DESIGN CRITERIA FOR DRAIN TILE FILTERS AND ENVELOPES

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DESIGN CRITERIA FOR DRAIN TILE FILTERS AND ENVELOPES

PROGRESS REPORT 1961

Colorado Participating Project

to

Regional Research Project W-51

COLORADO AGRICULTURAL EXPERIMENT STATION

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COLORADO CONTRIBUTING PROJECT W-51

Progress Report 1961

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U.S.D.A.--Agricultural Research Service
Colorado Soil Conservation Service

Title

Design Criteria for Drain Tile Filters

Objectives

To establish the functional requirements and design criteria for extremely non-uniform filters around tile drains.

Introduction (need for study)

Non-cohesive soil materials frequently flow into wells and tile drains causing serious maintenance problems, or in extreme cases, failure of the facility. Filters are needed in such instances which will exclude the soil materials yet preserve favorable hydraulic characteristics near the facility. Gravel or sand has been used for this purpose with notable success in the case of wells but with limited success in the case of tile drains.

Design criteria have been developed for uniform filters (small range of particle size distribution) especially for wells (3) (4) (8) (10) (21) (23). Criteria for filters having a degree of non-uniformity are also fairly well established, at least by laboratory experiments (3) (4) (8) (10) (21). Unfortunately, the filter for a tile line involves a great volume of material for which the cost of sizing is prohibitive. No confirmed design criteria are available for a filter such as might be obtained from pit-run gravels or a slight modification thereof.

The study undertaken by this contributing project seeks to determine the limitations on the use of highly non-uniform gravel filters used with a uniform fine sand aquifer.

Design of Experiment

Factors

The follwing tabulation shows factors considered and the range or levels used for each:

FACTOR		LEVELS
Aquifer sand		
D_{50}	(constant)	0.205 mm
σ	(constant)	0.0702 mm
Filter gravel		
D_{50}		2.55 mm to 12.0 mm
F/A		12.42 mm to 58.6 mm
σ		0.67 mm to 13.05 mm
Tile diameter	(constant)	6 inches
Head on tile		4 ft. and 6 ft.
Tile joint opening		$\frac{1}{2}$ D_{85} (F)

Equipment

The schematic sketch of the model and its accessories is shown in Figure 1. The model is a 5/8-inch plywood box 69.25 inches high, 45.25 inches wide, and 1 foot deep, with a removable front panel. A semi-cylinder made of galvanized sheet metal 6 inches in diameter having 1-inch flanges on each side was used to represent a 6-inch tile drain. It was attached as shown in Figures 1 and 2.

Provisions were made for an adjustable joint opening approximately 1 inch from the front face of the model. The joint opening was varied with each filter so as to be equal to one-half the 85-per cent size of filter. A globe valve outlet was provided so that backwater in the tile could be created if necessary.

Hardware cloth having four openings per linear inch was used to separate gravel from sand. It was held in place by a frame of one-foot radius as shown in Figure 2. The front panel was bolted to angle iron flanges provided on the front edges of the box.

For the first four tests, half-inch plexiglass was used as a front panel on the model. This was replaced by a 3/4-inch plywood face because the plexiglass developed cracks at bolt holes.

Twenty-seven piezometers were used to record the pressure distribution in the sand, gravel, and at the sand-gravel interface. Piezometers consist of 2.5 millimeter I.D. glass tubing connected to 1/8-inch I.D. tygon plastic tubing.

The plastic tubing was connected to brass taps, 1 1/2 inches long, 1/16 inch I.D., threaded over half their length. These taps were inserted into the front panel where desired. When plexiglass was used as a front panel, holes were threaded in it to match the threads of the brass taps. When plywood was used, holes were drilled and countersunk on each side of the plywood for 3/32 brass nuts. These were glued on the inside of the front panel with Armstrong adhesive. Thus the brass taps could be easily screwed into the nuts. Rubber washers of 1/4 inch outer diameter were used to make the taps water tight.

Piezometers used to determine the piezometric head were arranged in a grid pattern with one foot intervals, except over the gravel zone where they were arranged on radial lines radiating from the center of the tile at 45° intervals. This arrangement is shown in Figure 1.

The taps were projected 1/2 inch into the sand and gravel so that they recorded the piezometric head in the plane of the tile joint. Glass wool was used in the taps to exclude sand from the piezometer tubing.

Initially the front panel had to be removed each time a new gravel was placed for testing. This required much labor and time. Therefore, the plexiglass front was replaced by a plywood front in which an access panel 30 inches by 15 inches was provided over the area where the gravel was placed.

Two small stop cocks were provided at the top of the box as air vents to get rid of the air which collected at the top of the model during filling from the bottom or during the test.

Another hole at the top center of the box was provided for the inlet of water during the test. A half-inch male hose-to-pipe adapter was fixed to this hole for the hose connection.

The water from the water supply was first stored in the 50-gallon tank which supplied water to the 22-gallon constant head tank, which in turn delivered water to the model at a desired constant head. The arrangement is shown in Figure 1. The constant head tank was placed on a wooden tower with supports at one-foot intervals.

Materials

Water supply.--The water used in the model was from the city water supply. It was temporarily stored in the 50-gallon tank to bring it to room temperature.

Aquifer sand.--The sand used as the aquifer was obtained from a commercial source and is referred to as silica dust. It contained a great amount of dust and was very non-uniform in size. Since uniform sand was required as aquifer material, this sand was passed twice through a pneumatic separator. The very fine and the very coarse fractions were discarded. The remaining sand was washed to remove clay adhering to the sand particles.

The grain size distribution of this sand is shown in Figure 7. The mean diameter of the sand was 0.205 mm and the standard deviation was 0.0702 mm.

Filter gravel.--The gravels tested as filters in these studies are those shown in Figures 19-29. Natural river gravel, angular to round in shape, was obtained from a local gravel pit. This was sieved and sorted to have the various fractions available for designing any particular filter.

Plots of the gravels to be used as filters were made first as straight lines on a logarithmic probability paper as shown in Figures 8-18. The fractions lying between different sizes were taken from these plots, and were mixed together to give the desired grain size distribution.

Table 1 shows the characteristics of the gravels used in these studies. The standard deviation of a sample can also be found from these plots as discussed in the following paragraphs.

Standard deviation.--(Dixon and Massey (2) show that in a large; normally distributed sample, the area enclosed by the ordinates through points at a distance of 1.645 σ (where σ is the standard deviation of the sample) on each side of the mean contains 90 per cent of the total variates in the sample. Therefore, the standard deviation (σ) can be found from an accumulation grain size distribution plot on logarithmic probability paper, (on which a normal distribution plots as a straight line), by dividing the interval between the 95-per cent and the 5-per cent size by 2 x 1.645 = 3.29.

Procedure

The gravel to be tested was placed in the model in the annular space between the tile and the hardware cloth (see Figure 2) in layers of 3 inches. Each layer was carefully compacted with a 3 x 3-inch wooden ram until no more consolidation occurred. The top surface of the gravel was then smoothed and brought to the level of the edge of the box. Compacting was necessary to prevent the gravel from slumping when model set upright.

Table 1. Characteristics of gravel filters used in the experiments.

Experiment No.	$D_{50}(F)$ mm	$\frac{D_{50}(F)}{D_{50}(A)}$	$D_{15}(F)$ mm	$\frac{D_{15}(F)}{D_{15}(A)}$	$D_{95}(F)$ mm	$D_5(F)$ mm	$\sigma(F)$ mm	$C_u(F)$	Remarks
1	3.8	18.55	3.13	21.65	5.10	2.8	0.67	1.3	
2	3.7	18.05	2.3	15.86	7.6	1.76	1.778	1.99	
3	4.0	19.5	2.0	13.75	12.0	1.35	3.325	2.825	
4	6.68	32.6	5.5	37.9	9.15	4.8	1.868	1.333	failed
5	9.4	45.8	6.0	41.4	18.3	4.64	4.18	9.925	failed
6	12.0	58.6	5.05	34.8	46.0	3.0	13.05	3.56	
7	12.0	58.6	7.6	52.4	26.5	5.8	5.93	1.985	failed
8	12.0	58.6	5.8	40.0	38.0	3.8	10.4	2.9	
9	12.0	58.6	6.65	45.8	31.5	4.4	7.34	2.415	failed
10	2.55	12.42	1.8	12.4	4.52	1.45	0.927	1.625	
11	2.55	12.42	1.4	9.66	6.6	1.0	1.705	2.454	
Aquifer	0.205		0.145				0.0702	1.658	

Water was introduced into the box and the aquifer sand was carefully placed in water in the rest of the space in the box. The sand was then compacted partly wet and was leveled at the top. In subsequent experiments, since the sand was already wet and was not replaced, only the gravel to be tested was renewed and compacted similar to the above procedure.

Each time new gravel was used the tile joint width was changed in order to maintain an opening equal to half the 85-per cent size of the gravel. After adjusting the opening to the desired width, small pieces of galvanized sheet metal, 1/8 inch wide, were soldered across it at three places, to maintain a constant width during the experiment.

In all the experiments following Experiment No. 1, the sand near the interface was removed to break any bridging of the sand particles and to be sure that the sand maintained the same distribution there as at any other place in the box.

Since the box was quite heavy, weighing about two tons, it had to be lifted with two chain hoists.

After erecting the model on its base, it was filled with water through an inlet provided at the bottom, so that the rising water level in the sand pushed the air upwards and expelled it through the valves provided at the top of the box. Later procedures were developed using carbon dioxide gas to displace air in the box before filling.

When the model was full, the control valve on the tile was opened and about 45 minutes were allowed for the flow to equilibrate. When the system reached a steady state the piezometer readings were taken and the discharge from the tile was collected for a given time and weighed. Two such readings were taken for each applied hydraulic head and three heads were applied for each experiment.

The air-dry weight of the gravel used as filter was recorded each time it was renewed. The temperature of the discharged water was also recorded, although temperature is assumed to have no appreciable effect on the filtering action of the gravel.

Results

The main experiment concerns the efficiency of filters having a wide range of size distribution. Figure 34 is a plot of the standard deviation versus F-A ratio for all the filters used. Filters which failed are shown by (X). It is observed that there is a distrinct relationship between F-A ratio and the standard deviation of the filters. For a given F-A ratio there is evidently a lower limit for standard deviation for a successful filter. A tentative line is selected at this lower limit based upon data available from experiment.

Figure 30 is a section of a successful filter following the test. Depth of sand penetration is outlined.

Summary

These studies were mainly devoted to the use of the non-uniform filters. The U.S.B.R. has recommended some criteria for the design of graded filters for tile drains. However, sufficient importance was not given to the uniformity or distribution of the grain sizes of the filters.

In this study it has been found that the uniformity of the filter plays a very important role in the stability of the filter-aquifer system. Standard deviation (σ) which represents the degree of dispersion of the size of all particles about the mean size has been chosen to express the non-uniformity of the filters.

It has been found that there is a minimum value for the standard deviation of the filter at a particular F-A ratio; below which the filter will fail.

It has been also concluded that a recommendation for standard deviation is more important than a recommendation for $\frac{D_{15}(F)}{D_{15}(A)}$ ratio which is unnecessary if the standard deviation of the filter is used along with the F-A ratio.

A range of hydraulic heads representative of the field installations (ponded water case) of tile drains were used in these experiments and their effects on the filter aquifer stability and the amount of water discharged were studied.

Plans For Next Year

Filter Experiment

Further experiments are being conducted on gravel filters to obtain data at more F/A ratios both within the present range and to extend the range. Numerous questions have arisen in the course of the present studies which will be investigated; as for example, How far does sand penetrate a given filter?, What is the effect of this penetration on the hydraulic characteristics of the filter system?, What minimum filter thickness is required?

Gravel-filled Mole Drain

Experiments will be conducted on the performance of gravel-filled mole drains. Flow characteristics of such channels will be determined. Gravel size and uniformity, channel size, and channel shape will be variables. The relations between gravel characteristcs and channel stability will also be investigated.

Publications

Qazi, A. R., Design Criteria for Tile Drain Filters, Masters Thesis, 1961, Colorado State University 100 p. tpw.

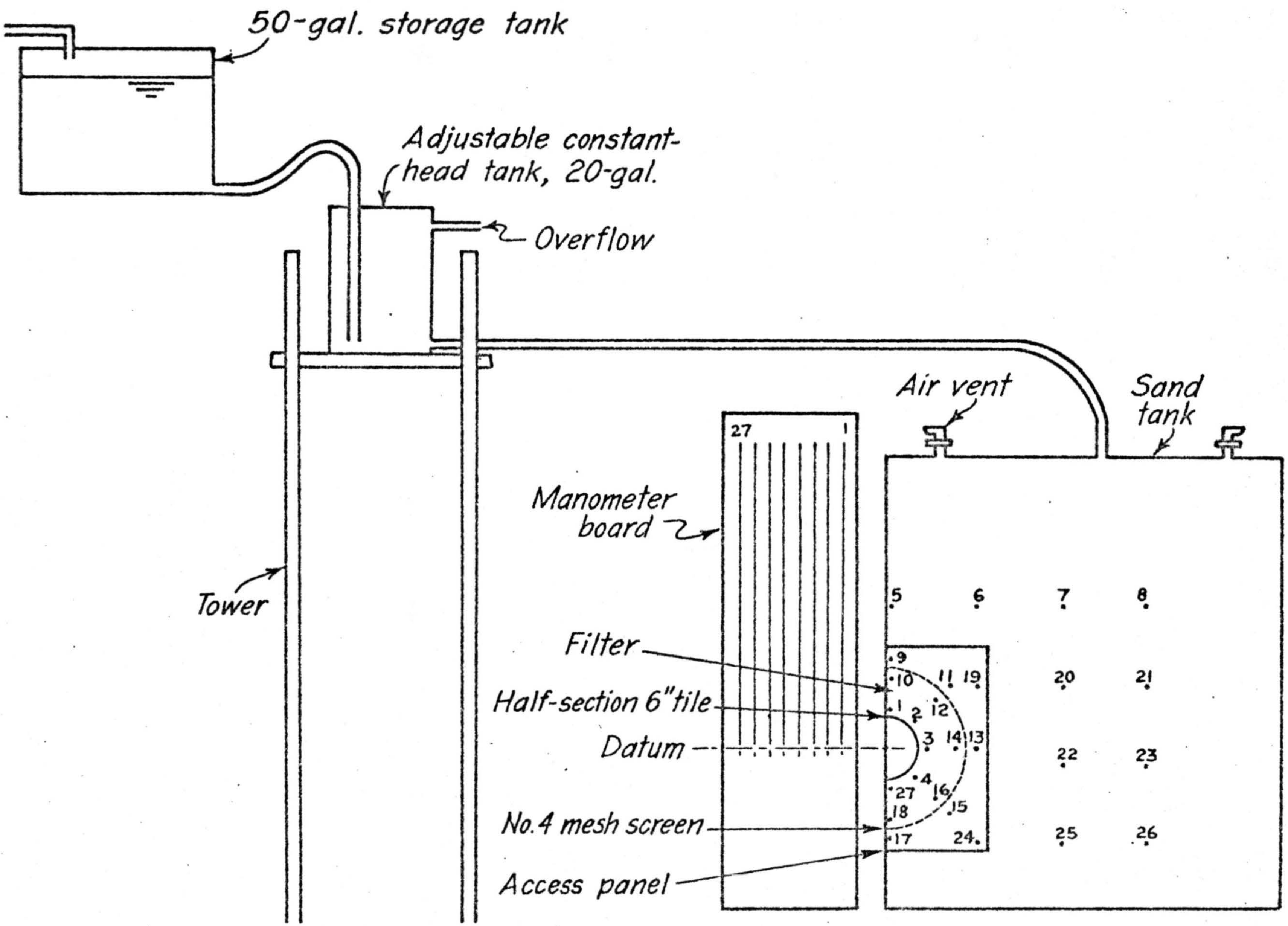


Fig. 1 Tank model and water supply

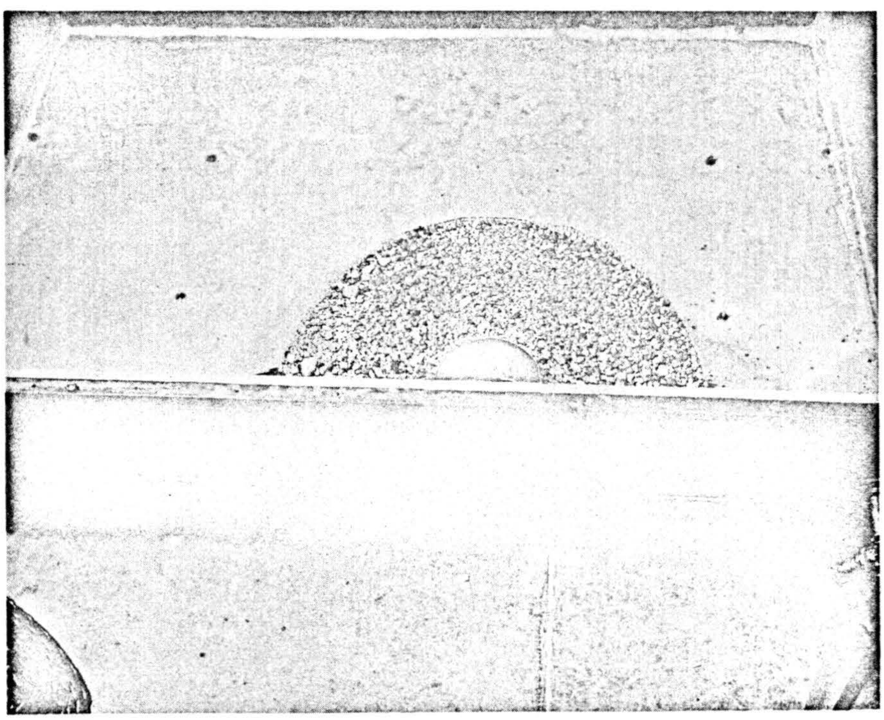


FIGURE 2

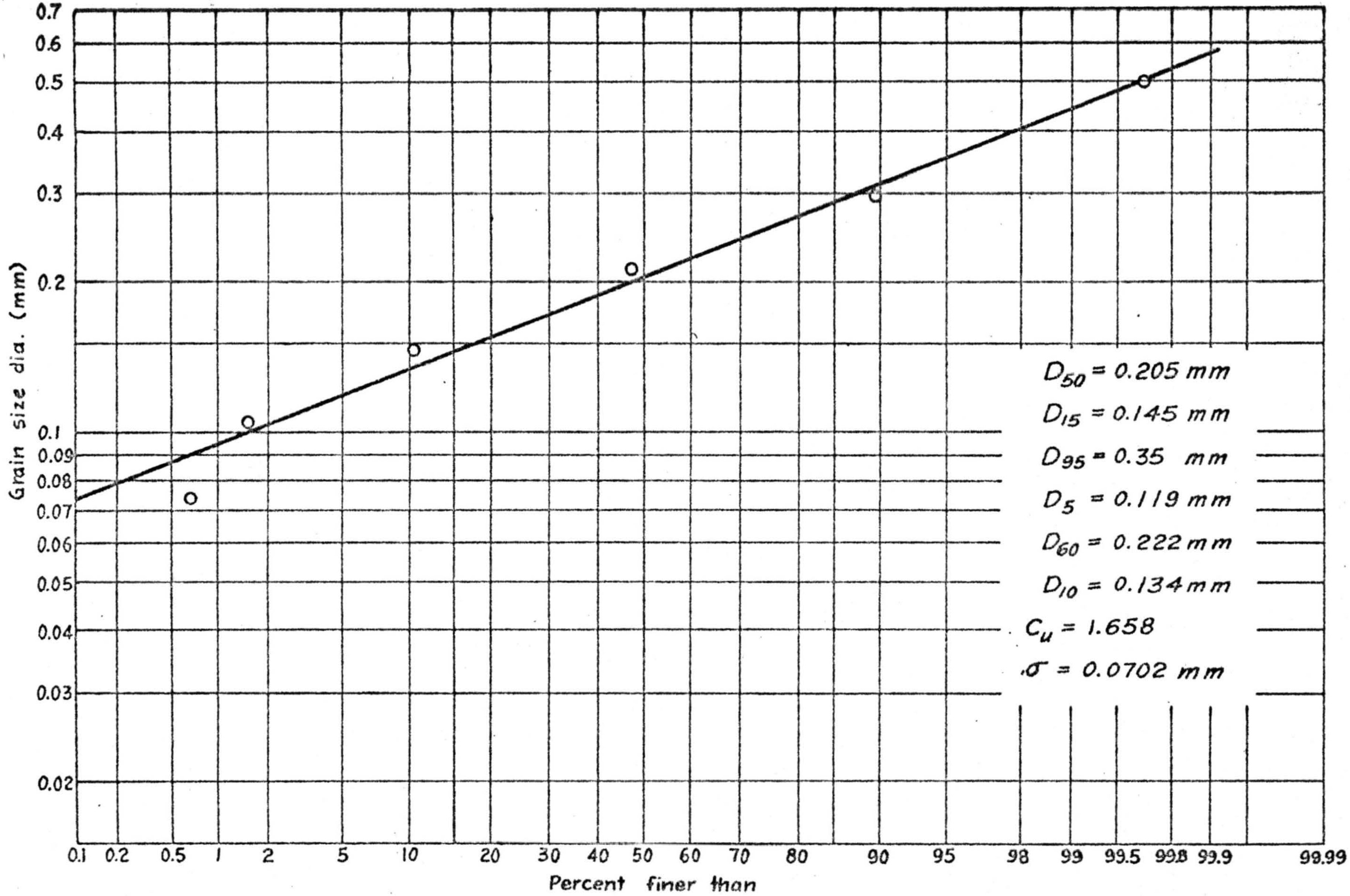


Fig. 7 Average grain size distribution of aquifer sand

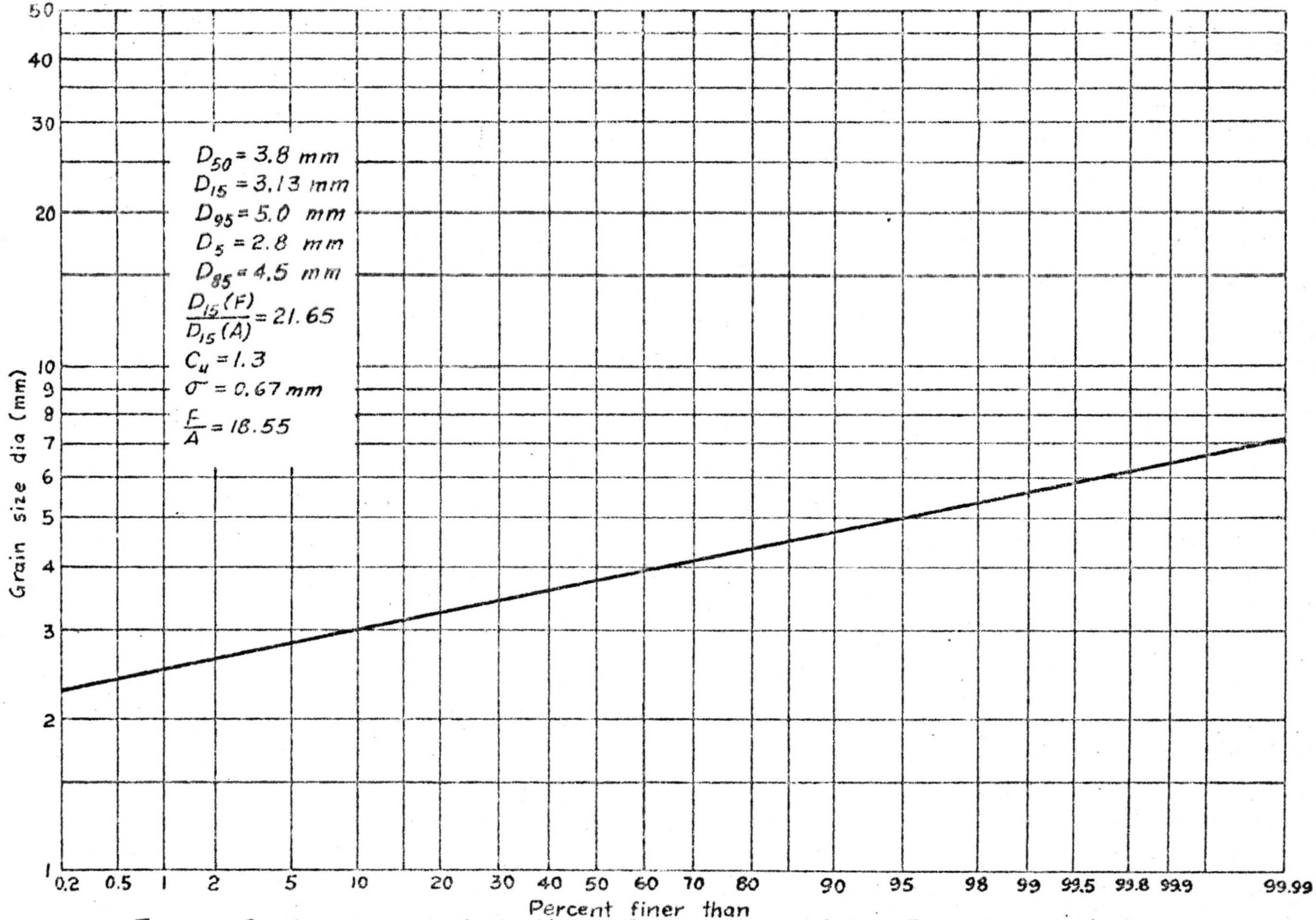


Fig.(Grain size distribution of gravel used in Experiment No. I

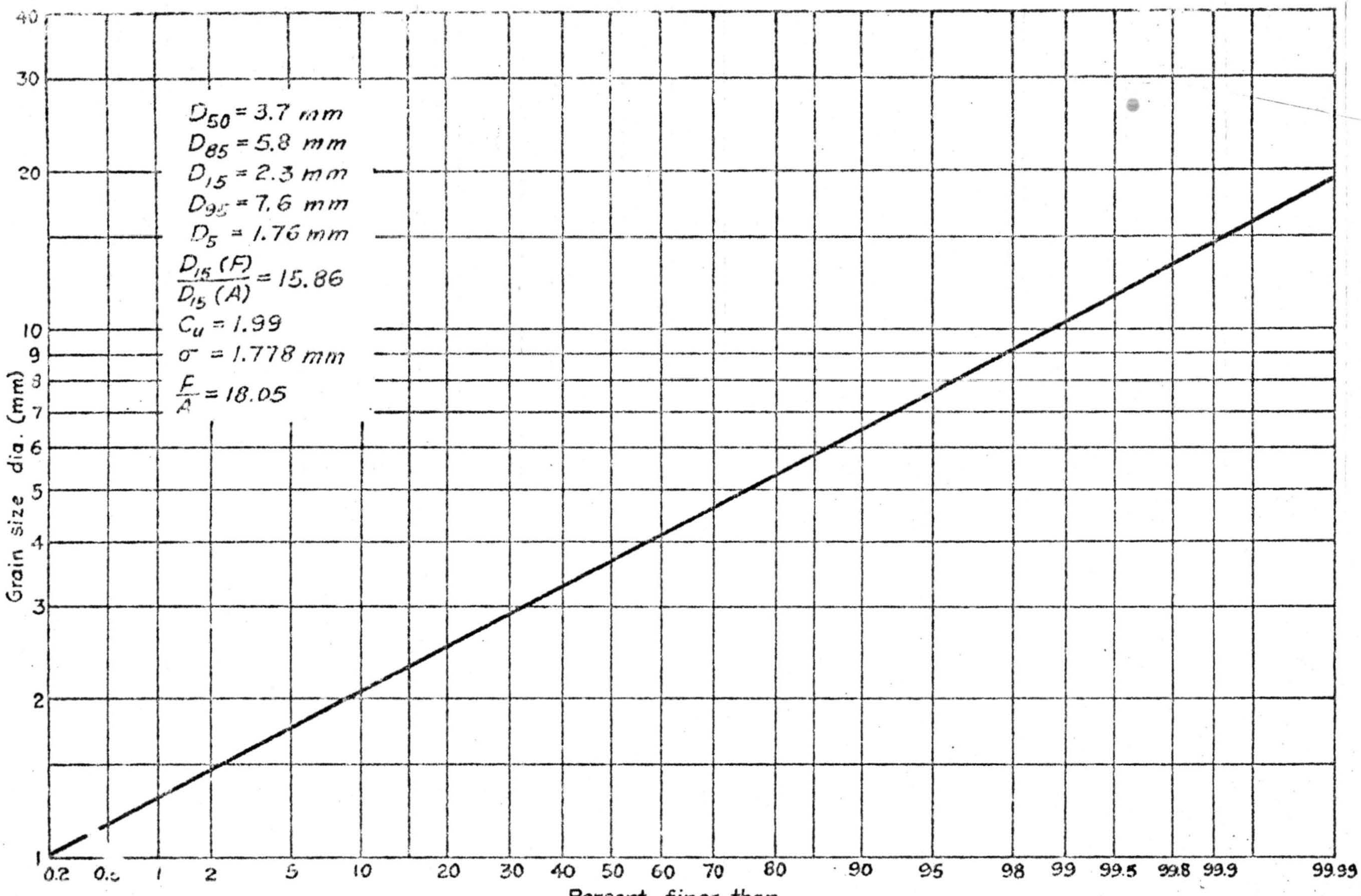


Fig. 9 Grain size distribution of gravel used in Experiment No. 2

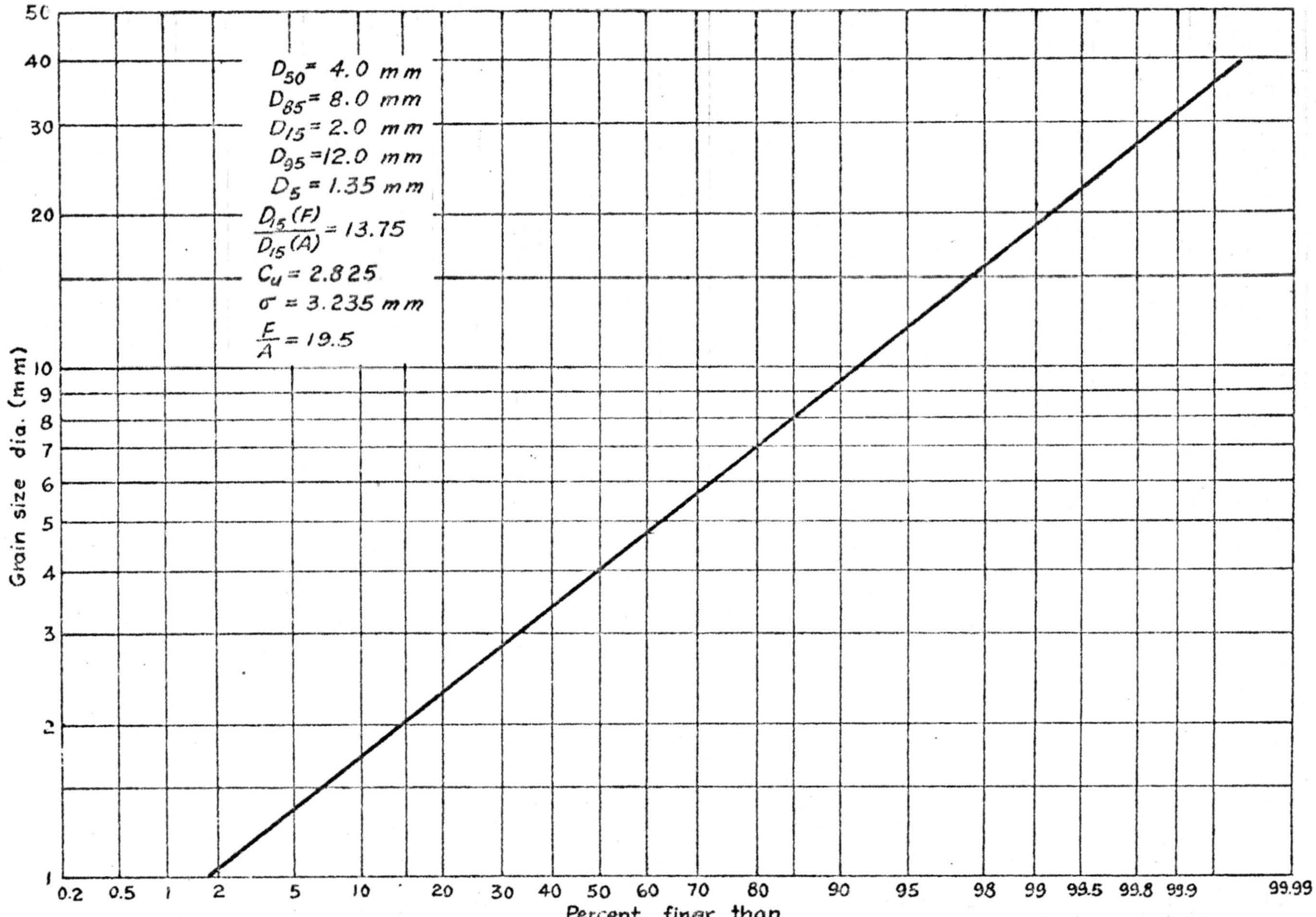


Fig. 10 Grain size distribution of gravel used in Experiment No. 3

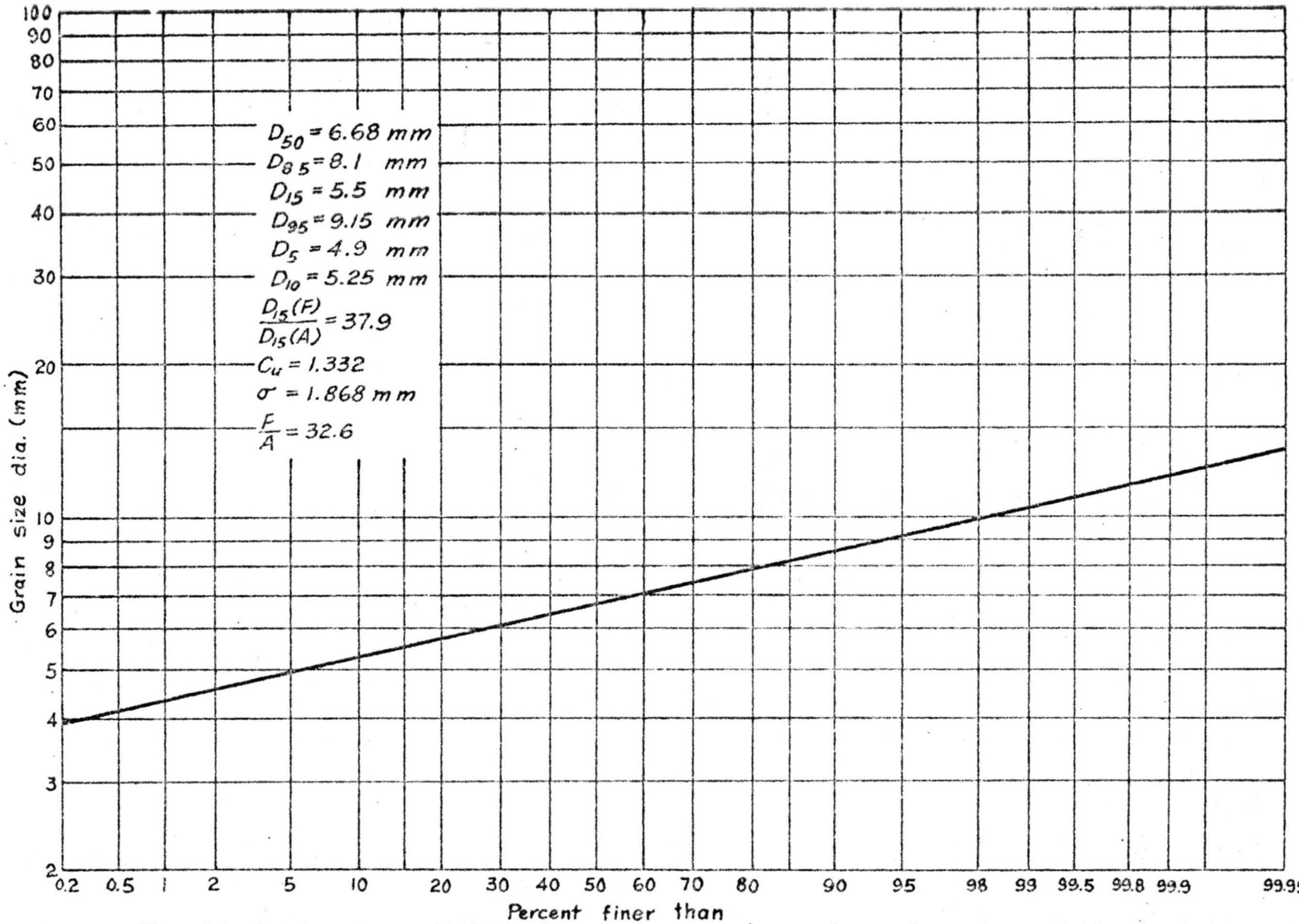


Fig. 11 Grain size distribution of gravel used in Experiment No. 4

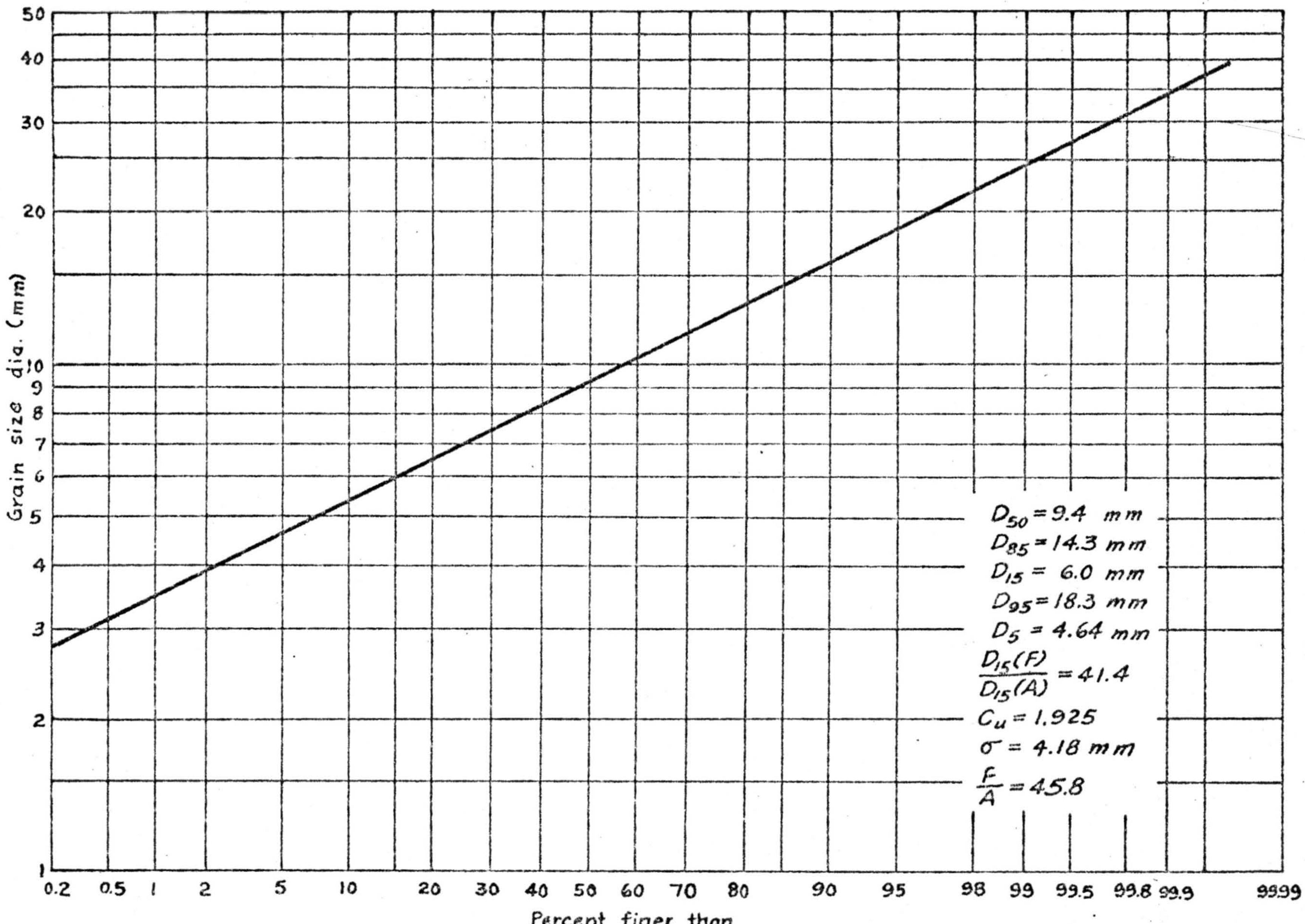


Fig. 12 Grain size distribution of the gravel used in Experiment No. 5

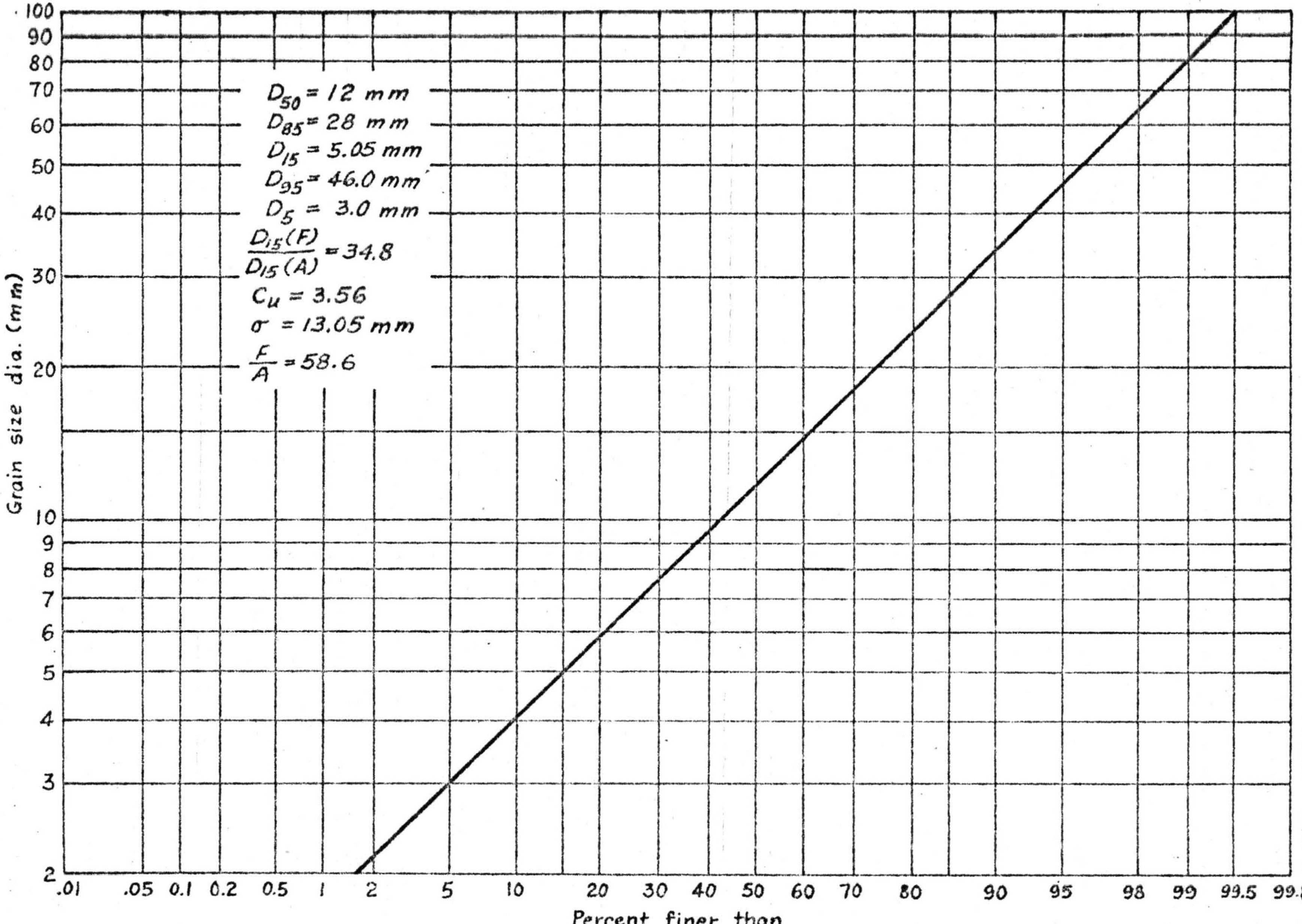


Fig. 13 Grain size distribution of gravel filter used in Experiment No. 6

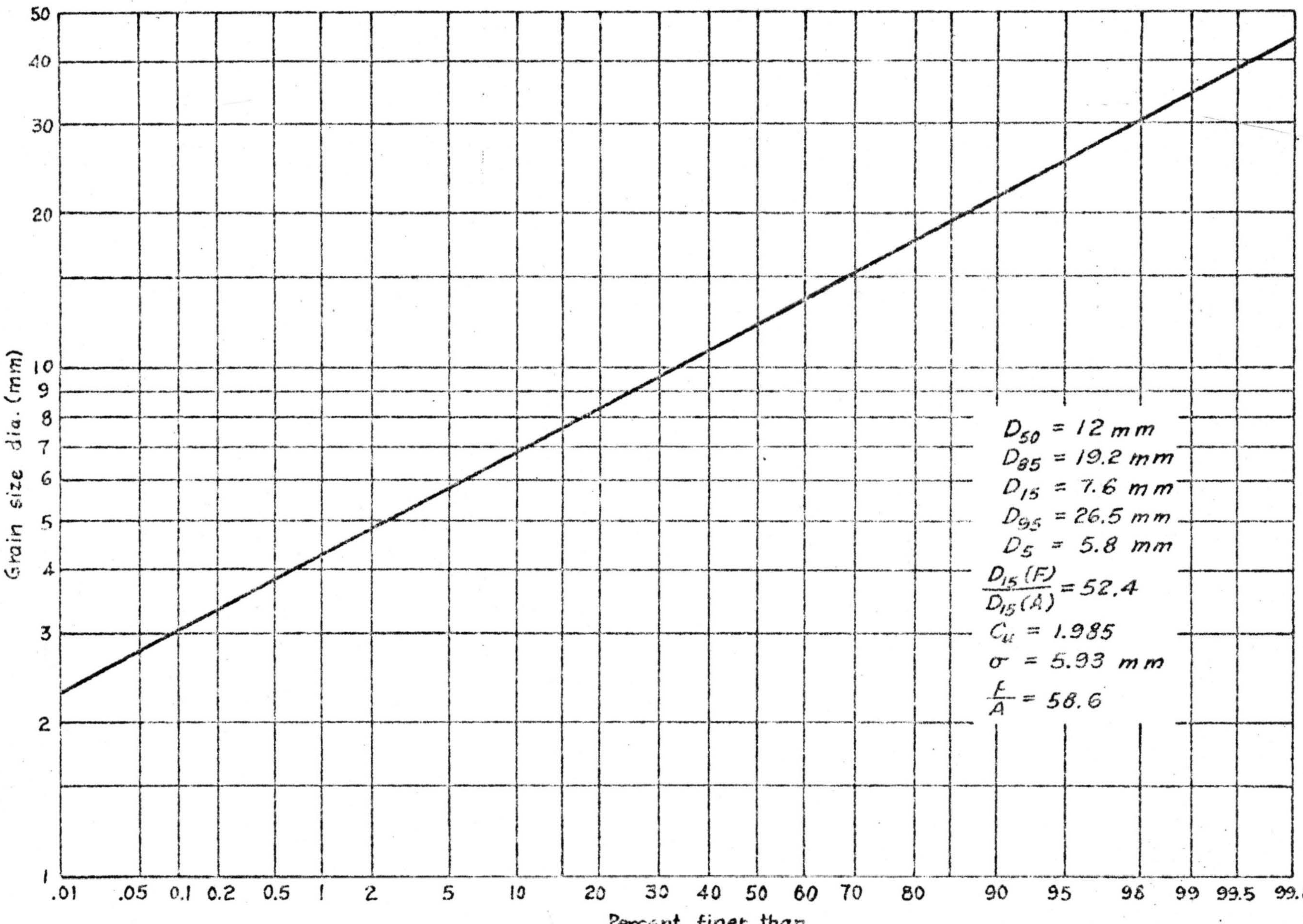


Fig. 14 Grain size distribution of gravel used in Experiment No.7

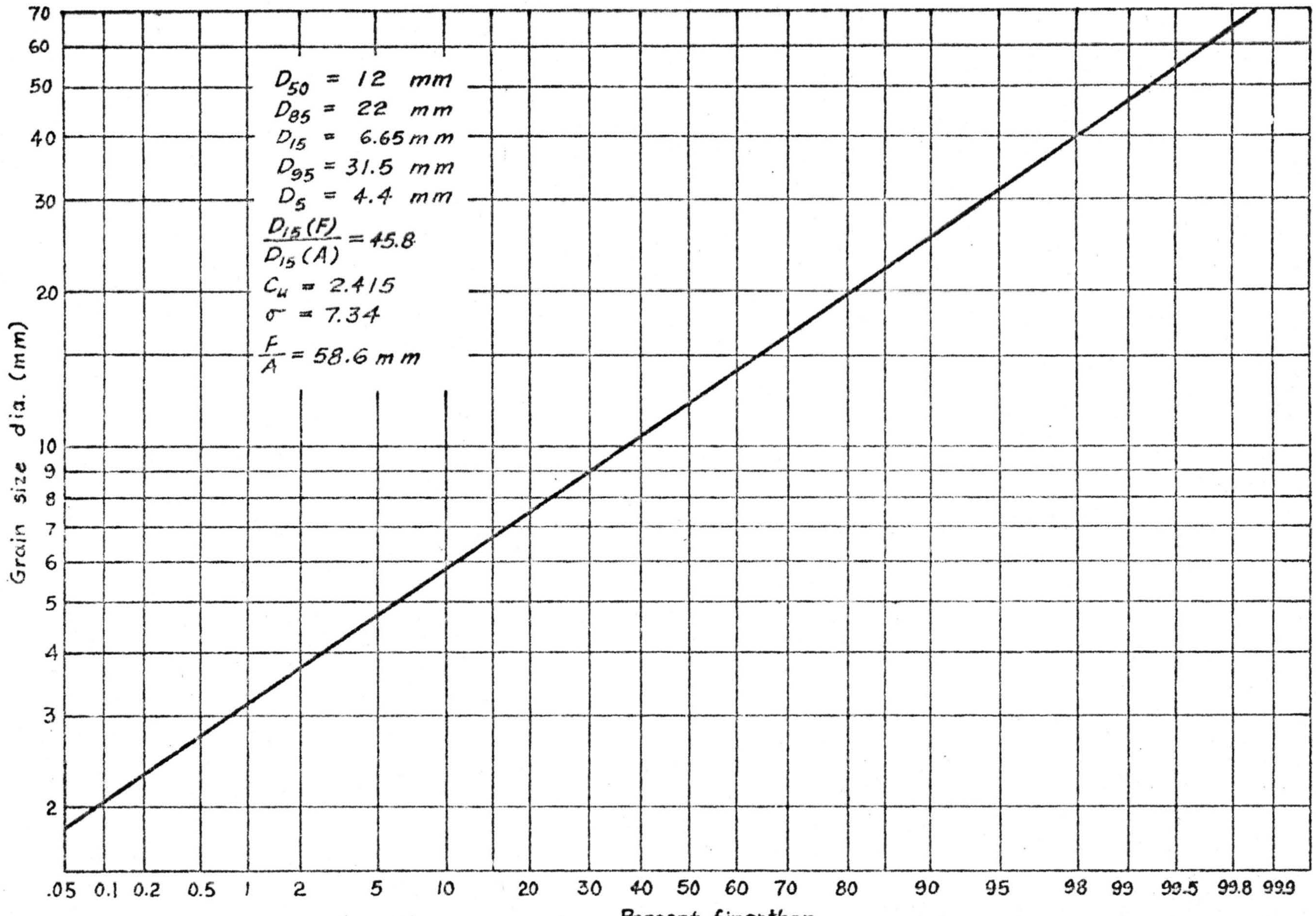


Fig.16 Grain size distribution of gravel filter used in Experiment No.9

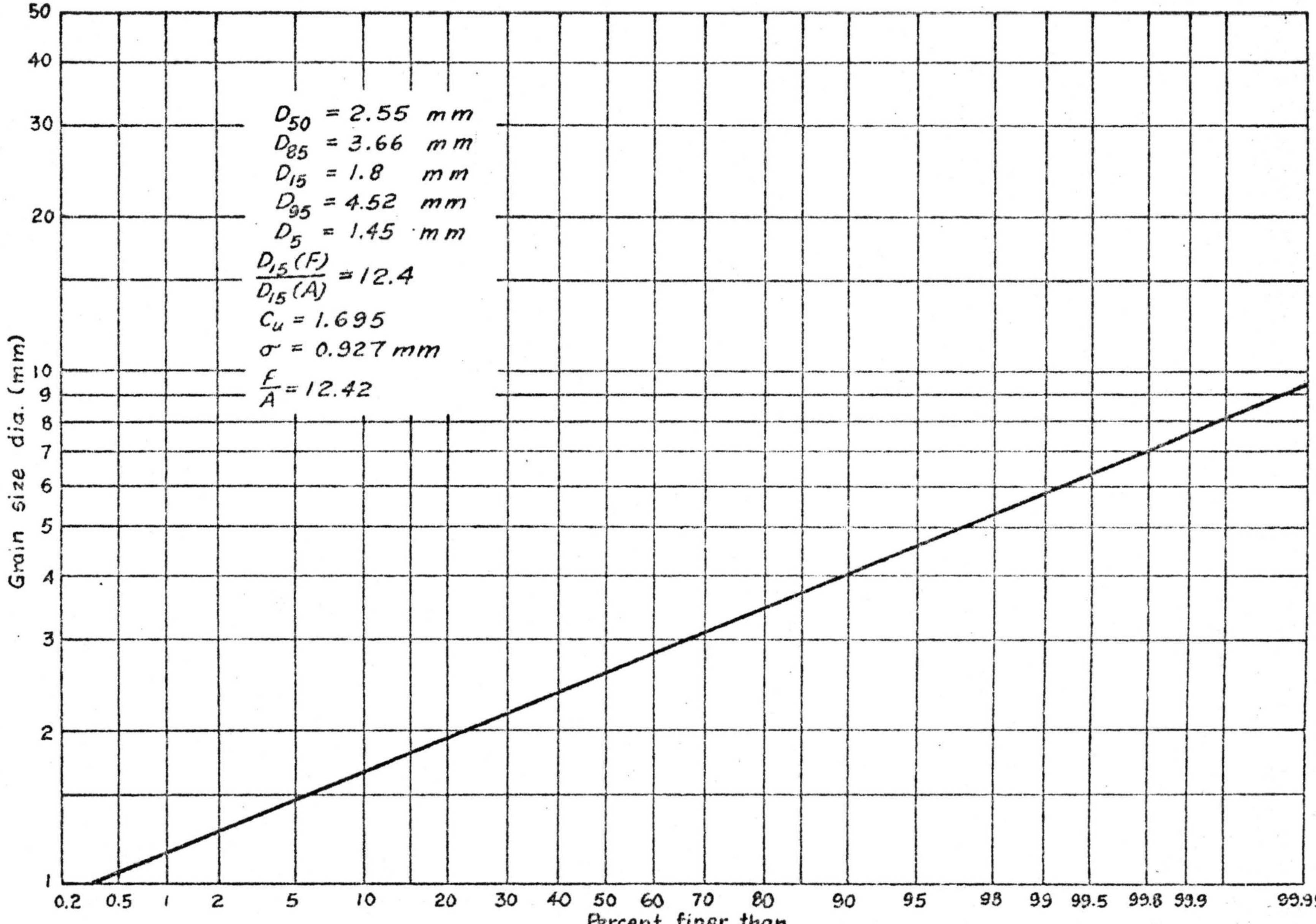


Fig. 17 Grain size distribution of gravel used in Experiment No. 10

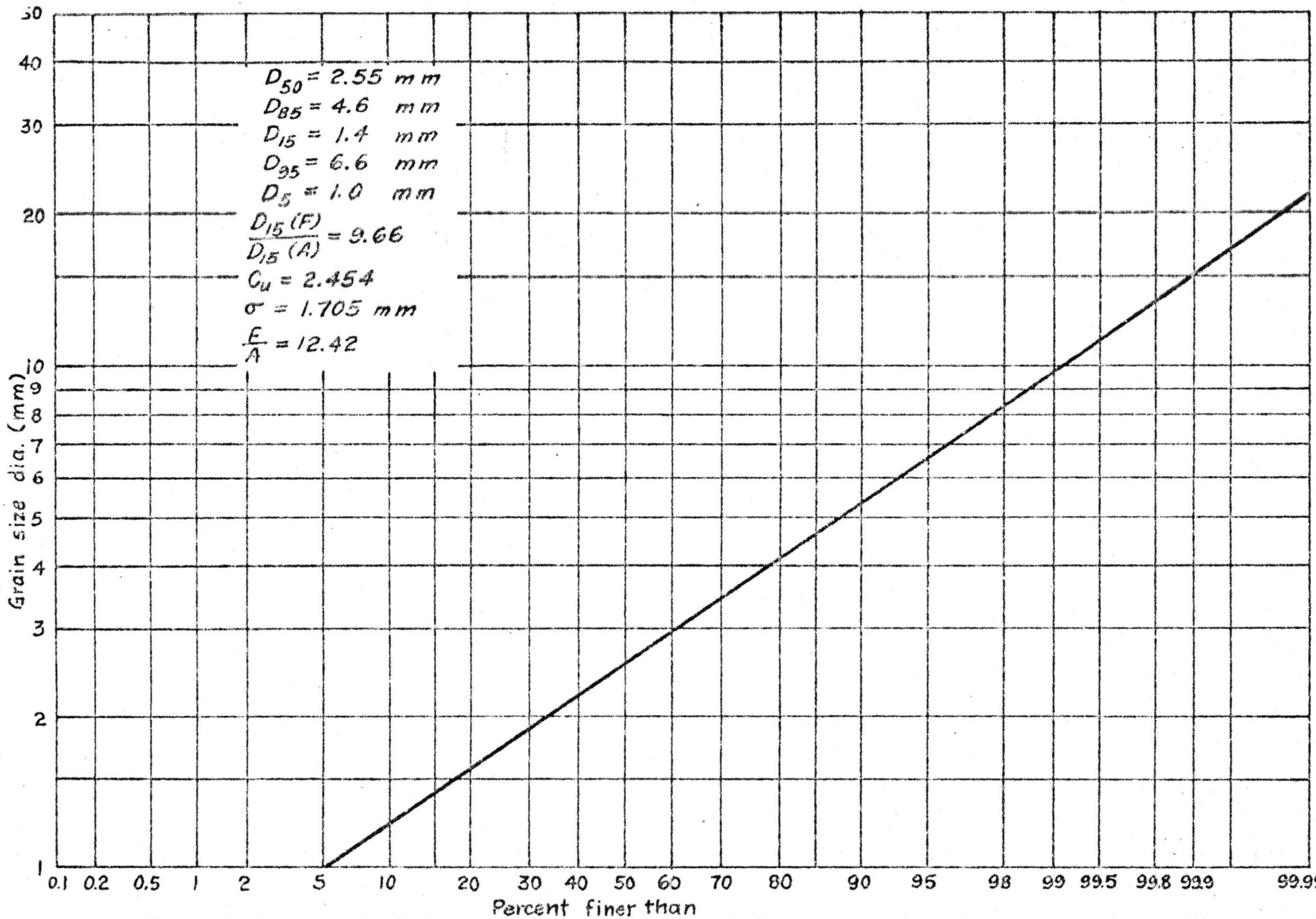
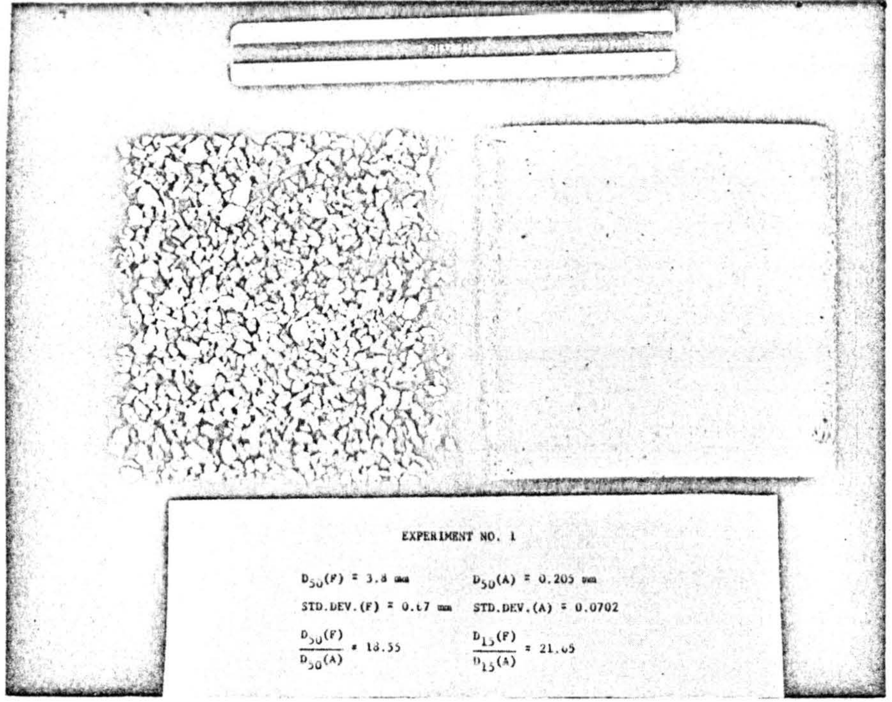
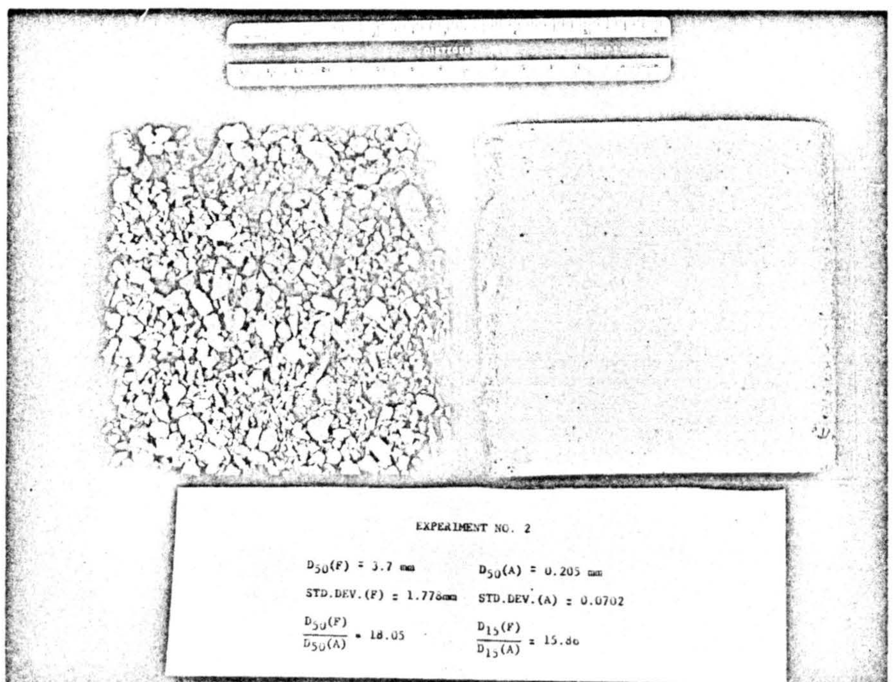
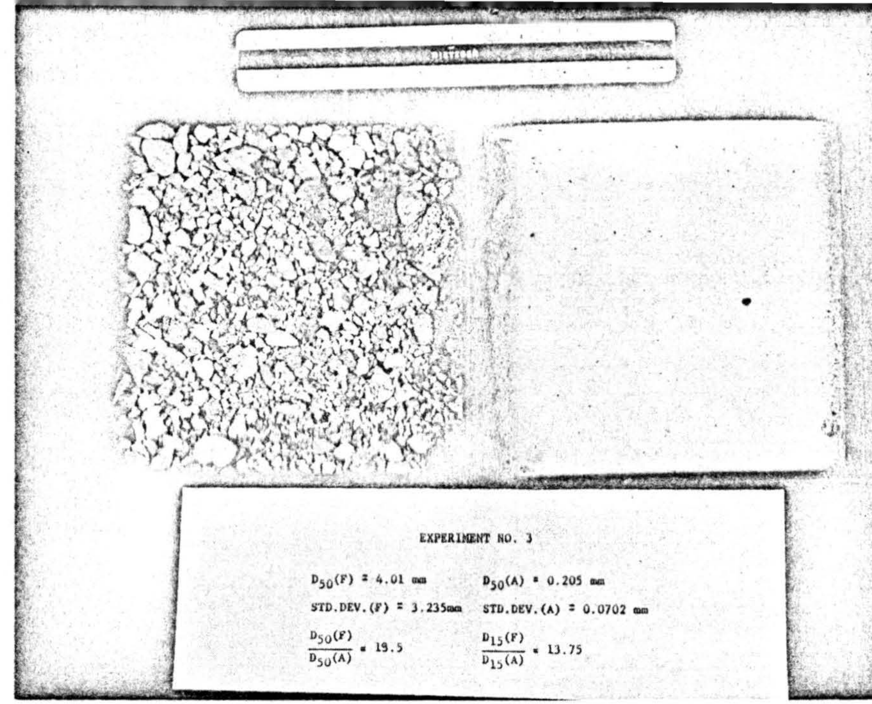
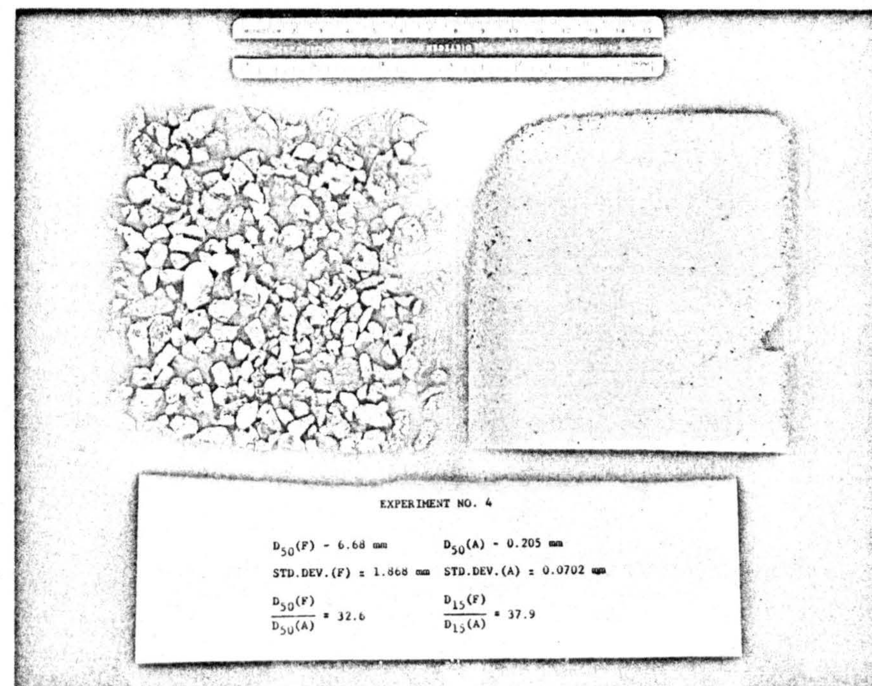


Fig. 18 Grain size distribution of gravel filter used in Experiment No. 11

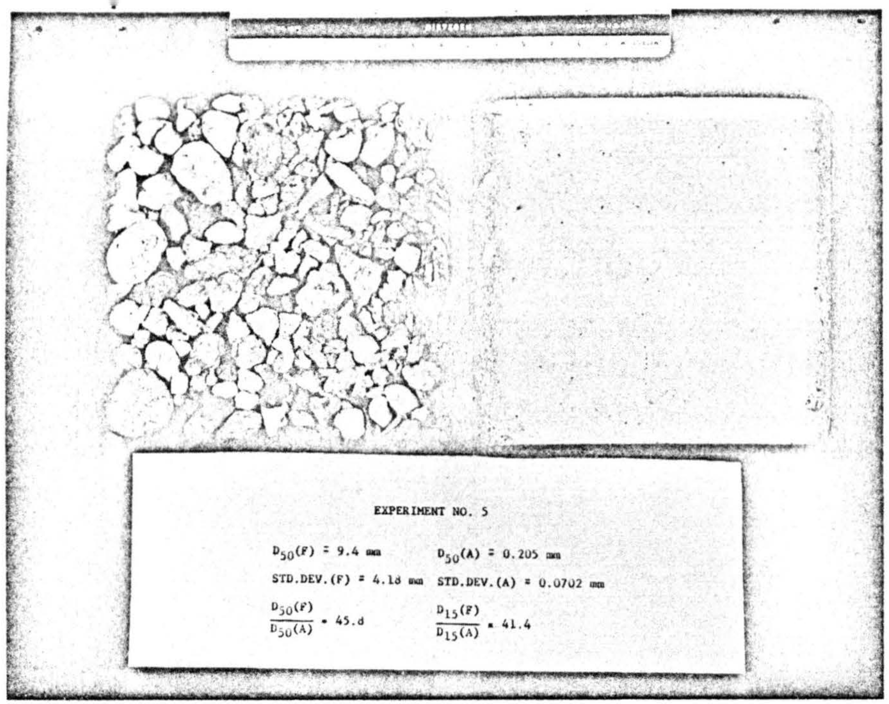


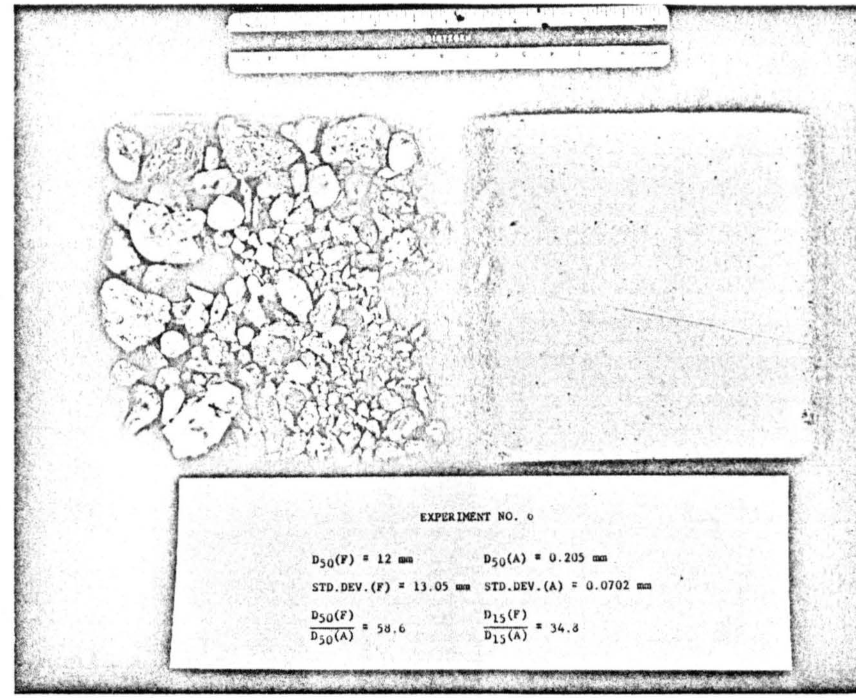


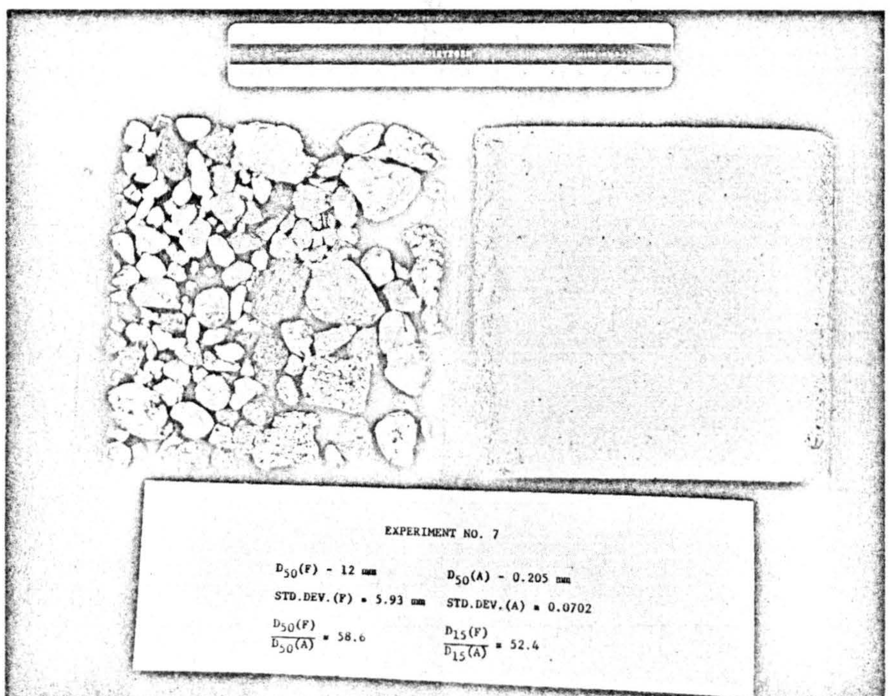


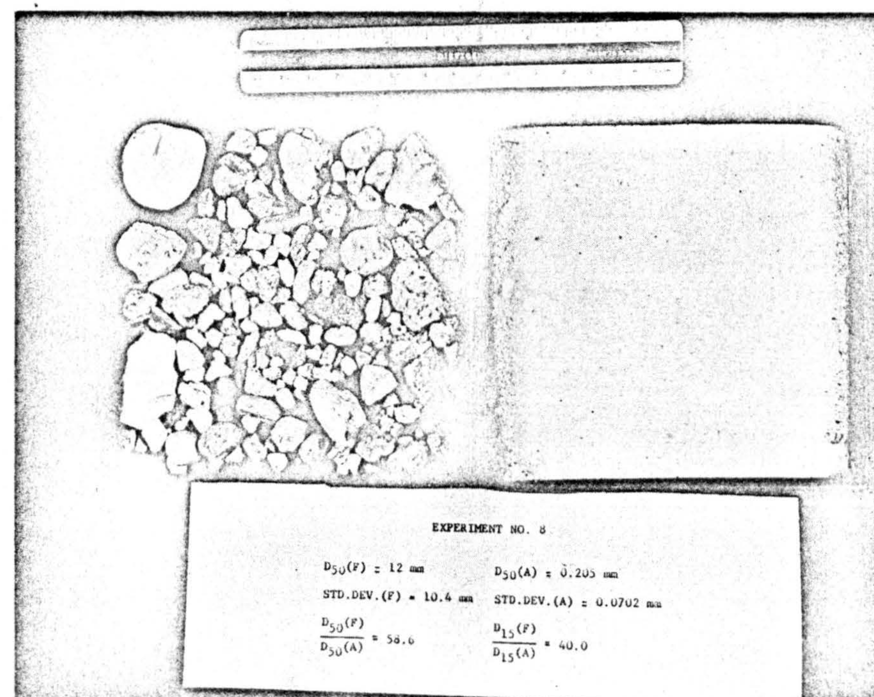


FIGURES 19-22

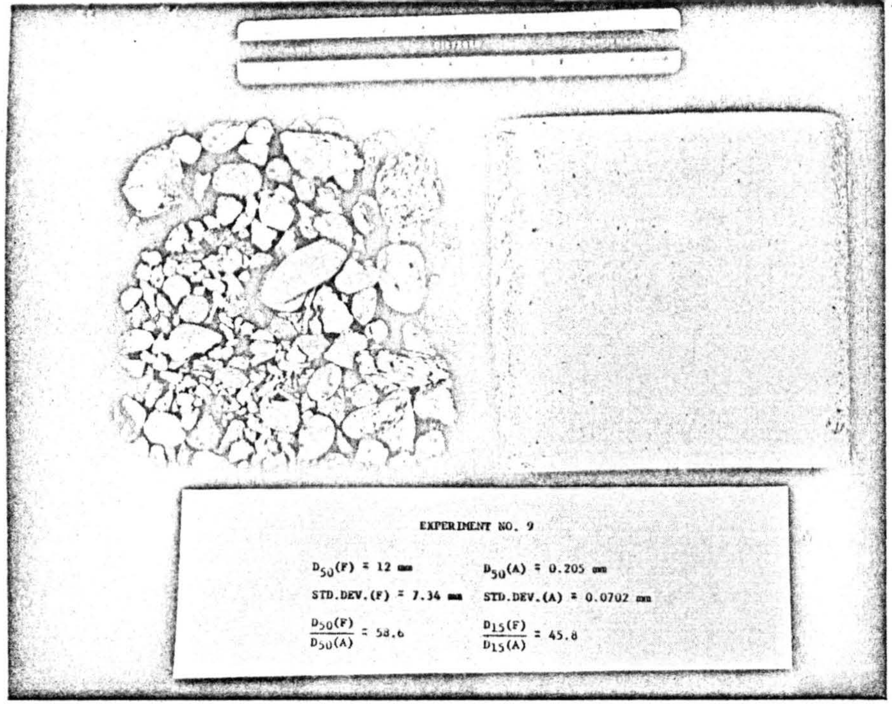


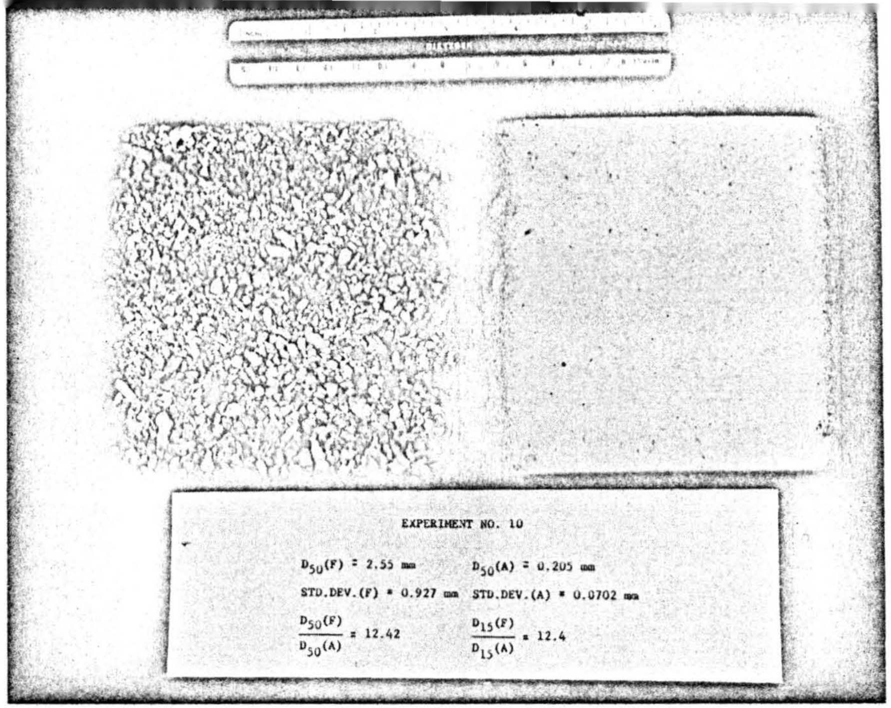


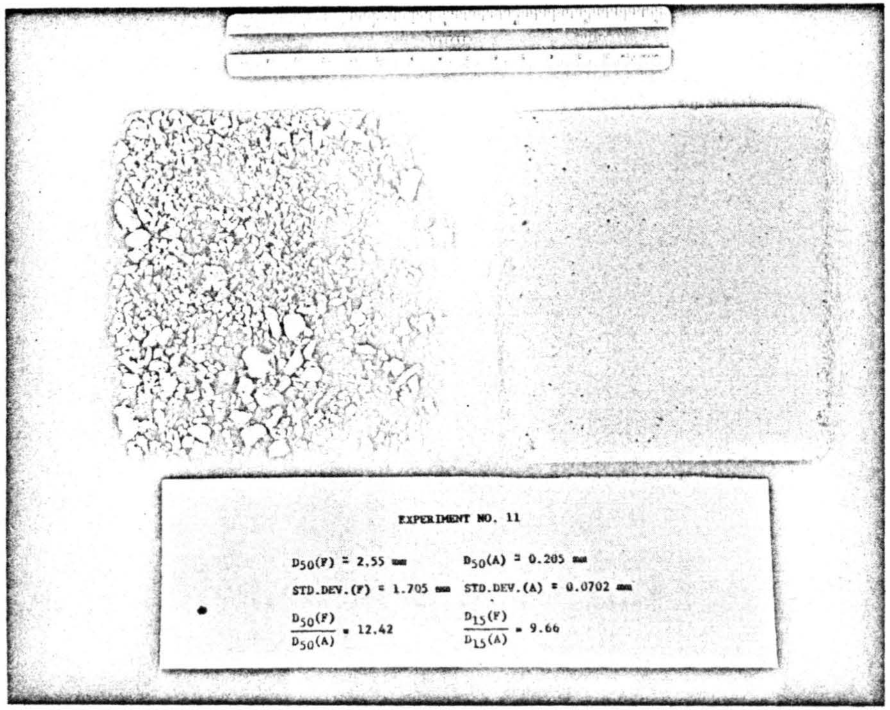


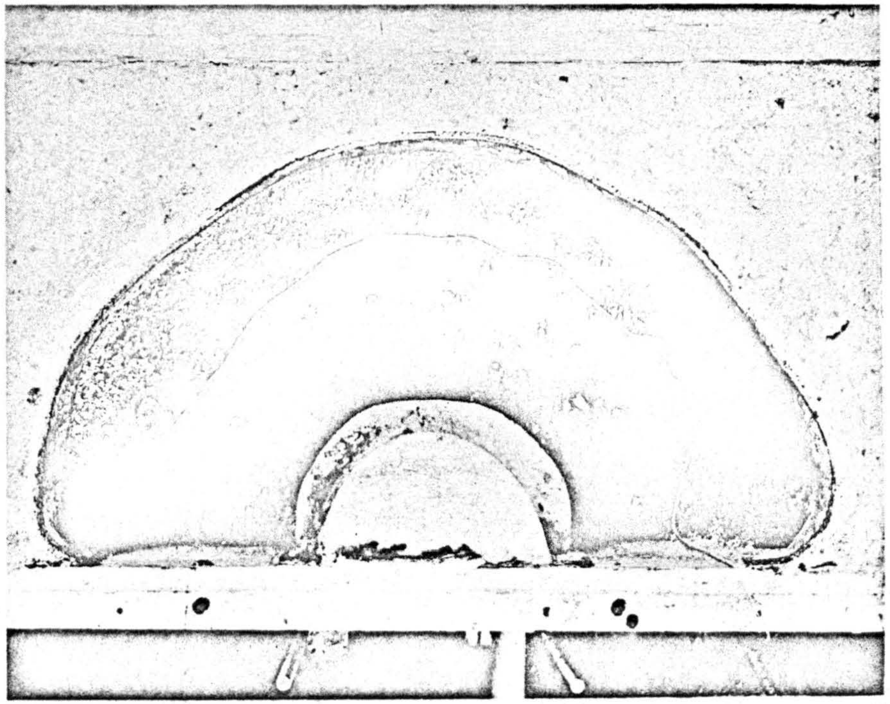


FIGURES 23-26









FIGURES 27–30

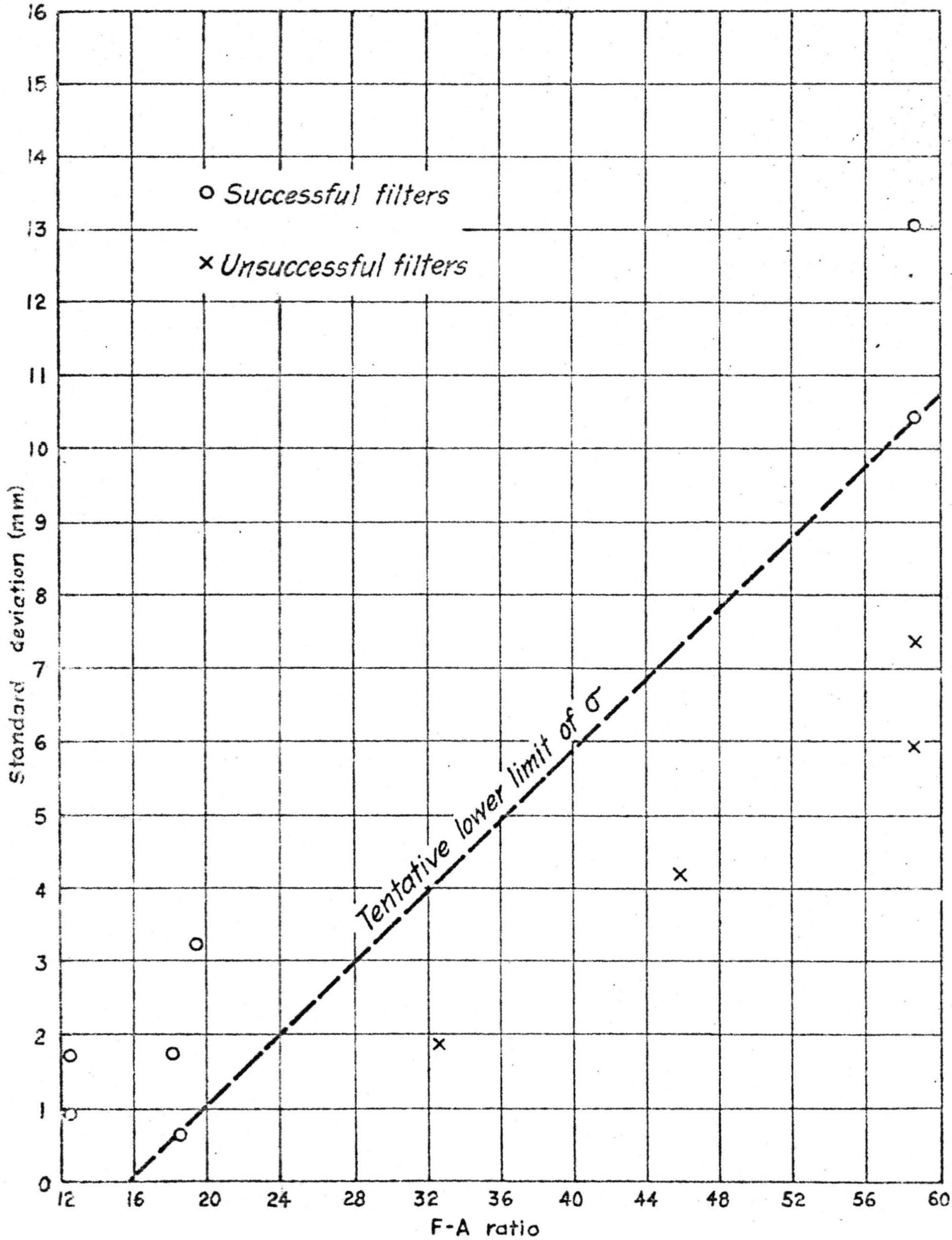


Fig. 34 Lower range of allowable standard deviation with allowab' F-A ratios