE V.

PLATE NO. VI

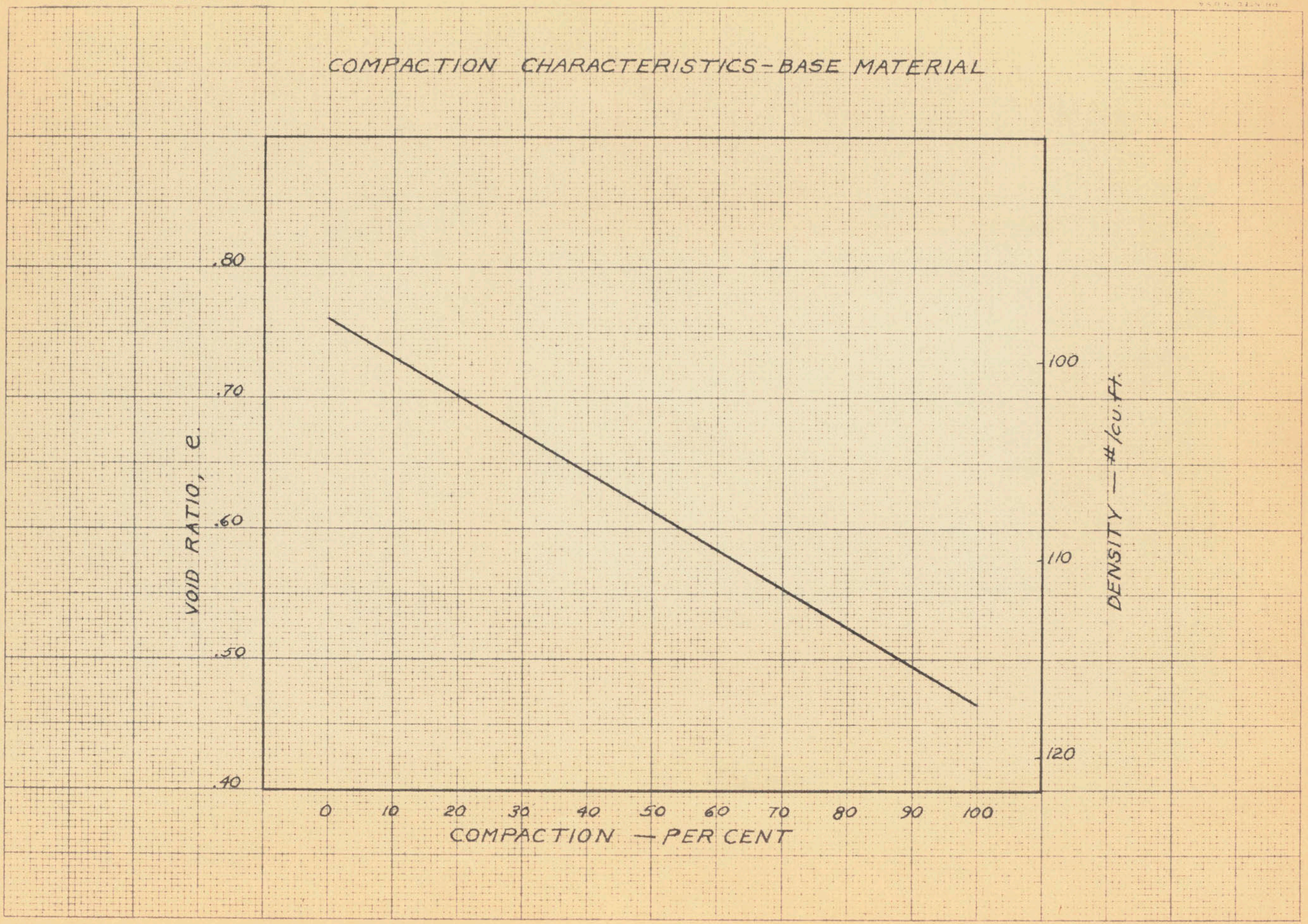
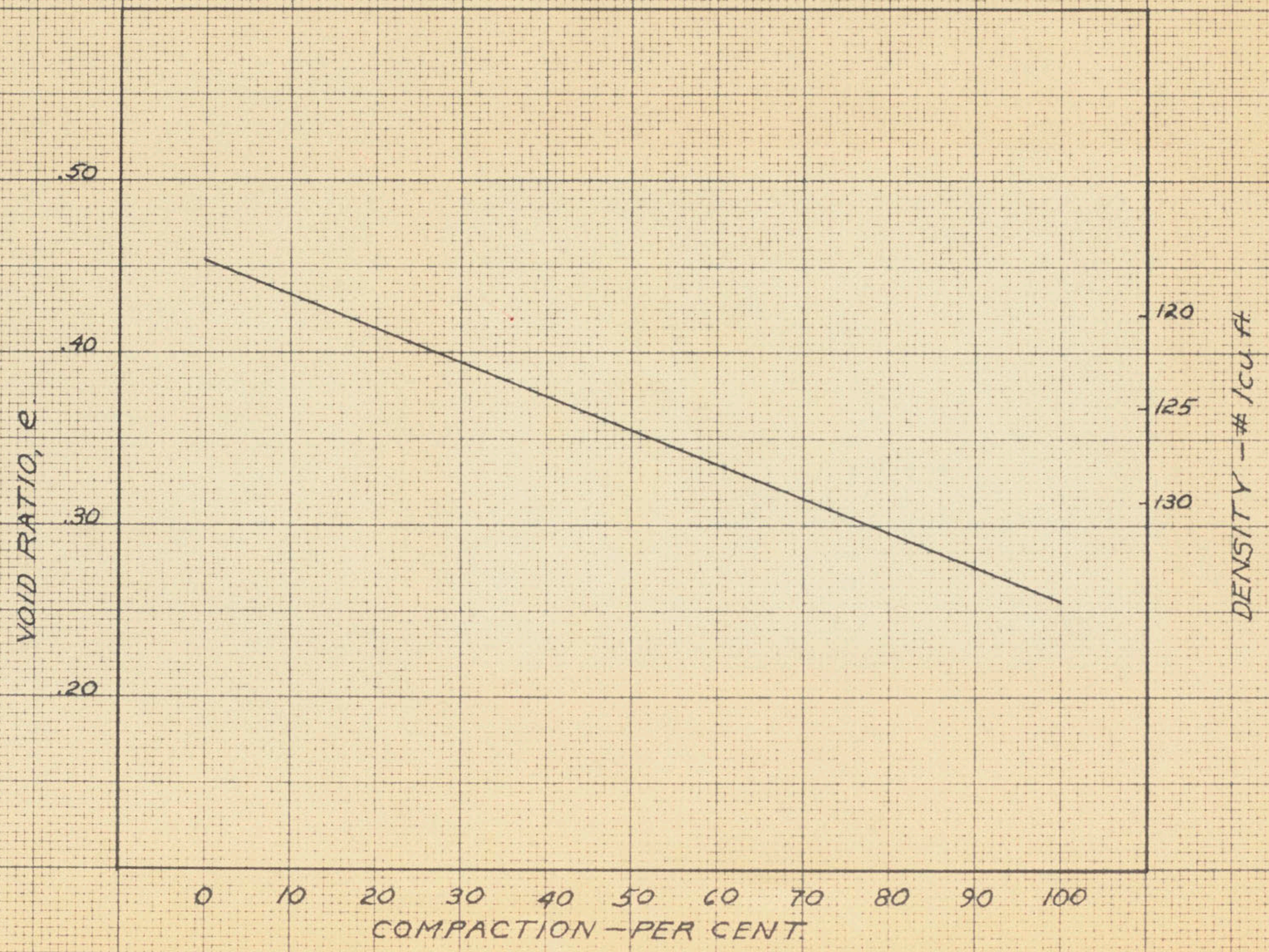
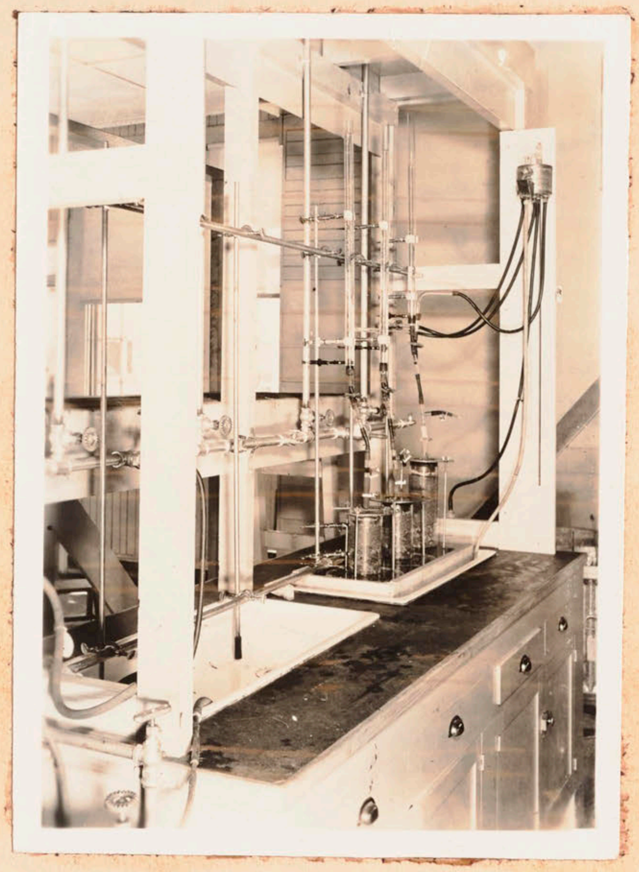

COMPACTION CHARACTERISTICS-BASE MATERIAL
.80
.70
.60
.50
.40
VOID RATIO, e.
100
110
120
DENSITY — #/cu. ft.
0
10
20
30
40
50
60
70
80
90
100
COMPACTION — PER CENT

PLATE NO. VII

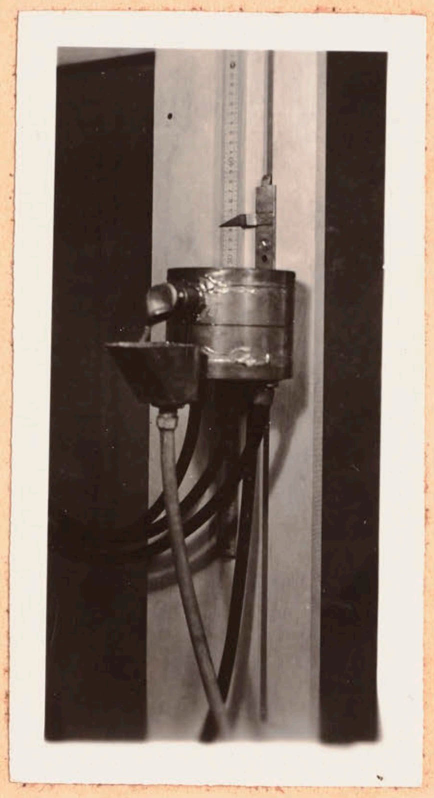
COMPACTION CHARACTERISTICS - FILTER MATERIAL





PHOTOGRAPH NO. I

GENERAL SET-UP OF APPARATUS



PHOTOGRAPH NO. II

CONSTANT HEAD DEVICE

PHOTOGRAPH NO. III

SAMPLE PREPARATION APPARATUS

PHOTOGRAPH NO. IV

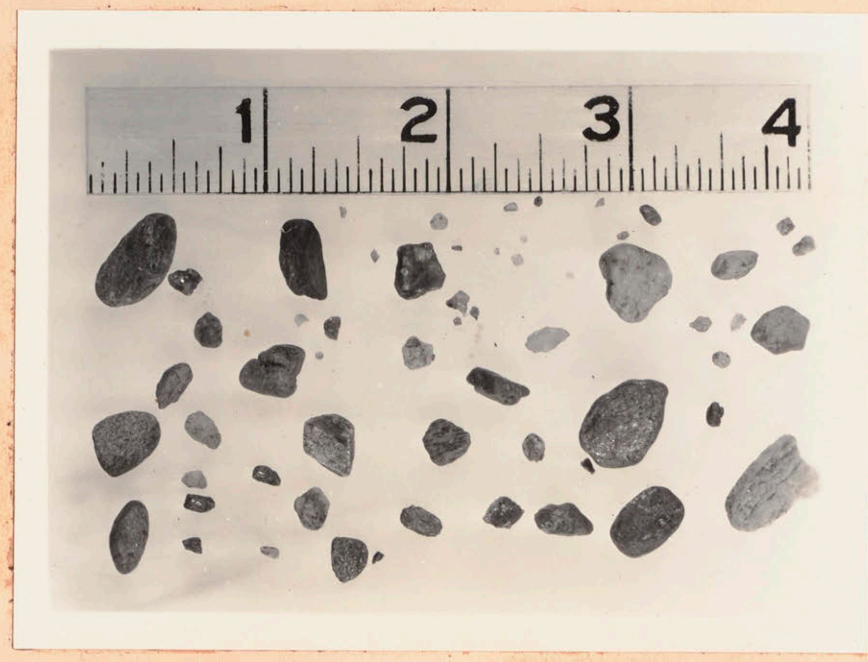
TYPICAL FAILURE

Material passing #E screen and retained on #20 screen

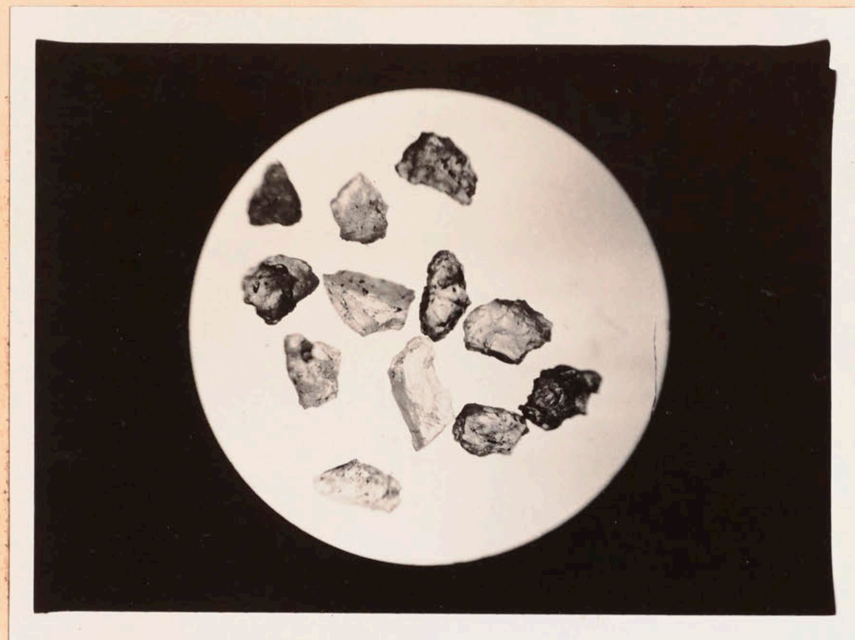
Material passing #20 screen and retained on #35 screen
(Magnification 14x)

PHOTOGRAPH NO. V

BASE MATERIAL



Material passing #E screen and retained on #20 screen



Material passing #20 screen and retained on #35 screen
(Magnification 14x)

PHOTOGRAPH NO. V

FILTER MATERIAL

PHOTOGRAPH VI

BORROW AREA "B"

KNIGHTVILLE DAM

PHOTOGRAPH VII

TYPICAL DEPOSIT - BORROW AREA "A"

BIRCH HILL DAM

PHOTOGRAPH VIII

BORROW AREA "F"

SURRY MOUNTAIN DAM

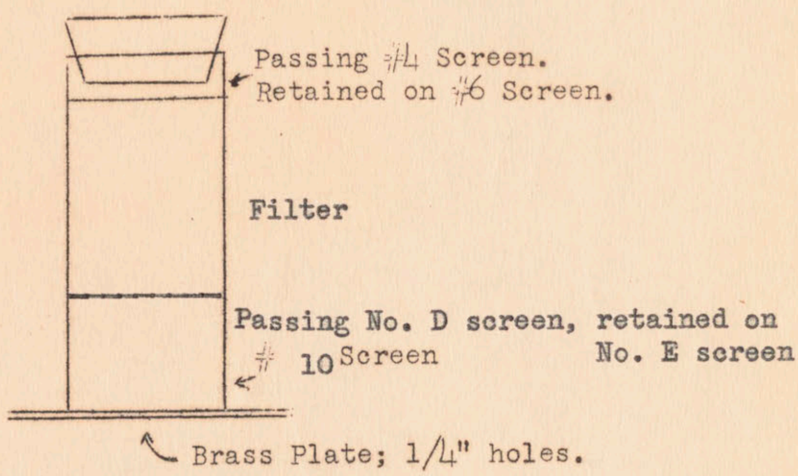
Date:	July 29, 1940
Test No.:	1
Cylinder Area:	67.6 sq.cm.
Cylinder Length:	16 in.
Total Time:	4 hr. 0 min.
Avg. Temp.:	33.5 °C
Head:	130.1 cm.
Gradient:	7.0
Permeability: k_{10} =	227 x 10^{-4} cm./sec.

SAMPLE

	Filter	Base
Weight:	2587 g.	- g.
Sp. Gravity:	2.74	-
Length:	18.5 cm.	- cm.
Void Ratio:	0.323	-
Compaction:	66 %	- %
Unif. Coef.:	12.0	-
Eff. Size:	0.35 mm.	- mm.
Grain Sizes:		
10%	0.35 mm.	- mm.
60%	4.2 mm.	- mm.
15%	0.45 mm.	- mm.
50%	2.25 mm.	- mm.

Ratios of Grain Sizes:

15% Filter: 15% Base =	-
15% Filter: 50% Base =	-



COMMENTS:

Very stable.

Natural filter material only used, to check stability within itself. Uniform filter, passing No. D screen and retained on No. E screen, used to fill tube and support filter.

Material was packed dry.

Test run for first hour with de-aired water and for remaining 3 hours with tap water. Very slight shifting of material into uniform gravel when tube was inverted after packing. Slight settlement of material during first 5 minutes of test. No alteration noted beyond 3 cm above bottom.

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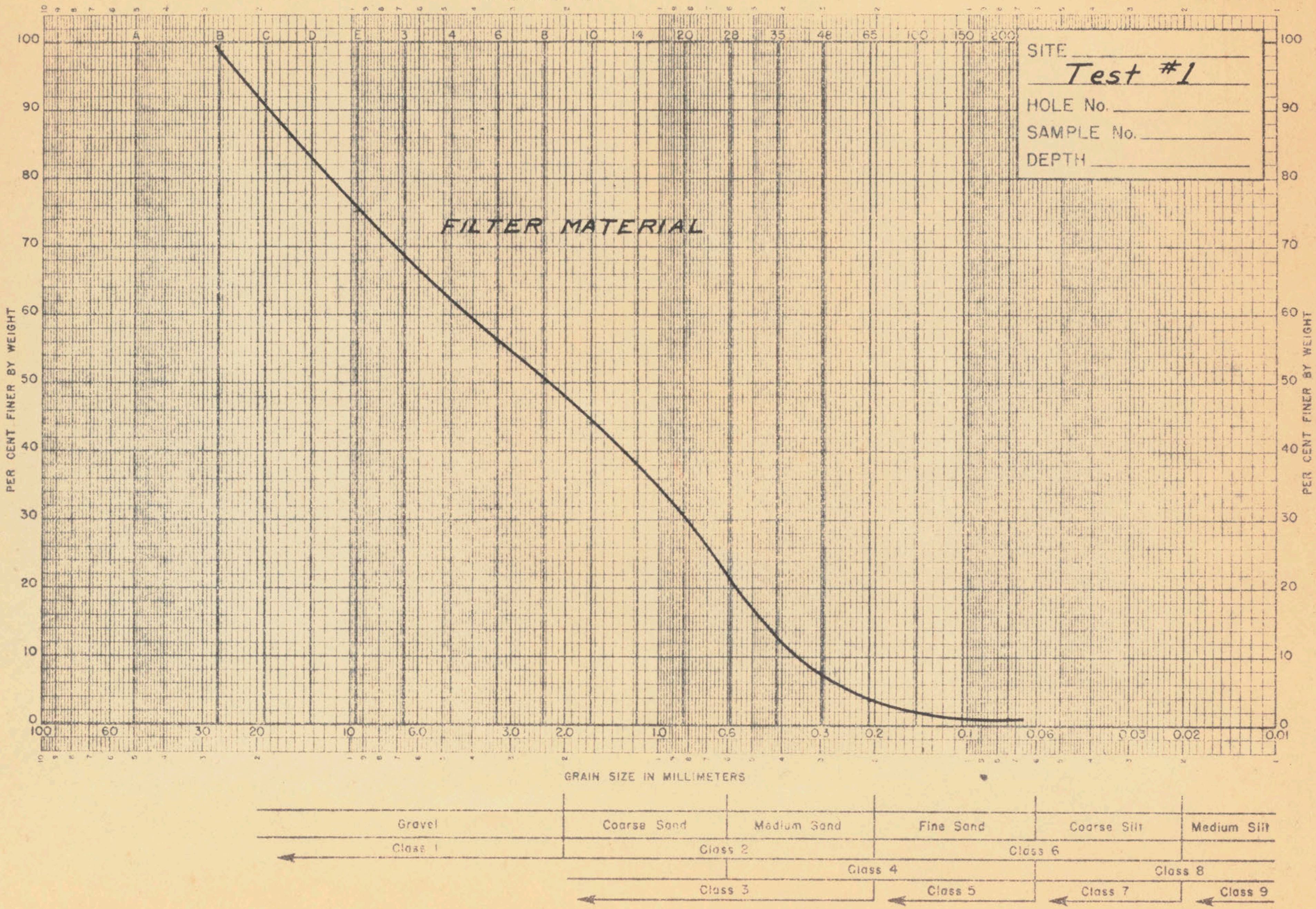


SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S.L. FORM NO. 56

U. S. GOVERNMENT PRINTING OFFICE

Date: July 31, 1940

Test No.: 2

Cylinder Area: 67.3 sq.cm.

Cylinder Length: 8 in.

Total Time: - hr, 10 min.

Avg. Temp.: 20.8 °C

Head: 114.9 cm.

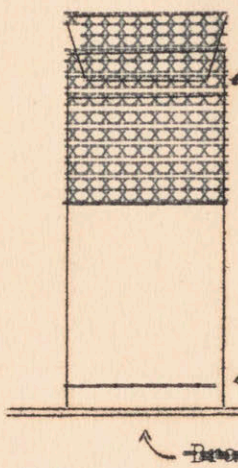
Gradient: 20.1

Permeability:
k_{10} = - x 10^{-4} cm./sec.

SAMPLE

	Filter	Base
Weight:	767 g.	- g.
Sp. Gravity:	2.74	-
Length:	5.7 cm.	- cm.
Void Ratio:	0.370	-
Compaction:	42 %	- %
Unif. Coef.:	16.8	
Eff. Size:	0.37 mm.	- mm.
Grain Sizes:		
10%	0.37 mm.	- mm.
60%	6.2 mm.	- mm.
15%	0.46 mm.	- mm.
50%	2.9 mm.	- mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = -
15% Filter: 50% Base = -



COMMENTS:

Complete failure.

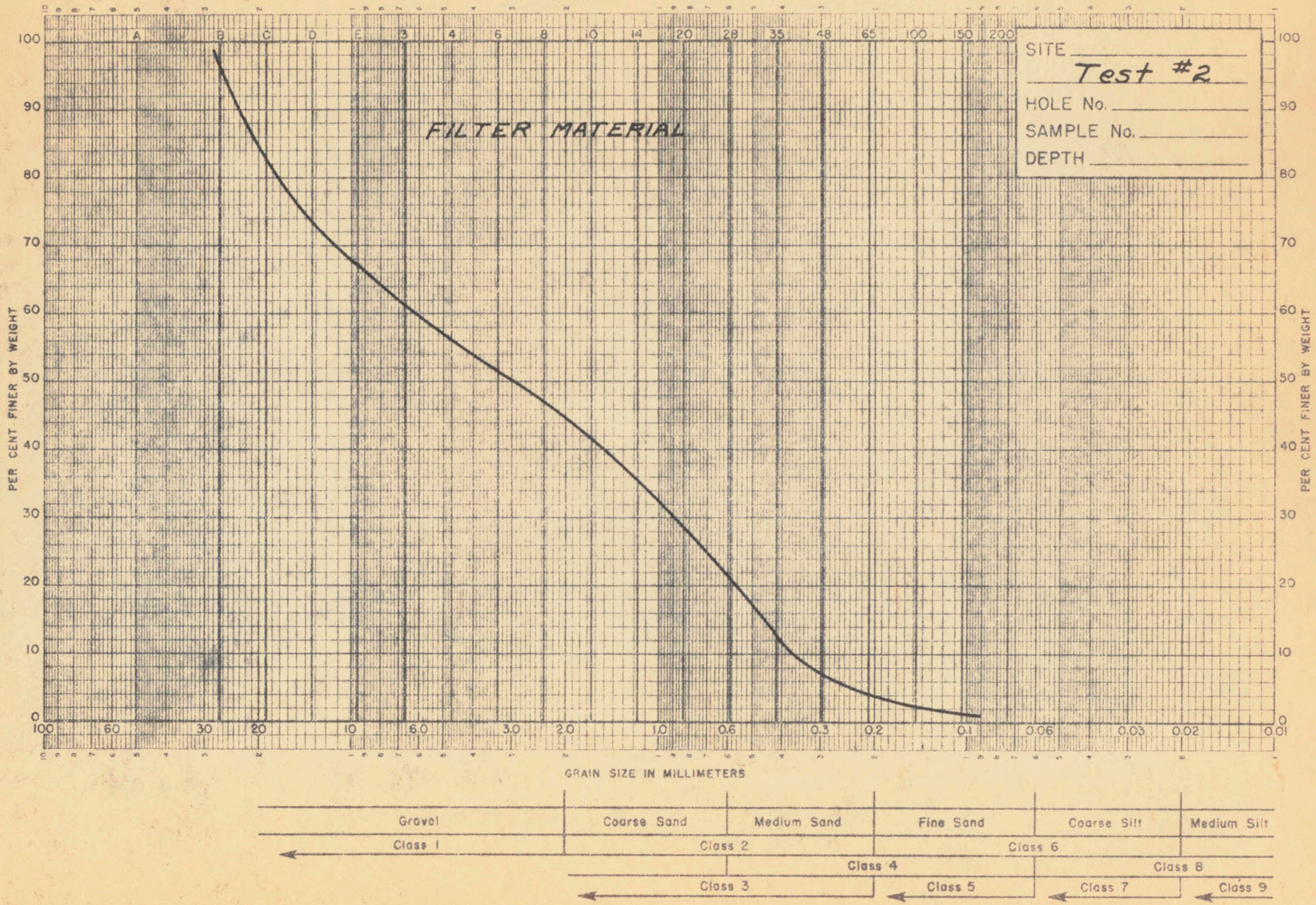
Natural run of bank filter material.

Packed dry.

Sample packed as shown, saturated by gradually allowing water to enter from bottom. No failure during saturation but immediately after total head was applied the sample heaved creating a large pipe hole 1.5 cm. in diameter near edge of cylinder. More finer material washed out as test continued. Heaving due to excessive gradient with no protection for material.

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY



SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S.L. FORM NO. 58

U. S. GOVERNMENT PRINTING OFFICE 192821

Date: July 31, 1940

Test No.: 3

Cylinder Area: 67.3 sq.cm.

Cylinder Length: 8 in.

Total Time: 7 hr. 0 min.

Avg. Temp.: 21.1 °C

Head: 130.1 cm.

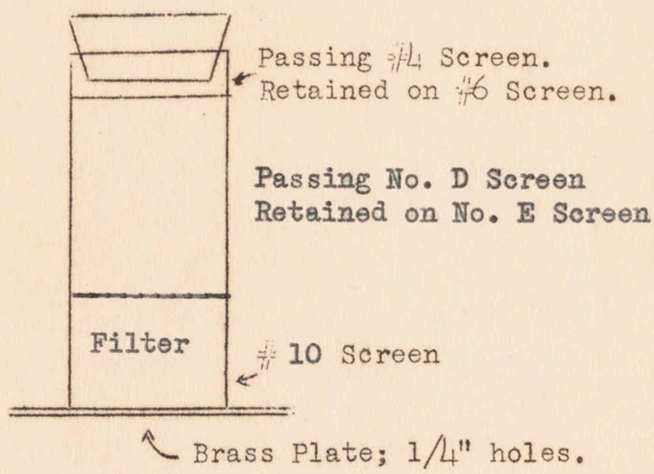
Gradient: 14.2

Permeability:
k_{10} = 99.5 x 10^{-4} cm./sec.

SAMPLE

	Filter	Base
Weight:	1282 g.	- g.
Sp. Gravity:	2.74	
Length:	9.2 cm.	- cm.
Void Ratio:	0.325	
Compaction:	65 %	- %
Unif. Coef.:	17.7	
Eff. Size:	0.35 mm.	- mm.
Grain Sizes:		
10%	0.35 mm.	- mm.
60%	6.20 mm.	- mm.
15%	0.44 mm.	- mm.
50%	2.90 mm.	- mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = -
15% Filter: 50% Base = -



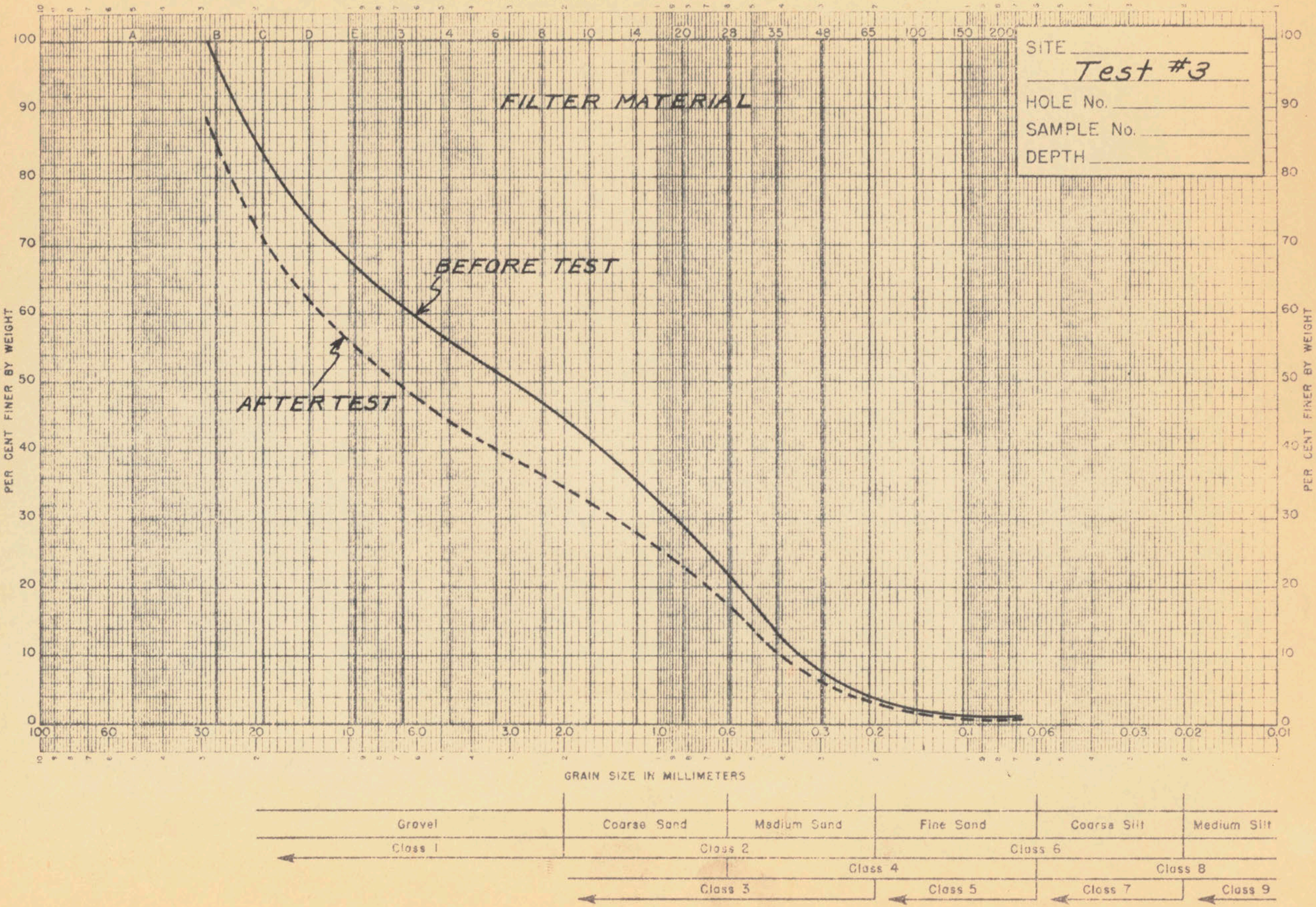
COMMENTS:

Stable.

Filter material only used; supported on a No. 10 screen.

Material packed dry.

No movement of particles noted in body of sample during test. Washing out of fines was apparent for only about 0.5 cm from the bottom. Fines passing the No. 10 screen weighed 14 g dry. The top 6 cm of sample were analysed after test.



U. S. GOVERNMENT PRINTING OFFICE

Date: July 31, 1940

Test No.: 4

Cylinder Area: 67.3 sq.cm.

Cylinder Length: 8 in.

Total Time: 10 hr. 30 min.

Avg. Temp.: 20.8 °C

Head: 130.1 cm.

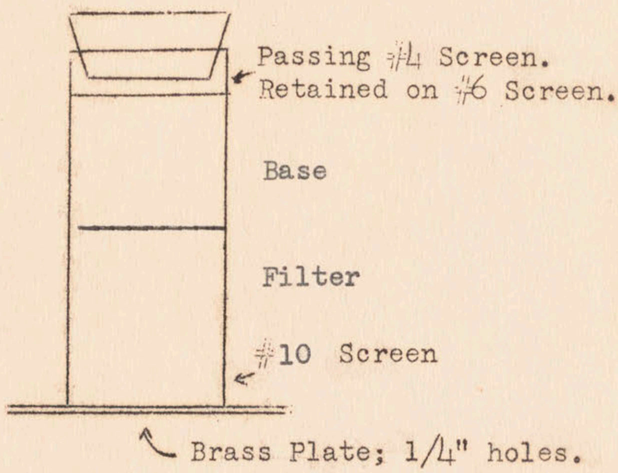
Gradient: 8.3

Permeability:
k_{10} = 168 x 10^{-4} cm./sec.

SAMPLE

	Filter	Base
Weight:	1294 g.	745 g.
Sp. Gravity:	2.74	2.71
Length:	9.2 cm.	6.4 cm.
Void Ratio:	0.308	0.567
Compaction:	73 %	66 %
Unif. Coef.:	25.7	3.4
Eff. Size:	0.35 mm.	0.25mm.
Grain Sizes:		
10%	0.35 mm.	0.25 mm.
60%	9.0 mm.	0.86 mm.
15%	0.45 mm.	0.28 mm.
50%	4.3 mm.	0.63 mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 1.6
15% Filter: 50% Base = 0.72



COMMENTS:

Very stable.

Filter. - Natural run of bank.

Packed dry.

No failure noted through tube at any time during saturation or during test. Tap water only used. Considerable air noted in voids toward end of run. Concluded that failure practically impossible with this combination. Fines passing through screen too small to weigh. No analysis of material after test.

WAR DEPARTMENT

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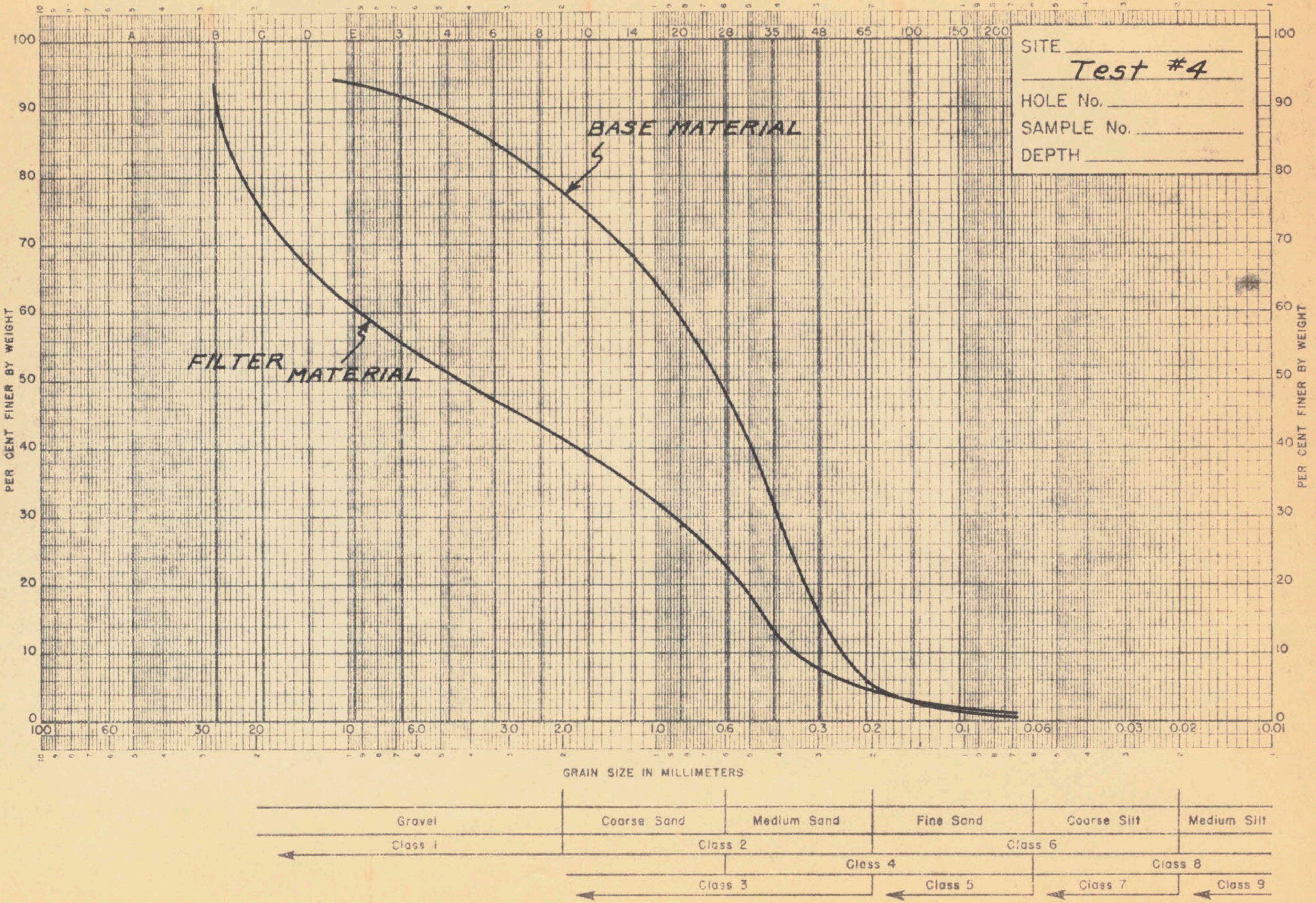


SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S. L. FORM NO. 56

U. S. GOVERNMENT PRINTING OFFICE 192621

Date: August 1, 1940

Test No.: 5

Cylinder Area: 67.1 sq.cm.

Cylinder Length: 8 in.

Total Time: 3 hr. 0 min.

Avg. Temp.: 20.1 °C

Head: 130.1 cm.

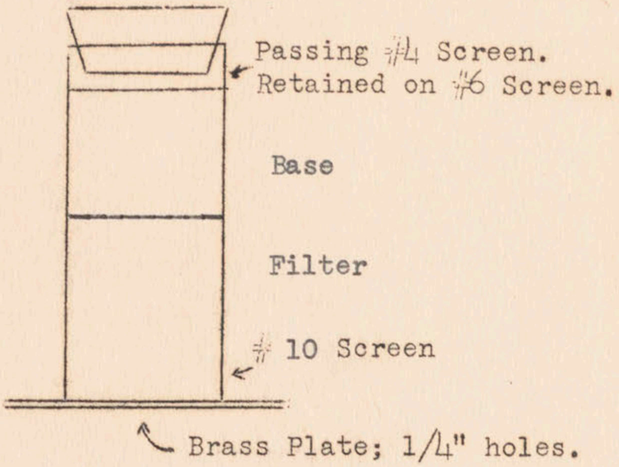
Gradient: 24.6

Permeability:
k_{10} = 352 x 10^{-4} cm./sec.

SAMPLE

	Filter	Base
Weight:	1355 g.	608 g.
Sp. Gravity:	2.74	2.71
Length:	11.9 cm.	5.3 cm.
Void Ratio:	0.618	0.589
Compaction:	- %	58 %
Unif. Coef.:	3.1	3.2
Eff. Size:	6.2 mm.	0.22 mm.
Grain Sizes:		
10%	6.2 mm.	0.22 mm.
60%	19.0 mm.	0.71 mm.
15%	7.1 mm.	0.25 mm.
50%	15.5 mm.	0.60 mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 28.4
15% Filter: 50% Base = 11.8



COMMENTS:

Failure.

Filter. - Wasting all particles passing No. 4 screen.

Packed dry.

Considerable failure observed in dry materials when sample was inverted.

67g fines washed through No. 10 screen. Since mechanical analysis of top portion of base material changed very little during test it is believed that settlement of dry material when sample was inverted led to eventual failure. Mechanical analysis after test made on top 1.4 cm. of base and bottom 10.1 cm. of filter.

WAR DEPARTMENT

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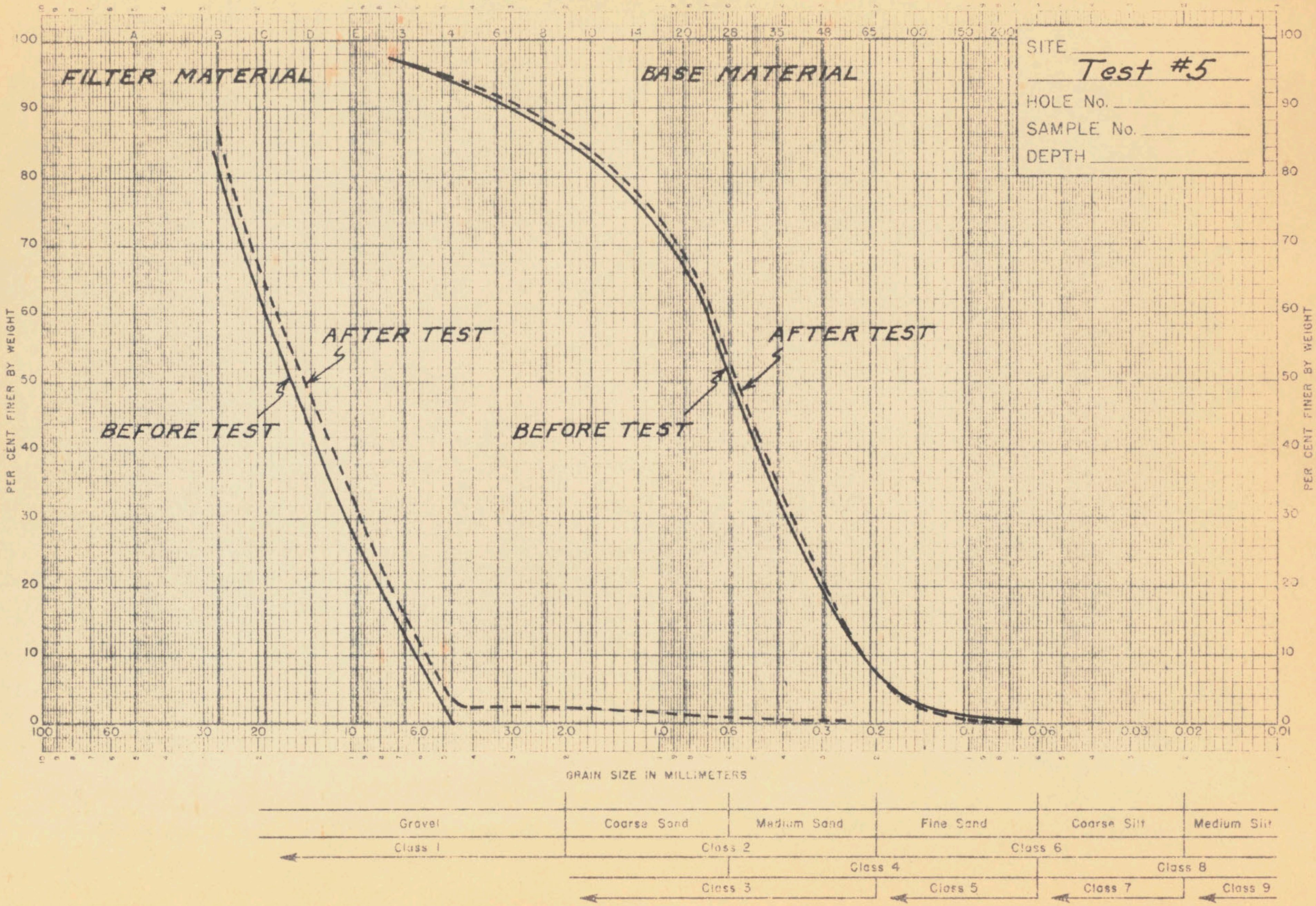


SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S L FORM NO 58

U. S. GOVERNMENT PRINTING OFFICE 102691

Date: August 2, 1940

Test No.: 5-A

Cylinder Area: 67.1 sq.cm.

Cylinder Length: 8 in.

Total Time: 1 hr. 15 min.

Avg. Temp.: 20.3 °C

Head: 130.1 cm.

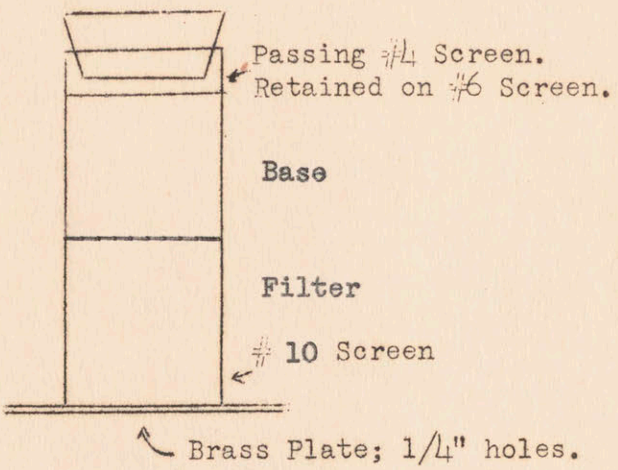
Gradient: 21.4

Permeability:
k_{10} = 243 x 10^{-4} cm./sec.

SAMPLE

	Filter		Base	
Weight:	1289	g.	717	g.
Sp. Gravity:	2.74		2.71	
Length:	11.2	cm.	6.1	cm.
Void Ratio:	0.595		0.549	
Compaction:	-	%	71	%
Unif. Coef.:	2.86		3.54	
Eff. Size:	6.3	mm.	0.24	mm.
Grain Sizes:				
10%	6.3	mm.	0.24	mm.
60%	18.0	mm.	0.85	mm.
15%	7.2	mm.	0.29	mm.
50%	15.0	mm.	0.58	mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 24.8
15% Filter: 50% Base = 12.4



COMMENTS:

Very stable.

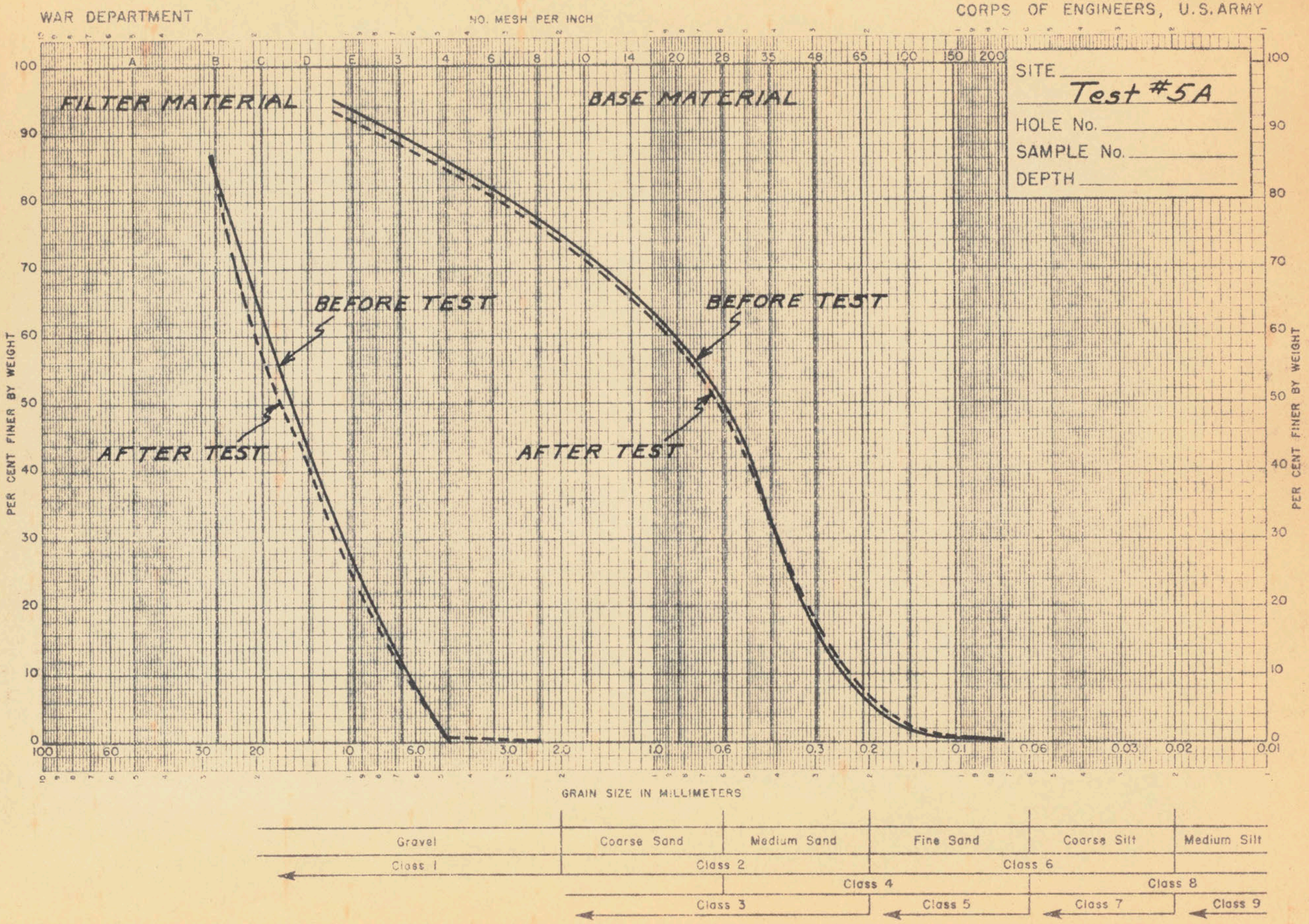
Filter. - Wasting all particles passing No. 4 screen.

Packed dry.

Special care was taken with tamping and saturating in this case to avoid the conditions of the previous test. No noticeable settlement of the base occurred during any part of the operation. Amount of fines passing the No. 10 screen was negligible. 10 cm of the filter and 4.5 cm of base were analysed after test.

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY



SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S.L. FORM NO.58

Date: August 2, 1940

Test No.: 6

Cylinder Area: 67.1 sq.cm.

Cylinder Length: 8 in.

Total Time: 6 hr. 30 min.

Avg. Temp.: 20.1 °C

Head: 130.1 cm.

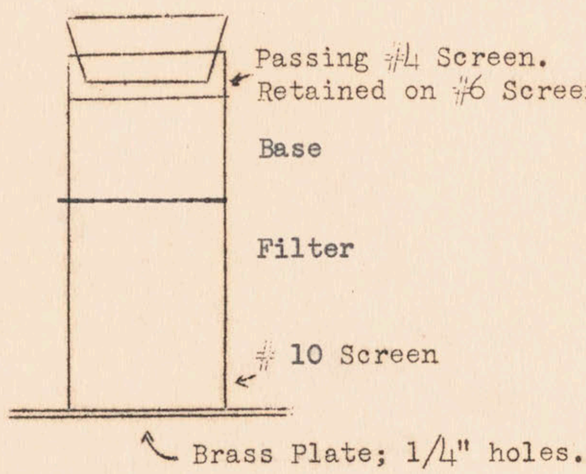
Gradient: 20.7

Permeability:
k_{10} = 250 x 10^{-4} cm./sec.

SAMPLE

	Filter	Base
Weight:	1281 g.	751 g.
Sp. Gravity:	2.74	2.71
Length:	10.8 cm.	6.3 cm.
Void Ratio:	0.548	0.527
Compaction:	- %	79 %
Unif. Coef.:	2.20	4.35
Eff. Size:	8.2 mm.	0.23 mm.
Grain Sizes:		
10%	8.2 mm.	0.23 mm.
60%	18.0 mm.	1.00 mm.
15%	9.2 mm.	0.28 mm.
50%	16.0 mm.	0.67 mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 32.9
15% Filter: 50% Base = 13.7



COMMENTS:

Stable.

Filter. - Wasting particles passing No. 3 screen.

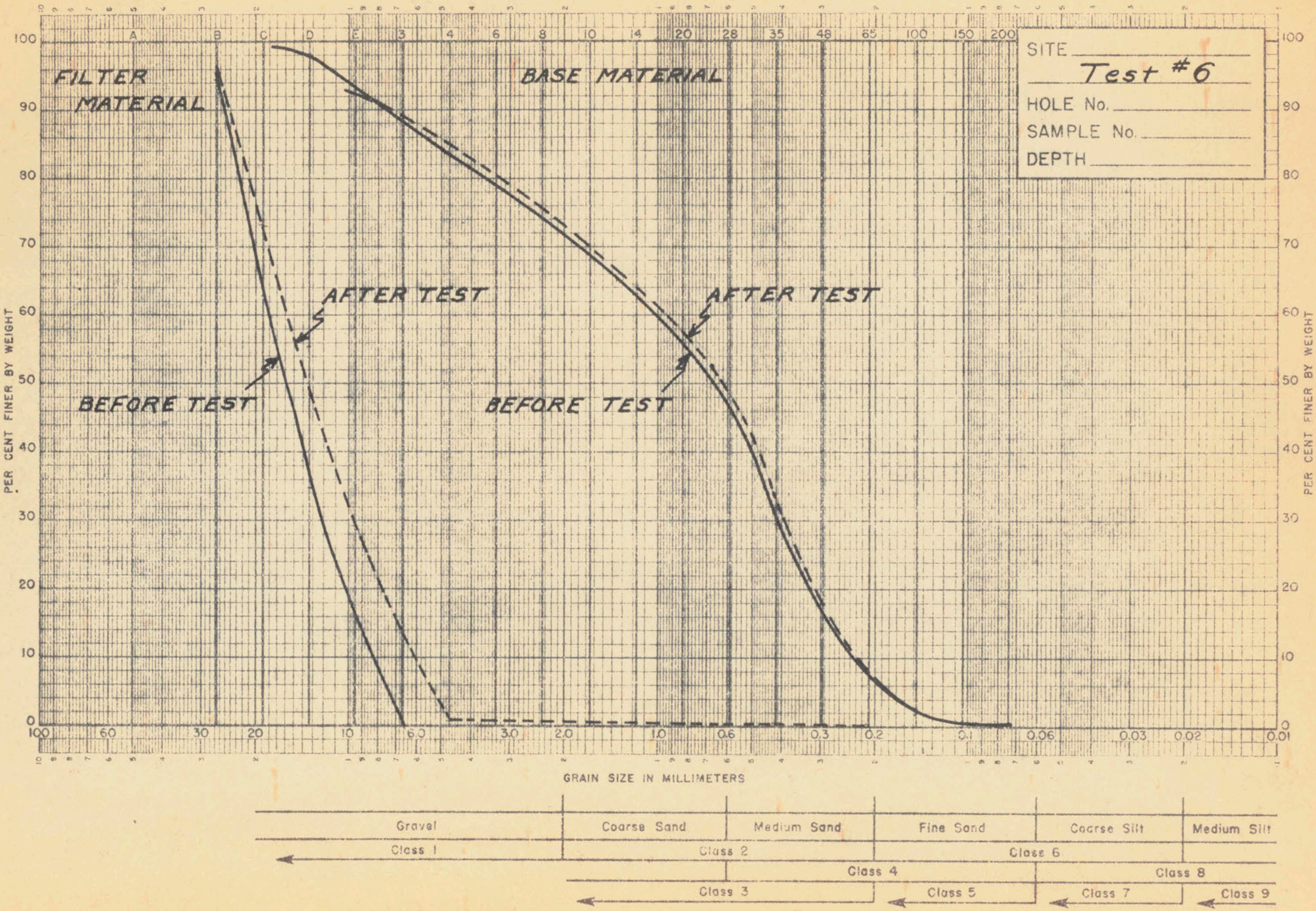
Packed dry.

No failure noted when inverted. Slight gap of about one cm. by 1.5 cm. formed during test. This believed due to a large void in filter. Sample quickly reached stability.

4g fines washed through No. 10 screen. Mechanical analysis run on top 3.5 cm. of base and bottom 6 cm. of filter. Practically no change noted in base material, indicating stability.

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY



SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S.L. FORM NO 58

U. S. GOVERNMENT PRINTING OFFICE 192621

Date: August 5, 1940

Test No.: 6-A

Cylinder Area: 67.1 sq.cm.

Cylinder Length: 8 in.

Total Time: 0 hr. 40 min.

Avg. Temp.: 28.0 °C

Head: 126.3 cm.

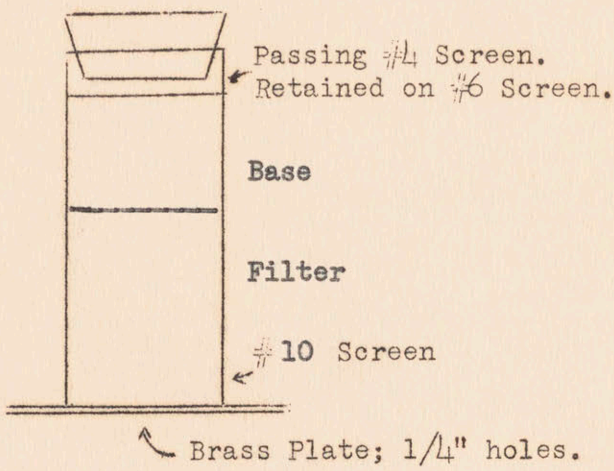
Gradient: 20.4

Permeability:
k_{10} = 287 x 10^{-4} cm./sec.

SAMPLE

	Filter	Base
Weight:	1223 g.	748 g.
Sp. Gravity:	2.74	2.71
Length:	10.8 cm.	6.2 cm.
Void Ratio:	0.622	0.507
Compaction:	- %	85 %
Unif. Coef.:	2.35	3.65
Eff. Size:	8.1 mm.	0.23 mm.
Grain Sizes:		
10%	8.1 mm.	0.23 mm.
60%	19.0 mm.	0.84 mm.
15%	9.0 mm.	0.29 mm.
50%	16.0 mm.	0.62 mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 31.0
15% Filter: 50% Base = 14.5



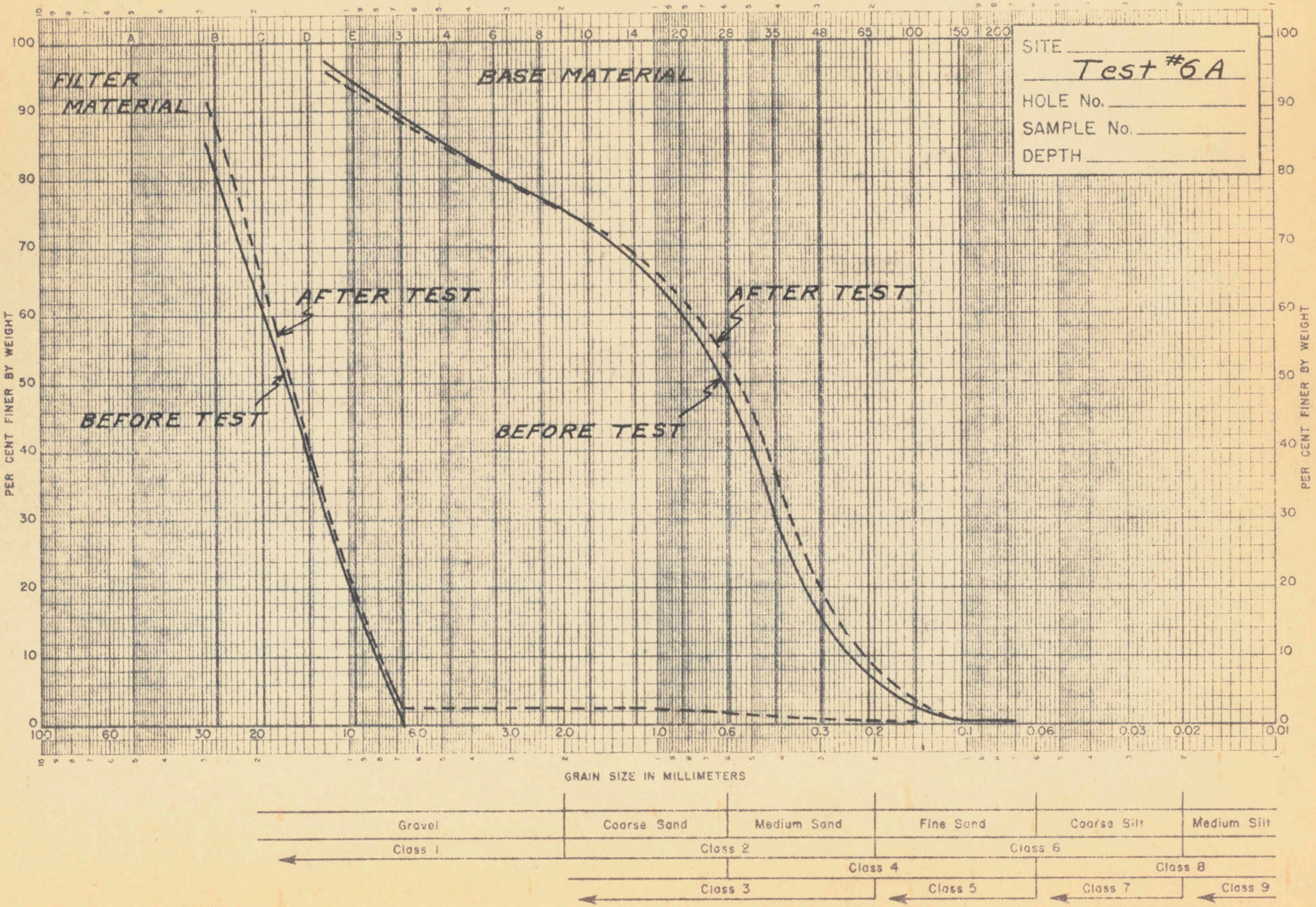
COMMENTS:

Stable.

Filter: Wasting particles passing No. 3 screen.

Packed dry.

Very slight settlement of base into filter when tube was inverted, which continued to a very small degree during the run. De-aired water was used during entire test to check Test No. 6 which used tap water. Limited supply of de-aired water accounted for short run. 16 g dry weight of fines passed No. 10 screen. 9.5 cm of filter from the bottom and 4 cm of base from the top were analysed after test.



U. S. GOVERNMENT PRINTING OFFICE

Date: August 20, 1940

Test No.: 6-B

Cylinder Area: 159.3 sq.cm.

Cylinder Length: 16 in.

Total Time: 43 hr. 45 min.

Avg. Temp.: 20.0 °C

Head: 40.0 cm.

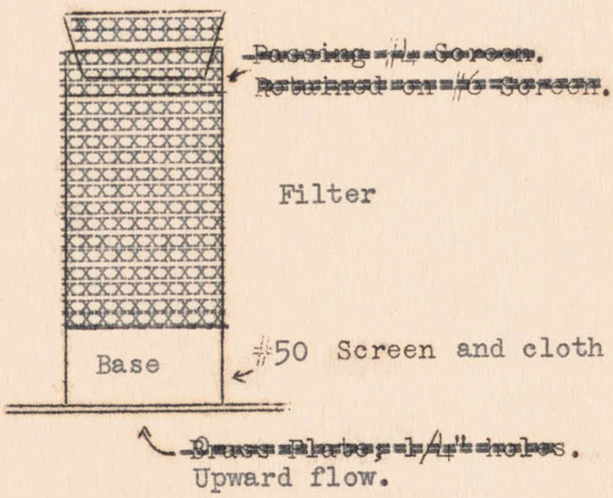
Gradient: 5.63

Permeability:
k_{10} = - x 10^{-4} cm./sec.

SAMPLE

	Filter	Base
Weight:	9460 g.	2010 g.
Sp. Gravity:	2.74	2.71
Length:	33.7 cm.	7.1 cm.
Void Ratio:	0.557	0.525
Compaction:	- %	80 %
Unif. Coef.:	2.25	3.26
Eff. Size:	8.0 mm.	0.27 mm.
Grain Sizes:		
10%	8.0 mm.	0.27 mm.
60%	18.0 mm.	0.88 mm.
15%	9.0 mm.	0.32 mm.
50%	16.0 mm.	0.63 mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 28.1
15% Filter: 50% Base = 14.3



COMMENTS:

Very stable.

Filter. - Wasting all particles passing No.3 screen.

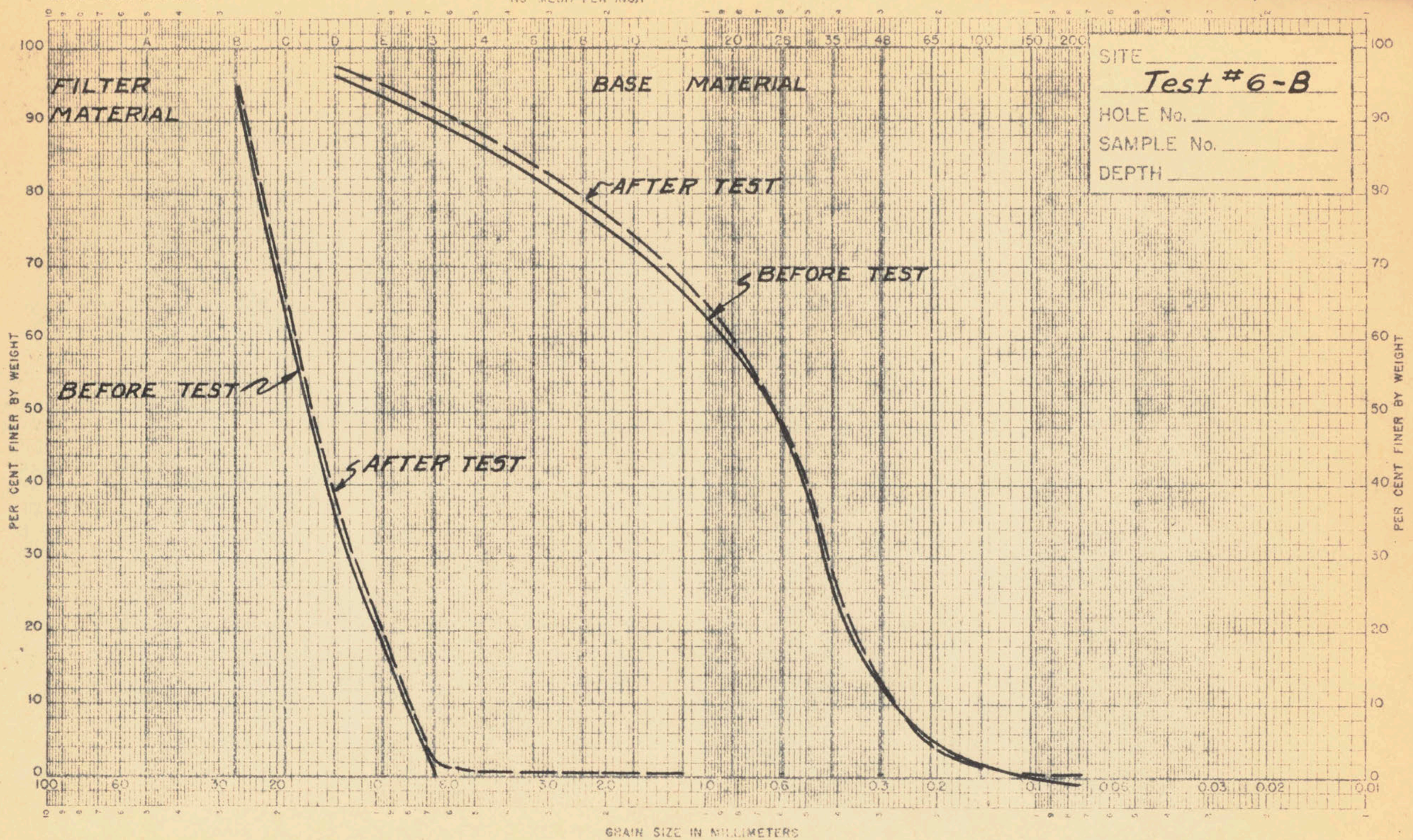
Base packed dry as densely as possible, with care to avoid any segregation. Sample was saturated very slowly from the bottom, and the head of 40 cm. applied gradually. Head limited to 40 cm. to prevent heaving of sample unrestrained on top.

No movement or disturbance of base particles observed during test. Considerable air collected in base. Upon dismantling base appeared as sound and firm as when packed. No fines noted in filter.

Filter between 1 cm. and 3 cm. above base and 5.9 cm. of base material analysed after test.

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY



Gravel	Coarse Sand	Medium Sand	Fine Sand	Course Silt	Medium Silt
Class 1	Class 2		Class 6		
		Class 4		Class 8	
	Class 3		Class 5	Class 7	Class 9

SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S.L. FORM NO. 58

U. S. GOVERNMENT PRINTING OFFICE

SAMPLE

	Filter		Base	
Weight:	1237	g.	714	g.
Sp. Gravity:	2.74		2.71	
Length:	10.8	cm.	6.1	cm.
Void Ratio:	0.608		0.558	
Compaction:	-	%	69	%
Unif. Coef.:	2.01		3.20	
Eff. Size:	10.9	mm.	0.25	mm.
Grain Sizes:				
10%	10.9	mm.	0.25	mm.
60%	21.9	mm.	0.80	mm.
15%	11.7	mm.	0.29	mm.
50%	19.4	mm.	0.60	mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 40.3
15% Filter: 50% Base = 19.5

Date: August 3, 1940

Test No.: 7

Cylinder Area: 67.1 sq.cm.

Cylinder Length: 8 in.

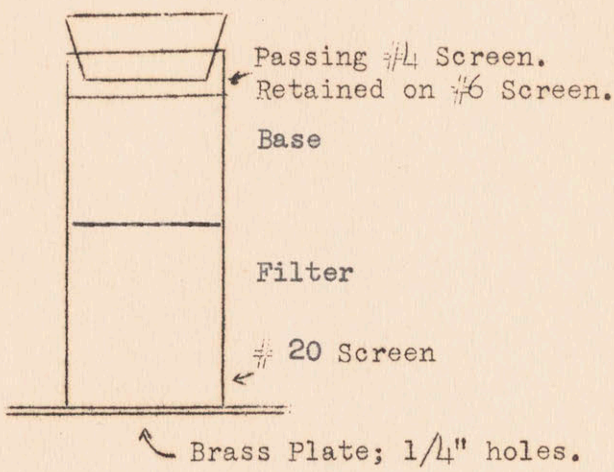
Total Time: 0 hr. 0 min.

Avg. Temp.: - °C

Head: - cm.

Gradient: -

Permeability:
k_{10} = - x 10^{-4} cm./sec.



COMMENTS:

Complete failure.

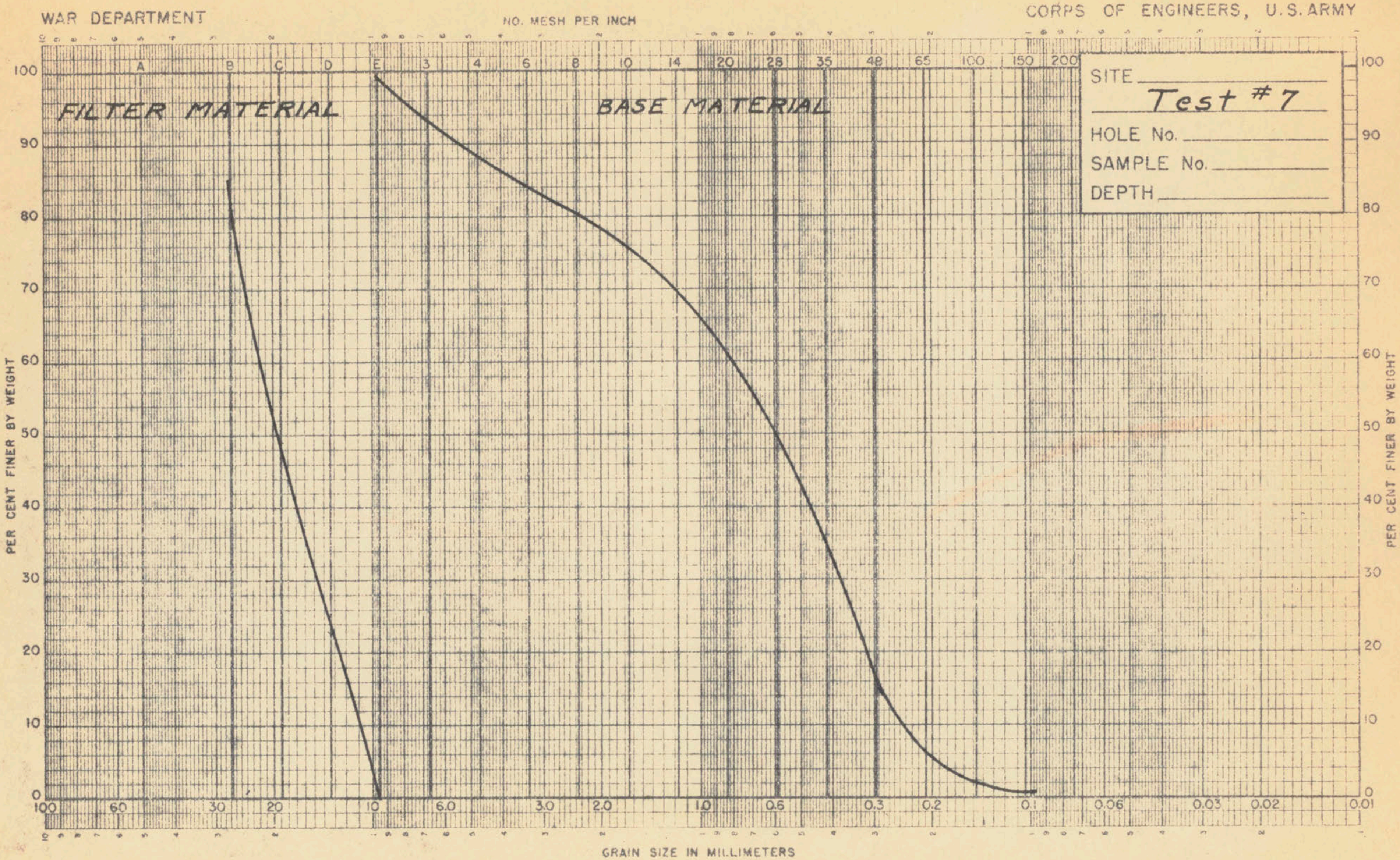
Filter. - Wasting particles passing No. E screen.

Packed dry.

Sample was packed as usual but failed when inverted, the finer particles of the base running down to fill the large voids in the filter. Decided to pack a similar sample moistening base to hold it in place until saturated. See test 7-A. No mechanical analysis taken after failure.

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY



Gravel | Coarse Sand | Medium Sand | Fine Sand | Coarse Silt | Medium Silt

Class 1 | Class 2 | Class 6

Class 4 | Class 8

Class 3 | Class 5 | Class 7 | Class 9

SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S.L. FORM NO. 56

U. S. GOVERNMENT PRINTING OFFICE 192621

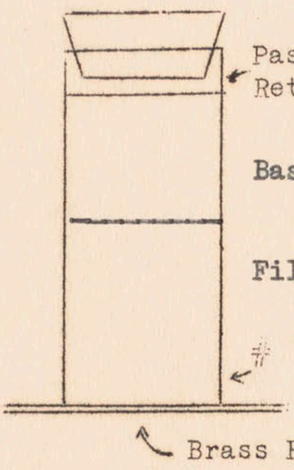
Date:	August 3, 1940		
Test No.:	7-A		
Cylinder Area:	67.1 sq.cm.		
Cylinder Length:	8 in.		
Total Time:	1 hr.30 min.		
Avg. Temp.:	20.3 °C		
Head:	130.1 cm.		
Gradient:	20.4		

Permeability:
k_{10} = - x 10^{-4} cm./sec.

SAMPLE

	Filter	Base
Weight:	1184 g.	757 g.
Sp. Gravity:	2.74	2.71
Length:	10.5 cm.	6.4 cm.
Void Ratio:	0.628	0.538
Compaction:	- %	75 %
Unif. Coef.:	2.00	3.28
Eff. Size:	11.0 mm.	0.25 mm.
Grain Sizes:		
10%	11.0 mm.	0.25 mm.
60%	22.0 mm.	0.82 mm.
15%	11.8 mm.	0.29 mm.
50%	20.0 mm.	0.60 mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 40.7
15% Filter: 50% Base = 19.7



COMMENTS:

Failure.

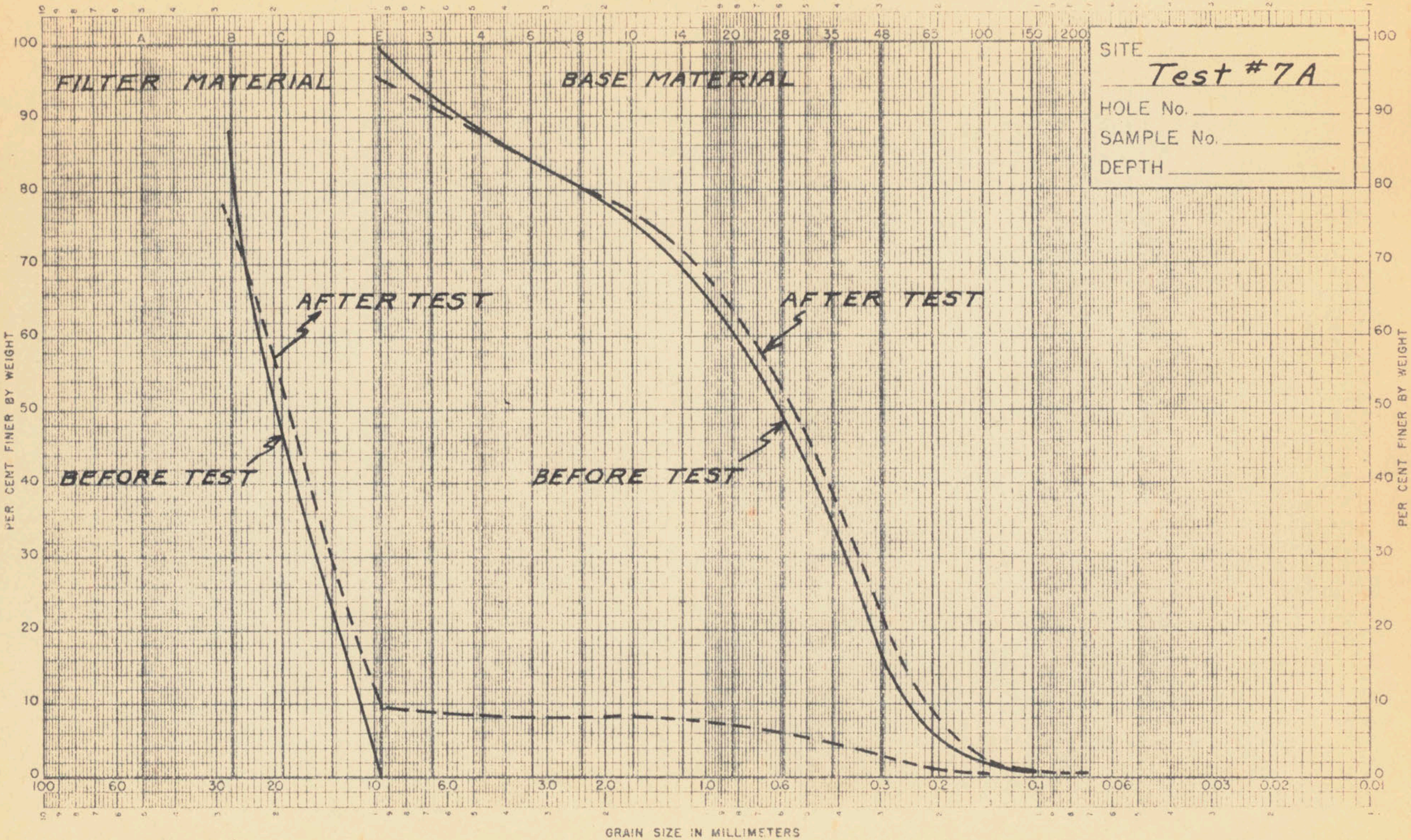
Filter: Wasting all particles below No. E screen.

Base packed in 1 cm layers, dry; each layer then slightly moistened to obtain some cohesion and prevent failure when tube was inverted. The base held until saturating de-aired water reached it from the bottom. The base settled to such an extent that a void about 1 cm long was left on top; the voids in the filter appeared to fill up with a large amount of sand from the base. Tap water was subsequently run through sample but no further failure resulted.

5 g dry weight of fines passed the No. 20 screen, 8.5 cm of filter from the bottom and about 3 cm of base from the top were analysed after the test.

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY



Gravel	Coarse Sand	Medium Sand	Fine Sand	Coarse Silt	Medium Silt

Class 1 | Class 2 | Class 6

Class 4 | Class 8

Class 3 | Class 5 | Class 7 | Class 9

SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S.L. FORM NO.59

U. S. GOVERNMENT PRINTING OFFICE 192621

Date: August 17, 1940

Test No.: 7-B

Cylinder Area: 159.3 sq.cm.

Cylinder Length: 16 in.

Total Time: 25 hr. - min.

Avg. Temp.: 20.0 °C

Head: 36.7 cm.

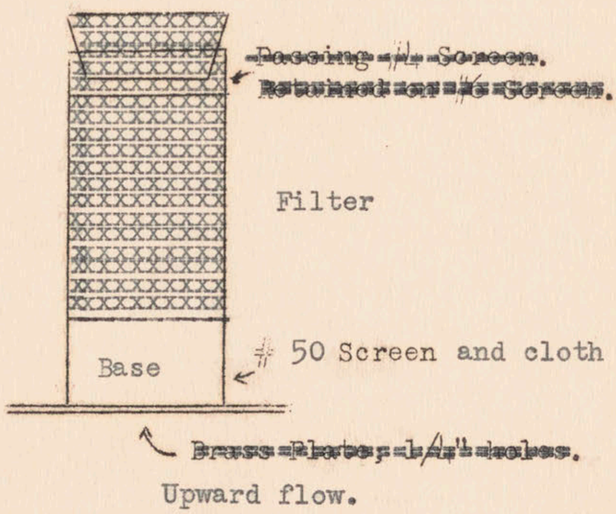
Gradient: 10.2

Permeability:
k_{10} = - x 10^{-4} cm./sec.

SAMPLE

	Filter	Base
Weight:	10,007 g.	991 g.
Sp. Gravity:	2.74	2.71
Length:	37.1 cm.	3.6 cm.
Void Ratio:	0.620	0.573
Compaction:	- %	64 %
Unif. Coef.:	2.09	3.08
Eff. Size:	11.0 mm.	0.24 mm.
Grain Sizes:		
10%	11.0 mm.	0.24 mm.
60%	23.0 mm.	0.74 mm.
15%	11.7 mm.	0.28 mm.
50%	20.7 mm.	0.57 mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 41.8
15% Filter: 50% Base = 20.5

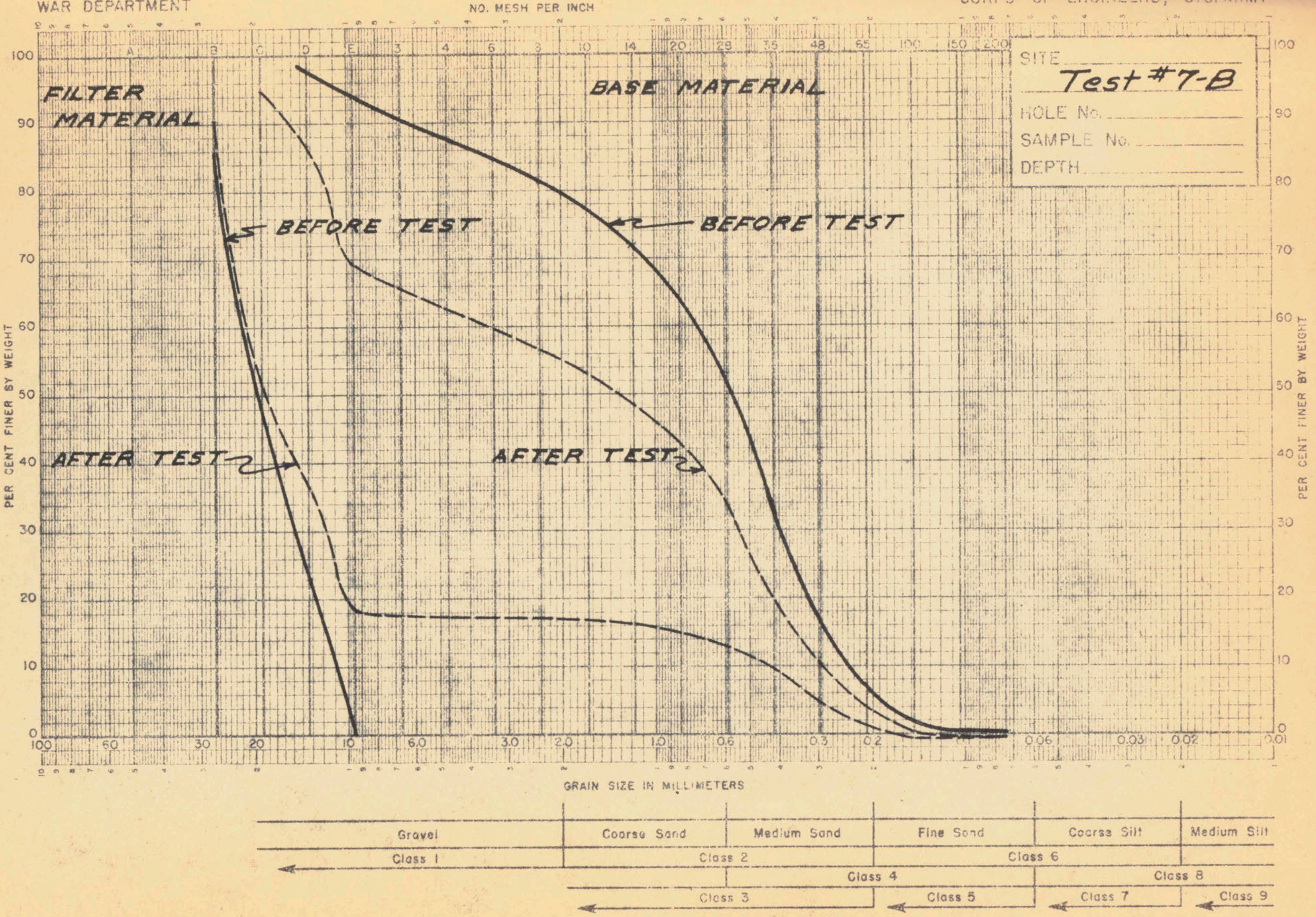


COMMENTS:

Complete failure.

Filter. - Wasting all particles below No. E screen.

Base packed as densely as possible for such a large diameter and short length. Entire sample saturated very slowly from bottom with de-aired water. No disturbance noted during saturation. A head of 28.2 cm. was applied gradually. Flotation of a few of the upper particles of the base occurred very quickly. When the full head was reached, base particles over a considerable area were violently jumping about. During two hours under the 28.2 cm. head fines washed as high as 8 cm. into the filter. Some filter gravel dropped into cavities caused by failure of base. Balance of test under 36.7 cm. head. Fines washed up to 20 cm. above original top of base. Filter between 2 and 6 cm. above original top of base and 2.7 cm. of base material were analysed after test.



SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S.L. FORM NO. 58

U. S. GOVERNMENT PRINTING OFFICE 102621

SAMPLE	Filter	Base
Weight:	1246 g.	734 g.
Sp. Gravity:	2.74	2.71
Length:	11.1 cm.	6.1 cm.
Void Ratio:	0.642	0.509
Compaction:	- %	85 %
Unif. Coef.:	1.16	3.4
Eff. Size:	14.0 mm.	0.24 mm.
Grain Sizes:		
10%	14.0 mm.	0.24 mm.
60%	16.3 mm.	0.82 mm.
15%	14.0 mm.	0.29 mm.
50%	16.0 mm.	0.61 mm.

Date: August 5, 1940

Test No.: 8

Cylinder Area: 67.1 sq.cm.

Cylinder Length: 8 in.

Total Time: 1 hr. 15 min.

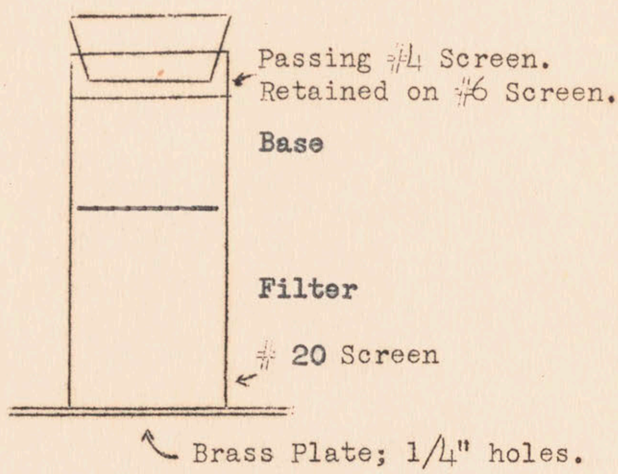
Avg. Temp.: 19.8 °C

Head: 130.1 cm.

Gradient: 21.4

Permeability:
$k_{10} = 384 \times 10^{-4}$ cm./sec.

Ratios of Grain Sizes:
15% Filter: 15% Base = 48.3
15% Filter: 50% Base = 22.9



COMMENTS:

Stable.

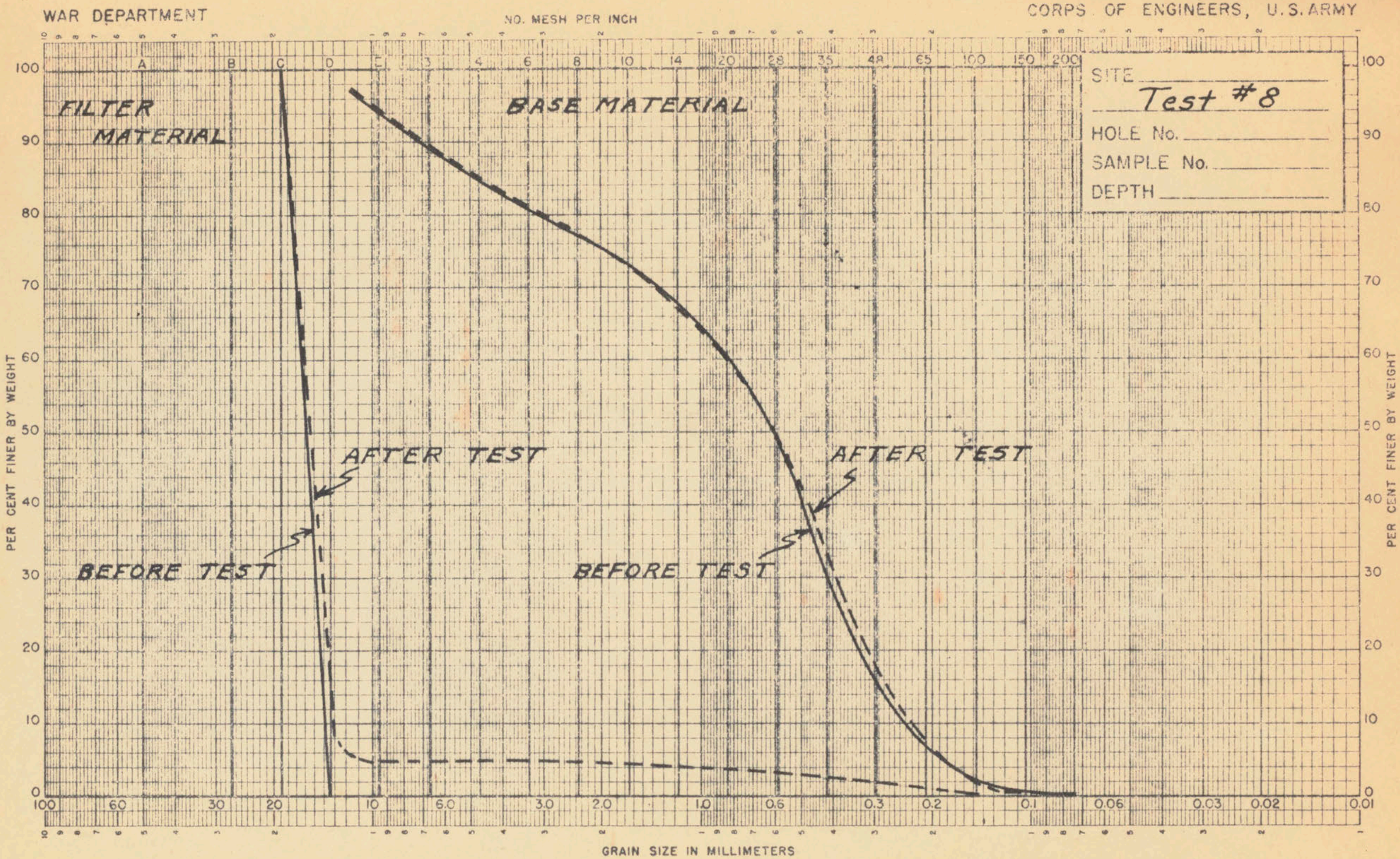
Filter: Uniform material, passing No. C screen, retained on No. D screen.

Packed dry.

Slight settlement of base into filter during early part of test, but no visible indication of definite failure. 16 g dry weight of fines passed the No. 20 screen. 7 cm of filter from bottom and 3.5 cm of base analysed after test.

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY



Gravel	Coarse Sand	Medium Sand	Fine Sand	Coarse Silt	Medium Silt
← Class 1	Class 2		Class 6		
		Class 4		Class 8	
	← Class 3		← Class 5	← Class 7	← Class 9

SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S.L. FORM NO. 58

U. S. GOVERNMENT PRINTING OFFICE 140624

Date: August 8, 1940

Test No.: 8-A

Cylinder Area: 67.4 sq.cm.

Cylinder Length: 8 in.

Total Time: 3 hr. 0 min.

Avg. Temp.: 19.9 °C

Head: 128.7 cm.

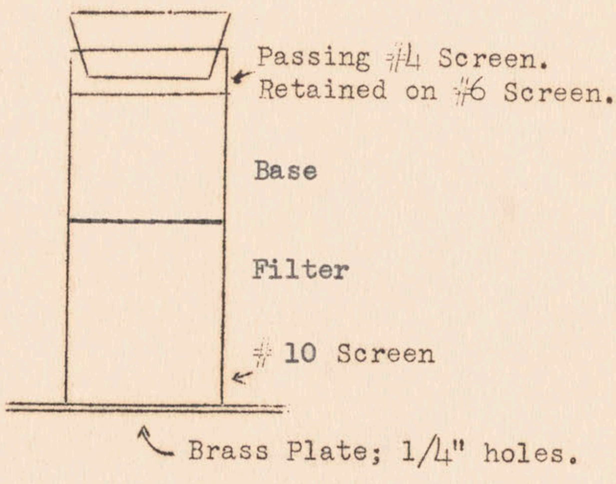
Gradient: 21.4

Permeability: -
k_{10} = - x 10^{-4} cm./sec.

SAMPLE

	Filter	Base
Weight:	1227 g.	721 g.
Sp. Gravity:	2.74	2.71
Length:	11.4 cm.	6.0 cm.
Void Ratio:	0.716	0.517
Compaction:	- %	82 %
Unif. Coef.:	1.19	3.70
Eff. Size:	13.8 mm.	0.24 mm.
Grain Sizes:		
10%	13.8 mm.	0.24 mm.
60%	16.4 mm.	0.89 mm.
15%	14.0 mm.	0.30 mm.
50%	15.9 mm.	0.64 mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 46.7
15% Filter: 50% Base = 21.9



COMMENTS:

Complete failure.

Filter. - 100% passing No. C screen, 100% retained on No. D sieve.

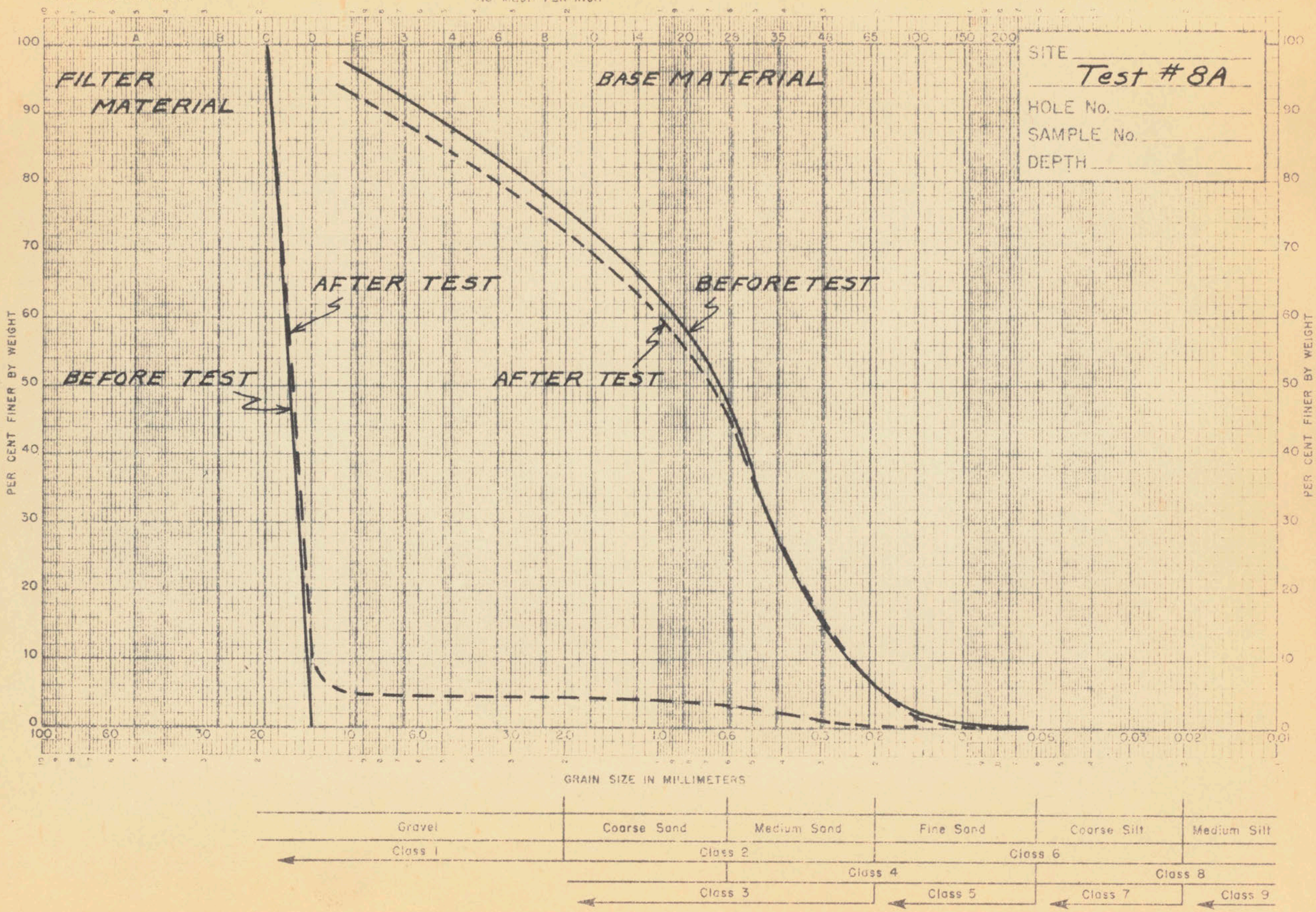
Packed dry.

Indication of failure during saturation. Sample subjected to downward flow as usual to check on completeness of failure. Sample continued to fail throughout test. At end of run, a large crater existed in top of base and large pipe hole was noted just inside tube.

59g of fines passed No. 10 screen. Mechanical analysis on top 3.5 cm. of base and bottom 8.2 cm. of filter.

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY



SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S.L. FORM NO 58

U. S. GOVERNMENT PRINTING OFFICE

Date: August 6, 1940

Test No.: 9

Cylinder Area: 67.1 sq.cm.

Cylinder Length: 8 in.

Total Time: - hr. - min.

Avg. Temp.: - °C

Head: - cm.

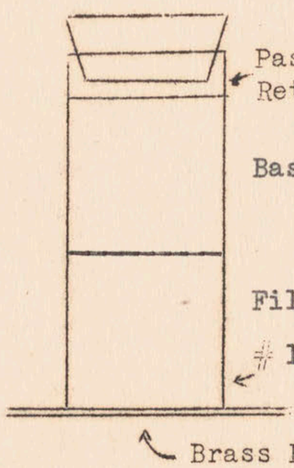
Gradient: -

Permeability:
k_{10} = - x 10^{-4} cm./sec.

SAMPLE

	Filter	Base
Weight:	1097 g.	733 g.
Sp. Gravity:	2.74	2.71
Length:	10.8 cm.	6.2 cm.
Void Ratio:	0.813	0.535
Compaction:	- %	76 %
Unif. Coef.:	1.16	4.77
Eff. Size:	19.8 mm.	0.22 mm.
Grain Sizes:		
10%	19.8 mm.	0.22 mm.
60%	23.0 mm.	1.05 mm.
15%	20.0 mm.	0.28 mm.
50%	22.4 mm.	0.70 mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 71.4
15% Filter: 50% Base = 28.6



COMMENTS:

Complete failure.

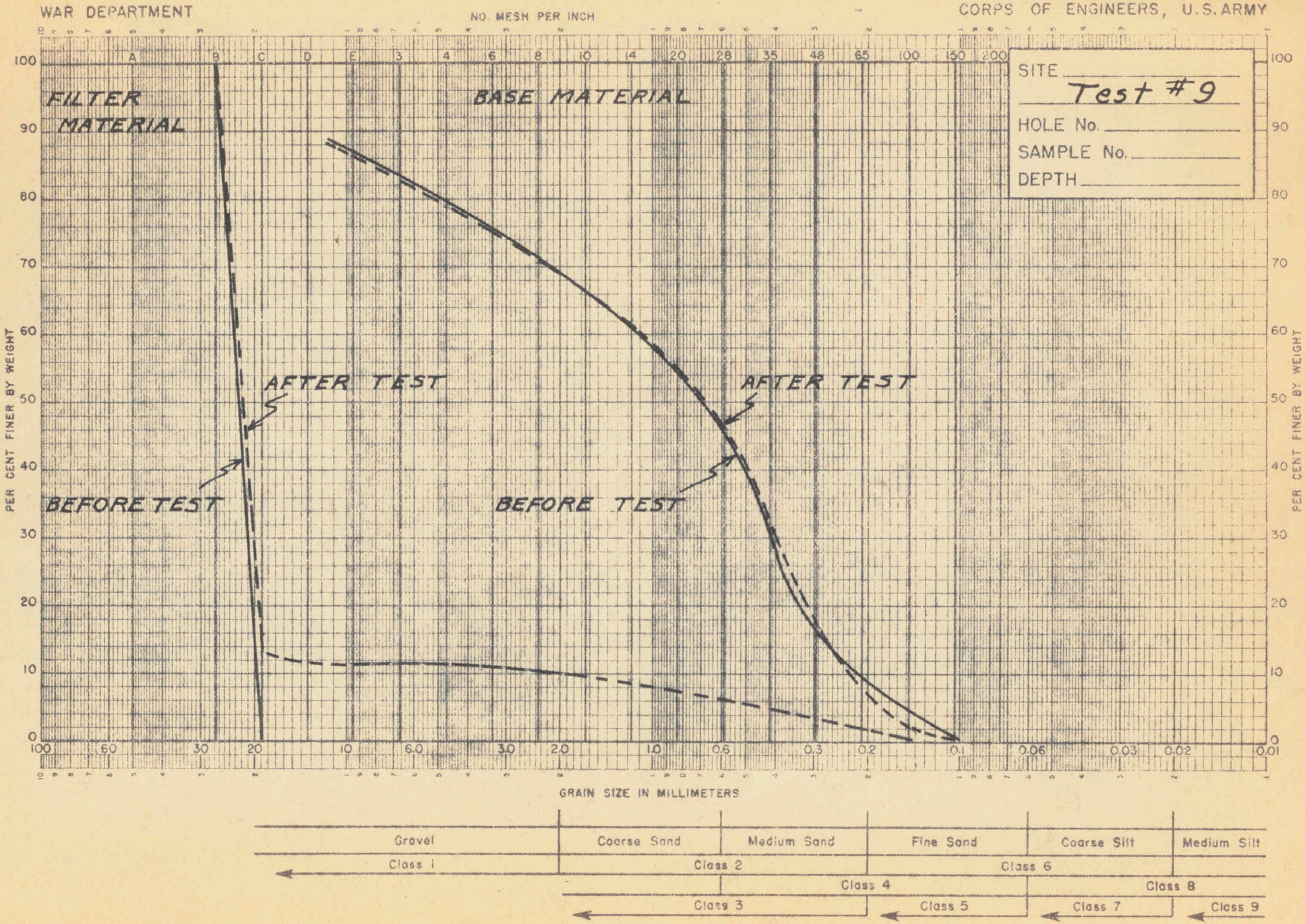
Filter. - Passing No. B screen, retained on No. C screen.

Packed dry and moistened to hold base in place when inverted.

Failure occurred while sample was being saturated. When apparent cohesion was destroyed during saturation the base material fell into the filter voids. Base material settled away from screen on top about one cm. Mechanical analysis run after test on top 3.7 cm. of base and bottom 8.7 cm. of filter.

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY



SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S.L. FORM NO.58

U. S. GOVERNMENT PRINTING OFFICE 192621

SAMPLE

	Filter	Base
Weight:	1172 g.	752 g.
Sp. Gravity:	2.74	2.71
Length:	11.2 cm.	6.2 cm.
Void Ratio:	0.758	0.502
Compaction:	- %	87 %
Unif. Coef.:	1.41	3.82
Eff. Size:	14.4 mm.	0.22 mm.
Grain Sizes:		
10%	14.4 mm.	0.22 mm.
60%	20.3 mm.	0.84 mm.
15%	15.0 mm.	0.26 mm.
50%	19.0 mm.	0.59 mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 57.7
15% Filter: 50% Base = 25.4

Date: August 6, 1940

Test No.: 10

Cylinder Area: 67.1 sq.cm.

Cylinder Length: 8 in.

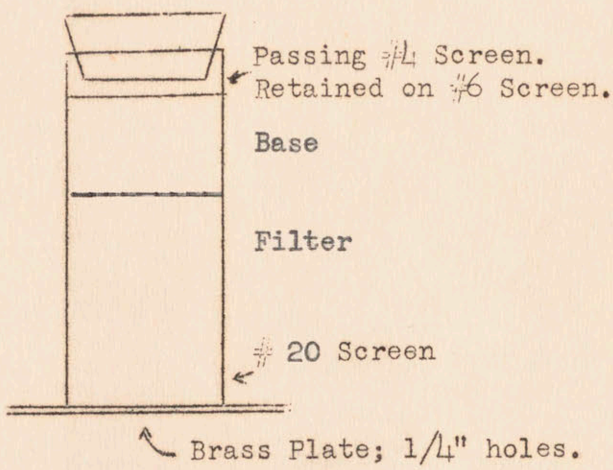
Total Time: 4 hr. 30 min.

Avg. Temp.: 20.8 °C

Head: 130.1 cm.

Gradient: 21.0

Permeability:
k_{10} = 337 x 10^{-4} cm./sec.



COMMENTS:

Complete failure.

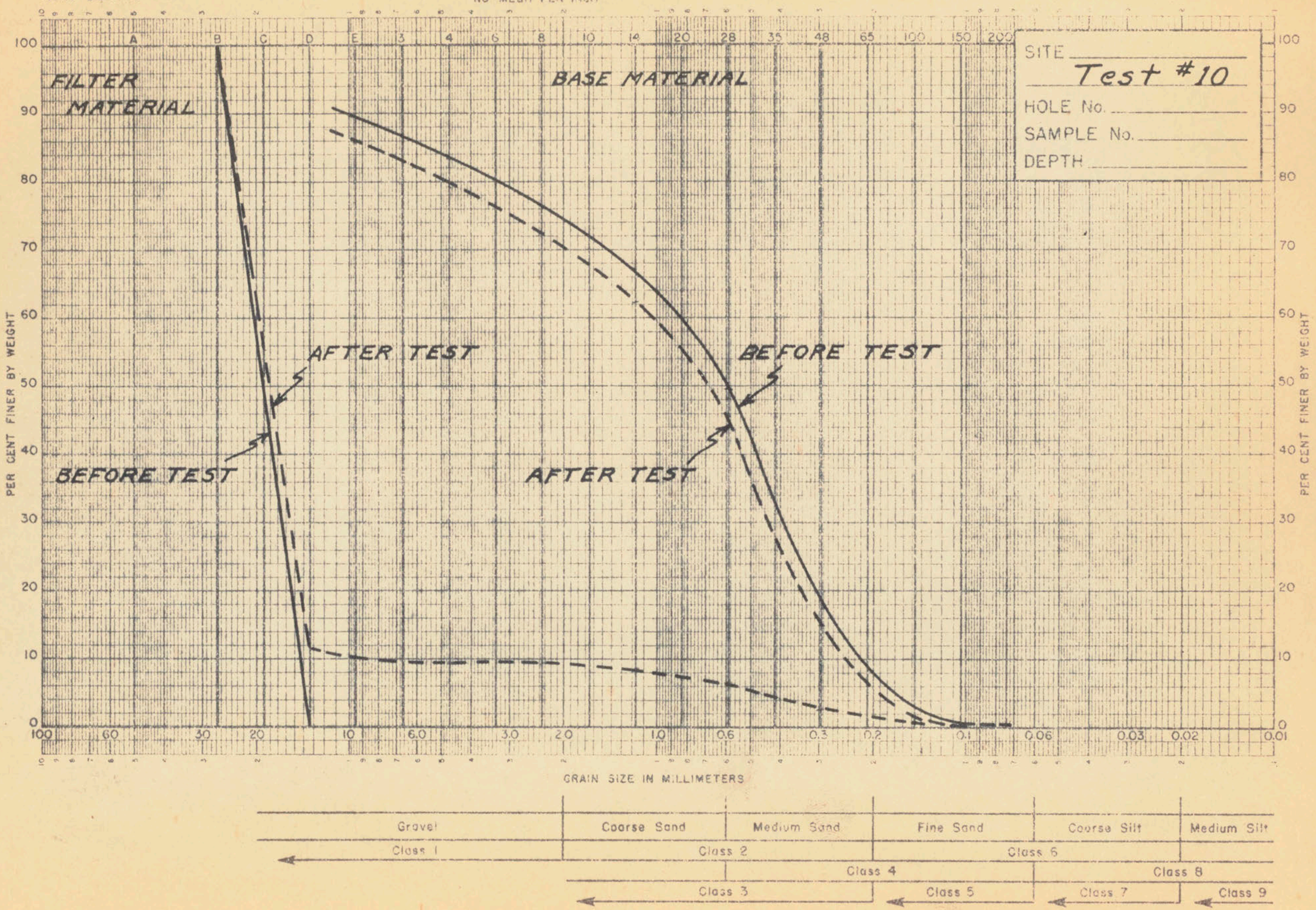
Filter: Uniform materials; passing No. B screen, 50% retained on No. C screen, 100% retained on No. D screen.

Base packed dry and then moistened to prevent failure when inverted.

Slight falling away of base into filter during saturation. During run pipe holes appeared in base. Entire base settled down from top about 0.3 cm. One crater, 3 cm in diameter, 1 cm deep, and two craters about half that size occurred on top surface of base. 10 cm of filter from the bottom, about 4.5 cm of base from the top were analysed after test.

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY



SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S.L. FORM NO.58

U. S. GOVERNMENT PRINTING OFFICE 102621

SAMPLE	Filter	Base
Weight:	1254 g.	732 g.
Sp. Gravity:	2.74	2.71
Length:	11.4 cm.	6.1 cm.
Void Ratio:	0.676	0.515
Compaction:	- %	83 %
Unif. Coef.:	1.41	3.84
Eff. Size:	12.0 mm.	0.25 mm.
Grain Sizes:		
10%	12.0 mm.	0.25 mm.
60%	17.0 mm.	0.96 mm.
15%	12.3 mm.	0.29 mm.
50%	16.0 mm.	0.64 mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 42.4
15% Filter: 50% Base = 19.2

Date: August 7, 1940

Test No.: 11

Cylinder Area: 67.1 sq.cm.

Cylinder Length: 8 in.

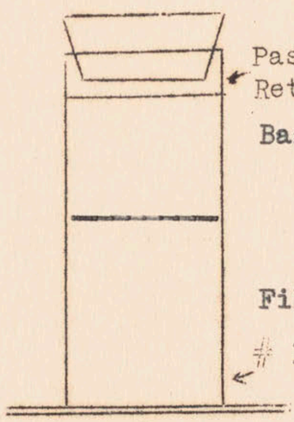
Total Time: 8 hr. 30 min.

Avg. Temp.: 21.3 °C

Head: 130.1 cm.

Gradient: 21.3

Permeability:
k_{10} = 302 x 10^{-4} cm./sec.



COMMENTS:

Complete failure.

Filter: Passing No. B screen, 25% retained on No. C screen, 75% retained on No. D screen, 100% retained on No. E screen.

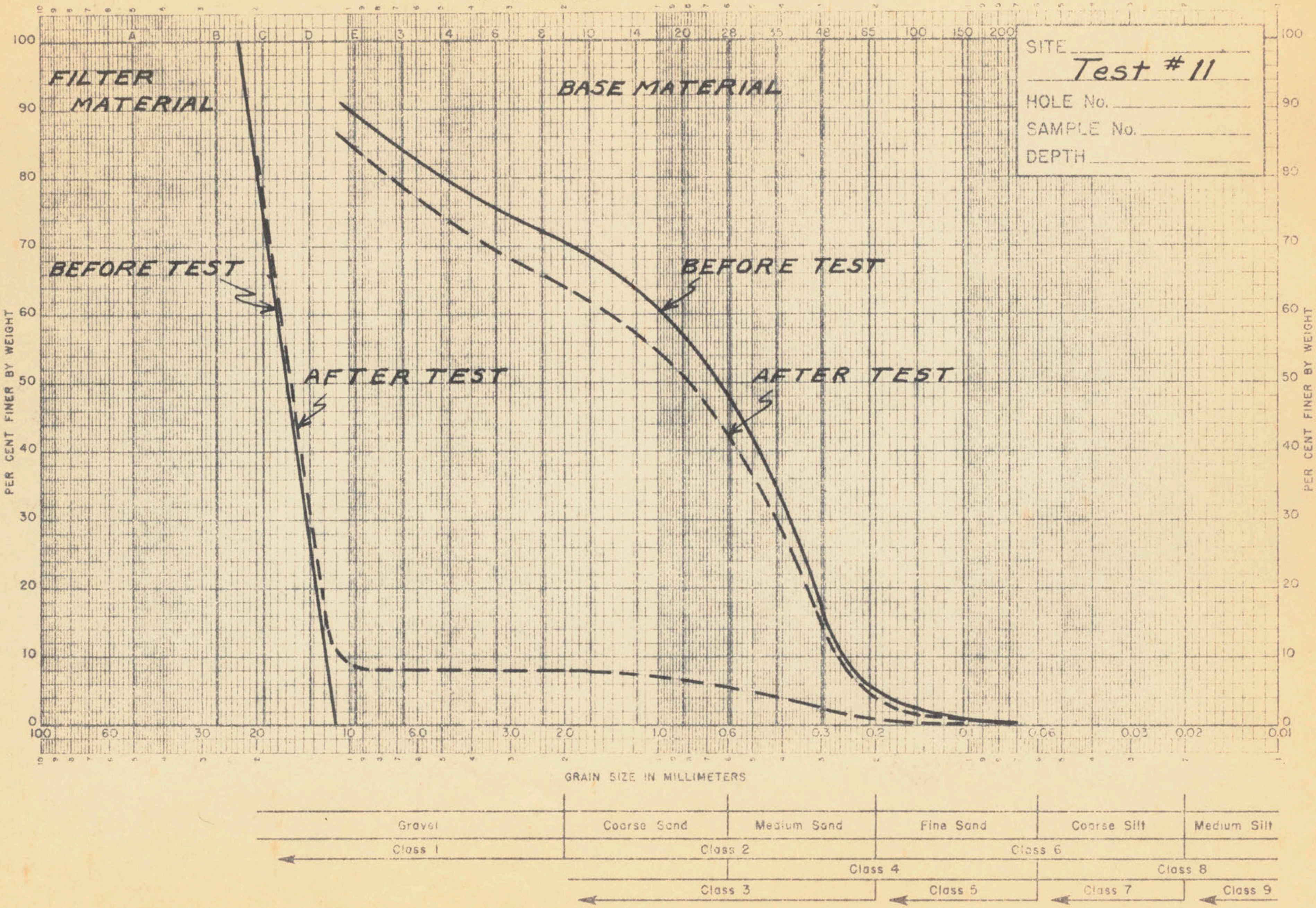
Base packed dry and then moistened slightly to keep it in place when inverted.

No apparent failure during saturation. Signs of failure appeared during first 5 minutes of run. Failure kept increasing throughout first 4 hours. Very large amount of base settled into filter leaving several distinct piping holes, free from fines in base. Top of base settled away from screen over about two-thirds of the area.

51 g of fines passed the No. 10 screen. About 6.5 cm from bottom of filter and 3.5 cm from top of base were analysed after test.

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY



SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R. I.

S. L. FORM NO. 56

U. S. GOVERNMENT PRINTING OFFICE 102021

Date: August 7, 1940

Test No.: 12

Cylinder Area: 67.4 sq.cm.

Cylinder Length: 8 in.

Total Time: 4 hr. 30 min.

Avg. Temp.: 21.2 °C

Head: 130.1 cm.

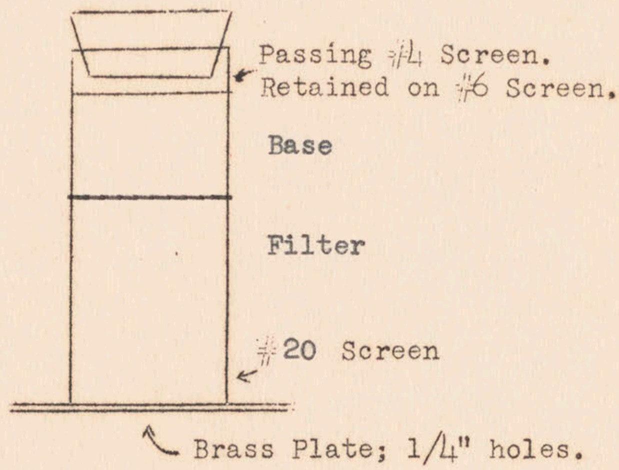
Gradient: 21.4

Permeability:
k_{10} = 211 x 10^{-4} cm./sec.

SAMPLE

	Filter	Base
Weight:	1256 g.	742 g.
Sp. Gravity:	2.74	2.71
Length:	10.9 cm.	6.1 cm.
Void Ratio:	0.602	0.500
Compaction:	- %	88 %
Unif. Coef.:	1.65	3.7
Eff. Size:	10.7 mm.	0.23 mm.
Grain Sizes:		
10%	10.7 mm.	0.23 mm.
60%	17.7 mm.	0.85 mm.
15%	11.2 mm.	0.28 mm.
50%	16.0 mm.	0.61 mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 40.3
15% Filter: 50% Base = 18.5



COMMENTS:

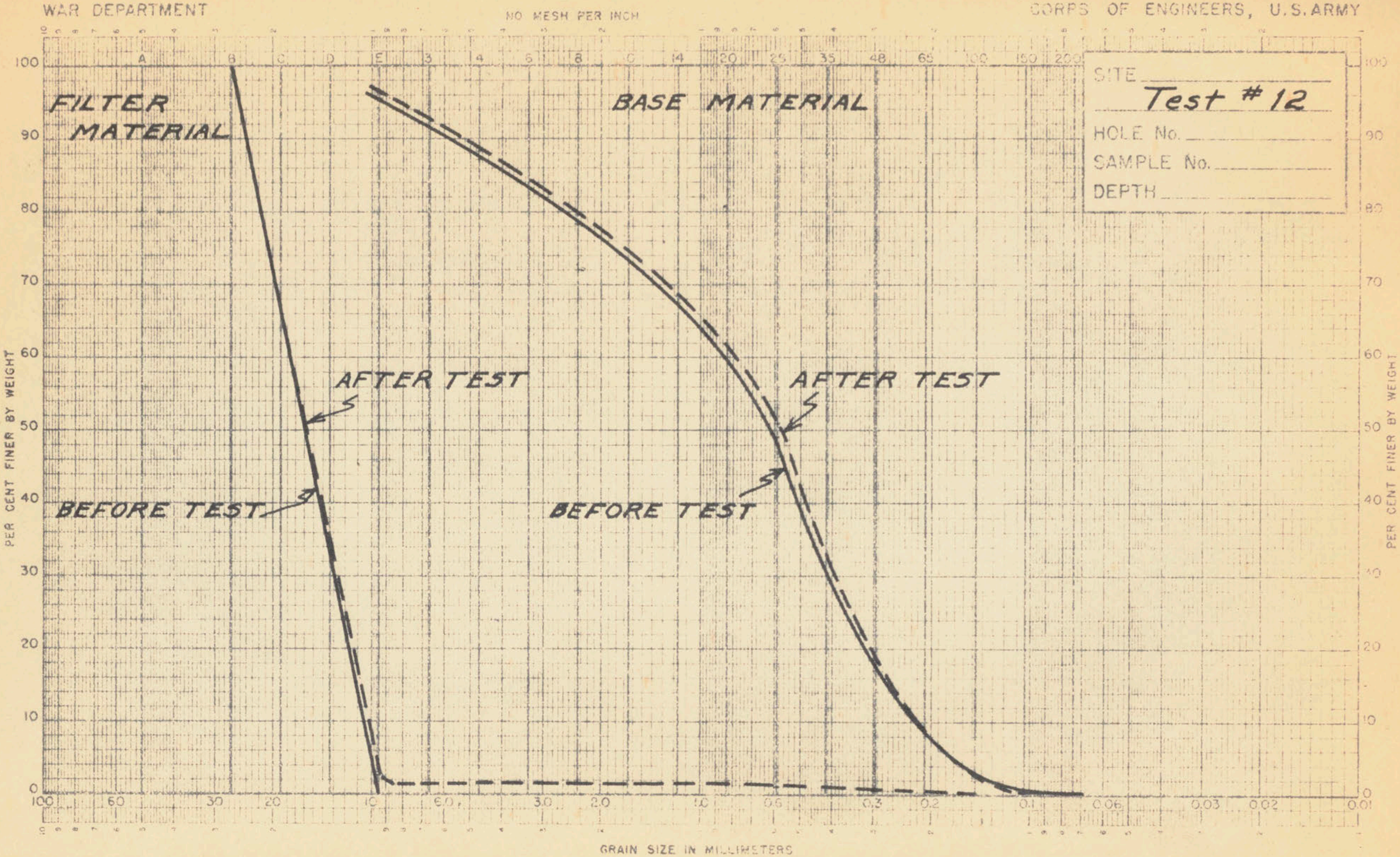
Stable.

Filter. - Passing No. B screen, 33.3% retained on No. C, 66.7% retained on No. D, 100% retained on No. E.

Packed dry and moistened.

No failure when inverted. Very slight amount of base worked into filter during test. Two very minute piping passages appeared on outside causing very small craters on surface. No craters or apparent piping in center part of base.

3g fines passed No. 20 screen. Mechanical analysis run on top 4.2 cm. of base and bottom 8.3 cm. of filter.



Gravel	Coarse Sand	Medium Sand	Fine Sand	Coarse Silt	Medium Silt
Class 1	Class 2		Class 6		
		Class 4		Class 8	
	Class 3		Class 5	Class 7	Class 9

Date: August 9, 1940

Test No.: 12-A

Cylinder Area: 67.4 sq.cm.

Cylinder Length: 8 in.

Total Time: 5 hr. 15 min.

Avg. Temp.: 20.4 °C

Head: 130.1 cm.

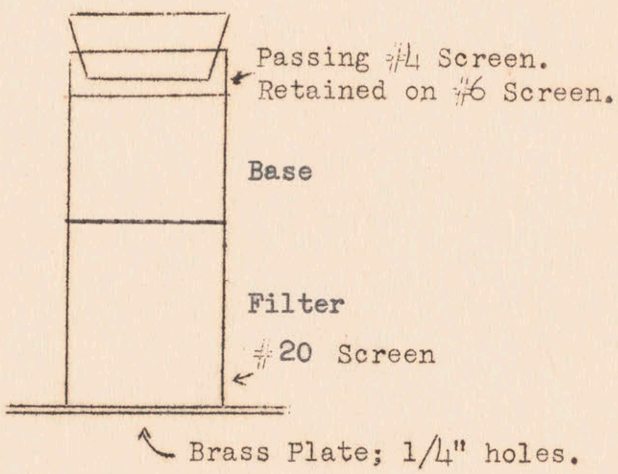
Gradient: 21.0

Permeability:
k_{10} = 286 x 10^{-4} cm./sec.

SAMPLE

	Filter		Base	
Weight:	1239	g.	770	g.
Sp. Gravity:	2.74		2.71	
Length:	10.7	cm.	6.3	cm.
Void Ratio:	0.595		0.494	
Compaction:	-	%	90	%
Unif. Coef.:	1.64		3.36	
Eff. Size:	11.0	mm.	0.22	mm.
Grain Sizes:				
10%	11.0	mm.	0.22	mm.
60%	18.0	mm.	0.74	mm.
15%	11.6	mm.	0.27	mm.
50%	16.3	mm.	0.56	mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 43.0
15% Filter: 50% Base = 20.7



COMMENTS:

Complete failure.

Filter. - Passing No. B screen, 33% retained on No. C, 67% retained on No. D and 100% retained on No. E.

Packed dry.

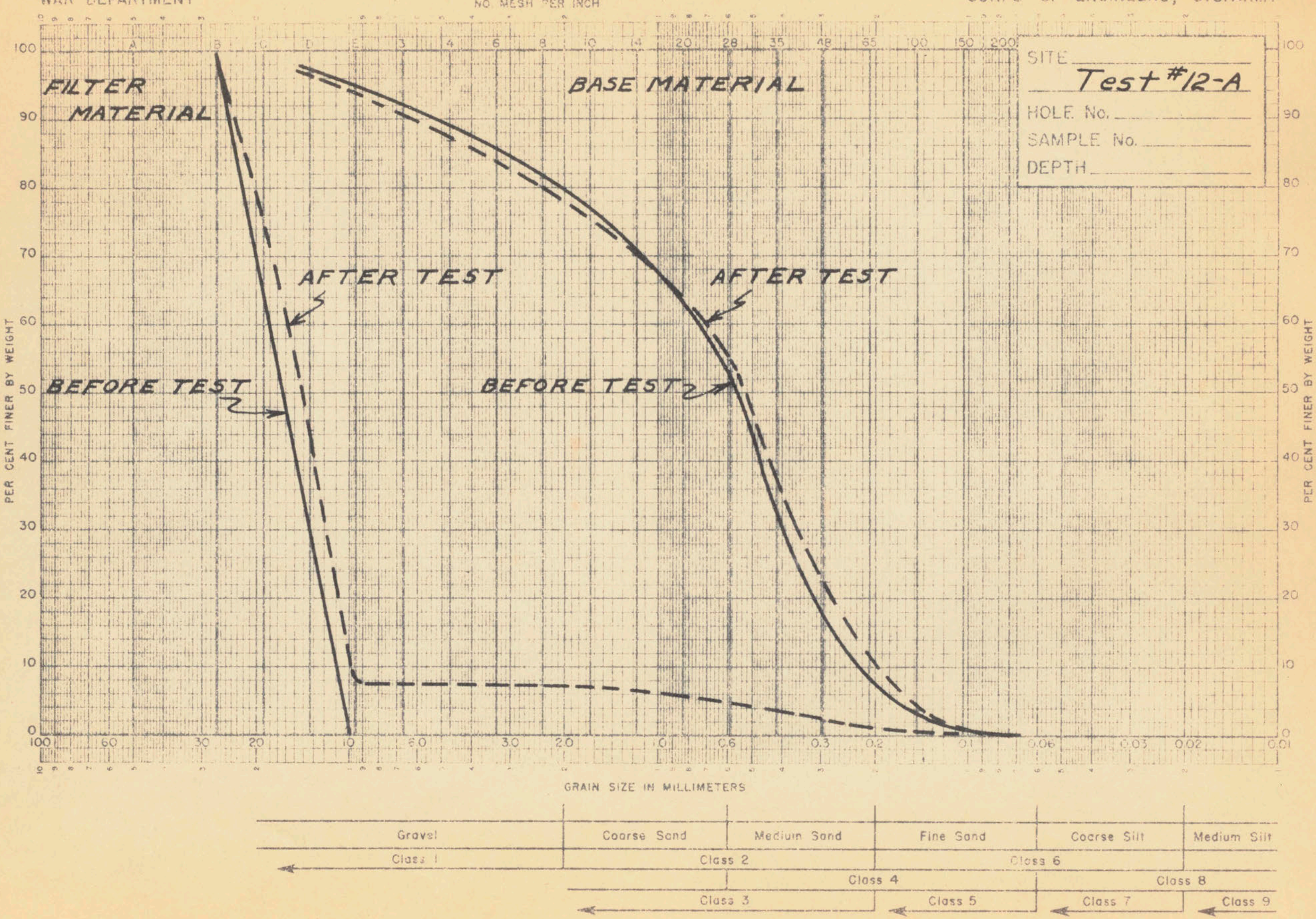
Considerable settlement at one point when tube was inverted, leaving space at top of base about 1.5 cm. wide and 3 cm. deep. Settlement increased during saturation.

Two distinct failure zones appeared during early part of run and resulted in large piping holes of about 3 cm. in diameter extending about half the length of the base. Upon removing, base material had a coarser grained appearance than when packed. Material felt punky and honeycombed.

20g of fines passed the No. 20 screen. Bottom 8 cm. of filter, and top 4.5 cm. of base were analysed after test.

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY



SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R. I.

SAMPLE

	Filter	Base
Weight:	1220 g.	774 g.
Sp. Gravity:	2.74	2.71
Length:	10.7 cm.	6.4 cm.
Void Ratio:	0.618	0.513
Compaction:	- %	84 %
Unif. Coef.:	1.41	3.45
Eff. Size:	10.3 mm.	0.22 mm.
Grain Sizes:		
10%	10.3 mm.	0.22 mm.
60%	14.5 mm.	0.76 mm.
15%	10.6 mm.	0.27 mm.
50%	13.4 mm.	0.57 mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 39.2
15% Filter: 50% Base = 18.6

Date: August 8, 1940

Test No.: 13

Cylinder Area: 67.4 sq.cm.

Cylinder Length: 8 in.

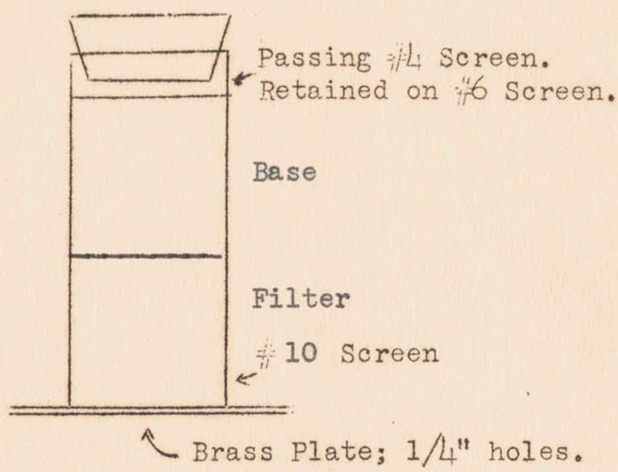
Total Time: 3 hr. 15 min.

Avg. Temp.: 21.5 °C

Head: 130.1 cm.

Gradient: 20.3

Permeability:
k_{10} = 172 x 10^{-4} cm./sec.



COMMENTS:

Complete failure.

Filter.- Passing No. C screen, 50% retained on No. D, 100% retained on No. E.

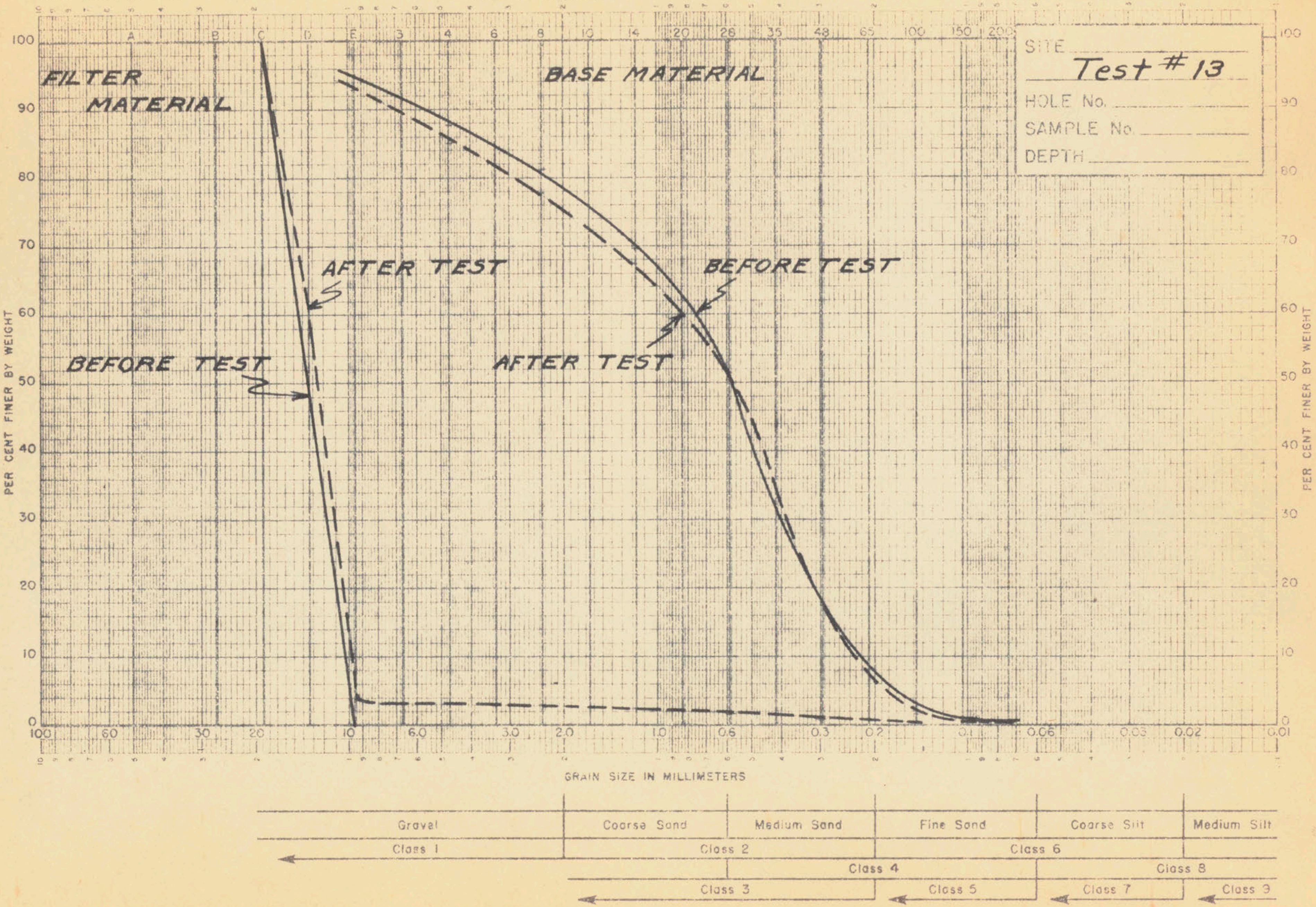
Packed dry.

No appreciable settlement of base into filter when inverted or during first hour of test. Considerable subsidence from top noted after about 1-1/2 hours with several small piping channels appearing on face of cylinder. Finally large crater resulted on top with large pipe hole leading into filter.

72g of fines passed No. 10 screen. Mechanical analysis run on top 3.3 cm. of base and bottom 5.5 cm. of filter.

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY



SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S.L. FORM NO.56

U. S. GOVERNMENT PRINTING OFFICE 192821

Date: August 8, 1940

Test No.: 14

Cylinder Area: 67.1 sq.cm.

Cylinder Length: 8 in.

Total Time: 7 hr. 0 min.

Avg. Temp.: 21.5 °C

Head: 130.1 cm.

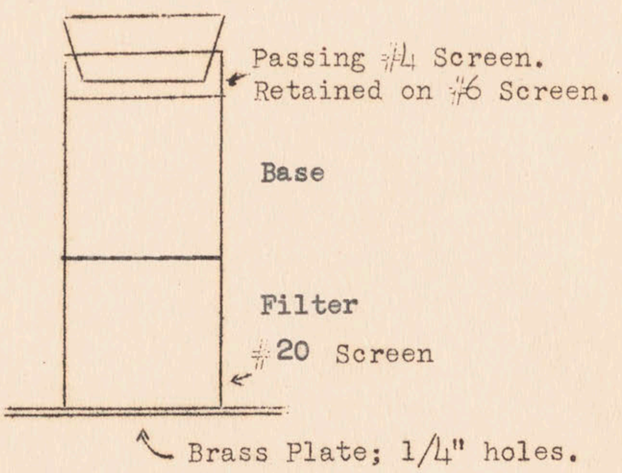
Gradient: 20.3

Permeability:
k_{10} = 330 x 10^{-4} cm./sec.

SAMPLE

	Filter	Base
Weight:	1232 g.	773 g.
Sp. Gravity:	2.74	2.71
Length:	10.9 cm.	6.4 cm.
Void Ratio:	0.627	0.509
Compaction:	- %	85 %
Unif. Coef.:	1.71	3.41
Eff. Size:	12.3 mm.	0.24 mm.
Grain Sizes:		
10%	12.3 mm.	0.24 mm.
60%	21.0 mm.	0.82 mm.
15%	13.0 mm.	0.29 mm.
50%	19.1 mm.	0.58 mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 44.8
15% Filter: 50% Base = 22.4



COMMENTS:

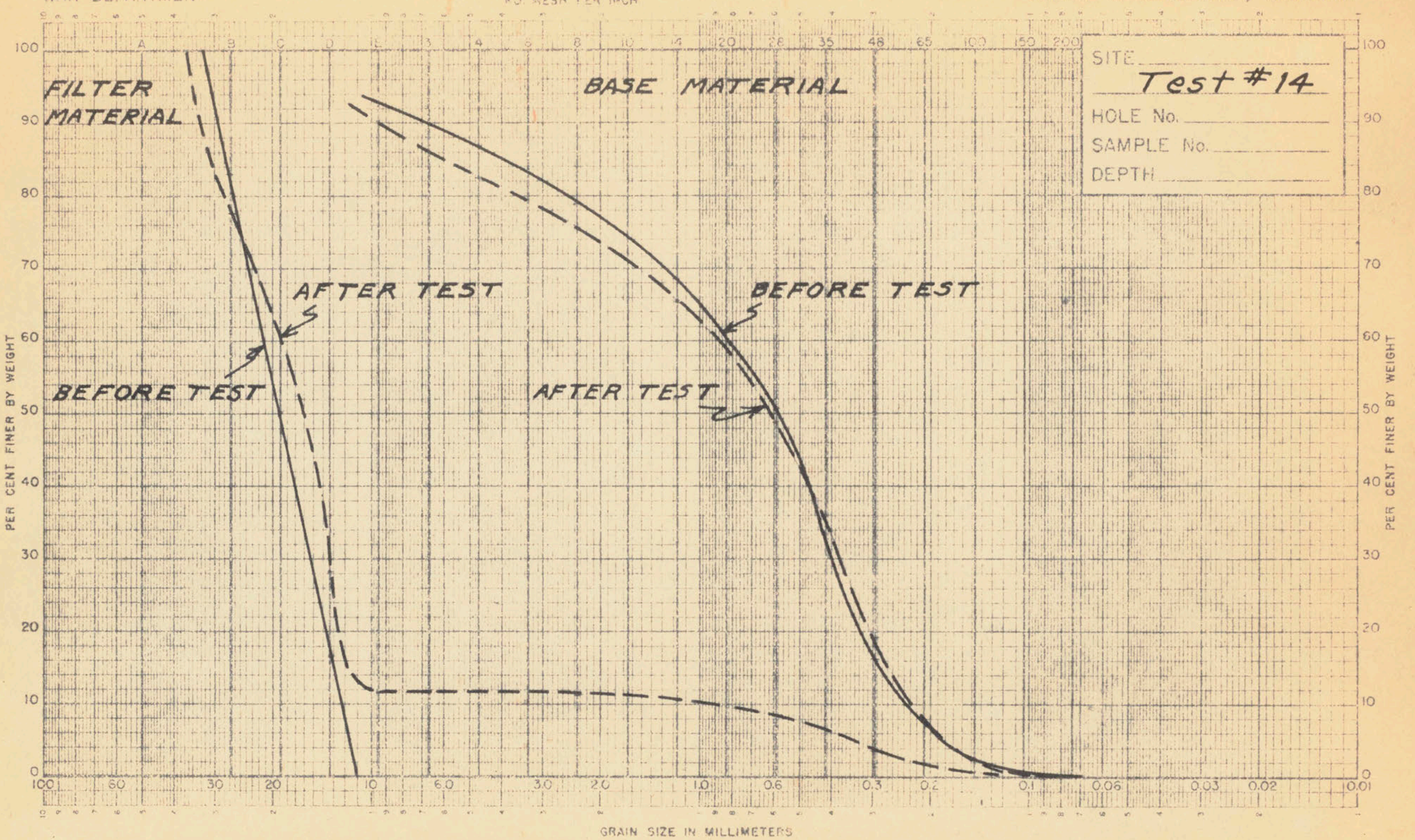
Failure.

Filter. - Passing 1-1/2 inch screen, 16.7% retained on No. B, 50% retained on No. C, 83.3% retained on No. D, 100% retained on No. E.

Packed dry.

Definite indication of failure during saturation of sample, top of base settled away from screen on top about 2 mm. During progress of test large amounts of fines appeared to collect in filter. No large definite piping holes appeared, but entire base seemed to be permeated with small piping channels. Final settlement of base away from top screen about 0.5 cm.

20g fines passed No. 20 screen. Mechanical analysis run on top 2.3 cm. of base and bottom 9.5 cm. of filter.



Gravel	Coarse Sand	Medium Sand	Fine Sand	Coarse Silt	Medium Silt
Class 1	Class 2		Class 6		
		Class 4		Class 8	
	Class 3		Class 5	Class 7	Class 9

Date: August 9, 1940

Test No.: 15

Cylinder Area: 67.1 sq.cm.

Cylinder Length: 8 in.

Total Time: 4 hr. 0 min.

Avg. Temp.: 20.4 °C

Head: 130.1 cm.

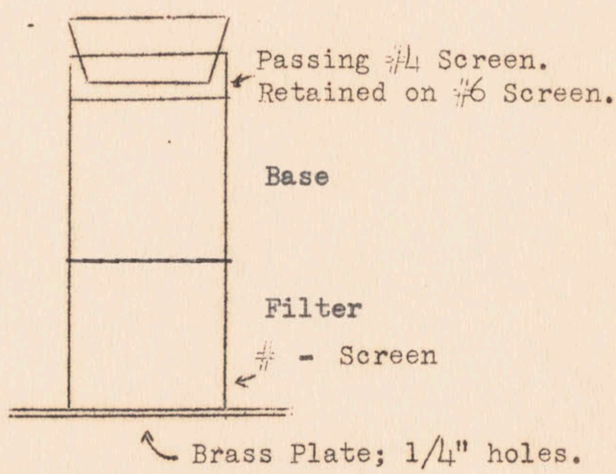
Gradient: 20.7

Permeability:
k_{10} = 265 x 10^{-4} cm./sec.

SAMPLE

	Filter	Base
Weight:	1244 g.	771 g.
Sp. Gravity:	2.74	2.71
Length:	10.6 cm.	6.3 cm.
Void Ratio:	0.568	0.490
Compaction:	- %	91 %
Unif. Coef.:	1.41	3.54
Eff. Size:	8.5 mm.	0.22 mm.
Grain Sizes:		
10%	8.5 mm.	0.22 mm.
60%	12.0 mm.	0.78 mm.
15%	8.8 mm.	0.27 mm.
50%	11.3 mm.	0.59 mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 32.6
15% Filter: 50% Base = 14.9



COMMENTS:

Stable.

Filter. - Passing No. C screen, 25% retained on No. D, 75% retained on No. E, 100% retained on No. 3.

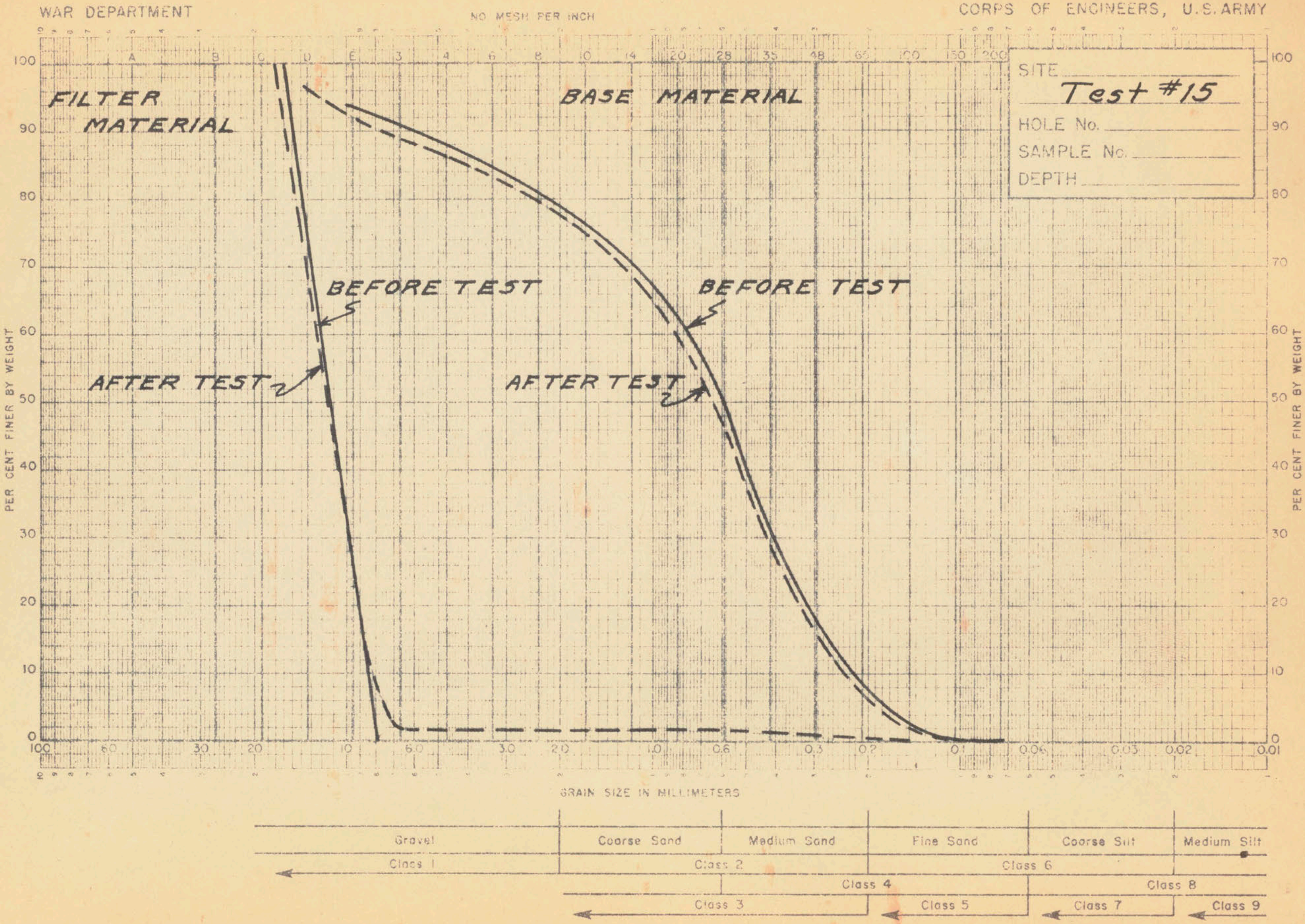
Packed dry.

Very slight readjustment of particles in base during saturation. No evidence of failure during first hour of test. Base had a coarser, slightly honeycombed appearance next to the tube but examination upon removal showed no visible change within the sample, 0.25 cm. from tube. One very small crater was found on the surface of the base, less than one cm. in diameter and about 0.5 cm. deep.

22g of fines passed the 1/4" holes in the brass plate. Bottom 6.5 cm. of filter and top 5.2 cm. of base were analysed after test.

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY



SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S.L. FORM NO. 58

U. S. GOVERNMENT PRINTING OFFICE 192021

Date: August 10, 1940

Test No.: 15-A

Cylinder Area: 67.4 sq.cm.

Cylinder Length: 8 in.

Total Time: 3 hr. 20 min.

Avg. Temp.: 29.0 °C

Head: 127.6 cm.

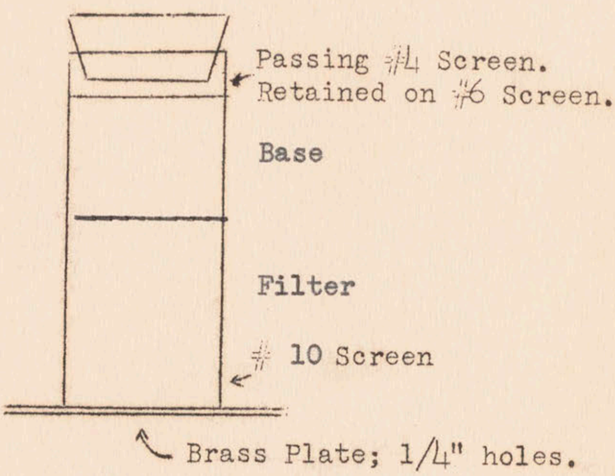
Gradient: 19.6

Permeability:
k_{10} = 201 x 10^{-4} cm./sec.

SAMPLE

	Filter	Base
Weight:	1225 g.	784 g.
Sp. Gravity:	2.74	2.71
Length:	10.5 cm.	6.5 cm.
Void Ratio:	0.584	0.512
Compaction:	- %	84 %
Unif. Coef.:	1.40	3.41
Eff. Size:	8.6 mm.	0.24 mm.
Grain Sizes:		
10%	8.6 mm.	0.24 mm.
60%	12.0 mm.	0.82 mm.
15%	8.9 mm.	0.28 mm.
50%	11.4 mm.	0.61 mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 31.7
15% Filter: 50% Base = 14.6



COMMENTS:

Stable.

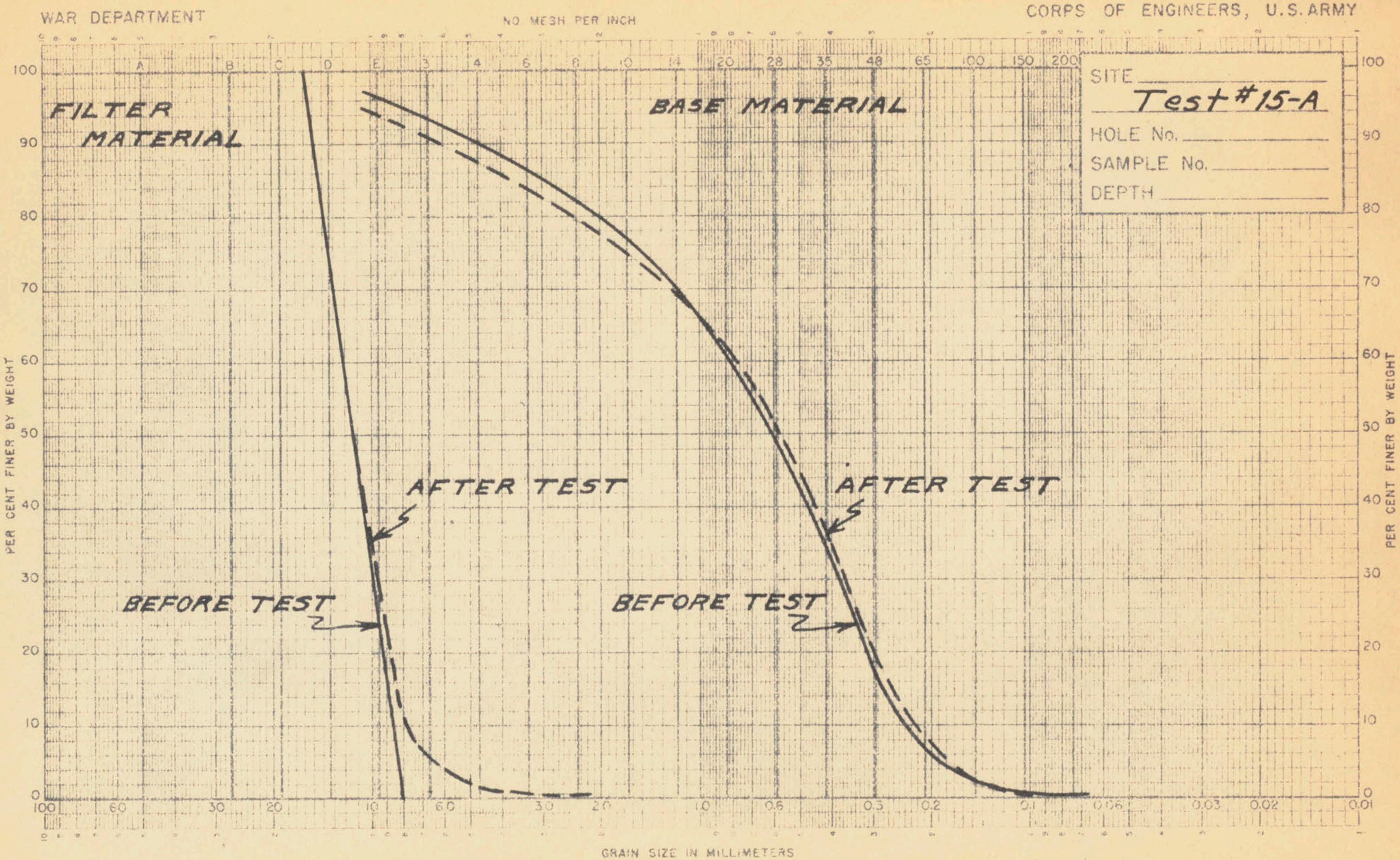
Filter. - Passing No. C screen, 25% retained on No. D, 75% retained on No. E, 100% retained on No. 3.

Packed dry.

No evidence of failure noted when inverted and saturated. De-aired water used for first 45 minutes of test with no failure. Permeability dropped very slightly during this time. Tap water used to complete test. Sample appeared very stable during remainder of test. Upon removing, the sample appeared unchanged, having a firm and solid feel. One gram of fines washed through the No. 10 screen. The top 3.3 cm. of base and bottom 10.0 cm. of filter were analysed after test.

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY



Gravel	Coarse Sand	Medium Sand	Fine Sand	Coarse Silt	Medium Silt
Class 1	Class 2		Class 6		
		Class 4		Class 8	
	Class 3		Class 5	Class 7	Class 9

SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S.L. FORM NO.58

U.S. GOVERNMENT PRINTING OFFICE 1-2621

Date: August 9, 1940

Test No.: 16

Cylinder Area: 67.4 sq.cm.

Cylinder Length: 8 in.

Total Time: 7 hr. 10 min.

Avg. Temp.: 20.6 °C

Head: 130.1 cm.

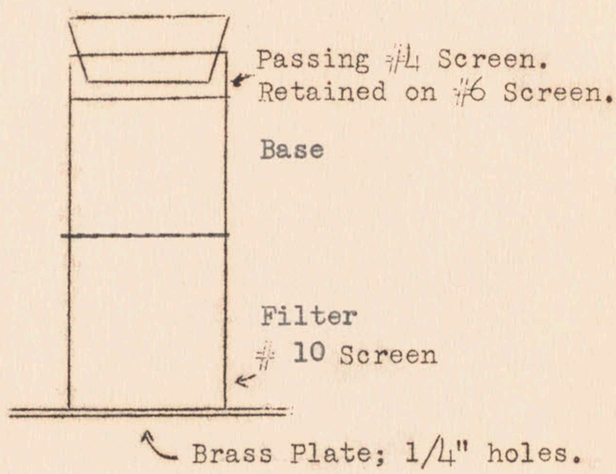
Gradient: 20.3

Permeability:
k_{10} = 181 x 10^{-4} cm./sec.

SAMPLE

	Filter	Base
Weight:	1206 g.	782 g.
Sp. Gravity:	2.74	2.71
Length:	10.8 cm.	6.4 cm.
Void Ratio:	0.653	0.497
Compaction:	- %	89 %
Unif. Coef.:	1.17	3.54
Eff. Size:	10.0 mm.	0.22 mm.
Grain Sizes:		
10%	10.0 mm.	0.22 mm.
60%	11.7 mm.	0.74 mm.
15%	10.1 mm.	0.27 mm.
50%	11.3 mm.	0.59 mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 37.4
15% Filter: 50% Base = 17.1



COMMENTS:

Very stable.

Filter. - Passing No. D screen, 100% retained on No. E.

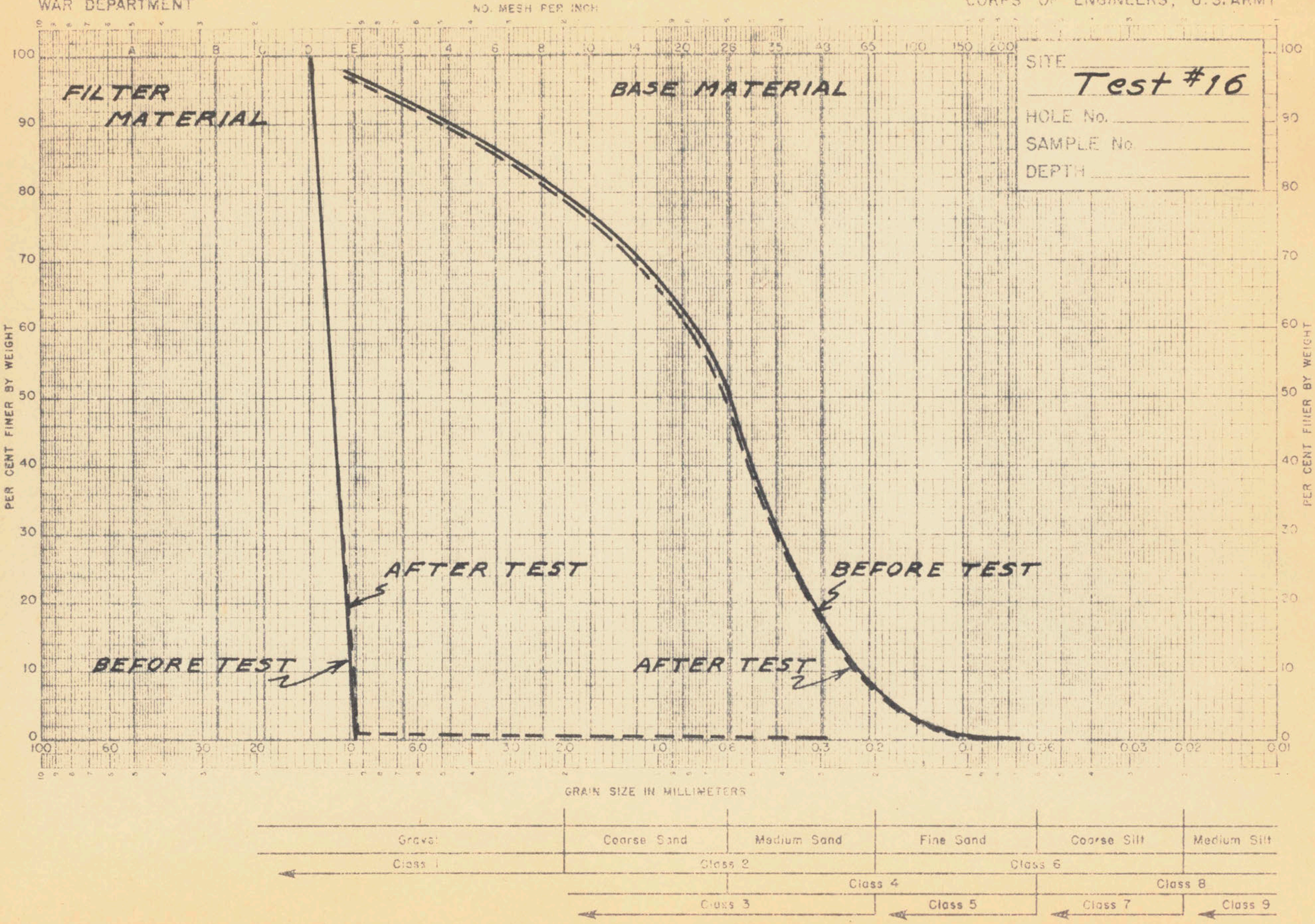
Packed dry.

No indication of failure whatsoever during or after test. No fines could be seen in filter and no subsidence of base occurred. Base material had same appearance at end of test as when packed. This test was one of the most stable to date. Small amount of fines in filter probably fell from extreme bottom of base when sample was inverted.

3g of fines passed the No. 10 screen. Lower 6.6 cm. of filter and top 4.8 cm. of base were analysed after test.

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY



SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S.I. FORM NO.58

U.S. GOVERNMENT PRINTING OFFICE

Date: August 12, 1940

Test No.: 16-A

Cylinder Area: 67.4 sq.cm.

Cylinder Length: 8 in.

Total Time: 7 hr. 40 min.

Avg. Temp.: 20.5 °C

Head: 130.1 cm.

Gradient: 20.3

Permeability:
k_{10} = 222 x 10^{-4} cm./sec.

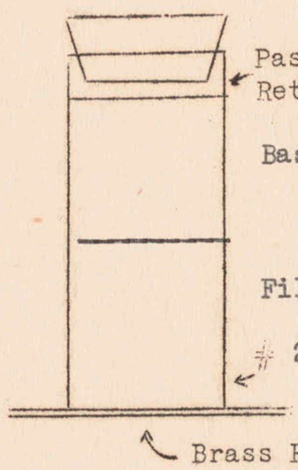
SAMPLE

	Filter	Base
Weight:	1205 g.	776 g.
Sp. Gravity:	2.74	2.71
Length:	10.5 cm.	6.4 cm.
Void Ratio:	0.607	0.507
Compaction:	- %	86 %
Unif. Coef.:	1.16	3.40
Eff. Size:	10.0 mm.	0.25 mm.

Grain Sizes:

	Filter	Base
10%	10.0 mm.	0.25 mm.
60%	11.6 mm.	0.85 mm.
15%	10.1 mm.	0.30 mm.
50%	11.2 mm.	0.62 mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 33.7
15% Filter: 50% Base = 16.3



COMMENTS:

Stable.

Filter. - Passing No. D screen, retained on No. E.

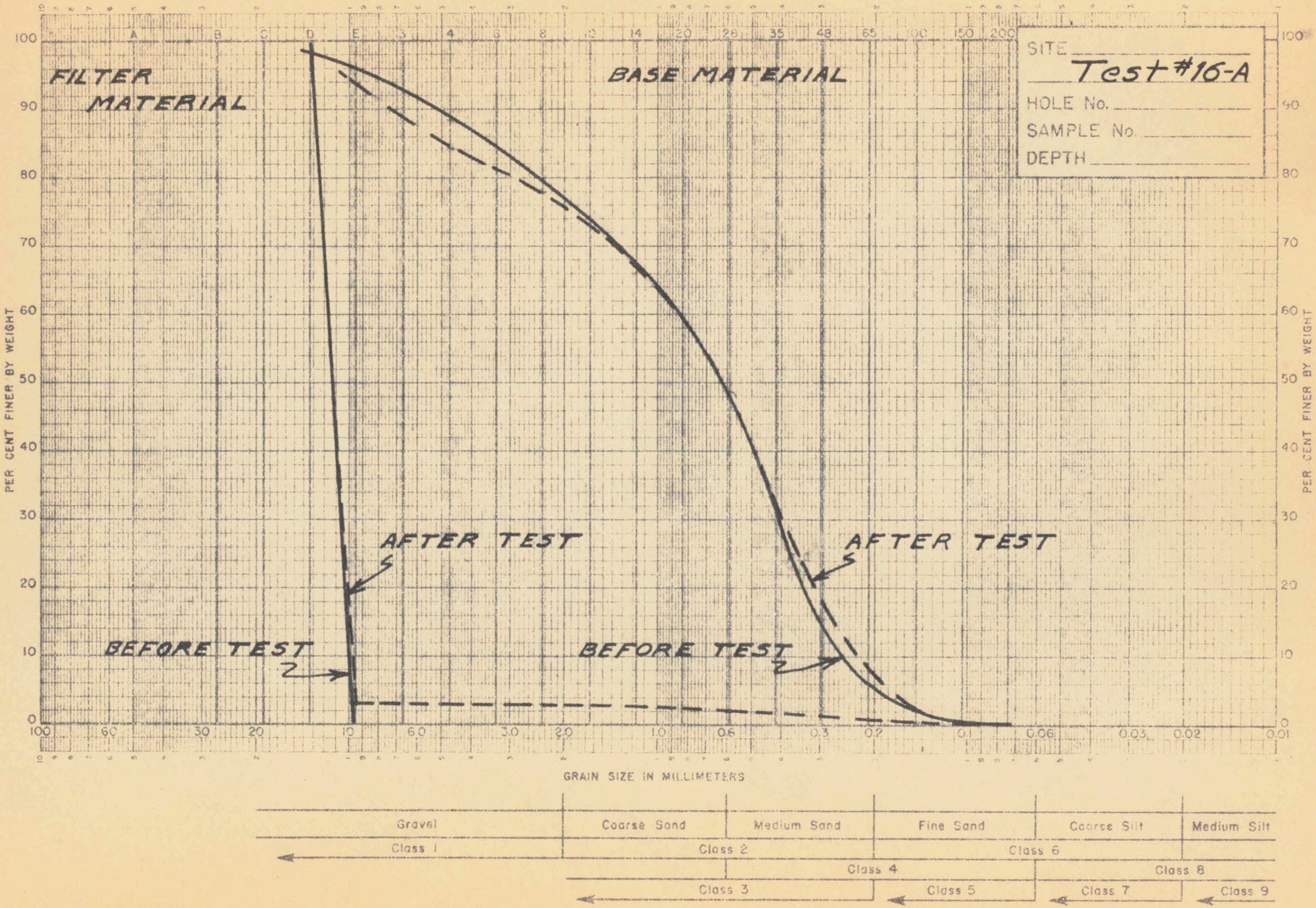
Packed dry.

As the sample was turned over a few fines of the base trickled down into the filter. At no point were they enough to cause settlement of the base. The base appeared to be stable during saturation and throughout the test. Base material was found to be firm and unchanged when opened. Fine grains were packed tightly around the walls with no evidence of piping.

6g of fines washed through the No. 20 screen. The top 4.0 cm. of base and bottom 9.8 cm. of filter were analysed after test.

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY



SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R. I.

S. L. FORM NO. 58

U. S. GOVERNMENT PRINTING OFFICE

SAMPLE

	Filter		Base	
Weight:	1271	g.	780	g.
Sp. Gravity:	2.74		2.71	
Length:	10.7	cm.	6.5	cm.
Void Ratio:	0.547		0.510	
Compaction:	-	%	84	%
Unif. Coef.:	1.67		3.40	
Eff. Size:	9.0	mm.	0.25	mm.
Grain Sizes:				
10%	9.0	mm.	0.25	mm.
60%	15.0	mm.	0.85	mm.
15%	9.3	mm.	0.29	mm.
50%	13.3	mm.	0.62	mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 32.0
15% Filter: 50% Base = 15.0

Date: August 10, 1940

Test No.: 17

Cylinder Area: 67.1 sq.cm.

Cylinder Length: 8 in.

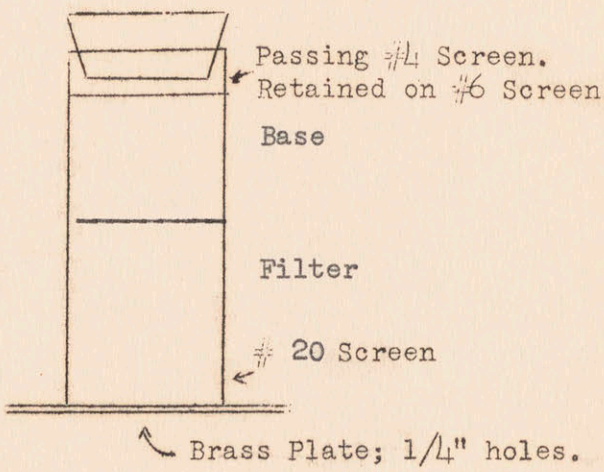
Total Time: 4 hr. 30 min.

Avg. Temp.: 20.7 °C

Head: 130.1 cm.

Gradient: 20.7

Permeability:
k_{10} = 164 x 10^{-4} cm./sec.



COMMENTS:

Very stable.

Filter. - Passing No. B screen, 16.7% retained on No. C, 50% retained on No. D, 83.3% retained on No. E, 100% retained on No. 3 sieve.

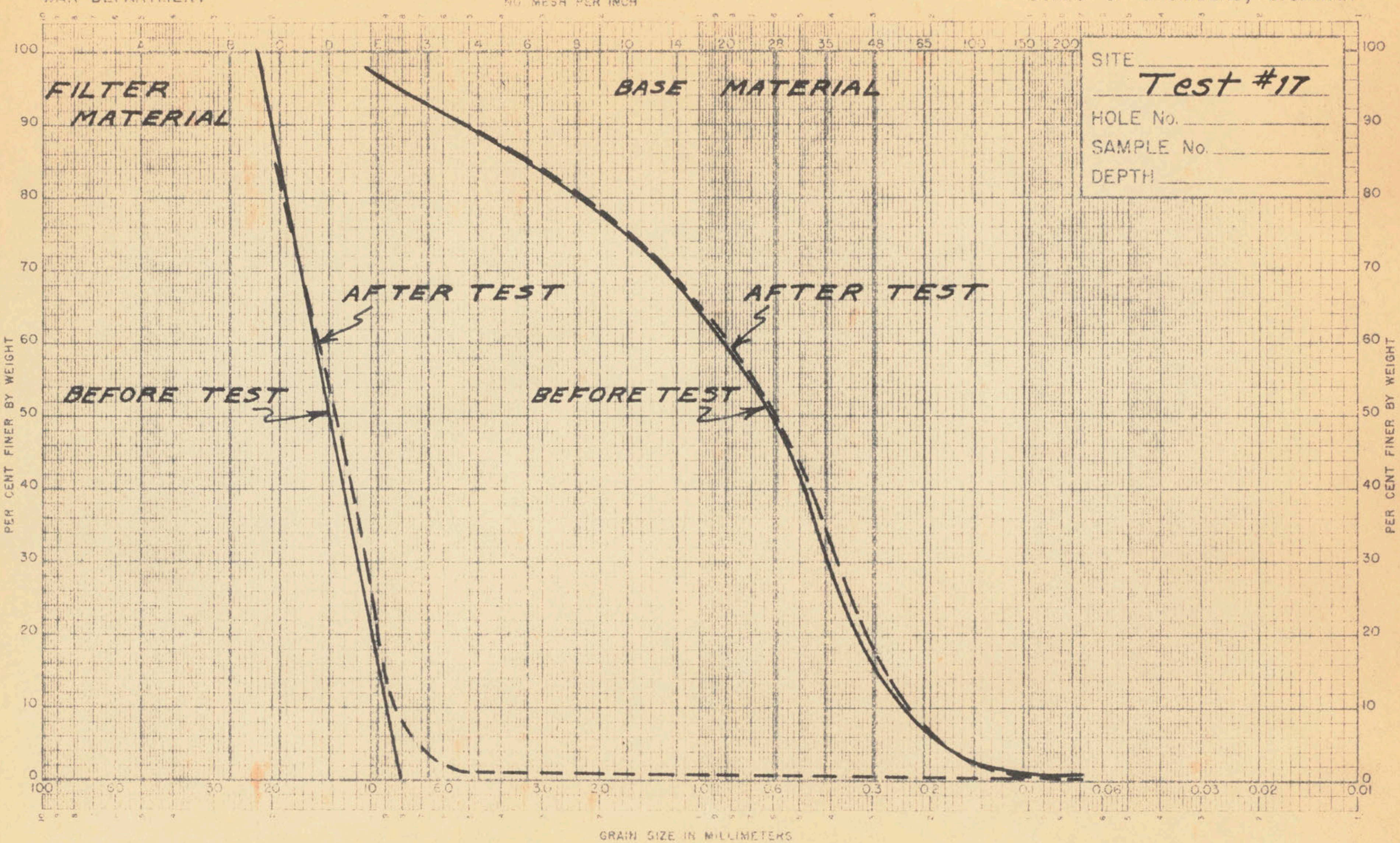
Packed dry.

Very few fines fell into filter upon inverting or during saturation. No signs of failure at any time during test. Upon removal the materials had the same appearance as when packed. The base material was inspected from the top and a firm, solid, well-filled out appearance was noted.

One gram of fines washed through the No. 20 screen. The top 3.1 cm. of base and bottom 9.6 cm. of filter were analysed after the test.

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY



Gravel	Coarse Sand	Medium Sand	Fine Sand	Coarse Silt	Medium Silt
Class 1	Class 2		Class 6		
		Class 4		Class 8	
	Class 3		Class 5	Class 7	Class 9

SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S. L. FORM NO 58

U. S. GOVERNMENT PRINTING OFFICE 192621

SAMPLE	Filter	Base
Weight:	1263 g.	777 g.
Sp. Gravity:	2.74	2.71
Length:	10.7 cm.	6.5 cm.
Void Ratio:	0.557	0.524
Compaction:	- %	80 %
Unif. Coef.:	1.66	3.33
Eff. Size:	9.0 mm.	0.24 mm.

Grain Sizes:

	Filter	Base
10%	9.0 mm.	0.24 mm.
60%	14.9 mm.	0.80 mm.
15%	9.4 mm.	0.29 mm.
50%	13.4 mm.	0.61 mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 32.4
15% Filter: 50% Base = 15.4

Date: August 12, 1940

Test No.: 17-A

Cylinder Area: 67.1 sq.cm.

Cylinder Length: 8 in.

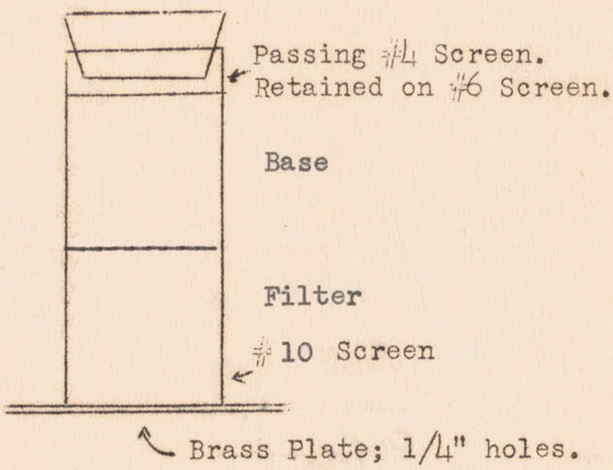
Total Time: 9 hr. 15 min.

Avg. Temp.: 20.6 °C

Head: 130.1 cm.

Gradient: 20.0

Permeability:
k_{10} = 223 x 10^{-4} cm./sec.



COMMENTS:

Stable.

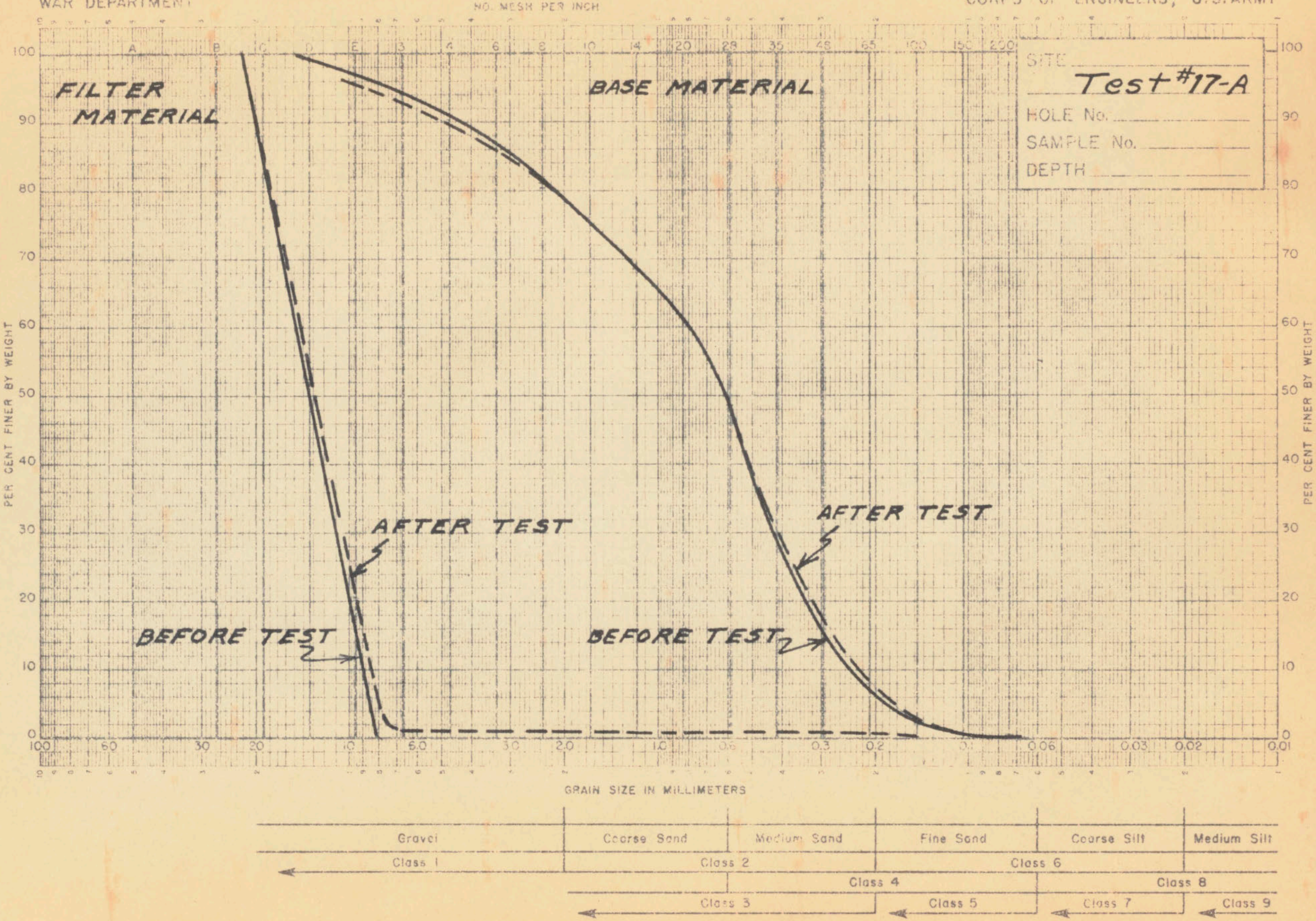
Filter. - Passing No. B screen, 16.7% retained on No. C, 50% retained on No. D, 83.3% retained on No. E, 100% retained on No. 3.

Packed dry.

When inverted dry fines from base settled slightly into filter in two places. Slight additional trickles of base into filter occurred during saturation. No evidence of failure during test. One very small crater was noted at the surface of base at end of test, due no doubt to the settlement during saturation. This was not considered an indication of failure as no alteration whatsoever could be noted during the test. Bottom 10 cm. of filter and top 4.4 cm. of base were analysed after test.

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY



SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S.L. FORM NO 58

U.S. GOVERNMENT PRINTING OFFICE 192621

Date: August 13, 1940

Test No.: 18

Cylinder Area: 159.3 sq.cm.

Cylinder Length: 16 in.

Total Time: 6 hr. 30 min.

Avg. Temp.: 20.5 °C

Head: 130.1 cm.

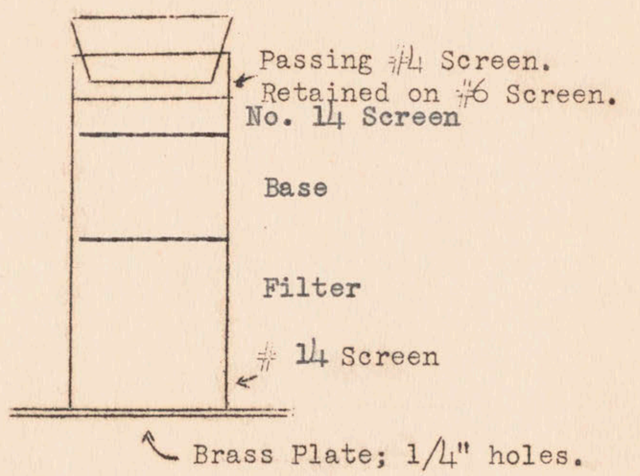
Gradient: 19.4

Permeability:
k_{10} = 183 x 10^{-4} cm./sec.

SAMPLE

	Filter	Base
Weight:	9693 g.	1890 g.
Sp. Gravity:	2.74	2.71
Length:	34.2 cm.	6.7 cm.
Void Ratio:	0.544	0.532
Compaction:	- %	78 %
Unif. Coef.:	3.18	3.00
Eff. Size:	5.2 mm.	0.26 mm.
Grain Sizes:		
10%	5.2 mm.	0.26 mm.
60%	16.5 mm.	0.78 mm.
15%	6.2 mm.	0.31 mm.
50%	13.2 mm.	0.61 mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 20.0
15% Filter: 50% Base = 10.2



COMMENTS:

Stable.

Filter. - Washed, screened, selected, gravel from Borrow Pit "F", Surry Mountain.

Packed dry.

Base material did not fail at any time during test except for slight trickling when sample was overturned. No evidence of piping or craters noticed upon removal. This combination is stable but care must be taken to obtain proper distribution of large amount "B" size material in tube.

11g of fines washed through the No. 14 screen. Top 4.6 cm. of base and 5 cm. of filter between 5 and 10 cm. below base analysed after test.

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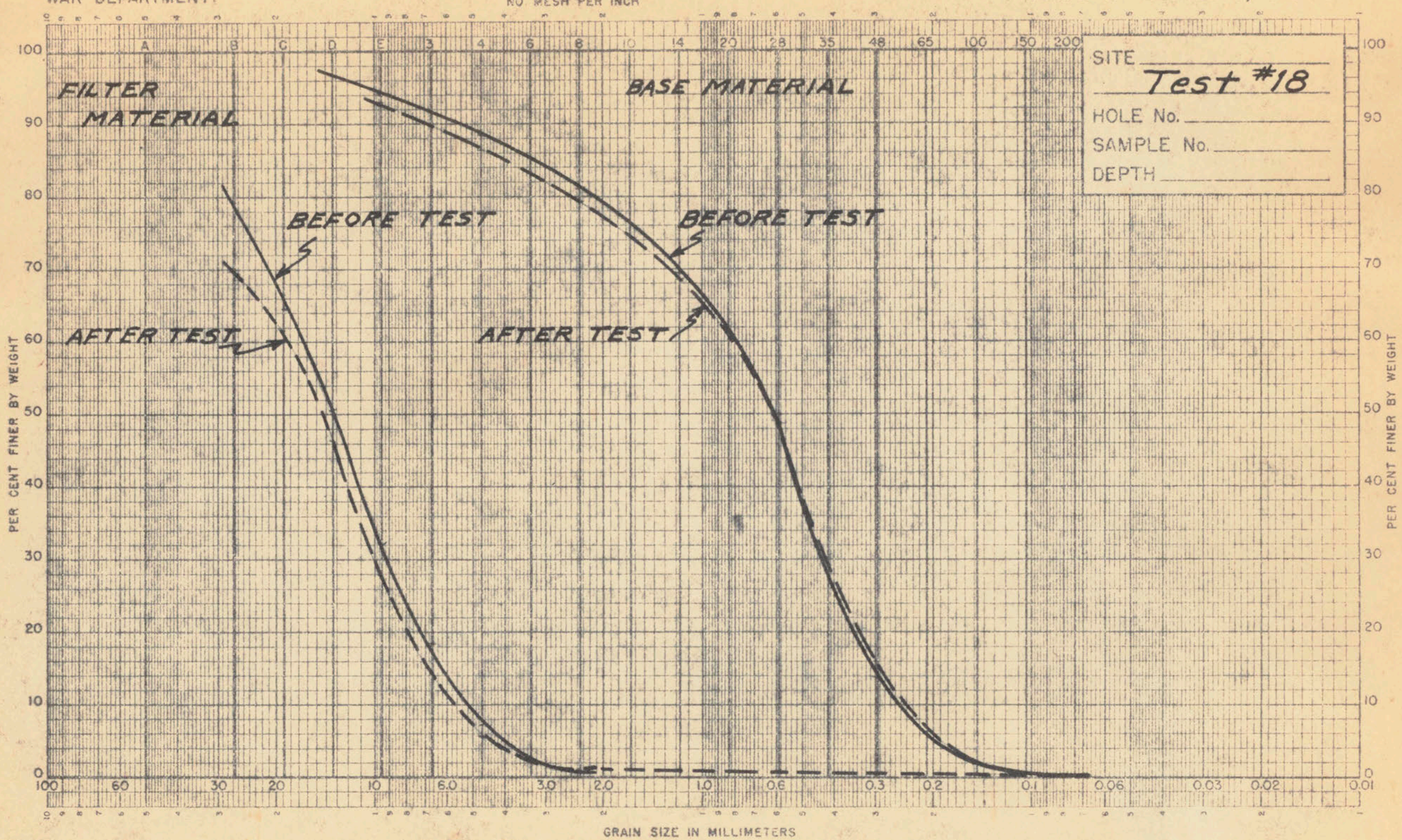

SITE Test #18
HOLE No.
SAMPLE No.
DEPTH

Gravel	Coarse Sand	Medium Sand	Fine Sand	Coarse Silt	Medium Silt
Class 1	Class 2		Class 6		
		Class 4		Class 8	
	Class 3		Class 5	Class 7	Class 9

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MECHANICAL ANALYSIS

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Date: August 13, 1940

Test No.: 19

Cylinder Area: 67.4 sq.cm.

Cylinder Length: 8 in.

Total Time: 3 hr. 0 min.

Avg. Temp.: 20.5 °C

Head: 117.4 130.1 cm.

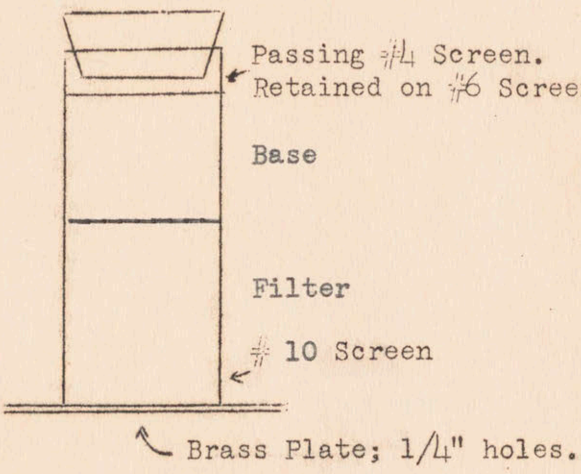
Gradient: 19.0 20.0

Permeability:
k_{10} = 236 x 10^{-4} cm./sec.

SAMPLE

	Filter	Base
Weight:	1336 g.	764 g.
Sp. Gravity:	2.74	2.71
Length:	10.9 cm.	6.2 cm.
Void Ratio:	0.509	0.483
Compaction:	- %	93 %
Unif. Coef.:	3.64	5.0
Eff. Size:	5.5 mm.	0.24 mm.
Grain Sizes:		
10%	5.5 mm.	0.24 mm.
60%	20.0 mm.	1.20 mm.
15%	6.8 mm.	0.29 mm.
50%	15.7 mm.	0.79 mm.

Ratios of Grain Sizes:
15% Filter: 15% Base = 23.5
15% Filter: 50% Base = 9.2



COMMENTS:
Stable

Filter. - Selected, washed and screened from Borrow "F", Surry Mountain Dam.

Packed dry. Filter found to be very dusty and dirty.

De-aired water used for first 40 minutes of test with head of 117.4 cm. Test continued with tap water under head of 130.1 cm. Very slight settlement noted during saturation and handling. One small crater, 1 cm. in diameter and 0.75 cm. deep about 1 cm. from edge of tube was found on top of base at end of test.

11g of fines washed through No. 10 screen. Bottom 7.6 cm. of filter and top 3.2 cm. of base were analysed after test.

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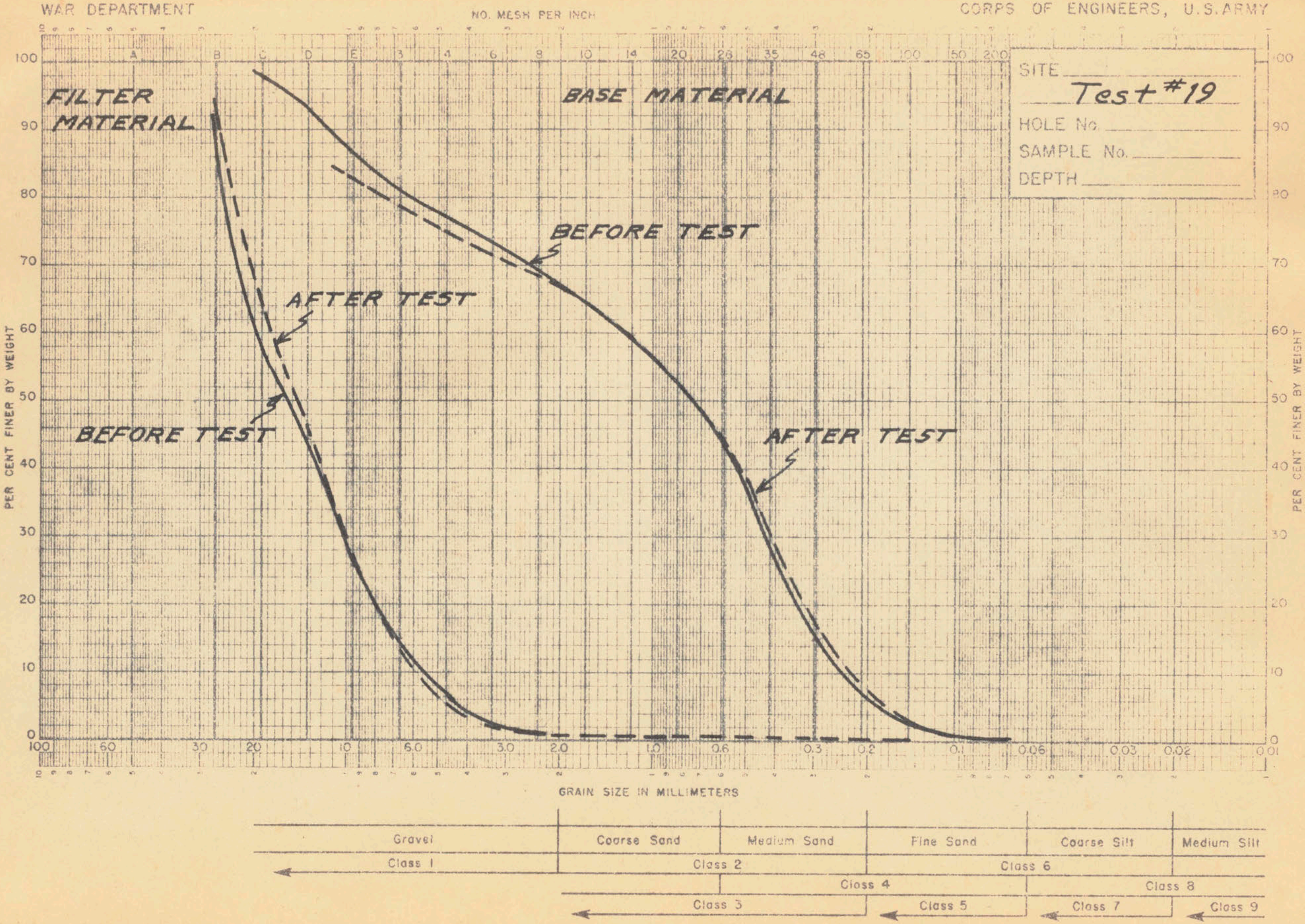

SOILS LABORATORY

MECHANICAL ANALYSIS

PROVIDENCE, R.I.

S.L. FORM NO 58

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